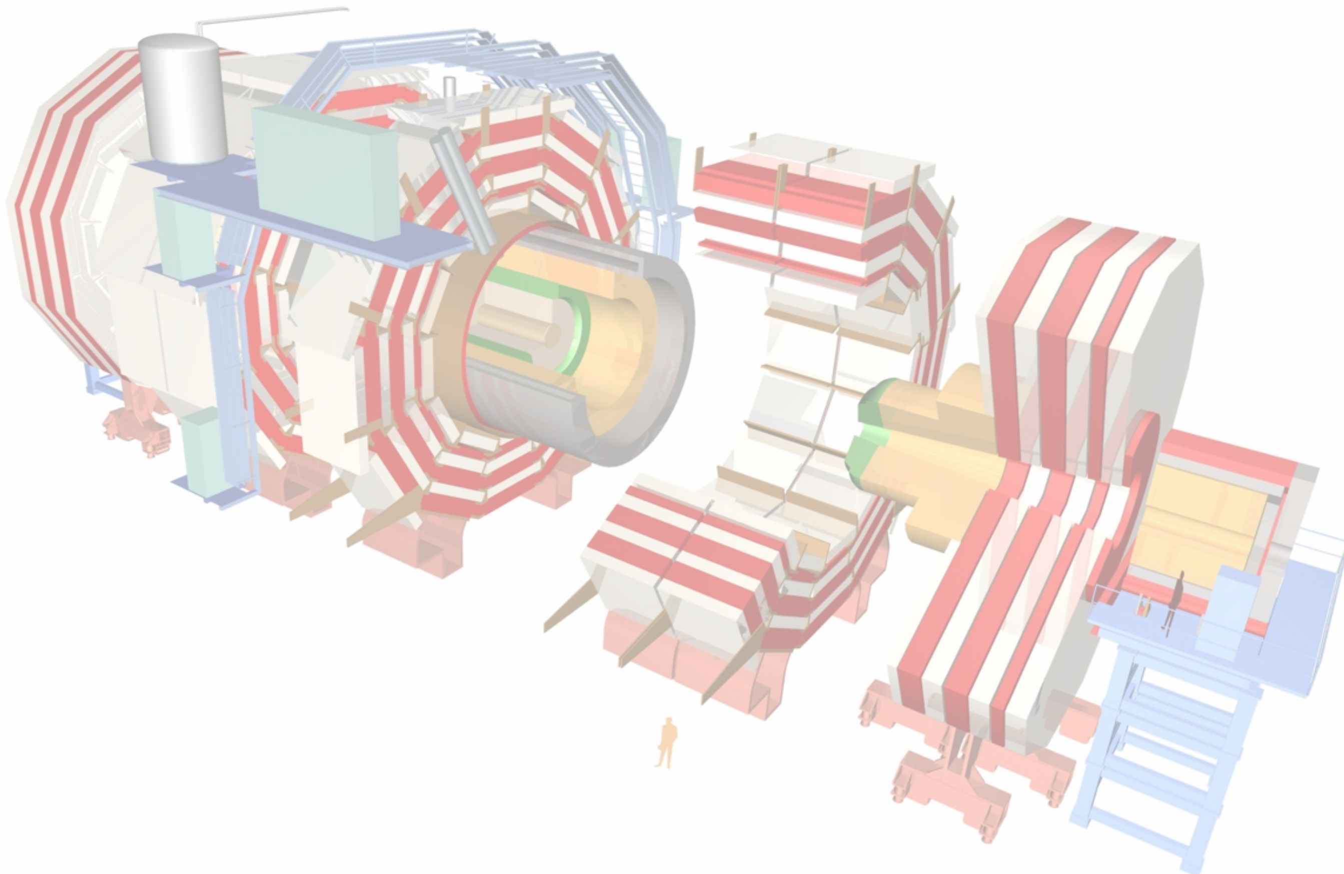
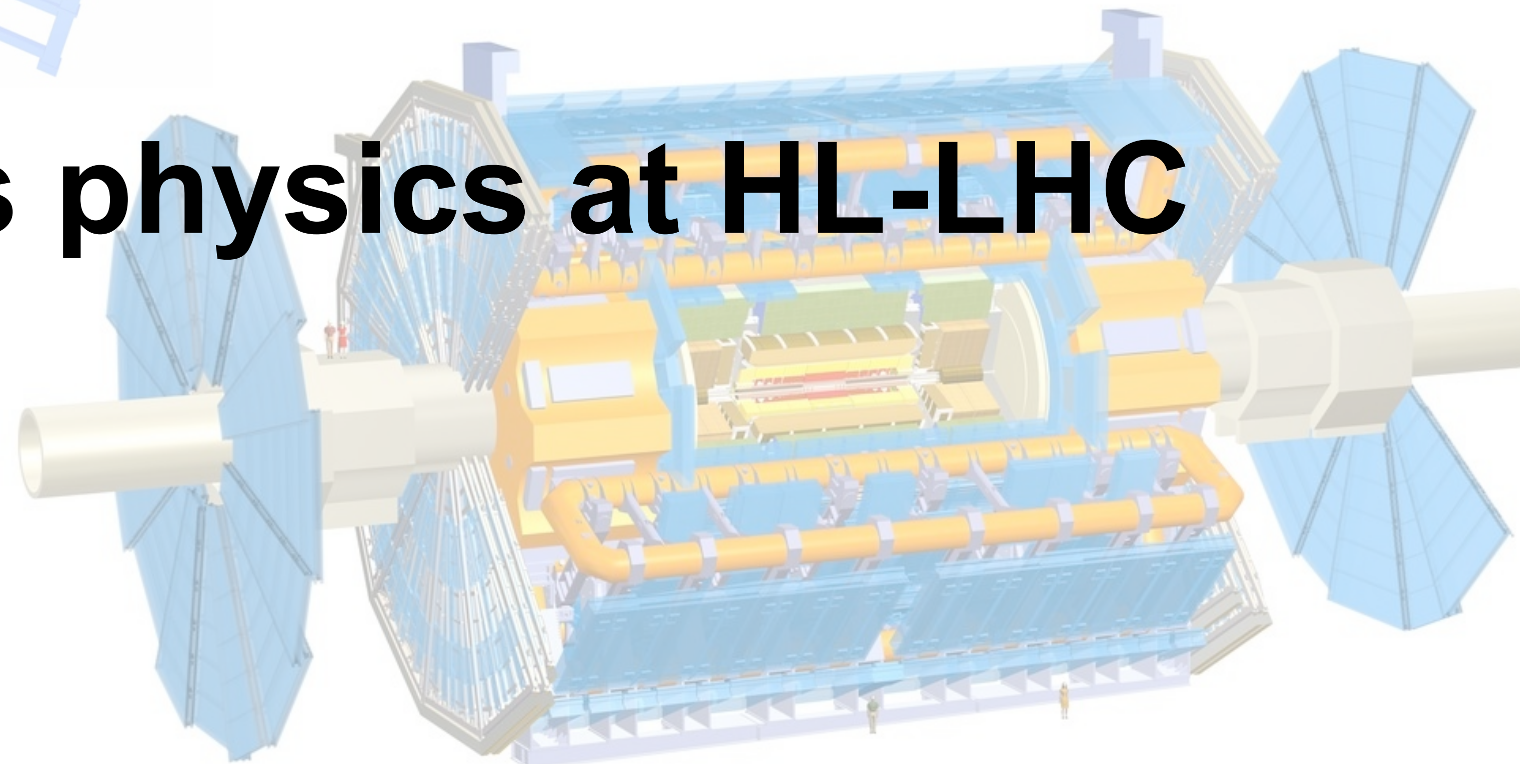
Physics seminars



Future Higgs physics at HL-LHC



Paolo Giacomelli (INFN Bologna)

***Physics seminar*, DESY, Hamburg and Zeuthen**

Tuesday, November 4-5, 2014

Outline

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- Where we stand today

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- LHC and HL-LHC luminosity projections

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- Physics priorities

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- VV scattering

Important Caveat

In this talk *Higgs boson* stands for the scalar boson predicted independently by R. Brout, F. Englert and P.W. Higgs, a more appropriate name would be *BEH boson*

Integrated luminosity in 2012

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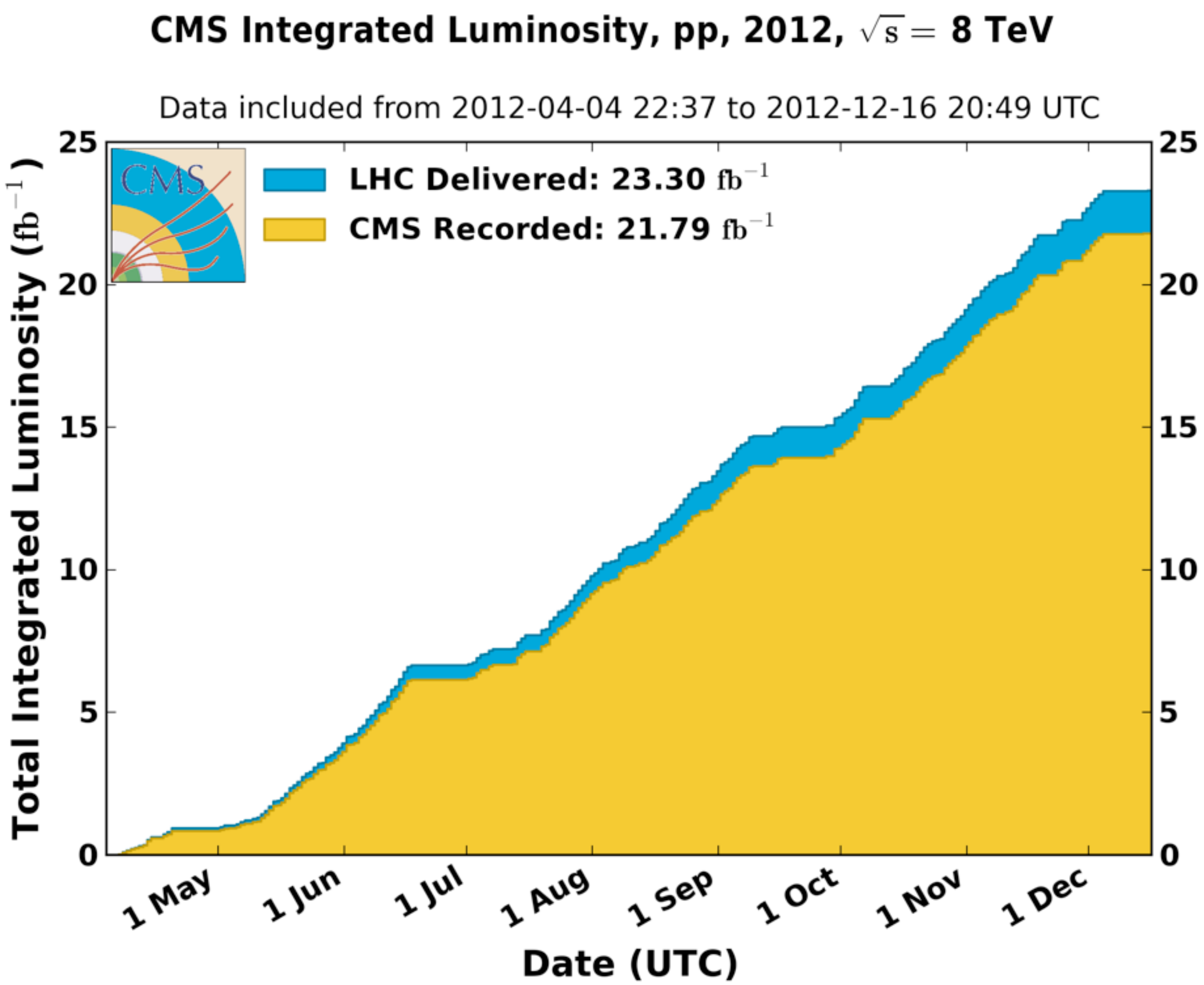

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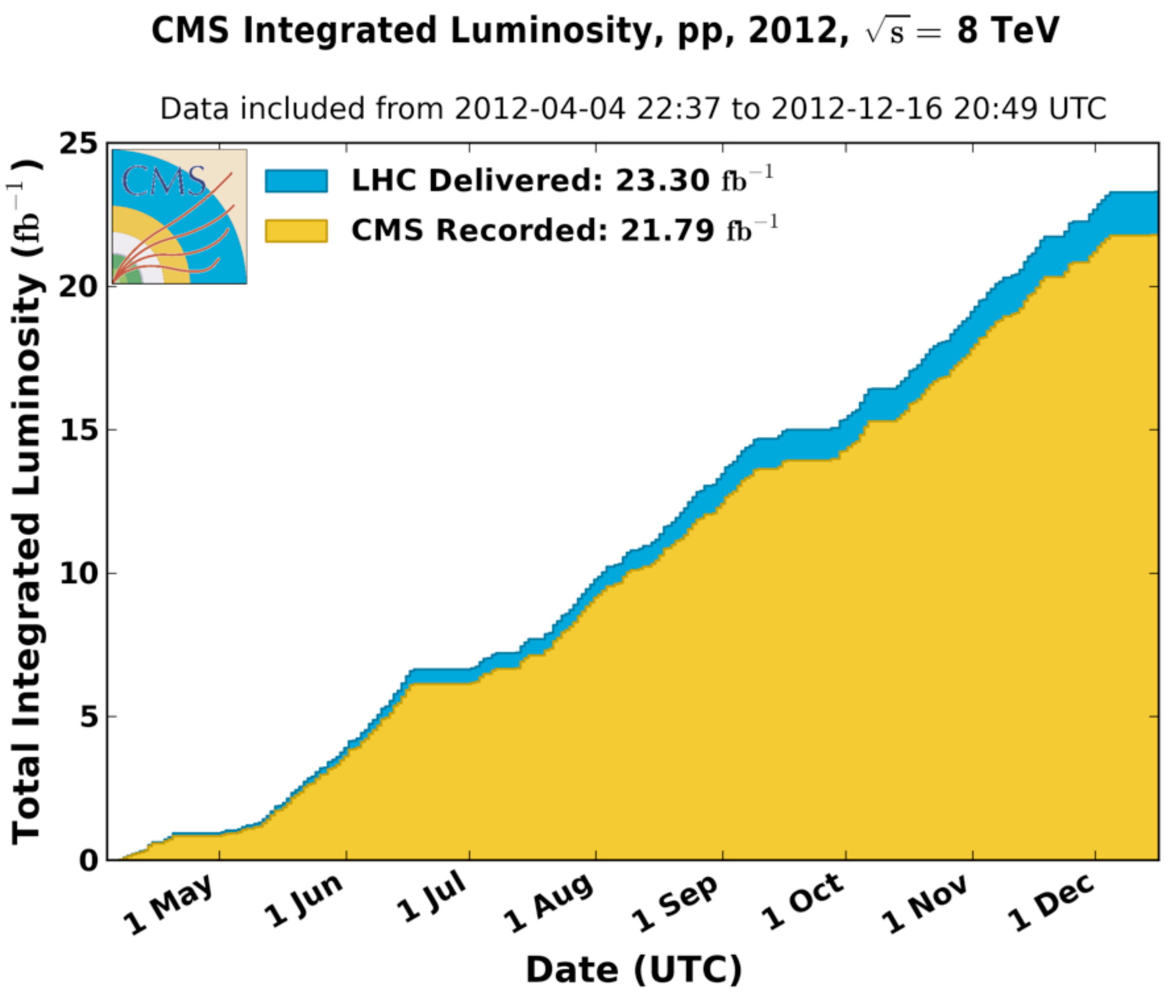
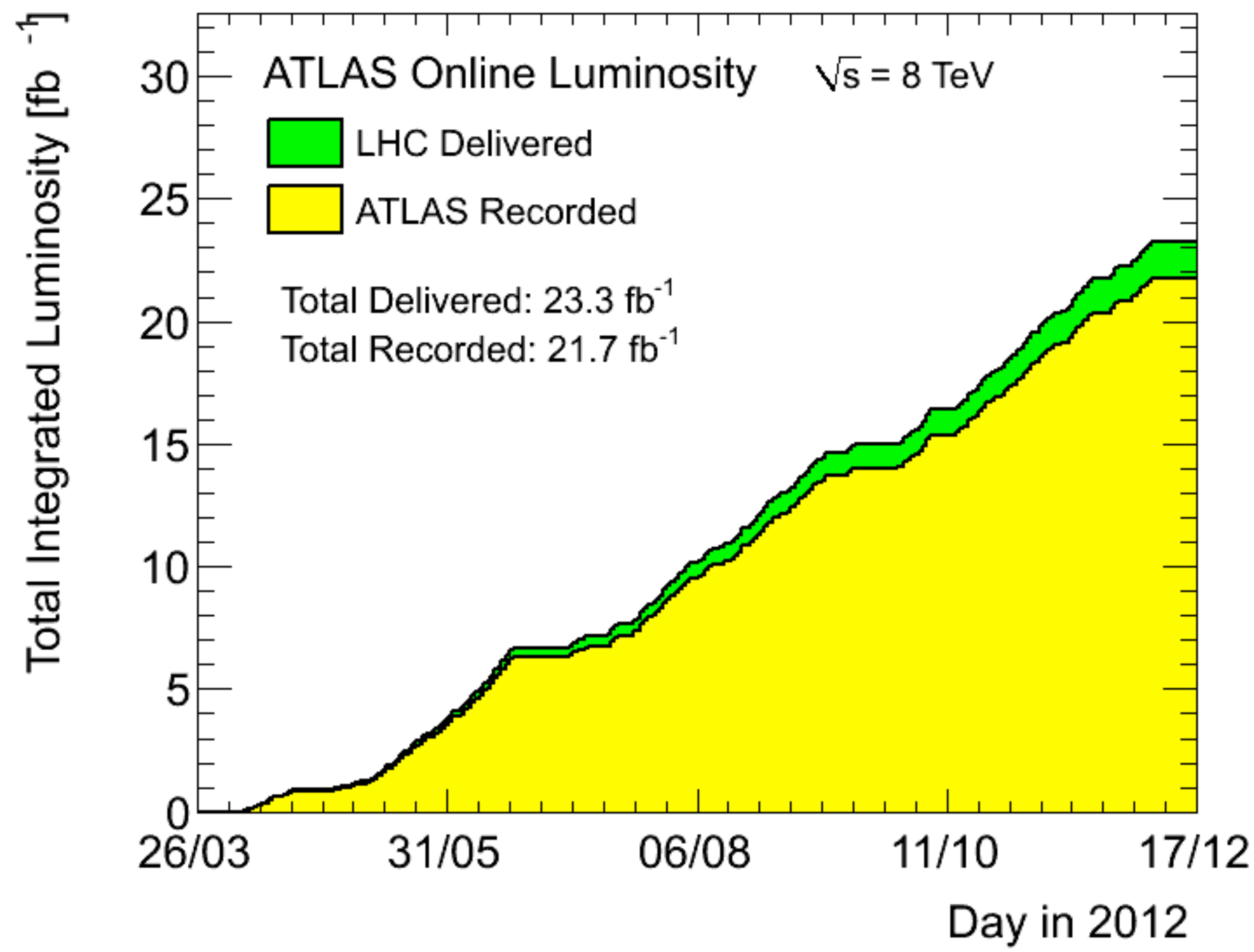
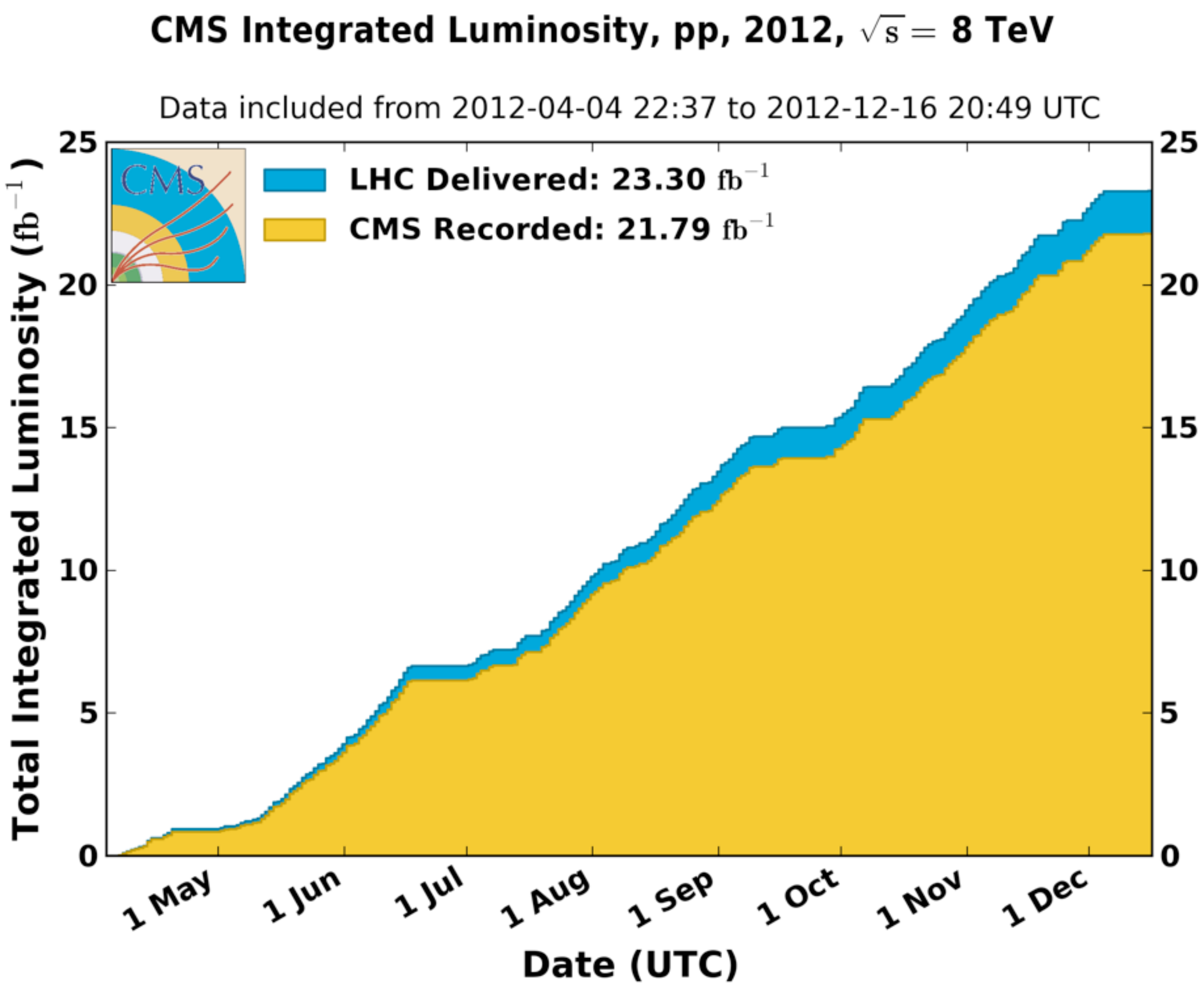
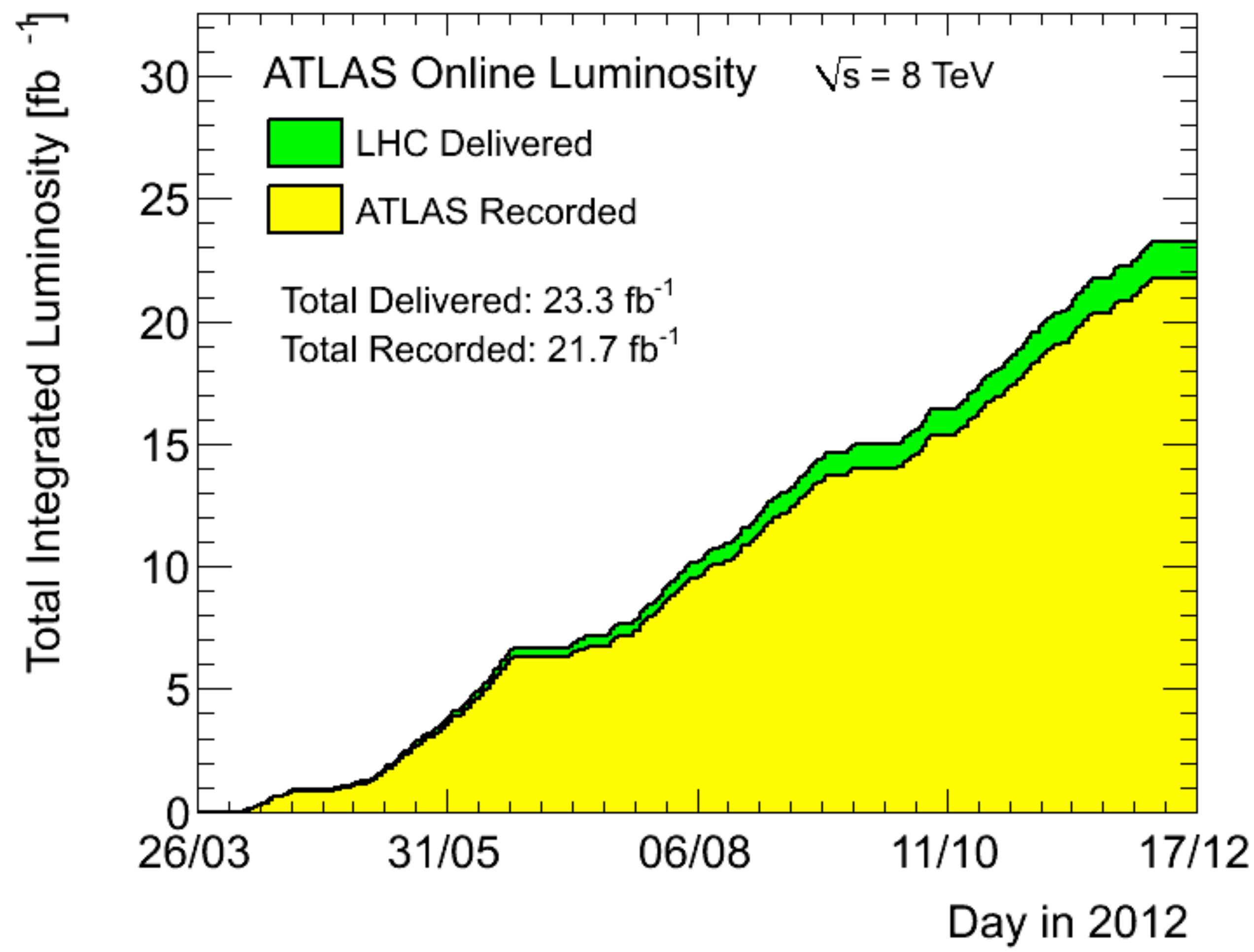




Integrated luminosity in 2012

Integrated luminosity recorded in 2012: **~22 fb^{-1}**





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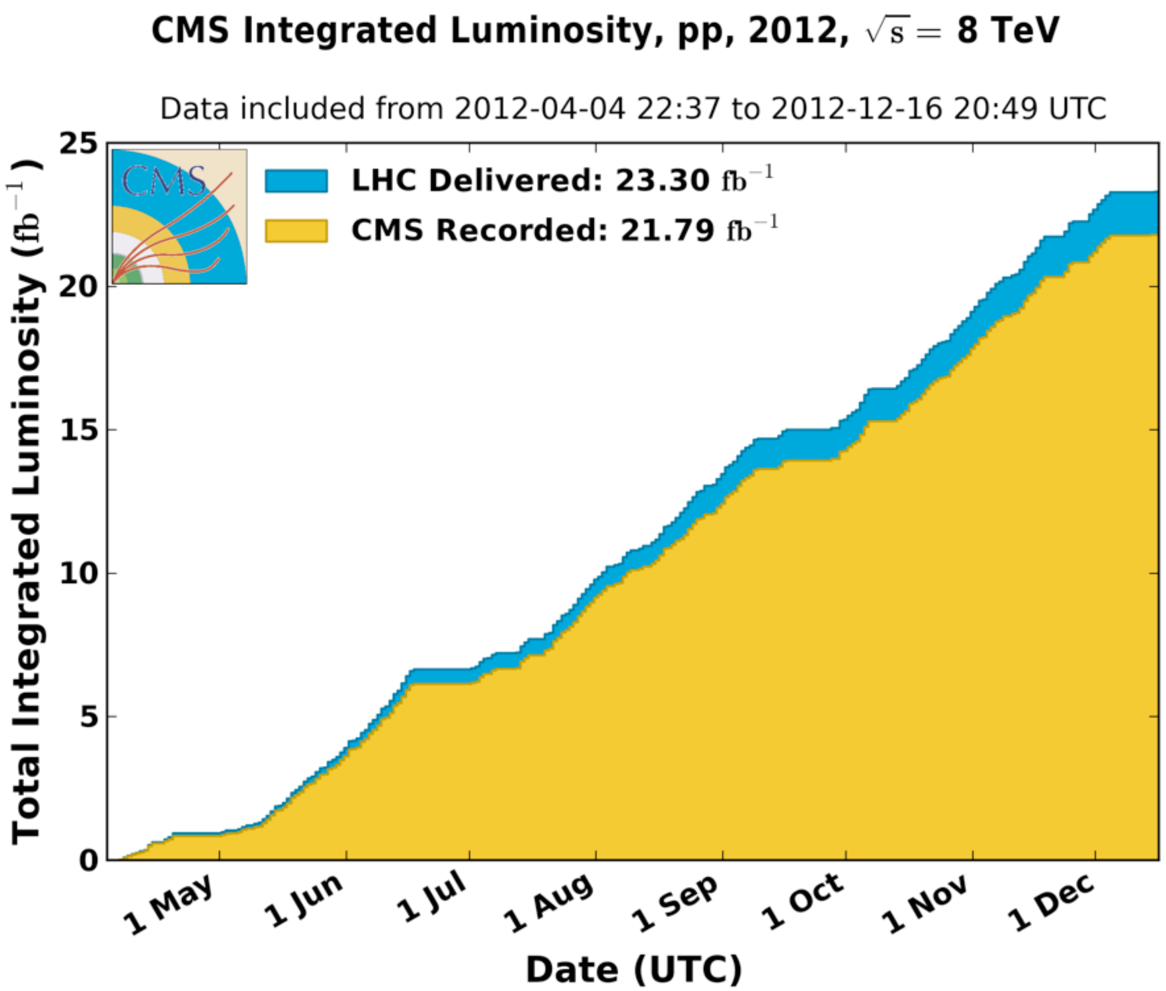
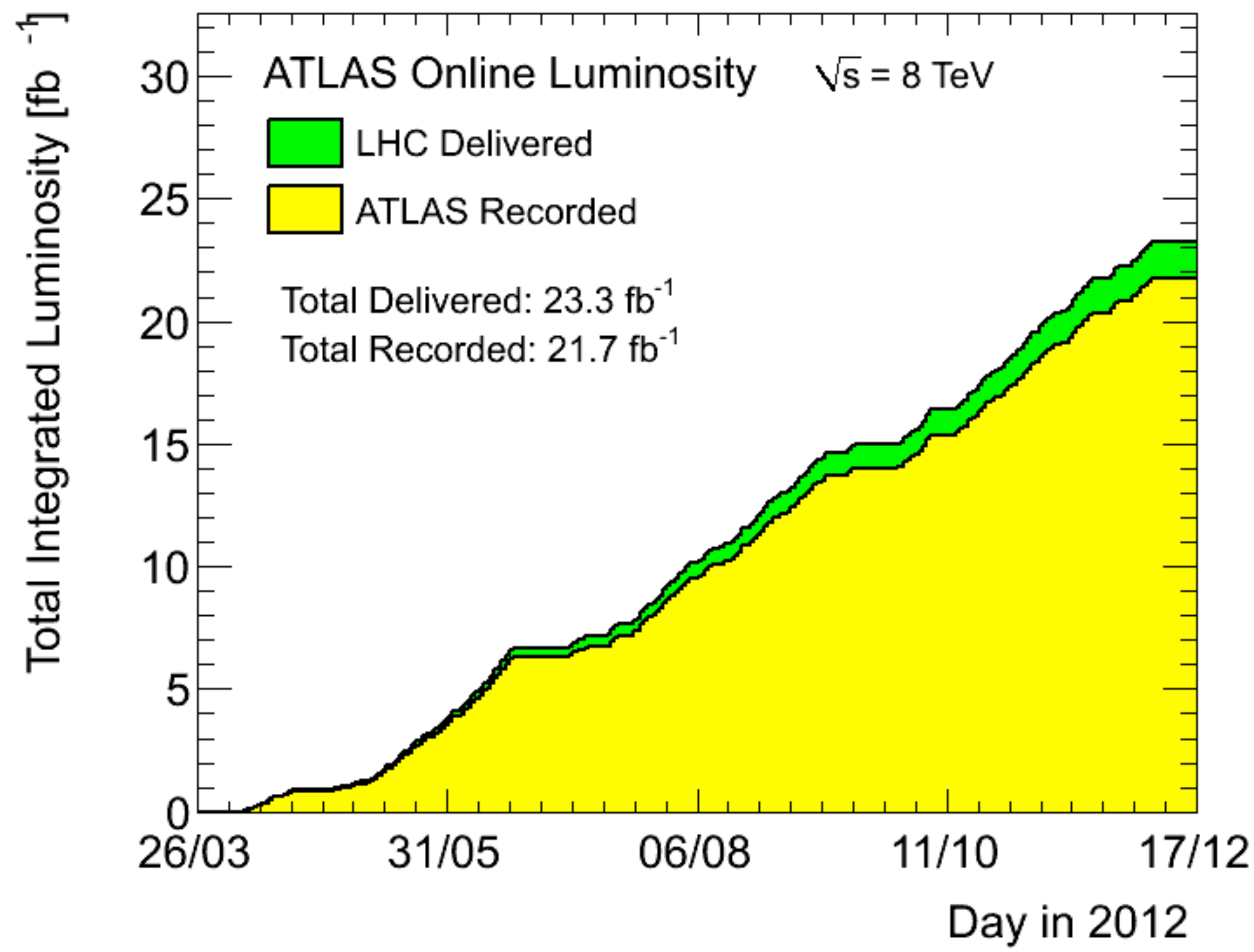
2011: L=~6 fb^{-1}





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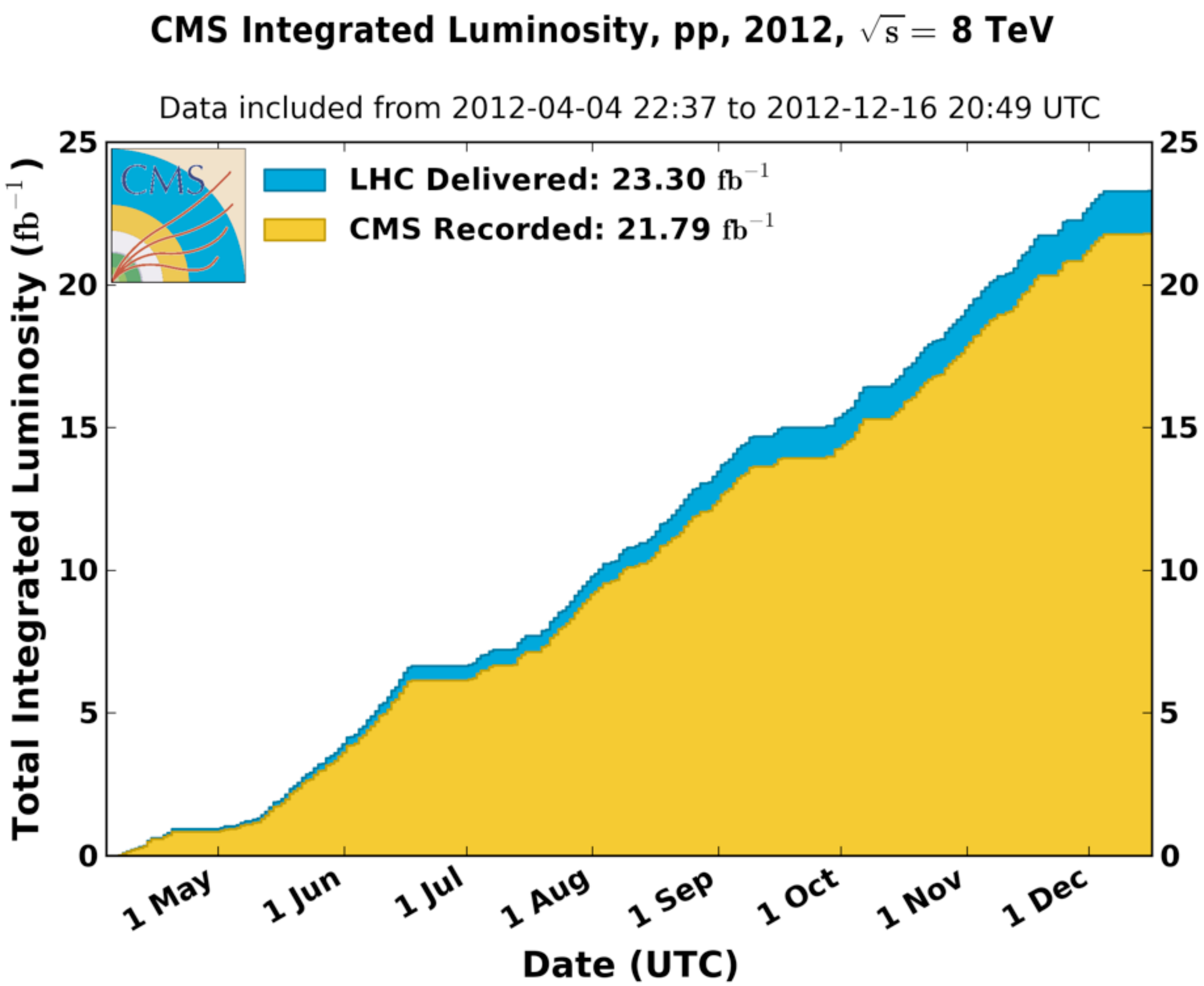

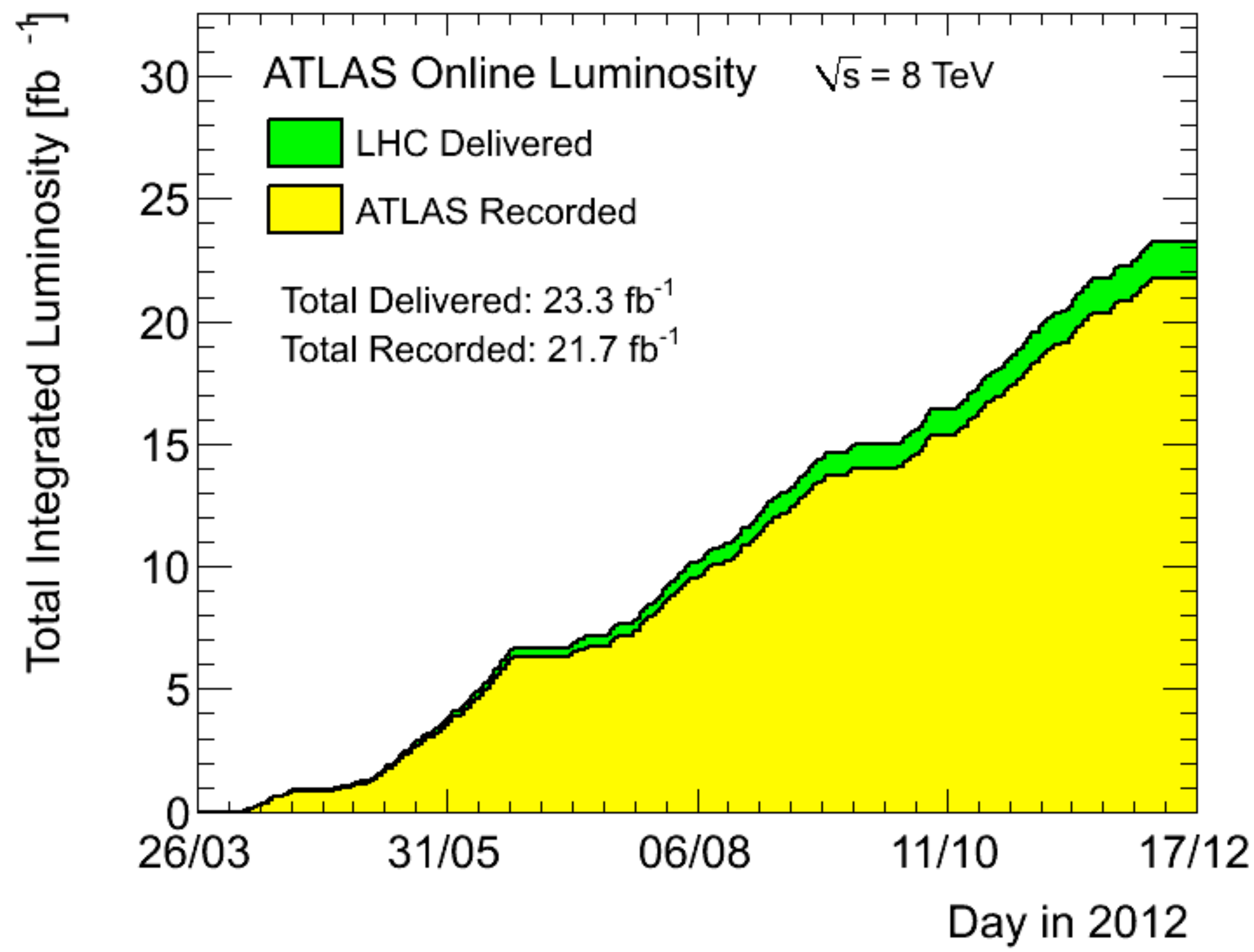

Total delivered luminosity: **~30 fb^{-1}**

Total recorded luminosity: **~27 fb^{-1}**

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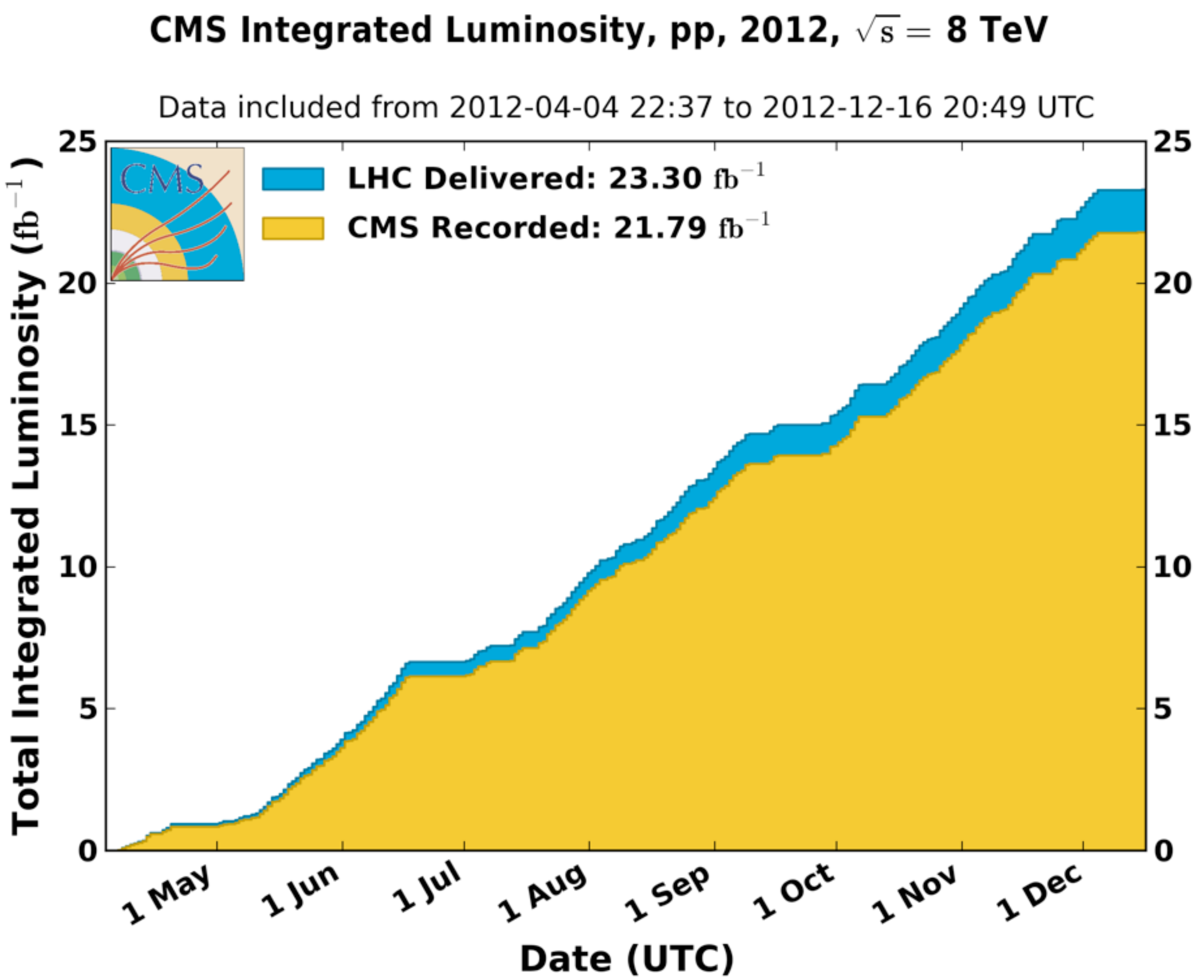

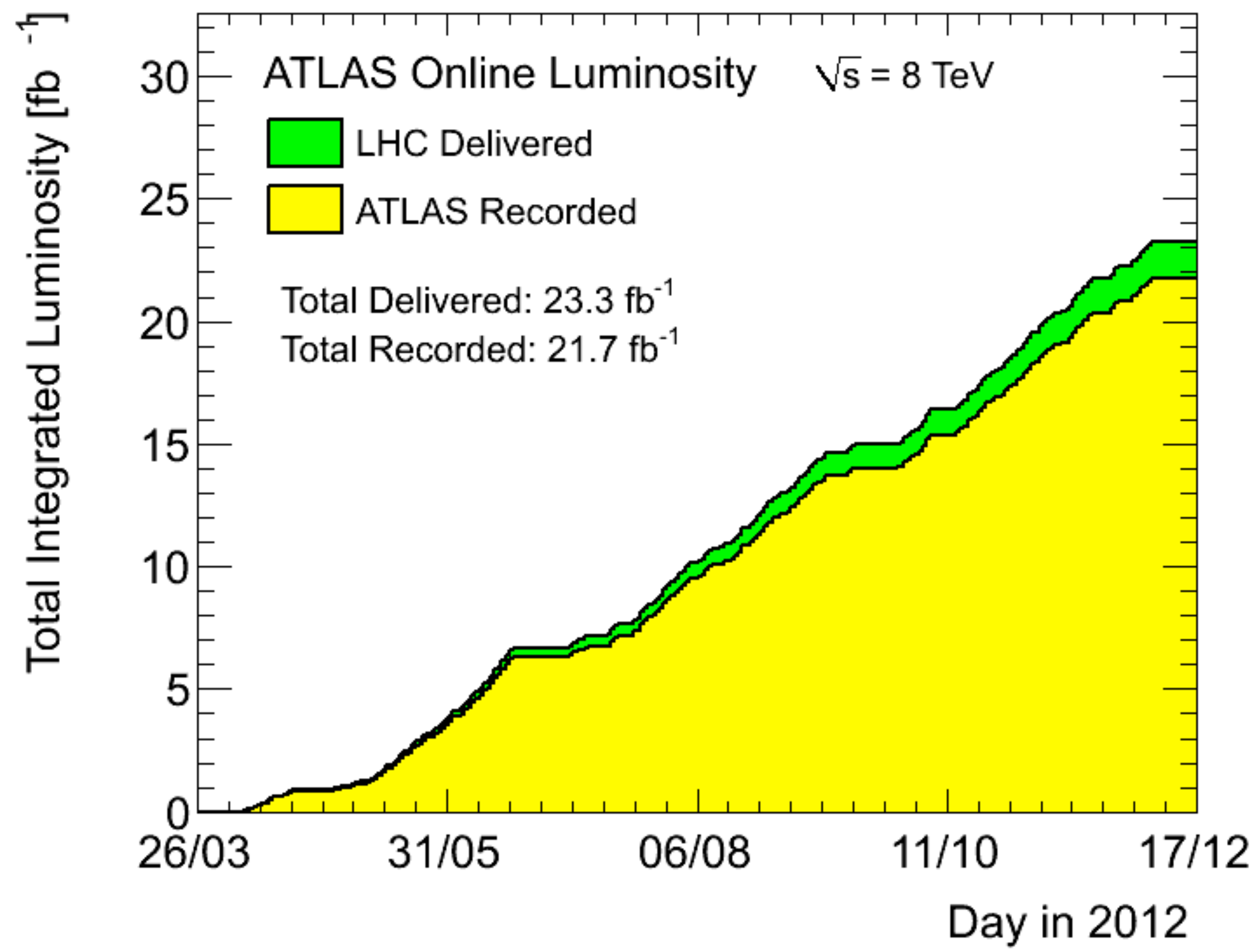

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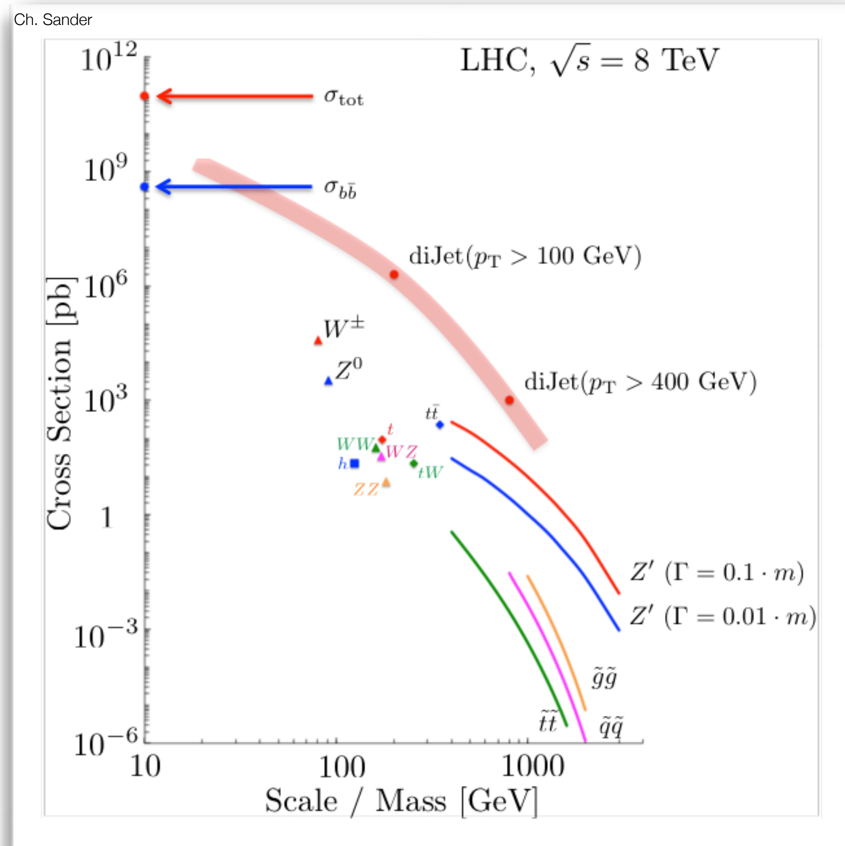
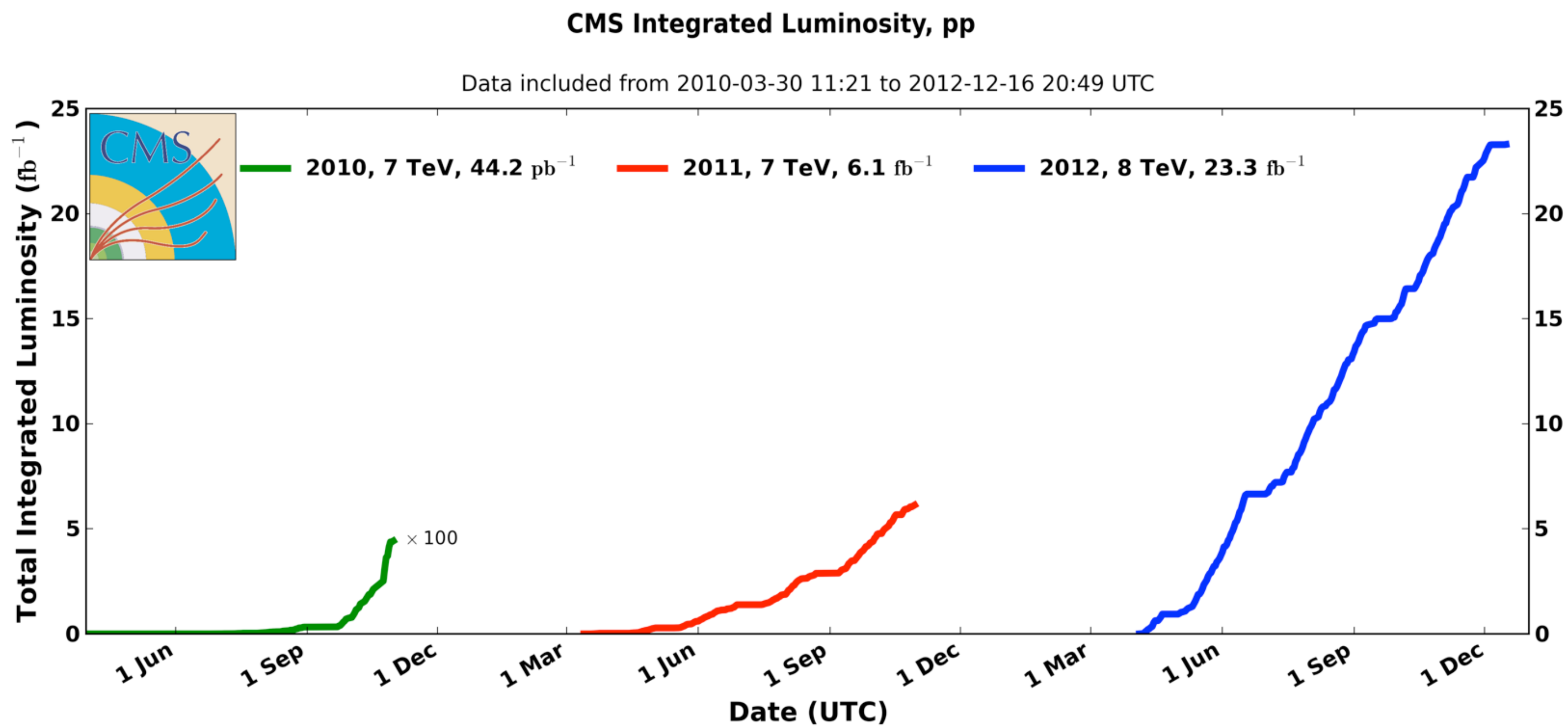
Excellent LHC peformance and very high data-taking efficiency of the two detectors

A 3-year long sprint....

CMS as example ...





From G. Dissertori (ETH)

δ .. relative uncert.
Δ .. absolute uncert.

A 3-year long sprint....

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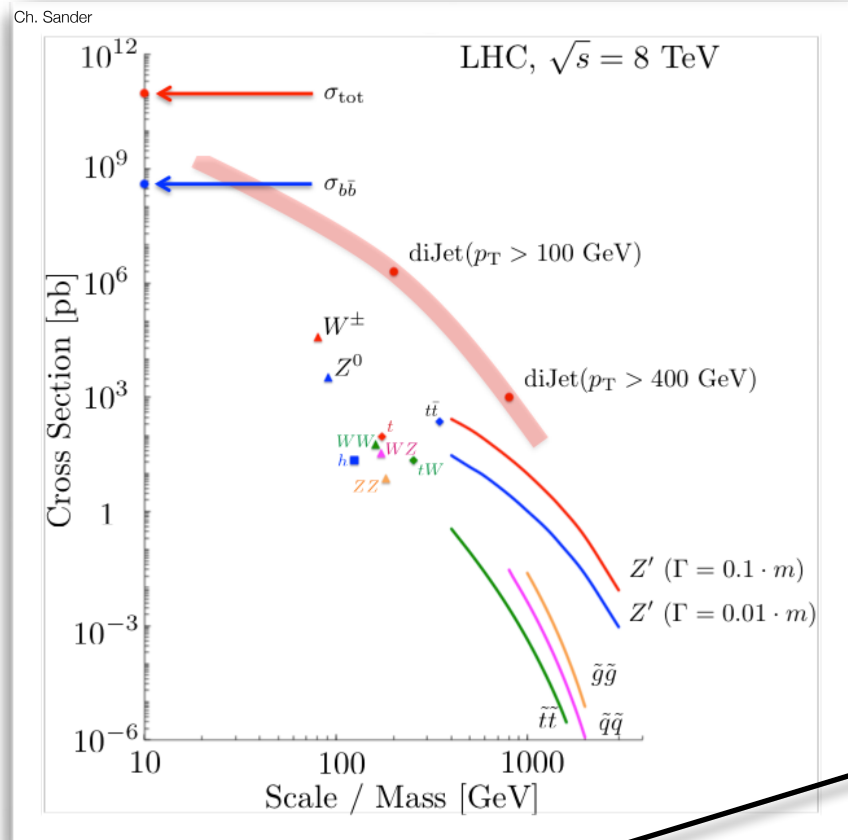

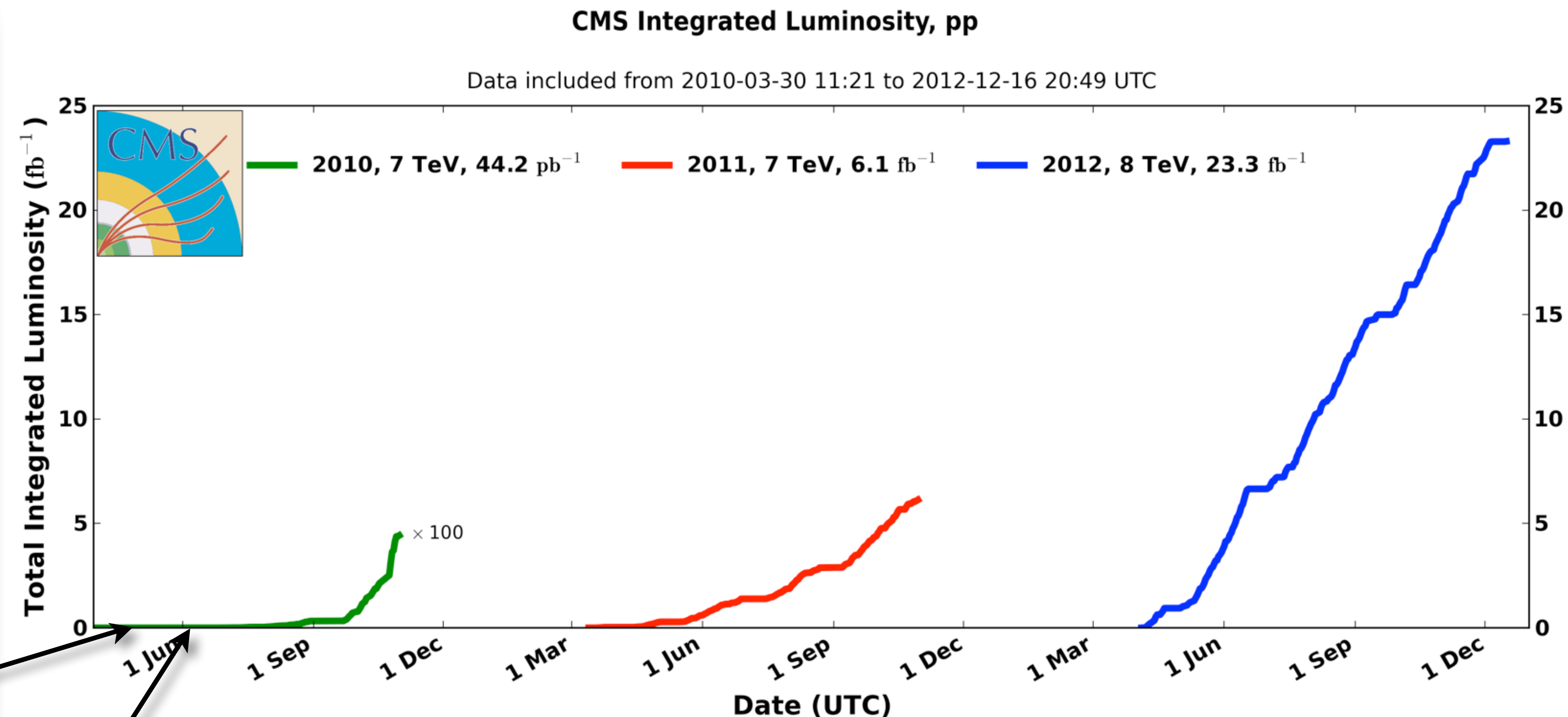

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studies, particle multiplicities

first incl. jet x-section, PF jets
60/nb δ ~ 20-30%

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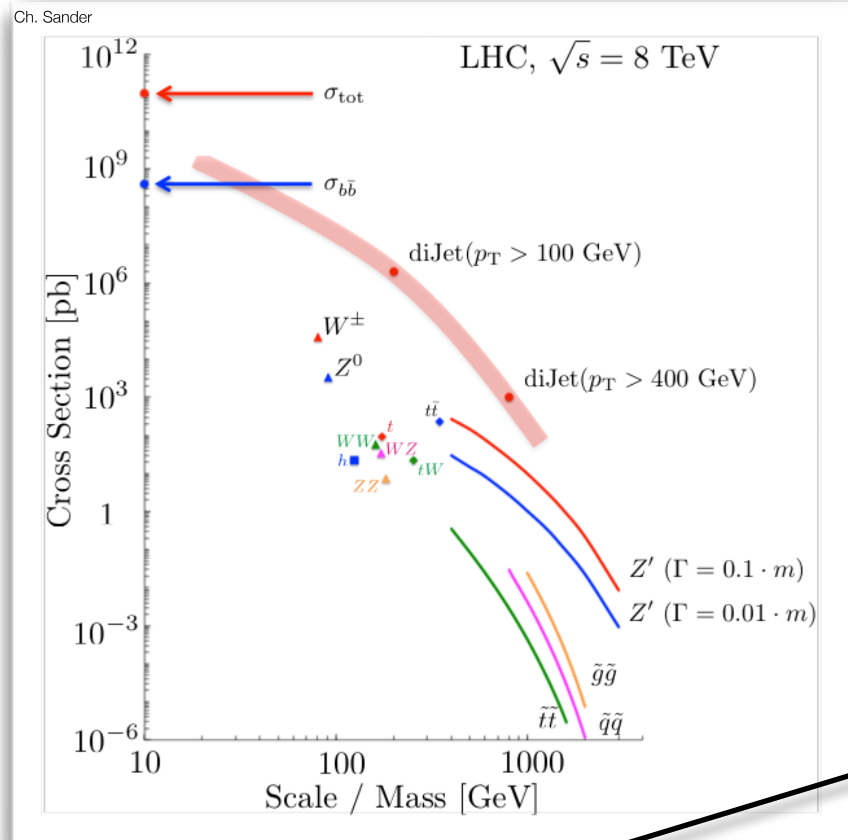

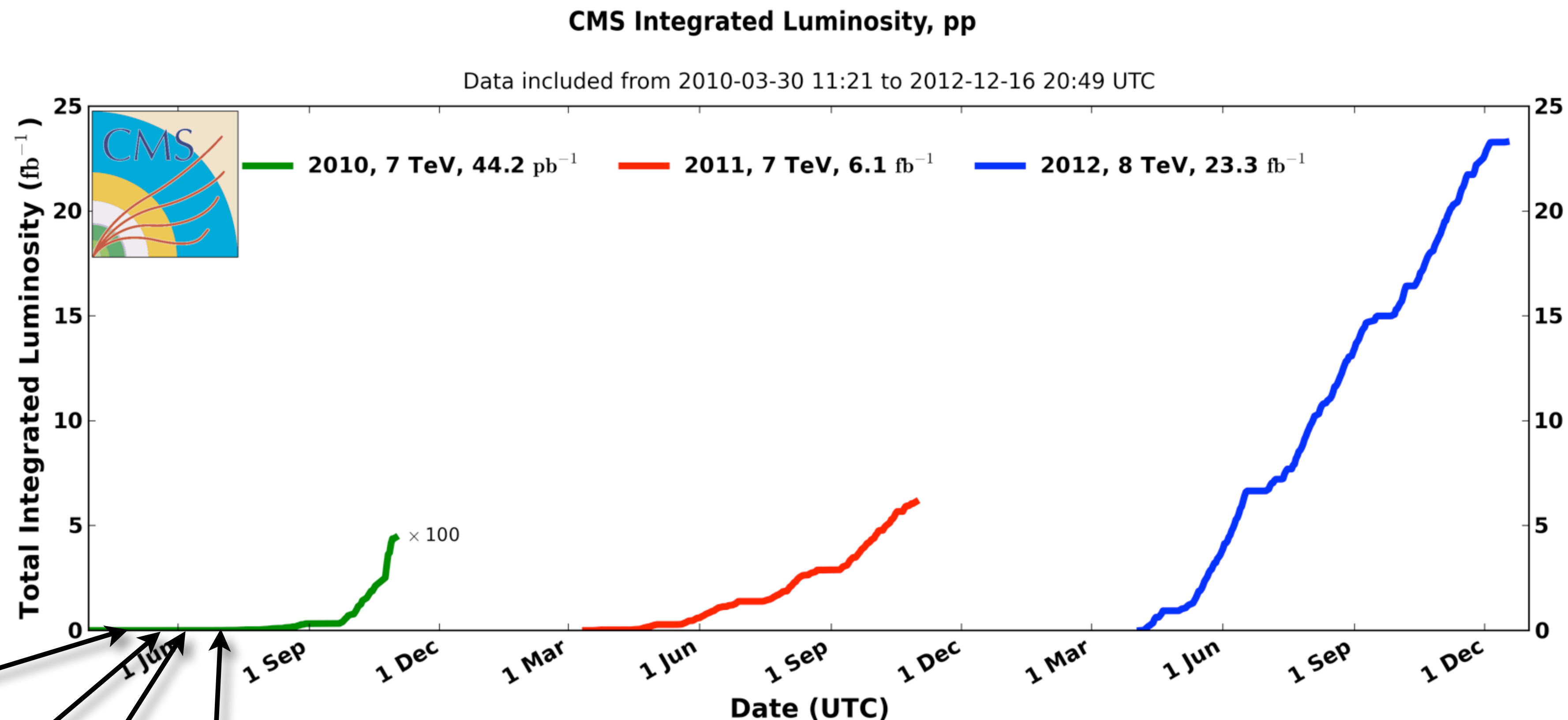

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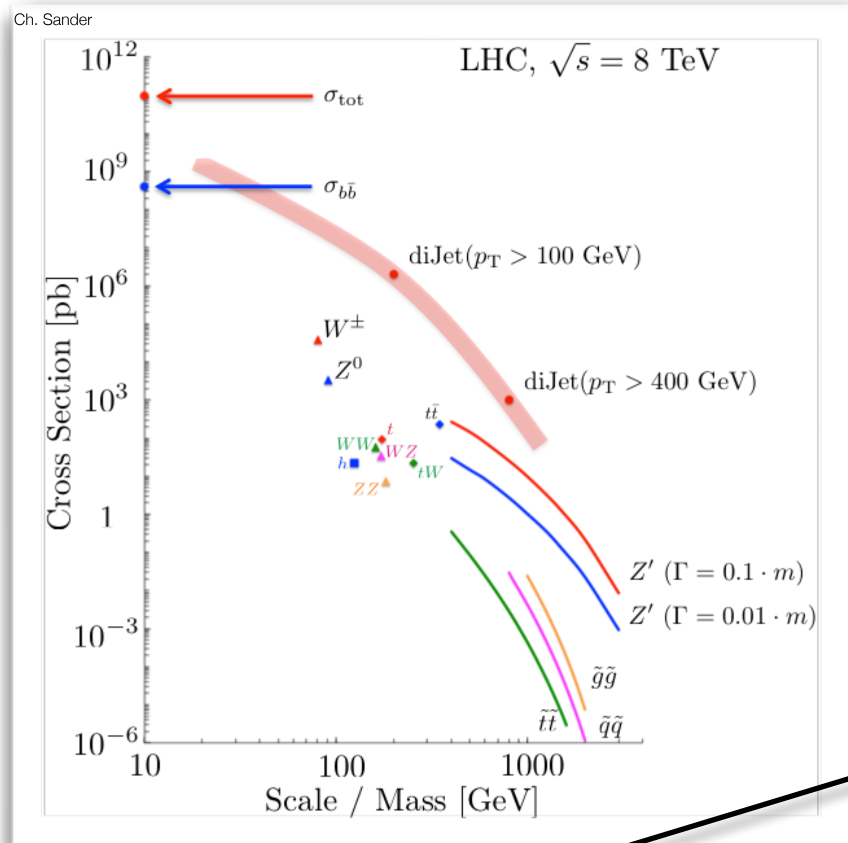

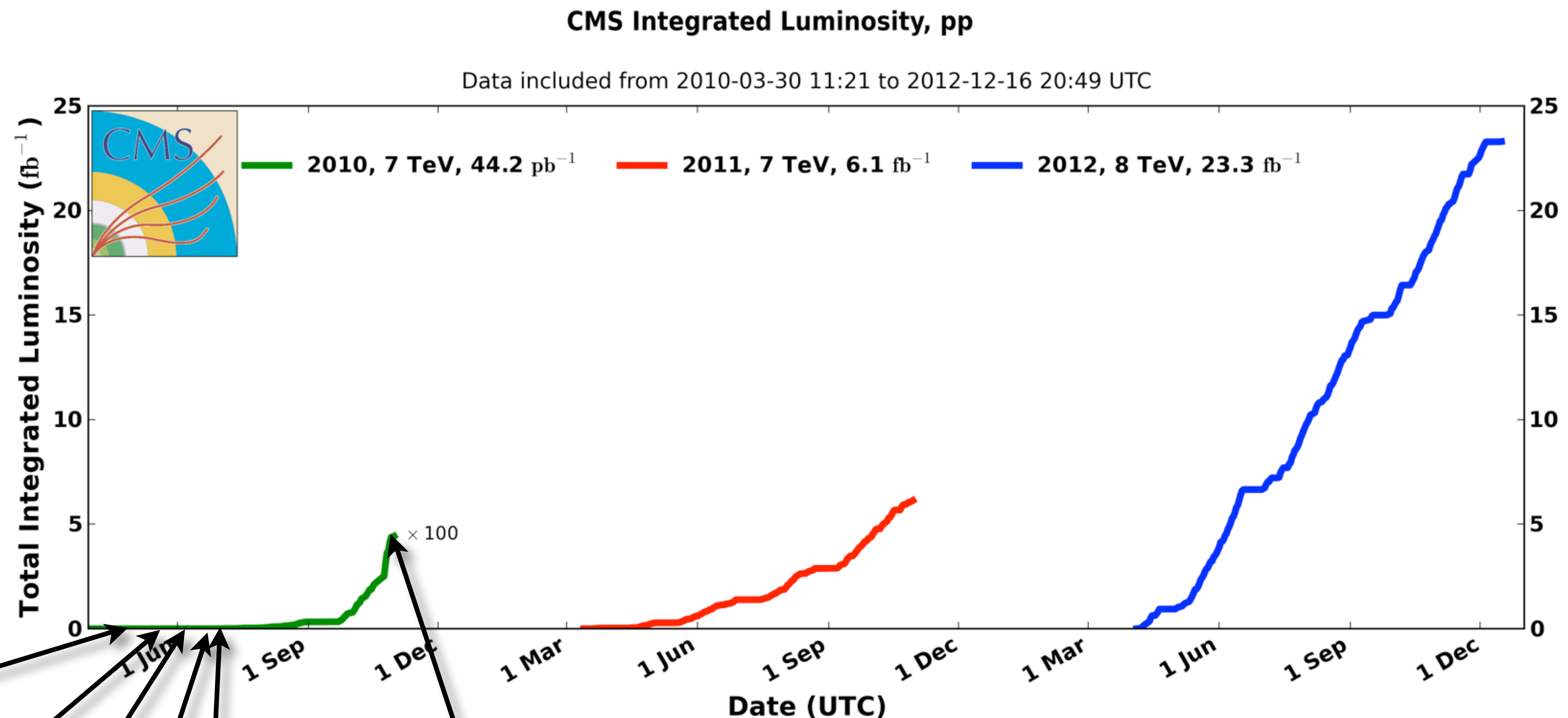

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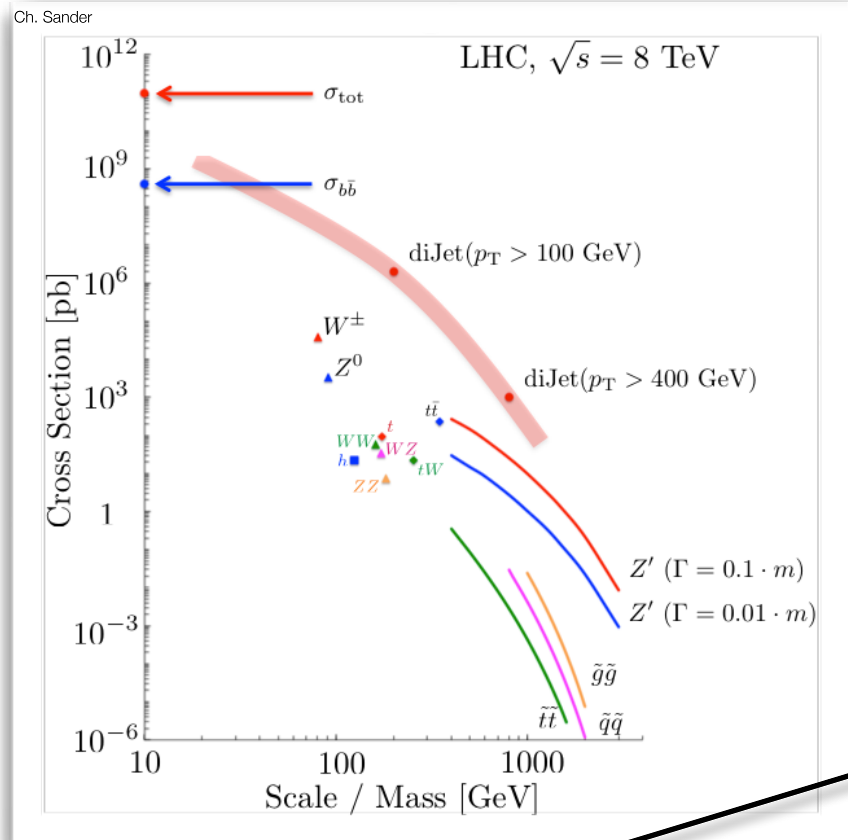

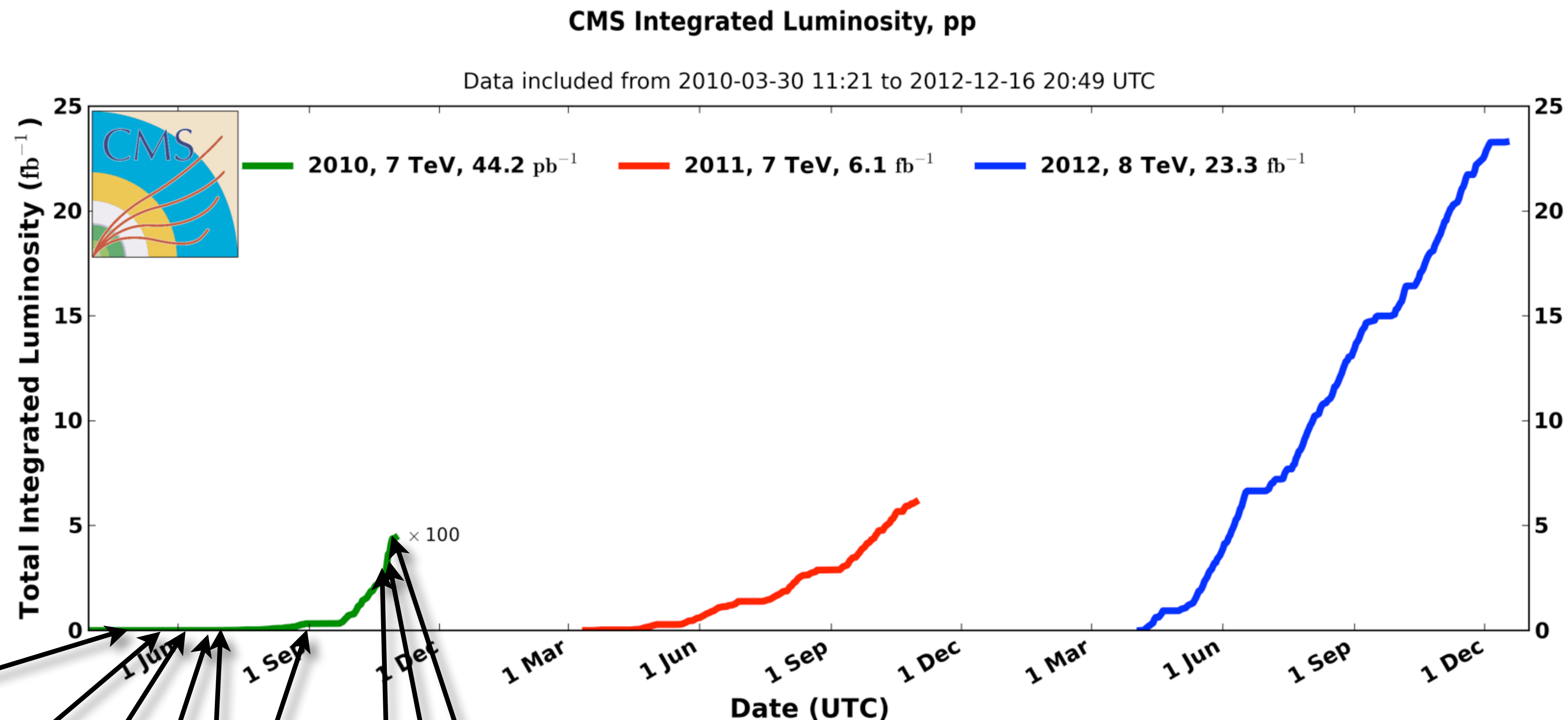

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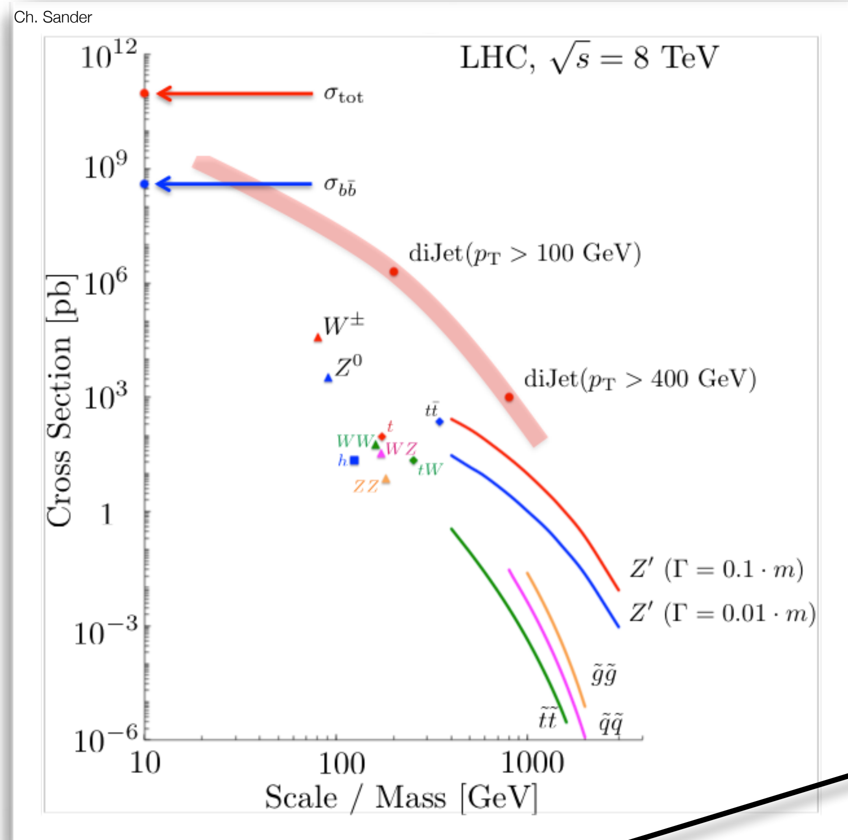

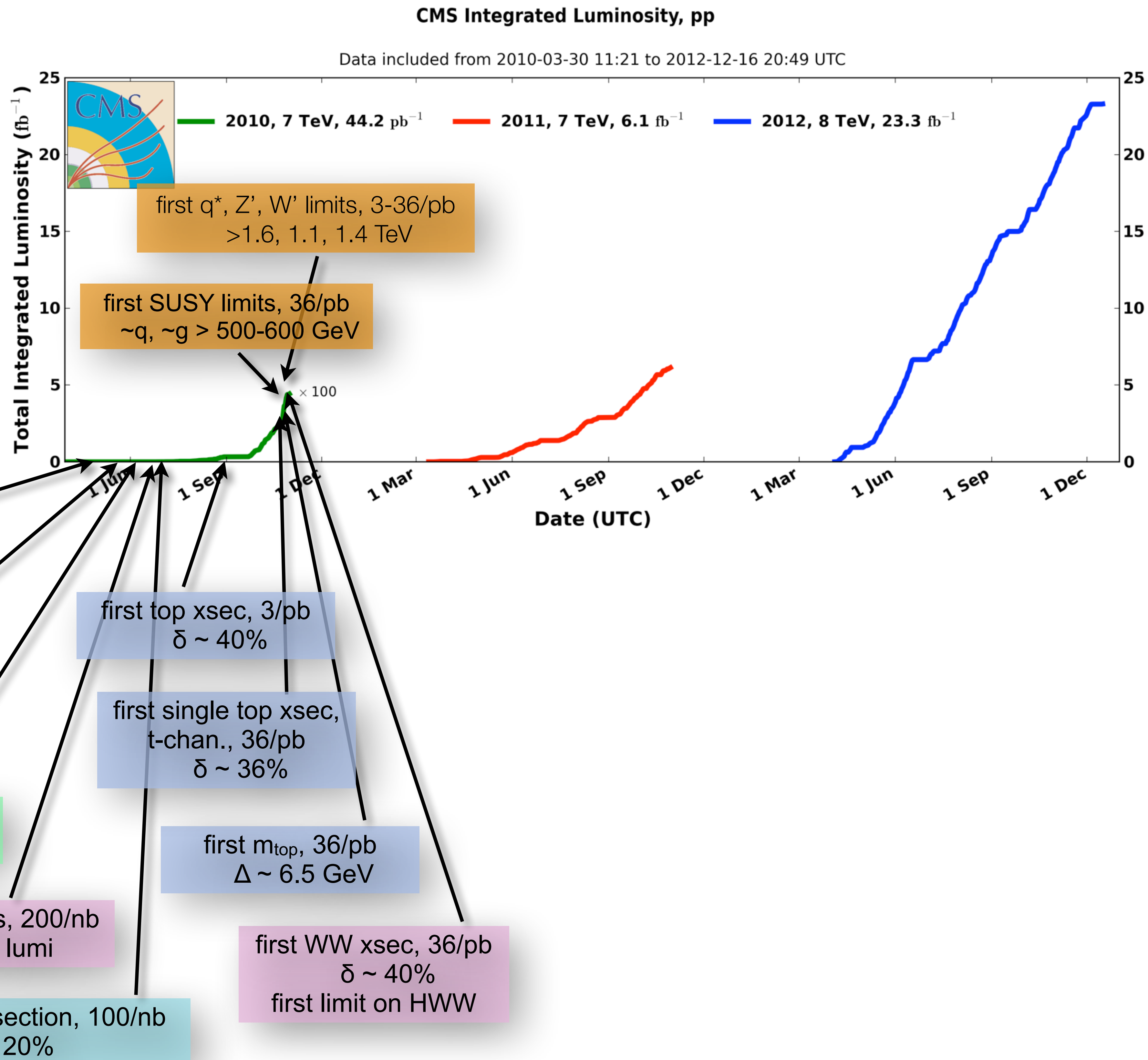

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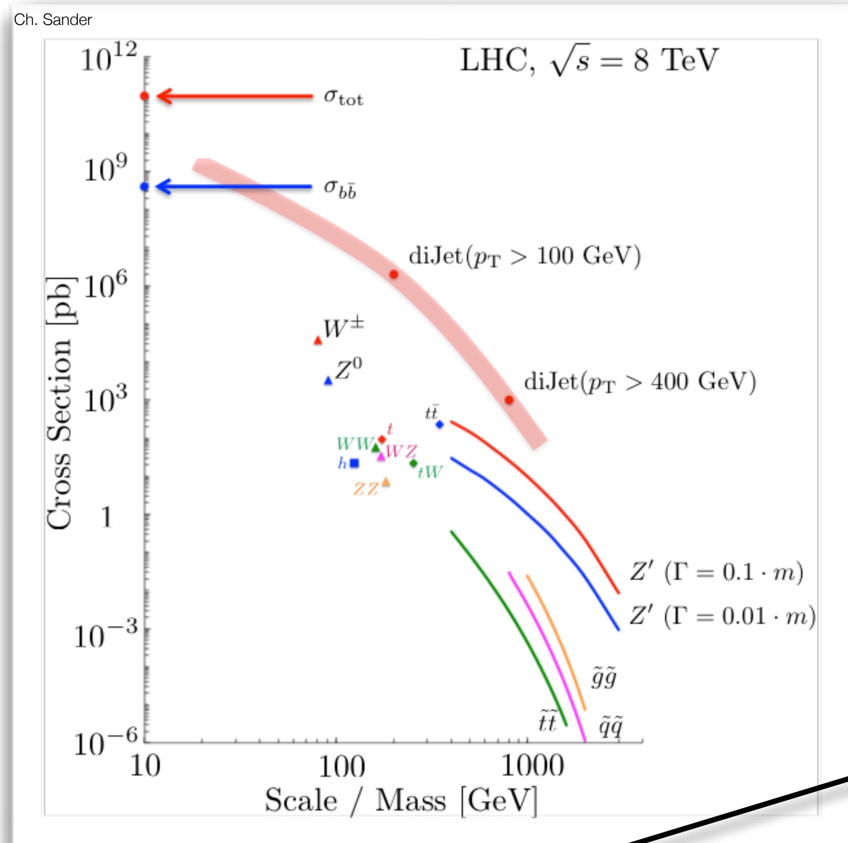

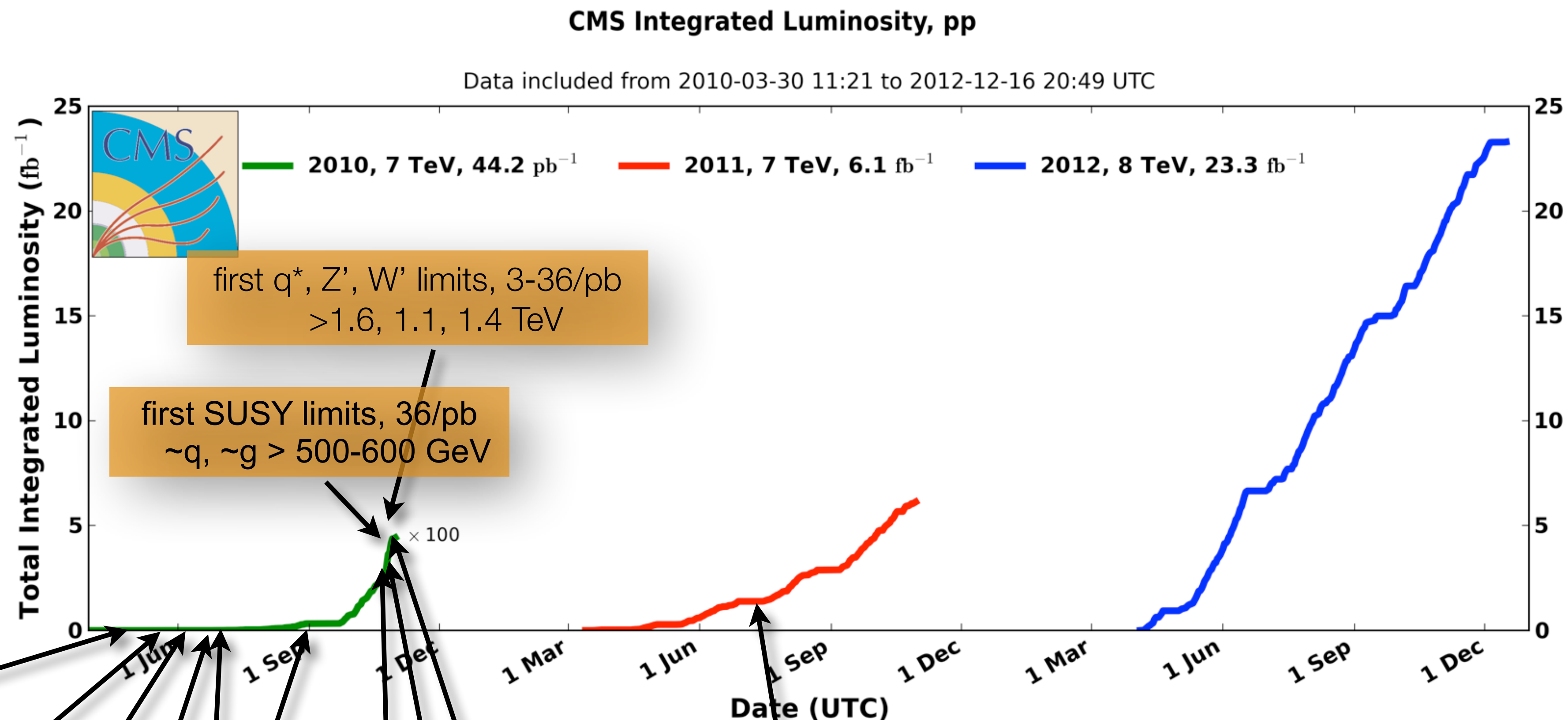

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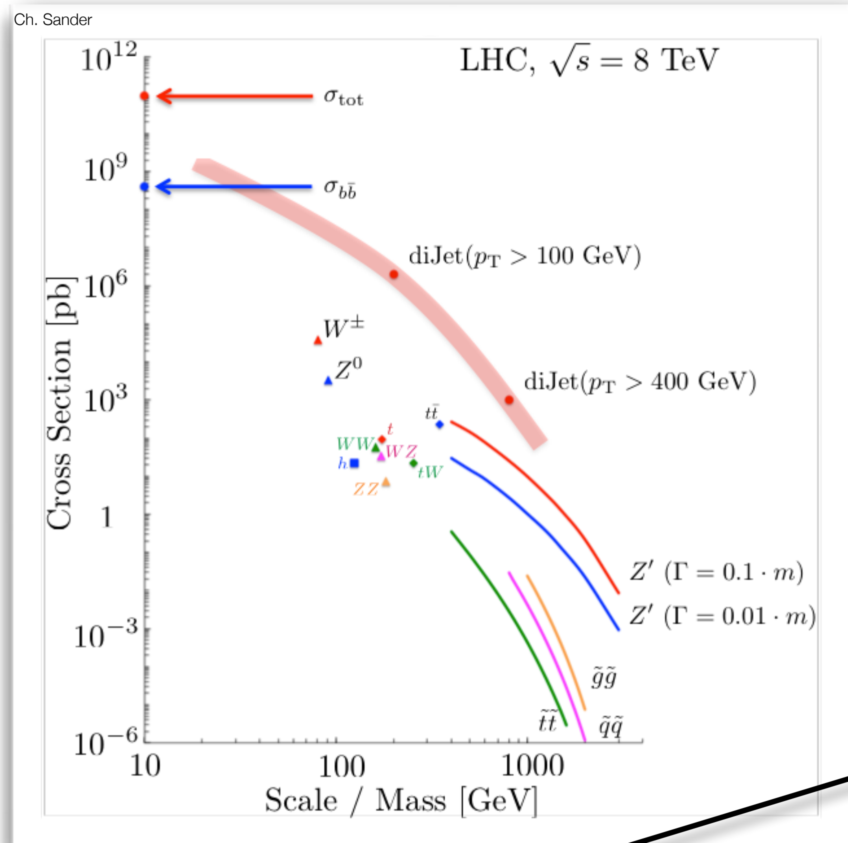

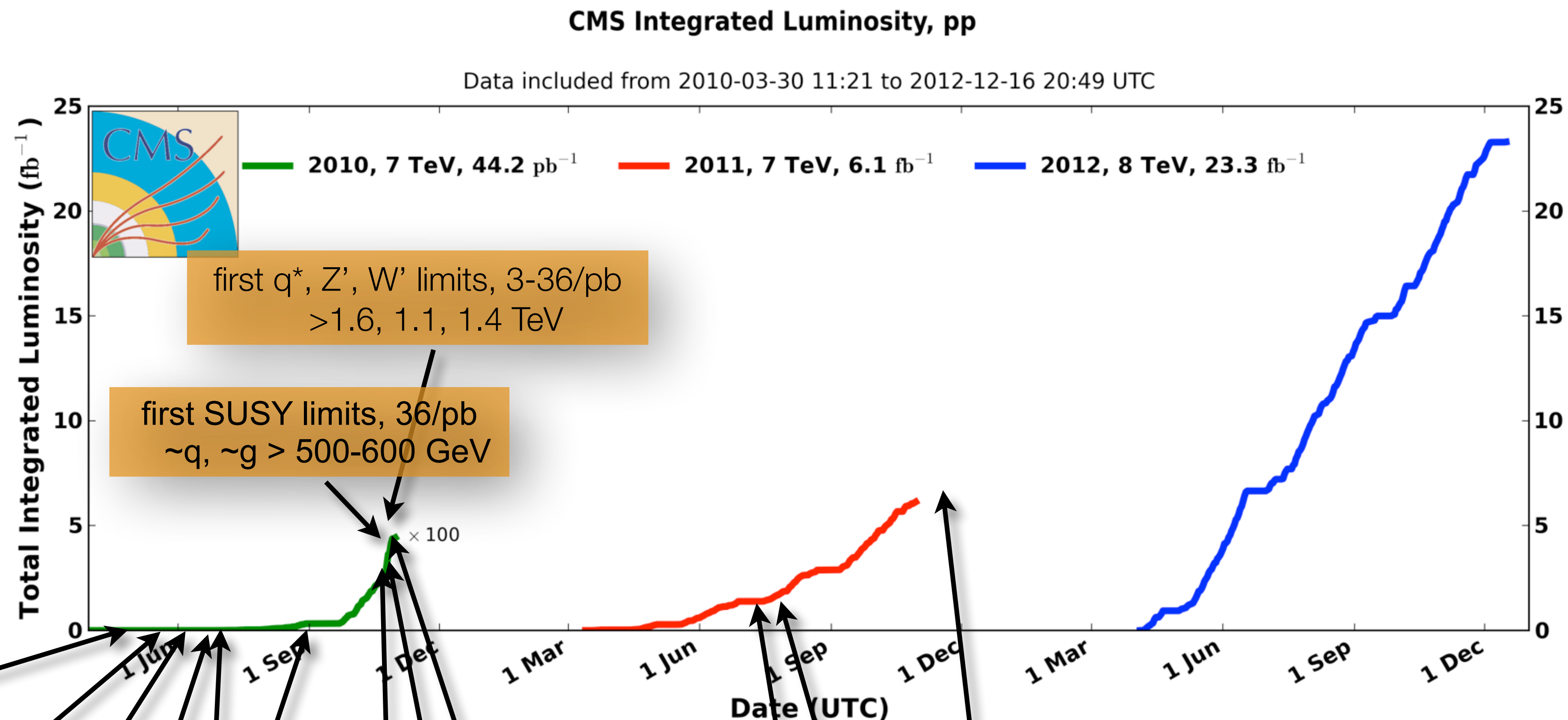

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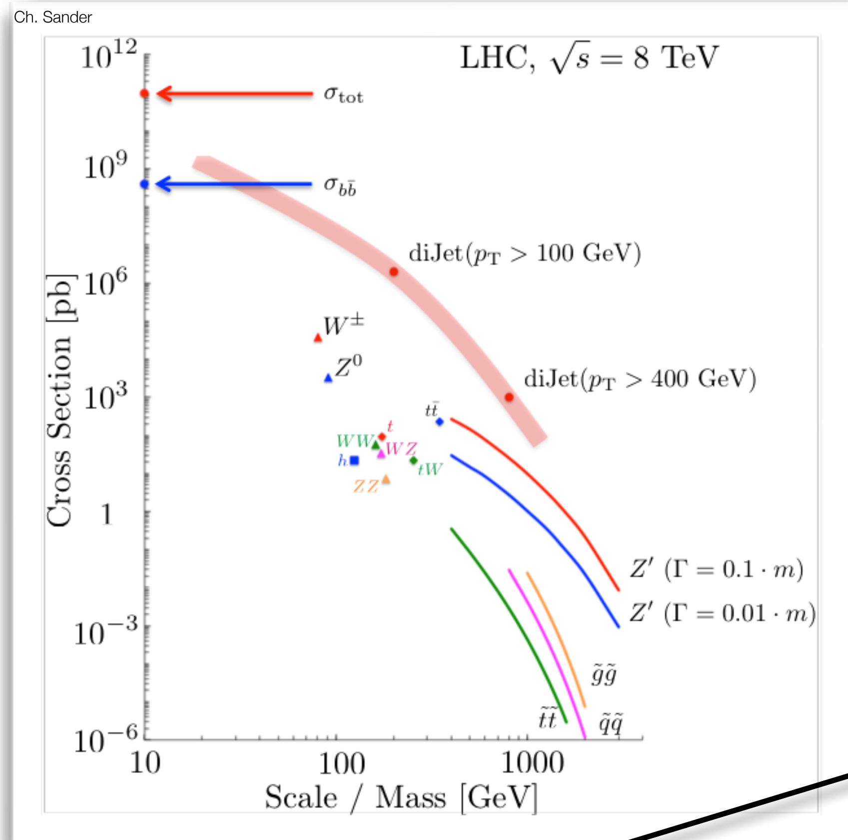

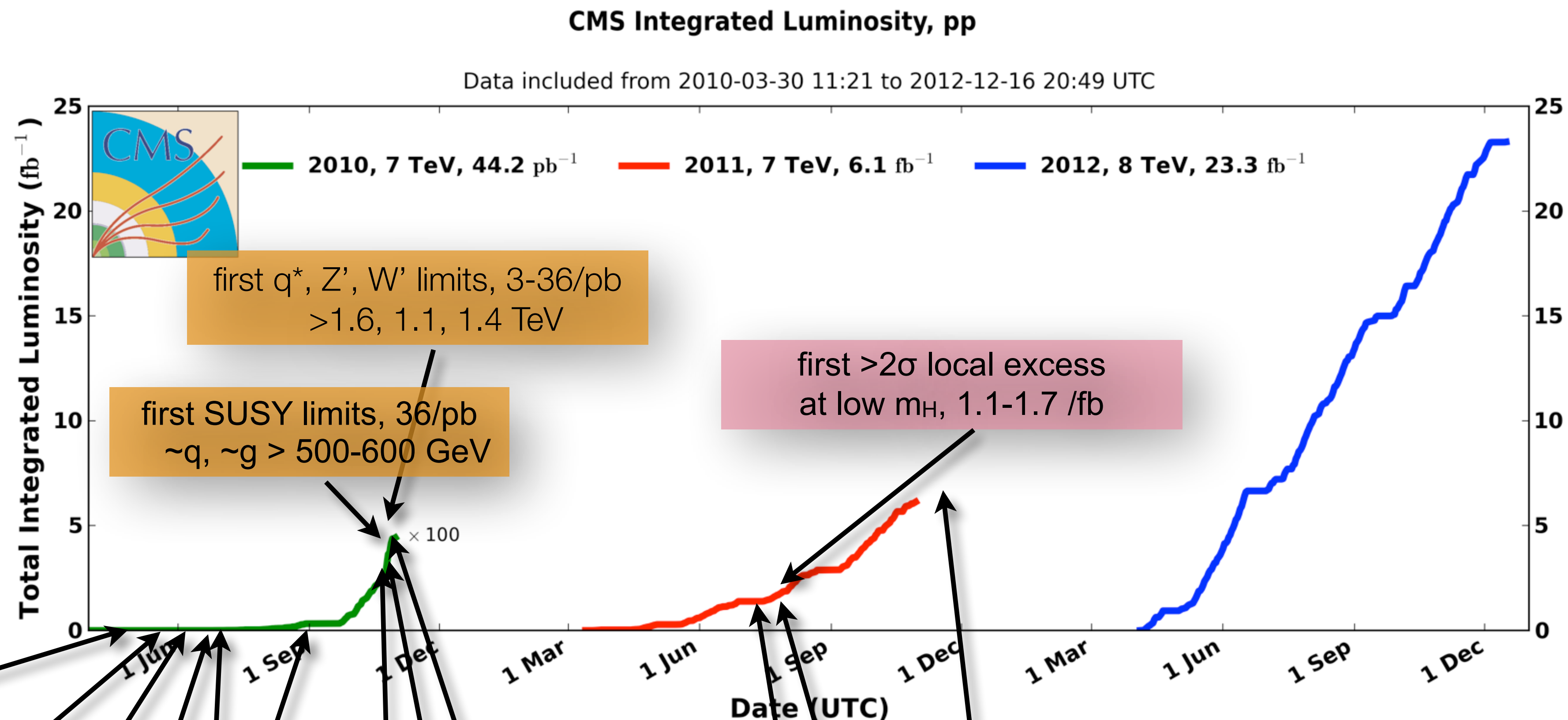

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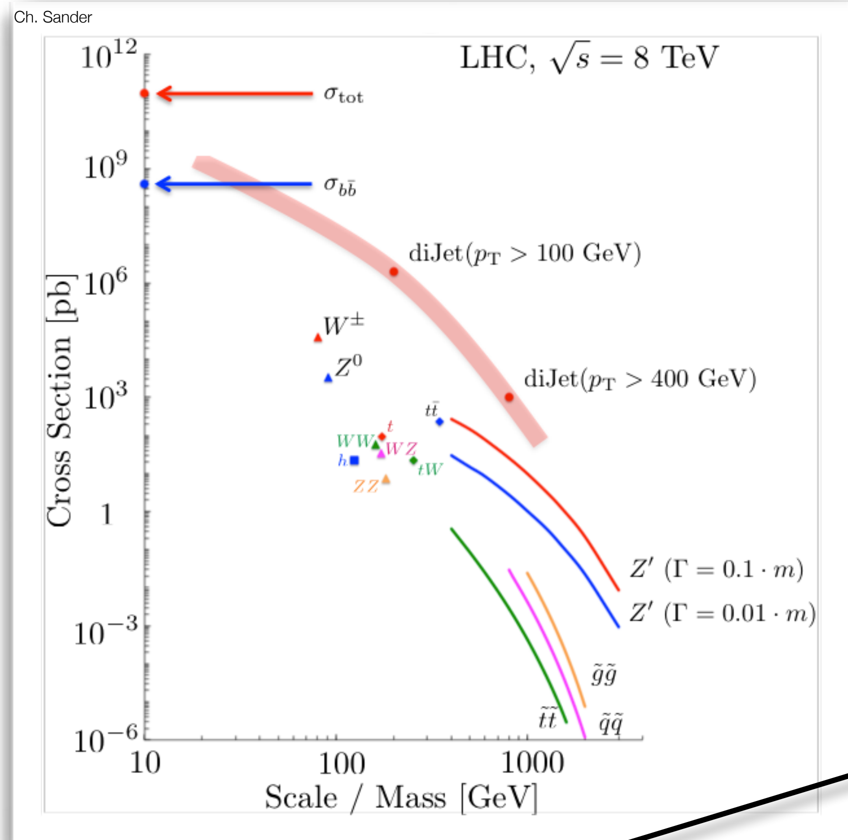

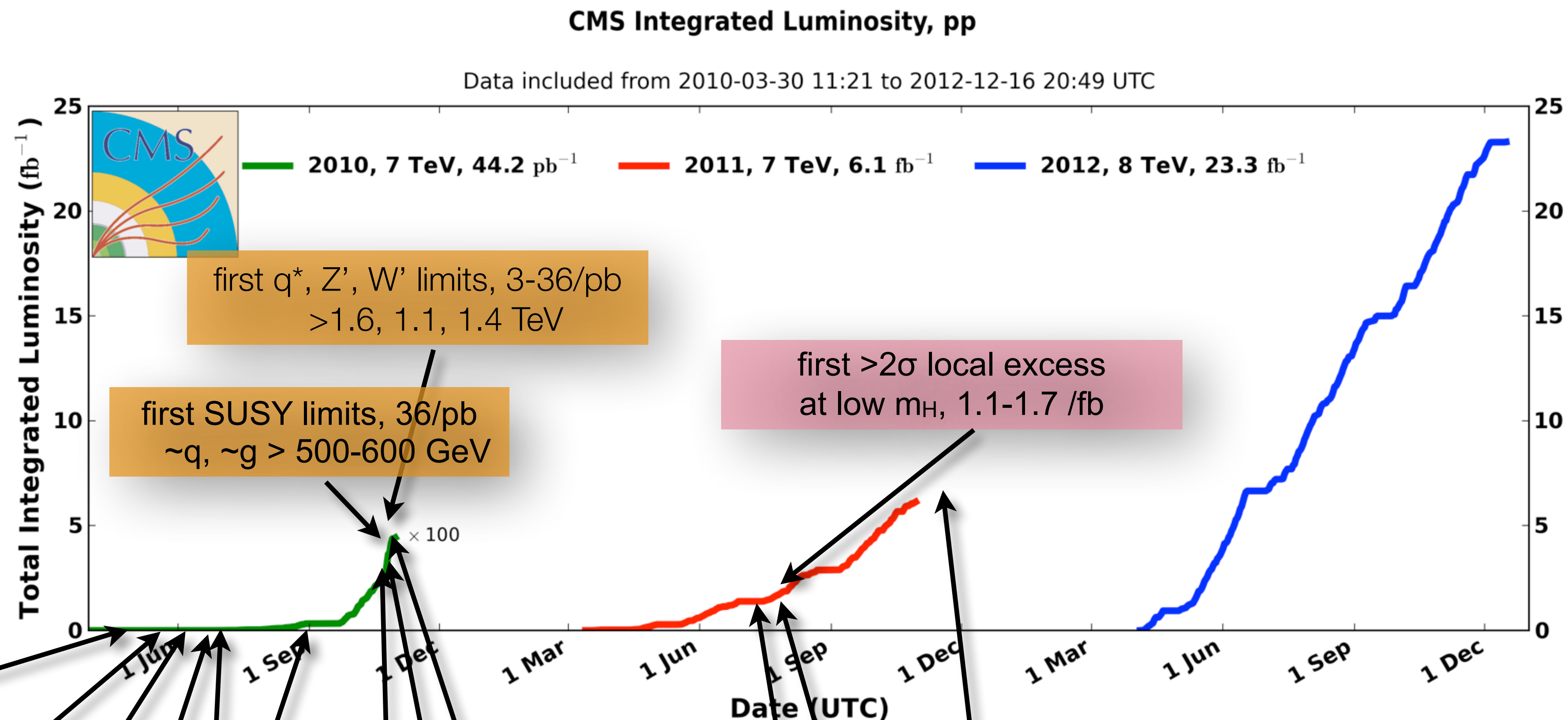

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BSM searches continue,
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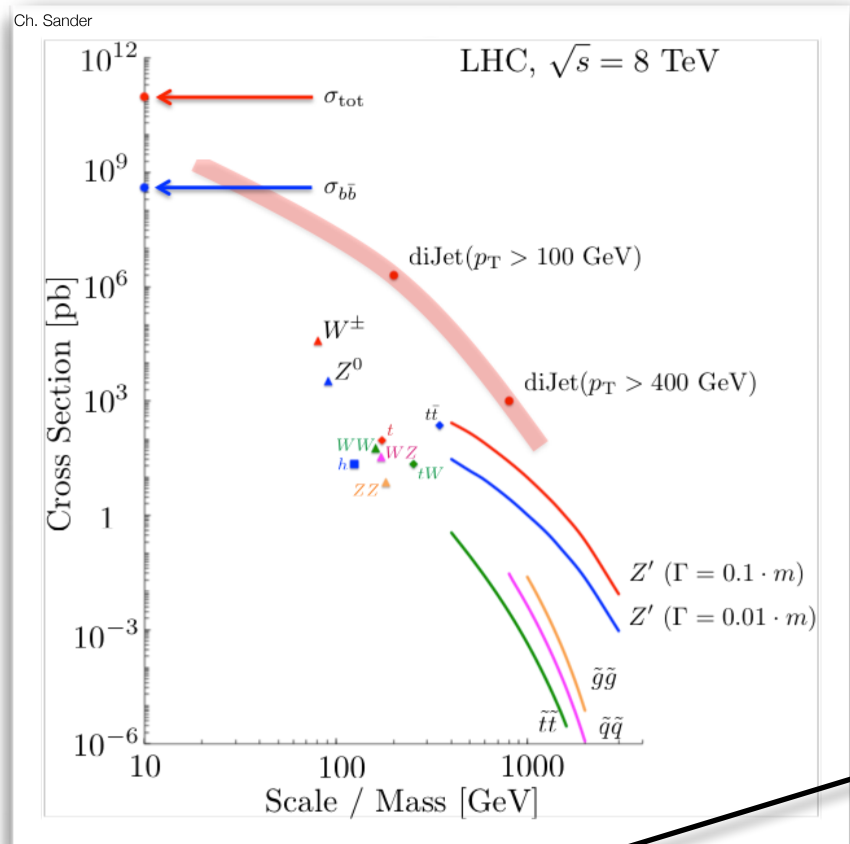

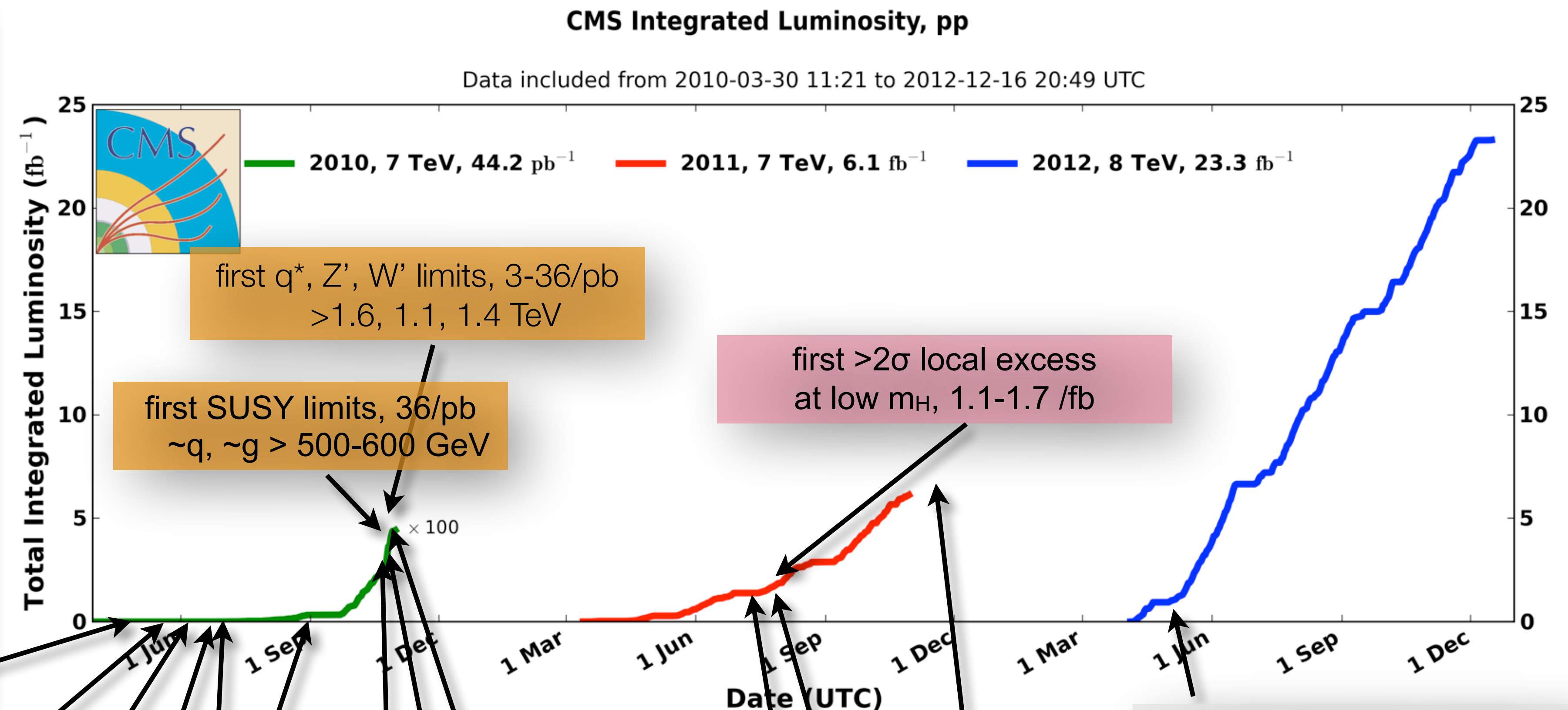

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repeating the program at 8 TeV

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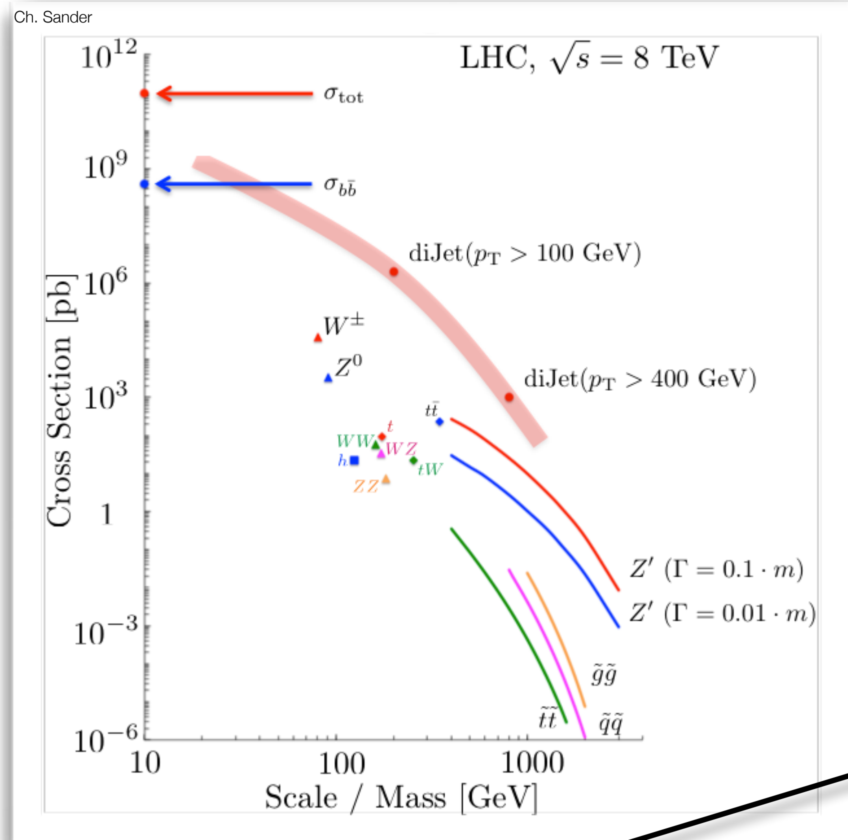

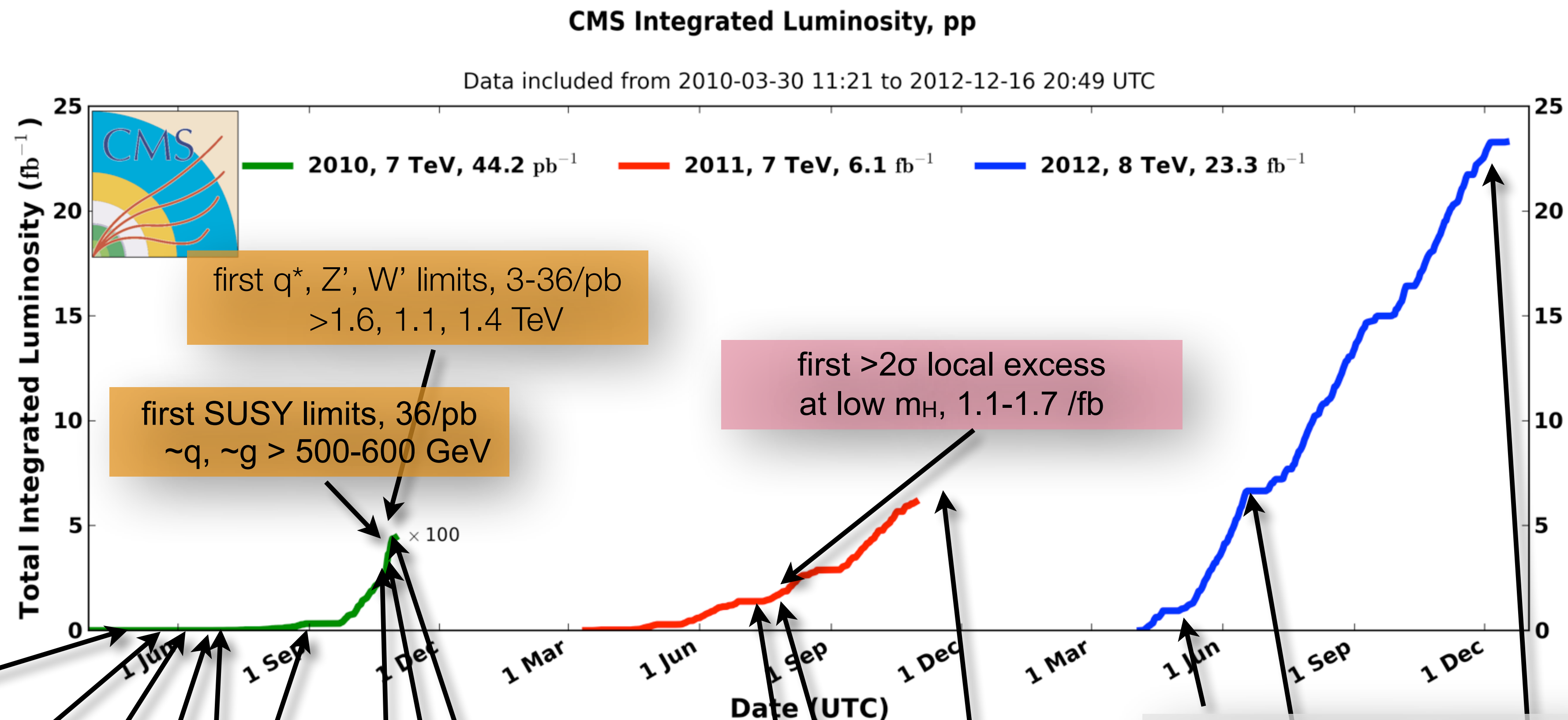

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a new boson is announced, 5 /fb

first spin parity analysis of the boson, 17 /fb

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From G. Dissertori (ETH)

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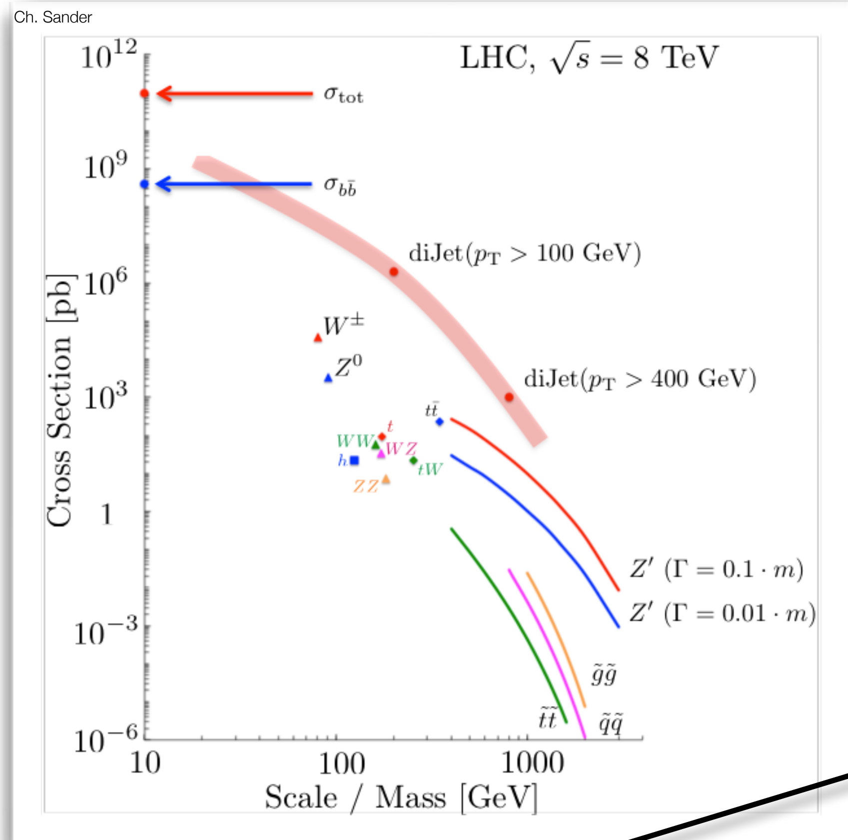

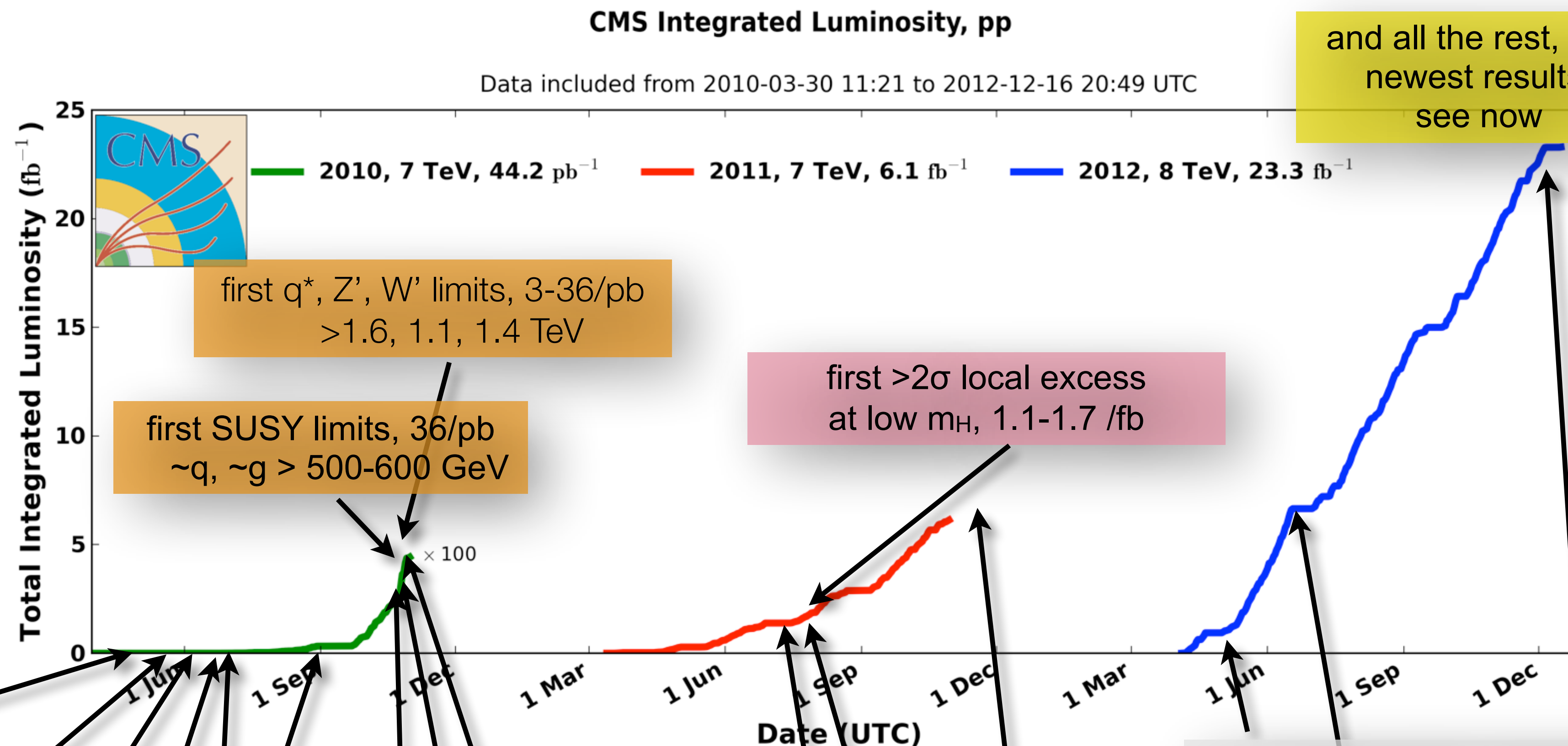

and all the rest, plus newest results: see now

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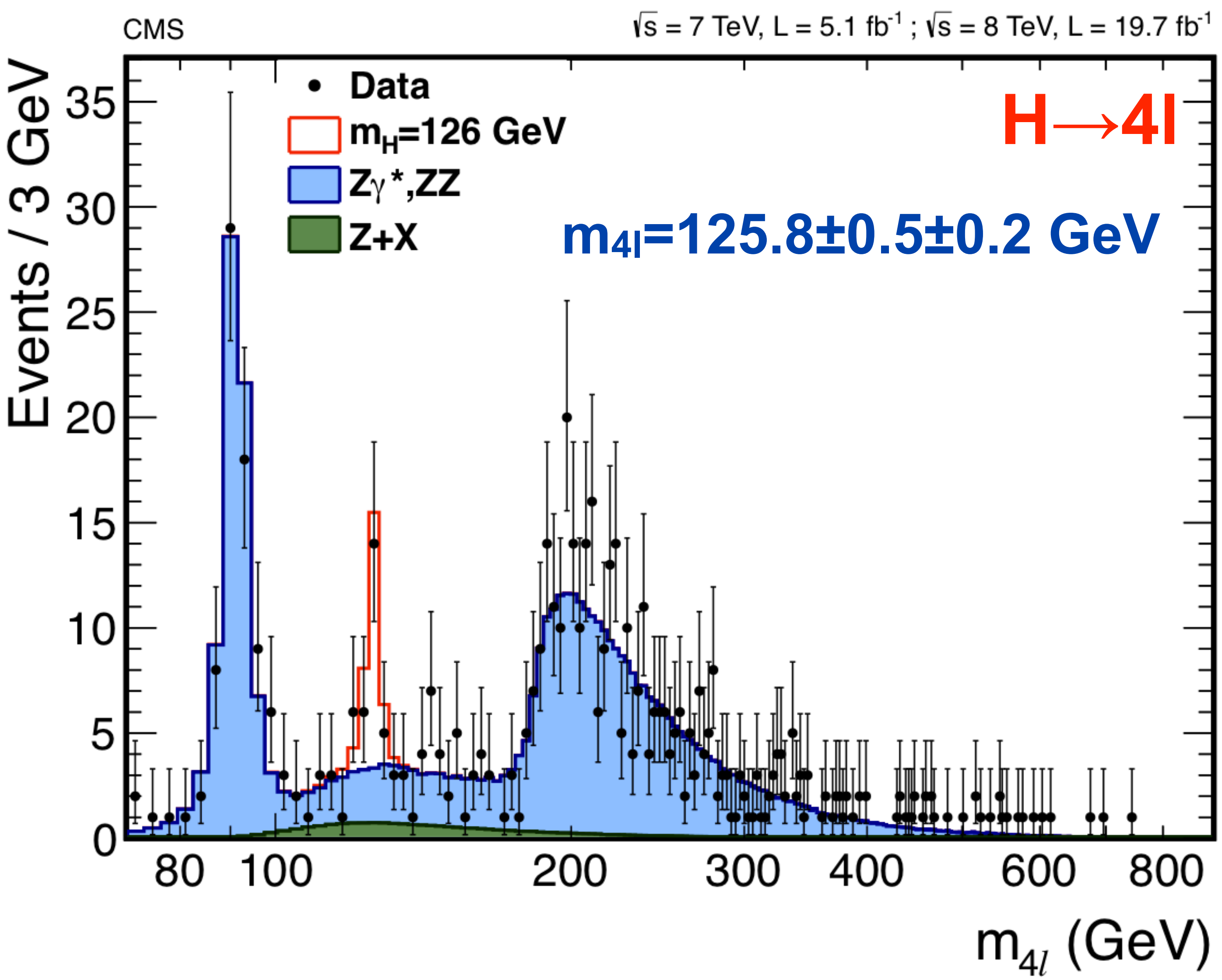
From G. Dissertori (ETH)

New boson with a mass of ~125 GeV

New boson with a mass of ~125 GeV



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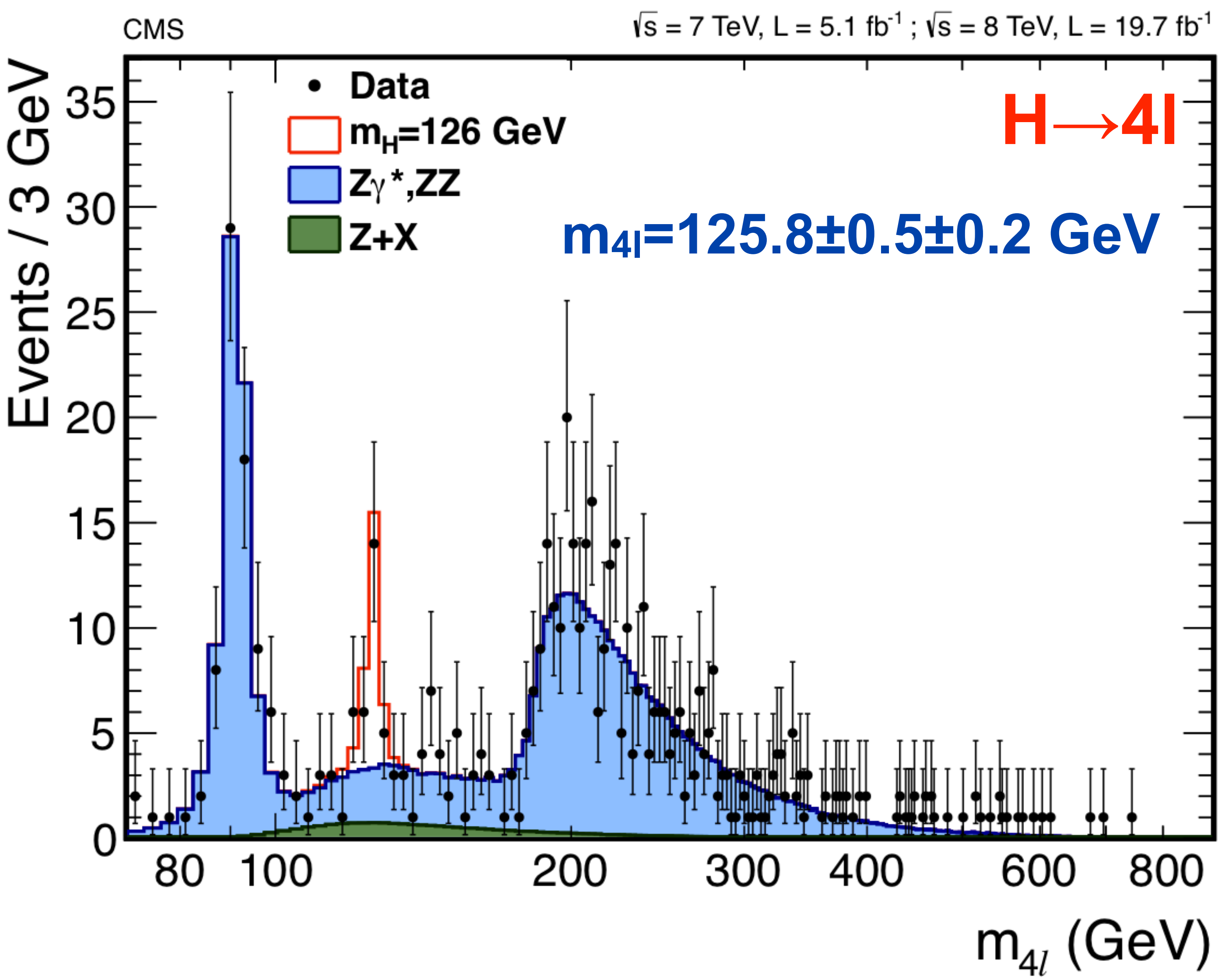

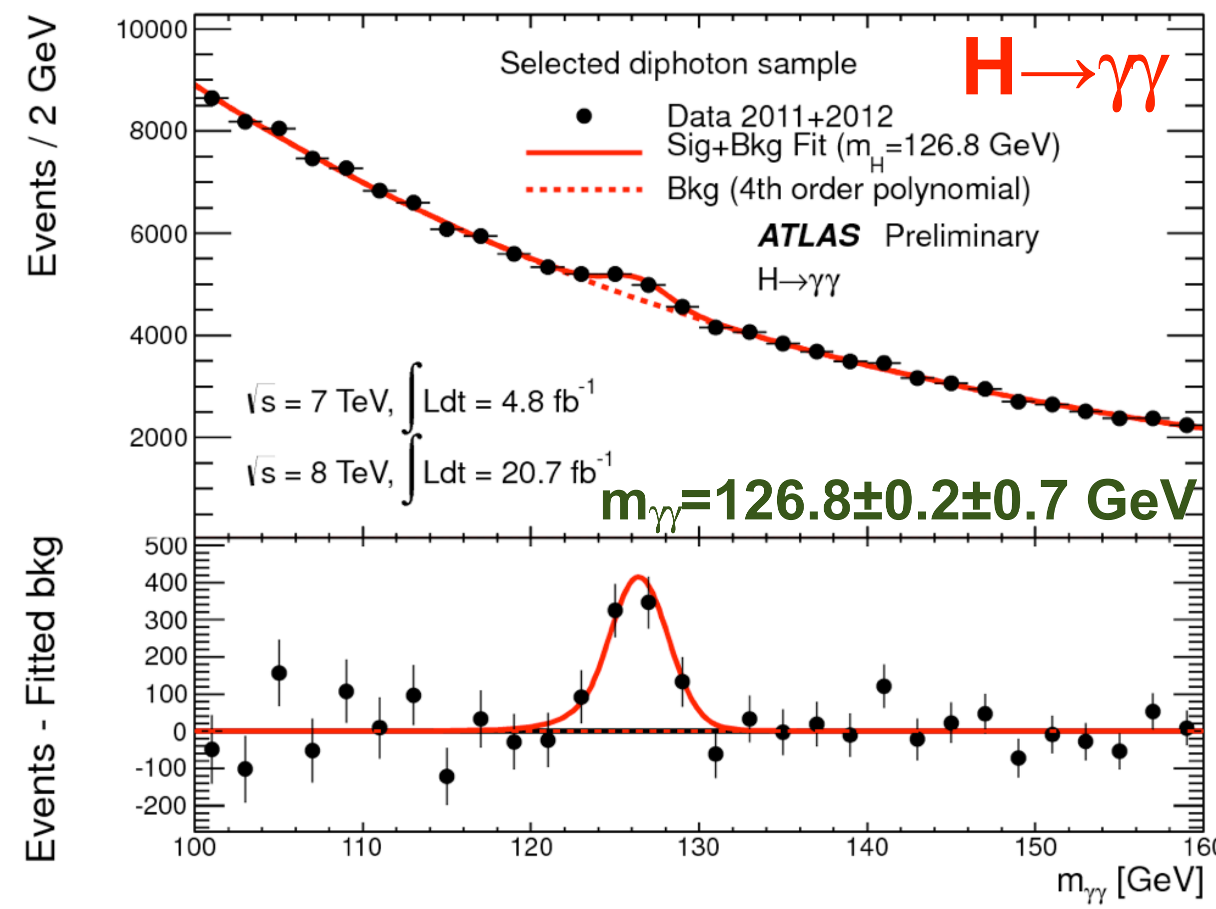

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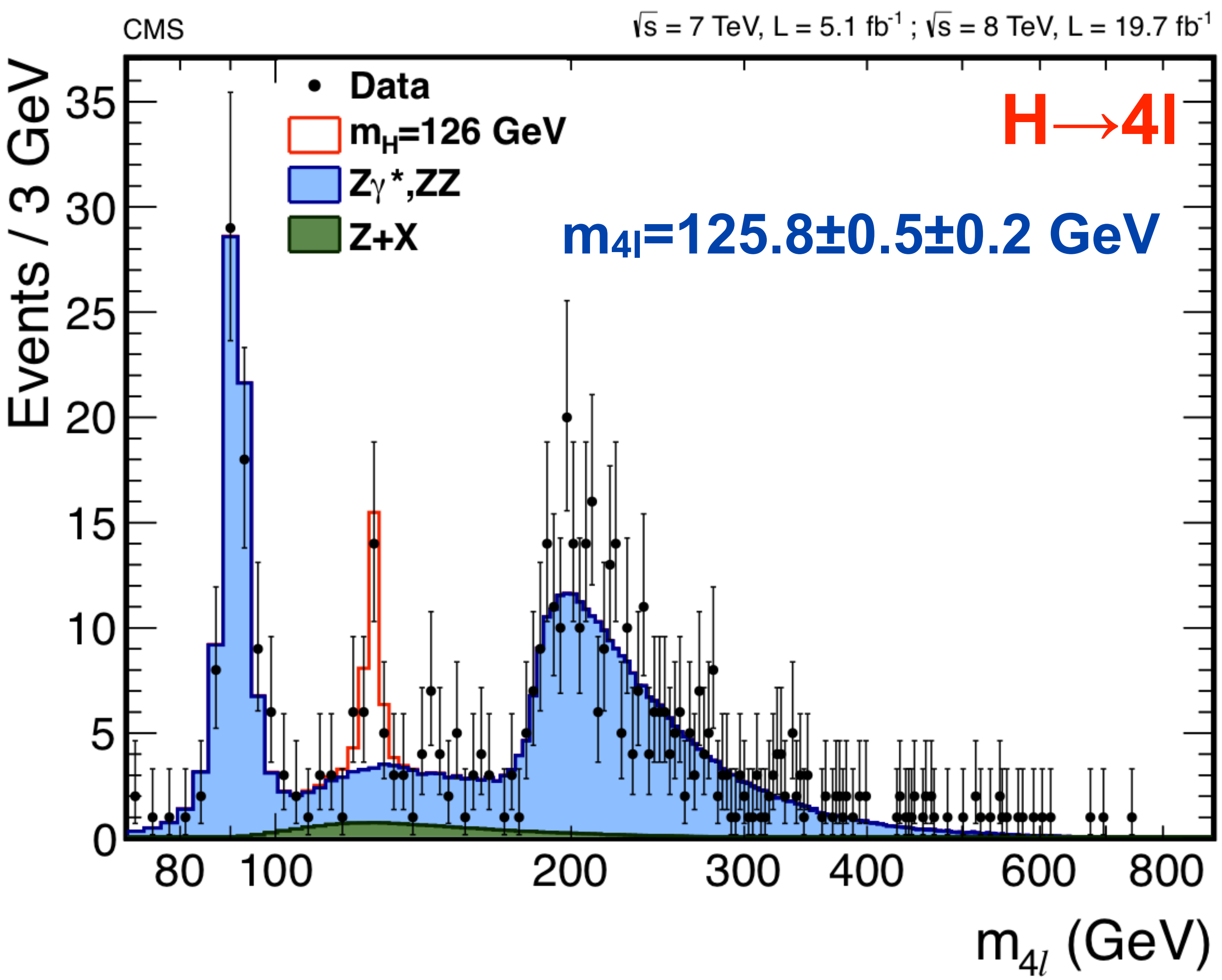
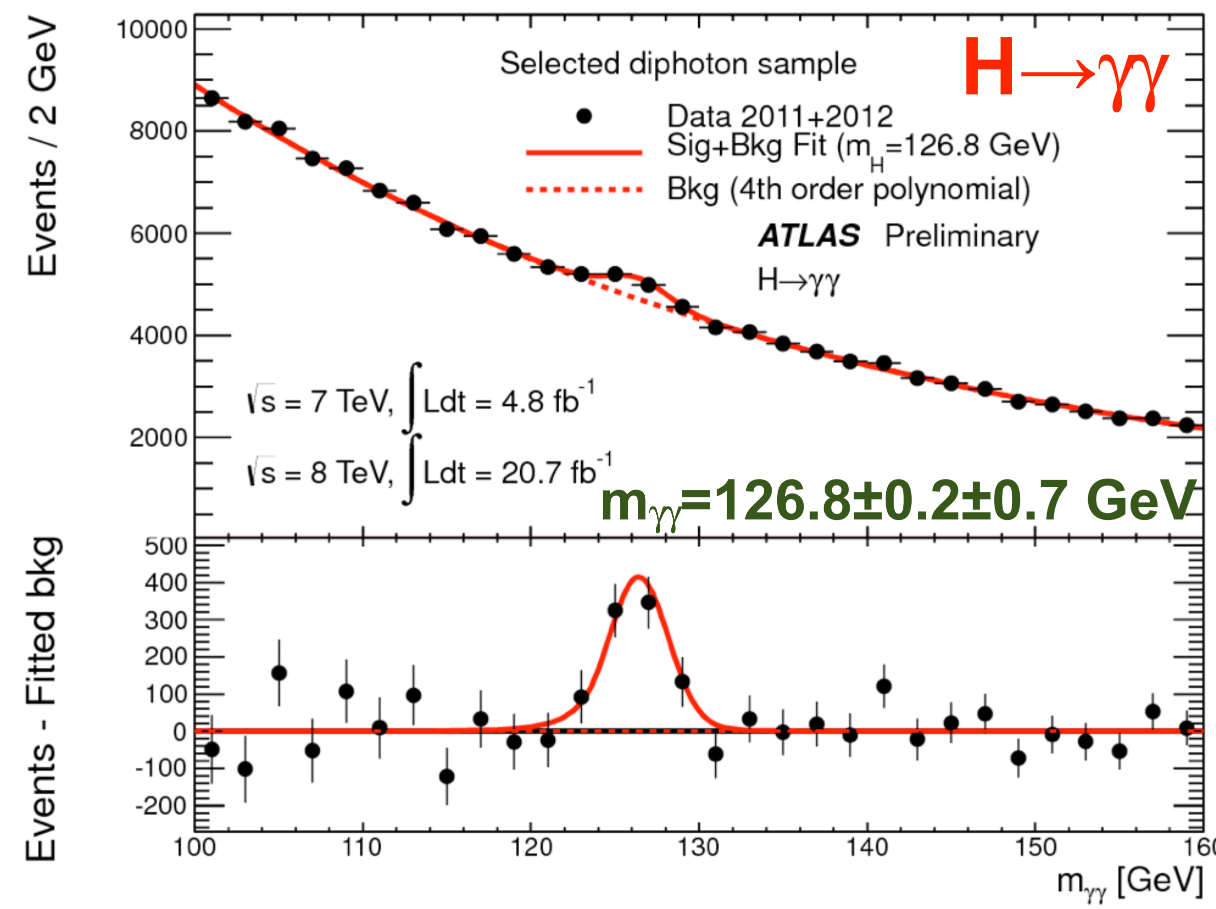
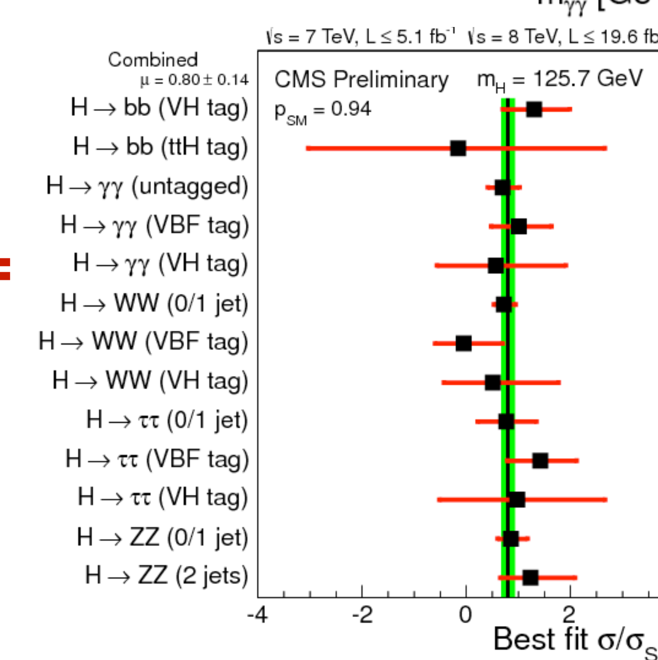




$\mu = \sigma/\sigma_{SM}$ = 0.80±0.14



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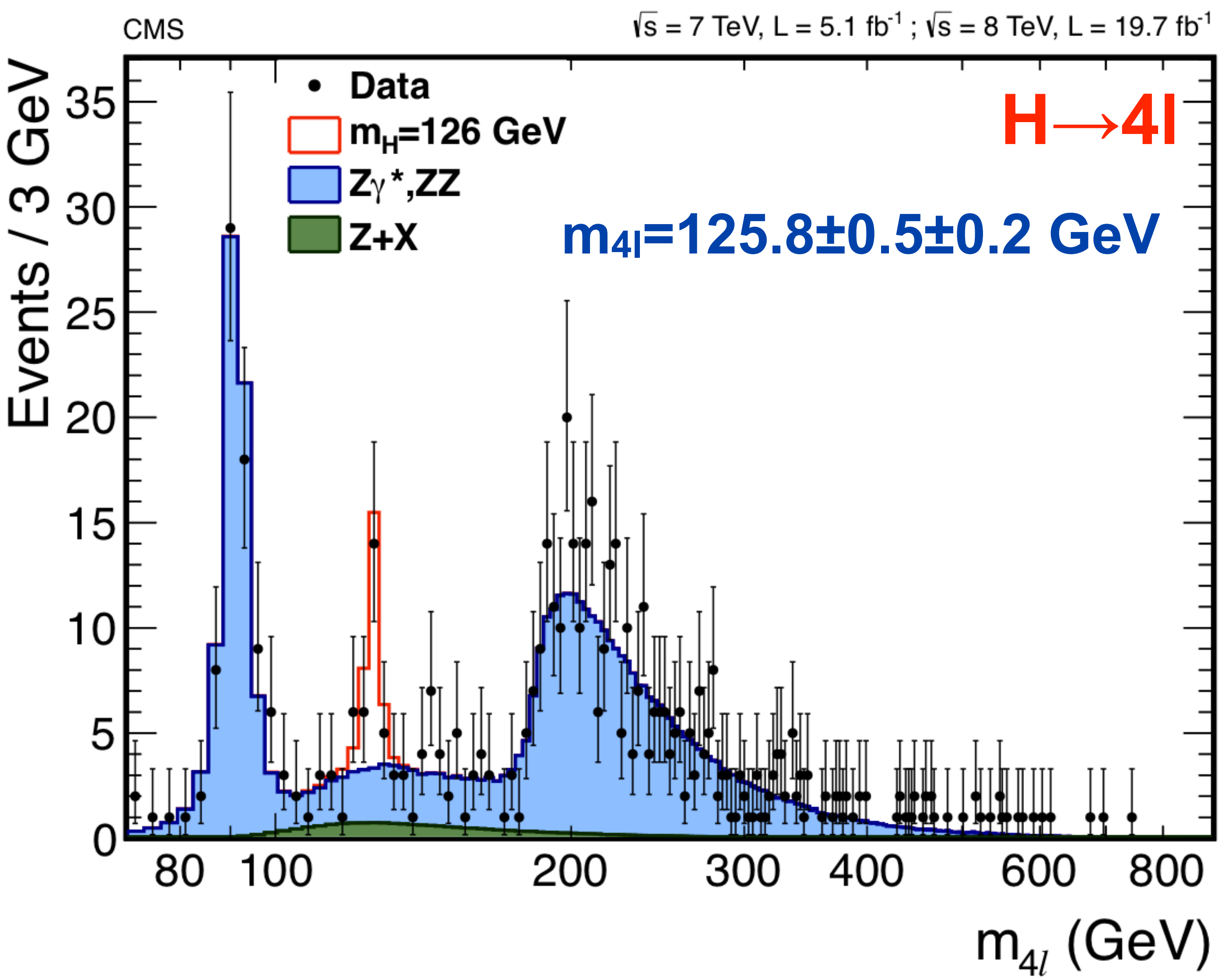

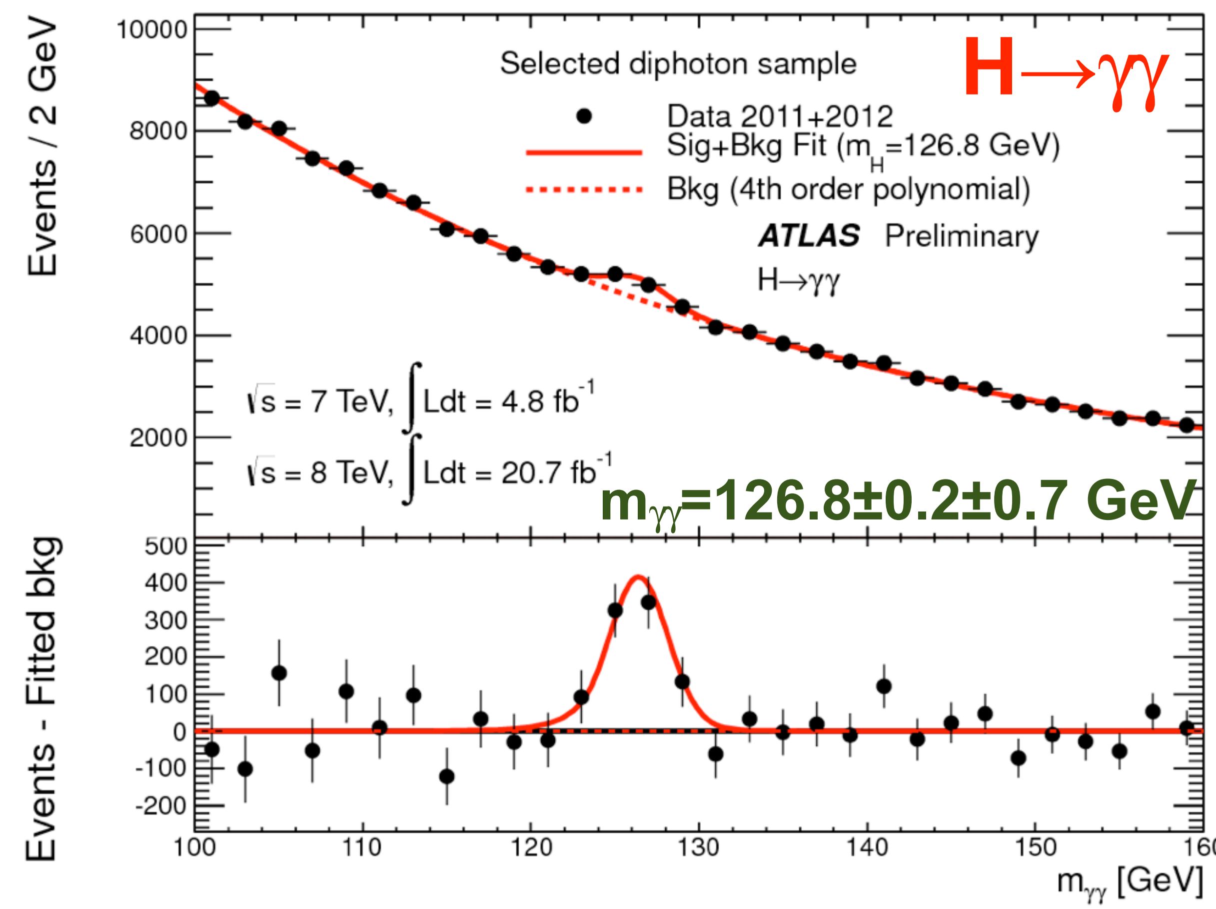

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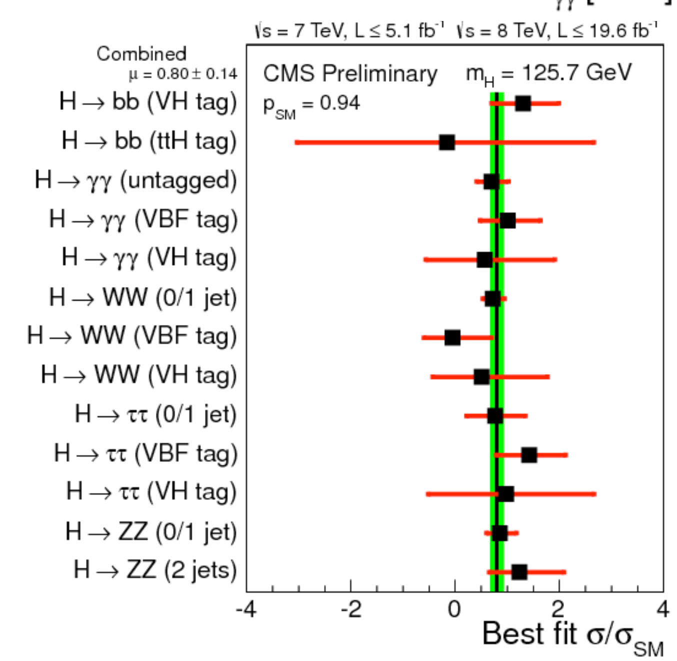
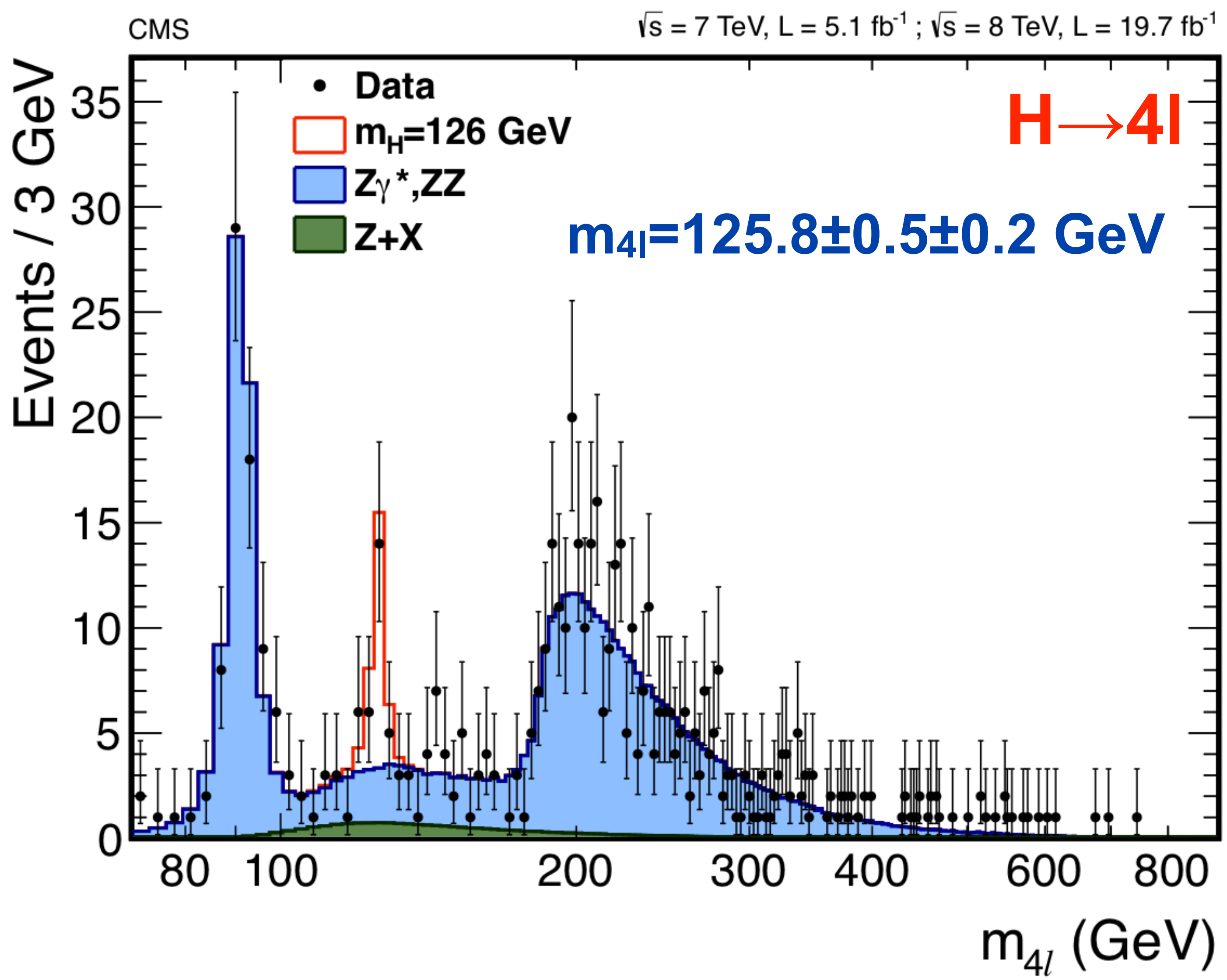
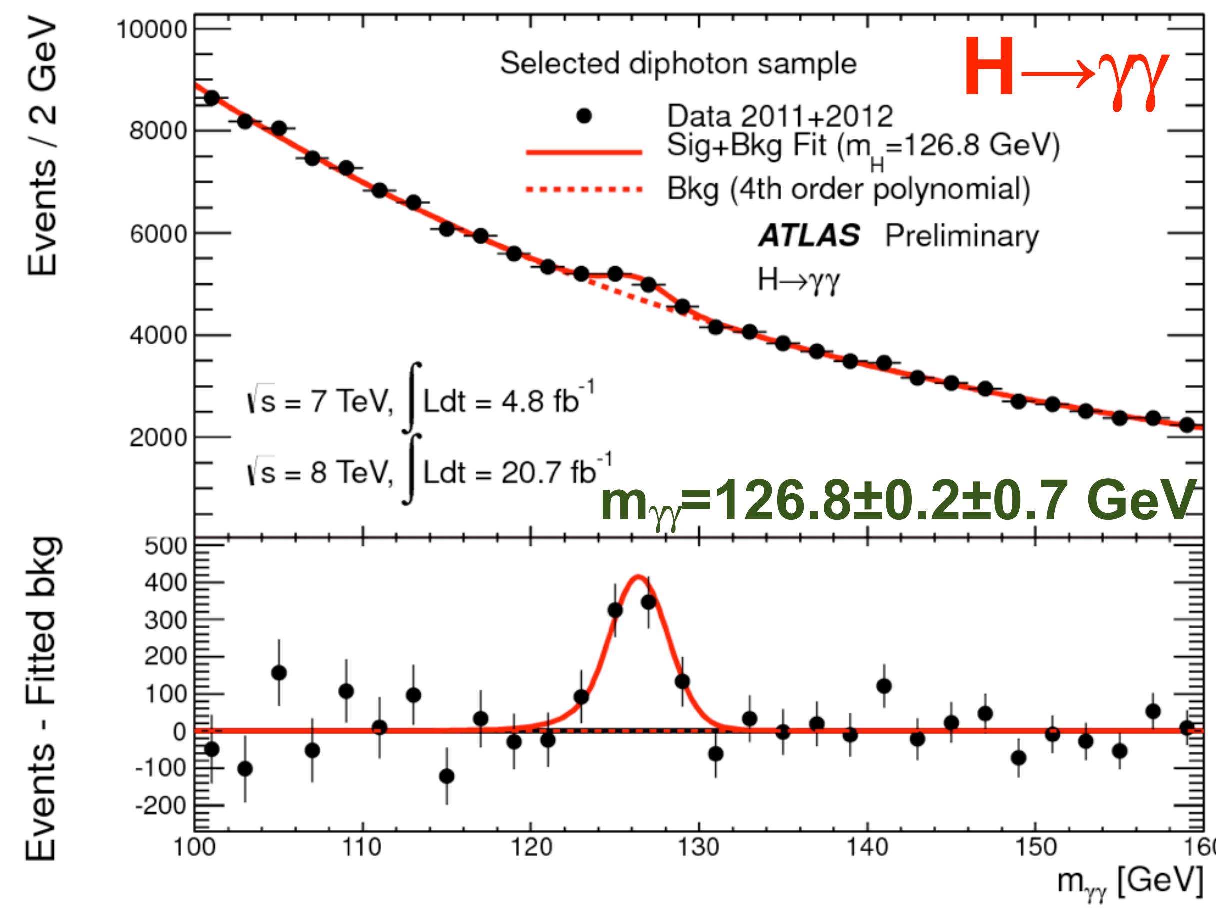


The new boson is consistent with being the SM Higgs boson

New boson with a mass of ~125 GeV

- We have discovered a SM-like scalar boson with a mass of ~125 GeV.
- J^{PC}, consistent with SM scalar boson, couplings will need more data.





