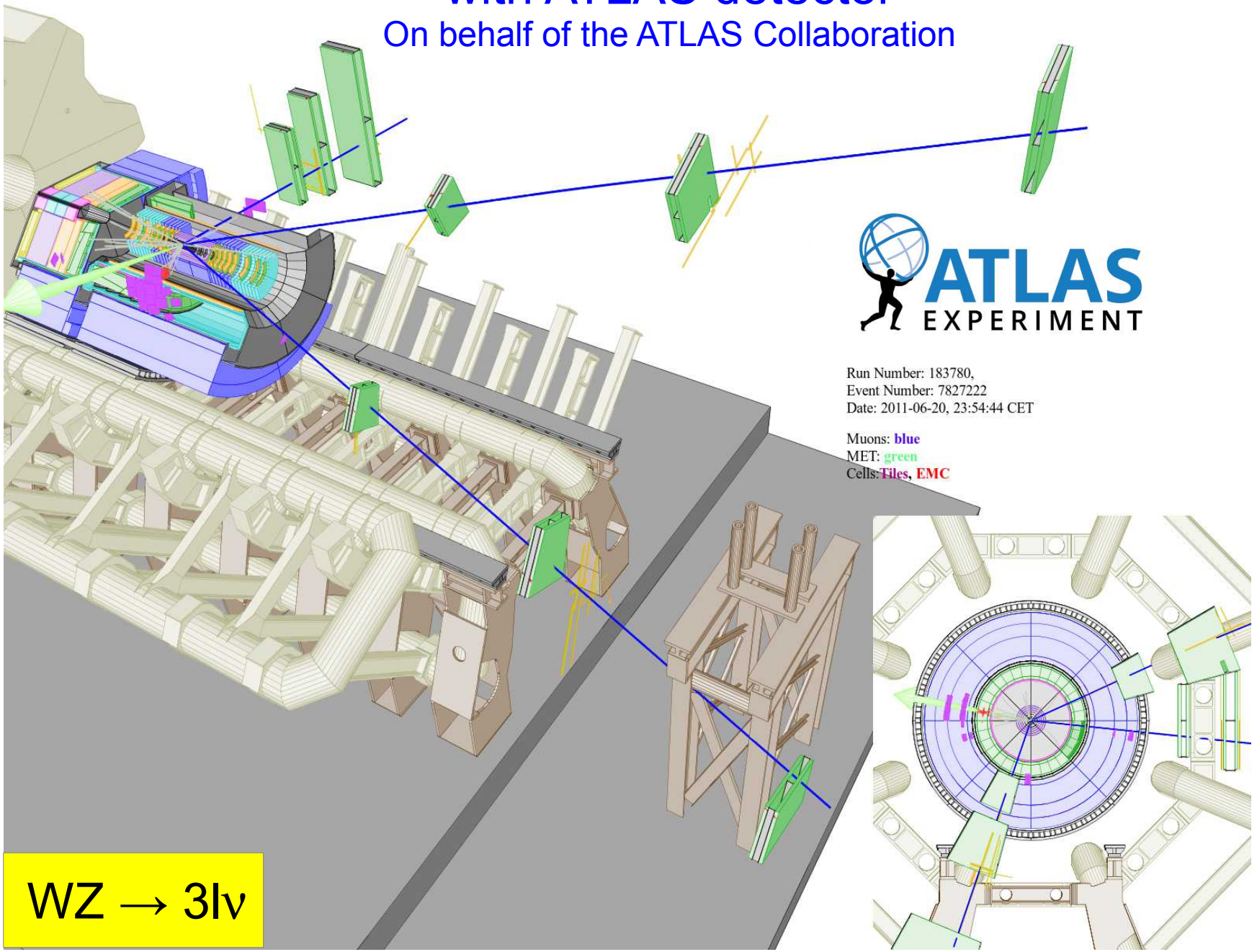
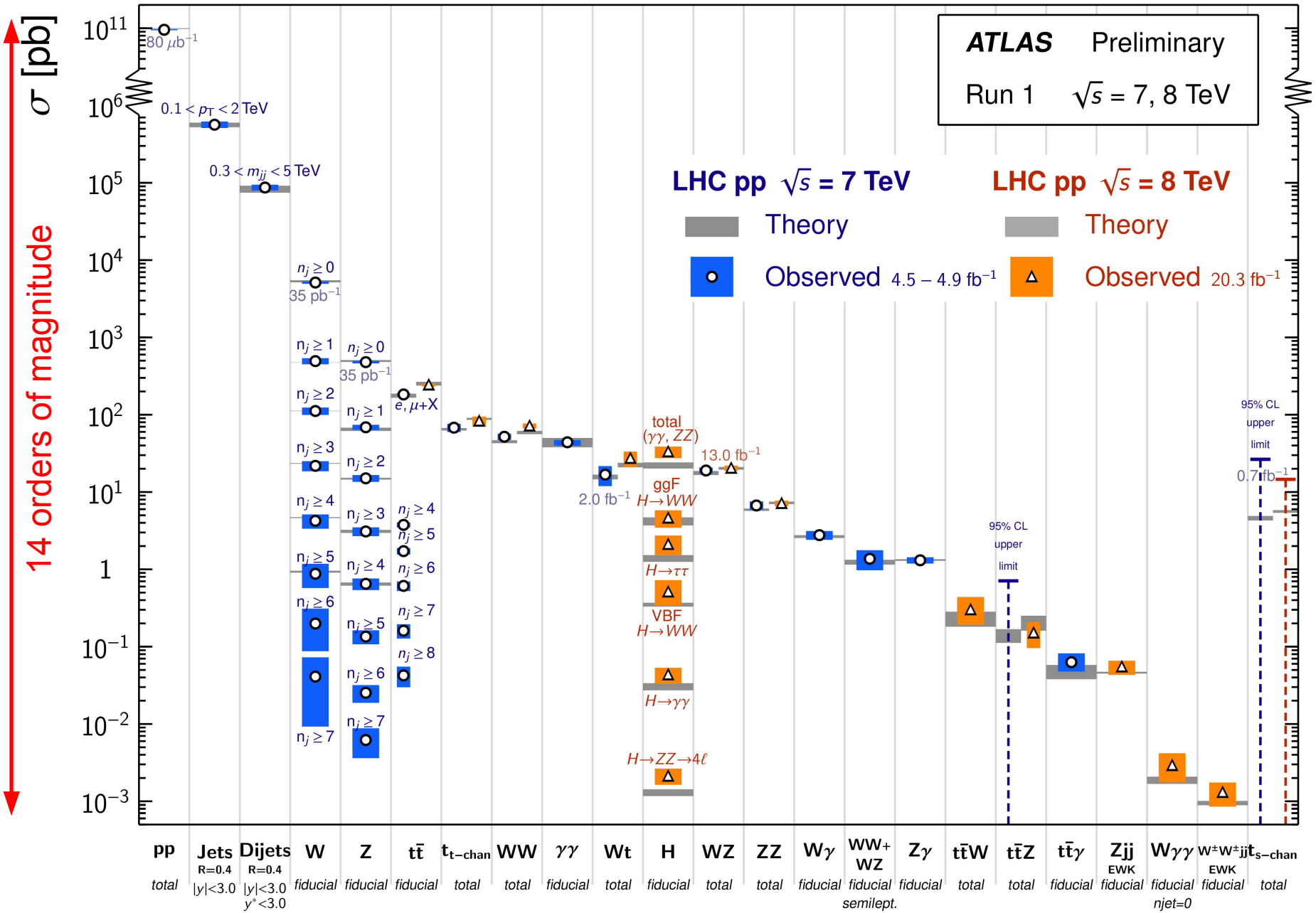
Di-boson production measurements with ATLAS detector

On behalf of the ATLAS Collaboration



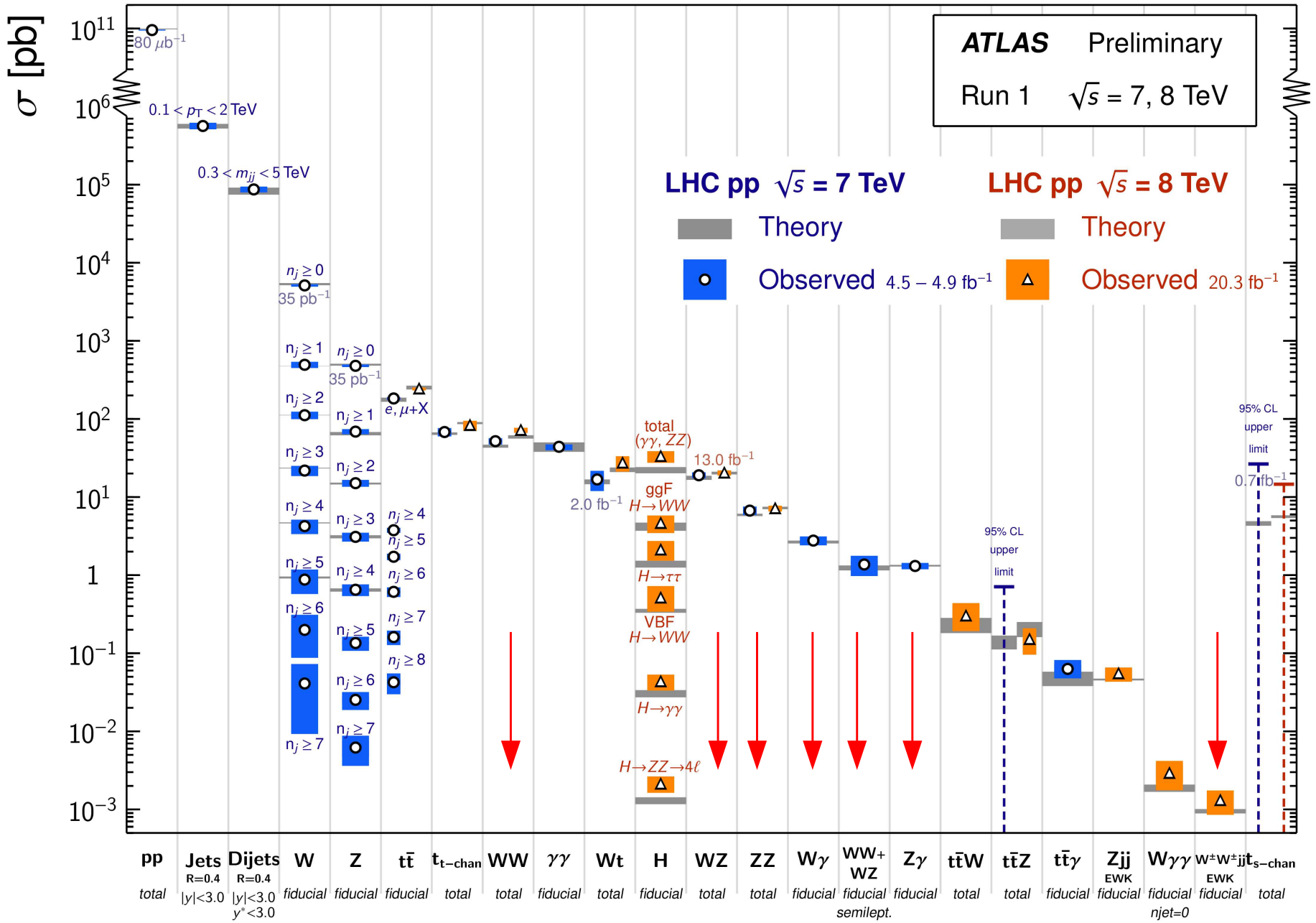
Laurent Chevalier
CEA-Saclay, eps-hep 2015, Vienna 22-29 July

LHC measurements → Standard Model: almost perfect?



But: DM, Mass hierarchy, … New physics? How quantify?

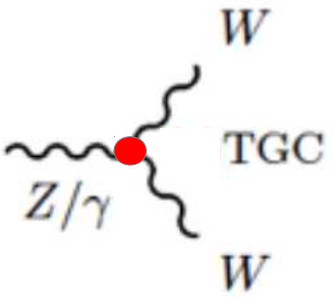
→ Precise measurements
→ Anomalous coupling

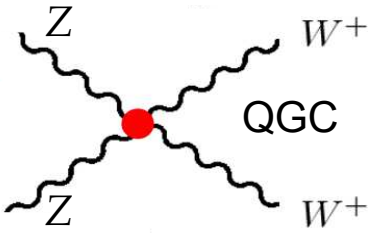


SM

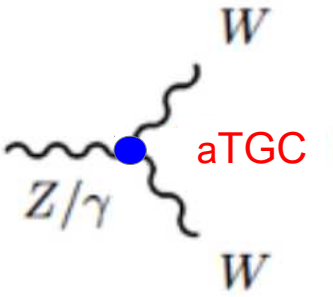
Non-Abelian structure of $SU(2)_L \times U(1)_y$

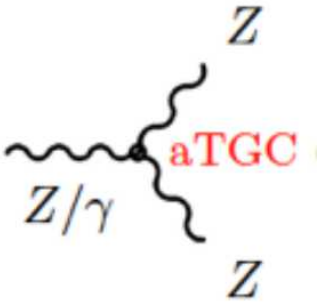
allow TGC(charged only) & QGC (charged only)





aTGC





coupling	aTGC parameters (All = 0 in SM)	channel
$WW\gamma$	λ_γ, $\Delta\kappa_\gamma$	WW, $W\gamma$
WWZ	λ_Z, $\Delta\kappa_Z$, Δg_1^Z	WW, WZ
$ZZ\gamma$	h_3^Z, h_4^Z	$Z\gamma$
$Z\gamma\gamma$	h_3^γ, h_4^γ	$Z\gamma$
$Z\gamma Z$	f_{40}^γ, f_{50}^γ	ZZ
ZZZ	f_{40}^Z, f_{50}^Z	ZZ

