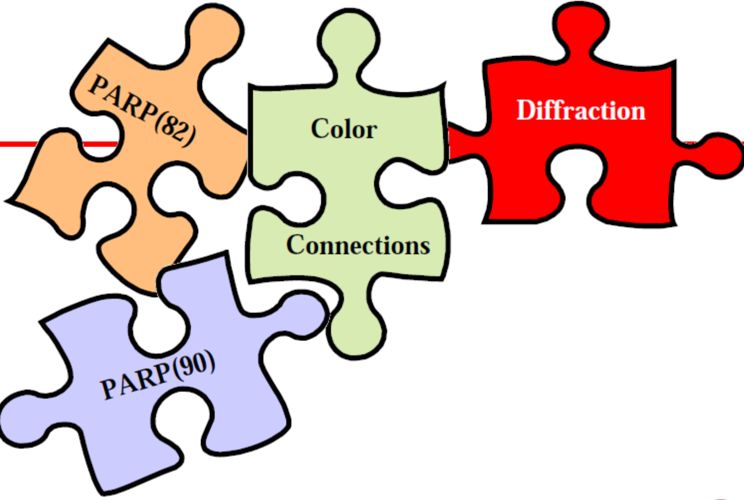
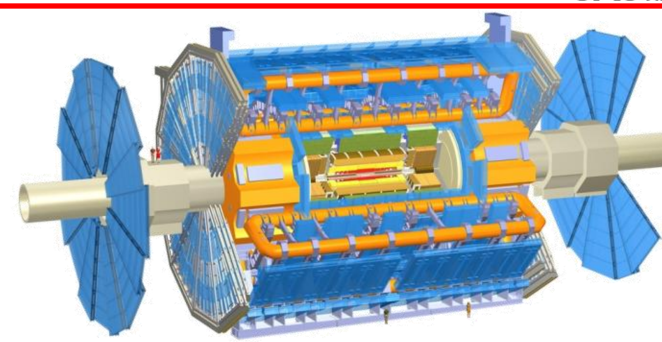
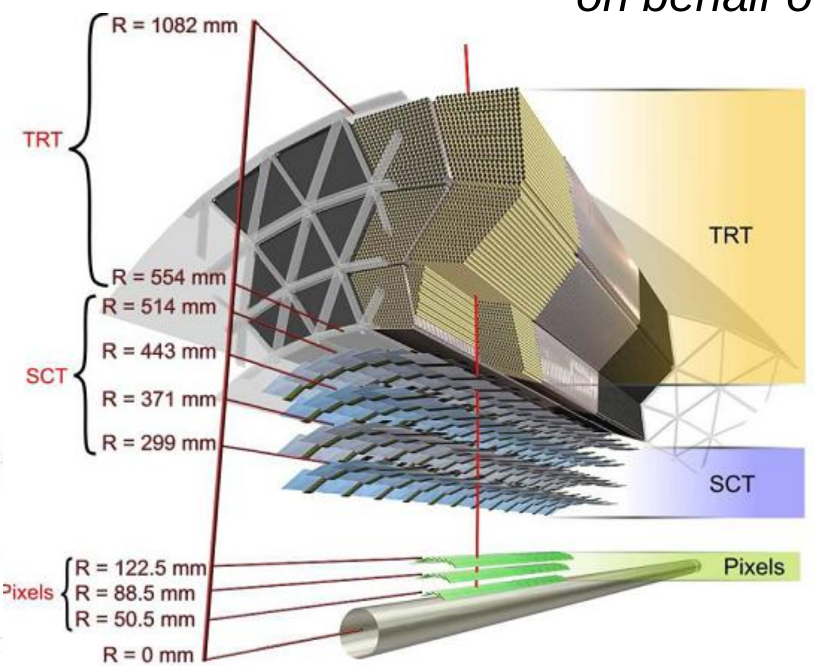




ATLAS measurements of minimum bias and soft QCD

Maaike Limper, University of Iowa

on behalf of the ATLAS experiment



In memory of Beppe Nardulli

Introduction

ATLAS minimum bias measurements made for proton-proton collisions at different center of mass energies: $\sqrt{s}$=900 GeV and $\sqrt{s}$=7 TeV

Minimum bias is a combination of non-diffractive and diffractive p-p processes:

$$\sigma_{total\text{-}inelastic} = \sigma_{sd} + \sigma_{dd} + \sigma_{nd\text{-}inelastic}$$

Predictions of charged particle multiplicity at LHC energies based on Monte Carlo models tuned on measurements from previous experiments

Diffractive cross sections and differential distributions only very roughly known

ATLAS aims is to make model independent measurement of charged particle multiplicity in a specific phase space

N_{ch}=number of primary charged particles within the kinematic range $|\eta|< 2.5$ and p_T > 500 MeV

Charged particle multiplicity studied in events with at least one primary charged particle (n_{ch}>=1) and diffractive limited phase space (n_{ch}>=6)

No removal of single diffractive component!

Luminosity for measurements presented today:

- **~8 μb^{-1} for $\sqrt{s}$=900 GeV data** (2009 data)
- **~7 μb^{-1} for $\sqrt{s}$=7 TeV data** (first 7 TeV run 30 March 2010)

Measurement strategy

Event and track selection match the kinematic range of charged particles chosen for the ATLAS measurements, $|\eta| < 2.5$ and $p_T > 500$ MeV

Require single primary vertex in event to reduce contribution from beam-background and events with multiple proton-proton interactions to neglible level

Event level requirements:

- **single-arm trigger “MBTS1”:**
  - **= at least 1 hit in the forward Minimum Bias Trigger Scintillators at $2.09 < |\eta| < 3.84$**
- primary vertex in event
- pile-up veto: reject events with a second primary vertex with 4 or more tracks
- >=1 “primary track” in event

“Primary track” selection:

- track $p_T > 500$ MeV and track $|\eta| < 2.5$
- a minimum of one Pixel and six* SCT (Semiconductor Tracker) hits on the track
- $|d0_{PV}| < 1.5$ mm and $|z0_{PV}|\sin\theta < 1.5$ mm, impact parameters with respect to primary vertex

Event-level correction uses trigger and vertex efficiency derived from data

Track-to-particle correction uses track reconstruction efficiency derived from simulation

Systematic uncertainty of tracking efficiency based on data/simulation comparison

Trigger efficiency

Minimum Bias Trigger Scintillators (MBTS)

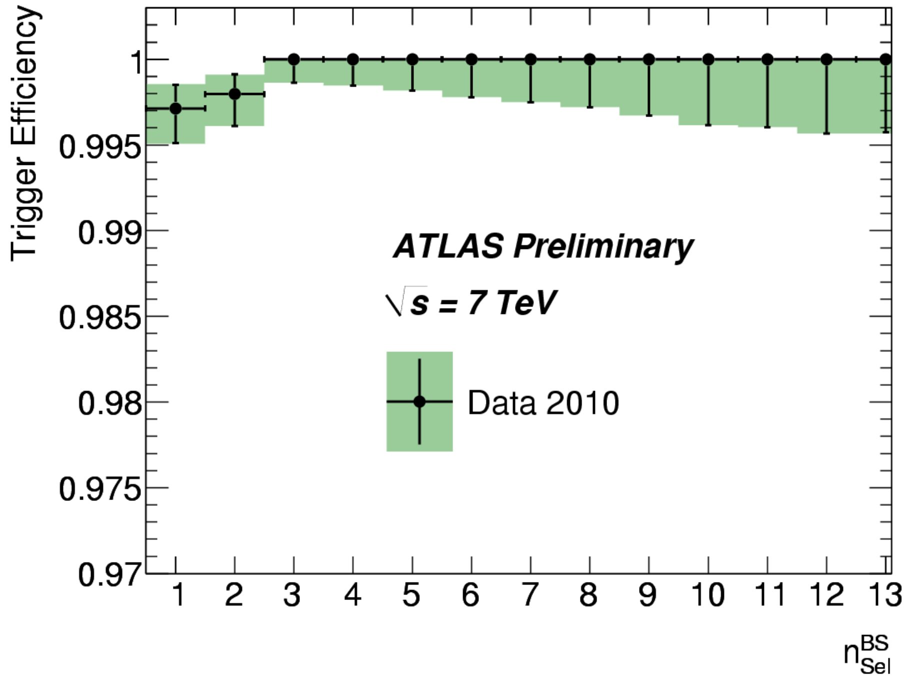
2 units in η (2.09 < η < 2.82, 2.82< η < 3.84)

z = -3560 mm, 8 units in φ

MBTS1: at least 1 hit in one of 16 MBTS

Trigger efficiency measured from data versus number of selected primary tracks (using beamspot instead of primary vertex for the d0 cut)

n^{BS}_{Sel}=number of tracks passing “good track” criteria using $|d0_{BS}| < 4$mm instead of $d0_{PV}/z0_{PV}$ cuts



Analysis trigger: L1 MBTS single-arm minimum-bias trigger

Measure trigger efficiency of L1 MBTS with respect to control trigger

Control trigger: random trigger coincident with colliding bunches with at least 4 pixel clusters and at least 4 SCT space points at L2

The single-arm trigger was measured to be almost fully efficient for chosen phasespace except for slightly lower efficiency in low multiplicity events

Vertex reconstruction efficiency

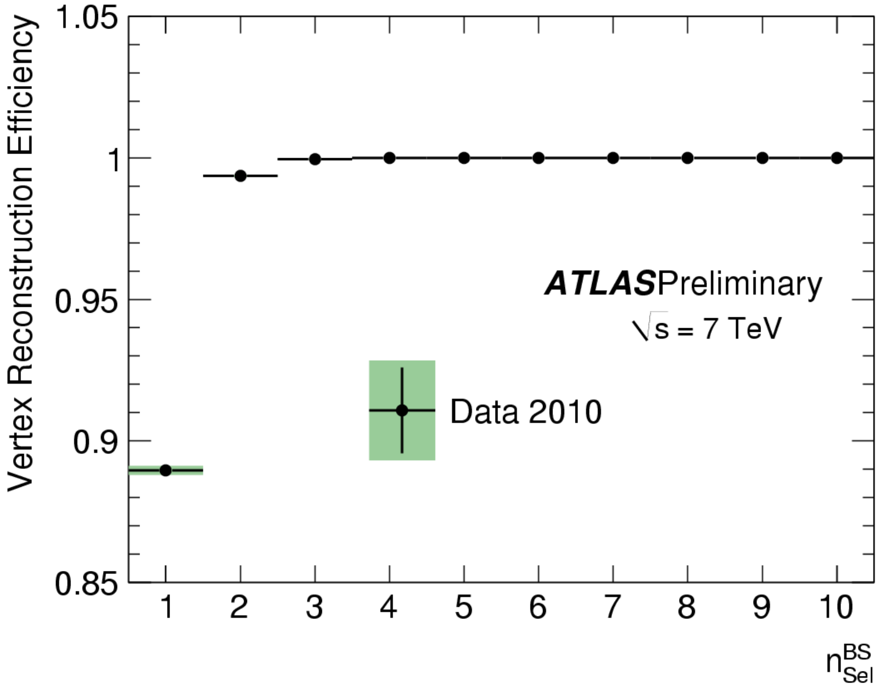
Primary vertex reconstruction uses beamspot position and at least two tracks with:

track p_T > 100 MeV

$|d0_{BS}|$< 4 mm

>=1 pixel hit and >= 4 SCT-hits

>=6 SCT+Pixel hits



Vertex reconstruction efficiency is measured in data using all MBTS1 events

For n^{BS}_{Sel}<3, vertex reconstruction efficiency is corrected in bins of η

pile-up veto: reject events with a second primary vertex with 4 or more tracks

contribution from pile-up and beam-background studied and found to be neglible

Track reconstruction

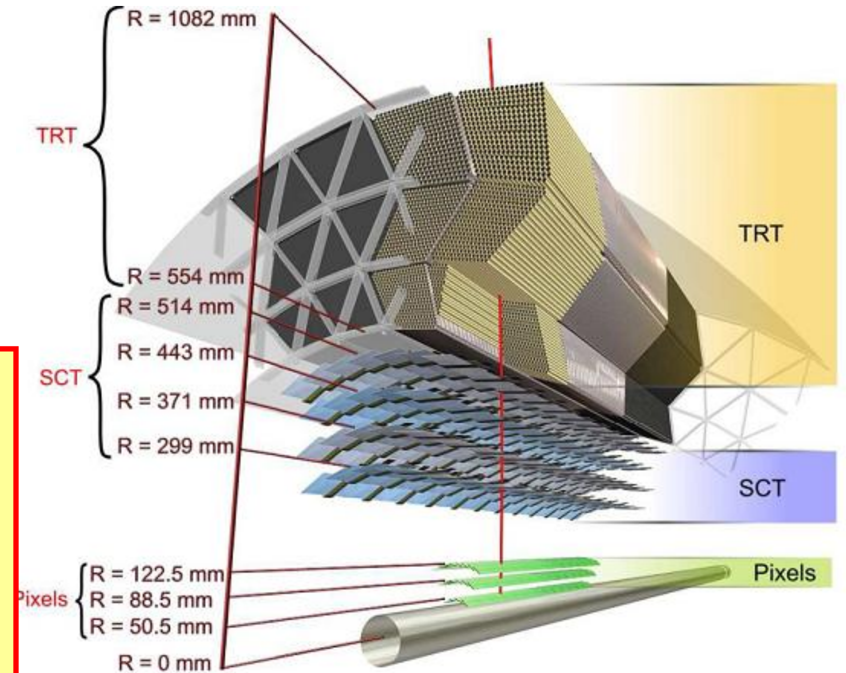
Charged particle with p_T>0.5 GeV passing through full ATLAS inner detector produces on average:

3 silicon pixel hits

8 SemiConductor Tracker (SCT) hits

(2 overlapping silicon strips per SCT module)

~30 Transition Radiation Tracker (TRT) hits



"Primary track" definition

- **track p_T > 500 MeV and track $|\eta|$< 2.5**
- **a minimum of one Pixel and six* SCT (Semiconductor Tracker) hits on the track**
- **$|d0_{PV}|$ < 1.5 mm and $|z0_{PV}|\sin\theta$ < 1.5 mm,** impact parameters with respect to primary vertex

Rate of secondaries passing primary track cuts measured from data using fit of d0 distribution

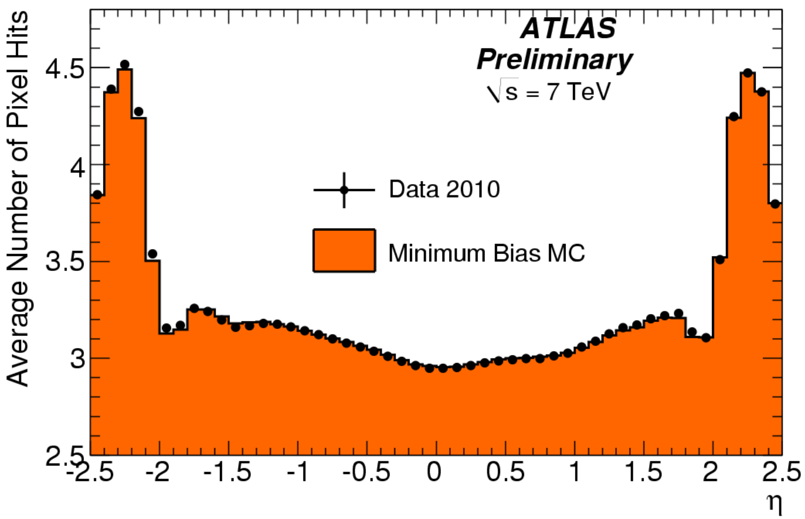
Track reconstruction efficiency determined from simulation

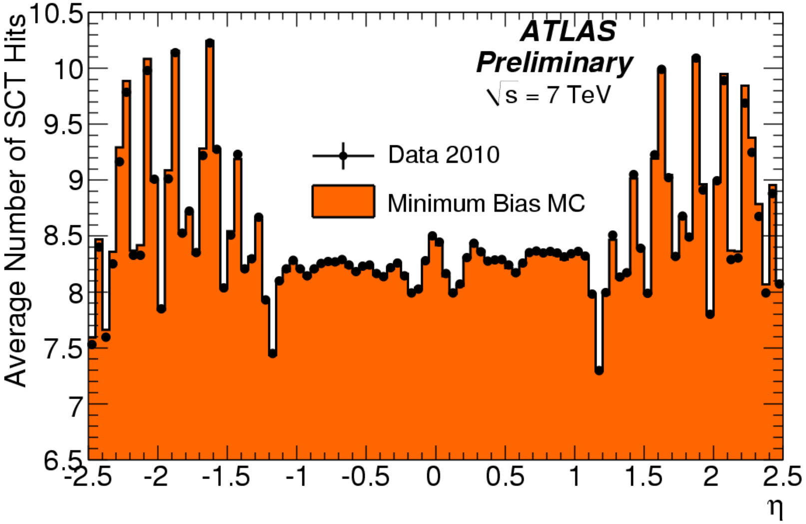
Simulation of the ATLAS silicon detectors found to describe the data to high accuracy

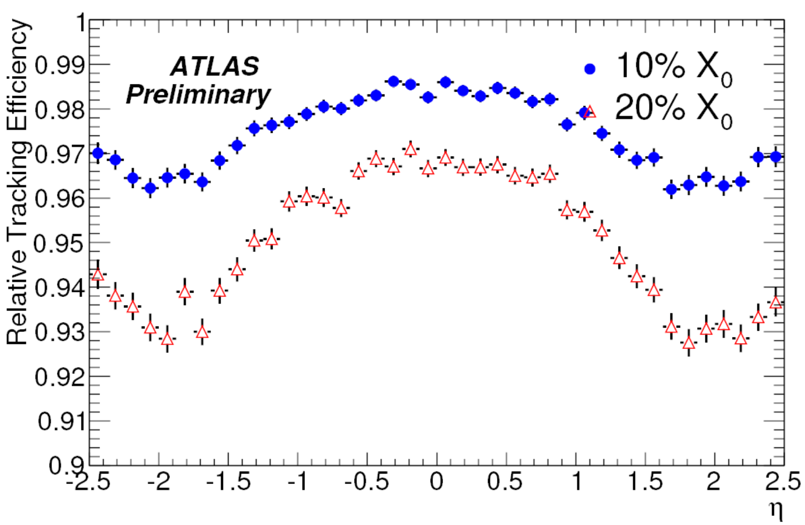
Differences between simulation and data are expressed as systematic uncertainty on tracking efficiency

Data/simulation comparison

Good agreement between data and MC for number of silcion hits on track:







Largest systematic uncertainty comes from material description in simulation
upper limit of 10% uncertainty on material gives 3% uncertainty on track reconstruction efficiency

Disagreement between data/simulation adds increased uncertainty in specific eta regions

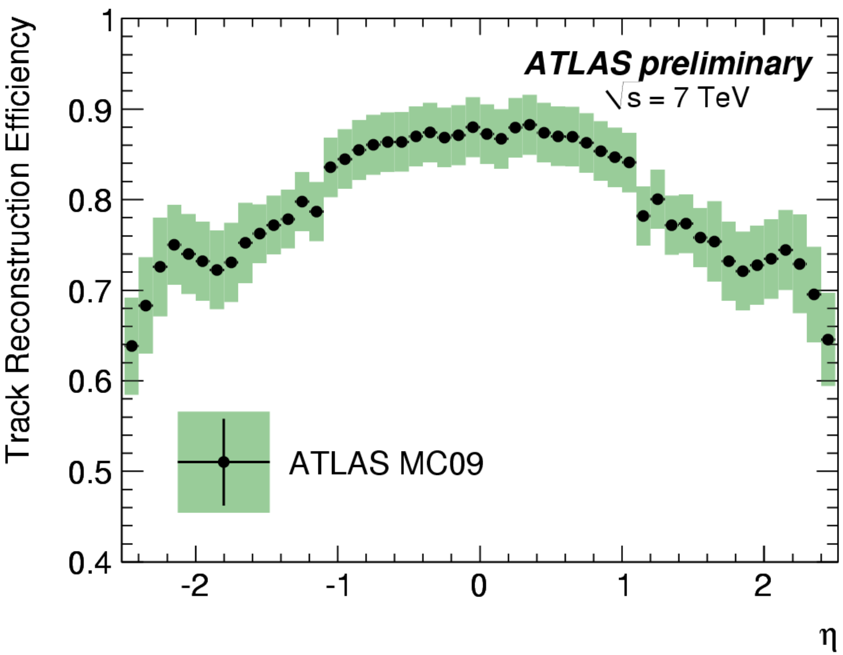
Track reconstruction efficiency

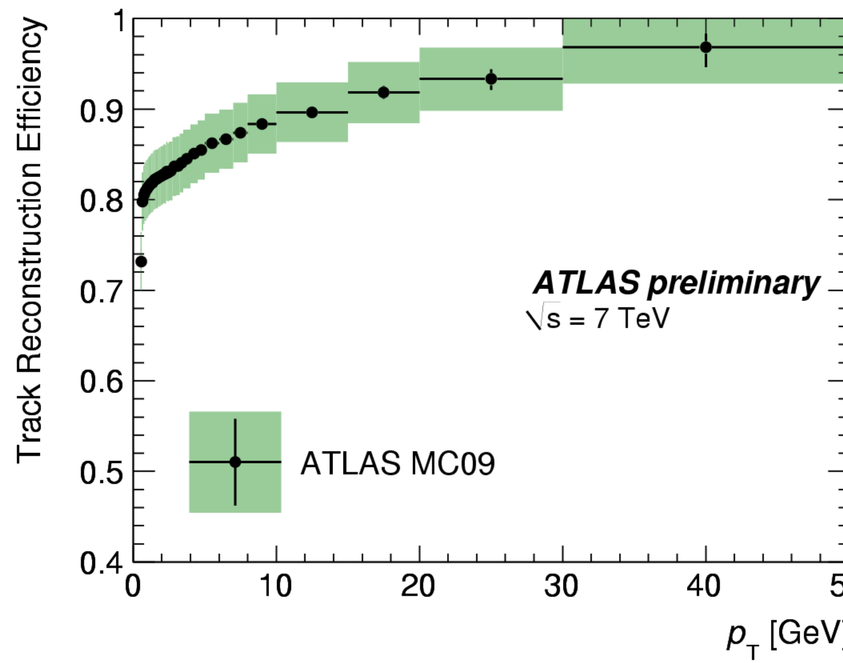
Track reconstruction efficiency is determined from MC sample using 10 million non-diffractive events at 7 TeV collisions from ATLAS MC09 tune