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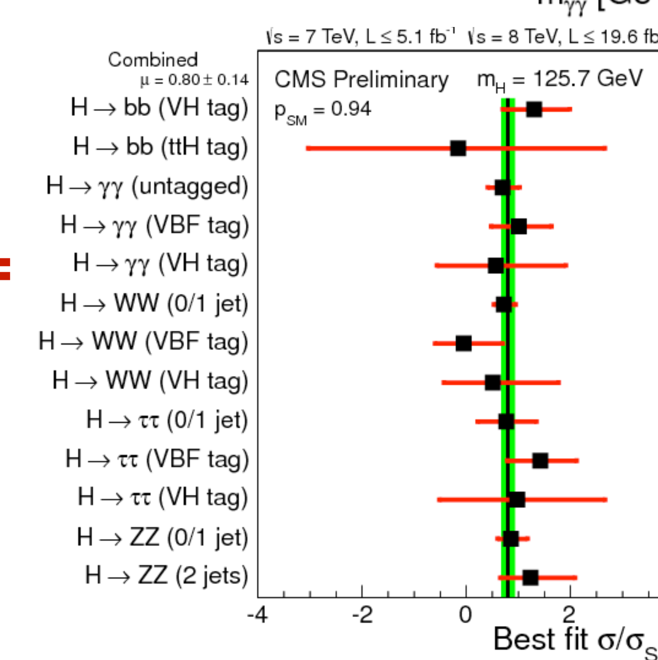
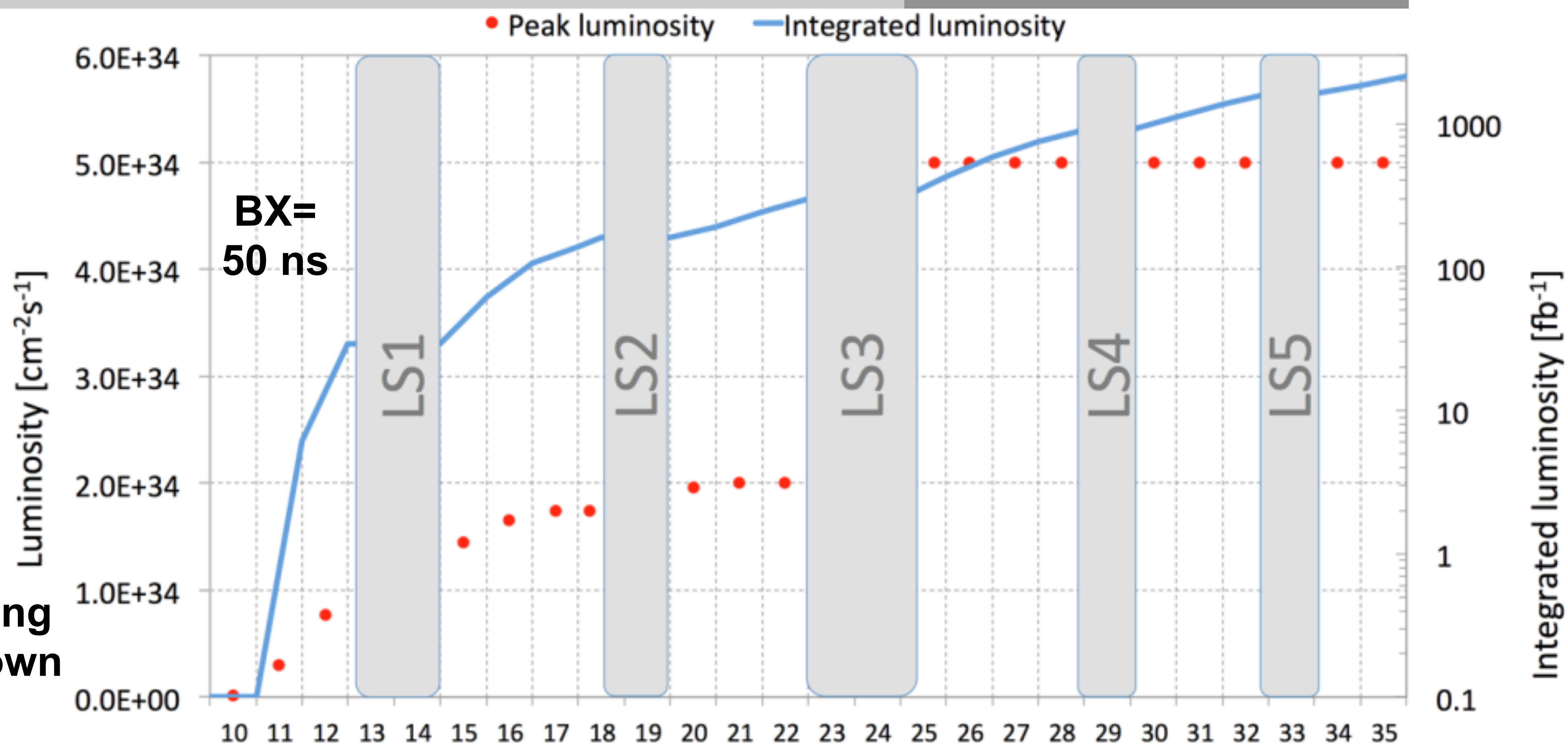


The new boson is consistent with being the SM Higgs boson

LHC and HL-LHC

LHC | HL-LHC



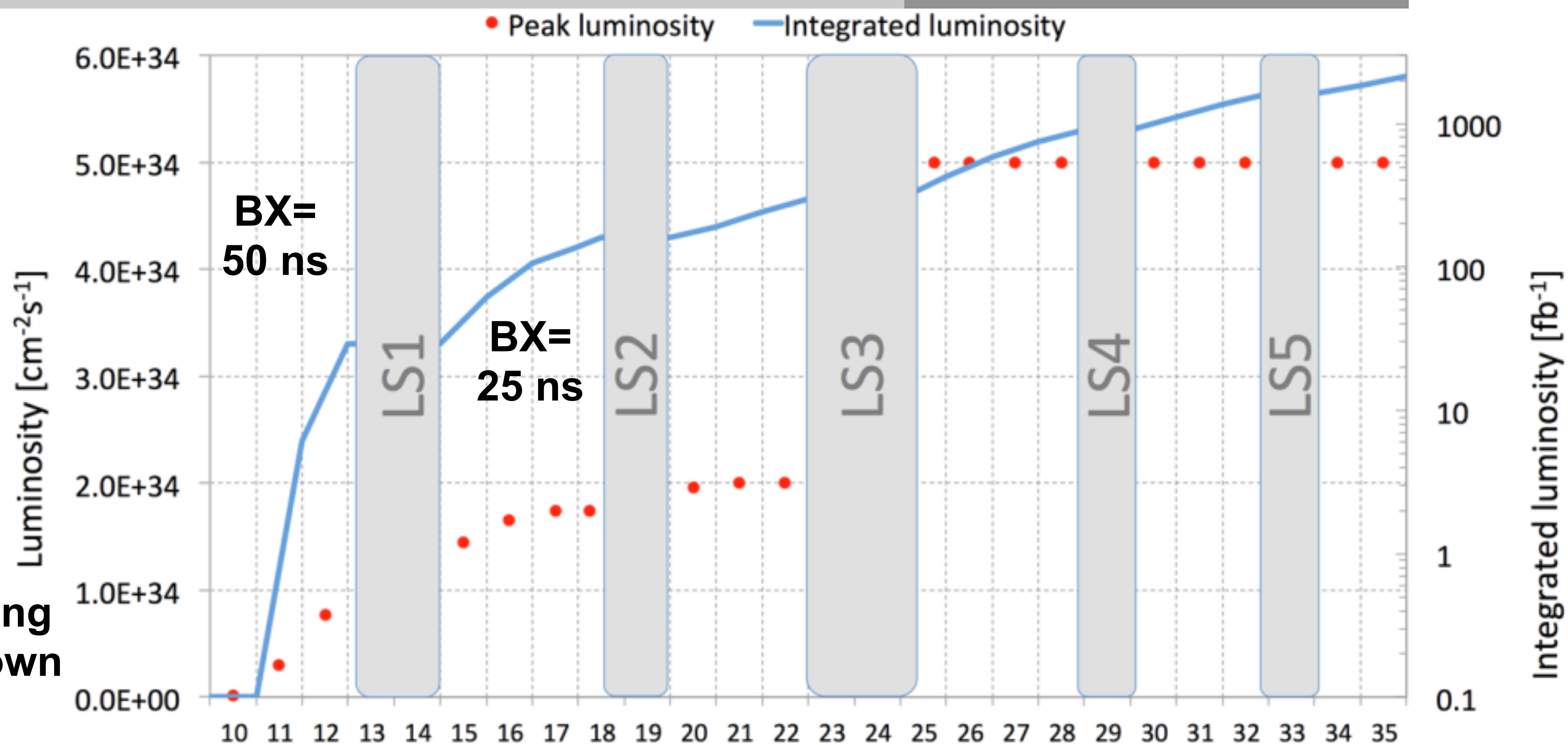
LS= Long Shutdown

$L_{instantaneous}$
$L_{integrated}$
Pile Up

LS1 → LS3 →

LHC and HL-LHC

LHC — Energy increase 8 TeV to 13/14 TeV — **HL-LHC**



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→ LS1 → LS3 →

LHC and HL-LHC

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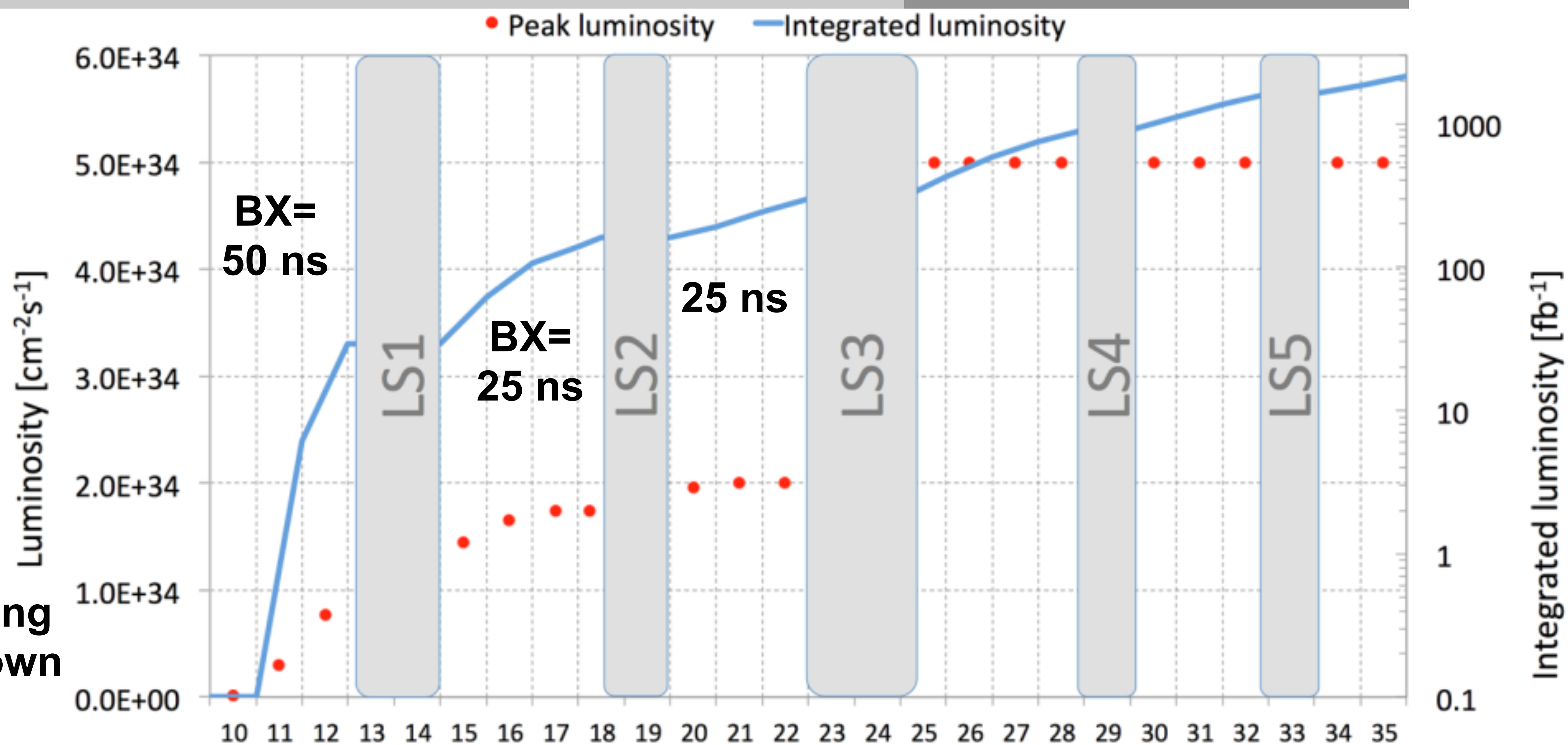

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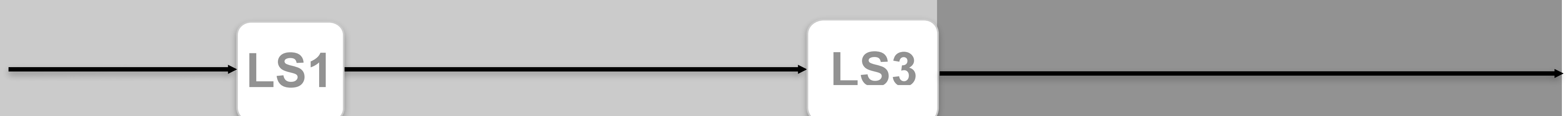
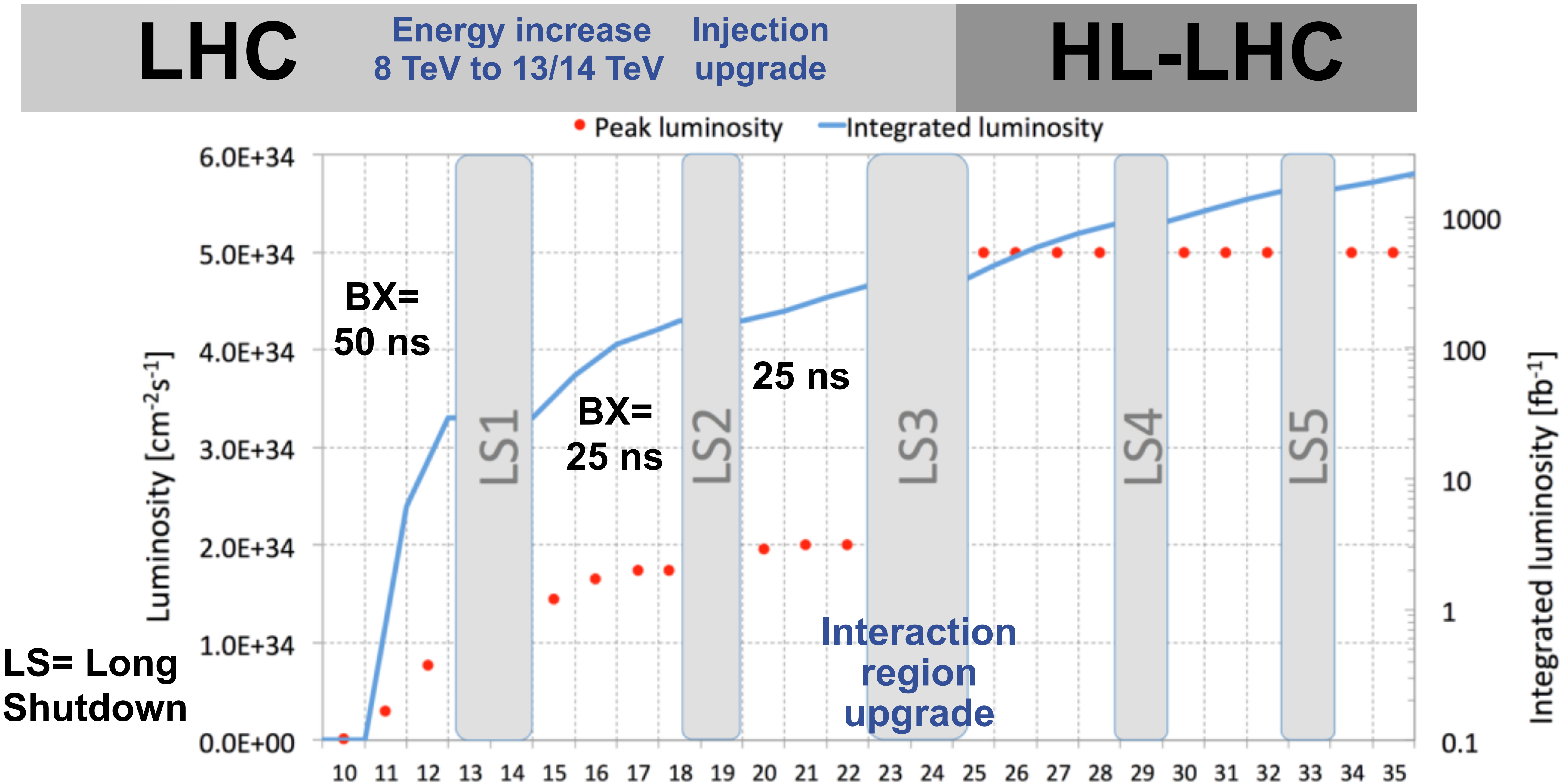
Linstantaneous
Lintegrated
Pile Up



LHC and HL-LHC



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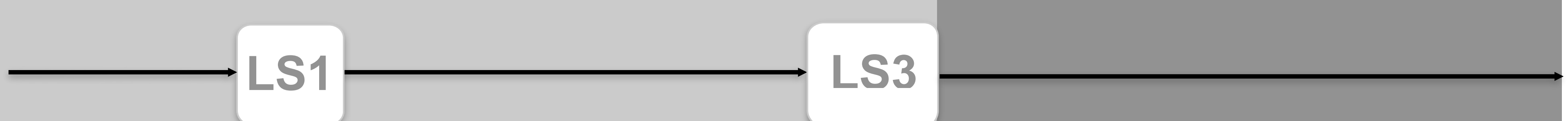

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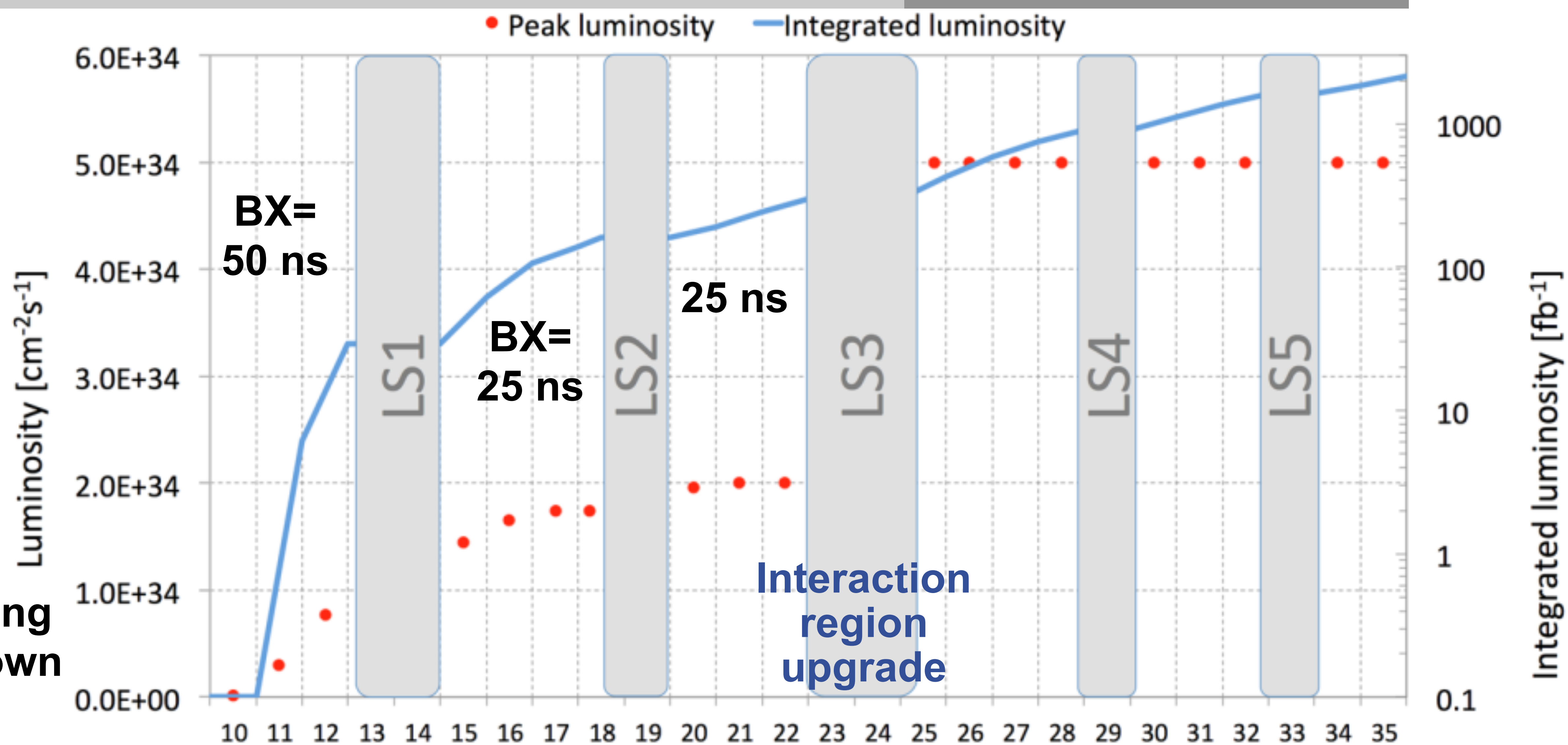

LS= Long Shutdown

$L_{\text{instantaneous}}$ 8×10^{33} Hz/cm^2

$L_{\text{integrated}}$ 30 fb^{-1}

Pile Up PU ~40

LS1 → LS3 →

LHC and HL-LHC

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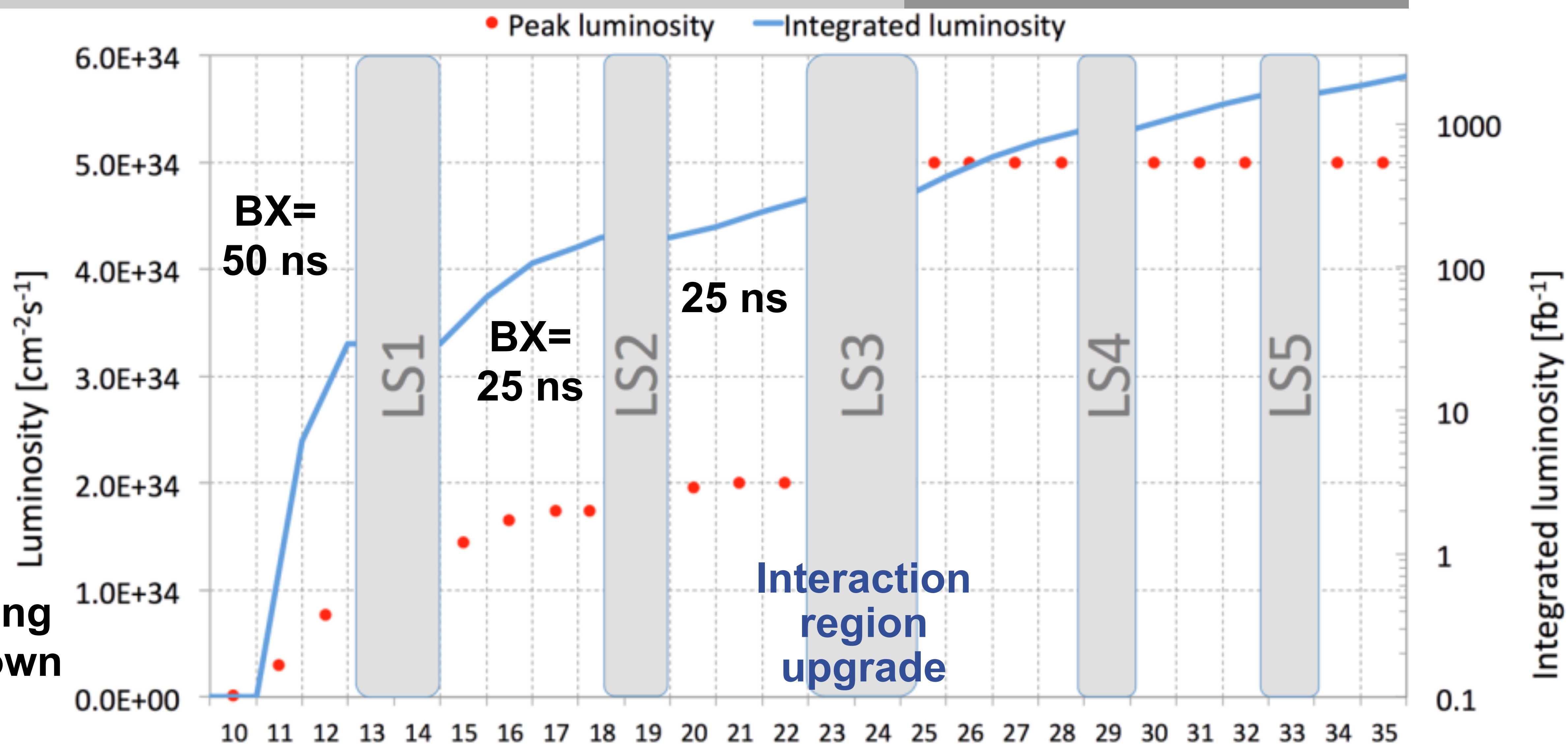


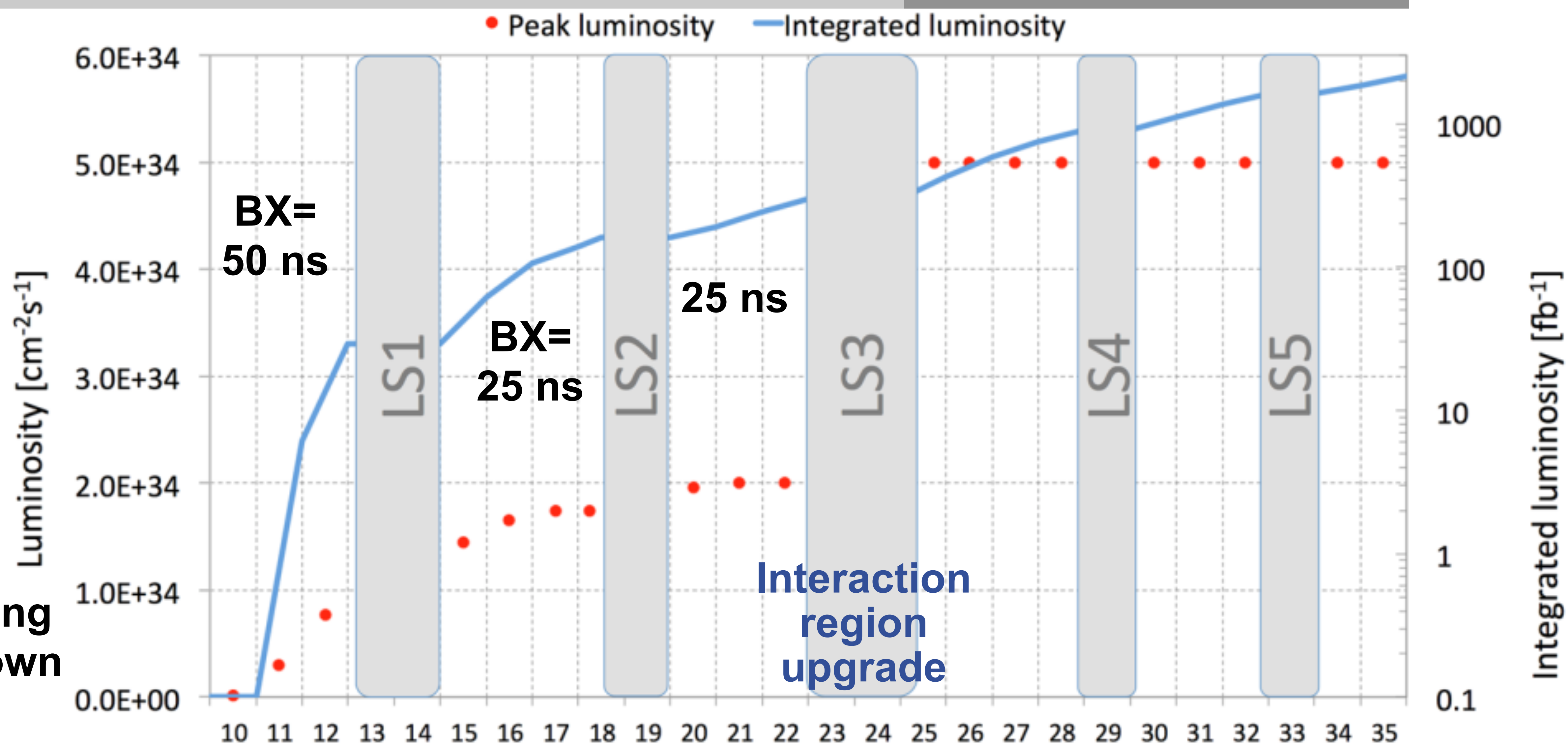
LS= Long Shutdown

	LHC (before LS1)	LHC (LS1 to LS3)
$L_{instantaneous}$	8×10^{33} Hz/cm^2	2×10^{34} Hz/cm^2
$L_{integrated}$	30 fb^{-1}	300 fb^{-1}
Pile Up	PU ~40	PU ~50

LS1 → LS3 →

LHC and HL-LHC

LHC	Energy increase 8 TeV to 13/14 TeV	Injection upgrade	HL-LHC



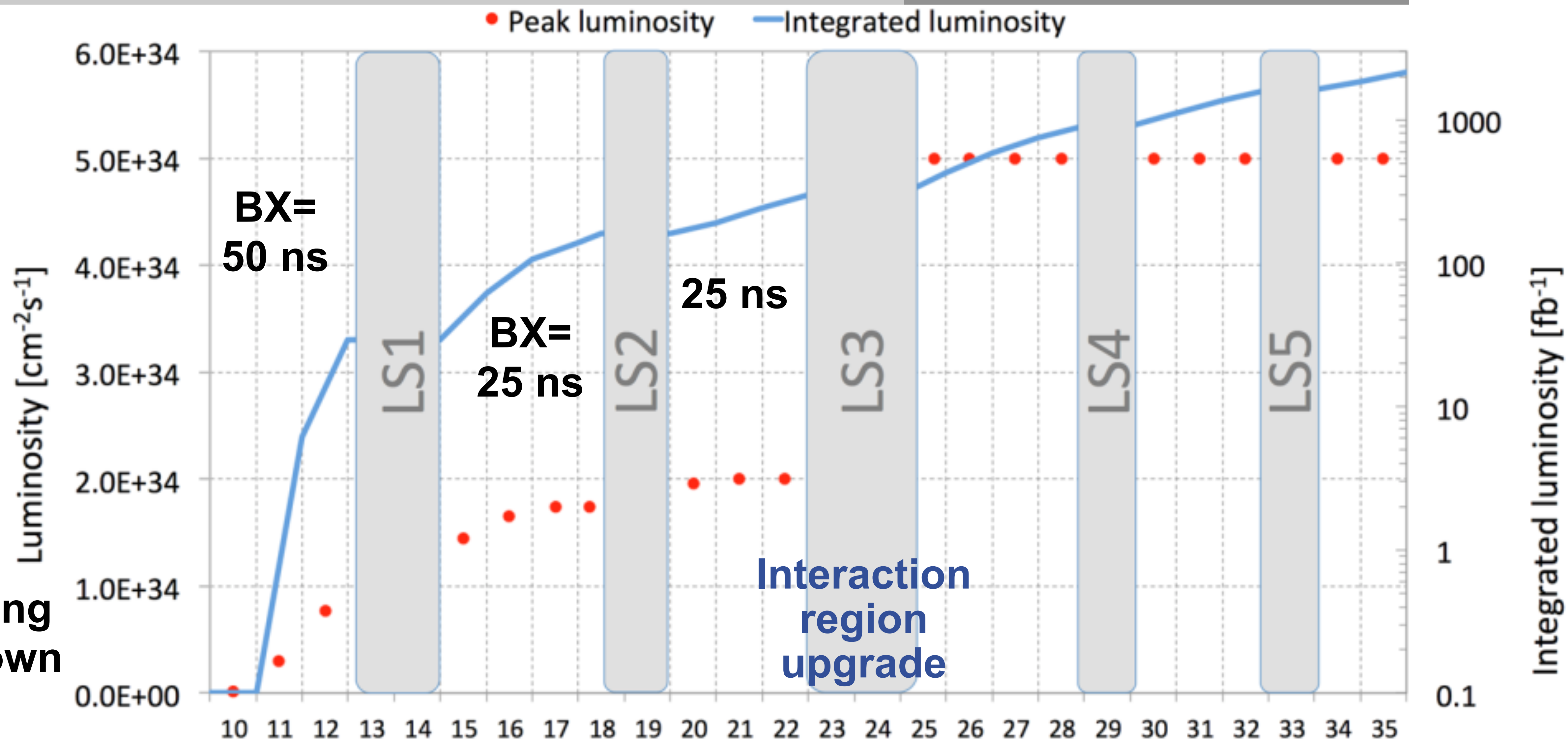
LS= Long Shutdown

	LHC (until LS1)	LHC (LS1 to LS3)	HL-LHC (after LS3)
$L_{instantaneous}$	8×10^{33} Hz/cm^2	2×10^{34} Hz/cm^2	5×10^{34} Hz/cm^2
$L_{integrated}$	30 fb^{-1}	300 fb^{-1}	3000 fb^{-1}
Pile Up	PU ~40	PU ~50	PU ~140

→ LS1 → LS3 →

LHC and HL-LHC

LHC | Energy increase 8 TeV to 13/14 TeV | Injection upgrade | **HL-LHC**



LS= Long Shutdown

	LHC		HL-LHC
$L_{instantaneous}$	8×10^{33} Hz/cm^2	2×10^{34} Hz/cm^2	5×10^{34} Hz/cm^2
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→ LS1 → LS3 →

ATLAS, CMS Upgrade plan

LHC and HL-LHC

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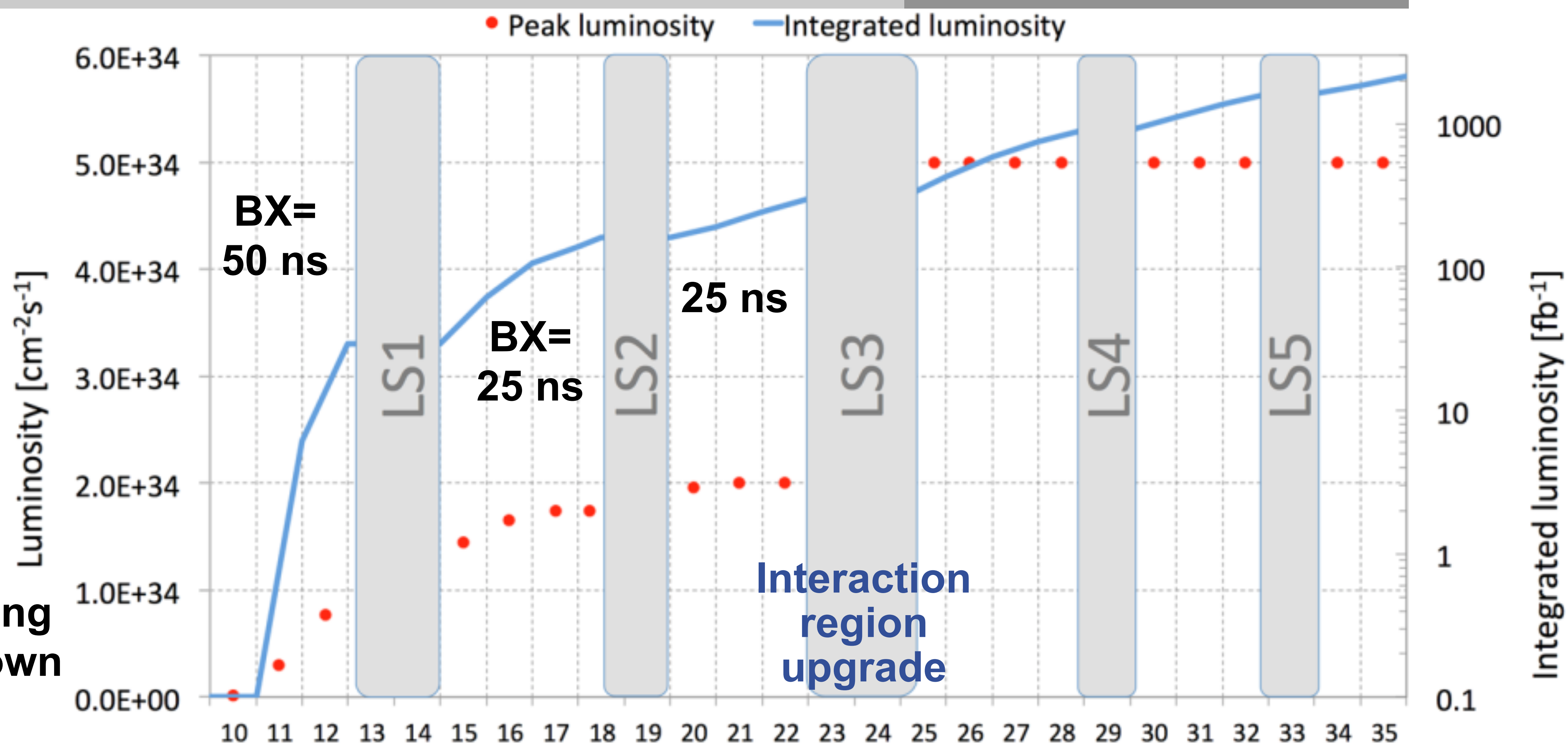

LS= Long Shutdown

	LHC (before LS1)	LHC (LS1 to LS3)	HL-LHC (after LS3)
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ATLAS, CMS Upgrade plan

Phase 1 Upgrade →

LHC and HL-LHC

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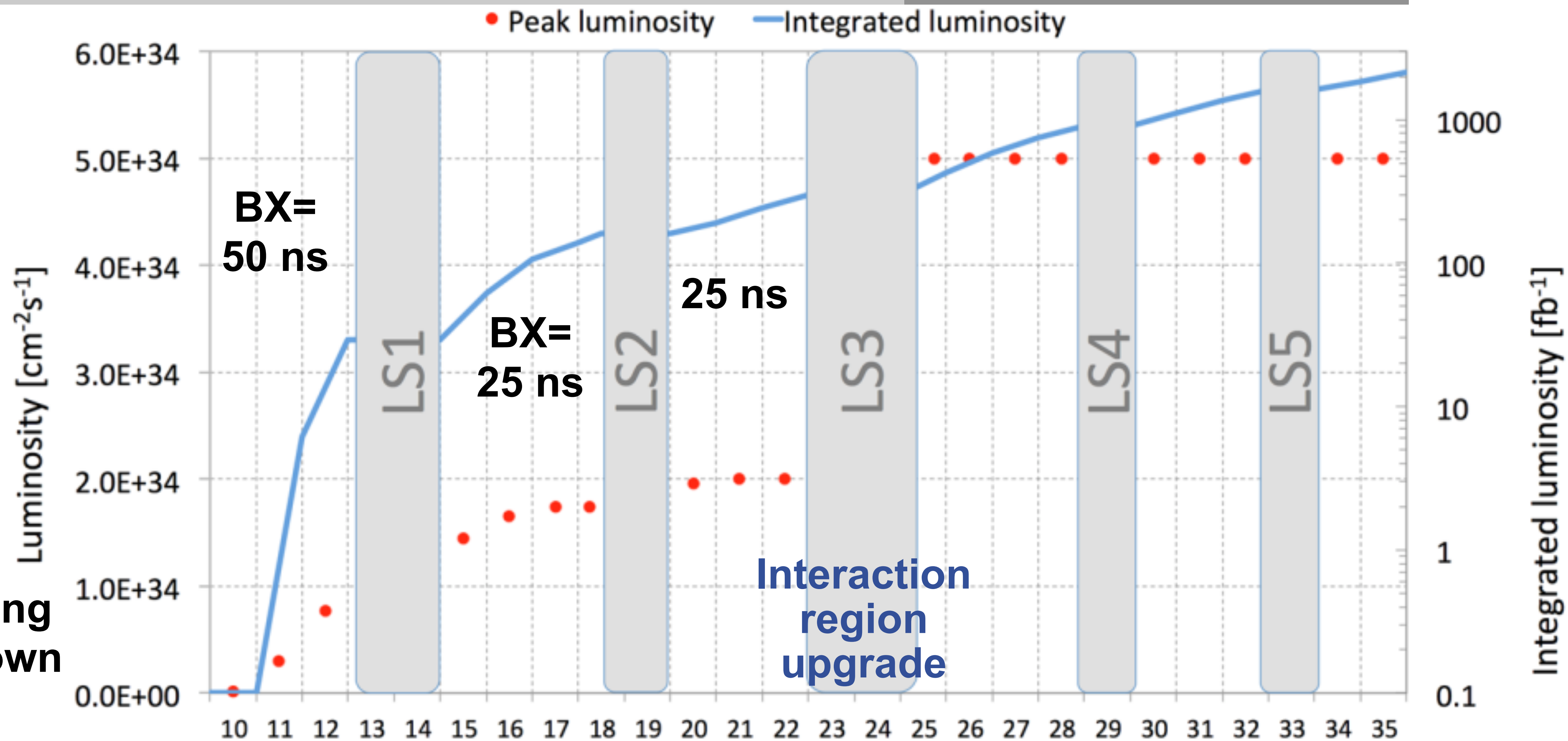

LS= Long Shutdown

	LHC (Phase 1)		HL-LHC
$L_{instantaneous}$	8×10^{33} Hz/cm^2	2×10^{34} Hz/cm^2	5×10^{34} Hz/cm^2
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Pile Up	PU ~40	PU ~50	PU ~140

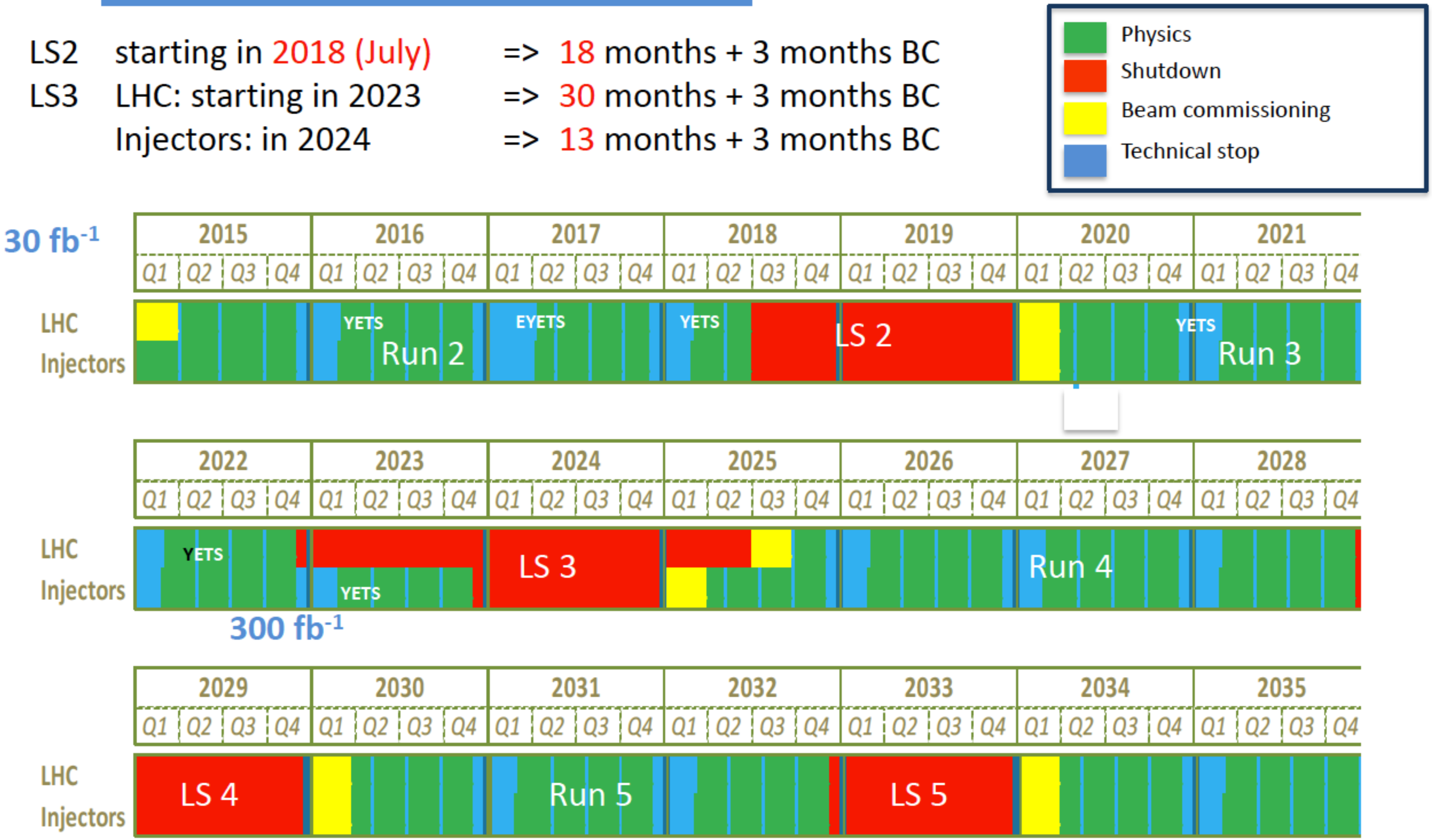
LS1 → LS3 →

ATLAS, CMS Upgrade plan: Phase 1 Upgrade → Phase 2 Upgrade

LHC schedule

LHC schedule beyond LS1

LS2	starting in 2018 (July)	=>	18 months + 3 months BC
LS3	LHC: starting in 2023	=>	30 months + 3 months BC
	Injectors: in 2024	=>	13 months + 3 months BC



(Extended) Year End Technical Stop: (E)YETS

LHC after LS1

From G. Dissertori (ETH)

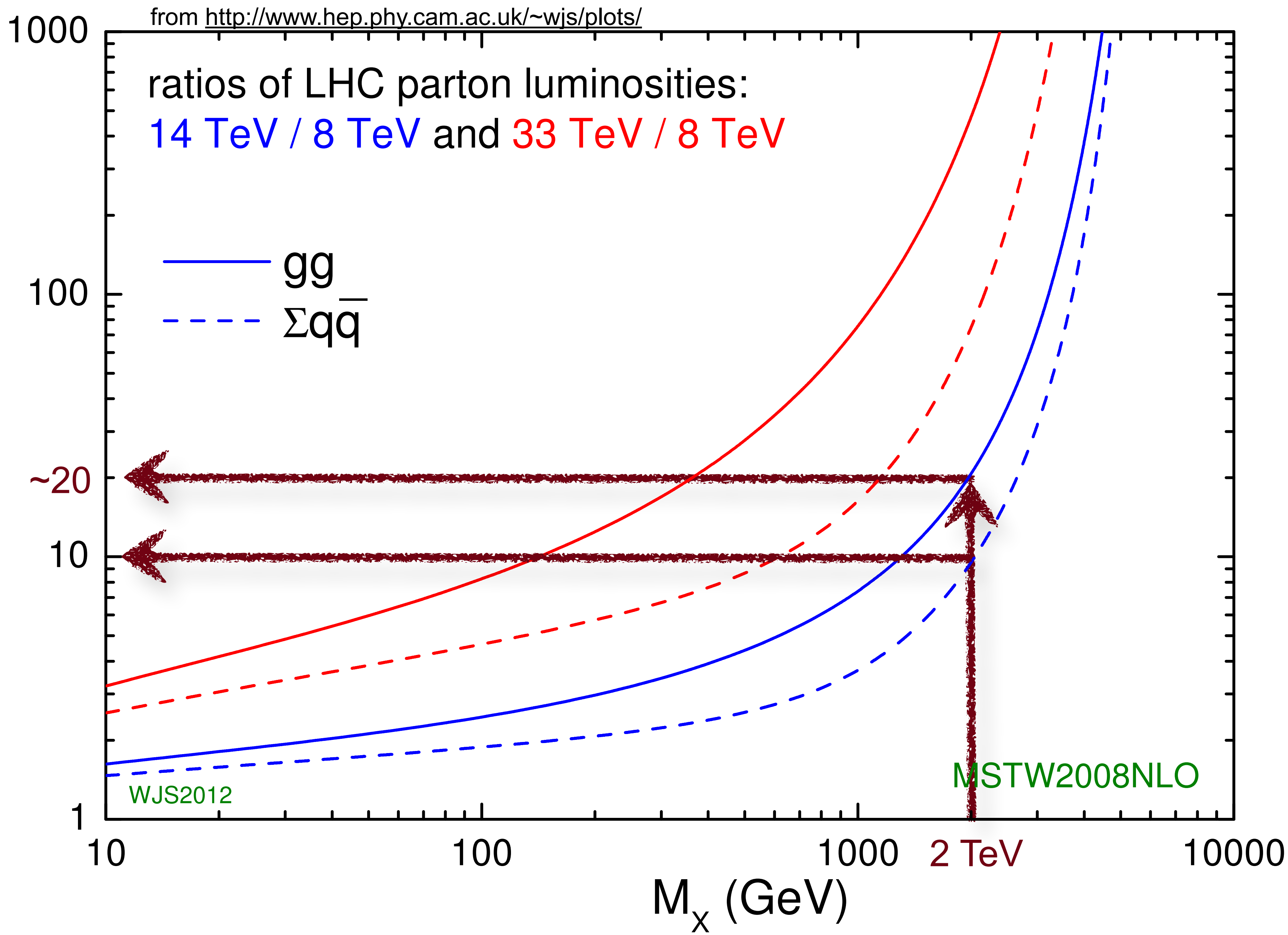
LHC after LS1

Ratios of parton luminosities at 14 TeV

From G. Dissertori (ETH)

LHC after LS1

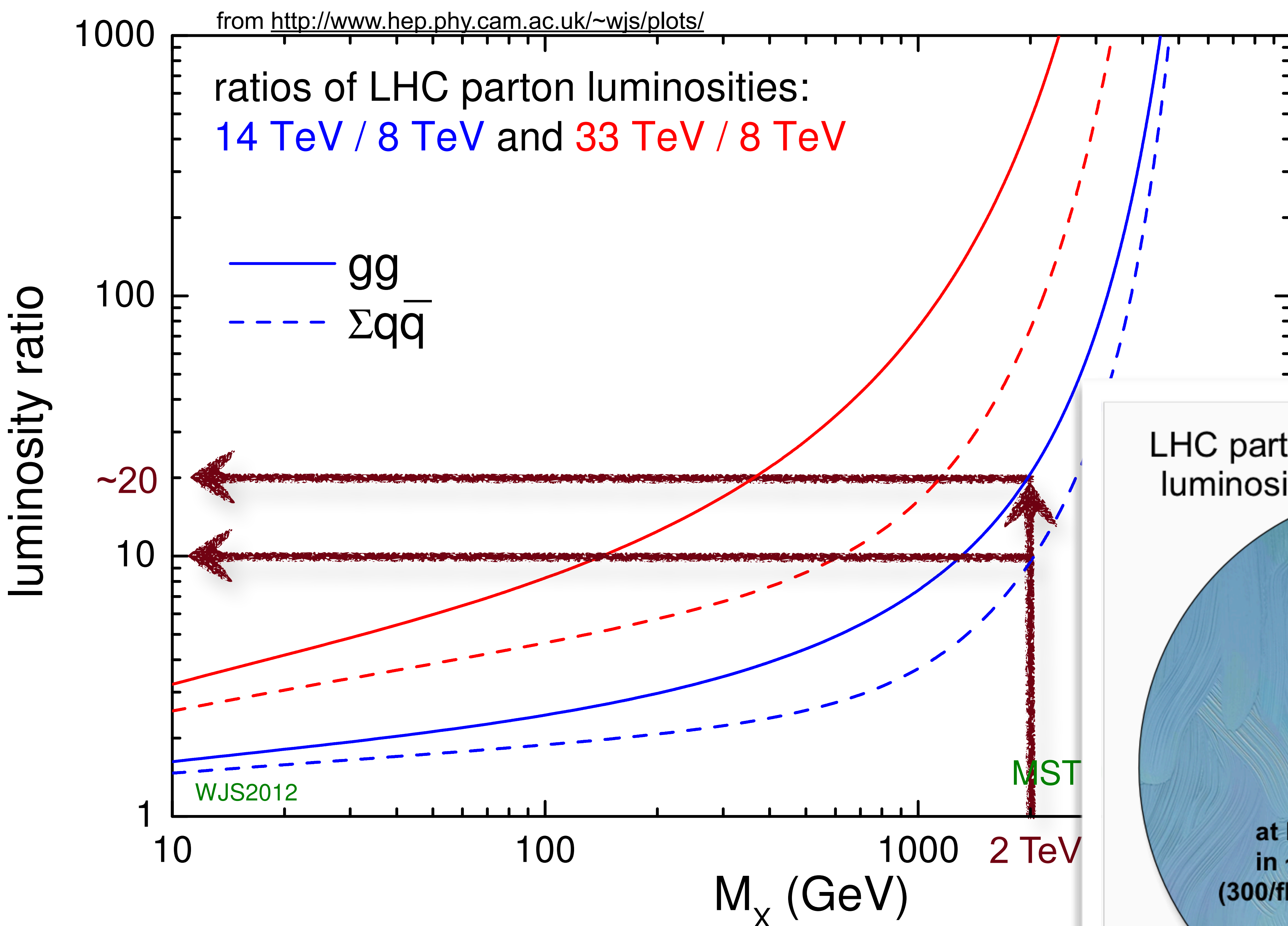
Ratios of parton luminosities at 14 TeV

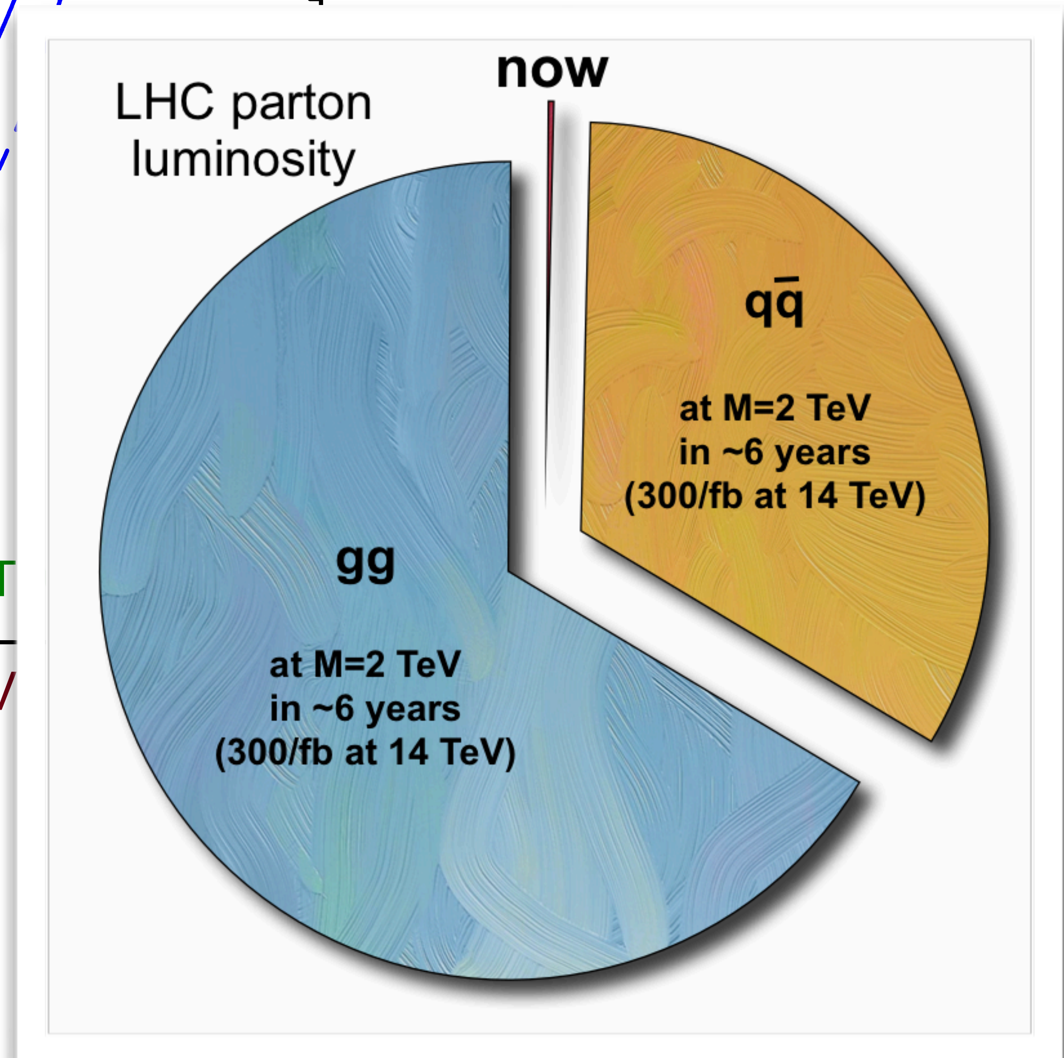


From G. Dissertori (ETH)

LHC after LS1

Ratios of parton luminosities at 14 TeV





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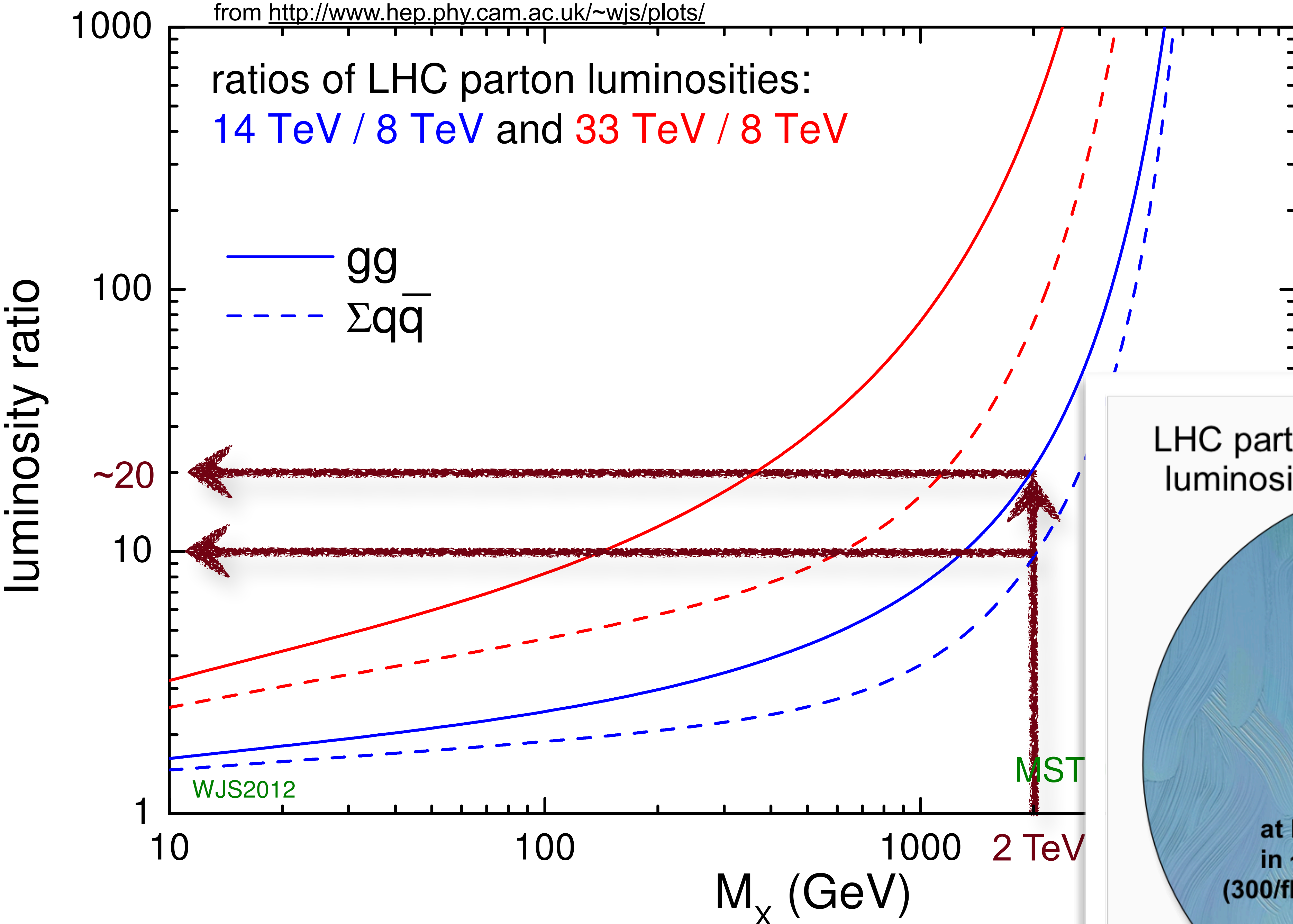

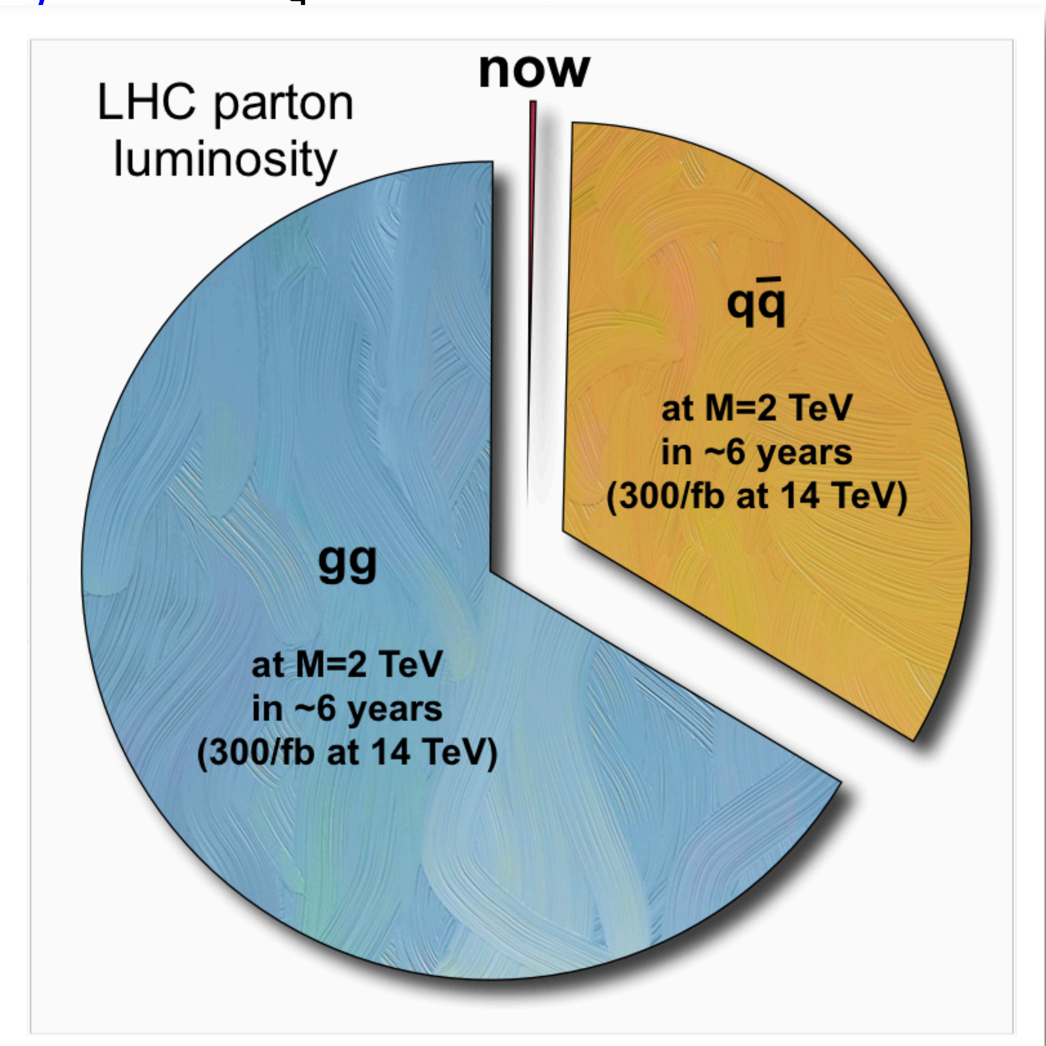

From G. Dissertori (ETH)

We are about to explore a new territory!

Pileup in 2012

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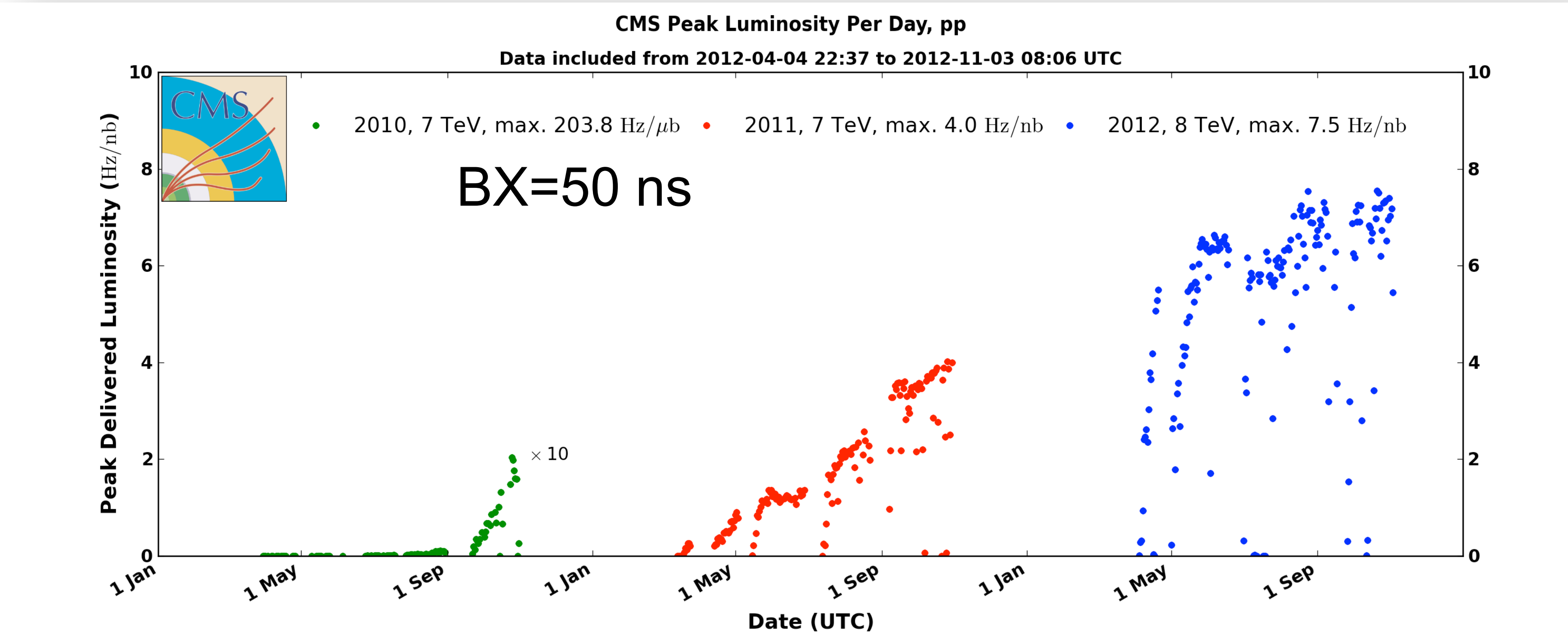

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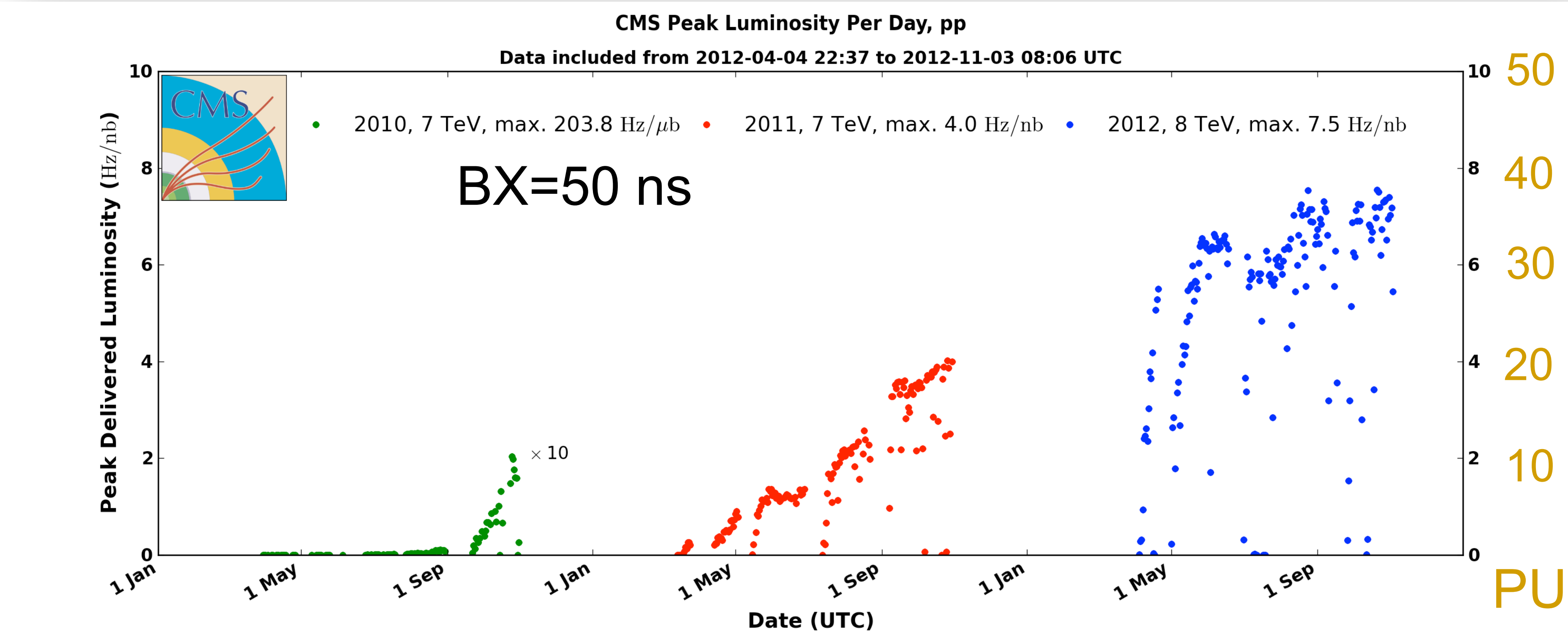

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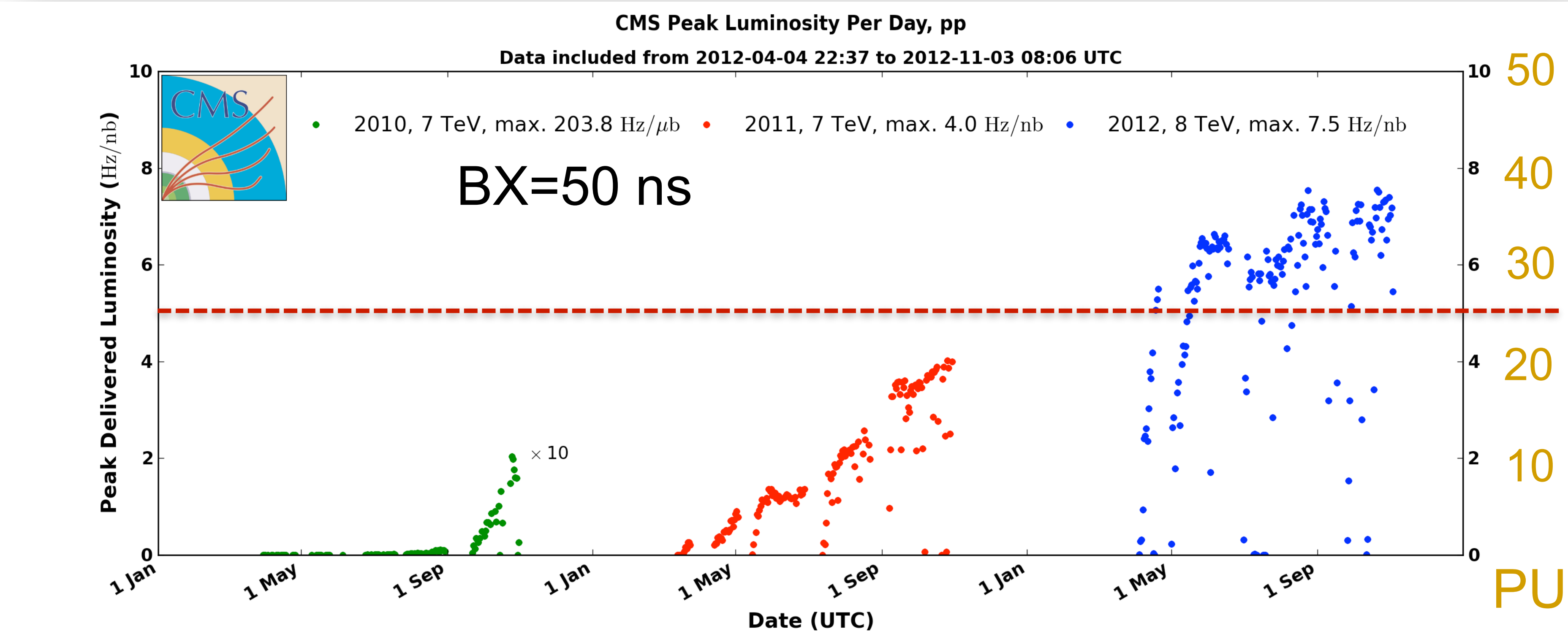
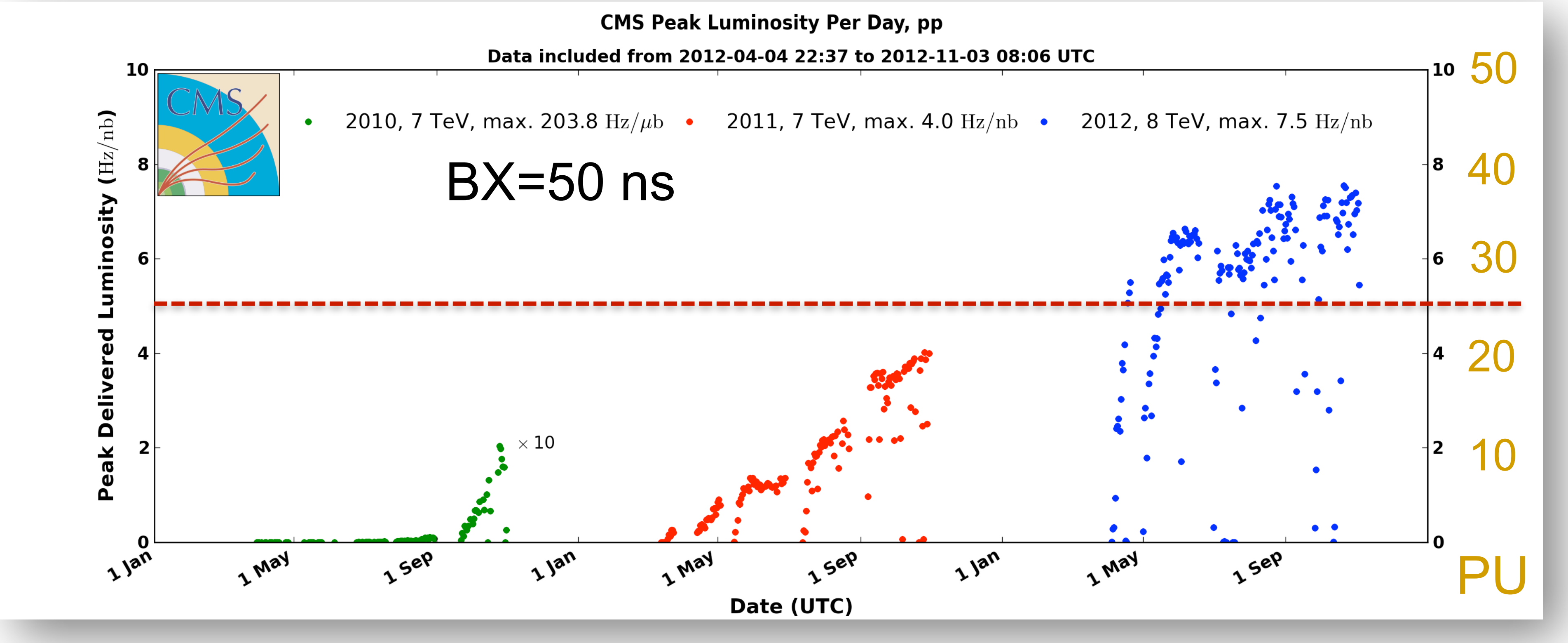


Design value
25 pileup events
(L=10^{34}, BX=25 ns)

Pileup in 2012



Peak: 37 pileup events

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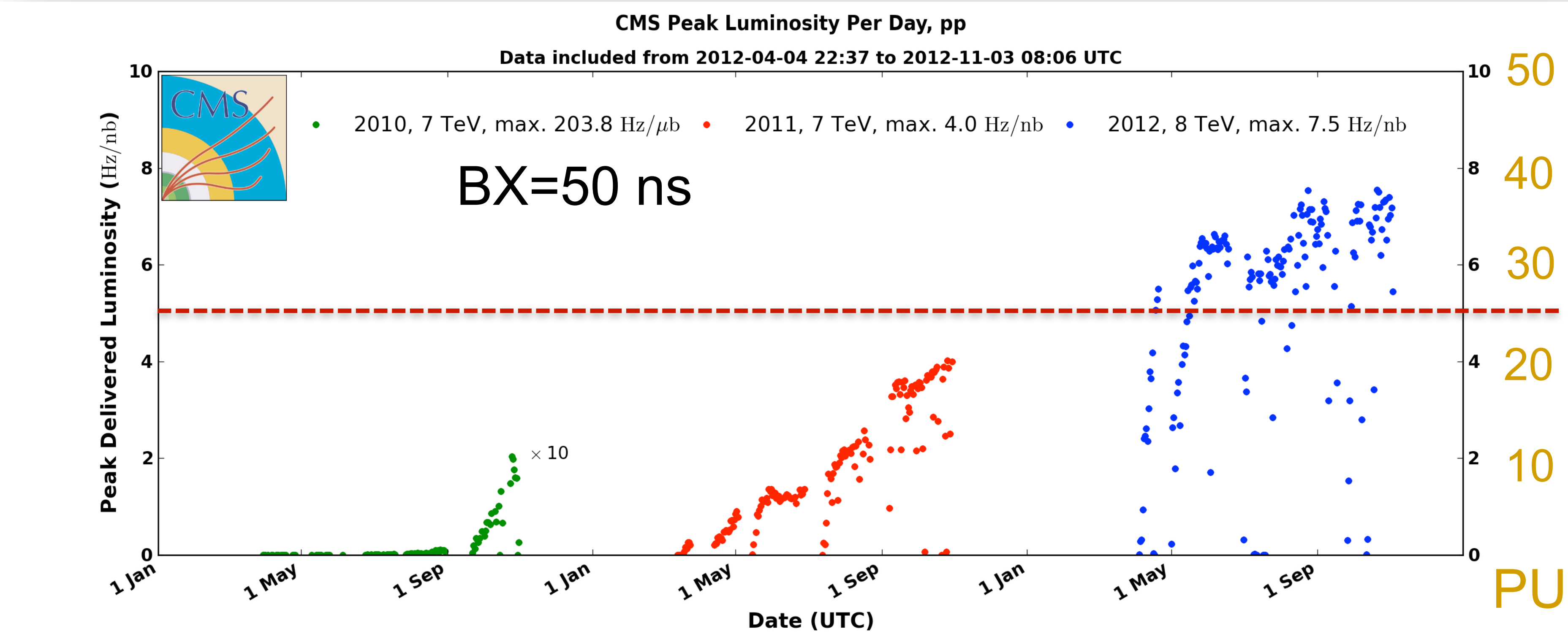

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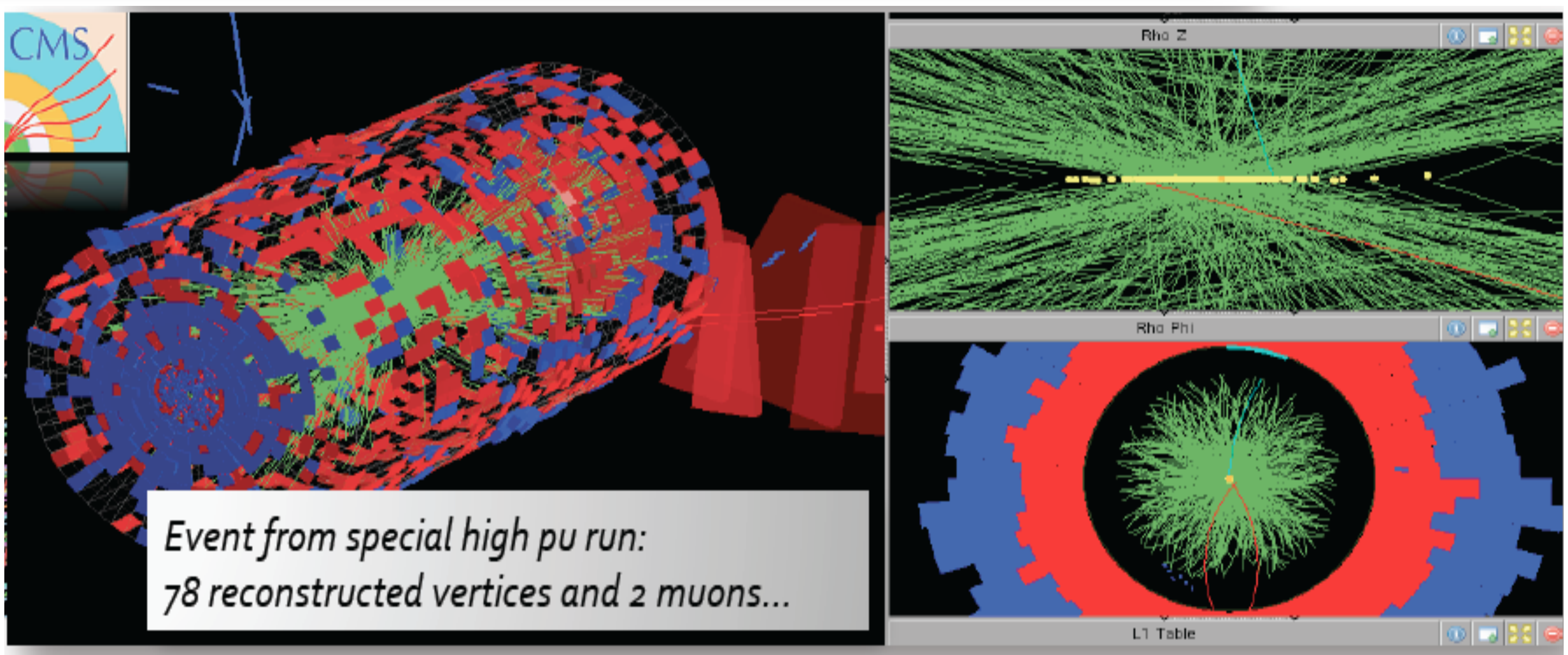

Pileup in Run 2 and at HL-LHC

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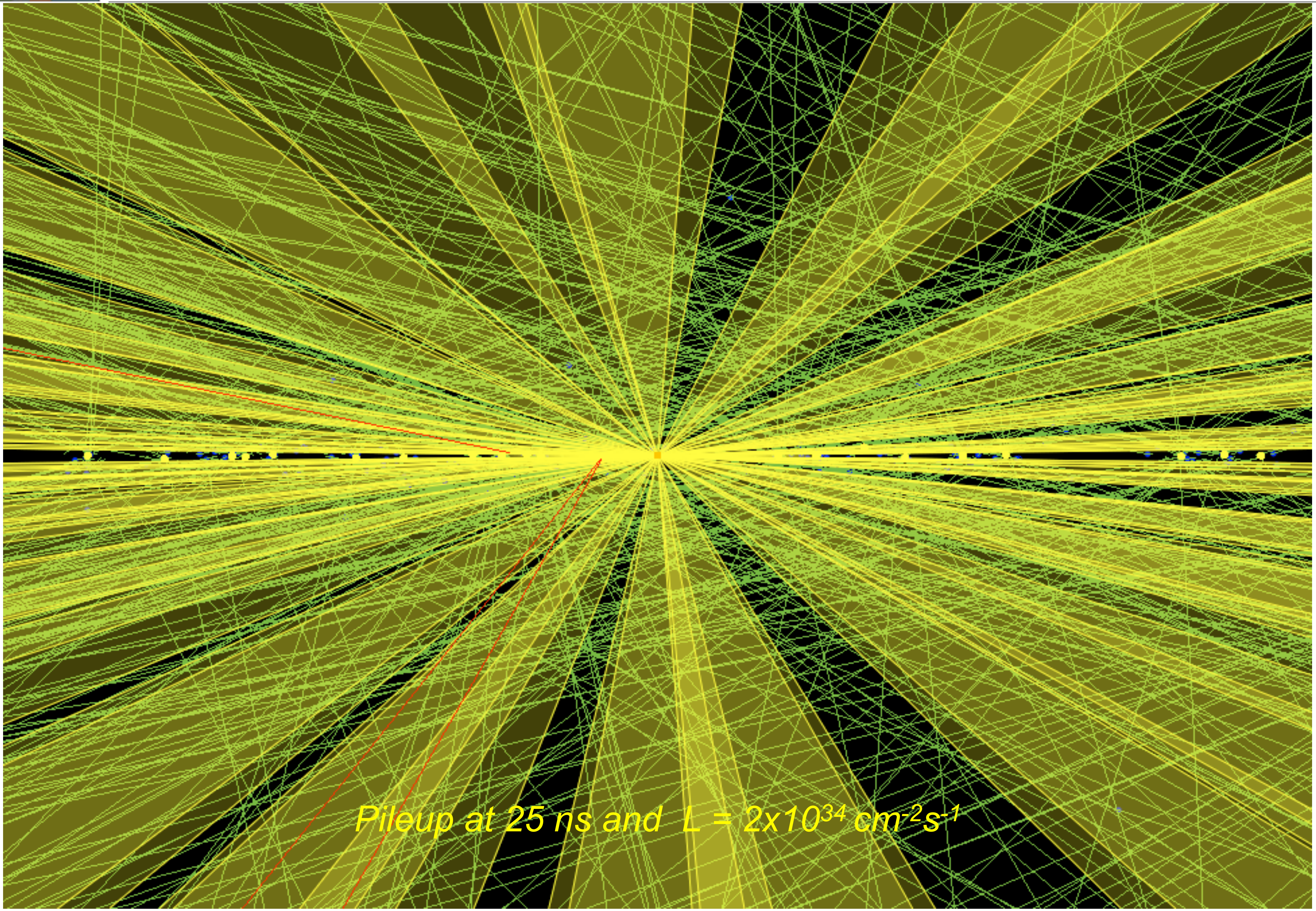

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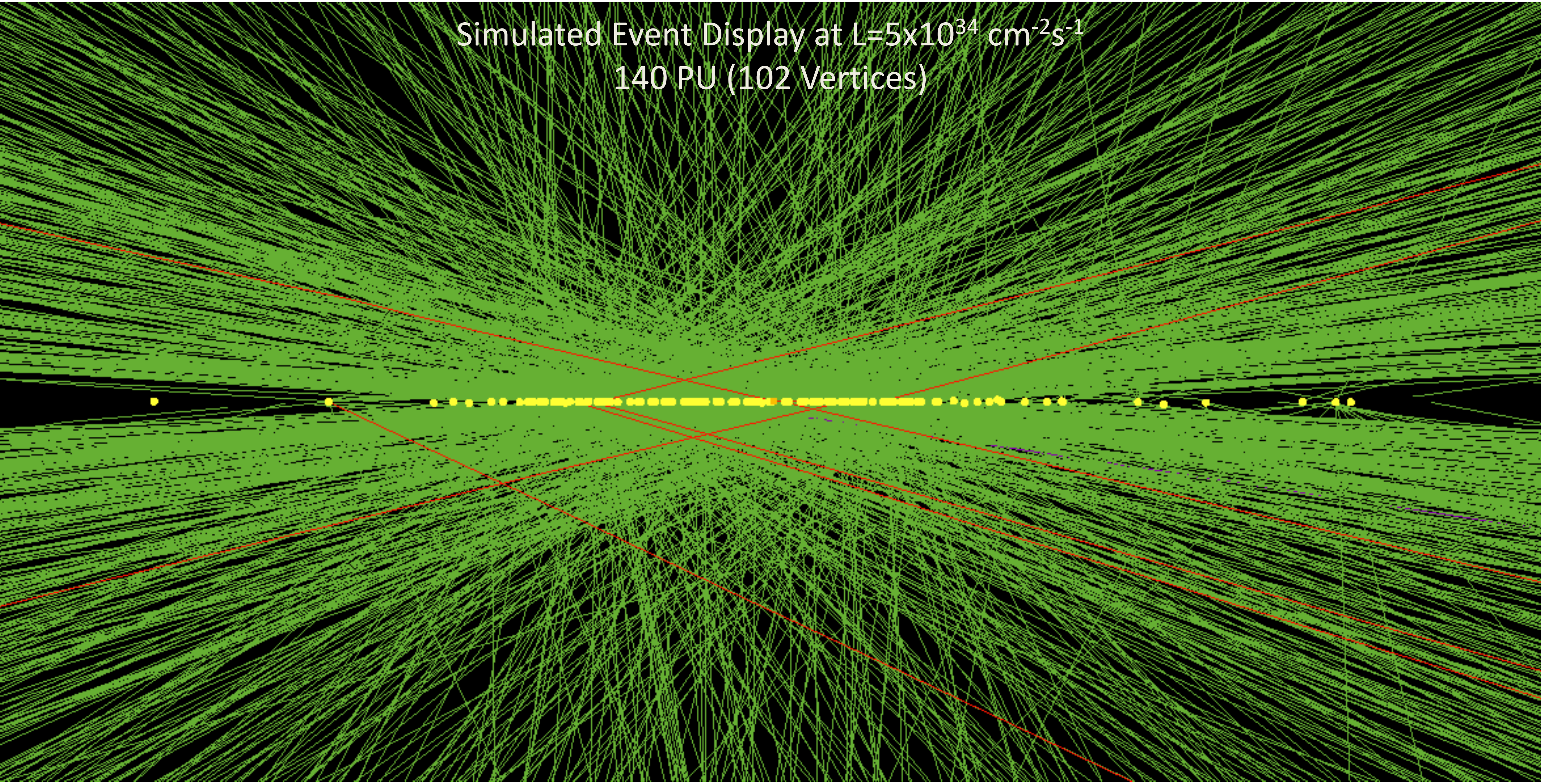

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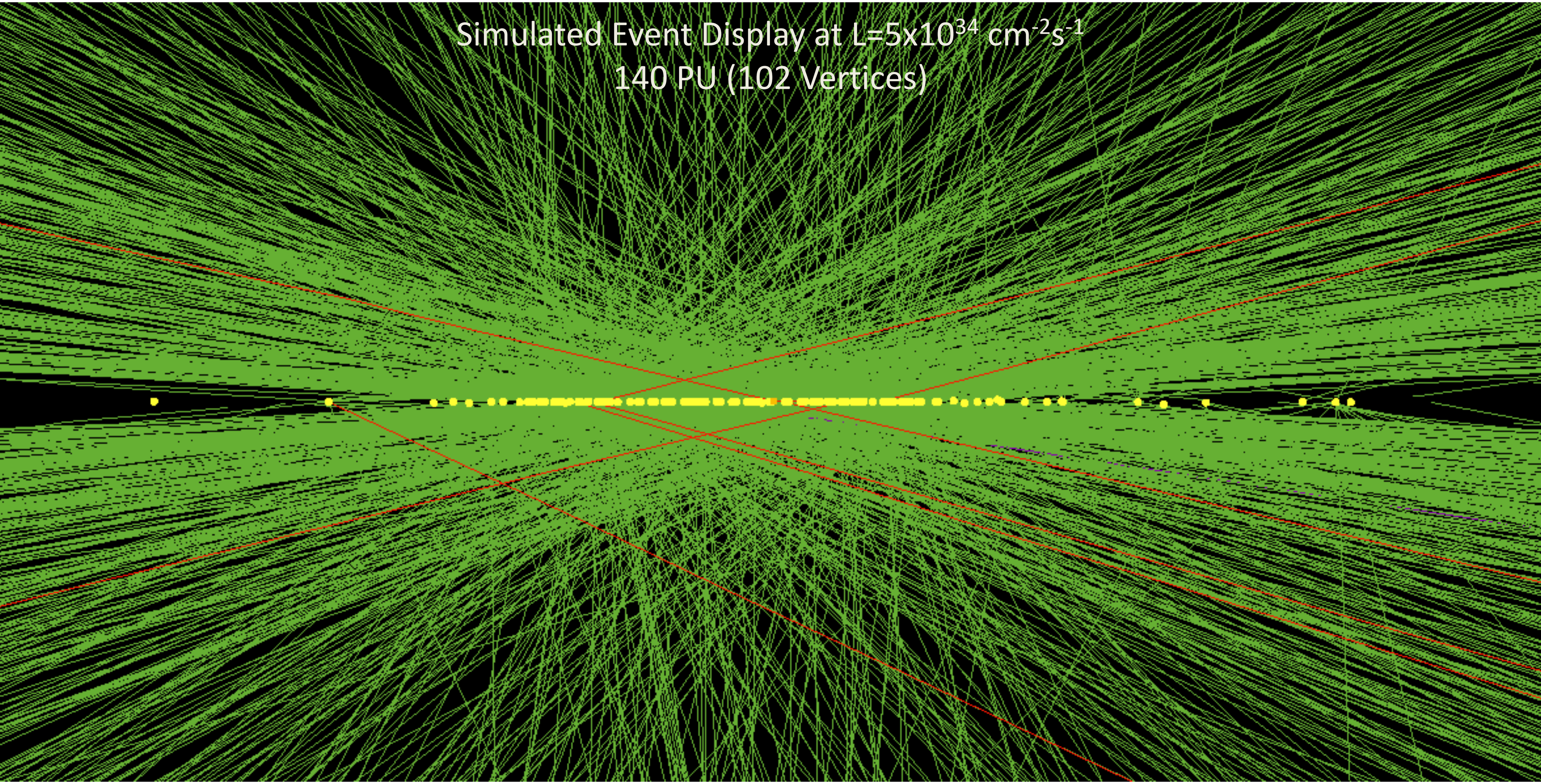

Basically, life will not be easy…

Detector and trigger challenges

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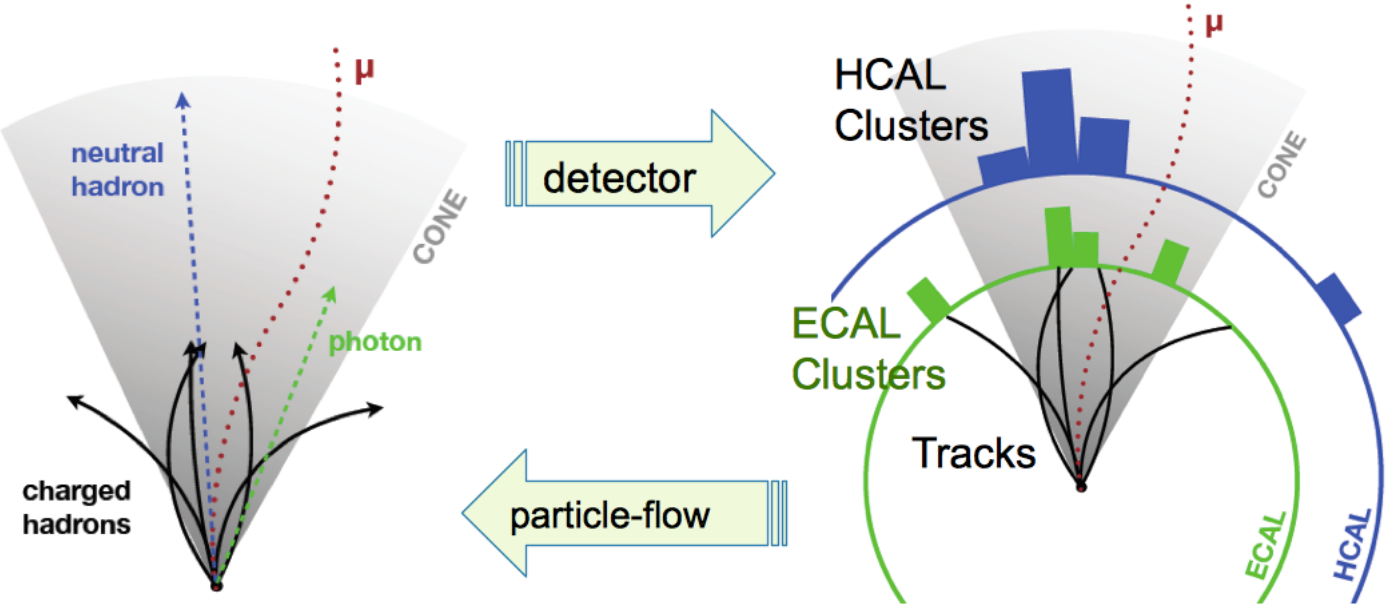
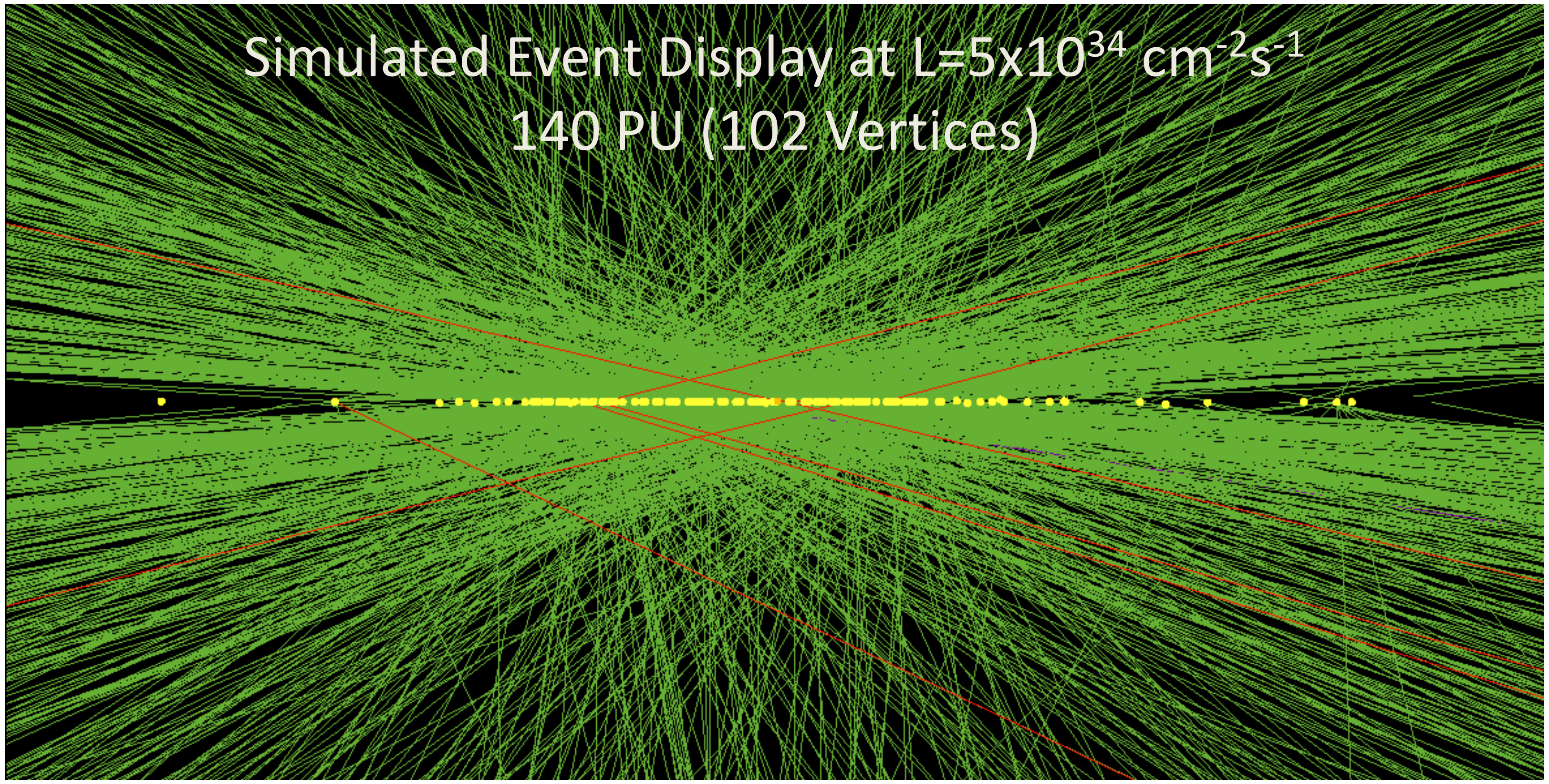
ATLAS and CMS were designed to cope with L= 1-2 x10^{34} $cm^{-2}s^{-1}$

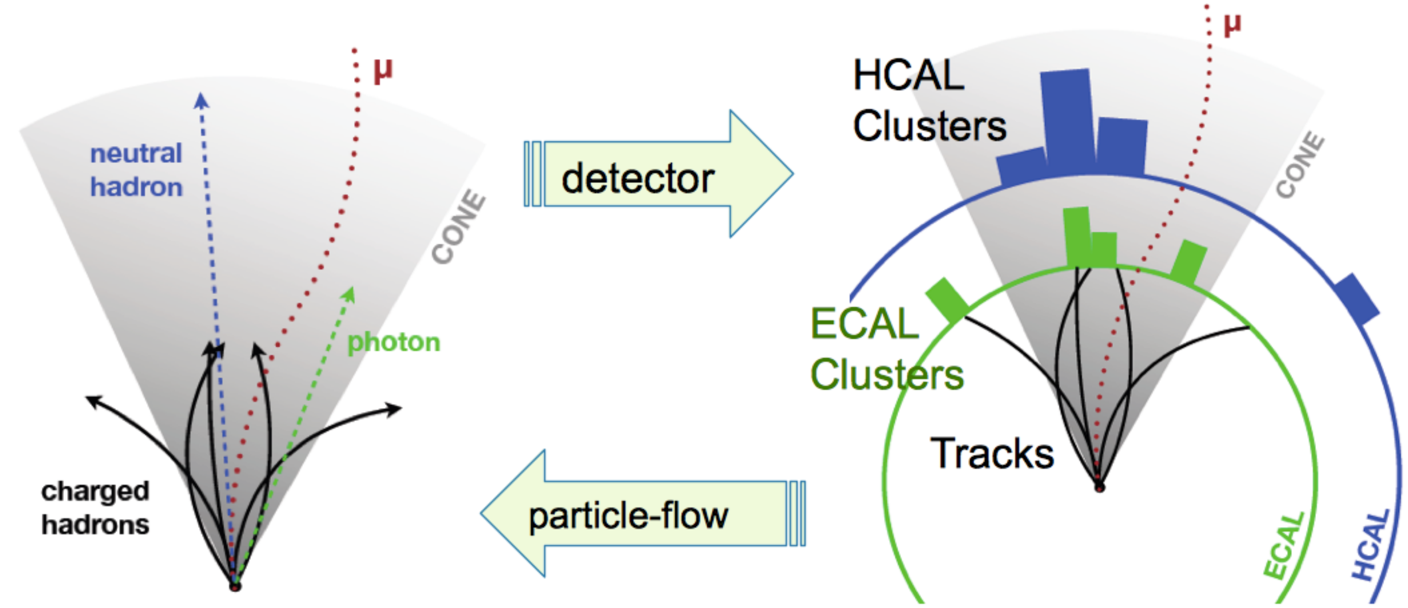
Upgrade challenges and recipe

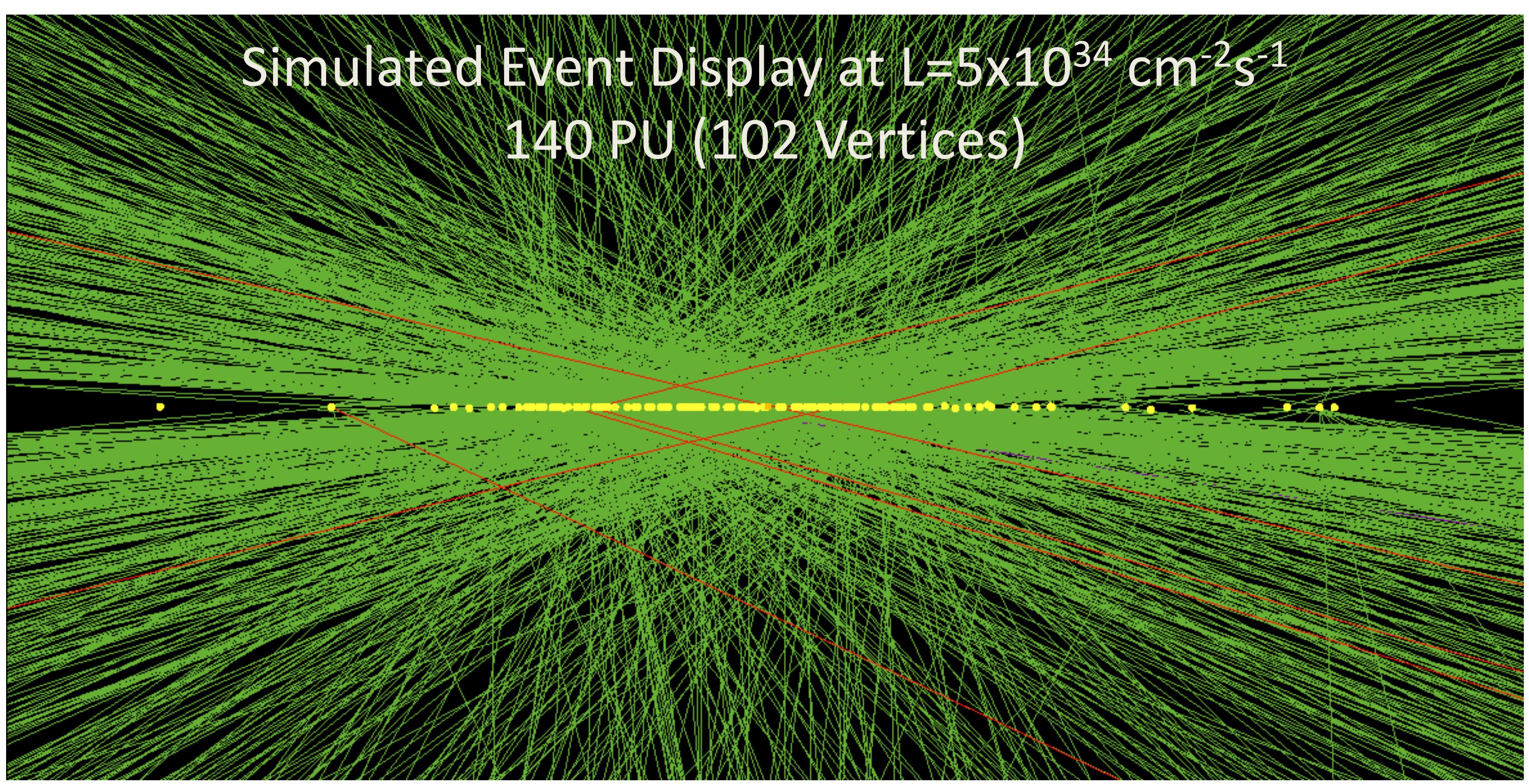




Upgrade challenges and recipe

Maintain low trigger thresholds, efficient particle and physics object reconstruction at high rate and pile-up

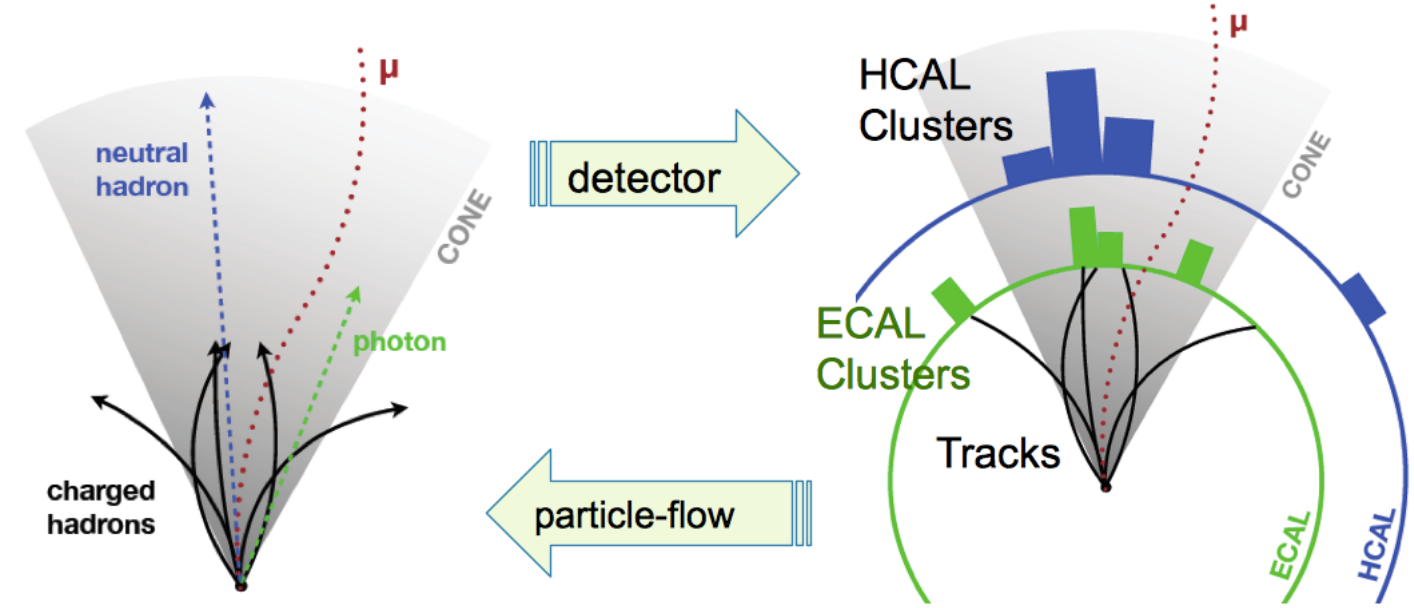


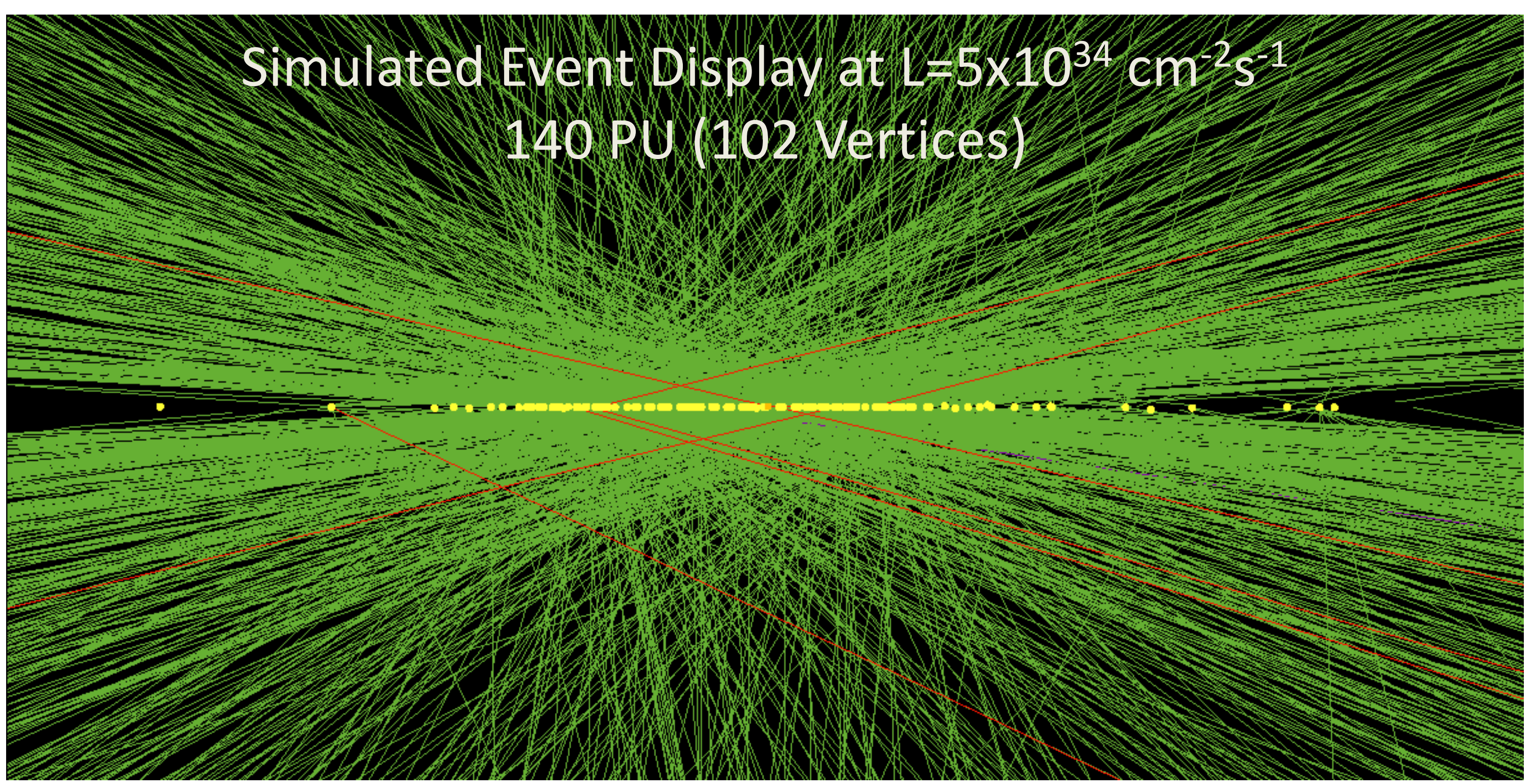


Upgrade challenges and recipe

Maintain low trigger thresholds, efficient particle and physics object reconstruction at high rate and pile-up

Need new technology R&Ds to:



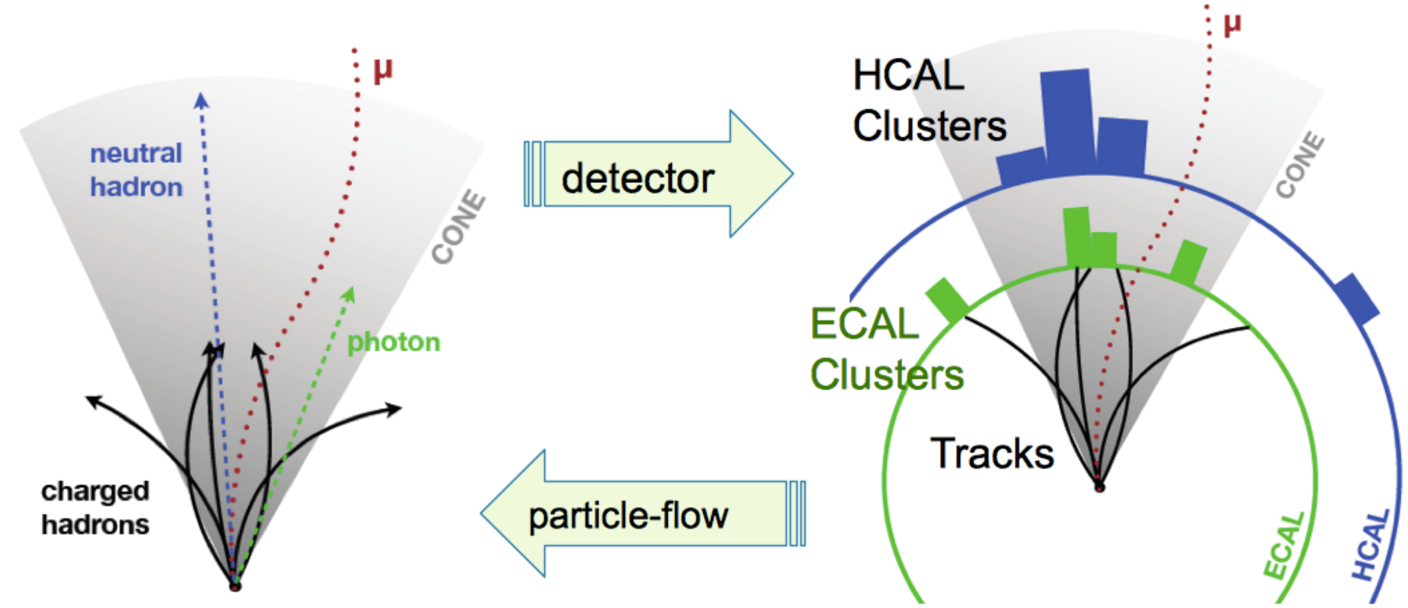


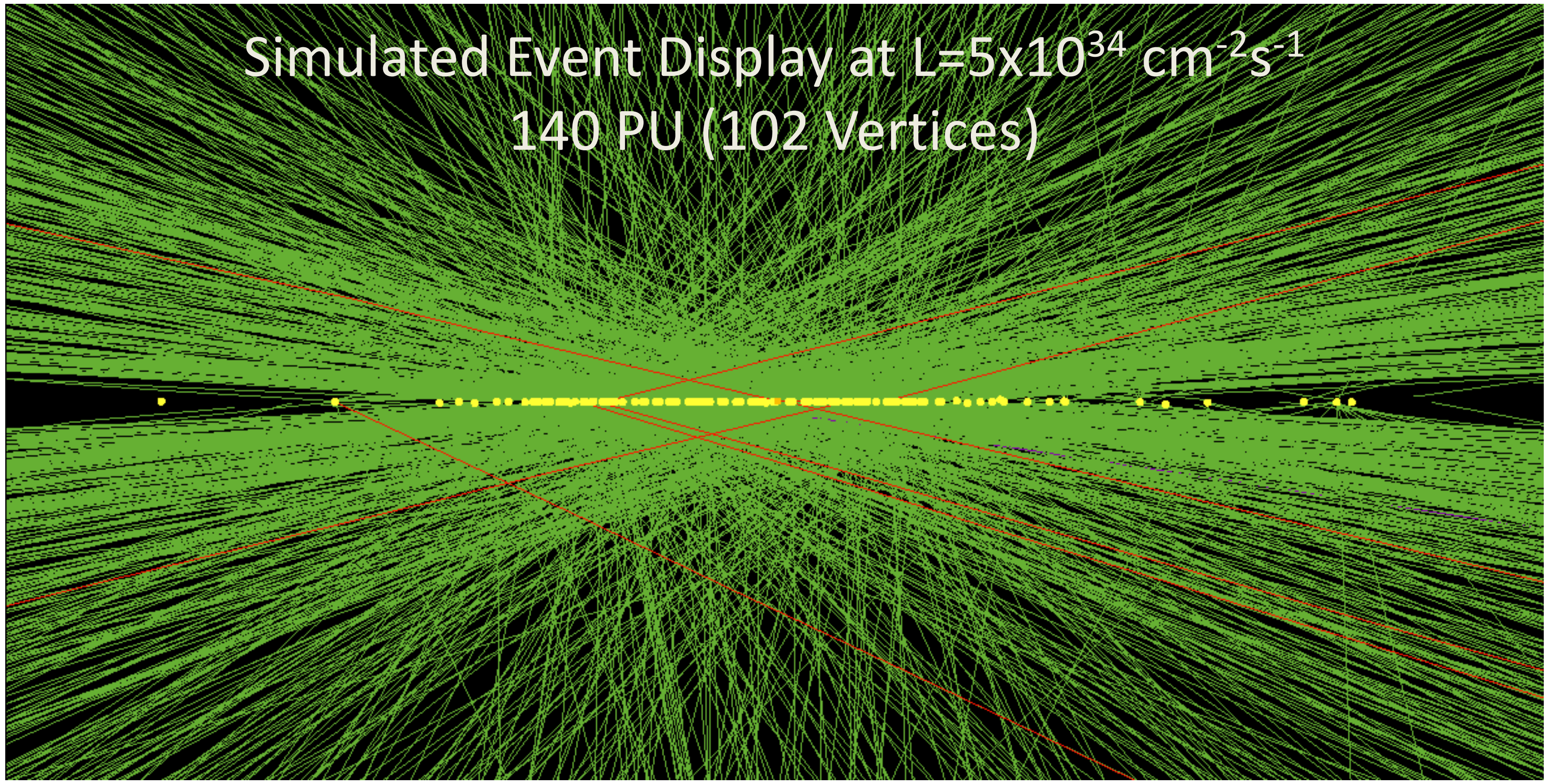
Upgrade challenges and recipe

Maintain low trigger thresholds, efficient particle and physics object reconstruction at high rate and pile-up

Need new technology R&Ds to:

– Increase granularity





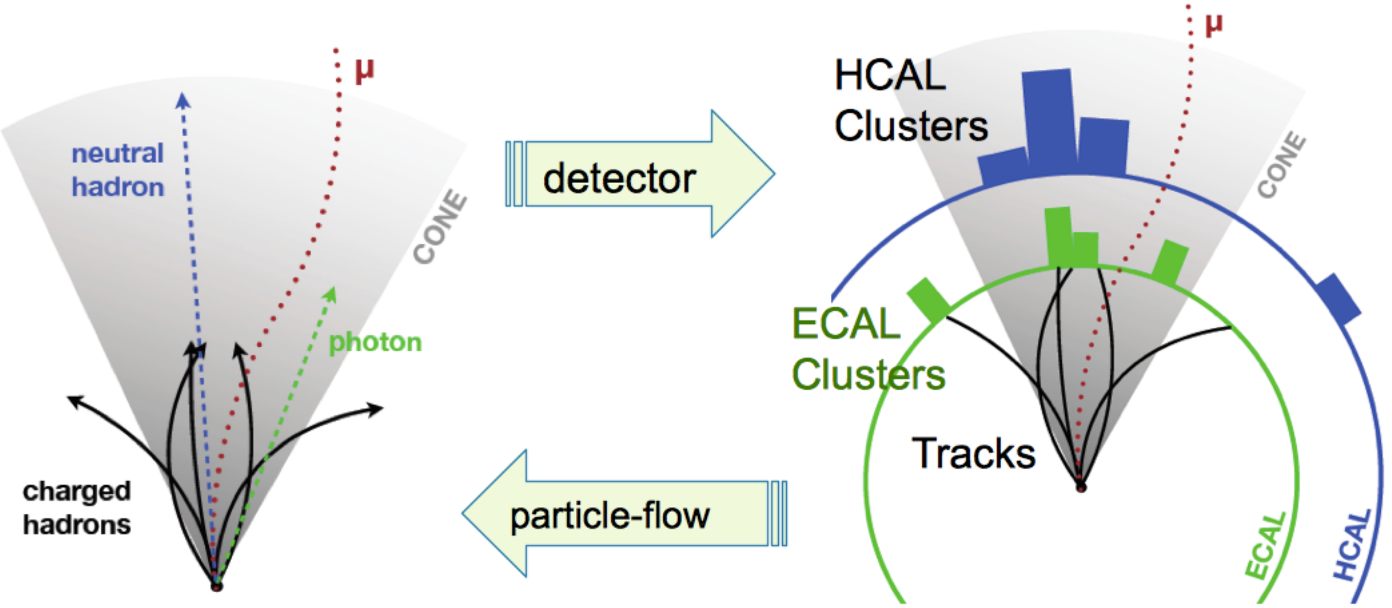
Upgrade challenges and recipe

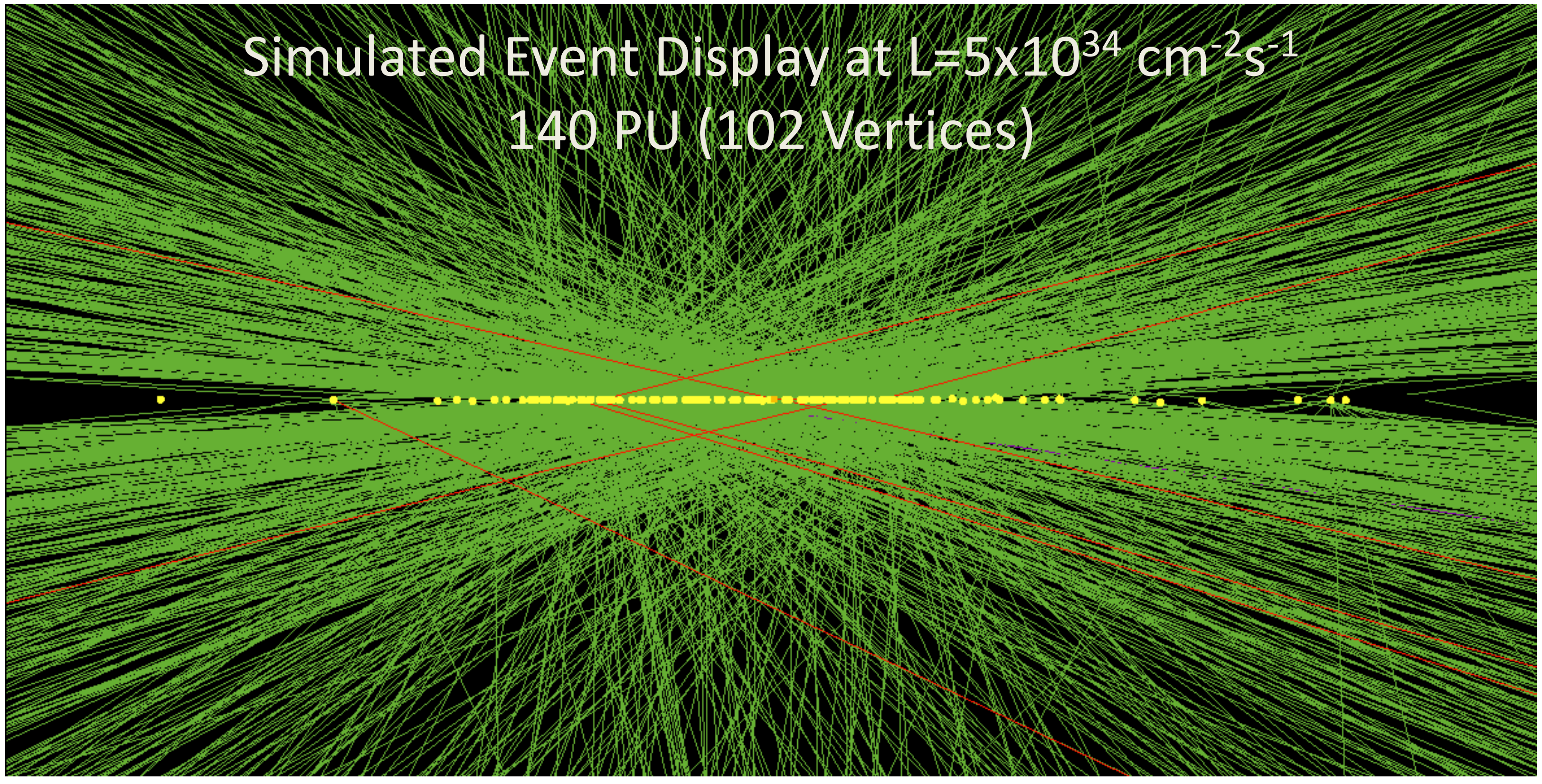
Maintain low trigger thresholds, efficient particle and physics object reconstruction at high rate and pile-up