EFT

Λ: scale of new physics

$\mathcal{O}_i^{(d)}$: new operators of higher dimensions (d)

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_d \sum_i \frac{c_i^{(d)}}{\Lambda^{d-4}} \mathcal{O}_i^{(d)}$$

=> Modify differential and total cross sections

Wγ & Zγ cross sections at 7 TeV

Phys. Rev. D 87,112003

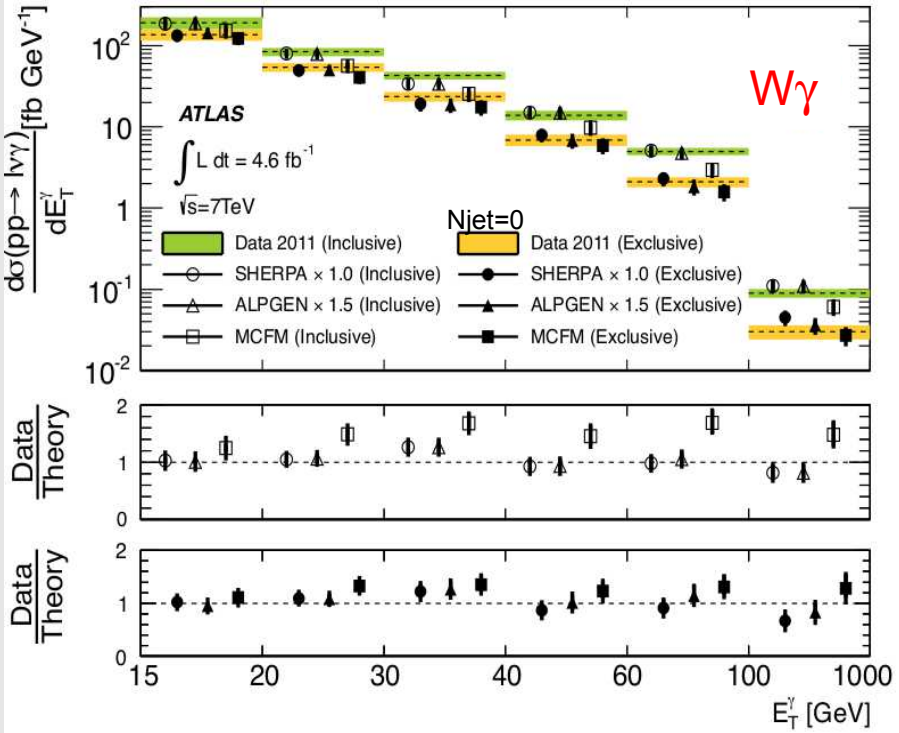
$W\gamma / Z\gamma \rightarrow l\nu\gamma, ll\gamma, \nu\nu\gamma$

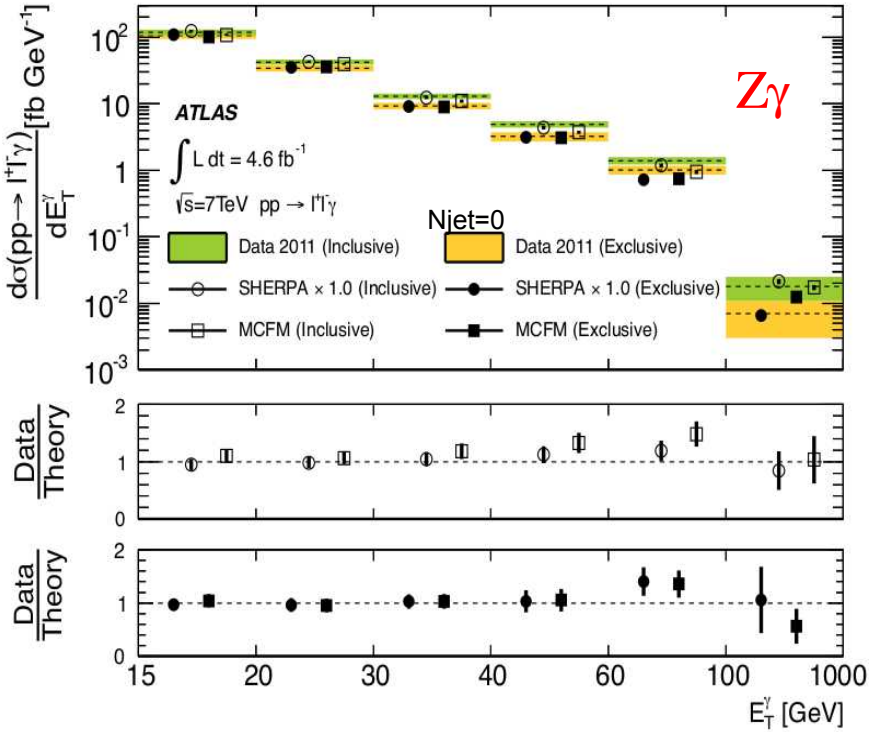
- high E^T isolated photon
- high p^T isolated lepton
- $\Delta R_{(lepton,photon)} > 0.7$

BKG
- W/Z+jets
- γ +jets
- $W \rightarrow e\nu$

Remarks:

- Z γ fair agreement
- Wγ measurement above NLO
- NNLO QCD corrections are needed (see next slide)

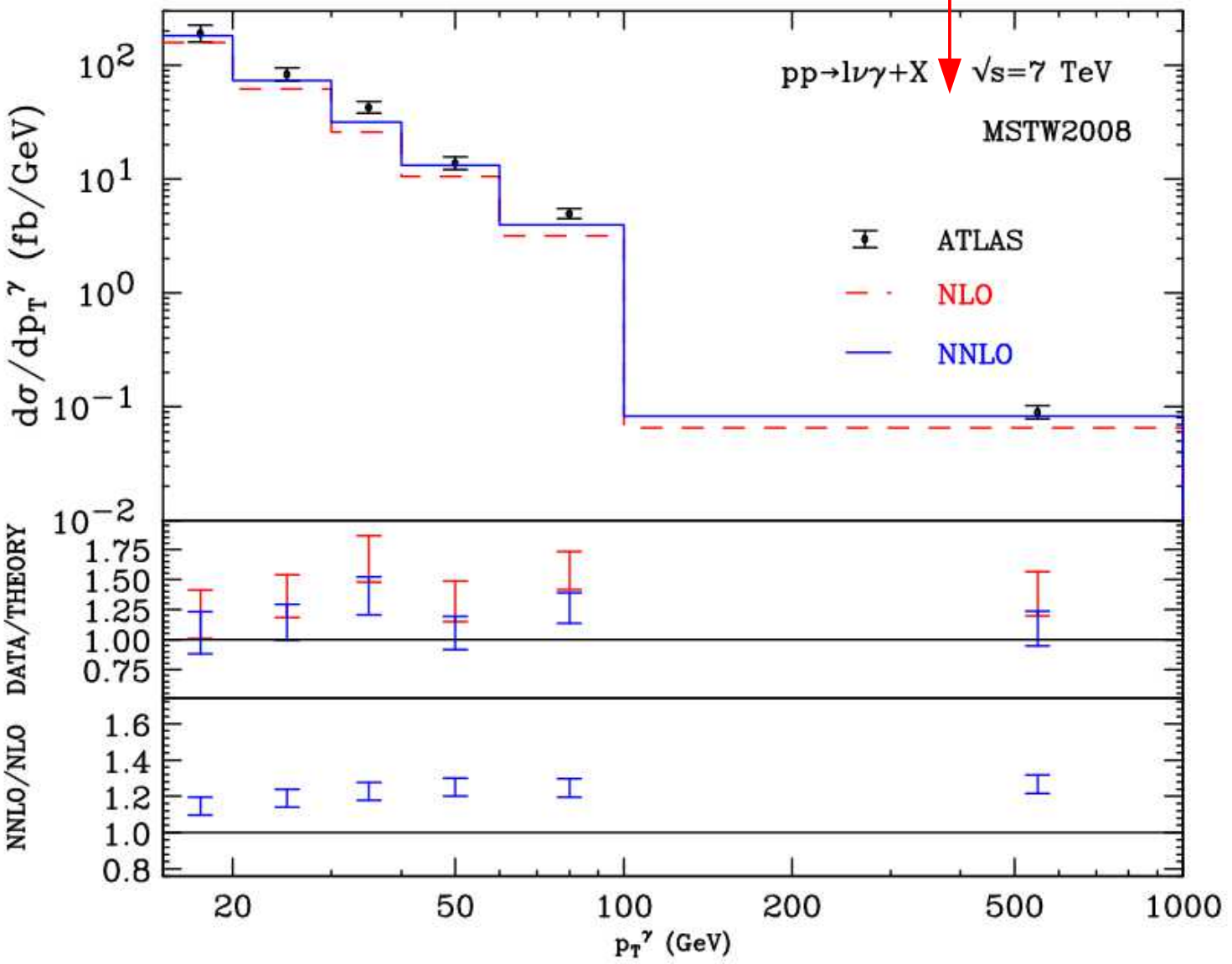




Wγ & Zγ cross sections at 7 TeV

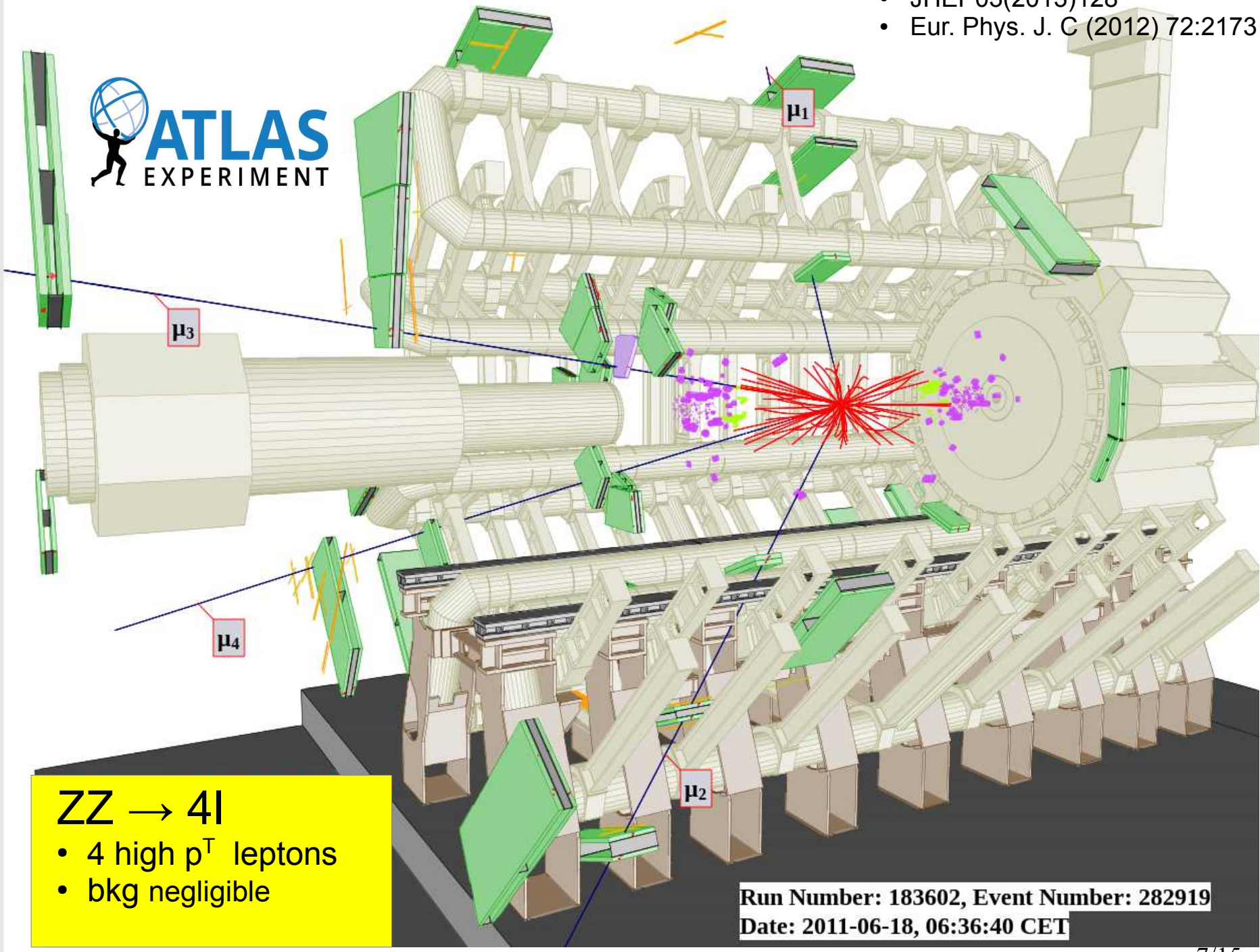
NNLO QCD corrections are needed

- Wɣ : arXiv:1407.1618v1 [hep-ph]
- Zɣ : Phys. Lett. B731 (2014) 204



WZ & ZZ cross sections at 7 and 8 TeV

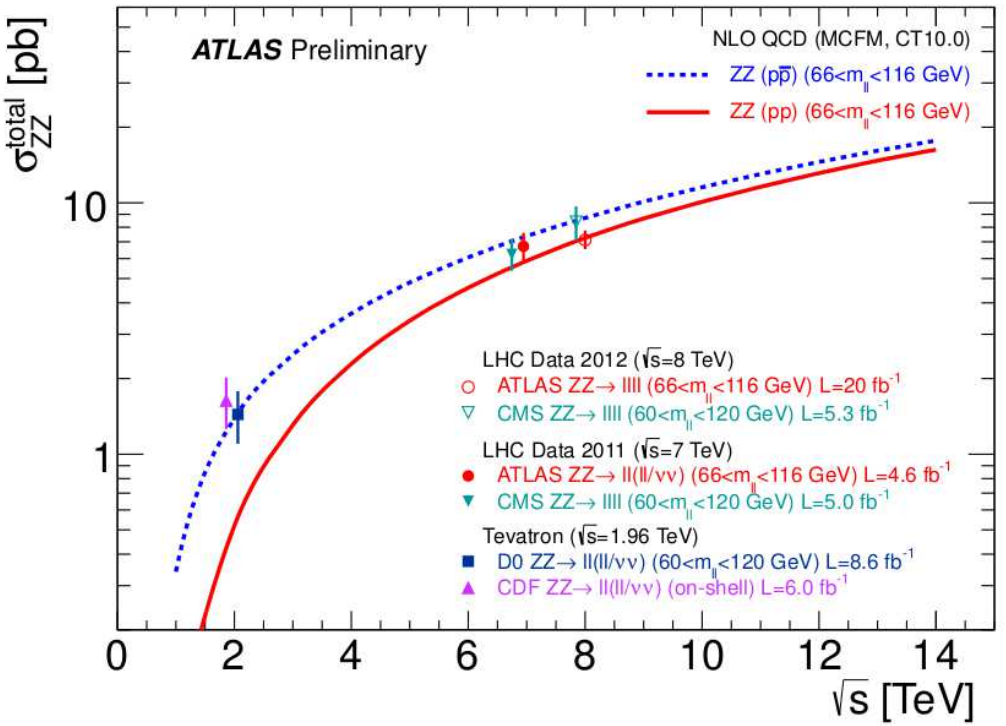
- ATLAS-CONF-2014-033
- ATLAS-CONF-2013-020
- JHEP03(2013)128
- Eur. Phys. J. C (2012) 72:2173



