QCD in ATLAS

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University of Edinburgh & ATLAS Collaboration

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Introduction

QCD studies remain a major active analysis area in ATLAS

Several main facets:

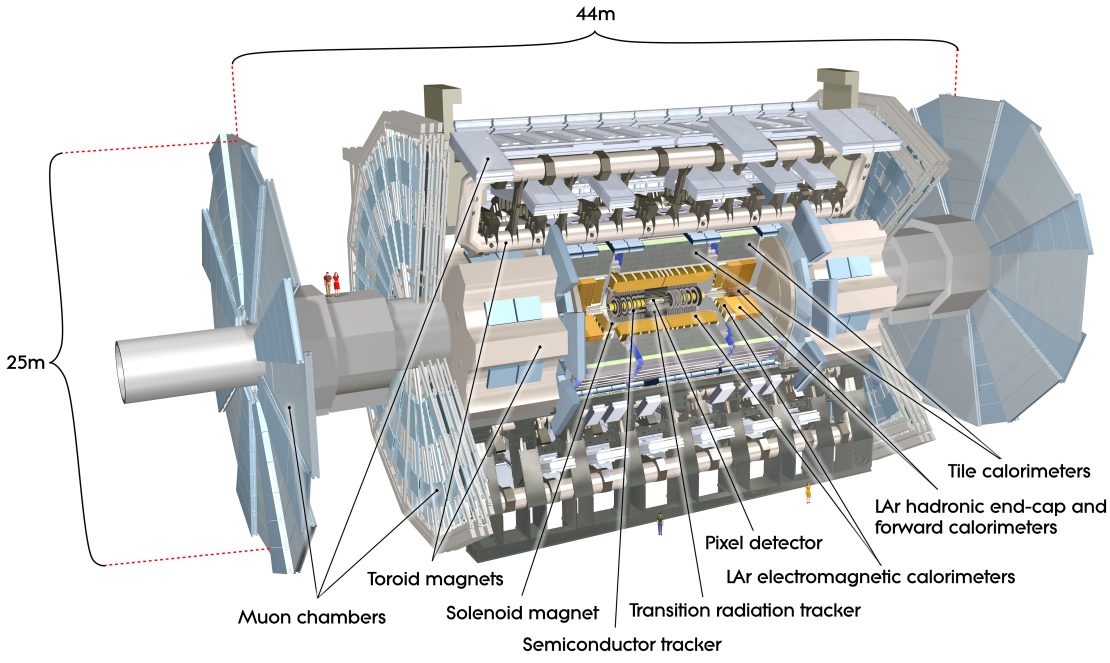
- "Soft" QCD (MPI and diffractive)
- Jet kinematics
- Jet flavour
- Whole-event structure & particle/energy flow
- W, Z/γ^* and photon events with QCD sensitivity

QCD measurements test both perturbative and non-perturbative aspects of QCD: from hard jets/EW bosons and PDFs to multi-parton interactions and hadronisation.

As well as providing **input to MC- and data-driven background estimates and systematics in new physics / Higgs searches** (and measurements).

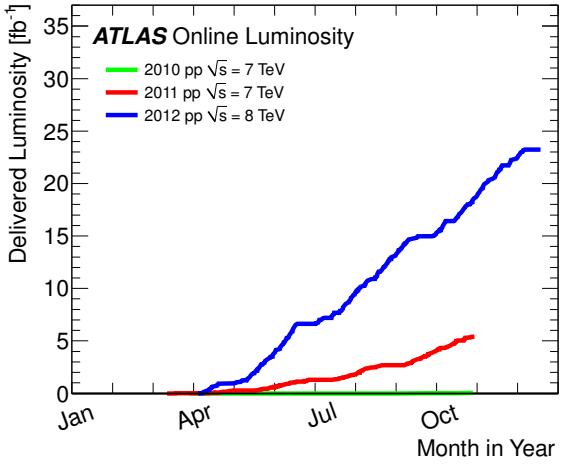
LHC & ATLAS

ATLAS:

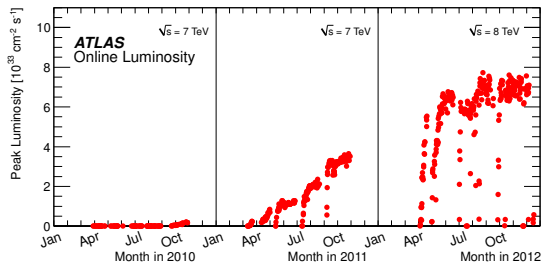


Tracking: $|\eta| < 2.5$
Calorimeters: $|\eta| < 4.9$

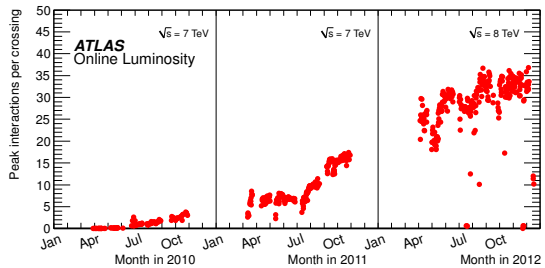
Integrated lumi



Instantaneous lumi



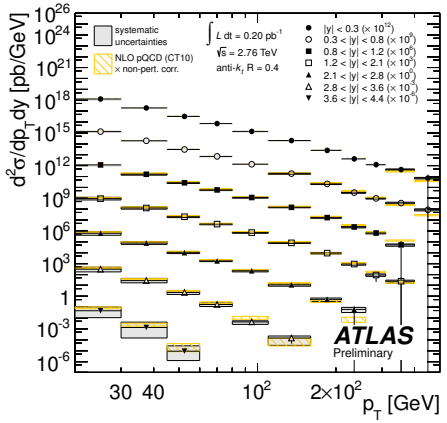
Pile-up $\langle\mu\rangle$ lumi

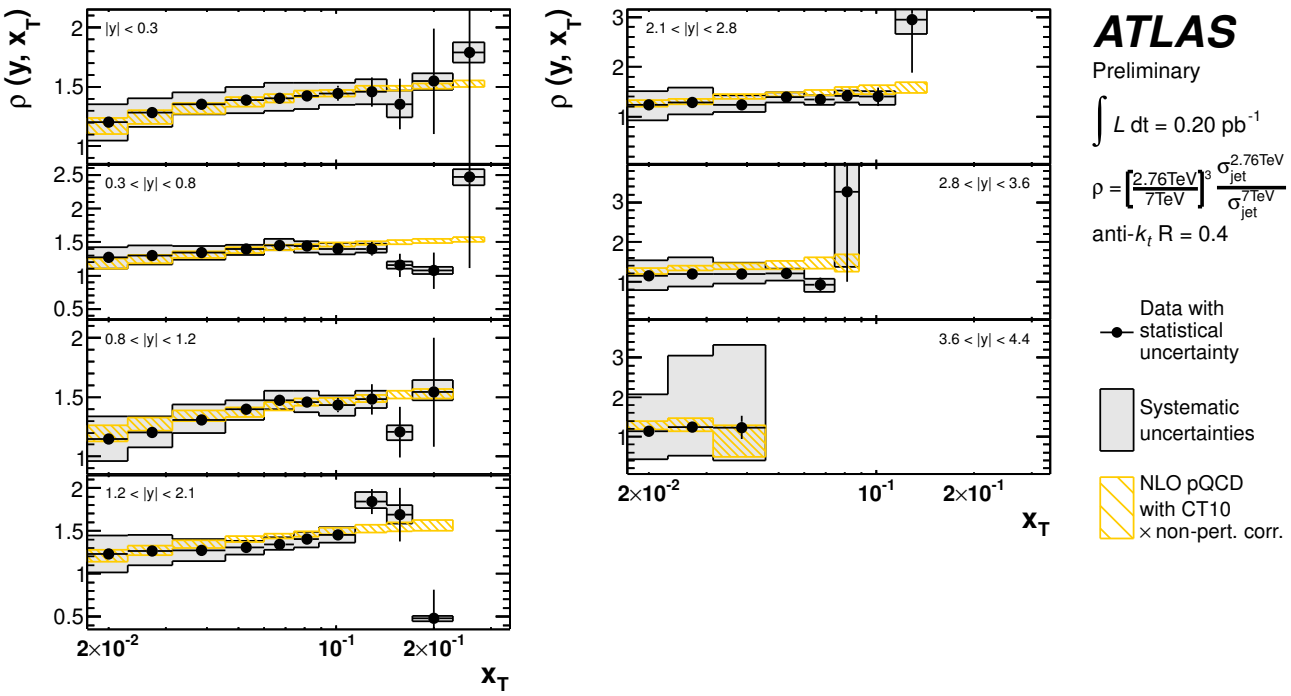


Inclusive jet cross-section at 2.76 TeV

ATLAS-CONF-2012-128

- Double-differential jet $\mathrm{d}^2\sigma/\mathrm{d}p_T\,\mathrm{d}y$ at 2.76 TeV, for anti-kT $R = 0.4$ & 0.6
- Comparison to NLO pQCD with non-perturbative corrections from MC, ratio w.r.t. 7 TeV with dimensionless $x_T = 2p_T/\sqrt{s}$





