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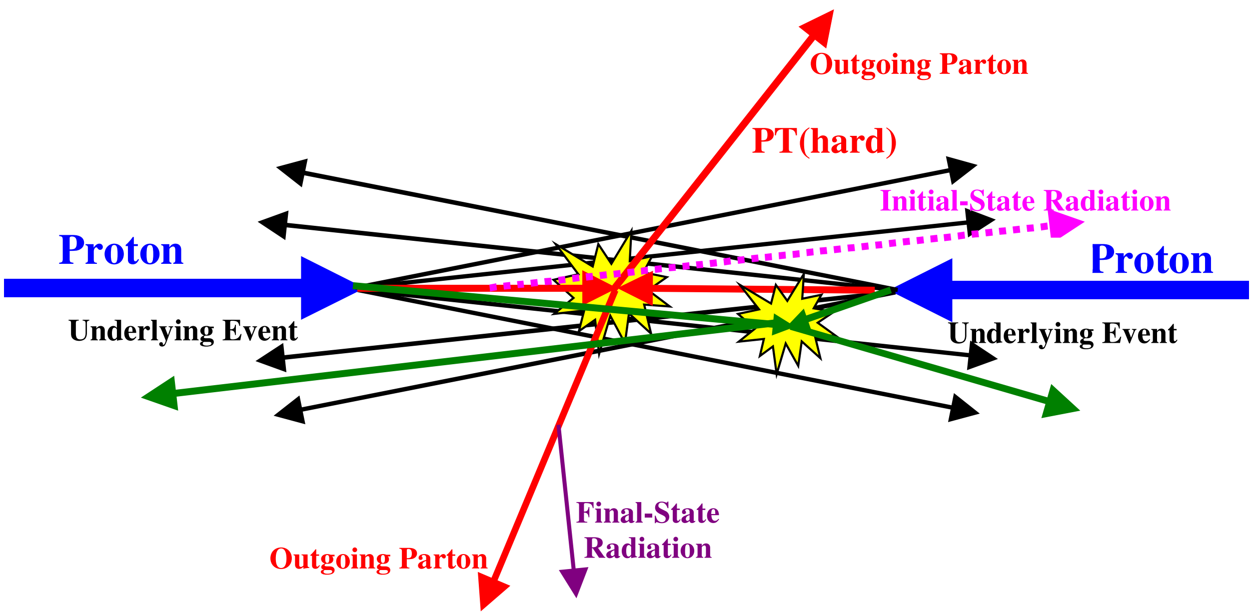
Study of charged particle correlations and underlying events with the ATLAS detector

VIth Workshop on Particle Correlations and Femtoscopy, Kiev, September 14th 2010

Motivation

- Pertubative QCD calculations cannot be done in the "soft" regime where the transverse momentum transfer between initial and final states is small
  - Underlying event (UE): beam-beam remnants, multiple parton interactions, initial and final state radiation, etc.



Motivation

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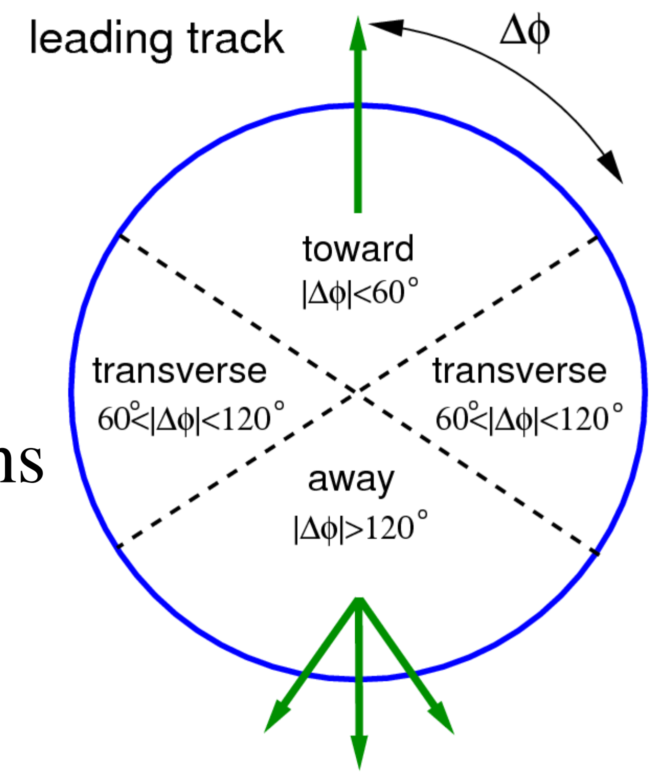
- Pertubative QCD calculations cannot be done in the "soft" regime where the transverse momentum transfer between initial and final states is small
  - Underlying event: beam-beam remnants, multiple parton interactions, initial and final state radiation, etc.
- Data predictions done in MC simulations via phenomenological models with many parameters
  - New/improved measurements of quantities sensitive to soft QCD effects deepens physics understanding and improves models.

Track-based underlying event studies

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2010-081/

Underlying event sensitivity

- Consider charged tracks in minimum bias events
  - Align event leading p_T track at $\varphi=0$
- Define 3 equal regions in $|\Delta\varphi|$
  - Transverse region most sensitive to UE, perpendicular to hardest scattering axis
- Measure track-based observables in all regions
  - Charged particle multiplicity vs $p_{T\,lead}$
  - Scalar p_T sum vs $p_{T\,lead}$
  - $<p_T>$ vs $p_{T\,lead}$
  - φ distribution of track density



Minimum bias sample

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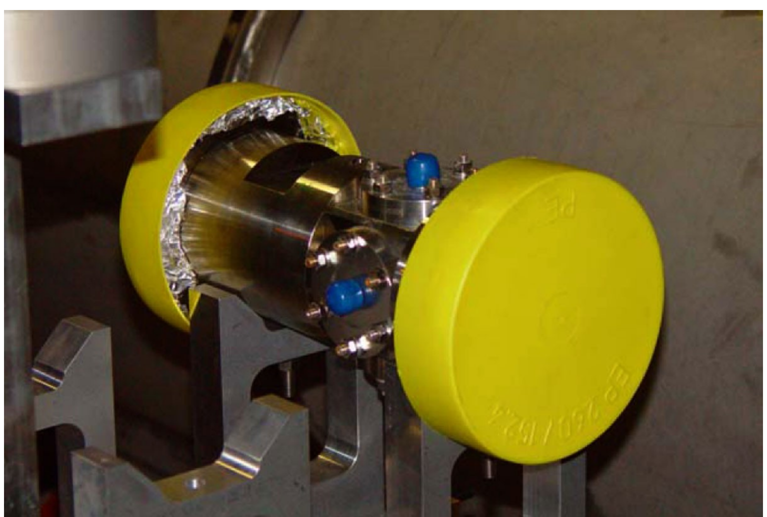
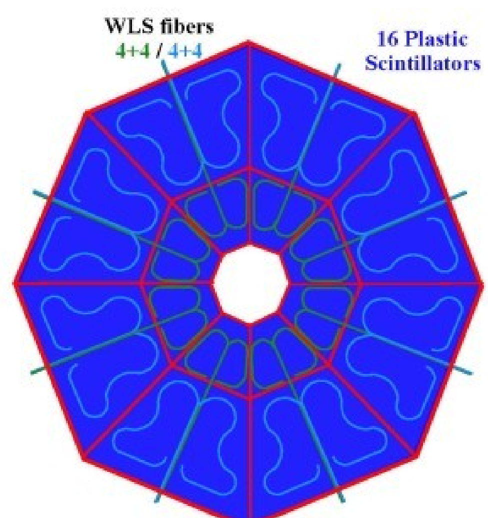
- Samples collected with the ATLAS minimum bias trigger
  - Beam Pickup Timing devices (BPTX) – signals beam presence
    - electrostatic beam pick-ups ±175 m from centre
  - Minimum Bias Trigger Scintillators (MBTS)
    - at detector ends in front of endcap-calorimeter at ±3.56 m
    - $2.09 < |\eta| < 3.84$





Event/Track selections

- Presence of a good reconstructed primary vertex (PV) according to ATLAS criteria
- Pile-up rejection
- At least one track with:
  - p_T>1 GeV
  - $|\eta|$< 2.5
  - 1 pixel detector cluster and 6 hits in the silicon central tracker
  - transverse and weighted longitudinal distances of closest approach <1.5mm relative to PV
  - for tracks with p_T>10 GeV, χ^2 probability of track fit >0.01 (remove mismeasured tracks)
- Add to sample all other good tracks with p_T>500 MeV

Corrections and Unfolding

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- Data corrected and unfolded to particle level to allow comparisons
- Corrections
  - Event: Trigger and vertex reconstruction efficiency, lead track requirement
  - Track: Reconstruction efficiency correction in p_T and η, secondaries, fakes, kinematic range limits
- Unfolding
  - Event reorientation (unreconstructed lead particle)
  - Bin-to-bin migrations

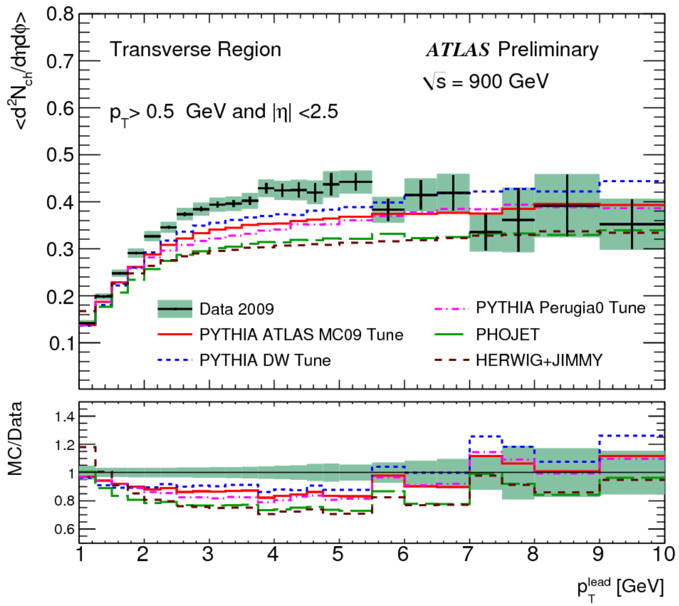
Efficiencies measured in data!

