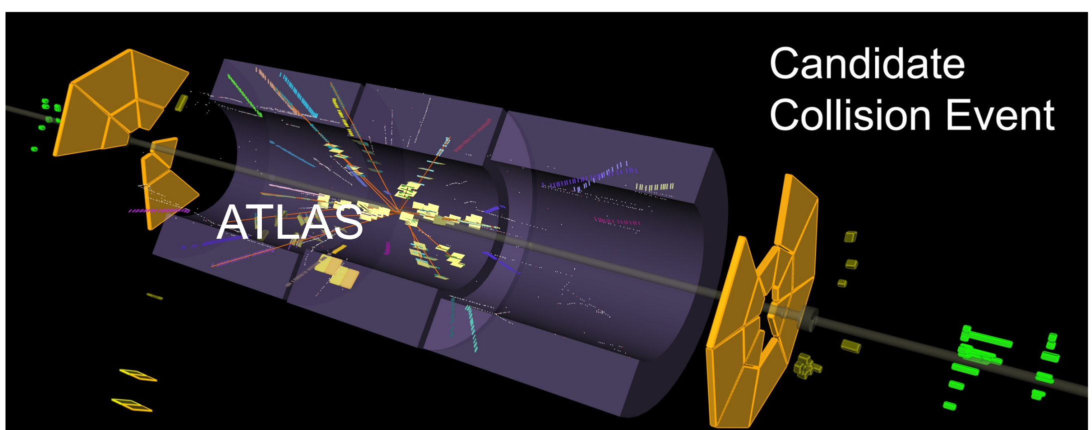
# *Charged-particle multiplicities in p-p interactions at $\sqrt{s}$=900 GeV and $\sqrt{s}$=7 TeV*

*Gerhard Brandt* (DESY)

- 900 GeV Analysis - First ATLAS Paper [arXiv:1003.3124]
- 7 TeV Fast Analysis - ATL-COM-PHYS-2010-189
- Results and their Application
- Outlook

Example for Minimum Bias Event




*Uni Würzburg Gruppenseminar - 16. April 2010*

# Introduction: Minimum Bias Events

- Bulk of physics happening at LHC are low-$p_T$ “minimum bias” events (soft QCD)
- Need to understand these since they will be present as background / pile-up in every event with interesting high-$p_T$ signals
- Total cross section:

$$\sigma_{tot} = \sigma_{elas} + \sigma_{sd} + \sigma_{dd} + \sigma_{nd}$$

14 TeV
CSC Note
NSD
Predictions

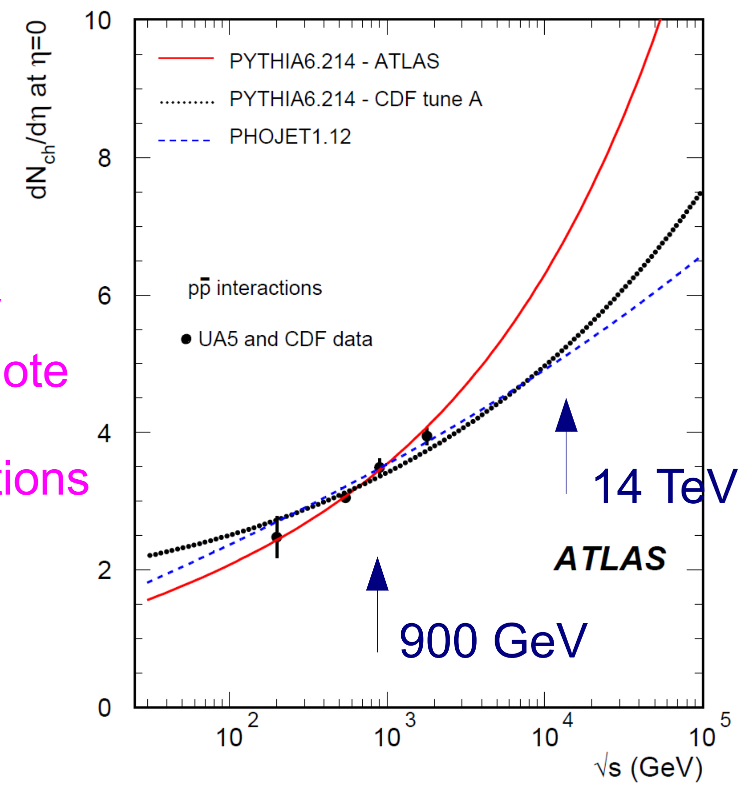



Fig. 1: Central charged particle density for non-single diffractive inelastic $p$-$\bar{p}$ collisions.

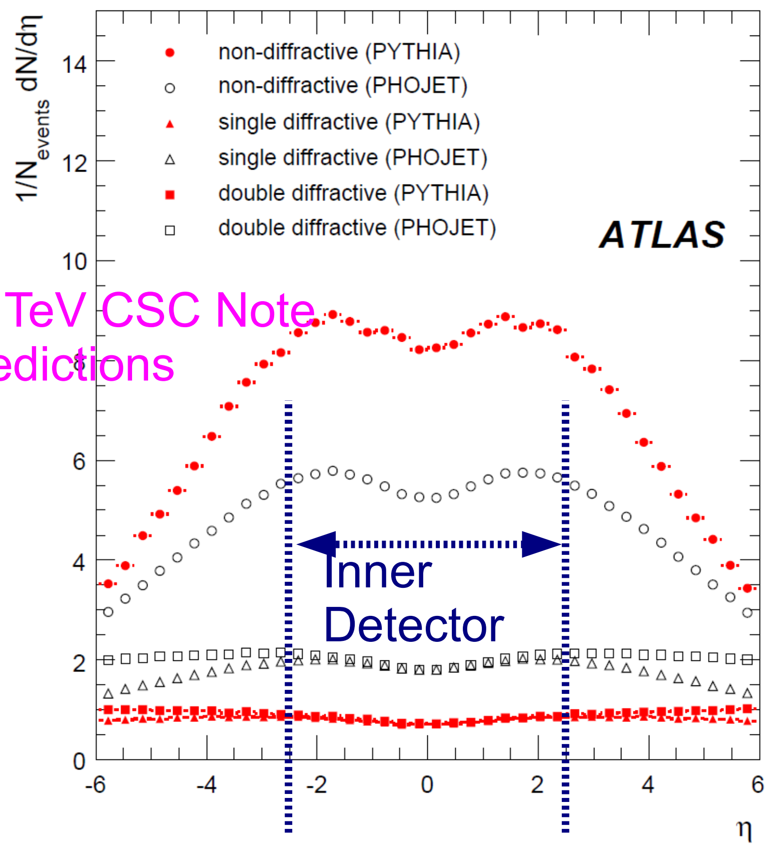
- Look at Charged Particle Density at $\eta$=0
  - Predictions by different generators (PYTHIA, PHOJET) and different PYTHIA tunes (MC09, CDF, …) diverge towards large centre of mass energies
- Need to measure to constrain phenomenological models!
- Previous measurements
  - remove single-diffractive (sd) component using MC
  - Reduce sd due to coincidence trigger: “NSD” measurements
  - They extrapolate down to $p_T$>=0MeV

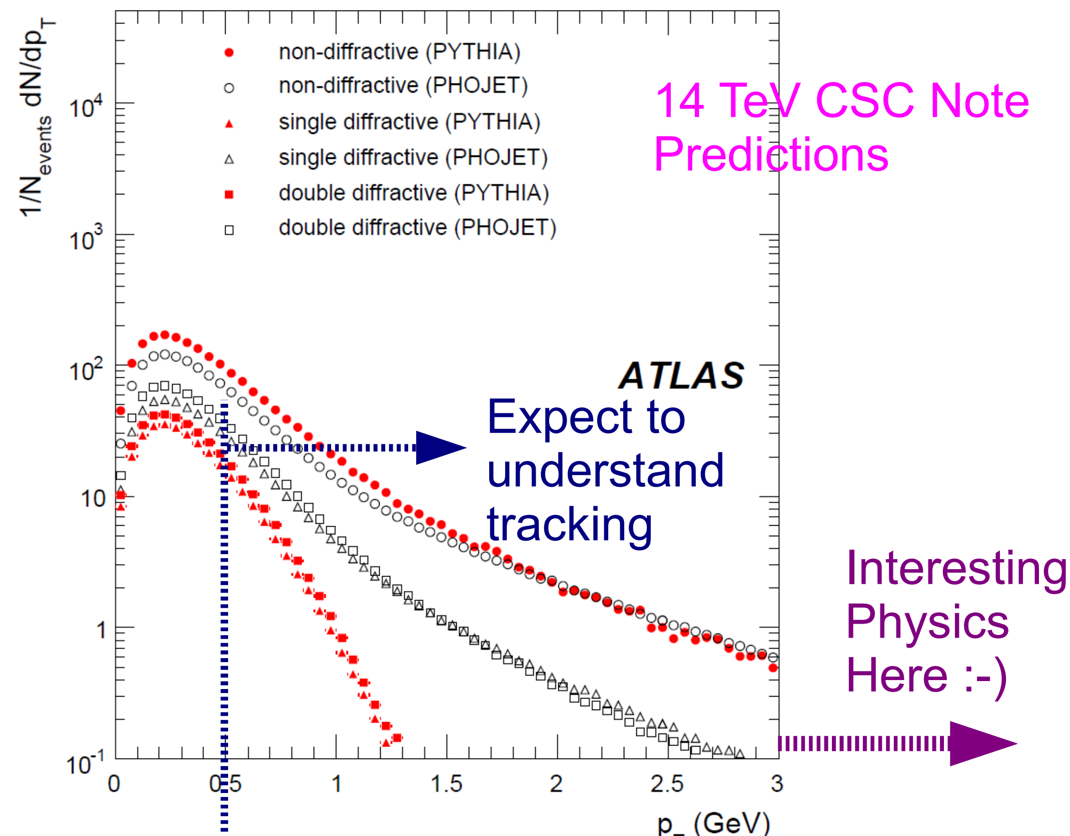
# This ATLAS Minimum Bias Measurement

- Measure charged particle multiplicities in p-p collisions
- In this analysis we can see only part of  total cross section:
- triggered inelastic events with charged particles in geometrical acceptance in regime of well-understood tracking ($p_T$ not too low)

- Kinematic range $|\eta|<2.5$, $p_T$ > 500 MeV, $N_{ch} \geq 1$
  - Avoid taking $N_{ch}$=0 from Monte Carlo
  - Measure corrections from data if possible

**Avoid model dependences as much as possible!**

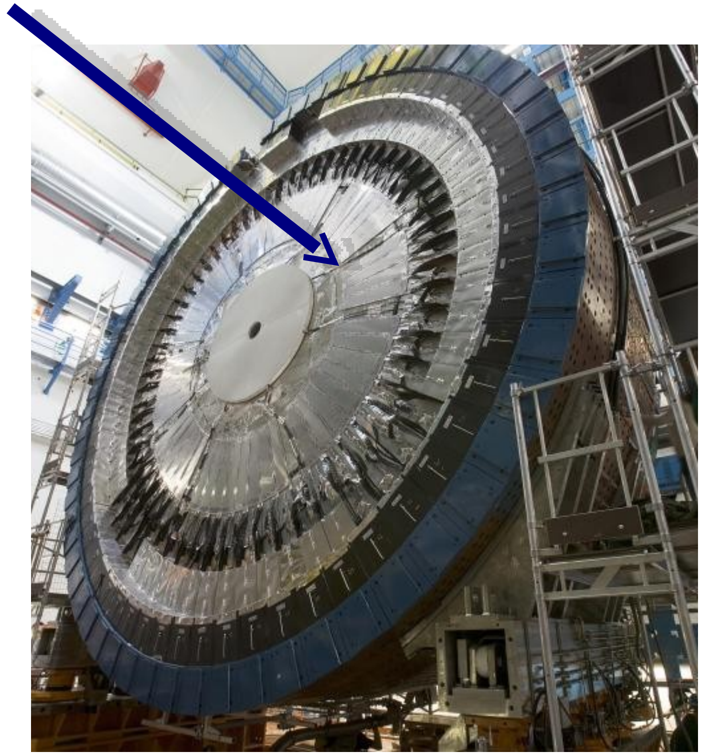


# Trigger and Data Quality

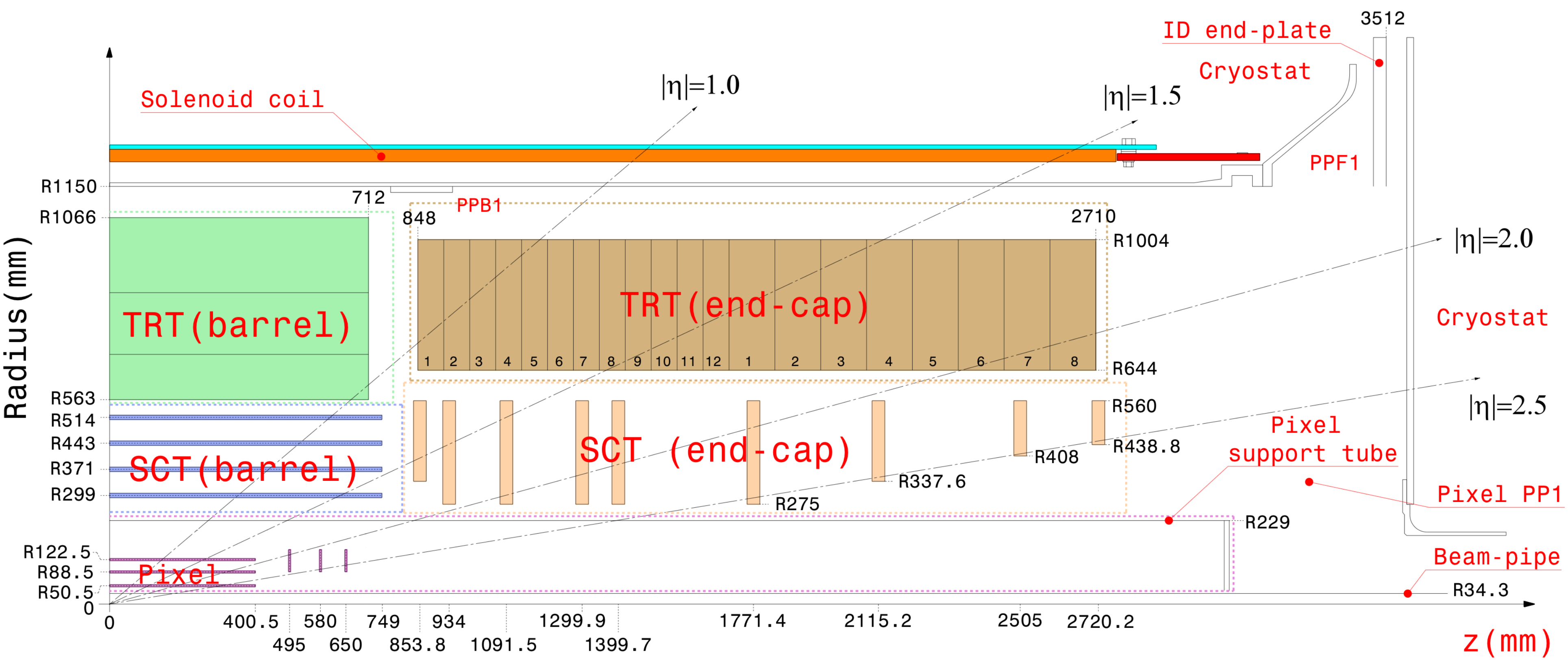
- Require at least one hit above threshold from either side of the detector **L1_MBTS_1**
- Prevents bias on diffractive components
- Require fully operational Inner Detector and Solenoidal *B*-Field
- Look at collision bunch crossings only
- ~455000 events selected in whole 2009 900 GeV data

Minimum Bias Trigger Scintillators **MBTS**



# Control Trigger and Inner Detector

- mbSpTrk - L1 Beam-pickup, filtered by L2 Pixel and Silicon microstrip (SCT) spacepoints, and EF track.



