Results on VBF, Diboson Production and aTGCs

Final states:
$W\gamma$, WW, WZ, VBF W

Kristin Lohwasser (DESY)

Multiboson Workshop, Wisconsin, 25. August 2016

Multiboson final states

Complex final states

- Large high-order QCD corrections and nontrivial contribution from gluons
- Give strict test of SM in predictions of such complex final states
- Constrain and motivate high-order calculations
- study of anomalous Triple/Quartic-Gauge-boson-Couplings (aTGCs/aQGCs)

Popular in searches of new physics:

- Alternative EWSB models or Higgs partners?
- Sensitivity to Gravitons
- SUSY searches (multiple leptons)
- Dark matter searches (Z+X)

Experimentally accessible and reliable

Low backgrounds in leptonic final states

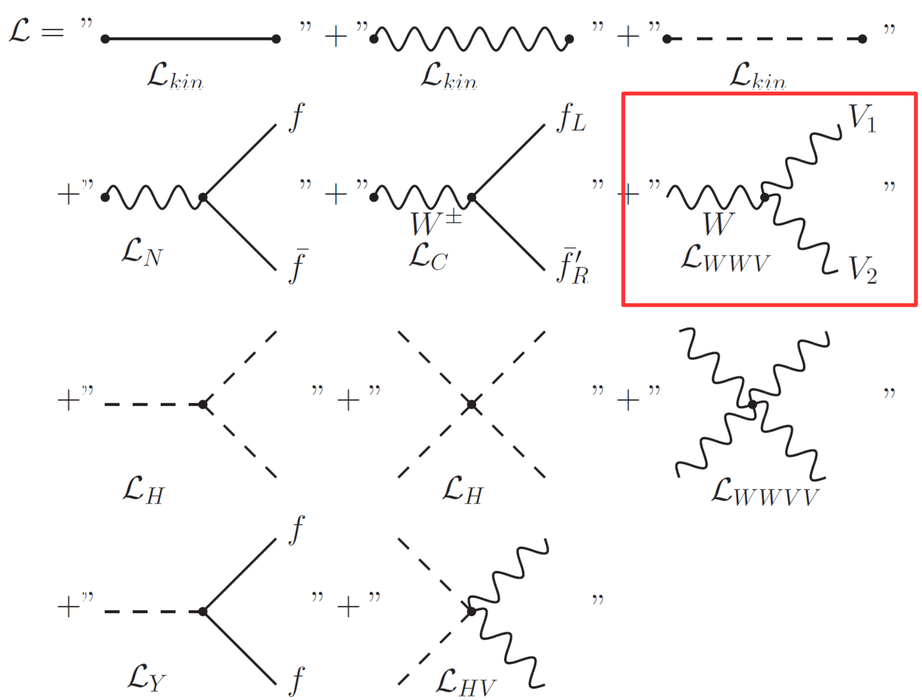
LHC first collider with ample statistics to explore many new channels

Triple gauge boson couplings in the Standard Model

- **Standard Model Lagrangian:**

$$\mathcal{L}_{EW} = \mathcal{L}_{Kin} + \mathcal{L}_N + \mathcal{L}_C + \boxed{\mathcal{L}_{WWV}} + \mathcal{L}_{WWVV} + \mathcal{L}_H + \mathcal{L}_{HV} + \mathcal{L}_Y$$

$$\mathcal{L}_{WWV} = \boxed{-\frac{1}{4}W^a_{\mu\nu}W^{\mu\nu}_a - \frac{1}{4}B_{\mu\nu}B^{\mu\nu}} - \frac{1}{4}G^a_{\mu\nu}G^{\mu\nu}_a$$



- **Triple gauge couplings direct consequence of non-Abelian structure of SU(2)xU(1) electroweak theory**
  - Charged couplings: g_1^Z, k^Z, $k^\gamma = 1$
  - Neutral couplings: $\lambda^\gamma = \lambda^Z = 0$

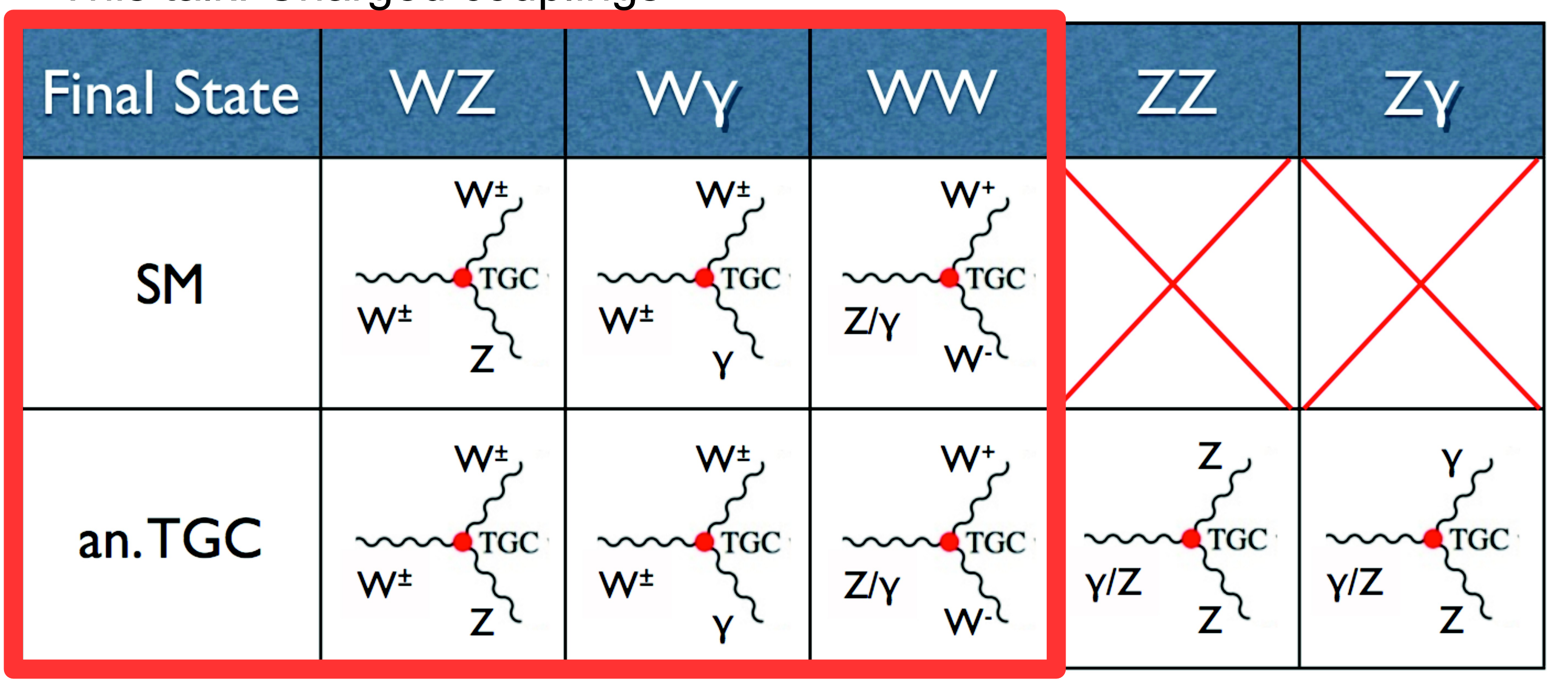
$$\boxed{L = ig_{WWV}\left(g_1^V (W^+_{\mu\nu}W^{-\mu} - W^{+\mu}W^-_{\mu\nu})V^\nu + k^V W^+_\mu W^-_\nu V^{\mu\nu} + \frac{\lambda^V}{M_W^2} W^{\nu+}_\mu W^{-\rho}_\nu V^\mu_\rho)\right)}$$

Anomalous triple gauge couplings

> Multiple diagrams contribute and interfere in Multiboson production

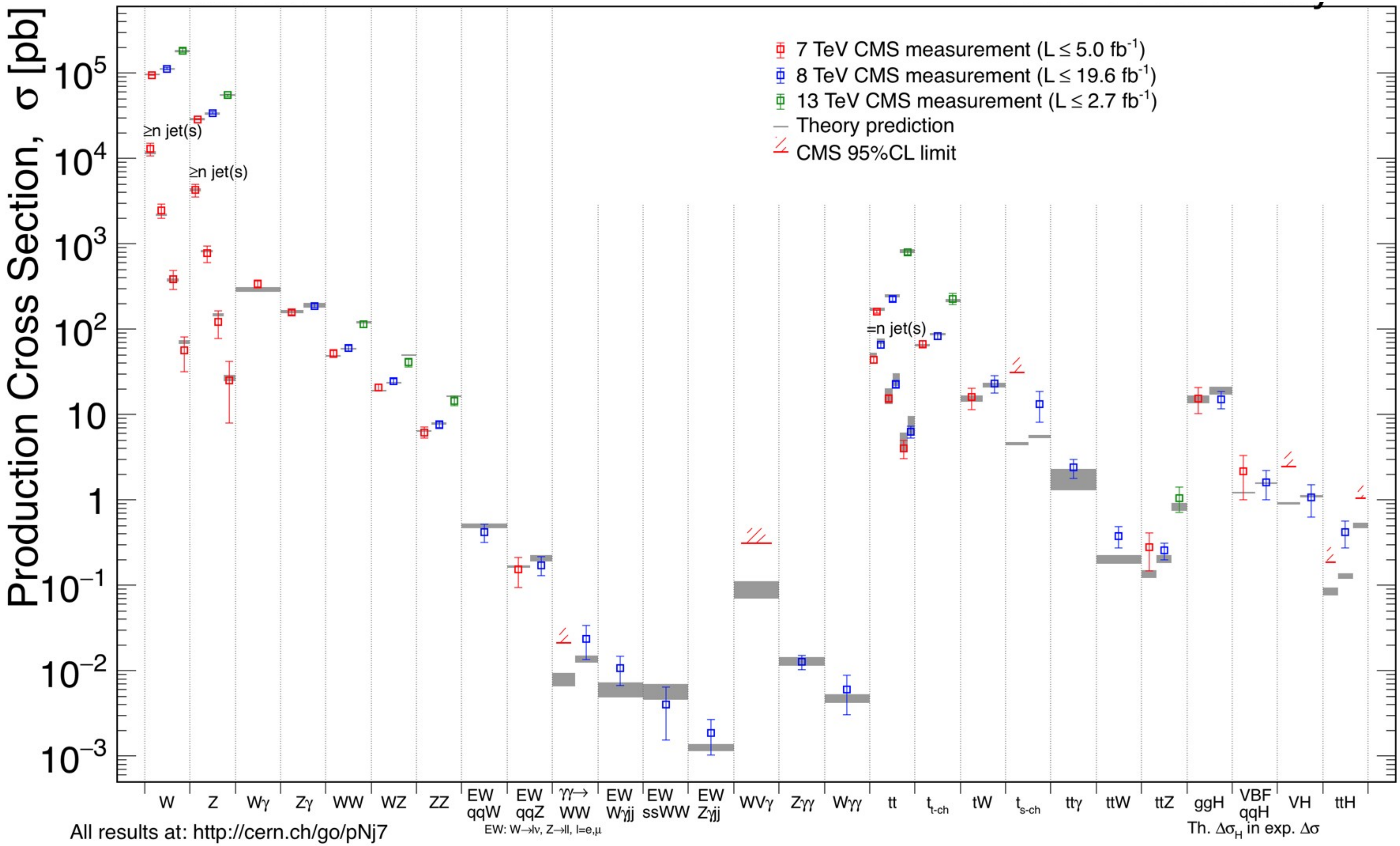
- Delicate cancellation among diagrams restores unitarity
- Sensitivity to new physics through contributions to these diagramms

- This talk: Charged couplings

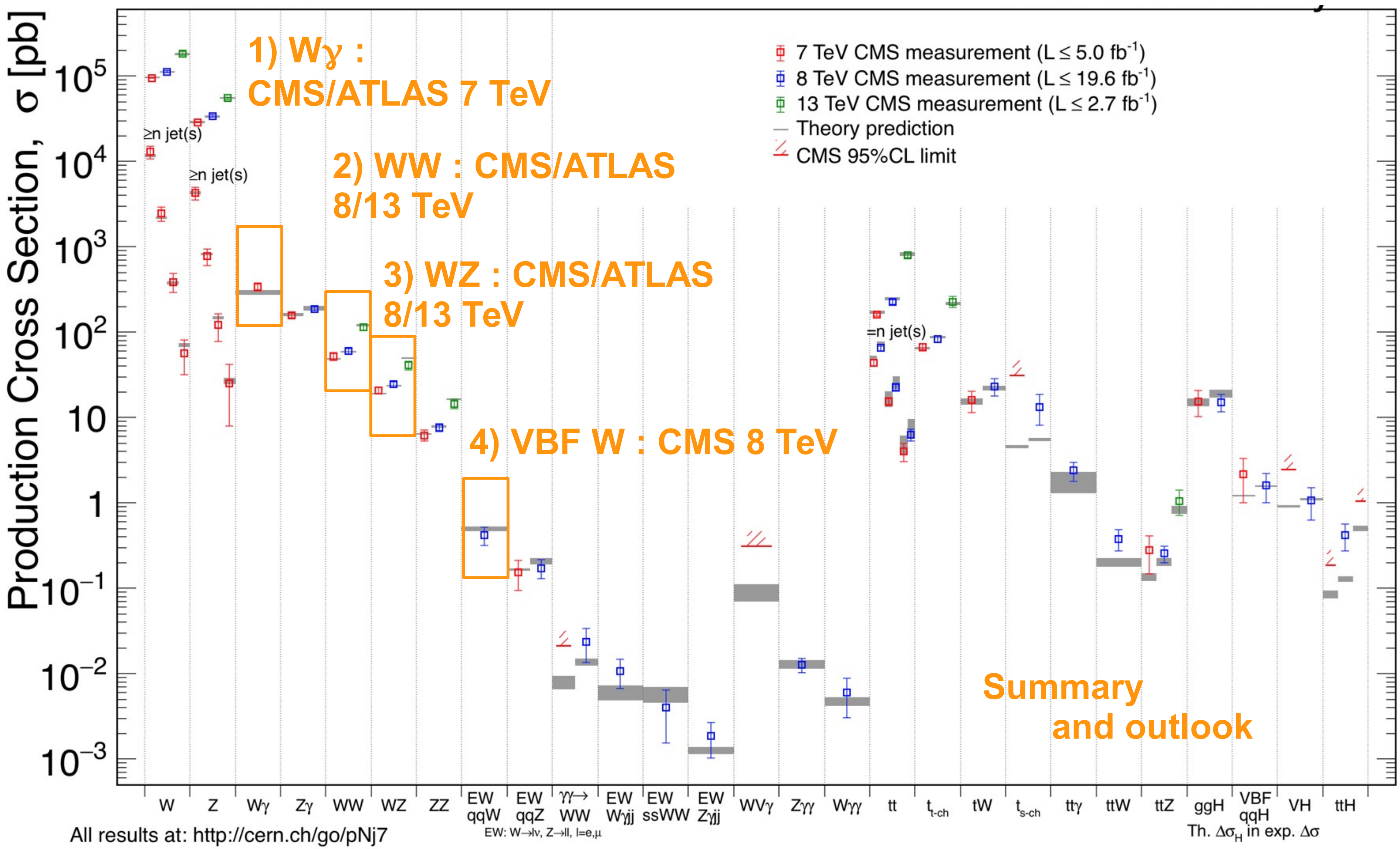


- (Mostly) neutral couplings: Senka Đurić, Wednesday, 11.00 (link)

Standard model processes at the LHC



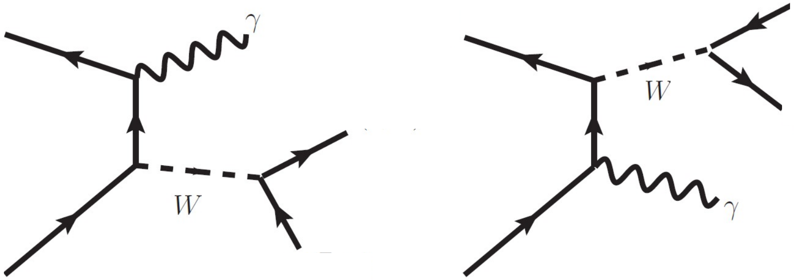
Diboson processes with charged couplings



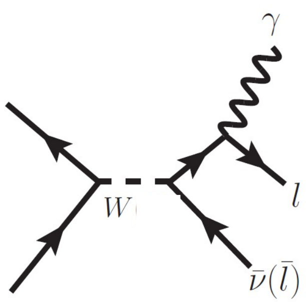
Wγ.