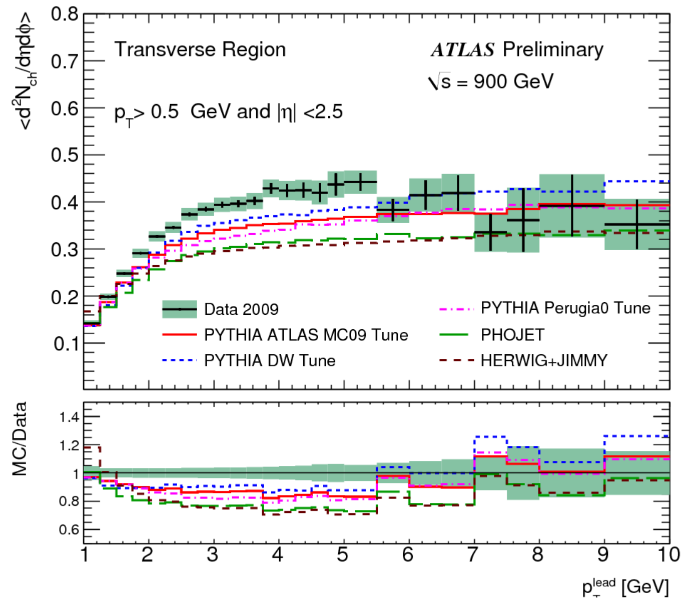
Measured in MC, validated with data

Systematic Uncertainties

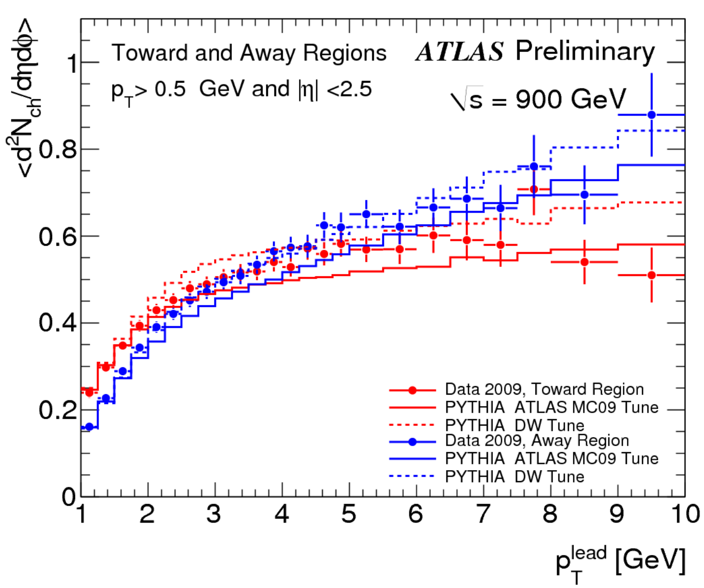
	Lowest p_T bin	Intermediate p_T bin	Highest p_T bin
Systematic uncertainty on unfolding			
Difference between PYTHIA and PHOJET	4%	2%	2%
Statistical uncertainty on PYTHIA unfolding	$< 0.1\%$	1% (2%)	4% (5%)
Systematic uncertainties from efficiency corrections			
Track reconstruction	3%	4%	4%
Leading track requirement	1%	$< 0.1\%$	$< 0.1\%$
Trigger and vertex efficiency	——	$< 0.1\%$ (everywhere)	——
Total from efficiency corrections	2.5%	4%	4%
Total systematic uncertainty	4.5%	4.5% (5%)	6% (6.5%)

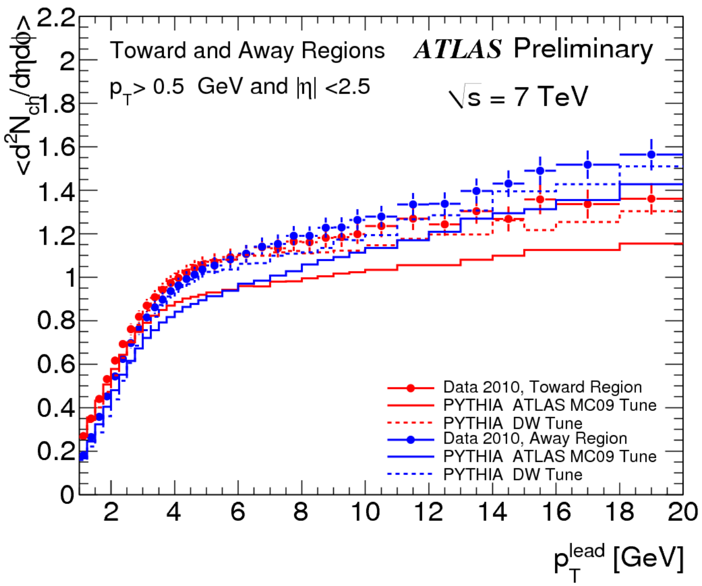
Charged particle multiplicity





More tracks are present in UE than predicted!





Tune DW provides good description of other regions

Scalar p_T sum of charged particles

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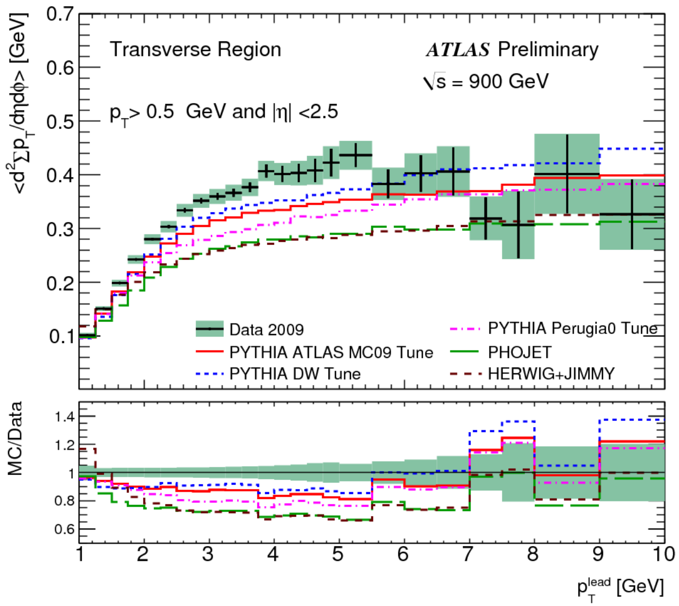
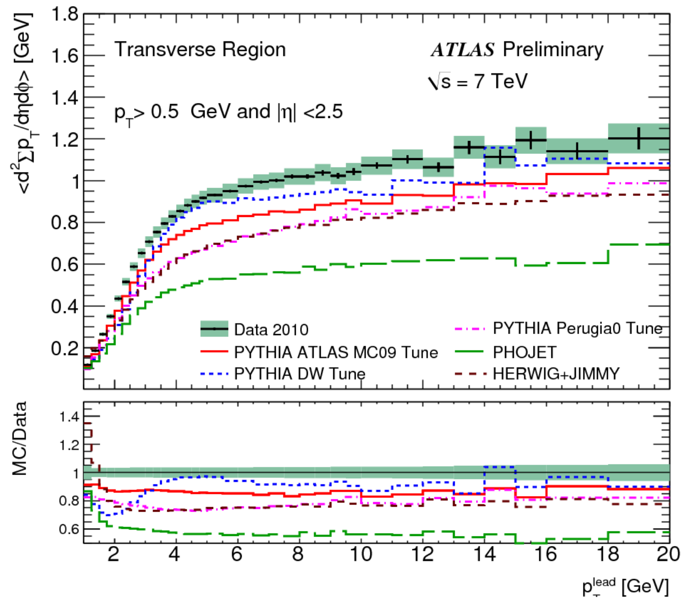
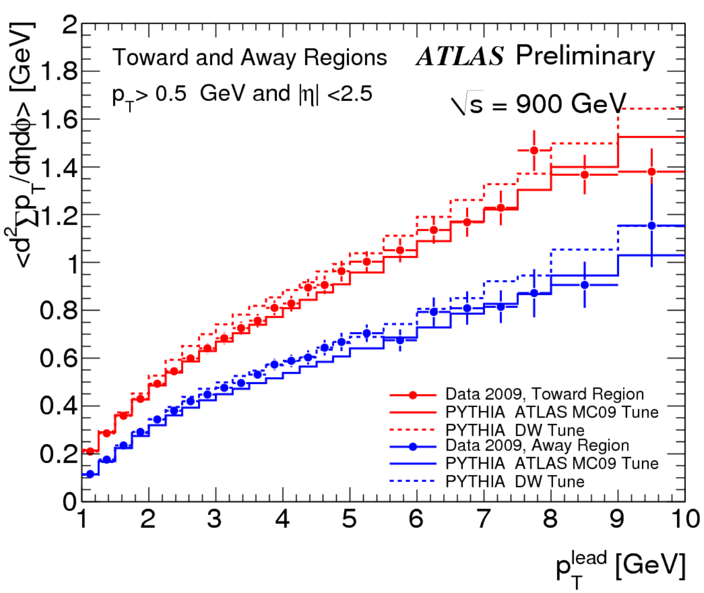
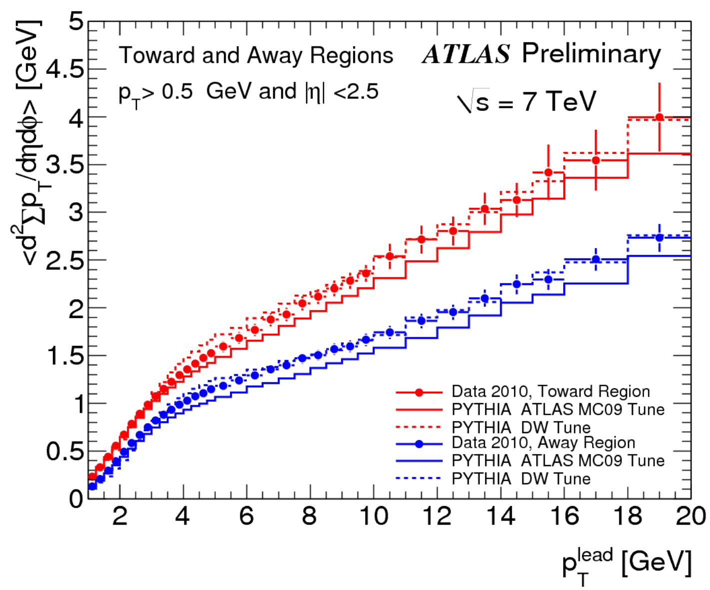