# Offline Selection

## Event Selection

- Require L1 MBTS trigger
- Primary vertex
  - Including ≥3 tracks ($p_T$ > 150 MeV)
- Number of selected tracks ≥ 1

Selection causes loss of events that needs to be corrected for

**Trigger Correction**

**Vertex Correction**

**Track Reconstruction Correction**

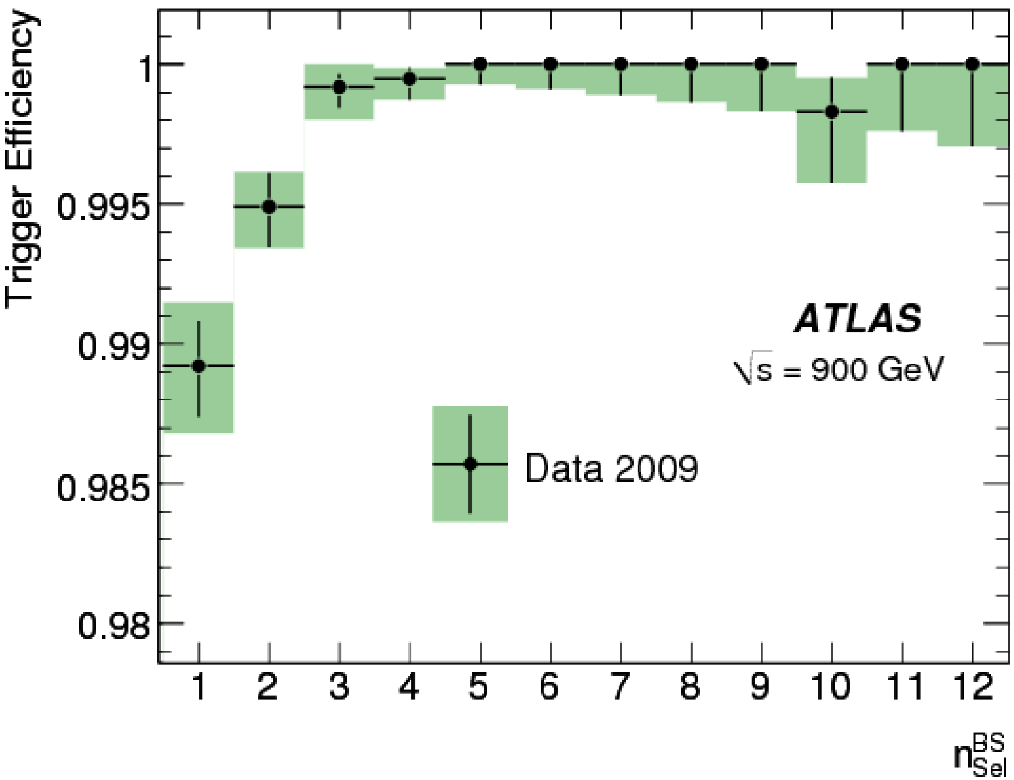
## Track Selection

- $p_T$ > 500 MeV
- $|\eta| < 2.5$
- Number of Pixel Hits ≥ 1
- Number of SCT Hits ≥ 6
- $|d_0^{PV}| < 1.5$ mm
- $|z_0^{PV} \sin(\theta^{PV})| < 1.5$ mm
- Inside out track reconstruction

} ATLAS Si Detectors: Pixel and Silicon Strip (SCT)

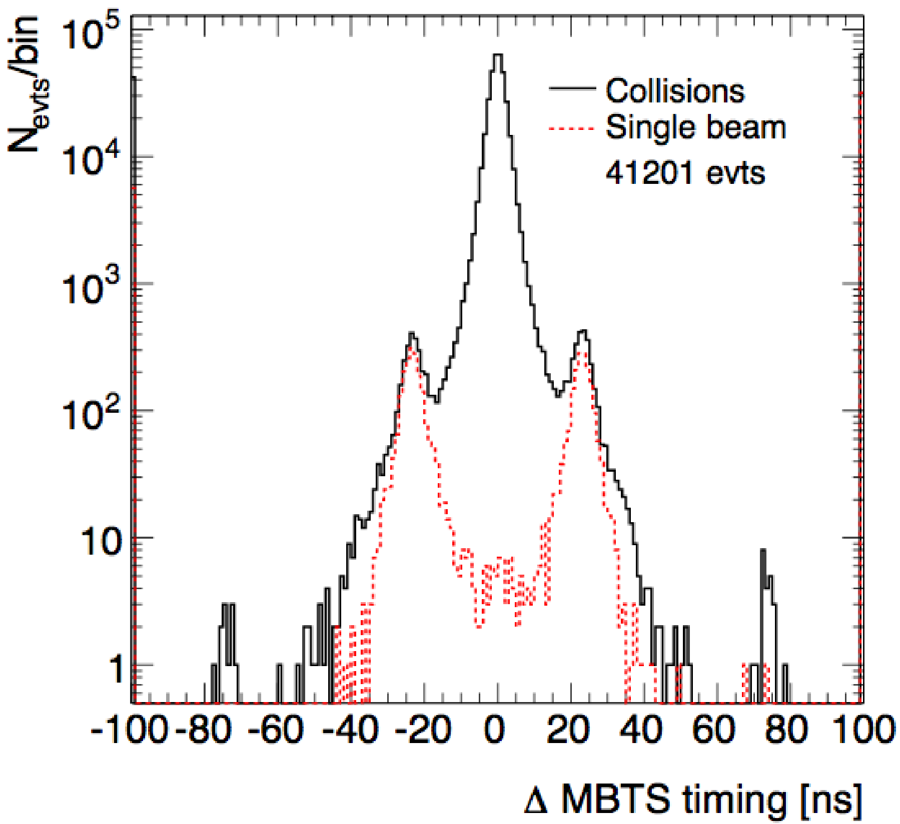
} Transverse and Longitudinal Track Impact-Parameters evaluated Wrt. Primary Vertex (PV)

# Trigger Efficiency

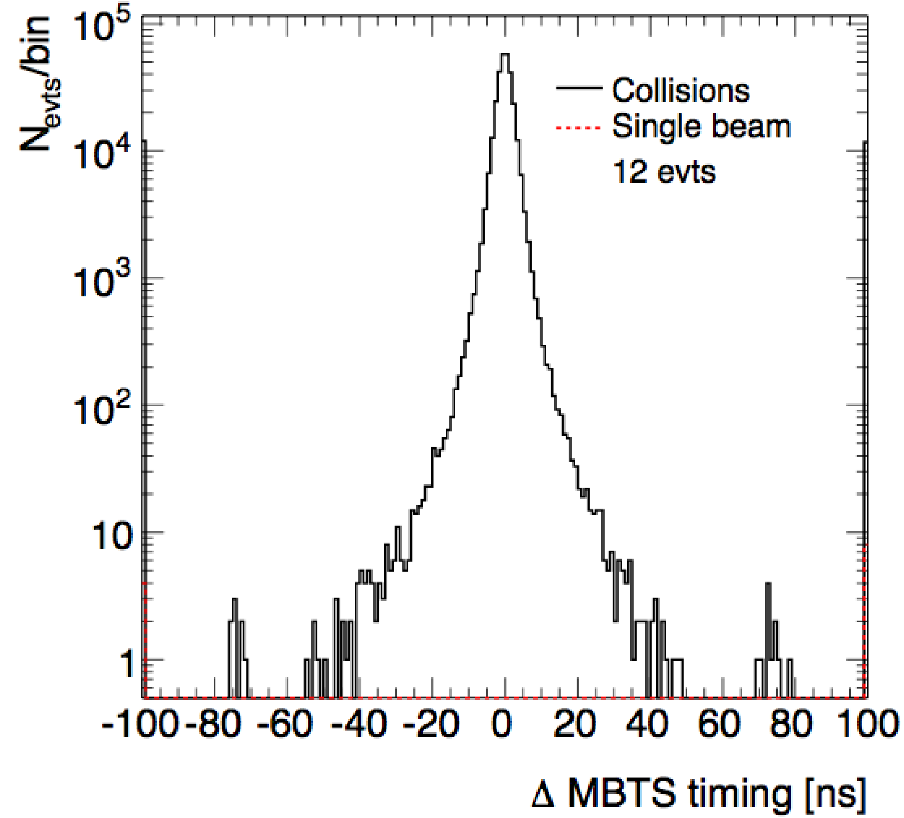



- Parametrised as function of offline selected tracks (w/o vertex requirement – wrt beamspot BS)
- Determined by comparing to Control Trigger mbSpTrk
- Very high – small correction

# Beam Background



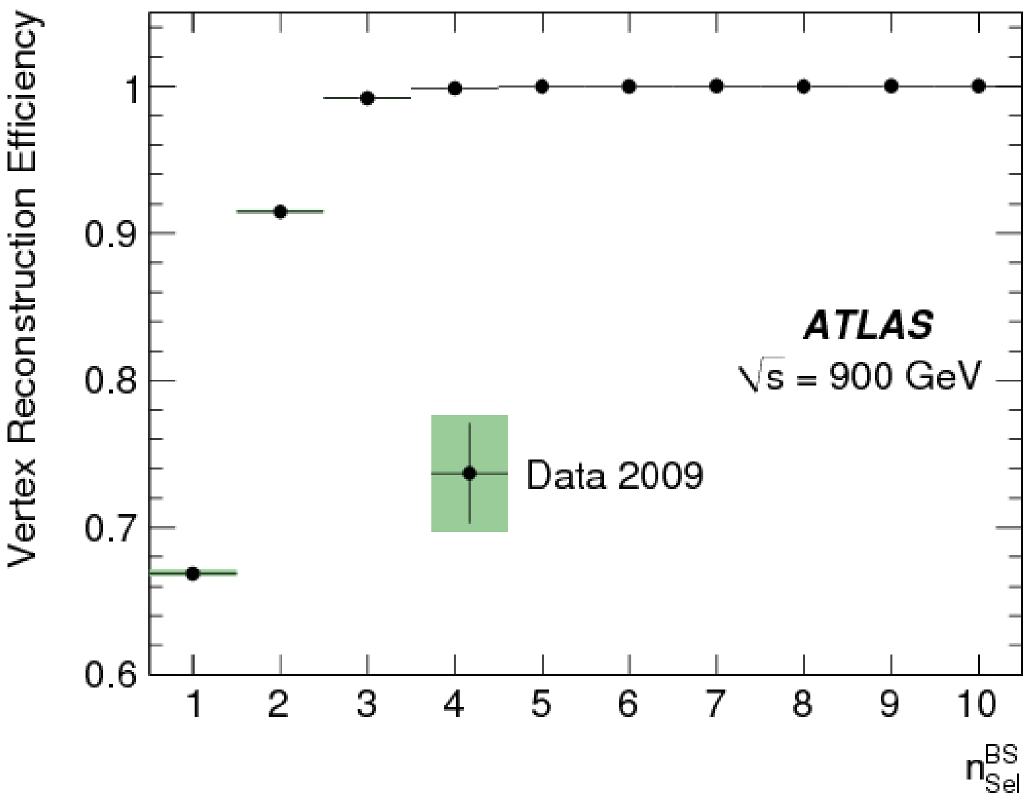

Trigger Selection




Final selection

- Measure time difference from offline readout of MBTS
- (Timing cut is not used in analysis selection.)
- Look at collisions events (paired bunches) and single beam (unpaired bunches)
- Beam background rate at $10^{-4}$ level

# Vertex Efficiency




- Measured from data:

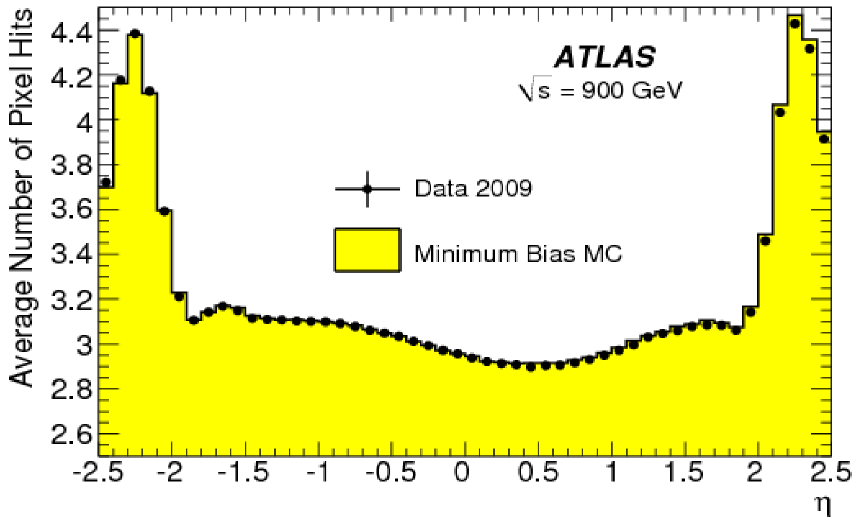
Ratio of triggered events with vertex / all triggered events

- Tiny systematic from beam background.

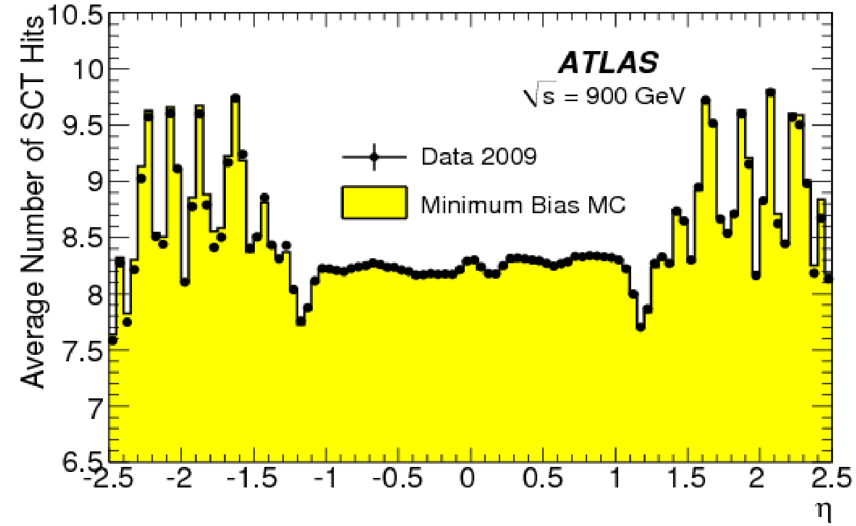
- Software setup to find at most one vertex per event
- No pile-up in data
- Require at least 3 tracks with pt>150 MeV fitted to vertex

# Simulation of Tracks in Inner Detector

Average Number of Pixel Hits

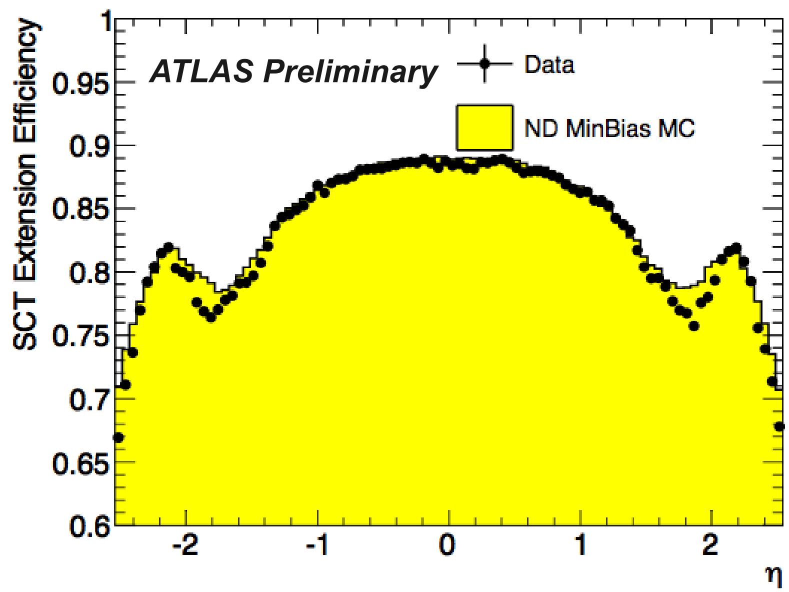



Average Number of SCT Hits




Detailed Studies of
- Material
- Alignment
- Resolution

Excellent Description of Tracks
Global Systematic: 2.8%
(Conservative, depends on region)

