



Review of Current Standard Model Results in ATLAS

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on behalf of ATLAS



Light Cone 2017 (LC2017)
Frontiers in Light Front Hadron Physics: Theory and Experiment
18th - 22nd September 2017, University of Mumbai



BERGISCHE
UNIVERSITÄT
WUPPERTAL

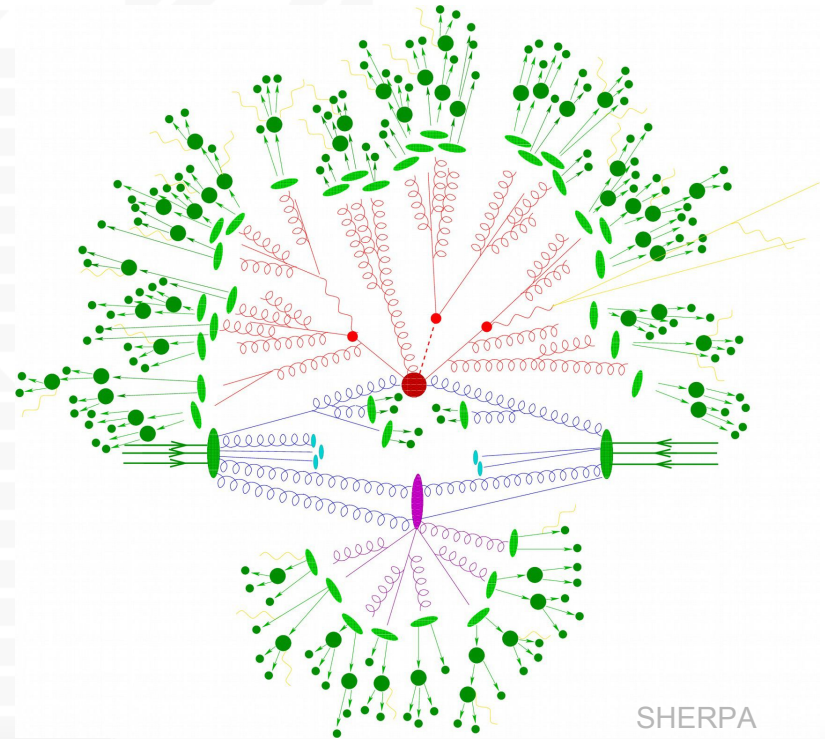
Standard Model Physics in p - p Collisions at the LHC

Can measure from **soft interactions** ...

- Test non-perturbative QCD
- Hadronization, underlying event, multi-parton interactions, long-range color exchange
- Parametrization of phenomenological models used in MC (generator tuning)
- Parton distribution functions

... to **hard scattering**

- Test perturbative QCD
- Jets (large multiplicities, substructure)
- Precision fundamental SM parameters
- Vector boson and photon production
- Electroweak physics:
Multi-boson final states, VBF, VBS
- Searches for new physics
 - Deviations from the SM (constraints on models)
 - Background predictions for BSM searches



SHERPA
authors

Data and Detector for SM Measurements

Precision SM Physics:

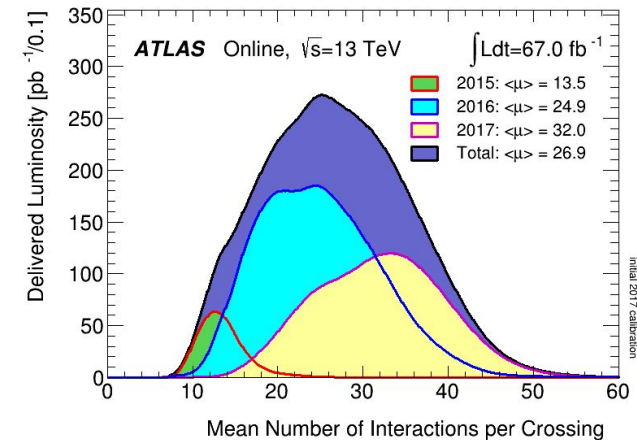
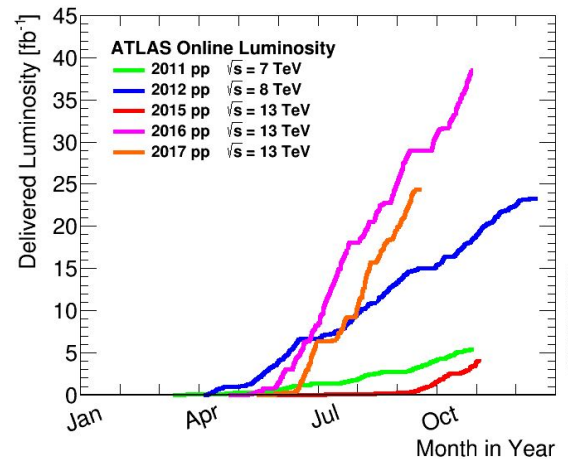
- 2011: 4.6 fb^{-1} @ 7 TeV
- 2012: 20.2 fb^{-1} @ 8 TeV

Establishing SM @ 13 TeV:

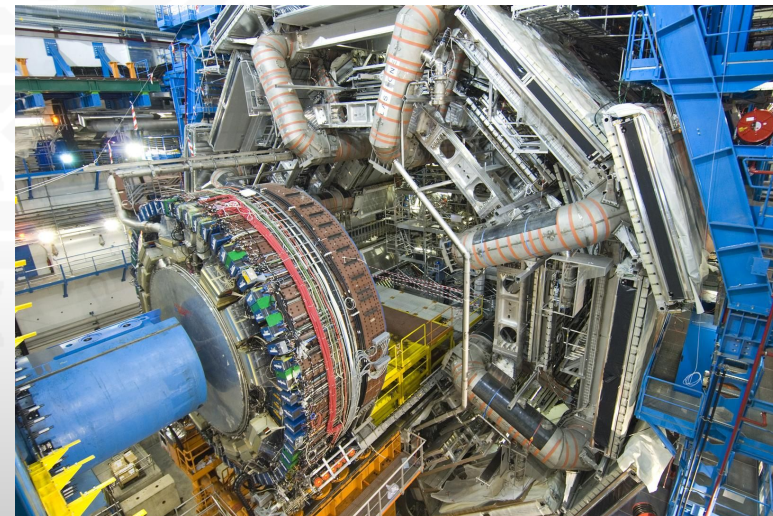
- 2015: 4.2 fb^{-1}
- 2016: 41 fb^{-1}
- 2017: 22.7 fb^{-1}