Efficiency based on track-truth matching between track and MC particle within a ΔR cone of 0.05

$$\epsilon_{\mathrm{bin}}(p_{\mathrm{T}},\eta) = \frac{N_{\mathrm{rec}}^{\mathrm{matched}}(p_{\mathrm{T}},\eta)}{N_{\mathrm{gen}}(p_{\mathrm{T}},\eta)}$$

The bin size varies with p_T and was determined by the statistics available in the simulation sample





Correction for track reconstruction efficiency is made using 2D efficiency vs p_T and eta to remove model dependence from p_T and eta distributions

Correction procedure

Events lost due to trigger and vertex requirements are corrected using a weight per event:

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

where $\varepsilon_{\mathrm{trig}}(n_{\mathrm{Sel}}^{\mathrm{BS}})$ and $\varepsilon_{\mathrm{vtx}}(n_{\mathrm{Sel}}^{\mathrm{BS}})$ are the trigger and vertex reconstruction efficiencies.

The p_T and η distributions of selected tracks are corrected by using a weight for each track:

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

where ε_{bin} is the track reconstruction efficiency, $f_{\mathrm{sec}}(p_{\mathrm{T}})$ is the fraction of secondaries and $f_{\mathrm{okr}}(p_{\mathrm{T}}, \eta)$ is the fraction of the selected tracks produced by particles outside the kinematic range

The n_{ch} distribution from the data is obtained by using a matrix $M_{Nch,Nsel}$, that relates the number of selected tracks n_{sel} to the number of charged particles n_{ch}

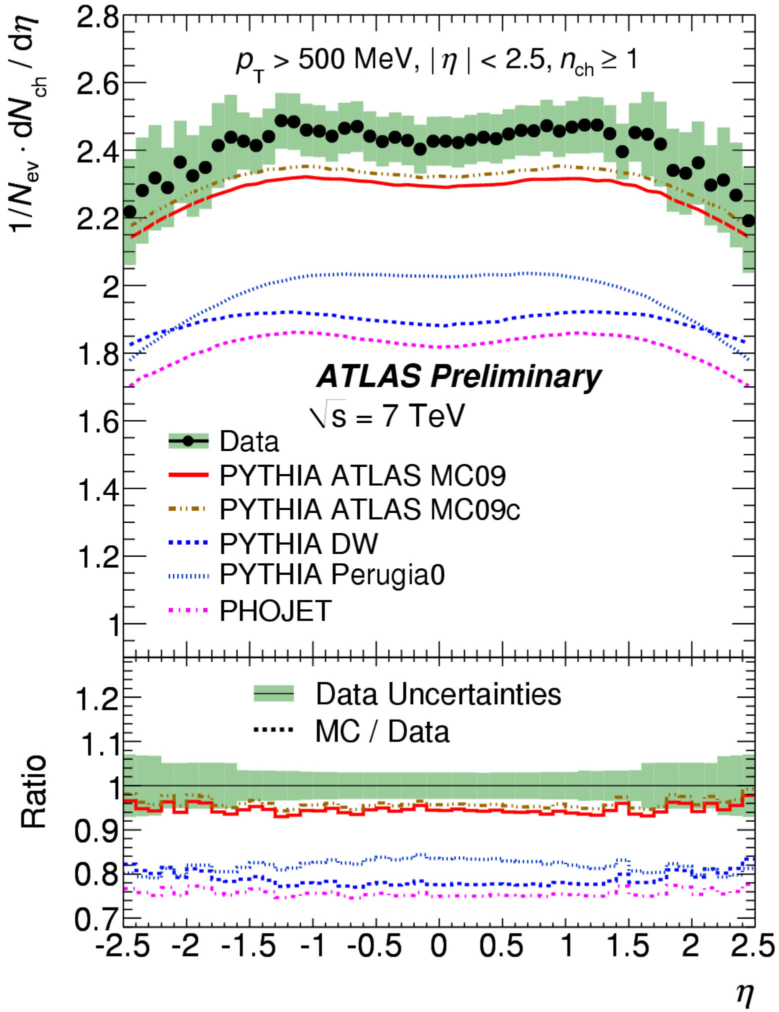
$M_{Nch,Nsel}$ is populated from MC but the resulting distribution is n_{ch} used to re-populate the matrix and the correction is re-applied to remove model dependence. This procedure is repeated till it converges after four iterations

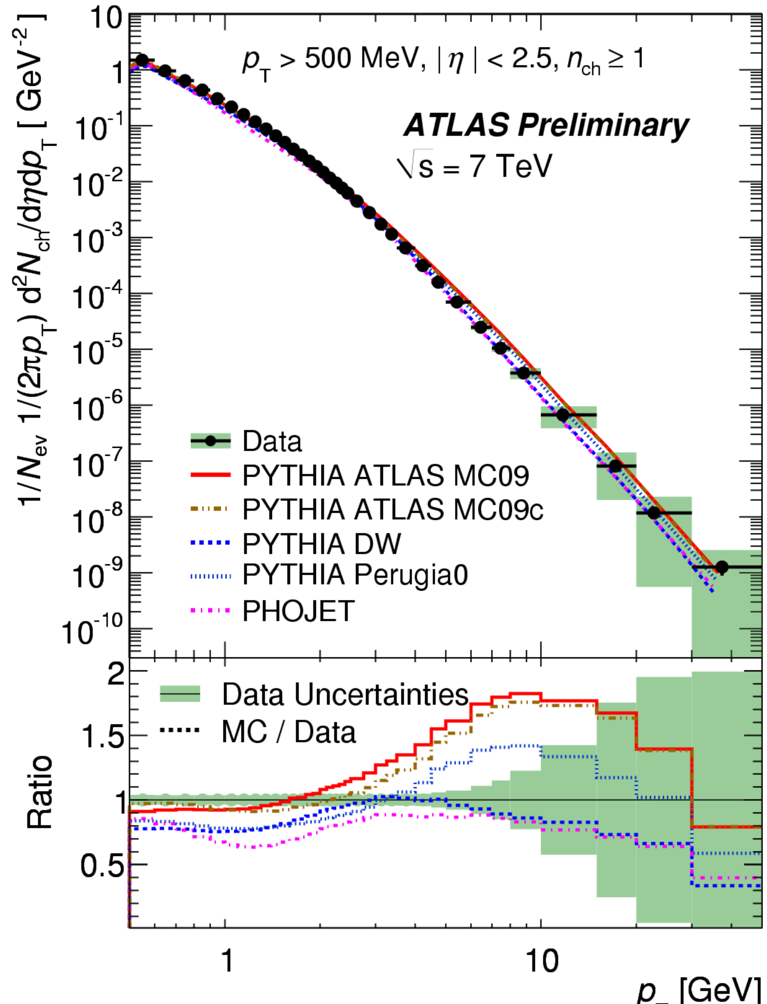
Minimum bias distributions for n_{ch}>=1

Measured charged particle multiplicity $1/N_{ev} \cdot dN_{ch}/d\eta$ best described by the ATLAS MC09c

- predicts same shape for η distribution but is about 5% lower
- predicts a significantly harder spectrum at p_T>4 GeV

$1/N_{ev} \cdot dN_{ch}/d\eta$ at η=0 is 2.418±0.004(stat)±0.076(syst)

