Standard Model Measurements with the ATLAS Detector

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Outline

1. Electroweak physics
   - W^+W^- production
   - Electroweak production of dijet and Z
   - Evidence for electroweak production of $W^{\pm}W^{\pm}jj$
2. W/Z boson production
   - Z/γ^* transverse momentum
   - Associated Z and b-jets production
   - W+jets and Rjets at 7 TeV
   - W+c measurement
3. Jet Physics
   - Inclusive jet cross section
   - 3-jets at 7 TeV
   - Dijet production with a jet veto
4. Soft QCD
   - Underlying Event in jet and Z events

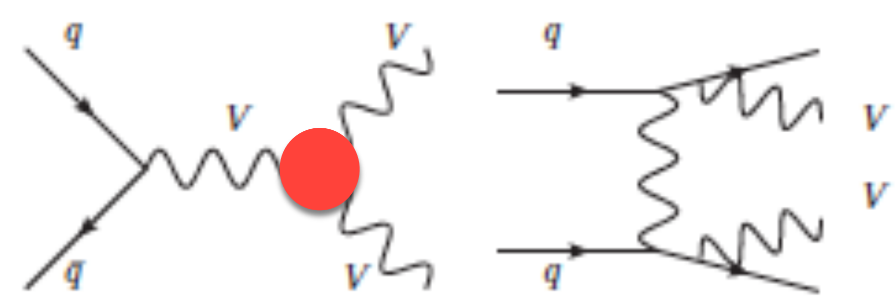
Electroweak Measurements

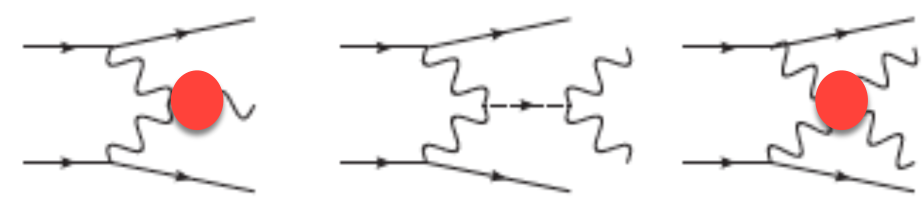
1. W^+W^- production
2. Electroweak production of dijet and Z
3. Evidence for electroweak production of $W^\pm W^\pm jj$

Di-boson Production

- Di-boson production provides a test of the SM at the TeV scale
  - precise measurement of the fiducial, total and differential cross sections

- Probe gauge-boson self-coupling (triple and quartic) to test the EW theory and to scrutinise EWSB mechanism
  - Electroweak di-boson production
  - Vector Boson Scattering
    - is the Higgs the only responsible for unitarity?
    - unitarity in $V_L V_L \rightarrow V_L V_L$ scattering to complement g_{HVV} measurements





- Test NLO EW corrections and of QCD calculations (NNLO)
- Irreducible background to Higgs and beyond SM-searches

$W^+ W^-$ production at 8TeV

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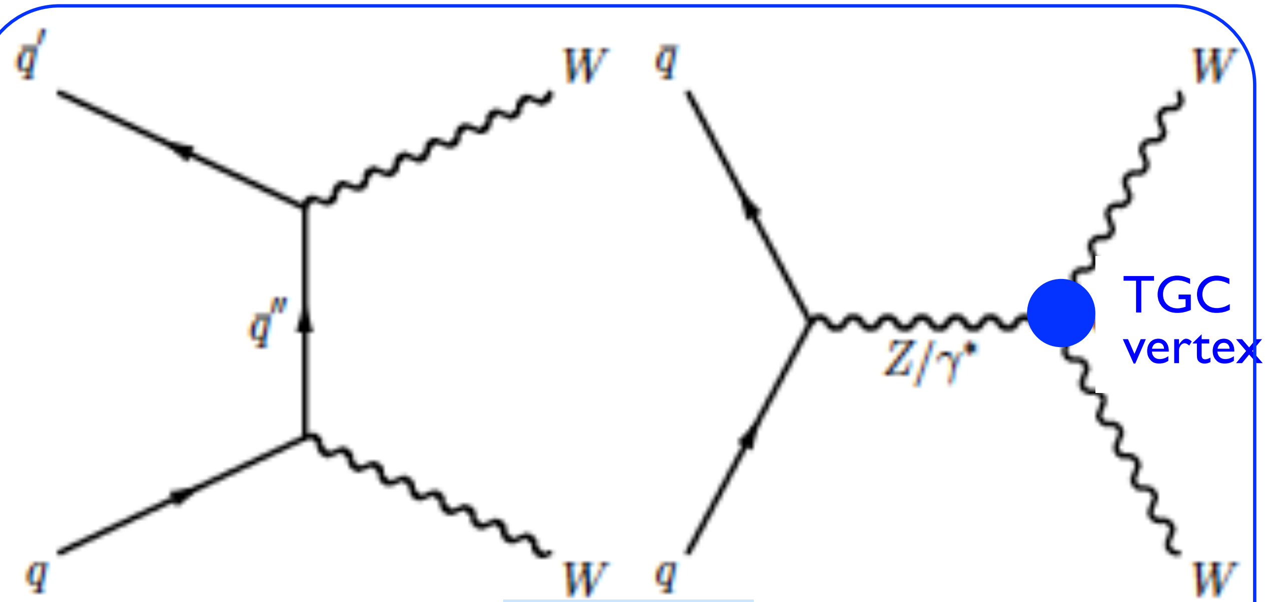
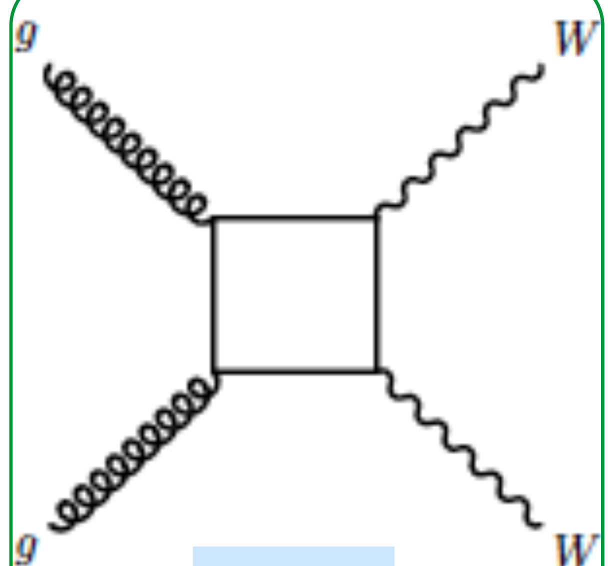


~91%

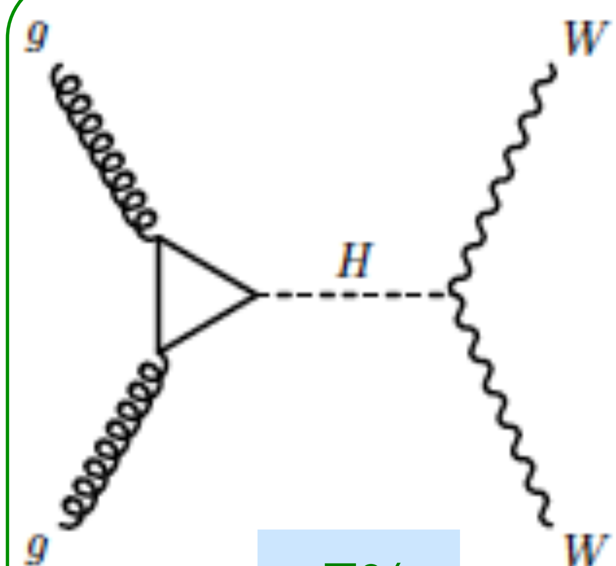
MCFM NLO (CT10 PDF)

Contains triple gauge coupling



~2%

MCFM LO (CT10 PDF)



~7%

NNLO MSTW2008 LHC Higgs XS WS

arXIv:1307.1347

- Other contributions (γγ, VBS, DPI) are neglected

Standard Model prediction: $58.7\,^{+3.0}_{-2.7}$ pb

$W^+ W^-$ production at 8TeV

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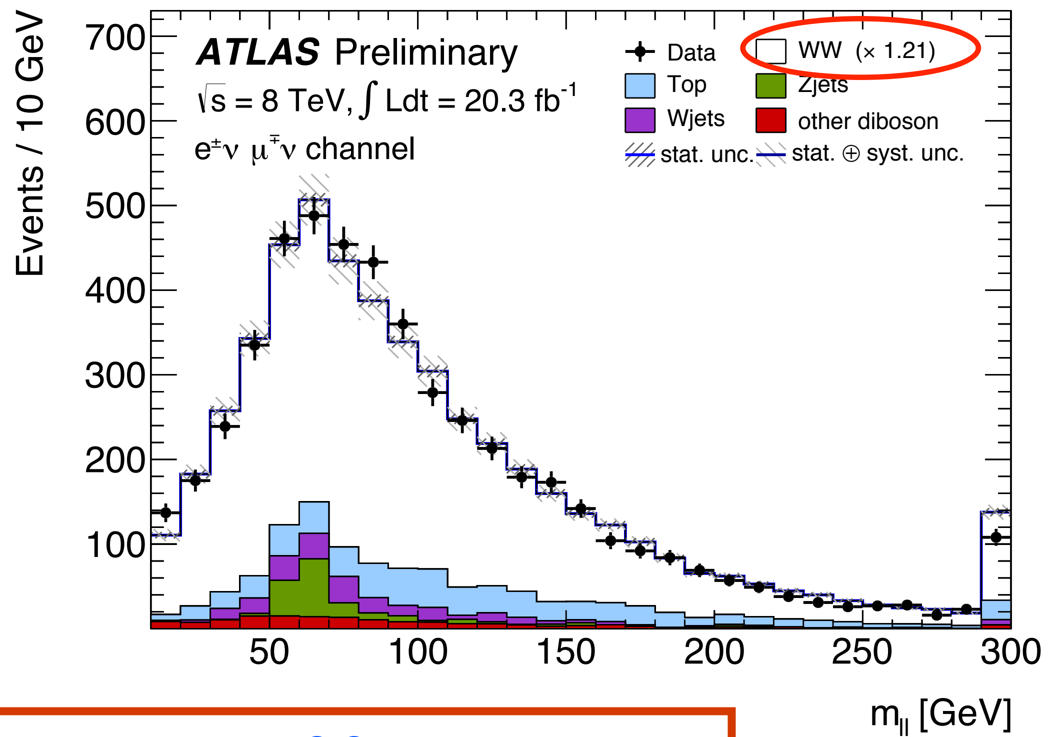
- $W^+W^- \rightarrow l\nu l\nu$ ($l=e, \mu$) + jet veto
- Background processes
  - Top (~15%)
  - Drell-Yan (~5%)
  - W+jet (~5%)
  - Diboson (~3%)



$\sigma^{tot} = 71.4 \pm 1.2(stat)\ ^{+5.0}_{-4.4}(syst)\ ^{+2.2}_{-2.1}(lumi)pb$

$\sigma^{theo} = 58.7^{+3}_{-2.7}$ pb

- Measurement still dominated by systematics (uncorrelated):
  - Background uncertainty 3-6%
  - Jet-veto requirement 4-5%
  - Jet energy scale 2%
  - E_T^{miss} 2-4%

Channel	σ_{WW}^{total} [pb]
$e\mu$	$71.4^{+1.3}_{-1.3}$ (stat) $^{+5.0}_{-4.4}$ (syst) $^{+2.1}_{-2.0}$ (lumi)
ee	$68.6^{+4.2}_{-4.1}$ (stat) $^{+7.8}_{-6.7}$ (syst) $^{+2.1}_{-2.0}$ (lumi)
$\mu\mu$	$68.6^{+3.1}_{-3.0}$ (stat) $^{+6.6}_{-5.6}$ (syst) $^{+2.1}_{-2.0}$ (lumi)
Combined	$71.4^{+1.2}_{-1.2}$ (stat) $^{+5.0}_{-4.4}$ (syst) $^{+2.2}_{-2.1}$ (lumi)

$W^+ W^-$ production at 8TeV

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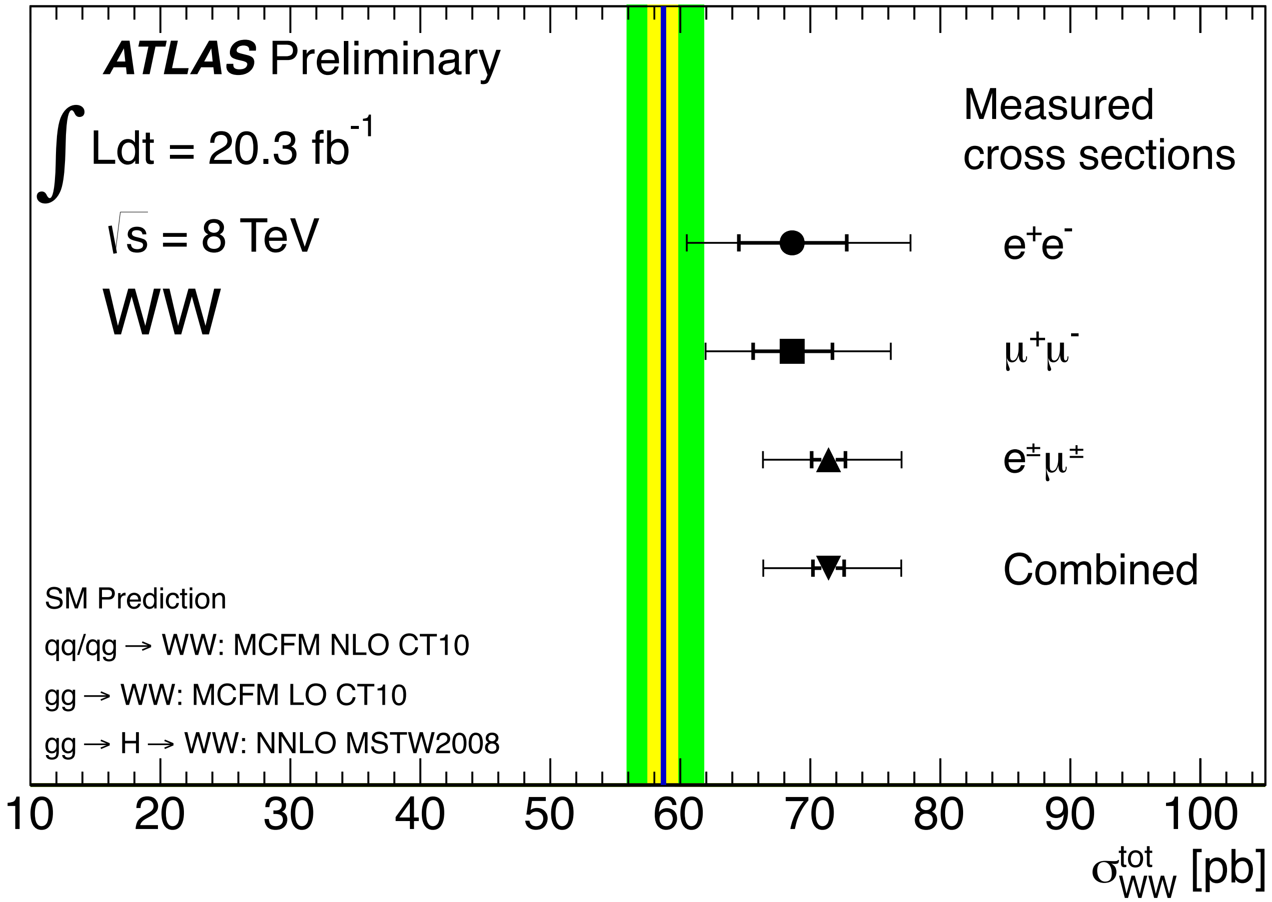

