ATLAS EXPERIMENT
CMS
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Vector Boson Scattering: a new toolkit to probe the standard model and beyond

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The Standard Model of particle physics

$$\begin{aligned}\mathcal{L} = & -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} \\ & + i \bar{\psi} \not{D} \psi \\ & + \psi_i y_{ij} \psi_j \phi + h.c \\ & + |D_\mu \phi|^2 - V(\phi)\end{aligned}$$

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- **Particle content**

The Higgs boson was found 7 years ago!

→ no significant deviation from the SM found in its properties

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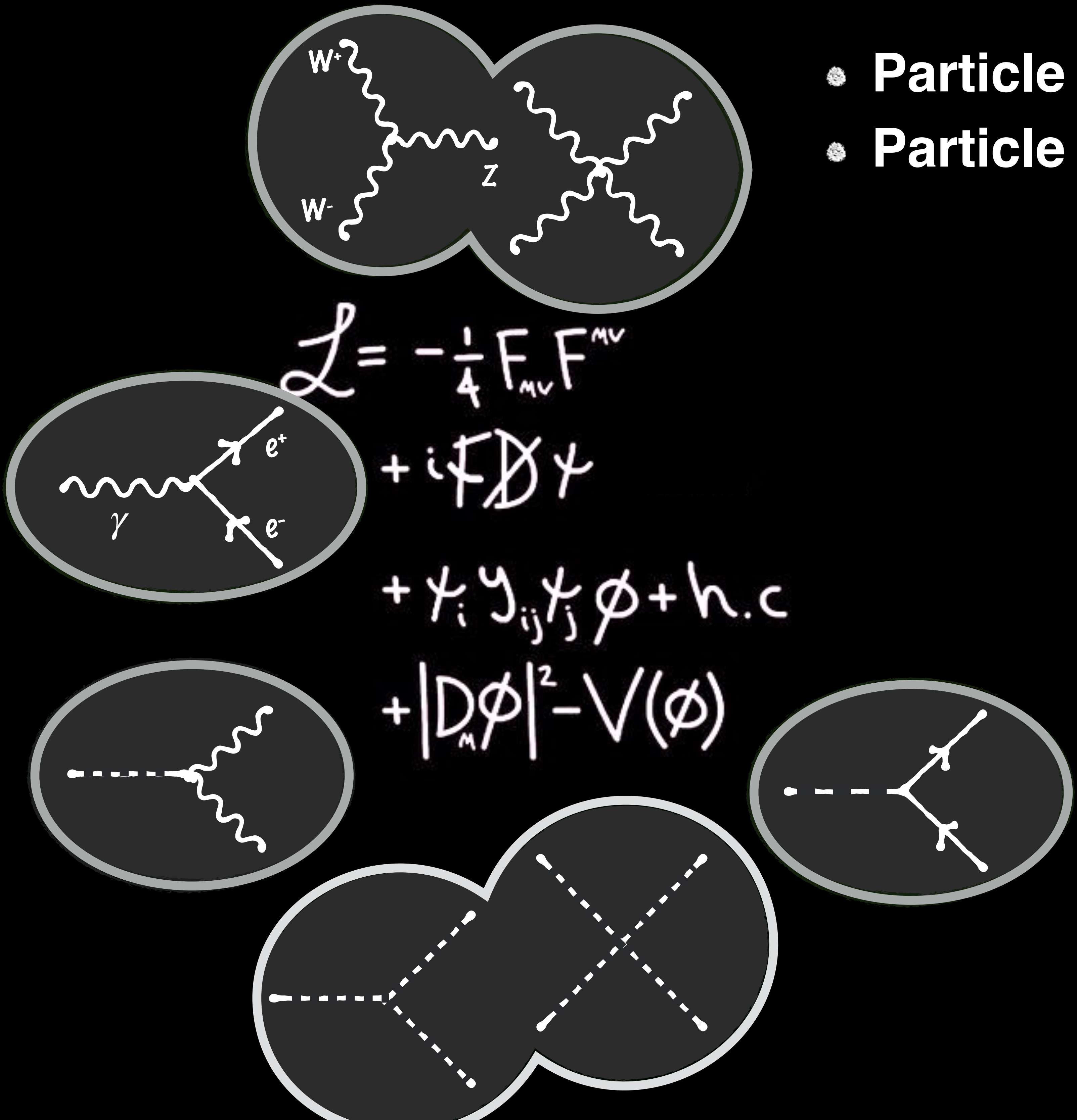
Is the SM complete?

The Standard Model of particle physics



$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\psi}\not{D}\psi + \psi_i y_{ij}\psi_j\phi + h.c + |D_\mu\phi|^2 - V(\phi)$$

- **Particle content**
- **Particle interactions**

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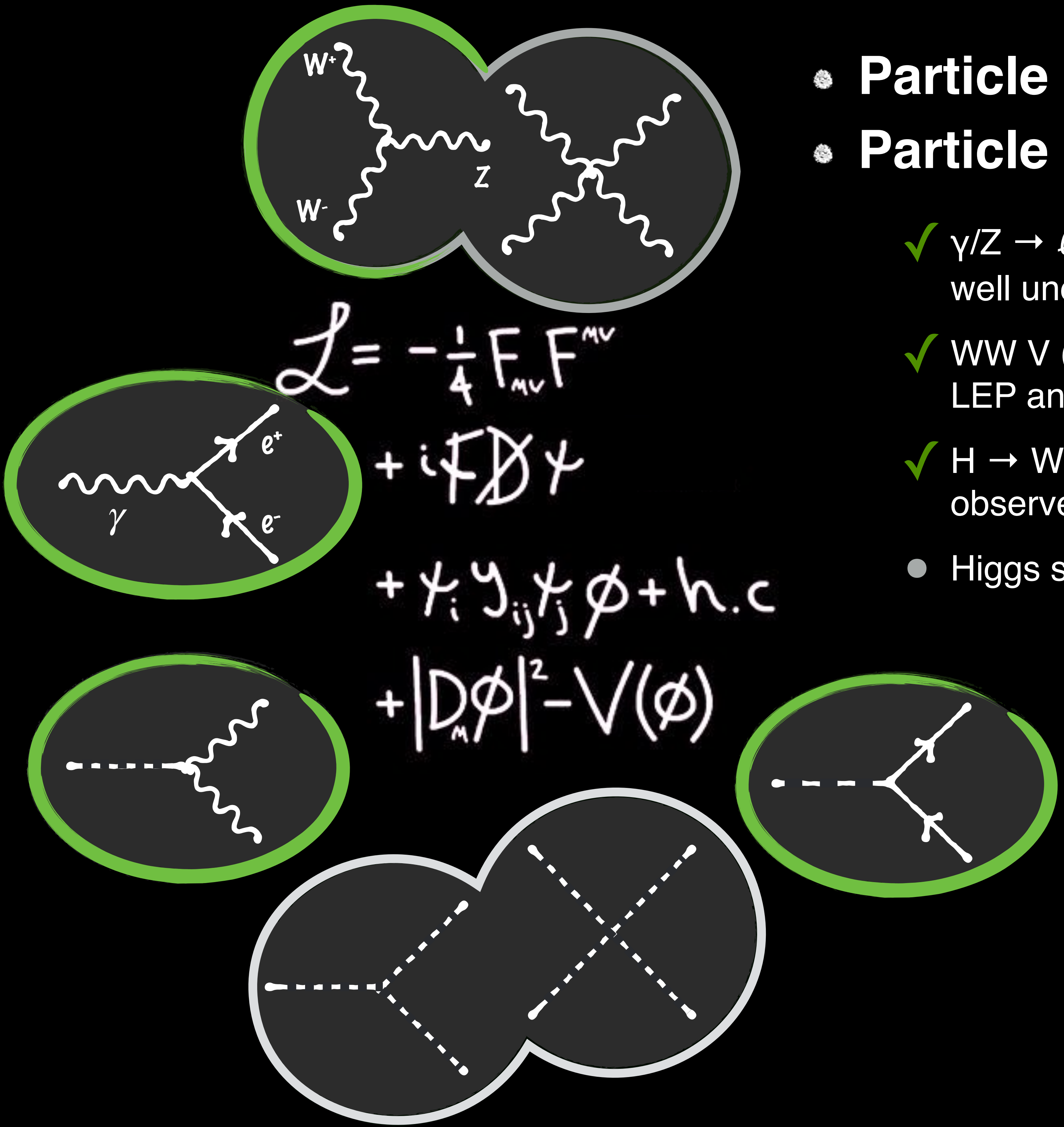

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- **Particle content**
- **Particle interactions**
  - ✓ γ/Z → ℓℓ, W → ℓν most frequent and very well understood
  - ✓ WW V (V = W, Z, γ) precisely measured at LEP and the LHC
  - ✓ H → WW,ZZ, γγ and H → ττ recently observed at LHC
  - ● Higgs self couplings not yet seen

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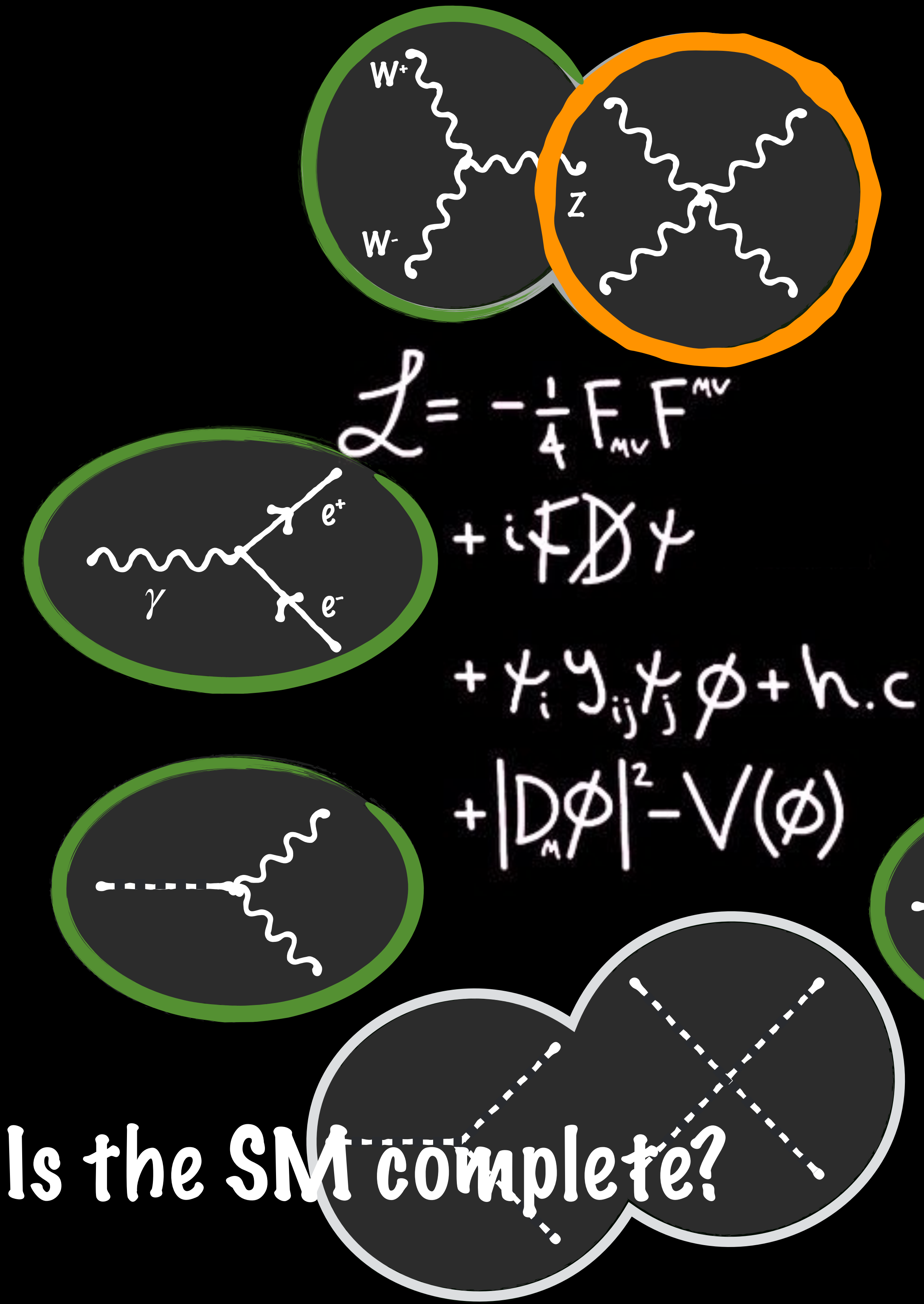

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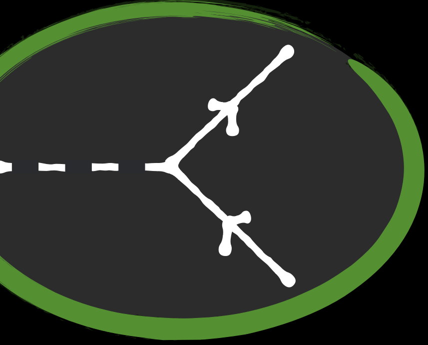

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  - ● Higgs self couplings not yet seen
  - ● WW VV was limited by experimental data

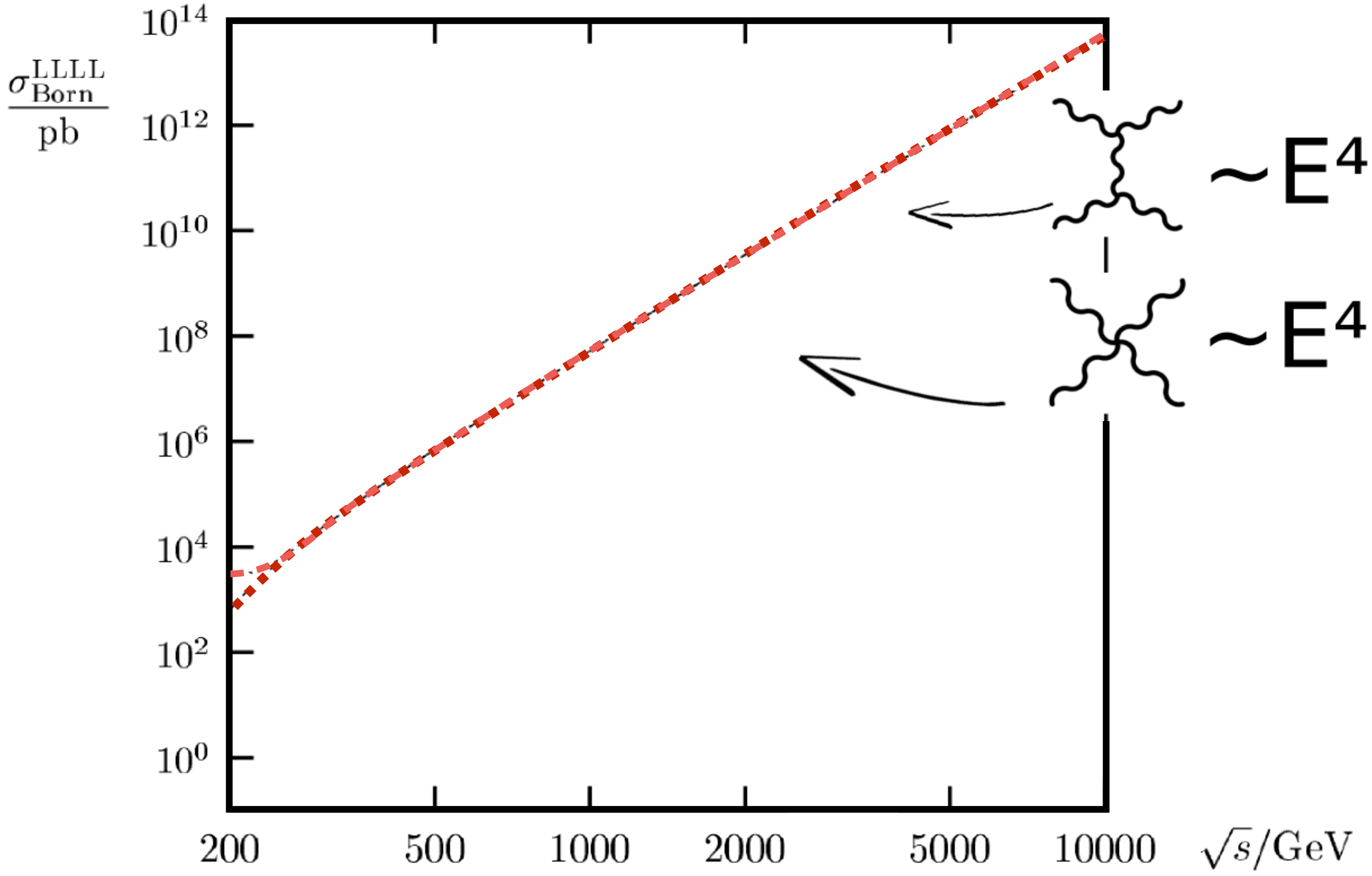
Is the SM complete?

A new chapter is now accessible if we look at Vector Boson Scattering !!

Why Vector Boson scattering is interesting?

- Example: Cross-section for longitudinal $W_L^+W_L^- \rightarrow W_L^+W_L^-$ scattering

[Denner, Hahn, 1997]



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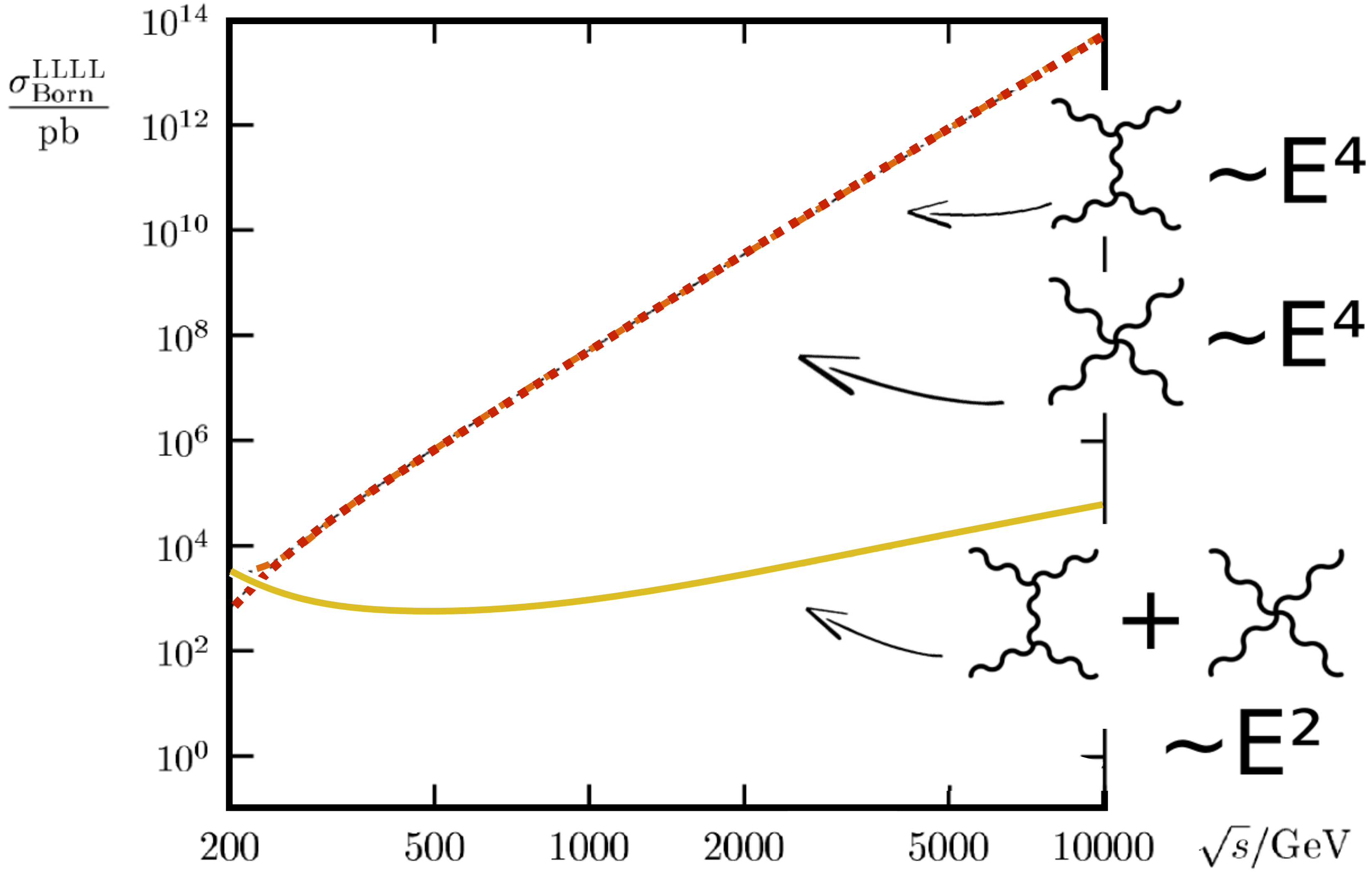

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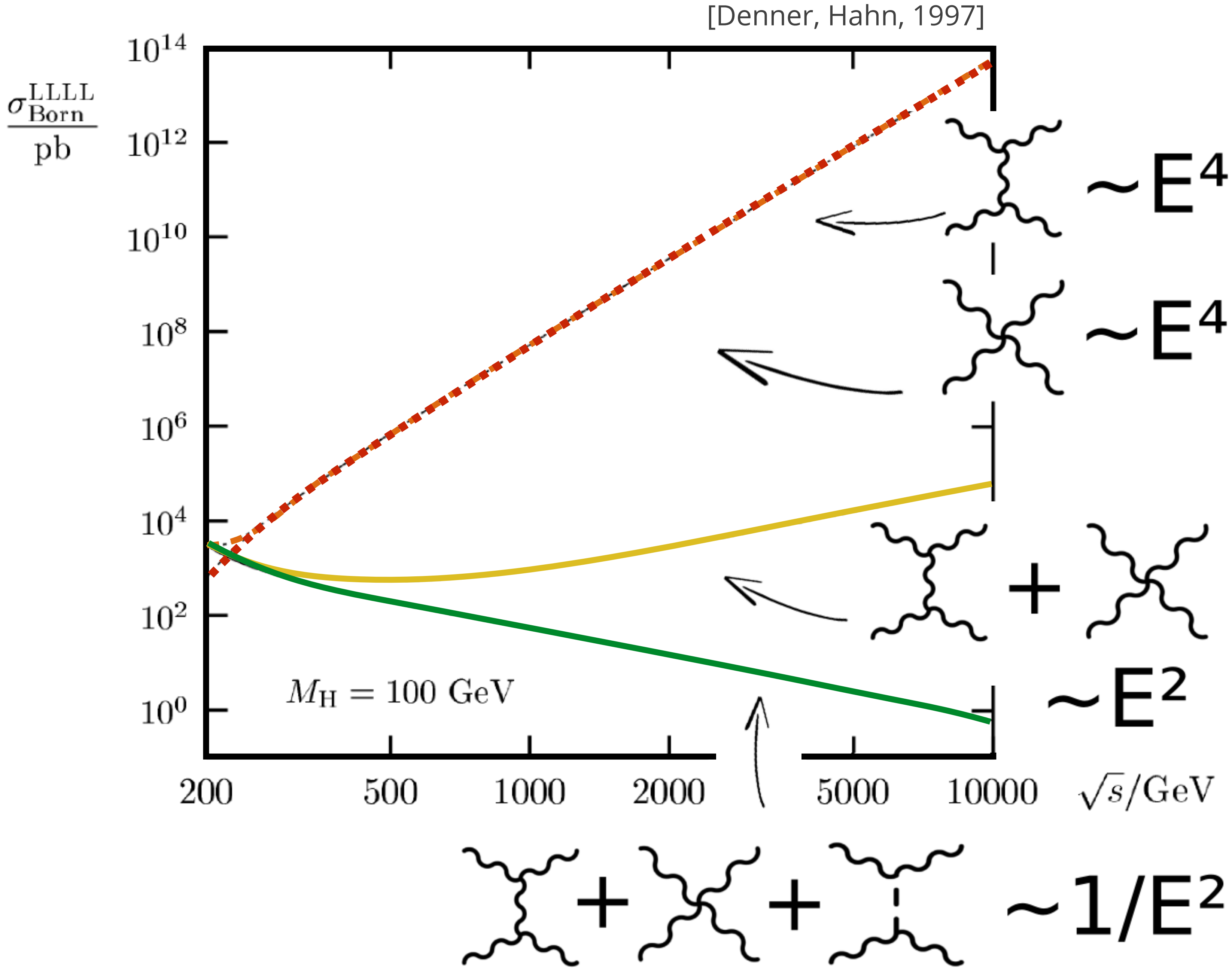
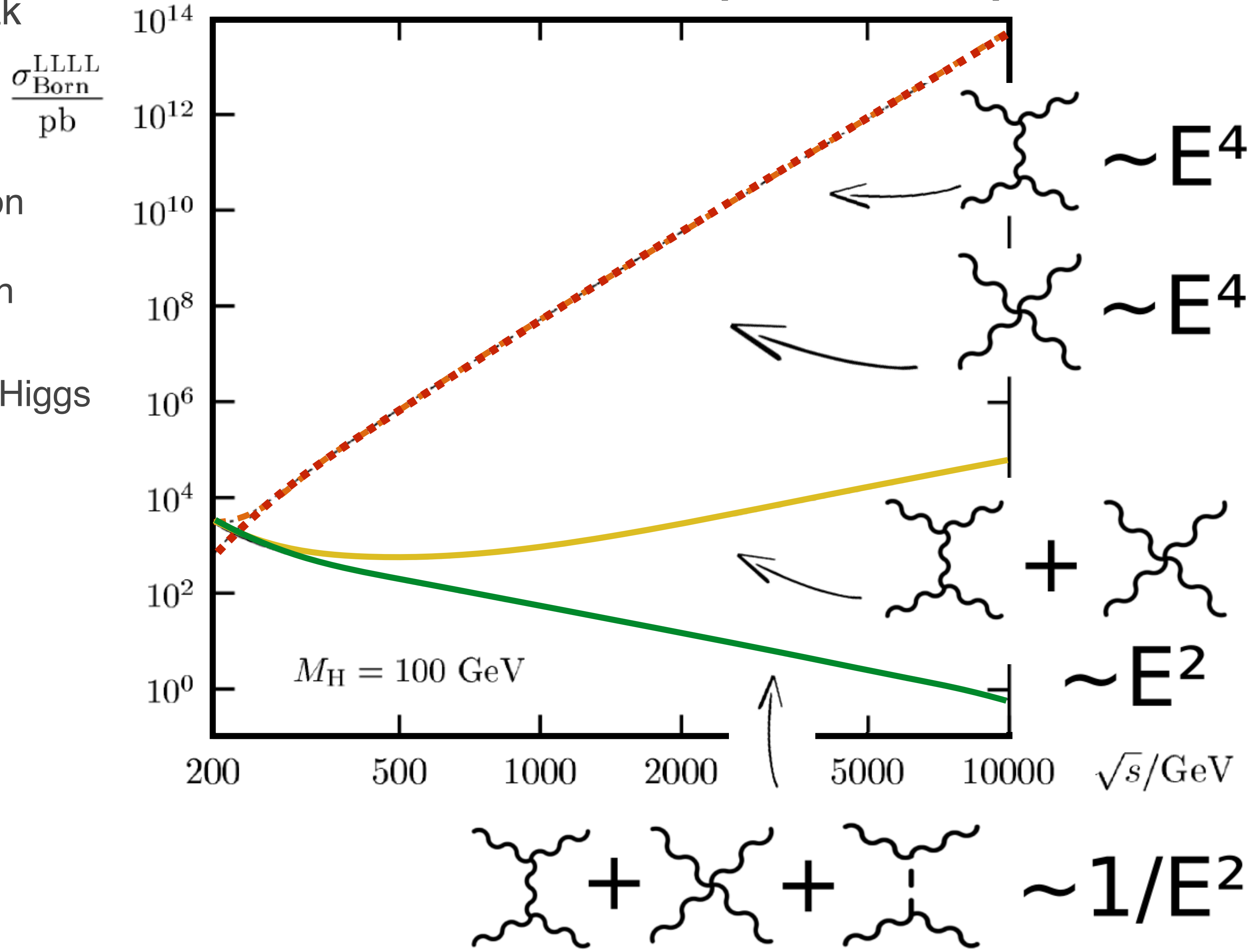


Why Vector Boson scattering is interesting?

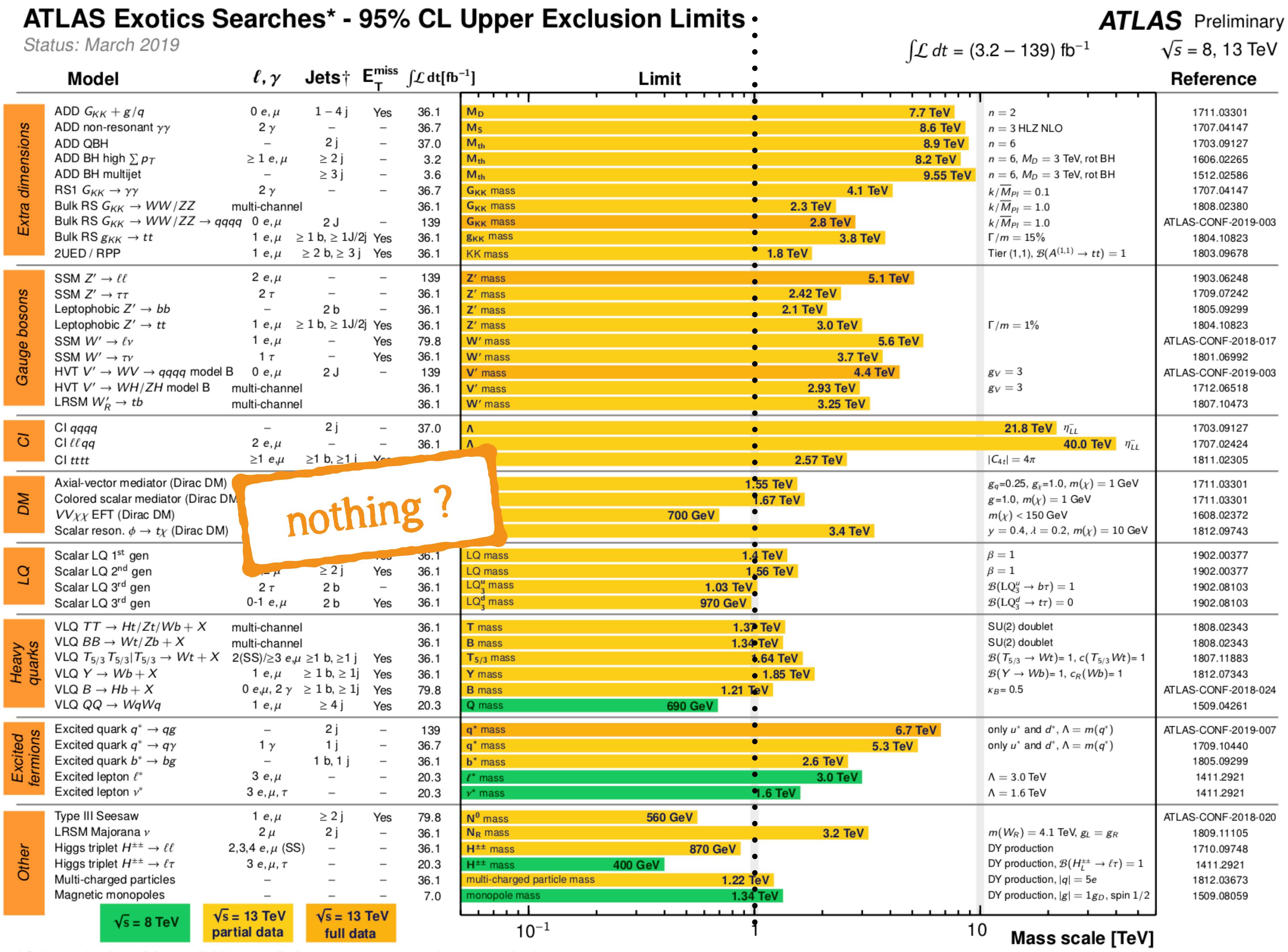
- Example: Cross-section for longitudinal $W_L^+W_L^- \rightarrow W_L^+W_L^-$ scattering
- Vector Boson Scattering (VBS) important test of electroweak sector and EW Symmetry Breaking
  - Interaction with Higgs boson unitarizes the scattering amplitude → is unitarization complete ?
  - Complementary to “direct” Higgs boson property studies

[Denner, Hahn, 1997]



Why Vector Boson scattering is interesting?

- Looking for new physics?



*Only a selection of the available mass limits on new states or phenomena is shown.

†Small-radius (large-radius) jets are denoted by the letter j (J).