Need new technology R&Ds to:

– Increase granularity

– Increase data bandwidth





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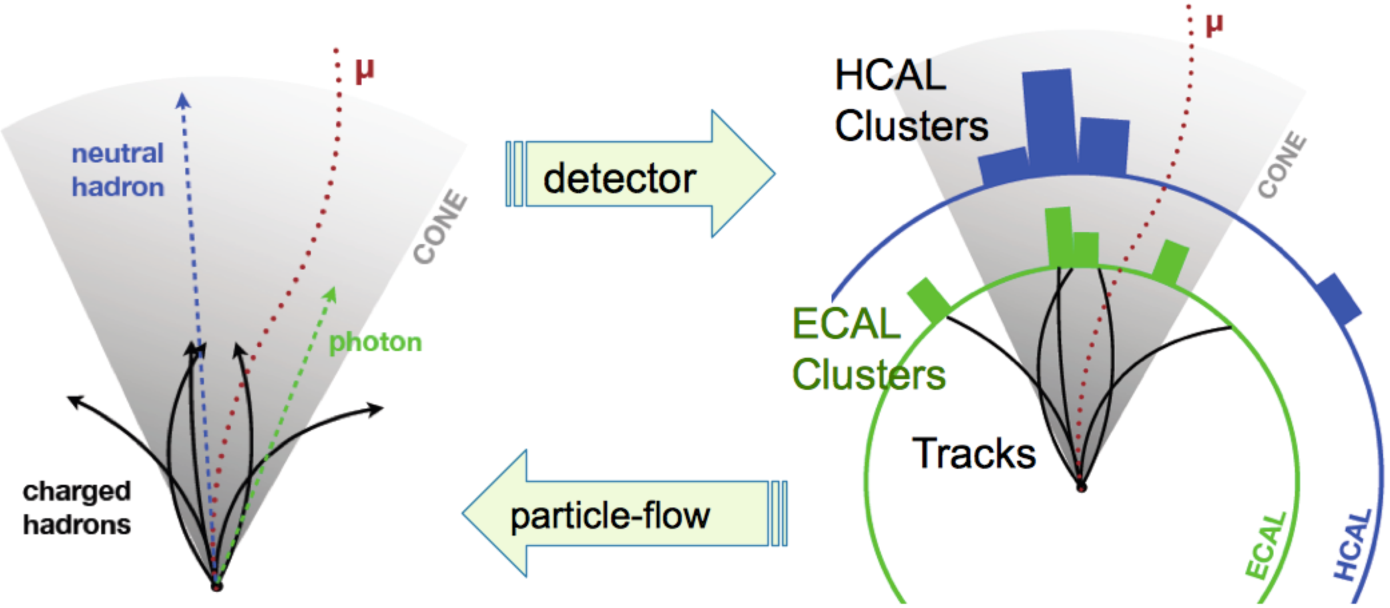
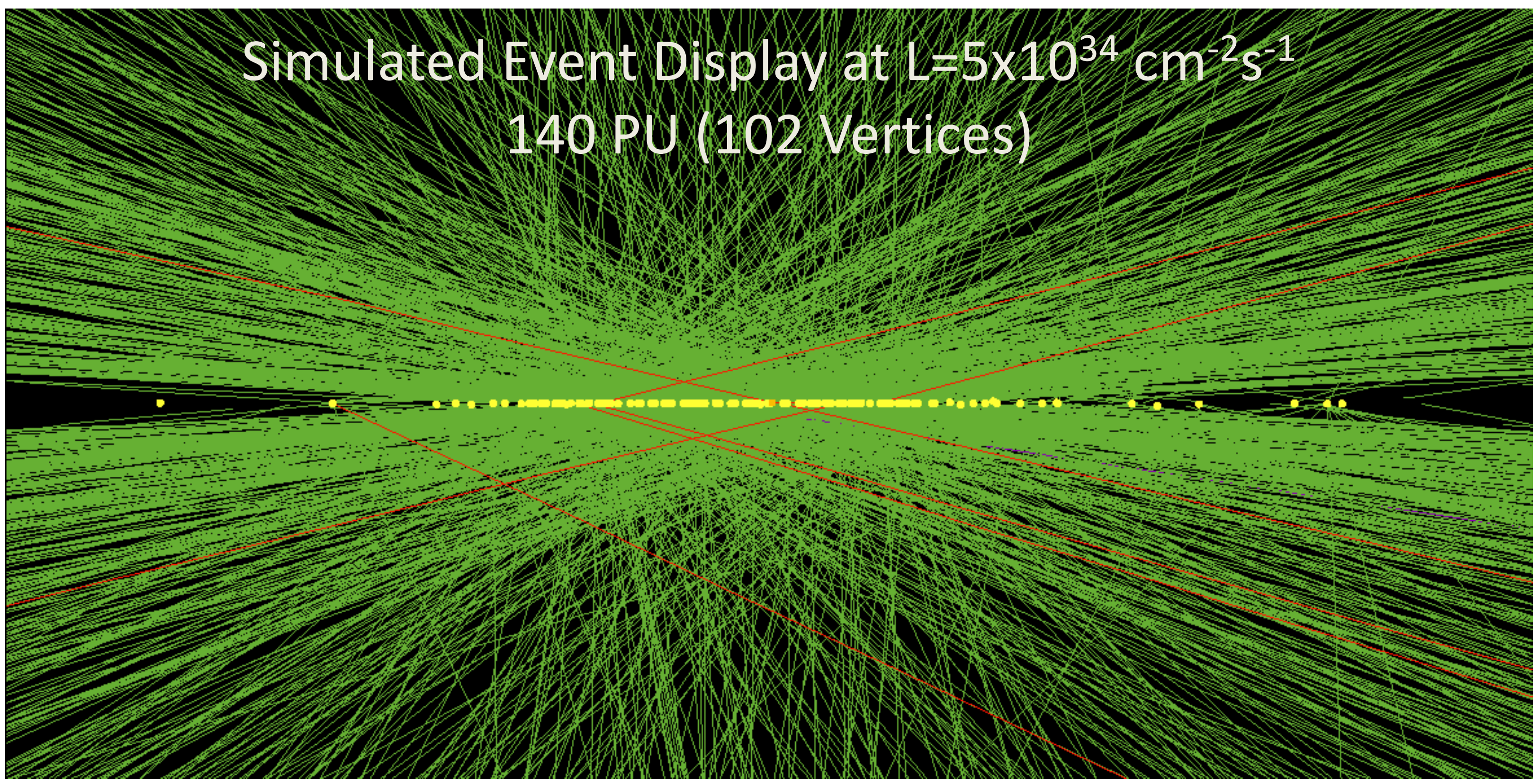
– Increase processing power





Upgrade challenges and recipe

Maintain low trigger thresholds, efficient particle and physics object reconstruction at high rate and pile-up

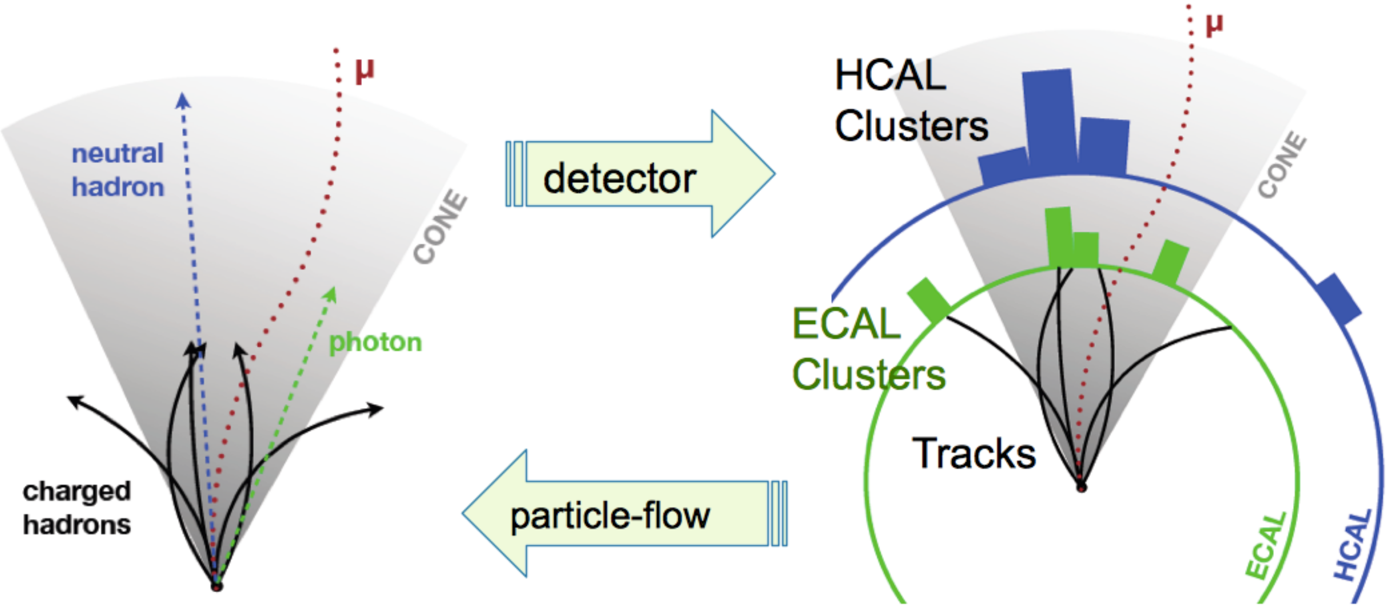
Need new technology R&Ds to:

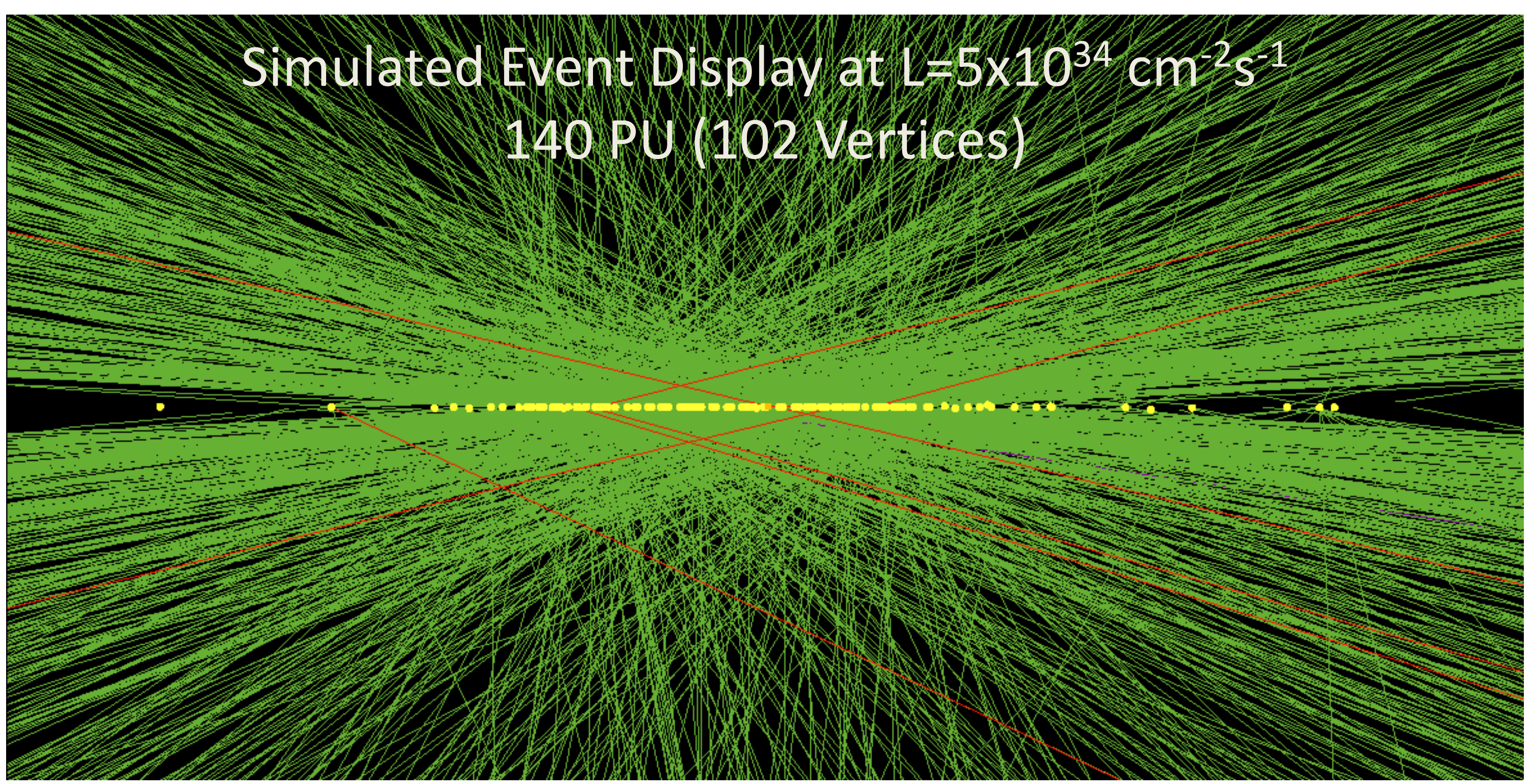
– Increase granularity

– Increase data bandwidth

– Increase processing power

– Improve radiation hardness





Upgrade challenges and recipe

Maintain low trigger thresholds, efficient particle and physics object reconstruction at high rate and pile-up

Need new technology R&Ds to:

– Increase granularity
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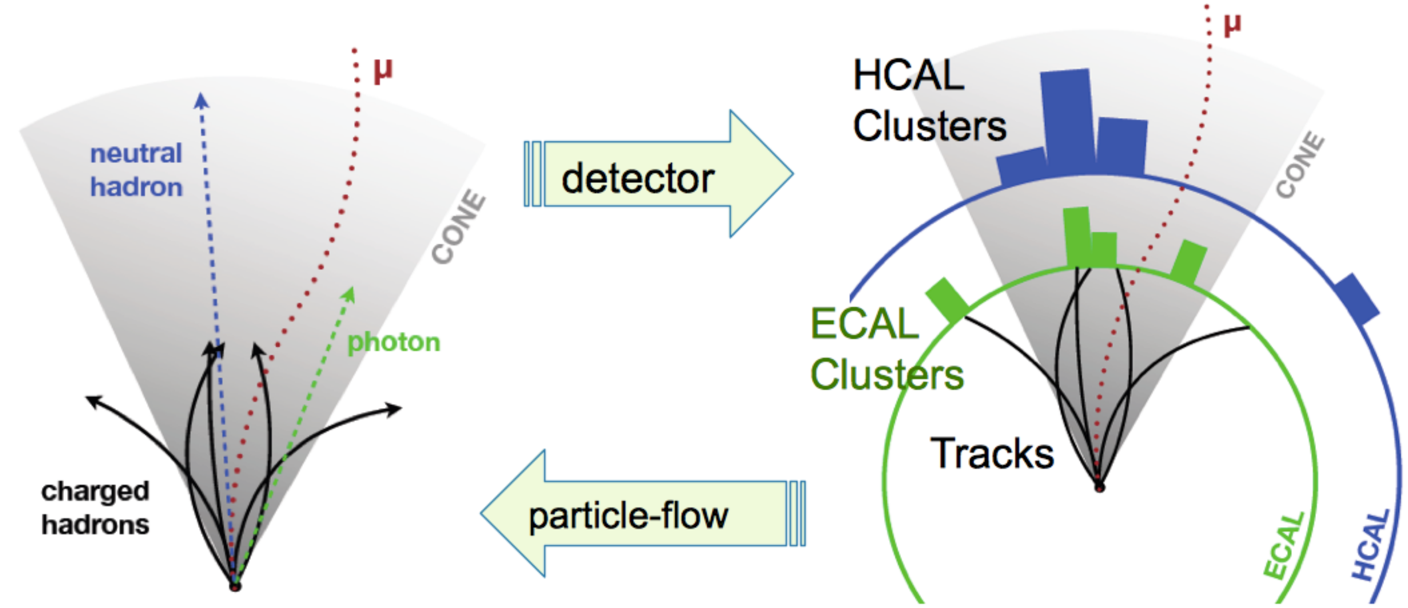

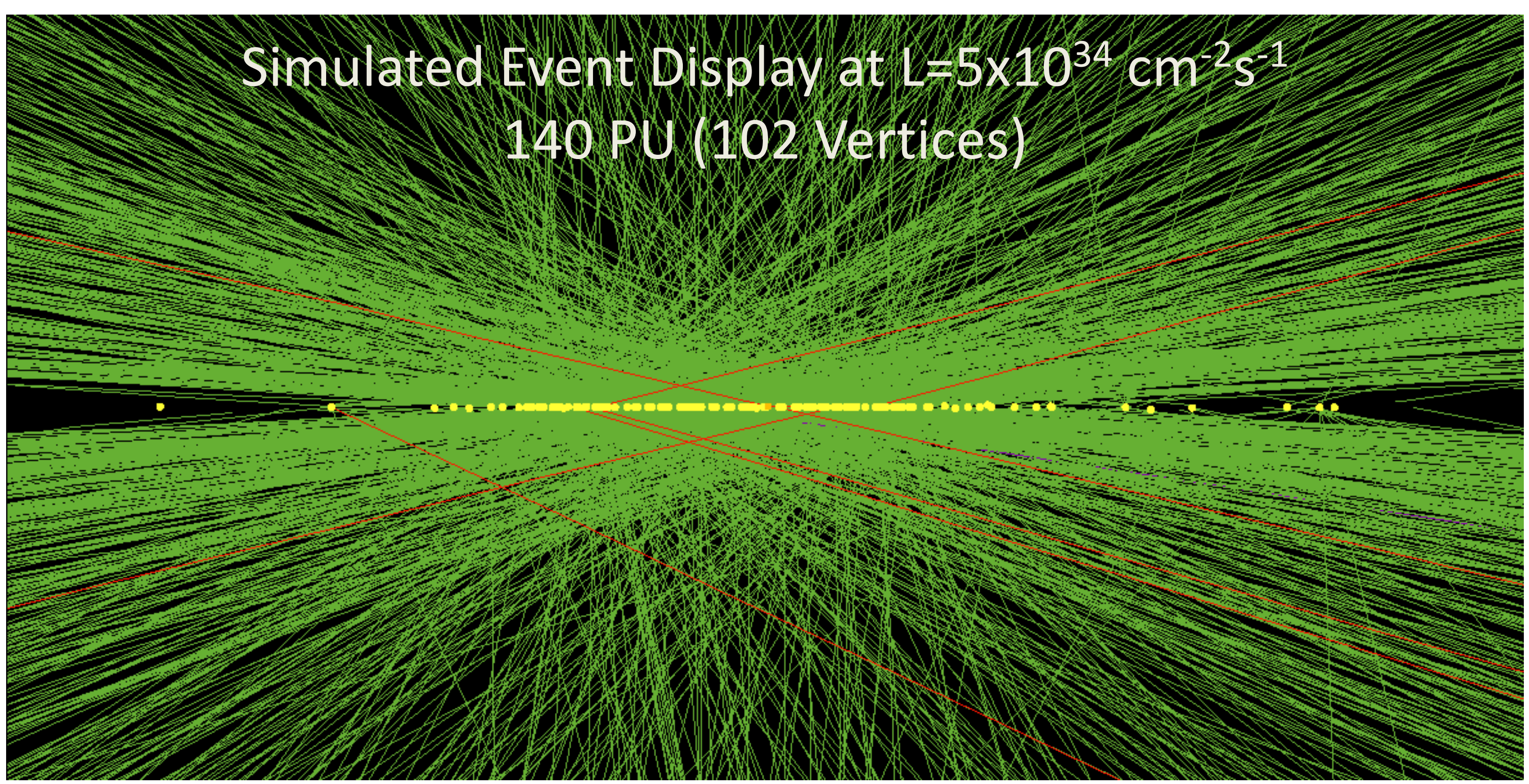

Physics program priorities

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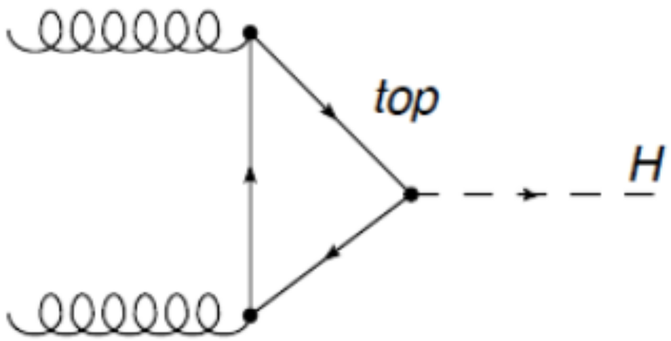
  - Search for new physics in very rare processes

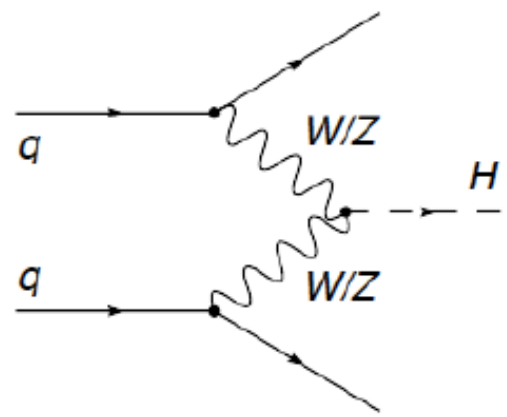
Higgs Physics at HL-LHC

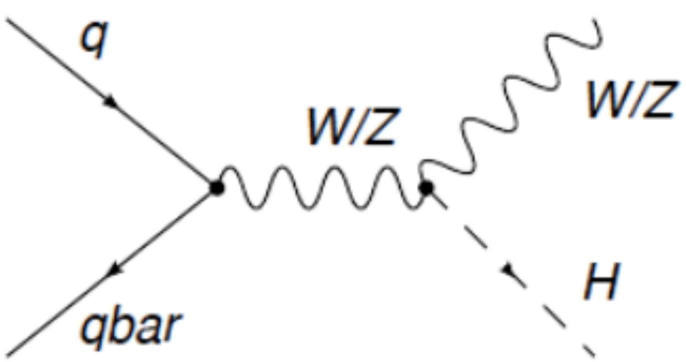
Higgs Physics at HL-LHC

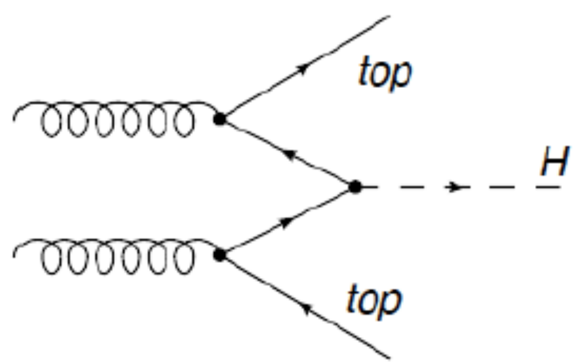
Production

Production



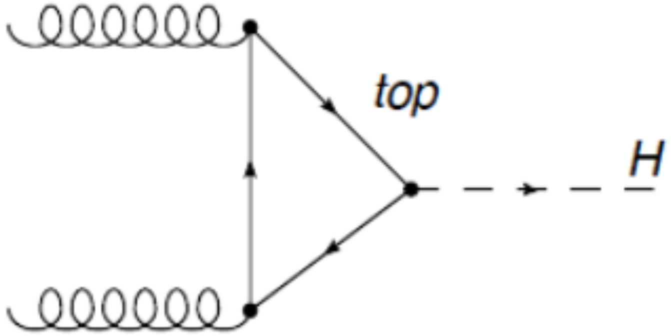


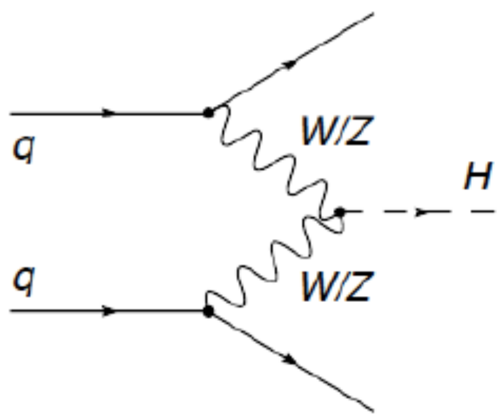


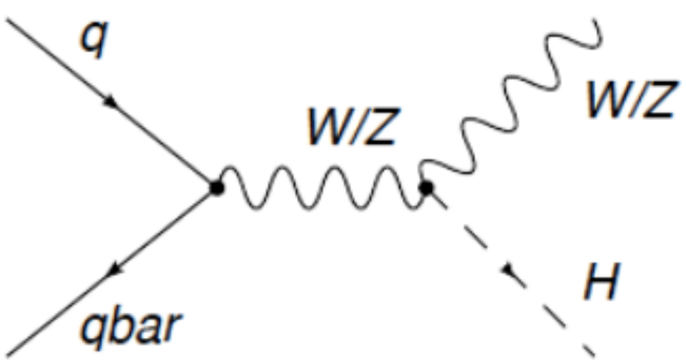


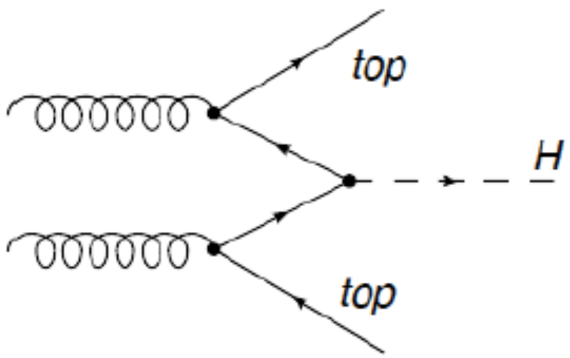
Production

gg fusion









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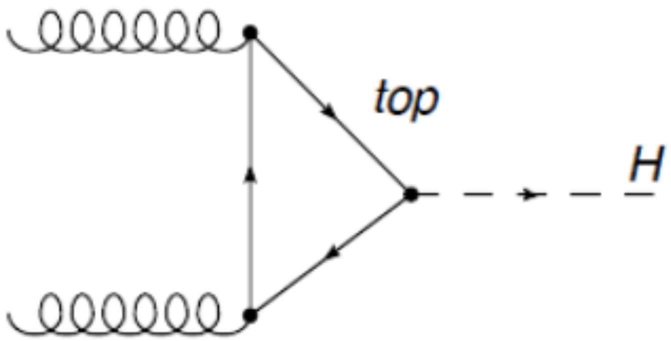
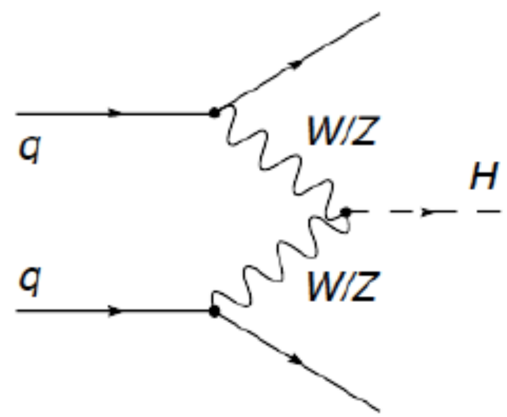
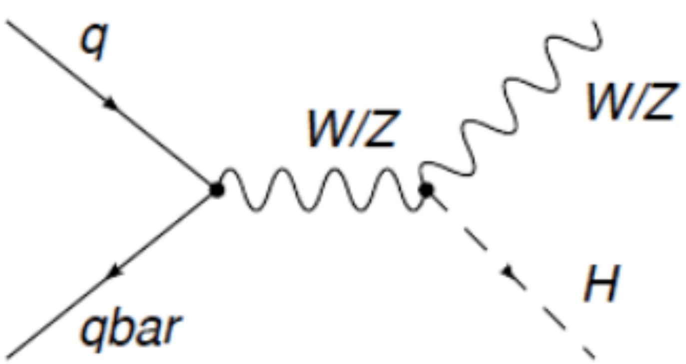
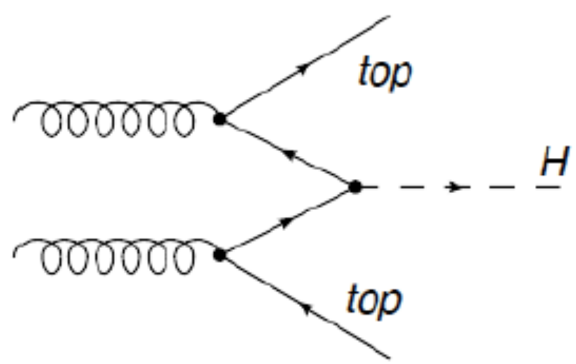


VBF







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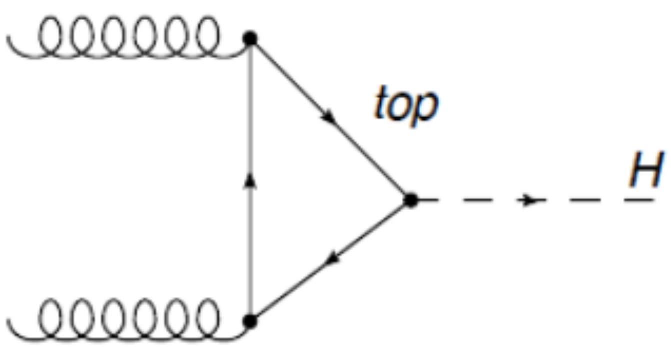

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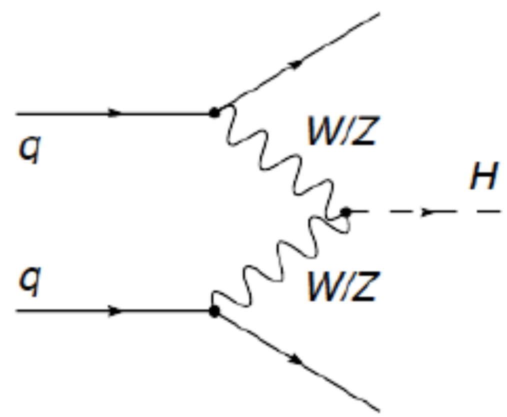

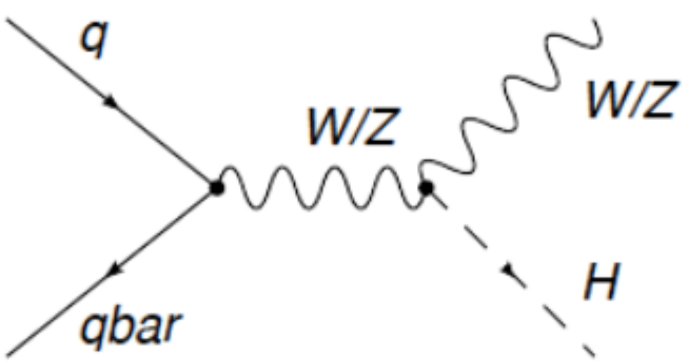

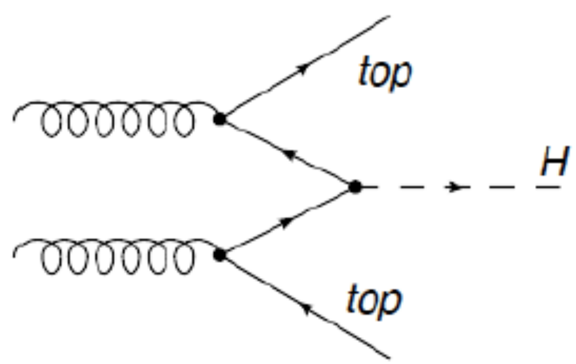

ttH

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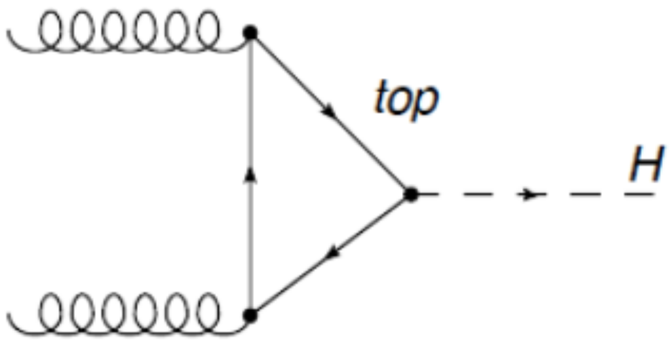

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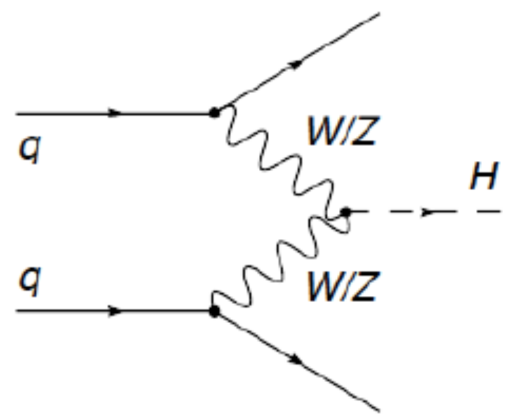
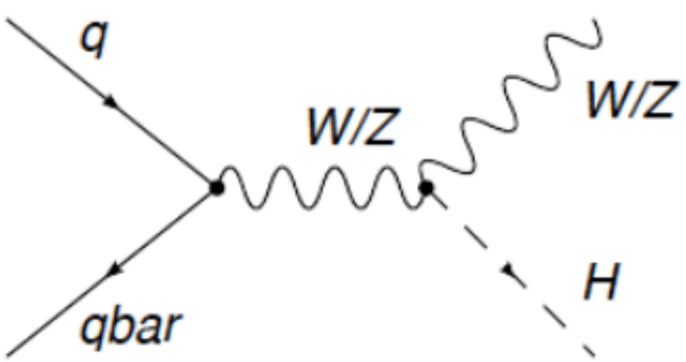
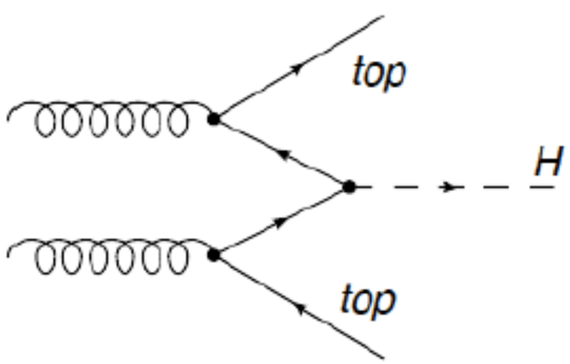




Associated production (Higgstrahlung)



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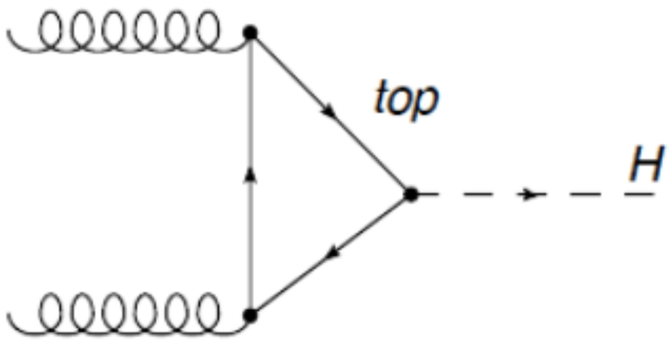
Higgs Physics at HL-LHC

Production

Decay

gg fusion



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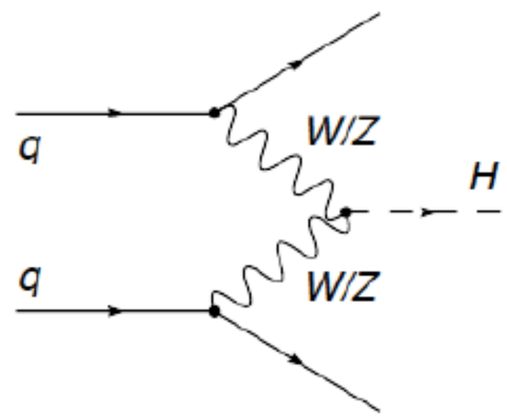

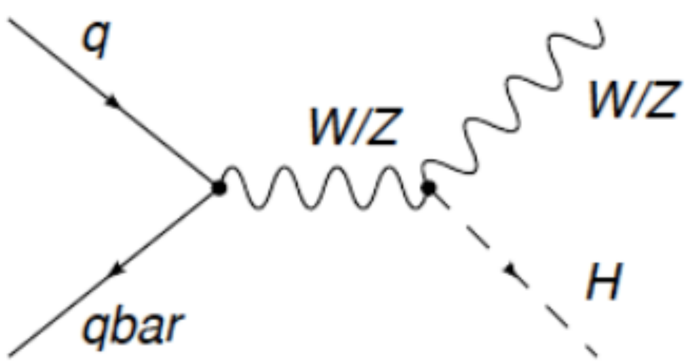

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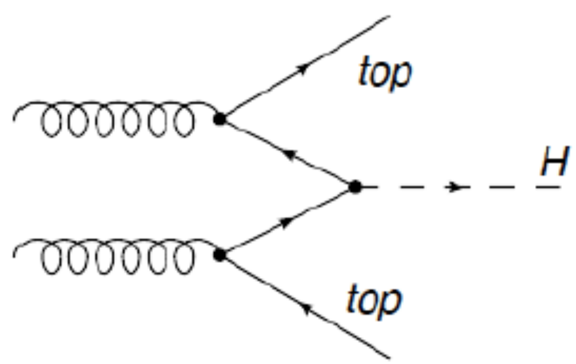

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Higgs Physics at HL-LHC

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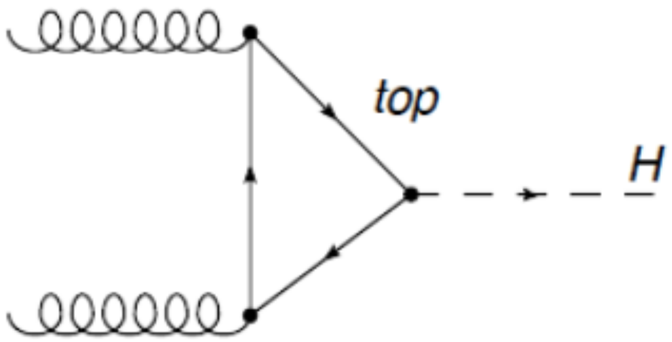
gg fusion



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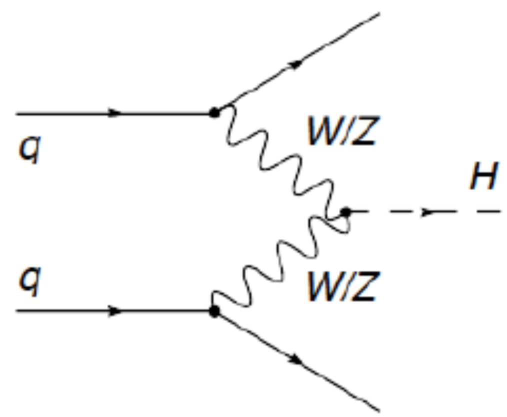

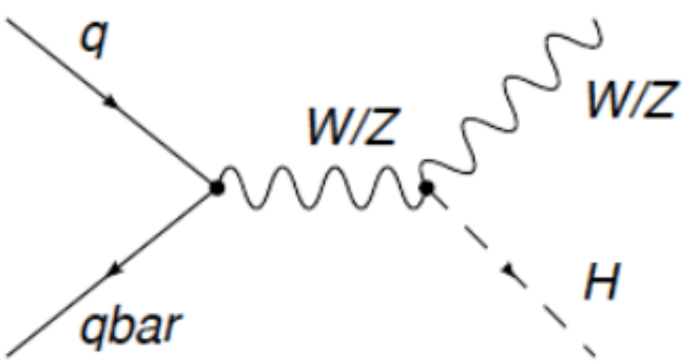

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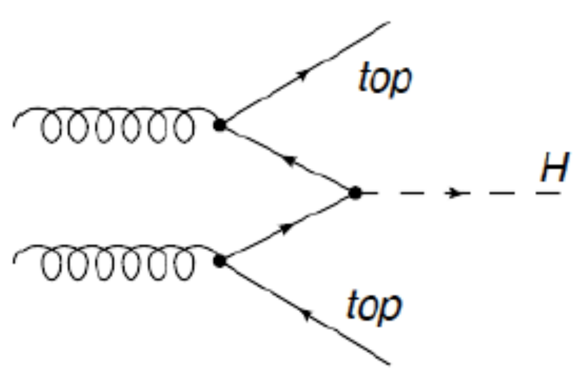

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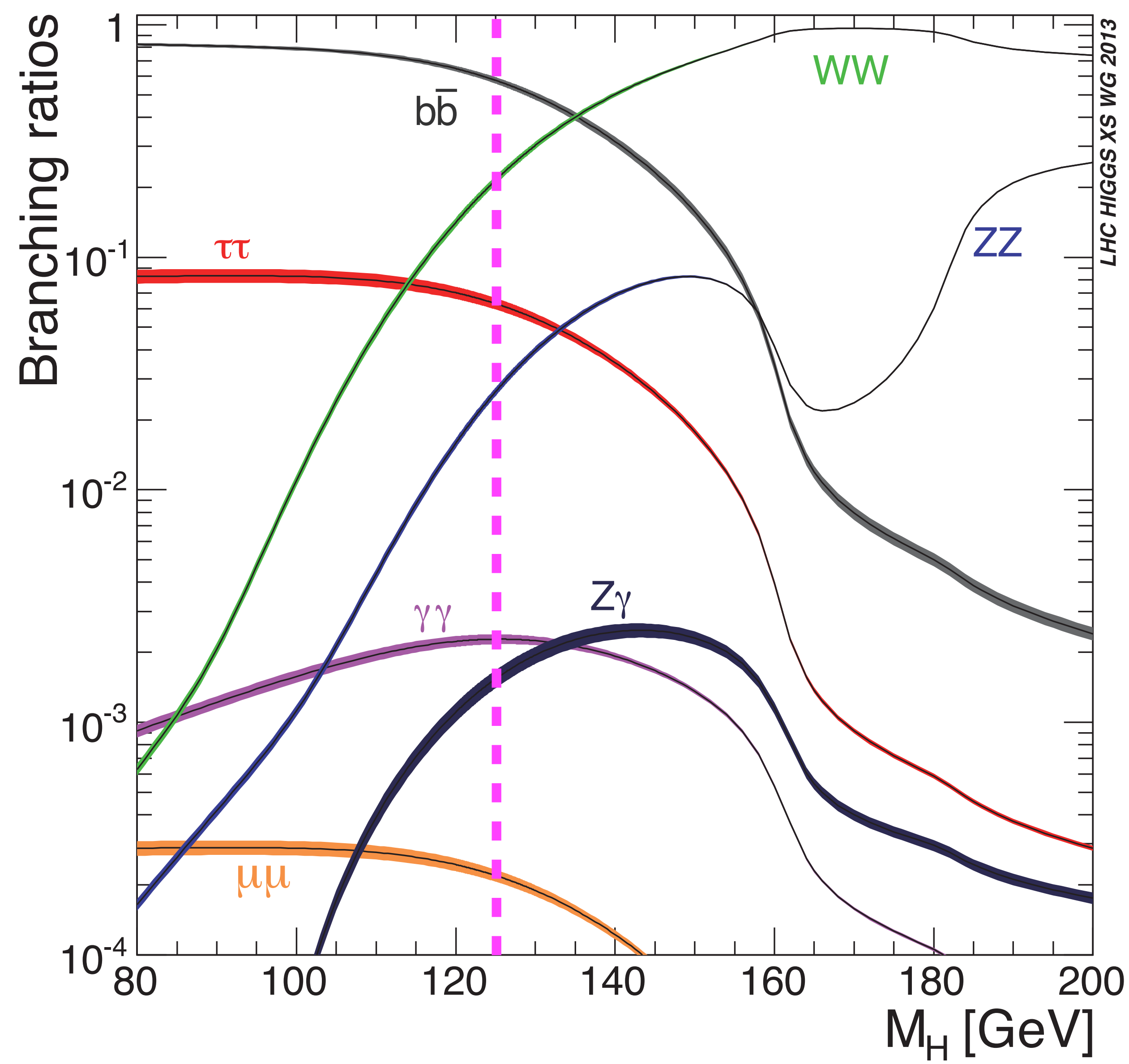

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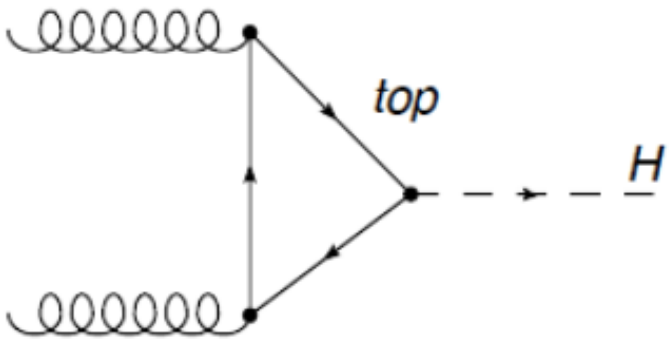

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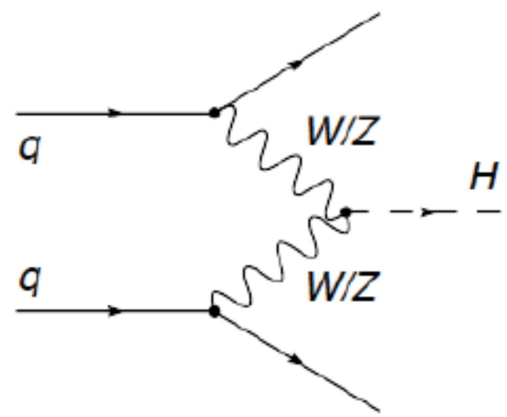

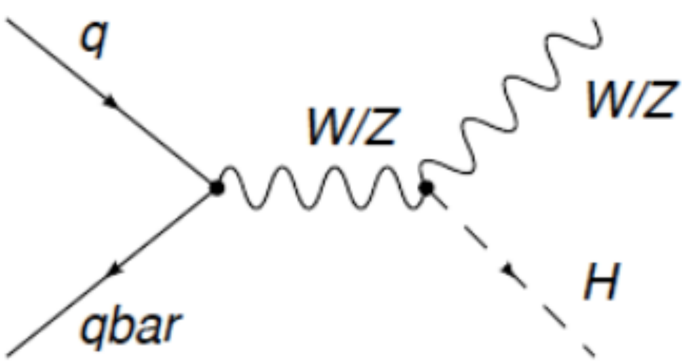

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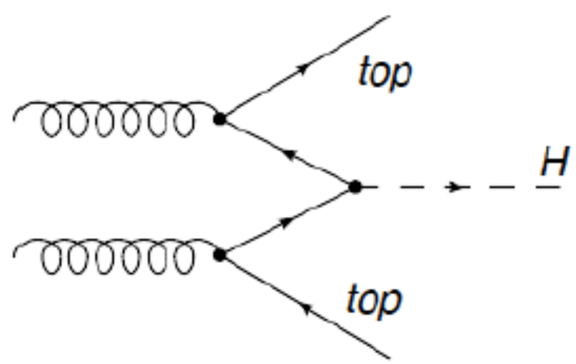

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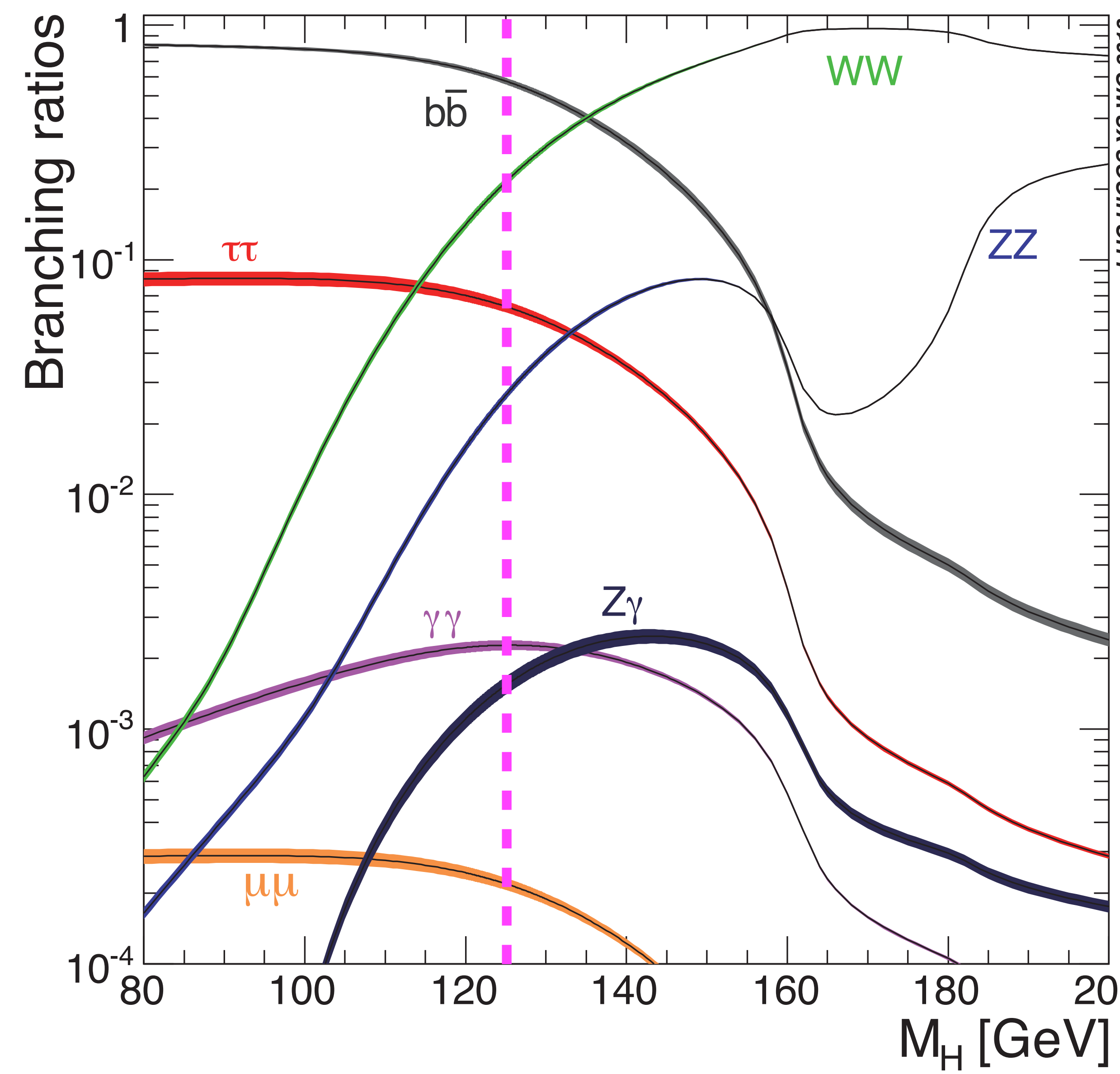

Large variety of final states to study

Higgs Physics at HL-LHC

Higgs Physics at HL-LHC

HL-LHC is a Higgs factory!

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HL-LHC 3000 fb	Higgs bosons at √s=14 TeV

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Higgs Physics at HL-LHC

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  - Vector boson scattering
  - Look for small deviations from SM predictions

Higgs Physics at HL-LHC

"If you don't have the ball, you cannot score"

Now with the Higgs boson in their hands,
particle physicists can... play as well as Germans against Brazilians

Higgs as a target

- observe it in as many channels as possible to measure its properties
- check of the coupling structure of the SM and its deformations
- interpret deviations of Higgs couplings as a sign of NP

Higgs as a tool

- a portal to New Physics
- in initial states: rare decays

  e.g., $h \rightarrow \mu\tau$, $h \rightarrow J/\Psi+\gamma$
- in final states as an object that can be reconstructed and tagged

  e.g., $t \rightarrow h+c$, $H \rightarrow hh$

see G. Perez's talk

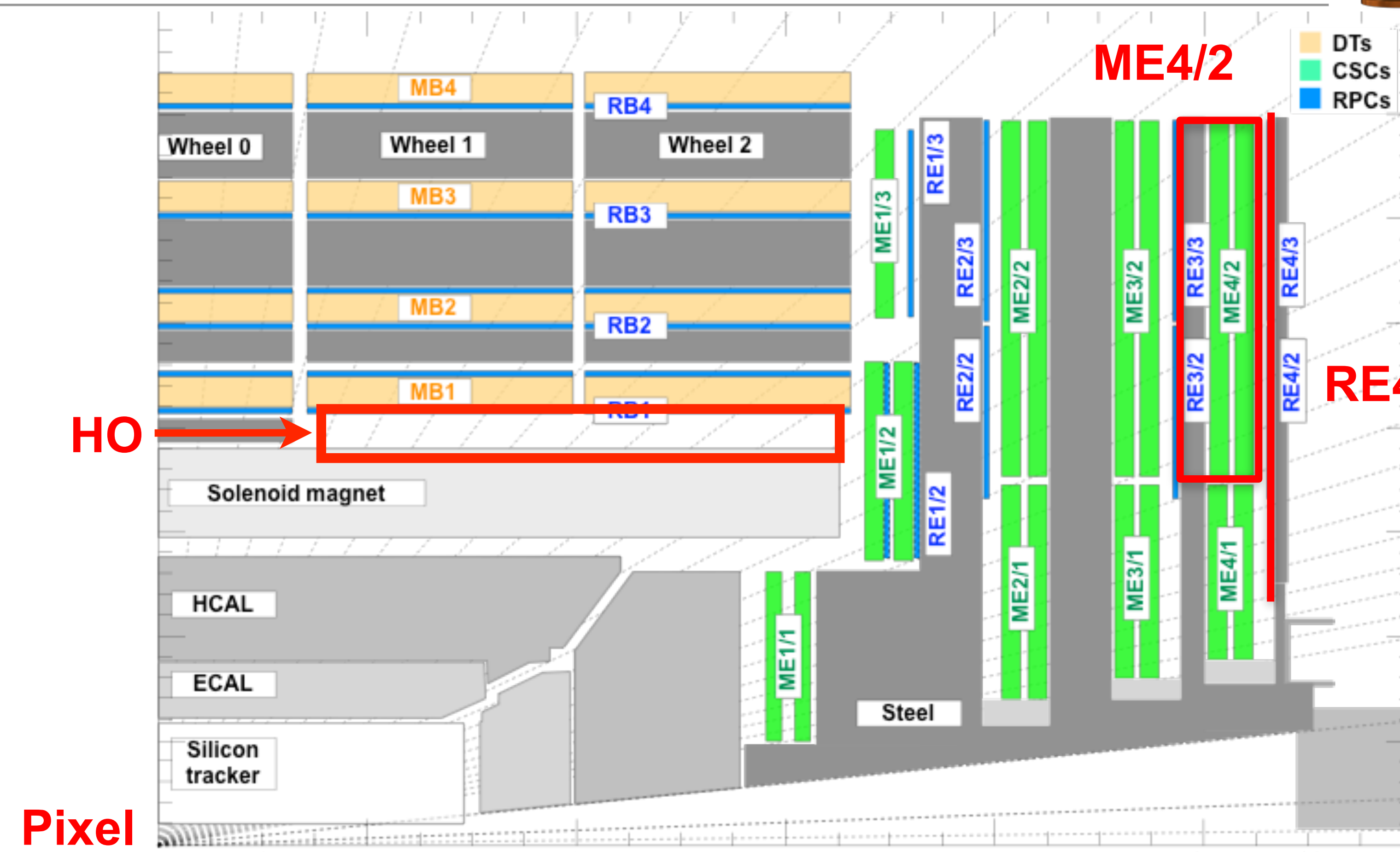
C. Grosjean - ECFA 2014

Why going for HL-LHC? To gain more statistics!
The winners are the channels that

1) are very rare: $\sigma * L < O(1)$ @ 300/fb but $\sigma * L > O(1)$ @ 3/ab
2) do not saturate the statistical uncertainties, such that $S/\sqrt{B}$ still scales like $\sqrt{L}$

(need to reduce the theoretical uncertainties as much as possible)

CMS upgrade program



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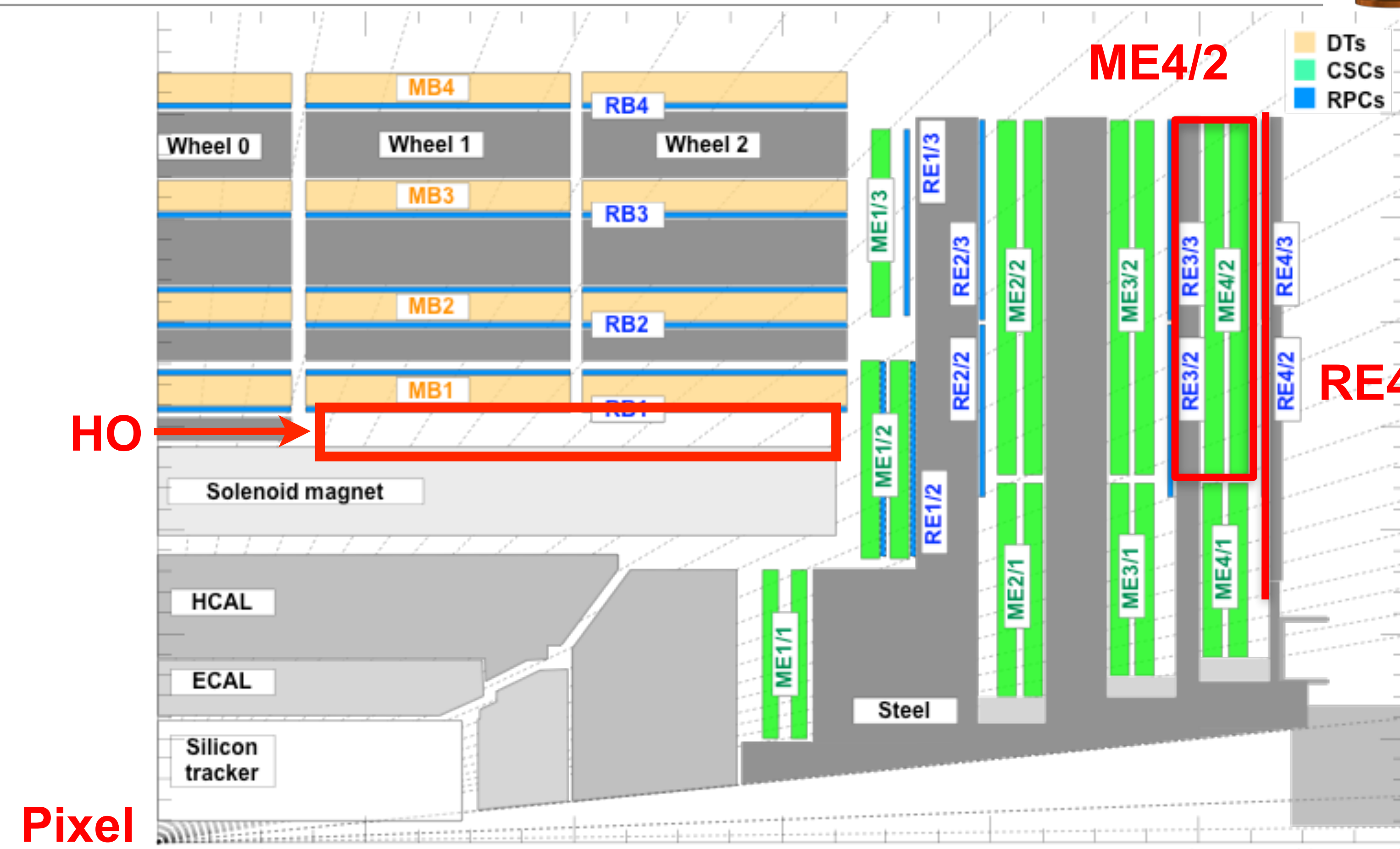

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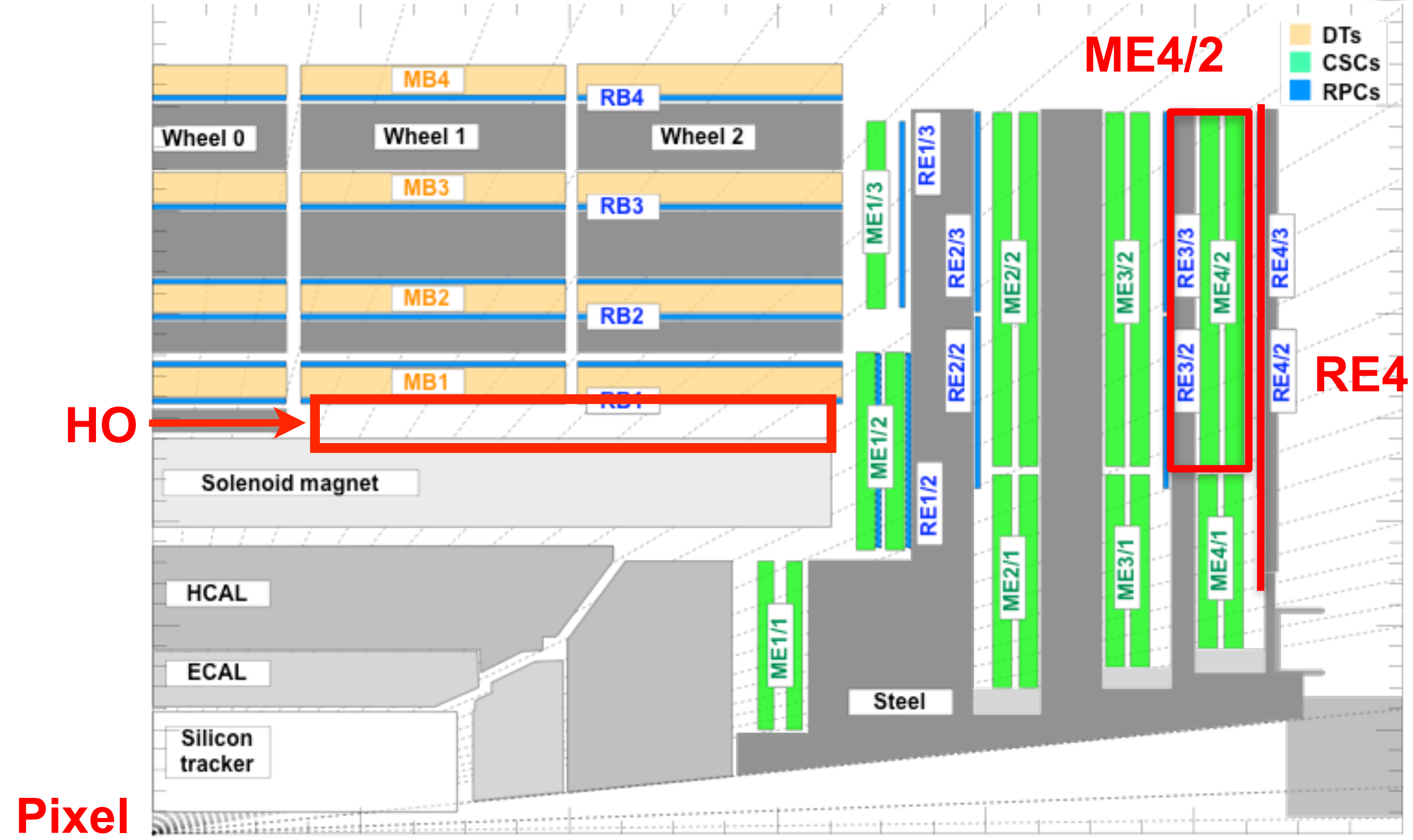
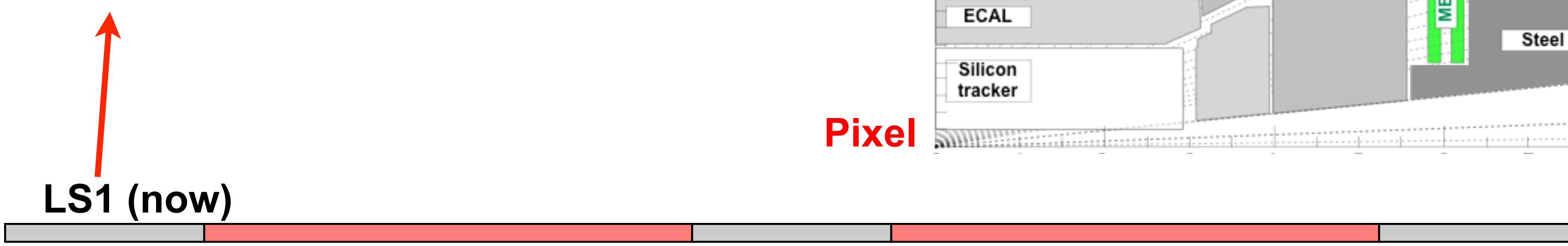
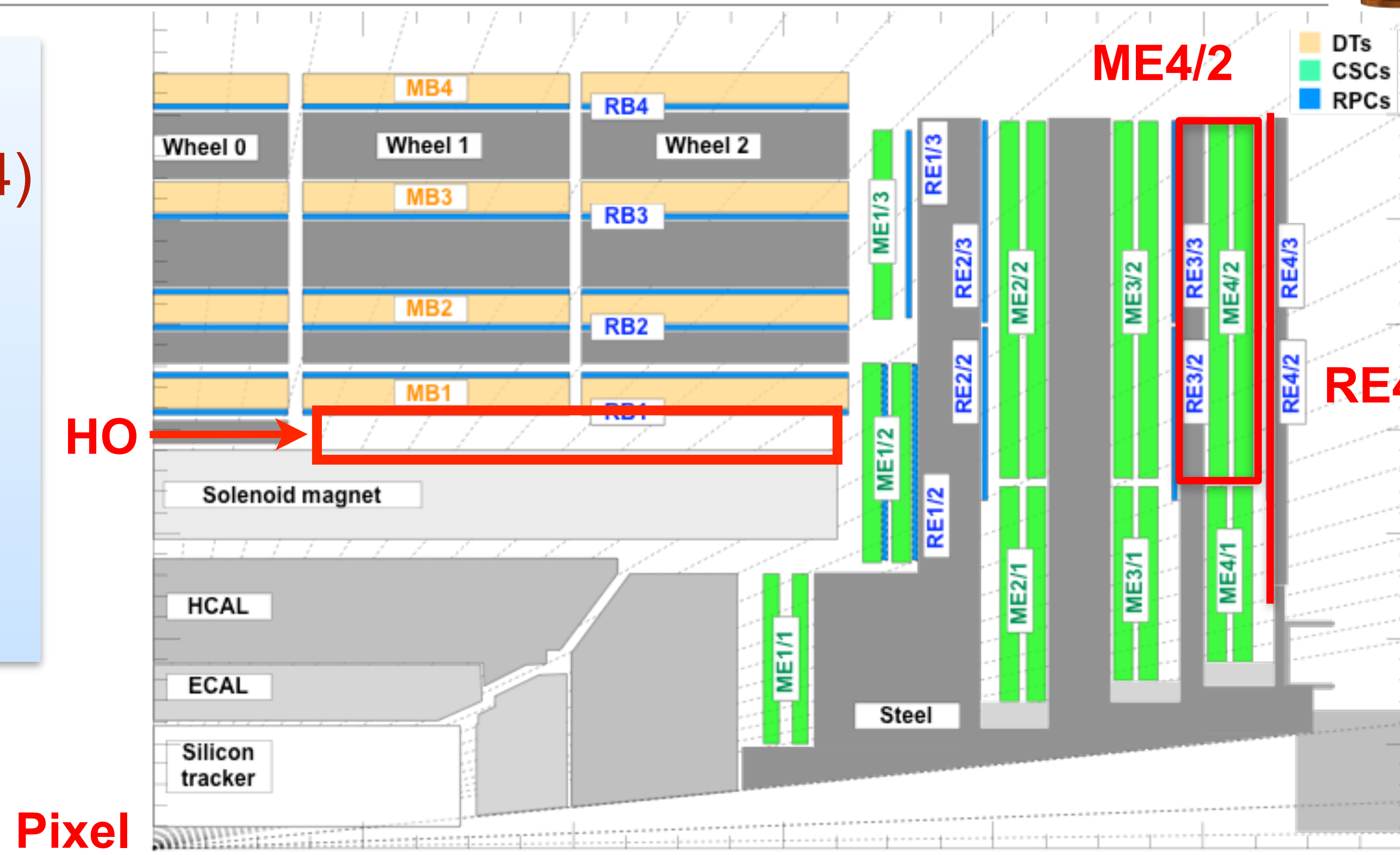




CMS upgrade program

LS1 Projects

- Complete Muon coverage (ME,RE4)
- Improve muon operation, DT electronics
- Replace HCAL photo-detectors in Forward (new PMTs) and Outer (HPD→SiPMs)
- DAQ1→DAQ2



LS1 (now)

CMS upgrade program

LS1 Projects

- Complete Muon coverage (ME,RE4)
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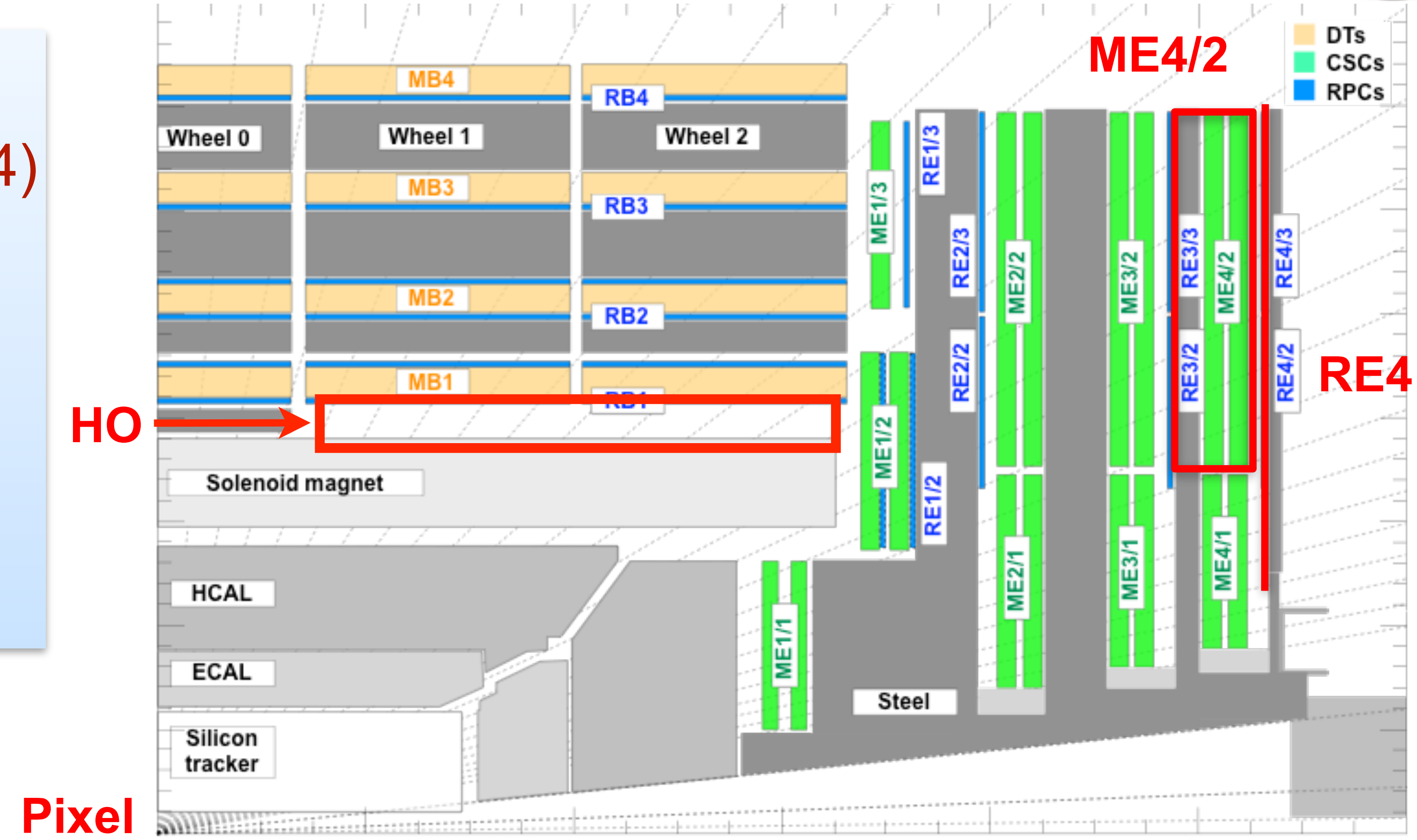

LS1 (now) LS2 (2018)

Phase 1 Upgrades

- New Pixel detector, HCAL electronics and L1-Trigger upgrade
- GEMs for forward muon det. under review
- Preparatory work during LS1
  - New beam pipe for pixel upgrade
  - Install test slices of pixel, HCAL, L1-trigger
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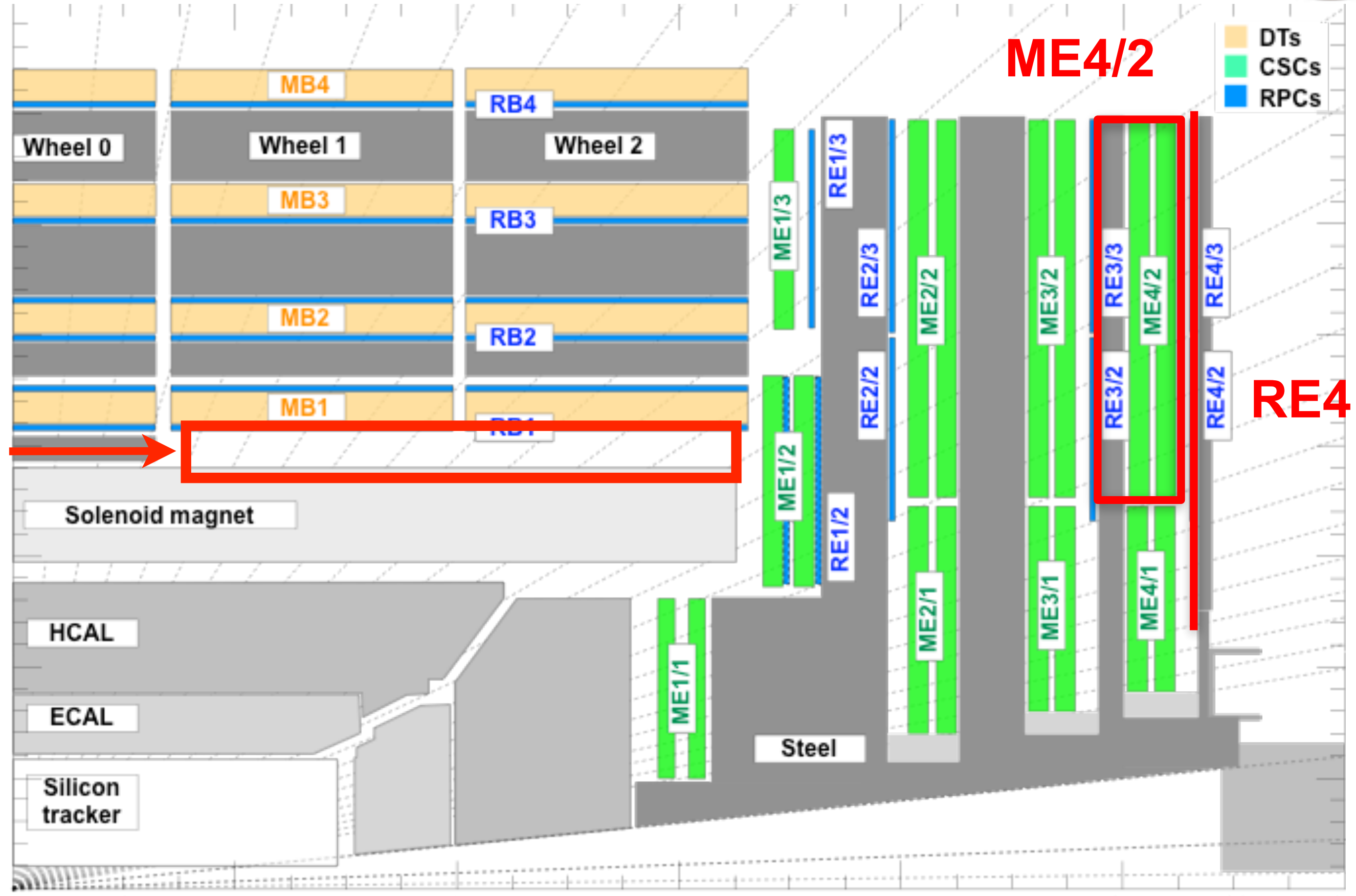

LS1 (now) LS2 (2018) LS3 (~2023)

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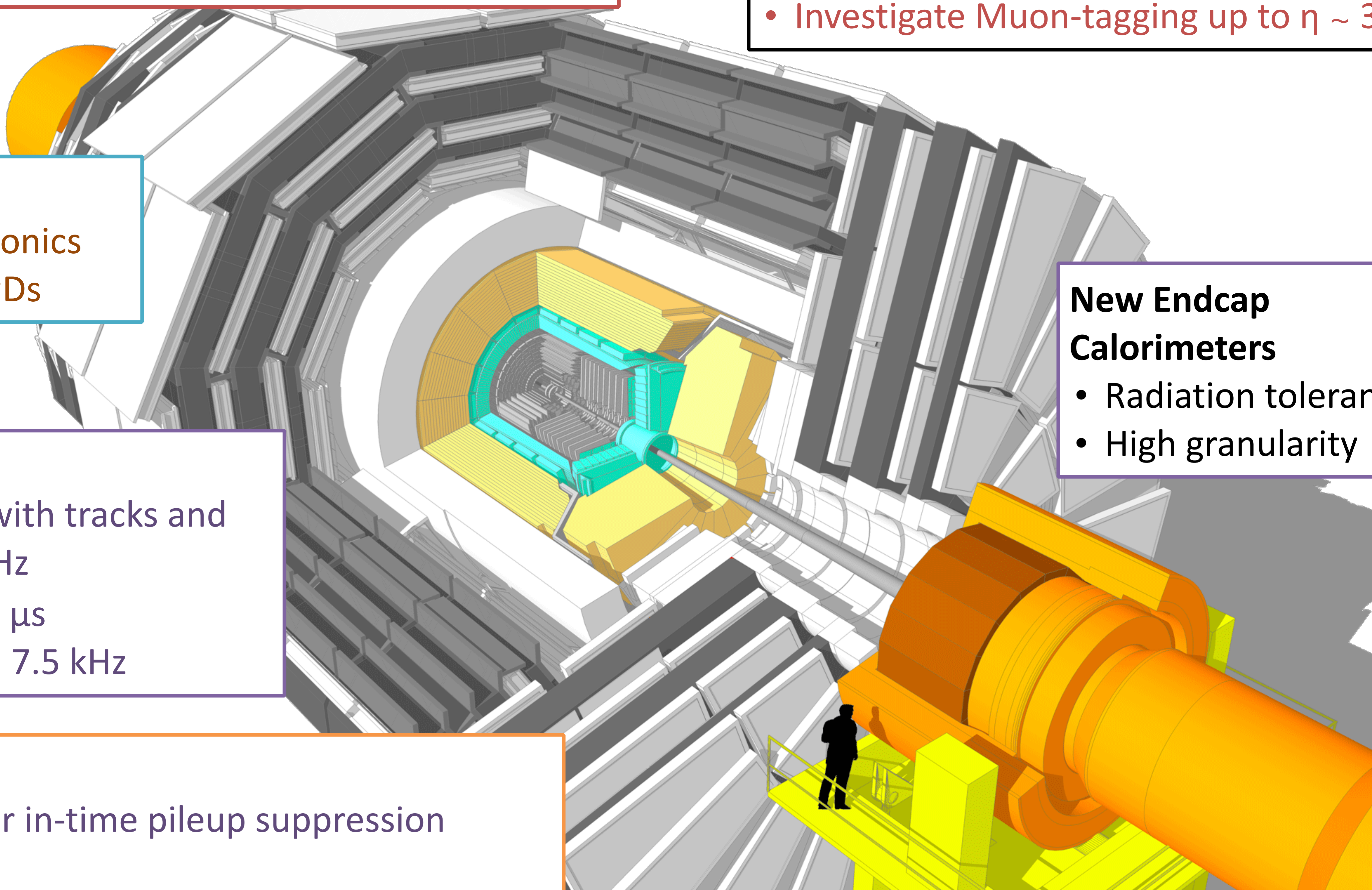
Phase 2: being defined now

- Tracker replacement, L1 Track-Trigger
- Forward: calorimetry, muons and tracking
- High precision timing for PU mitigation
- Further Trigger upgrade
- Further DAQ upgrade

CMS Phase II upgrade program

New Tracker
- Radiation tolerant - high granularity - less material
- Tracks in hardware trigger (L1)
- Coverage up to η ~ 4

Muons
- Replace DT FE electronics
- Complete RPC coverage in forward region (new GEM/RPC technology)
- Investigate Muon-tagging up to η ~ 3



Barrel ECAL
- Replace FE electronics
- Cool detector/APDs

New Endcap Calorimeters
- Radiation tolerant
- High granularity

Trigger/DAQ
- L1 (hardware) with tracks and rate up ~ 750 kHz
- L1 Latency 12.5 μs
- HLT output rate 7.5 kHz

Other R&D
- Fast-timing for in-time pileup suppression
- Pixel trigger

CMS Phase II detector simulations

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Increase det. acceptance up to $|\eta|$=3.0

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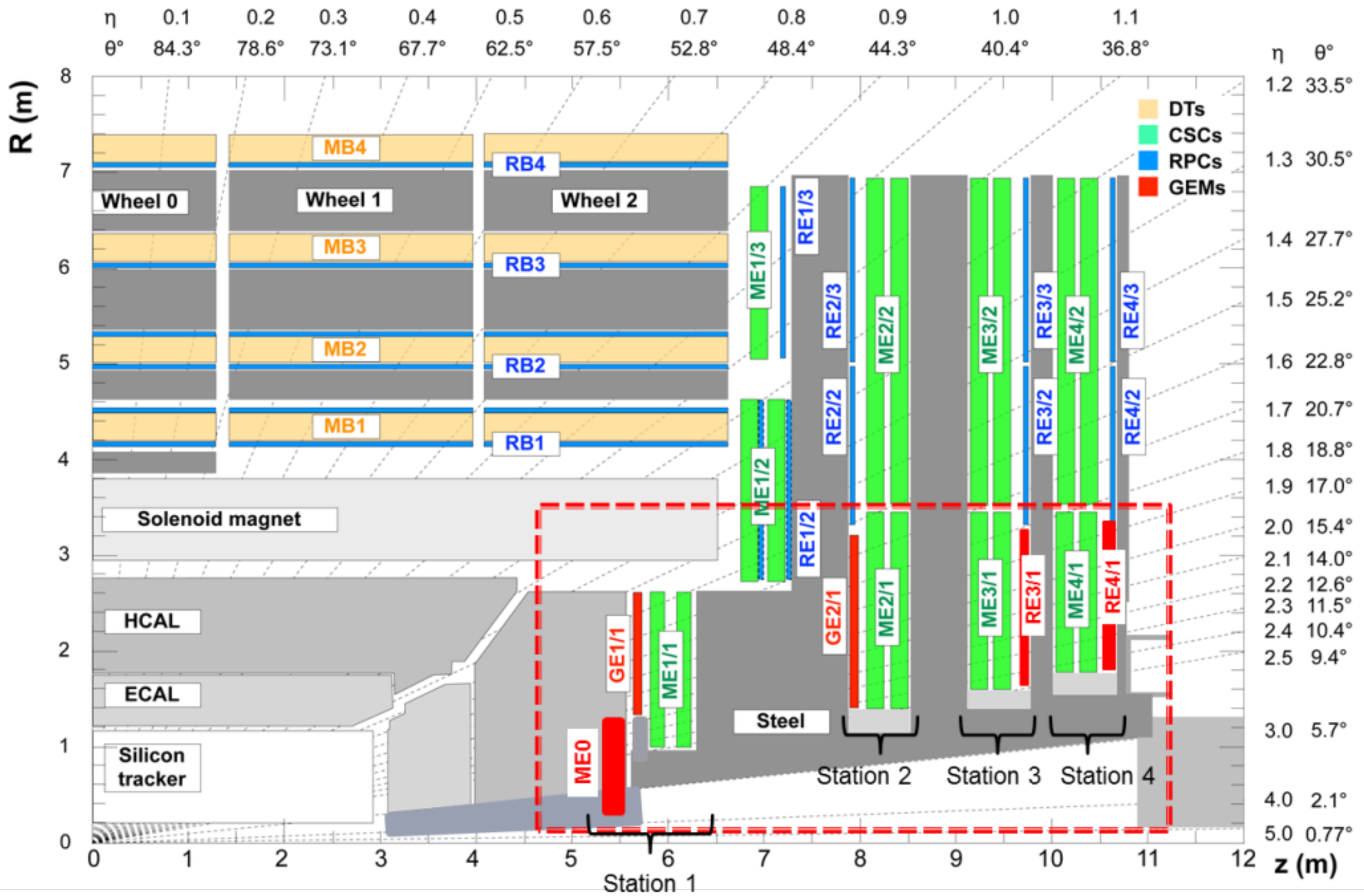

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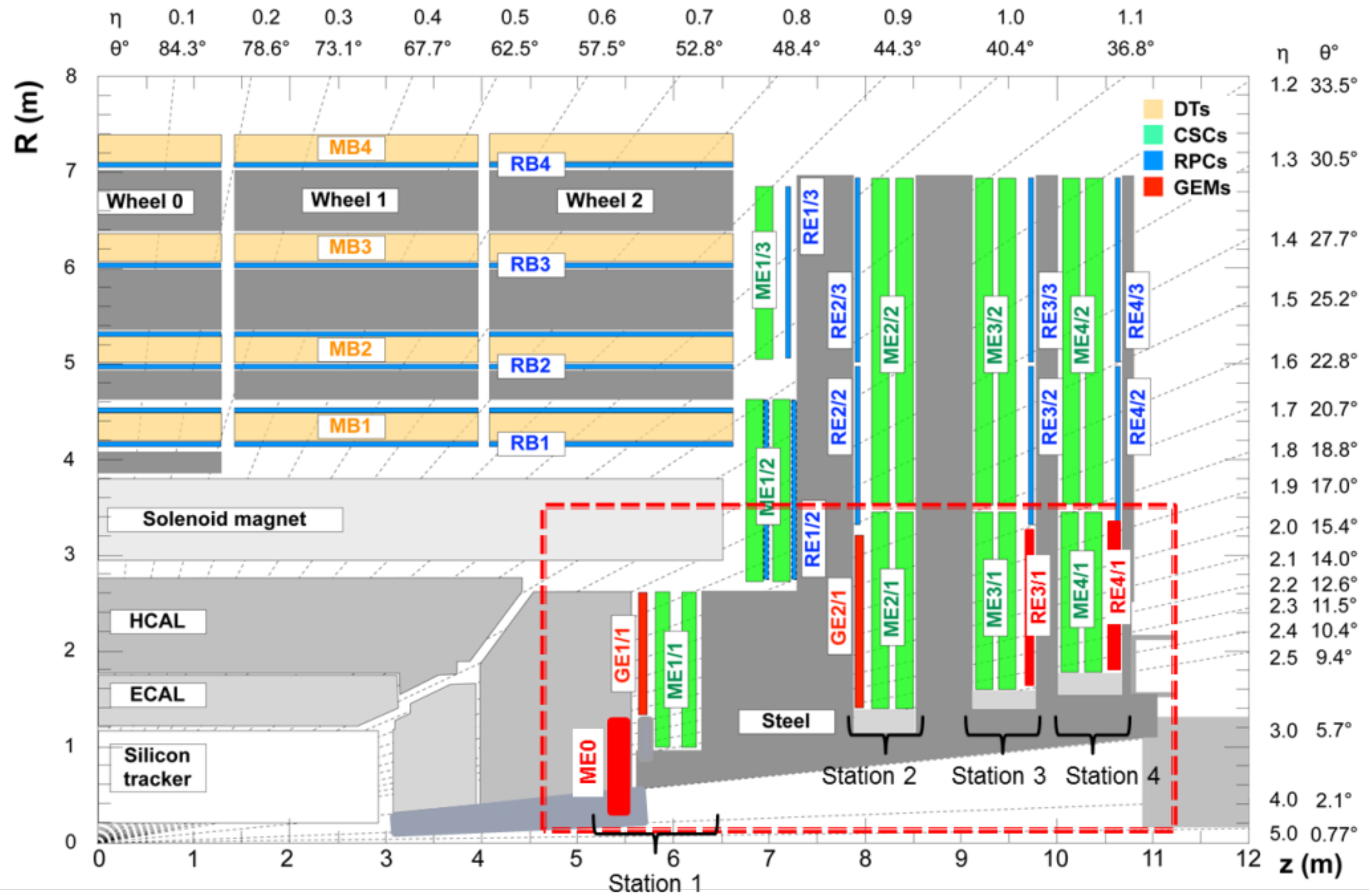

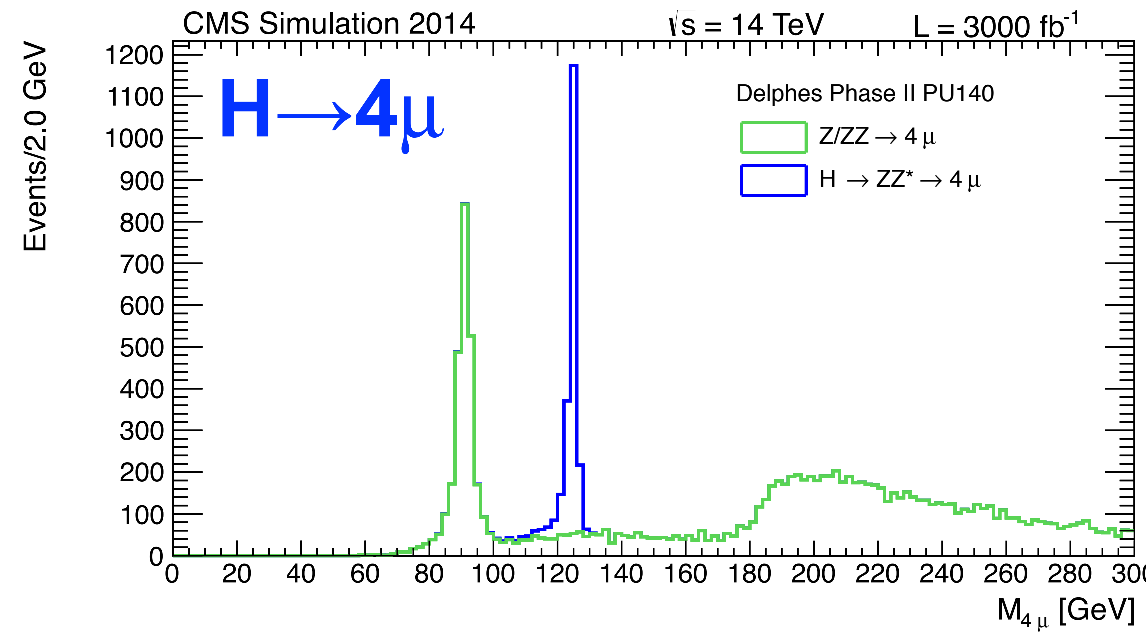

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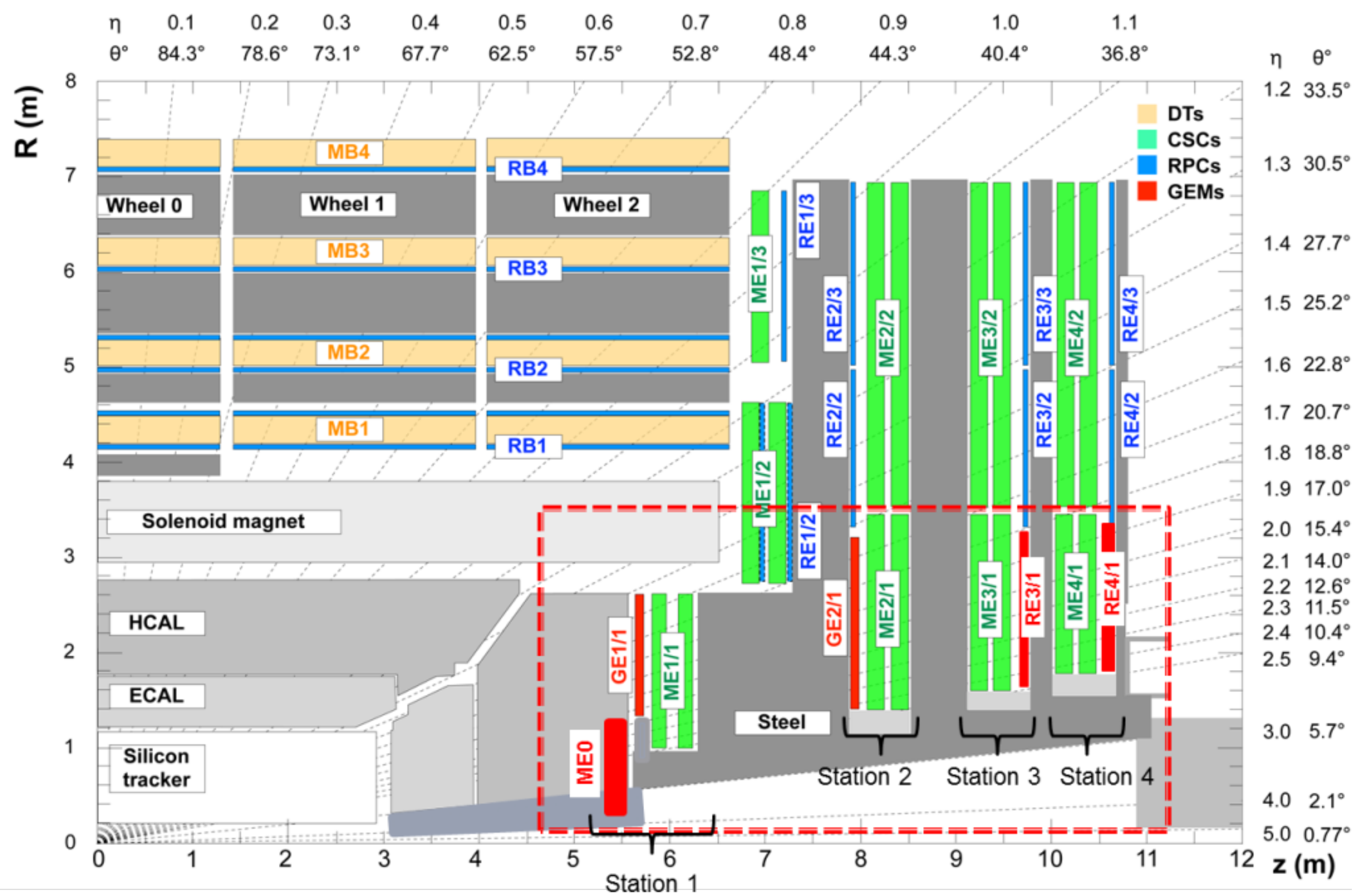

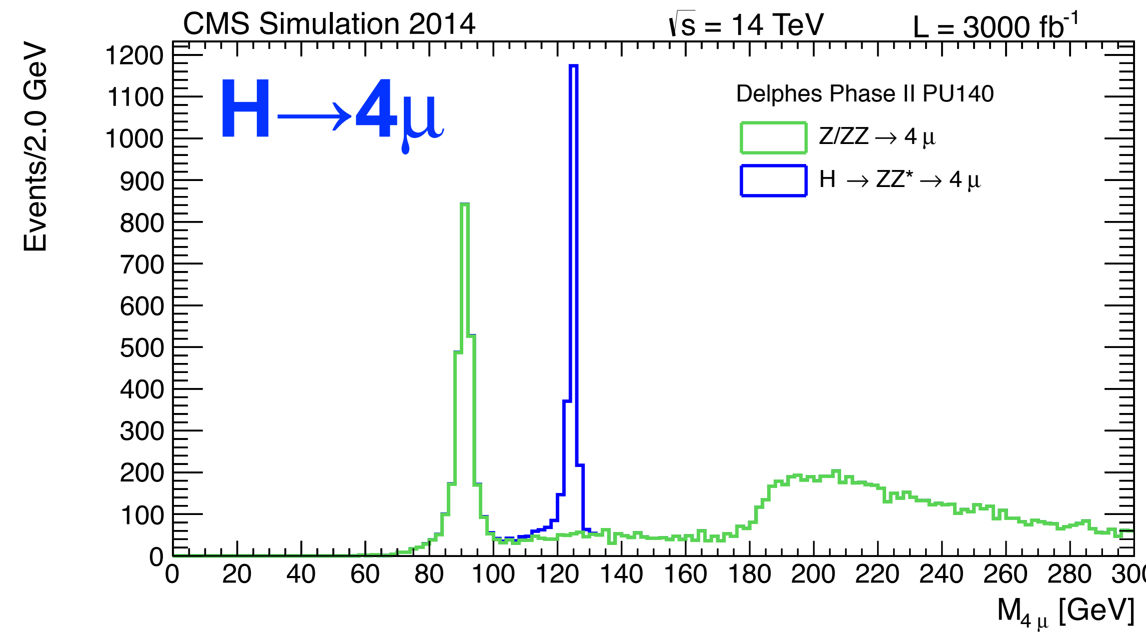

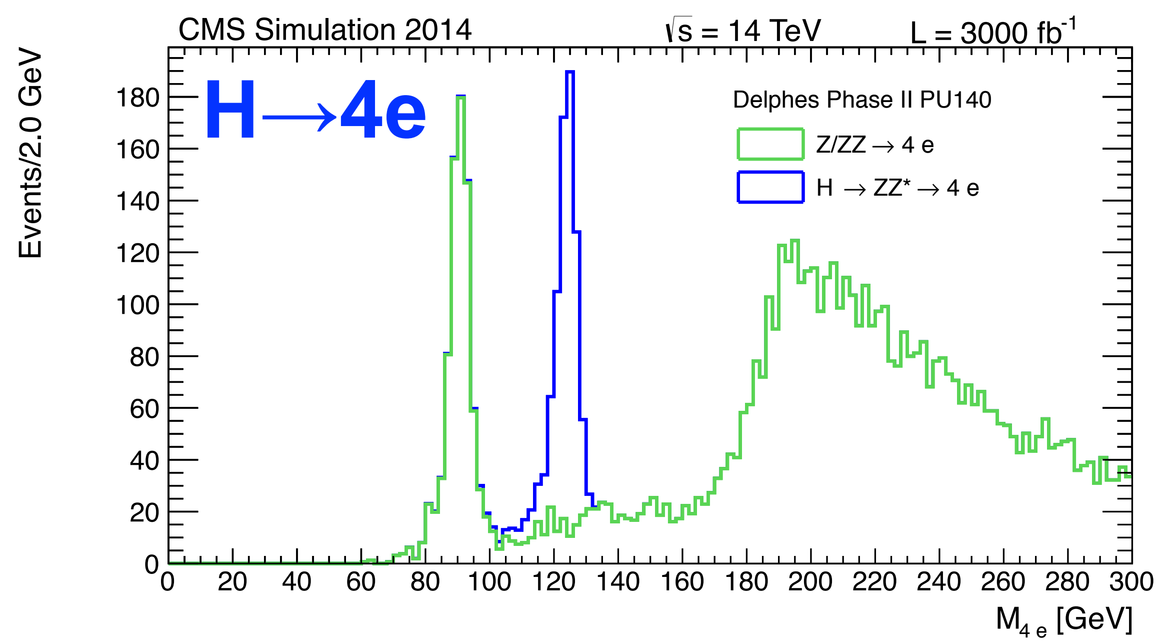

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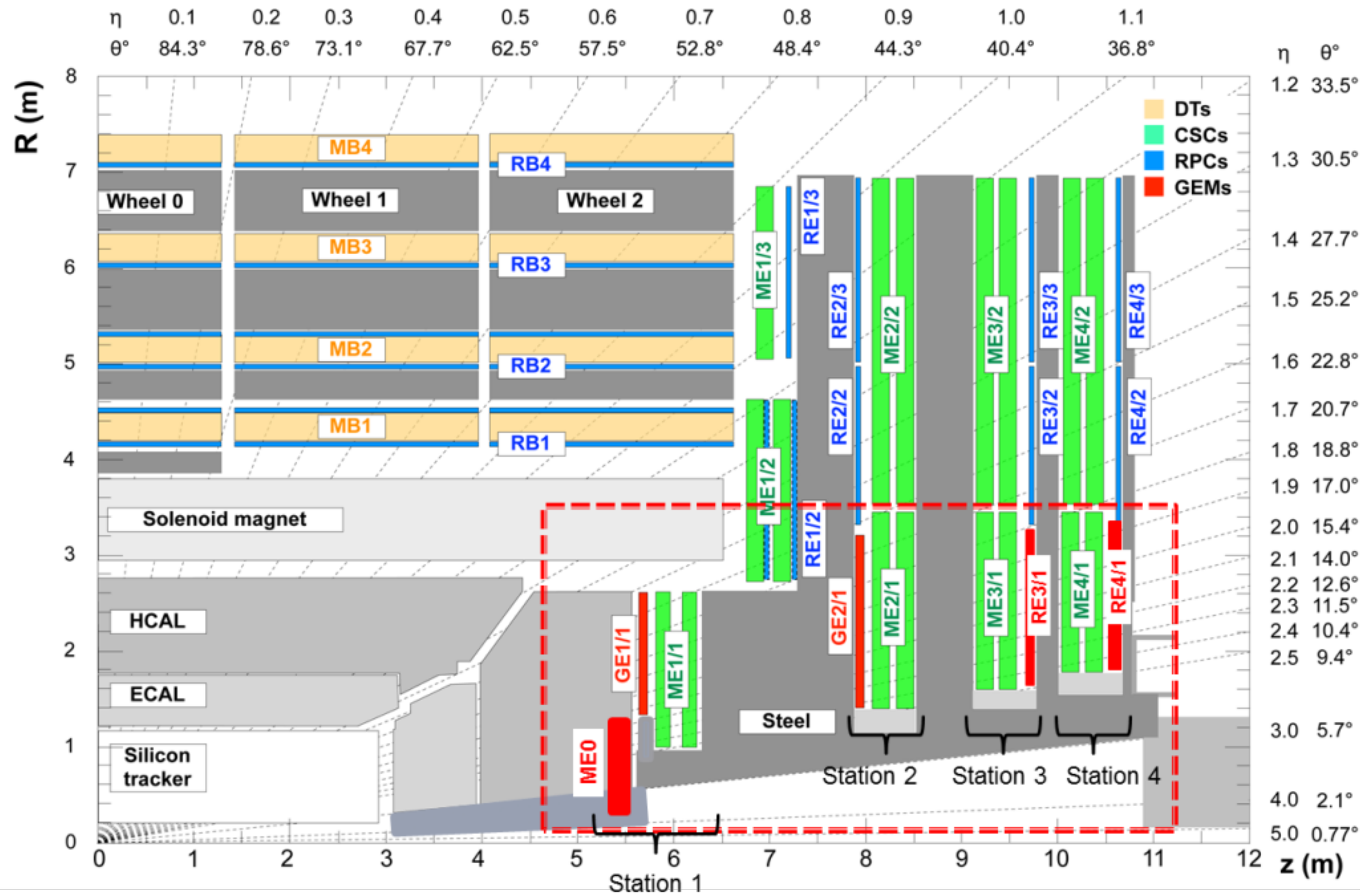

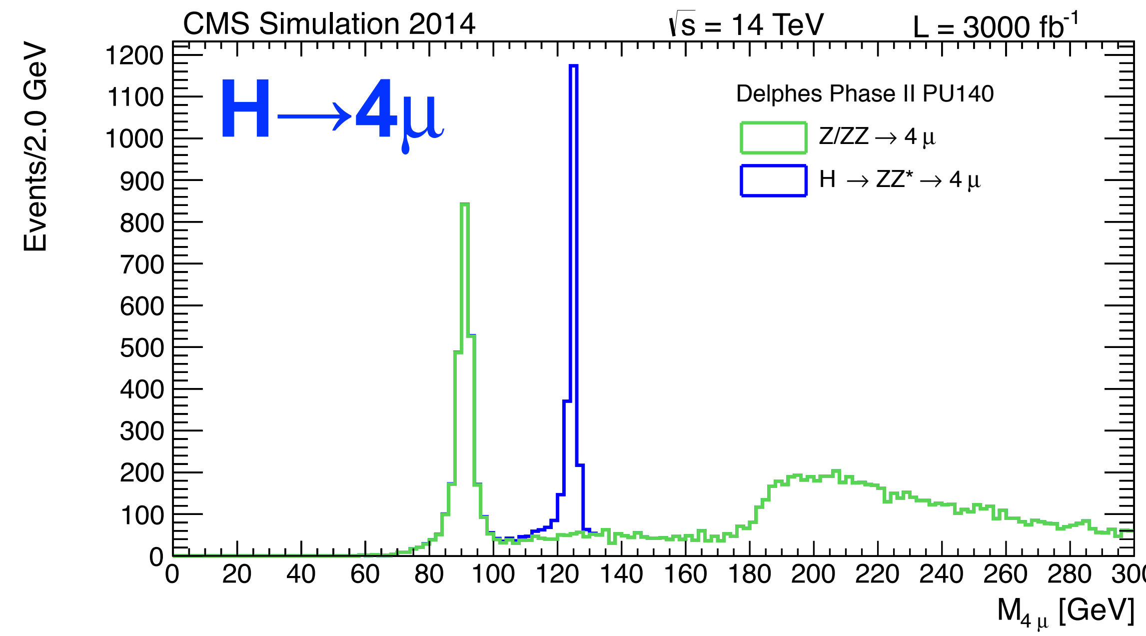

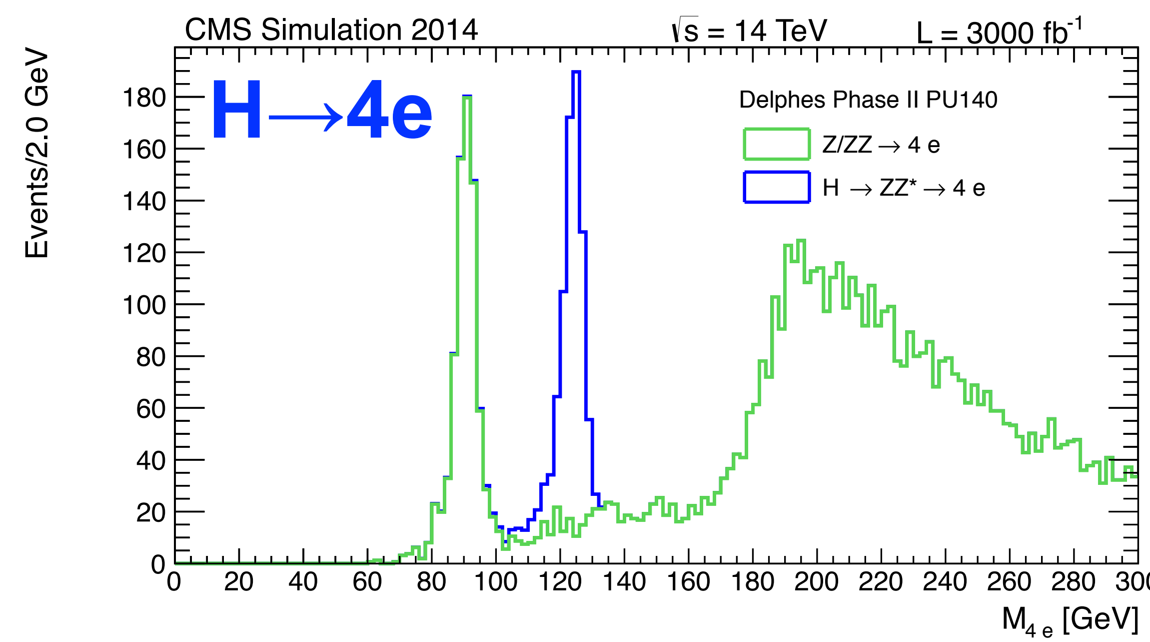

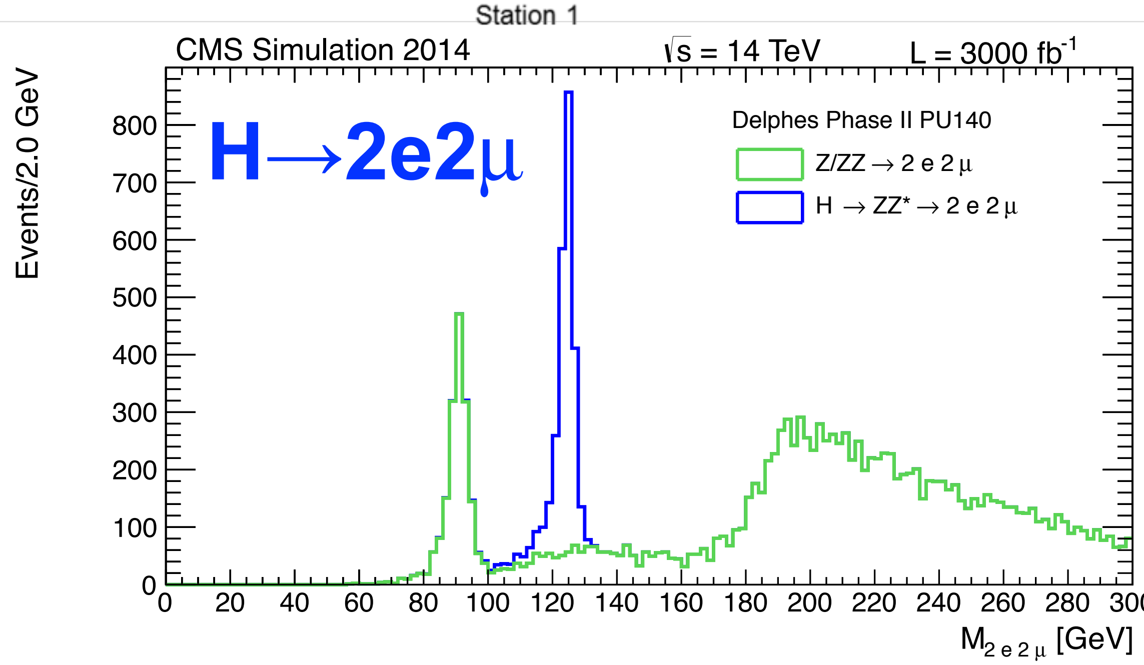

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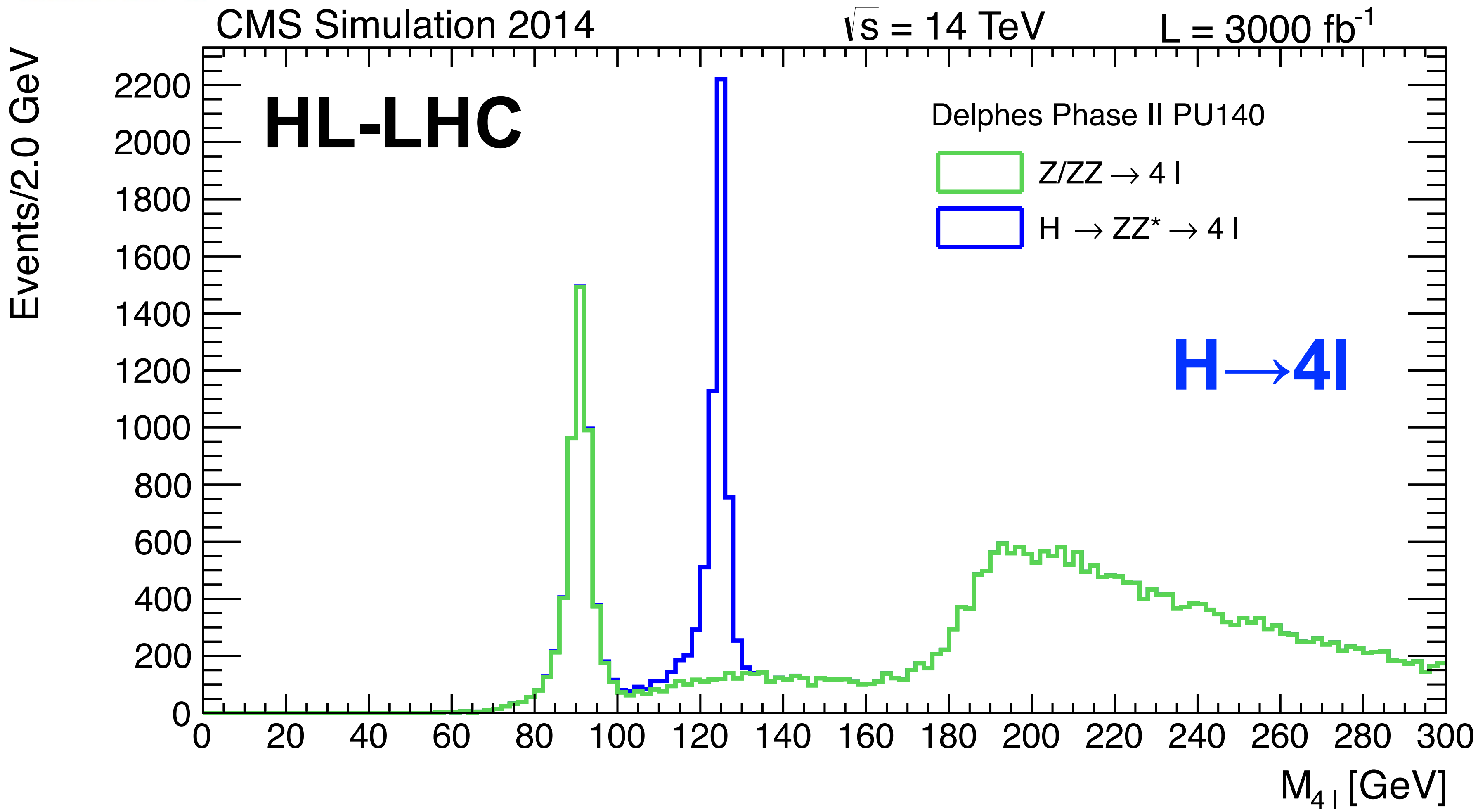

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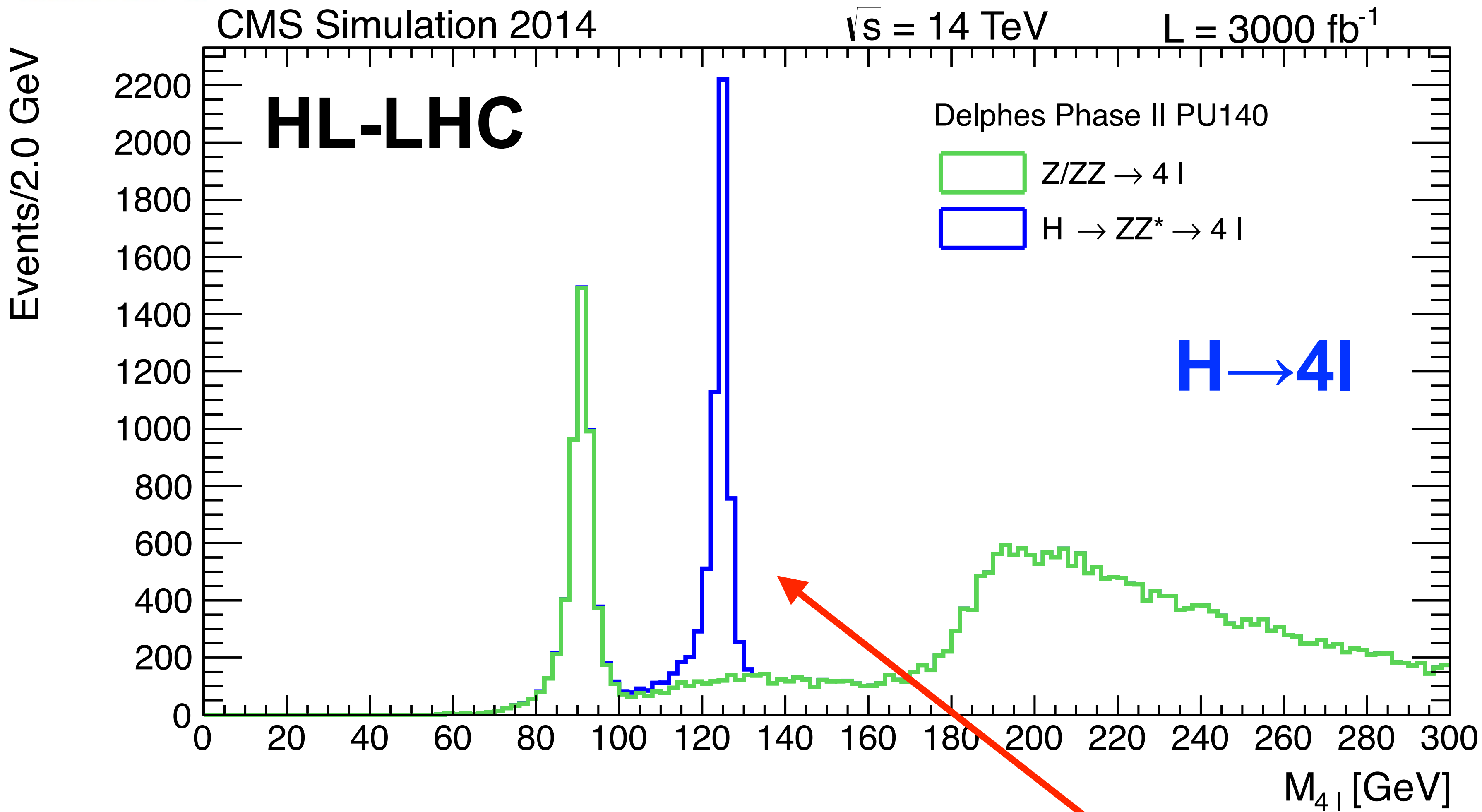

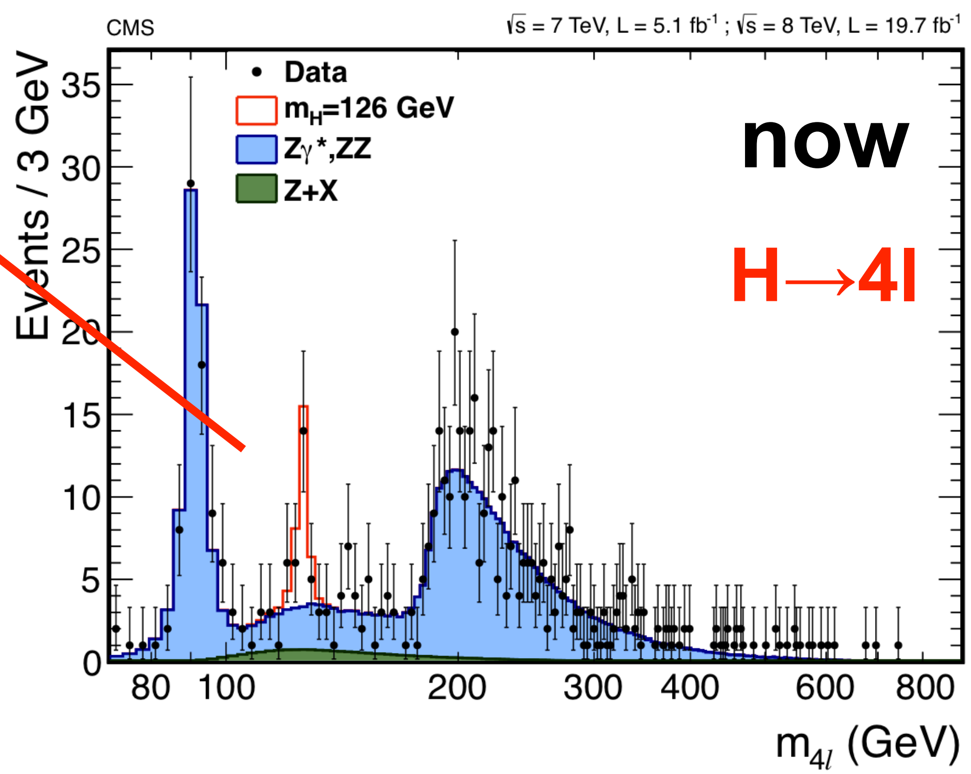

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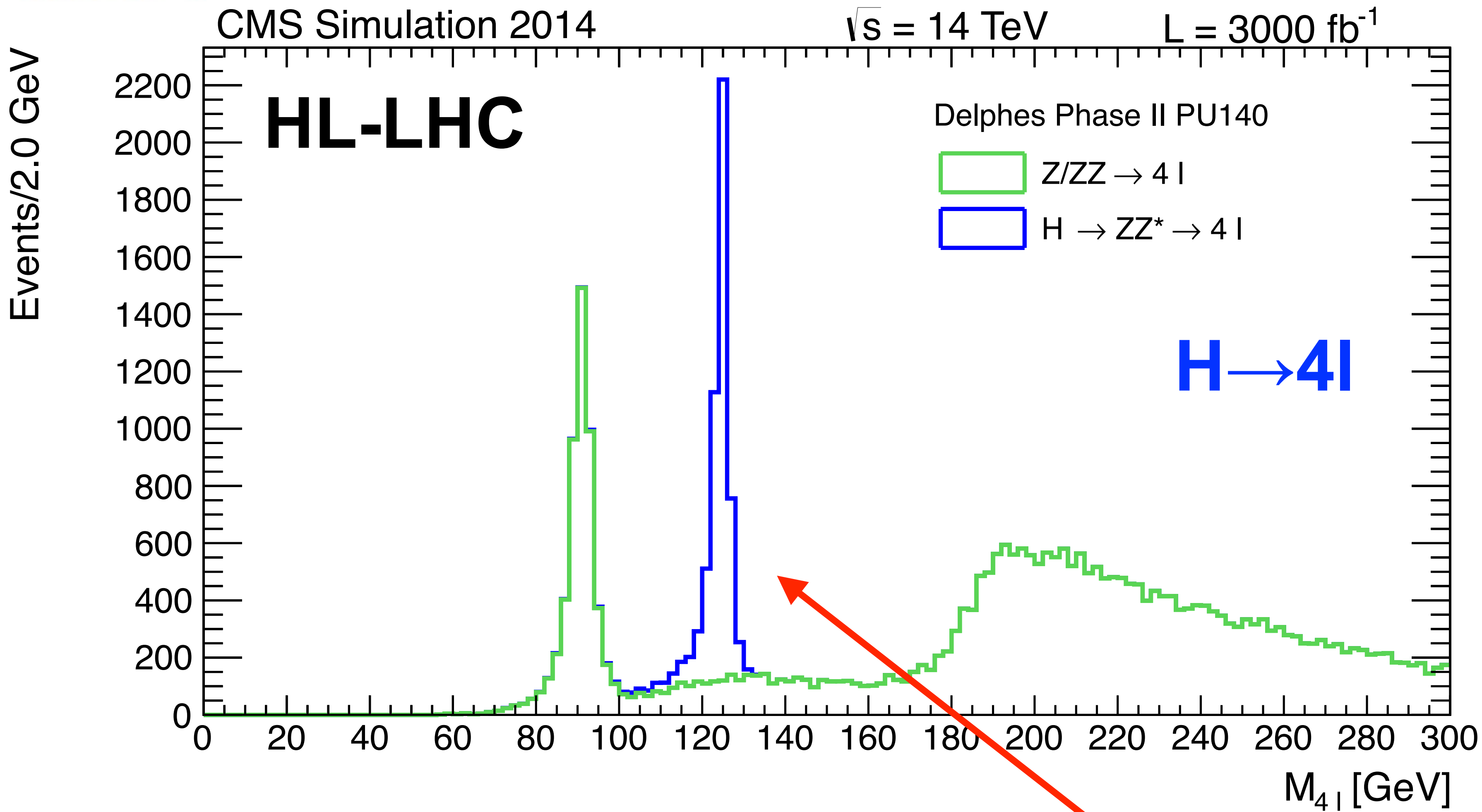
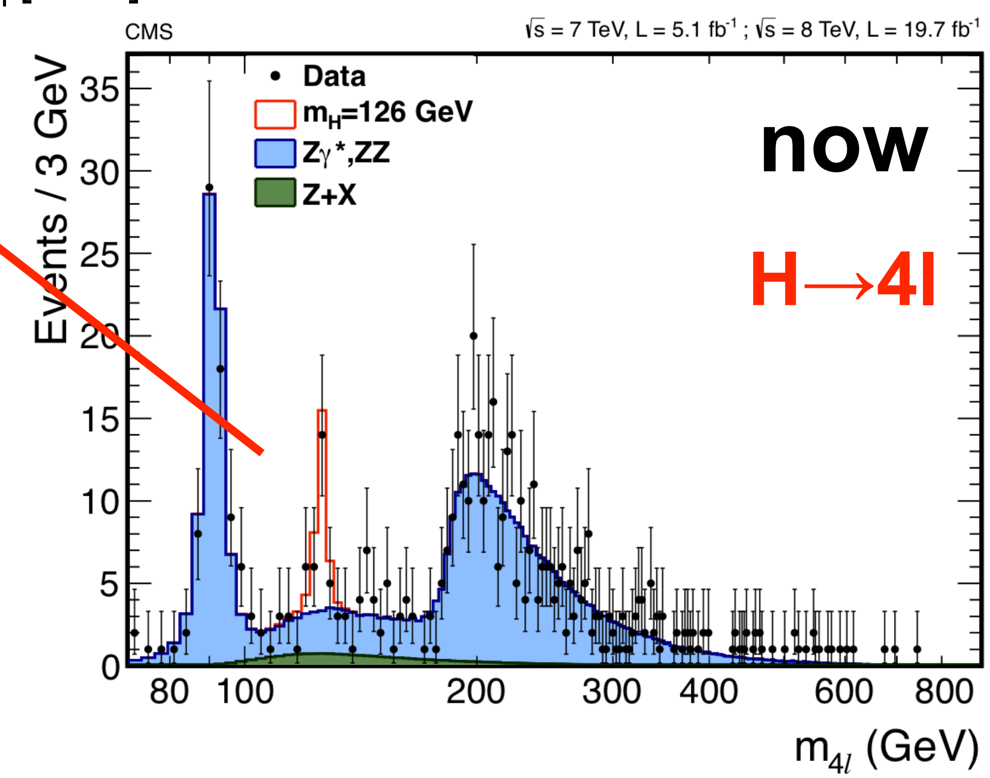
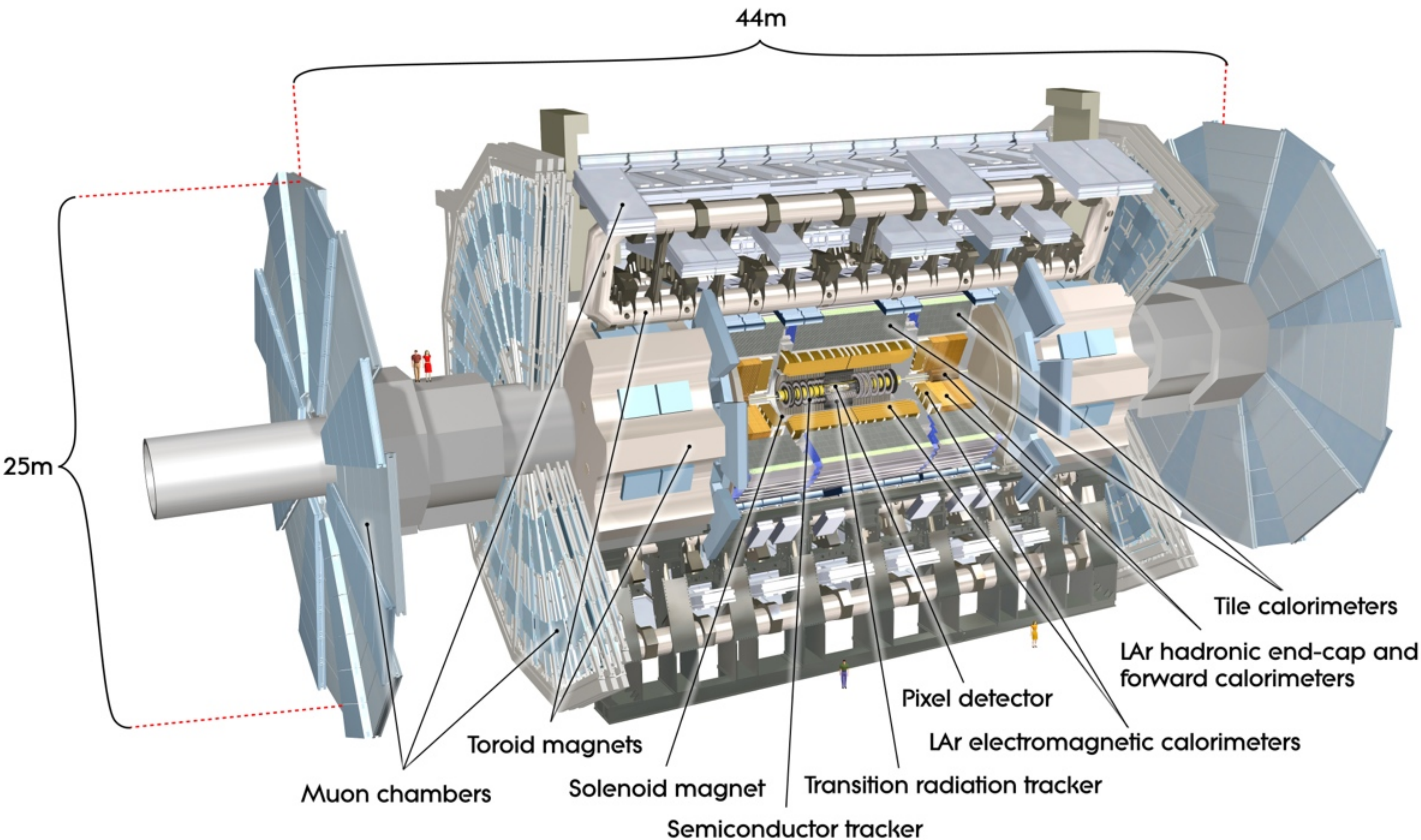


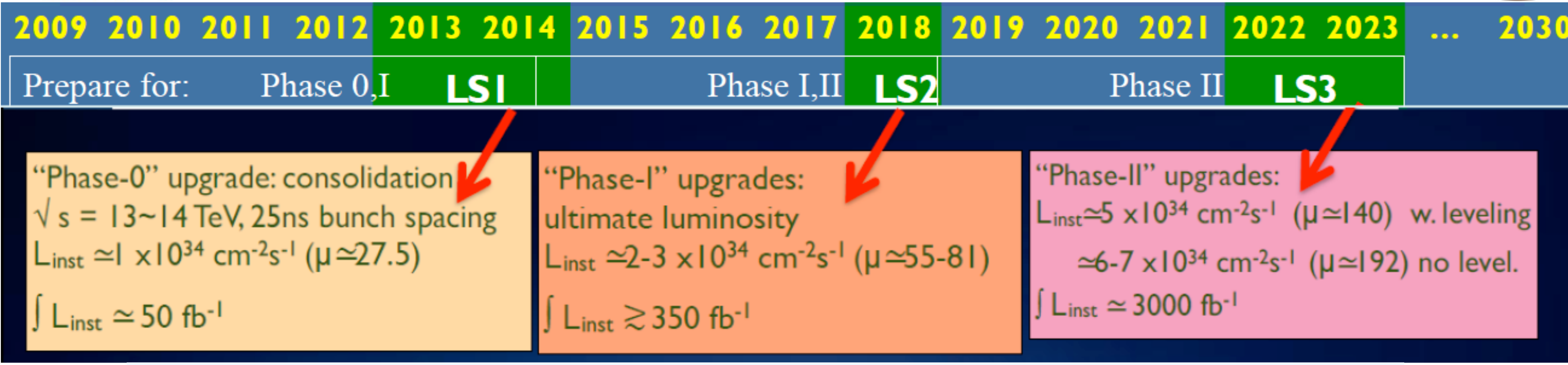


Dramatic increase in statistics!

