標準模型の物理結果

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Standard Model Physics at LHC

How much precision can we achieve at LHC?

i.e. How well can we describe “known” SM processes?

- Improvement of measurements of SM parameters.
  - Couplings (α_S, TGC), …
  - Any deviation from SM?
- Improvement of QCD description.
  - LO, NLO and higher order corrections…
  - Non-perturbative effects
- Improvement of understanding of proton structure.
  - Parton distribution functions (PDFs)

Contents

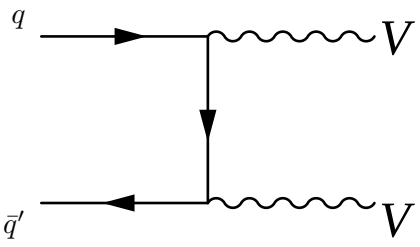
- Diboson production
- Inclusive W and Z production
- W and Z production in association with jets
- Jet production
- Photon production

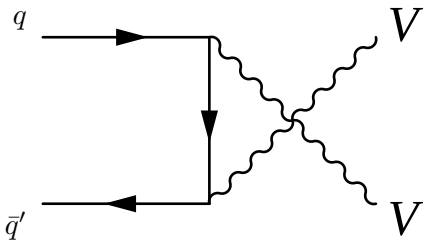
Will not cover soft QCD.

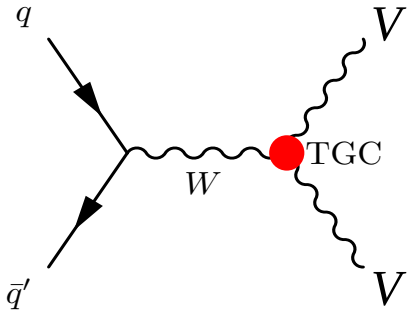
Diboson production

- Check of the gauge structure in the EW sector of the SM.
  - Production cross section
  - Triple gauge coupling

  If any non-SM physics exists, these would be affected.







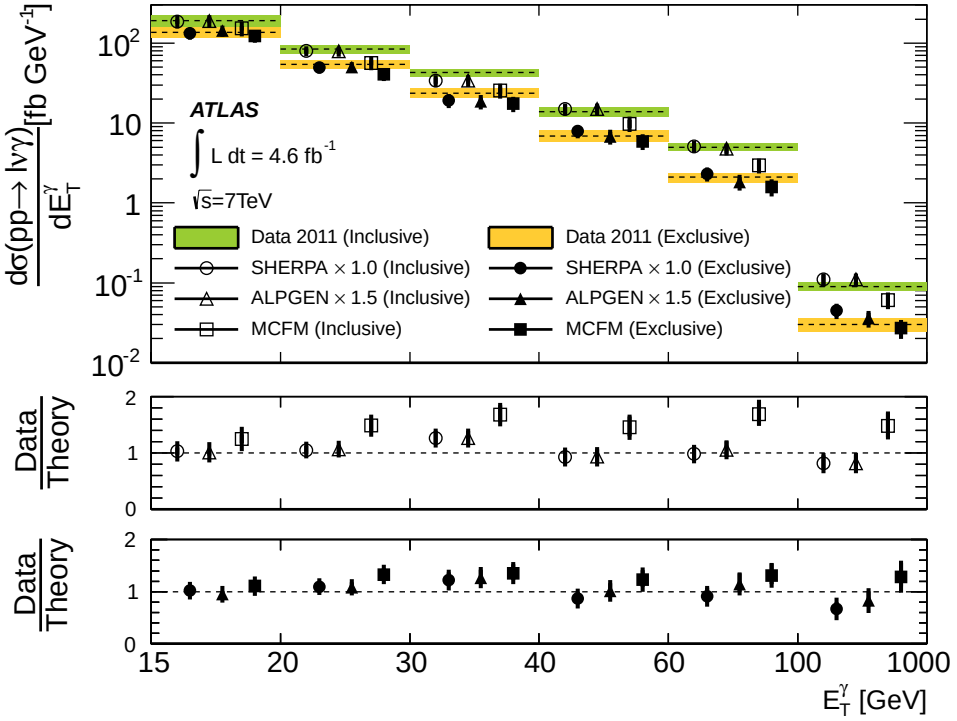
Wγ and Zγ

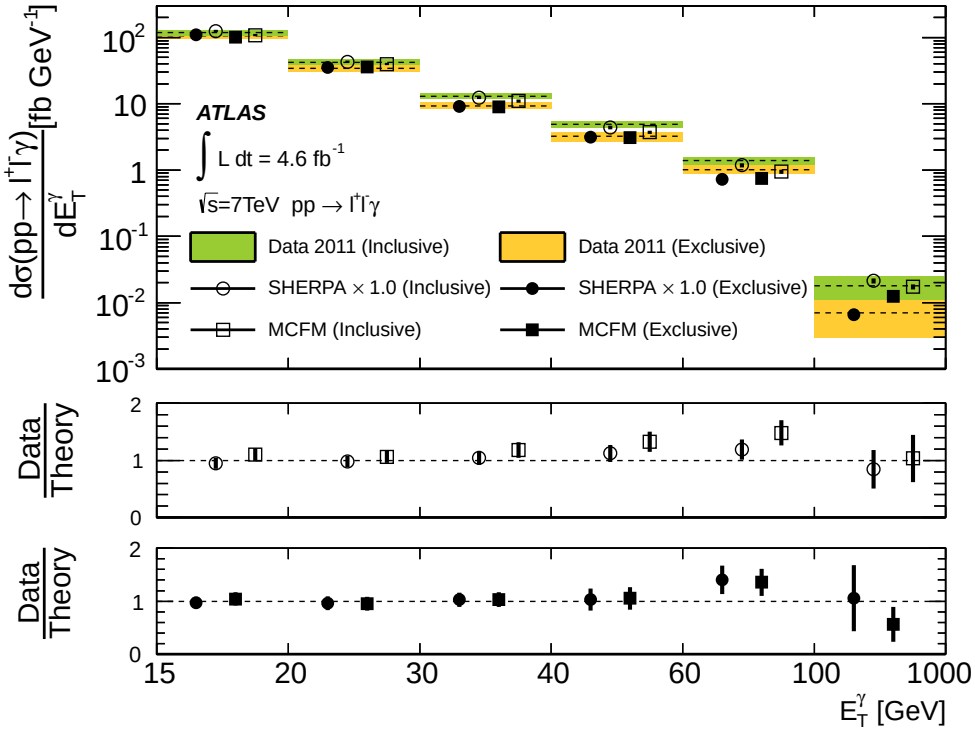
Inclusive : Njet>=0

Exclusive: Njet=0

(jet: anti-kt, R=0.4, p_T>30GeV)

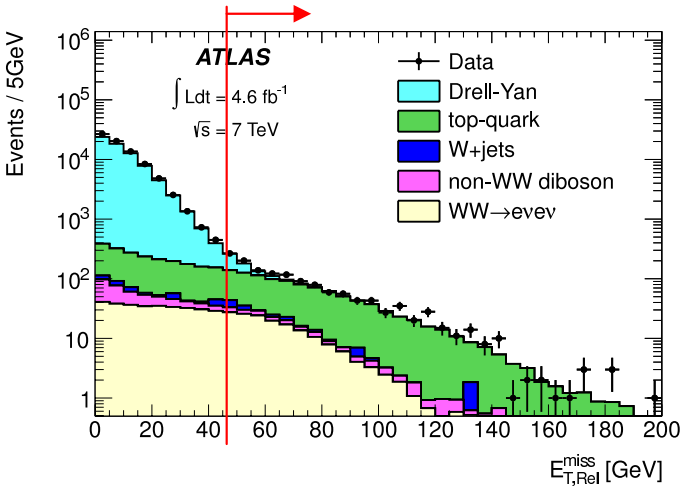
- lepton p_T>25 GeV
- E_T^{γ} > 15 GeV
- $\Delta R(l, \gamma) > 0.7$

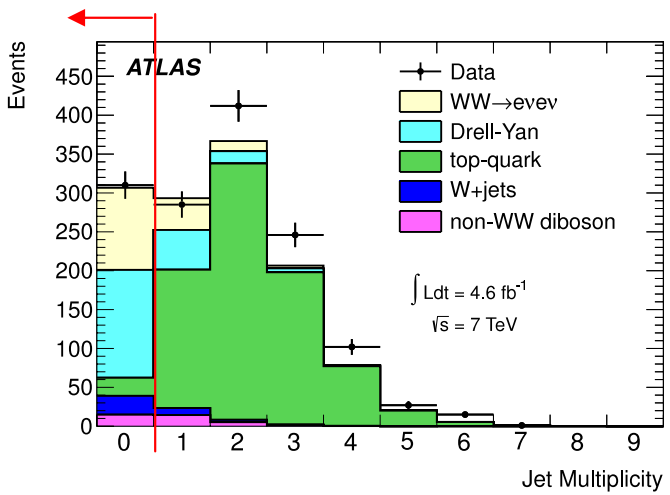




- SHERPA and normalised ALPGEN reproduce the data.
  - MC with Multi-leg LO Matrix Element.
- MCFM, NLO generator, deviates from data at higher E_T for inclusive cross section.
  - lack of additional multiple quark/gluon emission.

WW → l ν l ν

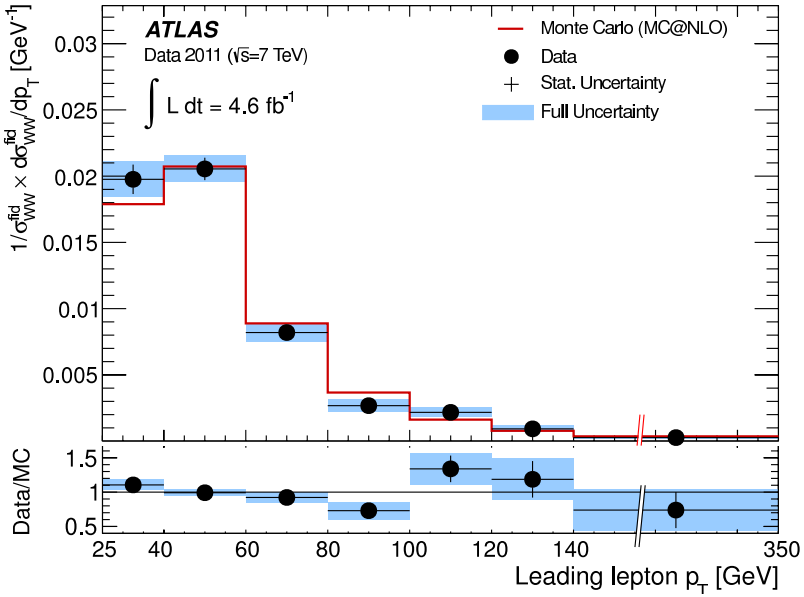




- 2 isolated opposite sign leptons with p_T>25 GeV, p_T > 20 GeV.
- Z mass veto
- **Jet Veto**
- **missing E_T** > 45GeV (25 GeV for e μ)
- p_T(ll') > 30 GeV

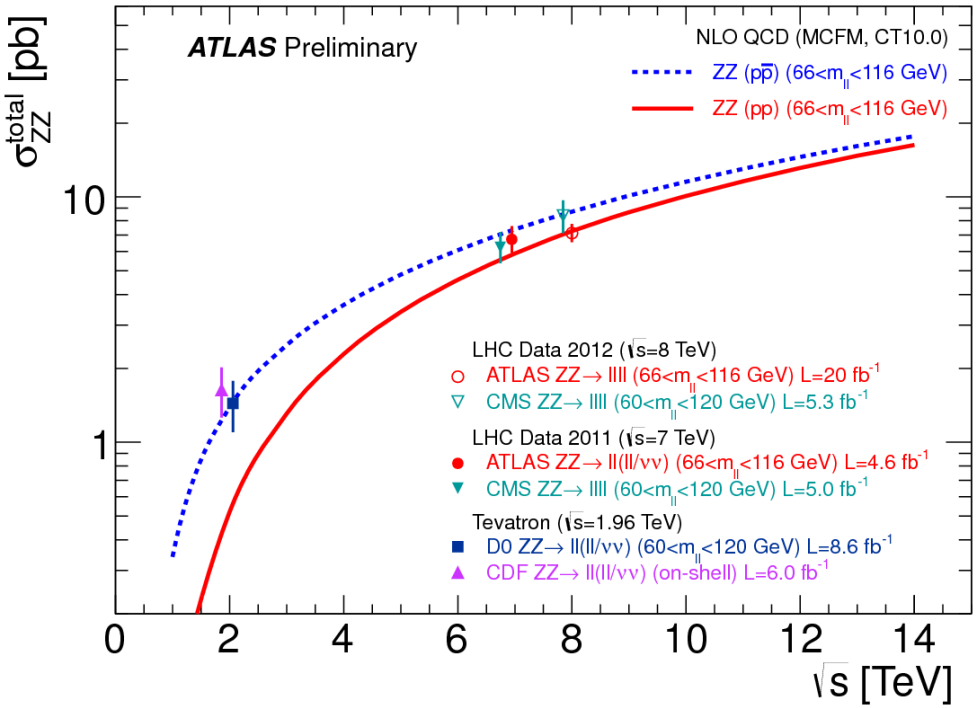
Normalised differential fiducial cross section:

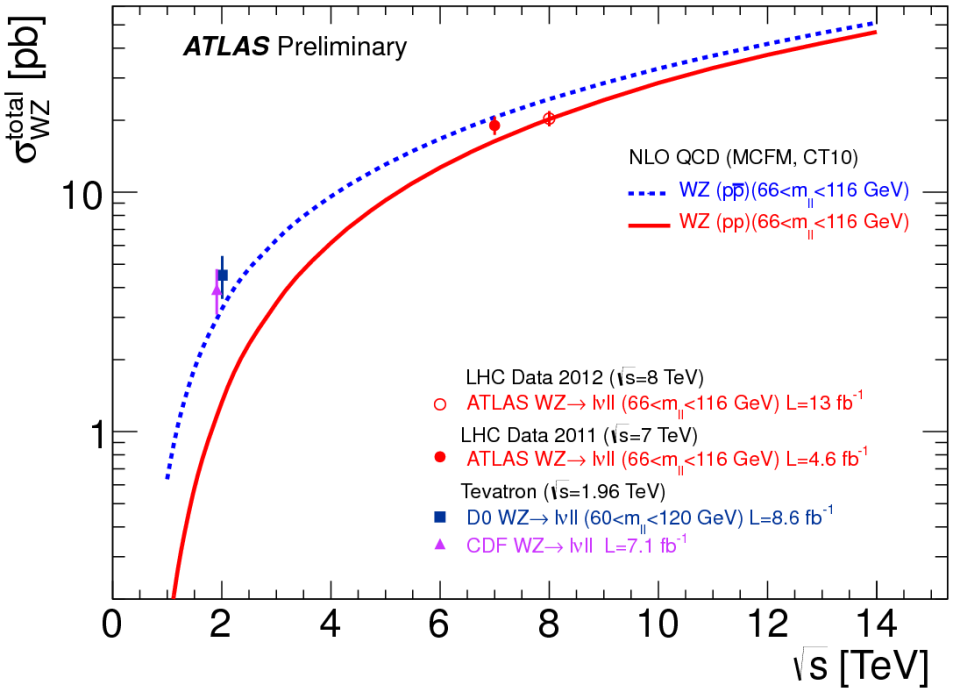
- Reasonable description by MC@NLO (+Herwig/Jimmy) prediction.