ZZ → 4l

- 4 high p^T leptons
- bkg negligible

WZ & ZZ cross sections at 7 and 8 TeV



ZZ→llll

- 4 high p^T leptons

BKG negligible

ZZ→llνν (7 TeV only)

- Axial E^{miss}_T > 80 GeV

BKG

- WZ (~20%) : from MC
- WW+Top (~16%) : data driven

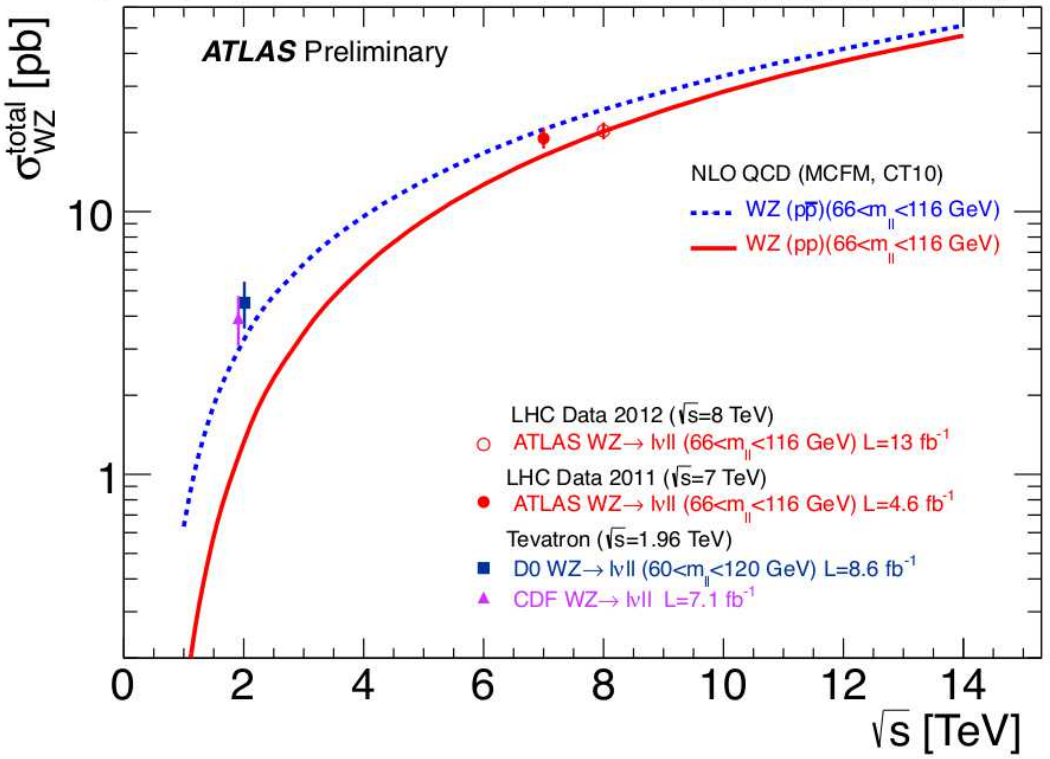
WZ→lνll

- 3 high p^T & isolated leptons
- E^{miss}_T > 25 GeV
- 66 GeV < $M_{z->ll}$ < 116 GeV

BKG

- Z+jets (~15%) : data driven
- ZZ (~5%) : from MC
- Top (~4%) : data driven
- W/Z+γ (~3%) : from MC

ATLAS-CONF-2013-021



WW + WZ in semi-leptonic mode at 7 TeV

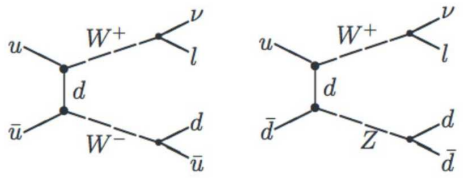
- JHEP01(2015)049
- arXiv:1410.7238

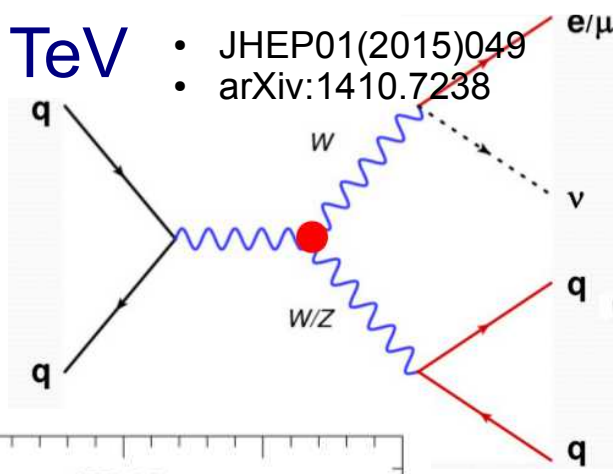
WW+WZ→lνjj

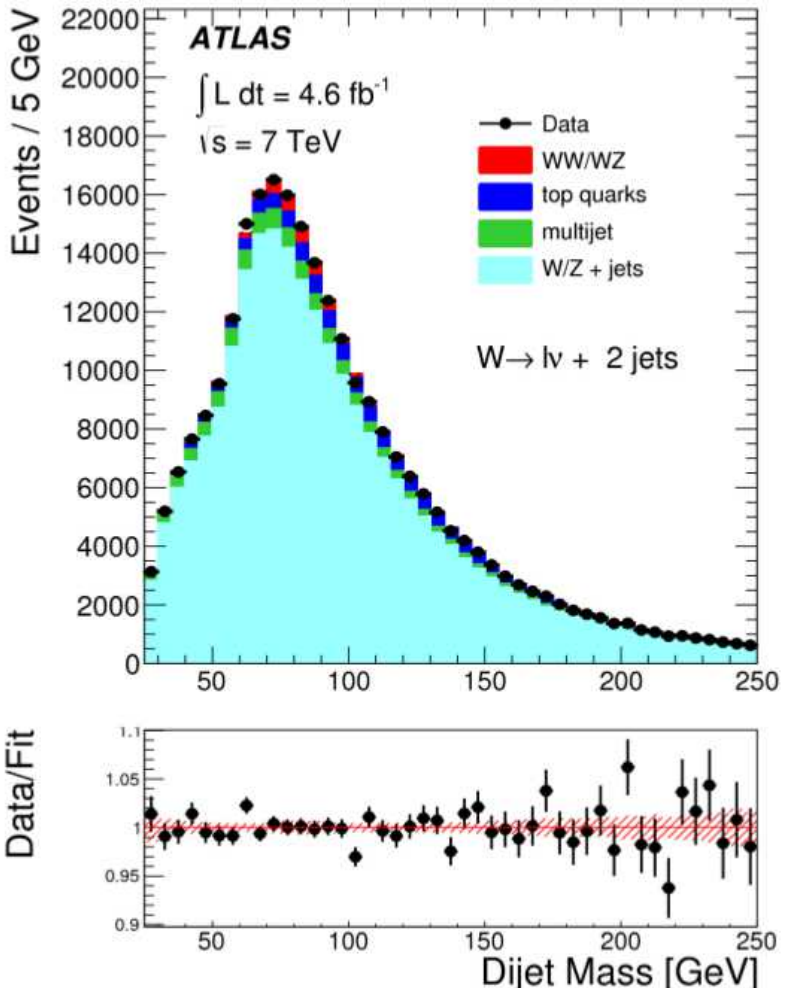
- high p^T isolated lepton
- E^{miss}_T cuts

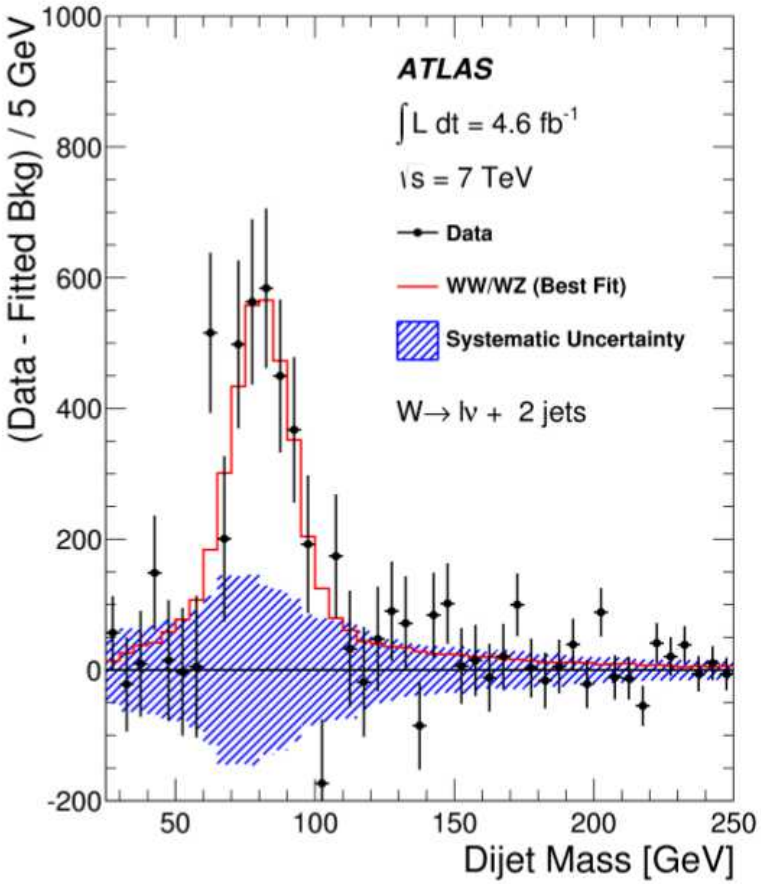
BKG

- W/Z+jets (~89%) : data driven
- multi-jets (~5%) : data driven
- Top (~4%) : from MC





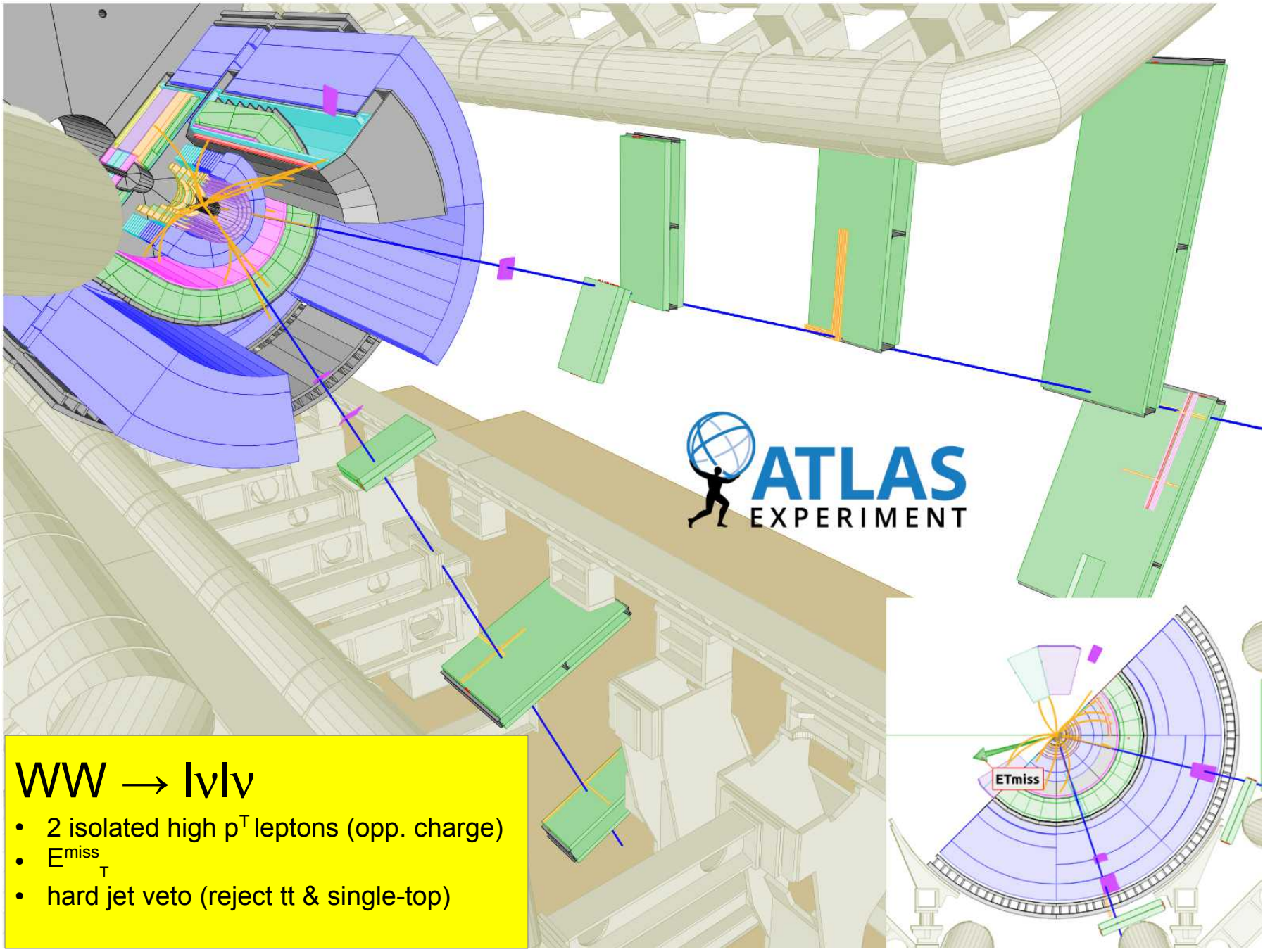




- All contributions including TGC, observed with a 3.4 σ confidence
- SM consistent