→ LHC performance far exceeds expectations

67 fb^{-1} @ 13 TeV to date

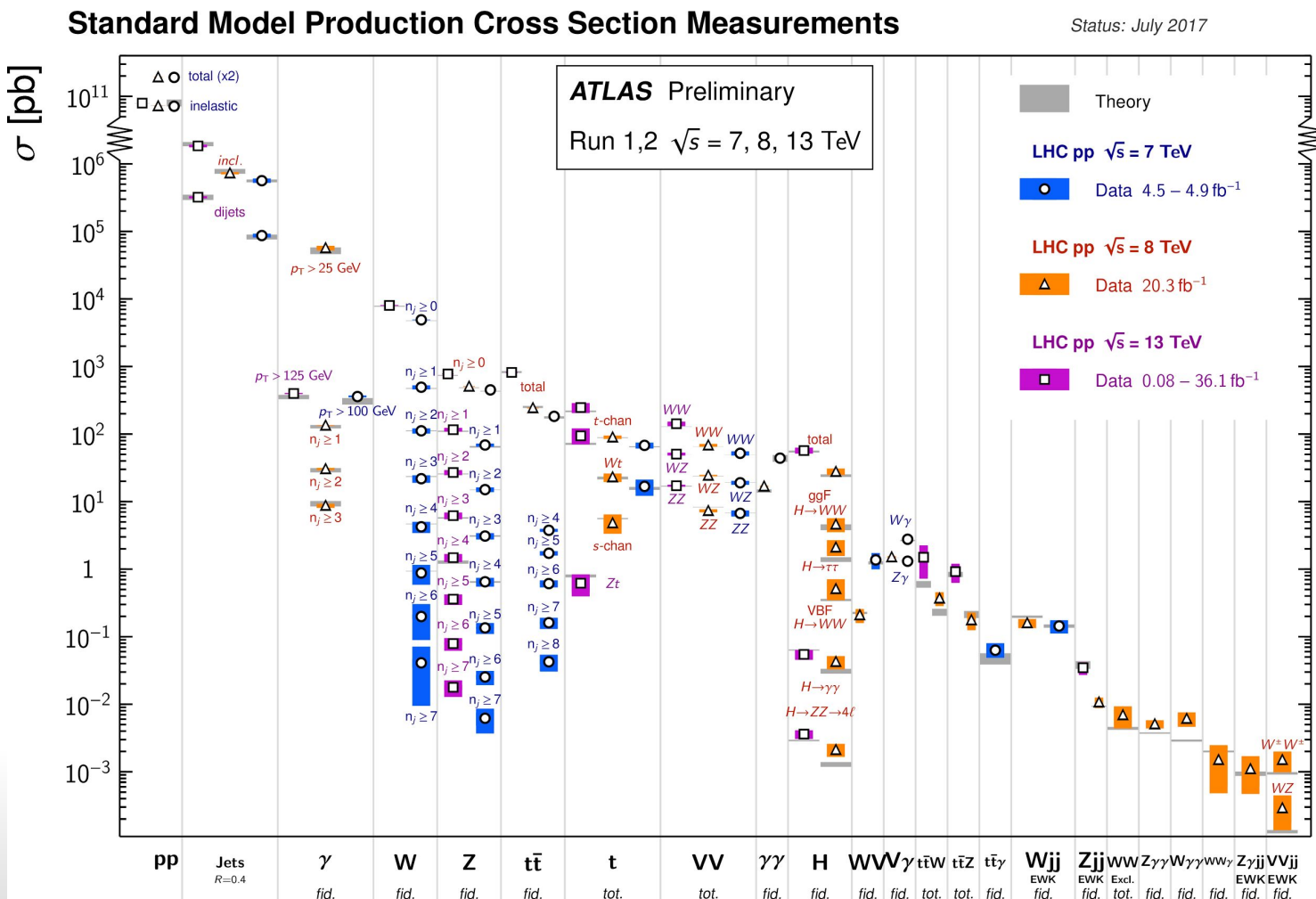


- General purpose detector with 4π coverage
- Sub-detectors optimized to reconstruct final states as produced by objects in SM processes:
Jets, charged leptons, neutrinos



Summary of ATLAS Standard Model Programme

- Huge number of results
- > 120 publications, not all in plot
- General good agreement of theory and data
- A few recent highlights presented here



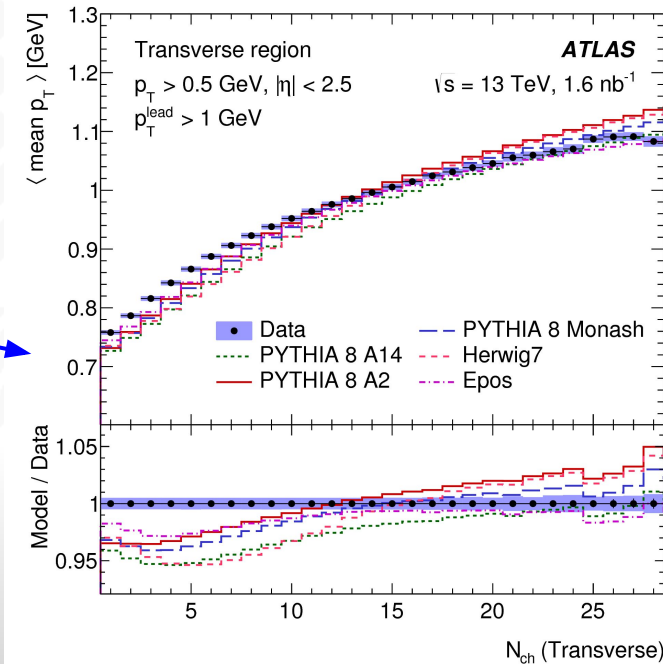
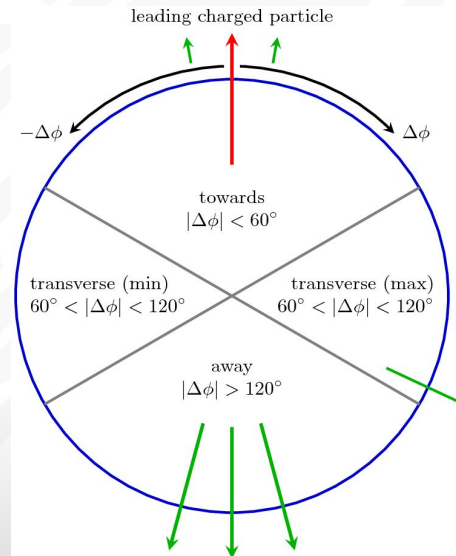
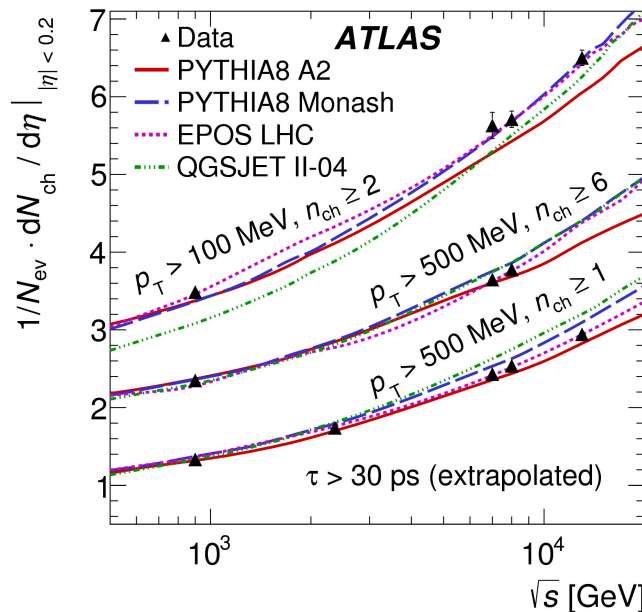
<https://twiki.cern.ch/twiki/bin/view/AtlasPublic/StandardModelPublicResults>

Charged Particle Production and Underlying Event

Eur. Phys. J. C 76 (2016) 502

1701.05390 JHEP 03 (2017) 157

- Measurement of charged particle production (“Minimum Bias”) very important to describe pile-up
- Measured in all data sets, with track p_T down to 100 MeV
- Underlying event (= everything except hard scatter, ie. ISR, FSR, MPI, CR) from charged particles @ 13 TeV (1.6nb^{-1})
- Measurement in transverse region with respect to leading particle ($p_T > 500\text{ MeV}$)
- Agreement with models within $\sim 5\%$



