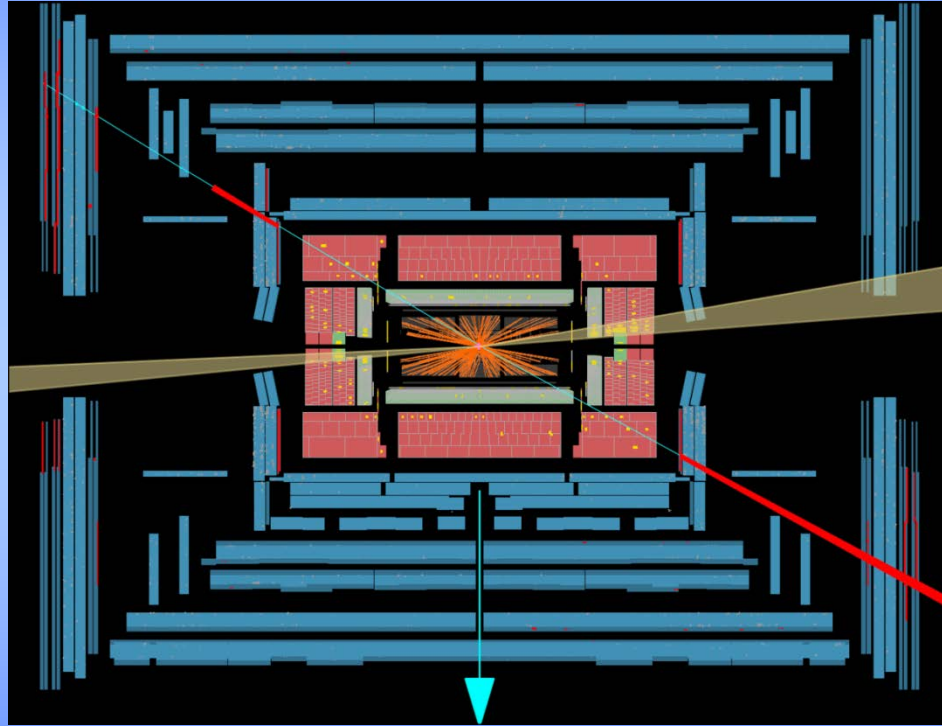


Measuring Weak Boson Scattering with ATLAS



Marc-André Pleier
BNL

BROOKHAVEN
NATIONAL LABORATORY



U.S. DEPARTMENT OF
ENERGY

Office of
Science

DESY Physics Seminar, April 14/15 2015

Why?

Fundamental Questions

Fundamental Questions

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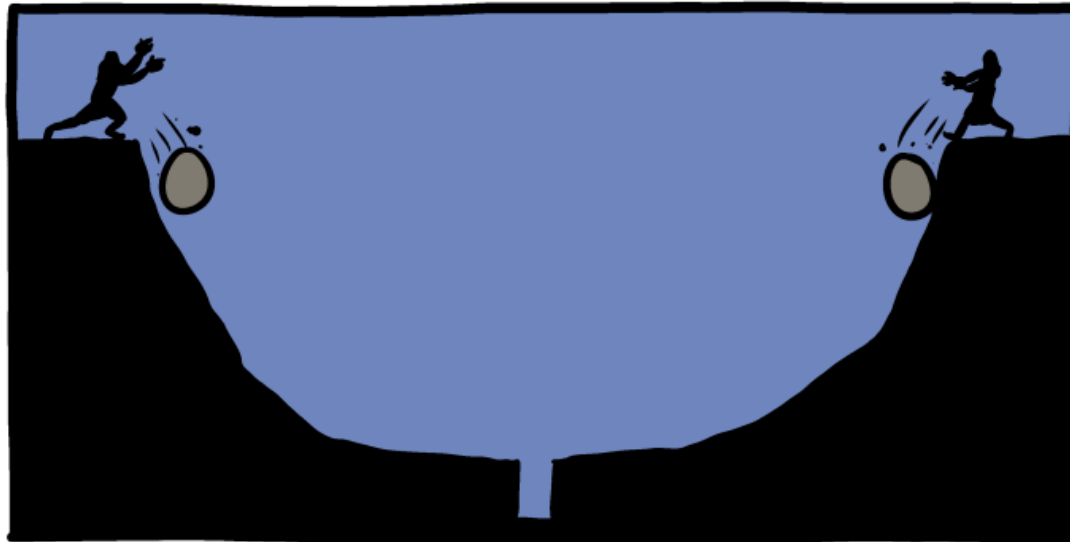
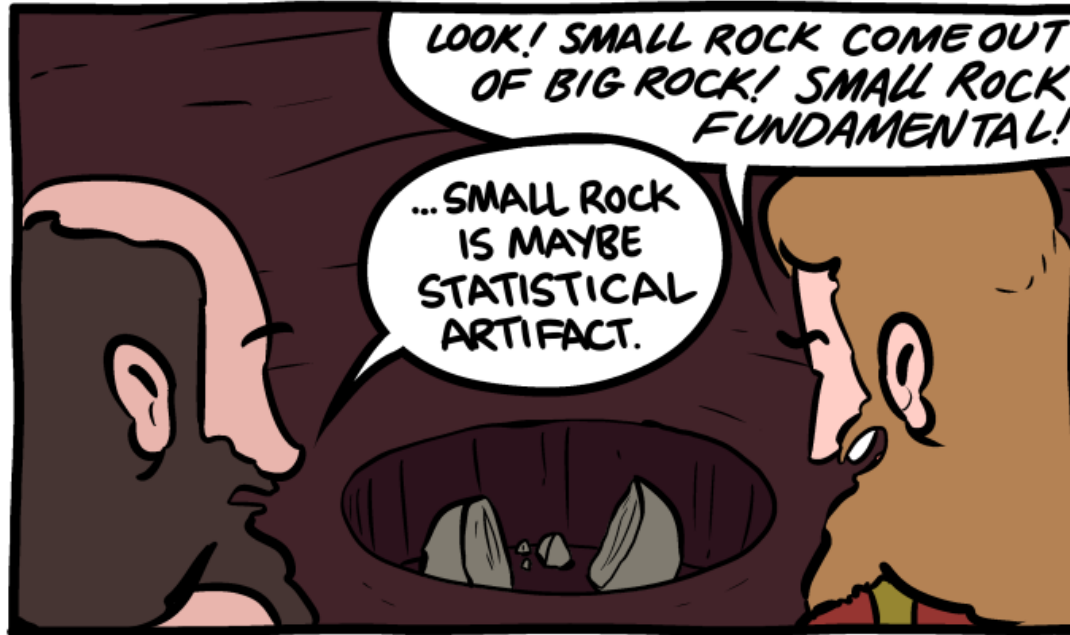
No historical accuracy is implied.



Fundamental Questions

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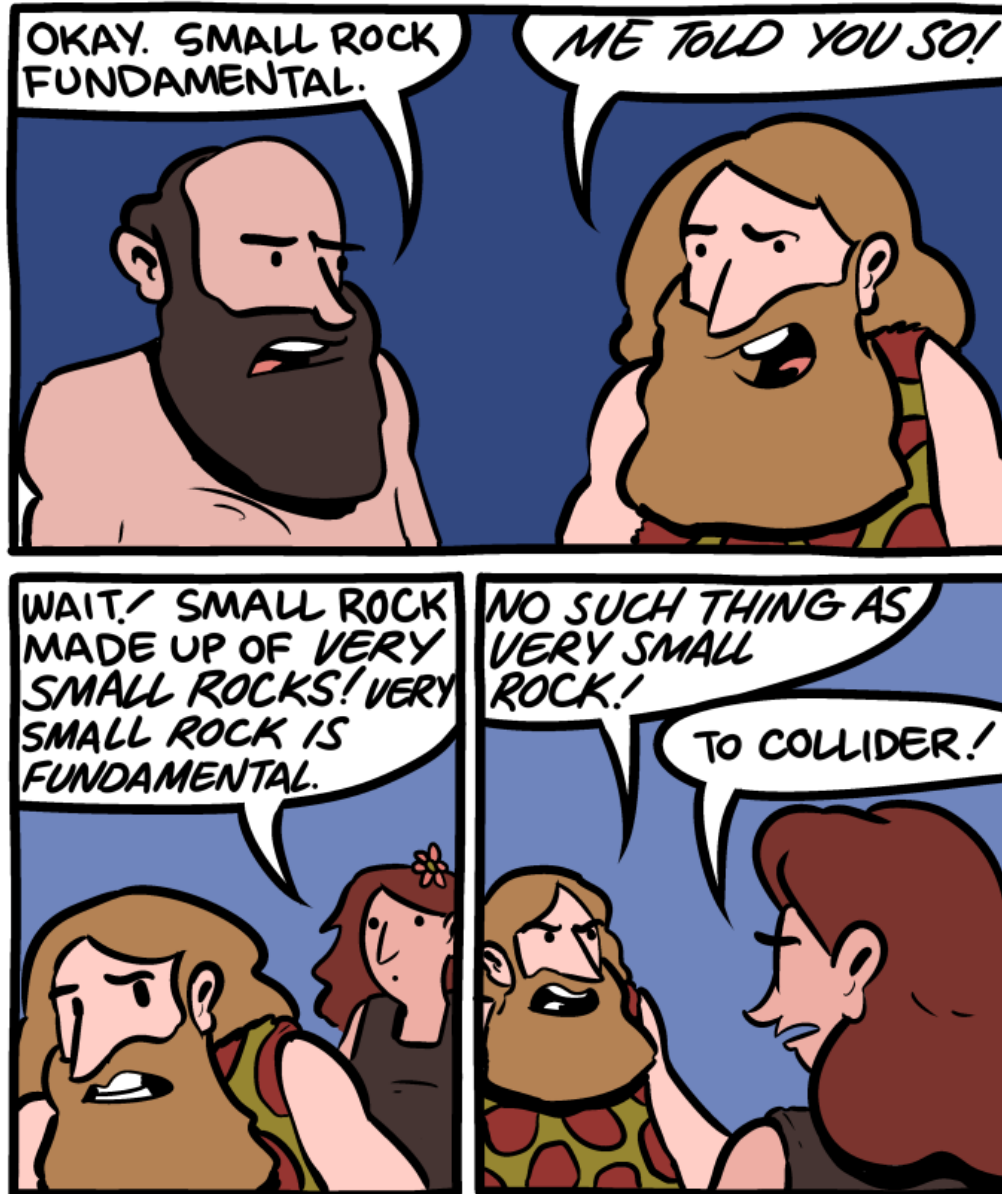
No historical accuracy is implied.



Fundamental Questions

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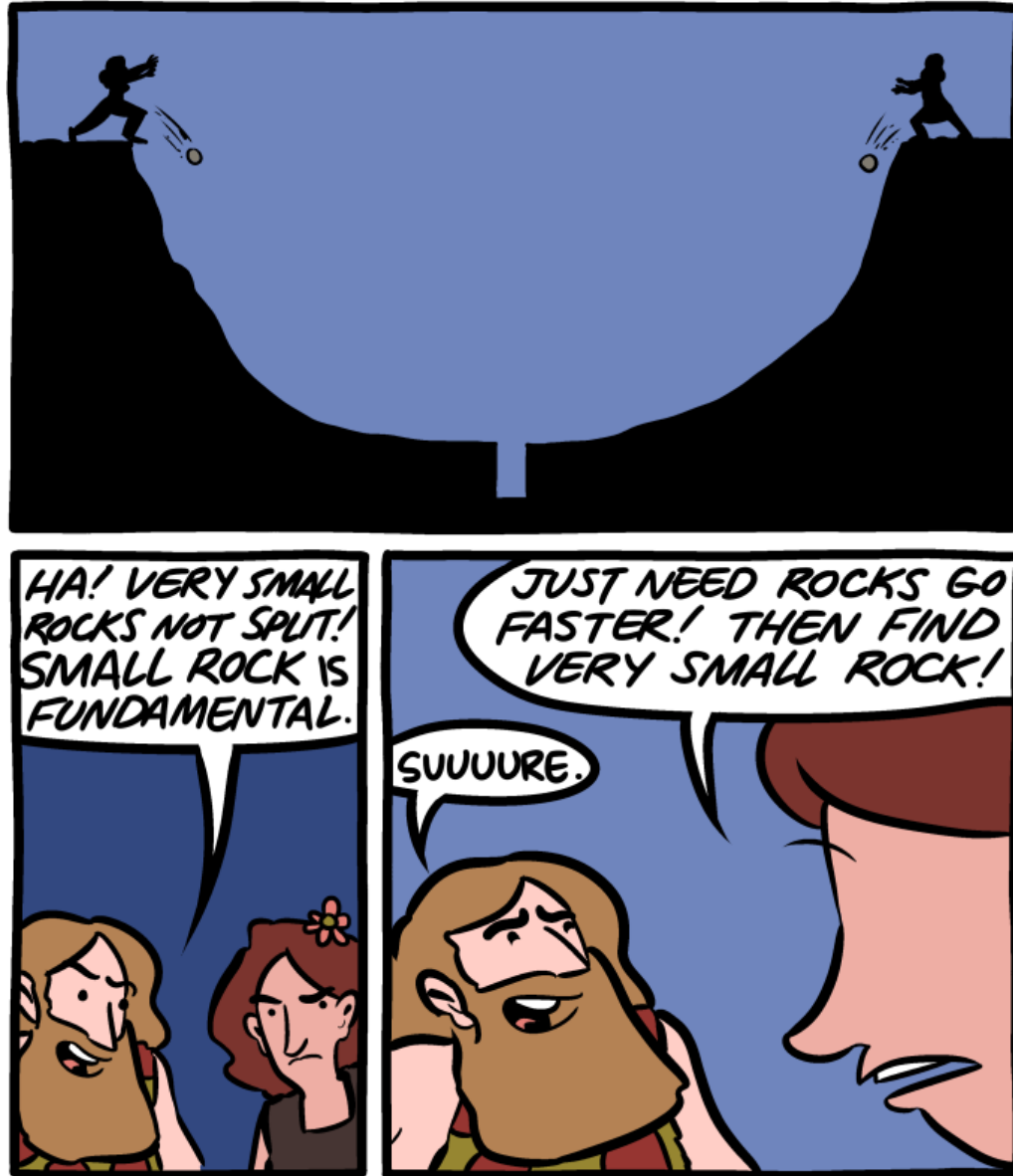
No historical accuracy is implied.



Fundamental Questions

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No historical accuracy is implied.

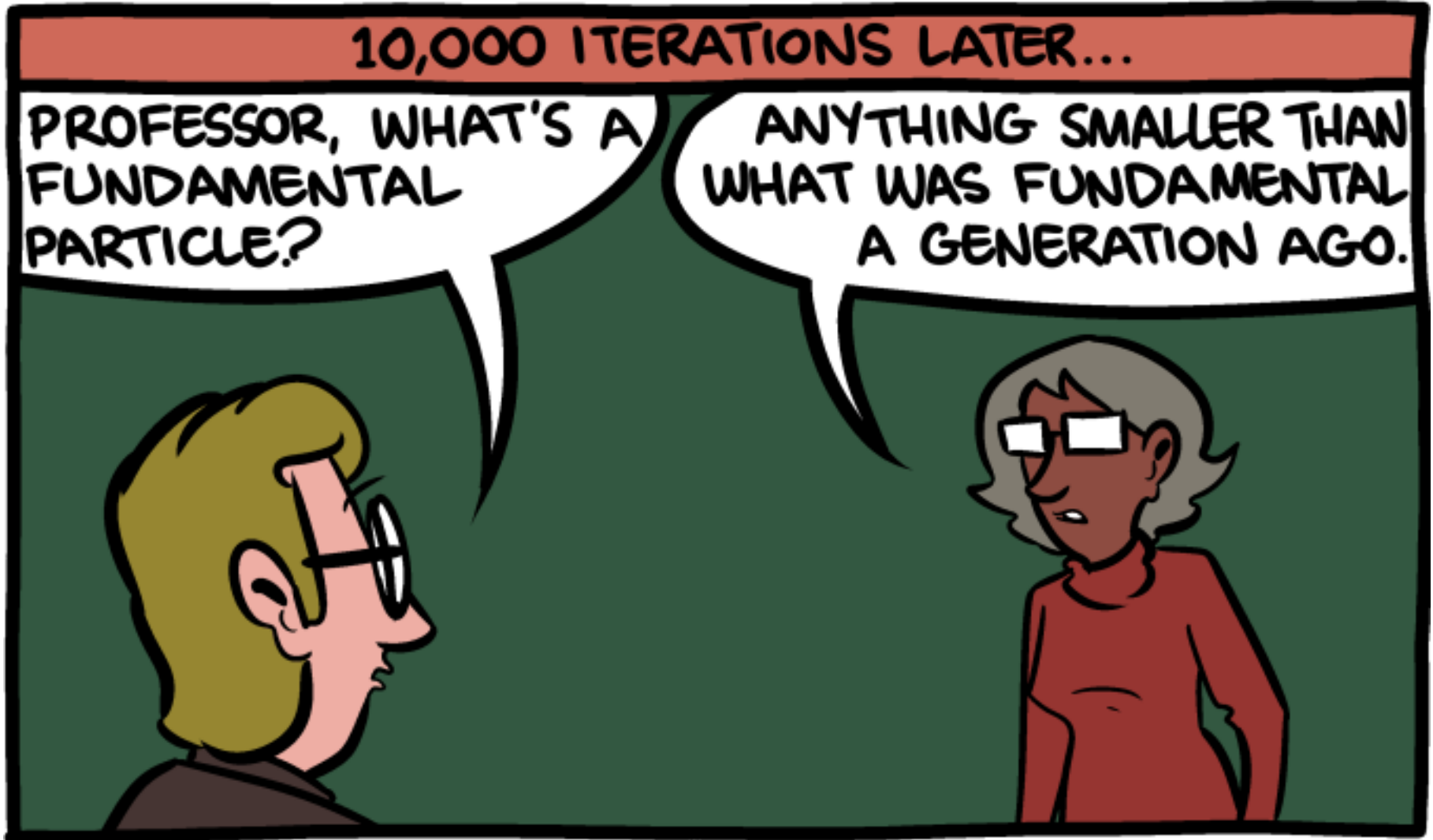


Fundamental Questions

10,000 ITERATIONS LATER...

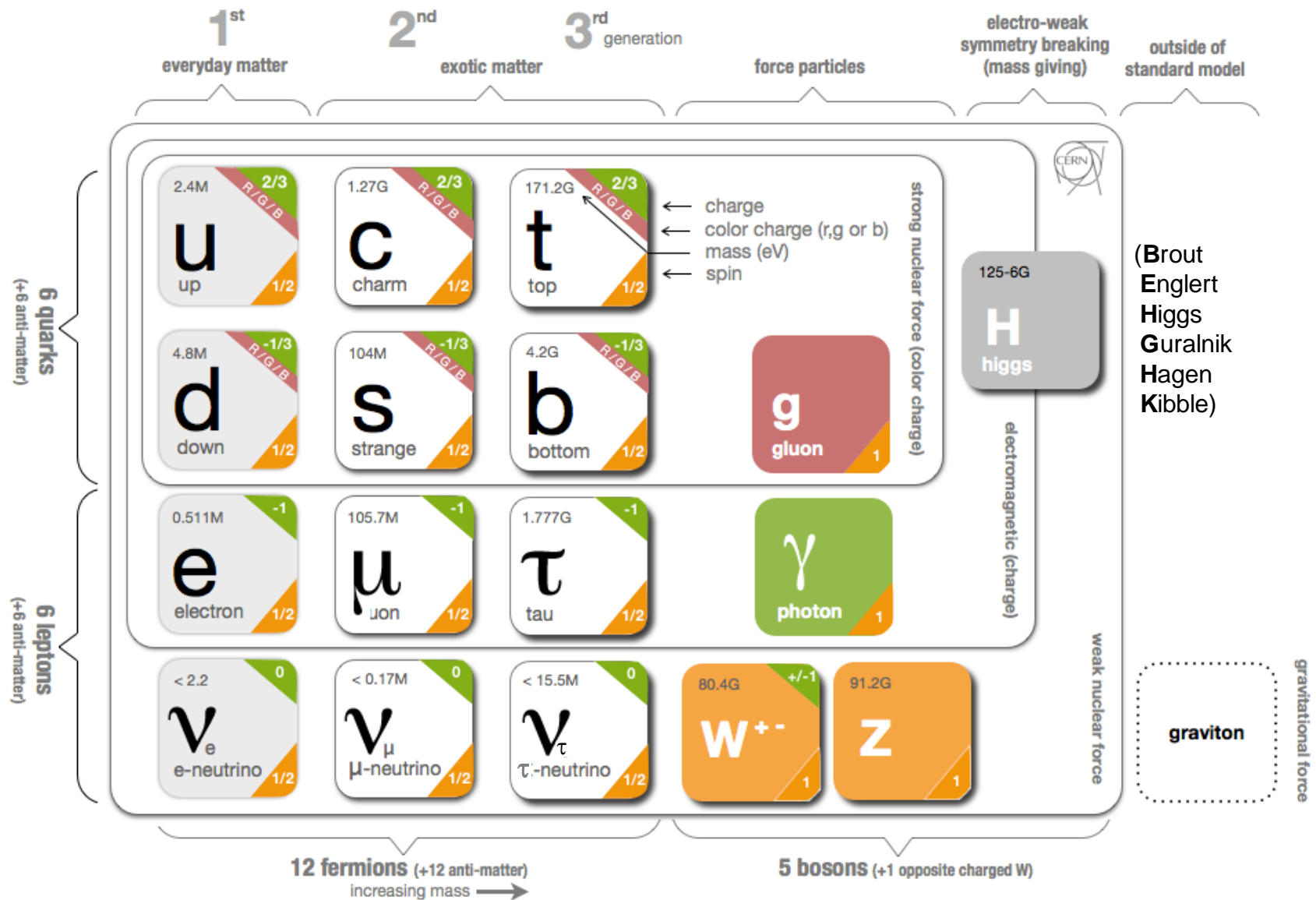
PROFESSOR, WHAT'S A FUNDAMENTAL PARTICLE?

ANYTHING SMALLER THAN WHAT WAS FUNDAMENTAL A GENERATION AGO.

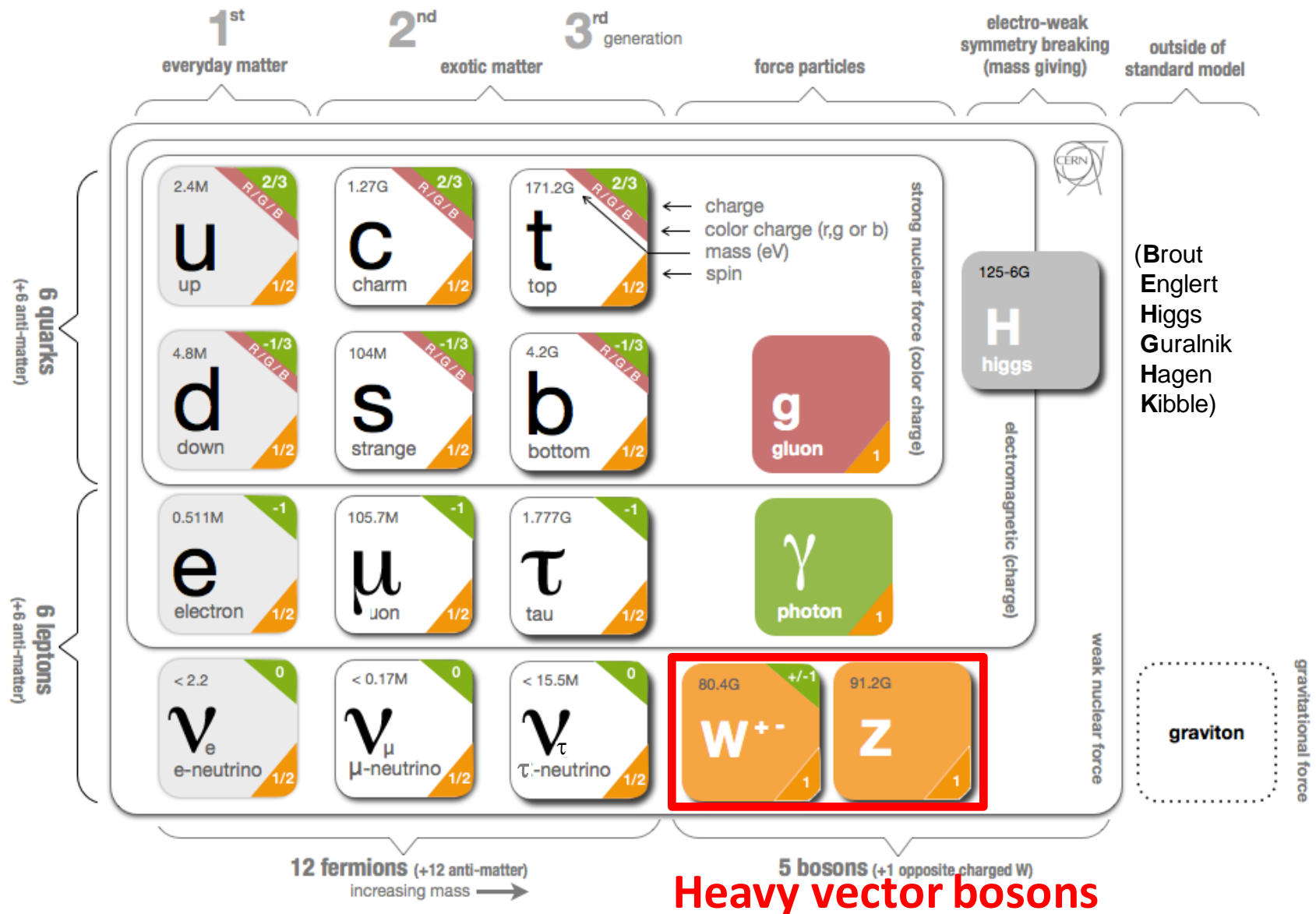


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Building Blocks of Matter & their interactions



Building Blocks of Matter & their interactions



Higgs-Search until...



July 4th 2012: DISCOVERY!



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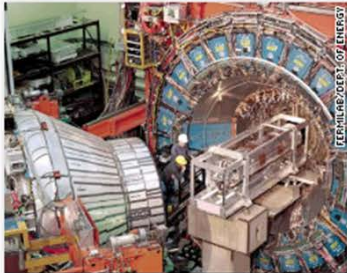
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updated 10:42 AM EDT, Wed July 4, 2012

The Washington Post

84° Washington, DC July 4, 2012 Edition: U.S. | Regional Make us your homepage



Scientists discover particle consistent with Higgs boson

Brian Vastag and Joel Achenbach



(Scientists listen to an update on the Higgs boson in Geneva. | Reuters)

Scientists announce the discovery of a particle theorized to be so fundamental that without it, nothing would exist.

Why Higgs boson is a big deal | Photos: "God particle" hunt

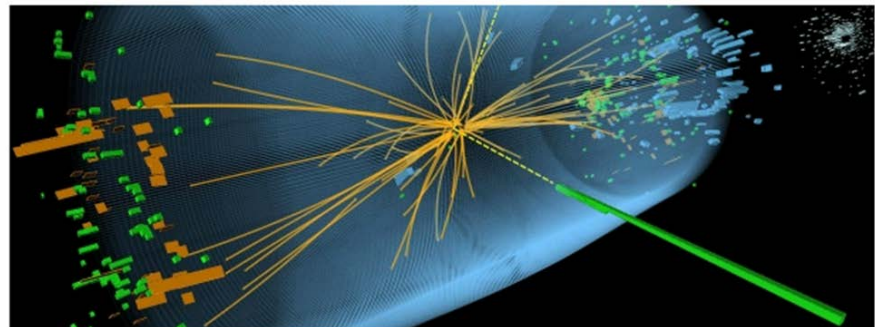
Scientists may have found 'God particle'

Frankfurter Allgemeine

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Politik Wirtschaft Feuilleton Sport Gesellschaft Finanzen Technik & Motor Wissen Reise



Erfolg bei Suche nach Higgs-Teilchen

„Eine wissenschaftliche Sensation“

Wissenschaftler im Teilchenforschungszentrum Cern in Genf glauben, das jahrzehntelang gesuchte Higgs-Teilchen gefunden zu haben. Monatlang war im weltgrößten Teilchenbeschleuniger danach gefahndet worden – jetzt liegen die bahnbrechenden Ergebnisse vor. [Mehr](#) 41 15

Higgs: Jagd nach einem Phantom

Nobelpreisträger im Interview

„Ich denke, wir haben es“

Die Entdeckung des Higgs-Teilchens ist ein historischer Moment auch für vier Nobelpreisträger, die mit der F.A.Z. auf der Nobelpreisträger-Tagung in Lindau gesprochen haben. Sehen Sie ihre Erläuterungen im Video. [Mehr](#)

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 TV: CNN | CNNi | CNN en Español | HLN

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updated 10:42 AM EDT, Wed July 4, 2012



Scientists may have found 'God particle'

21 December 2012 | \$10

Science

BREAKTHROUGH of the YEAR

The **HIGGS BOSON**



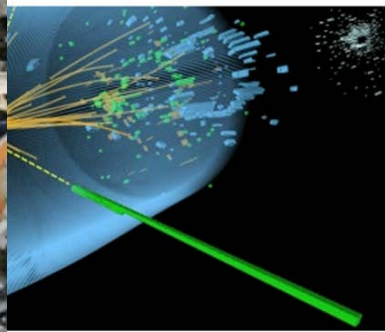
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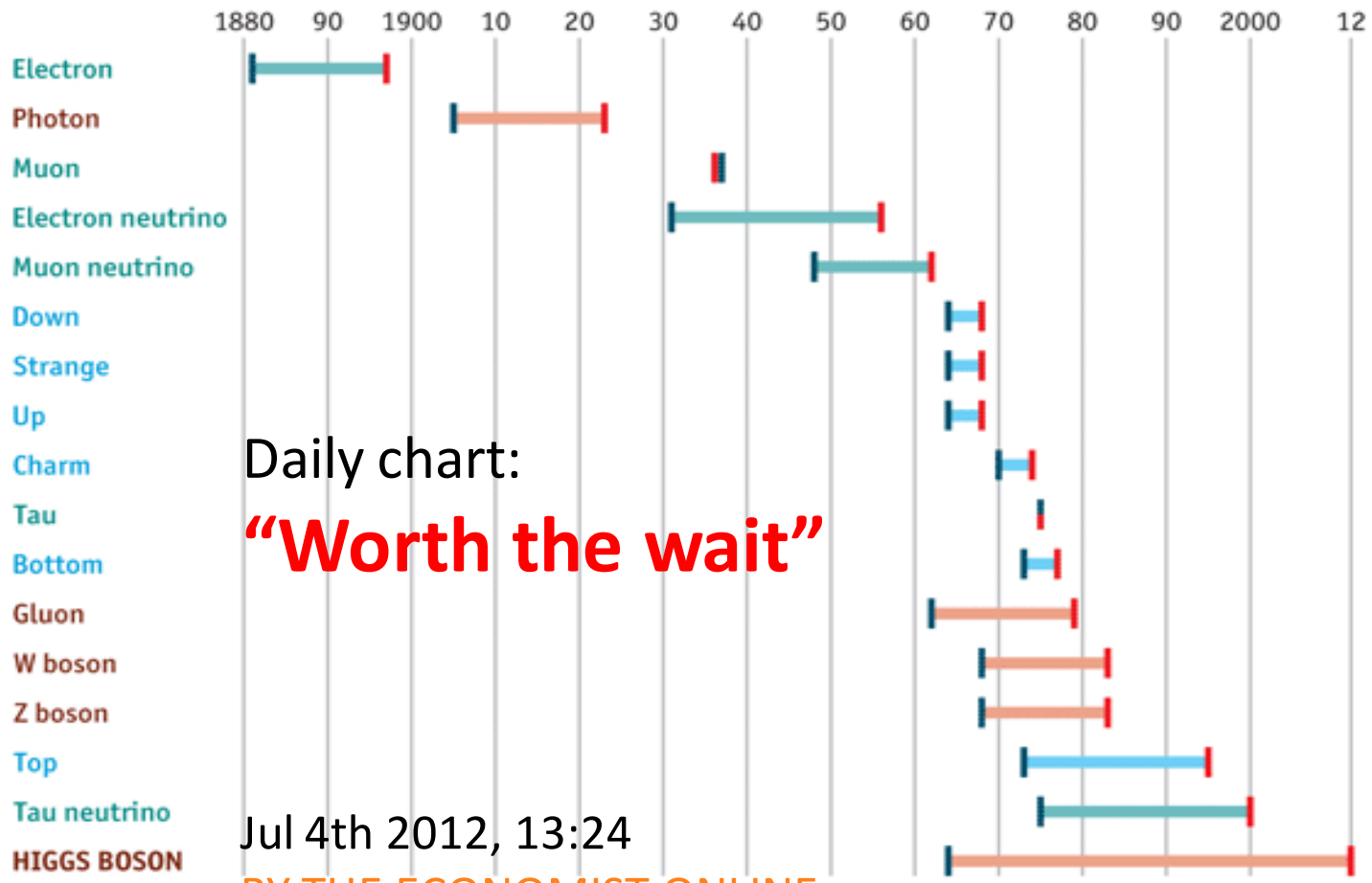
July 4th 2012: DISCOVERY

SET EDITION
TV: CNN
Home
updated 10:42
Scientist
'God pa

The Standard Model of particle physics

Years from concept to discovery

Leptons
Bosons
Quarks
Theorised/explained
Discovered



Daily chart:
"Worth the wait"

Jul 4th 2012, 13:24
BY THE ECONOMIST ONLINE

Source: The Economist

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Wissen Reise



es"
ilchens
uch für
der
er-
haben.

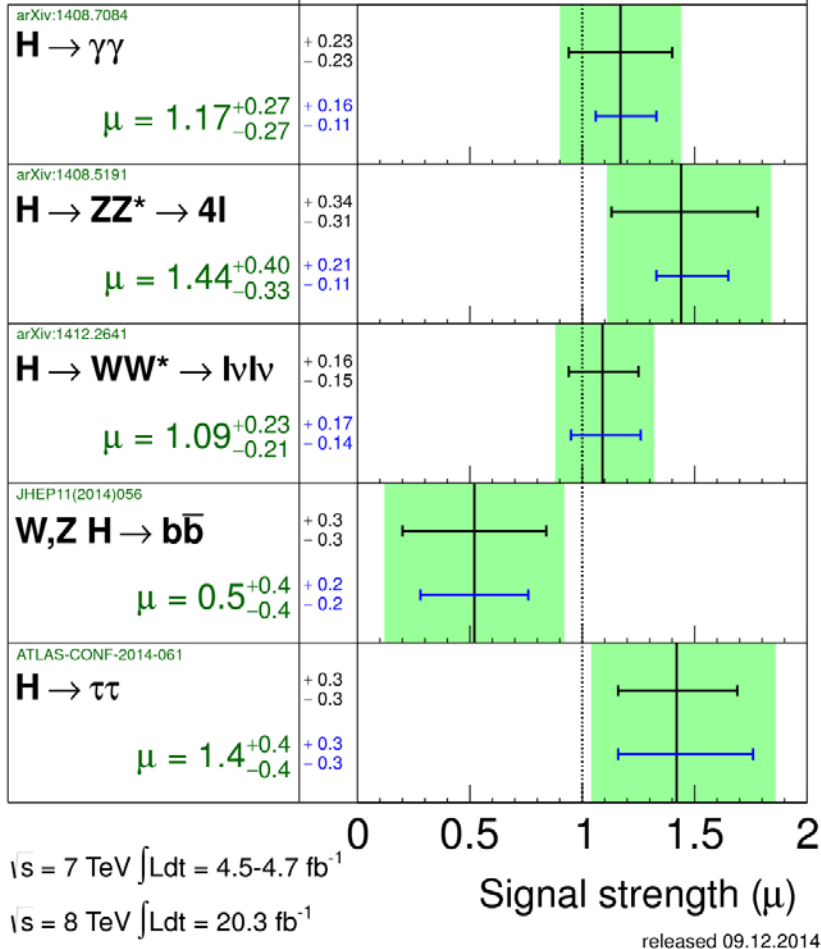
sehen Sie Ihre Entscheidungen im Video. Mehr >

Back to work...