Exclusions are model dependent

- Yet no sign of new physics with **direct searches** @LHC

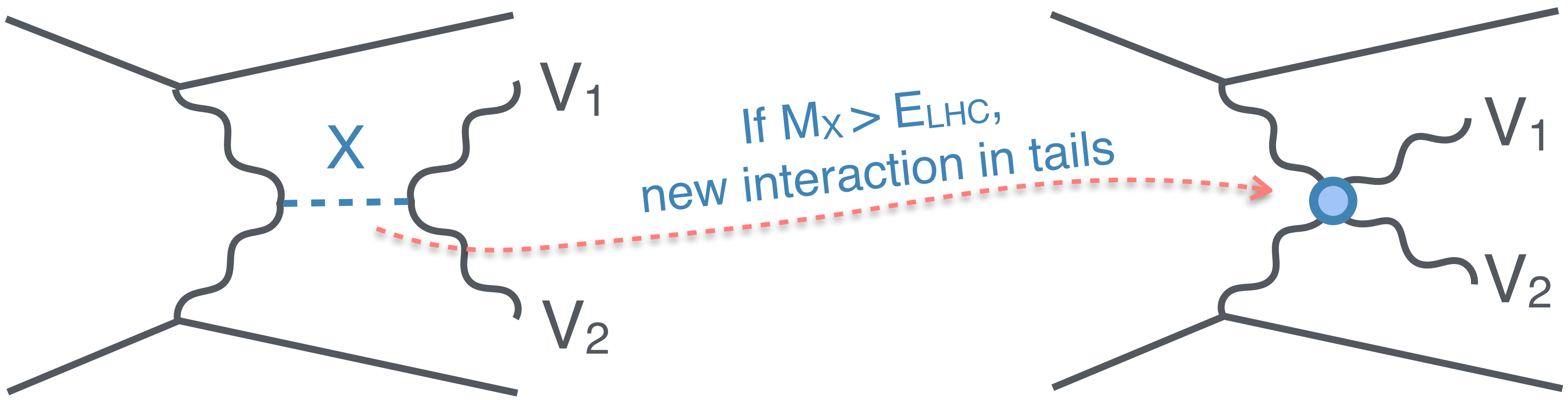
New physics in bumps and tails

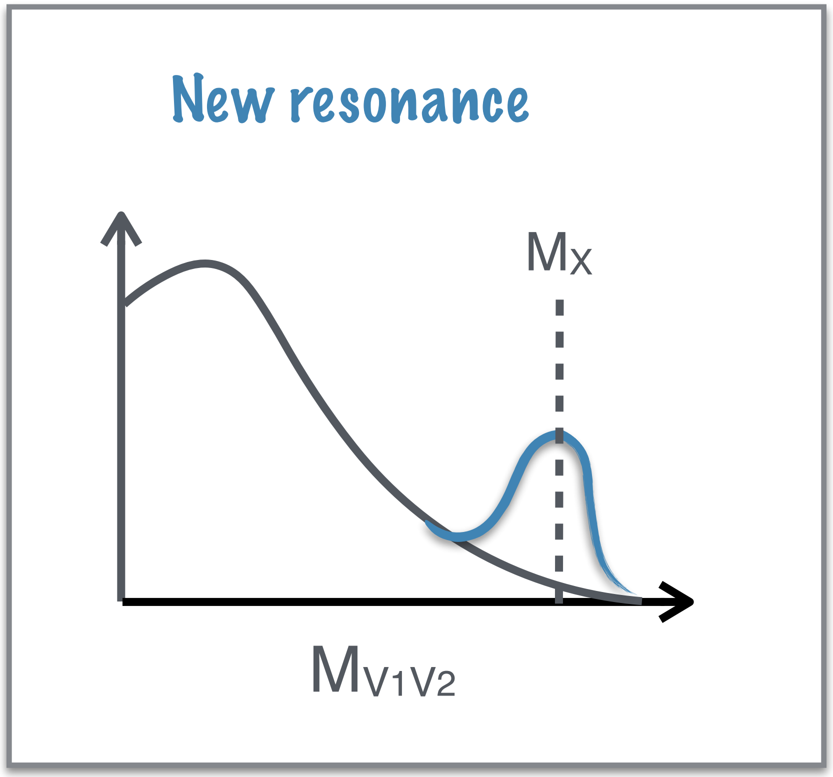
Direct search approach

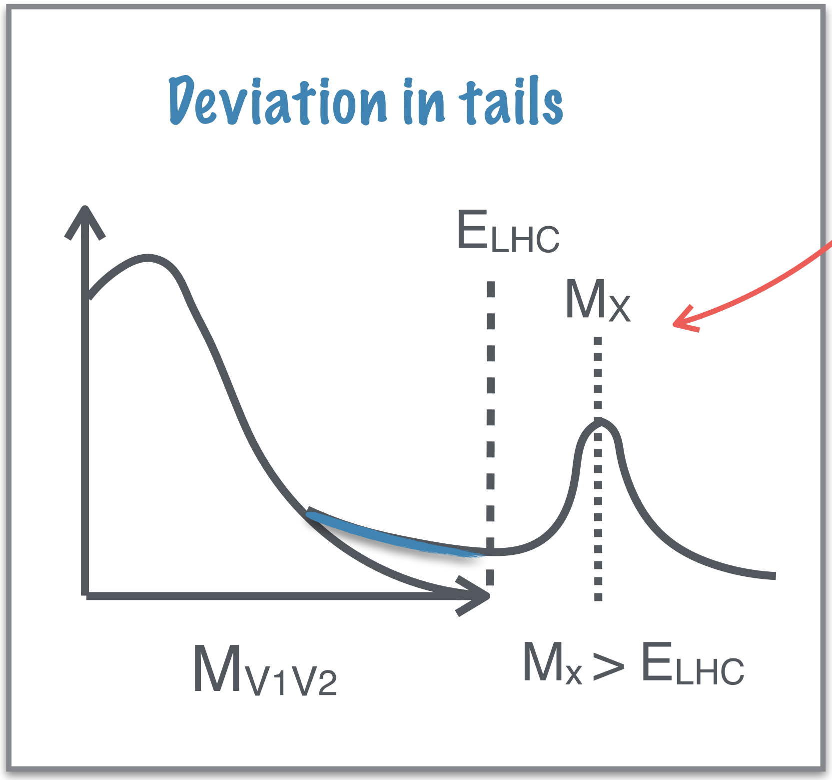
(model dependent)

Indirect search approach

(model independent)







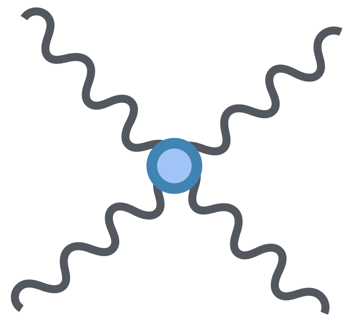
New physics may be (just) beyond our reach

Effective Field Theory (EFT)

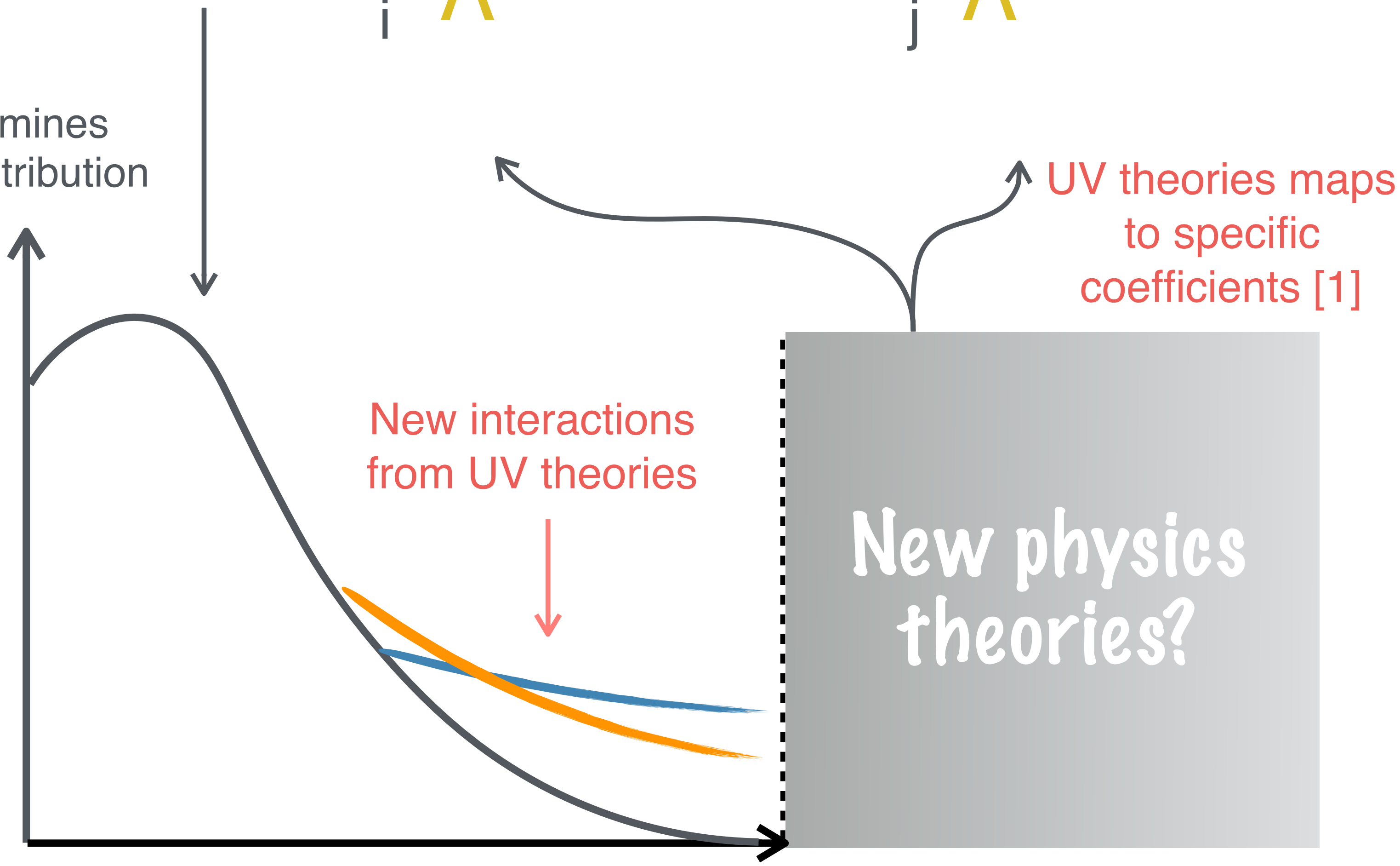
- Deviations are parametrized by higher order operators from SM fields

$$L_{EFT} = L_{SM} + \sum_i \frac{c_i}{\Lambda^2} O_{i,dim-6} + \sum_j \frac{c_j}{\Lambda^2} O_{j,dim-8}$$

dim-8 operators can affect VBS at tree level



L_{SM} ~ determines the bulk distribution



UV theories maps to specific coefficients [1]

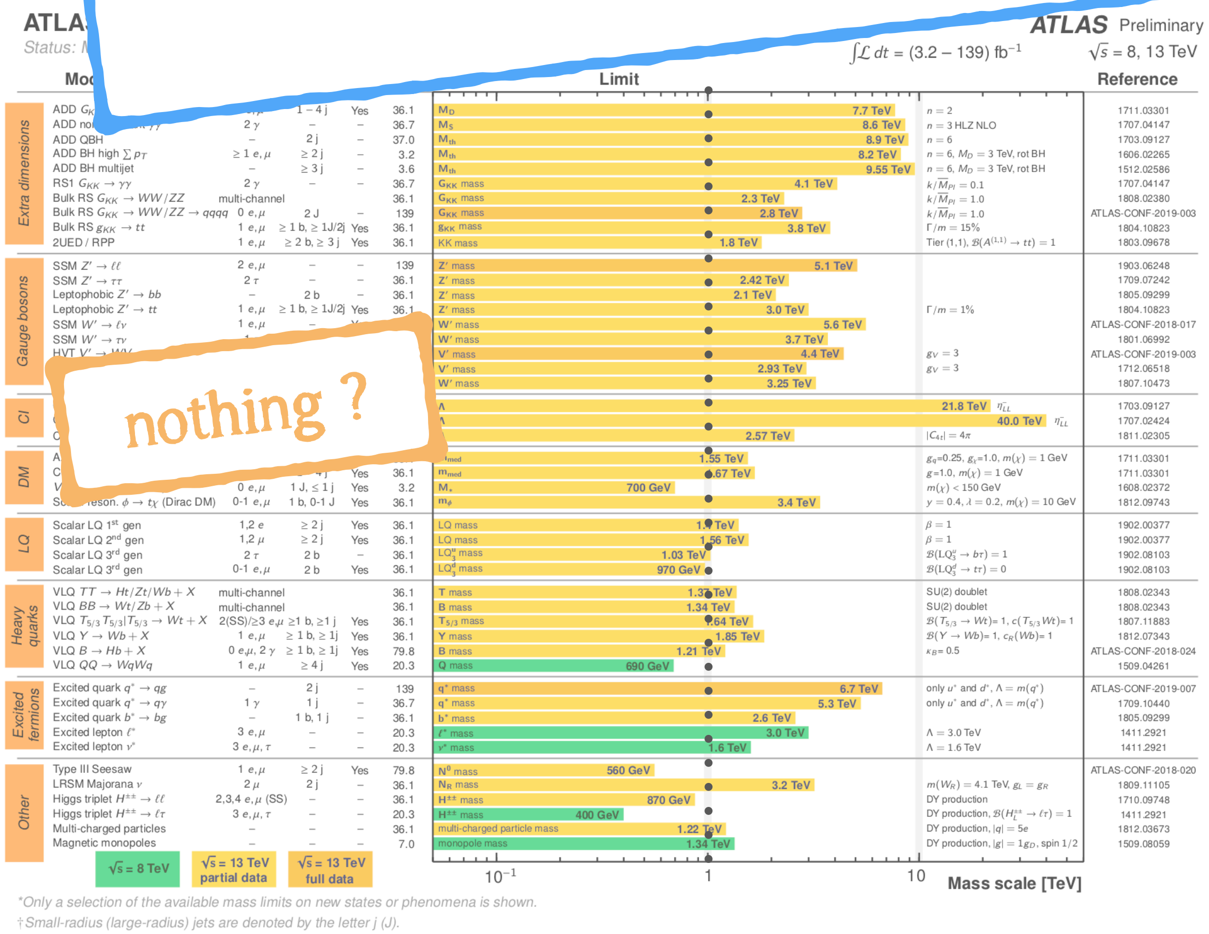
New interactions from UV theories

- EFT are model independent and self consistent framework for parametrizing deviations from the SM

Why Vector Boson scattering is interesting?

Vector Boson Scattering is important

1. Test the consistency of the SM
2. Deviations from predictions can be sign for new physics



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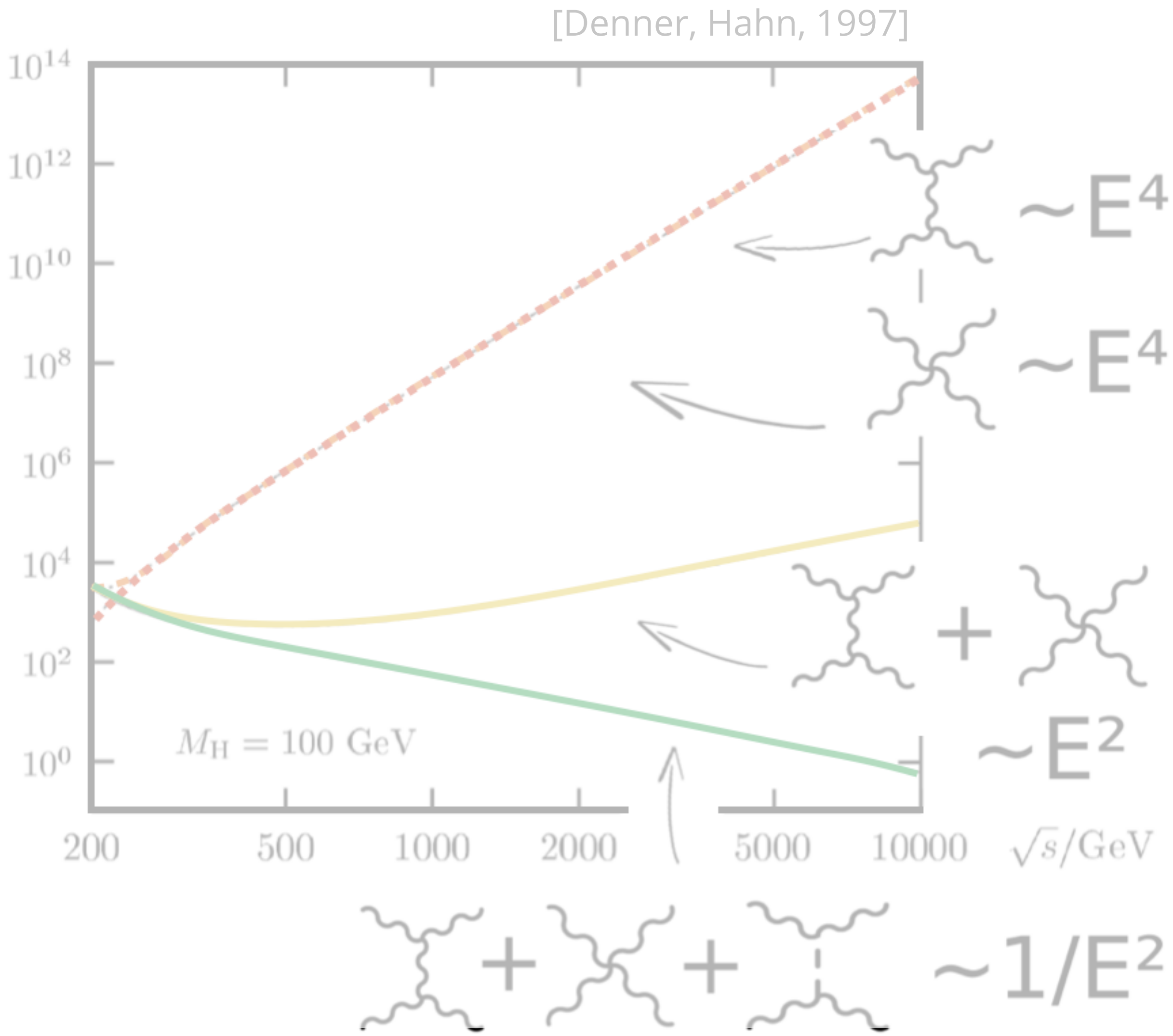
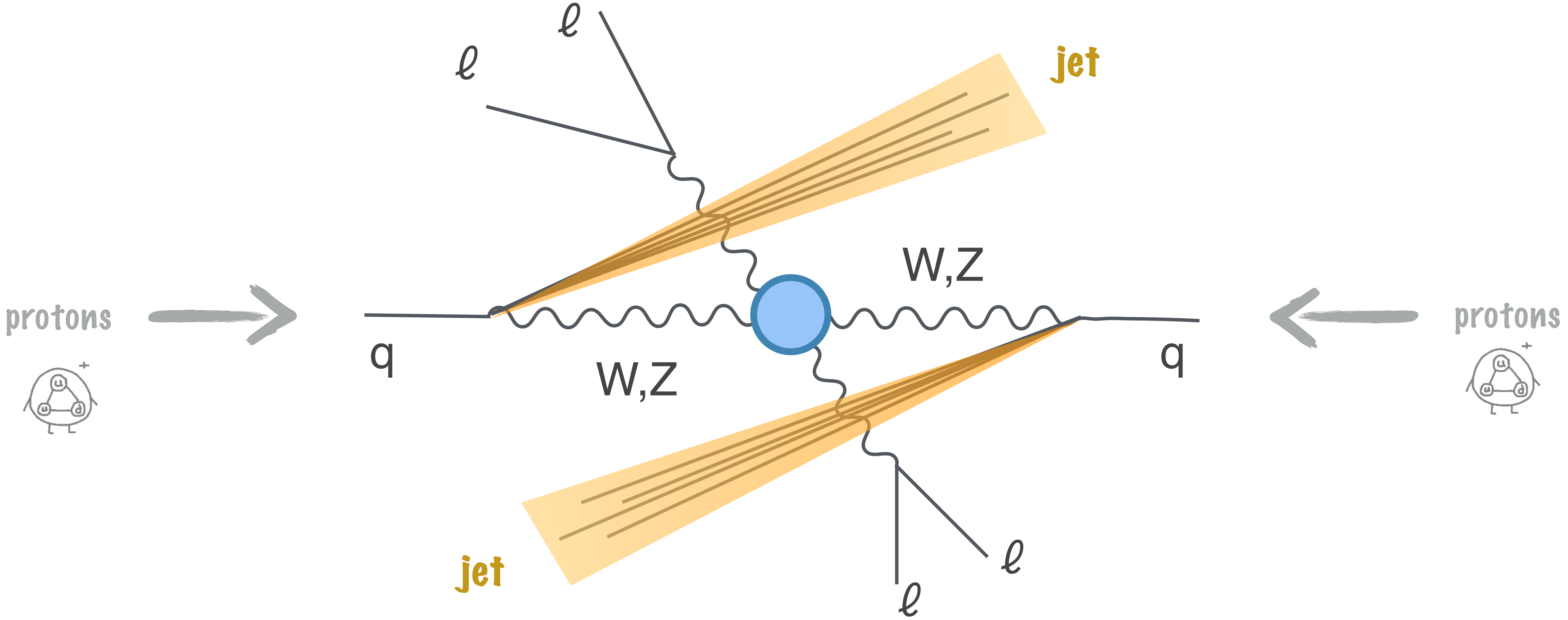


- Today we will discuss the most recent experimental results obtained at the LHC

Vector Boson Scattering at the LHC

Protons in LHC serve as source of vector boson beams.



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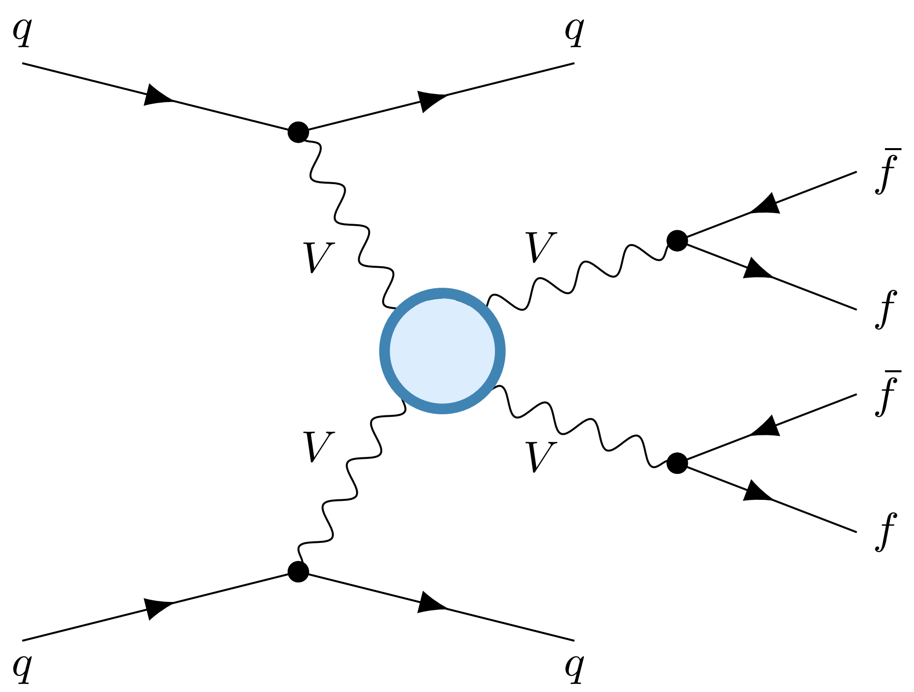
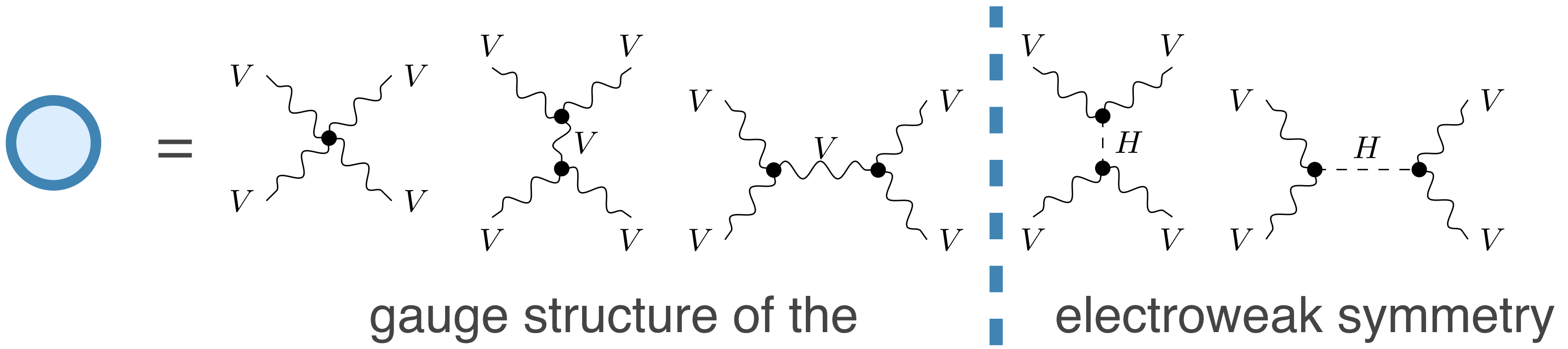
O(α^{6}_{W}) process with following diagrams at LO:





gauge structure of the Standard Model

electroweak symmetry breaking

Vector Boson Scattering at the LHC

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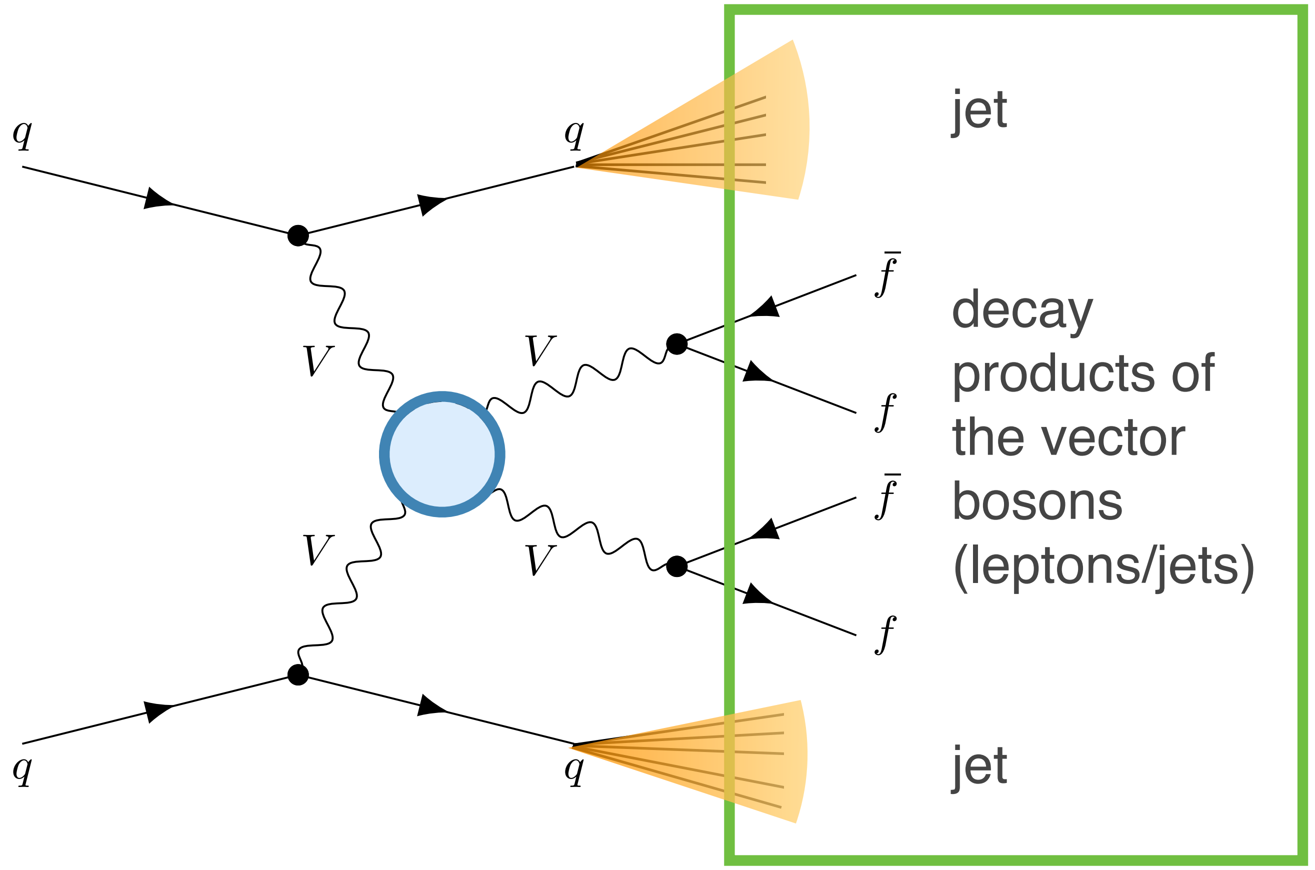
$O(\alpha^6_W)$ process with following diagrams at LO:

final state



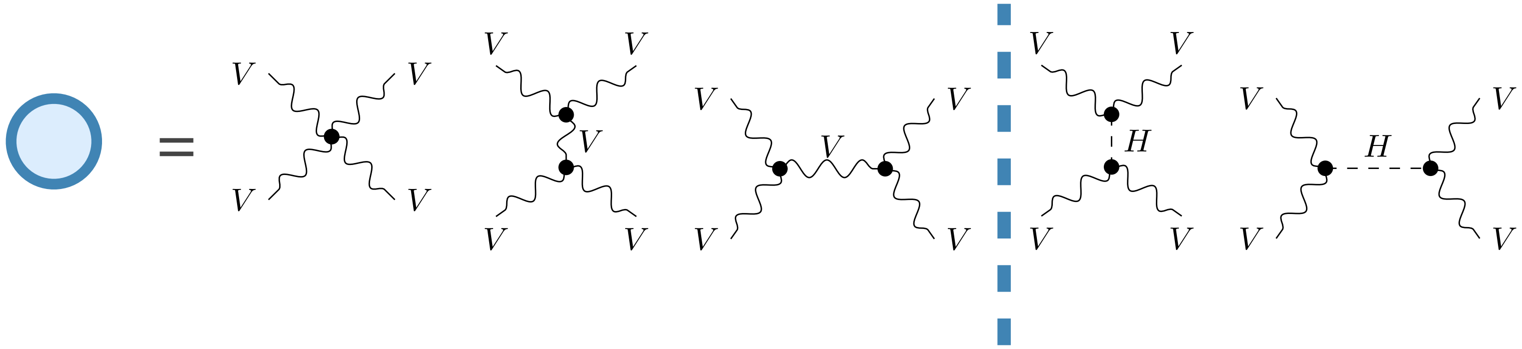
jet

decay products of the vector bosons (leptons/jets)

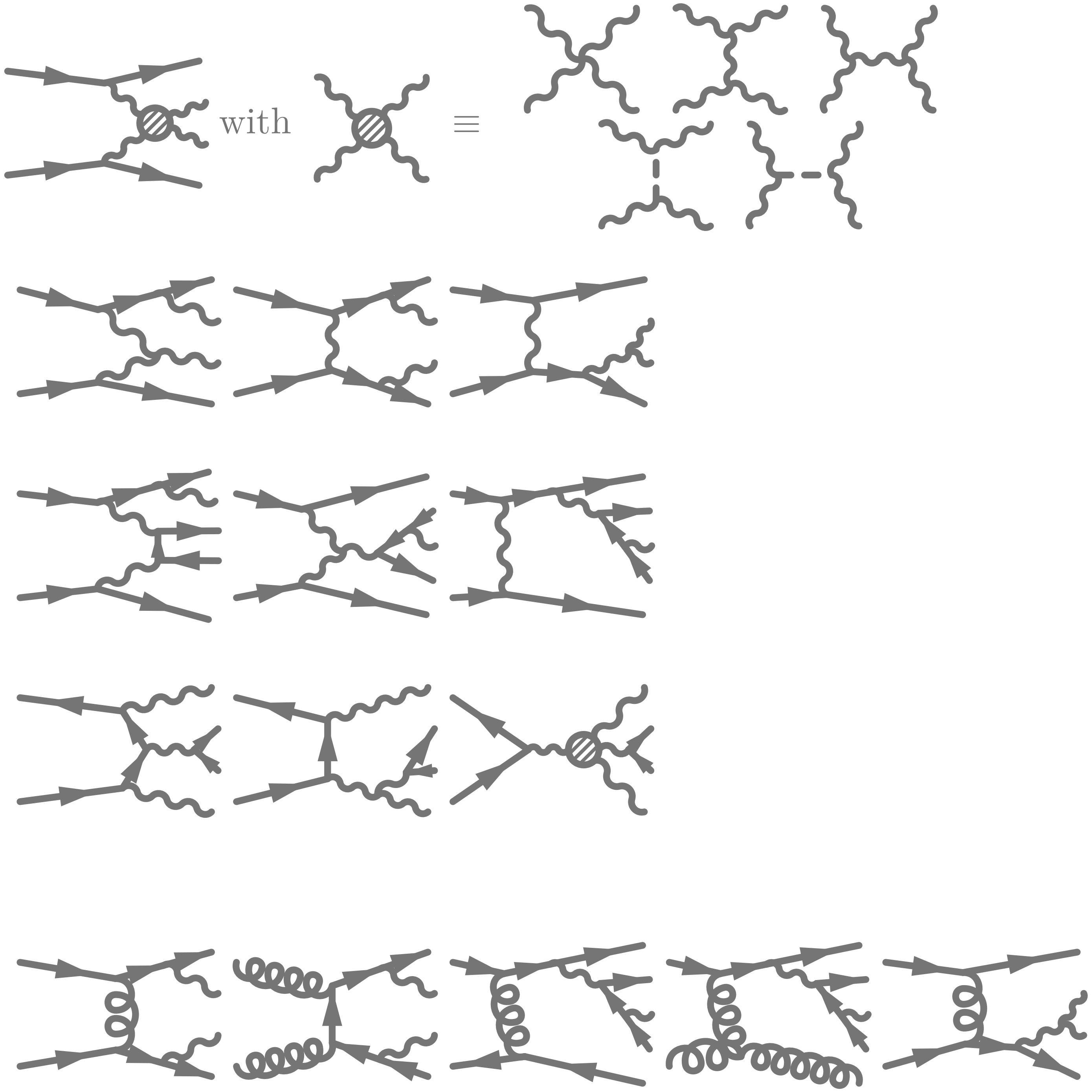
jet

VVjj

(V=W,Z)



