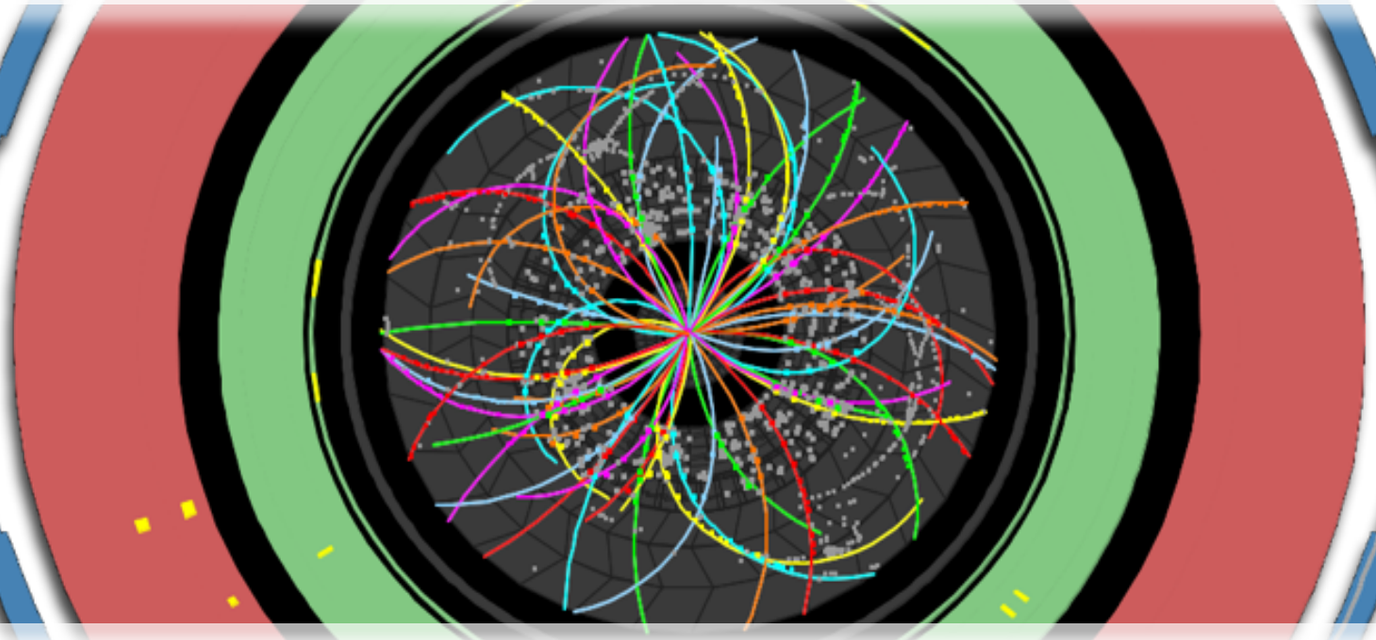
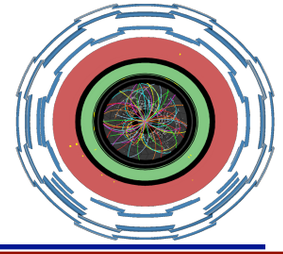
Underlying Event and Diffraction With Charged Particles in ATLAS

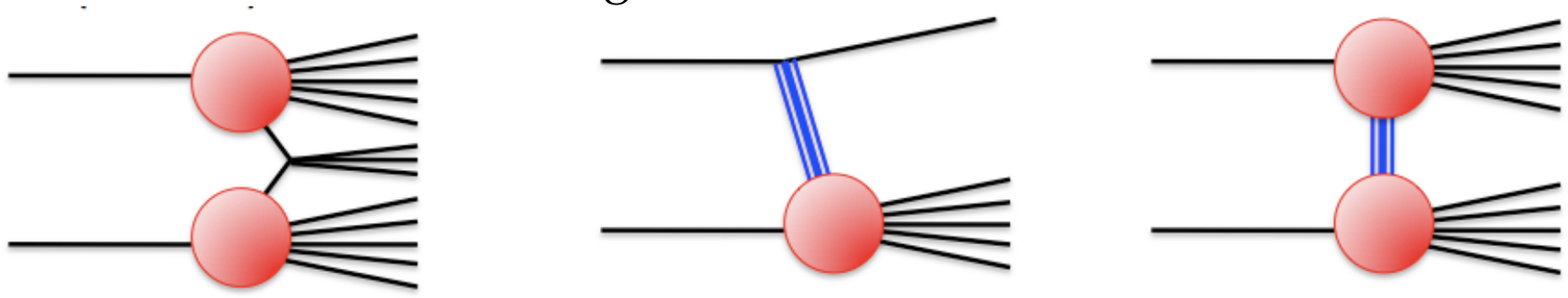


Lauren Tompkins (UCB/LBNL)
for the
ATLAS Collaboration

Soft QCD

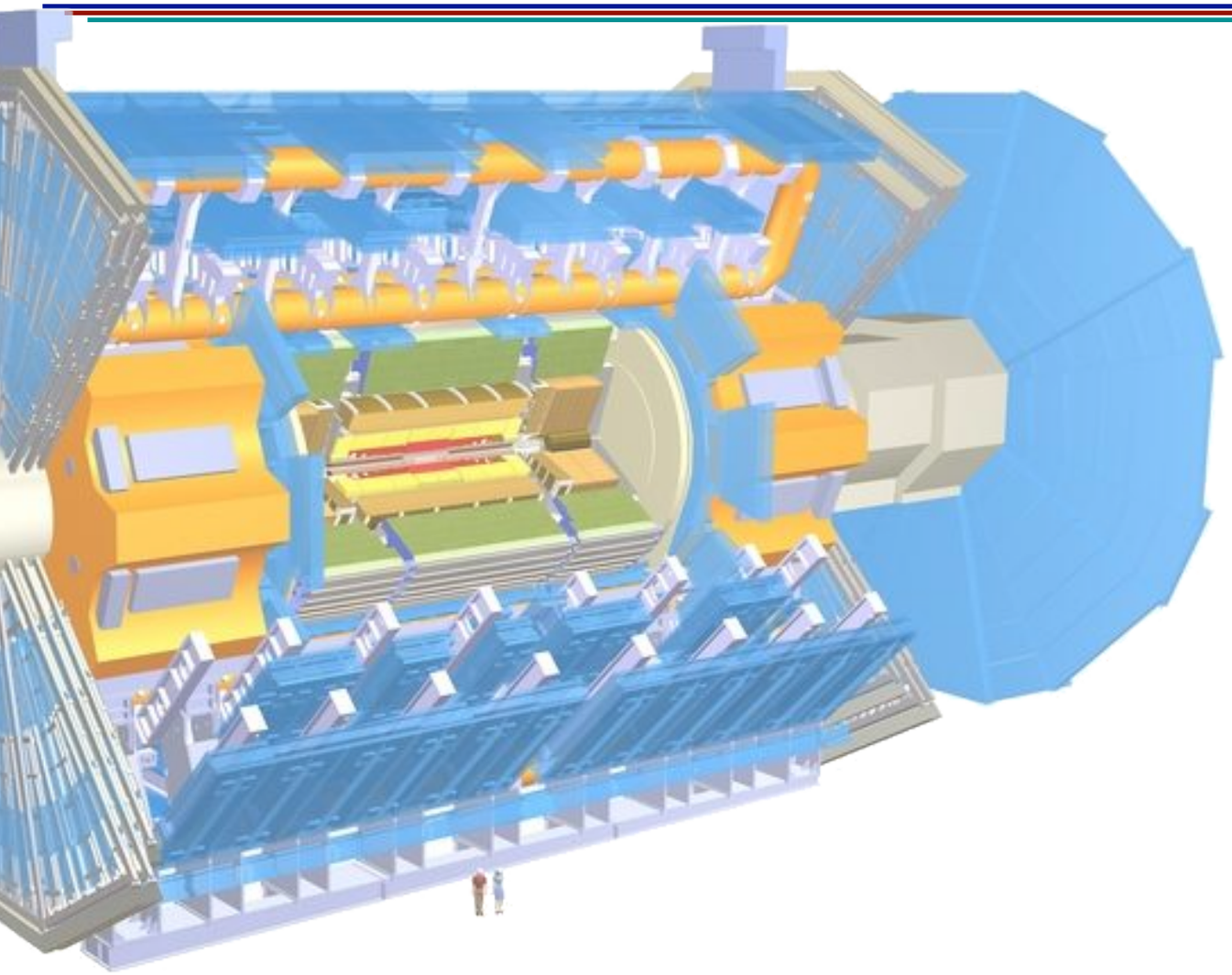


Non-Diffractive (ND) Single Diffractive (SD) Double Diffractive (DD)

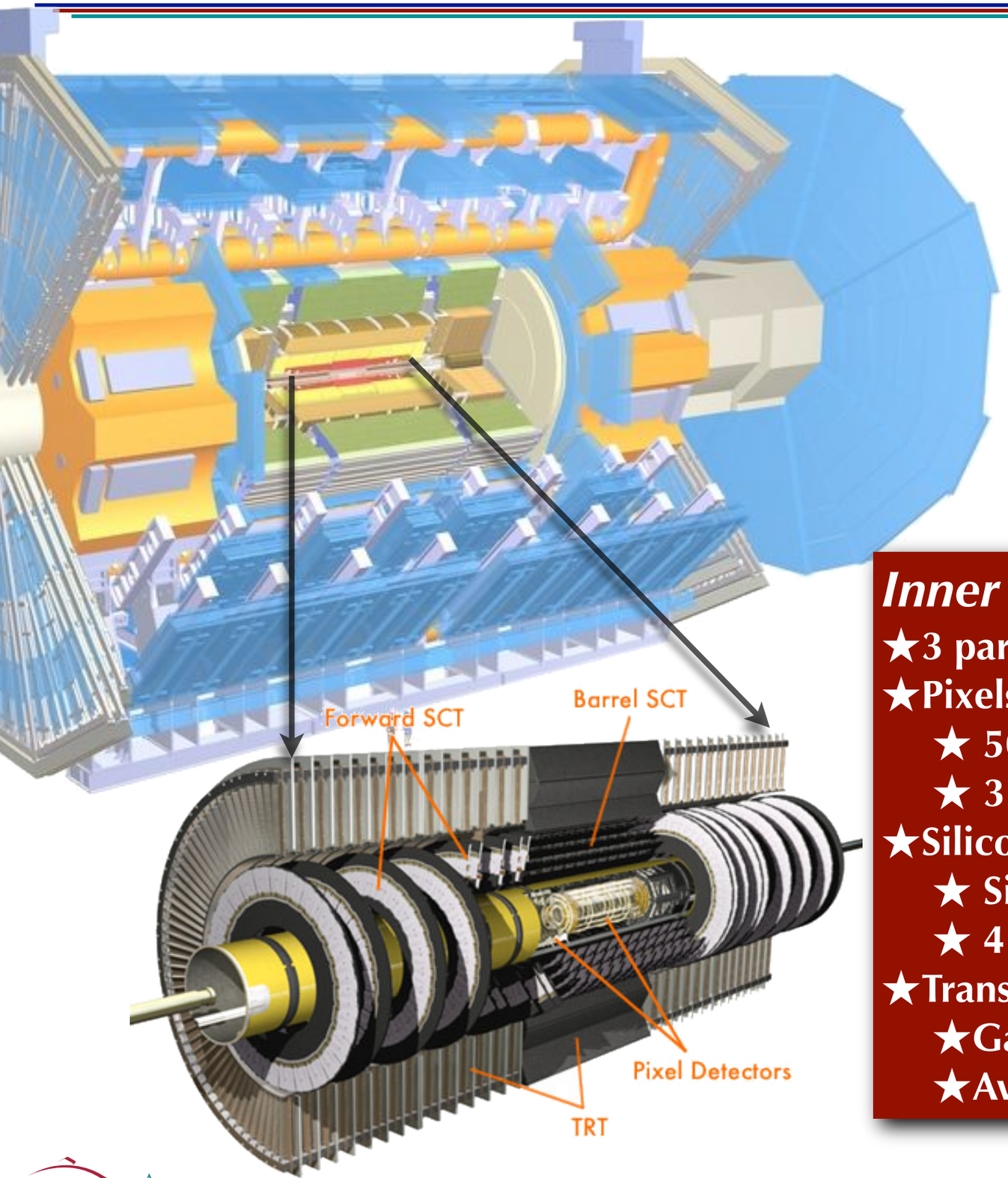


- Majority of pp collisions belong to the realm of Soft QCD
- Soft QCD is non perturbative ⇒ theoretical understanding is driven by models fit to existing data
- Measurements presented here use inclusive Minimum Bias selection, then study charged particle properties in restricted phase space
- Why: to study subdominant processes of pp collisions
  - Underlying Event (UE): everything that is happening apart from the hard scatter
    - Important for understanding jet corrections, missing energy, etc.
  - Diffraction: p-p interactions with colorless exchange
    - Significant portion of total pp cross section, largely unconstrained
- Can use measurements to tune MC and improve models!

ATLAS Detector



ATLAS Detector



***Inner Detector*:**

★3 part tracker covering $|\eta|<2.5$:

★Pixels:

- ★ 50x400 micron silicon pixels
- ★ 3 barrel layers, 2x3 endcap layers

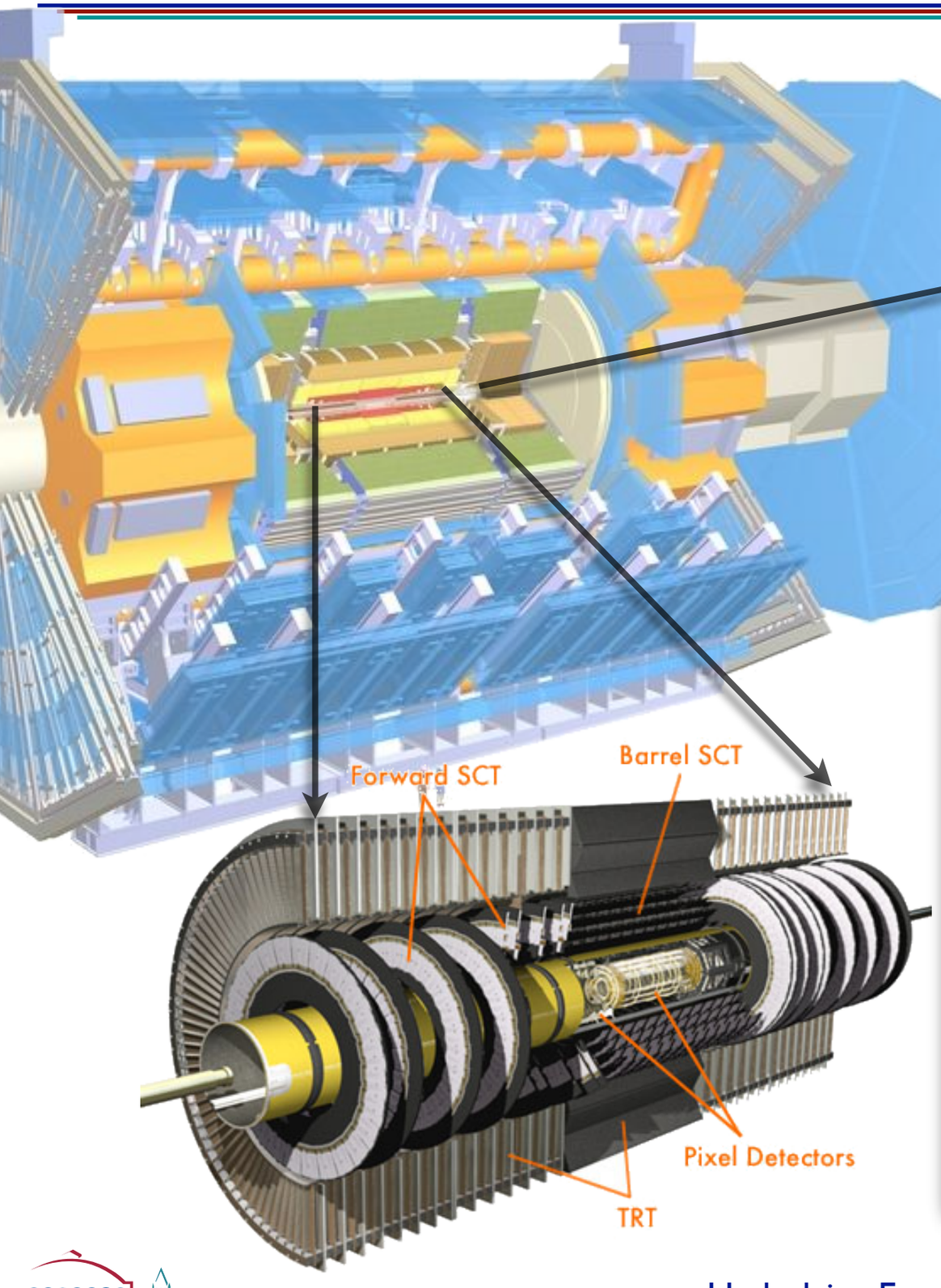
★Silicon Tracker (SCT)