ATLAS detector



ATLAS upgrade program



ATLAS has devised a 3 stage upgrade program

From M. Diemoz

ATLAS upgrade program

2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	...	2030
Prepare for:			Phase 0,I	LS1				Phase I,II	LS2			Phase II	LS3			

"Phase-0" upgrade: consolidation
$\sqrt{s}$ = 13~14 TeV, 25ns bunch spacing
$L_{inst} \simeq 1 \times 10^{34}\ cm^{-2}s^{-1}$ ($\mu \simeq 27.5$)
$\int L_{inst} \simeq 50\ fb^{-1}$

"Phase-I" upgrades:
ultimate luminosity
$L_{inst} \simeq 2\text{-}3 \times 10^{34}\ cm^{-2}s^{-1}$ ($\mu \simeq 55\text{-}81$)
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"Phase-II" upgrades:
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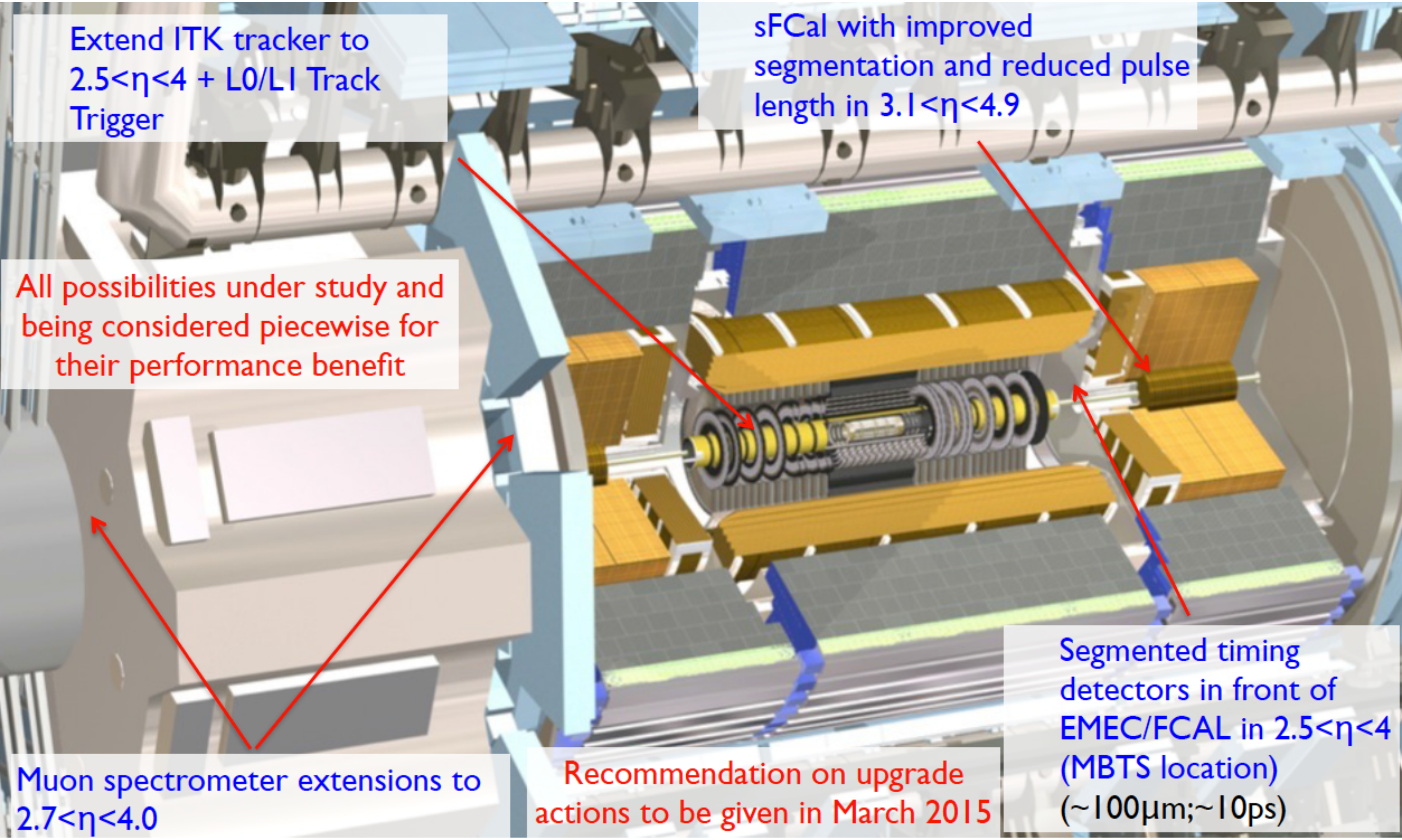
- Completely new tracking detector
- Calorimeter electronics upgrades
- Upgrade part of the muon system
- Possible L1-trigger track trigger
- Possible changes to the forward calorimeters

From M. Diemoz

ATLAS upgrade performances



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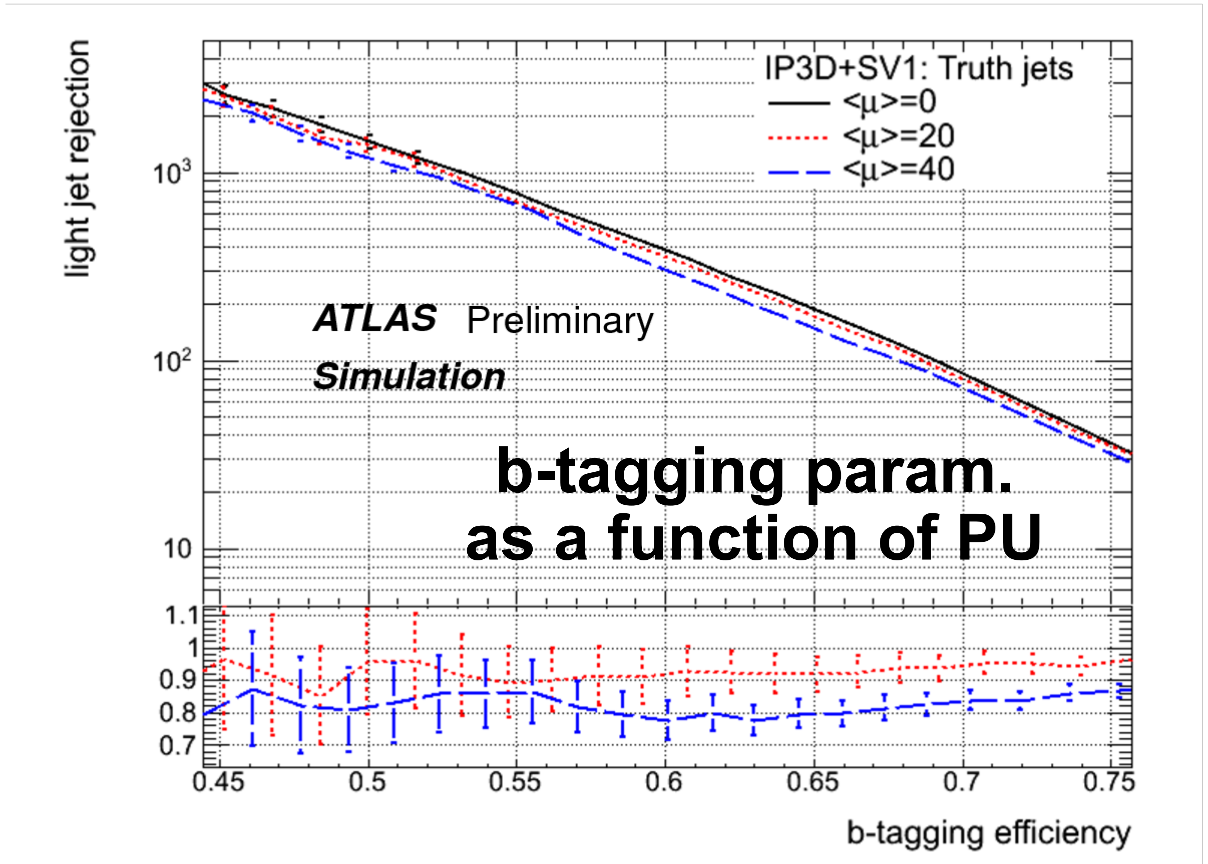

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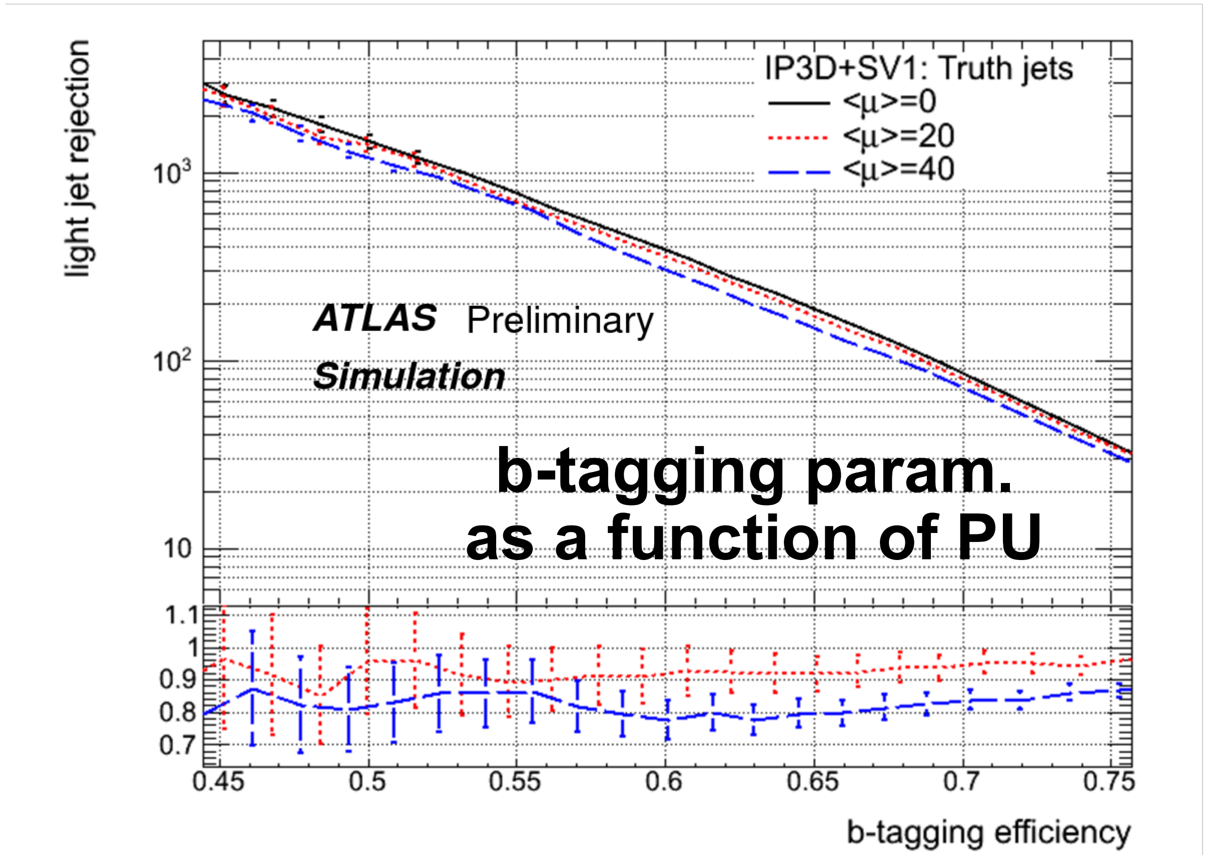

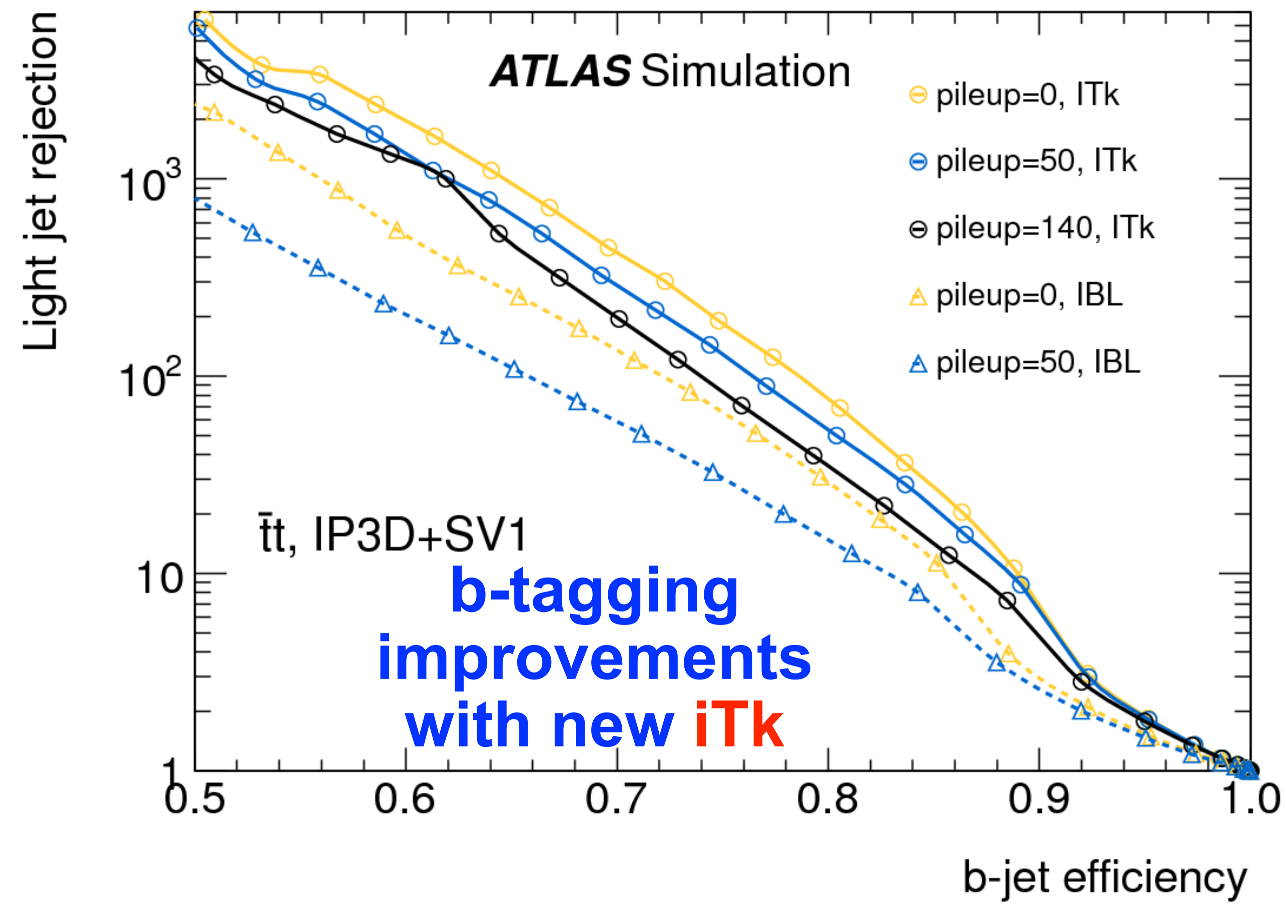

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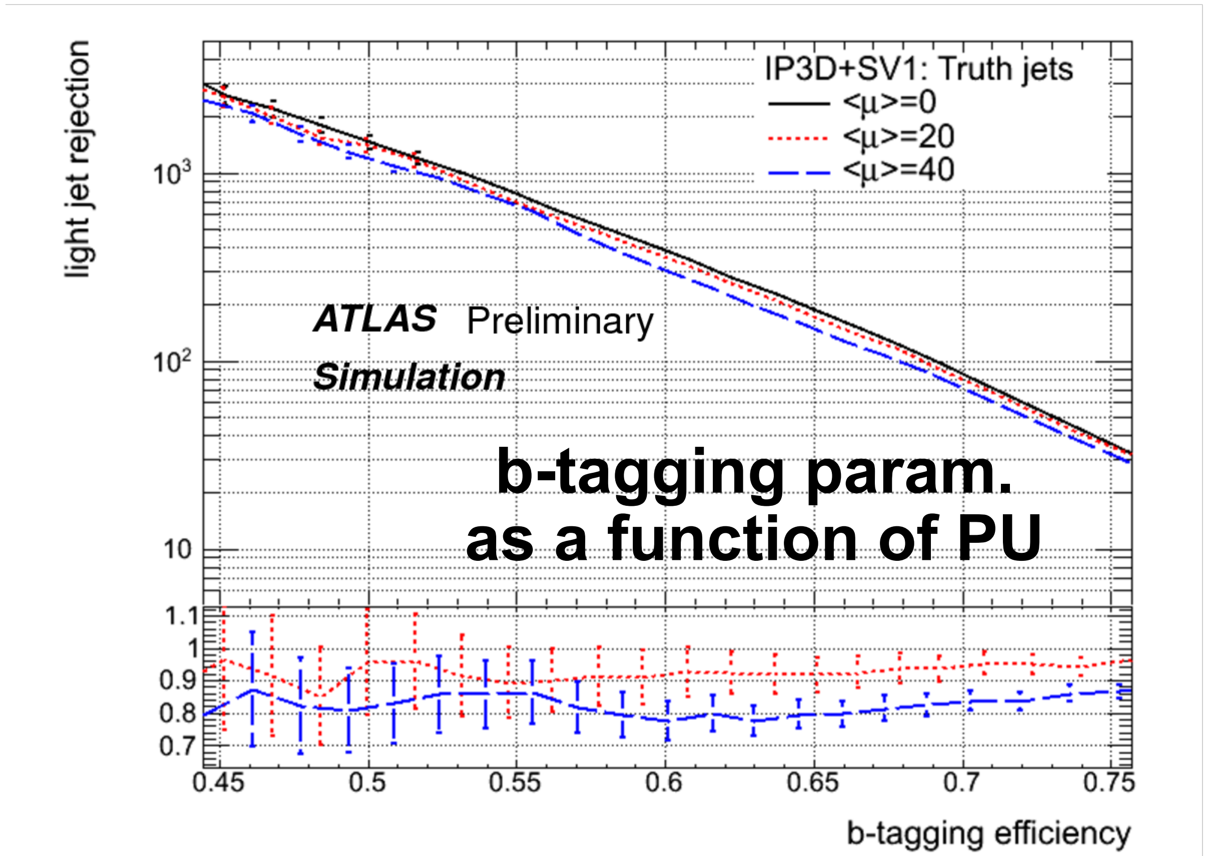
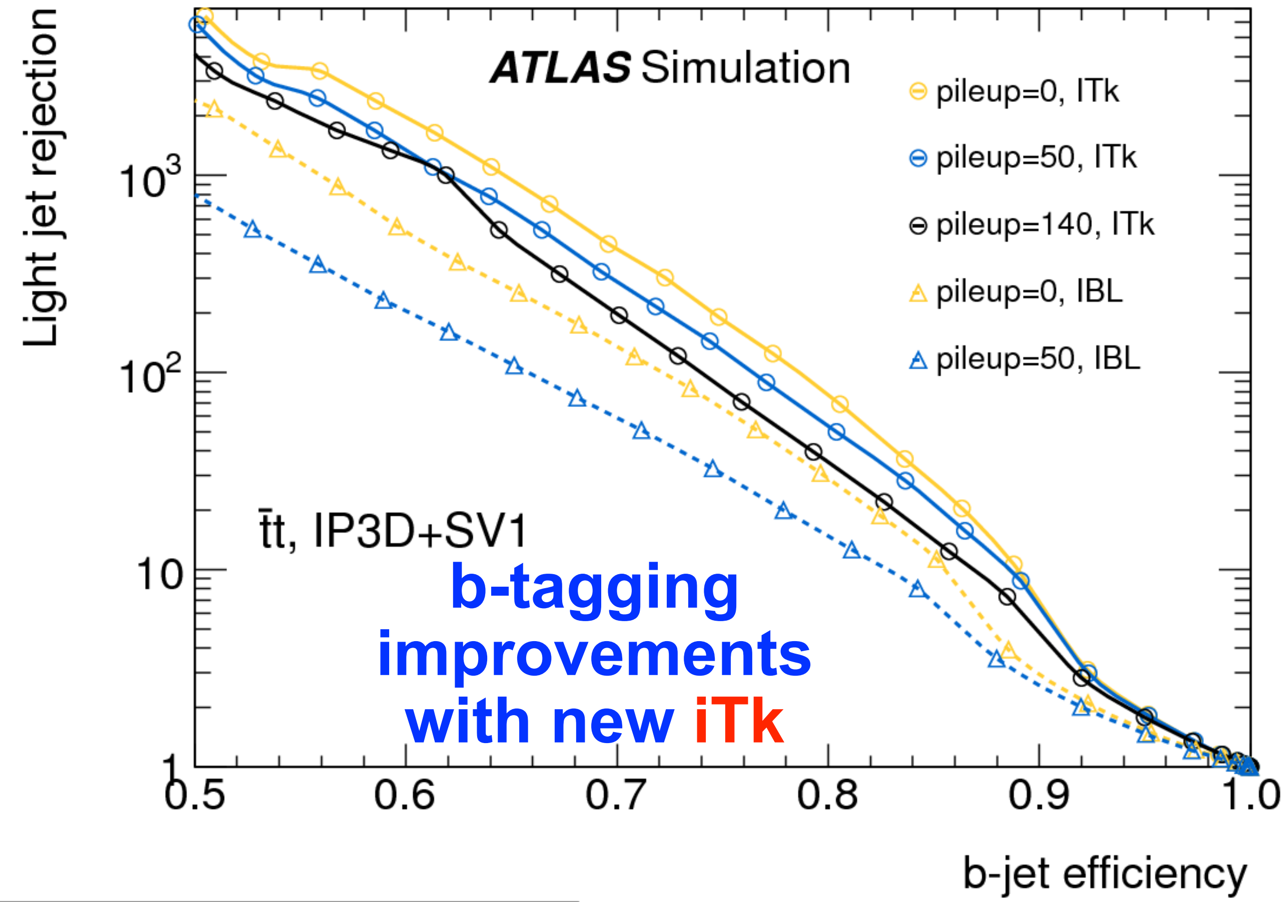
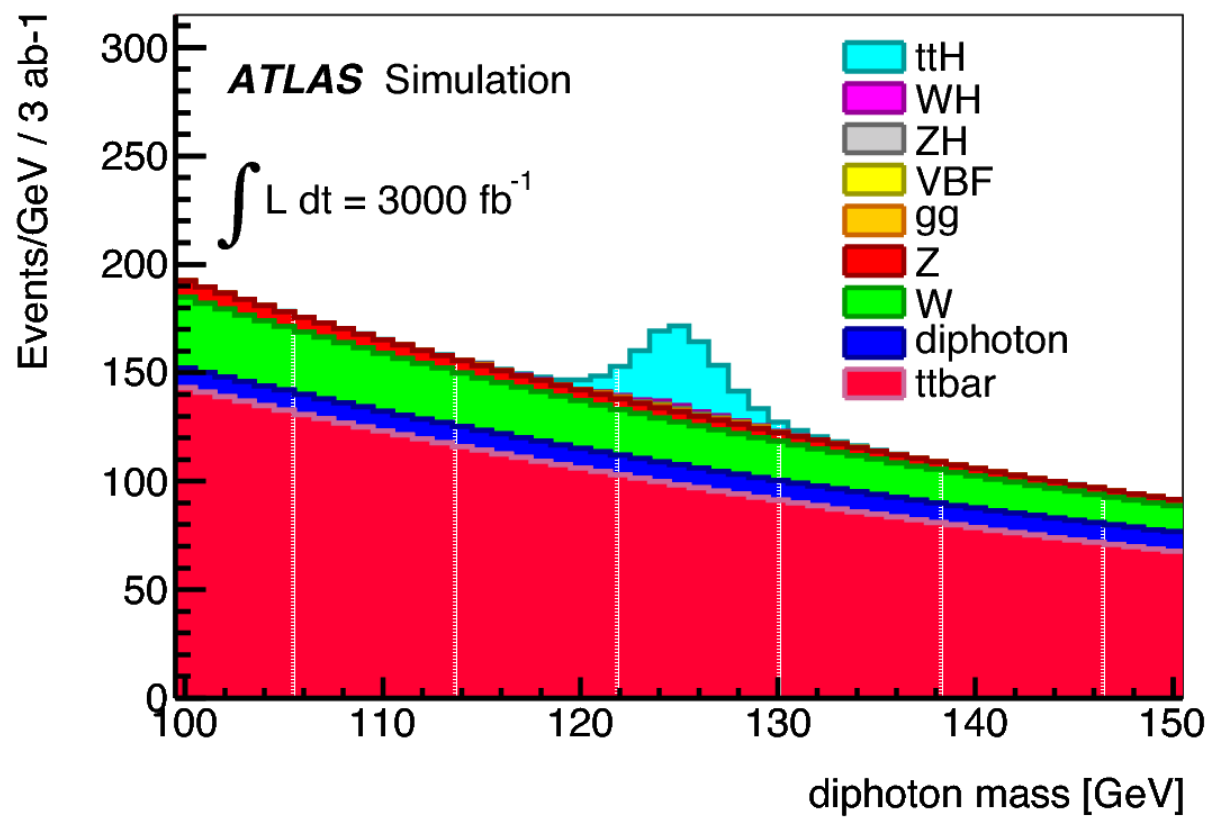


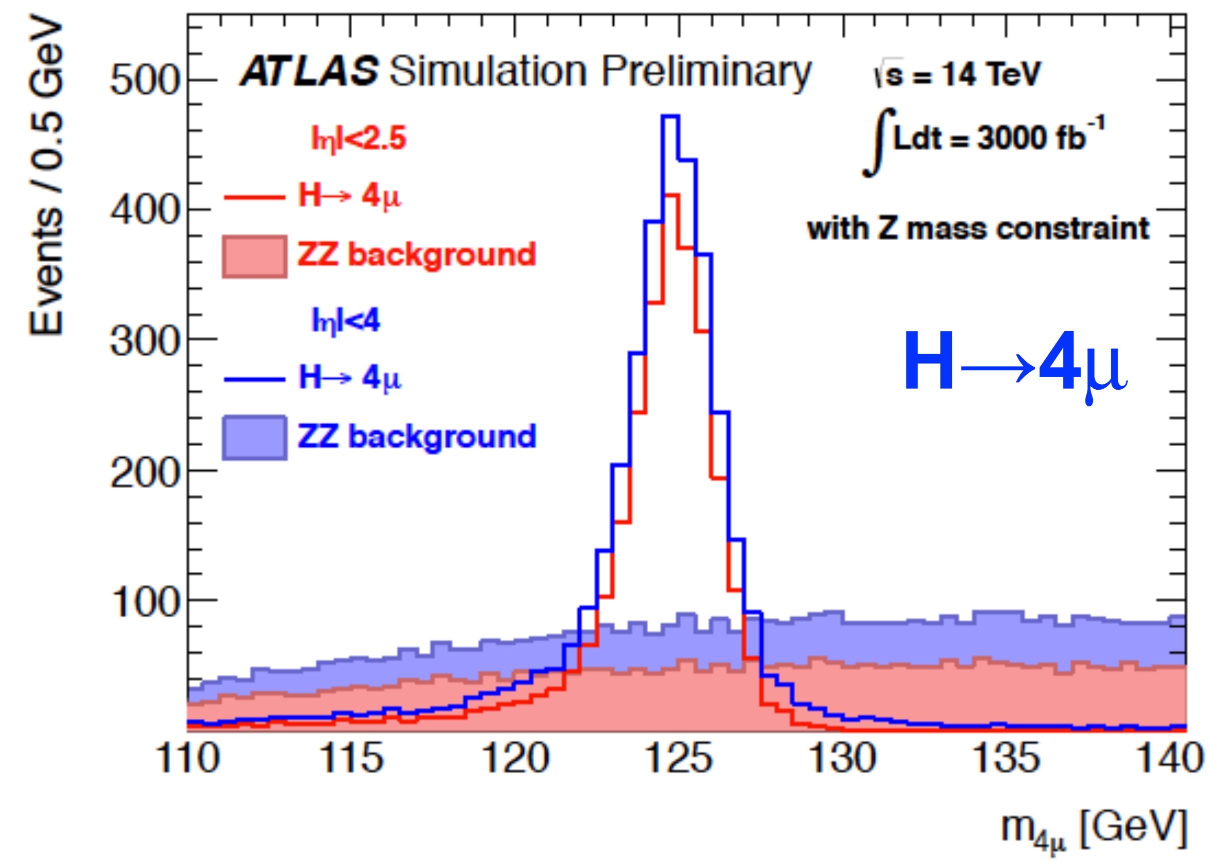


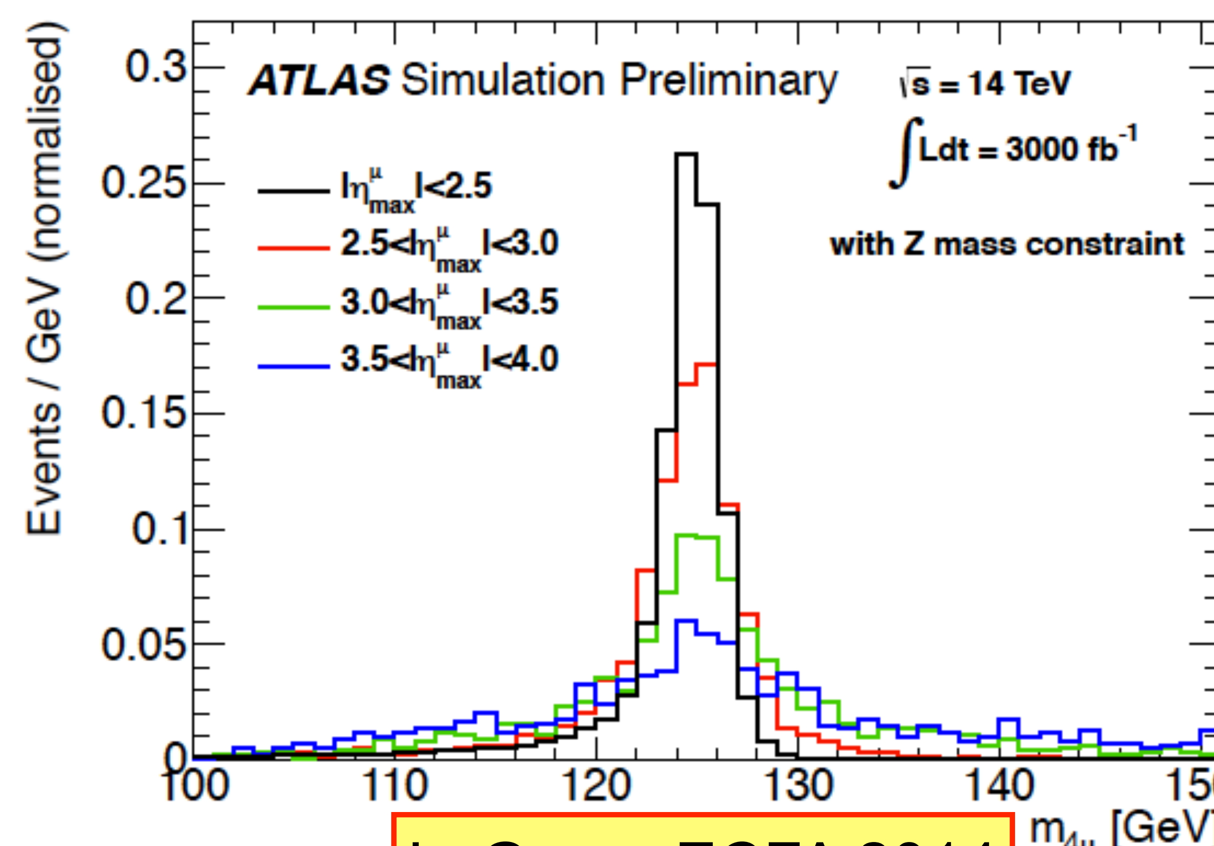
di-photon mass resolution in ttH channel



ATLAS upgrade performances

- Study impact of various ITK and MS p_T resolution and trigger acceptance scenarios
- Lepton requirements
  - p_T μ > 20,15,10,6 GeV
  - ΔR, m12, m34 as in Run1 analysis
- Using the best setup:
  - 7μm pixel reso., full muon upgrade
  - 35% Acceptance gain from nearly 100% efficient muon reconstruction
  - Mass resolution degrades quickly with η





L. Grey - ECFA 2014

From 2012 to HL-LHC

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- From 30 to 3000 fb^{-1}: two orders of magnitude extrapolation in luminosity

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Need upgraded detectors to offset the much harsher LHC conditions and radiation damage

ATLAS and CMS have launched a comprehensive upgrade program

Higgs boson projections after LS1

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Approaches adopted for physics projections

Higgs boson projections after LS1

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  - Scenario 3: set theoretical uncertainties to zero, leave other syst. uncertainties the same as in 2012

Higgs signal strength with 300 fb^{-1}

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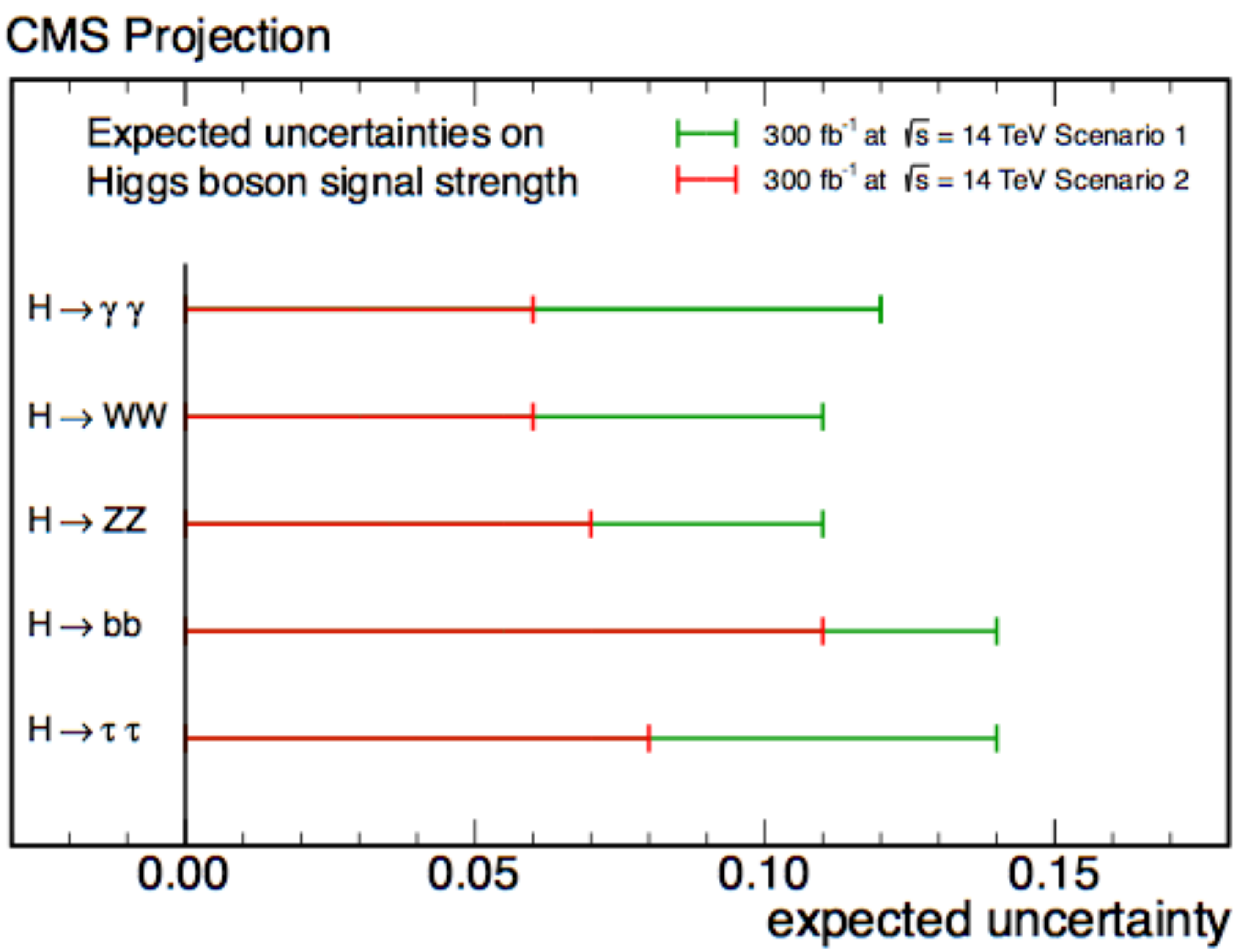

300 fb^{-1}, 14 TeV (Scenario 1)
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$\mu = \sigma/\sigma_{SM}$

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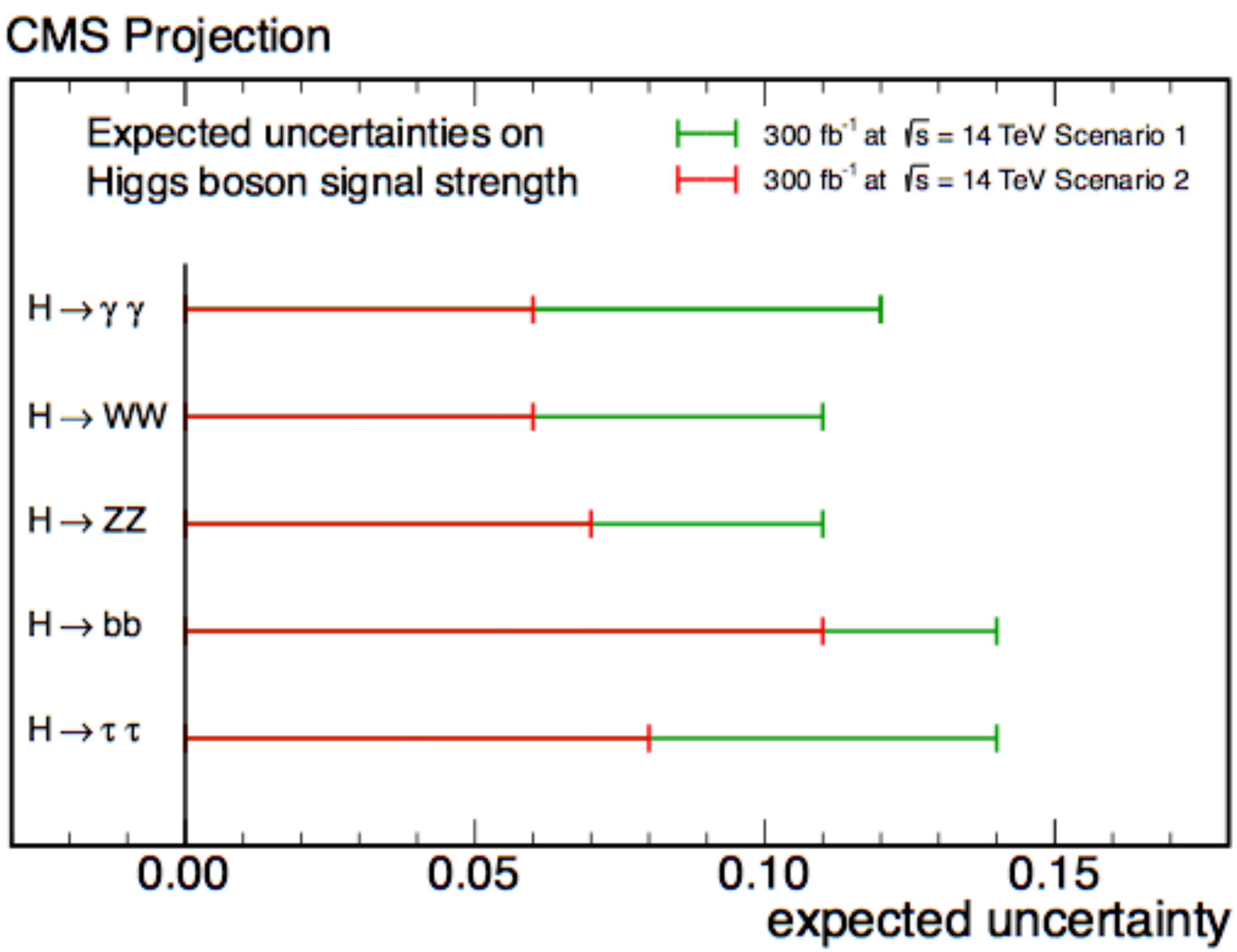

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With 300 fb^{-1} the precision on the signal strength, $\mu = \sigma/\sigma_{SM}$, is expected to be 10-15% per channel

Higgs signal strength with 3000 fb^{-1}

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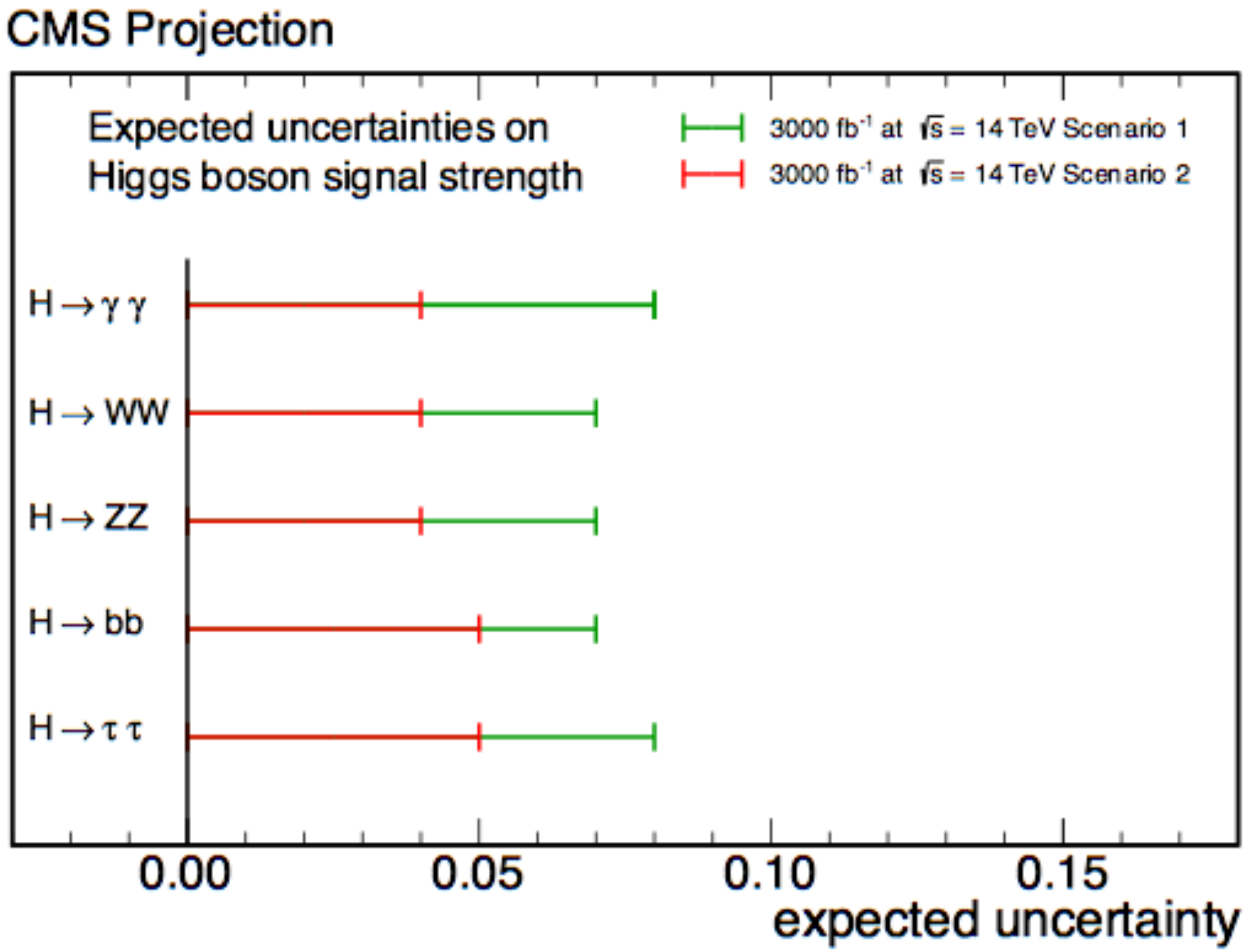

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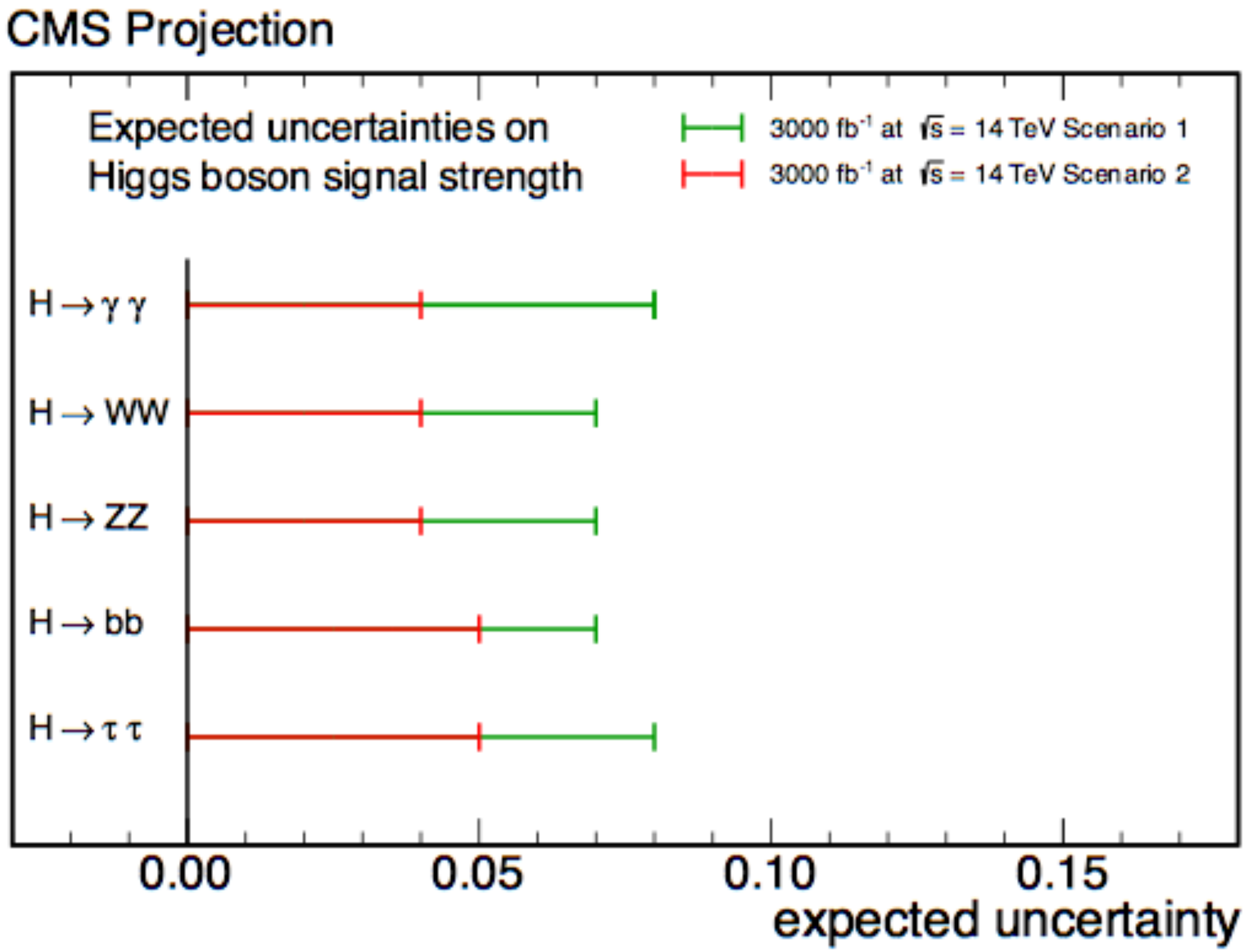
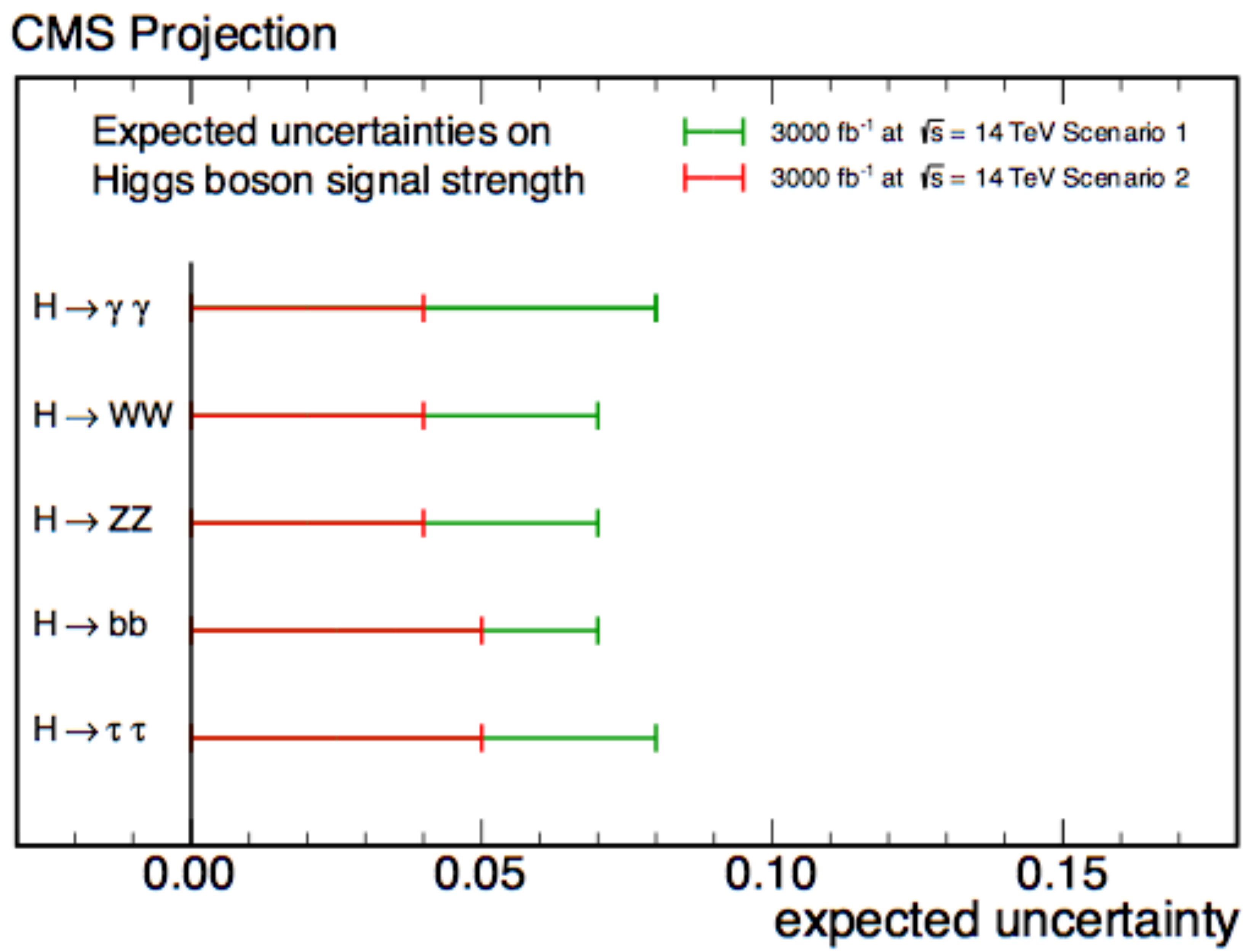


$\mu = \sigma/\sigma_{SM}$

L (fb	H→γγ	H→WW	H→ZZ	H→bb	H→ττ	H→Zγ	H→μμ	H→inv.
300	[6,12]	[6,11]	[7,11]	[11,14]	[8,14]	[62,62]	[40,42]	[17,28]
3000	[4,8]	[4,7]	[4,7]	[5,7]	[5,8]	[20,24]	[20,24]	[6,17]

Higgs signal strength with 3000 fb^{-1}



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With 3000 fb^{-1} the precision on μ is expected to be 4-8% per channel

Higgs boson couplings fit framework

A. Apyam - 2014 ECFA HL-LHC workshop

Higgs boson couplings fit framework

- Leading order tree level framework
- Signal cross section scaled
- Quantify possible small deviations from SM
- Assumptions:
  - Single resonance with m=125 GeV 2012
  - Zero width approximation
  - Tensor structure of Lagrangian assumed the same of the SM
- Effective couplings for loop induced processes
  - $H \rightarrow \gamma\gamma$, $H \rightarrow Zg\gamma$, $gg \rightarrow H$

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$$\frac{\sigma \cdot B\,(gg \to H \to \gamma\gamma)}{\sigma_{\rm SM}(gg \to H) \cdot B_{\rm SM}(H \to \gamma\gamma)} = \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2}$$

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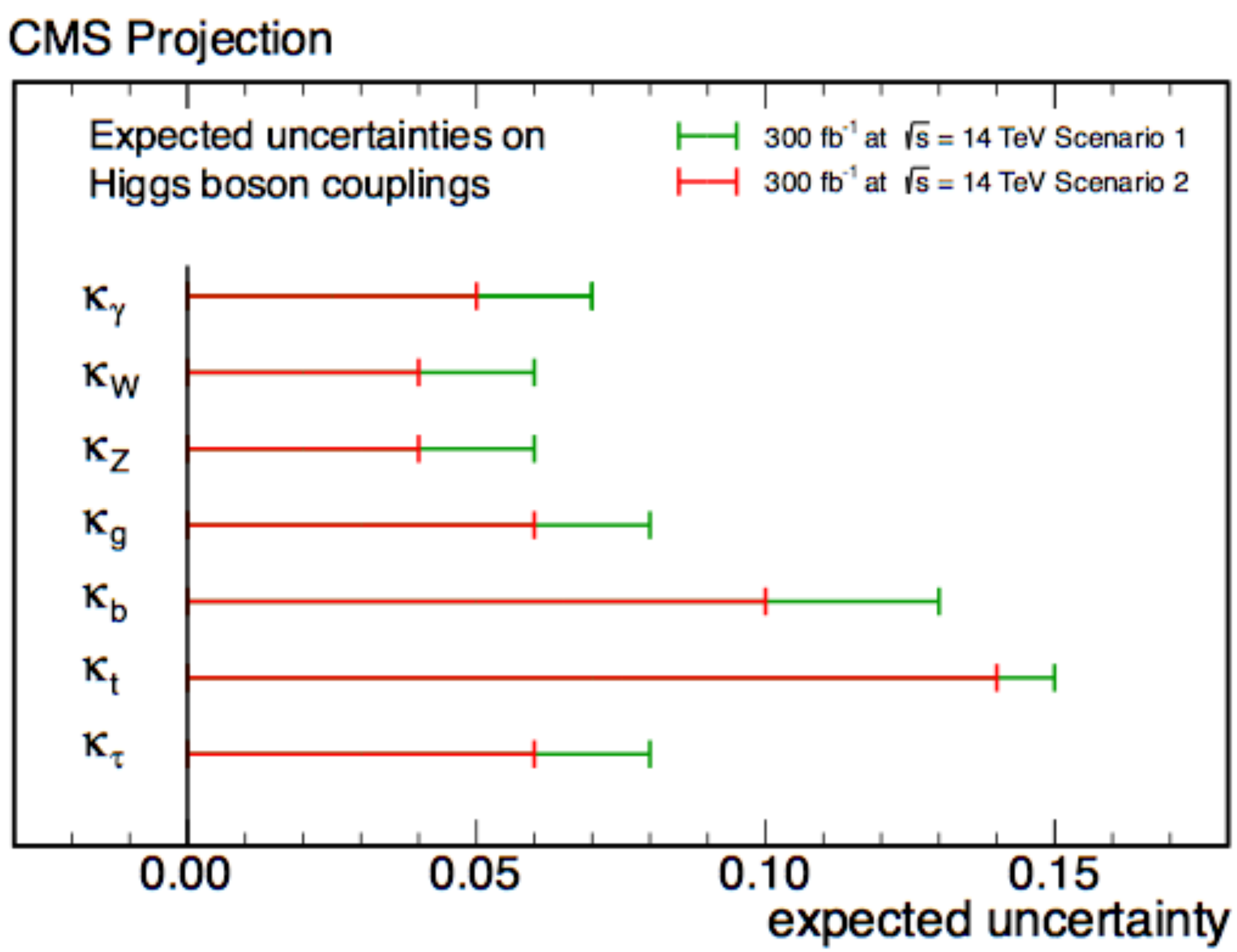


300 fb^{-1}, 14TeV (Scenario 1)

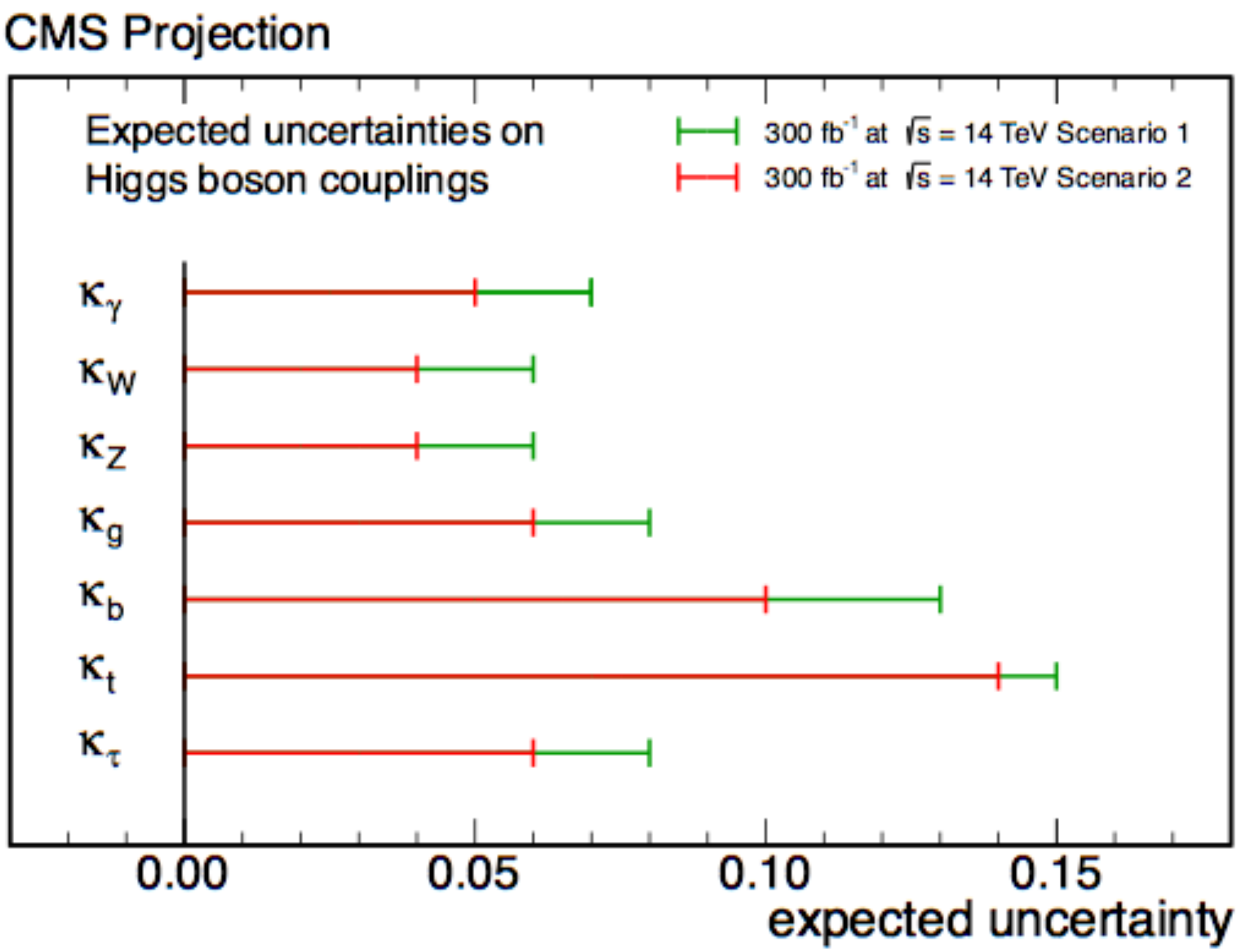
300 fb^{-1}, 14TeV (Scenario 1)

300 fb^{-1} 14 TeV, Scenario 1

300 fb^{-1} 14 TeV, Scenario 2

Higgs boson couplings @300 fb^{-1}

- Two scenarios:
  - Scenario 1: same systematics as in 2012
  - Scenario 2: theory systematics scaled by a factor ½, other systematics scaled by 1/√L



300 fb^{-1}, 14TeV (Scenario 1)
300 fb^{-1}, 14TeV (Scenario 1)

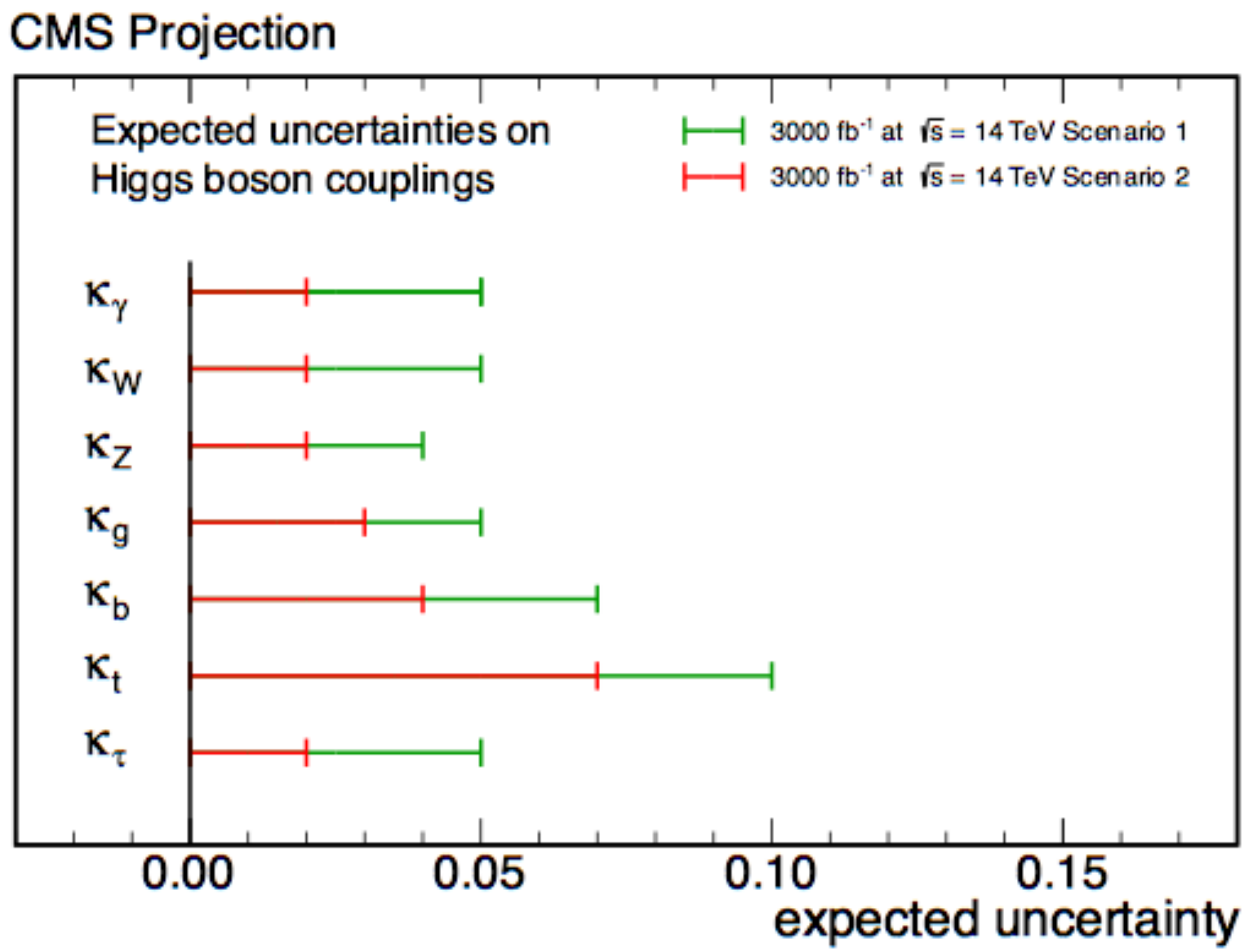
300 fb^{-1} 14 TeV, Scenario 1
300 fb^{-1} 14 TeV, Scenario 2

With 300 fb^{-1} the uncertainties on the Higgs couplings uncert. should be in the range $\sigma(\kappa_V) \sim$ 4-7%

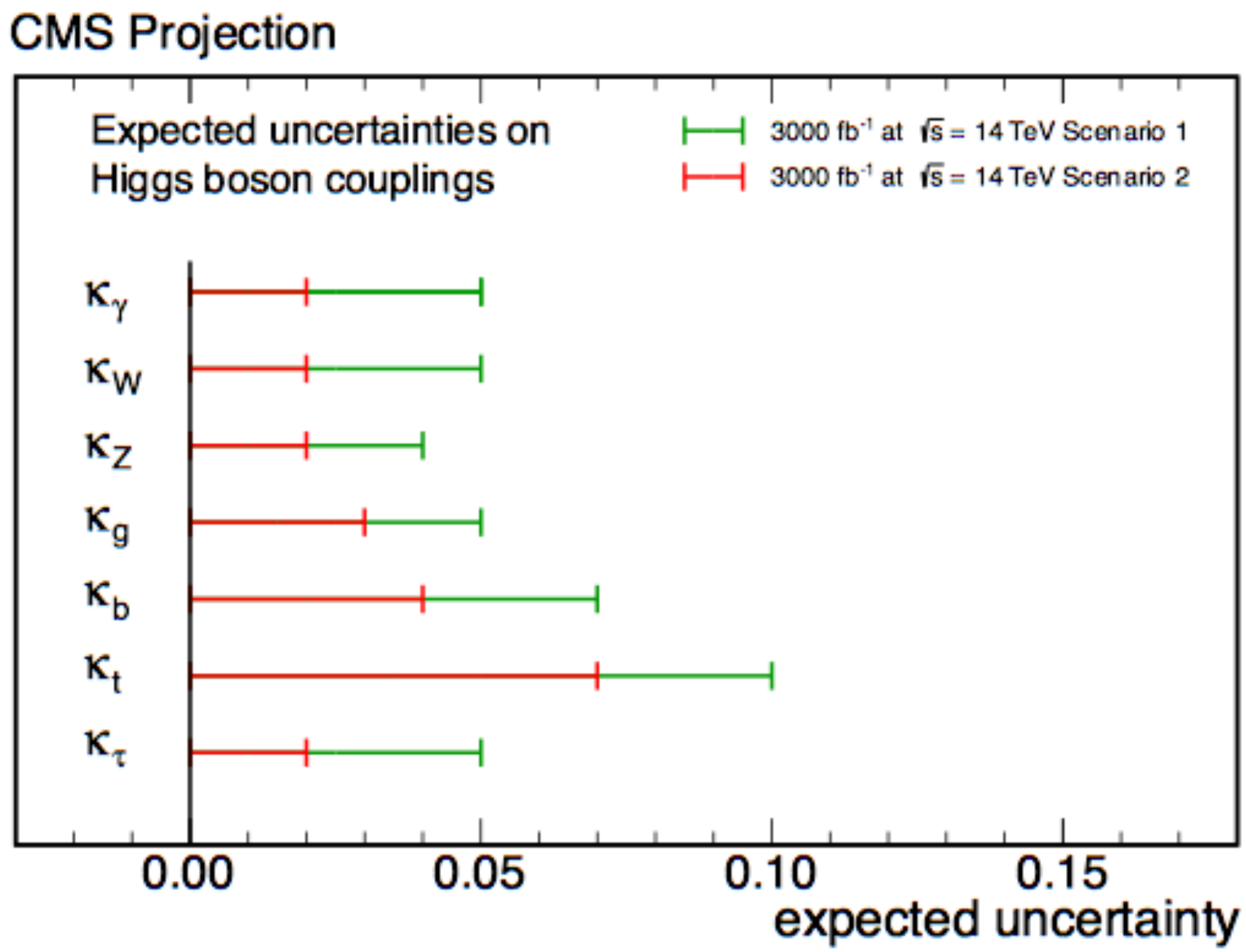
$\sigma(\kappa_f) \sim$ 6-15%

Higgs boson couplings @3000 fb^{-1}

Higgs boson couplings @3000 fb^{-1}

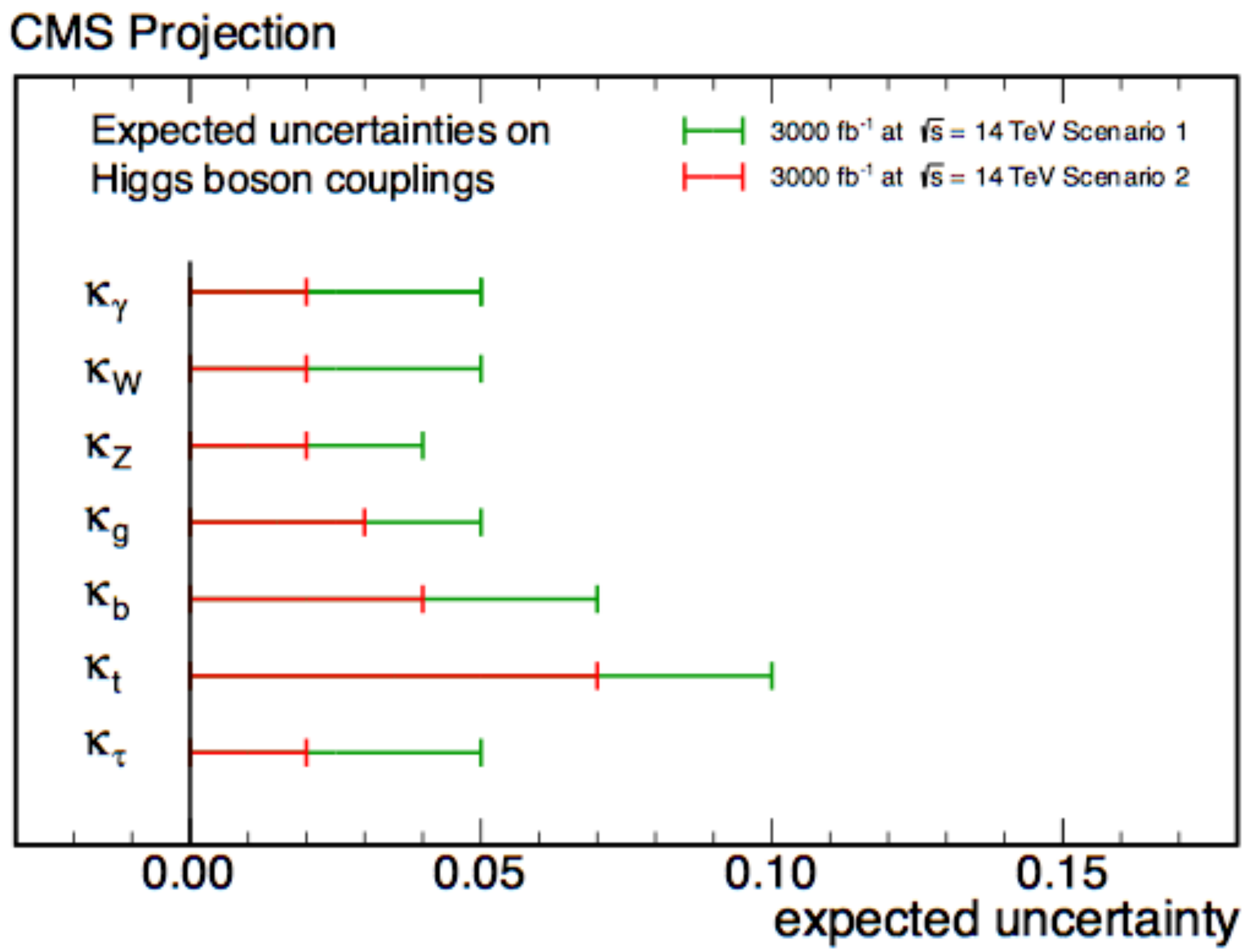


Higgs boson couplings @3000 fb^{-1}



L (pb		K	K	K	K	K	K	K	K	K
300	CMS	[5,7]	[4,6]	[4,6]	[6,8]	[10,13]	[14,15]	[6,8]	[41,41]	[23,23]
3000	CMS	[2,5]	[2,5]	[2,4]	[3,5]	[4,7]	[7,10]	[2,5]	[10,12]	[8,8]
300	ATLAS	[9,9]	[9.9]	[8,8]	[11,14]	[22,23]	[20,22]	[13,14	[24,24]	[21,21]
3000	ATLAS	[4,5]	[4,5]	[4,4]	[5,9]	[10,12]	[8,11]	[9,10]	[14,14]	[7,9]

Higgs boson couplings @3000 fb^{-1}



L (pb		K	K	K	K	K	K	K	K	K
300	CMS	[5,7]	[4,6]	[4,6]	[6,8]	[10,13]	[14,15]	[6,8]	[41,41]	[23,23]
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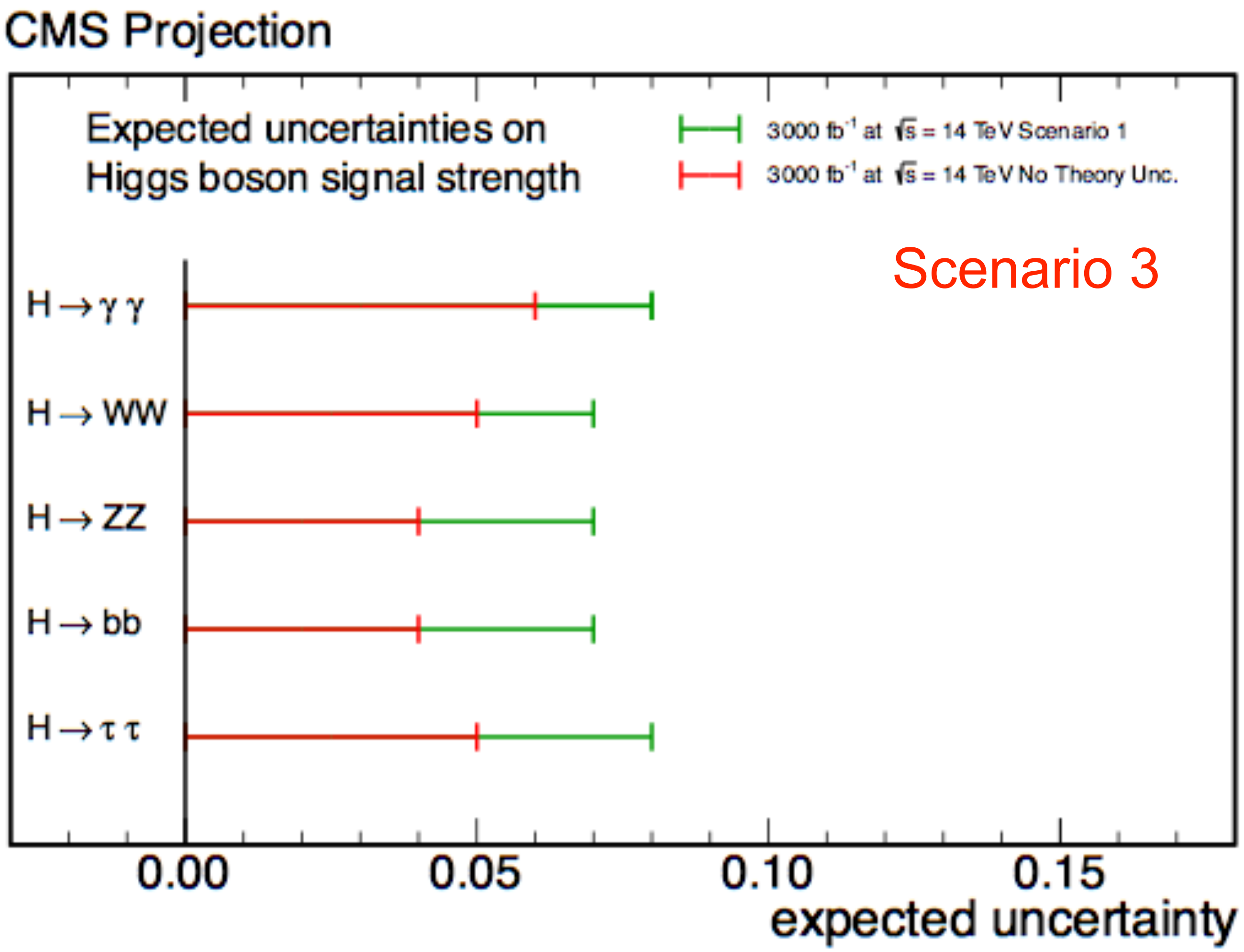
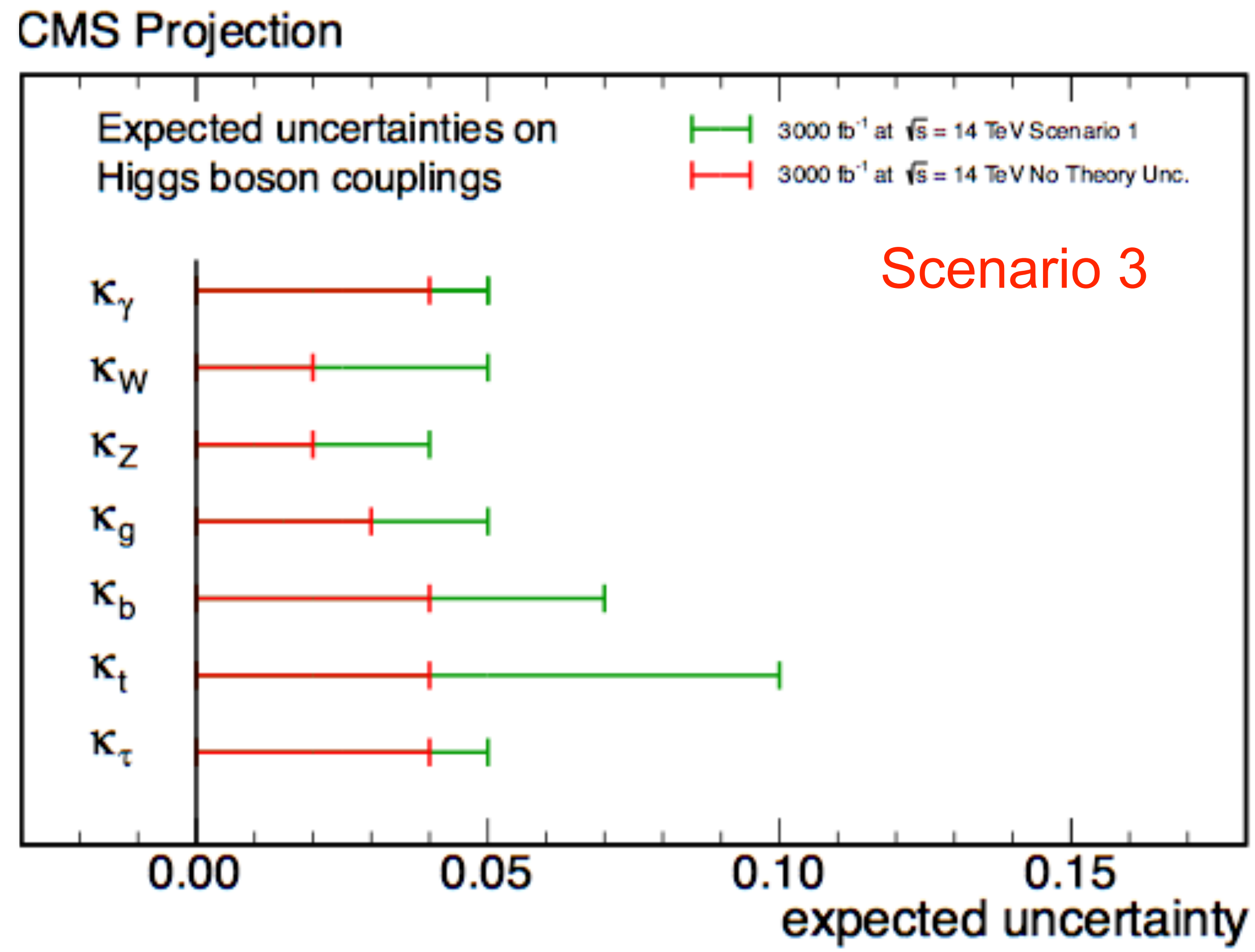
300	ATLAS	[9,9]	[9.9]	[8,8]	[11,14]	[22,23]	[20,22]	[13,14	[24,24]	[21,21]
3000	ATLAS	[4,5]	[4,5]	[4,4]	[5,9]	[10,12]	[8,11]	[9,10]	[14,14]	[7,9]

With 3000 fb^{-1} the Higgs couplings can be determined with high precision (2-7%)

Higgs projections @3000 fb^{-1}

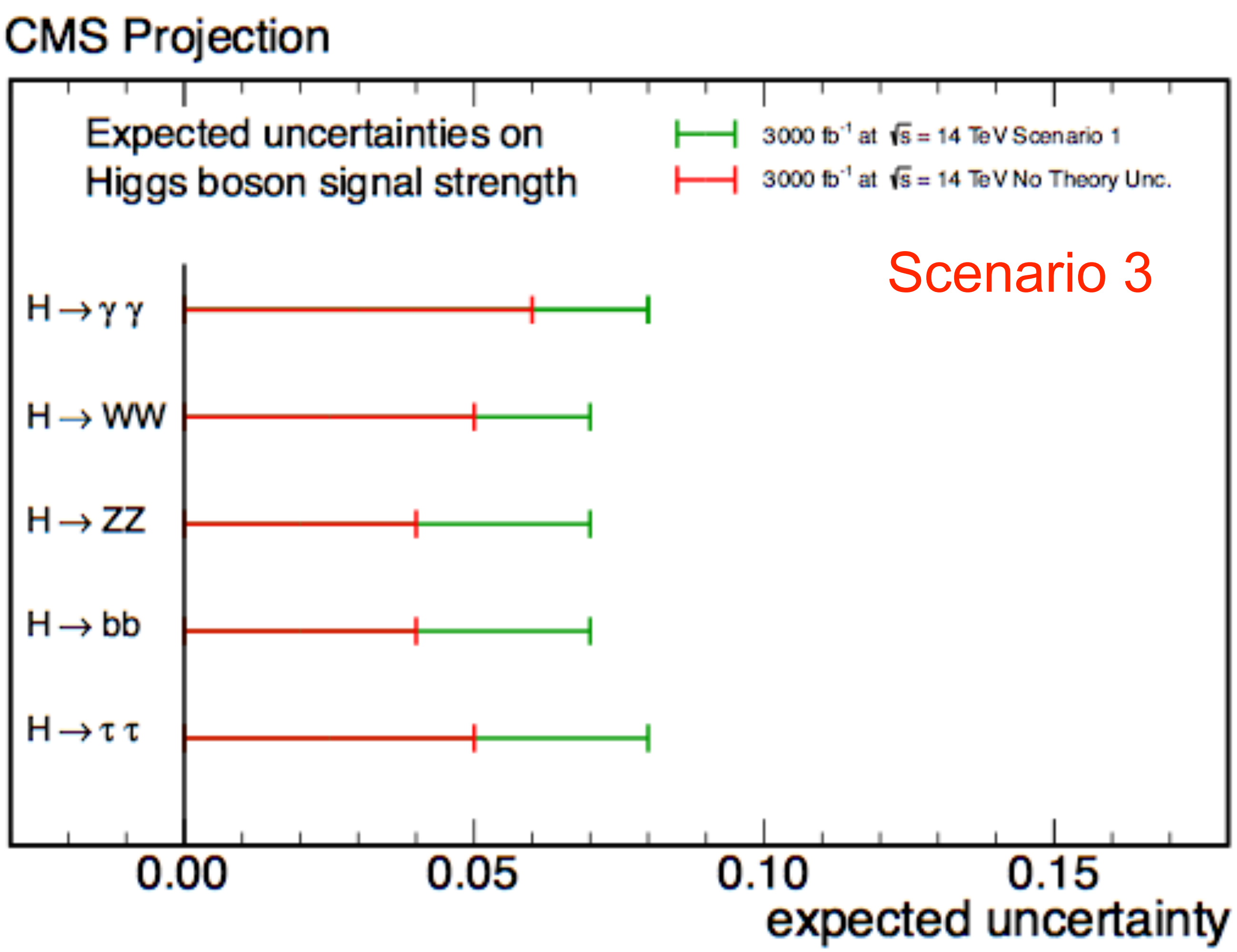
Scenario 3: No Theory uncertainty

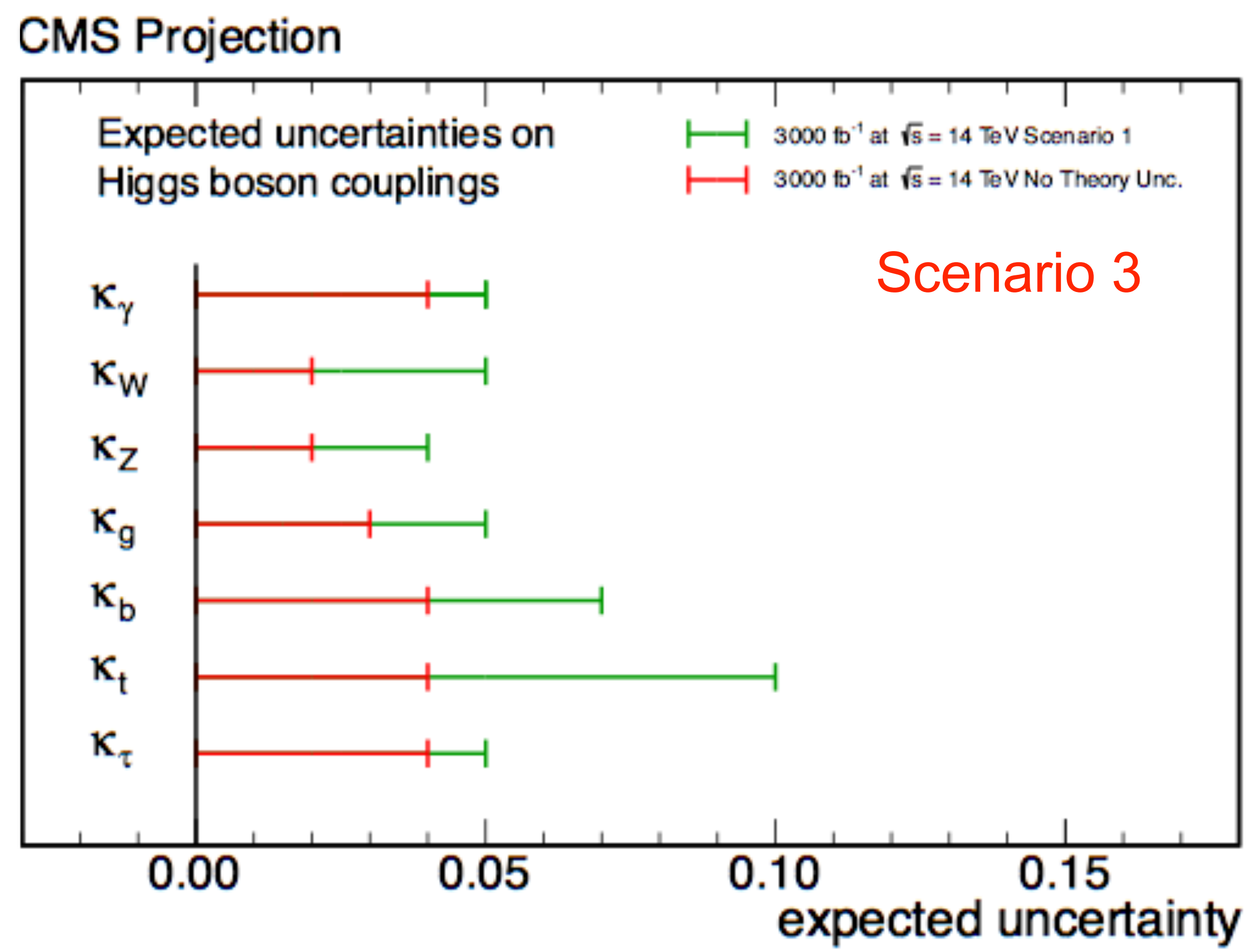




Higgs projections @3000 fb^{-1}

Scenario 3: No Theory uncertainty

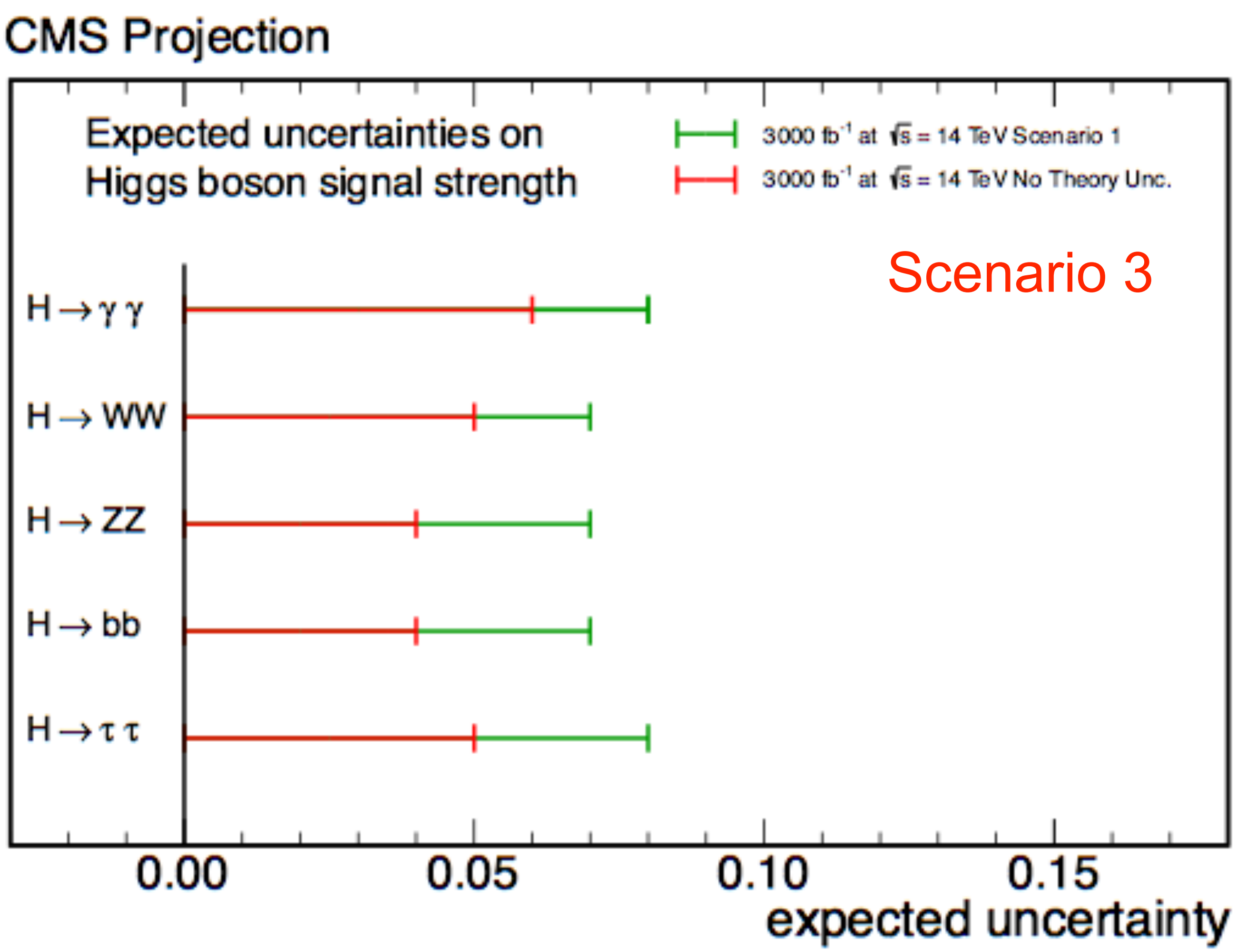


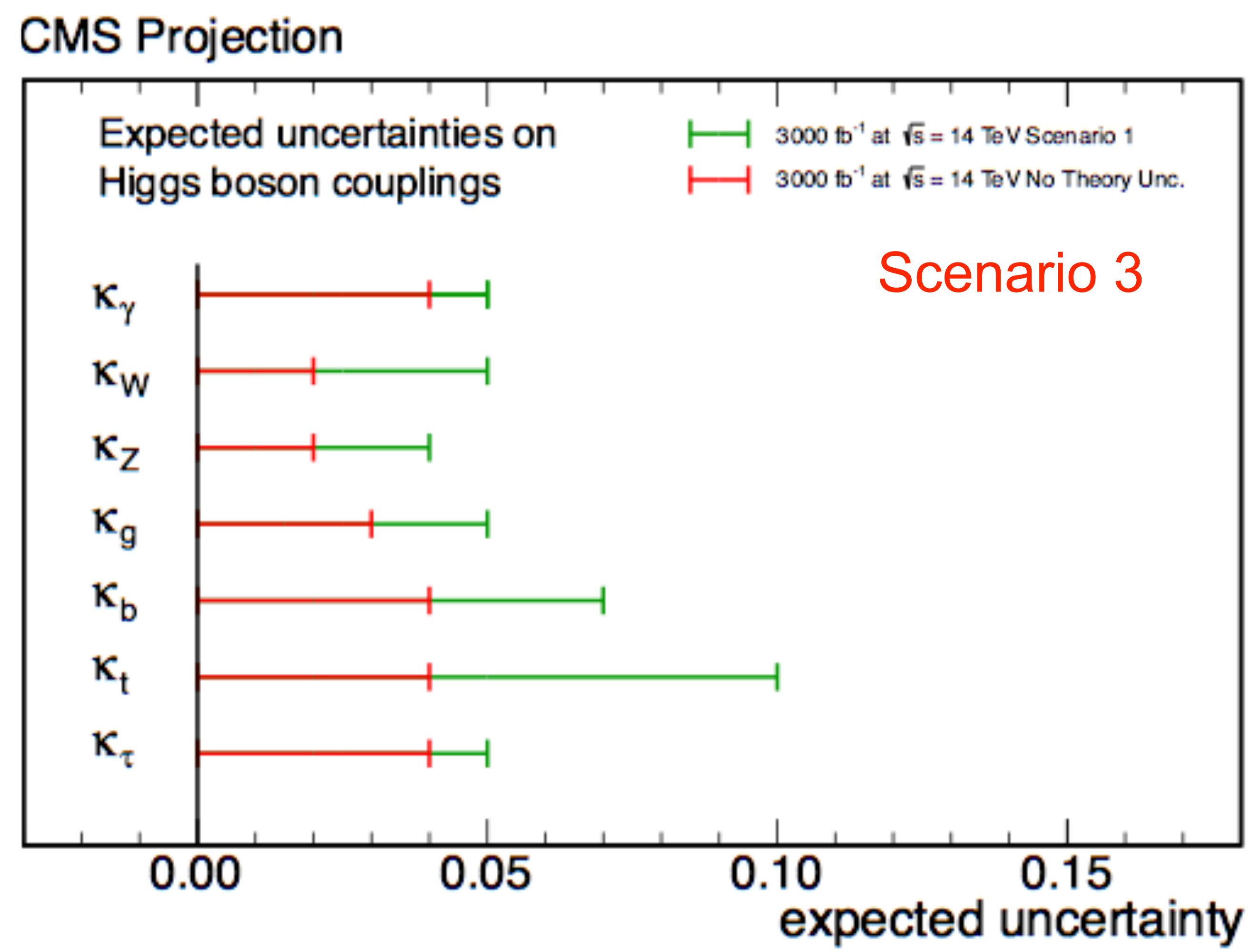


- Extrapolation by two orders of magnitude to higher luminosity
  - is subject to large uncertainties

Higgs projections @3000 fb^{-1}

Scenario 3: No Theory uncertainty





- Extrapolation by two orders of magnitude to higher luminosity
  - is subject to large uncertainties
- Results will become syst. limited due to theory uncertainties. We must encourage our theoretical friends to improve their calculations!

Higgs couplings @3000 fb^{-1}

Higgs couplings @3000 fb^{-1}

- Remove assumption on total width
  - Only ratios of the coupling scale factors can be determined at LHC
  - Use given process as a reference ($H \rightarrow ZZ$)

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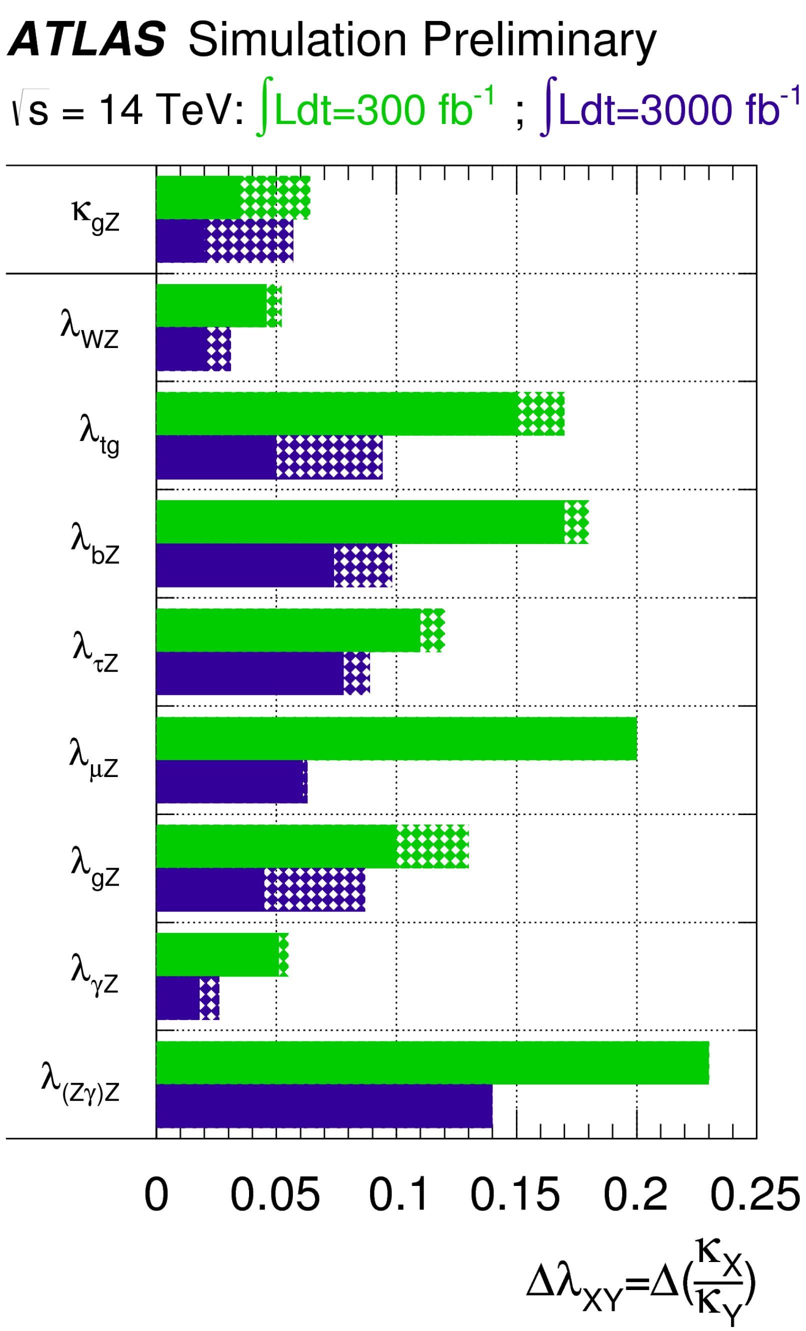
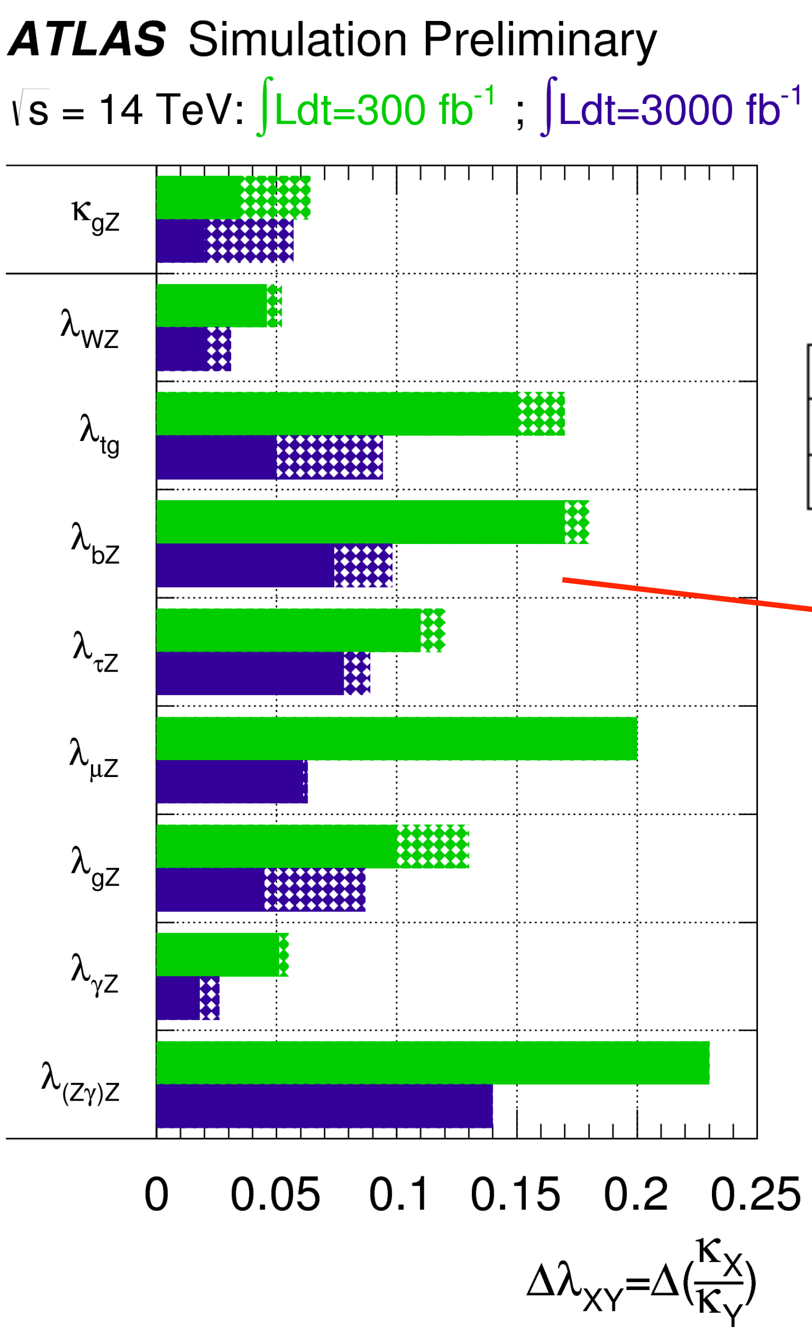


Higgs couplings @3000 fb^{-1}

- Remove assumption on total width
  - Only ratios of the coupling scale factors can be determined at LHC
  - Use given process as a reference (H→ZZ)



CMS (scenario 2, scenario 1)

L (fb^{-1})	$\kappa_g \cdot \kappa_Z / \kappa_H$	κ_γ/κ_Z	κ_W/κ_Z	κ_b/κ_Z	κ_τ/κ_Z	κ_Z/κ_g	κ_t/κ_g	κ_μ/κ_Z	$\kappa_{Z\gamma}/\kappa_Z$
300	[4,6]	[5,8]	[4,7]	[8,11]	[6,9]	[6,9]	[13,14]	[22,23]	[40,42]
3000	[2,5]	[2,5]	[2,3]	[3,5]	[2,4]	[3,5]	[6,8]	[7,8]	[12,12]

5.7	2.6	3.1	9.8	8.9	8.7	9.4	5.3	14

Higgs couplings @3000 fb^{-1}

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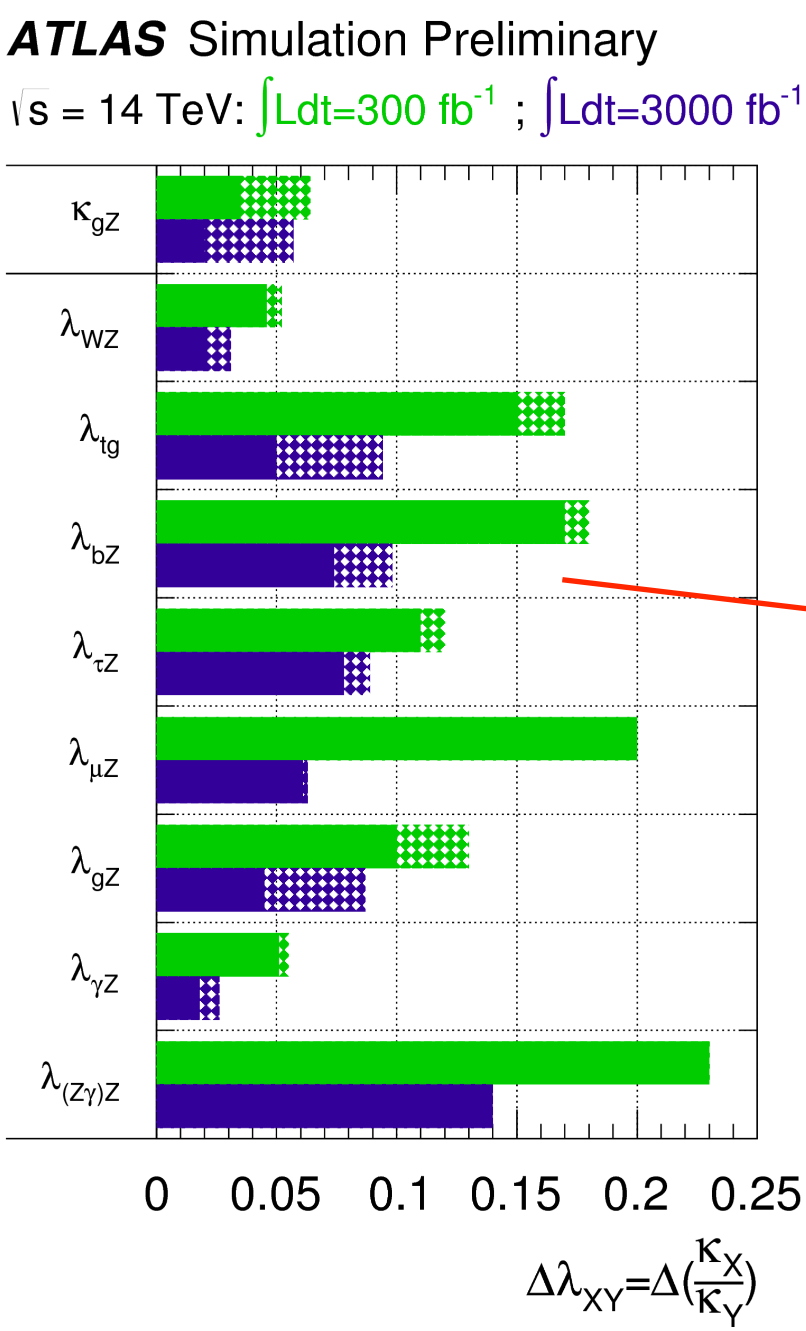


CMS (scenario 2, scenario 1)

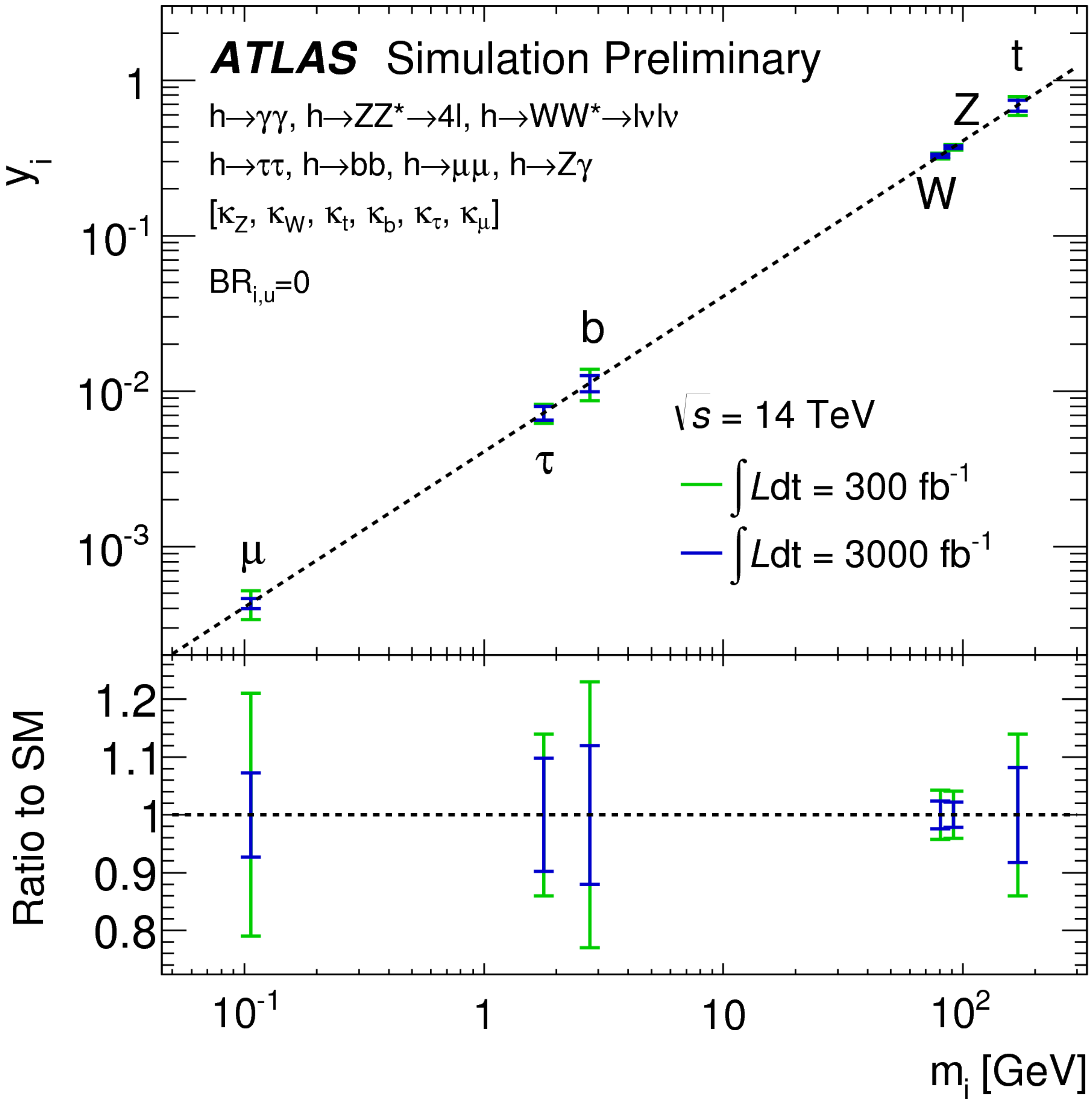
L (fb^{-1})	$\kappa_g \cdot \kappa_Z / \kappa_H$	κ_γ / κ_Z	κ_W / κ_Z	κ_b / κ_Z	κ_τ / κ_Z	κ_Z / κ_g	κ_t / κ_g	κ_μ / κ_Z	$\kappa_{Z\gamma} / \kappa_Z$
300	[4,6]	[5,8]	[4,7]	[8,11]	[6,9]	[6,9]	[13,14]	[22,23]	[40,42]
3000	[2,5]	[2,5]	[2,3]	[3,5]	[2,4]	[3,5]	[6,8]	[7,8]	[12,12]

5.7	2.6	3.1	9.8	8.9	8.7	9.4	5.3	14

- With 3000 fb^{-1} the couplings can be determined with high precision (up to a few %)

Higgs coupling ratios vs. mass

Mass-scaled coupling ratios vs. particle mass



Reduced coupling parameters

$$q_V = \sqrt{\frac{Y_V}{v}} = \sqrt{\kappa_V}\frac{m_V}{v}$$

$$q_f = \frac{Y_f}{\sqrt{2}} = \kappa_f\frac{m_f}{v}$$

Rare Higgs decays

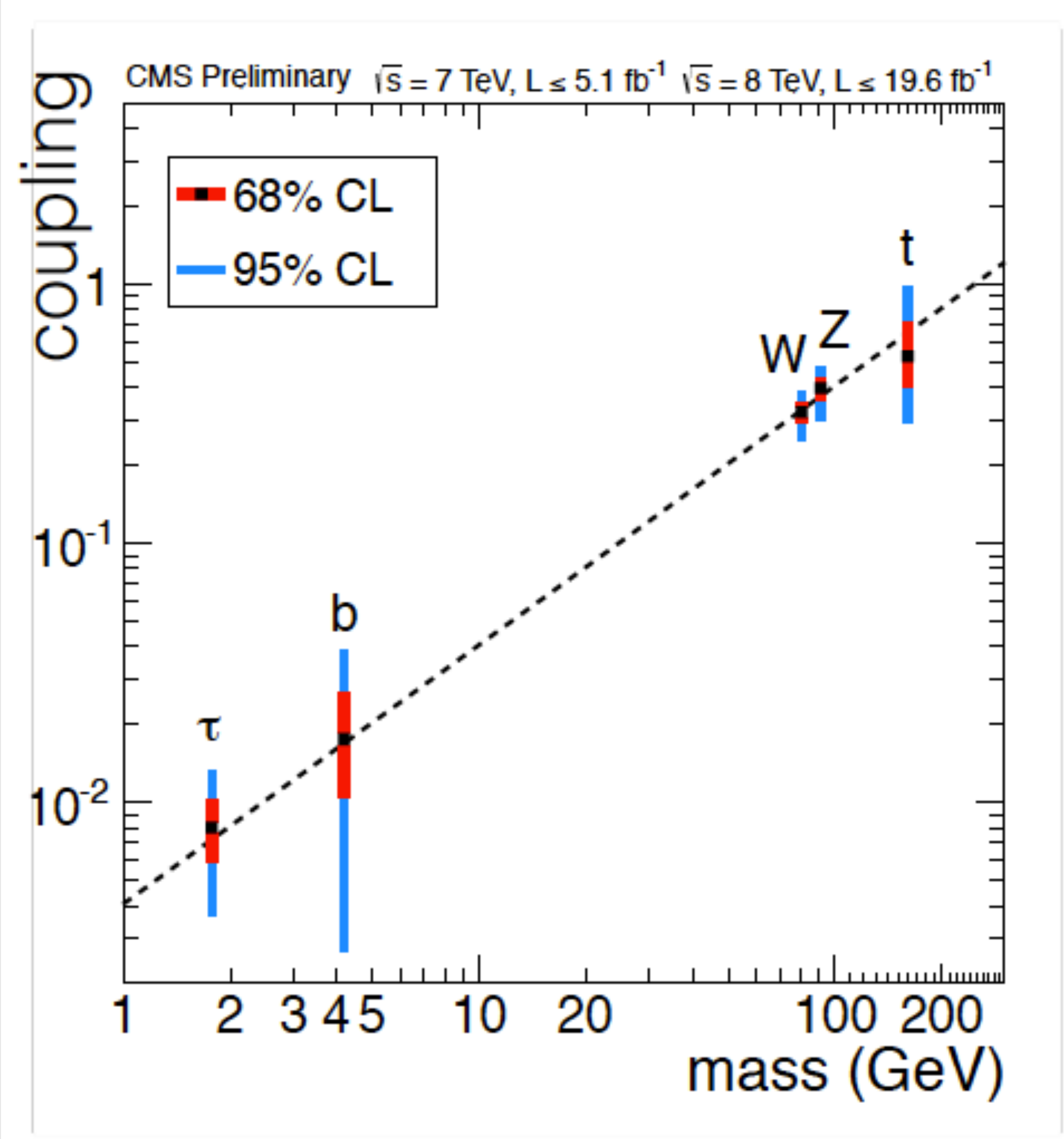
H→μμ

G. Salam, A. Weiler

- By LHC14@300, we'll have probed all 3rd generation fermion couplings to O(10–20%)
- H → $\mu^+\mu^-$ gives us access to 2nd lepton generation, i.e. is the mass-generation mechanism same for all generations, for quarks and leptons?

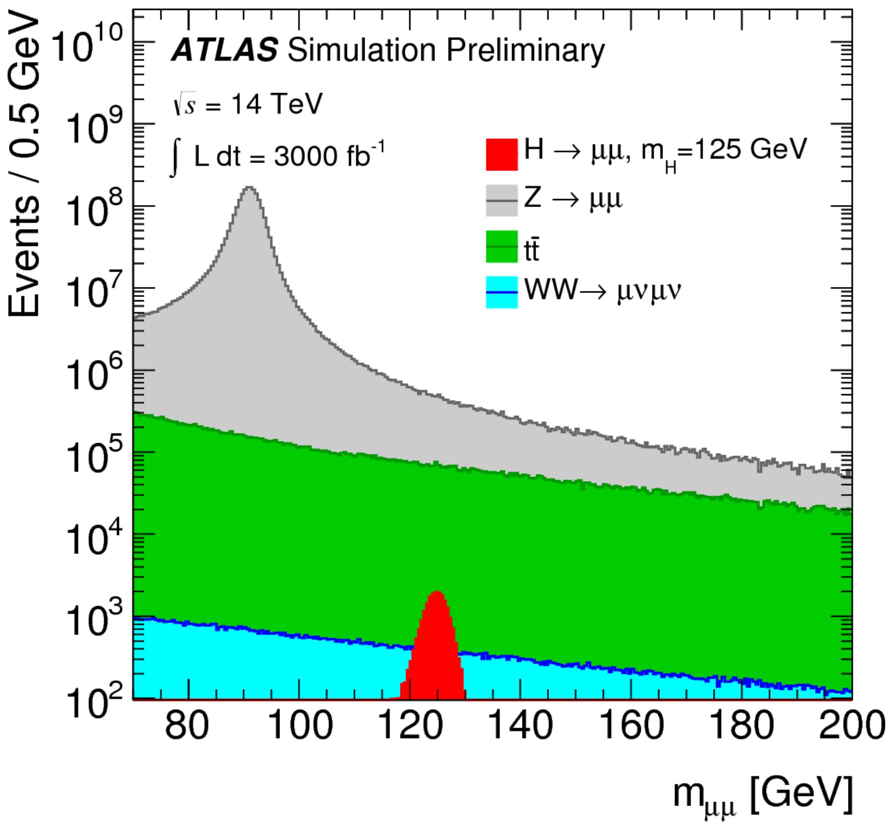
mass ∝ coupling to Higgs ?

$$Br(H \to \mu^+\mu^-)_{\mathrm{SM}} = 2.2 \cdot 10^{-4}$$



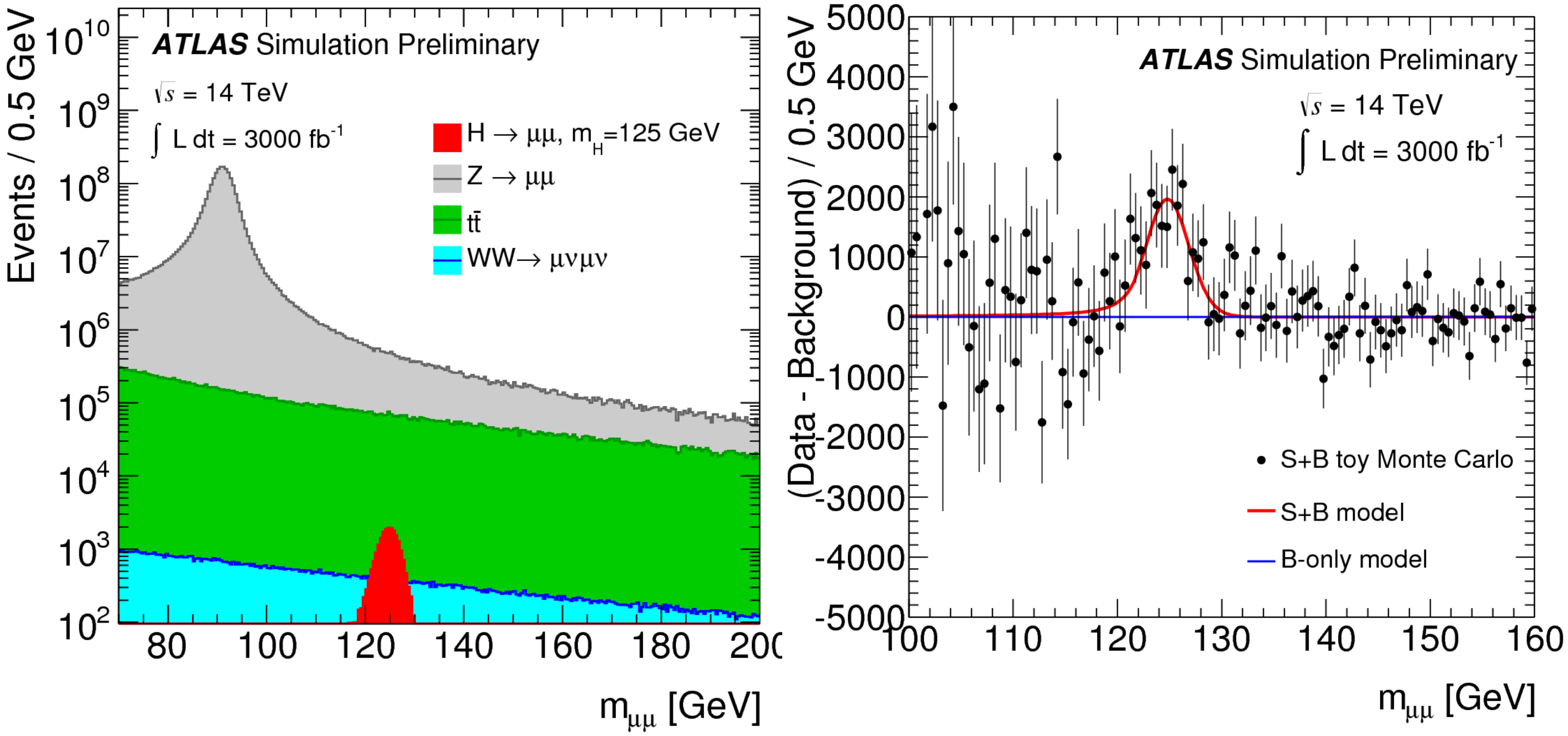
$H \rightarrow \mu\mu$

H→μμ



ATLAS Simulation Preliminary
√s = 14 TeV
∫ L dt = 3000 fb-1
H → μμ, mH=125 GeV
Z → μμ
tt̄
WW→ μνμν
Events / 0.5 GeV
mμμ [GeV]

H→μμ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√s = 14 TeV
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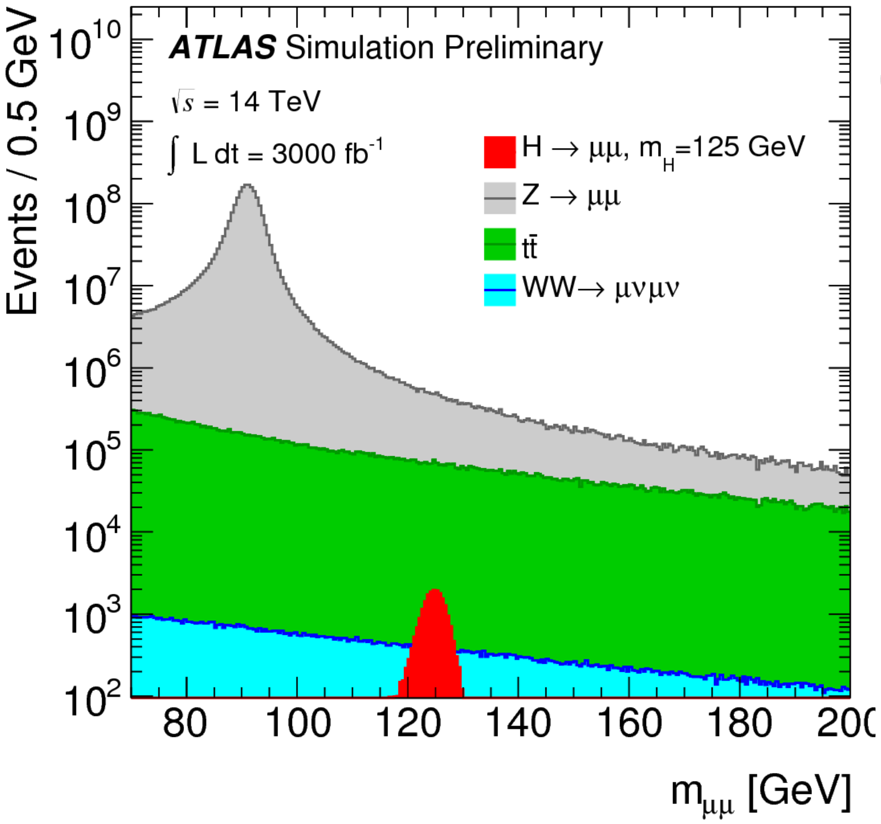
S+B toy Monte Carlo
S+B model
B-only model
(Data - Background) / 0.5 GeV
mμμ [GeV]

H→μμ



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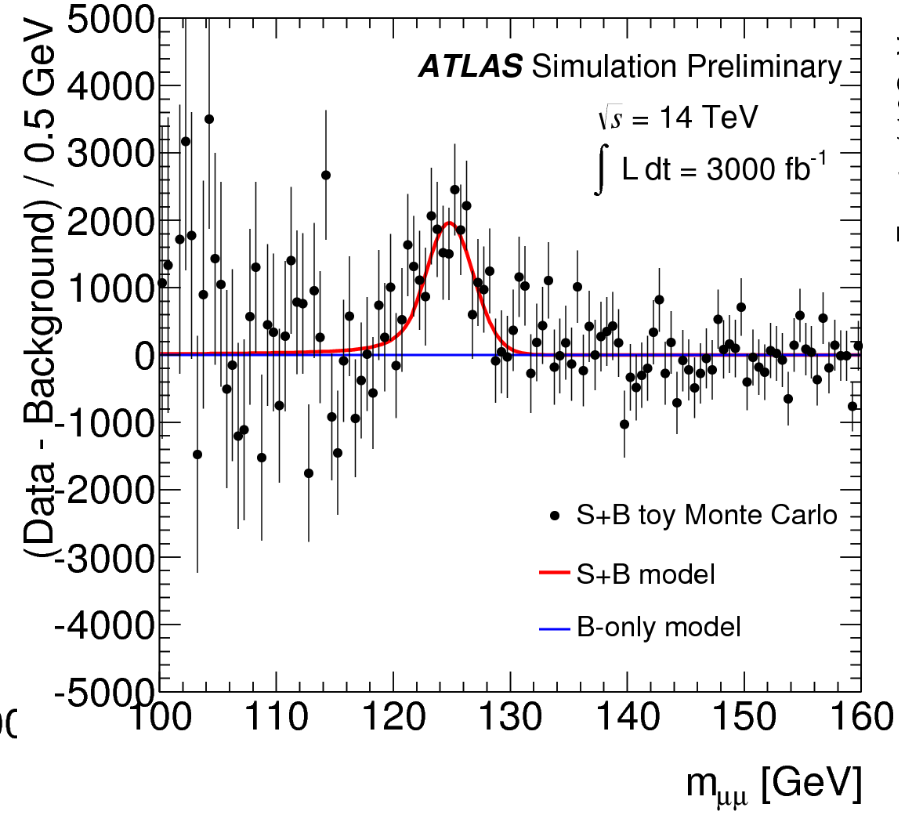
m_μμ [GeV]



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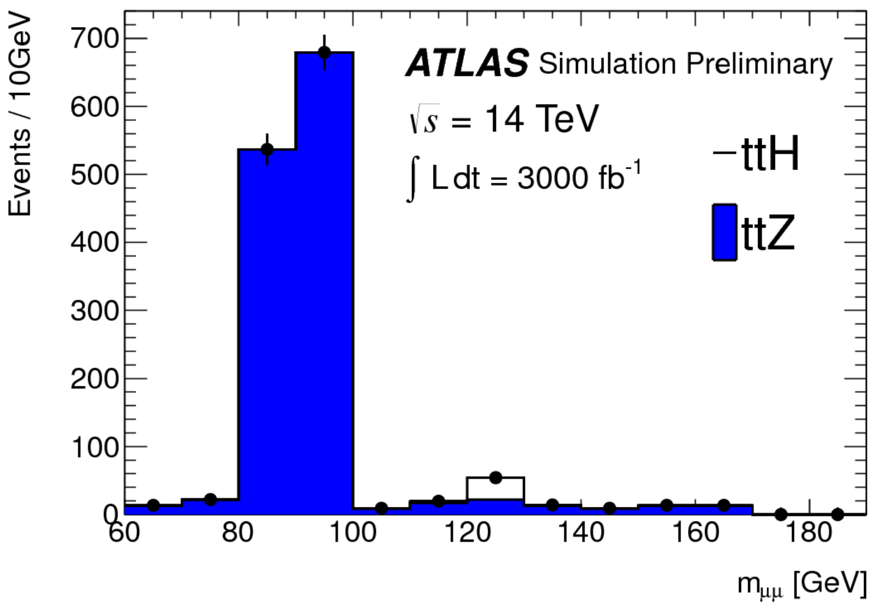
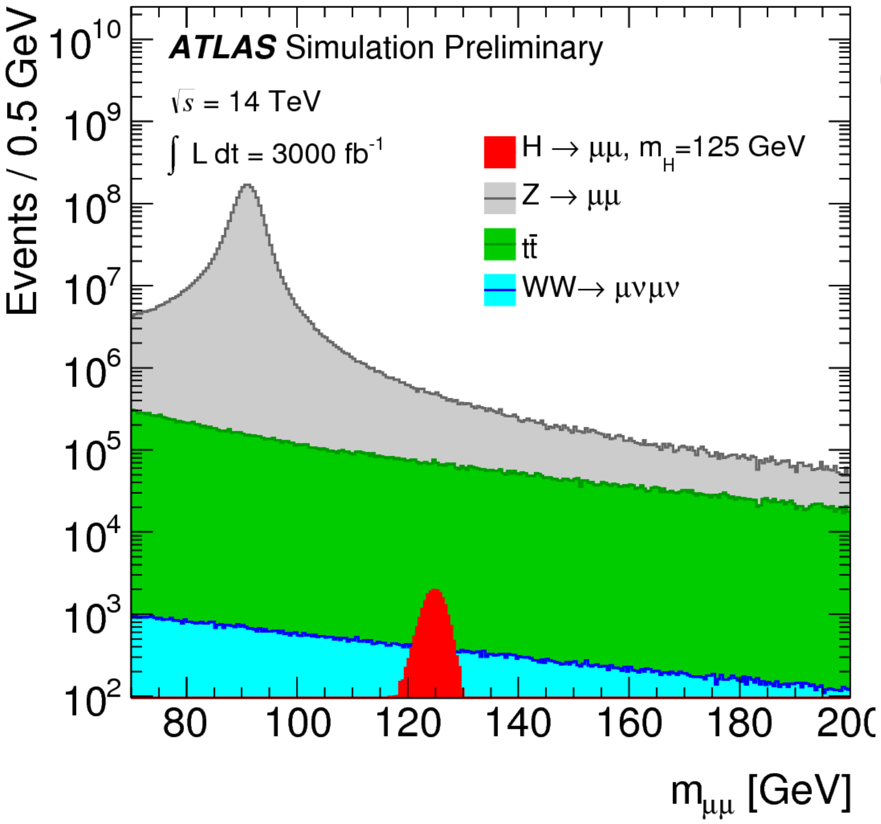


ATLAS Simulation Preliminary
√s = 14 TeV
∫ L dt = 3000 fb^-1
ttH
ttZ
Events / 10GeV
m_μμ [GeV]

H→μμ



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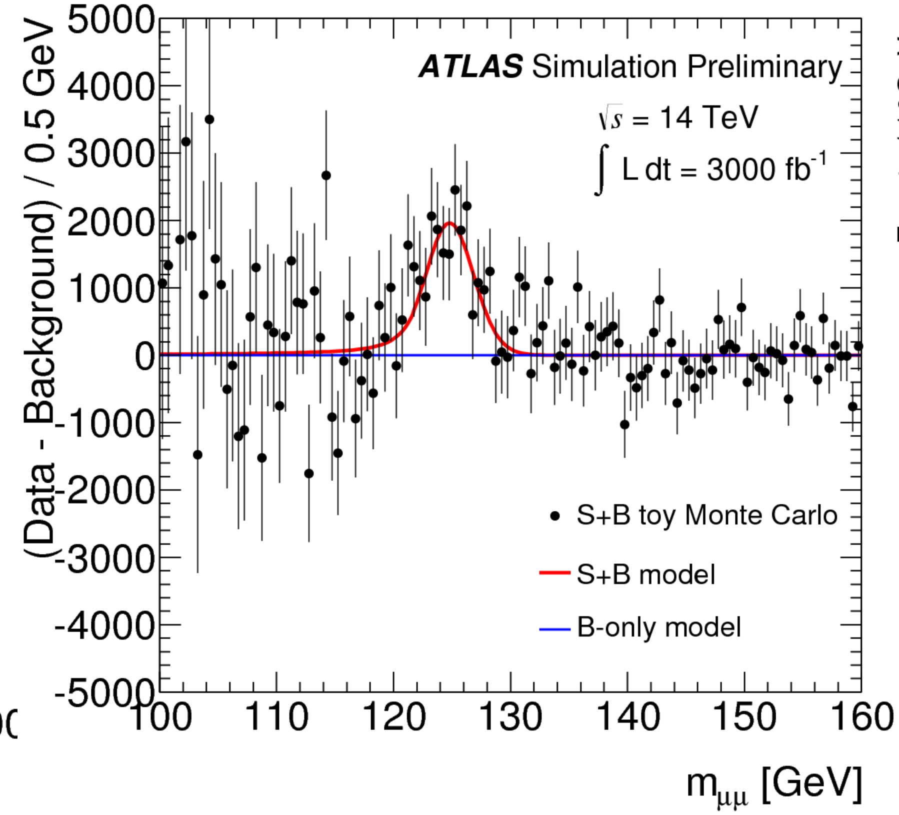

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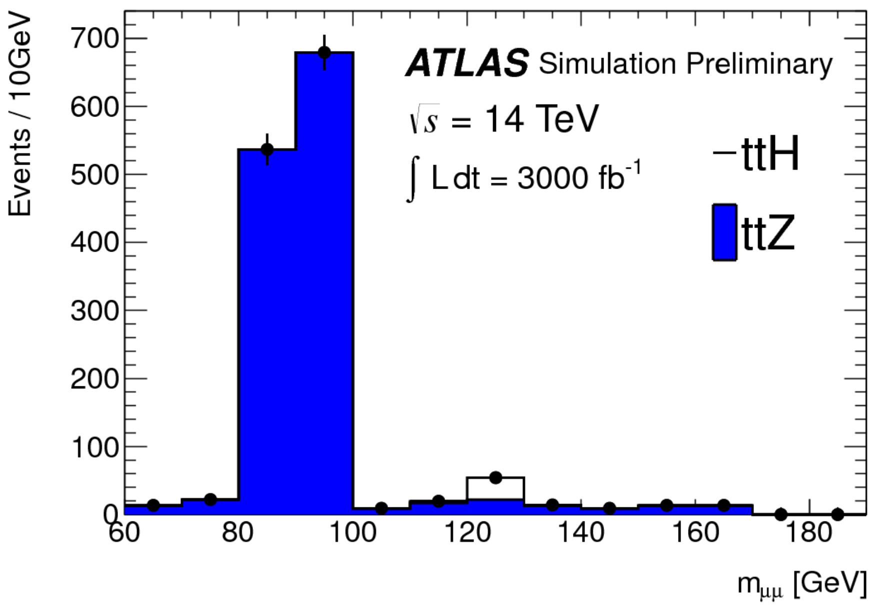

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ttH
ttZ
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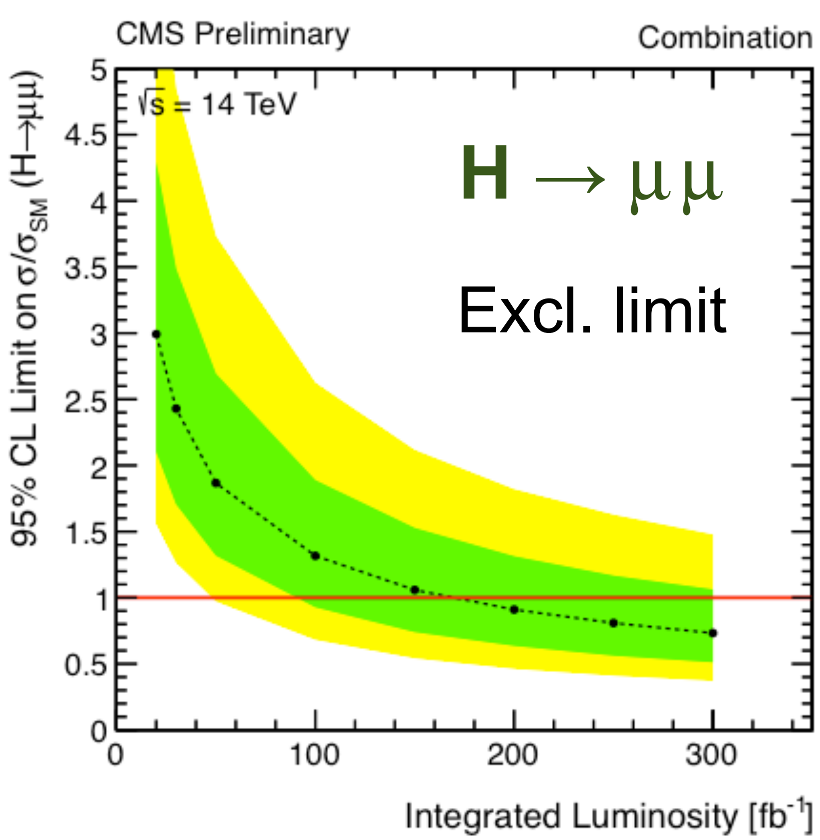
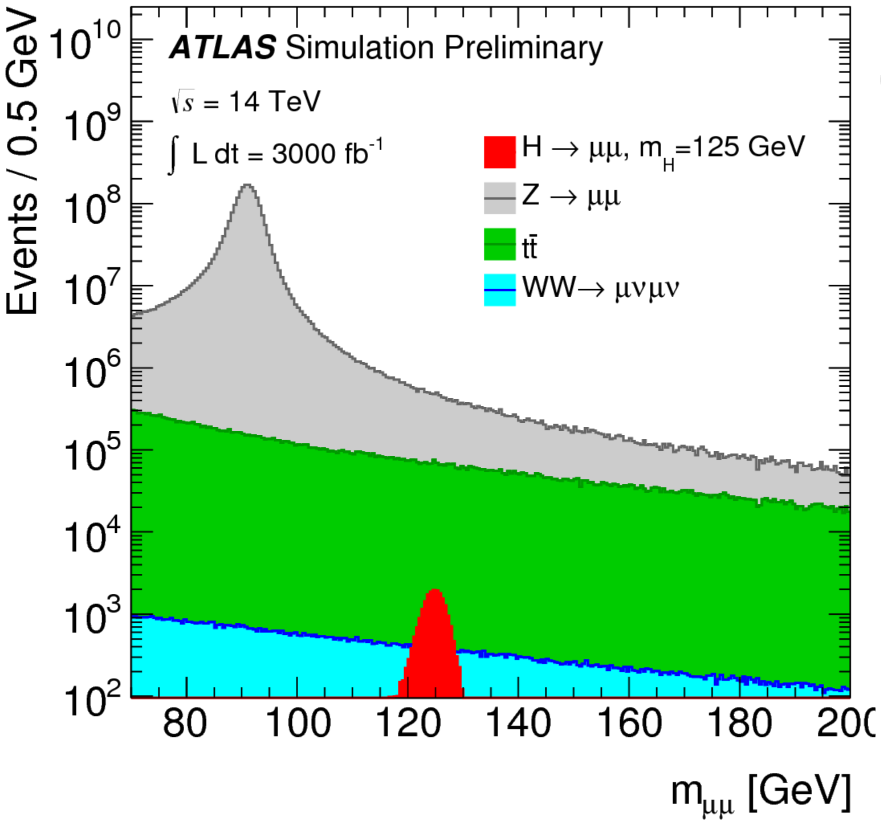


CMS Preliminary
Combination
$\sqrt{s}$ = 14 TeV
H → μμ
Excl. limit
95% CL Limit on σ/σ$_{SM}$ (H→μμ)
Integrated Luminosity [fb^{-1}]

$H \to \mu\mu$



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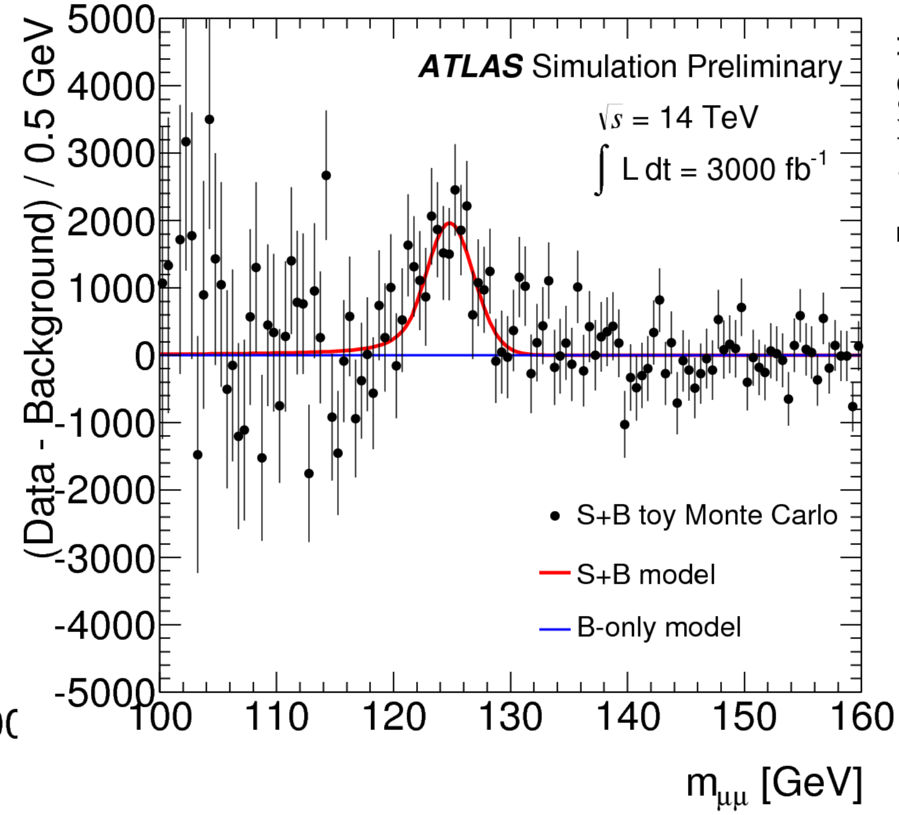
Z → μμ
tt̄
WW→ μνμν
Events / 0.5 GeV
m$_{\mu\mu}$ [GeV]



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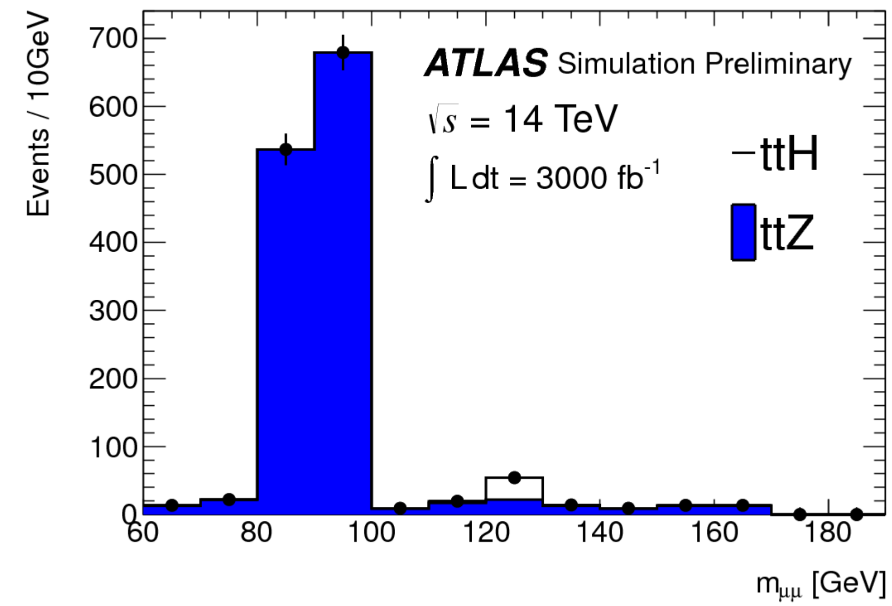

ATLAS Simulation Preliminary
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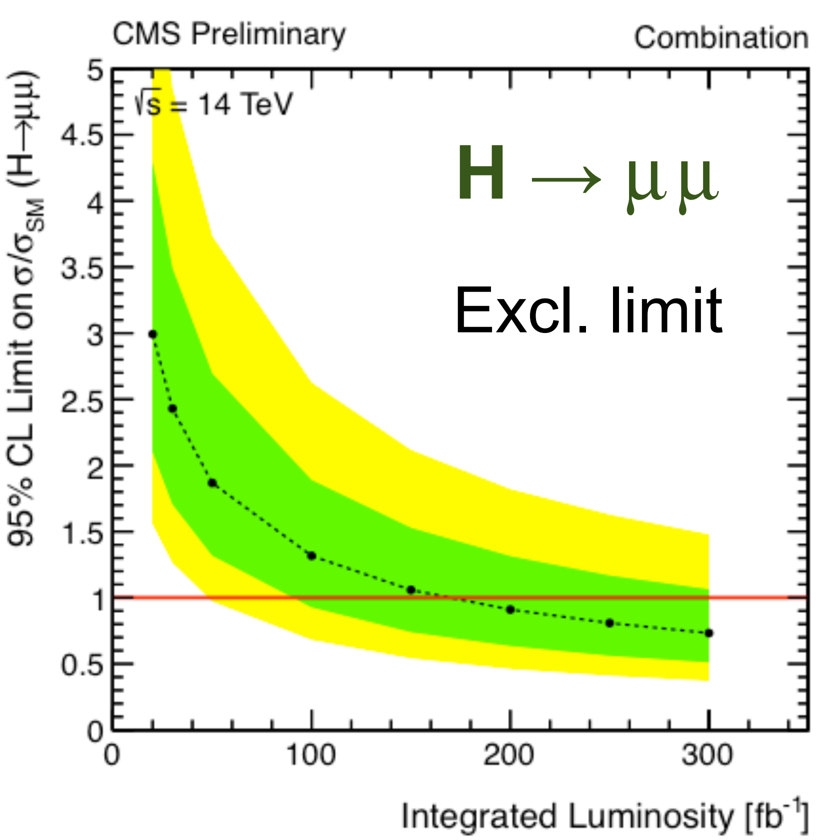
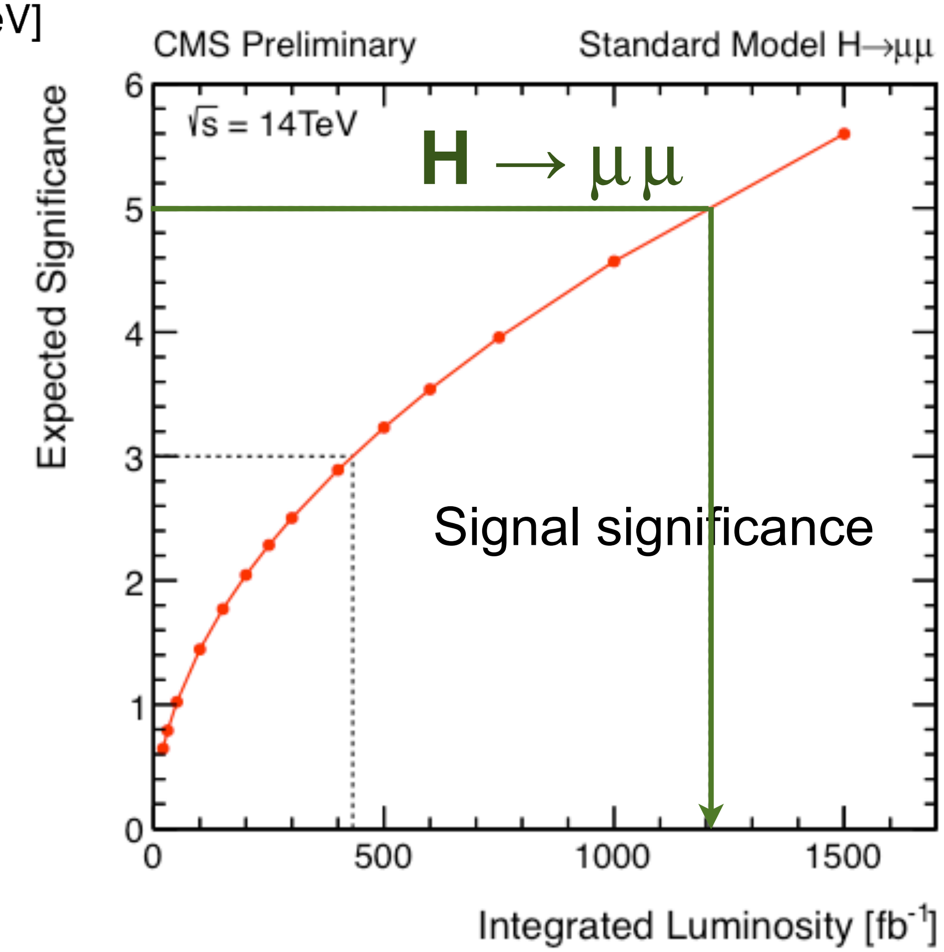
ttH
ttZ
Events / 10GeV
m$_{\mu\mu}$ [GeV]