- → All MB and UE data used in model tunes

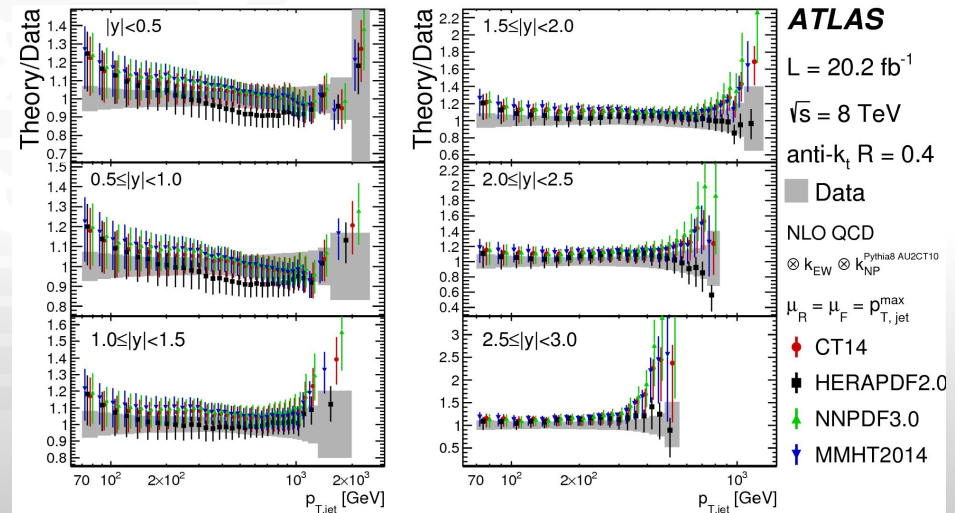
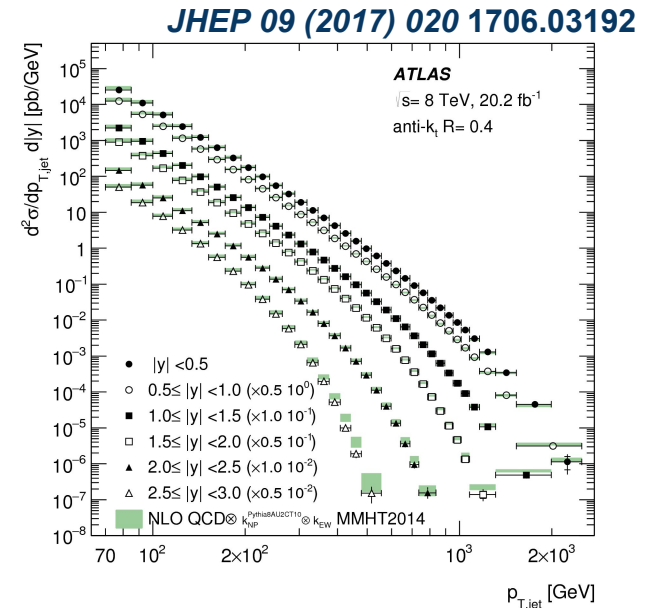
Jet Production Cross Sections

- @ 8 TeV: Reconstructed using anti- k_t jet clustering algorithm with $R = 0.4$ and $R = 0.6$ in $|\gamma| < 3$
- Dominant systematic uncertainty: jet energy calibration
- Significant reduction of the uncertainties compared to previous jet cross section measurements (at 7 TeV and 2.76 TeV)

JHEP 02, 153 (2015) 7TeV

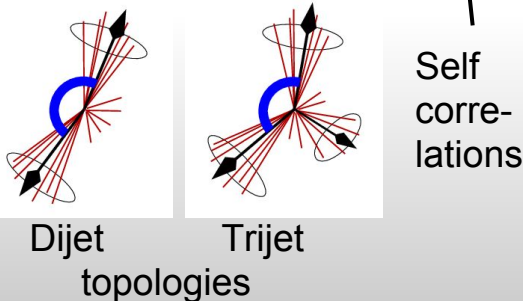
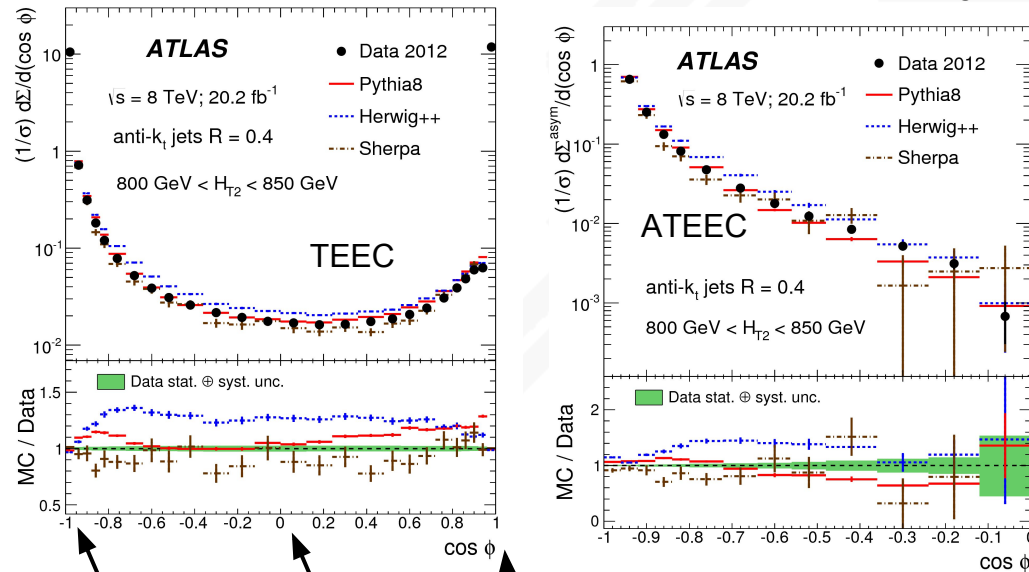
- QCD predictions at NLO with MMHT2014 PDF set corrected for non-perturb. and ew. effects describe data well
- Various other new PDF sets desc. within 10%-20% at low $|\gamma|, p_{T,jet}$
- Recent measurements ($R=0.4$) @ 13 TeV compare to NNLO
- Tensions, depending on QCD scale

ATLAS-CONF-2017-048



α_s from transverse correlations in multijets

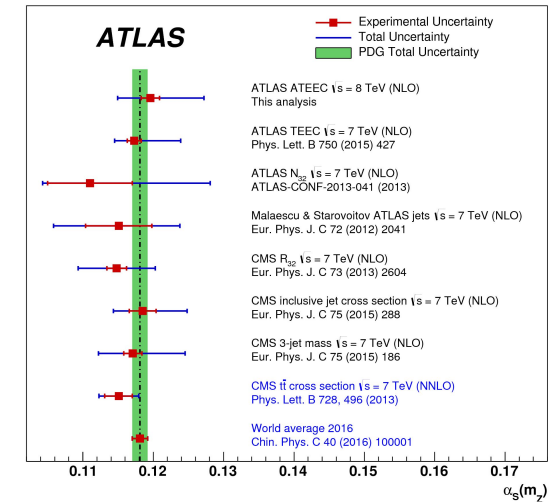
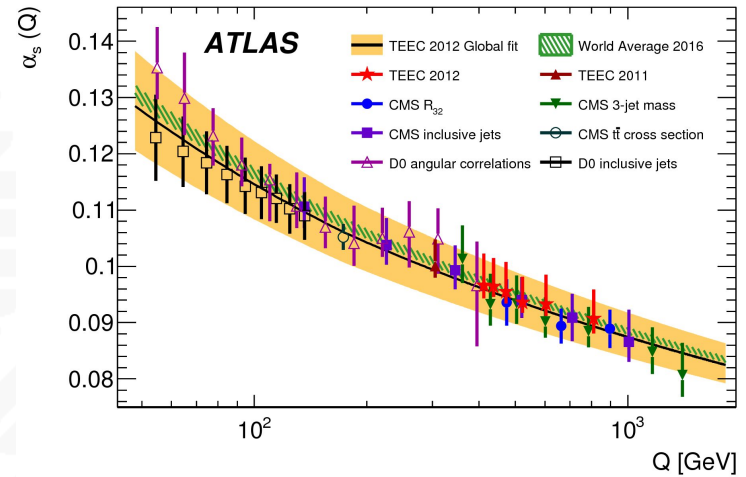
- Energy-energy-correlations of multijet events measured in transverse plane (TEEC) and its asymmetry (ATEEC) are sensitive to α_s



