Charged Particle Multiplicities & Correlations

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on behalf of

The ATLAS collaboration

Outline

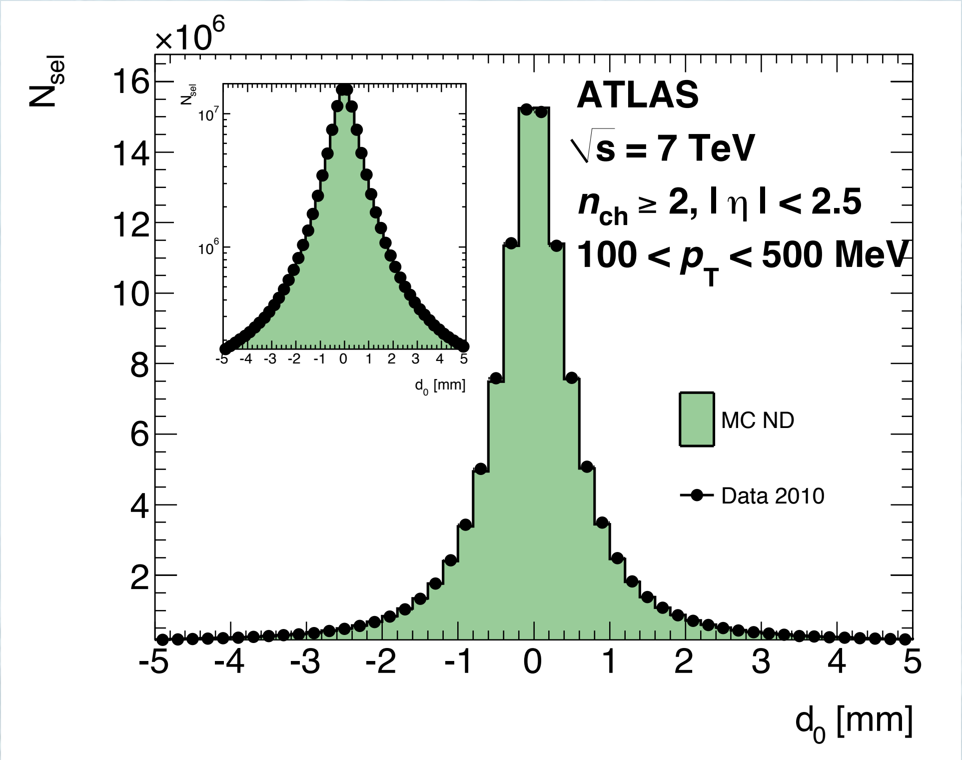
- Charged Particle Multiplicities
  - Introduction
  - Analysis Cuts
  - Results
- Two particle Correlations
  - Introduction to the observable
  - Corrections method
  - Results

Charged Particle Multiplicities

- Minimum Bias events - the “average” event at the LHC
- Such events are useful for validating and tuning models of particle production. Help deal with pile-up, soft backgrounds…
- Look at distributions of the number of charged particles per event and the η and pT distributions of those particles.

Analysis Cuts

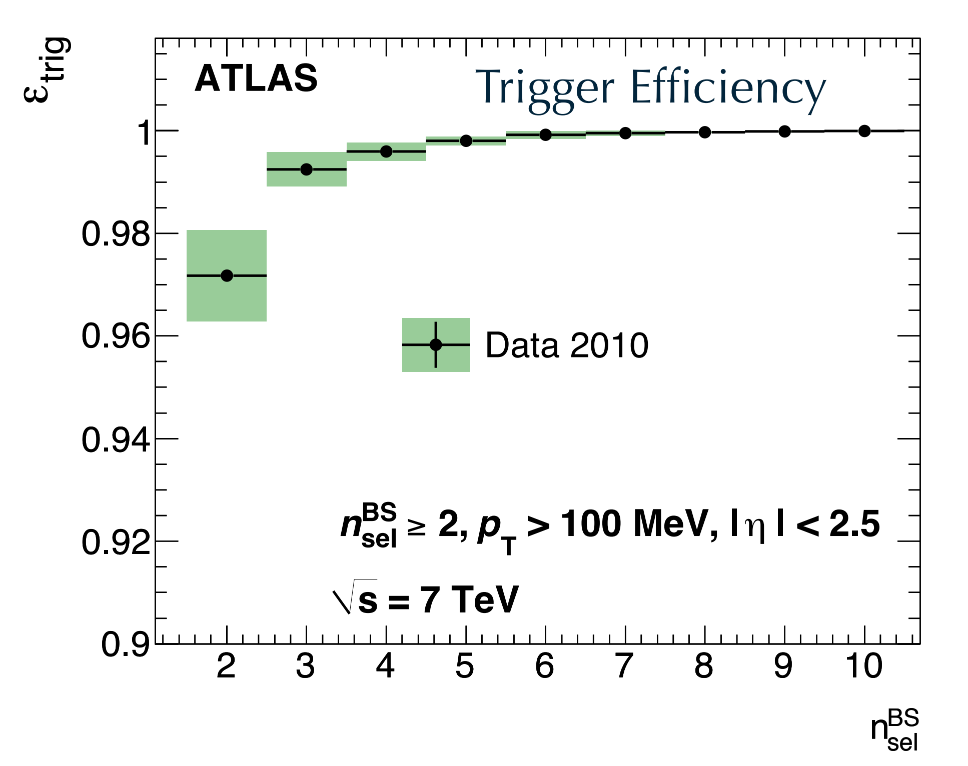
- Analysis uses charged tracks from ATLAS′ 2010 Min Bias data set (as in arxiv: 1012.5104)
- Single arm min bias trigger ("MBTS_1")
- Exactly one primary vertex. Veto pile-up vertices with > 4 tracks
- Tracks with:
  - Track quality cuts (pixel, SCT and layer-0 hits, track fit probability…)
  - Longitudinal impact parameter z0 * sin(θ) < 1.5 mm
  - Transverse impact parameter d0 < 1.5 mm
  - η < 2.5

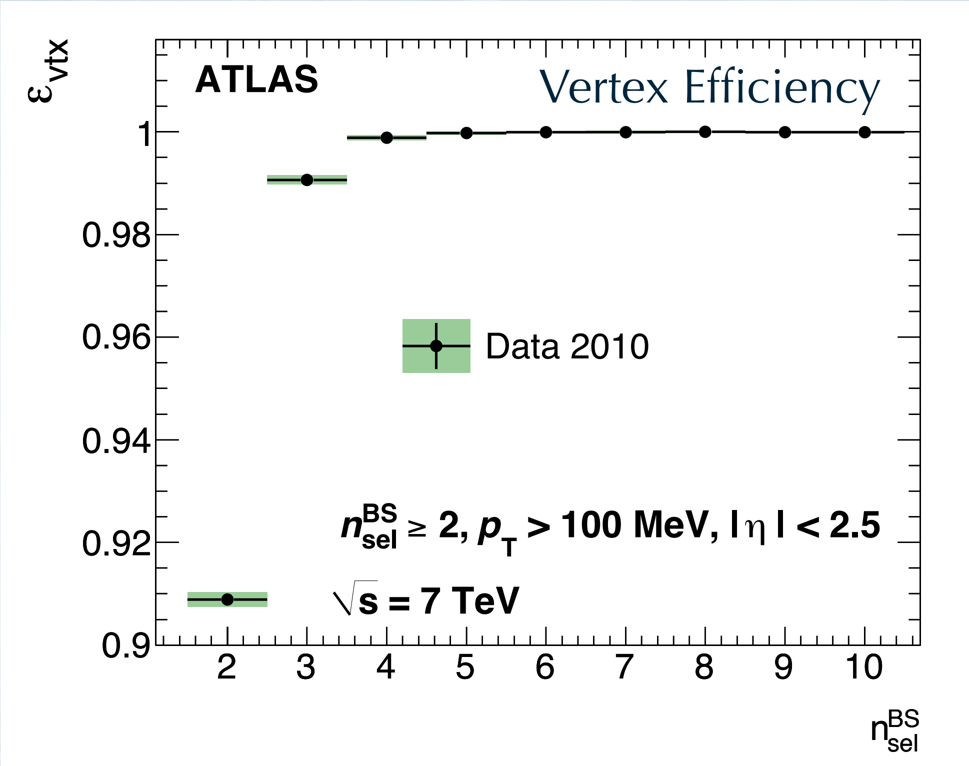


- Track pT cuts of 1 track with pT > 500 MeV *or* 2 tracks with pT > 100 MeV *or* 6 tracks with pT > 500 MeV (i.e. three different kinematic regions - different sensitivity to diffraction)
- Data at 900 GeV, 2.36 TeV and 7 TeV

Correcting for Vertexing and Trigger Efficiencies

- Each event is given a weight that is $1/(E_V E_T)$, where E_V is the vertexing efficiency and E_T is the trigger efficiency for the event.
- Efficiency is found as a function of the number of tracks
- Track reconstruction efficiency is corrected for by weighting each track by $1/E(pT, \eta)$, where $E(pT, \eta)$ is the tracking efficiency for a single charged particle





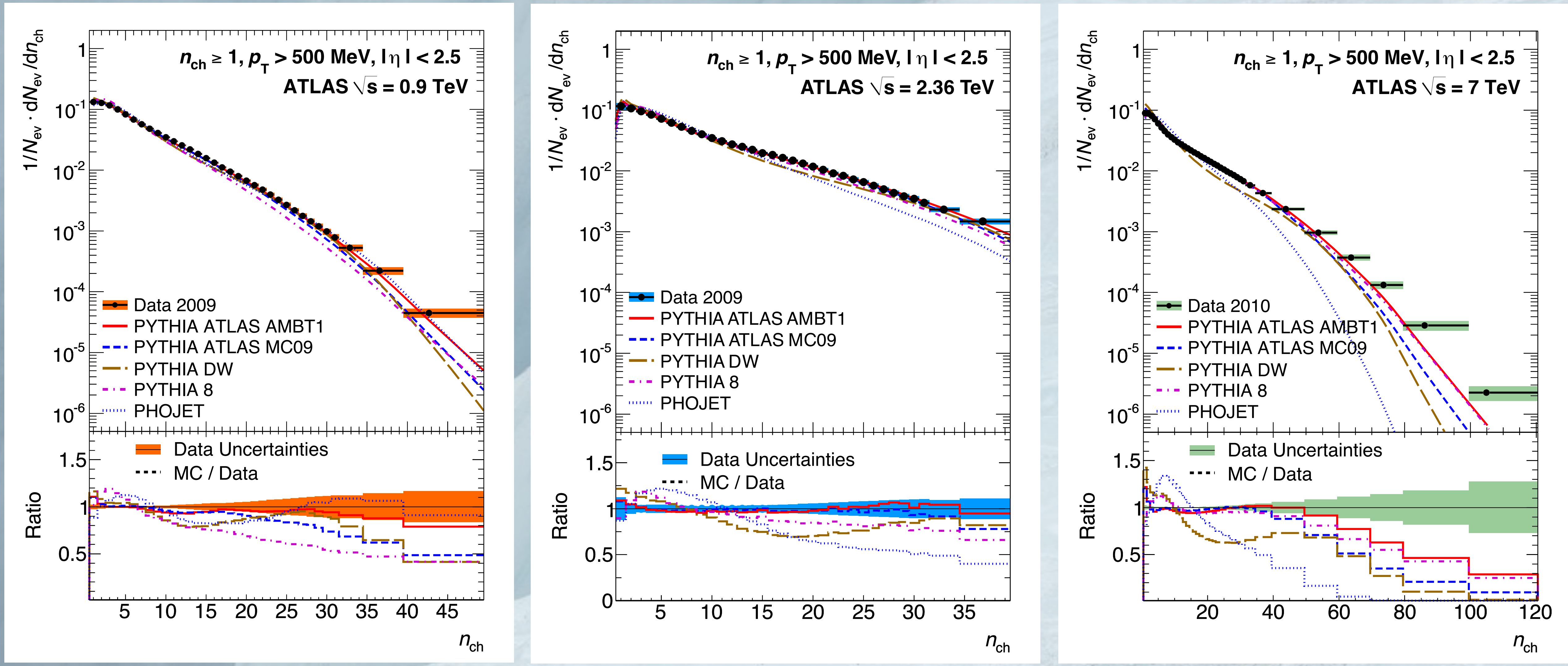
Bayesian unfolding of N_{ch}

- The observed number of charged tracks is corrected using a Bayesian technique
- Use Monte Carlo to create a matrix expressing the probabilities that N_{sel} observed tracks are due to N_{ch} true charged particles
- Apply that matrix to data and then re-derive it from the corrected data.
- Four such iterations

