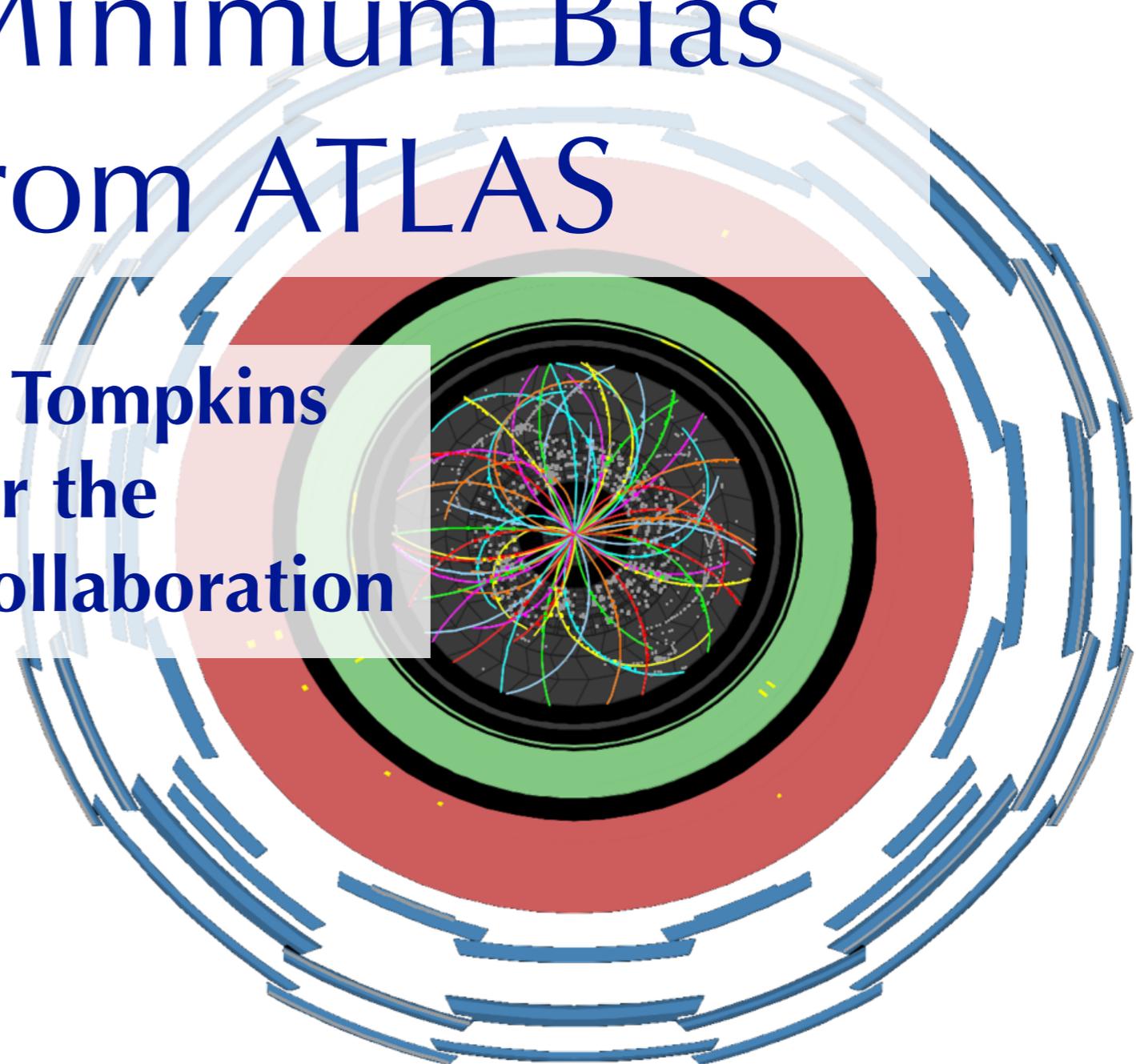
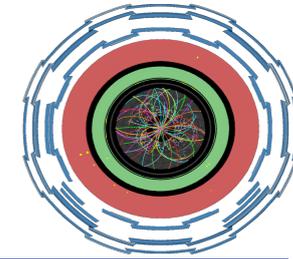


# Inclusive and Diffraction Enhanced Minimum Bias Results from ATLAS

**Lauren Tompkins  
for the  
ATLAS Collaboration**

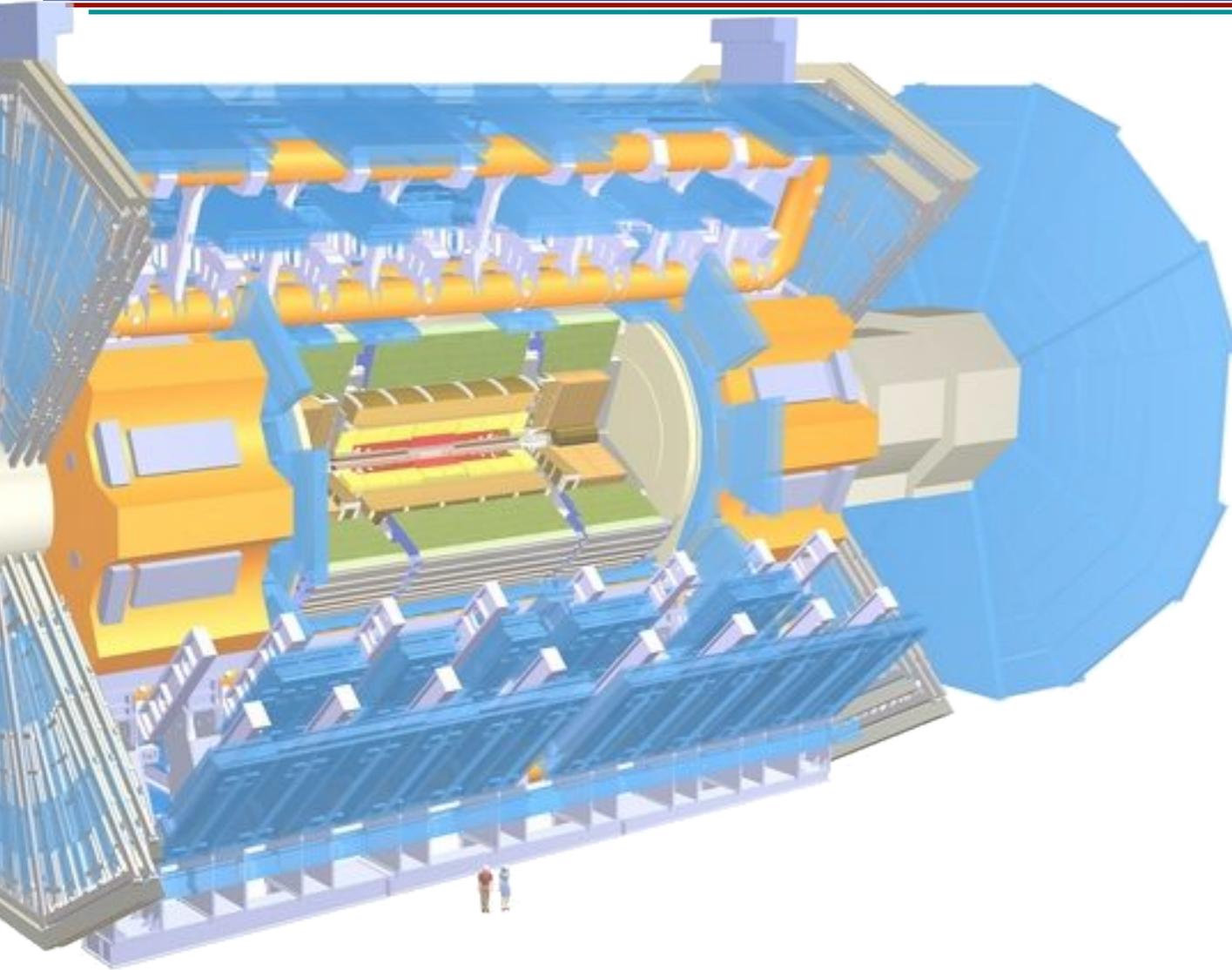
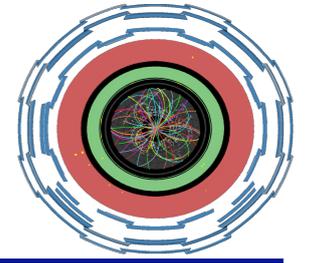


# Since we last met...



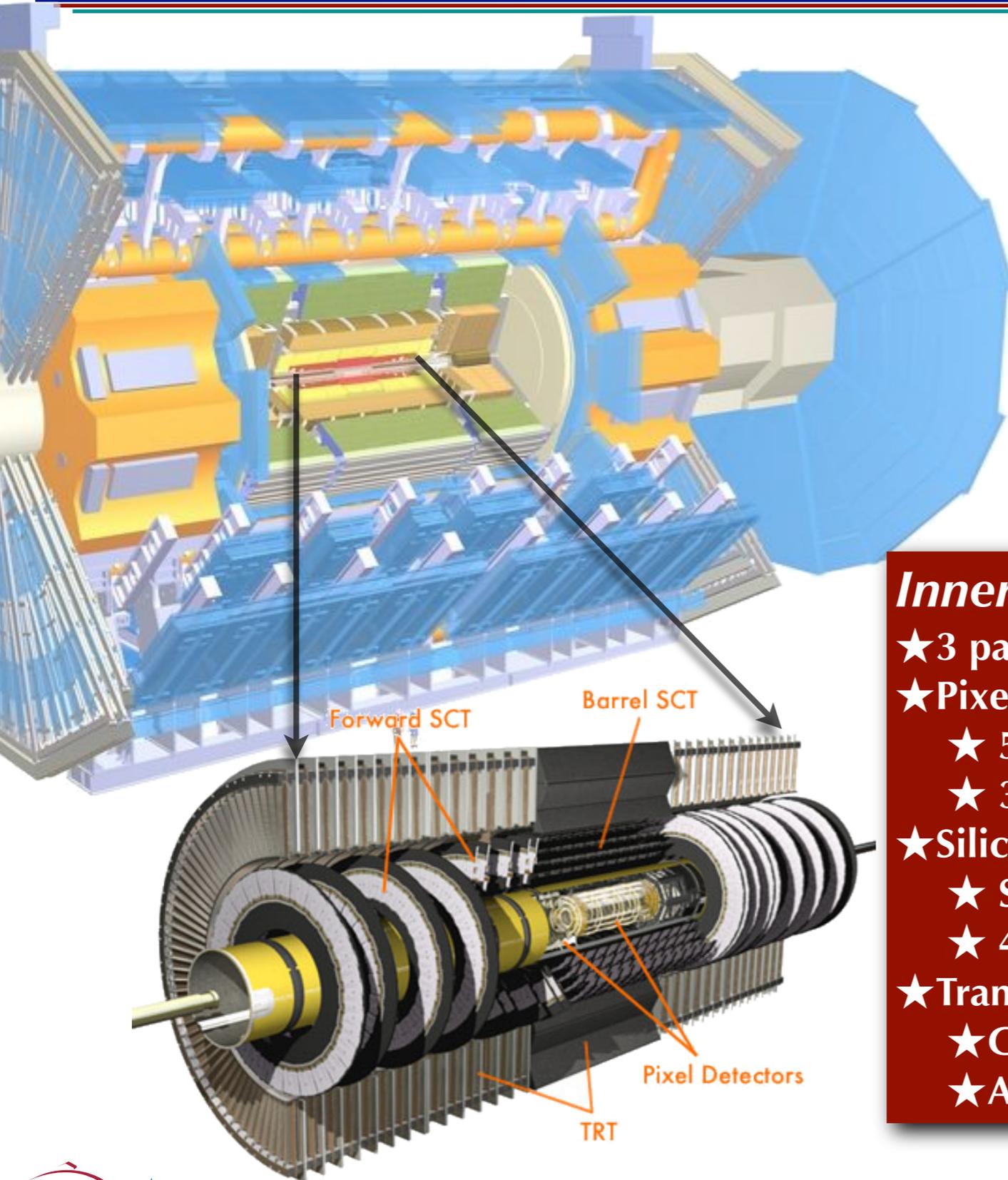
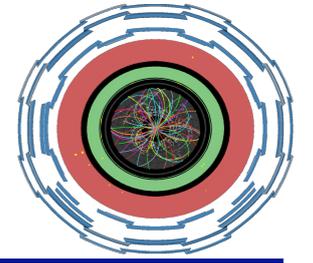
- Previously shown by ATLAS at UE&MB@LHC:
  - Inclusive min bias at @900 GeV & 7 TeV with min charged particle  $p_T$  of 500 MeV
  - Also showed tune from diffraction suppressed phase space ( $N_{ch} \geq 6$ ) : AMBT1 Tune
- Developments presented today:
  - **New phase space:** 900 GeV & 7 TeV inclusive distributions with min  $p_T$  of 100 MeV,  $N_{ch} \geq 2$
  - **New Energy:** 2.36 TeV data has been analyzed with 500 MeV min  $p_T$  cut,  $N_{ch} \geq 1$  (technically challenging)
  - **New exclusive selection:** diffractive enhanced sample achieved by requiring a rapidity gap using MB scintillators; 500 MeV min  $p_T$  cut,  $N_{ch} \geq 1$

# ATLAS Detector



Underlying Event and Diffraction with ATLAS  
Lauren Tompkins, August 11th, 2010

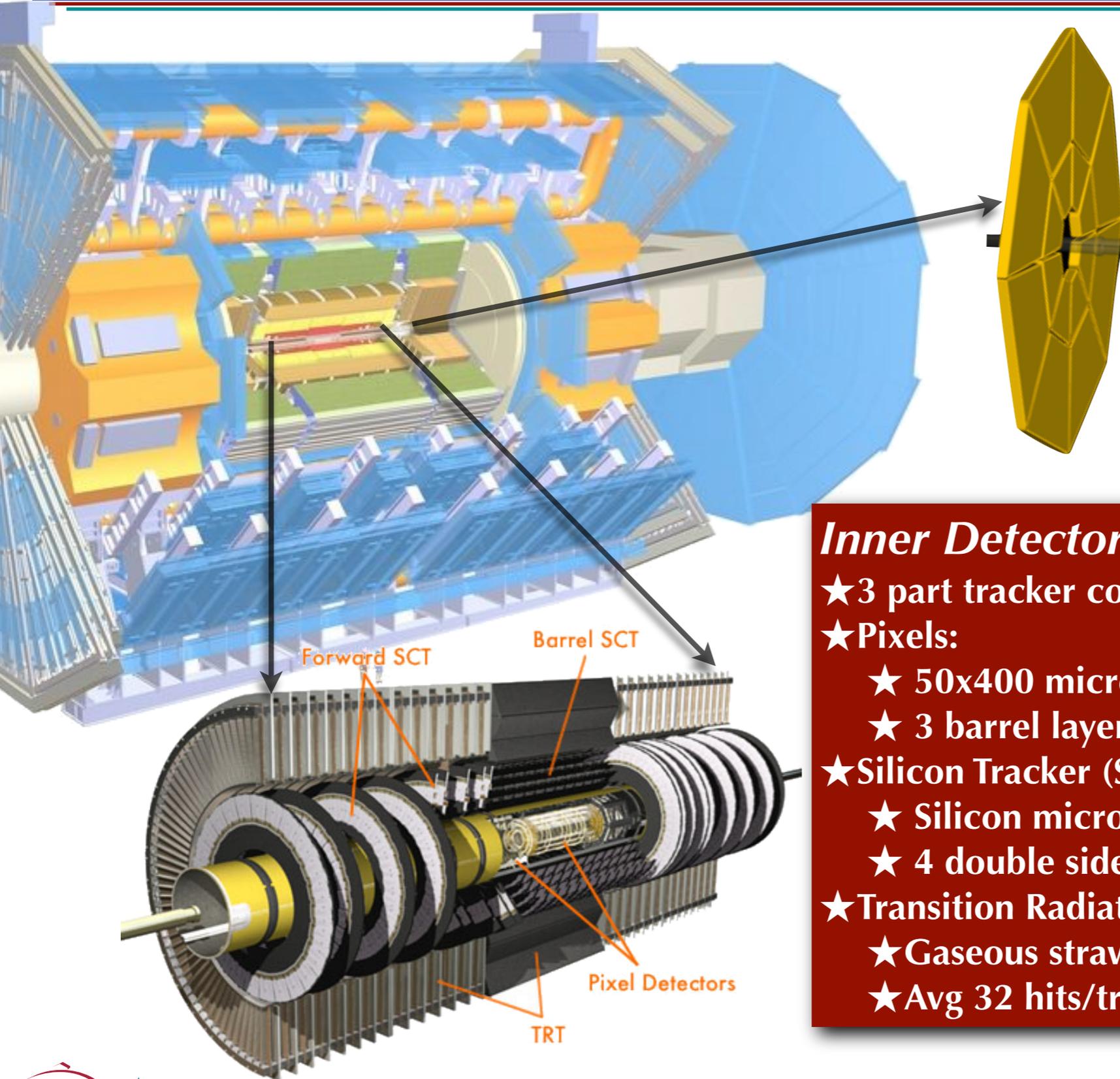
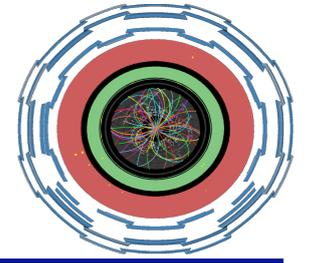
# ATLAS Detector



## *Inner Detector:*

- ★ 3 part tracker covering  $|\eta| < 2.5$ :
- ★ Pixels:
  - ★ 50x400 micron silicon pixels
  - ★ 3 barrel layers, 2x3 endcap layers
- ★ Silicon Tracker (SCT)
  - ★ Silicon microstrip detector
  - ★ 4 double sided barrel layers, 2x9 endcap
- ★ Transition Radiation Tracker (TRT):
  - ★ Gaseous straw tube detector
  - ★ Avg 32 hits/track

# ATLAS Detector



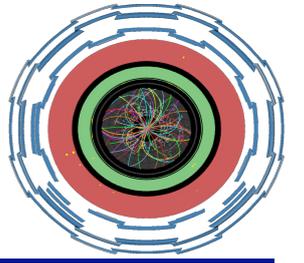
## *Minimum Bias Trigger Scintillator:*

- ★ Detector specifically for MB events
- ★ 2cm thick polystyrene scintillators
- ★ Mounted on endcap calorimeter cryostat face plates ( $Z = 3.6$  m)
- ★ Covers  $2.09 < |\eta| < 3.84$
- ★ 8 modules in  $\phi$ , 2 rings in  $\eta$  per side

## *Inner Detector:*

- ★ 3 part tracker covering  $|\eta| < 2.5$ :
- ★ Pixels:
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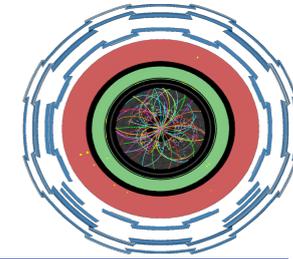
# Sketch of ATLAS Strategy



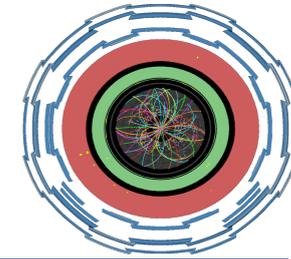
- Guiding principle: *Inclusive, model independent measurement in a well defined phase space*
- Select events passing:
  - Single armed minimum bias trigger scintillator
  - Presence of a good primary vertex
  - At least N good quality tracks passing impact parameter cuts with respect to the PV.
- Only correct for:
  - Tracking inefficiency
    - at both track and event level
  - Vertex and trigger inefficiencies
  - Contamination from secondaries and particles which migrate into phase space due to resolution effects

# From 500 to 100 MeV

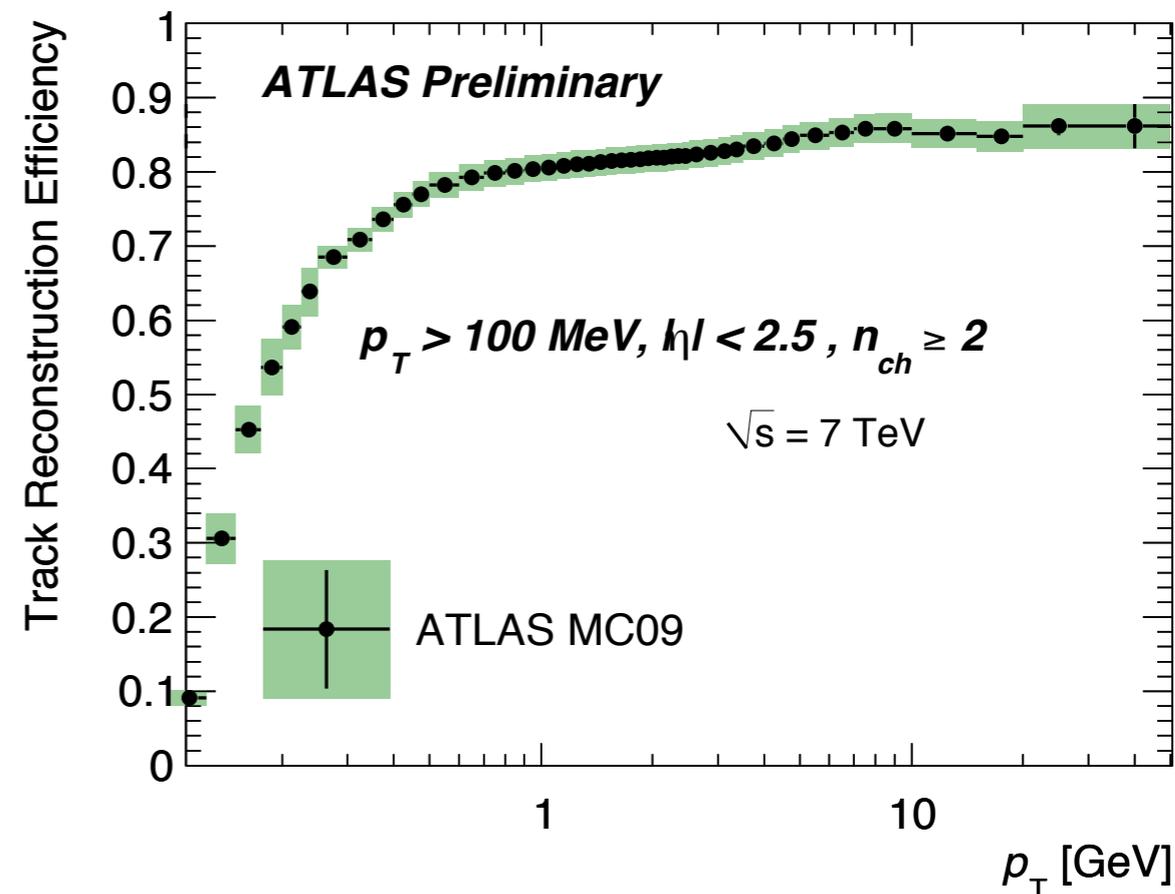
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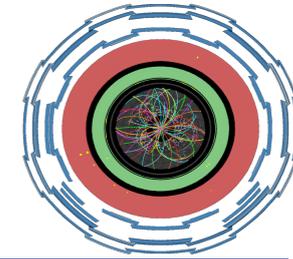
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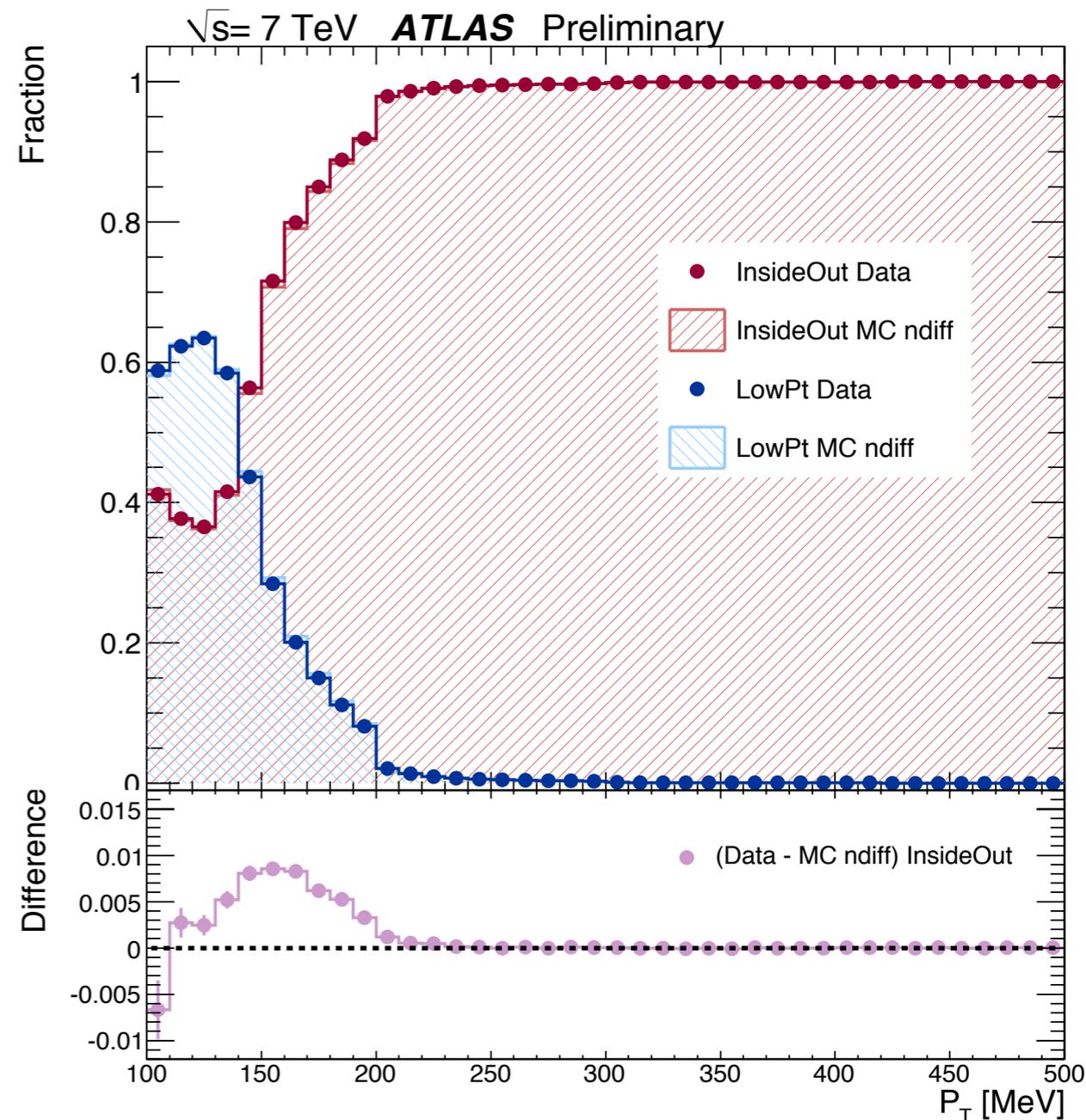
- Reducing the minimum  $p_T$  to 100 MeV faced a number of challenges:



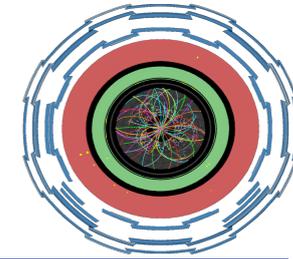
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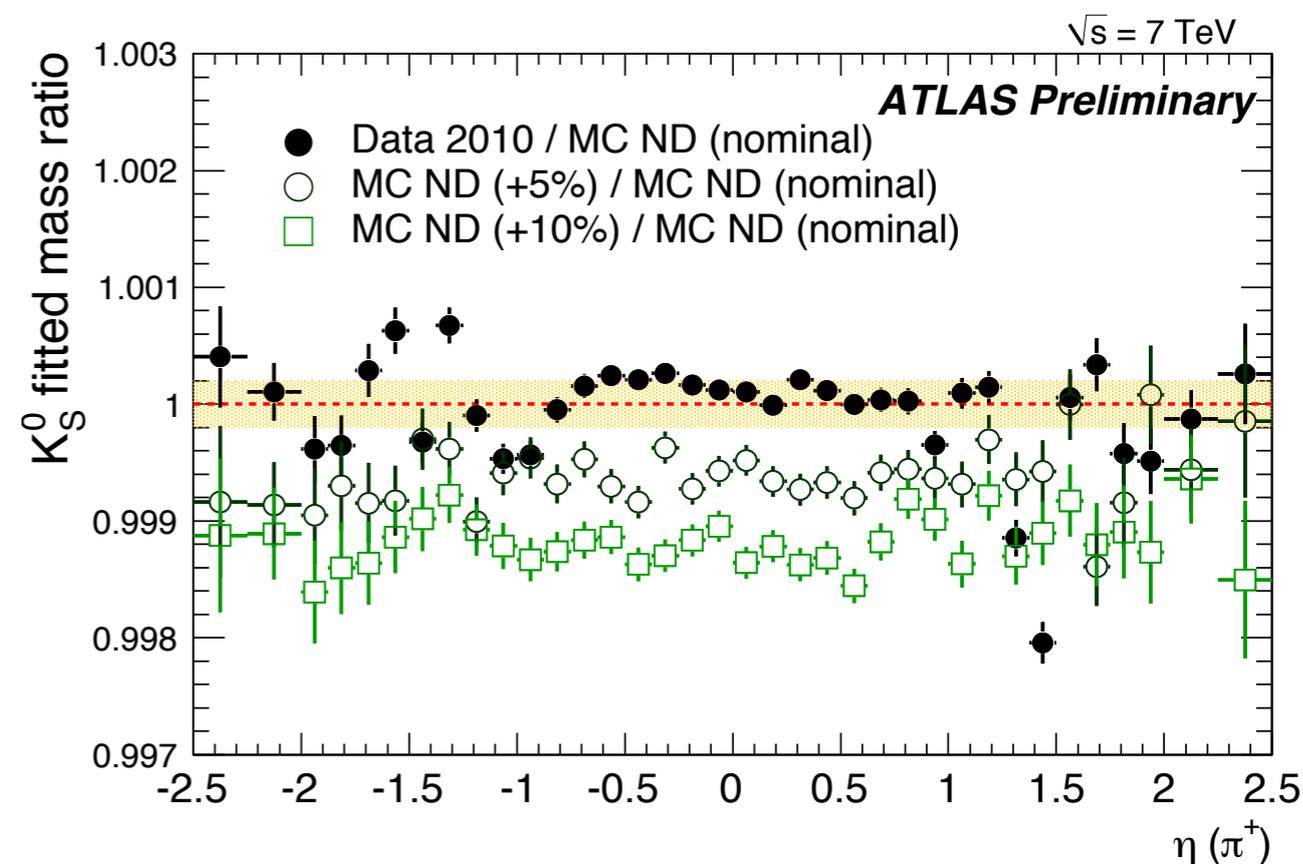
- Reducing the minimum  $p_T$  to 100 MeV faced a number of challenges:
- Do we understand how our tracking algorithms work at low  $p_T$ ?