- ATEEC fits yield the most precise value (smaller scale uncertainties)

$$\alpha_s(m_Z) = 0.1196 \pm 0.0013 \text{ (exp.)}^{+0.0075}_{-0.0045} \text{ (theo.)}$$

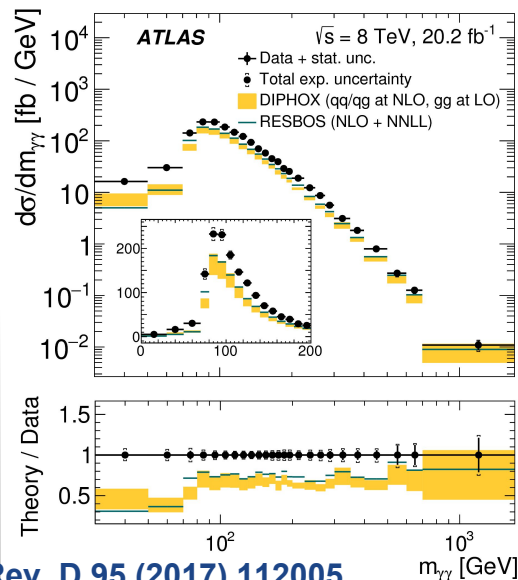
7 TeV: PLB 750, 427 (2015)
 8 TeV: 1707.02562 (Subm. EPJC)



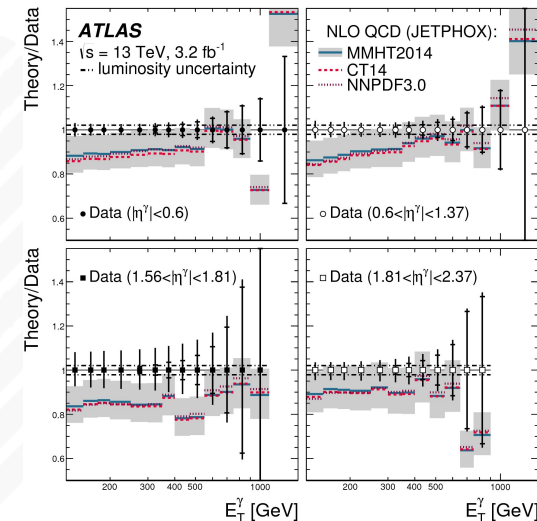
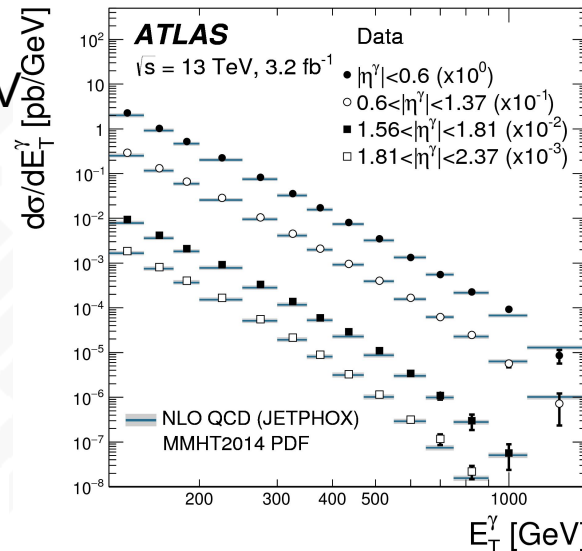
Prompt Photon Production

- Prompt photon production is a colorless probe of pQCD
- @13 TeV for E_T^γ up to 1.5 TeV
- Main challenge: background from jets misidentified as photons (data-driven subtr.)
- Good agreement with NLO calculation (JetPhox) and MC (PYTHIA, SHERPA 2.1.1)

13TeV: 1701.06882 PLB 770 (2017) 473
8 TeV: JHEP 06 (2016) 005



Phys. Rev. D 95 (2017) 112005



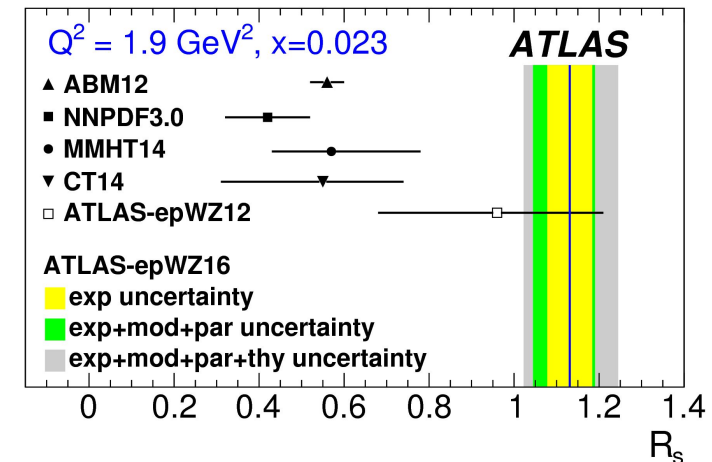
- Inclusive Diphoton cross sections @ 8 TeV
- Important background for $H \rightarrow \gamma\gamma$
- NLO calculation (DIPHOX) fails to describe data
- RESBOS (NLO+NNLL) and 2yNNLO improve description, SHERPA works best
- New: γ +jet @ 13TeV [ATLAS-CONF-2017-059](#)

Results from Precision W/Z Cross Sections

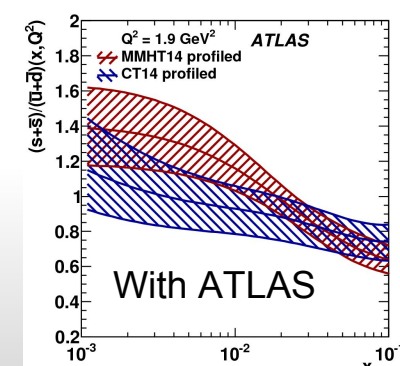
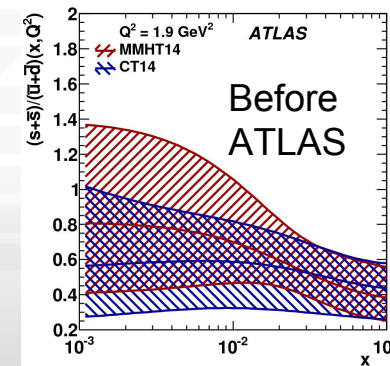
Eur. Phys. J. C 77 (2017) 367
1612.03016

- High precision measurements by ATLAS using 7 TeV data (4.6 fb^{-1})
- Cross sections measured to 0.6% (W^+), 0.5% (W^-), 0.32% (Z) precision