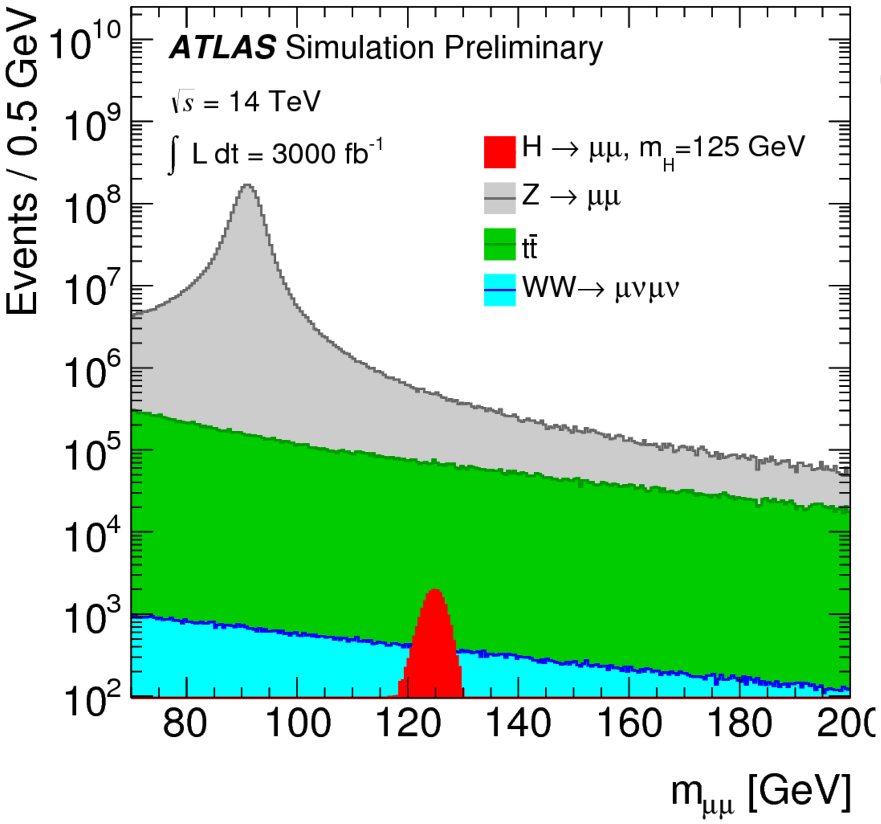


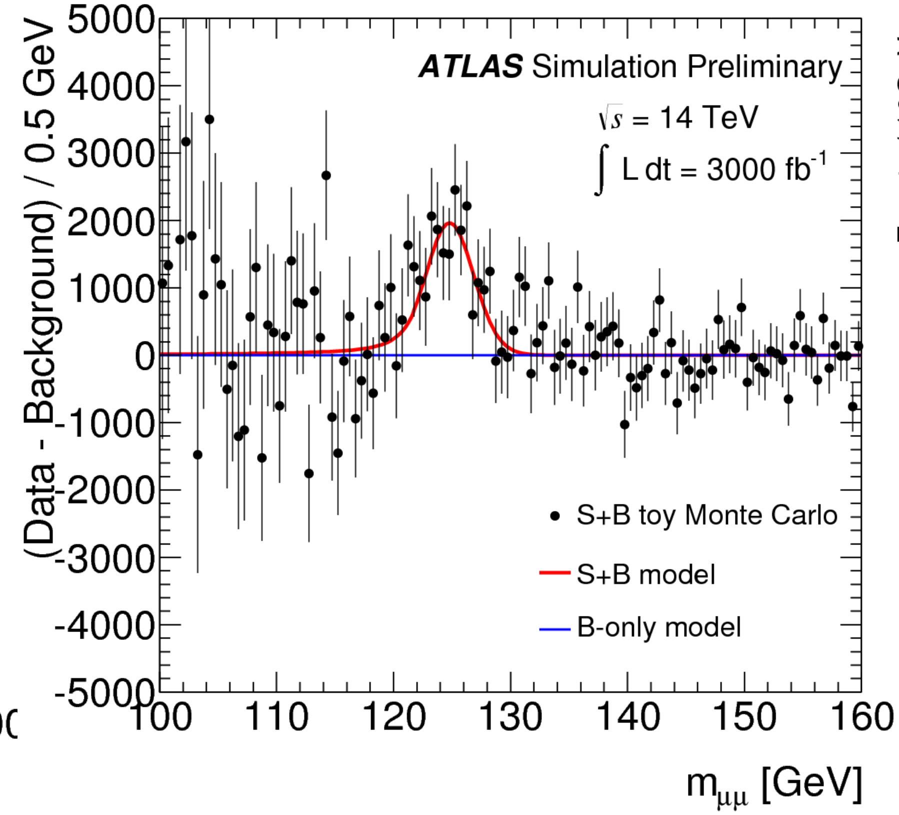
CMS Preliminary
Combination
$\sqrt{s}$ = 14 TeV
H → μ μ
Excl. limit
95% CL Limit on σ/σ$_{SM}$ (H→μμ)
Integrated Luminosity [fb^{-1}]

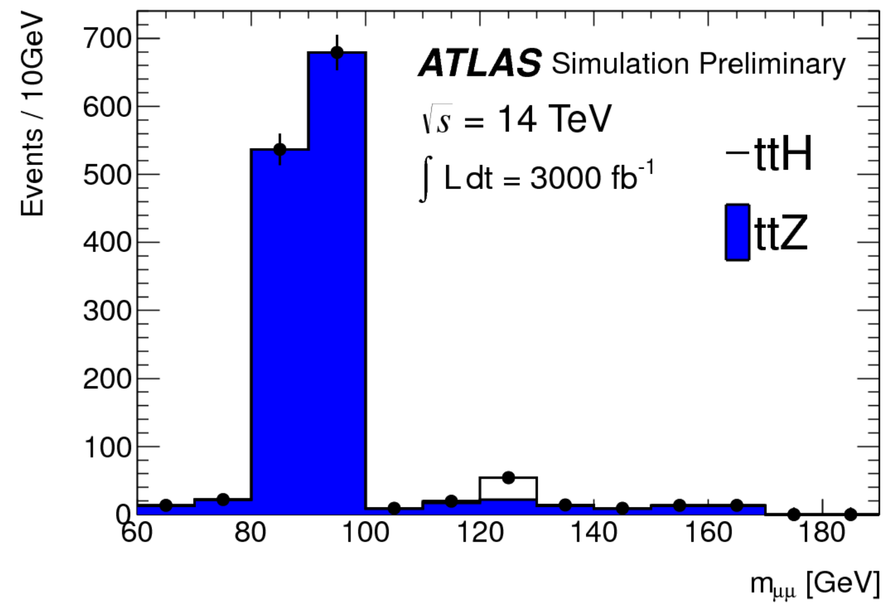


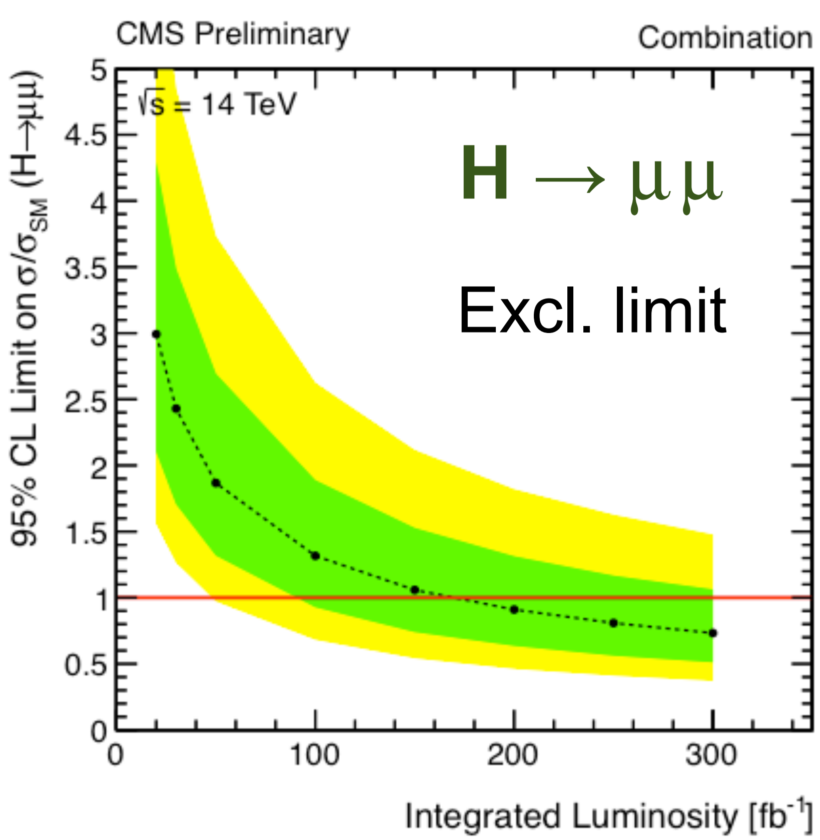
CMS Preliminary
Standard Model H→μμ
$\sqrt{s}$ = 14TeV
H → μ μ
Signal significance
Expected Significance
Integrated Luminosity [fb^{-1}]

H→μμ

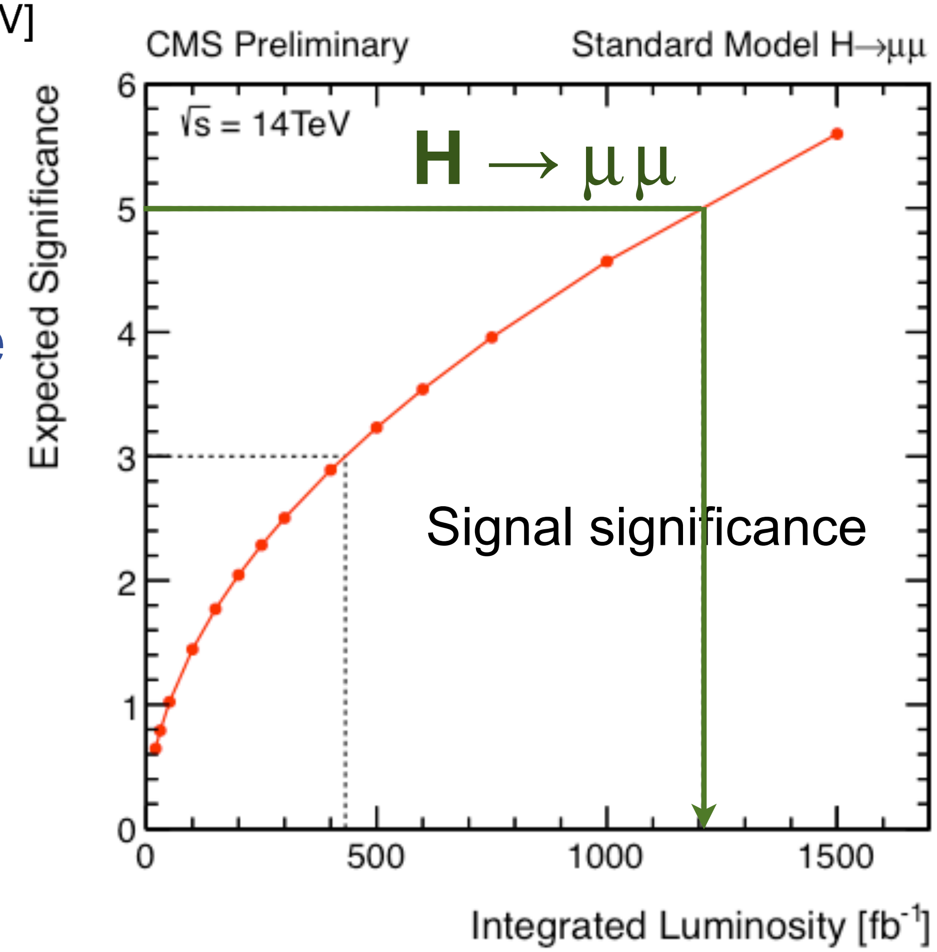








- The decay H→μμ can be observed with a significance of 5 sigma
  - measurement of the Hμμ coupling with a precision of ~10%



$H \rightarrow Z\gamma$

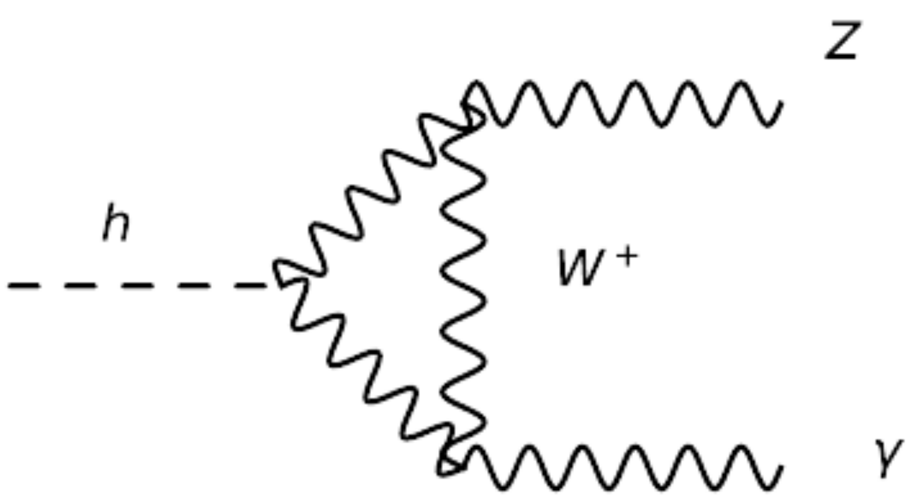
H→Zγ

- γZ like γγ and gg loop induced, but sensitive to effects invisible in γγ and gg (because of chiral couplings)

G. Salam, A. Weiler

- In composite Higgs: Not protected by Goldstone symmetry, large γZ while γγ and gg small

SM



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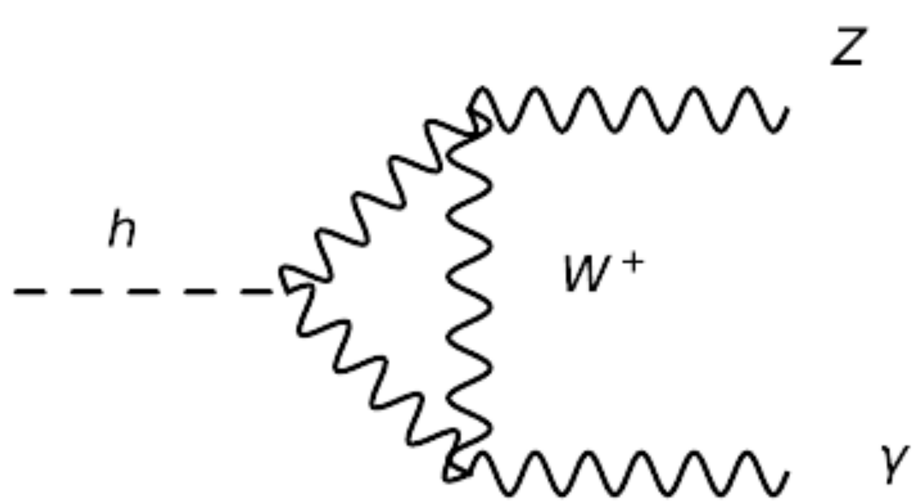
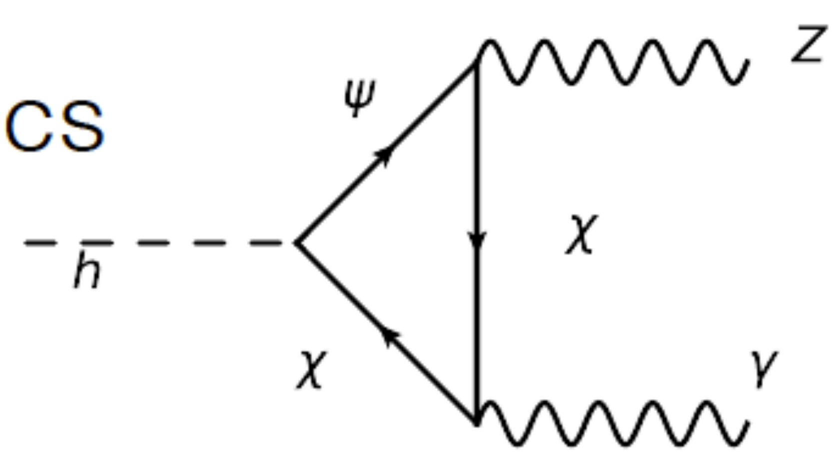


New physics



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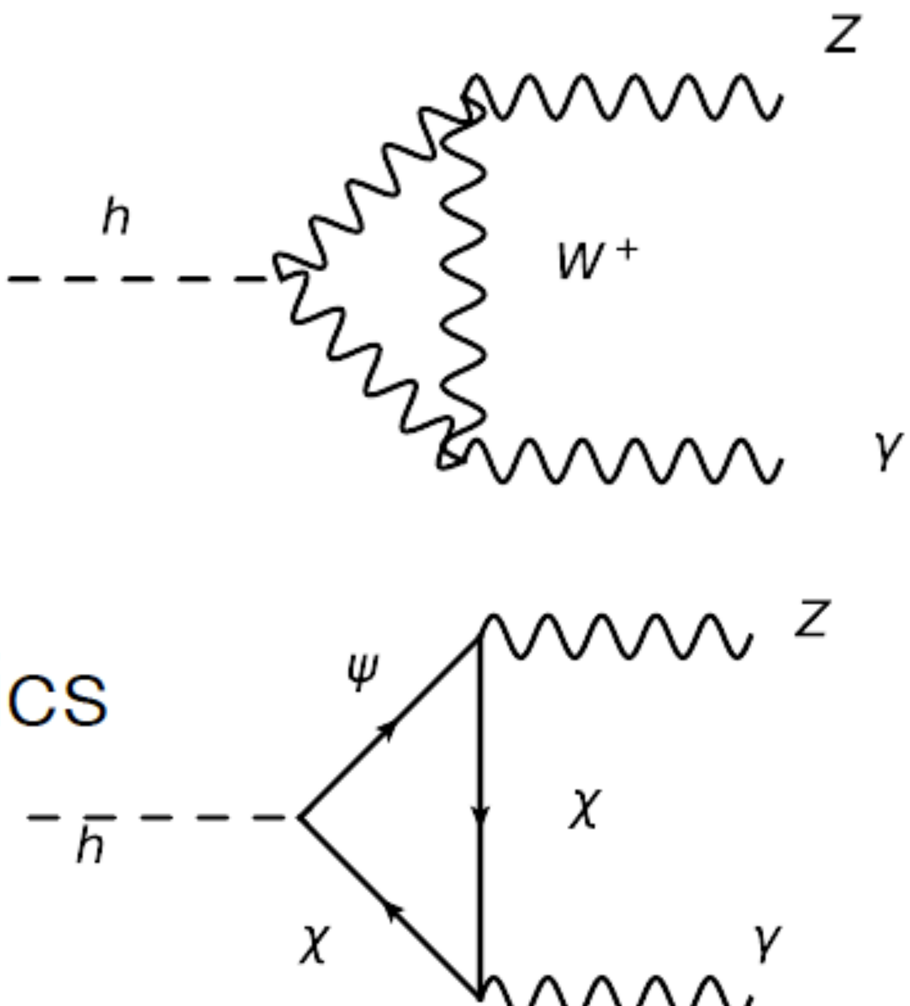
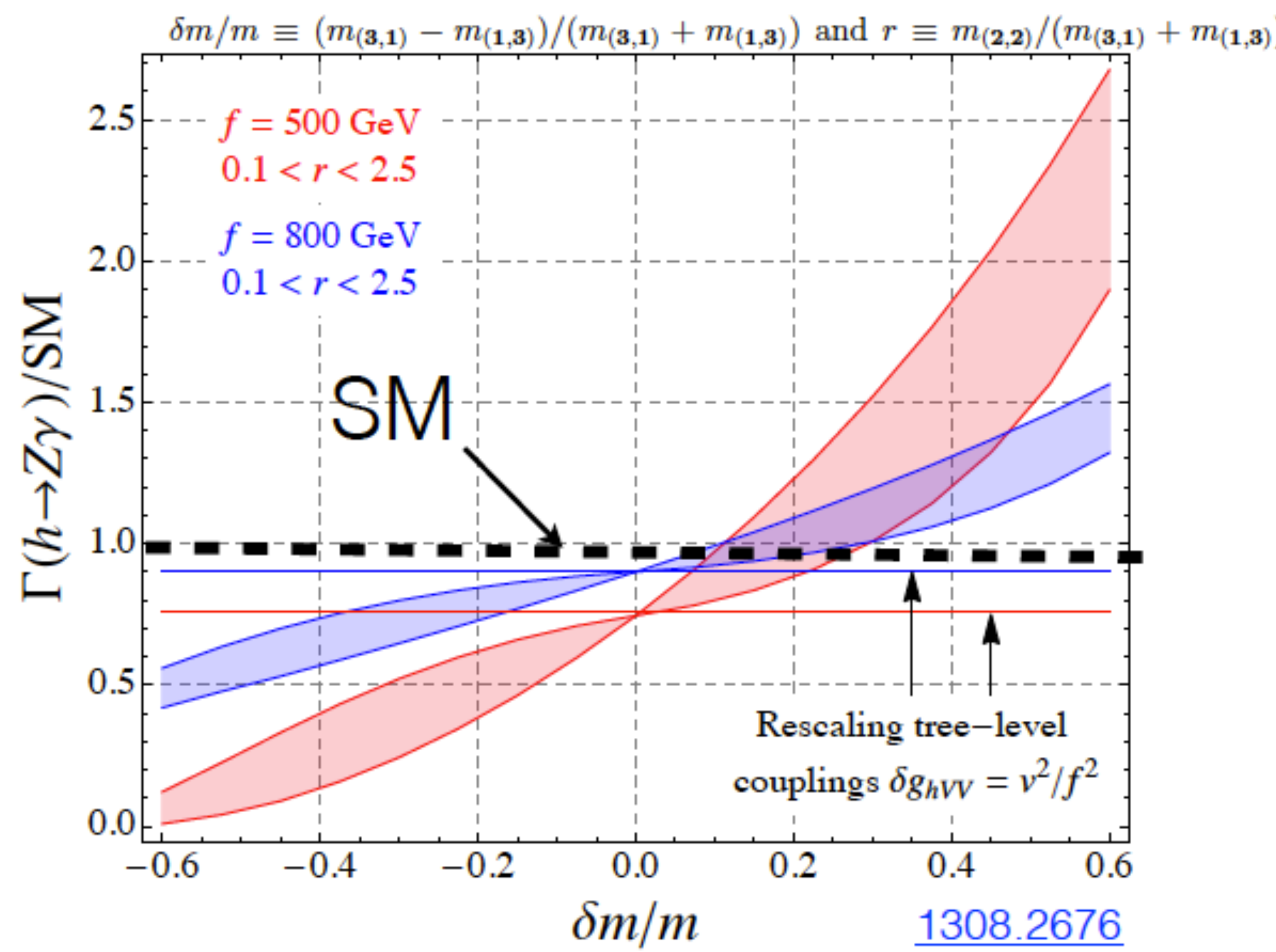
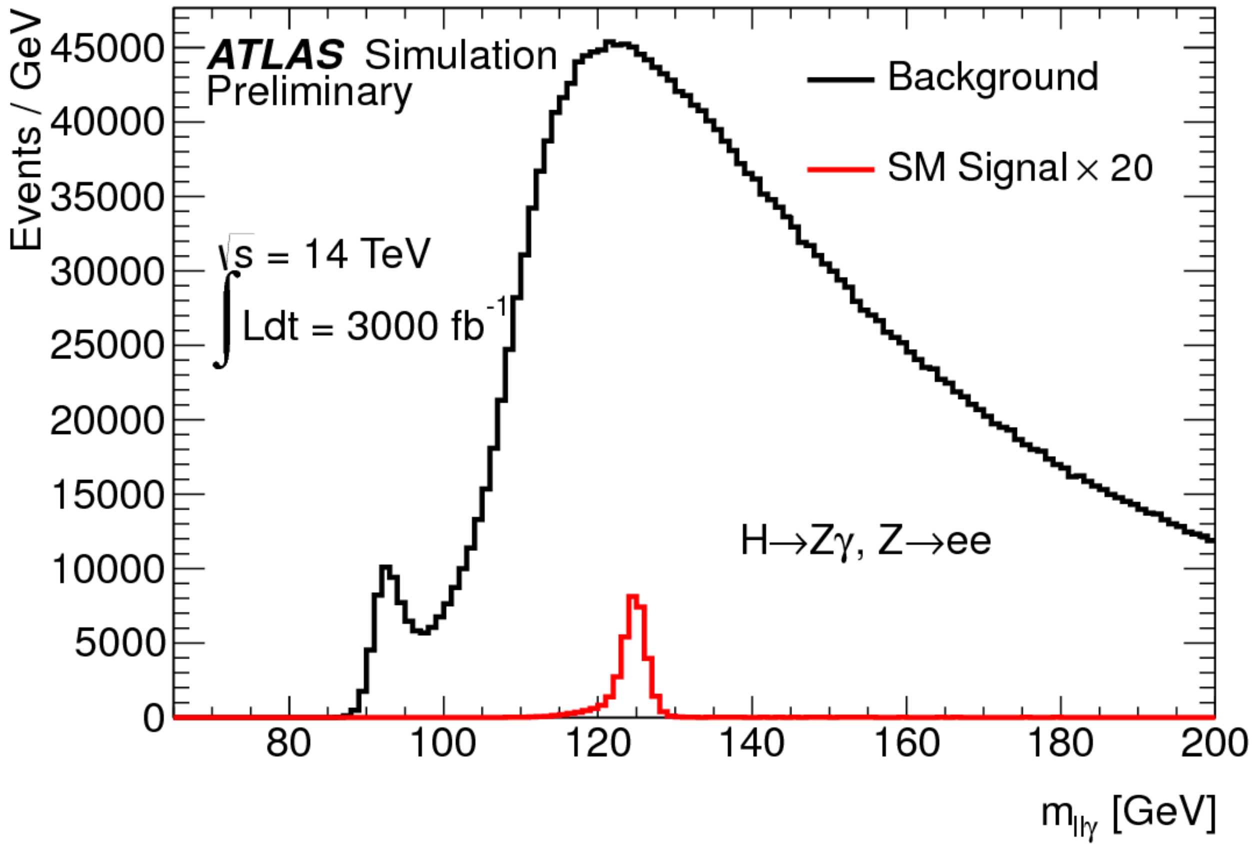


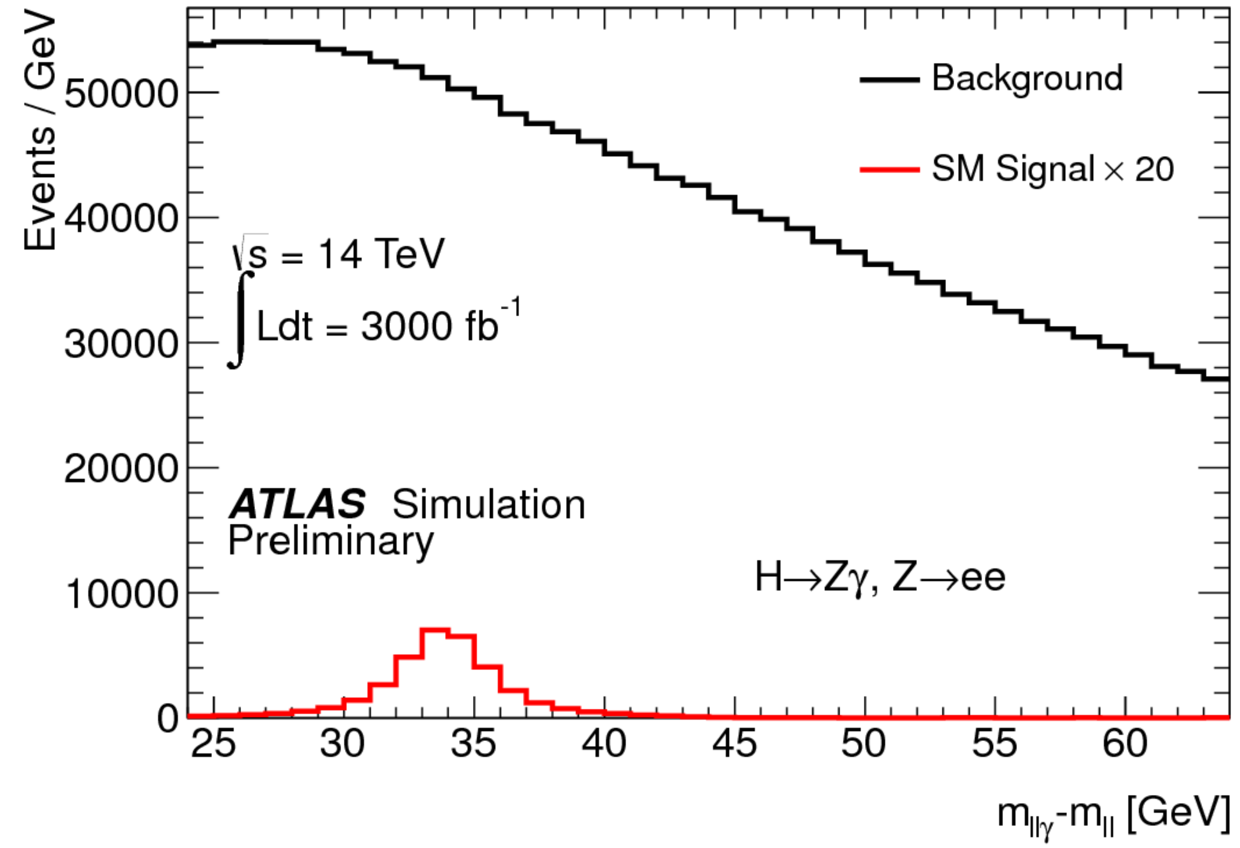


1308.2676

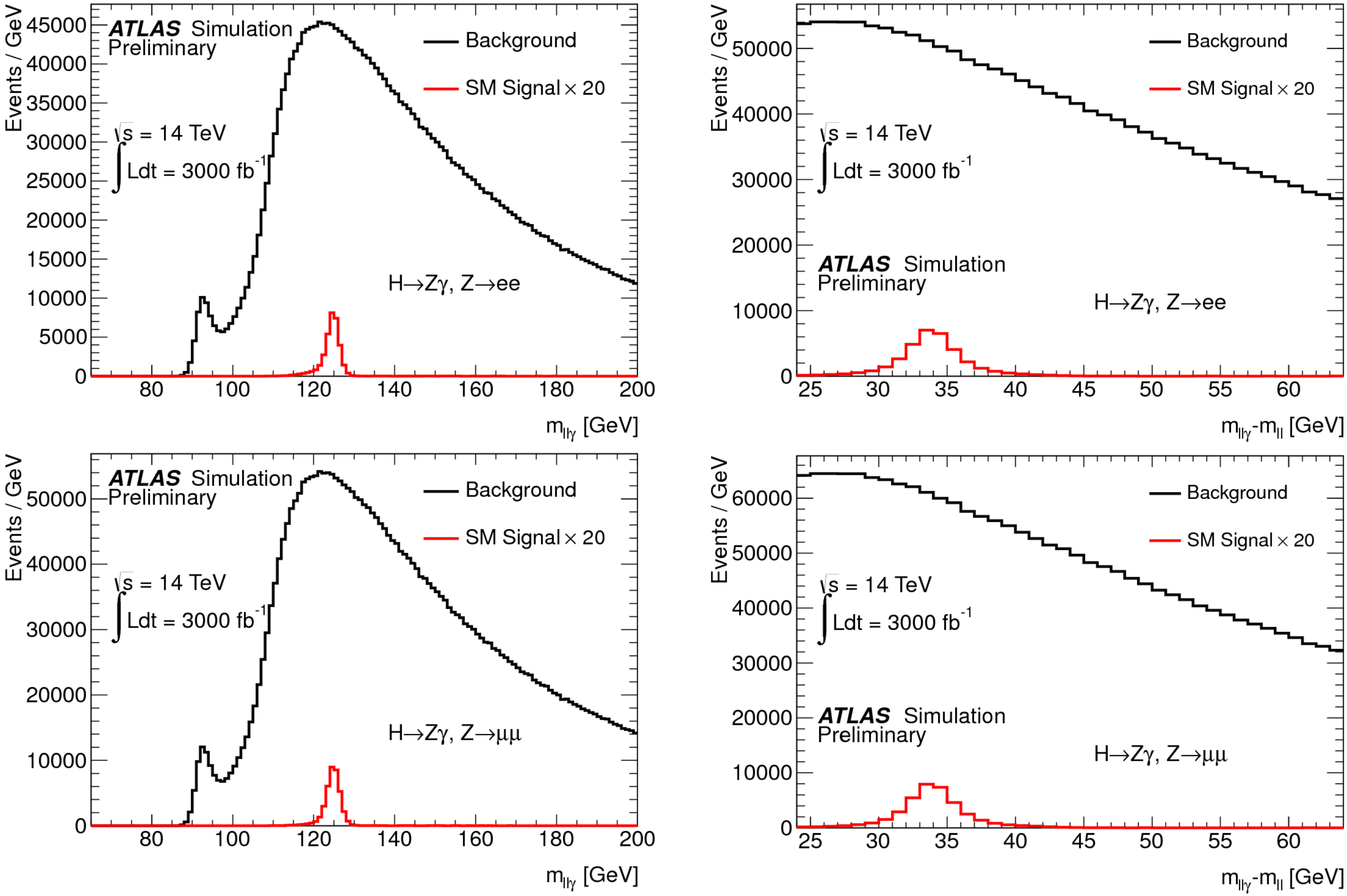
H→Zγ

H→Zγ


ATLAS Simulation
Preliminary
Events / GeV
Background
SM Signal × 20
√s = 14 TeV
∫Ldt = 3000 fb-1
H→Zγ, Z→ee
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
80
100
120
140
160
180
200
mllγ [GeV]


Events / GeV
Background
SM Signal × 20
√s = 14 TeV
∫Ldt = 3000 fb-1
ATLAS Simulation
Preliminary
H→Zγ, Z→ee
0
10000
20000
30000
40000
50000
25
30
35
40
45
50
55
60
mllγ-mll [GeV]

H→Zγ



ATLAS Simulation Preliminary
Background
SM Signal × 20
√s = 14 TeV
∫Ldt = 3000 fb⁻¹
H→Zγ, Z→ee
H→Zγ, Z→μμ
Events / GeV
$m_{ll\gamma}$ [GeV]
$m_{ll\gamma}$-m_{ll} [GeV]

H→cc

H→cc

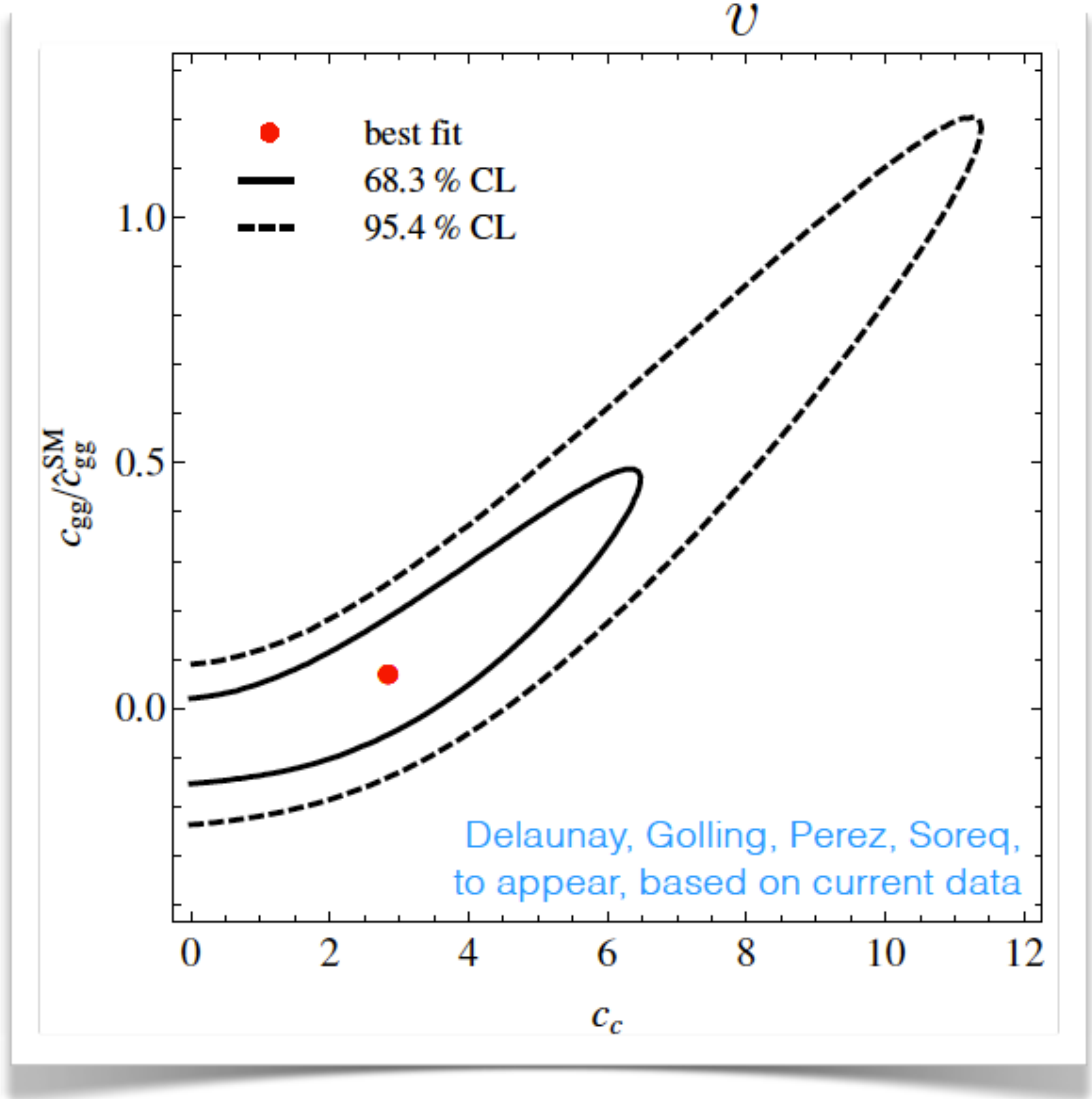
- Hcc coupling can still be 4-8 x SM

$$\mathcal{L} = c_c\, h\, \frac{m_c}{v} \bar{c}c + \ldots$$

- In composite Higgs

$$c_c \simeq 1 + \mathcal{O}\left(\frac{v^2}{f^2}\right) + \mathcal{O}\left(\epsilon_c^2 \frac{g_\psi^2 v^2}{m_\psi^2}\right)$$

large for composite charm and light charm partners



G. Salam, A. Weiler

H→cc

- Hcc coupling can still be 4-8 x SM

$$\mathcal{L} = c_c\, h\, \frac{m_c}{v} \bar{c}c + \ldots$$

- In composite Higgs

$$c_c \simeq 1 + \mathcal{O}\left(\frac{v^2}{f^2}\right) + \mathcal{O}\left(\epsilon_c^2 \frac{g_\psi^2 v^2}{m_\psi^2}\right)$$

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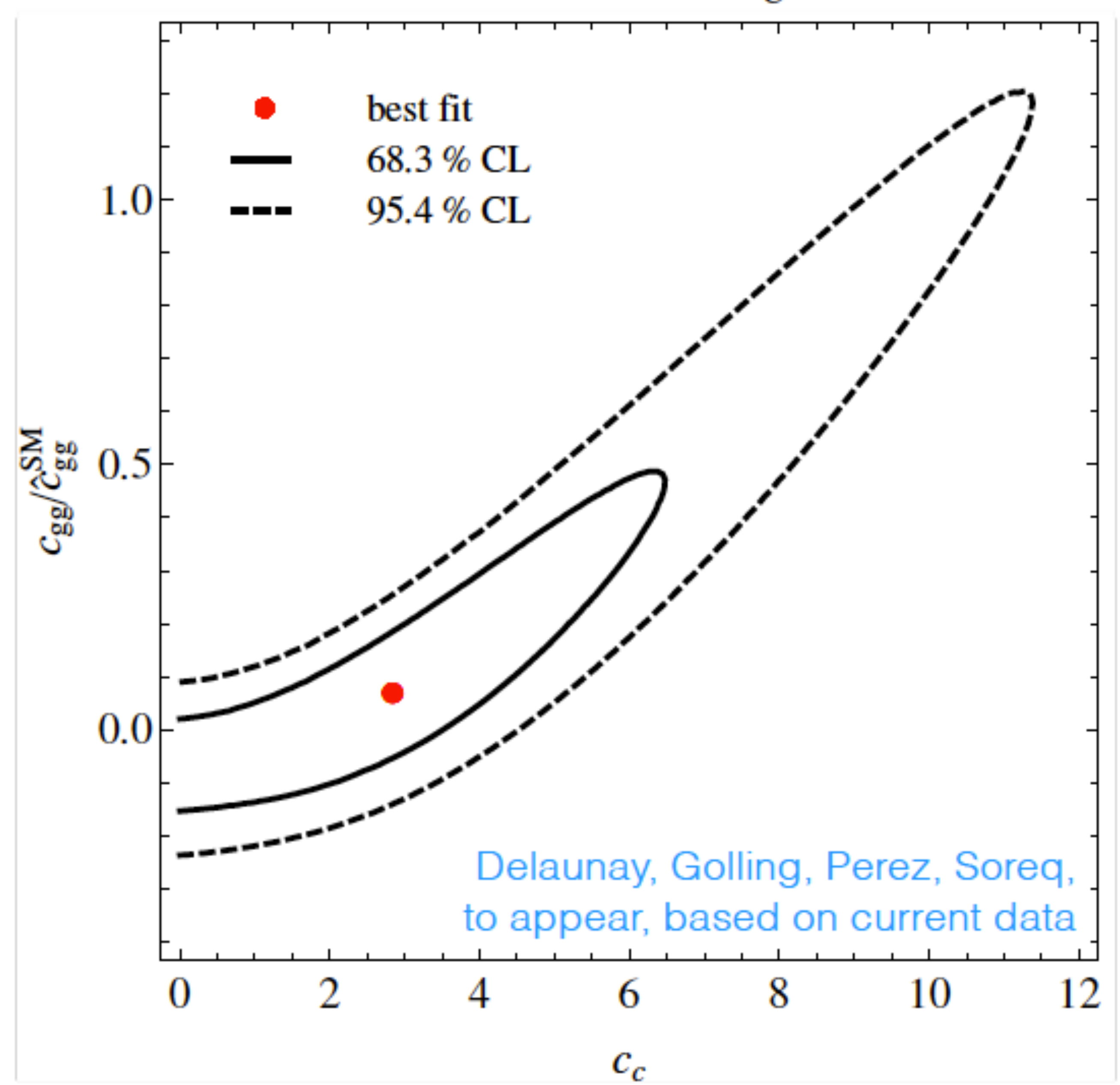


Measuring it?

Like H→bb, but with charm tagging?

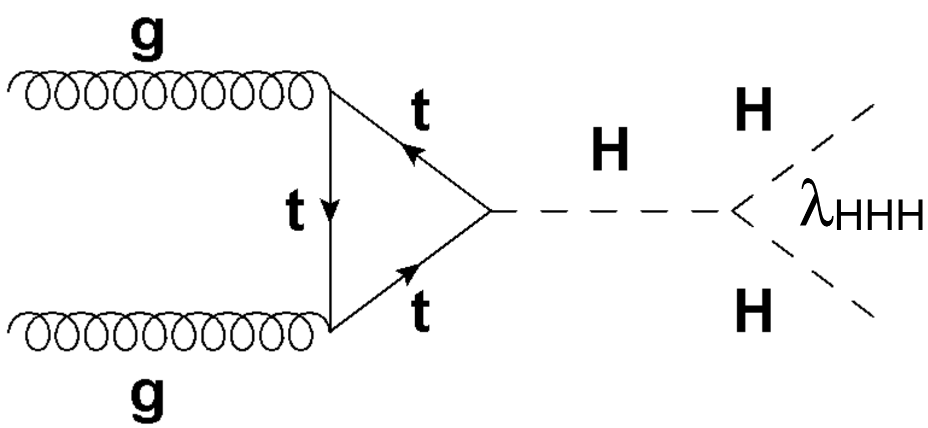
Or via H→ J/ψ γ ? 1306.5770

G. Salam, A. Weiler

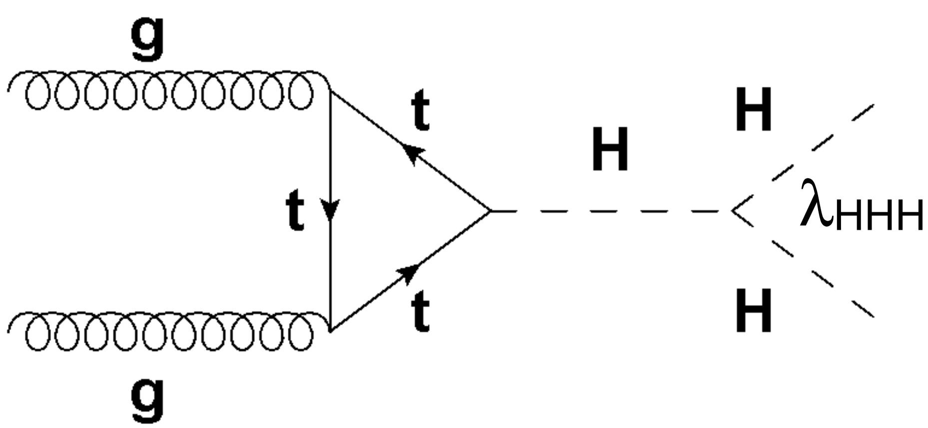
Higgs pair-production

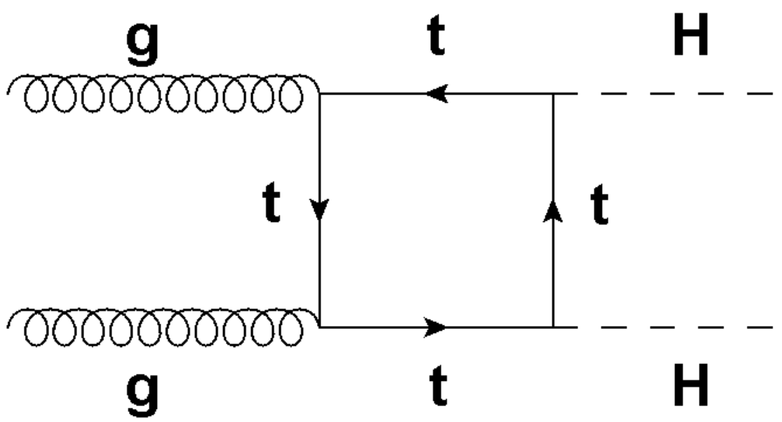
Higgs boson pair-production

Higgs boson pair-production



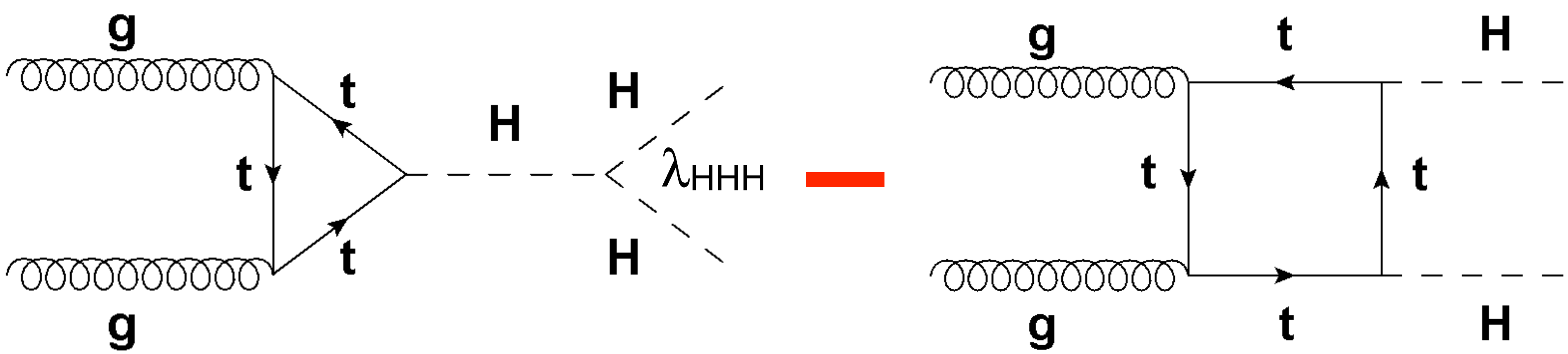
Higgs boson pair-production





Higgs boson pair-production

Destructive interference between the two diagrams



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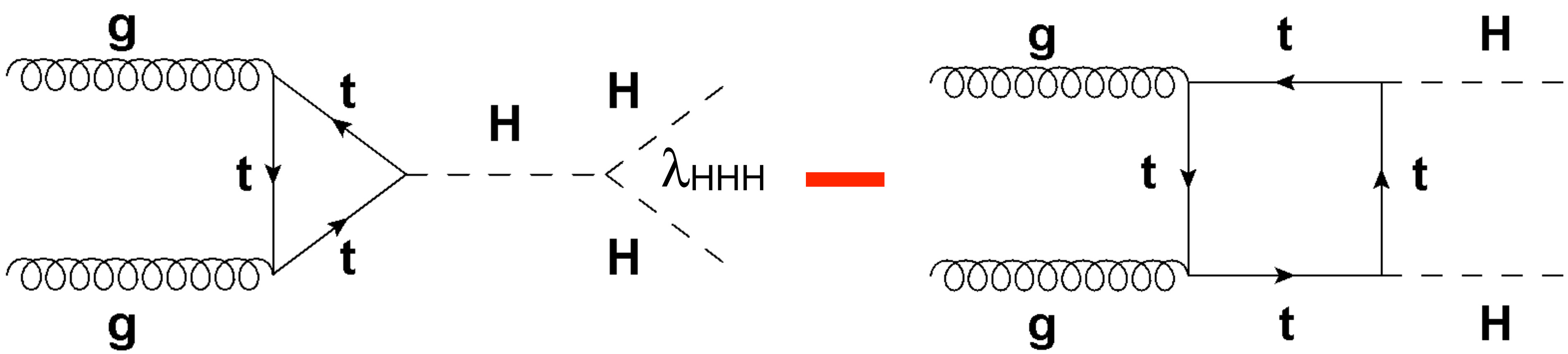
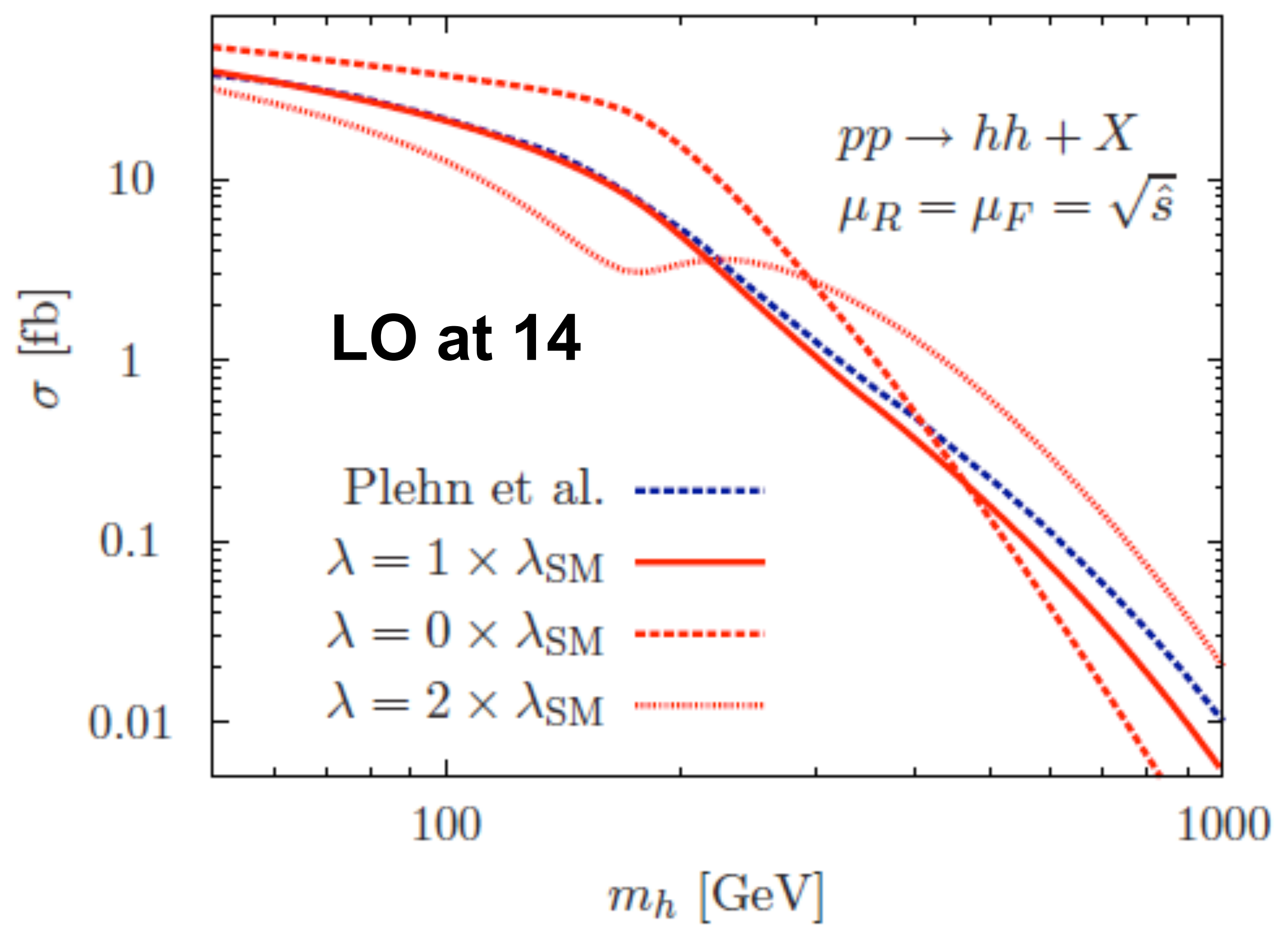


Taken from **"Higgs self-coupling measurements at the LHC"** by M. J. Dolan, C. Englert and M. Spannowsky, JHEP 10 (2012 112.



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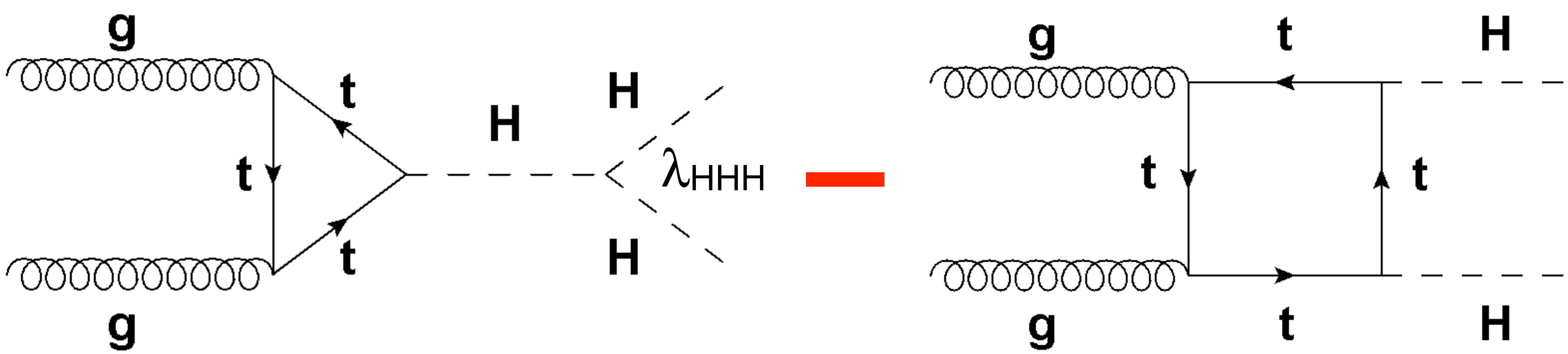

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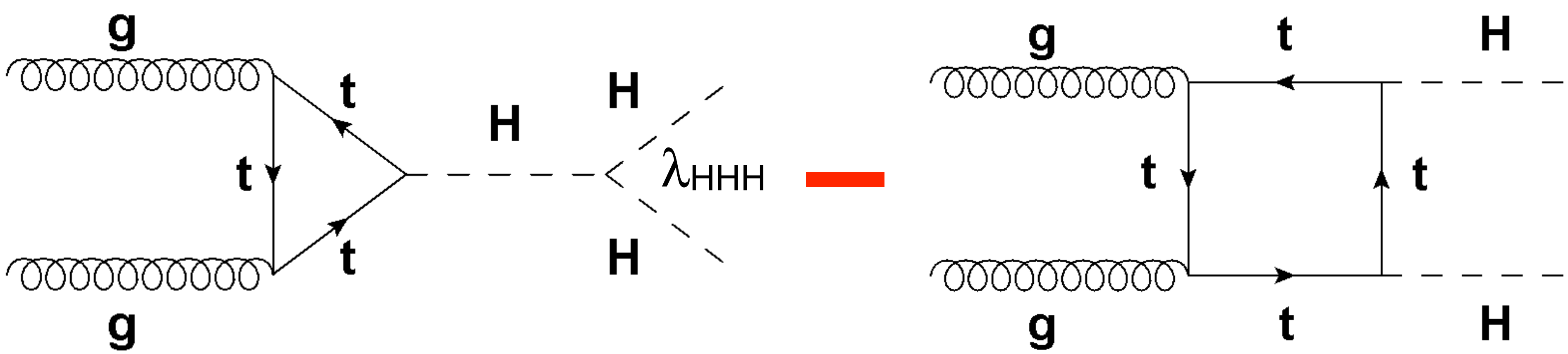

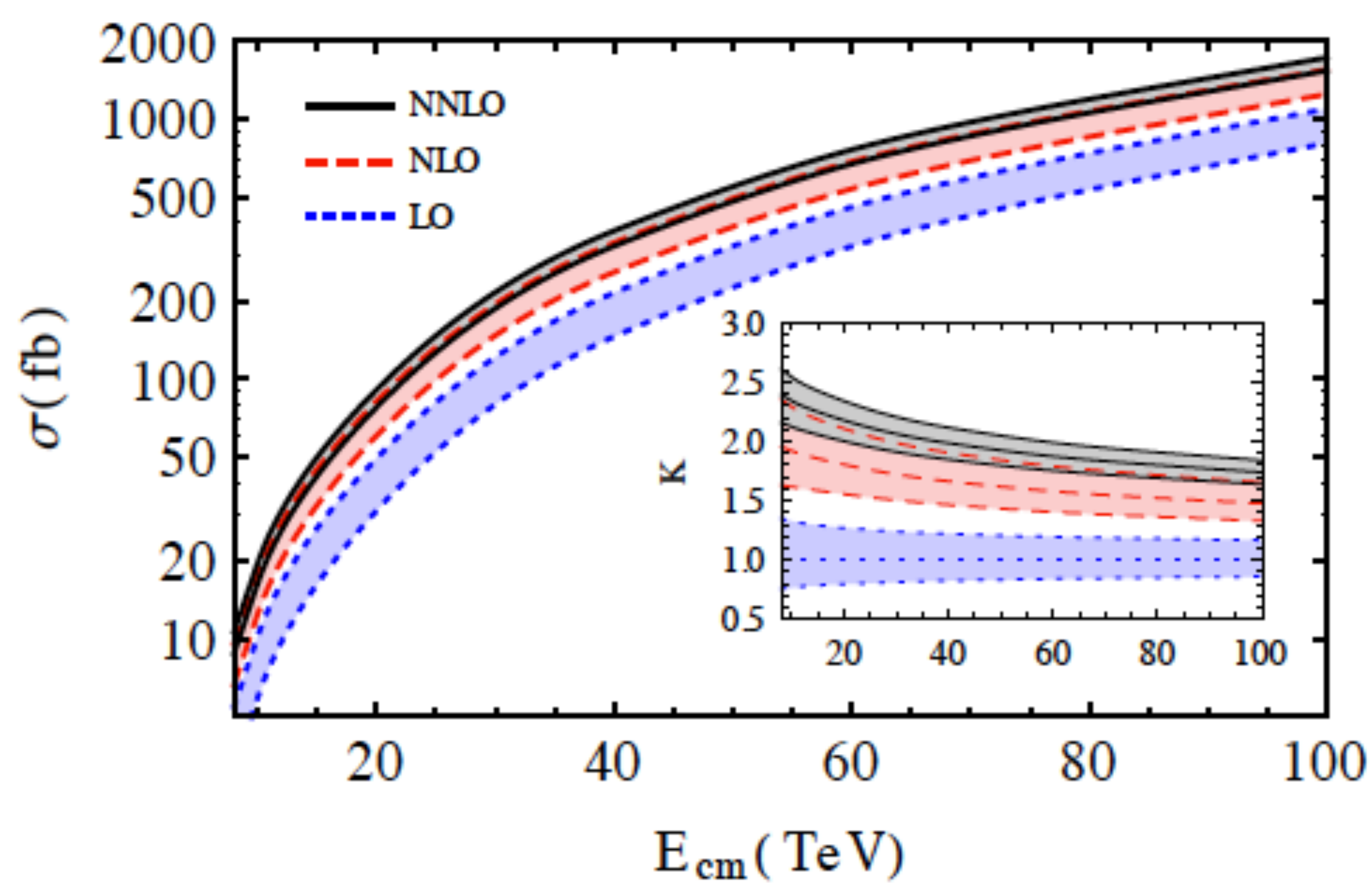

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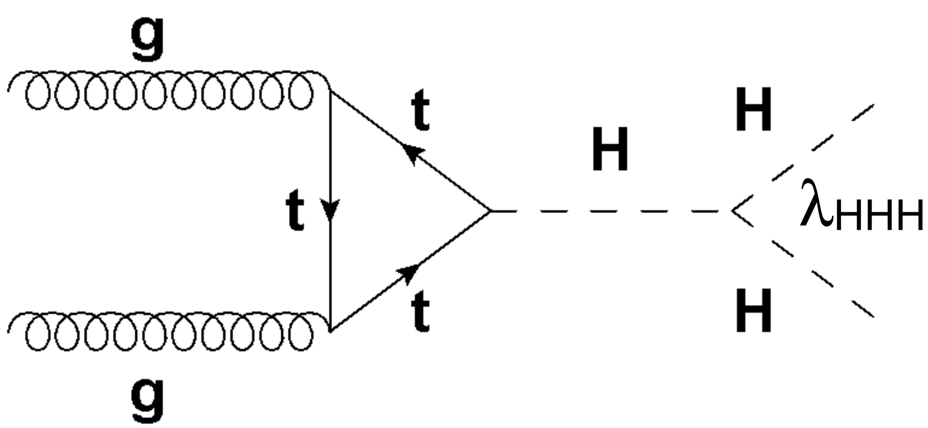
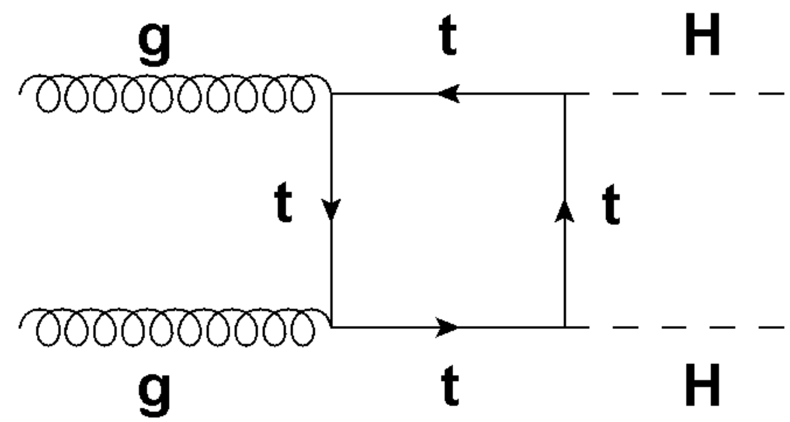
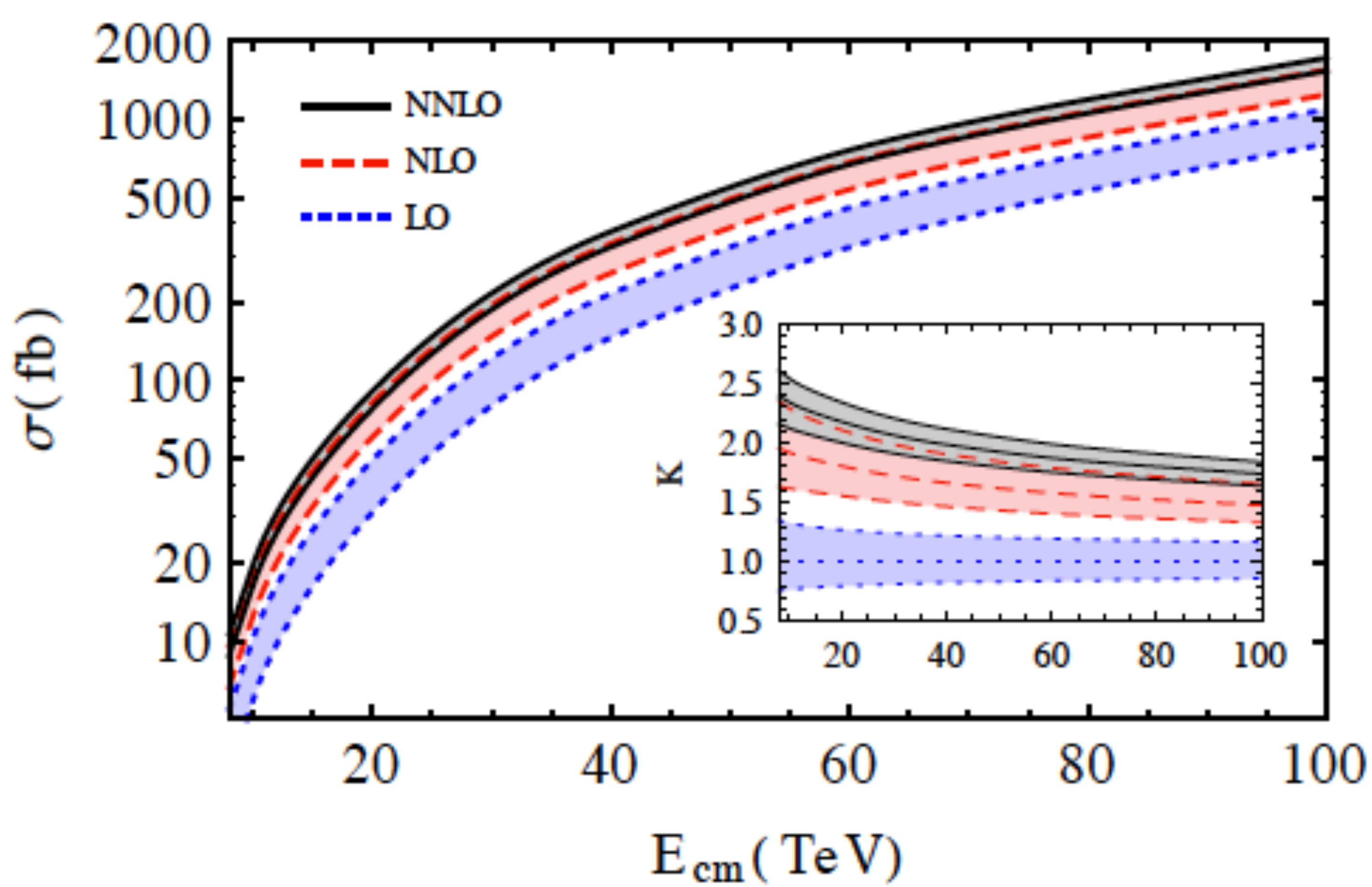






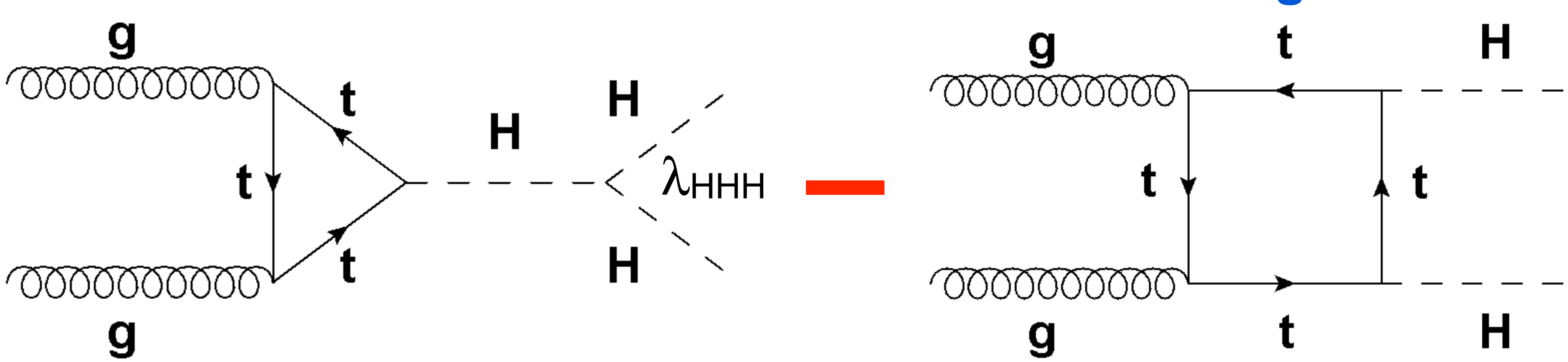
NNLO cross-section at m_H=125 GeV:

σ = 40 ± 3 fb

G. de Florian, J. Mazzitelli, 1309.6594

Higgs boson pair-production

Destructive interference between the two diagrams



Many channels to investigate. Most promising ones:

$b\bar{b}W^+W^-$ (large BR but large bkg.)

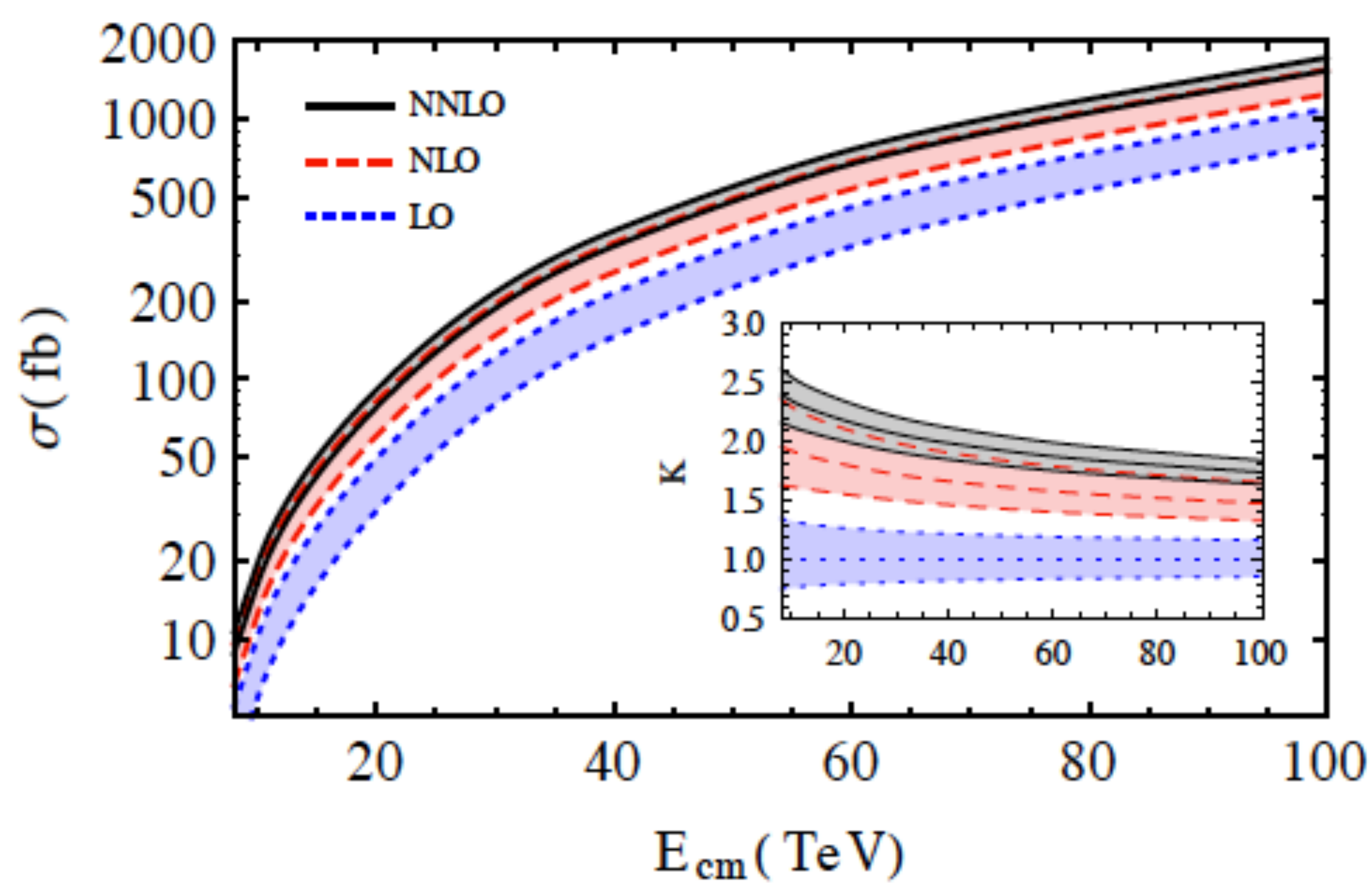
$b\bar{b}\gamma\gamma$ (clean but small BR)

$b\bar{b}\tau^+\tau^-$

$b\bar{b}\mu^+\mu^-$ also being considered

$b\bar{b}b\bar{b}$

$b\bar{b}2l2\nu$



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di-Higgs production

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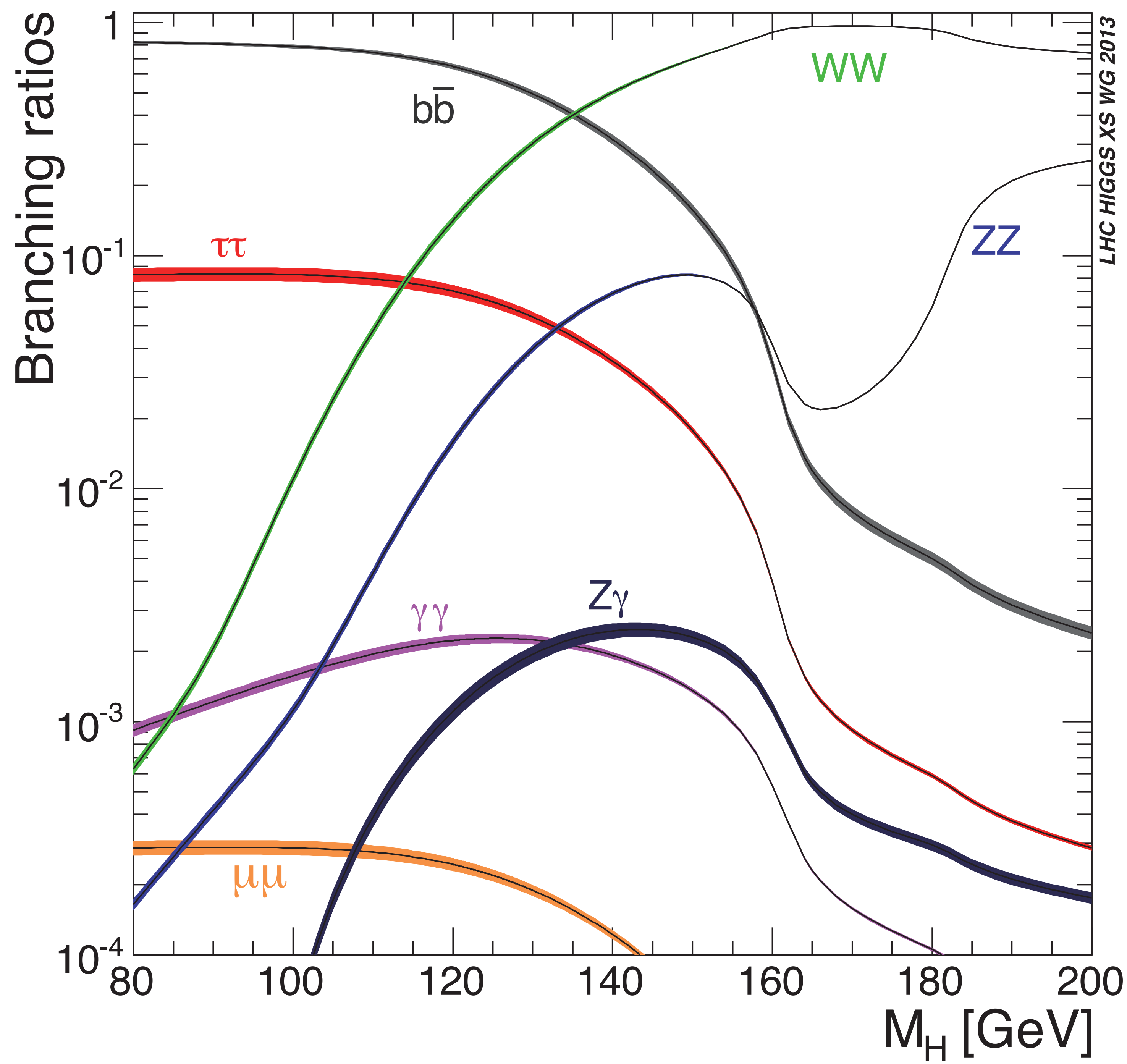

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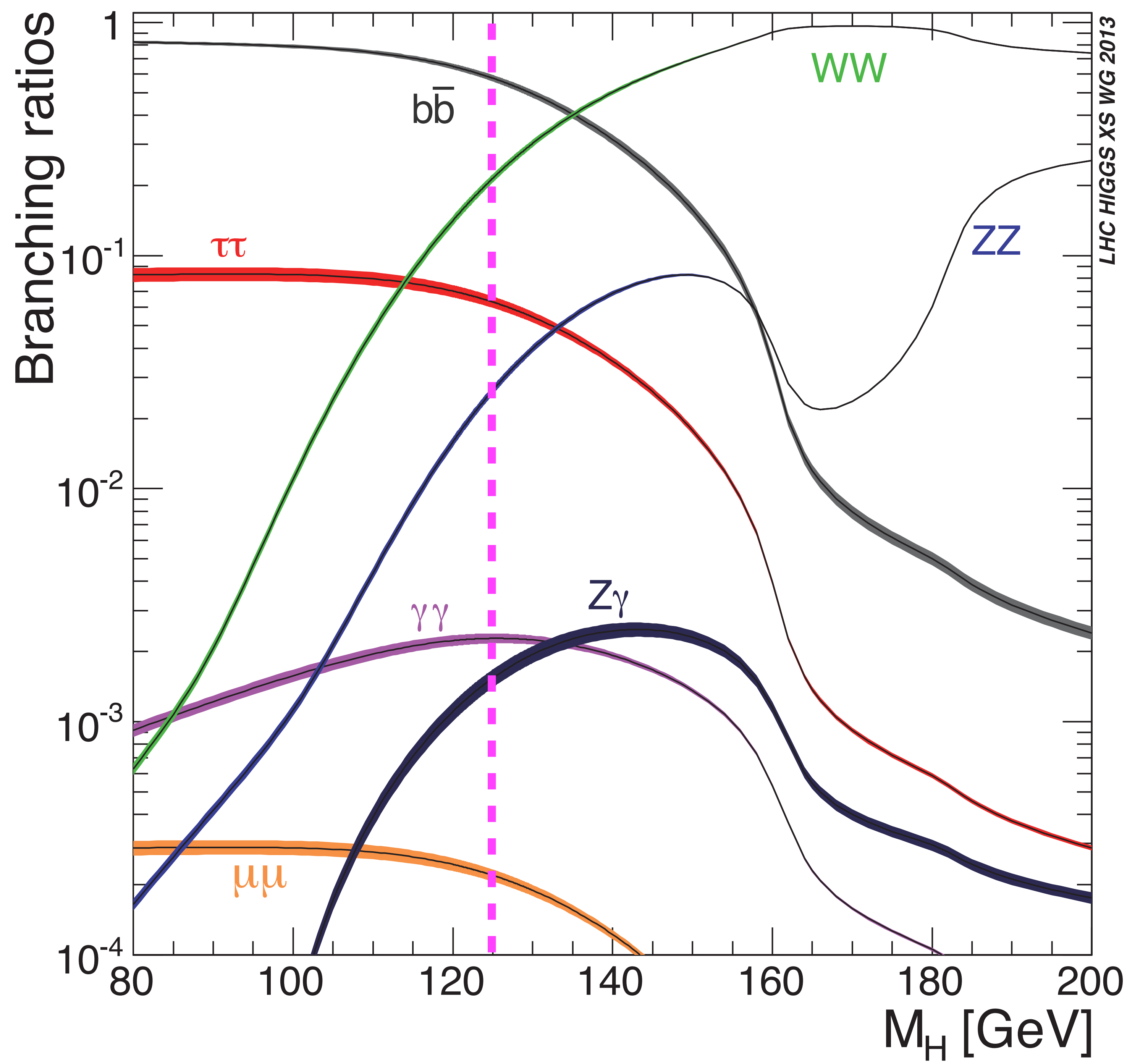

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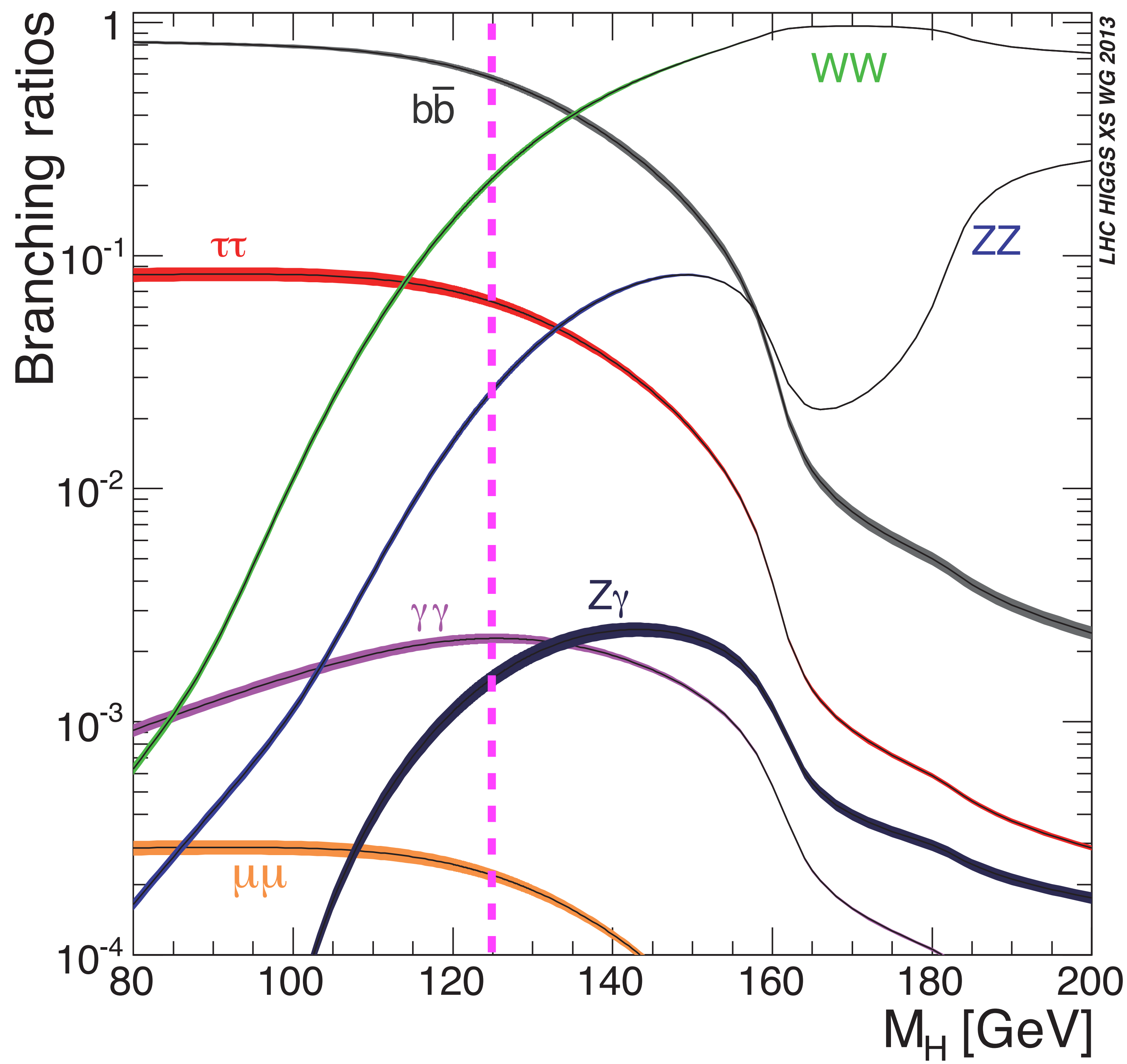

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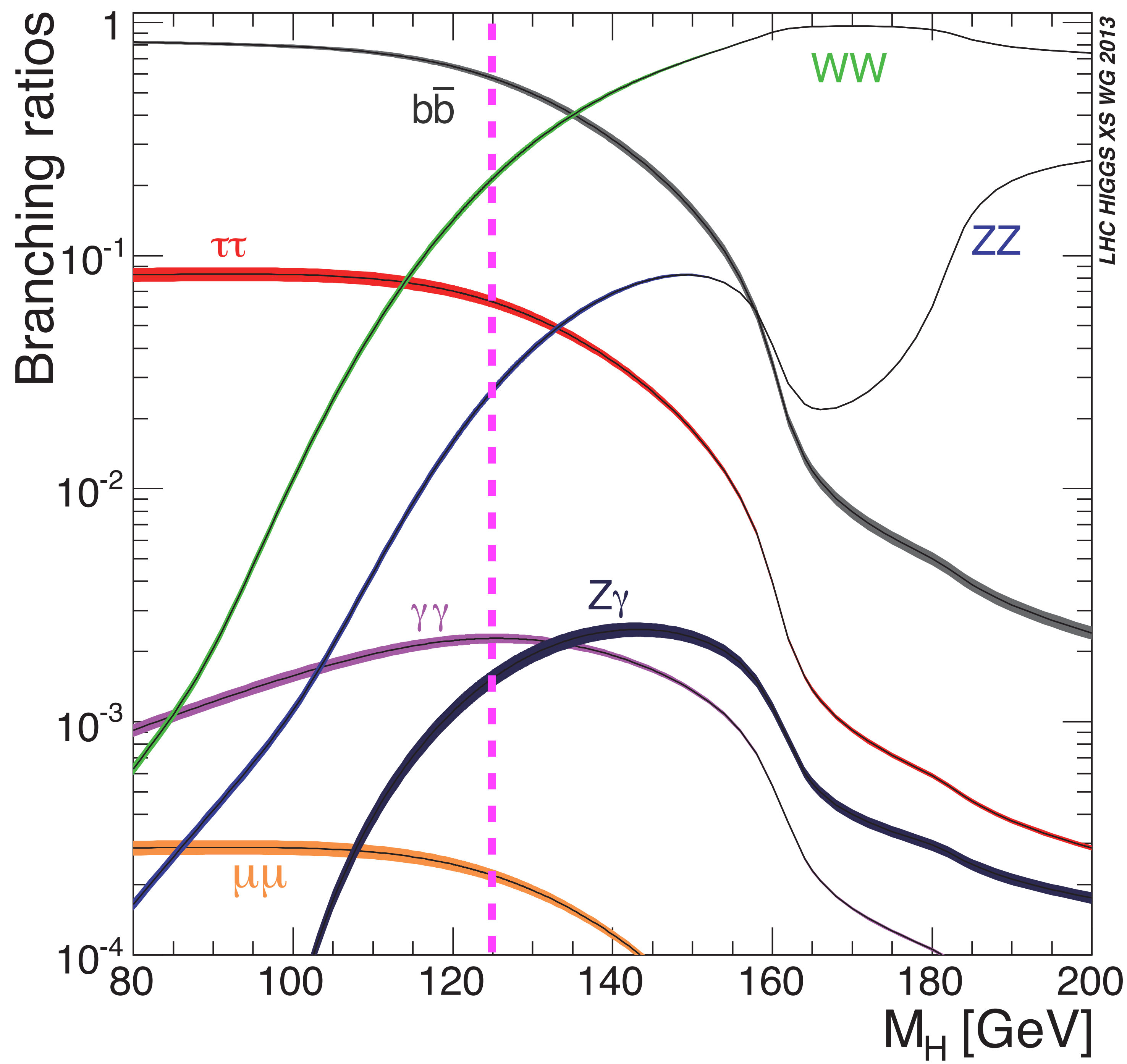
$b\bar{b}W^+W^-$ ~30000 events

$b\bar{b}\gamma\gamma$ ~ 320 events



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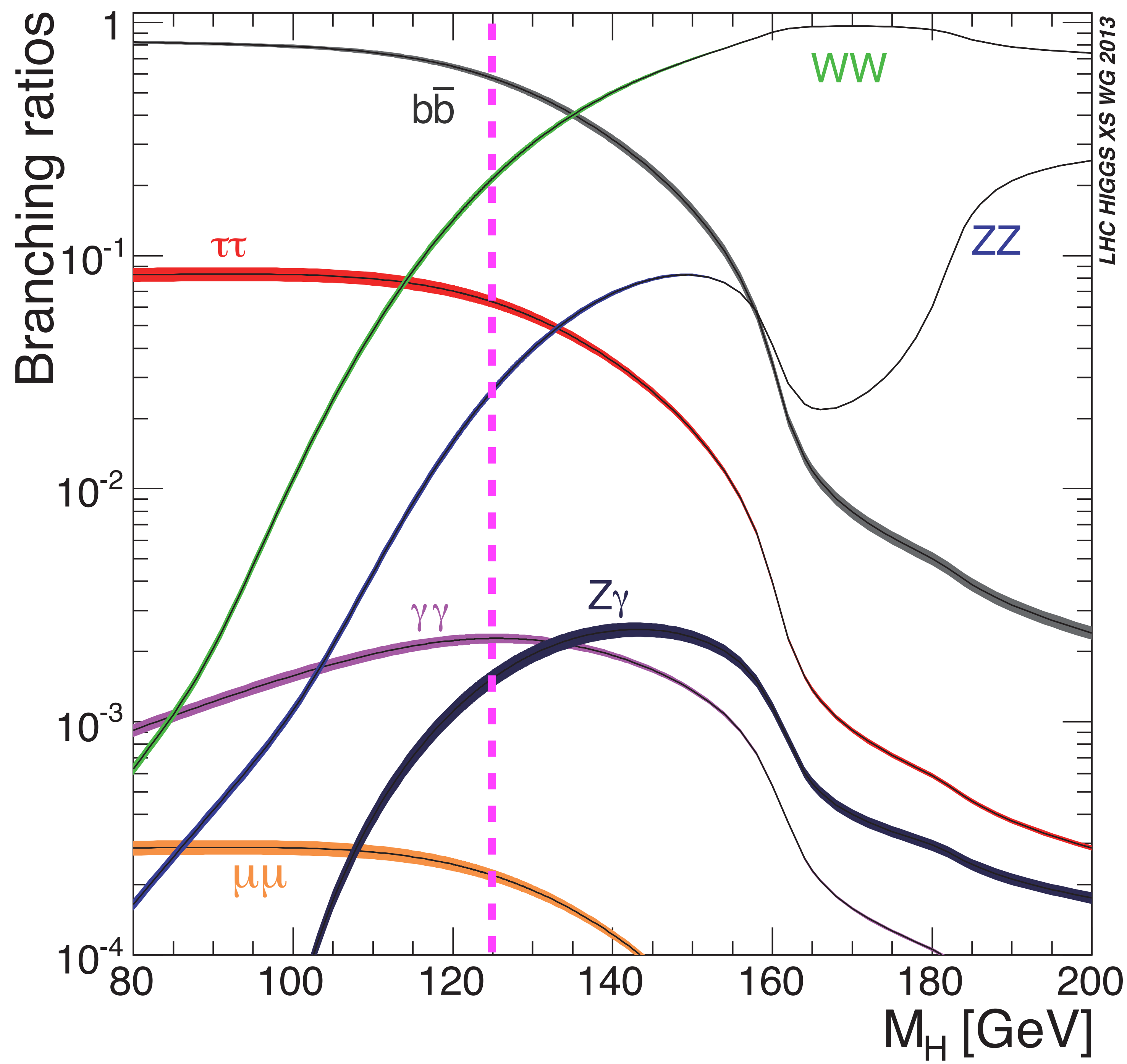

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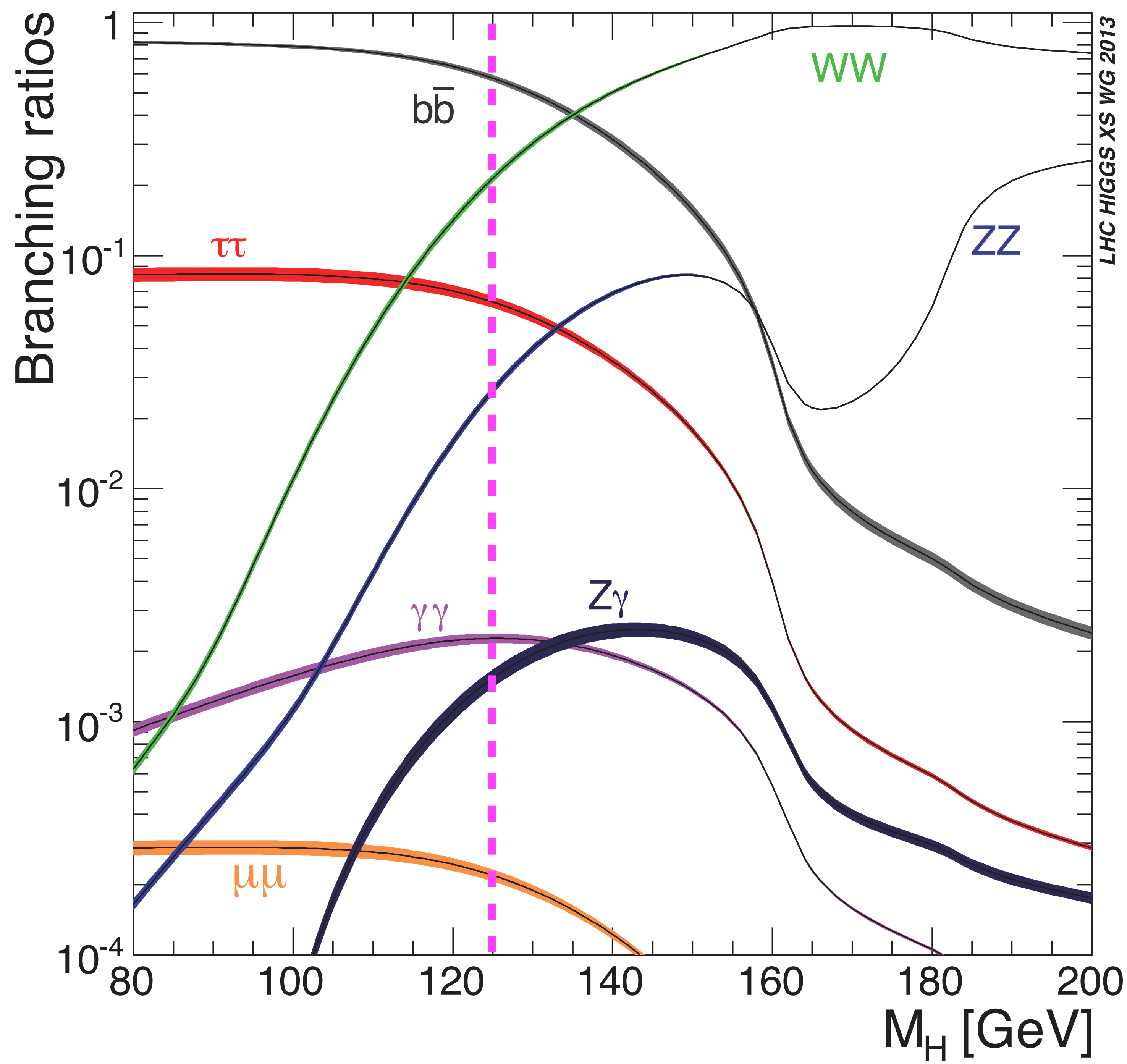

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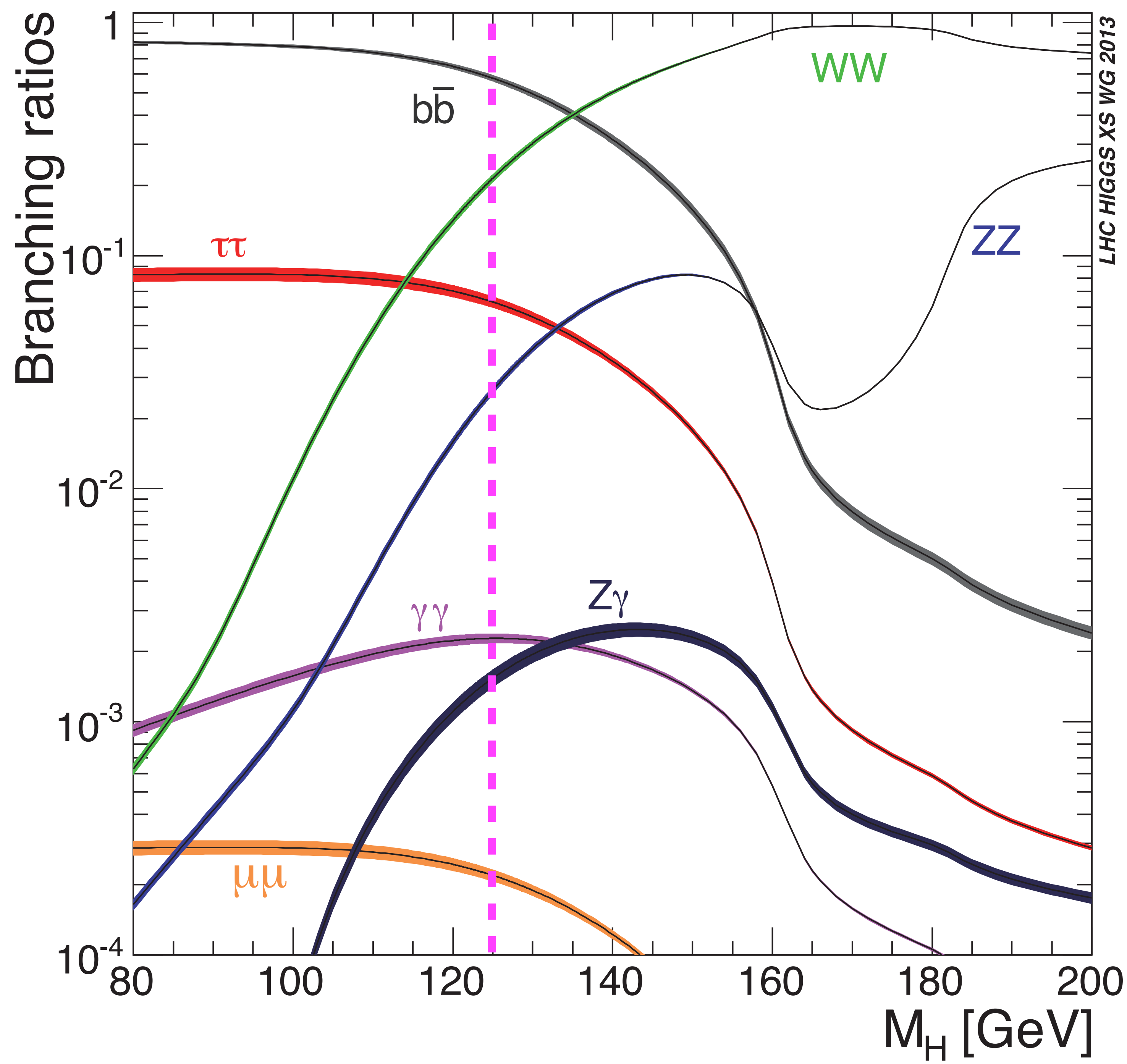
New preliminary results from ATLAS and CMS on

$b\bar{b}\gamma\gamma$

$b\bar{b}W^+W^-$



di-Higgs production

- Nominal performance for Phase II scenario and 3000fb^{-1}
- CMS:
  - Parameterized object performance tuned to CMS Phase II detector at <PU>=140
  - 2D fit of M_{bb} and $M_{\gamma\gamma}$ distributions
- ATLAS:
  - Parameterized object performance obtained from full simulation
  - Cut based analysis
  - Electron to photon misidentification probability of 2% (5%) in barrel (endcap) is assumed
  - ATL-PHYS-PUB-2014-019

A. Apyam - 2014 ECFA HL-LHC workshop

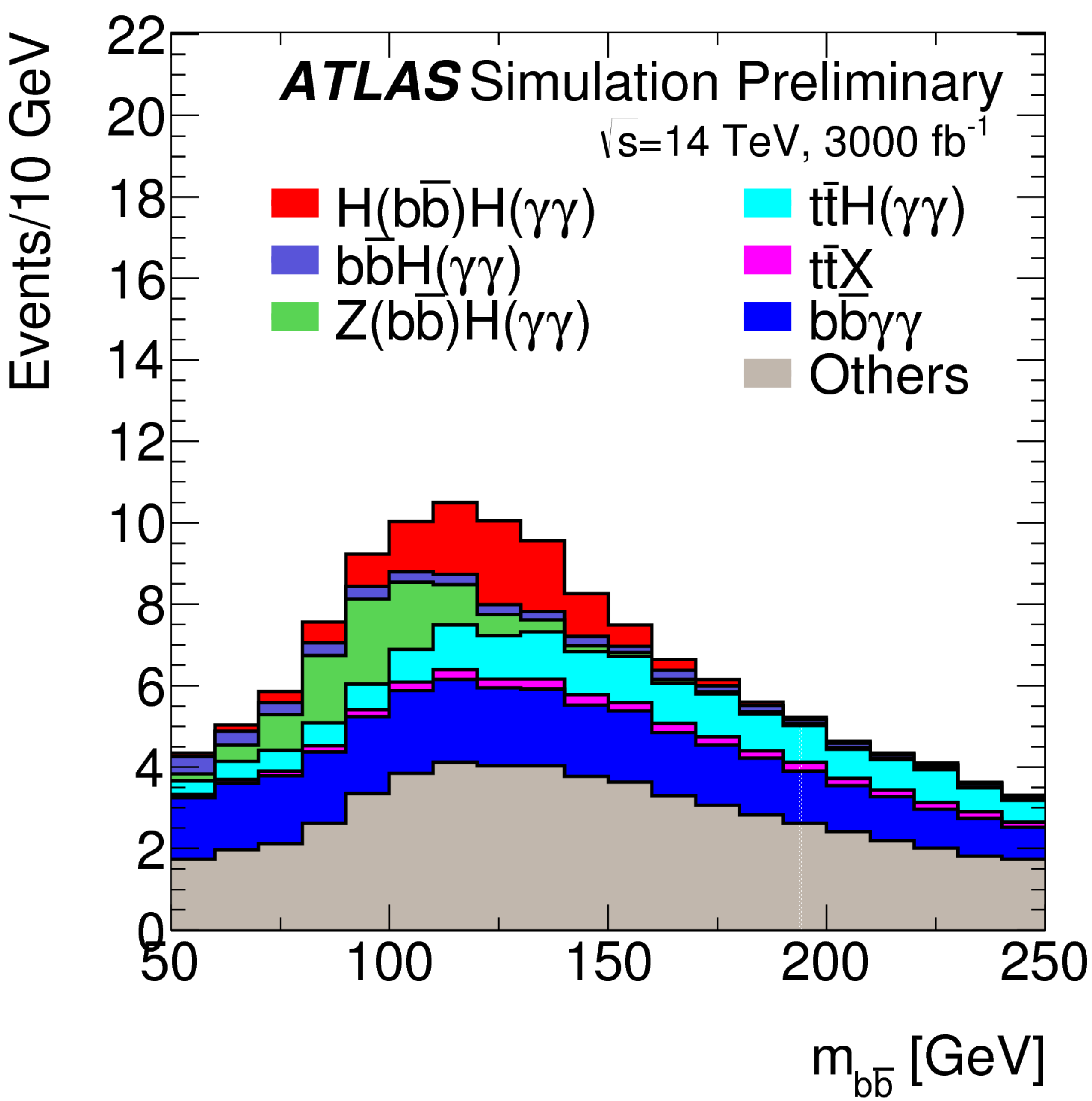
di-Higgs production

di-Higgs production

$HH \rightarrow b\bar{b}\gamma\gamma$

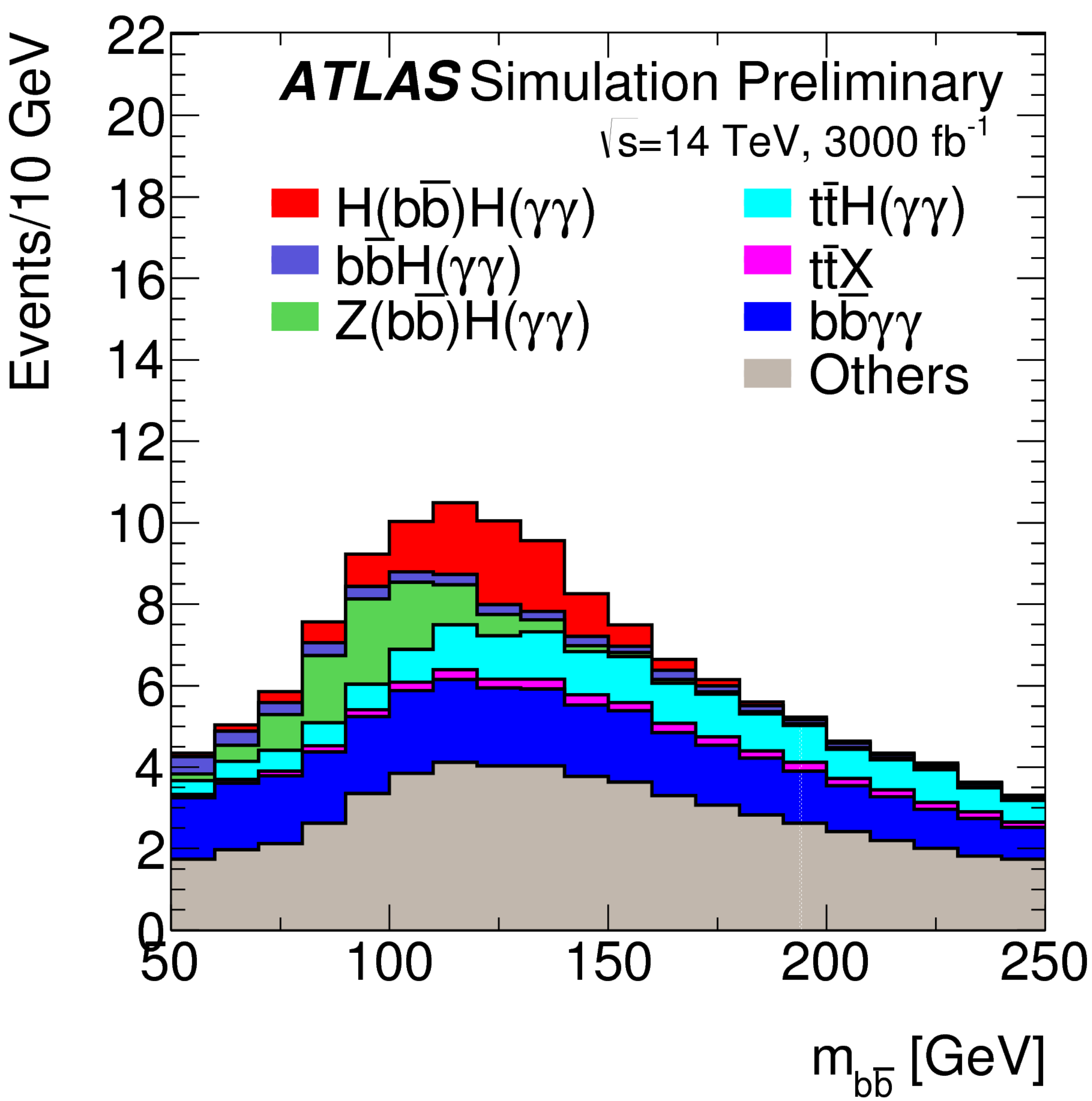
di-Higgs production

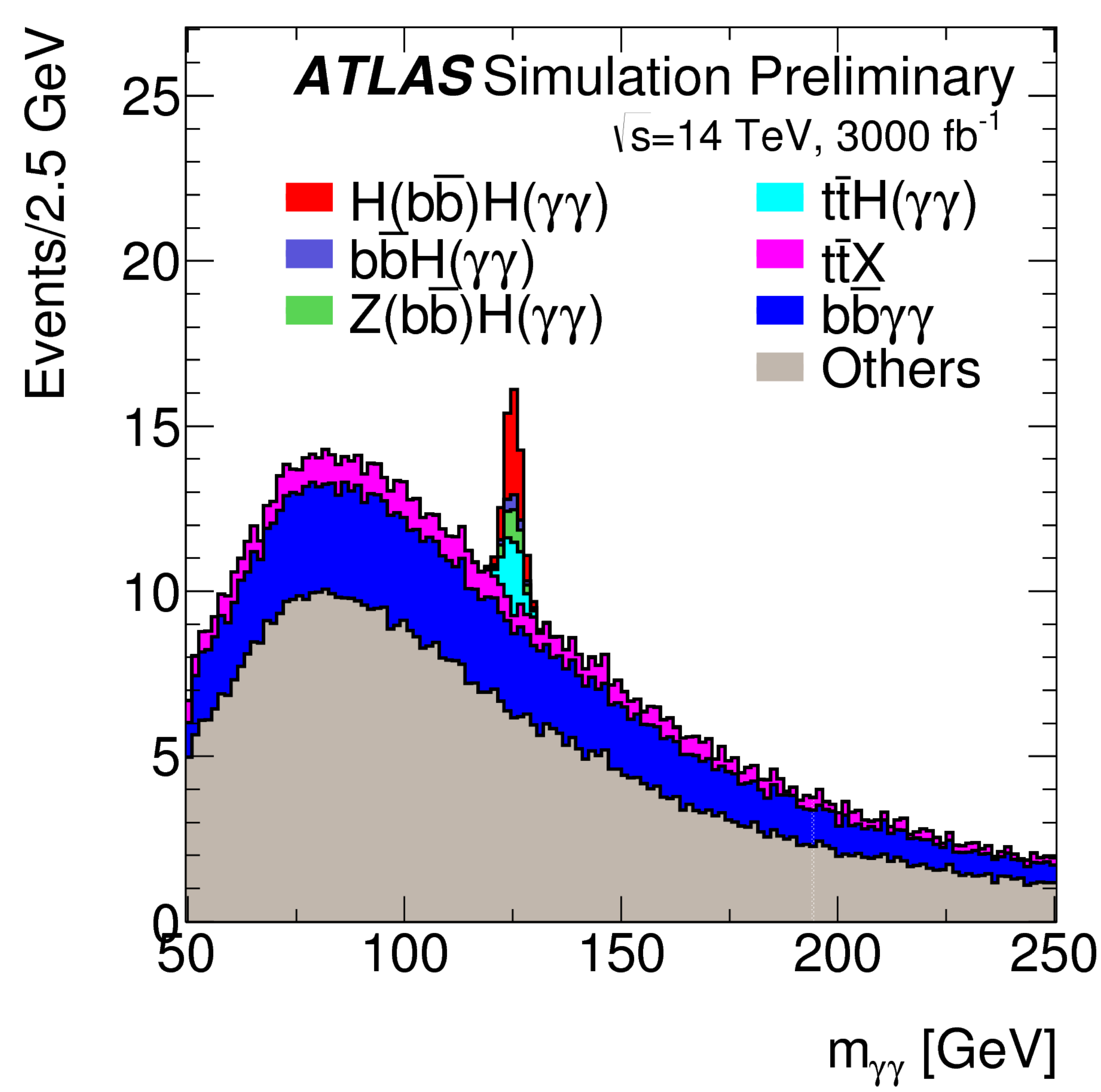
HH→bb̄γγ



di-Higgs production

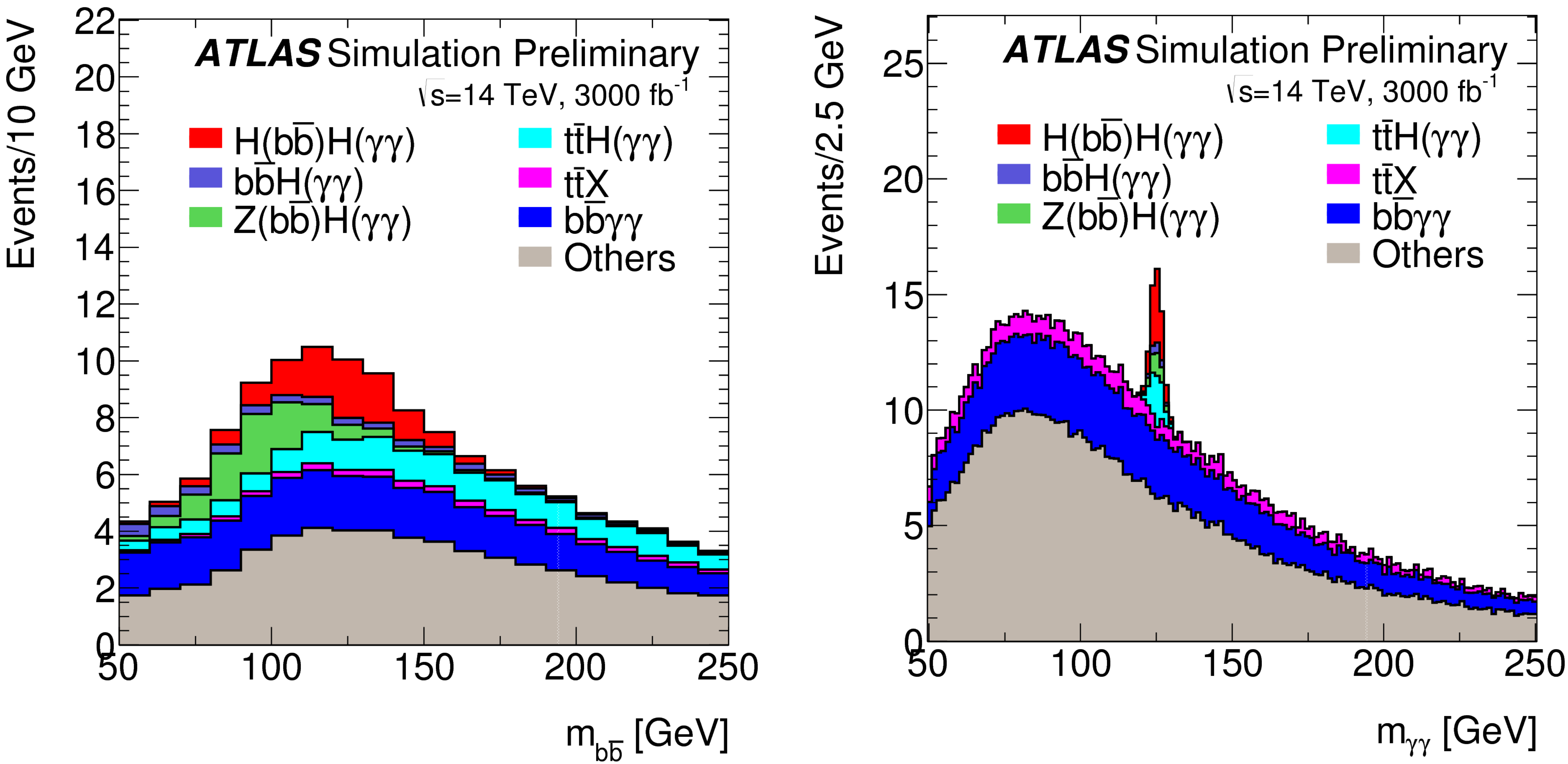
HH→b$\bar{b}$γγ





di-Higgs production

HH→bb̄γγ



Preliminary results with $L=3000\ fb^{-1}$

di-Higgs production

process	Expected events in 3000 fb^{-1}
SM $HH \rightarrow bb\gamma\gamma$	8.4± 0.1
$bb\gamma\gamma$	9.7 ± 1.5
$cc\gamma\gamma$, $bb\gamma j$, $bbjj$, $jj\gamma\gamma$	24.1 ± 2.2
top background	3.4 ± 2.2
$ttH(\gamma\gamma)$	6.1 ± 0.5
$Z(bb)H(\gamma\gamma)$	2.7 ± 0.1
$bbH(\gamma\gamma)$	1.2 ± 0.1
Total background	47.1 ± 3.5
$S/\sqrt{B}$ (barrel+endcap)	1.2
$S/\sqrt{B}$ (split barrel and endcap)	1.3

di-Higgs production

HH→$b\bar{b}\gamma\gamma$

process	Expected events in 3000 fb^{-1}
SM HH→bbγγ	8.4± 0.1
bbγγ	9.7 ± 1.5
ccγγ, bbγj, bbjj, jjγγ	24.1 ± 2.2
top background	3.4 ± 2.2
ttH(γγ)	6.1 ± 0.5
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di-Higgs production

ATLAS

HH→b$\bar{b}$γγ

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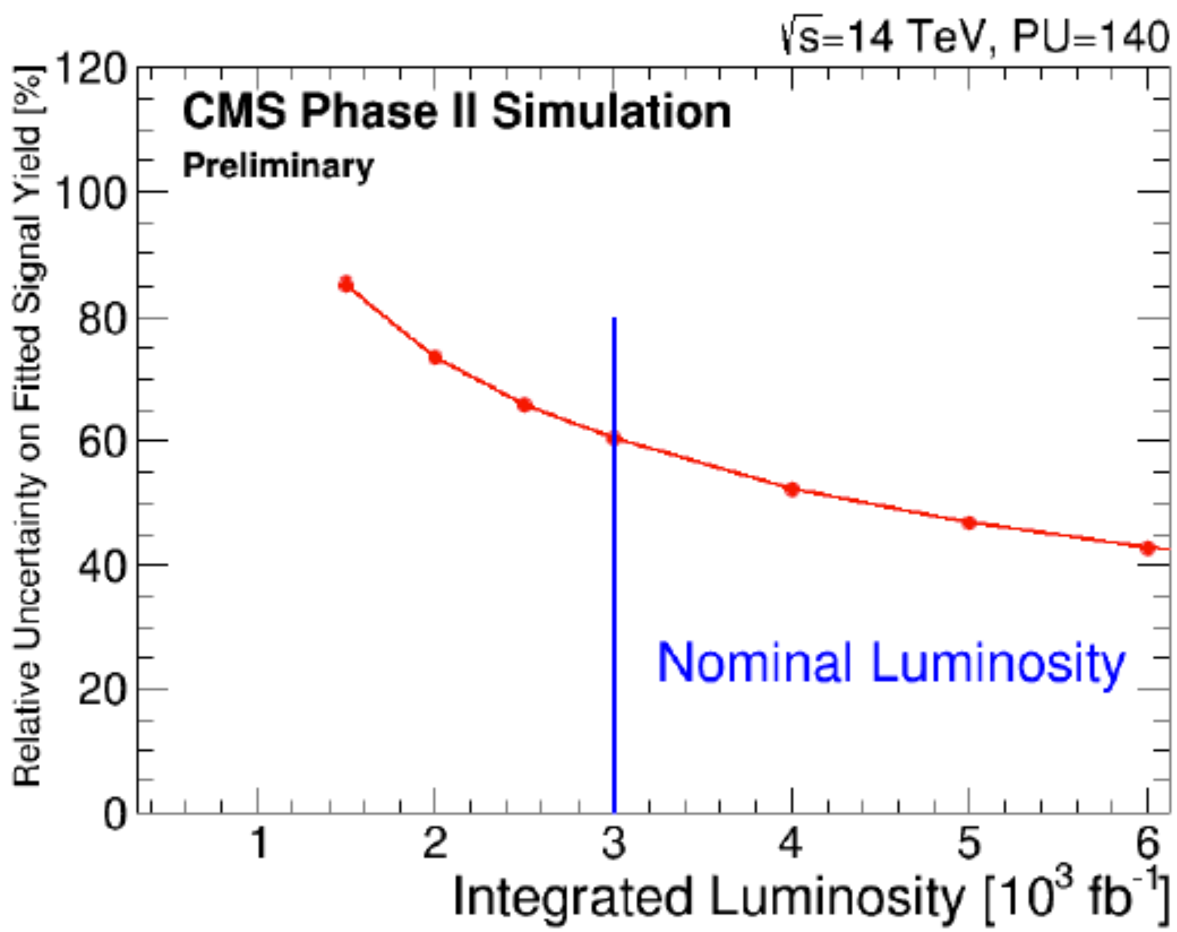
di-Higgs production

Process / Selection Stage	HH	ZH	$t\bar{t}H$	$b\bar{b}H$	$\gamma\gamma$+jets	γ+jets	jets	$t\bar{t}$
Object Selection & Fit Mass Window	22.8	29.6	178	6.3	2891	1616	292	113
Kinematic Selection	14.6	14.6	3.3	2.0	128	96.9	20	20
Mass Windows	9.9	3.3	1.5	0.8	8.5	6.3	1.1	1.1

Table 3: The expected event yields of the signal and background processes for 3000 fb^{-1} of integrated luminosity are shown at various stages of the cut-based selection for the both photons in the barrel region. Mass window cuts are 120 GeV to 130 GeV for $M_{\gamma\gamma}$ and 105 GeV to 145 GeV for M_{bb}. A large fit mass window, 100 GeV to 150 GeV for $M_{\gamma\gamma}$ and 70 GeV to 200 GeV for M_{bb}, is used for the likelihood fit analysis. The statistical uncertainties on the yields are of the order



ATLAS and CMS are discussing the analyses to continue to better understand remaining differences and avenues for sensitivity improvement

di-Higgs production

$HH \to b\bar{b}\gamma\gamma$

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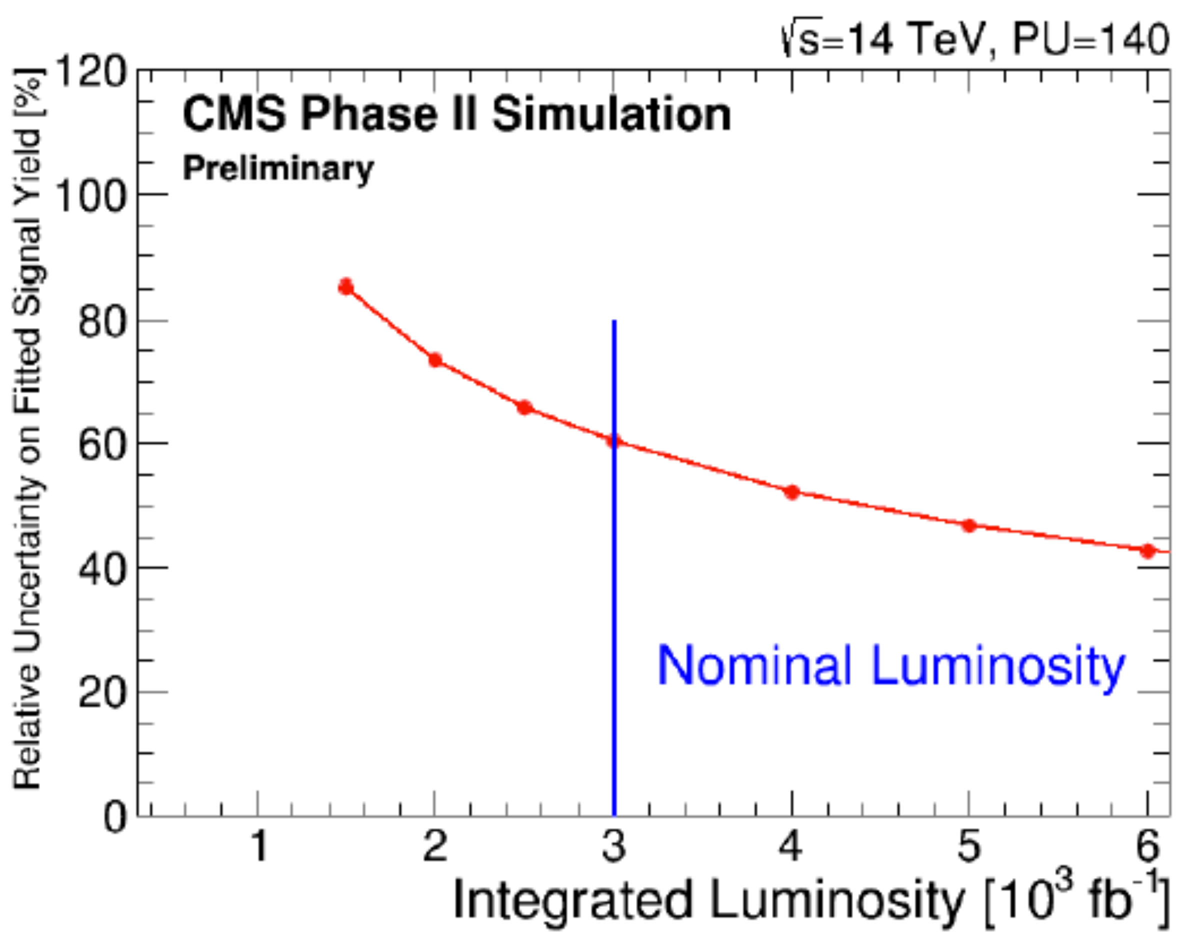

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di-Higgs production

CMS

$HH \rightarrow b\bar{b}\gamma\gamma$

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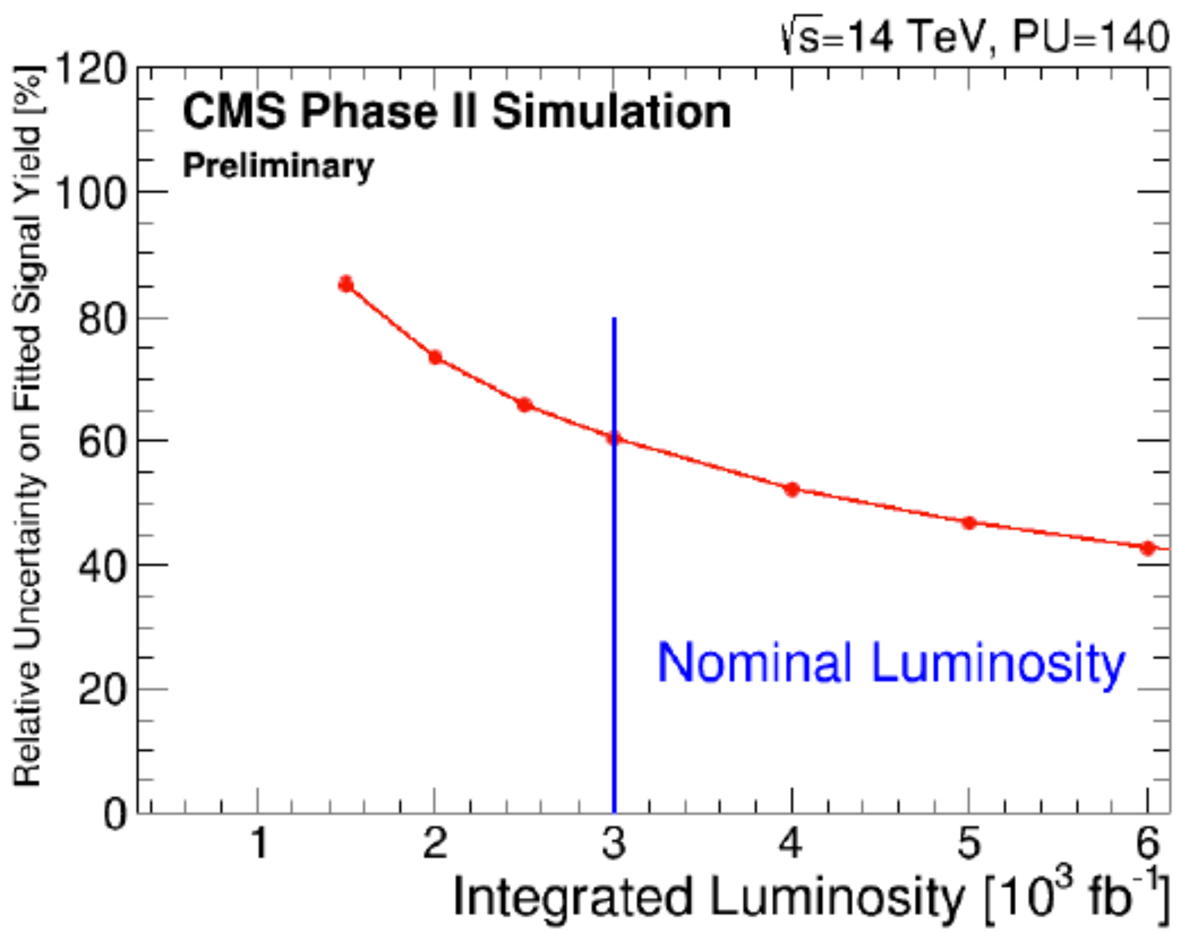

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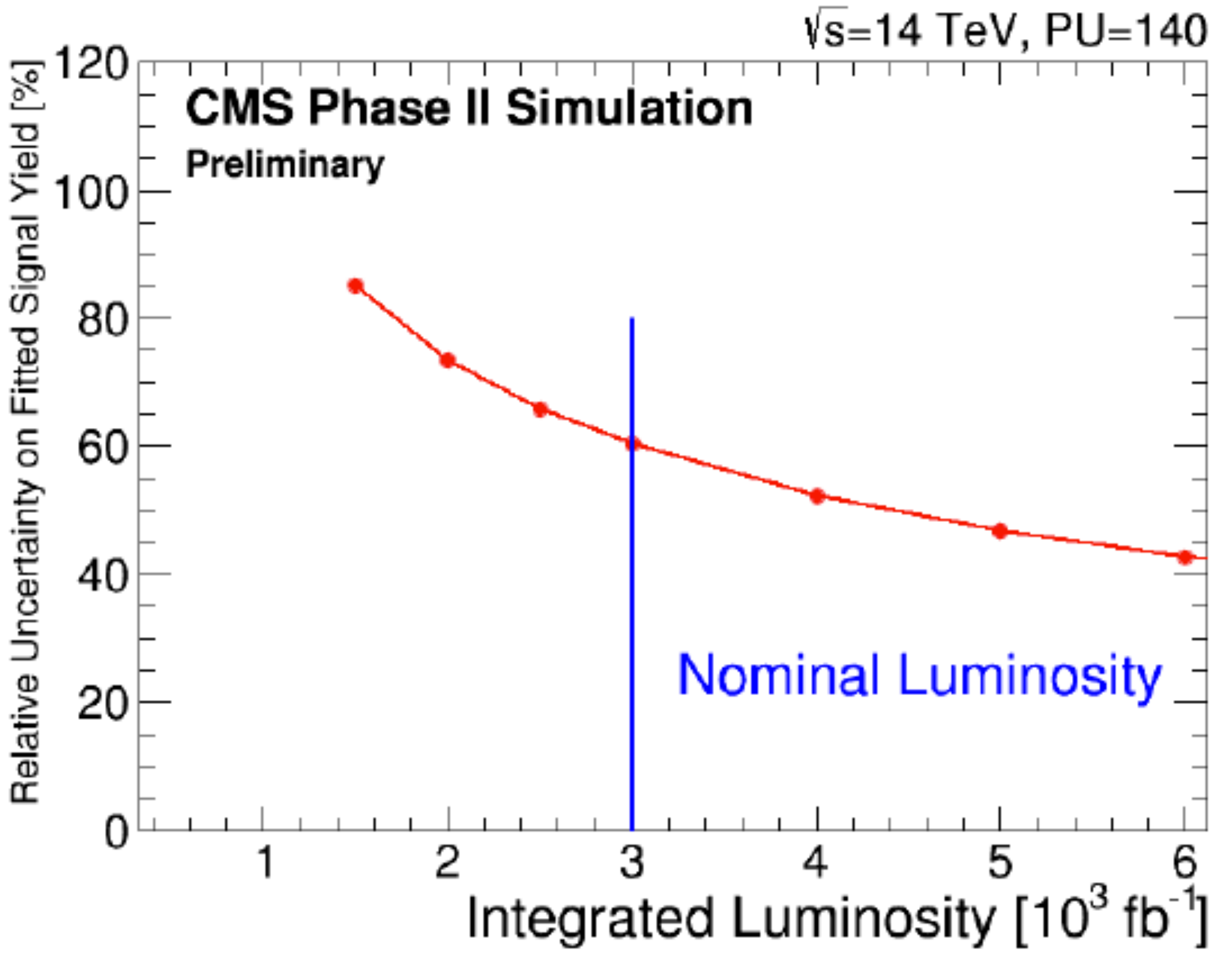
di-Higgs production

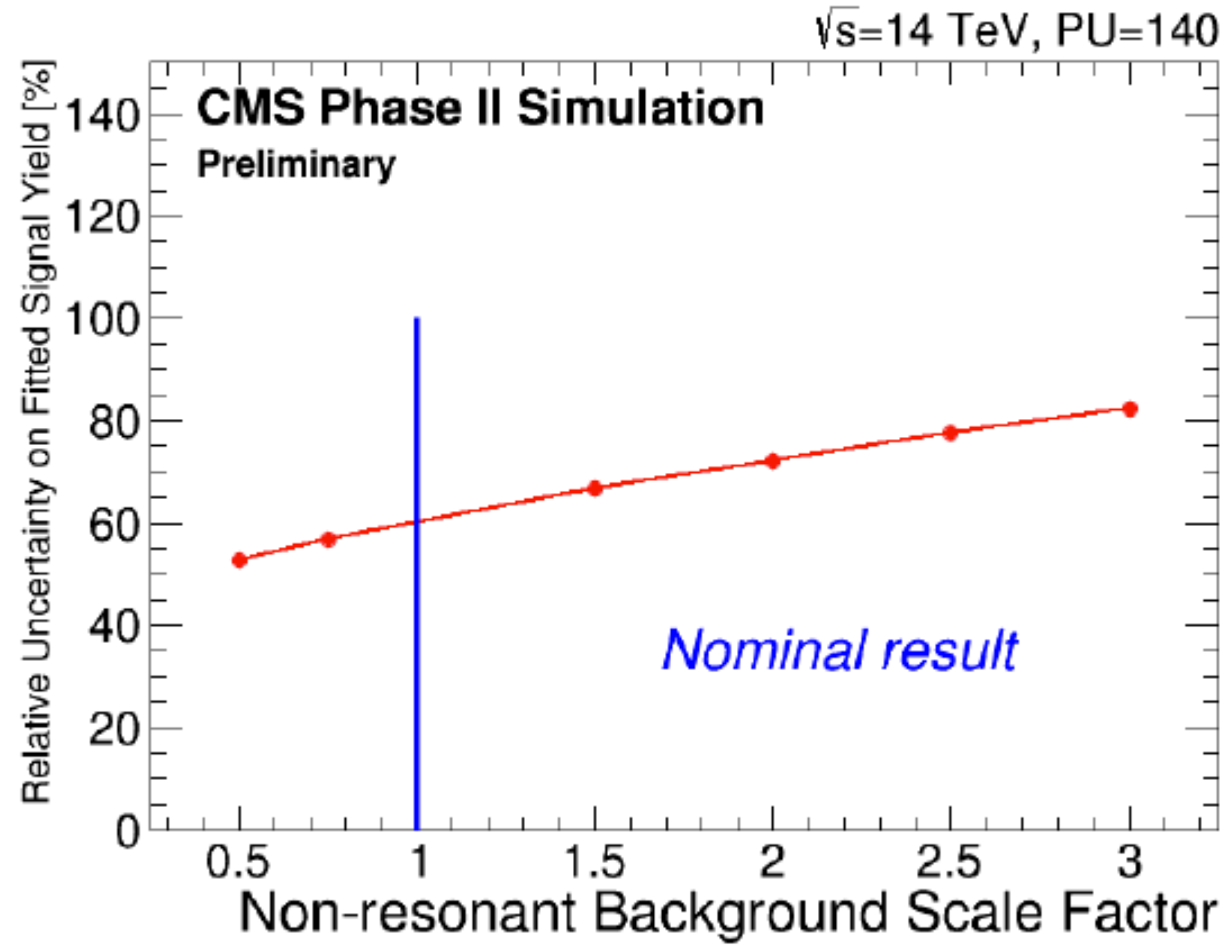
di-Higgs production

$HH \rightarrow b\bar{b}\gamma\gamma$

di-Higgs production

HH→bb̄γγ





- The average expected relative uncertainty on the di-Higgs cross section measurement is shown as a function of the integrated luminosity (left) and the scale factor for the non-resonant background (right).