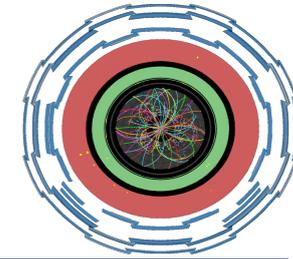
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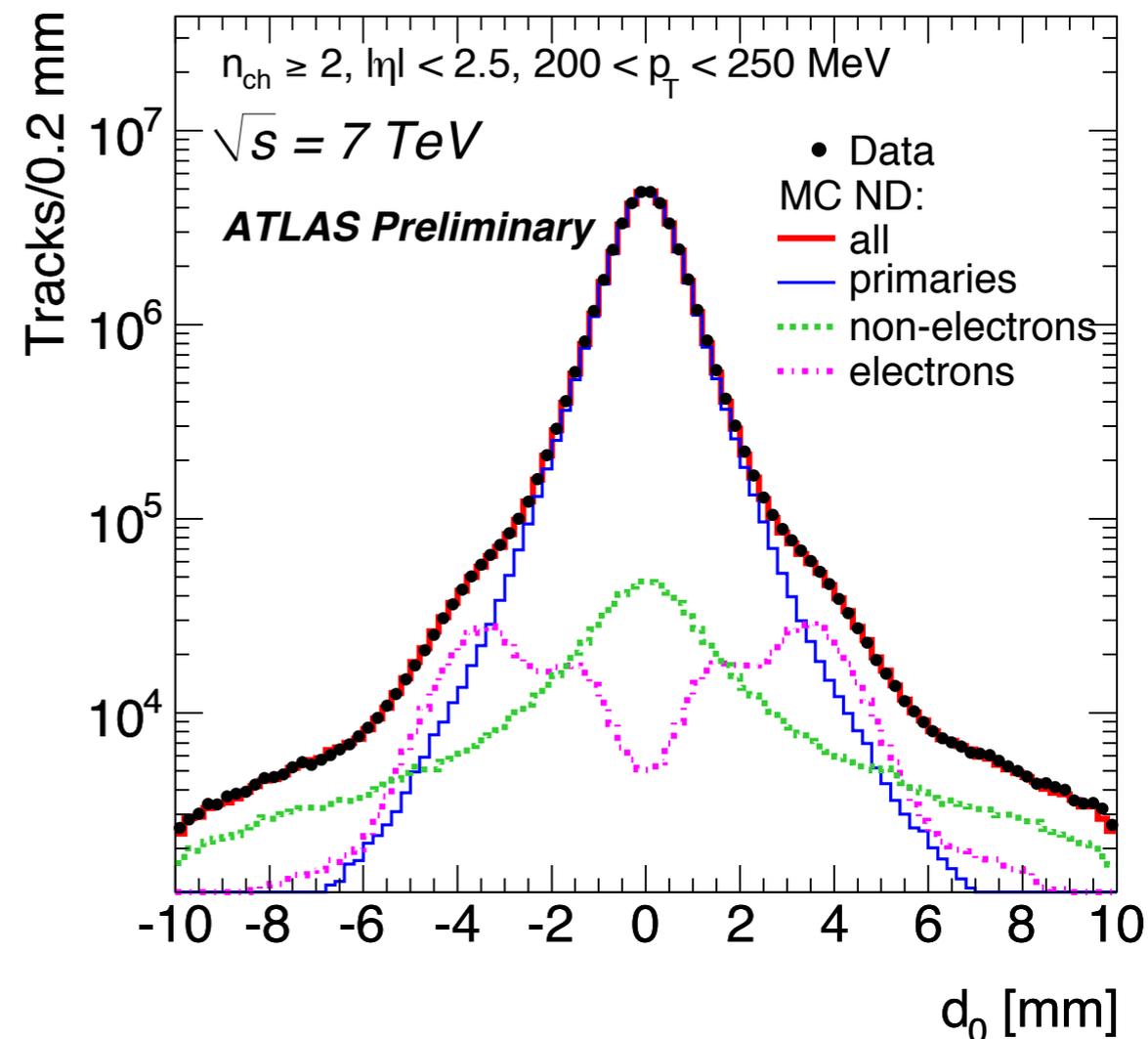
- Reducing the minimum  $p_T$  to 100 MeV faced a number of challenges:
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- Tracking efficiency: how well does the MC describe the data at relatively low average efficiency?



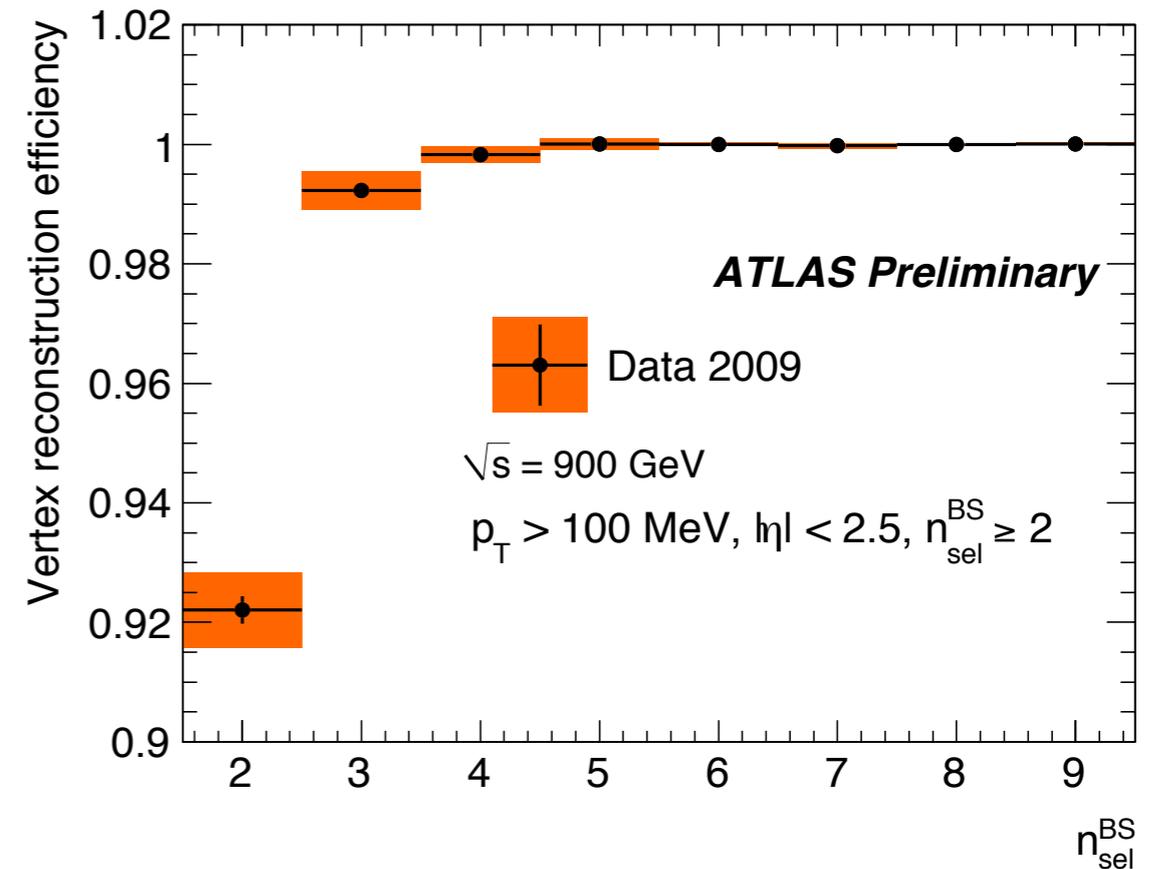
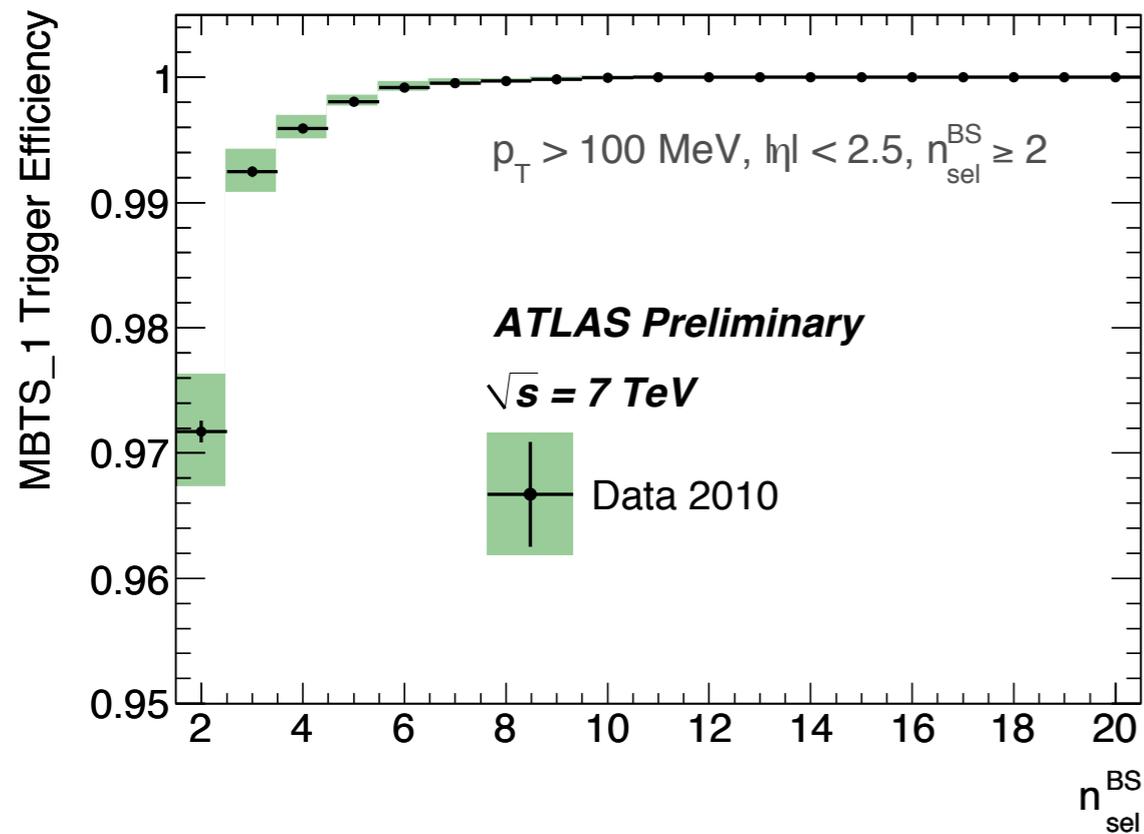
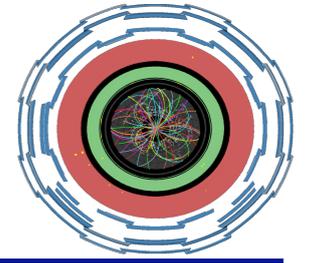
# From 500 to 100 MeV



- Reducing the minimum  $p_T$  to 100 MeV faced a number of challenges:
  - Do we understand how our tracking algorithms work at low  $p_T$ ?
  - Tracking efficiency: how well does the MC describe the data at relatively low average efficiency?
  - Secondaries: do we understand their composition and do data and MC agree?



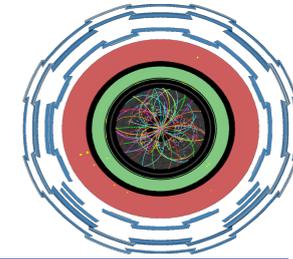
# Trigger & Vertex



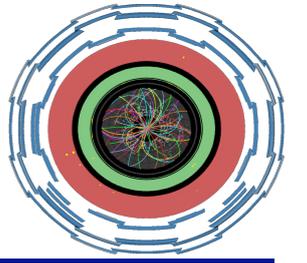
- Trigger and Vertex efficiency measured in data
- Single arm, single hit MBTS trigger requirement
  - Still very high even for events with only 2 tracks
- Vertex efficiency  $>99\%$  when 3 tracks are present

# The Special Case of 2.36 TeV

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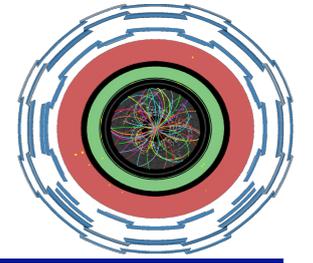


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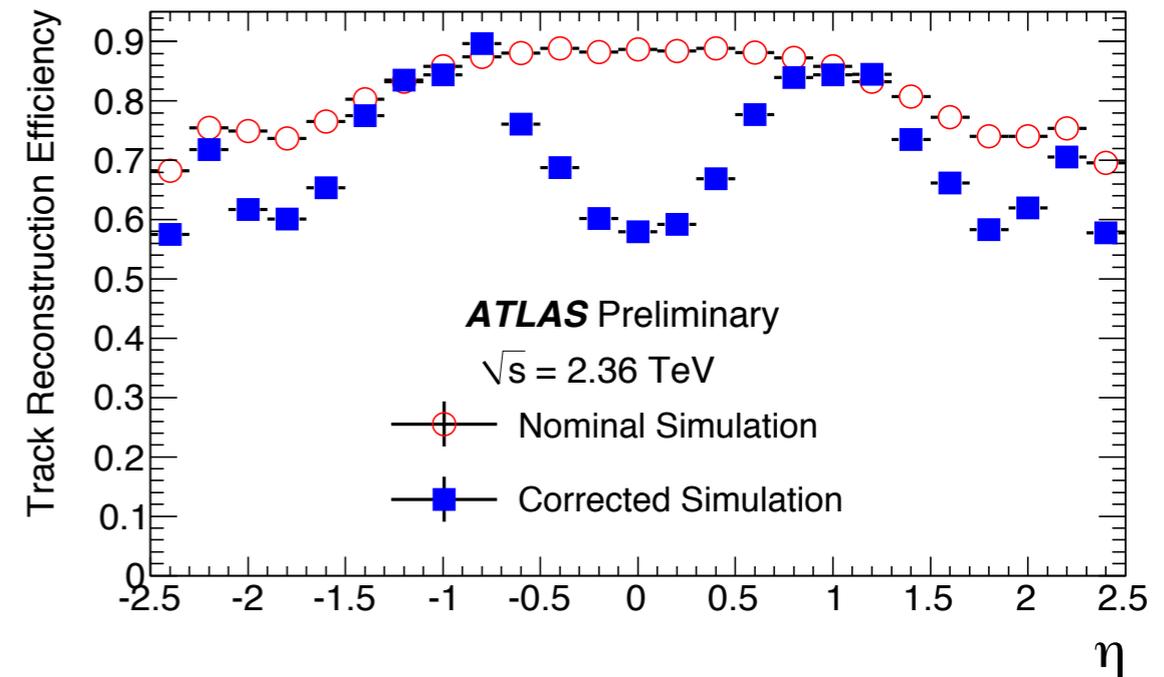


- December 13th&15th 2009 LHC ran at 2.36 TeV:  $\sim 0.1 \mu\text{b}^{-1}$
- Atlas detector was in a special run configuration
  - SCT at 20 V instead of nominal 150V
  - Pixel, TRT at full voltage

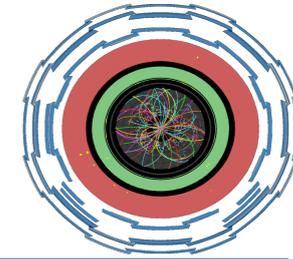
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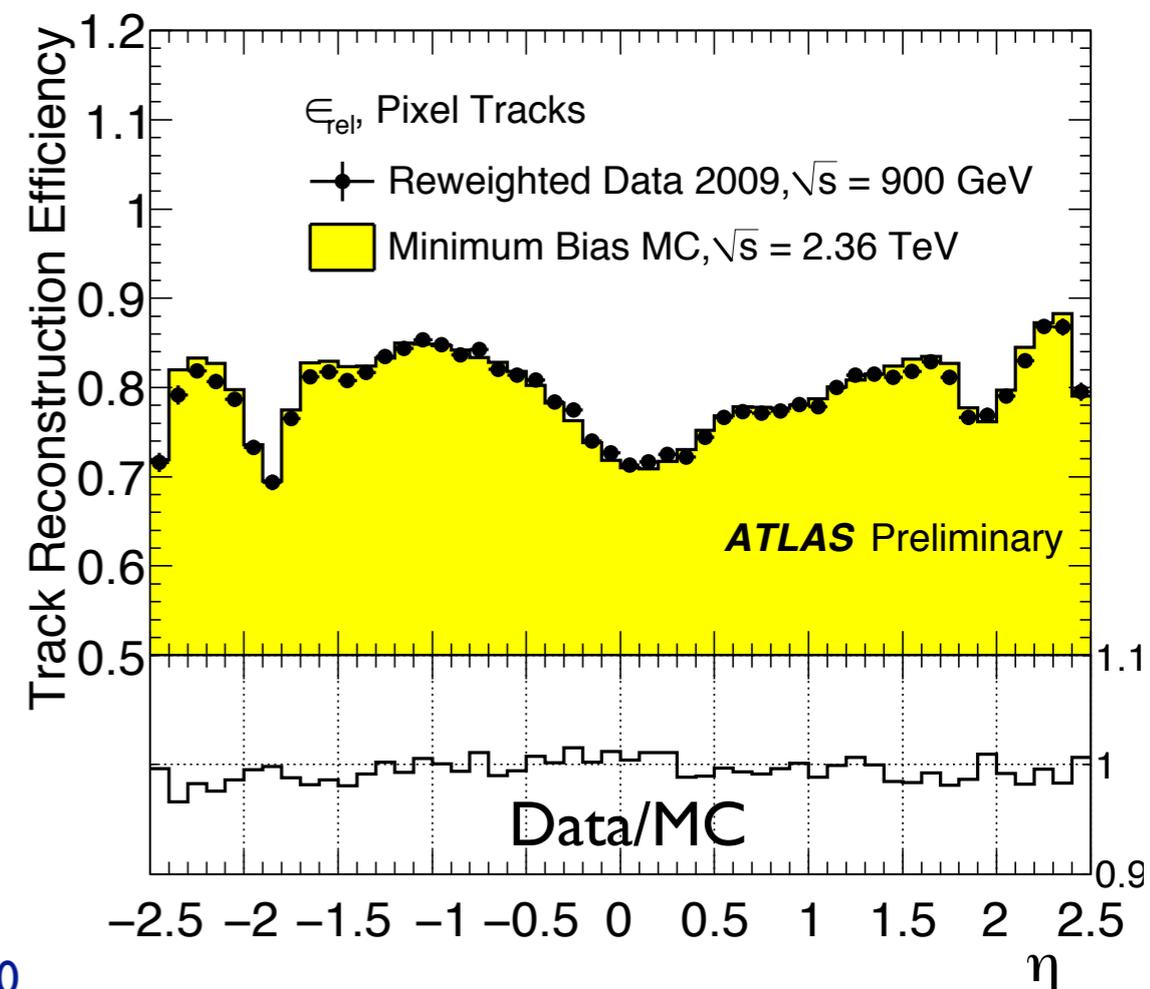
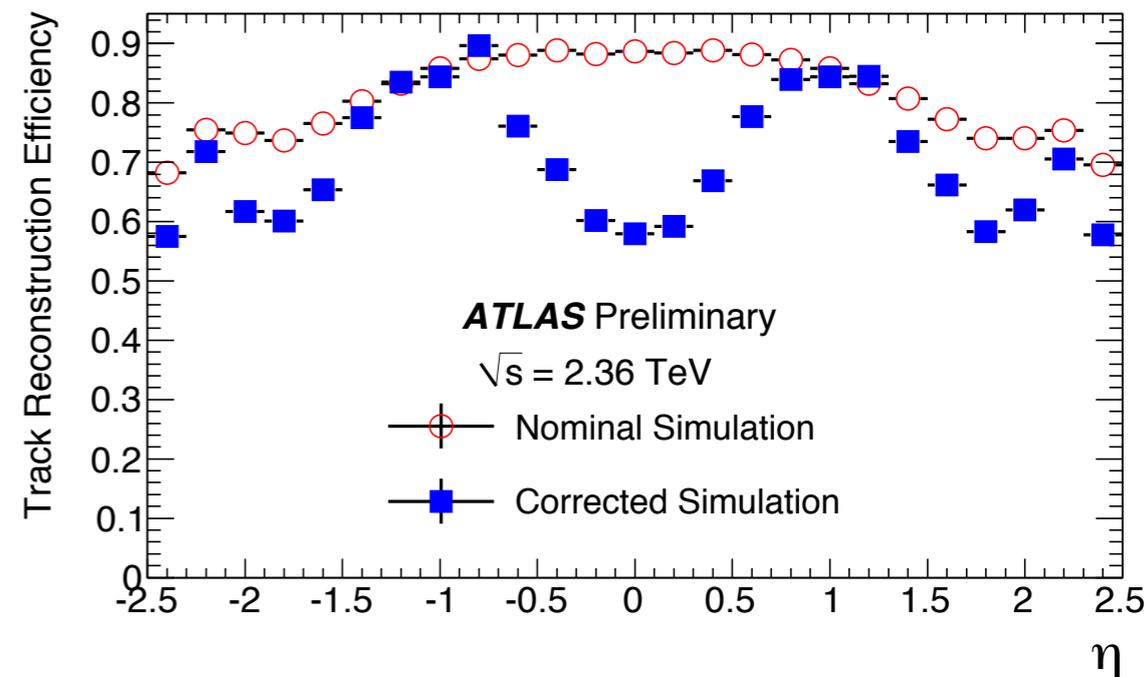
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  - Different tracking configuration
  - MC efficiency was corrected using data



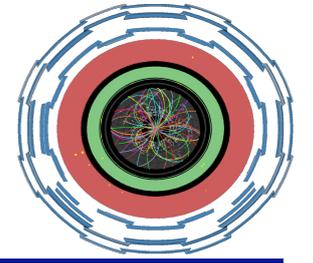
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  - SCT at 20 V instead of nominal 150V
  - Pixel, TRT at full voltage
- Low SCT voltage led to low hit efficiency
  - Different tracking configuration
  - MC efficiency was corrected using data
- Complementary and parallel analysis using Pixel only tracks
  - Higher hit efficiency and less susceptible to secondary contamination



# Reminder: AMBT1



Parameter	Related Model	MC09c value	scanning range	AMBT1 value
PARP(62)	ISR cut-off	1.0	fixed	1.025
PARP(93)	Primordial $k_T$	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

● Atlas AMBT1 tune was developed using *diffraction suppressed* phase space ( $N_{ch} \geq 6, p_T > 500 \text{ MeV}$ )

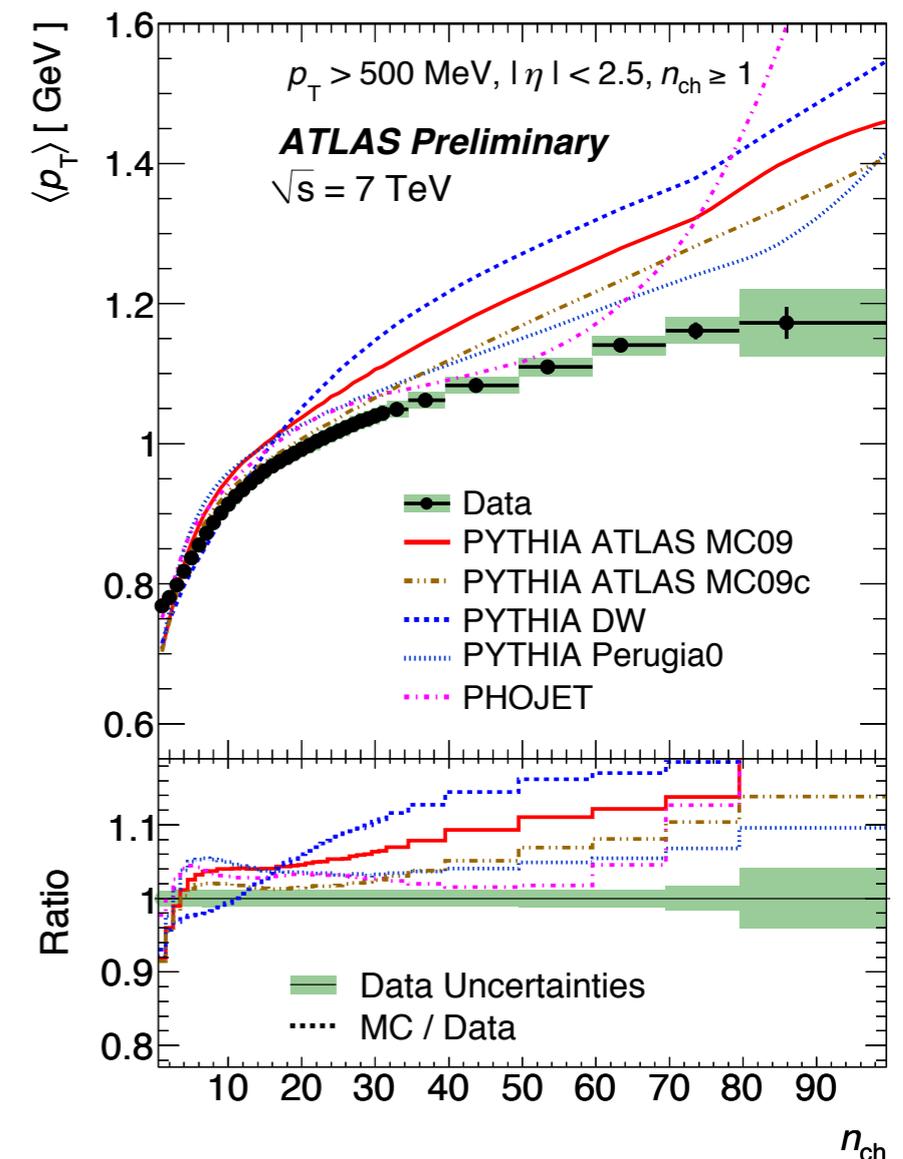
● Color reconnection (CR) and multiple parton interactions (MPI) tuned

● Biggest change in matter core fraction (parp 83) and CR parameters (parp 77&78)

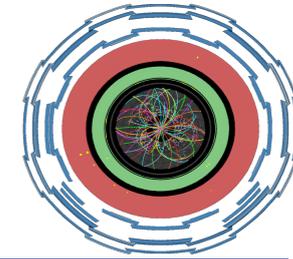
● Performance we expect for new phase space ( $p_T > 100 \text{ MeV}$ ):

● Good agreement for mid  $p_T$  range

● Low  $p_T$  and high  $p_T$  likely to remain problematic



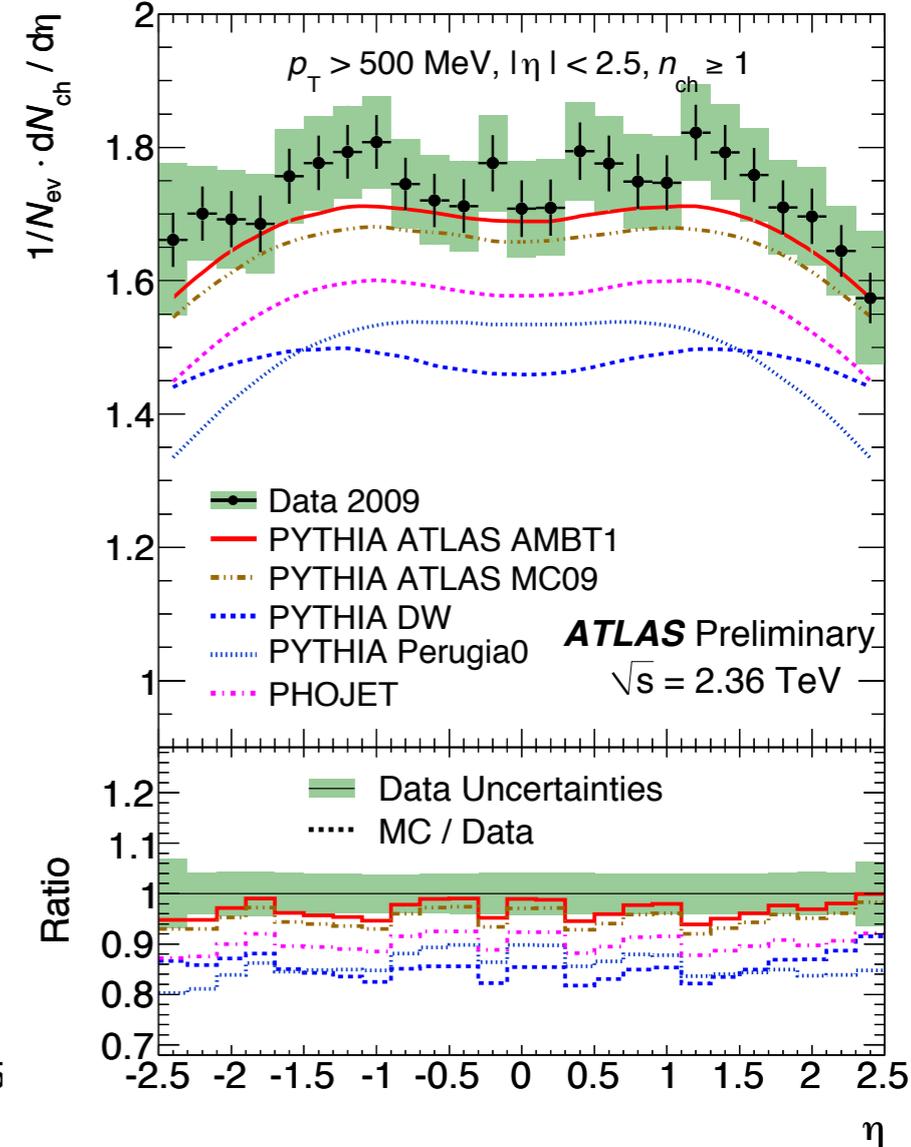
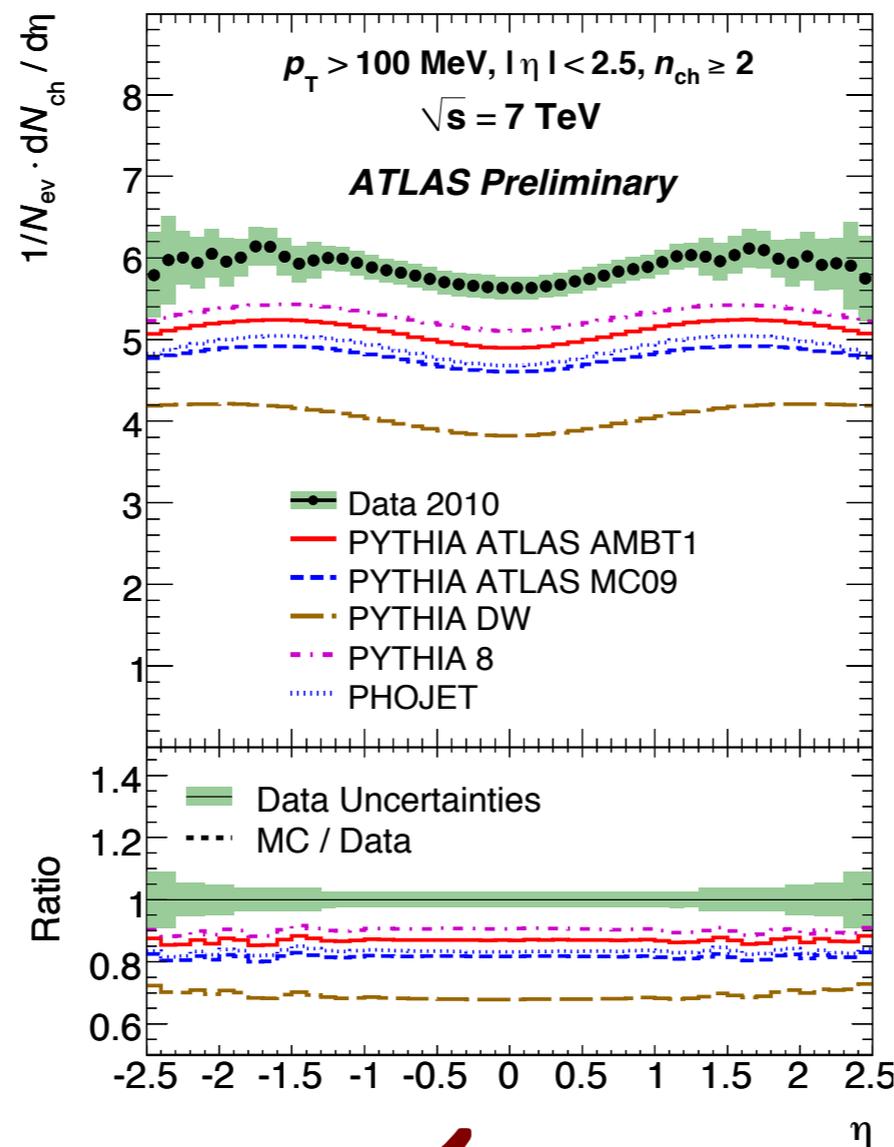
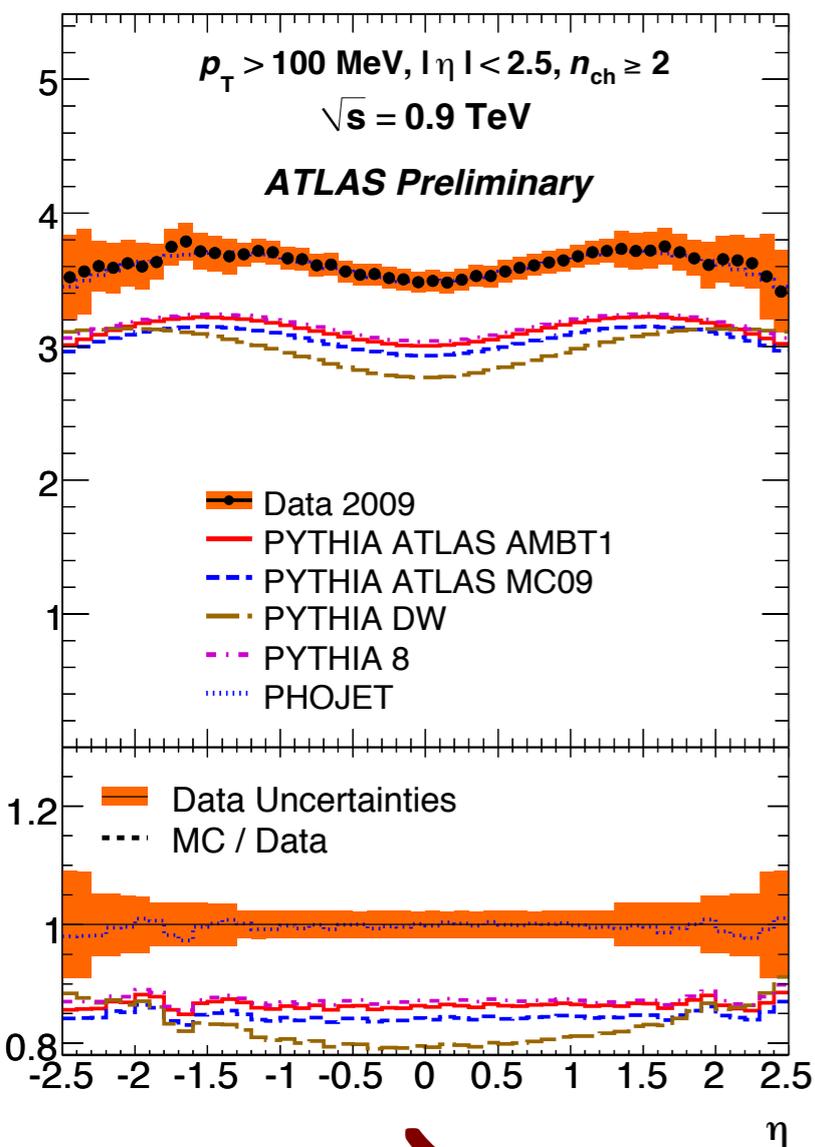
# $1/N_{ev} dN_{ch}/d\eta$