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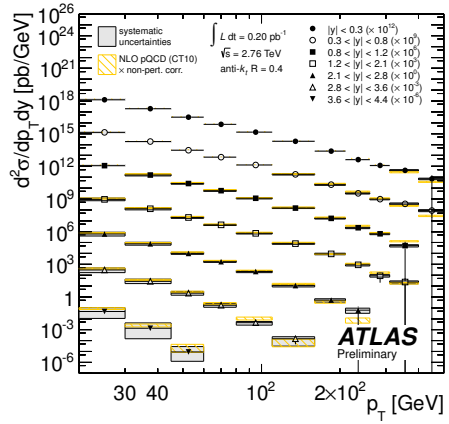
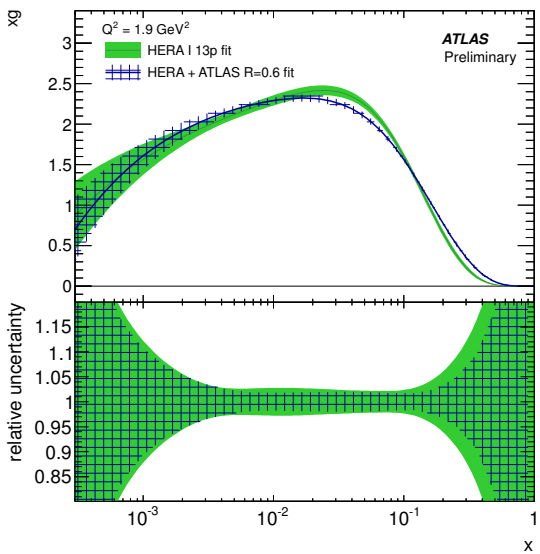
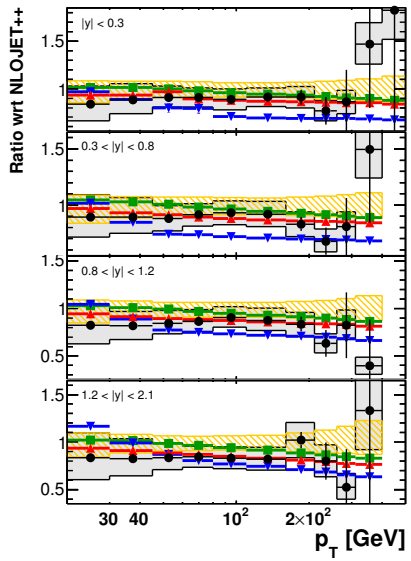
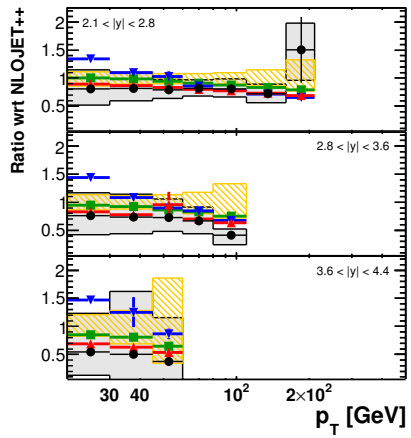
- Impact on gluon & sea PDFs studied: harder gluon, slightly softer high-x sea.

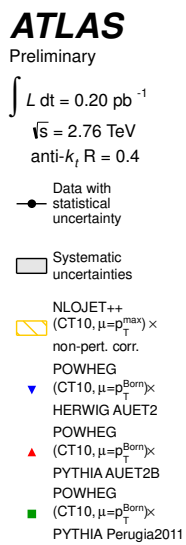
  POWHEG matching improvements required









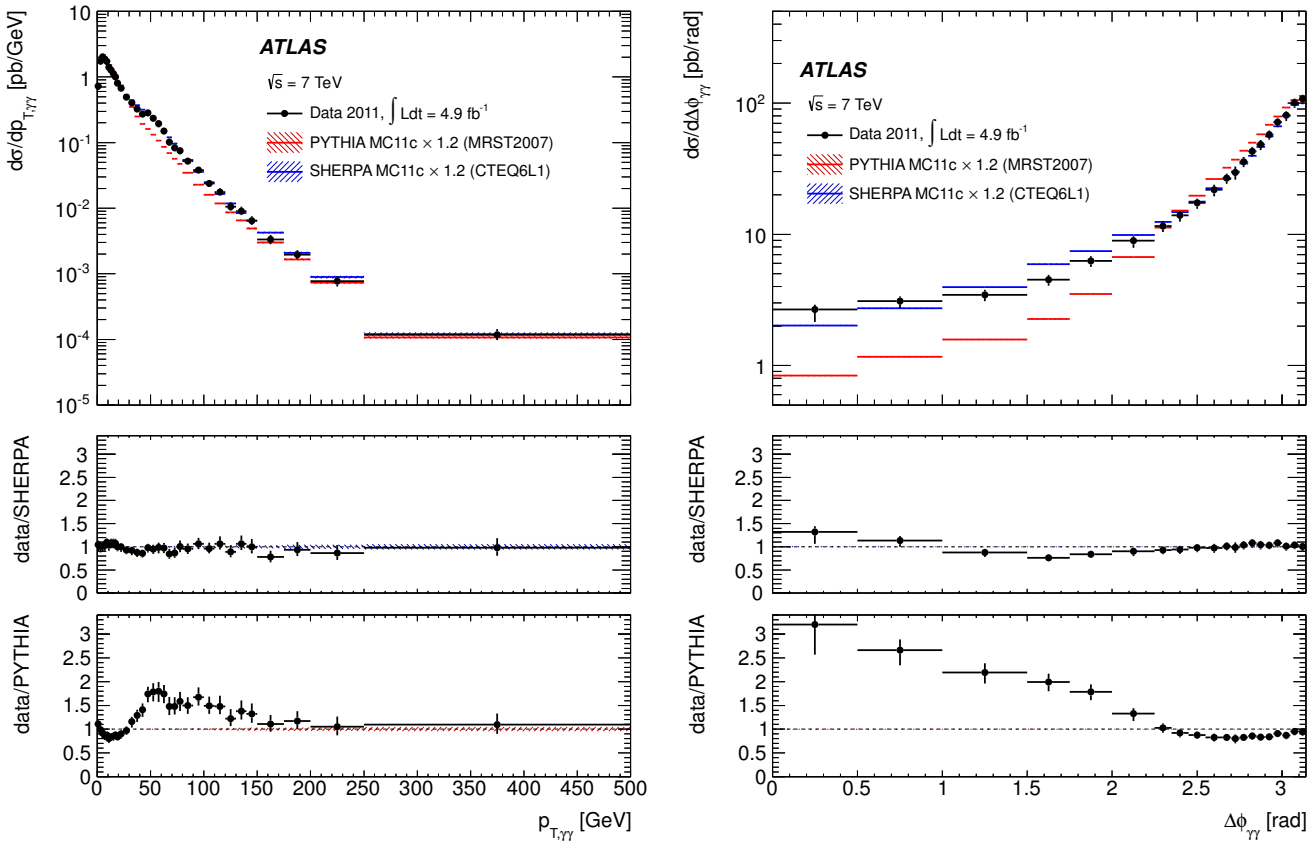


Isolated diphotons

JHEP01(2013)086 / arXiv:1211.1913

- Diff. cross-sections w.r.t. $m_{\gamma\gamma}$, $p_{T,\gamma\gamma}$, $\Delta\phi_{\gamma\gamma}$ & Collins–Soper $\cos\theta^*_{\gamma 1}$
- 1st distribution for resonance searches, 2th & 3rd probe higher-order QCD, 4th a testbed for Higgs spin measurement
- Jet backgrounds rejected binwise by 2D sidebands and fits.

LO: Sherpa extra ME emissions improve $\Delta\phi$ w.r.t. Pythia and describe p_T bump.



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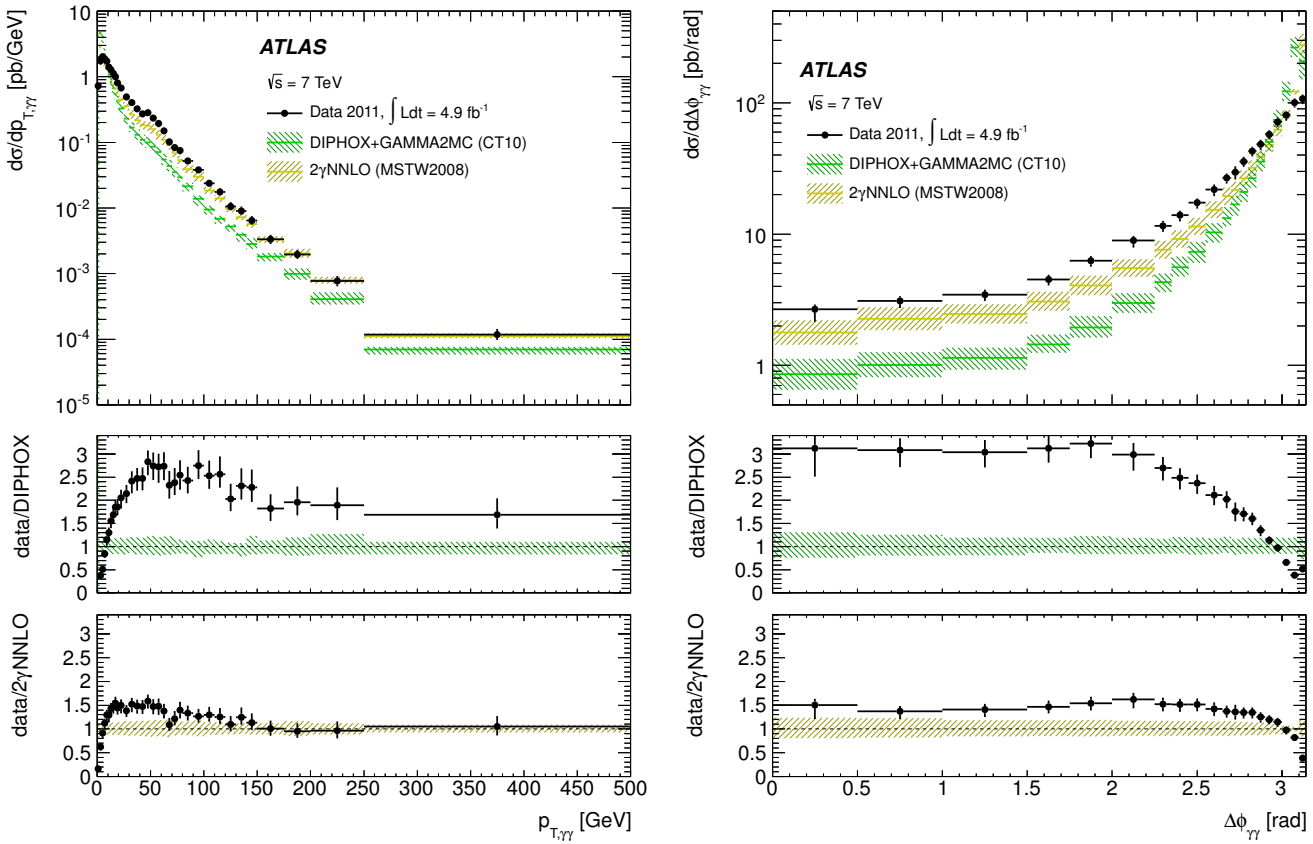
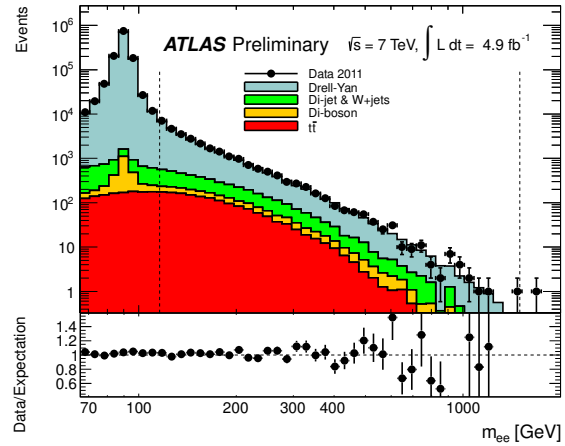
(N)NLO: DIPHOX+GAMMA2MC normalisation insufficient $\Rightarrow$ 2γNNLO much better

