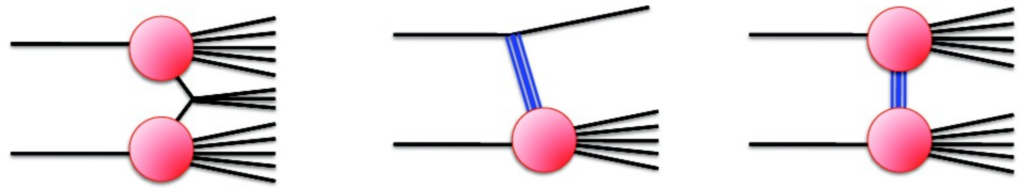
Low p_T-physics in ATLAS

Oldřich Kepka
(Institute of Physics, Academy of Sciences, Prague)

On behalf of the ATLAS Collaboration
October 5th, 2010, Split

Minimum Bias Physics



Non-diffractive | Single-diffractive | Double-diffractive

- Total = elastic + ND + SD + DD

Motivation:

- Improve understanding/modeling of non-perturbative soft QCD processes
- ND - QCD motivated models with many parameters; tuning important for high p_T-physics
  - Background when >1 interactions per bunch crossing
  - Parameters have impact on high p_T (e.g. color reconnection)
- SD+DD not well constrained by models and little data available

Objective:

- Measure spectra of primary charged particles corrected to hadron level ($\tau > 3\times10^{-11}$s)
- Inclusive measurement – do not apply model dependent corrections (e.g. Non-single diffractive distribution) => allow theorist to tune their models to data measured in well defined kinematic range

Minimum Bias in ATLAS

- **Inclusive charged particle spectra** @ 0.9 and 7 TeV

  $p_T > 100\,\mathrm{MeV}, n_{ch} \geq 2, |\eta| < 2.5$ ATLAS-CONF-2010-046 ◆

  $p_T > 500\,\mathrm{MeV}, n_{ch} \geq 1, |\eta| < 2.5$ Phys. Lett. **B** 688, 1, ATLAS-CONF-2010-024

  ATLAS-CONF-2010-047 (2.36 TeV)

  $p_T > 500\,\mathrm{MeV}, n_{ch} \geq 6, |\eta| < 2.5$ ATLAS-CONF-2010-031 ◆

  - diffraction suppressed sample, used to derive AMBT1

- **Underlying event using tracks** ATLAS-CONF-2010-081 ◆
- **Angular correlation between charged particles** ATLAS-CONF-2010-082 ◆
  - Measurements probing event topologies @ 0.9 and 7TeV (p_T>500 MeV)

- AMBT1 Pythia 6 Tune
  - using measurements of high-p_T tracks
  - gives better extrapolation down to 100 MeV

◆ discussed today

Outline

- Inner detector, dataset, event selection
- Correction procedure

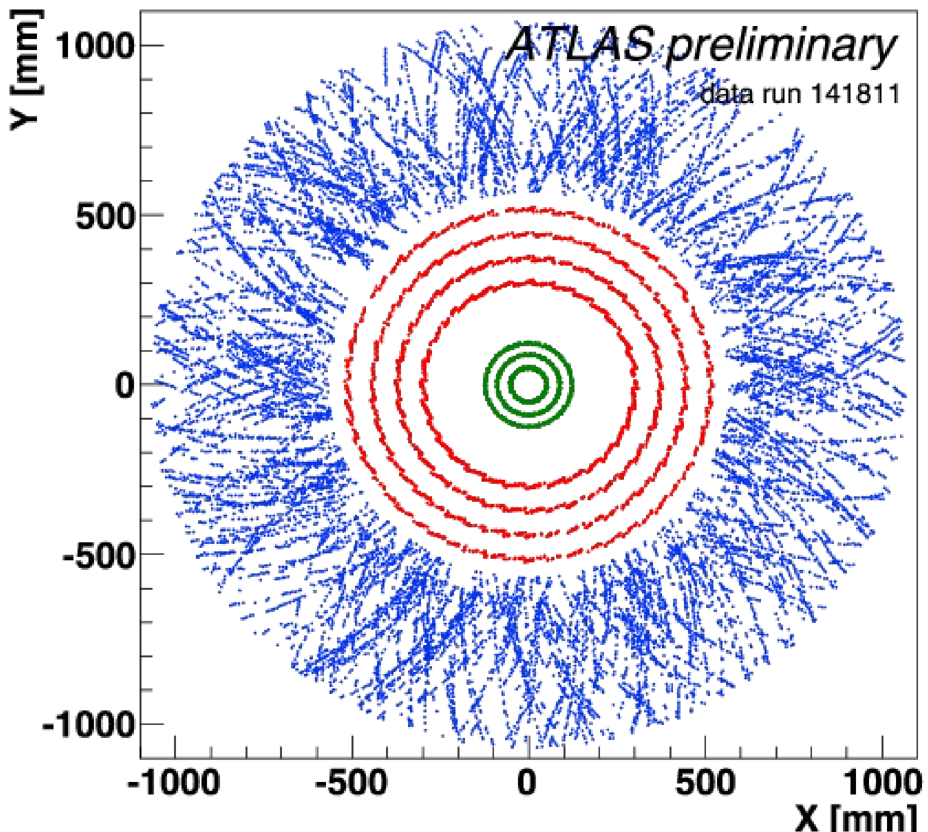
- **Inclusive charged particle spectra**

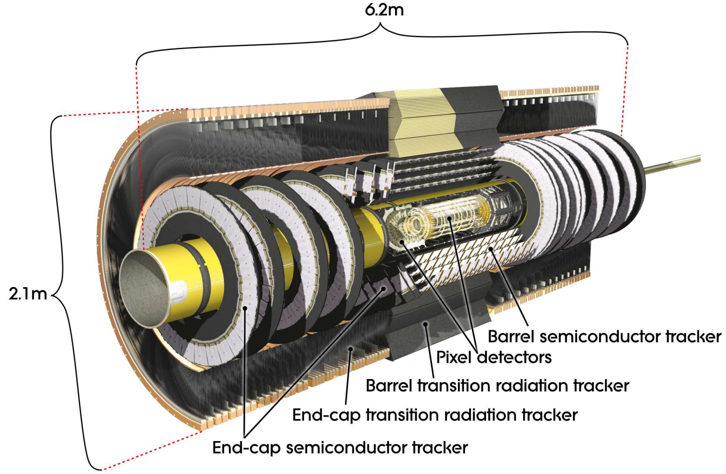
- **Angular correlations between charged particles**
  - new observable to probe models of MB physics

- **Underlying event measurement**

The ATLAS Inner Detector

Scatter Plot of Hits on Tracks



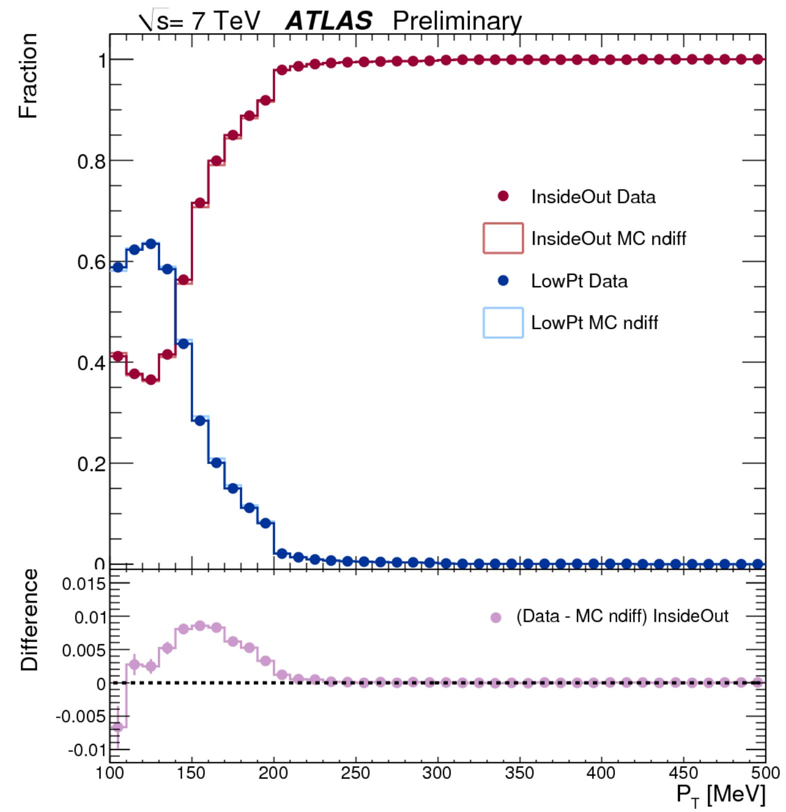


- **Pixel Detector**
  - 3 barrel layer; 2x3 end-cap disks
- **Silicon Strip Tracker (SCT)**
  - 4 double-sided barrel layers; 2x9 end-cap disks
- **Transition Radiation Tracker (TRT)**
  - 73 barrel straw tubes
  - ~32 hits per track
- **Minimum Bias Trigger Scintillator (MBTS)**
  - Inside the end-cap calorimeter
  - 2 disks covering $2.1<|\eta|<3.8$
  - 3.6 m from interaction point