ATLAS Prelim.

$m_H = 125.36$ GeV

— $\sigma(\text{stat.})$ Total uncertainty
 — $\sigma(\text{sys inc.})$ $\pm 1\sigma$ on μ
 — $\sigma(\text{theory})$

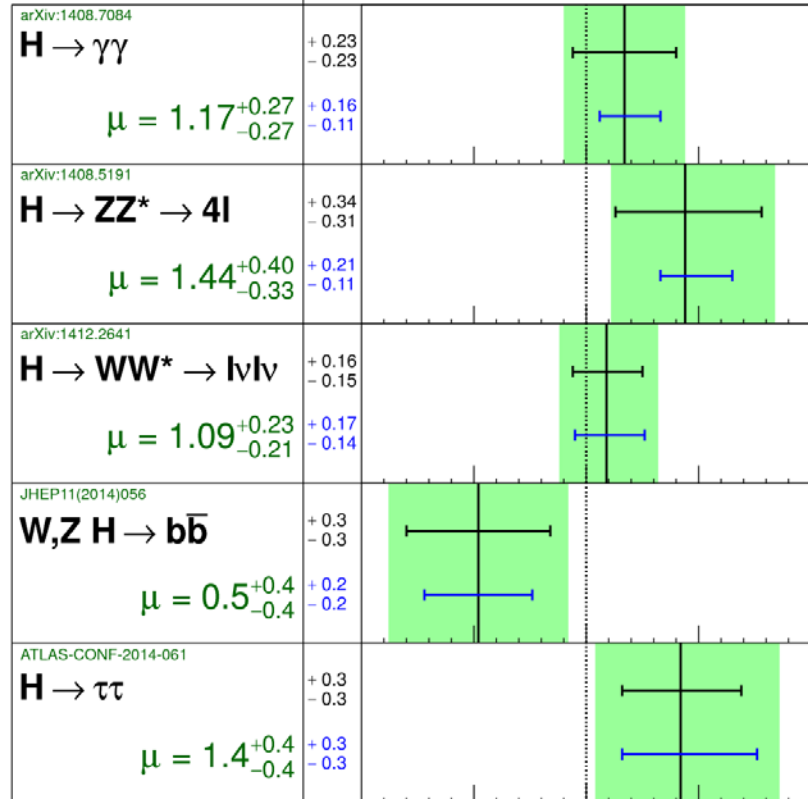


Back to work...

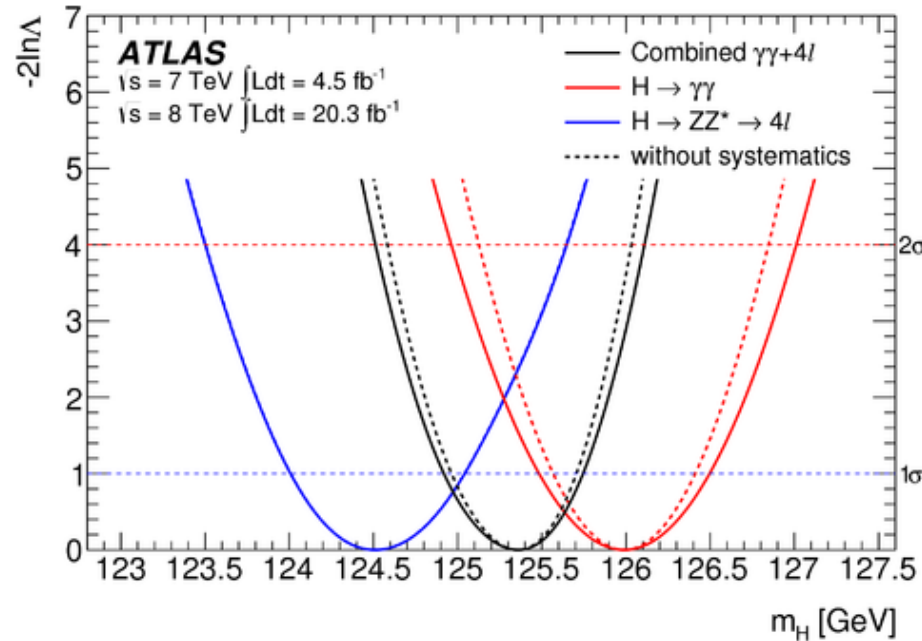
ATLAS Prelim.

$m_H = 125.36$ GeV

— $\sigma(\text{stat.})$ Total uncertainty
 — $\sigma(\text{sys inc. theory})$ ±1σ on μ



√s = 7 TeV ∫Ldt = 4.5-4.7 fb⁻¹
 √s = 8 TeV ∫Ldt = 20.3 fb⁻¹
 Signal strength (μ)
 released 09.12.2014

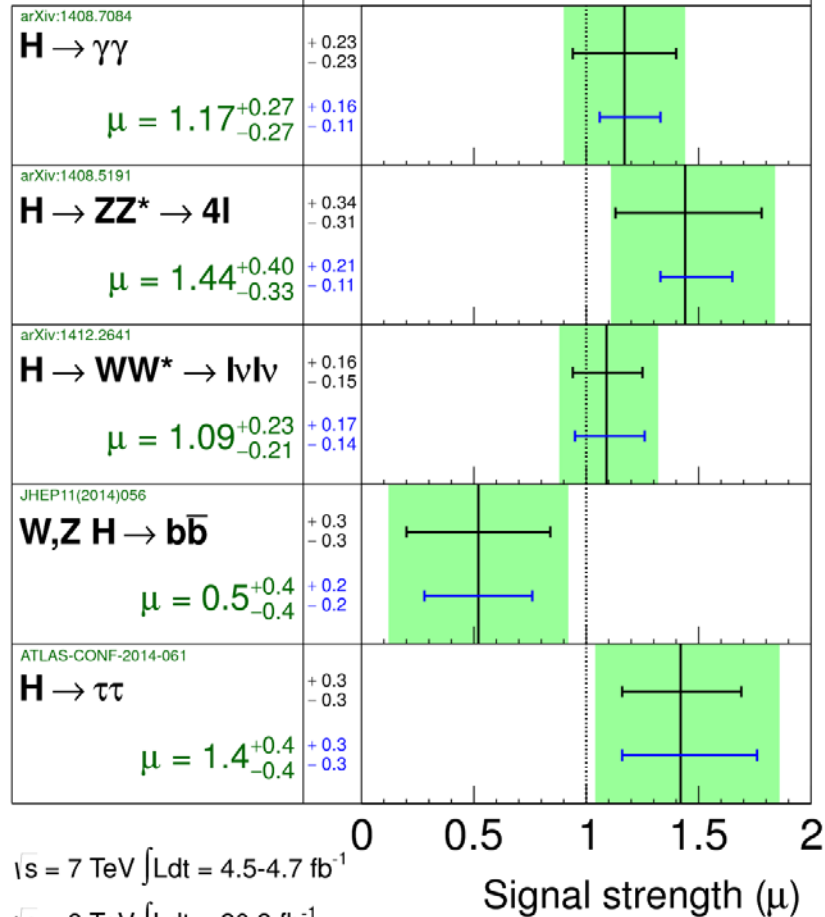


Back to work...

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$m_H = 125.36$ GeV

— $\sigma(\text{stat.})$ Total uncertainty
 — $\sigma(\text{sys inc.})$ $\pm 1\sigma$ on μ
 — $\sigma(\text{theory})$



released 09.12.2014

[[PRD 90, 052004 \(2014\)](#)]

$$m_H^{\gamma\gamma} = 125.98 \pm 0.42(\text{stat}) \pm 0.28(\text{syst}) \text{ GeV}$$

$$m_H^{ZZ^*} = 124.51 \pm 0.52 (\text{stat}) \pm 0.06 (\text{syst}) \text{ GeV}$$

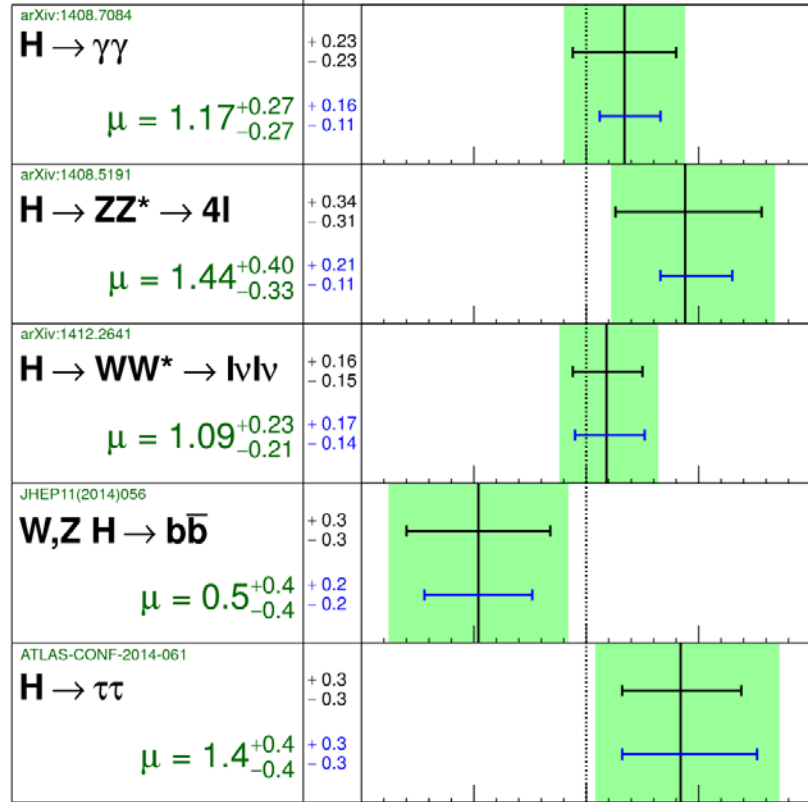
$$\Delta m_H = 1.47 \pm 0.67 (\text{stat}) \pm 0.28 (\text{syst}) \text{ GeV}$$

$$m_H^{\text{comb}} = 125.36 \pm 0.37 (\text{stat}) \pm 0.18 (\text{syst}) \text{ GeV}$$

Back to work...

ATLAS Prelim.

$m_H = 125.36$ GeV

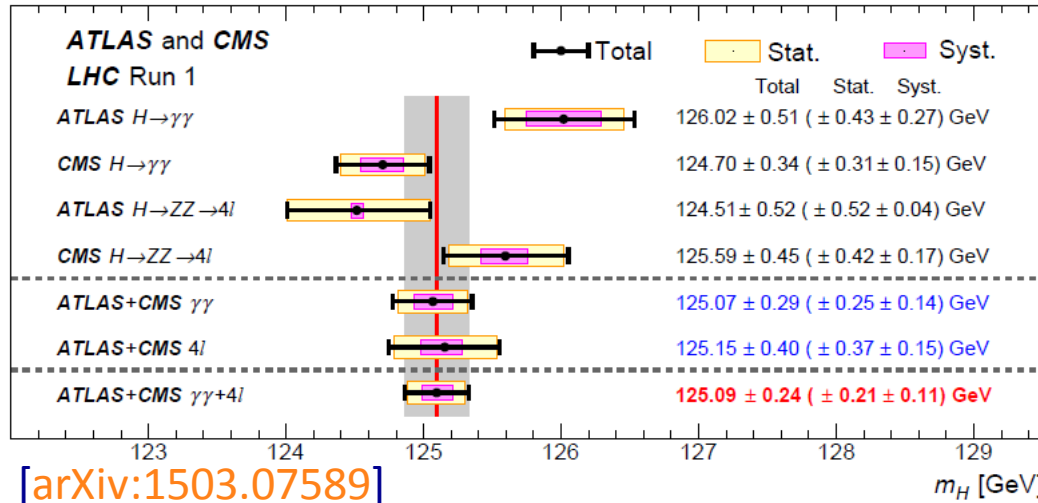


$\sqrt{s} = 7$ TeV $\int L dt = 4.5\text{-}4.7 \text{ fb}^{-1}$

$\sqrt{s} = 8$ TeV $\int L dt = 20.3 \text{ fb}^{-1}$

Signal strength (μ)

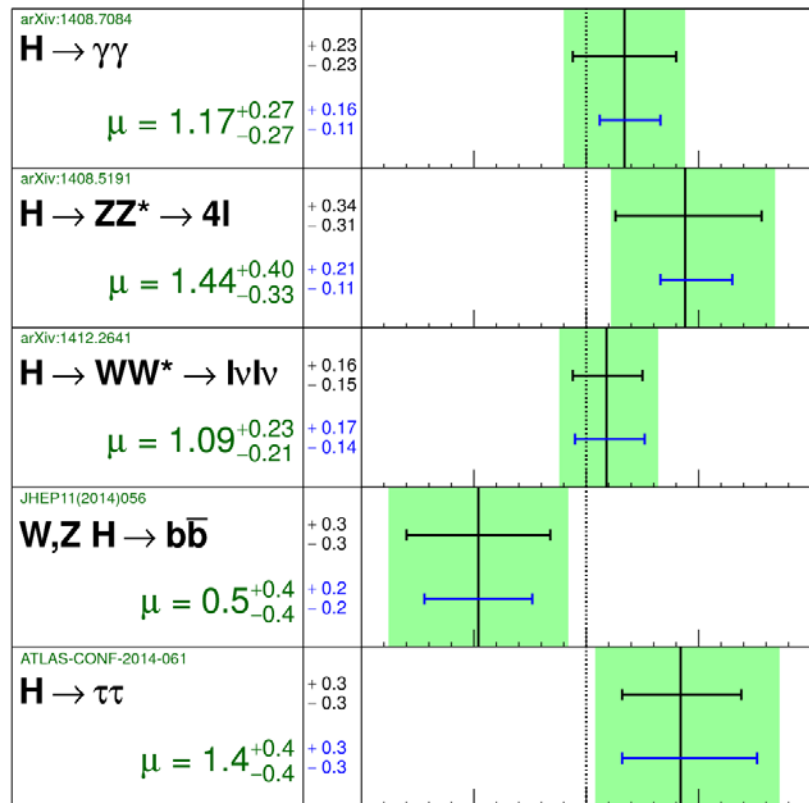
released 09.12.2014



Back to work...

ATLAS Prelim.

$m_H = 125.36$ GeV

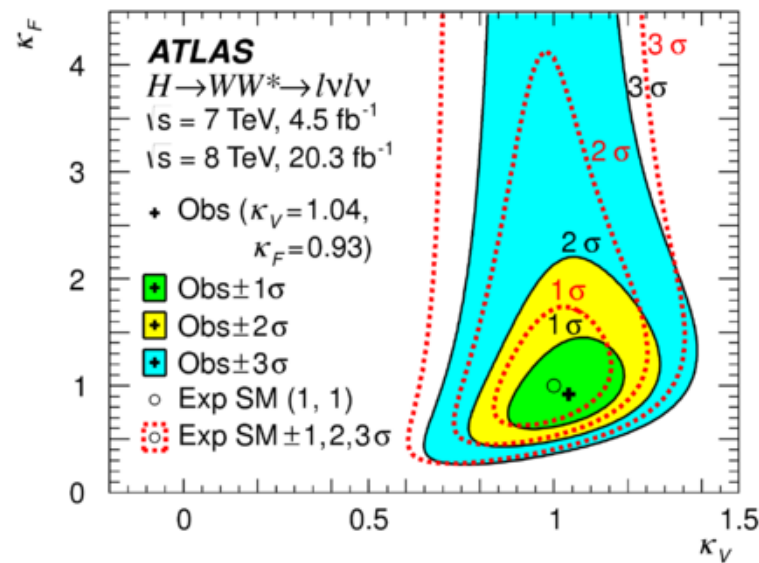
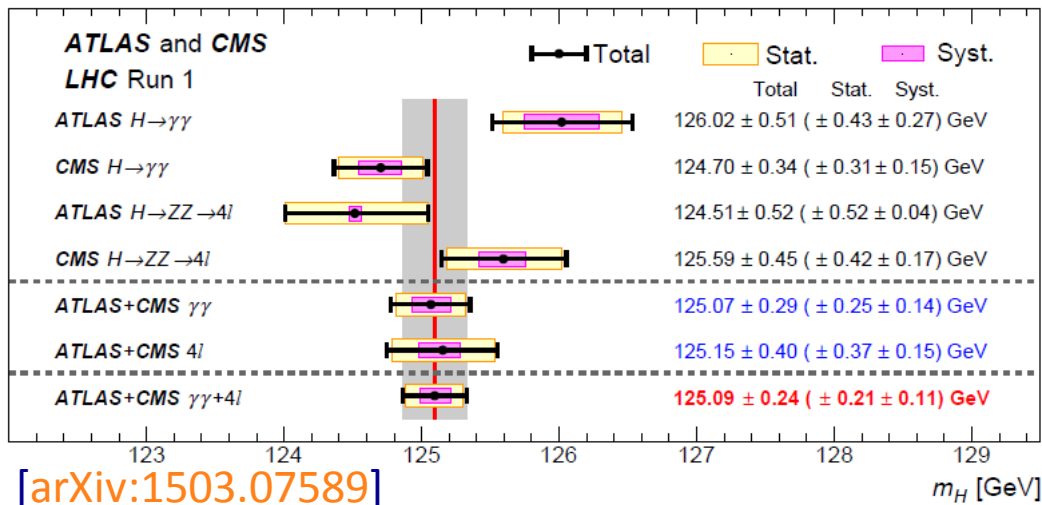


$\sqrt{s} = 7$ TeV $\int L dt = 4.5\text{-}4.7$ fb $^{-1}$

$\sqrt{s} = 8$ TeV $\int L dt = 20.3$ fb $^{-1}$

Signal strength (μ)

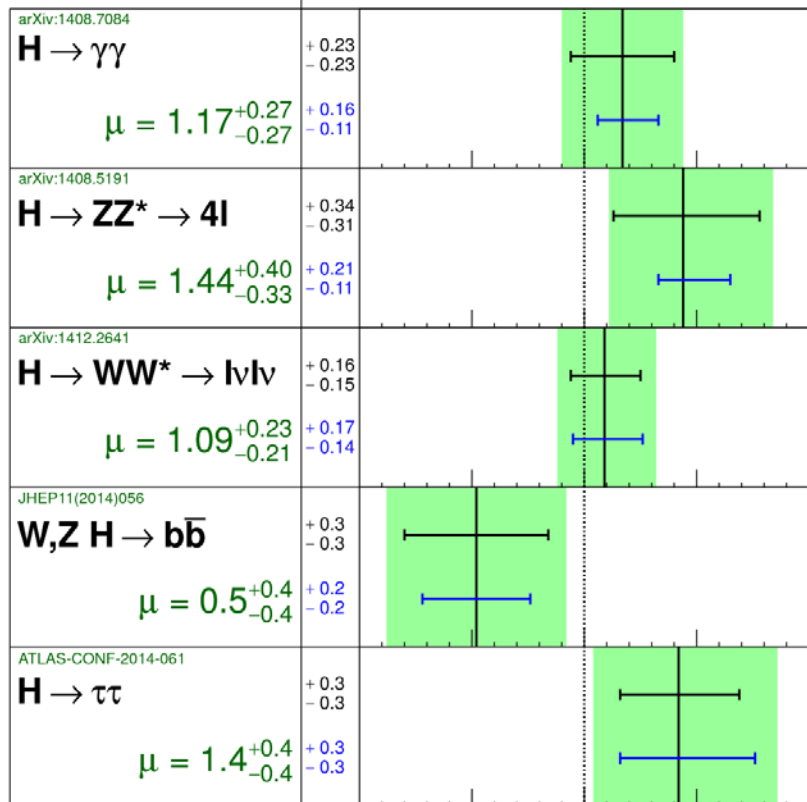
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Back to work...

ATLAS Prelim.

$m_H = 125.36$ GeV

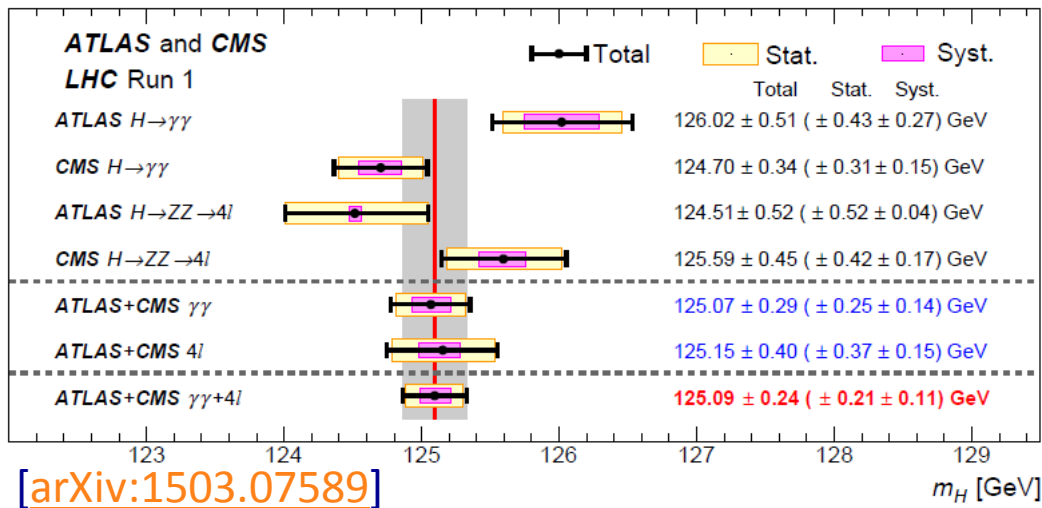


$\sqrt{s} = 7$ TeV $\int L dt = 4.5\text{-}4.7$ fb $^{-1}$

$\sqrt{s} = 8$ TeV $\int L dt = 20.3$ fb $^{-1}$

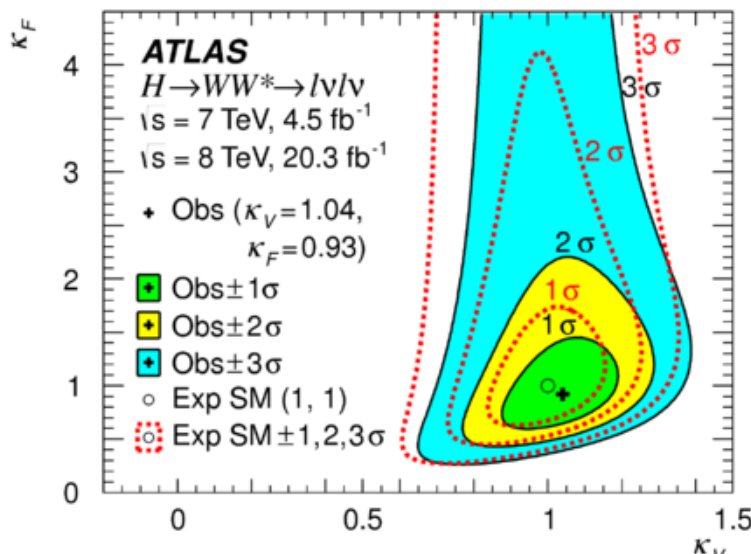
Signal strength (μ)

released 09.12.2014



[arXiv:1503.07589]

m_H [GeV]



[arXiv:1412.2641]

❖ Test of spin/parity J^P using angular distributions: 0^+ vs. 0^- , 1^+ , 1^- , 2^+ : compatible with SM expectation (0^+). [PLB 726 (2013) 120]

Is it “THE” Higgs?

- ❖ Does the Higgs play by the “Standard Model Rule-Book”?
- ❖ Can depict particle interactions in simple pictures: “Feynman diagrams”. **The cast:**

 Quarks (q), electrons, muons, ...

 Photon (γ), W & Z bosons

 Gluon (g)

 Higgs (H)

- ❖ The Standard Model of particle physics dictates how above lines can be put together: who can interact with whom?

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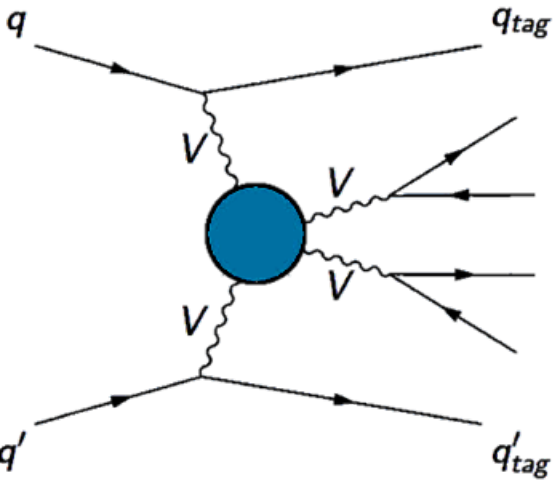
 Photon (γ), **W & Z bosons**
Heavy vector bosons

 Gluon (g)

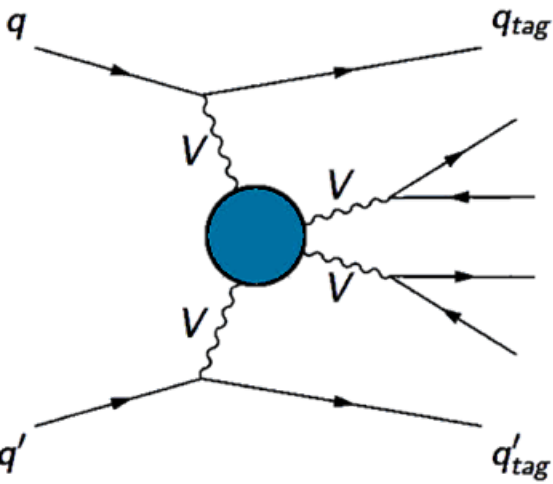
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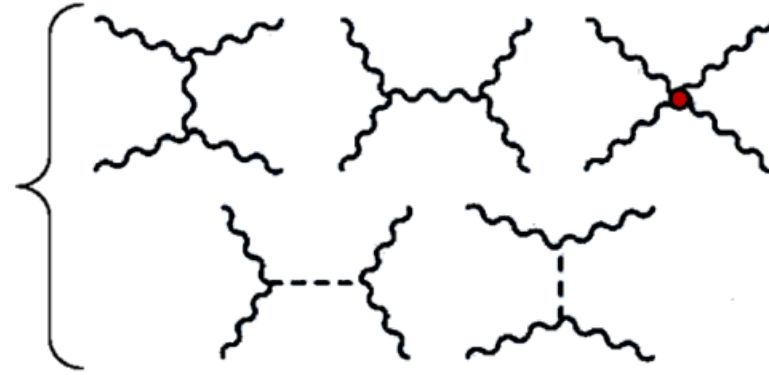
Vector Boson Scattering



Vector Boson Scattering



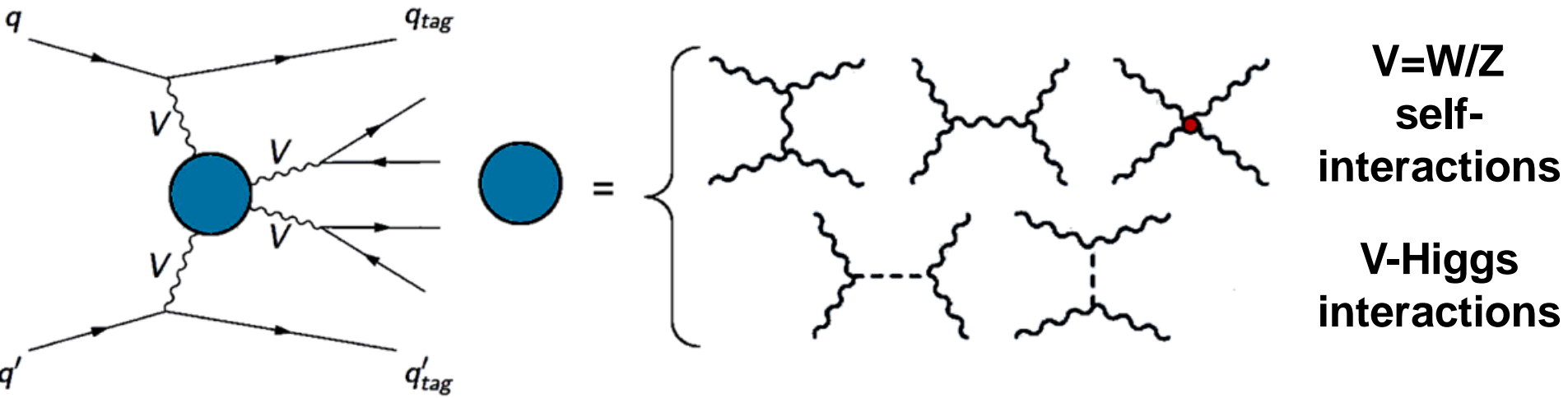
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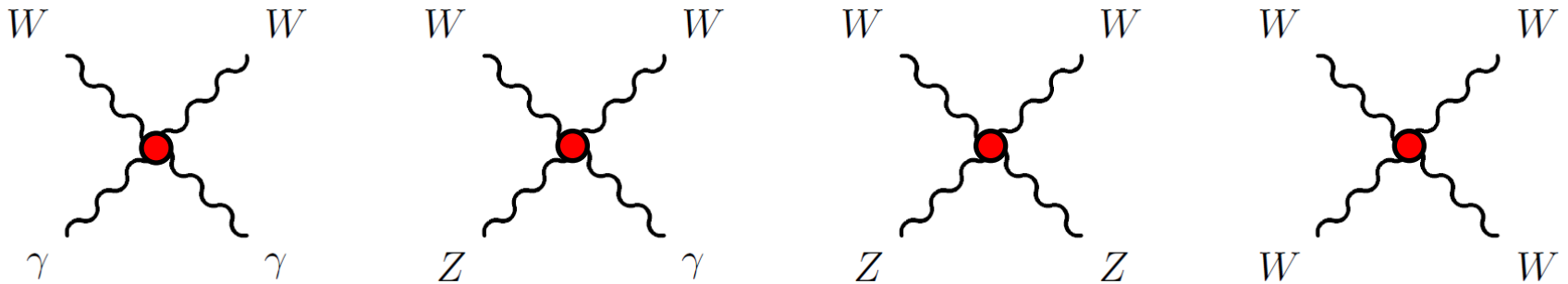
**V=W/Z
self-
interactions**

**V-Higgs
interactions**

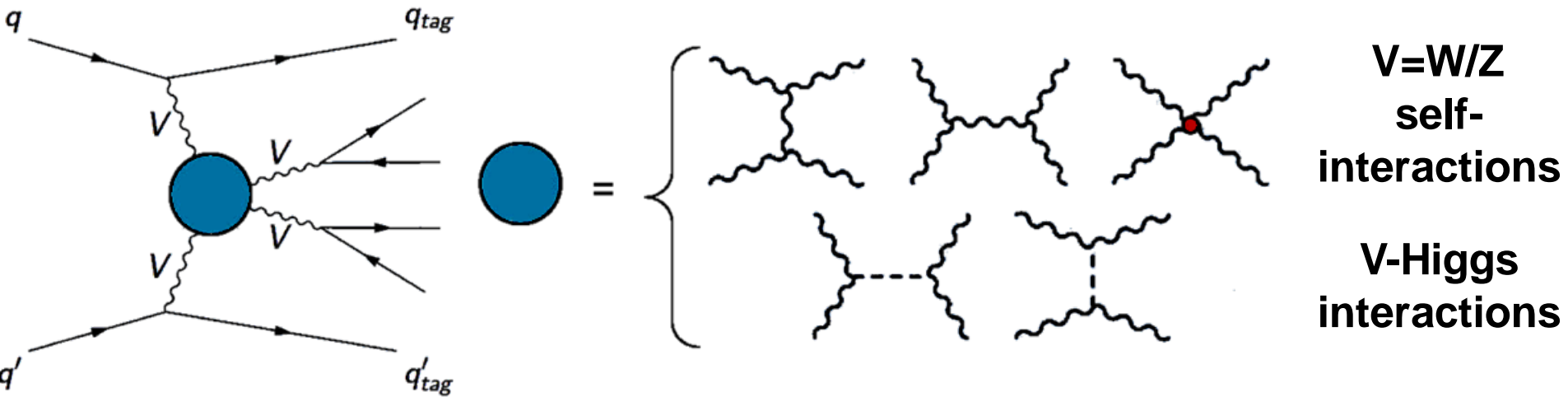
Vector Boson Scattering



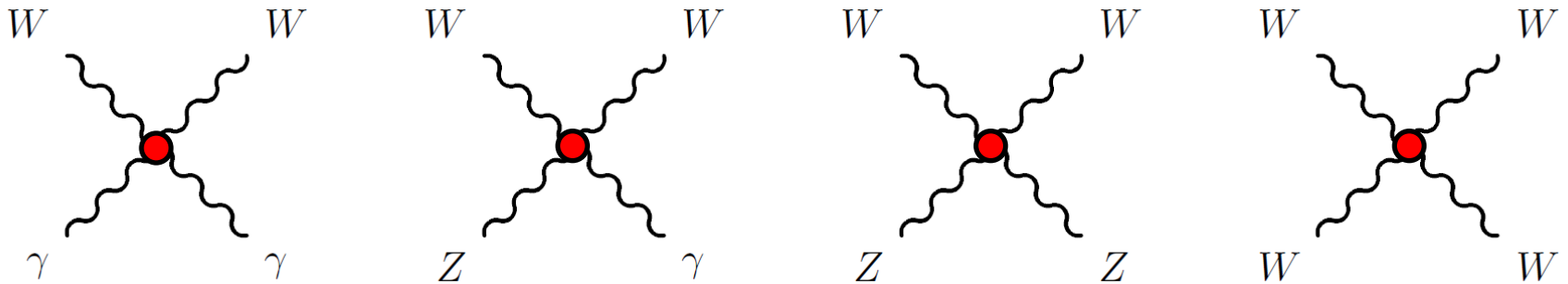
❖ **Quartic self-interactions of W/Z never observed before – untested territory!**



Vector Boson Scattering



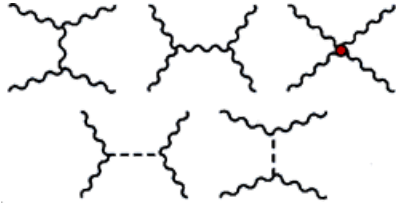
❖ **Quartic self-interactions of W/Z never observed before – untested territory!**



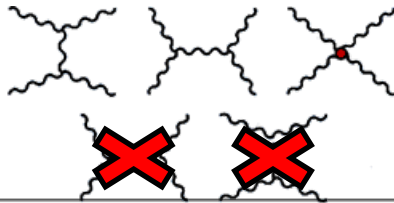
❖ **Quartic self interactions just involving γ/Z forbidden...**

Why the Higgs part matters

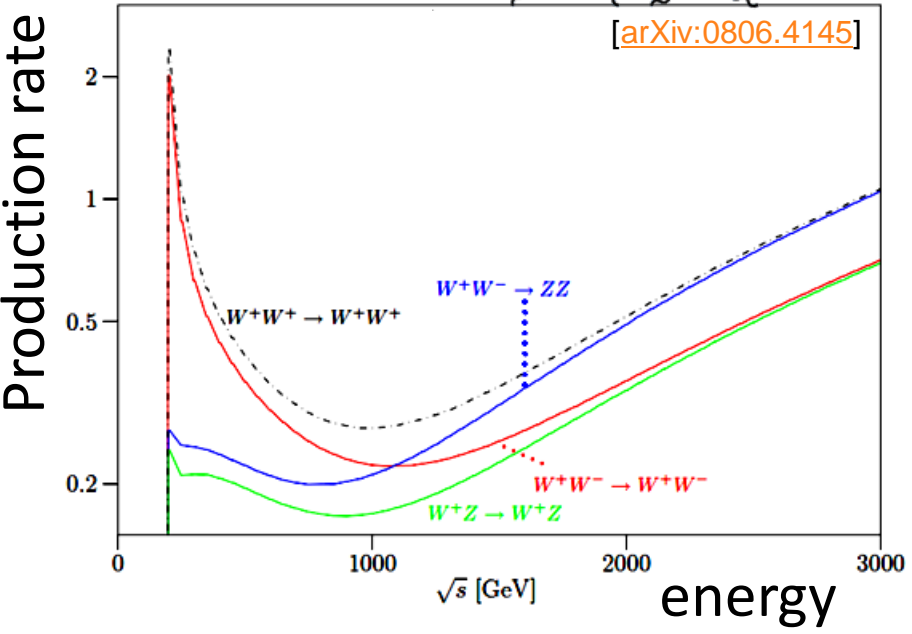
❖ No Higgs:



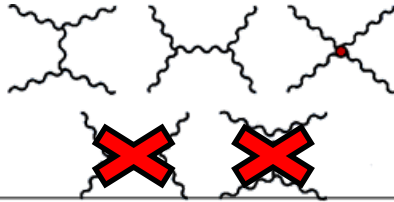
Why the Higgs part matters



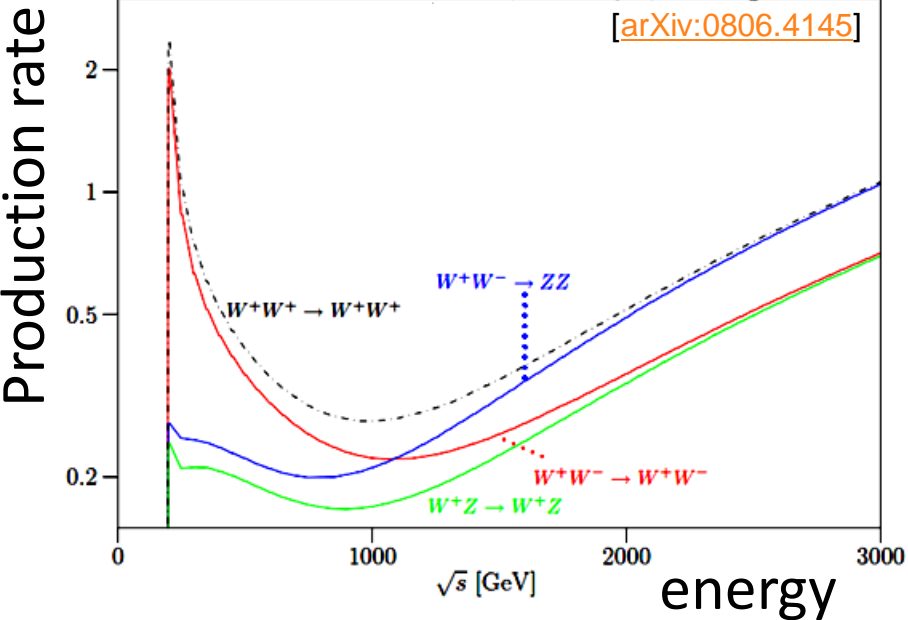
❖ No Higgs:



Why the Higgs part matters

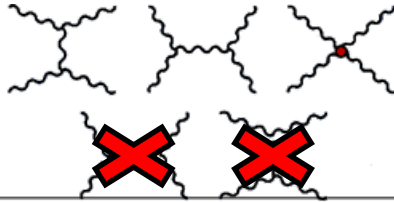


❖ No Higgs:

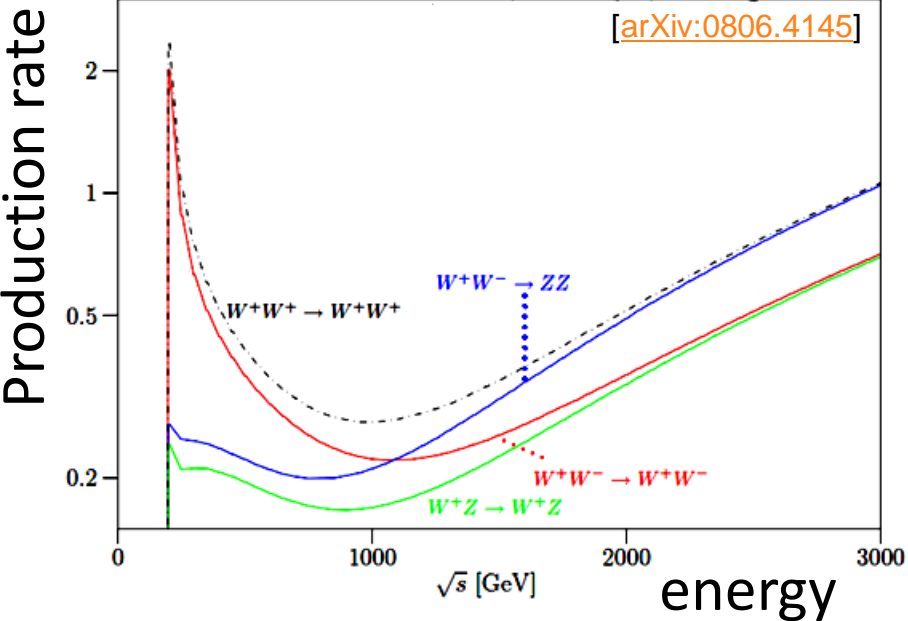


❖ Production rate **increases** with energy

Why the Higgs part matters



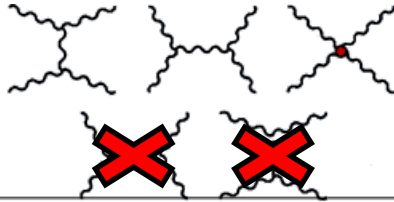
❖ No Higgs:



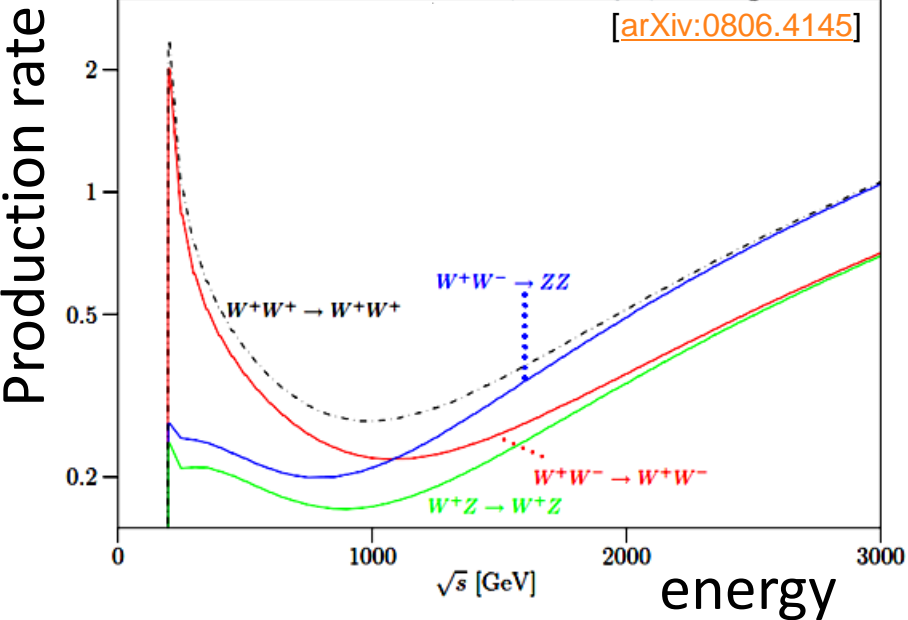
❖ Production rate **increases** with energy

❖ Probabilities > 1 at high energies

Why the Higgs part matters

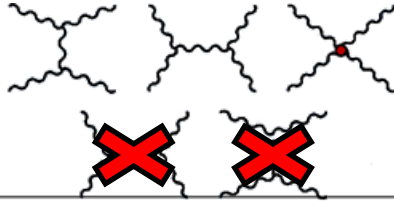


❖ No Higgs:

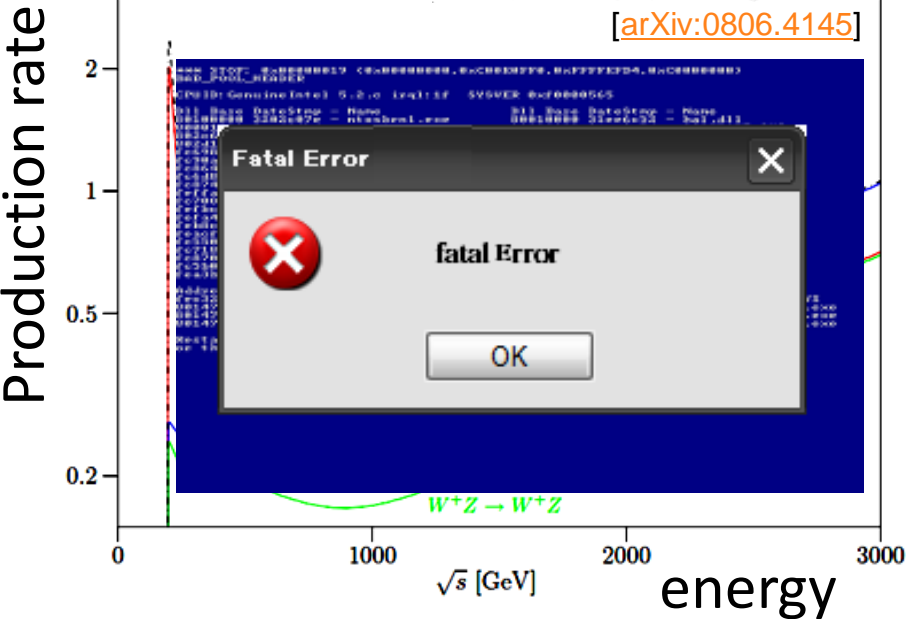


- ❖ Production rate **increases** with energy
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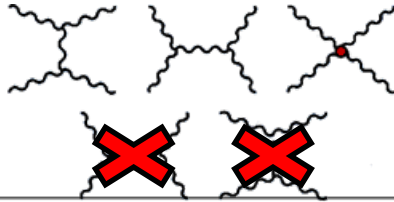


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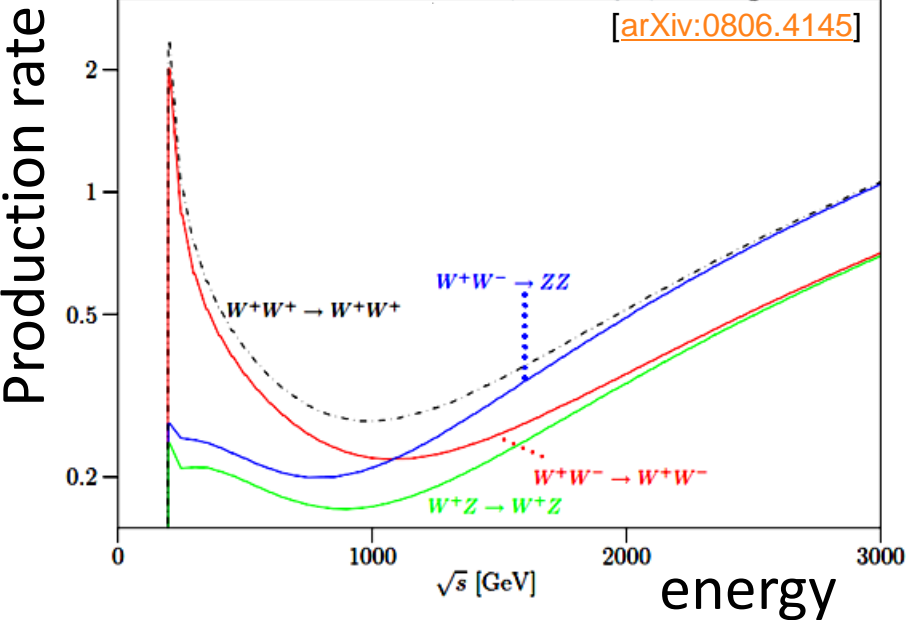


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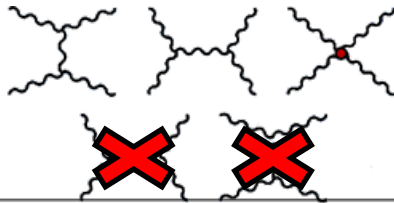


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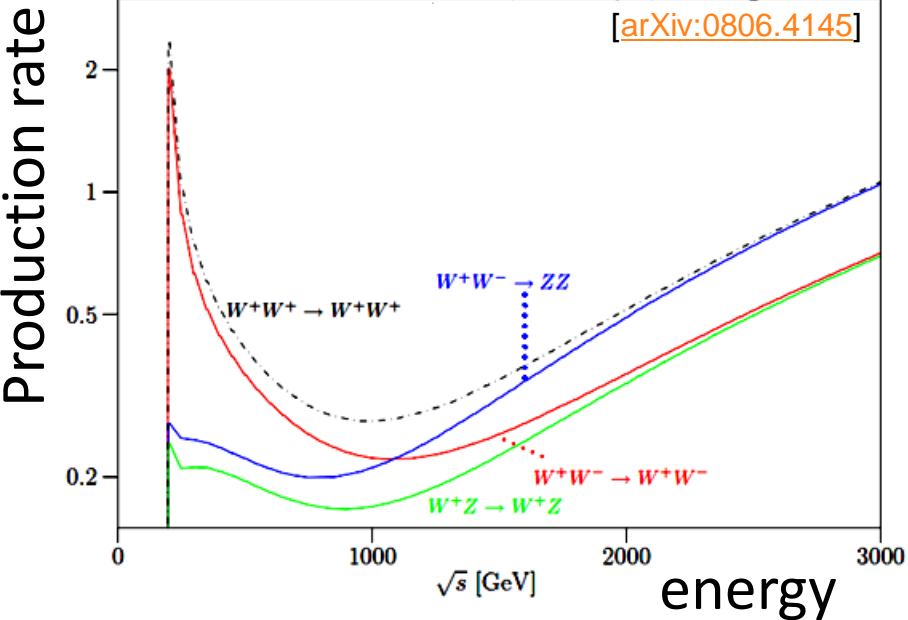


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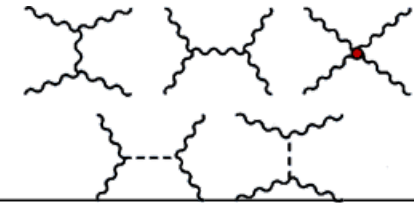
Why the Higgs part matters



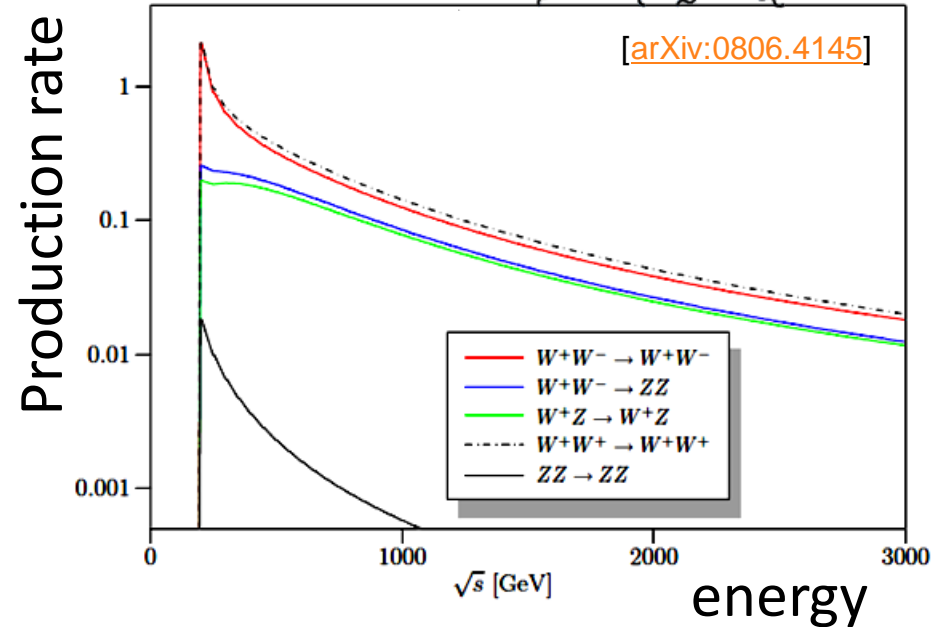
❖ No Higgs:



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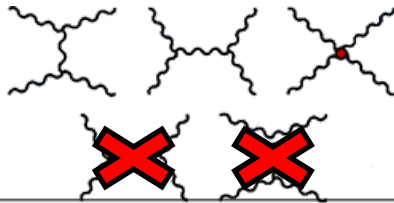


❖ With Higgs:

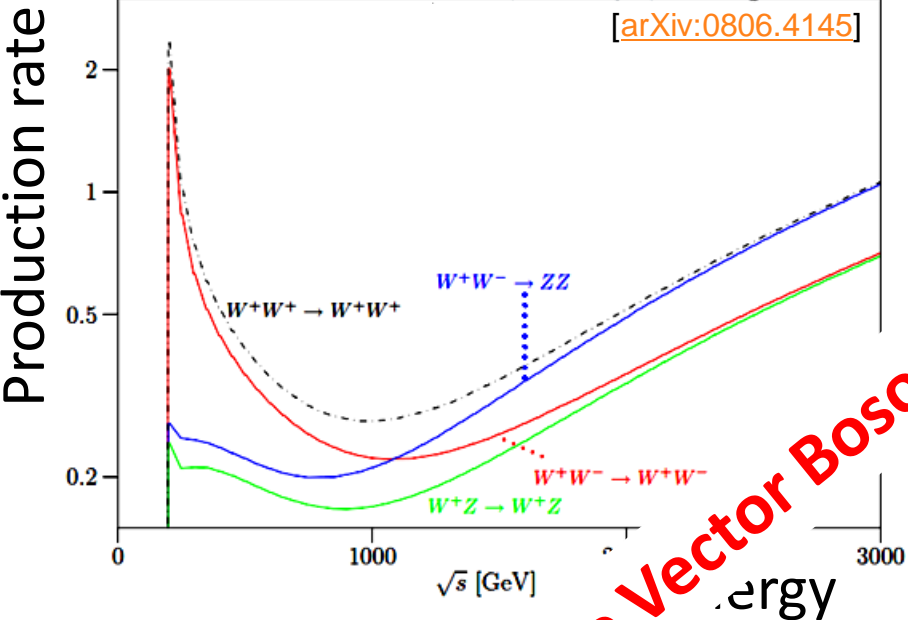


- ❖ Production rate **decreases** with energy
- ❖ Probabilities < 1 for all energies
- ❖ Standard Model alive & kicking!

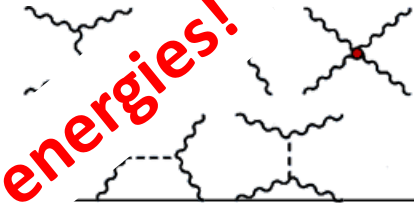
Why the Higgs part matters



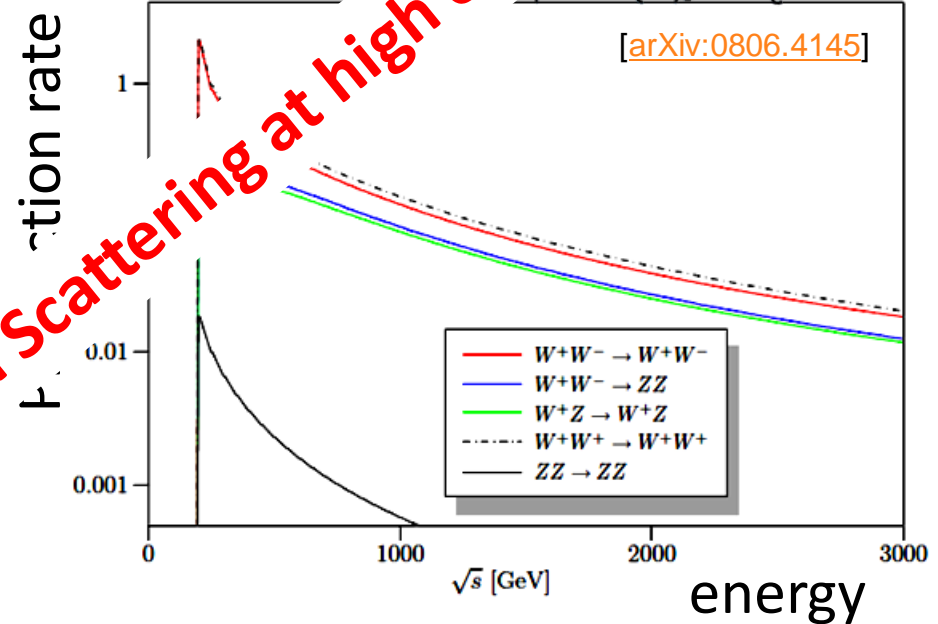
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- ❖ Production rate **decreases** with energy
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Need to measure Vector Boson Scattering at high energies!

How?

The Large Hadron Collider (LHC)

An aerial photograph of a rural landscape with a patchwork of brown and green fields. A large, thin white circle is drawn over the landscape, representing the LHC tunnel. The text 'LHC (circumference ~27km)' is overlaid in yellow. A smaller white circle is also visible in the lower right quadrant of the image.

LHC
(circumference ~27km)

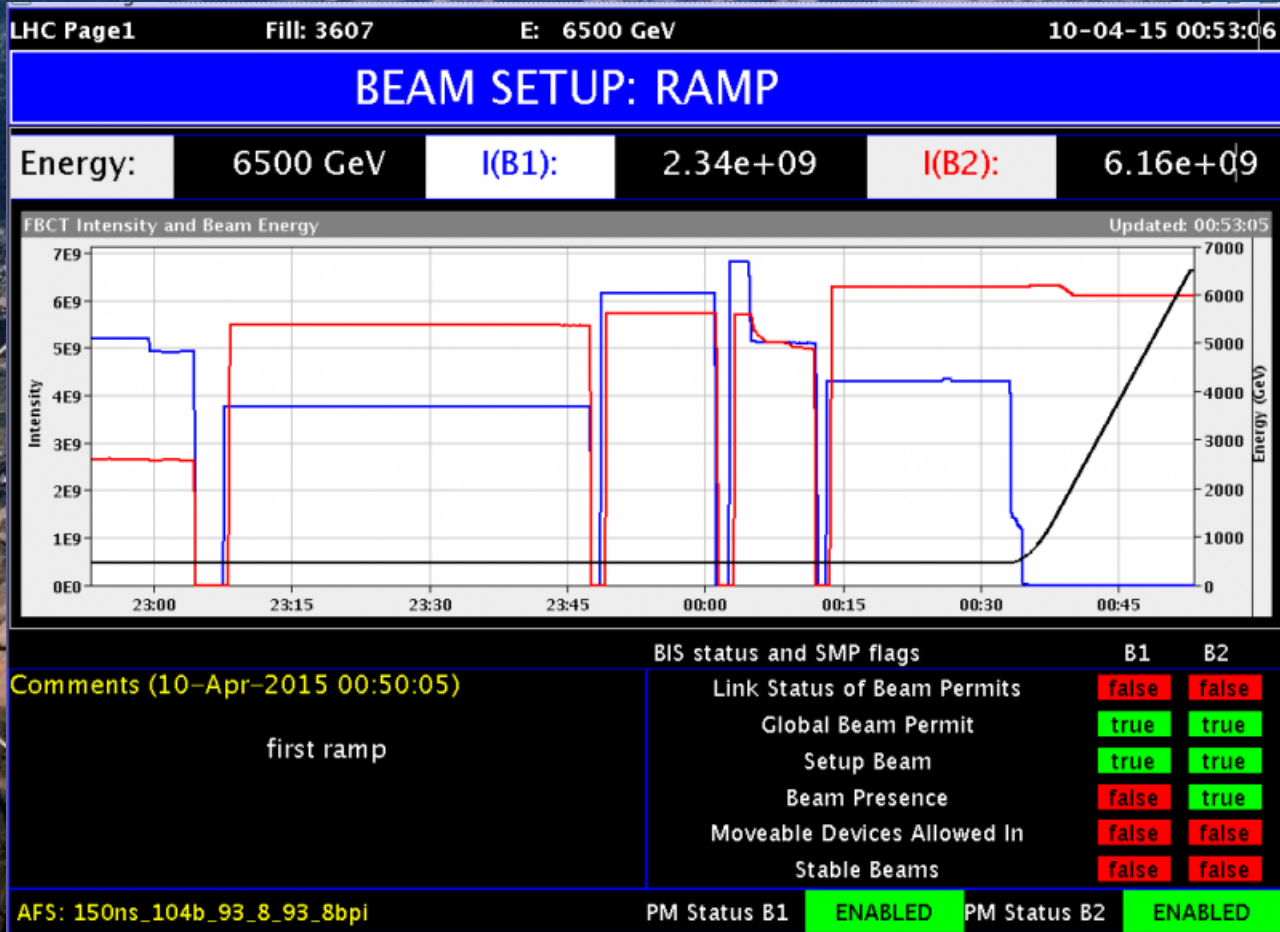
The Large Hadron Collider (LHC)

An aerial photograph of a rural landscape with a large white circle overlaid on it, representing the LHC tunnel. The landscape consists of a patchwork of green and brown fields, with some buildings and roads visible. The circle is centered in the middle of the image and extends across most of the width and height of the frame.

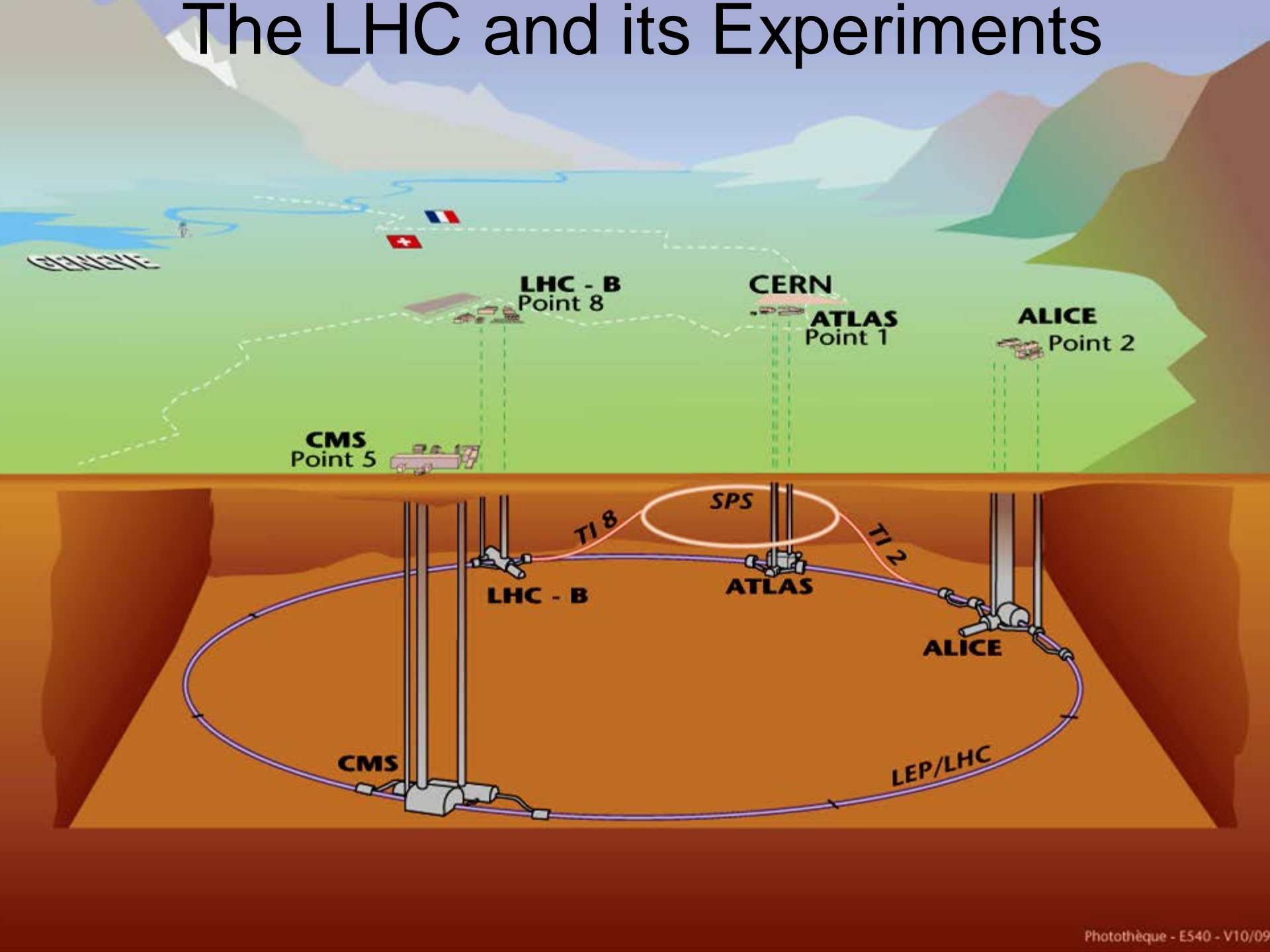
LHC
(circumference ~27km)

**First 7 TeV pp collisions
on March 30 2010 !**

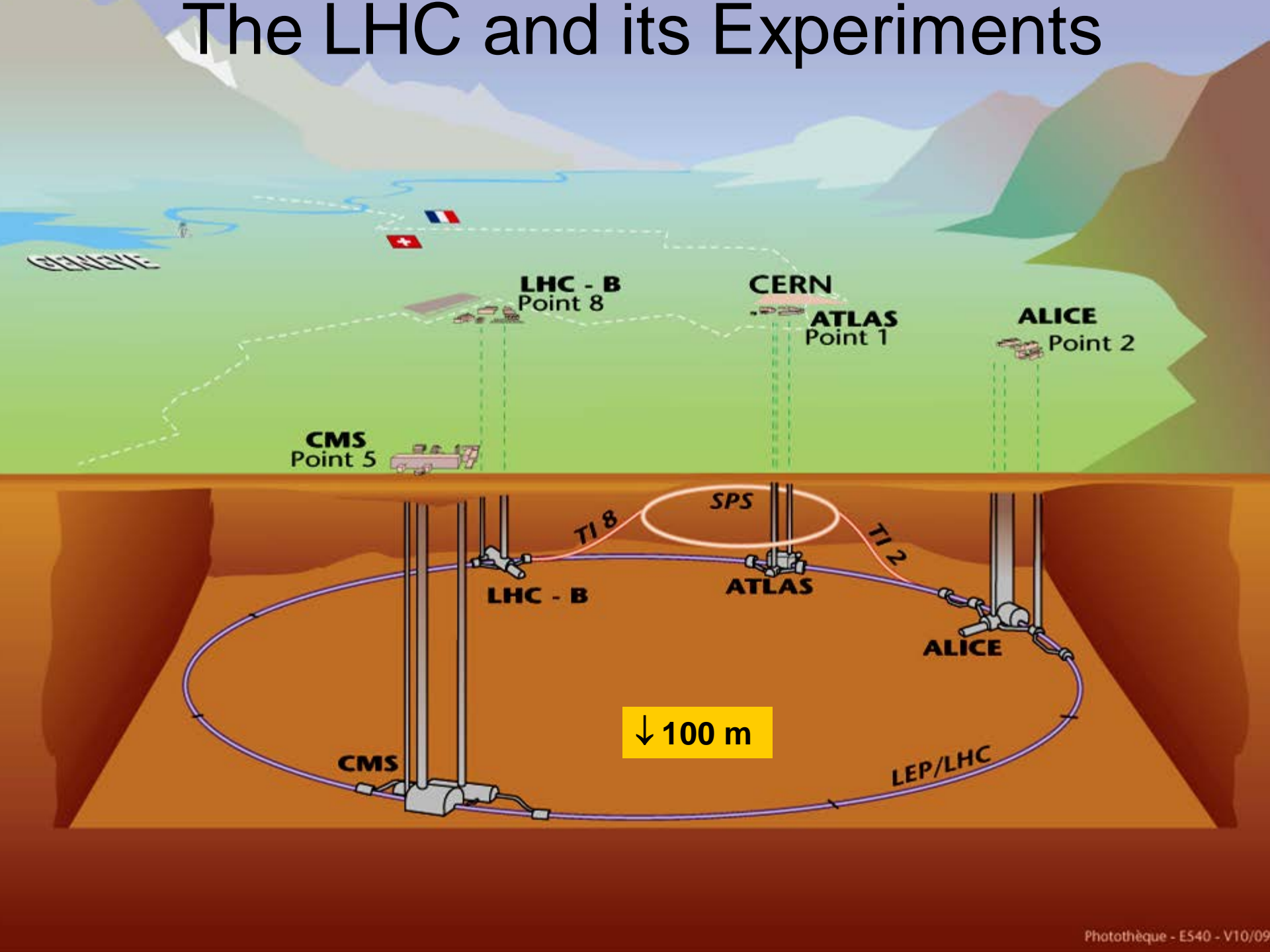
The Large Hadron Collider (LHC)