ZZ (→4l) and WZ (→ l ν ll)

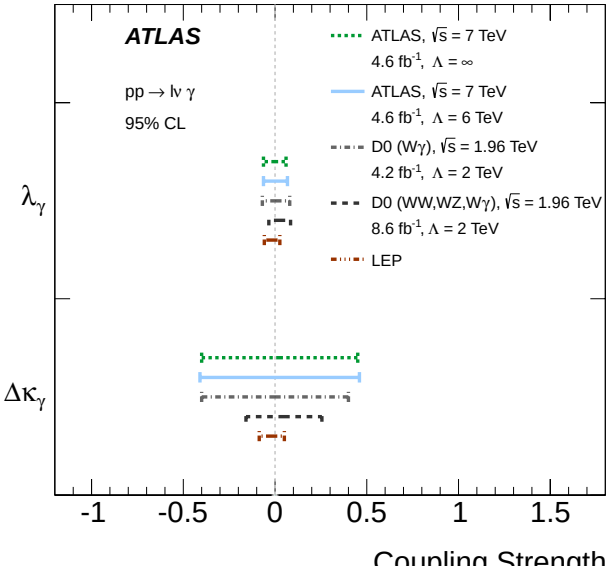
Cross section vs center-of-mass energy

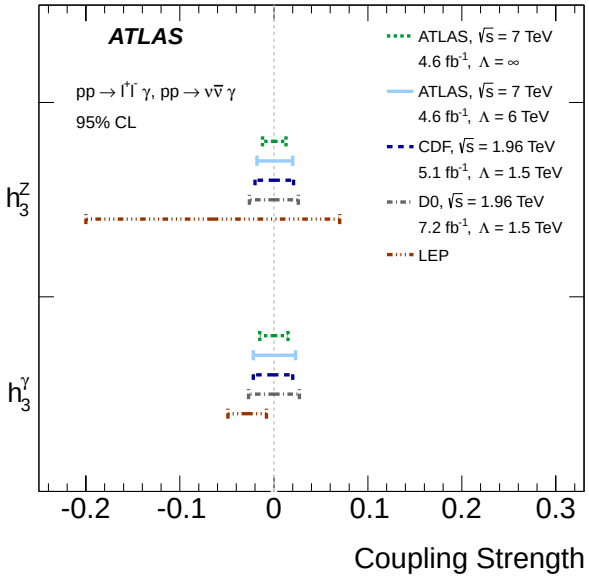


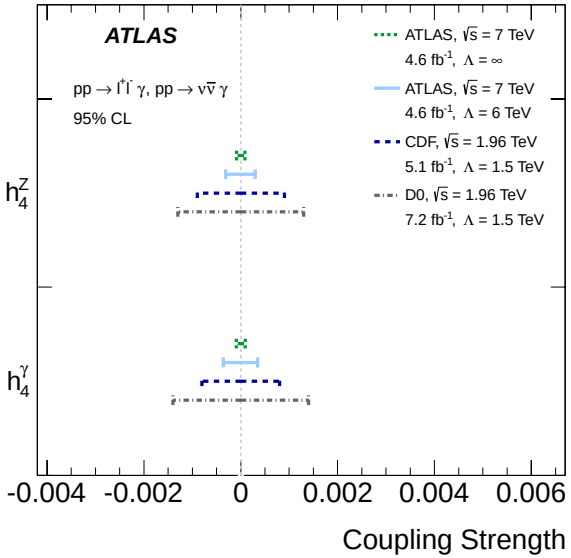


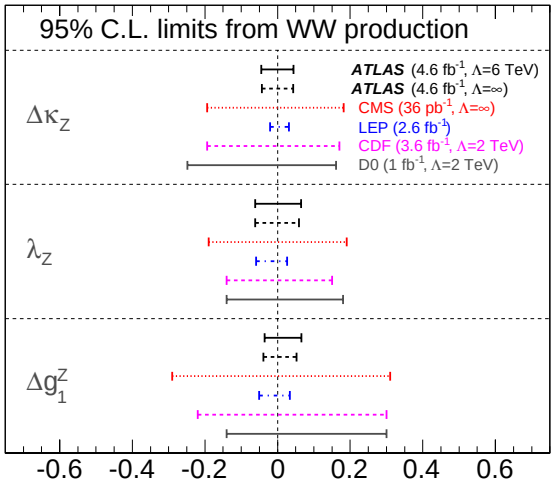
- Good agreement with SM.

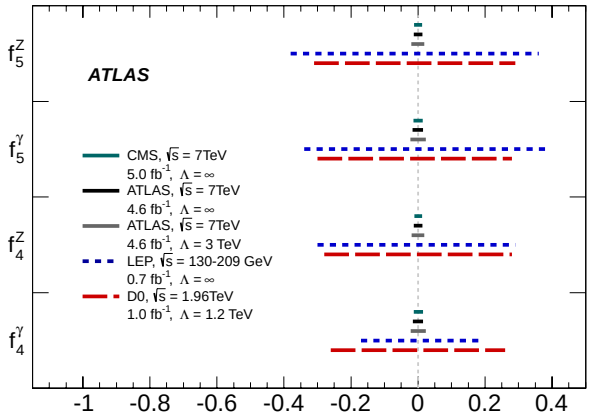
Anomalous Triple Gauge Coupling limits

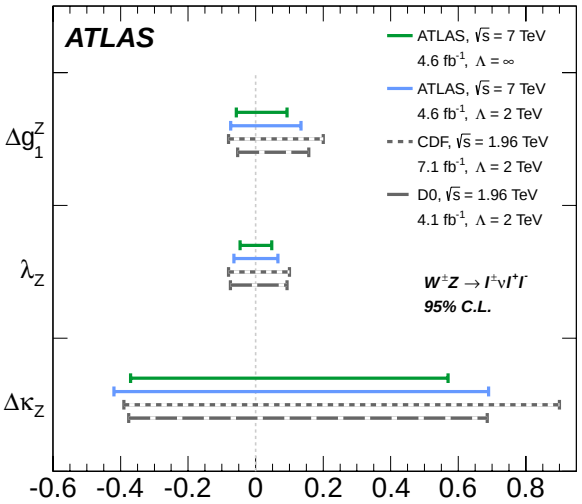








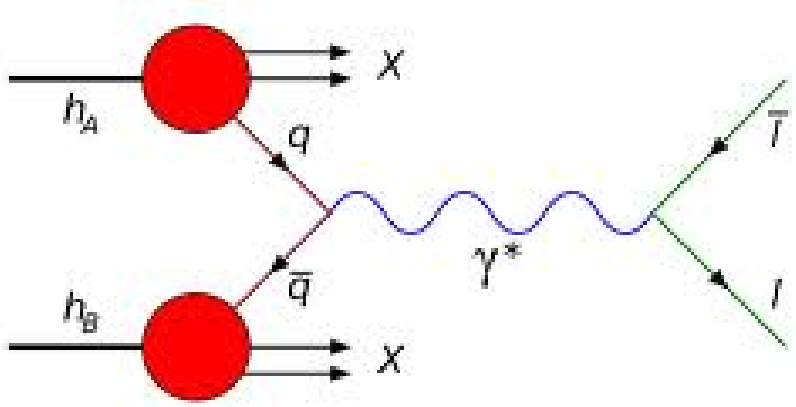


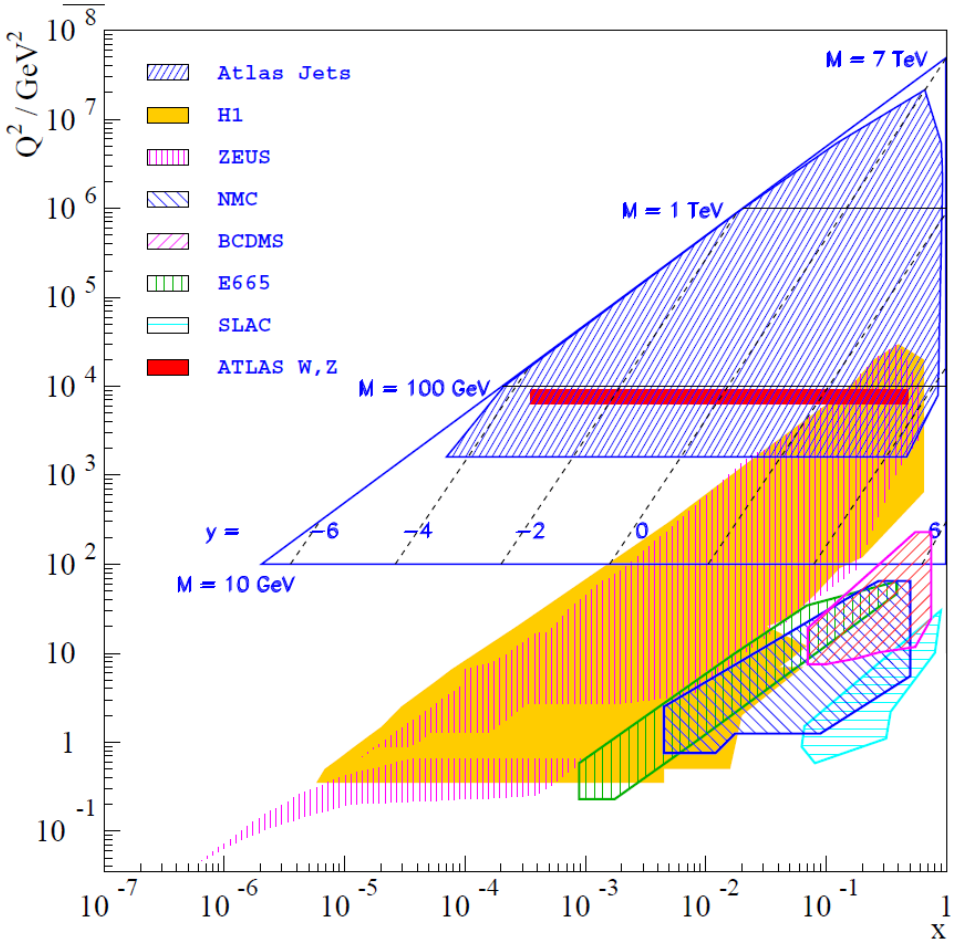


- No deviation from SM.

W and Z production

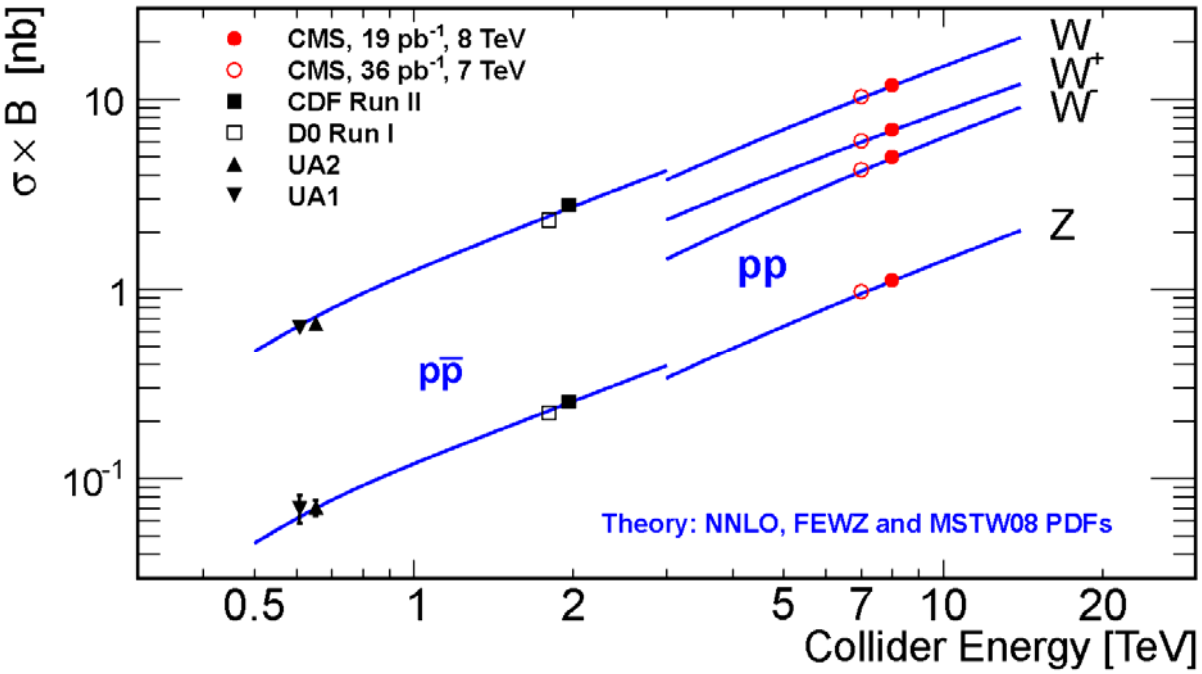
- Theoretically well understood.
- Clear experimental signature in the leptonic decay.





- Test of QCD at large scale.
- Feedback to understanding of proton PDFs.

W and Z production

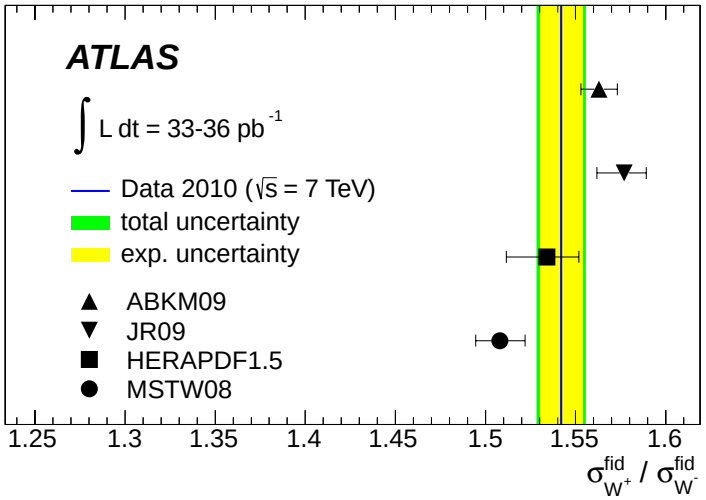


CMS-PAS-SMP-12-011
8TeV: low intensity run
muon >20GeV, el>25 GeV.