	7 TeV	8 TeV	13 TeV
ATLAS	Phys. Rev. D 87, 112003 (2013) Phys. Rev. D 91, 119901 (Erratum) (2015) 4.6 fb^{-1}	–	–
CMS	PRD 89 (2014) 092005 September 2013 5 fb^{-1}	–	–

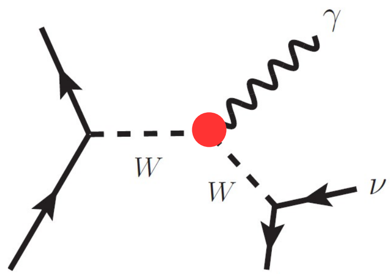
Wγ production: Analyses at 7 TeV from CMS and ATLAS



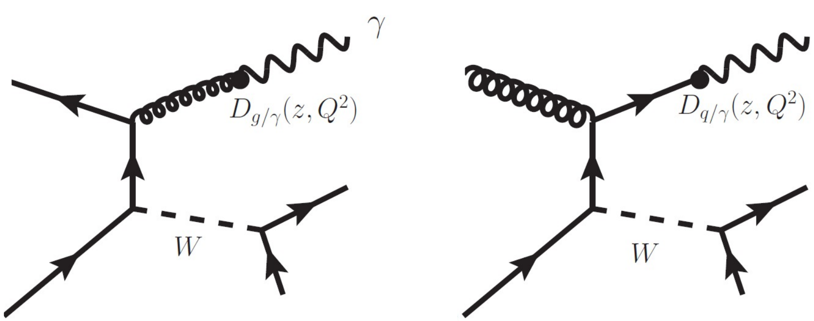
u- and t-channel: ISR



FSR



s-channel: TGC



Fragmentation (considered only by ATLAS) contributes < 4% (photons takes full energy)

> **Selections**

Selections	ATLAS	CMS
$p^T(\ell)$ [GeV]	25	35
$p^T(\gamma)$ [GeV]	15	15
$M_T(W)$* [GeV]	40	70
E^T_{Miss} [GeV]	35	-

$|\eta| < \sim 2.4$, ATLAS with Z veto ($M_{\ell\gamma}$)
CMS second lepton veto

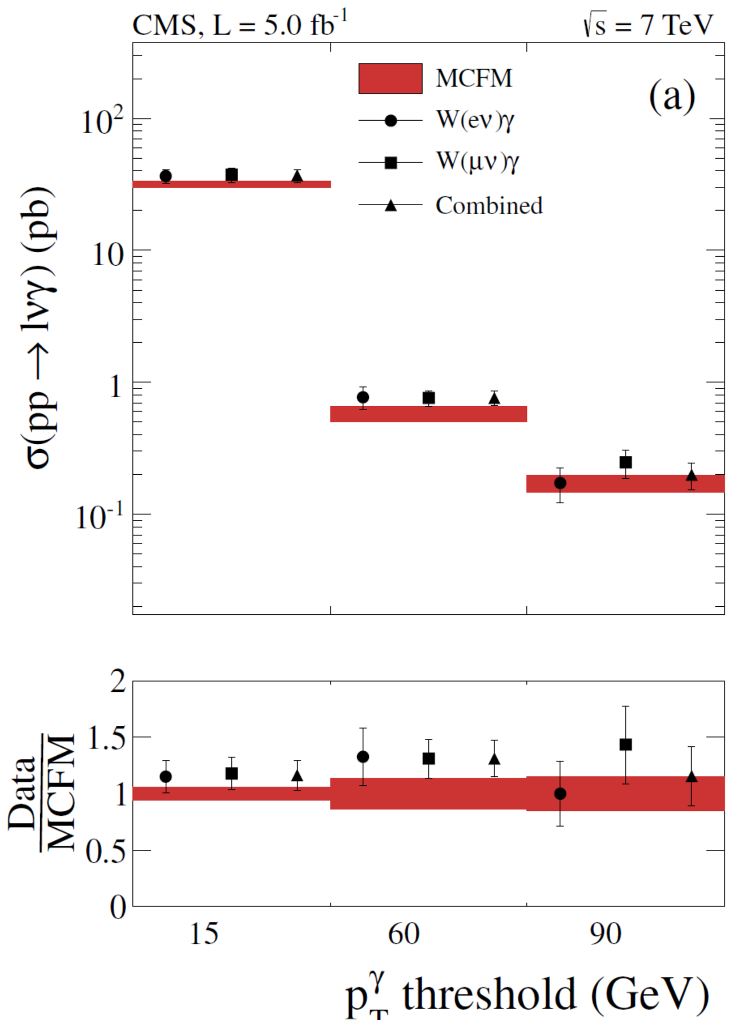
> **Similar number of observed events, CMS with larger W+jets background**

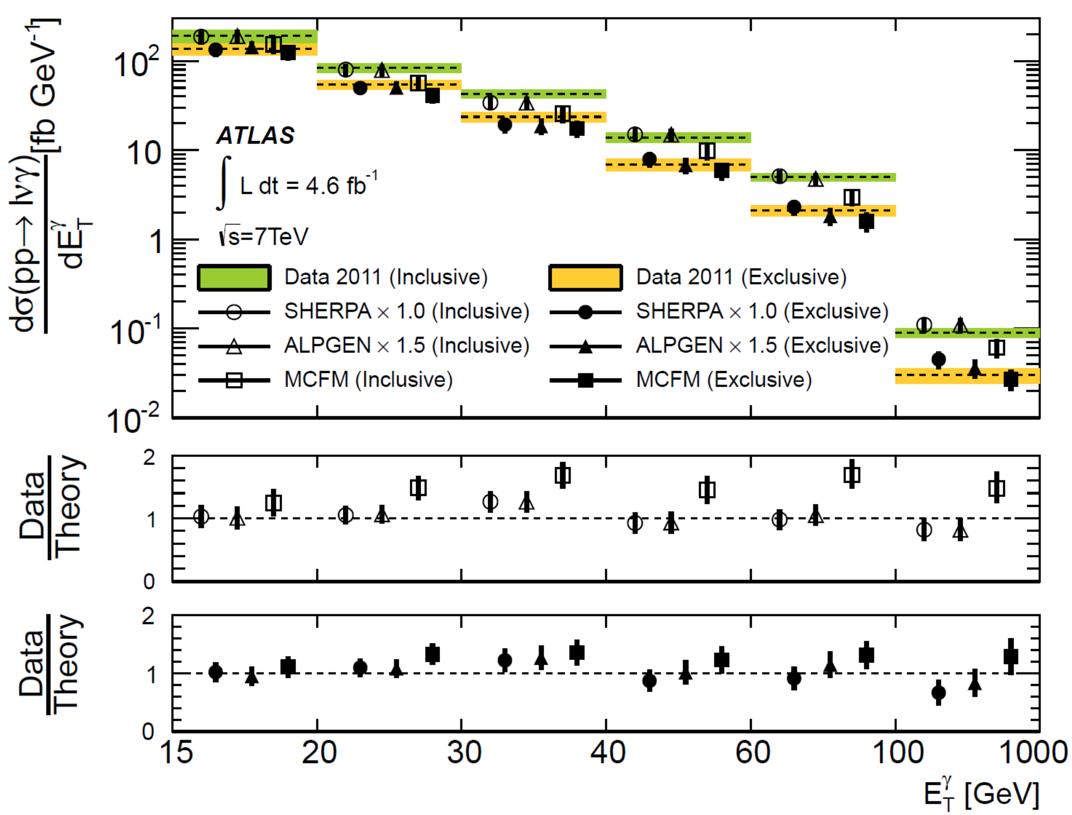
	ATLAS	CMS
N(obs, e)	7399	7470
N(sig,e)	4390	3200
N(obs, μ)	10914	10809
N(sig, μ)	6440	4970

$$^{*}m_T^W = \sqrt{2 \cdot p_T^{\nu} \cdot p_T^{\ell} \cdot [1 - \cos \Delta\phi(\ell, \nu)]},$$

Wγ production: Results

> **Similar picture for both experiments: data slightly above MCFM prediction**
  - Better agreement with Sherpa and Alpgen attributed to processes with larger parton multiplicities (higher orders of α_s), indicated by better agreement of exclusive measurement (N_{jet} =0)

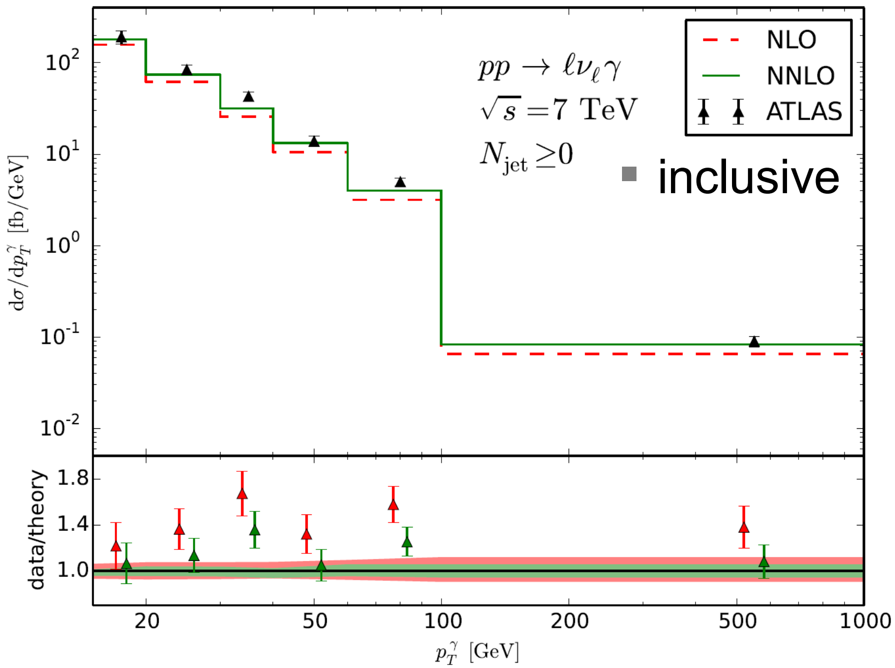


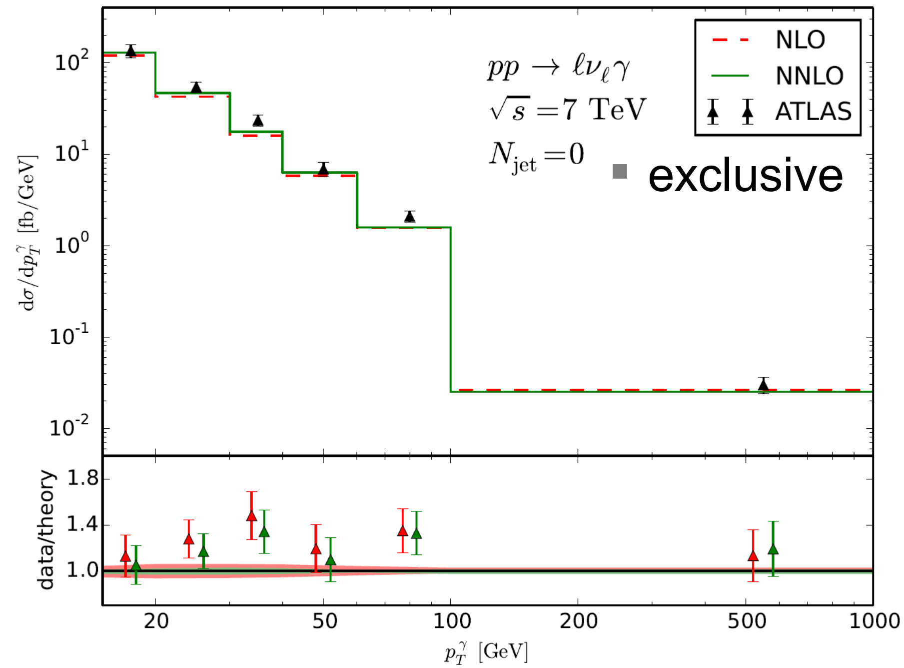


NNLO matters here

> **Wγ first process in which the necessity of NNLO corrections became evident**

- Grazzini, Kallweit, Rathlev published NNLO for Z/Wγ first predictgion in 2015
- Non-flat k-factor, better agreement for both, exclusive and inclusive processes



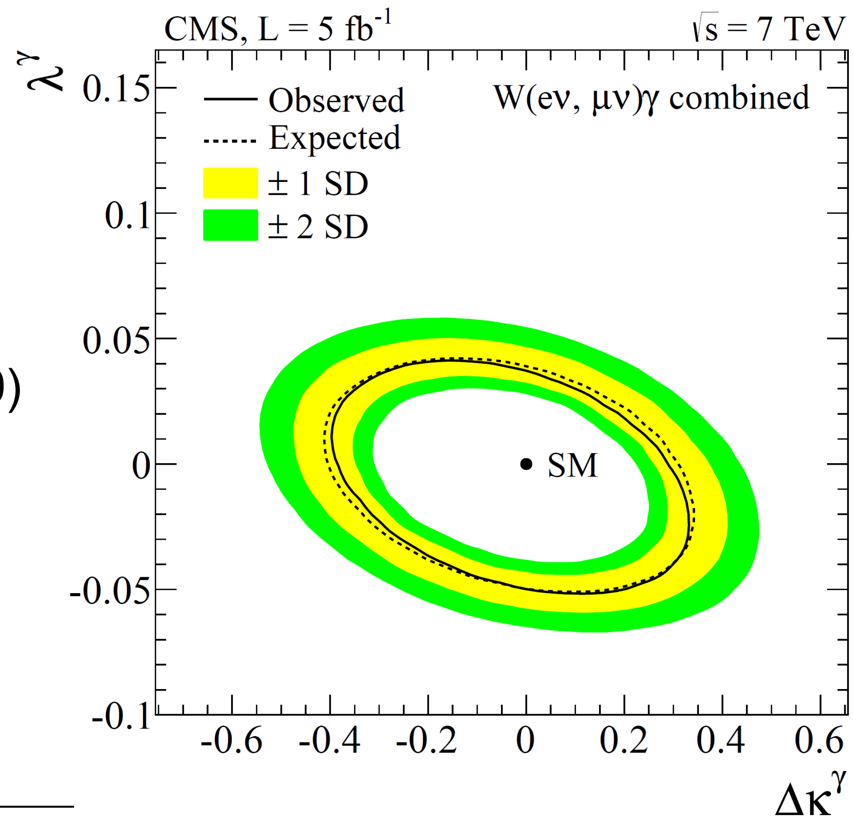


arXiv:1504.01330v1

Wγ production: Limits on anomalous couplings

> (Very!) slight data overshoot: Limits close to expectation

- ATLAS: MCFM for aTGC prediction
  CMS: Sherpa
  Both: using photon $E_T(\gamma)$ distribution
- ATLAS uses exclusive (N_{jets}=0) region
- Limits slightly more stringent for CMS (higher reach in photon energy, N_{Jets}>=0)