$\sigma_{W \rightarrow \ell \nu}^{\text{tot}}$ [pb]	
$W^+ \rightarrow \ell^+ \nu$	$6350 \pm 2 \text{ (stat)} \pm 30 \text{ (syst)} \pm 110 \text{ (lumi)} \pm 100 \text{ (acc)}$
$W^- \rightarrow \ell^- \bar{\nu}$	$4376 \pm 2 \text{ (stat)} \pm 25 \text{ (syst)} \pm 79 \text{ (lumi)} \pm 90 \text{ (acc)}$
$W \rightarrow \ell \nu$	$10720 \pm 3 \text{ (stat)} \pm 60 \text{ (syst)} \pm 190 \text{ (lumi)} \pm 130 \text{ (acc)}$
$\sigma_{Z/\gamma^* \rightarrow \ell \ell}^{\text{tot}}$ [pb]	
$Z/\gamma^* \rightarrow \ell \ell$	$990 \pm 1 \text{ (stat)} \pm 3 \text{ (syst)} \pm 18 \text{ (lumi)} \pm 15 \text{ (acc)}$



- Differential cross sections in many variables
- Obtained new PDF set ATLAS-epWZ16 by combining with HERA ep data in NNLO QCD analysis
- Extracted independent value for V_{cs}
- Constraints to parton behavior at low x : strange to light sea quark density is close to unity



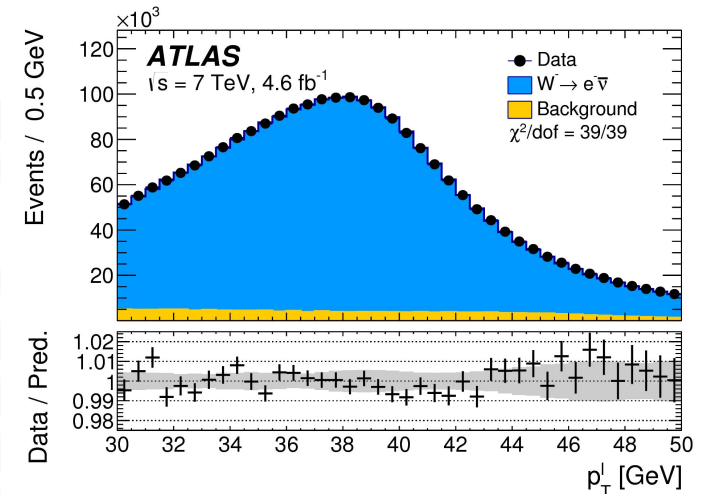
Measurement of the W Mass at 7 TeV

1701.07240, Subm. to EPJC

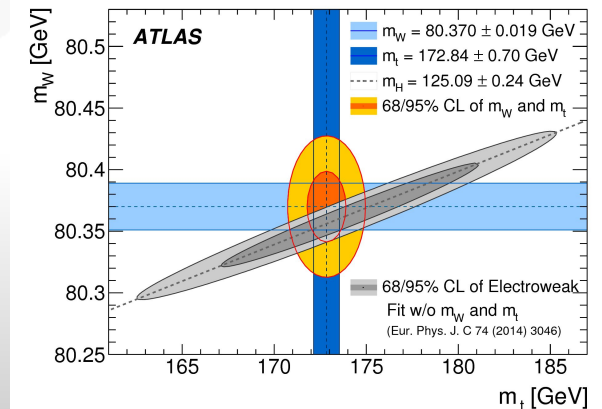
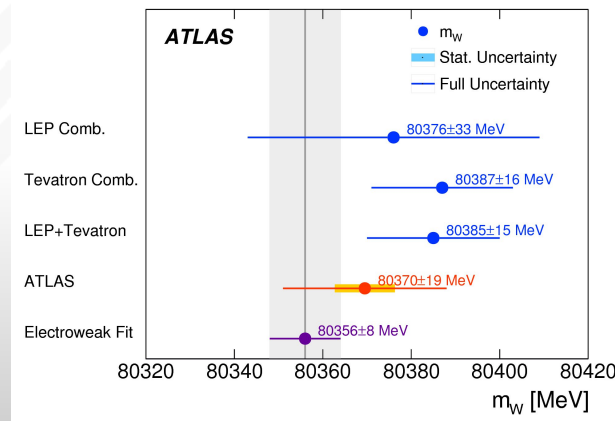
- First measurement of m_W at the LHC

$$m_W = 80370 \pm 19 \text{ MeV}$$

- Use Z^0 as standard candle for calibration
- Extract from fits to charged lepton p_T and reconstructed m_T^W
- Largest exp. systematics: lepton energy/momentum scale
- Largest modeling systematics: PDFs, parton showers
- Precision better than LEP combination, not far from Tevatron combination, compatible results



- Consistent with global EW fit



Vector Boson + Jets Production

- Vector boson production with associated jets is measured differentially with up to 7 jets now

- Very important background to many searches and test of pQCD

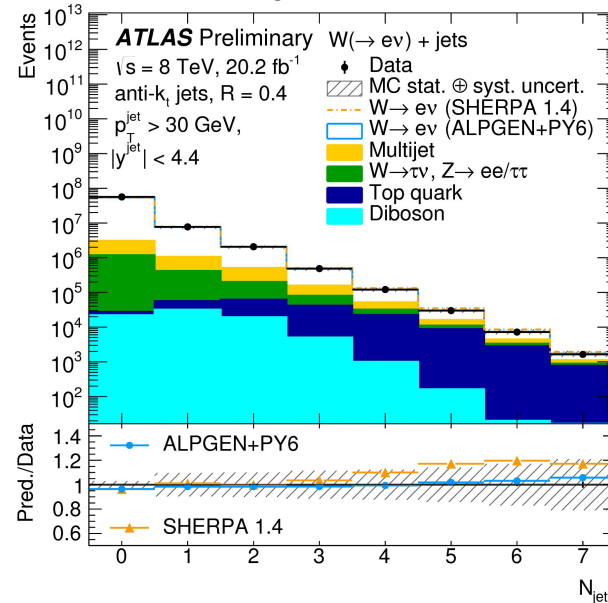
- Lots of differential distributions

- Agreement of simulations with data in range up to $p_T = 500$ GeV within systematic uncertainties

- Tensions become visible in high jet multiplicity region where jets in the parton shower become important

