CIPANP 2018

Studying the Electroweak Sector with the ATLAS Detector

Margherita Spalla (*)
on behalf of the ATLAS Collaboration

(*) Max Planck Institut für Physik, München

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Overview

- Electroweak (EW) sector with ATLAS: some recent results
  - Electroweak production of (multiple) vector bosons
    - focus on massive vector bosons
  - Precision measurements from Z decay
  - W Mass measurement: separate talk by Fabrice Balli

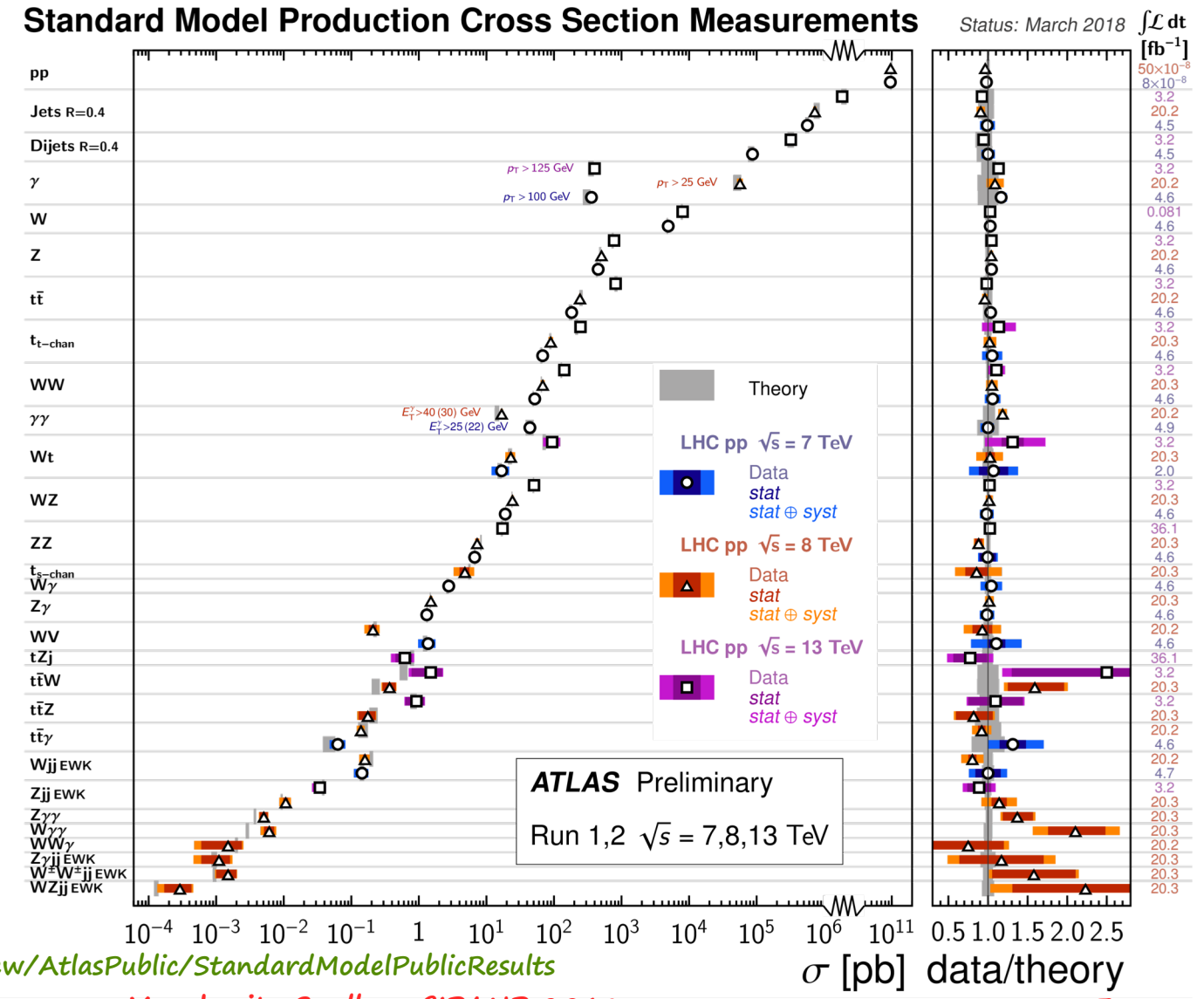
Why Electroweak physics in ATLAS?

- Precision Electroweak (EW) measurements in *pp* collisions
  - relevant for Standard Model (SM) results
    - ➢ even when less precise than in e^+e^-
  - sensitive to underlying QCD / PDF
- Direct test of SM through search for anomalous couplings
- Backgrounds for Higgs physics and beyond the SM searches

MULTI-BOSON PRODUCTION

Vector boson associated production: towards higher precision…

- Diboson production
- 'Vector Boson Fusion' (VBF)
- 'Vector Boson Scattering' (VBS)
- Triboson production



Ref. Standard Model public results and references therein.
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/StandardModelPublicResults

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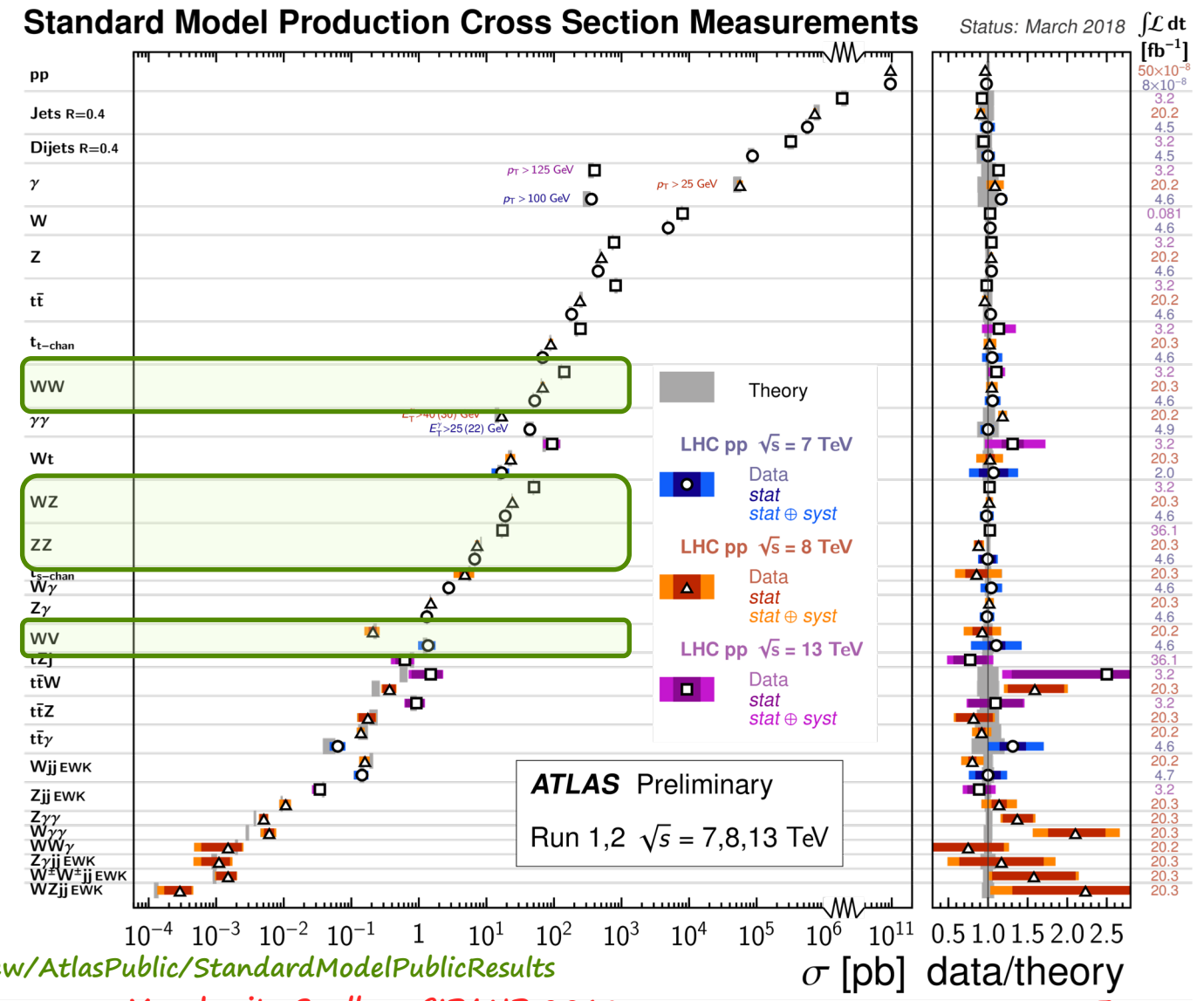