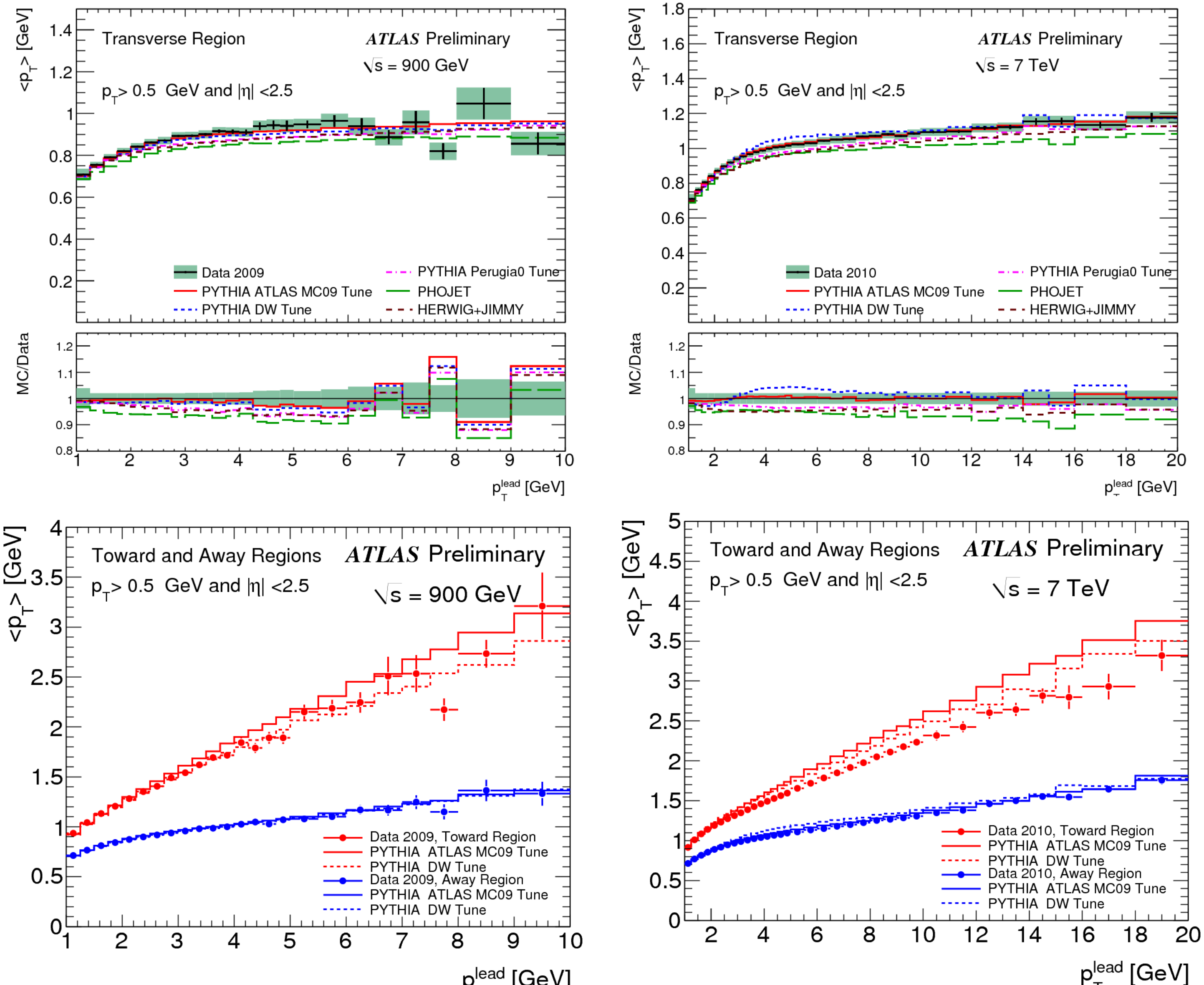
Plateau level 10-15% higher than predictions





As expected, toward region higher than away region.

$<p_T>$ of charged particles

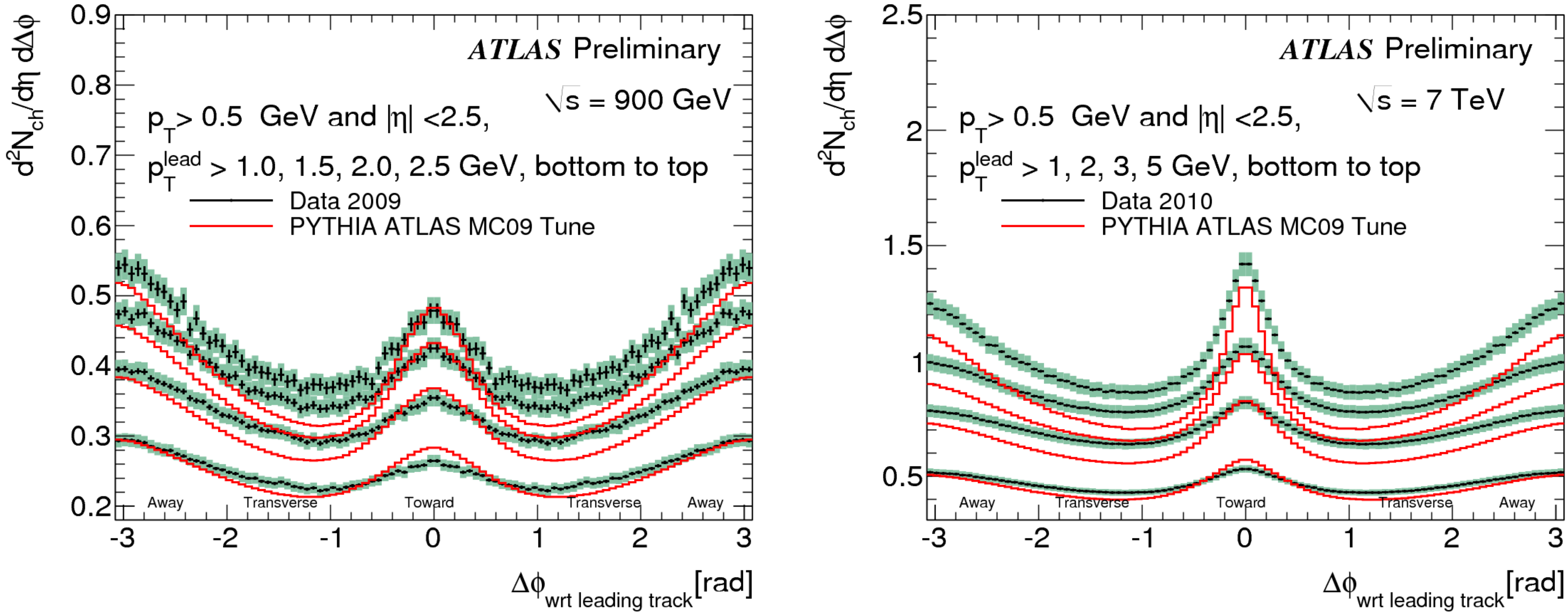


Plateau level slightly higher than predictions

As expected, toward region higher than away region.

φ distribution of track densities

- Emergence of jet structure as p_T requirement of leading track is increased



Summary of UE measurements

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- First measurements of UE characteristics with the ATLAS detector were presented
- Data was corrected and unfolded so that comparison to MC models was possible
- Provides valuable input to MC models
  - Transverse region/UE more active and energetic than expected
  - Measured $\langle p_T \rangle$ lies above the MC expectations
  - Formation of jet-like structures different from predictions

Angular correlations between charged particles

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2010-082/

Angular correlations in MB

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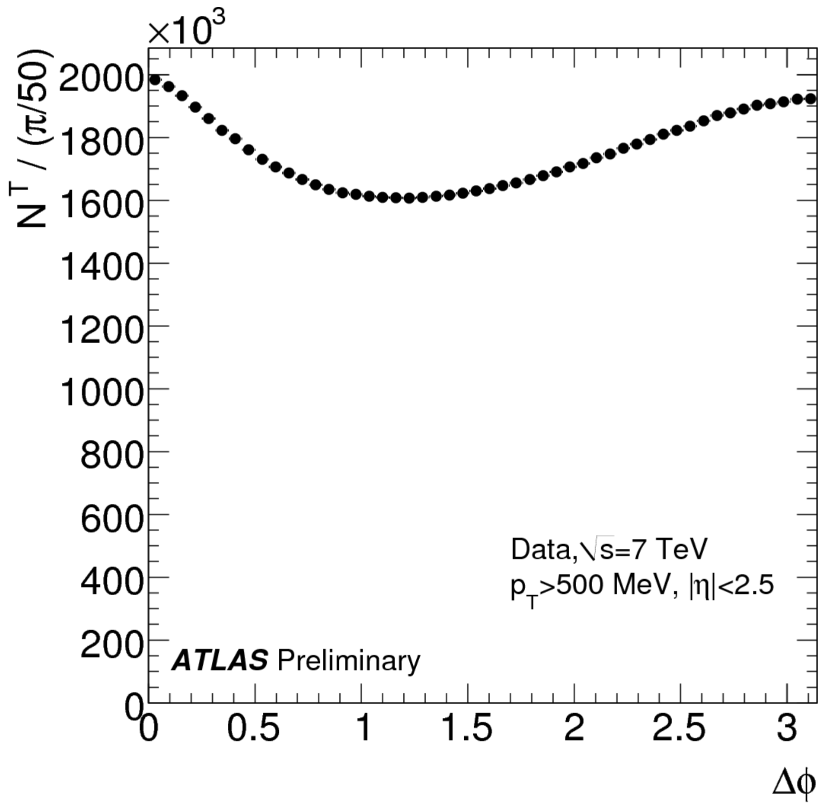
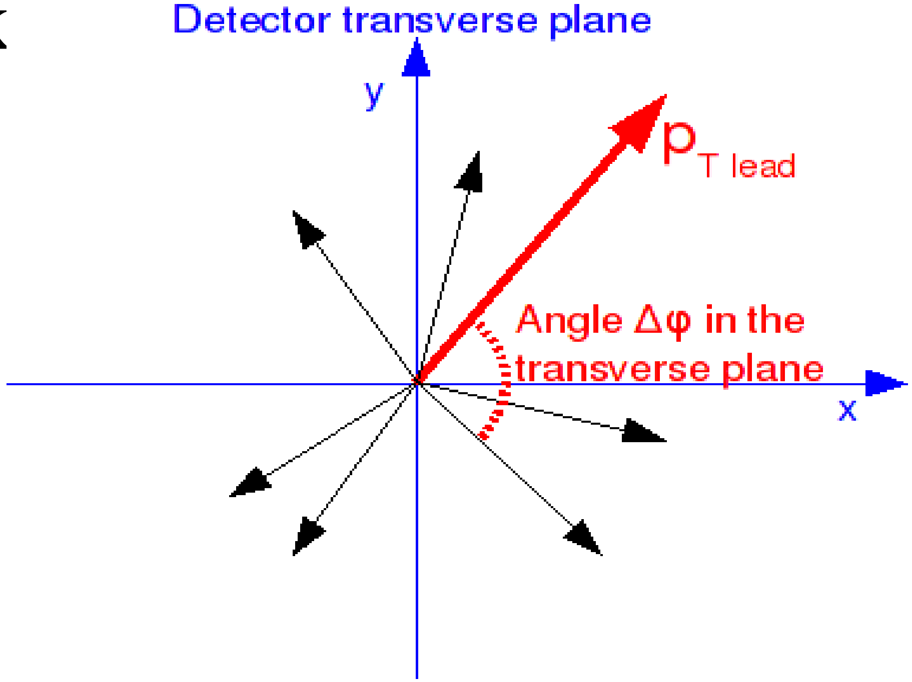
- Further investigation: turn the tables on the measurement of φ distribution of track density
  - Isolate the peaking features at zero and π
  - Carefully design measurements to decrease sources of systematic uncertainties
- Measurement can be used as input to tuning of phenomenological models in MC simulations

Crest shape variable

- Distance in φ between the leading track (highest p_T track) and each one of the other selected track

Use all tracks with p_T>500 MeV!