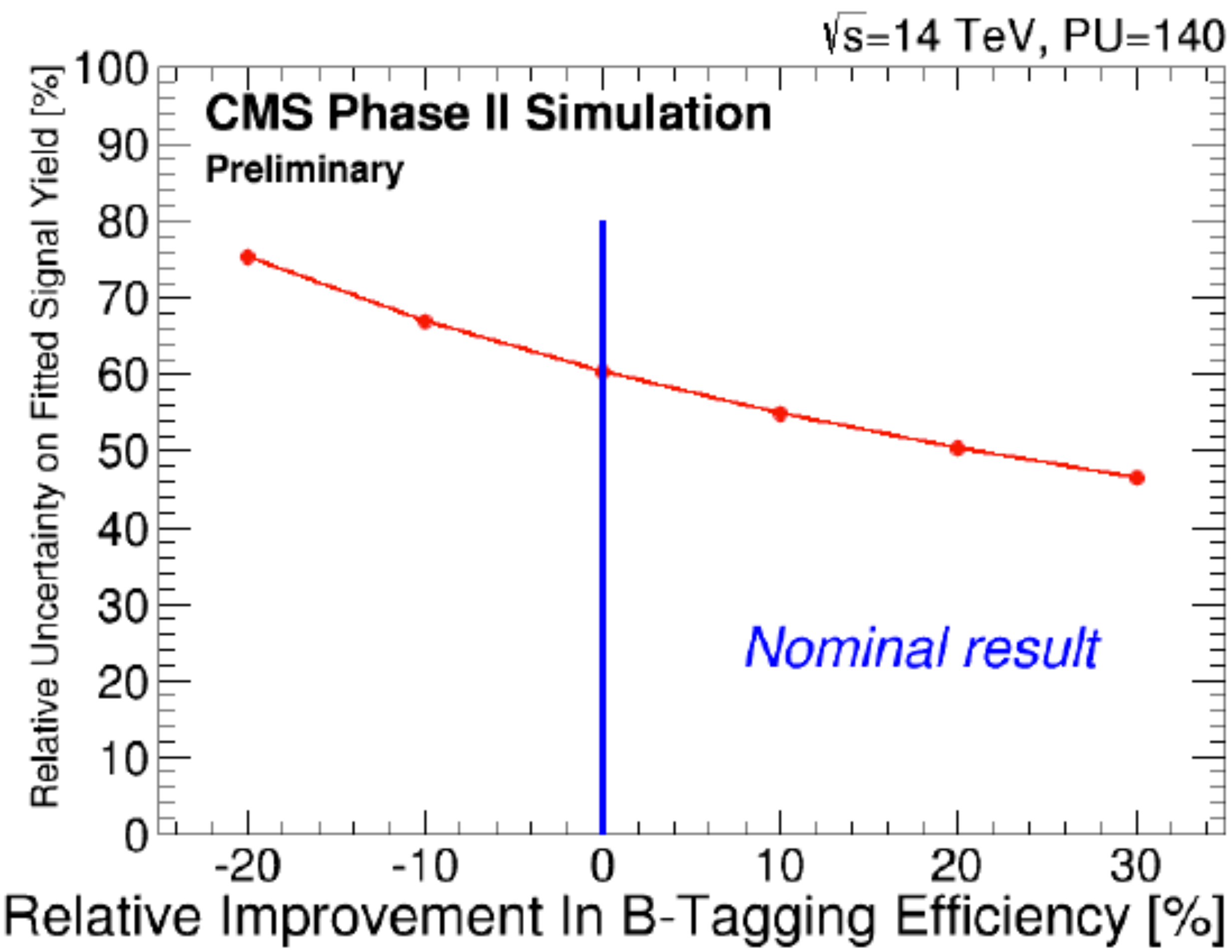
di-Higgs production

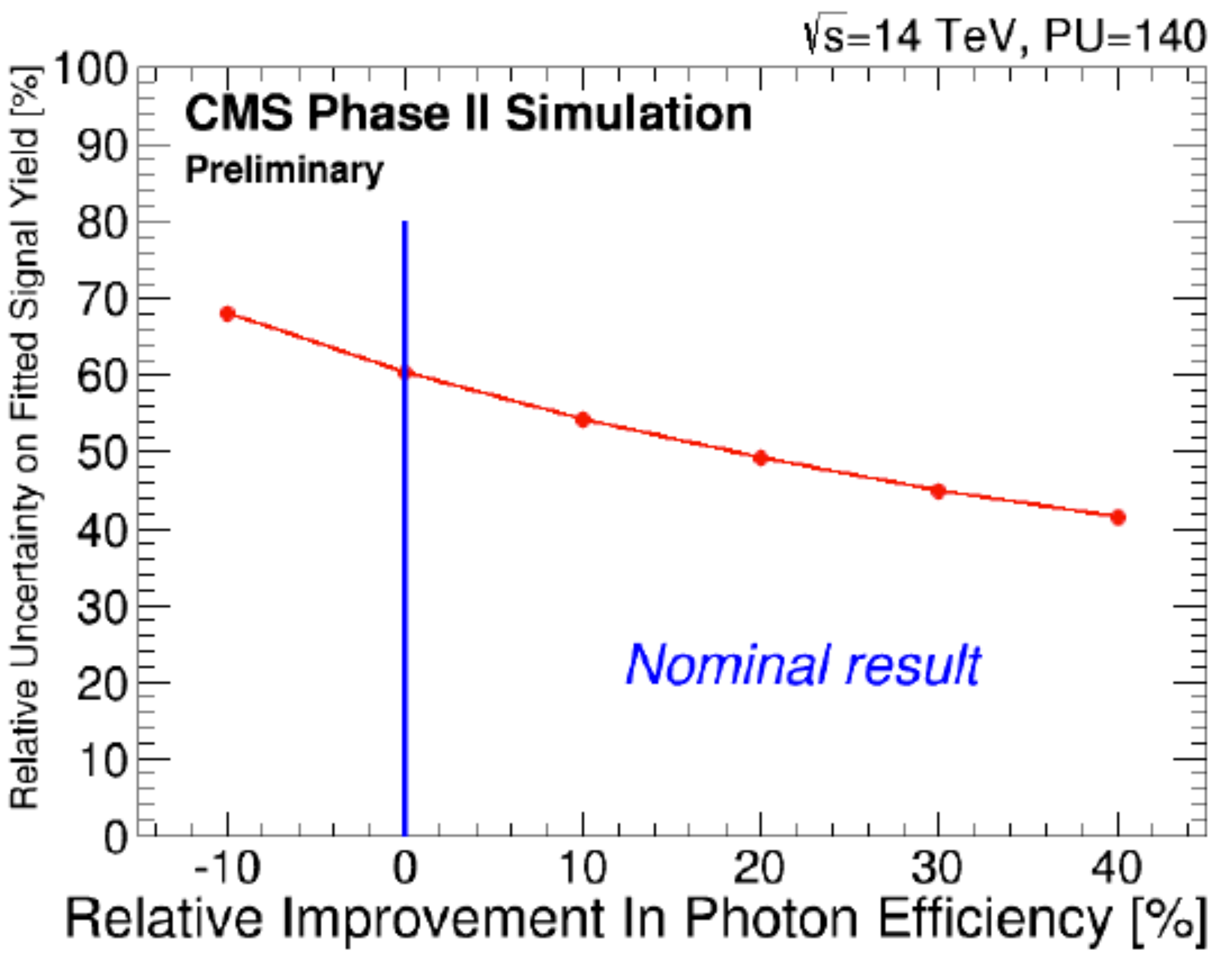
di-Higgs production

$HH \rightarrow b\bar{b}\gamma\gamma$

di-Higgs production

HH→bb̄γγ





- The average expected relative uncertainty on the di-Higgs cross section measurement is shown as a function of the b-tagging efficiency (left) and the photon efficiency (right).

di-Higgs production

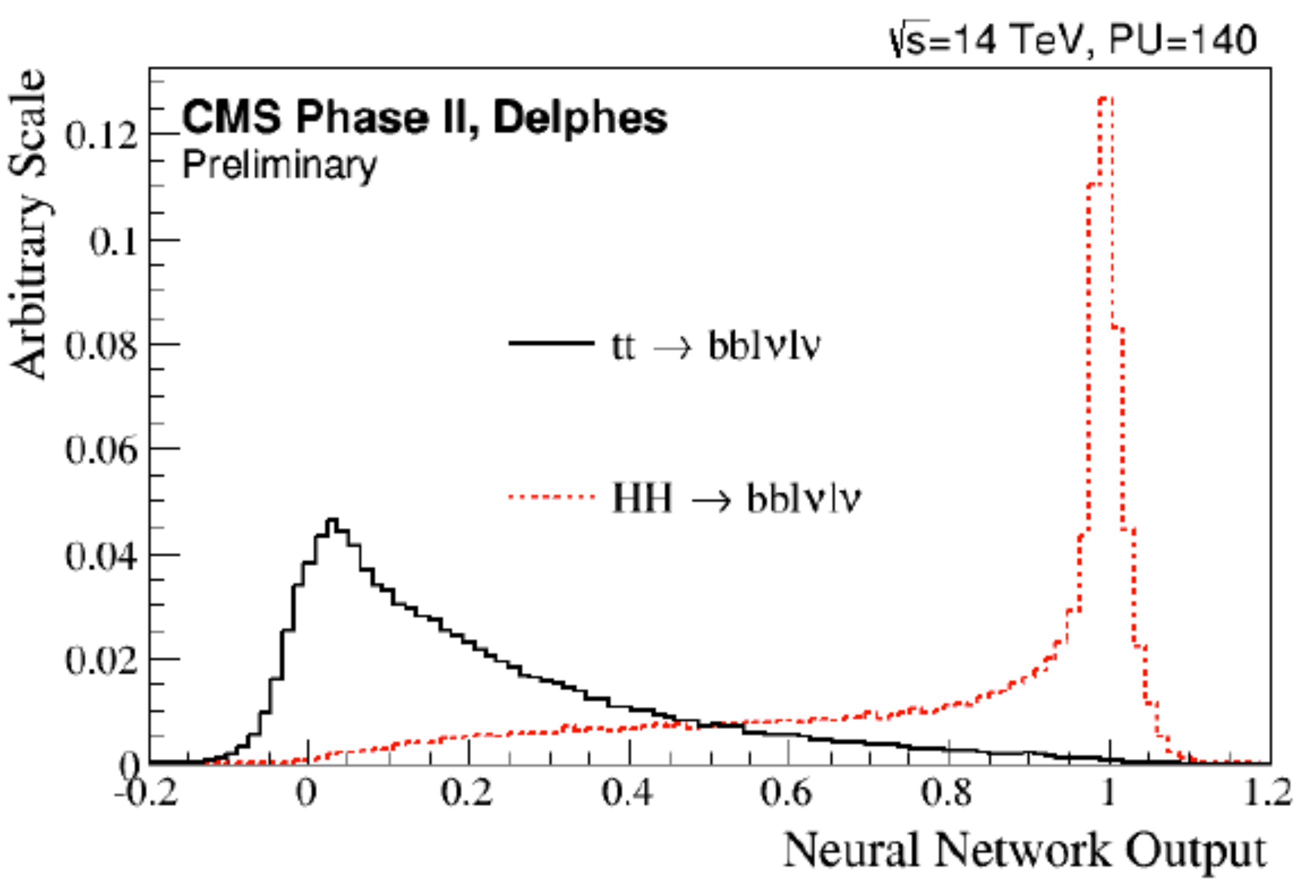
di-Higgs production

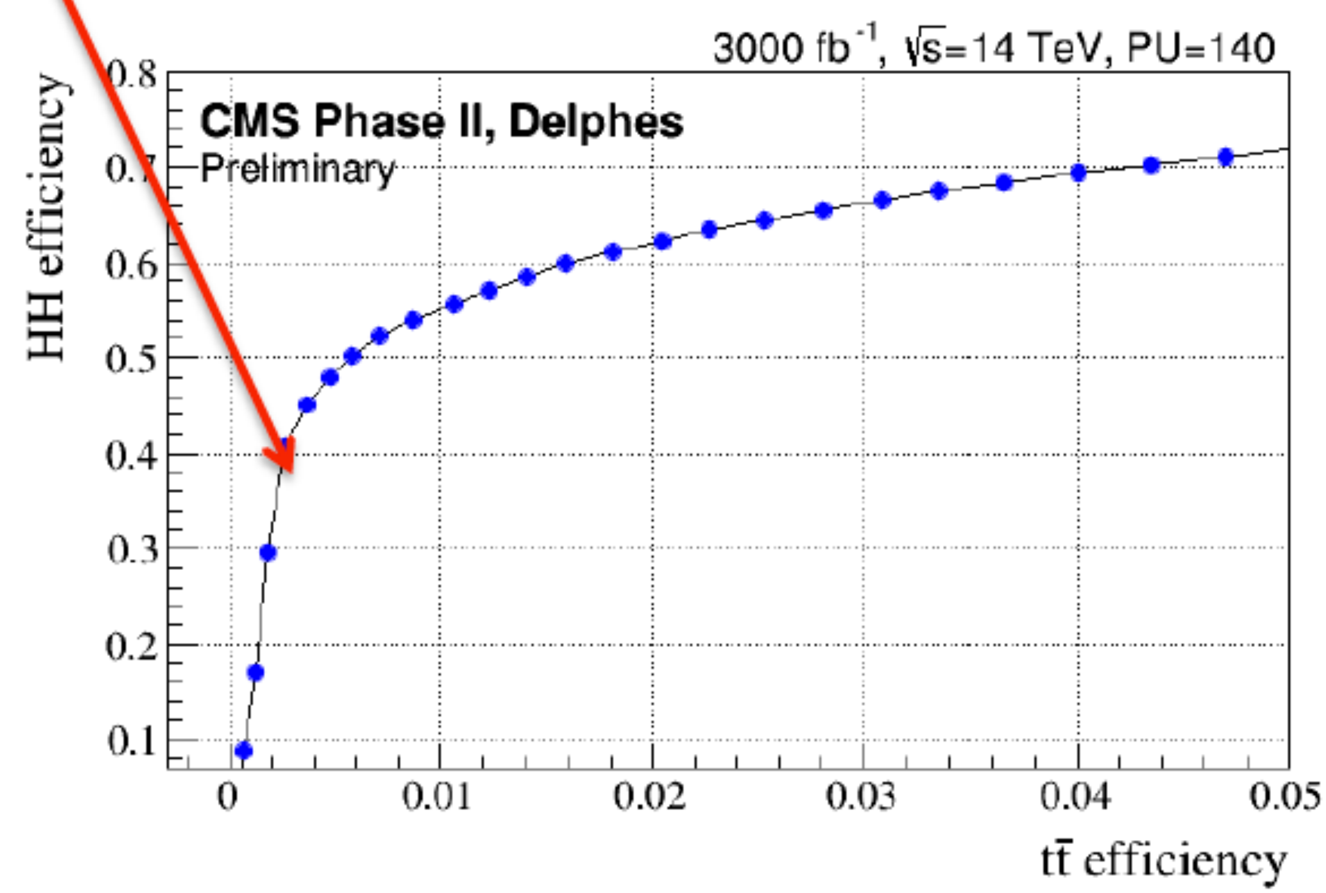
HH→b$\bar{b}$WW

di-Higgs production

HH→bb̄WW

- Based on Delphes fast simulation tuned to CMS Phase II detector
- Considering only the main tt background
- The rest of the SM processes are negligible
- Neural Network discriminant to suppress tt
  - Signal region: Neural Network output > 0.97





di-Higgs production

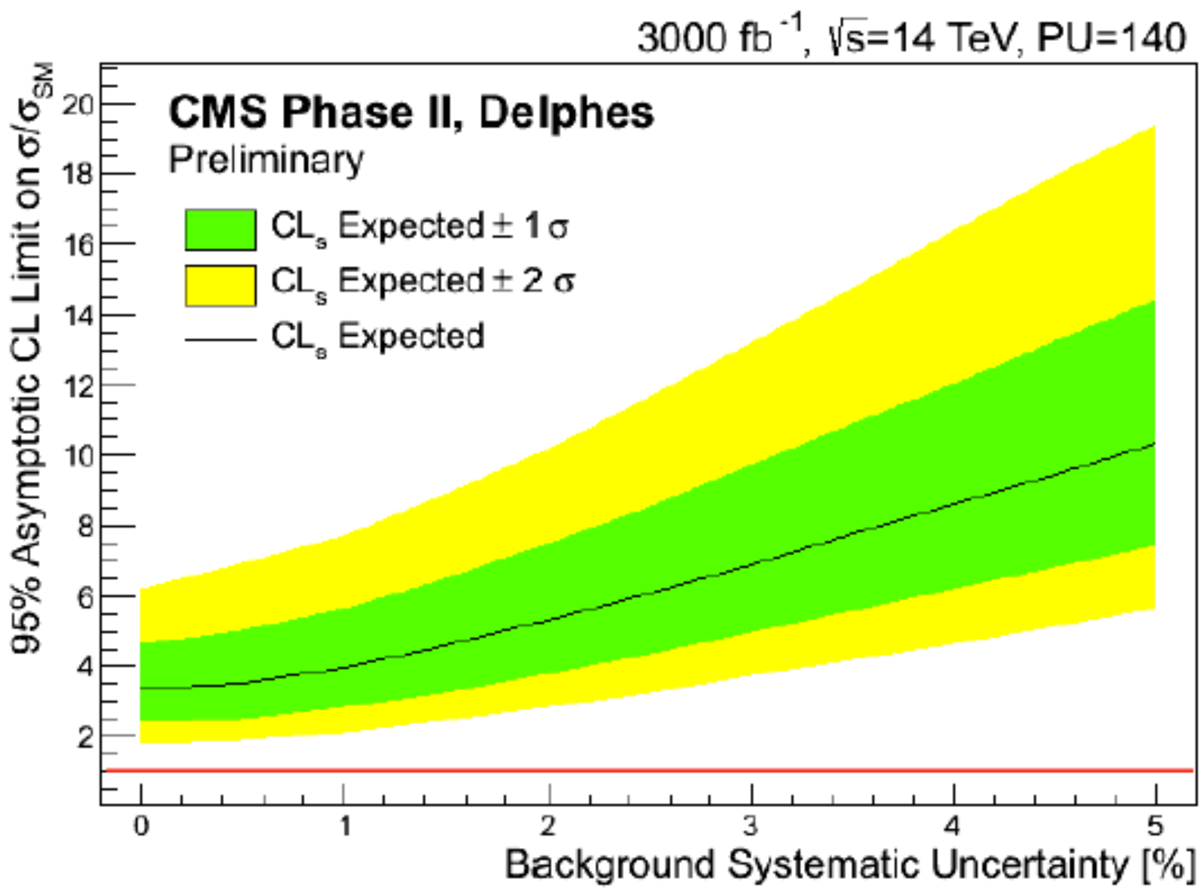
di-Higgs production

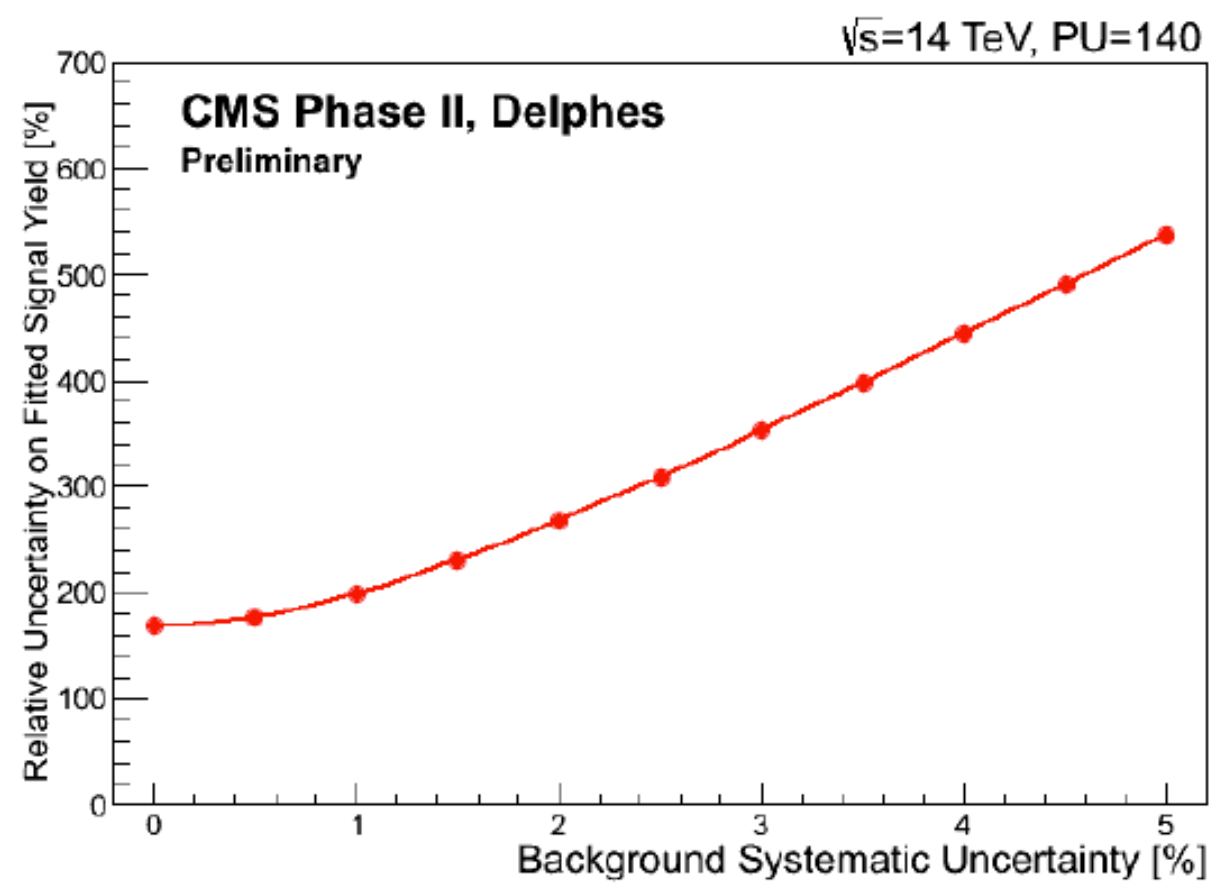
$HH \to b\bar{b}WW$

di-Higgs production

HH→bb̄WW

- Results are quoted as a function of the background systematic uncertainty
  - Data driven techniques will likely constraint the uncertainties to the percent level





di-Higgs production

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$b\bar{b}\tau^{+}\tau^{-}$ seems rather promising, studies are ongoing

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di-Higgs production

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There is ongoing work in both experiments in order to be able to assess the full potential at HL-LHC.

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There is ongoing work in both experiments in order to be able to assess the full potential at HL-LHC.

There is good hope to reach a sensitivity of ~3σ per experiment with $L=3000\ fb^{-1}$

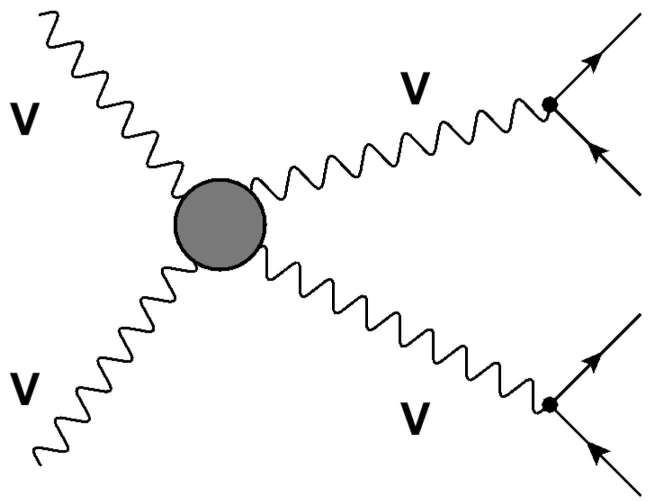
VV Scattering

VV scattering: unitarity violation

Taken from **"Prospects for VV scattering: latest news"** by S. Bolognesi (JHU)
talk at Implications of LHC results for TeV-Scale physics (March 2012)

VV scattering: unitarity violation

VV→VV



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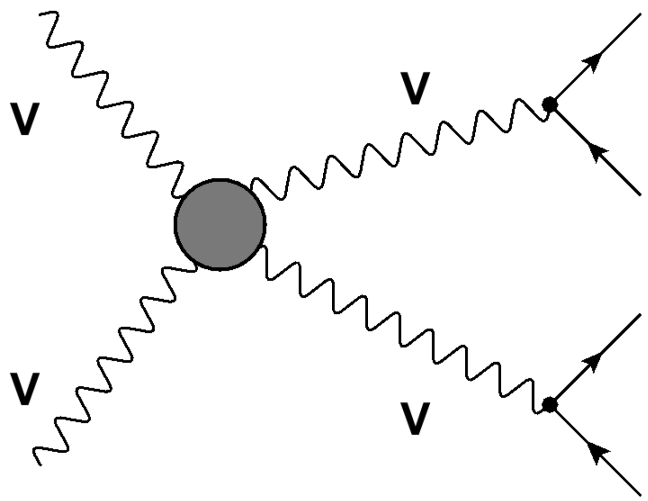

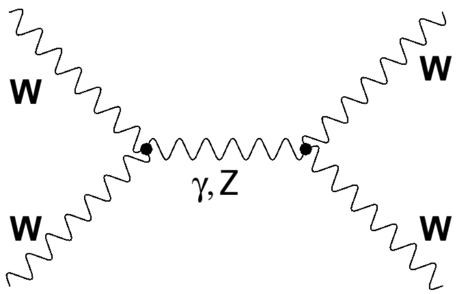

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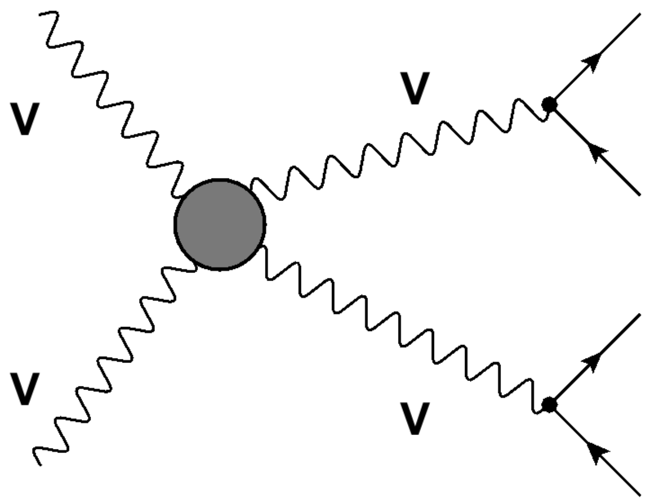

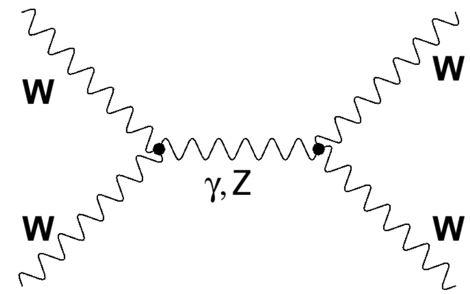

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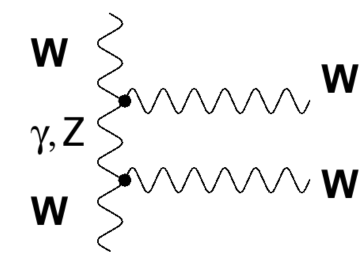

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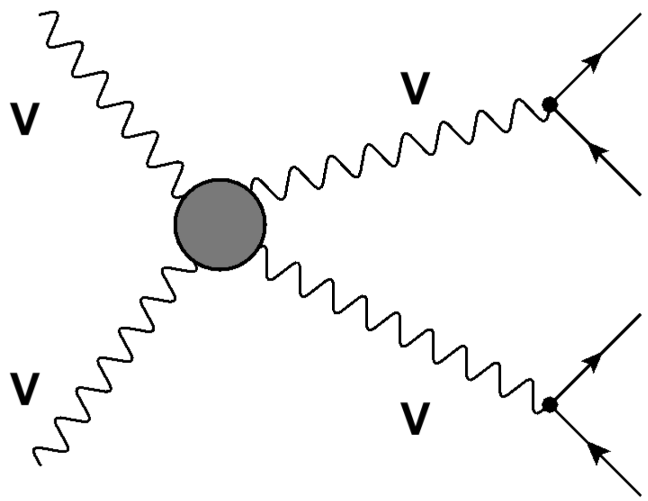

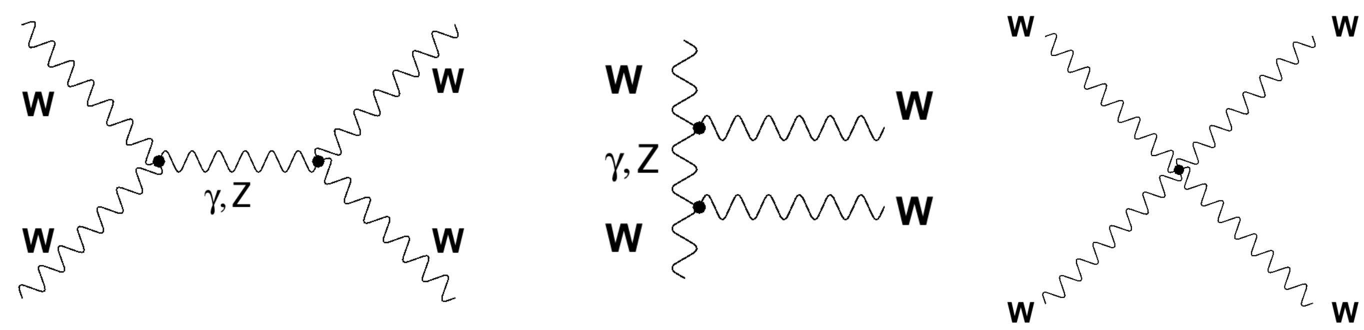

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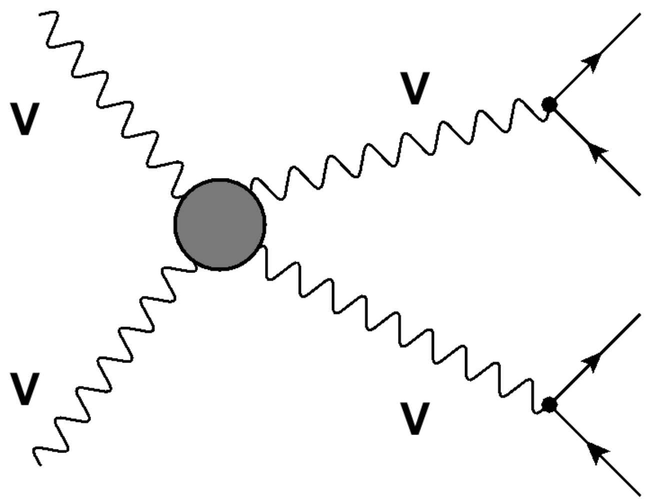

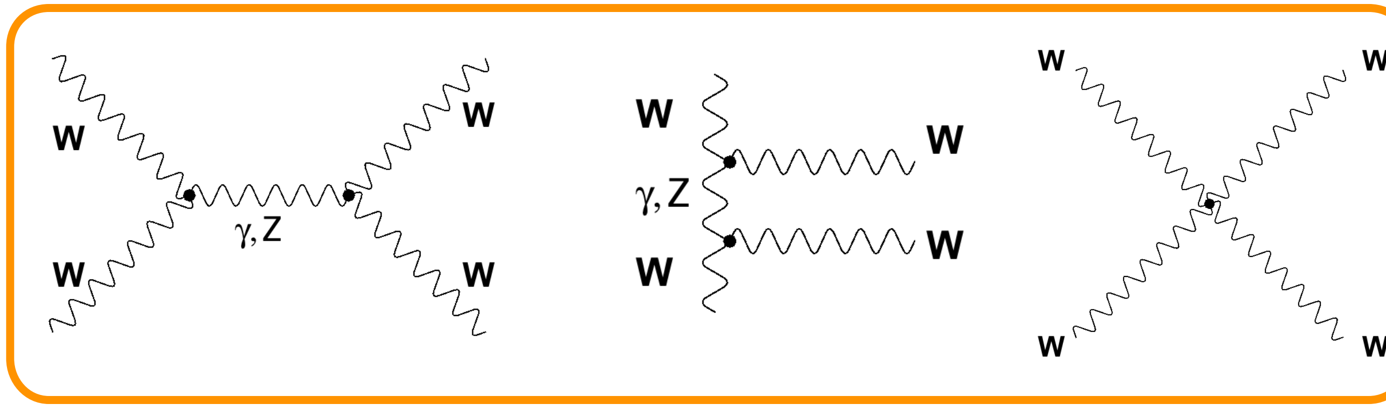

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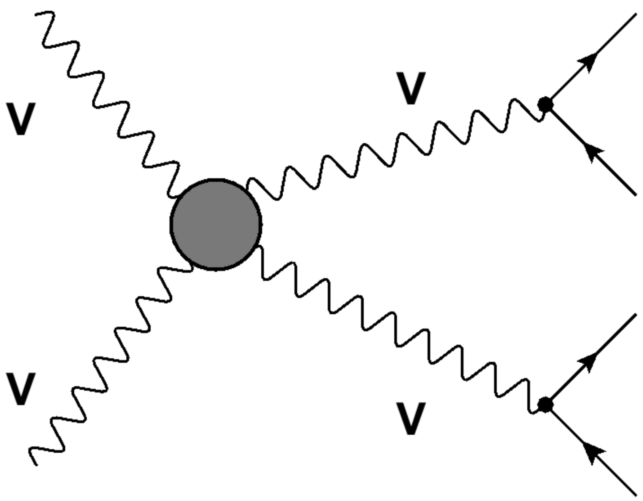

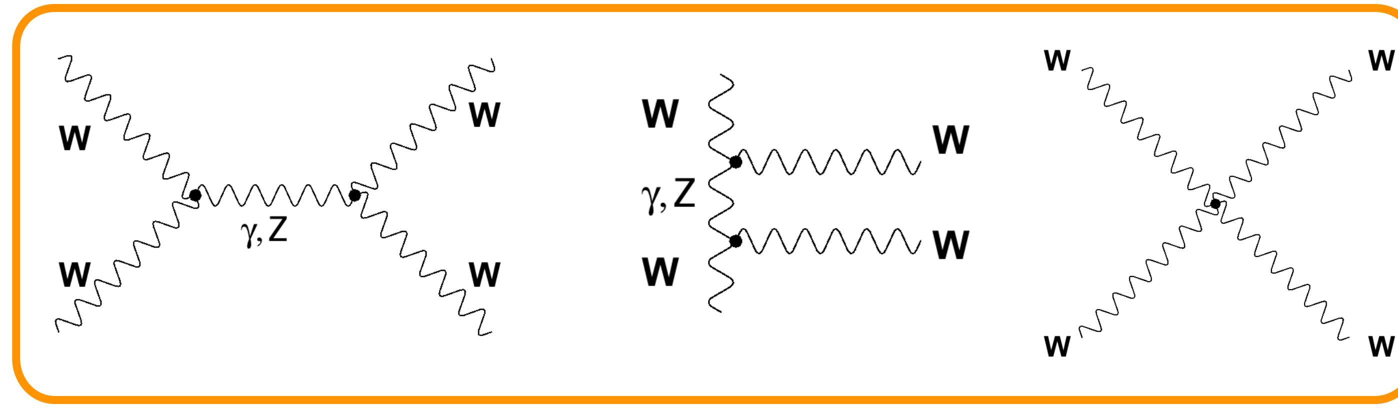

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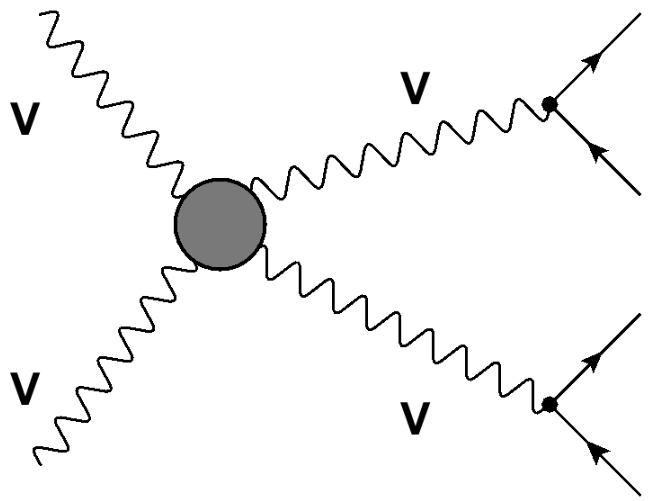

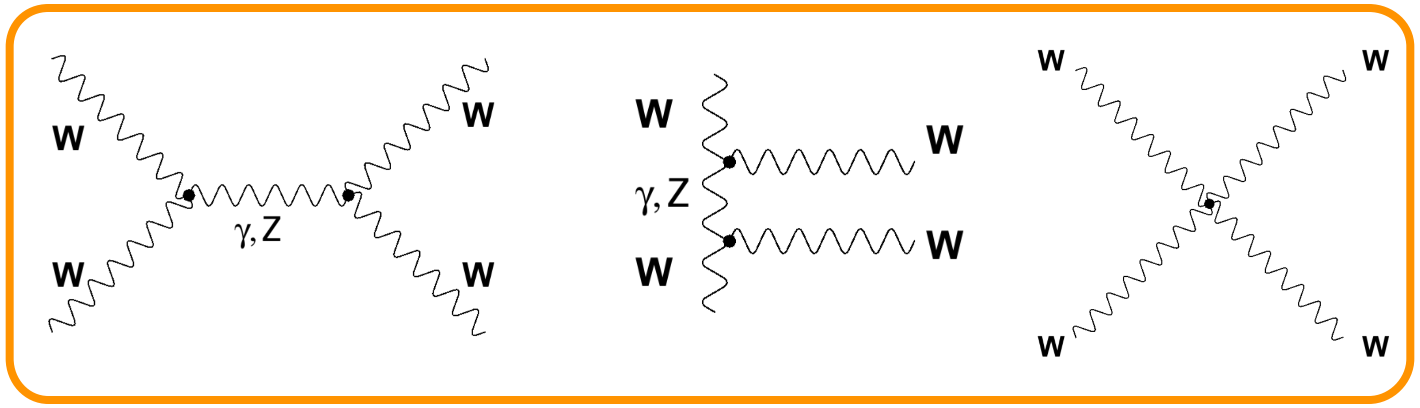

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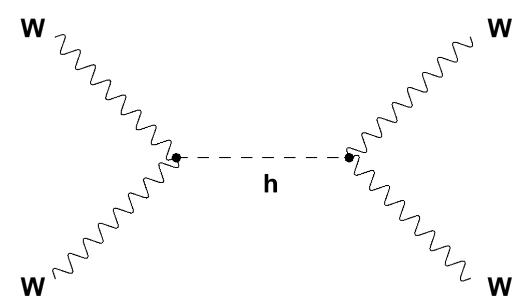

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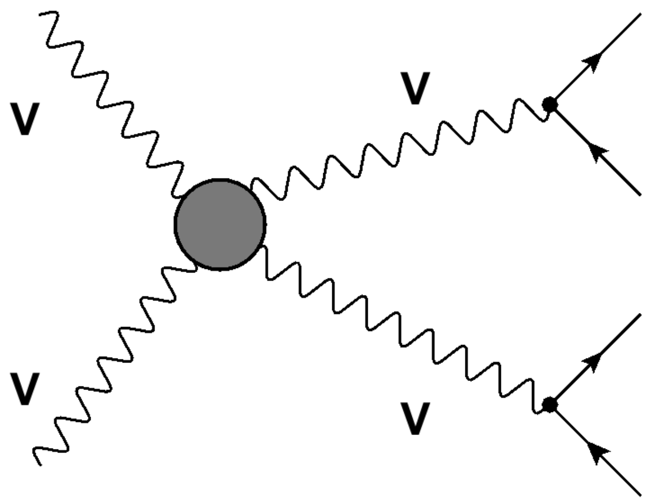

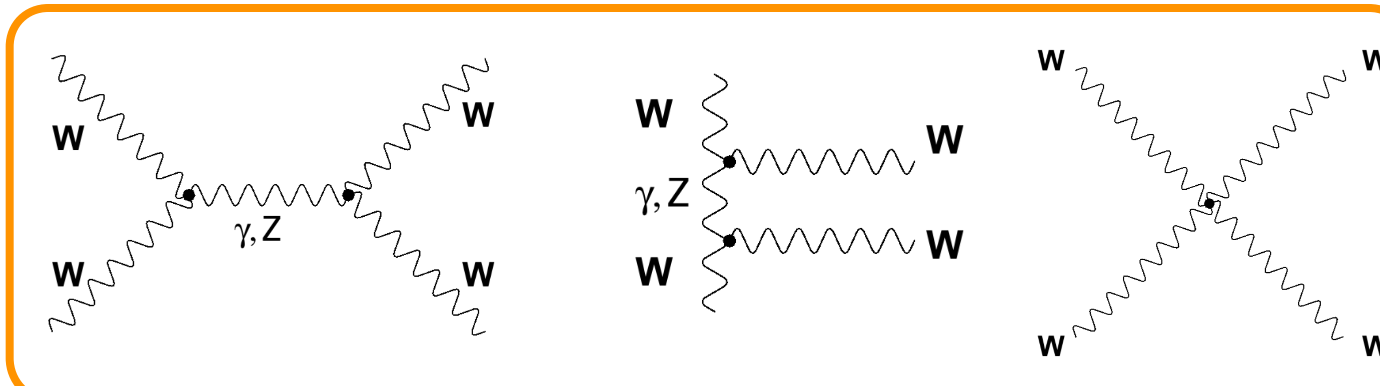

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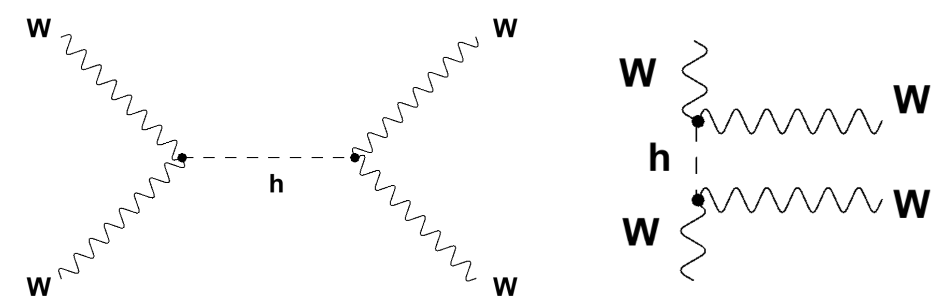

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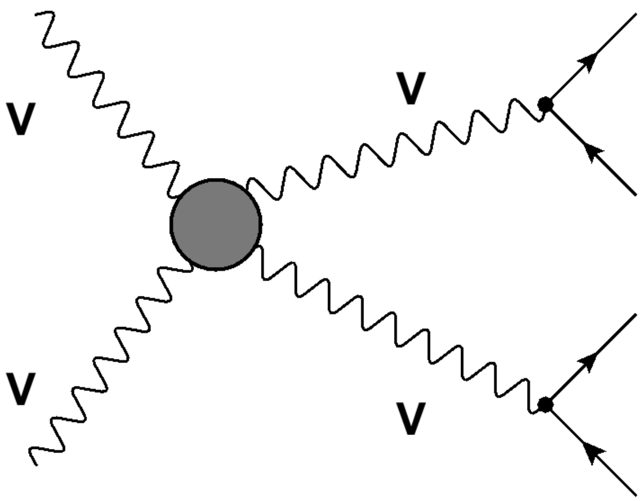

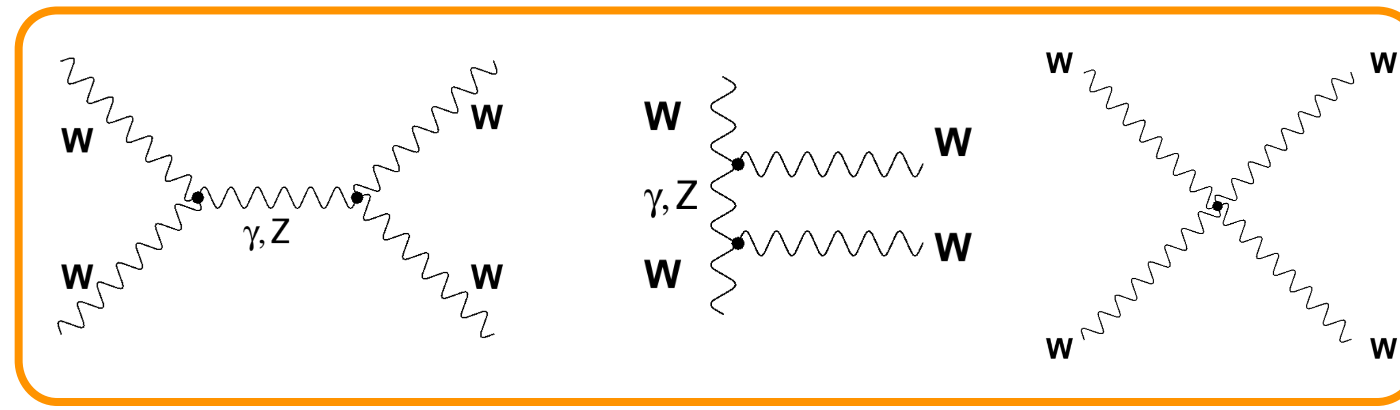

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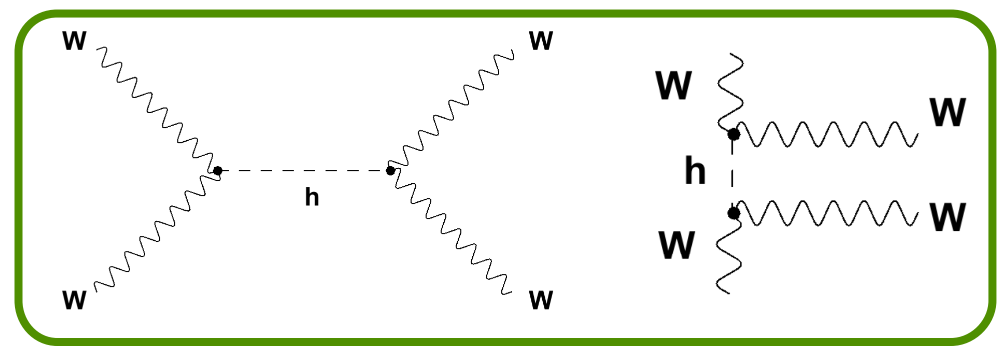

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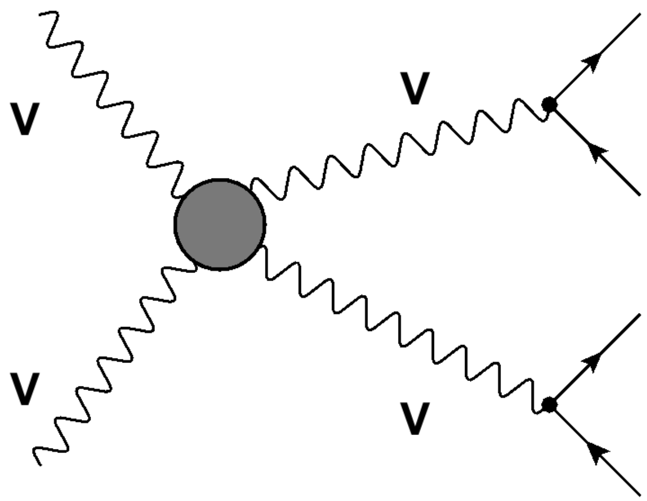

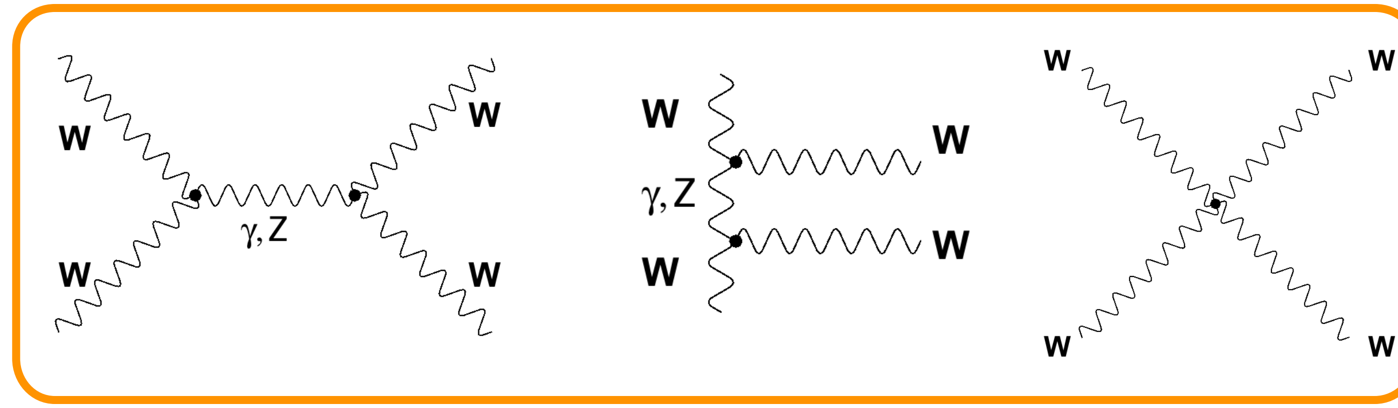

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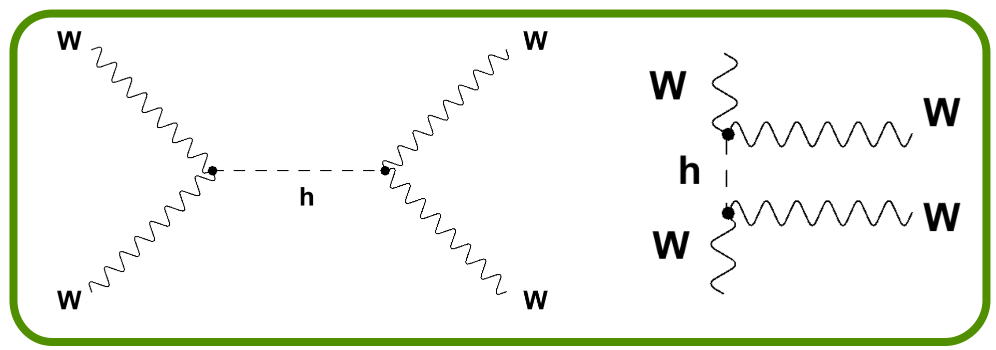

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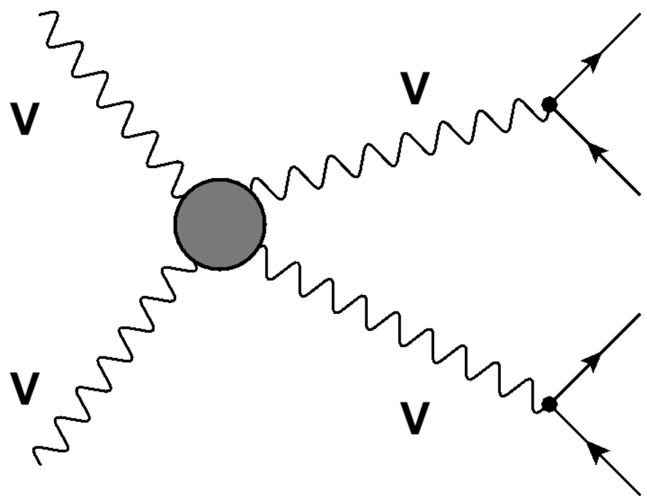

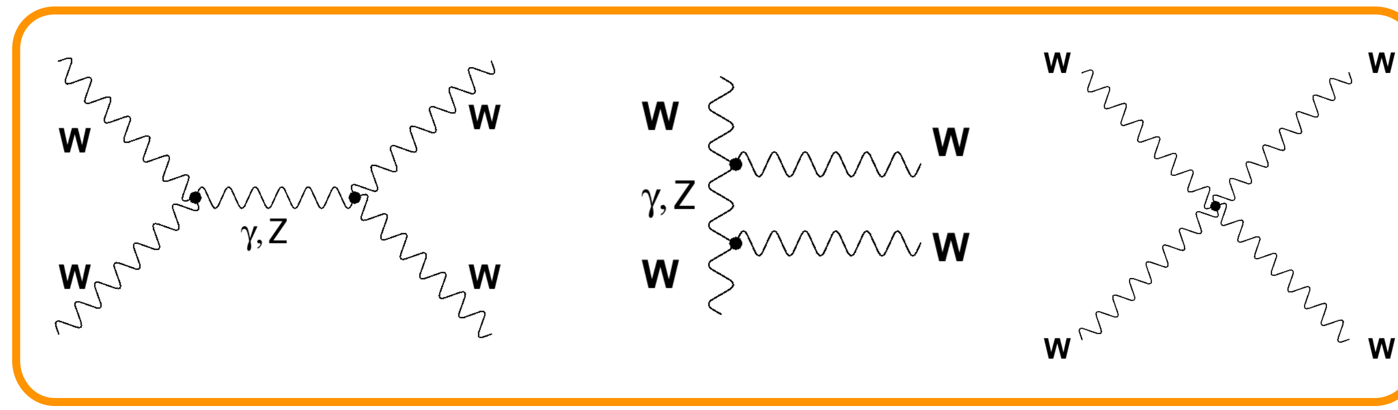

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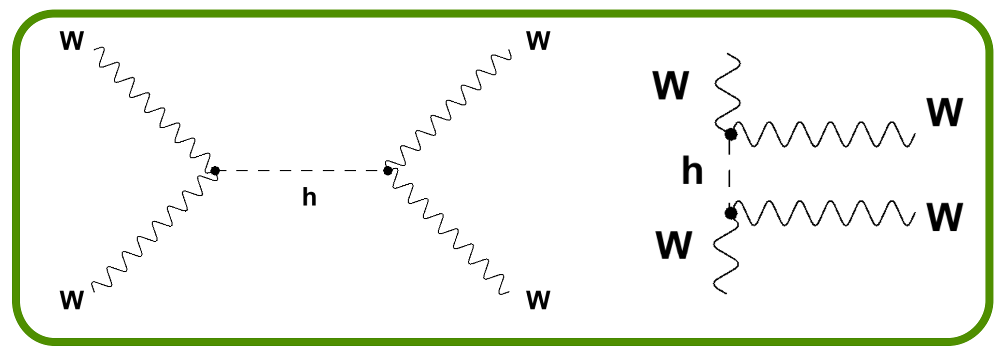

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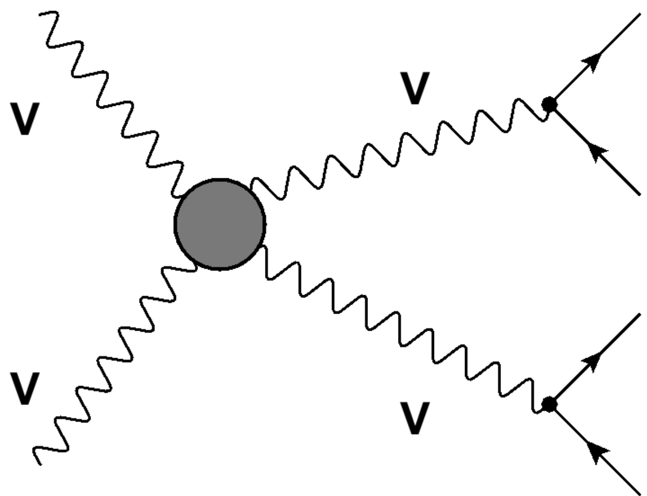

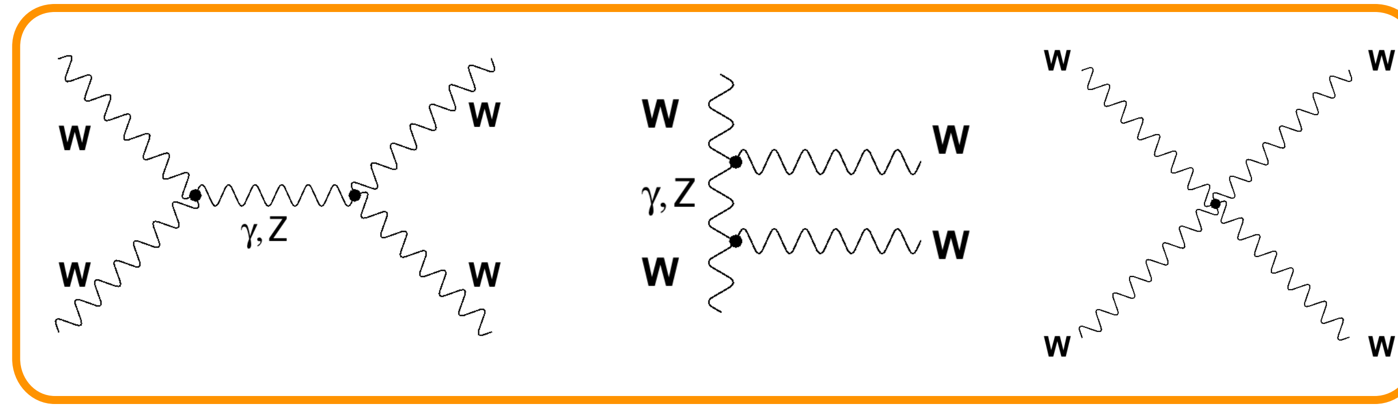

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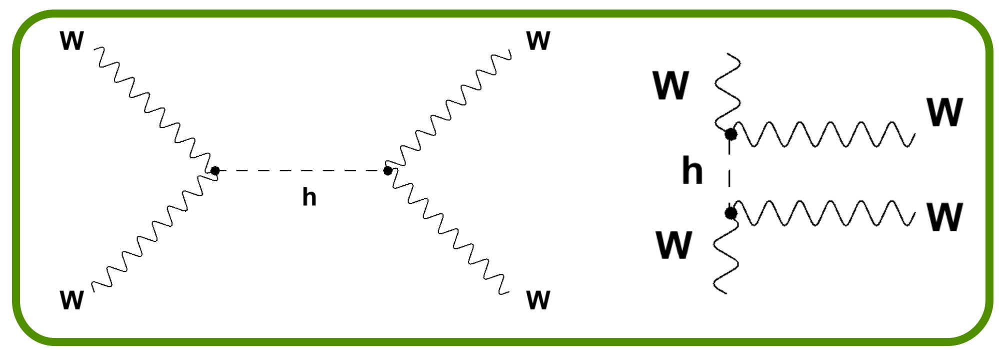

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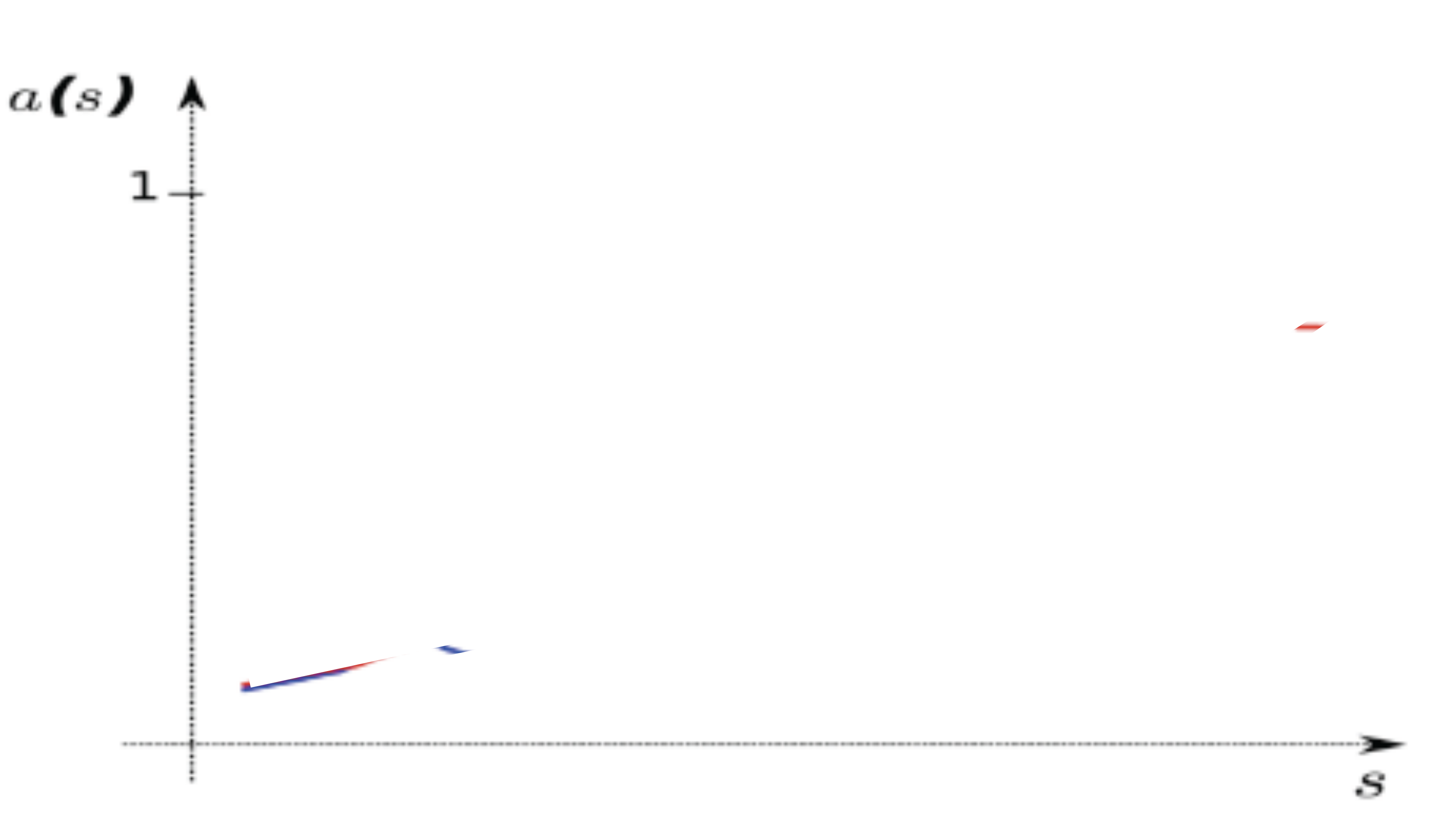
is the fundamental probe to test the nature of the BEH boson or to find an alternative EWSB mechanism



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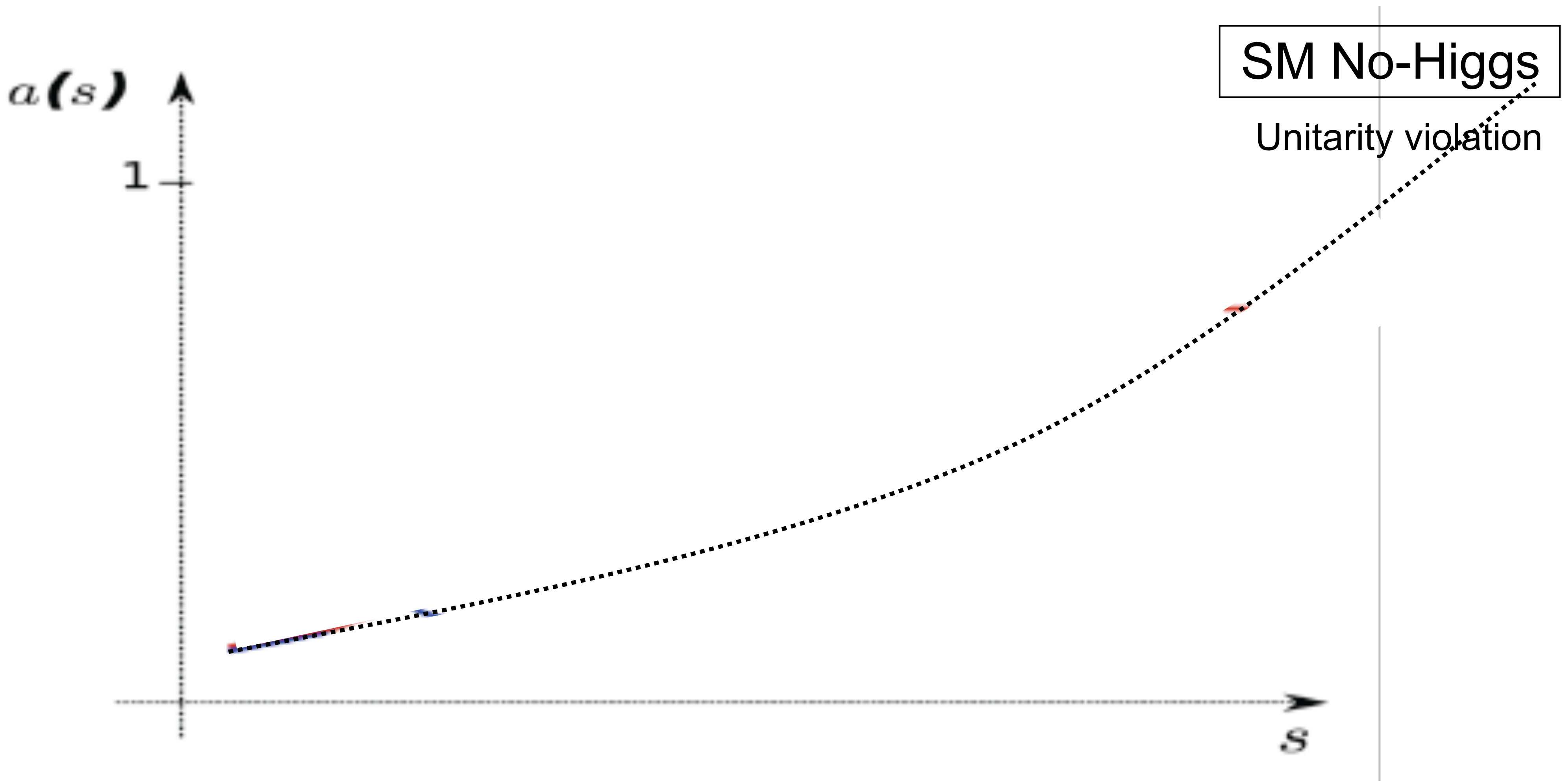

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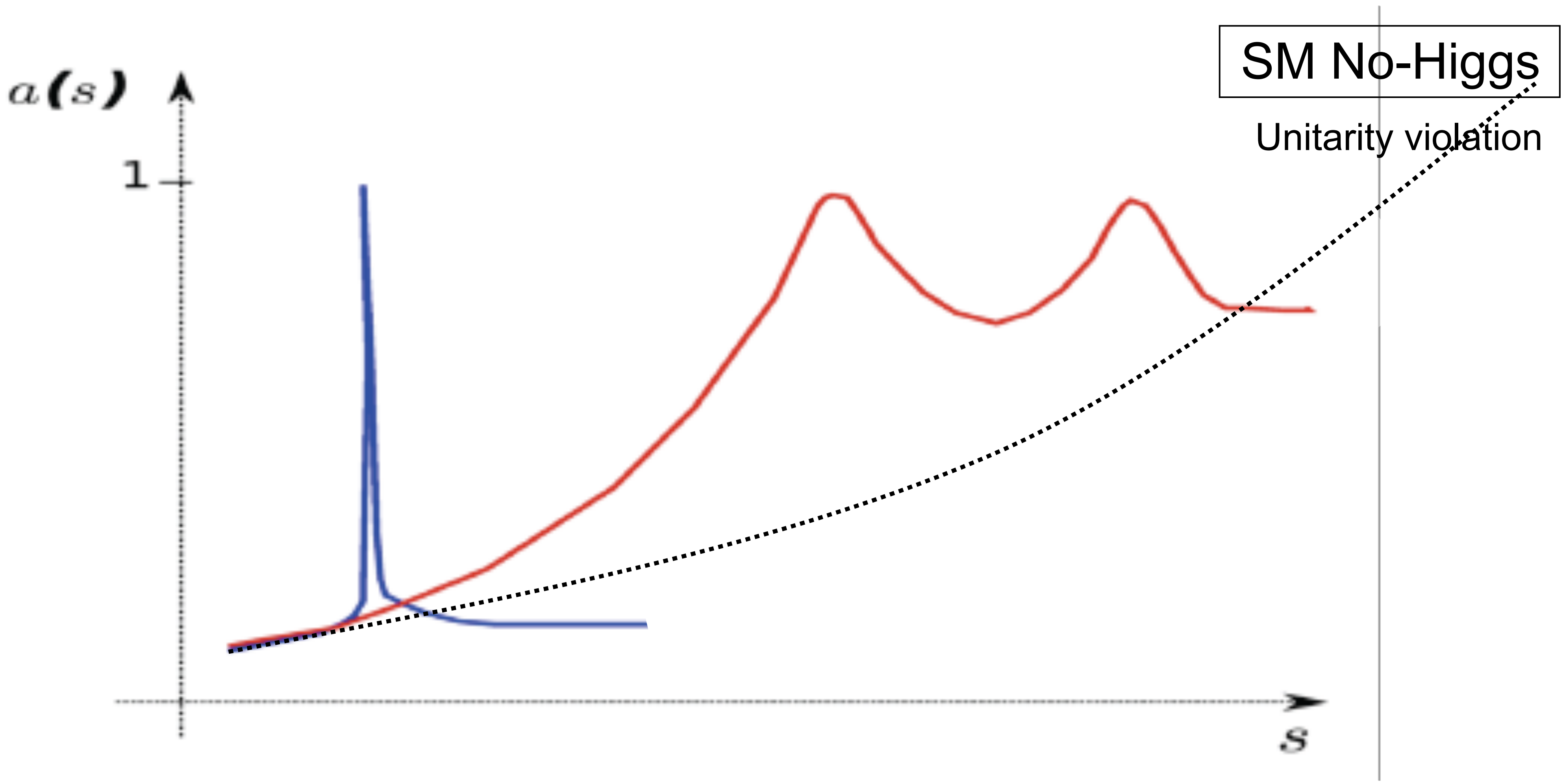

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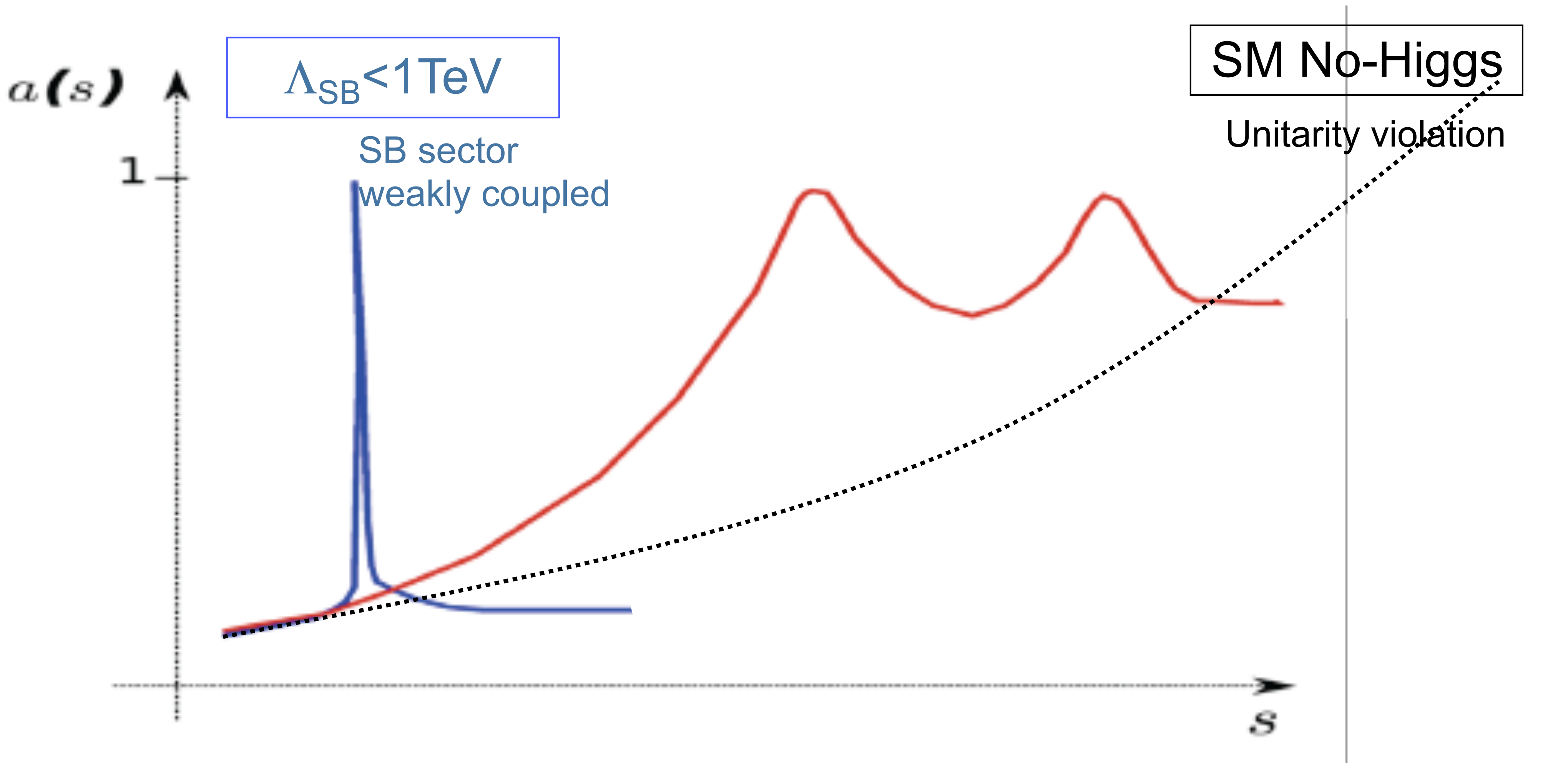

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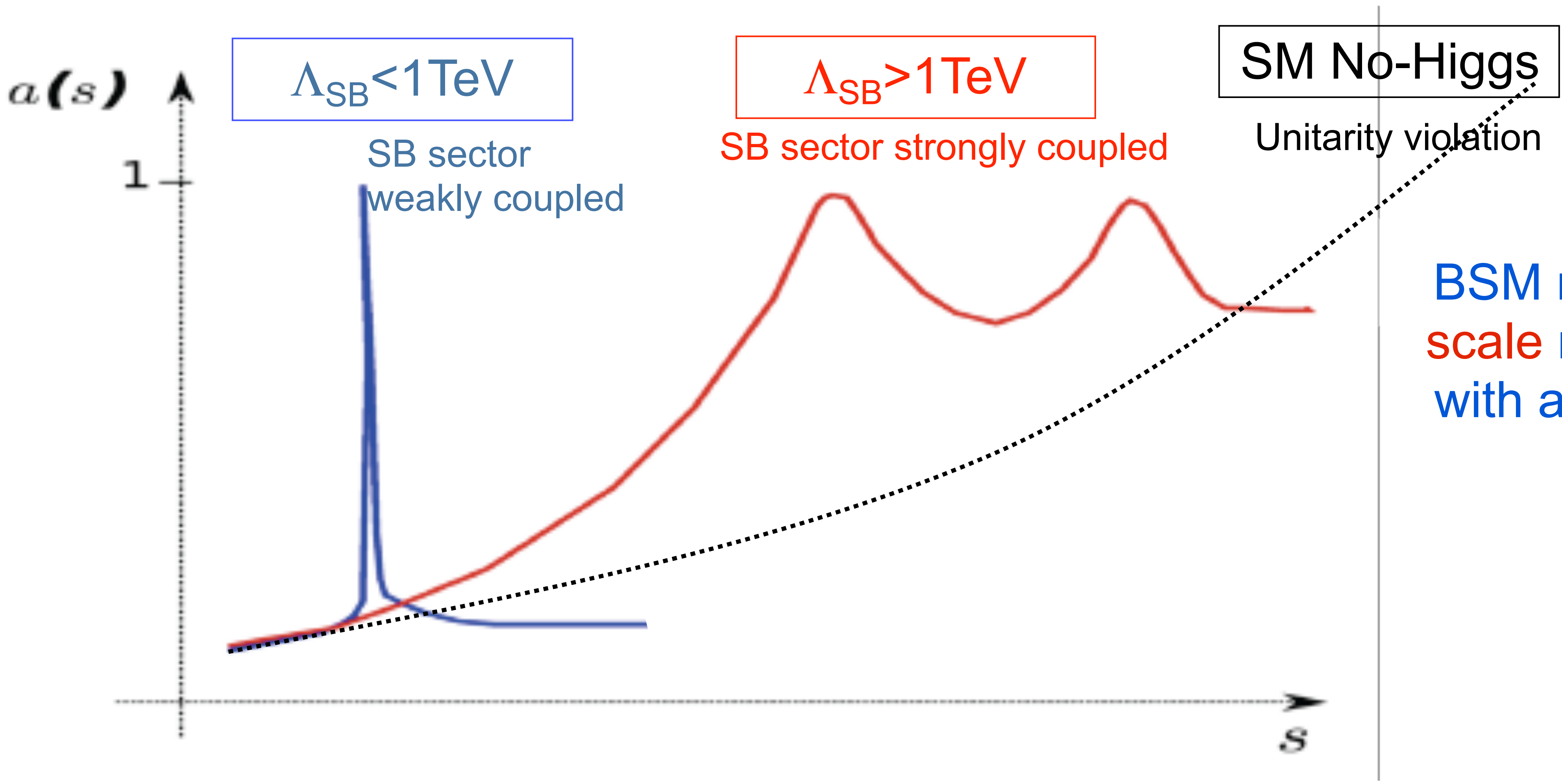

BSM models predict TeV-scale resonances "paired" with a light scalar particle

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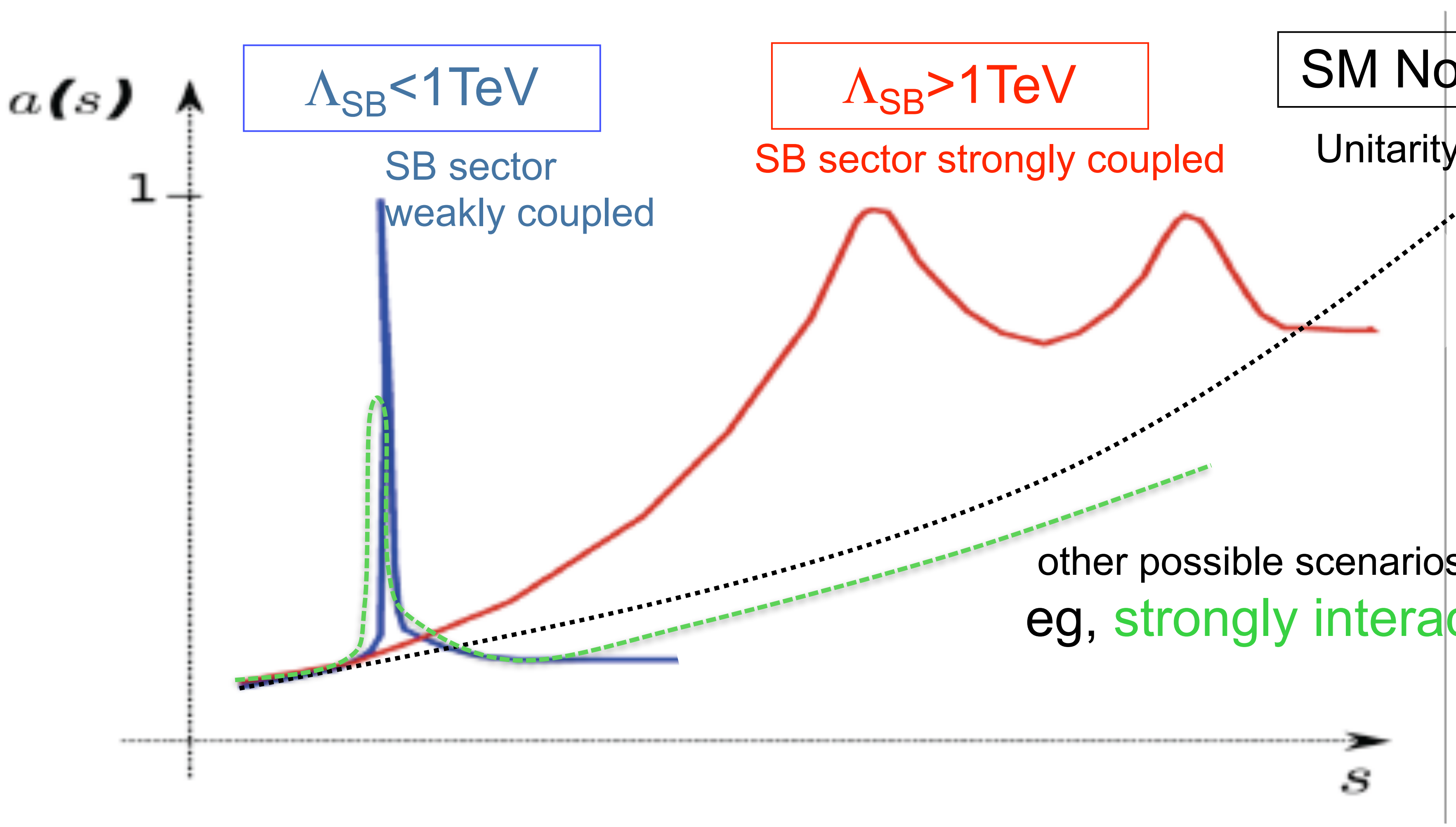

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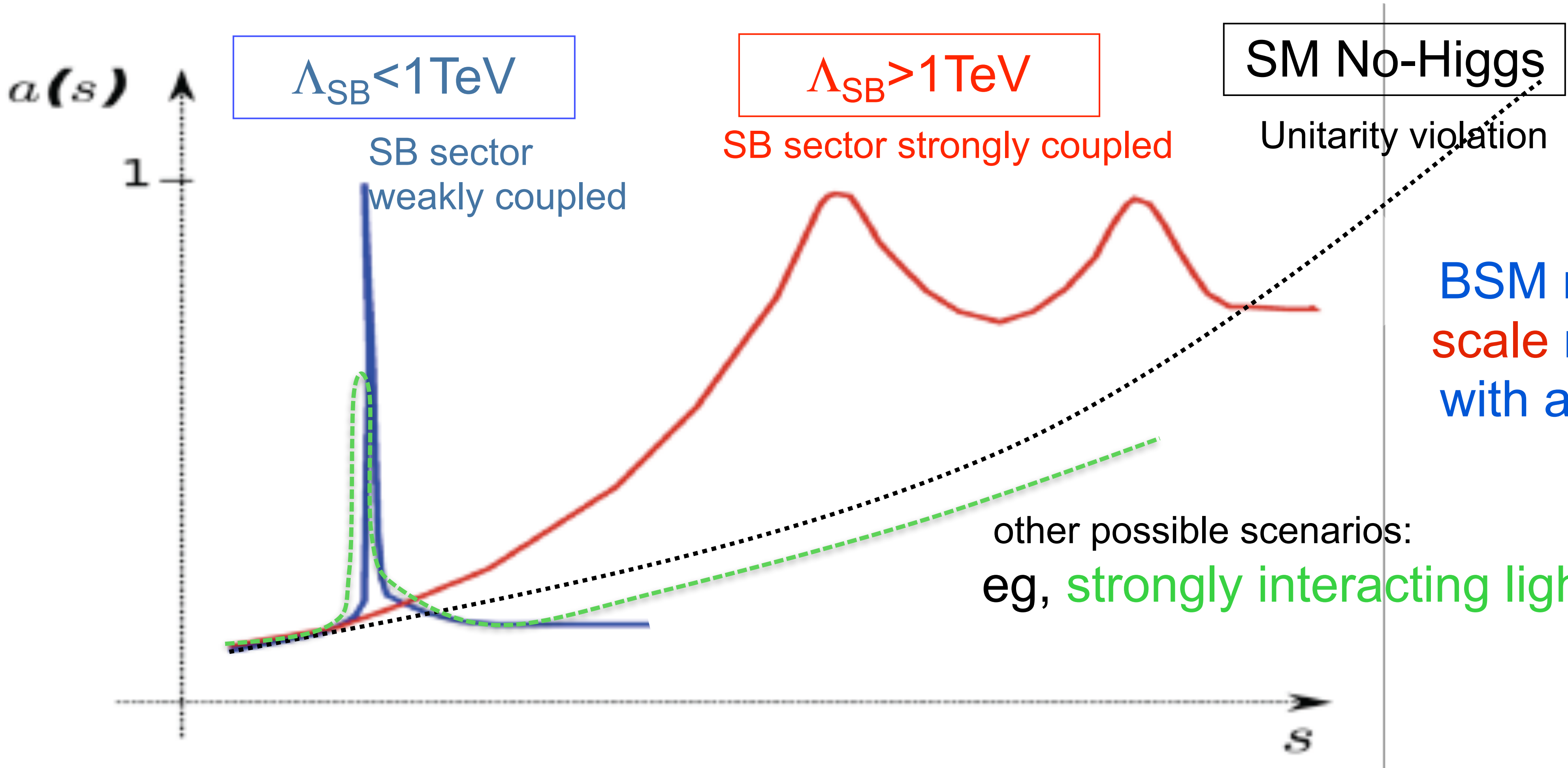

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Search for possible resonances in VV scattering (VBS) spectrum

Adaptation from **"Boson Boson scattering analysis"** by A.Ballestrero (INFN Torino) talk at First LHC to Terascale Workshop (Sept 2011):

VBS experimental signature

From **“Study of Vector Boson Scattering including Pile-up with the ATLAS Detector**”
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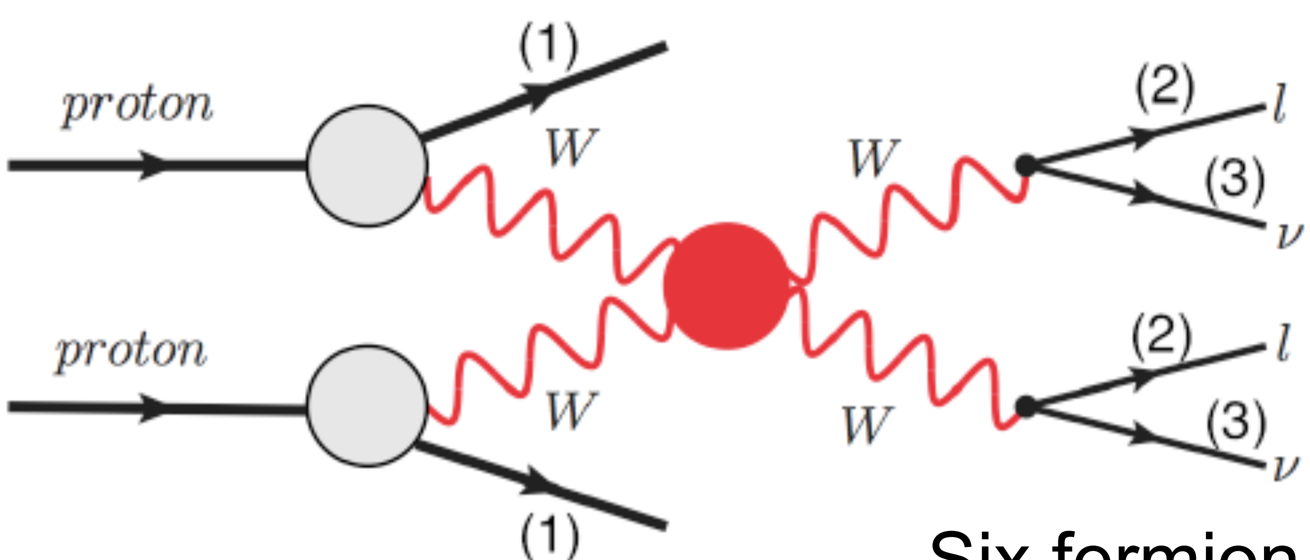

Six fermion final state

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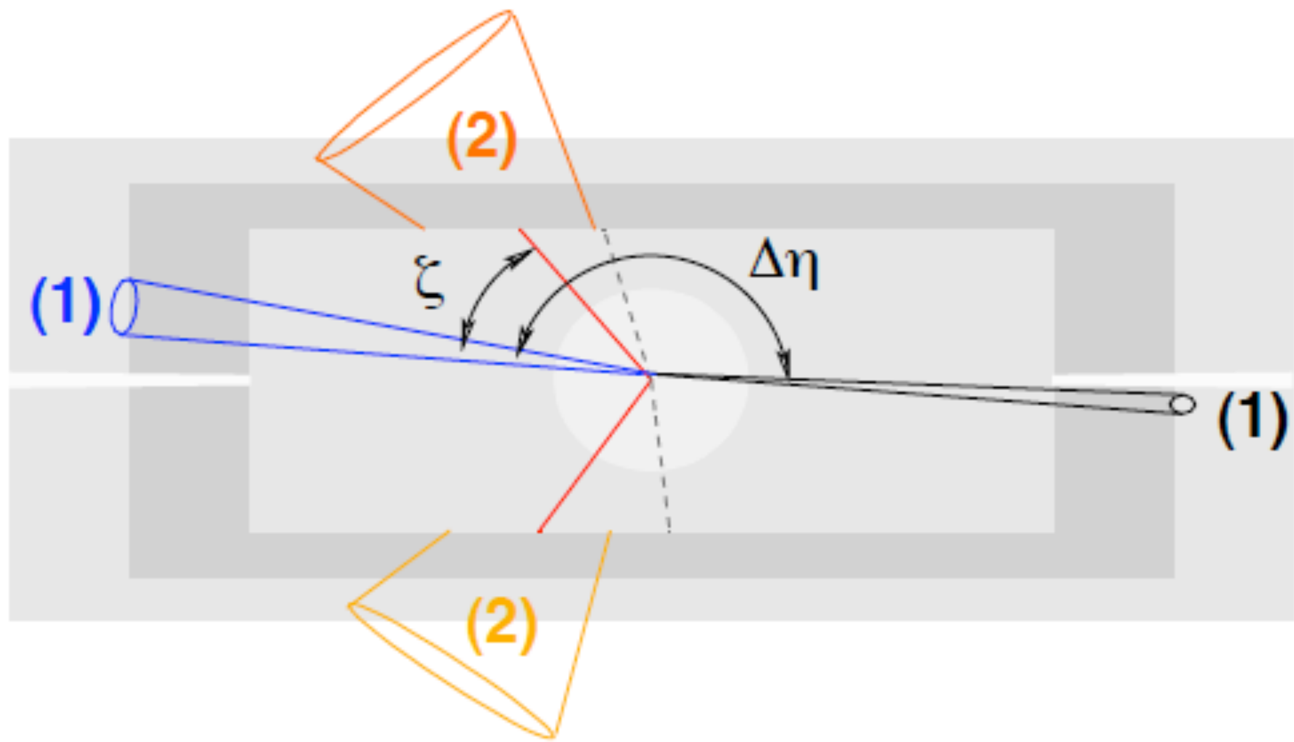
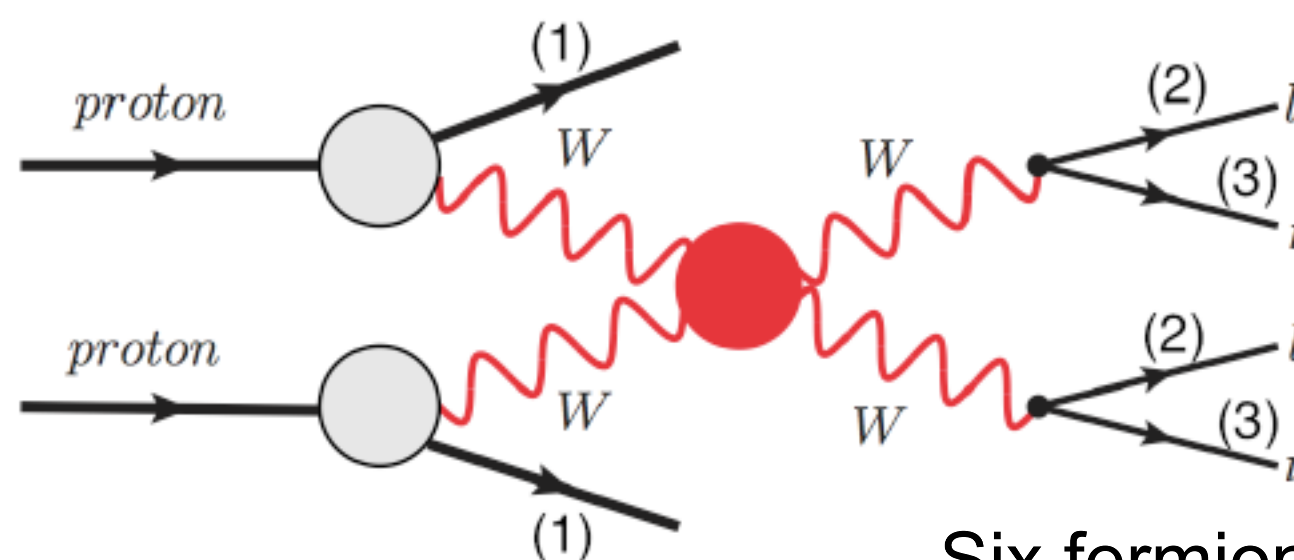
Longitudinal plane





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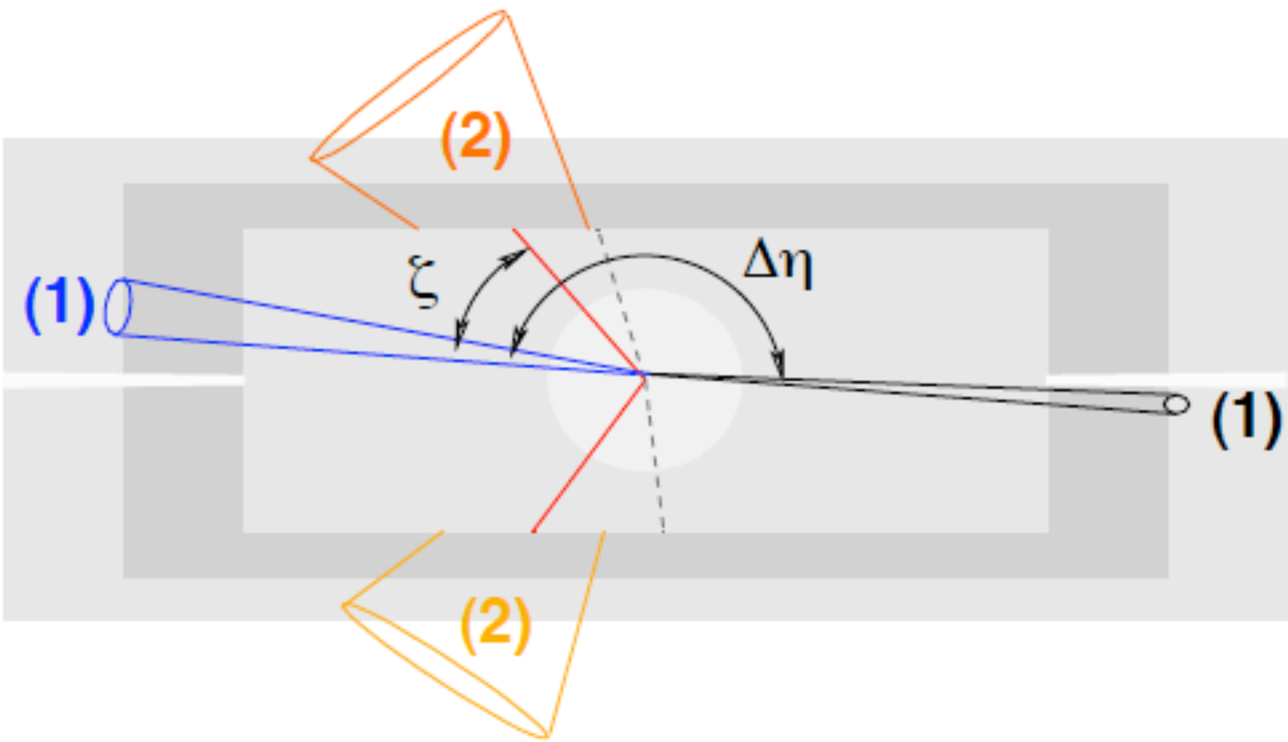
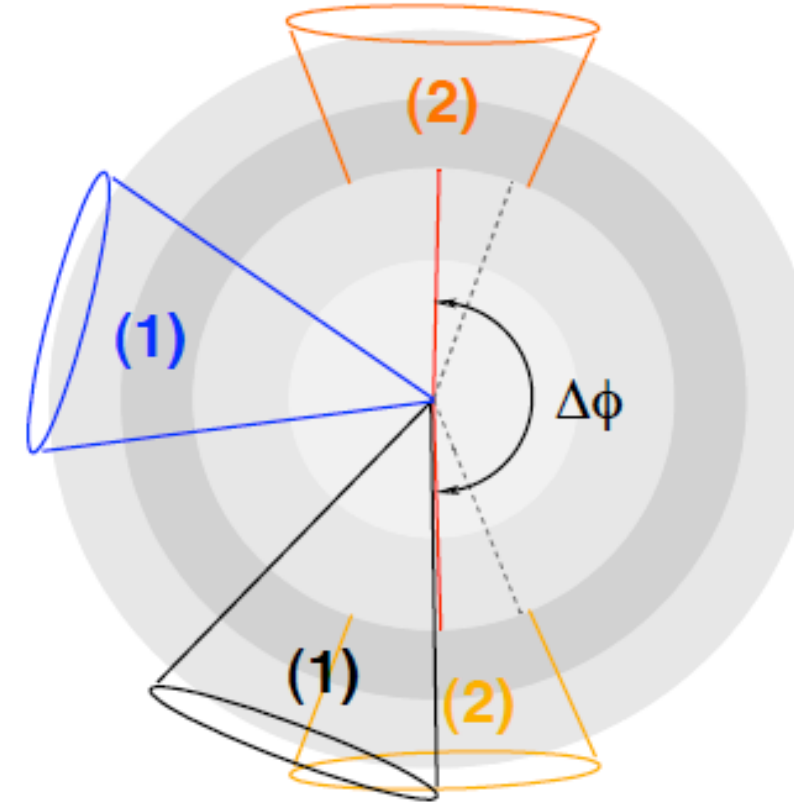
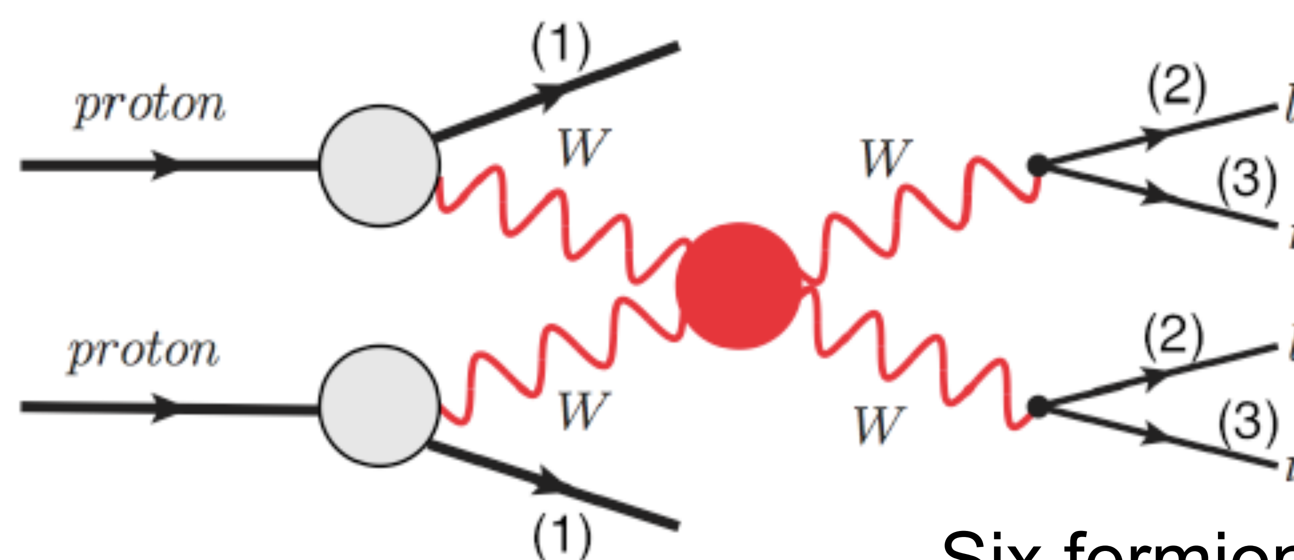


Transverse plane





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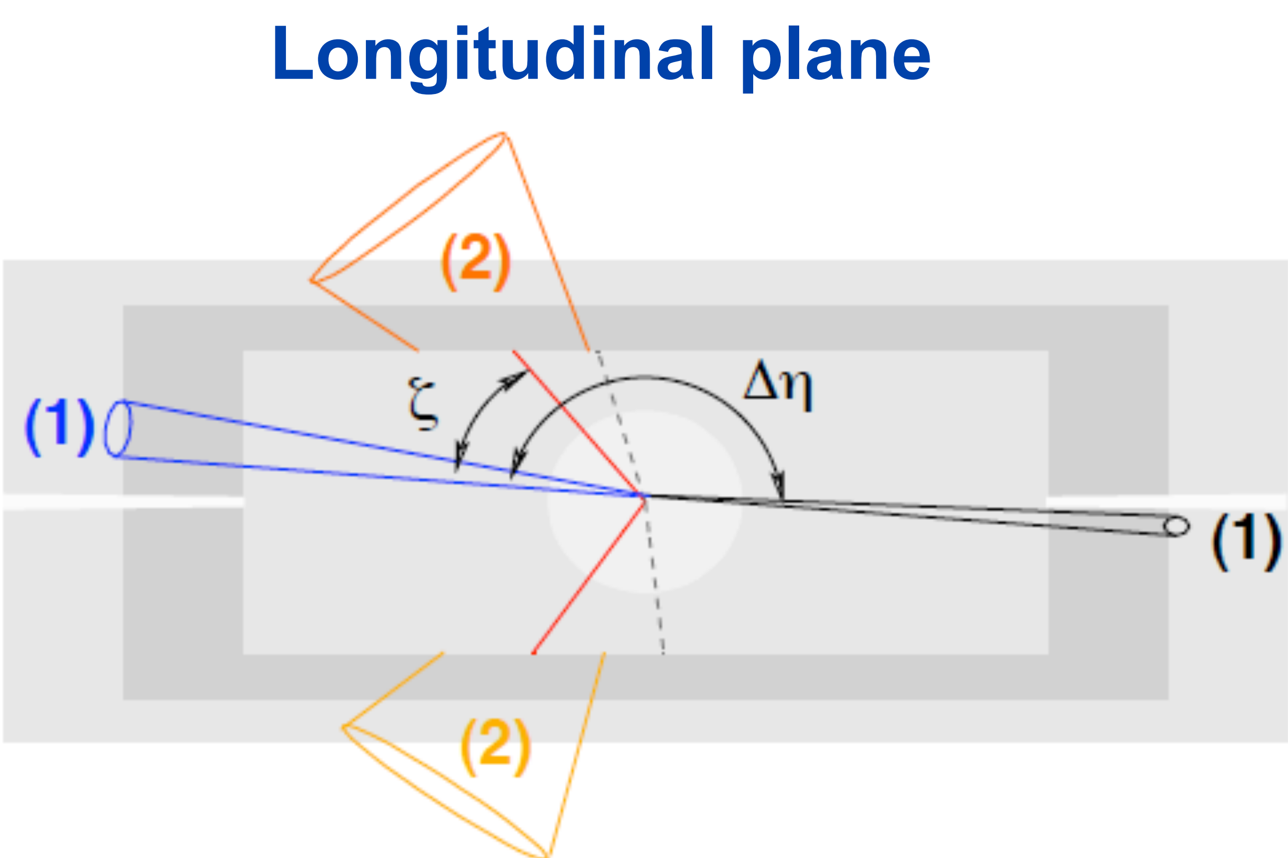
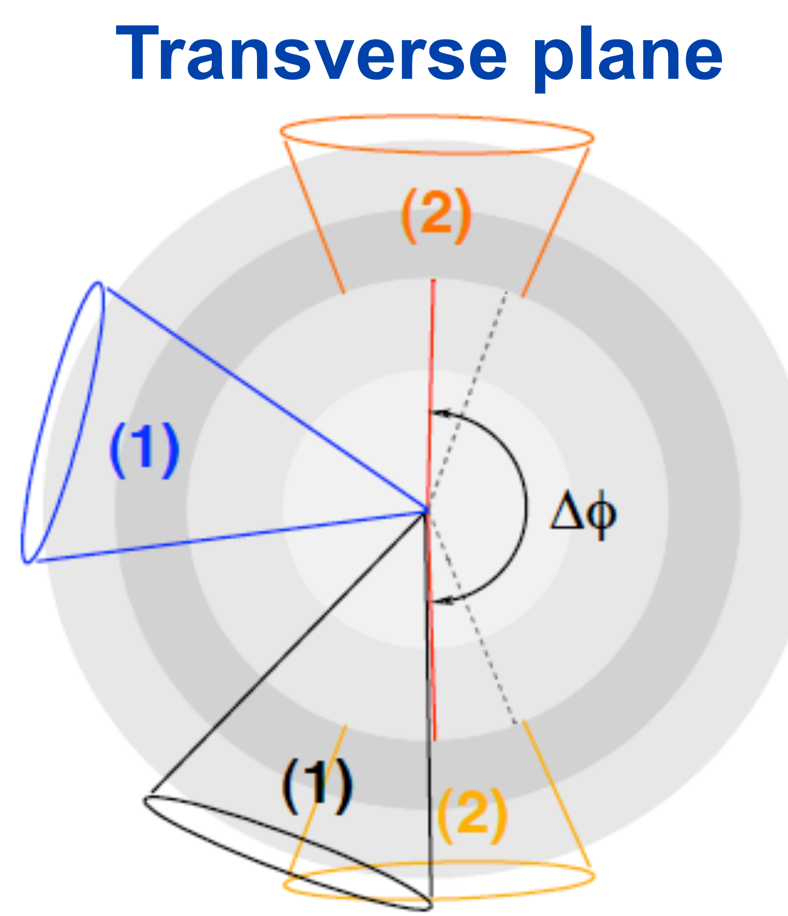
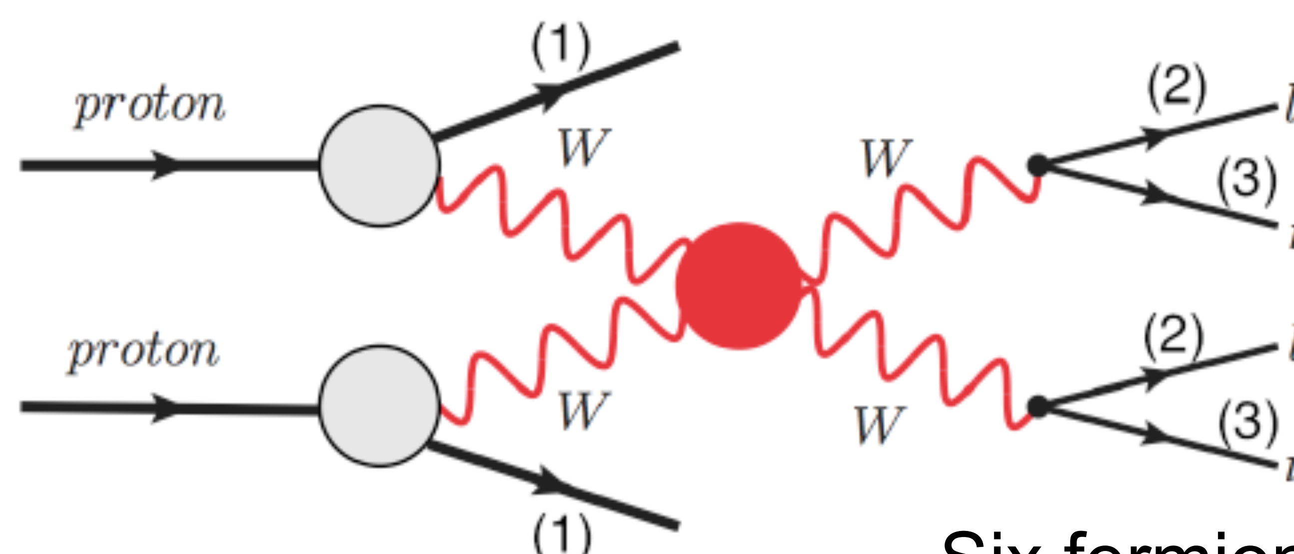




Signature: forward-backward "spectator" jets with very high energy



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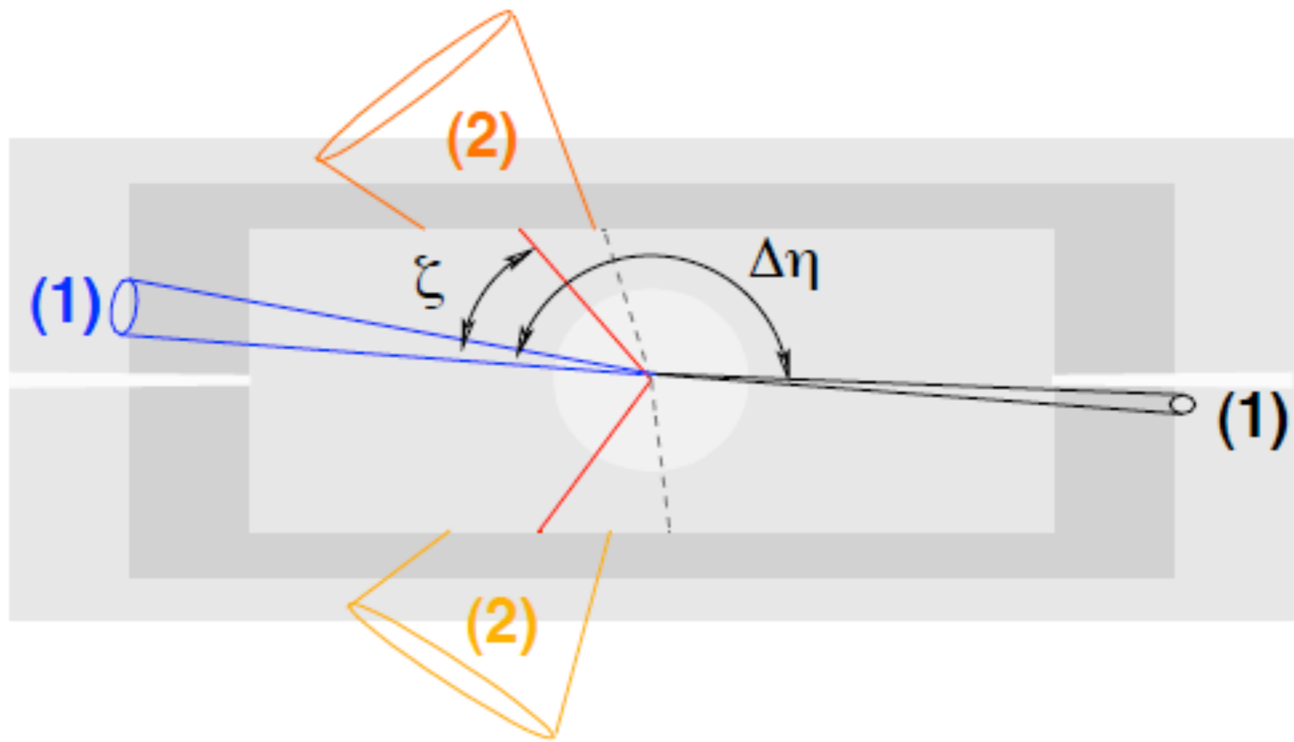

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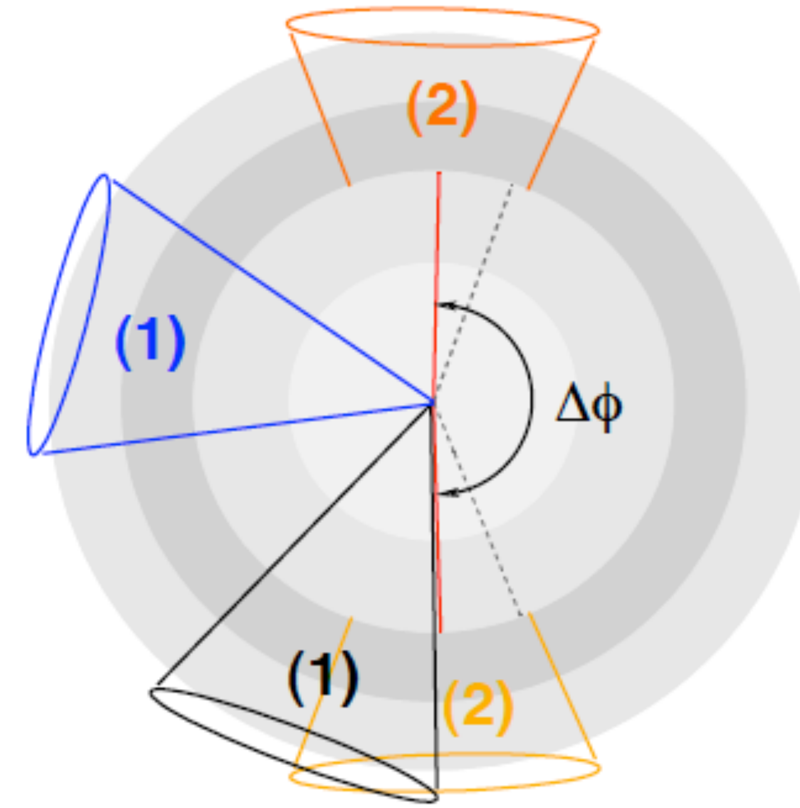
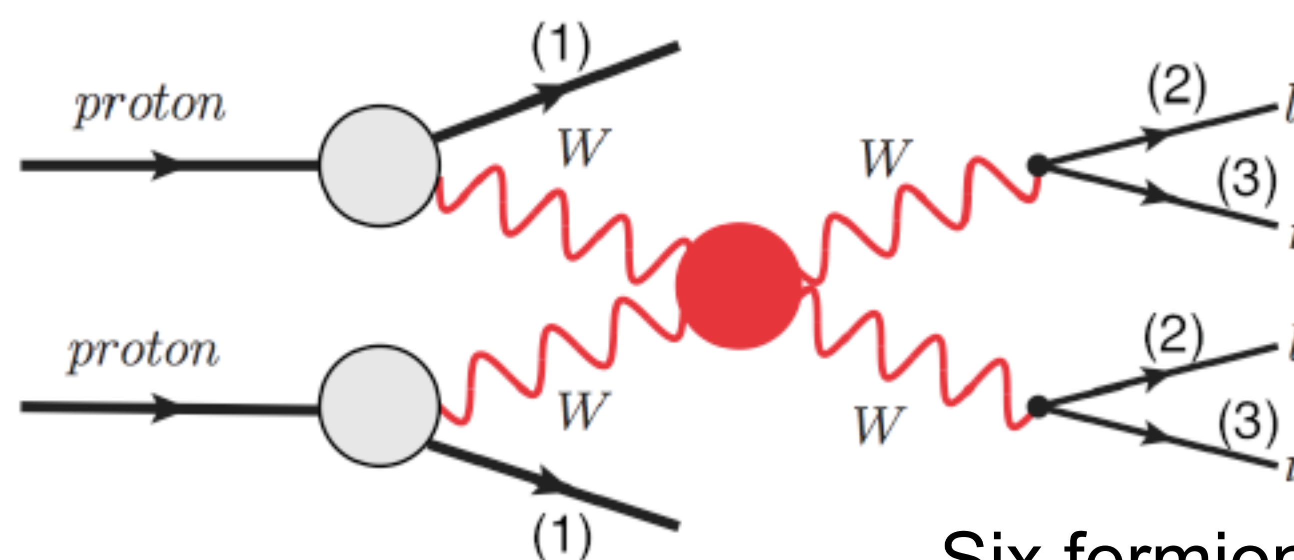


Signature: forward-backward "spectator" jets with very high energy

- *tagging jets* (1): large p_{T}, large $\Delta\eta$
- few jets between tagging jets
- final state $\ell\nu\ell\nu$:
  - *leptons* (2) between tagging jets
  - missing E_{T}(3)



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VBS final states

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- According to the vector bosons' decays we have a multitude of possible final states. We can group them in:
  - Fully leptonic
    - pp→qq ℓℓℓℓ (ℓ=μ,e)
    - pp→qq ℓℓℓν
    - pp→qq ℓℓνν
  - Semi-leptonic
    - pp→qq jetjet ℓℓ
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Can reconstruct m_{VV} (not with 2ν)

Very low yields...

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Better yields...

Large backgrounds

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    - pp→qq ℓℓνν

Clean

Can reconstruct m_{VV} (not with 2ν)

Very low yields...

  - Semi-leptonic
    - pp→qq jetjet ℓℓ
    - pp→qq jetjet ℓν

Better yields...

Large backgrounds

Detector needs

Excellent lepton ID, energy resolution, hermeticity, jet tagging at high η

VBS 2e2μ candidate event

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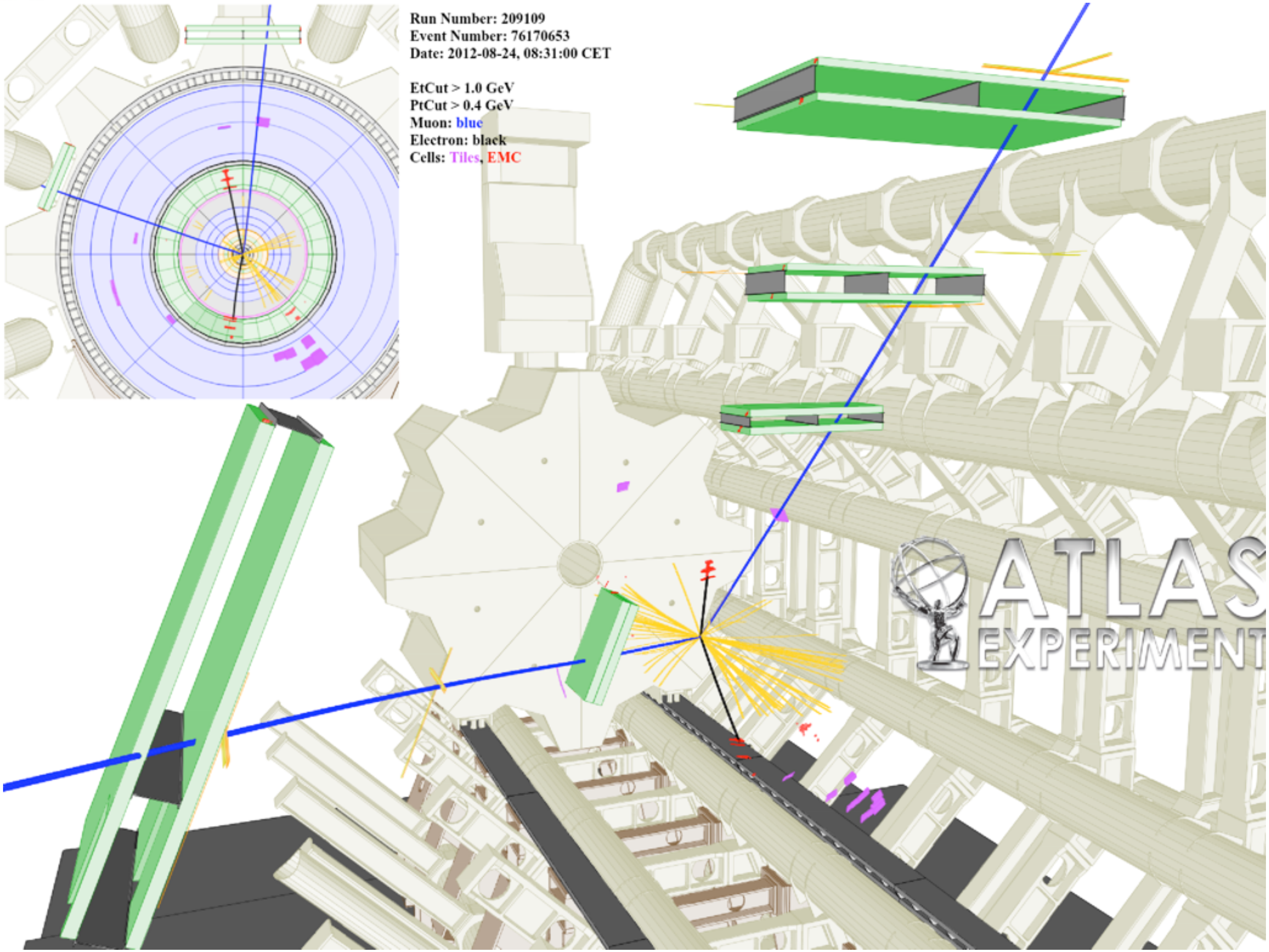
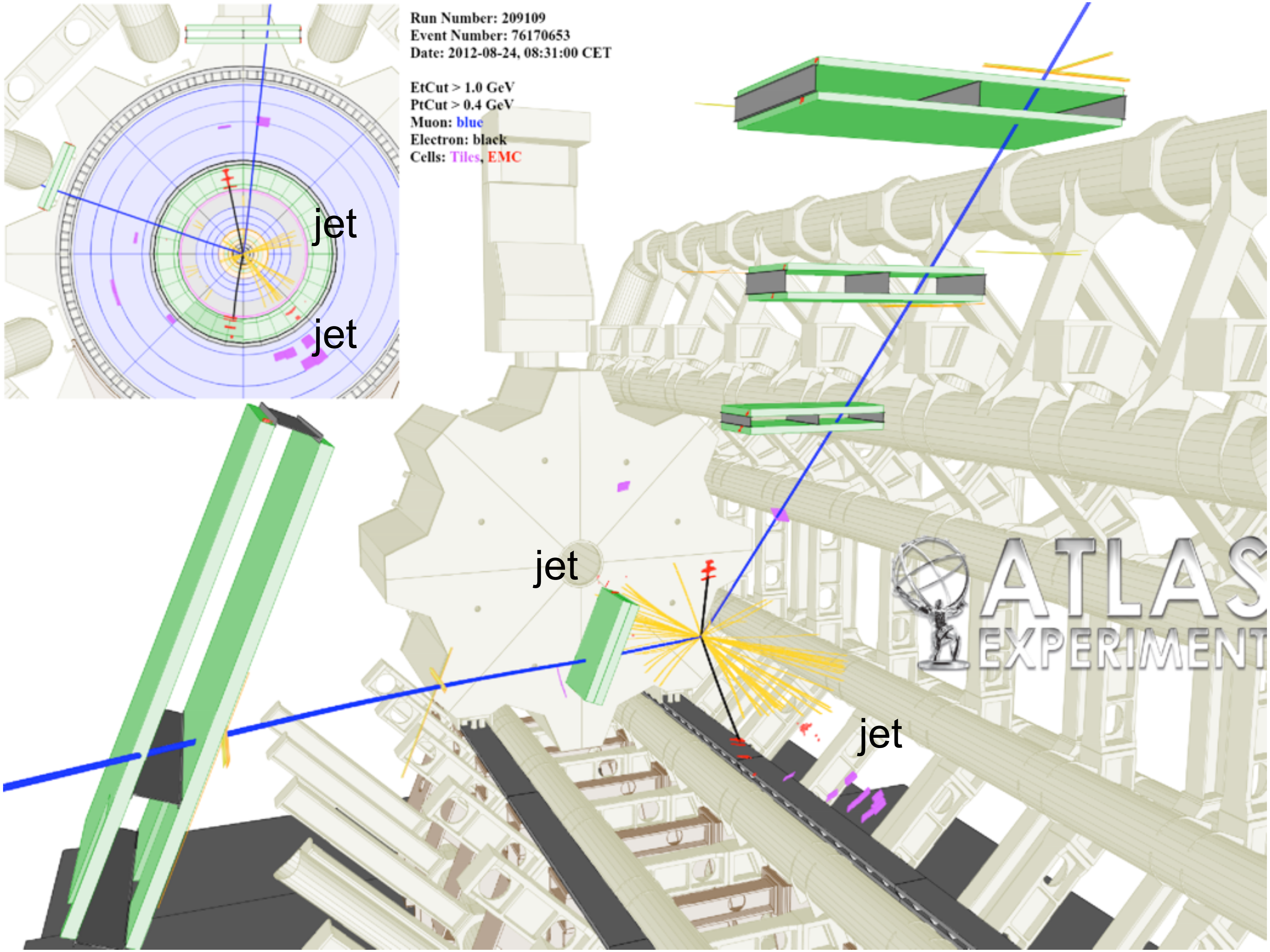


VBS 2e2μ candidate event



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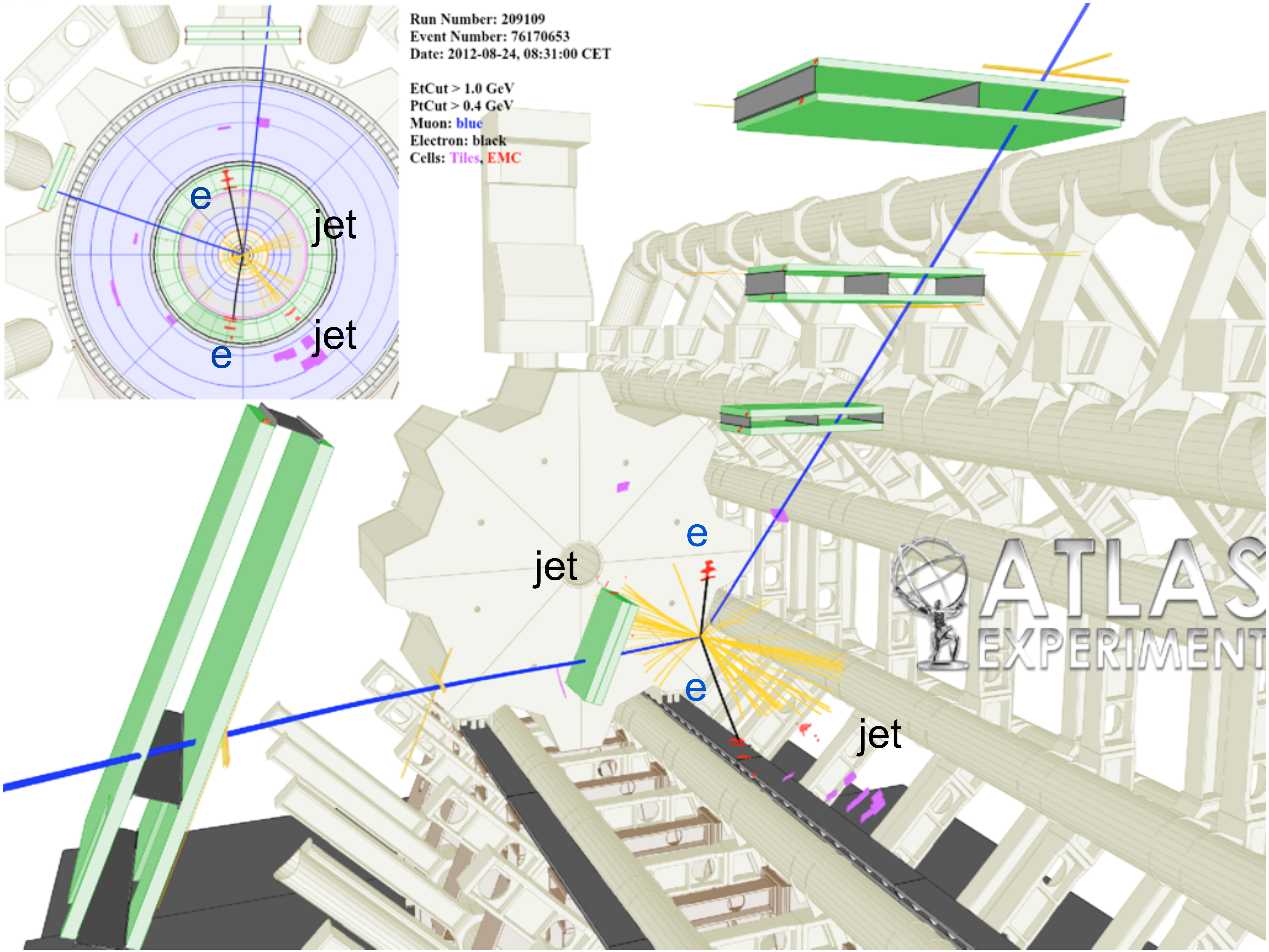

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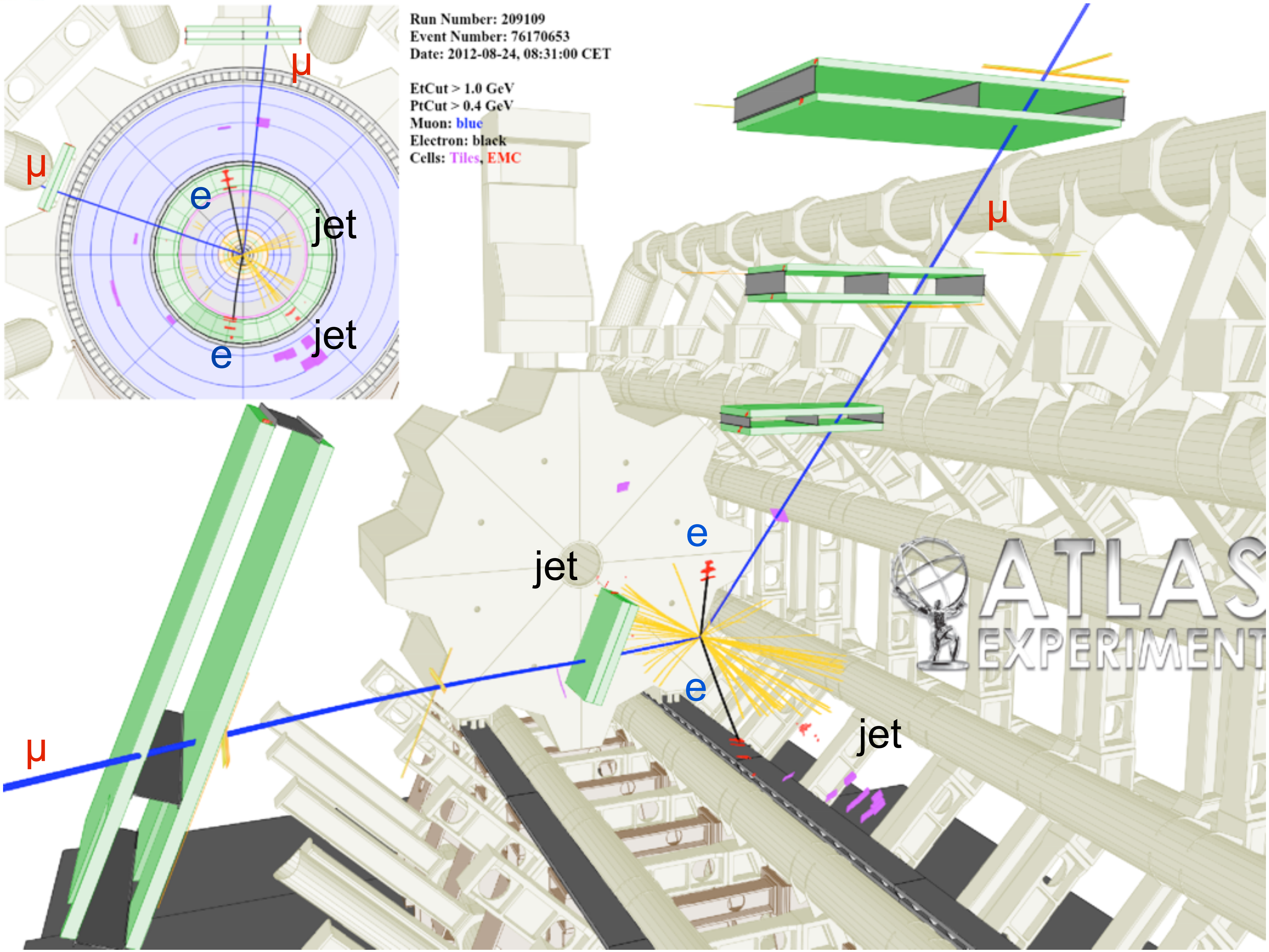

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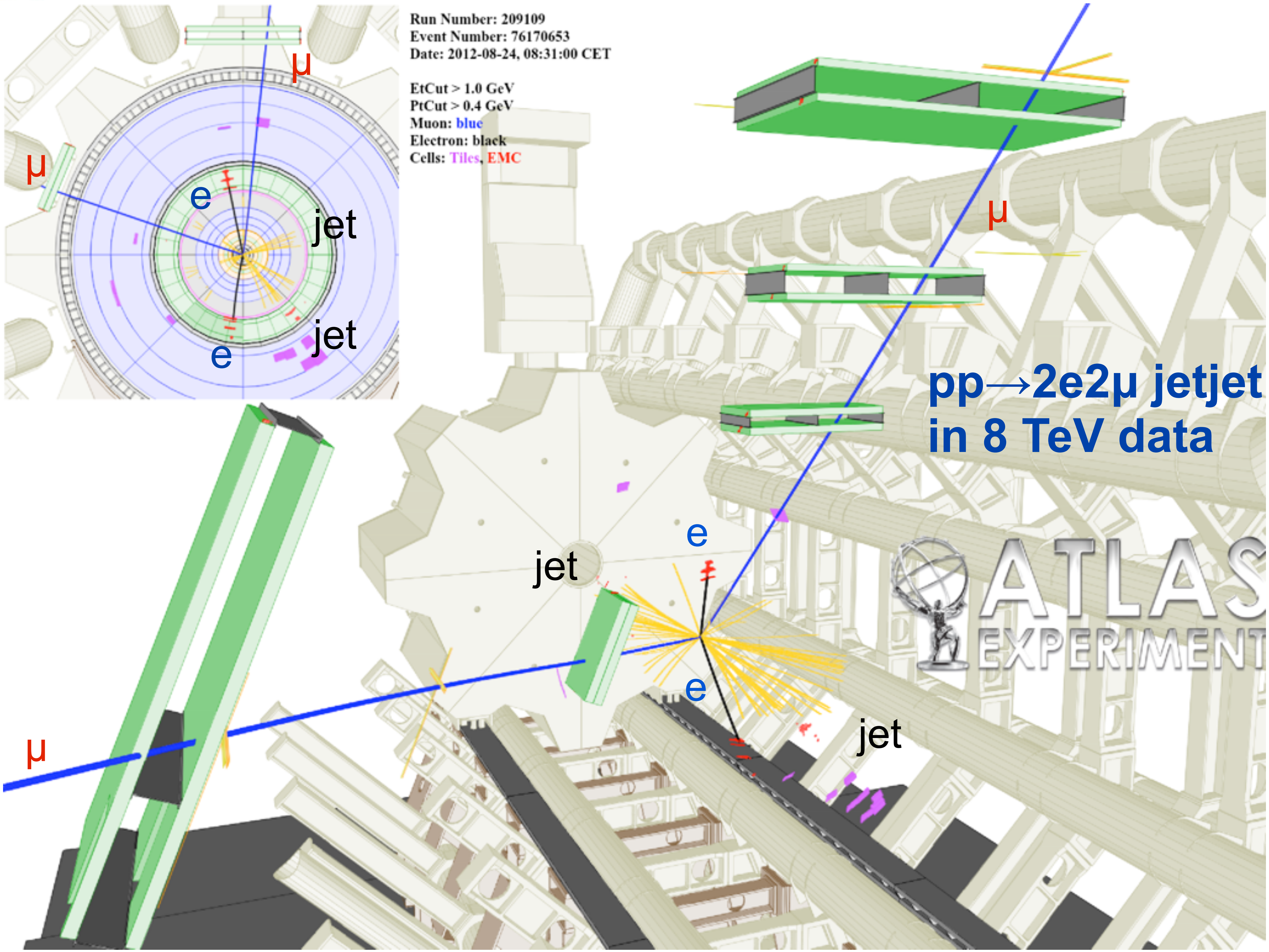

WZ resonance

WZ resonance

pp→WZ+2j→ℓ+ν+2ℓ+2j channel

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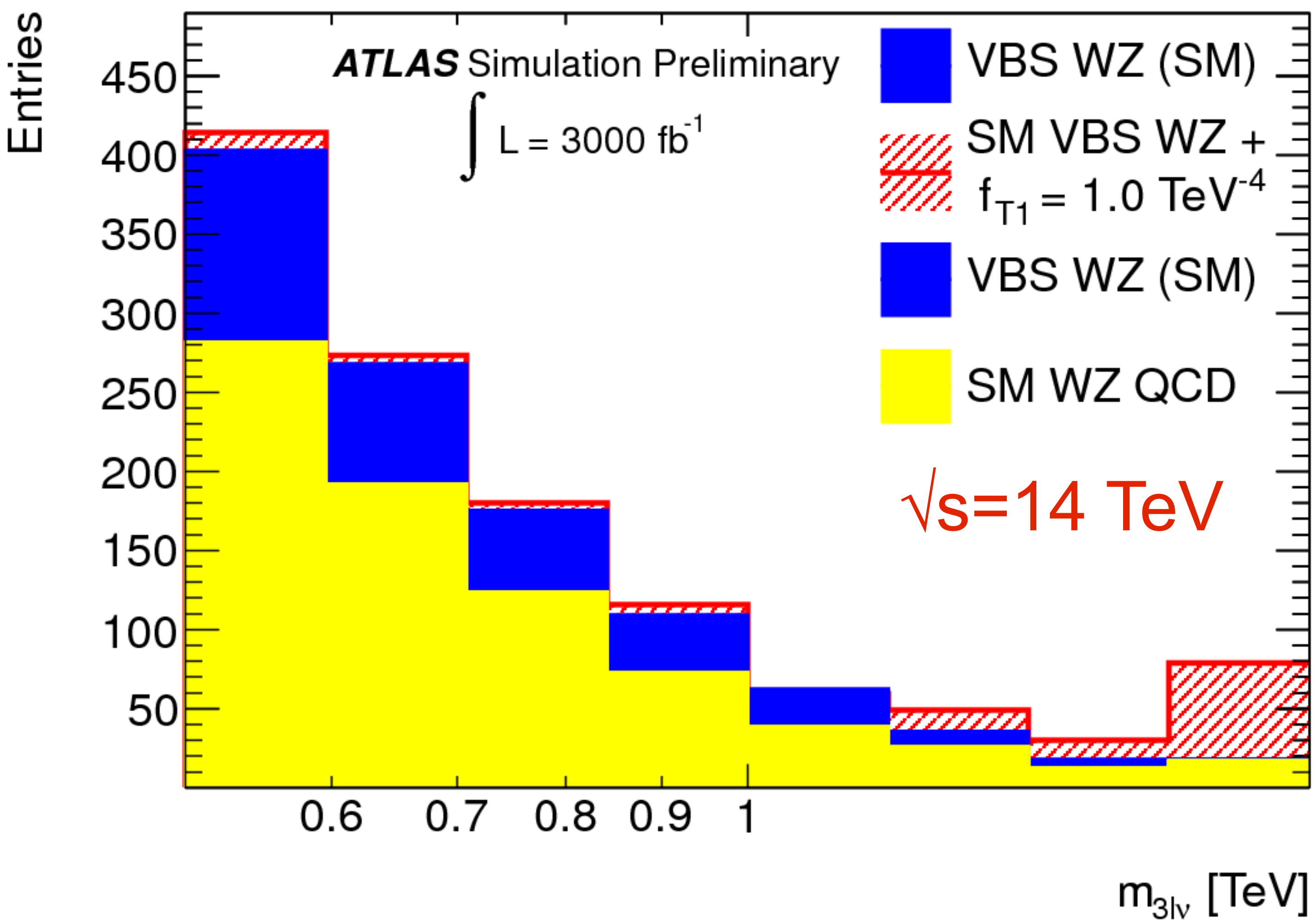

$$\mathcal{L}_{T,1} = \frac{f_{T1}}{\Lambda^4} \mathrm{Tr}[\hat{W}_{\alpha\nu}\hat{W}^{\mu\beta}] \times \mathrm{Tr}[\hat{W}_{\mu\beta}\hat{W}^{\alpha\nu}]$$

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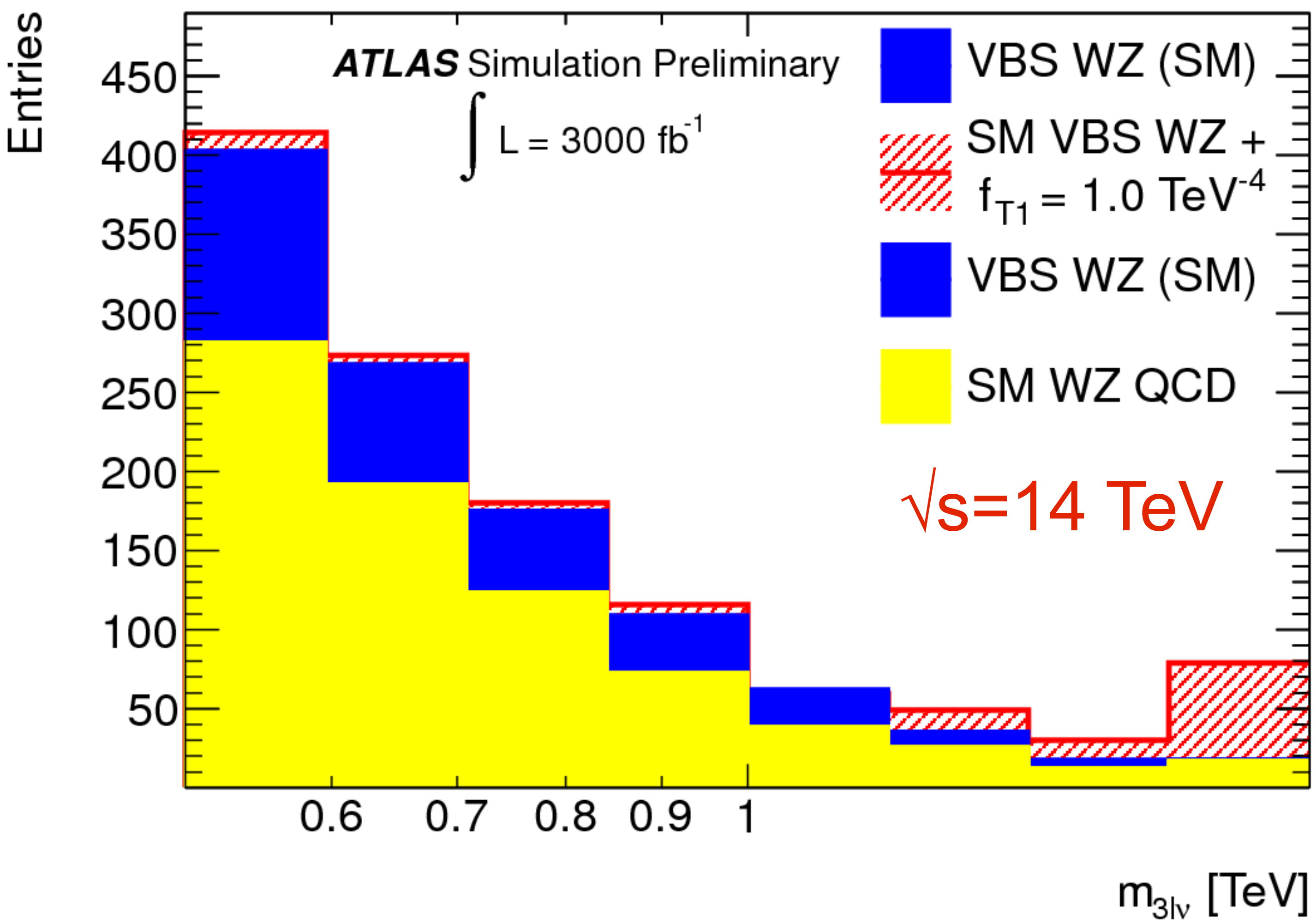

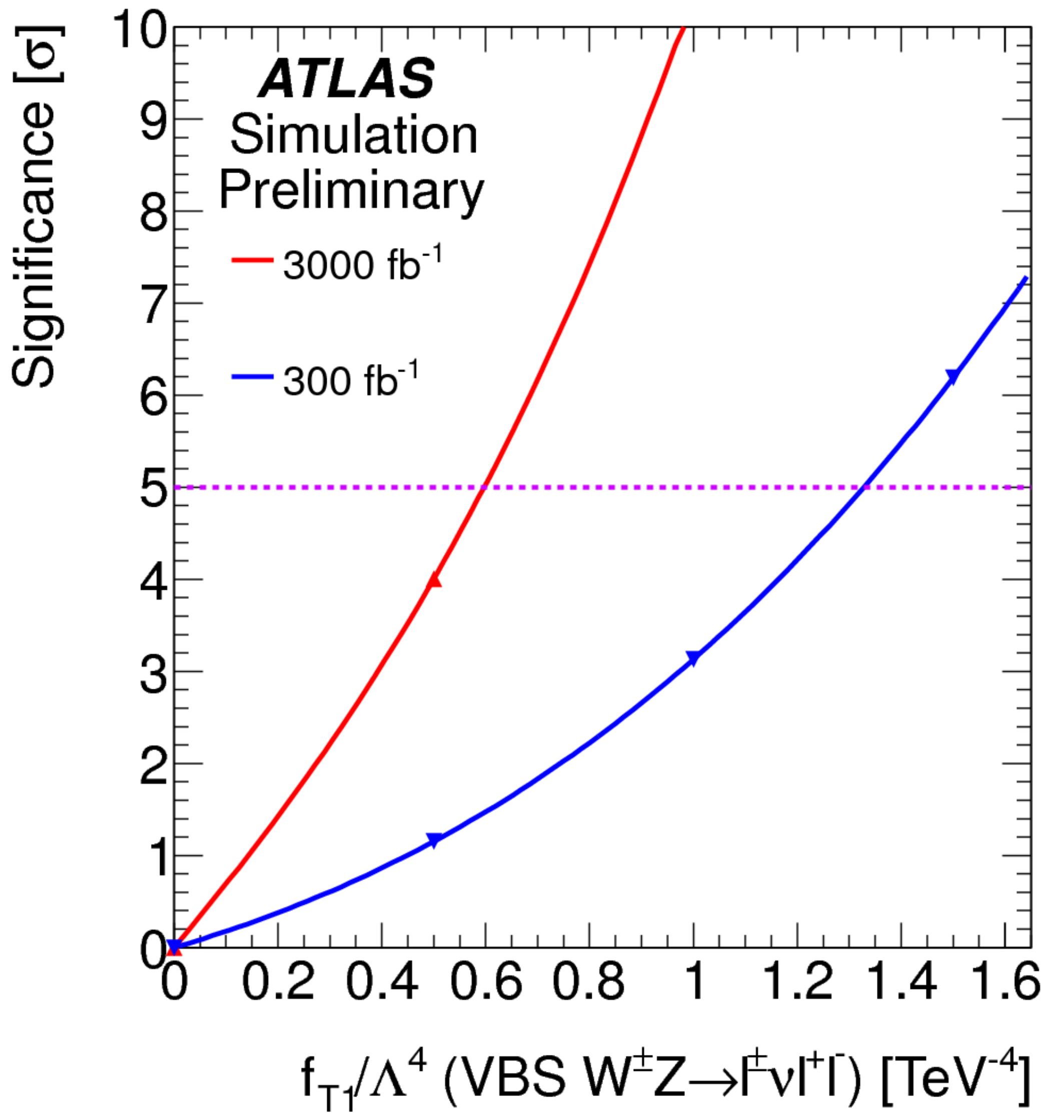

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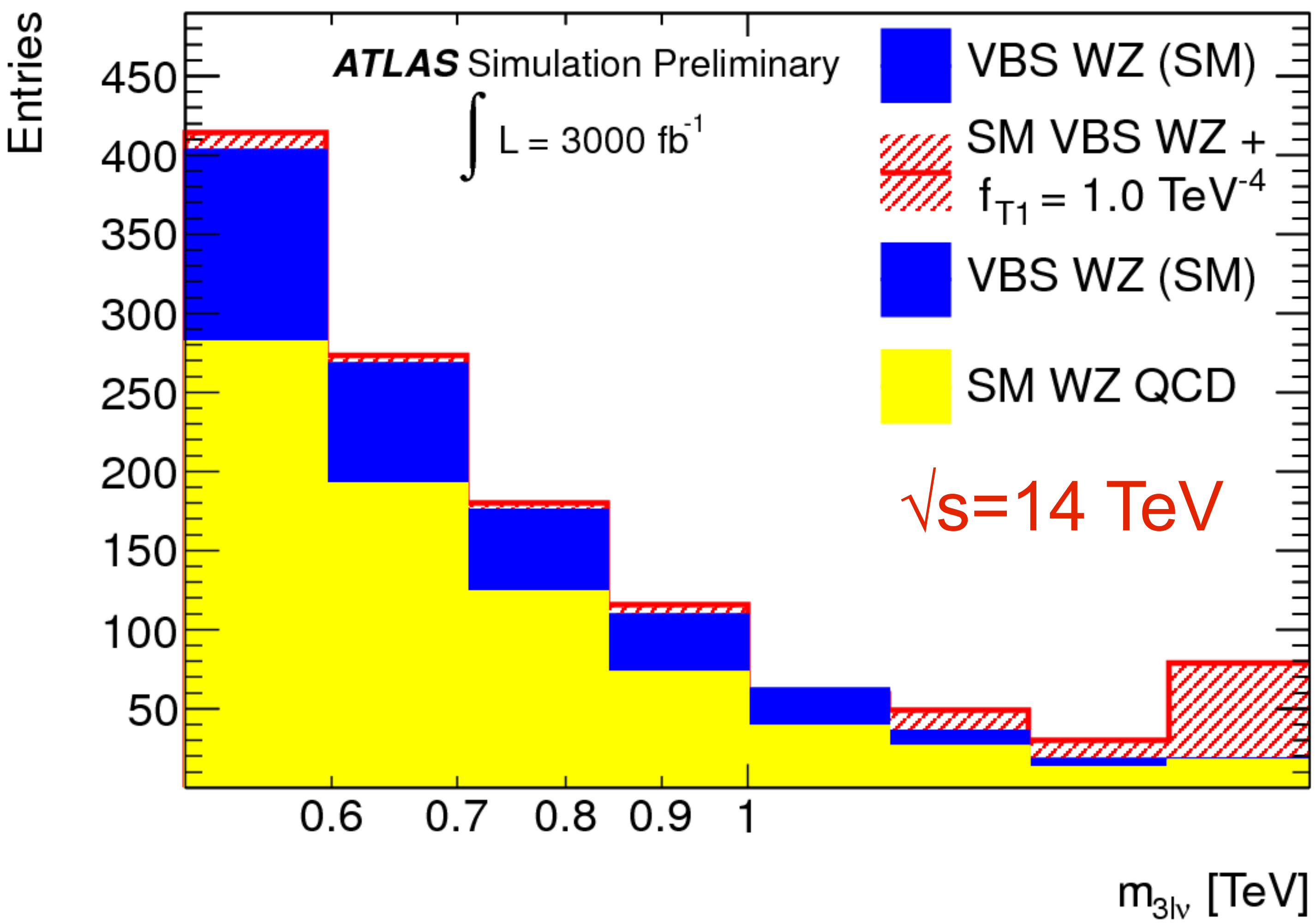