$\sqrt{s} = 0.9 \text{ TeV}$

$\sqrt{s} = 7.0 \text{ TeV}$

$\sqrt{s} = 2.36 \text{ TeV}$



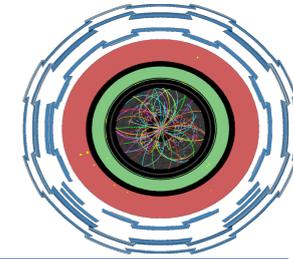
$N_{ch} \geq 2; p_T > 100 \text{ MeV}$

Shape agrees well, MC normalization low by 20%

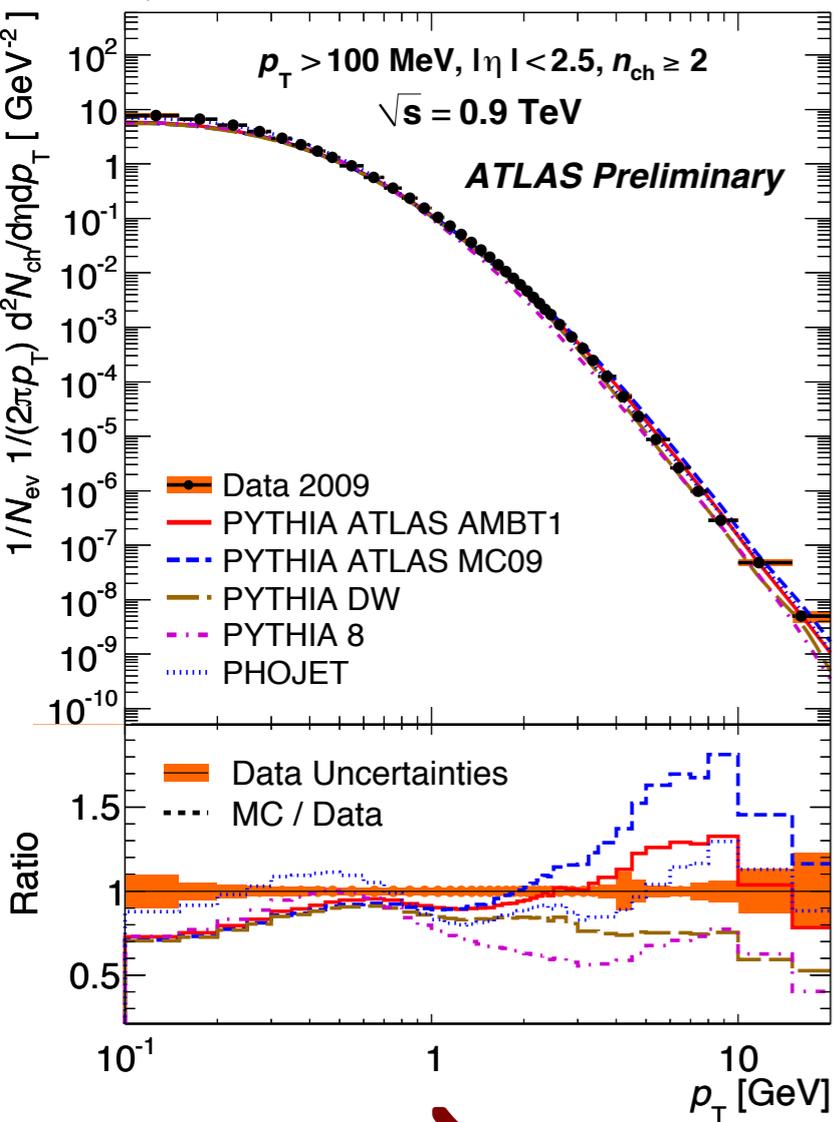
$N_{ch} \geq 1; p_T > 500 \text{ MeV}$

AMBT1 matches within errors

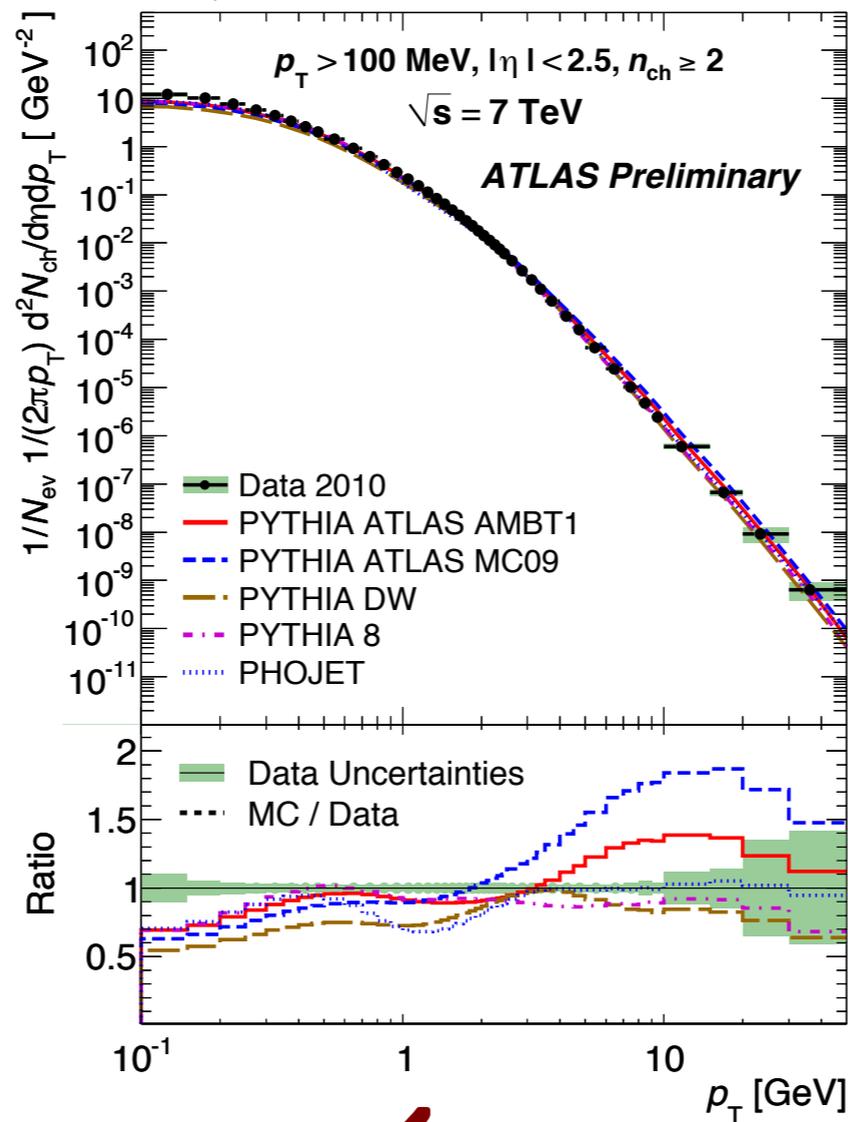
# $1/2\pi \frac{1}{N_{ev}} \frac{d^2 N_{ch}}{dp_T d\eta}$



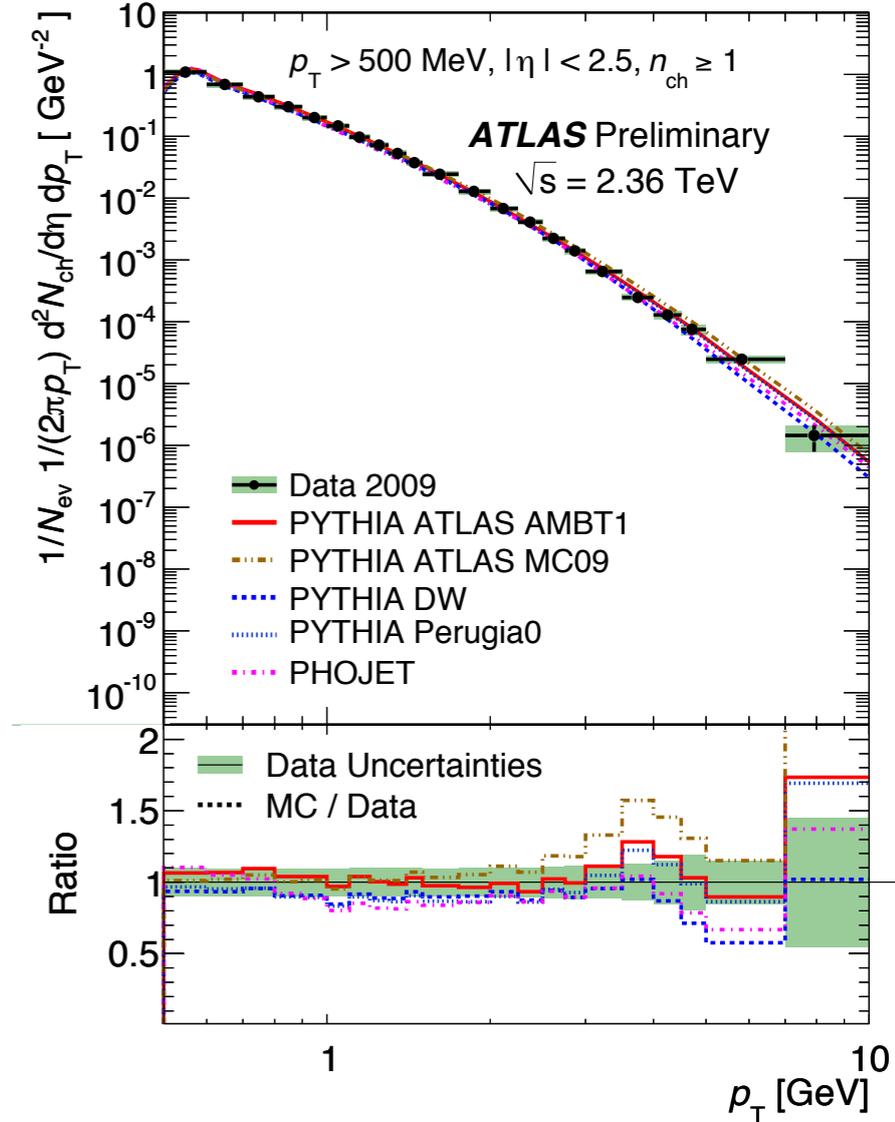
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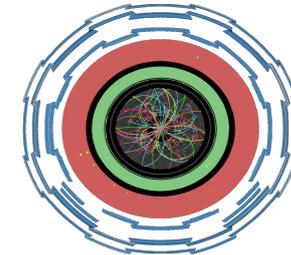
$N_{ch} \geq 2; p_T > 100 \text{ MeV}$

AMBT1: 10% agreement in mid  $p_T$  range,  
 30% at low and high  $p_T$

$N_{ch} \geq 1; p_T > 500 \text{ MeV}$

Good agreement within  
 errors of most MCs

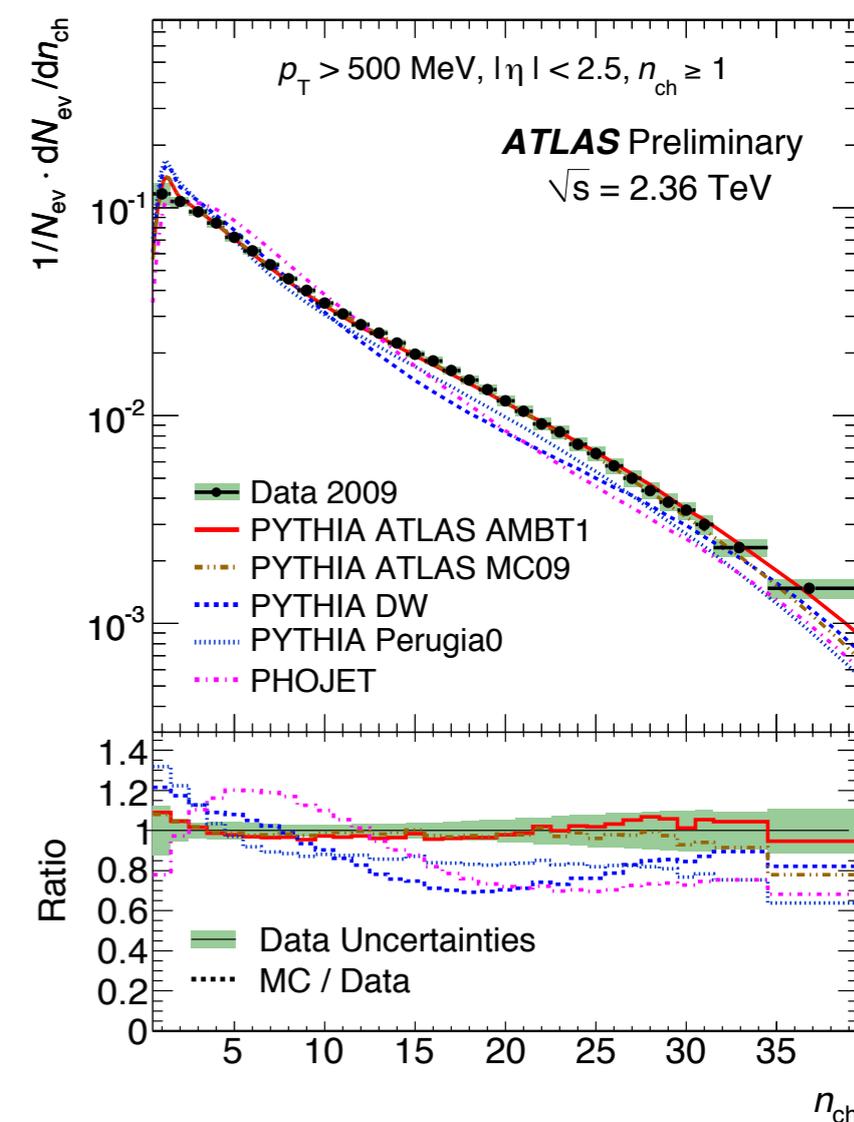
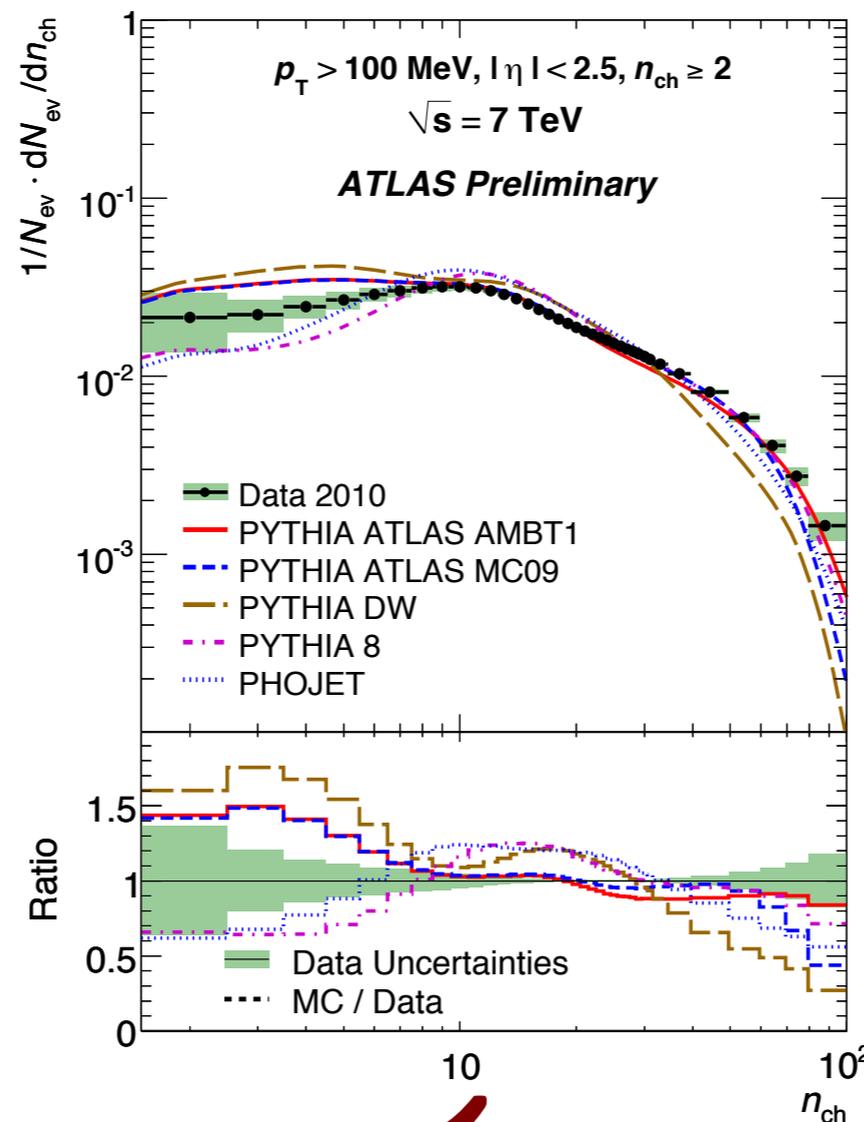
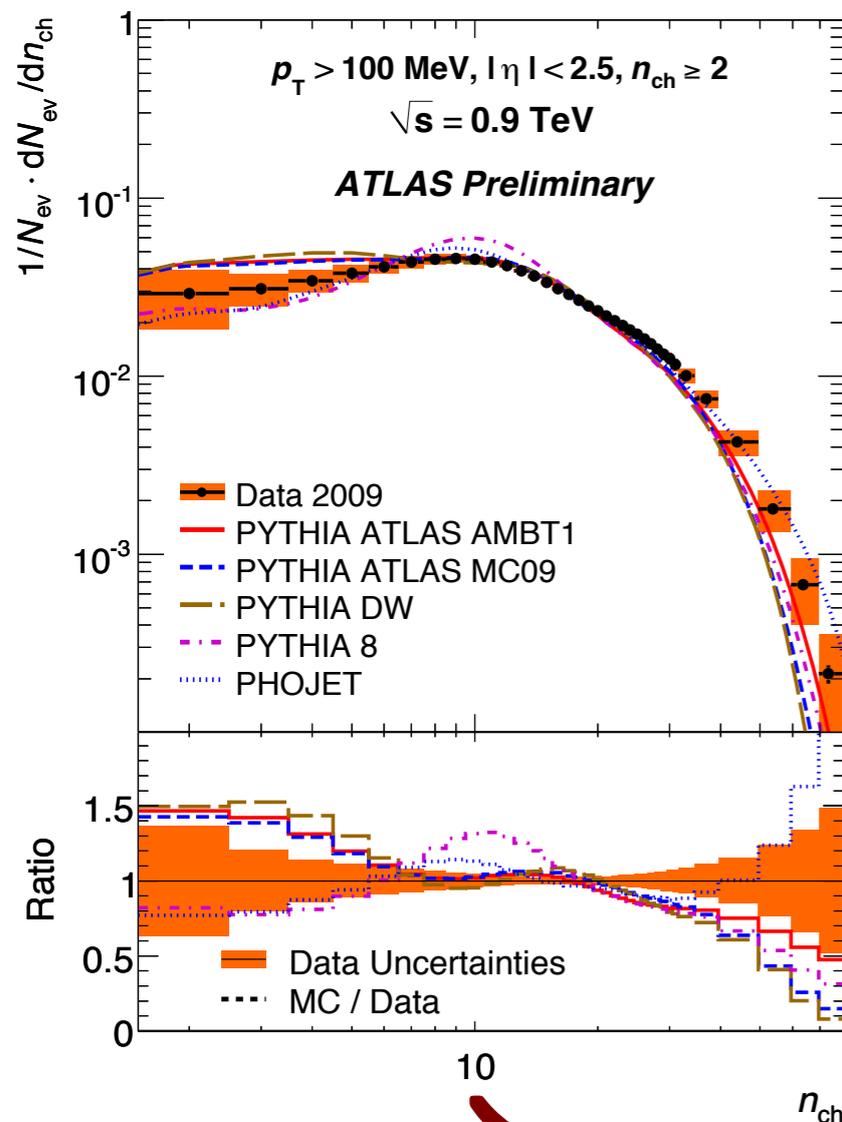
# $1/N_{ev} dN_{ev}/dN_{ch}$



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$\sqrt{s} = 7.0 \text{ TeV}$

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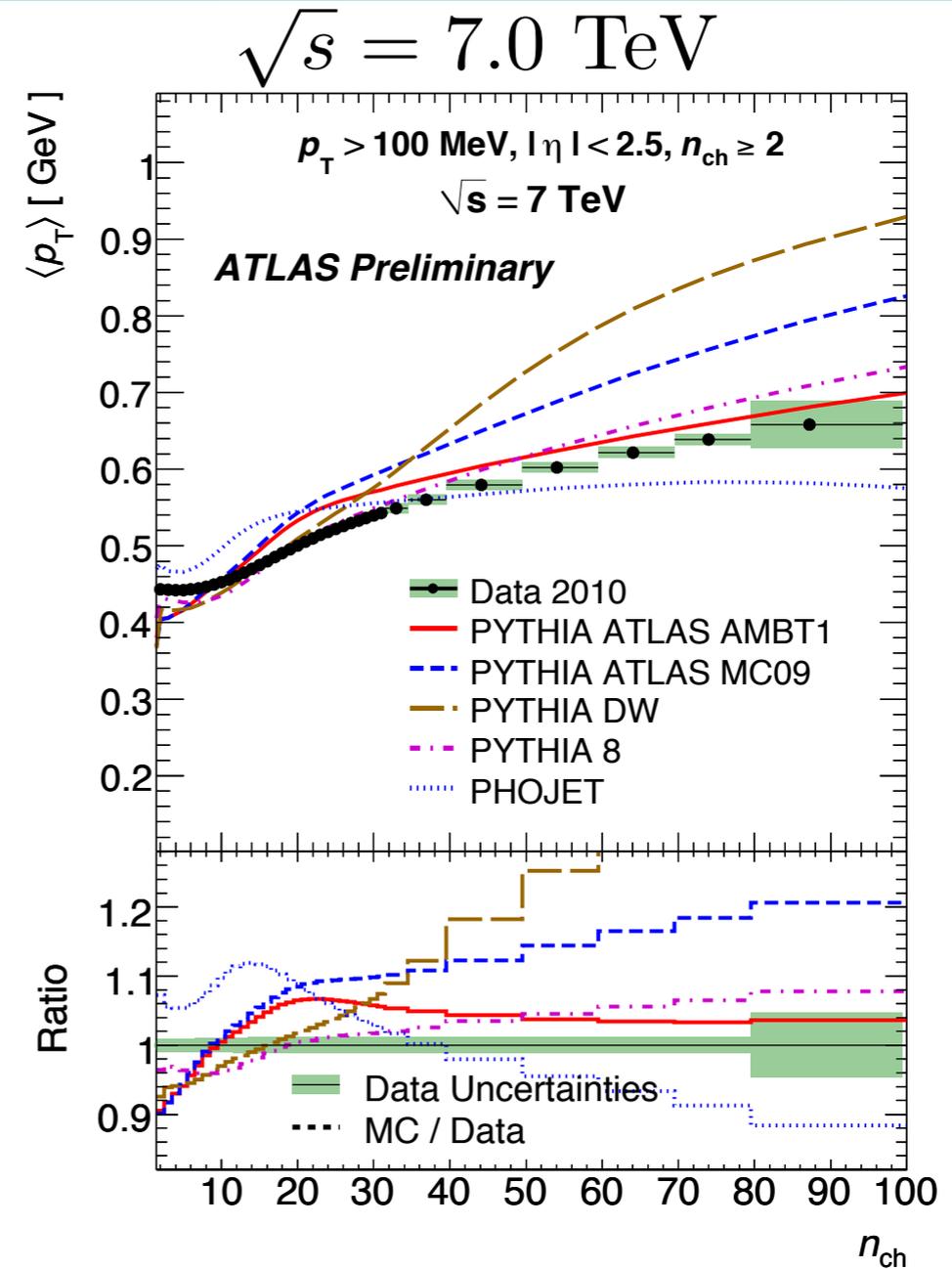
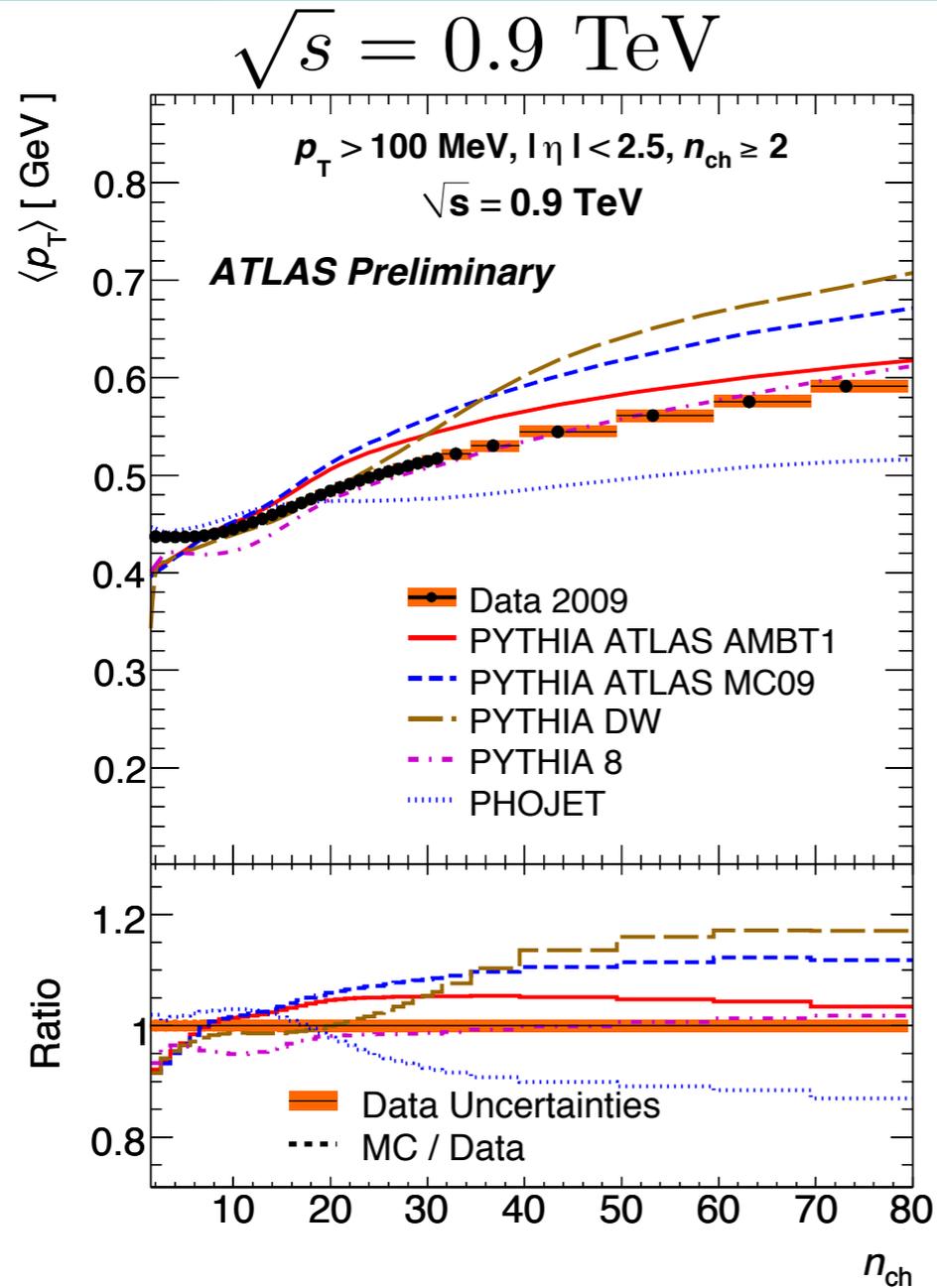
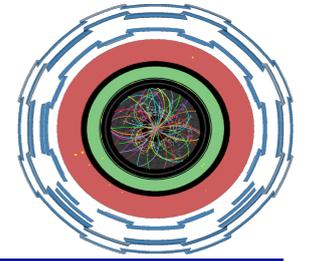


$N_{ch} \geq 2; p_T > 100 \text{ MeV}$   
 Significant discrepancies at low  $N_{ch}$   
 Pythia 8 & Phojet underestimates,  
 Pythia 6 overestimates

