Charged-particle multiplicities measured with the ATLAS detector at the LHC

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on behalf of the ATLAS collaboration
EPS 2015

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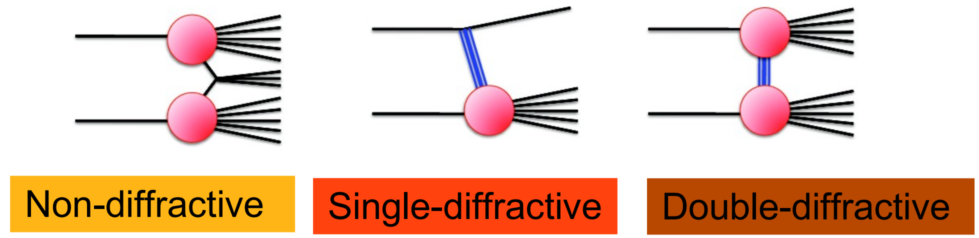
Why charged particle multiplicities?

- What is the composition of inelastic proton-proton collisions ?



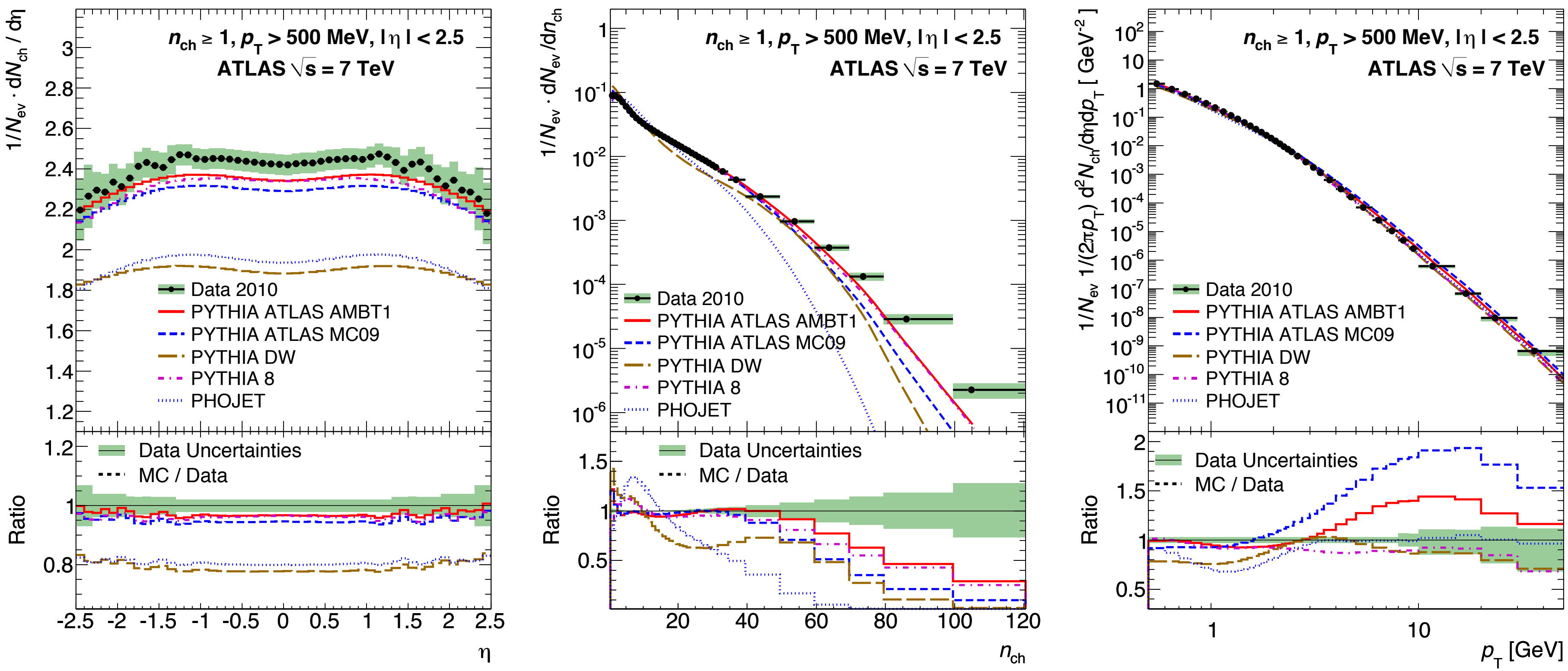
- Perturbative QCD describes only the hard-scattered partons, all the rest is "predicted" with phenomenological models
  - ND
    - QCD motivated models with many parameters
    - Background when >1 interactions per bunch crossing
    - Parameters have impact on the extrapolation to high p_T (e.g. colour reconnection)
  - SD+DD not well constrained by models and little data available
- Objective:
  - Measure spectra of primary charged particles corrected to hadron level

$$dN_{ev}/dn_{ch},\ \langle pT \rangle \text{ vs. } n_{ch},\ dN_{ch}/d\eta,\ d^2N_{ch}/d\eta dp_T$$

  - Inclusive measurement – do not apply model dependent corrections (e.g. Non-single diffractive distribution) => allow theorists to tune their models to data measured in well defined kinematic range

Previously…

- Published results at 0.9, 2.76, 7 TeV (http://arxiv.org/abs/1012.5104)

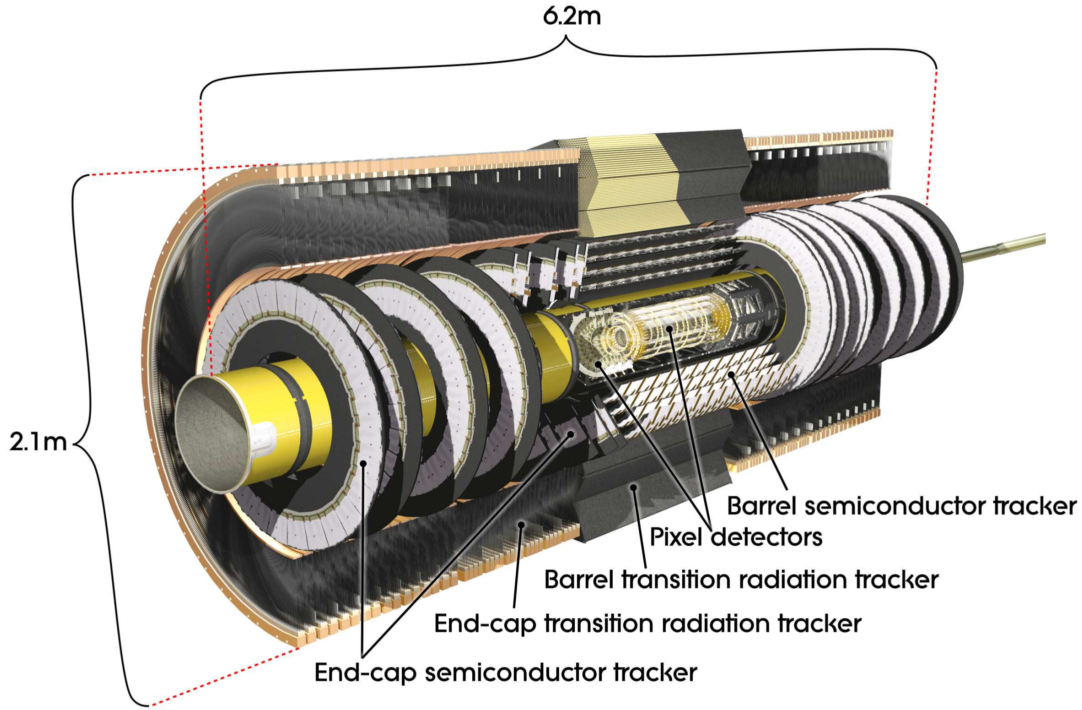


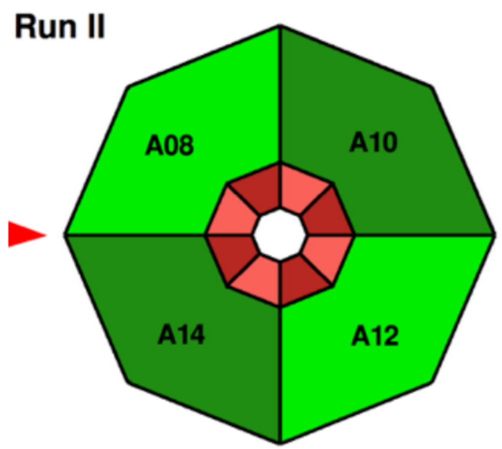
- Previous models/tunes generally under predicted the rate of charged particles, their multiplicity and mismodelled their p_T spectrum
  - Many refinements have been made in the past 5 years.
- Today will focus on a new measurement at 13 TeV (ATLAS-CONF-2015-028)
  - ≥ 1 selected tracks with p_T > 500 MeV & |η|<2.5