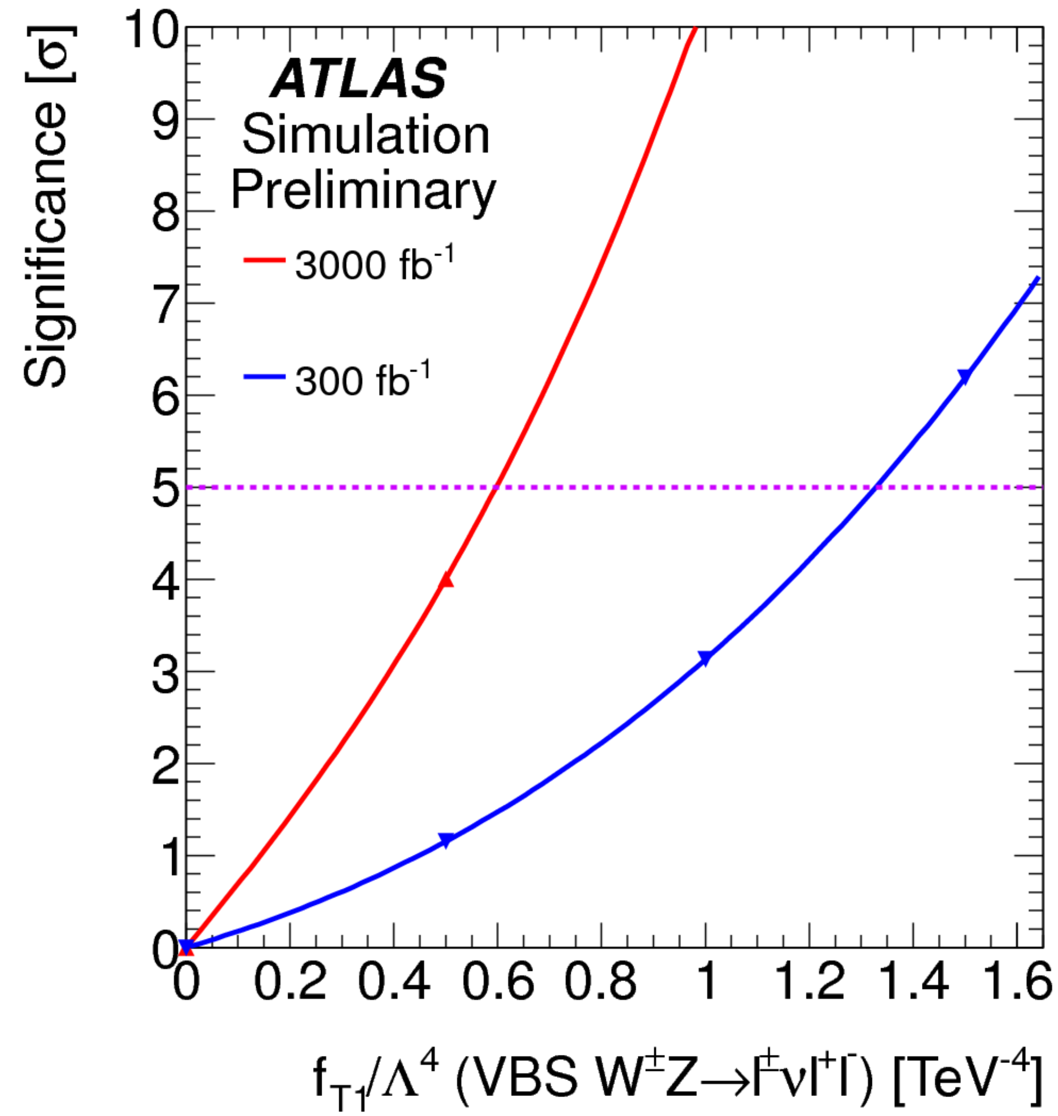

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	300 fb^{-1}	3000 fb^{-1}
f_{T1}/Λ^4	1.3 TeV^{-4}	0.6 TeV^{-4}

Sensitivity to anomalous WZ resonances in Vector boson scattering

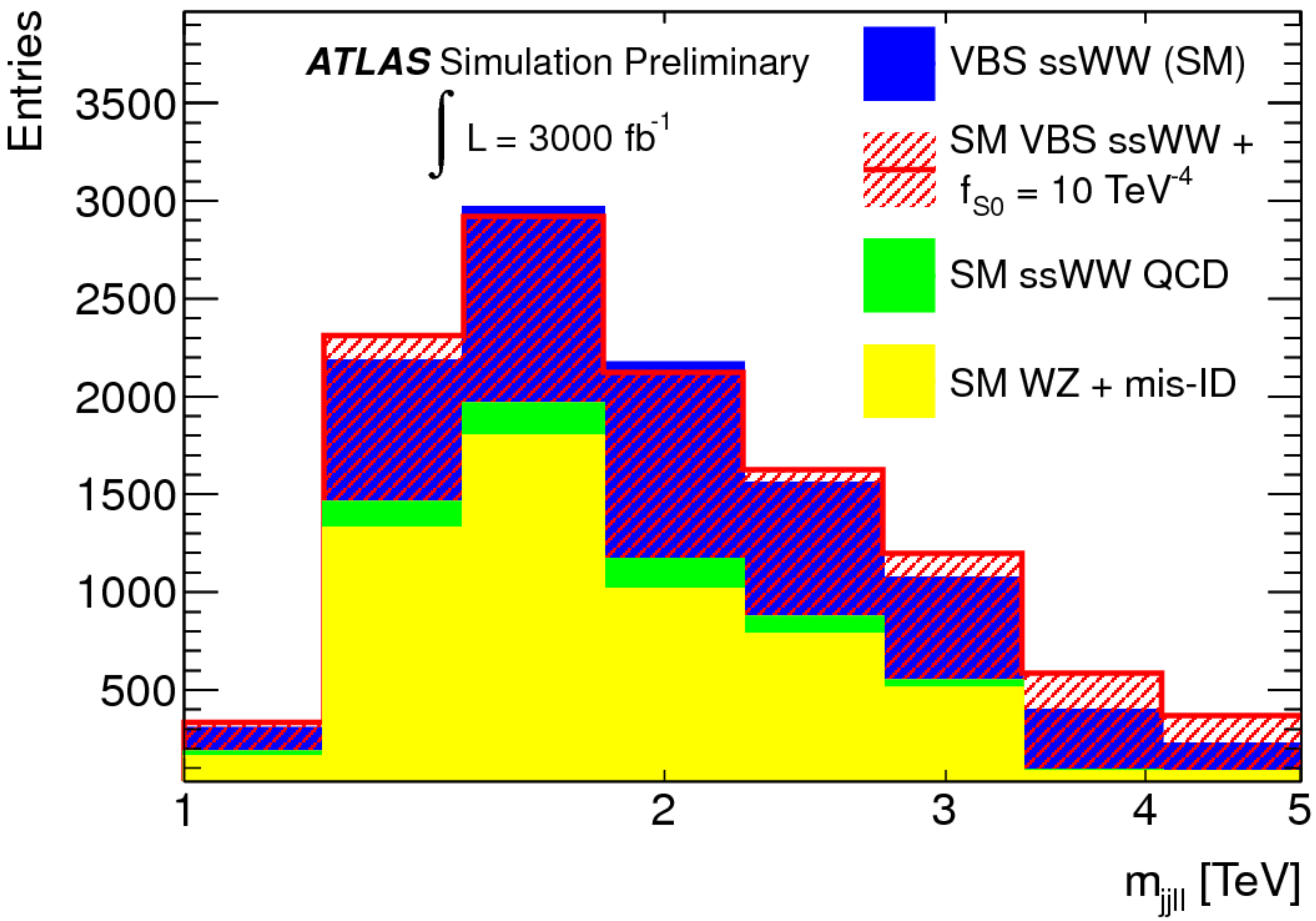
WW resonance

WW resonance

pp→WW+2j→2ℓ+2ν+2j channel

WW resonance

pp→WW+2j→2ℓ+2ν+2j channel



$$\mathcal{L}_{S,0} = \frac{f_{S0}}{\Lambda^4}[(D_\mu\phi)^\dagger D_\nu\phi)] \times [(D^\mu\phi)^\dagger D^\nu\phi)]$$

WW resonance

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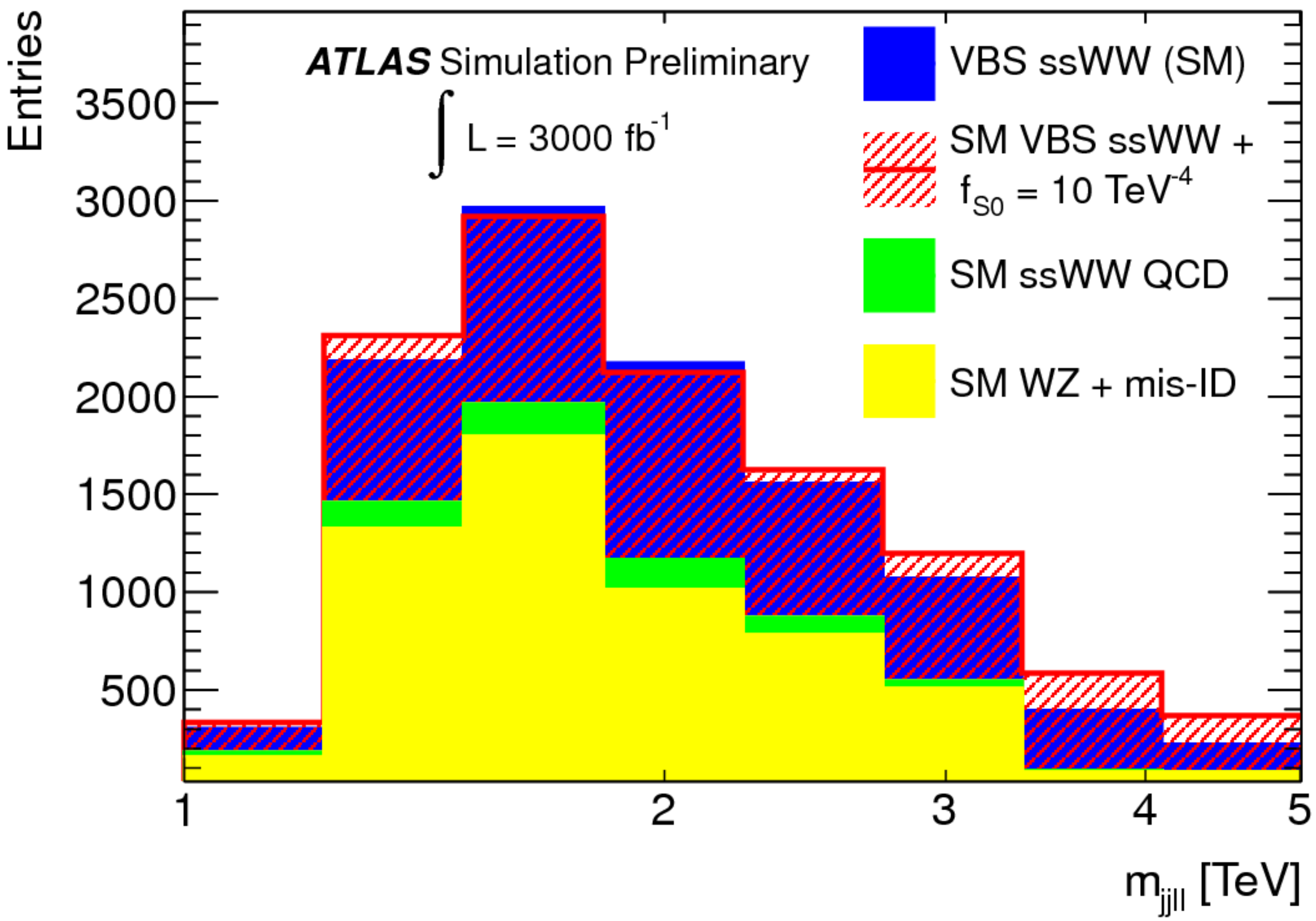

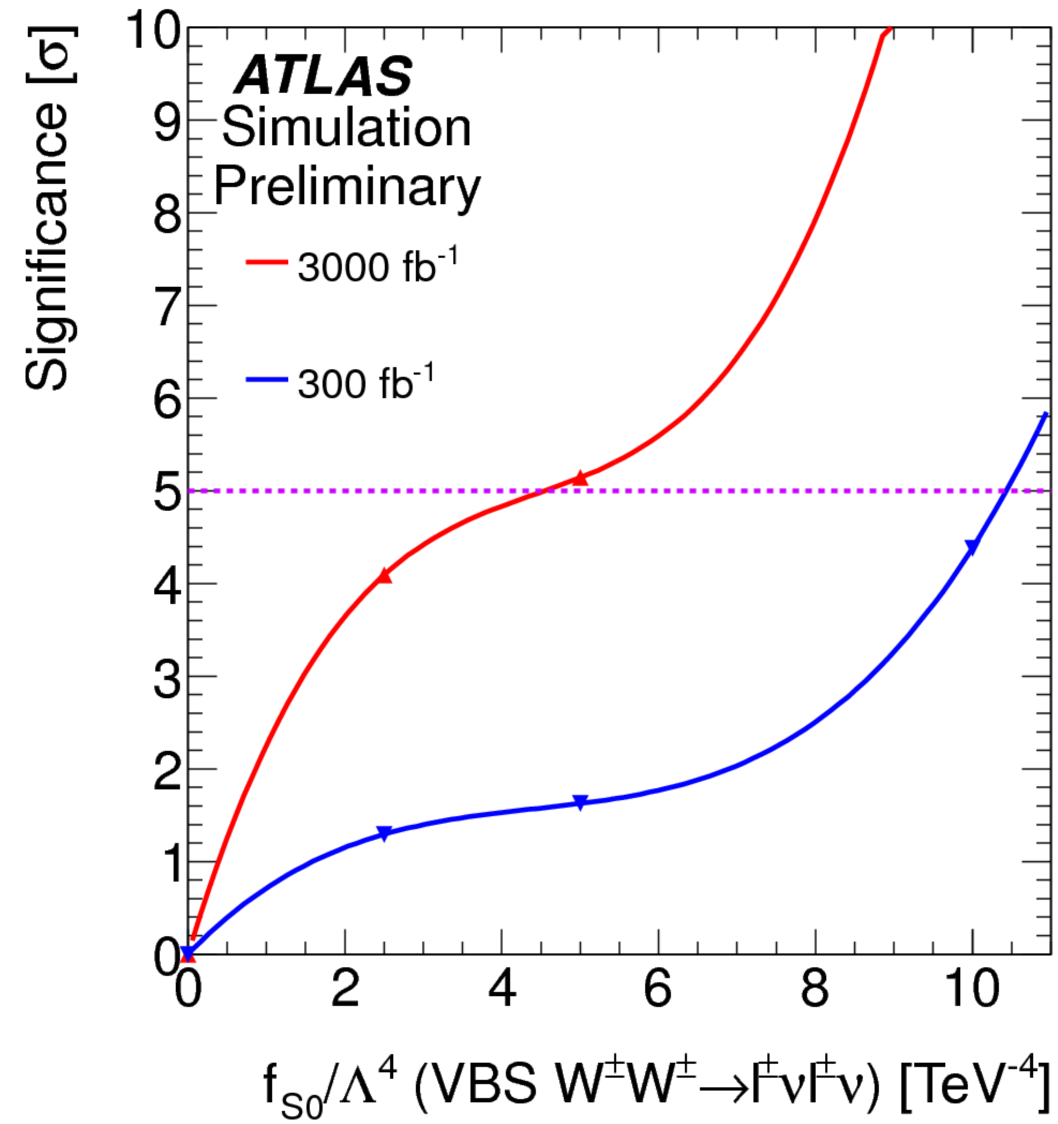

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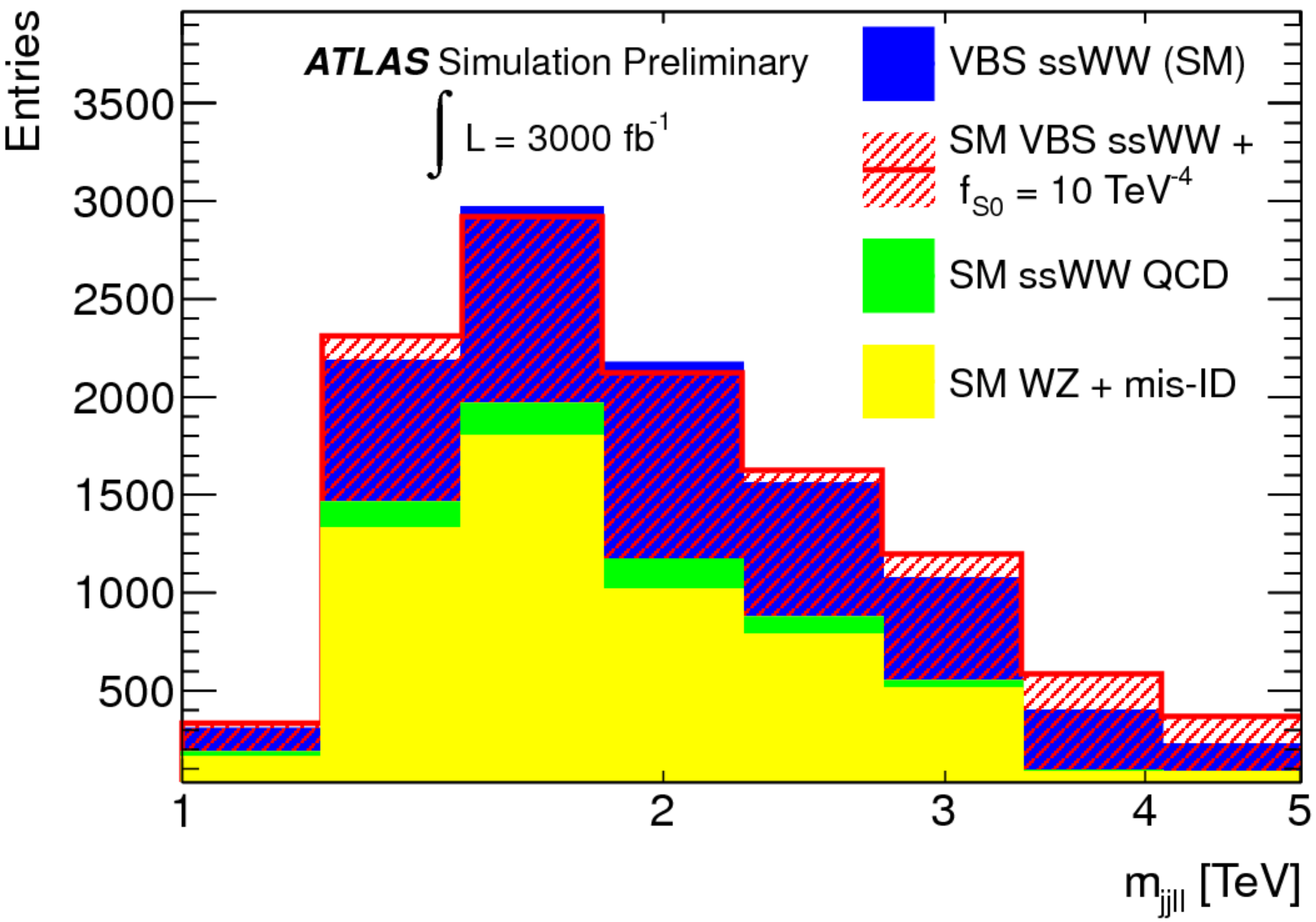

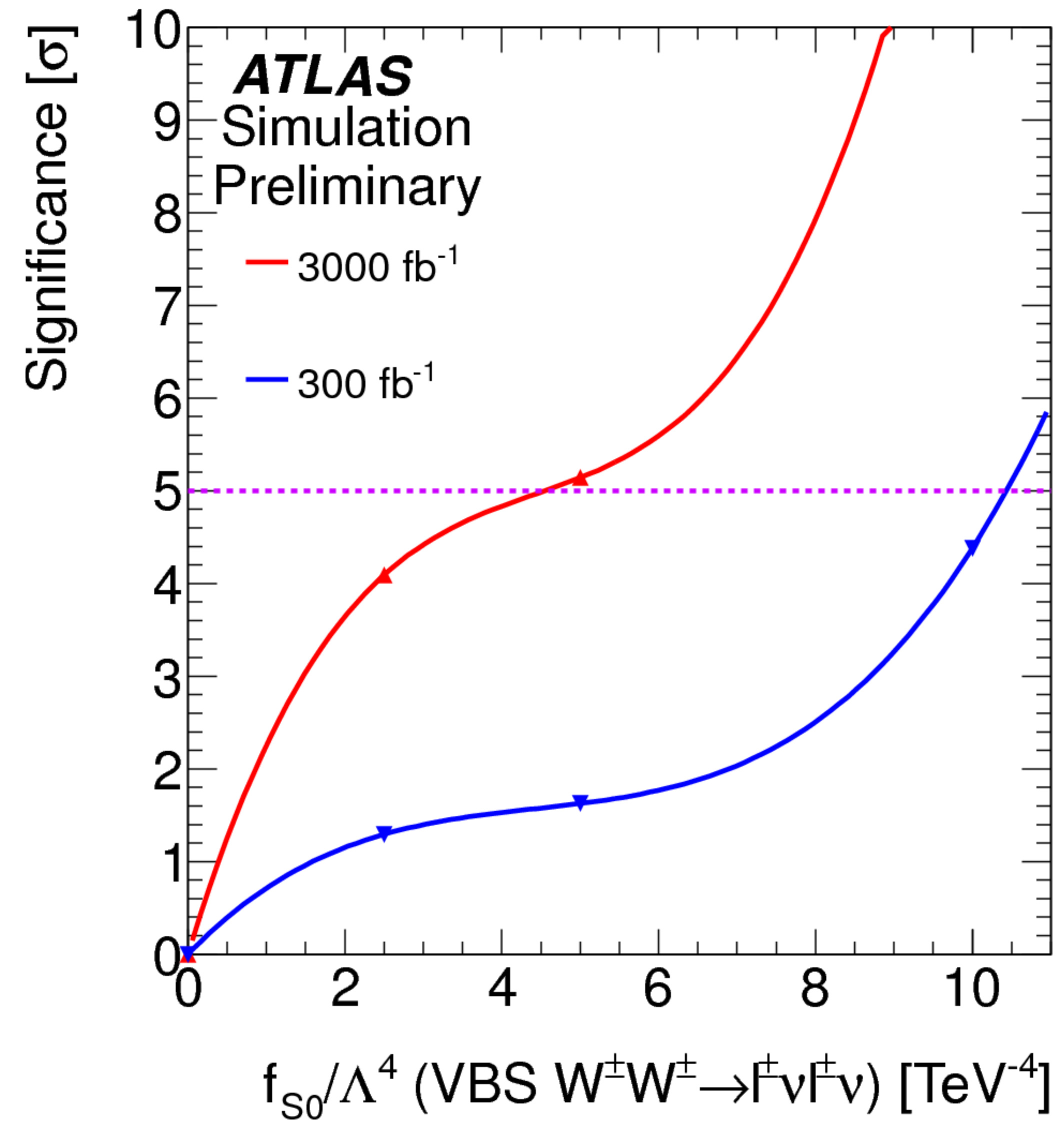

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model	300 fb^{-1}	3 ab^{-1}
f_{S0}/Λ^4	10 TeV^{-4}	4.5 TeV^{-4}

Sensitivity to anomalous WW resonances in Vector boson scattering

Conclusions

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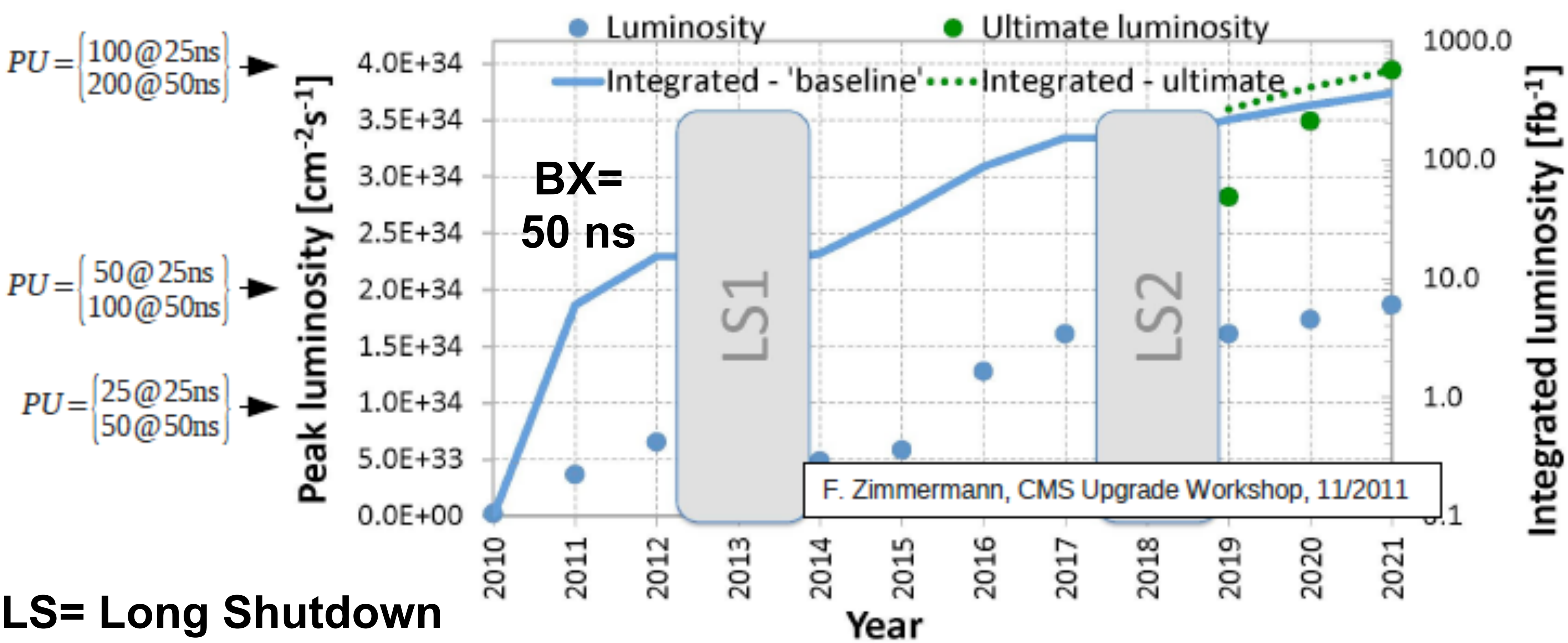
  - Higgs self-coupling studies possible
  - VV scattering will be probed
- LHC has an exciting physics program for the next twenty years!

Backup

LHC and HL-LHC

LHC | HL-LHC



Luminosity-leveled at $5x10^{34}$ $cm^{-2}s^{-1}$ in HL-LHC

LS= Long Shutdown

L

$L_{instantaneous}$
$L_{integrated}$
Pile Up

LHC and HL-LHC

LHC

Energy increase
8 TeV to 13/14 TeV

HL-LHC

$PU=\left\{\begin{matrix}100@25ns\\200@50ns\end{matrix}\right\}$ →

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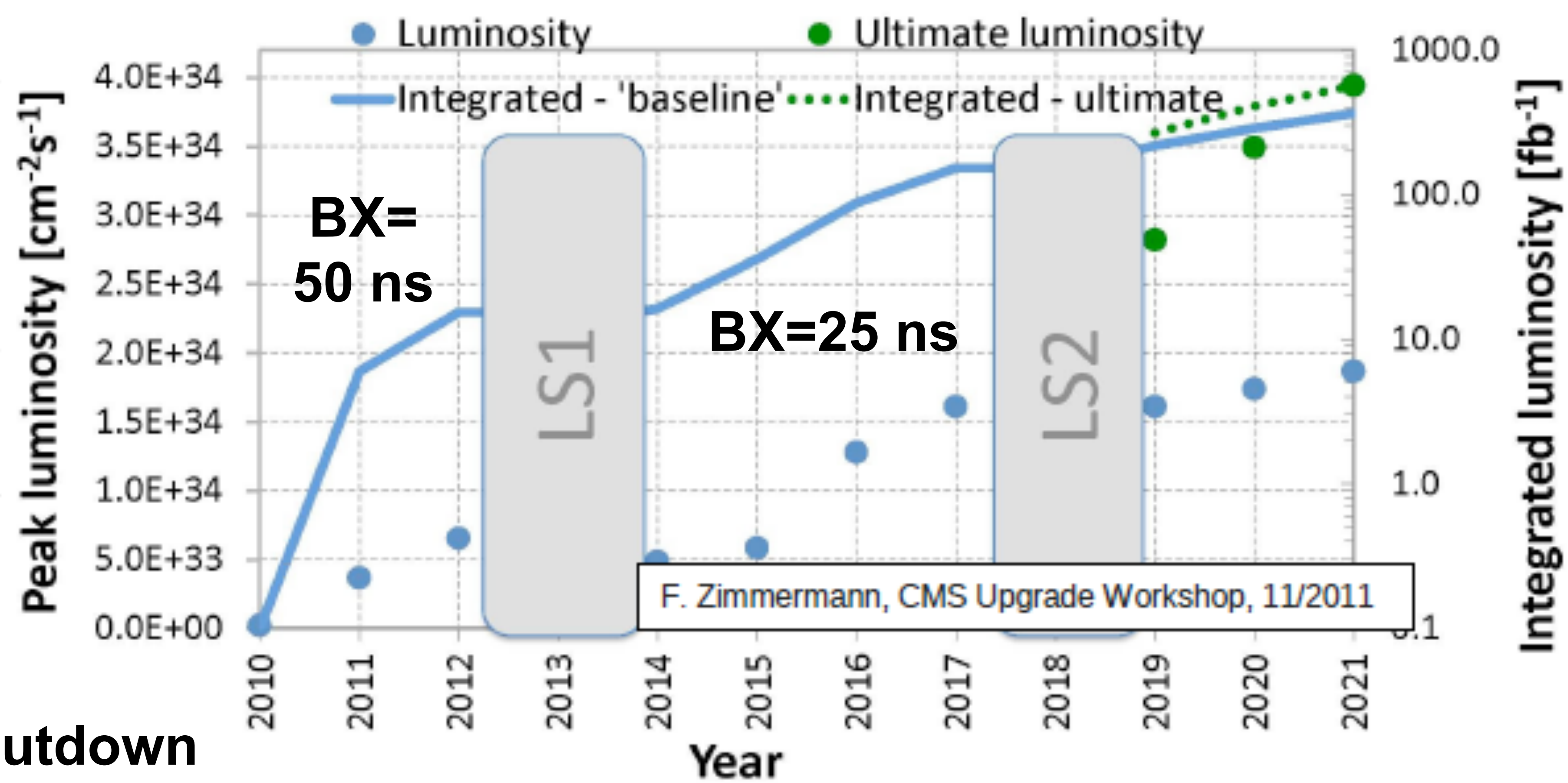

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LS= Long Shutdown

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Pile Up

→ LS1 → LS3 →

LHC and HL-LHC

LHC	Energy increase 8 TeV to 13/14 TeV	Injection upgrade	HL-LHC

$PU = \left\{ \begin{array}{l} 100@25ns \\ 200@50ns \end{array} \right\} \rightarrow$

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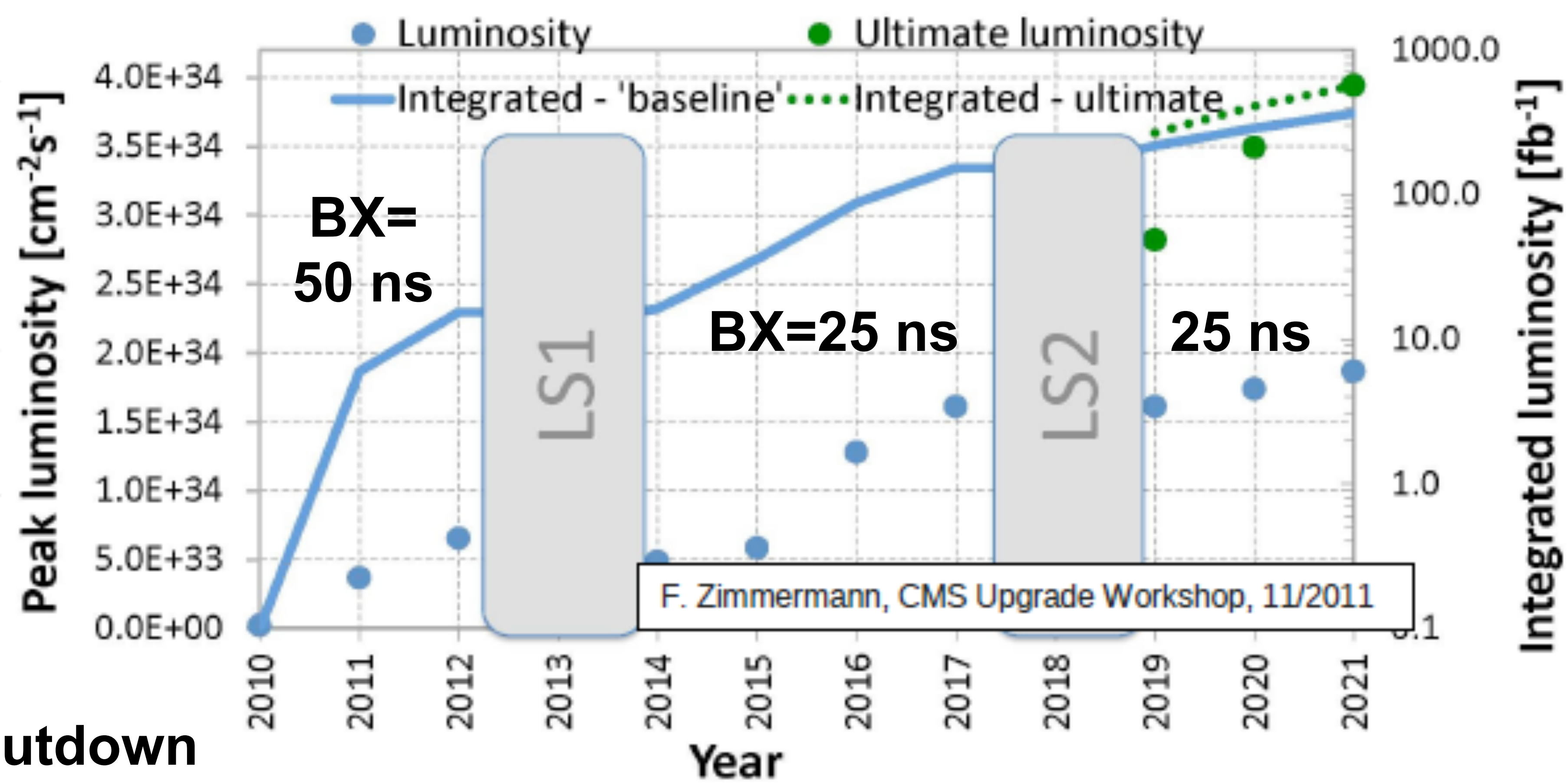

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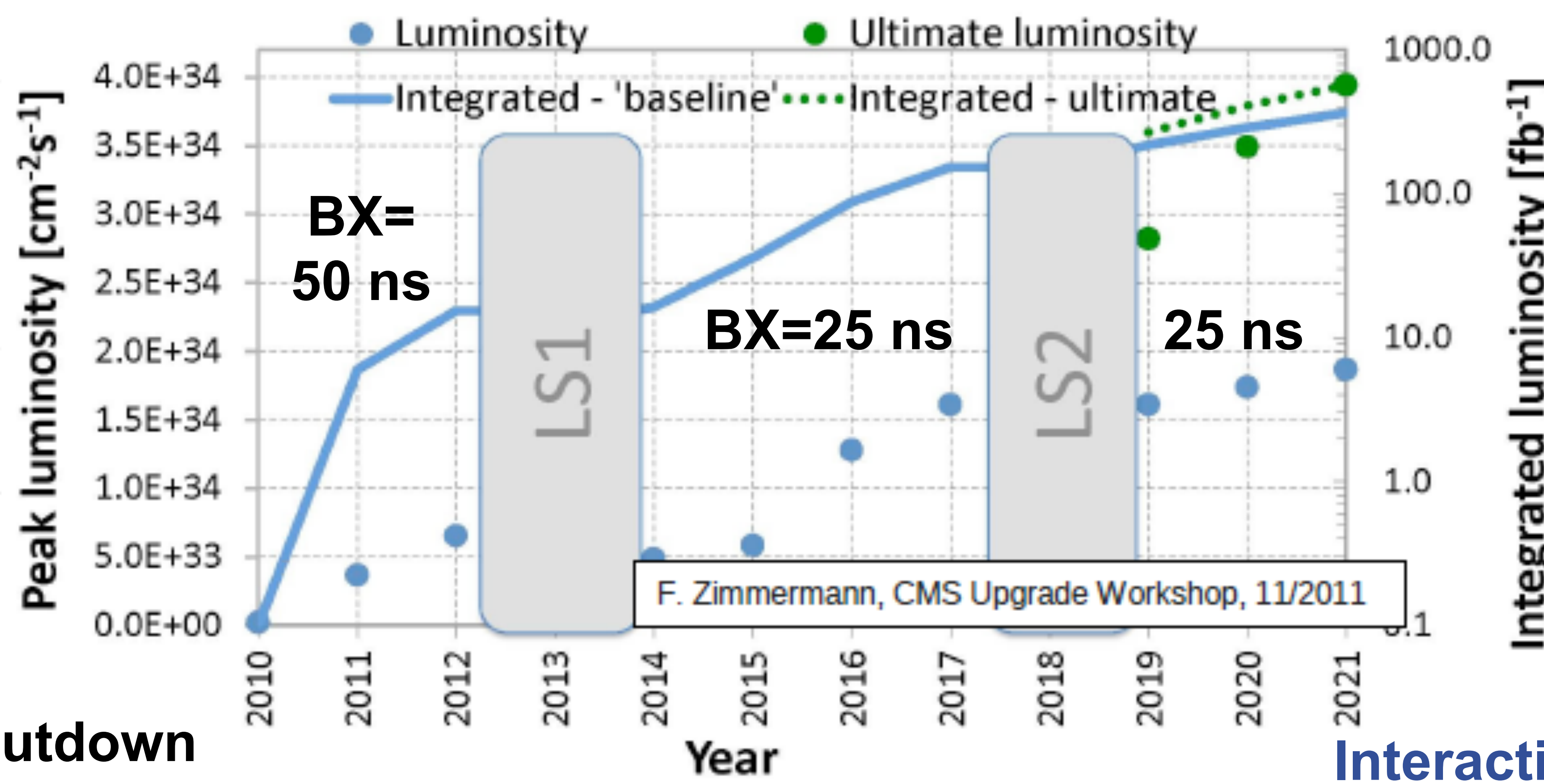

Luminosity-leveled at 5×10^{34} cm^{-2}s^{-1} in HL-LHC

LS= Long Shutdown

Interaction region upgrade

$L_{instantaneous}$

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Pile Up

→ LS1 → LS3 →

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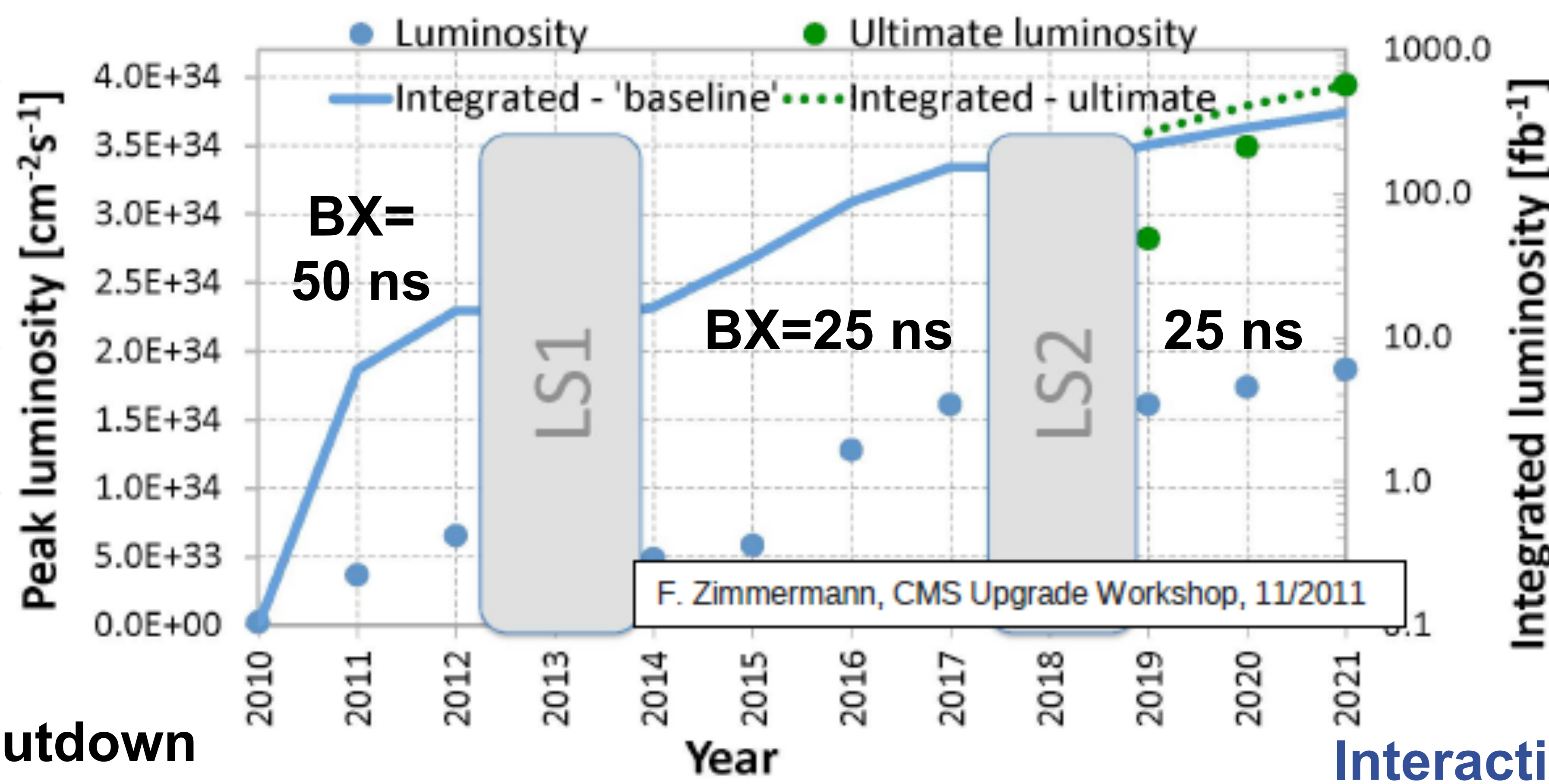

Luminosity-leveled at $5x10^{34}$ $cm^{-2}s^{-1}$ in HL-LHC

LS= Long Shutdown

Interaction region upgrade

$L_{instantaneous}$ $8x10^{33}$ Hz/cm^2

$L_{integrated}$ 30 fb^{-1}

Pile Up PU ~40

LS1 → LS3 →

LHC and HL-LHC

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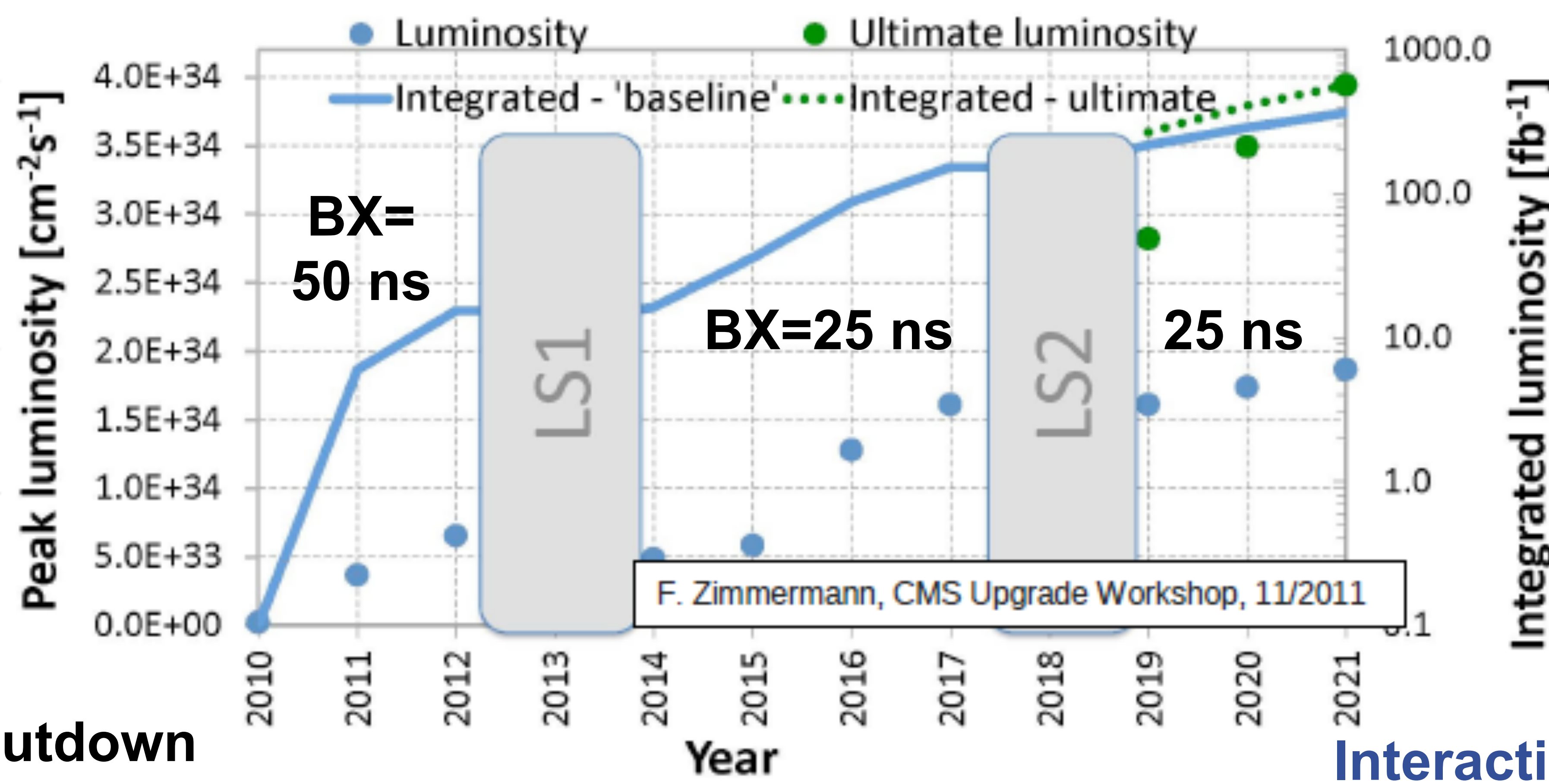

Luminosity-leveled at $5x10^{34}$ $cm^{-2}s^{-1}$ in HL-LHC

LS= Long Shutdown

Interaction region upgrade

	LHC (before LS1)	Between LS1 and LS3
$L_{instantaneous}$	$8x10^{33}$ Hz/cm^2	$2x10^{34}$ Hz/cm^2
$L_{integrated}$	30 fb^{-1}	300 fb^{-1}
Pile Up	PU ~40	PU ~50

LS1 → LS3 →

LHC and HL-LHC

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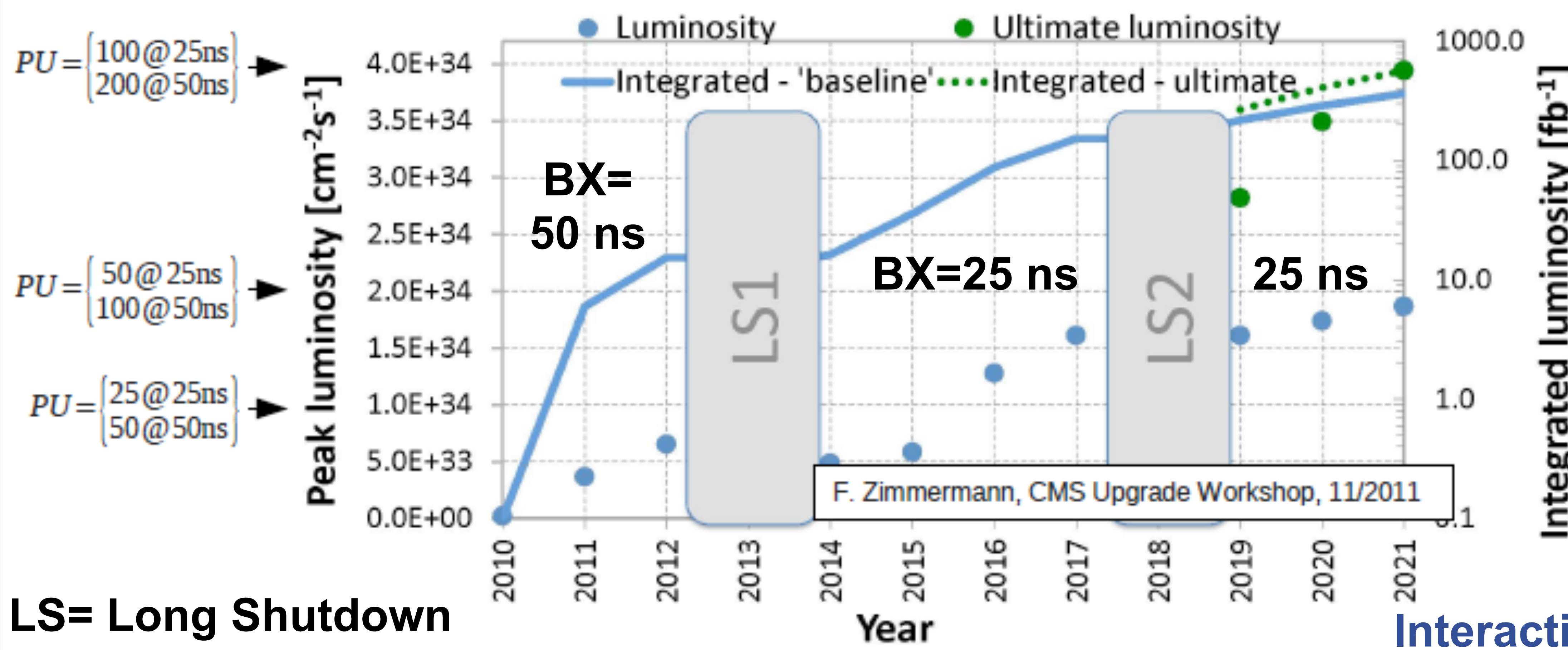

Luminosity-leveled at 5×10^{34} $cm^{-2}s^{-1}$ in HL-LHC

	LHC		LHC	Interaction region upgrade	HL-LHC
$L_{instantaneous}$	8×10^{33} Hz/cm^2		2×10^{34} Hz/cm^2		5×10^{34} Hz/cm^2
$L_{integrated}$	30 fb^{-1}		300 fb^{-1}		3000 fb^{-1}
Pile Up	PU ~40	LS1	PU ~50	LS3	PU ~140

LHC and HL-LHC

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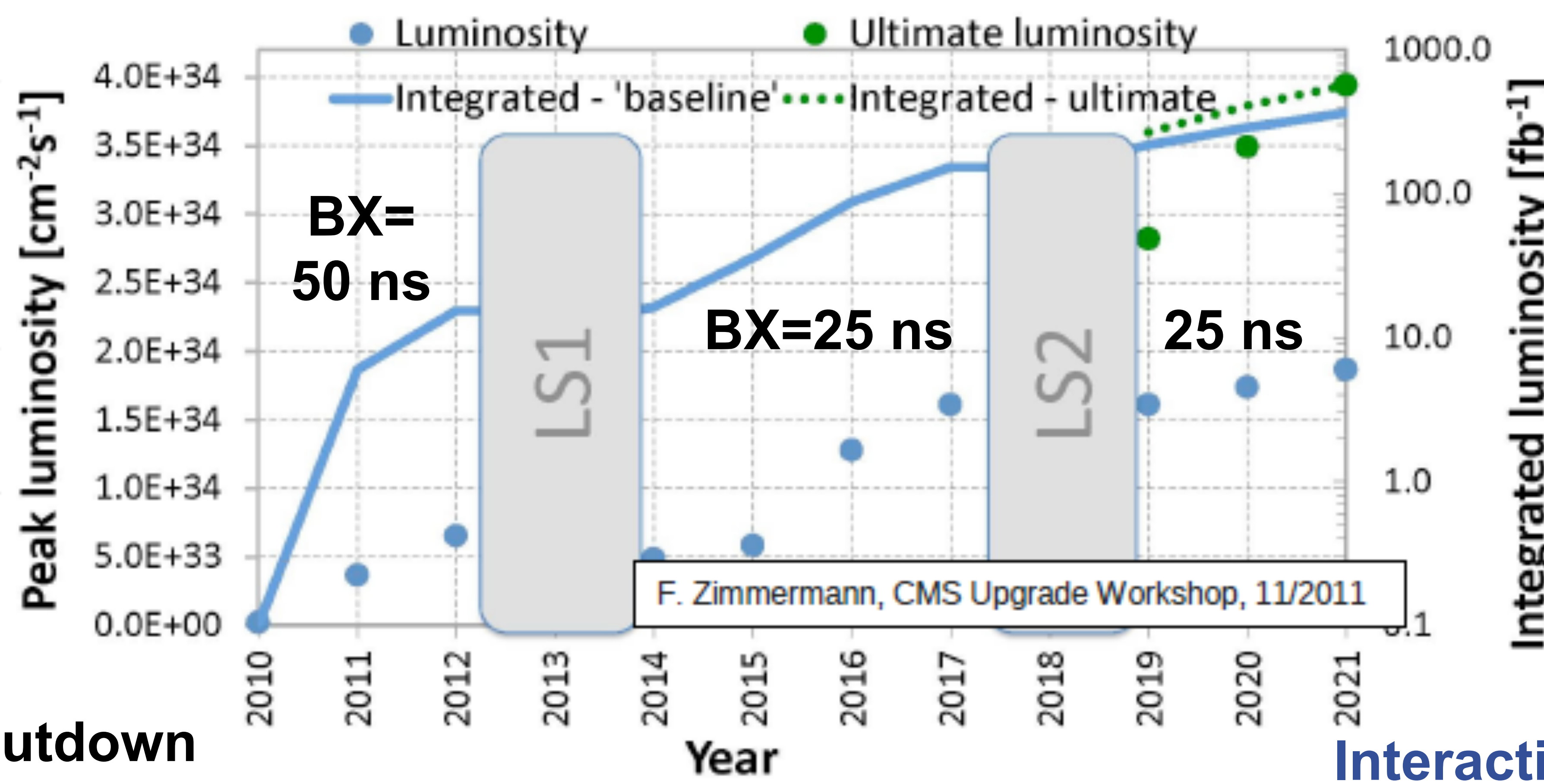

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Interaction region upgrade

	LHC				HL-LHC
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$L_{integrated}$	30 fb^{-1}	LS1	300 fb^{-1}	LS3	3000 fb^{-1}
Pile Up	PU ~40		PU ~50		PU ~140

ATLAS, CMS Upgrade plan

LHC and HL-LHC

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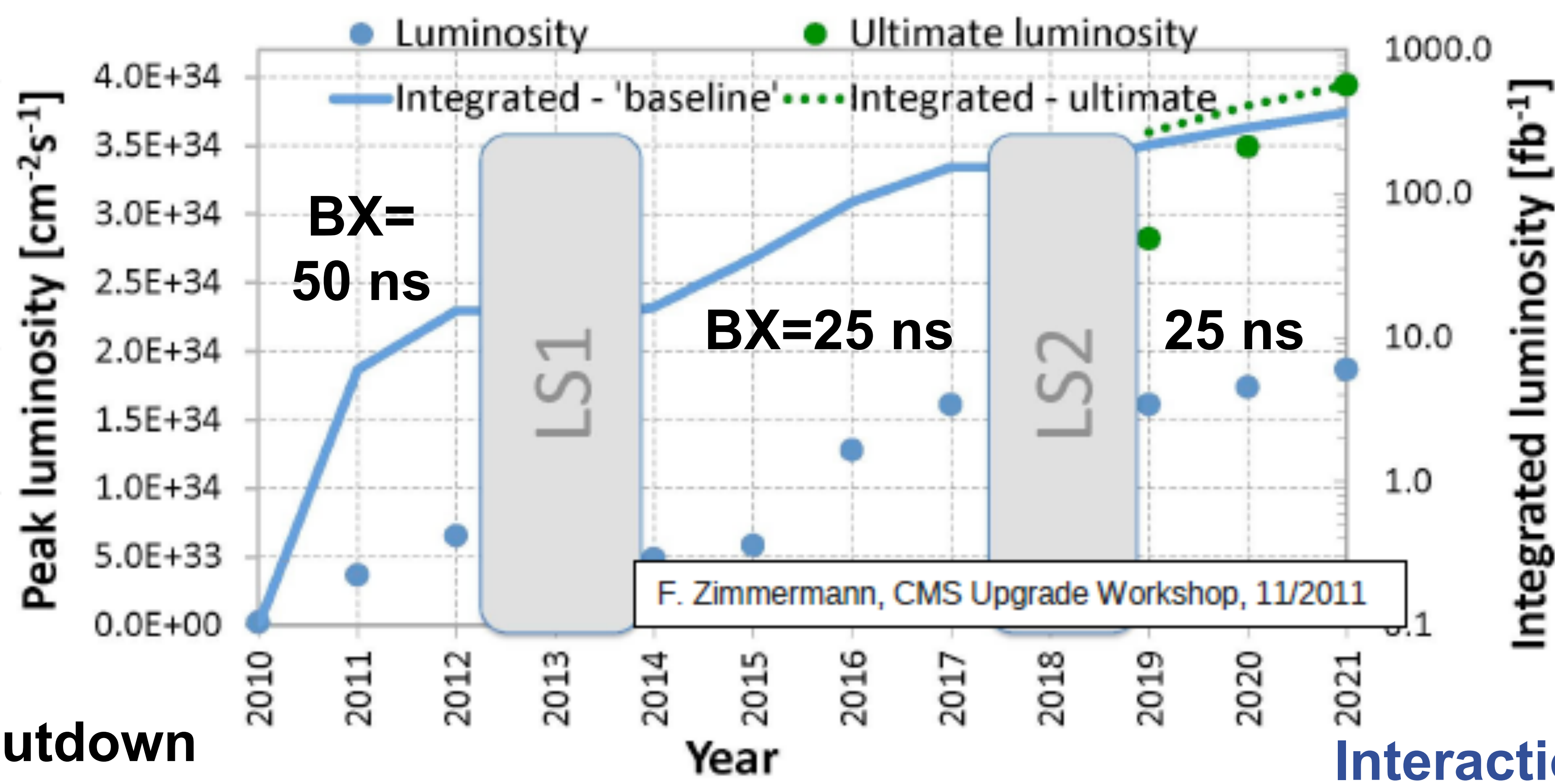

Luminosity-leveled at $5x10^{34}$ $cm^{-2}s^{-1}$ in HL-LHC

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Interaction region upgrade

	LHC			HL-LHC
$L_{instantaneous}$	$8x10^{33}$ Hz/cm^2	LS1	$2x10^{34}$ Hz/cm^2	LS3	$5x10^{34}$ Hz/cm^2
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ATLAS, CMS Upgrade plan

Phase 1 Upgrade

LHC and HL-LHC

LHC | **Energy increase 8 TeV to 13/14 TeV** | **Injection upgrade** | **HL-LHC**

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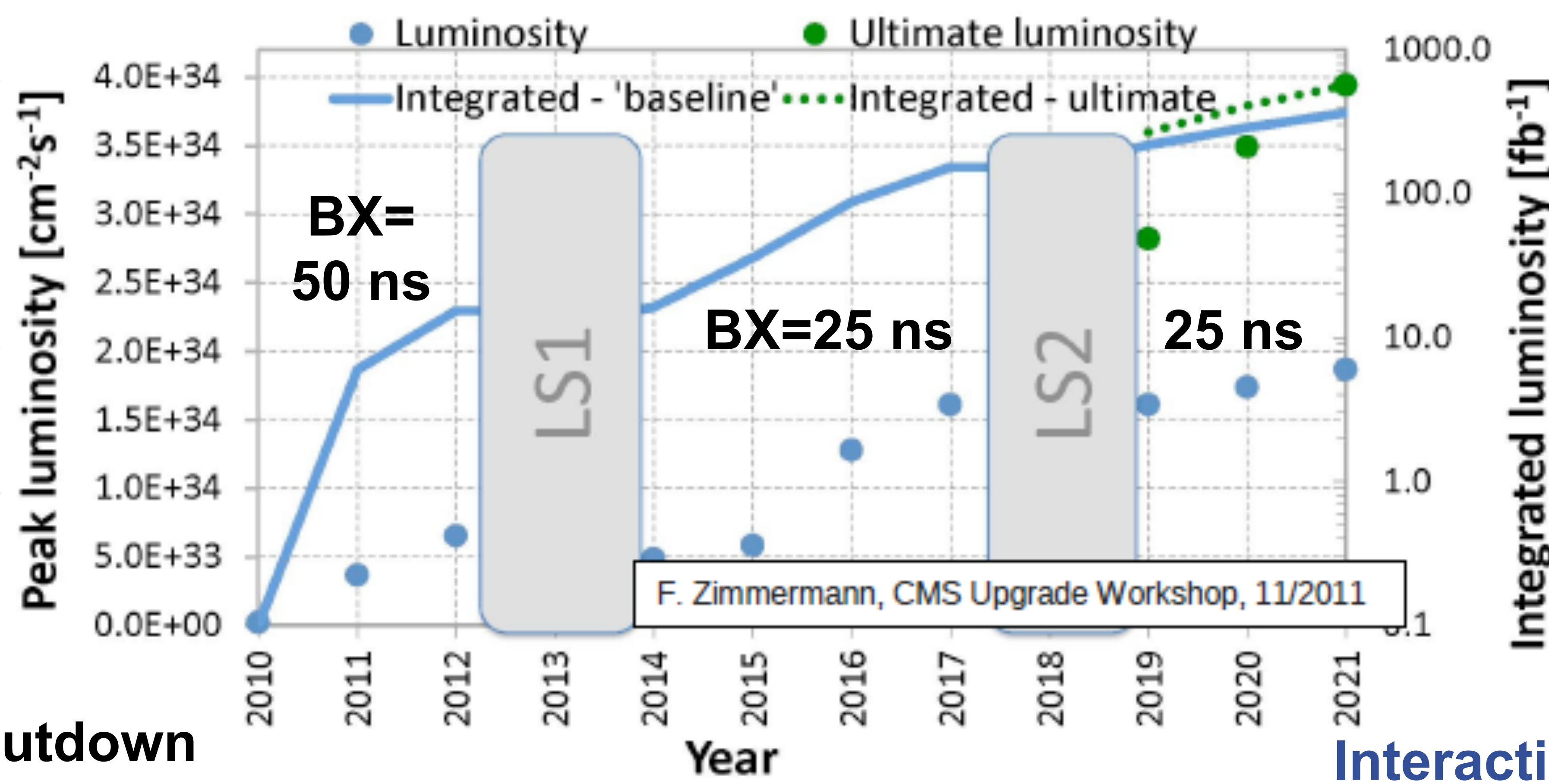

Luminosity-leveled at 5×10^{34} cm^{-2}s^{-1} in HL-LHC

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Interaction region upgrade

	LHC		Phase 1		HL-LHC
L instantaneous	8×10^{33} Hz/cm^2	LS1	2×10^{34} Hz/cm^2	LS3	5×10^{34} Hz/cm^2
L integrated	30 fb^{-1}		300 fb^{-1}		3000 fb^{-1}
Pile Up	PU ~40		PU ~50		PU ~140

ATLAS, CMS Upgrade plan

Phase 1 Upgrade

Phase 2 Upgrade

Expected Phase 1 improvements

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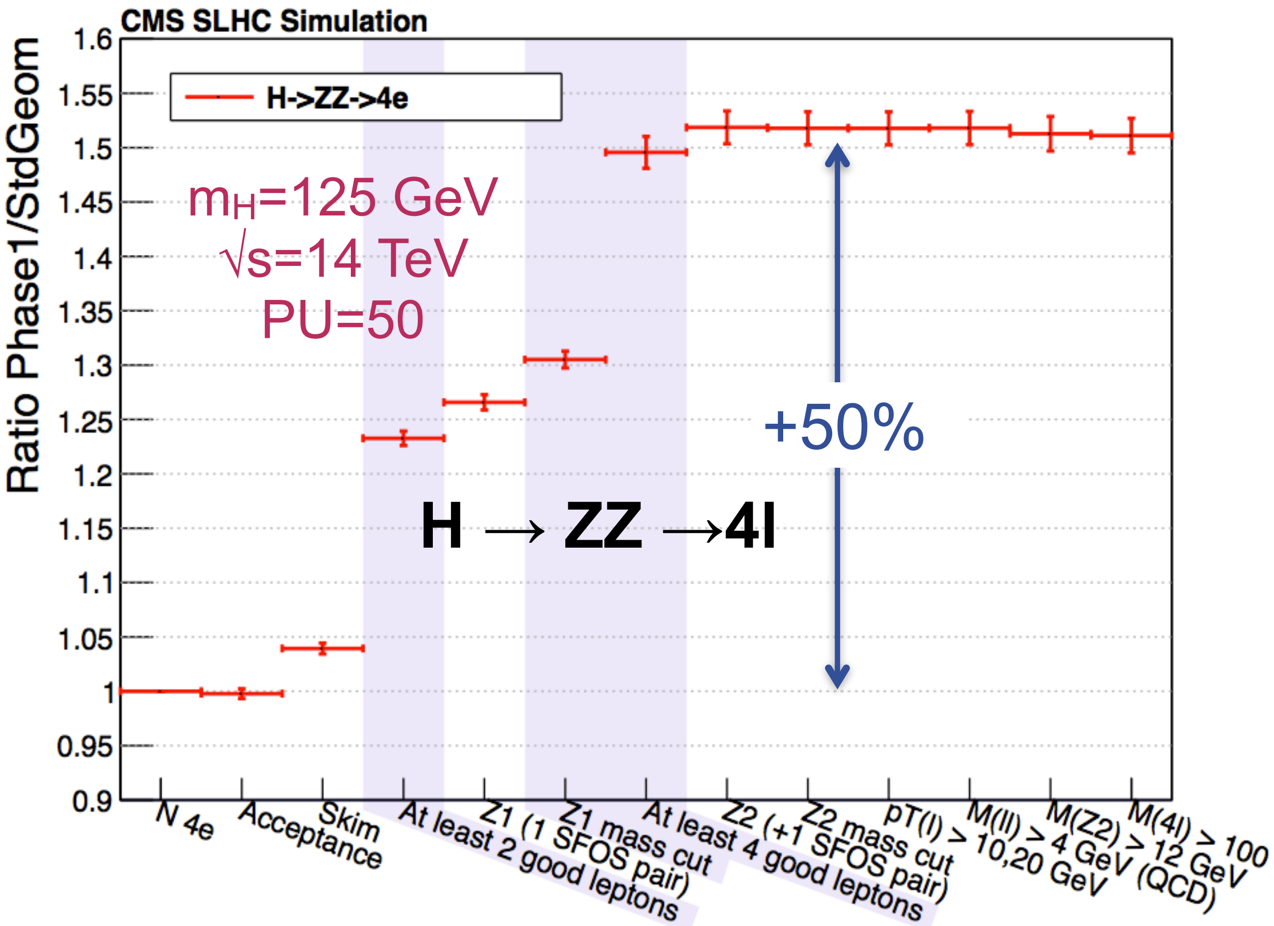

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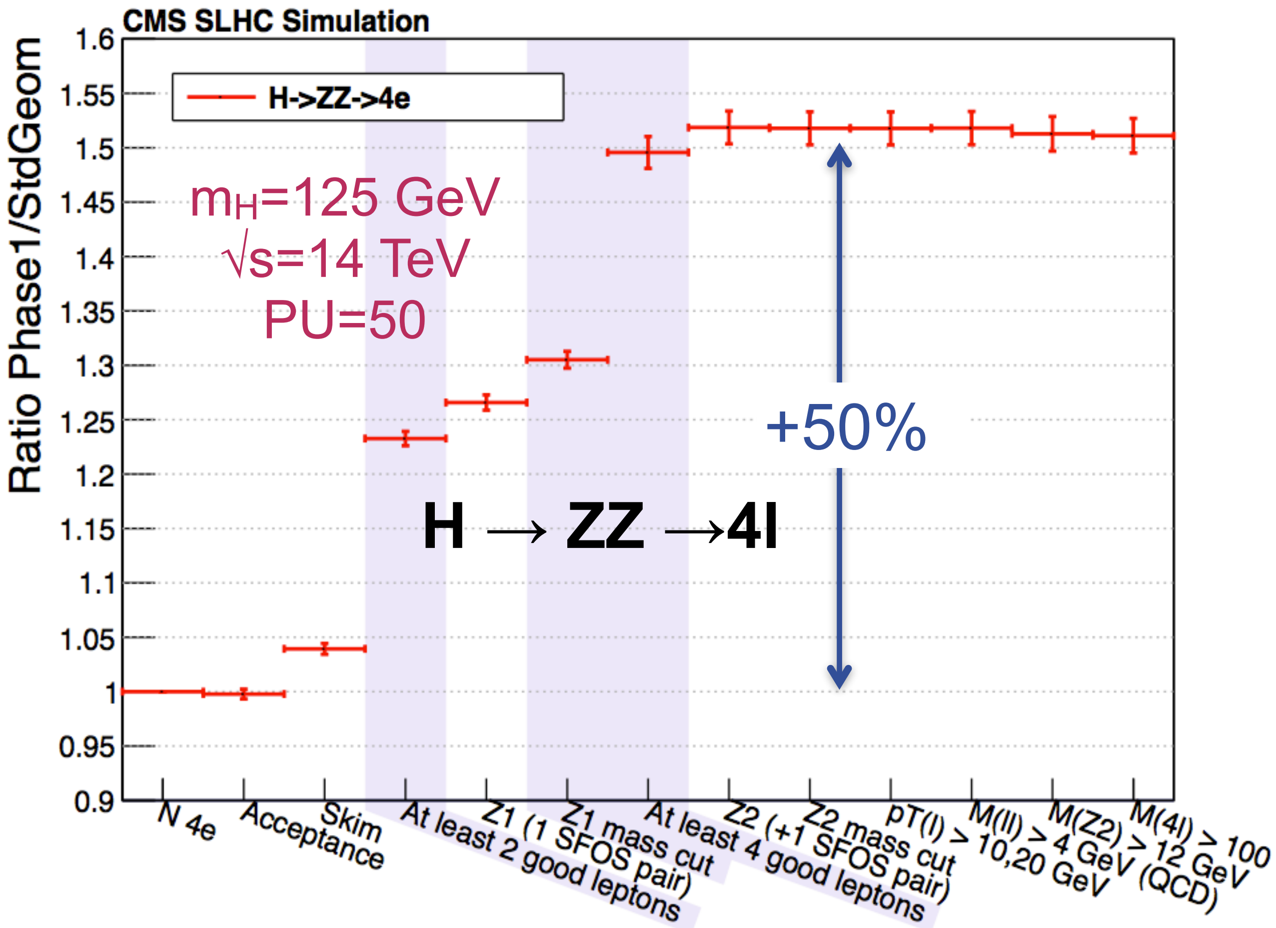
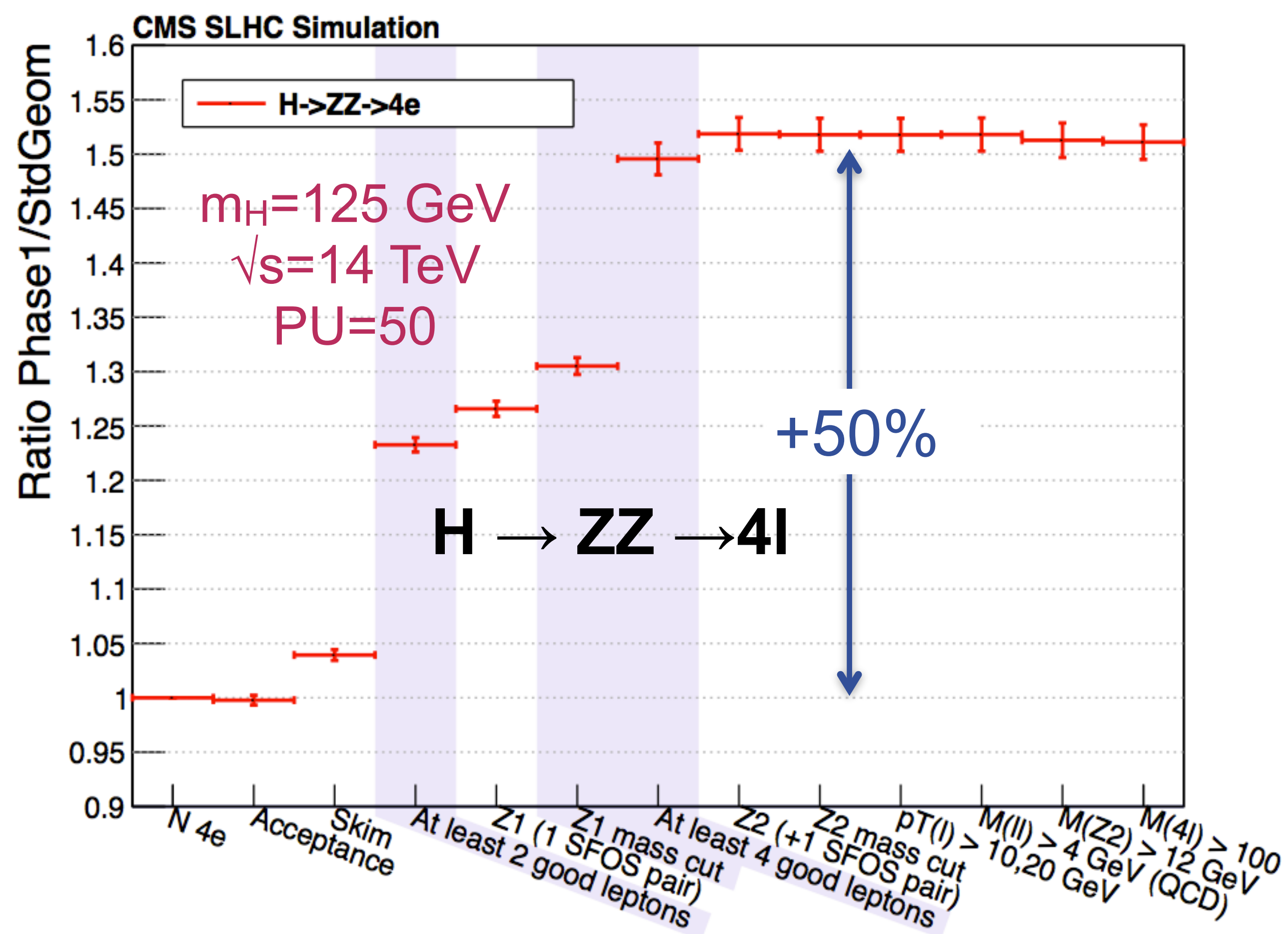
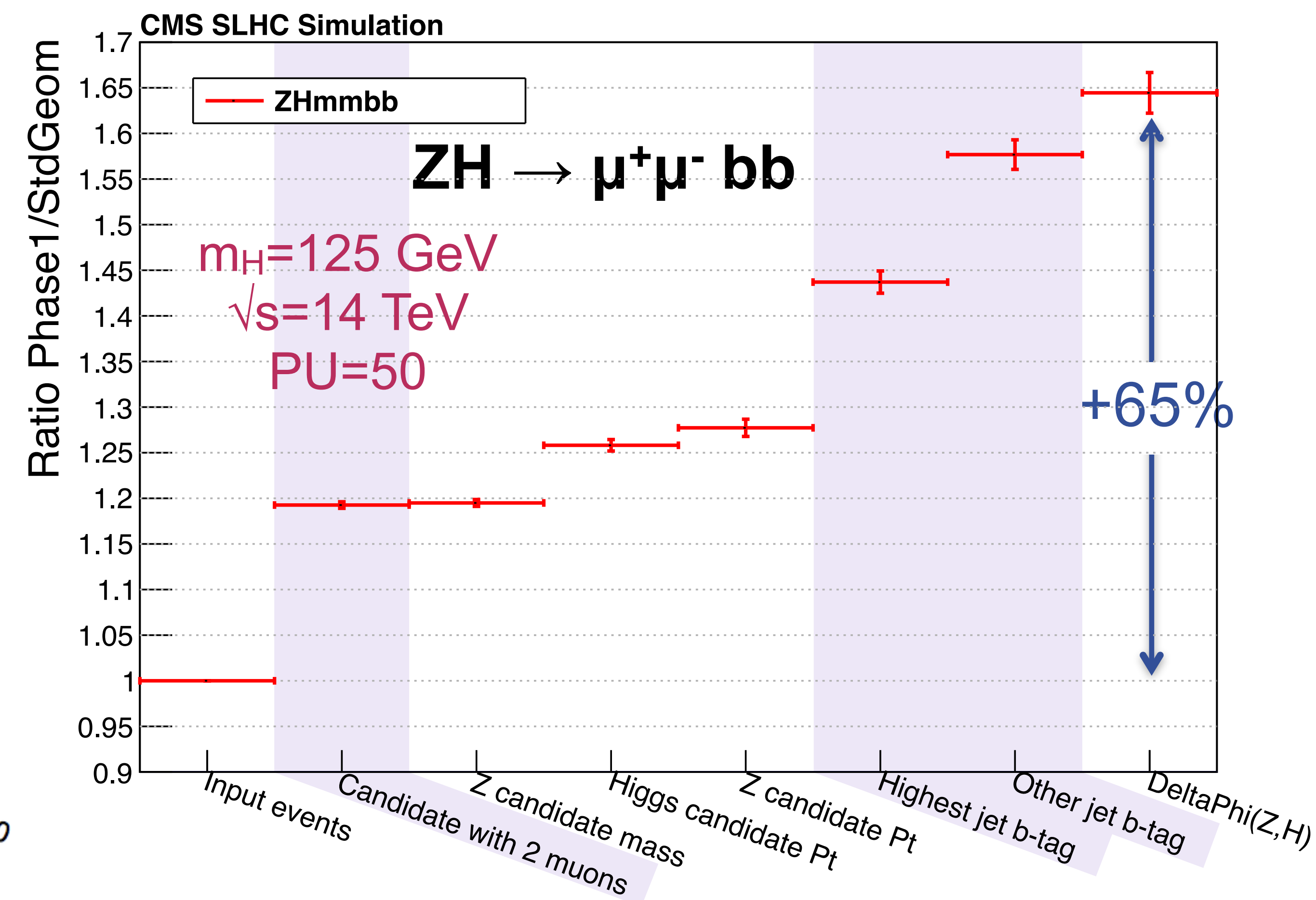


Significant gain in signal reconstruction efficiency:

H→ 4μ	+41%
H→ 2μ2e	+48%
H→ 4e	+51%

Expected Phase 1 improvements





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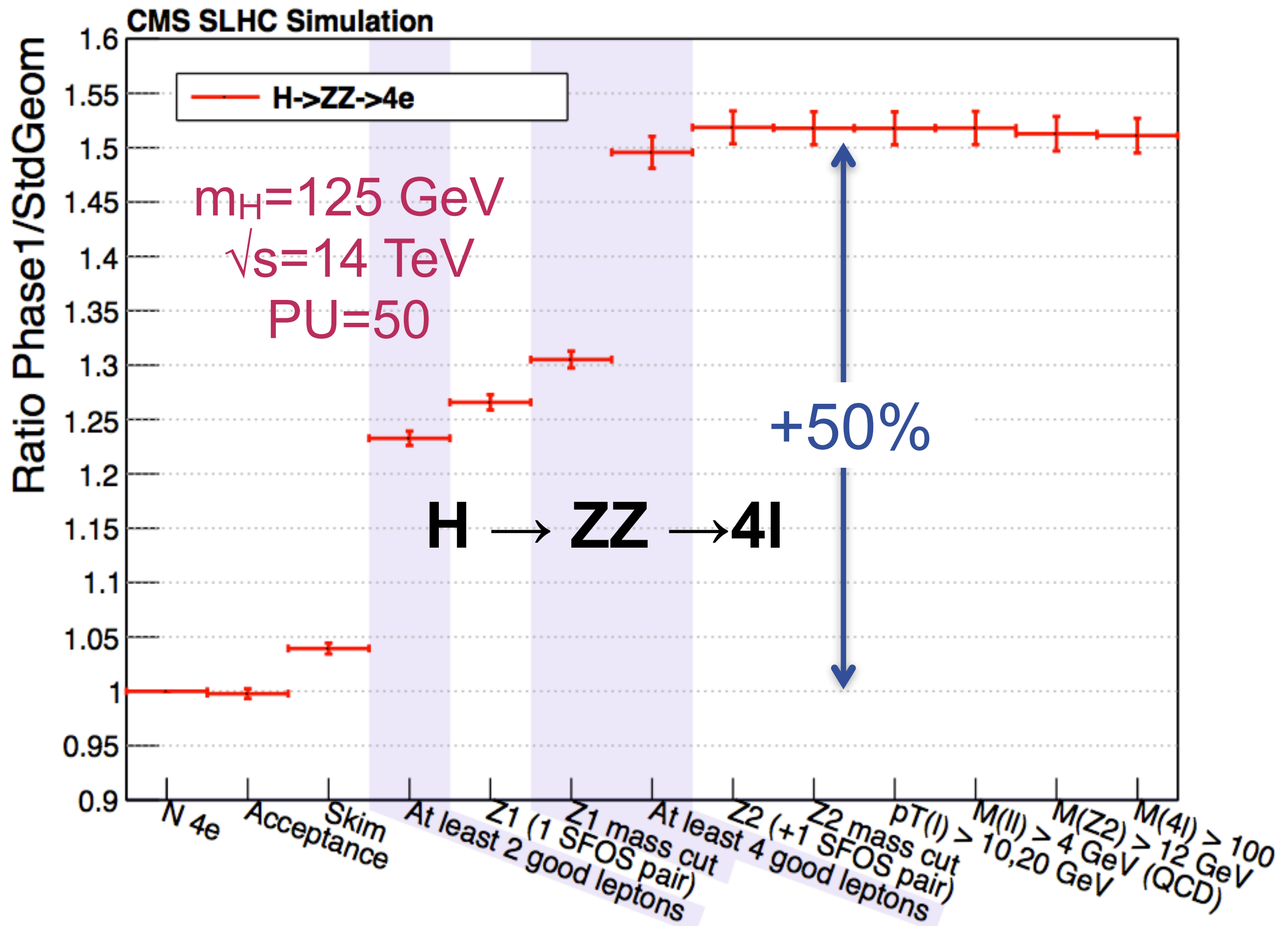

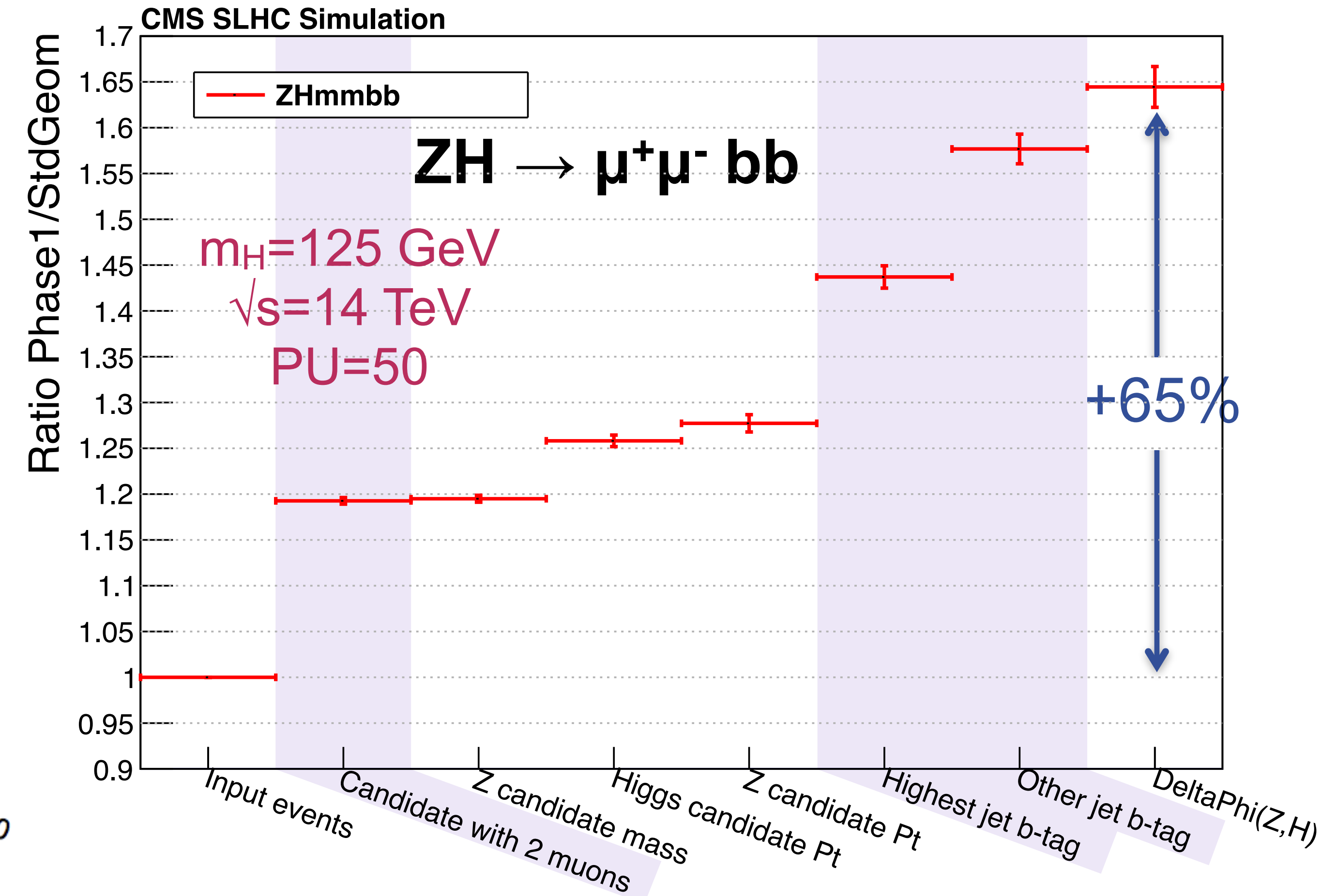

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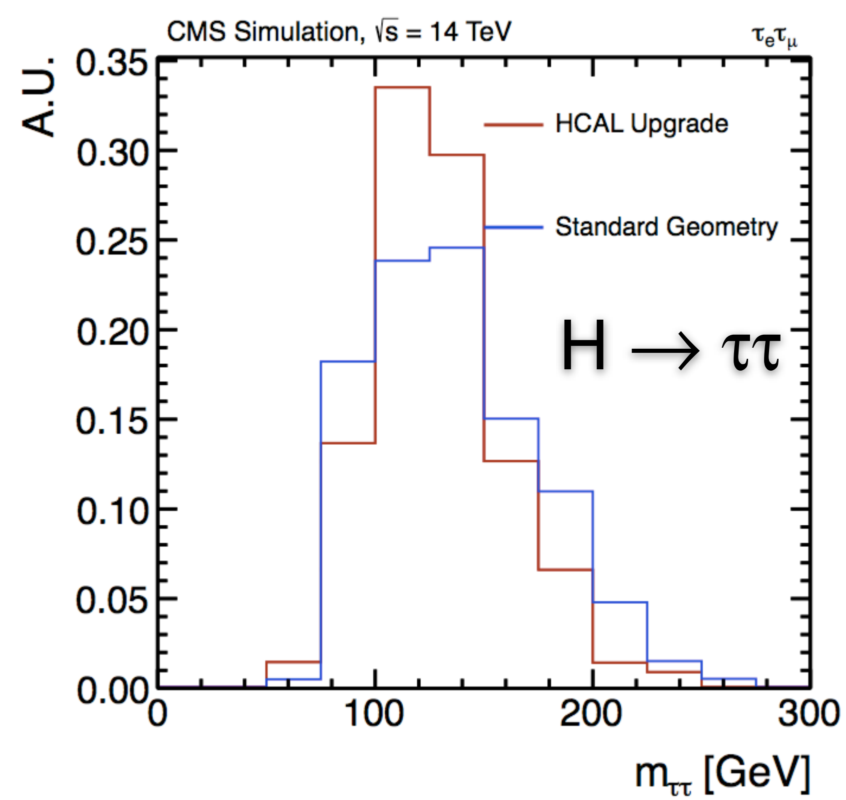

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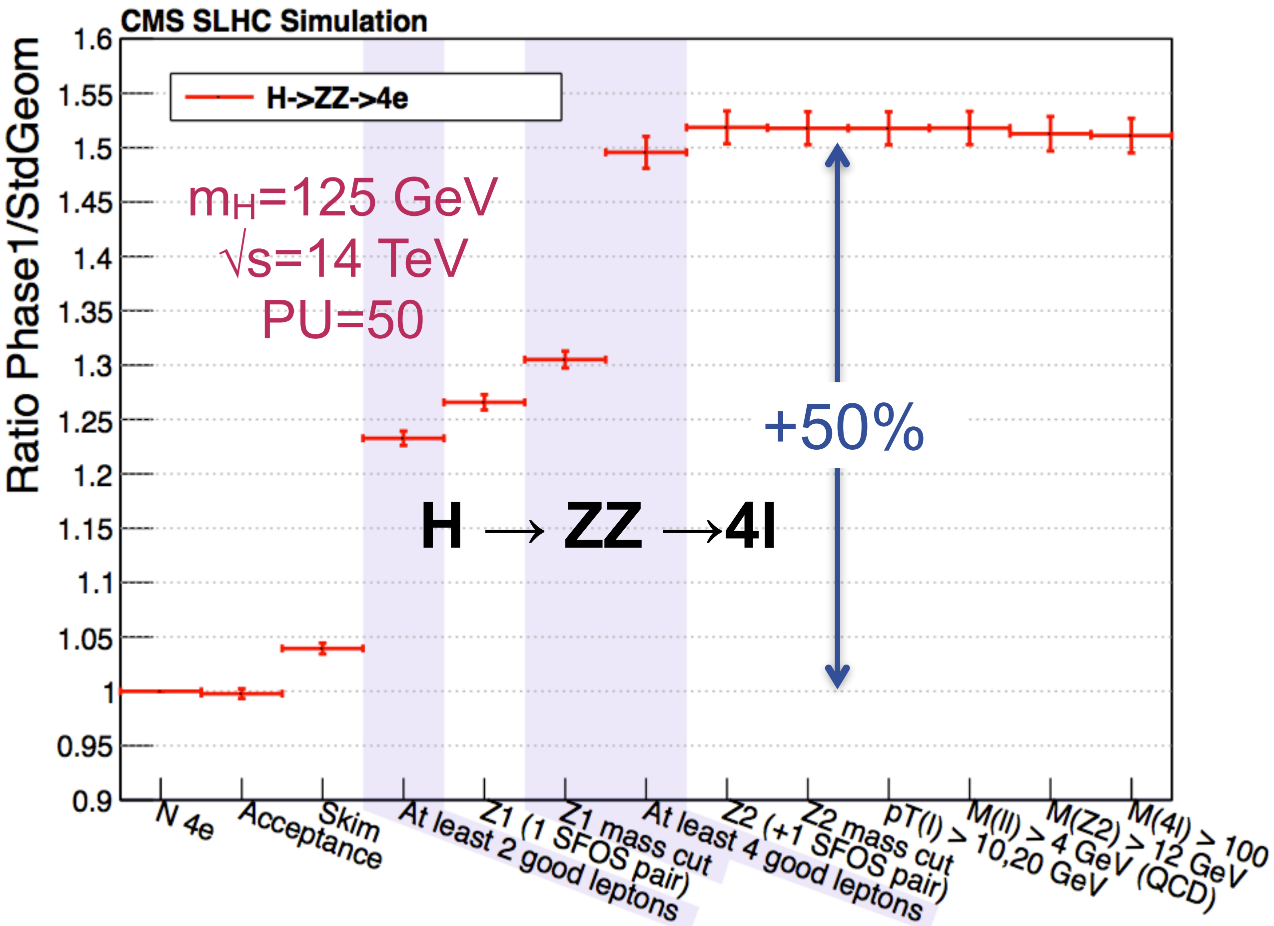

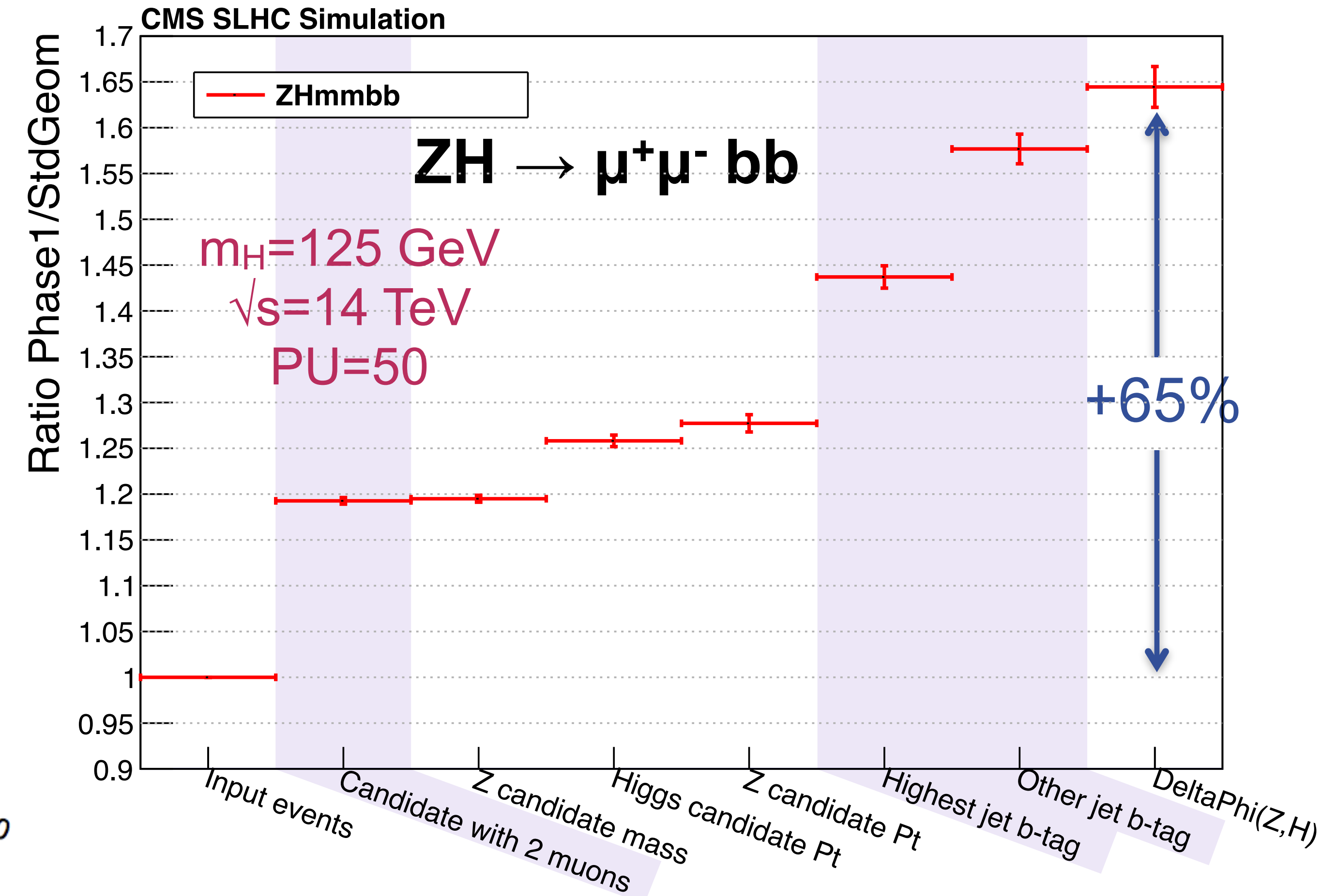

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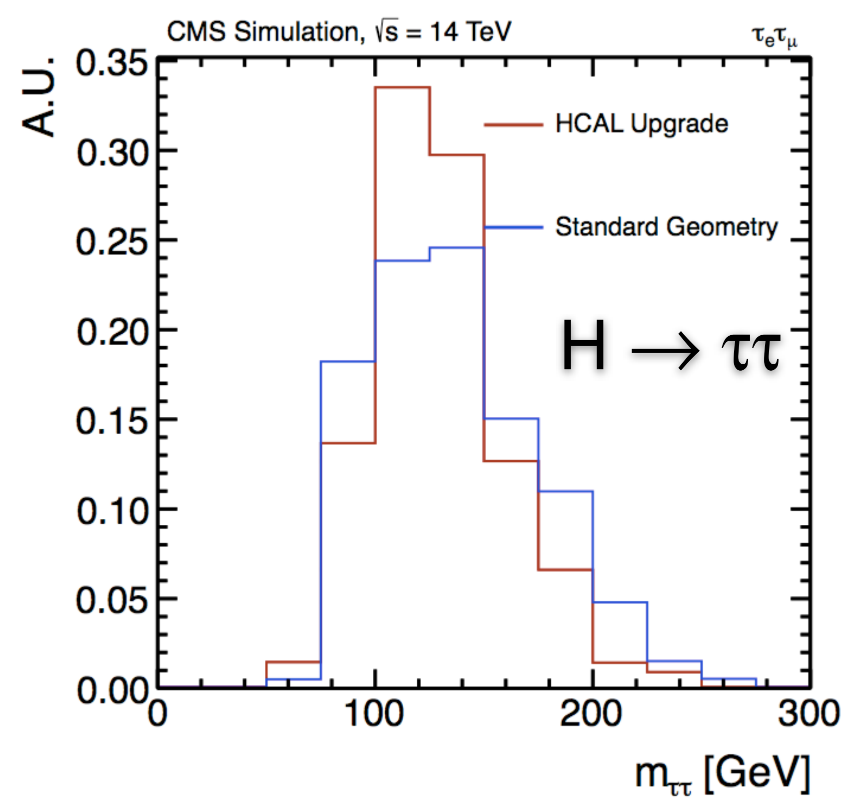
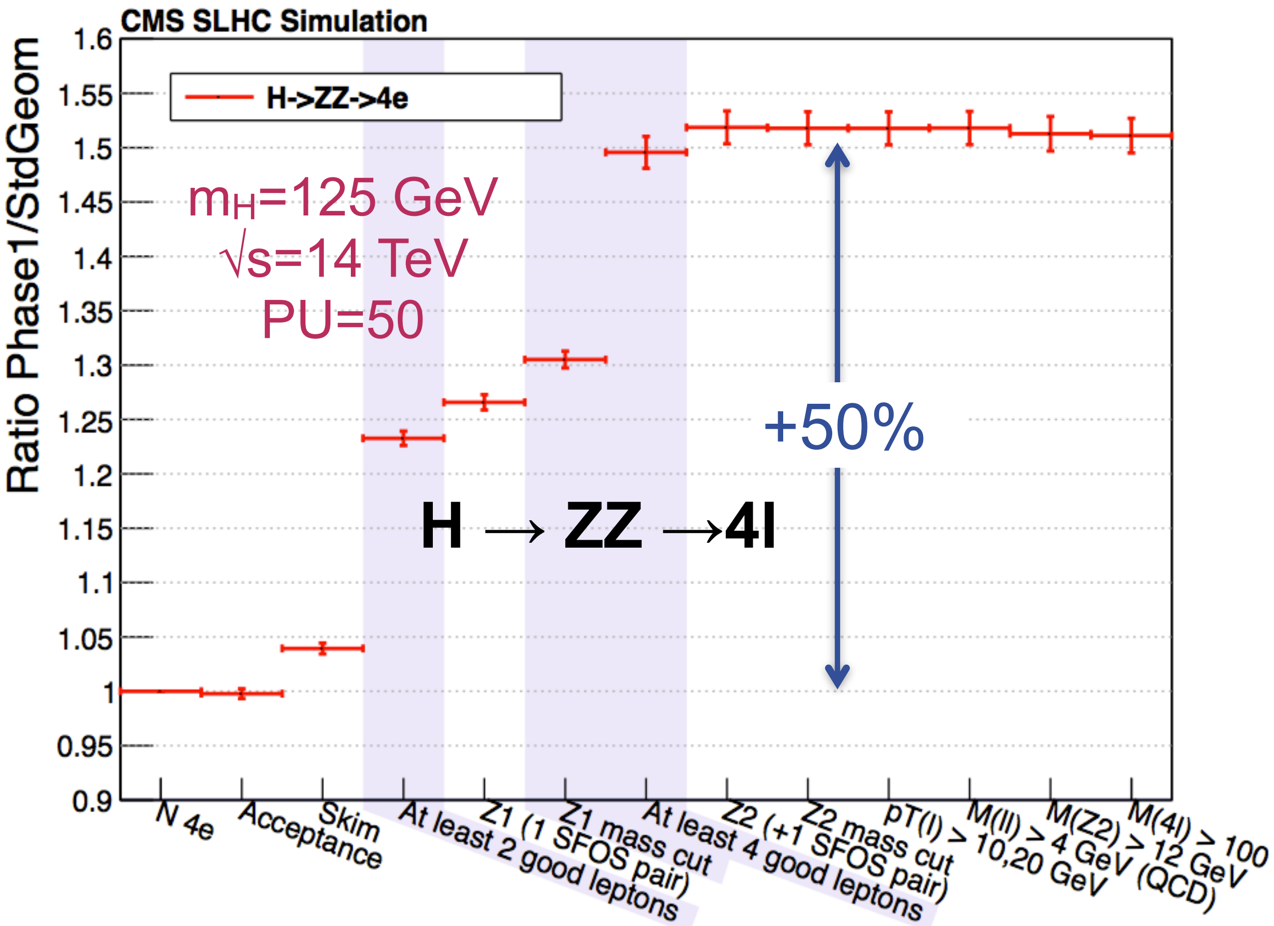
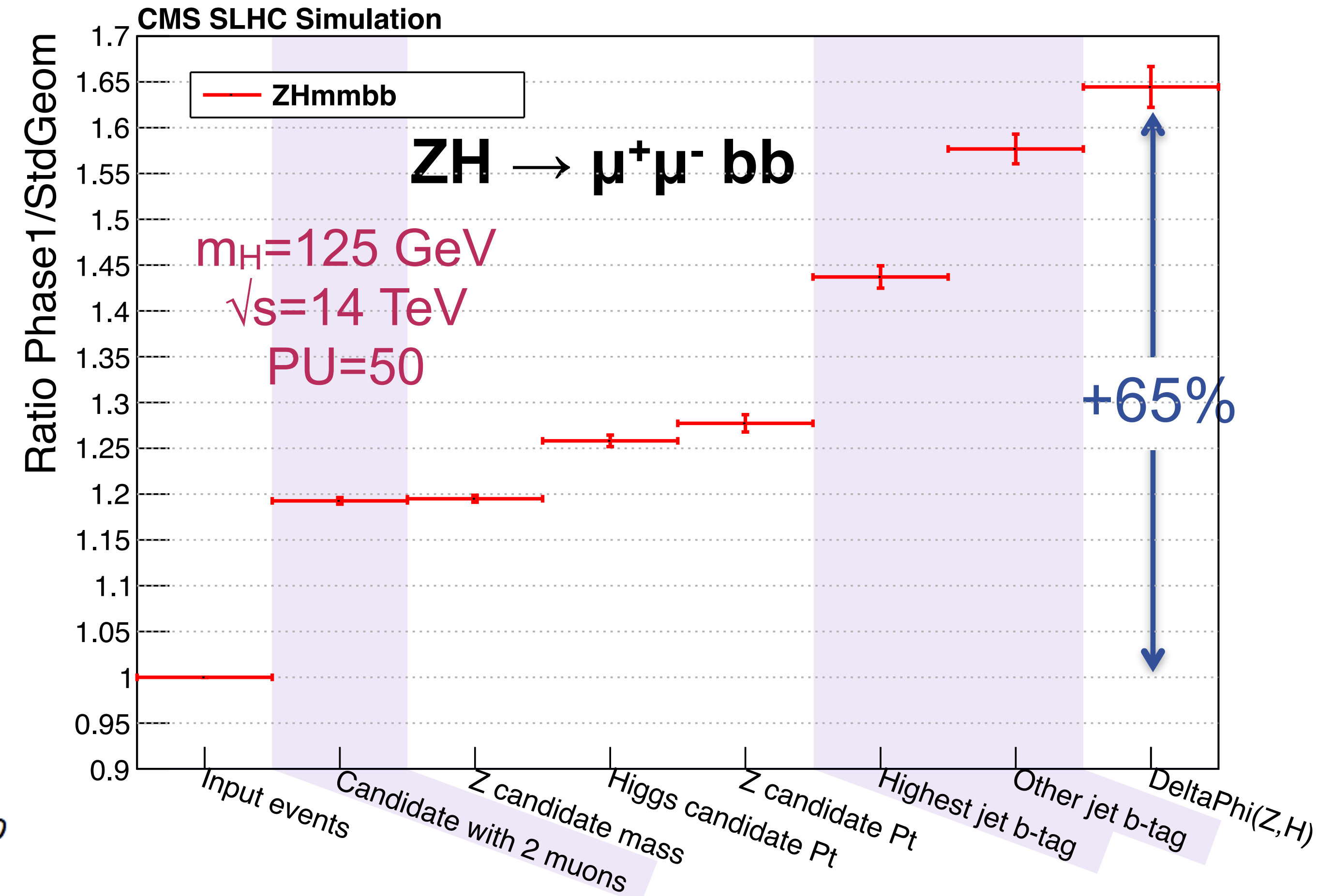


Total efficiency improvement: factor of 2.5 (4.5% → 11%)

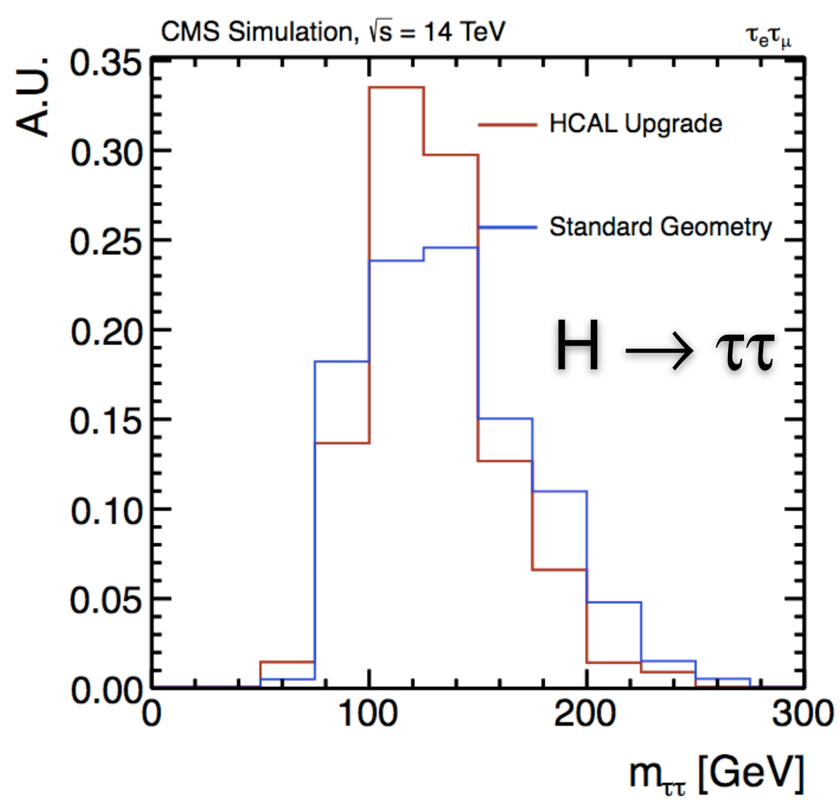
Expected Phase 1 improvements





Significant gain in signal reconstruction efficiency:

H→ 4μ	+41%
H→ 2μ2e	+48%
H→ 4e	+51%



Total efficiency improvement: factor of 2.5 (4.5% → 11%)

Improved jet and MET → 25% improvement in $m_{\tau\tau}$ resolution

CMS Phase II Muon detector

CMS Phase II Muon detector

Increase det. acceptance up to |η|=4.0

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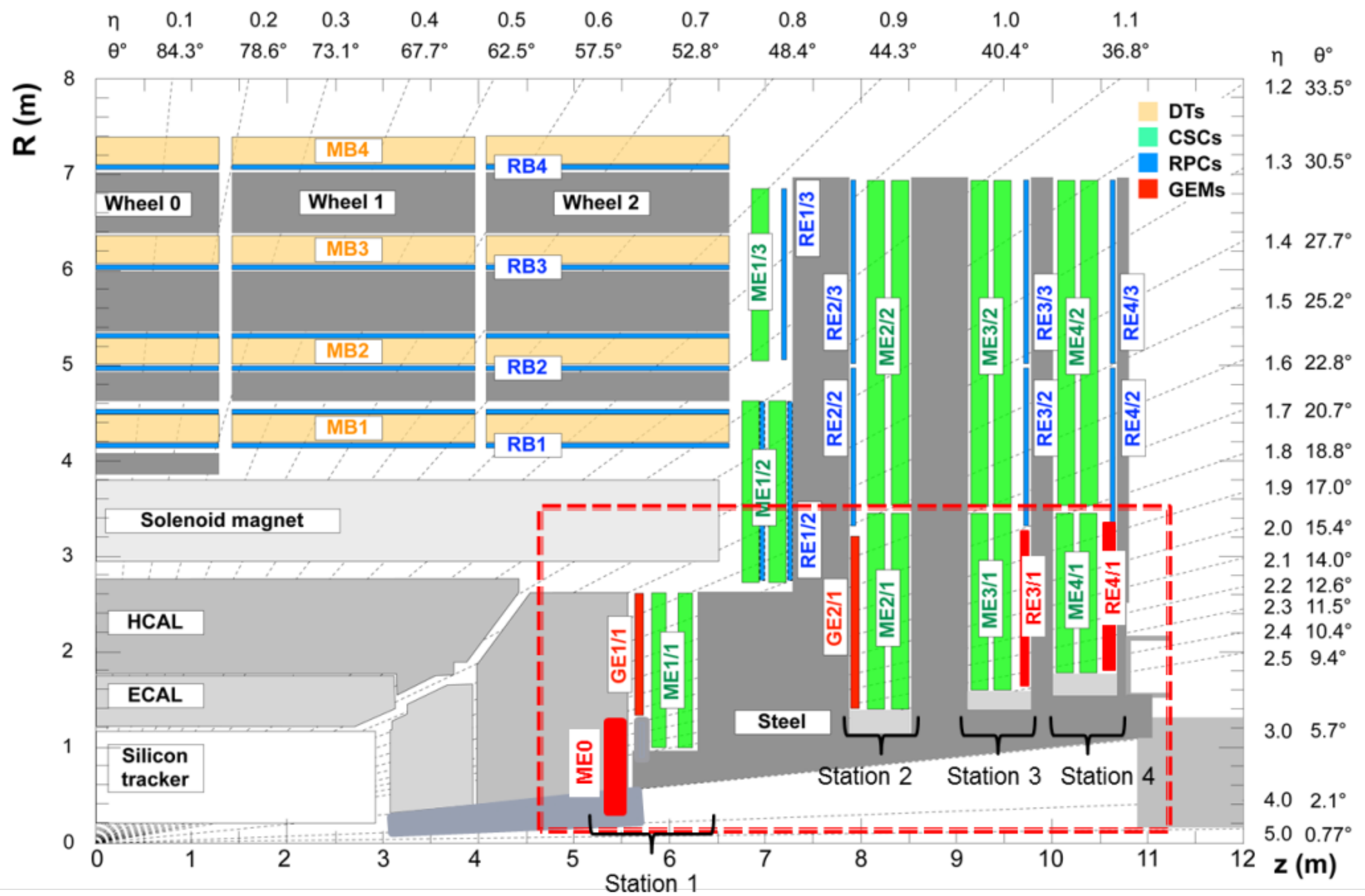

CMS Phase II Muon detector

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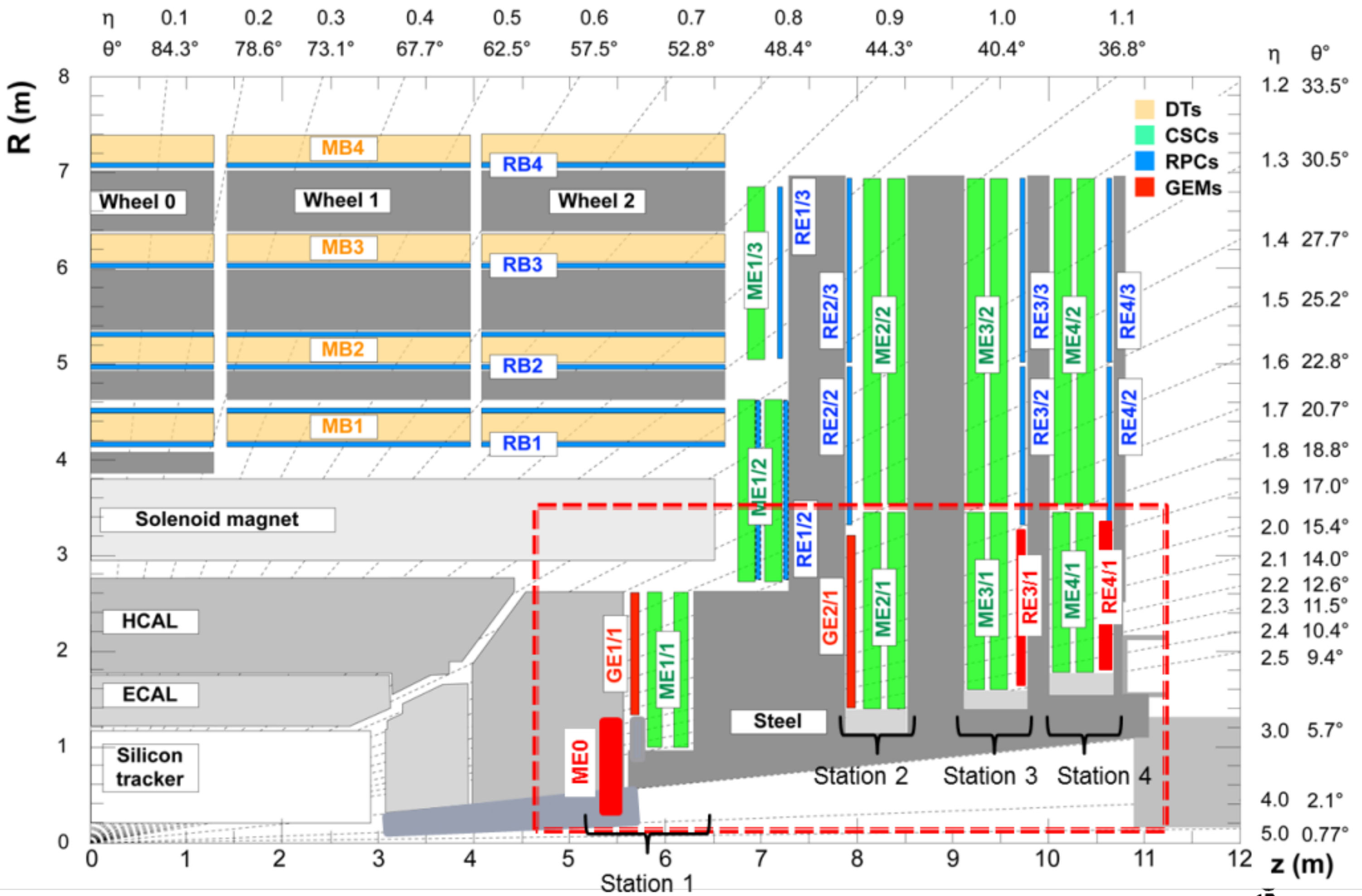

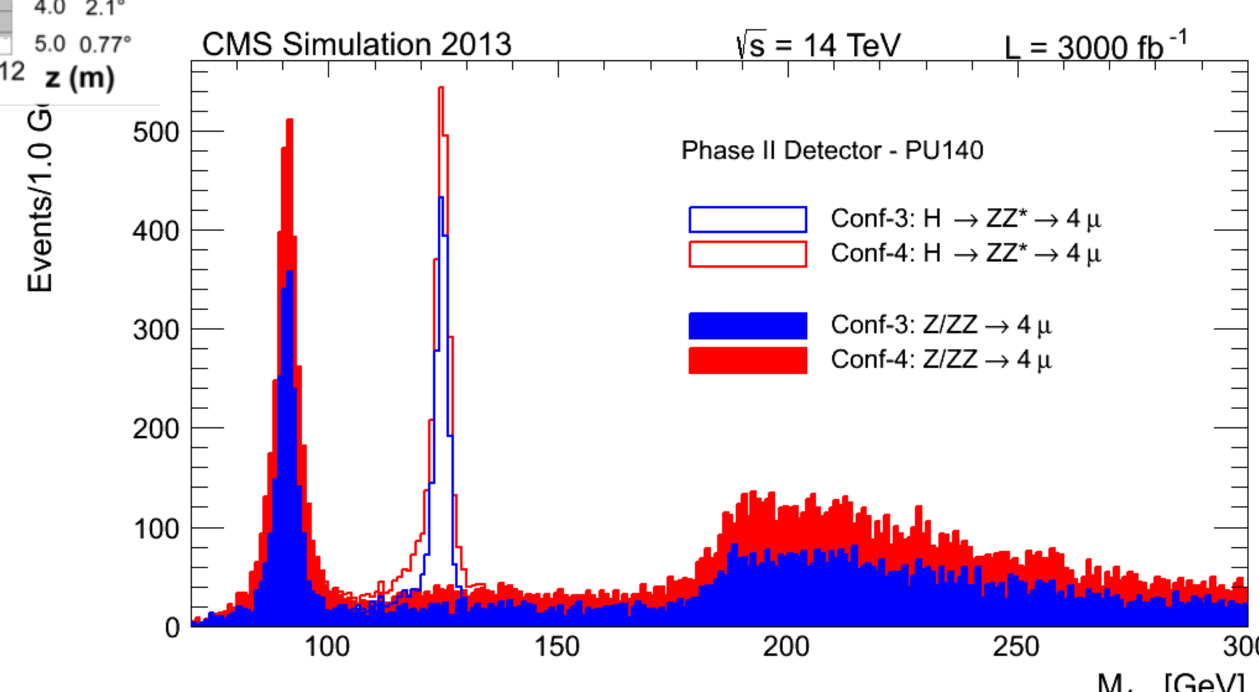

CMS Phase II Muon detector

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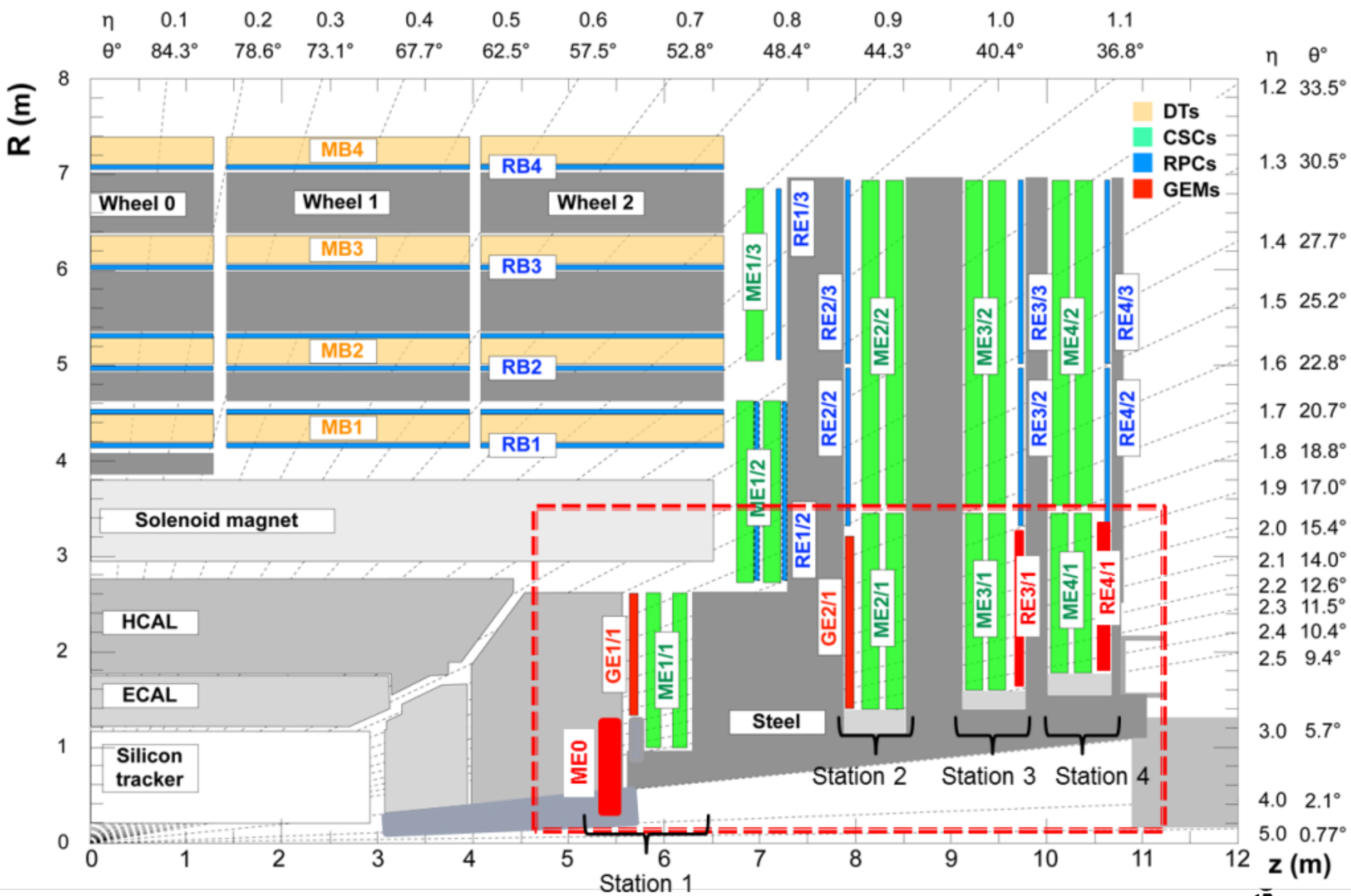
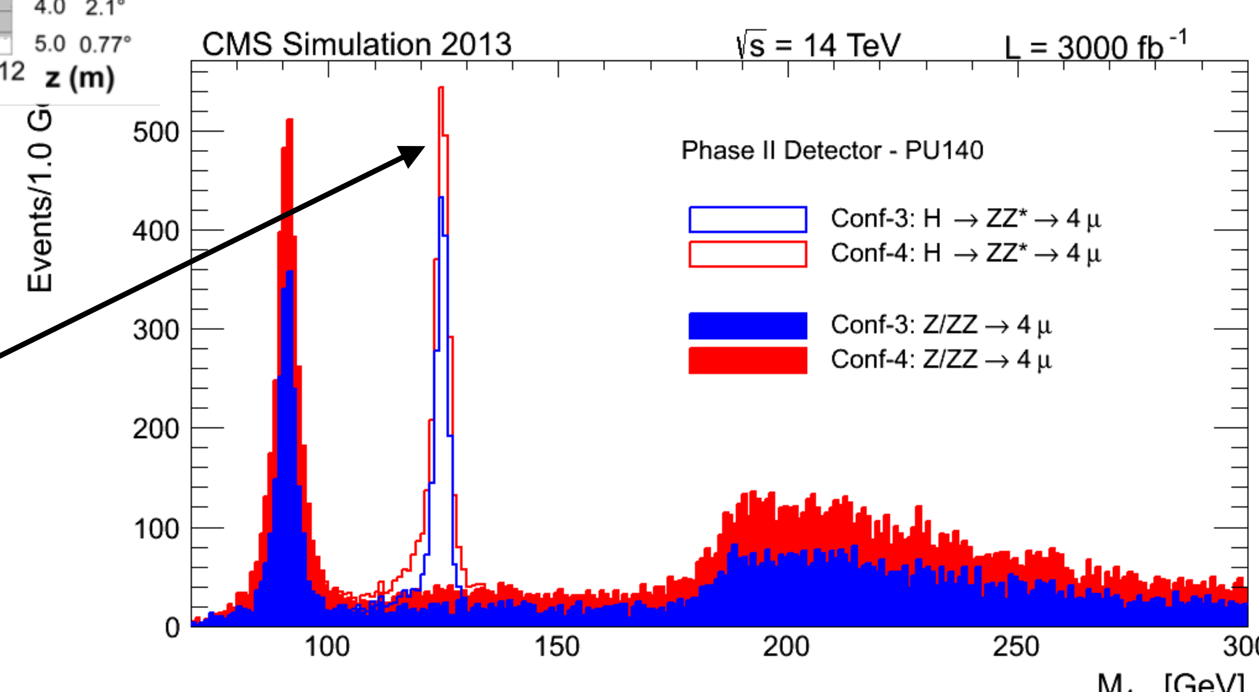
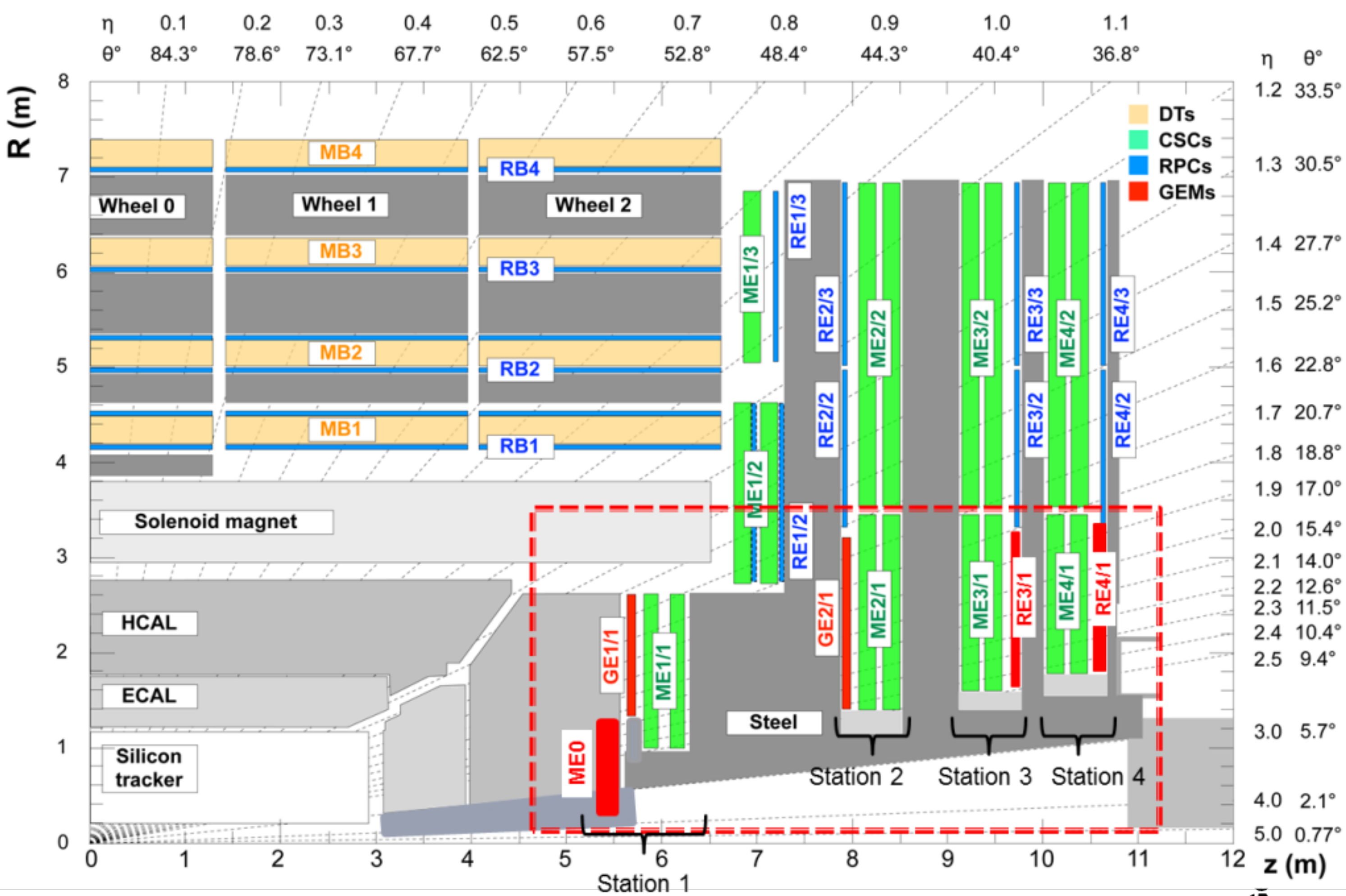


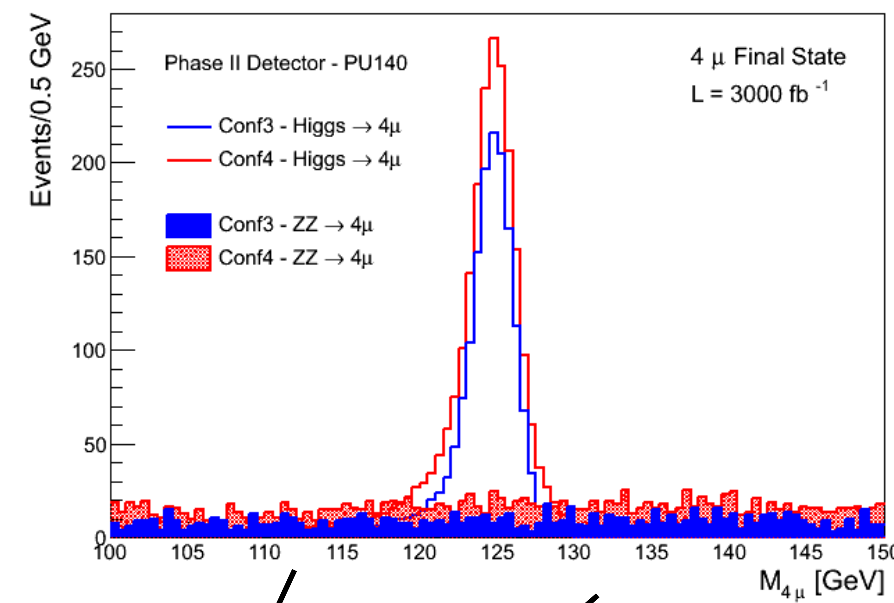


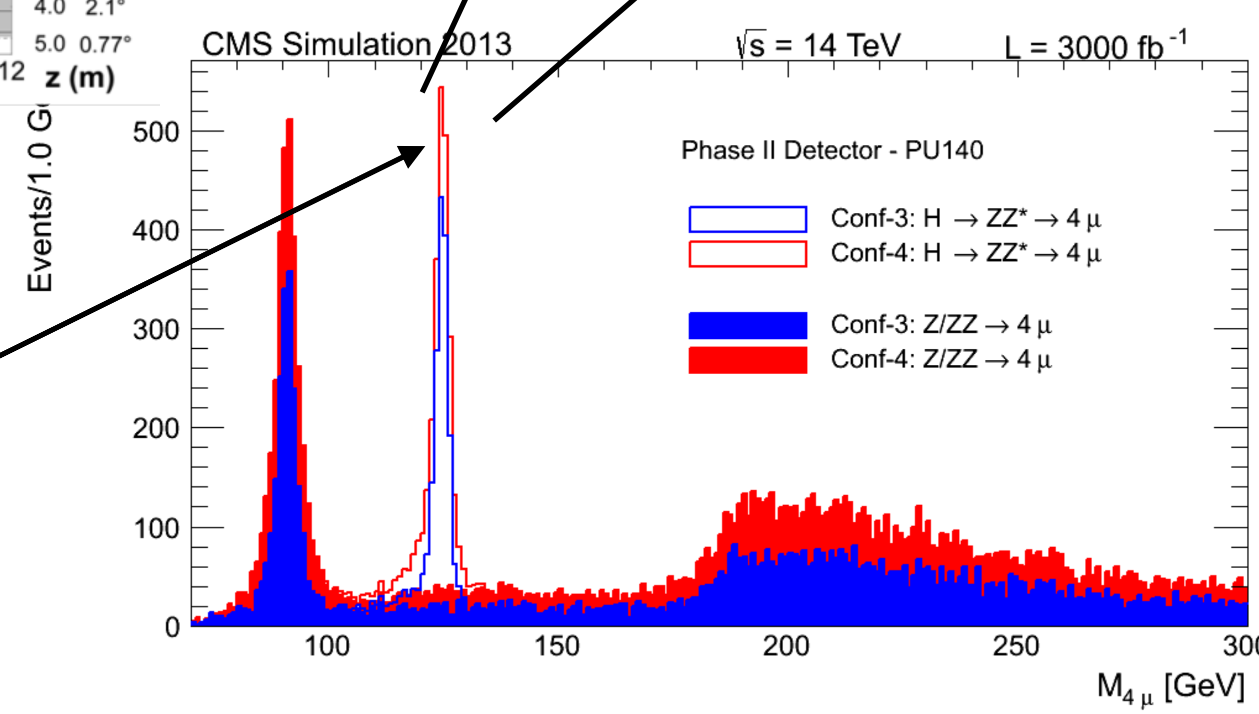
>40% more H→4μ events

CMS Phase II Muon detector

Increase det. acceptance up to |η|=4.0



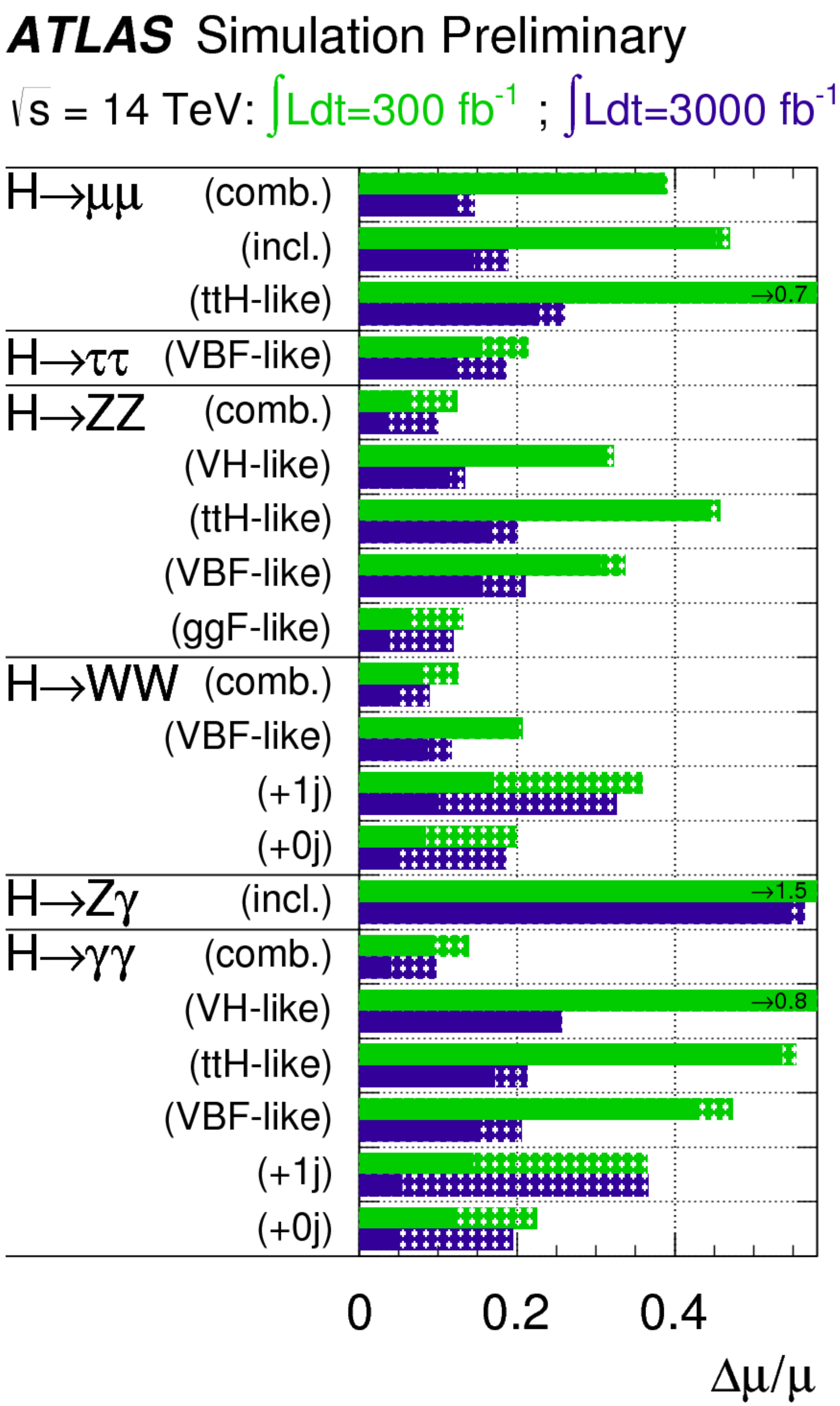




>40% more H→4μ events

Signal strength @3000 fb^{-1}

Signal strength @3000 fb^{-1}



$\mu = \sigma/\sigma_{SM}$

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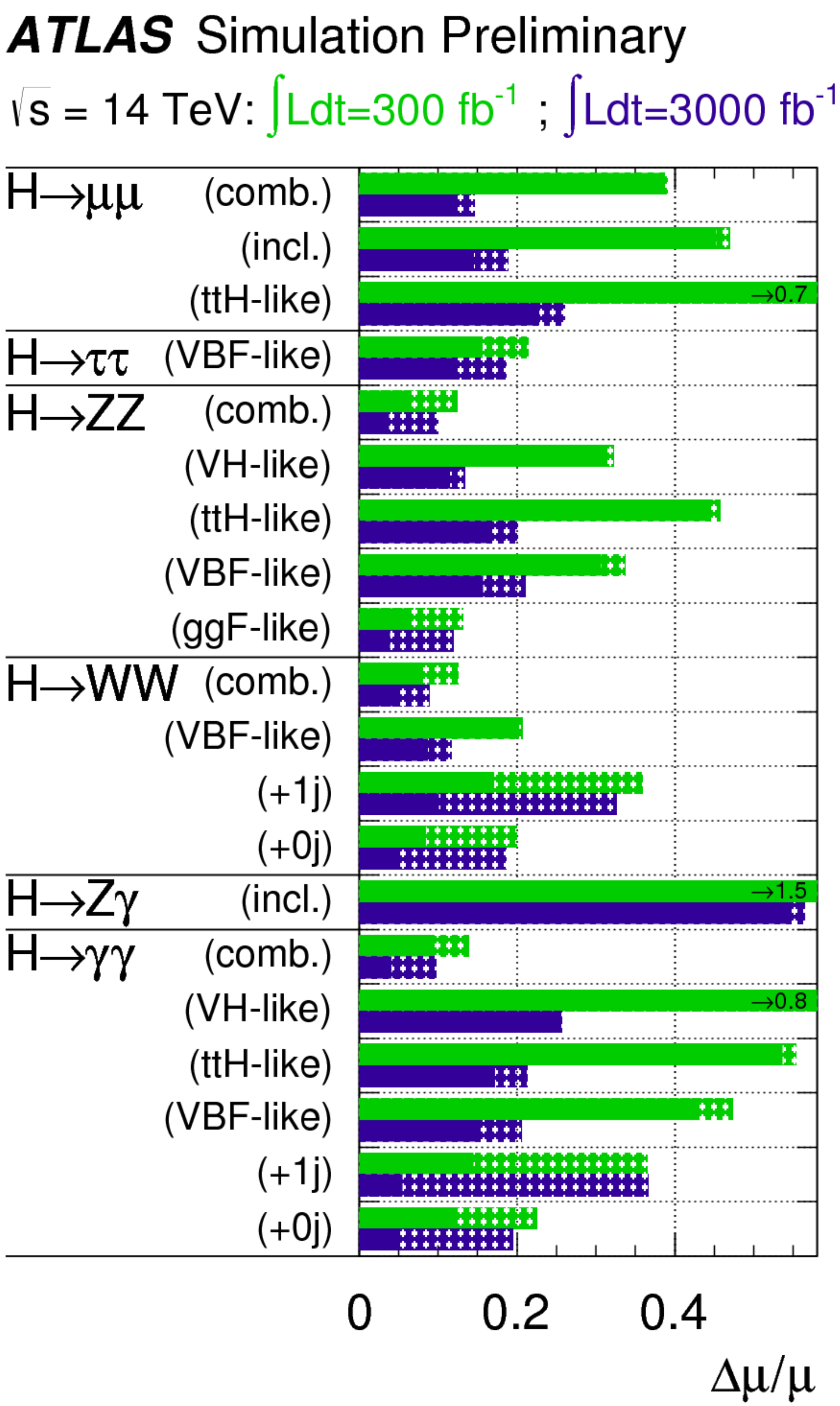