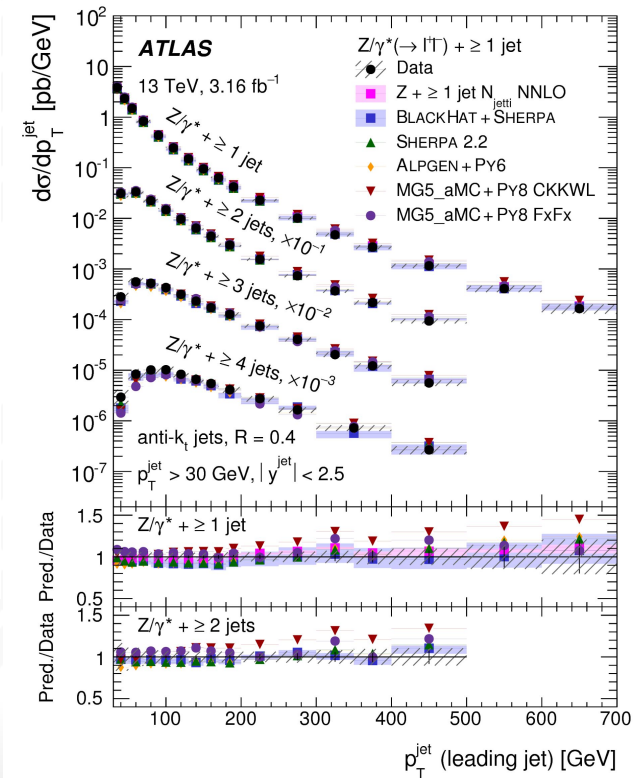
New prelim. result

W+jets @ 8 TeV



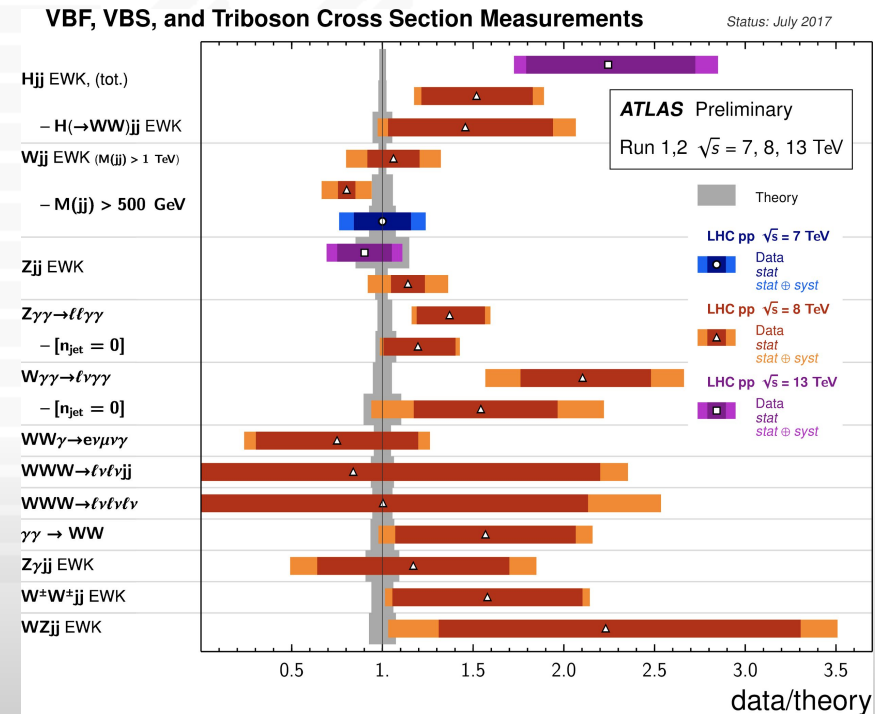
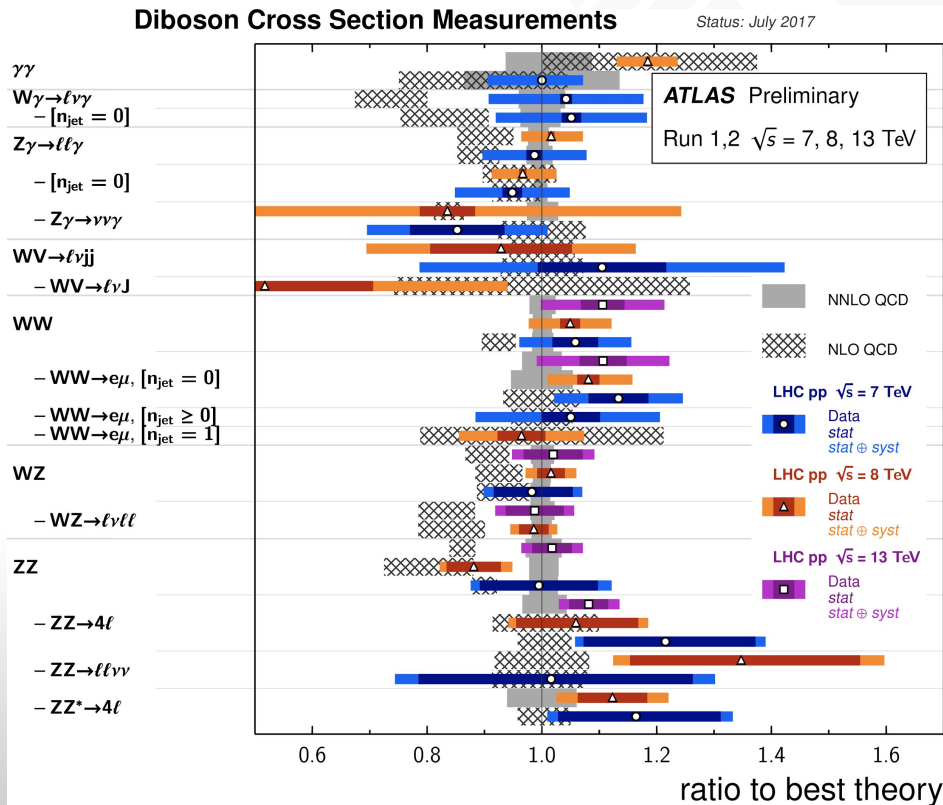
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Z+jets @ 13 TeV



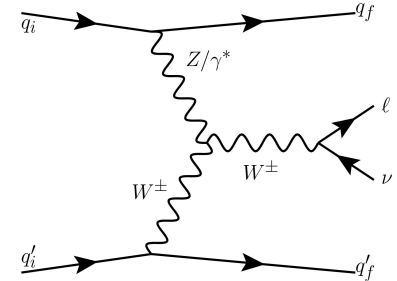
Diboson and Triboson Final States

- Large number of diboson processes observable and analysed
- Generally good agreement with SM
- Whole industry extracting constraints on aTGC, and effective QFT parameters
- Even more complex final states now also in reach: VBF, VBS, triboson production
- Some of them already observed
- Sensitivity to aQGC parameters



Electroweak Vector Boson Production

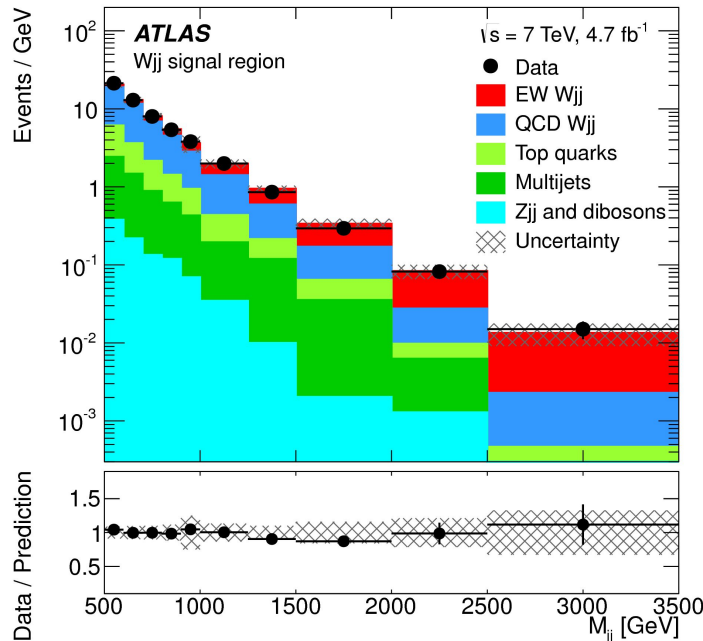
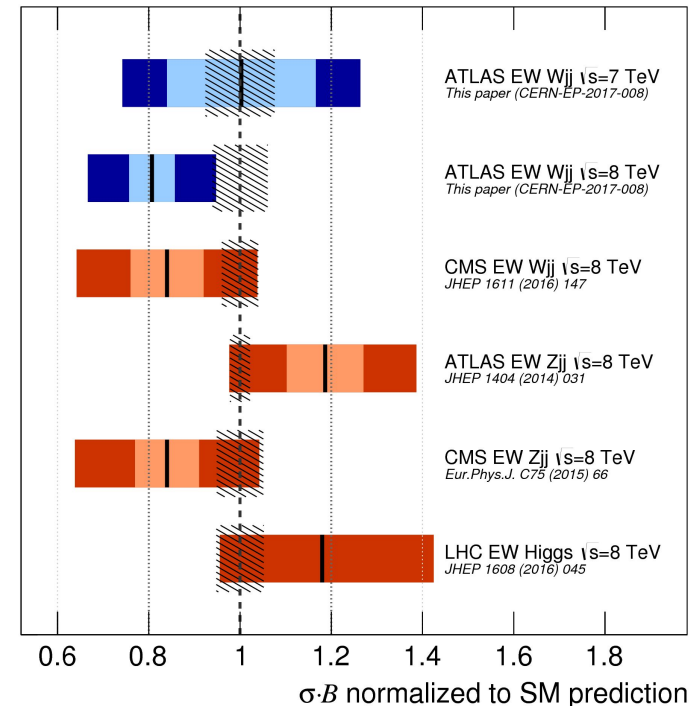
- Important background to Higgs and BSM searches
- Spectacular signature of two fwd. jets, rap. gap and high p_T central leptons
- Mixed with QCD diagrams, large backgrounds
- Observation $>5\sigma$ in $W, Z+jj$, cross sections extracted