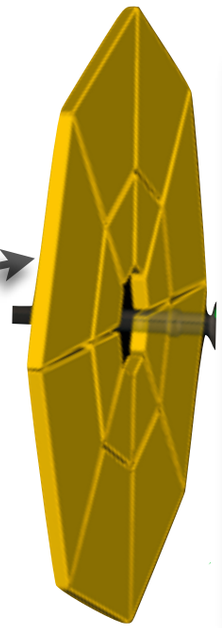
- ★ Silicon microstrip detector
- ★ 4 double sided barrel layers, 2x9 endcap

★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 ϕ, 2 rings in η per side

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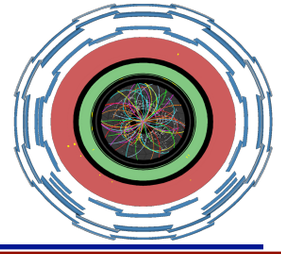
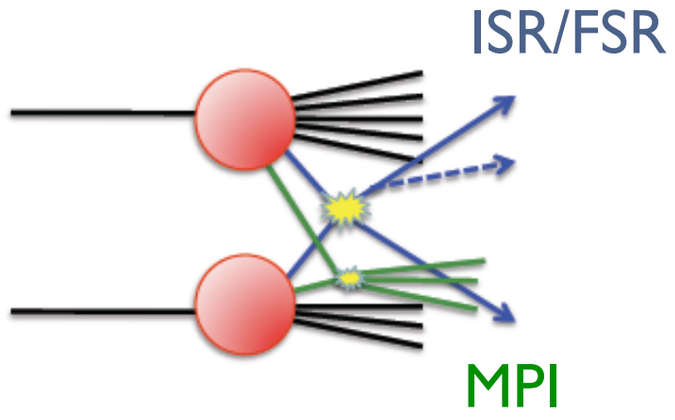
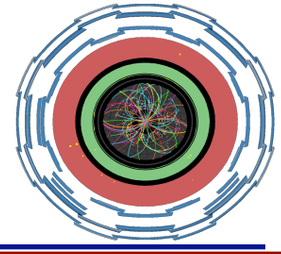
Underlying Event

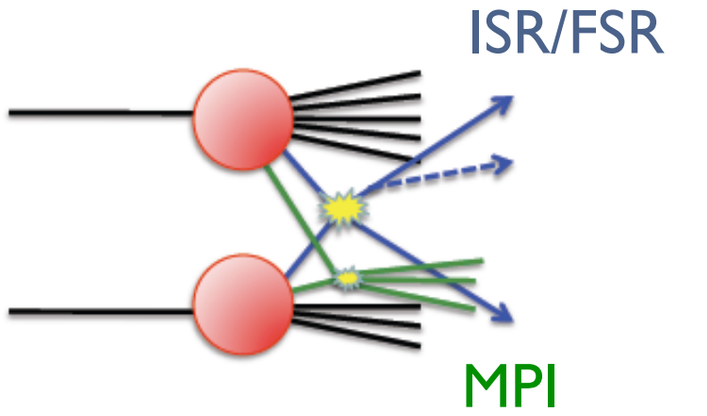


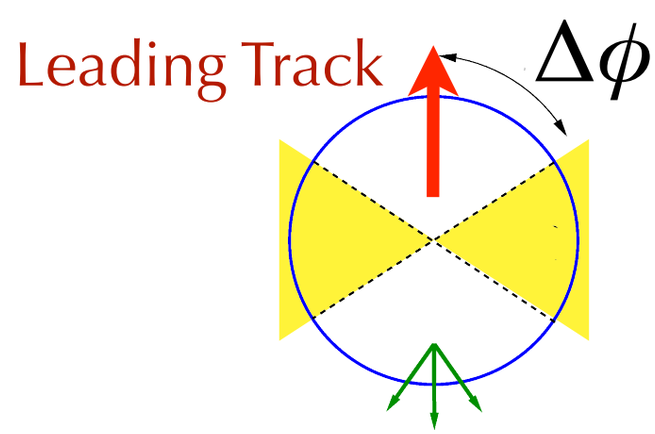
- Remove the hard scatter, underlying event remains:
  - Multiple parton interactions (MPI)
  - Initial and final state radiation (ISR/FSR)



Underlying Event







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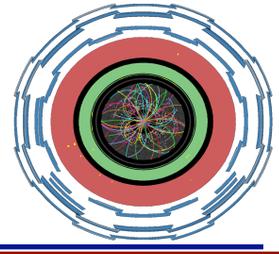
  - Highest p_T charged particle = axis

Underlying Event



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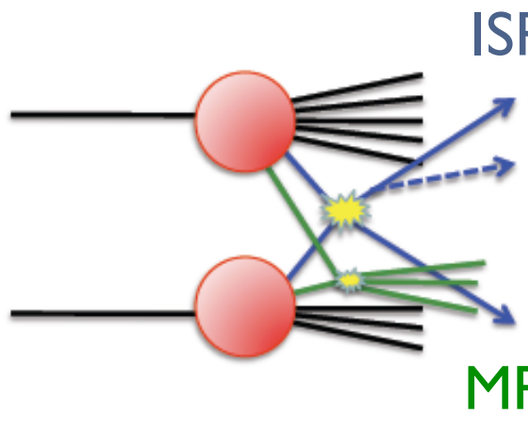
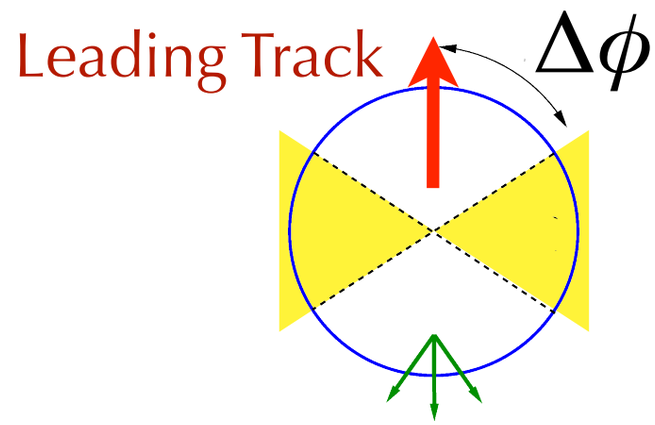
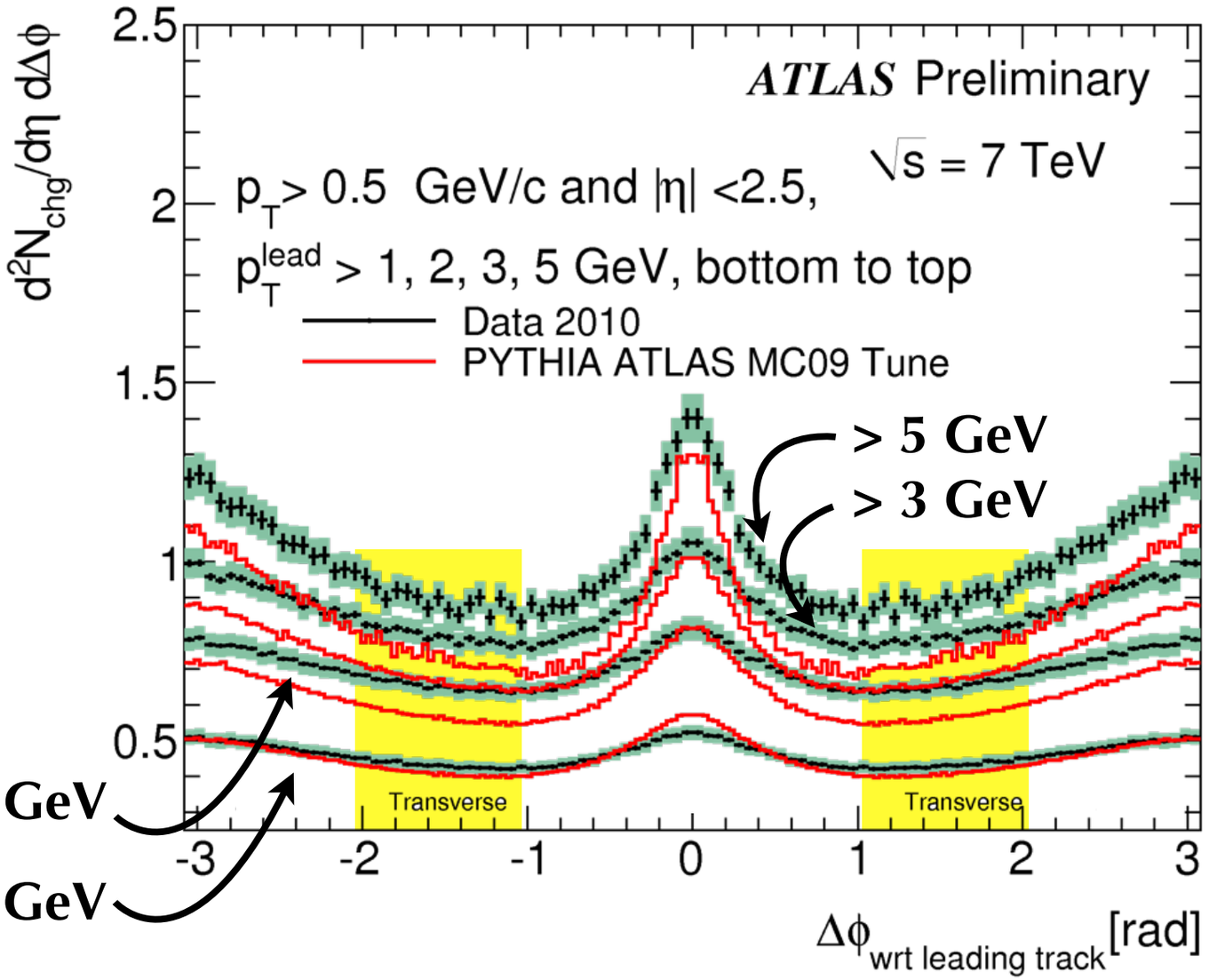
- Plot:
  - **charged particle density**
  - **Σp_T density**
  - $\langle p_T \rangle$ of charged particles vs N_{ch}
  - std. deviations of the densities







Measurement Details

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- Event Selection:
  - 9.1 μb^{-1} used for 900 GeV analysis, 6.7 μb^{-1} for 7 TeV (good data quality required)
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tracking efficiency

non primary fraction

fraction from outside acceptance

$$w_{trk}(p_T, \eta) = \frac{1}{\epsilon_{trk}}(1 - f_{non\ prim})(1 - f_{okr})$$

$$w_{ev} = \frac{1}{\epsilon_{trig}(n_{BS})} \frac{1}{\epsilon_{vert}(n_{BS}, \eta_{BS})} \frac{1}{\epsilon_{lead}}$$

trigger efficiency

vertex finding efficiency

Efficiency to find leading track

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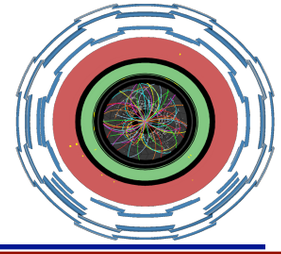