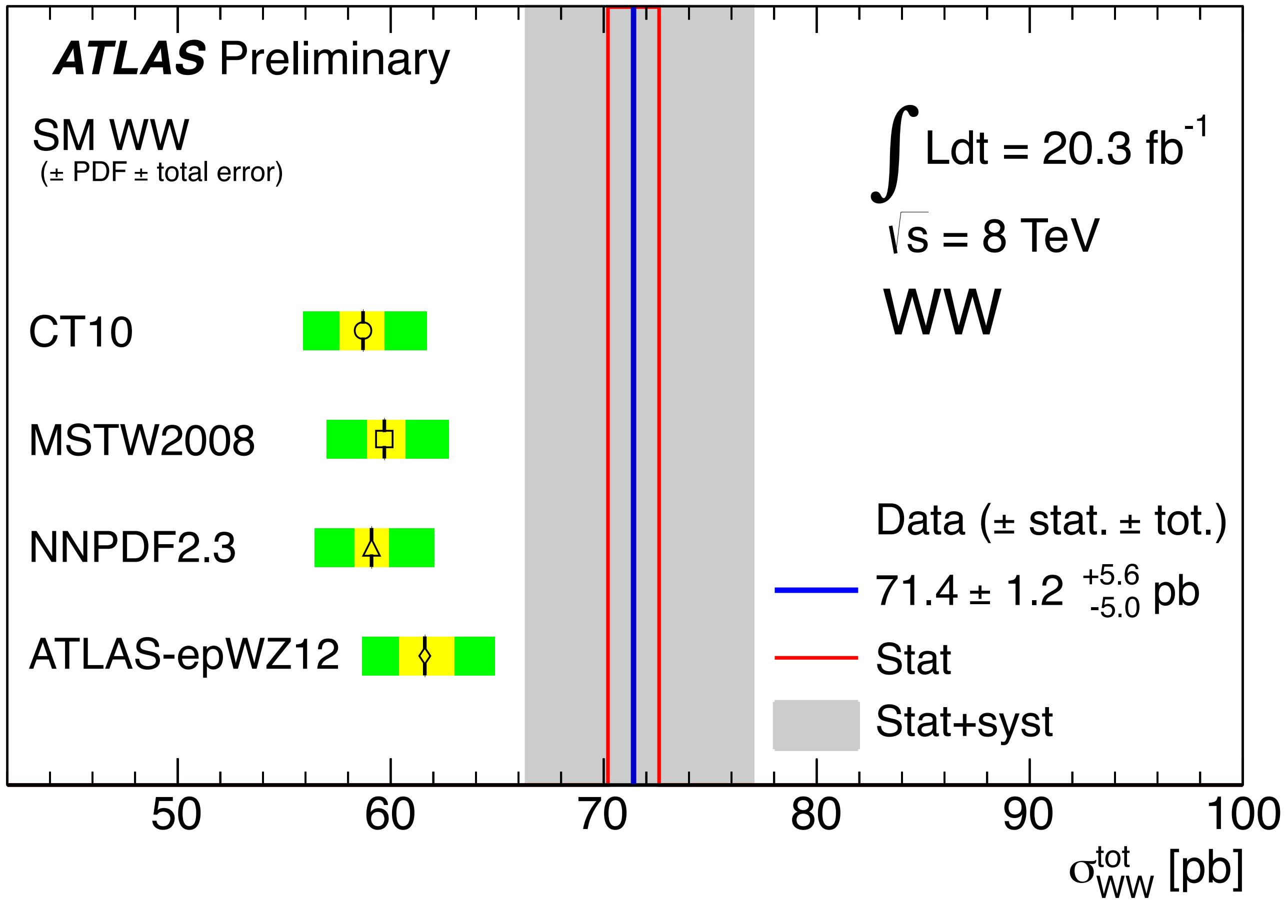

- WW cross section +2.1σ from theoretical prediction
- Effect from choice of PDF +2.9 pb
- qq→WW (NLO → NNLO+NNLL k-factor) +1.6 pb (arXiv: 1405.2219, 1307.3249)
- qq→WW (NLO electroweak corrections) - 0.5 pb (arXiv: 1208.3147)
- gg→WW (LO → NNLO+NNLL k-factor) +2.8 pb (arXiv:1304.3053)

(Recent papers on soft-WW p_T resummation(arXiv:1407.4537,arXiv: 1407.4481) claim an increase of 0-jet cross section by ~9%)

$W^+ W^-$ production at 8TeV

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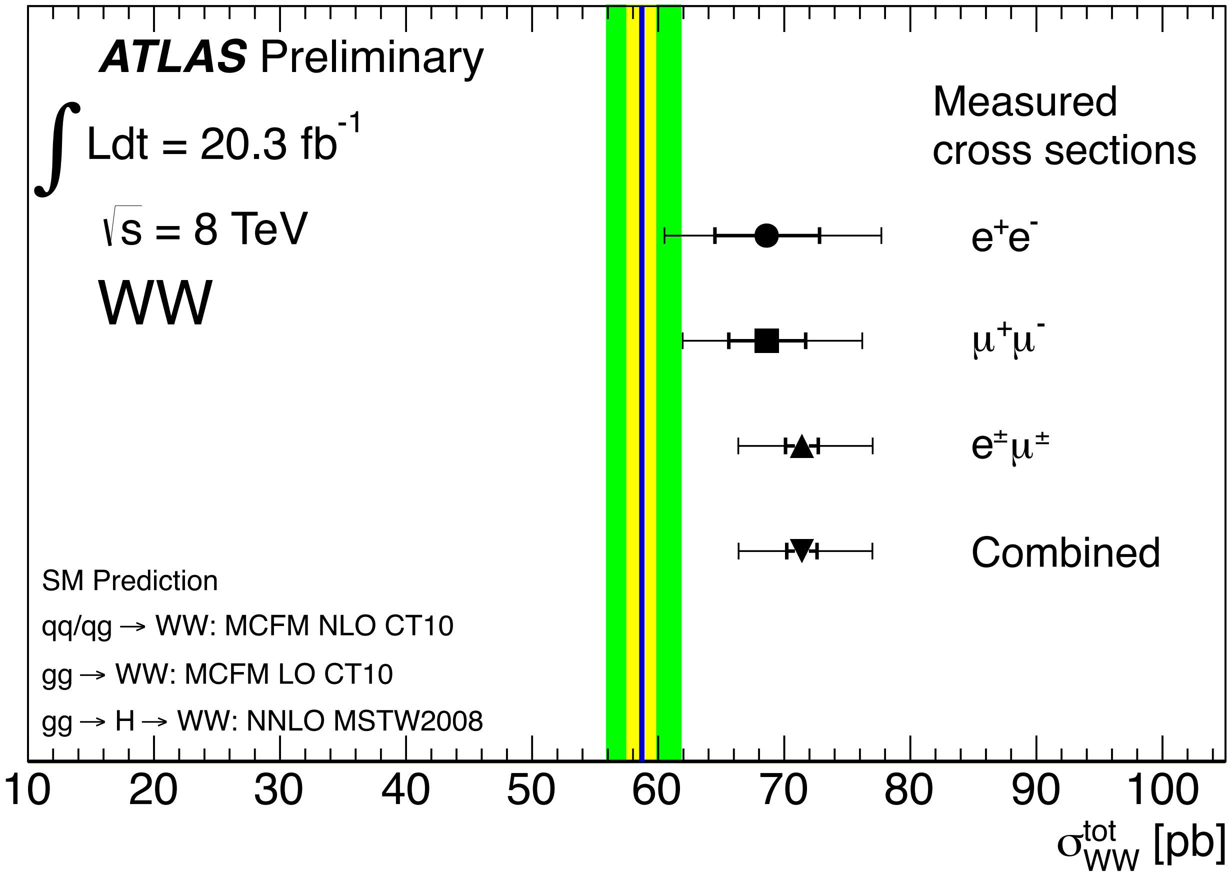
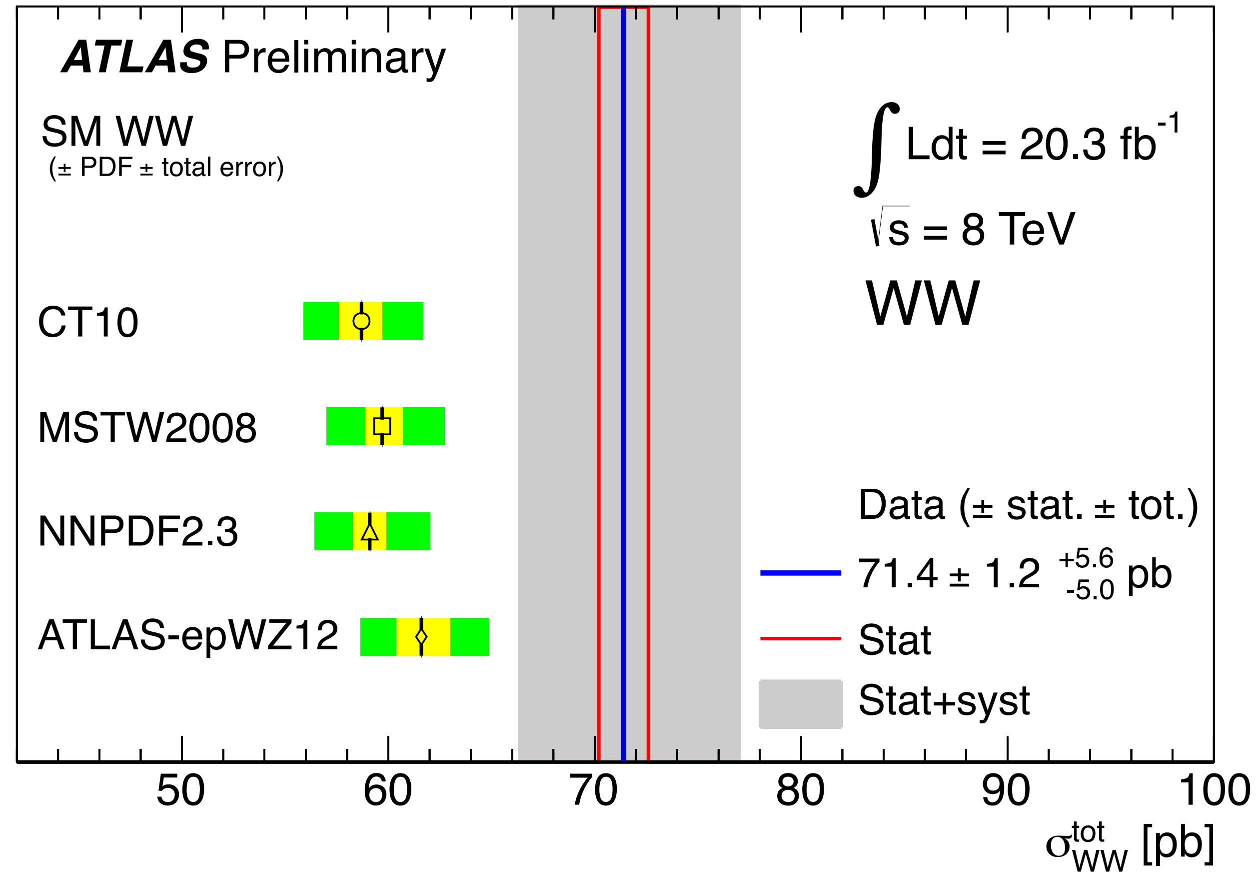
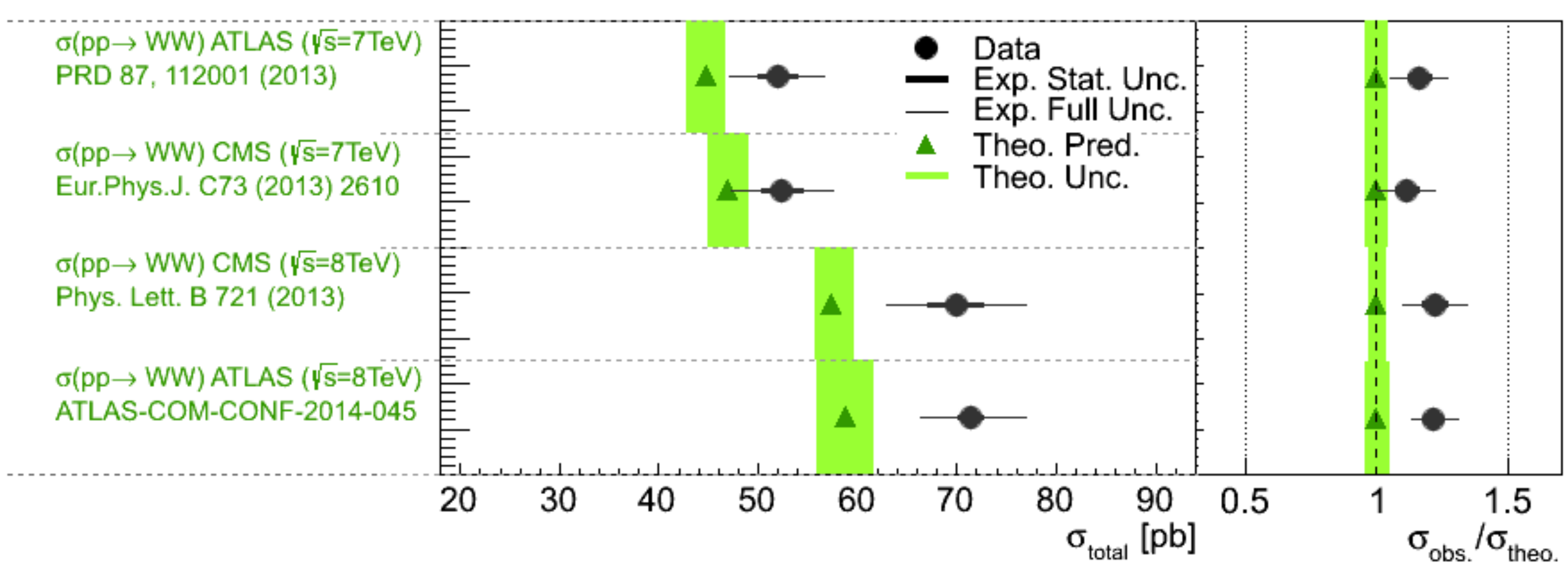




- Previous LHC measurements show an enhancement of data compared to the theoretical predictions



Significance

1.4 σ

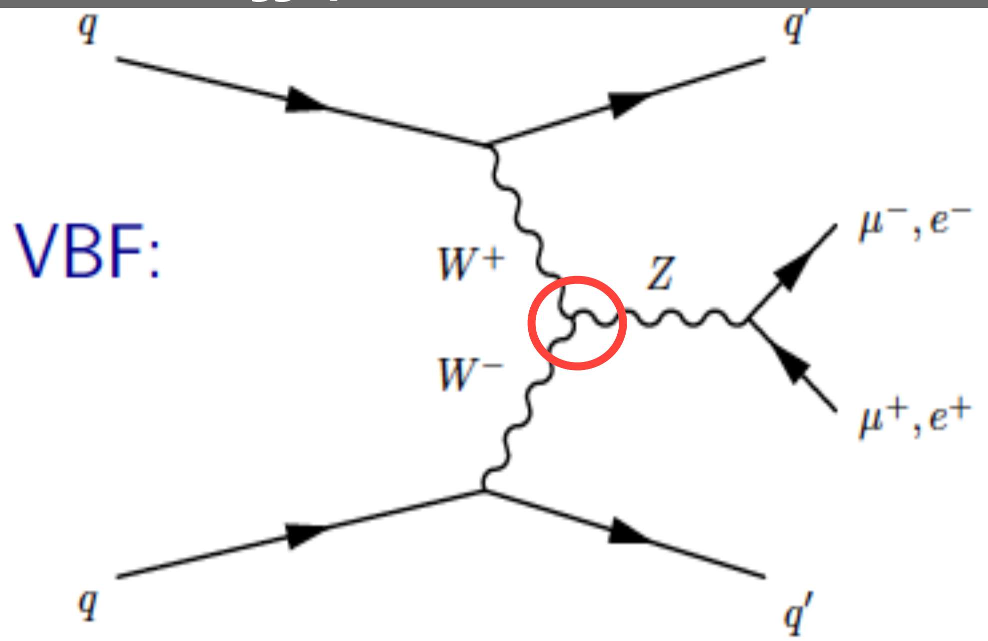
1.0 σ

1.7 σ

2.1 σ

Zjj production via Vector Boson Fusion at 8TeV

VBF:

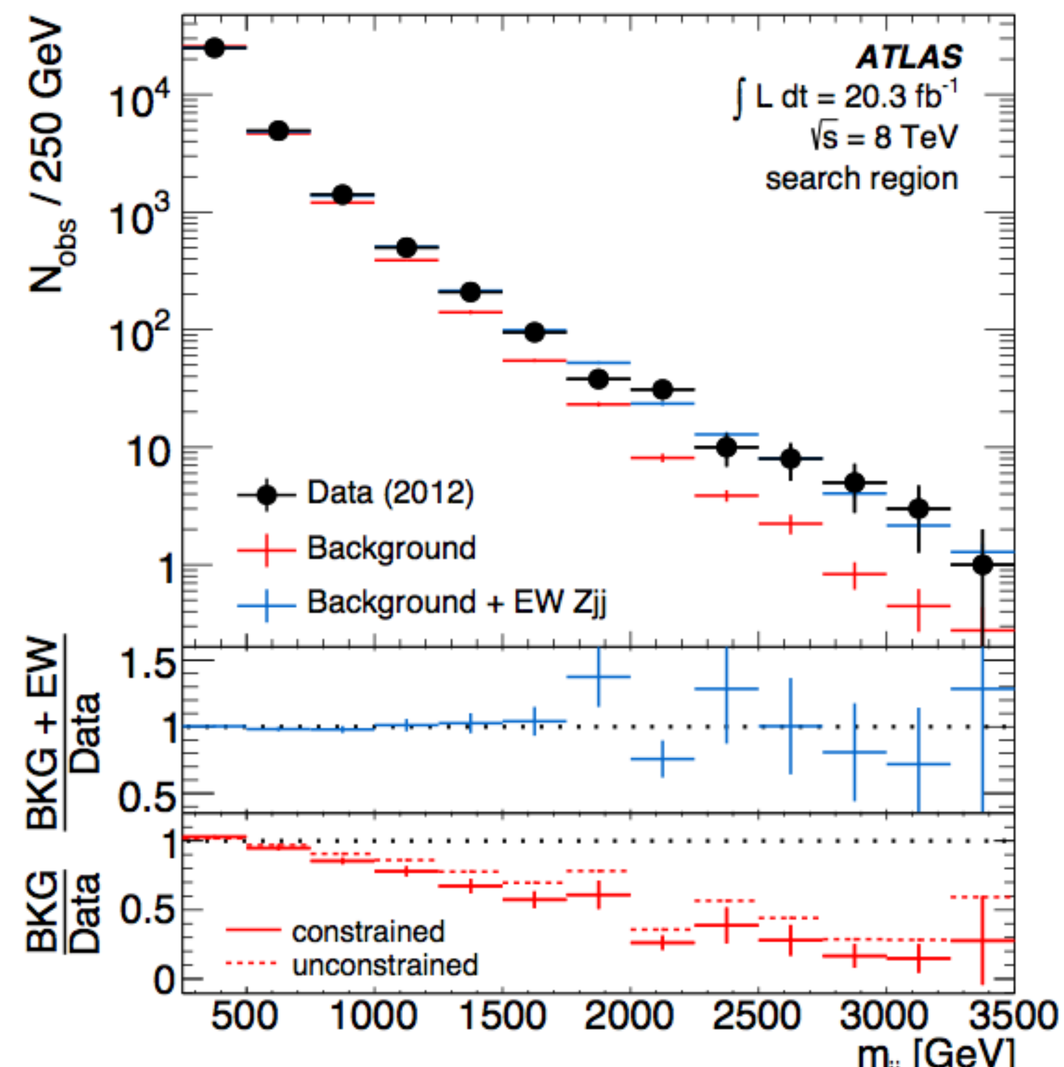


- Electroweak production of Zjj mainly via VBF channel
- Electroweak Zjj production **is rare ~1%** of inclusive Zjj cross section
- Strong Zjj production is dominant (~1nb)

- Electroweak Zjj has two high-p_T, well separated jets with large invariant mass mjj and little QCD radiation between them
- Electroweak Zjj component is extracted by a fit to mjj
- Fit for 1657 ± 134 (data stat.) EW Zjj events
- The background only hypothesis is rejected with a significance > 5σ

$\sigma^{EW} = 54.7 \pm 4.6(\text{stat})^{+9.8}_{-10.4}(\text{syst}) \pm 1.5(\text{lumi})$ fb

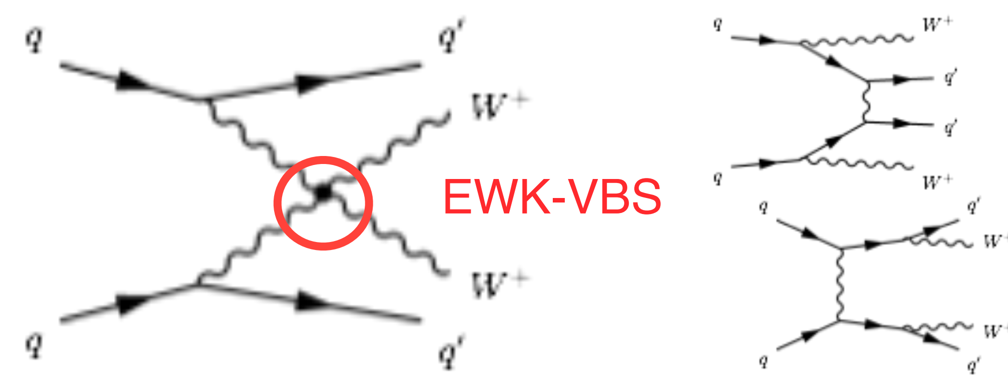
SM NLO (Powheg) = 46.1±1.0 fb

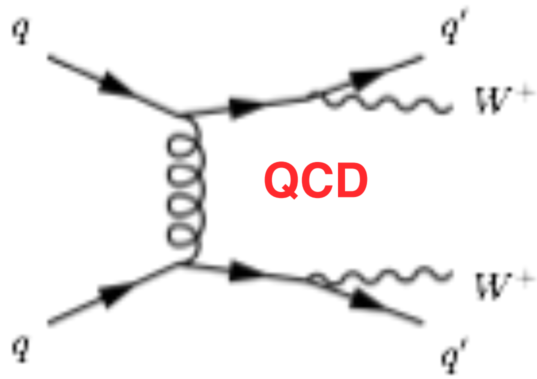


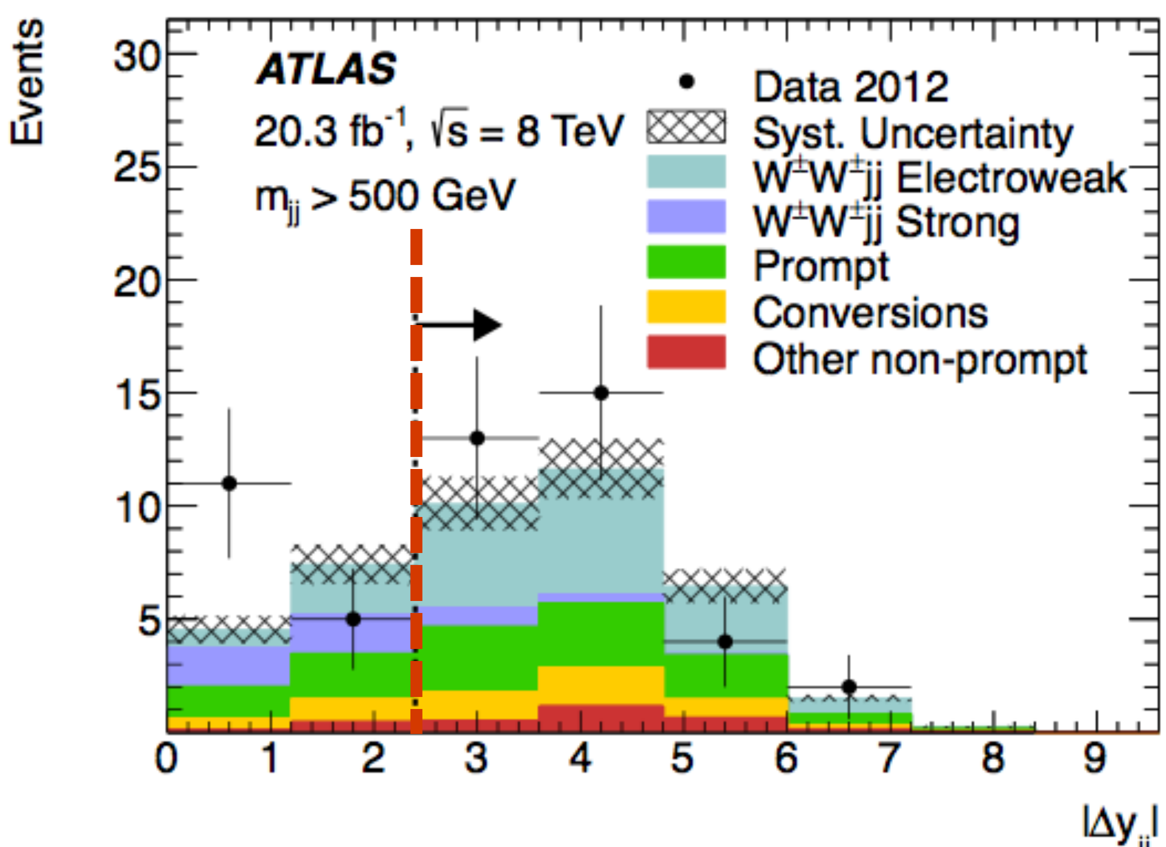
arXiv:1405.6241

Same sign W± W±jj production at 8TeV

- Measurement of inclusive and electroweak W± W±jj production cross sections
  - VBS may give rise to aQGCs via the WWWW
  - QCD production mechanism





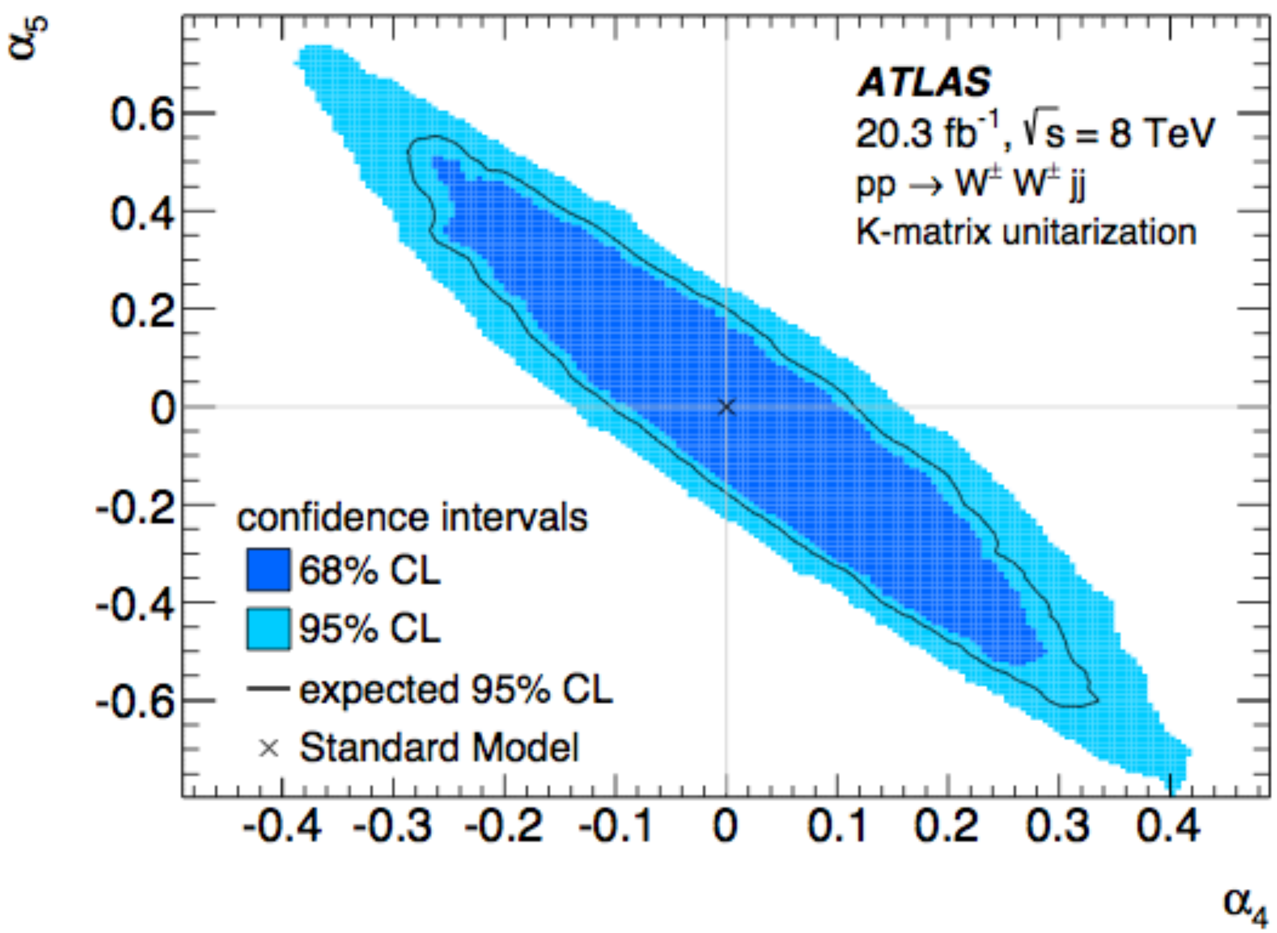


- Separate QCD & VBS production using large Δy between the two tag jets $|\Delta y_{jj}| > 2.4$
- The evidence for electroweak production is 3.6σ and agrees with prediction

$$\sigma^{EW}_{fid} = 1.3 \pm 0.4(stat) \pm 0.2(syst)\ \mathrm{fb}$$
$$\sigma^{EW}_{SM} = 0.95 \pm 0.06\ \mathrm{fb}$$

Constraints on aQGCs from $W^{\pm} W^{\pm}jj$ arXiv:1405.6241

- Exclusion limits on α_4 and α_5 extracted from cross section in VBS phase space
- Signal MC samples generated with Whizard using K-matrix unitarisation

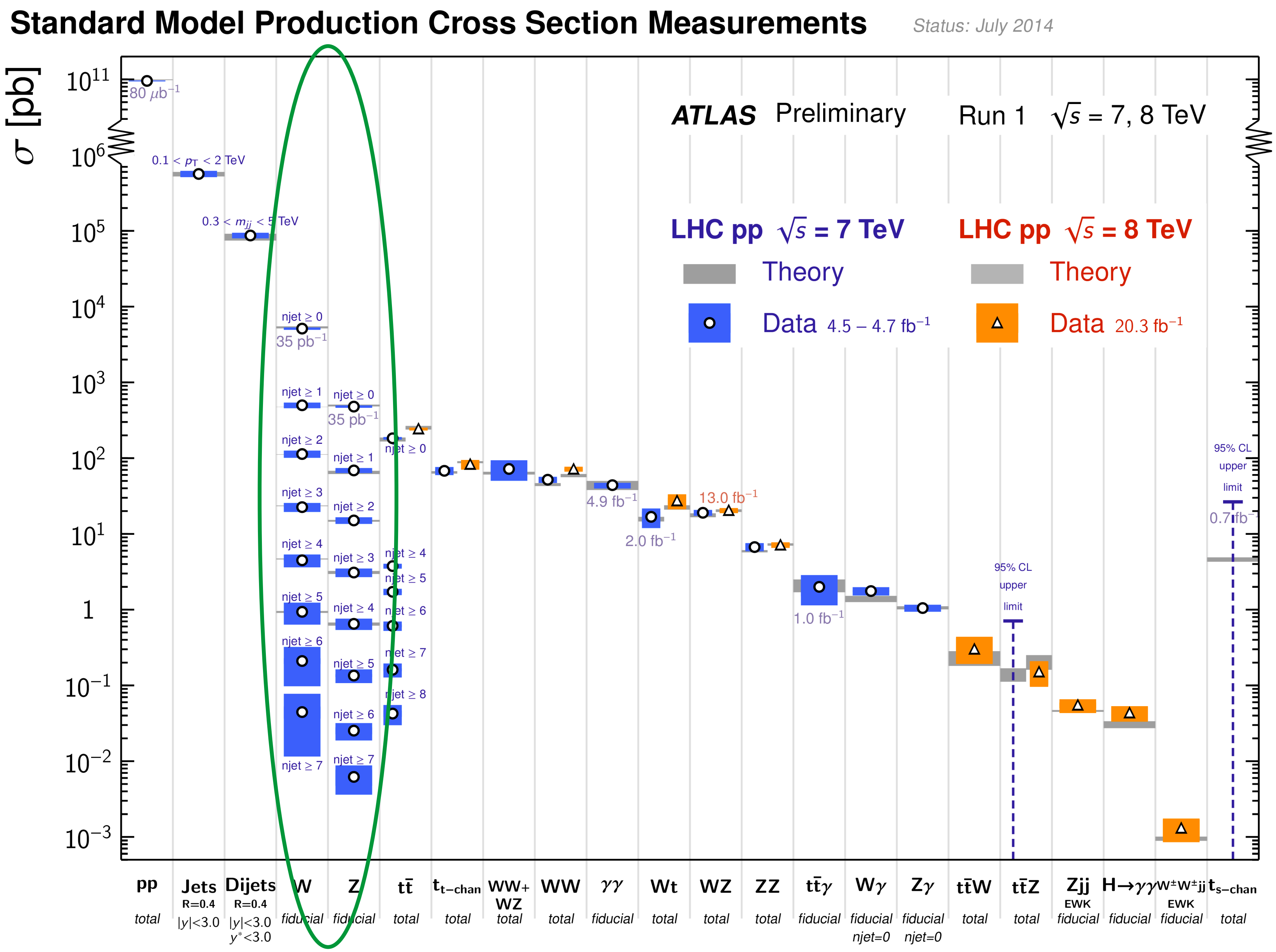


- 95% 1D condence intervals:
  - -0.14 < 4 < 0.16
  - -0.23 < 5 < 0.24
- Expected intervals:
  - -0.10 < 4 < 0.12
  - -0.18 < 5 < 0.20