Results

Charged particle multiplicities

900 GeV | 2.36 TeV | 7 TeV

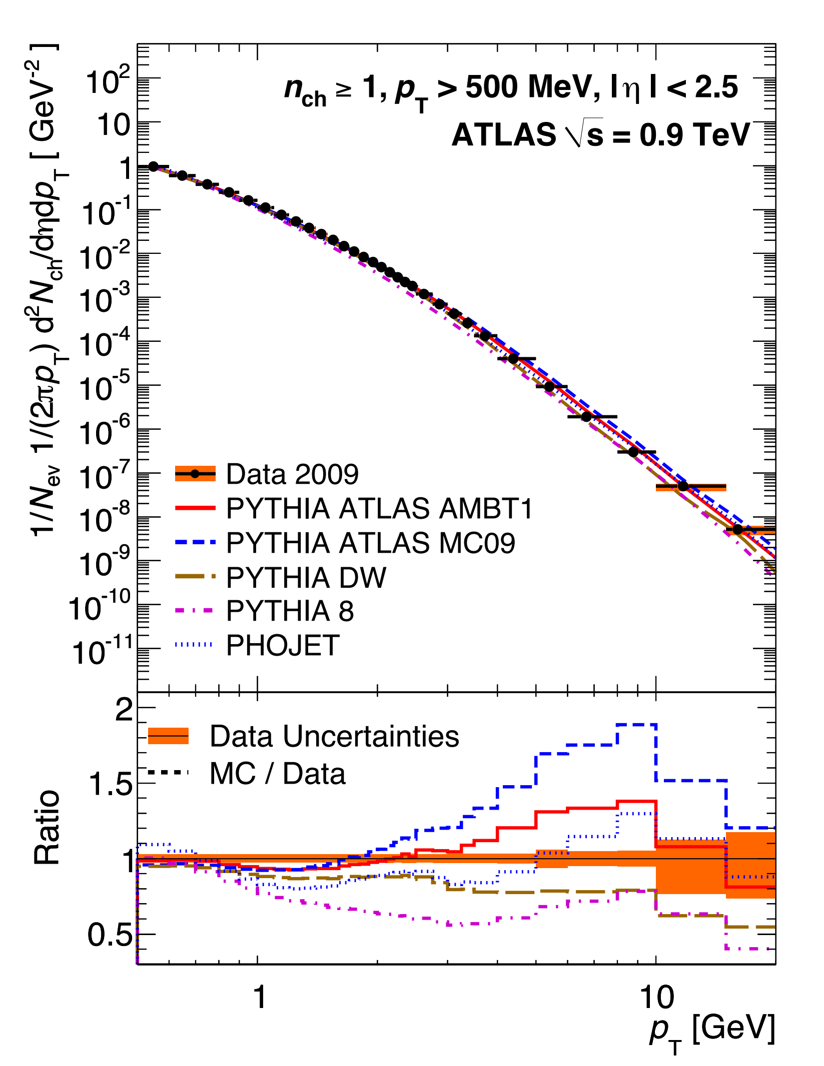


Using events with at least 1 track with pT > 500 MeV

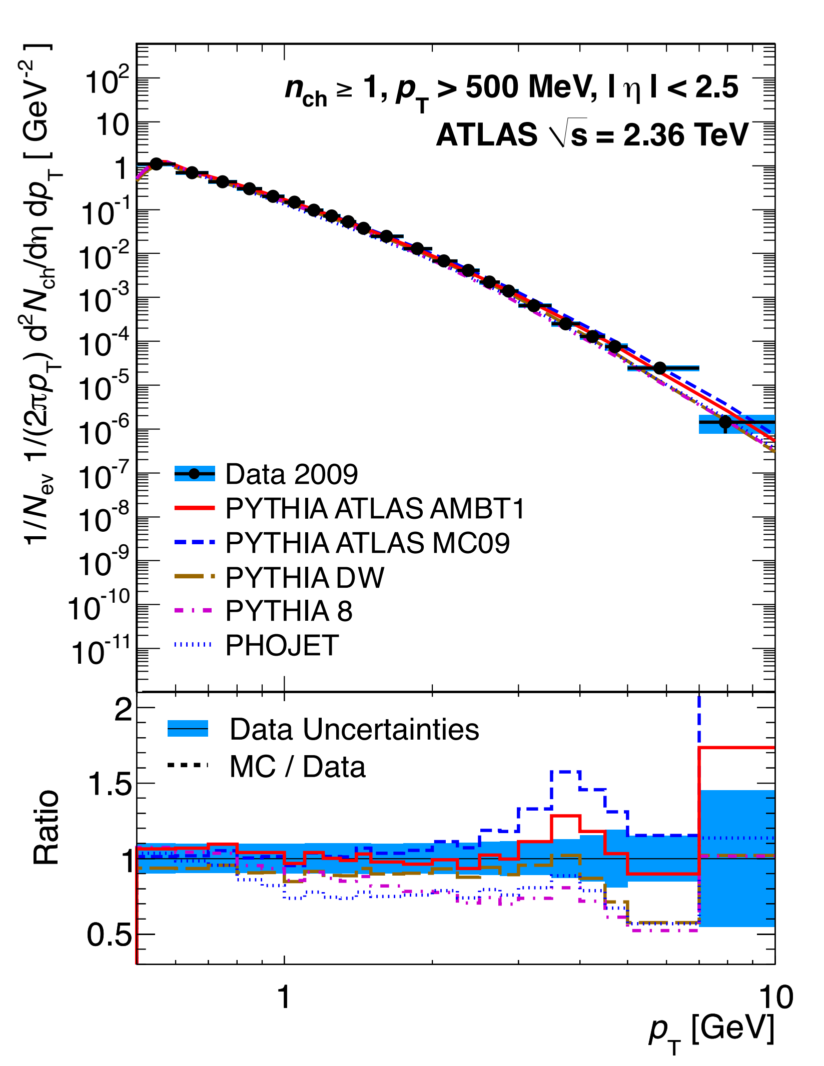
Results

pT dependence of charged particle multiplicities

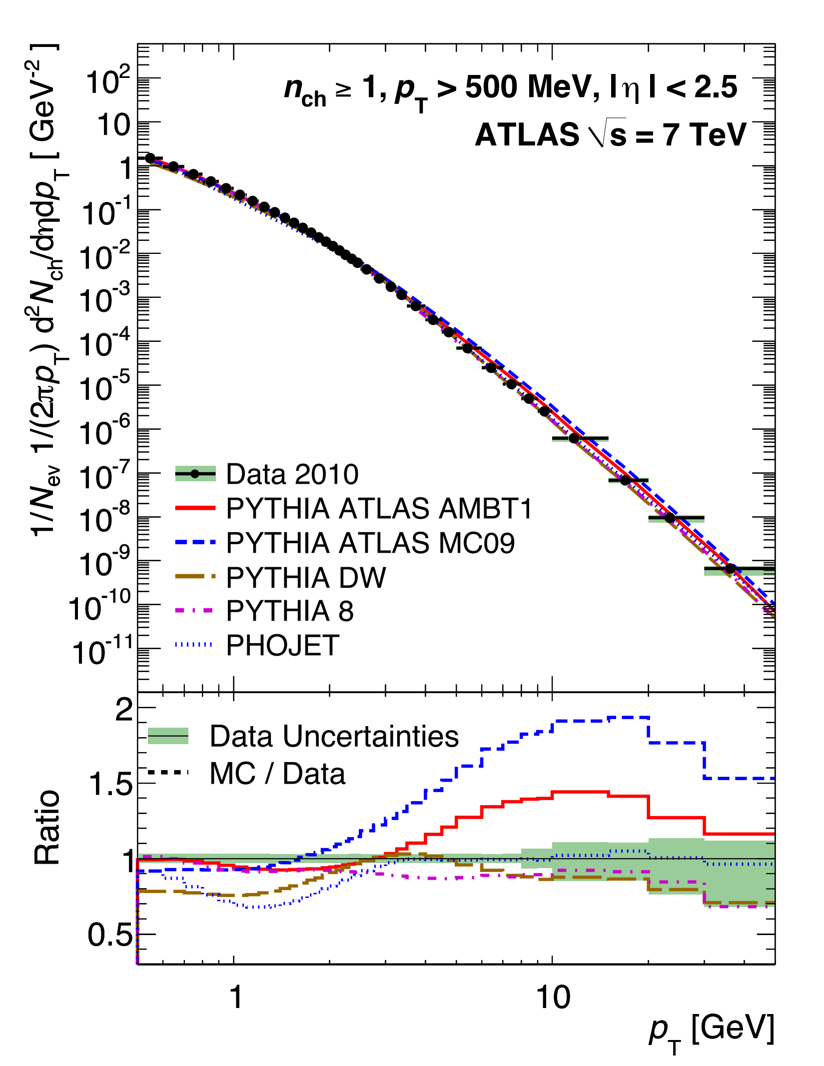
900 GeV



2.36 TeV



7 TeV

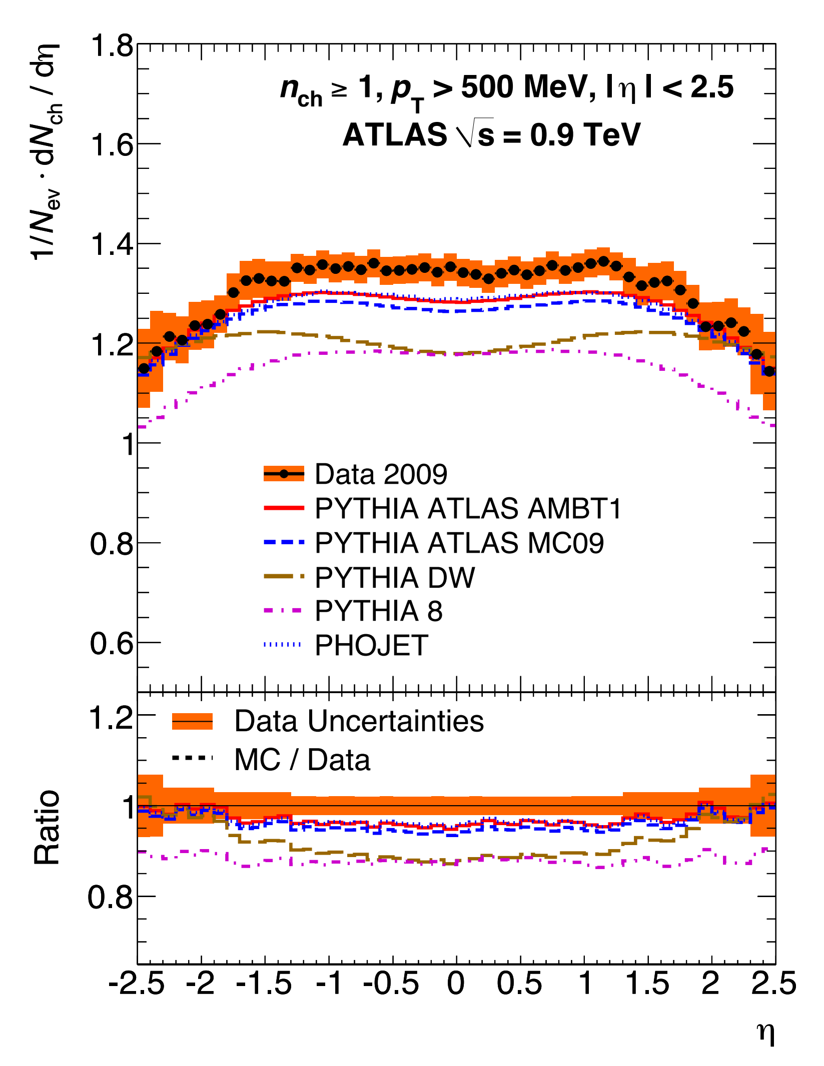


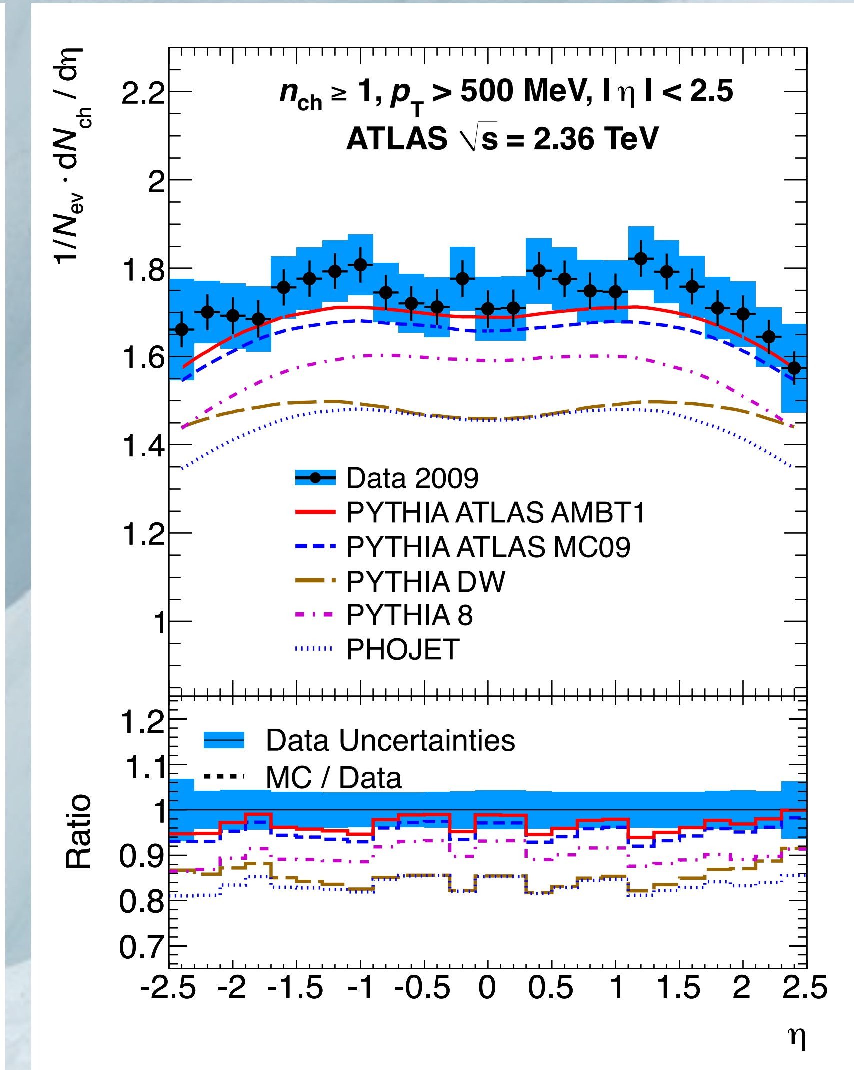
Using events with at least 1 track with pT > 500 MeV

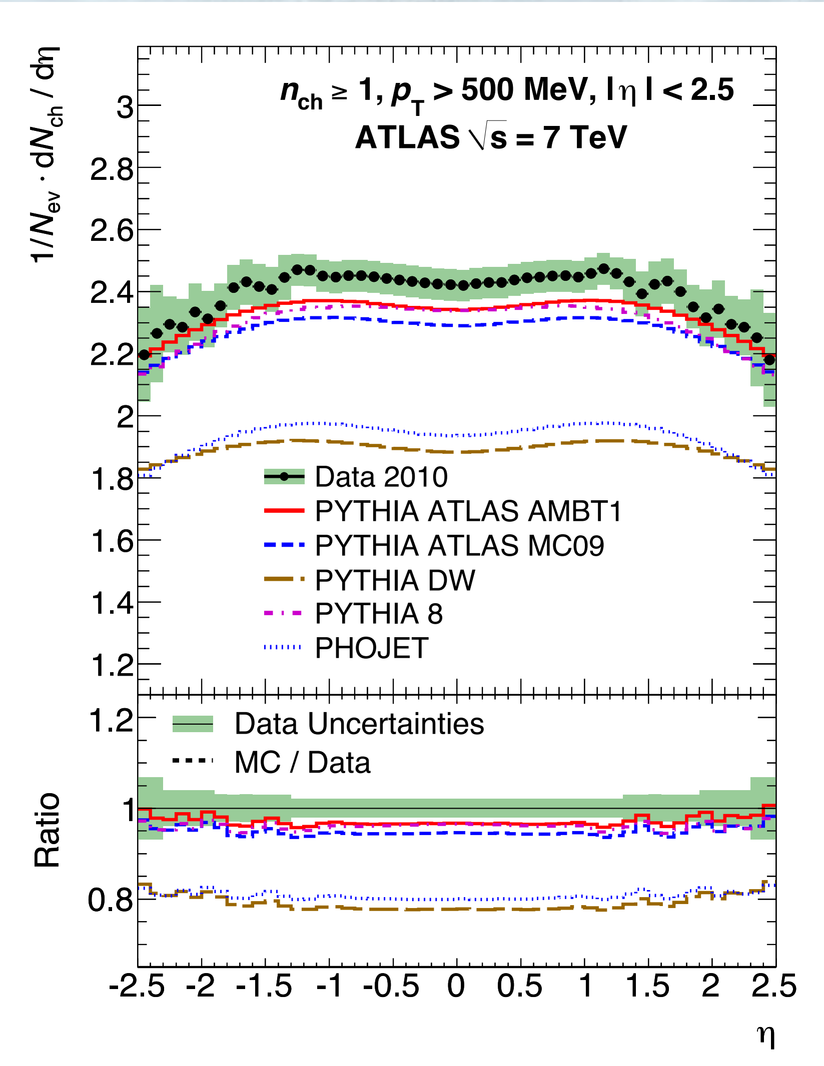
Results

η distribution of charged particles

900 GeV | 2.36 TeV | 7 TeV



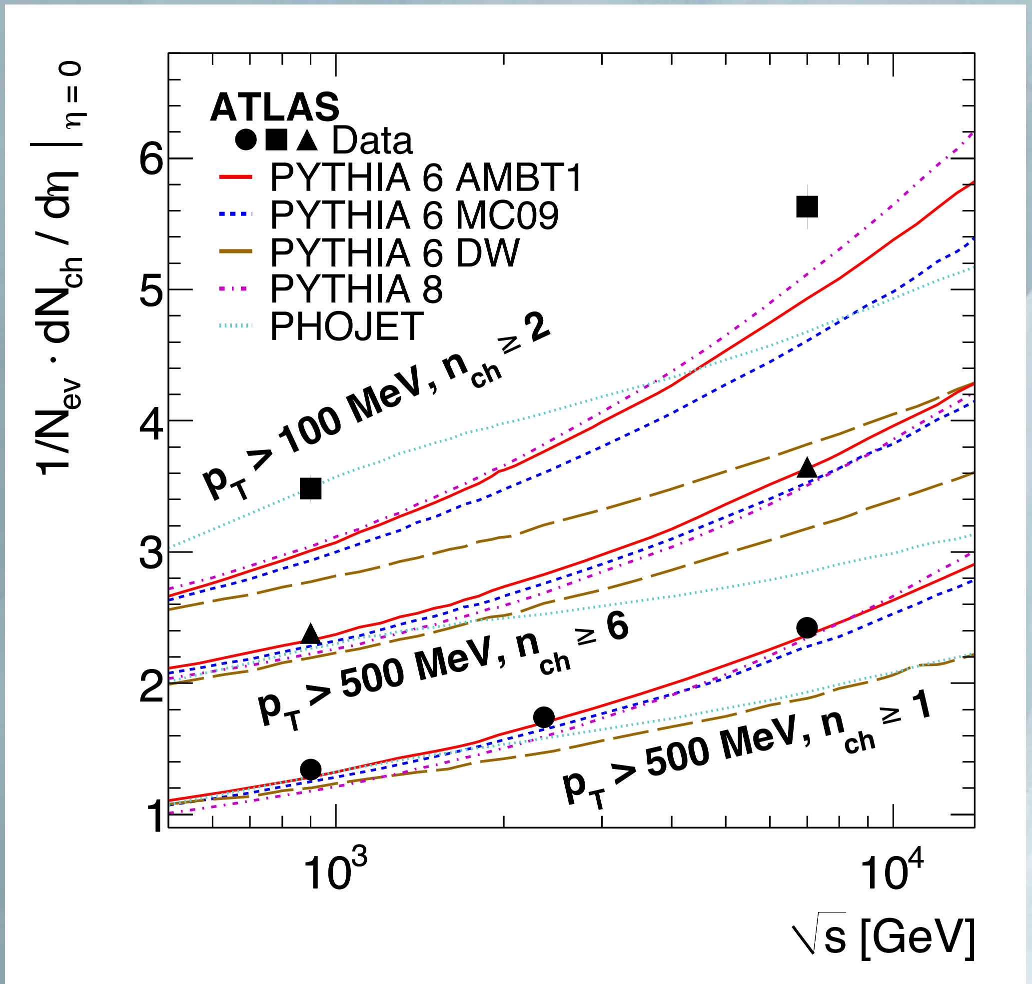