$N_{ch} \geq 1; p_T > 500 \text{ MeV}$   
 AMBT1 matches within  
 errors



# $\langle p_T \rangle$ vs. $N_{ch}$



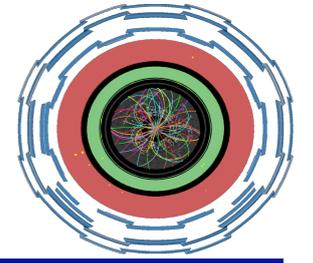
$N_{ch} \geq 2; p_T > 100 \text{ MeV}$

Most tunes predict too low  $\langle p_T \rangle$  at low  $N_{ch}$

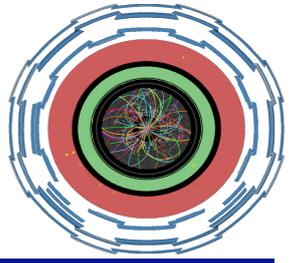
Older Pythia 6 tunes significantly over predict  $\langle p_T \rangle$  at low  $N_{ch}$

# (a piece of) The emerging picture

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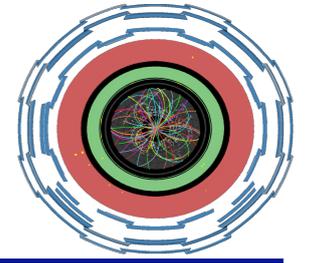


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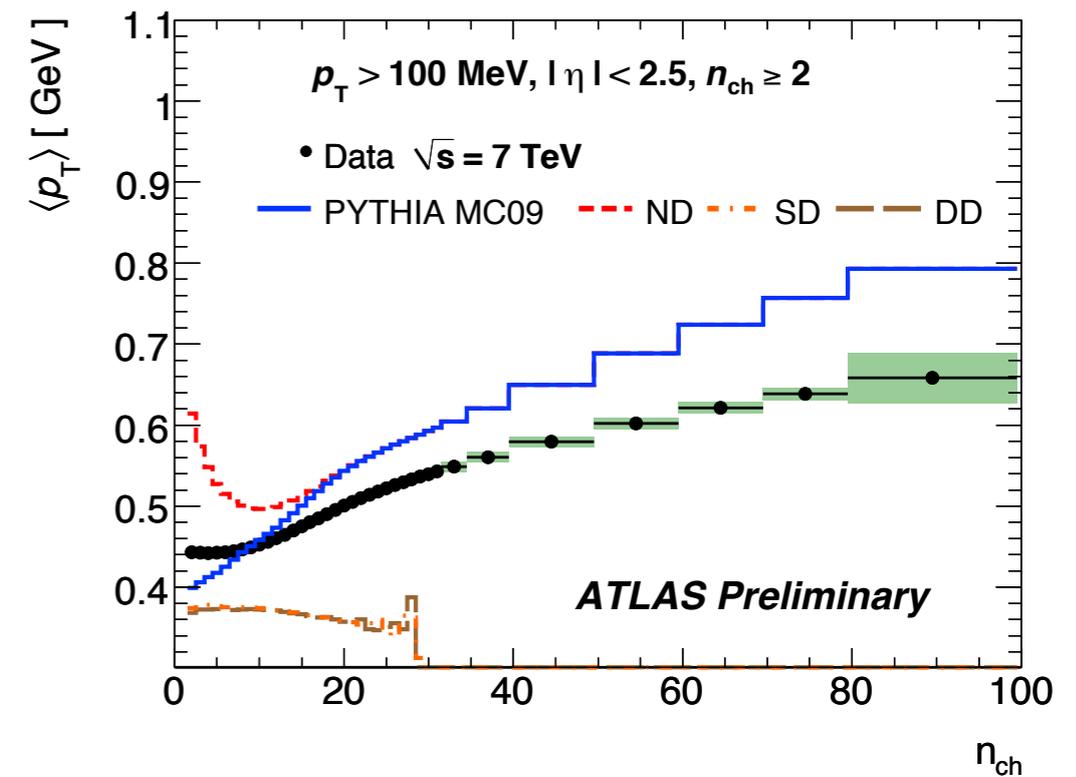


- The low  $p_T$ , low  $N_{ch}$  region is problematic
  - Diffractive component is important

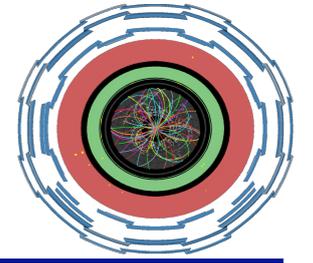
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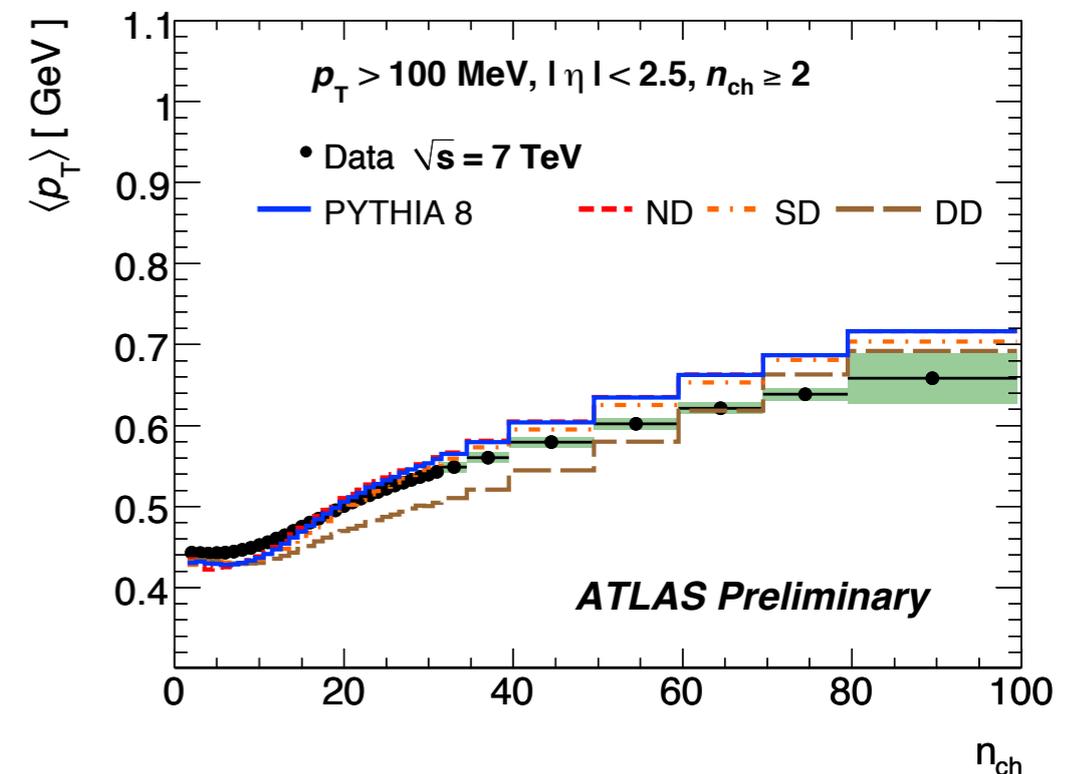
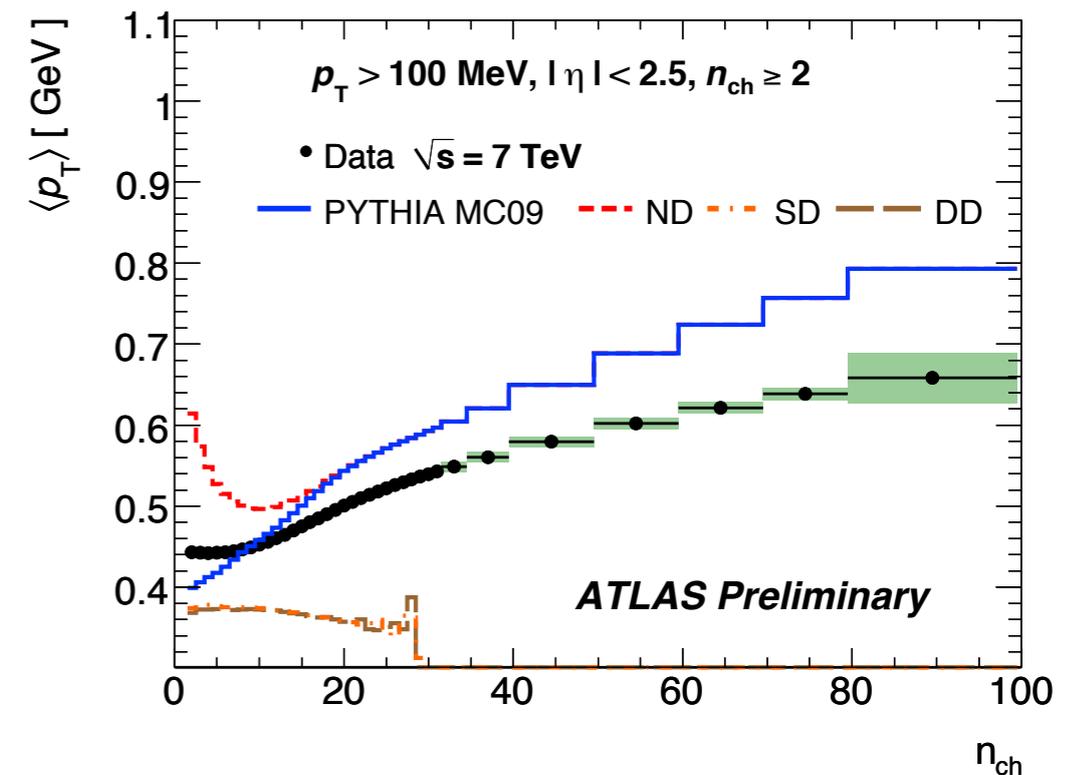
- The low  $p_T$ , low  $N_{ch}$  region is problematic
- Diffractive component is important
- Case study: Pythia 6 MC09
  - Diffractive component is very soft and low multiplicity
  - Under-predicts for low activity events
  - AMBT1 improves high  $N_{ch}$  events



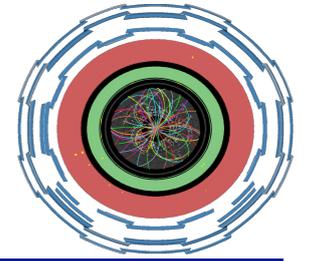
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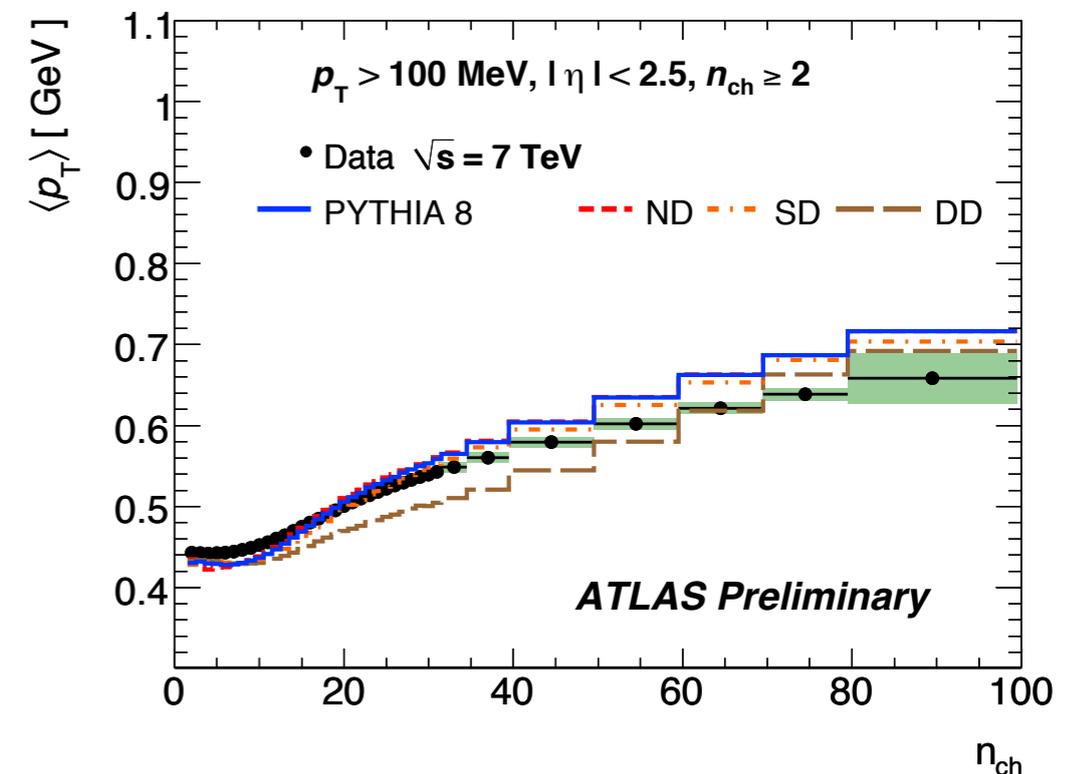
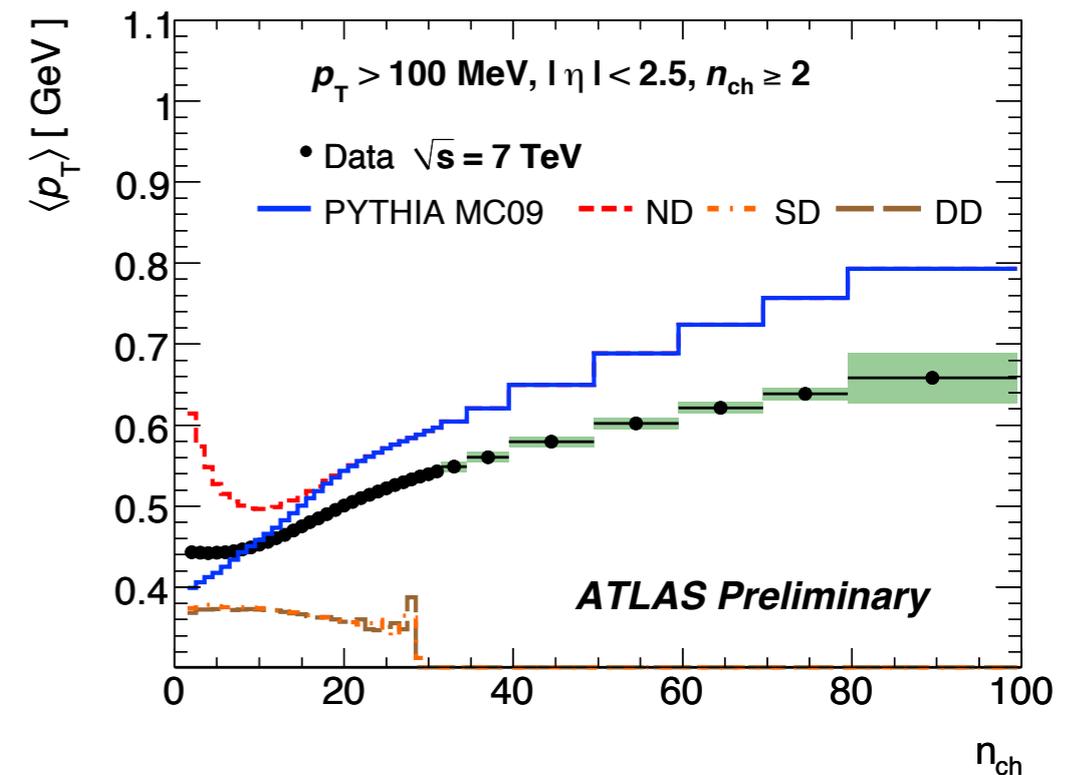
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- Case Study: Pythia 8
  - Best agreement with data for low to mid  $N_{ch}$
  - At low  $N_{ch}$   $\langle p_T \rangle$  is similar for SD, DD & ND



# (a piece of) The emerging picture

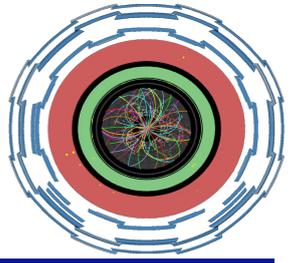


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- A better understanding diffraction is needed to constrain possible sources of disagreement

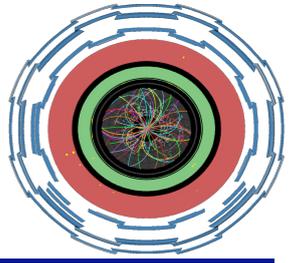


# The Diffraction Enhanced Analysis

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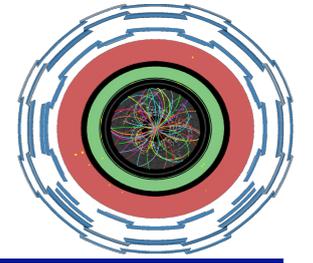


# The Diffraction Enhanced Analysis

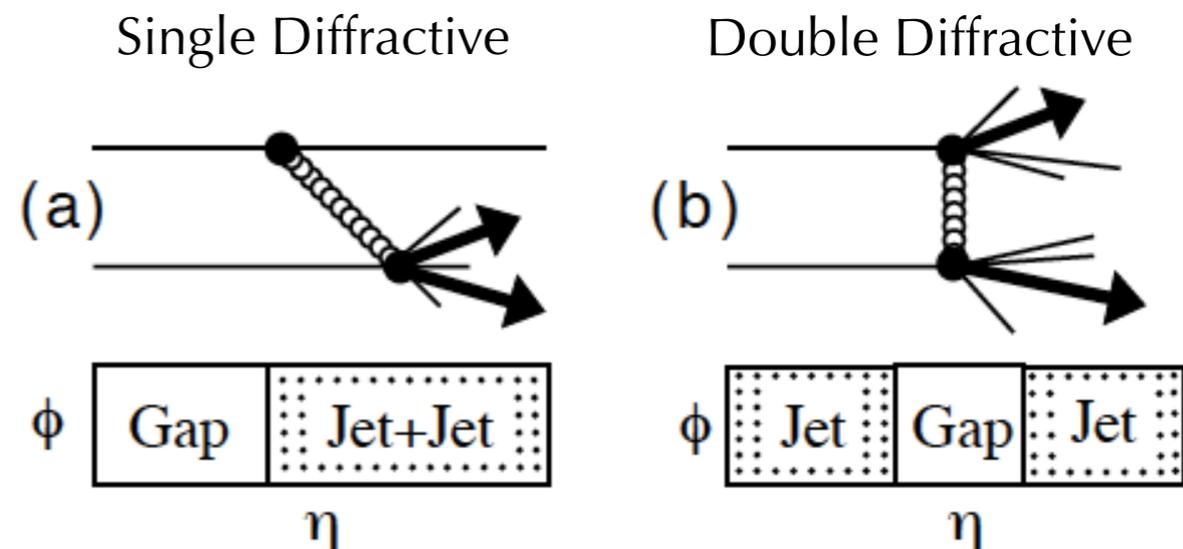
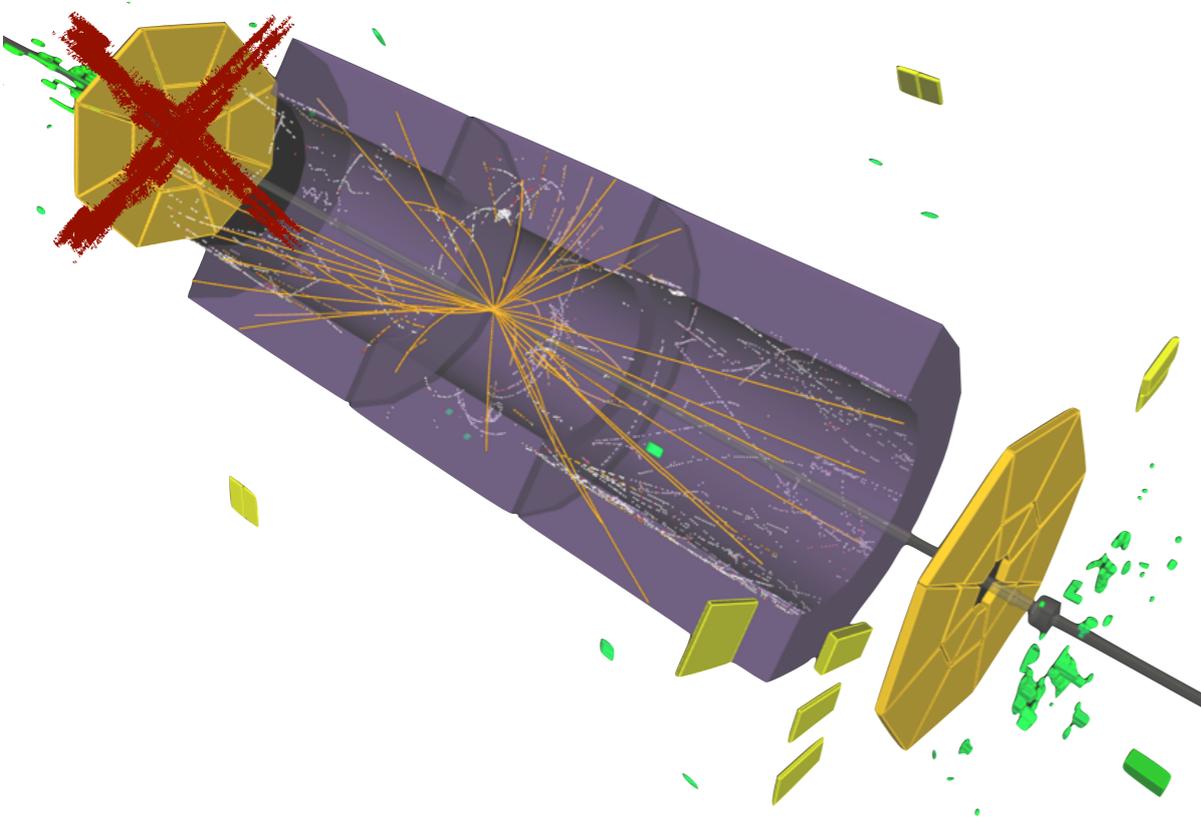


- The idea: *repeat a standard min bias analysis on a sample dominated by diffraction*

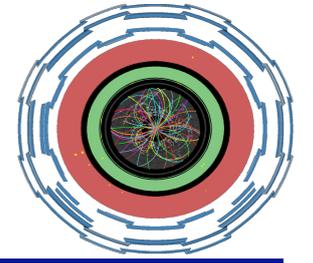
# The Diffraction Enhanced Analysis



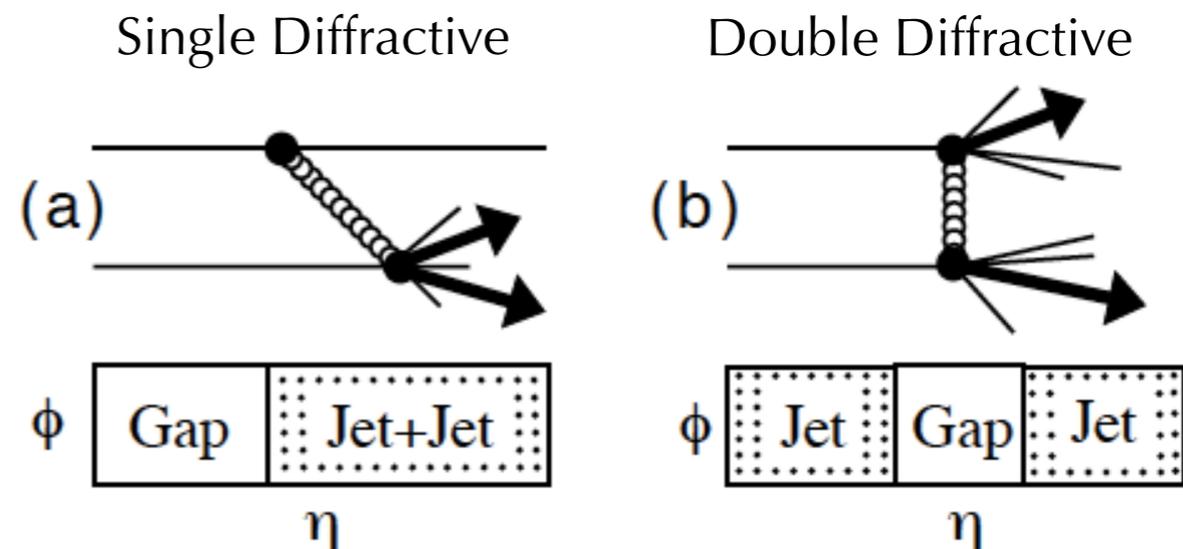
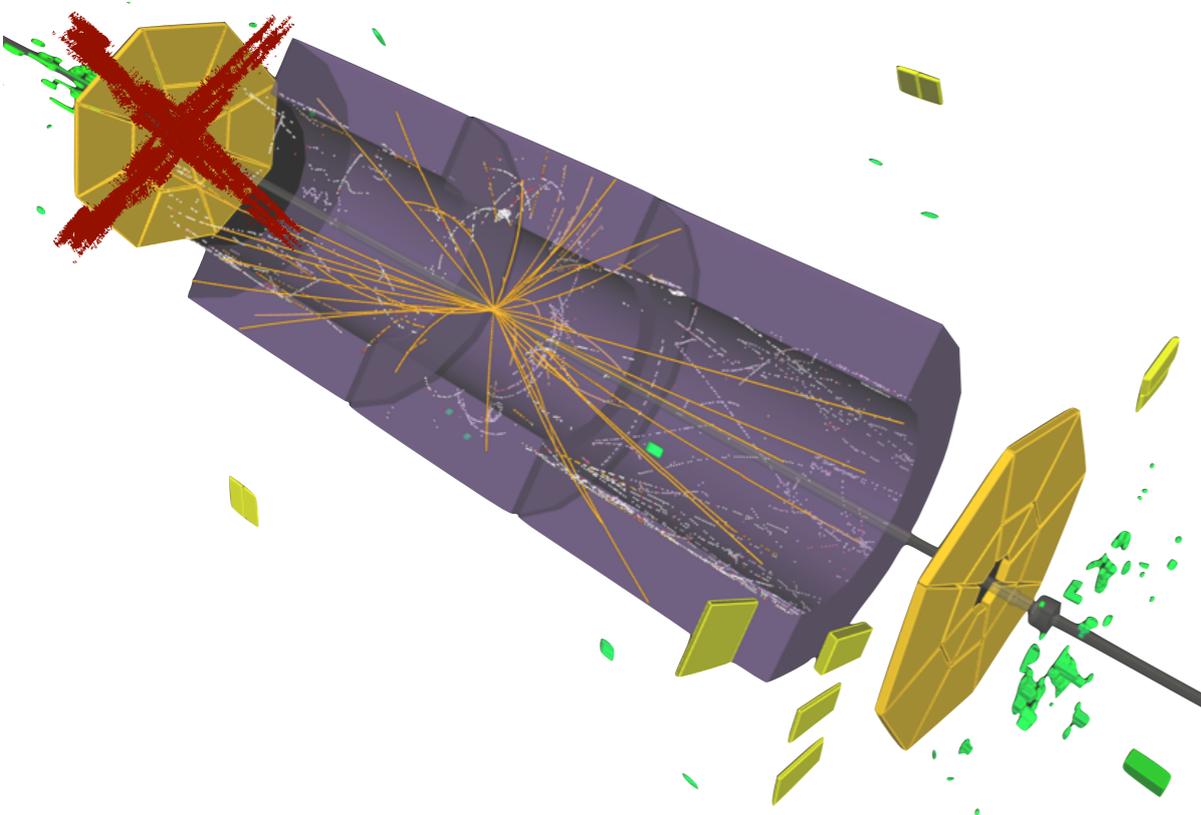
- The idea: *repeat a standard min bias analysis on a sample dominated by diffraction*
- Achieving a diffraction enhanced sample:
  - Require hits on **only** 1 side of MBTS detector  $\{2.09 < |\eta| < 3.84\}$
  - Increases the diffractive component from  $\sim 20\%$  to  $90+\%$  of event sample



# The Diffraction Enhanced Analysis

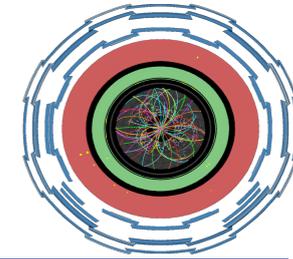


- The idea: *repeat a standard min bias analysis on a sample dominated by diffraction*
- Achieving a diffraction enhanced sample:
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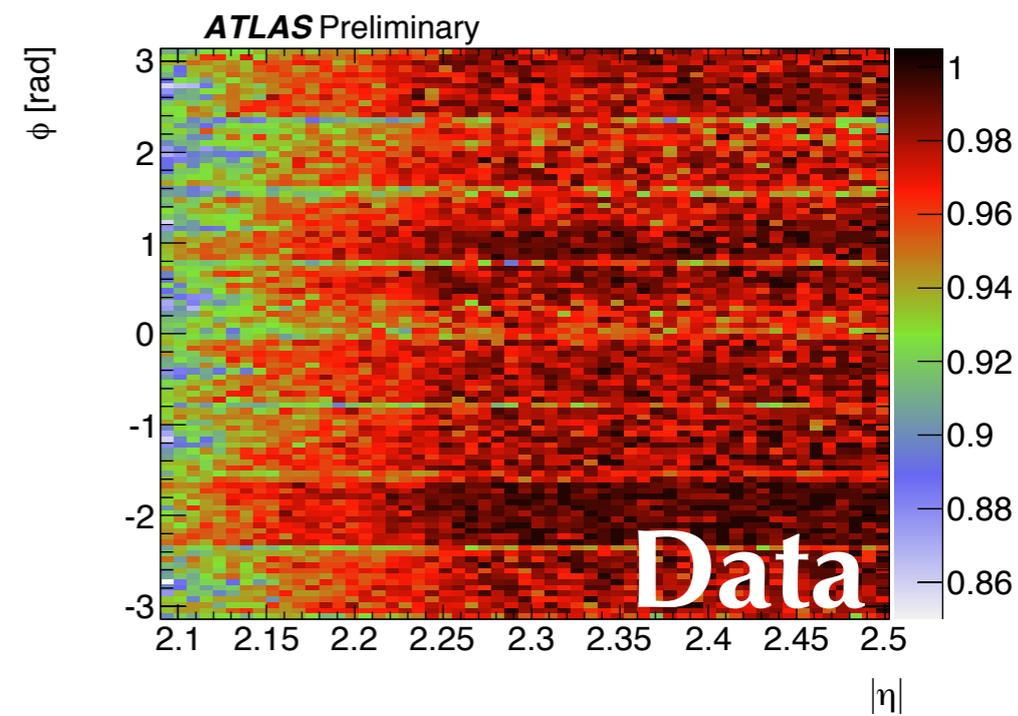


- The caveat: this analysis is ***not*** yet corrected for detector effects!