LHC electroweak Xjj production measurements

ATLAS

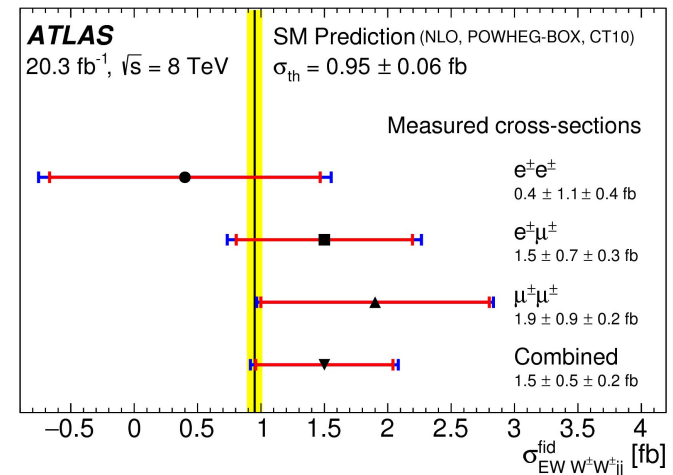
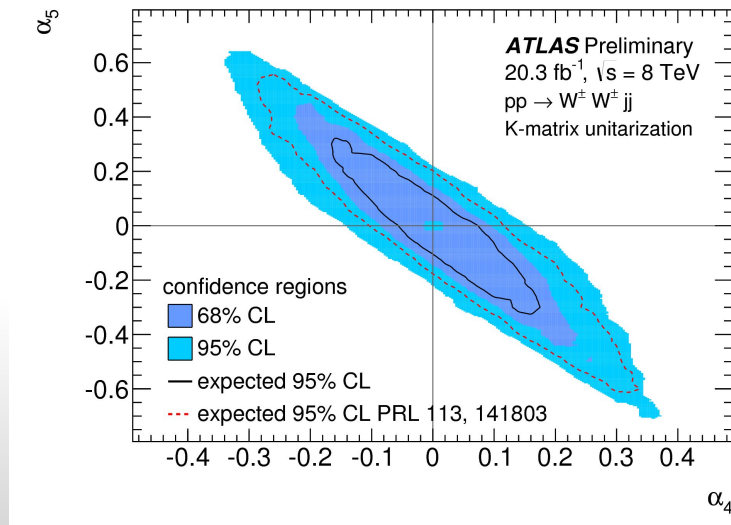
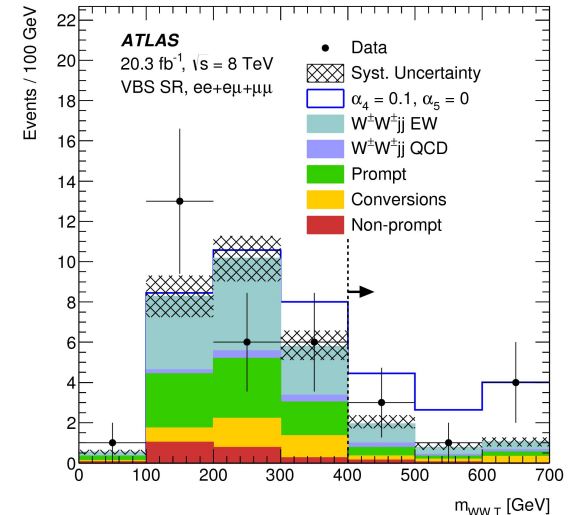
Stat. uncertainty Total uncertainty Theory uncertainty



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Same-sign WW Scattering @ 8 TeV

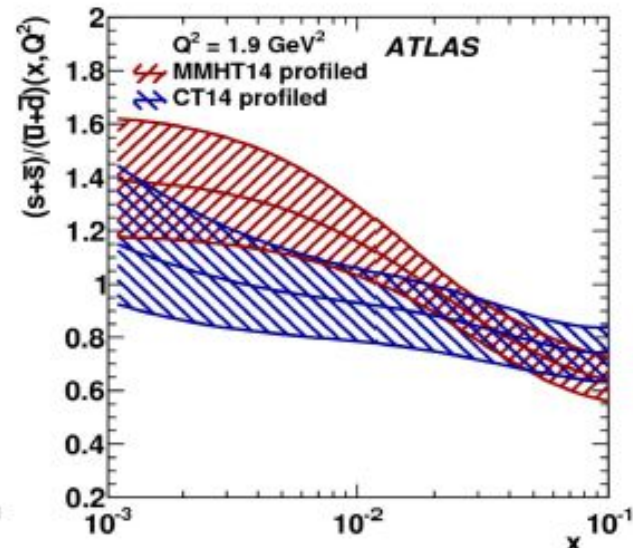
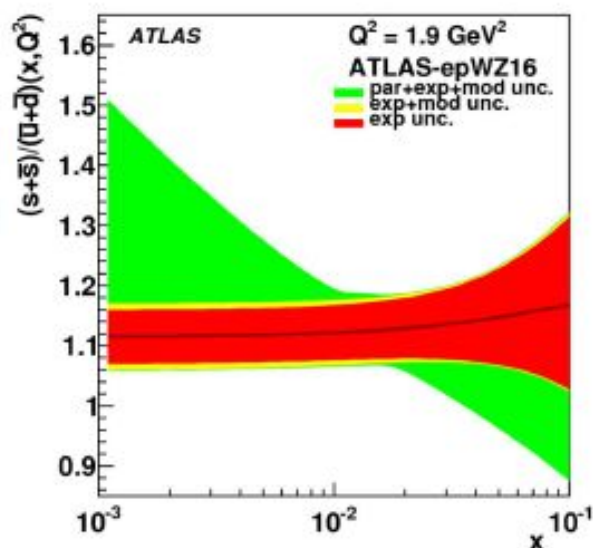
- Unique same-sign dilepton + MET signature
- Fundamental test of unitarity of EW sector
- Various EW and QCD processes contribute to VBS in the SM
- VBS alone not gauge invariant
- Not yet observed by ATLAS (8 events obs / 3.3 exp. in enhanced region)
- Already sensitive to aQGC parameters
→ set limits