Signal definition



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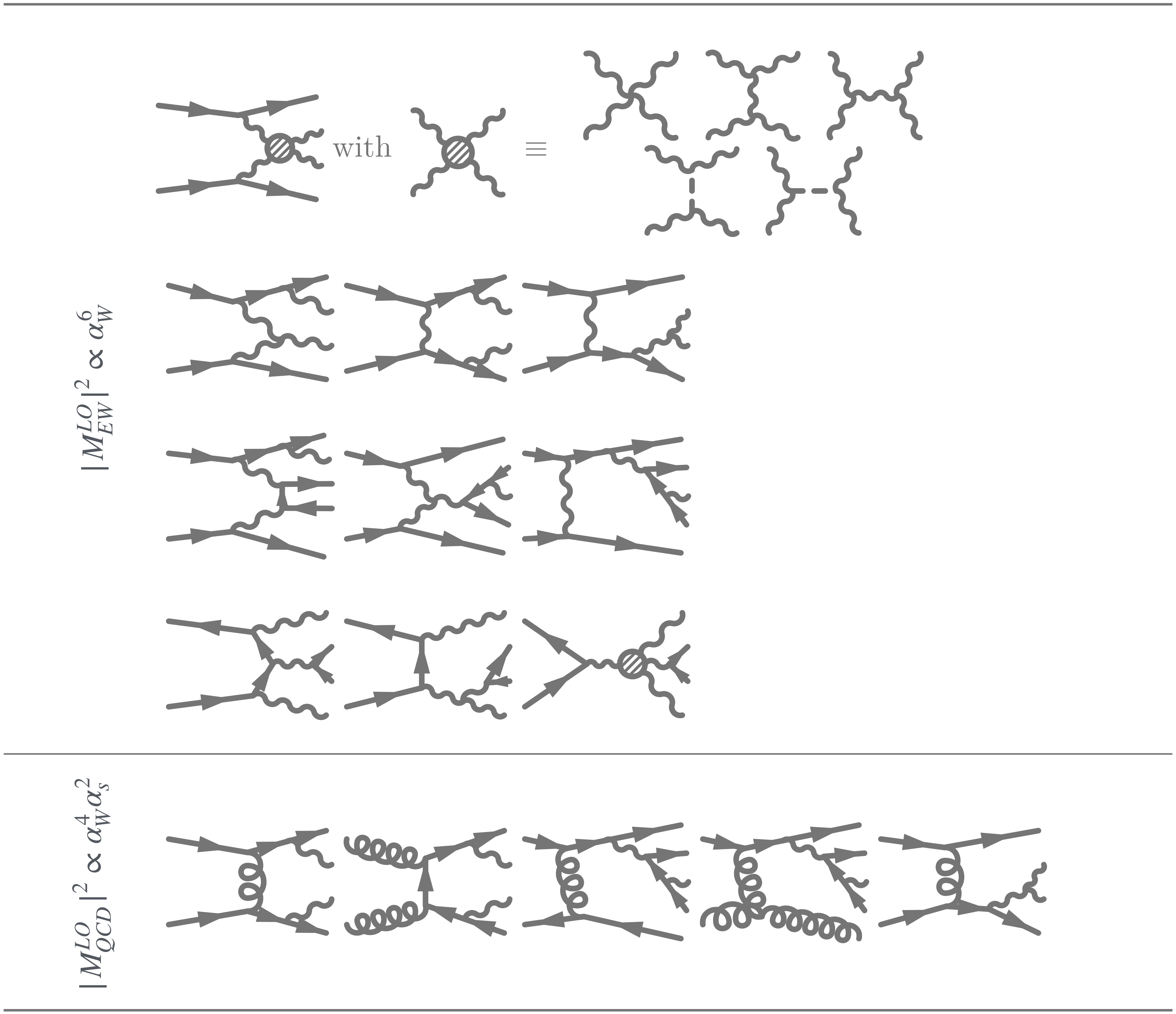

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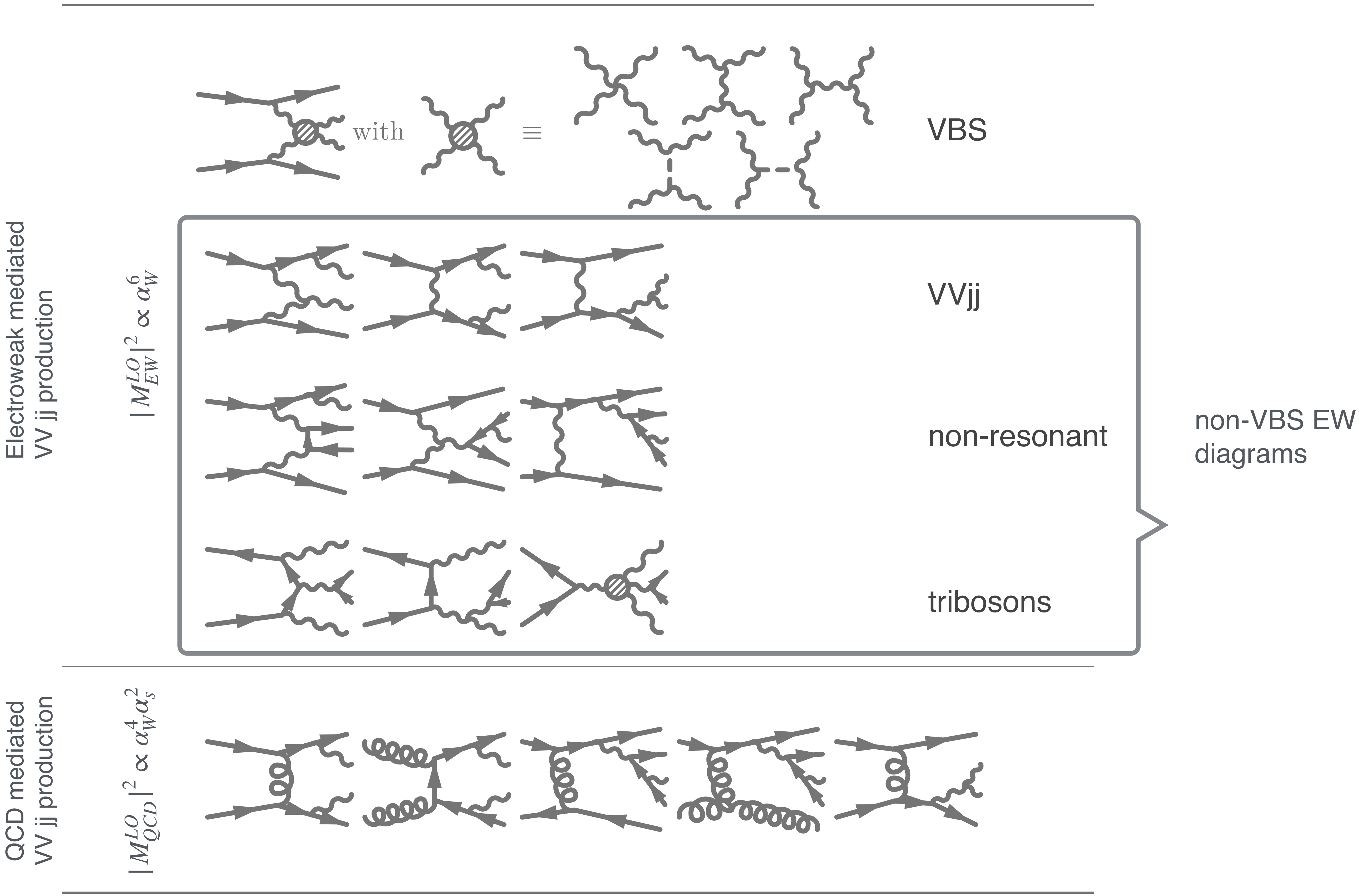


Electroweak mediated VV jj production

$|M_{EW}^{LO}|^2 \propto \alpha_W^6$

with

$\equiv$

VBS

VVjj

non-resonant

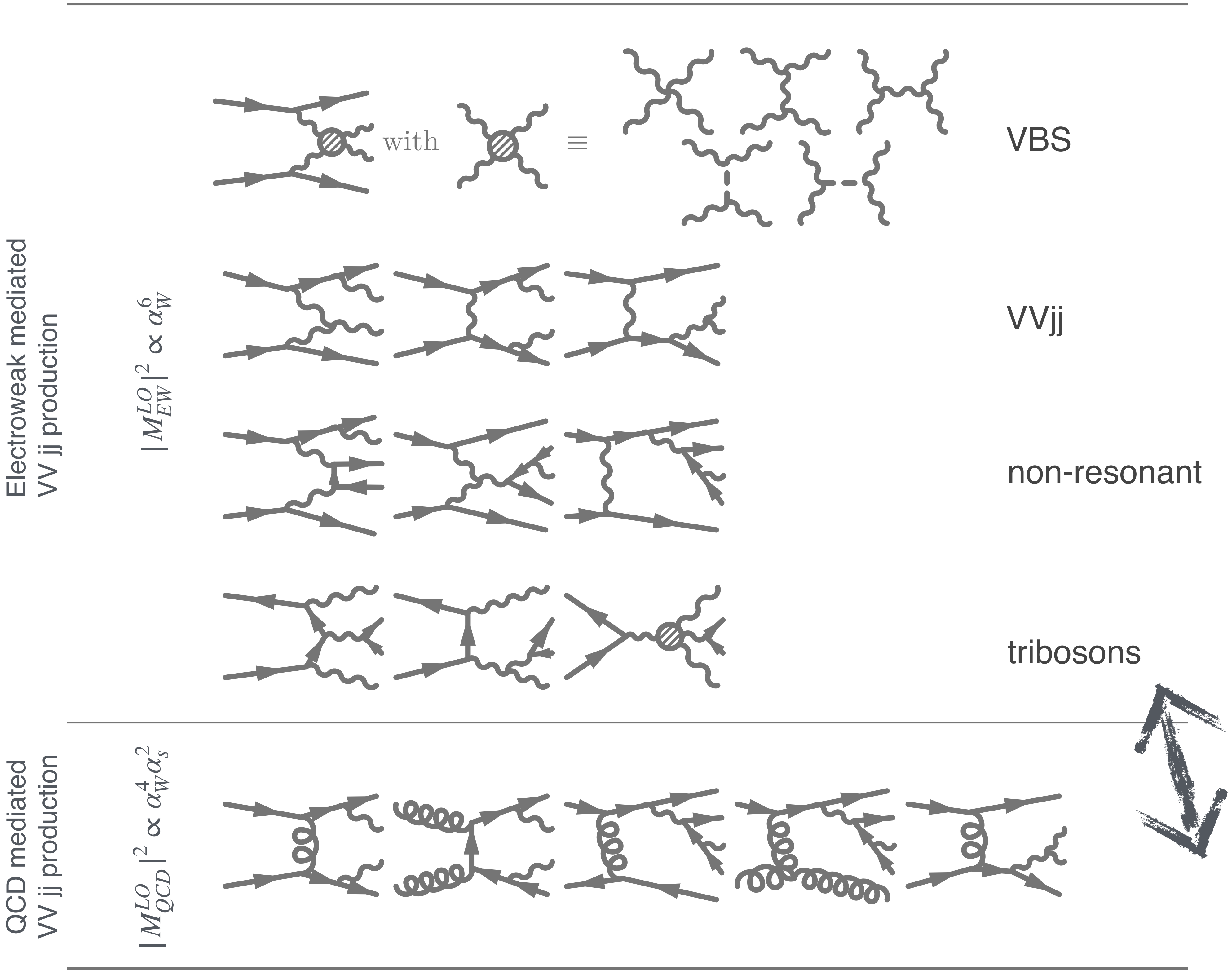
tribosons

non-VBS EW diagrams

QCD mediated VV jj production

$|M_{QCD}^{LO}|^2 \propto \alpha_W^4 \alpha_s^2$

Signal definition



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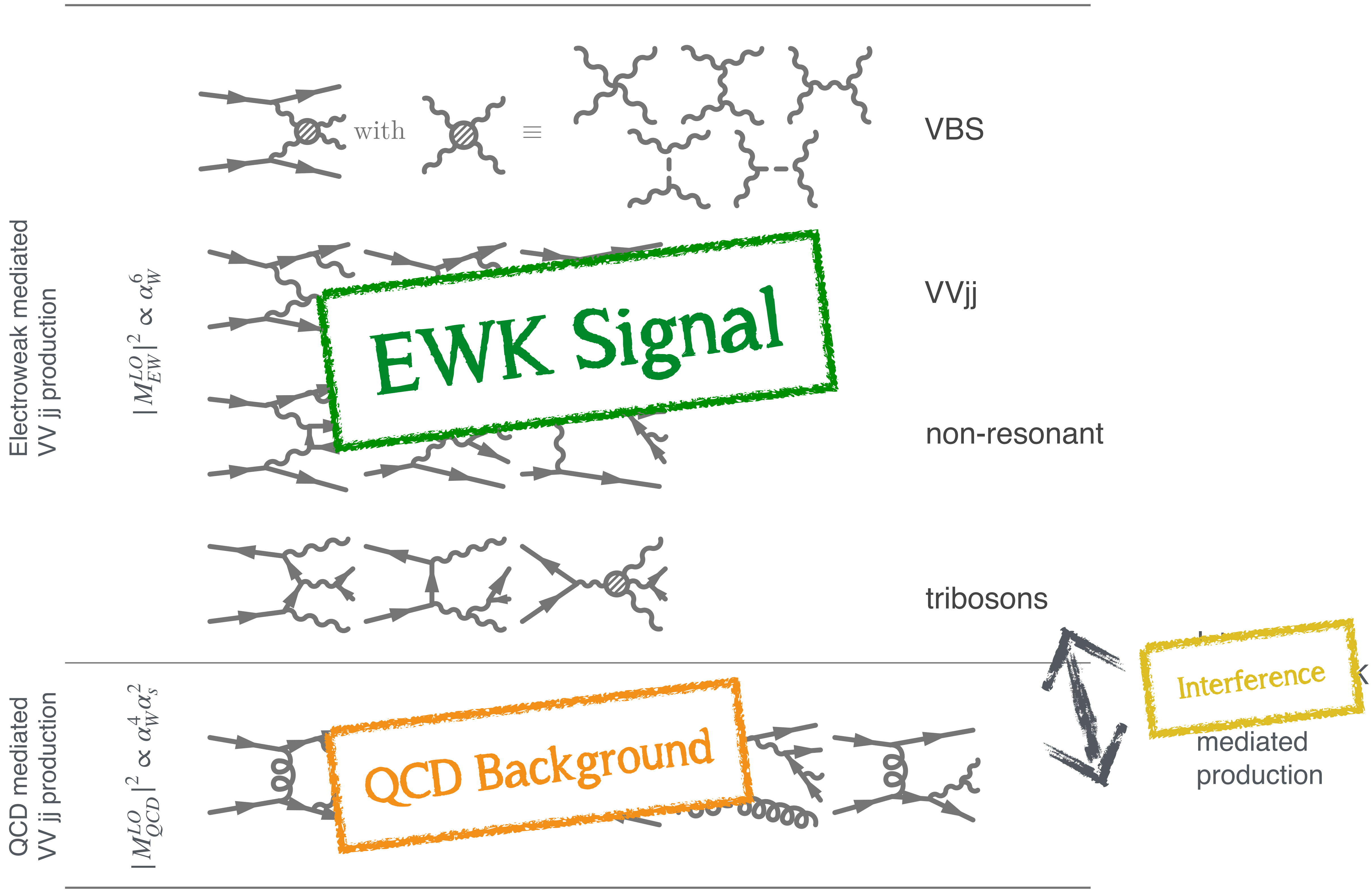
Interference between EWK and QCD mediated production

Signal definition



Electroweak mediated VV jj production

$|M^{LO}_{EW}|^2 \propto \alpha_W^6$

VBS

VVjj

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EWK Signal

QCD mediated VV jj production

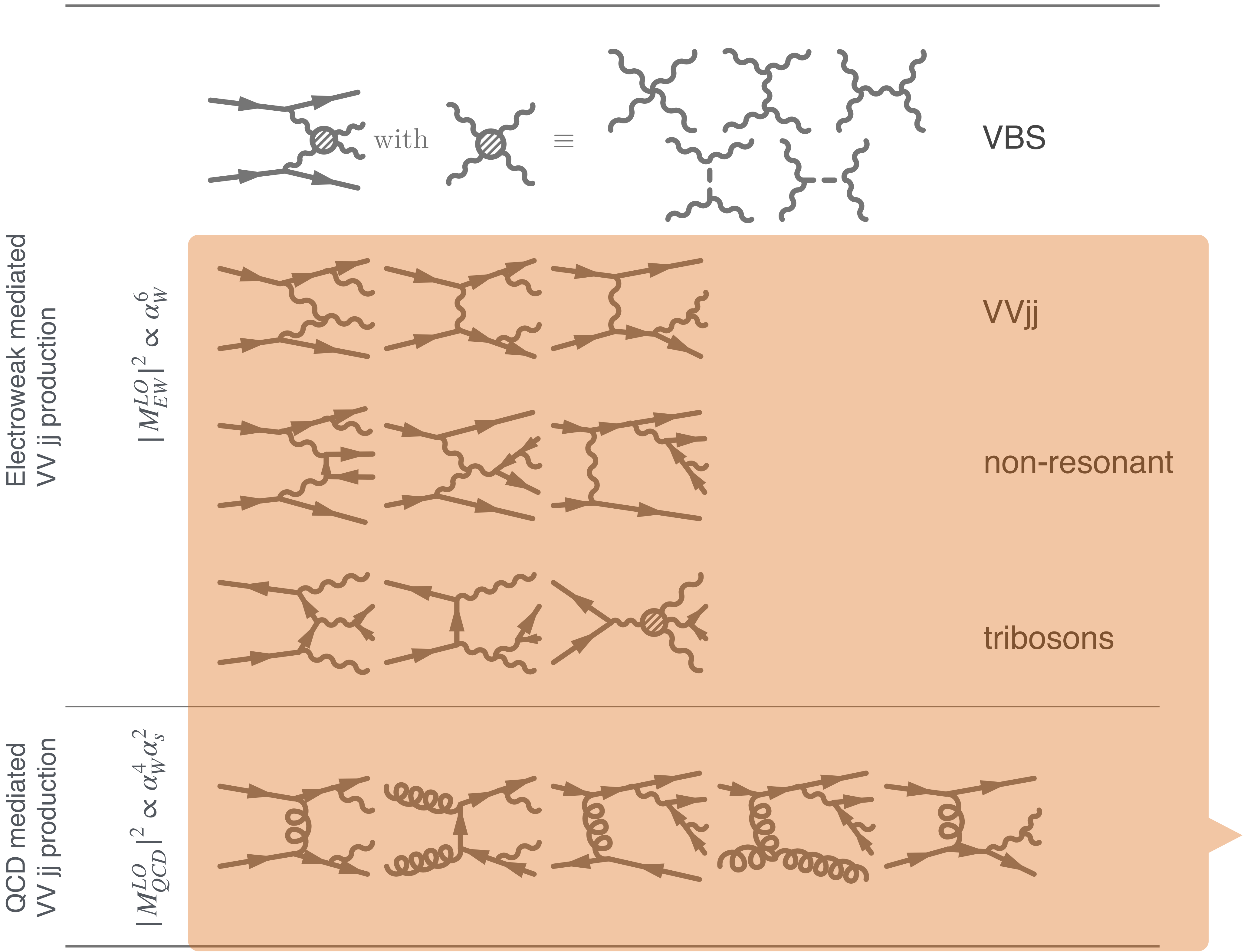
$|M^{LO}_{QCD}|^2 \propto \alpha_W^4 \alpha_s^2$

QCD Background

Interference

mediated
production

Signal definition



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Electroweak mediated VV jj production

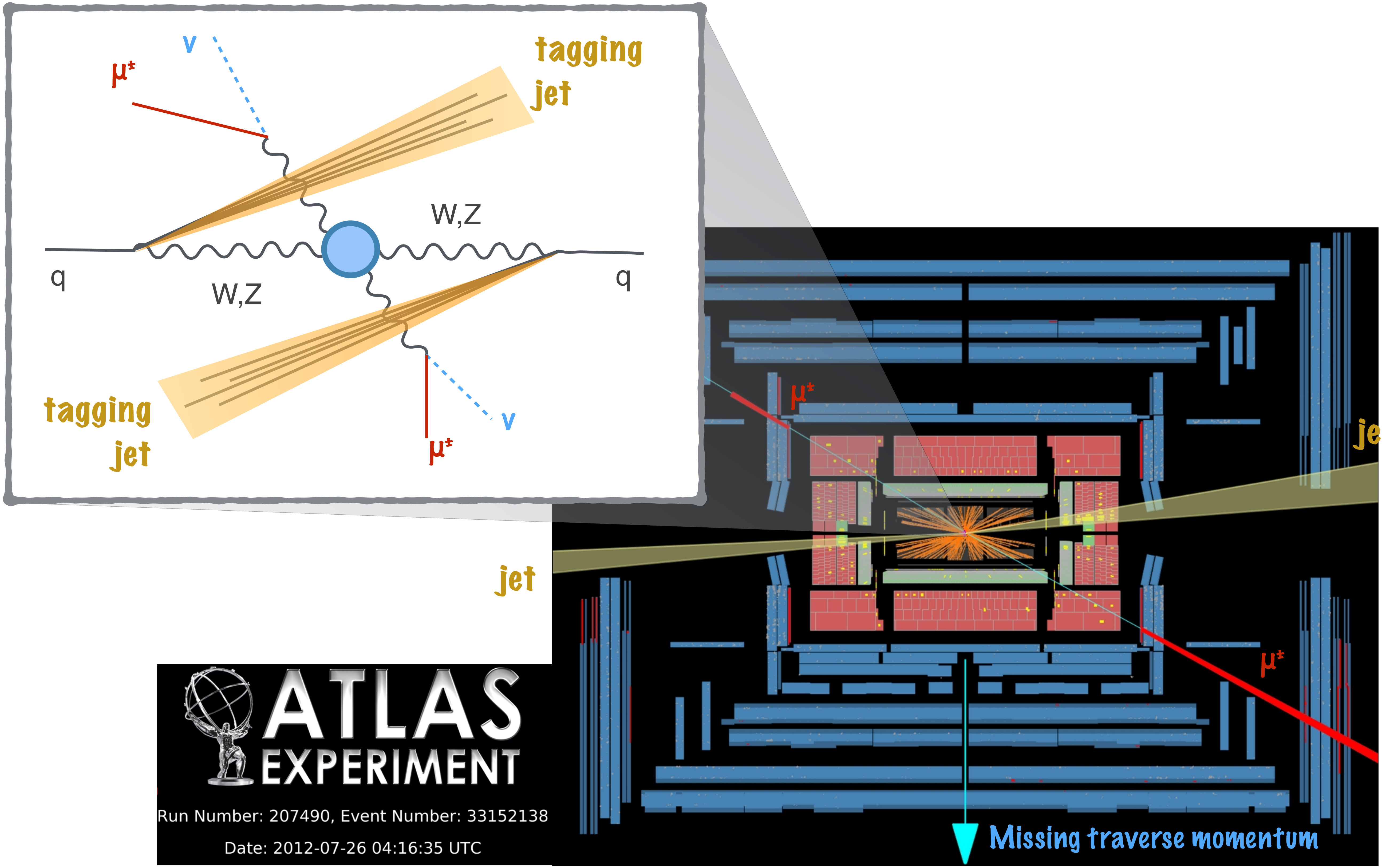
$|M_{EW}^{LO}|^2 \propto \alpha_W^6$

QCD mediated VV jj production

$|M_{QCD}^{LO}|^2 \propto \alpha_W^4 \alpha_s^2$

Can be reduced using the VBS topology

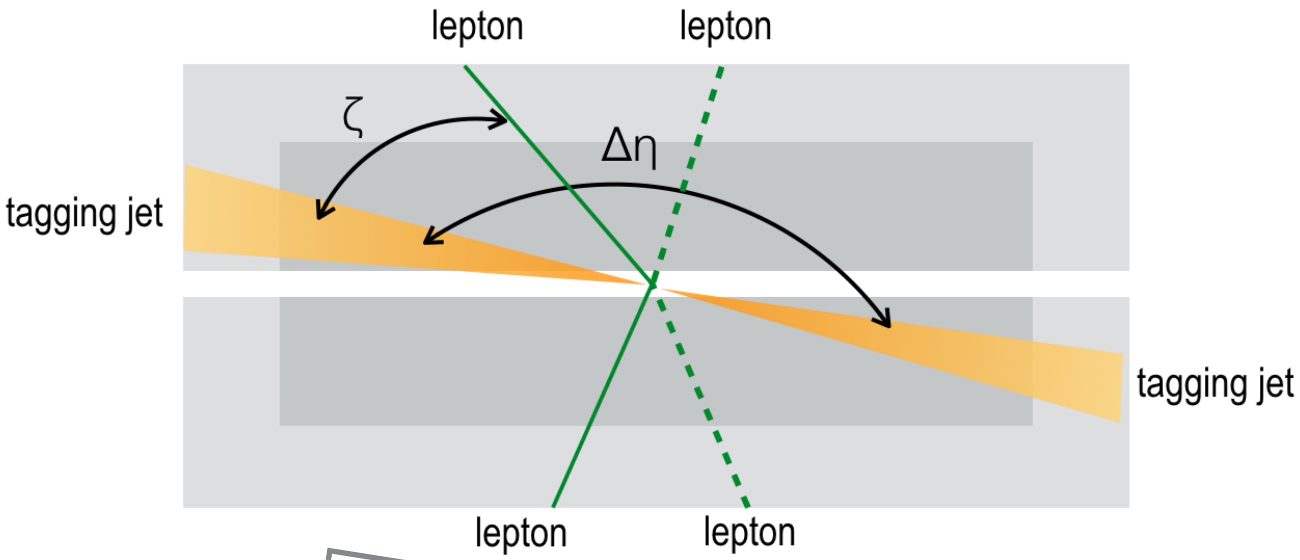
Vector Boson Scattering topology



Vector Boson Scattering topology

VBS at the LHC has a typical final state topology

- Two hadronic jets in forward and backward regions with very high energy (tagging jets)
- Two bosons produced ~back-to-back (lepton centrality ζ)
- Hadronic activity suppressed between the two jets due to absence of color flow between interacting partons → not used jet because of MC miss modeling



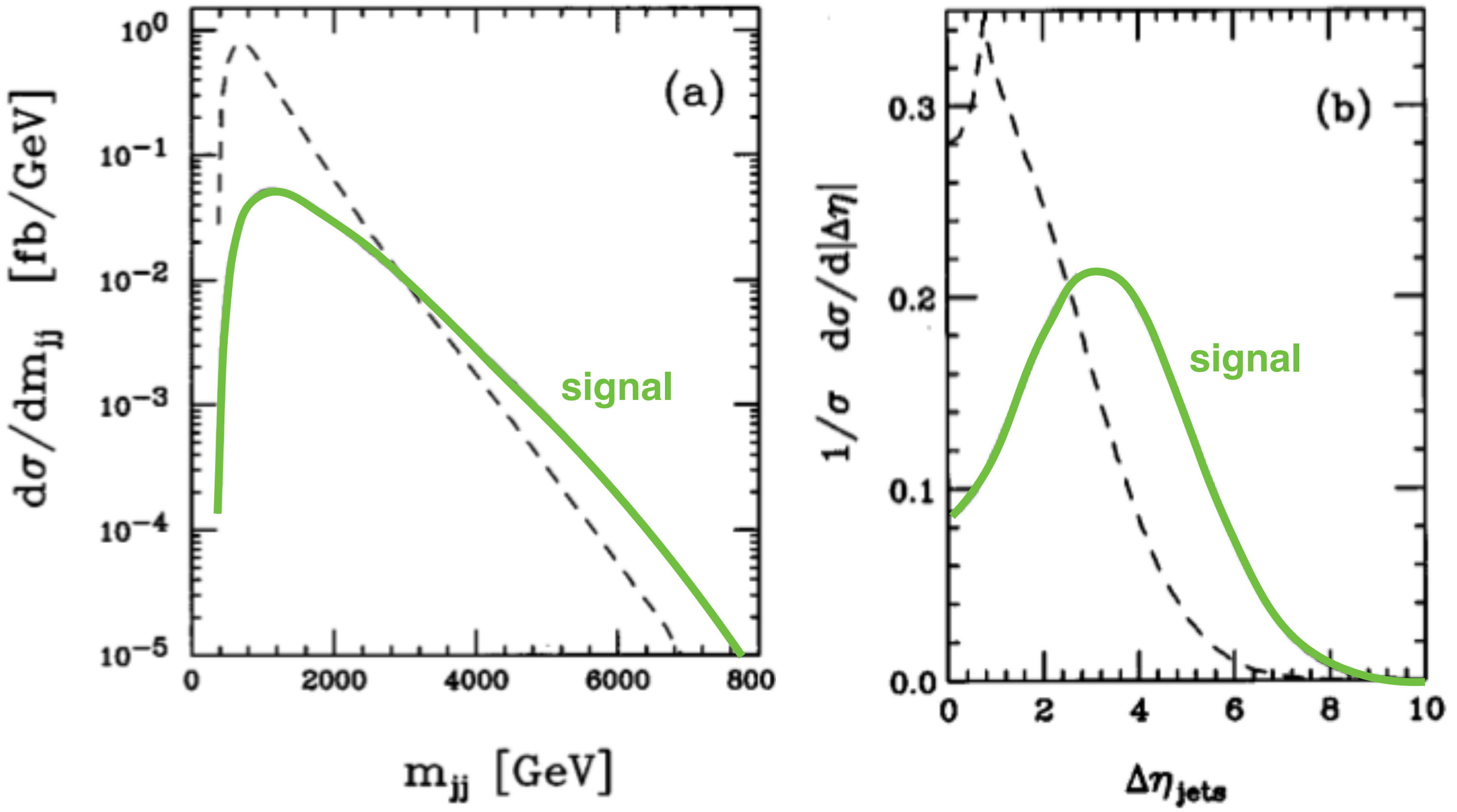

Probing color-singlet exchange in $Z+2$-jet events at the CERN LHC

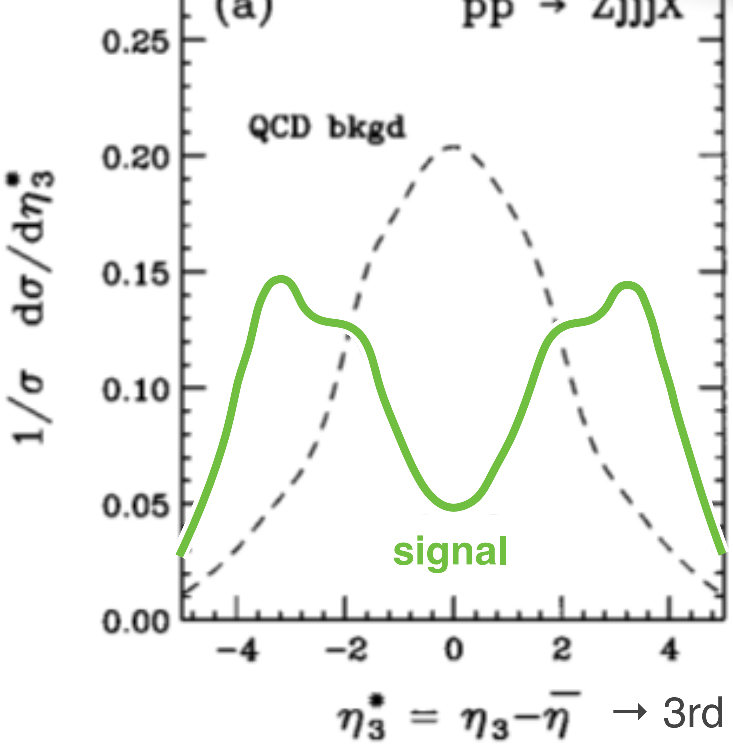
D. Rainwater
Department of Physics, University of Wisconsin, Madison, Wisconsin 53706

R. Szalapski
Theory Group, KEK, 1-1 Oho, Tsukuba, Ibaraki 305, Japan

D. Zeppenfeld
Department of Physics, University of Wisconsin, Madison, Wisconsin 53706

(Received 30 May 1996)





→ 3rd jet centrality

Zeppenfeld variable “centrality”