Dataset and Event Selection

Event selection

- MBTS single arm trigger
- 1 Reconstructed Vertex
  - 2 tracks + Beam Spot
  - Remove multiple interactions
    - If second vertex ≥ 4 tracks
- 0.9 and 7 TeV
  - ≥ 2 selected tracks
  - p_T > 100 MeV, |η|<2.5
  - Use low p_T-tracking to go down to 100 MeV



Dataset

- 0.9 TeV (~7 μb^{-1})
  360K events, 4.5M tracks
- 7 TeV (~190 μb^{-1})
  10M events, 210M tracks

Correction procedure

- Event-wise correction for trigger and vertex efficiencies

$$w_{\text{ev}}(n_{\text{Sel}}^{\text{BS}}) = \frac{1}{\varepsilon_{\text{trig}}(n_{\text{Sel}}^{\text{BS}})} \cdot \frac{1}{\varepsilon_{\text{vtx}}(n_{\text{Sel}}^{\text{BS}})}$$

n_{Sel}^{BS} – number of particles wrt. Beam Spot, cuts as close as possible to the final selection

- Track-wise correction – tracking efficiency

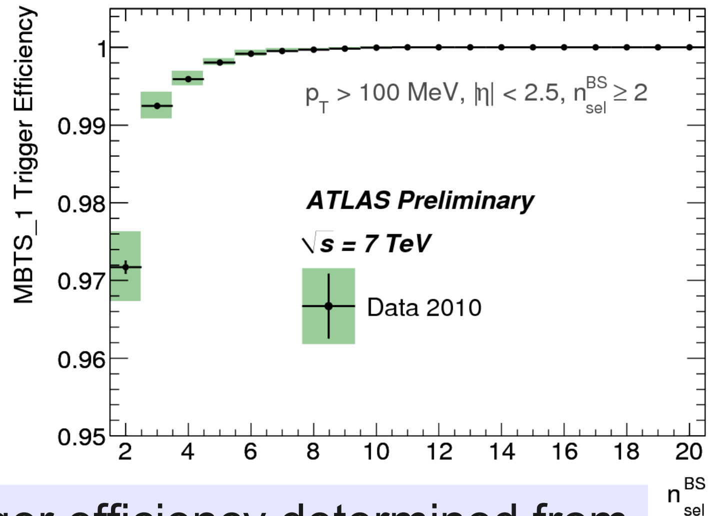
$$w_{\text{trk}}(p_{\text{T}}, \eta) = \frac{1}{\epsilon_{\text{bin}}(p_{\text{T}}, \eta)} \cdot (1 - f_{\text{sec}}(p_{\text{T}}, \eta)) \cdot (1 - f_{\text{okr}}(p_{\text{T}}, \eta))$$

  - Correct for tracks outside kinematic range: $f_{okr}(p_T, \eta)$
  - e.g. track p_T>100 MeV, but particle p_T below

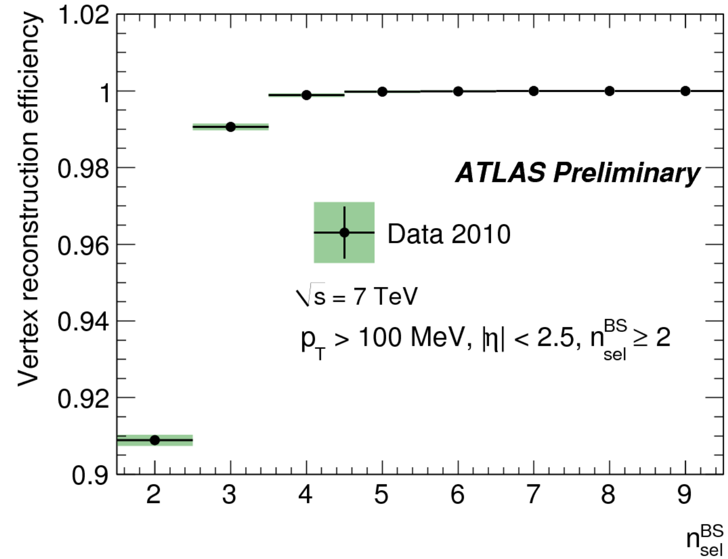
- Using Bayesian unfolding to correct both the multiplicity n_{ch} and p_T

- Mean p_T vs n_{ch} – bin-by-bin correction of average p_T, then n_{ch} migration

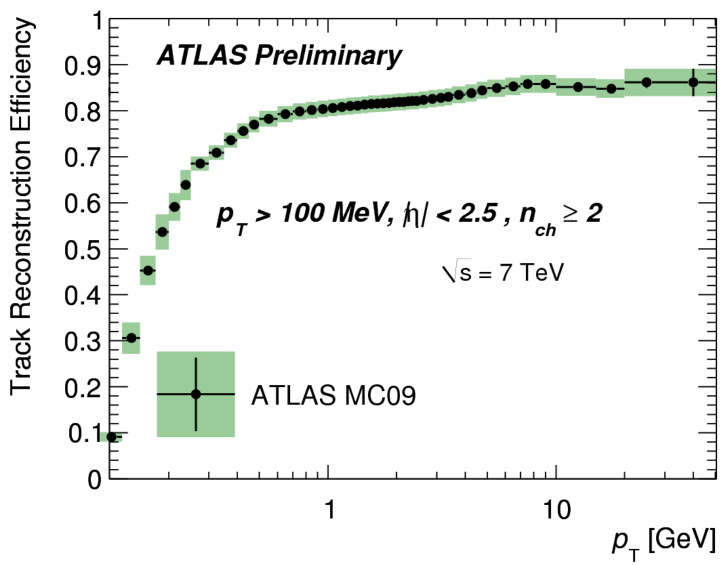
Efficiencies

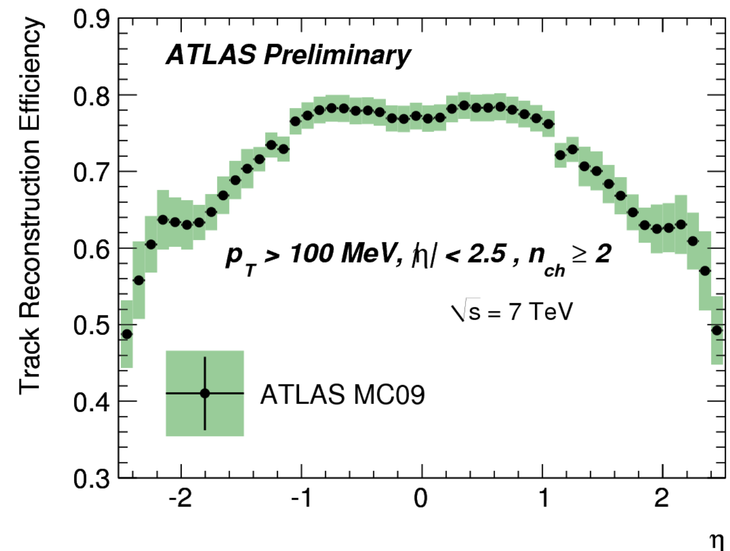


Trigger efficiency determined from data using orthogonal trigger



Vertex efficiency measured in data

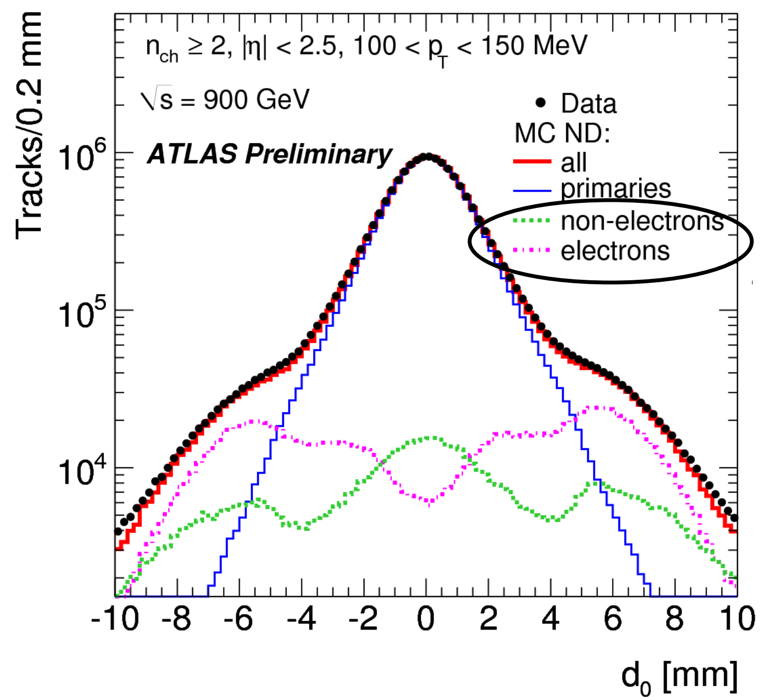




Tracking efficiency from MC – systematic dominated by knowledge of material budget (determined by SCT extension efficiency)

