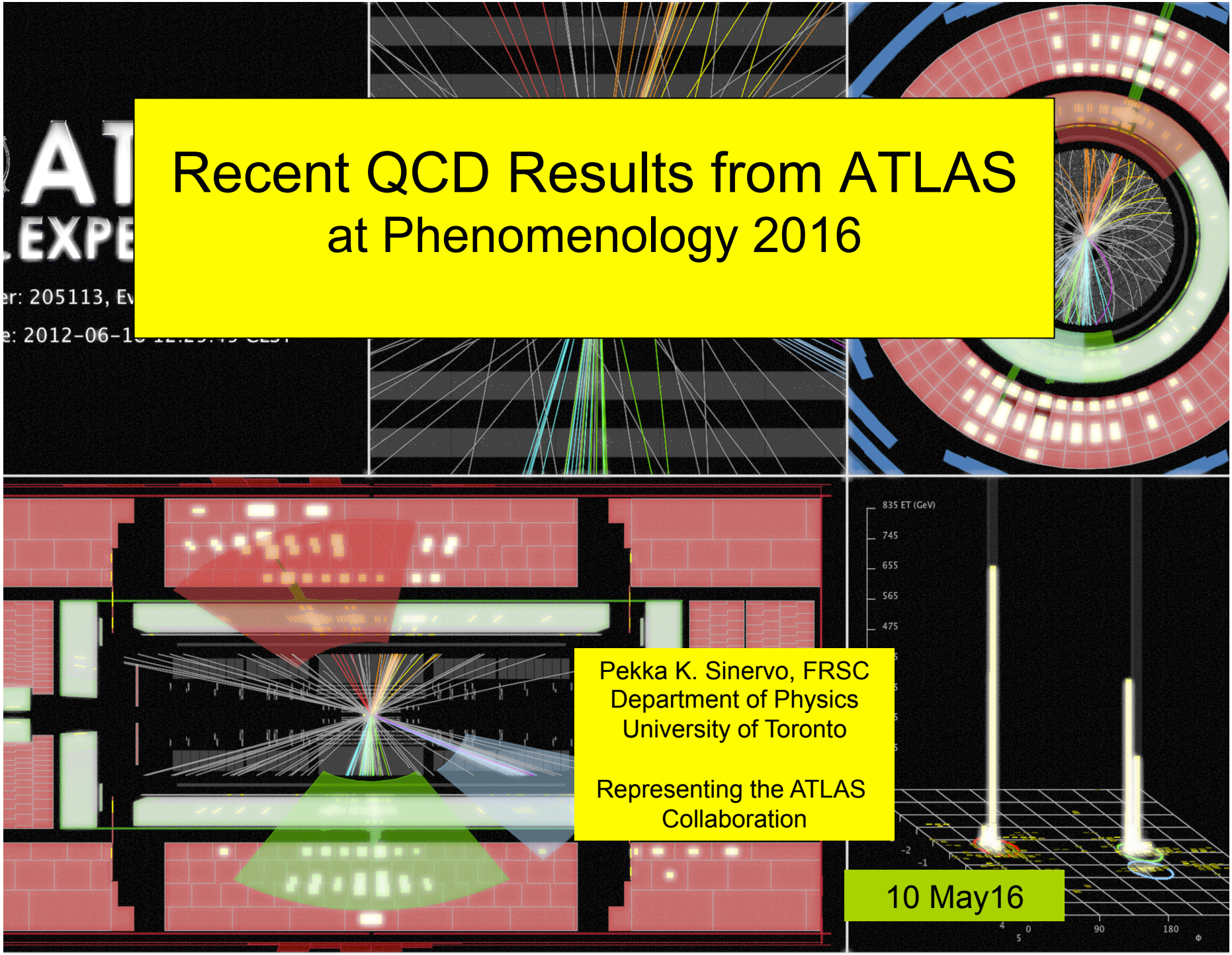

Recent QCD Results from ATLAS
at Phenomenology 2016

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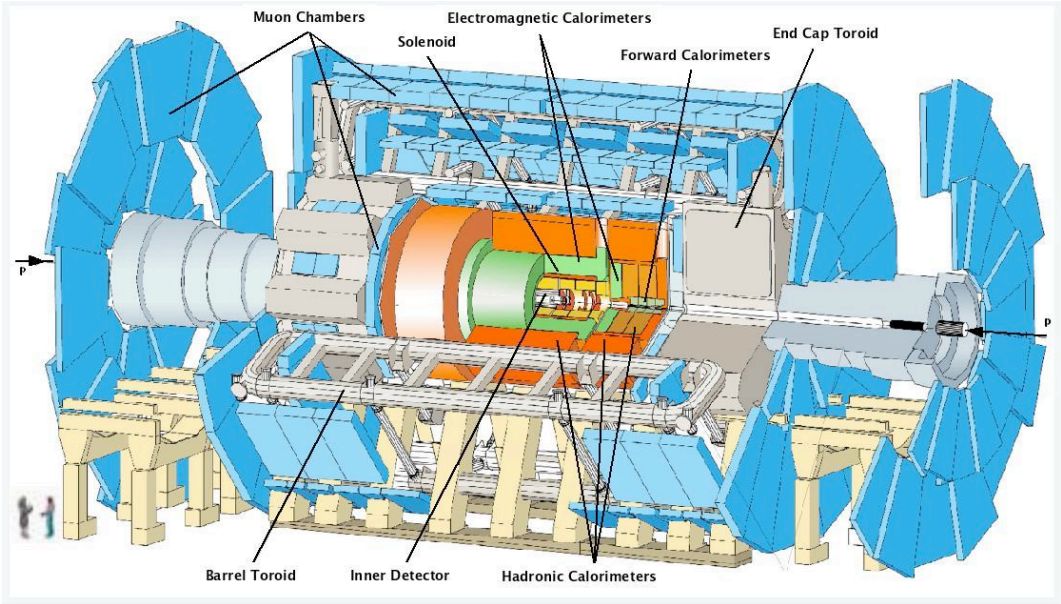
Department of Physics
University of Toronto

Representing the ATLAS Collaboration

10 May16

Outline

1. **Introduction to the ATLAS experiment**
2. **Overview of most recent QCD measurements**
   1. The inelastic pp cross section at 13 TeV
   2. Diffractive dijet production with a large rapidity gap
   3. Z boson event shape
   4. Isolated inclusive photon cross section
   5. b quark pair production
3. **Summary & Conclusions**



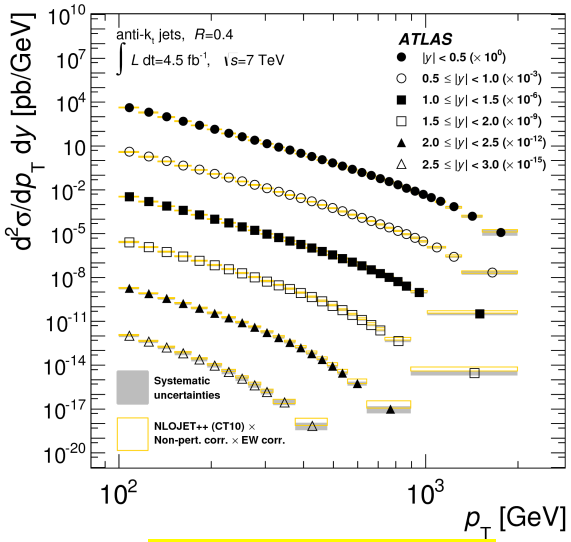
QCD Measurements by ATLAS

ATLAS has published **60** jet, soft QCD and direct photon studies

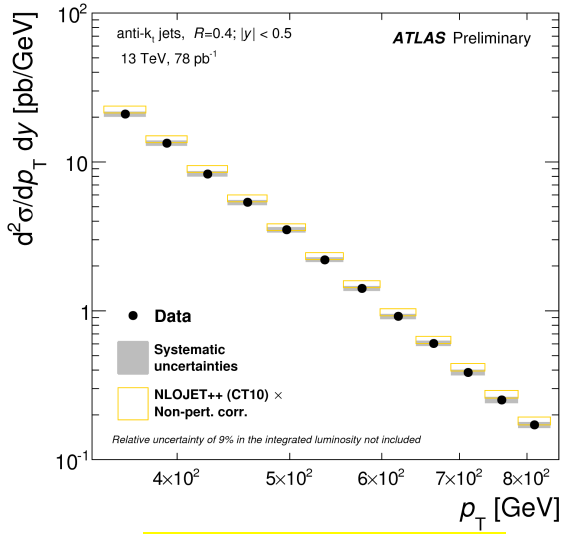
Extensive body of work, e.g.