The LHC and its Experiments

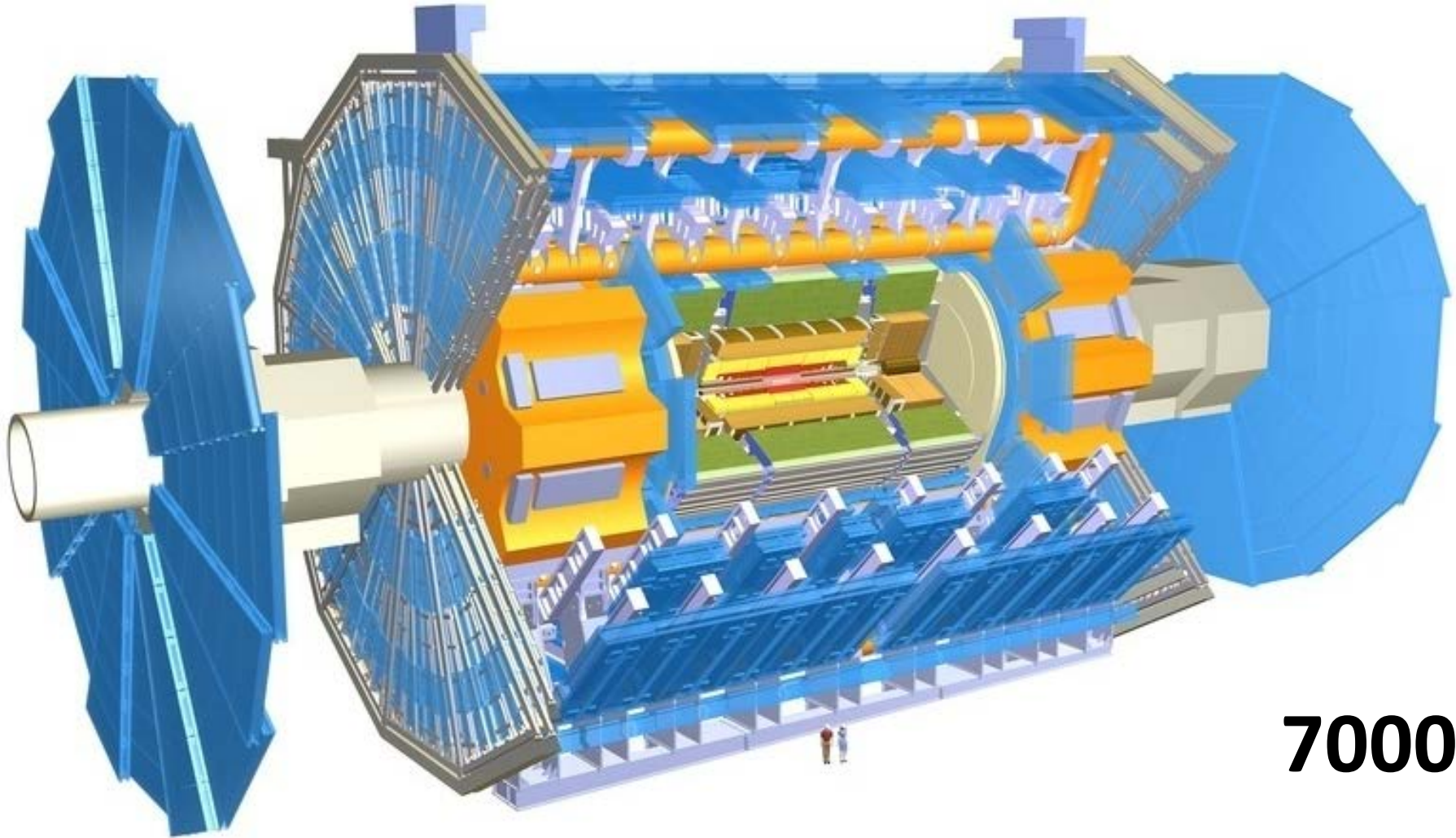


The LHC and its Experiments



The ATLAS-Detector

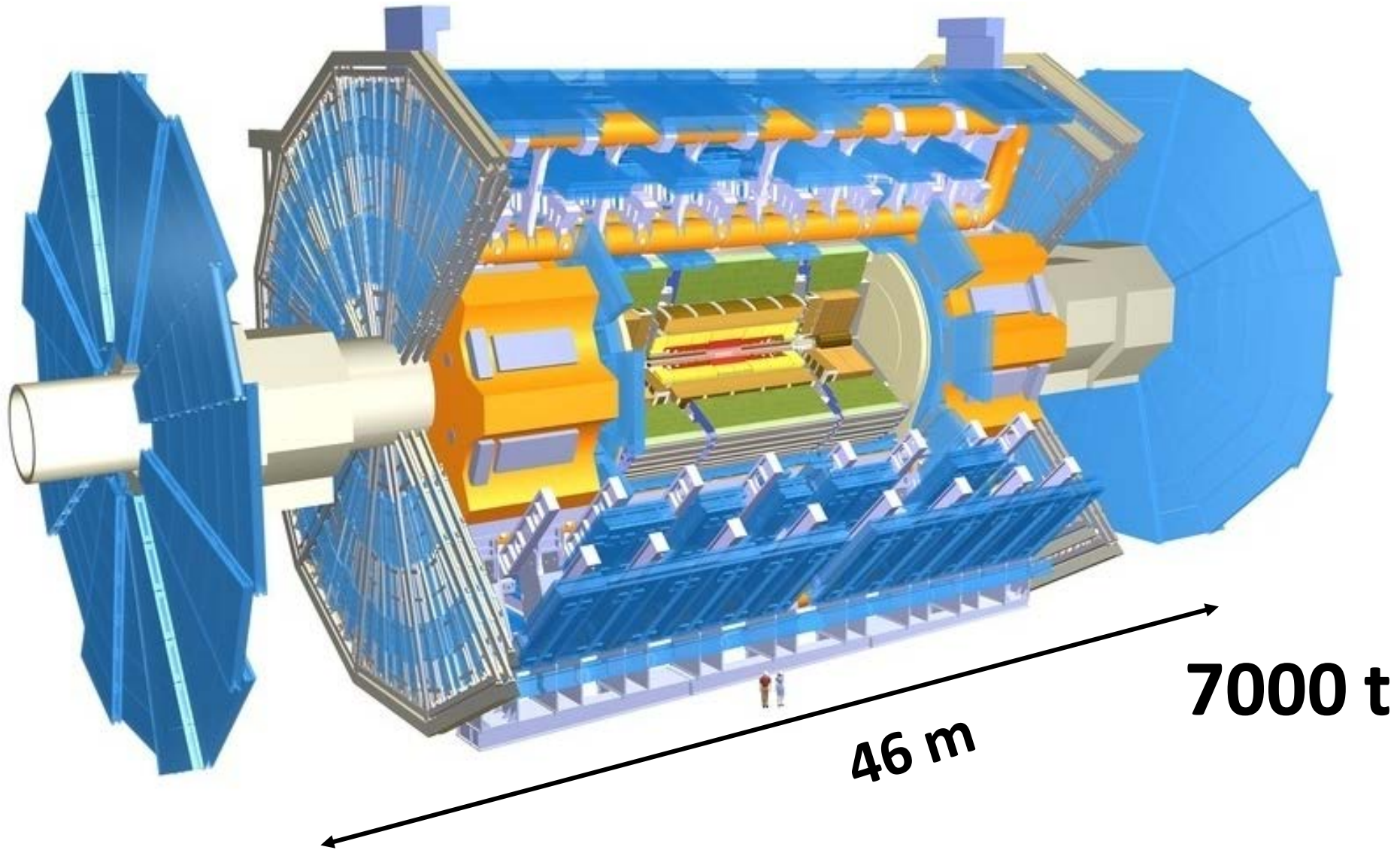
(A Toroidal LHC ApparatuS)



7000 t

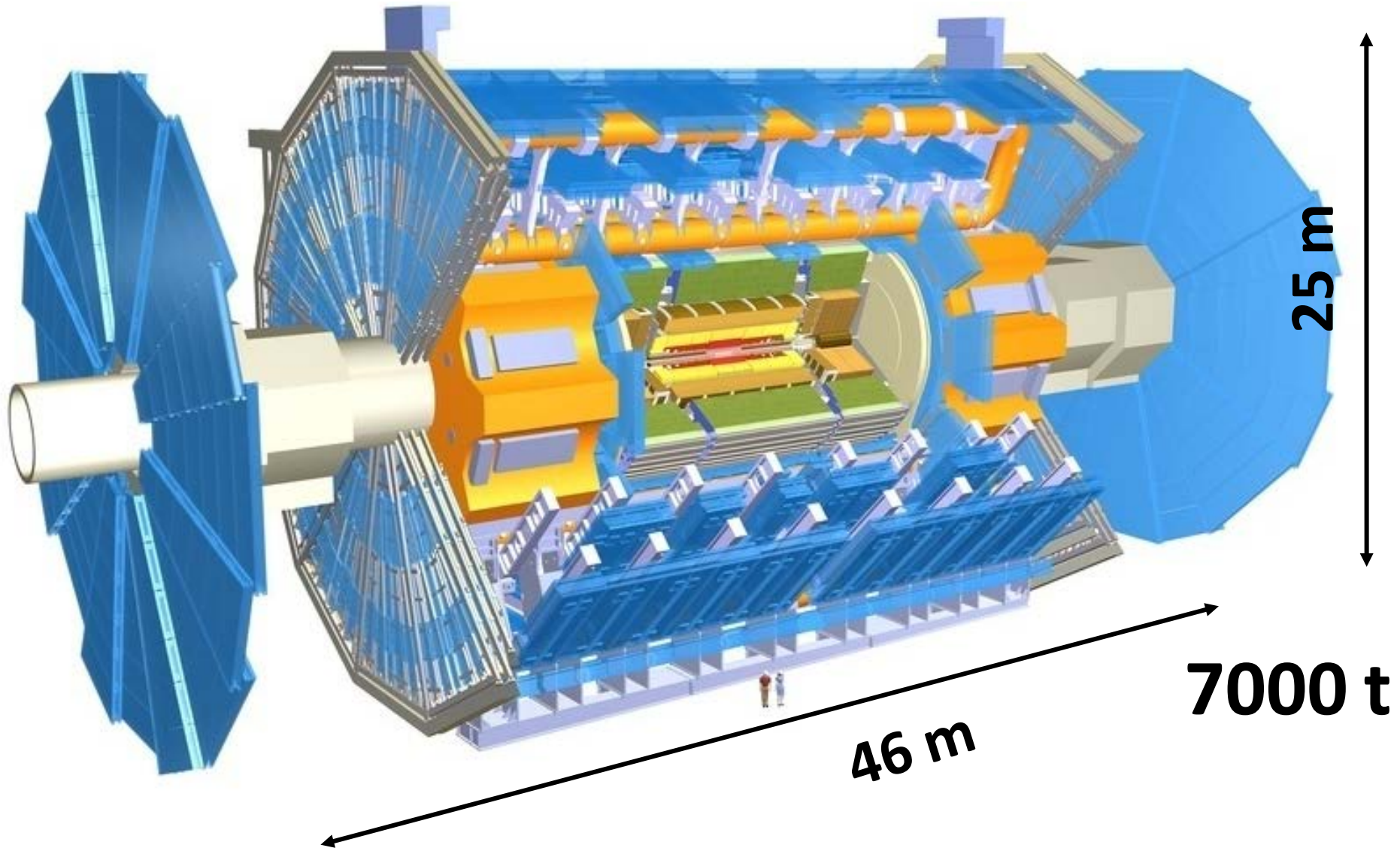
The ATLAS-Detector

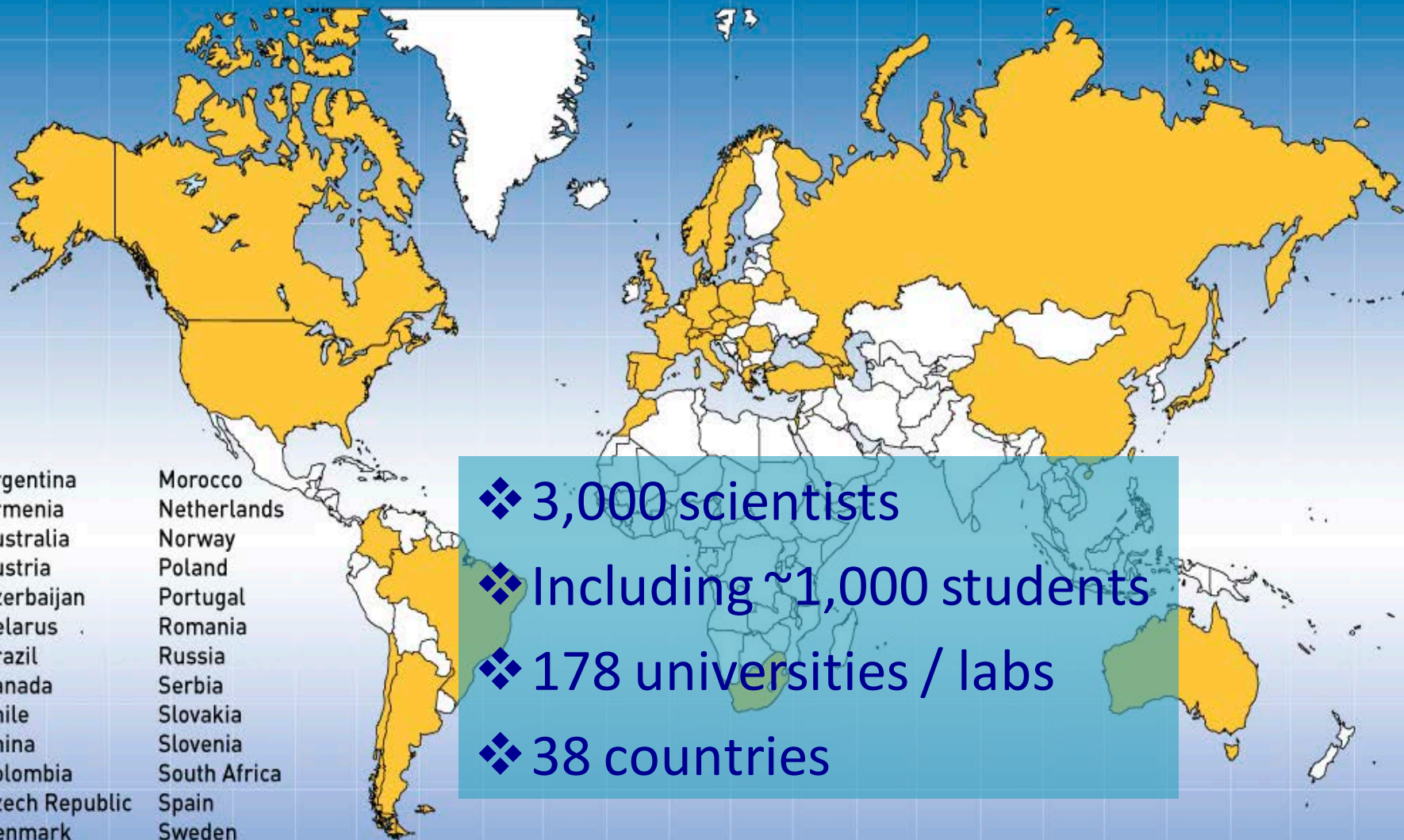
(A Toroidal LHC ApparatuS)



The ATLAS-Detector

(A Toroidal LHC ApparatuS)





- Argentina
- Armenia
- Australia
- Austria
- Azerbaijan
- Belarus
- Brazil
- Canada
- Chile
- China
- Colombia
- Czech Republic
- Denmark
- France
- Georgia
- Germany
- Greece
- Israel
- Italy
- Japan
- Morocco
- Netherlands
- Norway
- Poland
- Portugal
- Romania
- Russia
- Serbia
- Slovakia
- Slovenia
- South Africa
- Spain
- Sweden
- Switzerland
- Taiwan
- Turkey
- UK
- USA
- CERN
- JINR

- ❖ 3,000 scientists
- ❖ Including ~1,000 students
- ❖ 178 universities / labs
- ❖ 38 countries

ATLAS Collaboration



US in ATLAS:

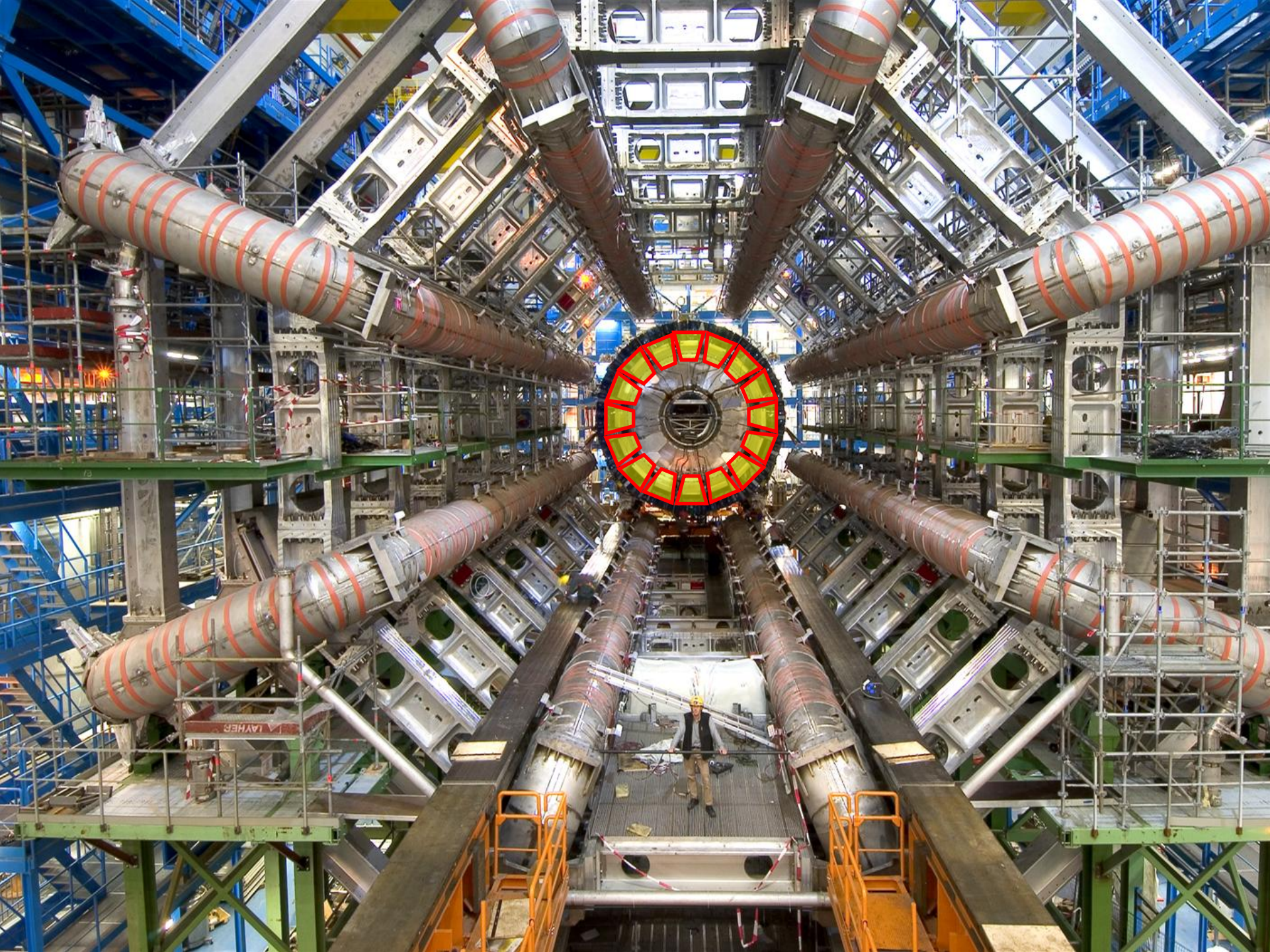
- 700 people
- Including 170 students
- 44 universities / labs
- 21 states

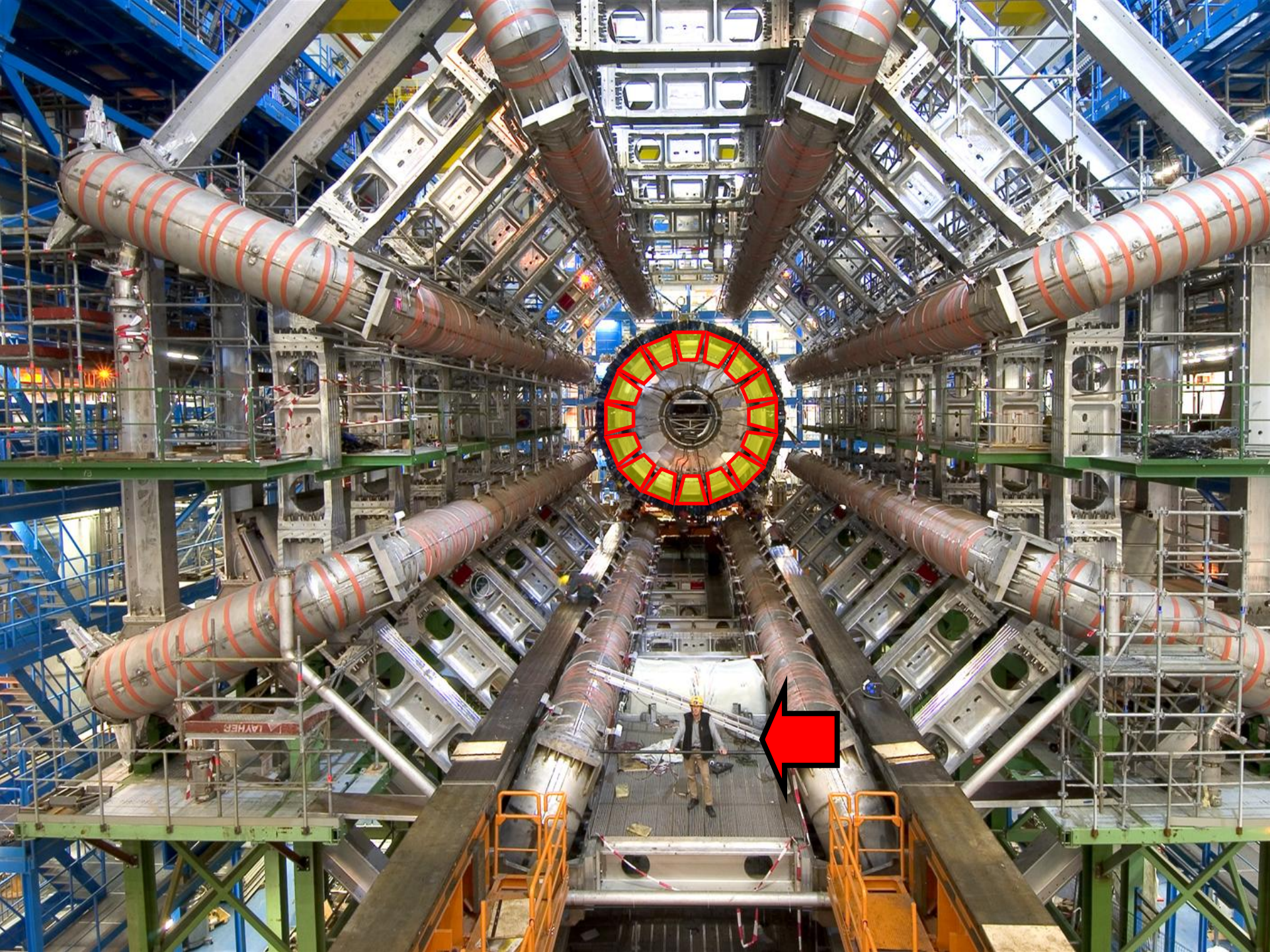
- | | |
|----------------|--------------|
| Argentina | Morocco |
| Armenia | Netherlands |
| Australia | Norway |
| Austria | Poland |
| Azerbaijan | Portugal |
| Belarus | Romania |
| Brazil | Russia |
| Canada | Serbia |
| Chile | Slovakia |
| China | Slovenia |
| Colombia | South Africa |
| Czech Republic | Spain |
| Denmark | Sweden |
| France | Switzerland |
| Georgia | Taiwan |
| Germany | Turkey |
| Greece | UK |
| Israel | USA |
| Italy | CERN |
| Japan | JINR |

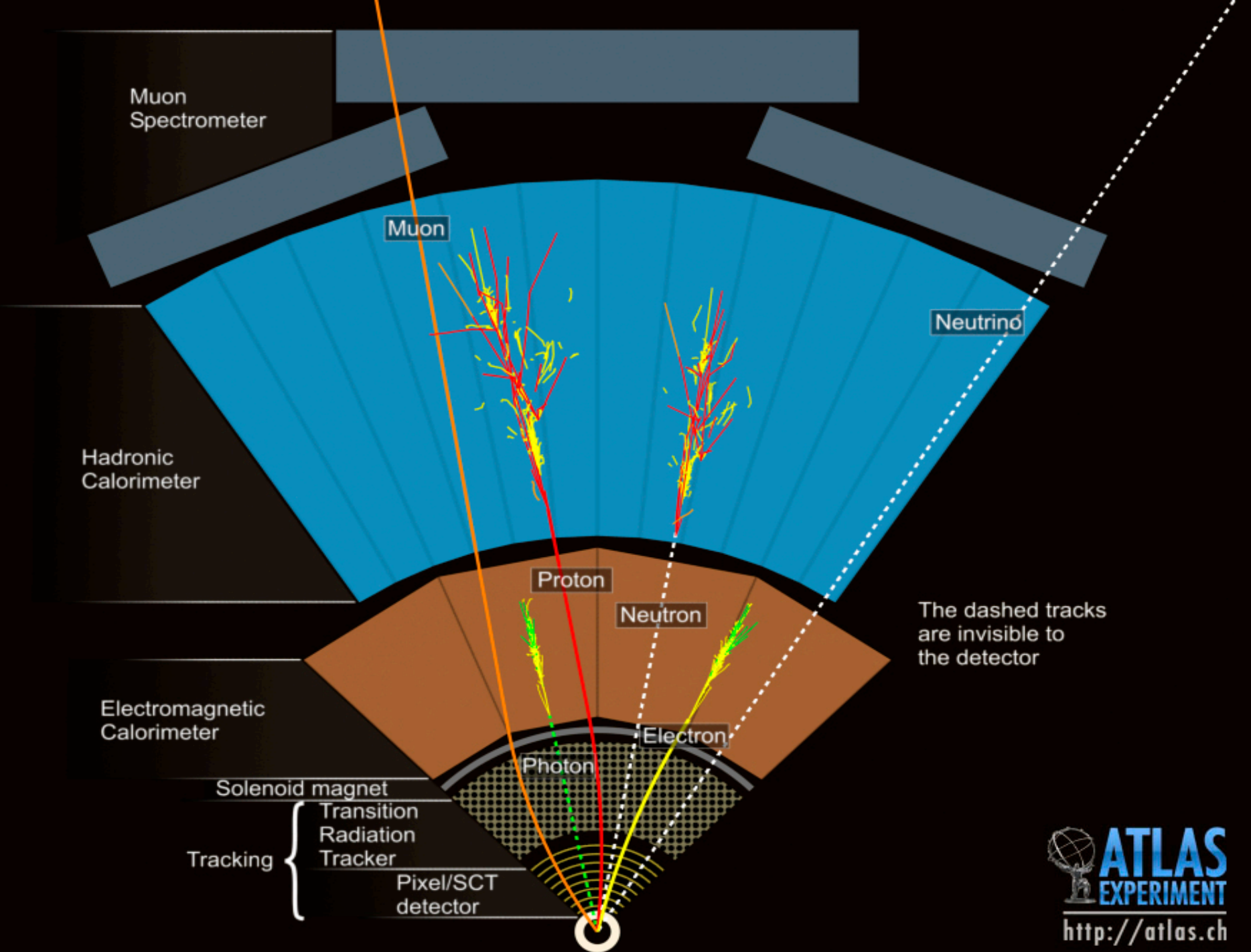
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ATLAS Collaboration







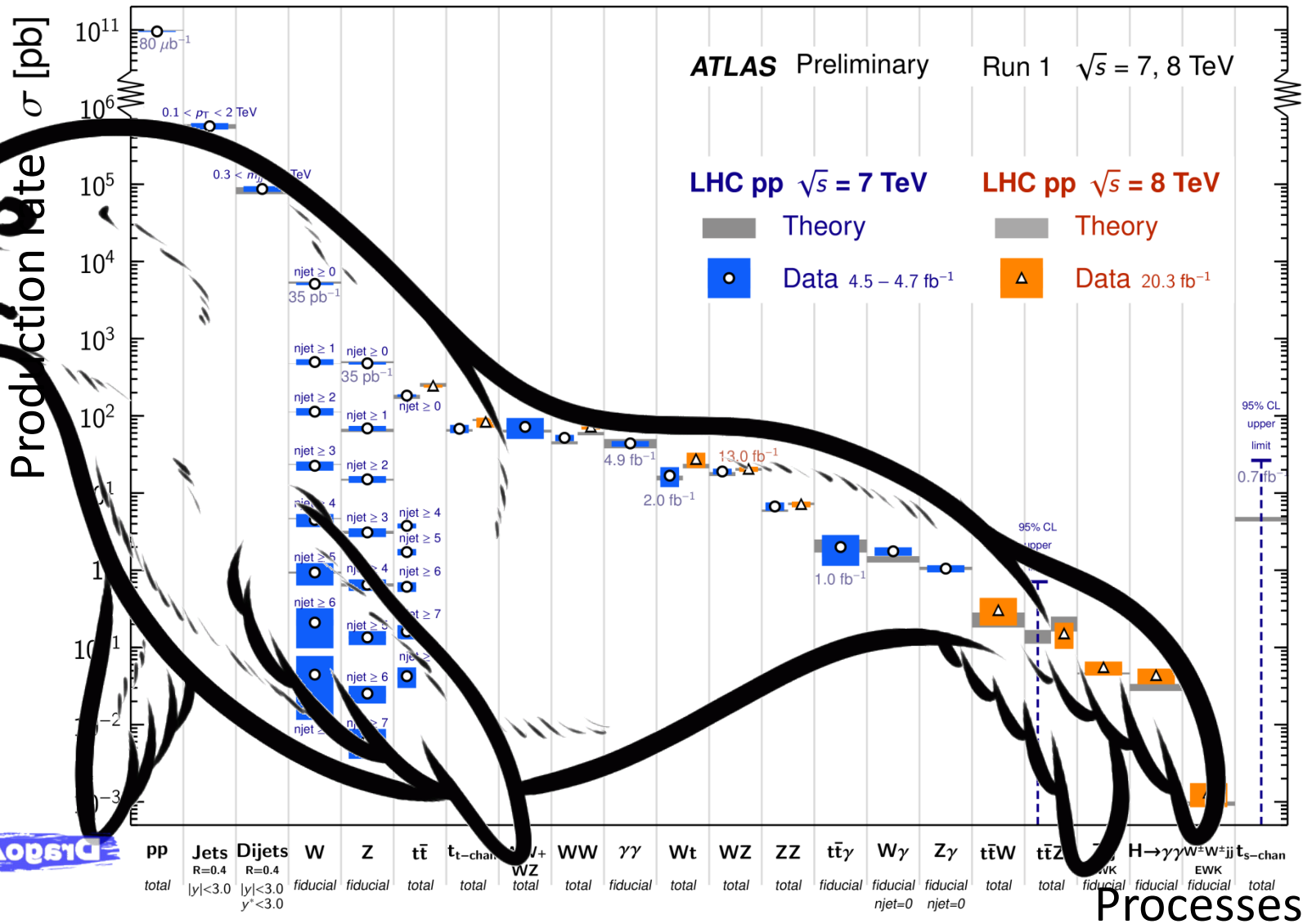




What we measure in ATLAS...

Standard Model Production Cross Section Measurements

Status: July 2014

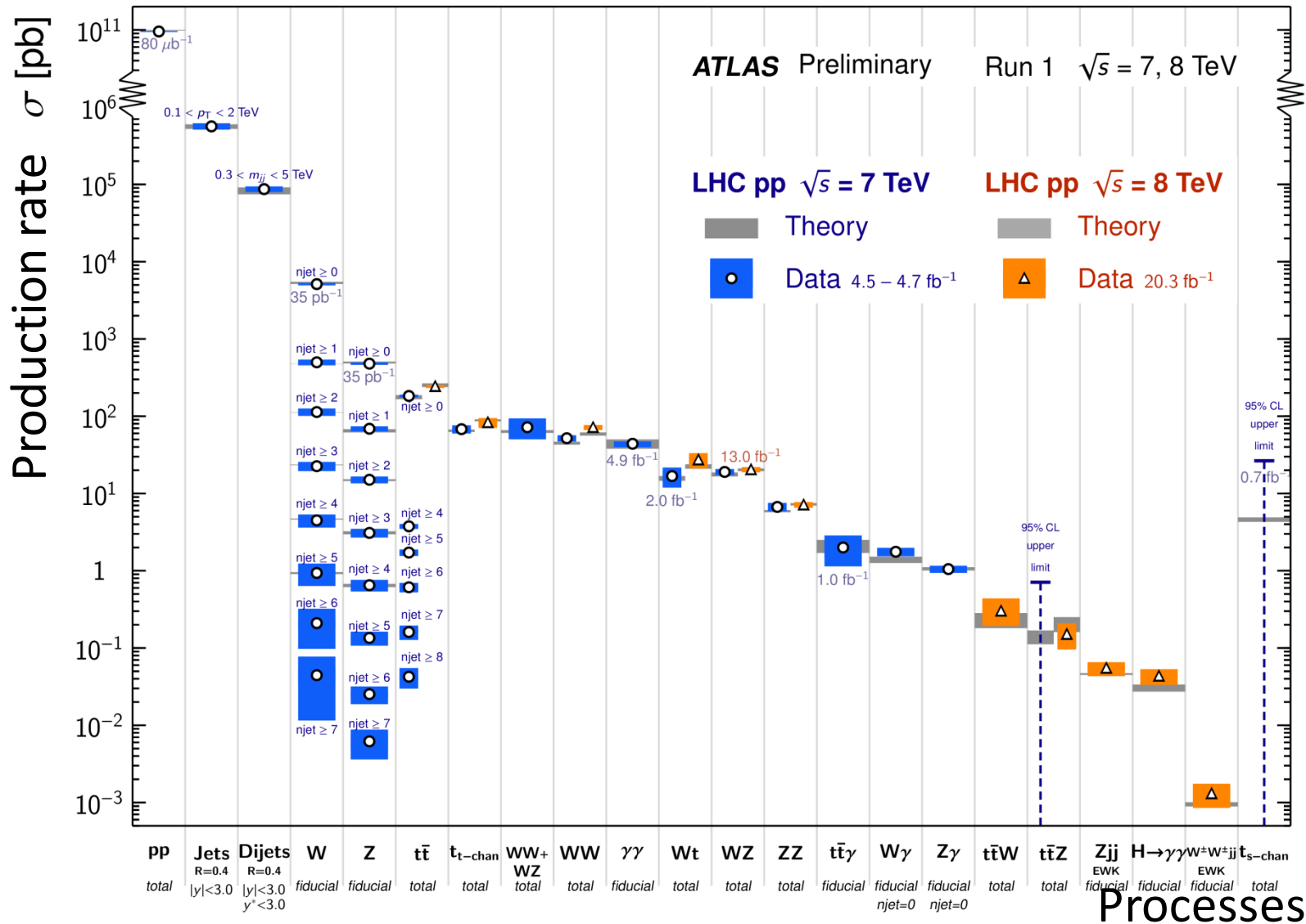


Disagor.com

What we measure in ATLAS...

Standard Model Production Cross Section Measurements

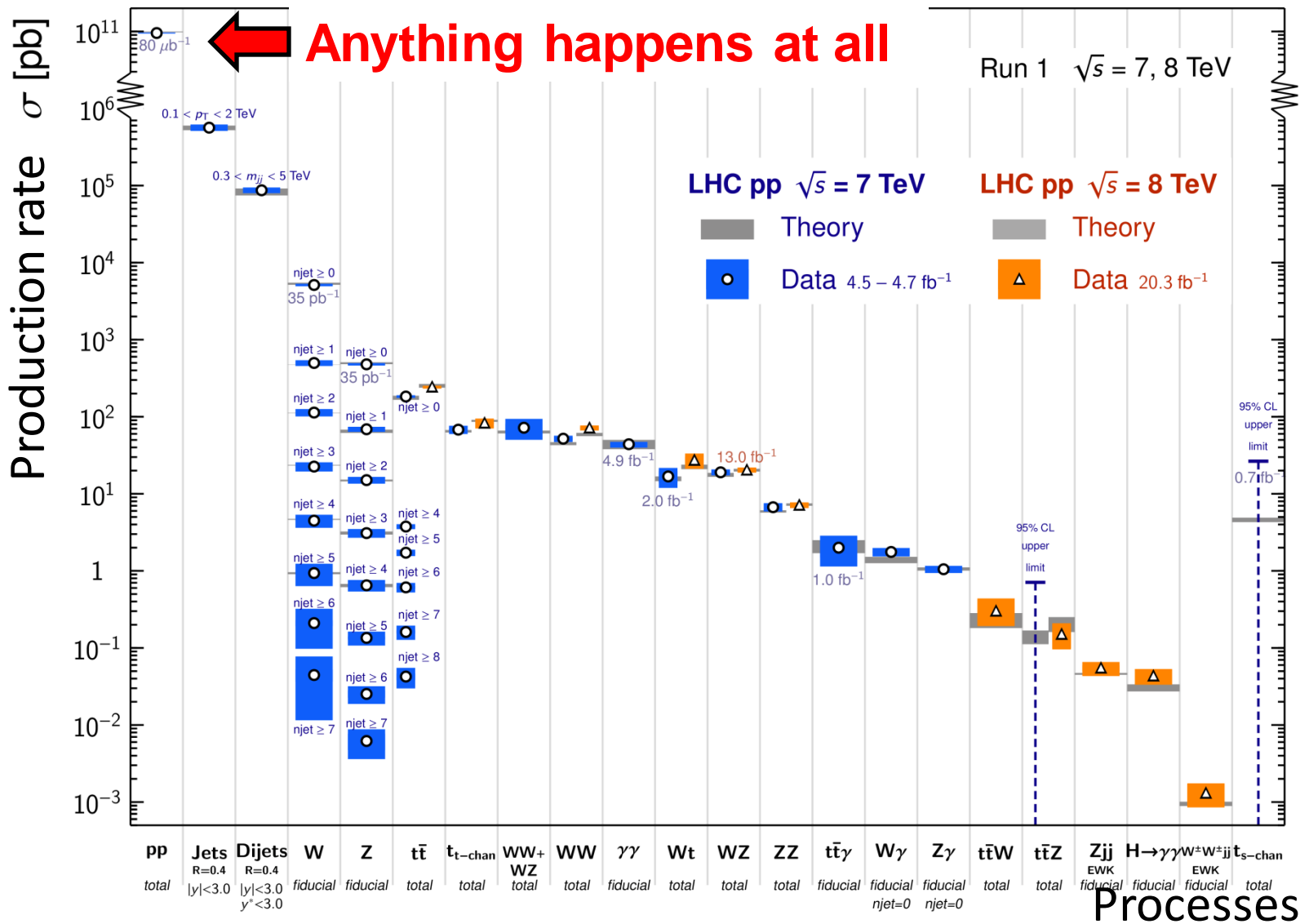
Status: July 2014



What we measure in ATLAS...