W/Z boson production

1. Z/γ^* transverse momentum
2. Associated Z and b-jets production
3. W+jets and Rjets at 7 TeV
4. W+c measurement

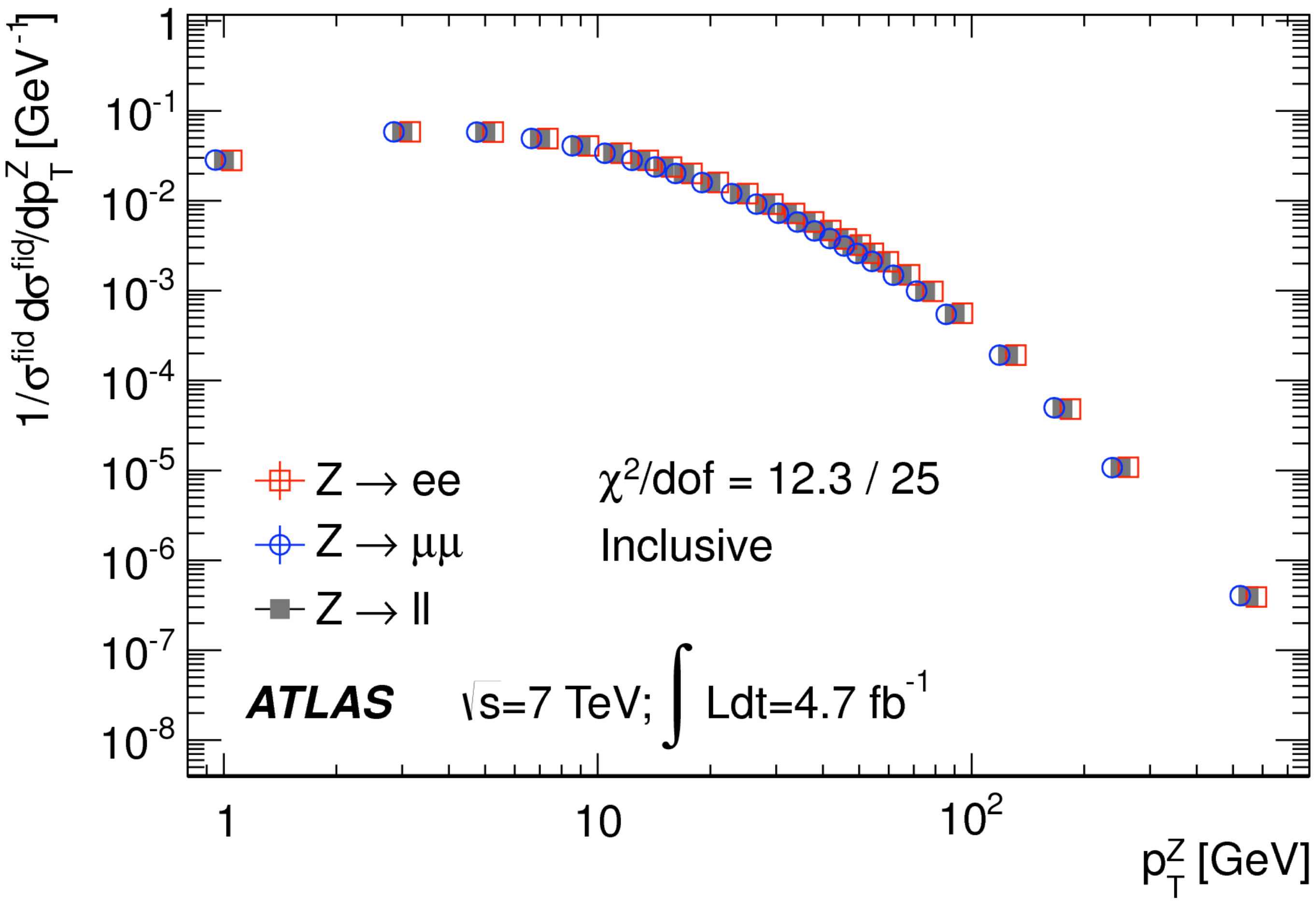
W/Z measurements

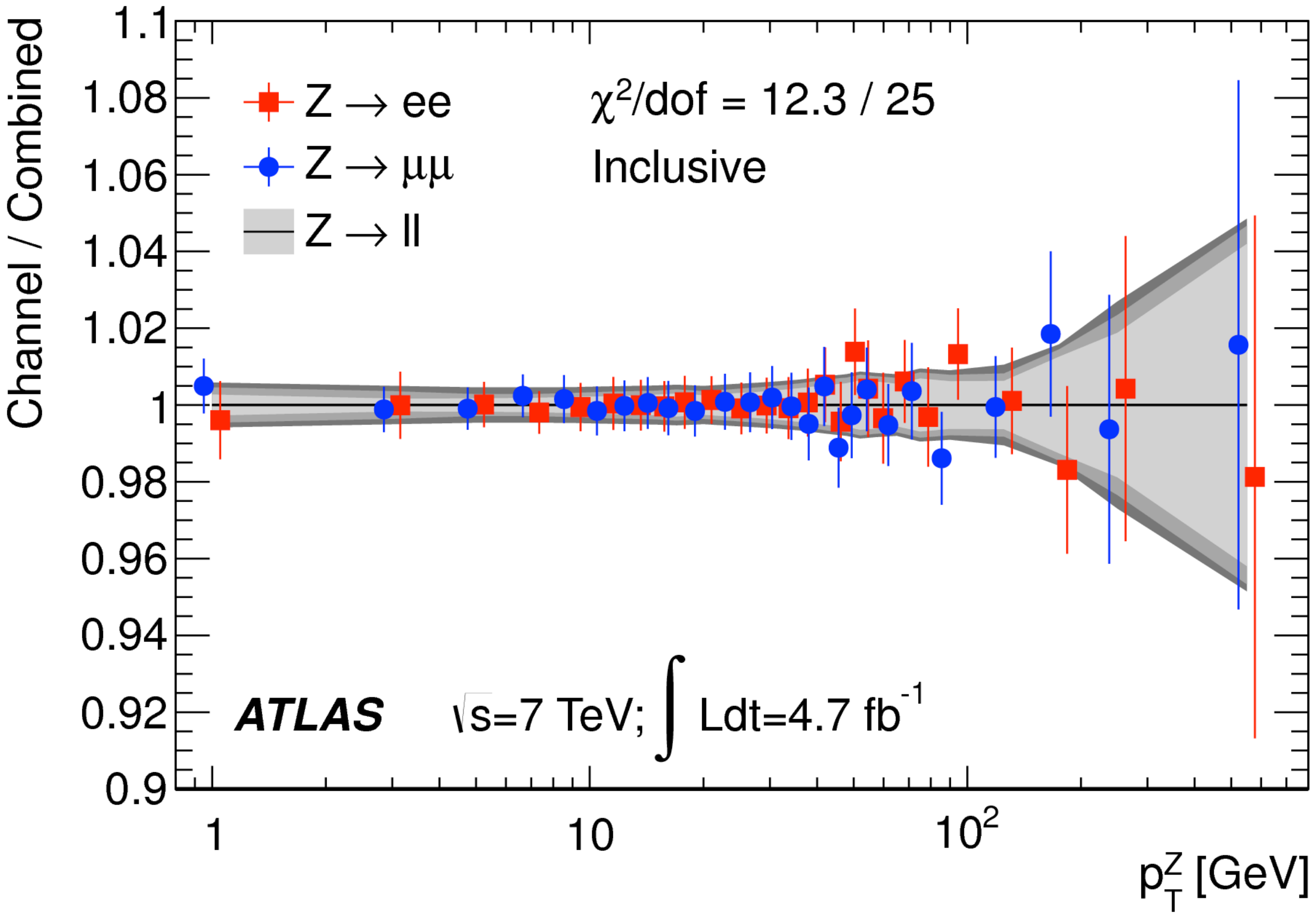


- Tests of perturbative QCD and EWK
- Constrain parton density functions of protons
- Background to Higgs and many New Physics phenomena
- Benchmark processes for detector calibration

Measurement of the Z/γ* transverse momentum

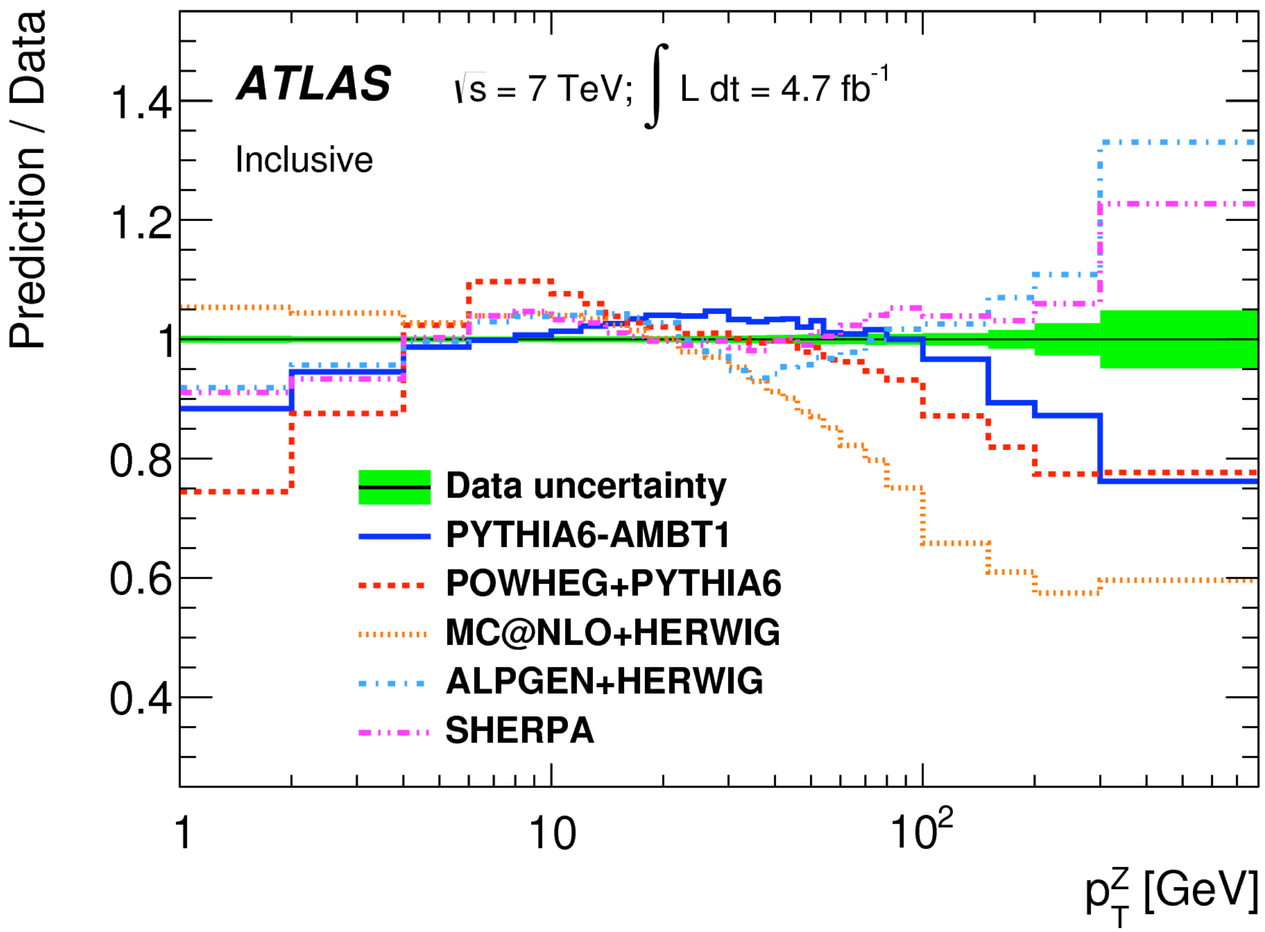
- p^Z_T is an excellent probe of the dynamics of QCD:
  - The low p_T spectrum is dominated by the emission of soft partons → Parton shower models and analytic resummation.
  - The high p_T region is dominated by hard parton emissions → Perturbative QCD, PDFs.

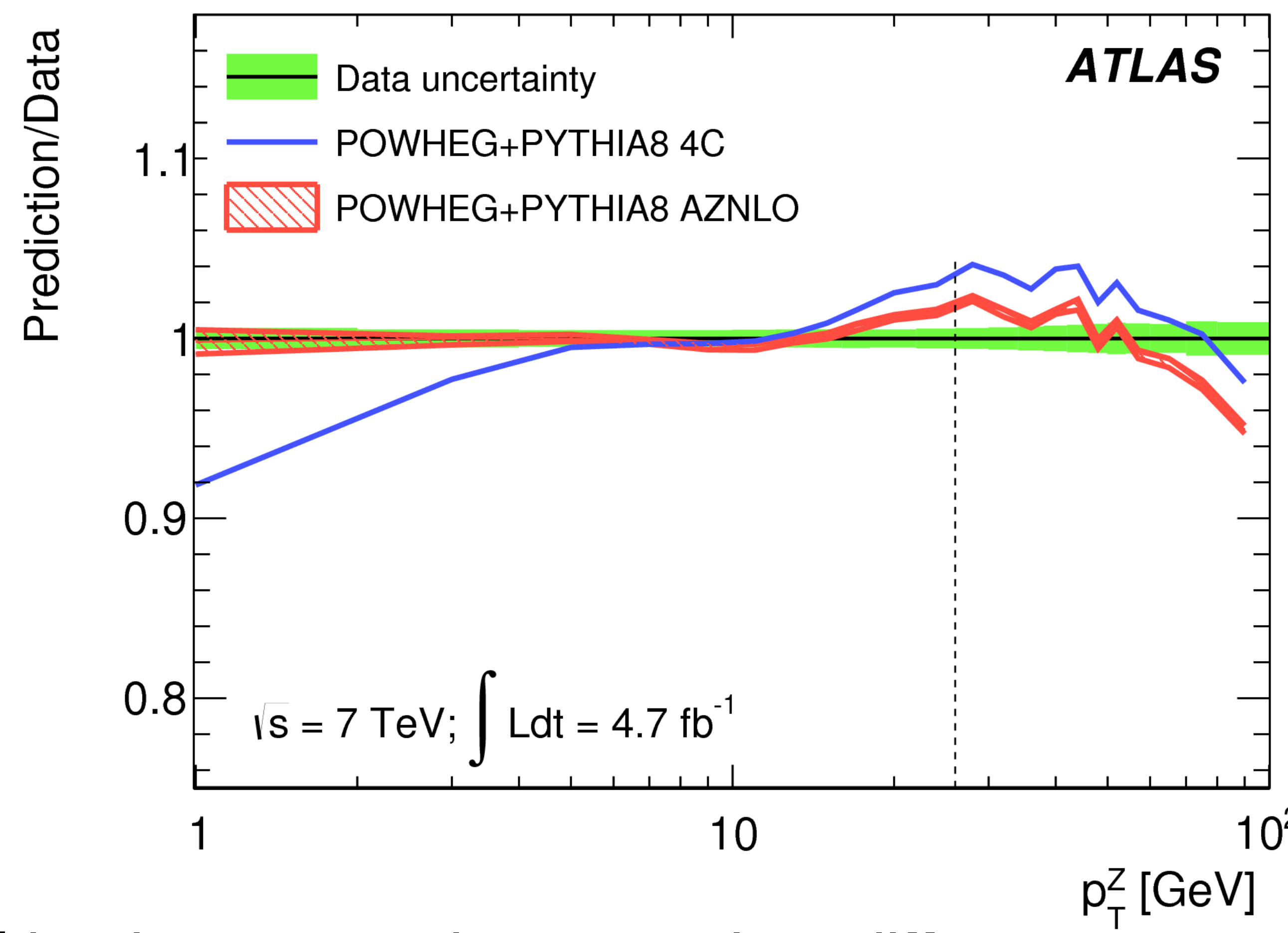




- Precision of 0.5 % - 1.1 % up to 150 GeV, rising up to 5 % towards the end of the spectrum