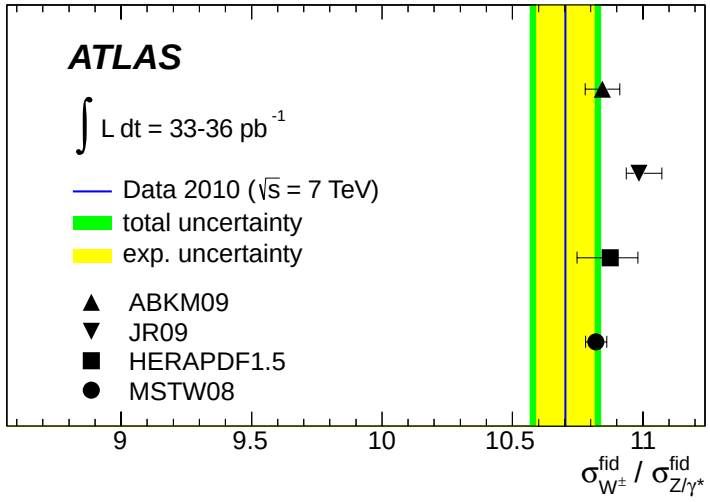
- Good agreement with theoretical expectations.

Cross section ratio @ 7TeV

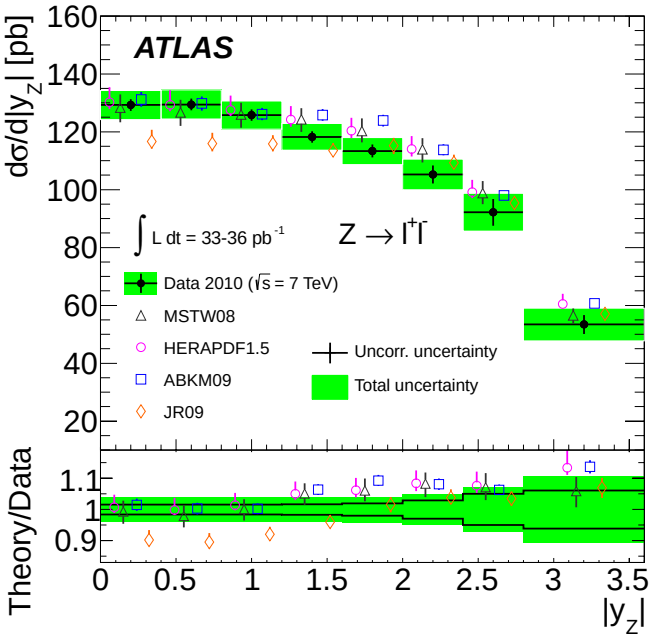
W^+/W^-

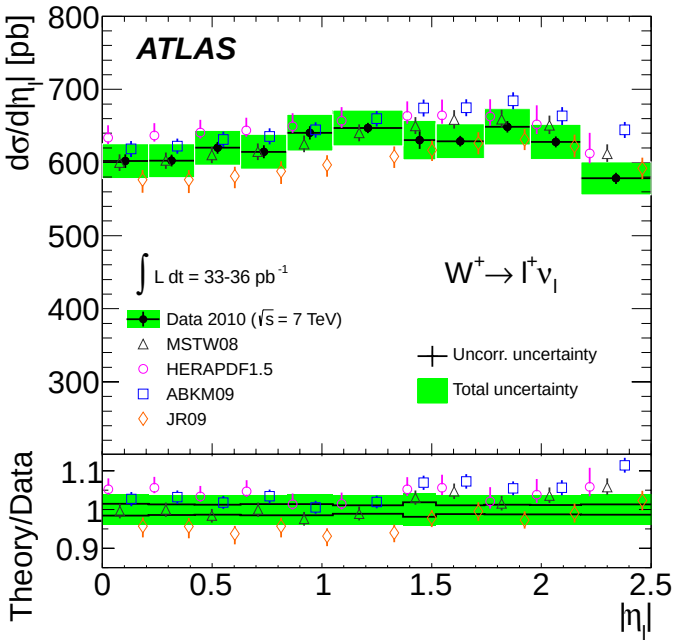


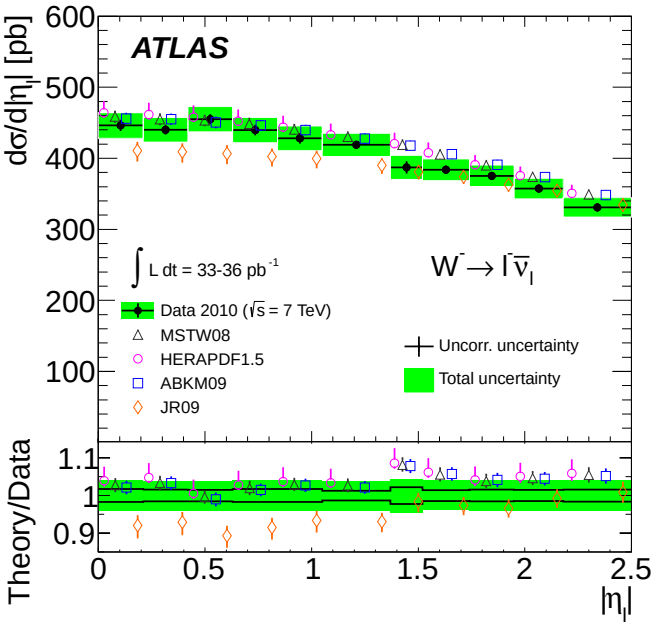
W/Z



Differential cross sections @ 7TeV

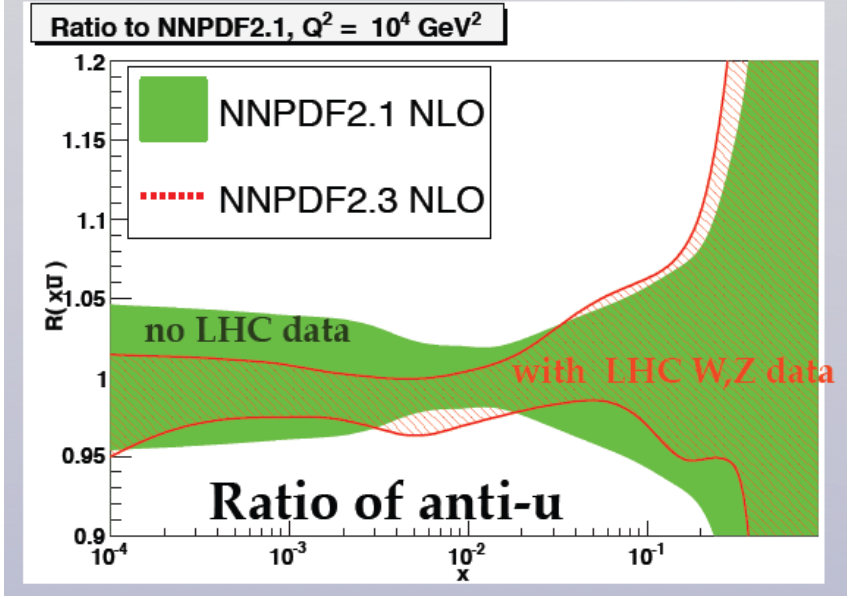






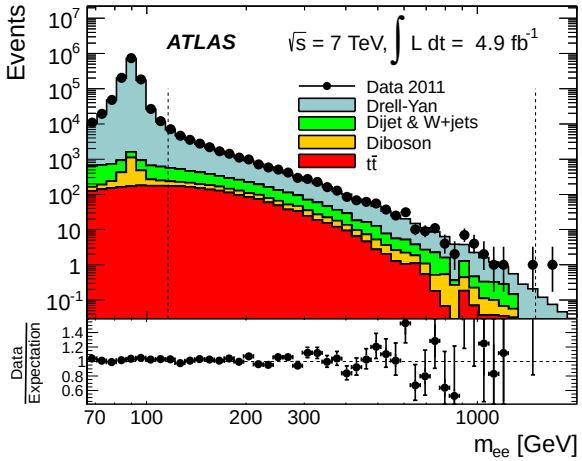
- They are sensitive to quark flavour separation and strangeness in the proton.

  → Useful in PDF determination.

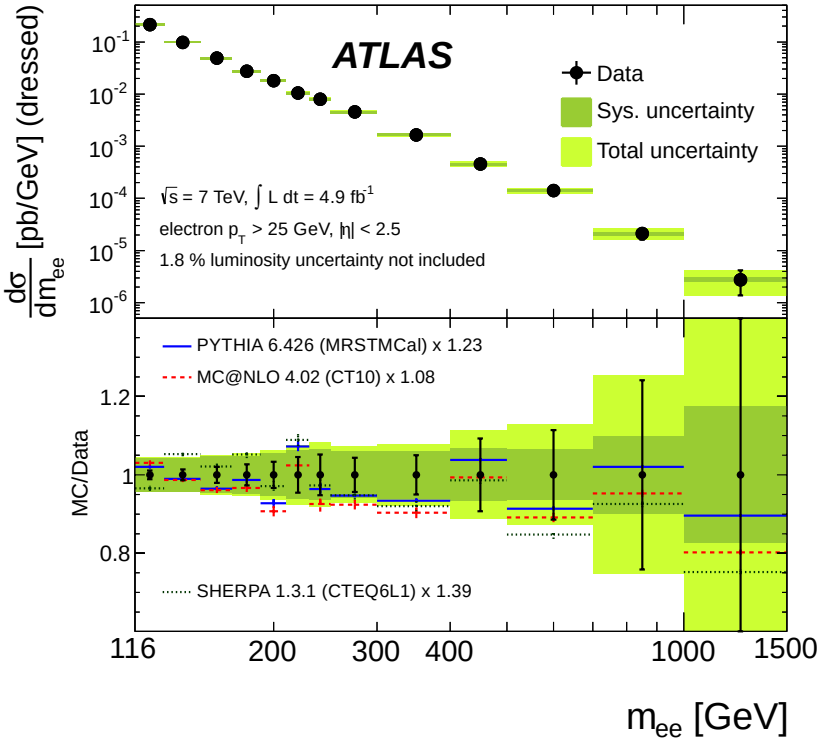


J.Rojo @ PDF4LHC(2013)

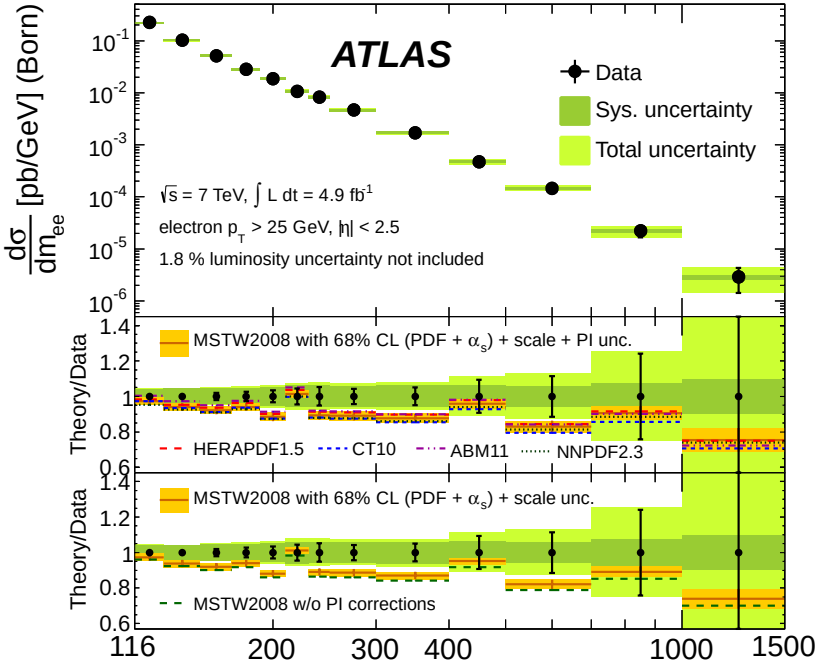
High mass Drell Yan



electrons:
p_T>25 GeV
$|\eta|$<2.47



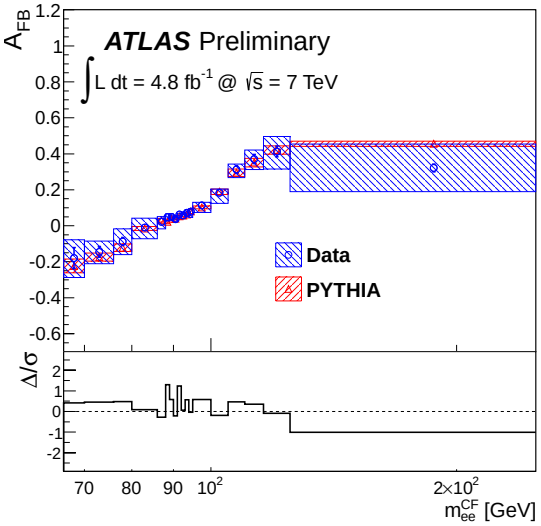
- Agreement in shape with normalised Pythia, MC@NLO and SHERPA.
- Agreement in shape with NNLO pQCD prediction with NLO EW correction.
  - Including photon-induced background.
  - Several PDFs.
- Data is systematically above.



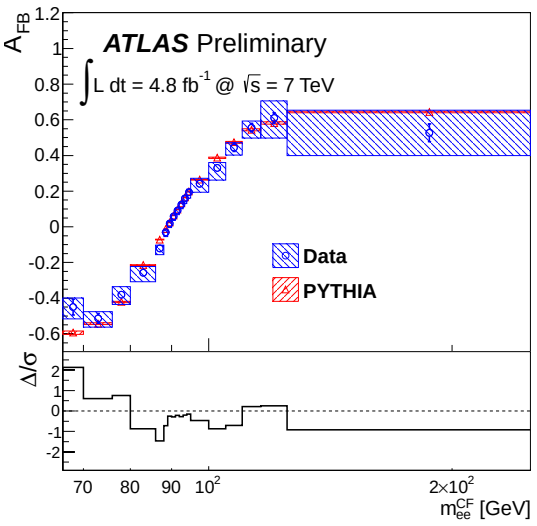
Z forward-backward asymmetry

$$A_{FB} = \frac{N_{\cos\theta^*_{CS}\geq 0} - N_{\cos\theta^*_{CS}<0}}{N_{\cos\theta^*_{CS}\geq 0} + N_{\cos\theta^*_{CS}<0}}.$$

CC: central-central
CF: central-forward



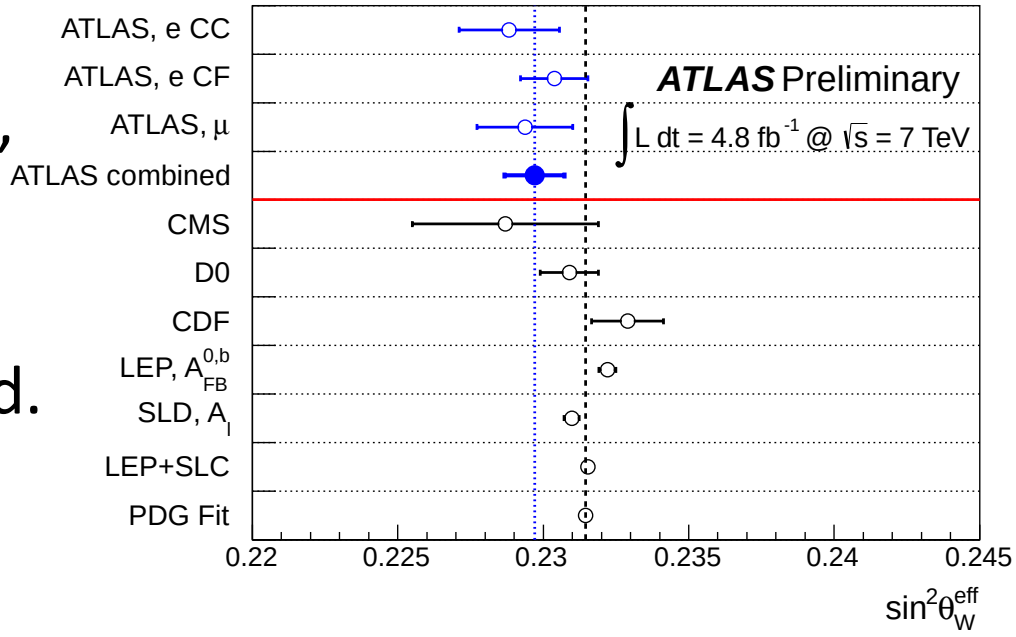
Raw A_{FB}



Unfolded A_{FB}

Raw A_{FB} distributions are fitted to extract $\sin^2\theta^{eff}_W$, based on shape dependence on it.