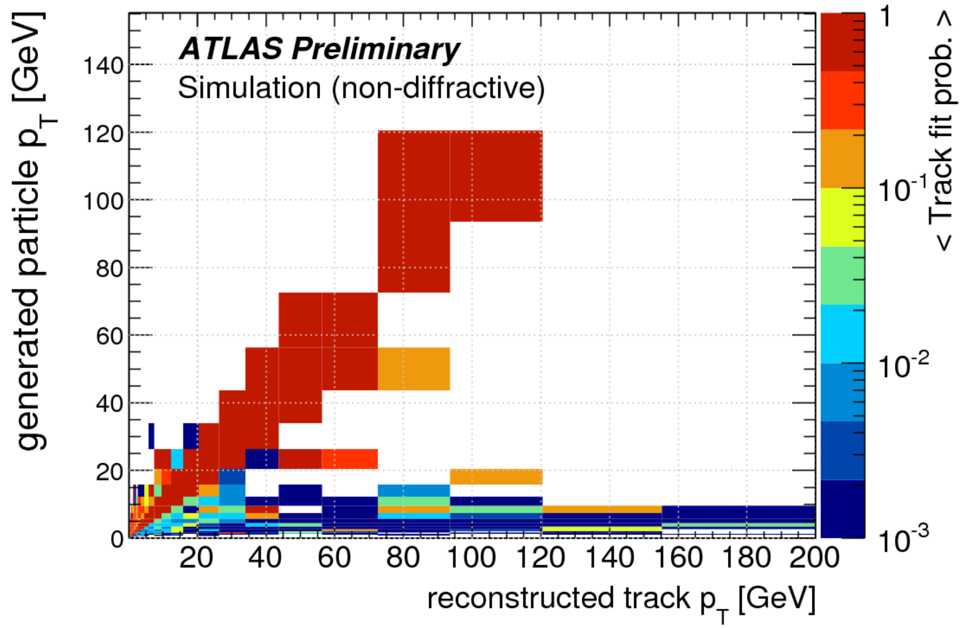
Removal of non-primary tracks

- Fraction of non-primaries



- Determined with side-band fits of d_0 and z_0 distributions to data
- Below p_T<500 MeV large electron component from photon conversions
- Removed on statistical basis

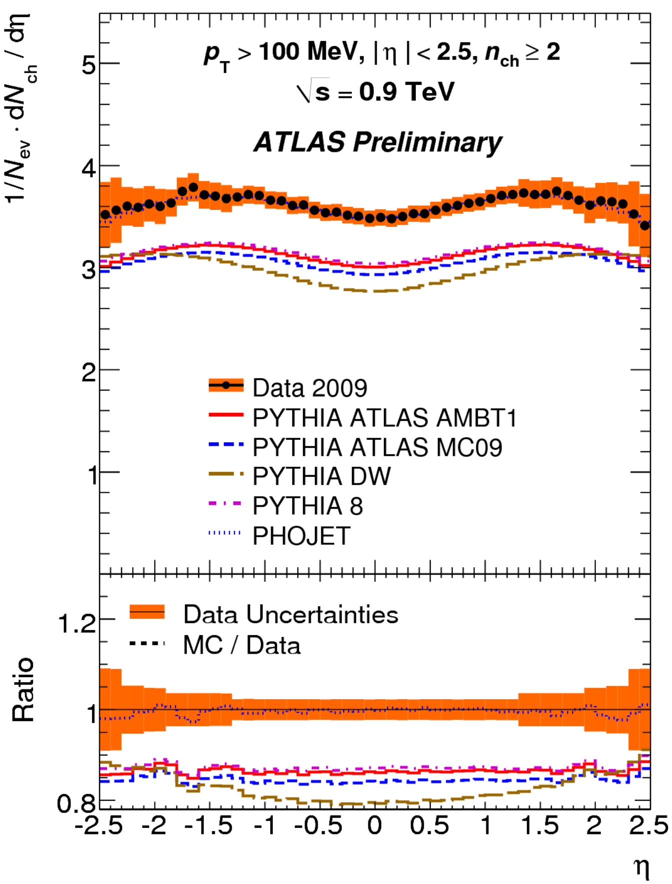
- High-p_T Tracks

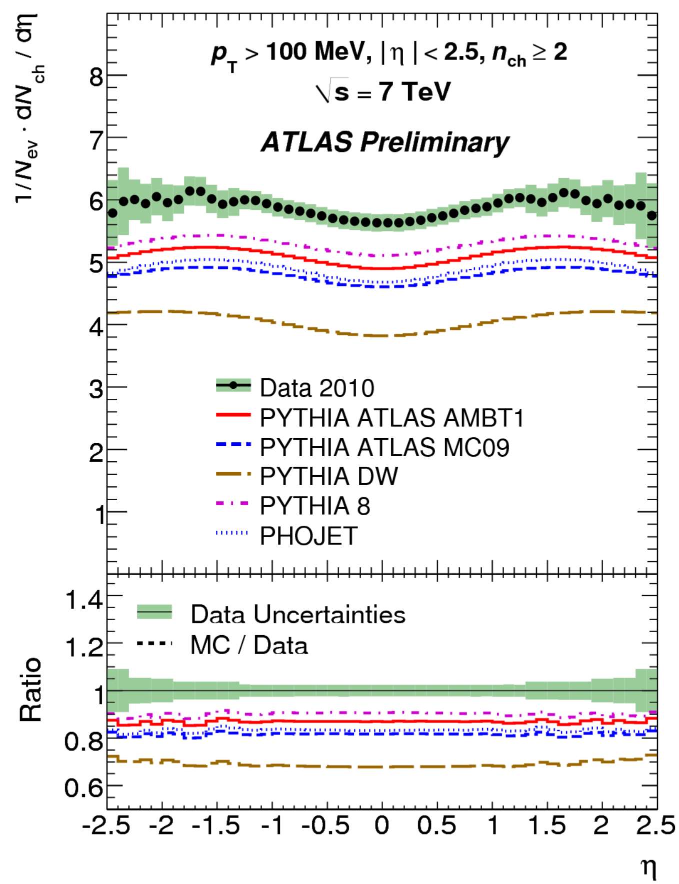


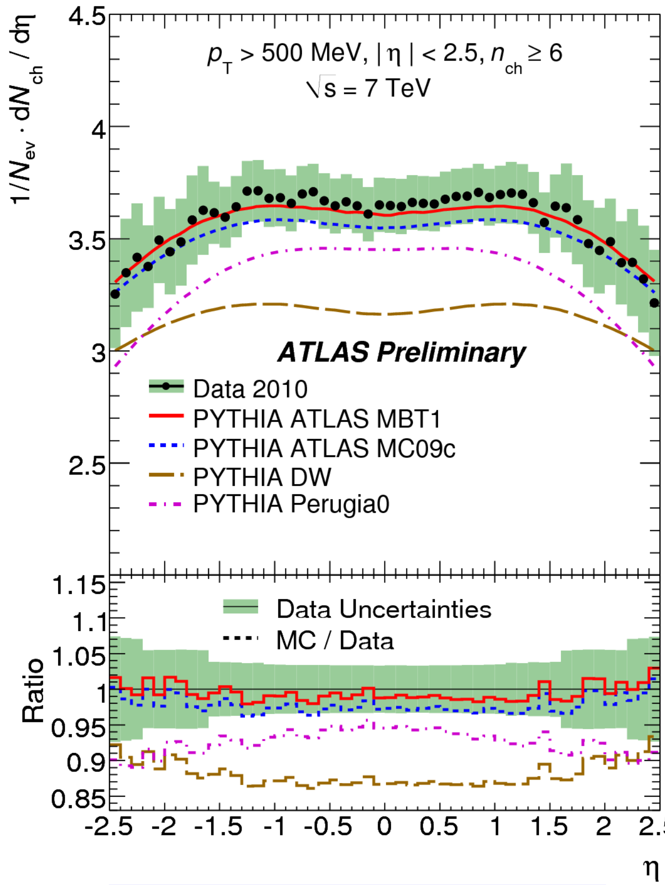
- At high $|\eta|$ large extrapolation distance (~1m) between SCT and Pixel, additional material
  - Some particles mis-reconstructed as high-p_T tracks
  - Remove by cut on χ^2 probability of the track fit above p_T>10 GeV

$1/N_{ev}\ dN_{ch}/d\eta$

- Models differ mainly in normalization, shape similar. Track multiplicity underestimated.
- $n_{ch} \geq 6$, $p_T > 500$ MeV measurement used in AMBT1 tune