WW cross section at 8 TeV

ATLAS-CONF-2014-033



WW → lνlν

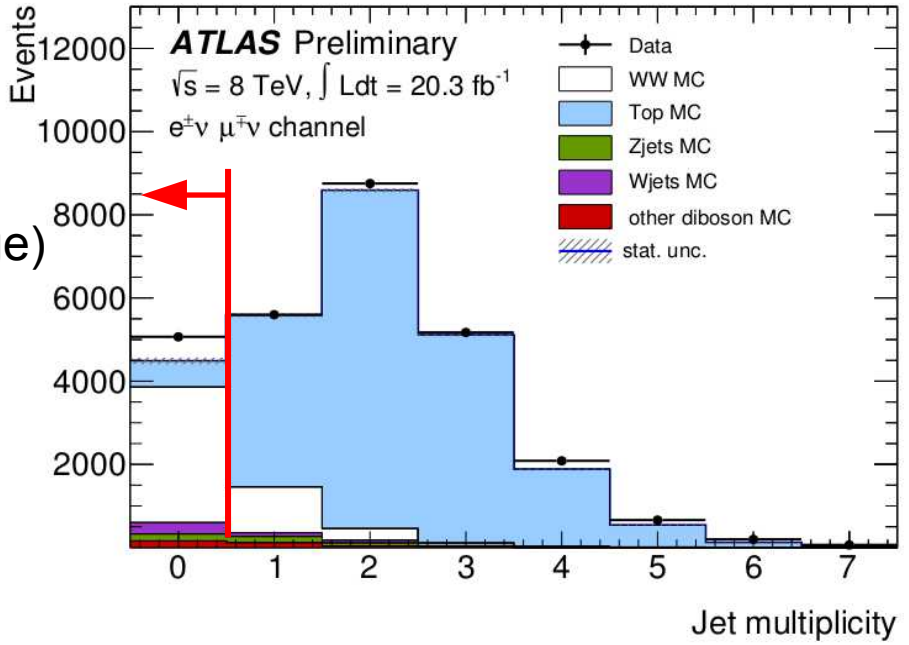
- 2 isolated high p^T leptons (opp. charge)
- E^{miss}_T
- hard jet veto (reject tt & single-top)

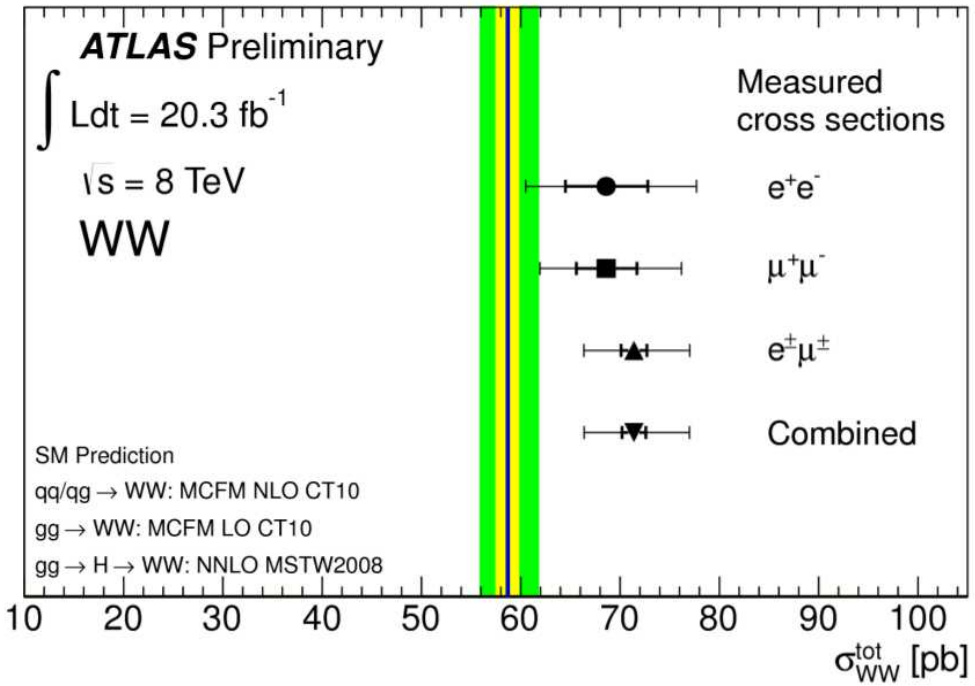
WW cross section at 8 TeV

WW→lνlν (in 0-jet bin)

- 2 isolated high p^T leptons (opp. charge)
- E^{miss}_T (45,45,25 GeV: ee,eμ,μμ)
- hard jet veto (reject tt & single-top)

BKG
- Top (~15%)
- W+jets (~5%)
- Drell-Yan (~5%)



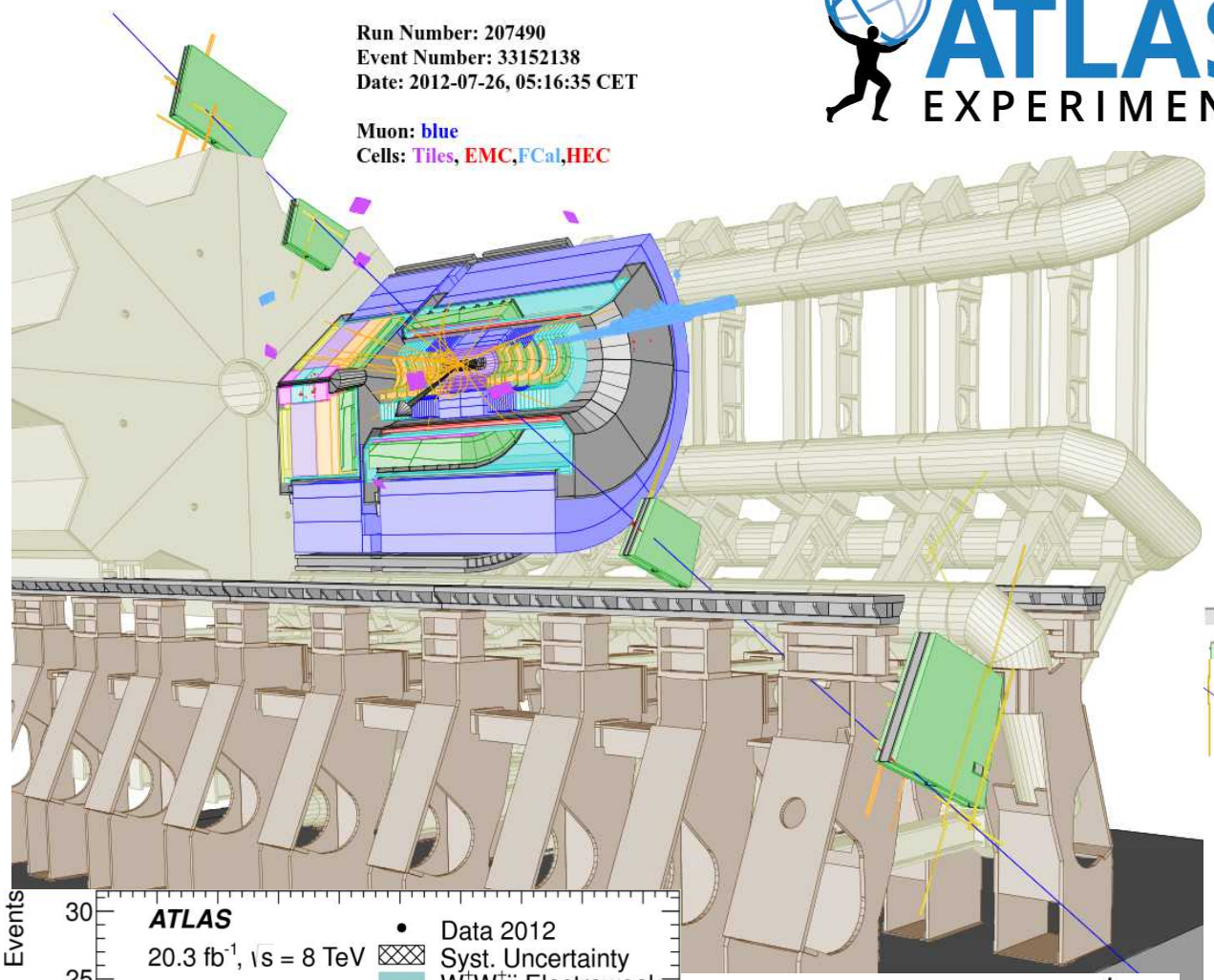


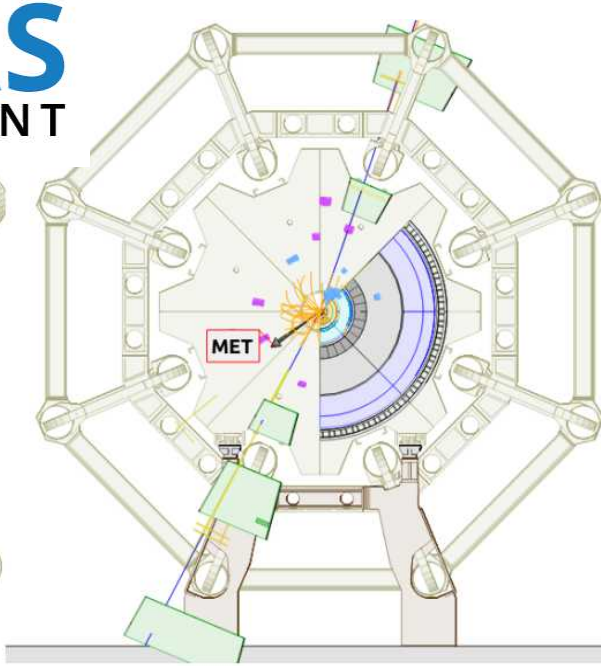
- Whatever the pdf chosen
  - CT10, MSTW2008,...
- NNLO corrections: up to 10%
  - See arXiv:1408.5243
- Re-summation at large logs partially explain excess → arXiv:
  - 1407.4537,1407.4481
  - 1507.02565v1

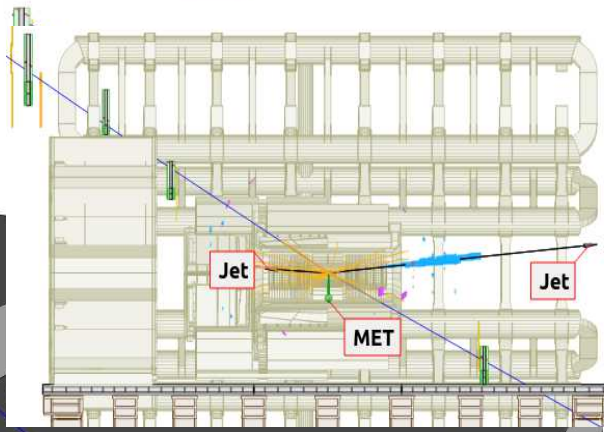
~2.1 σ higher than SM

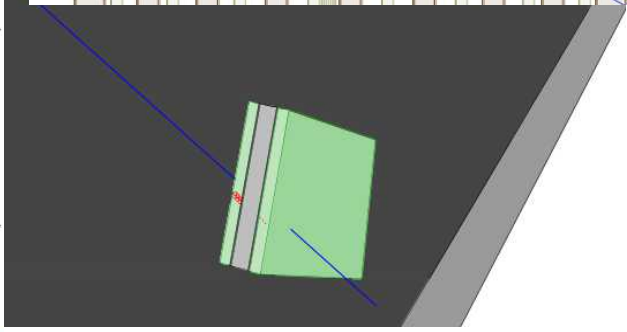
VBF/VBS (see talk N.L.Martinez)

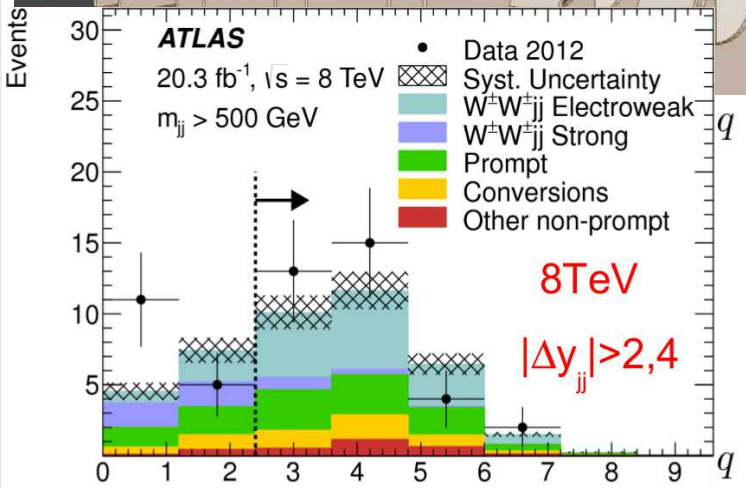
PRL 113, 141803 (2014)