Measurement of the Z/γ* transverse momentum

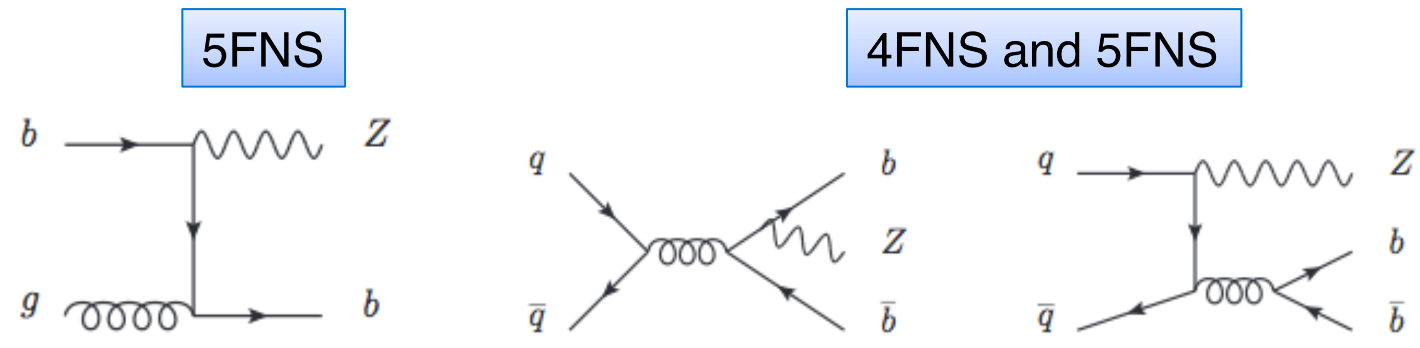


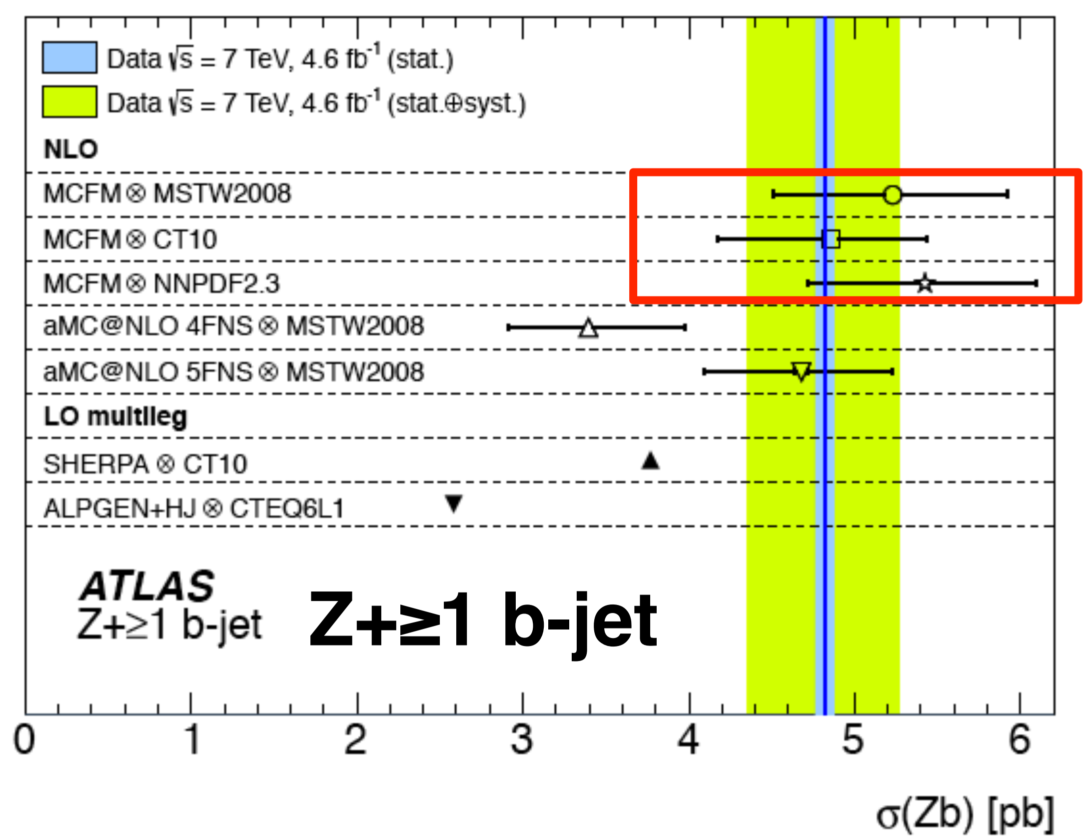


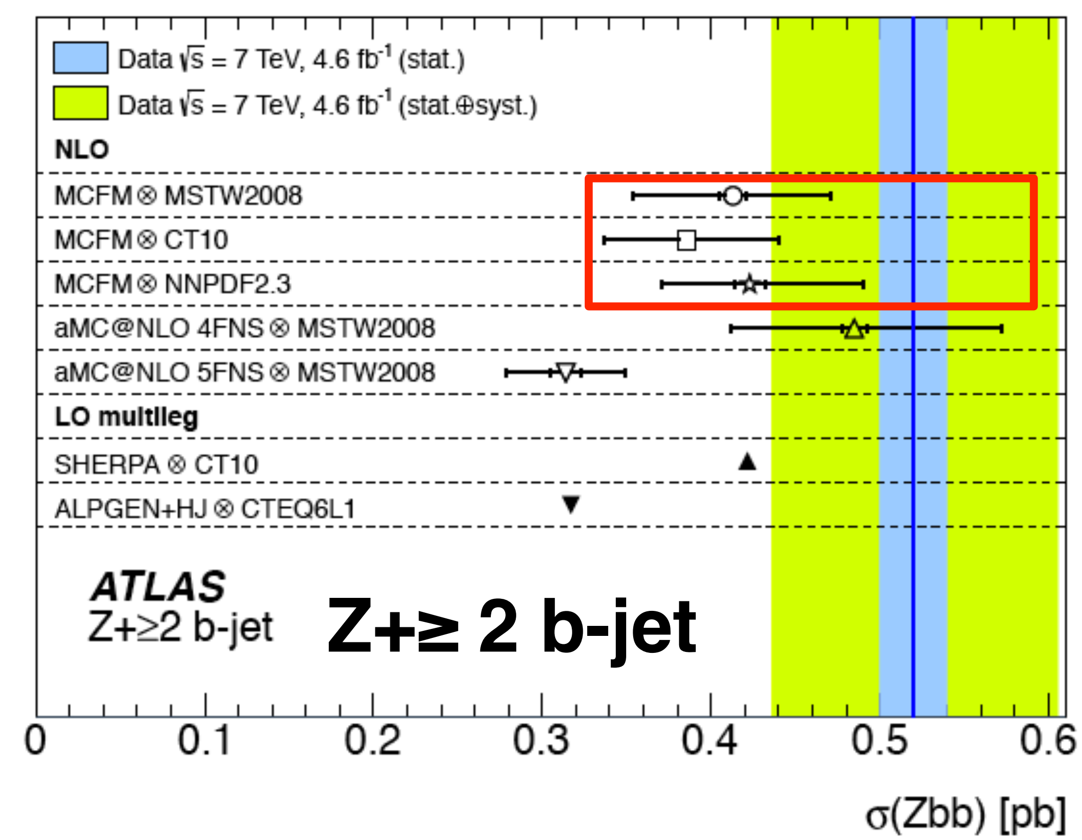
- At low p_T, the description is dominated by the parton shower tuning: different levels of agreement.
- At high p_T, (Pythia) LO and NLO generators underestimate the data, and LO multileg generators overestimate it.
- The measurement is used to tune the Pythia8 and Powheg+Pythia8 generators → tuned predictions are in agreement with the data within 2% for $p_T < 50$ GeV.

Associated Z and b-jets production at 7 TeV

- Test of Number Flavour schemes (4NFS / 5NFS)
- Measurement sensitive to b-PDF (Z+b) and gluon splitting (Z+bb)
- Test of NLO/LO multileg predictions



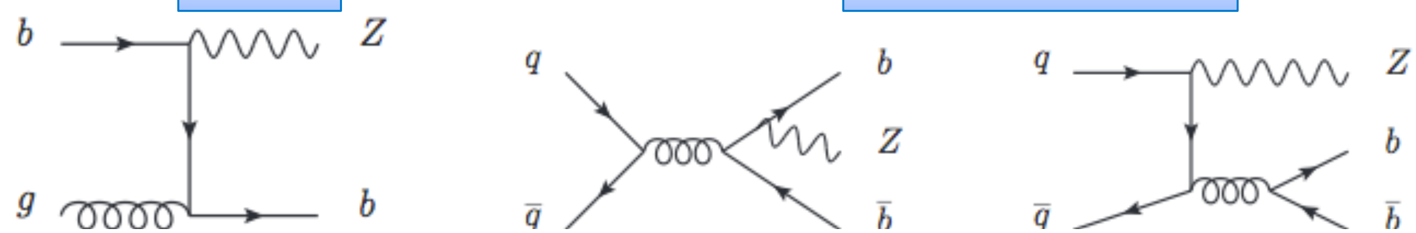


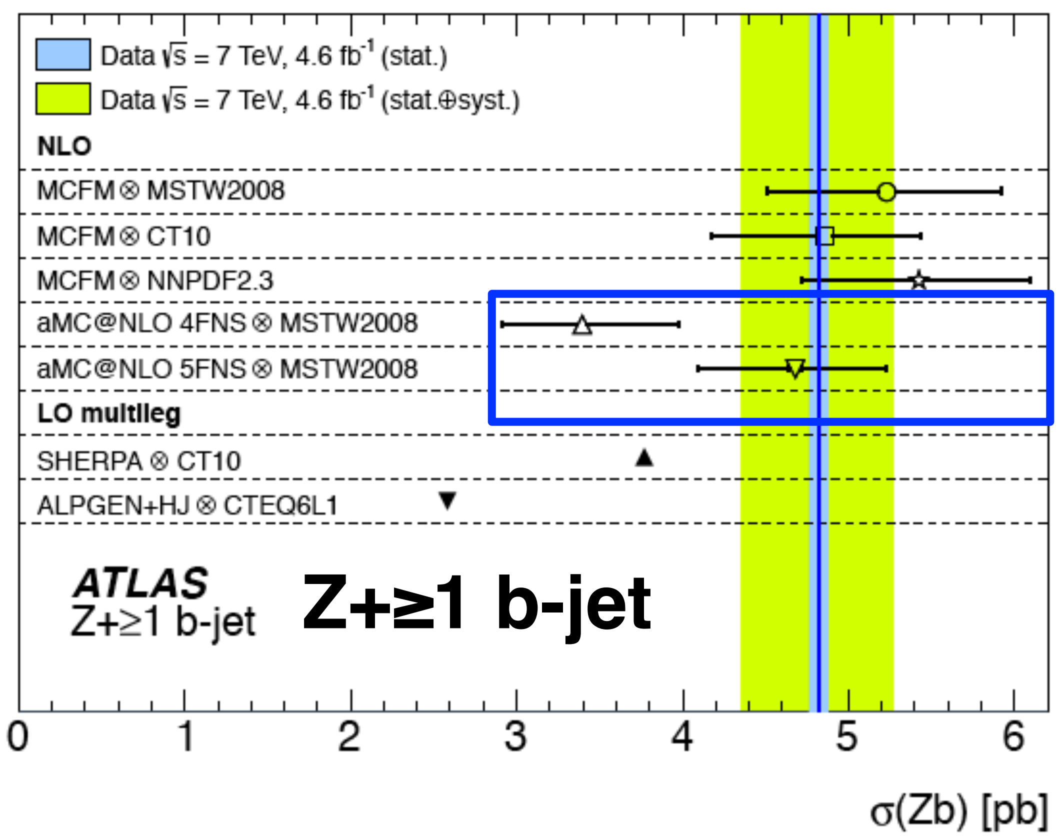


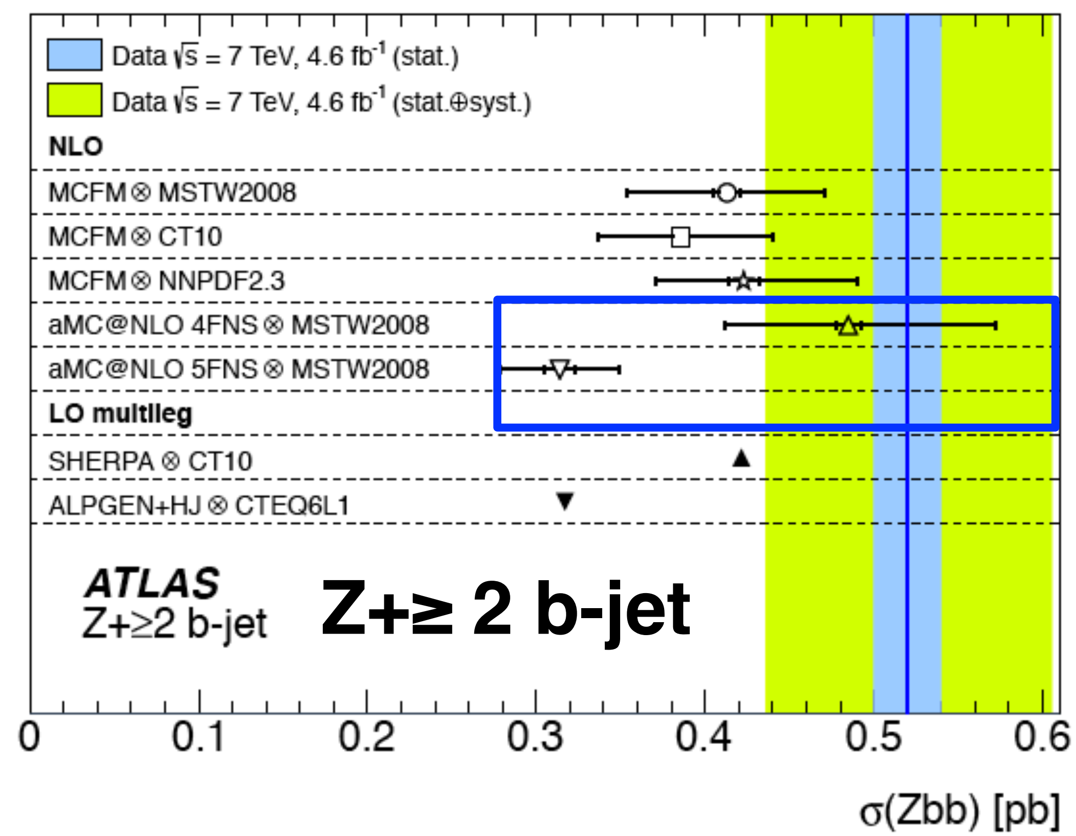
- MCFM agrees with data within uncertainties