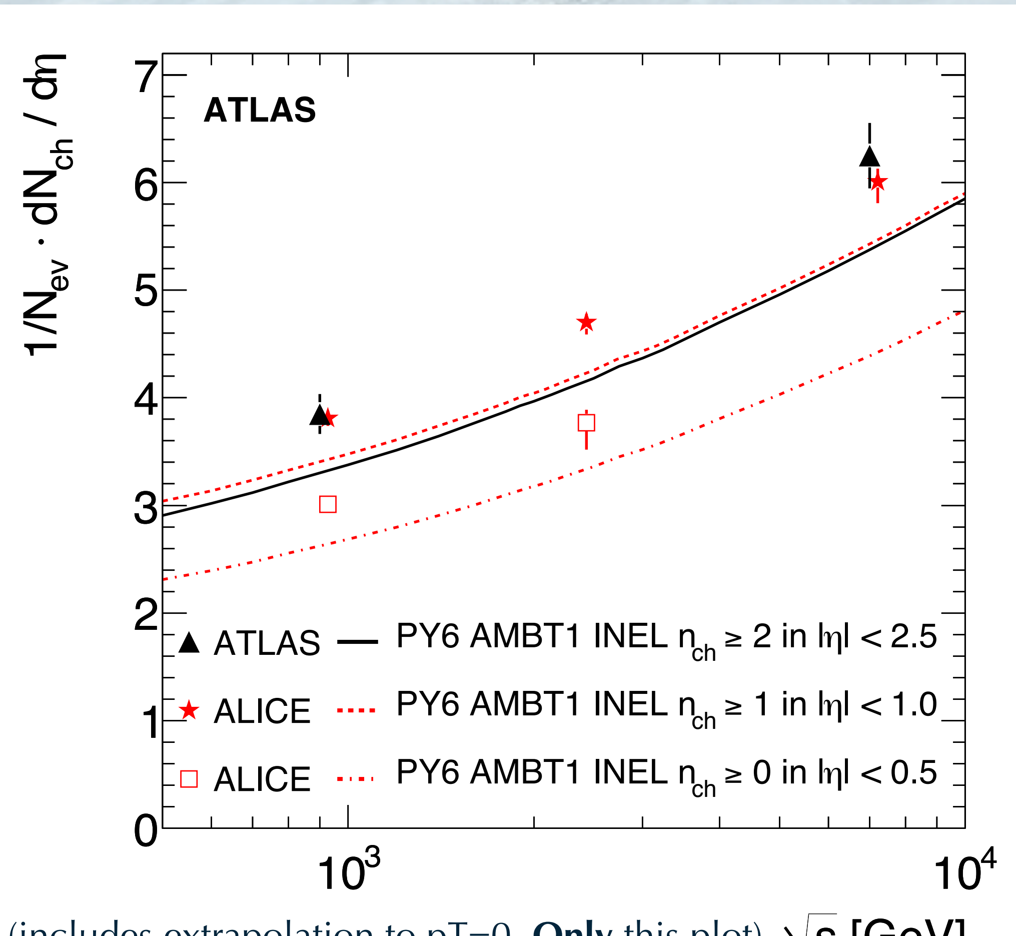


Using events with at least 1 track with pT > 500 MeV

Results

Collision energy dependence of the average number of charged particles per unit of rapidity





(includes extrapolation to pT=0. **Only** this plot)

Comments

- Many more results in the paper - too many to show here! http://arxiv.org/abs/1012.5104
- Measurement of the charged particle multiplicity and its pT and η dependence has been made at three different collision energies.
- Monte Carlo not a perfect fit to the data. Tends to under-shoot dN/dη, apart from at high η. In addition, the MC N_{ch} distribution falls somewhat too fast with N_{ch}. Diffraction?