CMS

	$\Delta\kappa_\gamma$	λ_γ
$W\gamma \to e\nu\gamma$	$[-0.45, 0.36]$	$[-0.059, 0.046]$
$W\gamma \to \mu\nu\gamma$	$[-0.46, 0.34]$	$[-0.057, 0.045]$
$W\gamma \to \ell\nu\gamma$	$[-0.38, 0.29]$	$[-0.050, 0.037]$

ATLAS

processes	$pp \to \ell\nu\gamma$	
Λ	∞	
	Measured	Expected
$\Delta\kappa_\gamma$	$(-0.41, 0.46)$	$(-0.38, 0.43)$
λ_γ	$(-0.065, 0.061)$	$(-0.060, 0.056)$

WW (fully leptonic)

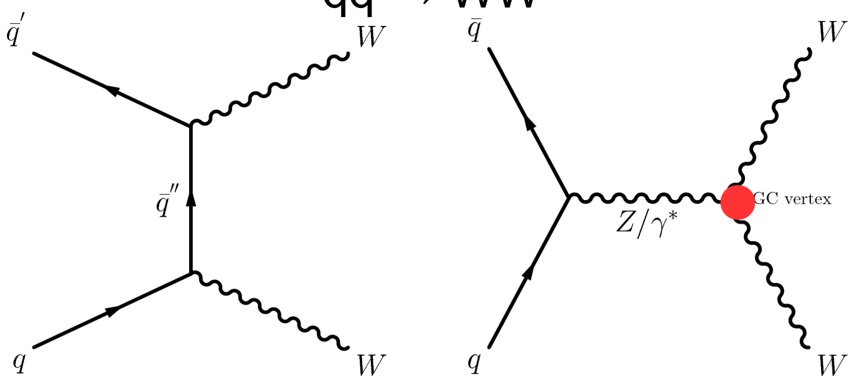
	7 TeV	8 TeV	13 TeV
ATLAS	Phys. Rev. D 87, 112001 (2013) Phys. Rev. D 88, 079906(Erratum) (2013) 4.6 fb^{-1}	sub. to JHEP arXiv:1603.01702 20.3 fb^{-1}	ATLAS-CONF-2016-090 3.16 fb^{-1}
CMS	EPJC 73 (2013) 2610 5 fb^{-1}	EPJC 76 (2016) 401 19.4 fb^{-1}	CMS-PAS-SMP-16-006 2.3 fb^{-1}

Speaking of excesses and overshoots: WW production

> A prime example of the complexities of diboson production processes

- Sum of a variety of very different processes

$qq \rightarrow WW$



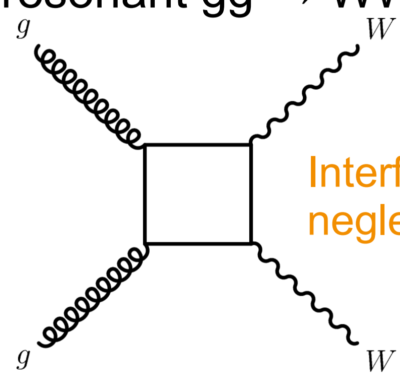
~86%

NNLO $\boldsymbol{O}(\alpha_s^{\,2})$

contains *triple gauge coupling*

(enhanced cross section for high p_T)

Non-resonant $gg \rightarrow WW$

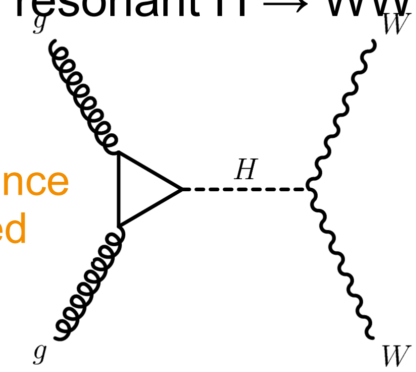


~5%

NLO $\boldsymbol{O}(\alpha_s^{\,3})$

Interference neglected

resonant $H \rightarrow WW$



~8%

N3LO $\boldsymbol{O}(\alpha_s^{\,5})$

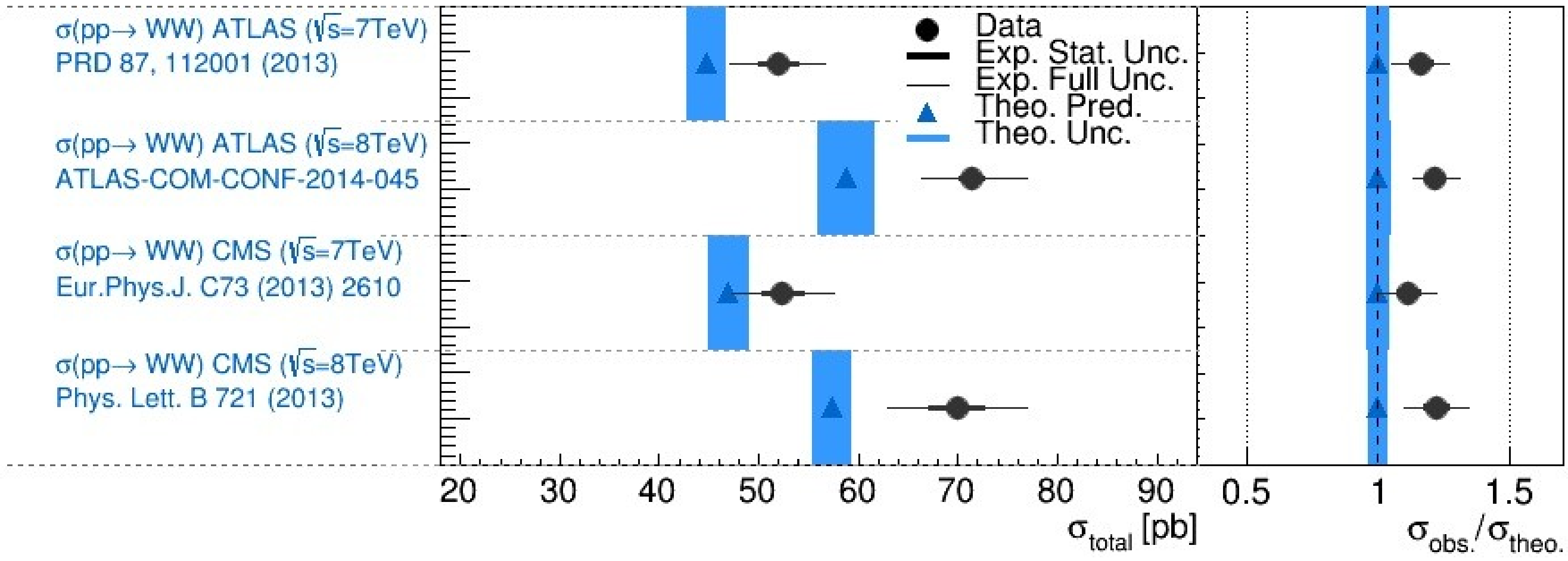
Debatable whether part of WW signal

> Contributions commonly neglected

Electroweak corrections	– 0.5 pb
γγ-induced WW	+ 0.5 pb
Vector boson scattering	+ 0.5 pb
Double parton interaction	+ 0.04 pb

> Not too long ago (ICHEP2014)

- Persistent excess of measurements (at both experiments) over data
- Wild speculations ensued....



WW production: A better picture perhaps

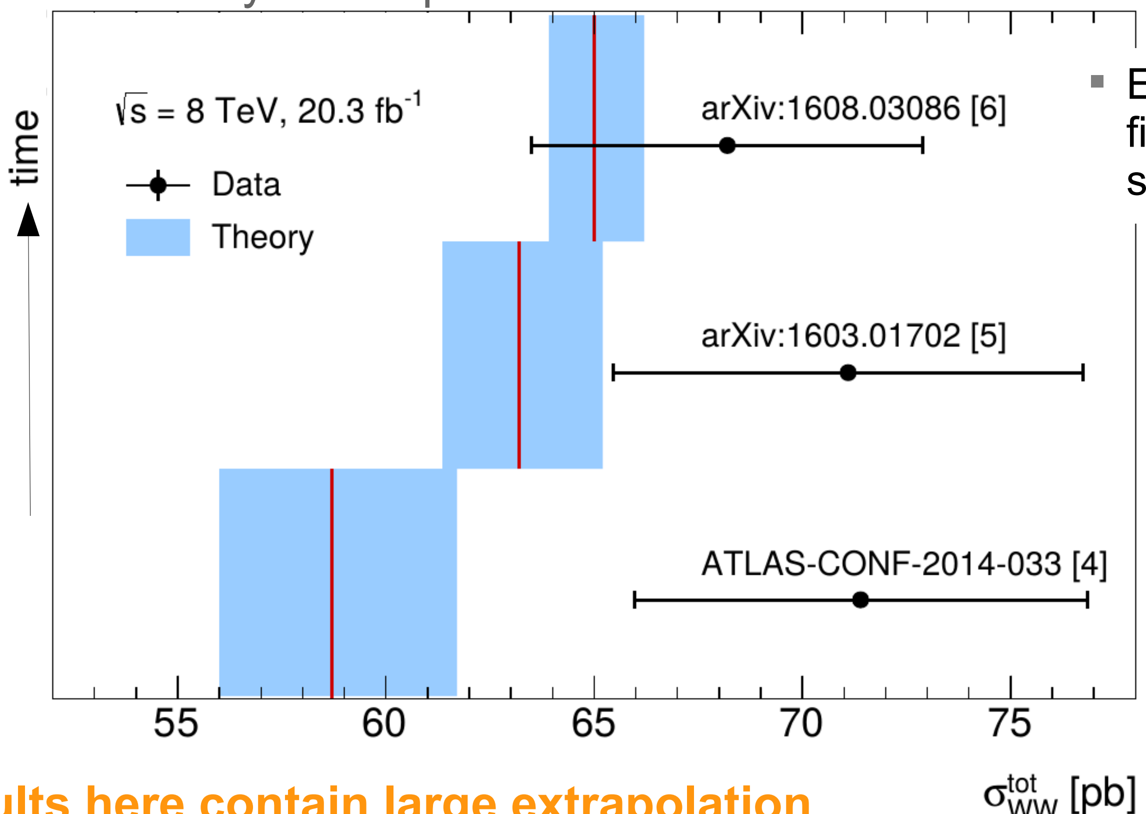
> Progress in predictions over the past two years

- Increase in QCD precision has improved agreement
- So what is the current status?

> Theory Progress

- Non-resonant gg NLO
- Higgs N3LO prediction
- (qq → WW) NNLO predictions
- Resummation effects due to jet veto

Courtesy of Philip Sommer



> Experimental Progress

- Extension of fiducial phase space

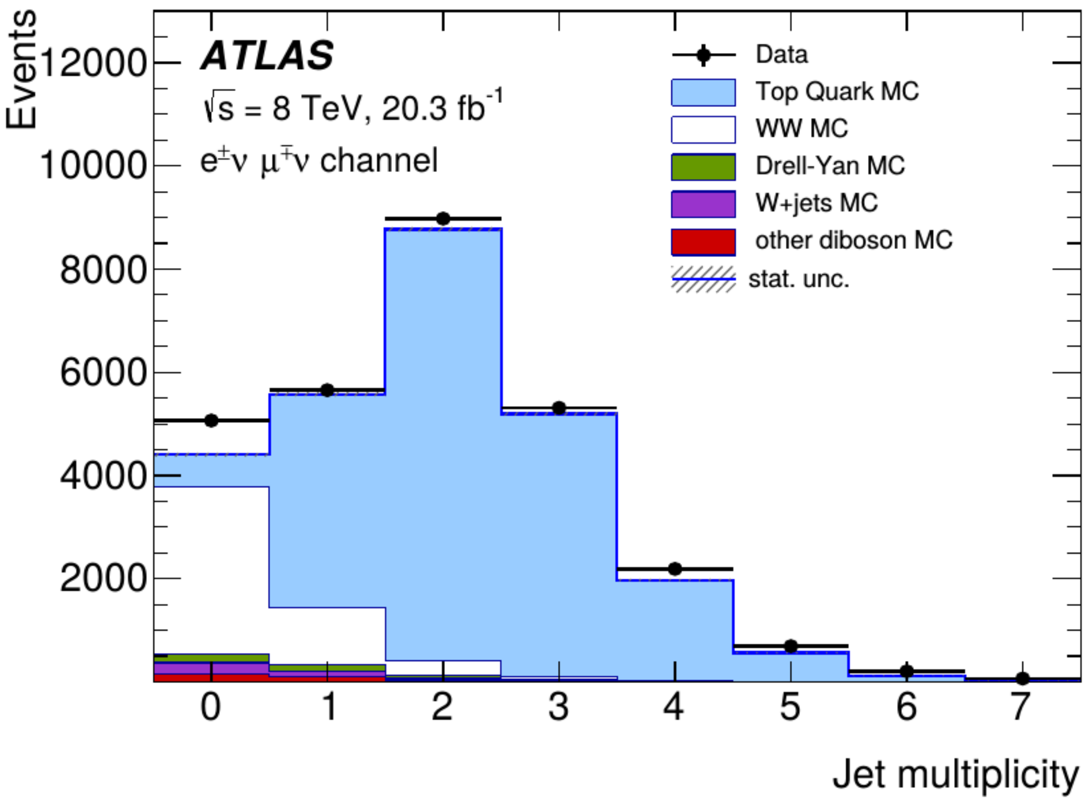
> Experimental results here contain large extrapolation
> Desirable: Compare theory to best fiducial measurement

WW production: Event selection

> Few conceptual differences between ATLAS and CMS

- CMS: Higgs is background (8% of total cross section, but only 3% of observed event yield)

- CMS: Allows for up to 1 additional jet
  Note: ATLAS has now a dedicated analysis with one jet in the final state
  (see: Kenneth Long, Wednesday, 17.15)



- $|\eta| < \sim 2.4(7) / 2.5$
- Tau contribution (~10%)

	ATLAS	CMS*
Exp Signal	3240	3678
Top bkg	18%	14%
W+jets	7%	5%
Diboson	5%	5%
Z Boson	5%	1%

* 3% Higgs
0-jet bin only
1% VVV

WW production: Event selection

> Few conceptual differences between ATLAS and CMS

- CMS: Higgs is background (8% of total cross section, but only 3% of observed event yield)
- CMS: Allows for up to 1 additional jet
  Note: ATLAS has now a dedicated analysis with one jet in the final state
  (see: Kenneth Long, Wednesday, 17.15)

	ATLAS	CMS
$p^T(\ell)$ [GeV]	25 (lead) / 20	20
p_T^{Miss} [GeV]	20	-
E^T_{Miss} (project.) [GeV]	15	20
$\Delta\phi\ (p_T^{Miss}, E^T_{Miss})$	<0.6	-
$p_T\ (\ell\ell)$ [GeV]	-	30
$M\ (\ell\ell)$ [GeV]	10	12
Lepton veto threshold [GeV]	7	10
Number of jets	0 (<=1)	<=1

For both analysis: different-flavour (+0-jet only) shown

- $|\eta| < \sim 2.4(7) / 2.5$
- Tau contribution (~10%)

	ATLAS	CMS*
Exp Signal	3240	3678
Top bkg	18%	14%
W+jets	7%	5%
Diboson	5%	5%
Z Boson	5%	1%

* 3% Higgs
0-jet bin only
1% VVV

Extrapolation to total cross section

> Calculation of cross section:

$$\sigma^{tot} = \frac{N_{sig}}{\mathcal{L} \times A \times C \times B}$$

Signal events
Luminosity
Acceptance correction
→ includes jet veto
Detector correction
Branching ratio

Signal efficiencies (A×C)		
	ATLAS	CMS
0-jet	12%	3% (tau)
1-jet	1.5%	1%

$C = N_{reco}/N_{fidtruth}$

(for ATLAS tau's only in numerator)

- Acceptance correction includes jet veto
- Not trivial to calculate: How to combine samples?