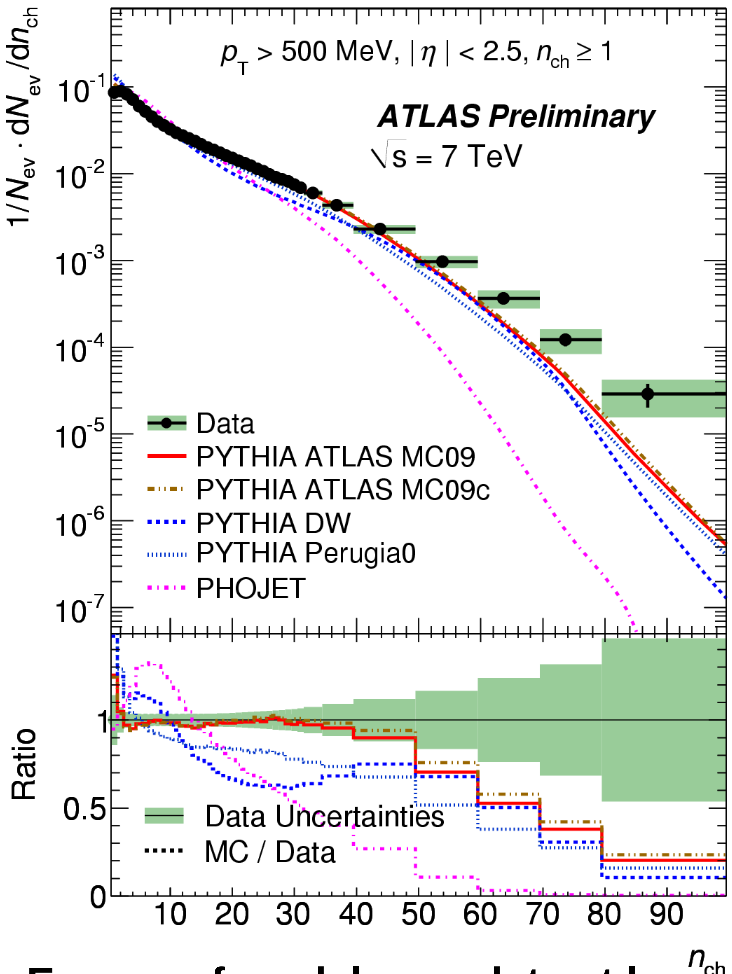




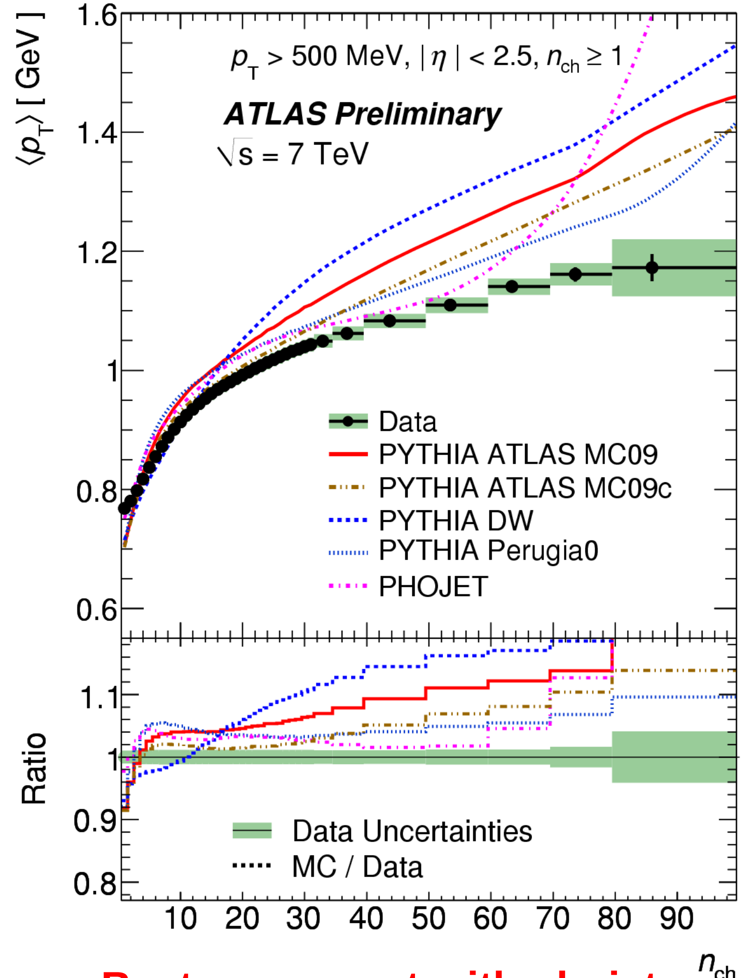
Minimum bias distributions for n_{ch}>=1

THE UNIVERSITY OF IOWA

Charged particle multiplicity versus number of charged particles n_{ch}

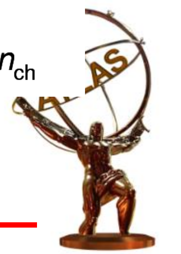


Average transverse momentum $<p_T>$ versus number of charged particles n_{ch}



Excess of model over data at lower n_{ch}
Highly influenced by the modelling of diffractive events

Best agreement with phojet
At n_{ch}>60 phojet show a rise not seen in the data



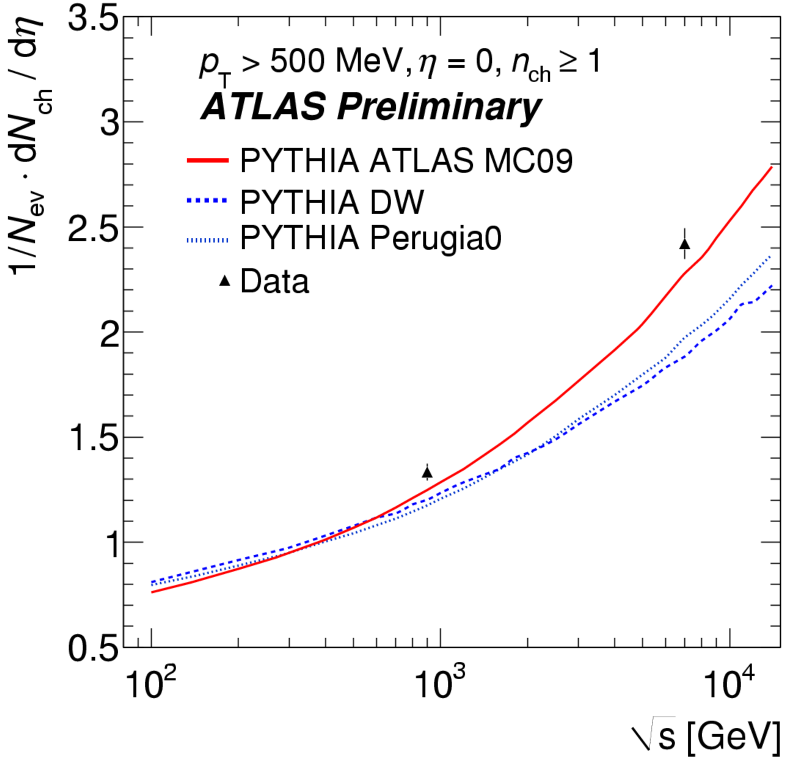
Minimum bias results as function of √s

Charged particle multiplicity studied in events with at least one primary charged particle (n_{ch}>=1) produced within the kinematic range |η|< 2.5 and p_T > 500 MeV

Measurement results for $1/N_{ev} \cdot dN_{ch}/d\eta$ at η=0

√s=900 GeV: 1.333±0.003(stat)±0.040(syst)

√s=7 TeV: 2.418±0.004(stat)±0.076(syst)



Energy dependence of the multiplicity is described within 5% by ATLAS MC09 tune (pythia6)

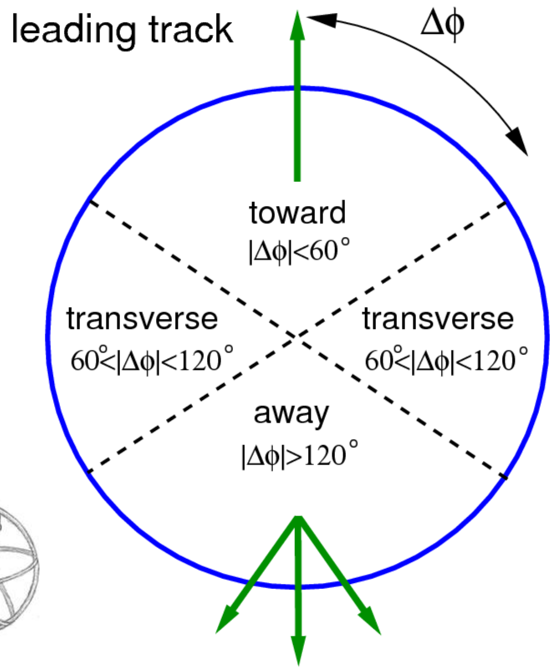
Track based underlying event studies

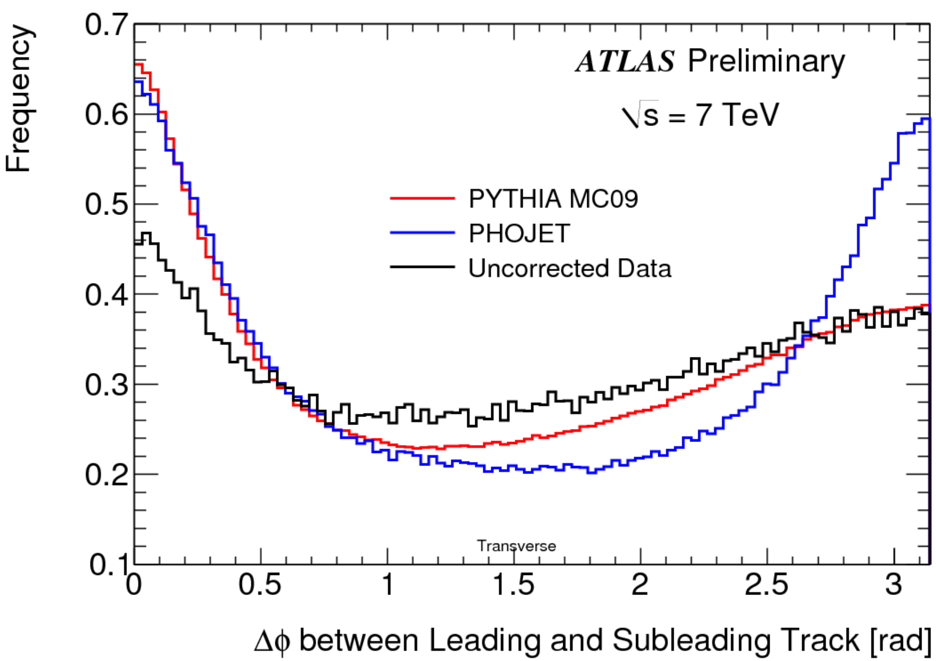
"Underlying Event": everything else besides the hard scattering process

At low energies it is sufficient to **use the highest p_T track (=leading track), rather than the highest E_T leading jet** (the leading track is usually found in the leading jet)

The ϕ region transverse to the leading tracks is assumed to be principally filled by the Underlying Event

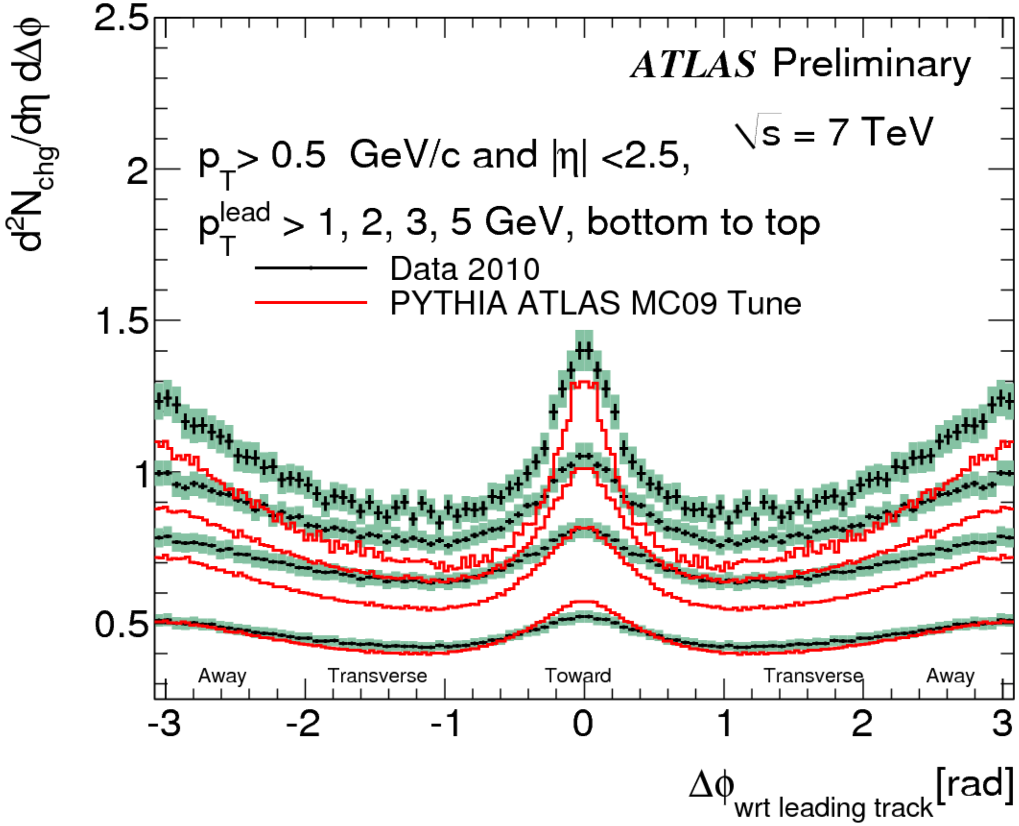
Corrections for vertex, trigger and tracking efficiency same as for minimum bias studies