Standard Model Production Cross Section Measurements

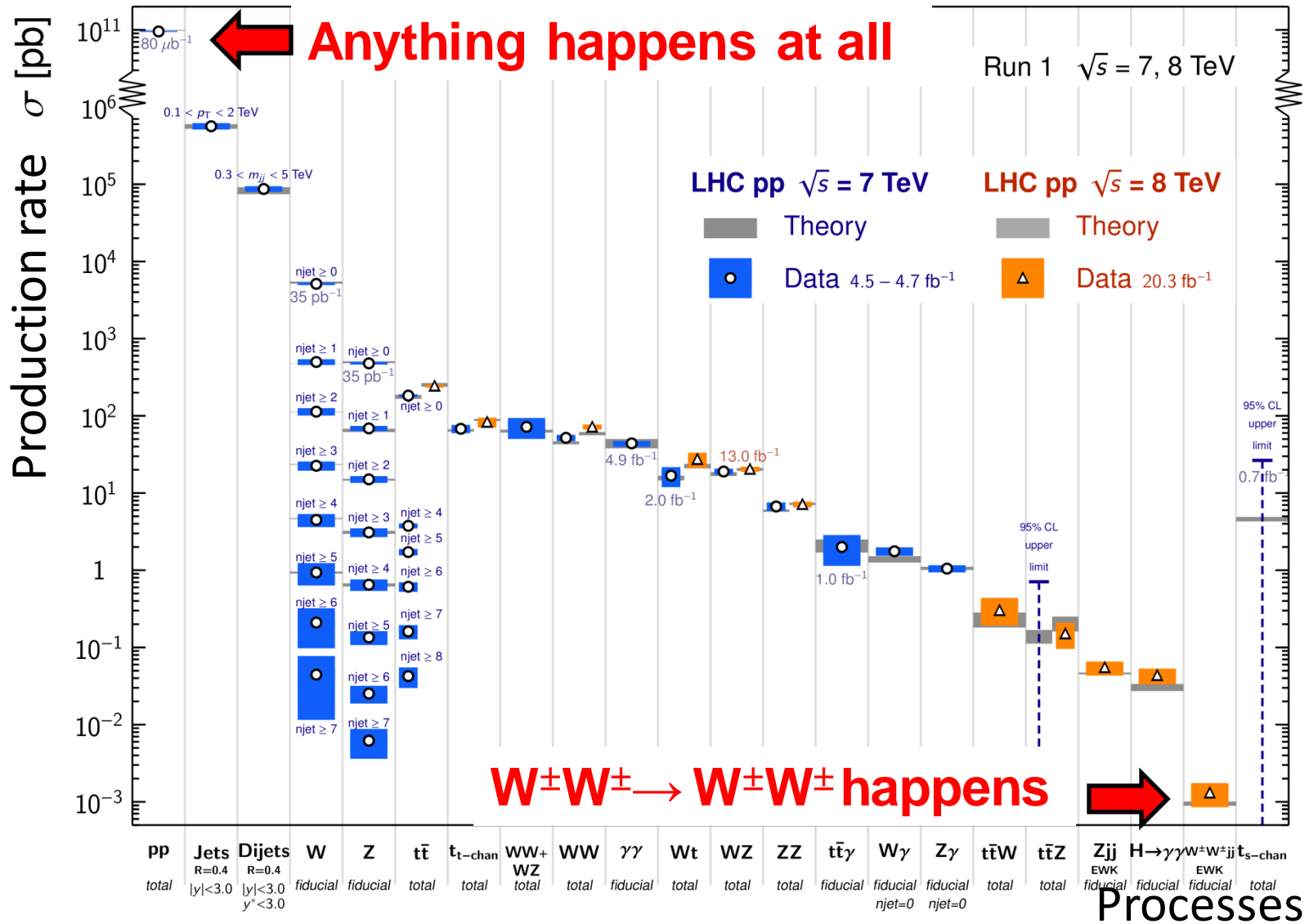
Status: July 2014



What we measure in ATLAS...

Standard Model Production Cross Section Measurements

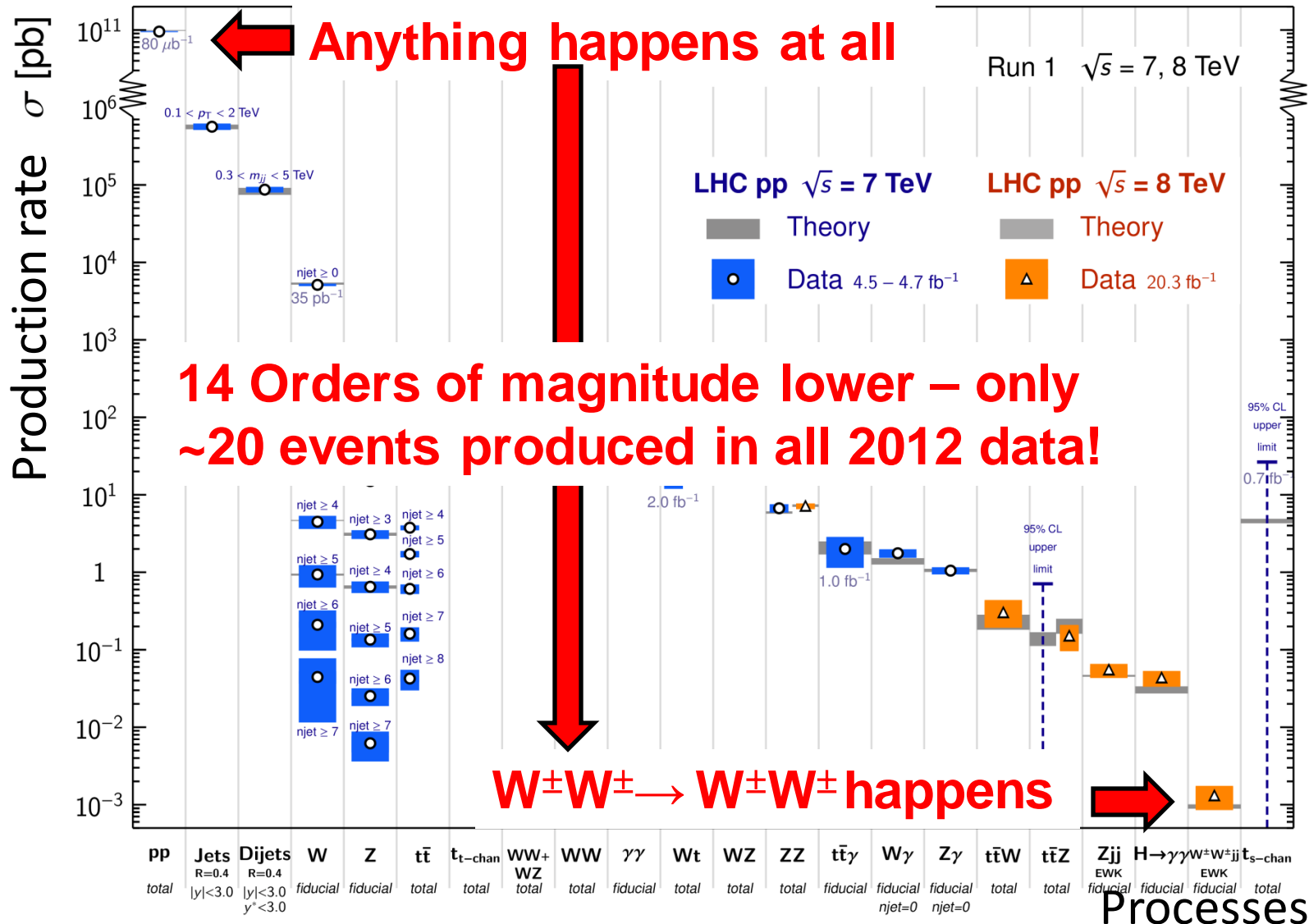
Status: July 2014



What we measure in ATLAS...

Standard Model Production Cross Section Measurements

Status: July 2014



Data selection

Looking for extremely rare processes:

$W^\pm W^\pm \rightarrow W^\pm W^\pm$ happens every
 $\sim 100,000,000,000,000$ collisions!

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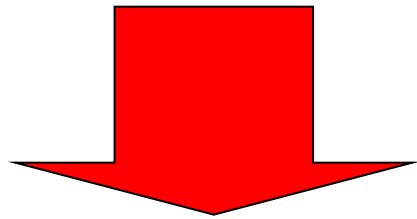


Data selection

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Need high proton-proton
collision rate: Up to
 $1,000,000,000$ per second!

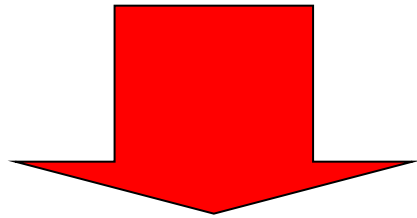


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Data selection

Selection of 100 'best' events/s:

40 MHz, 1 PB/s

Level 1: Coarse calo data &
muon trigger chambers

75 kHz, 75 GB/s

Level 2: Full info in
regions of interest

**1 kHz,
1 GB/s**

Event Filter:
full info

~100 Hz, ~100 MB/sec

~10 TB/day, 1 PB/yr recorded data

Data selection

Selection of 100 'best' events/s:

40 MHz, 1 PB/s

Level 1: Coarse calo data & muon trigger chambers

75 kHz, 75 GB/s

Level 2: Full info in regions of interest

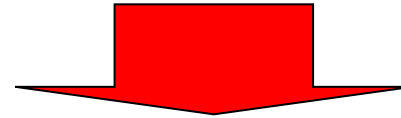
**1 kHz,
1 GB/s**

Event Filter:
full info

~100 Hz, ~100 MB/sec

~10 TB/day, 1 PB/yr recorded data

LHC data volume:
10-15 PB/yr



One CD: 650 MB
1 PB = 10^9 MB

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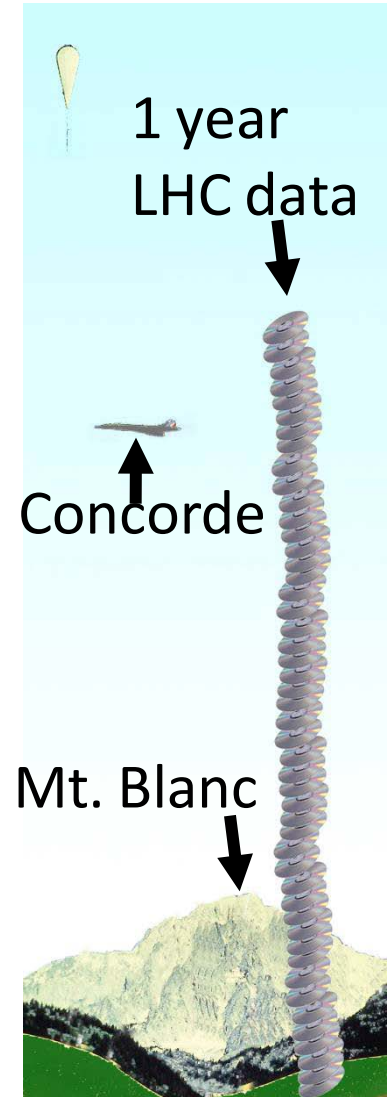
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1 PB = 10^9 MB

12-mile-high
stack of CDs!

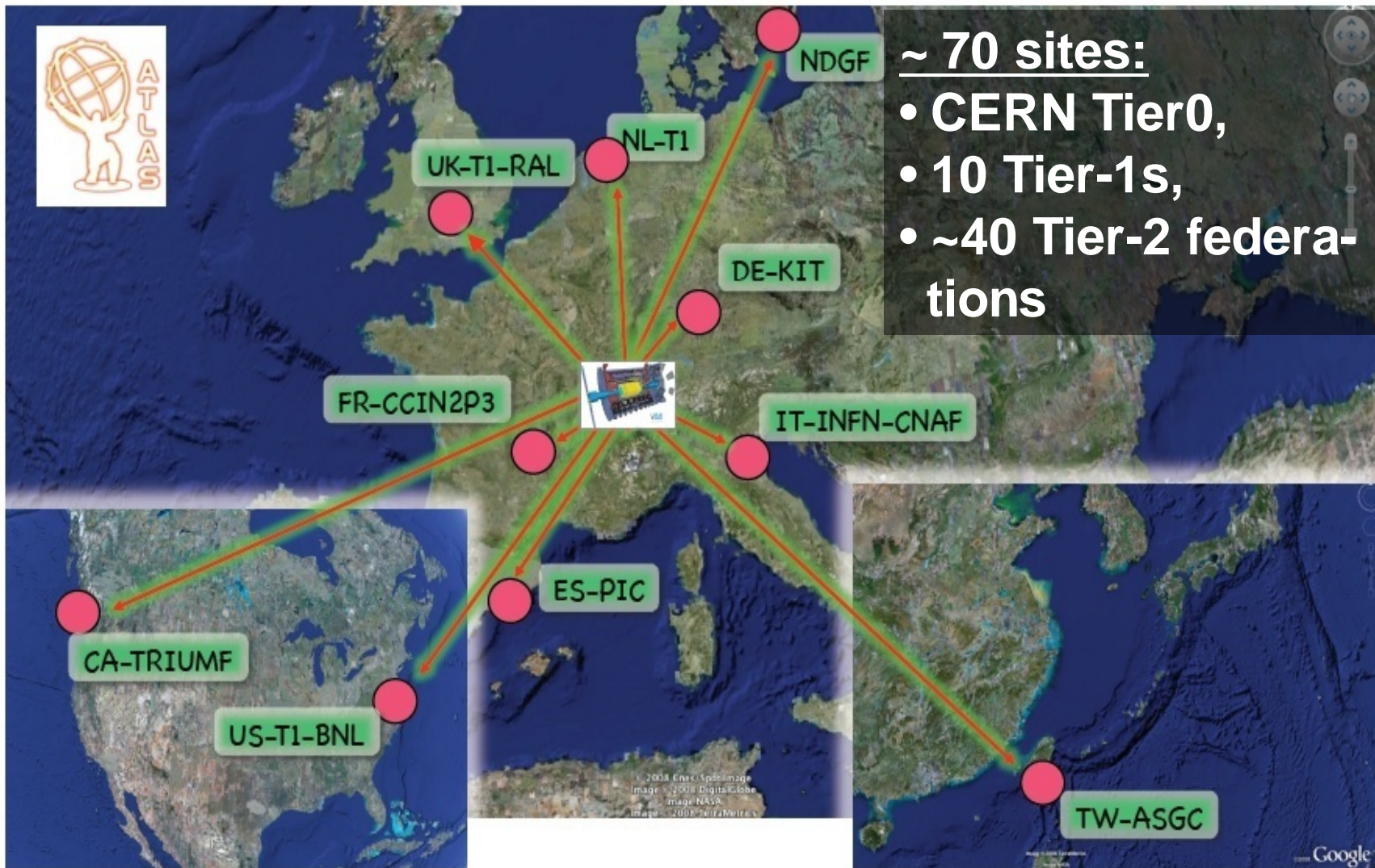


A Global Computing System

- ❖ Worldwide LHC **Computing Grid**
- ❖ 170 computing centers
- ❖ 40 countries
- ❖ National and international grid computing projects
- ❖ 2 million jobs run every day



ATLAS World-Wide Computing Grid



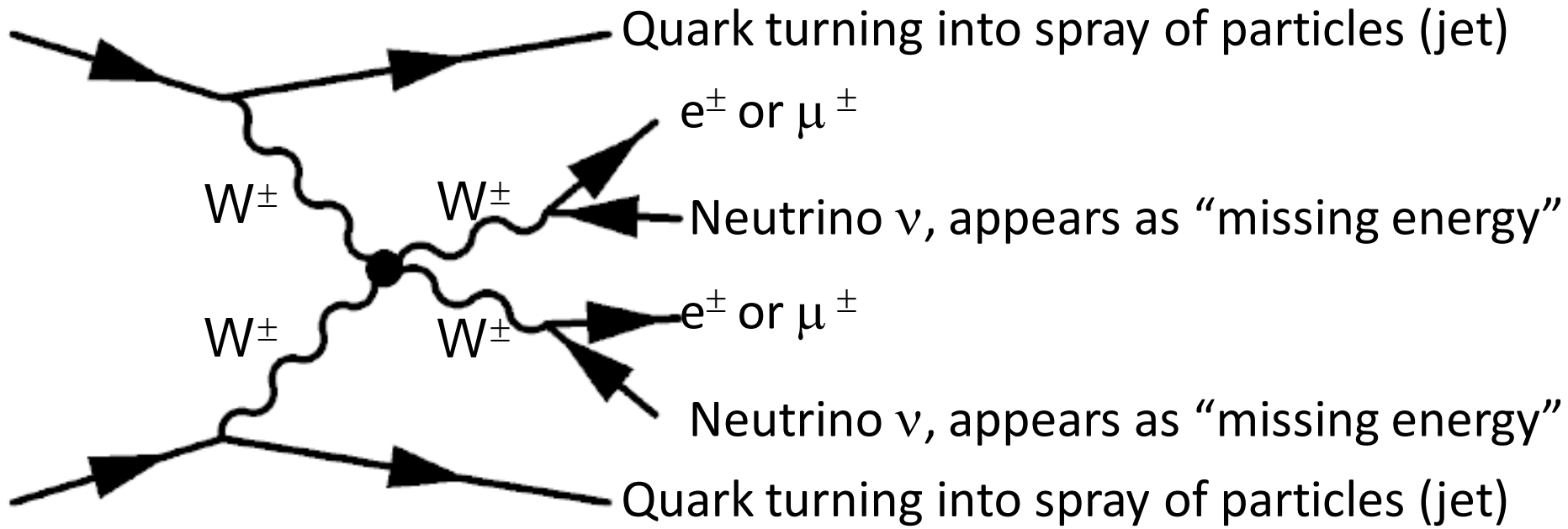
~ 70 sites:

- CERN Tier0,
- 10 Tier-1s,
- ~40 Tier-2 federations

ATLAS World-Wide Computing Grid

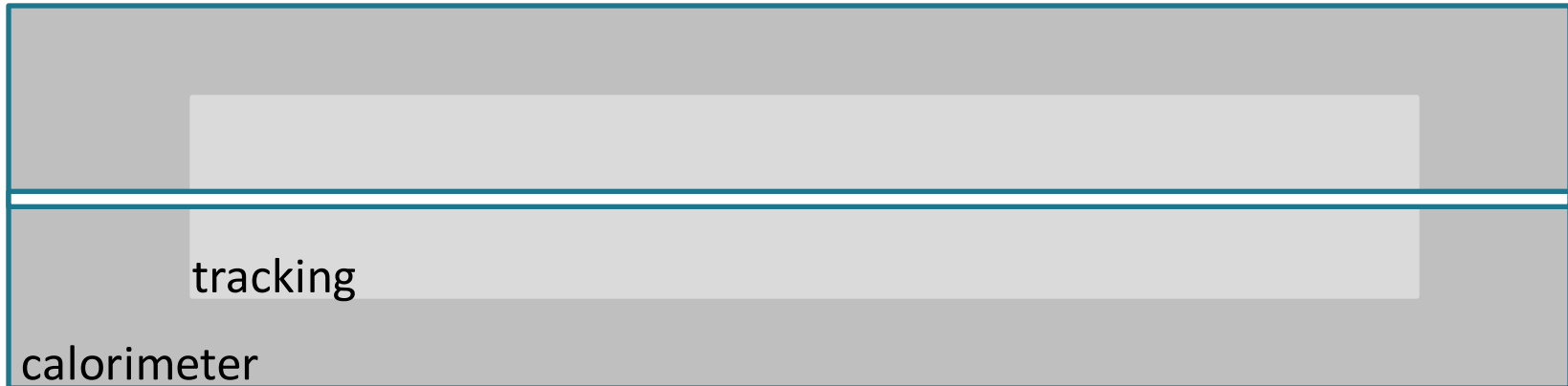
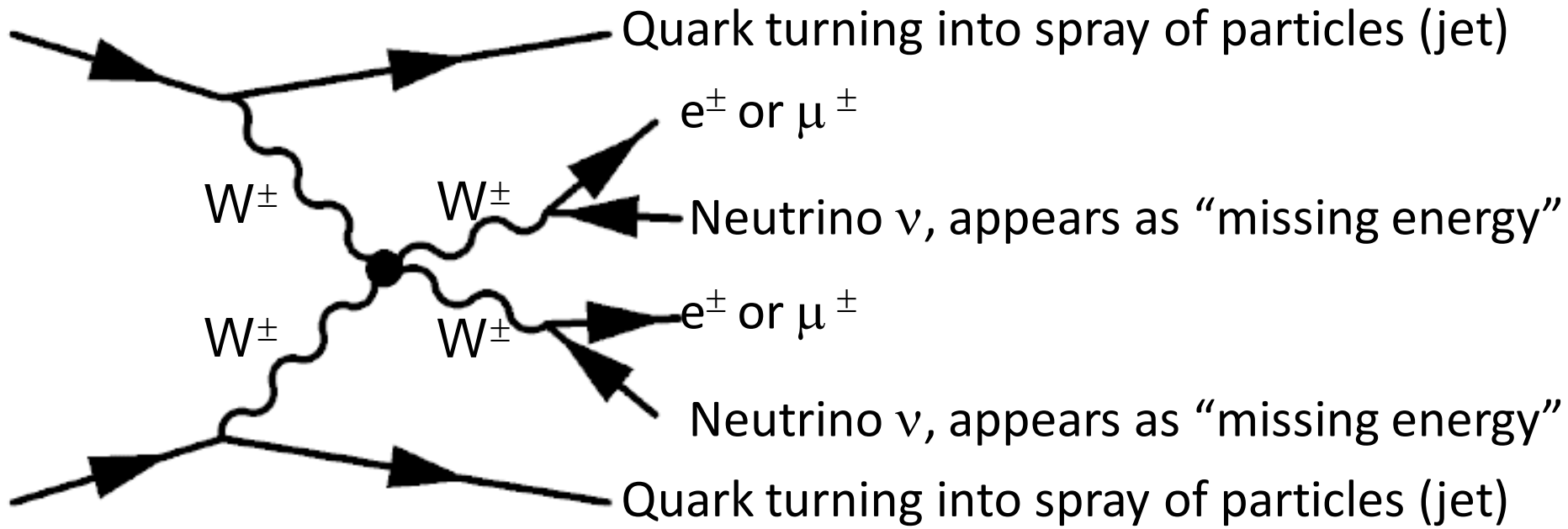


$W^\pm W^\pm \rightarrow W^\pm W^\pm$ Fingerprint

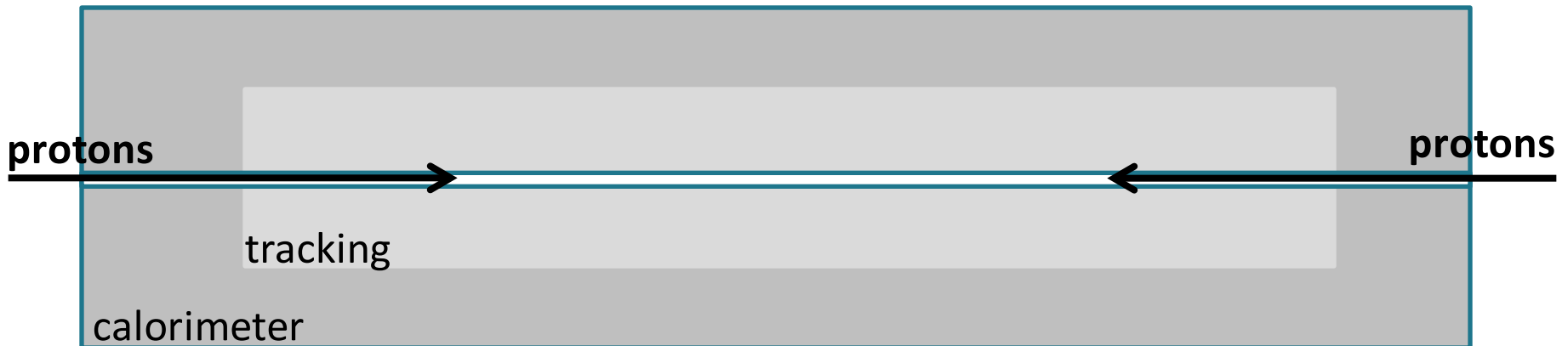
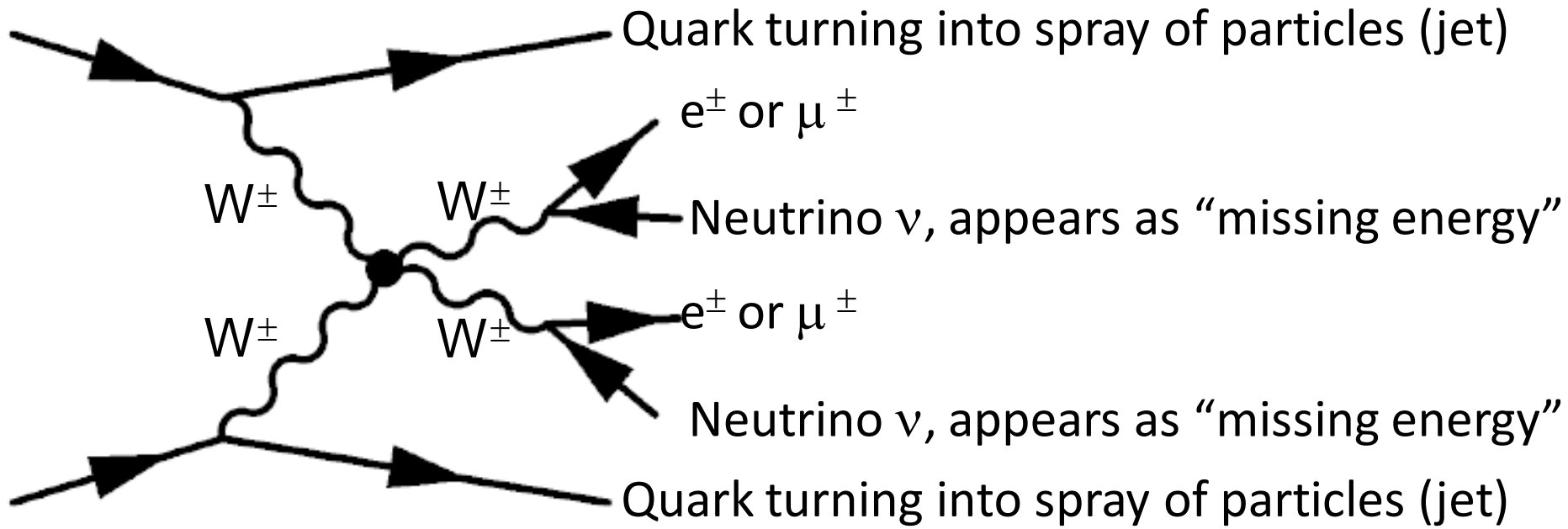


- ❖ Two jets in forward-backward constellation in detector
- ❖ Two energetic leptons (e^\pm or μ^\pm) of same electric charge
- ❖ "Missing energy" due to neutrinos escaping undetected

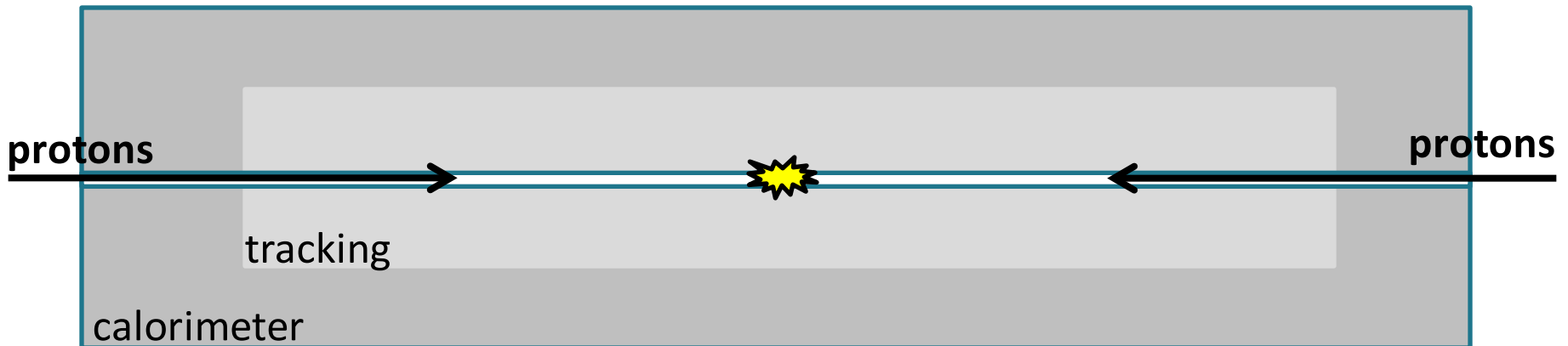
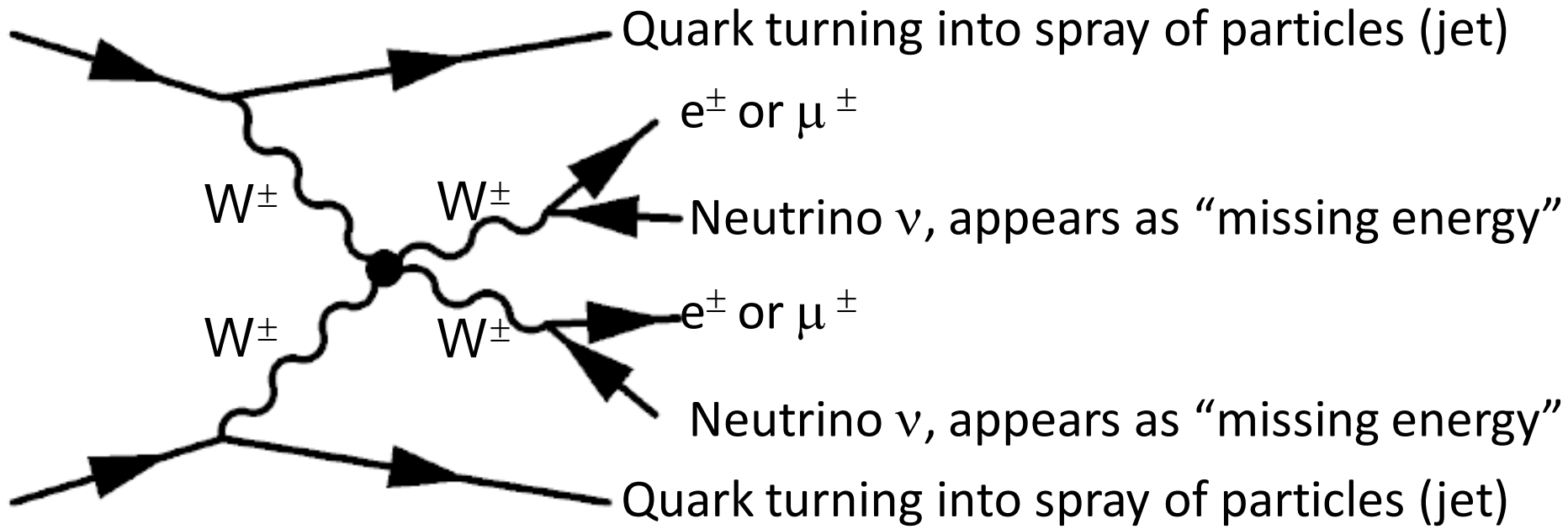
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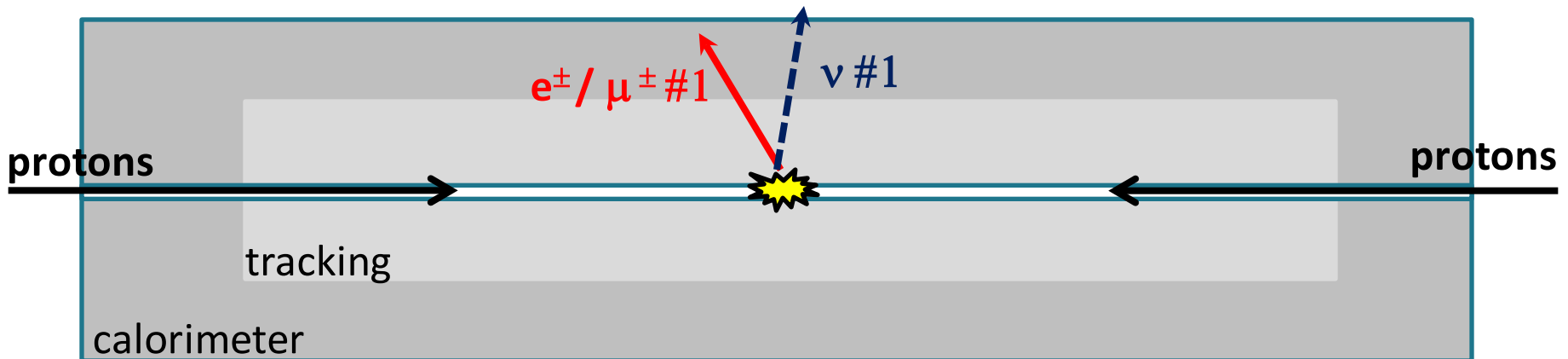
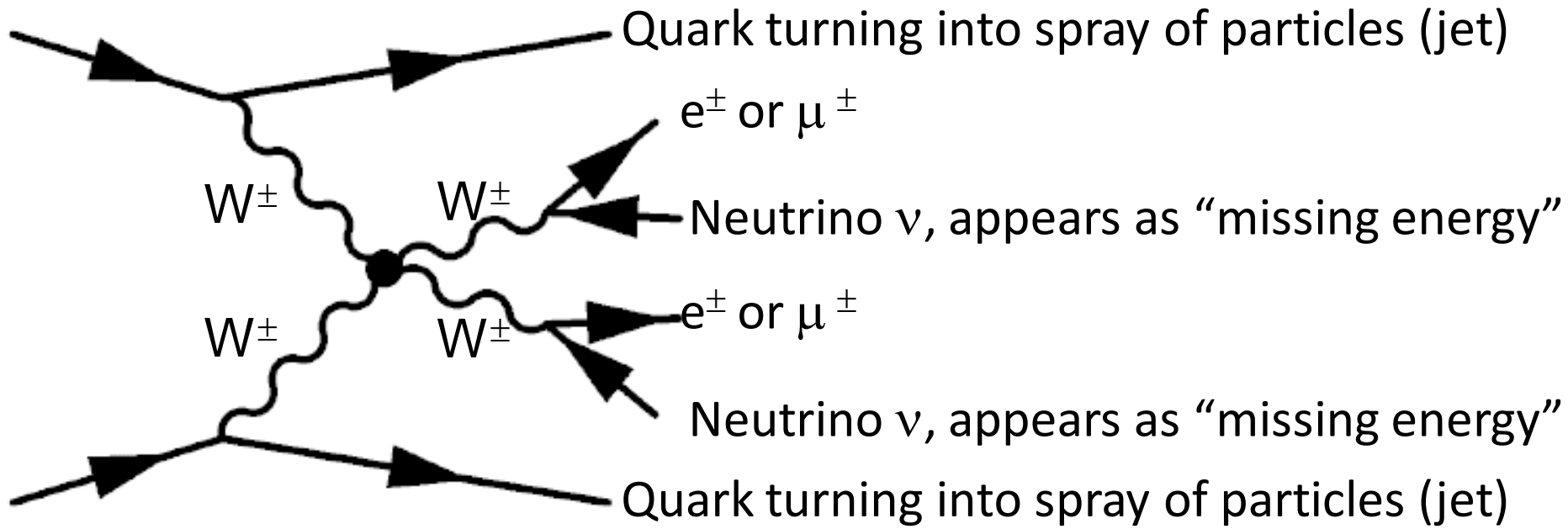
$W^\pm W^\pm \rightarrow W^\pm W^\pm$ Fingerprint