Associated Z and b-jets production at 7 TeV

5FNS | 4FNS and 5FNS





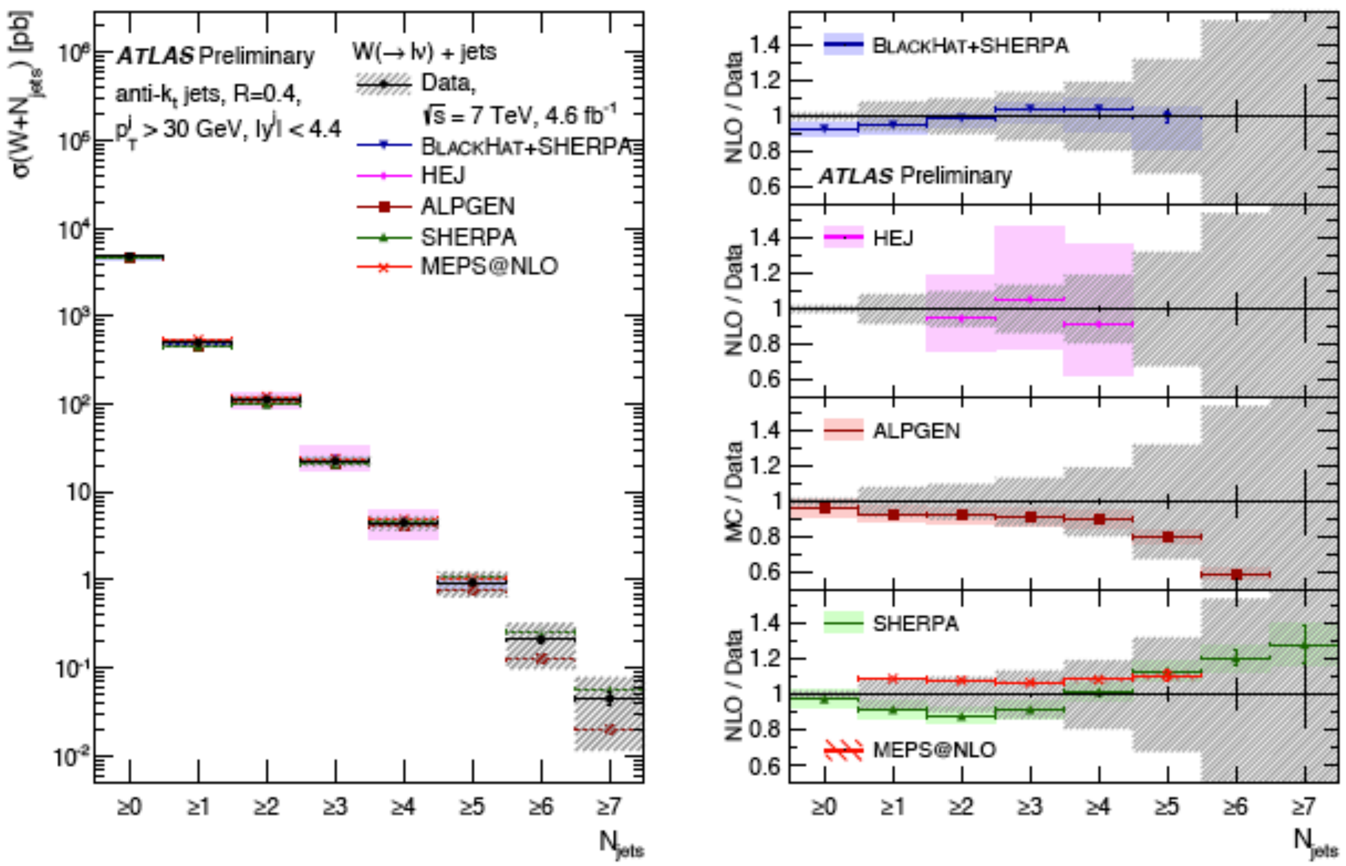


- aMC@NLO NLO calculation for Zb in 5FNS describe well data, while the prediction derived from the NLO matrix element for Zbb in 4FNS underestimate it
- aMC@NLO NLO calculation for Zbb in 4FNS agree with data (the prediction derived from the NLO matrix element for Zb in 5FNS is as expected low since it is LO)
- NLO is still too affected by scale uncertainty to be sensitive to PDFs

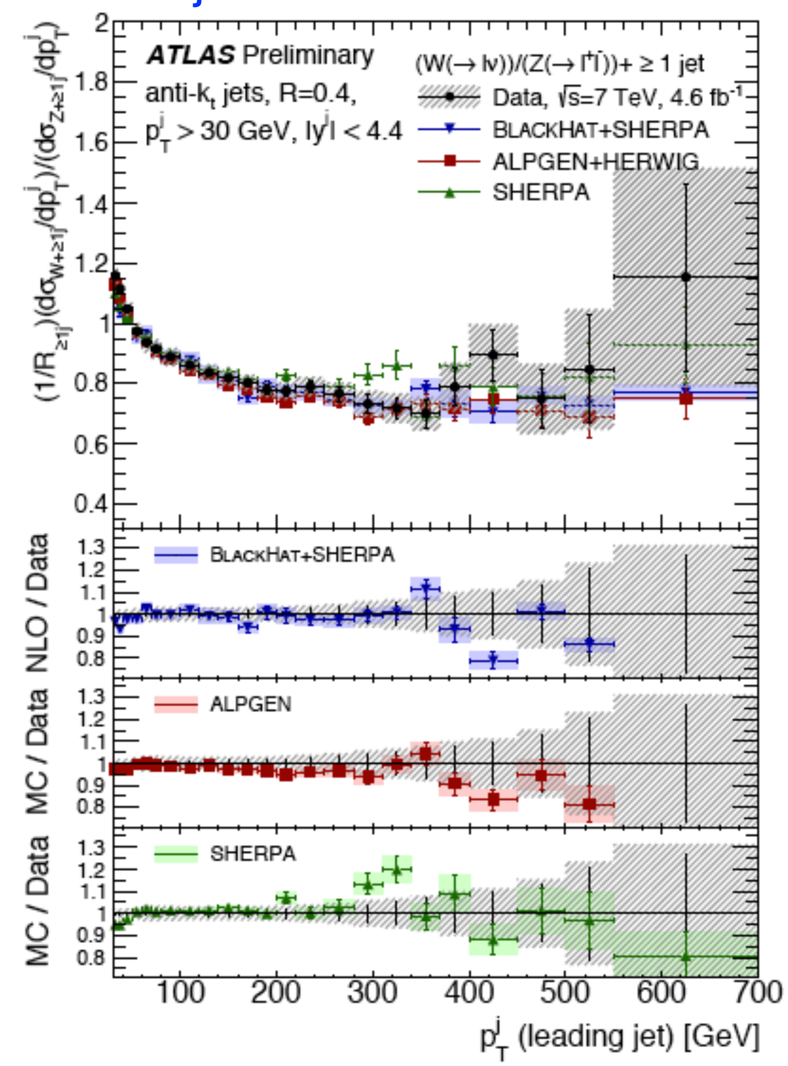
W+jets and R_{jets} at 7 TeV

ATLAS-CONF-2014-034

Jet multiplicity

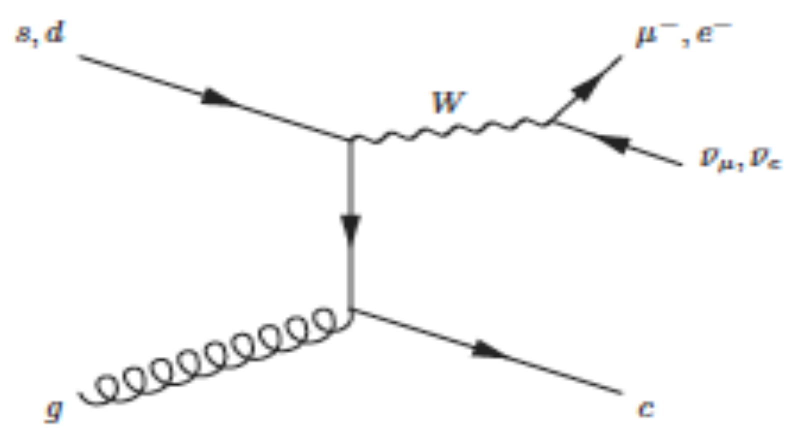


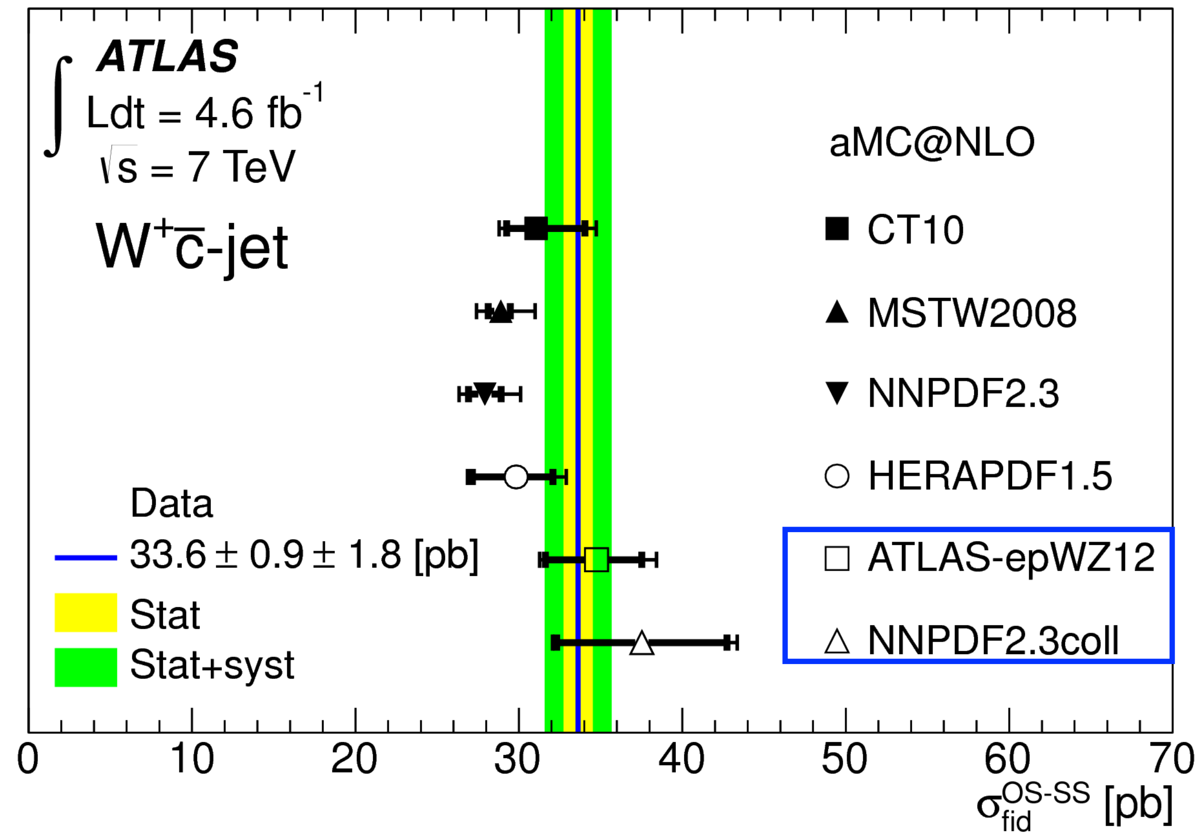
R_{jets} = W+jet/Z+jet



- Jet multiplicity well reproduced up to ≥7 jets on 5 order of magnitudes
- Best overall description NLO+PS (BlackHat+Sherpa) with some exception for high H_T, S_T distributions
- **R_{jets}** allows to reduce experimental systematic uncertainties and probes differences between kinematic properties of the jets recoiling against the W or Z bosons

W+c / W+D$^{(*)}$ Production JHEP 05 (2014) 068

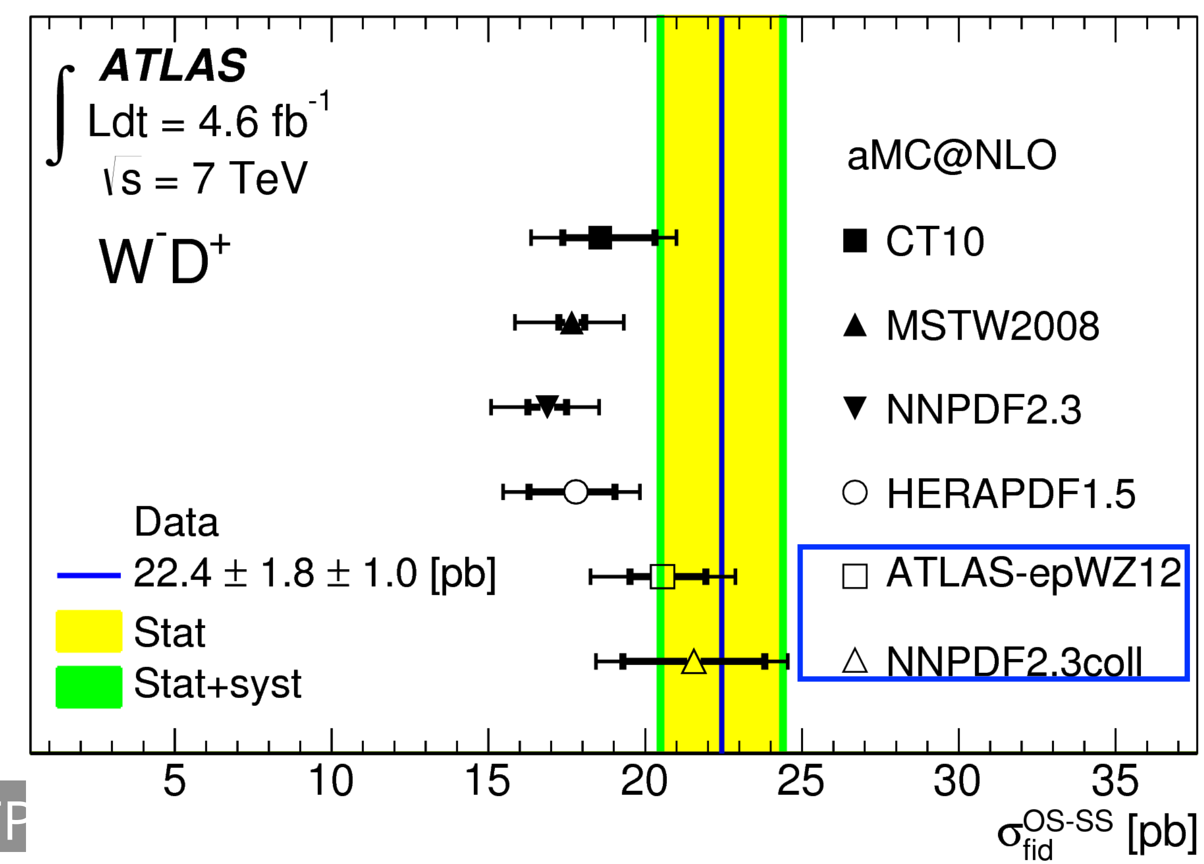




- Separate analysis for W+c jet and W+D(*) mesons

- Probes the strange content of the proton (contribution from d-quark about ~10%)

- Data better described with PDF with unsuppressed s-quark distribution (ATLAS-epW12, NNPDF2.3coll)