- Inclusive jet production at 7, 8 and 13 TeV
- Jet fragmentation at 8 TeV

Inclusive Jet Production at 7 and 13 TeV



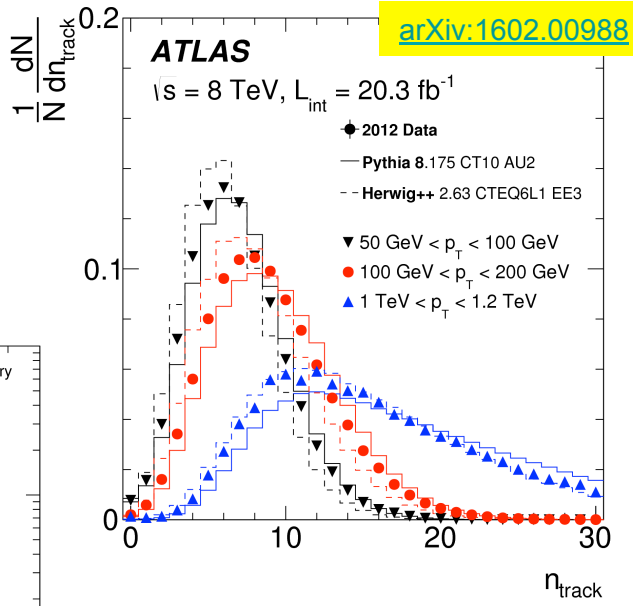
JHEP 02 (2015) 153



ATLAS-CONF-2015-034

Charged Particle Distributions in Jets

arXiv:1602.00988

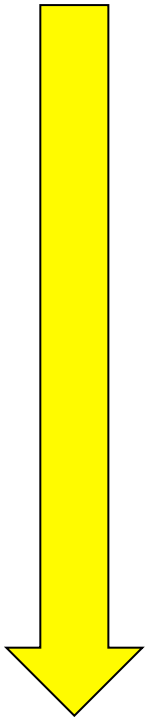


Working to better understand

- high-order effects
- non-perturbative “soft” regime

Recent ATLAS QCD Results

Soft QCD



High p_T QCD

Inelastic pp cross section

- No fundamental theory to make predictions
- Important for other studies of pp interactions

Diffractive dijet production with large rapidity gaps

- Probes our understanding of diffractive and doubly-diffractive processes

Z boson event shapes

- Underlying event structure in Z boson events
- Important for understanding interplay of soft and hard QCD

Inclusive photon differential cross section

- New measurement at 8 TeV
- Test of QCD and understanding of proton gluon density

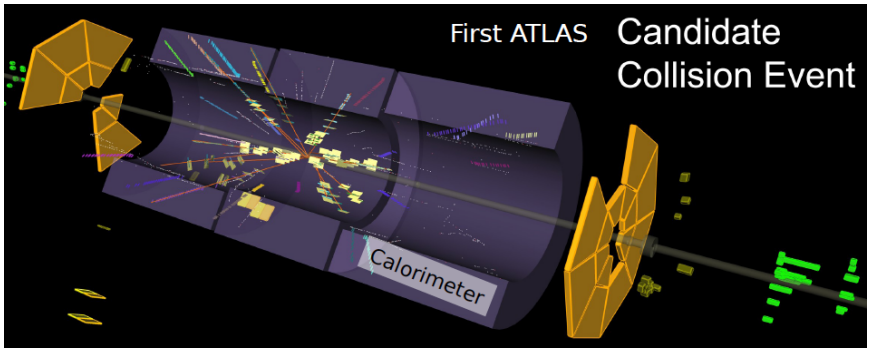
b-quark pair production differential cross section

- Important to understand QCD b-quark production

1. Inelastic Cross Section

The pp inelastic cross section characterizes the strong interaction

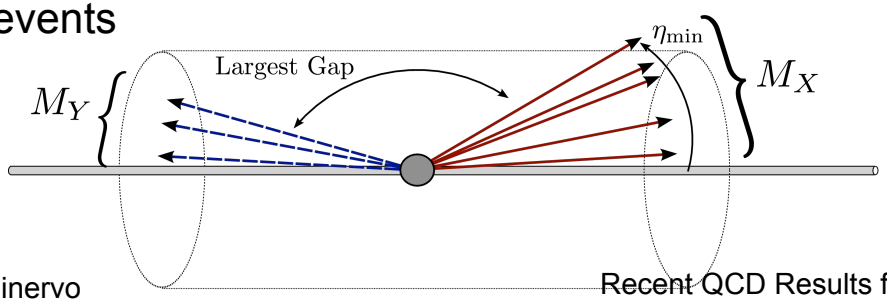
- But cannot be derived from first principles
- Constraints come from general considerations

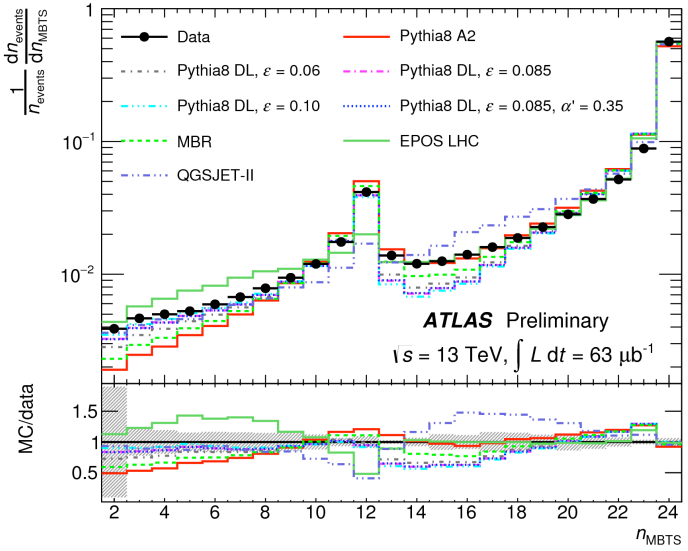


Dominated by low transverse momentum processes

$$\xi \equiv M_X^2 / s$$

- Analysis uses Minimum Bias Trigger System (MBTS)
- Counts single and double-diffractive events