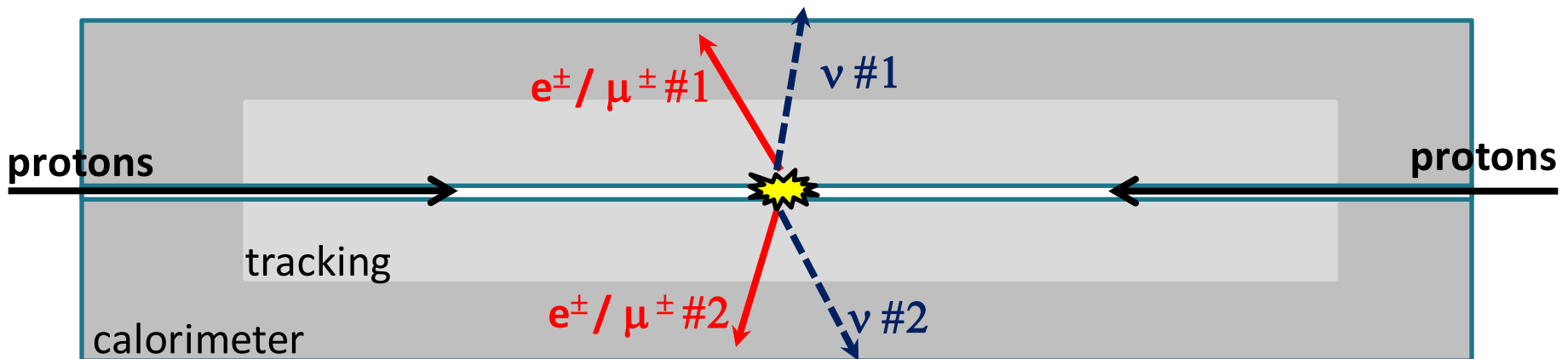
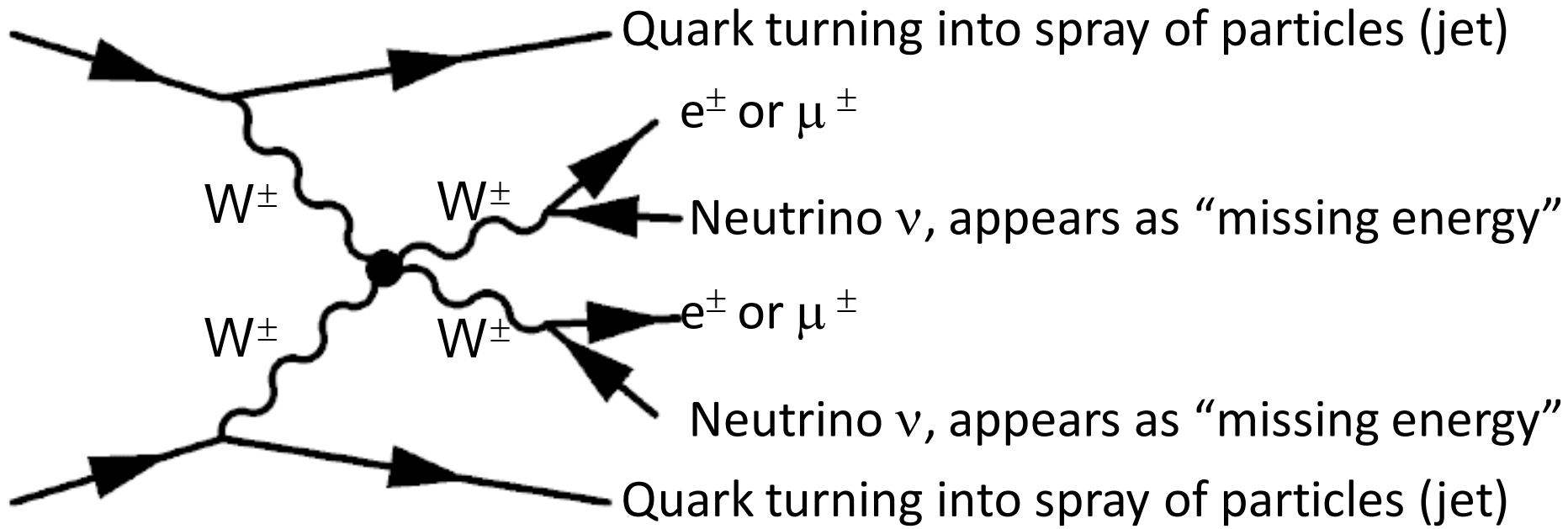
$W^\pm W^\pm \rightarrow W^\pm W^\pm$ Fingerprint



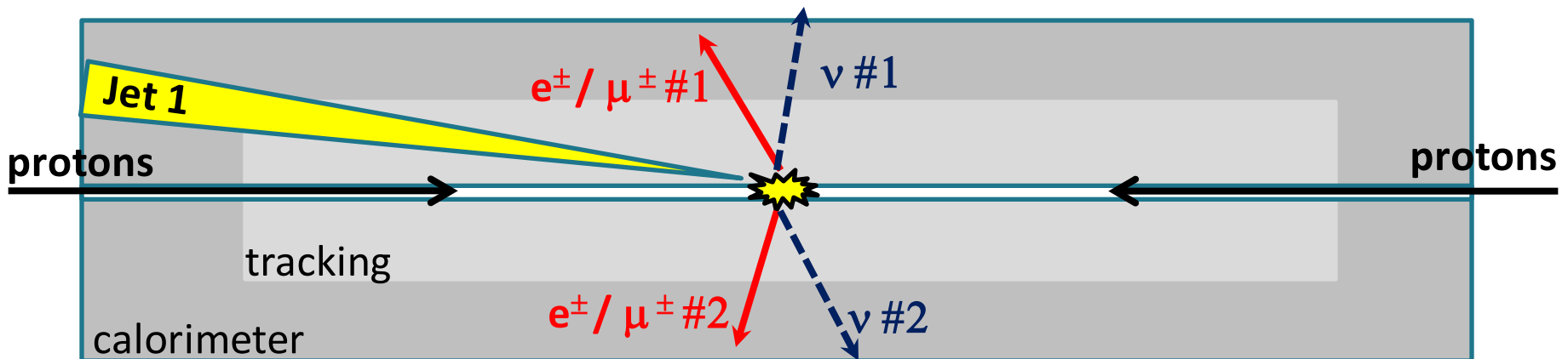
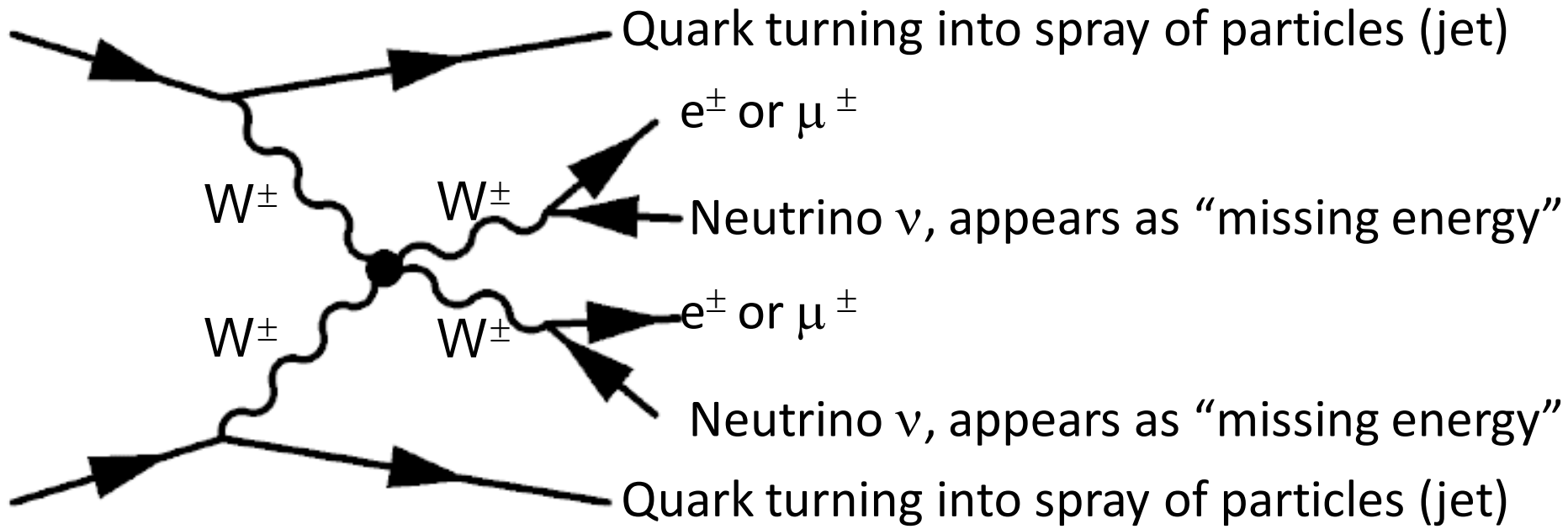
$W^\pm W^\pm \rightarrow W^\pm W^\pm$ Fingerprint



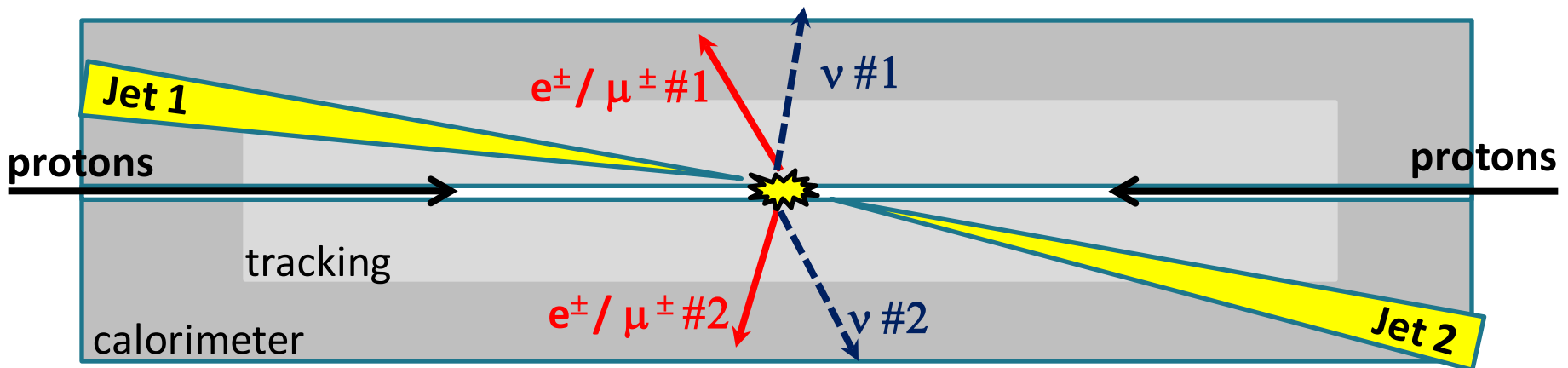
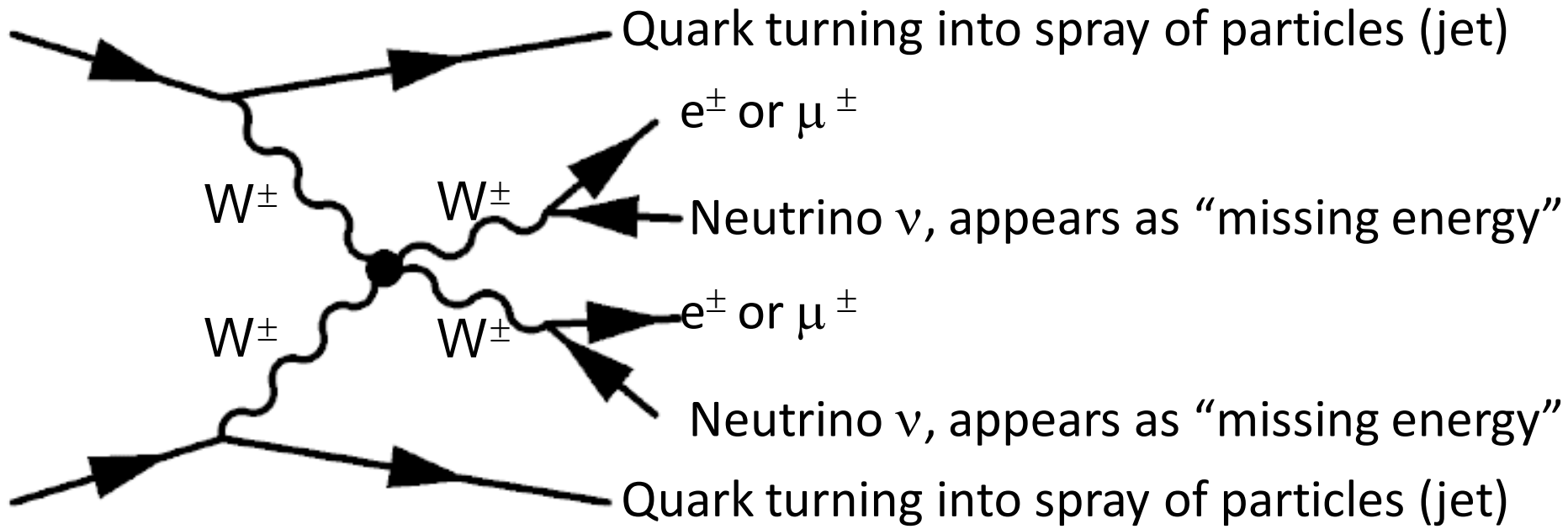
$W^\pm W^\pm \rightarrow W^\pm W^\pm$ Fingerprint



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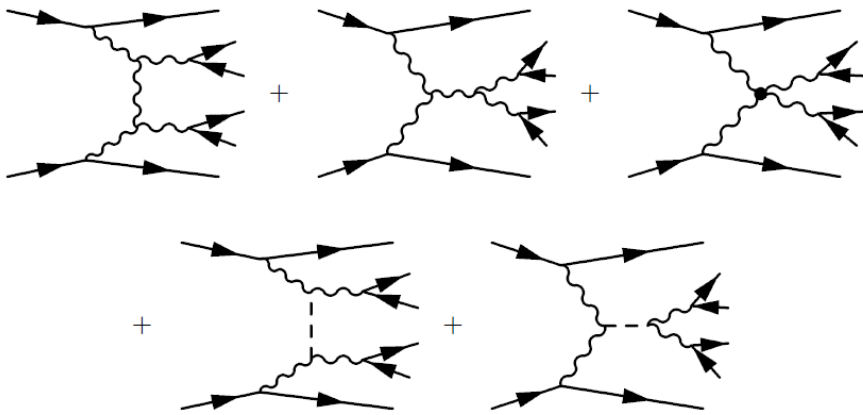
$W^\pm W^\pm \rightarrow W^\pm W^\pm$ Fingerprint



VVjj classification

❖ pure electroweak VV jj production:

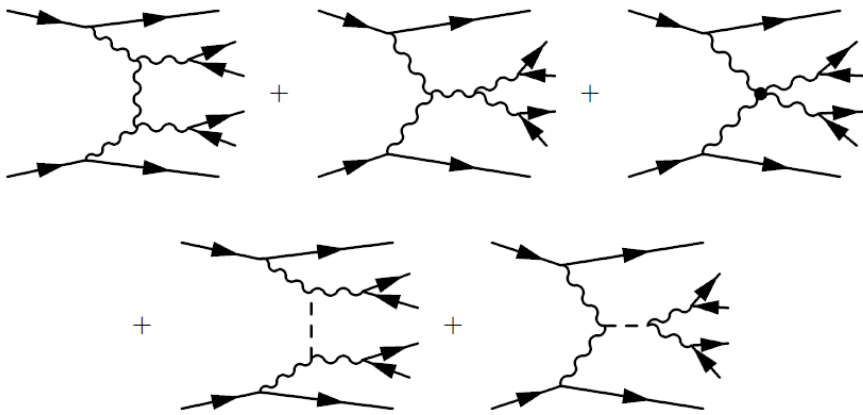
VBS diagrams (what we're after):



VVjj classification

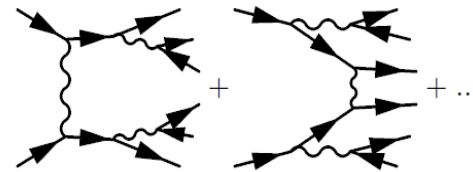
❖ pure electroweak VV jj production:

VBS diagrams (what we're after):



non-VBS diagrams, gauge invariantly

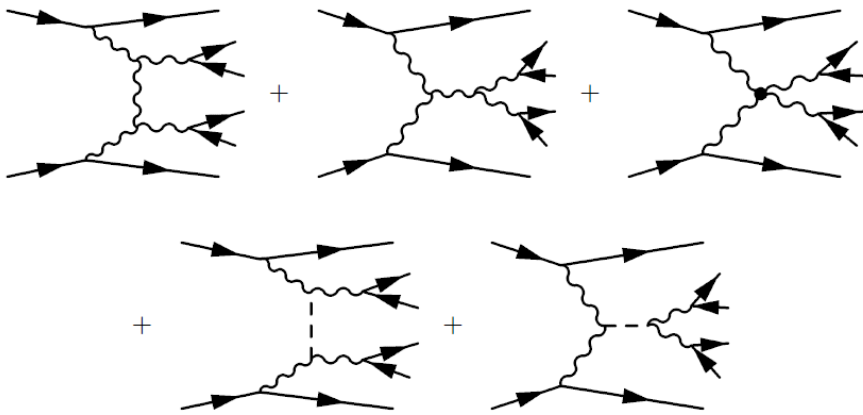
not separable:



VVjj classification

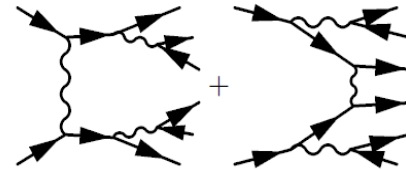
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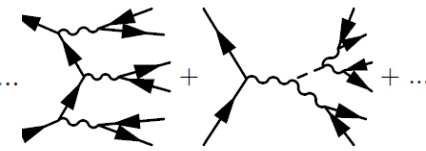


non-VBS diagrams, gauge invariantly

not separable:



separable:

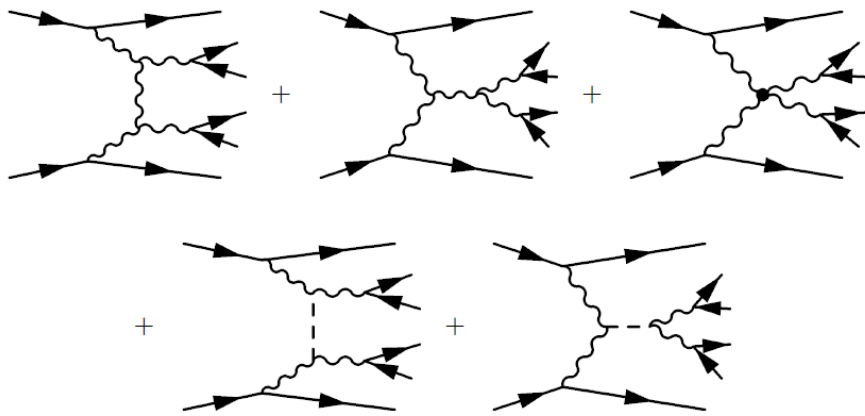


suppressed by
kinematic cuts

VVjj classification

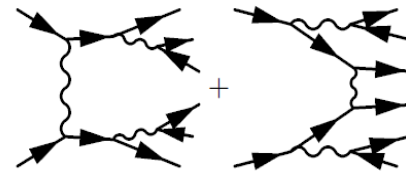
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VBS diagrams (what we're after):

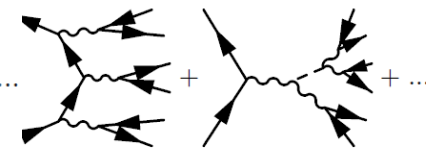


non-VBS diagrams, gauge invariantly

not separable:



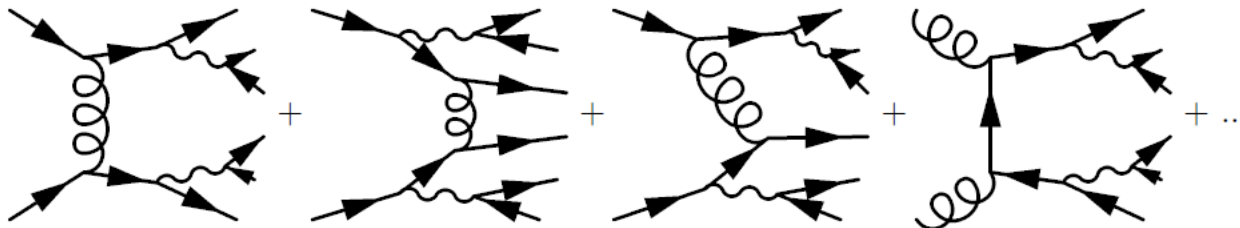
separable:



suppressed by kinematic cuts

❖ “strong” VV jj production:

gauge invariantly separable, suppressed by kinematic cuts



WBS Channels to Study


- ❖ LO WBS cross sections for pp collisions at 8 TeV, split by final state, EW and QCD contributions (SHERPA w/ $p_T(l) > 5$ GeV, $m_{ll} > 4$ GeV, $p_T(j) > 10$ GeV)

Final state	VV	σ_{VVjj} (EW) [fb]	σ_{VVjj} (QCD) [fb]
$l^+ \nu l^- \nu jj$ (opposite sign)	$W^+W^- + ZZ$	94	3192
$l^+l^- l^\pm \nu jj$	$W^\pm Z$	30	687
$l^+l^- l^+l^- jj$	ZZ	2	106
$l^\pm \nu l^\pm \nu jj$ (same sign)	$W^\pm W^\pm$	20	19

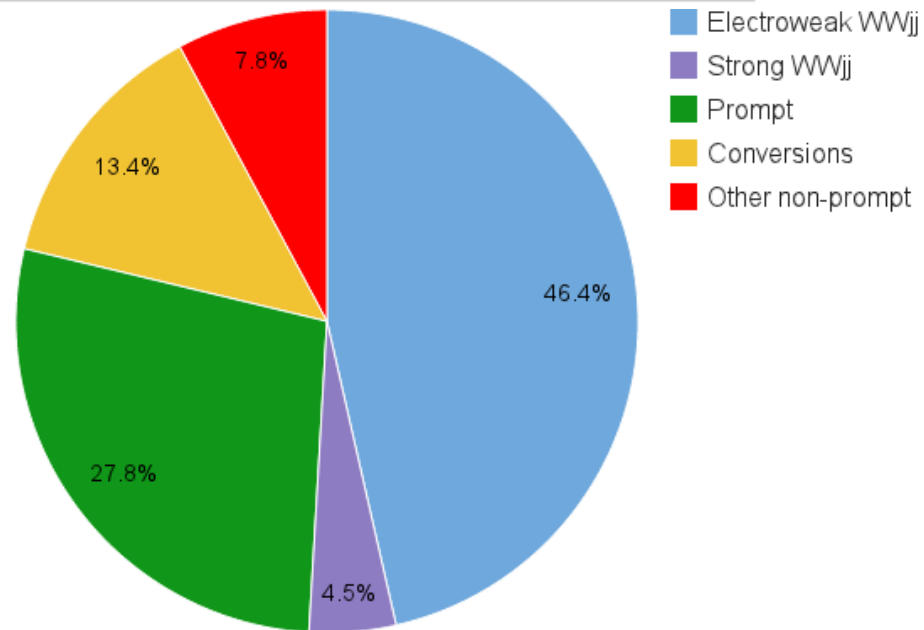
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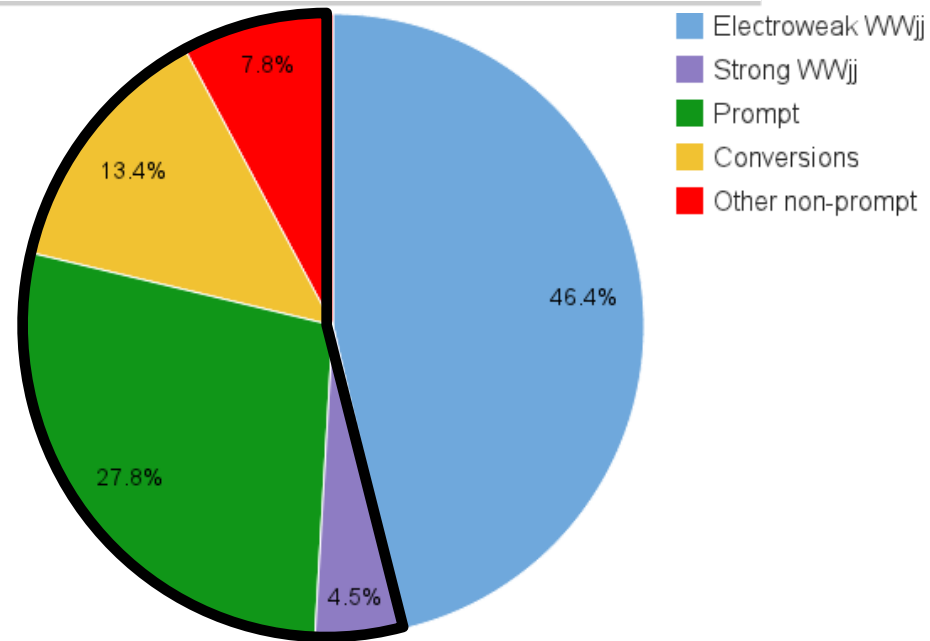
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- 
- + Same-sign requirement suppresses Z, top backgrounds
 - + Greatly reduced QCD background
 - Understand charge-mis-ID, jets faking leptons

$W^\pm W^\pm jj$ Background Sources



$W^\pm W^\pm jj$ Background Sources

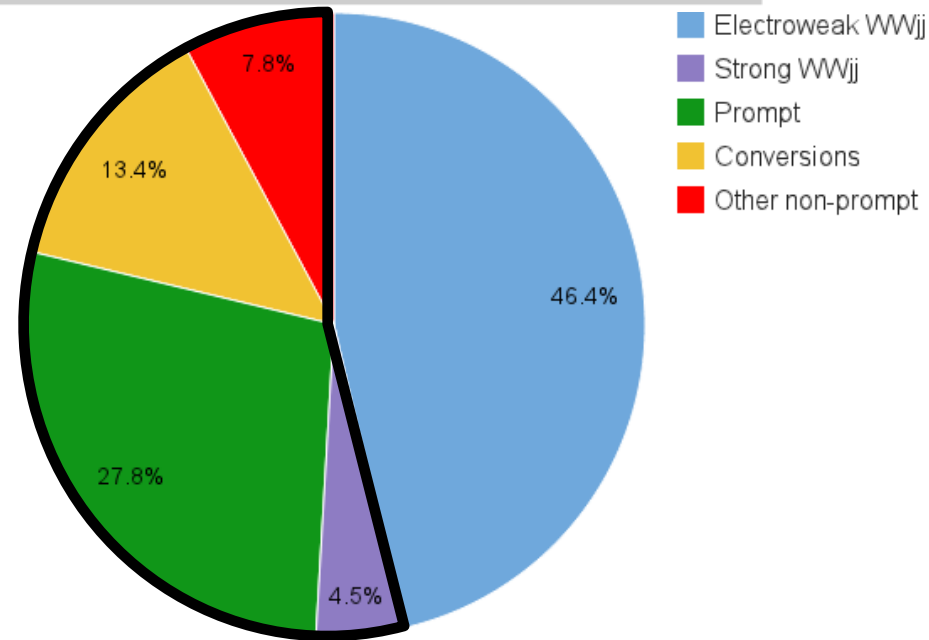


$W^\pm W^\pm jj$ Background Sources

❖ prompt background (28%):

■ 3 or more prompt leptons:

- WZ/γ^*+jets
- $ZZ+jets$
- $t\bar{t}+W/Z$
- tZj



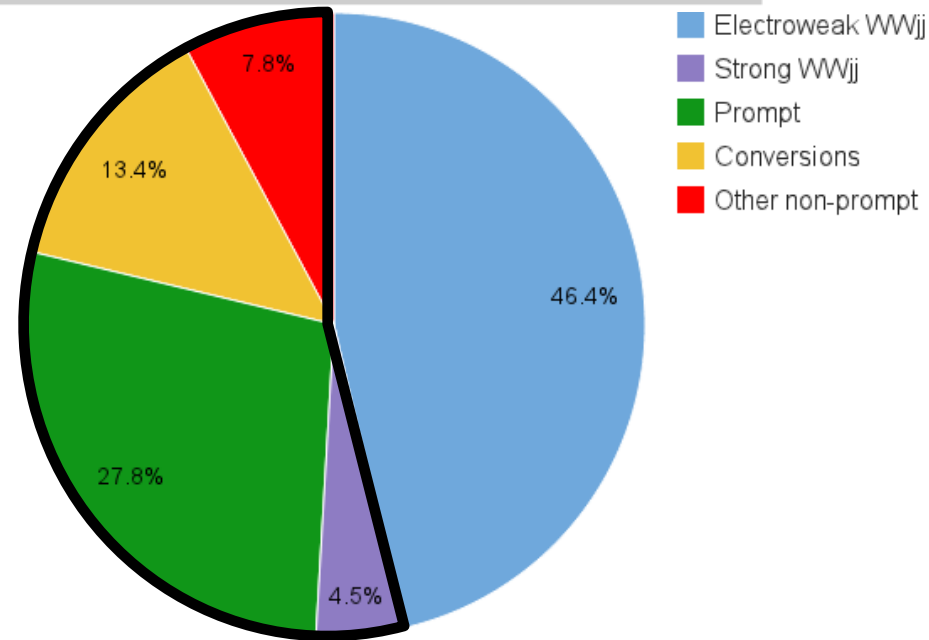
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❖ conversions (13%):

- prompt photon conversion
 - $W\gamma$
- charge mis-ID due to bremsstrahlung with conversion (data driven)
 - Z/γ^*+jets , di-leptonic $t\bar{t}$ decays, W^+W^-



$W^\pm W^\pm jj$ Background Sources

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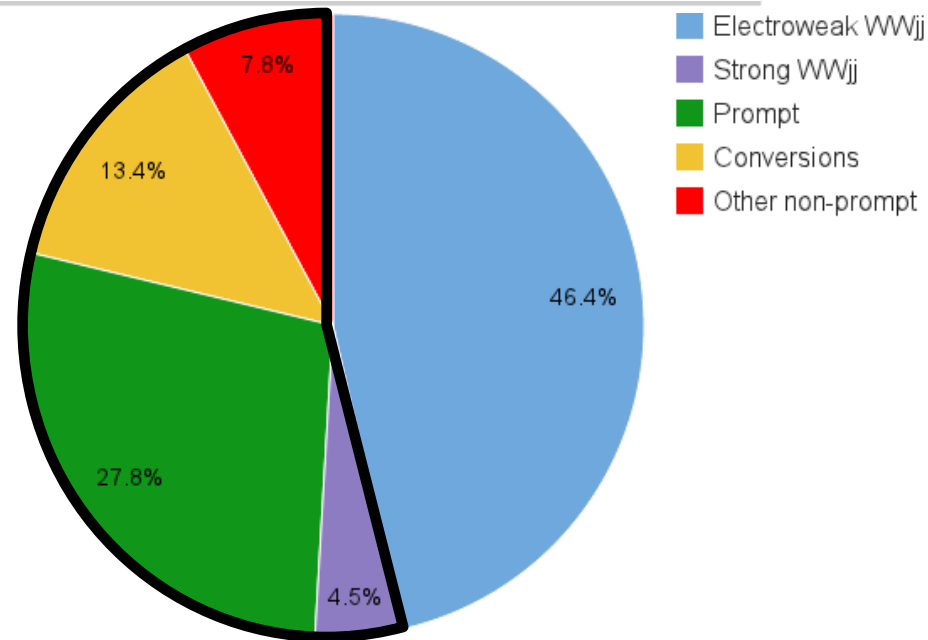
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 - Z/γ^*+jets , di-leptonic $t\bar{t}$ decays, W^+W^-

❖ other non-prompt background (8%):

- leptons from hadron decays in jets (data driven)
 - $W+jets$, semi-leptonic $t\bar{t}$ decays, multi-jet events



$W^\pm W^\pm jj$ Background Sources

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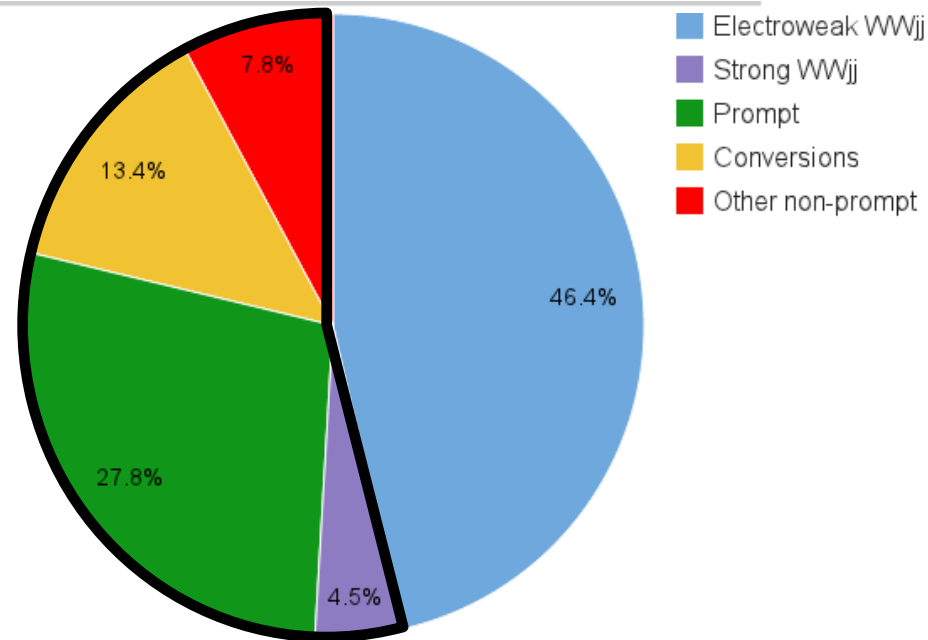
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❖ $WW jj$ strong (5%)



Background Control Regions

- ❖ Test background modelling with dedicated control regions
 - prompt background: trilepton control region (invert 3rd lepton veto, drop cuts on m_{jj} , Δy_{jj})
 - conversion and prompt backgrounds: control region with at most one jet (“ ≤ 1 jet”)
 - non-prompt leptons from top: at least one jet identified as b-jet
 - combined background model: invert m_{jj} selection