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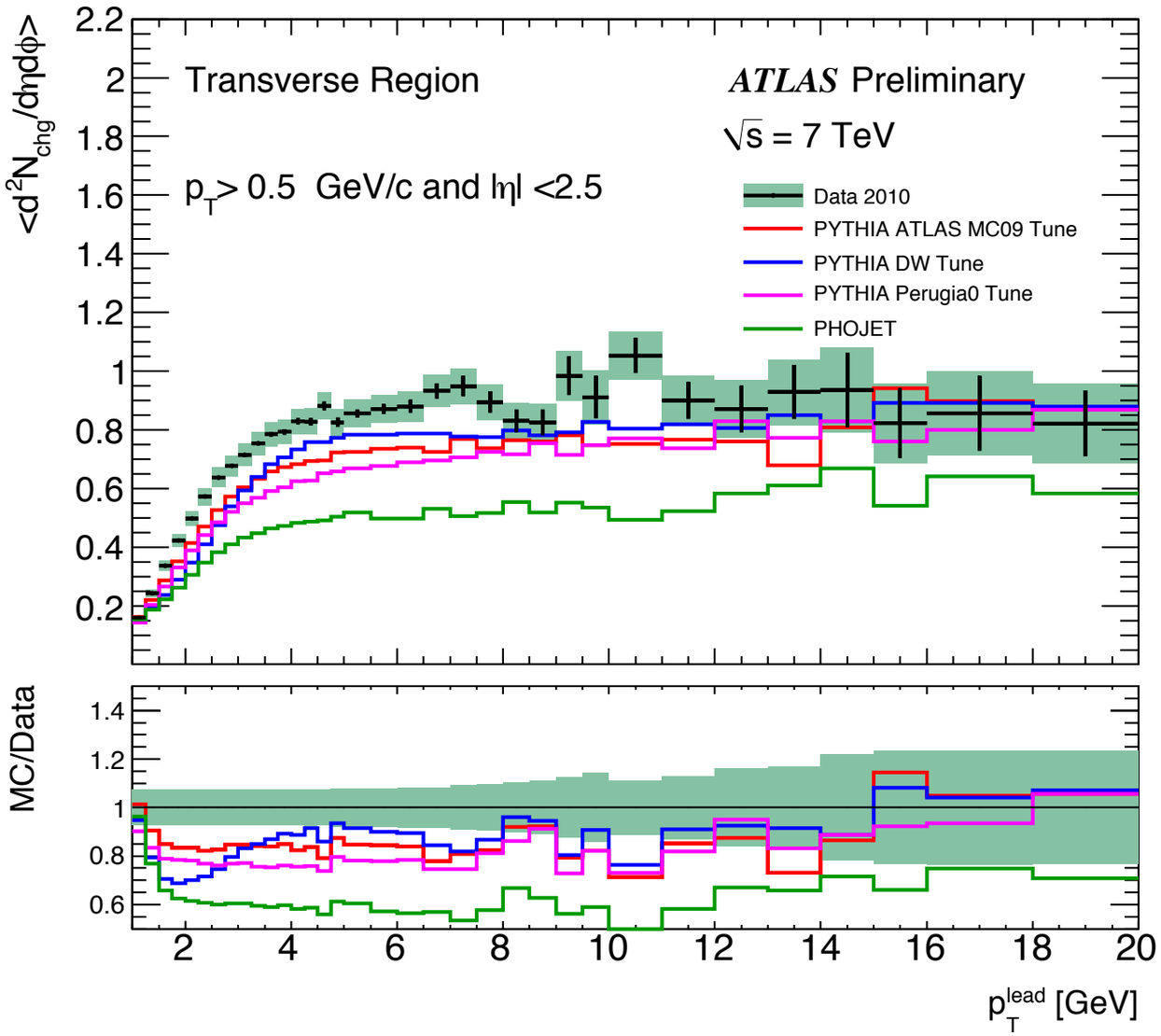
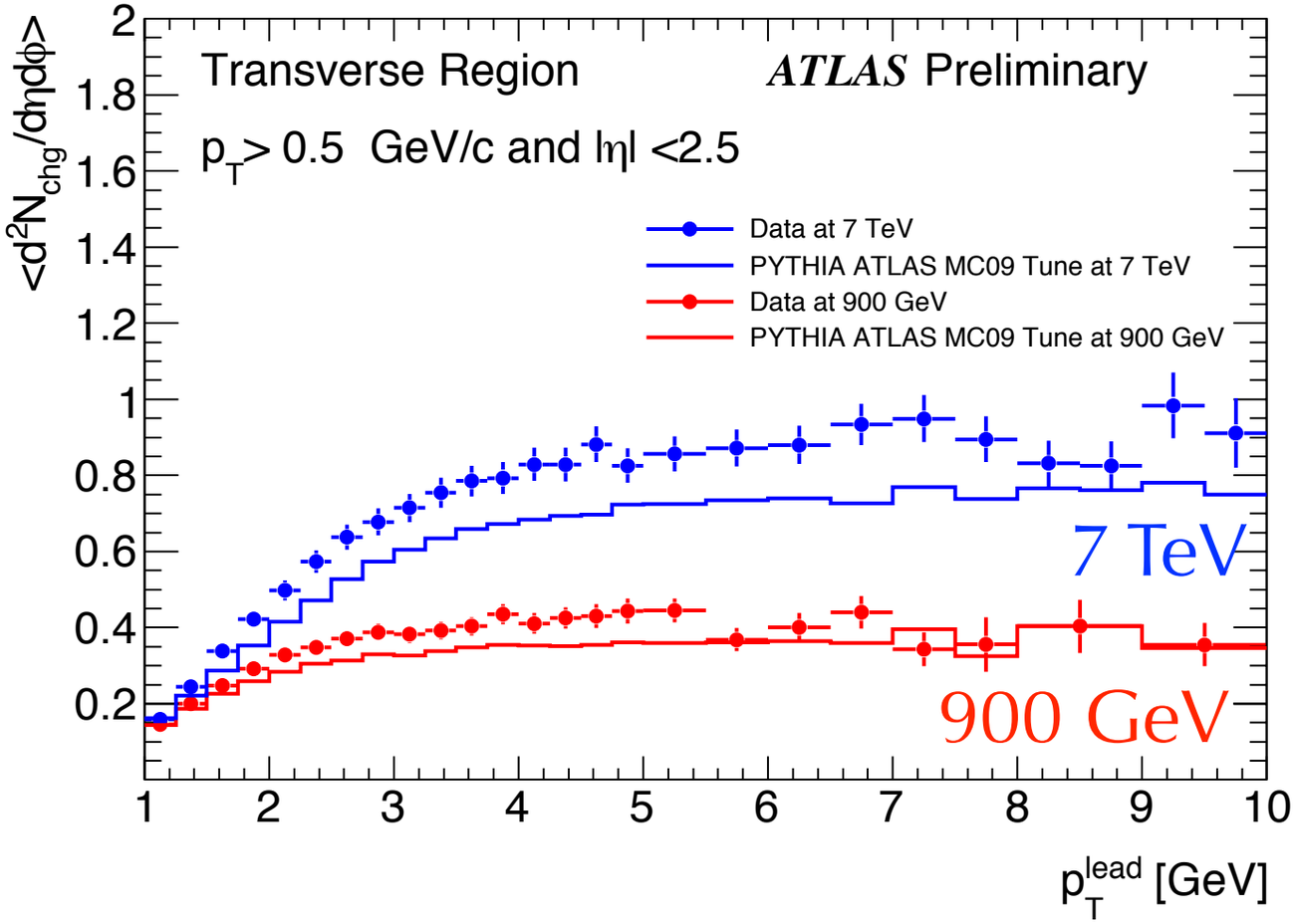
- Bin migration effects removed with bin-by-bin unfolding

Multiplicity Density

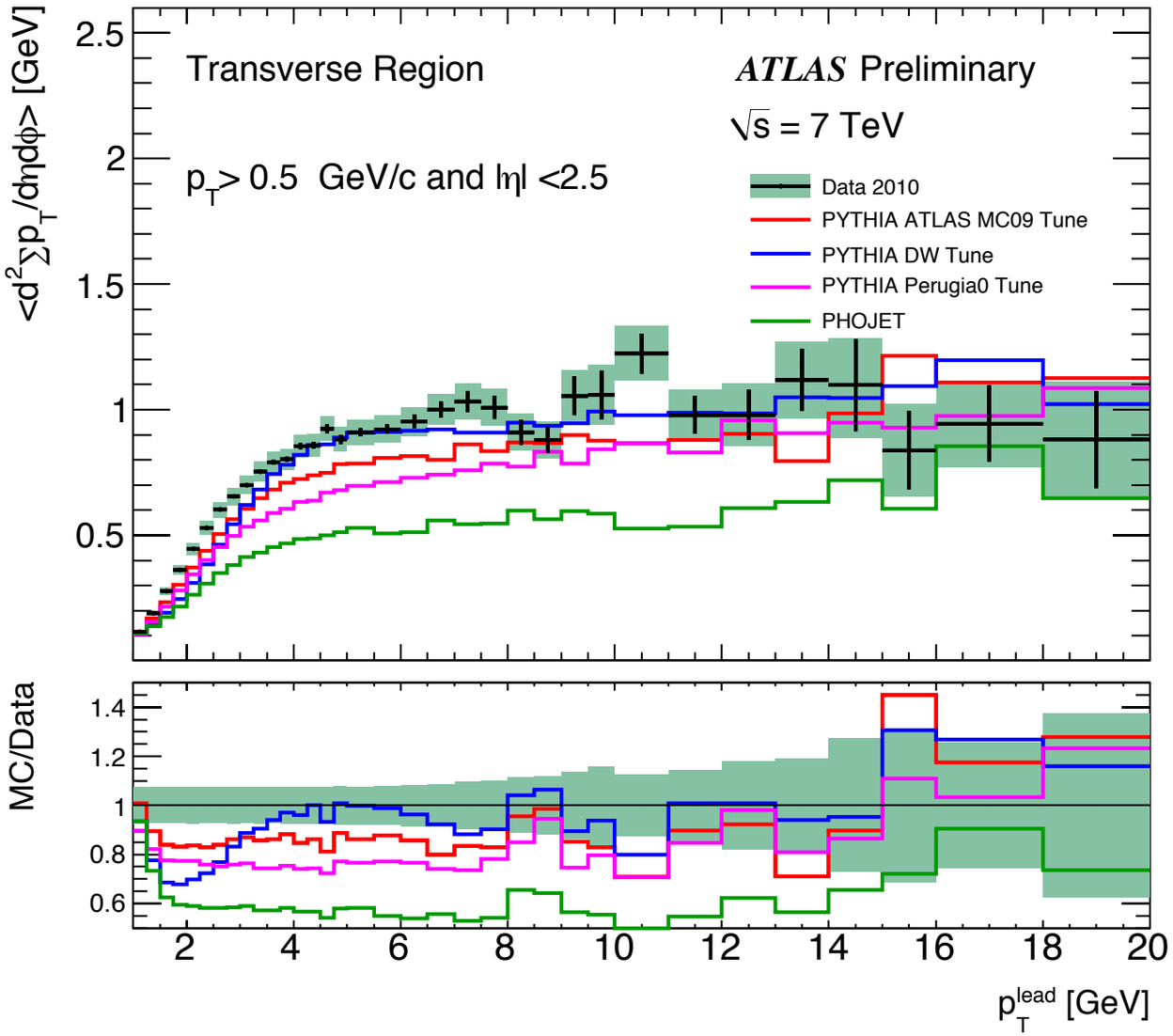


- Charged particle density underestimated for low leading track p_T at √s = 900 GeV & 7 TeV
- For high track p_T region, data and MC compatible

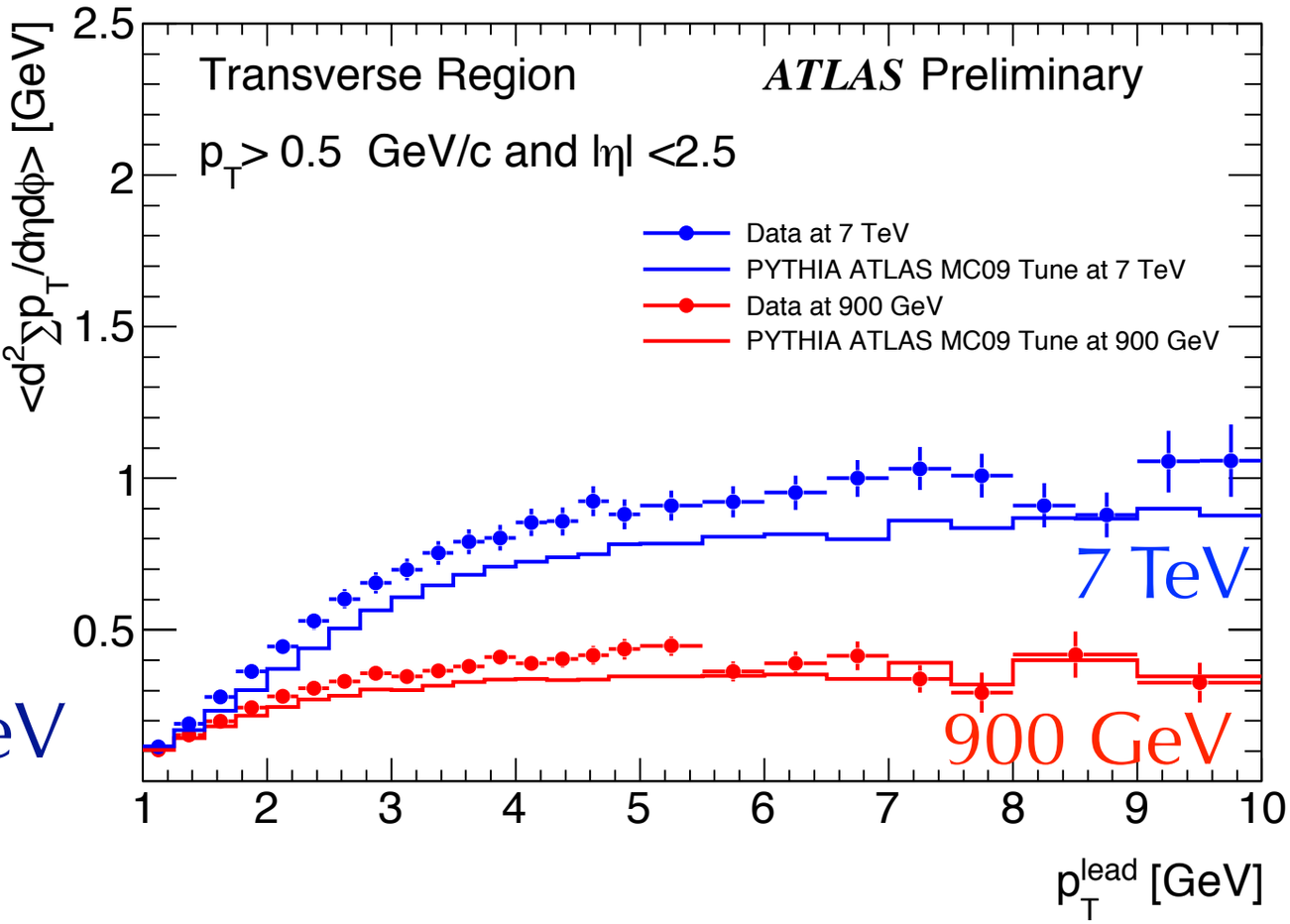


- Charged particle density is 2.5-3x higher at @ √s = 7 TeV than 900 GeV

Σp_T Density

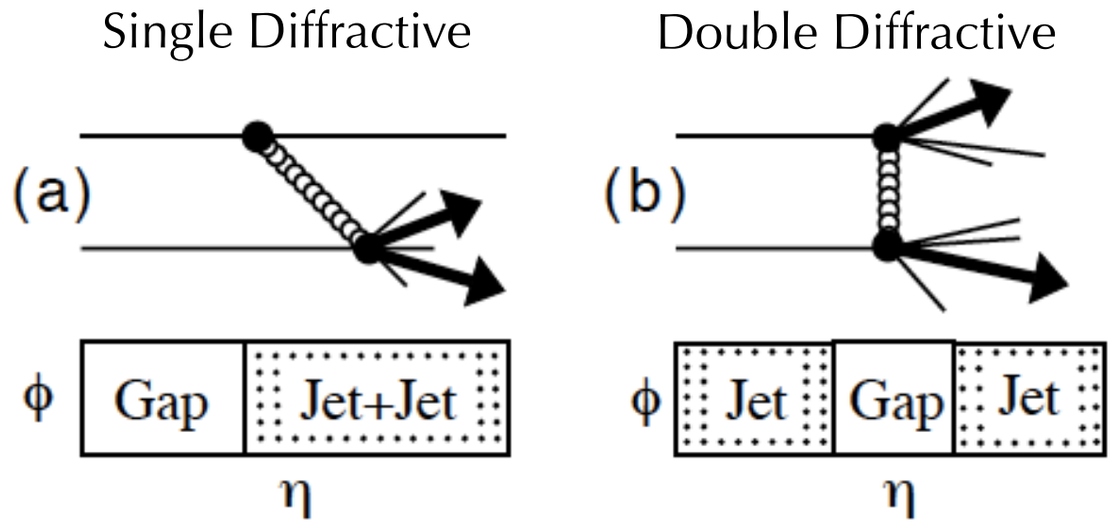


- Σp_T density underestimated for low leading track p_T at $\sqrt{s}$ = 900 GeV & 7 TeV
- For high track p_T region, data/MC agree within errors



- Σp_T density doubles in plateau region from $\sqrt{s}$ = 900 GeV to 7 TeV

Diffraction Enhanced Sample



- Diffractive processes: no exchange of quantum numbers
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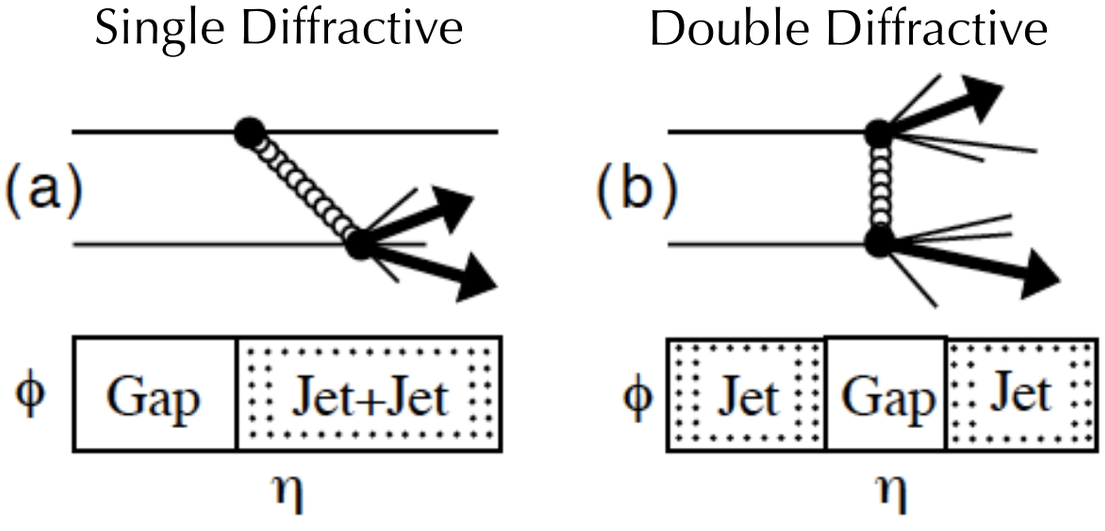