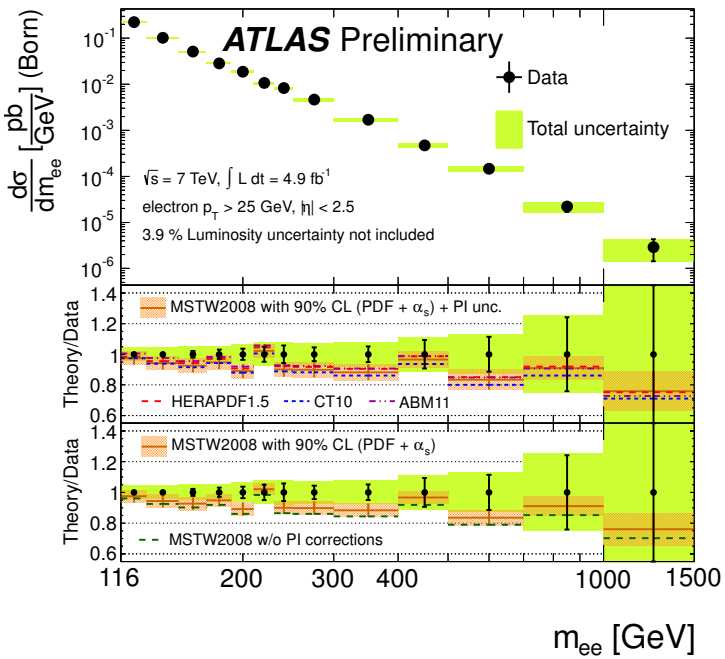


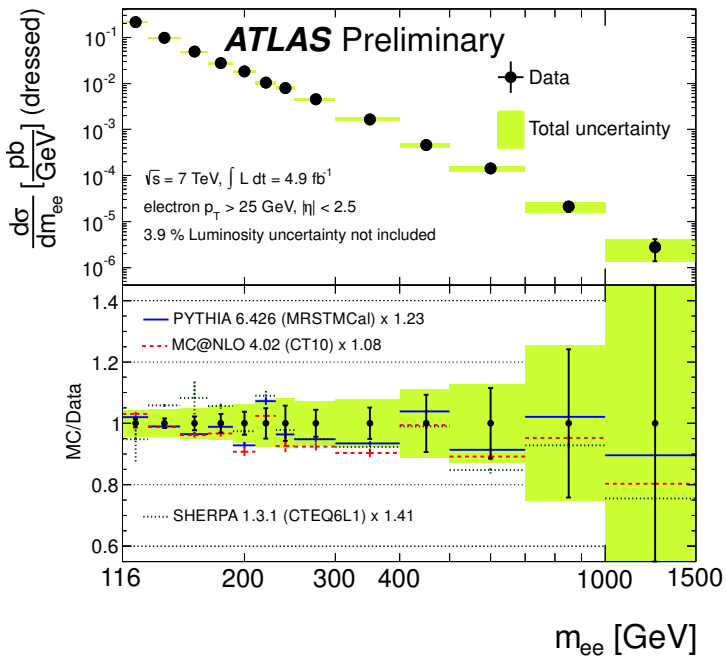
High-mass Drell-Yan

ATLAS-CONF-2012-159

- Measurement of $\mathrm{d}\sigma/\,\mathrm{d}m_{ee}$ in $116 < m_{ee}/\mathrm{GeV} < 1500$
- Both electrons in $|\eta| < 2.5$ and with $p_T > 25$ GeV
- Comparison to NNLO QCD prediction from FEWZ 3.1 + Pythia, Sherpa & MC@NLO







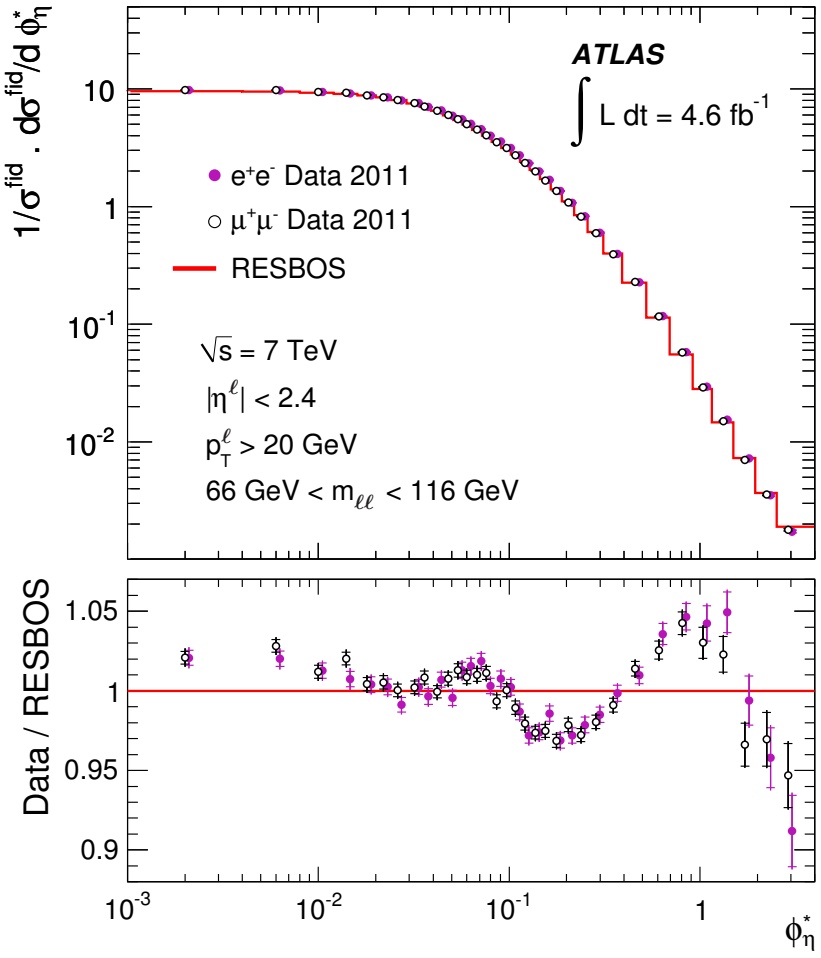
Z/γ^* transverse momentum at 7 TeV via ϕ^*

arXiv:1211.6899

- Z p_T originates from QCD recoil: jets in high-p_T region
- **For $p_T \ll m_Z$, large logs are important: precision test of QCD resummation**
- ϕ^* is a low-systematics measure of relevant physics $\Rightarrow$ **purely lepton-directional, hence no p resolution involved**
- $\phi^* \equiv \tan(\phi_{\text{acop}}/2)\ \sin(\theta^*_\eta)$

  with $\phi_{\text{acop}} \equiv \pi - \Delta\phi_{\ell\ell}$

  and $\cos(\theta^*_\eta) \equiv \tanh(\Delta\eta_{\ell\ell}/2)$



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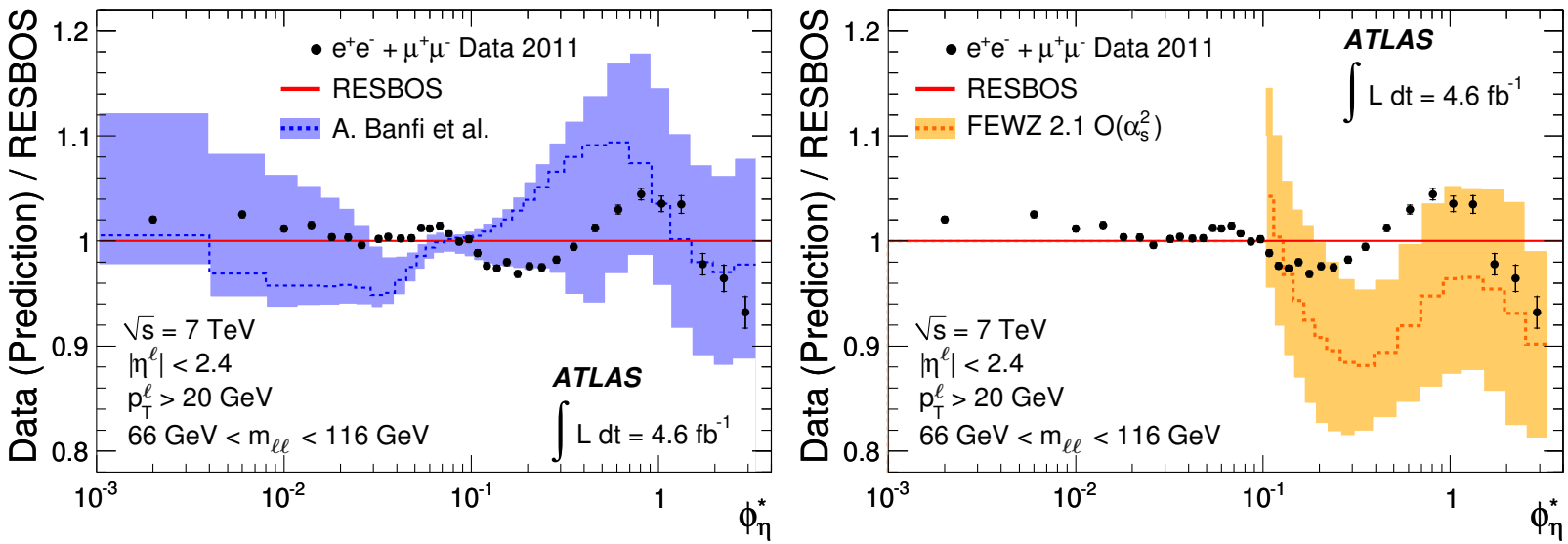
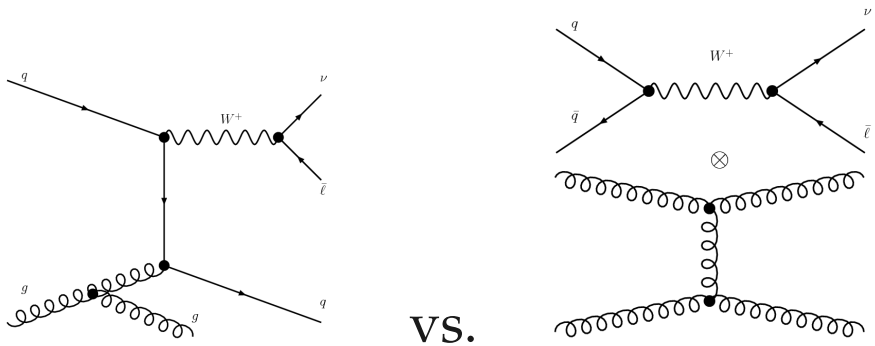