Angular distributions vs p_T^{lead}

Charged particle number density for tracks other than the leading track
(plots are reflected, so the same data points appear twice)

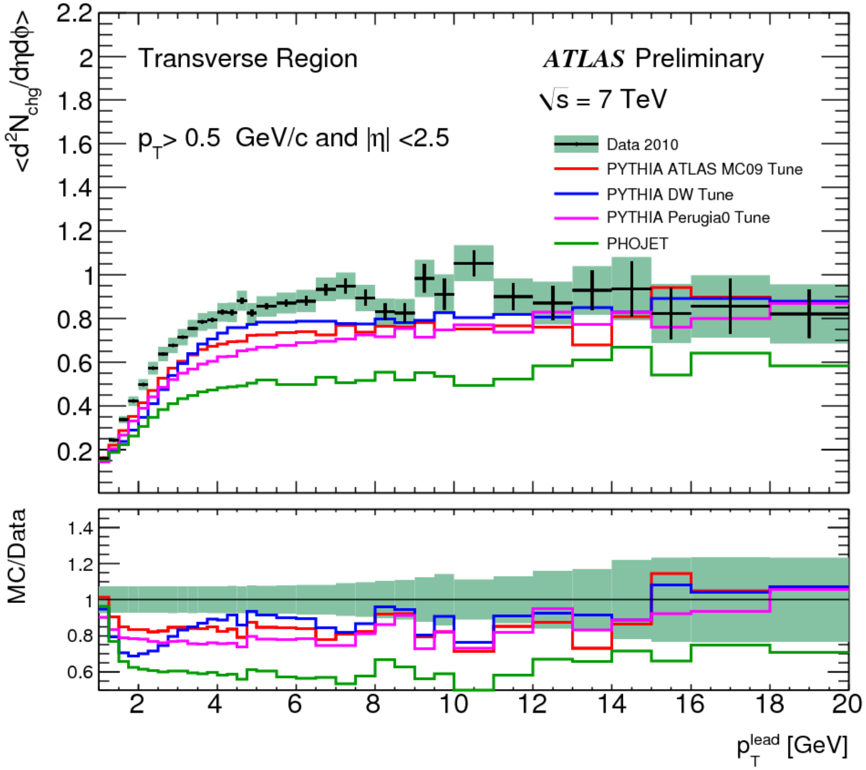


As the p_T of the leading track increases, the development of ‘jet-like’ region of higher density is observed adjacent to and opposite the leading track

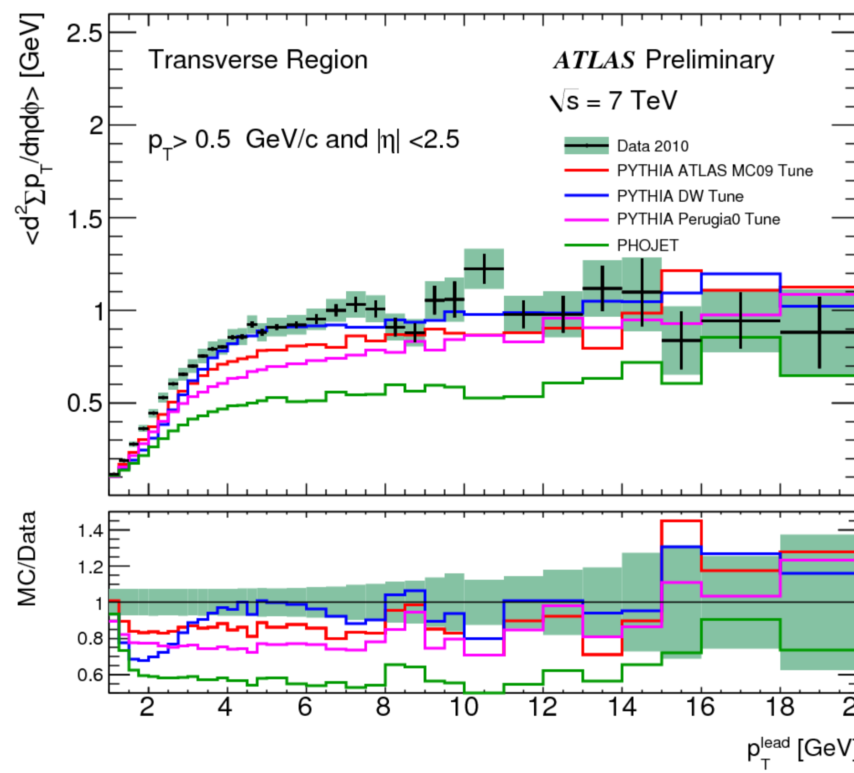
The number density is both higher and has a different angular distribution than was predicted

Charged particle number and p_T density

Charged particle number density vs p_T^{lead} in the transverse region



Charged particle p_T sum density vs p_T^{lead} in the transverse region

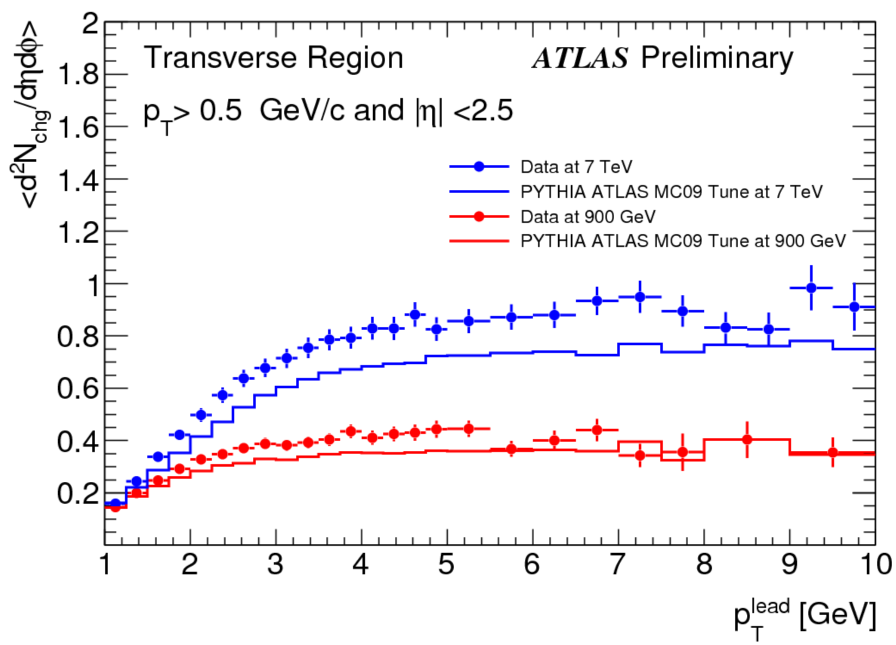


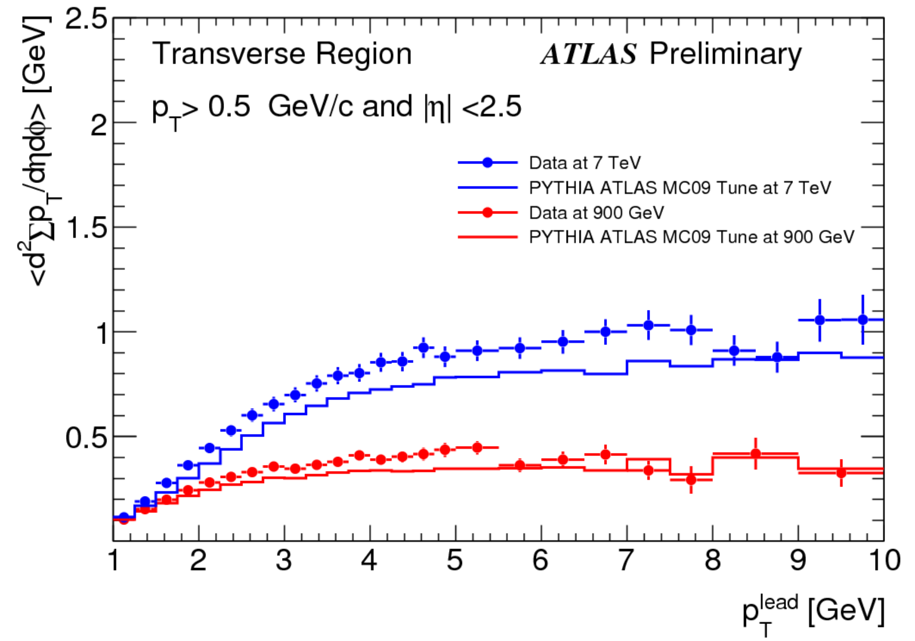
The number density is higher than predicted by any of the MC tunes

The higher number density implies a higher p_T density as well

The profiles characterize the contribution of UE to jets from the hard scatter

Underlying event results as function of √s





Underlying event activity increases by approximately a factor of two going from 900 GeV to 7 TeV data, roughly consistent with the increase predicted by MC

Charged particle density in the underlying in the plateau region is about a factor of two larger as seen in minimum measurements

consistent with high p_T track selection effect: more momentum exchange and lack of diffractive contributions in events with p_T^{lead} in plateau region

Monte Carlo tuning

Pythia6 tune ATLAS MC09 gives reasonable description of ATLAS measurements, except:

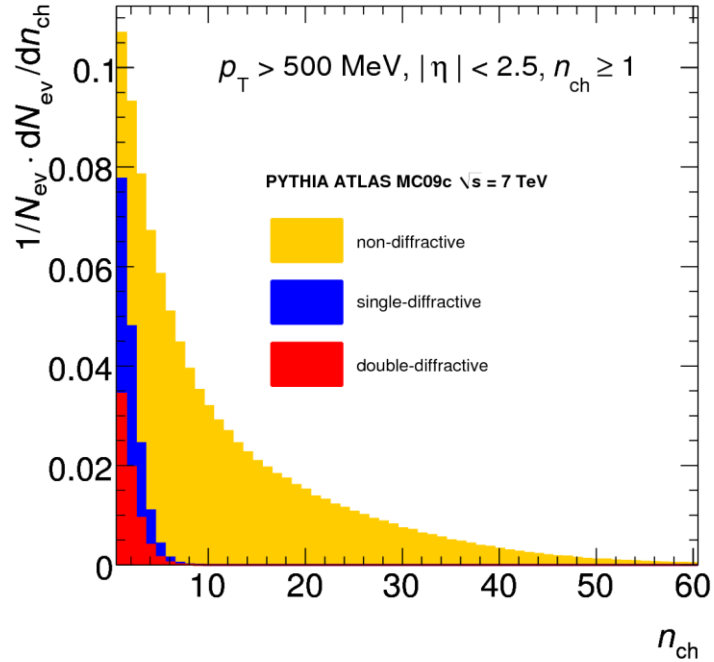
charged particle multiplicity is lower than predicted

the mean track p_T at high charged multiplicity is lower than predicted

Use ATLAS measurements to improve tuning of non-diffractive Monte Carlo (MC) models