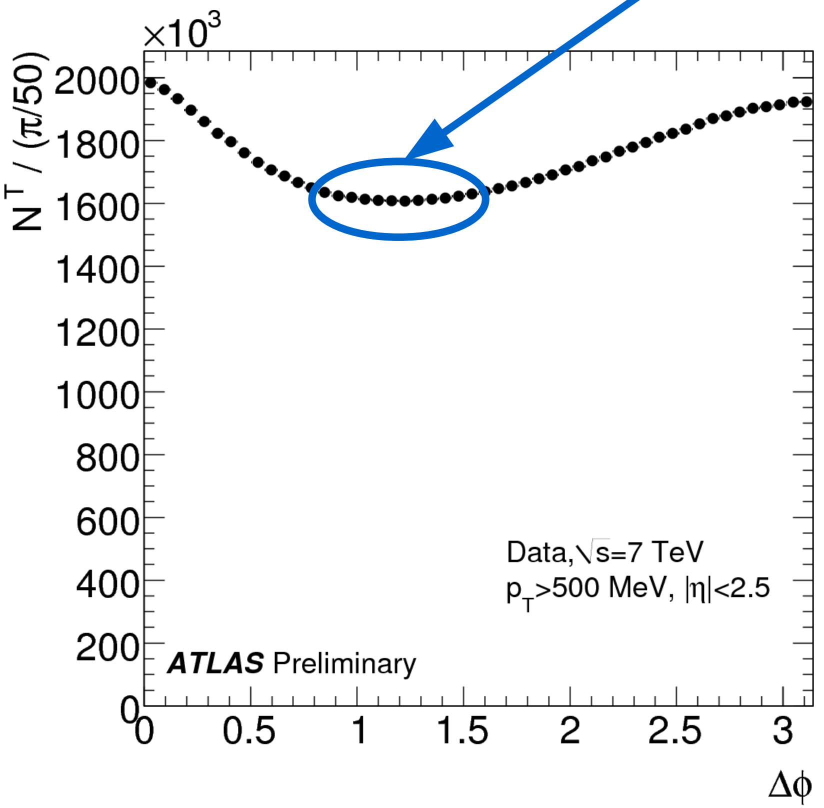


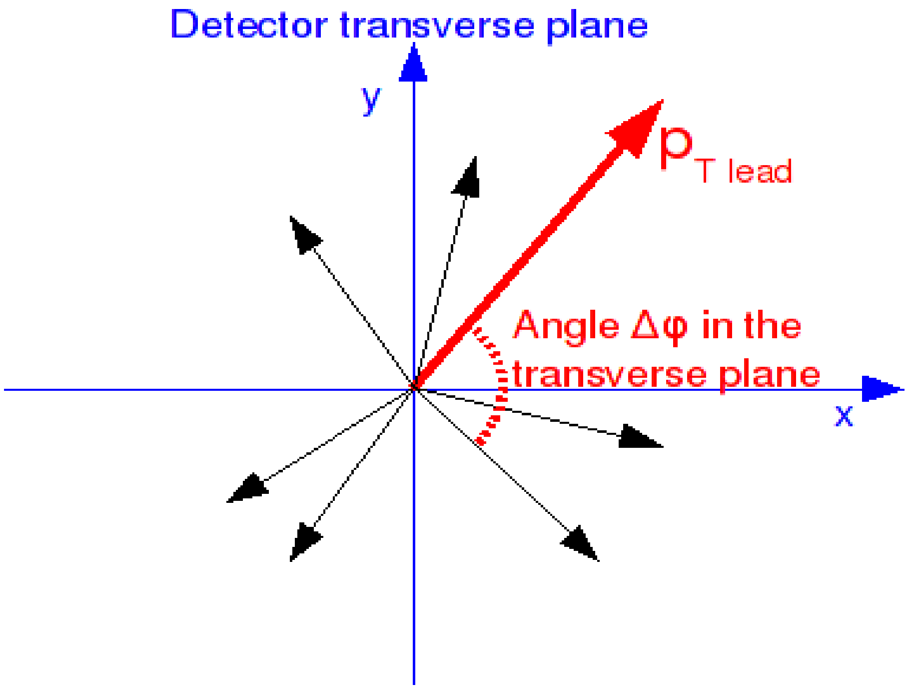


Crest shape variable

- Fit 2nd order polynomial to region around distribution minimum

Use all tracks with p_T>500 MeV!

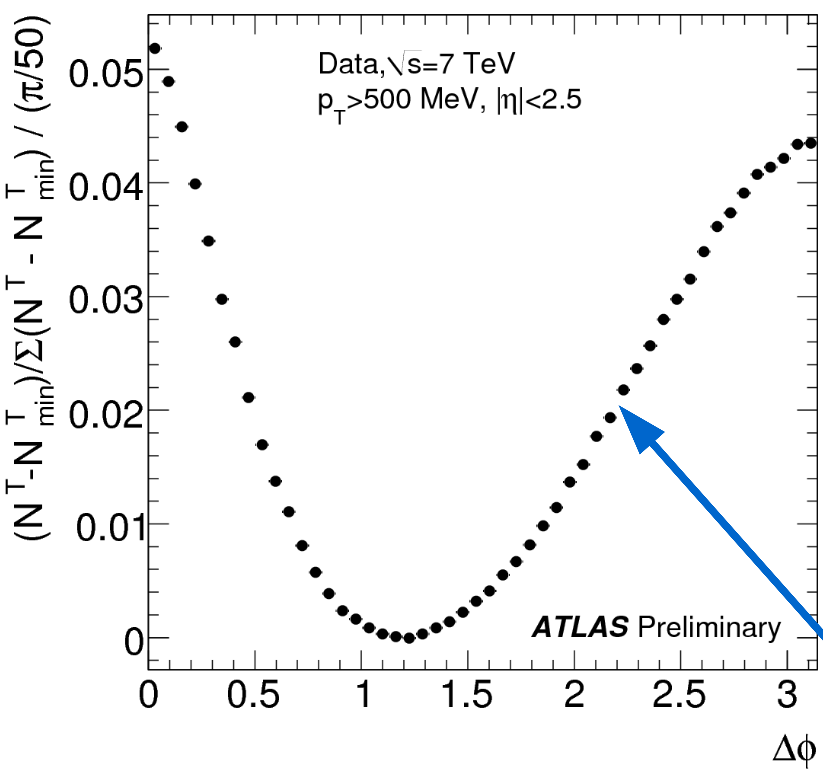


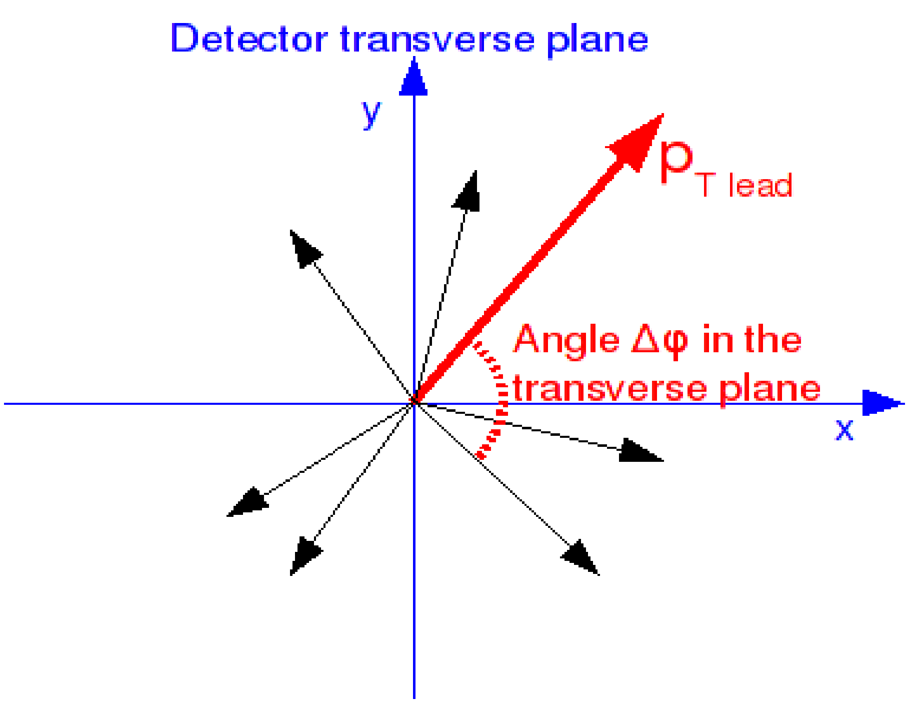


Crest shape variable

- Subtract fitted minimum value from each bin and normalise to unit area

Use all tracks with p_T>500 MeV!