Background Control Regions

❖ Test background modelling with dedicated control regions

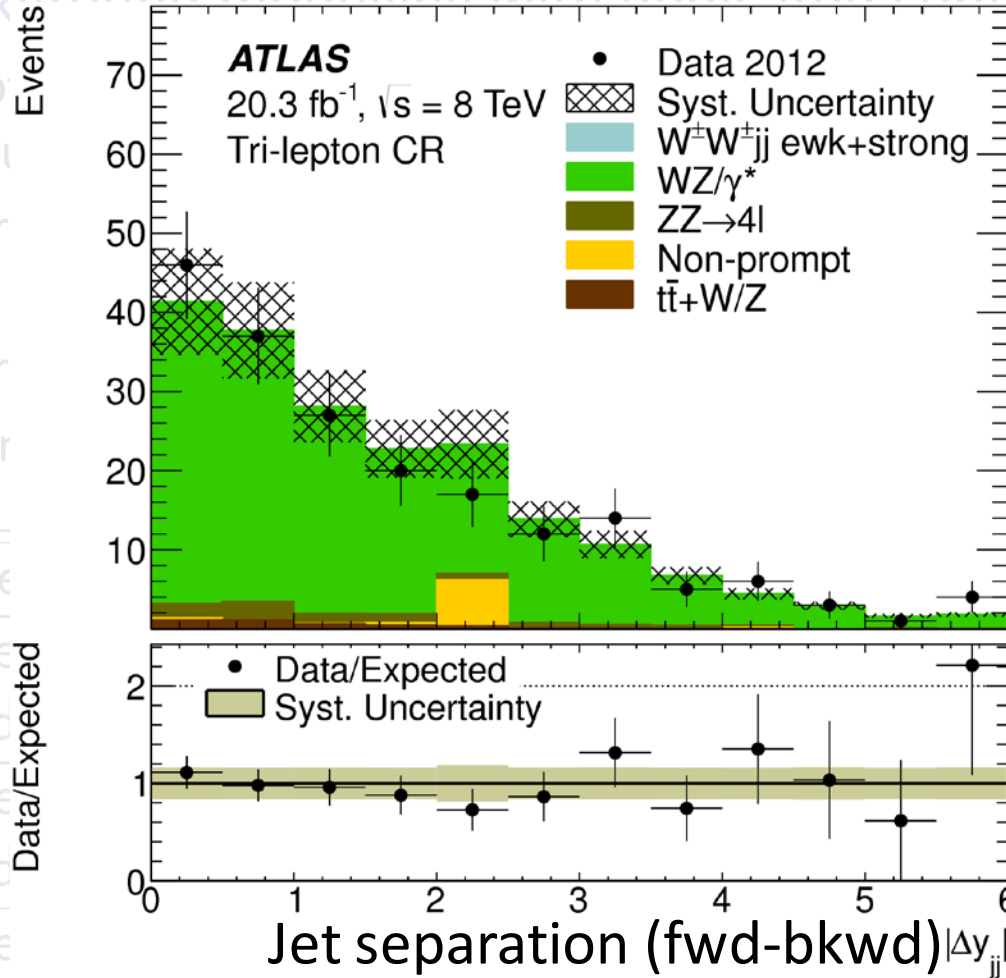
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- conversion and prompt backgrounds: control region with at most one jet (“ ≤ 1 jet”)
- non-prompt leptons from top: at least one jet identified as b-jet
- combined background model: invert m_{jj} selection

Control Region		Trilepton	≤ 1 jet	b -tagged	Low m_{jj}
$e^\pm e^\pm$	exp.	36 ± 6	278 ± 28	40 ± 6	76 ± 9
	data	40	288	46	78
$e^\pm \mu^\pm$	exp.	110 ± 18	288 ± 42	75 ± 13	127 ± 16
	data	104	328	82	120
$\mu^\pm \mu^\pm$	exp.	60 ± 10	88 ± 14	25 ± 7	40 ± 6
	data	48	101	36	30

Background Control Regions

Test background modelling with dedicated control regions

- prompt lepton veto,
- drop cut
- conversion veto,
- jet ("≤ 100 GeV)
- non-prompt
- combination



rd lepton veto,
with at most one
ed as b-jet

Control Regions

$e^{\pm}e^{\pm}$

$e^{\pm}\mu^{\pm}$

$\mu^{\pm}\mu^{\pm}$

data

48

101

36

Low m_{jj}

76 ± 9

78

127 ± 16

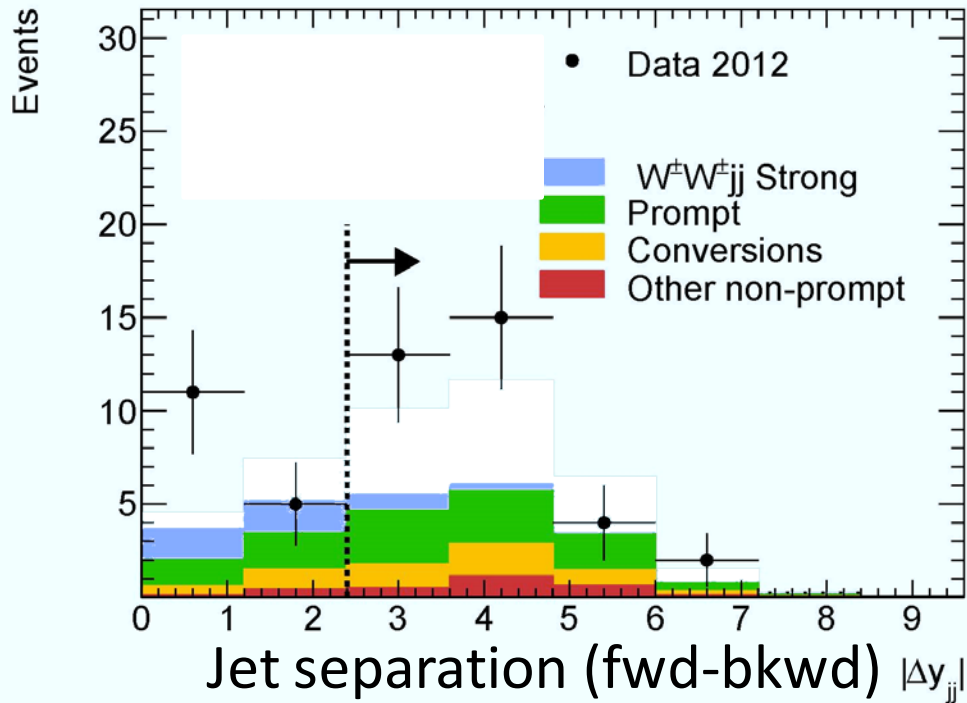
120

40 ± 6

30

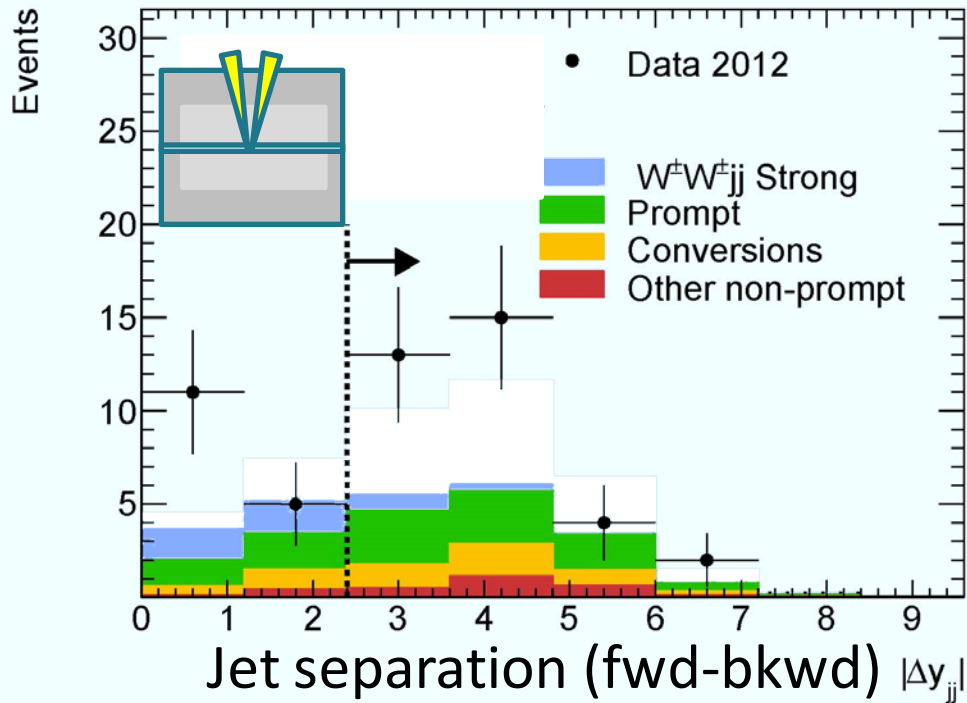
What do we see?

❖ Final selection – requiring forward-backward jets:



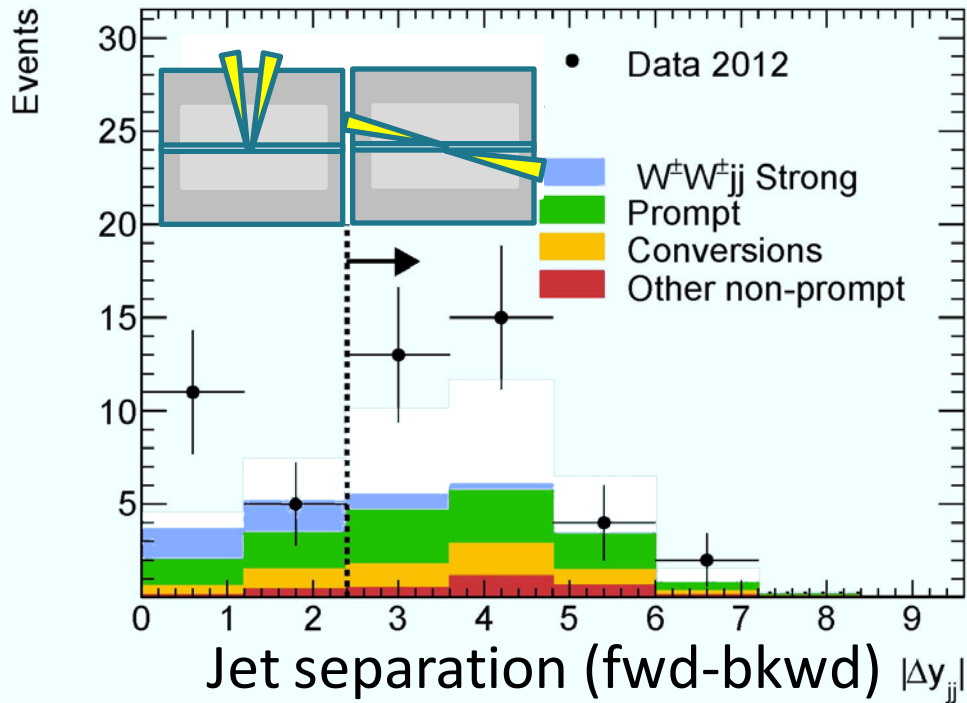
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❖ Final selection – requiring forward-backward jets:



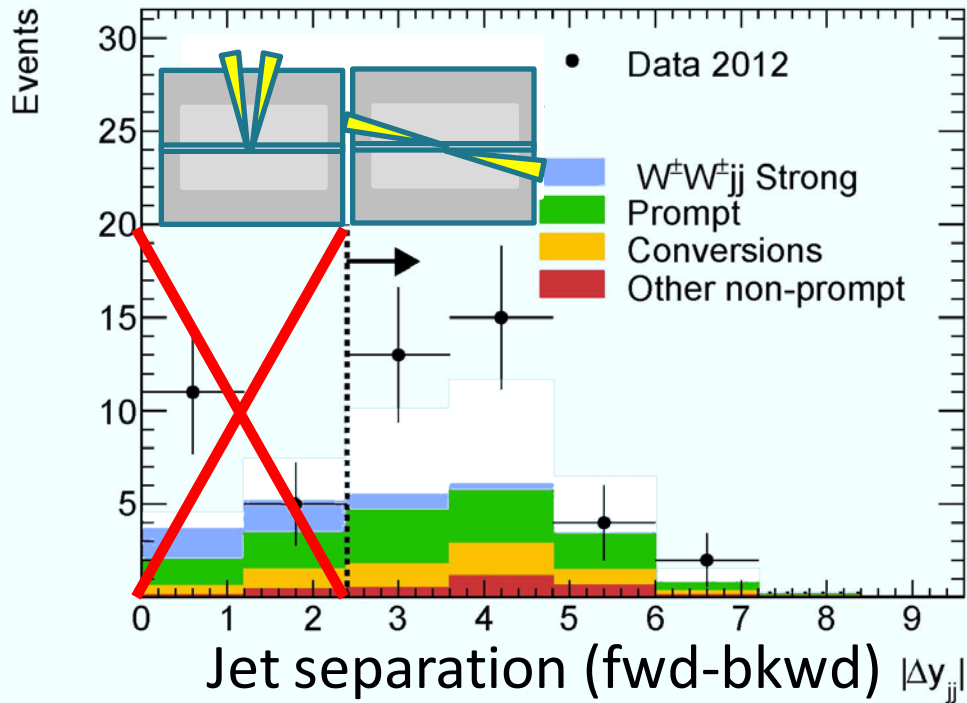
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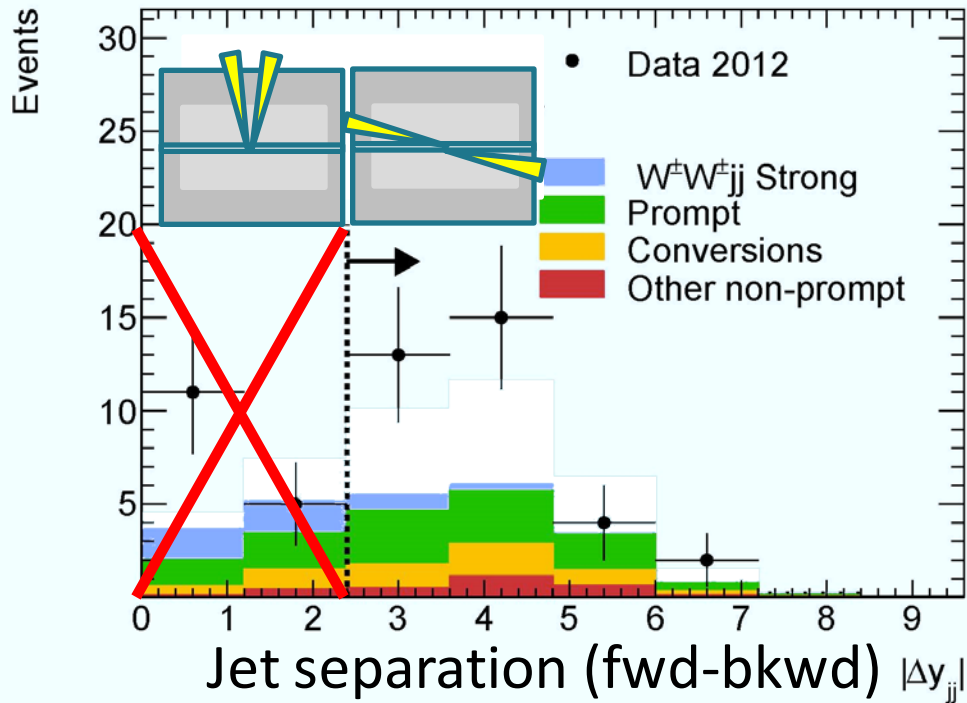
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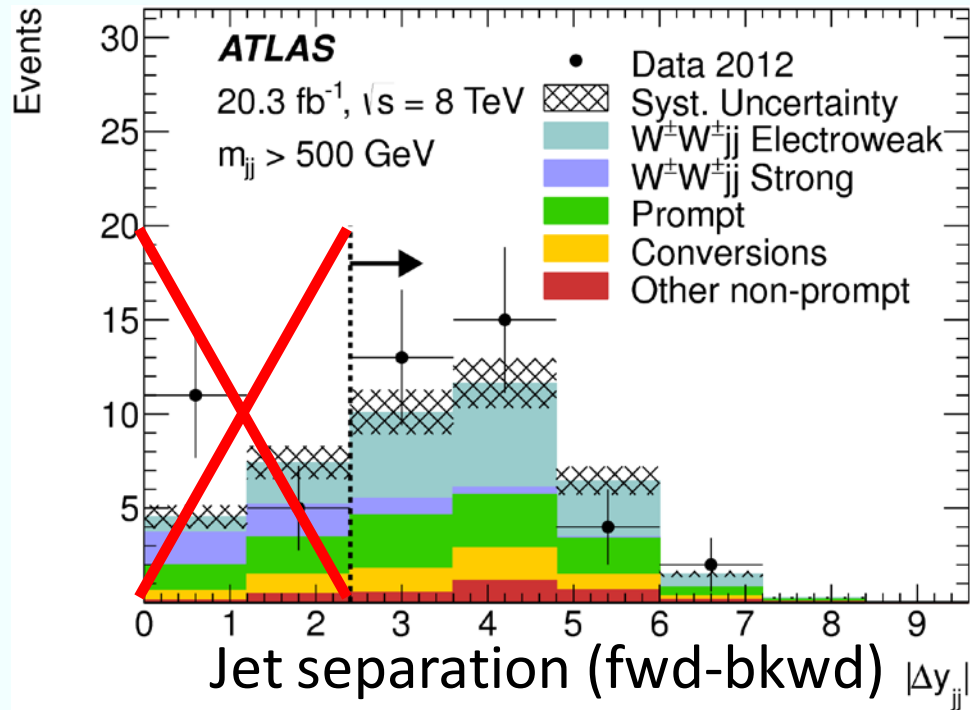
❖ Final selection – requiring forward-backward jets:



Predicted background	15.9±1.9
Observed events	34

What do we see?

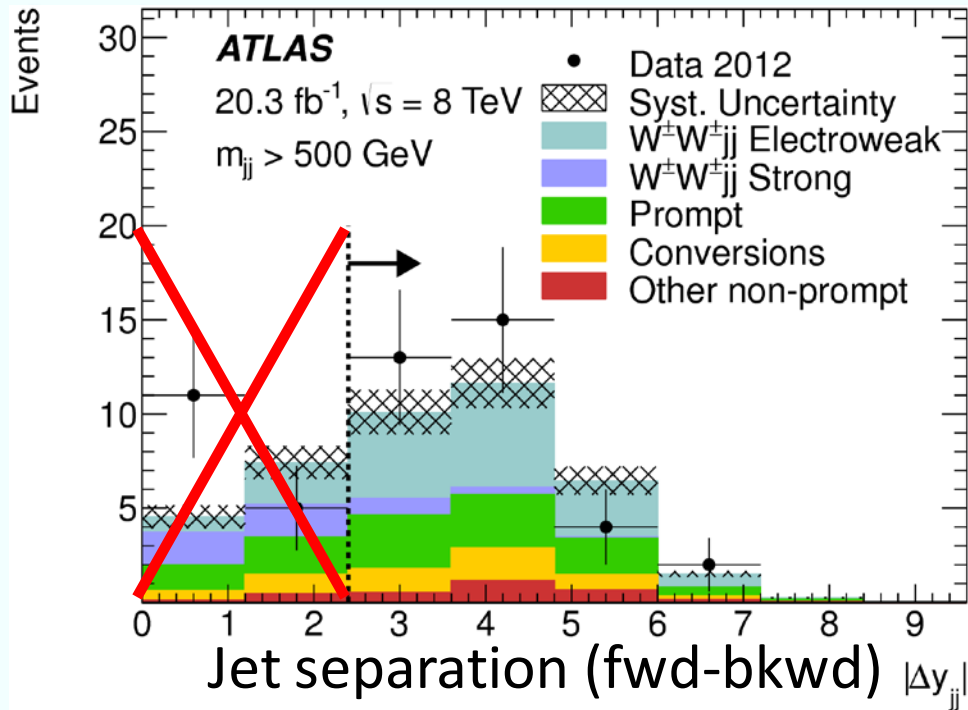
❖ Final selection – requiring forward-backward jets:



Predicted background	15.9±1.9
Predicted signal	13.9±0.8
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Published in PRL:

[Phys. Rev. Lett. 113 \(2014\) 141803](https://arxiv.org/abs/1307.7132)

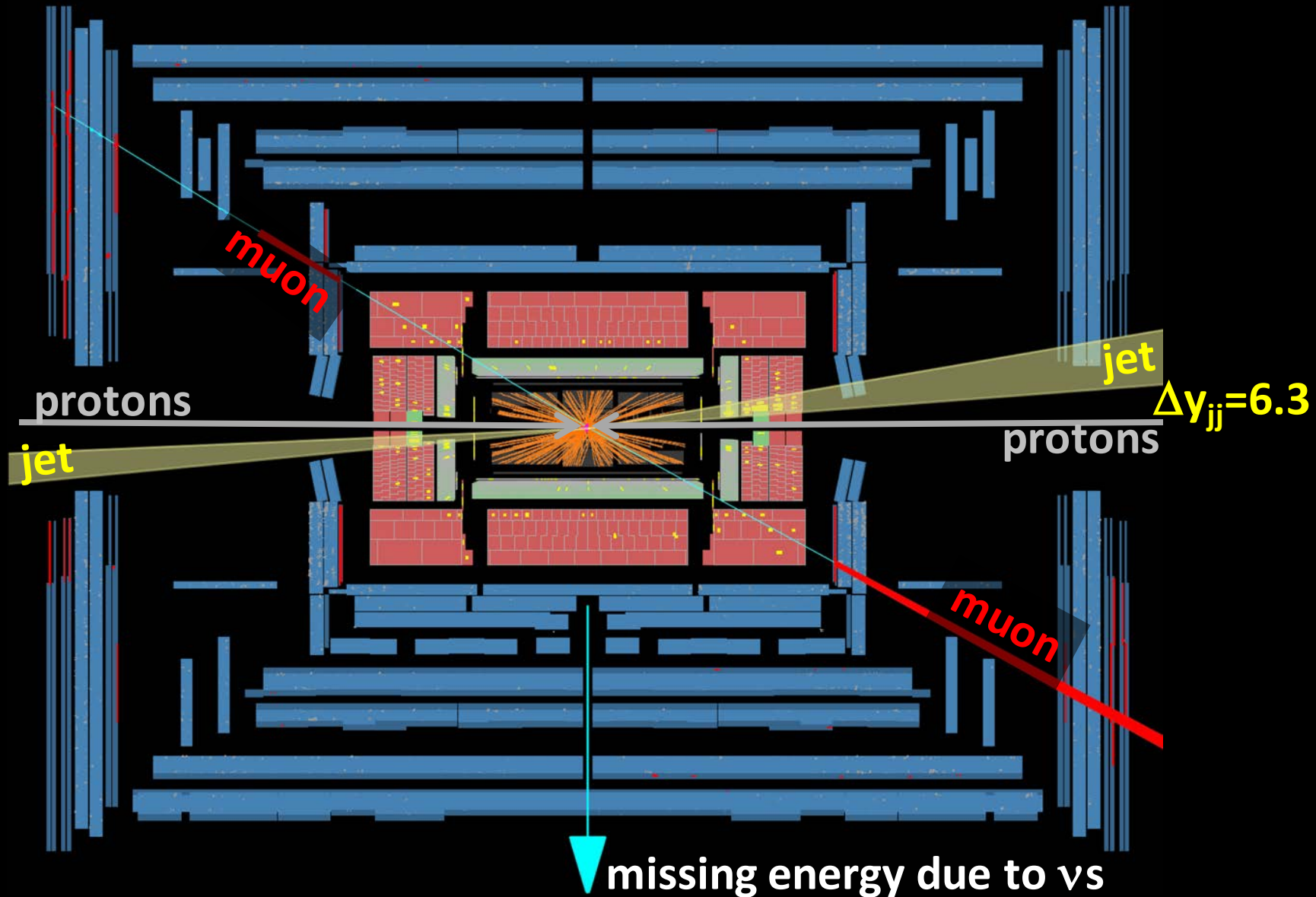
- ❖ First evidence (3.6 σ) for EW WWjj production

$$\sigma_{w^{\pm}w^{\pm}jj}^{EW} = 1.3 \pm 0.4(\text{stat}) \pm 0.2(\text{syst}) \text{ fb} \quad \text{SM} : \sigma_{w^{\pm}w^{\pm}jj}^{EW} (\text{NLO}) = 0.95 \pm 0.06 \text{ fb}$$

- ❖ First access to WWW vertex

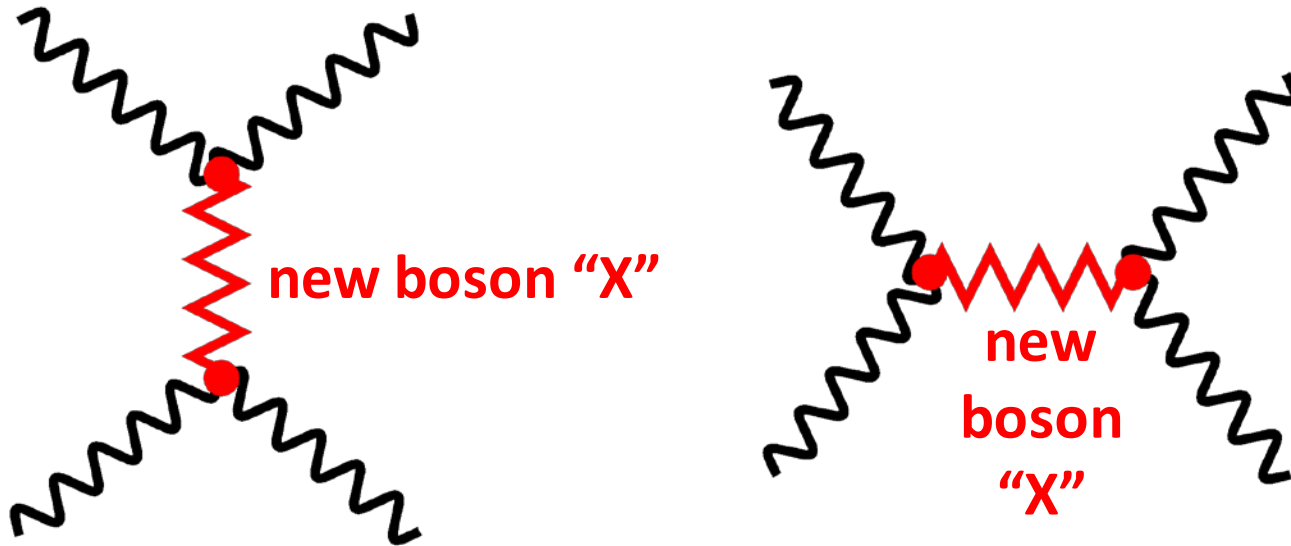
- ❖ Starting point of VBS program at LHC!

$W^\pm W^\pm jj \rightarrow \ell \nu \ell \nu jj$ candidate event



Exploring the unknown

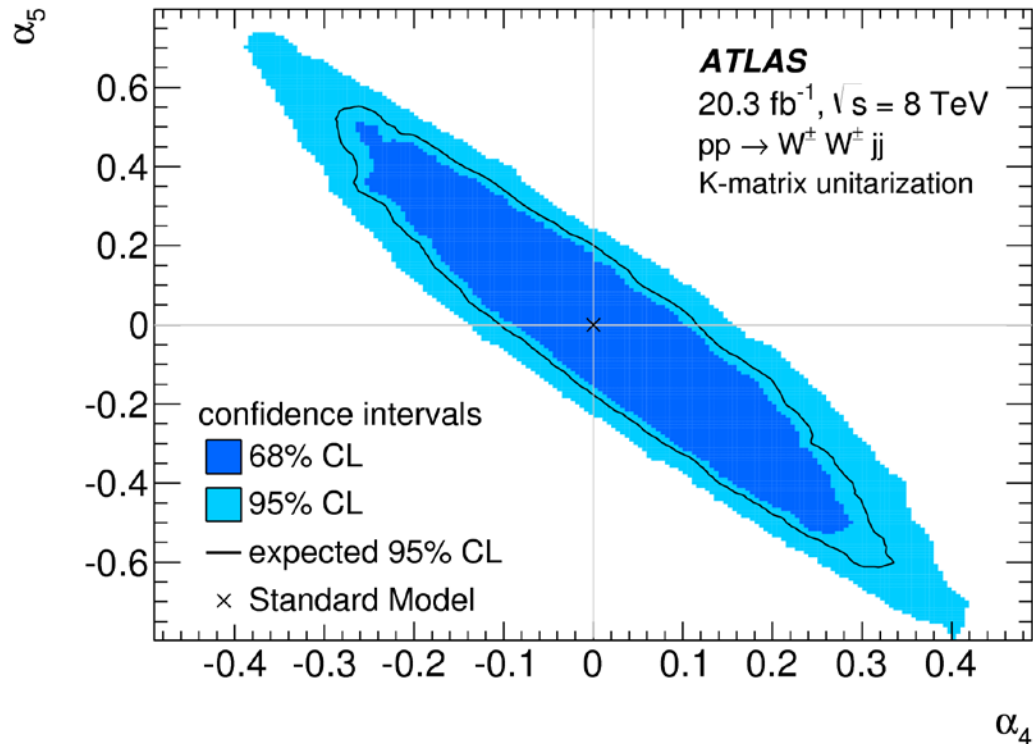
- ❖ Wealth of models propose extensions to Standard Model (which is known to be incomplete):



- ❖ Can search for specific models, or do a model-independent search for modifications from the Standard Model: “Effective Field Theory”
- ❖ “New Physics” will modify production rate and kinematics of decay products

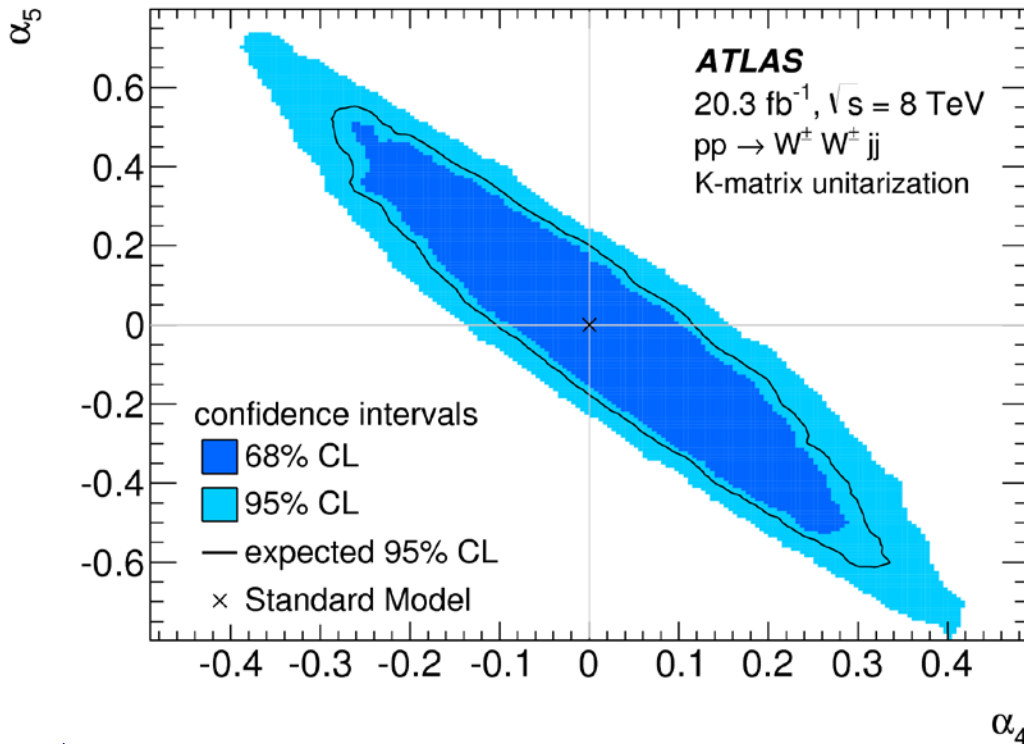
First constraints on New Physics

- ❖ Use our measurement to constrain admixture of anomalous couplings α_4 , α_5 (both = 0 in Standard Model):



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1D 95% CL intervals
expected:

$$-0.10 < \alpha_4 < 0.12$$

$$-0.18 < \alpha_5 < 0.20$$

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$$-0.14 < \alpha_4 < 0.16$$

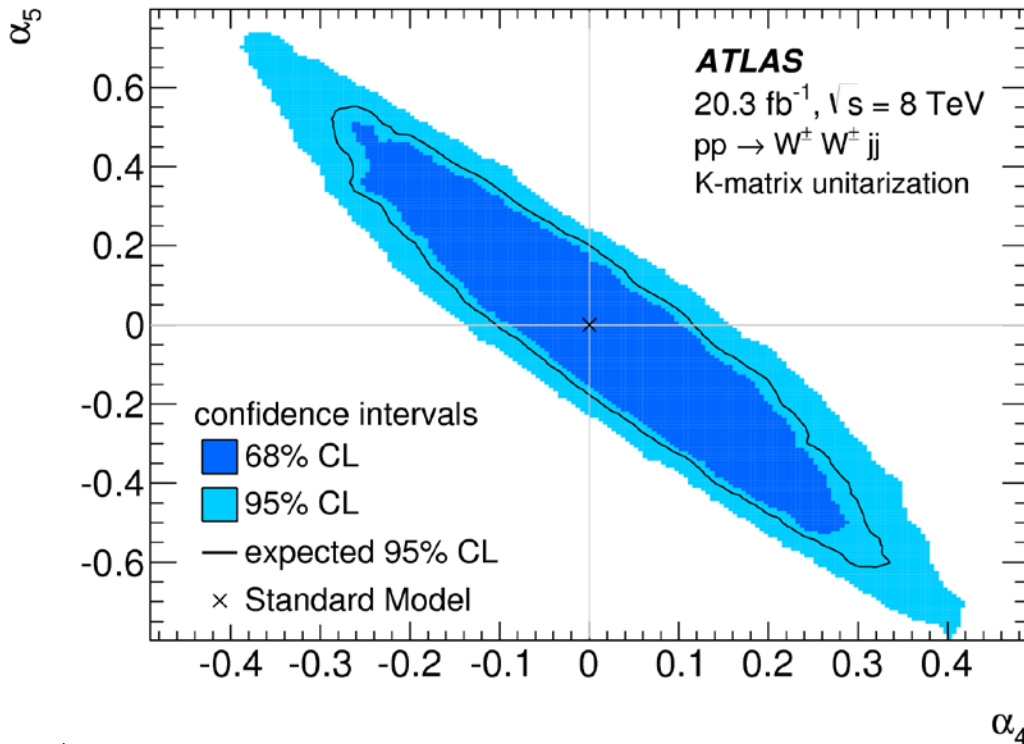
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(respective other $\alpha_i = 0$)

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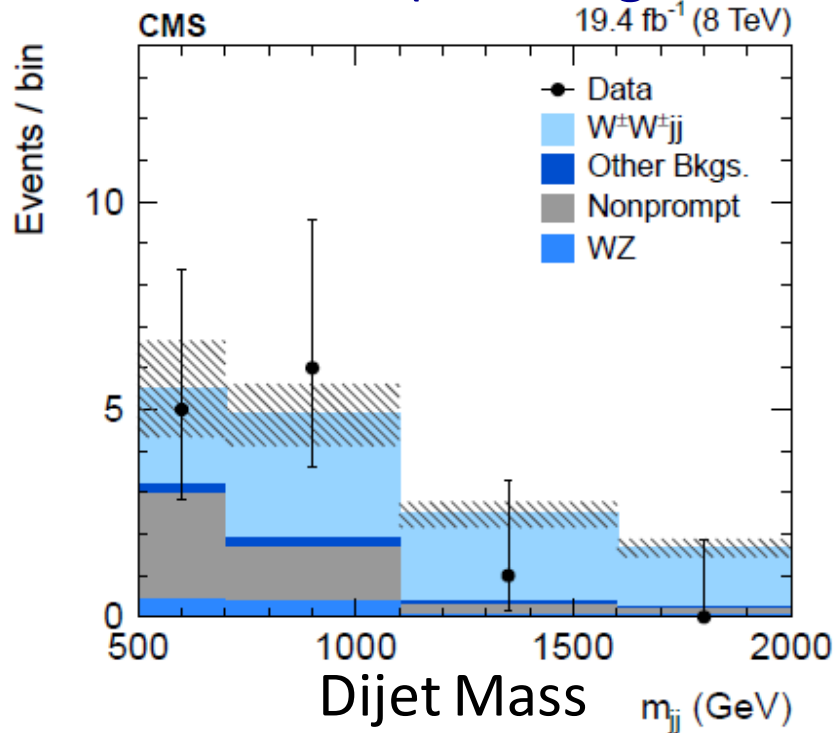
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- ❖ **First** limits on anomalous quartic couplings
- ❖ Scale of new physics: $\Lambda > 500 - 650$ GeV