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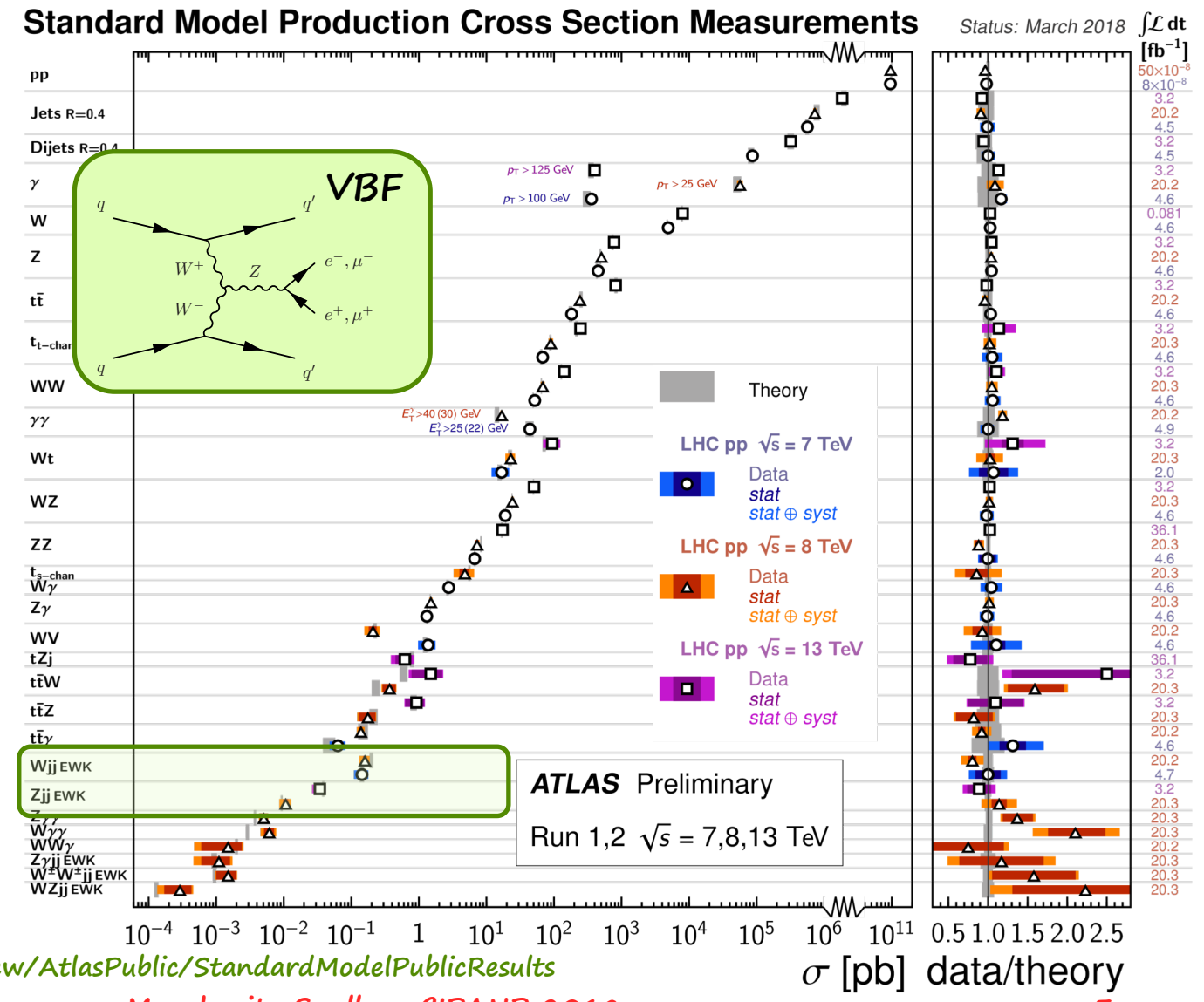

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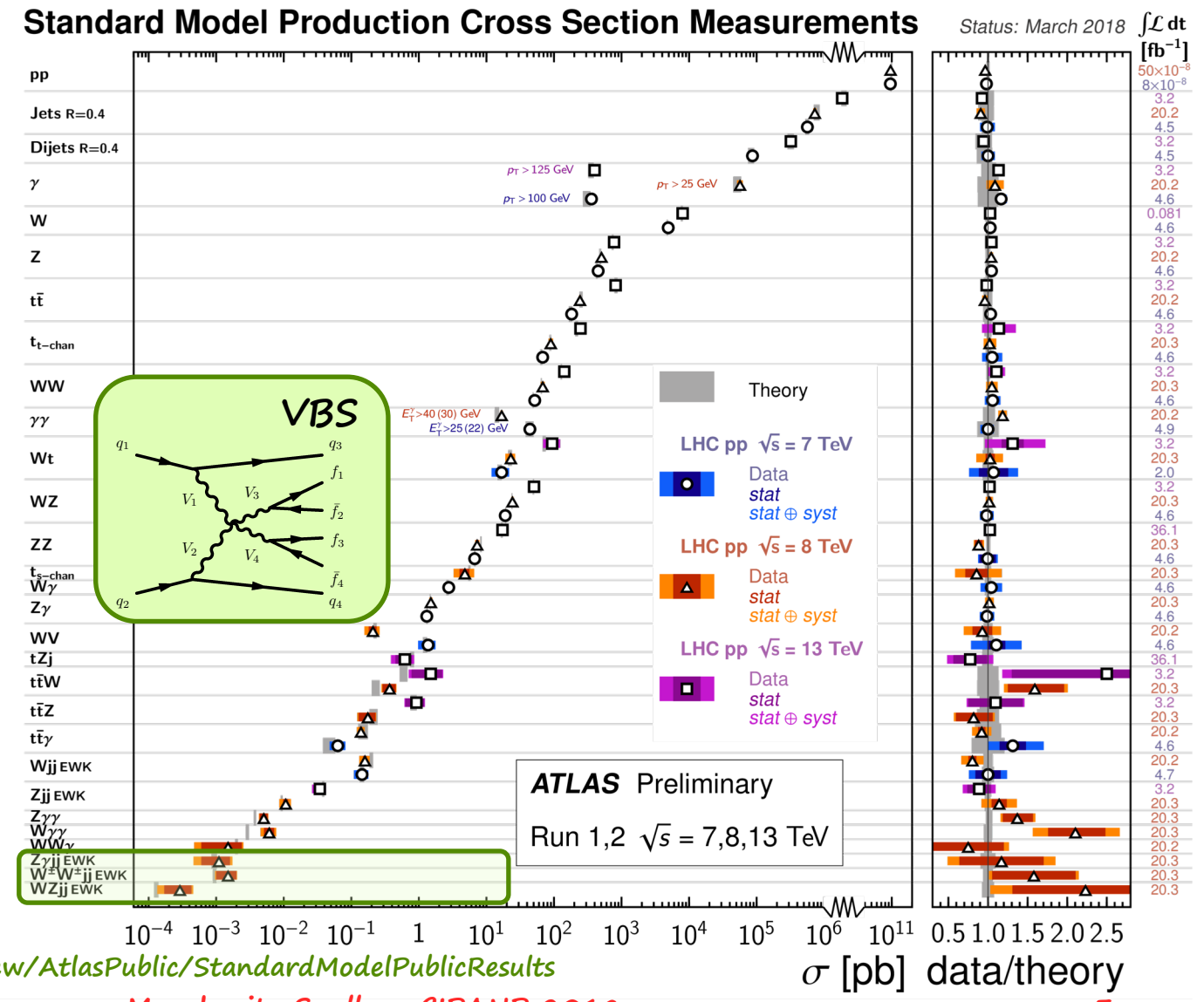