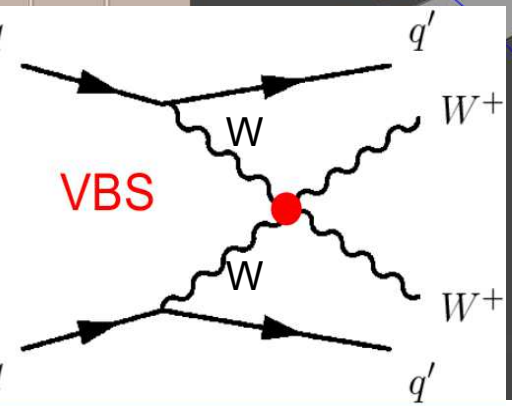








Pseudo-Rapidity between the 2 jets

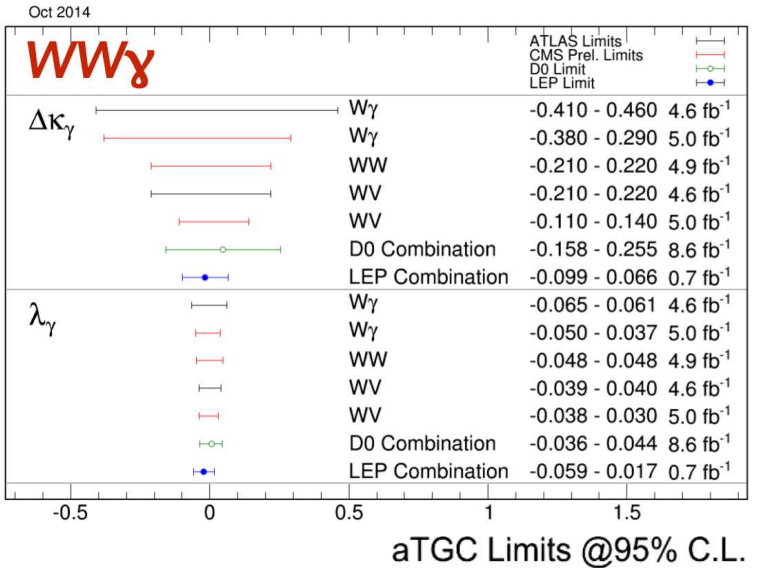


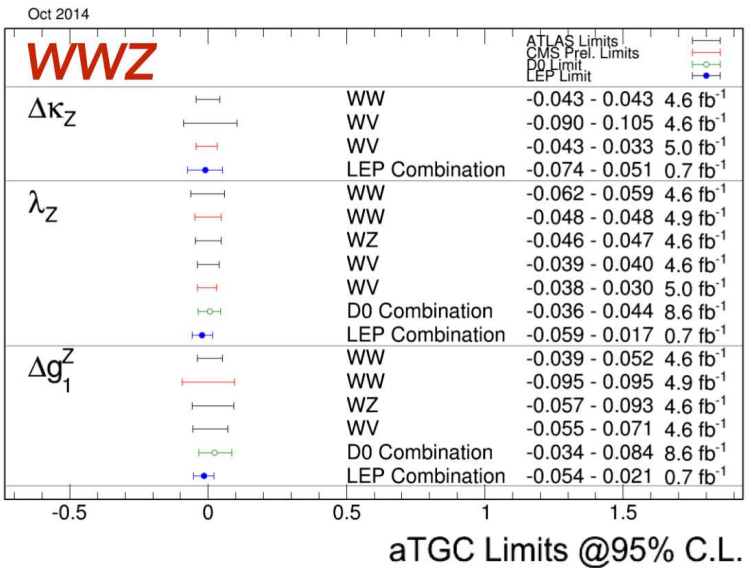
Topology: forward jets

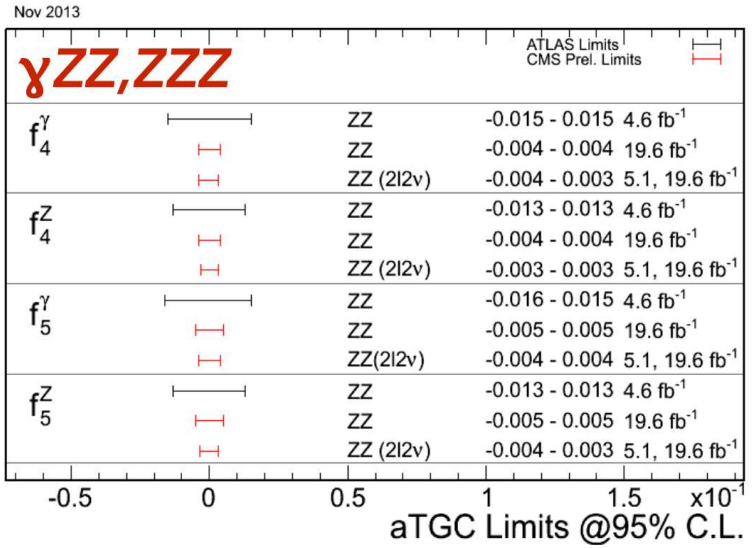
aTGC

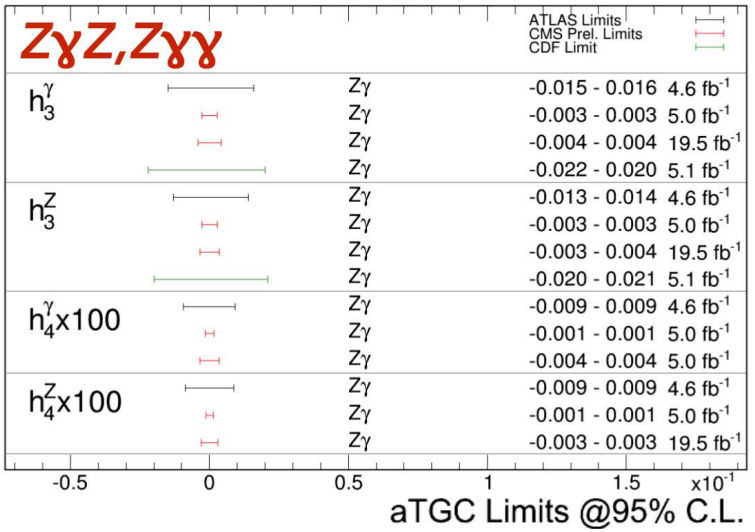
Anomalous couplings:

- increase cross sections and modification of kinematic distributions
- Anomalous effect from beyond SM
- physics can be modelled (SM+higher dimension operators)









No Deviation from SM

Summary of cross section

Data (pb) | Theory (pb)

Di-boson in ATLAS:

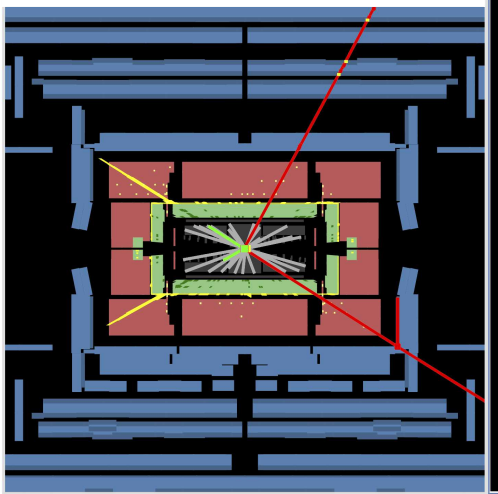
- Wγ , Zγ cross section at 7 TeV (4.6fb^{-1},NNLO)
  - $W\gamma \rightarrow l\nu\gamma$ 2.77 ±0.03 (stat) ±0.33(syst) ±0.14 (lumi) | 2.456 ±0.006
  - $Z\gamma \rightarrow ll\gamma$ 1.31 ±0.02 (stat) ±0.11(syst) ±0.05 (lumi) | 1.305 ±0.003
- WZ cross-section
  - 7 TeV 4.6fb^{-1} $19.0^{+1.4}_{-1.3}$ (stat.) ±0.9(syst.) ± 0.4 (lumi) | $17.6^{+1.1}_{-1.0}$
  - 8 TeV 13.0fb^{-1} $20.3^{+0.8}_{-0.7}$ (stat.) $^{+1.2}_{-1.1}$(syst.) $^{+0.7}_{-0.6}$(lumi) | 20.3±0.8
- ZZ cross-section
  - 7 TeV 4.6fb^{-1} 6.7 ±0.7(stat.) $^{+0.4}_{-0.3}$(syst.) ±0.3(lumi) | 5.89 $^{+0.22}_{-0.18}$
  - 8 TeV 20.3fb^{-1} 7.1 $^{+0.5}_{-0.4}$(stat.) ±0.3(syst.) ±0.2(lumi) | 7.2 $^{+0.3}_{-0.2}$
- WW+WZ semi-leptonic
  - 7 TeV 4.6fb^{-1} 68. ±7 (stat.) ±19(syst.) | 61.1±2.2
- WW cross-section
  - 7 TeV 4.6fb^{-1} 51.9 ± 2.0 (stat.) ± 3.9(syst.) ±2.0(lumi) | 44.7
  - 8 TeV 20.3fb^{-1} 71.4 ± 1.2 (stat.) $^{+5.0}_{-4.4}$(syst.) $^{+2.2}_{-2.1}$(lumi) | 58.7
  - ~2.1 σ higher than SM

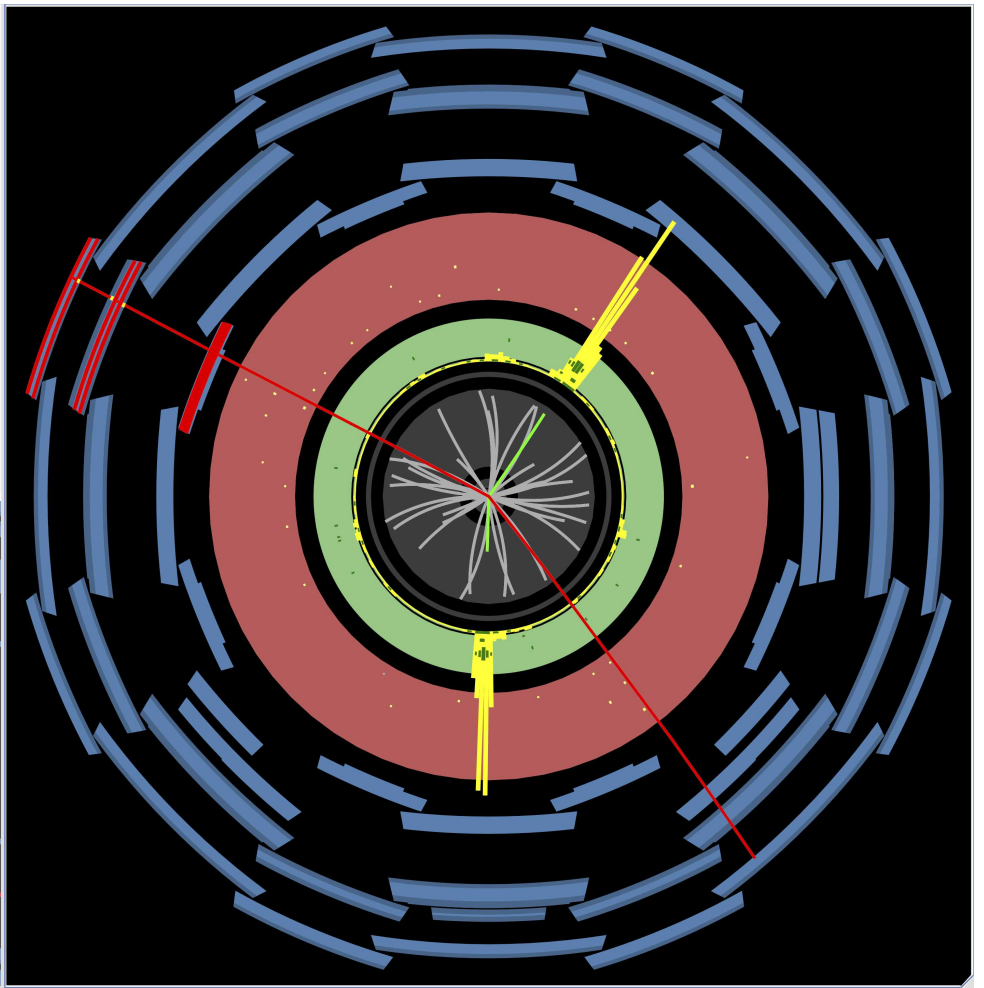
Including Higgs

- aTGC
  - No deviation

Summary

- Run-1 allowed to explore di-boson production processes:
  SM consistent
- Most di-boson measurements are systematically limited.
- Tri-boson and VBS processes are accessible.
- Promising Run-2 analysis!