ATLAS-CONF-2015-038

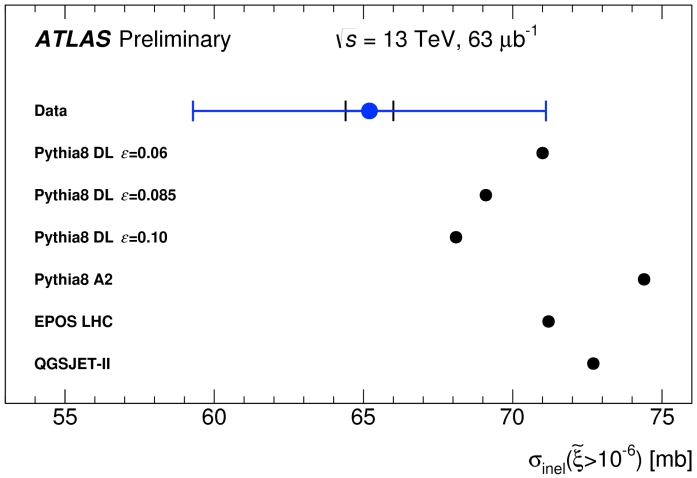
Inelastic Cross Section

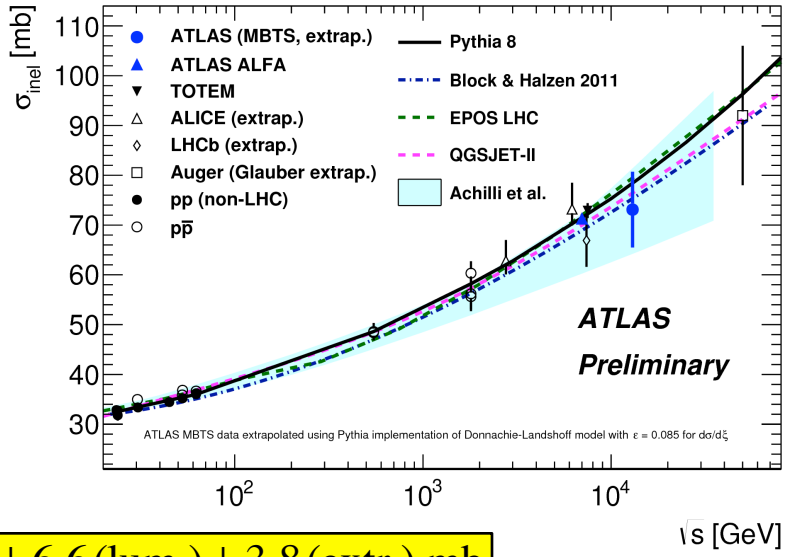
Performed a special low-luminosity run

$$\sigma_{inel}(\xi > 10^{-6}) = \frac{N - N_{BG}}{\varepsilon_{trig} \times L} \times \frac{1 - f_{\xi<10^{-6}}}{\varepsilon_{sel}}$$

- Use ratio of events passing single-sided and inclusive selection
- Donnachie & Landshoff model is best match to n_{MBTS} distribution – chosen as default model
- Extrapolate fiducial cross section to total phase space

Factor	Value	Rel. unc.
Number of selected events (N)	4159074	–
Number of background events (N_{BG})	43512	±100 %
Luminosity [$\mu\mathrm{b}^{-1}$] (L)	62.9	±9 %
Trigger efficiency (ϵ_{trig})	99.7%	±0.1 %
MC Correction factor ($(1 - f_{\tilde{\xi}<10^{-6}})/\epsilon_{\mathrm{sel}}$)	0.993	±0.5 %



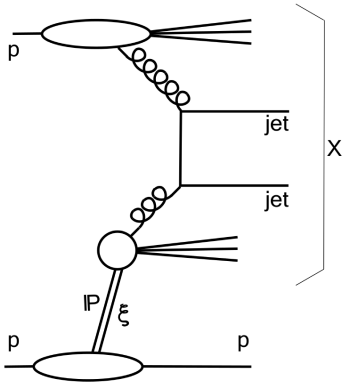


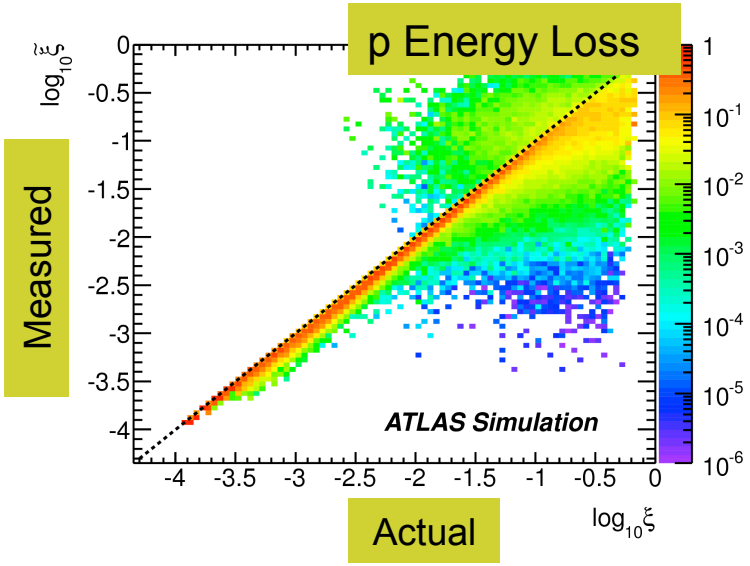
$$\sigma_{inel} = 73.1 \pm 0.9\,(\mathrm{exp.}) \pm 6.6\,(\mathrm{lum.}) \pm 3.8\,(\mathrm{extr.})\ \mathrm{mb}$$

2. Dijets with Rapidity Gaps

Diffractive dijet production probes proton structure

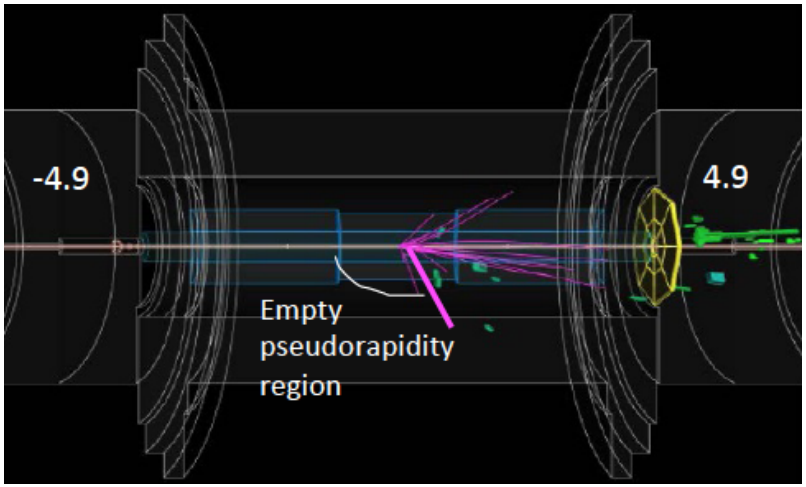
- Measurements at ep and hadron colliders not reconciled
- Use existence of “rapidity gap” to isolate process
- Measure ξ, fraction of energy lost by p, by summing over all particles





Used dedicated low-L run

- Events free of multiple pp interactions
- Collected 6.8 nb^{-1} at 7 TeV
- Select events with
  - 2 jets with pT > 20 GeV and |η|<2
- Use neutrals with p_T>200 MeV or charged particles with p_T>500 MeV to delimit gap
  - Gap $\Delta\eta^F$ is largest empty η interval on either side up to |η|=1.7 on other side



Dijets with Rapidity Gaps

Data shows large non-diffractive component

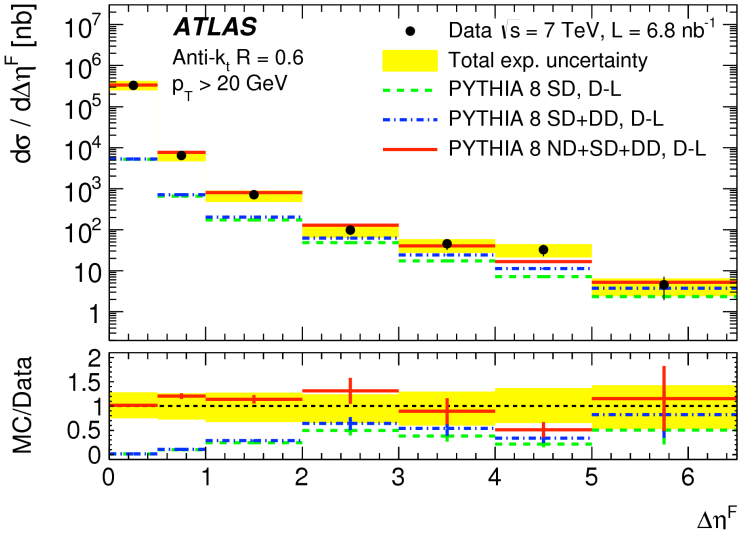
- Dominates at small $\Delta\eta^F$ and high ξ
- Model-dependent analysis provides some constraints on relative mixture