BACKUP

Supporting Arguments for the Enhanced Strangeness Interpretation

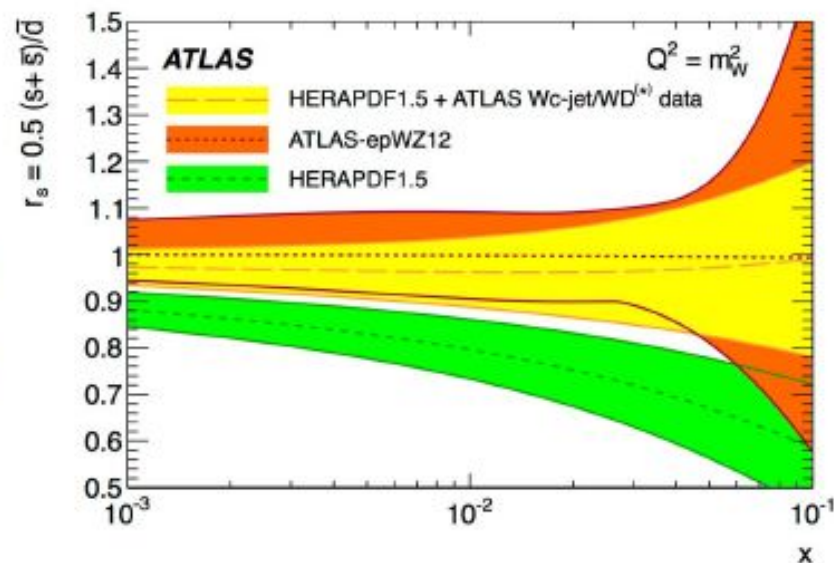
- Is that the ATLAS interpretation of the enhanced strangeness an artefact of a too restrictive parametrisation of the ATLAS PDF Set?



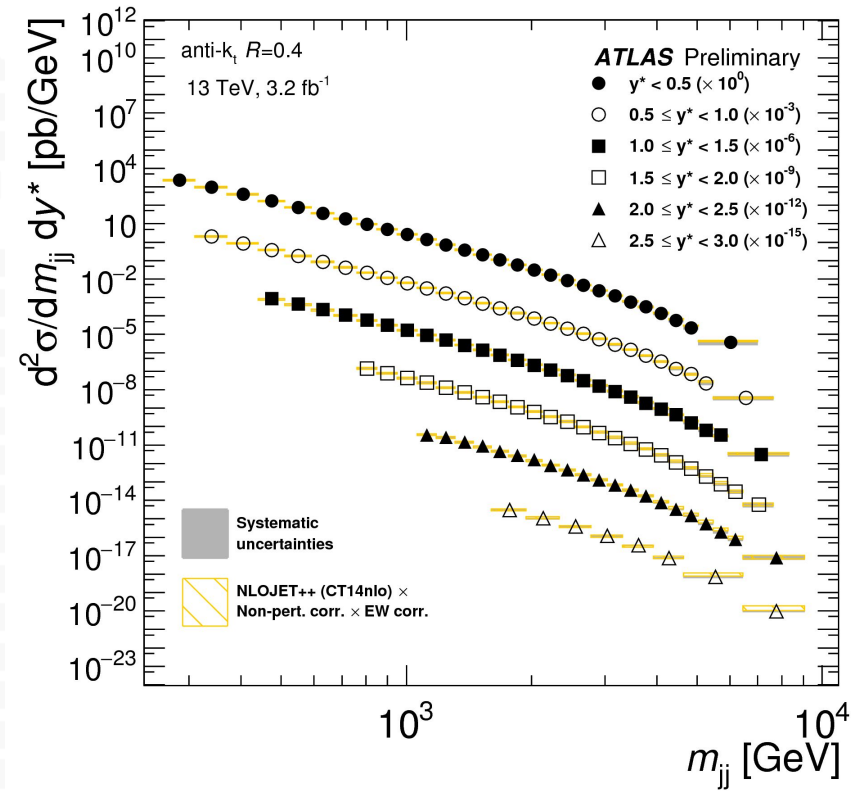
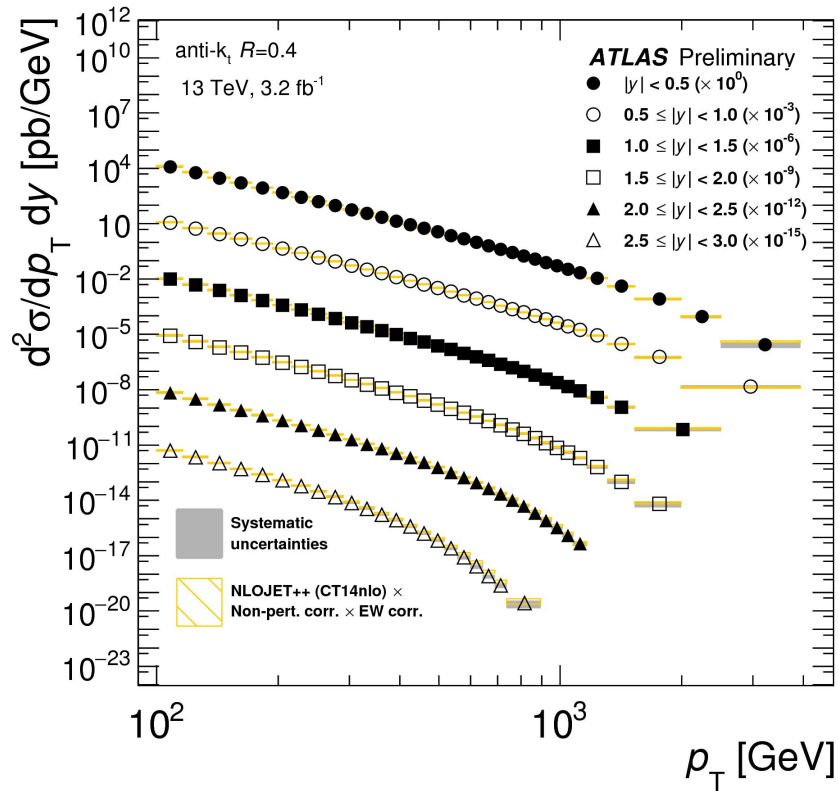
- Several Cross-Checks are already published in the 7 TeV W/Z high precision analysis (<https://arxiv.org/abs/1612.03016>):
 - We relaxed our parameterization and tested several variations, e.g. by freeing the low- x strange parameter $B_{\bar{s}}$; this leads to the green band (leftplot), still showing enhanced strangeness at $x=0.01$
 - We profiled other PDF-sets (MMHT14, CT14) with different parameterization assumptions to the ATLAS W/Z 7 TeV Data. Both profiled PDF-Sets lead also to an enhanced strangeness (right plot).

Supporting Arguments for the Enhanced Strangeness Interpretation

- Moreover, we tested
 - the sensitivity to the assumptions on the low- x behavior of light-sea quarks
 - the impact of adding measurement of the E866-experiment at $x=0.1$ to the ATLAS fitboth tests lead to a consistent result of enhanced strangeness
- The W/Z precision measurement at 7 TeV is not the only measurement that suggests an enhanced strangeness
 - The ATLAS measurement of $W+c$ production at 7 TeV (<https://arxiv.org/abs/1402.6263>) predicts a strange to down-sea quark ratio of 0.96 (see plot)
 - It should be noted that this is a fully independent measurement



Jet Cross sections at 13 TeV



Inclusive Jets @ 13TeV: QCD Scale Dependence