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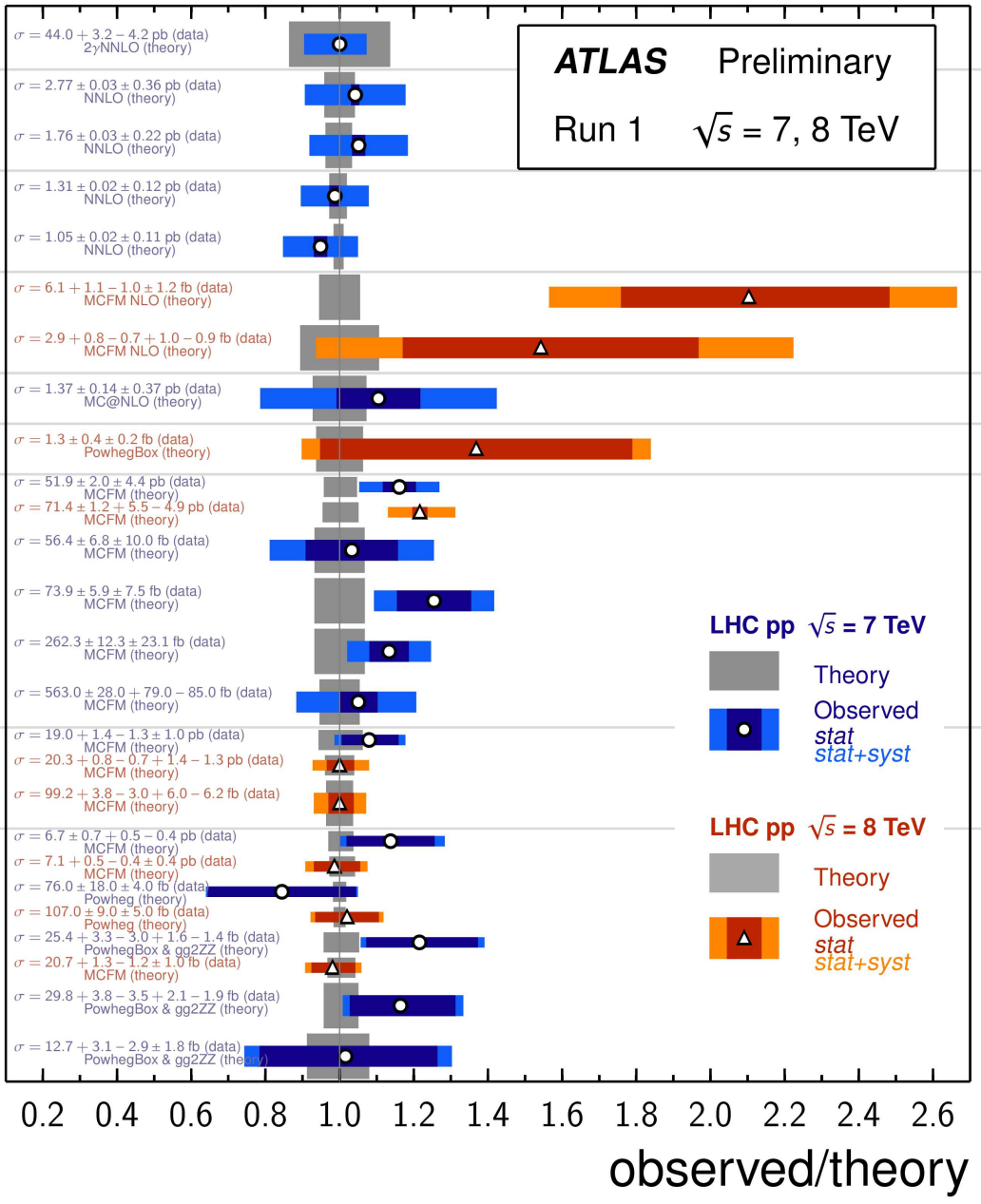
Multiboson Cross Section Measurements

Status: March 2015



	$\int \mathcal{L}\,dt$ [fb^{-1}]	Reference
$\sigma^{fid}(\gamma\gamma)[\Delta R_{\gamma\gamma} > 0.4]$	4.9	JHEP 01, 086 (2013)
$\sigma^{fid}(W\gamma \to \ell\nu\gamma)$	4.6	PRD 87, 112003 (2013) arXiv:1407.1618 [hep-ph]
– $[n_{jet} = 0]$	4.6	PRD 87, 112003 (2013)
$\sigma^{fid}(Z\gamma \to \ell\ell\gamma)$	4.6	PRD 87, 112003 (2013) arXiv:1407.1618 [hep-ph]
– $[n_{jet} = 0]$	4.6	PRD 87, 112003 (2013)
$\sigma^{fid}(W\gamma\gamma \to \ell\nu\gamma\gamma)$	20.3	arXiv:1503.03243 [hep-ex]
– $[n_{jet} = 0]$	20.3	arXiv:1503.03243 [hep-ex]
$\sigma^{fid}(pp \to WV \to \ell\nu qq)$	4.6	JHEP 01, 049 (2015)
$\sigma^{fid}(W^{\pm}W^{\pm}jj)$ EWK	20.3	PRL 113, 141803 (2014)
$\sigma^{total}(pp \to WW)$	4.6	PRD 87, 112001 (2013)
	20.3	ATLAS-CONF-2014-033
– $\sigma^{fid}(WW \to ee)$ $[n_{jet}=0]$	4.6	PRD 87, 112001 (2013)
– $\sigma^{fid}(WW \to \mu\mu)$ $[n_{jet}=0]$	4.6	PRD 87, 112001 (2013)
– $\sigma^{fid}(WW \to e\mu)$ $[n_{jet}=0]$	4.6	PRD 87, 112001 (2013)
– $\sigma^{fid}(WW \to e\mu)$ $[n_{jet}\geq 0]$	4.6	arXiv:1407.0573 [hep-ex]
$\sigma^{total}(pp \to WZ)$	4.6	EPJC 72, 2173 (2012)
	13.0	ATLAS-CONF-2013-021
– $\sigma^{fid}(WZ \to \ell\nu\ell\ell)$	13.0	ATLAS-CONF-2013-021
$\sigma^{total}(pp \to ZZ)$	4.6	JHEP 03, 128 (2013)
	20.3	ATLAS-CONF-2013-020
– $\sigma^{total}(pp \to ZZ \to 4\ell)$	4.5	arXiv:1403.5657 [hep-ex]
	20.3	arXiv:1403.5657 [hep-ex]
– $\sigma^{fid}(ZZ \to 4\ell)$	4.6	JHEP 03, 128 (2013)
	20.3	ATLAS-CONF-2013-020
– $\sigma^{fid}(ZZ^* \to 4\ell)$	4.6	JHEP 03, 128 (2013)
– $\sigma^{fid}(ZZ^* \to \ell\ell\nu\nu)$	4.6	JHEP 03, 128 (2013)

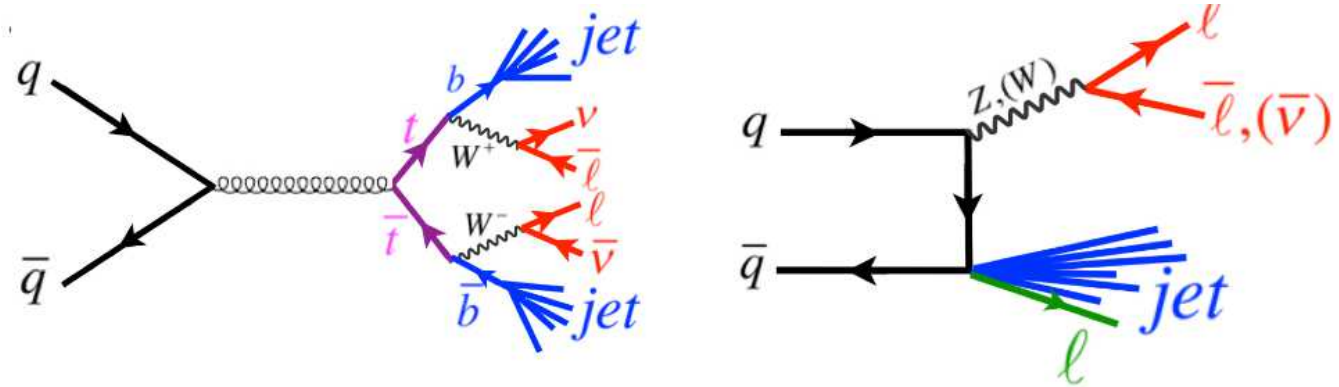
Signature

- Leptons/photons
  - High-pT
  - Isolated
- Z Bosons
  - Invariant mass in windows around the Z pole
- W Bosons
  - Large Missing ET to account for the neutrino
  - Transverse mass selection

Background

Estimated with data driven methods

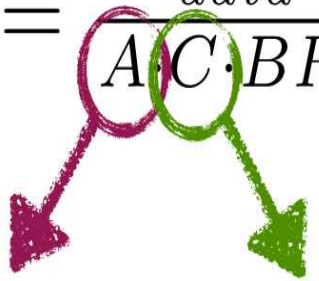
- V+jets
  - Genuine high-pt leptons from boson decay
  - Leptons from heavy flavour decaysJets misidentified as leptons/photons
  - Particles outside the detector acceptance => Missing ET
- tt(bar) and single top
  - Prompt isolated leptons from W leptons
  - Large Missing ET



N_{data}	Number of data events
N_{bkg}	Number of background events
L	Luminosity
BR	Branching Ratio
C	Efficiency corrections
A	Acceptance

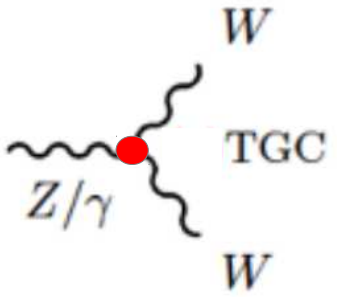
$$\sigma_{fid} = \frac{N_{data} - N_{bkg}}{C \cdot \int Ldt}$$

$$\sigma_{tot} = \frac{N_{data} - N_{bkg}}{A \cdot C \cdot BR \cdot \int Ldt}$$



$$A = \frac{N^{fid}_{MC,gen}}{N^{tot}_{MC,gen}} \qquad C = \frac{N^{Selected}_{Reco}}{N^{fid}_{MC,gen}}$$

SM



$$g_1^Z = 1 + c_W \frac{m_Z^2}{2\Lambda^2}$$

$$\kappa_\gamma = 1 + (c_W + c_B)\frac{m_W^2}{2\Lambda^2}$$

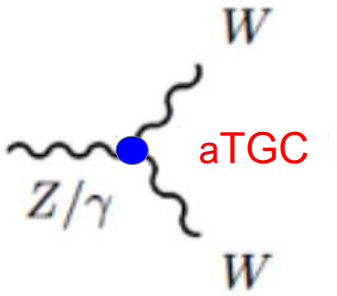
$$\kappa_Z = 1 + (c_W - c_B \tan^2\theta_W)\frac{m_W^2}{2\Lambda^2}$$

$$\lambda_\gamma = \lambda_Z = c_{WWW}\frac{3g^2 m_W^2}{2\Lambda^2}$$

aTGC

$$\Delta g_1^Z = \Delta\kappa_Z + \tan^2\theta_W \Delta\kappa_\gamma$$

$$g_4^V = g_5^V = 0$$



$$\tilde{\kappa}_\gamma = c_{\tilde{W}}\frac{m_W^2}{2\Lambda^2}$$

$$\tilde{\kappa}_Z = -c_{\tilde{W}} \tan^2\theta_W \frac{m_W^2}{2\Lambda^2}$$

$$\tilde{\lambda}_\gamma = \tilde{\lambda}_Z = c_{\tilde{W}WW}\frac{3g^2 m_W^2}{2\Lambda^2}$$

EFT

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_d \sum_i \frac{c_i^{(d)}}{\Lambda^{d-4}} \mathcal{O}_i^{(d)}$$

$$\begin{aligned}\mathcal{L} =& ig_{WWV}\Big(g_1^V(W^+_{\mu\nu}W^{-\mu} - W^{+\mu}W^-_{\mu\nu})V^\nu + \kappa_V W^+_\mu W^-_\nu V^{\mu\nu} + \frac{\lambda_V}{M_W^2}W^{\nu+}_\mu W^{-\rho}_\nu V^\mu_\rho \\ &+ ig_4^V W^+_\mu W^-_\nu(\partial^\mu V^\nu + \partial^\nu V^\mu) - ig_5^V\epsilon^{\mu\nu\rho\sigma}(W^+_\mu\partial_\rho W^-_\nu - \partial_\rho W^+_\mu W^-_\nu)V_\sigma \\ &+ \tilde{\kappa}_V W^+_\mu W^-_\nu \tilde{V}^{\mu\nu} + \frac{\tilde{\lambda}_V}{m_W^2}W^{\nu+}_\mu W^{-\rho}_\nu \tilde{V}^\mu_\rho\Big)\,,\end{aligned}$$

Wγ & Zγ cross sections at 7 TeV

Wγ / Zγ → lνγ, llγ, ννγ

- Single lepton or photon triggers:
  - Electrons: 20-22 GeV
  - Muons: 18 GeV
  - Photons: 80 GeV
- |d0 |/σd0 < 10(3) e(μ)
- |z0 | < 1mm
- Calorimeter isolation in cone ΔR < 0.3 less than 6 GeV (e)
- pT isolation in cone ΔR < 0.3 less than 15% of the μ pT
- W γ modelled with ALPGEN (CTEQ6L1)
- Z γ, νν γ modelled with Sherpa (CTEQ6.6M)

Cuts	$pp \to \ell\nu\gamma$	$pp \to \ell^+\ell^-\gamma$	$pp \to \nu\bar{\nu}\gamma$
Lepton	$p_T^\ell > 25$ GeV	$p_T^\ell > 25$ GeV	—
	$\lvert\eta_\ell\rvert < 2.47$	$\lvert\eta_\ell\rvert < 2.47$	—
	$N_\ell = 1$	$N_{\ell^+} = 1, N_{\ell^-} = 1$	$N_\ell = 0$
	$p_T^\nu > 35$ GeV	—	—
Boson	—	$m_{\ell^+\ell^-} > 40$ GeV	$p_T^{\nu\bar{\nu}} > 90$ GeV
Photon	$E_T^\gamma > 15$ GeV	$E_T^\gamma > 15$ GeV	$E_T^\gamma > 100$ GeV
	$\lvert\eta^\gamma\rvert < 2.37, \Delta R(\ell,\gamma) > 0.7$		
	$\epsilon_h^p < 0.5$		
Jet	$E_T^{\text{jet}} > 30$ GeV, $\lvert\eta^{\text{jet}}\rvert < 4.4$		
	$\Delta R(e/\mu/\gamma, \text{jet}) > 0.3$		
	Inclusive : $N_{\text{jet}} \geq 0$, Exclusive : $N_{\text{jet}} = 0$		