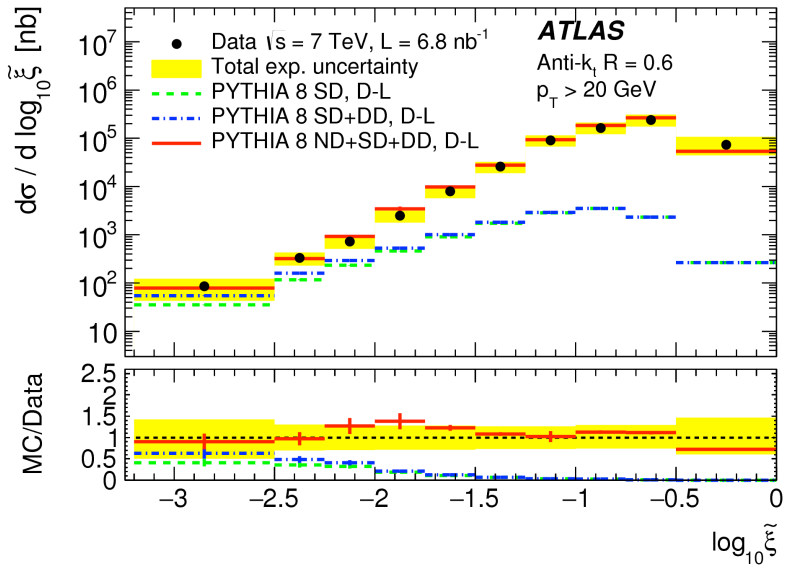
Translate into measurement of the absorption of non-diffractive σ

- Use POMWIG MC to describe non-diffractive component, with rapidity gap survival probability

$$S^2 = 0.16 \pm 0.04(\text{stat.}) \pm 0.08(\text{exp. syst.})$$

- Consistent with CMS and Tevatron measurements (but large uncertainty)
- Note that PYTHIA 8 can describe large $\Delta\eta^F$ data without suppression factor





Phys. Lett. B 754, 214 (2016)

3. Event Shapes in Z Boson Events

Underlying event (UE) in pp collisions important feature

- Many studies at Tevatron & LHC
- Important for understanding of hard-scattering process
- Models involve multi-parton interactions
- Rely on "tuning"

Use Z boson events

- Remove Z decay
- Measure charged track event observables sensitive to UE
- Study 4 observables as function of Z boson p_T
  - 0-6 GeV
  - 6-12 GeV
  - 12-25 GeV
  - > 25 GeV

$$B \equiv \sum p_T \cdot e^{-|\eta|}$$ Beam Thrust

$$T \equiv \max_{\hat{n}_T} \frac{\sum |\vec{p}_T \cdot \hat{n}_T|}{\sum p_T}$$ Transverse Thrust

$$S \equiv \frac{\pi^2}{4} \min_{\vec{n}=(n_x,n_y,0)} \left[\frac{\sum |\vec{p}_T \times \vec{n}|}{\sum p_T} \right]^2$$ Spherocity

$$F \equiv \frac{\lambda_1}{\lambda_2} \text{ where } \lambda_i \text{ eigenvalues of}$$

F-parameter

$$M^{lin} \equiv \sum_i \frac{1}{p_{T,i}} \begin{pmatrix} p_{x,i}^2 & p_{x,i}p_{y,i} \\ p_{x,i}p_{y,i} & p_{y,i}^2 \end{pmatrix}$$

Submitted to EPJC, ArXiv:1602.08980

Observed Event Shapes

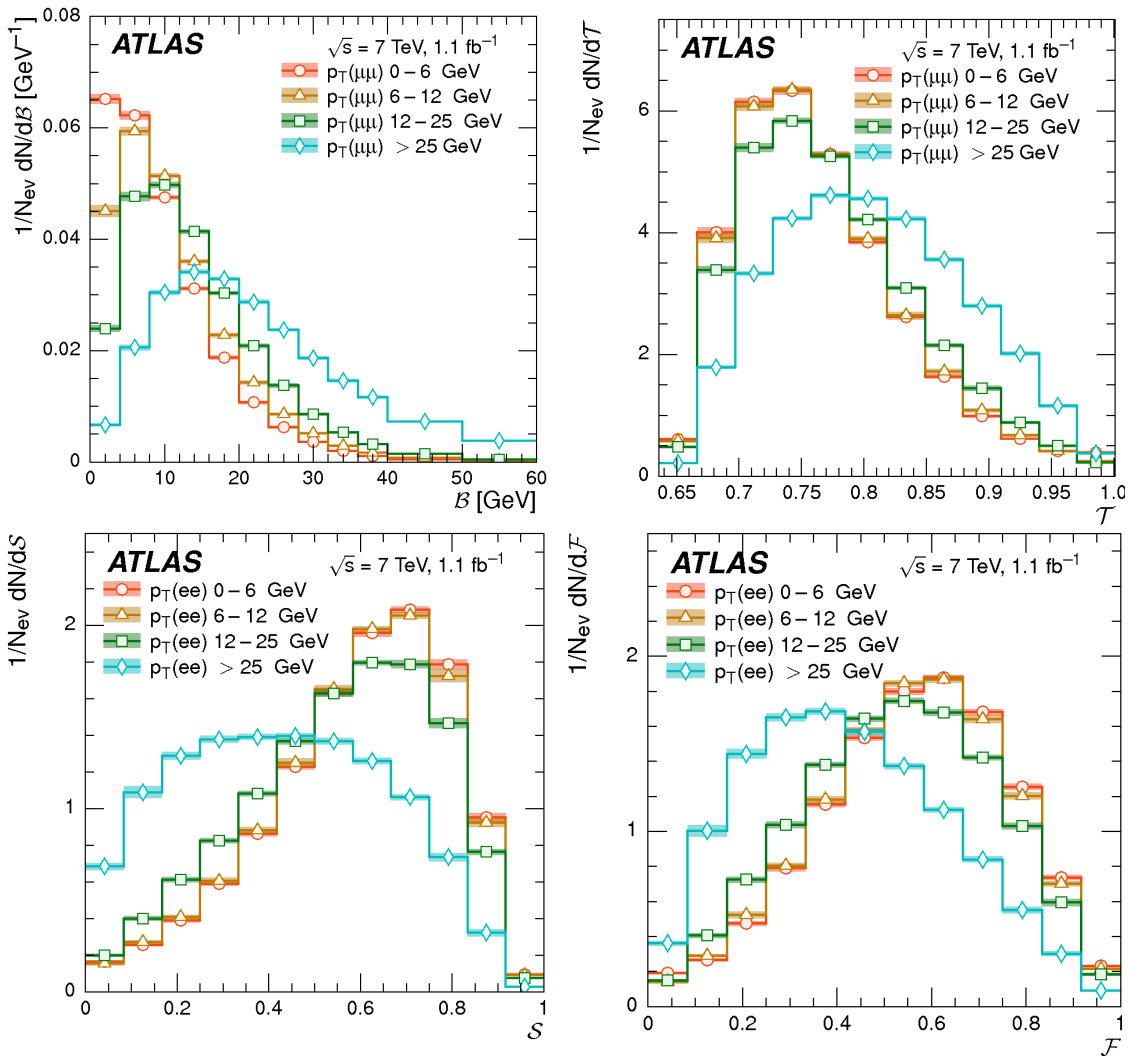
Analysis used 1.1 fb^{-1} of 7 TeV collisions

- Identified Z bosons via $\mu^+\mu^-$ & e+e- decays
- Removed Z boson tracks
- Corrected for pileup

See evolution with Z boson p_T

- Expect to see effects of Z+jet production in highest p_T bin
- Three lowest pT bins have similar behaviour

Next step: compare with models



Comparisons with UE Models

Compared to predictions:

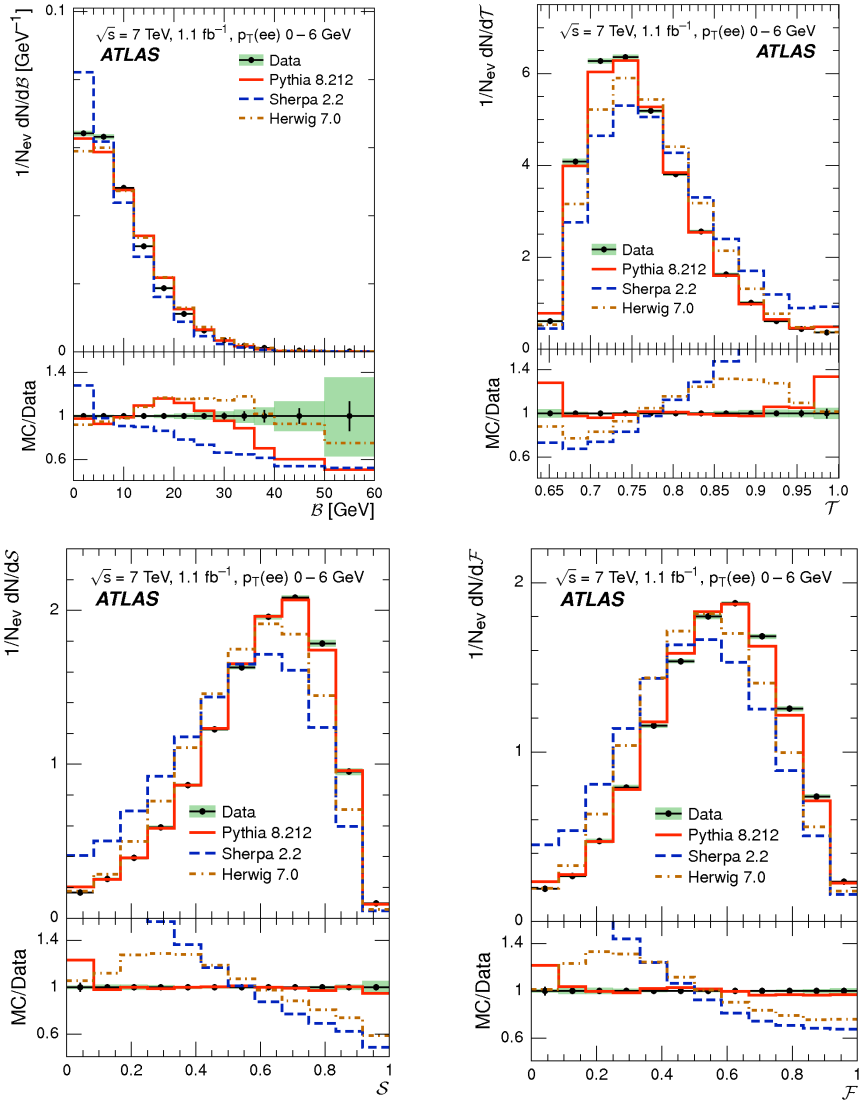
- SHERPA 2.2.0 at NLO with NNPDF 3.0
- PYTHIA 8.212 at LO with NNPDF2.3
- HERWIG 7.0 at NLO with MMHT2014

Employed default configurations

- PYTHIA 8.212 used Monash 2013 tune

Overall conclusions

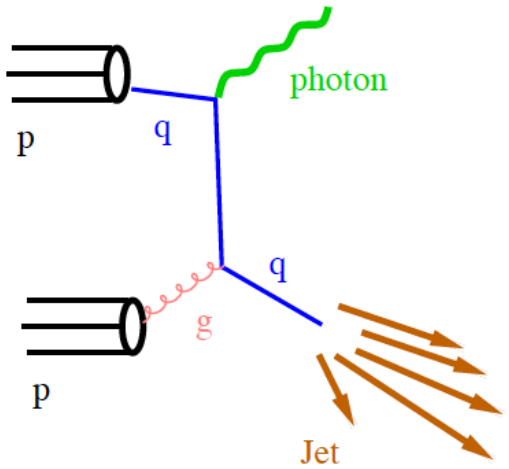
- HERWIG best with variables depending explicitly on # charged particles
- PYTHIA tends to do better on variables independent of # charged particles
- Low p_T sample has greatest variance
- Generally, all generators do better in the high p_T samples
- Overall, PYTHIA and HERWIG do better over most kinematic regimes



4. Inclusive Photon Cross Section

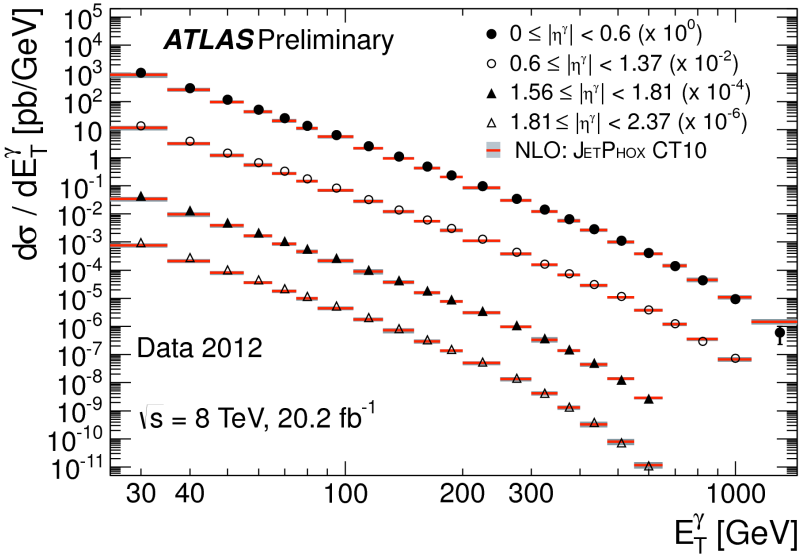
Isolated photon production important SM process

- Probes interplay of EW and QCD processes
- Probes the gluon PDF in proton
- Important background source to understand for other analyses



Measured differential cross section in 20 fb^{-1} of 8 TeV data

- Require isolation in η-φ cone R=0.4
- Cross section shown in 4 different |η| bins
- Compared with JETPHOX generator with CT10 PDFs
- Overall agreement appears reasonable