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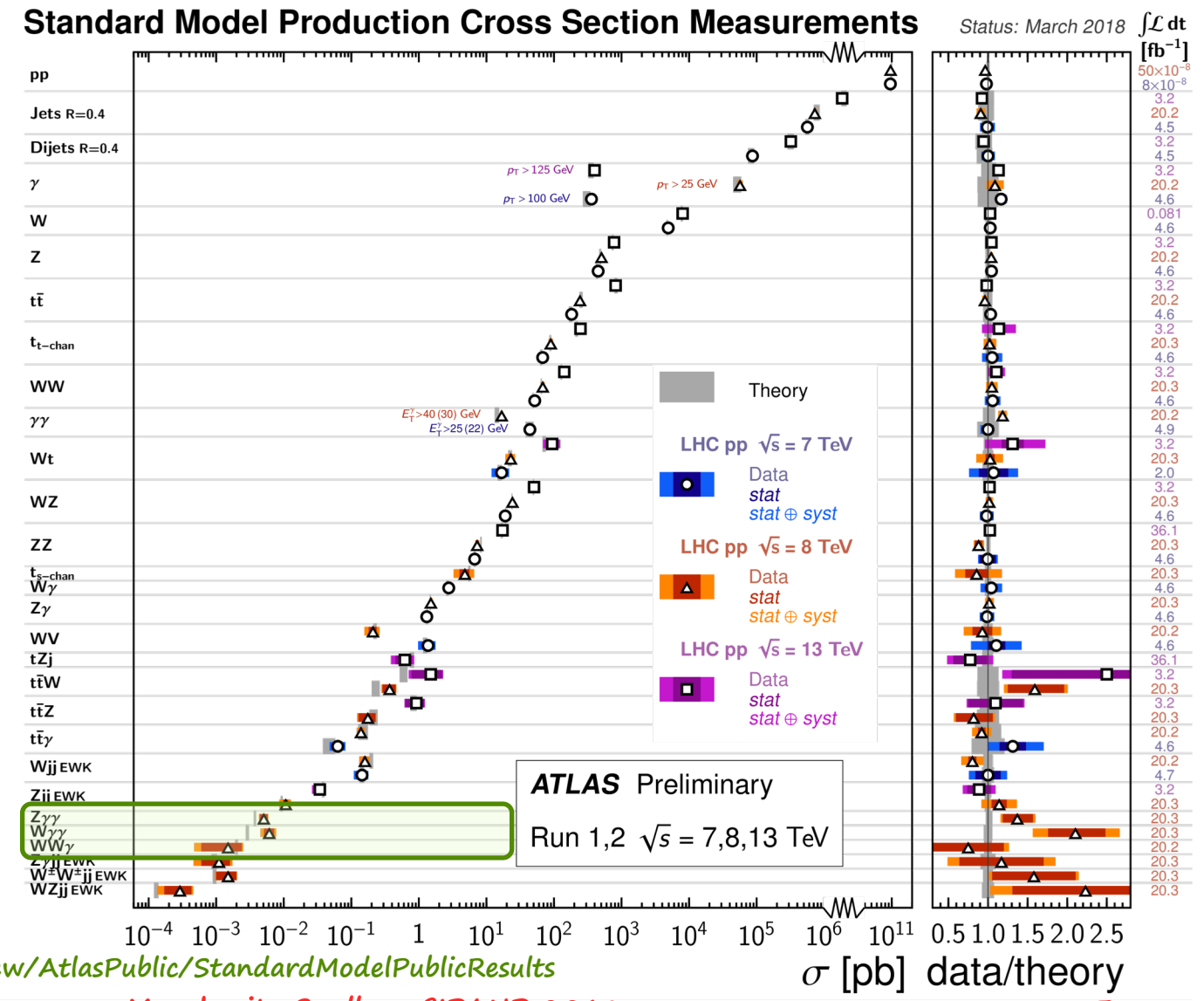

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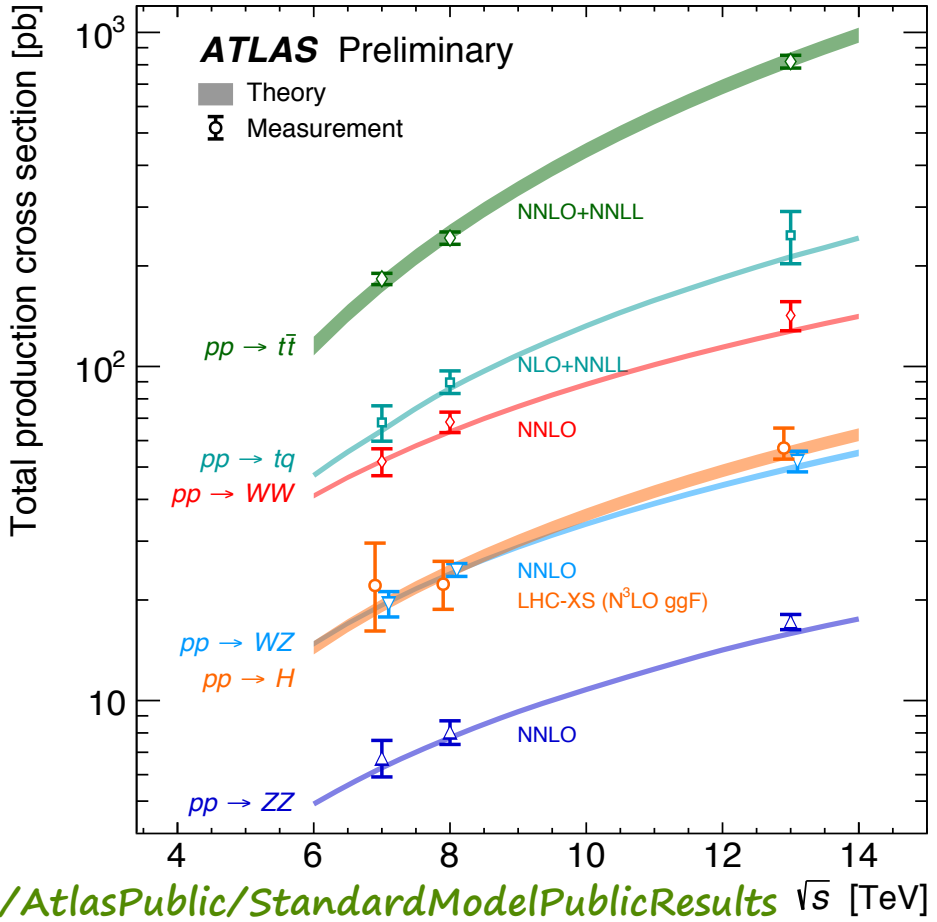
Diboson production

- Well measured at 7/8 TeV:
  - WW, WZ, ZZ: leptonic and semi-leptonic decay channels
- First 13 TeV results:
  - early WW and WZ
    - ➢ 3.2 fb^{-1} data
  - differential ZZ
    - ➢ 36.1 fb^{-1} data
- Generally good agreement with SM prediction



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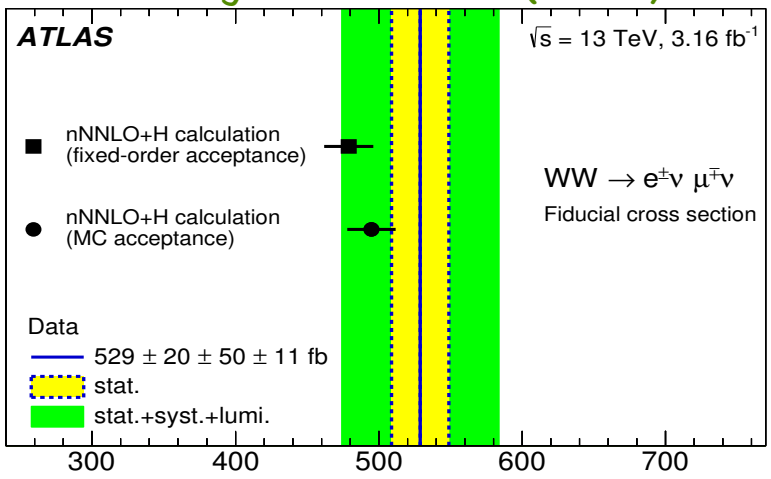
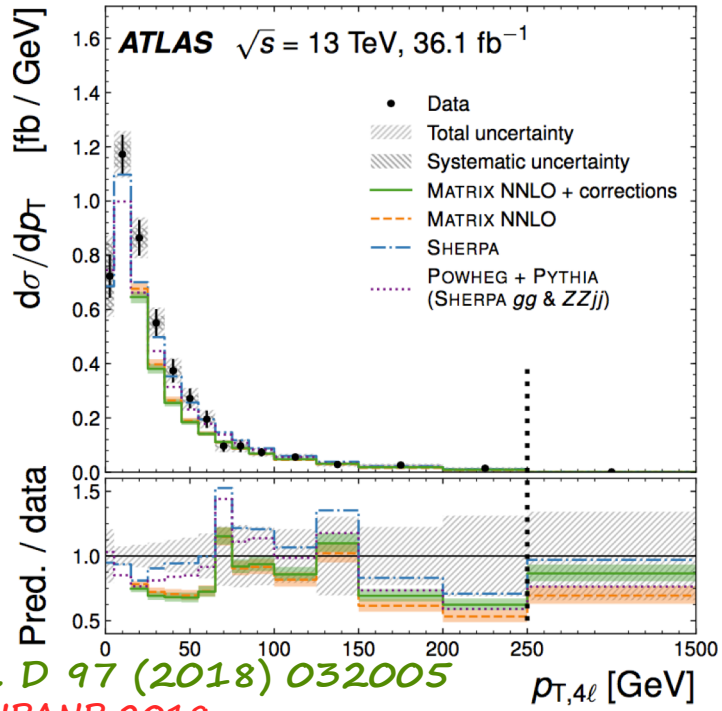
Latest diboson measurements