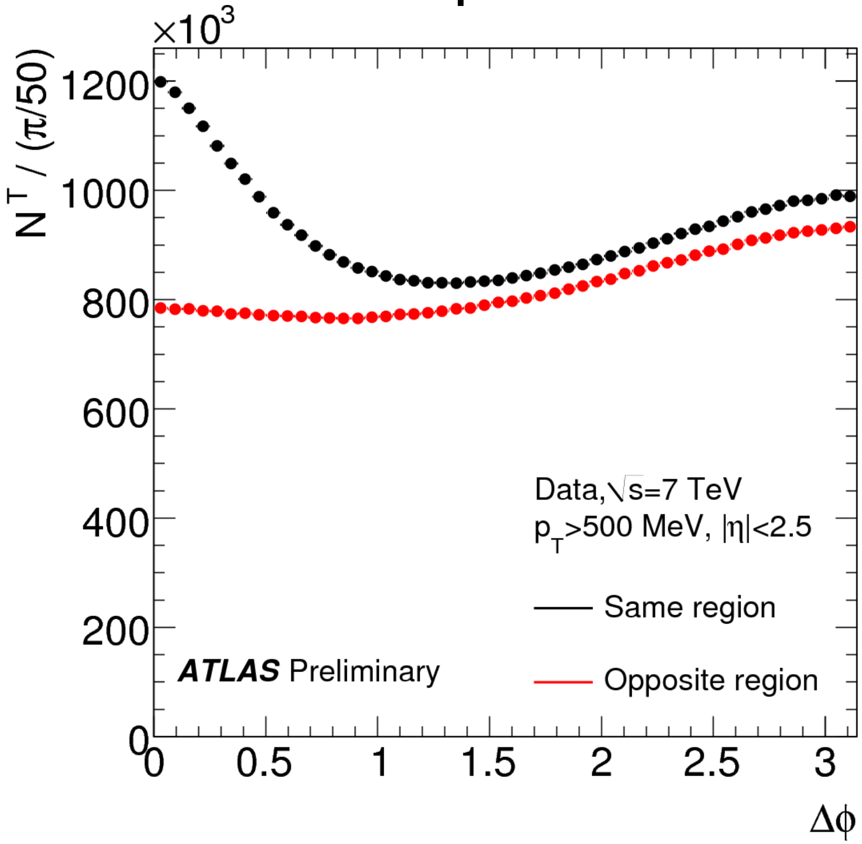


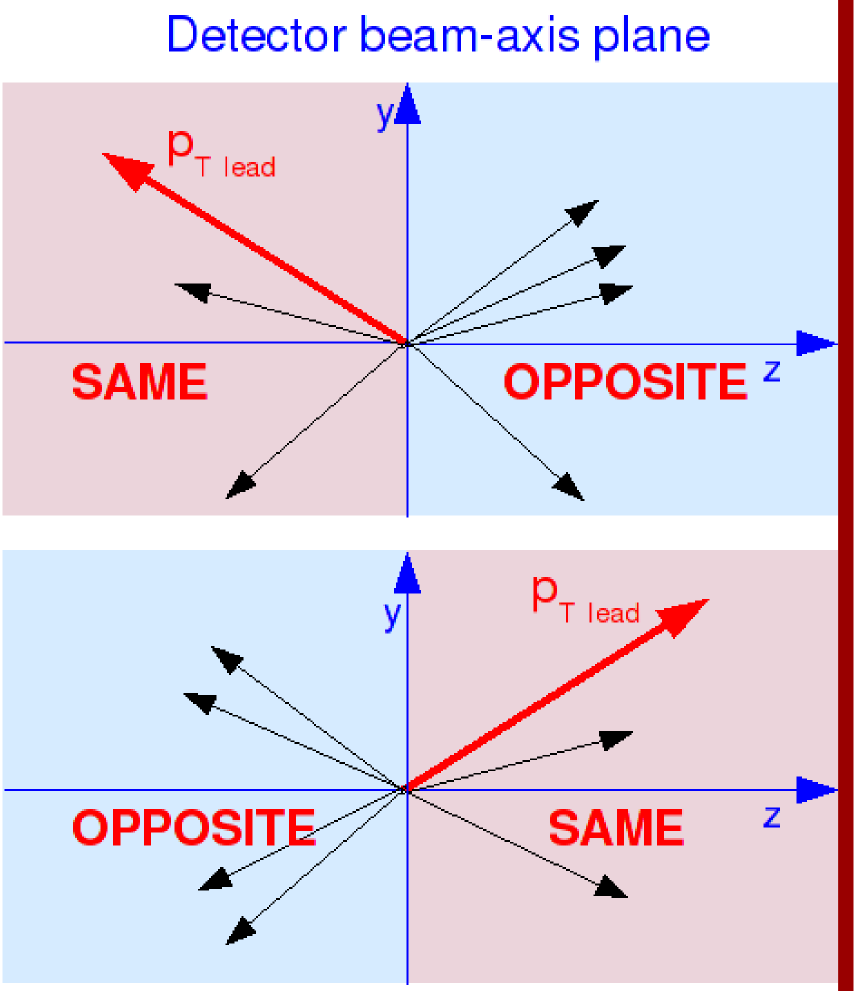


Measured crest shape characteristics: peak widths, relative heights, position of minimum

Same – opposite observable

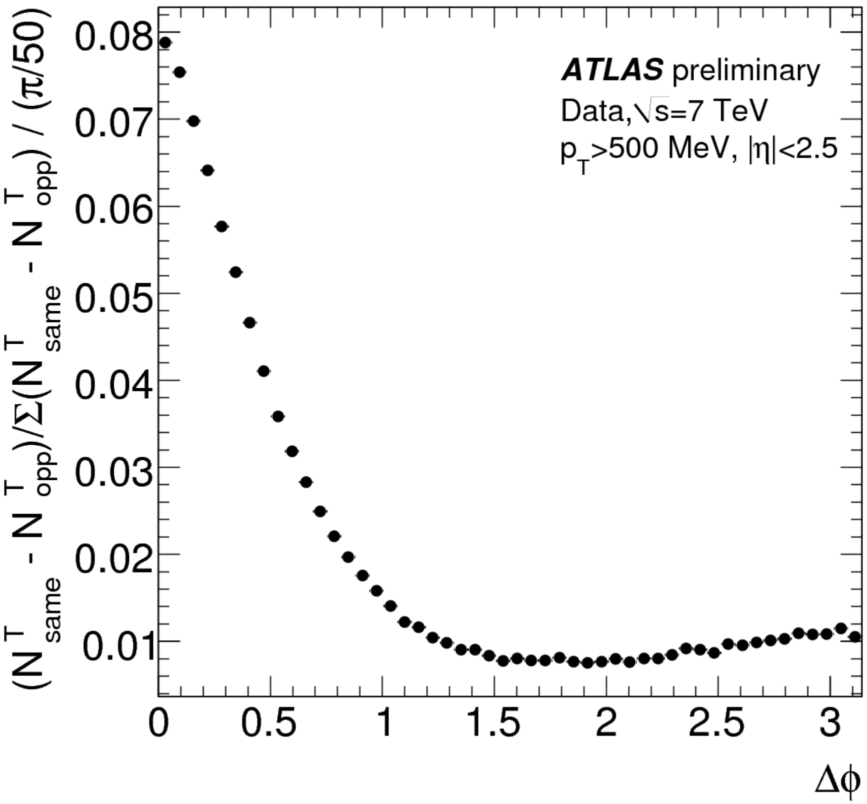
- Event-by-event, assign tracks to one of two detector regions
  - Based on η location of leading track