ATLAS Inner Detector & MBTS

Inner Detector

- Responsible for measuring the trajectories of charged particles originating from the interaction point
- Comprises three detector technologies:
  - Silicon pixels
    - 1.7k modules, 46k pixels each
  - Silicon microstrips (SCT),
    - 4k modules, 768 strips each
  - Drift tubes (Transition Radiation Tracker – TRT)
    - 360k straws & PID
- Located within a 2T solenoidal magnetic field



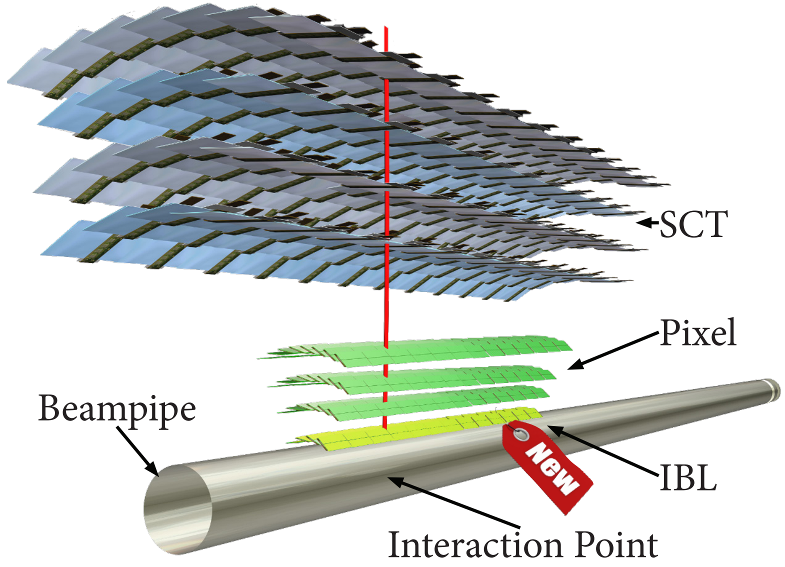


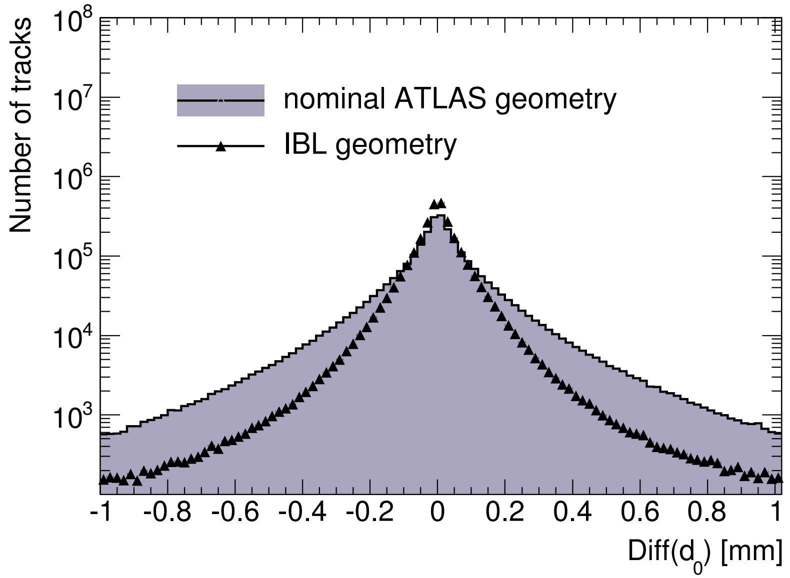
MBTS

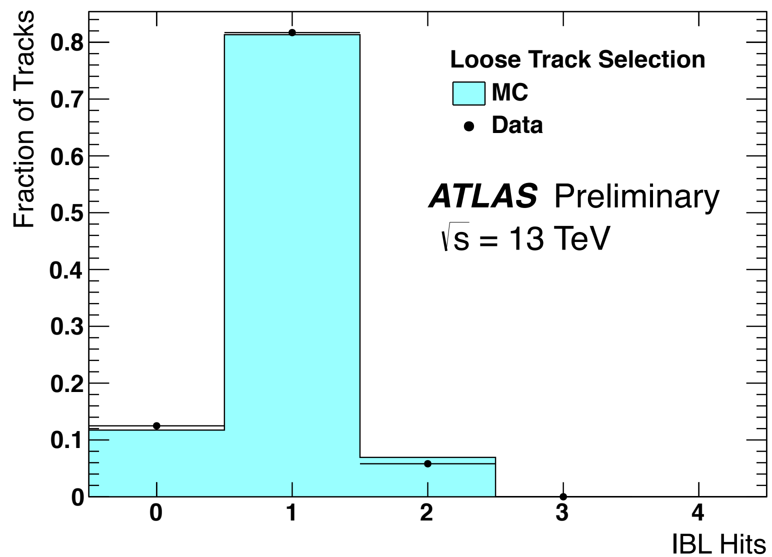
- Refurbished detector for Run 2
- Located in front of the end-cap calorimeters
  - 3.6m from the interaction point
- Coverage $2.1<|\eta| < 3.8$ in 2 disks

Pixel IBL

- A new layer has been added to ATLAS during LS1
- Provide security against detector ageing
- The additional measurement:
  - Improves IP resolution
  - And provides an additional point on the track — more robust tracking in high pile conditions
- See Karlos Potamianos's talk Friday Afternoon in the Detector R&D and Data Handling stream







Event Selection

- Low μ runs - <μ> ~ 0.005
- MBTS single sided trigger
- Use low p_T-tracking to reconstruct tracks down to 100 MeV
- 1 Reconstructed Vertex
  - 2 tracks + beam spot constraint
  - Remove events with multiple interactions
    - If second vertex ≥ 4 tracks