Vector Boson Scattering topology

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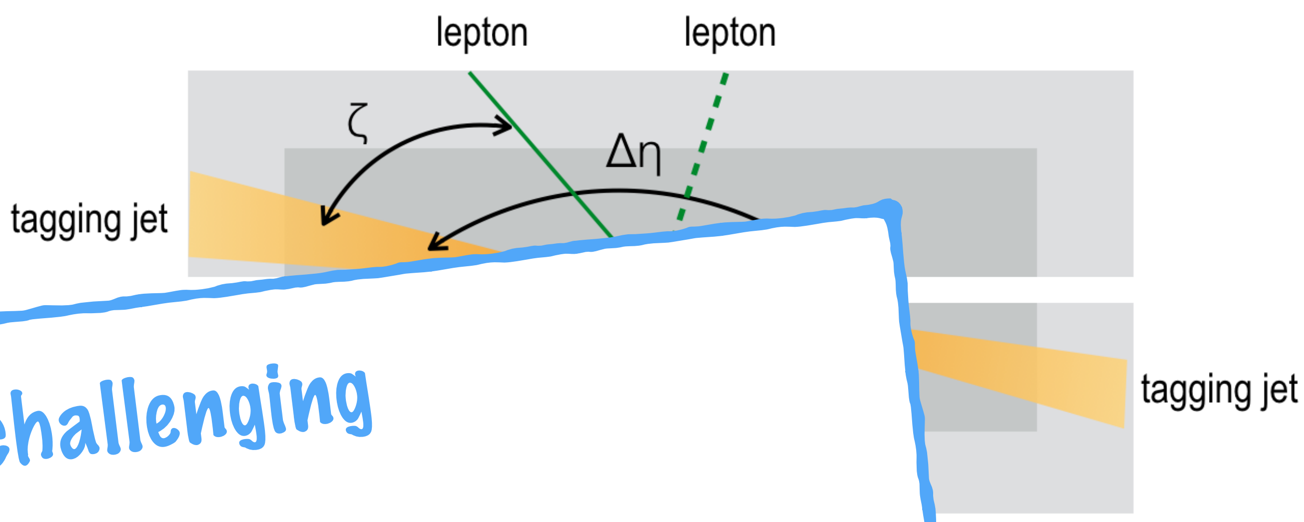
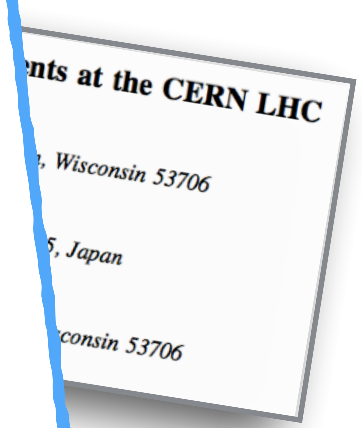


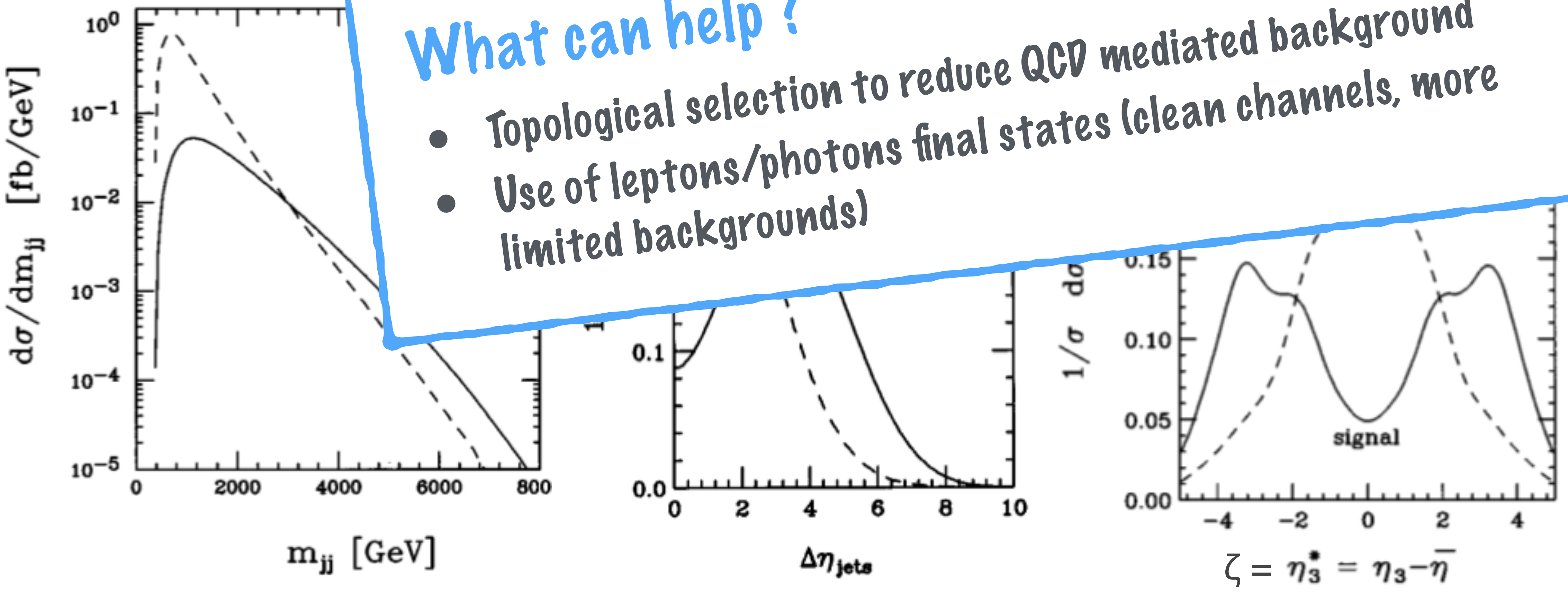
Experimentally VBS is challenging

- very low rate (O(fb))
- large background, generally from QCD mediated production of same final state

What can help ?

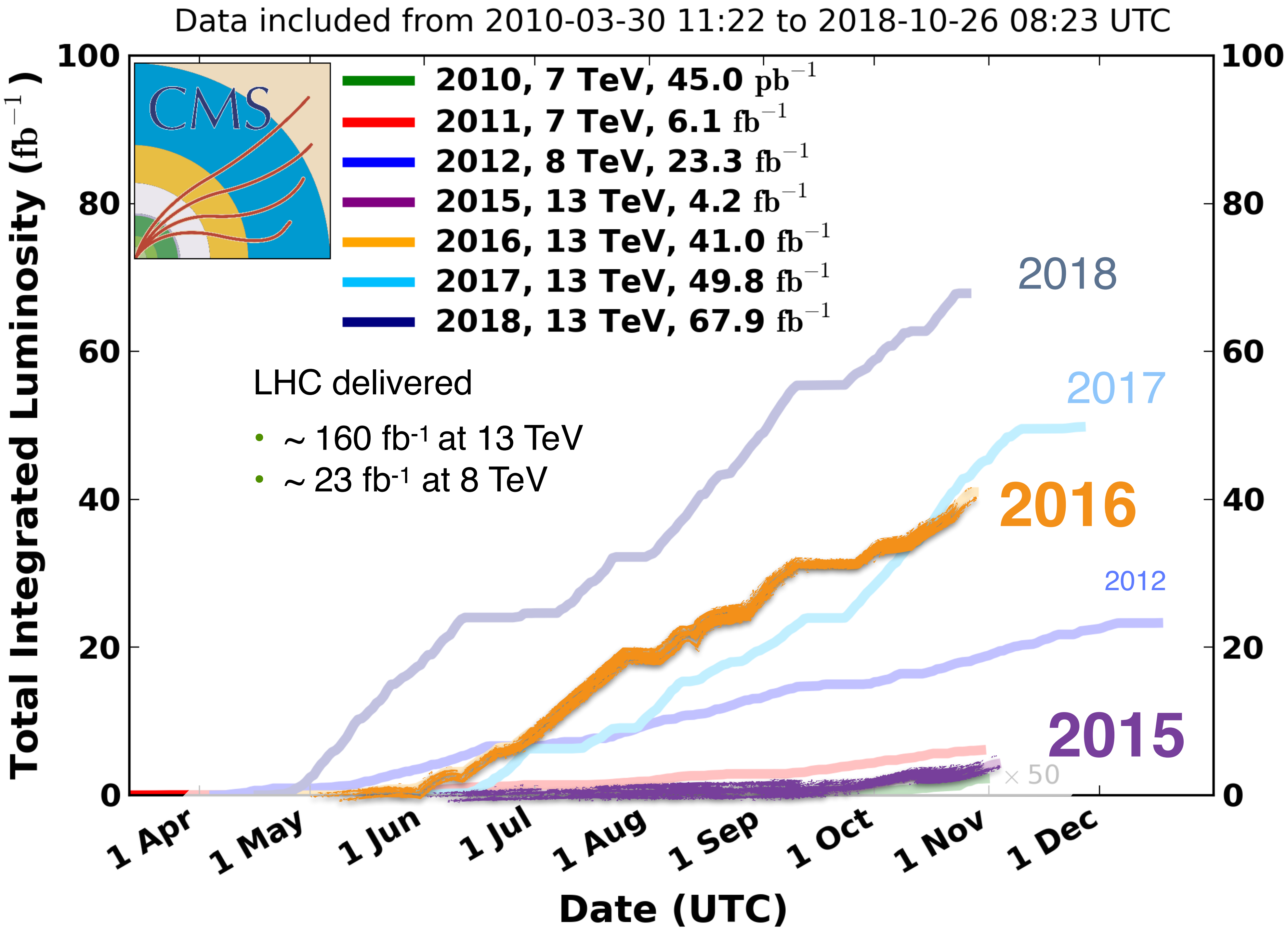
- Topological selection to reduce QCD mediated background
- Use of leptons/photons final states (clean channels, more limited backgrounds)





Zeppenfeld variable “centrality”

Experimental results



LHC delivered

- ~ 160 fb^{-1} at 13 TeV
- ~ 23 fb^{-1} at 8 TeV

Experimental results

- Datasets
  - ATLAS: 8 TeV (20.2 fb-1) and **13 TeV (36.1 fb-1)**
  - CMS: 8 TeV (19.7 fb-1) and **13 TeV (35.9 fb-1)**

- Channels studied

final state		CMS	ATLAS EXPERIMENT
$W^{\pm}W^{\pm}$	$l^{\pm}vl^{\pm}v$ jj	PRL 120 (2018) 081801	CONF-2018-030
$W^{\pm}Z$	$l^{\pm}vll$ jj	arXiv:1901.04060	arXiv:1812.09740
$W\gamma$	$l^{\pm}v\gamma$ jj	JHEP 06 (2017) 106	
$Z\gamma$	$ll\gamma$ jj	PLB 770 (2017) 380	JHEP07(2017)107
ZZ	llll jj	PLB 774 (2017) 682	
WV	$l^{\pm}vJ$ jj	PAS-SMP-18-006	arXiv:1905.07714
ZV	llJ jj		

Best EW/QCD

Largest cross section

very sensitive to new physics

First observation !!

Best EFT limits

ATLAS experimental results

$W^{\pm}Z \rightarrow \ell\nu\ell\ell$ [arXiv:1812.09740]

Fully leptonic decay channels

3 high p_T leptons (e, μ)

2ℓ of same flavour and opposite charge with p_T>15GeV

1ℓ with p_T>20 GeV

Z window (10 GeV)

$M_T(W)$>30GeV

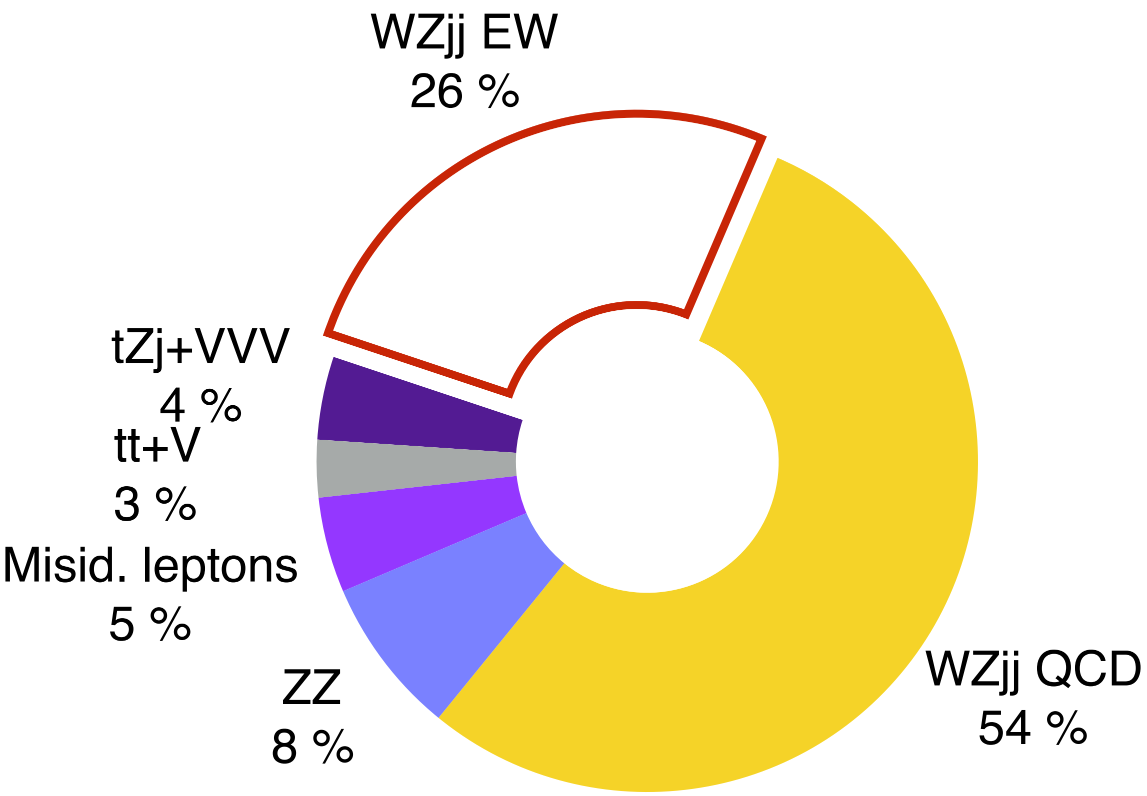
Bkg reduction

b-jet veto, 4 lepton veto

VBS topological

2 jets ($p_T > 40$ GeV)

$M_{jj} > 500$ GeV and jets in the opposite hemisphere



$W^{\pm}W^{\pm} \rightarrow \ell\nu\ell\nu$ [ATLAS-CONF-2018-030]

2 high p_T leptons (e, μ)

2ℓ of same charge p_T> 27 GeV

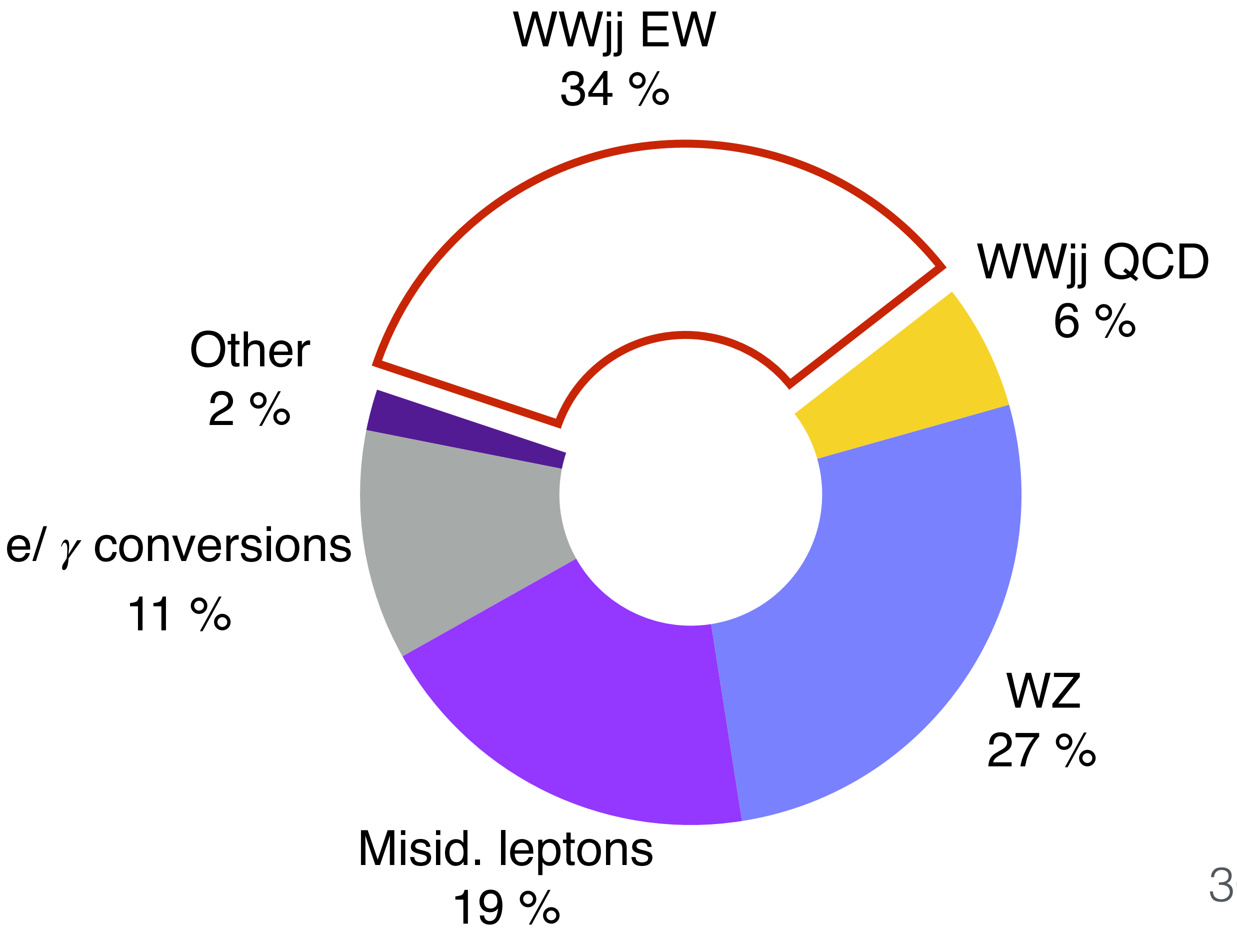
$m_{\ell\ell} > 20$ GeV

$E_T^{miss} > 30$ GeV

Veto ee pairs in Z mass window (15GeV), 3 lepton veto, b-jet veto

2 jets ($p_T > 65, 35$ GeV)

$M_{jj} > 500$ GeV and $|\Delta y_{jj}| > 2$



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2 high p_T leptons (e, μ)

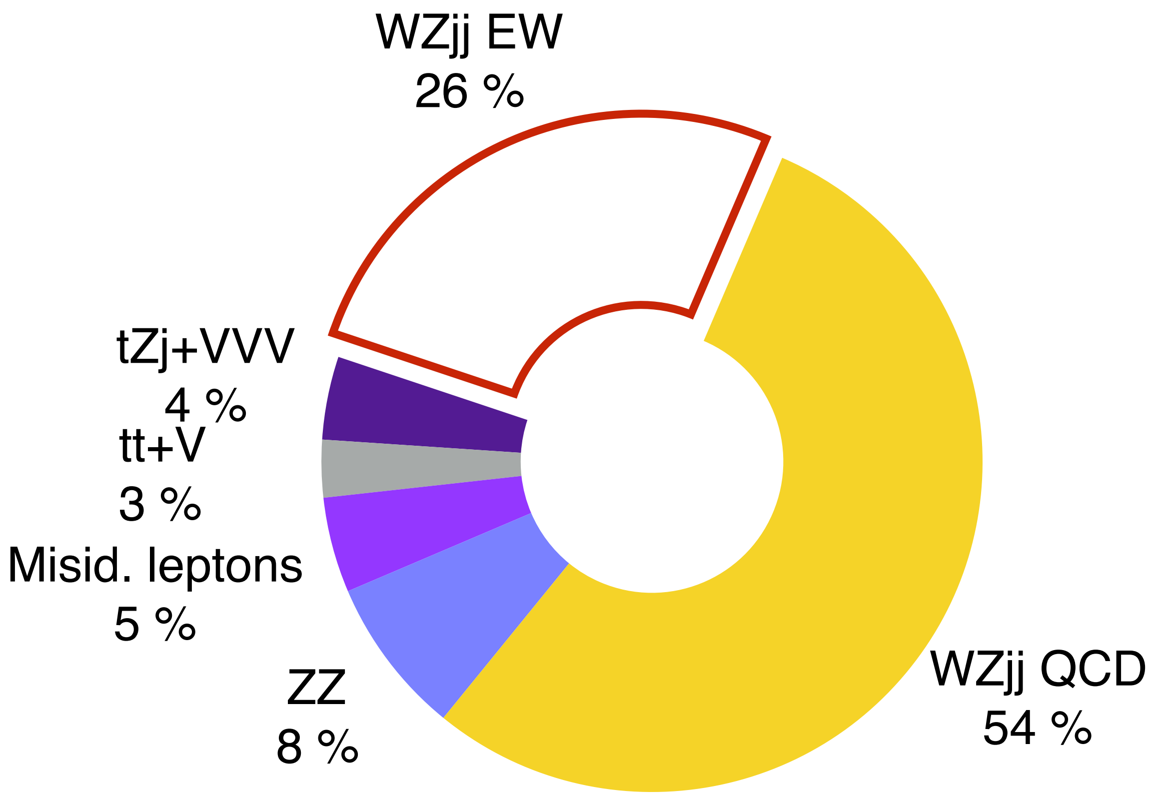
2ℓ of same charge p_T> 27 GeV

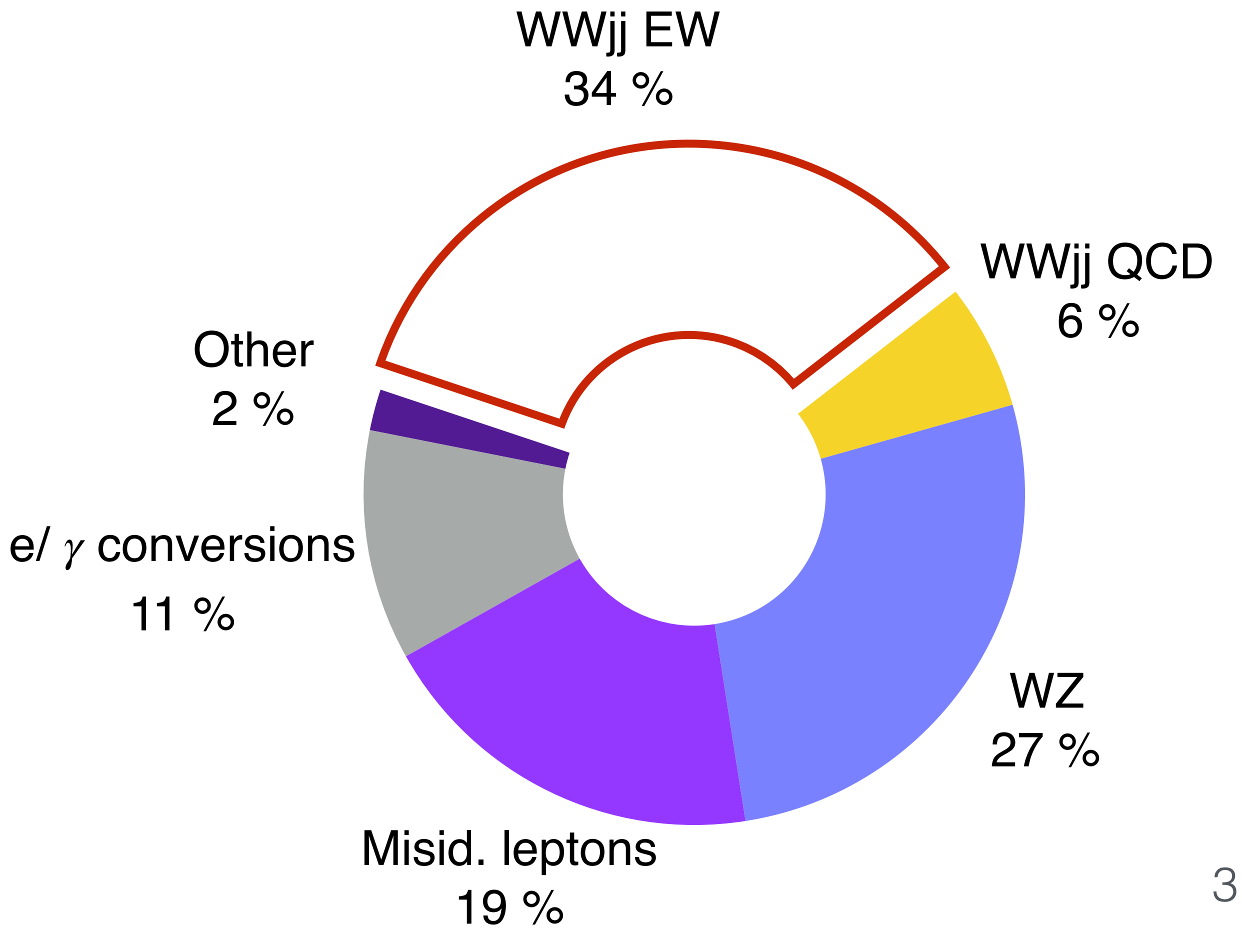
ow (15GeV), eto

V)

Δy_{jj} I > 2

- Small signal contribution (~30%)
  - **Exploit discriminant variables, BDT**
- Need to keep under control the backgrounds!
  - **Data Control Regions**





W±Z analysis

- Small signal contribution (~30%)
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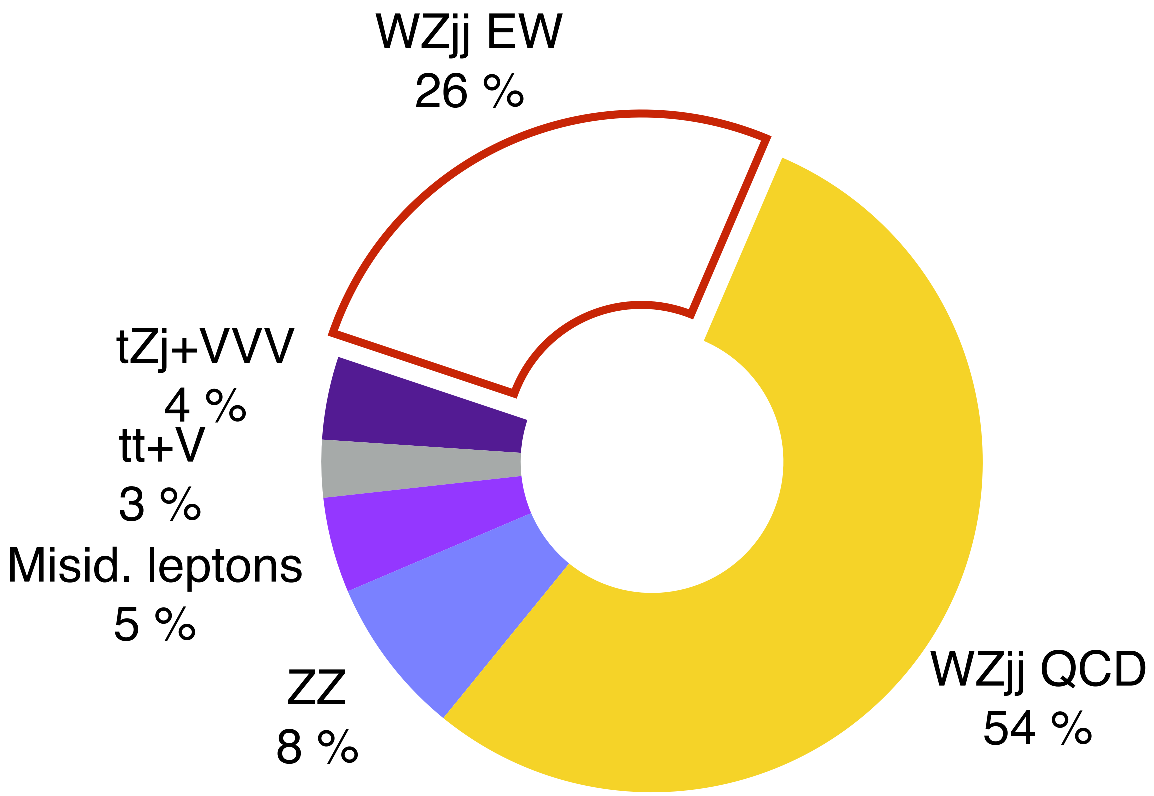


Control regions definition

WZ selection

2ℓ of same flavour and opposite charge with p_T>15GeV
1ℓ with p_T>20 GeV
Z window (10 GeV)
$M_T(W)$>30GeV

pass

2 jets (p_T > 40 GeV)

M_{jj} > 150 GeV and jets in the opposite hemisphere

pass

b-jet veto — fail → **b CR**

pass

4 lepton veto — fail → **ZZ CR**

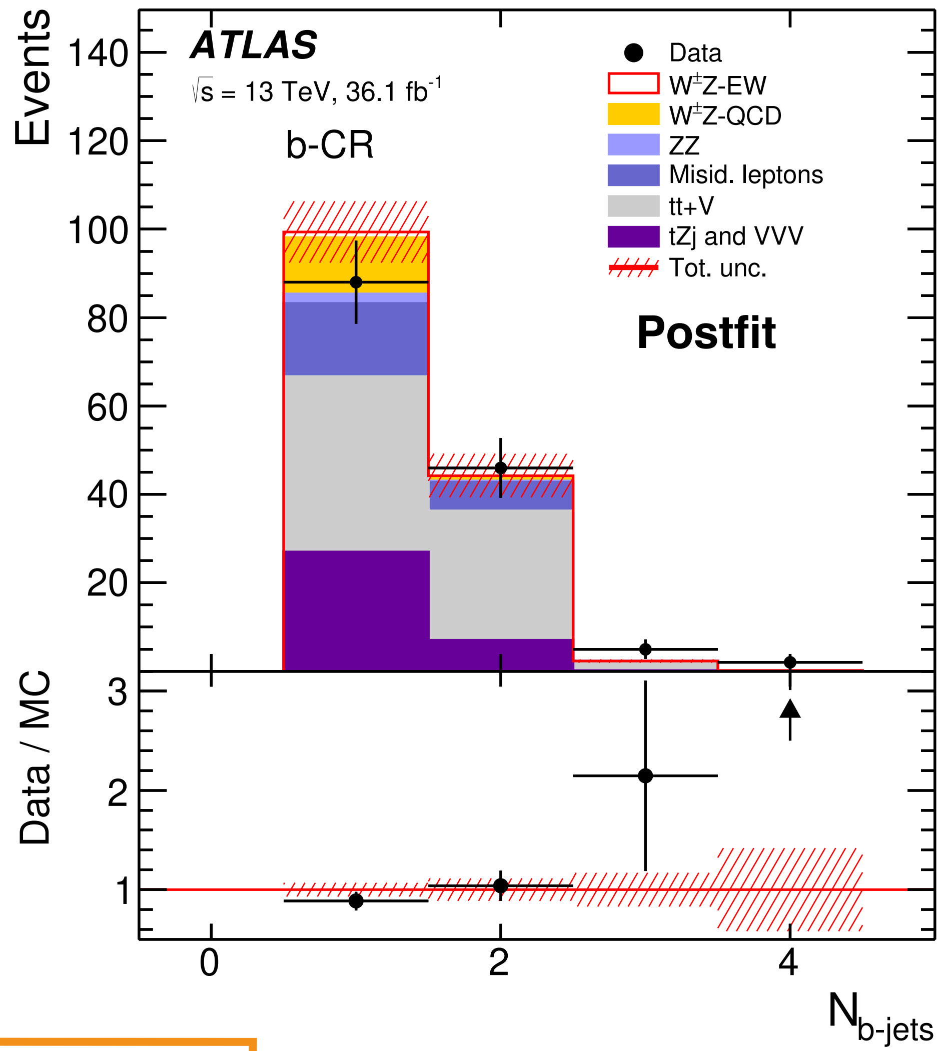
pass

Mjj > 500 GeV — fail → **QCD CR**

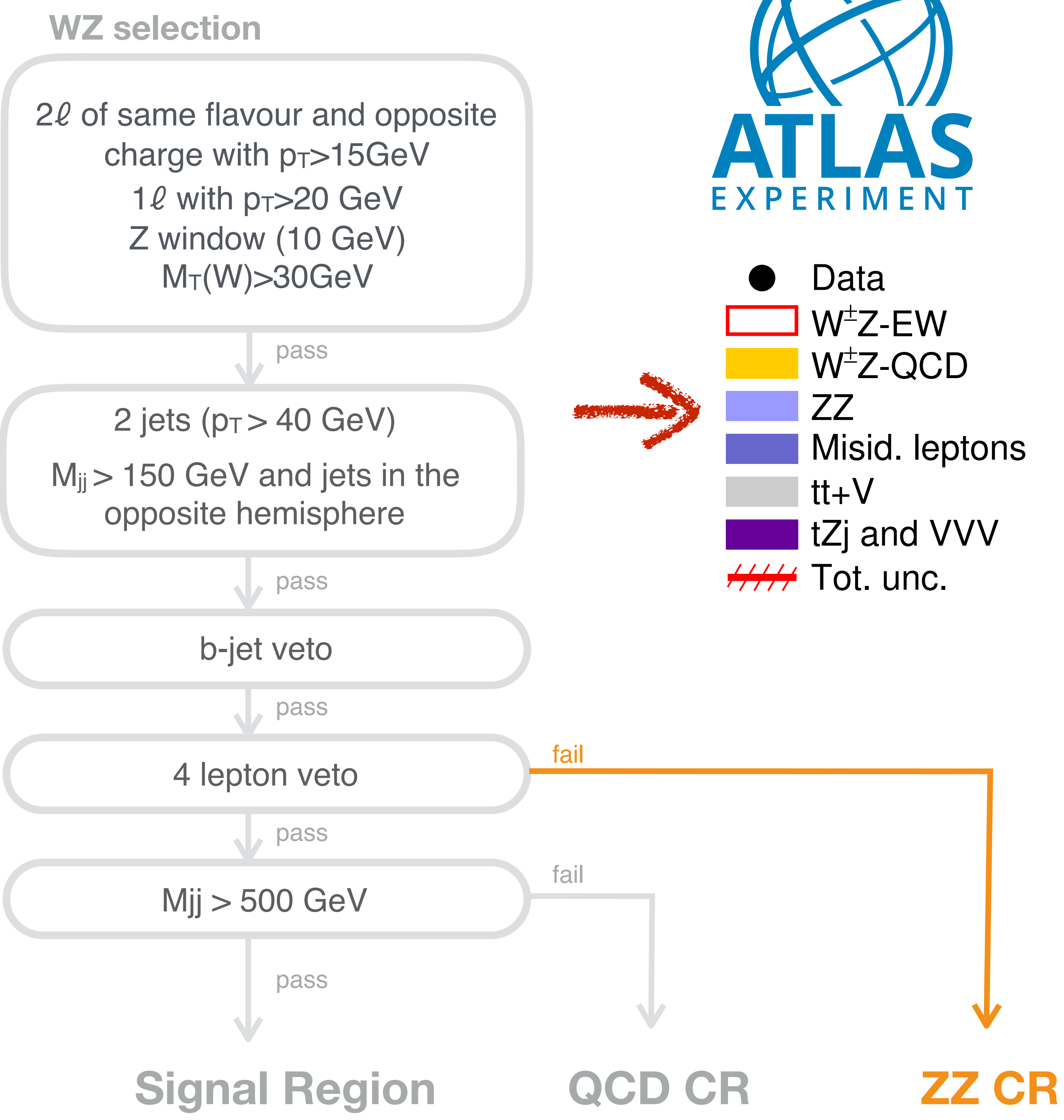
pass

Signal Region

● Data
☐ $W^{\pm}Z$-EW
🟨 $W^{\pm}Z$-QCD
■ ZZ
■ Misid. leptons
■ tt+V
■ tZj and VVV
▨ Tot. unc.