Comparisons to resummed calculations and QCD MC generators: data precision an order of magnitude better than current theoretical uncertainty

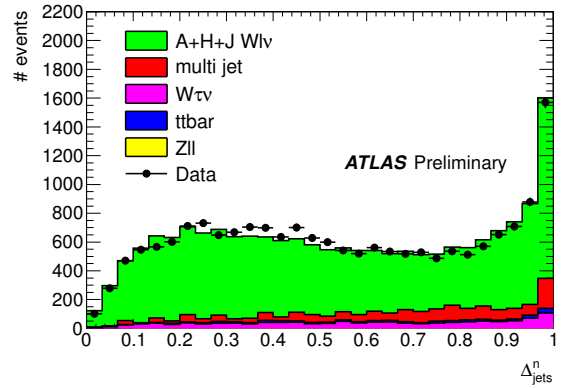
Double partonic scattering in $W + 2$ jet events

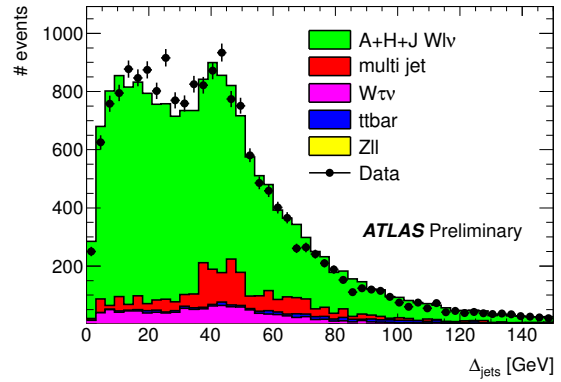
arXiv:1301.6872 / ATLAS-CONF-2011-160

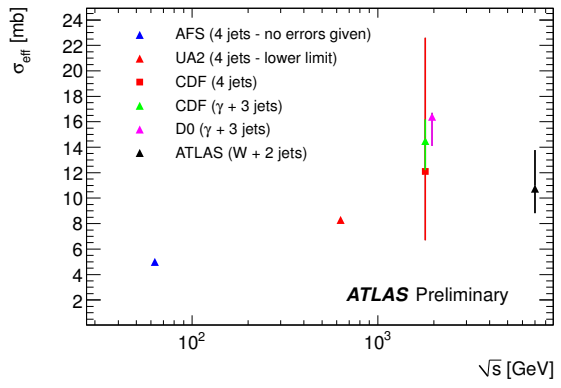
- Two LO contributions to $pp \to \ell\nu jj$:



- Measure contribution from DPI via MC templates from Alpgen+Herwig+Jimmy and Sherpa
- Direct observables: $\Delta_{\text{jets}} = \left|\vec{p}_{\perp,1} + \vec{p}_{\perp,2}\right|$, $\Delta^{\text{n}}_{\text{jets}} = \Delta_{\text{jets}} / \left|\vec{p}_{\perp,1}\right| + \left|\vec{p}_{\perp,2}\right|$
- Fraction of W+2j events from DPI: $f^{R}_{\text{DP}} = 0.16 \pm 0.01\,(\text{stat}) \pm 0.03\,(\text{sys})$
- $\sigma_{\text{eff}} = 11 \pm 1\,(\text{stat}) \pm 3\,(\text{sys})$ mb — consistent with previous measurements





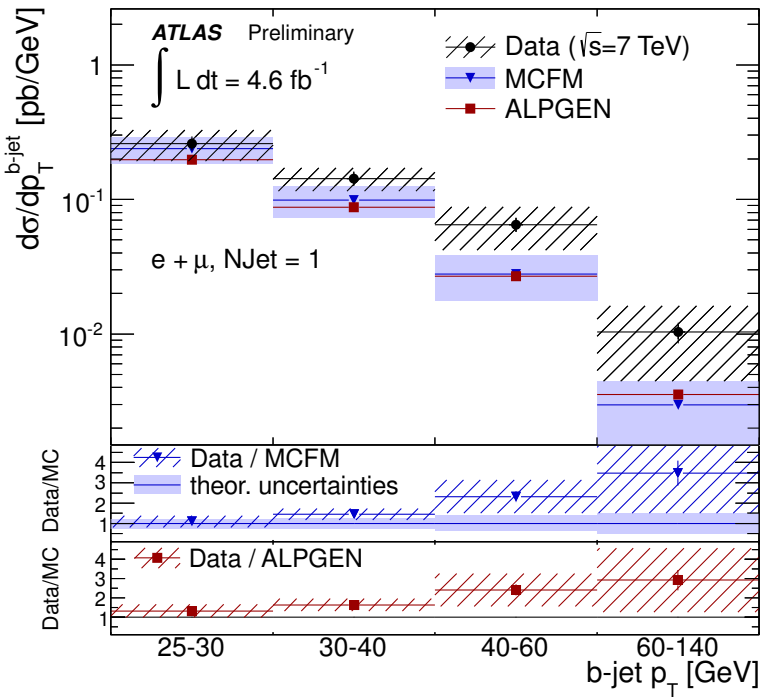


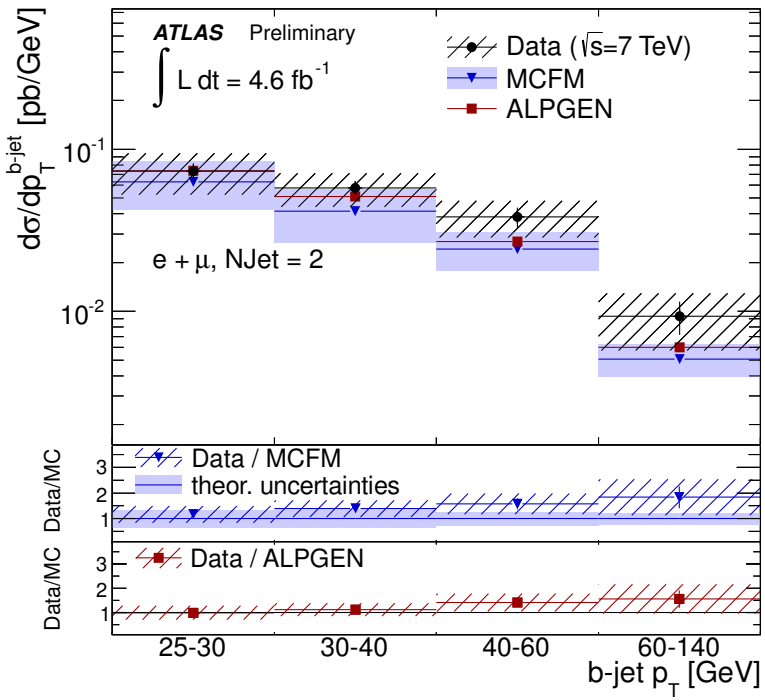
W + b-jets cross-section at 7 TeV

arXiv:1302.2929 / ATLAS-CONF-2012-156

- Measurement of differential $\mathrm{d}\sigma / \mathrm{d}p_T$ for leptonic-decay W + b-jets in $|y_{\mathrm{jet}}| < 2.1$, $p_T > 25$ GeV. **MPI contribution important.**
- Important to test QCD and **control $H \to b\bar{b}$ / BSM backgrounds**
- Separation into 1- and 2-jet events, with and without AcerMC single-top subtraction. **General MC undershoot at high-p_T.**