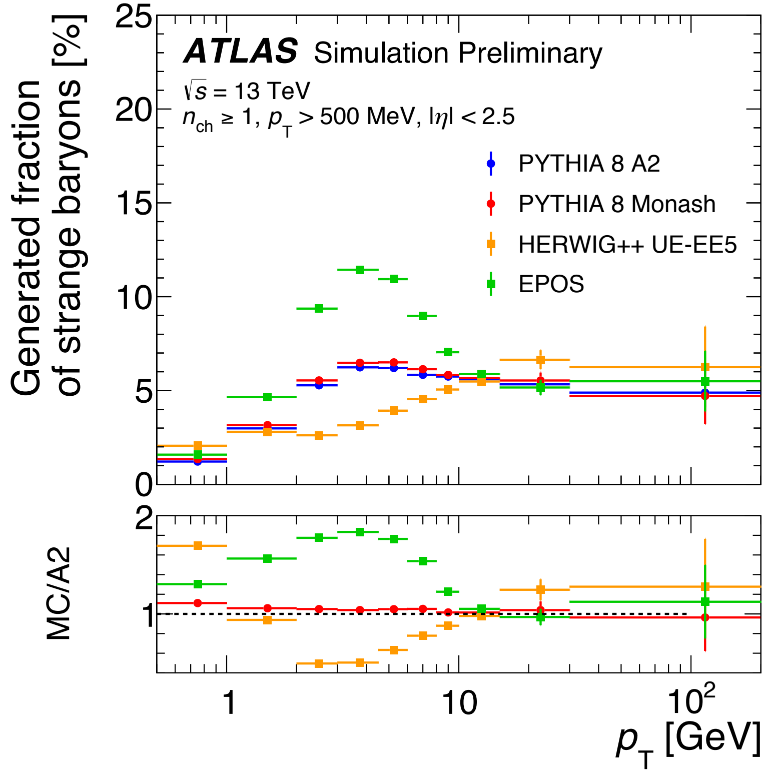
13 TeV
168 μb^{-1}
~10M events

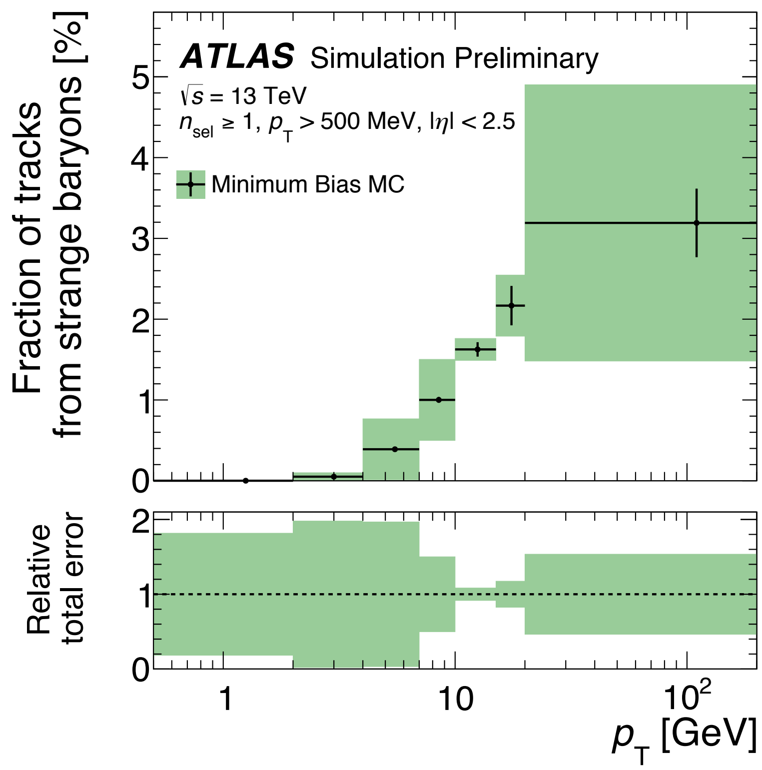
Track selection:

- ≥ 1 tracks, p_T > 500 MeV, $|\eta|<2.5$
- Tracks must have:
  - $d_0<1.5$mm, $z_0\sin\theta < 1.5$mm
  - A hit in the inner most layer of the detector
  - 6 SCT hits
  - for p_T > 10 GeV, $P(\chi^2) > 0.01$

Strange Baryons

- Particles with lifetime 30 ps < τ < 300 ps are no longer considered primary particles in the analysis, decay products are treated like secondary particles
- All of these particles were strange baryons
- Low reconstruction efficiency (<0.1%) and large variations in predicted rates lead to a model dependence





Corrections

- Event-wise correction for trigger and vertex efficiencies

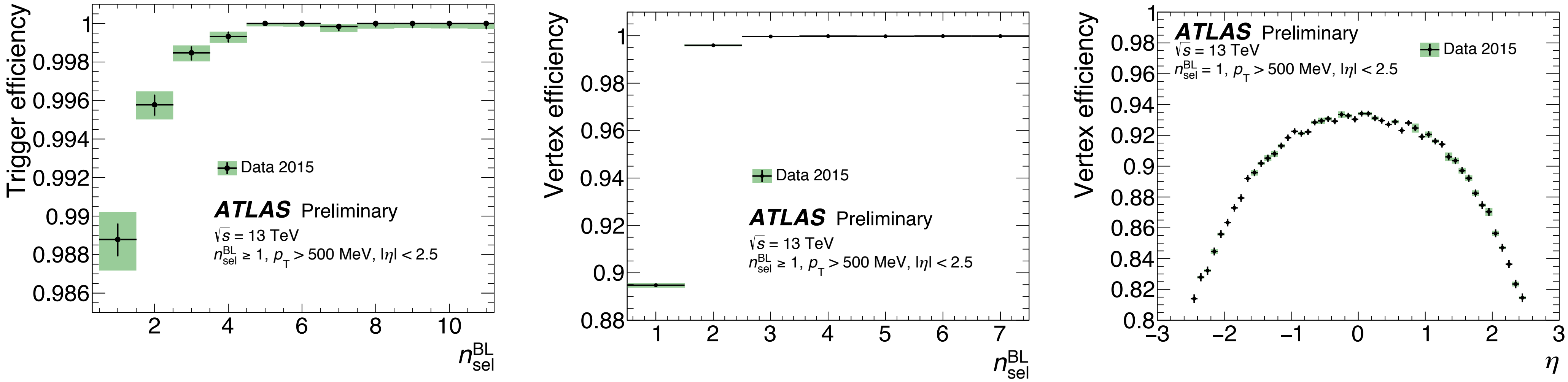
$$w_{\text{ev}}(n_{\text{sel}}^{\text{BL}}, \eta) = \frac{1}{\varepsilon_{\text{trig}}(n_{\text{sel}}^{\text{BL}})} \cdot \frac{1}{\varepsilon_{\text{vtx}}(n_{\text{sel}}^{\text{BL}}, \eta)},$$

- Track-wise correction – tracking efficiency

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

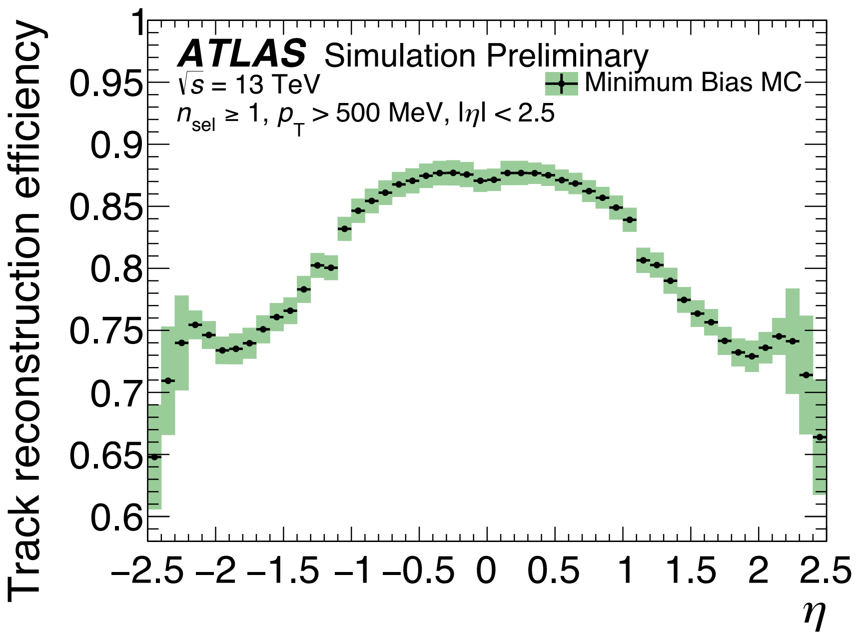
  - Correct for tracks
    - outside kinematic range: $f_{okr}(p_T, \eta)$ - e.g. track η >2.5, but particle pT below
    - secondary tracks: $f_{sec}(p_T, \eta)$
    - strange bayrons: $f_{sb}(p_T, \eta)$
- Using Bayesian unfolding to correct both the multiplicity n_{ch} and p_T
  - Additional correction for events out of kinematic range e.g. Events with ≥1 particles but <1 tracks
- Mean p_T vs n_{ch} – bin-by-bin correction of average p_T, then n_{ch} migration