$\sqrt{s}$ = 13 TeV

- $W^+W^- \rightarrow \mu\nu_\mu e\nu_e$
  - About 1σ deviation from SM at 8 TeV
  - 13 TeV data compared with more precise simulation.
- $ZZ \rightarrow \ell^+\ell^-\ell^+\ell^-$ (+ any jets)
  - Differential cross section in 20 observables
    - Sensitivity to PDF and QCD
  - Towards measurement of ZZjj from EW VBS.
- No significant discrepancy with SM emerges from 13 TeV results
  - Still room for modeling improvement

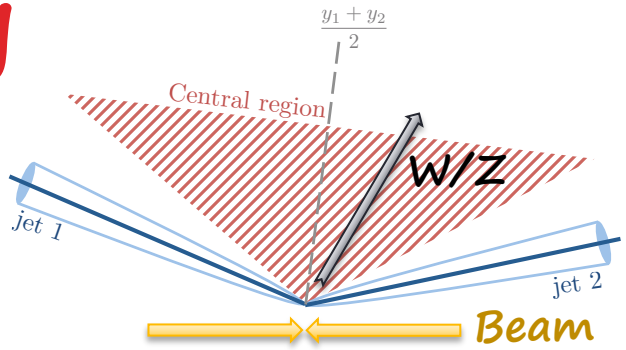
Phys. Lett. B 773 (2017) 354





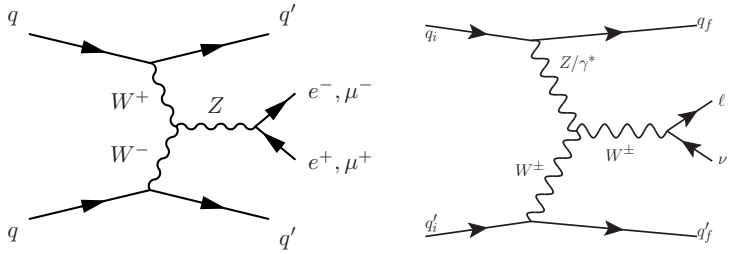
Phys. Rev. D 97 (2018) 032005

VBF Zjj/Wjj

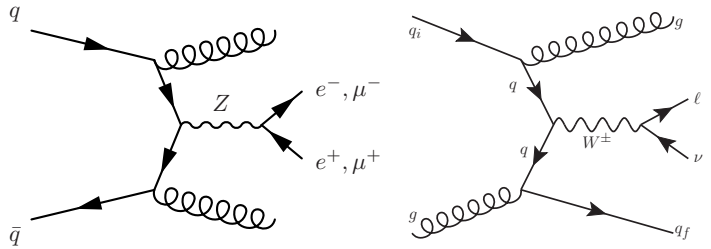


- A vector boson (W or Z) associated to forward-backward jets
- EW production interferring with larger QCD production
  - EW contribution larger at e.g.
    - low activity in central region
      - ➢ no color flow in EW
    - large jet-jet mass
- Tipical approach:
  - Fit simultaneously EW and QCD contribution
  - Control region used to rescale QCD W/Zjj to data
    - Effect of interference term treated as systematics
    - Found to be at percent level

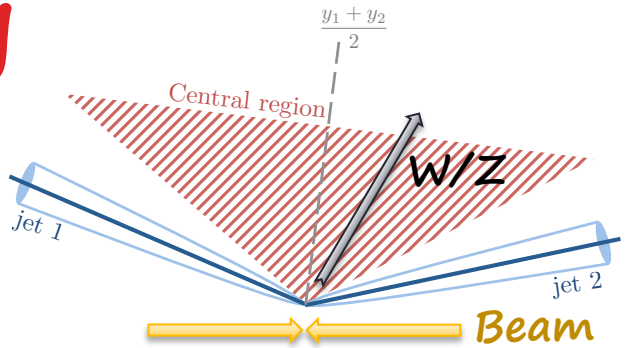
EW contribution



QCD contribution



VBF Zjj/Wjj



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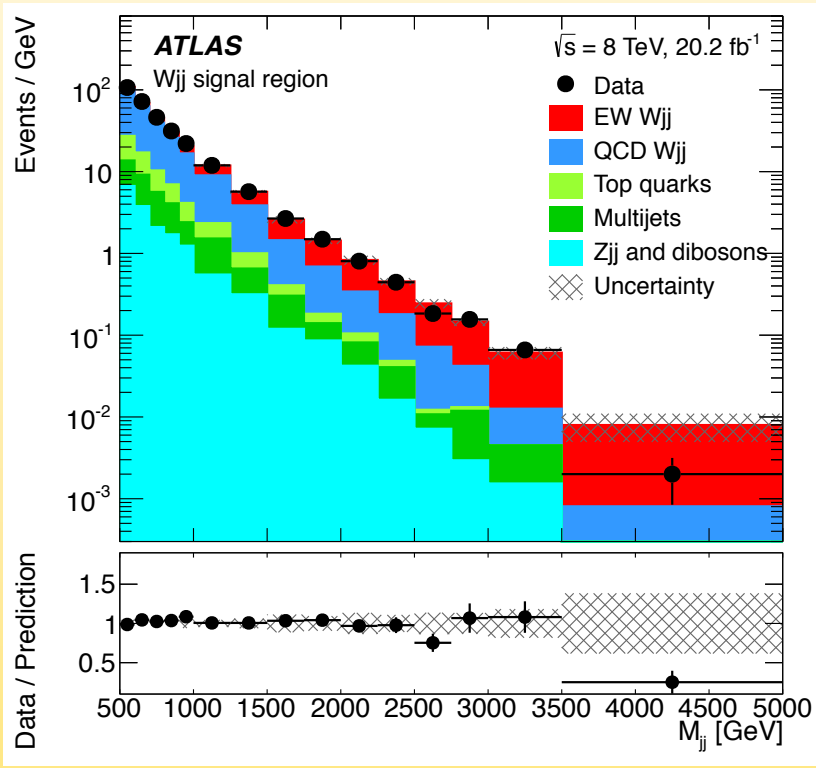
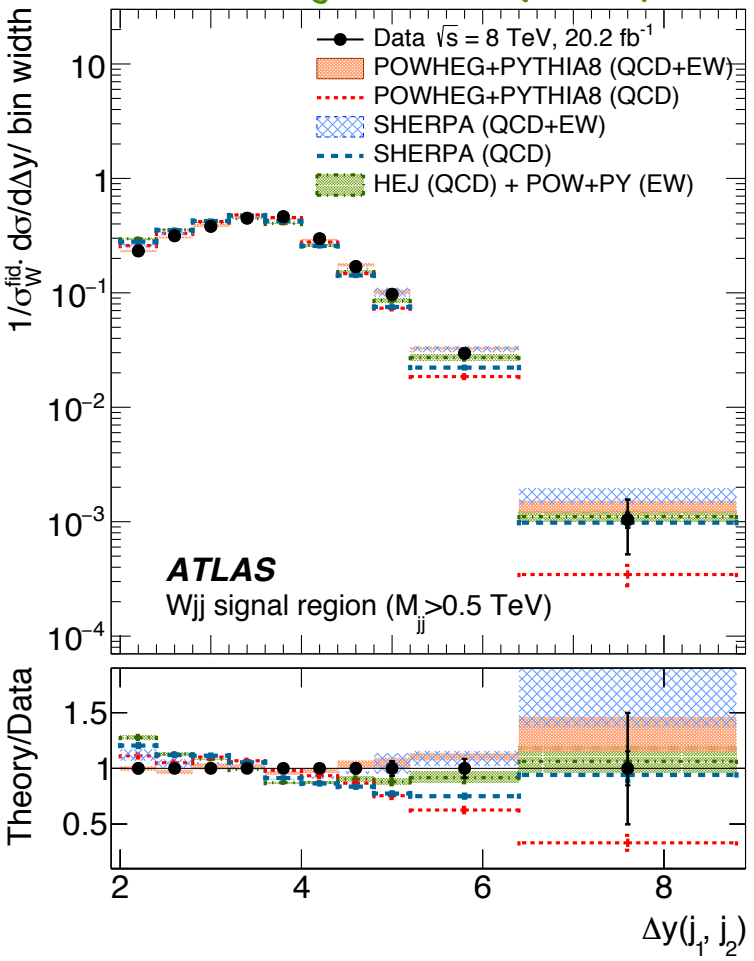