CMS $W^\pm W^\pm jj$ result

- Final selection (same signature, different cuts): [[PRL 114 \(2015\) 051801](#)]

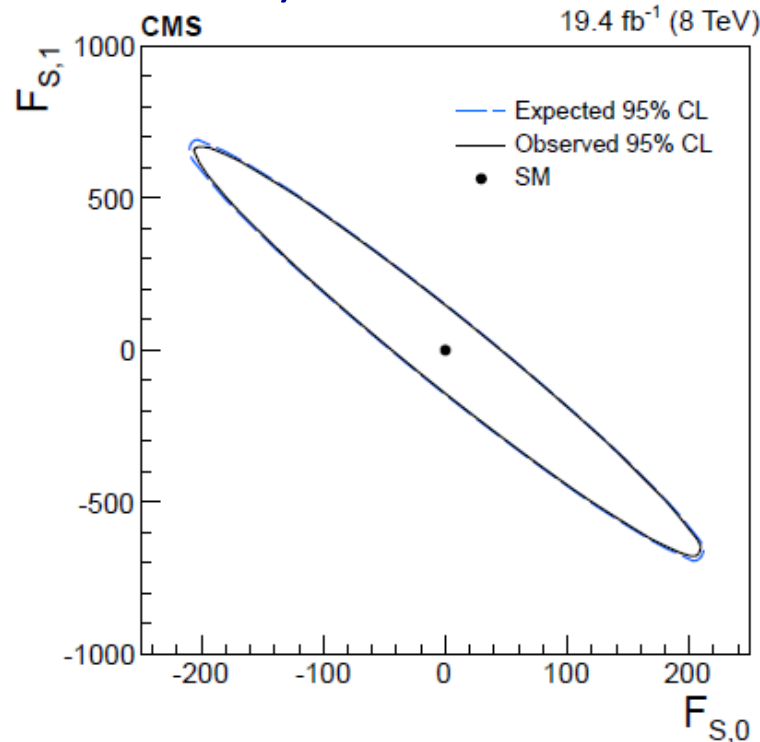
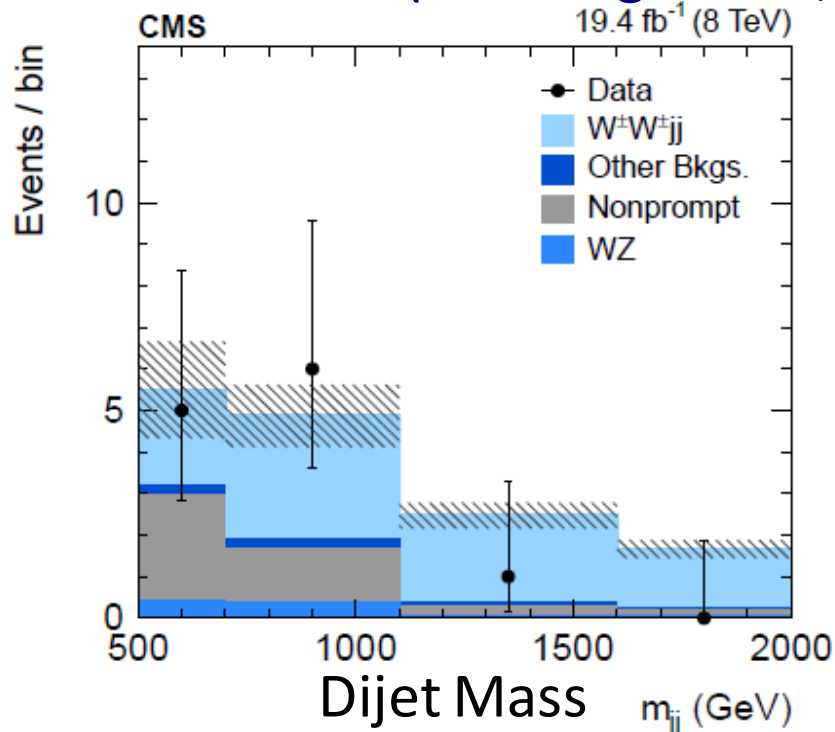


- Significance for EW $WWjj$ production: 2.9σ (exp), **1.9σ (obs)**

- $\sigma_{W^\pm W^\pm jj}^{EW} = 4.0_{-2.0}^{+2.4}(\text{stat})_{-1.0}^{+1.1}(\text{syst}) \text{ fb}$ SM : $\sigma_{W^\pm W^\pm jj}^{EW}(\text{NLO}) = 5.8 \pm 1.2 \text{ fb}$

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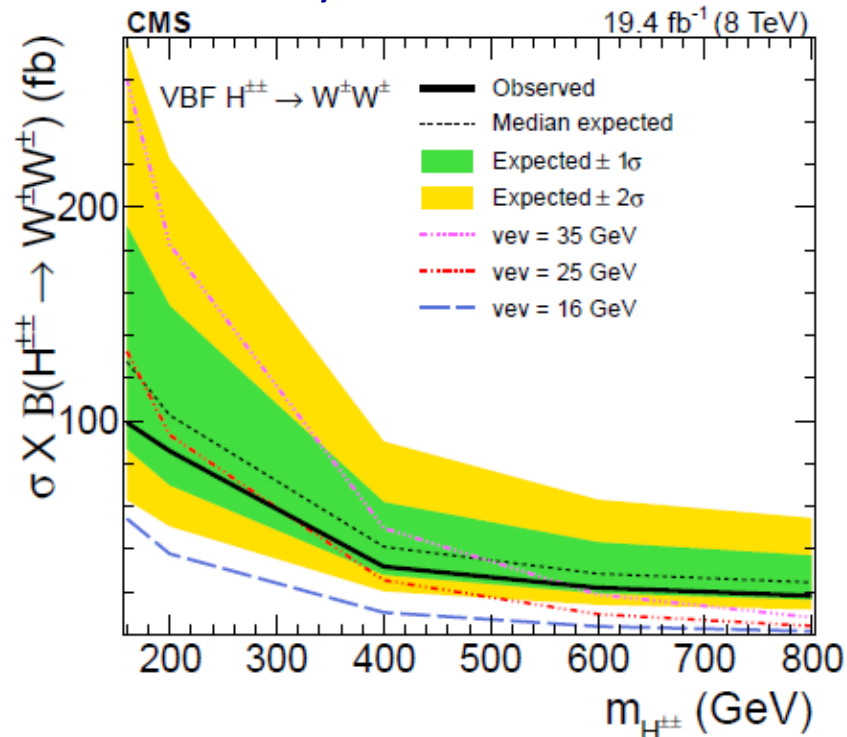
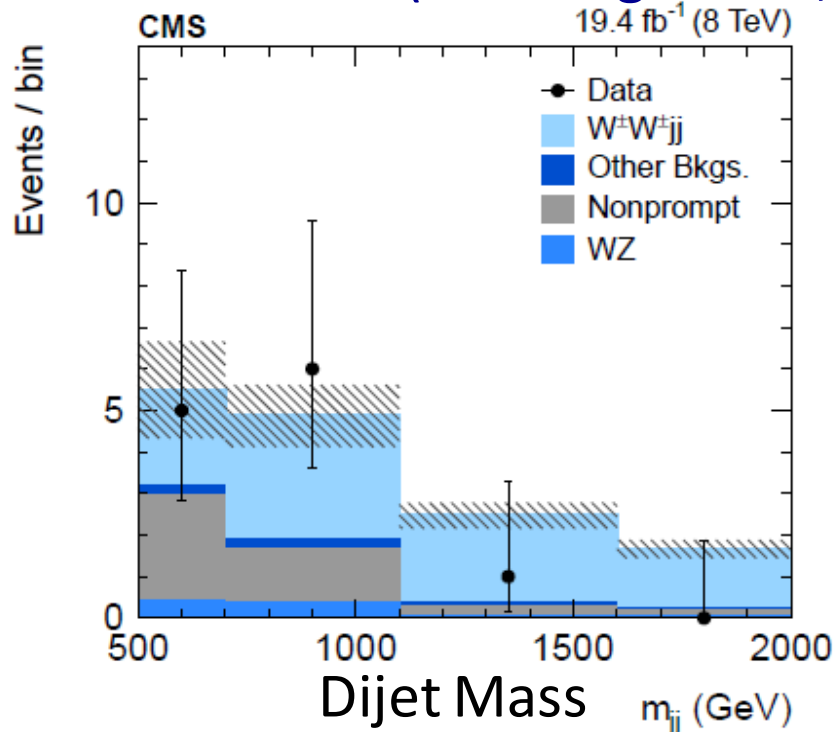
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- Limits on anomalous quartic gauge couplings (EFT model)

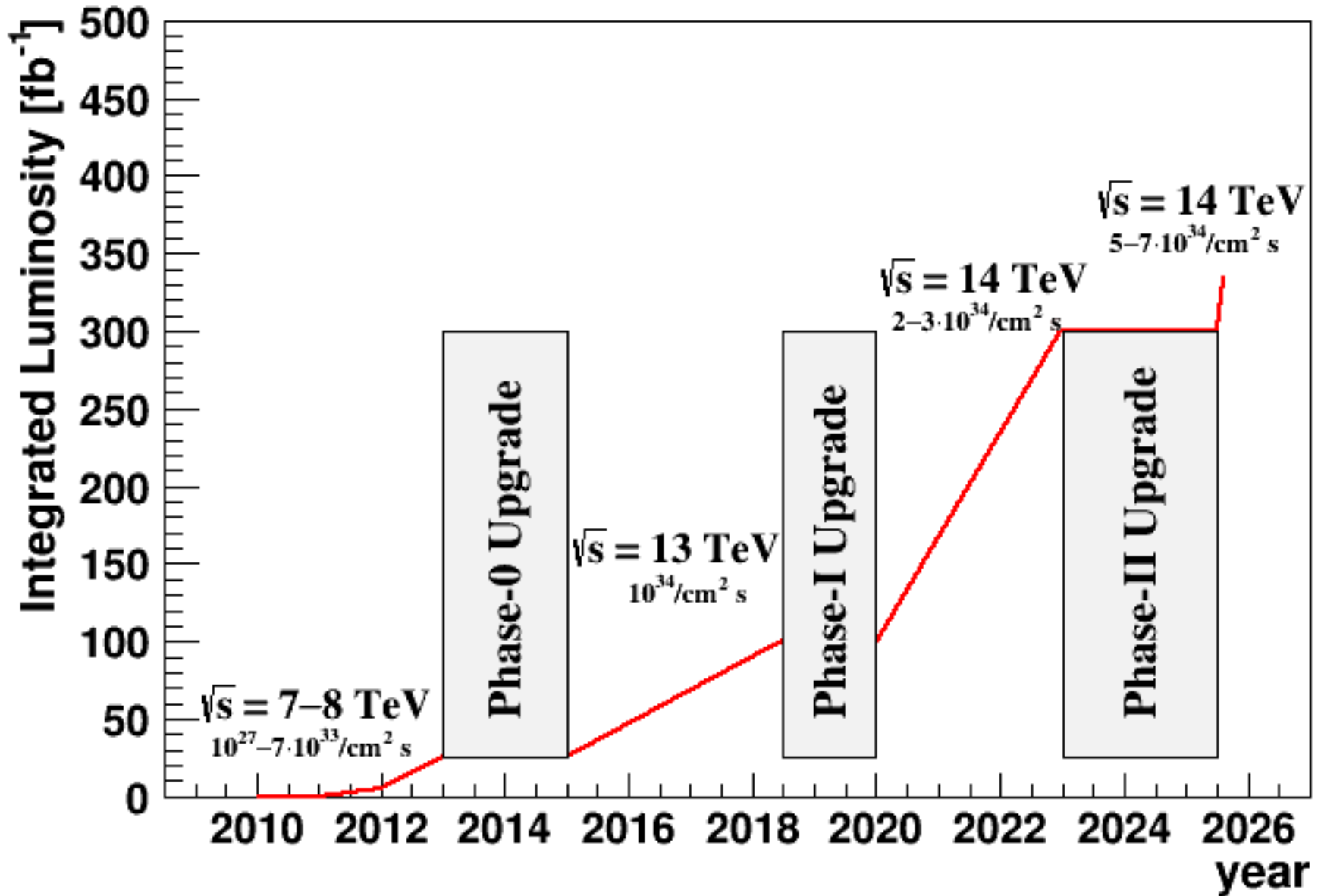
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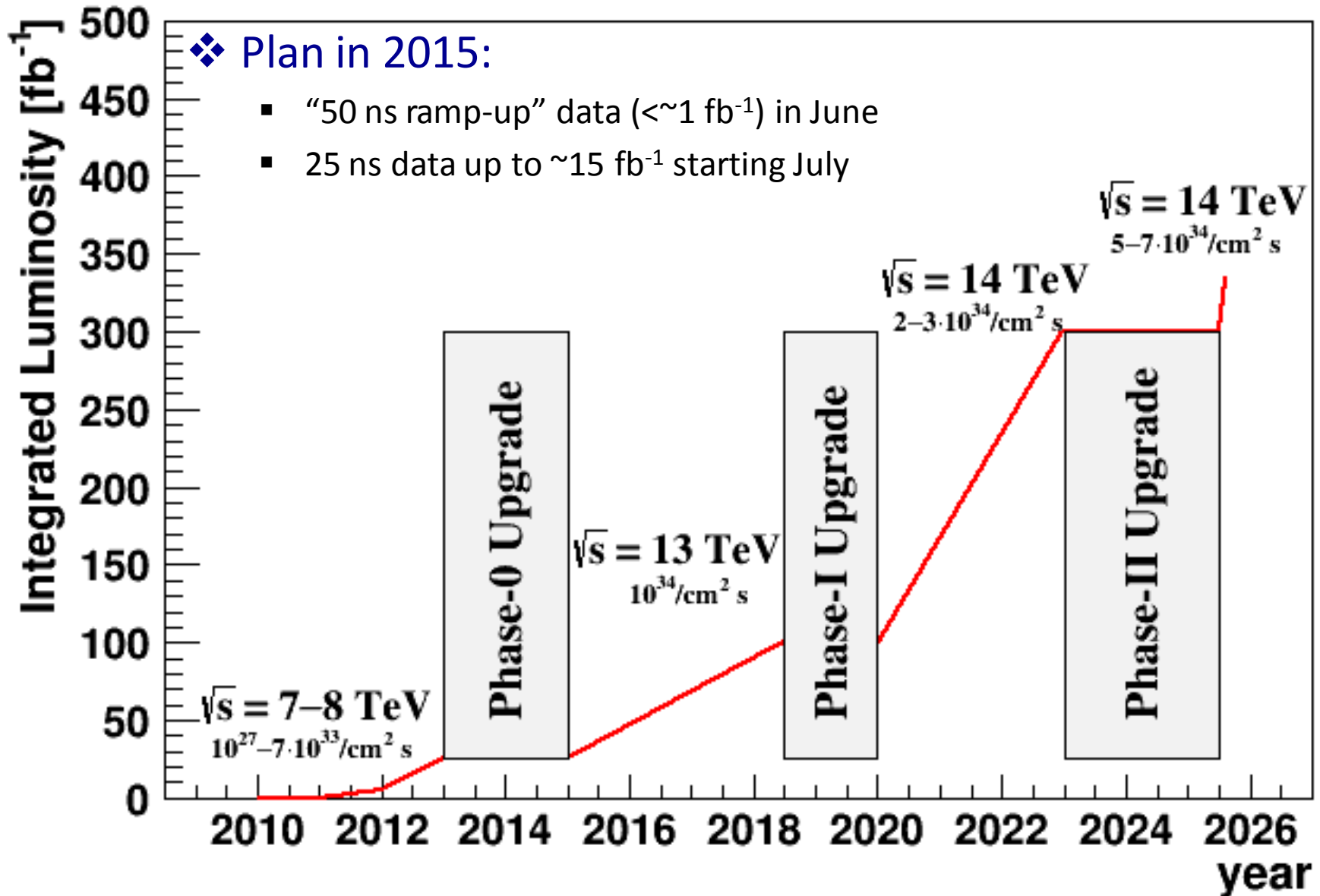


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- Limits on anomalous quartic gauge couplings (EFT model)
- Explicit BSM (Georgi-Machacek) model test: doubly-charged Higgs

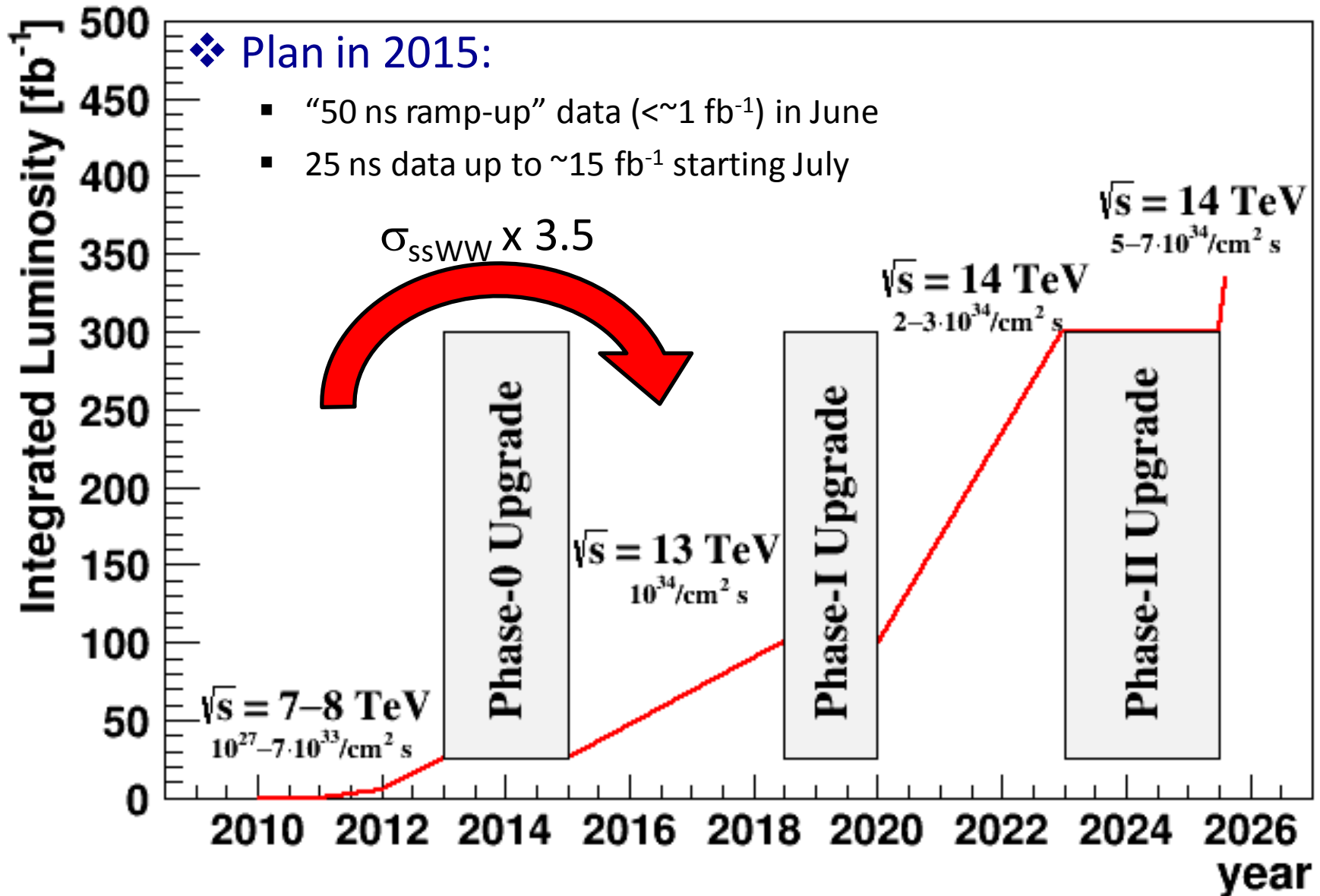
LHC Run Plan



LHC Run Plan



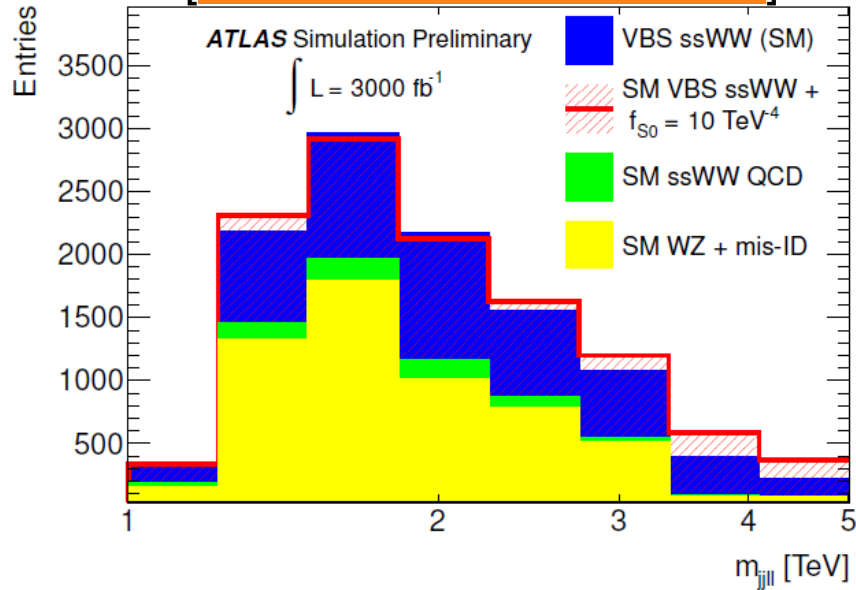
LHC Run Plan



Looking forward

- ❖ What could we see w/ 15 vs. 150 times the current dataset?

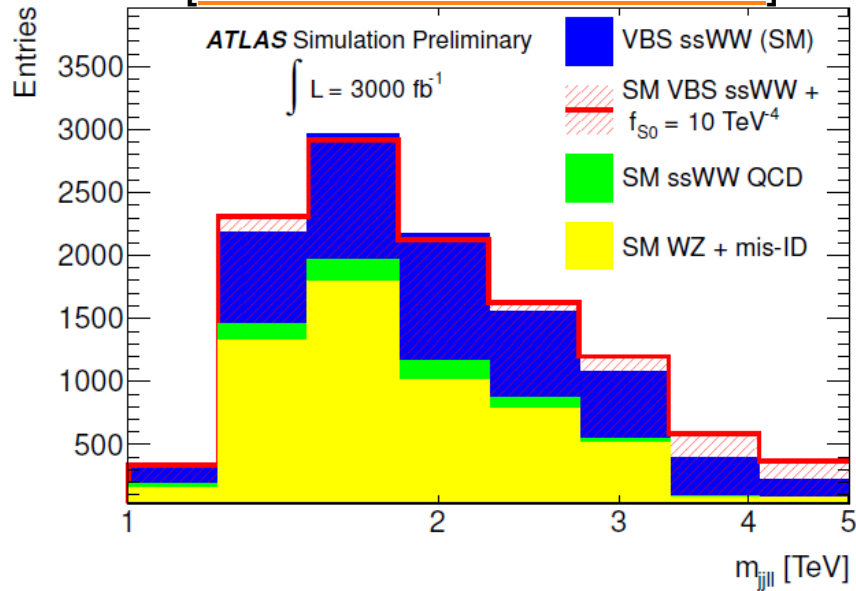
[ATL-PHYS-PUB-2013-006]



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[ATLAS-PHYS-PUB-2013-006]

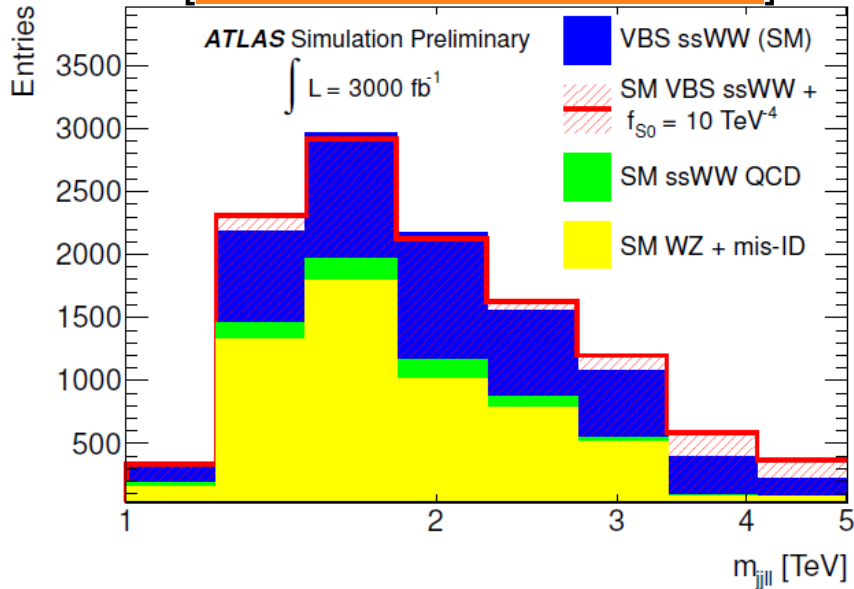


- ❖ Gain in sensitivity (5σ aQGC discovery) for HL-LHC:
factor of two.

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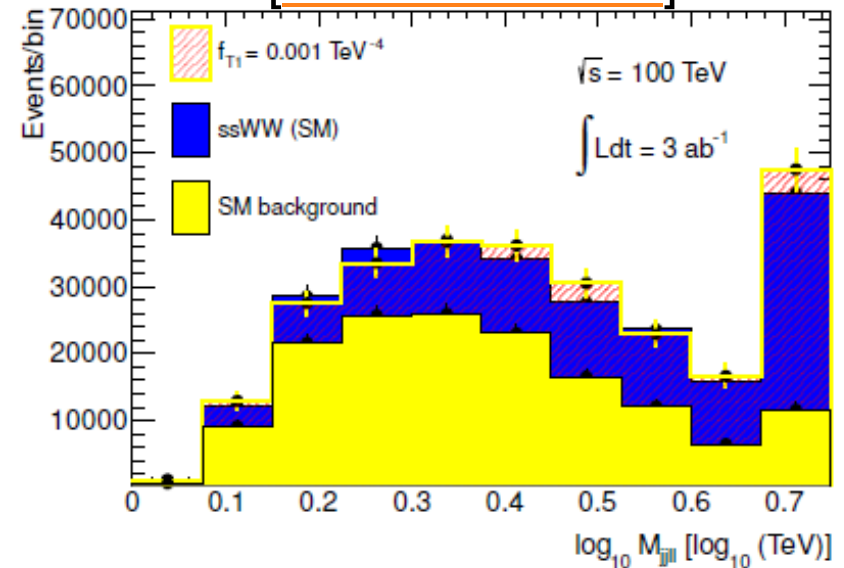
[ATL-PHYS-PUB-2013-006]



- ❖ Gain in sensitivity (5σ aQGC discovery) for HL-LHC: **factor of two.**



- ❖ What could we gain running at 100 TeV rather than 14 TeV?

[arXiv:1309.7452]



- ❖ Gain in sensitivity (5σ aQGC discovery) for 14→100 TeV: **factor of one hundred.**

October 2014 @ BNL



**MULTI-BOSON INTERACTIONS
WORKSHOP**

October 28-30, 2014 • Brookhaven National Laboratory • bnl.gov/mbi2014

TOPICS Multi-boson interactions in VBS, VBF, WW & VV production
Theory status of SM processes
Experimental status of measurements
Anomalous couplings, EFT and BSM physics
Unitarization issues
Prospects at 13 TeV LHC and beyond
Monte Carlo generators

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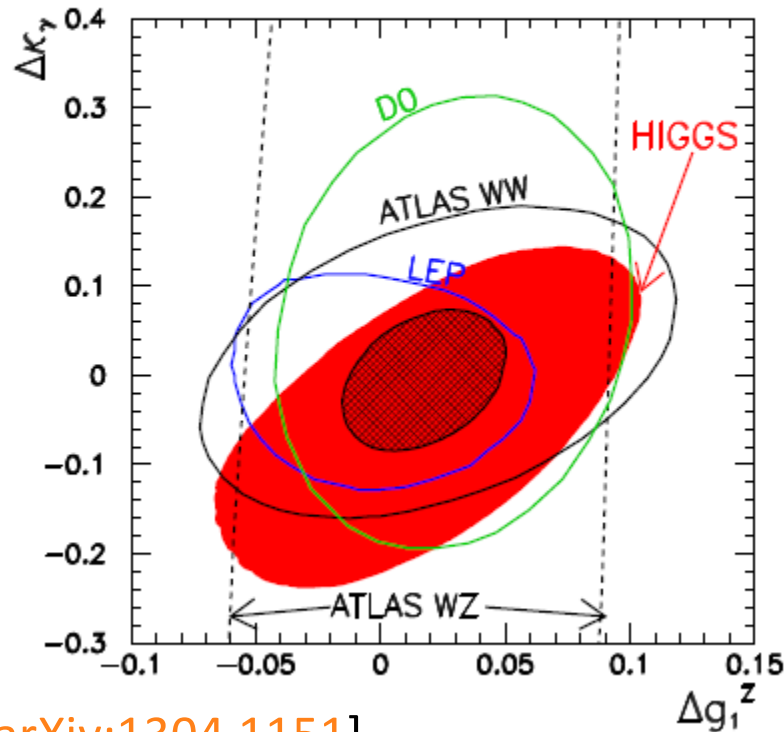
October 2014 @ BNL



More information: <https://indico.bnl.gov/event/mbi2014>

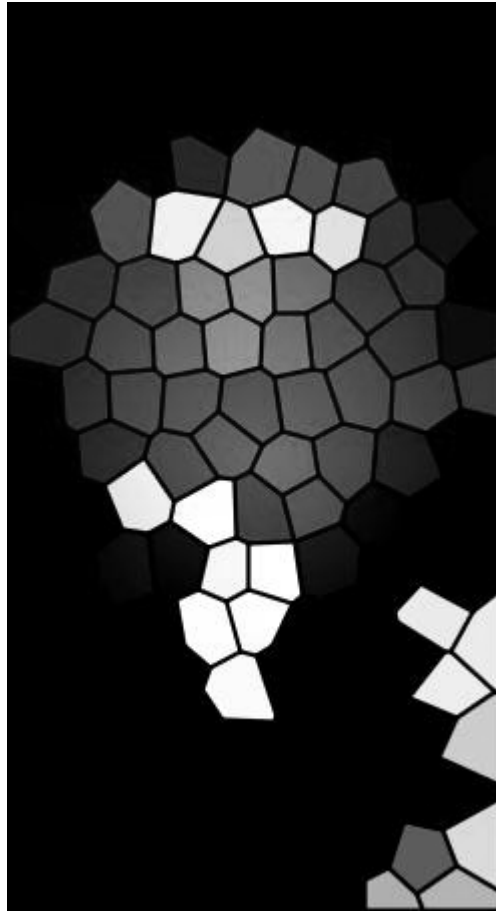
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Higgs and VV interactions
are related in EFTs!

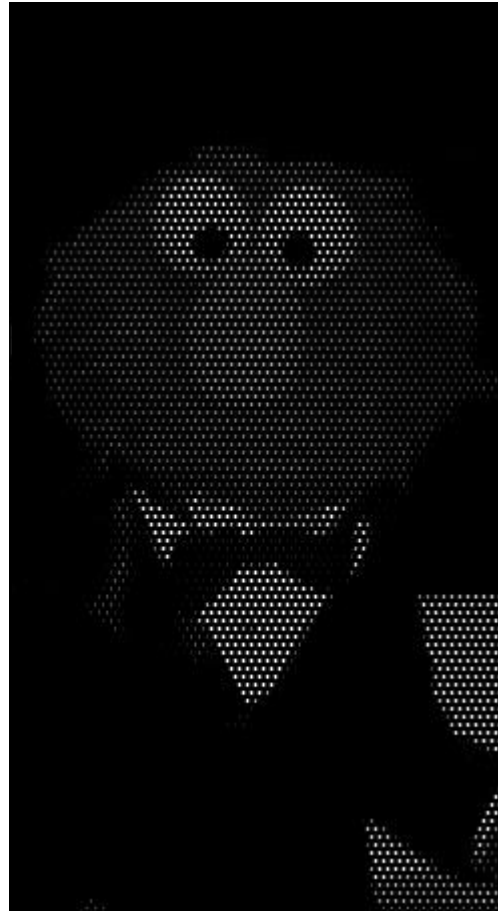


More information: <https://indico.bnl.gov/event/mbi2014>

What we see so far...



What we see so far...



... more data will help ...

Summary

- Many open fundamental questions in physics, today:
 - *Does the Higgs do its job as expected in WBS?*
- First ever results on WBS, involving a $WWWW$ vertex
- 13/14 TeV data will allow more detailed study of quartic vertex

Summary

Helmholtz Alliance
PHYSICS AT THE TERASCALE

PHYSICS AT THE TERA SCALE
Helmholtz Alliance

Deutsches Elektronen-Synchrotron DESY +++ Karlsruher Institut für Technologie - Großforschungsbereich +++ Max-Planck-Institut für Physik München +++ Rheinisch-Westfälische Technische Hochschule Aachen +++ Humboldt-Universität zu Berlin +++ Rheinische Friedrich-Wilhelms-Universität Bonn +++ Technische Universität Dortmund +++ Technische Universität Dresden +++ Albert-Ludwigs-Universität Freiburg +++ Justus-Liebig-Universität Gießen +++ Georg-August-Universität Göttingen +++ Universität Hamburg +++ Ruprecht-Karls-Universität Heidelberg +++ Karlsruher Institut für Technologie - Universitätsbereich +++ Johannes Gutenberg-Universität Mainz +++ Ludwig-Maximilians-Universität München +++ Universität Regensburg +++ Universität Rostock +++ Universität Siegen +++ Julia-Mechanik-Universität Würzburg +++ Bergische Universität Wuppertal +++

Multi-Boson Interactions (MBI) 2015
2-4 September 2015
DESY, Hamburg



Topics:

- Status of NLO/NNLO (QCD/EW) for V+jets, VV(+jets), VV scattering, Vector boson fusion
- Electroweak Sudakovs and showers
- Higgs Effective Field Theory
- Unitarization: methods/resonances/ coupled channels
- Models (SUSY, composite, extra-dimensions)
- Monte Carlos and other Tools
- Electroweak Precision Tests

Organising Committee:
Christophe Grojean (DESY), Michael Kobel (TU Dresden),
Kirstin Lohwasser (DESY), Isabell Melzer-Pellmann (DESY),
Jürgen Reuter (DESY, chair), Peter Schuler (Hamburg U.),
Thomas Schoerner-Sadenius (DESY), Anja Vest (TU Dresden)

Registration deadline: 15 August 2015
Please register at the workshop webpage:
<http://mbi2015.desy.de>



- Many open fun
- *Does the Hig*
- First ever result
- 13/14 TeV data

s, today:
WBS?

VW vertex

y of quartic vertex

What we know is a drop, what we don't know is an ocean.

Isaac Newton (1643 - 1727)