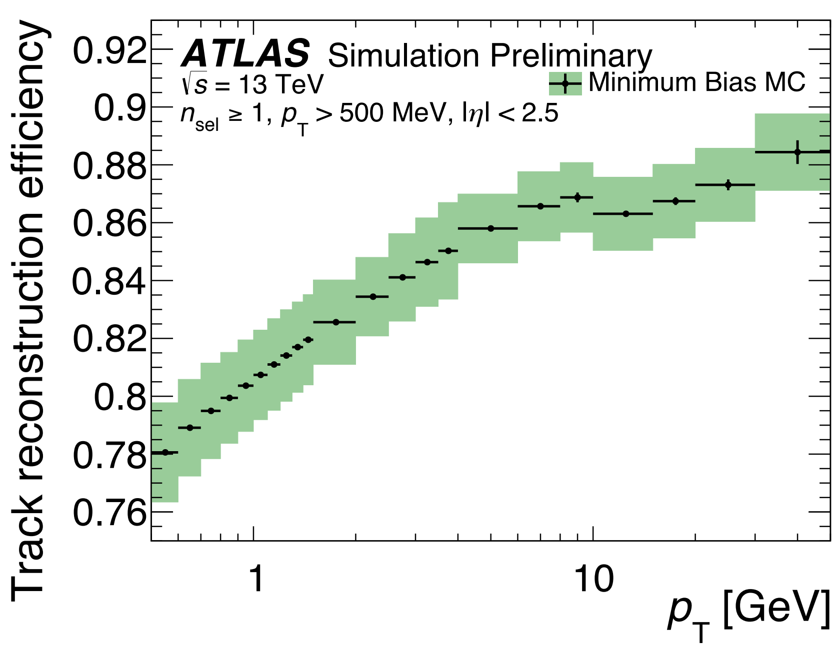
Event level corrections



- Trigger and vertex reconstruction efficiency are both measured in data
- Correlations with kinematic proprieties studied
  - no significant dependence on p_T was observed but a significant dependence on n_{sel} was seen
  - Systematic uncertainties are negligible

Track reconstruction

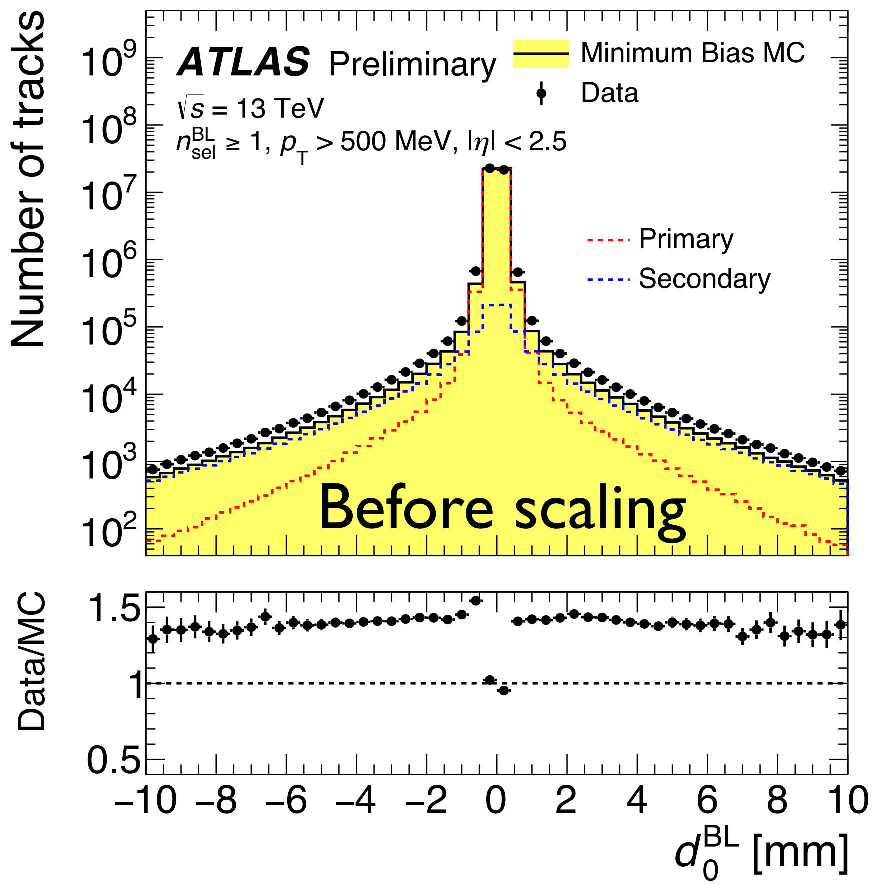




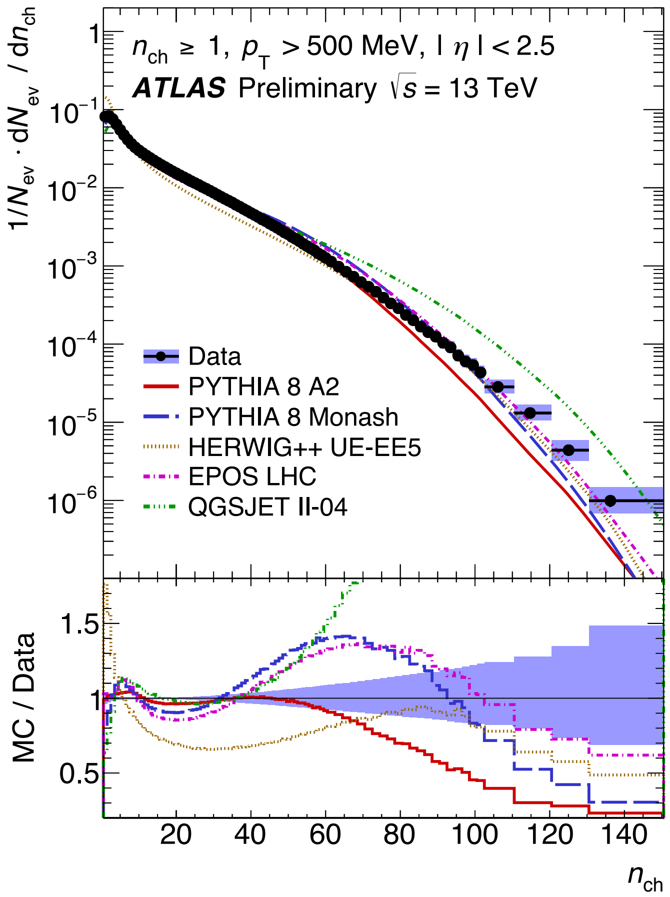
- Track reconstruction efficiency estimated from simulated samples
  - Systematic uncertainty dominated by our knowledge of the material in the Inner Detector
    - 1.1% uncertainty @ η = 0
  - Multiple methods used constrain the uncertainty
    - Photon conversion rate, Hadronic interaction rate etc. See Hideyuki Oide's Poster

Non-primary & other tracks

- Non primary tracks are the biggest background
  - Rate measured in data by performing a fit to the transverse impact parameter distribution
  - 2.2% ± 0.6% of our reconstructed tracks within the signal region
- High p_T tracks
  - measurable fraction of the tracks originate from low p_T tracks (scattering, in flight decays)
  - Our ability to select & remove these tracks was assessed in data
  - At most 1% of tracks between 30-50GeV