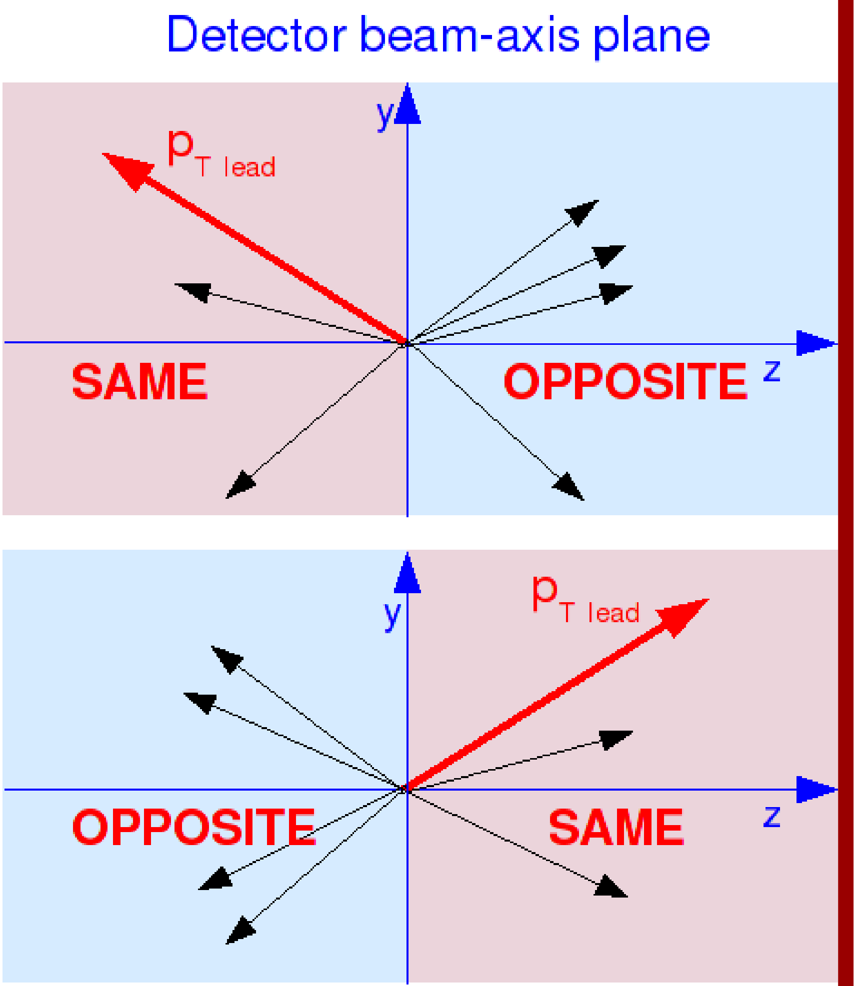




Same – opposite observable

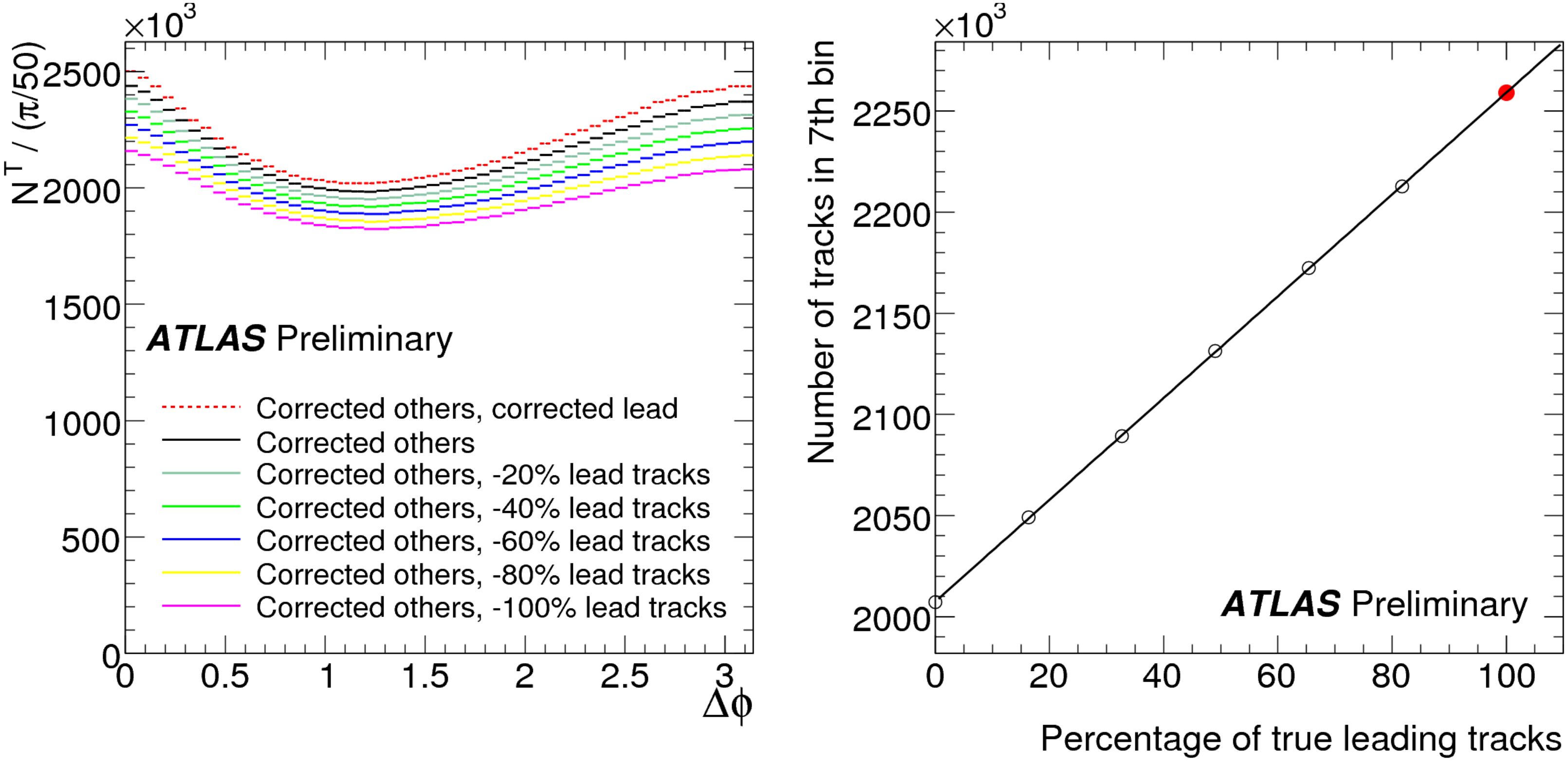
- Subtract "opposite" distribution from "same" and normalise
- Sensitive to η correlations





Correction for tracking efficiency

- **Tracking efficiency in p_T and η**
  - On non-leading tracks: apply weight to entry to correct for missing tracks (also fakes and secondary contamination)
  - On leading tracks: do a bin-by-bin shape correction based on knowledge of shape changes with extra loss of leading tracks



Summary of systematics

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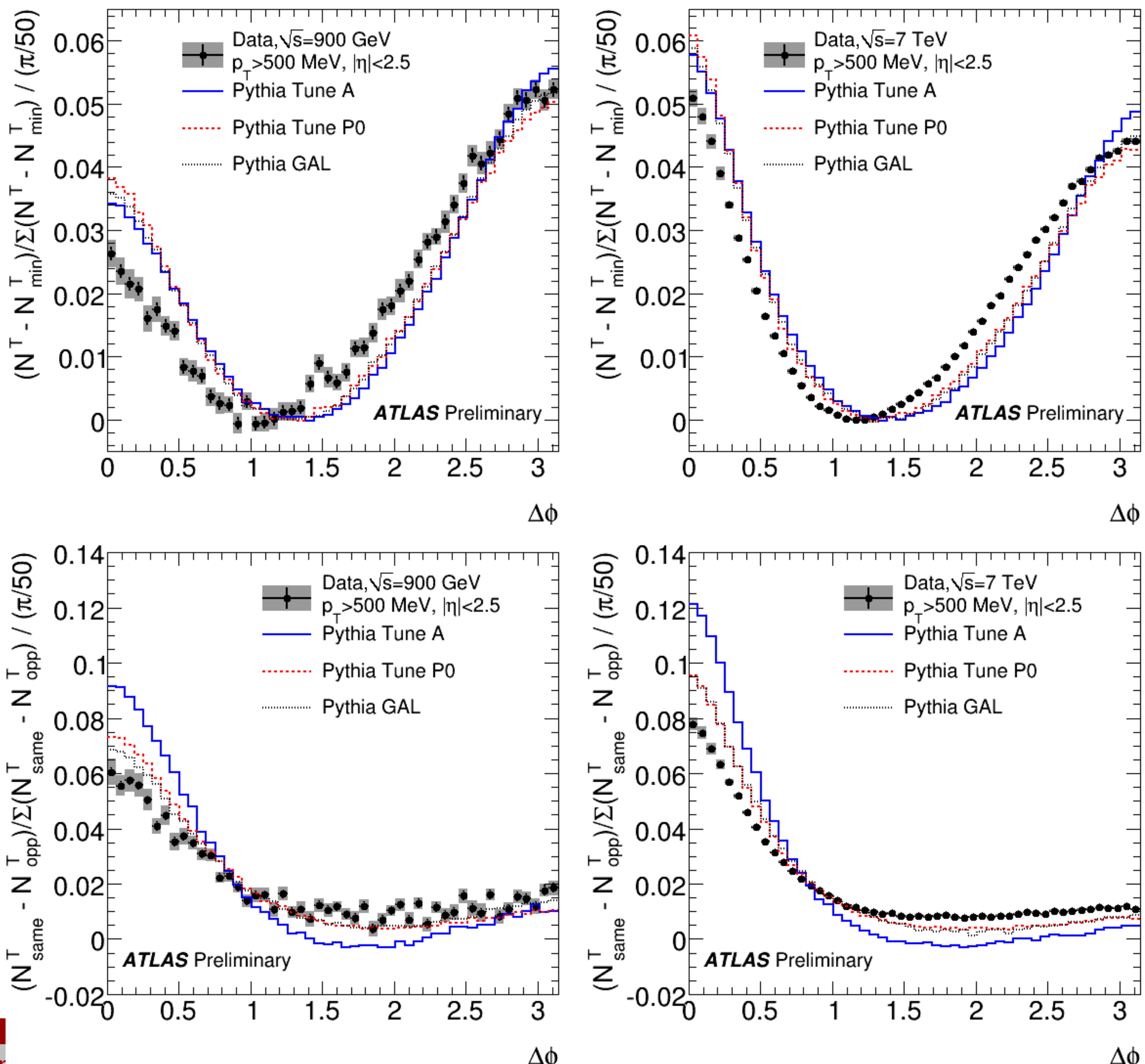
- Other large sources of systematic include p_T resolution effect and selection effects associated to the 2-track requirement

Table 1: Systematic uncertainties, summary table

Source of systematic uncertainty	Implemented	Relative uncertainty in first bins
Event selection inefficiency	bin-by-bin	1%-3%
Bias remaining after corrections	2% in first 4 bins	2%
Resolution - phase space boundaries	bin-by-bin	1%-2%
Resolution - leading track	bin-by-bin	0.1%-0.2%
Efficiency of leading tracks	bin-by-bin	0.1%-0.2%
Efficiency of non-leading tracks	0.2% in each bin	0.2%
ϕ dependence of the tracking efficiency	6×10^{-5} in each bin	0.1%-0.2%
Choice of the d_0^{PV} cut	9×10^{-5} in each bin	0.1%-0.3%
Statistical uncertainty		900 GeV: 3%-4% 7 TeV: 0.3%-0.4%