Control regions definition



WZ selection

2ℓ of same flavour and opposite charge with p_T>15GeV
1ℓ with p_T>20 GeV
Z window (10 GeV)
$M_T(W)$>30GeV

pass

2 jets (p_T > 40 GeV)

M_{jj} > 150 GeV and jets in the opposite hemisphere

pass

b-jet veto

pass

4 lepton veto

fail

pass

Mjj > 500 GeV

fail

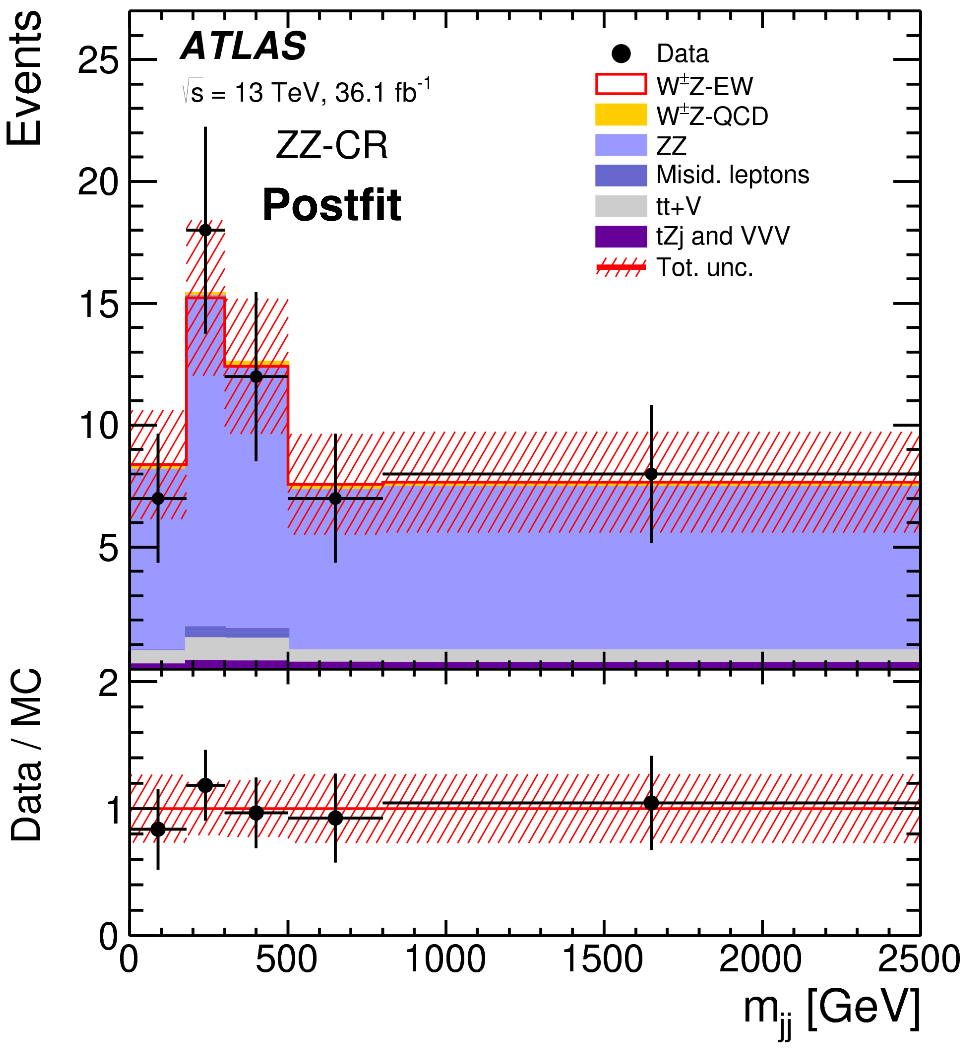
pass

Signal Region

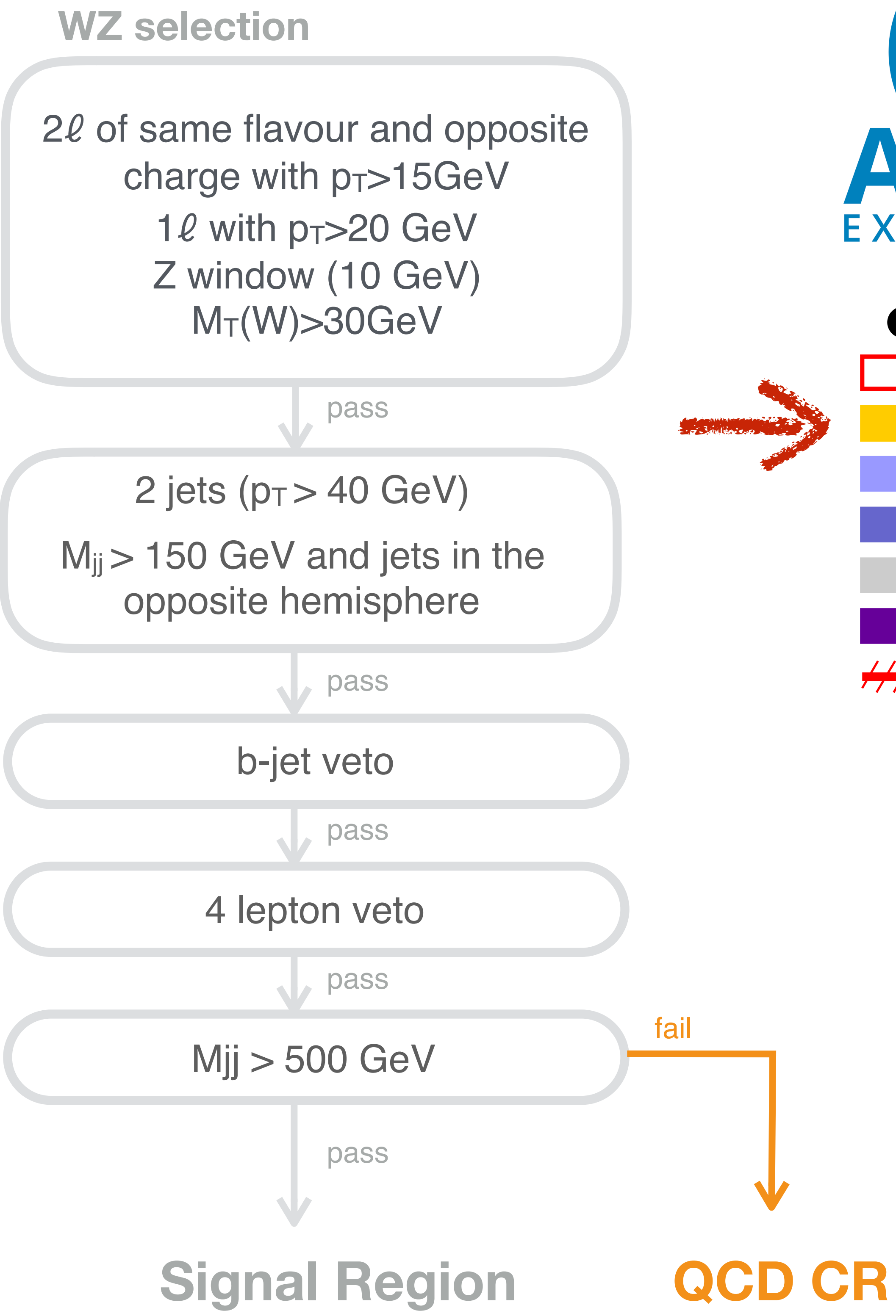
QCD CR

ZZ CR

● Data
☐ $W^{\pm}Z$-EW
🟨 $W^{\pm}Z$-QCD
🟦 ZZ
🟪 Misid. leptons
⬜ tt+V
🟪 tZj and VVV
▨ Tot. unc.



Control regions definition



WZ selection

2ℓ of same flavour and opposite charge with p_T>15GeV
1ℓ with p_T>20 GeV
Z window (10 GeV)
M_T(W)>30GeV

pass

2 jets (p_T > 40 GeV)

M_{jj} > 150 GeV and jets in the opposite hemisphere

pass

b-jet veto

pass

4 lepton veto

pass

Mjj > 500 GeV

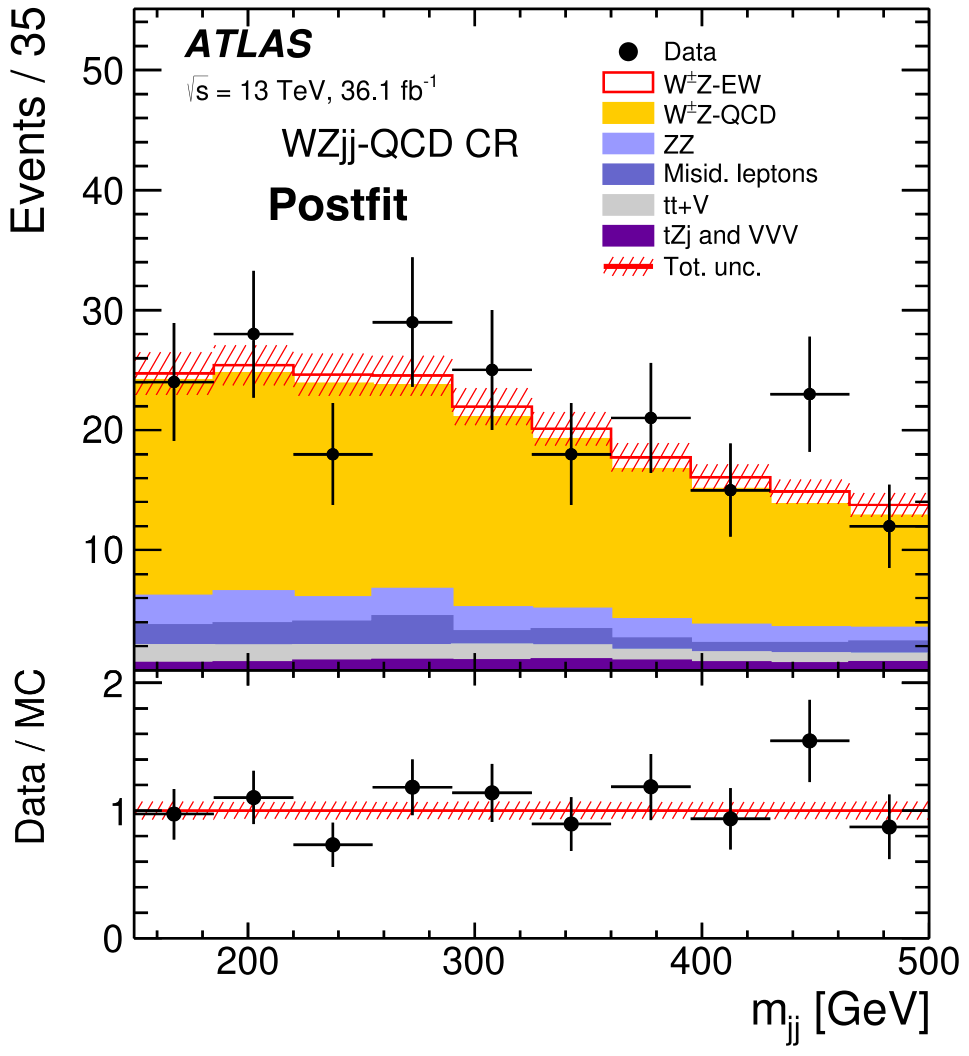
pass

fail

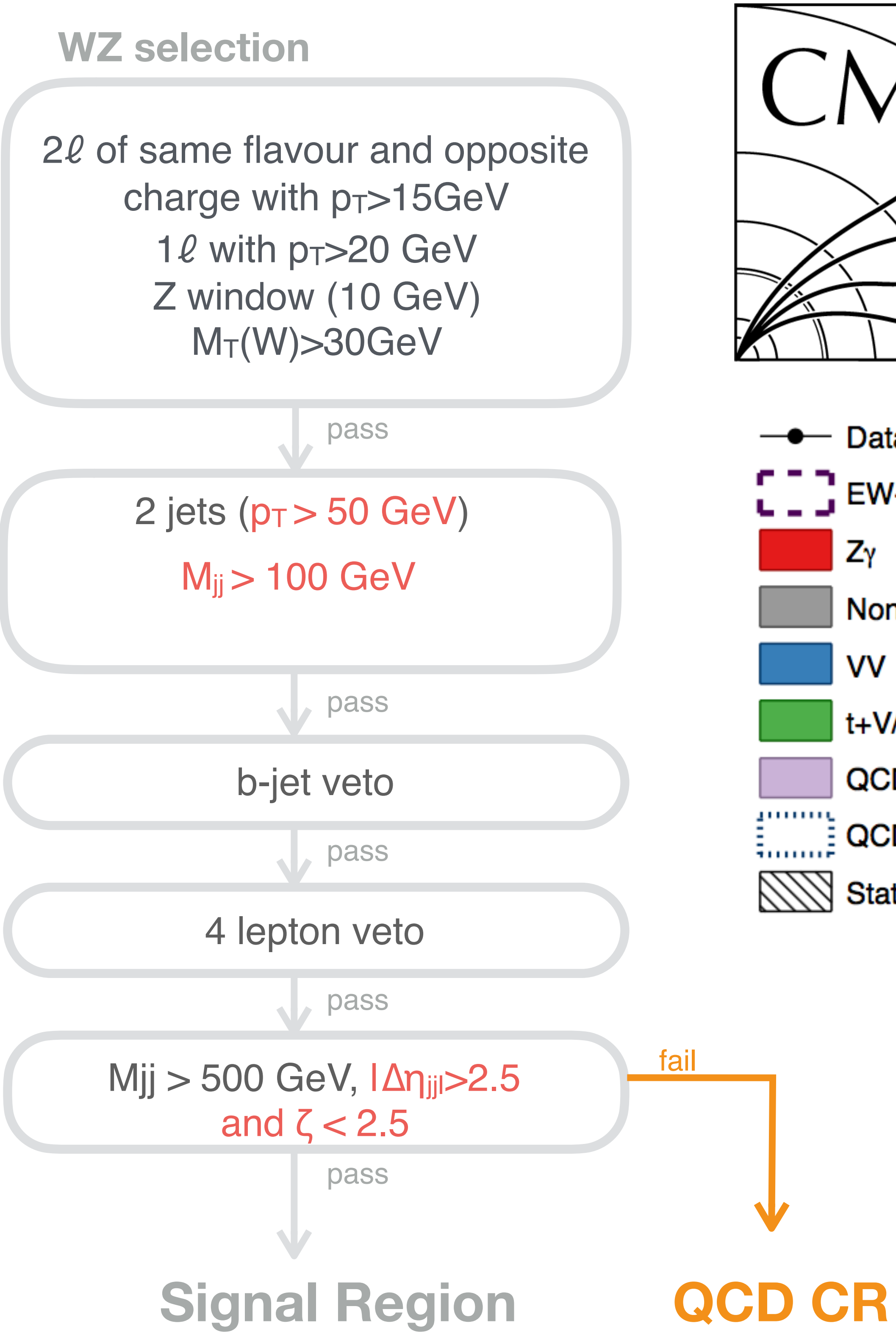
Signal Region

QCD CR

- ● Data
- ☐ $W^{\pm}Z$-EW
- 🟨 $W^{\pm}Z$-QCD
- 🟪 ZZ
- 🟦 Misid. leptons
- ⬜ tt+V
- 🟪 tZj and VVV
- ▨ Tot. unc.



Control regions definition



WZ selection

2ℓ of same flavour and opposite charge with p_T>15GeV
1ℓ with p_T>20 GeV
Z window (10 GeV)
M_T(W)>30GeV

pass

2 jets (p_T > 50 GeV)
M_{jj} > 100 GeV

pass

b-jet veto

pass

4 lepton veto

pass

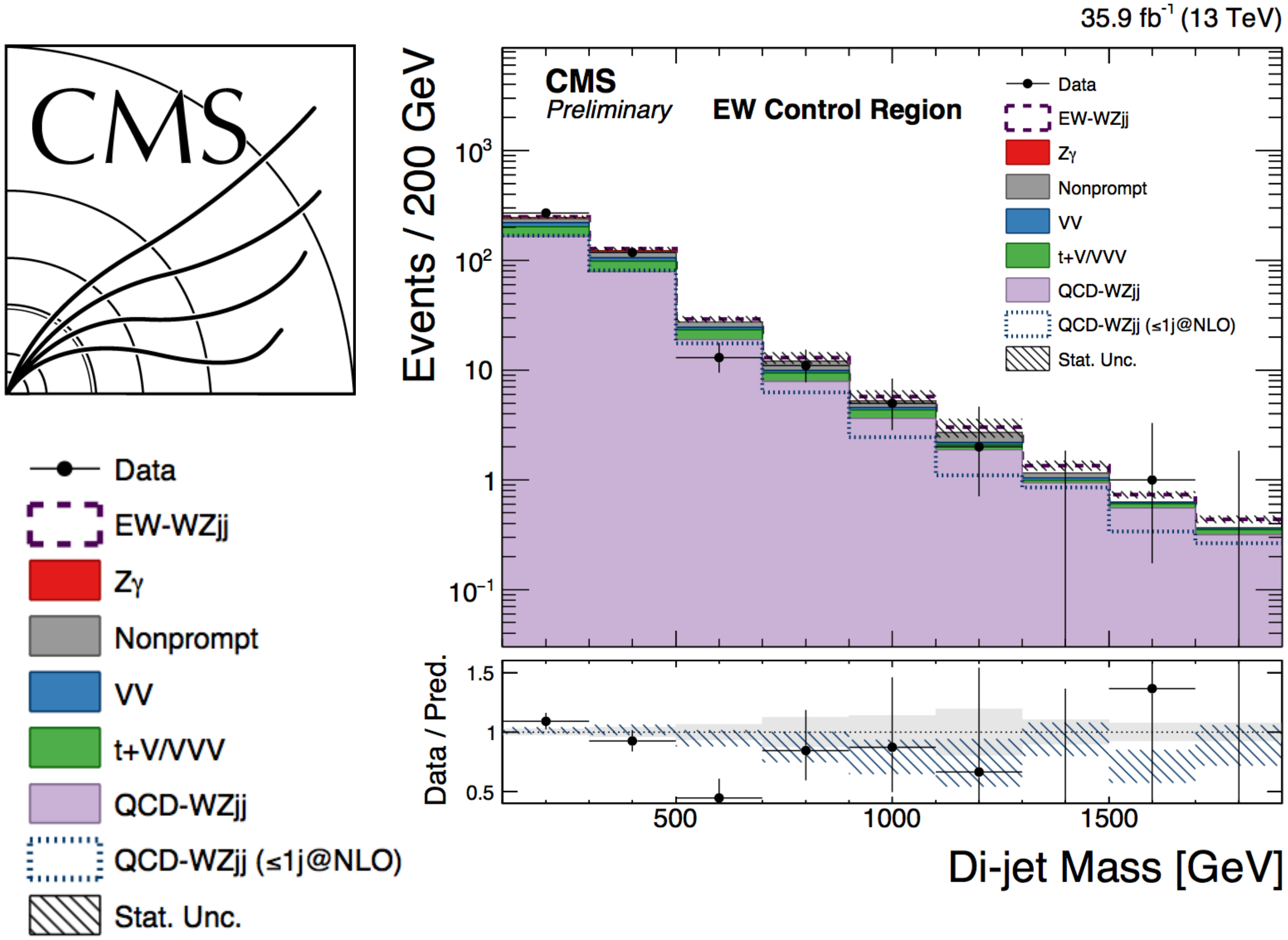
Mjj > 500 GeV, $|\Delta\eta_{jj}|$>2.5 and ζ < 2.5

pass

fail

Signal Region

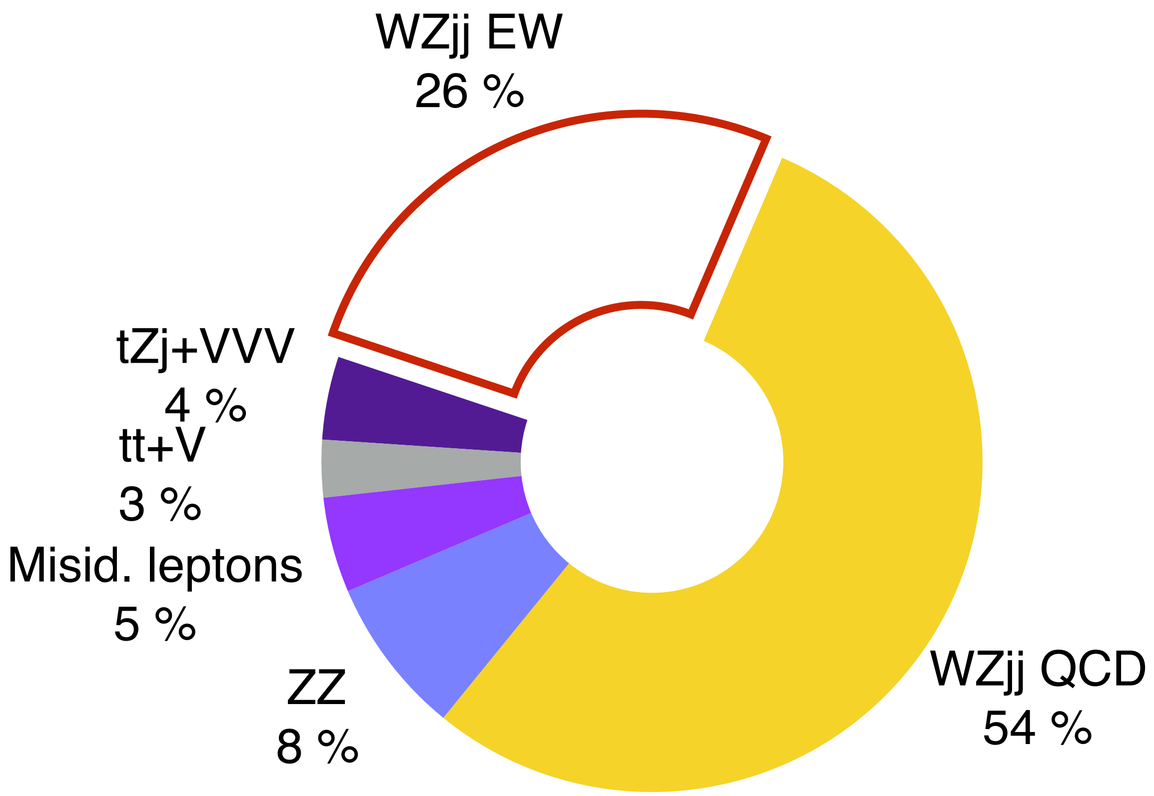
QCD CR



- Using this QCD CR definition allows to verify the high Mjj mass modeling

W±Z analysis

- Small signal contribution (~30%)
  - **Multivariate analysis, discriminant variables**
- Need to keep under control the backgrounds!
  - **Data Control Regions**



Multivariate analysis

Full set of BDT variables

m_{jj}, N_{jets}, p_T^{j1},p_T^{j2}, η^{j1}, $\Delta\eta_{jj}$, $\Delta\phi_{jj}$
$|y_{l,W} - y_Z|$, p_T^W , p_T^W, η^W, m_T^{WZ}
$\Delta R(j1, Z)$, R_{pT}^{hard}, ζ_{lep}

- Boosted Decision Tree used in signal region to distinguish between WZjj-EW and backgrounds

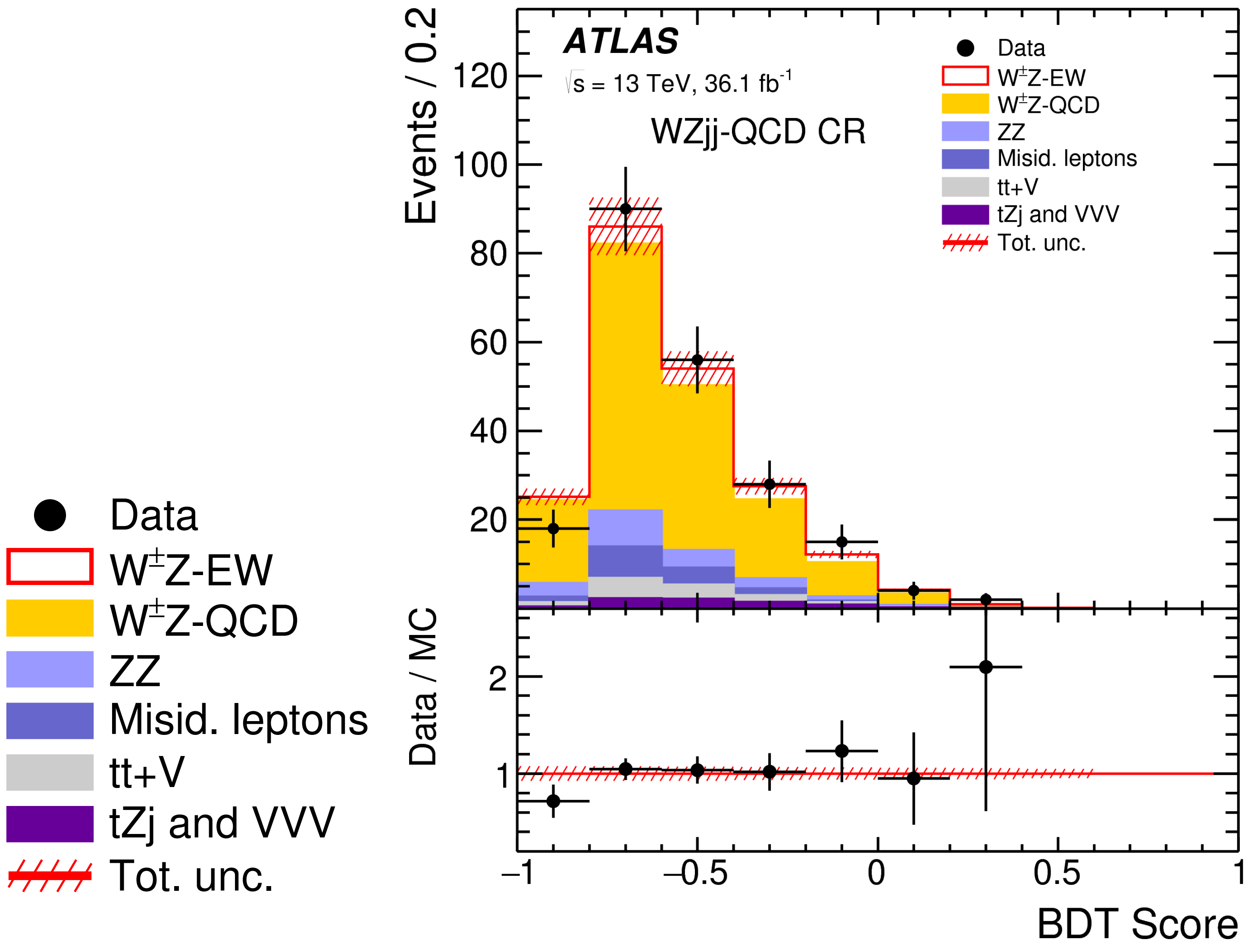
$$\zeta_{lep} = min(\Delta\eta_-, \Delta\eta_+)$$
$$\Delta\eta_- = min(\eta_l^W, \eta_{l1}^Z, \eta_{l2}^Z) - min(\eta_{j1}, \eta_{j2})$$
$$\Delta\eta_+ = max(\eta_{j1}, \eta_{j2}) - max(\eta_l^W, \eta_{l1}^Z, \eta_{l2}^Z)$$

$$R_{p_T}^{hard} = \frac{(\sum_{l,j} p)_T}{\sum_{l,j} p_T}$$

- 15 variables that have a characteristic signature.
  - In order of importance:
    1. $|y_Z - y_{\ell,w}|$
    2. ζ_{lep}
    3. R_{pT} har
    4. Jets multiplicity ($p_T > 25$ GeV)
    5. $\Delta\phi_{jj}$

- Trained on simulation events, to separate WZjj-EW from backgrounds

- Description of BDT score controlled in QCD-CR
  - good agreement observed with data

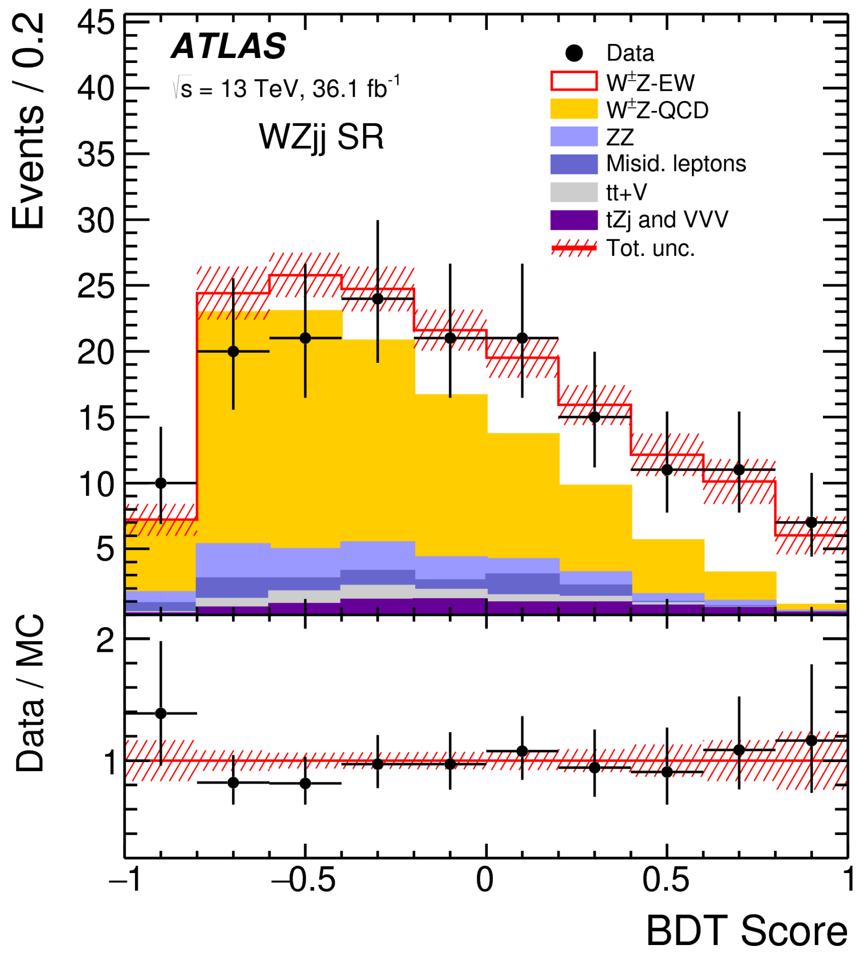


Signal extraction

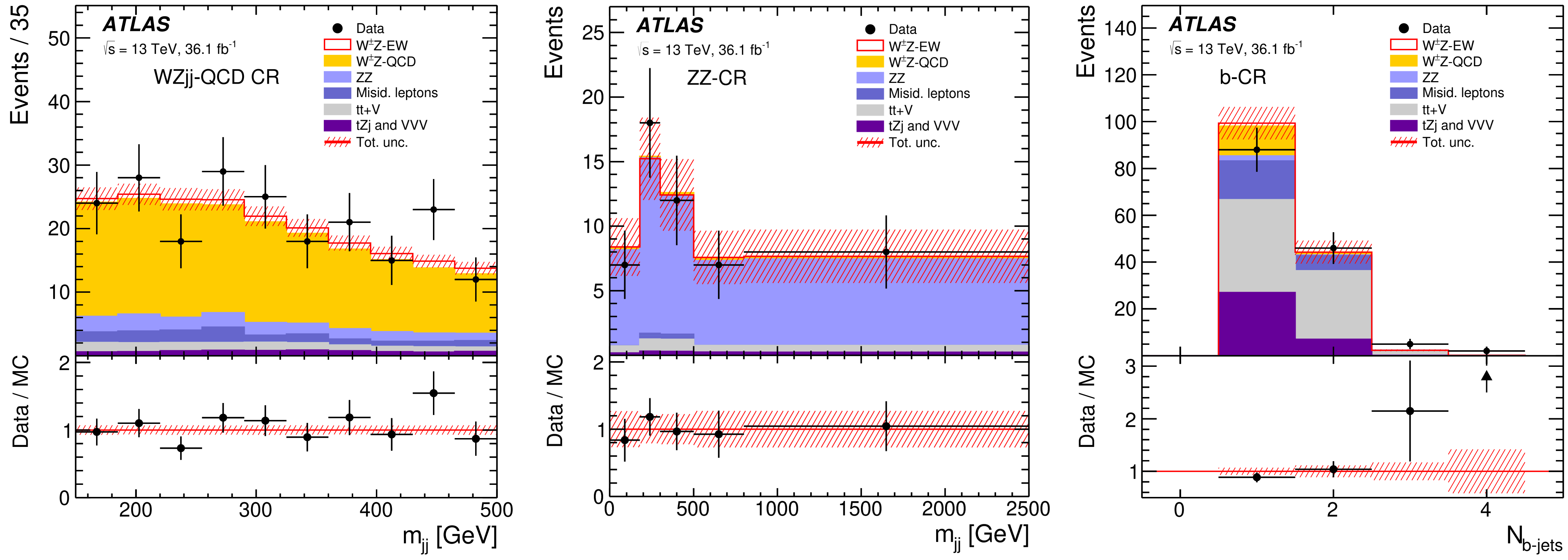
- Simultaneous template fit of BDT score in signal region and 3 different control regions
    - Signal and background normalization extracted from data
    - Shape fit → Consider uncertainties affecting shape and normalization

● Data
▭ $W^{\pm}Z$-EW
🟨 $W^{\pm}Z$-QCD
🟦 ZZ
🟦 Misid. leptons
⬜ tt+V
🟪 tZj and VVV
▨ Tot. unc.