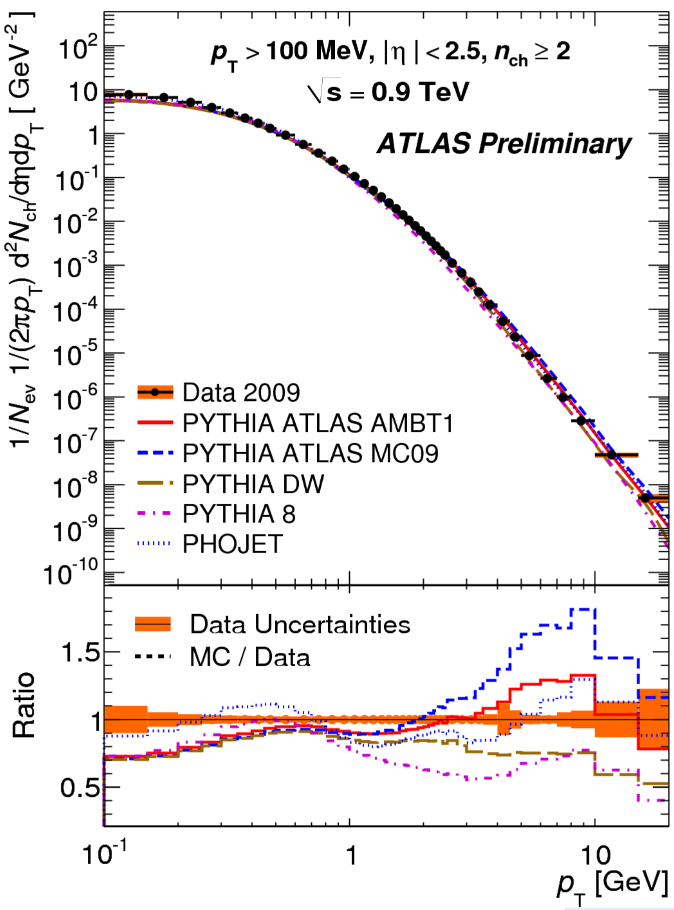


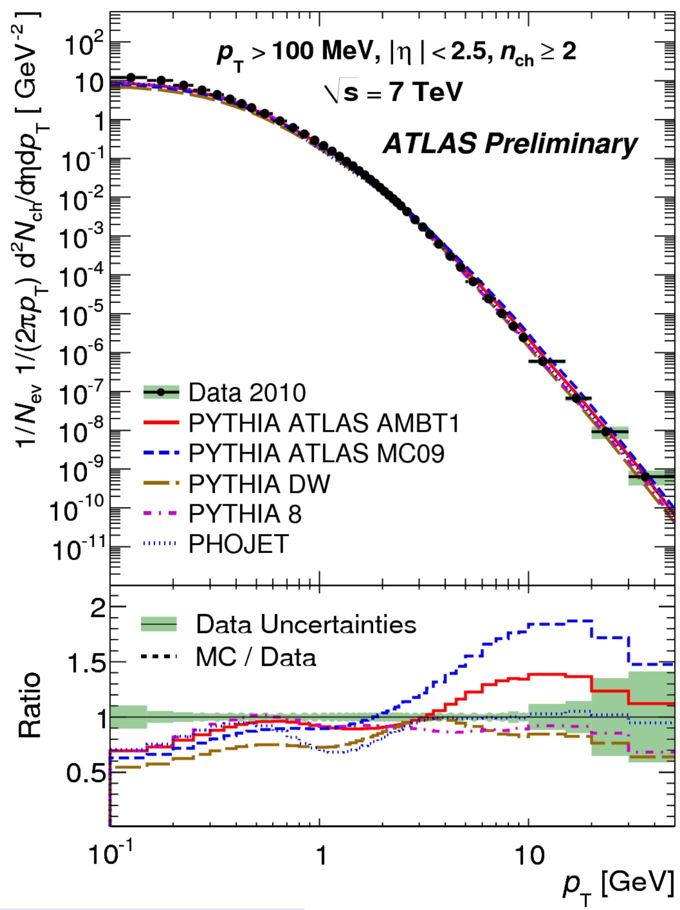
$n_{ch} \geq 2$, $p_T > 100$ MeV

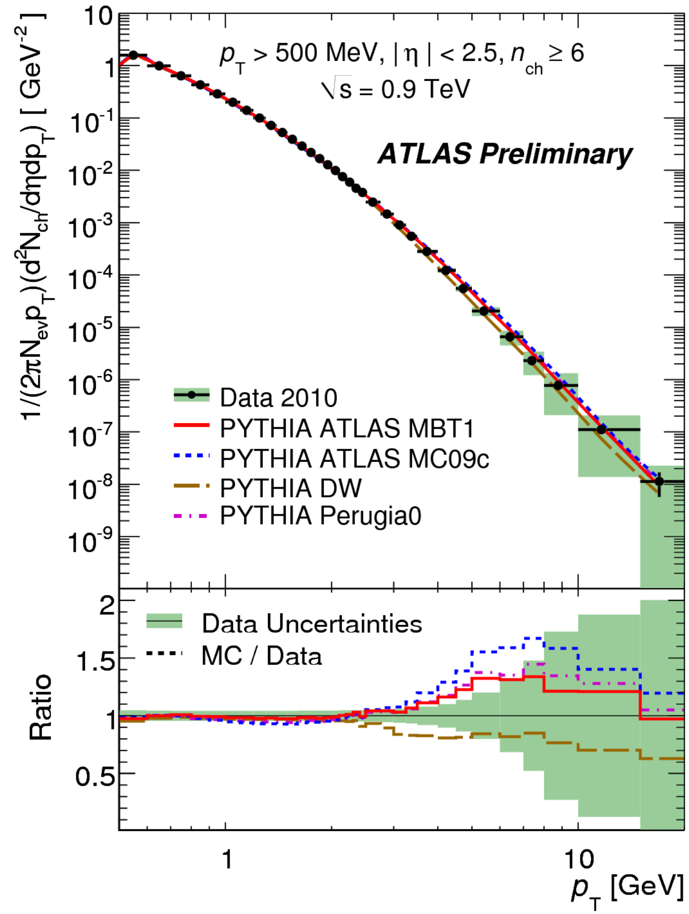
$n_{ch} \geq 6$, $p_T > 500$ MeV

$1/(2\pi p_T)\ 1/N_{ev}\ dN^2_{ch}/d\eta dp_T$

- Measurement spans 10 orders of magnitude
- Large disagreement at low p_T and high p_T
- Improvement at medium p_T for AMBT1 tune