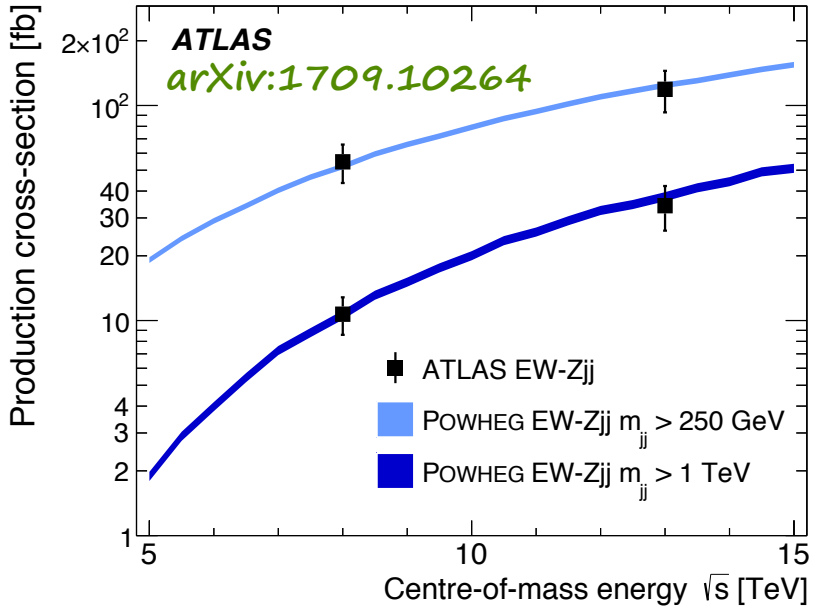
Eur. Phys. J. C77 (2017) 474

VBF Zjj/Wjj: recent results

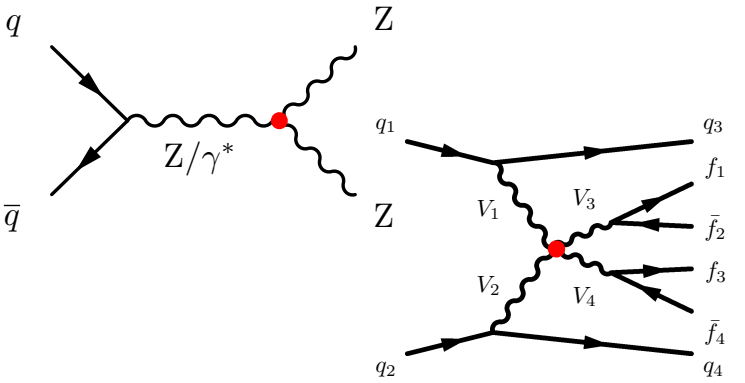
- Zjj: first measured at 8 TeV, repeated at 13 TeV (3.2 fb^{-1})
- 7+8 TeV Wjj recently published.
  - Include differential cross section in multiple fiducial regions
- Moving from first observations to kinematics measurement.

Eur. Phys. J. C77 (2017) 474



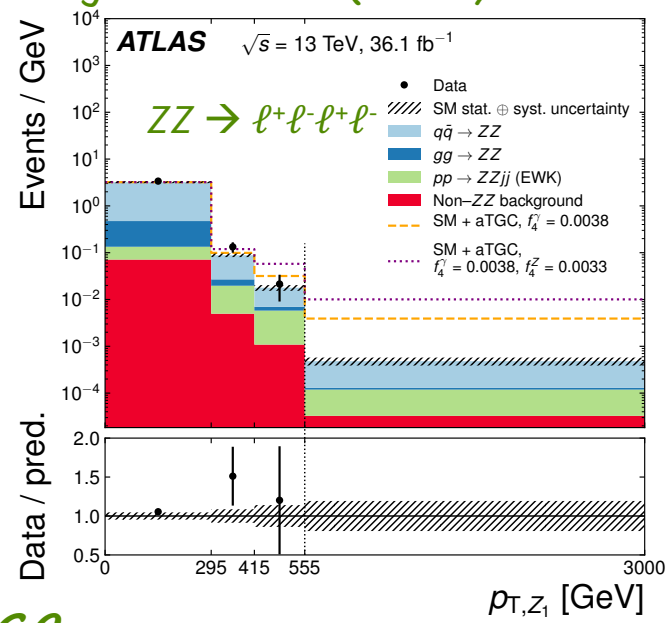


Anomalous Gauge Couplings: the meaning



- Triple (Quartic) Gauge Coupling
- Particles beyond the Standard Model might contribute through loops.
  - ➢ Anomalous Triple / Quartic Gauge Couplings (aTGC / aQGC)
    - Would increase production rate at high energy.
- Parametrized with model independent method (e.g. Effective Field Theory)
- Limits on the parameters from fit to most sensitive variable
  - mass, leading object's p_T, etc.

Phys. Rev. D 97 (2018) 032005



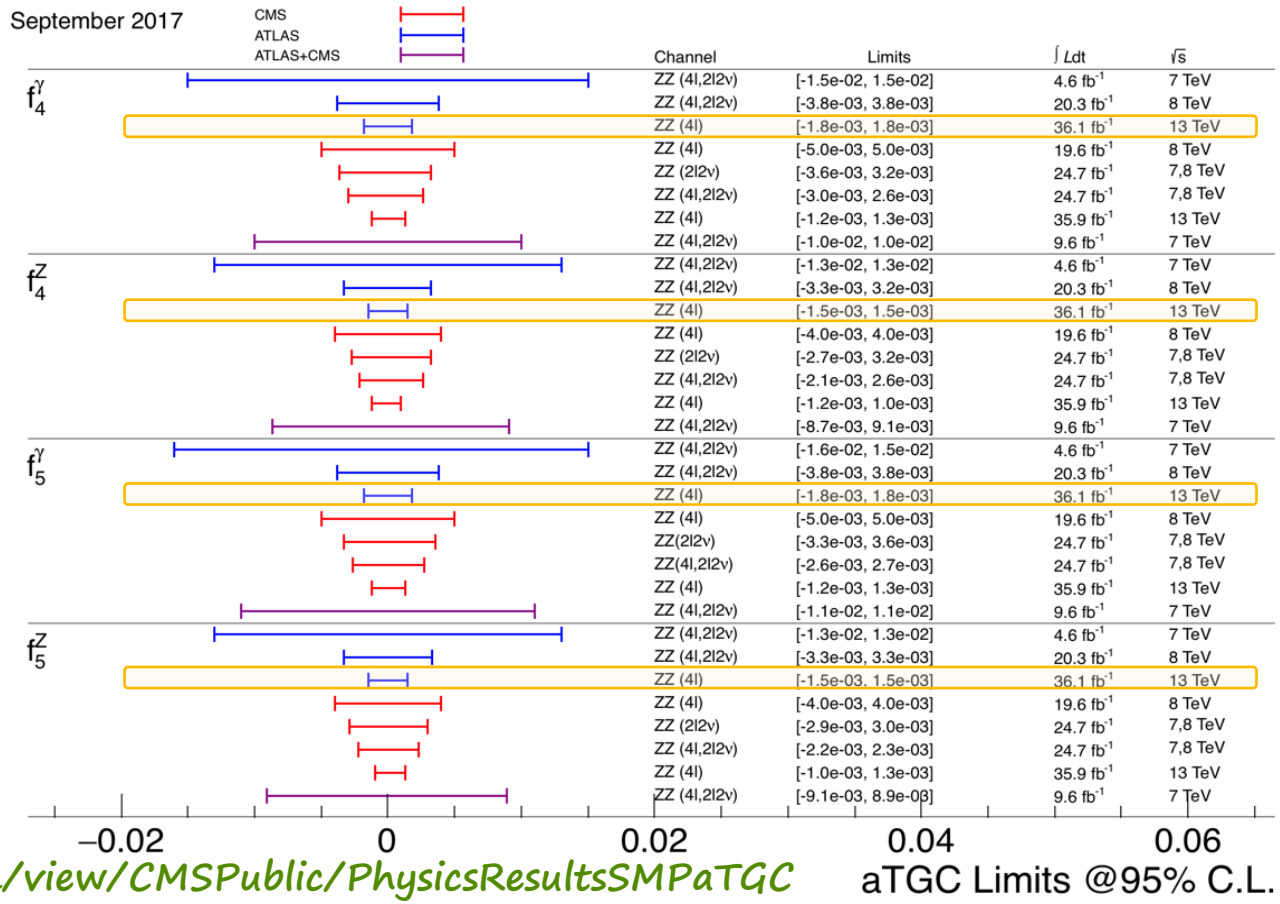
aTGC

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \frac{c_i}{\Lambda^2}\mathcal{O}_i(\dim 6) + \sum_i \frac{d_i}{\Lambda^4}\mathcal{O}_i(\dim 8) + \ldots$$

aQGC

aTGC

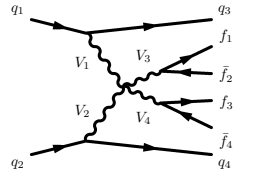
- Three bosons couplings: accessible by diboson and VBF analysis
- First 13 TeV results from $ZZ \rightarrow \ell^+\ell^-\ell^+\ell^-$ and $WZ \rightarrow \ell\nu\ell\ell$
- Results compatible with SM
- Best precision from ATLAS/CMS results