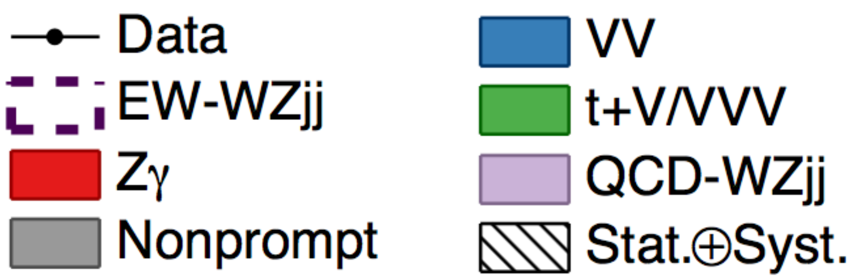
Signal region



Control regions

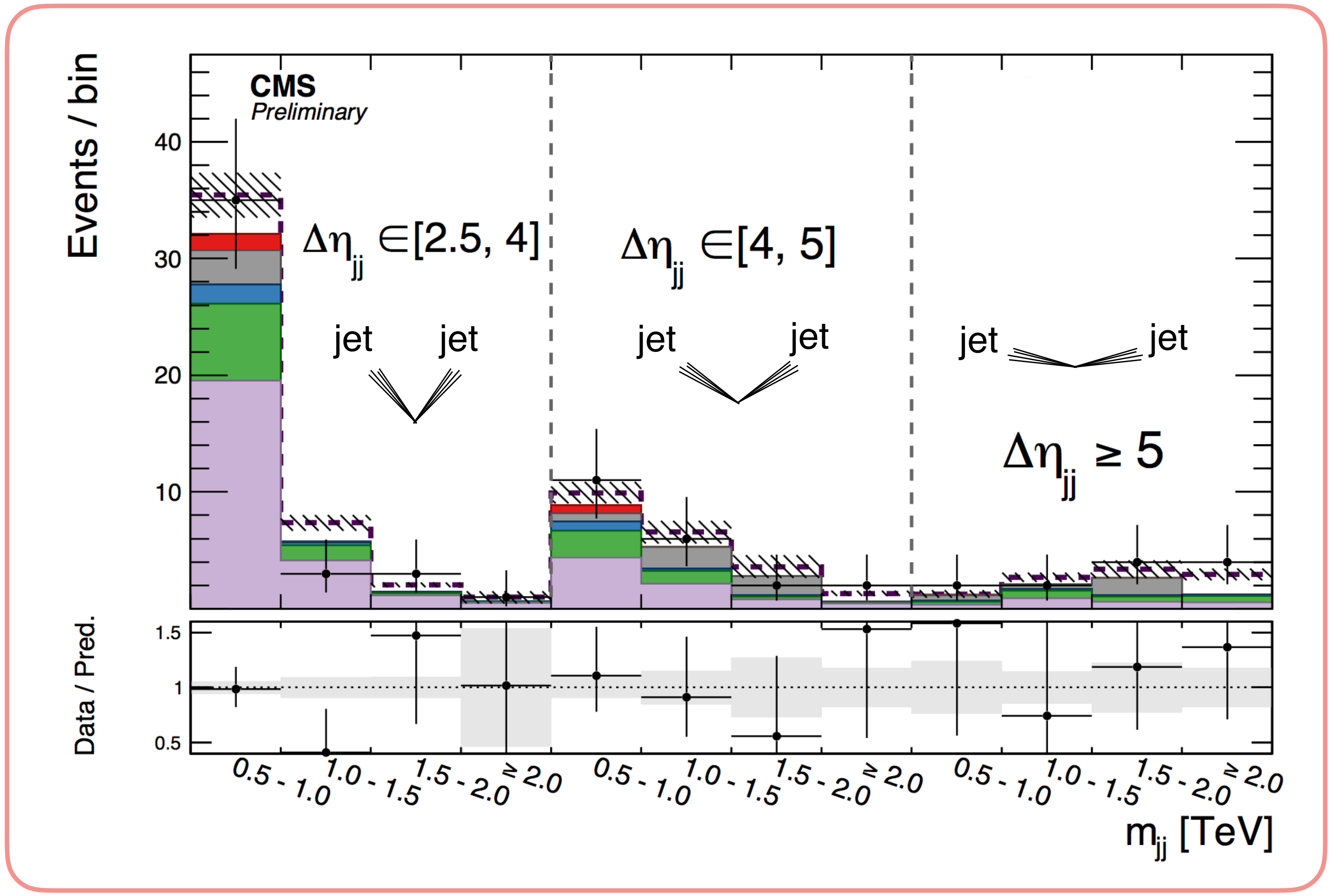


Signal extraction

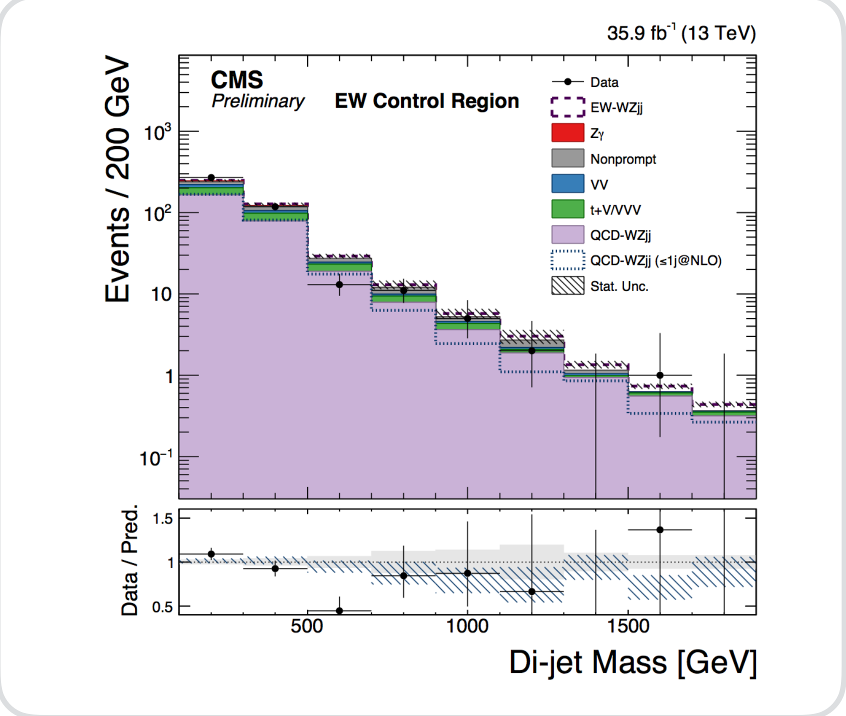


- Simultaneous template fit Mjj and Δηjj
  - separate by lepton flavors
- Signal and background normalization extracted from data
  - Shape fit → Consider uncertainties affecting shape and normalization

2D Signal region

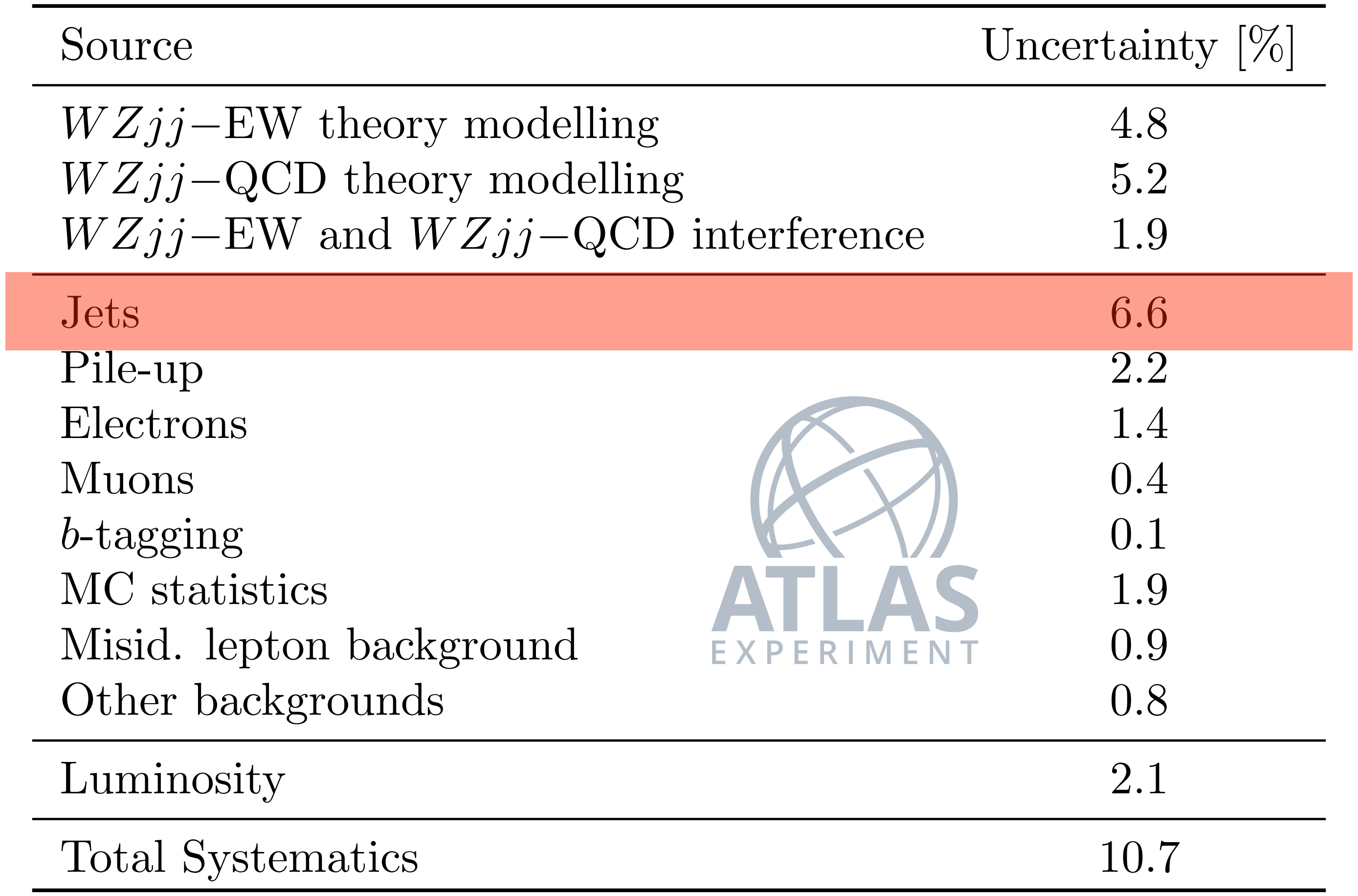


QCD Control region

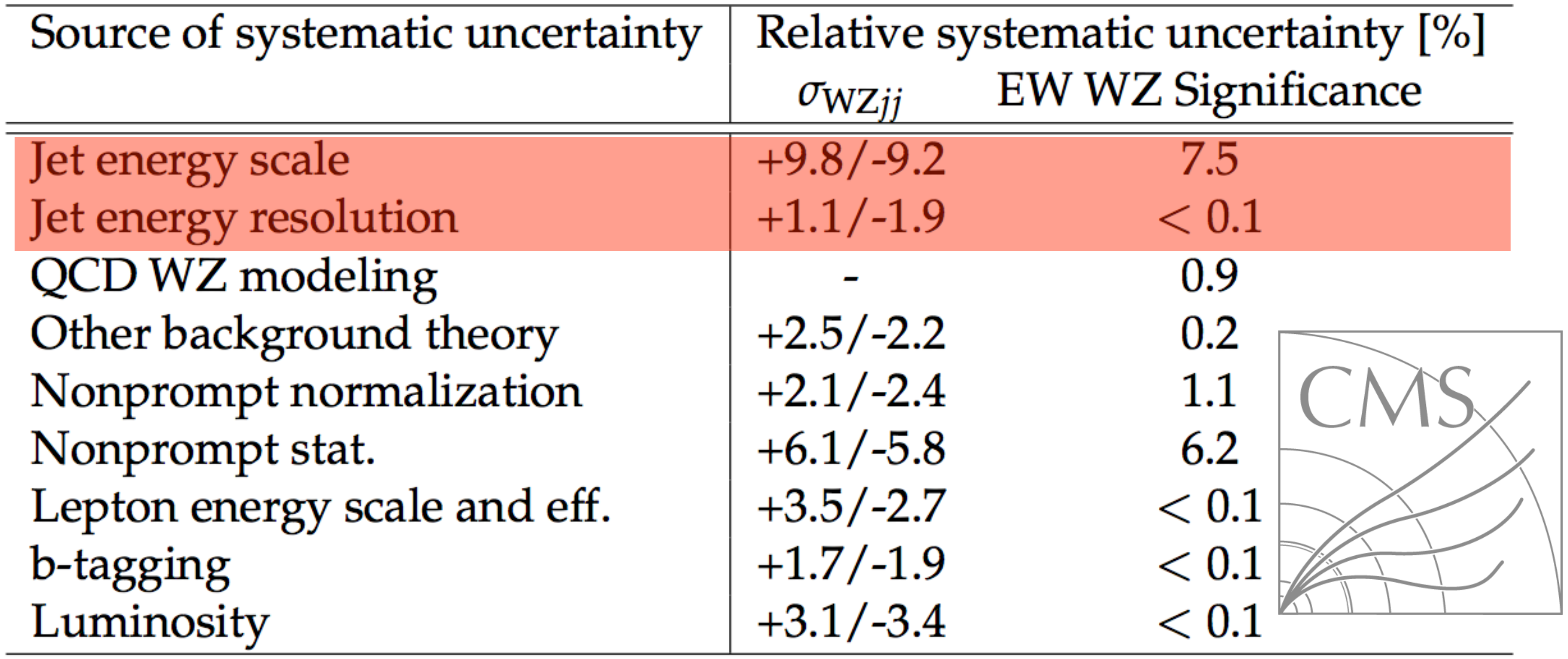


Systematics uncertainties

Jet reconstruction and calibration



Source	Uncertainty [%]
$WZjj$–EW theory modelling	4.8
$WZjj$–QCD theory modelling	5.2
$WZjj$–EW and $WZjj$–QCD interference	1.9
Jets	6.6
Pile-up	2.2
Electrons	1.4
Muons	0.4
b-tagging	0.1
MC statistics	1.9
Misid. lepton background	0.9
Other backgrounds	0.8
Luminosity	2.1
Total Systematics	10.7



Source of systematic uncertainty	Relative systematic uncertainty [%]	
	σ_{WZjj}	EW WZ Significance
Jet energy scale	+9.8/-9.2	7.5
Jet energy resolution	+1.1/-1.9	< 0.1
QCD WZ modeling	-	0.9
Other background theory	+2.5/-2.2	0.2
Nonprompt normalization	+2.1/-2.4	1.1
Nonprompt stat.	+6.1/-5.8	6.2
Lepton energy scale and eff.	+3.5/-2.7	< 0.1
b-tagging	+1.7/-1.9	< 0.1
Luminosity	+3.1/-3.4	< 0.1

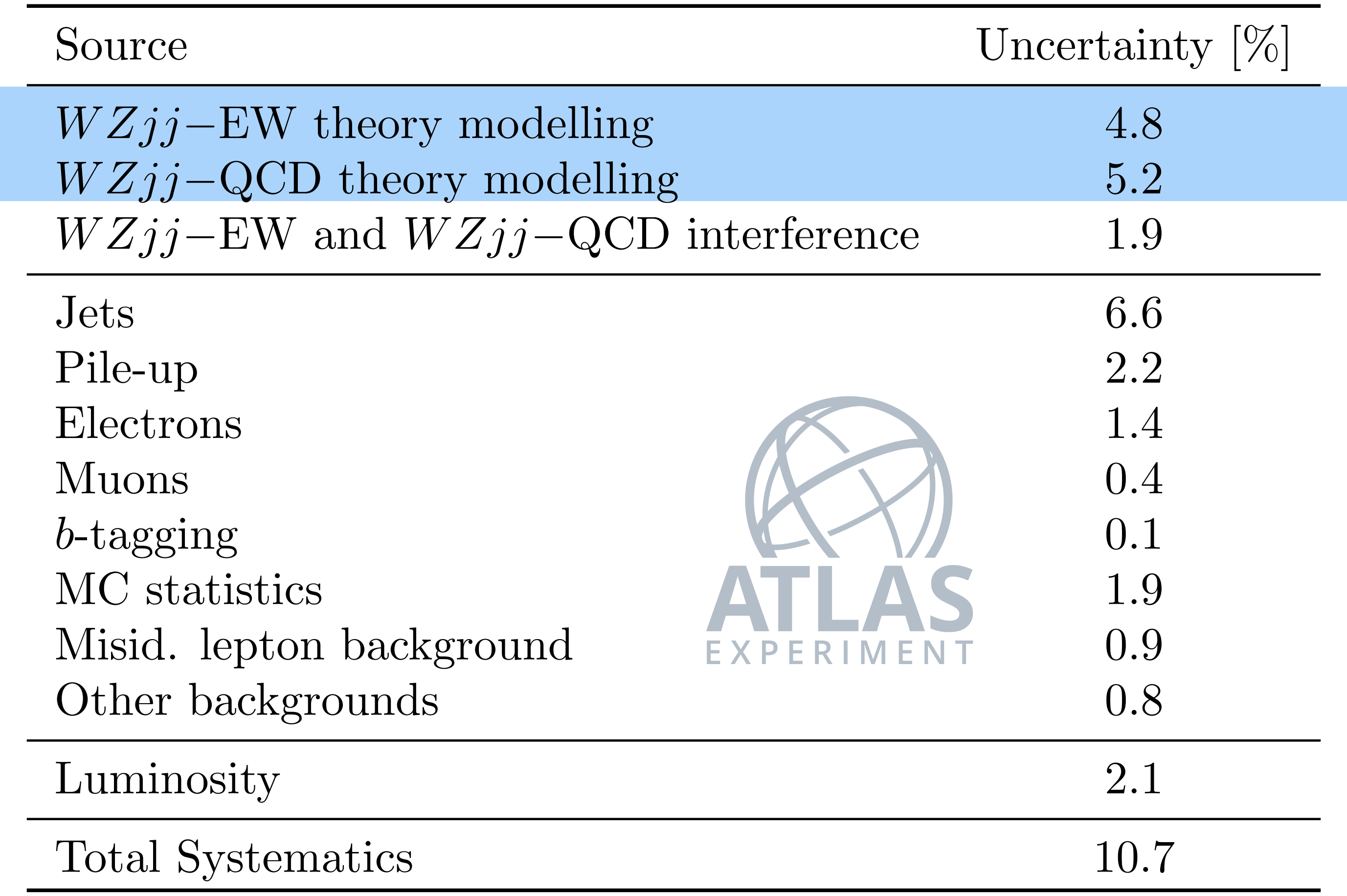
Systematics uncertainties

Theory uncertainties*

- QCD scale: vary renormalisation and factorization scale by 0.5 and 2
  - 20% to 30% effect in QCD,
  - 5% for EW
- PDF and as: standard PDF4LHC description:
  - Small effect (1-2%)

- **Signal modeling** (including parton shower)
  - shape difference between generators (Up to 14% effect)

- **WZ QCD background modeling**
  - shape difference between generators
    - 5-20% effect



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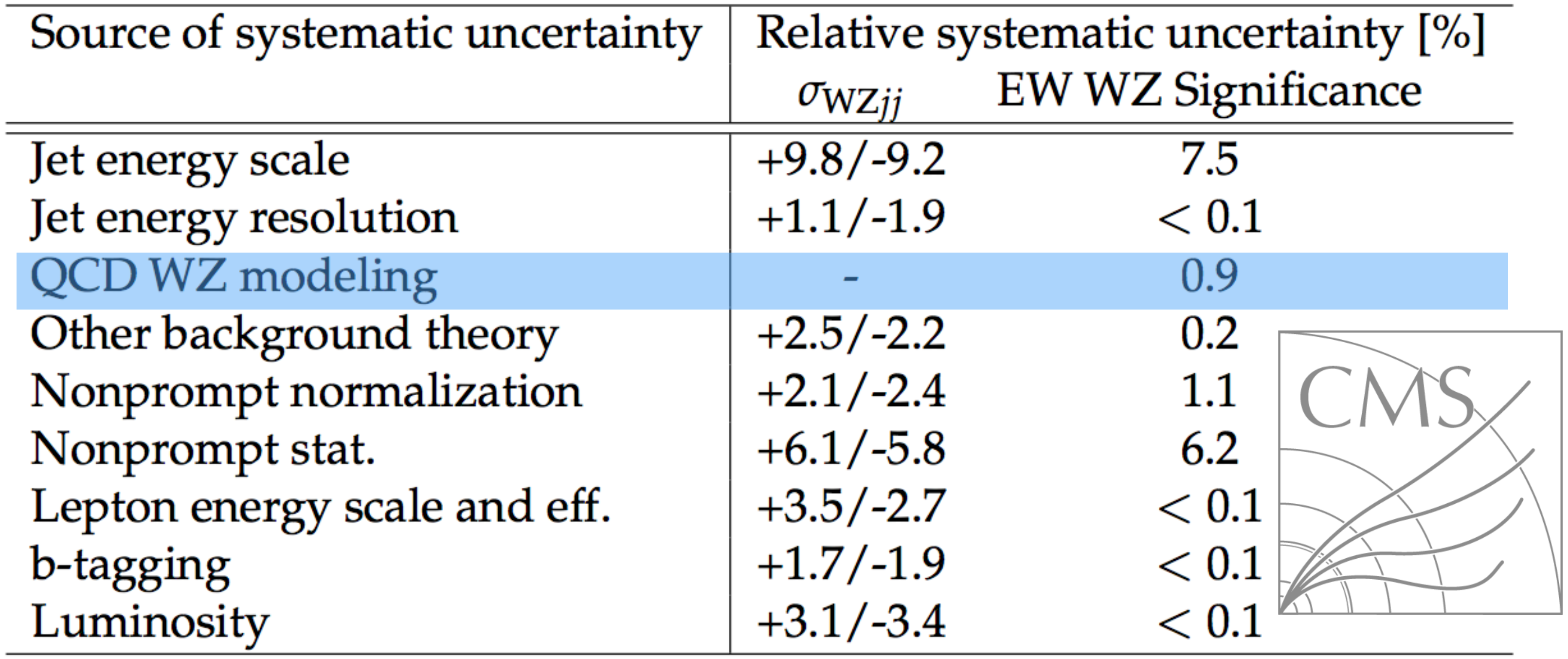

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b-tagging	+1.7/-1.9	< 0.1
Luminosity	+3.1/-3.4	< 0.1

* EW corrections to VBS WZ (~-19%) were not available by the time of the publication and are not included

Systematics uncertainties

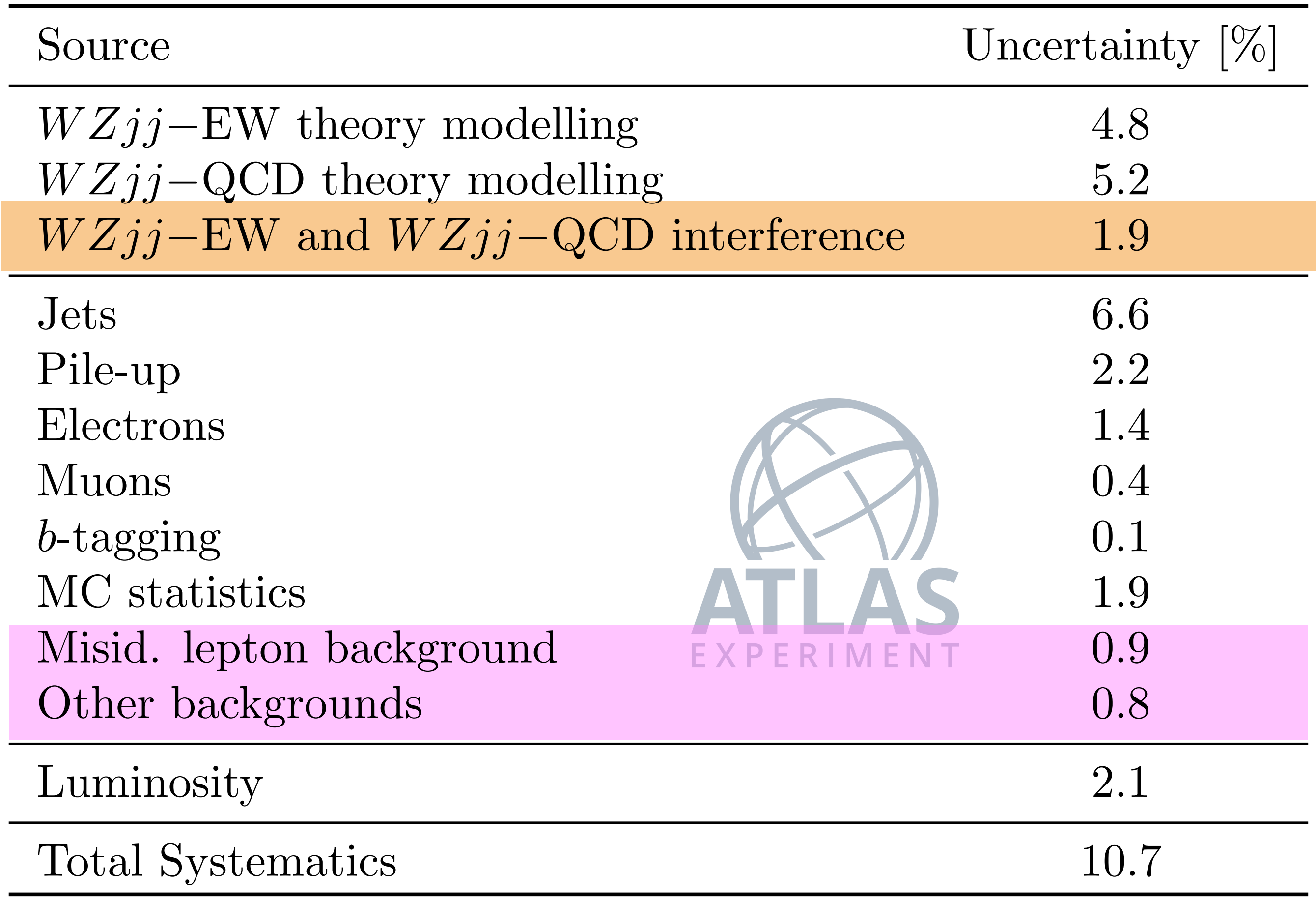
QCD/EWK Interference

- Part of the measured signal
- Included as shape uncertainty on signal
- Size of interference: +10% of EW WZjj

Other backgrounds

Normalization uncertainties applied on non-dominant background

- Large uncertainty in Misid. Leptons background (~40%)



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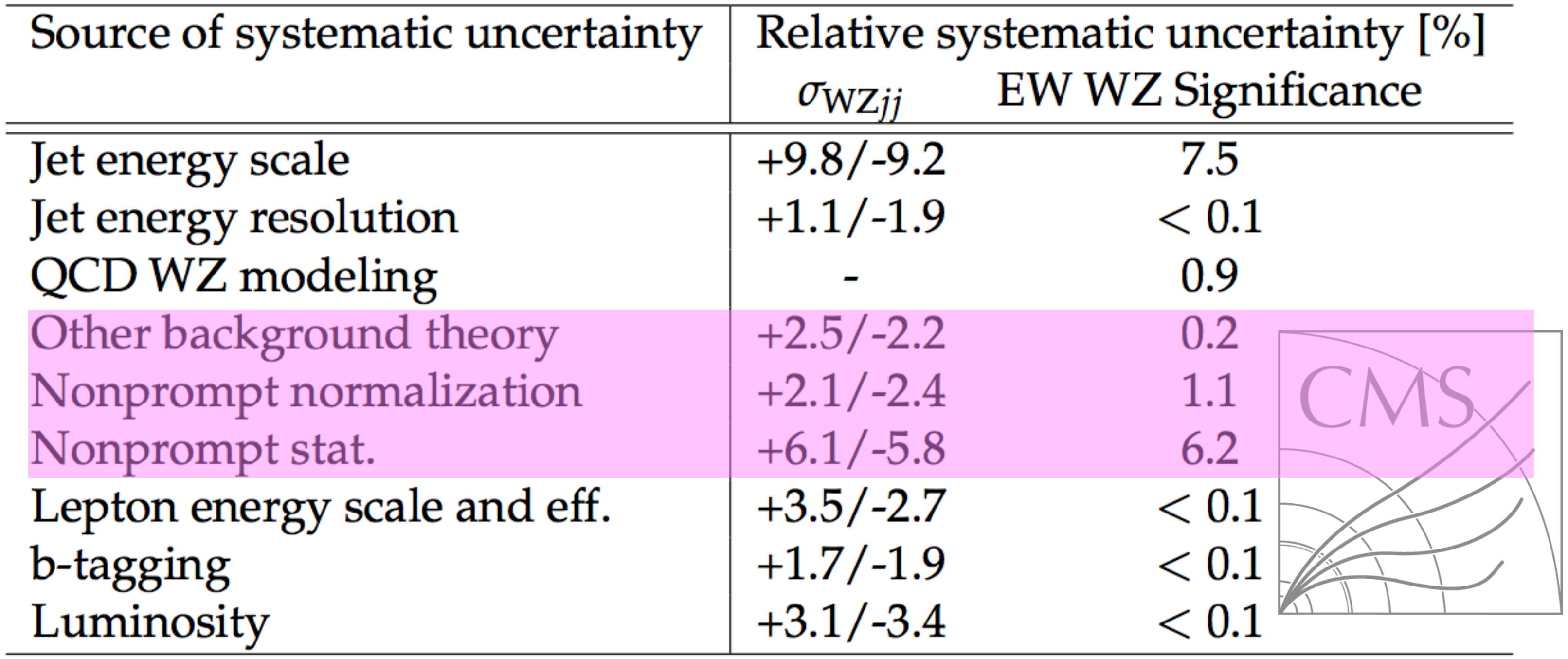
Electrons	1.4
Muons	0.4
b-tagging	0.1
MC statistics	1.9
Misid. lepton background	0.9
Other backgrounds	0.8
Luminosity	2.1
Total Systematics	10.7



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	$\sigma_{\mathrm{WZ}jj}$	EW WZ Significance
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WZjj-EWK: Fiducial Cross-Section

First observation of WZjj EWK process!