ATLAS-STDM-2014-09

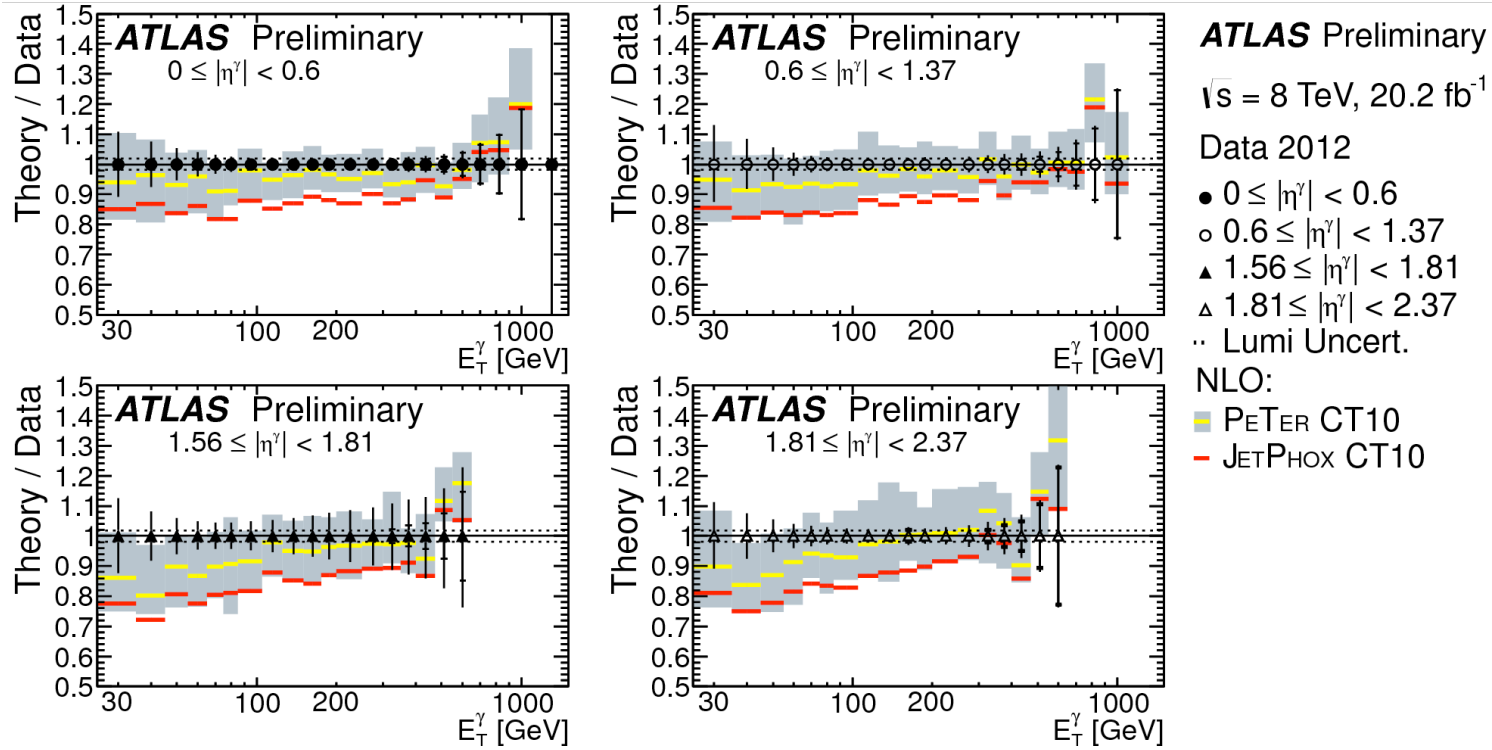
Inclusive Photon Cross Section

Detailed comparisons of differential cross sections against predictions by

- JetPhox CT10 – NLO
- PETER
- PYTHIA
- SHERPA

PETER best description

- Generally poor agreement in shape with other MC predictions



5. b-Quark Pair Production

b-quark pair production first heavy flavour creation process studied

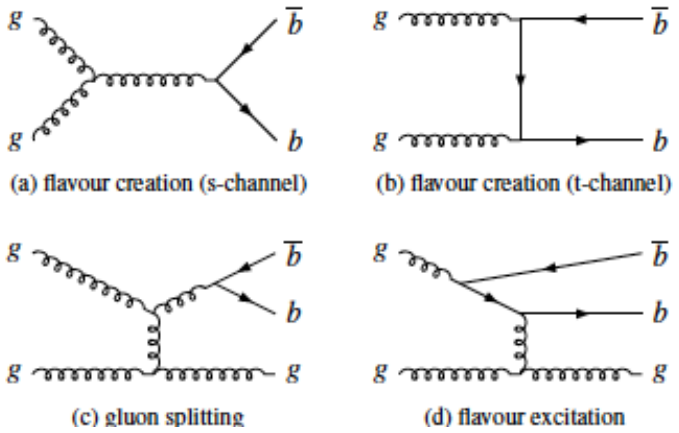
- Mixture of production diagrams
- Tests QCD heavy flavour calculations

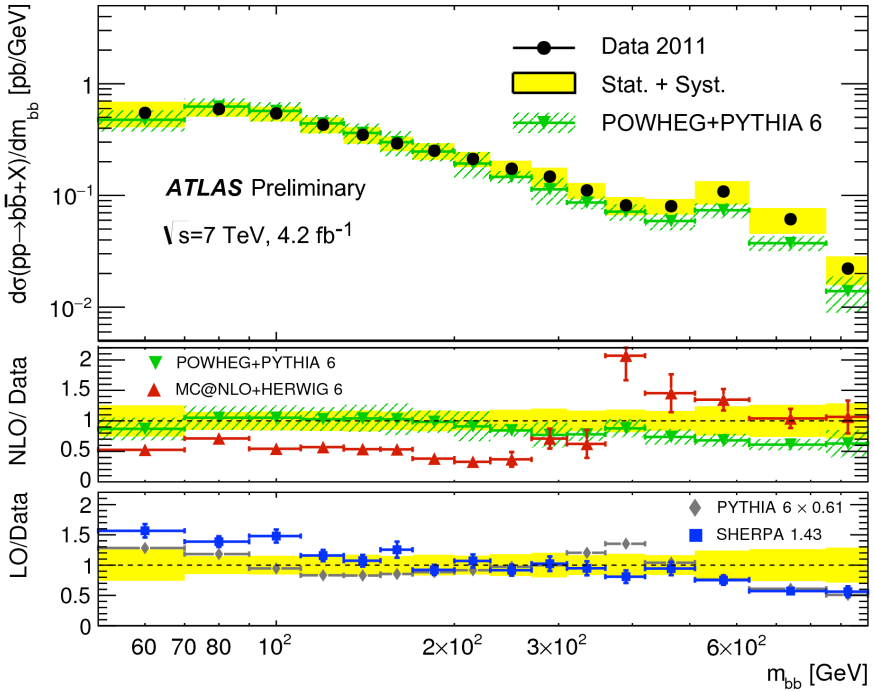
Measured differential cross section in 4.2 fb^{-1} of 7 TeV data

- Required two jets with p_T>20 GeV and |η| <2.5, both tagged as b-jets
- Required leading jet p_T > 270 GeV

Compared with POWHEG+PYTHIA, MC@NLO, PYTHIA AND SHERPA predictions

- Reasonable agreement with POWHEG
- Generally poor agreement with other calculations, both in shape and normalization





To be submitted: ATLAS-STDM-2013-03

Summary and Conclusions

Recent ATLAS measurements continue to probe QCD in both its non-perturbative and perturbative regime

1. Inelastic pp cross section
2. Diffractive dijet production with large rapidity gaps
3. Z boson event shapes
4. Inclusive photon differential cross section
5. b-quark pair production differential cross section

Give a “half-glass-full” picture of our understanding of QCD

- See good agreement in many challenging areas
- Still have discrepancies to resolve, especially soft QCD processes

Much to look forward to with next LHC data-taking run

Backup Slides

ATLAS Data Collection

ATLAS is one of 2 general-purpose experiments at the LHC

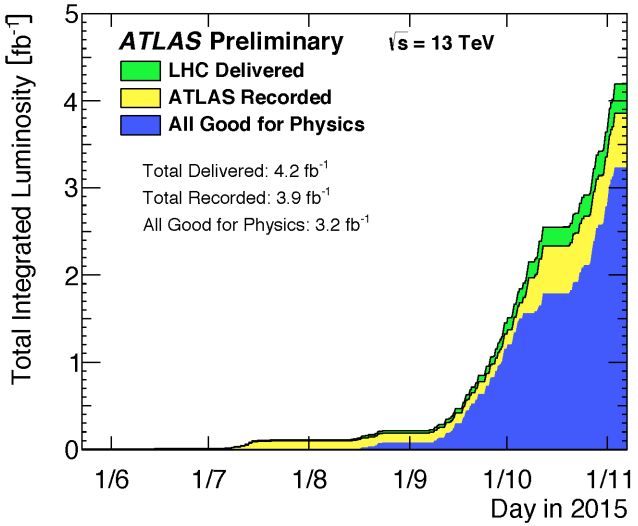
Collected data at 3 pp collision energies