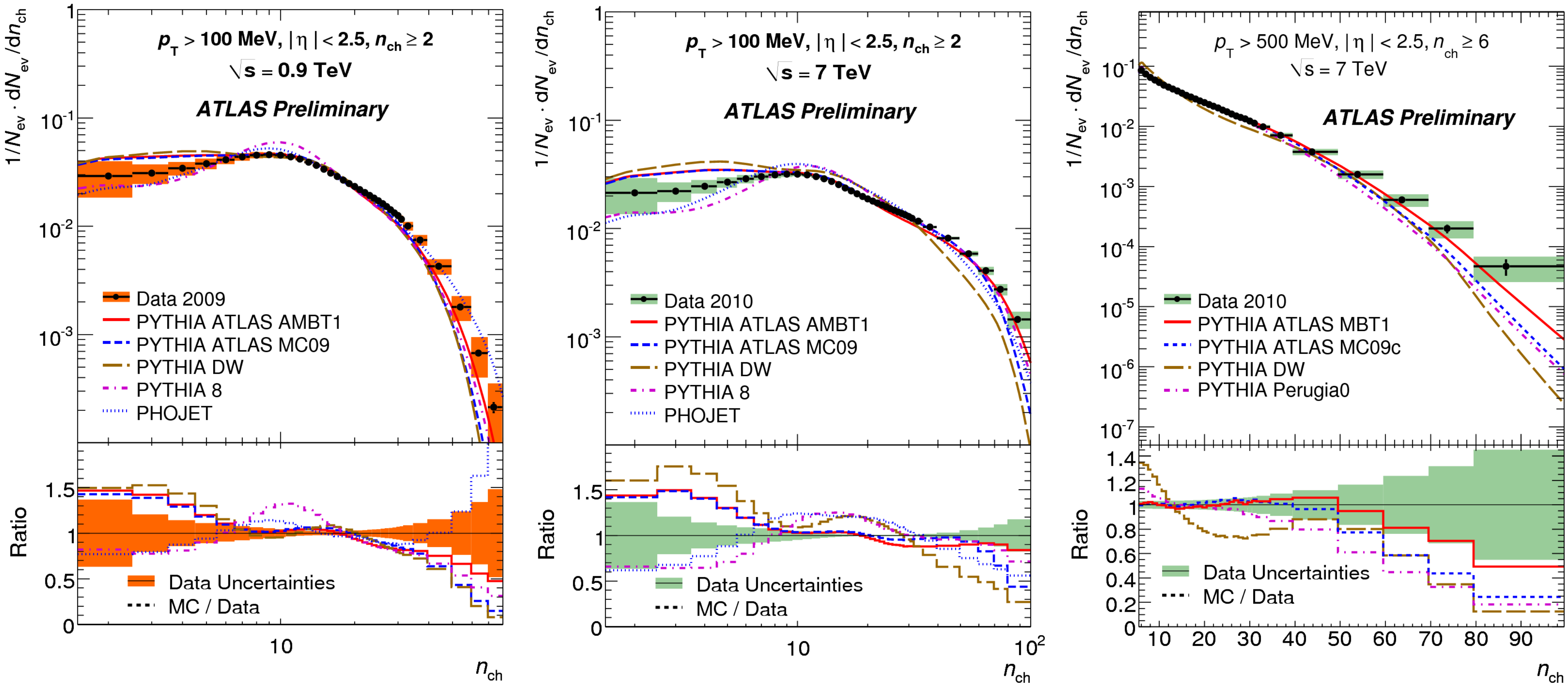


n_{ch}≥2, p_T>100 MeV

n_{ch}≥6, p_T>500 MeV

$1/N_{ev}\ dN_{ev}/dN_{ch}$

- Low n_{ch} not well modeled by any MC; large contribution from diffraction
- Peak at 10 particles well described by AMBT1

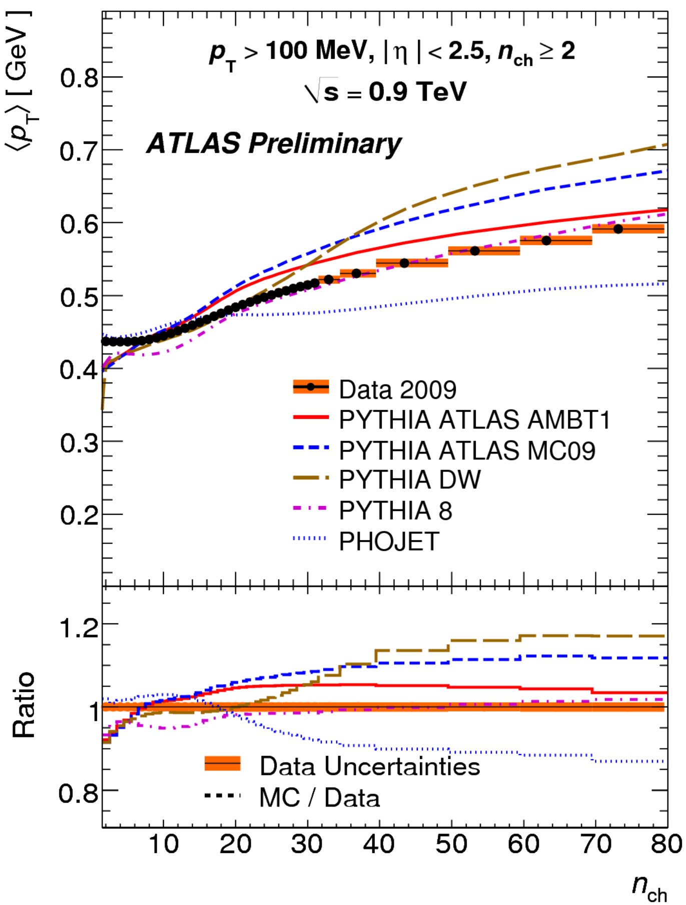


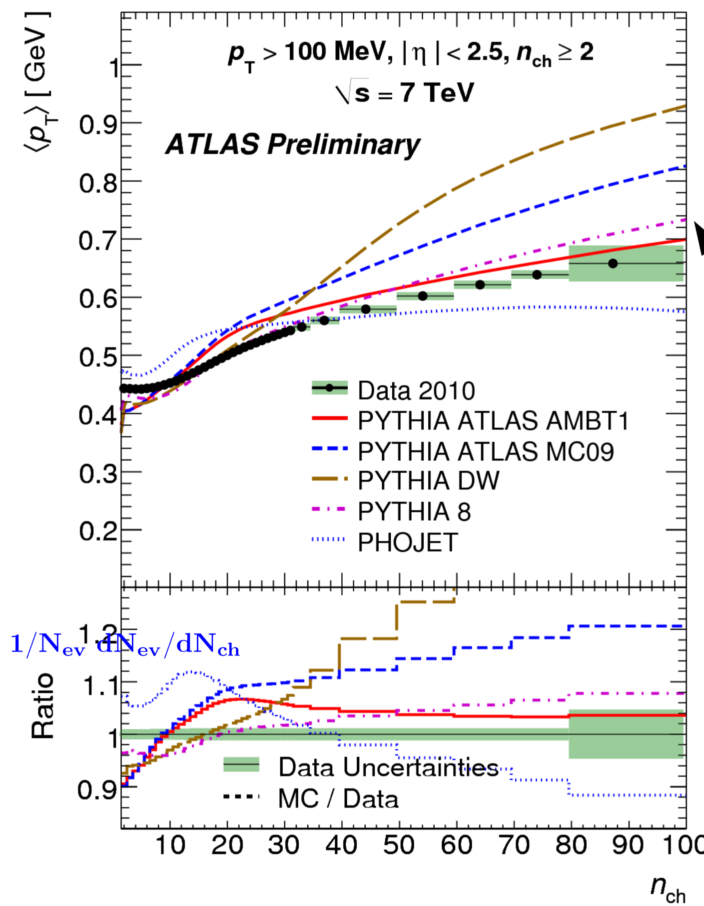
n_{ch}≥2, p_T>100 MeV

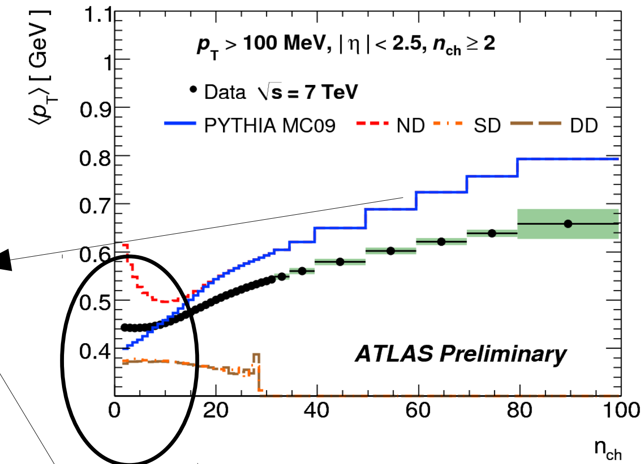
n_{ch}≥6, p_T>500 MeV

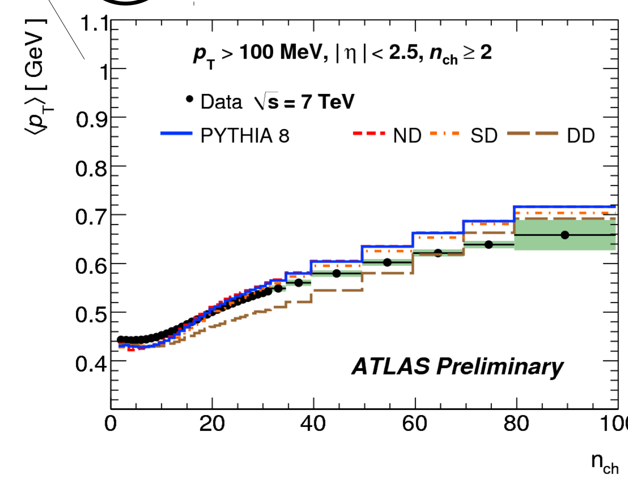
Mean p_T vs. N_{ch}

- AMBT1 and Pythia8 with hard diffractive component give best description
- Shape at low n_{ch} sensitive to ND, SD, DD fractions