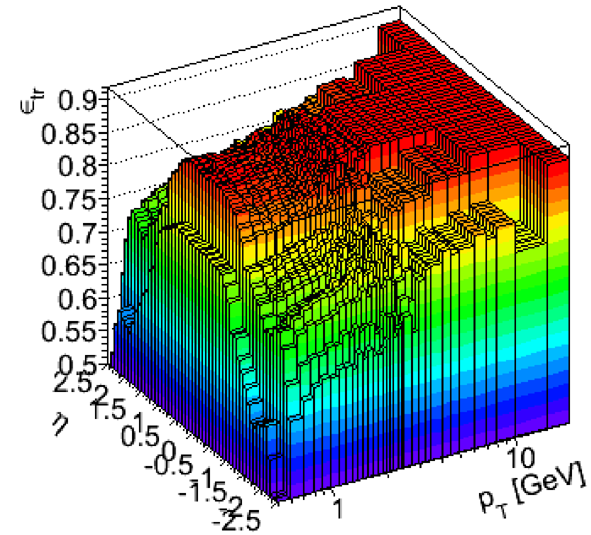


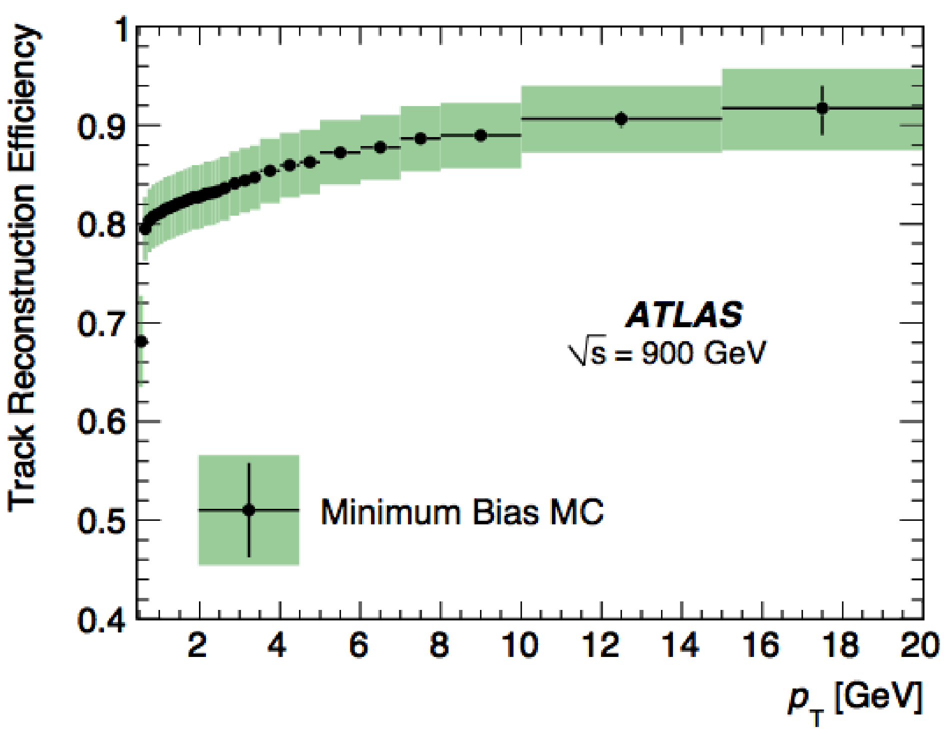

SCT Extension Efficiency

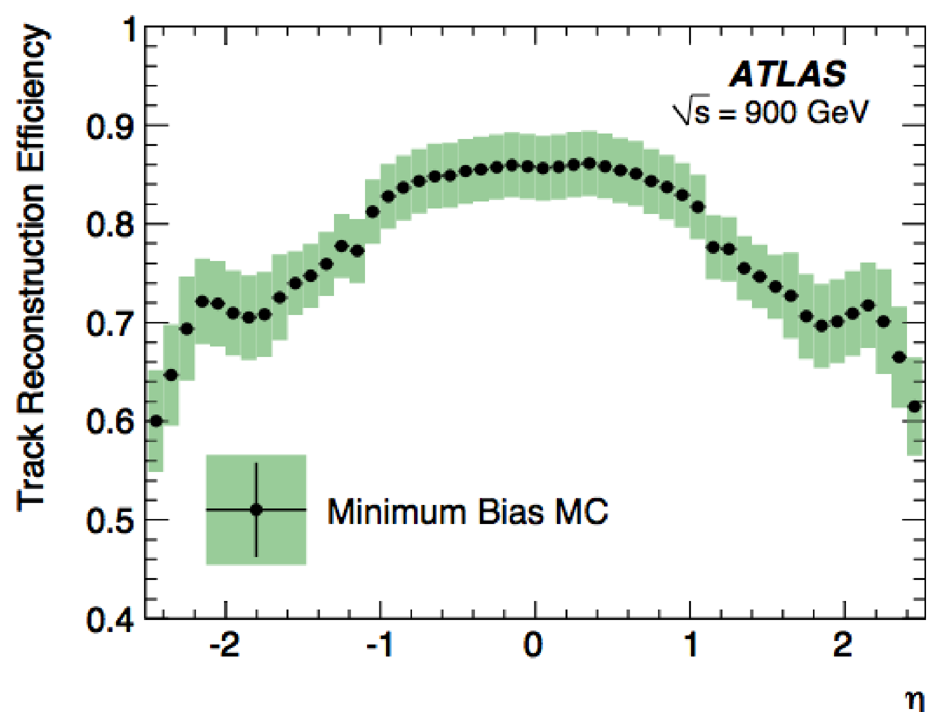
Probe of Material Description

# Track Reconstruction Efficiency

- Determined from Monte Carlo
  cone matching reco to true tracks
- Average Track Efficiency ~76%
- Fraction of Secondary Tracks (~2.2%) and
  Fake tracks (0.1%) also determined from MC



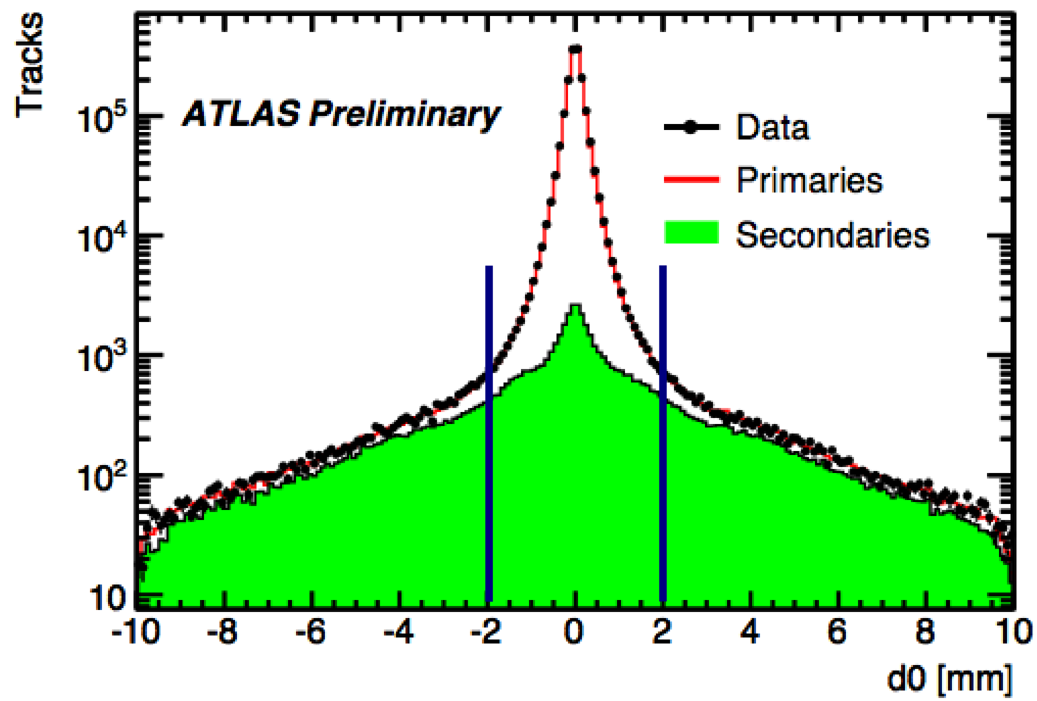



# Secondary Tracks

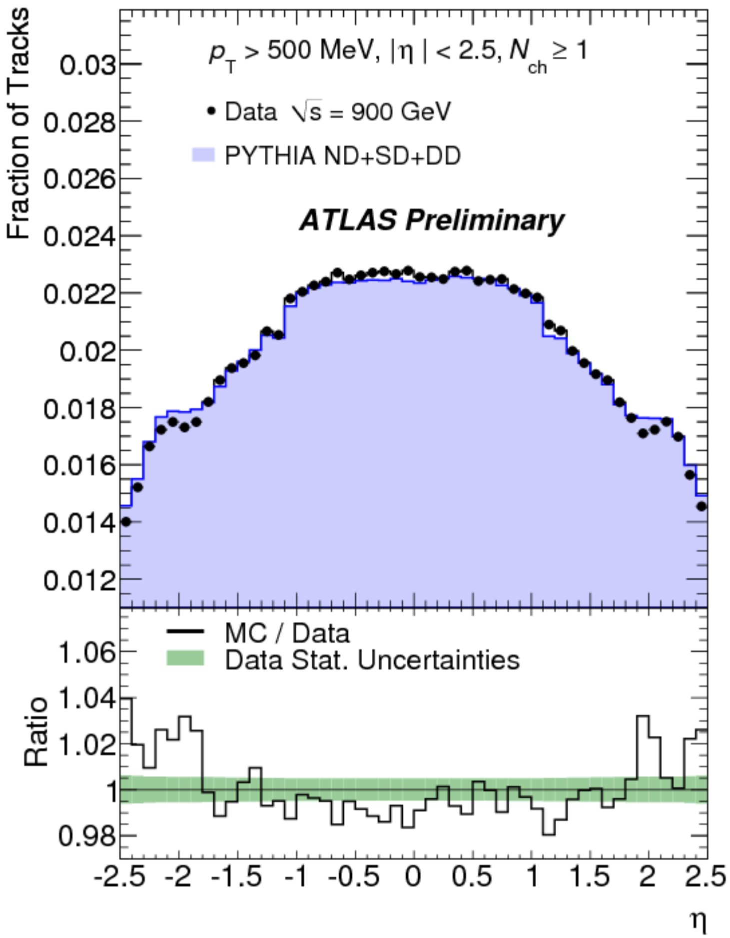
- Sources of secondary interactions:
  - Nuclear interactions
  - Weakly decaying particles (Ks, Lambda etc.)
  - Pion decays

- Define secondary as mean life time $\tau > 0.3 \times 10^{-10}$ s



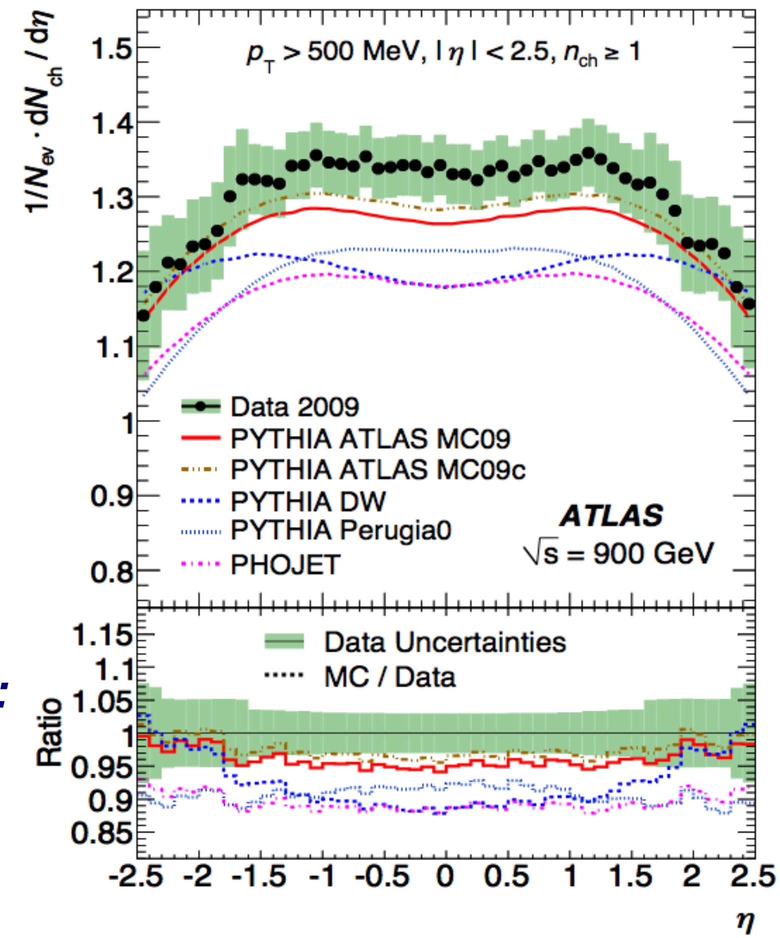

- Cut on d0 and z0 removes secondaries
- Estimate remaining secondaries in from fit of MC to data impact parameter distribution in $2 < d_0 < 10$ mm
- 2.20% ± 0.05 (stat.) ± 0.11 (syst.) of selected tracks
- Subtract from track yield

# Correction Procedure dN/d$\eta$ and dN/d$p_T$




***"Raw" Distribution:***
Measured Track Density

***Final Distribution:***
Charged Particle Density




- Apply efficiencies and additional corrections as weights during analysis

- Event-Weight
  Trigger, Vertex

$$w_{\rm ev}(N_{\rm Sel}^{\rm BS}) = \frac{1}{\epsilon_{\rm trig}(N_{\rm Sel}^{\rm BS})} \cdot \frac{1}{\epsilon_{\rm vtx}(N_{\rm Sel}^{\rm BS})}$$