Measured distributions |η|<2.5



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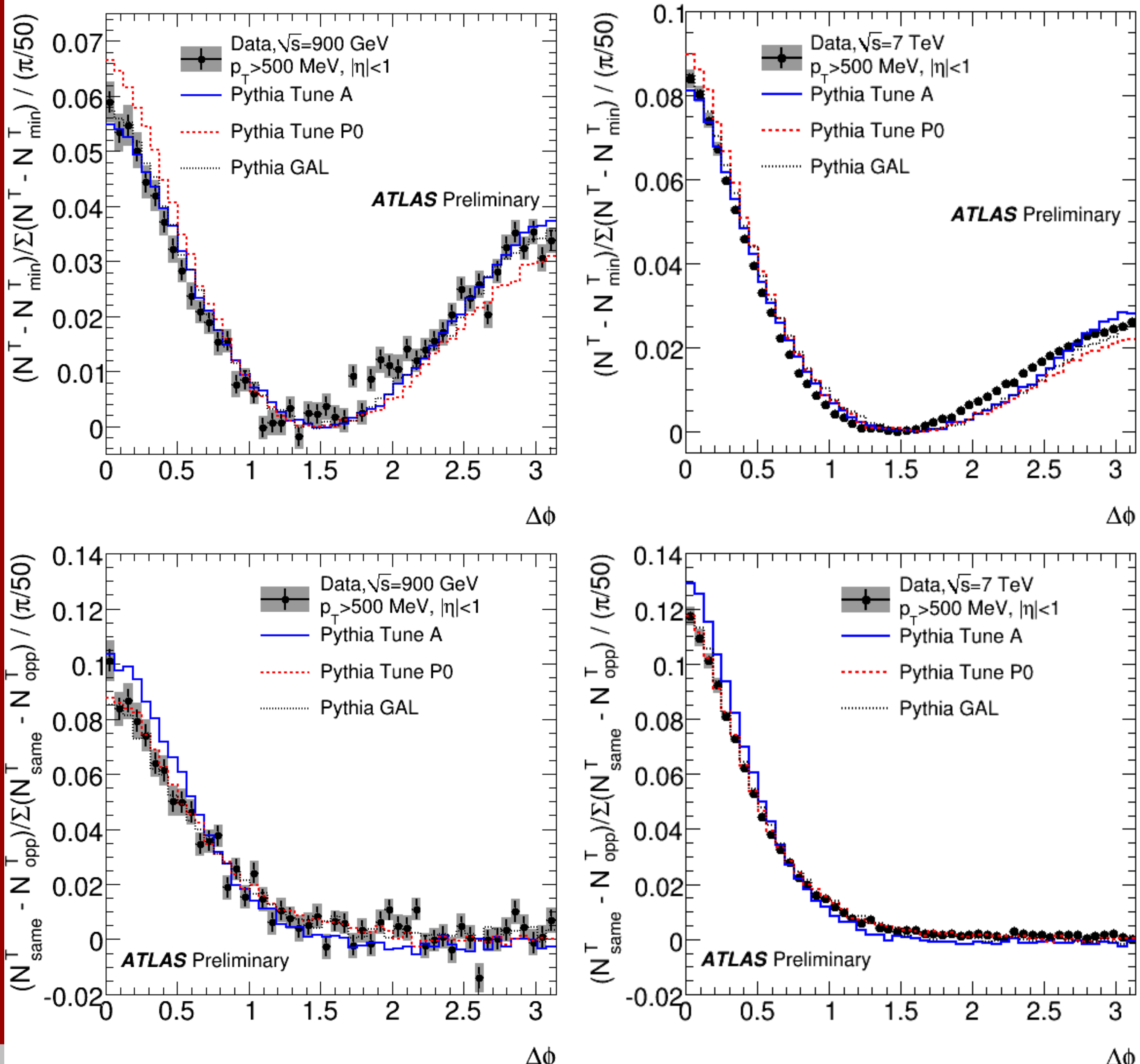
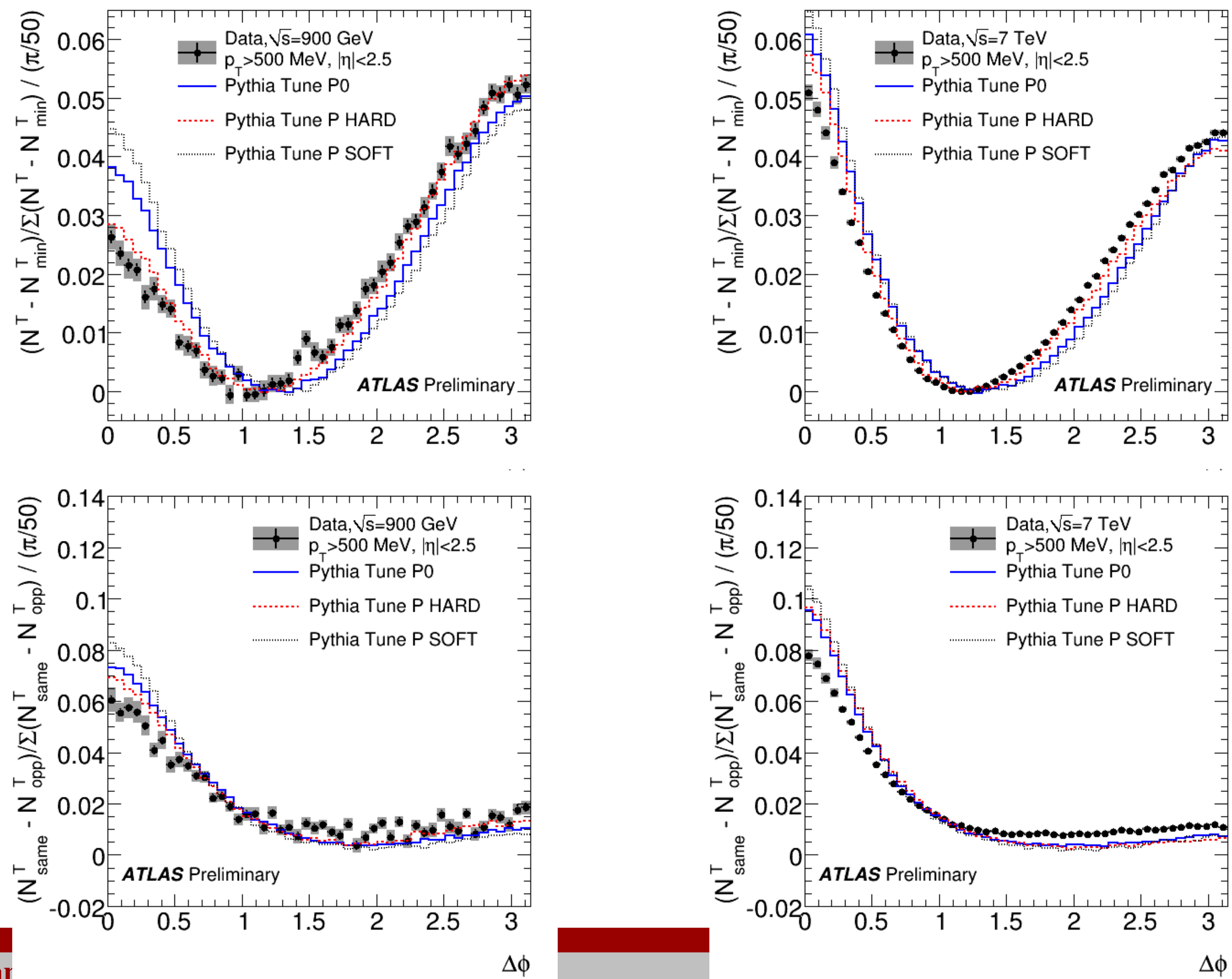
Measured distributions |η|<1



Better match for restricted region |η|<1 is expected: CDF tuning data available in that region

Comparison to Pythia tunes (6.1.4.21)

- p_T-ordered shower, Perugia tunes



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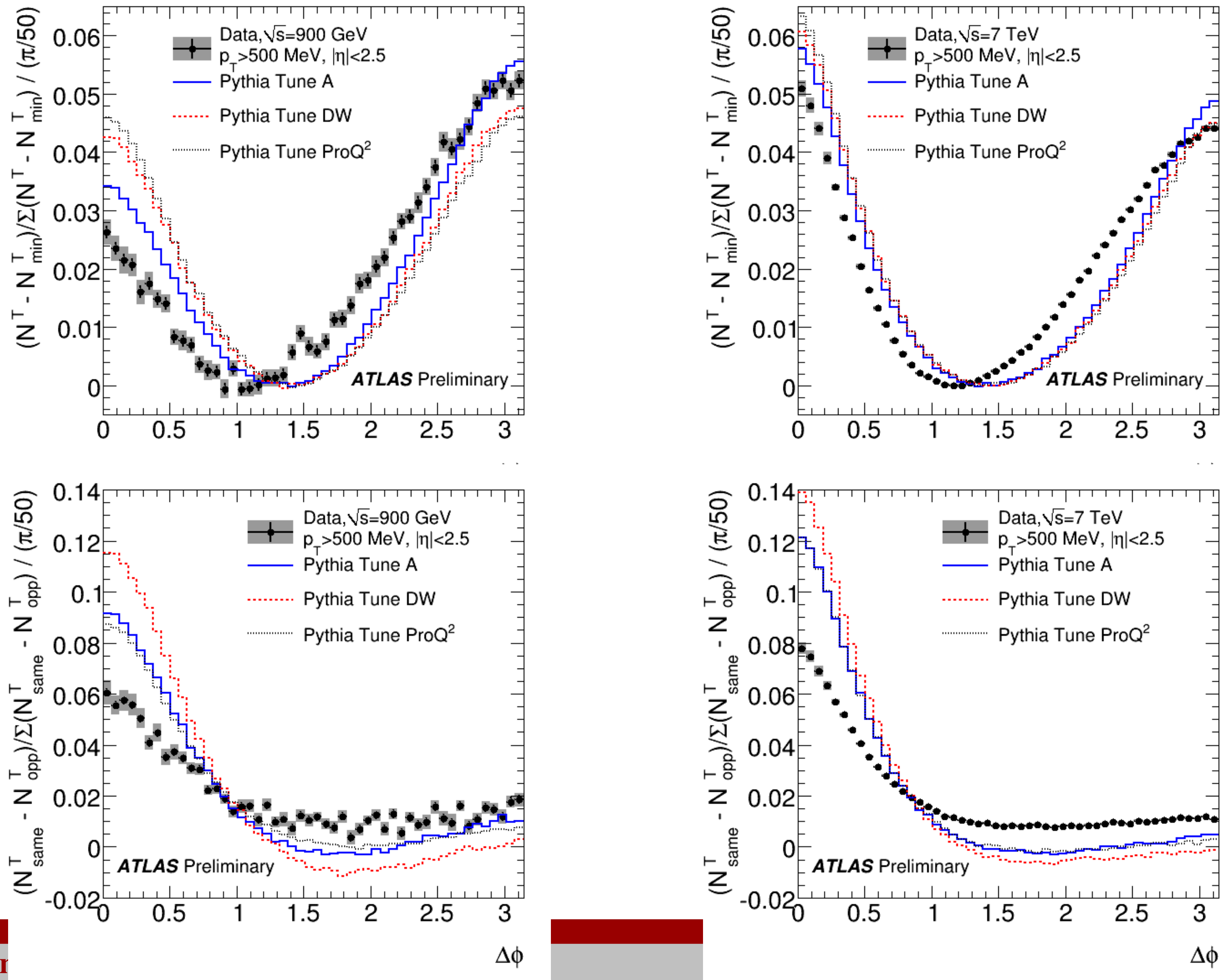
Comparison to Pythia tunes (6.1.4.21)

- Virtuality-ordered showers



Comparison to Pythia tunes (6.1.4.21)