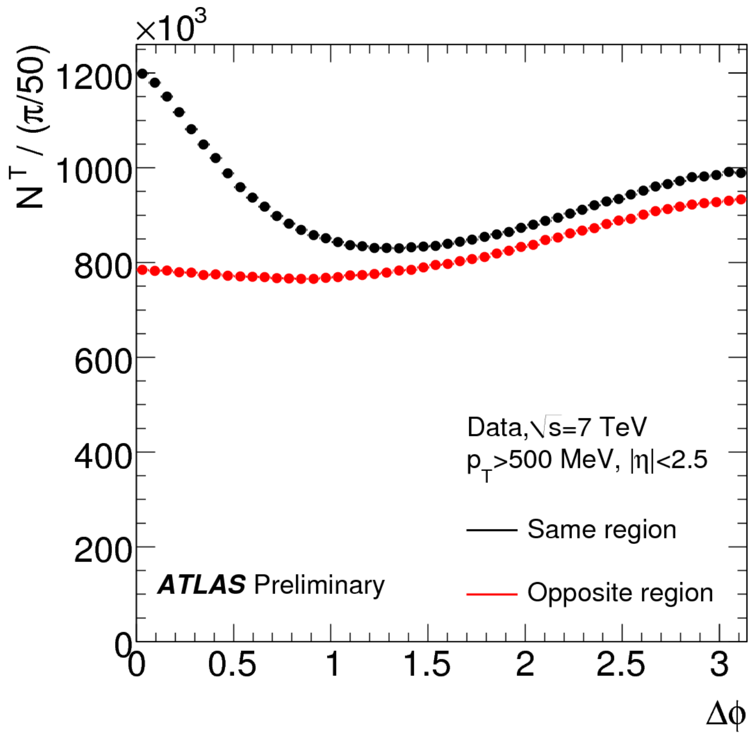


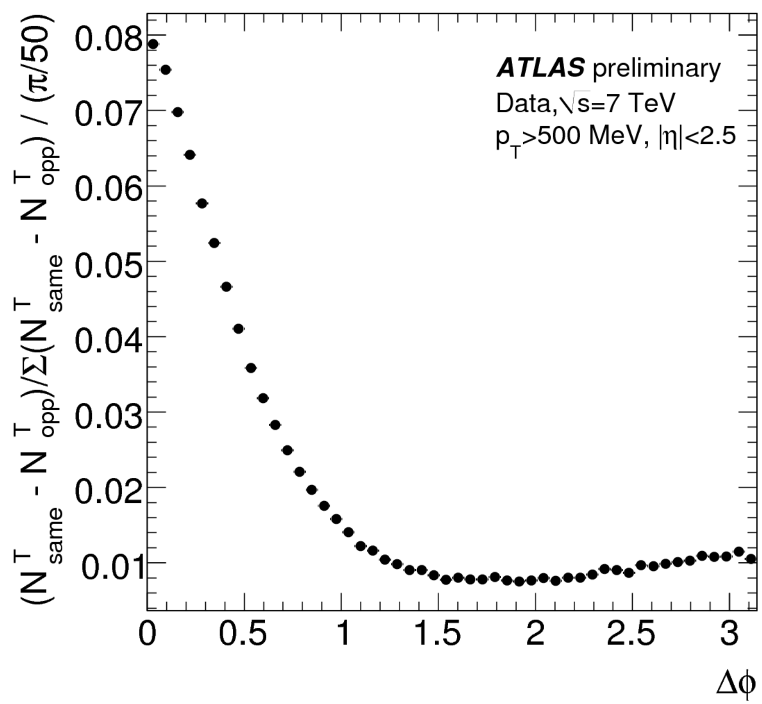
n_{ch}≥2, p_T>100 MeV

Pythia6 – softer spectrum at low n_{ch} – too large diffractive component?

Angular Correlations

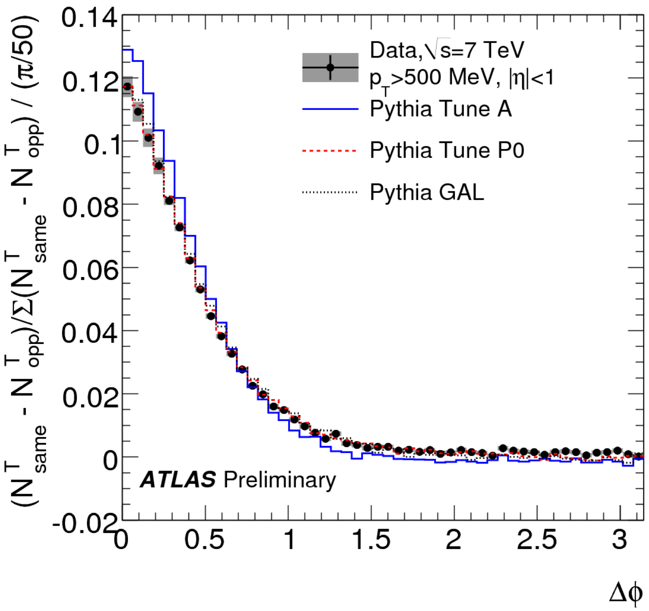
- Aim to measure new observable which is sensitive to differences between current models
- $\Delta\phi$ - azimuthal angle between p_T-leading particle and all non-leading ones
- Measured in **same** and opposite regions wrt. to leading particle
  (e.g. η(leading) < 0 => same $\eta<0$; opposite $\eta > 0$)
- More particles produced in **same** region
- Same minus opposite, subtract minimum => $\Delta\phi$ crest shape