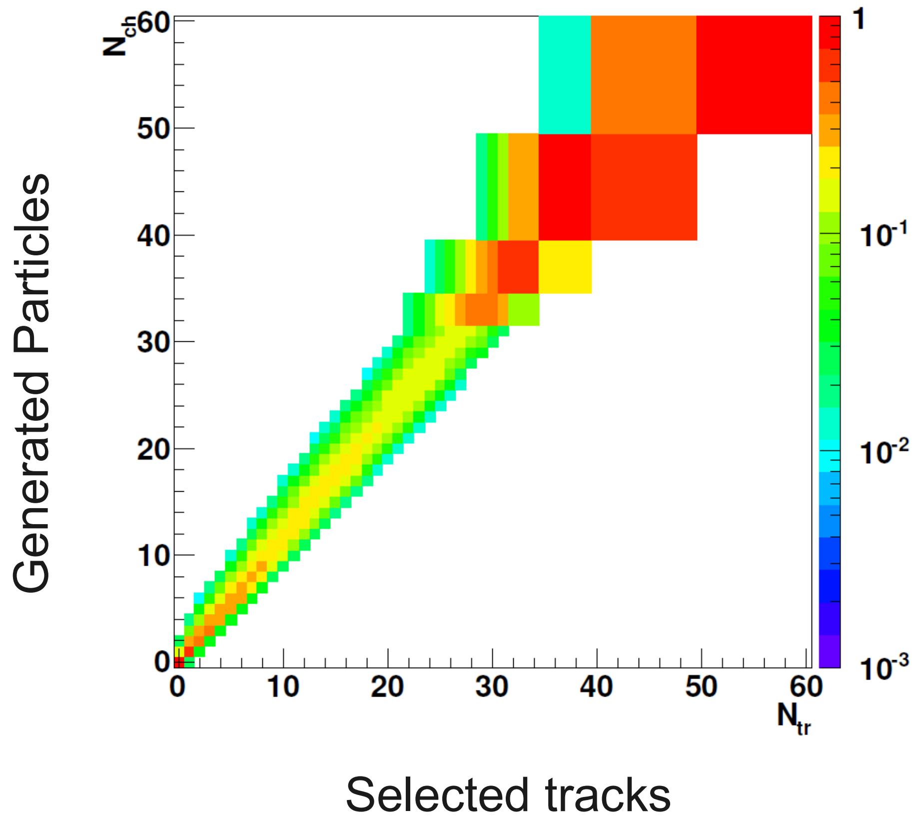
- Track-Weight
  Track Eff., Contaminations, Resolution

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

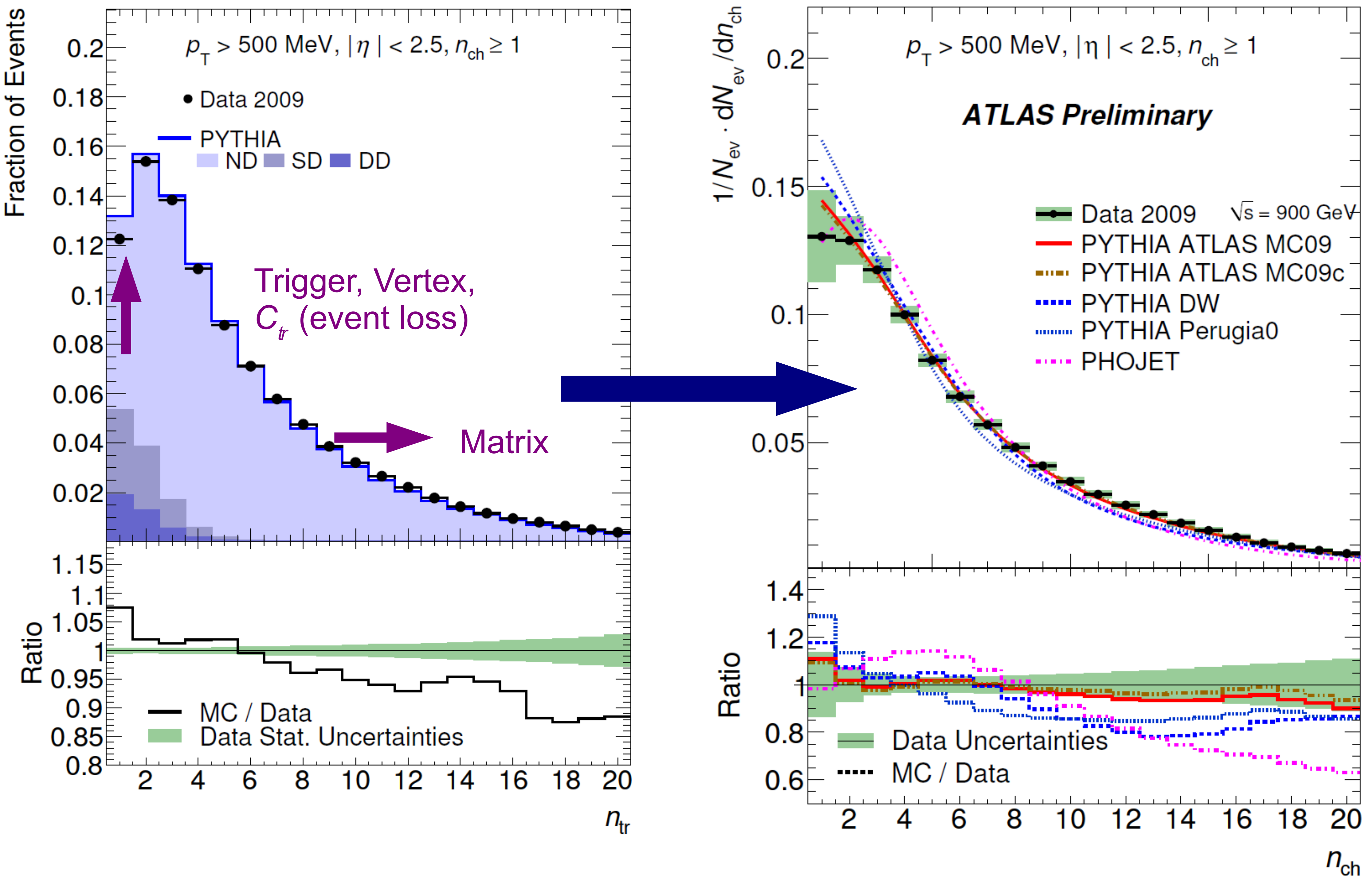
# $n_{ch}$ Correction

- Distributions in $n_{ch}$ need to be corrected for bin migrations due to track efficiency
- Use a matrix to distribute tracks to their particle multiplicity bins ("Bayesian Unfolding")
- This does not change overall number of events measured
- Use correction factor to recover events lost due to track efficiency

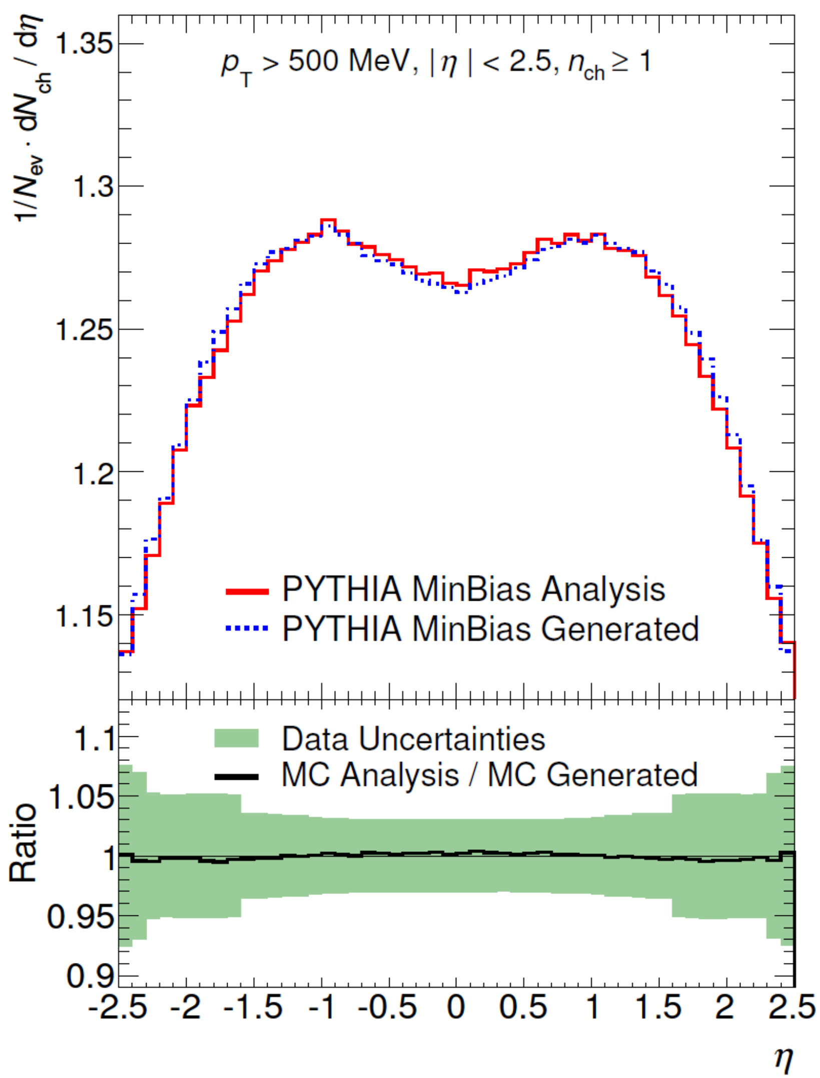
$$C_{tr}(\langle \varepsilon_{bin}(p_T,\eta)\rangle, n_{Sel}) = \frac{1}{1-(1-\langle \varepsilon_{bin}(p_T,\eta)\rangle)^i}.$$

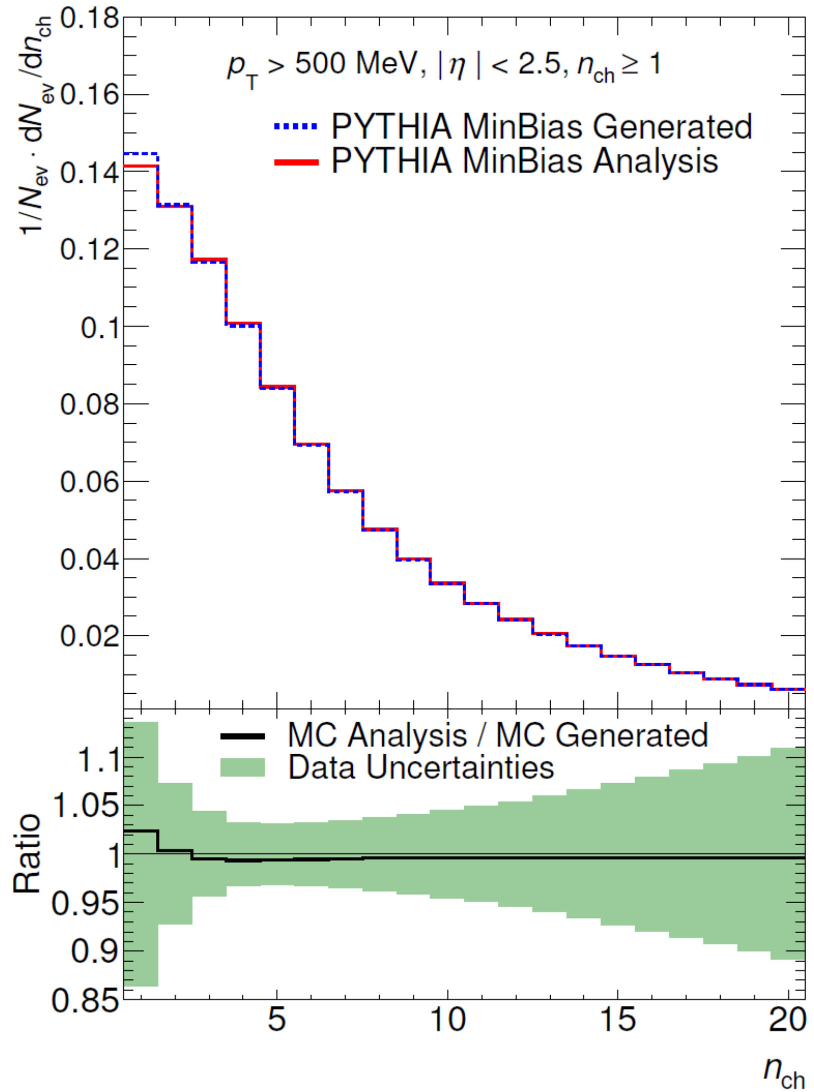


# $n_{ch}$ Correction



# Closure Tests



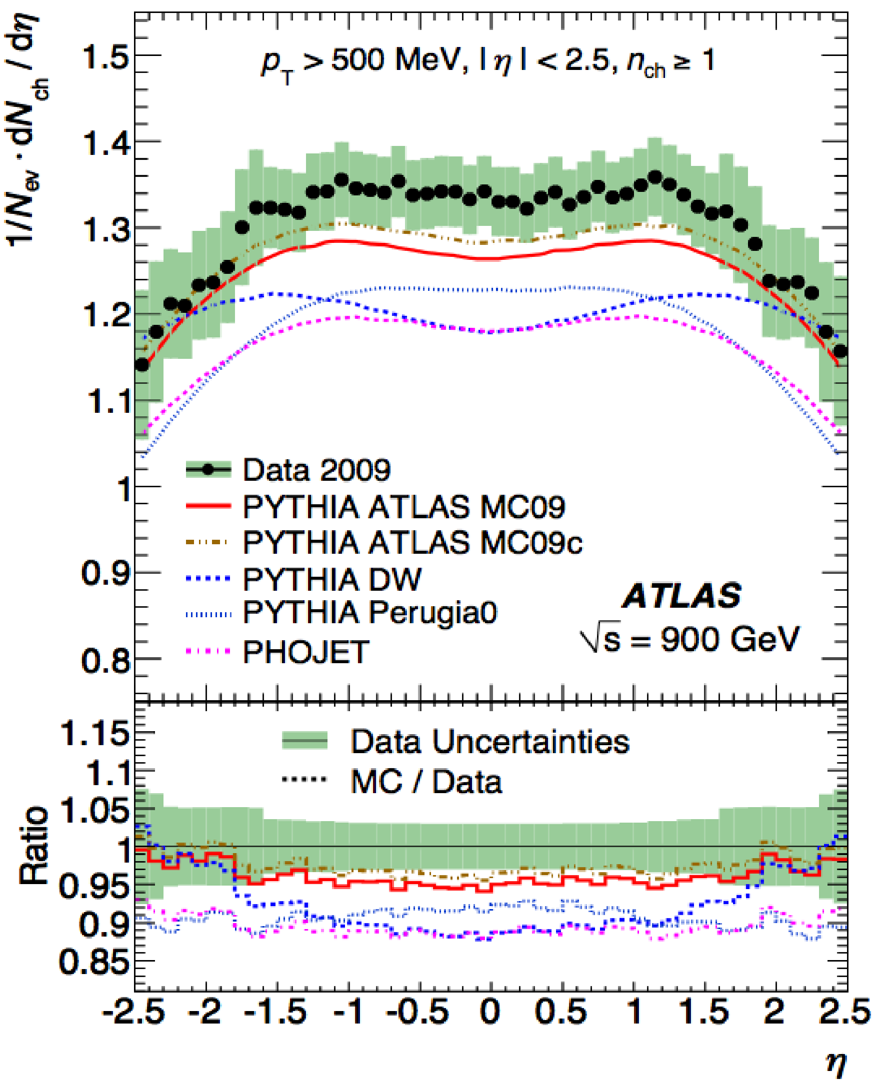



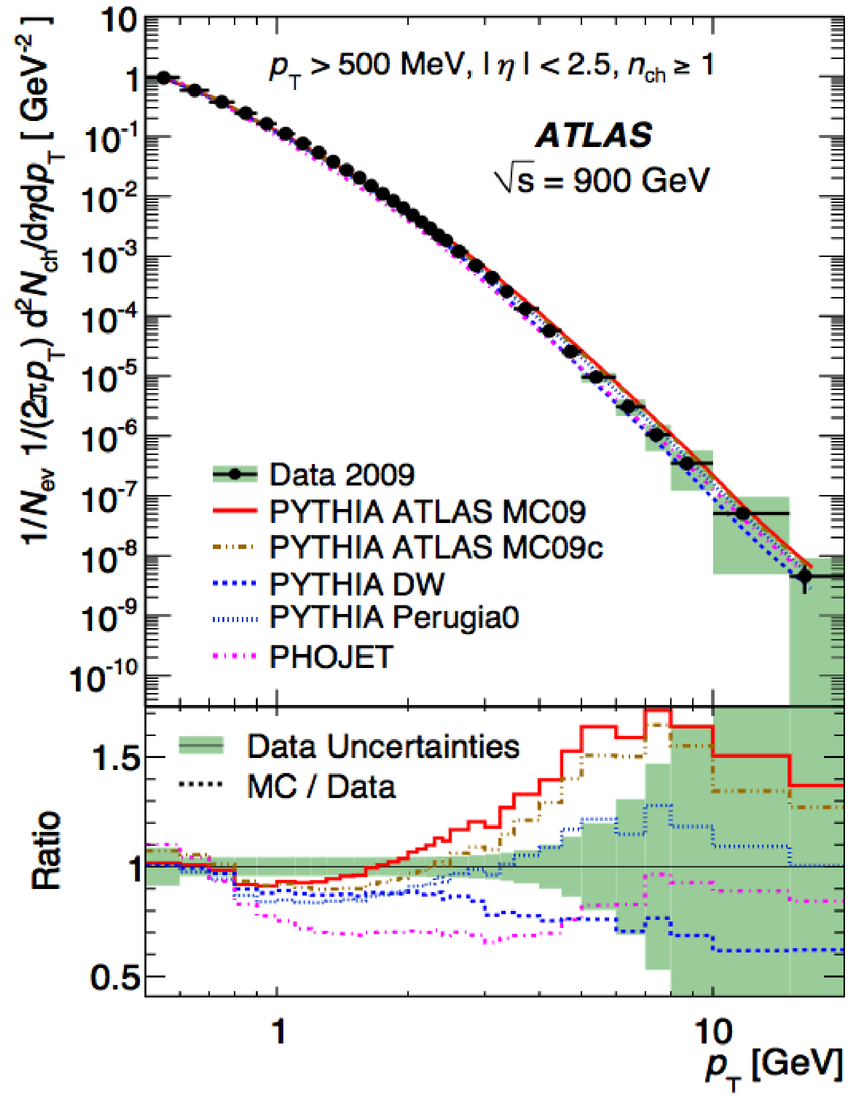

- Test with MC if the correction procedure works
- Apply full analysis chain to MC and compare to truth distributions