For this and other summaries:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMPaTGC

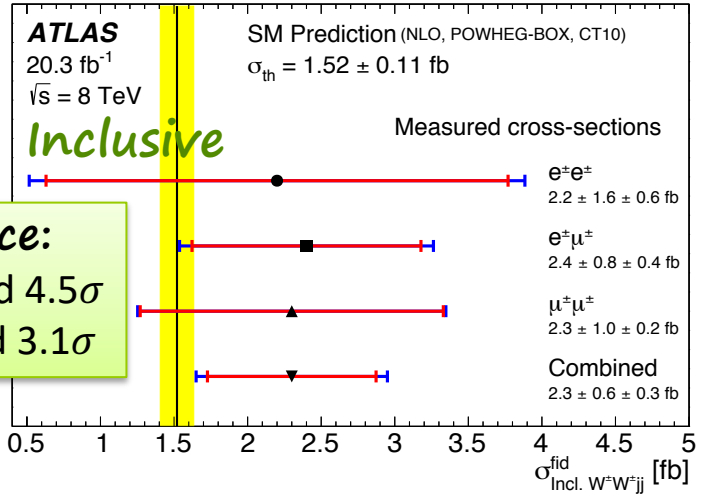
$\sqrt{s}$ =8 TeV

Processes involving four boson interaction: VBS $W^{\pm}W^{\pm}jj$

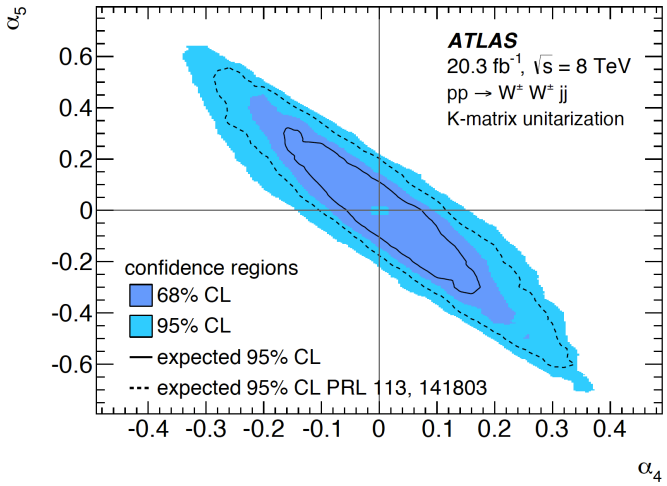


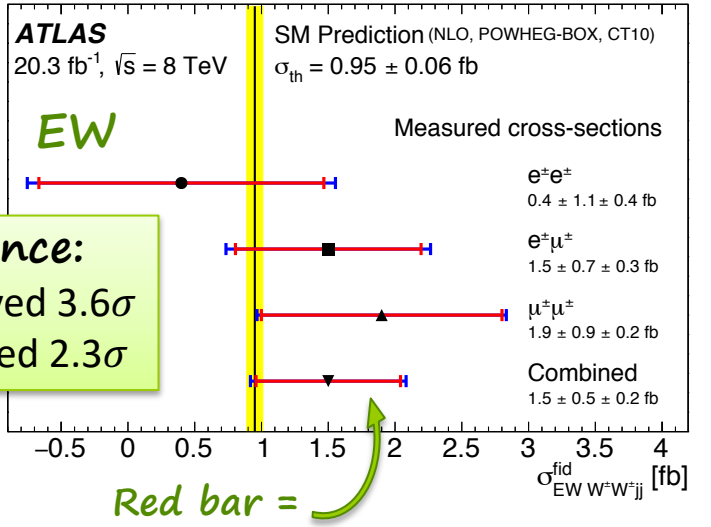
- Two leptons of same charge and two forward-backward jets
  - QCD and EW contribution
- Cross section measured
  - Both inclusive and EW
  - Large, statistically dominated uncertainty
- aQGC limits: improved precision

arXiv:1611.02428v2



Significance:
- Observed 4.5σ
- Expected 3.1σ





Significance:
- Observed 3.6σ
- Expected 2.3σ

Red bar = = statistical uncertainty.

$\sqrt{s}$ =8 TeV

Processes involving four boson interaction: WWγ/WZγ

- $WW\gamma \rightarrow e\nu\mu\nu\gamma$: cross section measurement
  - Significance 1.4 σ
- Upper limit for $WW\gamma/WZ\gamma \rightarrow \ell\nu jj\gamma$
  - 2 to 5 time larger than SM cross section
- All channels combined for aQGC search
  - Results consistent with SM

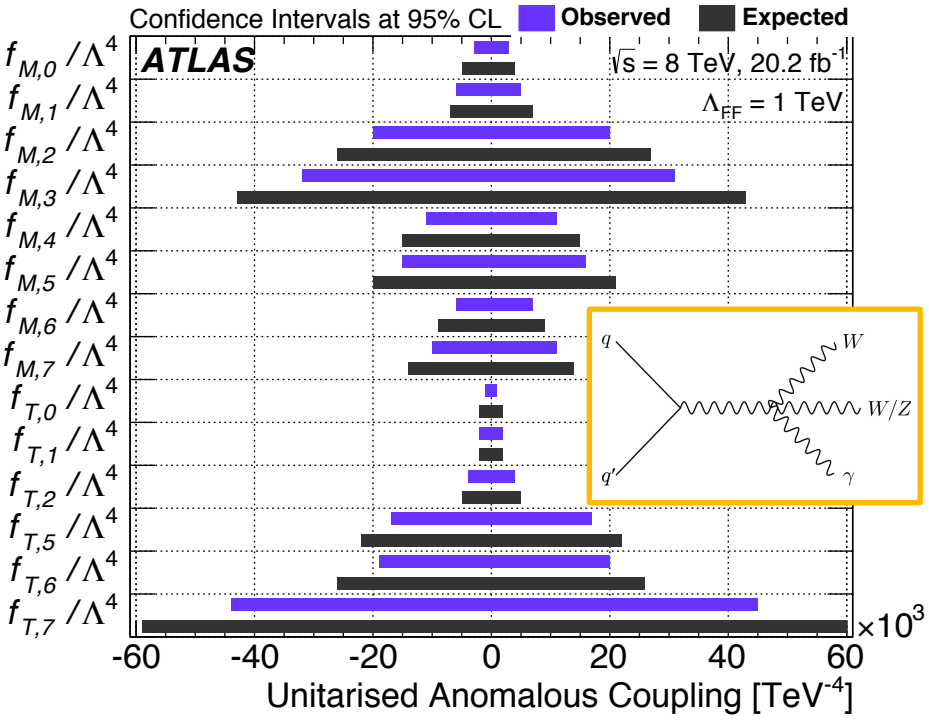
Eur. Phys. J. C 77, 646 (2017)

$$\sigma_{\text{fid}}^{e\nu\mu\nu\gamma} = 1.5 \pm 0.9(\text{stat.}) \pm 0.5(\text{syst.}) \text{ fb}$$

Theoretical prediction: 2.0 ± 0.1 fb

Upper limits

	Observed limit [fb]	Expected limit [fb]	SM Prediction σ_{theo} [fb]
$e\nu jj\gamma$	10	16^{+6}_{-4}	2.4 ± 0.1
$\mu\nu jj\gamma$	8	10^{+4}_{-3}	2.2 ± 0.1
$\ell\nu jj\gamma$	6	$8.4^{+3.4}_{-2.4}$	2.3 ± 0.1