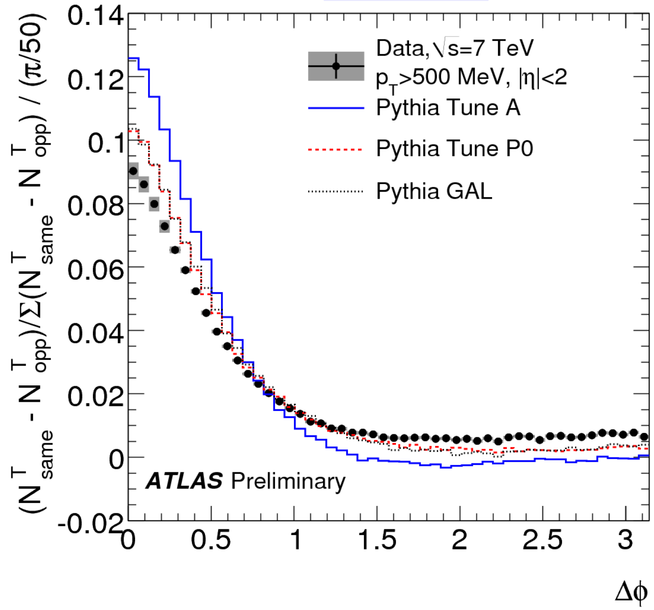


ΔΦ crest shape

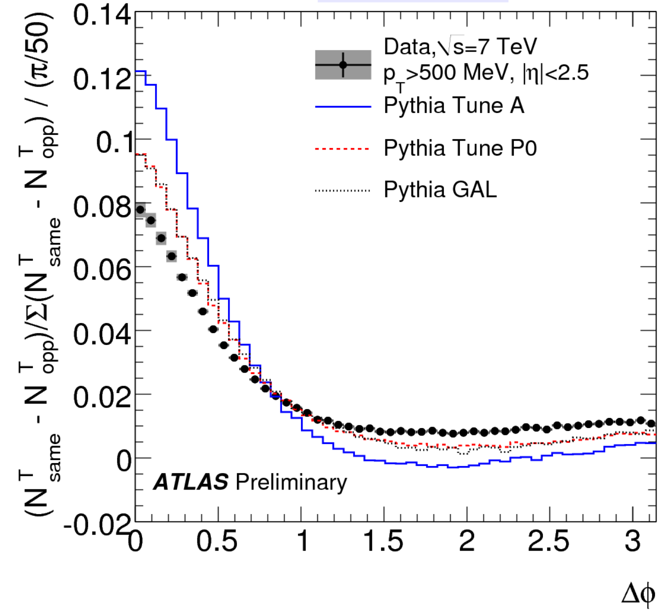
|η|<1



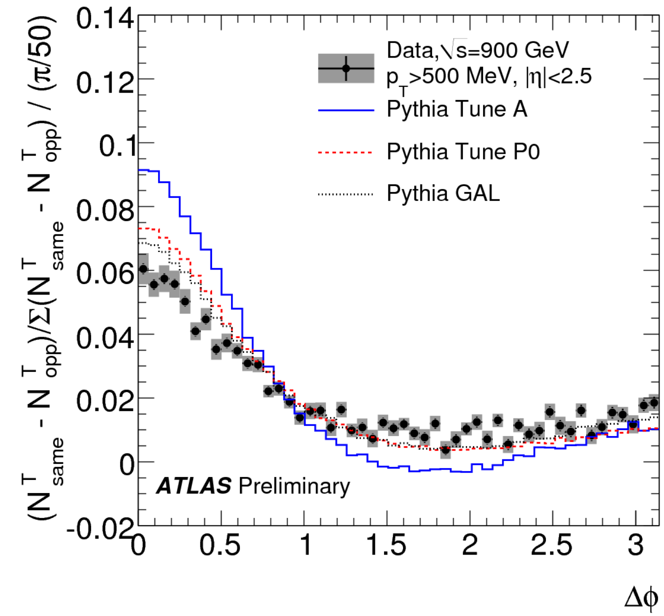
|η|<2



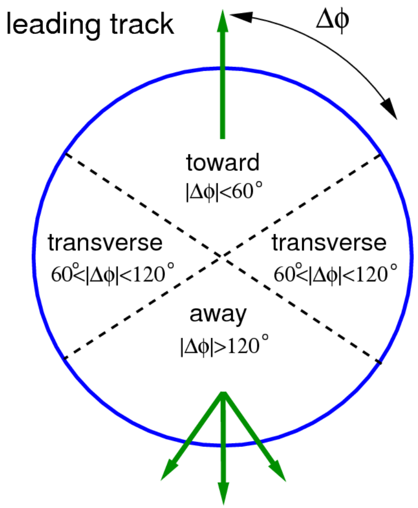
|η|<2.5



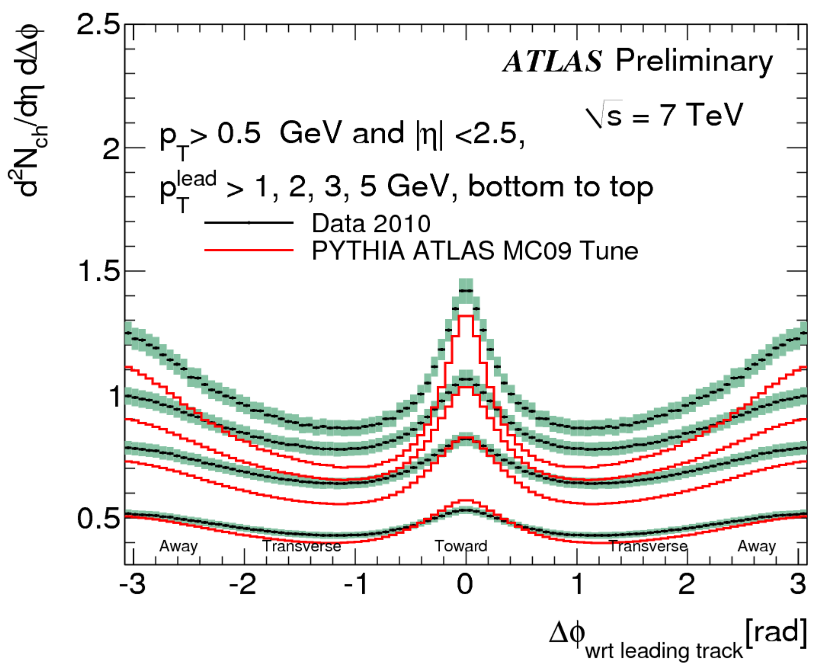
- Good description in central η
- Models poorly constrained at forward direction where reach of previous experiments limited
- Same discrepancy observed @ 0.9 TeV

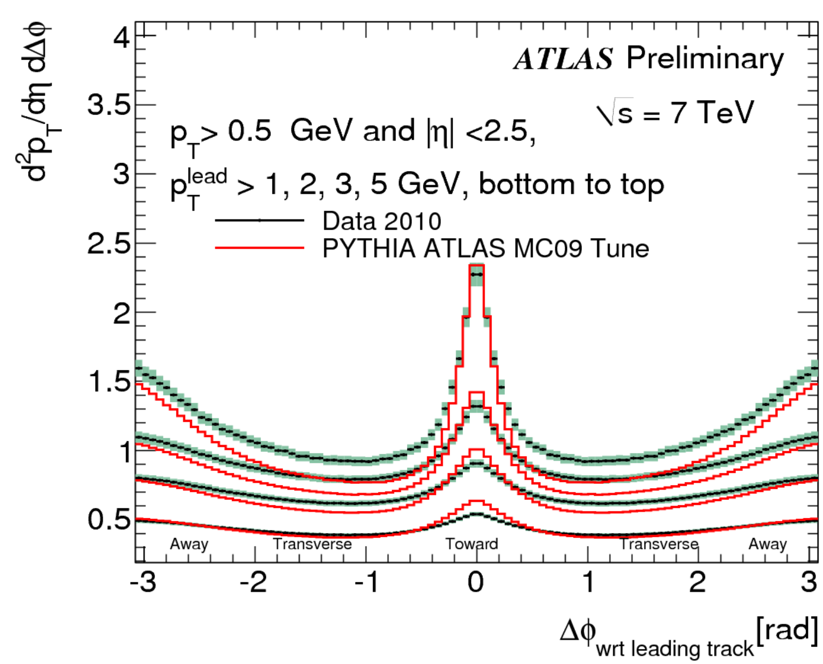


Underlying Event

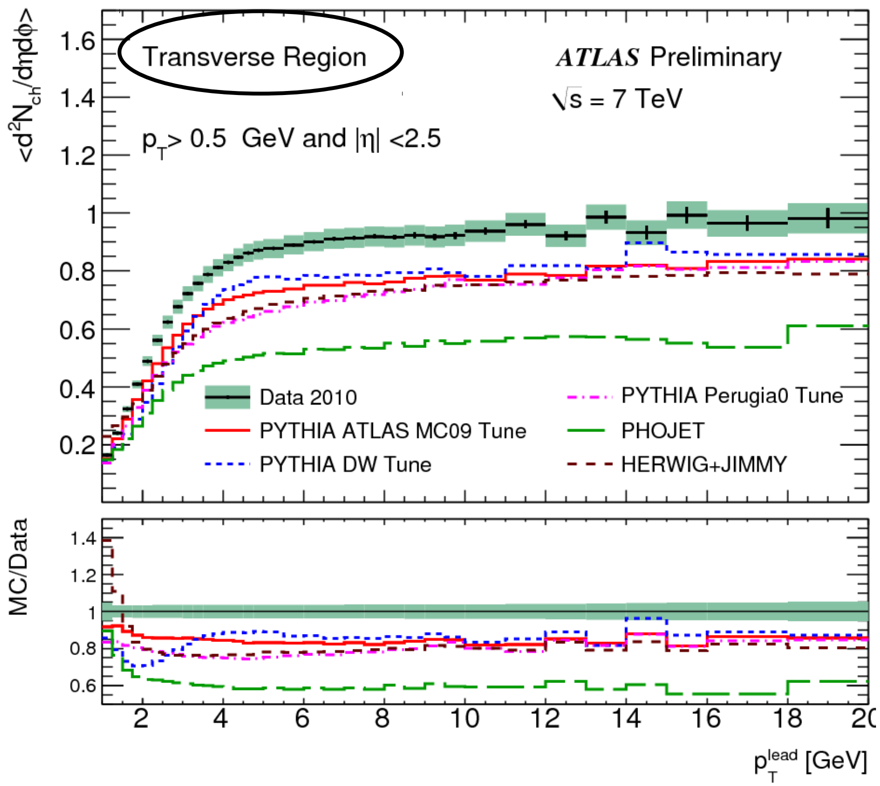


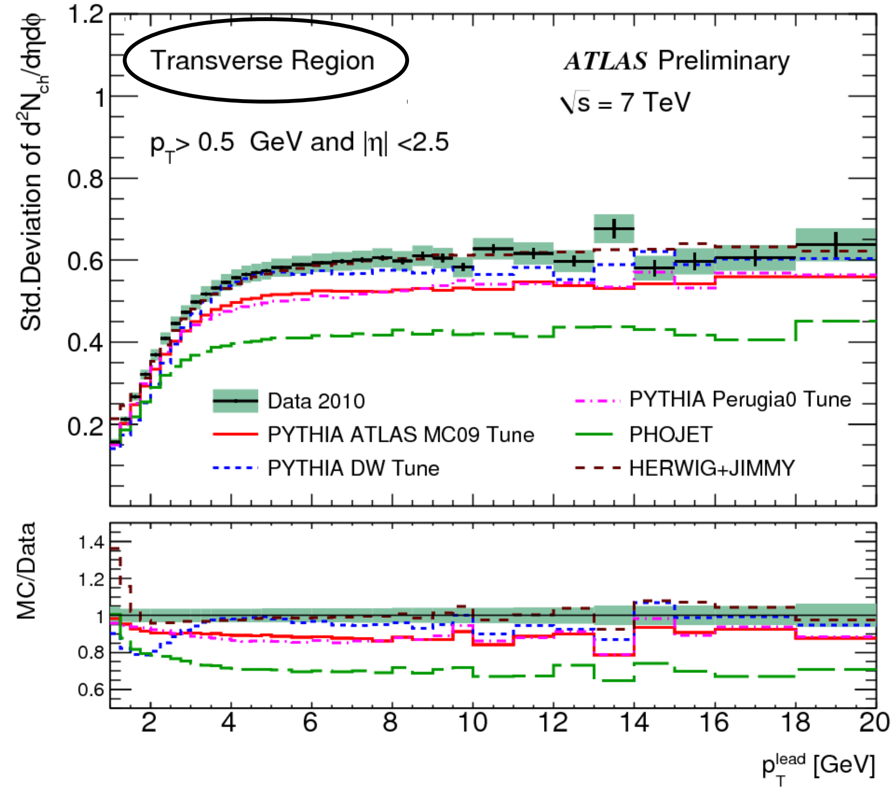
- Underlying event – processes occurring in addition to hard QCD scattering
  - Beam-beam remnants
  - Multi-parton interactions
  - Contributions from initial/final state radiation
- Transverse region perpendicular to hard scatter sensitive to UE
- Leading track p_T>1GeV to suppress diffraction
- Models have problems describing transverse region