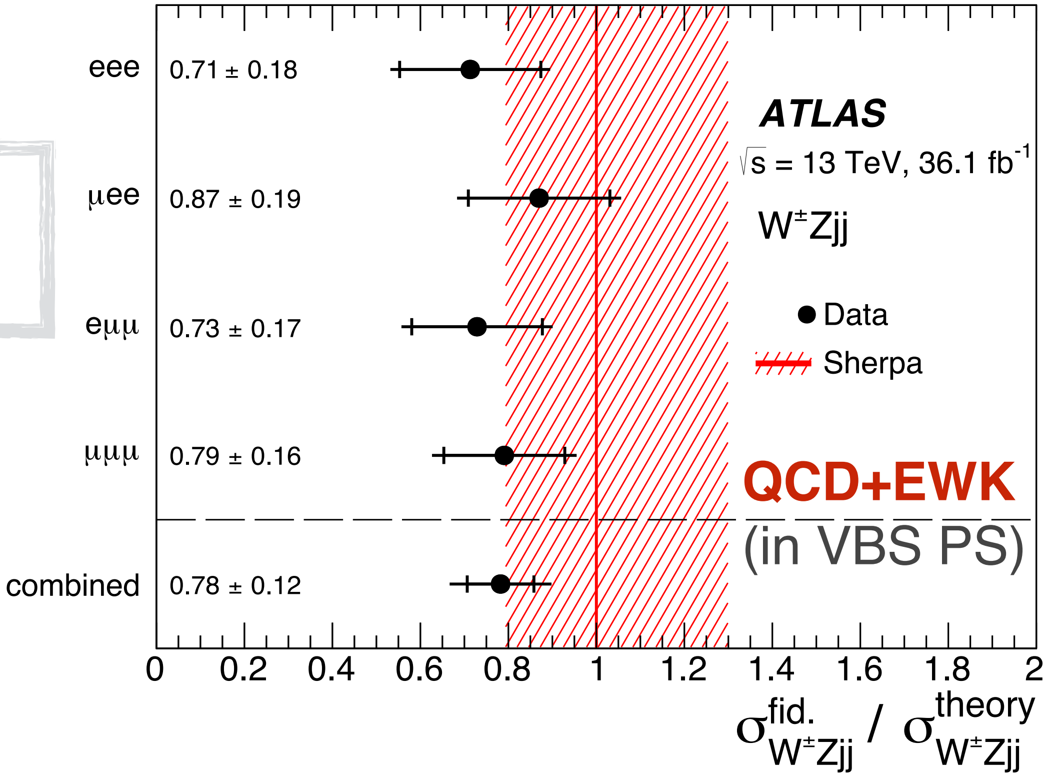
Observed (Expected with Sherpa) Significance is **5.3σ (3.2σ)**

- Measured **WZjj-EWK** fiducial cross section

$$\begin{aligned}\sigma^{\text{fid.}}_{WZjj-\text{EW}} &= 0.57\,^{+0.14}_{-0.13}\,(\text{stat.})\,^{+0.05}_{-0.04}\,(\text{exp. syst.})\,^{+0.05}_{-0.04}\,(\text{mod. syst.})\,^{+0.01}_{-0.01}\,(\text{lumi.})\ \text{fb}\\ &= 0.57\,^{+0.16}_{-0.14}\ \text{fb},\end{aligned}$$

LO Sherpa cross-section (No EW/QCD interference)

$$\sigma^{\text{fid., Sherpa}}_{WZjj-\text{EW}} = 0.321 \pm 0.002\,(\text{stat.}) \pm 0.005\,(\text{PDF})^{+0.027}_{-0.023}\,(\text{scale})\ \text{fb},$$



QCD+EWK

(in VBS PS)

Observed (Expected with Sherpa) Significance is **1.9σ (2.7σ)**

- Measured **WZjj EWK+QCD** fiducial cross section (including b-jets looser PS)

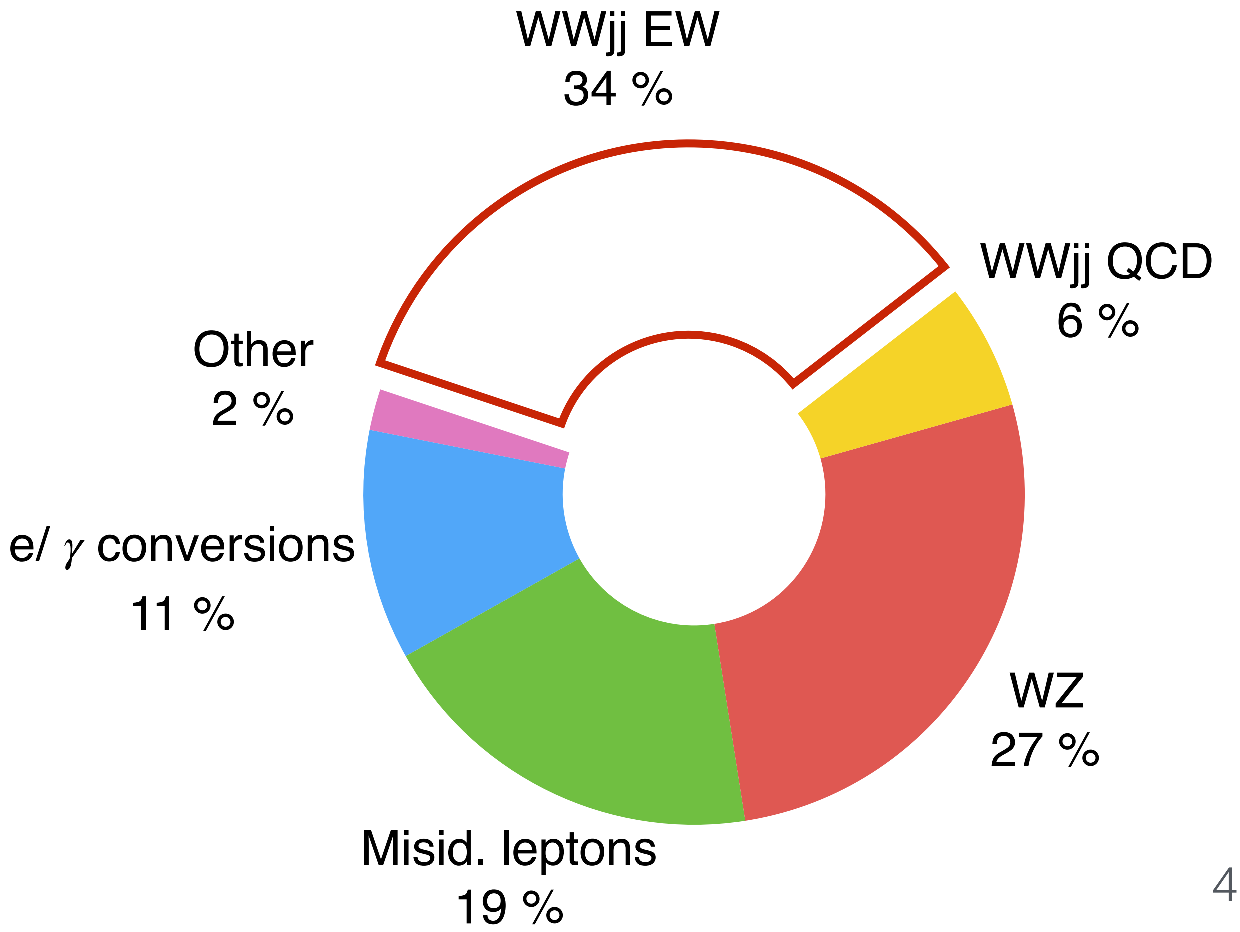
$$\sigma^{\text{fid}}_{\text{WZjj}} = 2.91^{+0.53}_{-0.49}\,(\text{stat})\ ^{+0.41}_{-0.34}\,(\text{syst}) = 2.91^{+0.67}_{-0.60}\ \text{fb}$$

MADGRAPH5 AMC@NLO at LO+PYTHIA

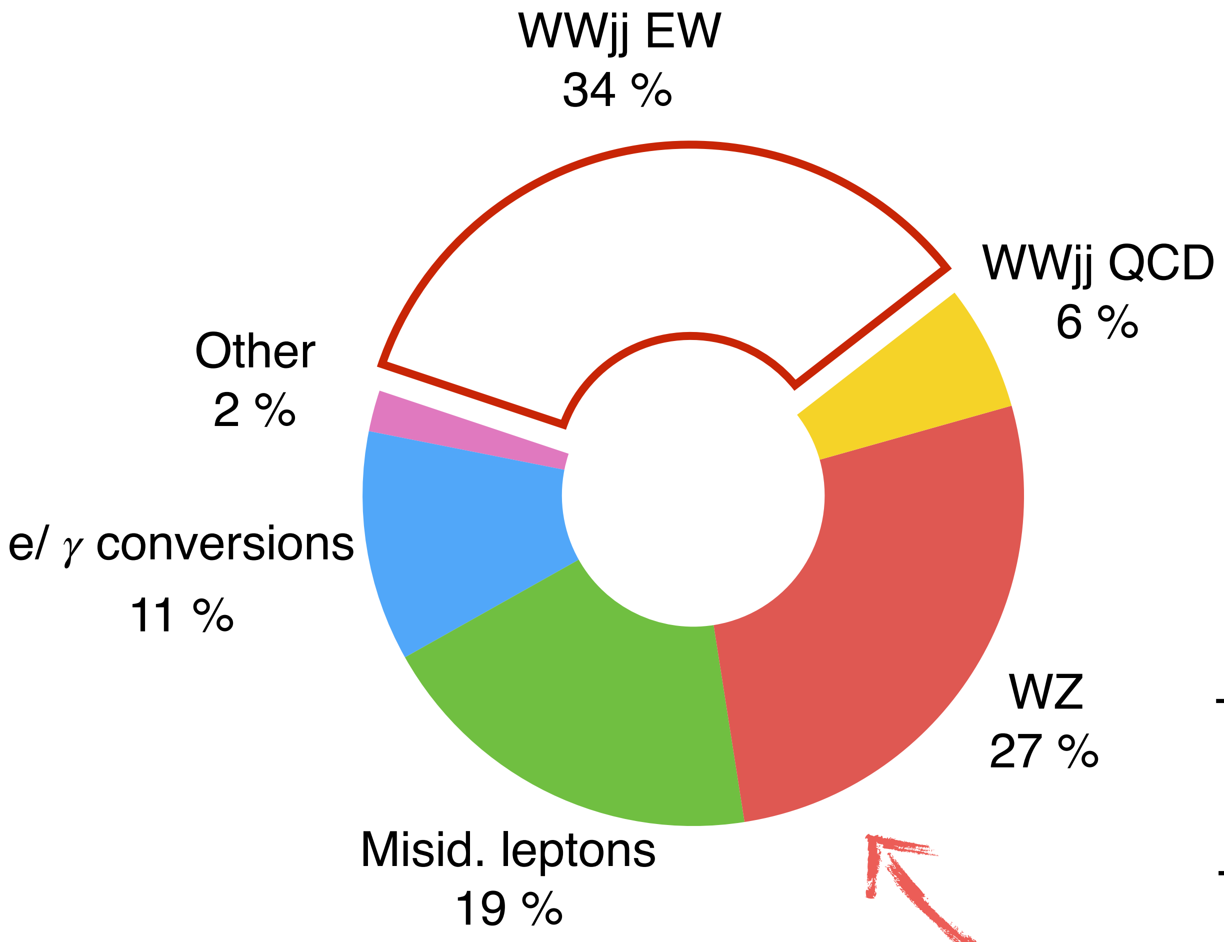
$$3.27\,^{+0.39}_{-0.32}(\text{scale}) \pm 0.15\,(\text{PDF})$$

W±W± analysis

- Small signal contribution (~30%)
  - **Exploit discriminant variables, BDT**
- Need to keep under control the backgrounds!
  - **Data Control Regions**

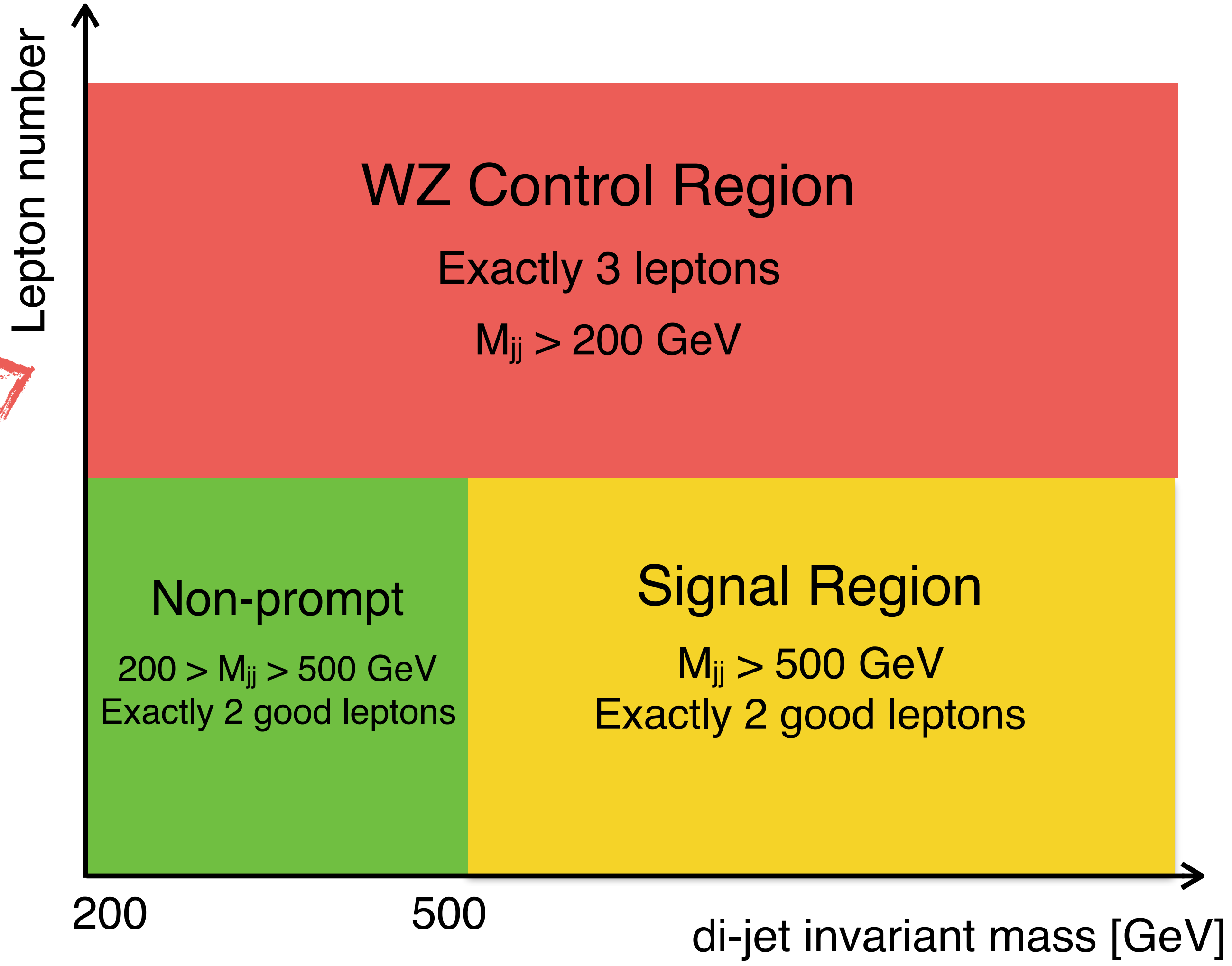


Backgrounds and control regions



WZ

- Shape taken from simulation
    - Modeling theory uncertainties applied (PDF, scale, shower)
- Normalization taken from data control region



WZ Control Region

Exactly 3 leptons

$M_{jj} > 200$ GeV

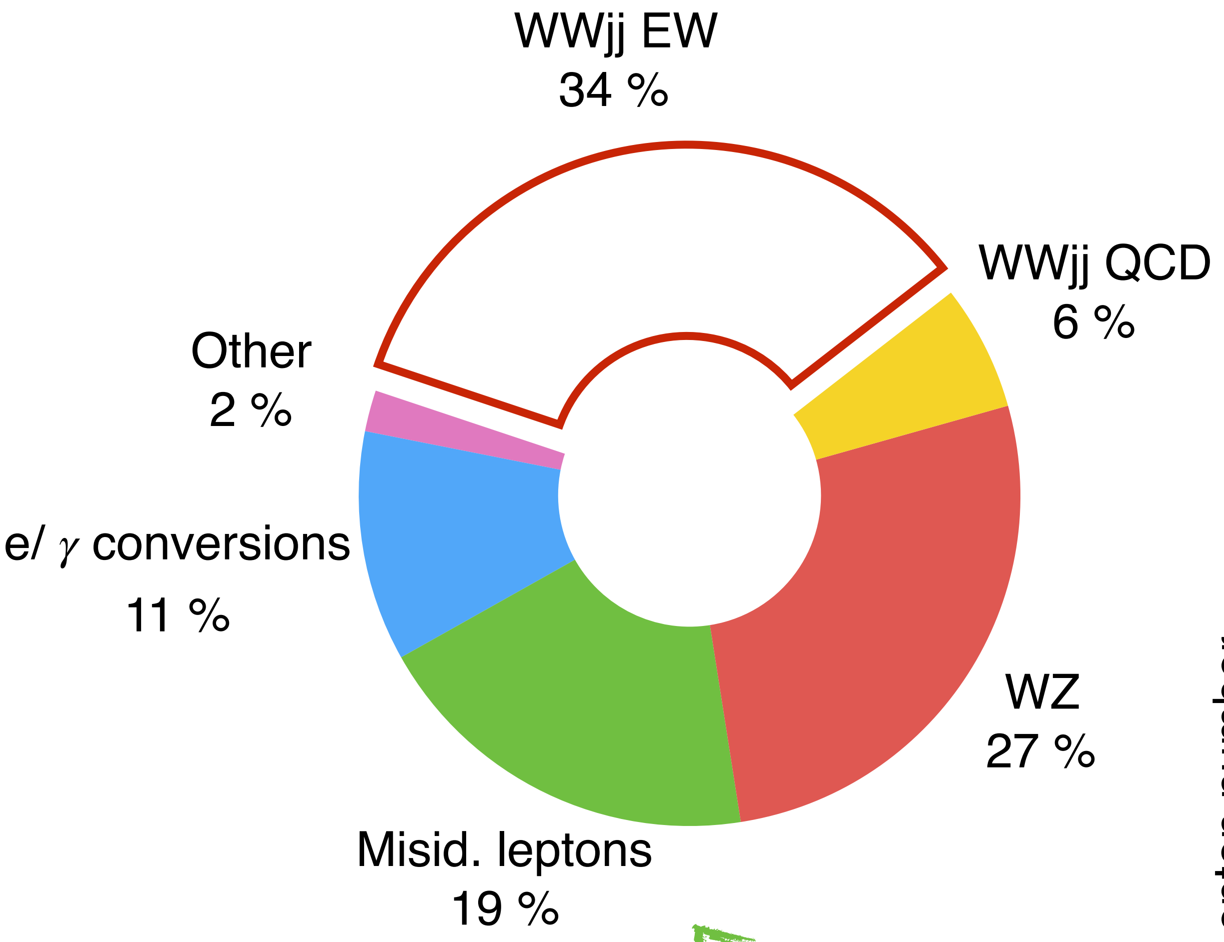
Non-prompt

$200 > M_{jj} > 500$ GeV
Exactly 2 good leptons

Signal Region

$M_{jj} > 500$ GeV
Exactly 2 good leptons

Backgrounds and control regions



WZ

- Shape taken from simulation
  - Modeling theory uncertainties applied (PDF, scale, shower)
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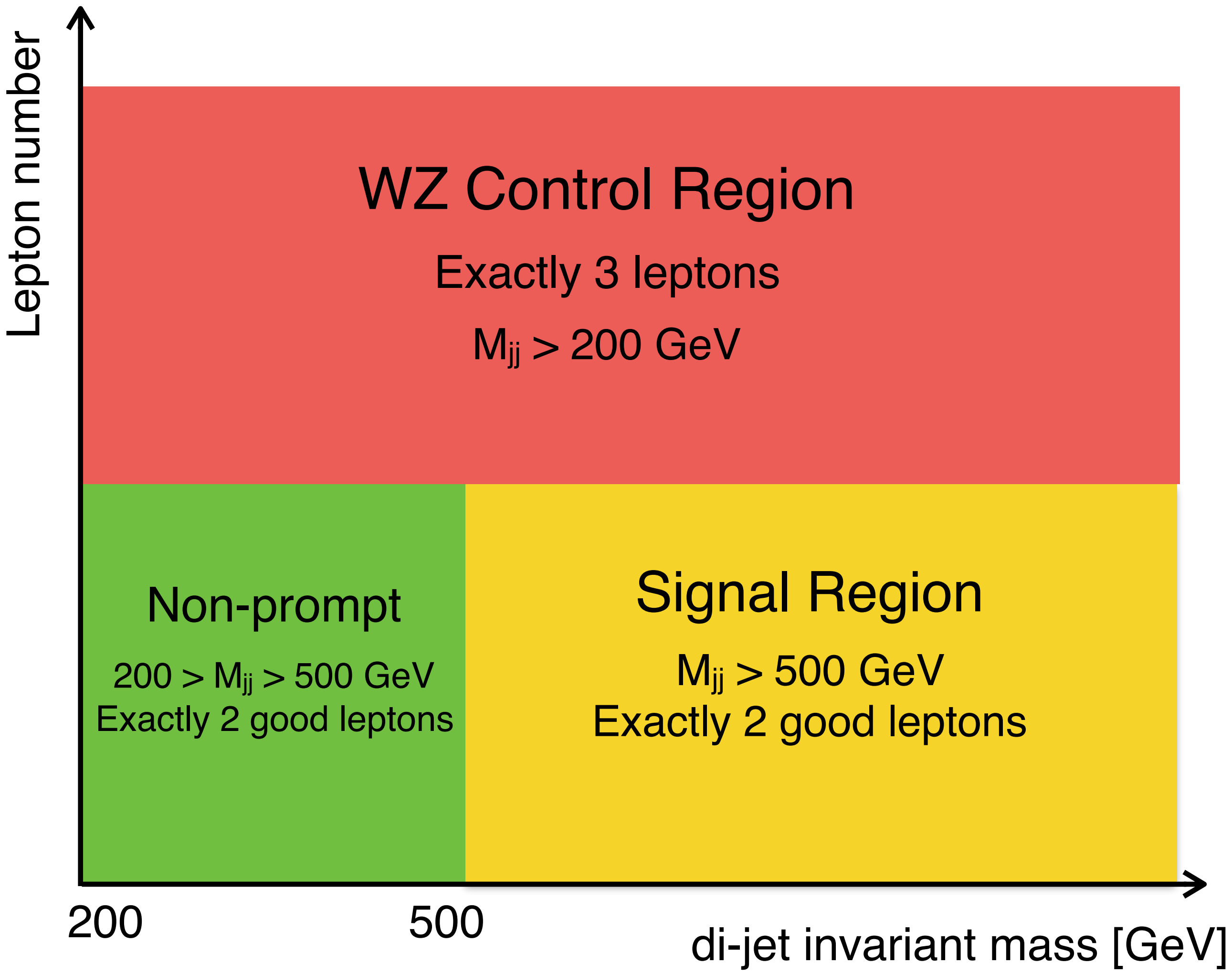
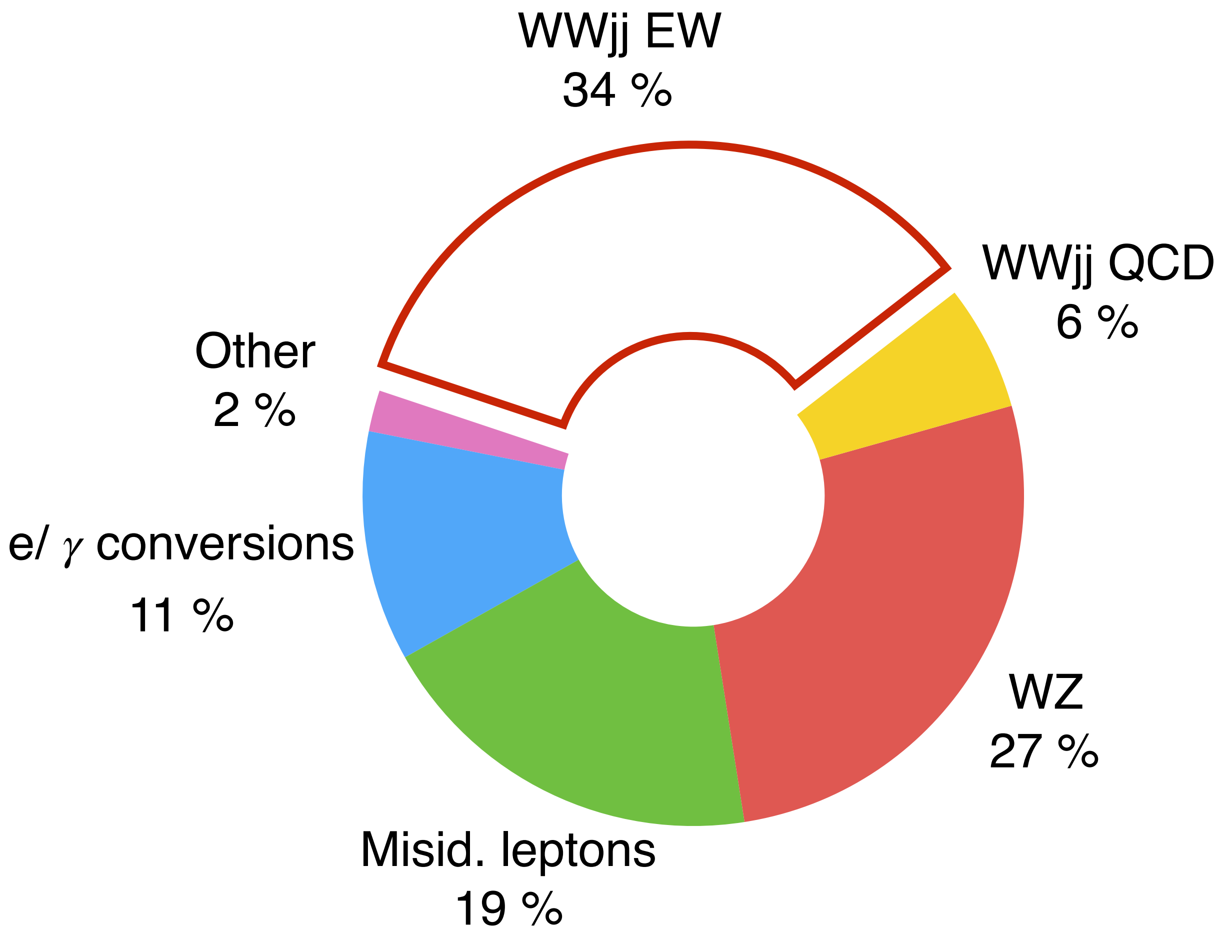


Non-prompt

- Shapes and normalization are taken from data
  - Fake factor calculated in a di-jet control region
  - Uncertainties 40-90% for the different channels μμ, μe and ee
- Control region region used to constrain

Backgrounds and control regions



WZ

- Shape taken from simulation
  - Modeling theory uncertainties applied (PDF, scale, shower)
- Normalization taken from data control region

e/γ conversions

- Charge miss-ID rates calculated from simulation and applied to data
  - Uncertainties 10% in forward region, 20% in central region

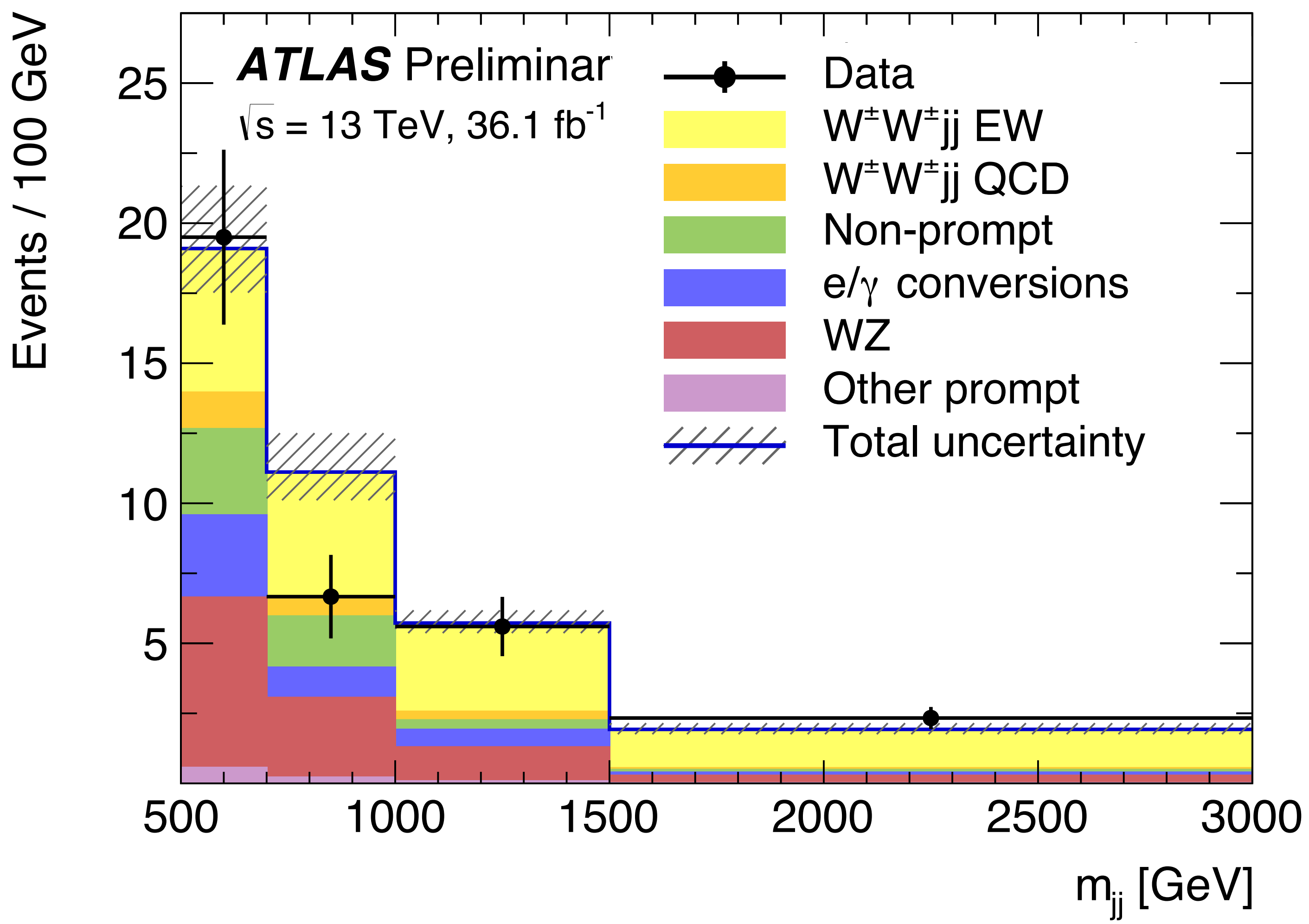
Non-prompt

- Shapes and normalization are taken from data
  - Fake factor calculated in a di-jet control region
  - Uncertainties 40-90% for the different channels μμ, μe and ee
- Control region region used to constrain

WWjj QCD, other prompts

- Taken from simulation
  - Theory uncertainties vary from 20% to 30%

Analysis strategy



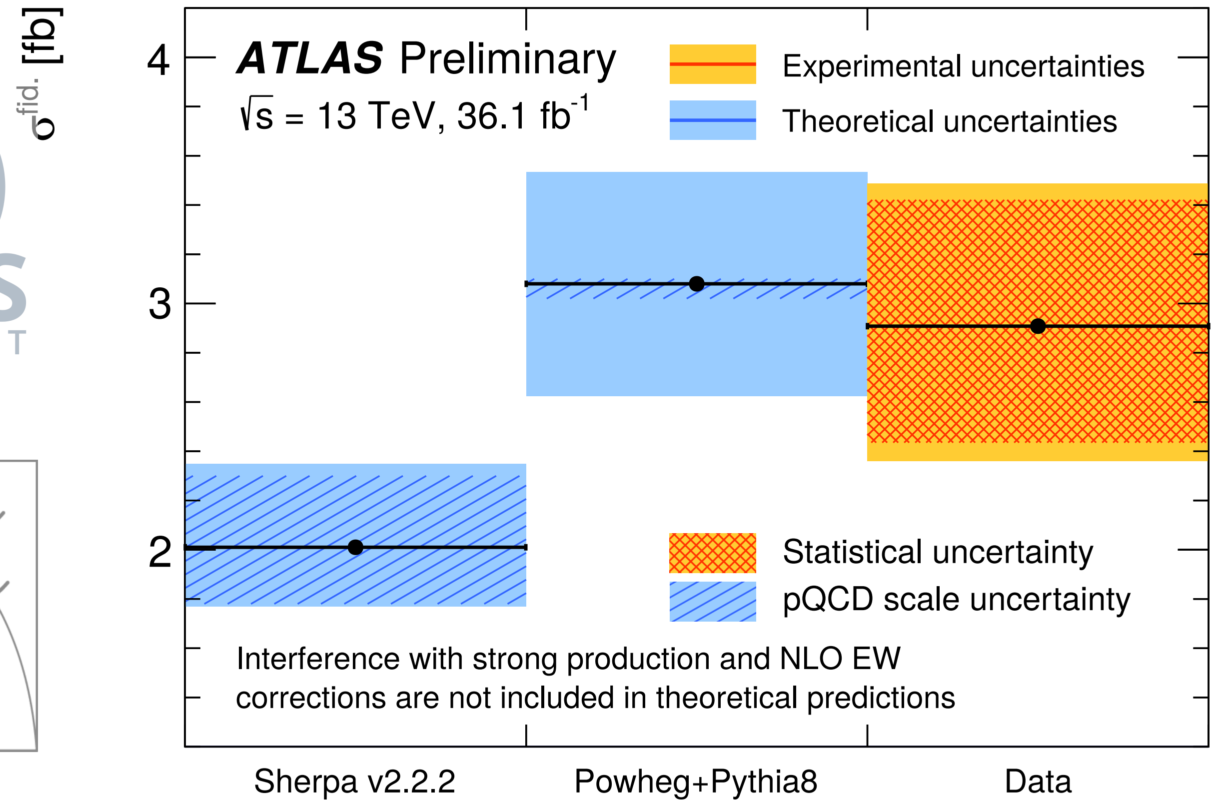
Signal extraction: used 6 binned M_{jj} distributions, separated by :

- lepton flavours: ee, eμ+μe, μμ
- charge: + + and - -

Perform simultaneous template fit in signal region and other observables in different control regions

ATLAS Result [ATLAS-CONF-2018-030]
Observed (expected with Sherpa) significance is **6.9σ** (4.9σ)