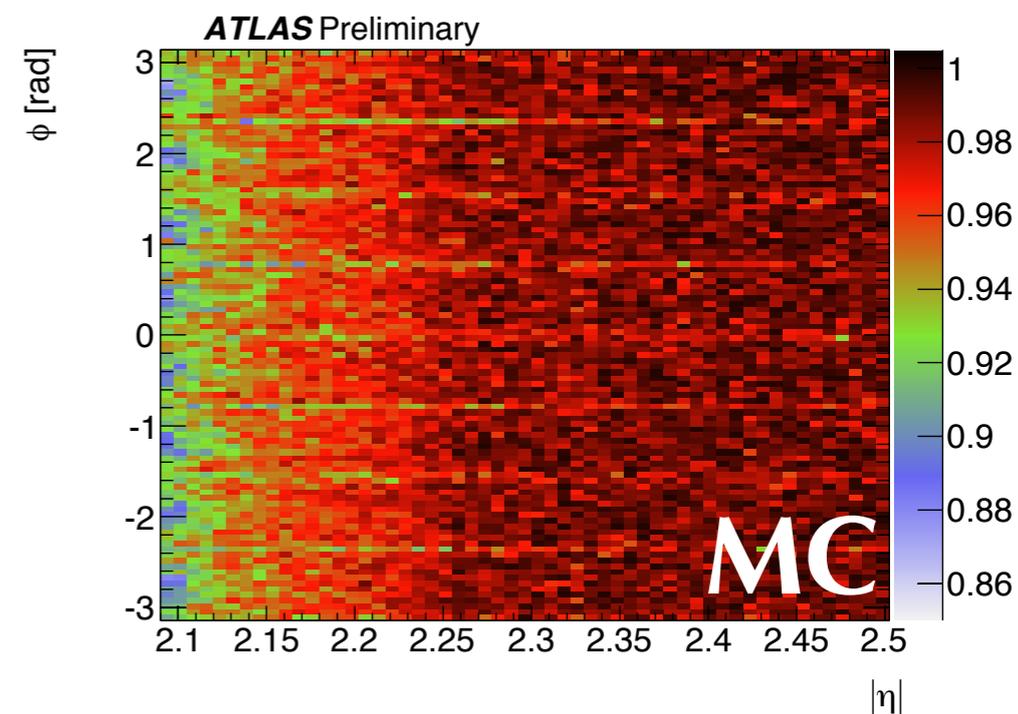
# Event and Track Selection

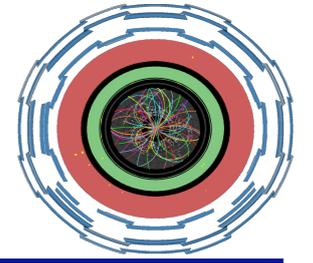


- Trigger on single sided MBTS trigger
  - Use offline MBTS values for discrimination between single and double sided events
  - Agreement between data & MC on MBTS response is primary uncertainty
- No vertex requirement: too low efficiency for diffractive events
- Track selection same as MB analysis except:
  - Transverse impact parameter cut with respect to beamspot, loose longitudinal cut
  - $p_T > 500 \text{ MeV}$

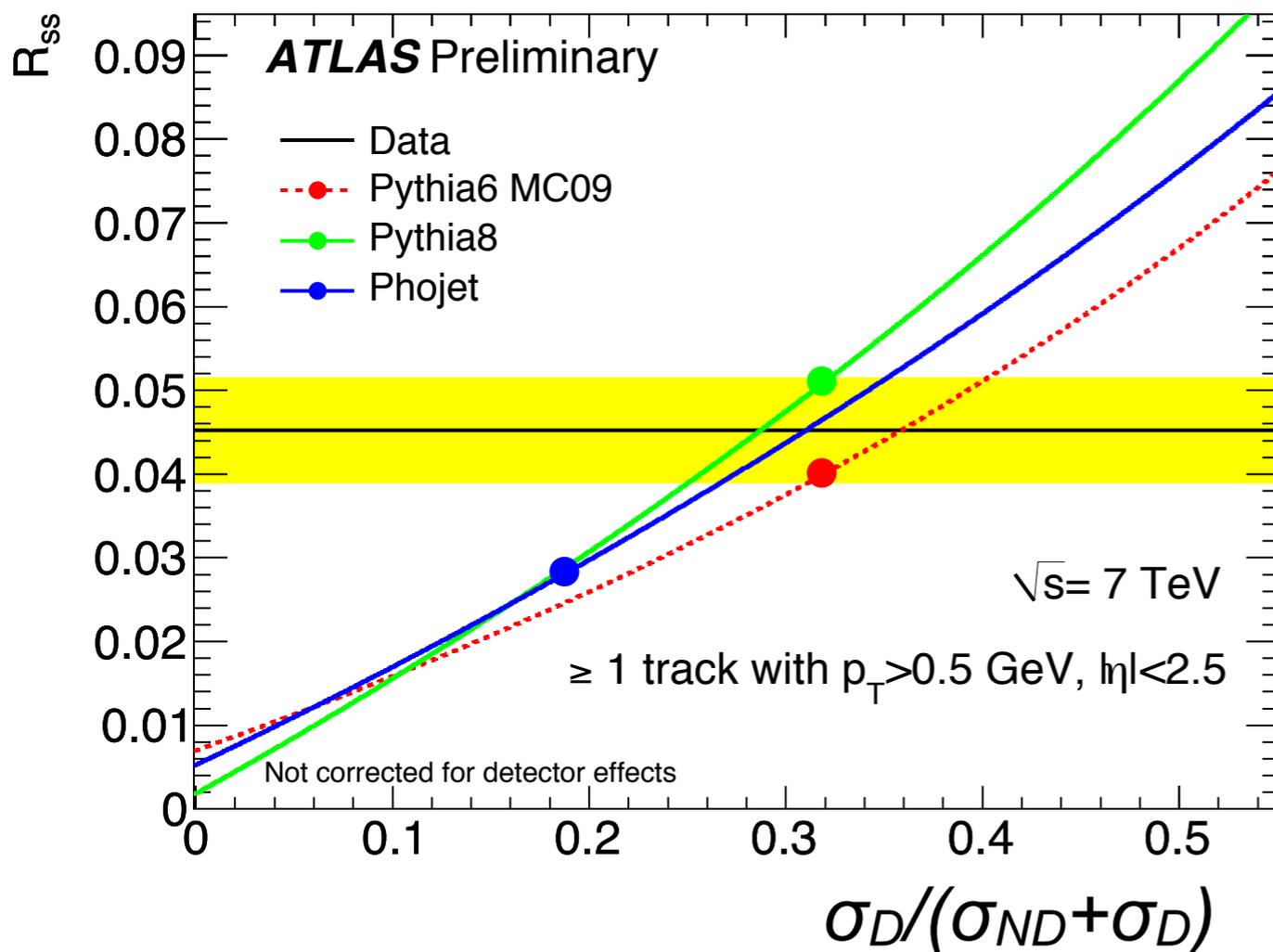


MBTS efficiency  
determined from tracks





- $R_{SS}$  := Fraction of MBTS1 triggered events with activity on only 1 side of the MBTS
- Require a track with  $p_T > 500$  MeV;  $|\eta| < 2.5$
- Sensitive to relative diffractive cross section
- All MC models prefer  $\sigma_D/(\sigma_{ND} + \sigma_D) \sim 0.3$

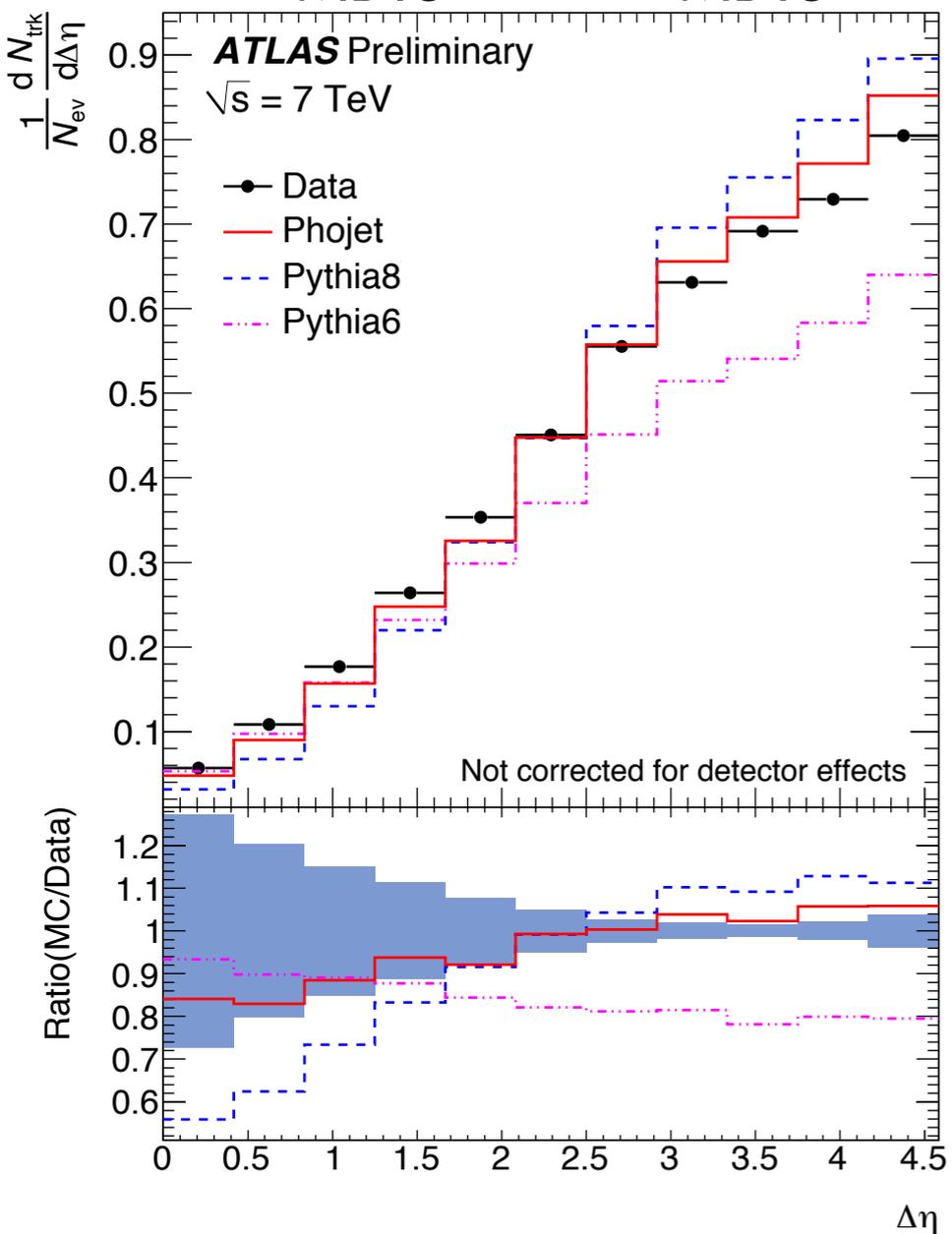
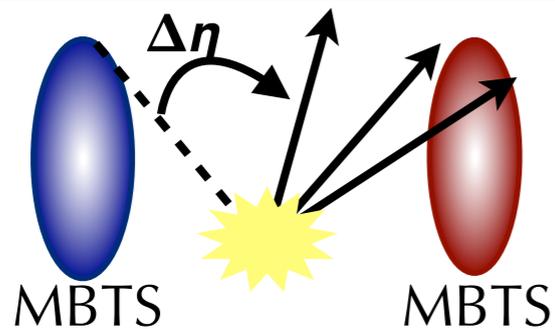
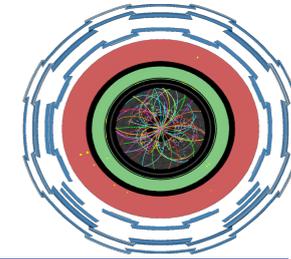


$$R_{SS} = \frac{N_{SS}}{N_{SS} + N_{ds}}$$

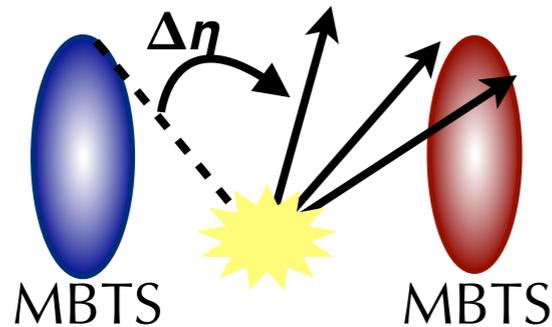
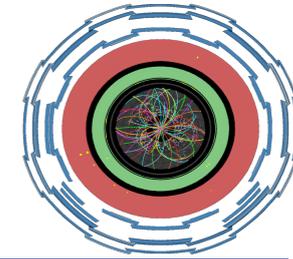
$$= \frac{A_{SS}^D \sigma_D + A_{SS}^{ND} \sigma_{ND}}{(A_{SS}^D + A_{ds}^D) \sigma_D + (A_{SS}^{ND} + A_{ds}^{ND}) \sigma_{ND}}$$

	$R_{SS}$ (%)
Data	$4.52 \pm 0.02$ (stat.) $\pm 0.61$ (syst.)
PYTHIA6	4.01
PYTHIA8	5.11
PHOJET	2.83

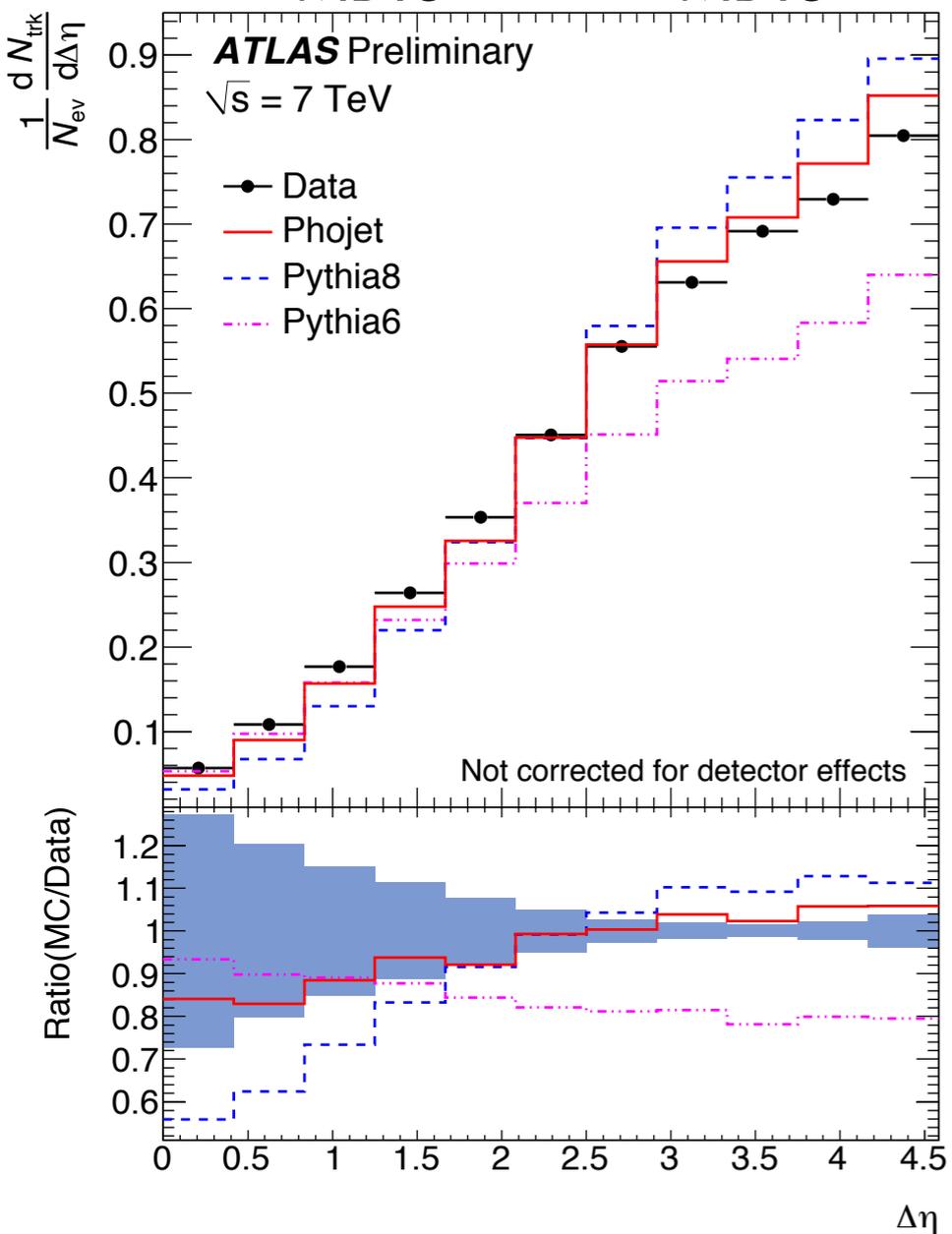
# $1/N_{\text{ev}} dN_{\text{trk}}/d\Delta\eta$



# $1/N_{ev} dN_{trk}/d\Delta\eta$



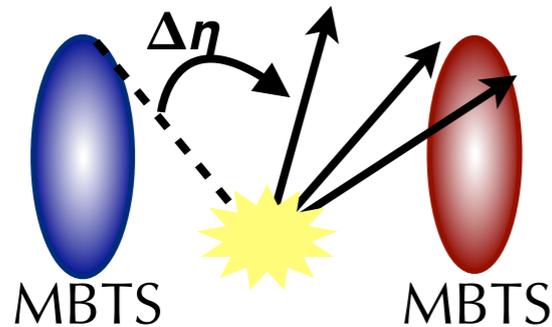
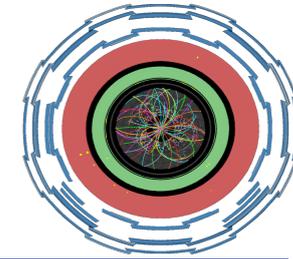
- $\Delta\eta = |\eta_{MBTS} - \eta_{trk}|$  is sensitive to gap structure



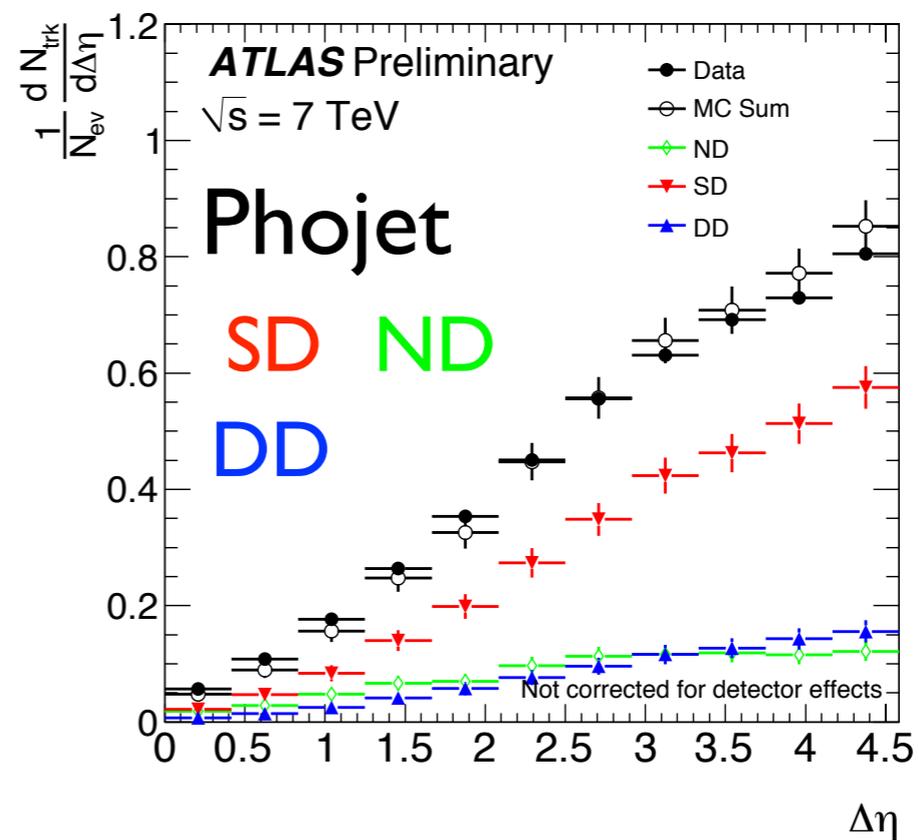
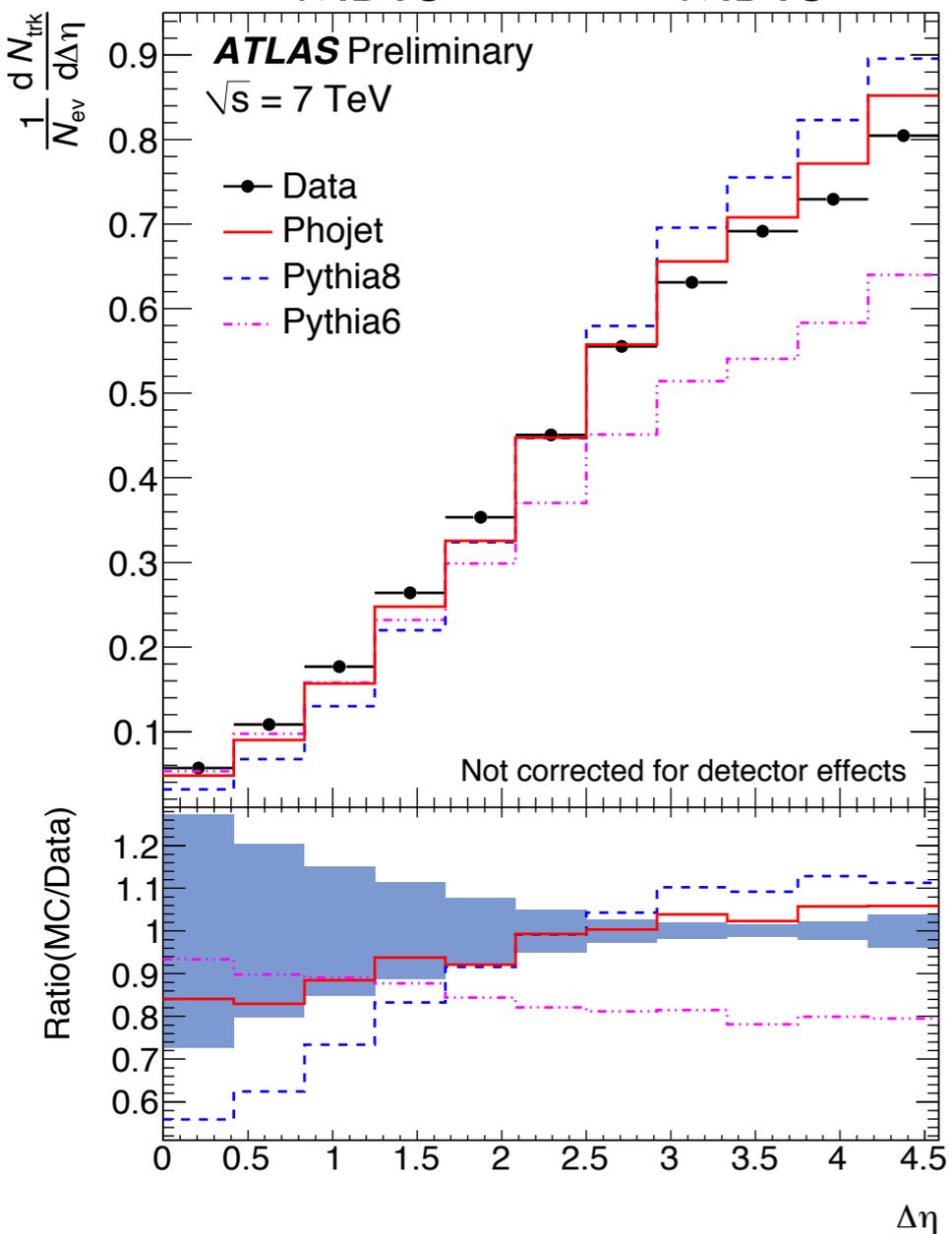
$\sqrt{s} = 7.0 \text{ TeV}$

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# $1/N_{ev} dN_{trk}/d\Delta\eta$

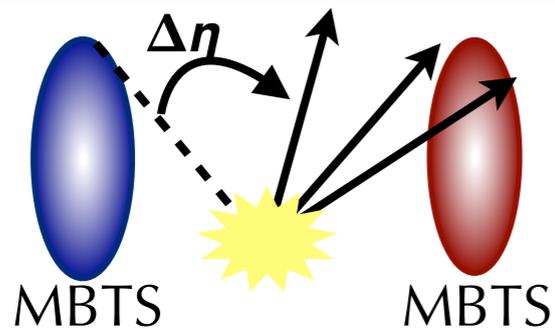
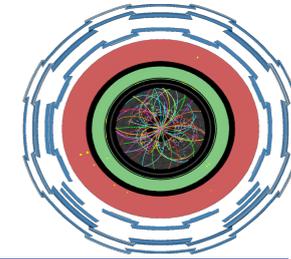


- $\Delta\eta = |\eta_{MBTS} - \eta_{trk}|$  is sensitive to gap structure
- Phojet shows best agreement
- Favors dominantly SD contributions

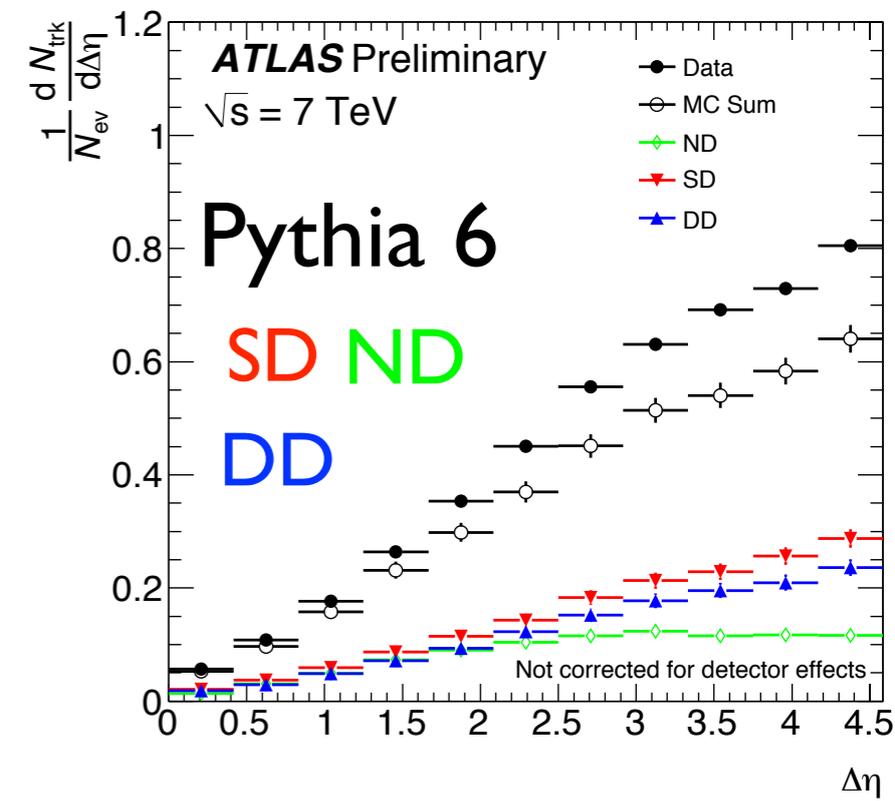
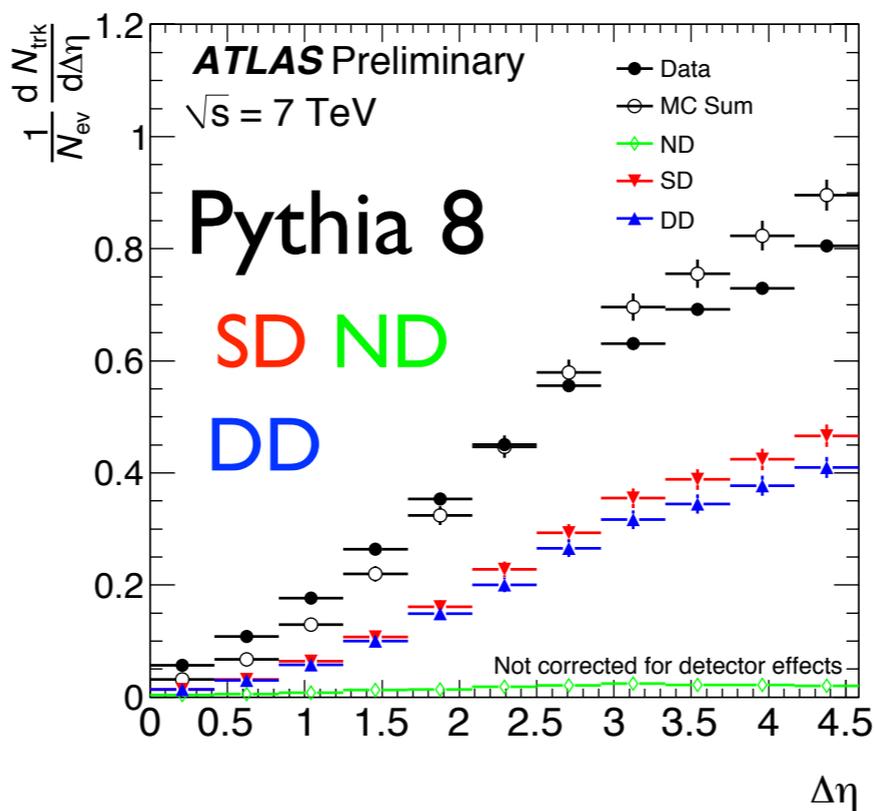
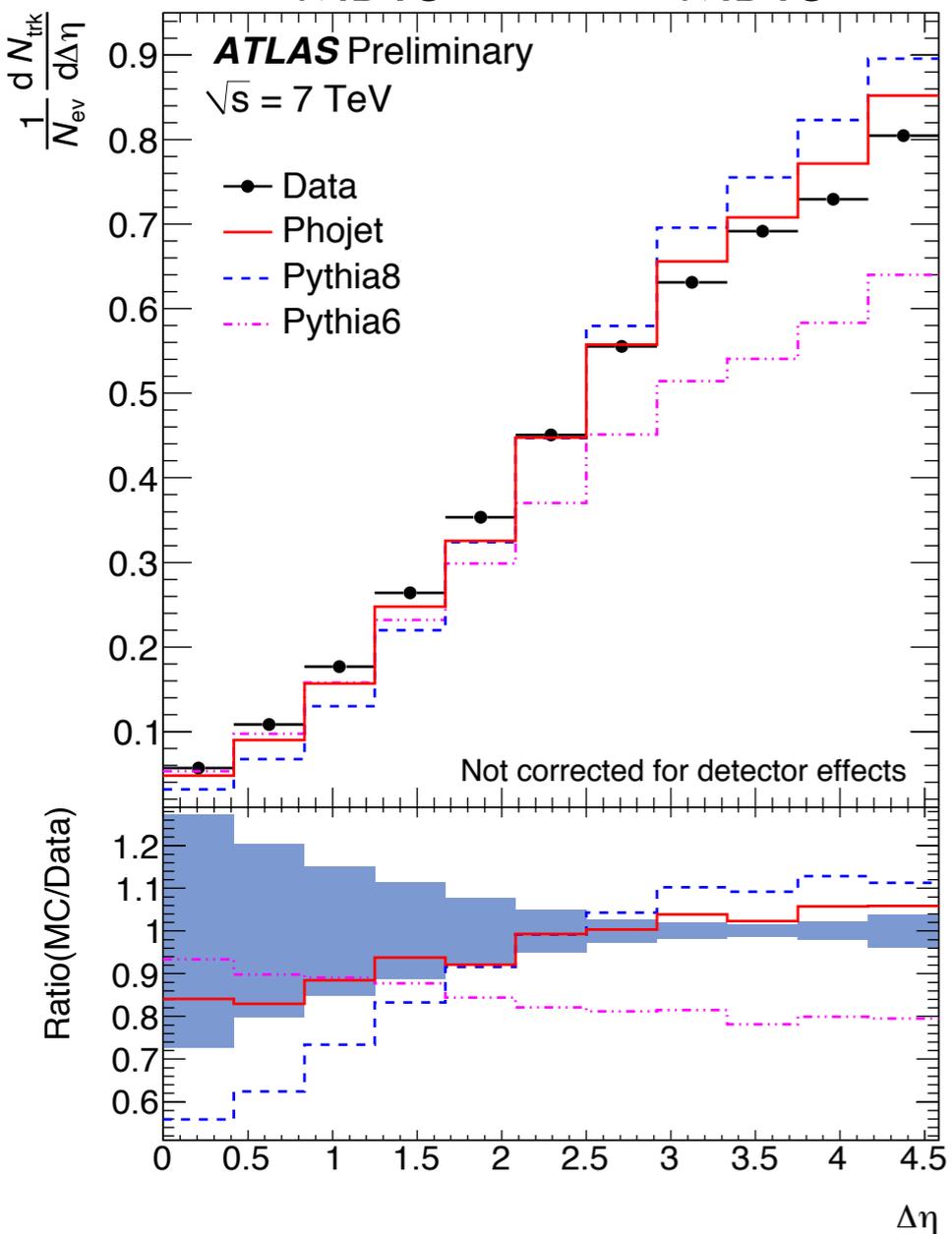