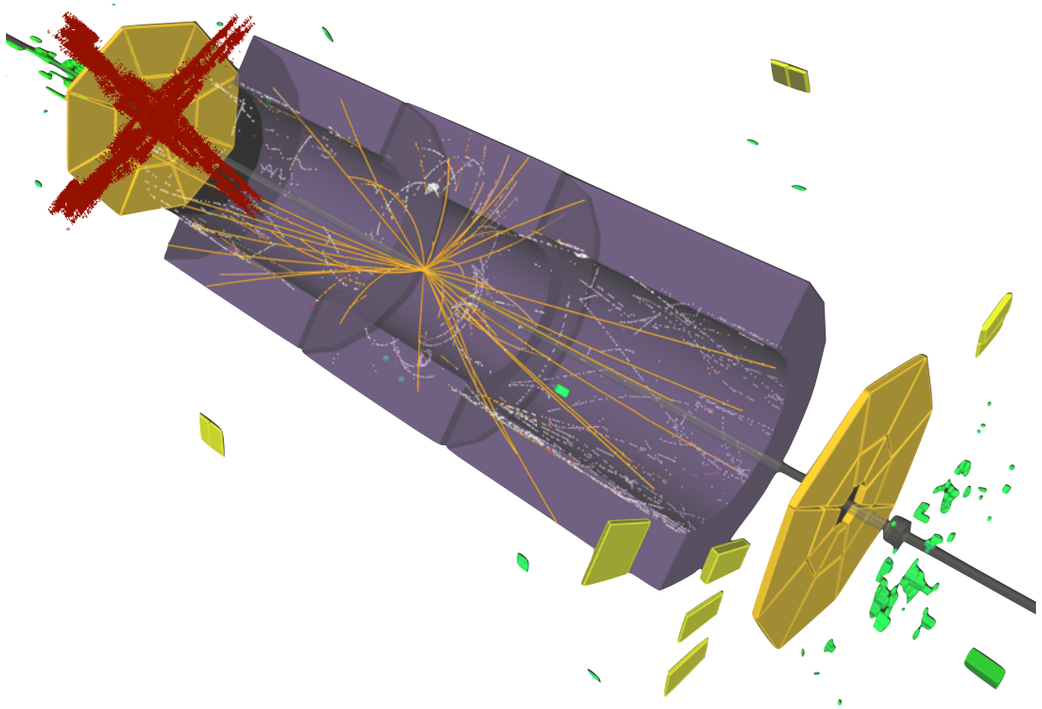

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- Event Selection:
  - at least 1 track with $p_T > 500$ MeV, $|\eta| < 2.5$
  - Hits on ***only*** 1 side of MBTS ($2.09 < |\eta| < 3.84$)
    - Increases diffractive component from ~20% of event sample to ~90%

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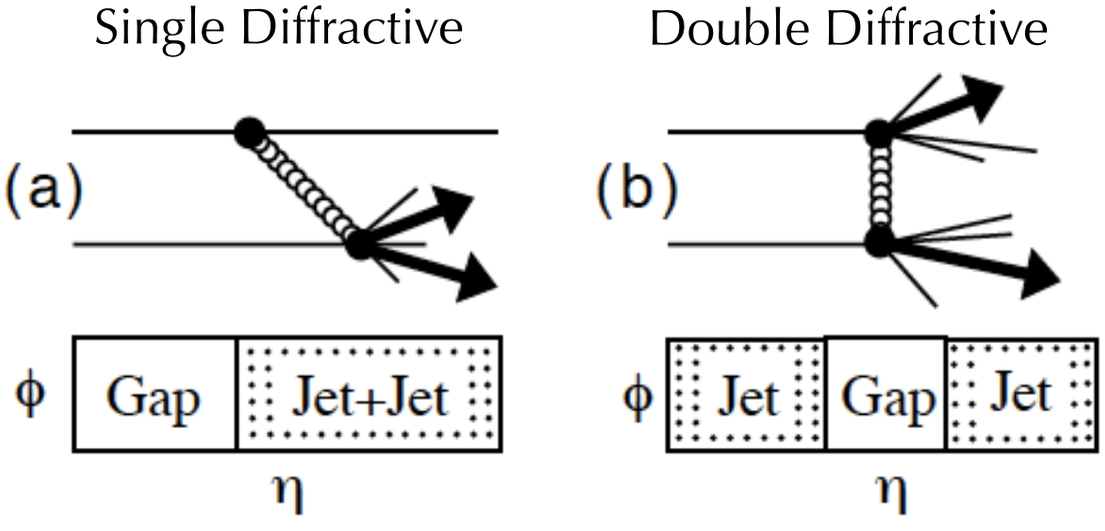

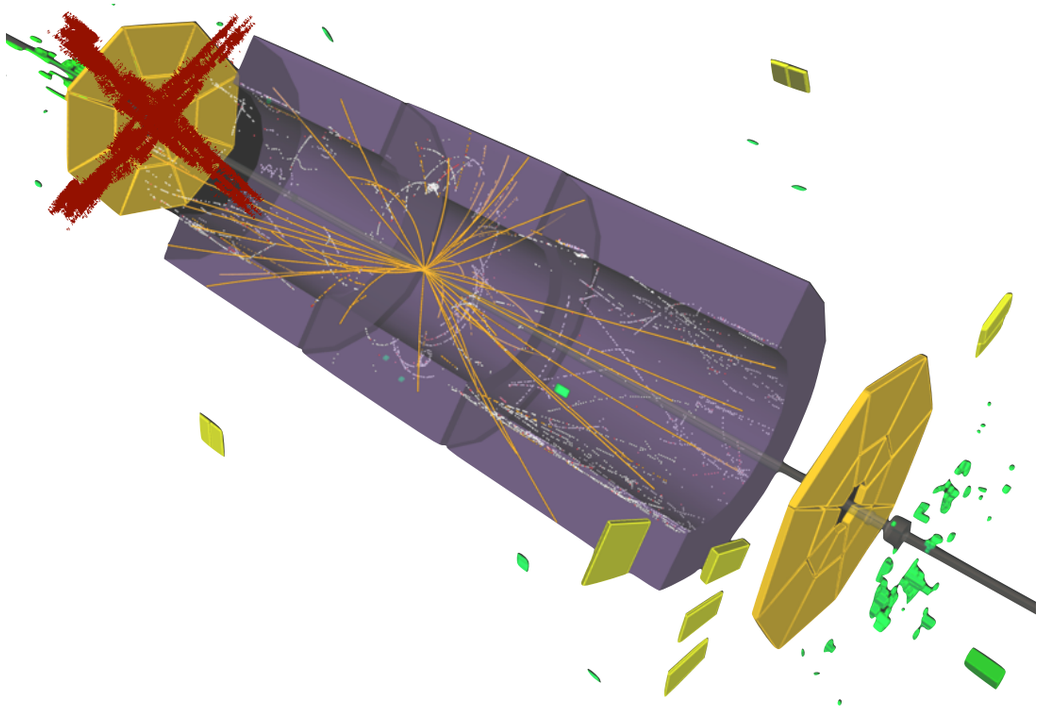

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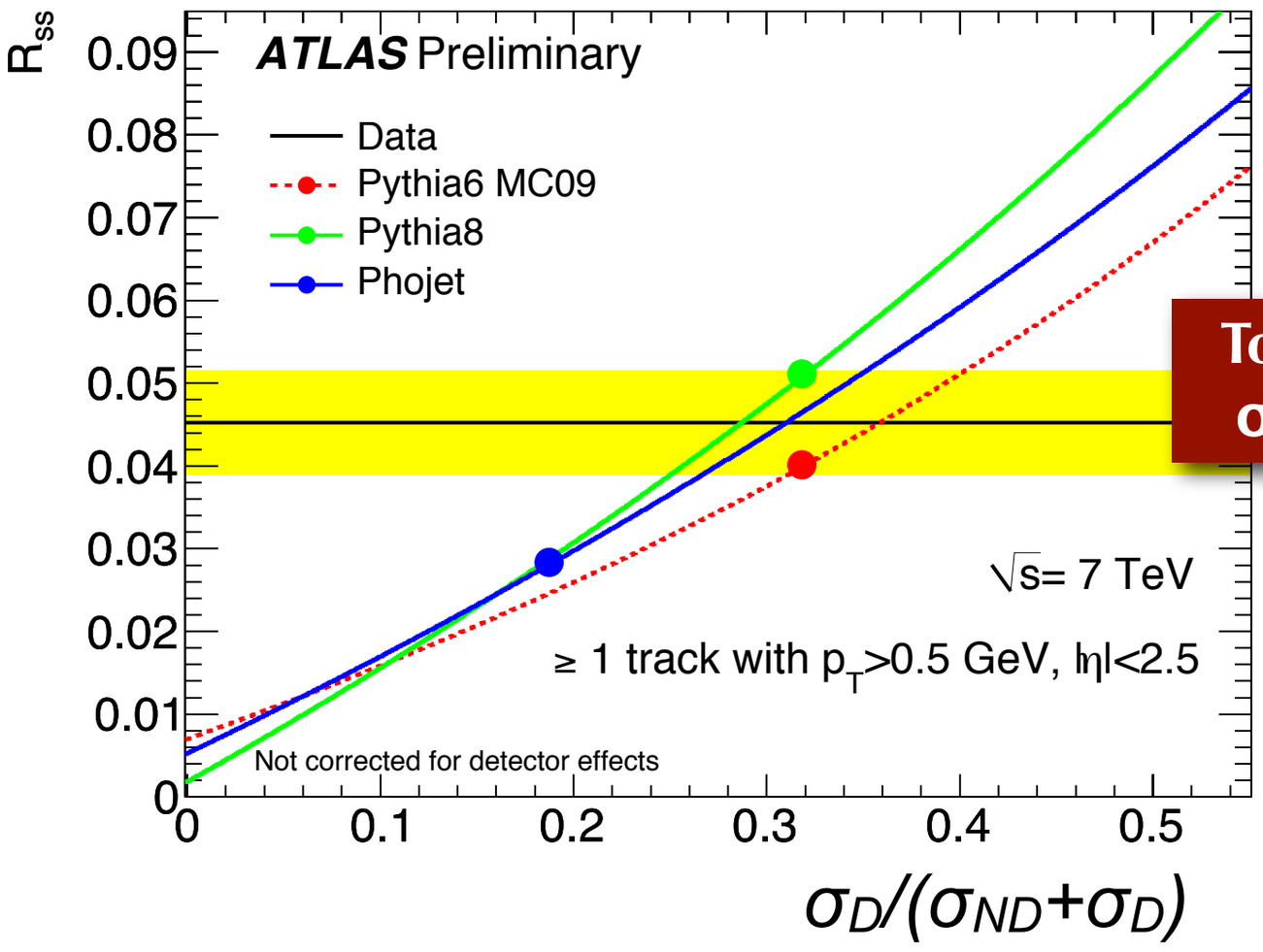
- Measure
  - **Ratio** of single to either sided events: R_{SS}
  - Track **kinematics** and multiplicities

Not yet corrected for detector effects!

R_{ss}

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

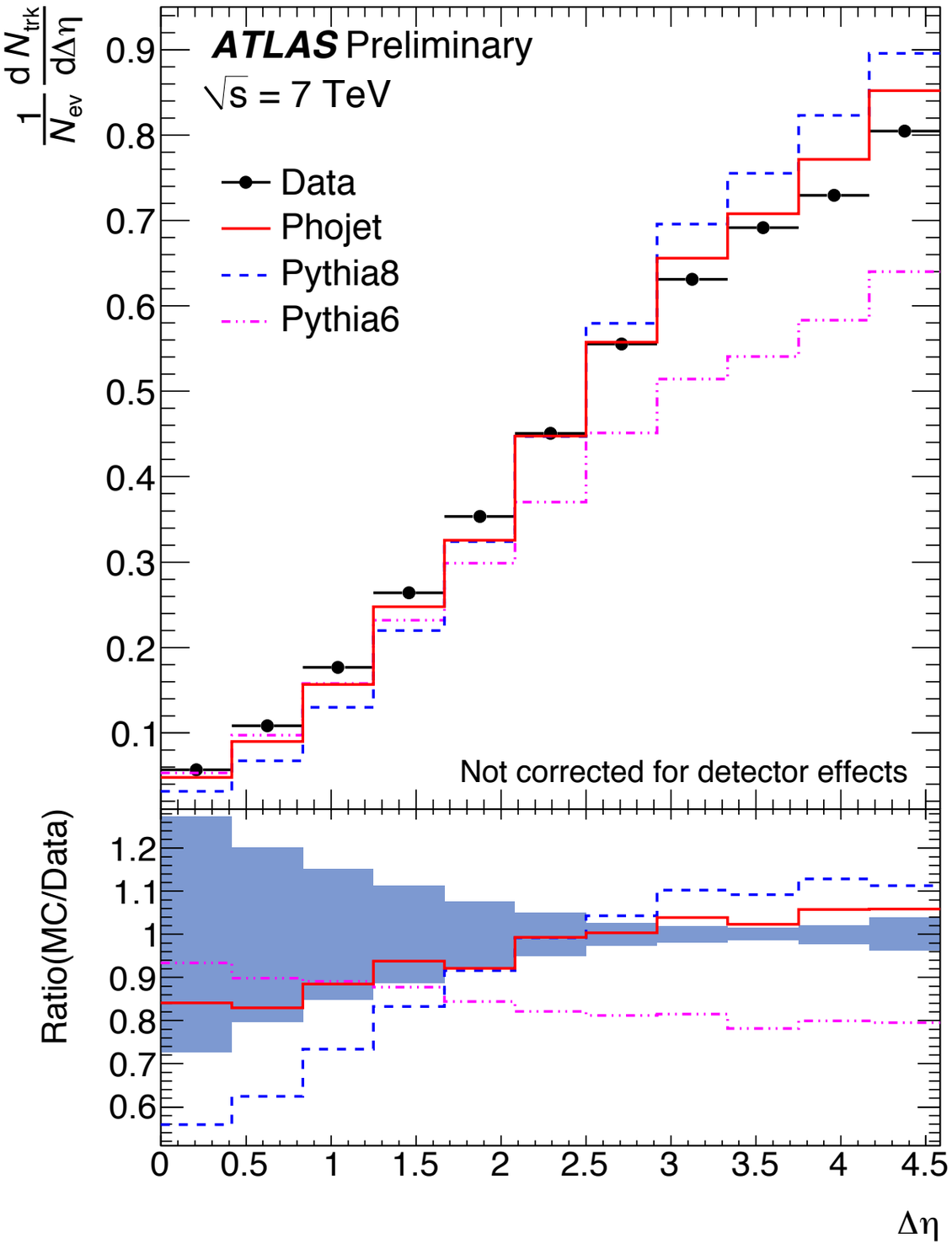


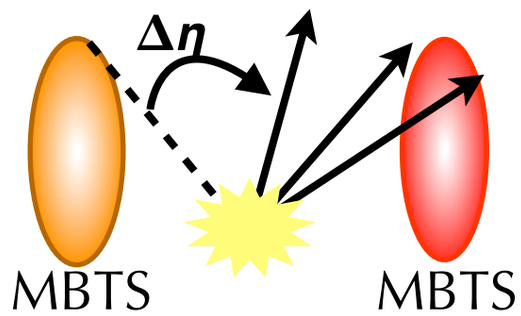
$$R_{ss} = \frac{N_{ss}}{N_{ss}+N_{ds}} = \frac{A_{ss}^{D}\sigma_D + A_{ss}^{ND}\sigma_{ND}}{(A_{ss}^{D}+A_{ds}^{D})\sigma_D + (A_{ss}^{ND}+A_{ds}^{ND})\sigma_{ND}}$$