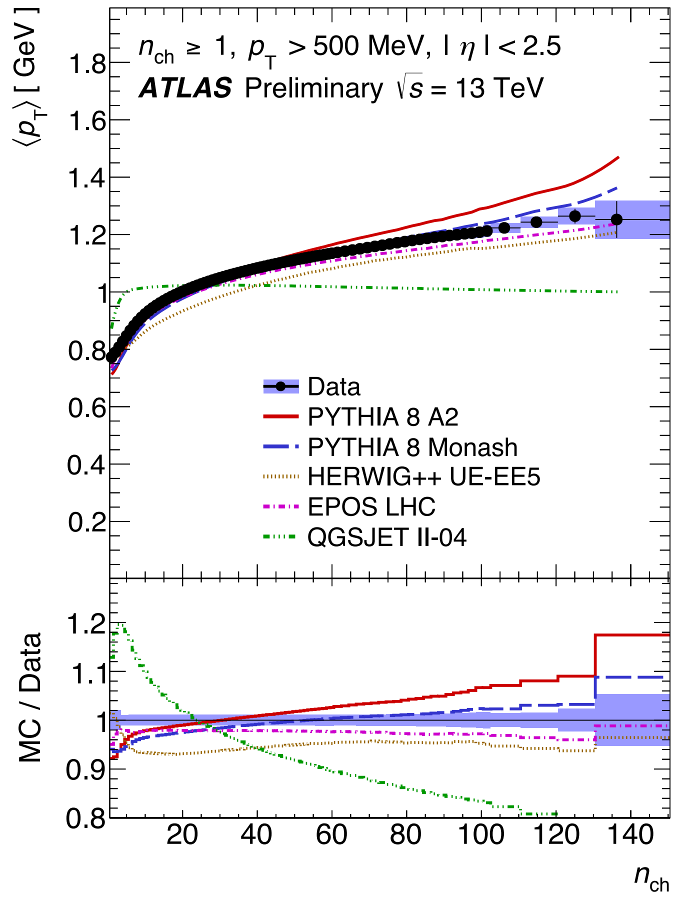


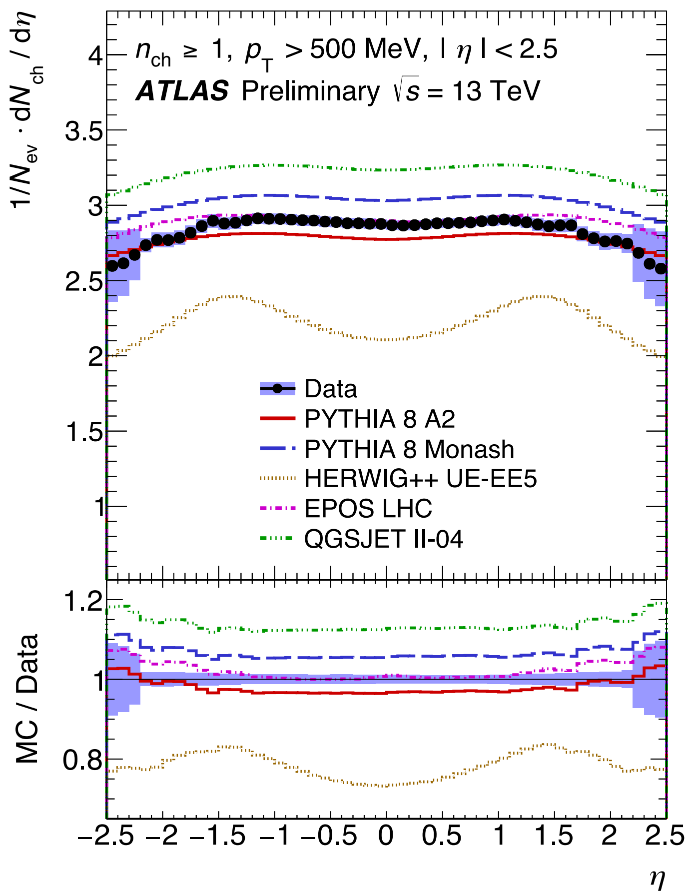
13 TeV Results



dN_{ev}/dn_{ch} & <pT> vs. n_{ch}

- Low n_{ch} not well modelled by any MC; large contribution from diffraction
- Models without colour reconnection (QGSJET) fail to model scaling with n_{ch} very well



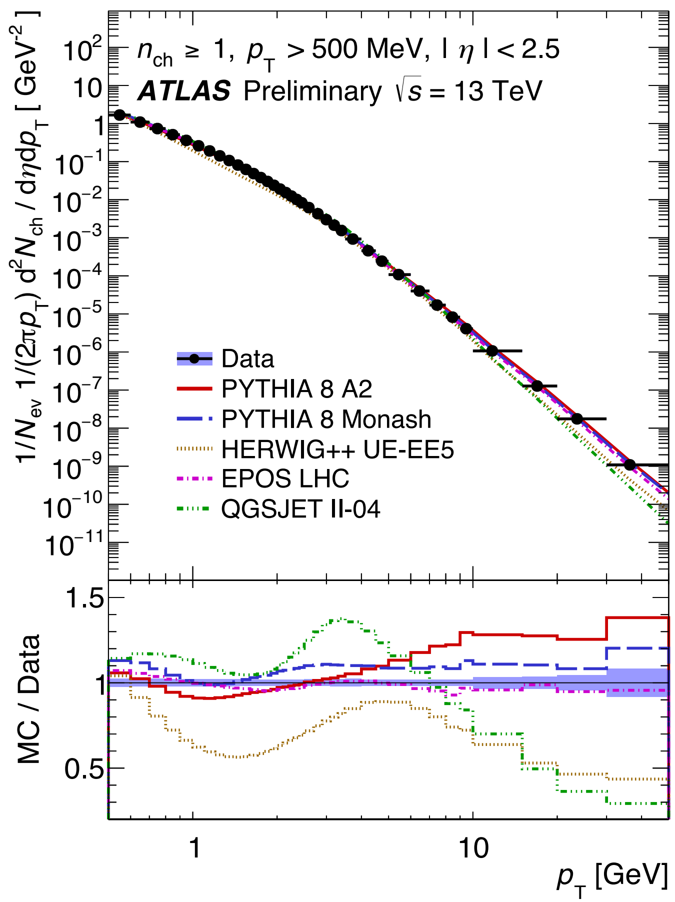


$dN_{ch}/d\eta$

- Models differ mainly in normalisation, shape similar
  - Exception is HERWIG tuned entirely on UE.

$d^2N_{ev}/d\eta dp_T$

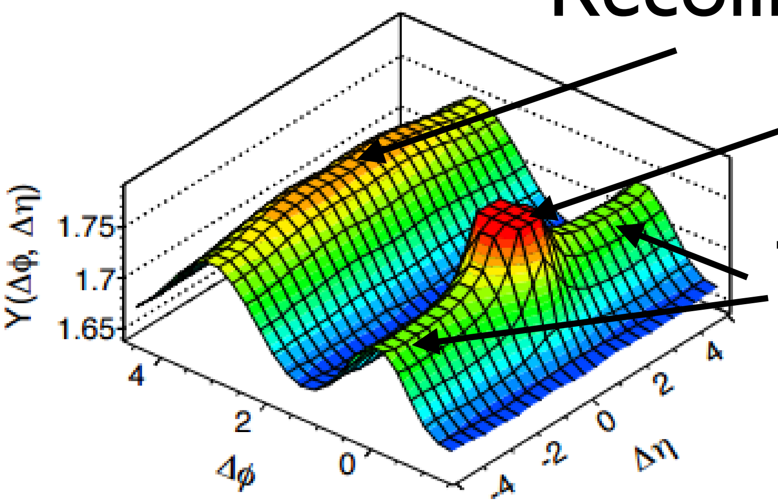
- Measurement spans 10 orders of magnitude
- Some Models/Tunes give remarkably good predictions (EPOS, Pythia)