$\sqrt{s} = 7.0 \text{ TeV}$

# $1/N_{ev} dN_{trk}/d\Delta\eta$



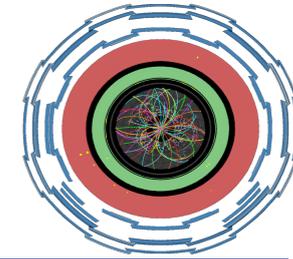
- $\Delta\eta = |\eta_{MBTS} - \eta_{trk}|$  is sensitive to gap structure
- Phojet shows best agreement
- Favors dominantly SD contributions
- Pythia 6 worst overall agreement, Pythia 8 favors high  $\Delta\eta$



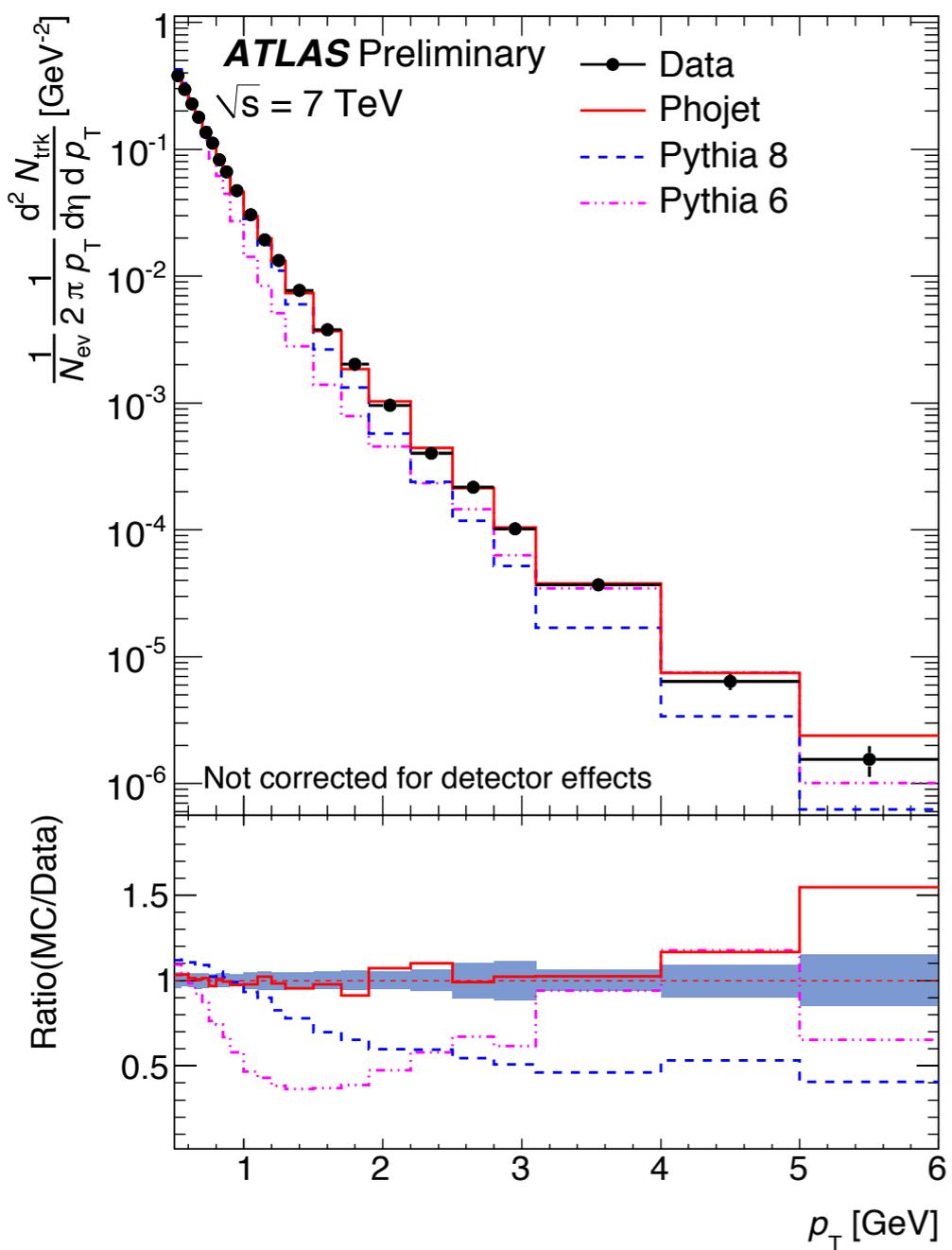
$\sqrt{s} = 7.0 \text{ TeV}$

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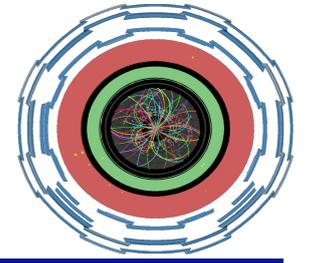
# $\frac{1}{2\pi} \frac{1}{N_{ev}} \frac{d^2 N_{trk}}{dp_T d\eta}$



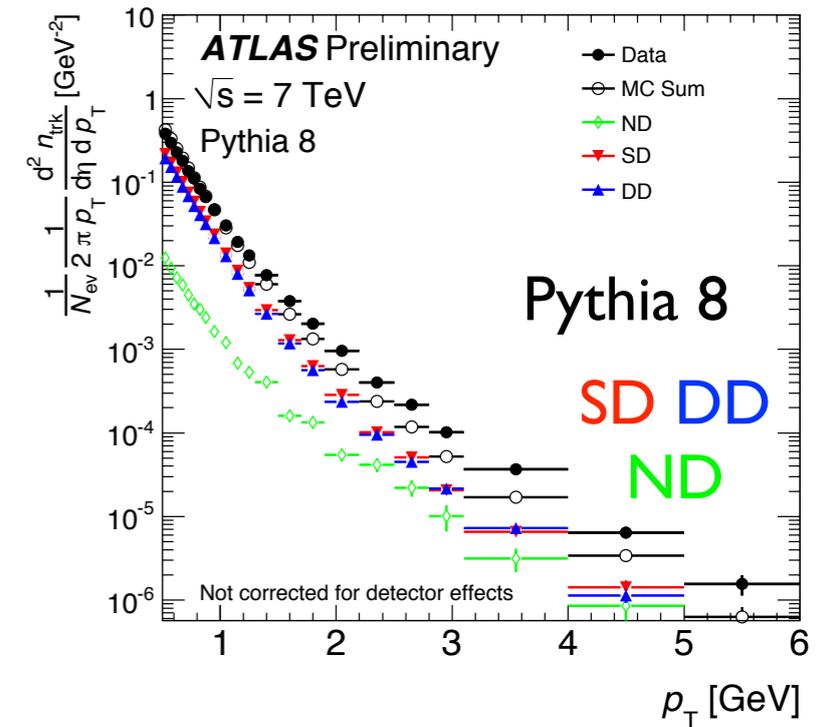
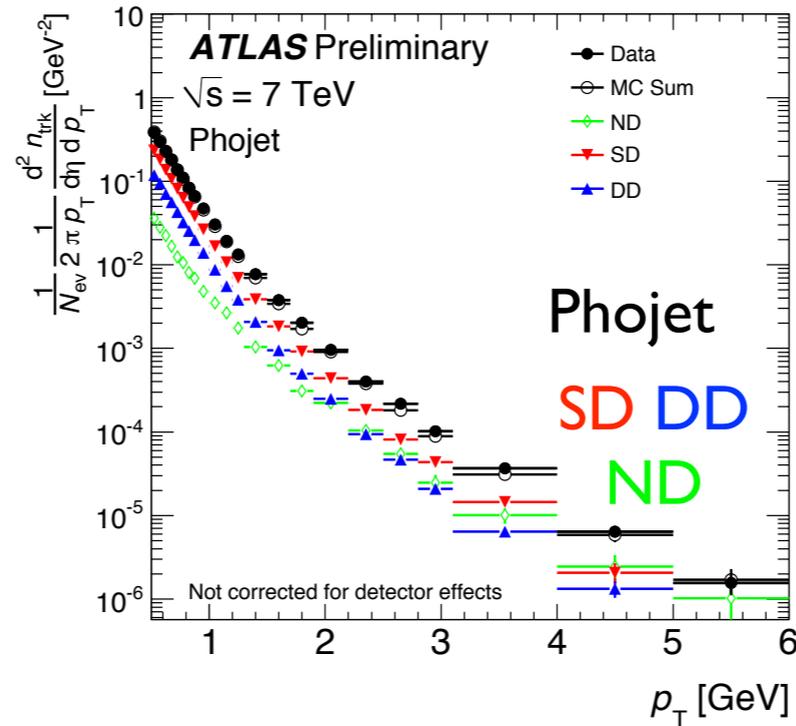
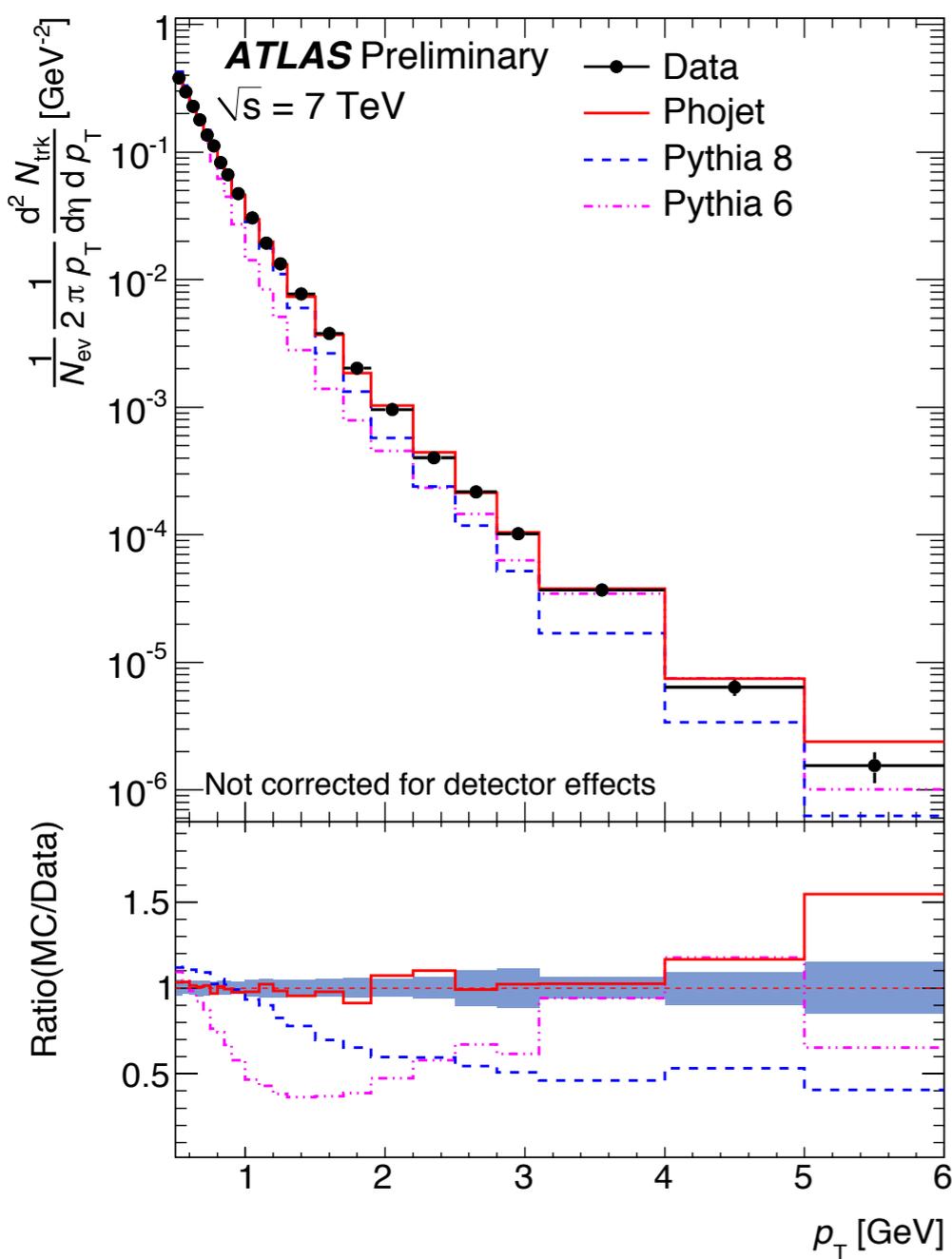
$\sqrt{s} = 7.0 \text{ TeV}$



# $1/2\pi \frac{1}{N_{ev}} \frac{d^2 N_{trk}}{dp_T d\eta}$

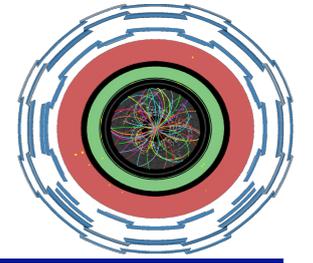


$\sqrt{s} = 7.0 \text{ TeV}$

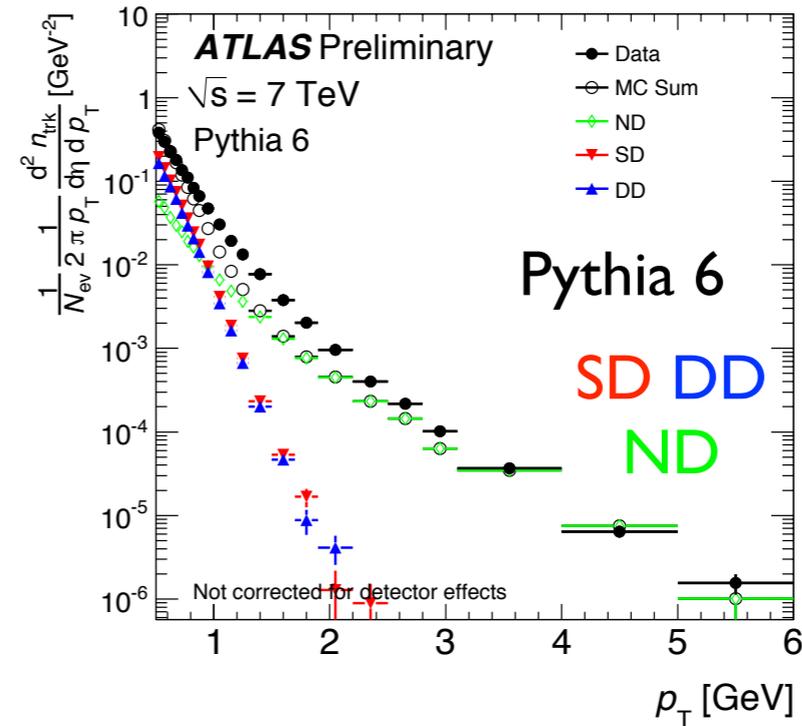
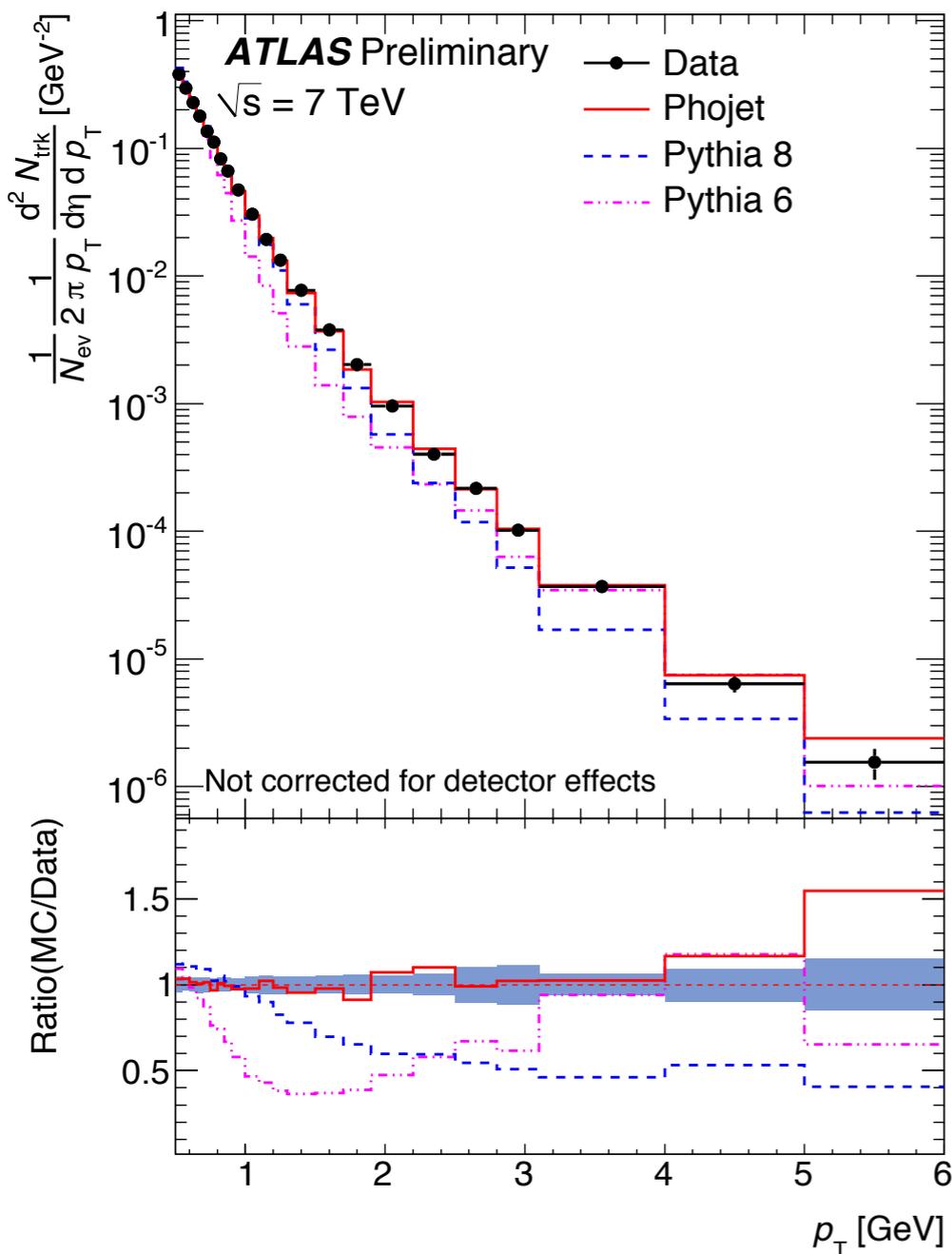


- ⦿ Phojet shows best agreement over full  $p_T$  range
- ⦿ Pythia 8 underestimates significantly at high  $p_T$

# $1/2\pi \frac{1}{N_{ev}} \frac{d^2 N_{trk}}{dp_T d\eta}$

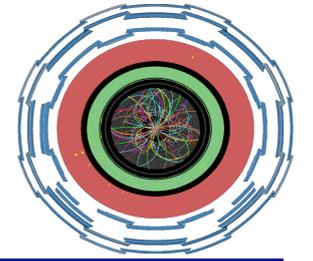


$\sqrt{s} = 7.0 \text{ TeV}$

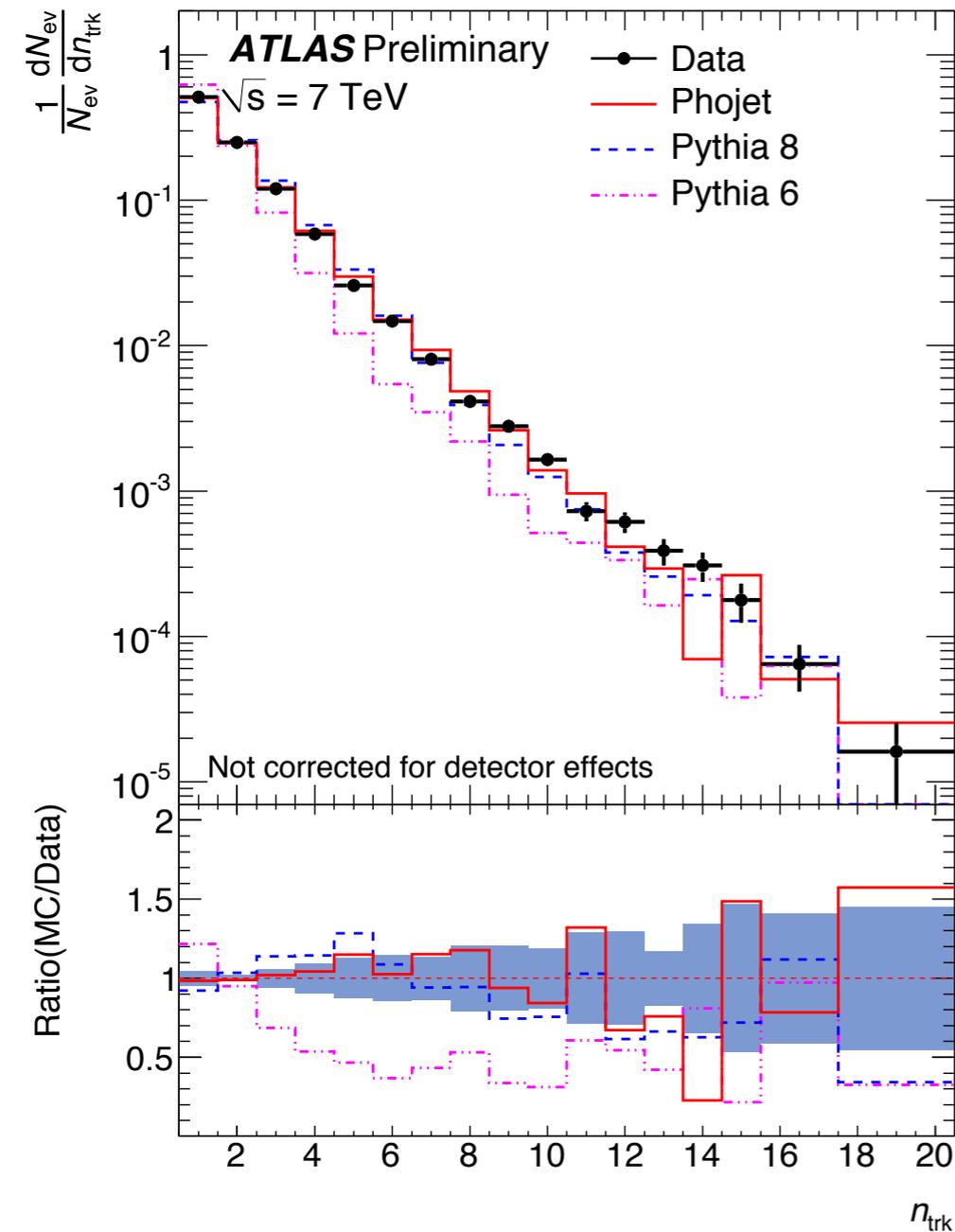


- Phojet shows best agreement over full  $p_T$  range
- Pythia 8 underestimates significantly at high  $p_T$
- Pythia 6 diffractive component very soft
  - Agrees fairly well in high  $p_T$  tail where ND component dominates

# $1/N_{\text{ev}} dN_{\text{ev}}/dN_{\text{trk}}$

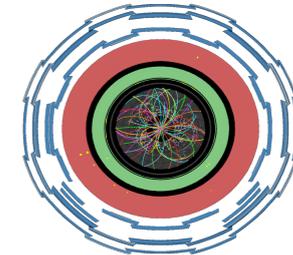


$\sqrt{s} = 7.0 \text{ TeV}$

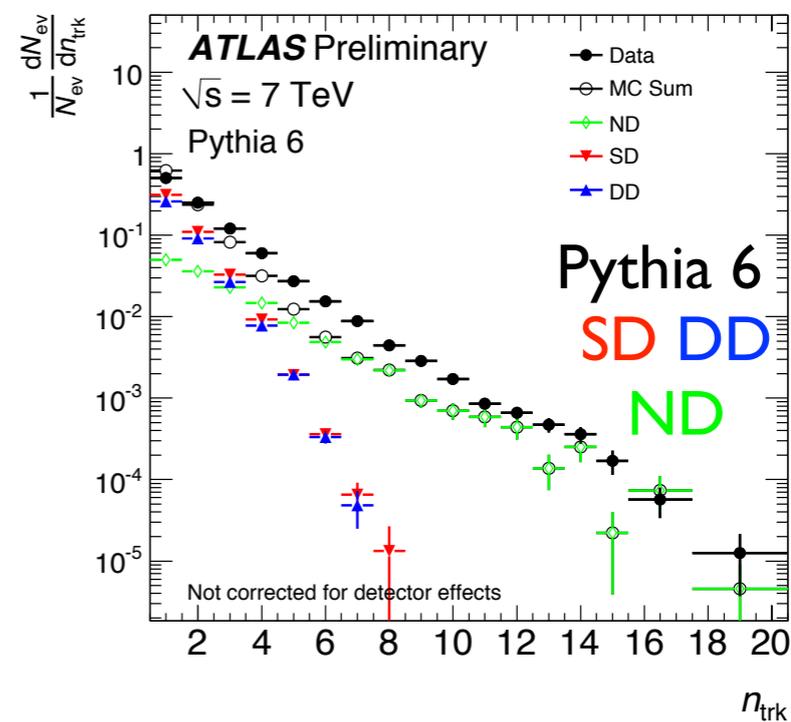
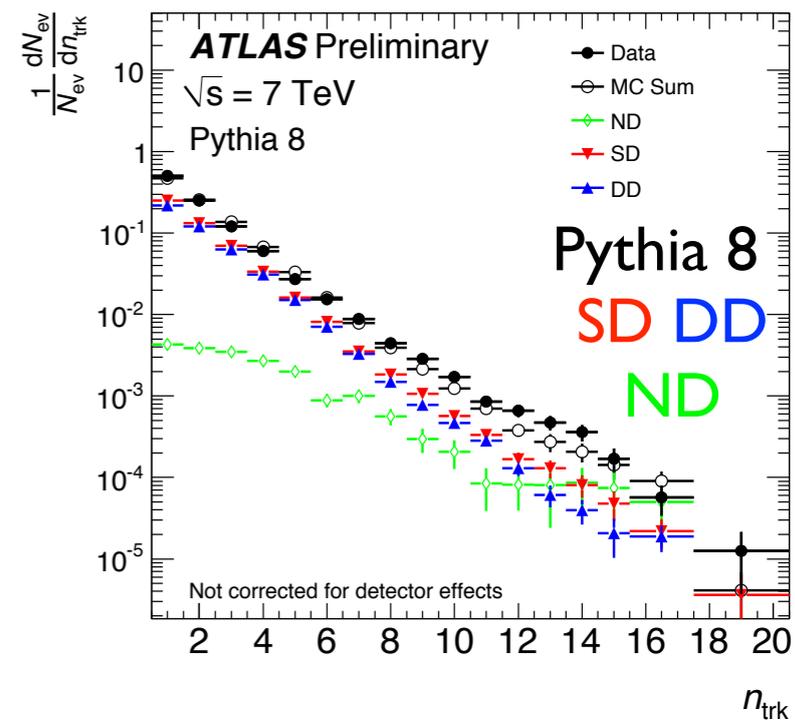
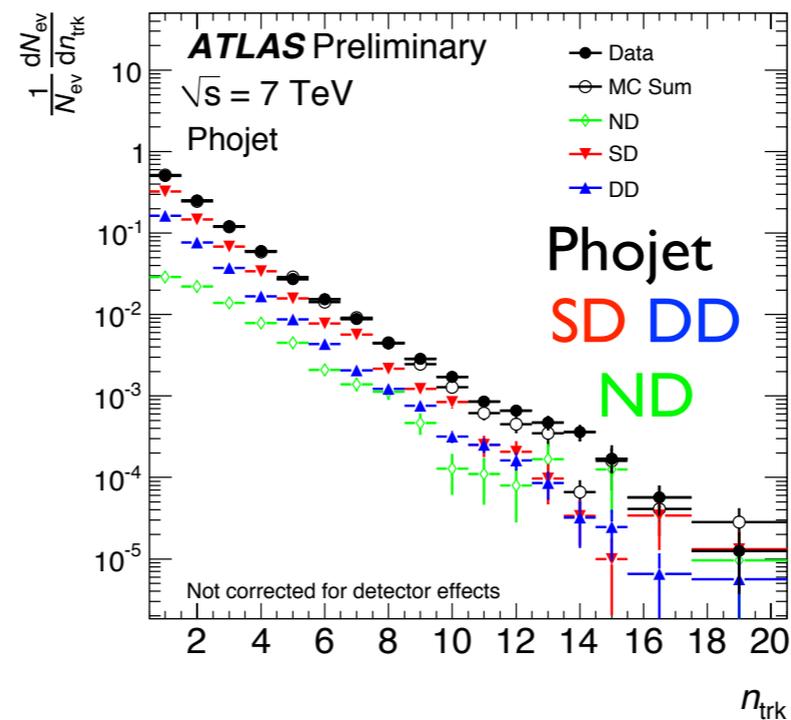
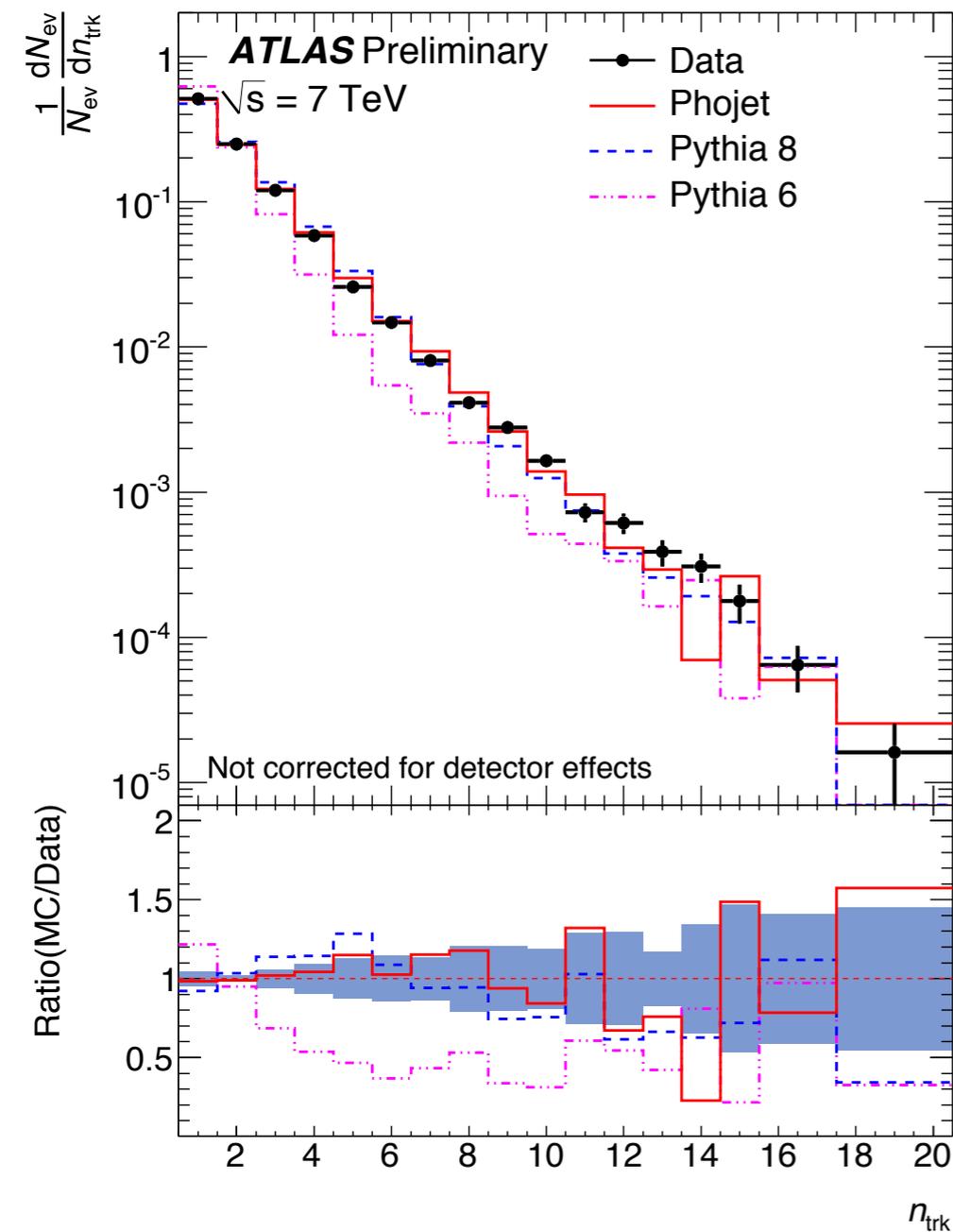


- Pythia 8 & Phojet reproduce the spectrum well
- Pythia 6 is too soft.