PRECISION MEASUREMENTS FROM Z DECAY

$\sqrt{s}$ =8 TeV

τ polarization from $Z \to \tau\tau$

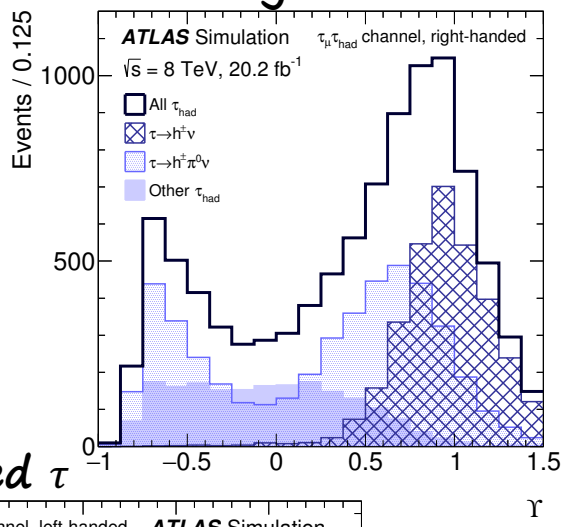
- Measure parity violation in interaction producing τ
- First LHC measurement
  - Precisely measured at LEP
- Semileptonic channel.
  - One leptonic tau needed for triggering events
- Maximum likelyhood fit to variable sensitive to τ polarization

$$P_\tau = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

arXiv:1709.03490

$$\Upsilon_{\text{theory}} = \frac{E_{\pi^\pm} - E_{\pi^0}}{E_{\pi^\pm} + E_{\pi^0}}.$$

Right handed τ



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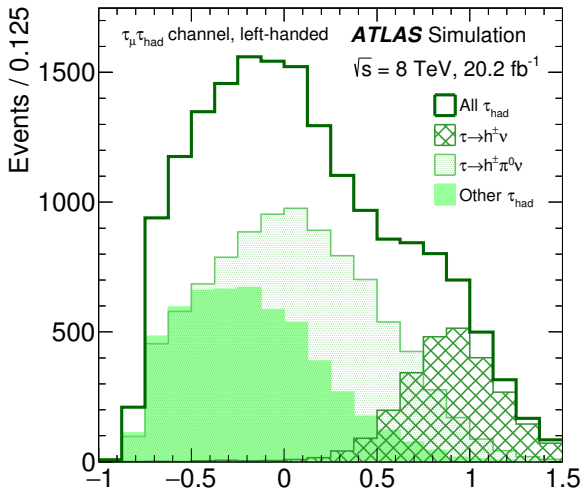


$\sqrt{s}$ =8 TeV

τ polarization from $Z \to \tau\tau$

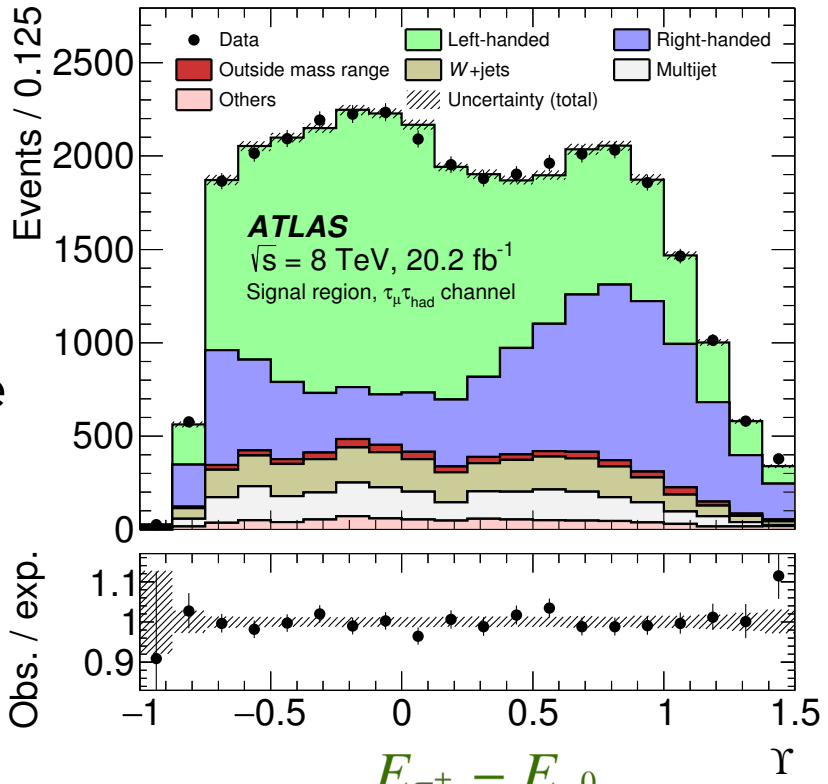
- M
  ir

Observed: $P_\tau = -0.14 \pm 0.02\ (\text{stat}) \pm 0.04\ (\text{syst})$

SM: $P_\tau = -0.1517 \pm 0.0019$

- First LHC measurement
  - Precisely measured at LEP
- Semileptonic channel.
  - One leptonic tau needed for triggering events
- Maximum likelyhood fit to variable sensitive to τ polarization
- Still much less precise than LEP
  - Combination not done

arXiv:1709.03490



$$\Upsilon_{\text{theory}} = \frac{E_{\pi^\pm} - E_{\pi^0}}{E_{\pi^\pm} + E_{\pi^0}}.$$

$\sqrt{s}$ = 8 TeV

Drell-Yan differential cross section and A_{FB}

JHEP 12 (2017) 059

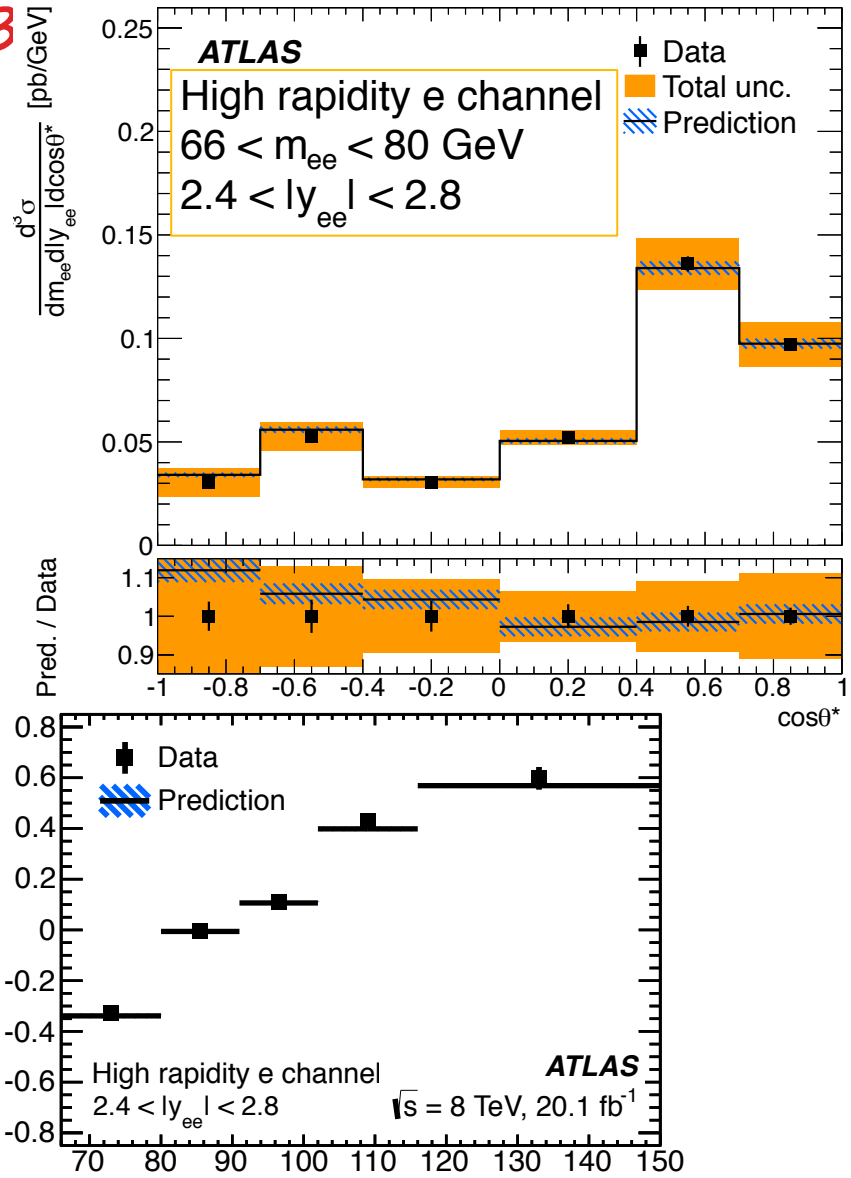
- Already extensively measured
  - Weak mixing angle from forward-backward asymmetry (A_{FB}) in $pp \rightarrow Z/\gamma^* \rightarrow \ell\ell$
- Triple-differential cross section:
  - Sensitive to both weak mixing angle and PDF

$$\frac{d^3\sigma}{dm_{\ell\ell}dy_{\ell\ell}d\cos\theta^*}$$

θ^* = ℓ decay angle in Collins-Soper frame

$$A_{FB} = \frac{d^3\sigma(\cos\theta^* > 0) - d^3\sigma(\cos\theta^* < 0)}{d^3\sigma(\cos\theta^* > 0) + d^3\sigma(\cos\theta^* < 0)}$$

- Reduce PDF uncertainty on weak mixing angle determination
- Results can also serve as input to PDF determination studies



Conclusions

- Electroweak studies in ATLAS go towards higher precision measurement and more rare processes.