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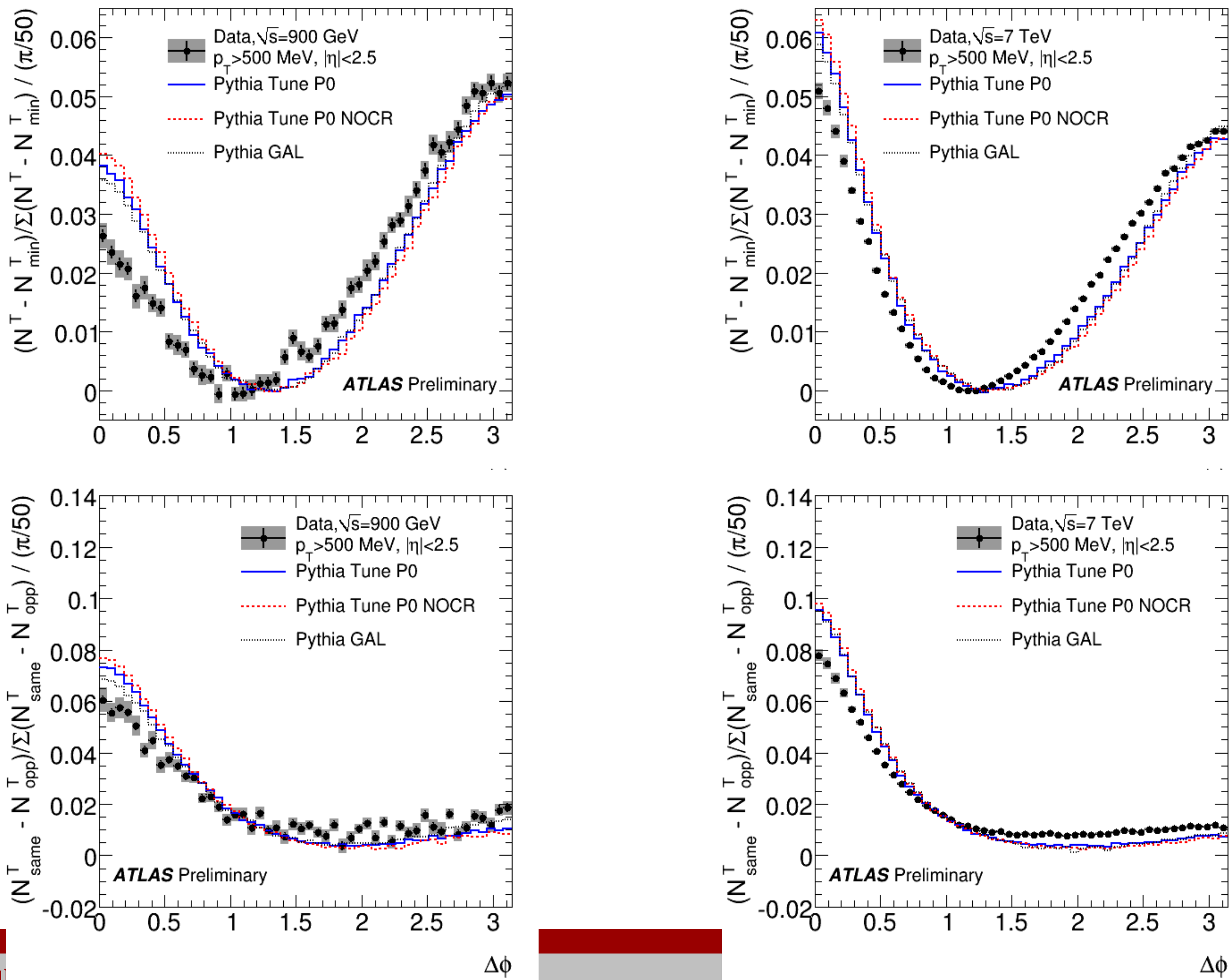
- Color reconnection models



Summary of angular correlations

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- Study soft QCD via angular correlations in minimum bias events
  - Currently poorly modeled in all tunes available in PYTHIA 6
- $\Delta\varphi$ observables are a potential input variable to future MC tuning
  - Very precise, low systematics

Summary

- ATLAS soft QCD research is in full bloom, already helping to
  - deepen our understanding of the UE and angular correlations
  - provide new, precise input to MC modeling
- New tune: ATLAS Minimum Bias Tune 1 (AMBT1)
  - Using MB results (presented here by E. Sarkisyan-Grinbaum)
  - And first UE measurements
- Expect more from ATLAS this fall
  - Particle correlations and fluctuations
  - Further improved tunes

BACKUP SLIDES

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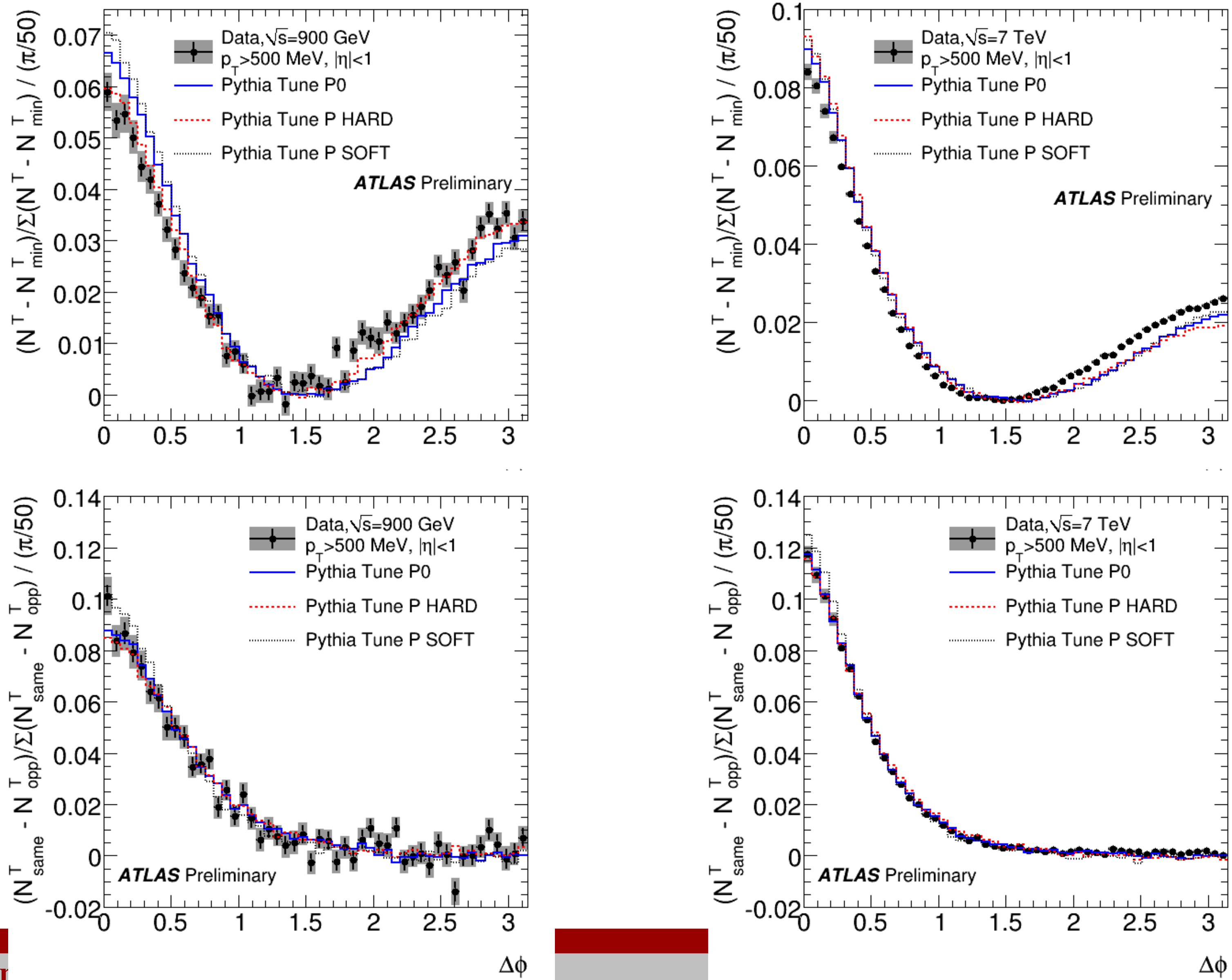
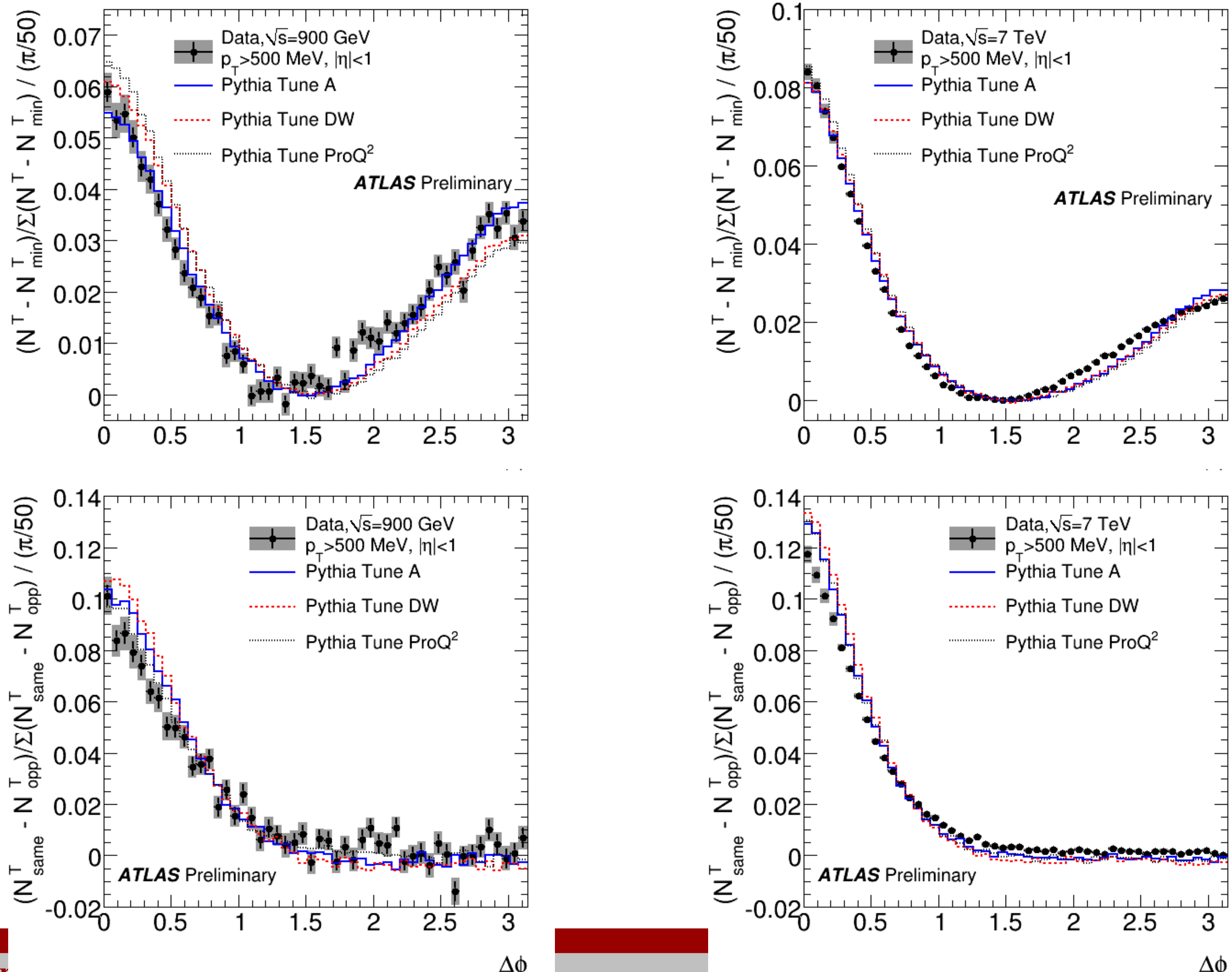
Comparison to PYTHIA tunes (6.1.4.21)

- p_T-ordered showers



Comparison to Pythia tunes (6.1.4.21)

- Virtuality-ordered showers



Comparison to PYTHIA tunes (6.1.4.21)

- Colour reconnections