NLO

- Wγ , Zγ cross section at 7 TeV (4.6fb^{-1})
  - Wγ → lνγ 2.77 ±0.03 (stat) ±0.33(syst) ±0.14 (lumi) 1.96 ±0.17
  - Zγ → llγ 1.31 ±0.02 (stat) ±0.11(syst) ±0.05 (lumi) 1.18 ±0.05
  - Zγ → lνν 0.133 ±0.01 (stat) ±0.02(syst) ±0.05 (lumi) 0.156 ±0.012

Wγ & Zγ cross sections at 7 TeV

pb (data) pb (theory)

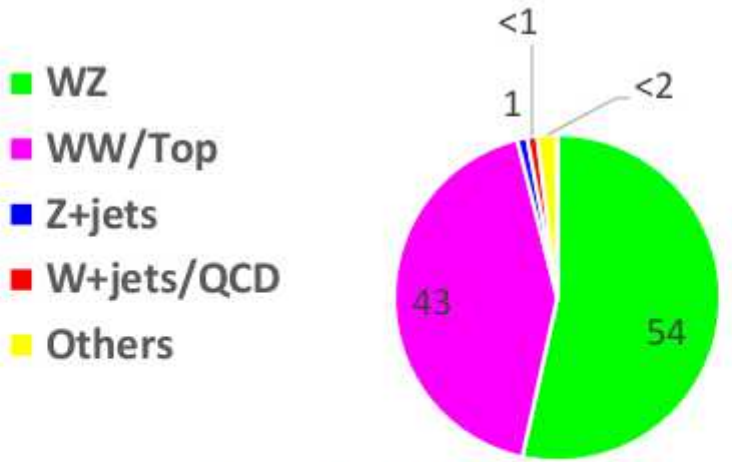
Di-boson in ATLAS:

- Wγ , Zγ cross section at 7 TeV (4.6fb^{-1})
  - $W\gamma \rightarrow l\nu\gamma$ 2.77 ±0.03 (stat) ±0.33(syst) ±0.14 (lumi) 1.96 ±0.17
  - $Z\gamma \rightarrow ll\gamma$ 1.31 ±0.02 (stat) ±0.11(syst) ±0.05 (lumi) 1.18 ±0.05
  - $Z\gamma \rightarrow l\nu\nu$ 0.133 ±0.01 (stat) ±0.02(syst) ±0.05 (lumi) 0.156 ±0.012

WZ & ZZ cross sections at 7 and 8 TeV

Backgrounds to ZZ→llνν:

- WZ→lνll: MC based, validated using trilepton control region
- WW/top/Zττ: real E_T^{miss}, data driven, flavor symmetry
- Z+jets: fake E_T^{miss}, estimated with γ+jets events
- W+jets/QCD: fake lepton, matrix method and fake-factor method
- Others: ZZ→4l



WZ & ZZ cross sections at 7 and 8 TeV

Electrons

Requirement	$\ell^+\ell^-\nu\bar{\nu}$ final state
Central Electron Selection:	
1. e: Type	`author==1 or 3`
2. e: Quality	`(OQ AND 1446 == 0)`
3. e: ID cut	`Medium++`
4. e: η	$\lvert\eta\rvert < 2.47$
5. e: E_T	$E_T > 25$ GeV
6. e: $z_0 * sin(\theta)$	$\lvert z_0 * sin(\theta)\rvert < 0.5$ mm
7. e: d_0	$\lvert d_0\rvert/\sigma(d_0) < 6$
8. e: Track isolation	$\Sigma p_T\ (\Delta R < 0.2)/p_T < 15\%$
9. e: Calo isolation	$\Sigma E_T\ (\Delta R < 0.2)/E_T < 15\%$
10. e: Overlap removal	a) Remove e if $\Delta R < 0.1$ from μ
	b) Remove lowest E_T e in
	$\Delta R < 0.1$ from another e

Muons

Requirement	$\ell^+\ell^-\nu\bar{\nu}$ final state
Standard Muons	
1. μ: type	Combined, "loose" STACO muons,
2. μ: p_T and η	$p_T > 25$ GeV, $\lvert\eta\rvert < 2.5$
3. μ: ID hits	MCP recommendations
4. μ: $z_0 * sin(\theta)$	$\lvert z_0 * sin(\theta)\rvert < 0.5$ mm
5. μ: d_0	$\lvert d_0\rvert/\sigma(d_0) < 3.0$
6. μ: track iso	$\Sigma p_T(\Delta R < 0.2)/p_T < 15\%$
7. μ: calo iso	$\Sigma E_T(\Delta R < 0.2)/E_T < 15\%$

Jets

Requirement	$\ell^+\ell^-\nu\bar{\nu}$ final state
AntiKT4LCTopo Jets	
1. jet: p_T and η	$p_T > 25$ GeV, $\lvert\eta\rvert < 4.5$
2. jet: Bad Jets	Remove events with "LooserBad" jets
3. jet: JVF	$\lvert JVF\rvert > 0.5$ or $\lvert\eta\rvert > 2.4$ or $p_T > 50$ GeV
4. jet: Overlap removal	Remove jets if overlapped with selected leptons, $\Delta R < 0.3$

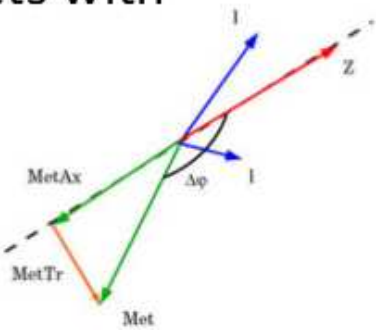
MET:
RefFinal

WZ & ZZ cross sections at 7 and 8 TeV

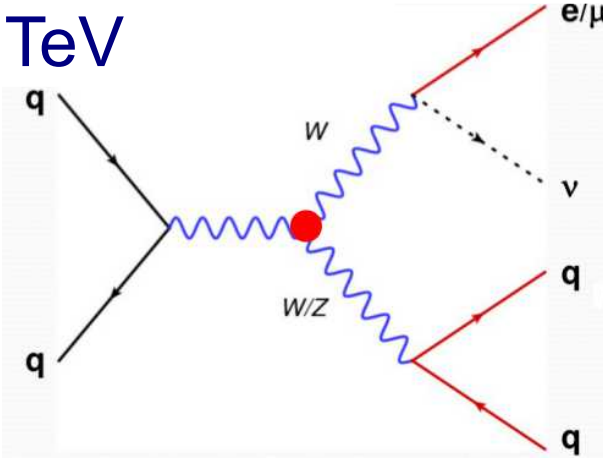
Total phase-space: $66 < m_{Z1}, m_{Z2} < 116$ GeV

Fiducial phase-space:

- 2 pairs of opposite sign same flavor leptons
- $p_T^{\ell} > 7$ GeV
- $66 < m_Z < 116$ GeV
- $\Delta R(\ell, \ell) > 0.2$ (all leptons)
- 4μ: $|\eta_\mu| < 2.7$
- $2e2\mu$:
  - $|\eta_\mu| < 2.7$
  - $|\eta_e| < 2.5$ (both e) , OR $|\eta_{e_1}| < 2.5$ and $|\eta_{e_2}| < 4.9$
- $4e$:
  - $|\eta_e| < 2.5$ (all e), OR $|\eta_e| < 2.5$ ($3e$) and $|\eta_{e_4}| < 4.9$
- 2 same-flavor opposite sign leptons
- 76 GeV $< m_Z <$ 106 GeV
- $p_T^{\ell} > 25$ GeV
- Axial-$E_{\mathrm{T}}^{\mathrm{miss}} > 90$ GeV
- $\frac{|p_{\mathrm{T}}^{\nu\bar{\nu}} - p_{\mathrm{T}}^{Z}|}{p_{\mathrm{T}}^{Z}} < 0.4$
- $|\eta^{\ell}| < 2.5$
- No jets with $p_{\mathrm{T}} > 25$ GeV and $|\eta| < 4.5$ (remove jets with electrons $\Delta R = 0.3$)
- $\Delta R(\ell, \ell) > 0.3$



WW & WZ in semi-leptonic mode at 7 TeV



WW/WZ→lνjj

- Exactly one high-pT isolated lepton pT>25 GeV
- |d0 / σ(d0)| < 3 (10) for muons (electrons)
- |z0| <1 mm
- ETmiss > 30 GeV, mT,W > 40 GeV
- Exactly two jets with pT > 25 GeV and |η| < 2.8 (pT > 30 GeV for the leading jet)
- Azimuthal angular separation between the leading jet pT and the Etmiss vectors must fulfil $|\Delta\varphi(ETmiss,j1)| > 0.8$
- $|\Delta\eta(j1,j2)| < 1.5$, $\Delta R(j1, j2) > 0.7$ if pT of the dijet system is less than 250 GeV
- 25 < mjj < 250 GeV

WW production at 8 TeV

WW→lνlν (in 0-jet bin)

- Lowest order:W±W± + 2jets, there is no SM inclusive W±W±
- for EW+strong measurement (“inclusive signal phase space”)
  - exactly 2 high pT same-sign leptons with pT > 25 GeV in |η| < 2.5
  - mll>20 GeV, ΔRll>0.3
  - ≥ 2 jets with pT>30 GeV, |η| < 4.5
  - ETmiss > 40 GeV (from W decays)
  - veto events containing b-jets
  - Z-veto in ee channel: |mee − mZ | > 10 GeV
  - mjj >500GeV
- for EW-only measurement (“VBS signal phase space”)
  - additional cut on |ΔYjj | > 2.4

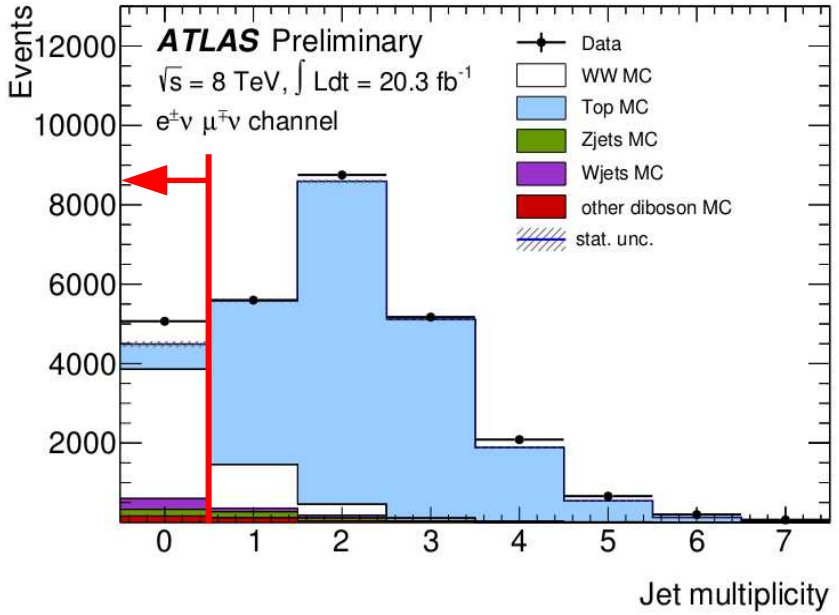
WW production at 8 TeV

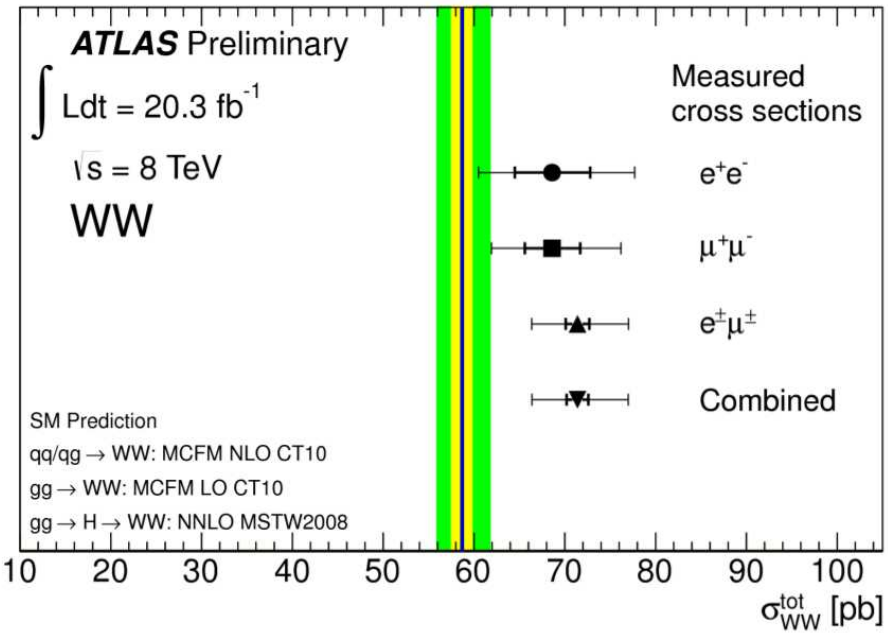
WW→lνlν (in 0-jet bin)