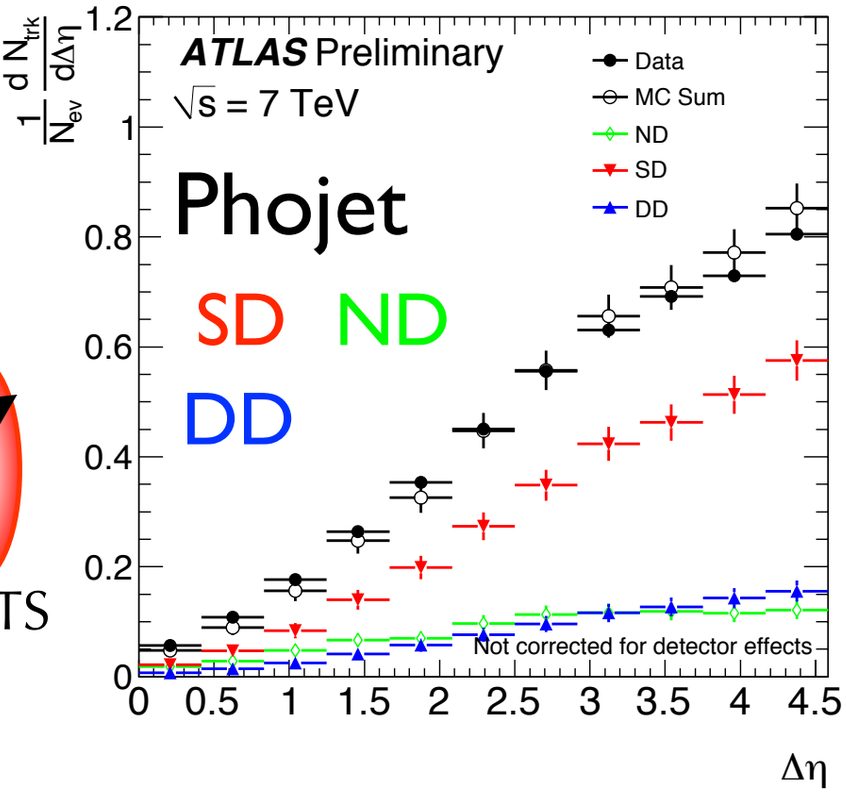
To generate MC curves, vary $\sigma_D/(\sigma_{ND}+\sigma_D)$, keep *A* fixed

	R_{ss} (%)
Data	4.52 ± 0.02 (stat.) ± 0.61 (syst.)
Pythia6	4.01
Pythia8	5.11
Phojet	2.83

Rapidity Gaps

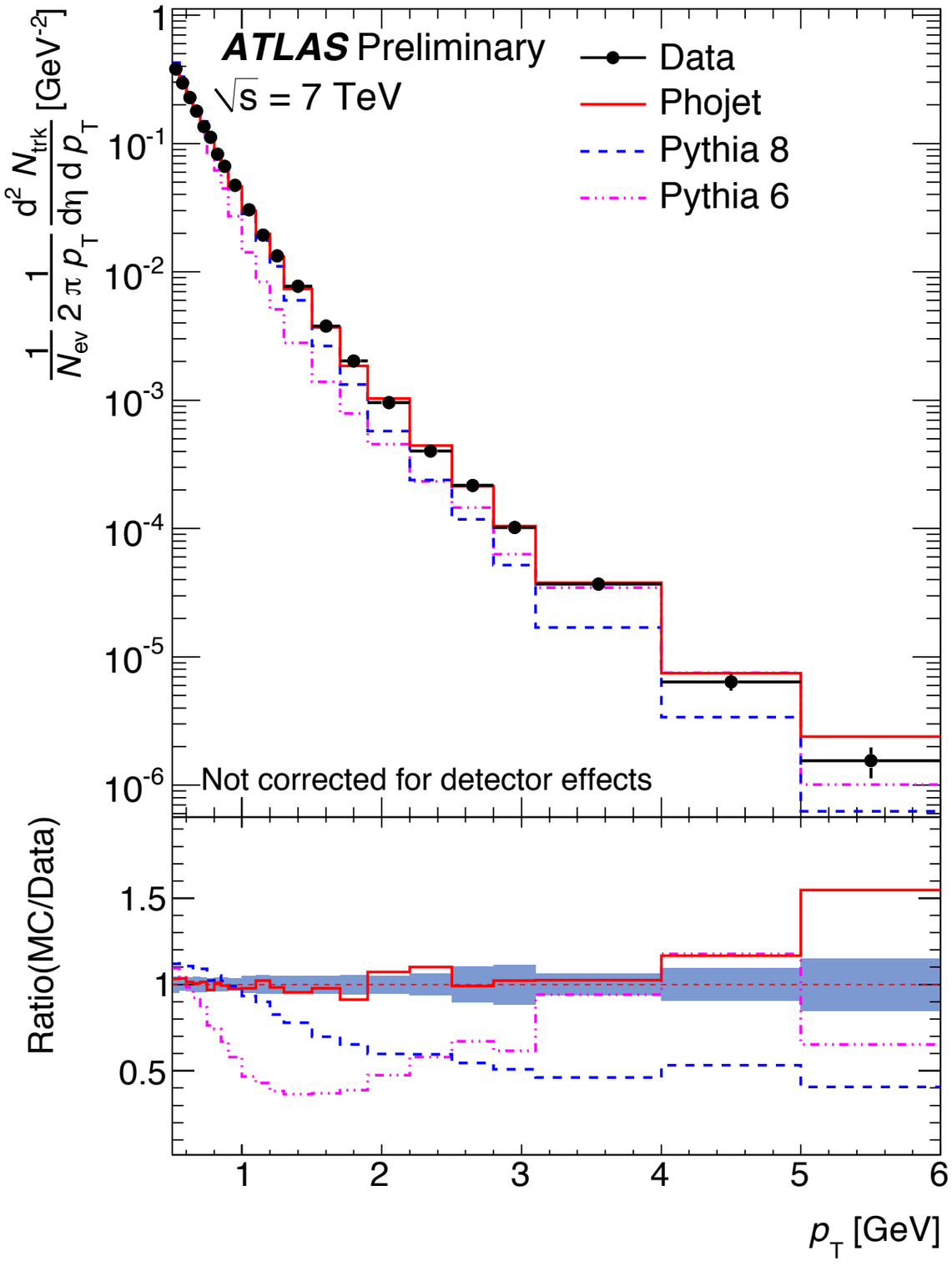


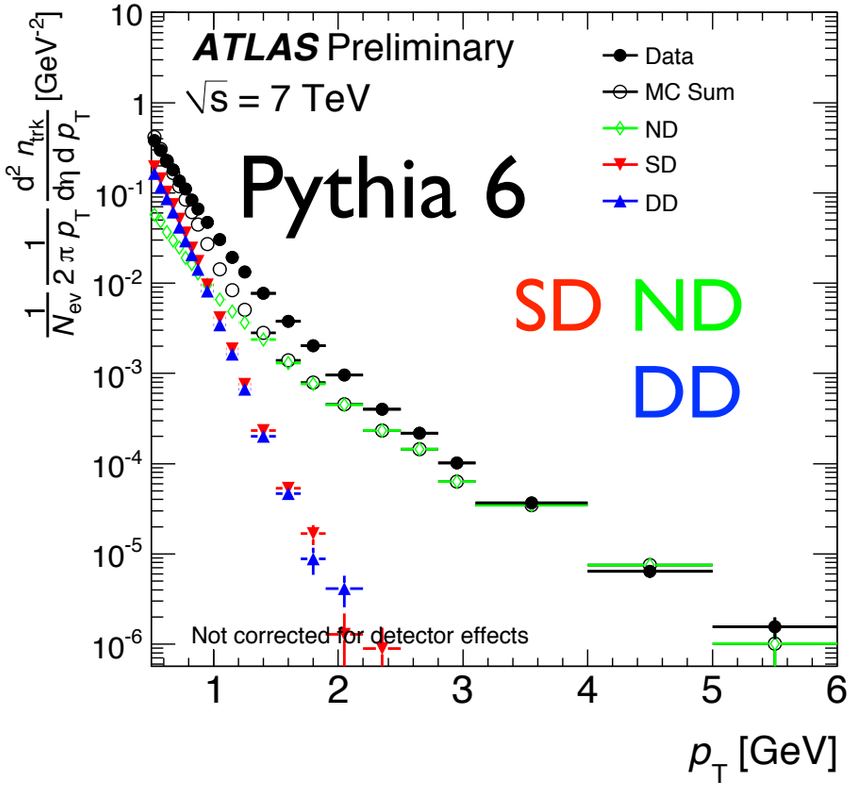




- $\Delta\eta = |\eta_{MBTS} - \eta_{trk}|$ is sensitive to gap structure
- Phojet shows best agreement
  - Favors dominantly SD contributions
- Pythia 6 worst overall agreement, Pythia 8 favors high $\Delta\eta$

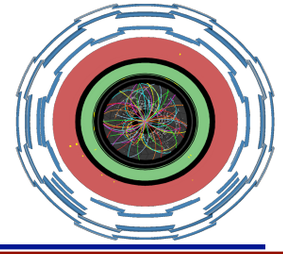
p_T Spectrum





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

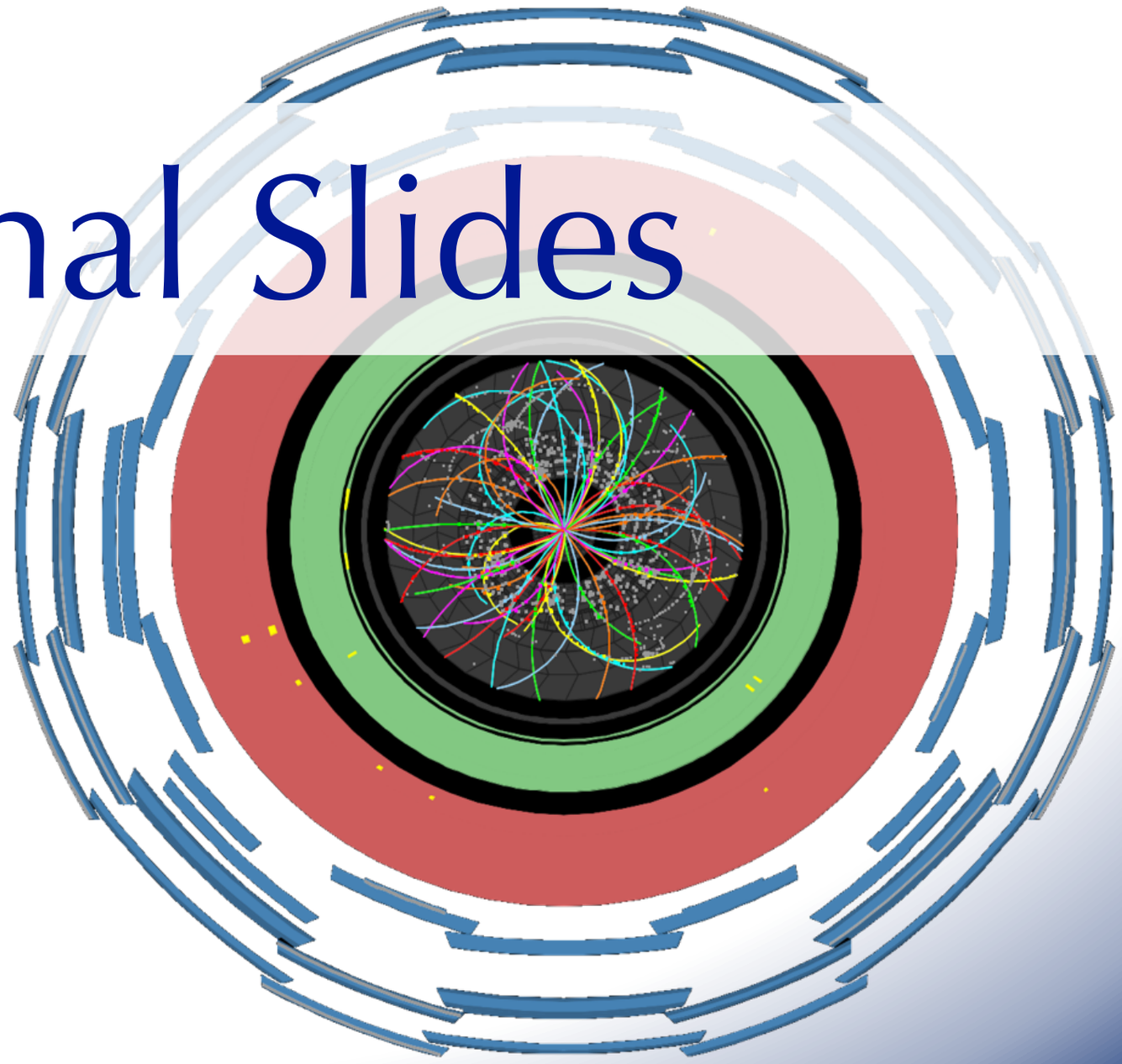
Conclusions



- Soft QCD measurements in restricted phase space give access to sub-dominant processes
  - Important for understanding environment of hard interactions
- Underlying Event studies show MC tunes underestimate particle production and momentum in soft events, consistent with data for high leading track p_T
  - Higher statistics analysis available soon
- Diffractive enhanced sample favors Pythia relative cross sections and Phojet kinematics
  - Will be corrected for detector effects in the future
- There is much to be learned from soft QCD @ 7 TeV!

For more information
Underlying Event Studies: **ATLAS-CONF-2010-029**
Diffraction Enhanced Studies:**ATLAS-CONF-2010-048**

Additional Slides



UE Systematic Uncertainties

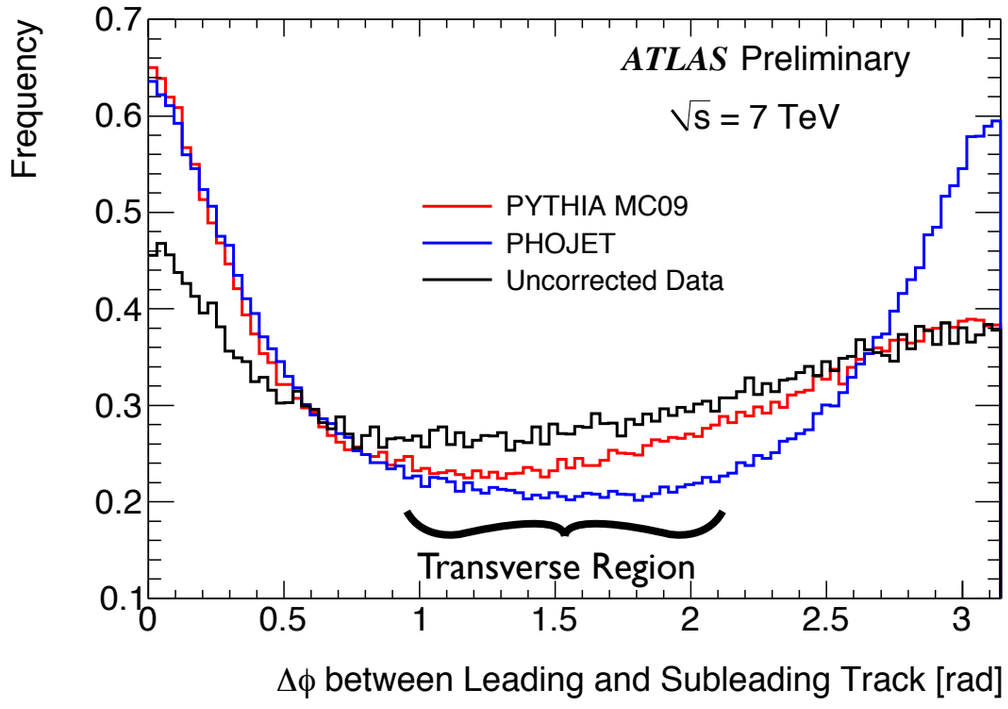
Track Reconstruction	5%
Leading Track Reconstruction	1.0- 0.1%
Trigger and Vtx	< 0.1%
Unfolding Model Dependence	2.0%
Unfolding Stat. Dependence	0.1% to 15%

- Systematics dominated by 2 sources: tracking & unfolding
- Tracking:
  - Majority of the uncertainty comes from knowledge of the detector material: 3% absolute uncertainty on the efficiency
- Unfolding:
  - Limited data and MC statistics were used to in the unfolding procedure
  - At high leading track p_T large bin-to-bin fluctuations are dominated by the MC statistics used in the unfolding (up to 15% systematic)