- Good precision is achieved.



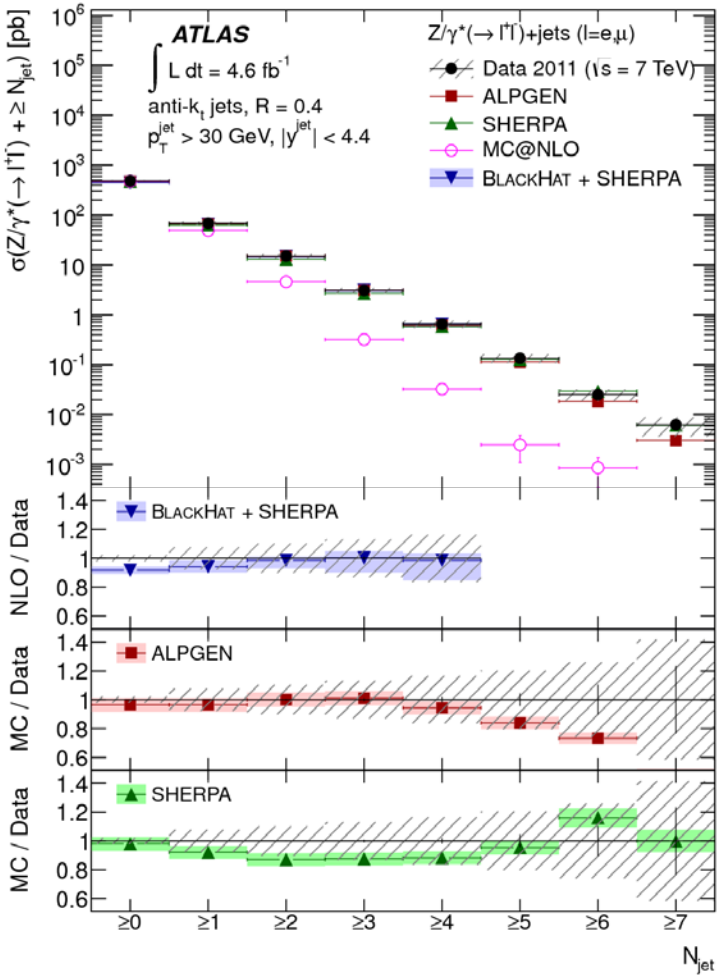
W and Z production in association with jets

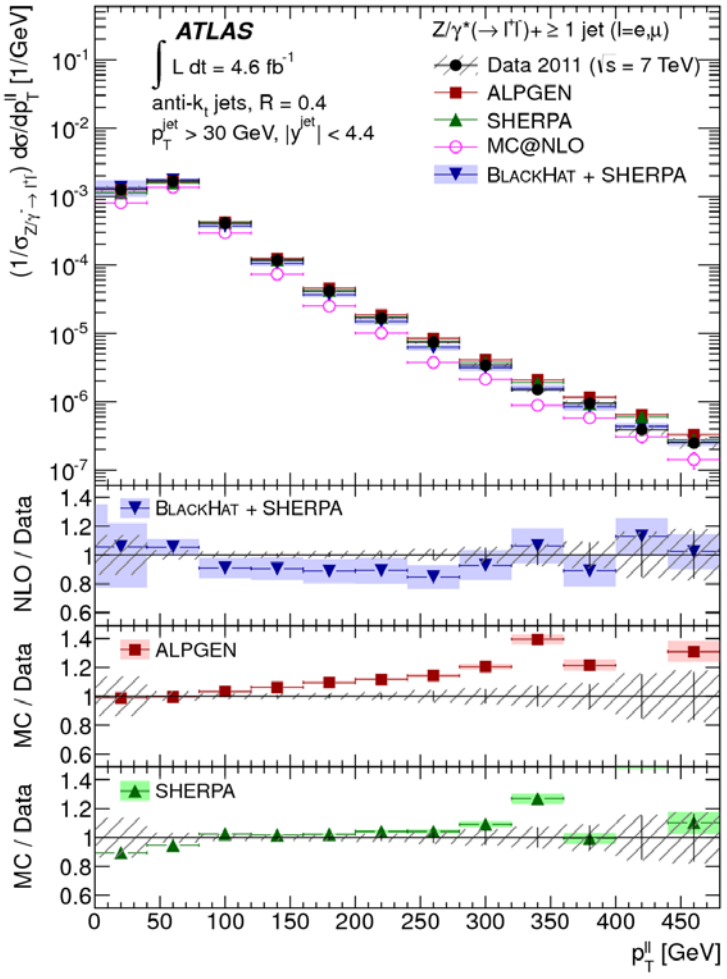
- Test of perturbative QCD (pQCD)
  - Comparison of calculation and generators.
- Can probe the heavier parton distribution in the proton.
- Dominant background for other processes.

Z + jets

- opposite sign leptons with lepton p_T >20 GeV
- jet p_T > 30 GeV, |y|<4.4
- Δ R(l,j) > 0.5

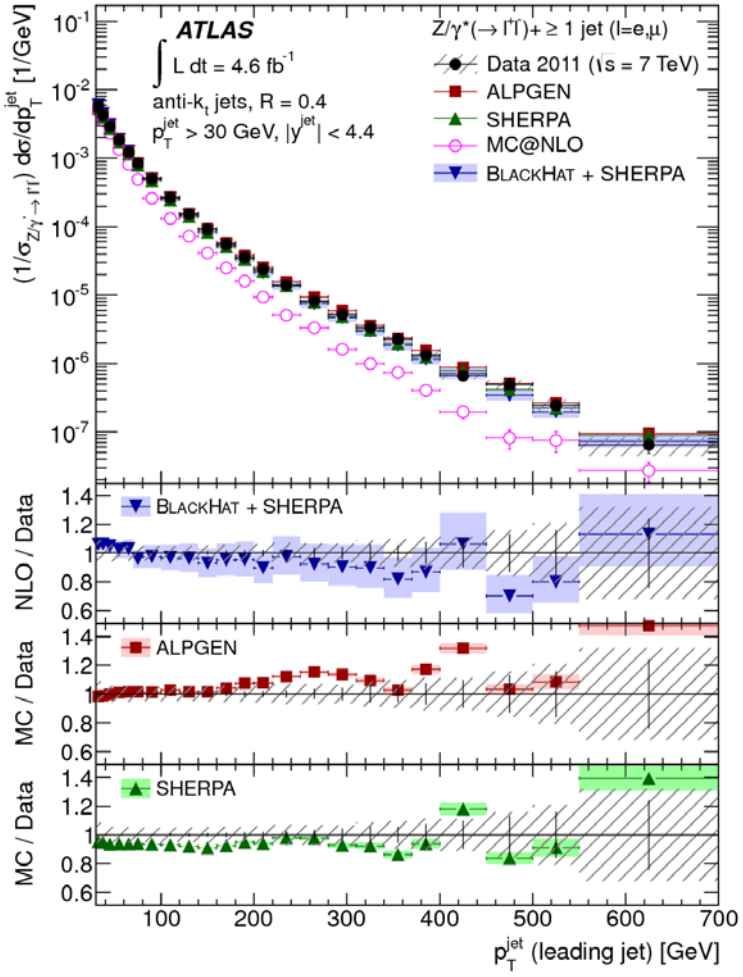
- Fixed-order NLO: BlackHat+SHERPA up to + 4 jets
- LO Multi-leg ME: ALPGEN, SHERPA up to + 5 partons
- MC@NLO+HERWIG/JIMMY: DY + 1 parton +PS

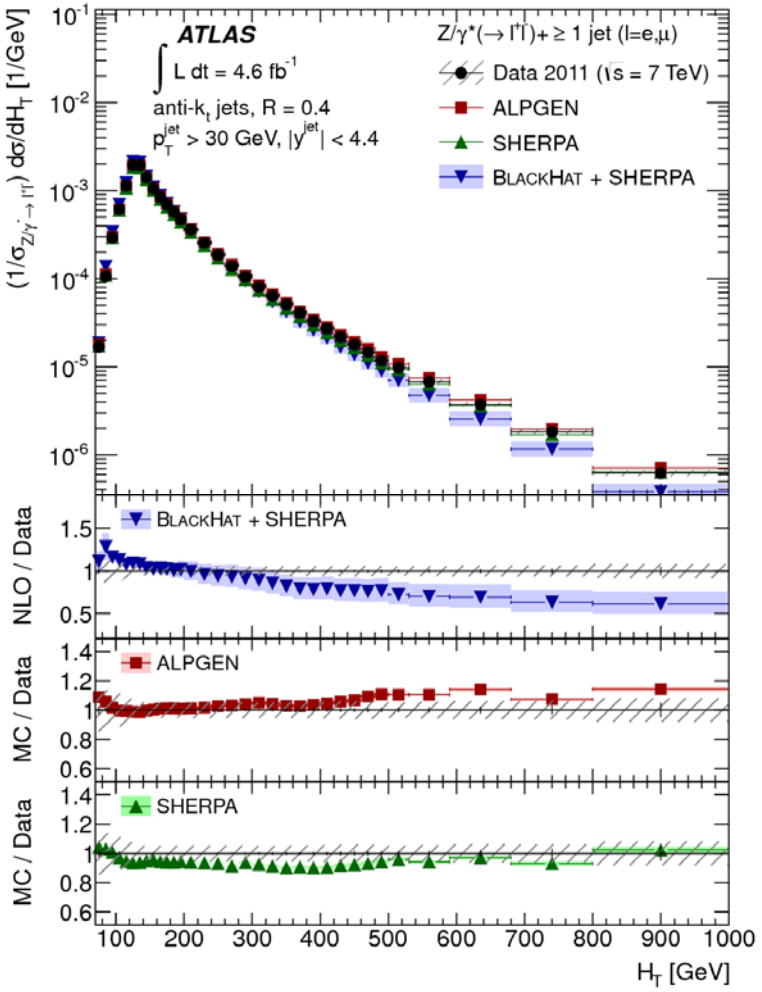




- MC@NLO fails to describe the data.
- BlackHat+SHERPA gives reasonable description.
- ALPGEN gives harder Z bosons.

Z+jet

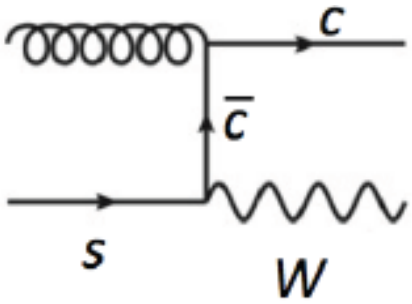




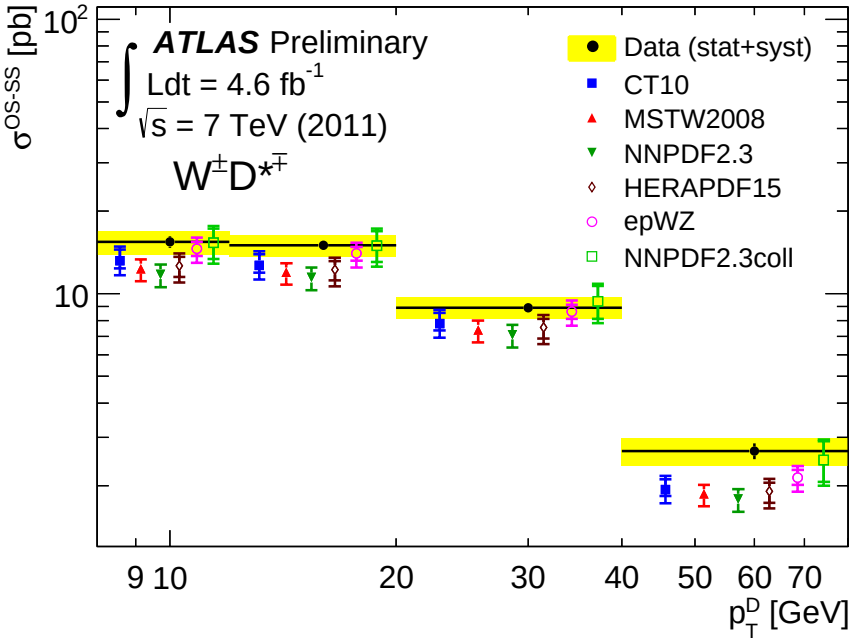
- Leading jet p_T is well described by BlackHat+SHERPA, though it fails to describe scalar sum of all final-state objects (H_T).
  - Need more jets

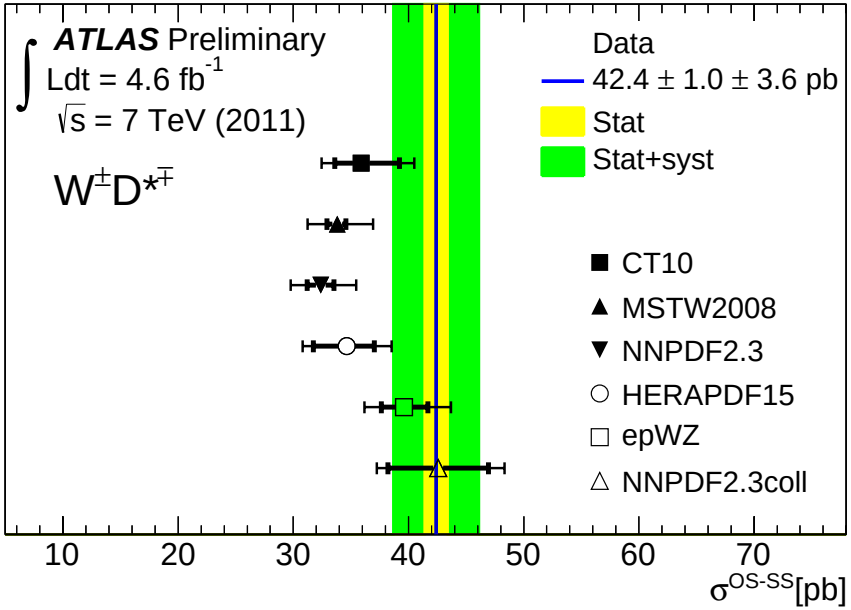
W + c-jet

- Sensitive to strange quark in the proton



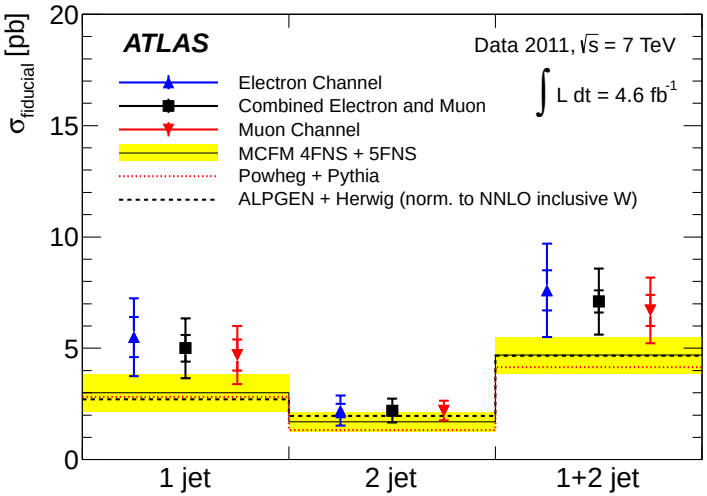
- Compared with several PDFs.
  - NNPDF2.3coll uses HERA, Tevatron and LHC only.
- Similar shape of dependence on p_T^D, but some discrepancy seen.