> CMS Approach

- qq → WW (Powheg) ***reweighted to re-summed calculations***
  gg → WW from gg2WW
  added according to Powheg / gg2WW predictions
  normalized to NNLO prediction

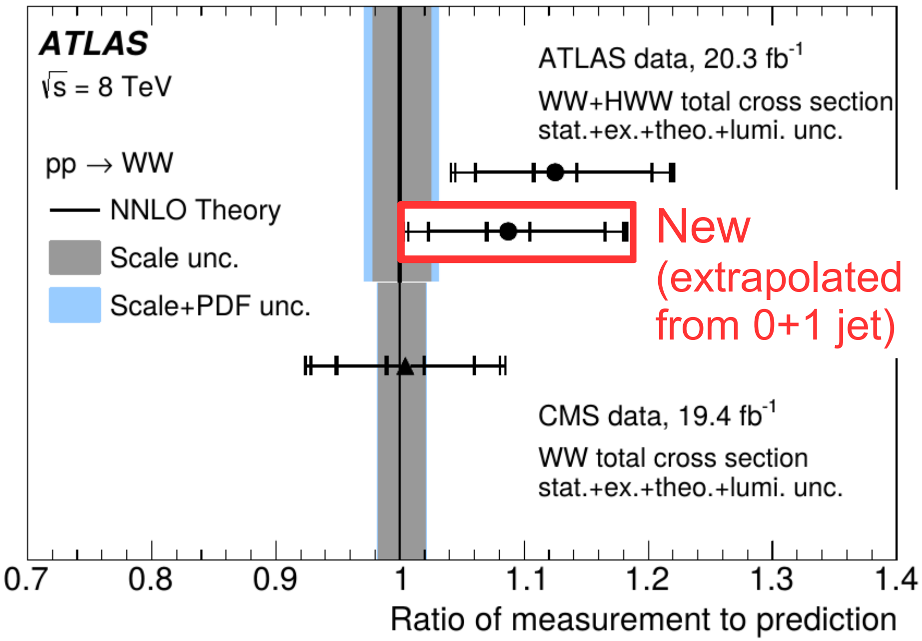
> ATLAS Approach

- qq → WW and H → WW (Powheg) ***normalized to MCFM / HiggsXSWG NNLO***
  gg → WW from gg2WW
  added according to normalization, then normalized to NNLO prediction

- Re-summed and NNLO differential distributions disagree by 4%
  (pointed out in last years workshop by Jamie Tattersal - link)

WW production: Total cross section

> 8 TeV



> 13 TeV – NEW

	ATLAS*	CMS
Measurement	142 ± 14 pb	115.3 ± 10.9 pb
Prediction	128 +3.5 -3.8 pb	120.3 ± 3.6 pb

*Higgs included as signal

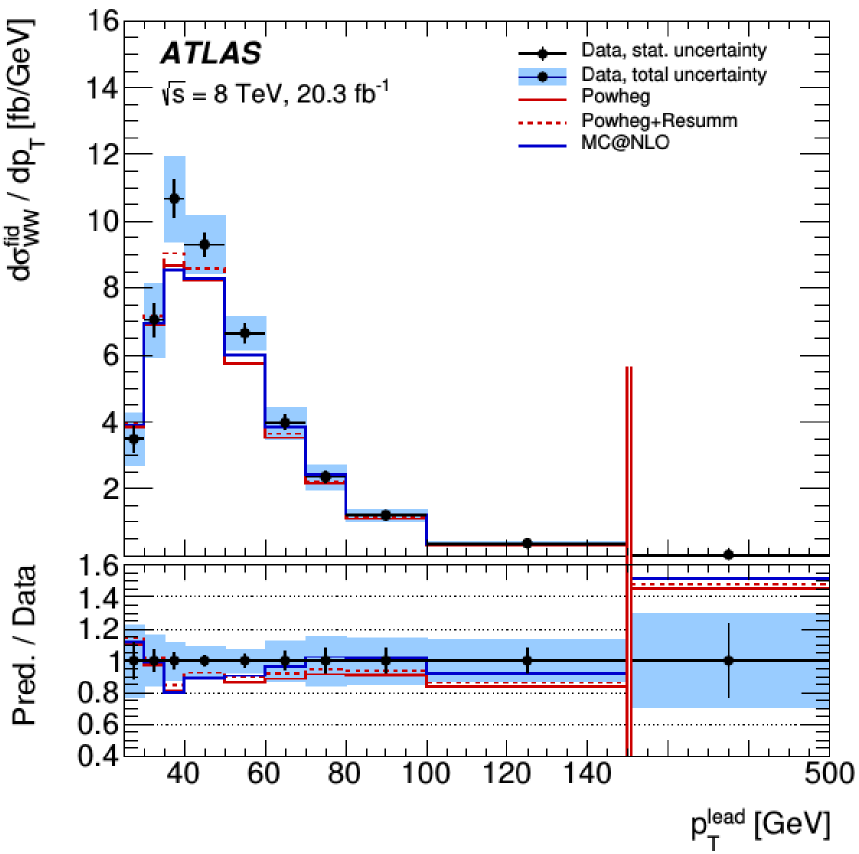
- More on the 13 TeV measurements: Friday, 8.25, Valerio Dao

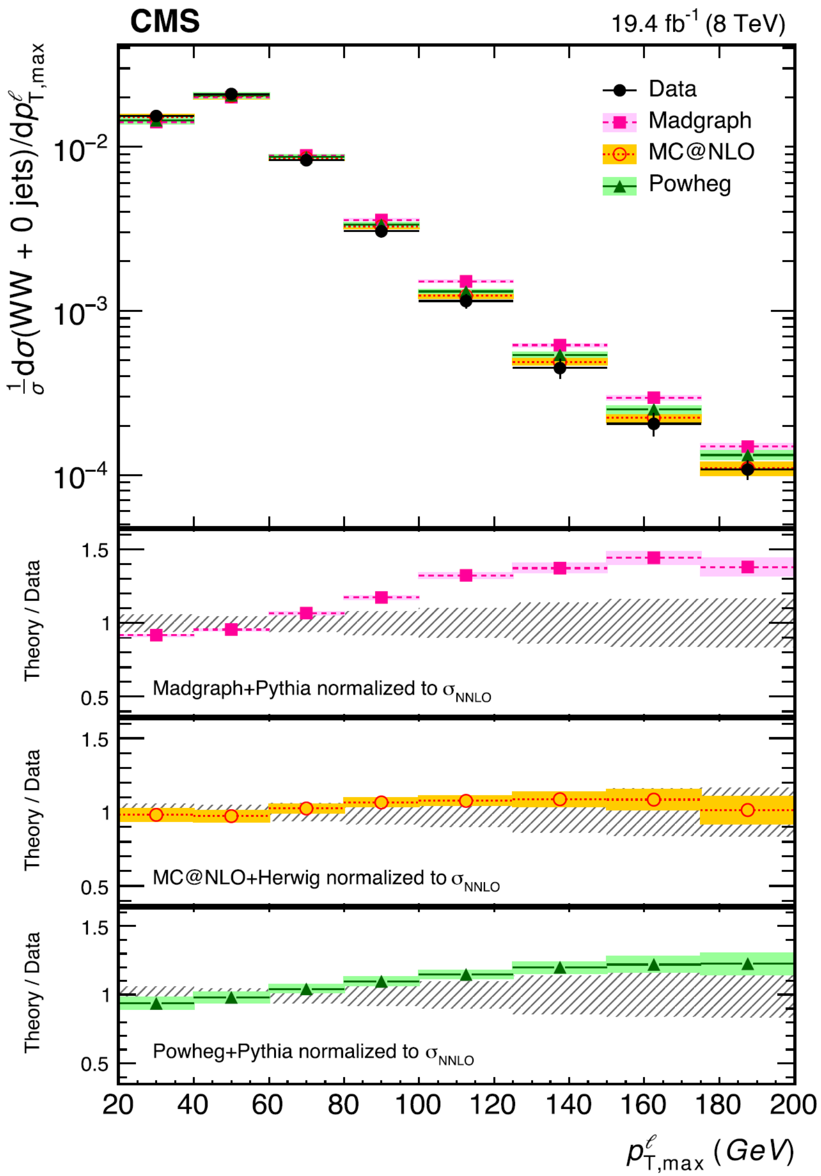
> With better predictions, the excess seems to be mostly gone

WW production: More interesting observations

> Differential distributions

- Measured for leading lepton p_T
- CMS with slope between data and theory

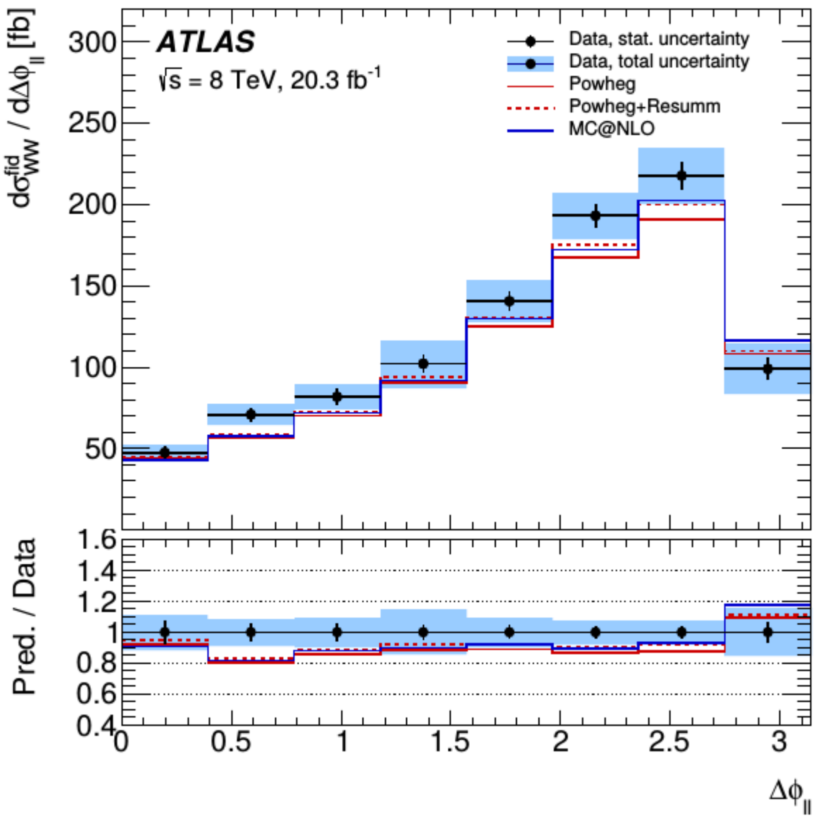


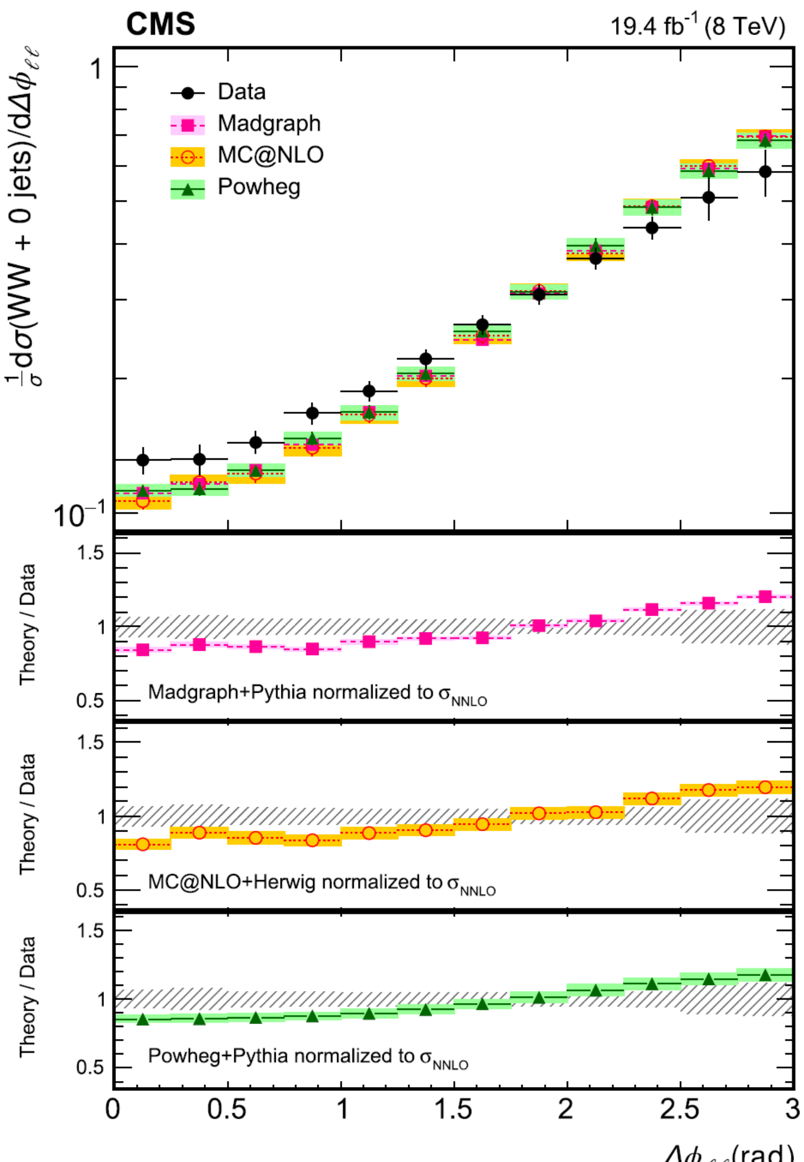


WW production: More interesting observations

> Differential distributions

- Measured for $\Delta\phi(\ell\ell)$
- Slope between data and theory





WW production: Anomalous triple gauge couplings

ATLAS: leading lepton pT distribution

- Optimized binning and choice of variable, applying NLO electroweak corrections
- Setting limits on aTGCs and effective field theory operators

p_T^{lead} [GeV]	25–75	75–150	150–250	250–350	350–1000
SF_{EW}	< 1%	−4%	−10%	−16%	−24%
δSF_{EW}	0.1%	<0.5%	2%	4%	7%

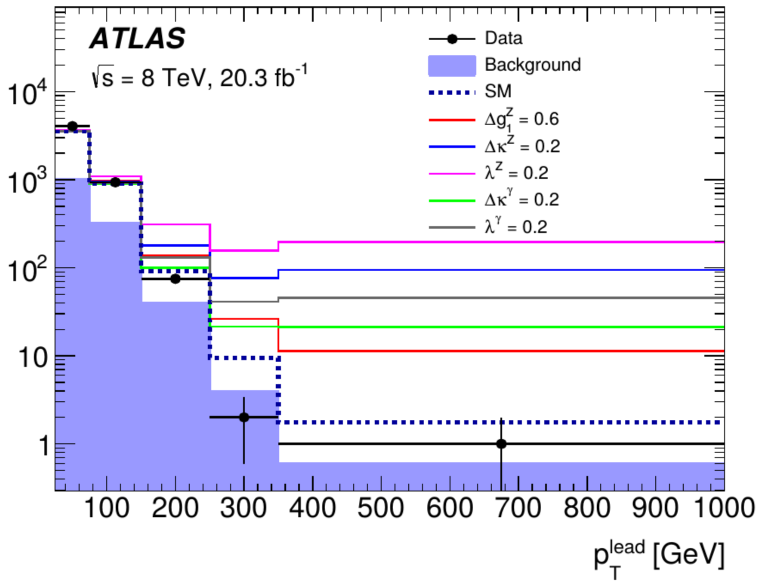
S. Gieseke, T. Kasprzik and J. H. Kühn, *Vector-boson pair production and electroweak corrections in HERWIG++*, Eur. Phys. J. C **74** (2014) 2988, arXiv: 1401.3964 [hep-ph].