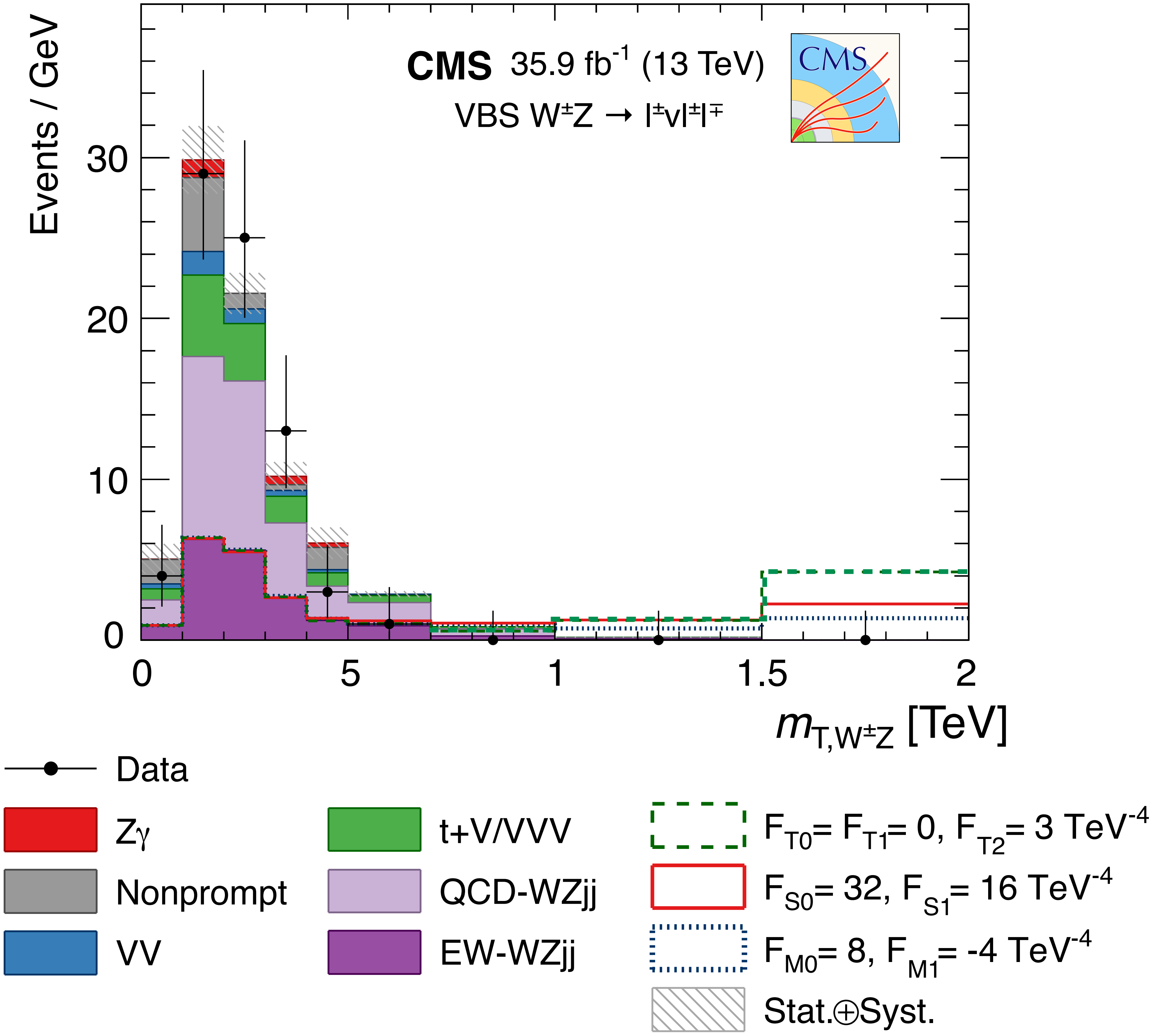
CMS Result [PRL 120 (2018) 081801]
Observed (expected with Madgraph) significance is **5.5σ** (5.7σ)



Looking for new physics

Looking for new physics WZ→ lvll

- Let’s take as an example the WZ→lvll result from CMS



Looking for new physics WZ → lνll

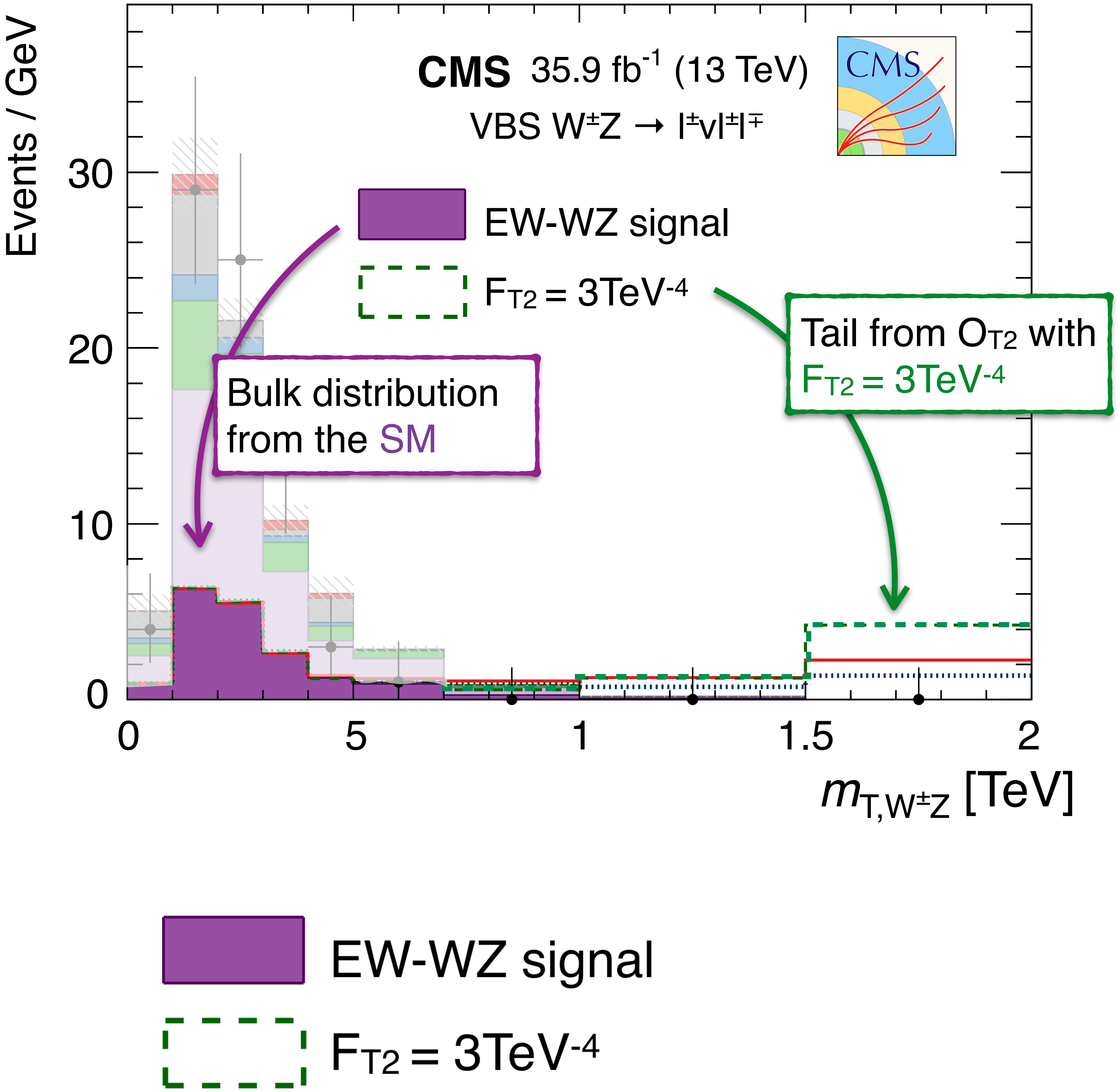
- Let’s take as an example the WZ→lνll result from CMS

BSM interaction of SM particles ↓

$$L_{EFT} = L_{SM} + F_{T2}\, O_{T2}$$

↑ Coefficient

- The tails will show discrepancies with the SM and can be used to look for new physics



Bulk distribution from the SM

Tail from O_{T2} with $F_{T2} = 3TeV^{-4}$

Looking for new physics

WZjj → lvJ jj / llJ jj / vvJ jj

- Now lets have a look on the WZ semileptonic

BSM interaction of SM particles

↓

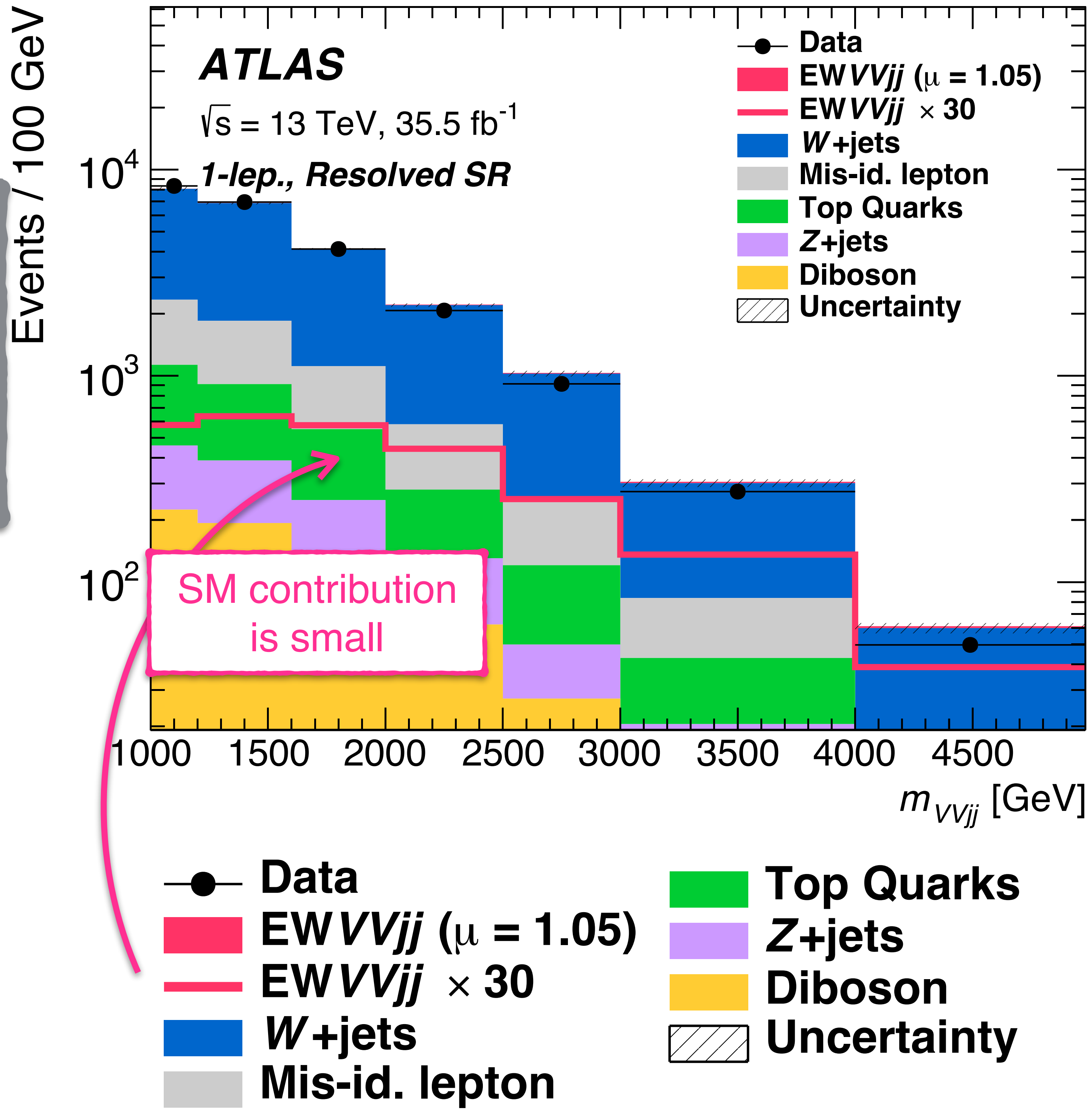
$$L_{EFT} = L_{SM} + F_{T2}\, O_{T2}$$

↑

Coefficient

- Boosted jets allow us to get events higher in the energy tails

- Small sensitivity to the SM rate



SM contribution is small

Looking for new physics

WZjj → lvJ jj / llJ jj / vvJ jj

- Now lets have a look on the WZ semileptonic

BSM interaction of SM particles

↓

$$L_{EFT} = L_{SM} + F_{T2}\, O_{T2}$$

↑

Coefficient

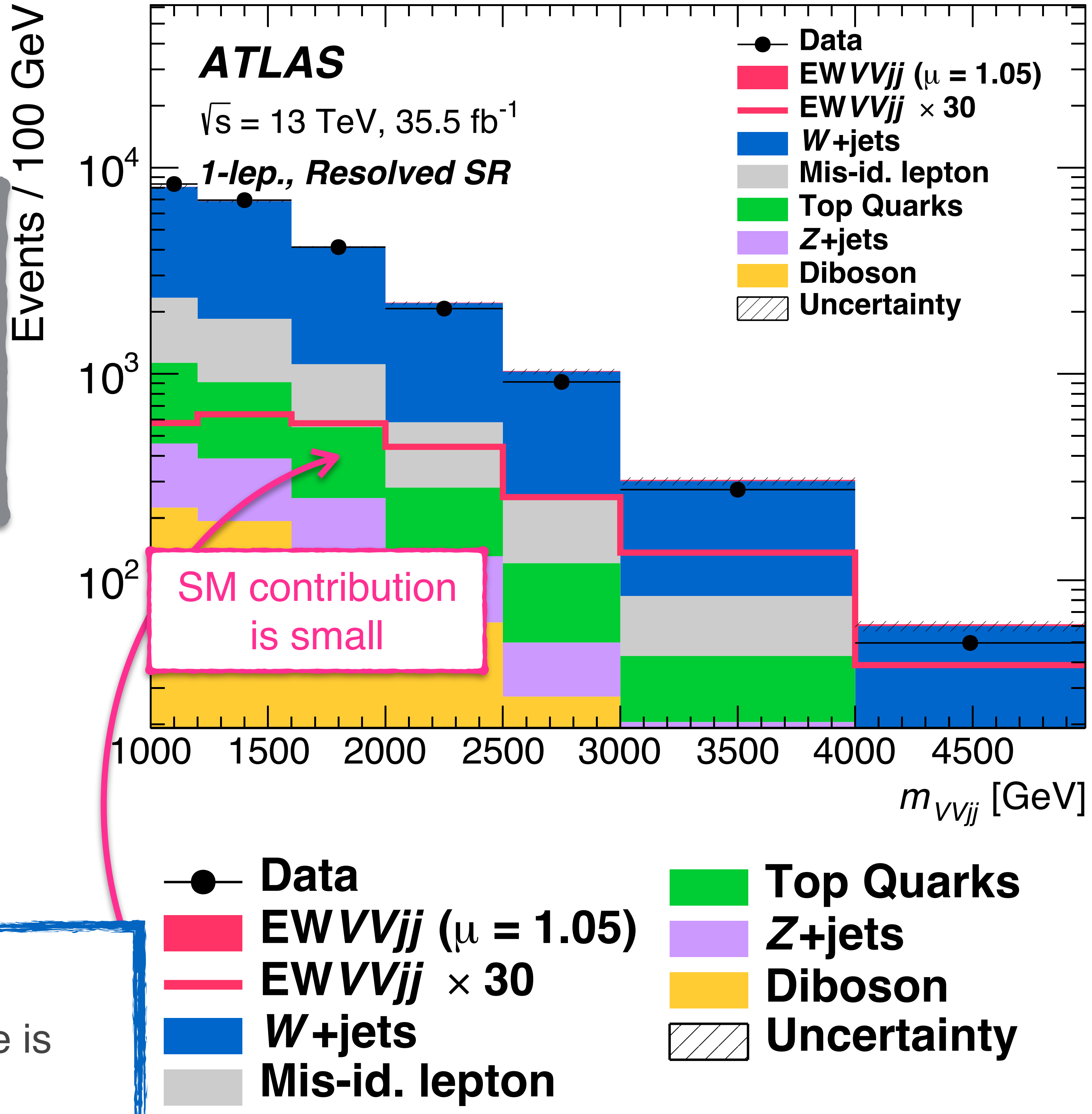
- Boosted jets allow us to get events higher in the energy tails
- Small sensitivity to the SM rate

ATLAS Result [arXiv:1905.07714]

Observed (expected) significance is

2.7σ (2.5σ)

$45.1 \pm 8.6\,(\text{stat})\,^{+15.9}_{-14.6}\,(\text{syst.})$ fb

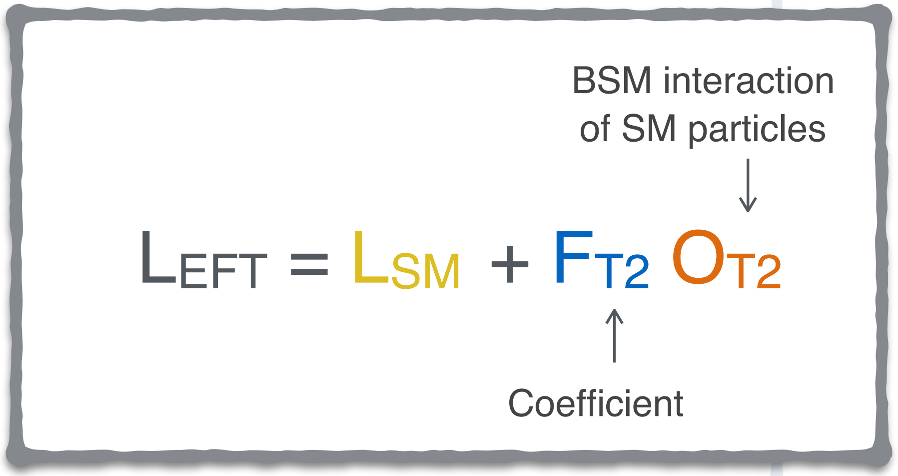


SM contribution is small

Looking for new physics

WZjj → lνJ jj / llJ jj

- Now lets have a look on the WZ semileptonic

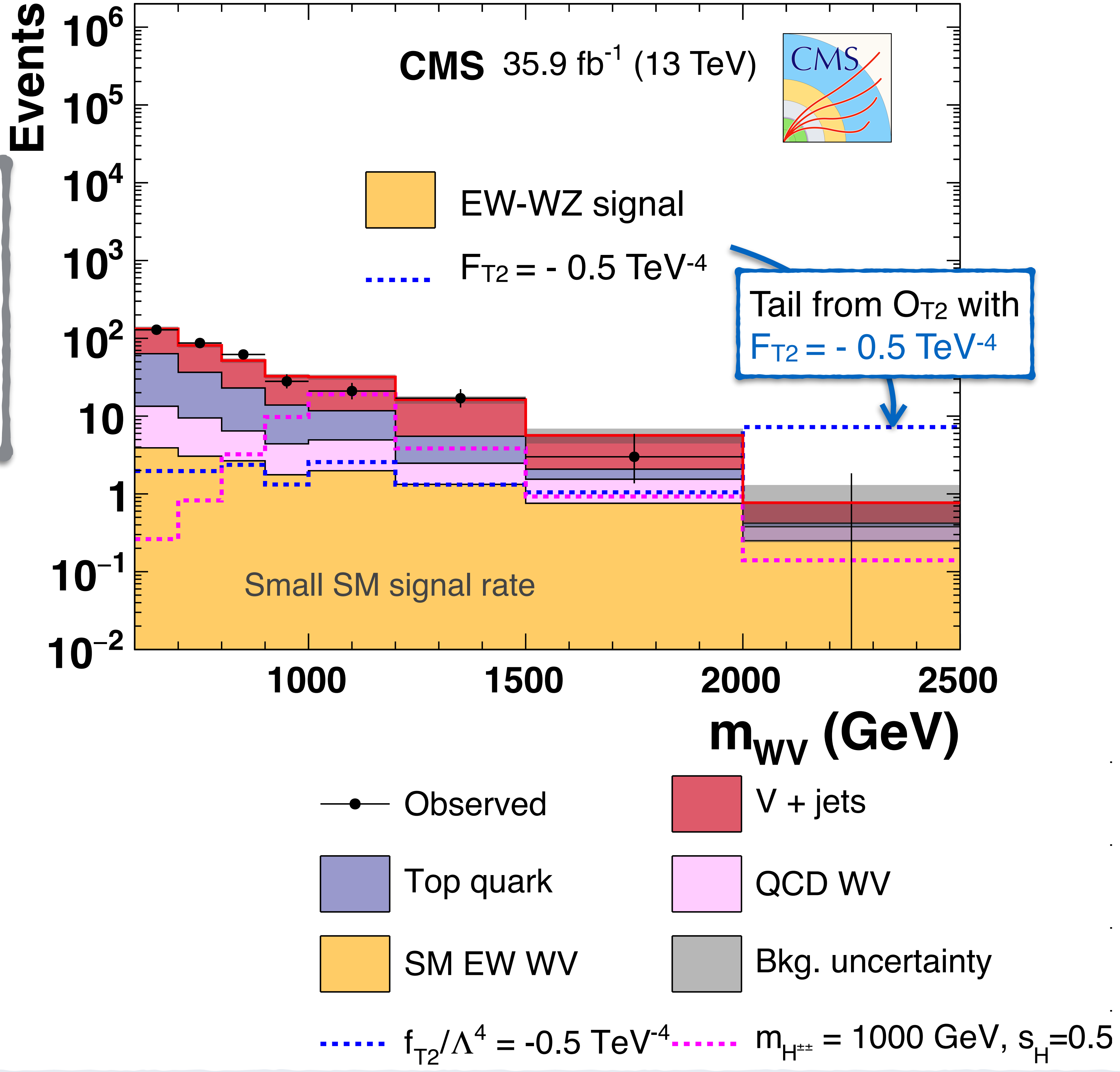


BSM interaction of SM particles

$$L_{EFT} = L_{SM} + F_{T2}\, O_{T2}$$

Coefficient

- Boosted jets allow us to get events higher in the energy tails
- Small sensitivity to the SM rate but strong limits



Tail from O_{T2} with F_{T2} = - 0.5 TeV^{-4}

Small SM signal rate

Looking for new physics

$WZjj \rightarrow l\nu J\, jj\, /\, llJ\, jj$

- Now lets have a look on the WZ semileptonic

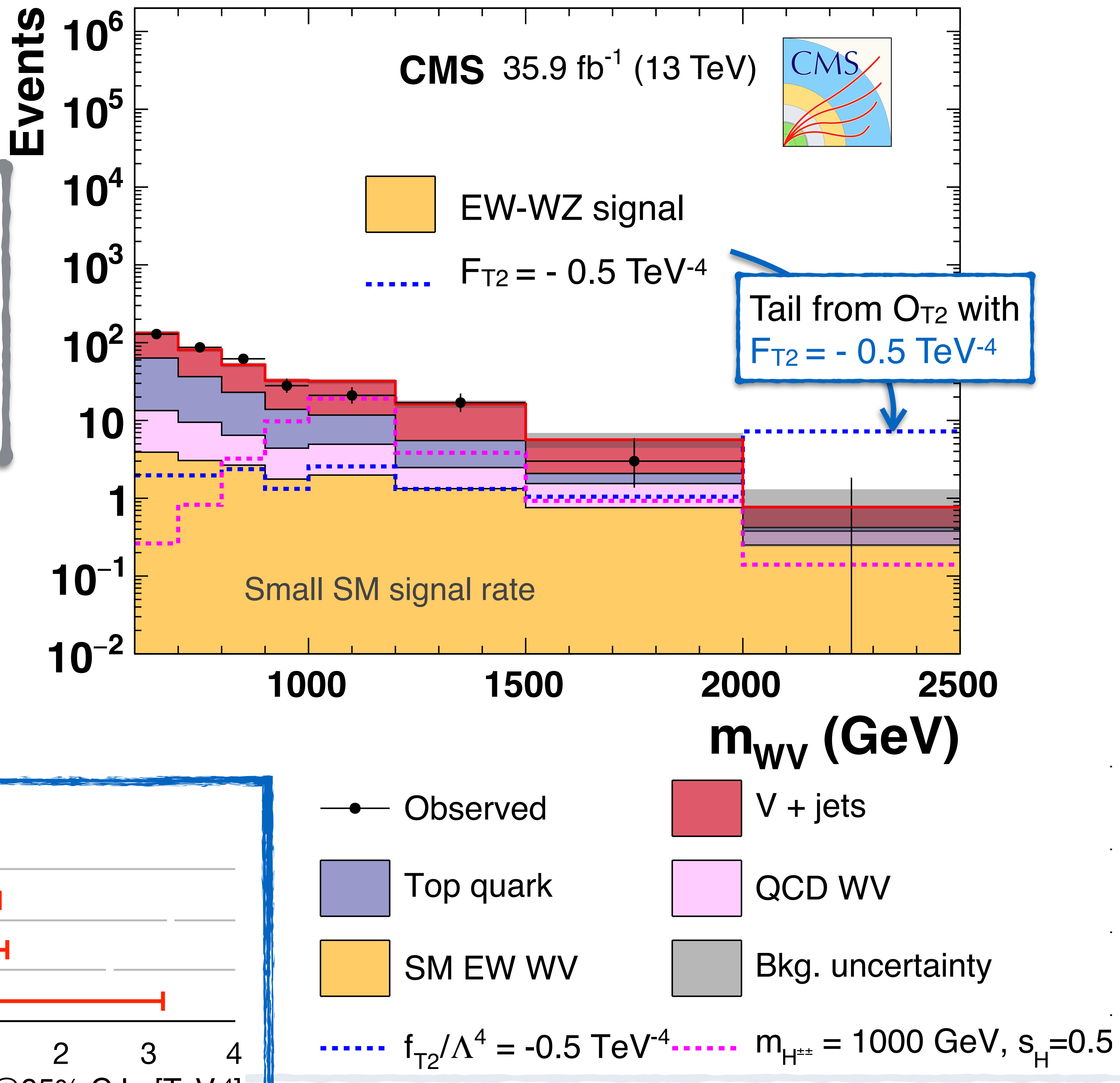
BSM interaction of SM particles

$$L_{EFT} = L_{SM} + \underbrace{F_{T2}}_{\text{Coefficient}} \overset{\text{BSM interaction of SM particles}}{O_{T2}}$$

Coefficient

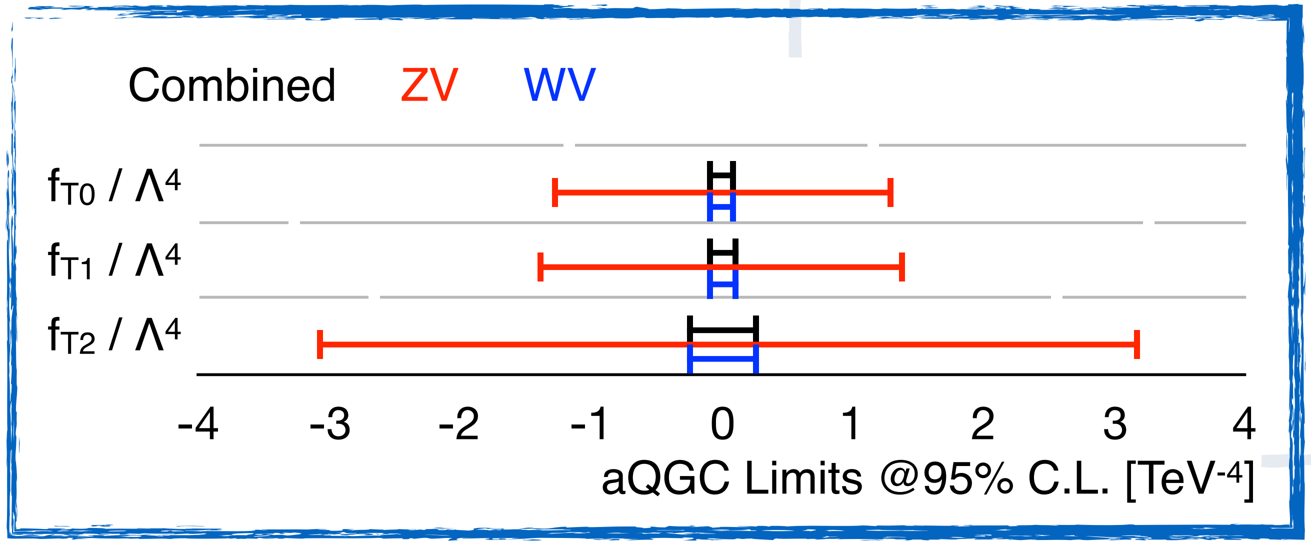
- Boosted jets allow us to get events higher in the energy tails

- Small sensitivity to the SM rate but strong limits

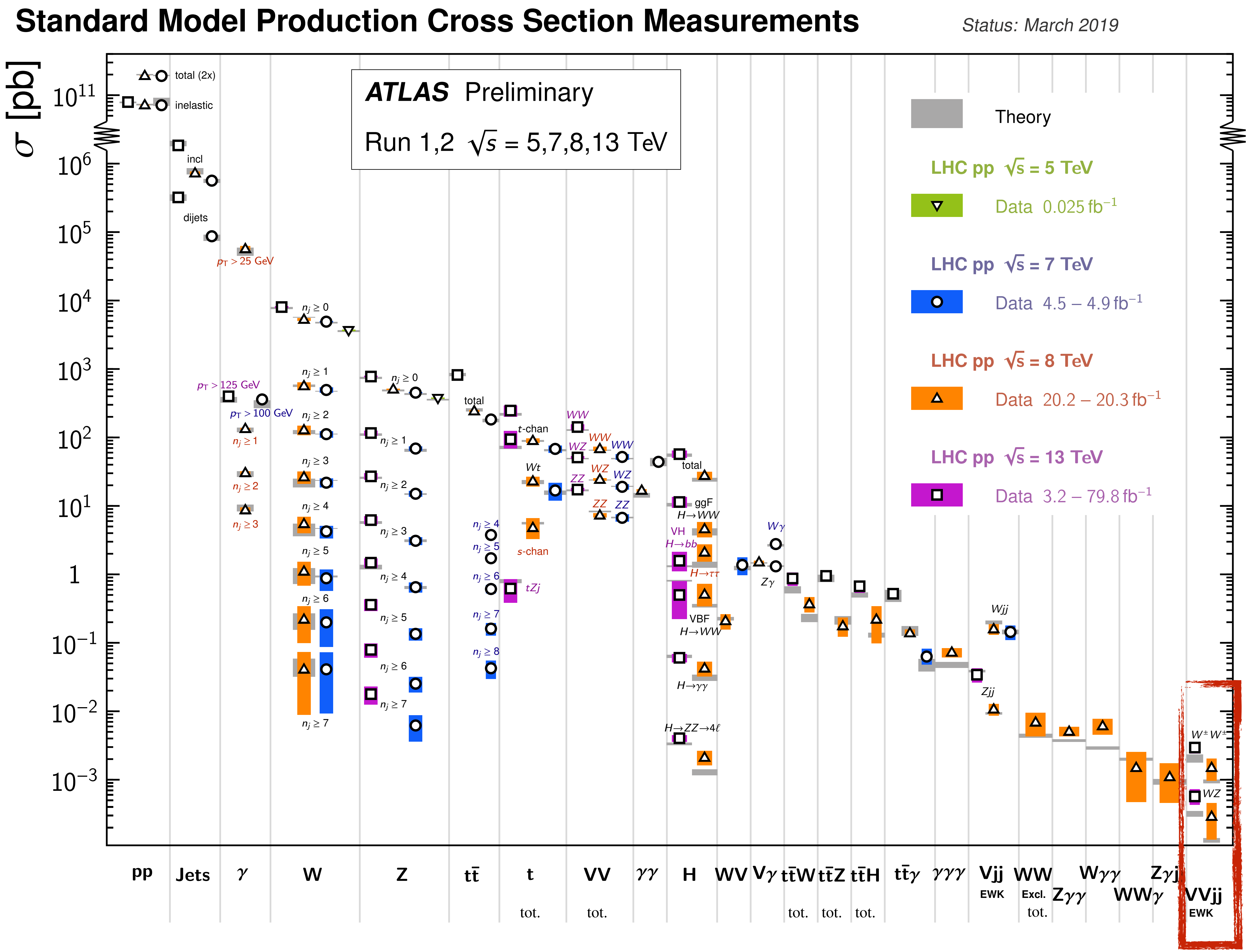


Tail from O_{T2} with F_{T2} = - 0.5 TeV^{-4}

Small SM signal rate



VBS in Context of full SM



A new chapter of the SM now accessible ‼

- ✓ **Observation the EWK production of vector boson pairs**
  - ✓ WZ and same charge WW with a significances higher than 5σ
    - ✓ Huge efforts to extract a small signal over a big background
  - ○ More channels to come

- ✓ **Mesure for the first time a process that include QGC at tree level**
  - ○ Test Electroweak Symmetry breaking and Higgs properties
    - ○ e.g. Longitudinal component $V_L V_L \rightarrow V_L V_L$ no measurement yet (150fb^{-1}, HL-LHC ?)
  - ○ Look for new physics using the EFT approach
    - ○ More data can bring us surprises

- ○ Precise measurements will need :

  - ○ Much more data (Full Run-2, HL-LHC!)
  - ○ Precise theory predictions for signal and background (Shape fits and multivariate analysis heavily rely on MC descriptions)
  - ○ Precise Jets