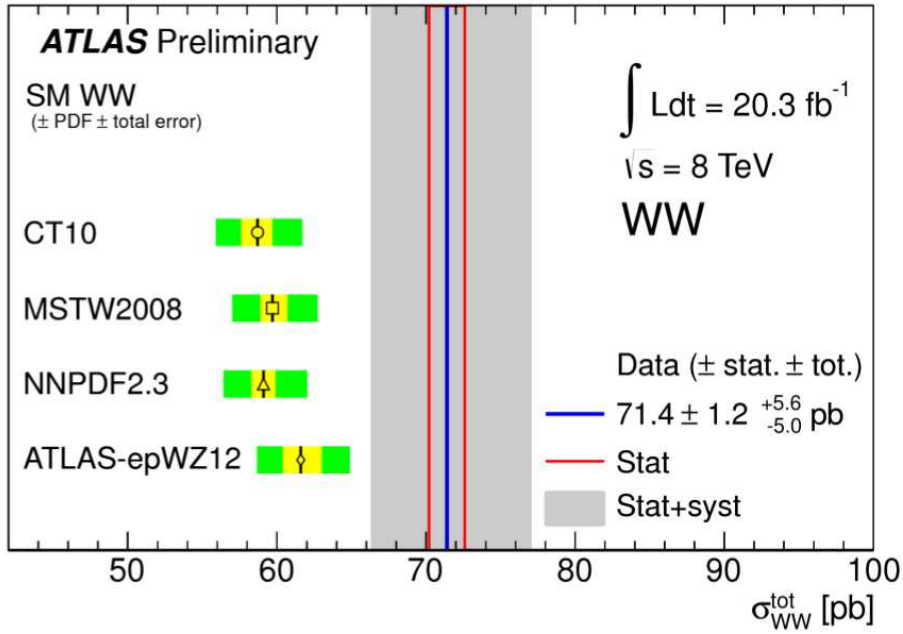
- 2 isolated high p^T leptons (opp. charge)
- E^{miss}_T (45,45,25 GeV: ee,eμ,μμ)
- hard jet veto (reject tt & single-top)
- Z veto (15,10 GeV: ee, μμ)

BKG

- Top (~15%)
- W+jets (~5%)
- Drell-Yan (~5%)

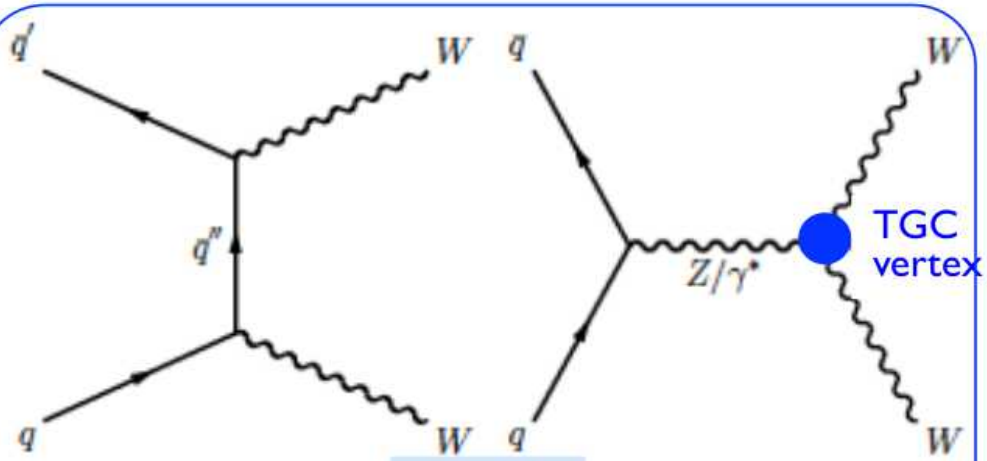






- NNLO corrections: up to 10% (arXiv:1408.5243)
- re summation at large logs: partially explain excess (arXiv:1407.4537,1407.4481,1507.02565v1)

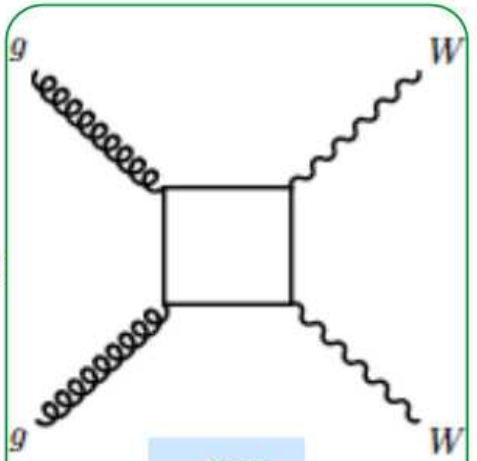
WW production at 7 & 8 TeV



~91%

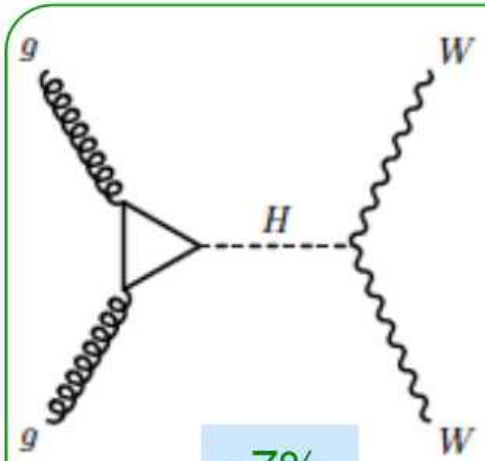
MCFM NLO (CT10 PDF)

Contains triple gauge coupling



~2%

MCFM LO (CT10 PDF)



~7%

NNLO MSTW2008 LHC Higgs XS WS

arXIv:1307.1347

CMS $60.1 \pm 0.9\,(\text{stat.}) \pm 3.2\,(\text{exp.}) \pm 3.1\,(\text{th.}) \pm 1.6\,(\text{lum.})\,\text{pb}$.

ATLAS $71.4^{+1.2}_{-1.2}\,(\text{stat})\,^{+5.0}_{-4.4}\,(\text{syst})\,^{+2.2}_{-2.1}\,(\text{lumi})\,\text{pb}$

ATLAS and CMS in agreement.

Theoretical predictions cited:

59.8 ± 1.2 pb (CMS)

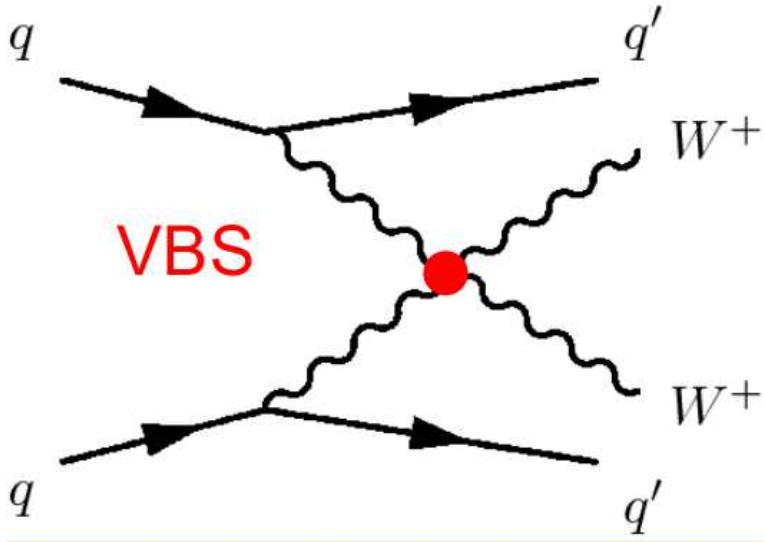
NNLO "qqbar+qq" (no H)

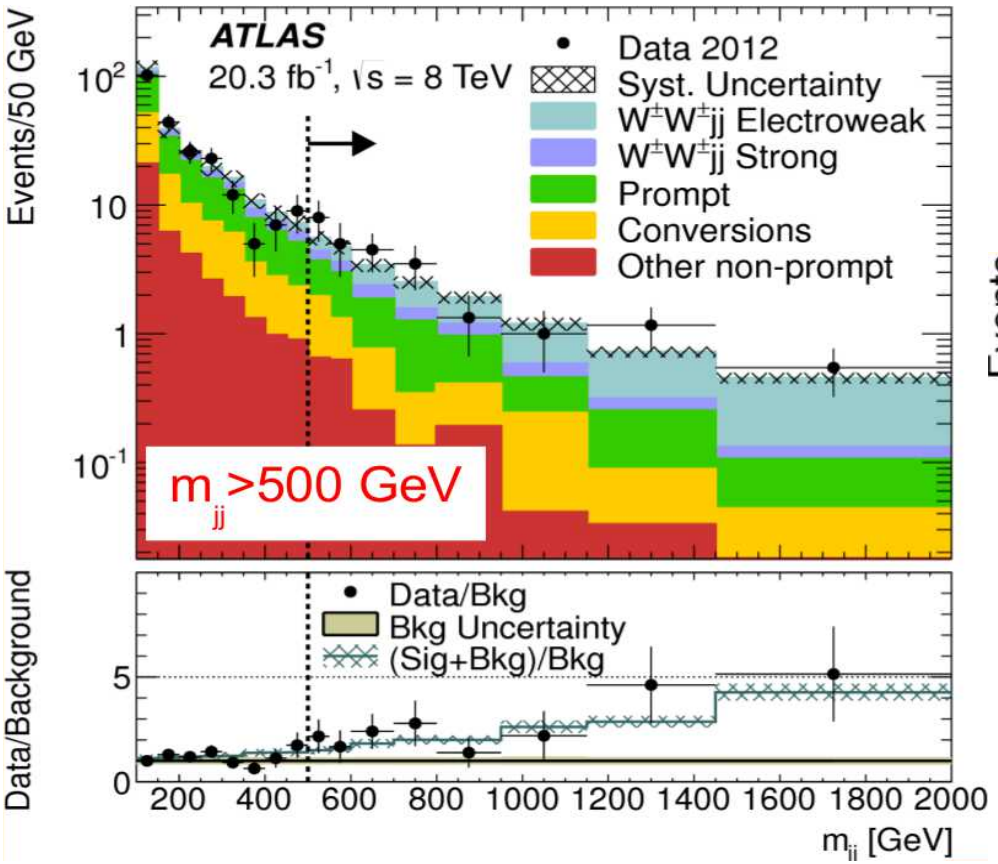
58.7 ± 2.9 pb (ATLAS)

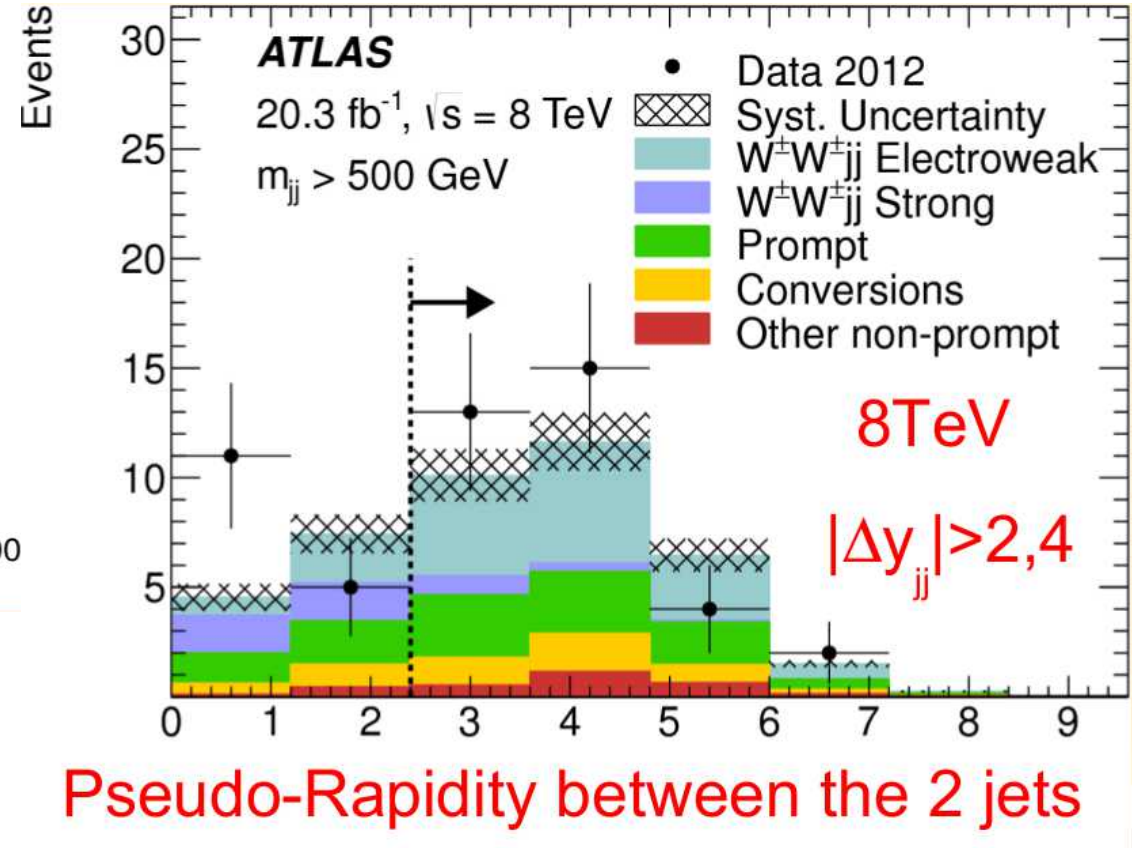
NLO qqbar + LO gg + NNLO H

VBS Phys. Rev. Lett. 113, 141803

Vector Boson Scattering topology: unitary issue
Pair of same charge W with 2 jets
Quartic Gauge Vertex contribution
W in leptonic mode: W→lν (l=e,μ)







1507.02565v1

Transverse-momentum resummation for vector-boson pair production at NNLL+NNLO

Massimiliano Grazzini, Stefan Kallweit, Dirk Rathlev, Marius Wiesemann