# Systematic Uncertainties

| **Systematic uncertainty on the number of events, $N_{ev}$** | |
|---|---|
| Trigger efficiency | $< 0.1\%$ |
| Vertex-reconstruction efficiency | $< 0.1\%$ |
| Track-reconstruction efficiency | $1.1\%$ |
| Different MC tunes | $0.4\%$ |
| Total uncertainty on $N_{ev}$ | $1.2\%$ |
| **Systematic uncertainty on $(1/N_{ev})\cdot(dN_{ch}/d\eta)$ at $\eta = 0$** | |
| Track-reconstruction efficiency | $4.0\%$ |
| Trigger and vertex efficiency | $< 0.1\%$ |
| Secondary fraction | $0.1\%$ |
| Total uncertainty on $N_{ev}$ | $-1.2\%$ |
| Total uncertainty on $(1/N_{ev})\cdot(dN_{ch}/d\eta)$ at $\eta = 0$ | $2.8\%$ |

# Charged Particle Density vs. $\eta$ and $p_T$

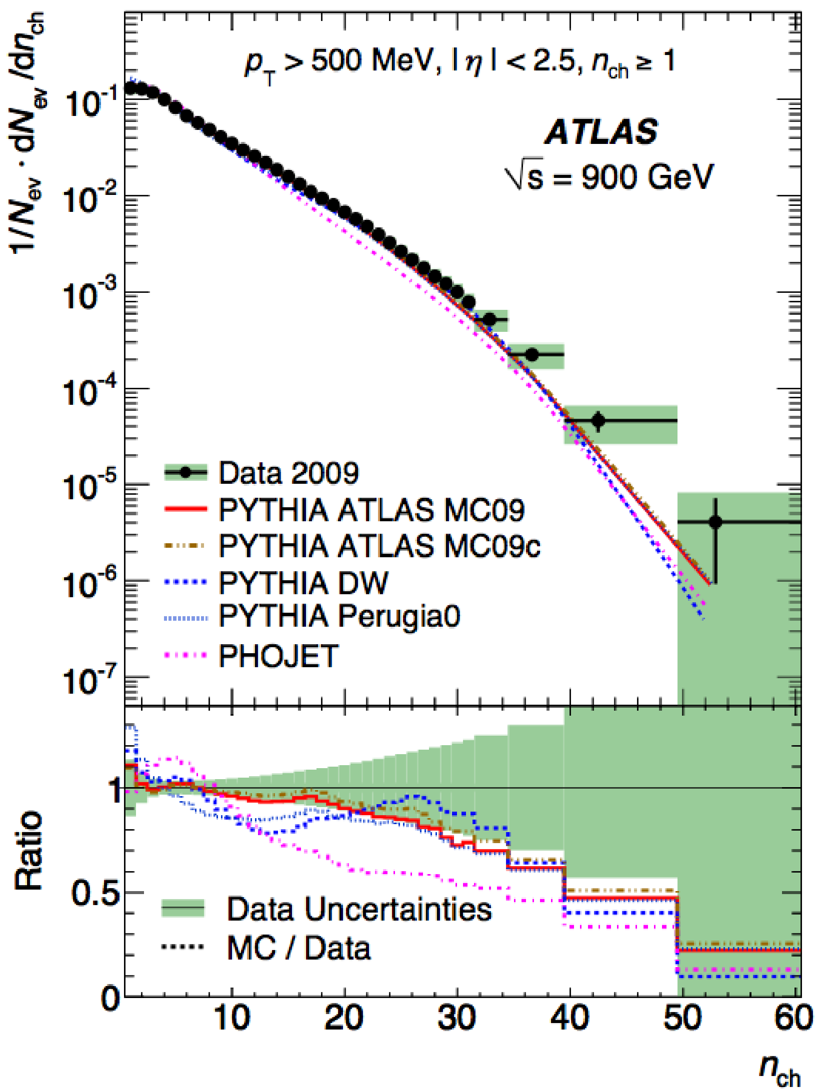


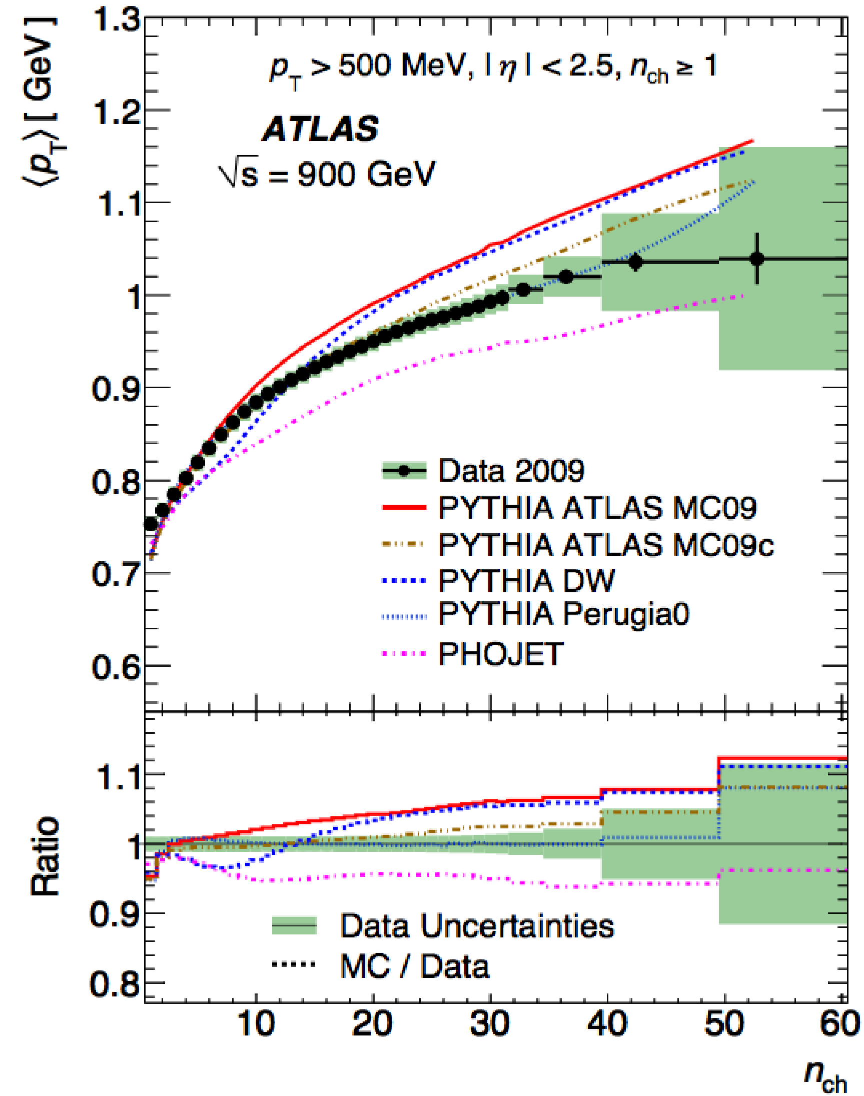




- Data are 5%-15% above Monte Carlo predictions
- Models were tuned in different phase space

- Transverse momentum agrees well only below $p_T$ < 0.7 GeV

# Charged Particle Multiplicity and Average $p_T$



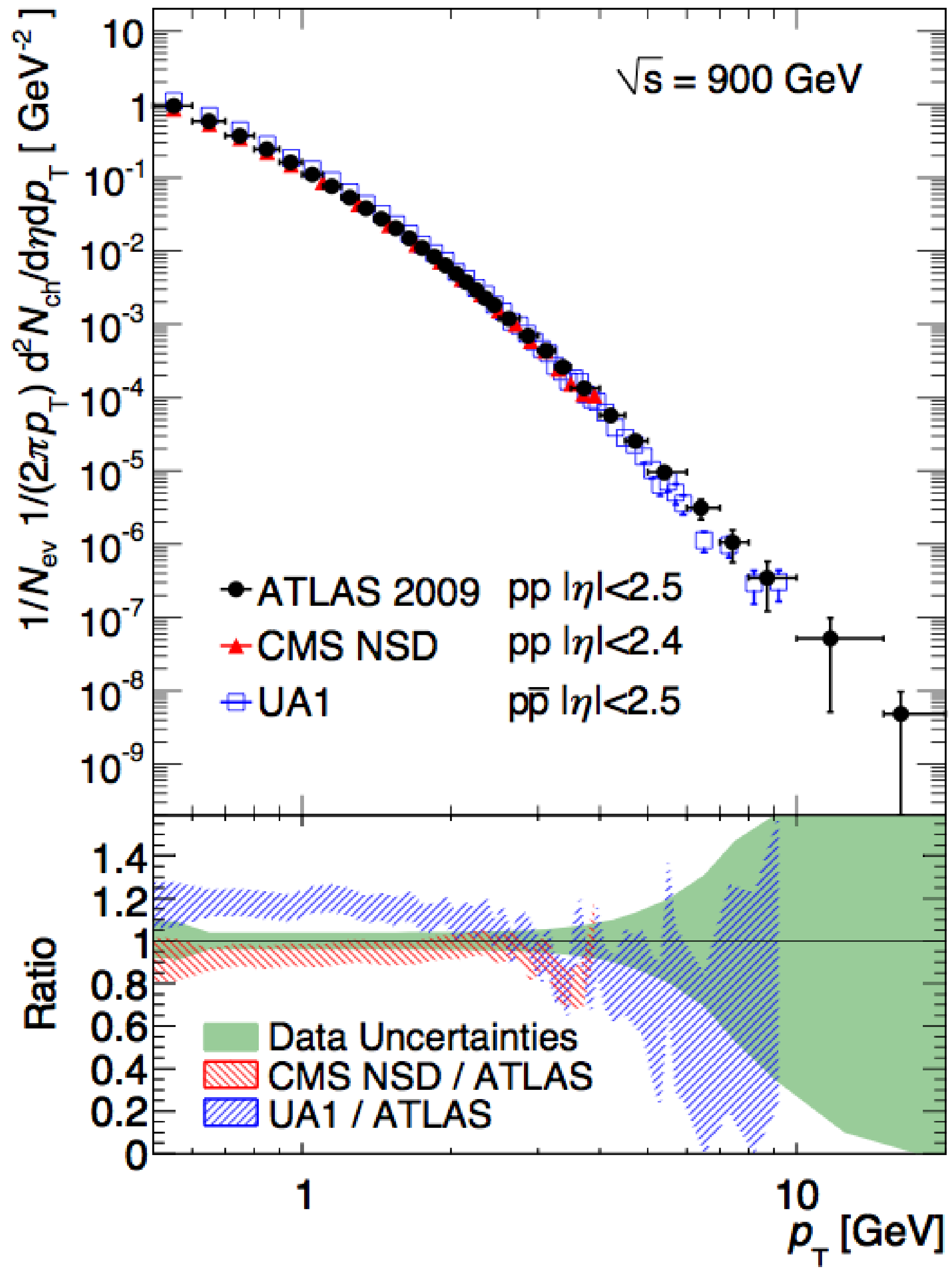

- Too many tracks for $n_{ch}$=1
- To few above $n_{ch}$ >10

- Increase of $\langle p_T \rangle$ with $n_{ch}$
- Change in slope around $n_{ch}$=10

# Comparison to UA1 and CMS

Use invariant yield to compare different experiments

- $p_T$ spectrum similar to CMS NSD result.
  - Agree within uncertainties when ATLAS is converted to CMS NSD.
- Interpreted UA1 data are higher at low $p_T$
  - Expect this is a measurement definition difference.