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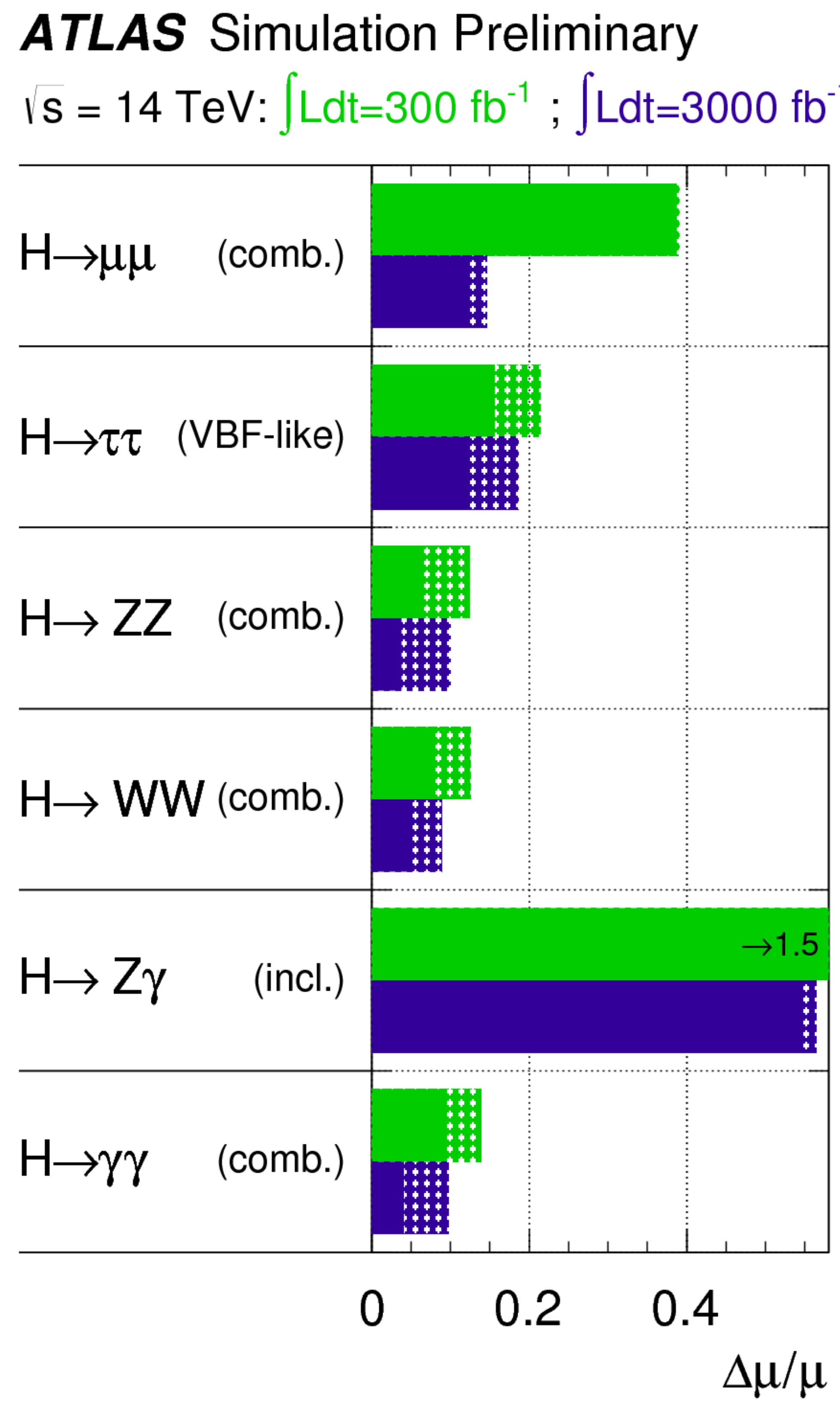

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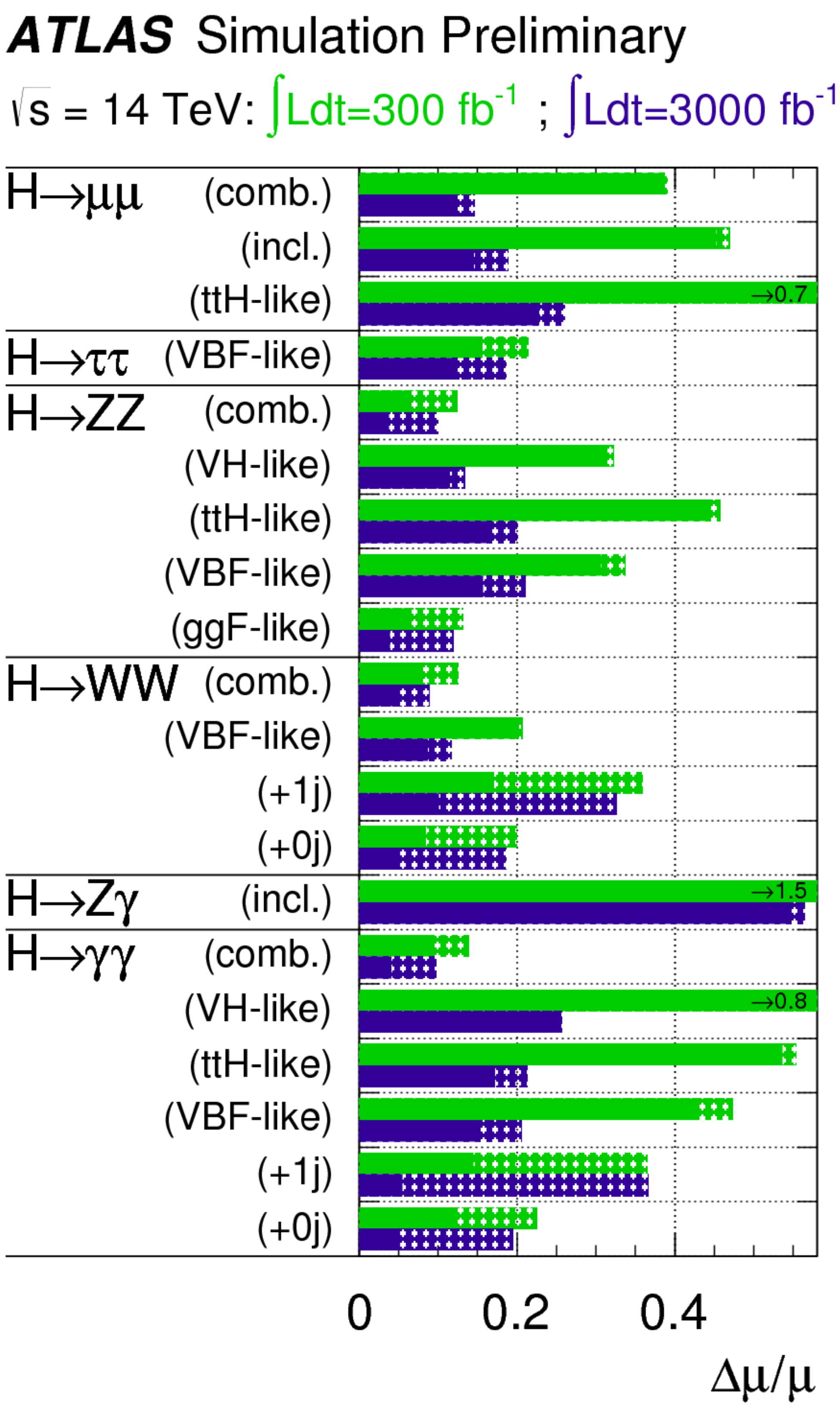

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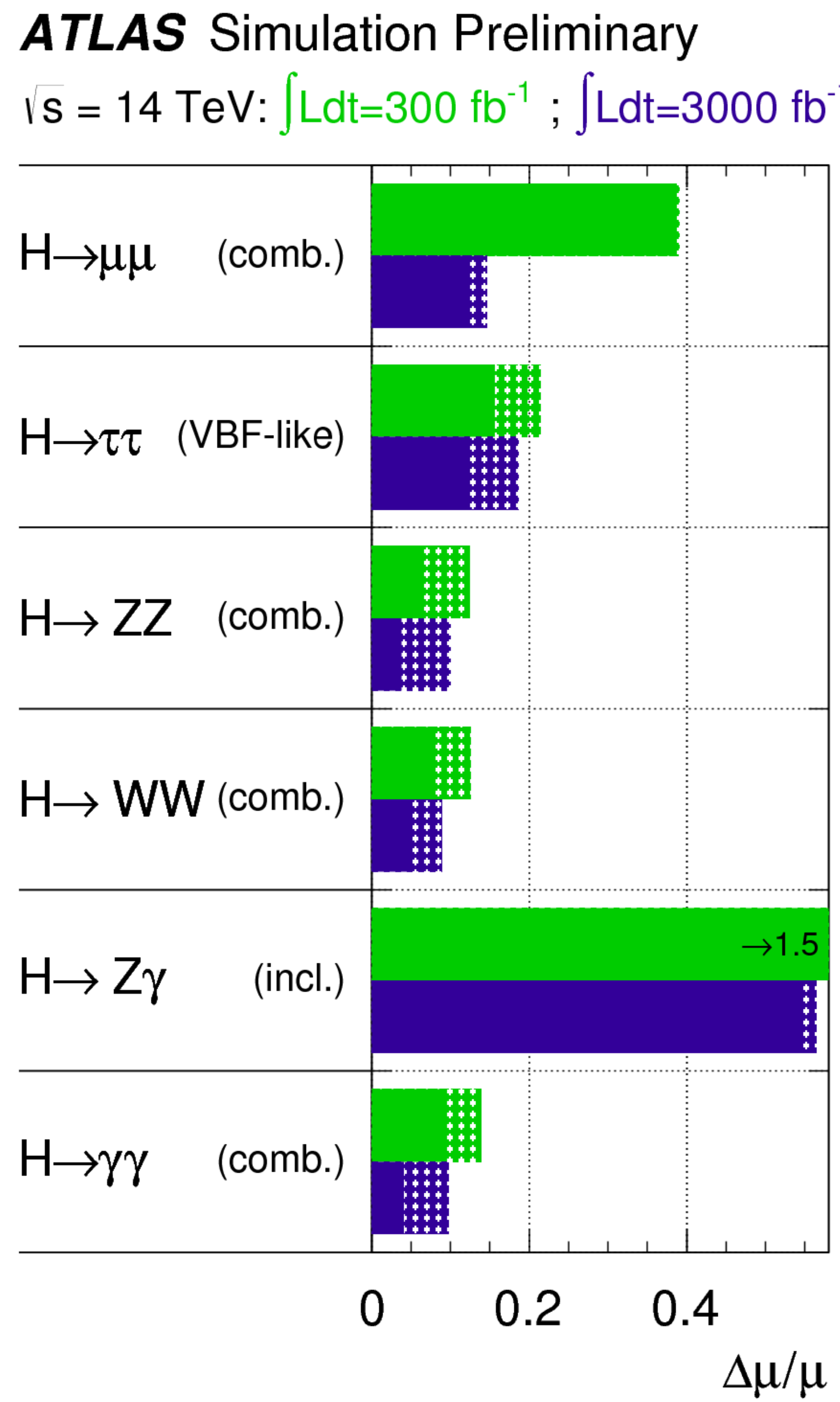
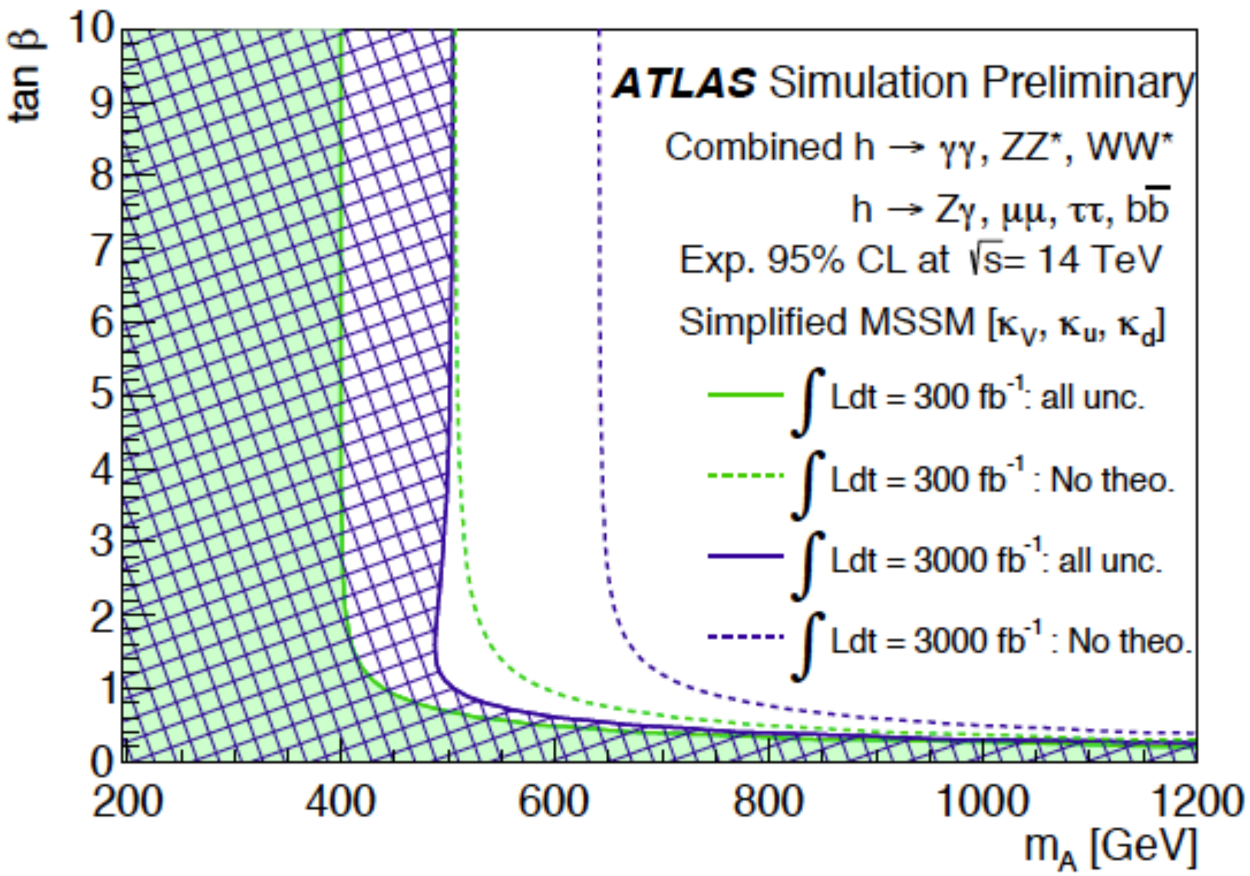


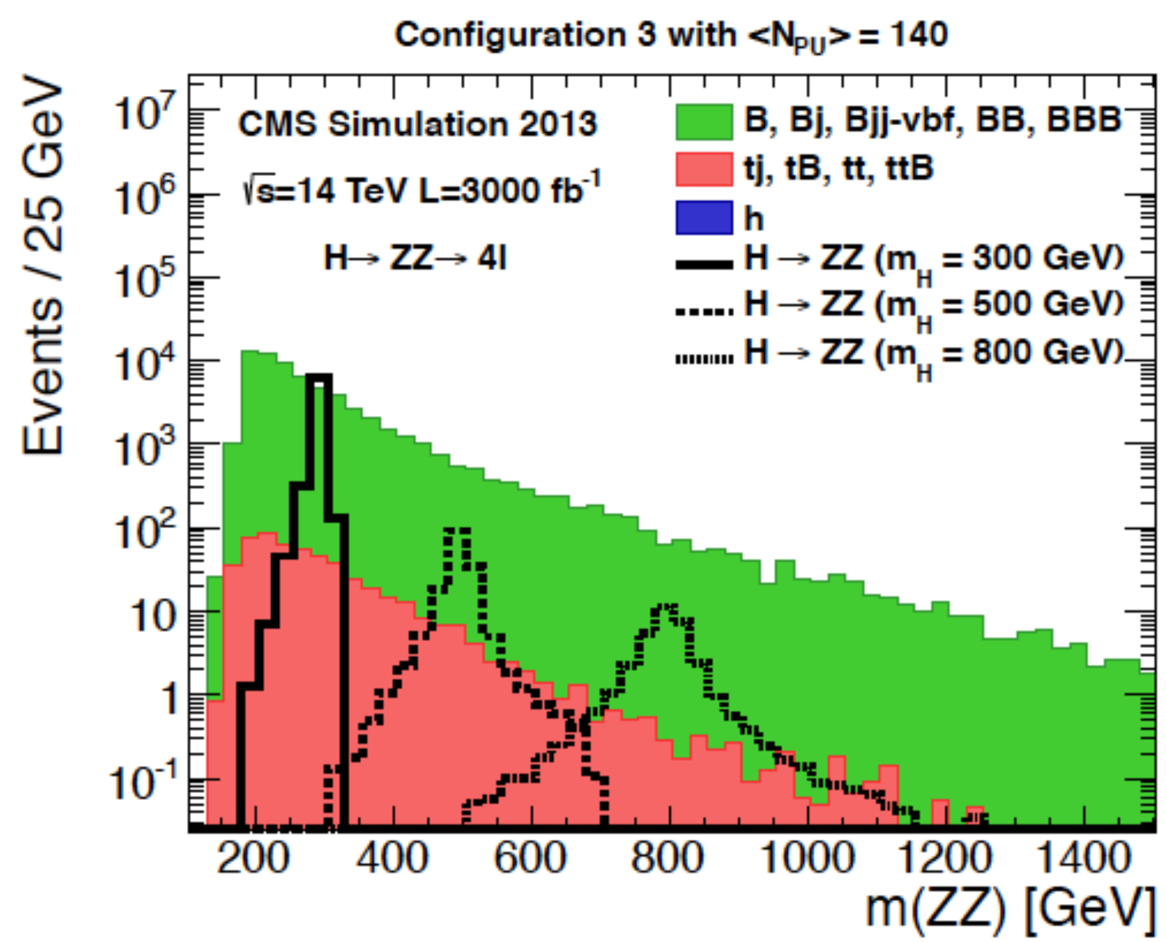
- With 3000 fb^{-1} the couplings can be determined with high precision (a few %)

2 HDM models

- Second Higgs doublet present in many BSM models
- Existence of 5 observable Higgs bosons
- Both experiments set exclusion limits for large areas of parameter space

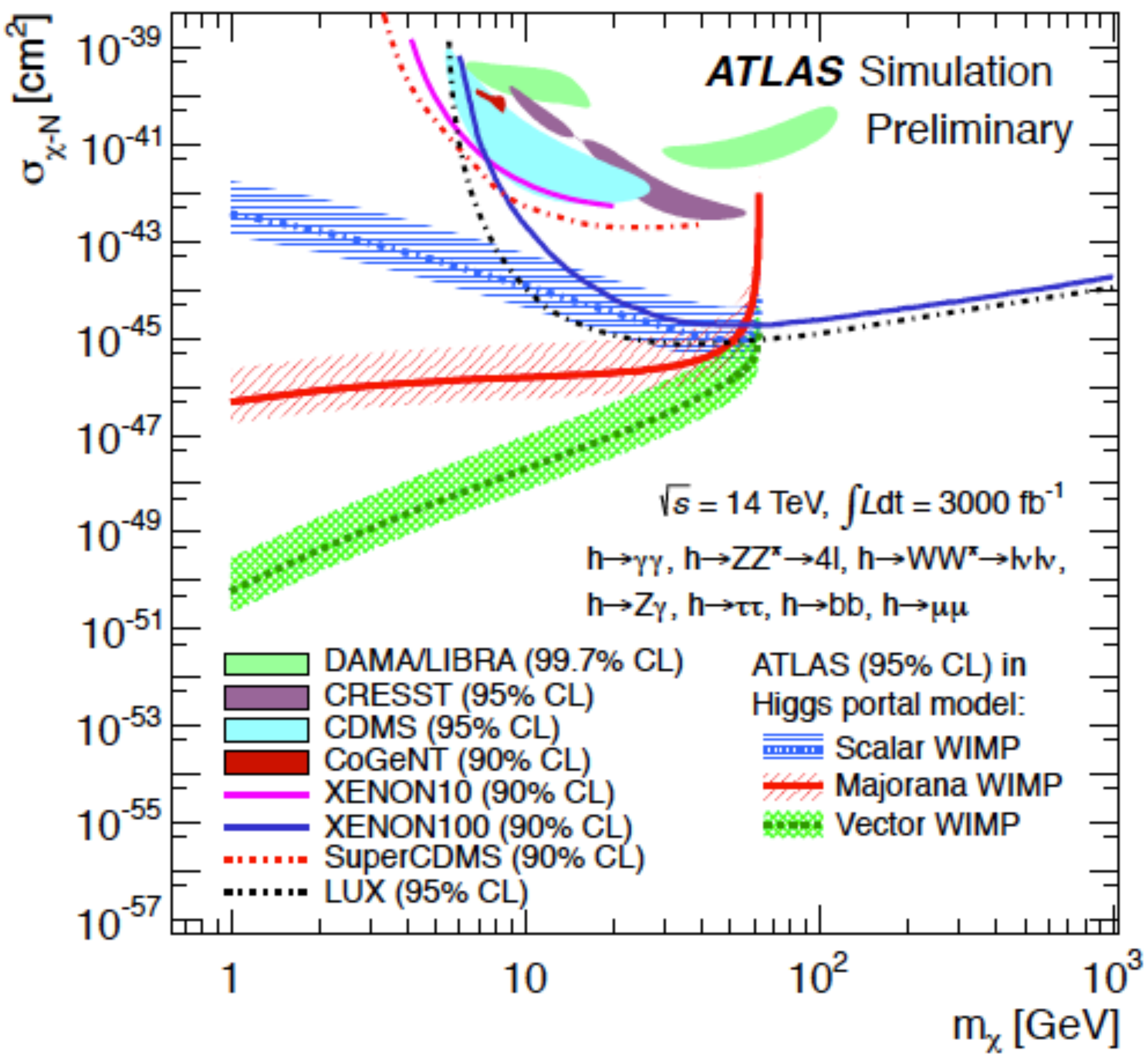


ATL-PHYS-PUB-2014-017



Higgs portal to dark matter

- BR of Higgs decays to invisible final states
  - ATLAS: $BR_{inv} < 0.13$ (0.09 w/out theory uncertainties) at $3000 fb^{-1}$
  - CMS: $BR_{inv} < 0.11$ (0.07 in Scenario 2) at $3000 fb^{-1}$
- The coupling of WIMP to SM Higgs taken as the free parameter
- Translate limit on BR to the coupling of Higgs to WIMP



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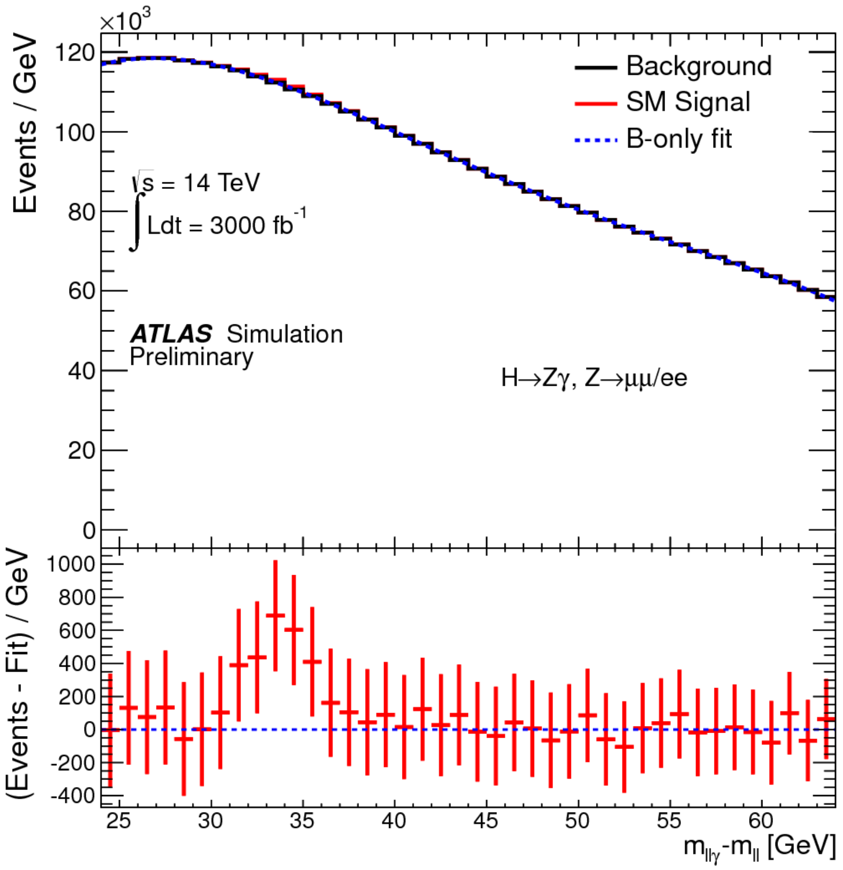
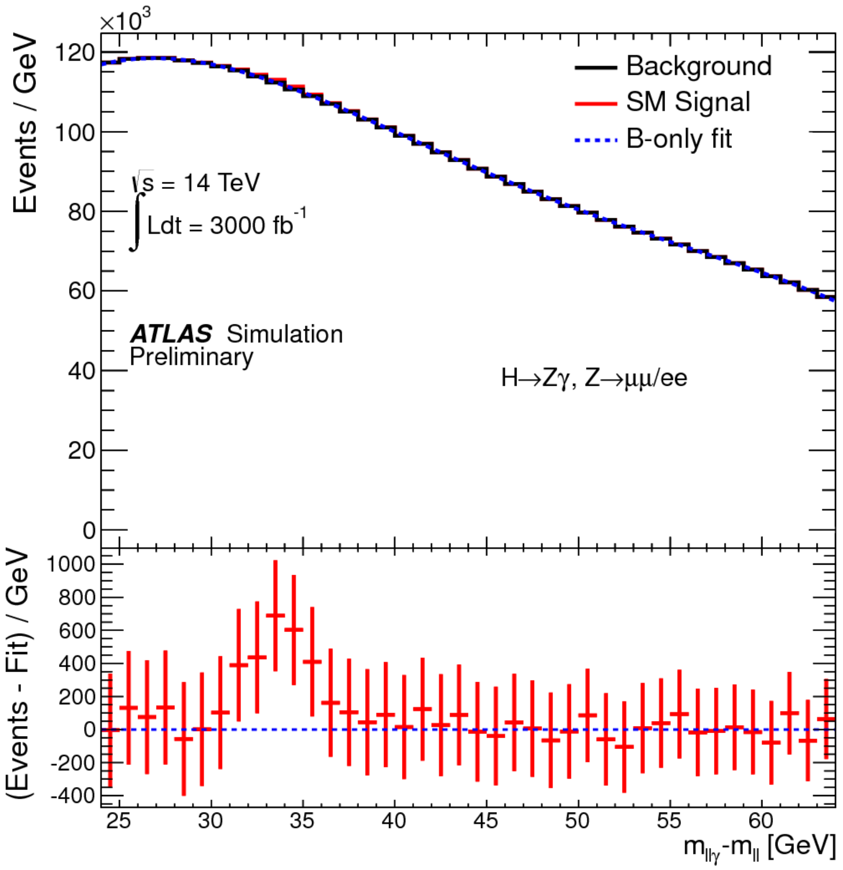
H→Zγ

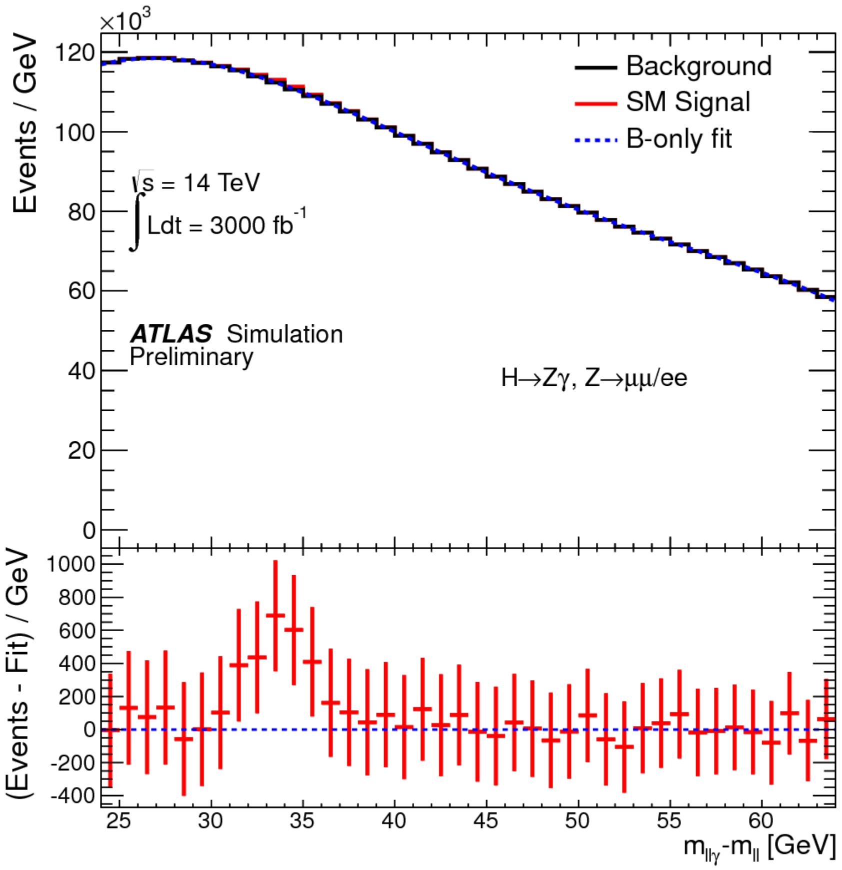

×10^3
Events / GeV
Background
SM Signal
B-only fit
√s = 14 TeV
∫Ldt = 3000 fb^-1
ATLAS Simulation
Preliminary
H→Zγ, Z→μμ/ee
(Events - Fit) / GeV
m_llγ-m_ll [GeV]

$H \rightarrow Z\gamma$



VBF signal (2 jets)

H→Zγ



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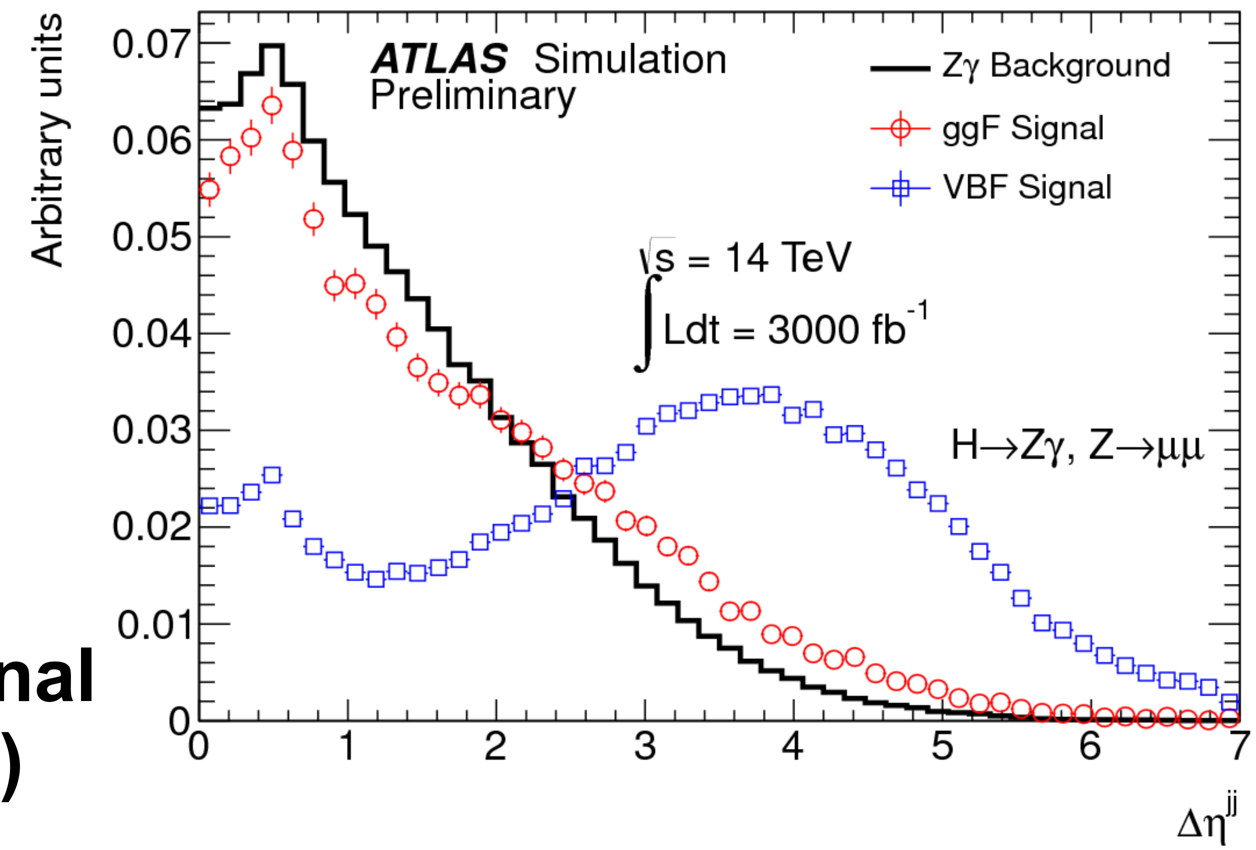
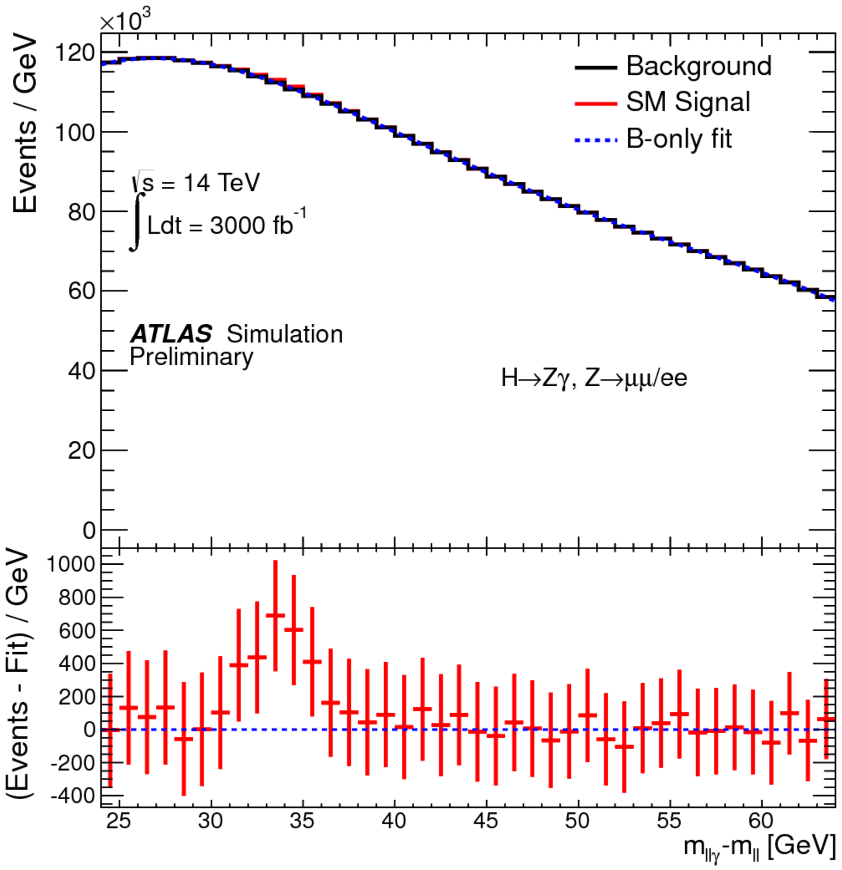
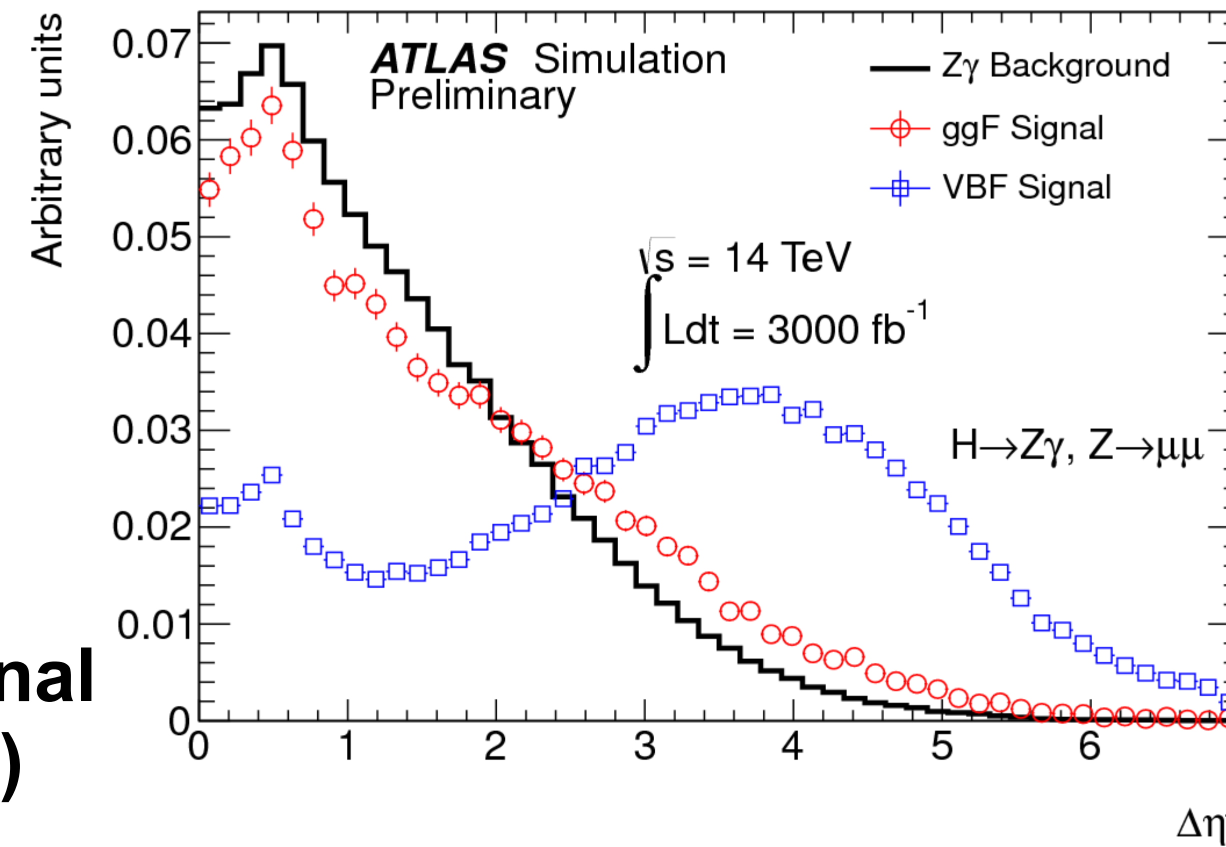
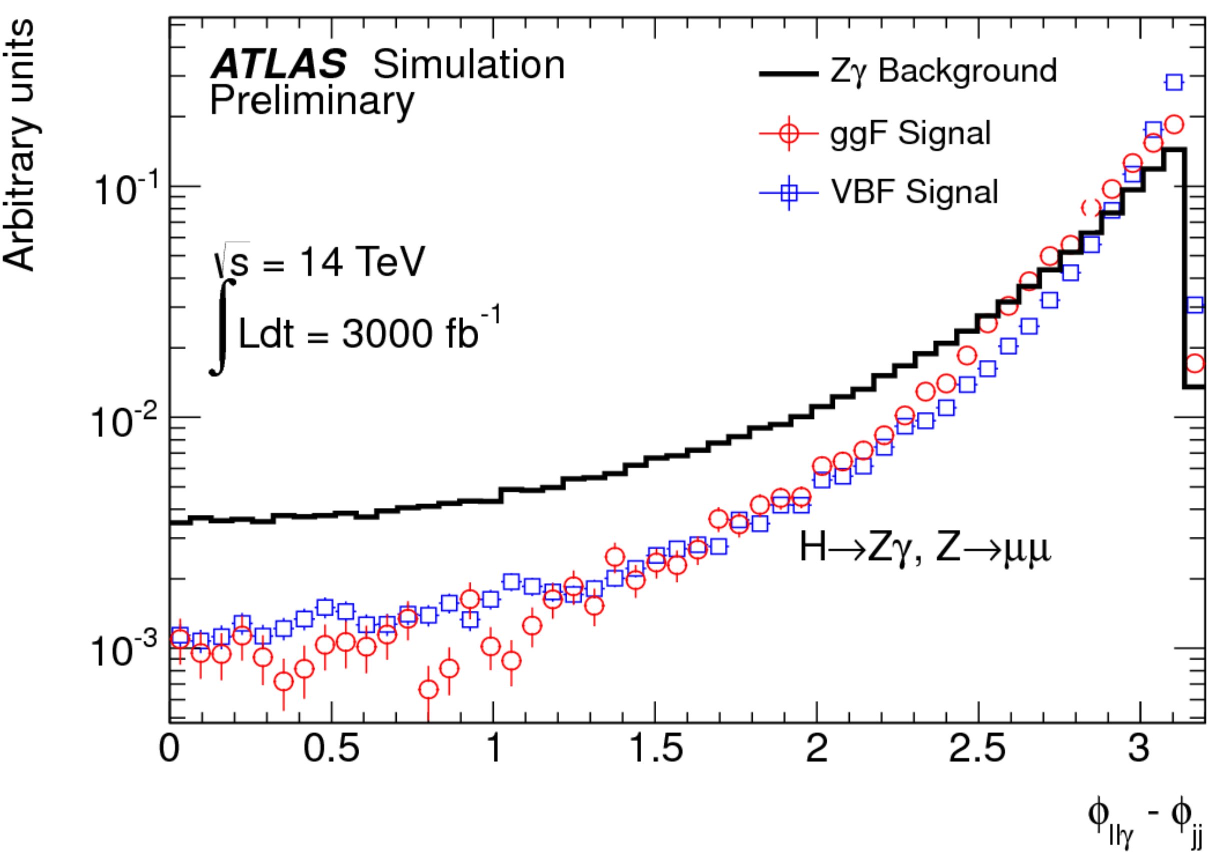


H→Zγ

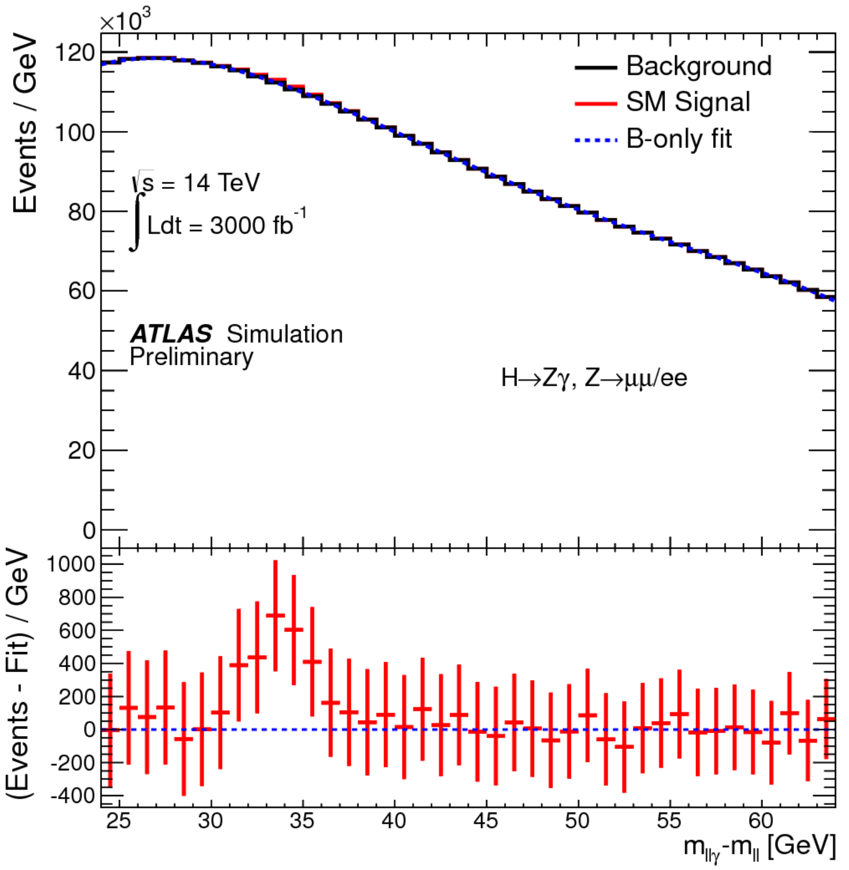


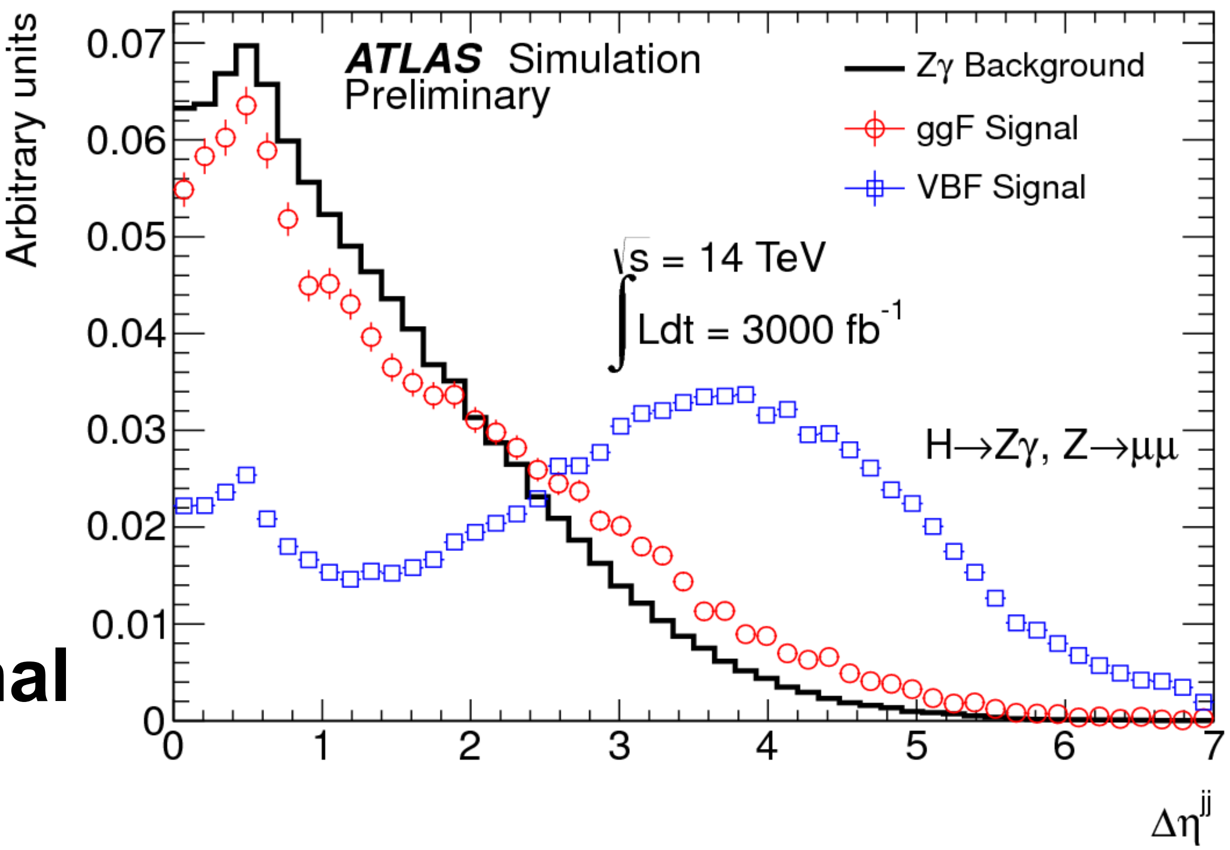
VBF signal
(2 jets)





H→Zγ





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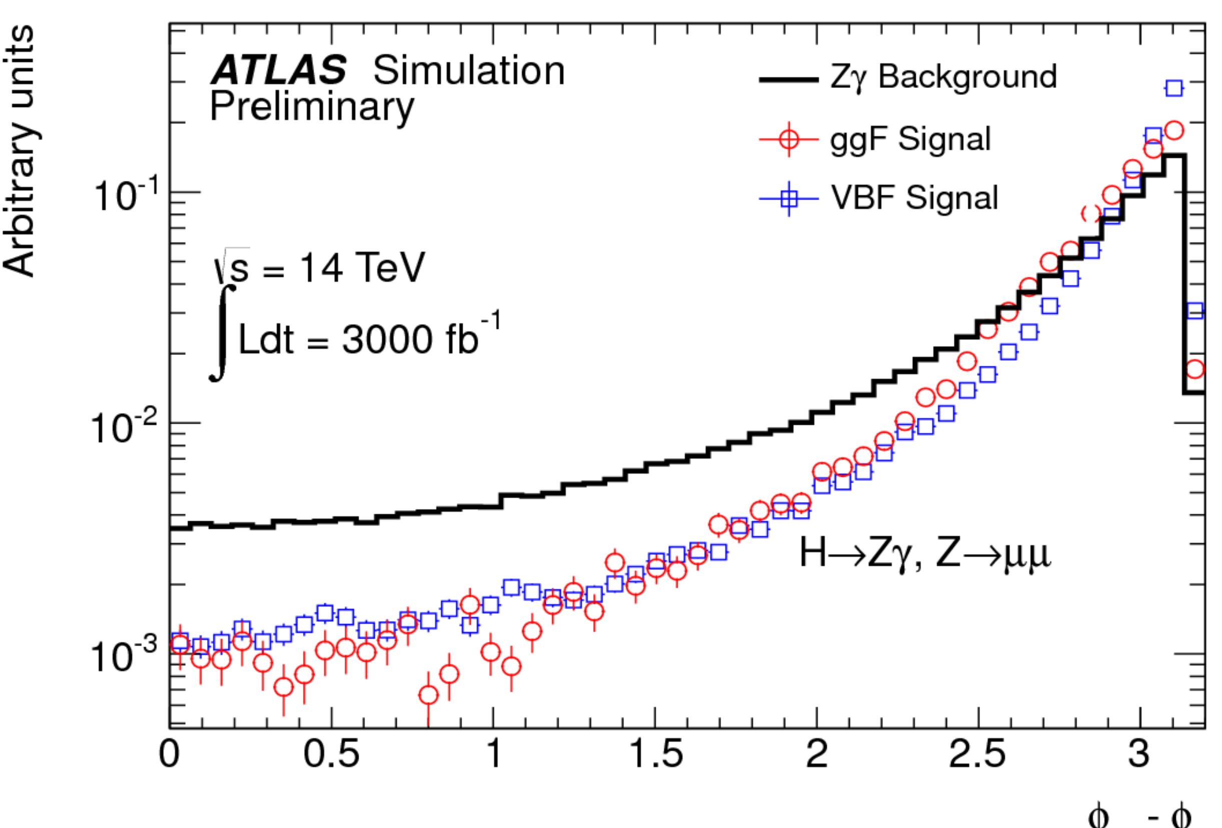
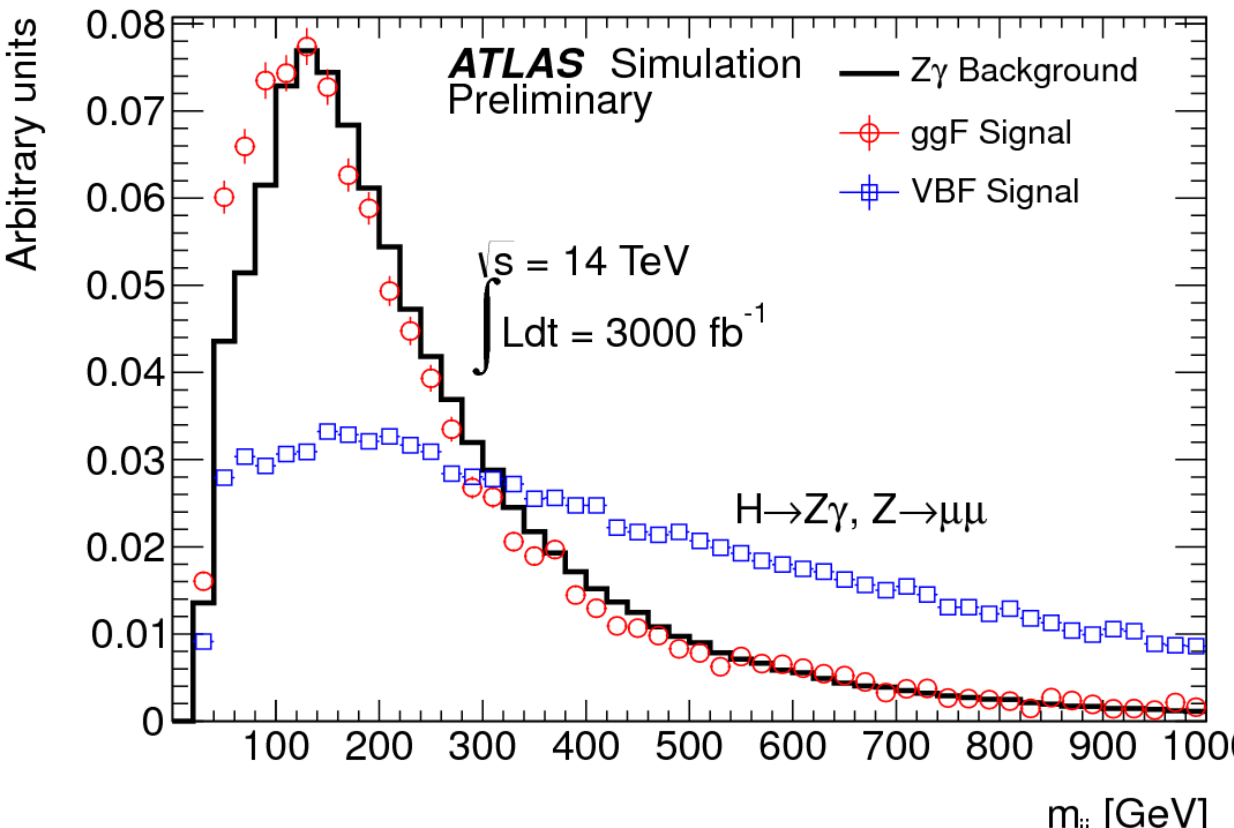




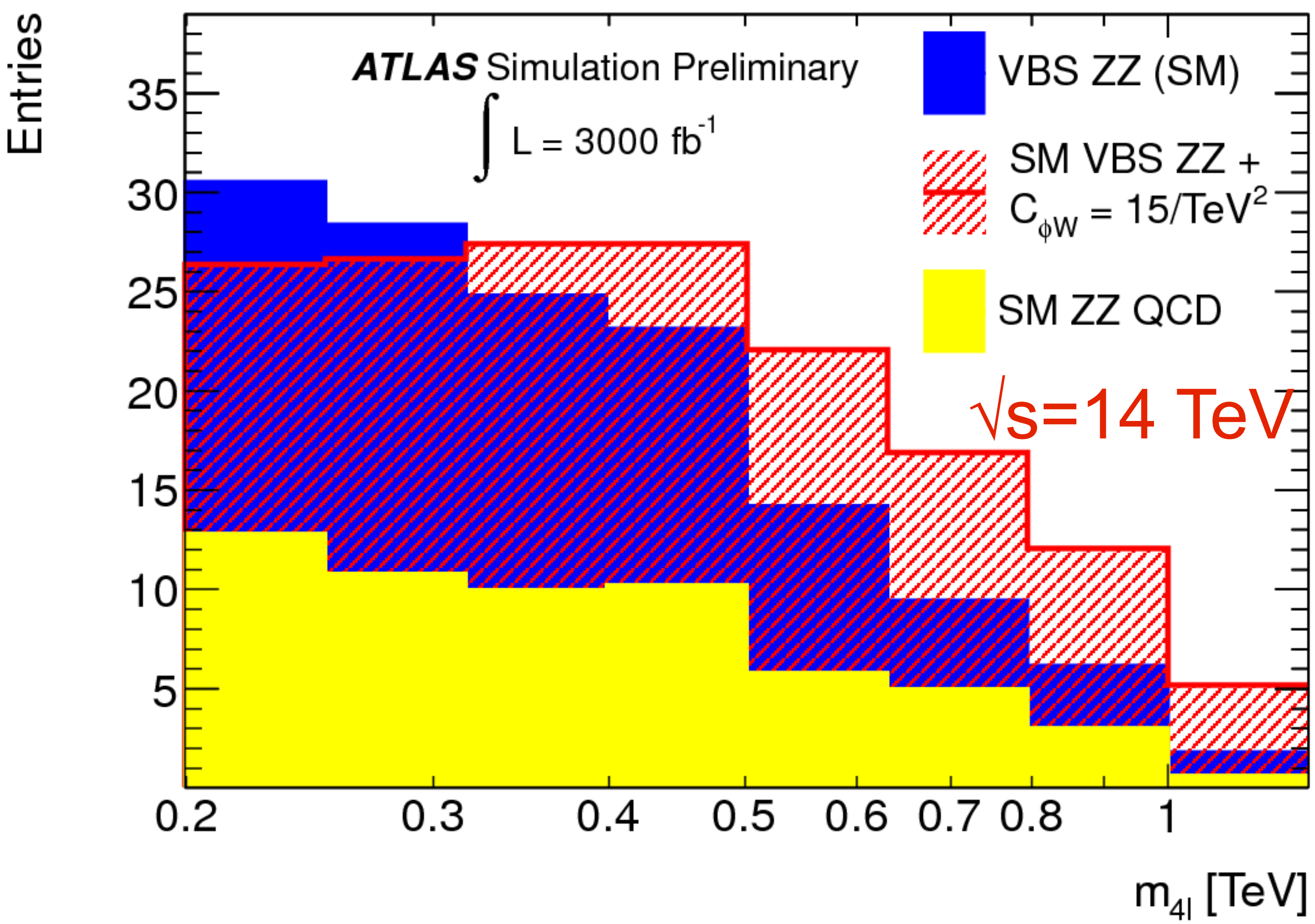
ZZ resonance

ZZ resonance

pp→ZZ+2j→4ℓ+2j channel

ZZ resonance

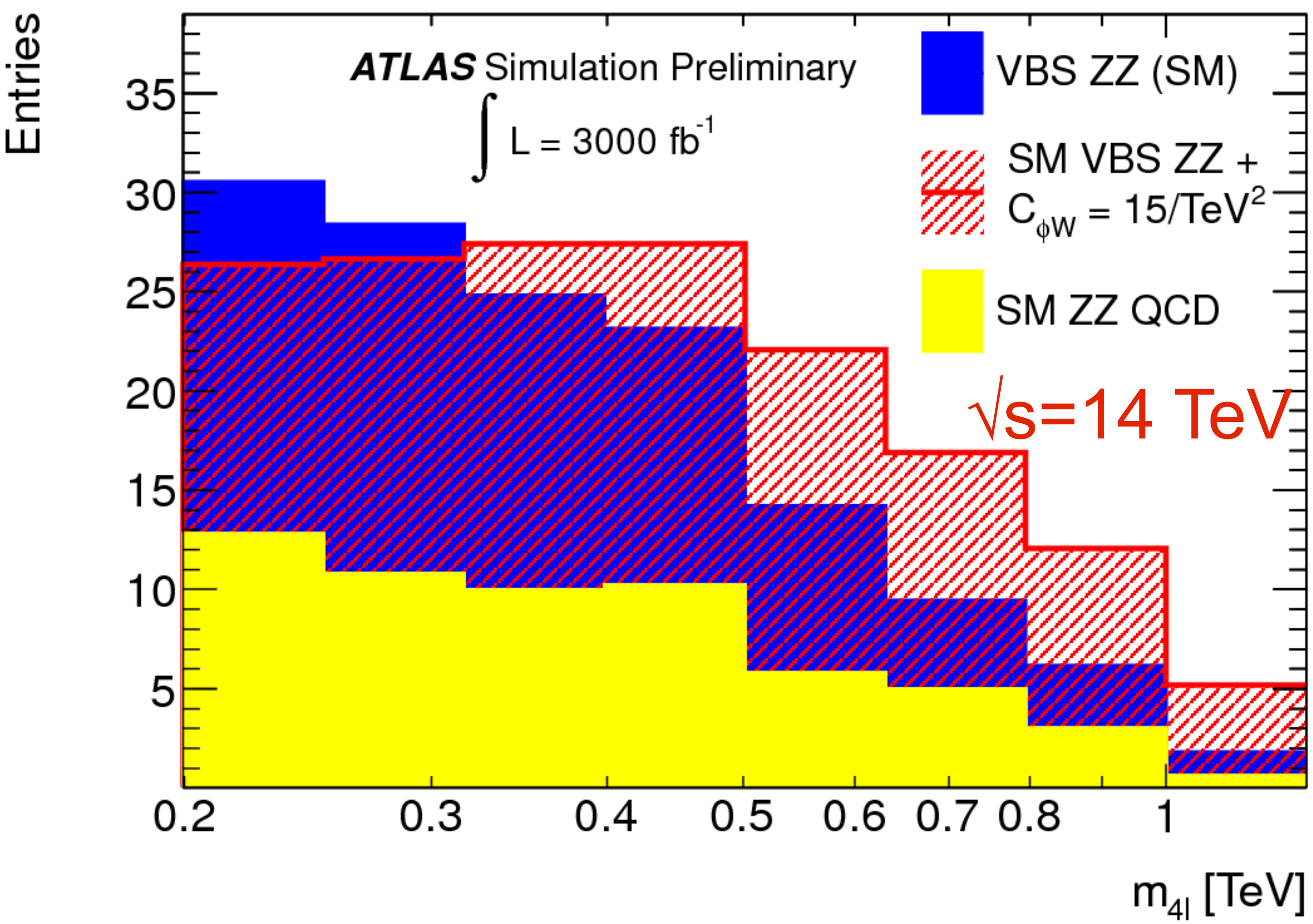
pp→ZZ+2j→4ℓ+2j channel

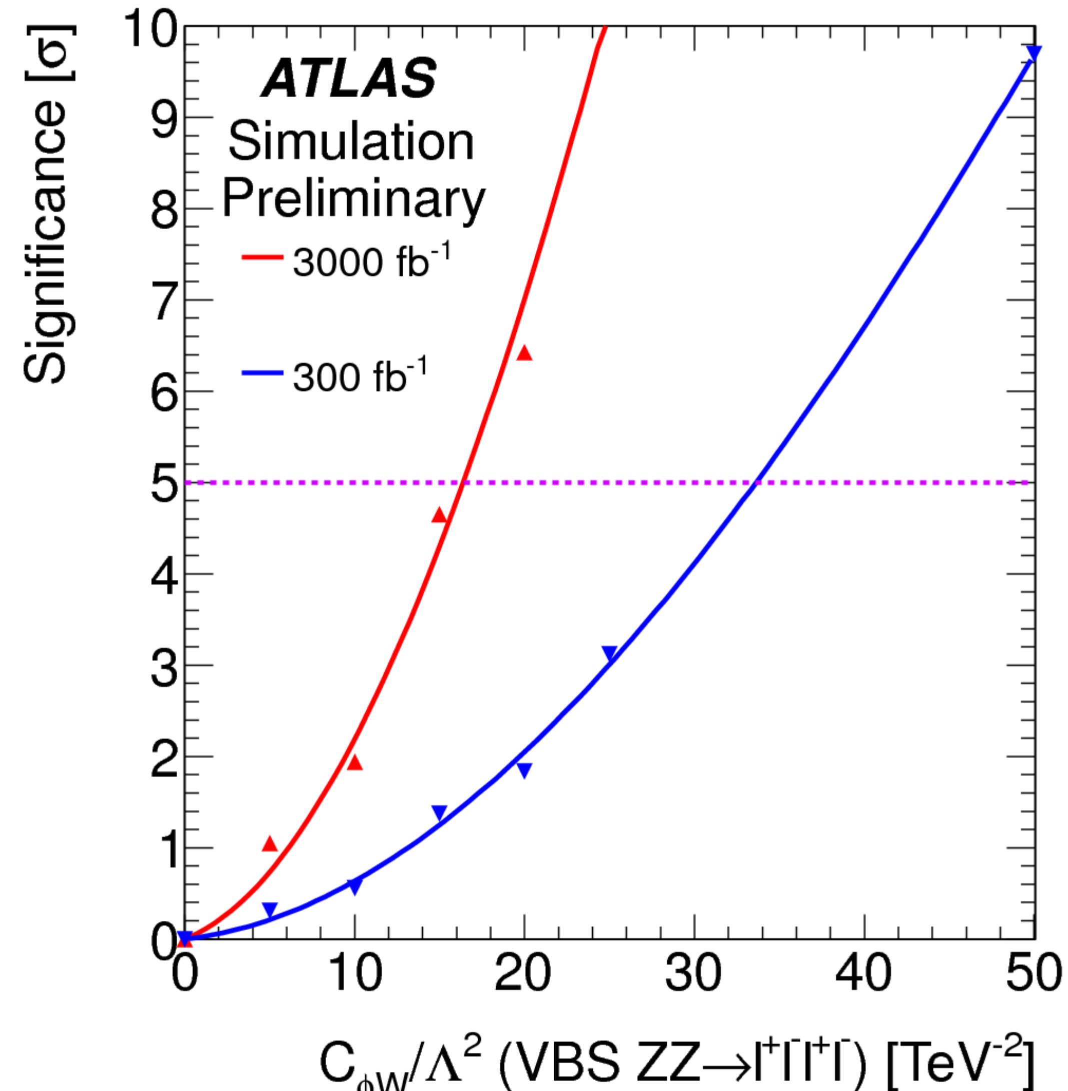


$$\mathcal{L}_{\phi W} = \frac{c_{\phi W}}{\Lambda^2}\mathrm{Tr}(W^{\mu\nu}W_{\mu\nu})\phi^\dagger\phi$$

ZZ resonance

pp→ZZ+2j→4ℓ+2j channel





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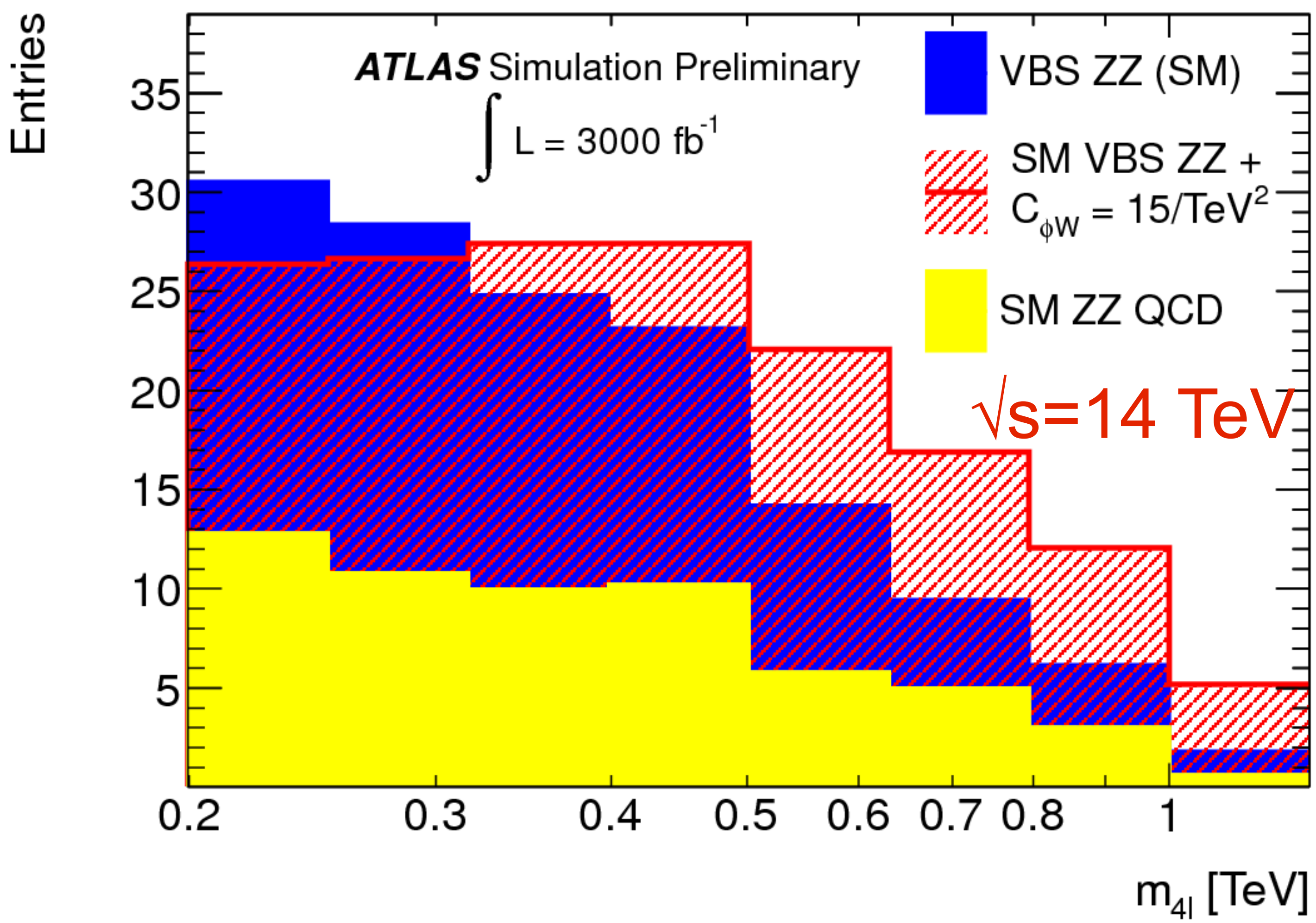

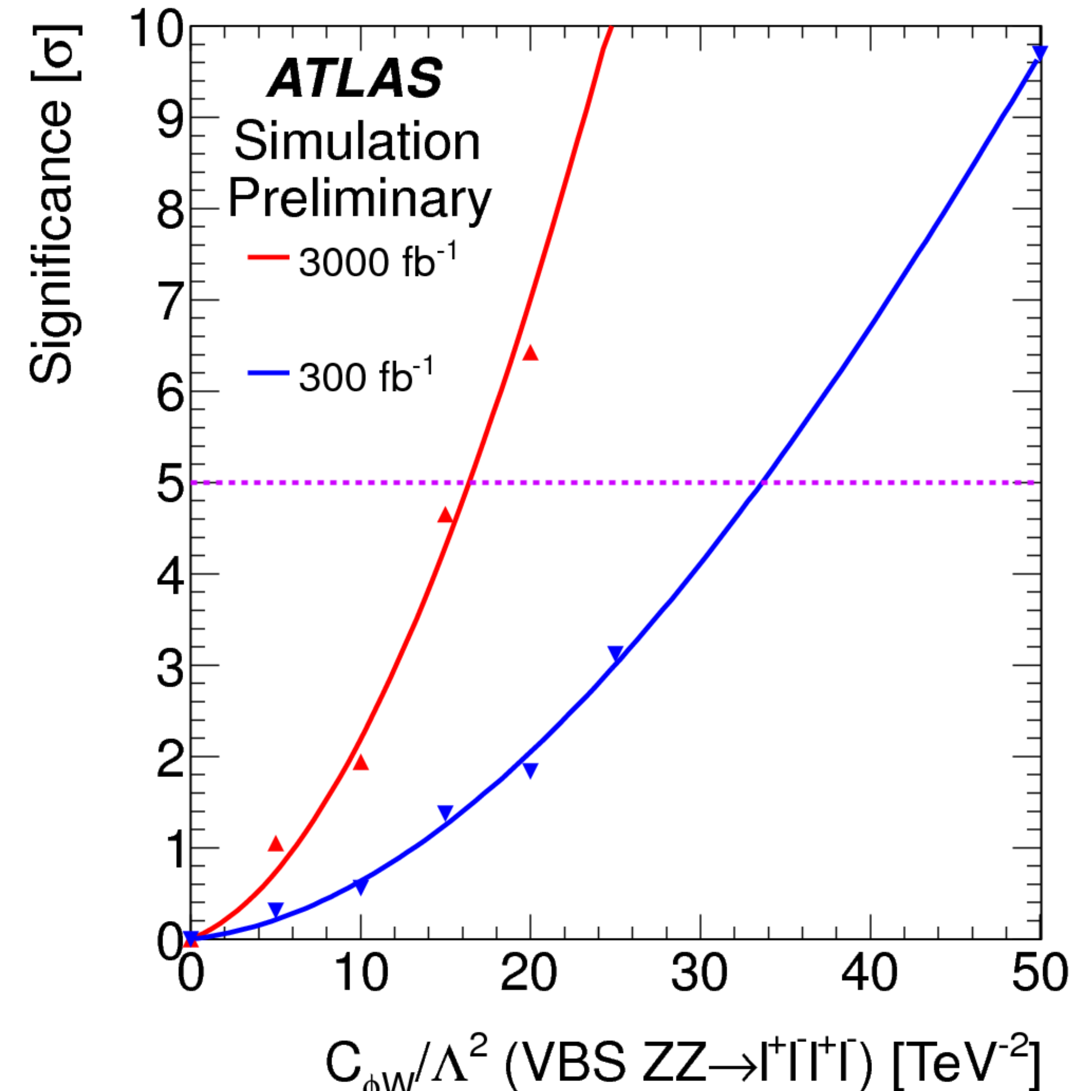

$$\mathcal{L}_{\phi W} = \frac{c_{\phi W}}{\Lambda^2}\mathrm{Tr}(W^{\mu\nu}W_{\mu\nu})\phi^\dagger\phi$$

	$300\ \mathrm{fb}^{-1}$	$3000\ \mathrm{fb}^{-1}$
$c_{\phi W}/\Lambda^2$	$34\ \mathrm{TeV}^{-2}$	$16\ \mathrm{TeV}^{-2}$

Sensitivity to anomalous ZZ resonances in Vector boson scattering

WZ scattering

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pp→WZ+2j→ℓ's+ν+2j channel

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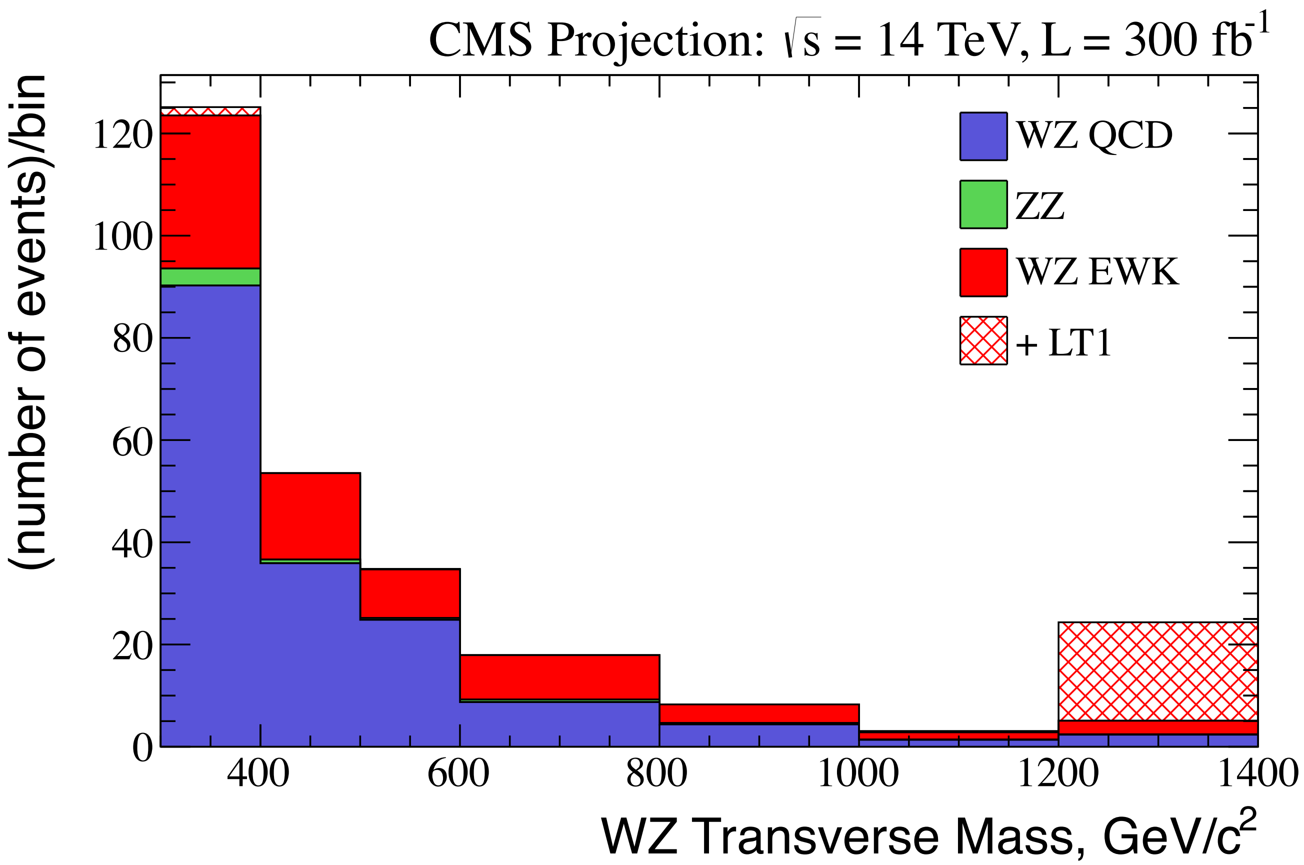
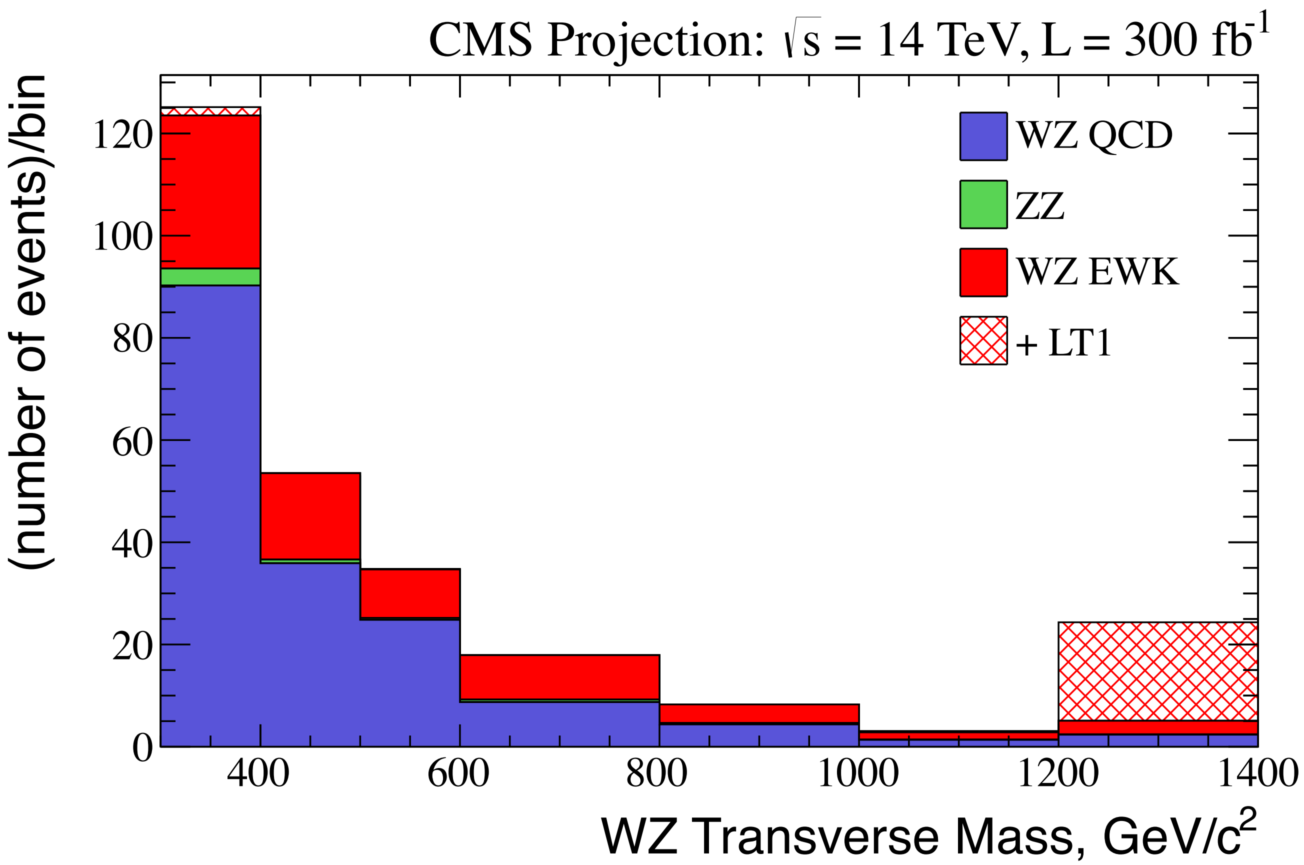
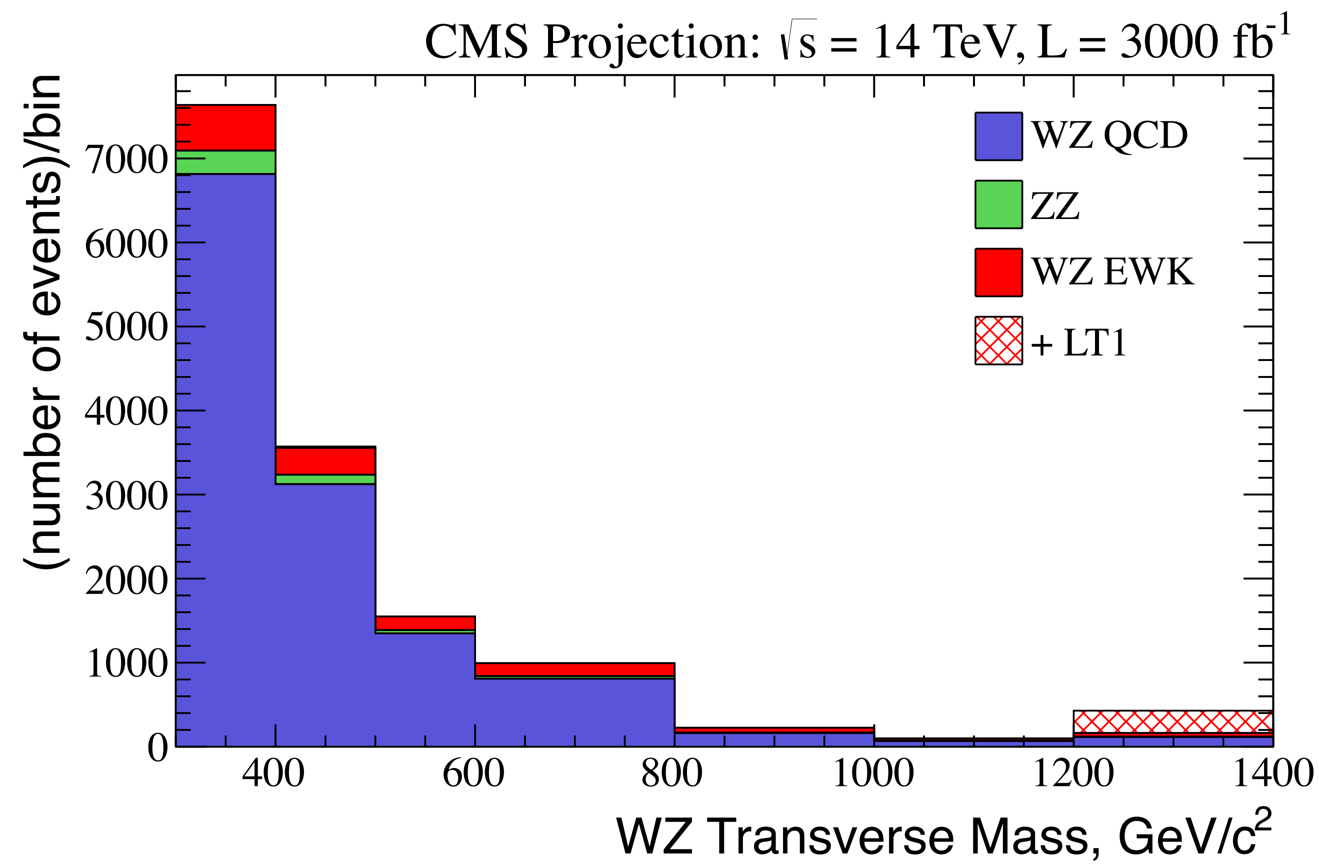


Sensitivity to anomalous WZ resonances in Vector boson scattering

WZ scattering

pp→WZ+2j→ℓ's+ν+2j channel





Sensitivity to anomalous WZ resonances in Vector boson scattering

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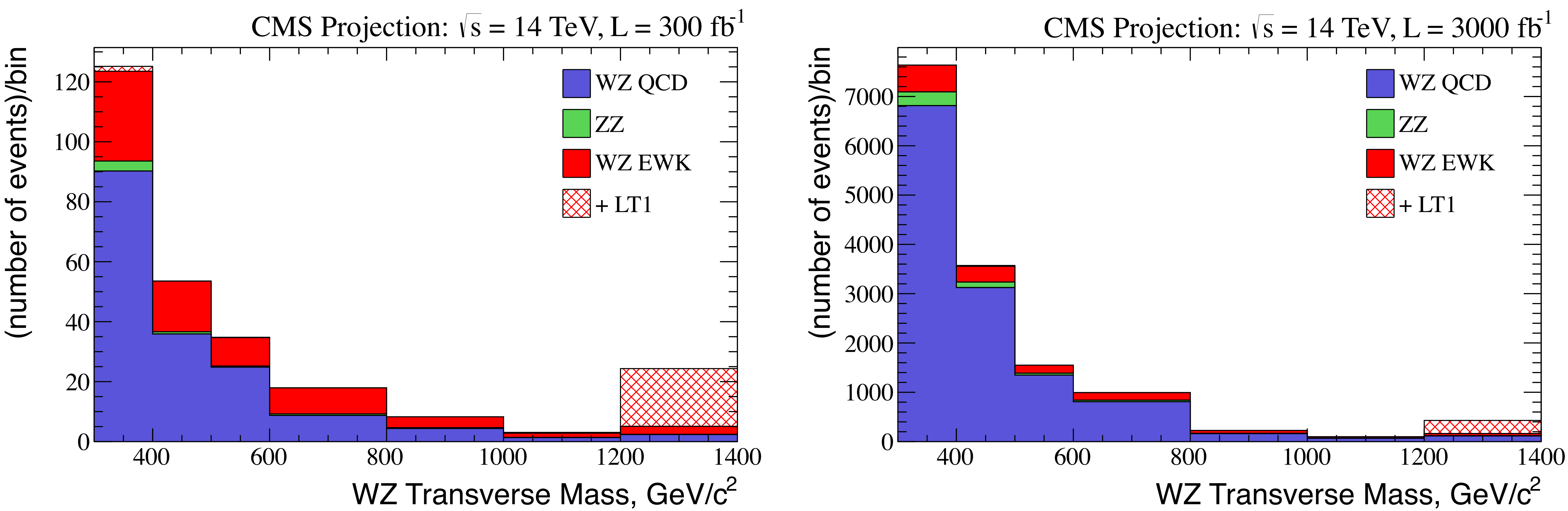

Significance	3σ	5σ
SM EWK Scattering Discovery	75 fb^{-1}	185 fb^{-1}
f_{T1}/Λ^4 at 300 fb^{-1}	0.8 TeV^{-4}	1.0 TeV^{-4}
f_{T1}/Λ^4 at 3000 fb^{-1}	0.45 TeV^{-4}	0.55 TeV^{-4}

Sensitivity to anomalous WZ resonances in Vector boson scattering

ZZ resonance

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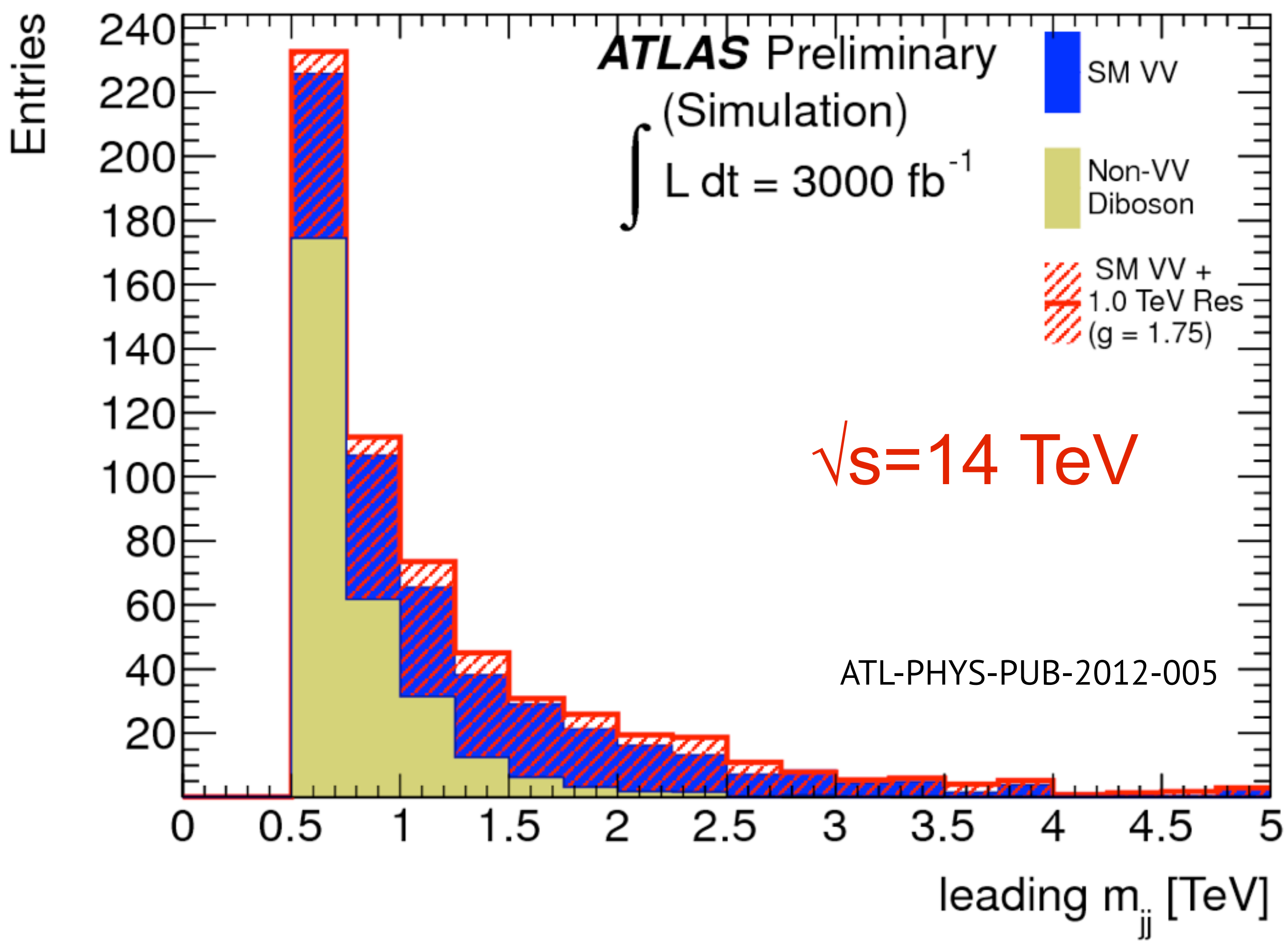

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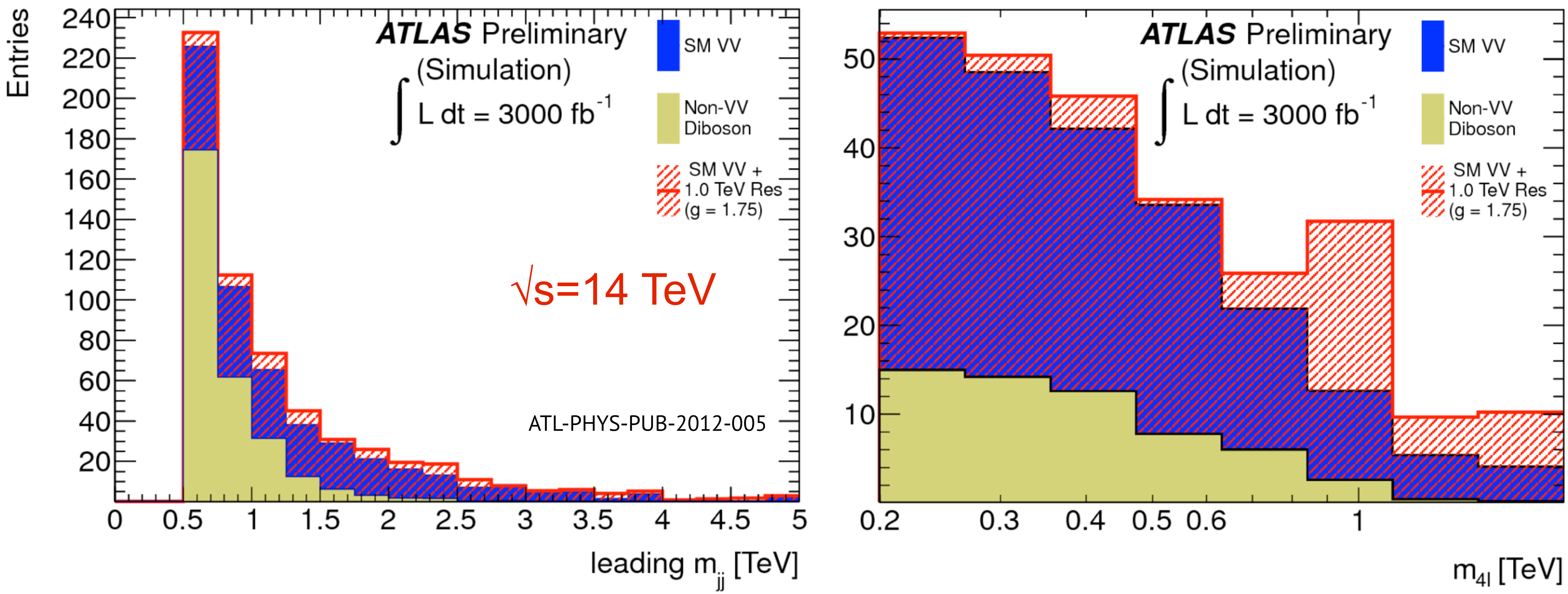

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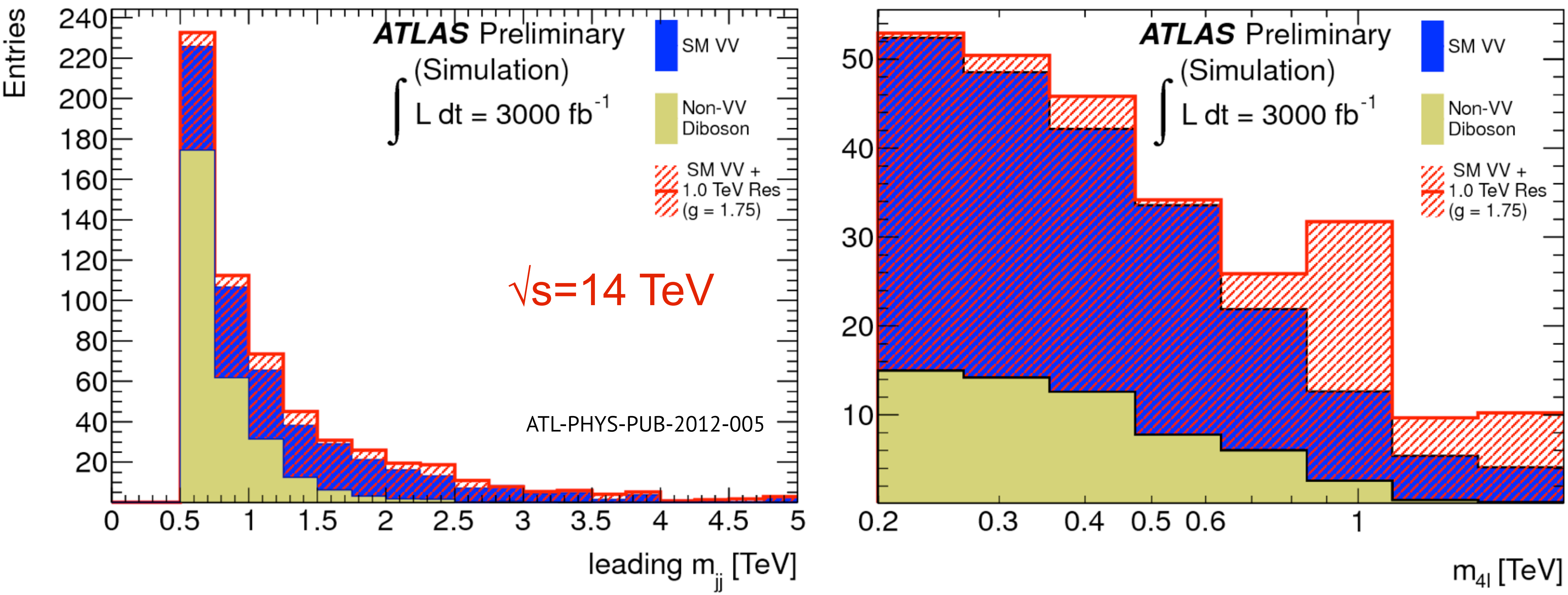
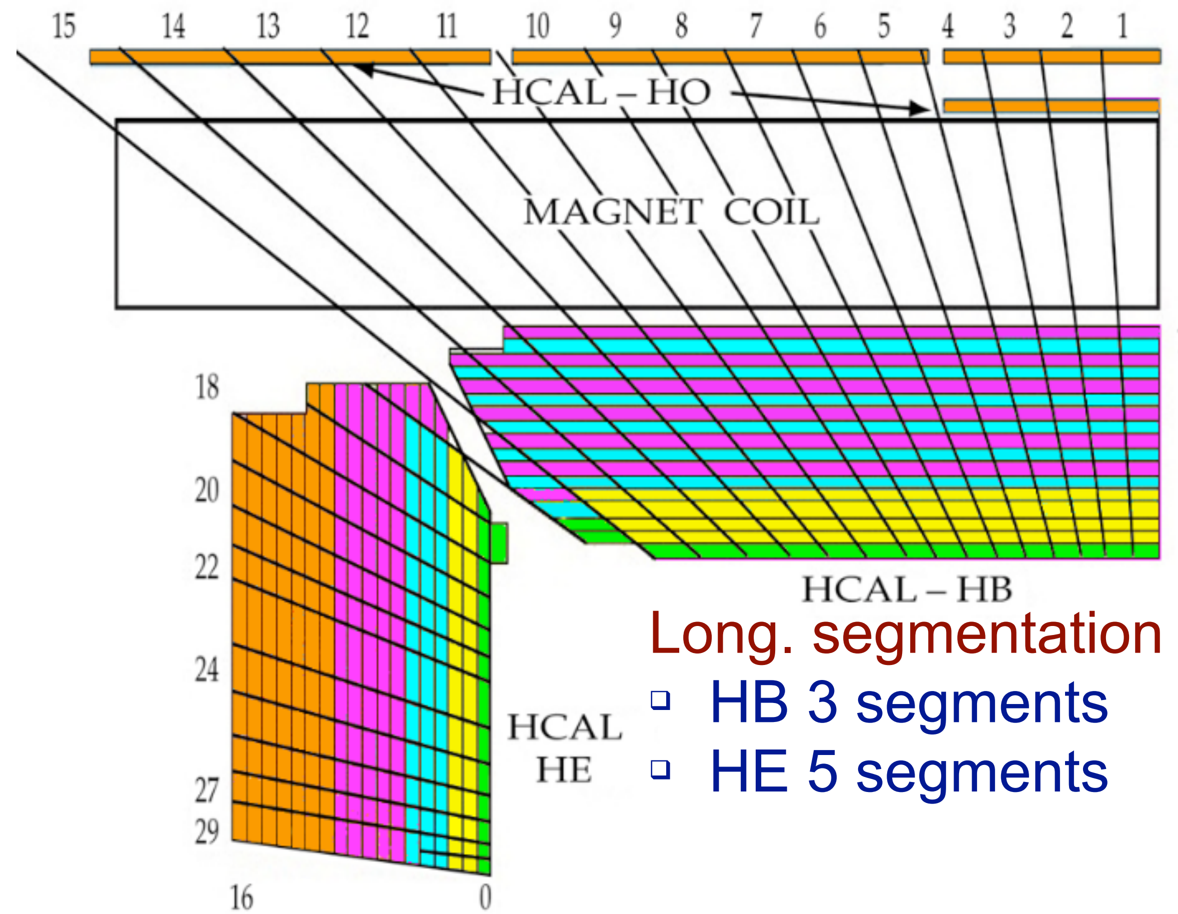


model	300 fb^{-1}	3000 fb^{-1}
$m_{resonance}$ = 500 GeV, $g = 1.0$	2.4σ	7.5σ
$m_{resonance}$ = 1 TeV, $g = 1.75$	1.7σ	5.5σ
$m_{resonance}$ = 1 TeV, $g = 2.5$	3.0σ	9.4σ

Sensitivity to anomalous ZZ resonances in Vector boson scattering

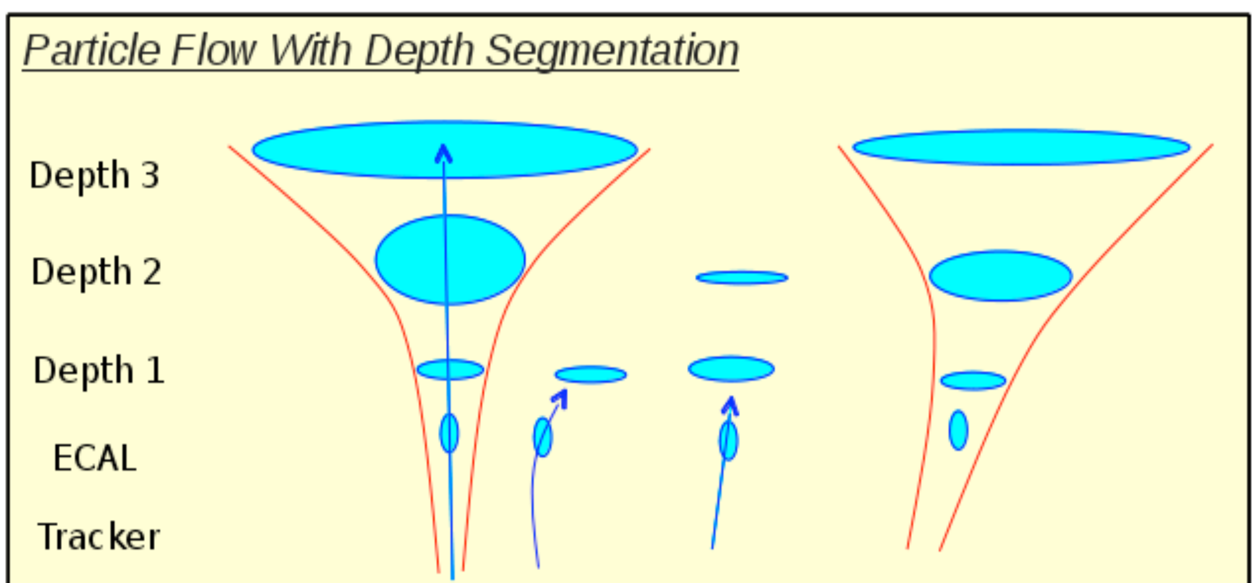
HCAL Upgrade

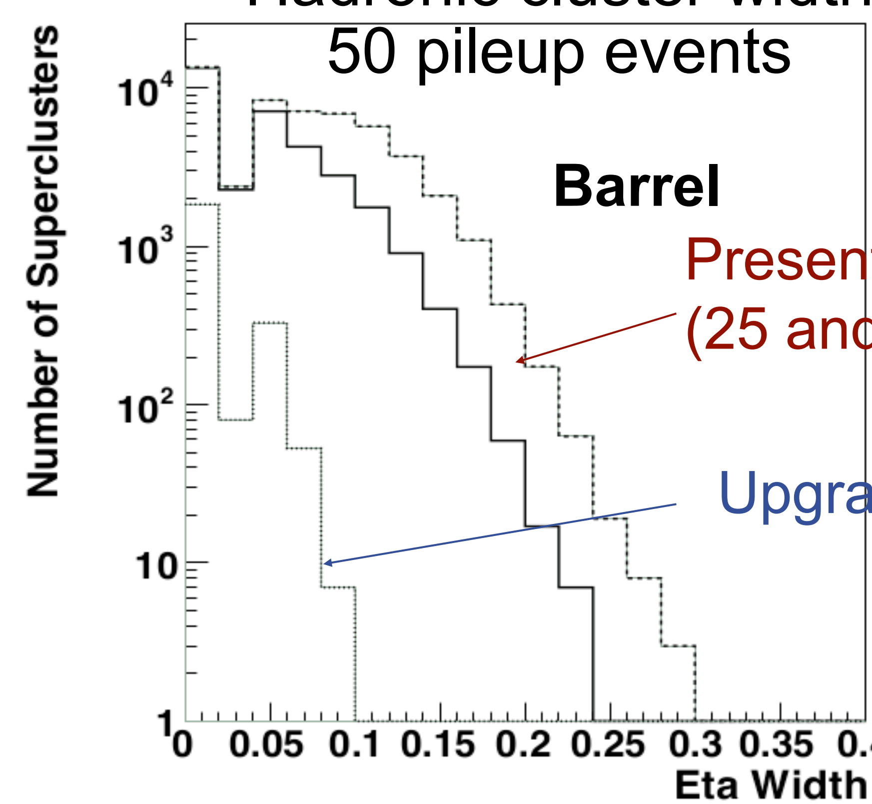
- Upgraded HCAL
  - New photodetectors
  - New electronics (frontend, backend)
  - Improved longitudinal segmentation
  - Improved background rejection, Missing E_T resolution and Particle Flow reconstruction



Long. segmentation
- HB 3 segments
- HE 5 segments

- Hadronic showers spread out with increasing depth



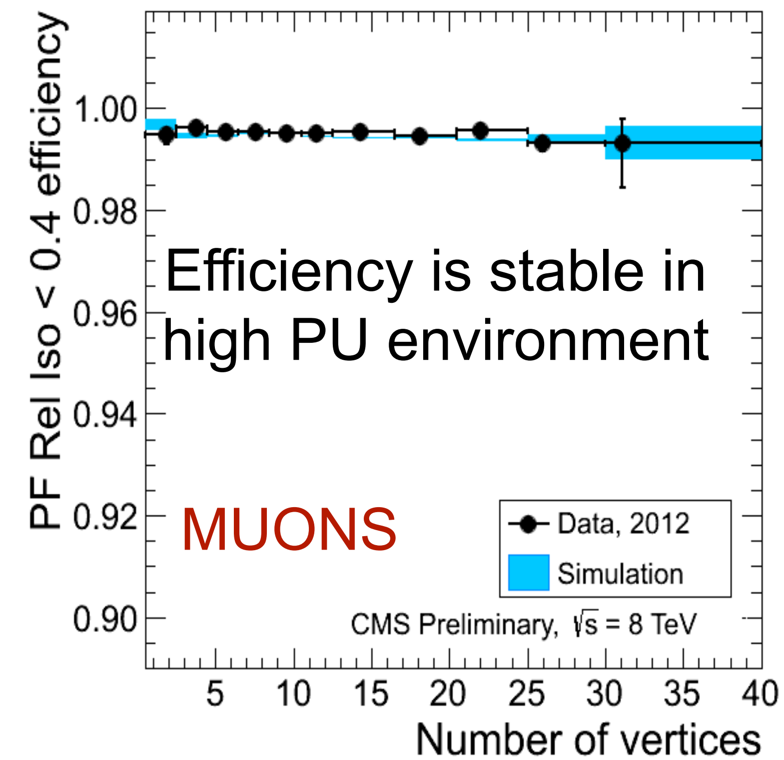


Pileup challenges

Reconstruction of hard collisions in high pileup environment requires detectors with very high granularity:

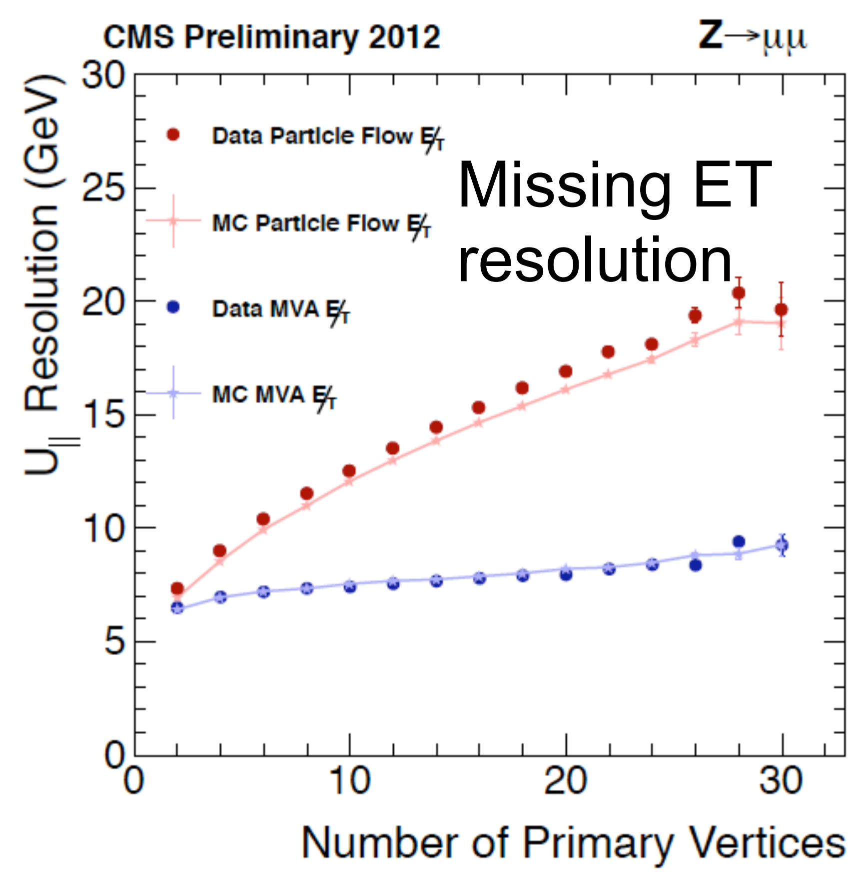
- efficient association of charged tracks to collision vertices
- reconstruction of charged and neutral particles in jets
- pileup neutrals corrected w/global energy density (ρ)

Muon isolation



Physics with high pileup requires full particle flow reconstruction assuring:

- precise jet energy correction
- robust missing energy measurement
- efficient lepton isolation

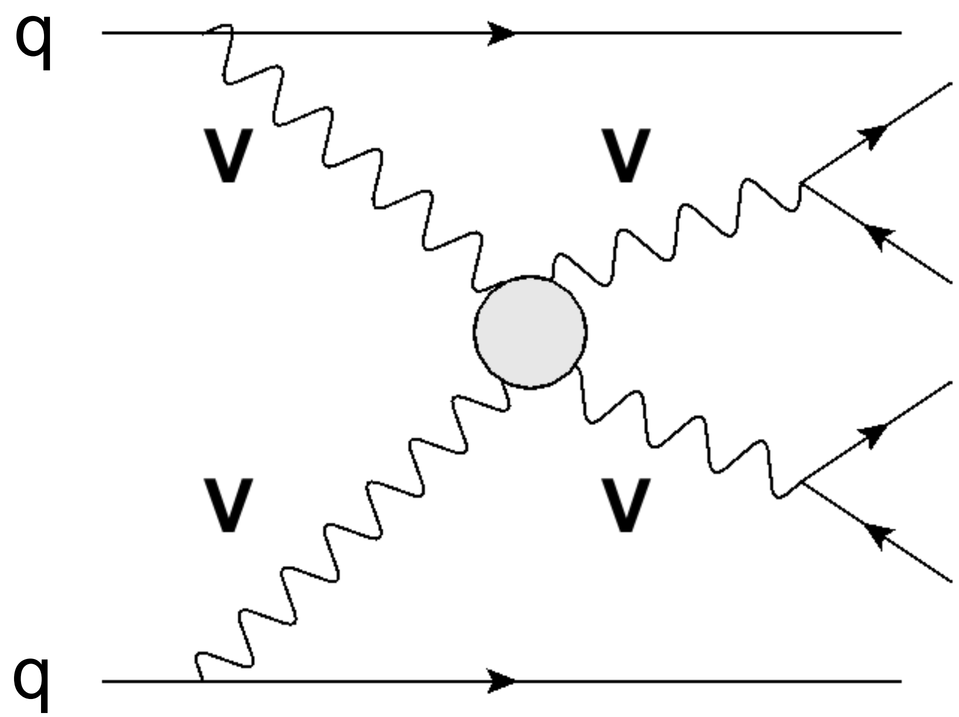


Very efficient reconstruction code is needed to stay within computing budget

Vector Boson Fusion (VBF)

Vector Boson Fusion (VBF)

Generic diagram for vector boson fusion (VBF) process



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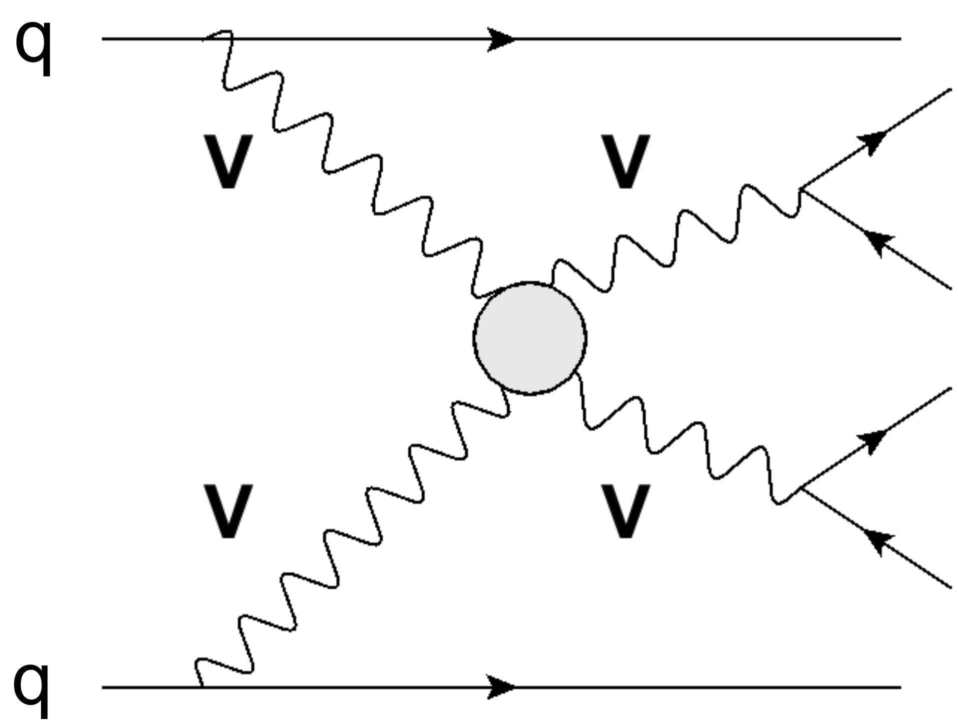

Signature: forward-backward "spectator" jets with very high energy

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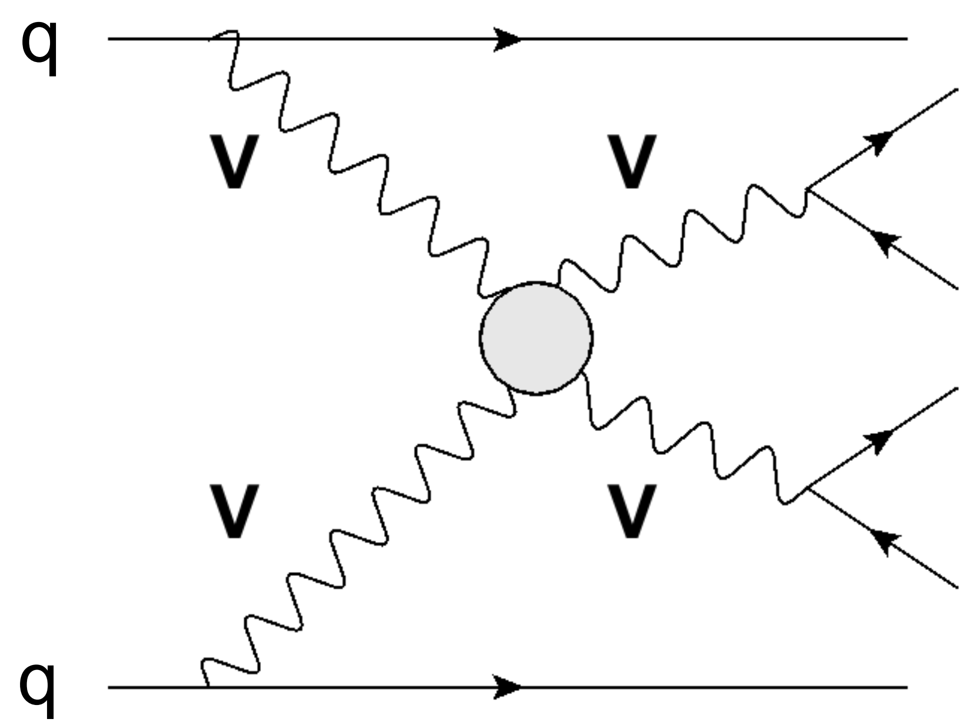

Signature: forward-backward "spectator" jets with very high energy

- Once the vector bosons decay, we have a six-fermion final state
- The full set of qq→6 fermions diagrams has to be considered
- In order to investigate EWSB, one has to isolate VV processes from all other six-fermion final states

  ➡ Apply tight kinematic cuts

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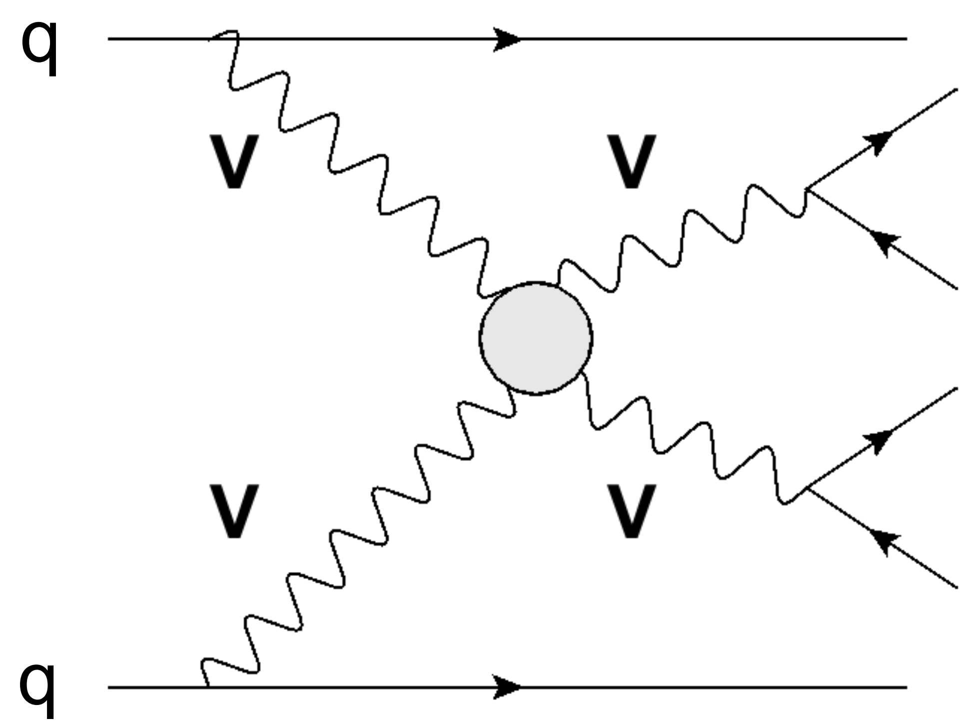
Generic diagram for vector boson fusion (VBF) process



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➡ Apply tight kinematic cuts

Typical kin. cuts

$p_{T,j} > 20$ GeV $|\eta_j|<5$ $p_T^{tag} > 30$ GeV $|\eta_{j1}-\eta_{j2}|>4.0$

$\eta_{j1}\cdot\eta_{j2} < 0$ $m_{jj} > 600$ GeV

VV scattering: semileptonic

Semileptonic is most promising: reasonable signal yield

Number of events for 20 fb^{-1} (fully MC based, no systematics, 14 TeV)

WV -> lnjj

ATLAS	N sign.	N back.
500 GeV	6.2	16
800 GeV	13	17
1.1 TeV	4.8	9.2

CMS	N sign.	N back.
500 GeV	337	20759
>1 TeV	45	3281

ZV -> lljj

CMS	N sign.	N back.
500 GeV	62	3415
>1 TeV	5	348

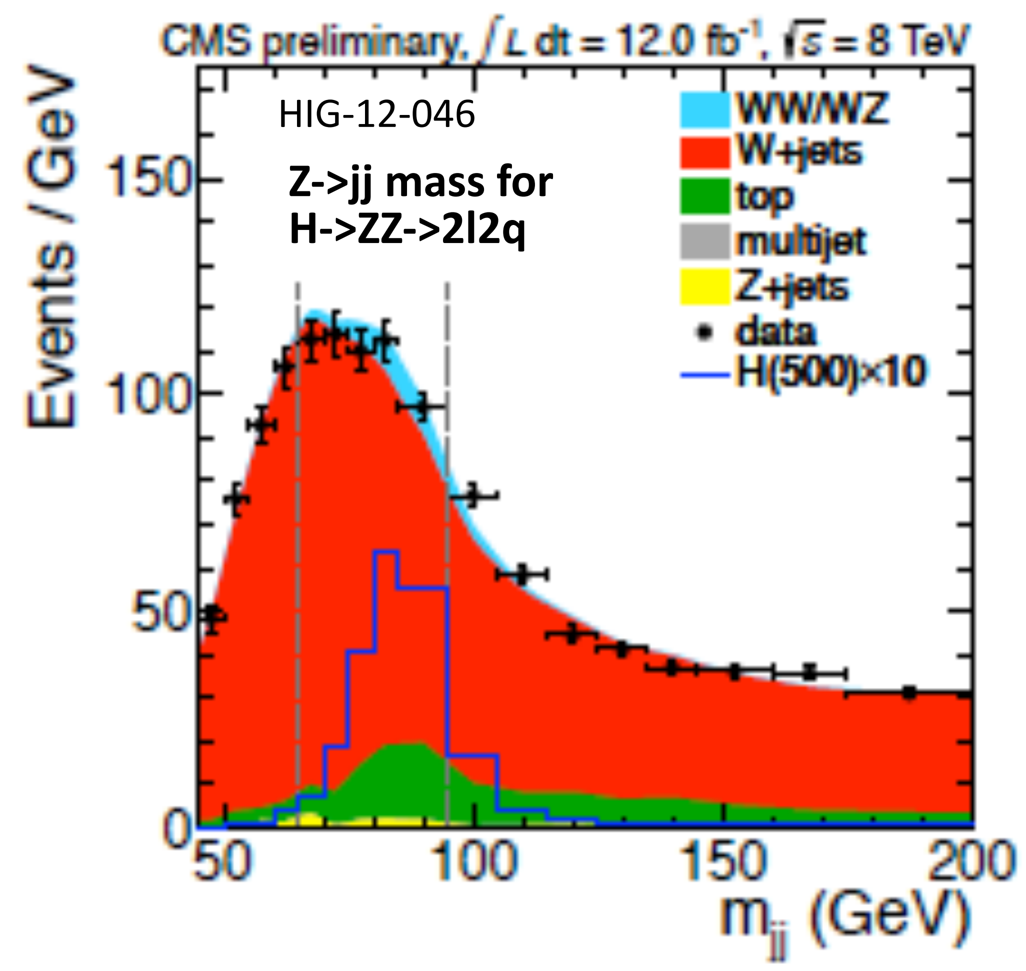
CERN-OPEN-2008-020

For recent inclusive Higgs search:

- more sophisticated analysis developed
(btag categories, angular analyses,
$m_{jj} = m_Z$ kinematic fit)

- data driven background

Improved JES: m_{jj} reso from 20-25% to 10-15%



Ratios of partial widths @3000 fb^{-1}

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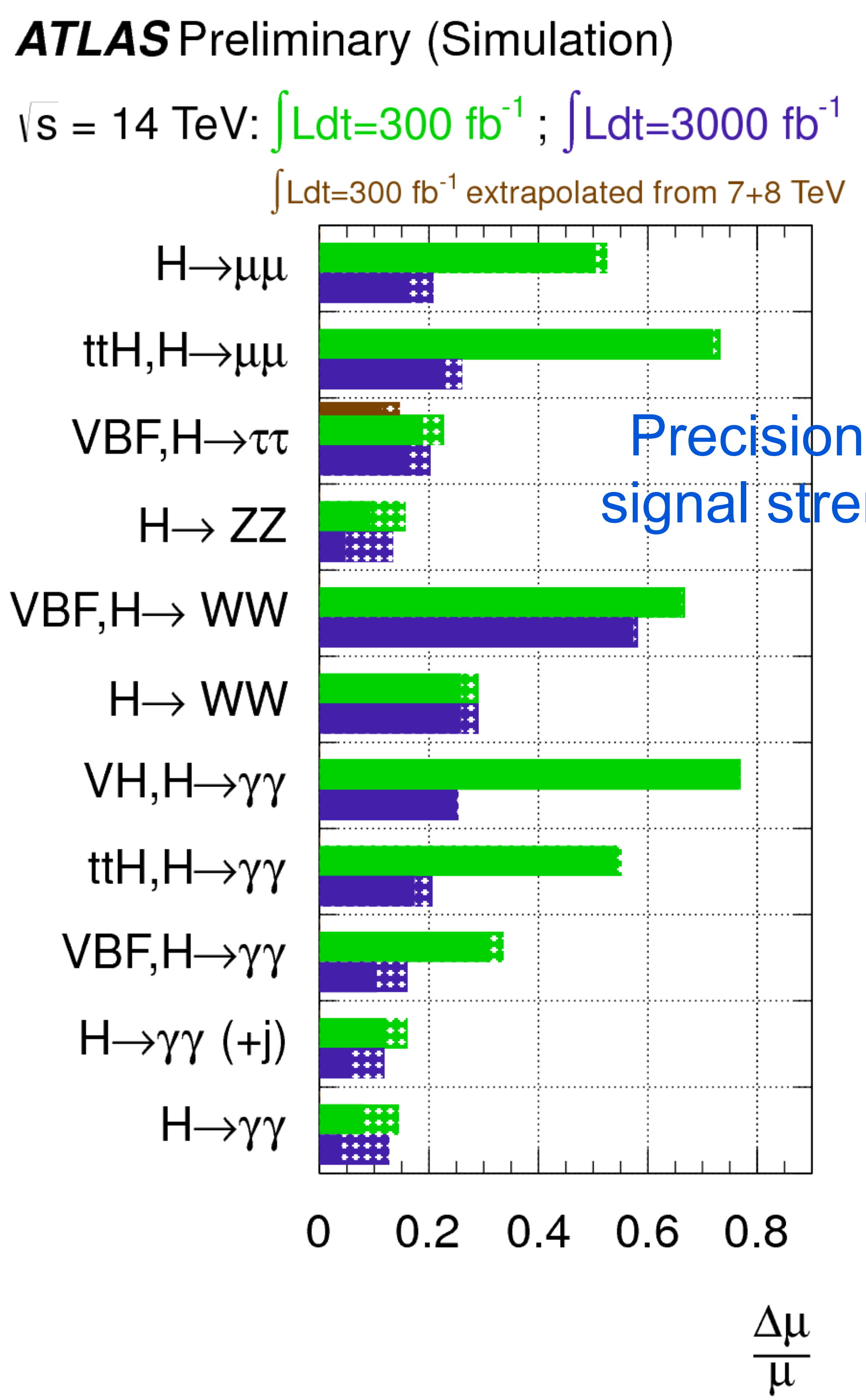
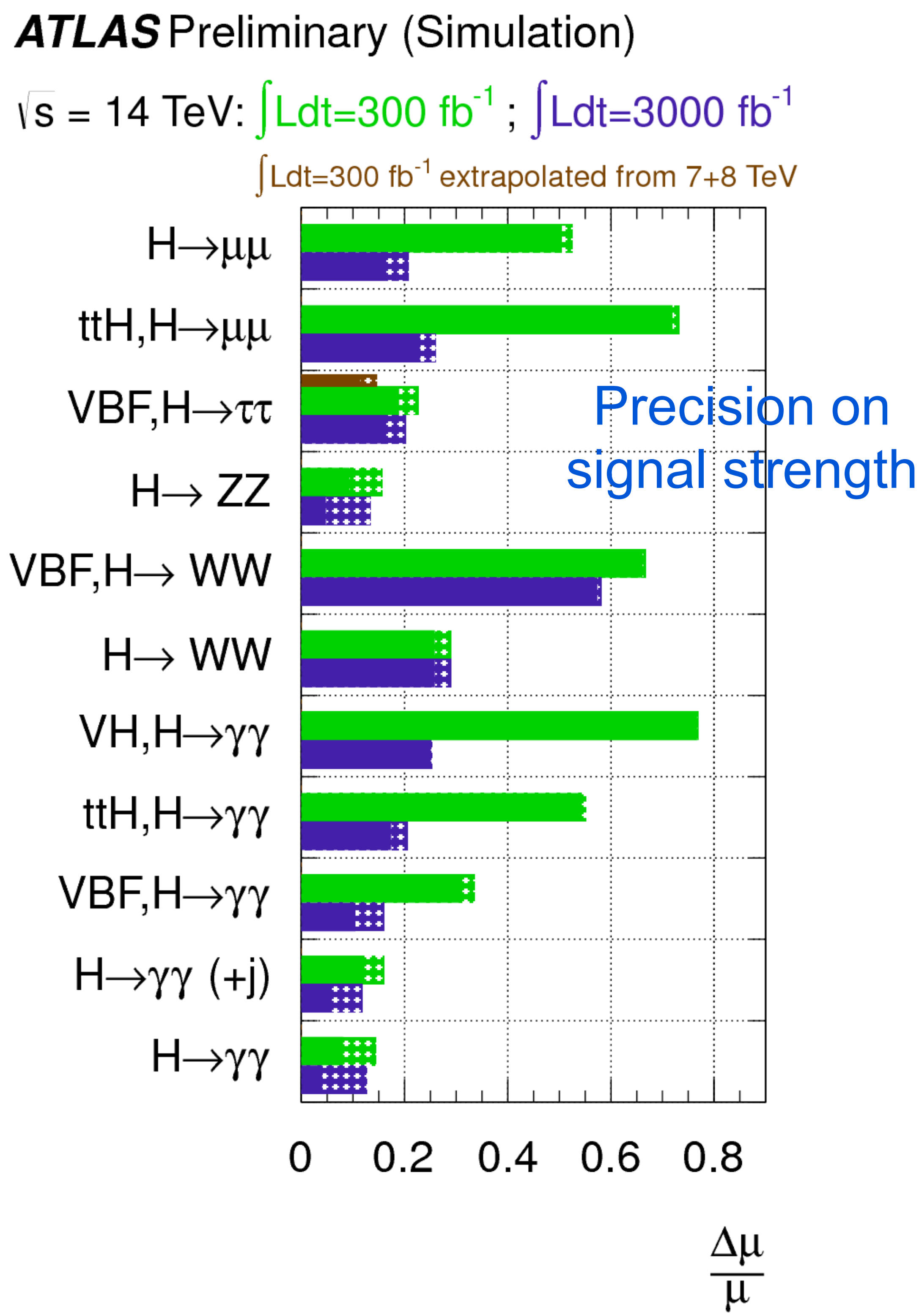
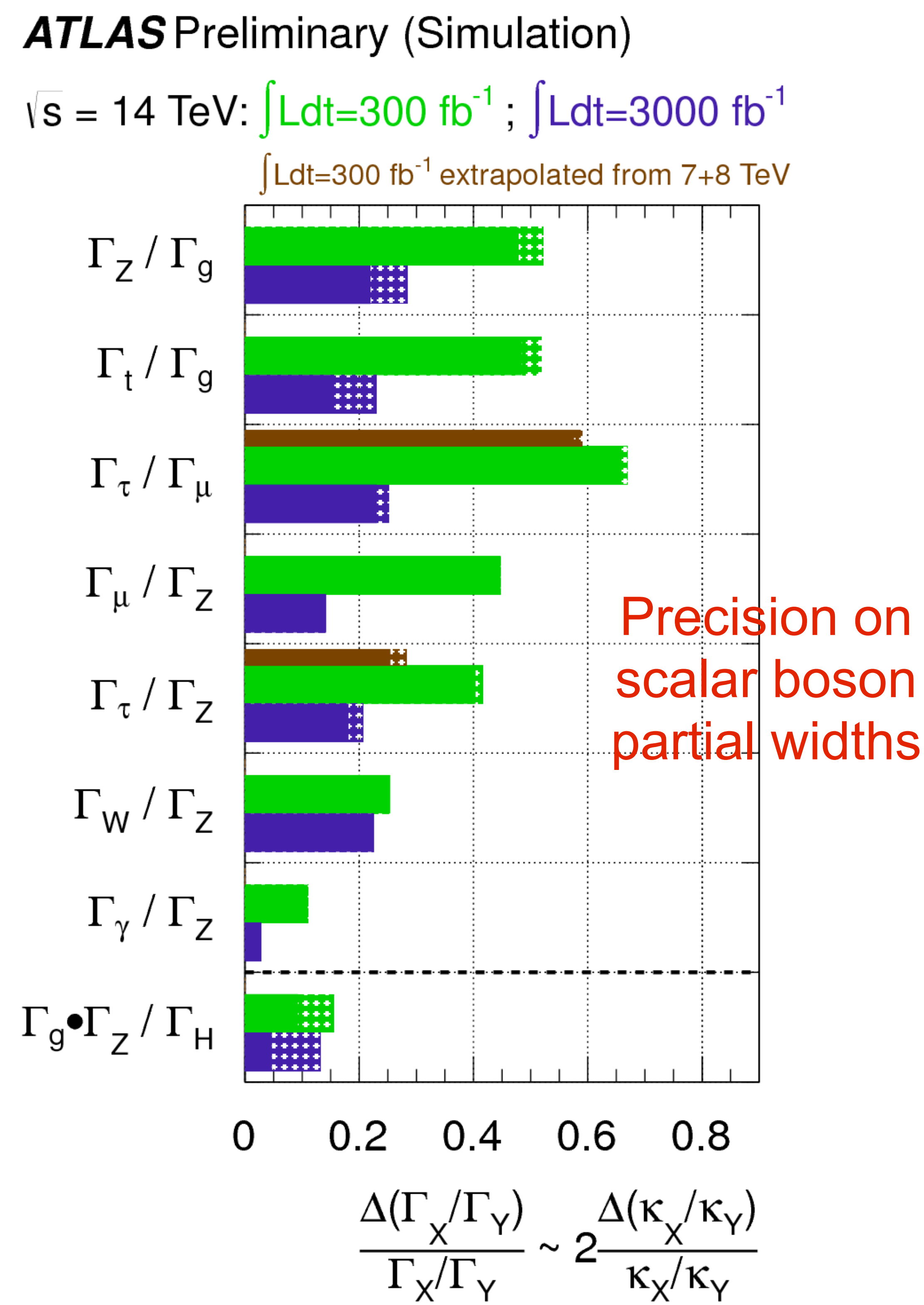


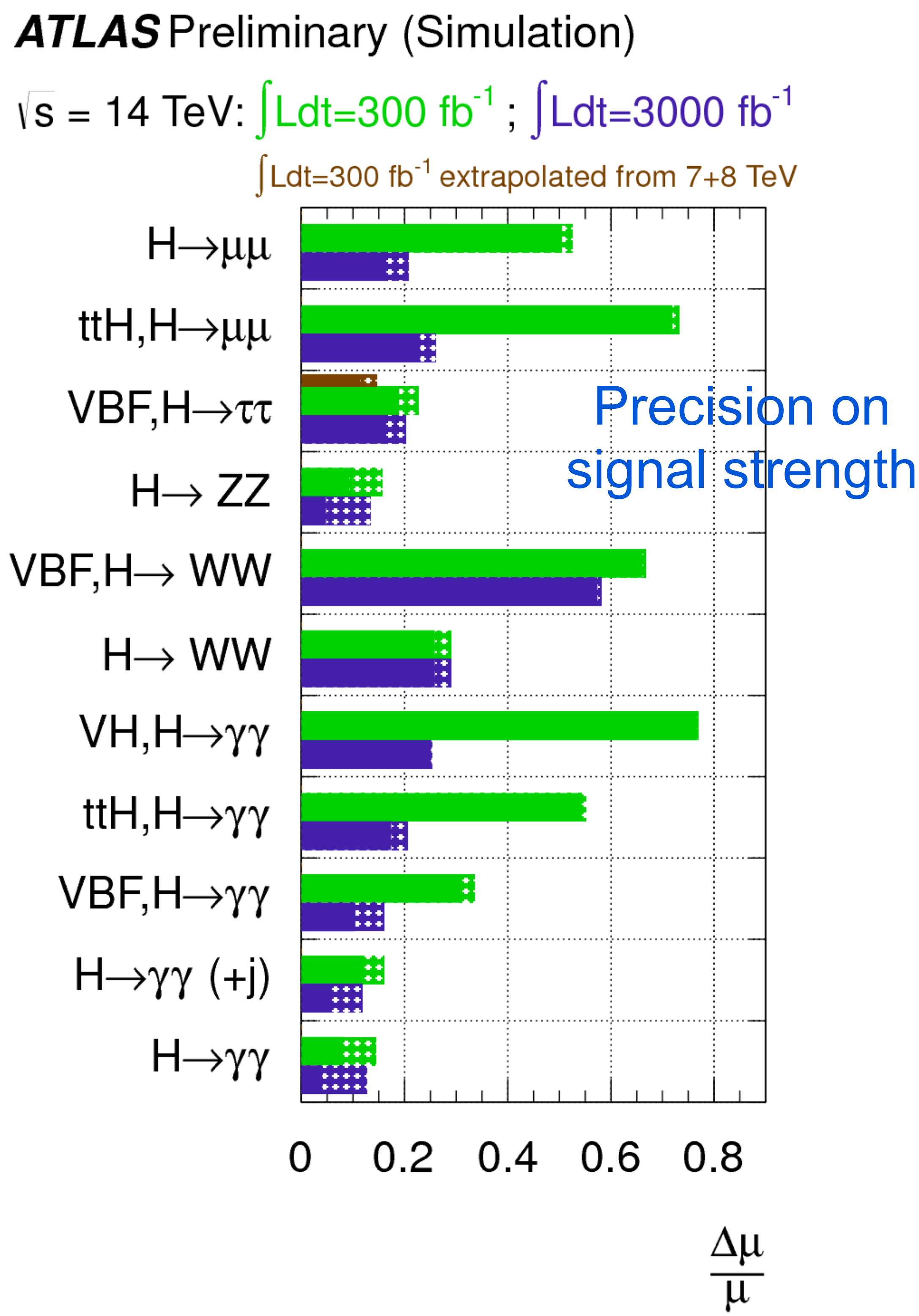
Precision on signal strength

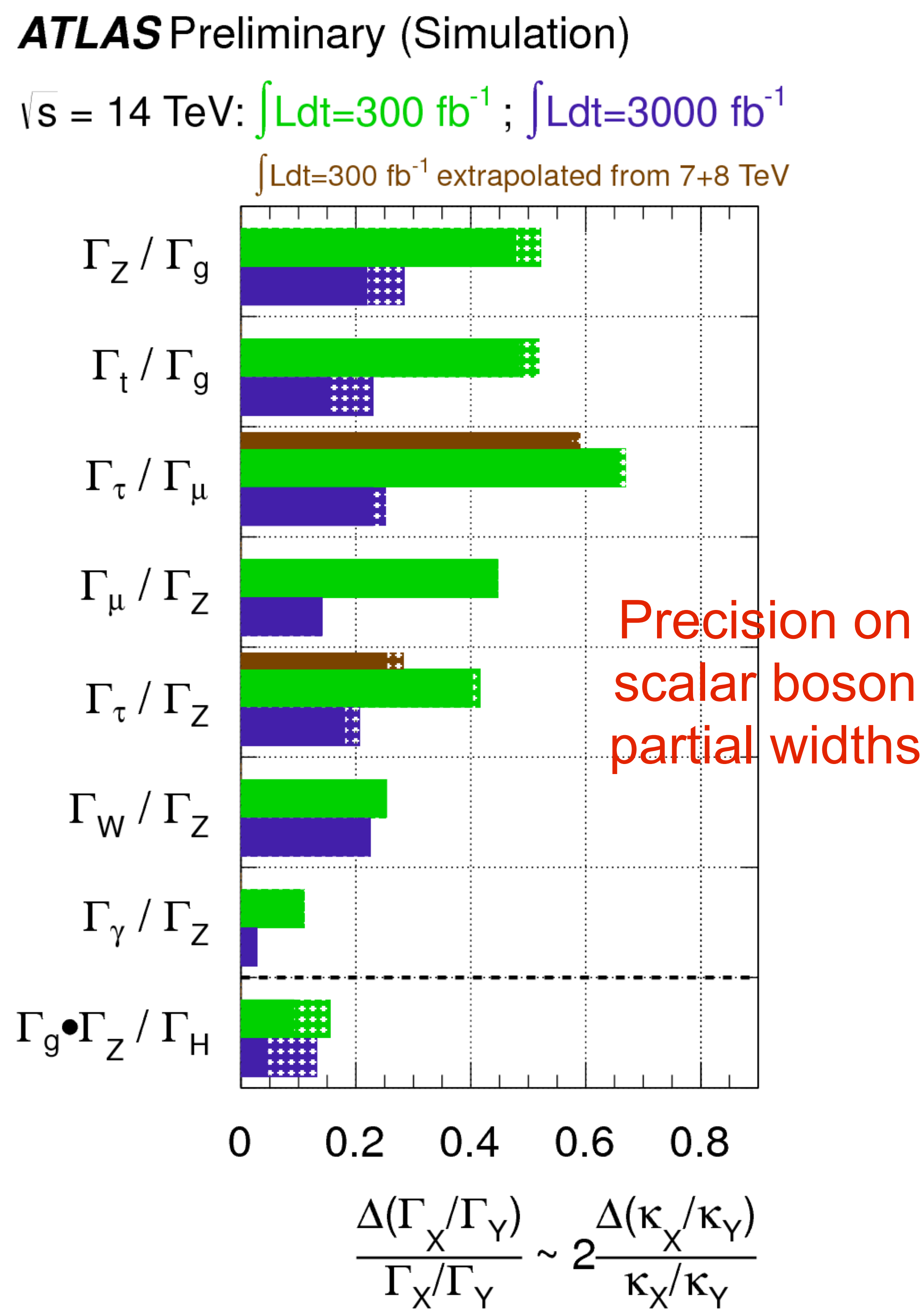
Ratios of partial widths @3000 fb^{-1}





Ratios of partial widths @3000 fb^{-1}





- With 3000 fb^{-1} the couplings can be determined with high precision (a few %)

Ratios of partial widths

Scenario 1

CMS

partialWidths	300/fb (% err.)	3000/fb (% err)
r_bZ	24 / -18	12 / -9
r_gZ	16 / -13	8
r_tZ	18 / -15	9 / -7
r_WZ	15 / -12	7 / -6
r_topglu	32 / -24	17 / -13
r_Zglu	17 / -16	10 / -9
c_gluZ	12 / -11	8

Scenario 1: systematics as in 2012
Scenario 2: theory syst. scaled by a factor ½,other systematics scaled by $1/\sqrt{L}$

Scenario 2

partialWidths	300/fb (% err.)	3000/fb (% err)
r_bZ	17 / -14	4.5
r_gZ	9	4.5
r_tZ	11	3.5
r_WZ	10 / -7	2.5
r_topglu	28 / -22	11
r_Zglu	11 / -10	5
c_gluZ	7.5 / -5.5	4