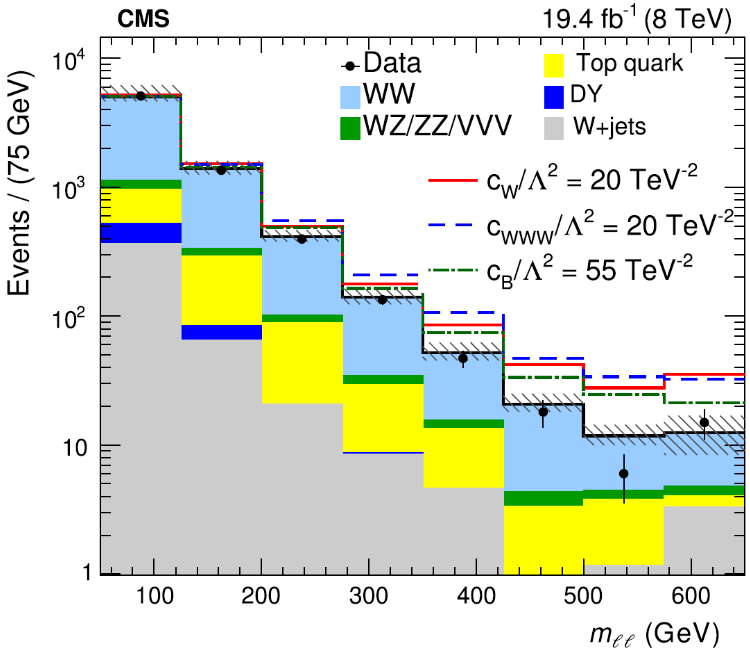
CMS: $M(\ell\ell)$ distribution

- Chosen as more robust variable towards mis-modelling
- Only investigating effective field theory operators

Still both experiments see "underfluctuation" in data (or MC mis-description)

- Note: electroweak corrections are applied





WW production: Anomalous triple gauge couplings

> **Limits better than expected for both experiments**

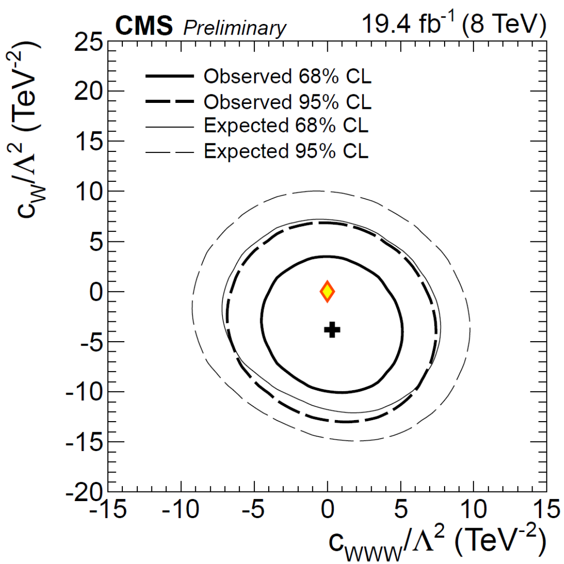
> **ATLAS better than CMS for observed limits (expected seem more similar)**

CMS

Coupling constant	This result (TeV^{-2})	Its 95 % CL interval (TeV^{-2})	World average (TeV^{-2})
c_{WWW}/Λ^2	$0.1^{+3.2}_{-3.2}$	$[-5.7, 5.9]$	-5.5 ± 4.8 (from λ_γ)
c_W/Λ^2	$-3.6^{+5.0}_{-4.5}$	$[-11.4, 5.4]$	$-3.9^{+3.9}_{-4.8}$ (from g_1^Z)
c_B/Λ^2	$-3.2^{+15.0}_{-14.5}$	$[-29.2, 23.9]$	$-1.7^{+13.6}_{-13.9}$ (from κ_γ and g_1^Z)

ATLAS

Scenario	Parameter	Expected [TeV^{-2}]	Observed [TeV^{-2}]
EFT	C_{WWW}/Λ^2	$[-7.62, 7.38]$	$[-4.61, 4.60]$
	C_W/Λ^2	$[-12.58, 14.32]$	$[-5.87, 10.54]$
	C_B/Λ^2	$[-35.8, 38.4]$	$[-20.9, 26.3]$



WZ (fully leptonic)

	7 TeV	8 TeV	13 TeV
ATLAS	Eur. Phys. J. C (2012) 72:2173 4.6 fb^{-1}	Phys. Rev. D 93, 092004 (2016) 20.3 fb^{-1}	Subm. To PLB arXiv:1606.04017 3.2 fb^{-1} ATLAS-CONF-2016-043 13.3 fb^{-1}
CMS	–	EPJC 76 (2016) 401 19.4 fb^{-1}	Subm. To PLB arXiv:1607.06943 2.3 fb^{-1} CMS-PAS-SMP-16-002 2.2 fb^{-1}

WZ production: Precise results at 8 TeV

arXiv:1603.02151

> Huge advantage:

- Higher cross section compared to ZZ,
- Less background compared to WW and semi-leptonic WV analyses (the later discussed by → Senka Đurić)

> CMS 8 TeV results still pending

$p^T(\ell)$ (Z) [GeV]	> 15
$p^T(\ell)$ (W) [GeV]	> 20
$\lvert\eta\rvert(\ell)$ [GeV]	< 2.5
$M(\ell\ell)$ (Z)	$\lvert M - M(Z)^{PDG}\rvert < 10$ Gev
M_T (W)* [GeV]	> 30
ΔR ($\ell\ell$) (Z,Z)	> 0.2
ΔR ($\ell\ell$) (W,Z)	> 0.3

total cross section defined for 66 < M(Z) < 116 GeV
for triggering purposes: in the data selection, one lepton must be > 25 GeV

- Generator-independent association of leptons with bosons using weighting based on nominal values

$$P = \left| \frac{1}{m^2_{(\ell^+,\ell^-)} - \left(m_Z^{\mathrm{PDG}}\right)^2 + i\,\Gamma_Z^{\mathrm{PDG}}\, m_Z^{\mathrm{PDG}}} \right|^2 \times \left| \frac{1}{m^2_{(\ell',\nu_{\ell'})} - \left(m_W^{\mathrm{PDG}}\right)^2 + i\,\Gamma_W^{\mathrm{PDG}}\, m_W^{\mathrm{PDG}}} \right|^2$$

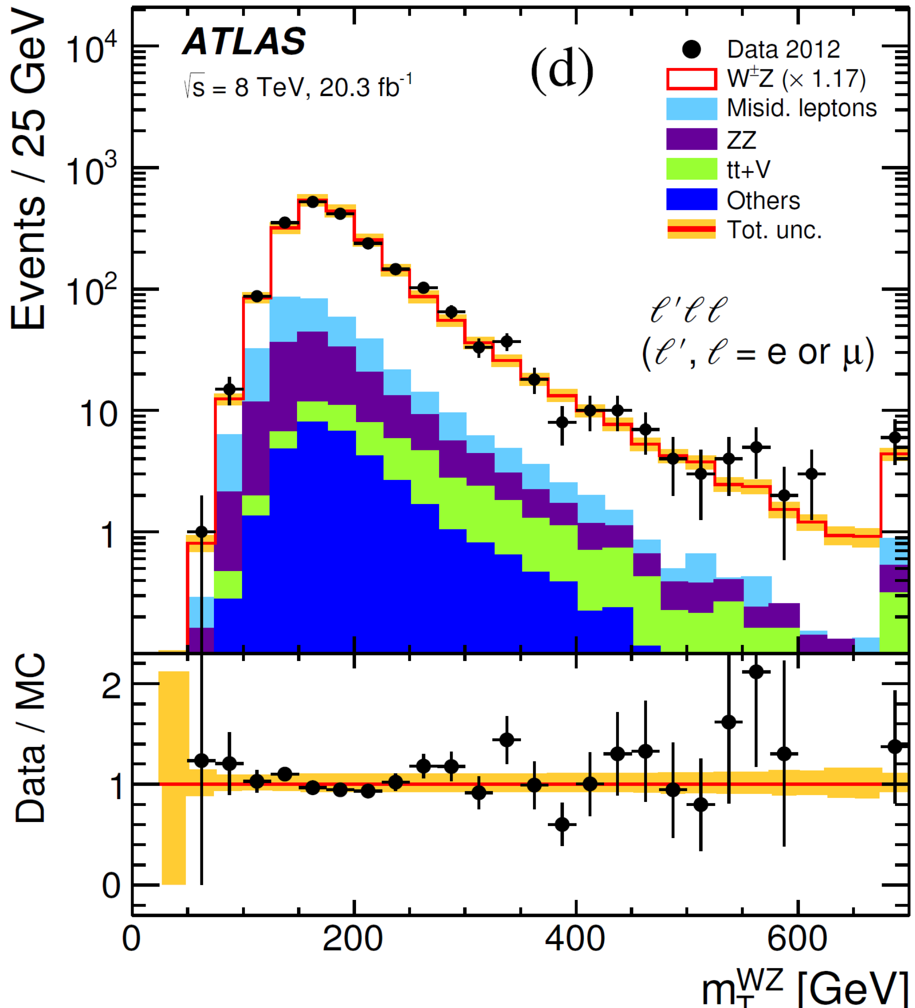
$$^*m_T^W = \sqrt{2 \cdot p_T^\nu \cdot p_T^\ell \cdot [1 - \cos\Delta\phi(\ell,\nu)]},$$

Also result from WZ VBS:
Results on VBS Production and aQGCs part I+II
Wed, 11:45 Jake Searcy
Thur, 16.30 James Faulkner

WZ production: Selection

- **Two main sources of background (20% in total):**
  - Reducible background from “fake” leptons (only 2% of those from 2-fakes)
  - Irreducible background from ZZ events (70%) and other multiple bosons / DPS
  - ZZ background scaled by 1.05 to account for NNLO QCD and NLO EWK
- **Defined as**

$$m_T^{WZ} = \sqrt{\left(\sum_{\ell=1}^{3} p_T^{\ell} + E_T^{\text{miss}}\right)^2 - \left[\left(\sum_{\ell=1}^{3} p_x^{\ell} + E_x^{\text{miss}}\right)^2 + \left(\sum_{\ell=1}^{3} p_y^{\ell} + E_y^{\text{miss}}\right)^2\right]}$$



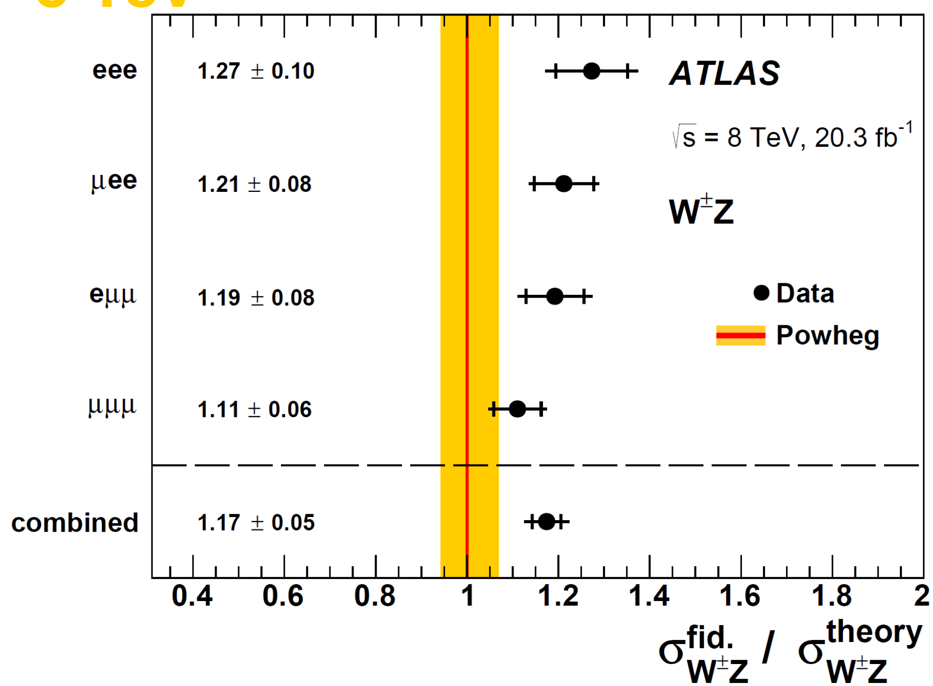
Note: scaled to measured cross section

WZ: Total cross section

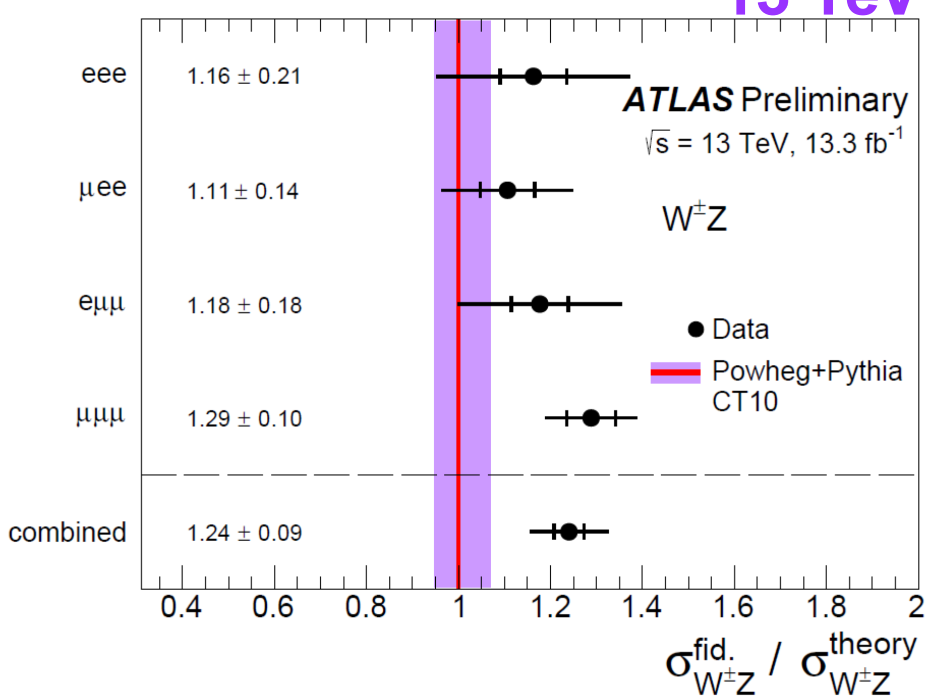
> **Comparison to NLO QCD calculation (Powheg+Pythia): Factor of 1.17 too low**

- Same level of disagreement as in the WW measurements (compared to NLO) consistent picture for fiducial cross section and for 13 TeV measurement
- Here however no jet veto applied as for WW measurement
  → no additional uncertainties due to large logarithms (Stewart-Tackmann)
- Scale choice is crucial: dynamic scale of $\mu_R = M_{WZ}$ with 4% unc. (usual procedure)
  → fixed scale of $\mu_R = (M_W + M_Z)/2$ yields 7% more events (but not added as unc.)