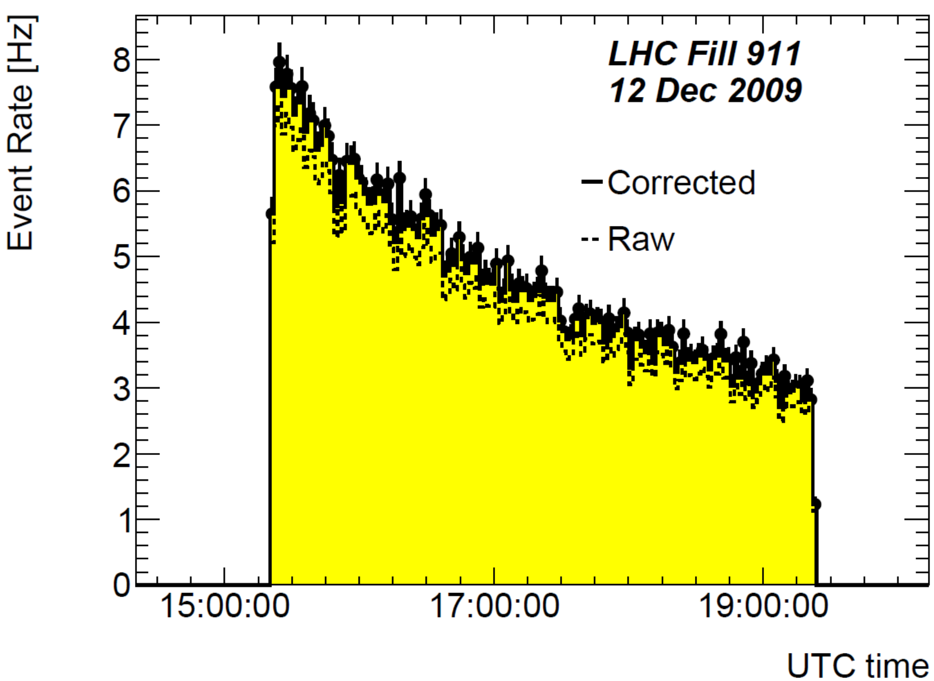


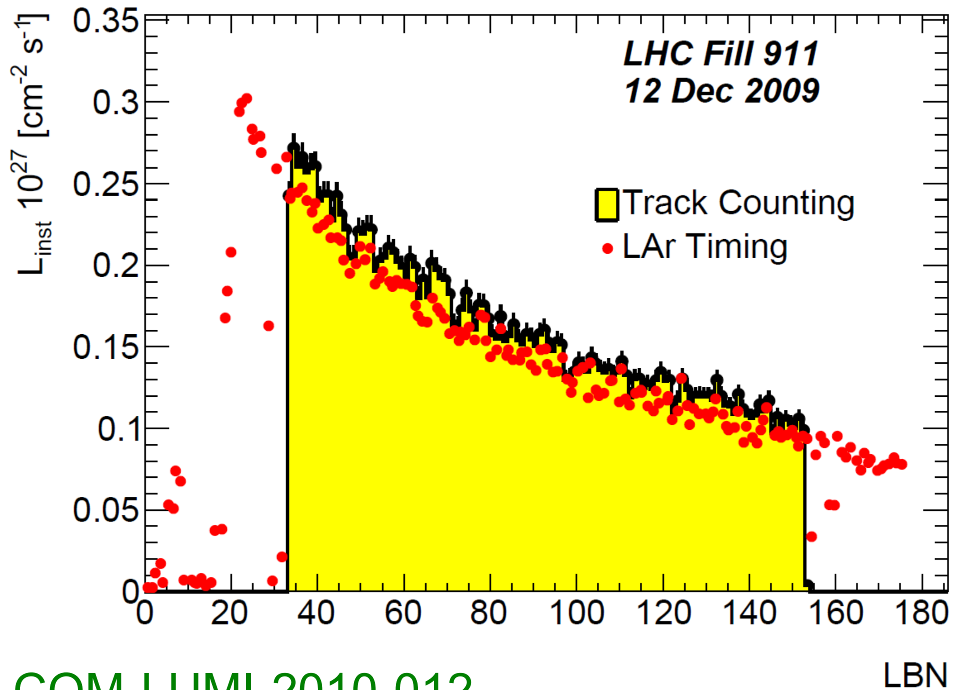
# Application: Luminosity Measurement

- Use measured event yield $N_{ev}$ and MC cross section predictions to calculate luminosity

$$\int \mathscr{L} dt = \frac{N_{ev}}{\sigma_{vis}} = \frac{N_{ev}}{\varepsilon_{ND}\sigma_{ND} + \varepsilon_{SD}\sigma_{SD} + \varepsilon_{DD}\sigma_{DD}}$$

- Compare to other methods (LAr timing) and especially other experiments (ALICE, CMS)
- Repeat analysis in restricted, common phase space ($\eta$<0.8) to derive correction factor for $N_{ev}$.
- Measure event rate as function of UTC time
- Calculate instantaneous luminosity using PHOJET xsection and acceptance predictions




ATL-COM-LUMI-2010-012
(circulating since yesterday)

# 7 TeV Analysis

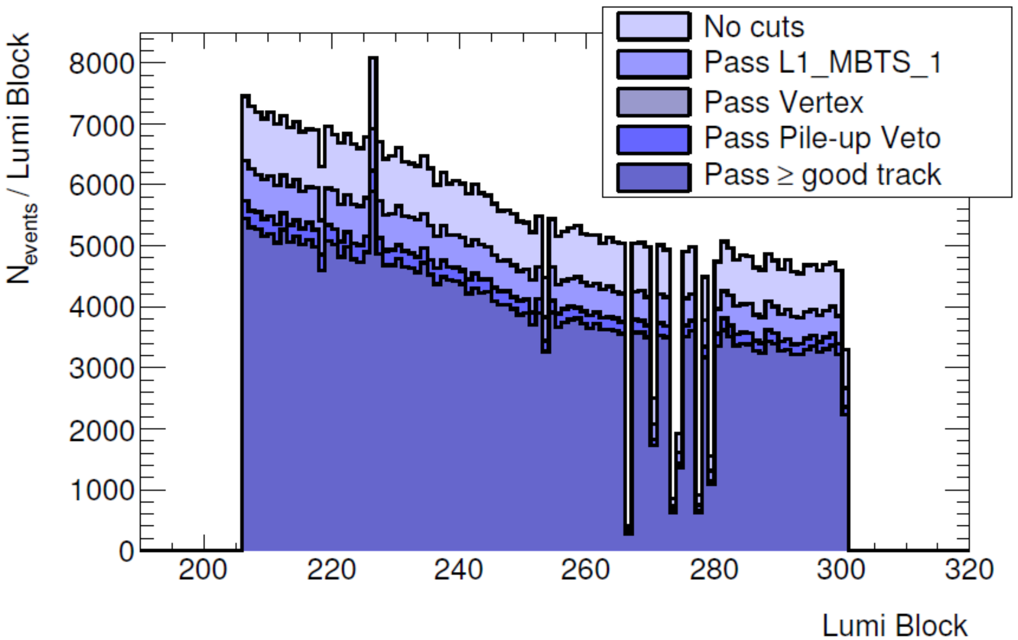
- This was the first ATLAS paper
- Now do it again with 7 TeV data

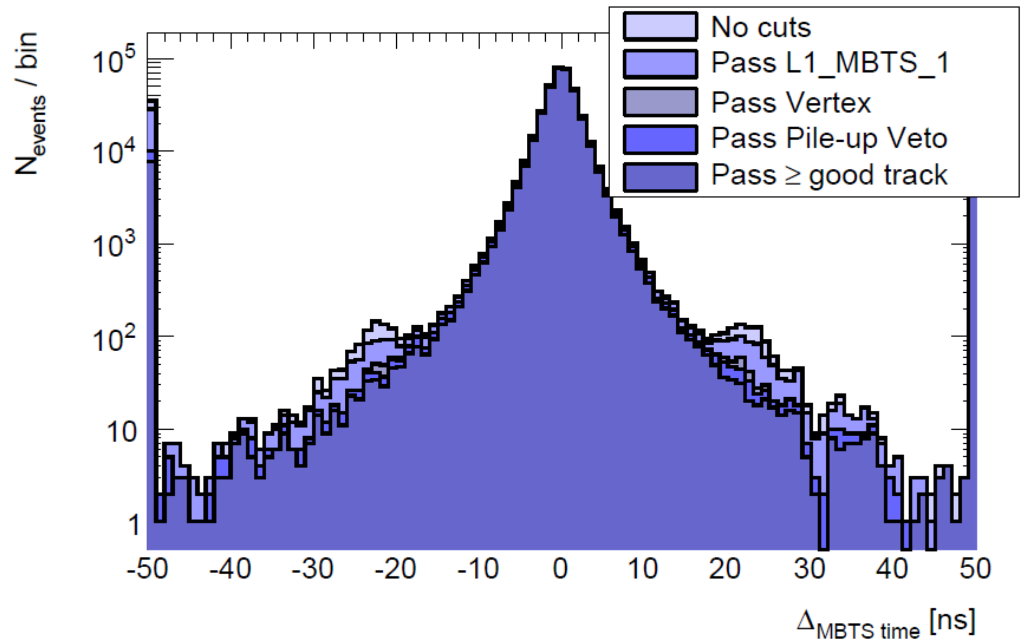
- Fast analysis of 7 TeV data for DIS'10 Conference

  - Just use first usable run: 152166
  - 369673 events, 3769168 tracks after selection
  - Already more statistics than 900 GeV data
  - Change the procedure as little as possible
  - Run new tracking scheme but use old cuts

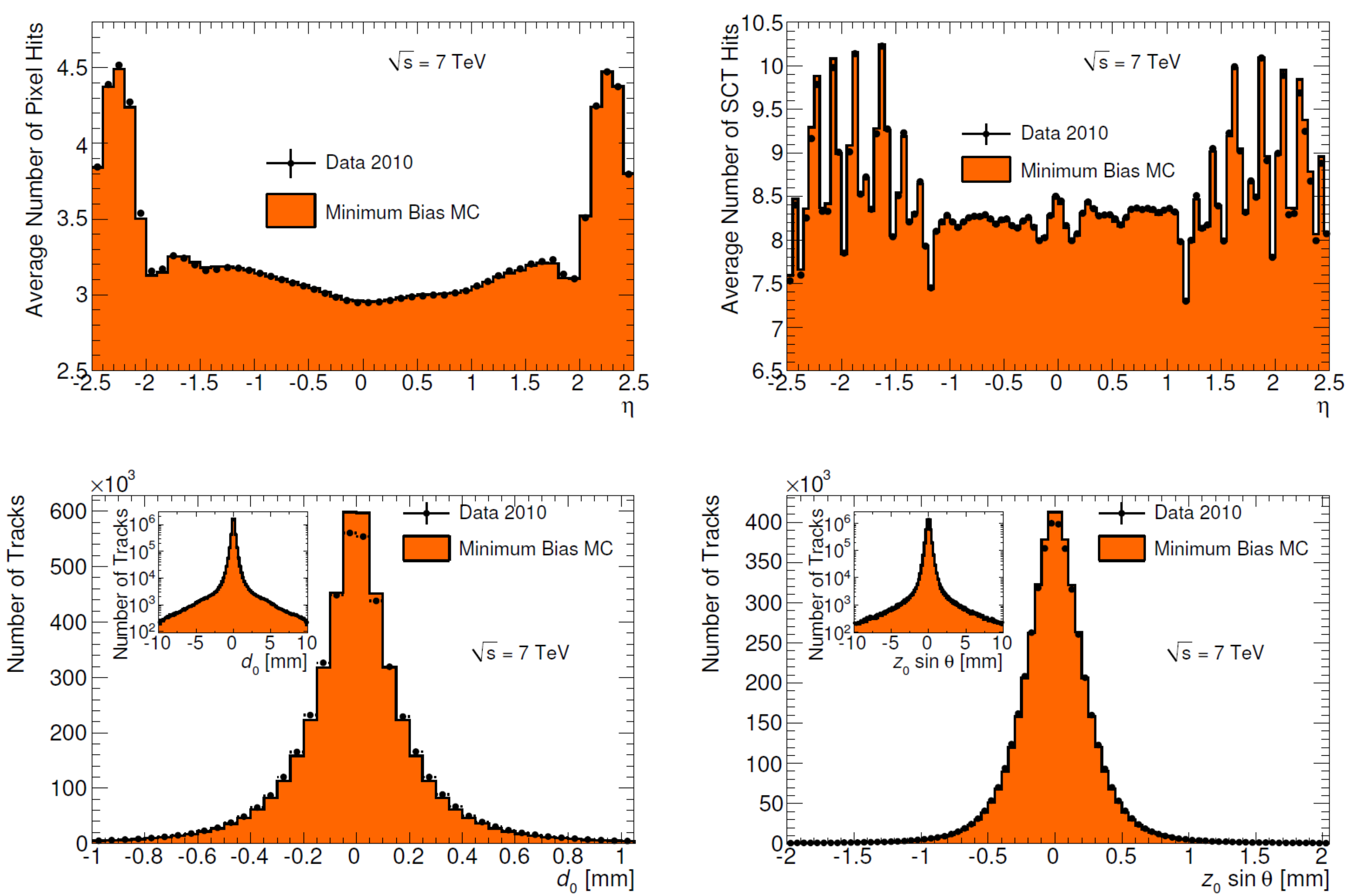
Status presented here
COM Notes in circulation
Not public results yet!