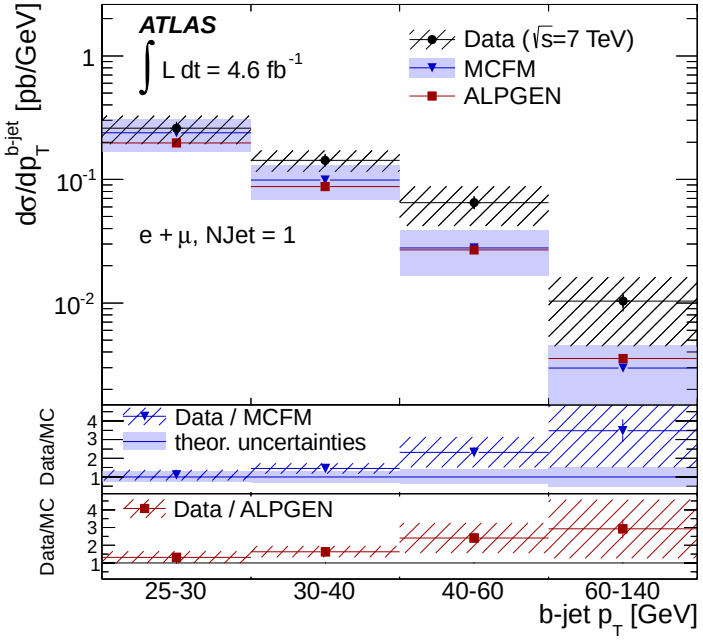


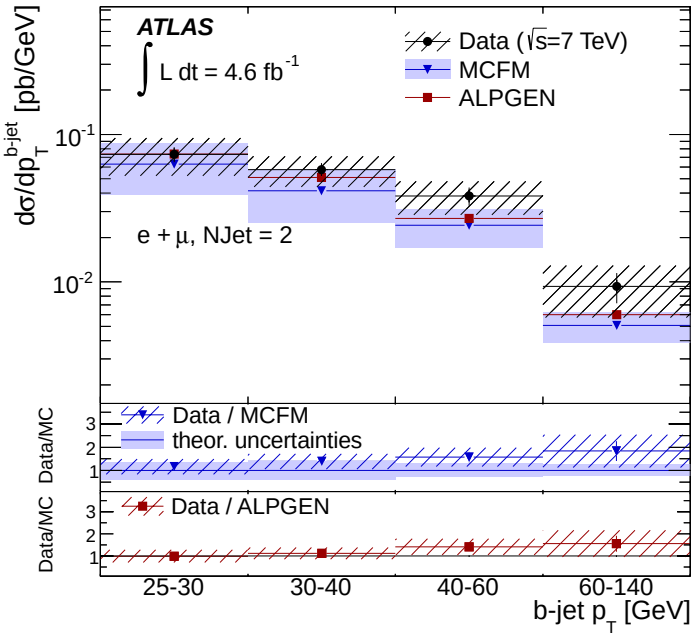


W + b-jet

- Flavour Number Scheme (FNS)
  - 4FNS: no b-quark in the proton
    - POWHEG (NLO), ALPGEN(LO)
  - 5FNS: intrinsic b-quark in the prot
    - Included in MCFM prediction.







Deviation at high b-jet p_T.

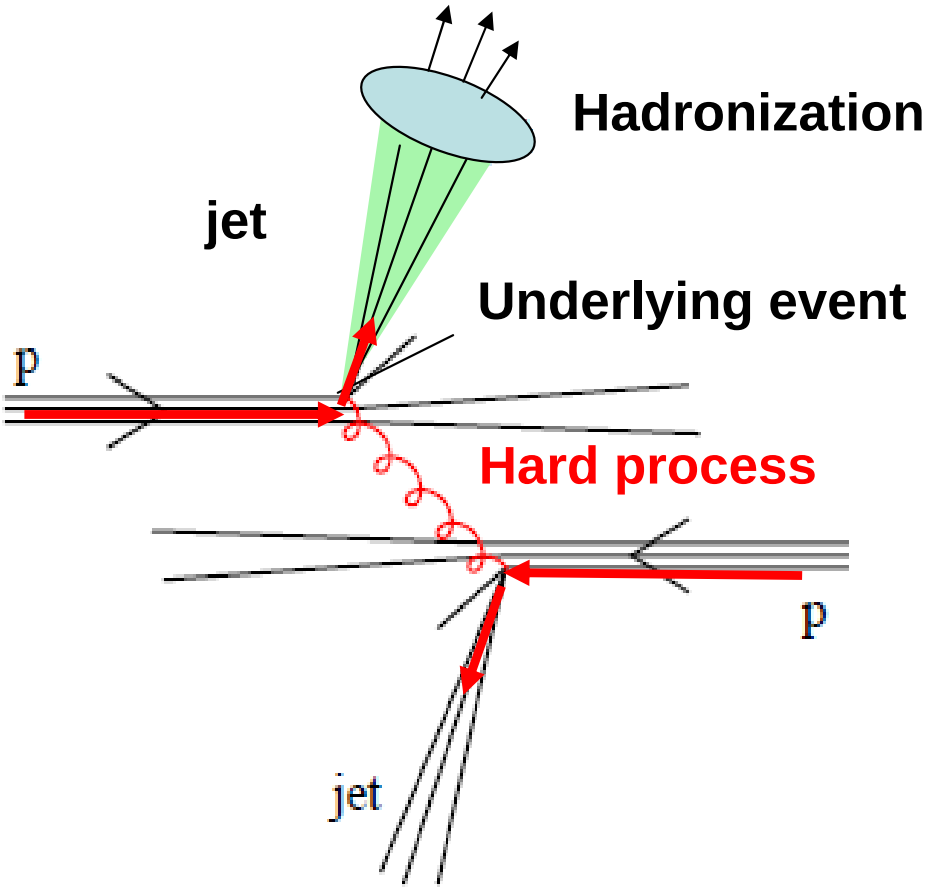
Jet production

- QCD process
  - Hard process
    - Scattering of quarks, gluons
    - Described by perturbative QCD (pQCD).
  - Underlying event, Hadronization
    - Non-perturbative effects

  ➔ Test of QCD

- Reflects proton structure

  → Determination of PDFs in pQCD framework

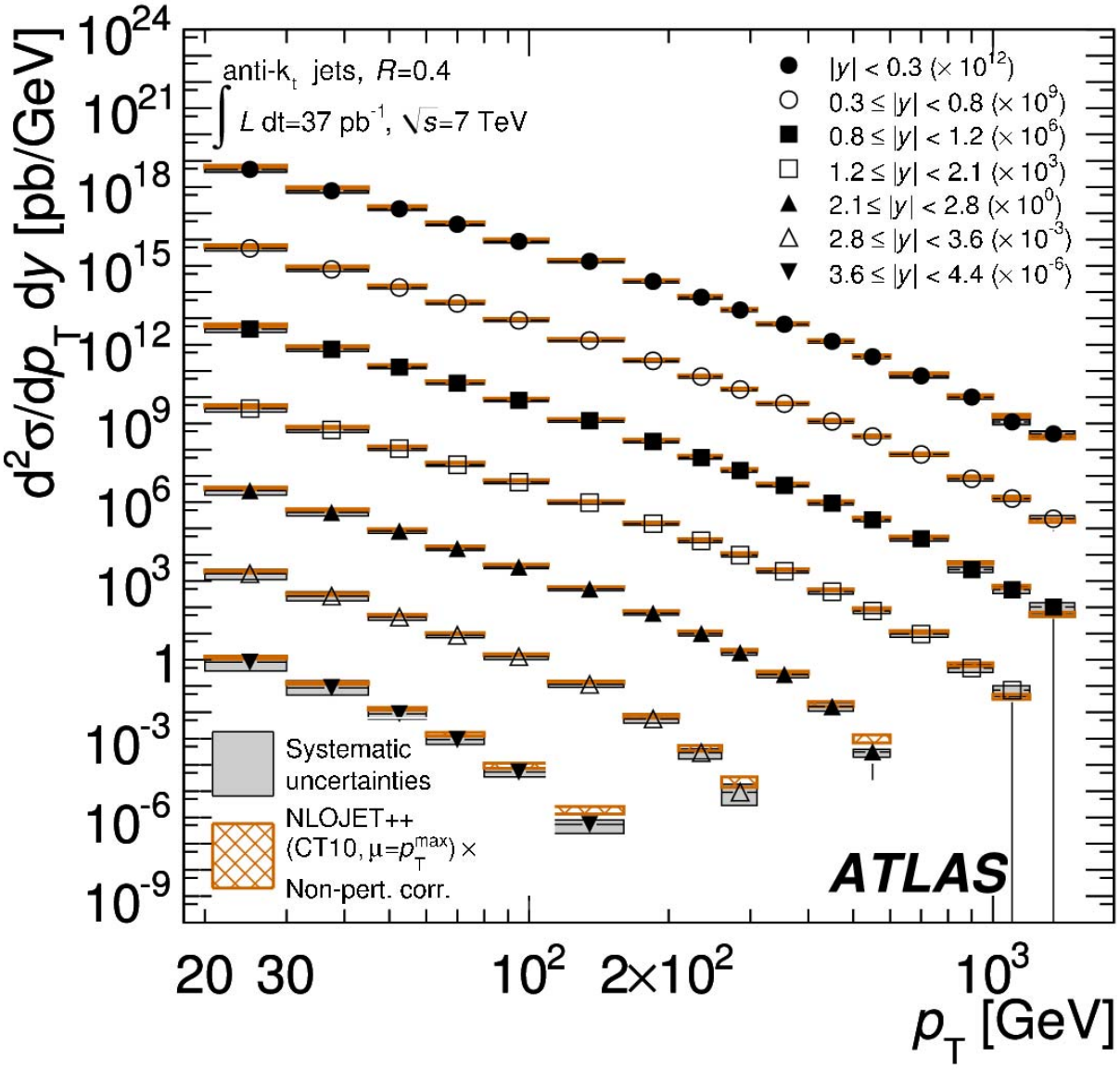


Inclusive jet measurement

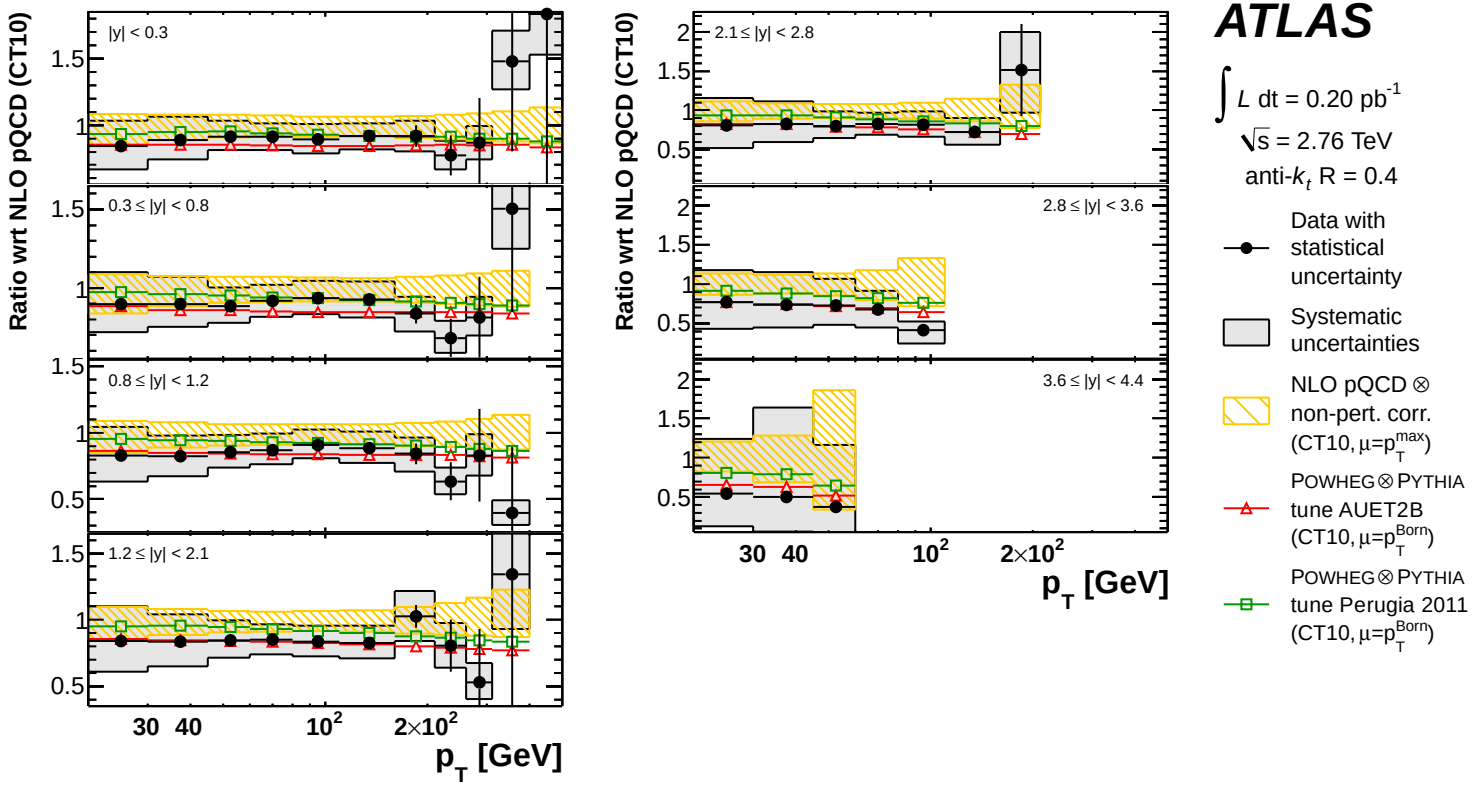
Covering large kinematic region.