Unfolding

$$m_i(x) = \frac{v_{true,i}(x)}{v^{corr}_{reco,i}(x)}$$

- Present UE analysis uses bin-by-bin unfolding after corrections for tracking efficiency and event loss are included
  - Dominant effect was axis reorientation when losing the leading track
  - Correction factors were derived from Pythia 6 MC09
  - Phojet was used to check systematics, yielding at most 2% differences
- Effect of limited MC statistics in high p_T^{lead} region is dominant uncertainty



$$\varepsilon_{stat}(x) = \varepsilon_{true}(x)$$

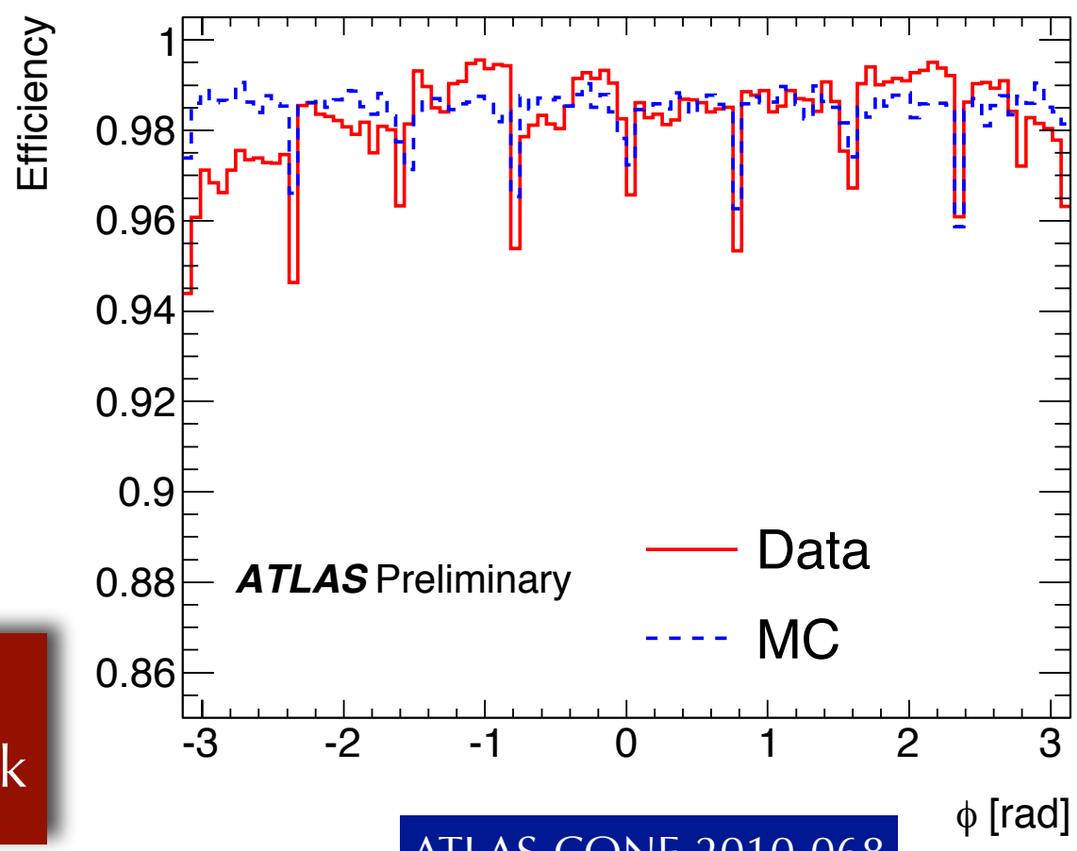
$$\varepsilon_{syst}(x) = \left| \varepsilon_{true}(x) - \varepsilon^{corr}_{reco}(x) * \frac{v_{true}(x)}{v^{corr}_{reco}(x)} \right|$$

Diffraction Analysis Systematics

- Dominant source of systematic uncertainty: Data/MC MBTS agreement
  - Detector simulation does not model some of the inefficiencies
- Tracking efficiency systematic dominated by knowledge of material
  - 3% absolute uncertainty on avg. efficiency
- Beam background and noise contamination found to be negligible

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

Efficiency := fraction of counters with charge > 0.15pC when tagged by an extrapolated track



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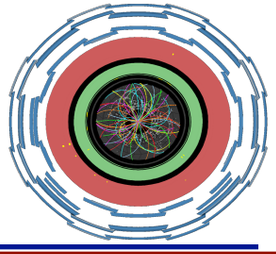
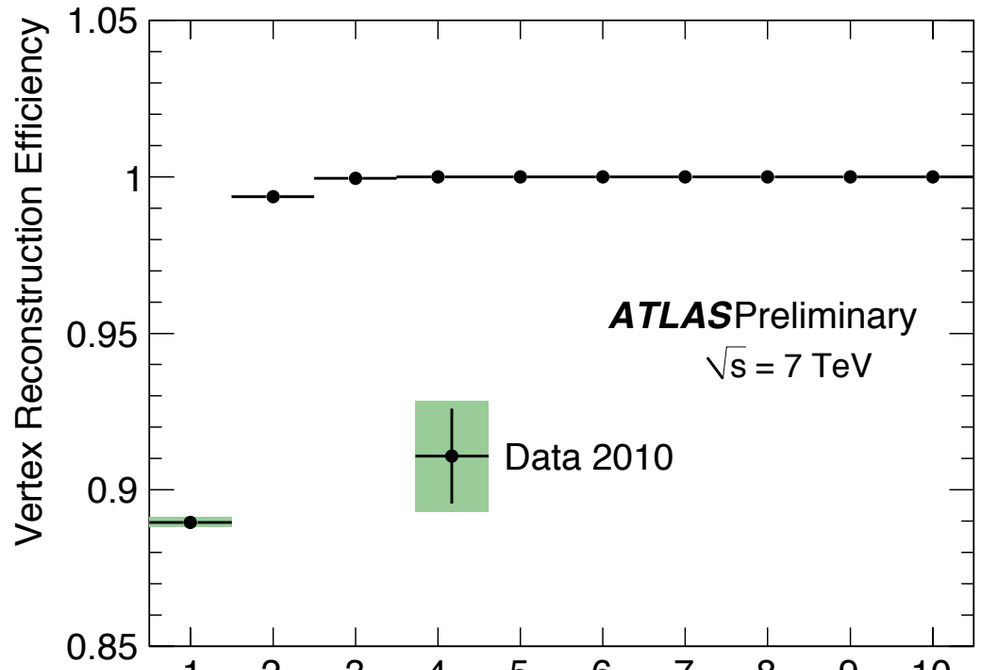
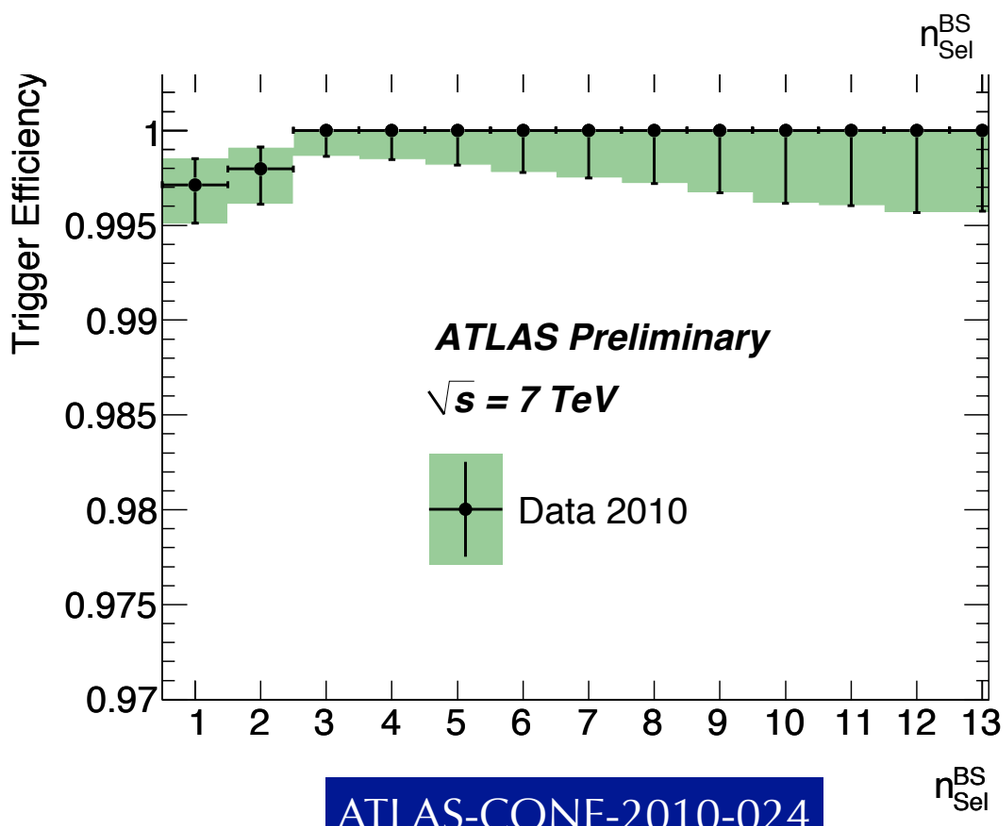
Trigger & Vertex Efficiency



- Single arm MBTS trigger is highly efficient for events with at least 1 track* with $p_T > 500$ MeV
  - Reduced to 97% for events with 1 track with $p_T > 100$ MeV
- Vertex finding 89% for events with one selected track*, > 99% for events with 2
  - Vertex requirement only applied to UE analysis





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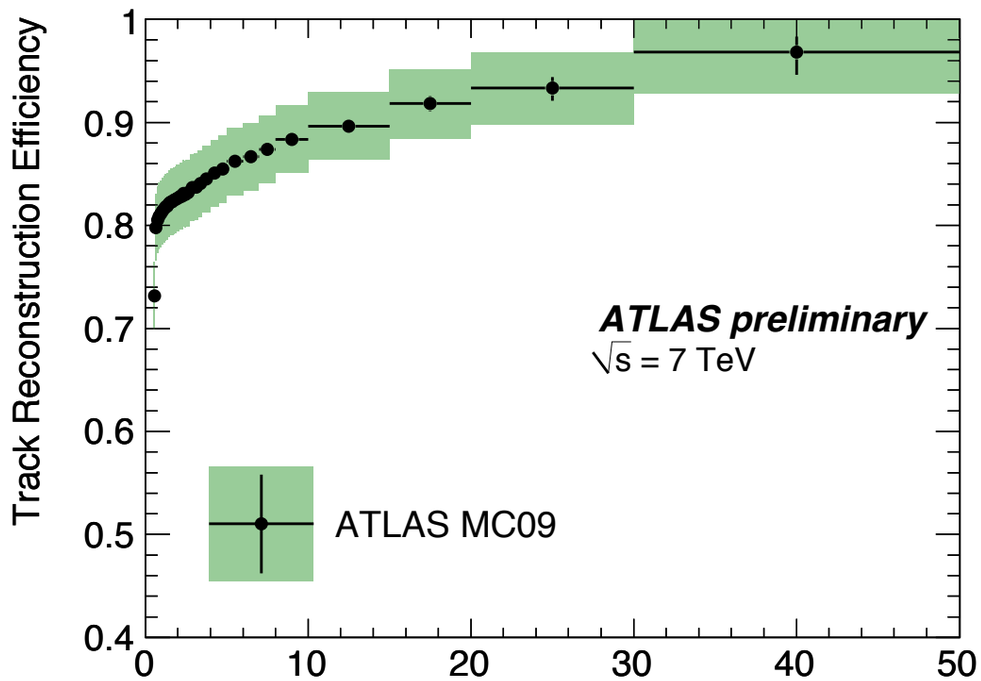
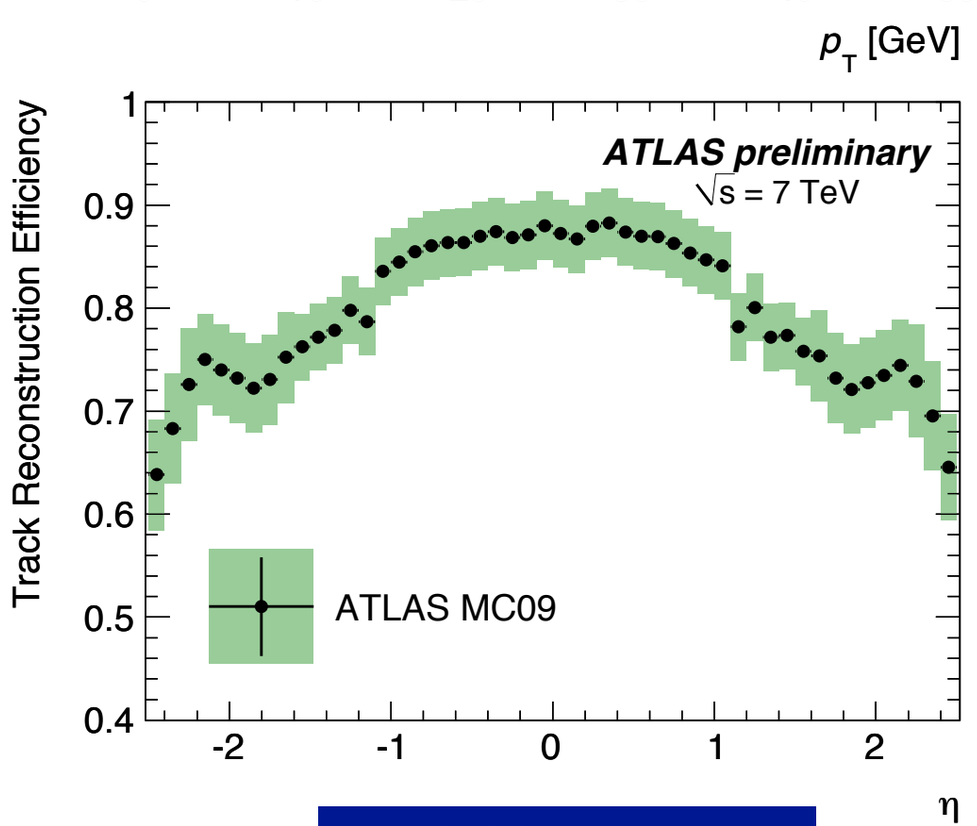
*impact parameter cuts w.r.t beam spot

Tracking Efficiency

Systematic Uncertainty	Systematic
Truth Primary Definition	$\pm 0.4\%$
Track Selection	$\pm 1\%$
Material	$\pm 3\%$
Alignment	$\pm 1\%$
SCT Extension	$\pm 6\%$ $(2.2 < \lvert\eta\rvert < 2.5)$ $\pm 4\%$ $(1.6 < \lvert\eta\rvert < 2.2)$
Particle Composition	$\pm 0.2\%$
Resolution	$\pm 1\%$ $(0.5 < p_{\mathrm{T}} < 0.6$ GeV$)$
Total	3.8 % ($p_{\mathrm{T}} > 0.6$ GeV, $\eta = 0$) 3.9 % ($0.5 < p_{\mathrm{T}} < 0.6$ MeV, $\eta = 0$) 7.1 % ($p_{\mathrm{T}} > 0.6$ MeV, $2.4 < \eta < 2.5$)



- Efficiency uncertainty dominated by material knowledge
- At high eta, have additional uncertainty due to reconstruction errors arising from large extrapolation distance and high material density.