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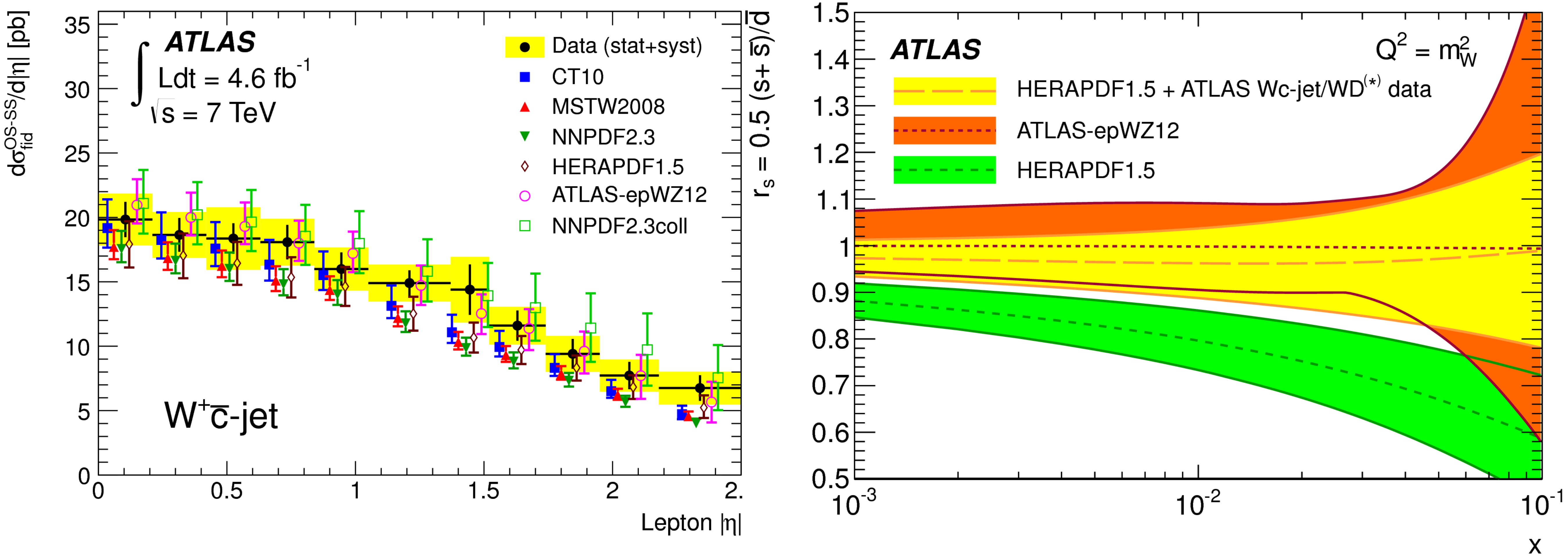
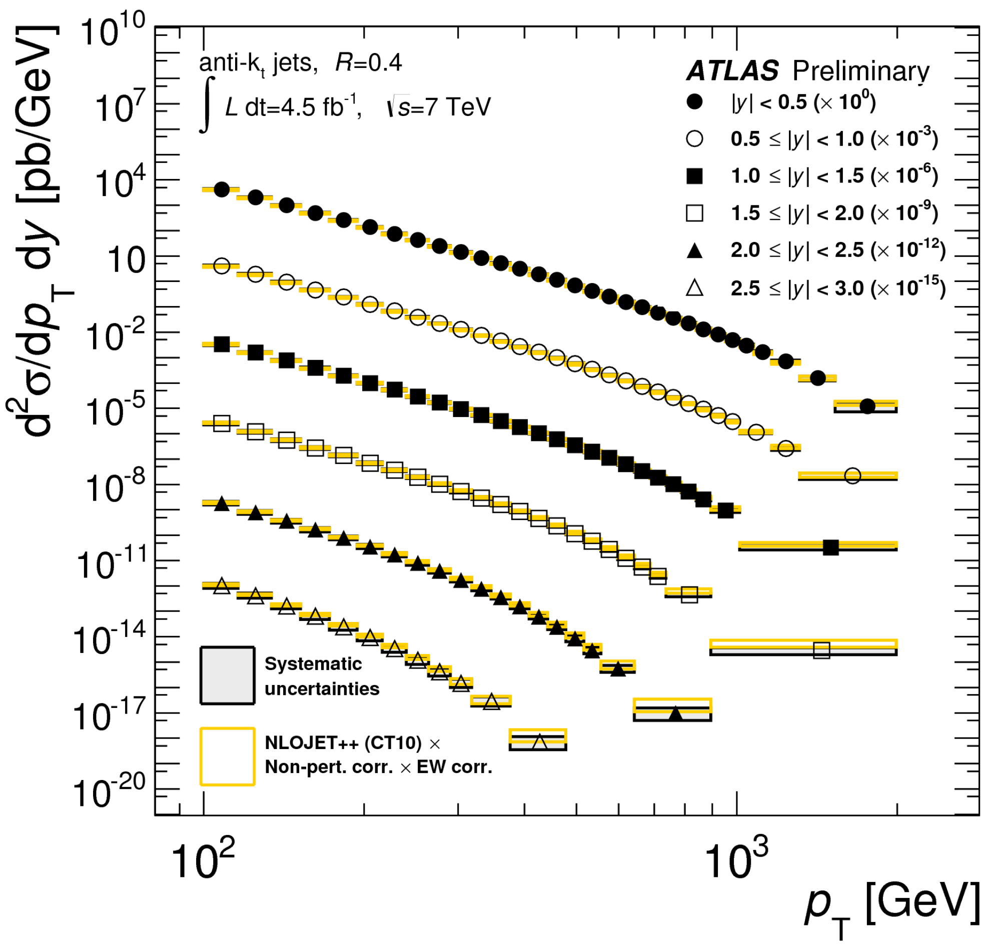


- Use W+c/W+D$^{(*)}$ data to fit the strange-to-down sea quark distributions
  - s/sbar-quark density suppressed compared to dbar-quark density for HERAPDF1.5
  - ATLAS data favour a symmetric light-quark density over the whole x-range of the measurement

Jet Physics

1. Inclusive jet cross section
2. Dijet production with a jet veto
3. 3-jets at 7 TeV

Inclusive jet cross section at 7 TeV



Observed p-values for the NLO pQCD predictions with corrections for non-perturbative and electroweak effects, in comparison to the measured cross-section

y ranges	$P_{\rm obs}$ (ATLAS Preliminary)					
	NLO PDF set:	CT10	MSTW2008	NNPDF2.1	HERAPDF1.5	ABM11
$\|y\| < 0.5$		84%	61%	72%	56%	< 0.1%
$0.5 \leq \|y\| < 1.0$		91%	93%	89%	49%	< 0.1%
$1.0 \leq \|y\| < 1.5$		89%	88%	85%	93%	2.7%
$1.5 \leq \|y\| < 2.0$		93%	88%	91%	75%	55%
$2.0 \leq \|y\| < 2.5$		86%	82%	85%	26%	57%
$2.5 \leq \|y\| < 3.0$		95%	94%	97%	82%	85%

- The inclusive measurement extends over [0.1,2] TeV p_T jet for |y|<3
- NLO pQCD predictions follow the measured cross sections which range over 8 orders of their magnitude in the 6 rapidity bins
- Quantitative comparison show that most of the NLO pQCD predictions are in agreement with the measurement
  → confirming that pQCD can describe jet production up to a jet p_T of 2 TeV

Three-jet production at 7 TeV

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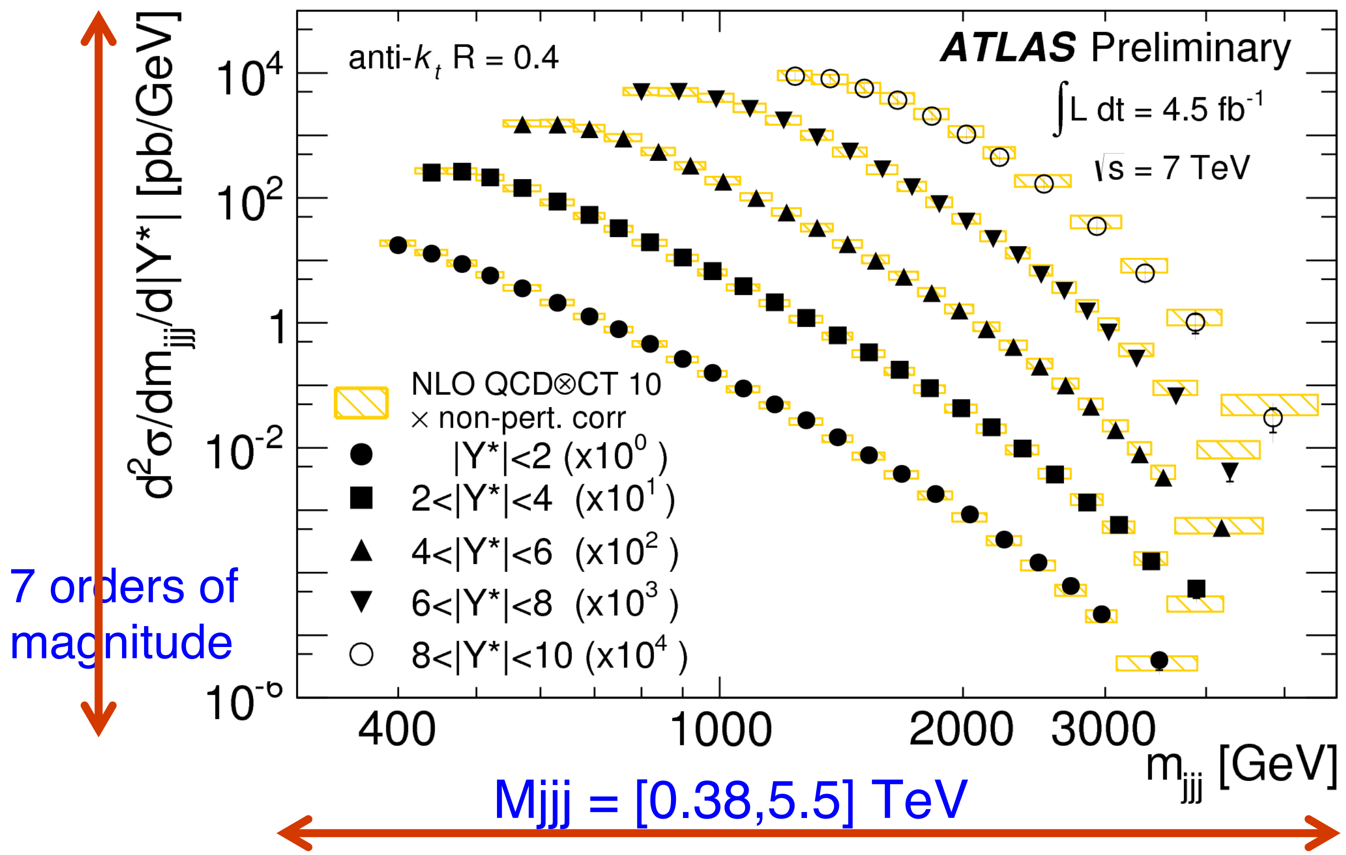
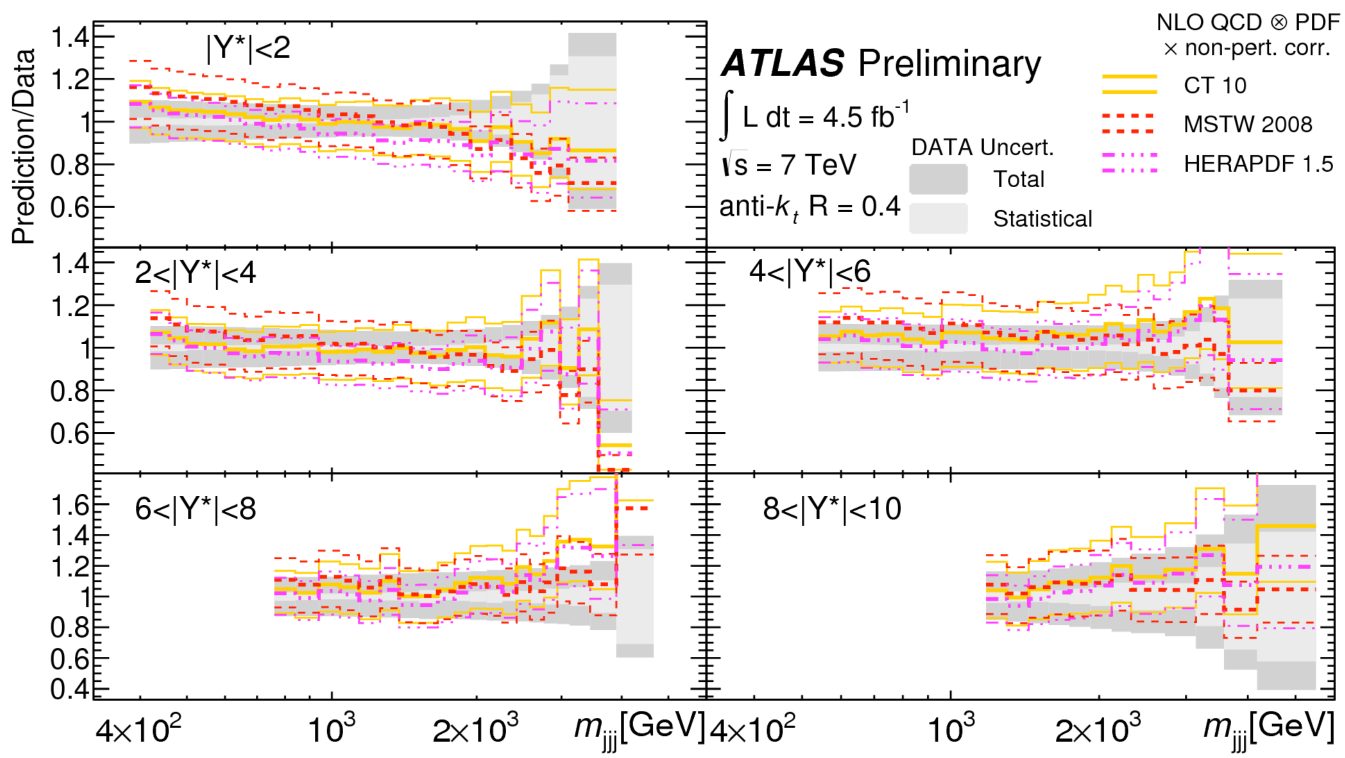


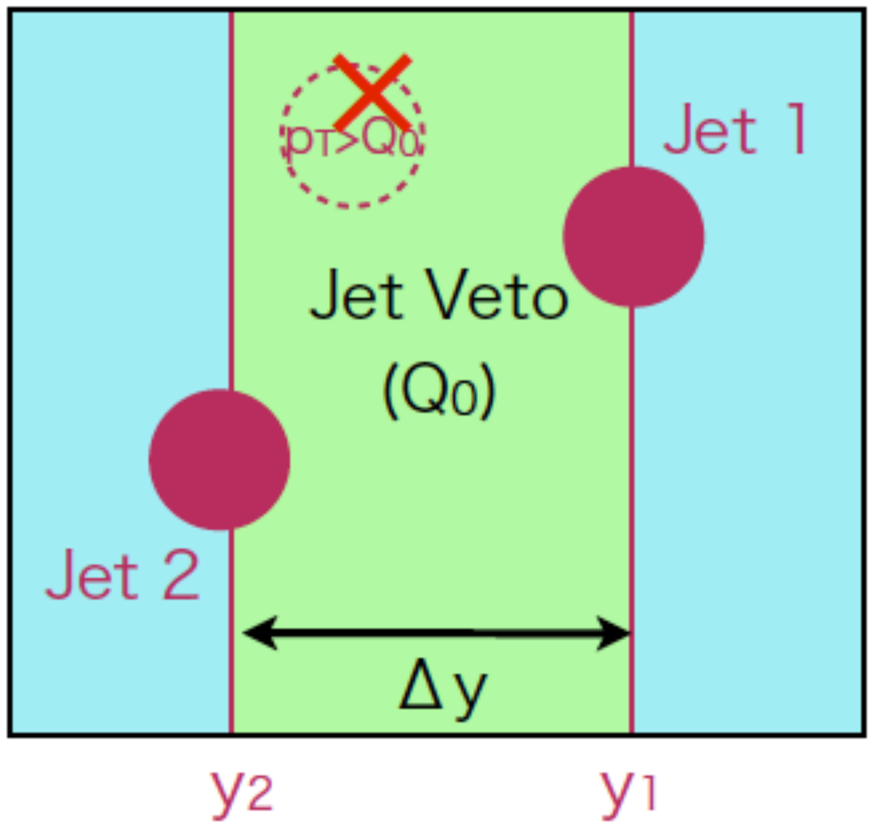


$|Y^*| = |y1-y2| + |y2-y3| + |y1-y3|$

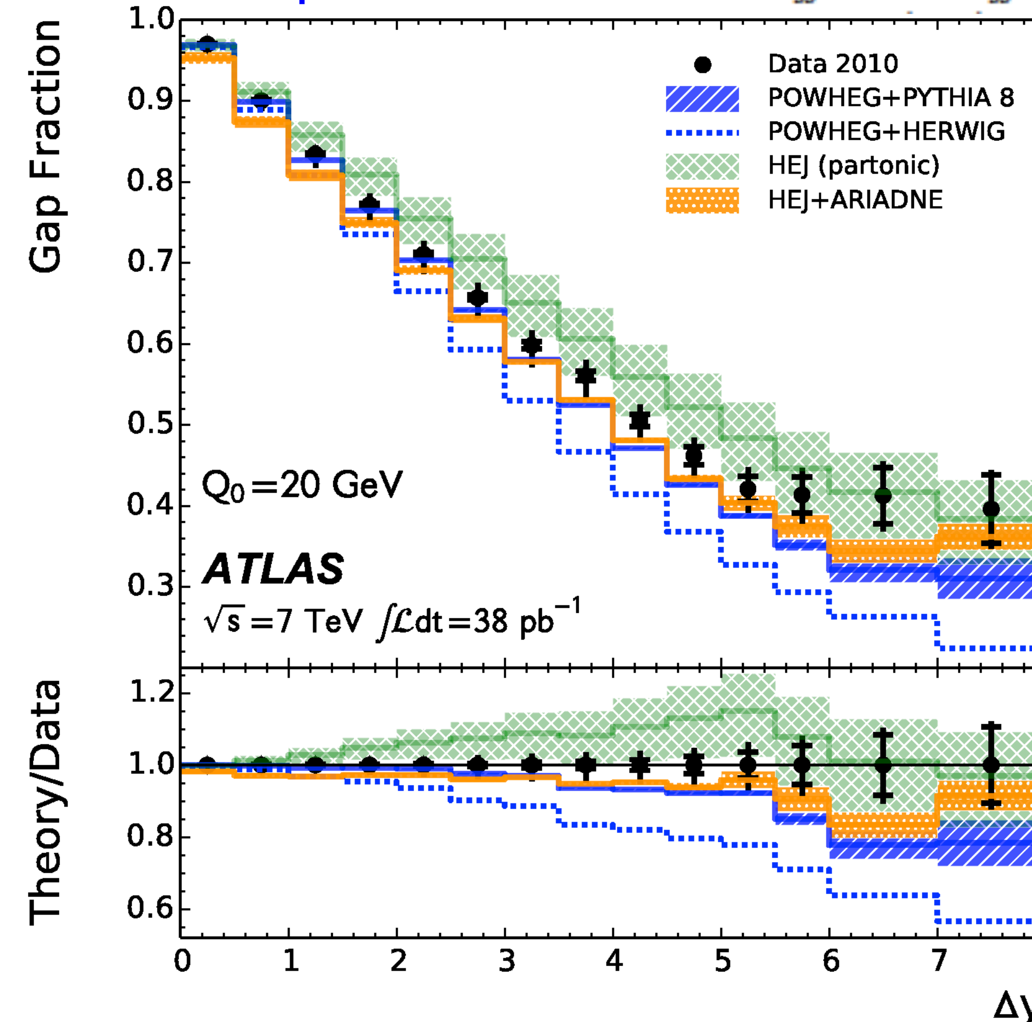
- Test pQCD calculations at high kinematic regions (TeV-scales), with different jet distance parameters R =0.4, 0.6 and different PDFs
- Good agreement between the data and the theoretical predictions over the full kinematic range, covering seven orders of magnitude in the measured cross-section
- Sensitivity to gluon PDF→ preference for harder gluon at high-x wrt HERAPDF1.5