Subtracted single-top





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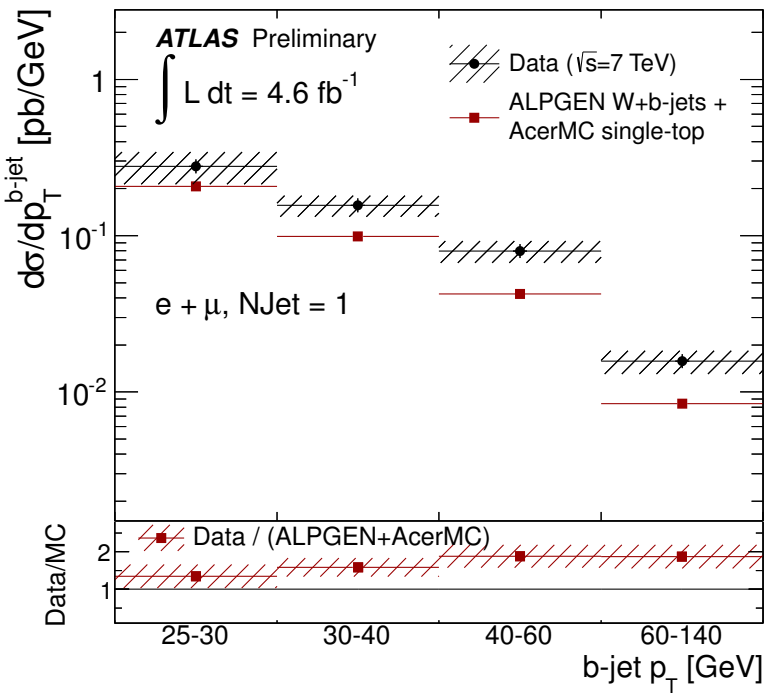
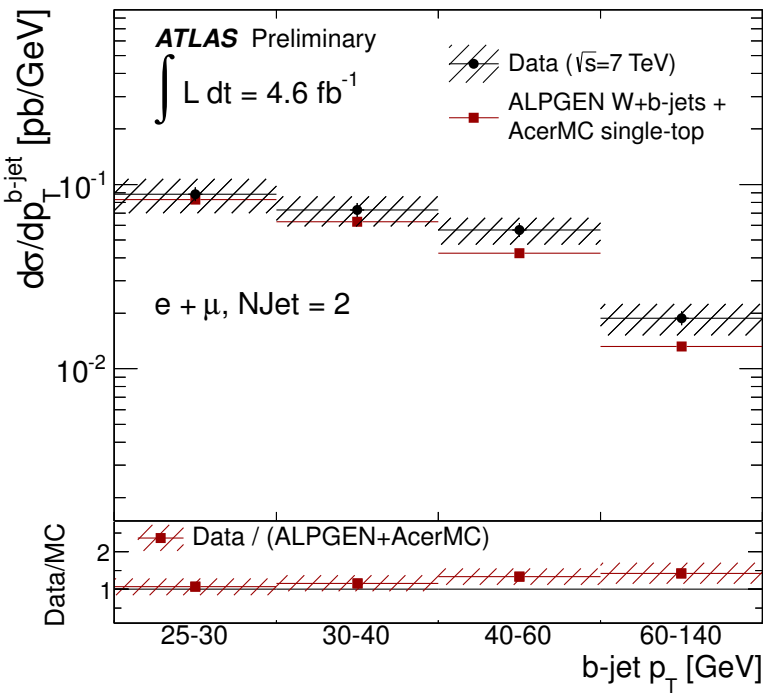
Including single-top

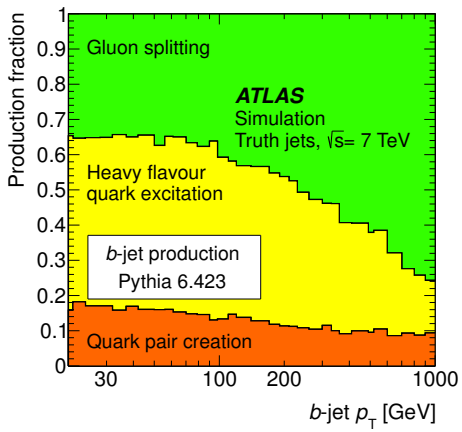




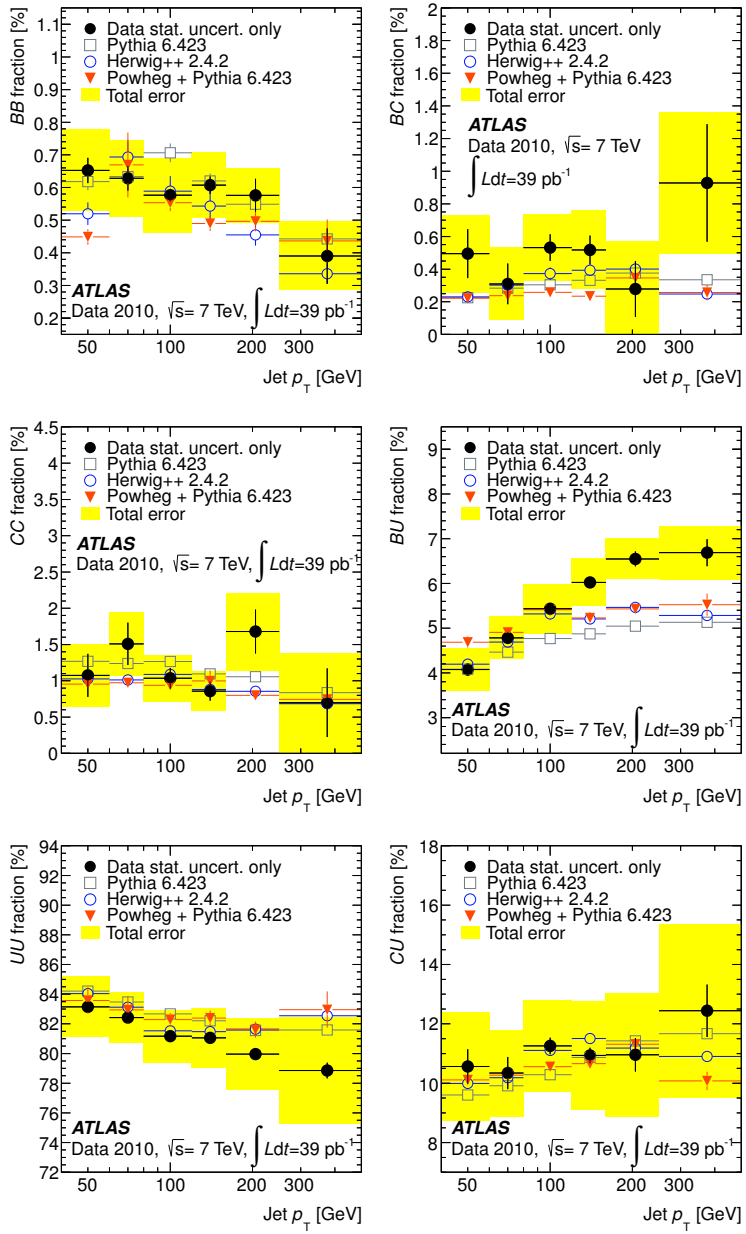
Dijet flavour composition

arXiv:1210.0441

Pythia6 prediction:



- Use of b-tagging and kinematics to build templates for fraction fitting
- Ability to identify jets containing two b-hadrons demonstrated
- MC modelling mostly good…but all underestimate BU fraction at high-p_T.

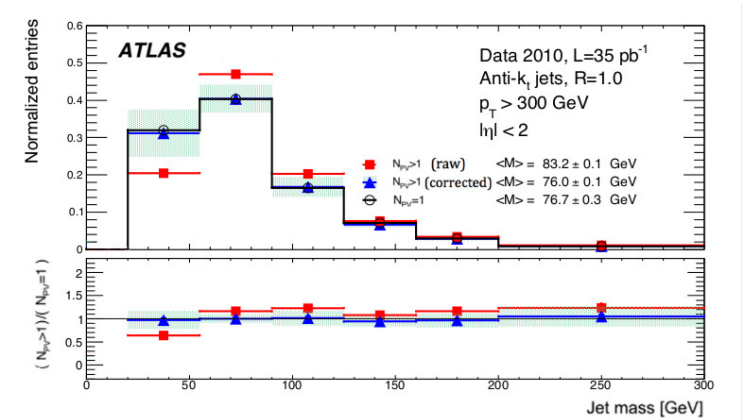


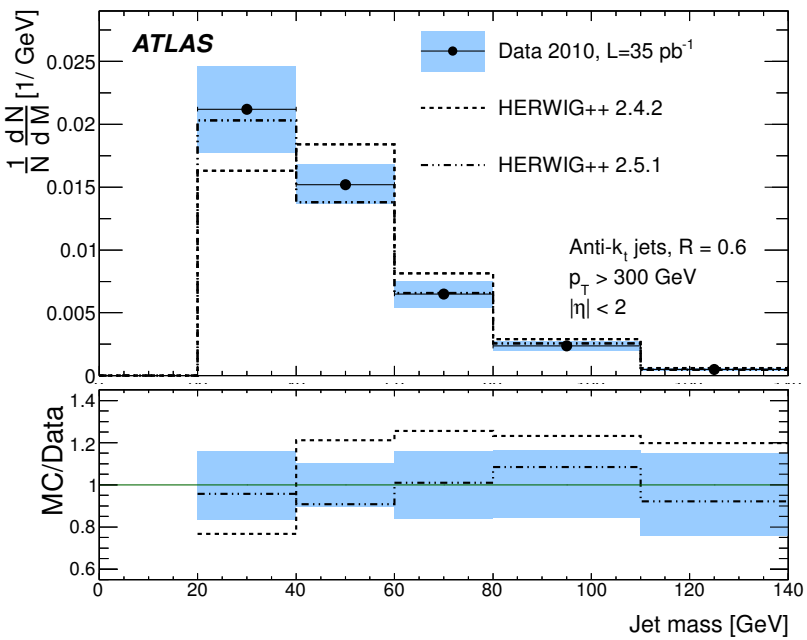
Jet properties for boosted particle searches

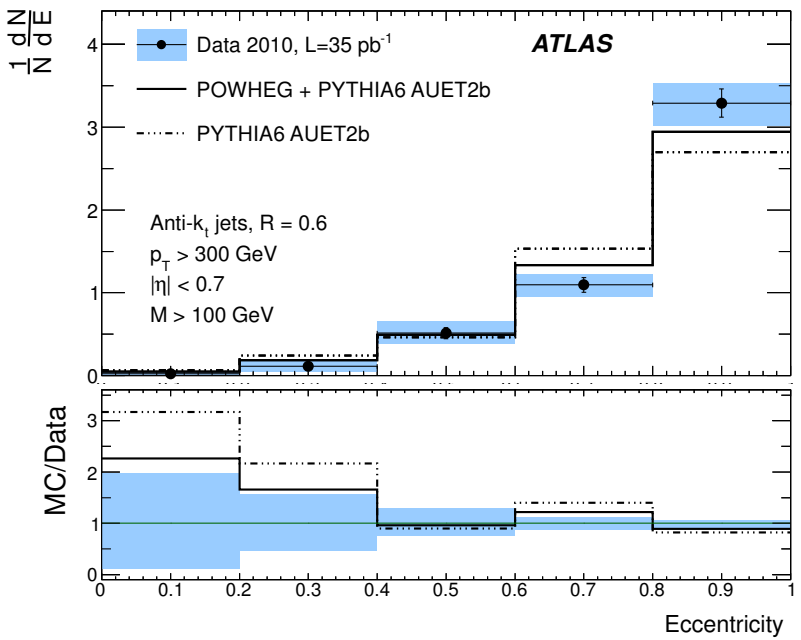
arXiv:1206.5369 / Phys. Rev. D 86 (2012) 072006