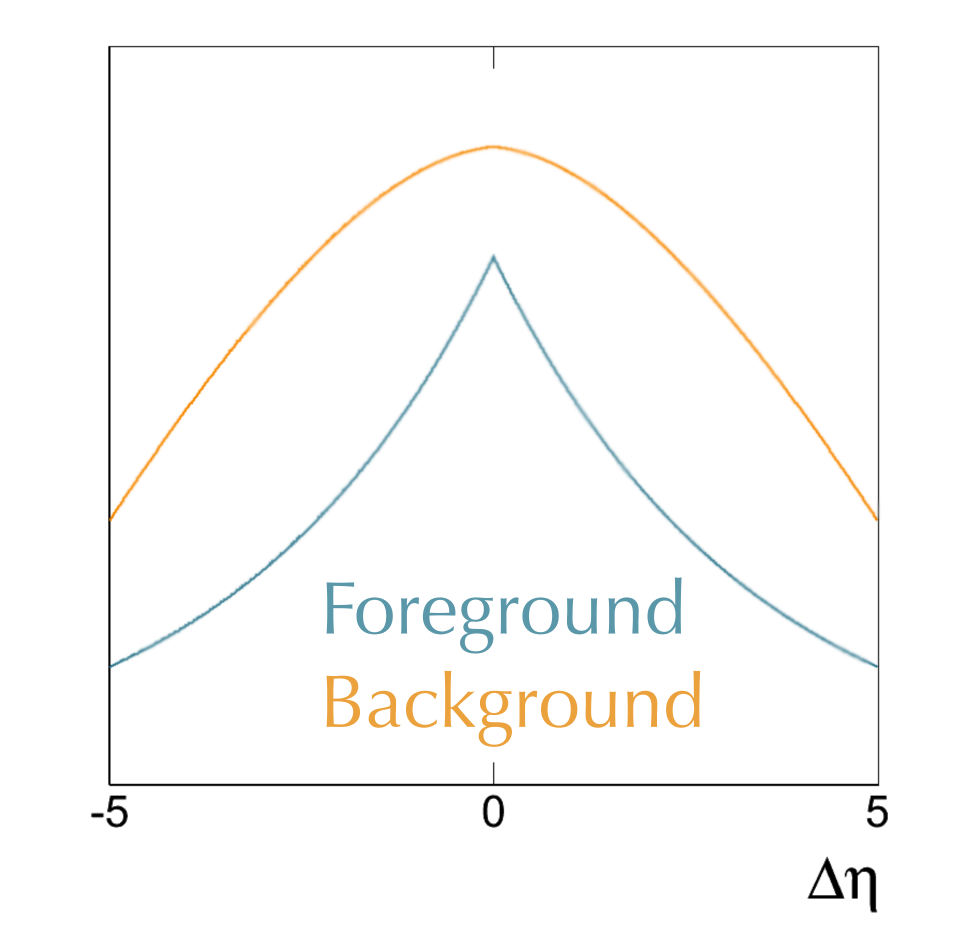
Two Particle Correlations

Why Correlations?

- The existence of correlations between final state particles is an indication that there is a common origin for their production.
- Simple example: decays of clusters could give rise to particles close together in η and ϕ.
- Another example: if radiation is emitted at a given angle, ϕ_0, then there will tend to also be emission close to π-ϕ_0 because of momentum conservation.
- In general, the pattern of correlations can be quite complicated. Models of soft QCD dynamics (as encapsulated in Monte Carlo generators) need to be able to describe this.

2 PC Observable

- Two particle correlations consist of a **foreground** and a **background**.
- Foreground = take **Δη** and **Δφ** between each pair of particles in an event. Fill a 2D histogram with those values
- Falls with **Δη** because of phase space, but there is also structure (e.g. peak at 0,0)



$$F(\Delta\eta, \Delta\phi) = \left\langle \frac{2}{N_{ch}(N_{ch}-1)} \sum_i \sum_{j \neq i} \delta_{\eta_i - \eta_j - \Delta\eta} \delta_{\phi_i - \phi_j - \Delta\phi} \right\rangle$$

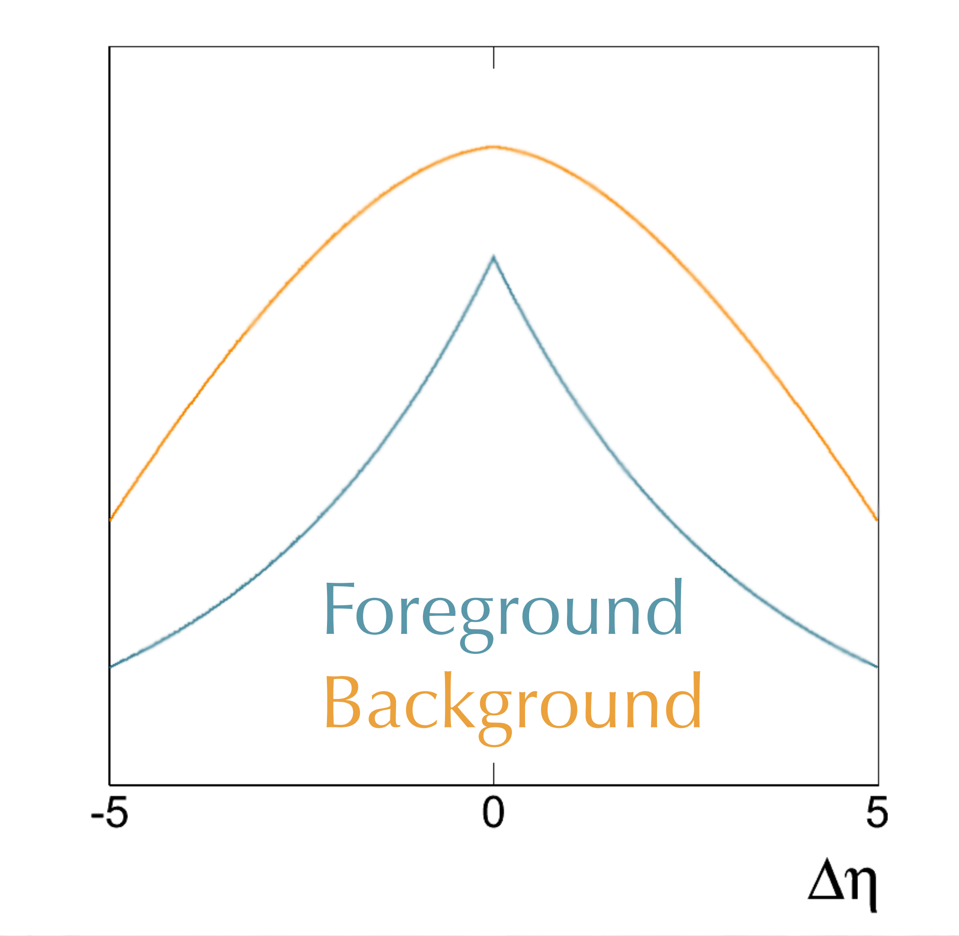
Foreground is normalised by dividing by total number of events

Means that each track has the same weight in the distribution , regardless of the track multiplicity of the event

N_{ch} = number of (charged) particles in the event

2 PC Observable

- For the background take the **Δη** and **Δφ** between particle pairs in **independent** events.
- Accounts for the phase space effect plus some other detector effects
- **Divide** the foreground by the background to give the observable



$$B(\Delta\eta) = \int_{-2.5}^{2.5}\int_{-2.5}^{2.5} \mathrm{d}\eta_1 \mathrm{d}\eta_2 \delta(\eta_1 - \eta_2 - \Delta\eta) \left.\frac{\mathrm{d}N_{ch}}{\mathrm{d}\eta}\right|_{\eta=\eta_1} \left.\frac{\mathrm{d}N_{ch}}{\mathrm{d}\eta}\right|_{\eta=\eta_2}$$

Note the different normalisation: the background is normalised by dividing by the number of entries (= the no. of tracks) to give unit integral

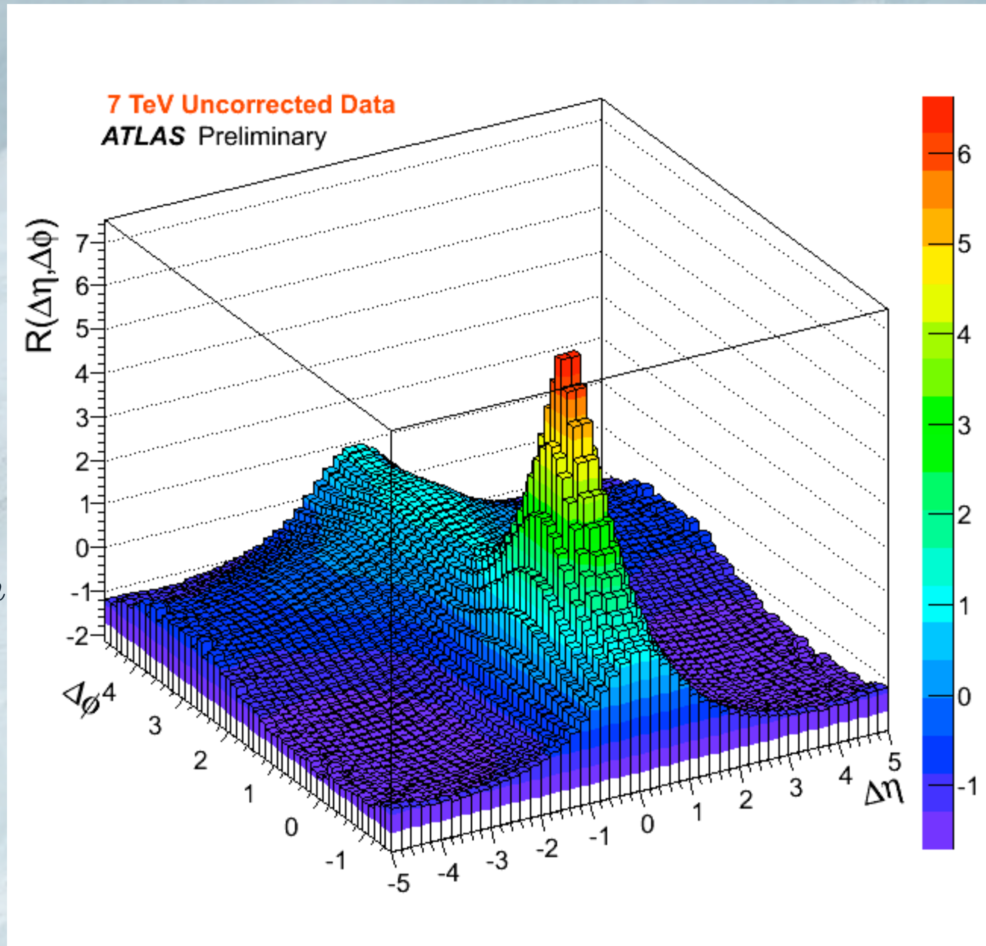
2 PC Observable

- Formally the 2PC observable used in this analysis is given by

$$R(\Delta\eta, \Delta\phi) = \frac{\langle (N_{ch} - 1)\, F(N_{ch}, \Delta\eta, \Delta\phi)\rangle_{ch}}{B(\Delta\eta, \Delta\phi)} - \langle N_{ch} - 1\rangle_{ch}$$

- The factor of <N-1> is included because (N-1)(F-B) was found in the past to be approximately multiplicity independent.

where $\langle \ldots \rangle_{ch}$ means average over contributions from all particle multiplicities



Ends up looking like this

Analysis Cuts

- Same as in min bias charged particle multiplicity analysis
- Require two tracks with pT > 100 MeV. Include all tracks with
  - pT > 100 MeV
  - $|\eta|<2.5$
- Data at 900 GeV and 7 TeV

- Same event-level correction (weighting) for trigger and vertexing efficiency as min-bias.
- Tracking efficiency correction is different...