ATLAS minimum bias measurement contain a significant fraction of diffractive events
(~16% according to pythia6 predictions)

Tune to MB measurements using a diffractive limited phase space: N_{ch}>=6 as all models predict diffractive events mostly at low nch



The ATLAS Minium Bias Tune 1

ATLAS MBT1: Adaption of ATLAS MC09c tune to the new LHC data

Tune 6 model parameters for multiple particle interaction (MPI) and color reconnection (CR)

Parameter	Related model	MC09c value	scanning range	AMBT1 value
PARP(62)	ISR cut-off	1.0	fixed	1.025
PARP(93)	Primordial kt	5.0	fixed	10.0
PARP(77)	CR suppression	0.0	0.25 – – – 1.15	1.016
PARP(78)	CR strength	0.224	0.2 – – – 0.6	0.538
PARP(83)	MPI (matter fraction in core)	0.8	fixed	0.356
PARP(84)	MPI (core of matter overlap)	0.7	0.0 – – – 1.0	0.651
PARP(82)	MPI (p_T^{min})	2.31	2.1 – – – 2.5	2.292
PARP(90)	MPI (energy extrapolation)	0.2487	0.18 – – – 0.28	0.250

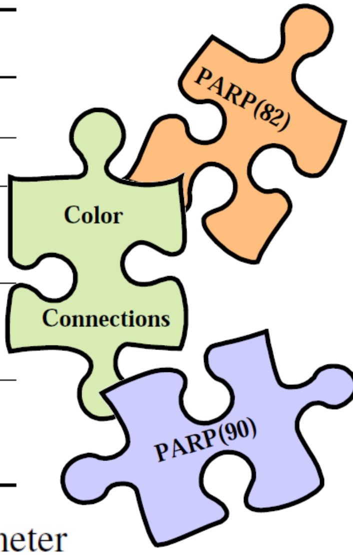


Table 5: Comparison of MC09c and resulting optimised parameters (AMBT1). The range for parameter variations in AMBT1 are also given.

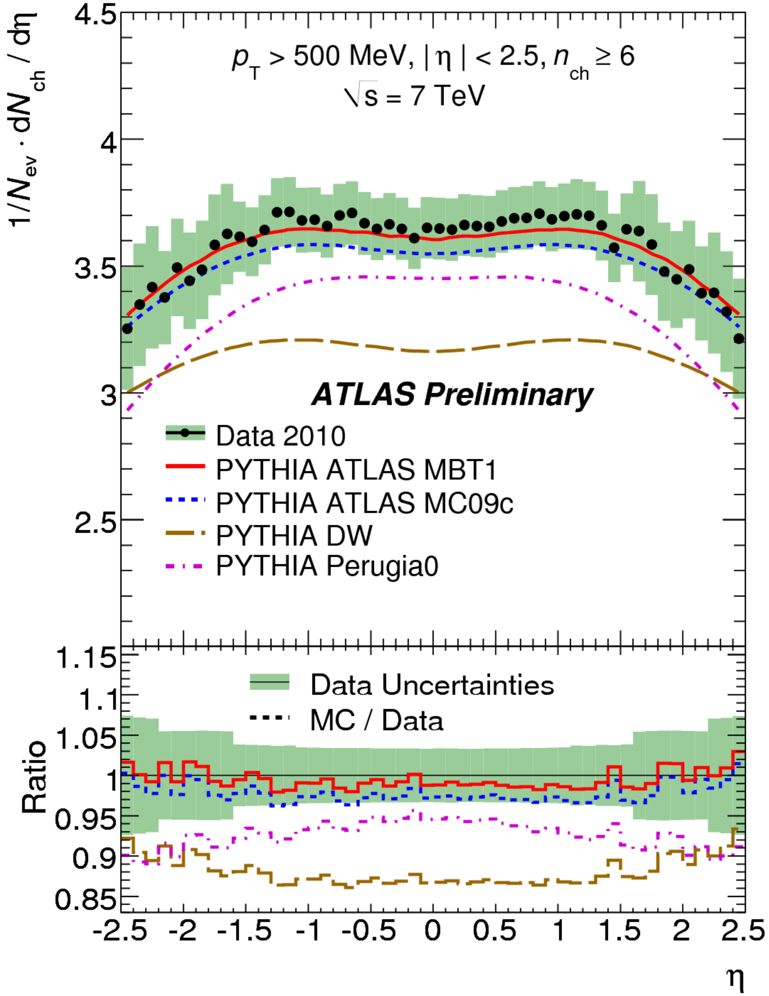
Inclusion of new parameter (parp77) for suppression of color reconnection in fast moving strings to describe <pt> vs nch

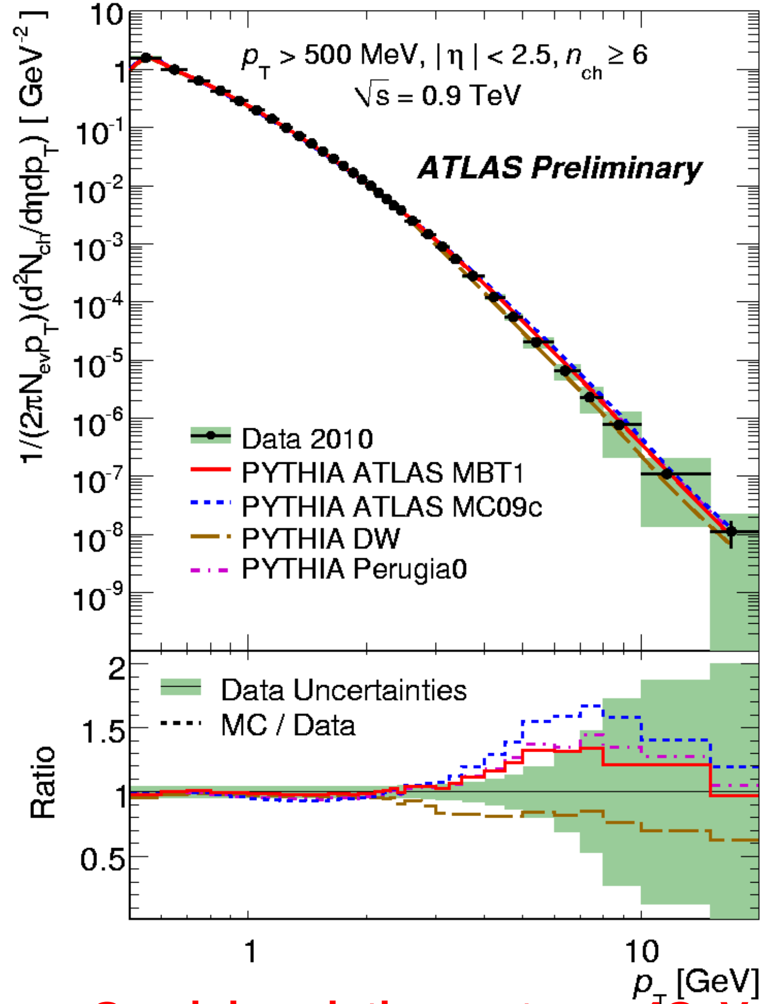
Force tuning of interesting regions using weights and regions of the data distribution

Tune performed with the *Professor Tuning Tool* (more information in back-up)

CDF data included in tuning to remain consistent with previous measurements

ATLAS MBT1 result MB n_{ch}>=6



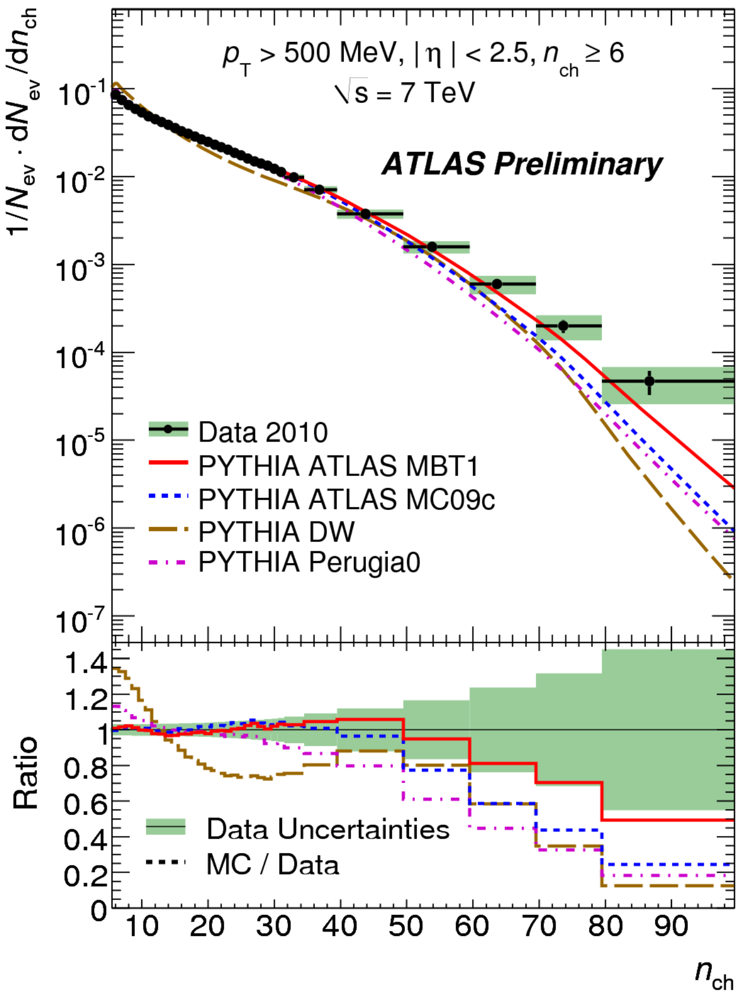


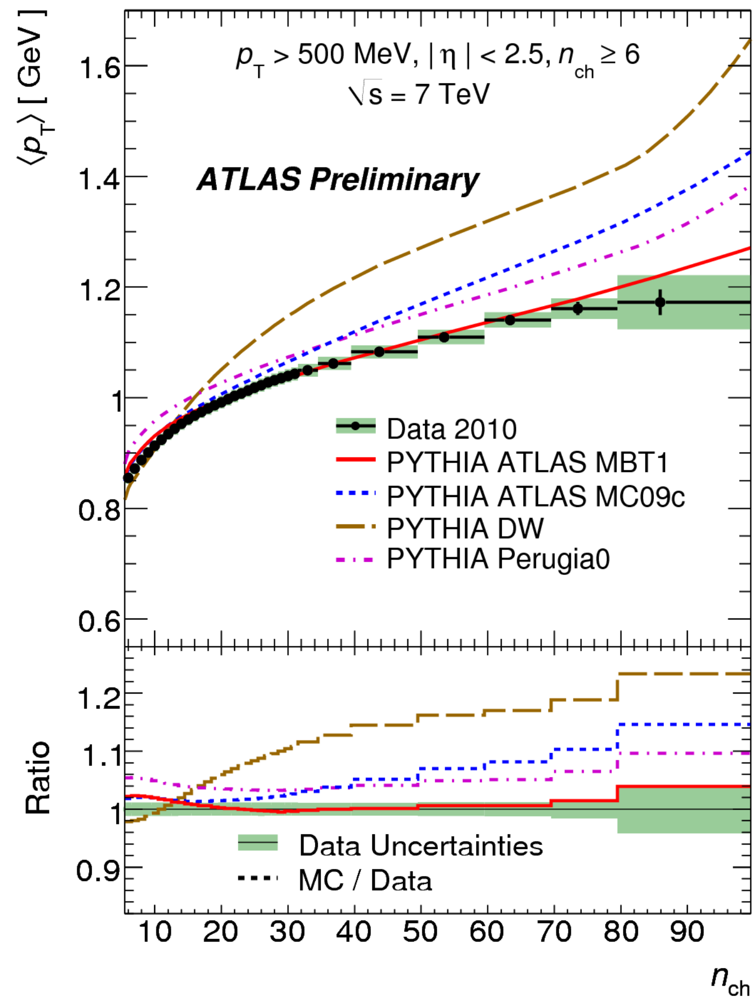
Improved already good agreement with respect to ATLAS MC09