- Jet mass and width (+ eccentricity, angularity & planar flow for $M > 100$ GeV)
- Measurements with anti-kT $R = 0.6$ & 1.0, $p_T > 300$ GeV, $|\eta| < 2$.
- Pile-up/UE subtraction applied via complementary cone, with N_{PV} used to disambiguate

Pile-up/UE correction:

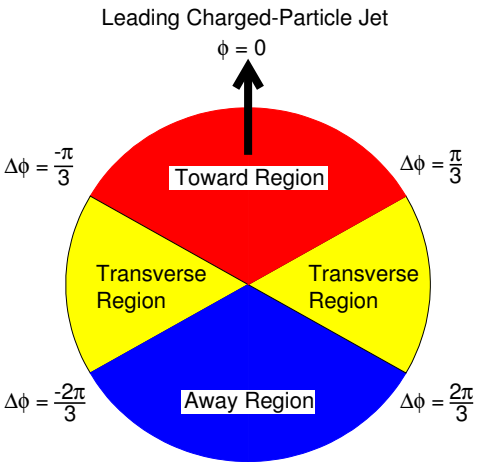


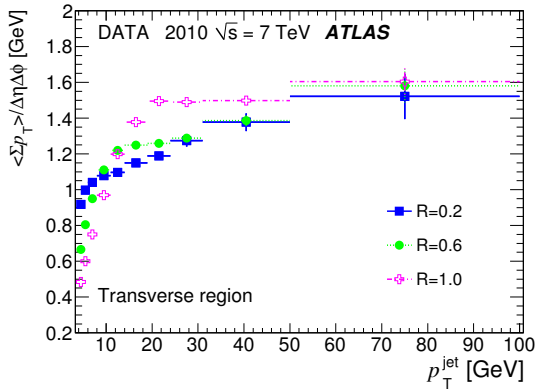


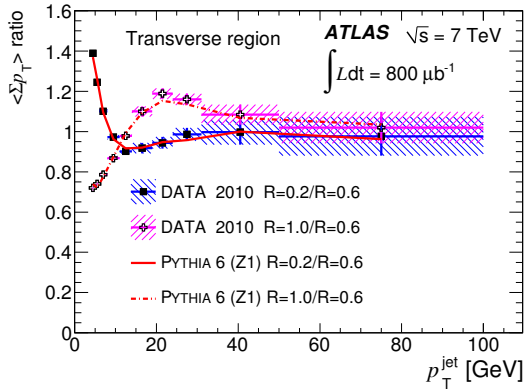


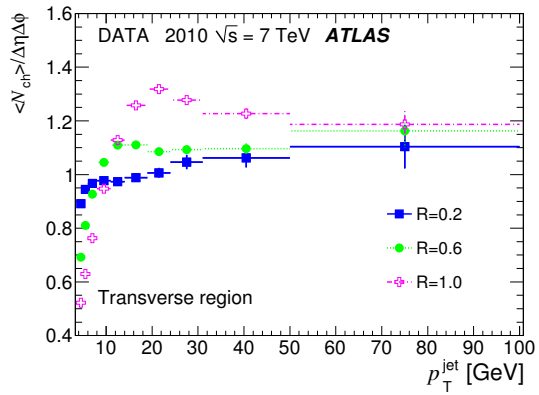
Track-jet underlying event

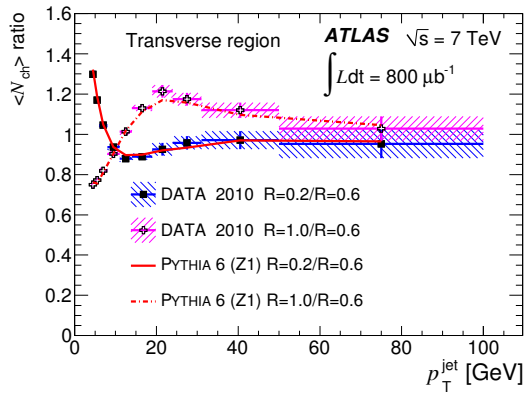
Phys. Rev. D 86 (2012) 072004 / arXiv:1208.0563









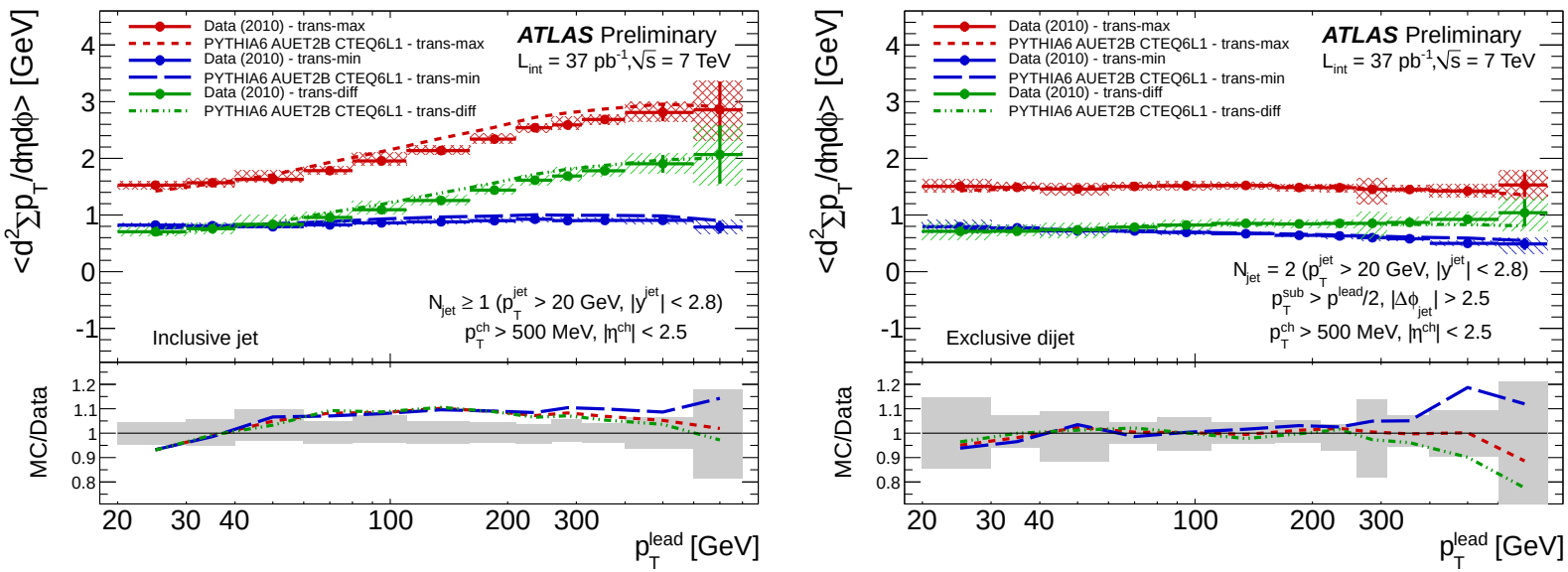


- First study of UE dependence on jet size.
- Transverse observables vs. lead jet pT for 3 different R values $\Rightarrow$ very good MC description!
- Huge number of observables for many different R and min p_T values: great input for MC tuning & validation

Calorimeter jet underlying event

ATLAS-CONF-2012-164

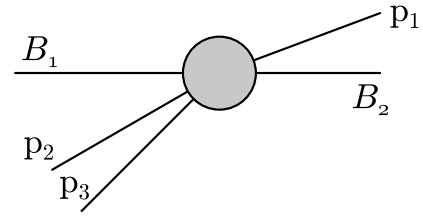
- Calorimeter jet p_T reach up to 800 GeV
- Separate study of inclusive jet & exclusive dijet events: **distinguish effect of extra hard jets**
- Usual track-based UE flow, but also calorimeter $\sum p_T$ $\Rightarrow$ **extends $|\eta|$ reach to 4.8**

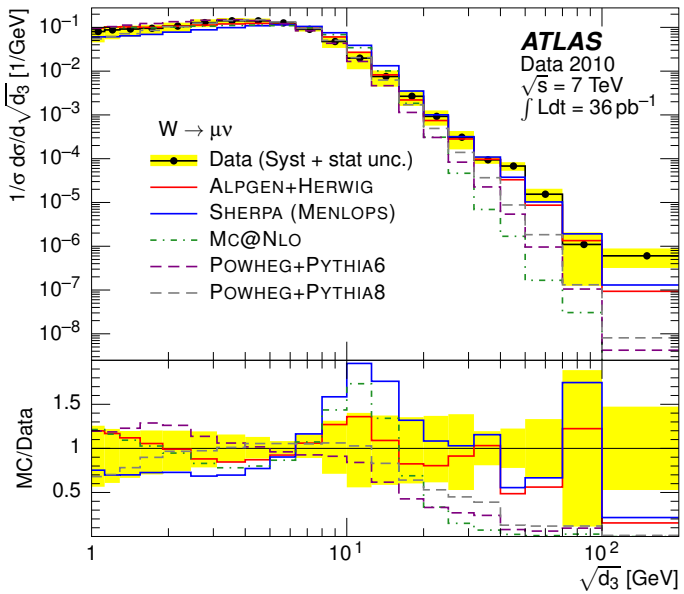


k_T splitting scales in $W \to \ell\nu$ events

arXiv:1302.1415

- Test of pQCD and resummation technology $\Rightarrow$ QCD backgrounds in searches
- Identify 4 hardest $k_\perp$ cluster splitting scales for transition from $n \to n-1$ jets
- Multi-jet and $t\bar{t}$ backgrounds subtracted. Detector effects corrected with RooUnfold.