Section 2, page 2-3 in the note

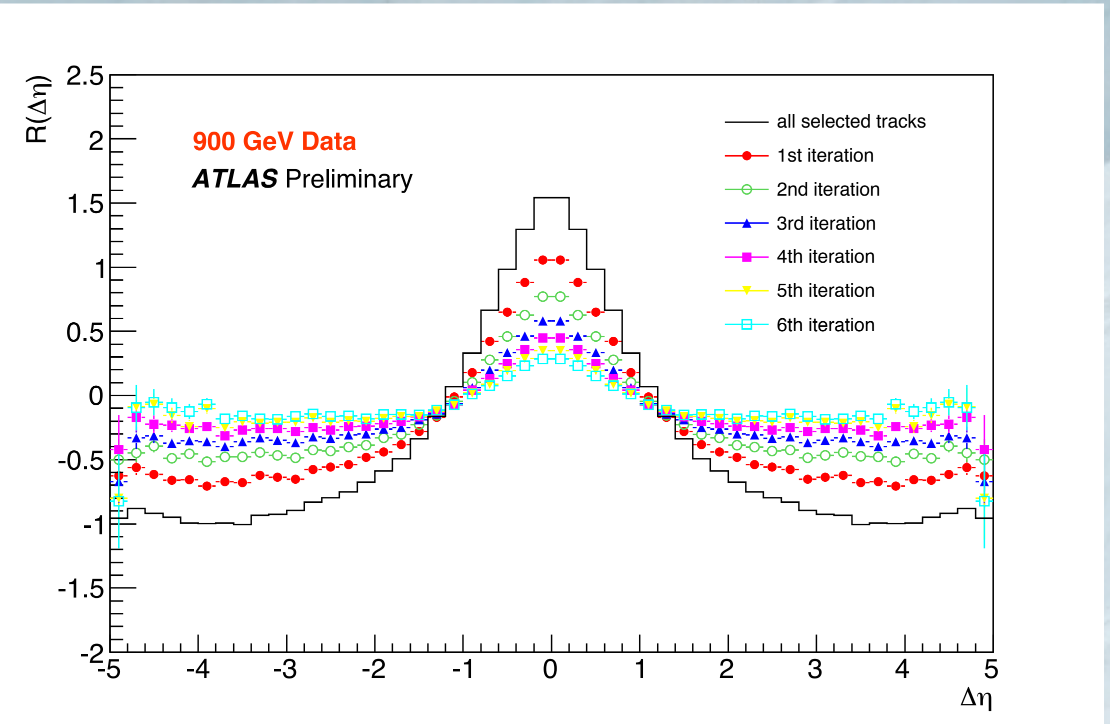
Tracking efficiency corrections

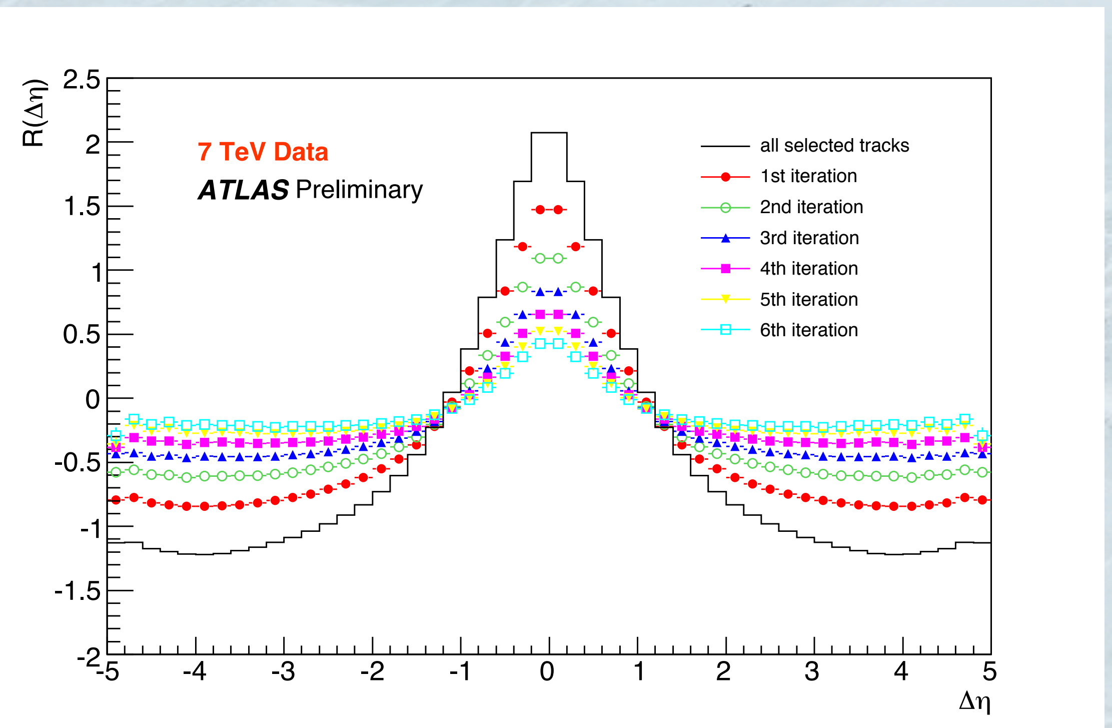
- More complicated observable ➡ effect of tracking inefficiencies and mis-reconstruction is not so straightforward/linear.
- Single particle efficiency is known (truth track-matching in Monte Carlo).
- Data-driven* scheme: In a given event use the single particle efficiency to quantify the detector effect by applying that efficiency to the known tracks in data

*Given that the accepted single particle efficiency is derived from MC + detector sim

Random Track Removal

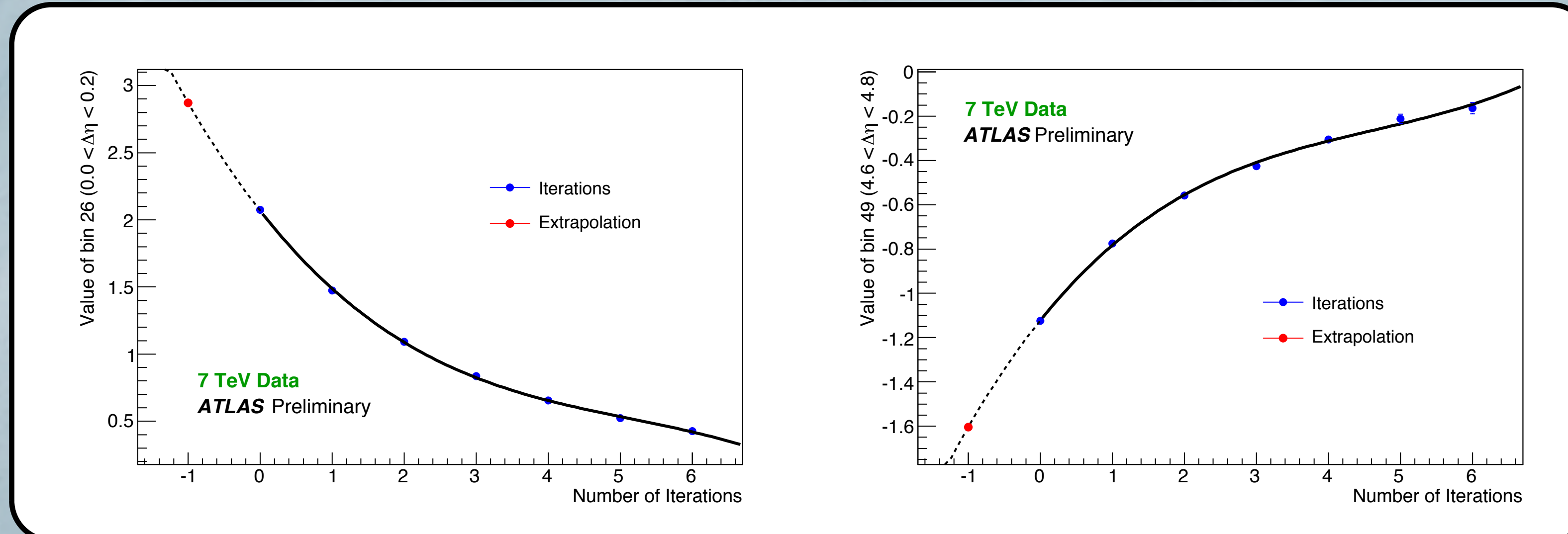
- In each event fill the histogram at the reconstruction (uncorrected) level.
- Go through the list of tracks in the event and for each one generate an independent random number (r_i) in the range {0,1}.
- Compare r_i to the reconstruction efficiency ($E_i(p_T, \eta)$) for that track and if $r_i > E_i$ then remove the track from the list
- Re-plot the observable with the reduced list of tracks
- Repeat for 5 additional iterations, each time using the tracks from the previous iteration as input to the next one