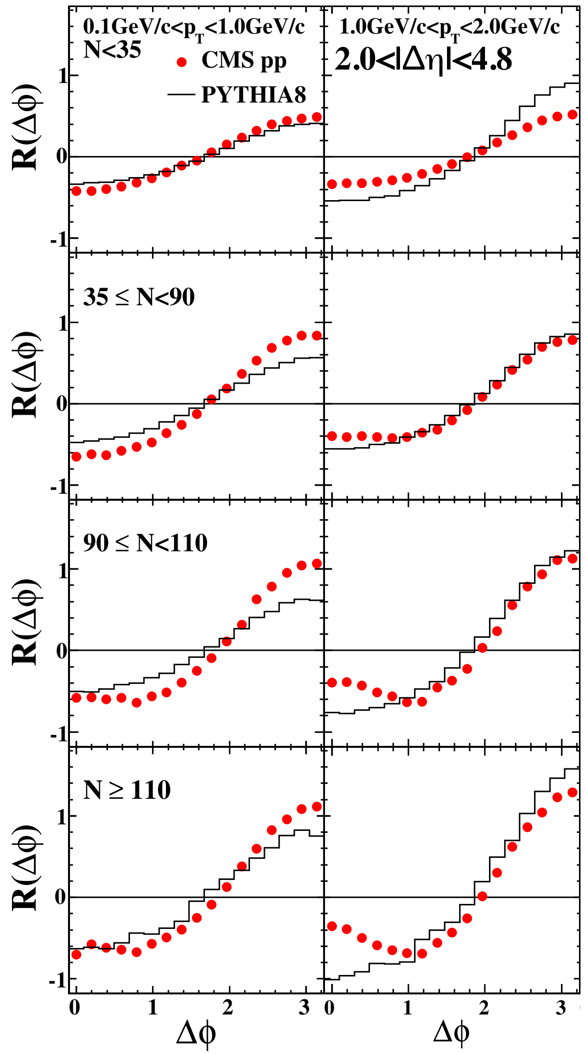
Two Particle correlations

- In high multiplicity events there is an enhancement in the particle production at Δφ ≈ 0 over wide range of Δη, "The Ridge"
- First observed in Pb-Pb collisions are was attributed to collective behaviour. It also has been measured in p-p and p-Pb systems.
- This feature is not described by any of the aforementioned MC generators

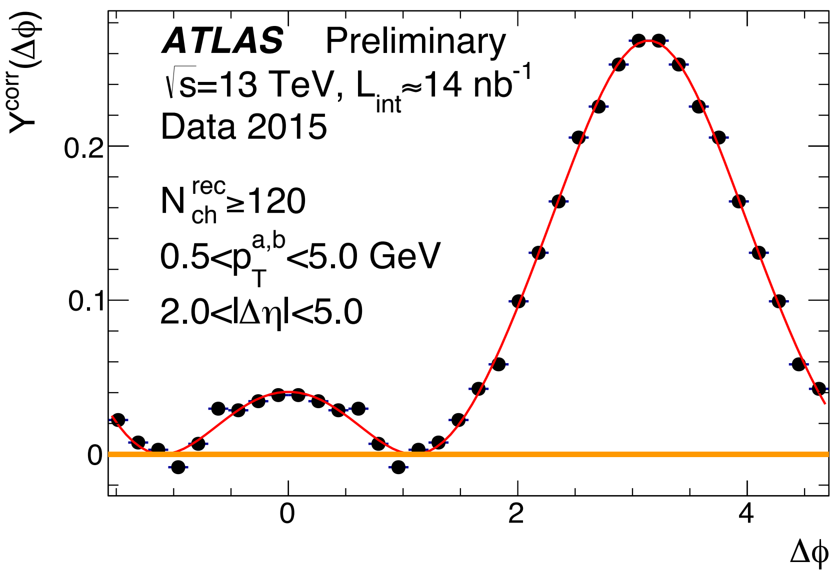
ATLAS, 1212.5198

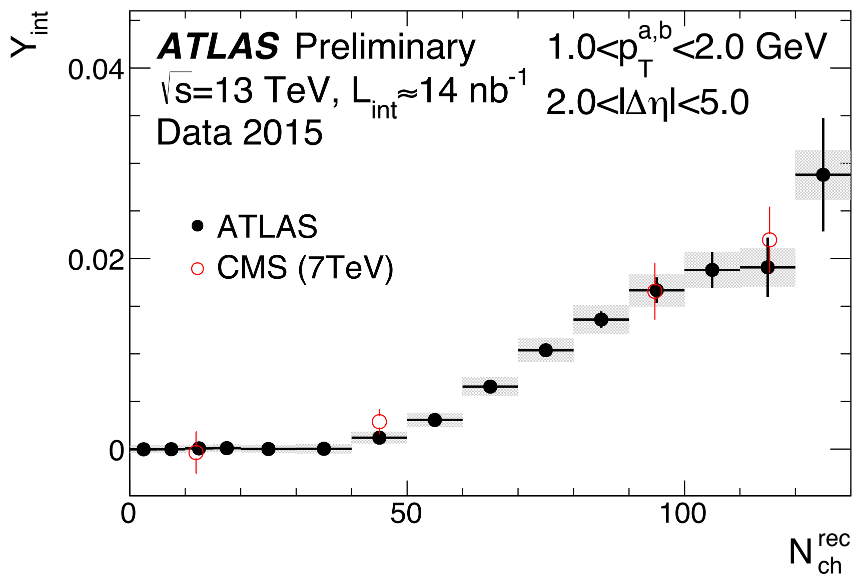


CMS, 1009.4122



Two Particle correlations @ 13 TeV

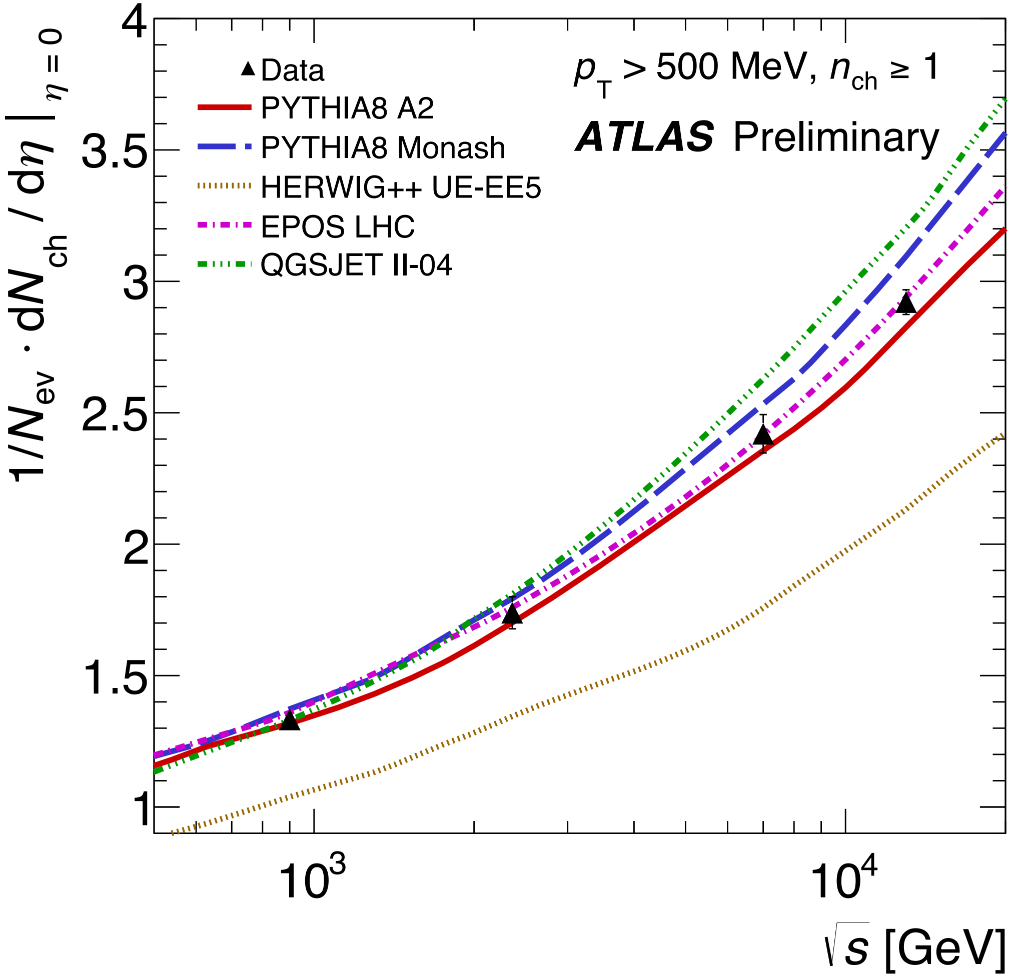




- ATLAS has again observed the ridge at 13 TeV
  - ATLAS-CONF-2015-027
- The yield of events is similar to that seen in 7 TeV p-p
- See Migual Arratia's talk on Friday morning in the Heavy Ion session for more details!