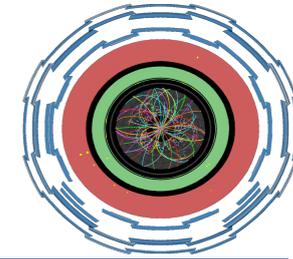
# $1/N_{ev} dN_{ev}/dN_{trk}$



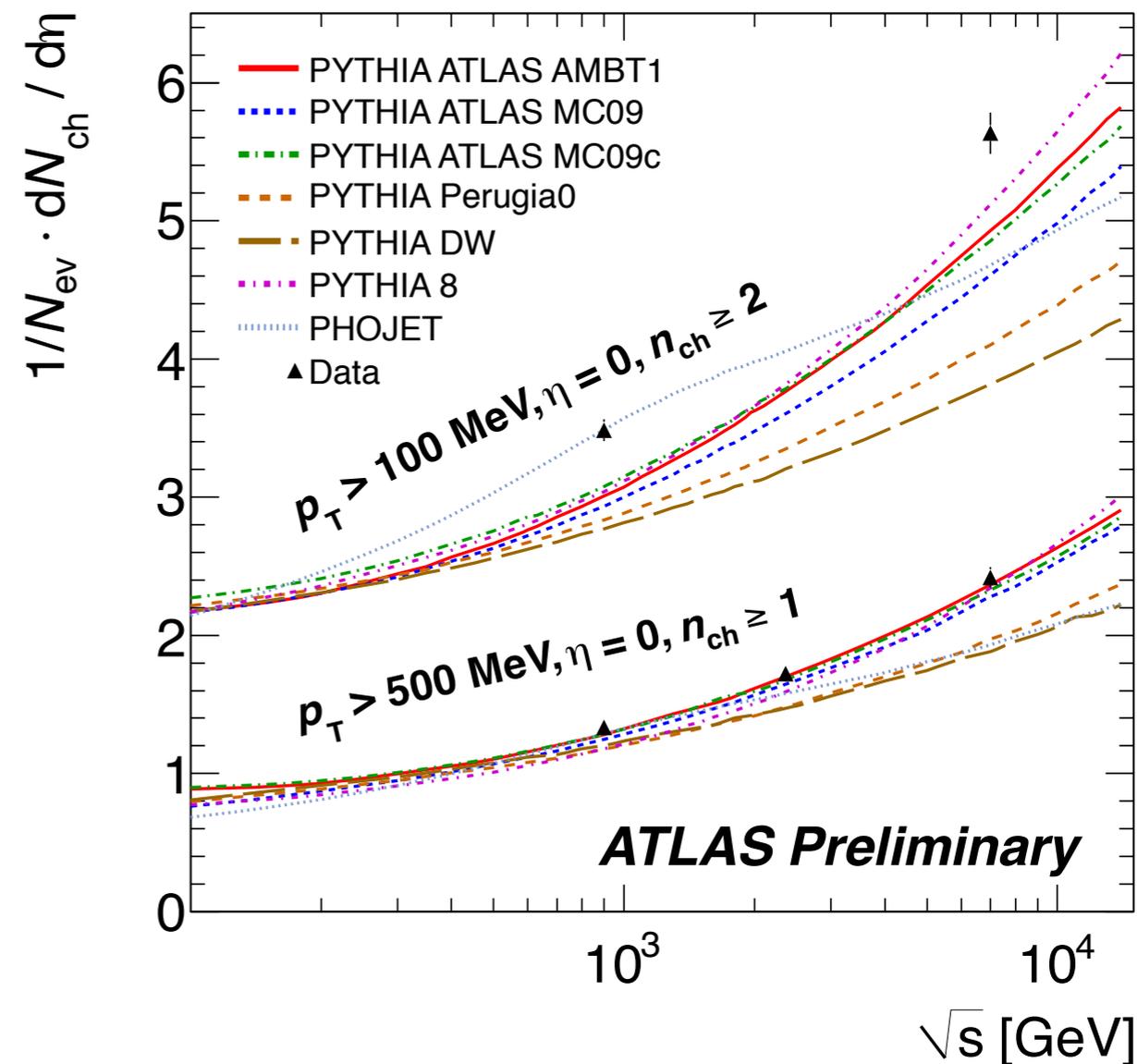
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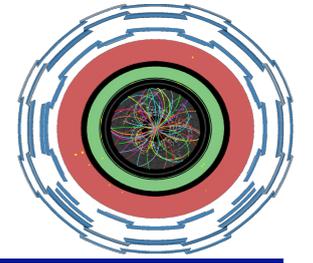
# Conclusions&Outlook



- ATLAS has now measured minimum bias events in 3 phase spaces and at 3 center of mass energies
  - Variety should aid in MC tuning
- Both low and high momentum/multiplicity inclusive MB events are not well described by MC
  - AMBT1 improves significantly on intermediate region
- Diffraction enhanced analysis favors 30% relative diffractive cross section and a hard diffractive component
  - Plan for a detector corrected result by the end of the year



# References



ATLAS-CONF-2010-046

*Charged particle multiplicities in pp interactions for track  $PT > 100$  MeV at  $\sqrt{s} = 0.9$  and 7 TeV measured with the ATLAS detector at the LHC*

20 July 2010

ATLAS-CONF-2010-047

*Charged particle multiplicities in pp interactions at  $\sqrt{s} = 2.36$  TeV measured with the ATLAS detector at the LHC*

16 July 2010

ATLAS-CONF-2010-024

*Charged particle multiplicities in pp interactions at  $\sqrt{s} = 7$  TeV measured with the ATLAS detector at the LHC*

21 April 2010

Publication

*Charged-particle multiplicities in pp interactions at  $\sqrt{s} = 900$  GeV measured with the ATLAS detector at the LHC*

15 March 2010

ATLAS-CONF-2010-031

*Charged particle multiplicities in pp interactions at  $\sqrt{s} = 0.9$  and 7 TeV in a diffractive limited phase-space measured with the ATLAS detector at the LHC and new PYTHIA6 tune*

31 May 2010

ATLAS-CONF-2010-048

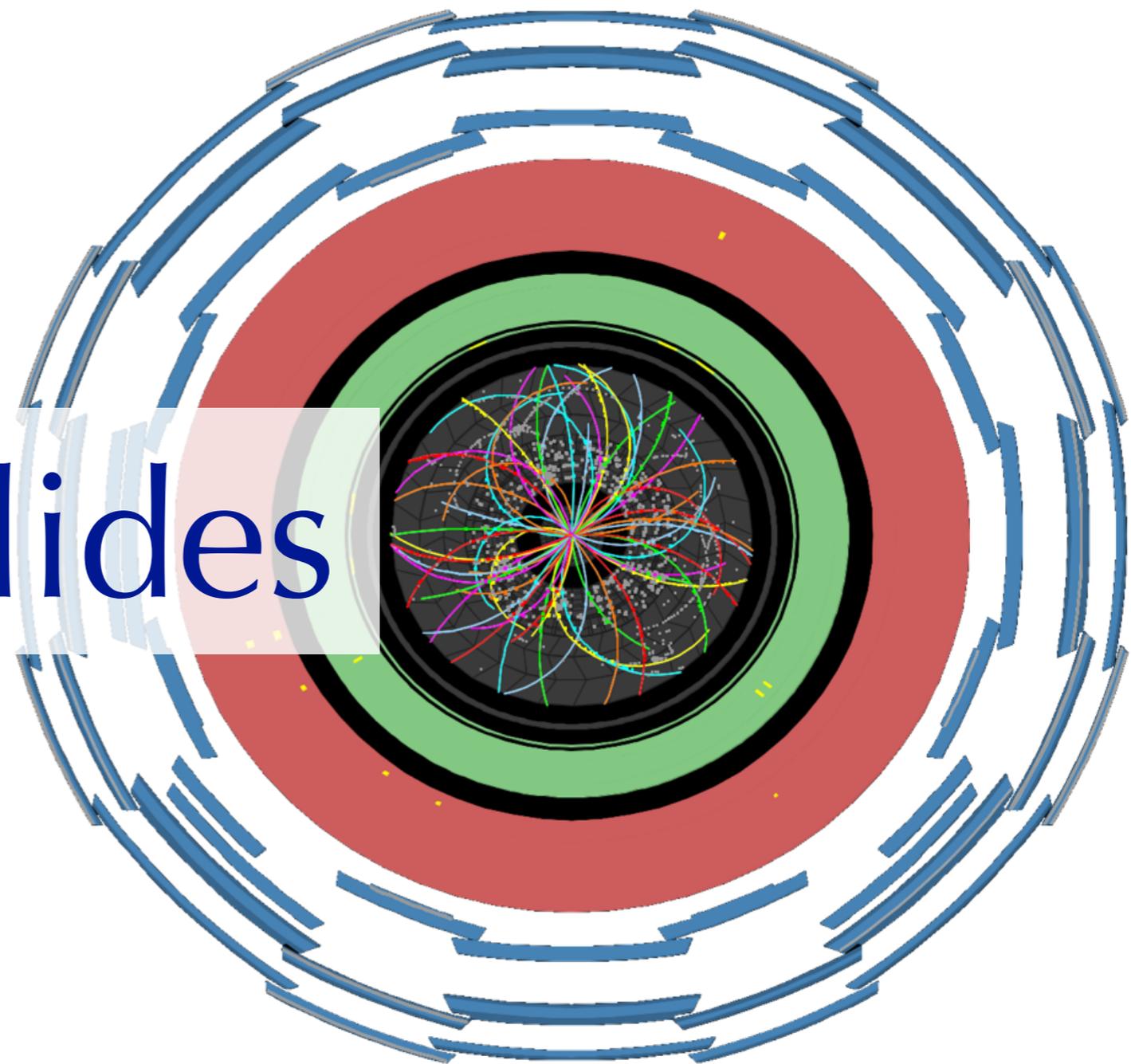
*Studies of Diffractive Enhanced Minimum Bias Events in ATLAS*

20 July 2010

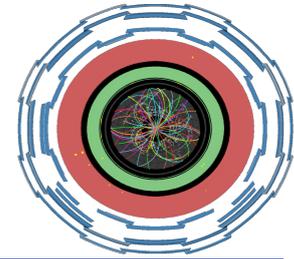
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Additional Slides

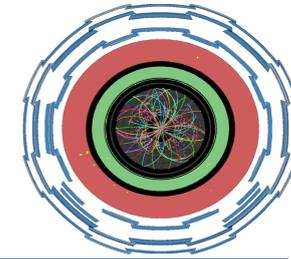


# Dataset Details



- Inclusive MB:
  - 900 GeV:  $7 \mu\text{b}^{-1}$ ; 350k events
  - 2.35 TeV:  $0.1 \mu\text{b}^{-1}$ ; 6k events
  - 7 TeV:  $190 \mu\text{b}^{-1}$ ; 10M events
- Diffraction enhanced (7 TeV):  $23 \mu\text{b}^{-1}$ ; 53k events
- Pile-up:
  - Negligible for 900 GeV, 2.36 TeV and 7 TeV diffraction enhanced
  - Removed by veto on second primary vertex in 7 TeV; sys. error is 0.03% at low multiplicities, up to 1% at highest multiplicities
- MCs:
  - Pythia 6: v6.4.21; MRST LO\* pdfs,
  - Pythia 8: v6.1.15
  - Phojet: v1.12.1.35 + pythia 6.1.15 for fragmentation

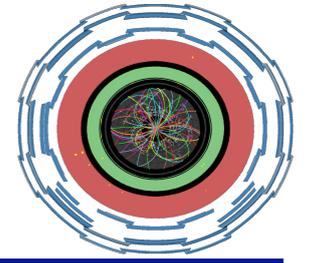
# Inclusive MB Systematics



Systematic uncertainty on the number of events, $N_{ev}$		
	$\sqrt{s} = 0.9$ TeV	$\sqrt{s} = 7.0$ TeV
Trigger efficiency	0.2%	0.2%
Vertex-reconstruction efficiency	< 0.1%	< 0.1%
Track-reconstruction efficiency	1.0%	0.7%
Different Monte Carlo tunes	0.4%	0.4%
Total uncertainty on $N_{ev}$	1.1%	0.8%
Systematic uncertainty on $(1/N_{ev}) \cdot (dN_{ch}/d\eta)$ at $\eta = 0$		
Track-reconstruction efficiency	3.1%	3.1%
Trigger and vertex efficiency	< 0.1%	< 0.1%
Secondary fraction	0.4%	0.4%
Total uncertainty on $N_{ev}$	-1.1%	-0.8%
Total uncertainty on $(1/N_{ev}) \cdot (dN_{ch}/d\eta)$ at $\eta = 0$	2.1%	2.3%

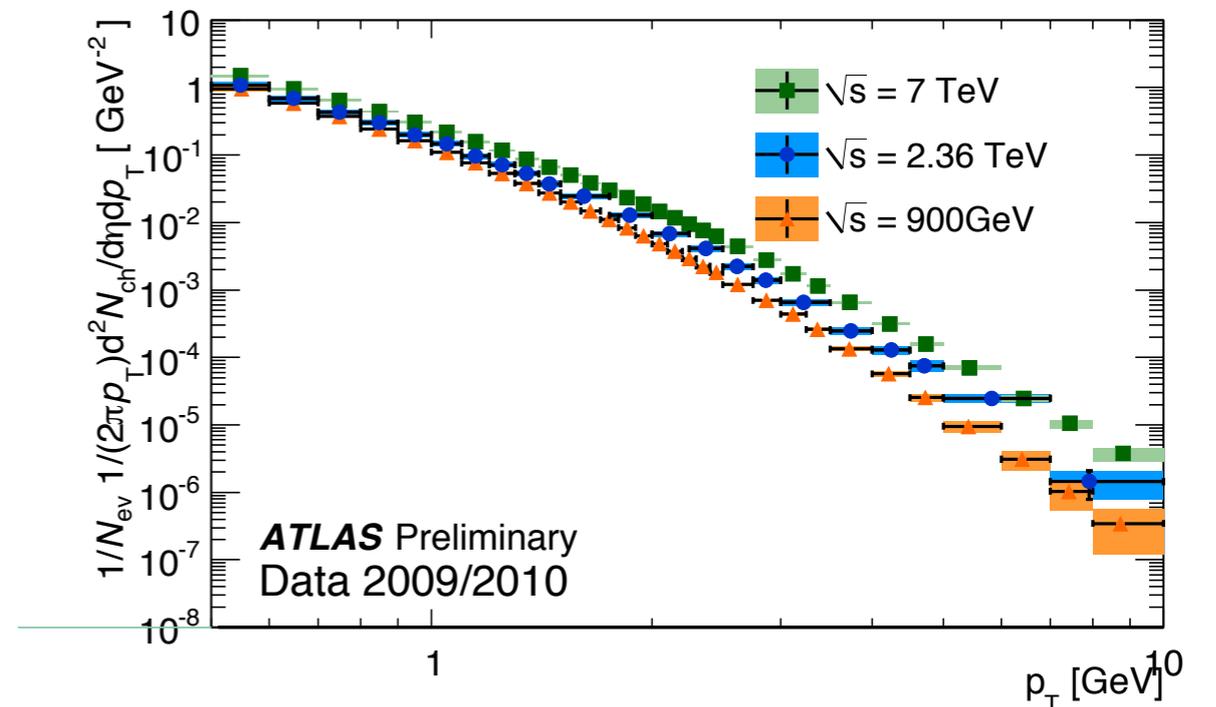
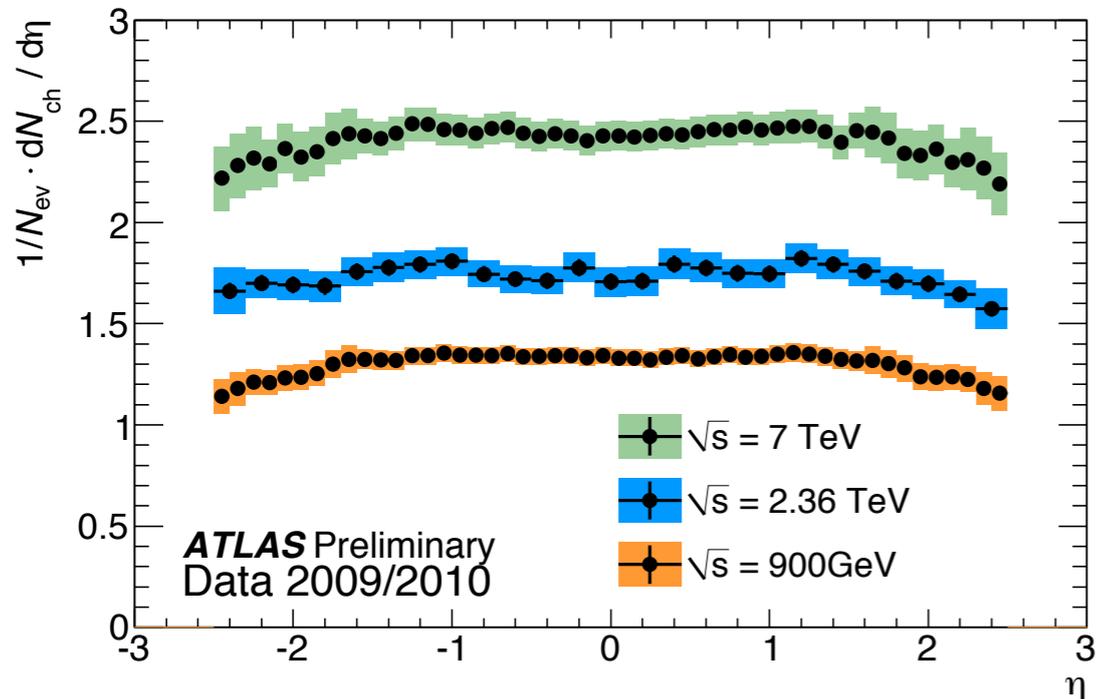
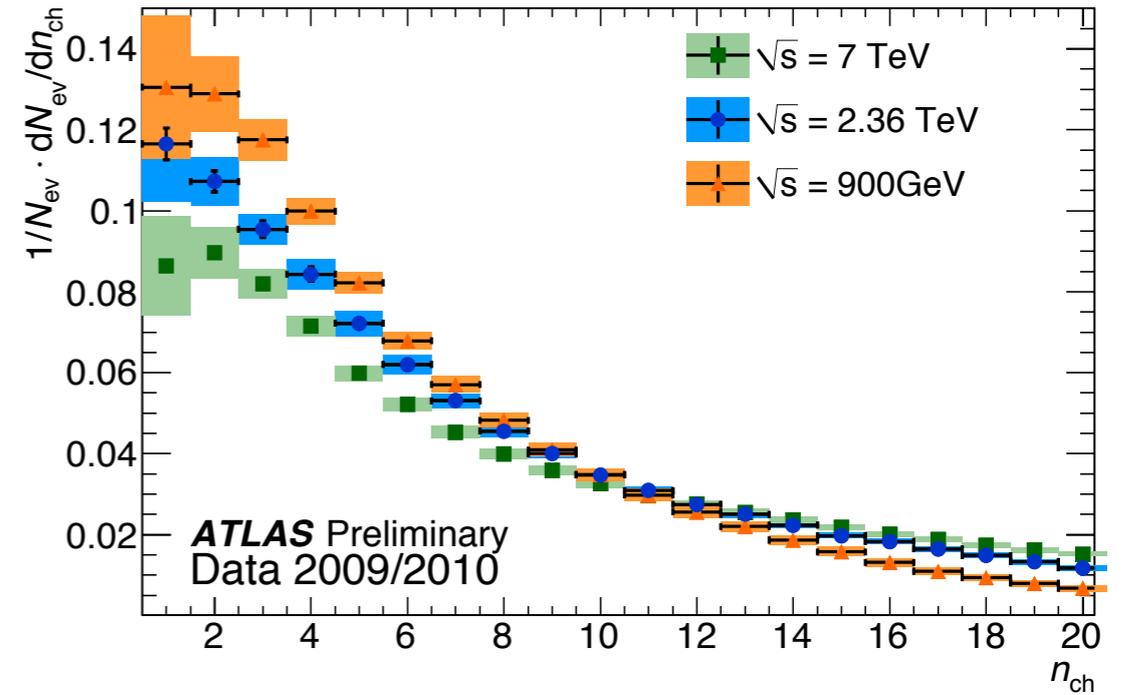
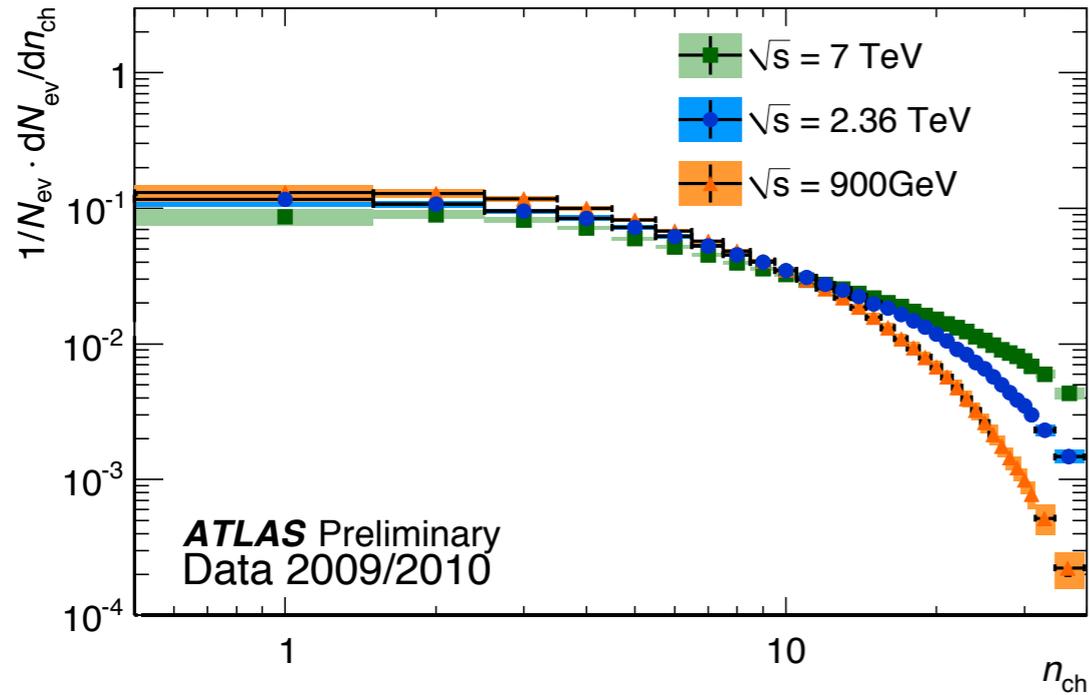
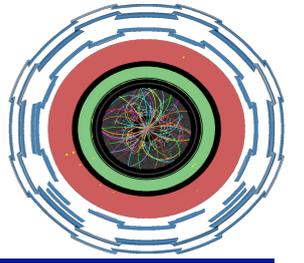
Table 1: Summary of systematic uncertainties on the number of events,  $N_{ev}$ , and on the charged-particle density  $(1/N_{ev}) \cdot (dN_{ch}/d\eta)$  at  $\eta = 0$ . All sources of uncertainty are assumed to be uncorrelated.

# Diffractive MB Systematics



Source	% of $R_{SS}$
Track Reconstruction	3%
MBTS Data/MC Agreement	14%
Beam Background	<.1%
Noise Contamination	<.1%

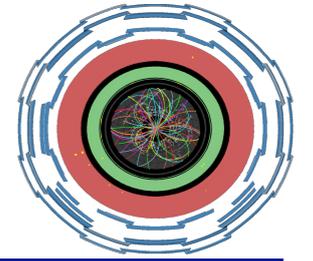
# Energy Comparisons



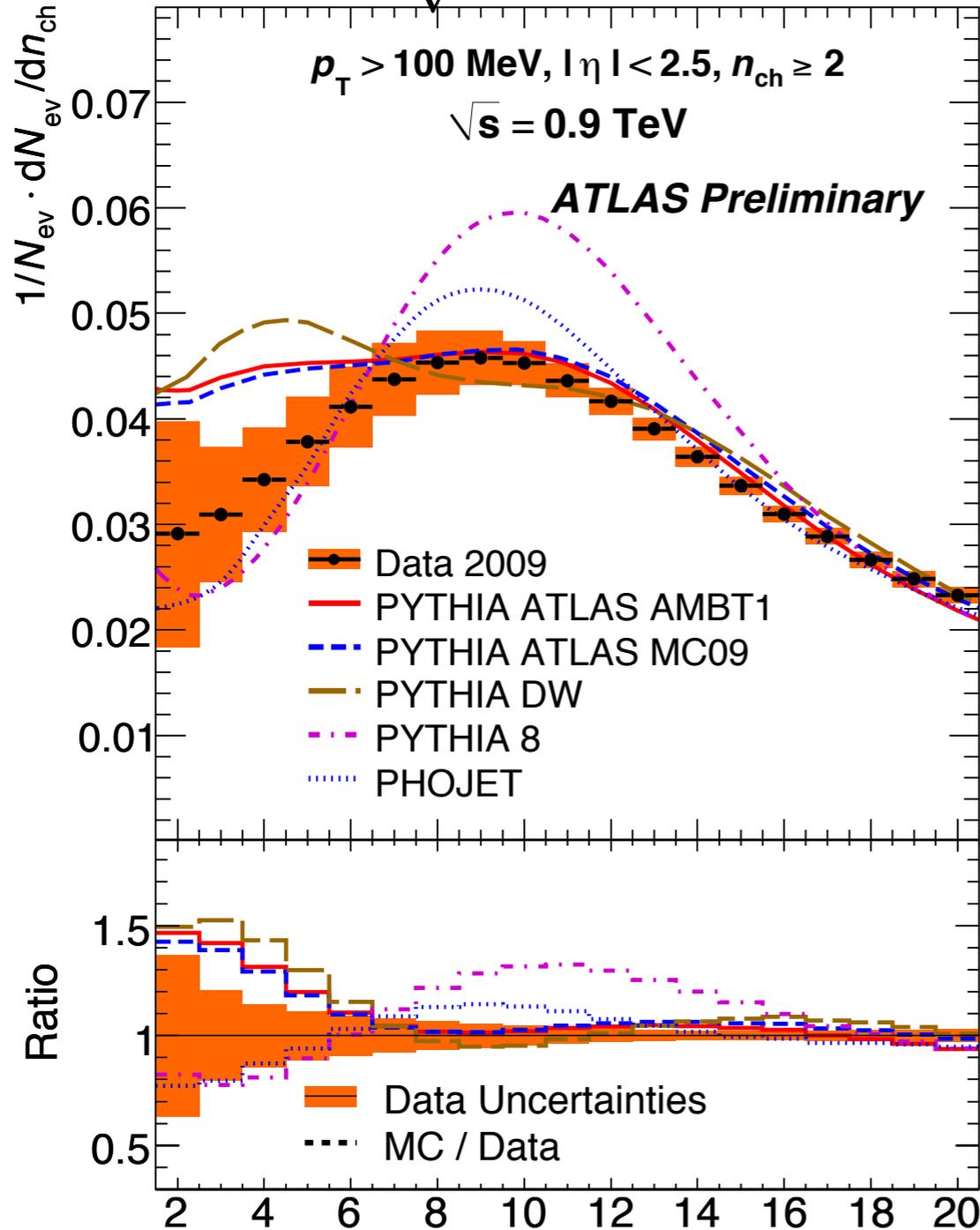
$N_{ch} \geq 1; p_T > 500$  MeV

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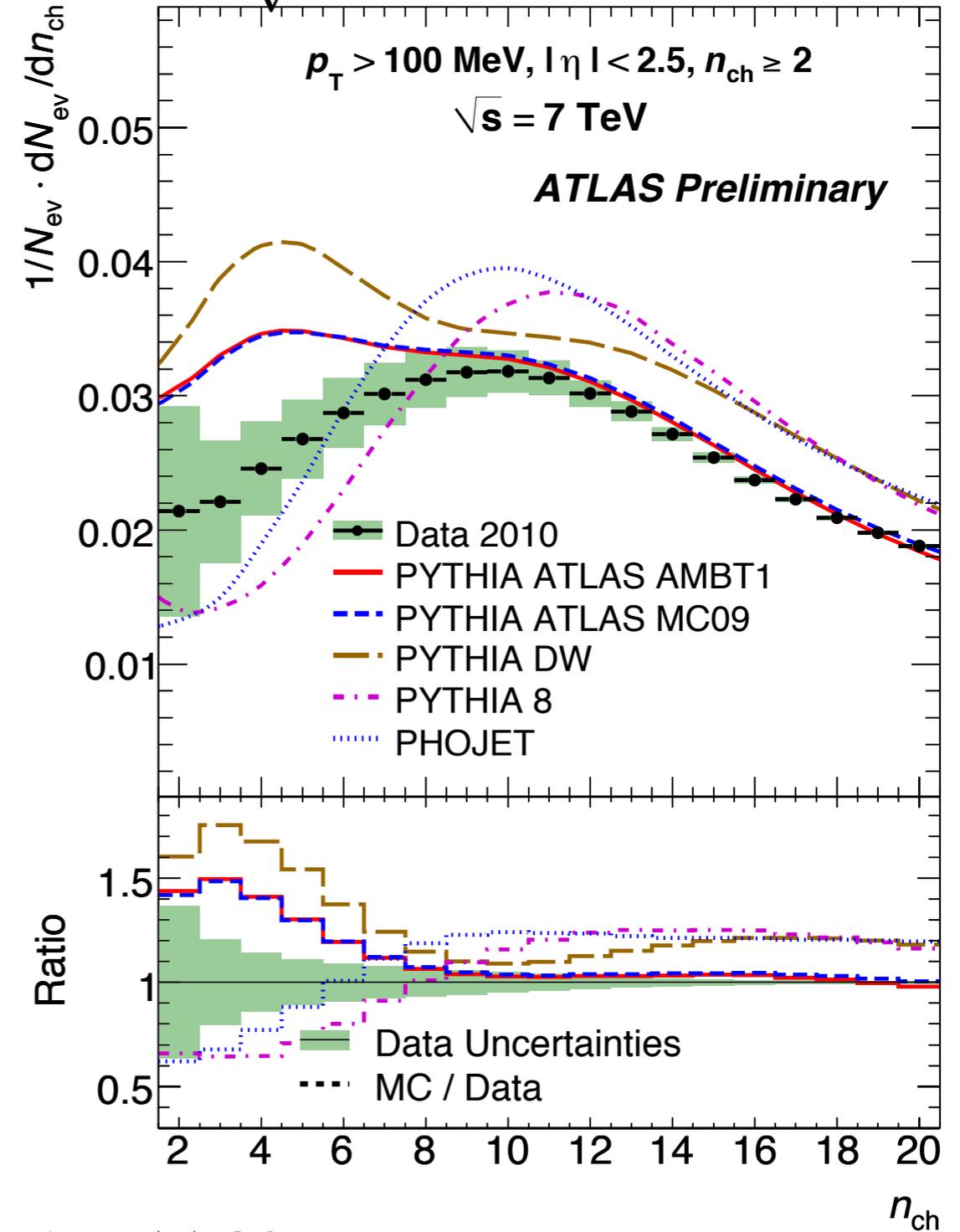
# Low $N_{ch}$