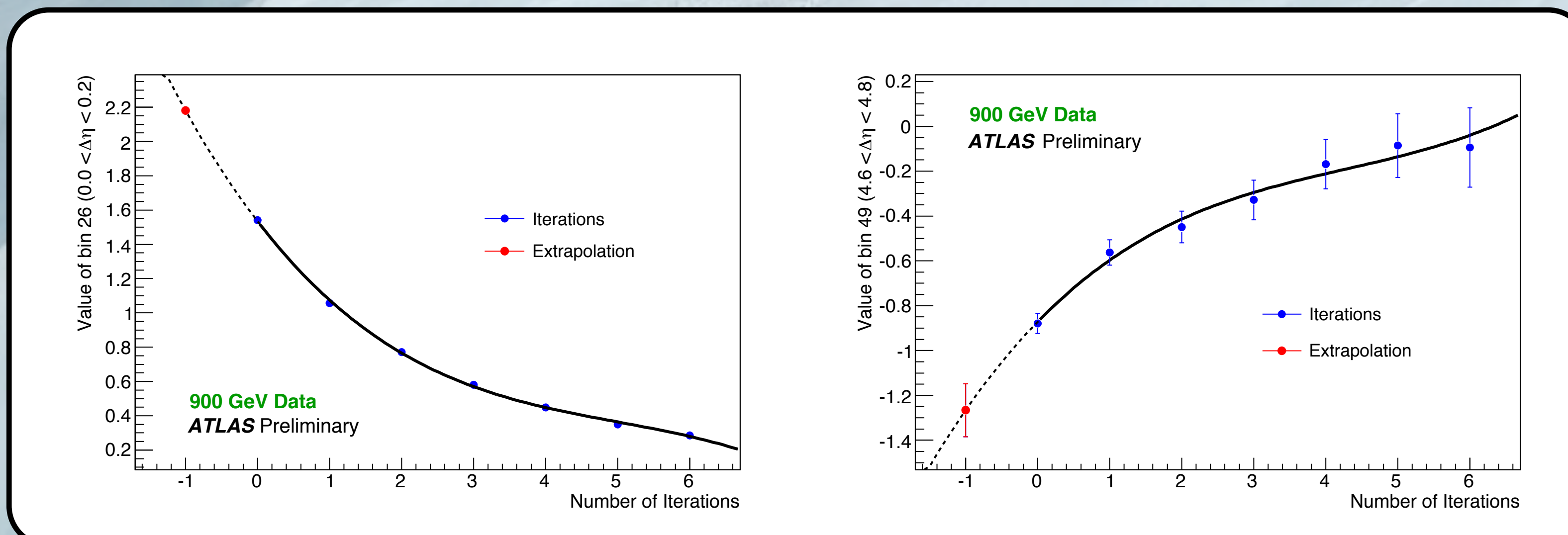




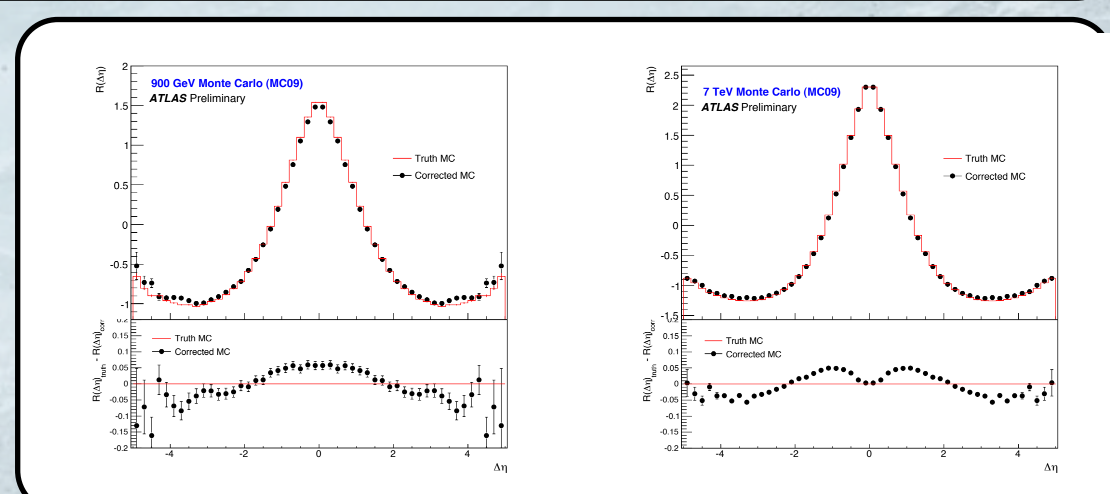
Extrapolation to N=-1

- In each bin of the observable plot the bin contents Vs. the number of track removal iterations.
- The 0 iteration is the raw uncorrected data
- The -1 iteration would be the true value of the observable before the imposition of any detector effects
- Fit a Polynomial of degree three and extrapolate to N=-1 to estimate the true value of the bin

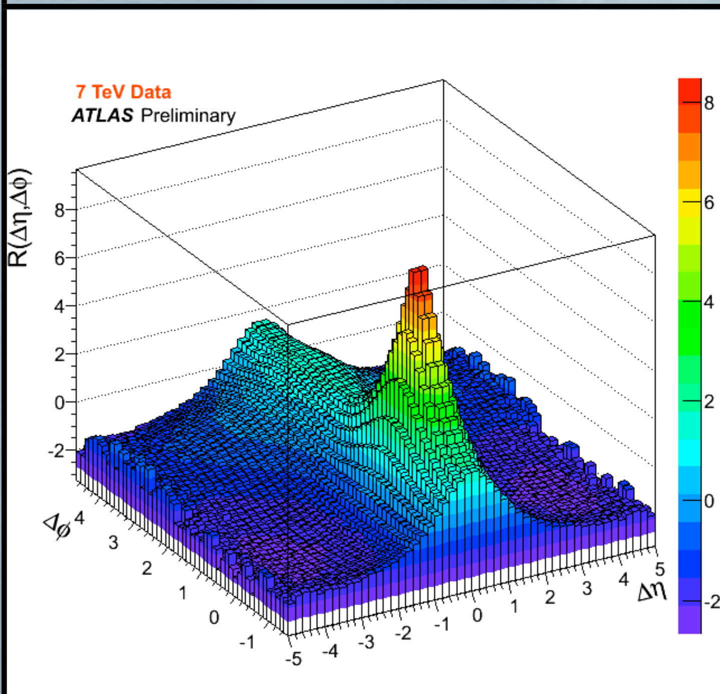
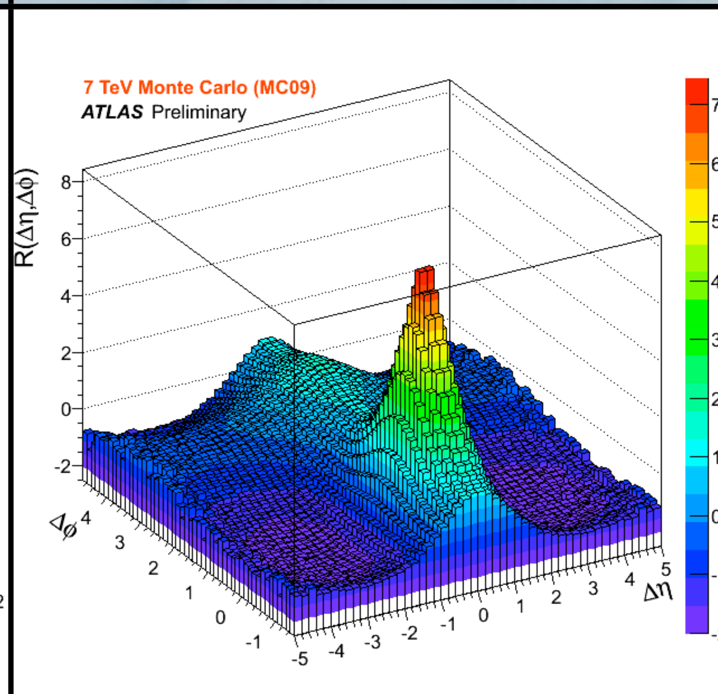
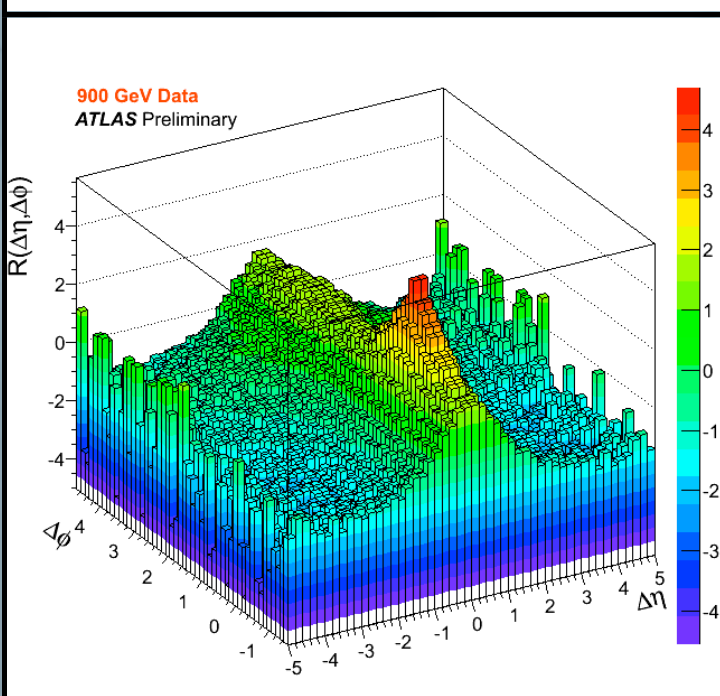
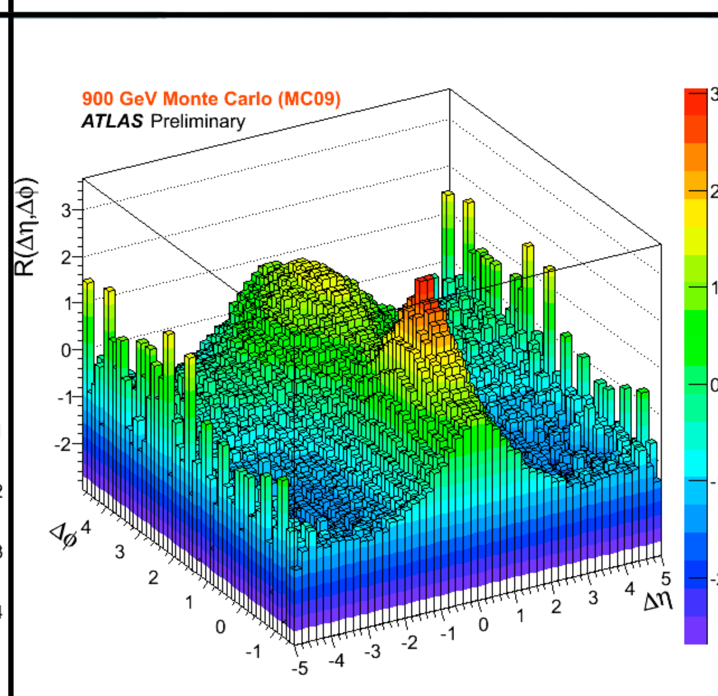