Summary

- ATLAS's first measurement of charged particle multiplicities @ 13 TeV
  - p_T > 500 MeV
- The models have given solid predictions for the latest centre of mass jump
- Analysis of additional phase spaces is ongoing:
  - $|\eta|<0.8$ for comparison to the various detectors
  - p_T > 100 MeV to really test diffractive regime
- Two particle correlation "Ridge" observed at 13 TeV - see Migual's talk for the details



Backup

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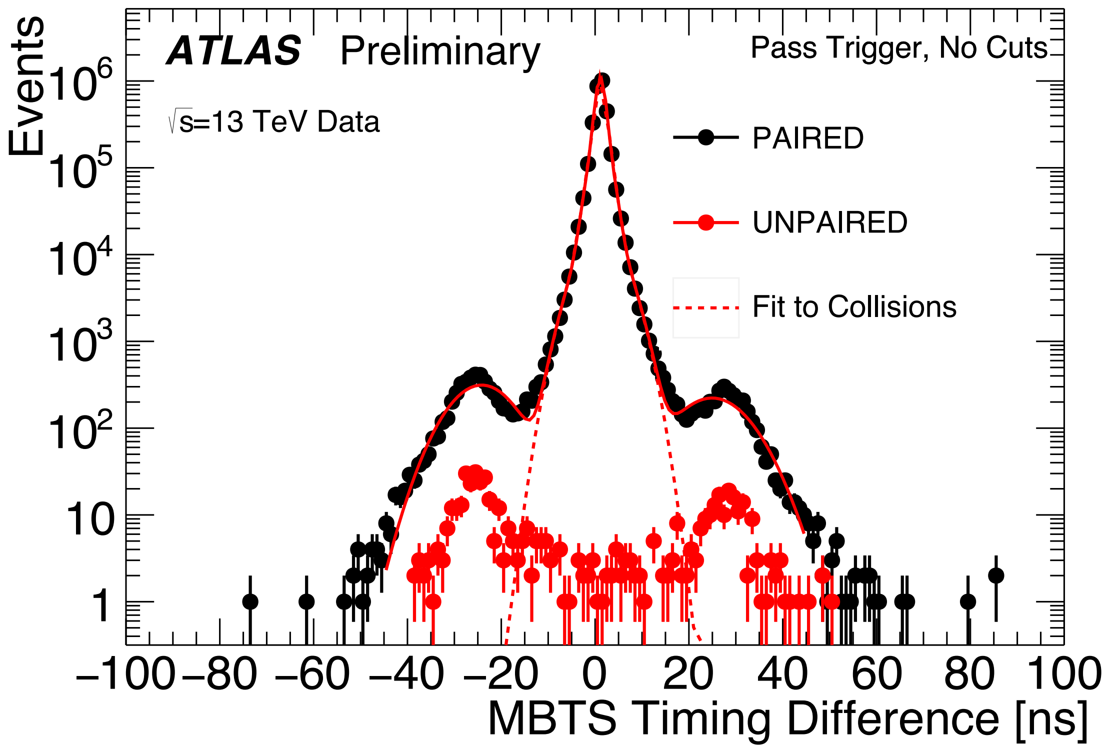
Tunes and Generators

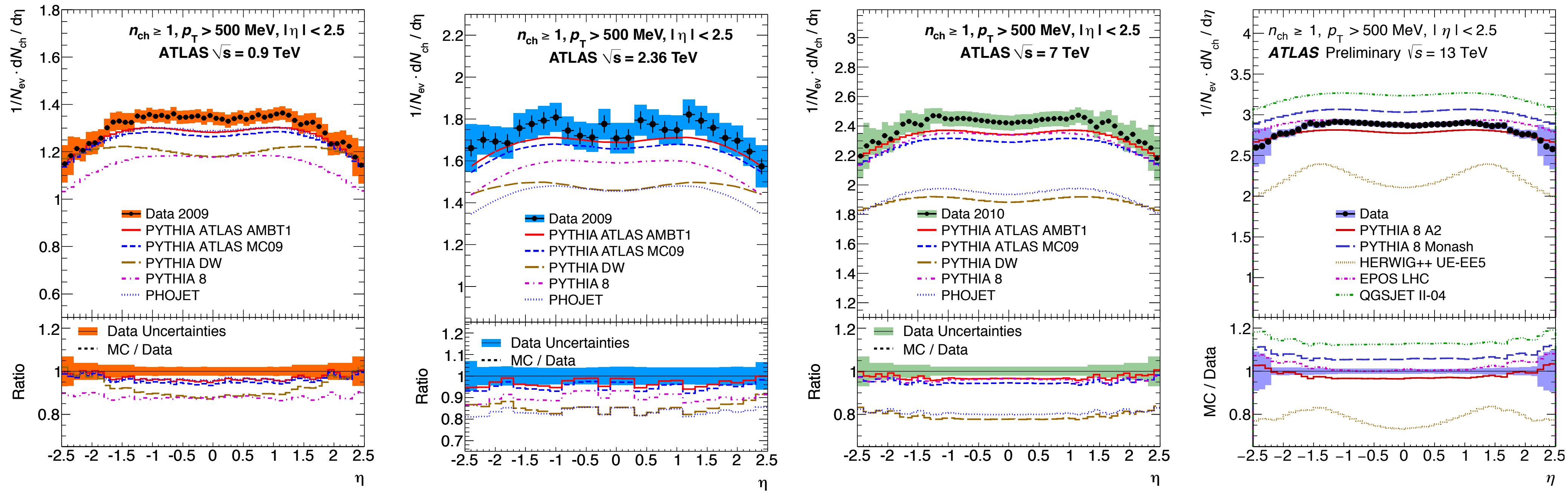
Generator	Version	Tune	PDF	7 TeV data	
				MB	UE
PYTHIA 8	8.185	A2	MSTW2008LO [19]	yes	no
PYTHIA 8	8.186	MONASH	NNPDF2.3LO [20]	yes	yes
HERWIG++	2.7.1	UE-EE-5-CTEQ6L1	CTEQ6L1 [21]	no	yes
EPOS	3.1	LHC	N/A	yes	no
QGSJET-II	II-04	default	N/A	yes	no

Table 1: Summary of MC tunes used to compare to the corrected data. The generator and its version are given in the first two columns, the tune name and the PDF used are given in the next two columns and the last two columns indicate whether the data used in the tune included 7 TeV minimum bias (MB) and/or underlying event (UE) data.