Multileg MCs differ in soft (shower) region < 20 GeV. NLO+PS MCs predict too little hard activity even for d_0

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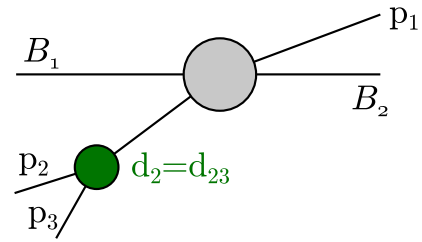

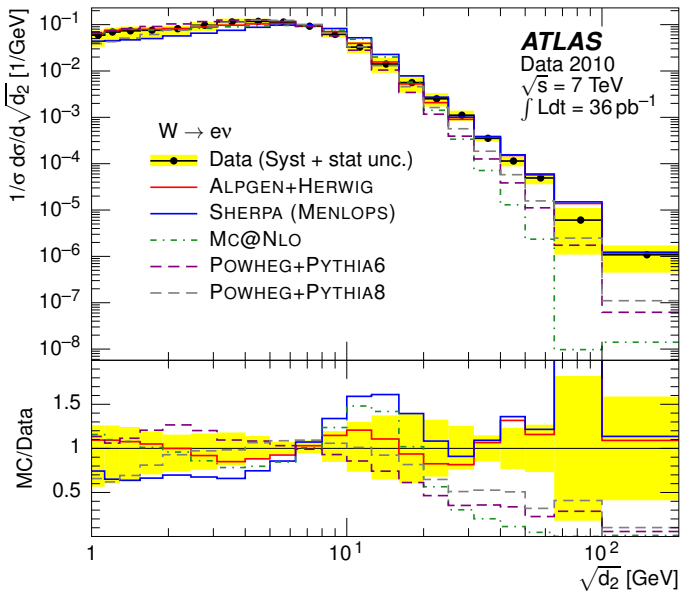

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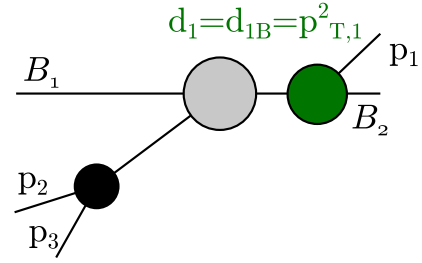

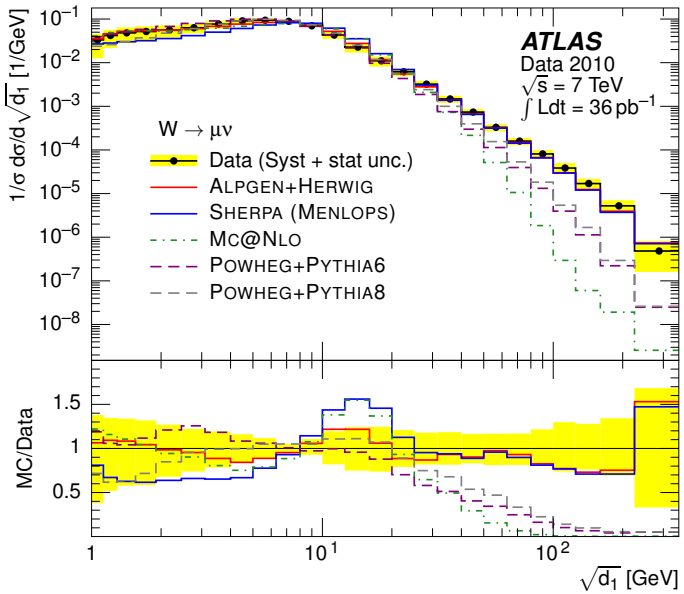

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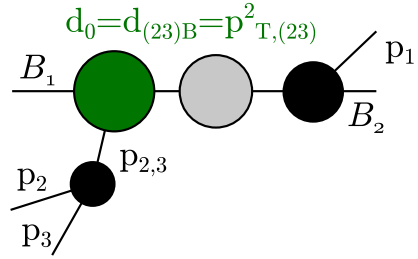
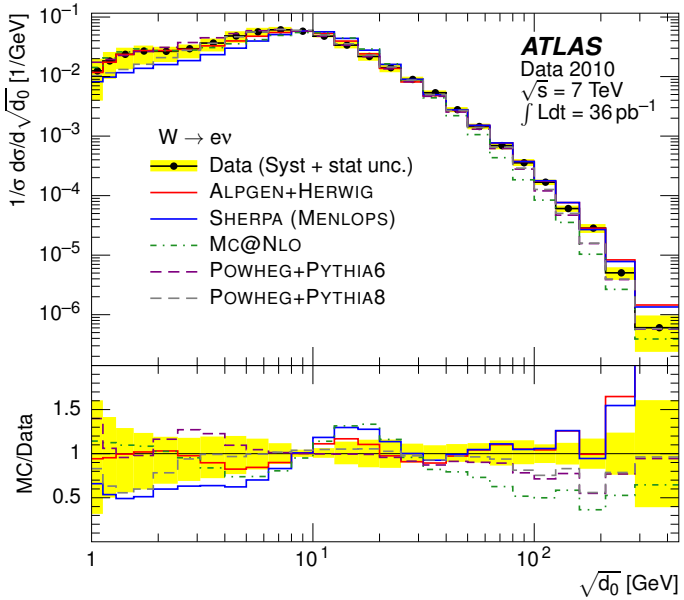




Multileg MCs differ in soft (shower) region < 20 GeV. NLO+PS MCs predict too little hard activity even for d_0

Summary

ATLAS QCD programme still very active: from diffraction and MPI to jet flavour, event/jet structure, and QCD effects on EW bosons.

Completed analyses are all thus far based on 7 TeV data.

8 TeV studies underway
$\Rightarrow$ plenty of Run 1 data to analyse through LS1.

Describing *all* the ATLAS QCD data simultaneously is a huge challenge for pQCD calculations and MC generators

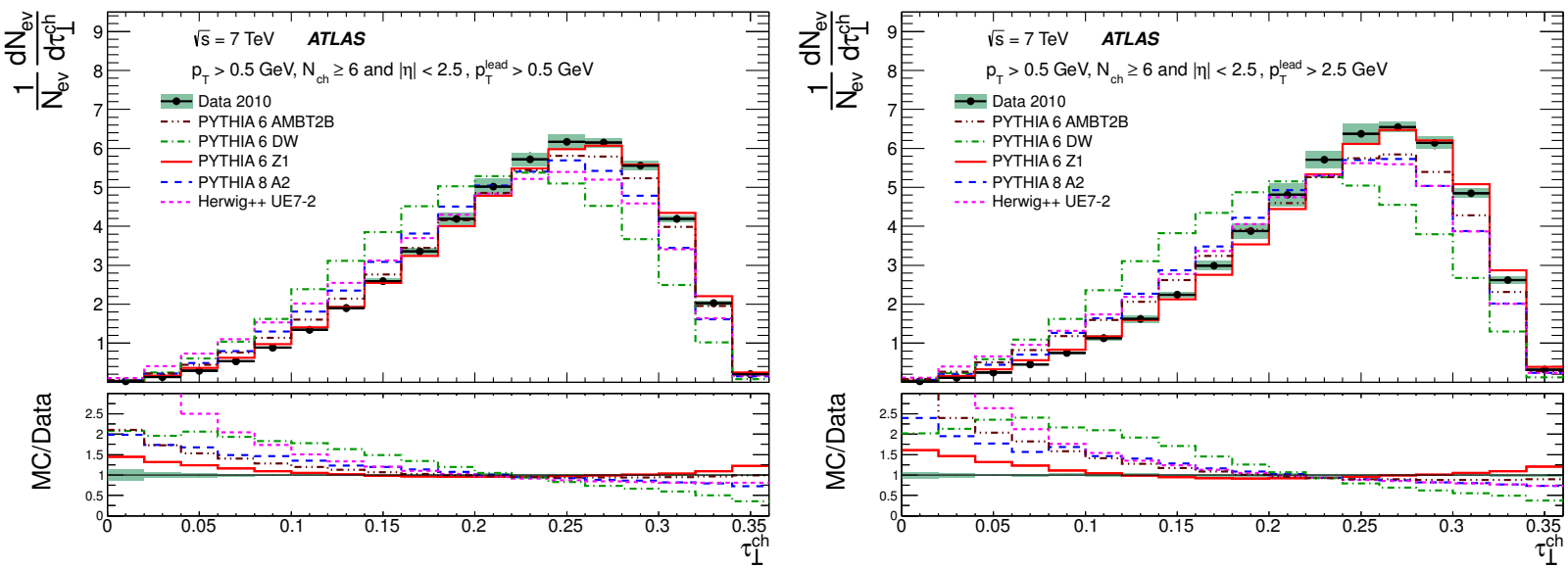
- many MC models and tunes have been eliminated
- new methods must address the experimental challenge.