Closure test on MC

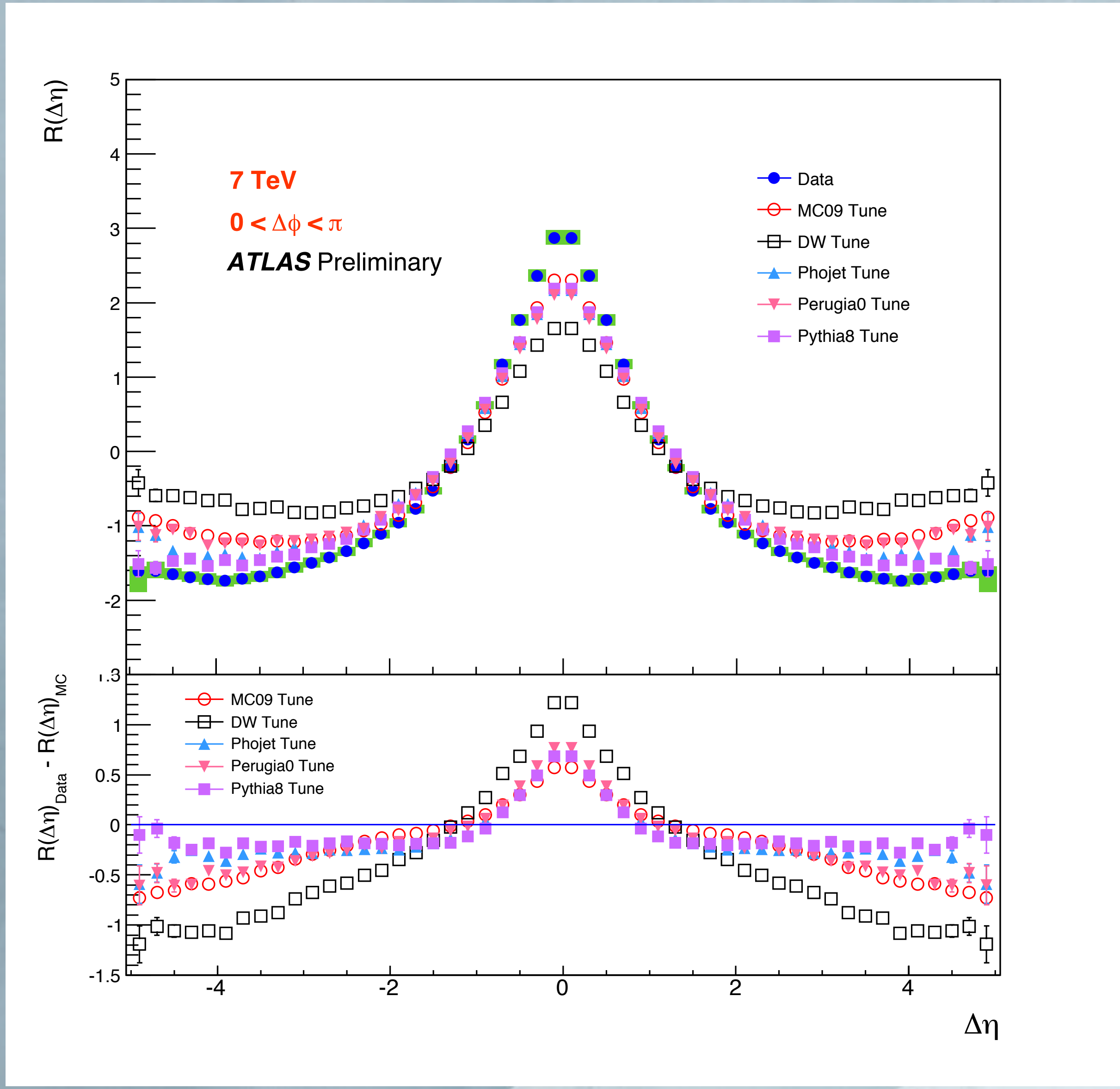


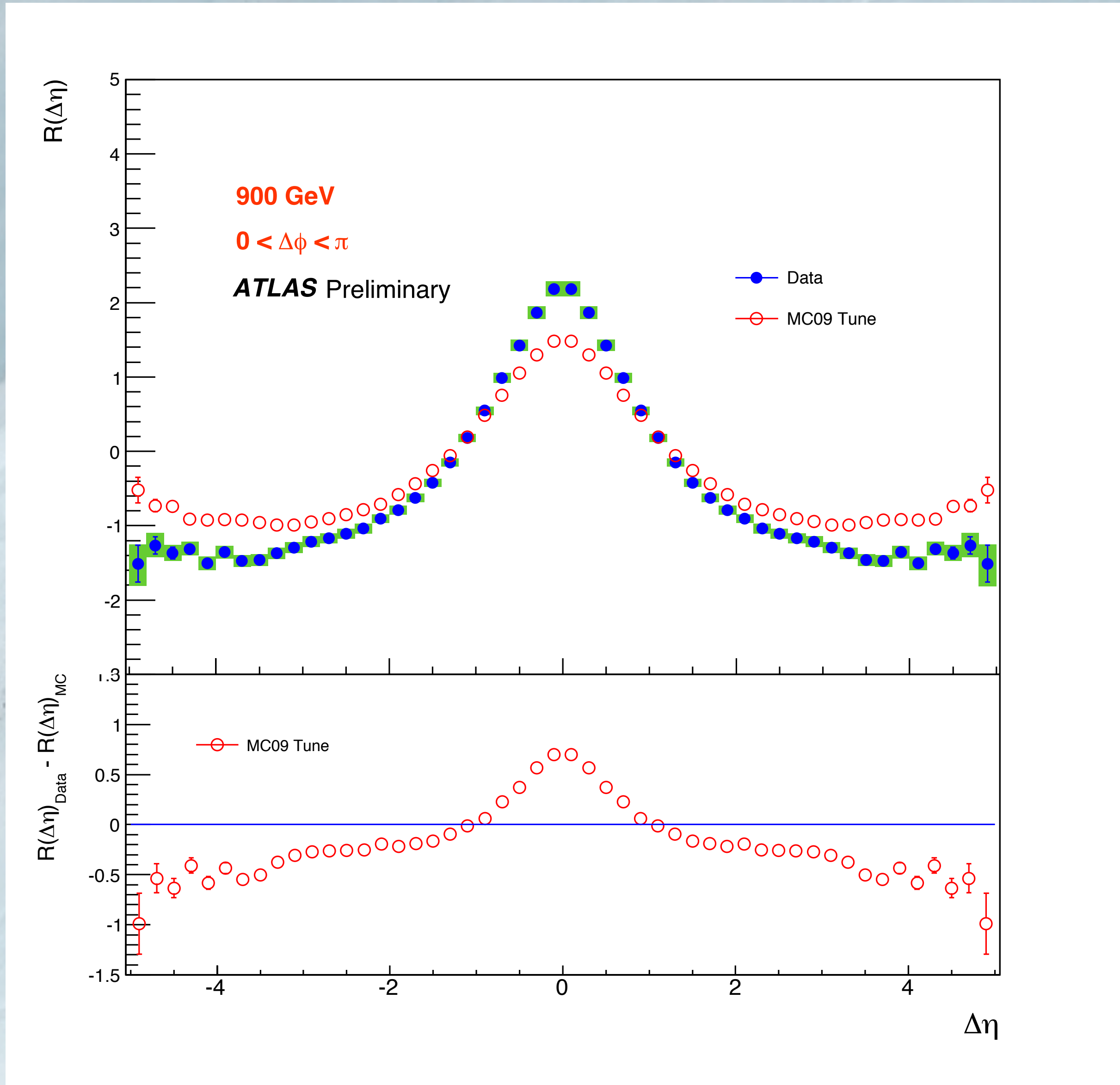
Full 2D Results

Data	Pythia 6	
		7 TeV
		900 GeV

Somewhat complicated structure. Note recoil ridge in "away" region (different shape in MC and data). Wells adjacent to the peak at {0, 0}

Δη Projections of the 2D results

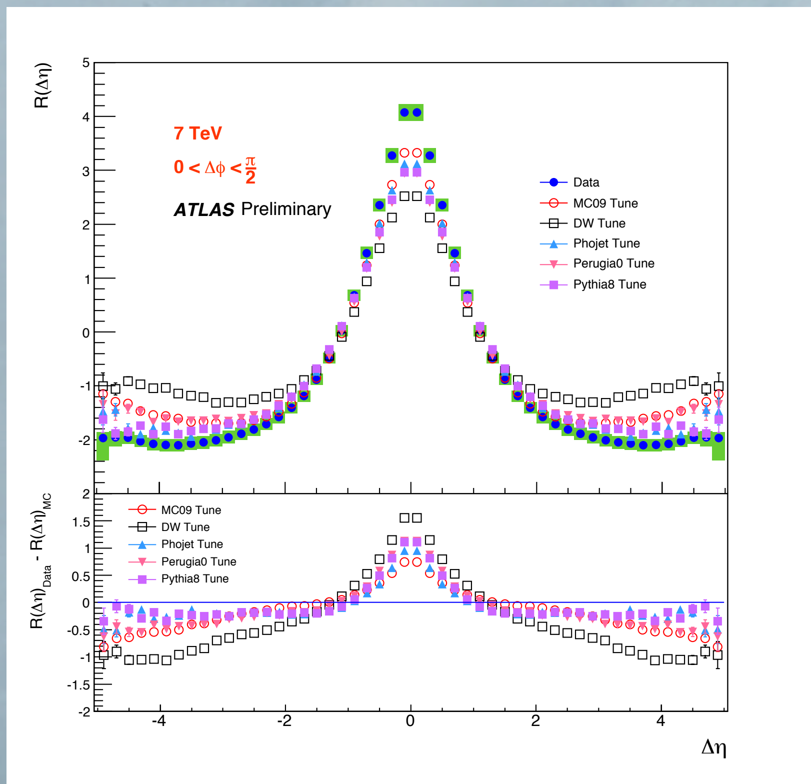


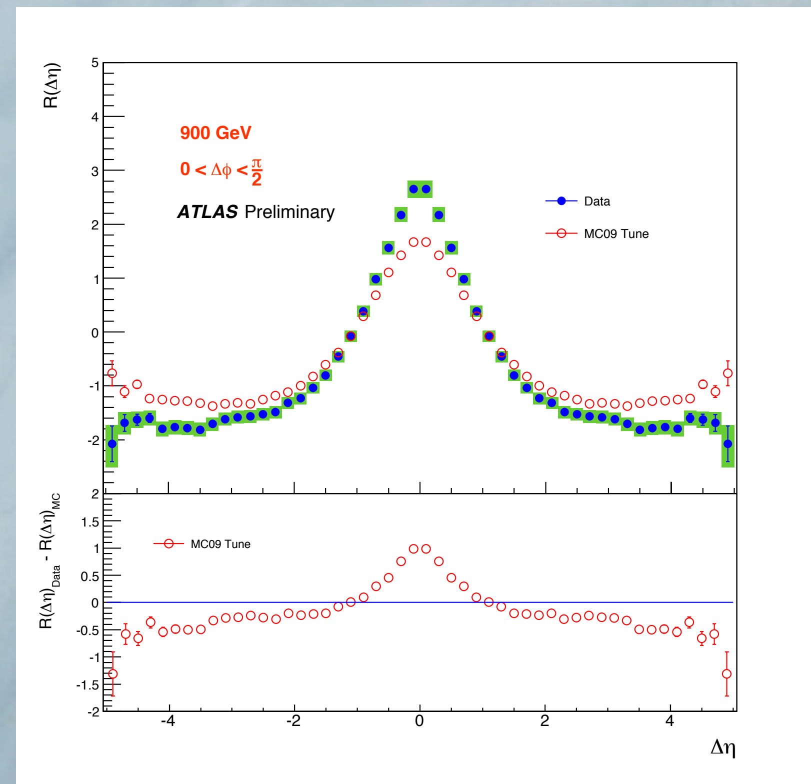


Easier to compare to MC by integrating over Δϕ

Δη distribution (by integrating the foreground and background separately over {0, π} at 7 TeV and 900 GeV)

Δη Projections of the 2D results



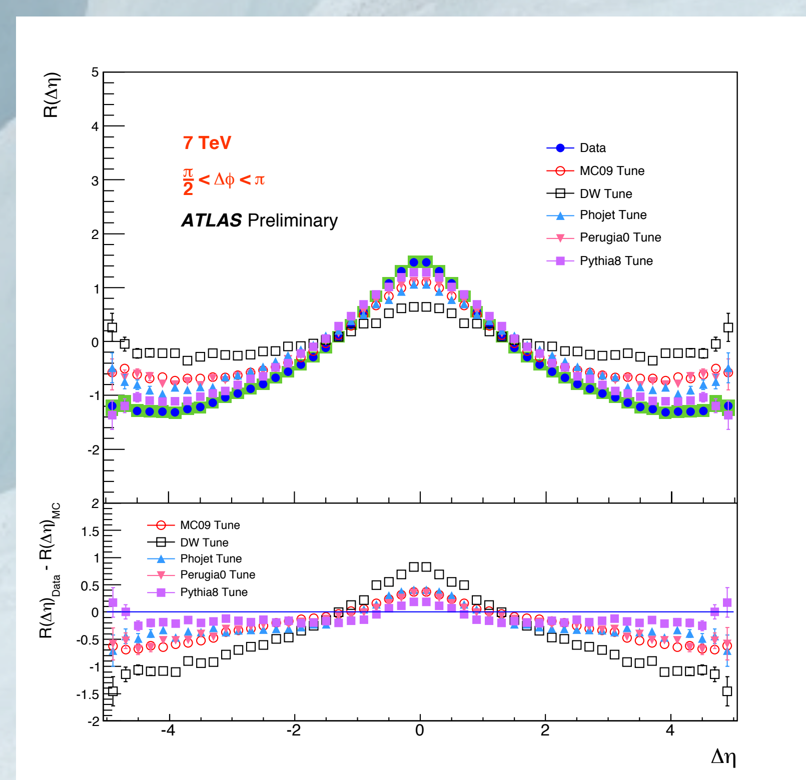


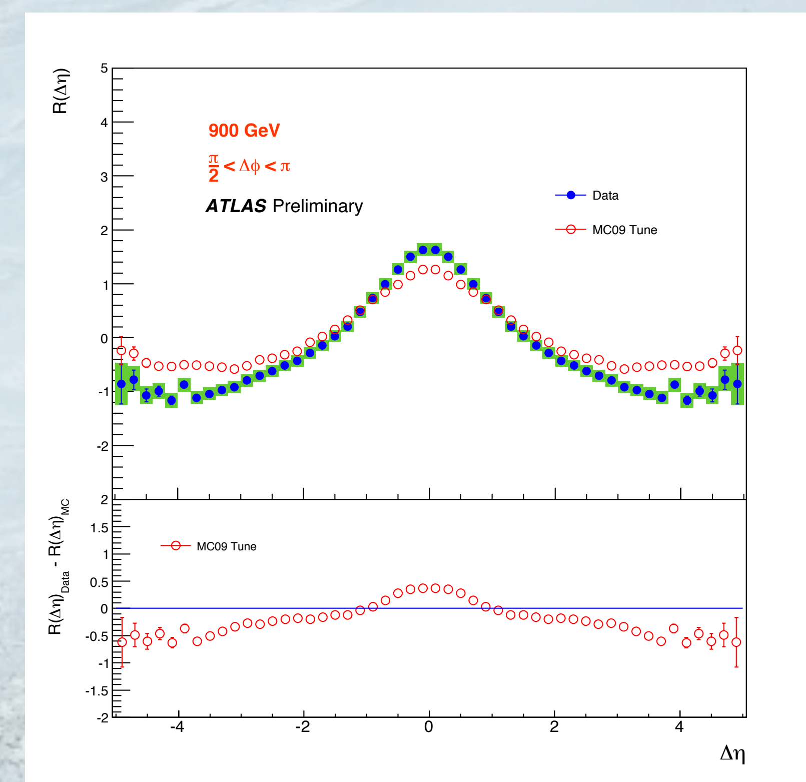
Δη distribution (by integrating the foreground and background separately over {0, π/2} at 7 TeV and 900 GeV)