8 TeV



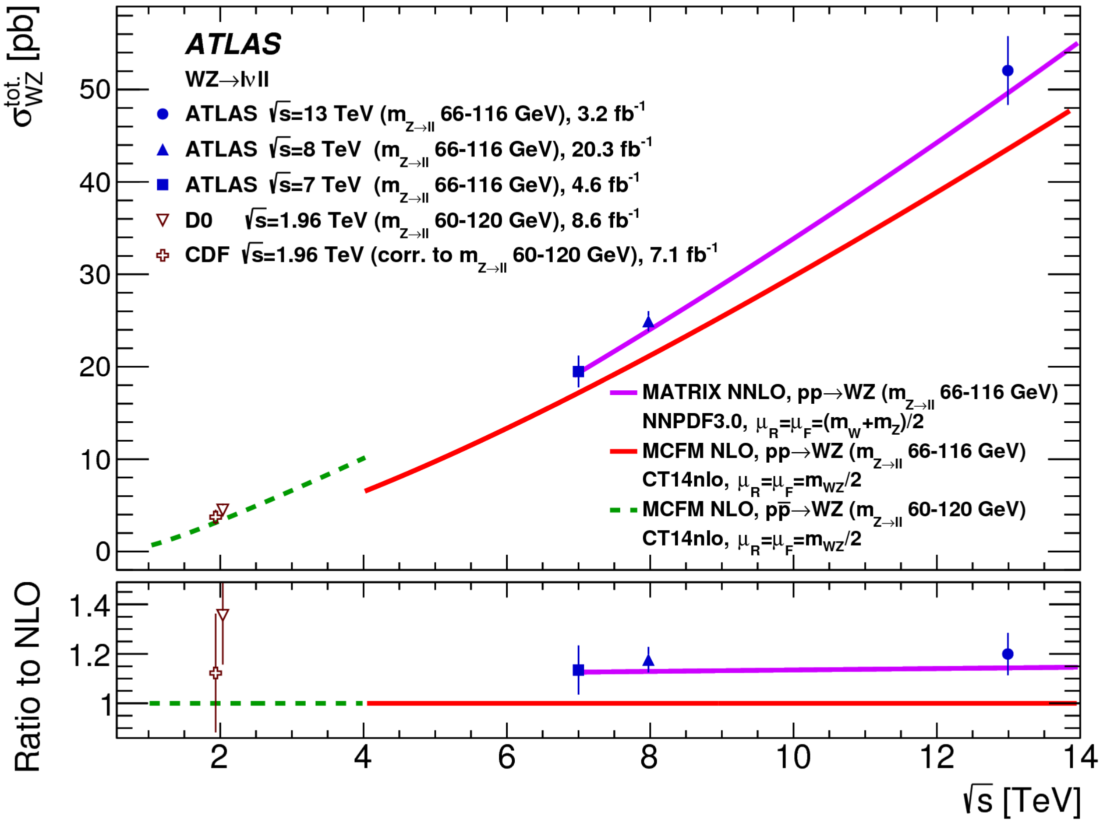
13 TeV



WZ: Effects on NNLO

> **Similar situation as for previous measurements: NNLO is required**

- Excellent agreement with NNLO prediction – similar to Wγ process: Disagreement *not* connected with jet veto (like WW) but some other configuration



https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2015-19/

WZ: First results at 13 TeV

> ATLAS and CMS with results for the total cross sections

- Small updates to selections (to adapt for larger pile-up)

- CMS fiducial cross section: 258 $\pm$21 (stat) +19 -20 (syst) $\pm$8 (lumi) fb
  60 < M($\ell\ell$) < 120 GeV 274 +11 -8 (scale) $\pm$4(PDF) (MCFM, altern. scale: 291 +16-13$\pm$4)
  + lepton pT selection

- Total: 39 $\pm$3.2 (stat) +2.9 -3.1 (syst) $\pm$1.3(lumi) $\pm$0.8(theo) pb
  60 < M($\ell\ell$) < 120 GeV 42 +1.4 -1.1 $\pm$0.6 (MCFM, alternative scale: 44.9 +2.2 -1.8 $\pm$0.7)
  50 +1.1/-1.0 (Matrix)

$p^T(\ell)$ (Z) [GeV]	> 15	> 10 (>20)
$p^T(\ell)$ (W) [GeV]	> 15 (one >25/27 GeV)	> 20
$\|\eta\|(\ell)$ [GeV]	< 2.5	< 2.5
M($\ell\ell$) (Z)	| M – $M(Z)^{PDG}$| < 10 Gev	76 < M($\ell\ell$) < 106 GeV
M(3ℓ)	–	> 100 GeV
M_T (W)* [GeV]	> 30	–
E_T^{Miss}	–	> 30 GeV

nominal scale:
dynamic m_{WZ}

Alternative scale (Matrix):
fixed $(m_Z + m_W) / 2$

WZ: Differential distributions

> **Unfolded using Powheg+Pythia, compared to approximate $\overline{\text{n}}$NLO predictions (applied as k-factors)** F. Campanario and S. Sapeta, Phys. Lett. B **718** (2012) 100

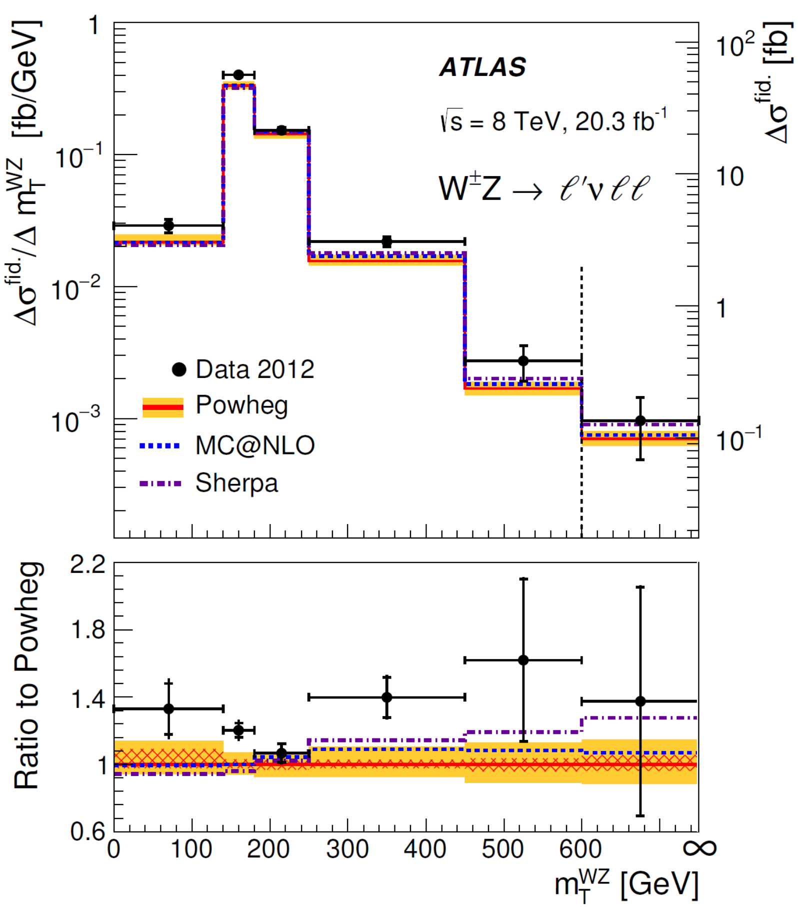
- Sizeable corrections of 30-100%, smallest effect (<10%) on m_T^{WZ} (used therefore for aTGC extraction)
- Valid only for the dominant part of the NNLO corrections and restricted phase space

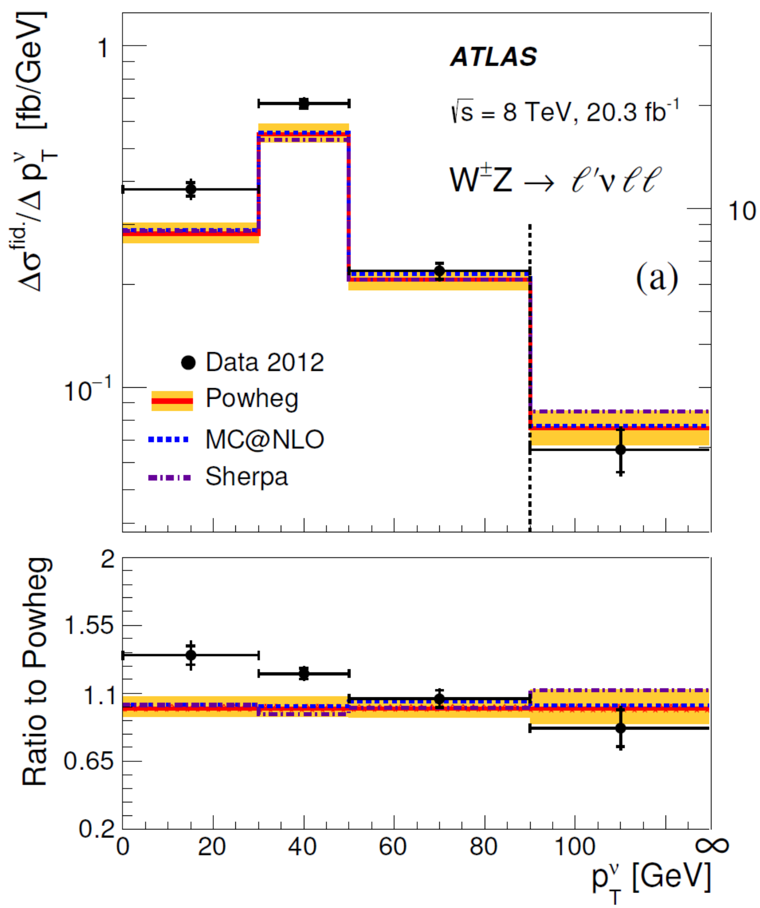
> **NLO EW corrections used as uncertainty**

- Effect of (-0.3-3.2%) on $p_T(Z)$, (0.12%-1.1% for m_T^{WZ})
- Uncertainties of QCD, PDF, EW applied linearly

WZ: Differential distributions

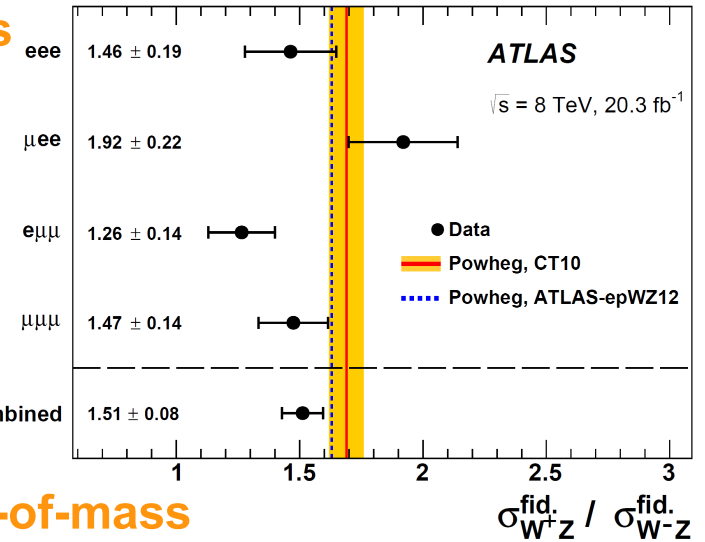
- **In most distributions: Flat deviation of MC from data**
  - M_T^{WZ} – least sensitive variable to scale variations – with possible slope
- **Notable difference: $p_T(\nu)$ with pronounced slope**
  - Observable more sensitive to polarisation effects (compared to $p^T(\ell)$) no kinematic restrictions)



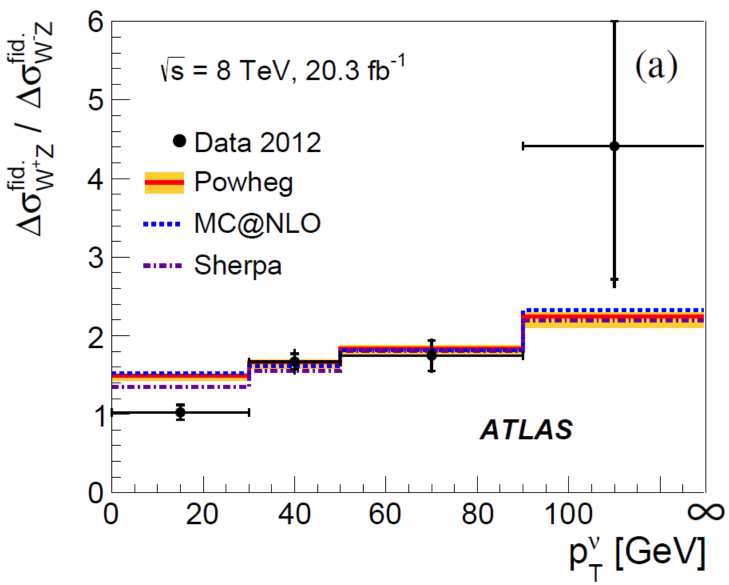


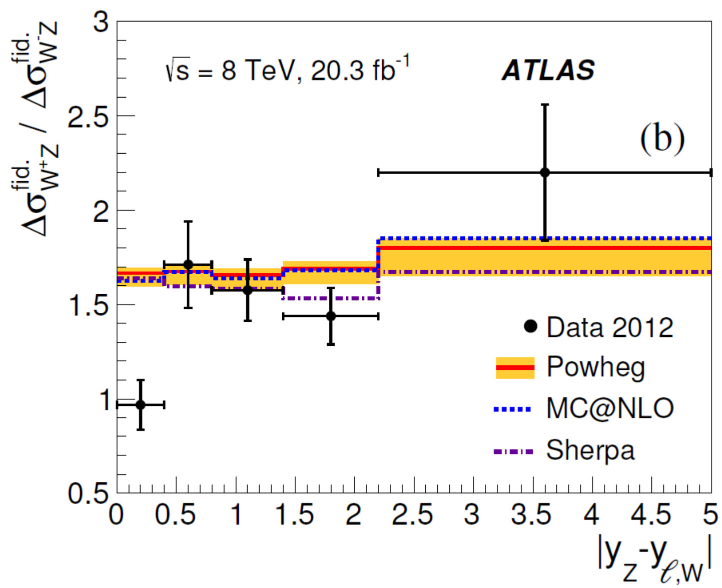
WZ: Possibility to probe PDF effects

- **Ratio of W+Z to W-Z production sensitive to PDFs**
  - Production via $u\bar{d}$ versus $d\bar{u}$ –
    Expect factor of ~1.5: More u- than d-valence
  - Probes larger Q^2 and more extreme *x*-values compared to single vector boson production
  - Data below CT10 and ATLAS epWZ12 PDF set