ATL-COM-PHYS-2010-188/189



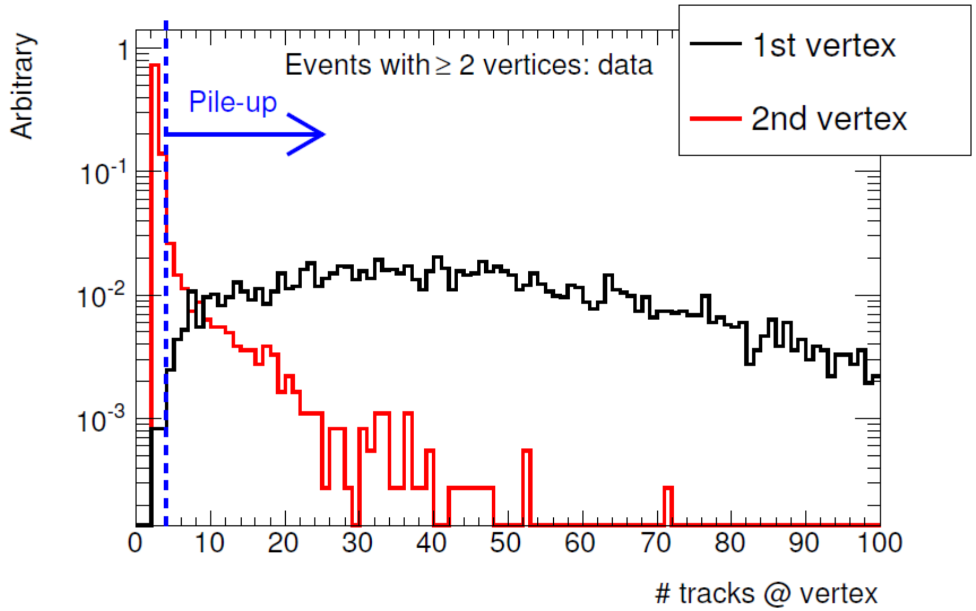
# Tracking at 7 TeV

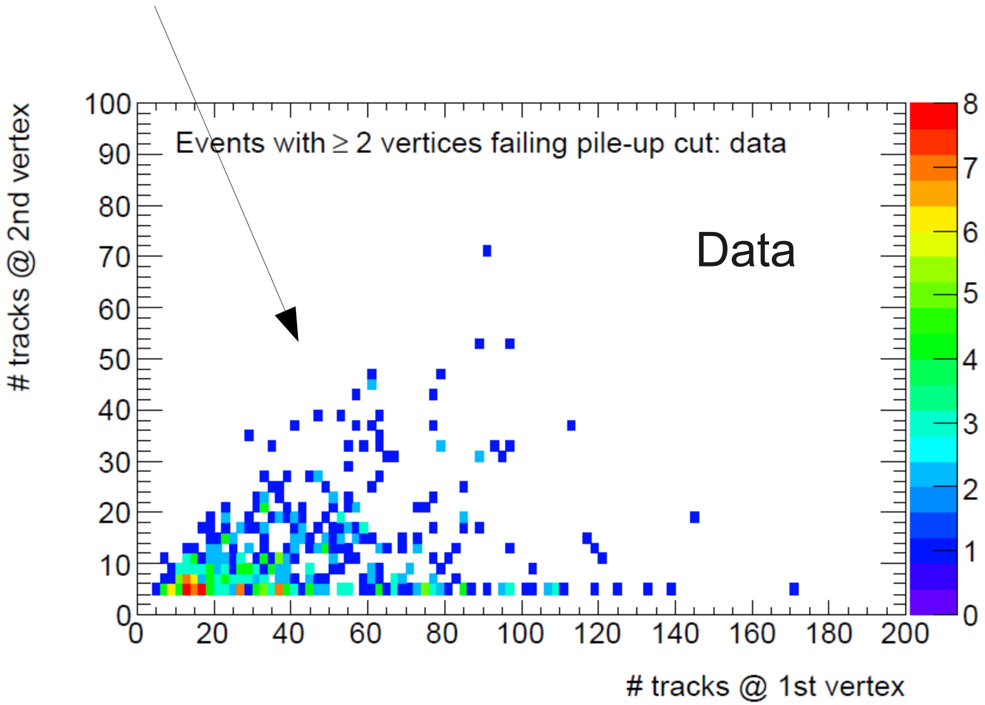


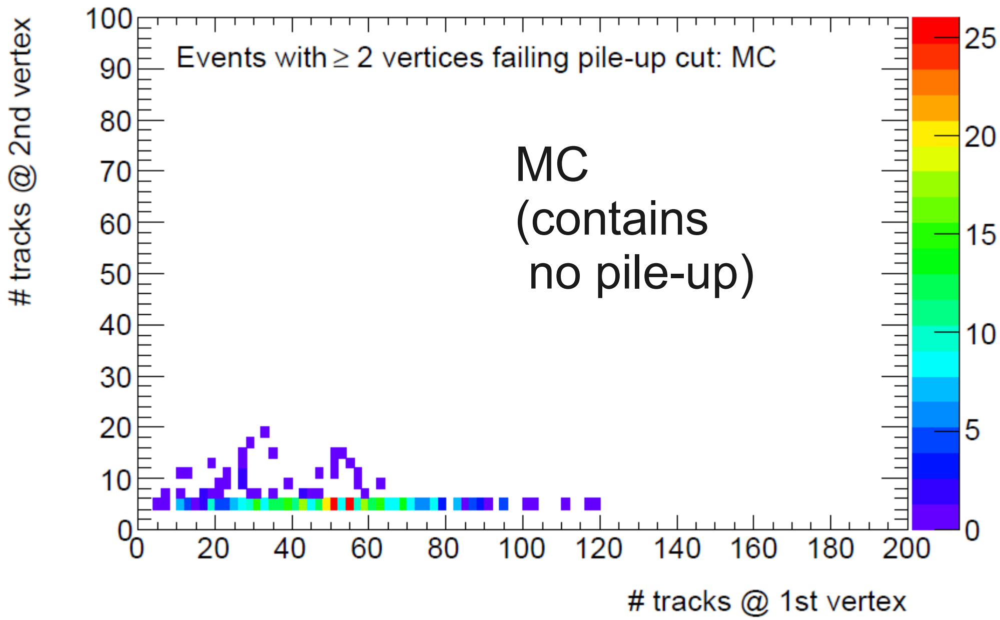

Pixel Hits, SCT Hits and Impact Parameters just as described as in 900 GeV data

# Vertexing at 7 TeV

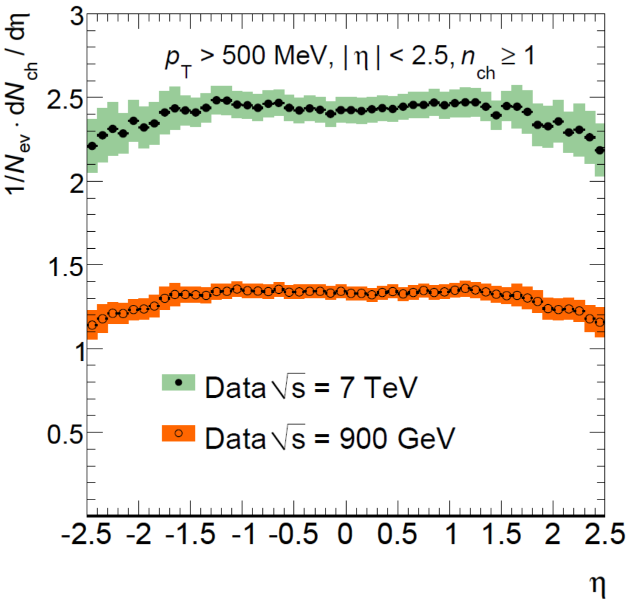
- Pile-up possible at high beam intensity
- (Almost) not the case in the present data sample
- Studied in detail nevertheless
- Strategy: Remove real pile-up events
- Define anti-pile-up cut:
  Second vertex may not have more than 3 track
- Estimate $10^{-4}$ pileup events remaining in data



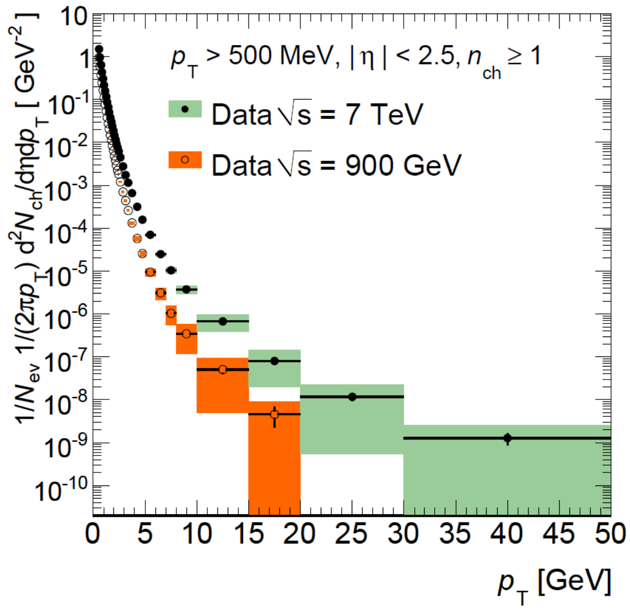



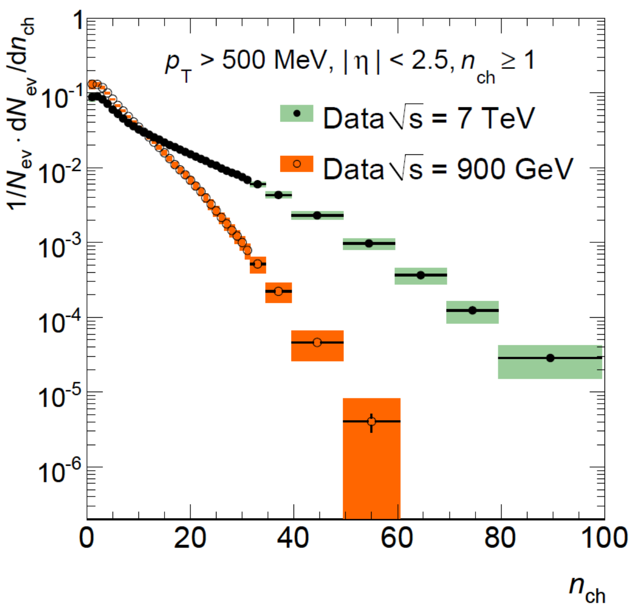
# Comparison 900 GeV and 7 TeV Data

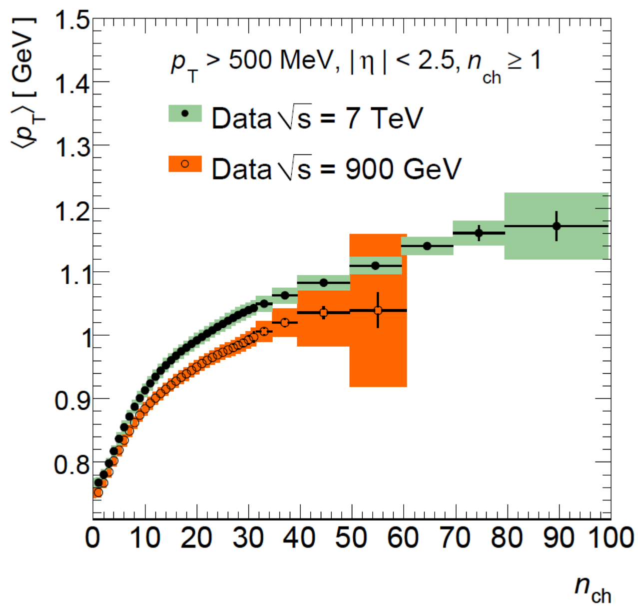



(a)



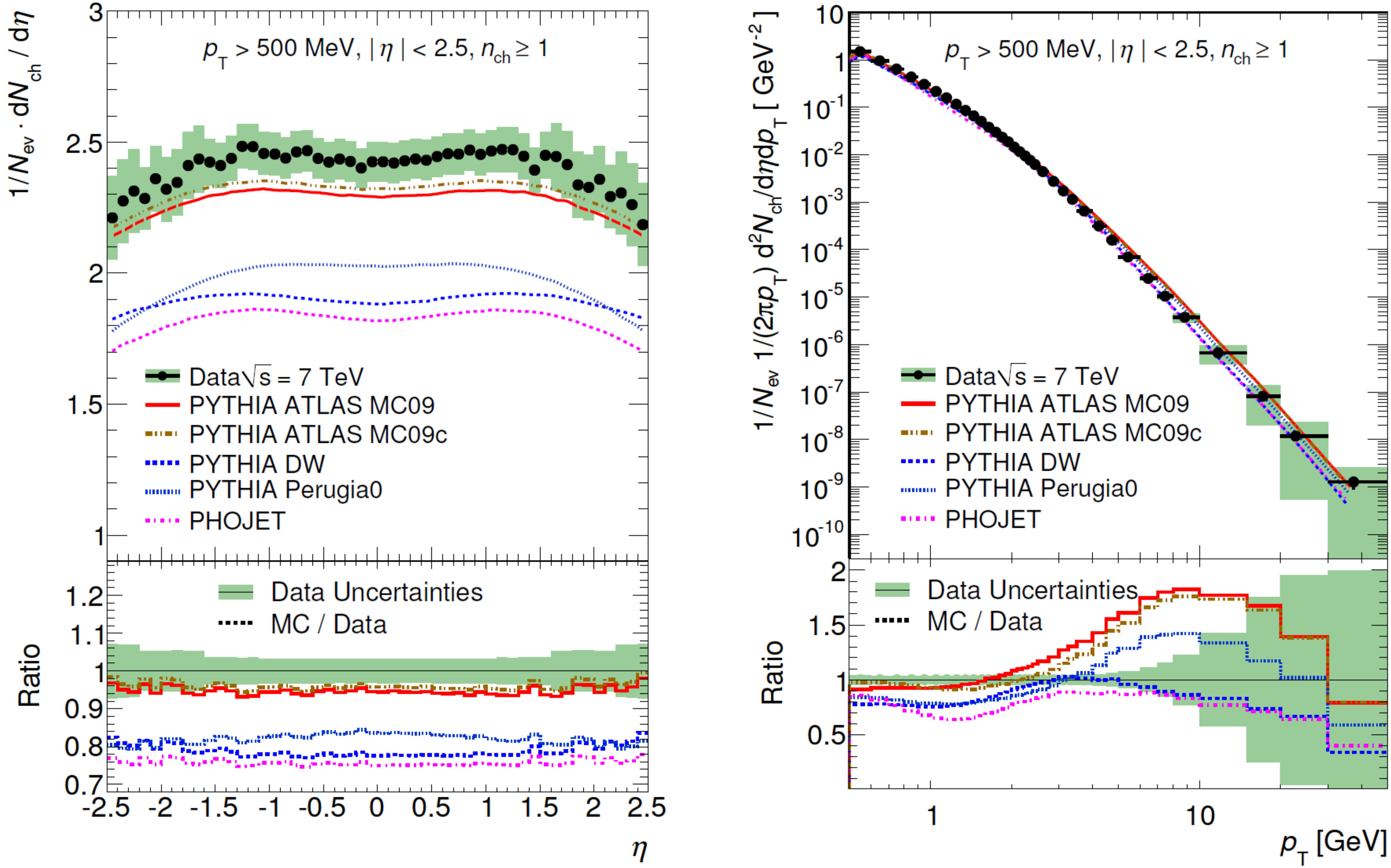

(b)