Sharper peak because only taking the region closer **Δϕ** = 0

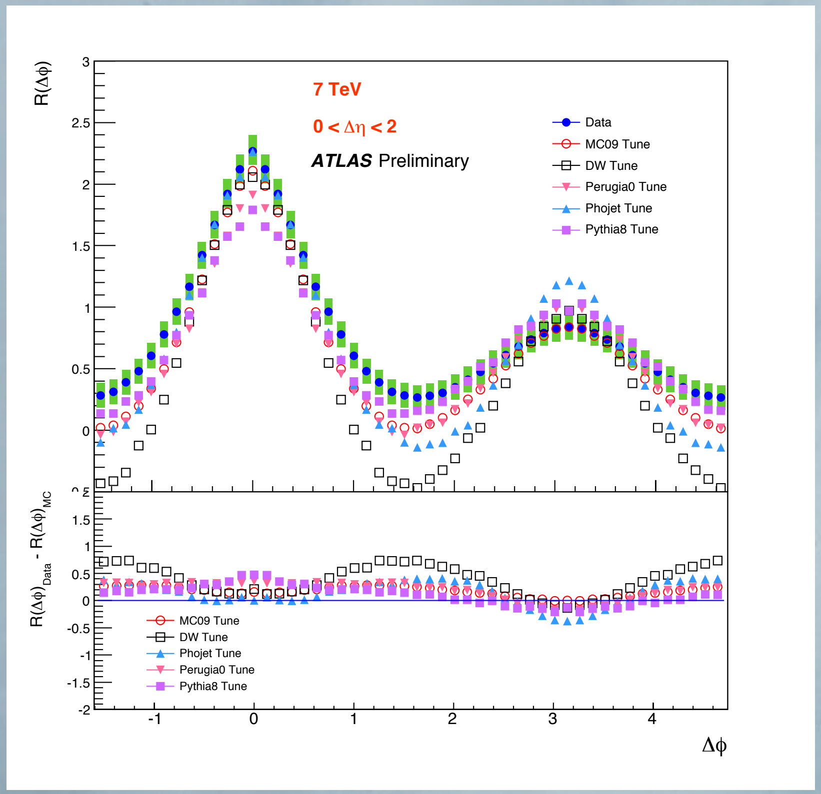
Δη distribution (by integrating the foreground and background separately over {0, π/2} at 7 TeV and 900 GeV)

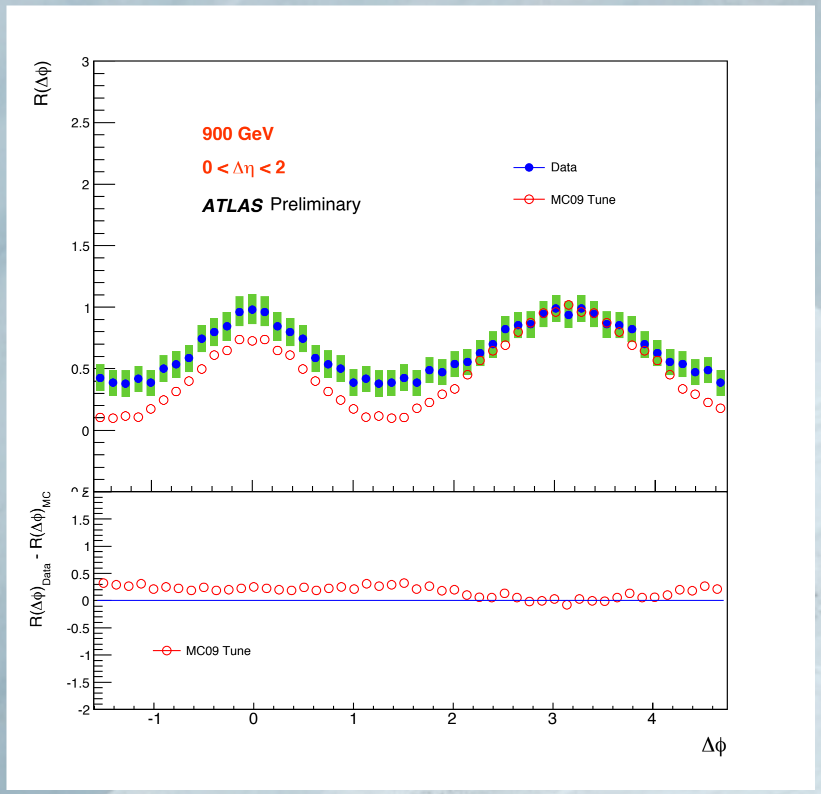
Wider peak because this region does not include the {0, 0} region





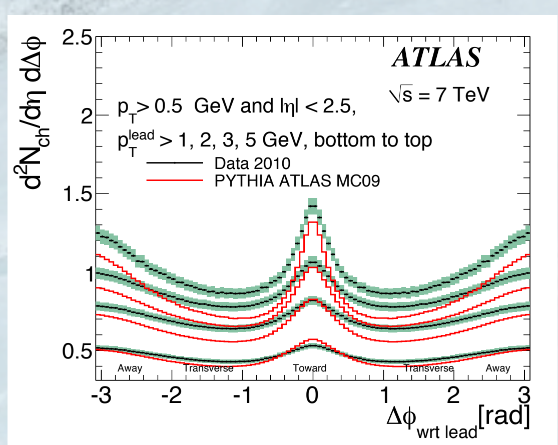
Δφ Projections of the 2D results





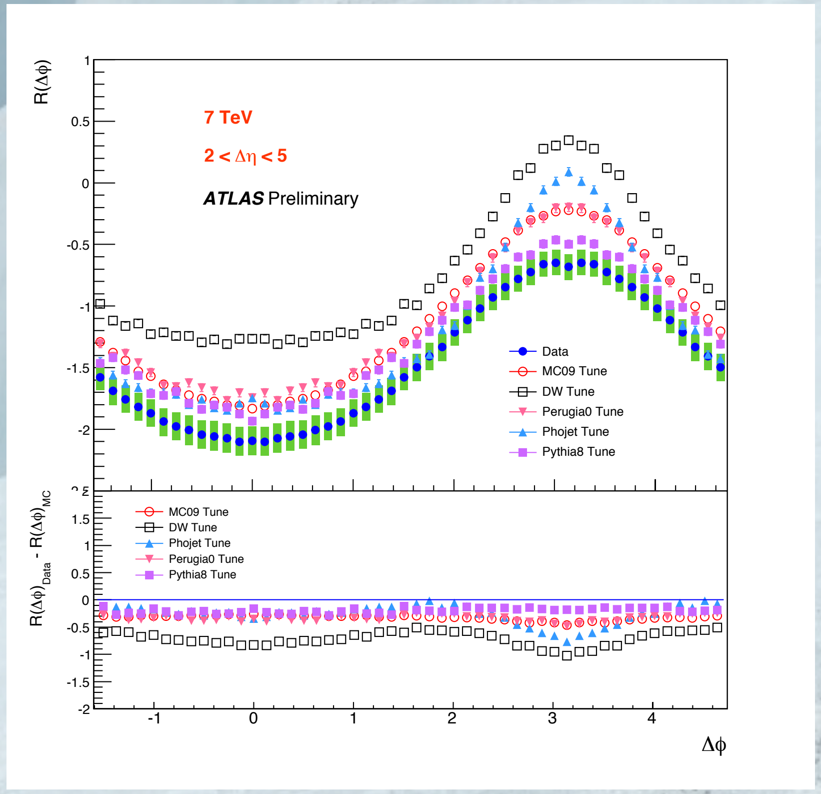
Δφ distribution (by integrating the foreground and background separately Δη over {0, 2} at 7 TeV and 900 GeV)

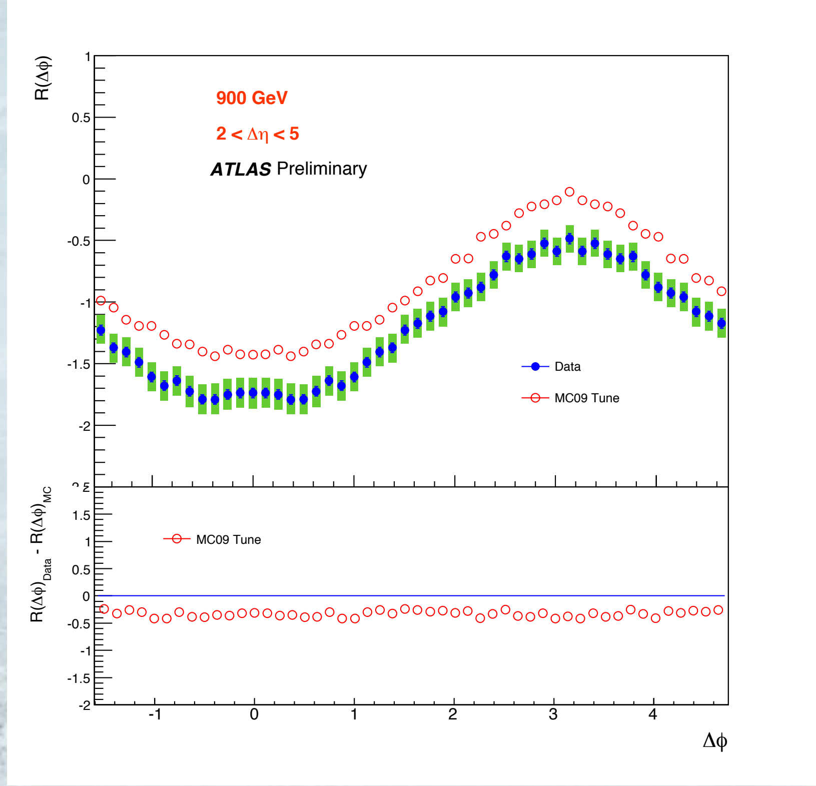
Double peak due to back-to-back recoil. Similar to some underlying event distributions



Δφ distribution (by integrating the foreground and background separately Δη over {2, 5} at 7 TeV and 900 GeV)

Integrating over **Δφ** region that does not include main peak - we see the away side recoil, but a dip on the near side





Comments

- Two Particle Correlation distribution sensitive to soft behaviour in QCD
- Measured in ATLAS tracks
- Corrected for detector effects
- Many different projections through the 2D function taken