- **$|y_W-y_Z|$ is boost-invariant substitute for the centre-of-mass scattering angle of the W with respect to the direction of the incoming quark**





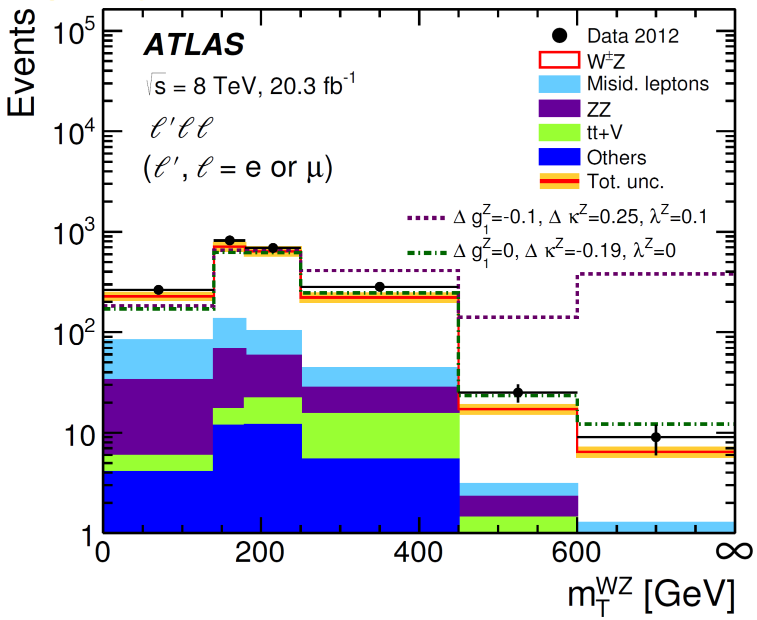
WZ: Limits on anomalous couplings

> Limits on anomalous couplings

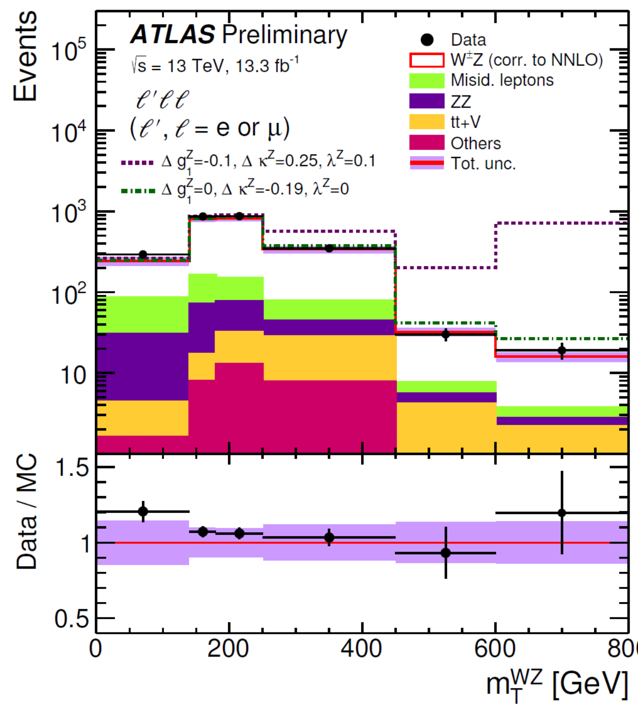
- Comparable between 8 and 13 TeV
- Combination strengthens limits
- Observed and expected limits close despite normalization issue of total cross section

Dataset	Coupling	Expected	Observed
13 TeV	Δg_1^Z	[-0.017; 0.032]	[-0.016; 0.036]
	$\Delta\kappa_1^Z$	[-0.18; 0.24]	[-0.15; 0.26]
	λ^Z	[-0.015; 0.014]	[-0.016; 0.015]
8 TeV	Δg_1^Z	[−0.016 ; 0.032]	[−0.019 ; 0.029]
	$\Delta\kappa^Z$	[−0.17 ; 0.25]	[−0.19 ; 0.30]
	λ^Z	[−0.016 ; 0.016]	[−0.016 ; 0.016]
8 and 13 TeV	Δg_1^Z	[-0.014; 0.029]	[-0.015; 0.030]
	$\Delta\kappa_1^Z$	[-0.15; 0.21]	[-0.13; 0.24]
	λ^Z	[-0.013; 0.012]	[-0.014; 0.013]

8 TeV



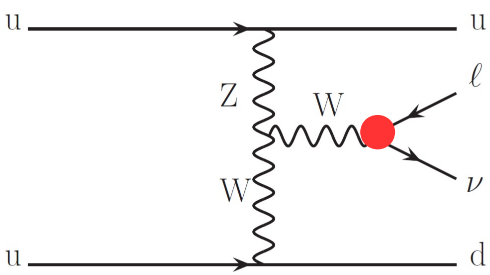
13 TeV



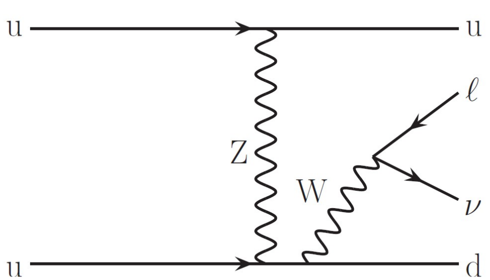
Wjj (electroweak)

	7 TeV	8 TeV	13 TeV
ATLAS	–	–	–
CMS	–	Submitted to JHEP arXiv:1607.06975JC 19.4 fb^{-1}	–

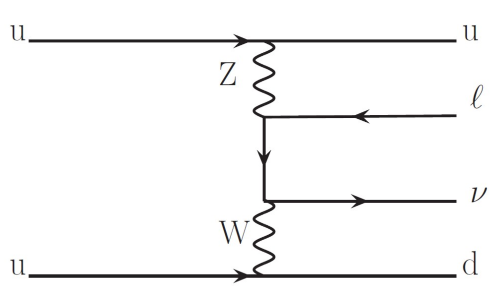
Electroweak Wjj production at 8 TeV



Vector boson Fusion



Bremsstrahlung



Multiperipheral process

> **Measured so far only by CMS**

> **Process characterized by**
- Forward jets with large invariant mass
- Large rapidity gap

p^T (e) (Z) [GeV]	> 30
p^T (μ) (W) [GeV]	> 25
E_T^{Miss} [GeV]	> 25 (30 for μ final state)
$M(\ell\ell)$ (Z)	$\mid M – M(Z)^{PDG} \mid$ < 10 Gev
M_T (W)* [GeV]	> 30
$P_{Tj}^{1(j2)}$ [GeV]	> 60 (50 subleading)
M_{j1j2} [GeV]	> 1000
$\lvert y_w – (y_{j1} + y_{j2})/2 \rvert$	< 1.2

Second lepton veto

$$^{*}m_{\mathrm{T}}^{W} = \sqrt{2 \cdot p_{\mathrm{T}}^{\nu} \cdot p_{\mathrm{T}}^{\ell} \cdot [1 - \cos\Delta\phi(\ell,\nu)]},$$

Electroweak Wjj production at 8 TeV

> Two stage approach

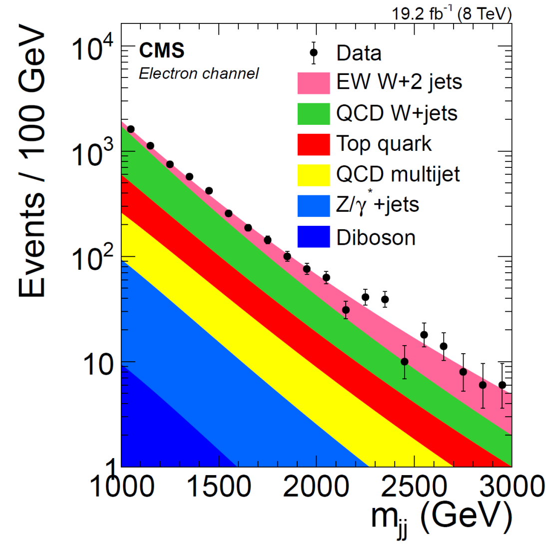
- BDT to estimate background contributions from W+jets
- Likelihood fit to m_{jj} distribution to extract signal

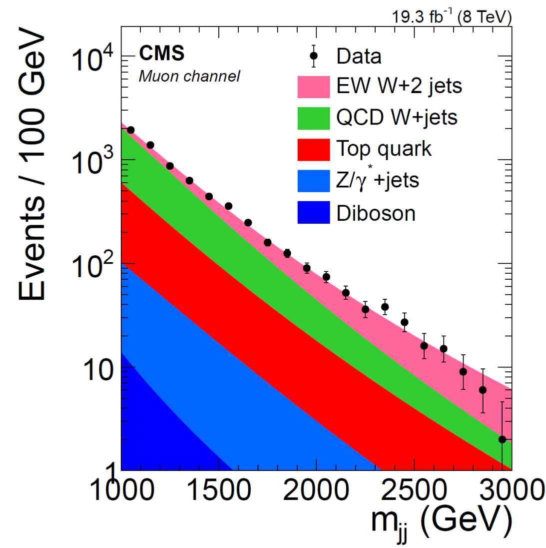
$$\mathcal{F} = \frac{1}{m_{jj}^{\,a_0 + a_1 \ln(m_{jj}/8000)}}$$

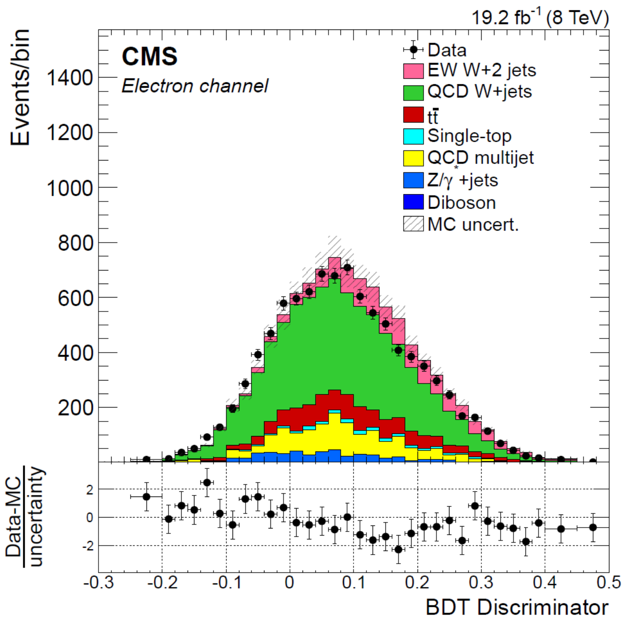
- Good agreement with SM

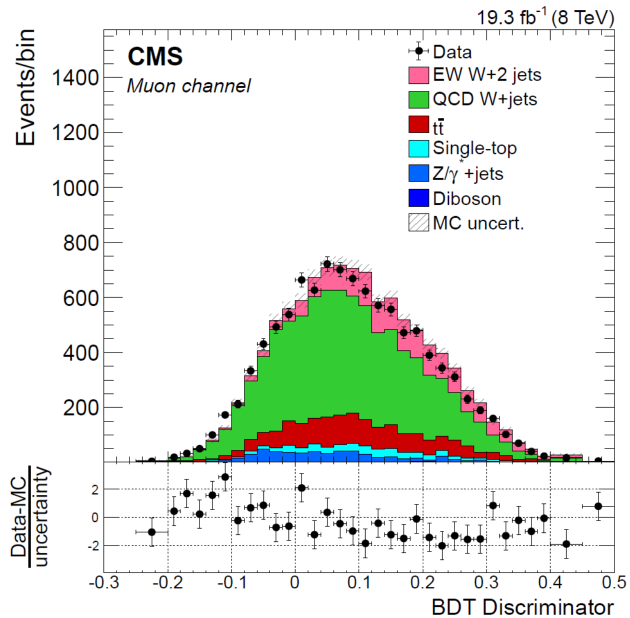
Channel	Measured cross section
Electron	$0.41 \pm 0.04\,(\text{stat}) \pm 0.09\,(\text{syst}) \pm 0.01\,(\text{lumi})\,\text{pb}$
Muon	$0.43 \pm 0.04\,(\text{stat}) \pm 0.10\,(\text{syst}) \pm 0.01\,(\text{lumi})\,\text{pb}$
Combined	$0.42 \pm 0.04\,(\text{stat}) \pm 0.09\,(\text{syst}) \pm 0.01\,(\text{lumi})\,\text{pb}$