Good description up to p_T~4GeV

Deviations at high pt reduced with respect to ATLAS MC09 tune

ATLAS MBT1 result MB n_{ch}>=6





Improved description with respect to MC09 to within errors

ATLAS MBT1 tune describes data within 2%, large improvement with respect to ATLAS MC09

Conclusions

Presented first ATLAS measurements of minimum bias and underlying event in p-p collisions at √s=900 GeV and √s=7 TeV

First data at √s= 7 TeV means predictions, without foreknowledge, tested with NEW data

ATLAS chose a specific phase space, without substracting single diffractive component, to make a model-indepent measurement

Charged primary particles in kinematic range $|\eta|< 2.5$ and $p_T > 500$ MeV

Charged particle multiplicity studied in events with at least one primary charged particle (n_{ch}>=1) and diffractive limited phase space (n_{ch}>=6)

Atlas Minimum Bias Tune 1: first Monte Carlo tune to ATLAS measurements

- Improved the MC/data agreement with respect to ATLAS MC09 tune
- Remaining differences in p_T spectrum of charged particles above 4 GeV
- Underlying event region in high p_T region well described - however large statistical uncertainties of the data limit precise model comparisons

Other ATLAS measurements soon to come in paper near you:

minimum bias measurements at √s= 2.36 TeV

minimum bias measurements with lowered p_T cut: p_T>100 MeV

increased luminosity of 7 TeV data sample from 7 → ~168 μb^{-1}

References

ATLAS minimum bias measurements at √s=900 GeV √s=7 TeV

Phys Lett B 688, Issue 1, 21-42

http://arxiv.org/PS_cache/arxiv/pdf/1003/1003.3124v2.pdf

ATLAS-CONF-2010-024 (ATLAS public conference note)

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2010-024/ATLAS-CONF-2010-024.pdf

***Track-based underlying event measurements* at √s=900 GeV and at √s=7TeV**

ATLAS-CONF-2010-029 (ATLAS public conference note)

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2010-029/ATLAS-CONF-2010-029.pdf

***New pythia6 tune using ATLAS measurements at* √s=900 GeV and at √s=7TeV in a diffraction limited phase space**

ATLAS-CONF-2010-029 (ATLAS public conference note)

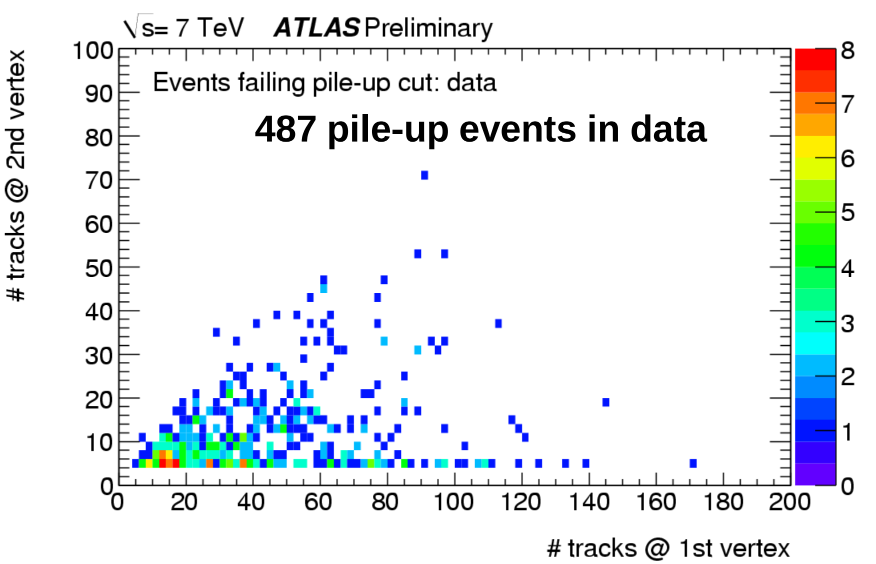
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2010-029/ATLAS-CONF-2010-029.pdf

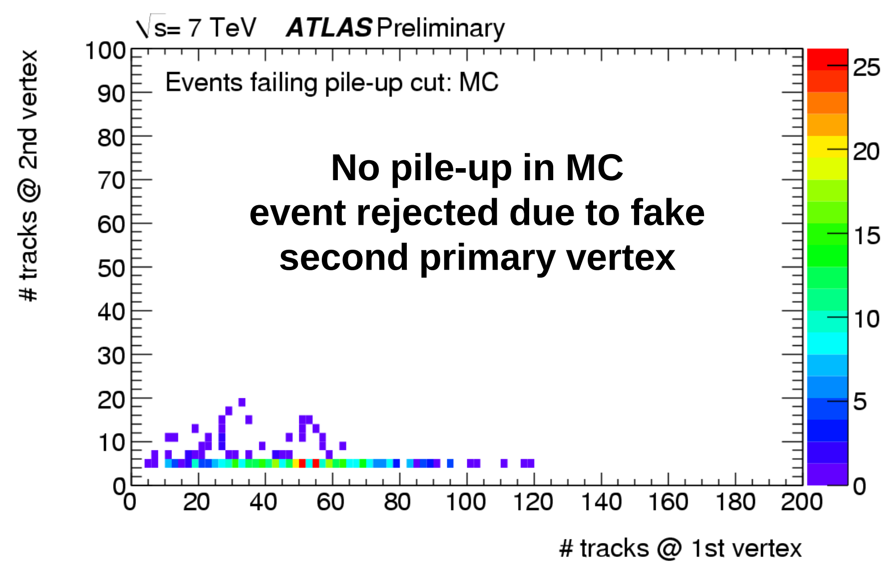
Backup

Pile-up veto

Take into account possibility of multiple proton-proton interactions inside same bunch crossing by allowing reconstruction of multiple primary vertices

pile-up veto: reject events with a second primary vertex with 4 or more tracks





Expected fraction of pile-up events is 10^{-3} at LHC conditions for this data

487 events were removed by pile-up veto, corresponding to 0.1% of our data

Fraction of removed events that are not true pile-up is estimated to be 0.03%.

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Tuning with Professor Tool

1. Build fast analytic model of the generator:

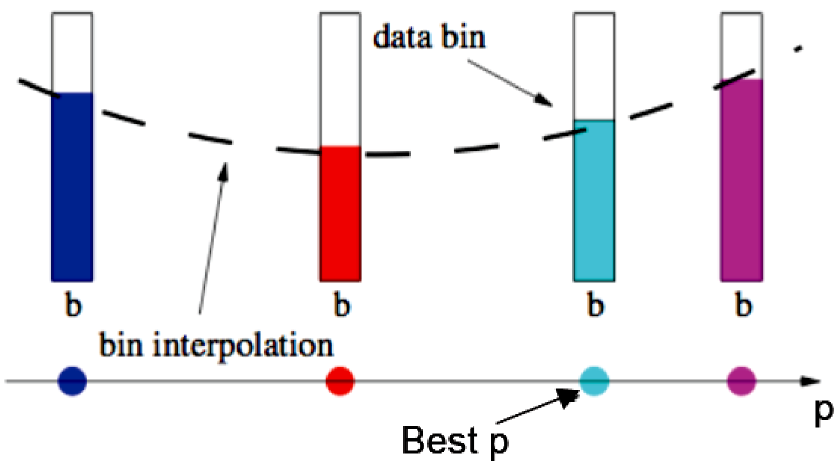
- ❖Random sampling: N parameters points in n-dimensional space
- ❖Run generator and fill histograms (Rivet)
- ❖For (each) bin: use Ñ points to fit interpolation (2nd or 3rd order polynomial)

2. **Construct overall** $\chi^2 = \sum_{bins} \frac{(interpolation - data)^2}{error^2}$

3. **Numerically minimize using pyMinuit, SciPy**

Generate at 152 random points for 5 parameter scan to oversample
Use oversampling to check stability and sensitivity of parameters

Use weights and regions of the data distributions to force the tuning of the interesting regions