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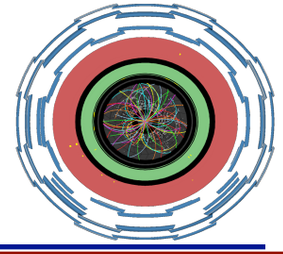
Cross Sections & Acceptances



Generator	σ_{DD} (mb)	σ_{SD} (mb)	σ_{ND} (mb)	σ_{inel} (mb)	$(\sigma_{SD}+\sigma_{DD})/\sigma_{inel}$
Pythia	9.3	13.7	48.5	71.5	32.2%
Phojet	3.9	10.7	61.6	76.2	19.2%

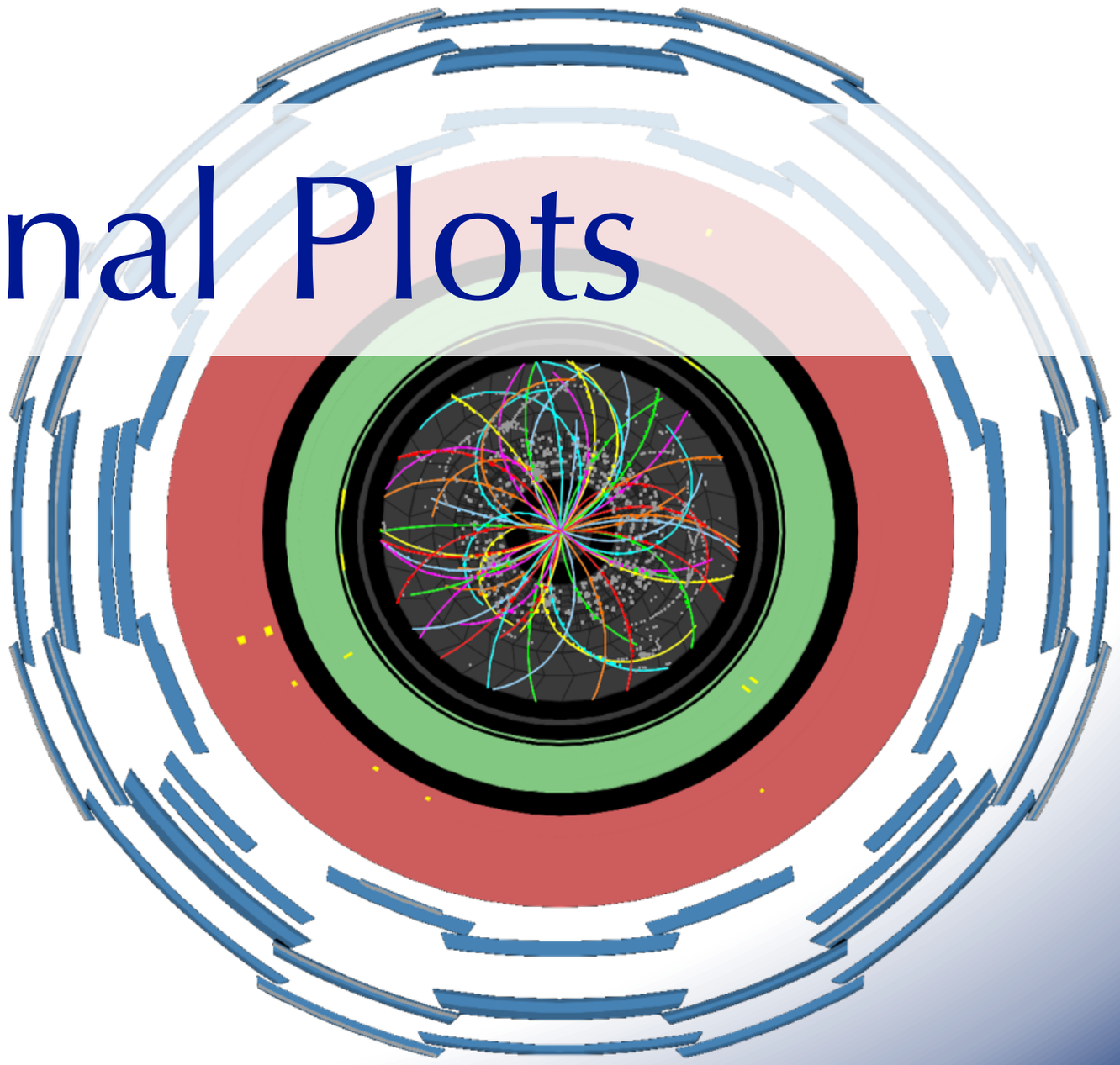
Generator	A^{DD}_{1-trk}	A^{SD}_{1-trk}	A^{ND}_{1-trk}
Pythia6	39.2%	37.0%	97.5%
Pythia8	50.1%	55.6%	97.3%
Phojet	52.2%	63.7%	95.9%

Table 1: Acceptances for events to have at least one track with $p_T > 500$ MeV and $|\eta| < 2.5$ for Pythia6, Pythia8 and Phojet for double-diffractive (DD), single-diffractive (SD) and non-diffractive (ND) events at $\sqrt{s} = 7$ TeV.

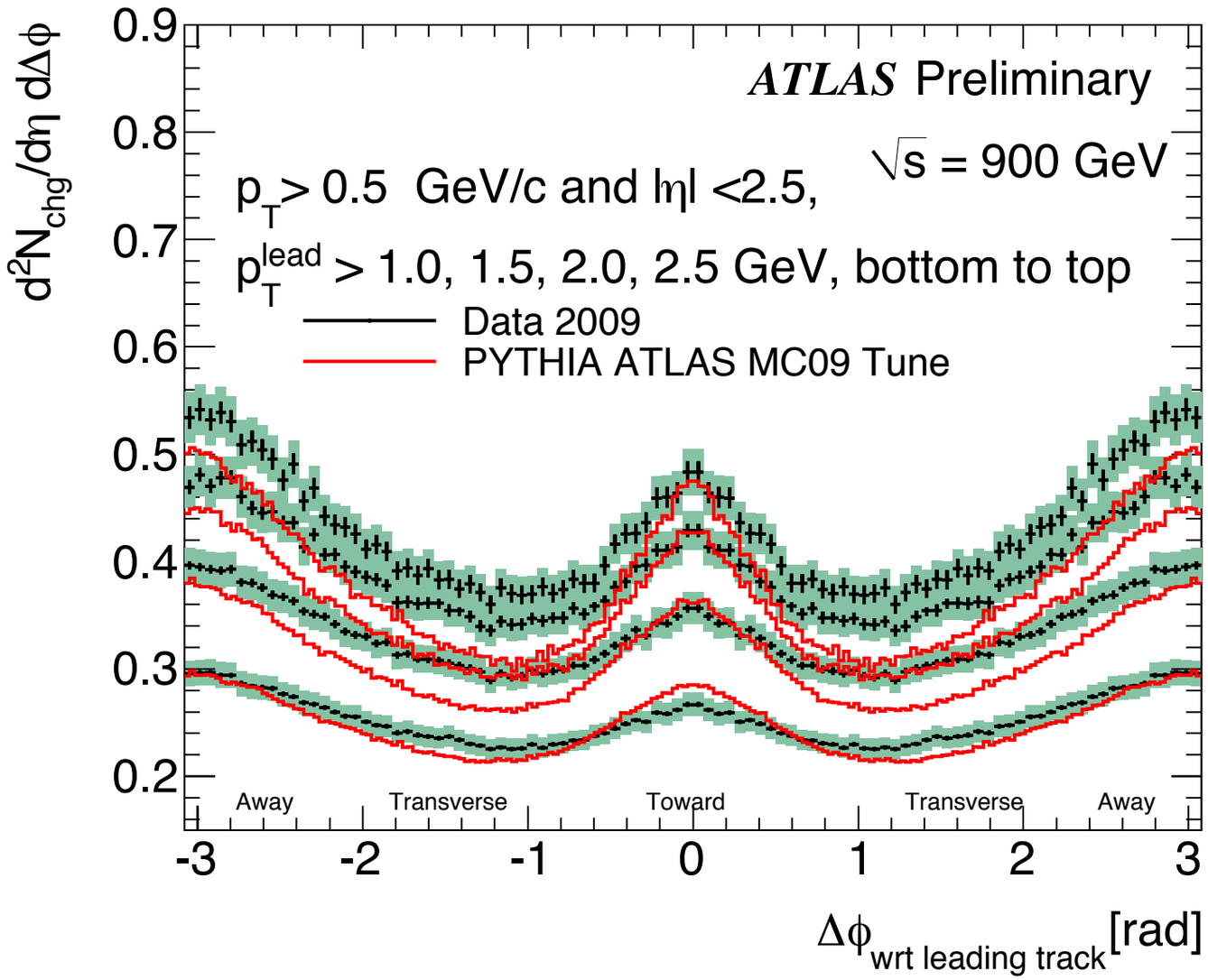
Generator	DD		SD		ND	
	A^{DD}_{any}	A^{DD}_{ss}	A^{SD}_{any}	A^{SD}_{ss}	A^{ND}_{any}	A^{ND}_{ss}
Pythia6	97.2%	23.9%	97.7%	20.7%	99.9%	0.7%
Pythia8	100%	27.0%	100%	22.9%	100%	0.1%
Phojet	97.9%	14.2%	97.8%	22.0%	100%	0.5%

Table 1: Acceptances for events with activity in either side of the MBTS, A_{any}, and on only one side of the MBTS, A_{ss}, for events at $\sqrt{s} = 7$ TeV with at least one track with $p_T > 500$ MeV and $|\eta| < 2.5$ for Pythia6, Pythia8 and Phojet for double-diffractive (DD), single-diffractive (SD) and non-diffractive (ND) events.