Multiplicity & Std. Deviation





- Average tracks multiplicity in the plateau about 2 times higher than seen in inclusive MB

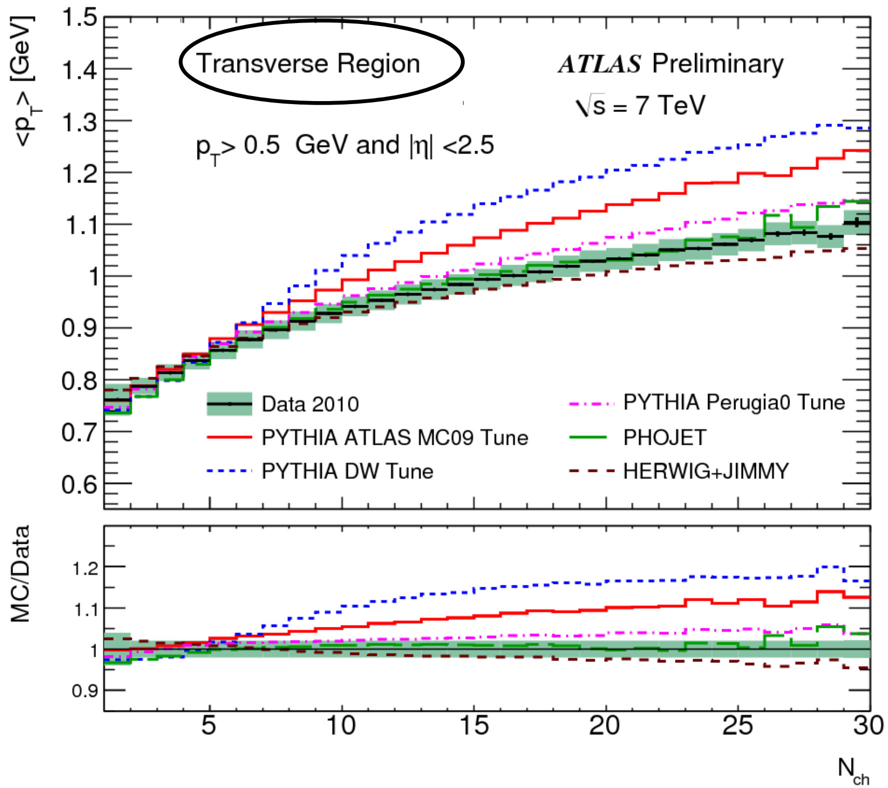
  (mean density 0.9 translates to 5.5 particles when towards/away regions included; to be compared with ~2.4 particles in inclusive MB)

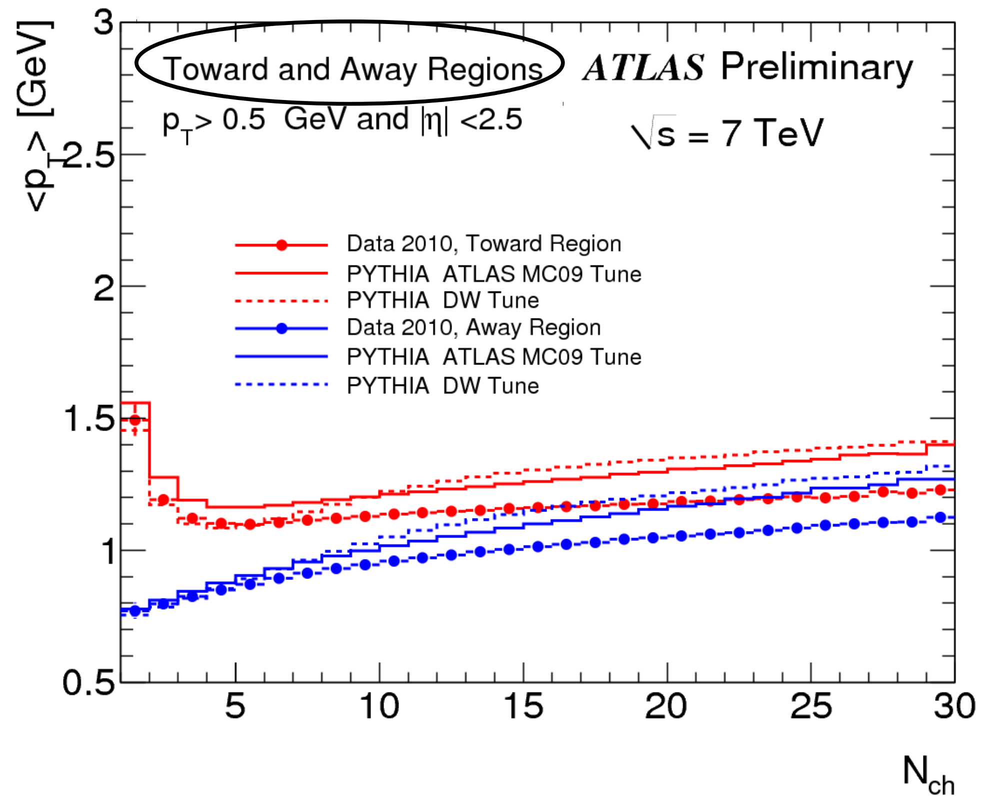
- If particles produced independently => Poisson distribution expected

$$\sqrt{0.9} \simeq 1.6 \times 0.6$$

Scaling factor 1.6 suggests that particles are not produced independently

Mean p_T vs. N_{ch}

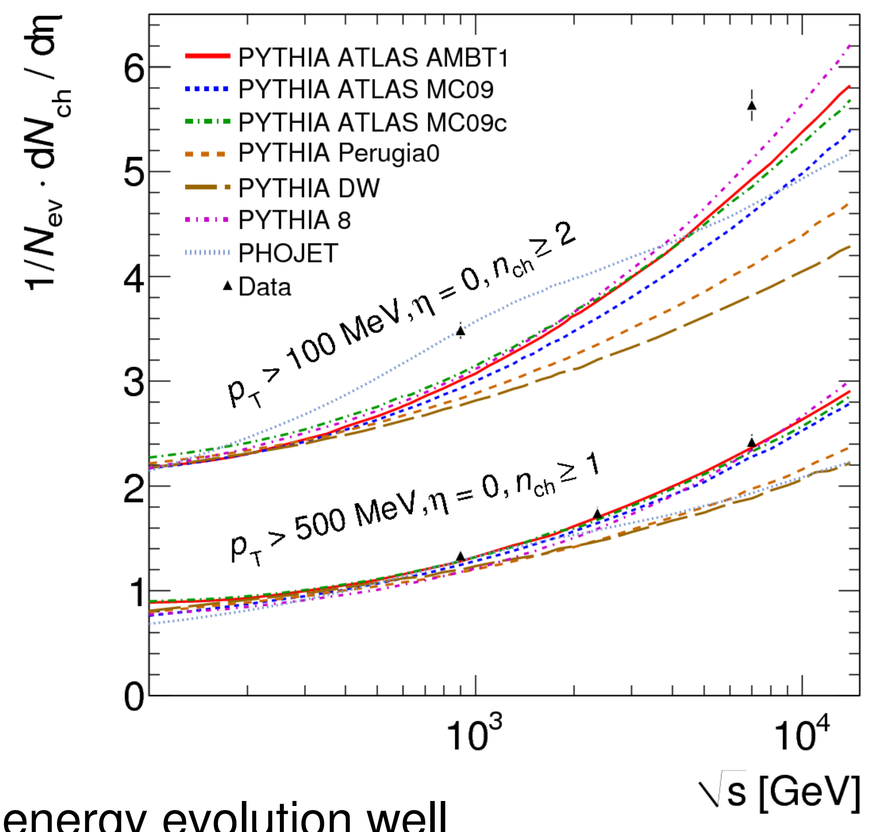




- Example: DW which was tuned to CDF UE data describes transverse region, but problems in away region
- Is not described either in inclusive MB
- Other variables: mean p_T vs p_T(lead), $\langle d^2\Sigma p_T/d\eta dp_T \rangle$
  => many observables for model tuning

Conclusion

- ATLAS measures charged particle spectra down to 100 MeV
- @ 0.9, 2.36, 7 TeV
- No-model dependent corrections



- p_T> 100 MeV
  - model extrapolation to higher energies very different
  - models underestimate the particle multiplicity down to low-p_T
- p_T> 500 MeV
  - AMBT1(tunned to first LHC data) describes energy evolution well

- Angular correlation and UE measurements add information about the event structure
- All MB and UE measurements corrected to hadron level

- Publication of data dedicated to tuning of phenomenological models in preparation