- 20 GeV <p_T<1.5 TeV
- |y|<4.4

Compared to predictior from NLO pQCD calculation with non-perturbative correction



Inclusive jet @ 2.76 TeV

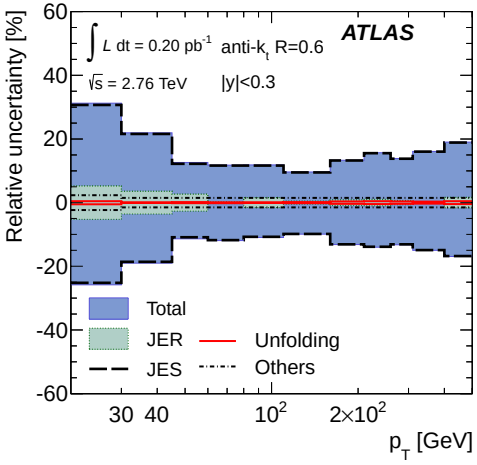


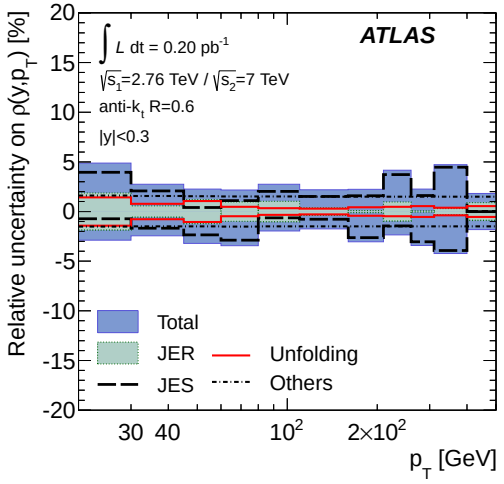
- Good agreement between data and predictions of:
  - NLO pQCD prediction with non-perturbative correction.
  - MC prediction from NLO Matrix Element with matched parton shower (POWHEG+Pythia).
    - Following input from ATLAS, a new version of POWHEG was released.

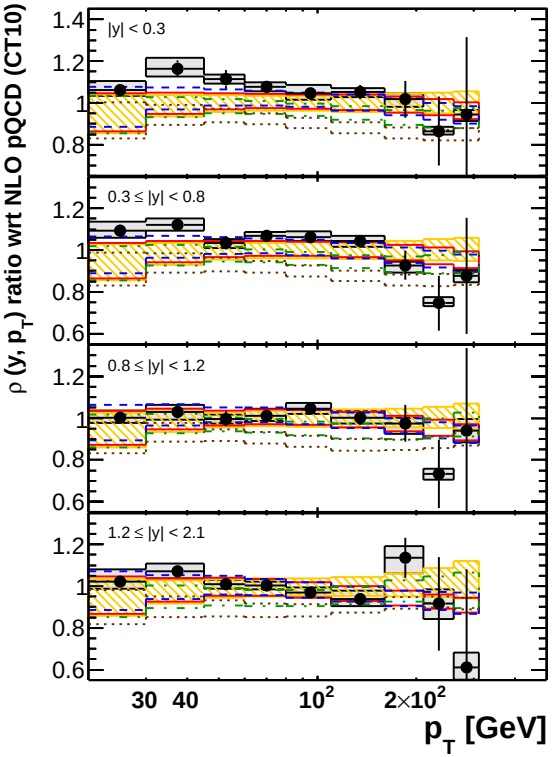
Cross section ratio 2.76 TeV / 7TeV

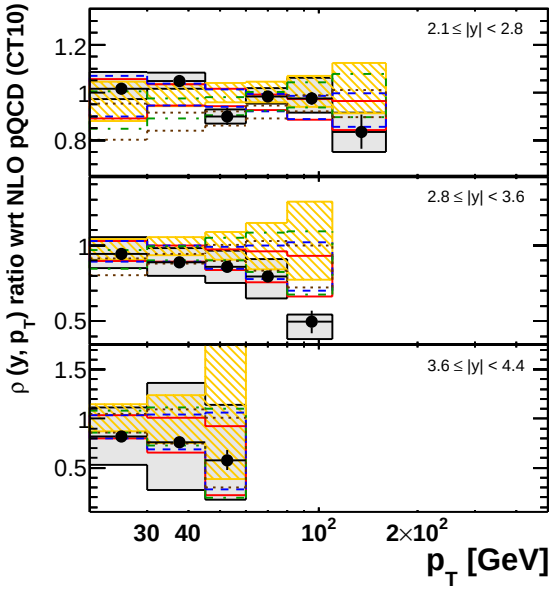
Same jet calibration is used.

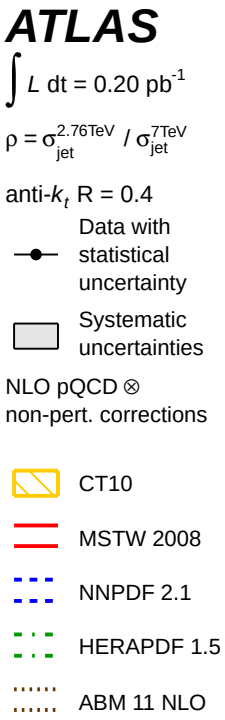
→ Can be cancelled in a ratio of the two measurement.







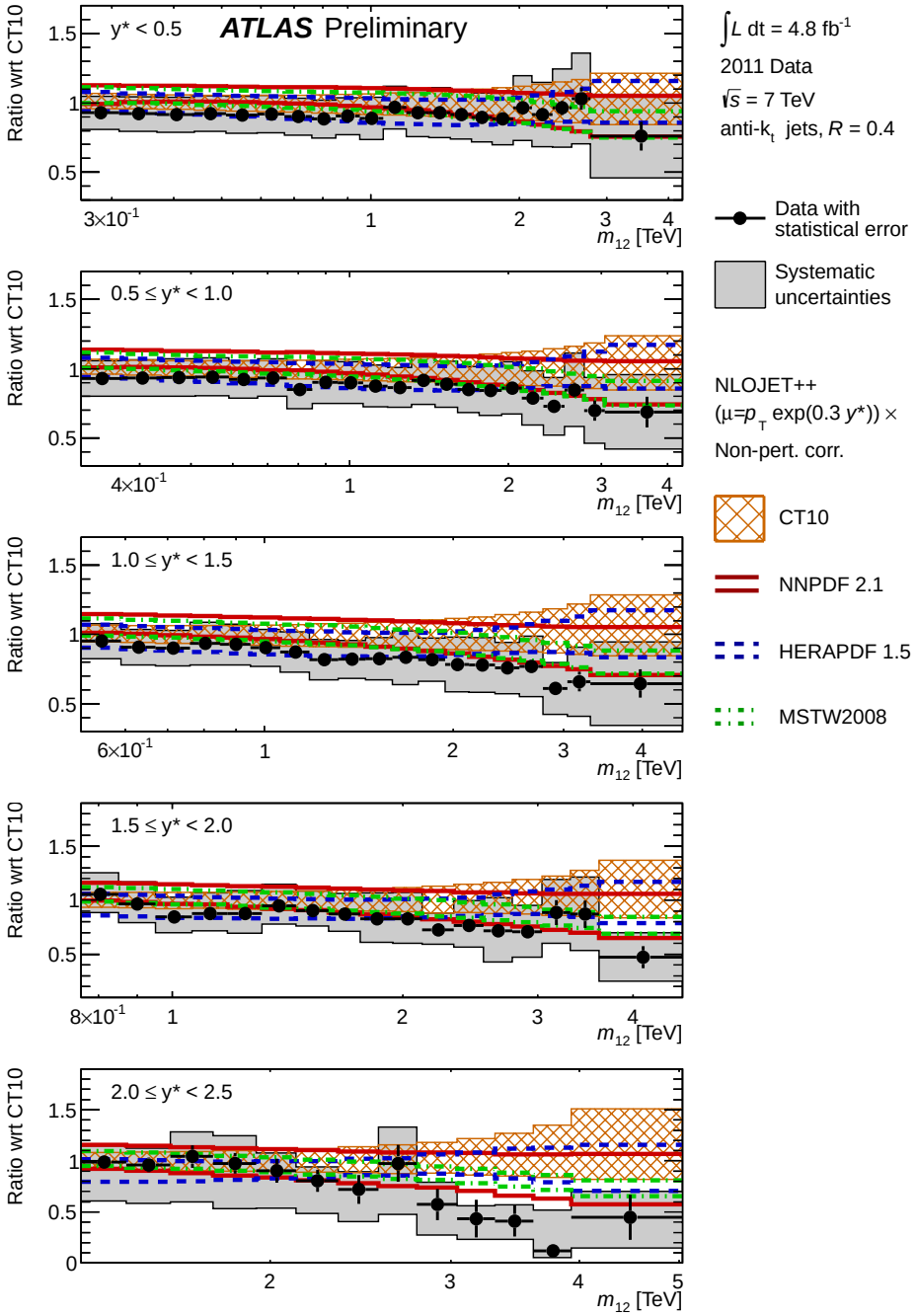




By considering correlation of the two measurement, more sensitivity to PDFs is obtained.

Dijet measurement

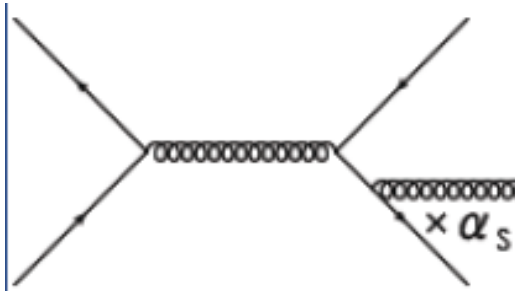
- Invariant mass < 5TeV.
  - leading jet p_T > 100GeV
  - subleading p_T > 50 GeV
  - $|y|$<3.0
- Well described NLO pQCD prediction with NP correction.
- Compared with several PDFs.



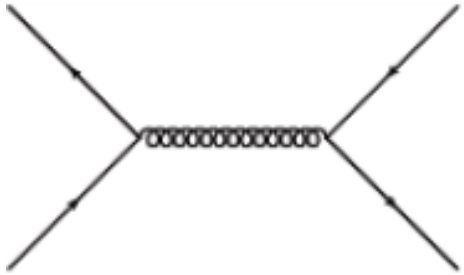
3 jets to 2 jets ratio

- Cross section ratio of 3 jets to 2 jets reflects α_s.
- ATLAS uses the variable

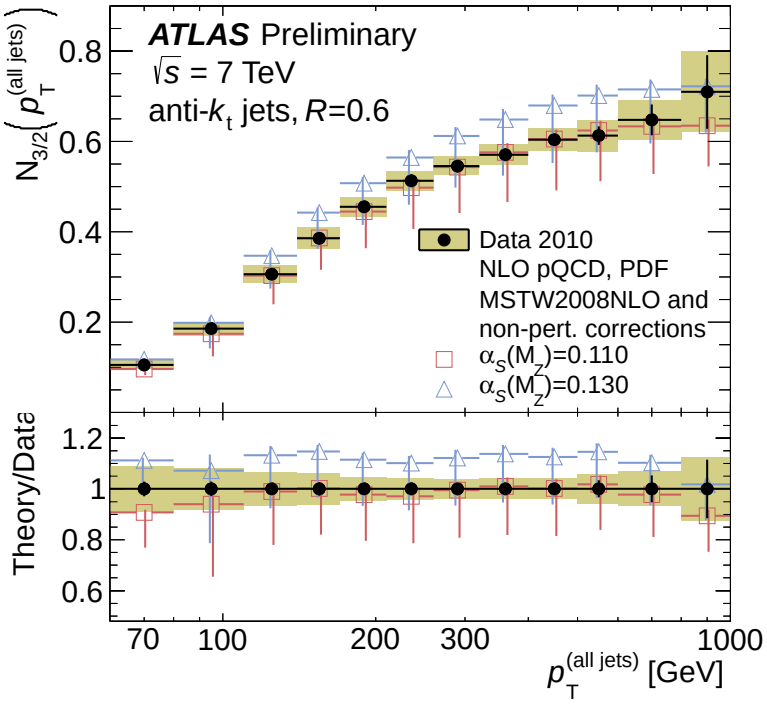
$$N_{3/2}\left(p_T^{\text{all jets}}\right) = \sum_i^{N_{\text{jets}}} \frac{d\sigma_{N_{\text{jets}}\geq 3}}{dp_{T,i}} \Big/ \sum_i^{N_{\text{jets}}} \frac{d\sigma_{N_{\text{jets}}\geq 2}}{dp_{T,i}}$$

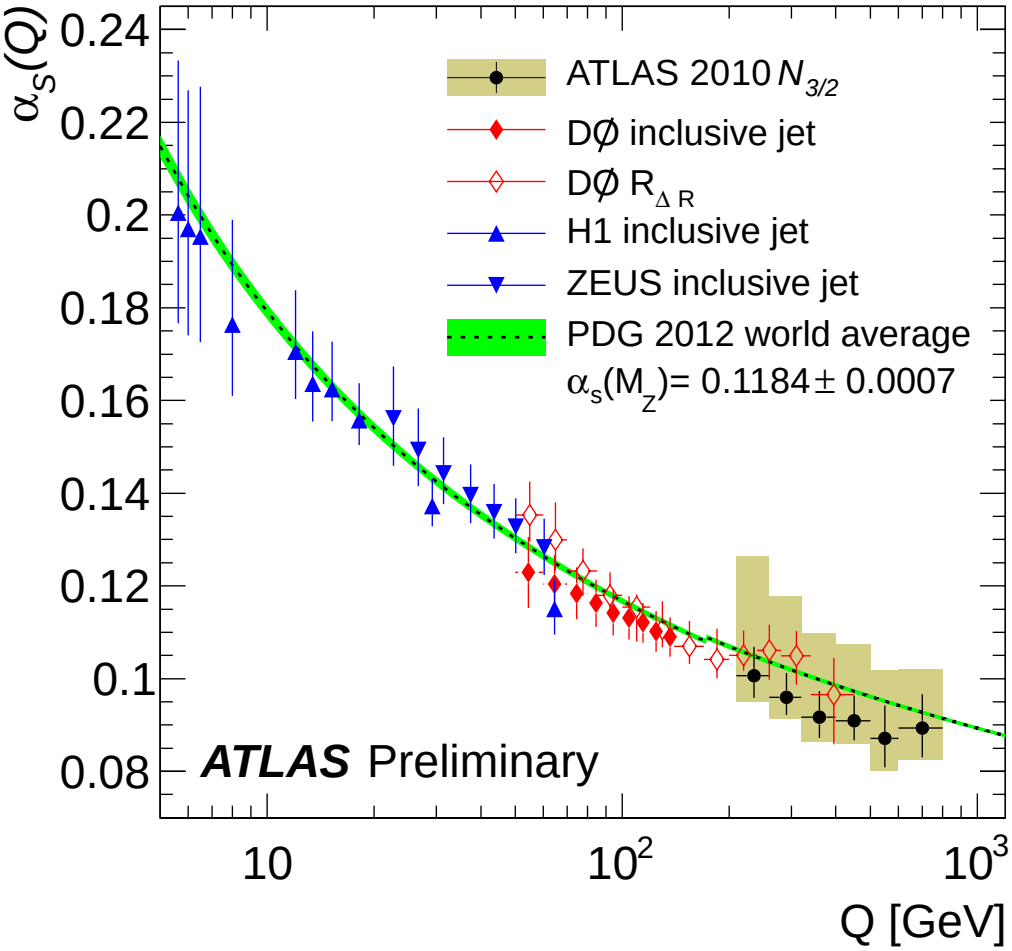


Smaller dependence on factrization and renormalization scales than ratio taken as a function of leading jet p_T.