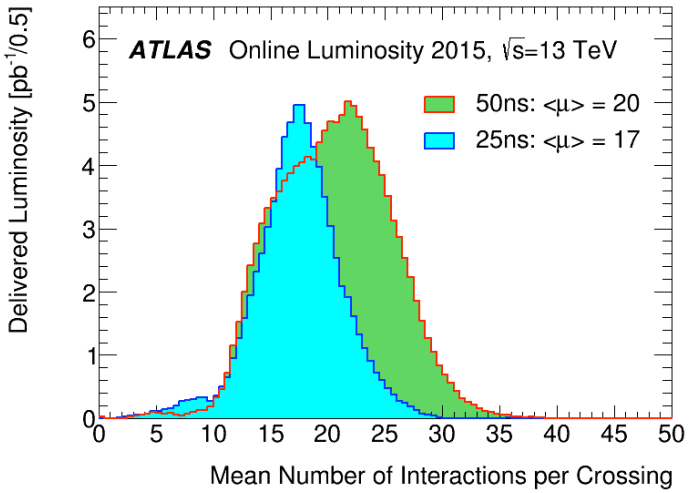
- 7 Tev in 2011 → 4.6 fb^{-1}
- 8 TeV in 2012 → 20.2 fb^{-1}
- 13 TeV in 2015 → 3.2 fb^{-1}

Significant changes in running condition

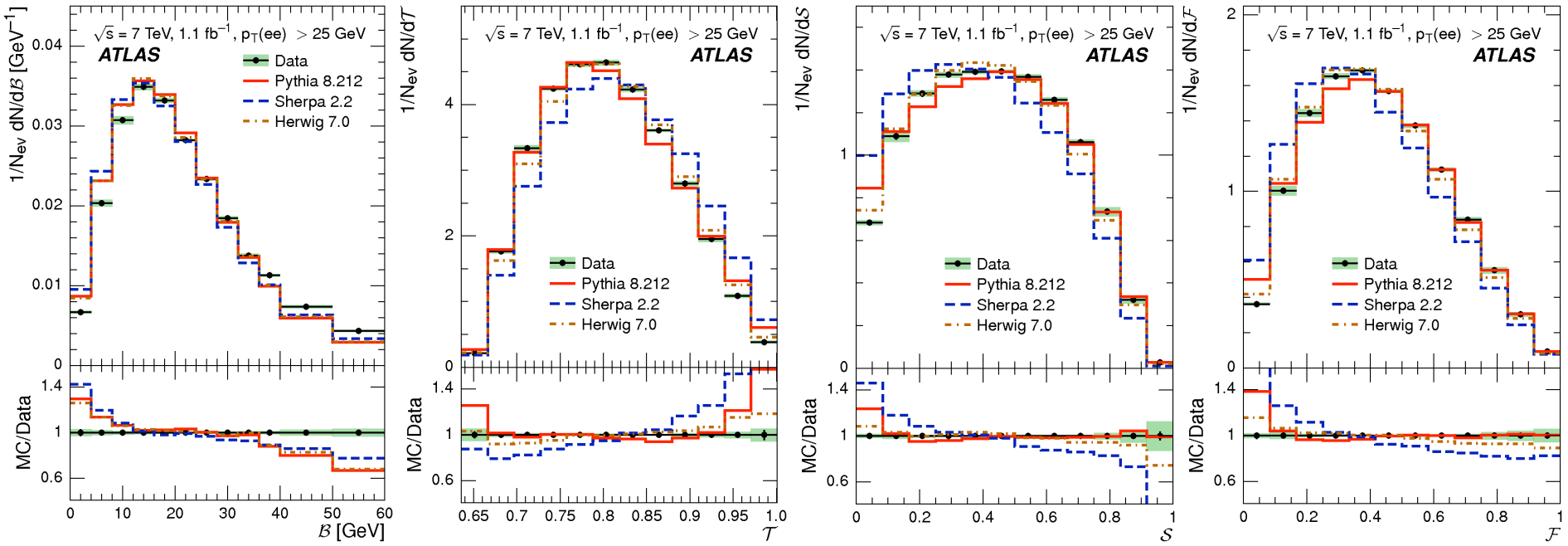
- Increased pile-up
- Moved from 50 ns to 25 ns bunch spacing

ATLAS pp 25ns run: August-November 2015										
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
93.5	99.4	98.3	99.4	100	100	100	100	100	100	97.8
All Good for physics: 87.1% (3.2 fb^{-1})										





High pT Z Boson Event Shapes



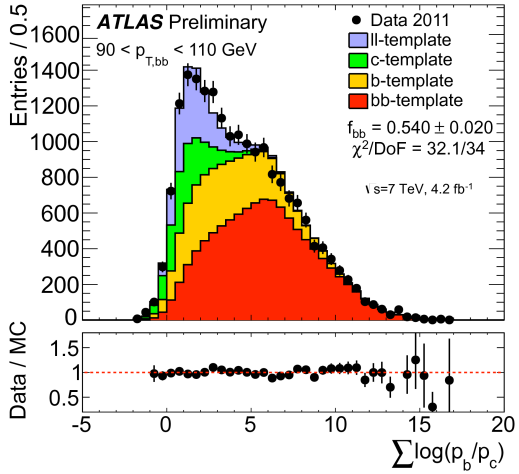
Event shape distributions for Z boson p_T>25 GeV

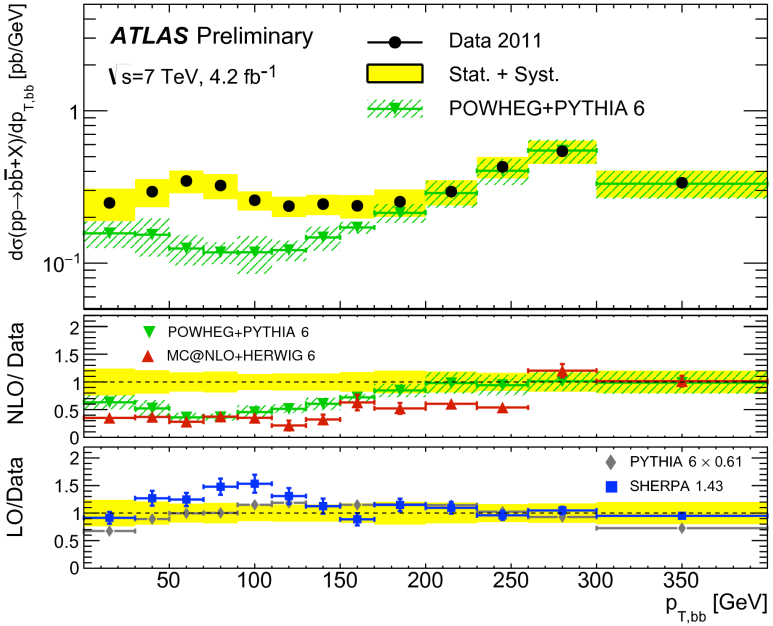
More on b Quark Pair Production

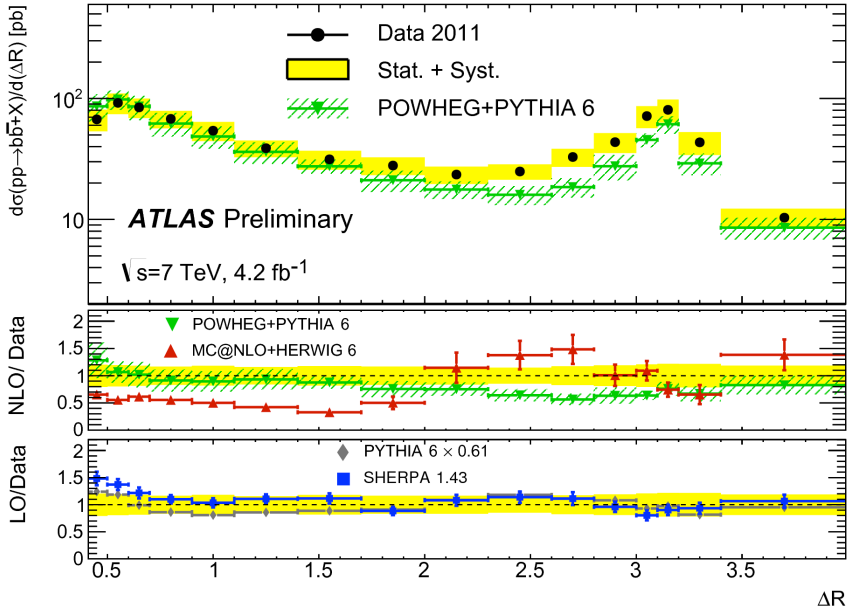
Measured b-quark purity using b-tagging algorithm templates