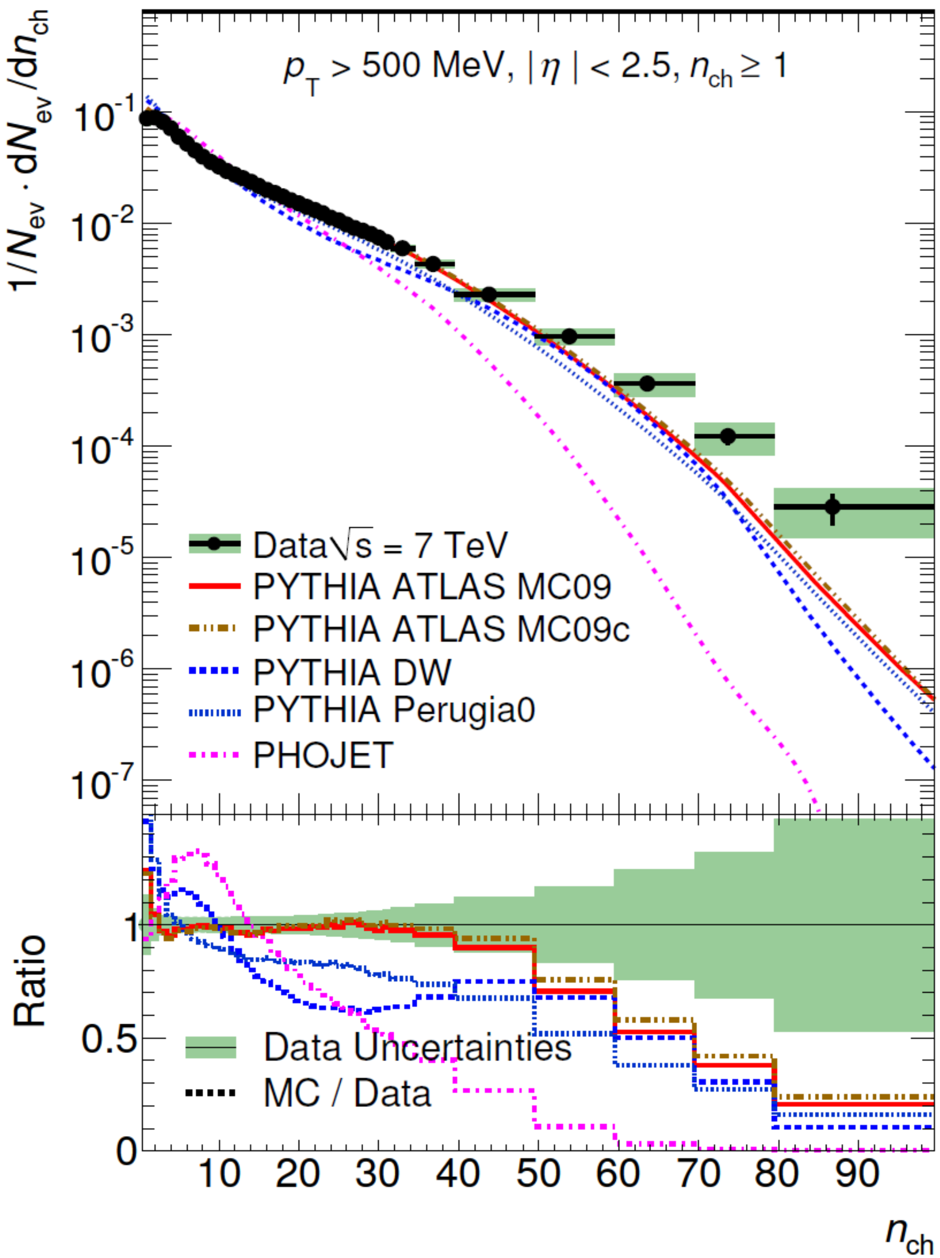



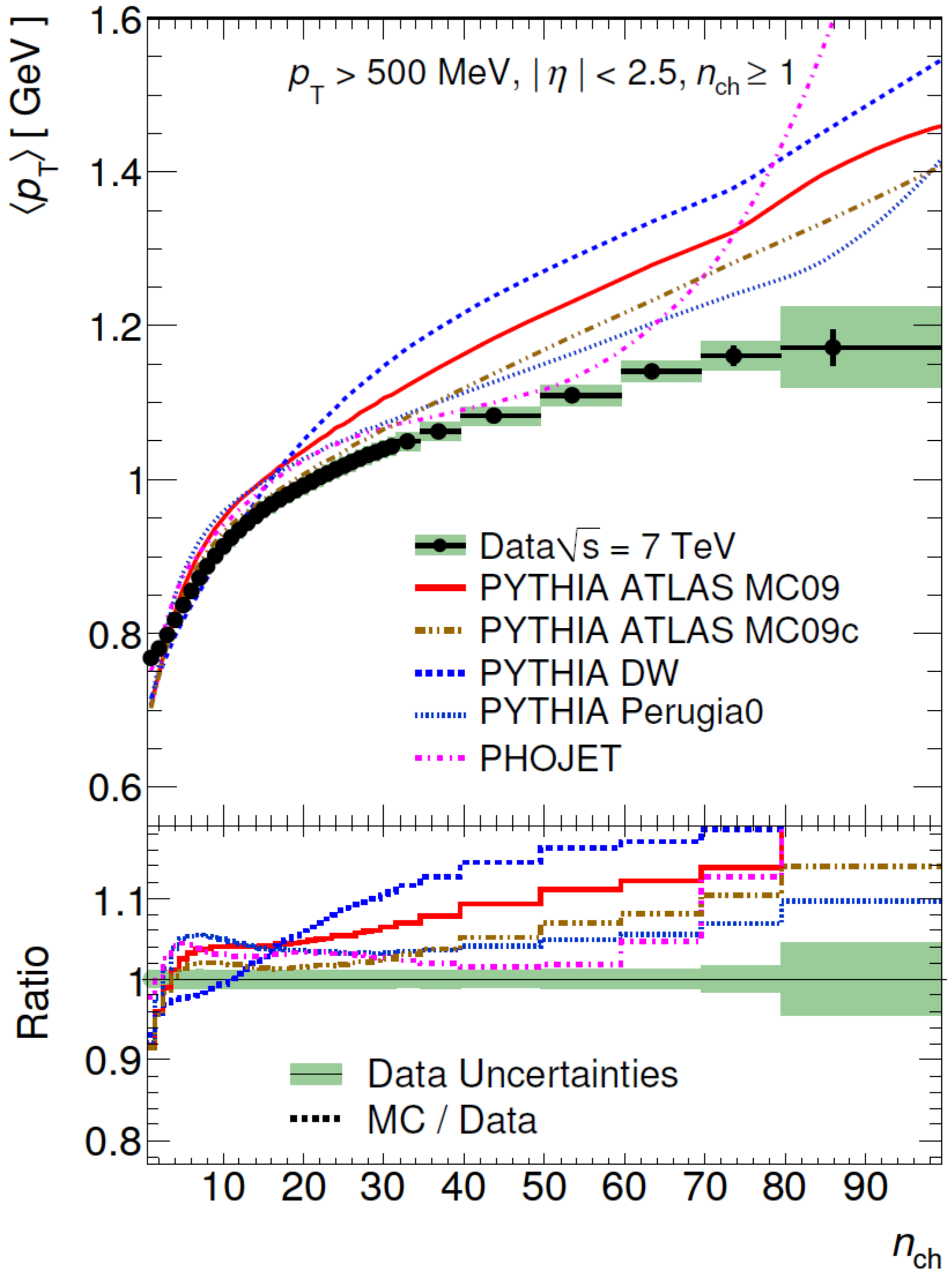

- Higher particle multiplicity and densities in all distributions

# First look at 7 TeV Data



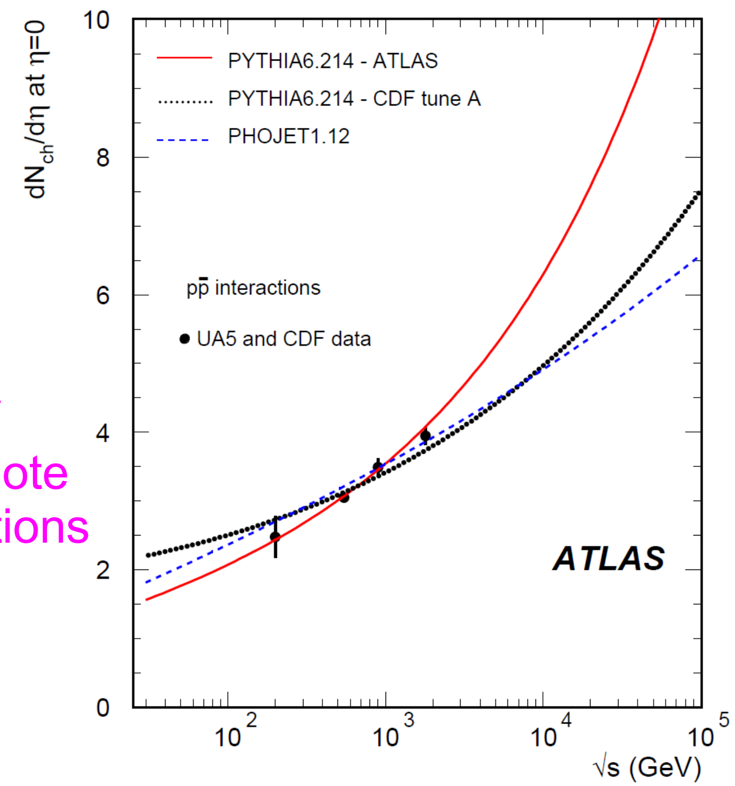
# First Look At 7 TeV Data

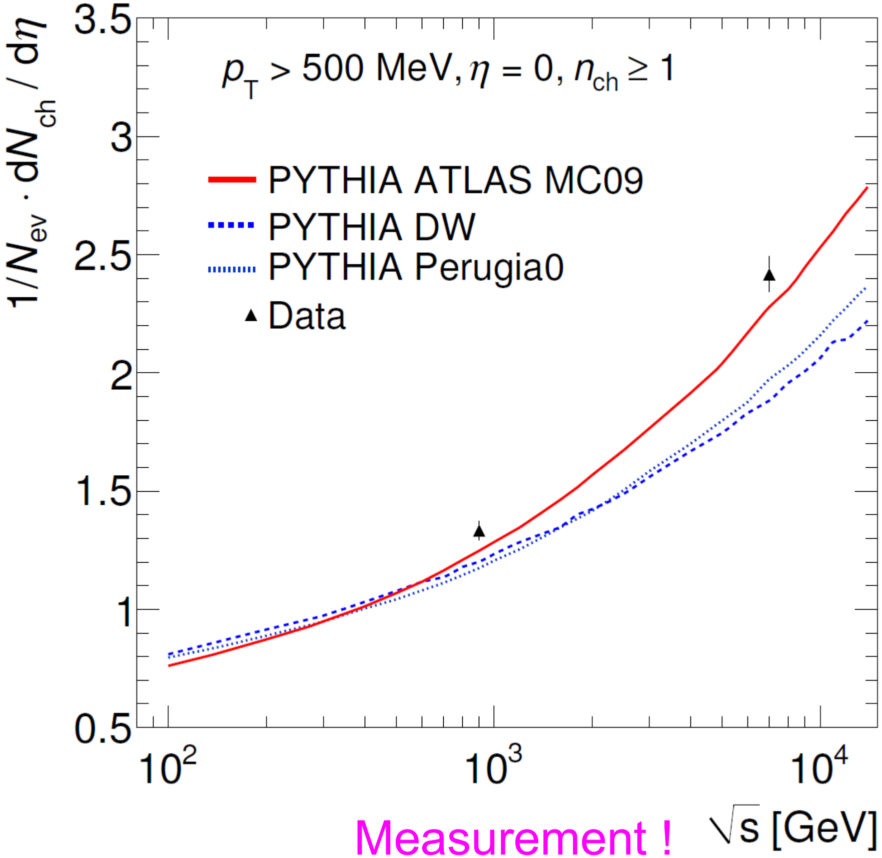


# Energy Dependence of dN/d$\eta$ at $\eta$=0

14 TeV
CSC Note
Predictions




Measurement !

Fig. 1: Central charged particle density for non-single diffractive inelastic $p$-$\bar{p}$ collisions.

- Difficult to compare different experiments due to different phase space definitions ($p_T$>0 / > 500 MeV cut, NSD / inelastic, …)
- Only feature ATLAS on plot
- Surprisingly well agreement with MC predictions

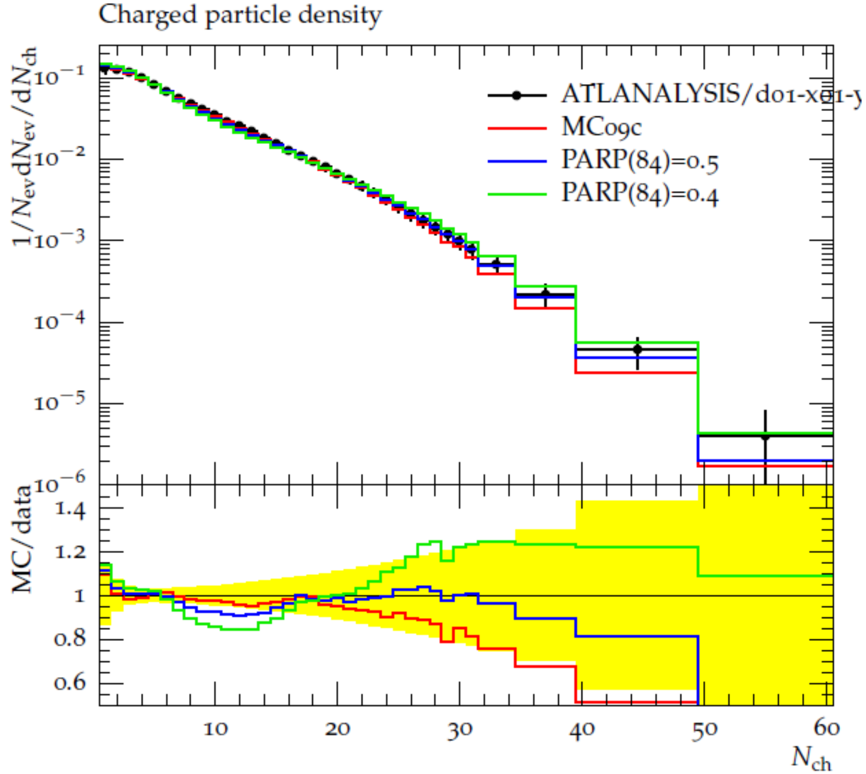
# Application: MC Tuning

- ATLAS has its own MC tuning group – extremely fast response to new data
- Tune to results already in progress – problems with diffraction – removal preferred

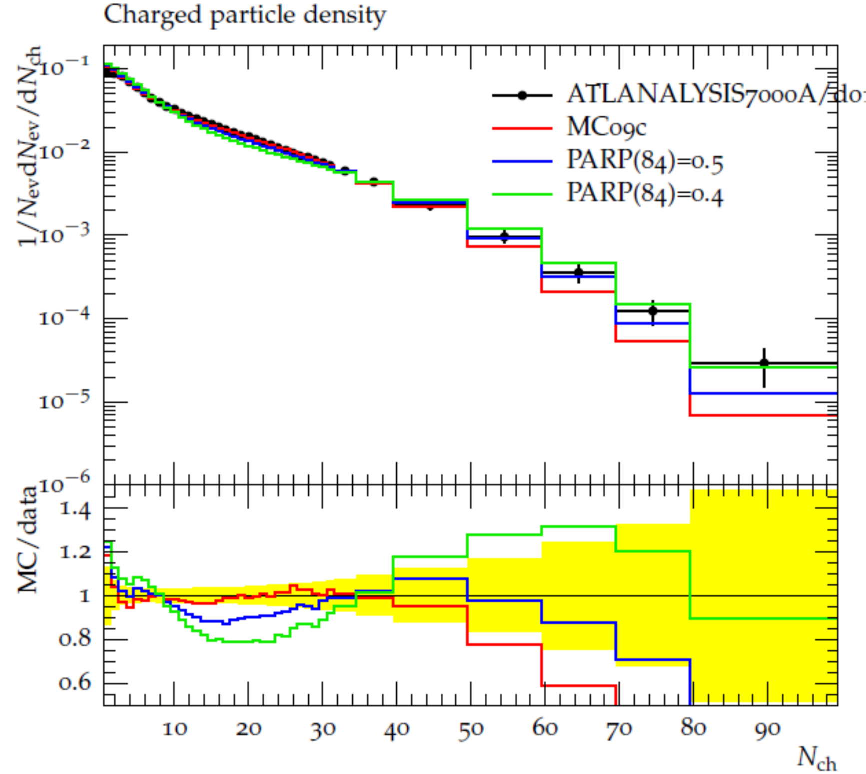
Yes we can...

M. Warsinsky

900 GeV:



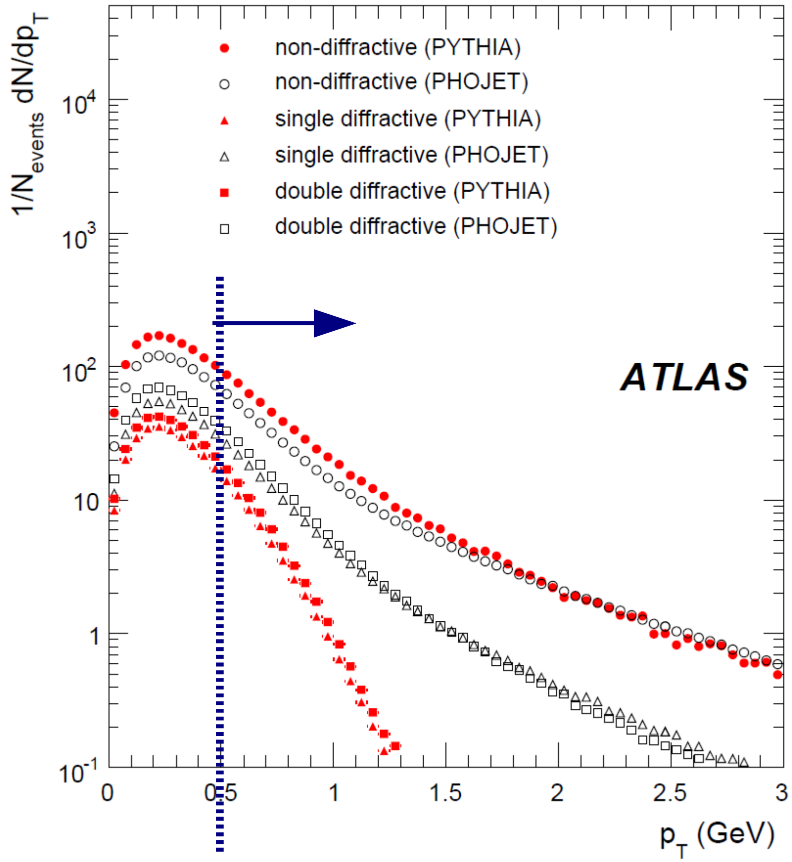

7 TeV:




- This is just to show that there are model parameters that can only be deduced from the non-diffractive part
- Is not a tune yet, but we can use this only if we can sure that there is no diffraction left!

# Outlook: 7 TeV Analysis for Paper

- Planned for the next 1-2 months
- Again just analyse data
  (no fits, extrapolations etc.)
- Data samples frozen last friday
- Use new tracking scheme
  including low $p_T$ tracking
- Go to $p_T$ as low as possible ~150 MeV?




Need data below $p_T$>500 MeV to
Eventually allow good fit down to
$p_T$ = 0 GeV

# Conclusion

- First Physics Results from ATLAS using *p-p* collisions at LHC Charged Particle Production in Inelastic Events
- Excellent Description of Inner Detector by Monte Carlo Simulation.
- Tracks corrected to particles with minimal model dependence.
- Charged Particle Multiplicity per Event and Unit of Pseudorapidity 5%-15% higher than Monte Carlo models.
- Application of Results
  - MC Tuning group works on improved tune.
  - Work to cross-calibrate lumi across experiments and constrain models further in progress.

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Just the supporting notes for the first paper