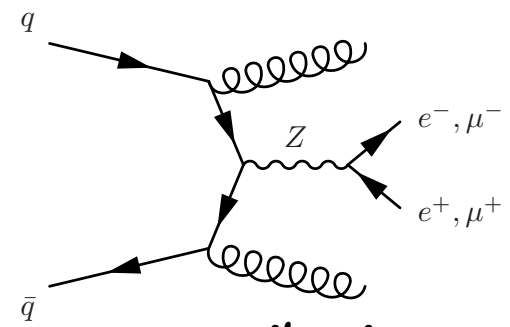
- Can provide significant input to precision SM constraints.
  - And insight into non perturbative QCD.

- Direct test for deviation from SM (anomalous couplings) found no evidence of beyond the SM contribution.

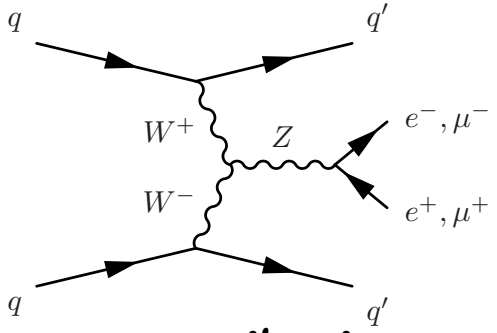
BACKUP

EW and QCD contributions in VBF

Zjj



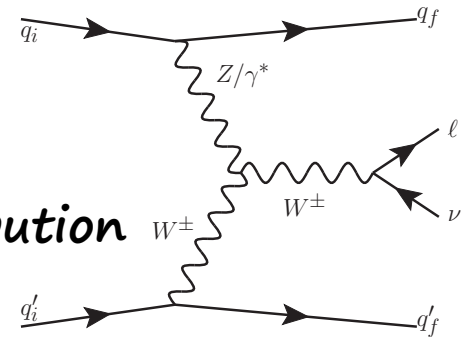
QCD contribution

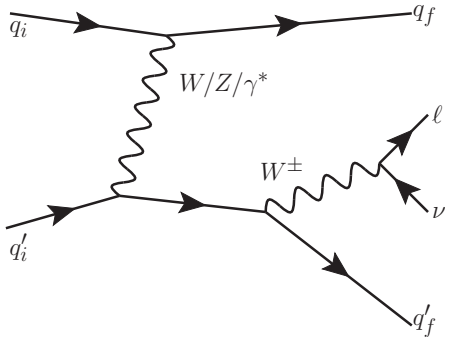


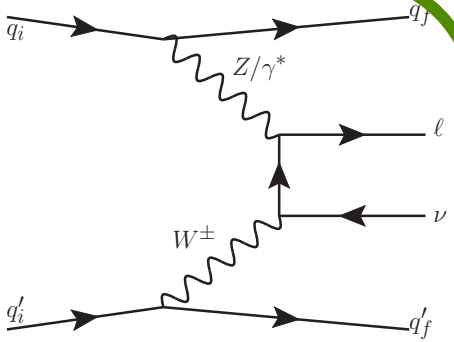
EW contribution

Wjj

EW contribution







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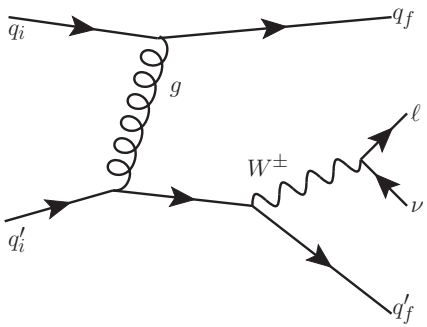
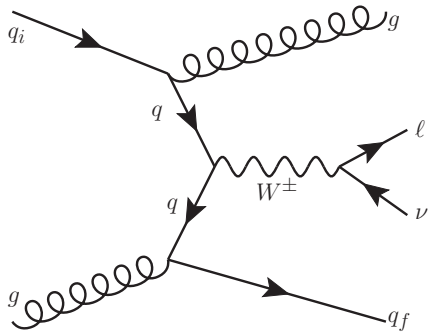
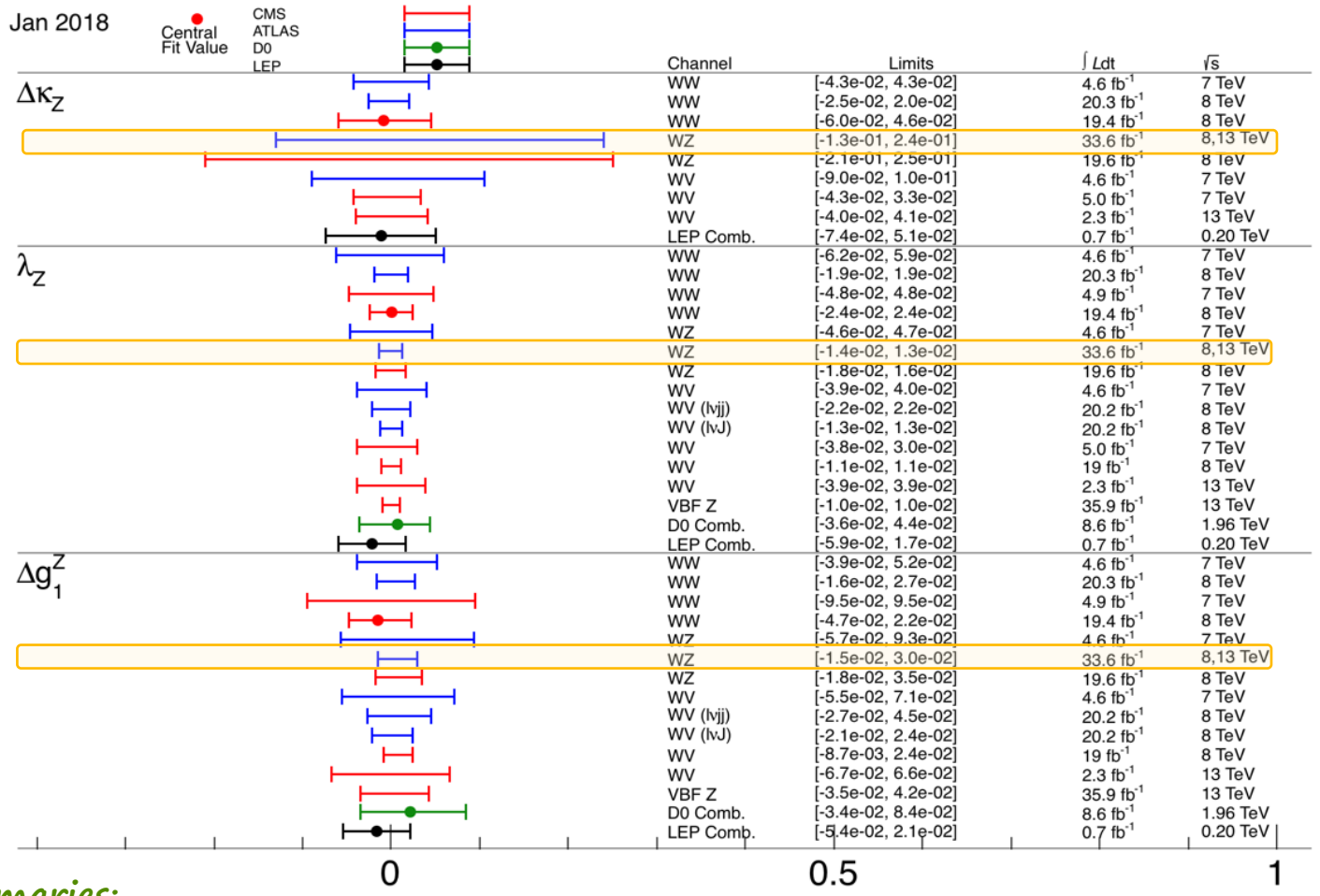




aTGC limits for WWZ vertex

- From: $WZ \rightarrow \ell\nu\ell\ell$

Analysis paper: ATLAS-CONF-2016-043



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Leptonic WZ at 13 TeV

ATLAS-CONF-2016-043