- Employed likelihood fits to b and light flavour contributions

Measured differential cross sections in various variables



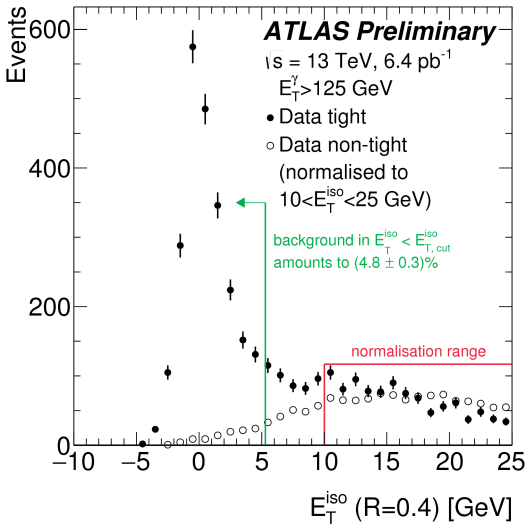


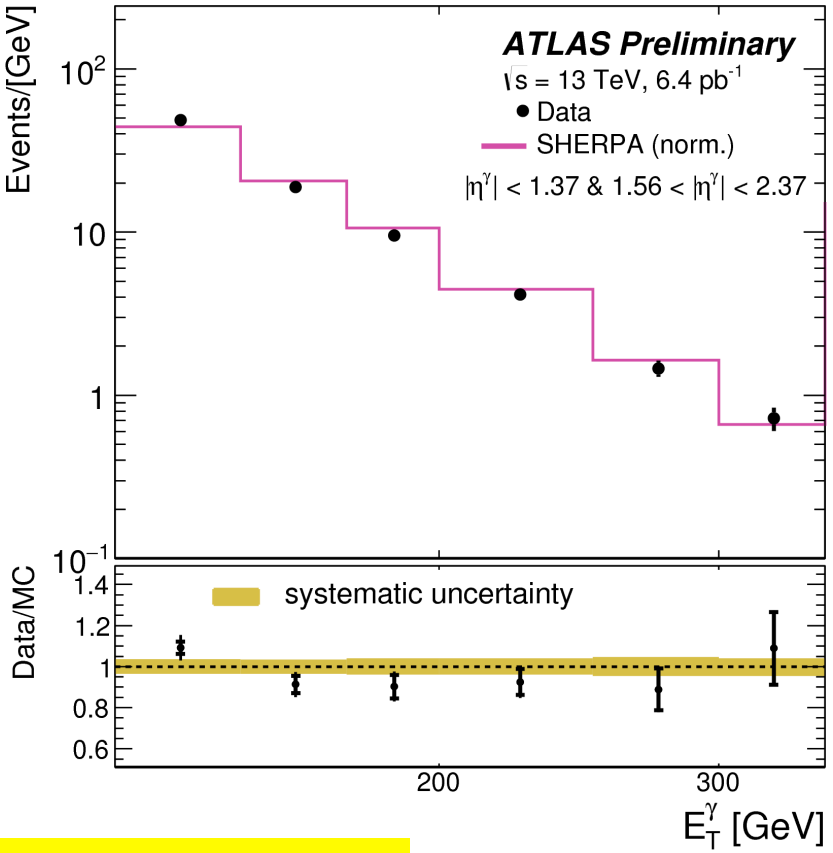


Inclusive Photons at 13 TeV

Made preliminary measurement of inclusive photon cross section at 13 TeV

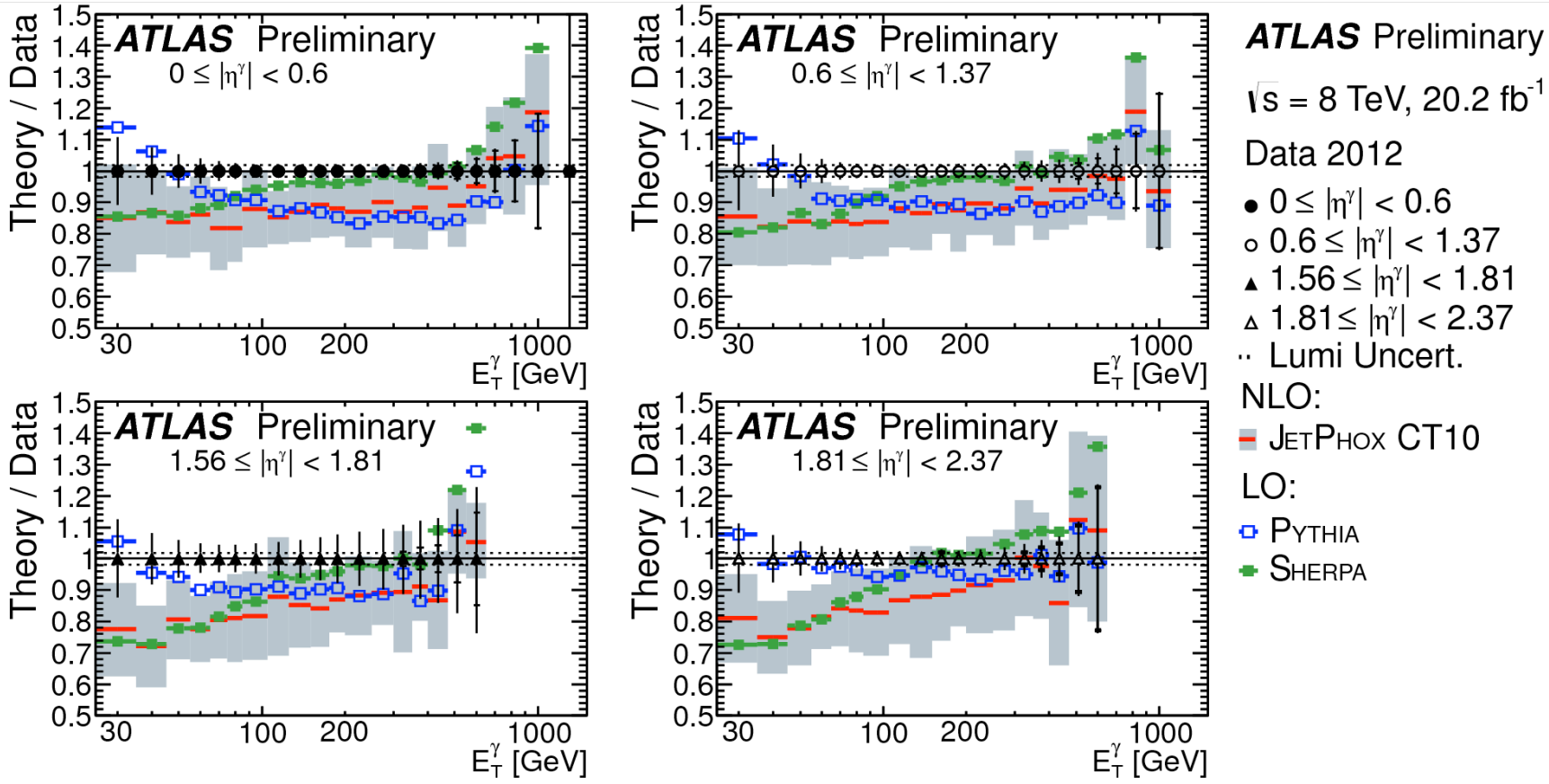
- Similar analysis to 8 TeV
- Normalized background using non-isolated photon candidates





ATLAS-PHYS-PUB-2015-016

Inclusive Photon Cross Section



Comparison with JETPHOX, PYTHIA AND SHERPA generators