Dijet production with a jet veto

Δy: Gap separation
Q_0 : Jet veto scale
$p_T^{avg}=(p_T^1+p_T^2)/2$



Gap Fraction $f(Q_0) = \sigma_{jj}(Q_0)/\sigma_{jj}$



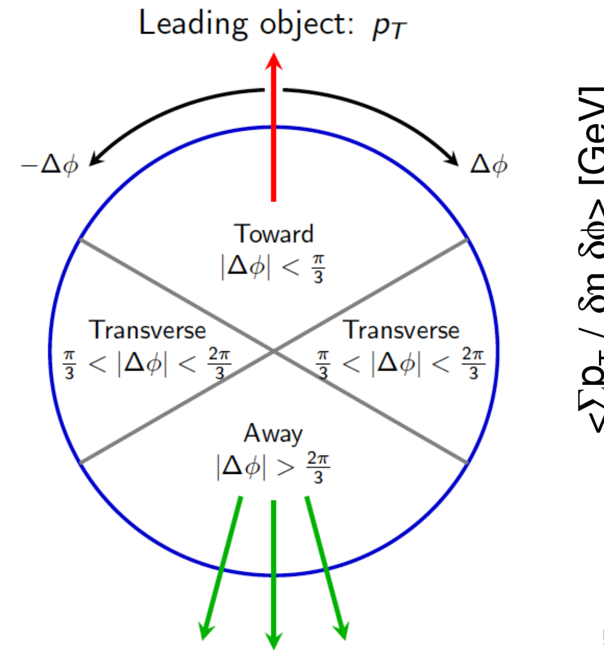
- Study dijet topologies when the two jets have a large Δy separation and a veto is applied to additional jet activity in Δy
- Probe different approaches to resummation of higher orders in terms of ln(1/x) (BFKL) and ln(Q^2) (DGLAP)
- Data compared to HEJ (LL multijet→BFKL-like) and POWHEG (NLO dijet →DGLAP-like) predictions.
  →None of them is able to simultaneously describe the data over the full phase-space region

Soft QCD

1. Underlying Event in jet events

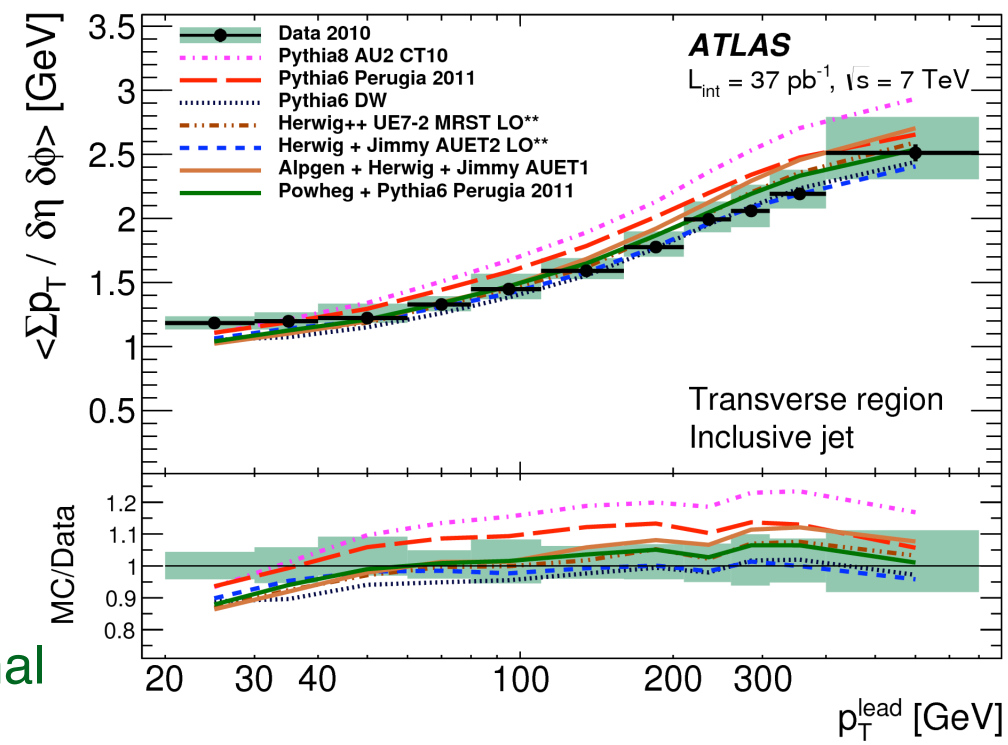
2. Underlying Event in inclusive Z events

Underlying event with jet events

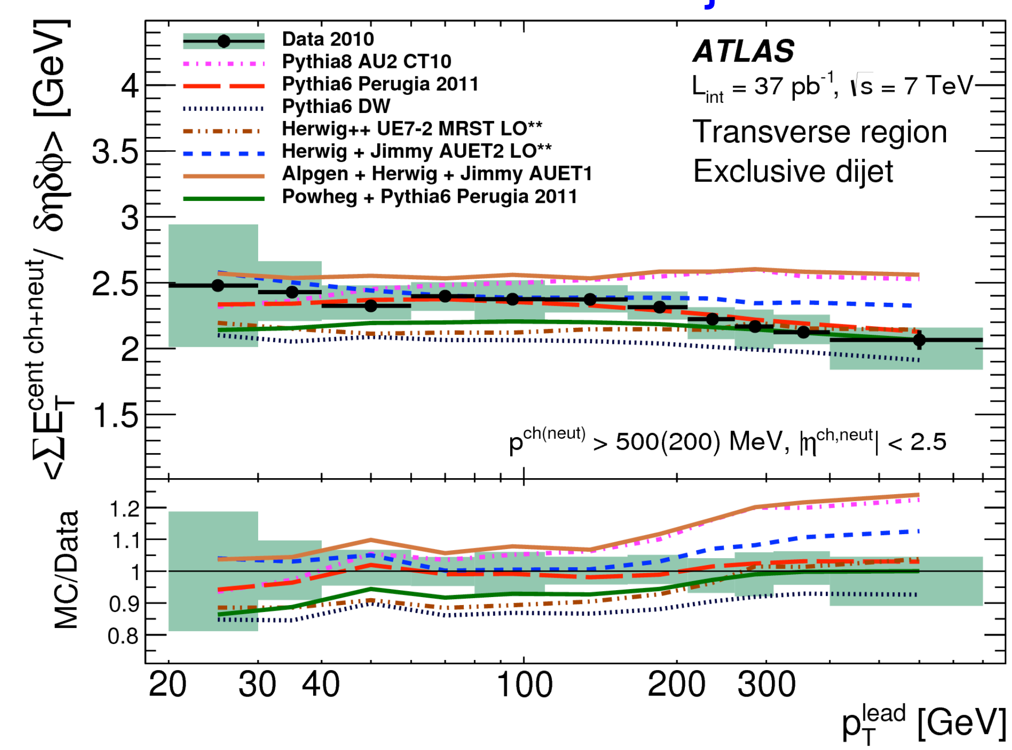


Conventional UE azimuthal division of events

Inclusive Jet

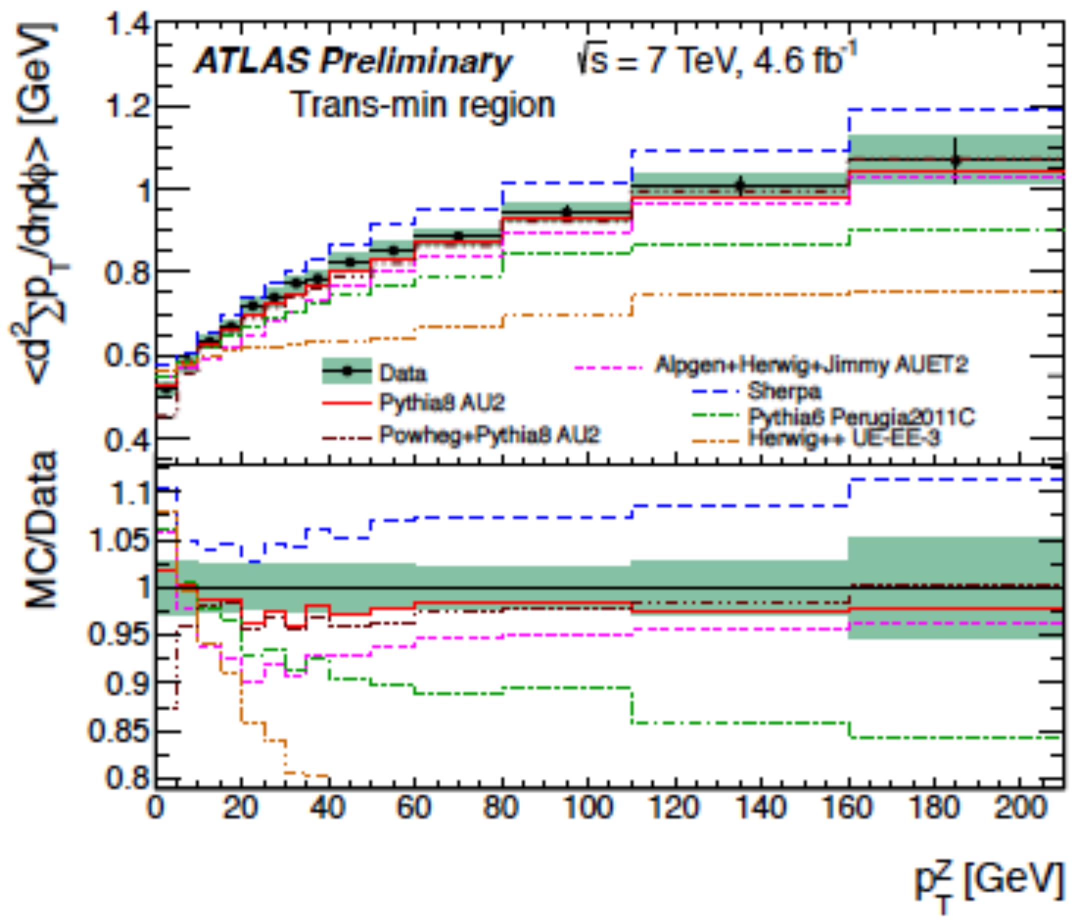


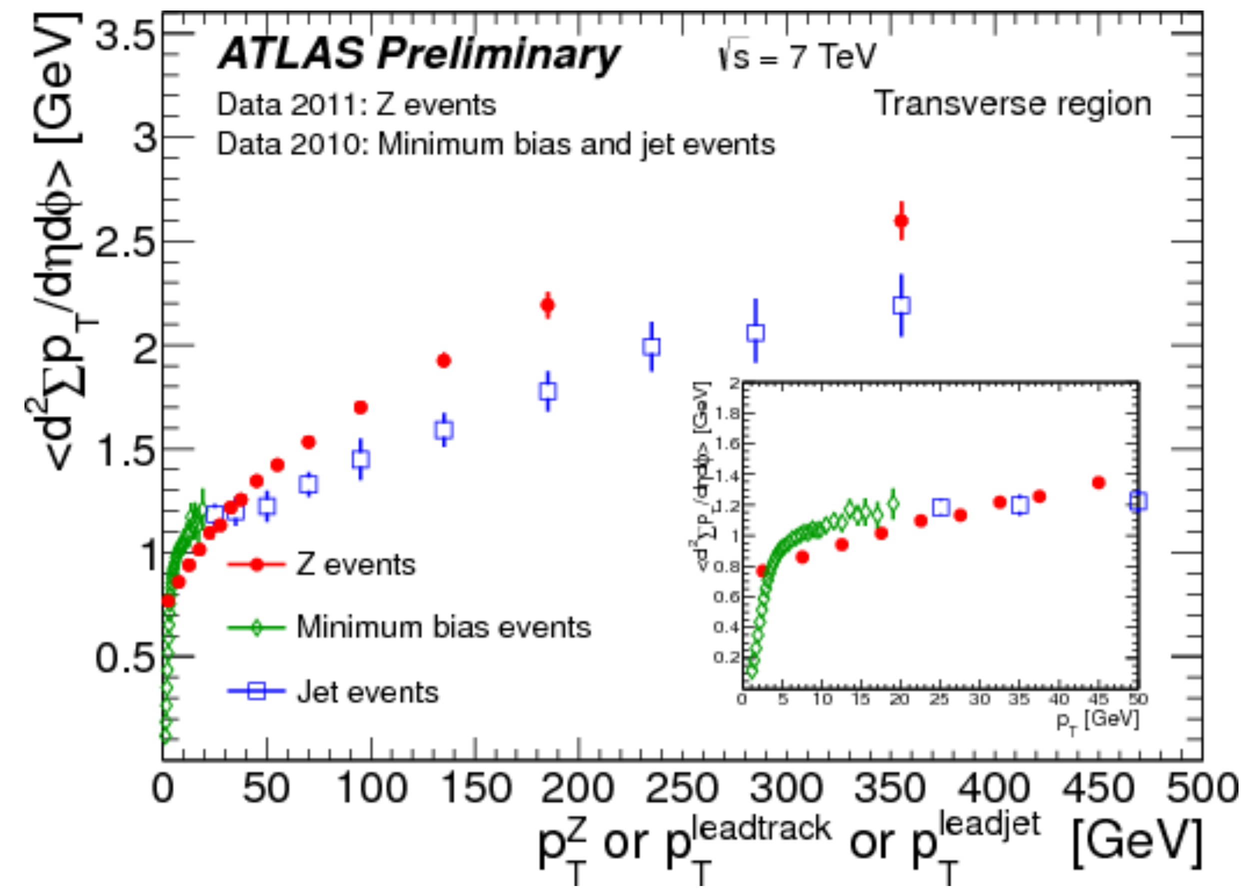
Exclusive dijet



- Relatively well described by the MC generators, but Pythia tuned to ATLAS UE data gives worse agreement
- **Inclusive jets** : rising transverse-region activity as a function of leading jet
  → contribution from wide angle emissions from the hard scattering
- **Exclusive dijets** : application of an exclusive dijet selection requirement removes this feature → MPI activity can largely be modelled as independent of hard process scale

Underlying event : inclusive Z events





- MC model predictions qualitatively describe the data well, but with some significant discrepancies
- A comparison between Z and purely jet events shows similar underlying event activity for a consistent choice of scales

Summary

- New results on W^+W^- cross section at 8TeV
- Observation of VBF in the Zjj channel
- Evidence for VBS in same sign WW+2jets and first exclusion limits on aQGCs
- Being able to measure **di-bosons** at 8TeV, is the first step in the exploration of EWSB sector beyond the SM-BEH mechanism in the future

- **QCD tested** in new kinematic regions up to TeV, with exclusive and inclusive measurement, often differential or double differential measurements are performed
  - Soft QCD results improve the phenomenological models of the underlying event
  - Hard QCD results with jets can further constrain the PDFs