α_s





$$\alpha_S\,(M_{\mathrm{Z}}) = 0.111 \pm 0.006(\mathrm{exp.})^{+0.016}_{-0.003}(\mathrm{theory})$$

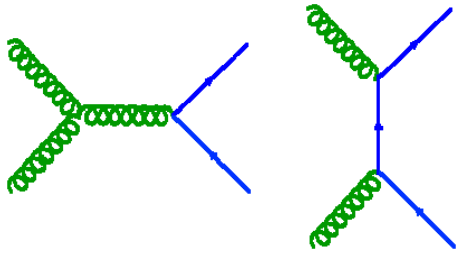
- α_s running is well reproduced by Renormalization group equation upto 1 TeV.

Dijet flavour composition

Three mechanisms of heavy flavour production in a dijet system:

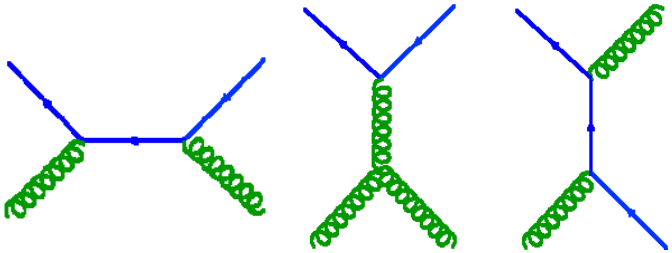
1. Heavy flavour quark pair creation

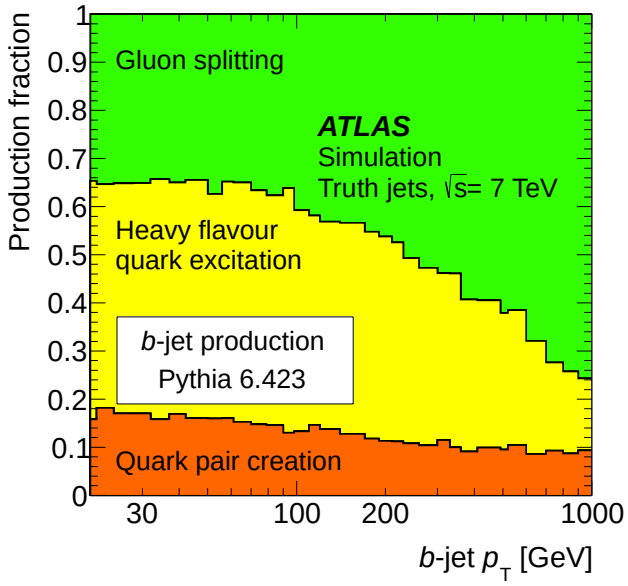
   Two heavy quarks
   in hard interaction
   → pQCD



2. Heavy flavour quark excitation

   Single heavy quark
   in hard interaction
   → PDFs





Pythia MC prediction

3. Gluon splitting

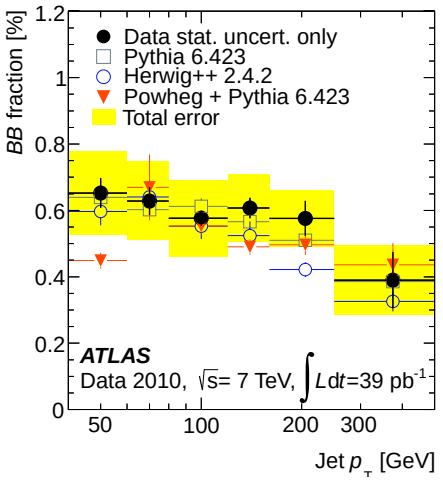
   No heavy quark in hard interaction→ non-perturbative QCD

- Using kinematics of secondary vertex in a jet, dijet flavour composition is extracted.

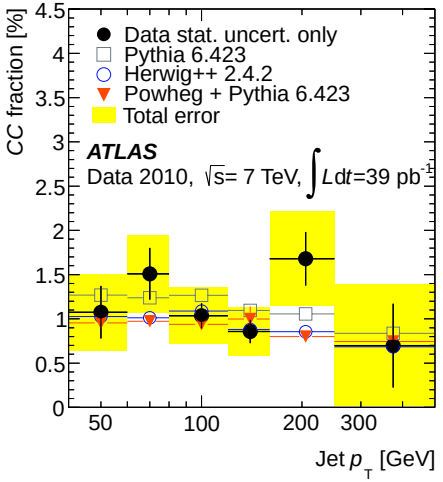
Measured flavour composition

B: b-jet (a jet includes bottom hadrons) ,
C: c-jet,
U: light-quark jet (u, d, s, g)

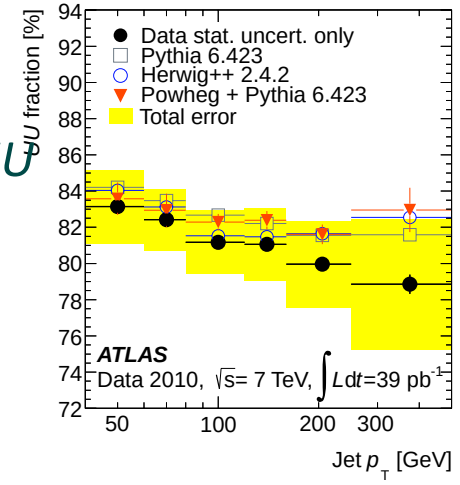
BB



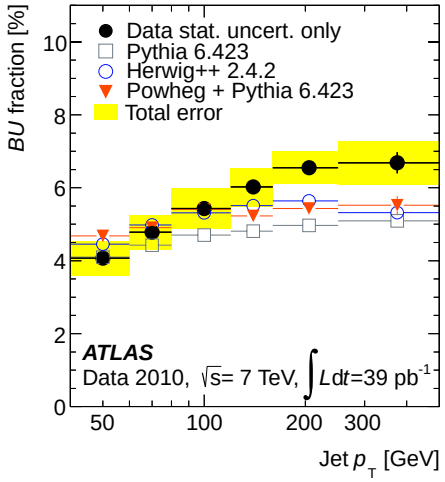
CC



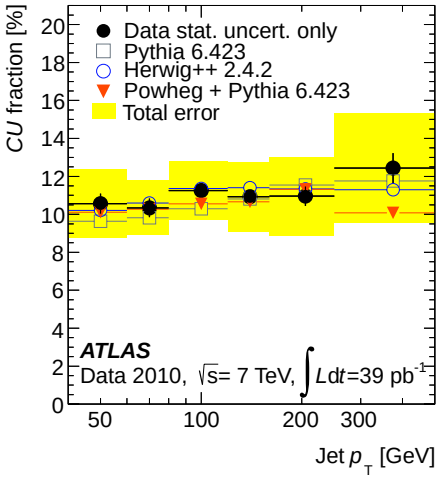
UU



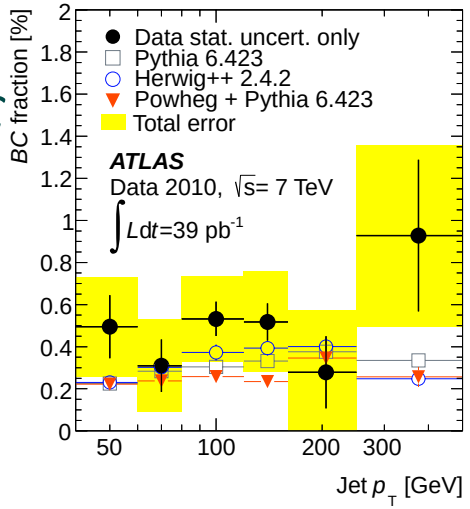
BU



CU



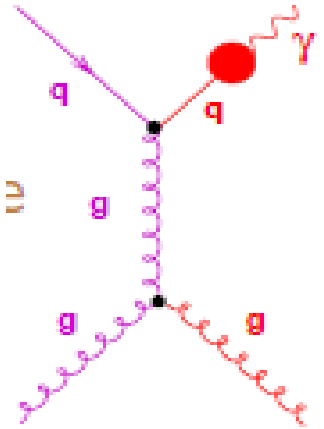
BC

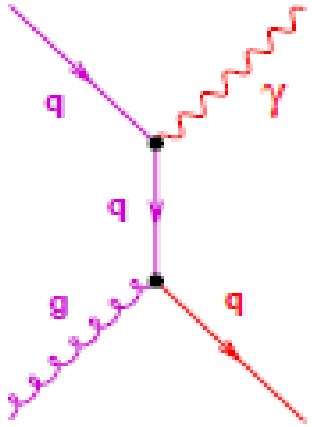


- Generally reproduced by NLO or LO predictions, except for BU fraction.
- Measured BU fraction is higher than predictions at p_T>100 GeV.

Photon measurements

- High-p_T prompt photons can be produced via two mechanism
  - Fragmentation process
  - Direct photon process

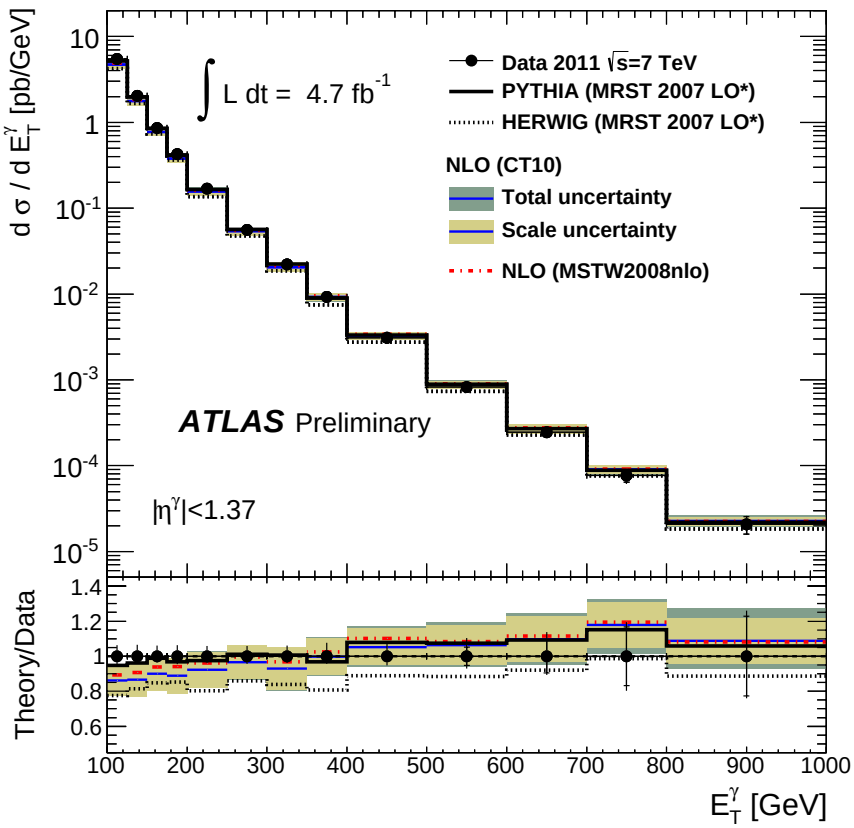


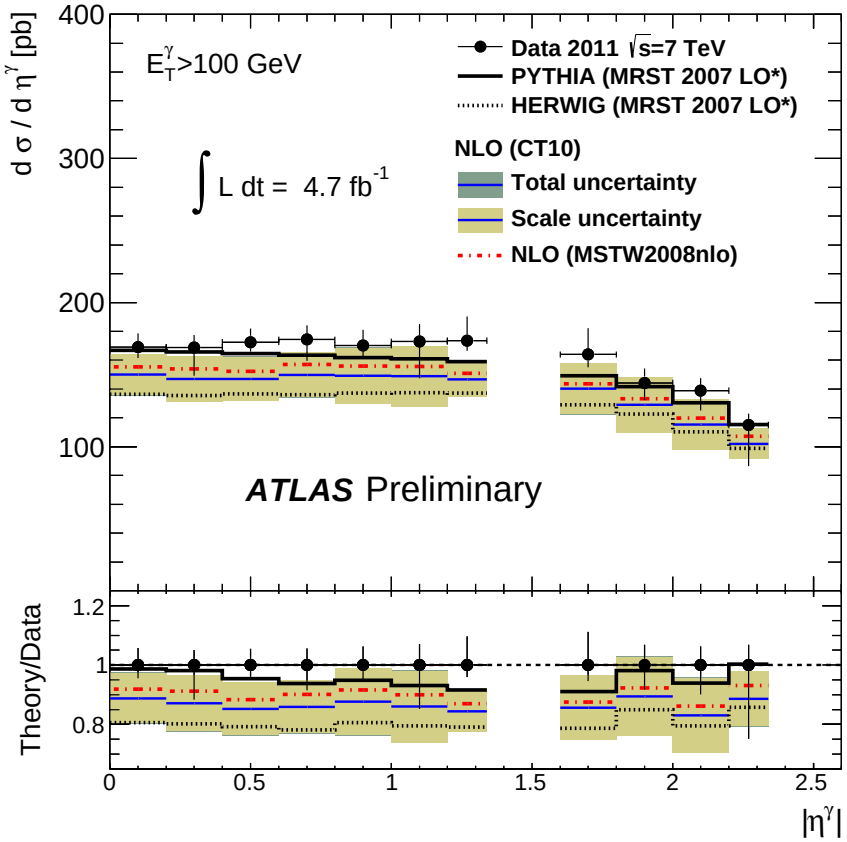


- Test of pQCD
- Constraint on the gluon PDF.
- Check contribution from photon fragmentation processes.