ATLAS data used in AMBT1 tune

Analysis	Observable	Tuning range
ATLAS 0.9 TeV, minimum bias, $n_{\text{ch}} \geq 6$	$\frac{1}{N_{\text{ev}}} \cdot \frac{\mathrm{d}N_{\text{ch}}}{\mathrm{d}\eta}$	-2.5 – 2.5
ATLAS 0.9 TeV, minimum bias, $n_{\text{ch}} \geq 6$	$\frac{1}{N_{\text{ev}}} \cdot \frac{1}{2\pi p_{\text{T}}} \cdot \frac{\mathrm{d}^2 N_{\text{ch}}}{\mathrm{d}\eta \mathrm{d}p_{\text{T}}}$	≥ 5.0
ATLAS 0.9 TeV, minimum bias, $n_{\text{ch}} \geq 6$	$\frac{1}{N_{\text{ev}}} \cdot \frac{\mathrm{d}N_{\text{ev}}}{\mathrm{d}n_{\text{ch}}}$	≥ 20
ATLAS 0.9 TeV, minimum bias, $n_{\text{ch}} \geq 6$	$\langle p_{\text{T}} \rangle$ vs. n_{ch}	≥ 10
ATLAS 0.9 TeV, UE in minimum bias	$\langle \frac{\mathrm{d}^2 N_{\text{chg}}}{\mathrm{d}\eta \mathrm{d}\phi} \rangle$ (towards)	≥ 5.5 GeV
ATLAS 0.9 TeV, UE in minimum bias	$\langle \frac{\mathrm{d}^2 N_{\text{chg}}}{\mathrm{d}\eta \mathrm{d}\phi} \rangle$ (transverse)	≥ 5.5 GeV
ATLAS 0.9 TeV, UE in minimum bias	$\langle \frac{\mathrm{d}^2 N_{\text{chg}}}{\mathrm{d}\eta \mathrm{d}\phi} \rangle$ (away)	≥ 5.5 GeV
ATLAS 0.9 TeV, UE in minimum bias	$\langle \frac{\mathrm{d}^2 \sum p_{\text{T}}}{\mathrm{d}\eta \mathrm{d}\phi} \rangle$ (towards)	≥ 5.5 GeV
ATLAS 0.9 TeV, UE in minimum bias	$\langle \frac{\mathrm{d}^2 \sum p_{\text{T}}}{\mathrm{d}\eta \mathrm{d}\phi} \rangle$ (transverse)	≥ 5.5 GeV
ATLAS 0.9 TeV, UE in minimum bias	$\langle \frac{\mathrm{d}^2 \sum p_{\text{T}}}{\mathrm{d}\eta \mathrm{d}\phi} \rangle$ (away)	≥ 5.5 GeV
ATLAS 7 TeV, minimum bias, $n_{\text{ch}} \geq 6$	$\frac{1}{N_{\text{ev}}} \cdot \frac{\mathrm{d}N_{\text{ch}}}{\mathrm{d}\eta}$	-2.5 – 2.5
ATLAS 7 TeV, minimum bias, $n_{\text{ch}} \geq 6$	$\frac{1}{N_{\text{ev}}} \cdot \frac{1}{2\pi p_{\text{T}}} \cdot \frac{\mathrm{d}^2 N_{\text{ch}}}{\mathrm{d}\eta \mathrm{d}p_{\text{T}}}$	≥ 5.0
ATLAS 7 TeV, minimum bias, $n_{\text{ch}} \geq 6$	$\frac{1}{N_{\text{ev}}} \cdot \frac{\mathrm{d}N_{\text{ev}}}{\mathrm{d}n_{\text{ch}}}$	≥ 40
ATLAS 7 TeV, minimum bias, $n_{\text{ch}} \geq 6$	$\langle p_{\text{T}} \rangle$ vs. n_{ch}	≥ 10
ATLAS 7 TeV, UE in minimum bias	$\langle \frac{\mathrm{d}^2 N_{\text{chg}}}{\mathrm{d}\eta \mathrm{d}\phi} \rangle$ (towards)	≥ 10 GeV
ATLAS 7 TeV, UE in minimum bias	$\langle \frac{\mathrm{d}^2 N_{\text{chg}}}{\mathrm{d}\eta \mathrm{d}\phi} \rangle$ (transverse)	≥ 10 GeV
ATLAS 7 TeV, UE in minimum bias	$\langle \frac{\mathrm{d}^2 N_{\text{chg}}}{\mathrm{d}\eta \mathrm{d}\phi} \rangle$ (away)	≥ 10 GeV
ATLAS 7 TeV, UE in minimum bias	$\langle \frac{\mathrm{d}^2 \sum p_{\text{T}}}{\mathrm{d}\eta \mathrm{d}\phi} \rangle$ (towards)	≥ 10 GeV
ATLAS 7 TeV, UE in minimum bias	$\langle \frac{\mathrm{d}^2 \sum p_{\text{T}}}{\mathrm{d}\eta \mathrm{d}\phi} \rangle$ (transverse)	≥ 10 GeV
ATLAS 7 TeV, UE in minimum bias	$\langle \frac{\mathrm{d}^2 \sum p_{\text{T}}}{\mathrm{d}\eta \mathrm{d}\phi} \rangle$ (away)	≥ 10 GeV

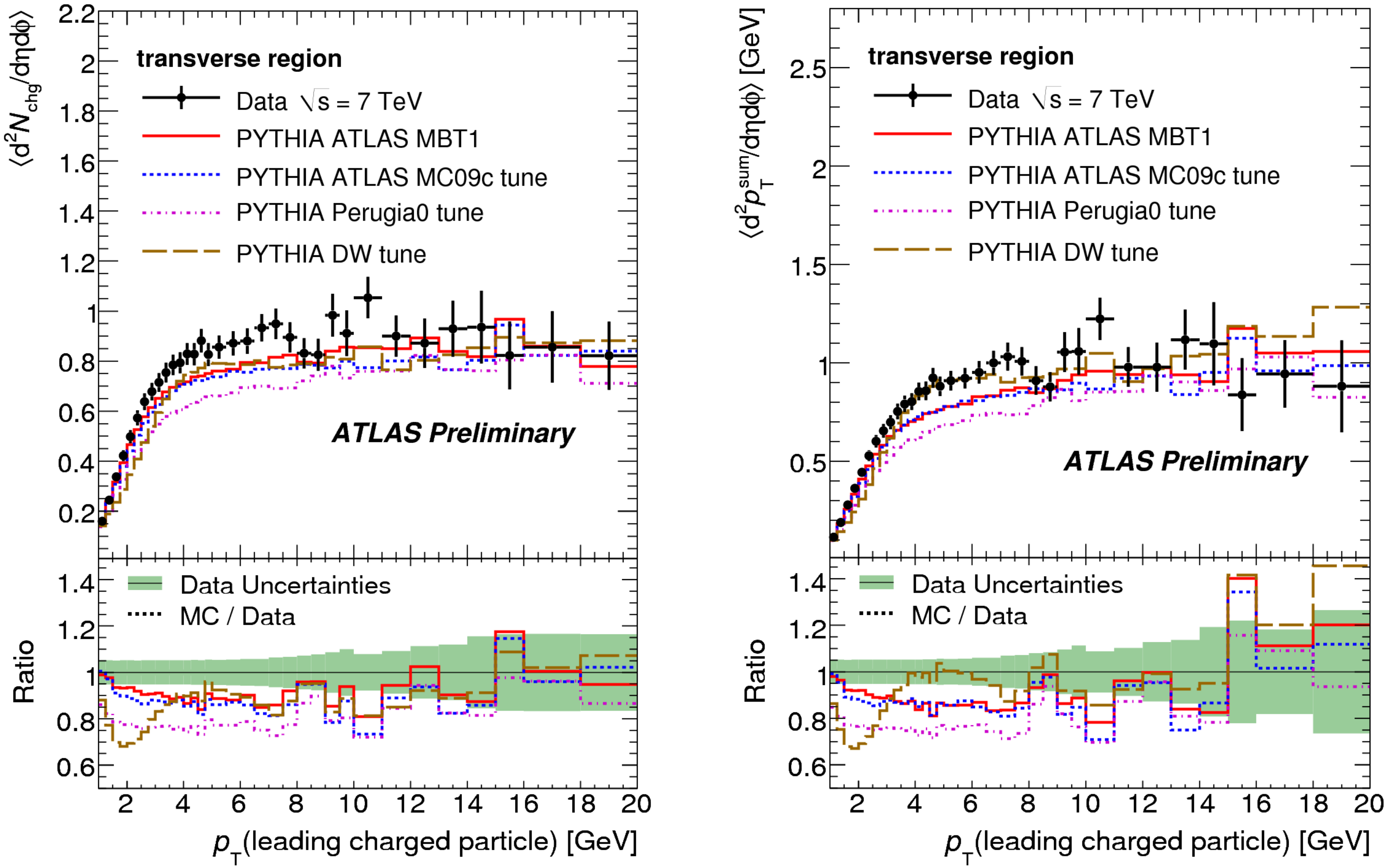
Table 3: ATLAS observables and ranges of distributions used in the tuning.

CDF data used in AMBT1 tune

CDF Run I underlying event in dijet events[13] (leading jet analysis)
N_{ch} density vs leading jet p_T (transverse), JET20
N_{ch} density vs leading jet p_T (toward), JET20
N_{ch} density vs leading jet p_T (away), JET20
$\sum p_T$ density vs leading jet p_T (transverse), JET20
$\sum p_T$ density vs leading jet p_T (toward), JET20
$\sum p_T$ density vs leading jet p_T (away), JET20
N_{ch} density vs leading jet p_T (transverse), min bias
N_{ch} density vs leading jet p_T (toward), min bias
N_{ch} density vs leading jet p_T (away), min bias
$\sum p_T$ density vs leading jet p_T (transverse), min bias
$\sum p_T$ density vs leading jet p_T (toward), min bias
$\sum p_T$ density vs leading jet p_T (away), min bias
p_T distribution (transverse), leading $p_T > 5$ GeV
p_T distribution (transverse), leading $p_T > 30$ GeV
CDF Run I underlying event in MIN/MAX-cones[14] ("MIN-MAX" analysis)
$\langle p_T^{\mathrm{max}} \rangle$ vs. E_T^{lead}, $\sqrt{s} = 1800$ GeV
$\langle p_T^{\mathrm{min}} \rangle$ vs. E_T^{lead}, $\sqrt{s} = 1800$ GeV
$\langle p_T^{\mathrm{diff}} \rangle$ vs. E_T^{lead}, $\sqrt{s} = 1800$ GeV
$\langle N_{\mathrm{max}} \rangle$ vs. E_T^{lead}, $\sqrt{s} = 1800$ GeV
$\langle N_{\mathrm{min}} \rangle$ vs. E_T^{lead}, $\sqrt{s} = 1800$ GeV
Swiss Cheese p_T^{sum} vs. E_T^{lead} (2 jets), $\sqrt{s} = 1800$ GeV
$\langle p_T^{\mathrm{max}} \rangle$ vs. E_T^{lead}, $\sqrt{s} = 630$ GeV
$\langle p_T^{\mathrm{min}} \rangle$ vs. E_T^{lead}, $\sqrt{s} = 630$ GeV
$\langle p_T^{\mathrm{diff}} \rangle$ vs. E_T^{lead}, $\sqrt{s} = 630$ GeV
Swiss Cheese p_T^{sum} vs. E_T^{lead} (2 jets), $\sqrt{s} = 630$ GeV
D0 Run II dijet angular correlations[15]
Dijet azimuthal angle, $p_T^{\mathrm{max}} \in [75, 100]$ GeV
Dijet azimuthal angle, $p_T^{\mathrm{max}} \in [100, 130]$ GeV
Dijet azimuthal angle, $p_T^{\mathrm{max}} \in [130, 180]$ GeV
Dijet azimuthal angle, $p_T^{\mathrm{max}} > 180$ GeV
CDF Run II minimum bias[16]
$\langle p_T \rangle$ of charged particles vs. N_{ch}, $\sqrt{s} = 1960$ GeV
CDF Run I Z p_T[17]
$\frac{d\sigma}{dp_T^Z}$, $\sqrt{s} = 1800$ GeV

Tevatron datasets used in the tuning. No specific cuts on the tuning ranges were made

ATLAS MBT1 results for UE



Results ATLAS MBT1 not significantly changed compared to MC09c

Reasonable description of distributions at p_T^{lead}>10GeV