Charged particle event shapes

arXiv:1207.6915

- Measurement of transverse thrust (and minor), and transverse sphericity
- Calculated from minimum bias events with ≥ 6 charged particles
- Evolutions of mean shape variables with lead p_T, $\sum p_T$, and N_{ch}

Transverse thrust: $p_T^{\text{lead}} > 0.5$ GeV vs. > 2.5 GeV $\Rightarrow$ Z1 and AMBT2B best, DW worst



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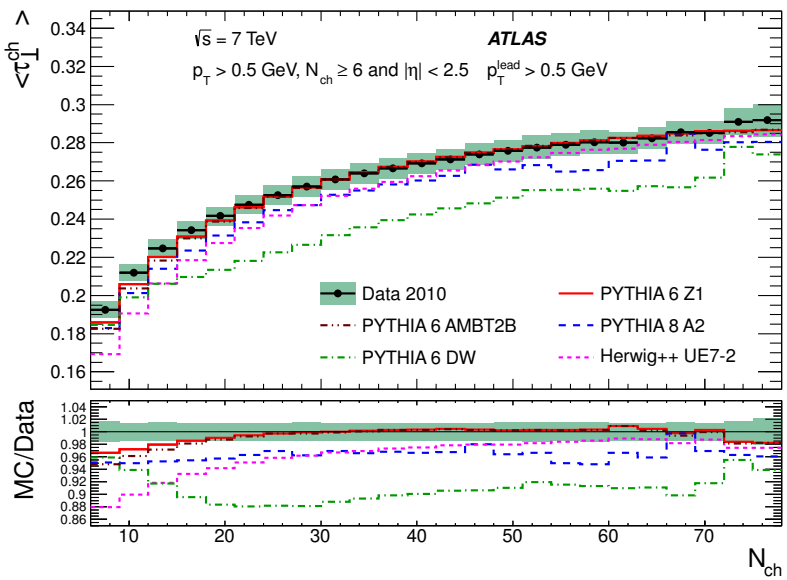
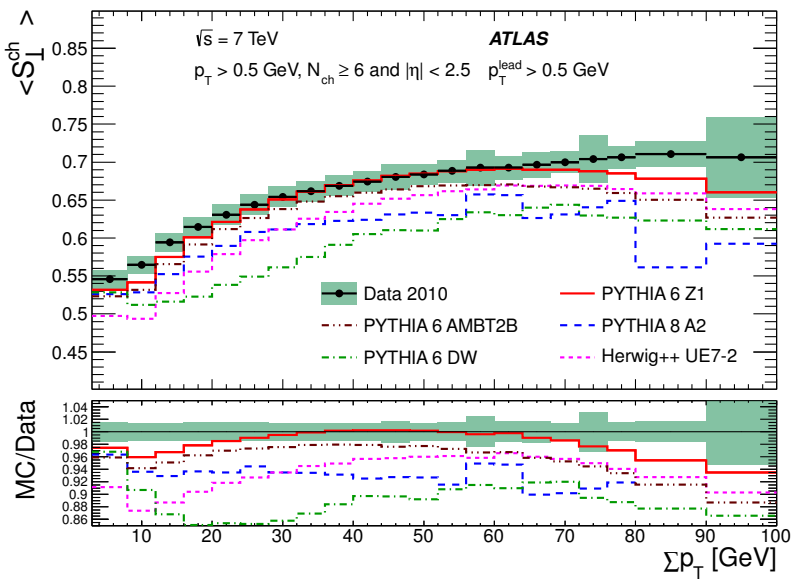
Transverse thrust & sphericity vs. N_{ch} and $\sum p_T \Rightarrow$ Z1 and AMBT2B best, DW worst



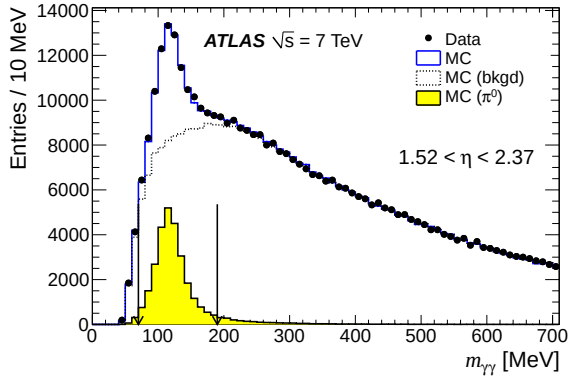


ET flow

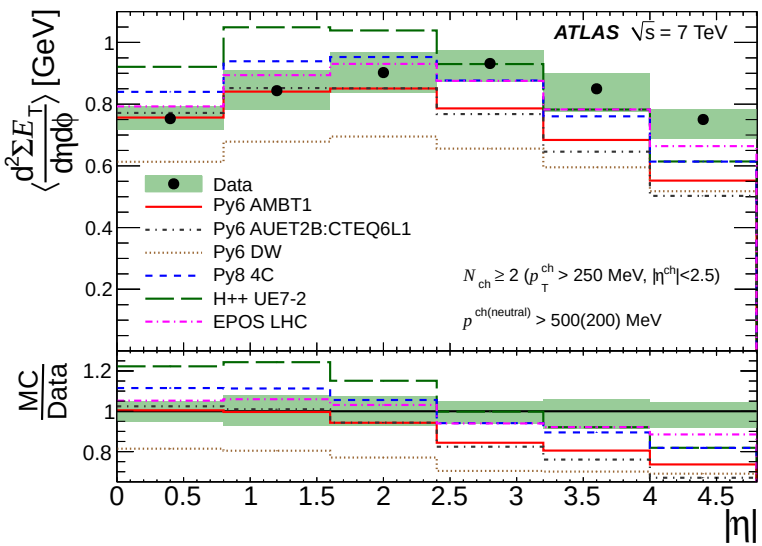
arXiv:1208.6256 / JHEP11(2012)033

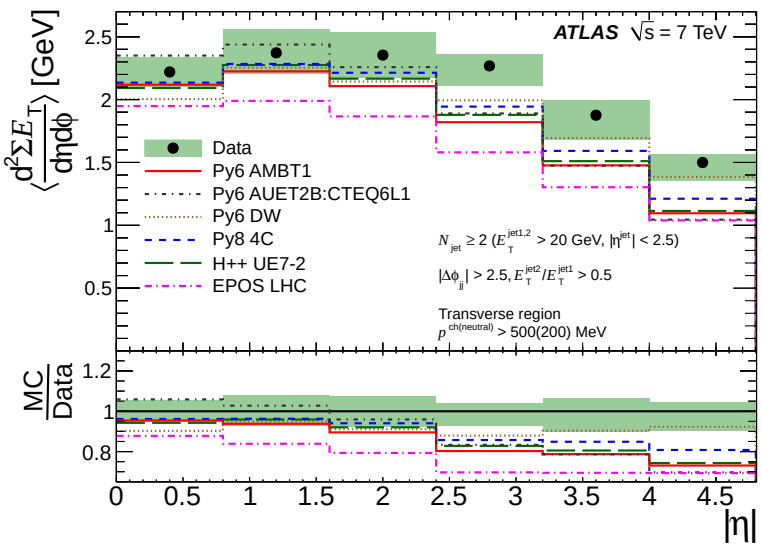
- Calorimeter measurement of $E_\perp$ as a function of $|\eta|$. Calibrated cluster energy on $\pi^0 \to \gamma\gamma$:
- Using both inclusive minimum bias and dijet event selections. Unfolded data.
- Important input to pile-up, beam remnant and diffractive modelling + e.g. VBF searches

$\pi^0 \to \gamma\gamma$ calibration:



$E_\perp$ vs. $|\eta|$ for min bias & dijet events





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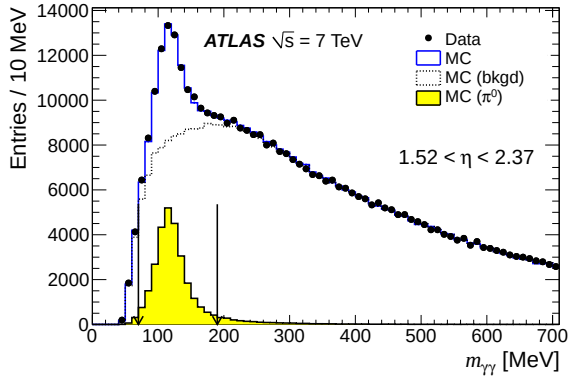
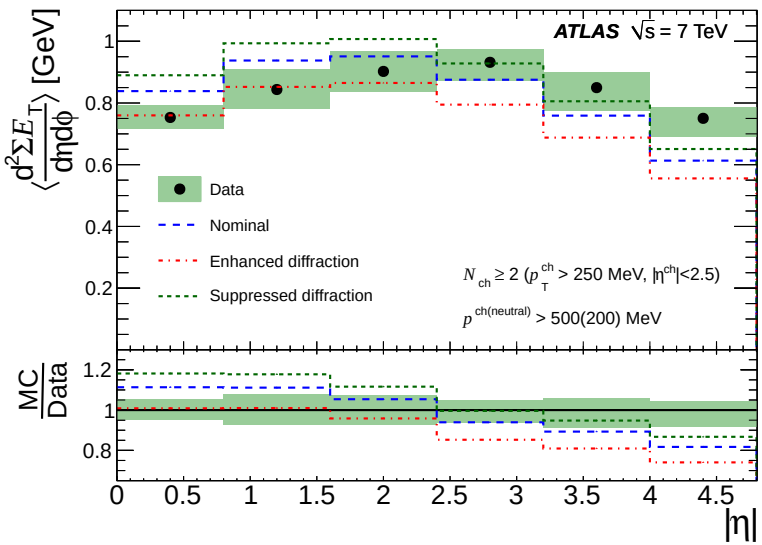
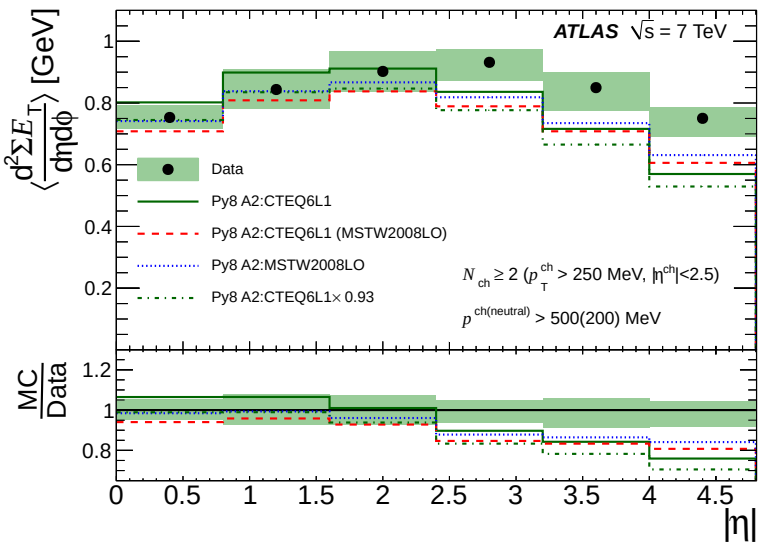


Effects of diffractive params and PDFs on min bias flow





A personal note!

Alec, 3 weeks old today 🙂