$\sqrt{s} = 0.9 \text{ TeV}$



$\sqrt{s} = 7.0 \text{ TeV}$

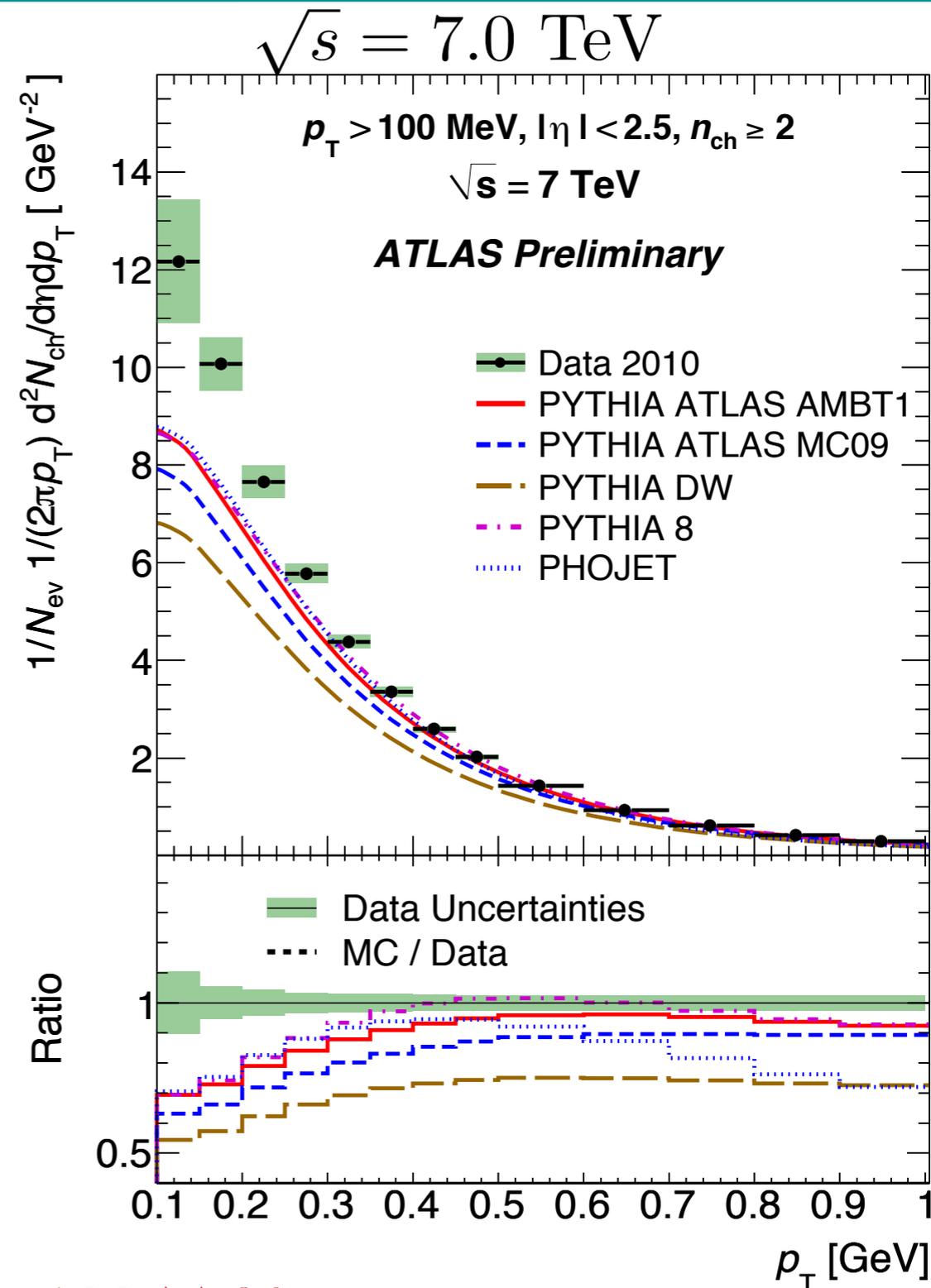
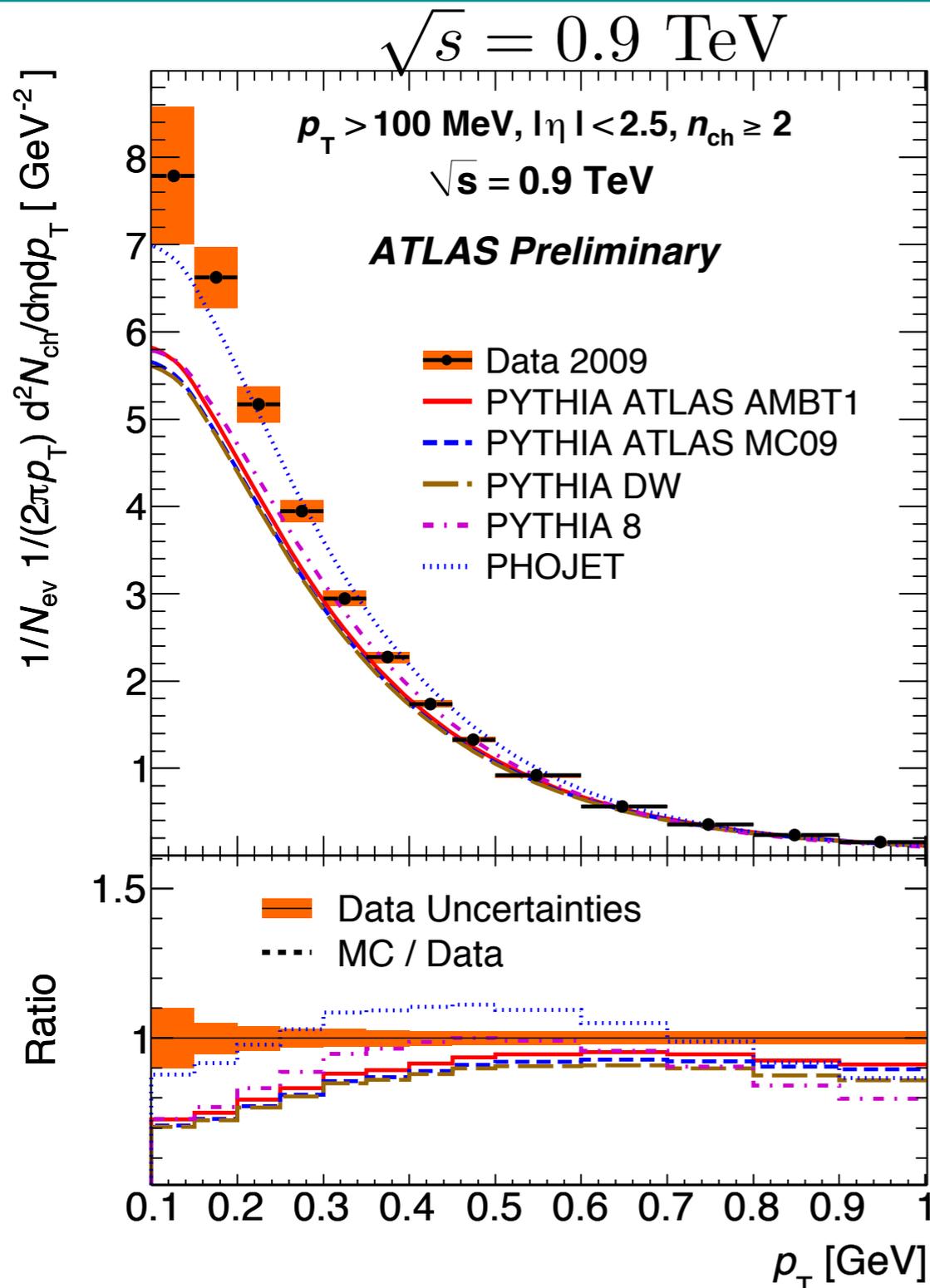
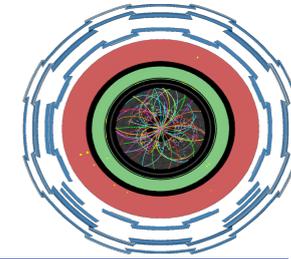


$N_{ch} \geq 2; p_T > 100 \text{ MeV}$

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# Low $p_T$

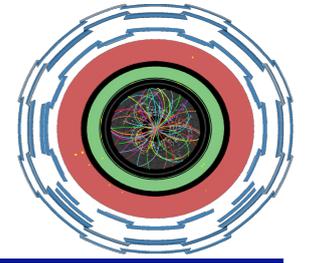


$N_{\text{ch}} \geq 2; p_T > 100 \text{ MeV}$

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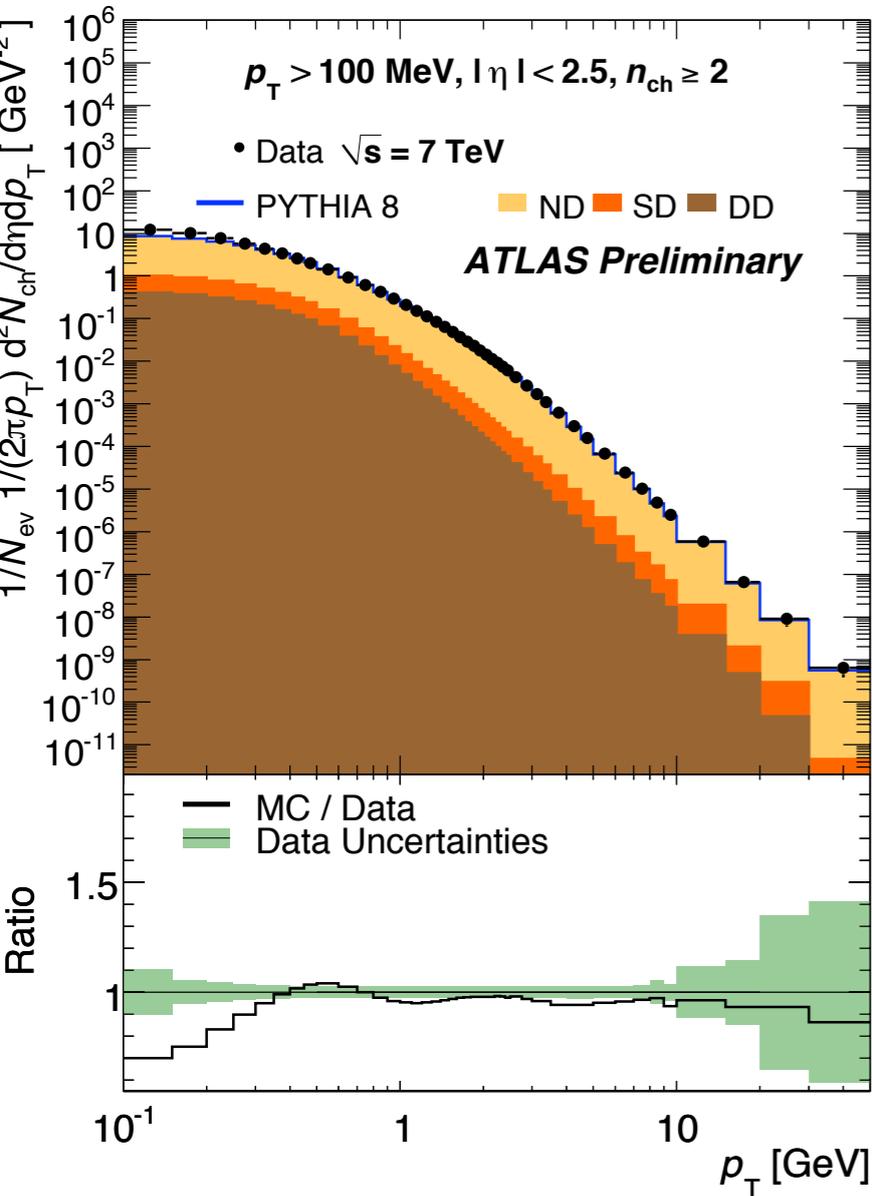
September 6th, 2010

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

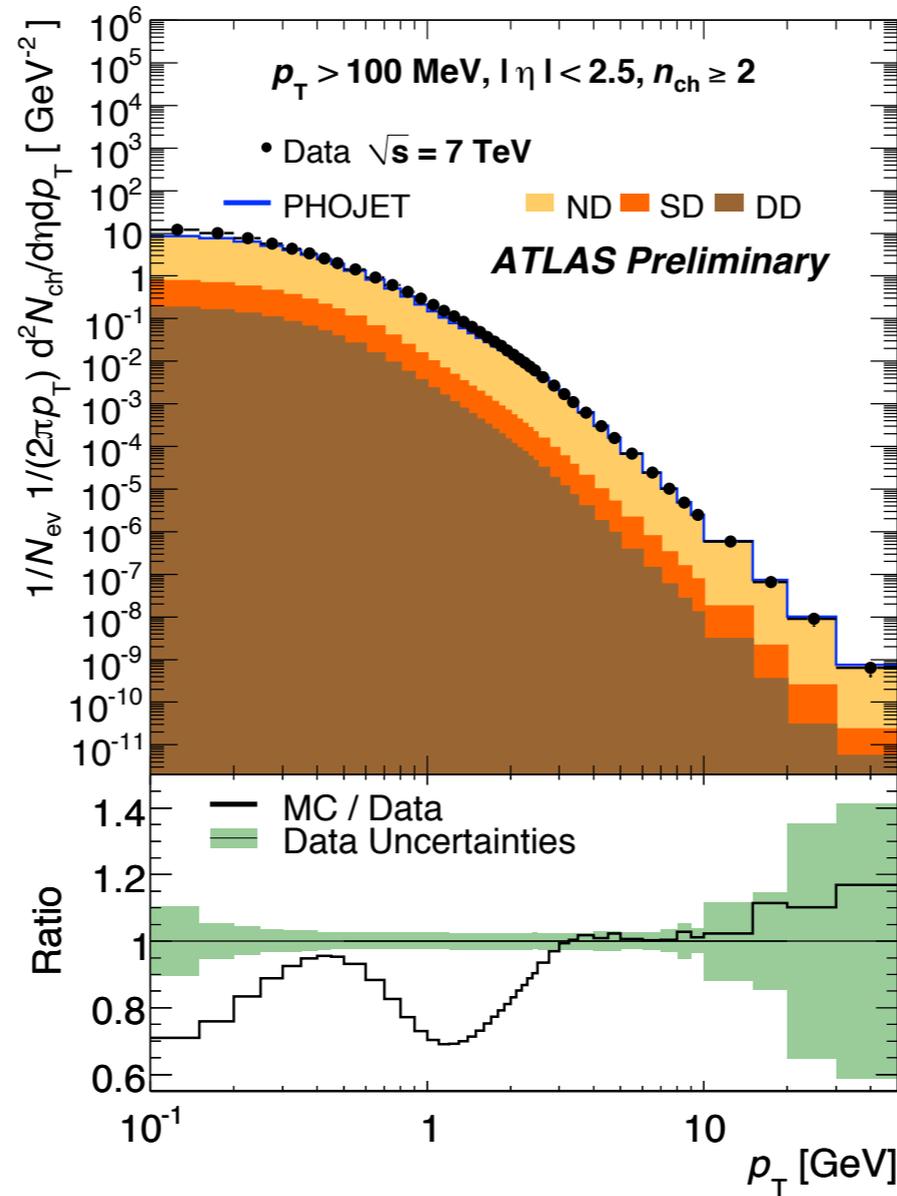


$\sqrt{s} = 7.0$  TeV

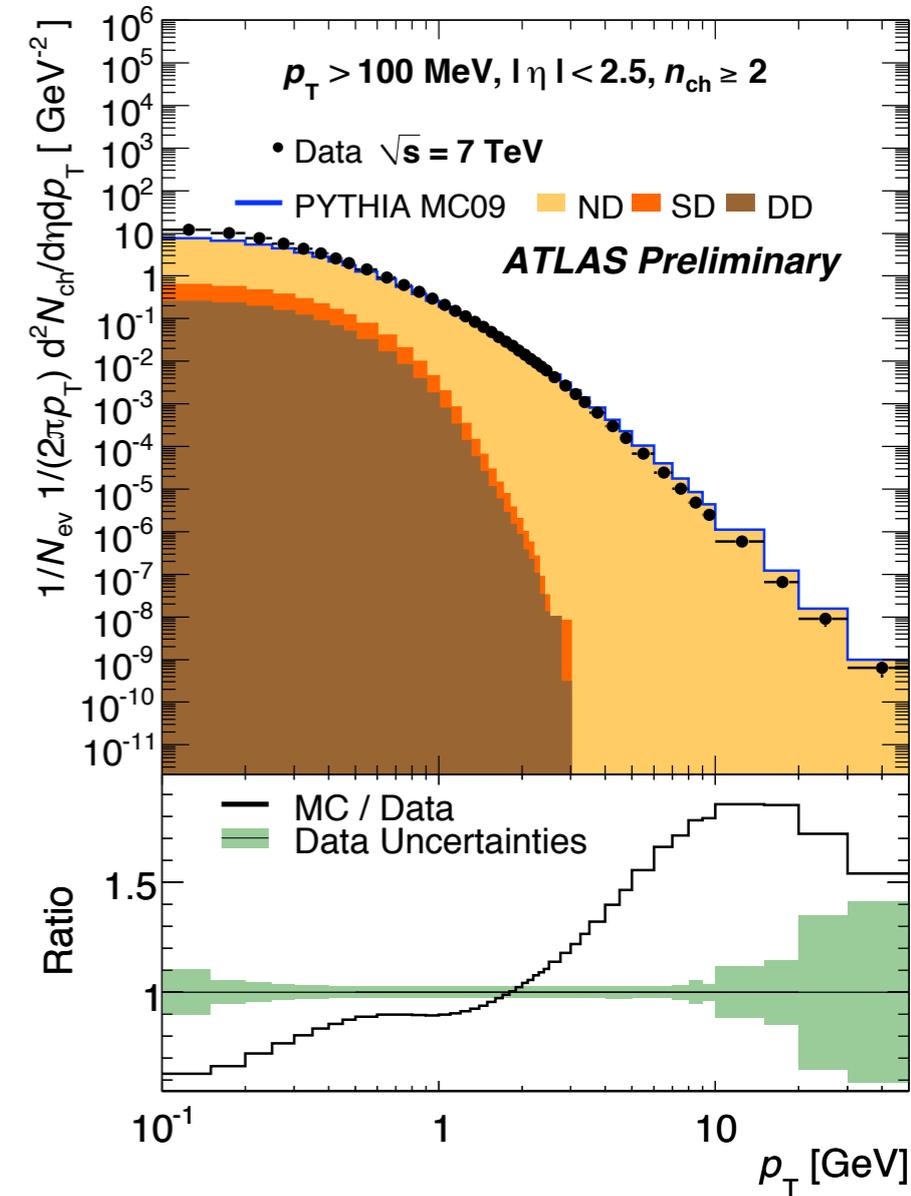
Pythia 8



Phojet



Pythia 6 MC09

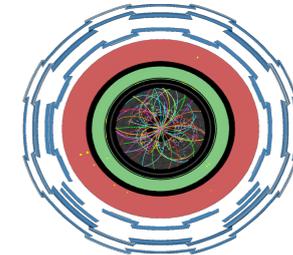


$N_{ch} \geq 2; p_T > 100$  MeV

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September 6th, 2010

# $1/N_{ev} dN_{ev}/dN_{ch}$

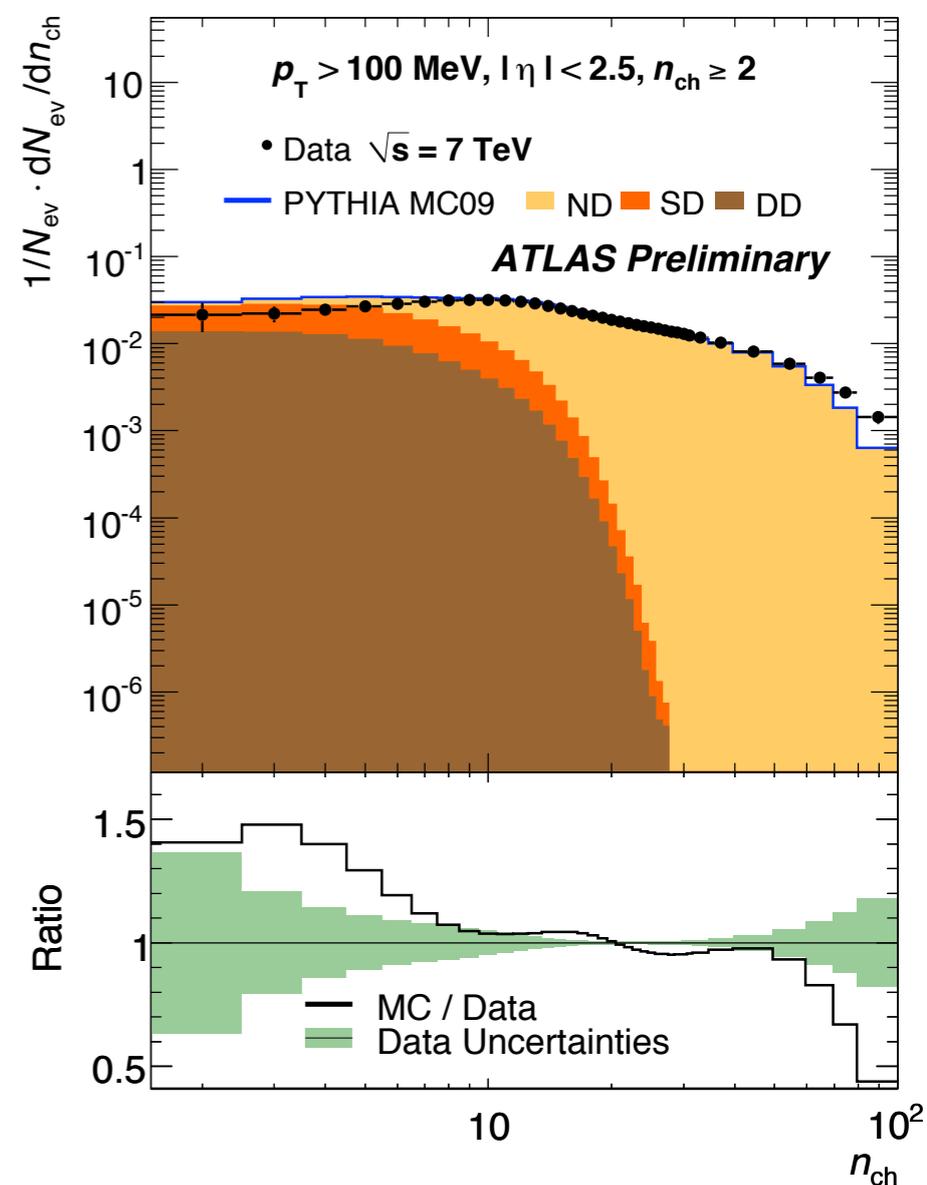
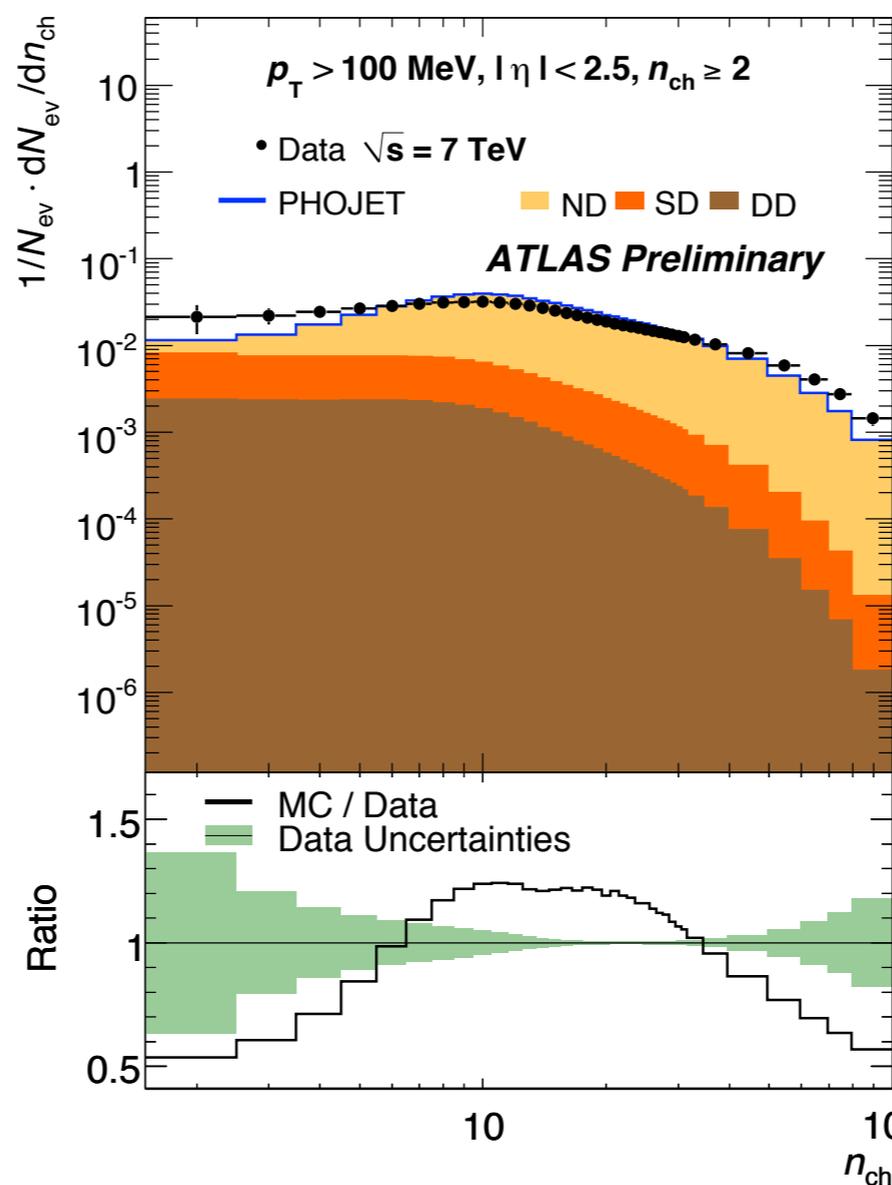
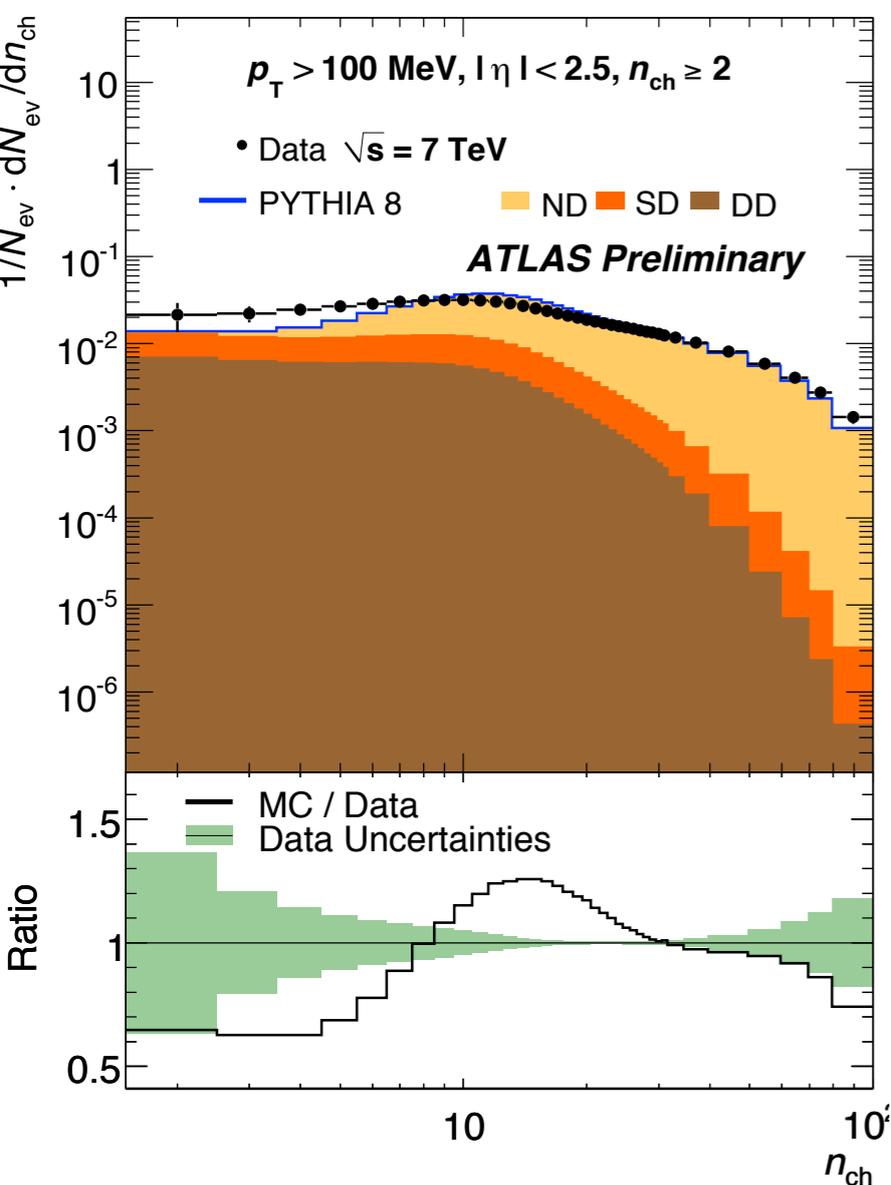


$\sqrt{s} = 7.0 \text{ TeV}$

Pythia 8

Phojet

Pythia 6 MC09

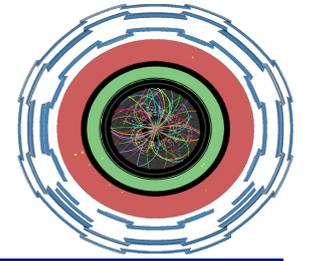


$N_{ch} \geq 2; p_T > 100 \text{ MeV}$

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# Reminder: AMBT1



Parameter	Related Model	MC09c value	scanning range	AMBT1 value
PARP(62)	ISR cut-off	1.0	fixed	1.025
PARP(93)	Primordial $k_T$	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

- Atlas AMBT1 tune was developed using *diffraction suppressed* phase space ( $N_{ch} \geq 6, p_T > 500 \text{ MeV}$ )
  - Color reconnection (CR) and multiple parton interactions (MPI) tuned
    - Biggest change in matter core fraction (parp 83) and CR parameters (parp 77&78)
- Performance we expect for new phase space ( $p_T > 100 \text{ MeV}$ ):
  - Good agreement for mid  $p_T$  range
  - Low  $p_T$  and high  $p_T$  likely to remain problematic