- The level of non-collisions beam background was estimated in data by measuring the time difference between hits in the MBTS detector on the two different sides of the detector

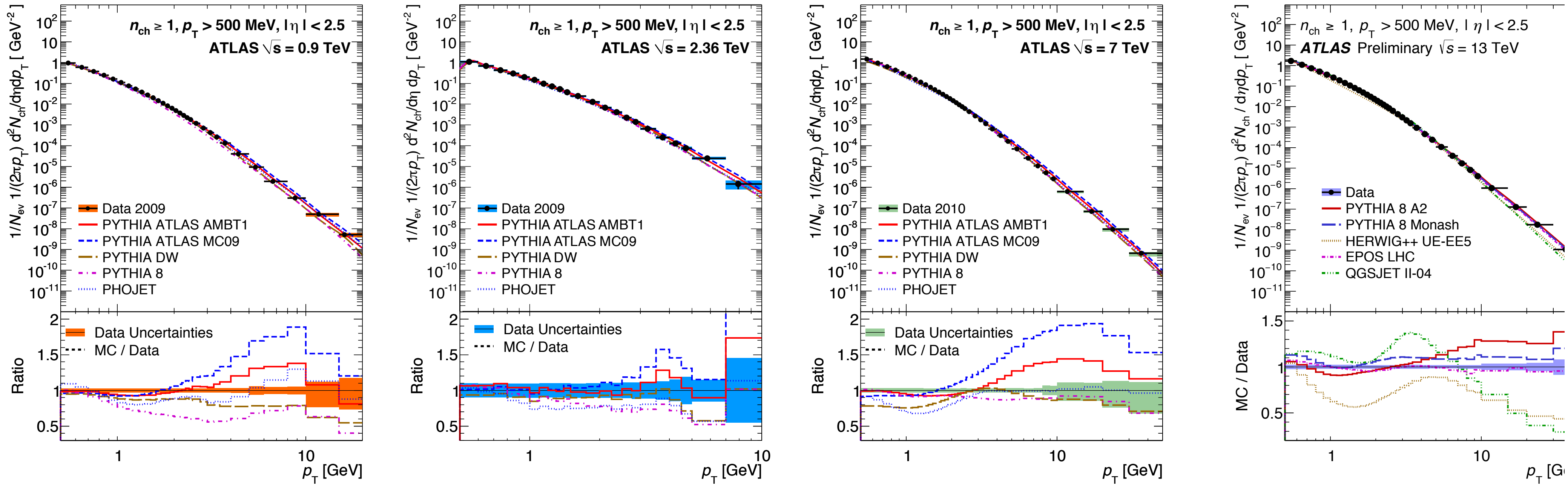


$1/N_{ev}\, dN_{ch}/d\eta$



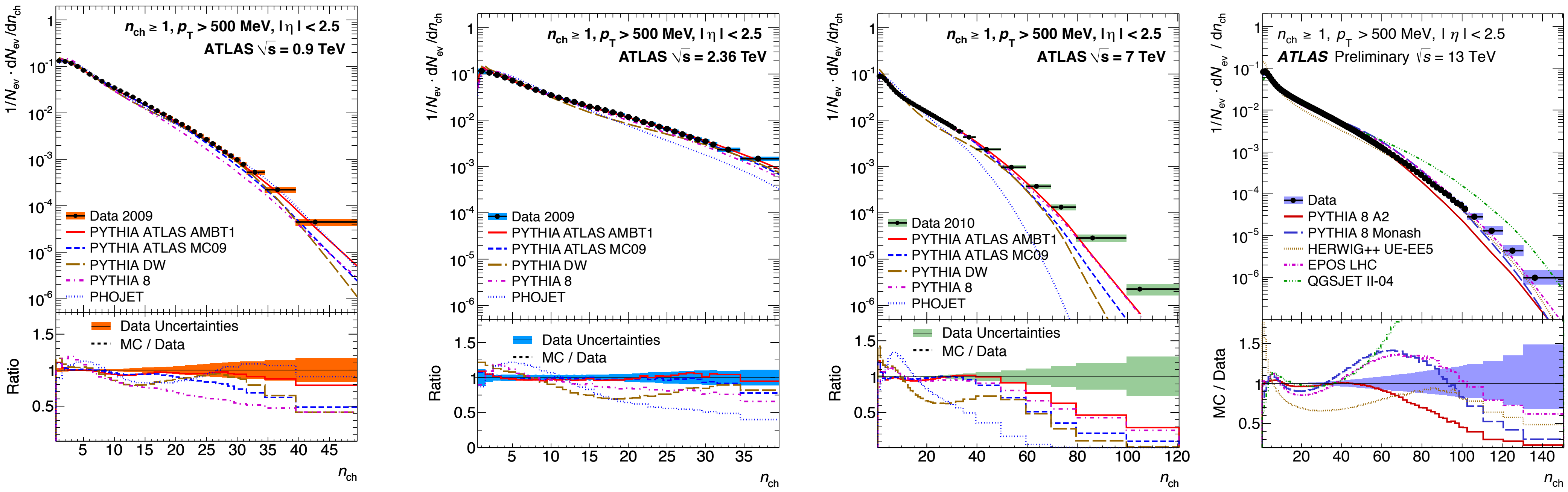
- Models differ mainly in normalisation, shape similar.
- Track multiplicity underestimated.

$1/N_{ev}\ d^2N_{ch}/d\eta dp_T$



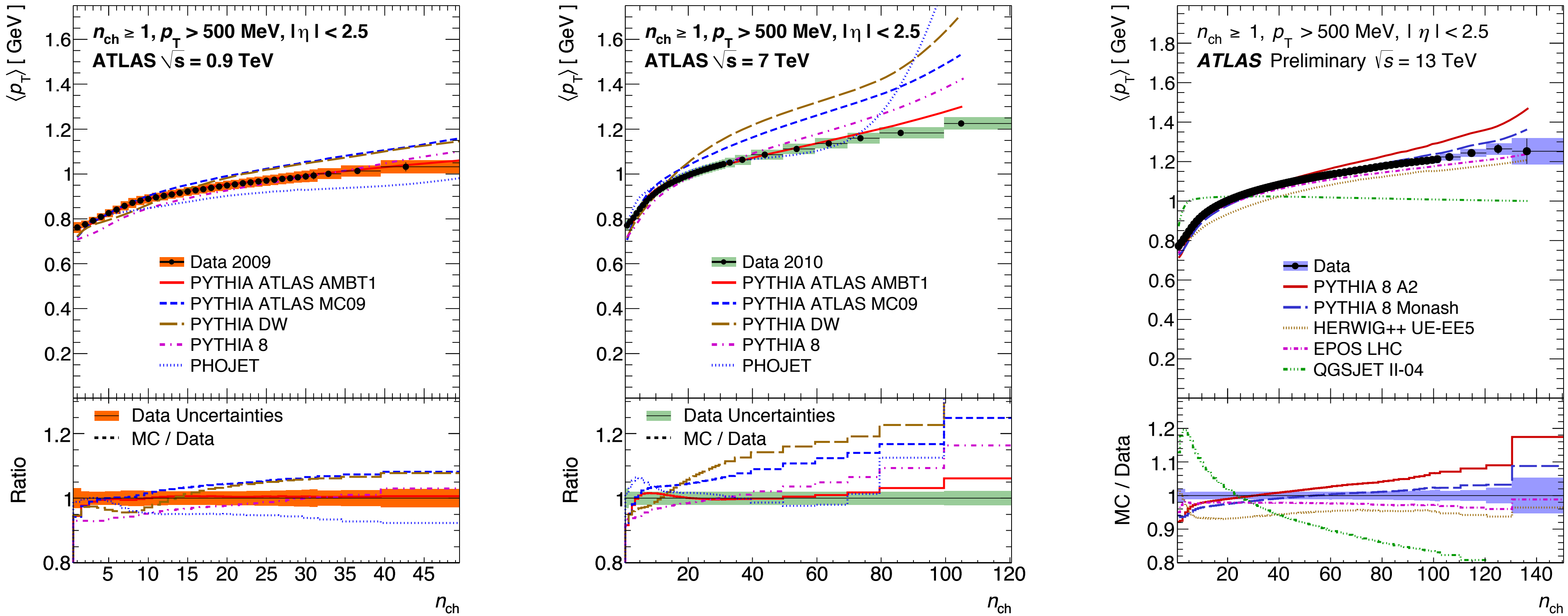
- Measurement spans 10 orders of magnitude
- Large disagreement at low p_T and high p_T

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



- Low n_{ch} not well modelled by any MC; large contribution from diffraction

$\langle p_T \rangle$ vs. n_{ch}



- Pythia8 with hard diffractive component give best description
- Shape at low n_{ch} sensitive to ND, SD, DD fractions especially when using a 100 MeV selection