SM LO $0.50 \pm 0.02(\text{scale}) \pm 0.02(\text{PDF})$







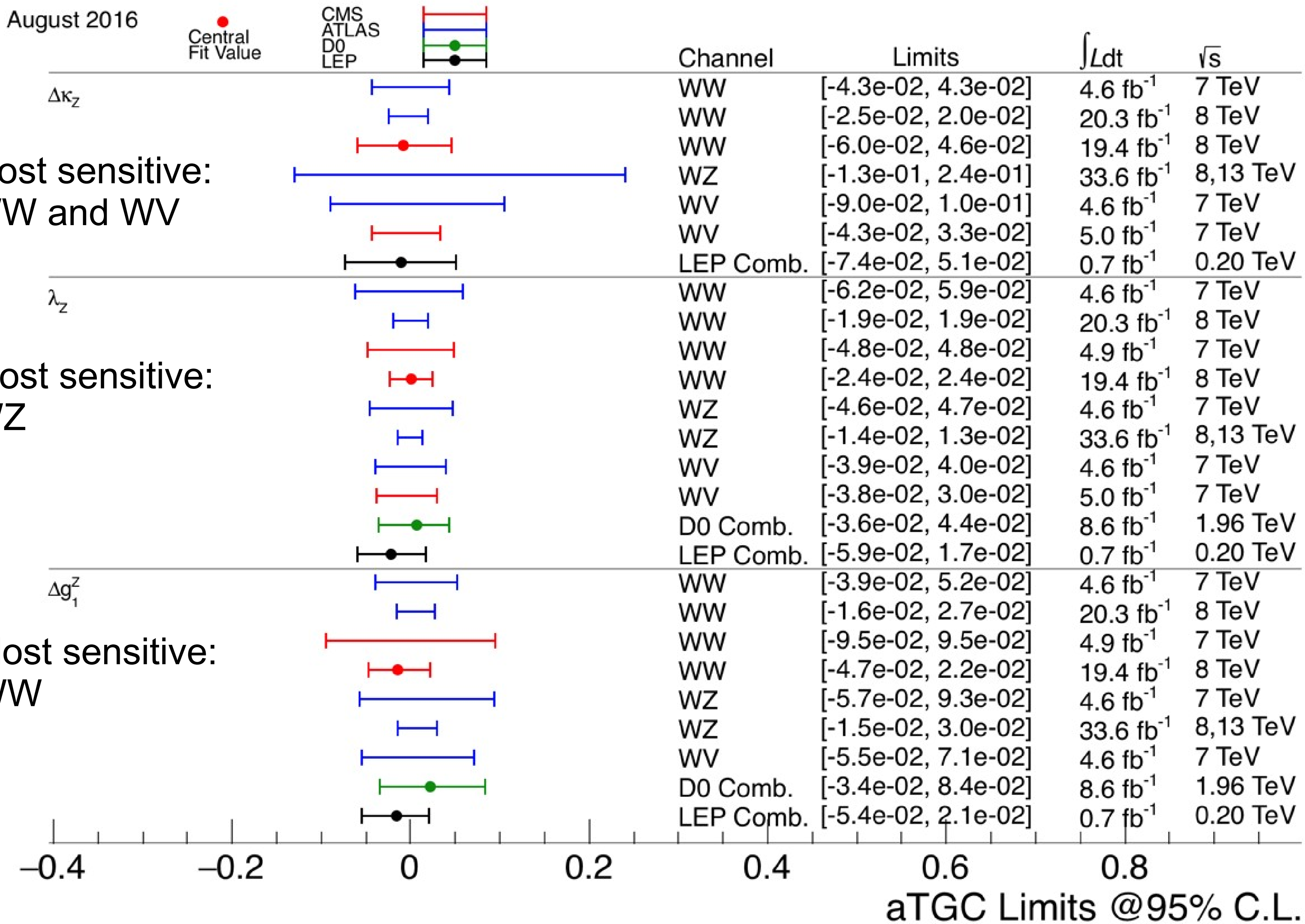


Overview over charged coupling limits

Most sensitive: WW and WV

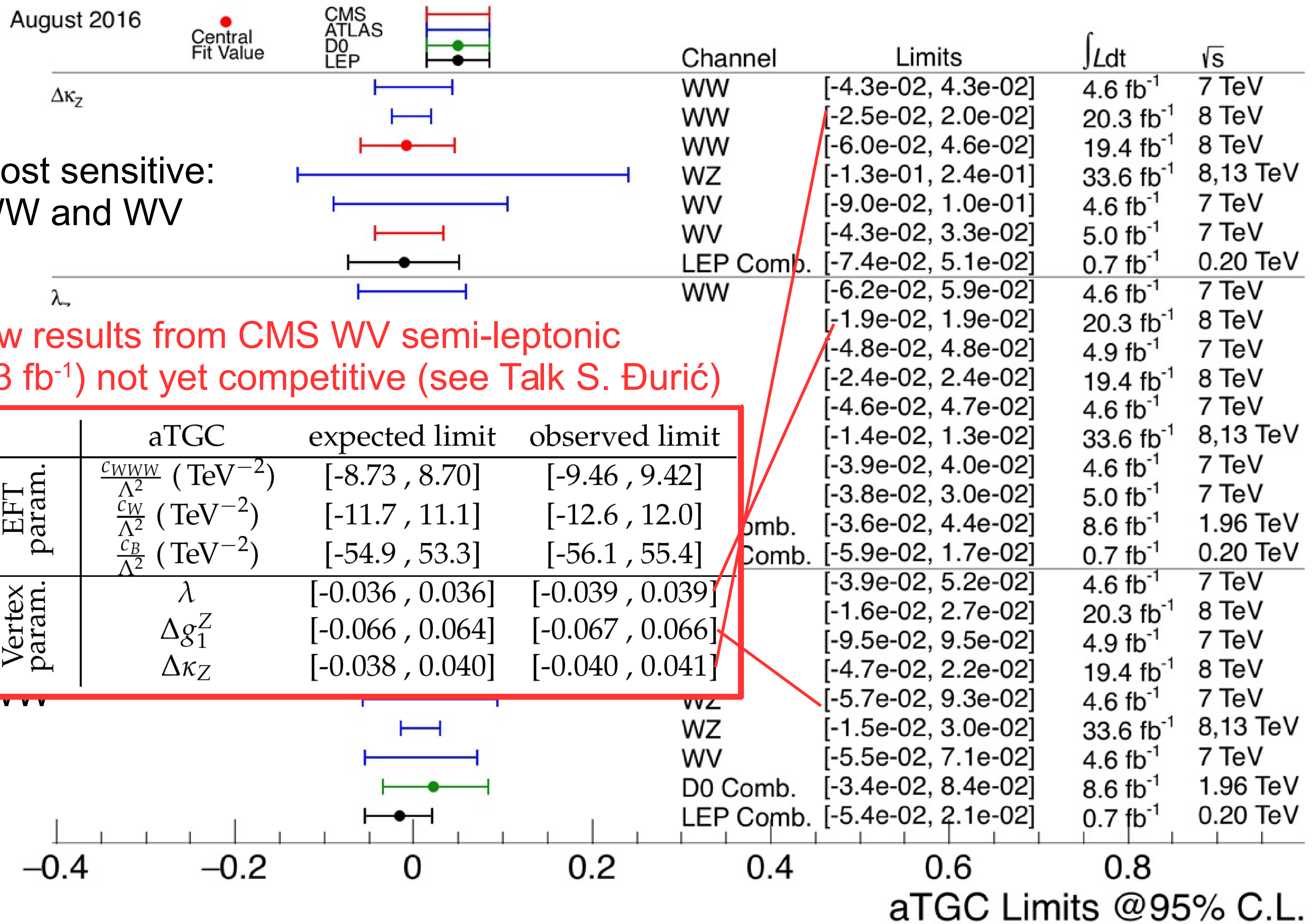
Most sensitive: WZ

Most sensitive: WW



Overview over charged coupling limits

Most sensitive:
WW and WV

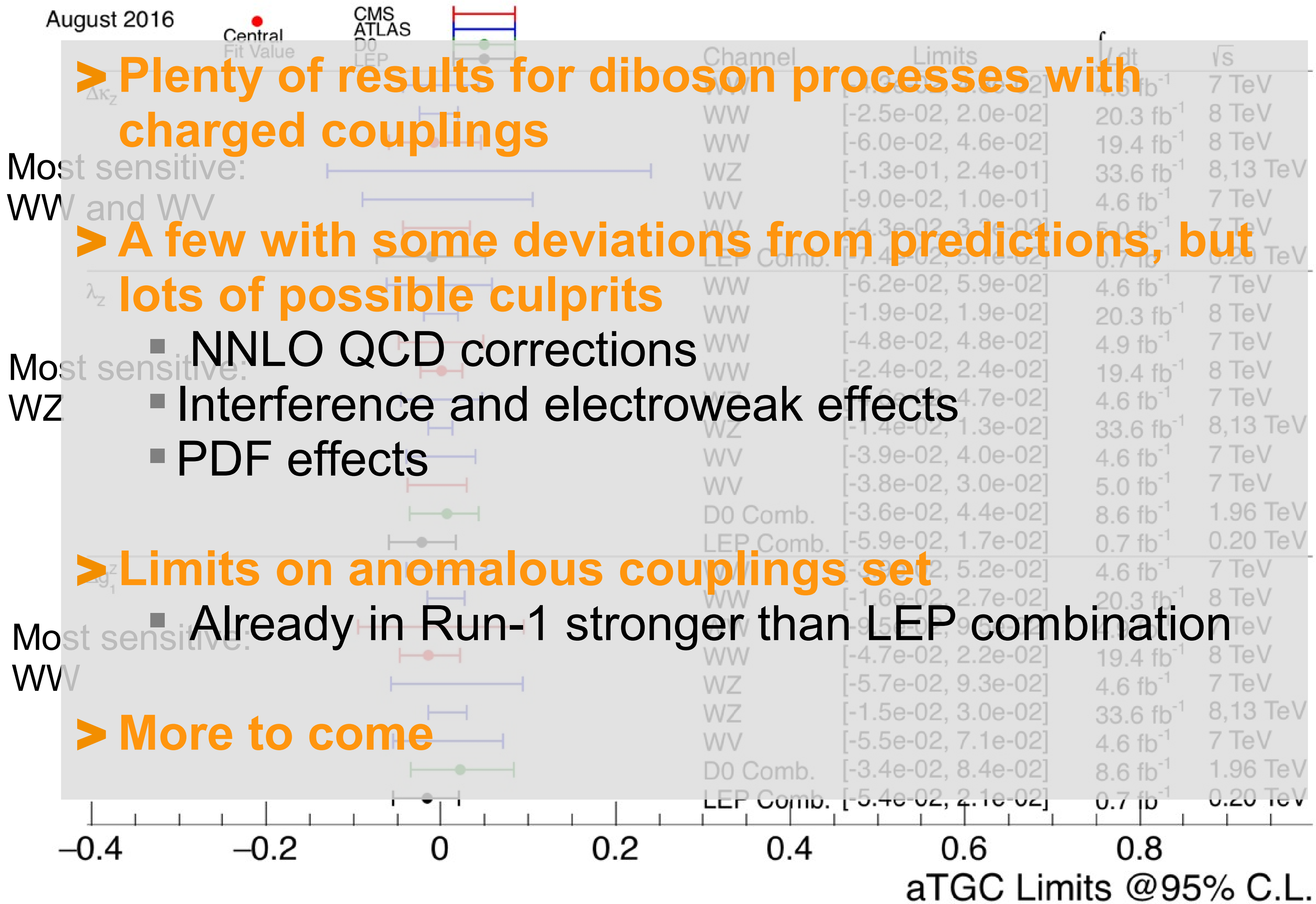


New results from CMS WV semi-leptonic ($2.3\ \mathrm{fb}^{-1}$) not yet competitive (see Talk S. Đurić)

	aTGC	expected limit	observed limit
EFT param.	$\frac{c_{WWW}}{\Lambda^2}$ (TeV^{-2})	[-8.73 , 8.70]	[-9.46 , 9.42]
	$\frac{c_W}{\Lambda^2}$ (TeV^{-2})	[-11.7 , 11.1]	[-12.6 , 12.0]
	$\frac{c_B}{\Lambda^2}$ (TeV^{-2})	[-54.9 , 53.3]	[-56.1 , 55.4]
Vertex param.	λ	[-0.036 , 0.036]	[-0.039 , 0.039]
	Δg_1^Z	[-0.066 , 0.064]	[-0.067 , 0.066]
	$\Delta\kappa_Z$	[-0.038 , 0.040]	[-0.040 , 0.041]

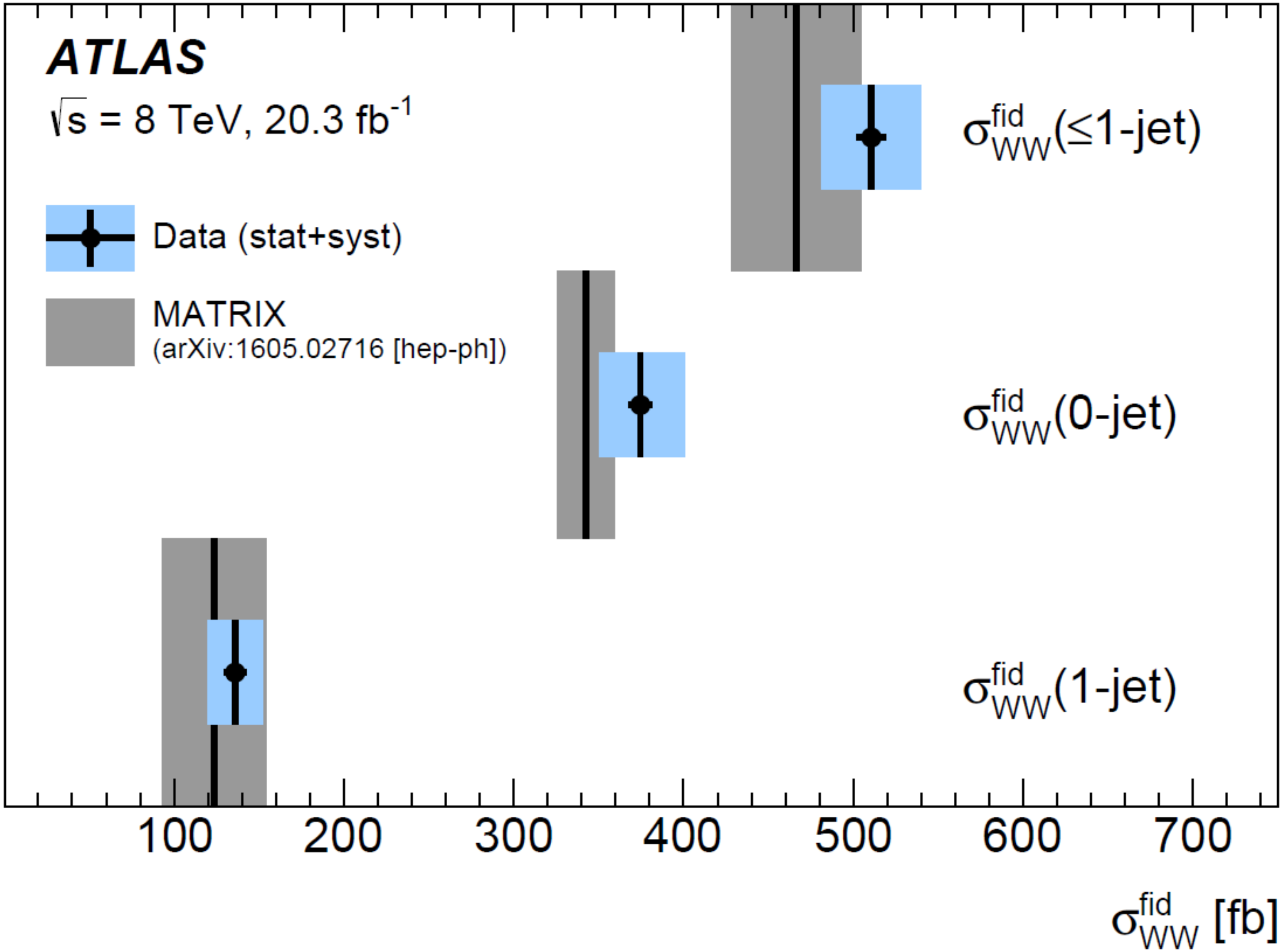
Summary

- Plenty of results for diboson processes with charged couplings
- A few with some deviations from predictions, but lots of possible culprits
  - NNLO QCD corrections
  - Interference and electroweak effects
  - PDF effects
- Limits on anomalous couplings set
  - Already in Run-1 stronger than LEP combination
- More to come



Backup slides.

Fiducial WW-jet-cross sections



Ratios of WW+1 to WW+0 jet production