Inclusive isolated prompt photon

- Measured up to 1 TeV, η <2.4

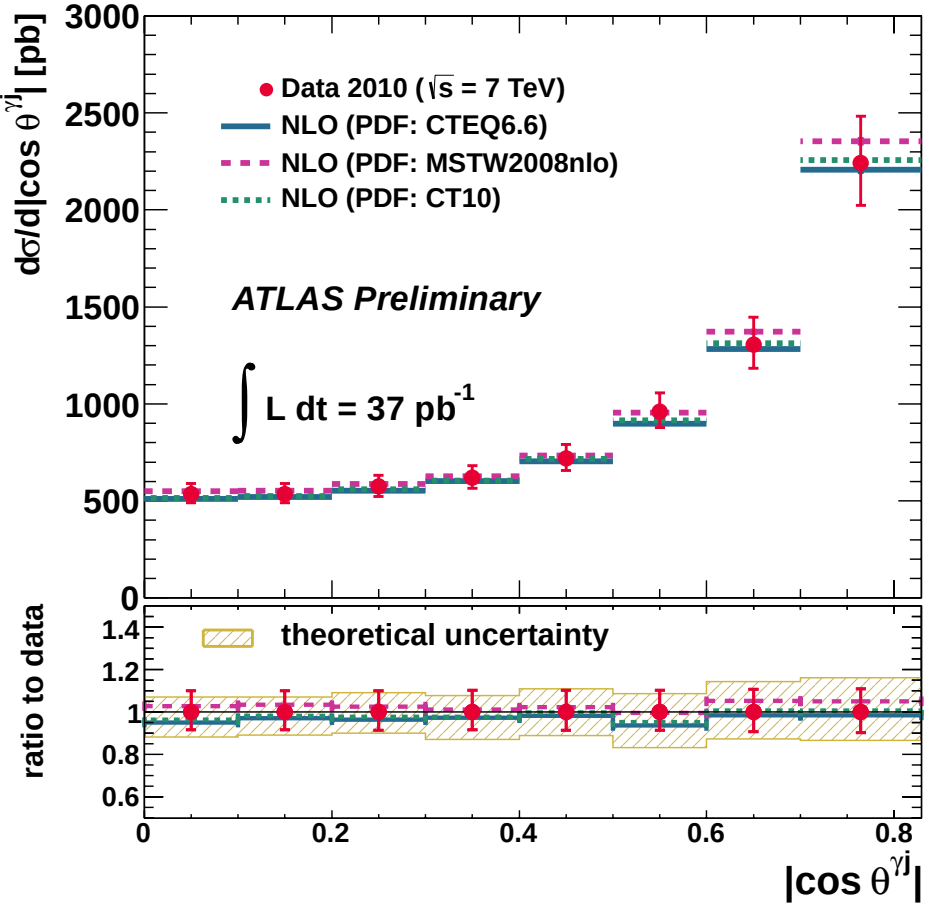


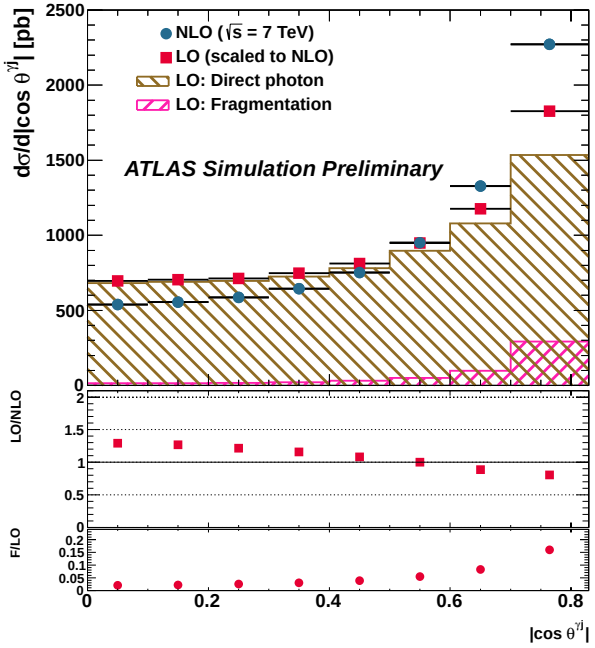


- NLO prediction describes the measurement in the central region.
- Lower in the forward region.

photon + jet

- Fragmentation process and direct process has different $\cos\theta^{\gamma j}$ dependence due to spin of boson.



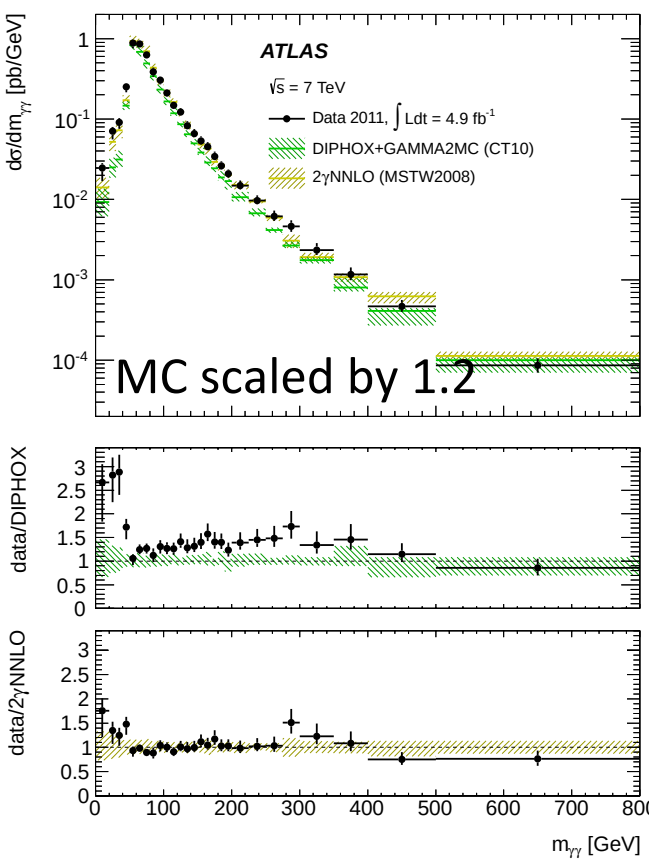


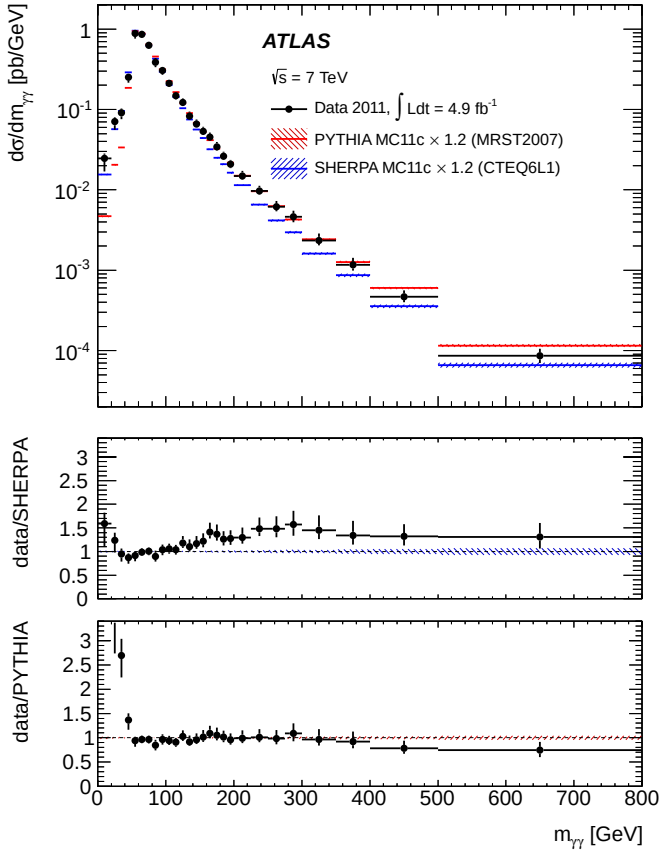
- NLO describe the measurement well.
- LO probably needs more fragmentation process.

Diphoton cross section

- Measured for m $_{\gamma\ \gamma}$, p_T, $\Delta\phi$, $\cos\theta^*$.
- Compared to
  - LO+PS: Pythia, Sherpa
  - NLO: DIPHOX
  - NNLO: 2 γ NNLO, but no fragmentation process.

NNLO improves the description but not pefrect due to lack of fragmentation contribution.





Summary

- Many precise measurements are done and also ongoing.
  - Comparison with calculation and simulation to give feedback and improve them.
    - Especially in QCD.
  - Many input to PDF determination.

  → Important in order to have best precision at LHC experiment.

- Not all the results are shown.
  - Please see

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

    http://cms.web.cern.ch/org/cms-papers-and-results

  for more.

PDF whishlist at the LHC

Traditional

- Inclusive jets and dijets, central and forward: **large-x quarks and gluons**
- Inclusive W and Z production and asymmetries: **quark flavor separation, strangeness**

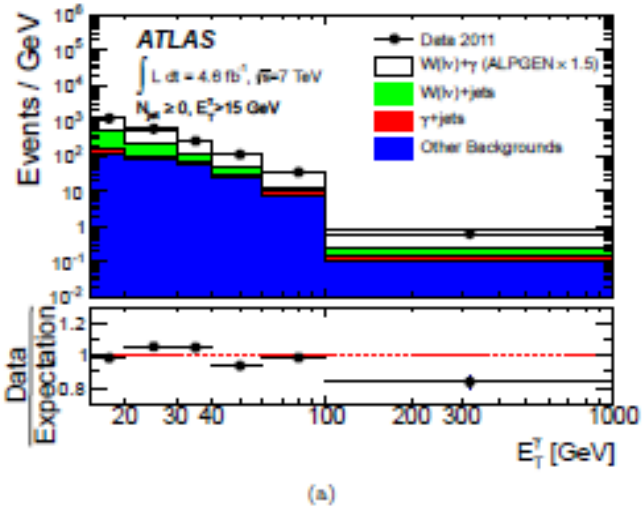
New @ LHC

- Isolated photons, photons+jets: **medium-x gluons**
- W production with charm quarks: **direct handle on strangeness**
- W and Z production at high p_T: **medium and small-x gluon**
- Off resonance Drell-Yan and W production at high mass: **quarks at large-x**
- Low mass Drell-Yan production: **small-x gluon**
- Top quark cross-sections and differential distributions: **large-x gluon**

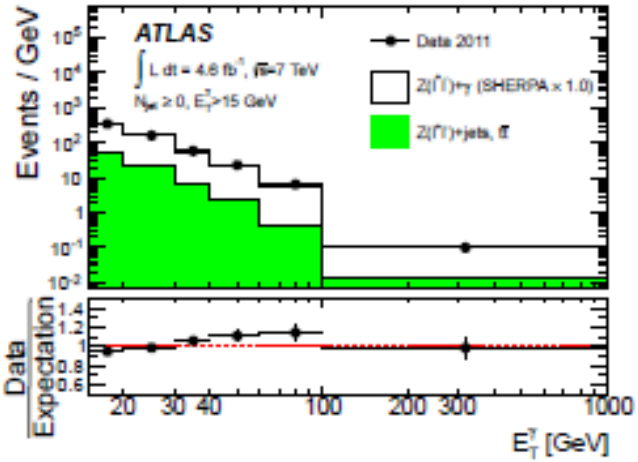
Speculative

- Z+charm: **intrinsic charm PDF**
- Single top production: **gluon and bottom PDFs**
- Charmonium production: **small-x gluon**
- Open heavy quark production: **gluon and intrinsic heavy flavor**

W γ and Z γ



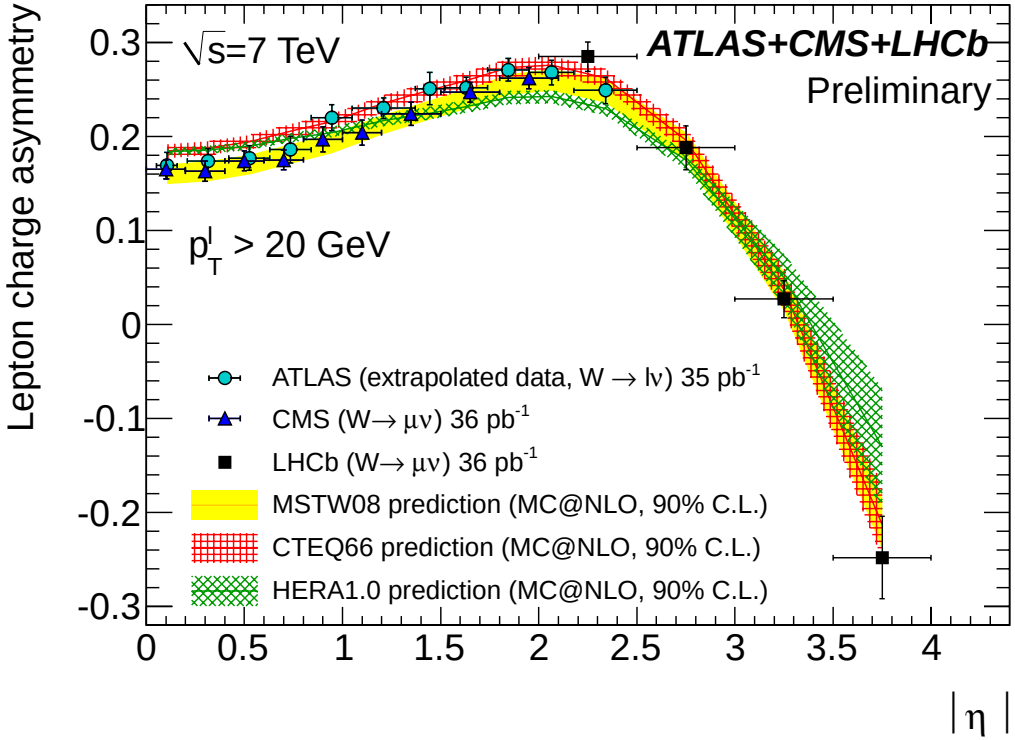
(a)



- Wγ ➔ lνγ and Zγ ➔ llγ
  - W/Z + isolated photon, $E_T(\gamma) > 15$ GeV
  - $\Delta R(l,\gamma) > 0.7$ (suppress FSR)
  - Background: W/Z/γ+jets
- Zγ ➔ ννγ
  - Missing transverse energy + isolated photon
  - $E_T(\gamma) > 100$ GeV (ATLAS)
  - $E_T(\gamma) > 145$ GeV (CMS)
  - Background: W, Wγ, γ+jets

W charge asymmetry

$$\mathcal{A}(\eta) = \frac{d\sigma/d\eta(W^+ \to \ell^+\nu) - d\sigma/d\eta(W^- \to \ell^-\bar{\nu})}{d\sigma/d\eta(W^+ \to \ell^+\nu) + d\sigma/d\eta(W^- \to \ell^-\bar{\nu})}$$



- Good agreement between experiments.