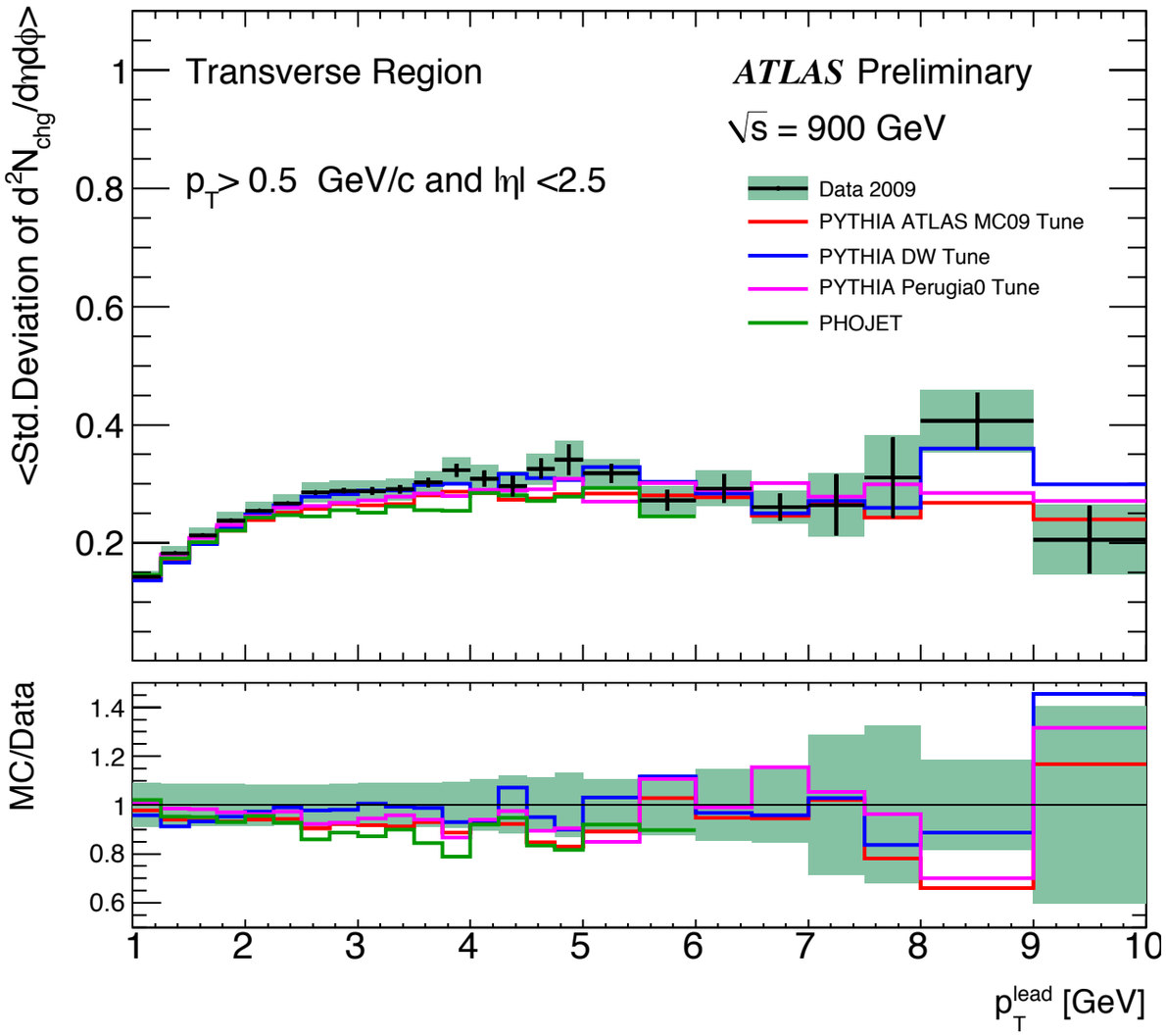
Additional Plots

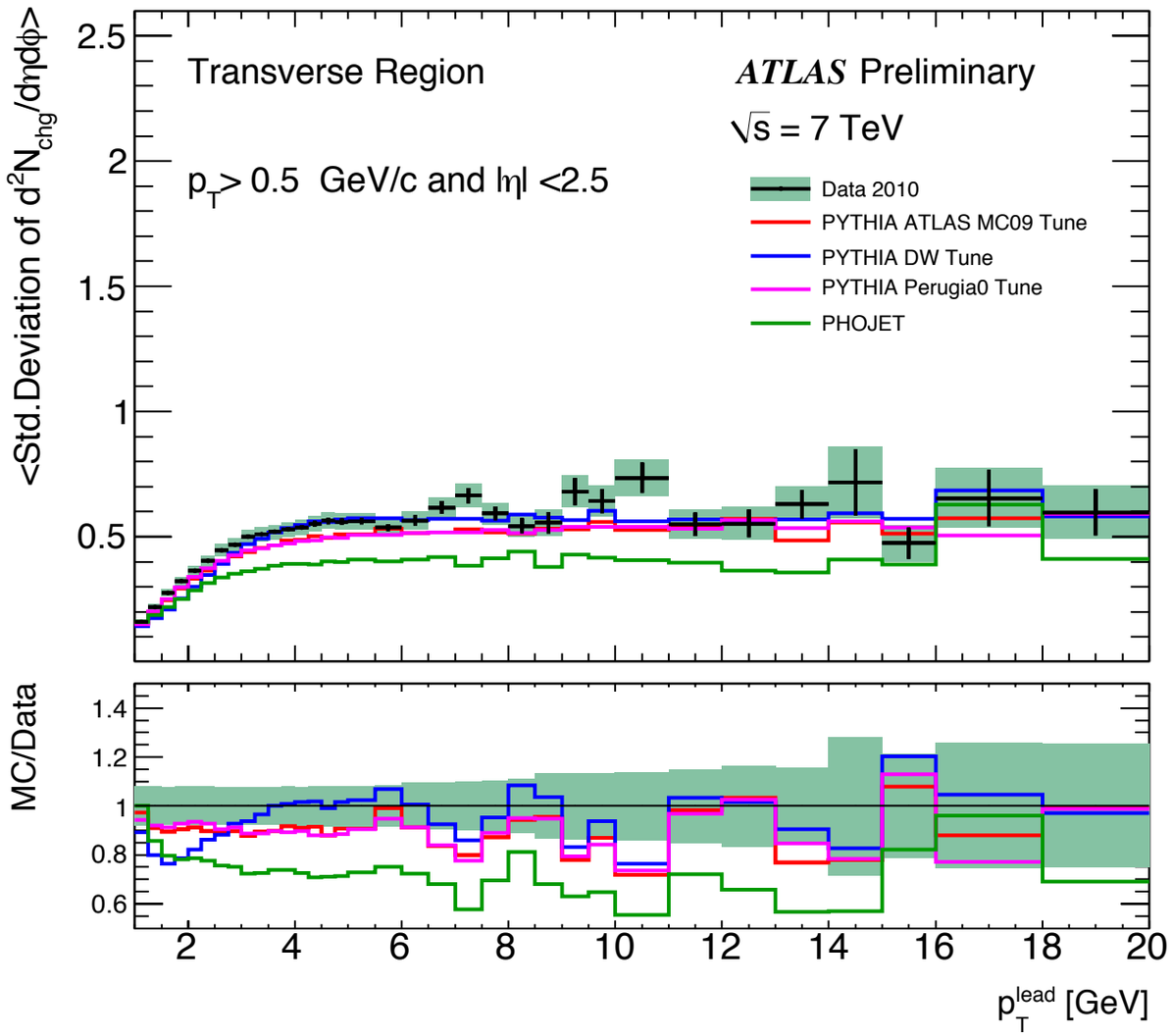


UE: $\Delta\phi$ @ 900 GeV

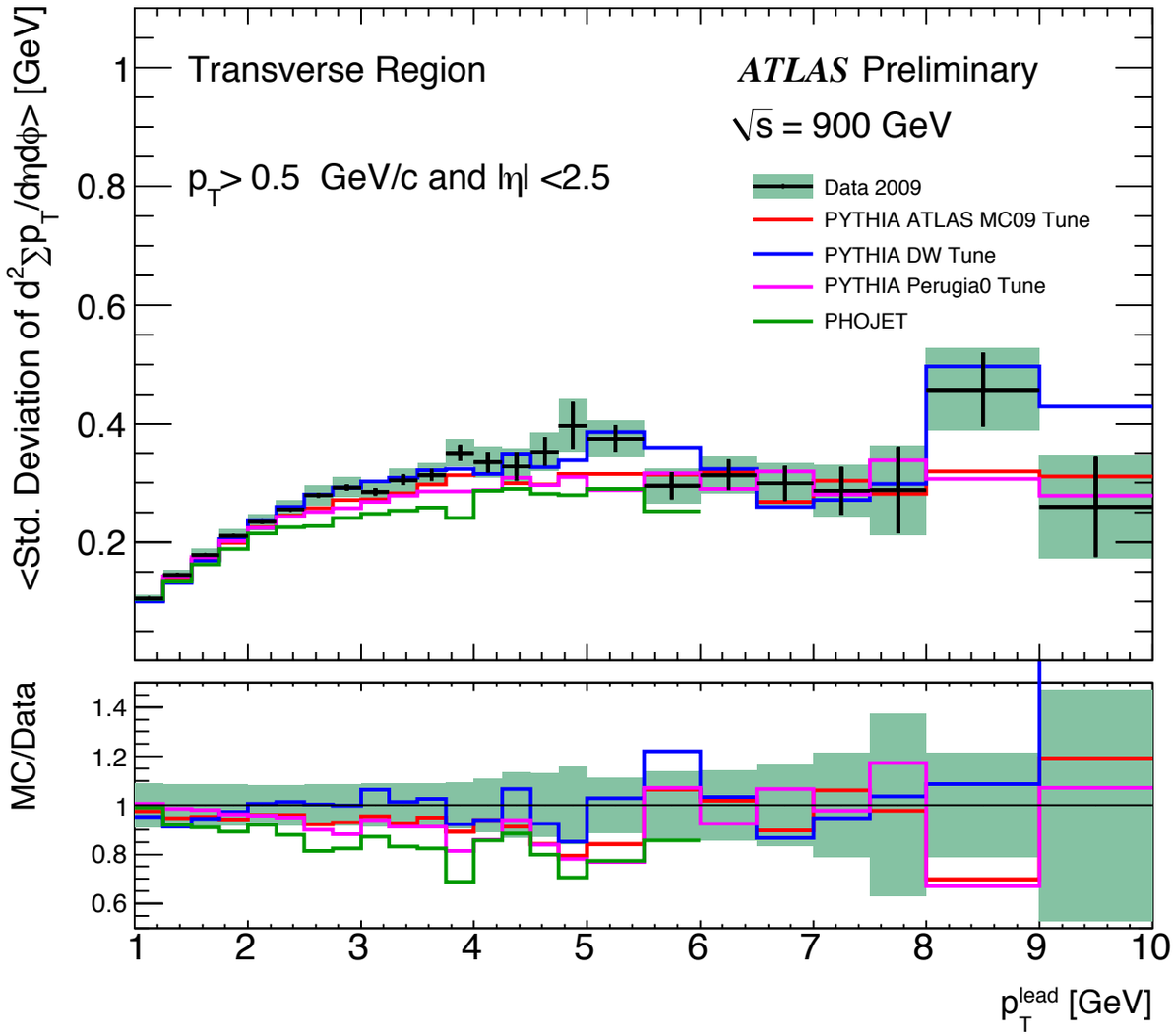


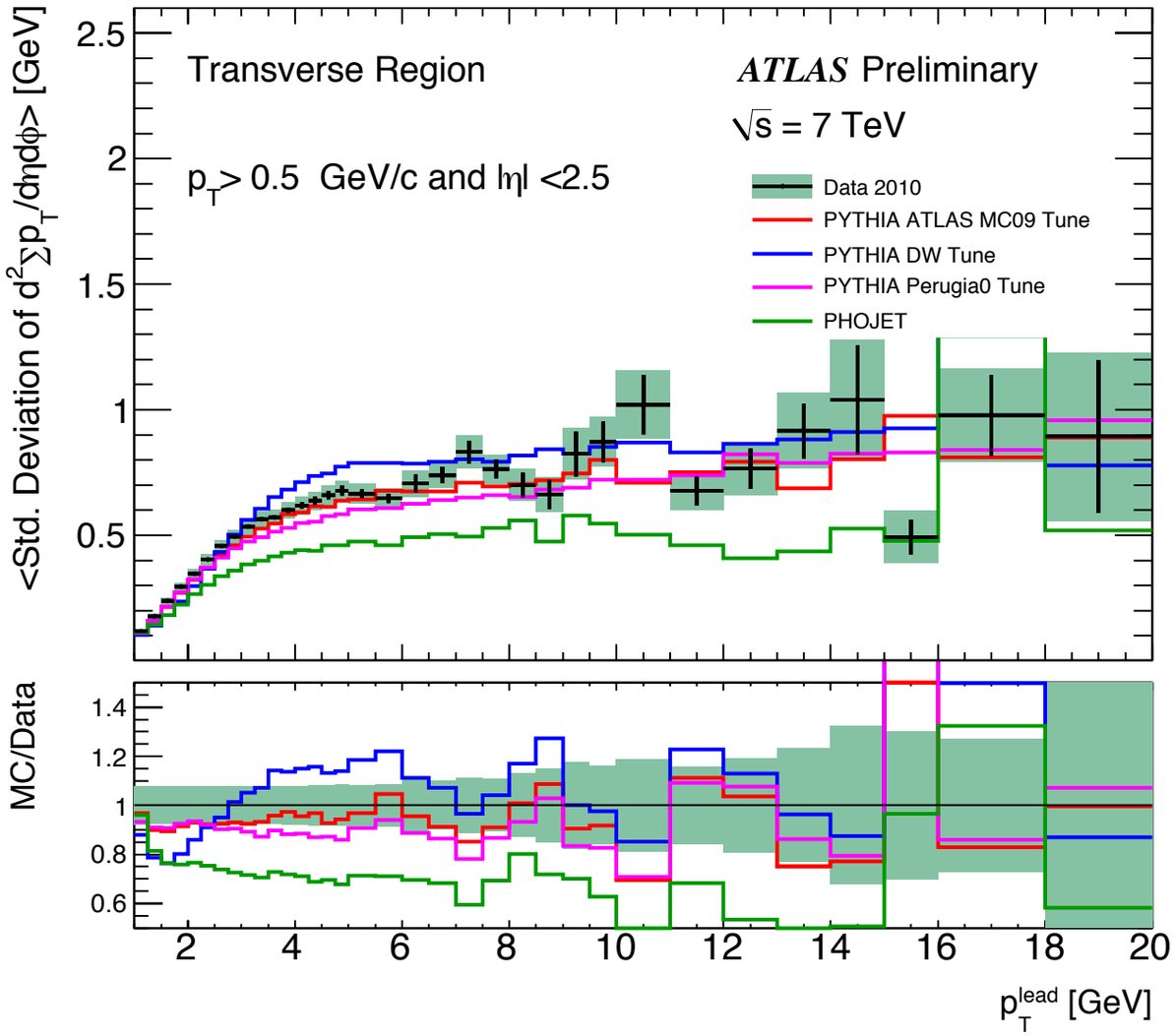
UE: Std. Deviation of N_{ch}



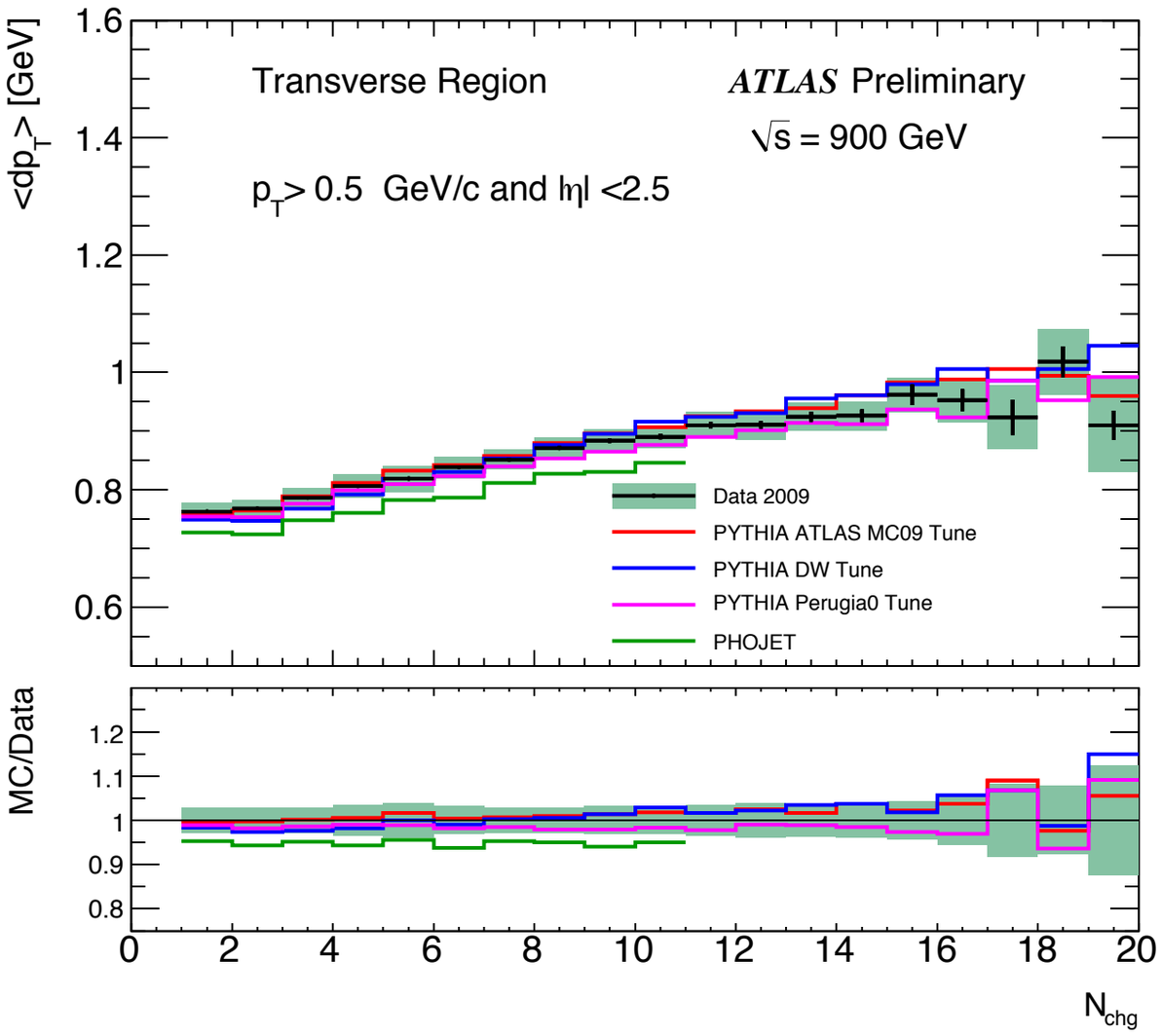


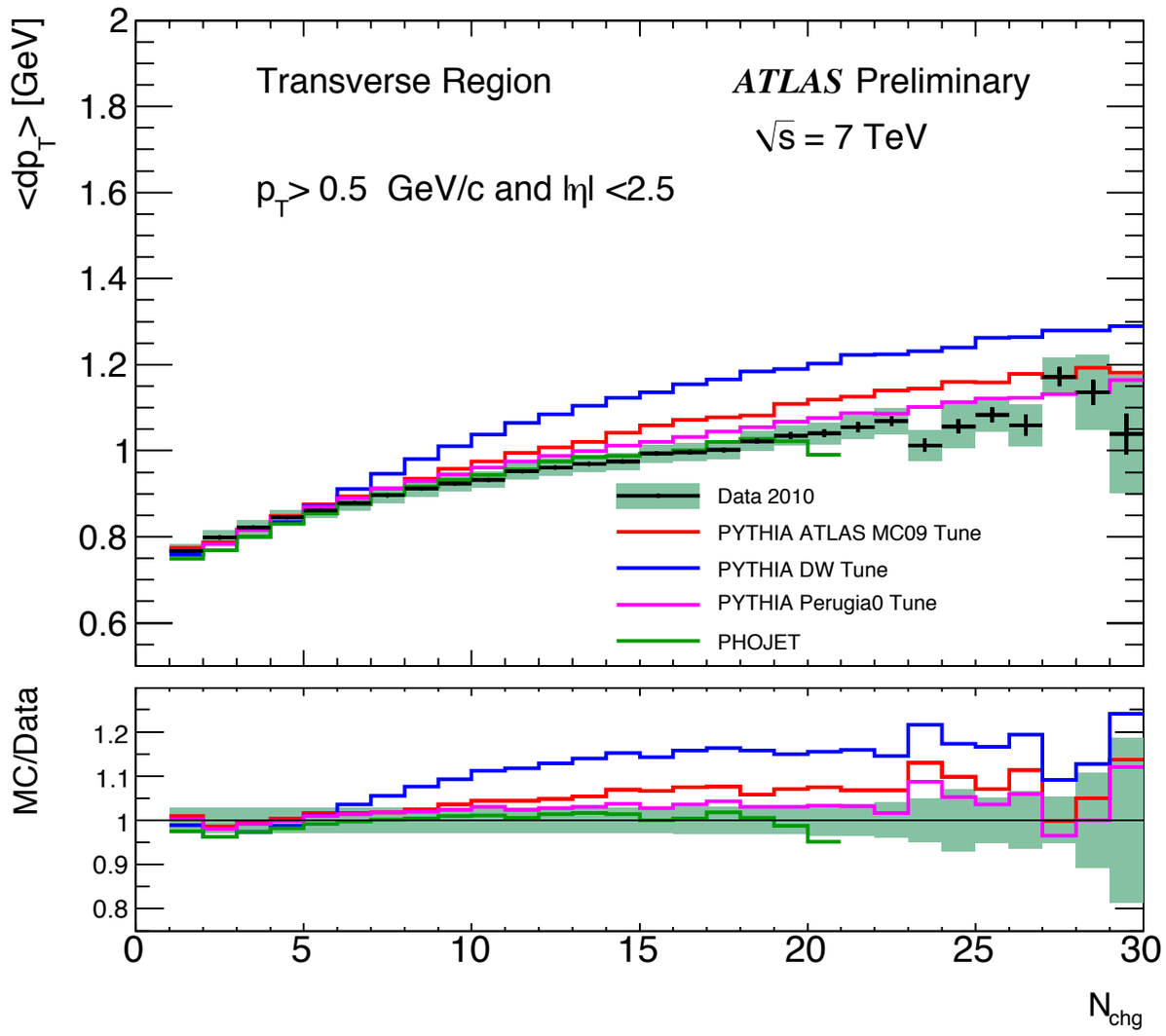
UE: Std. Deviation of Σp_T



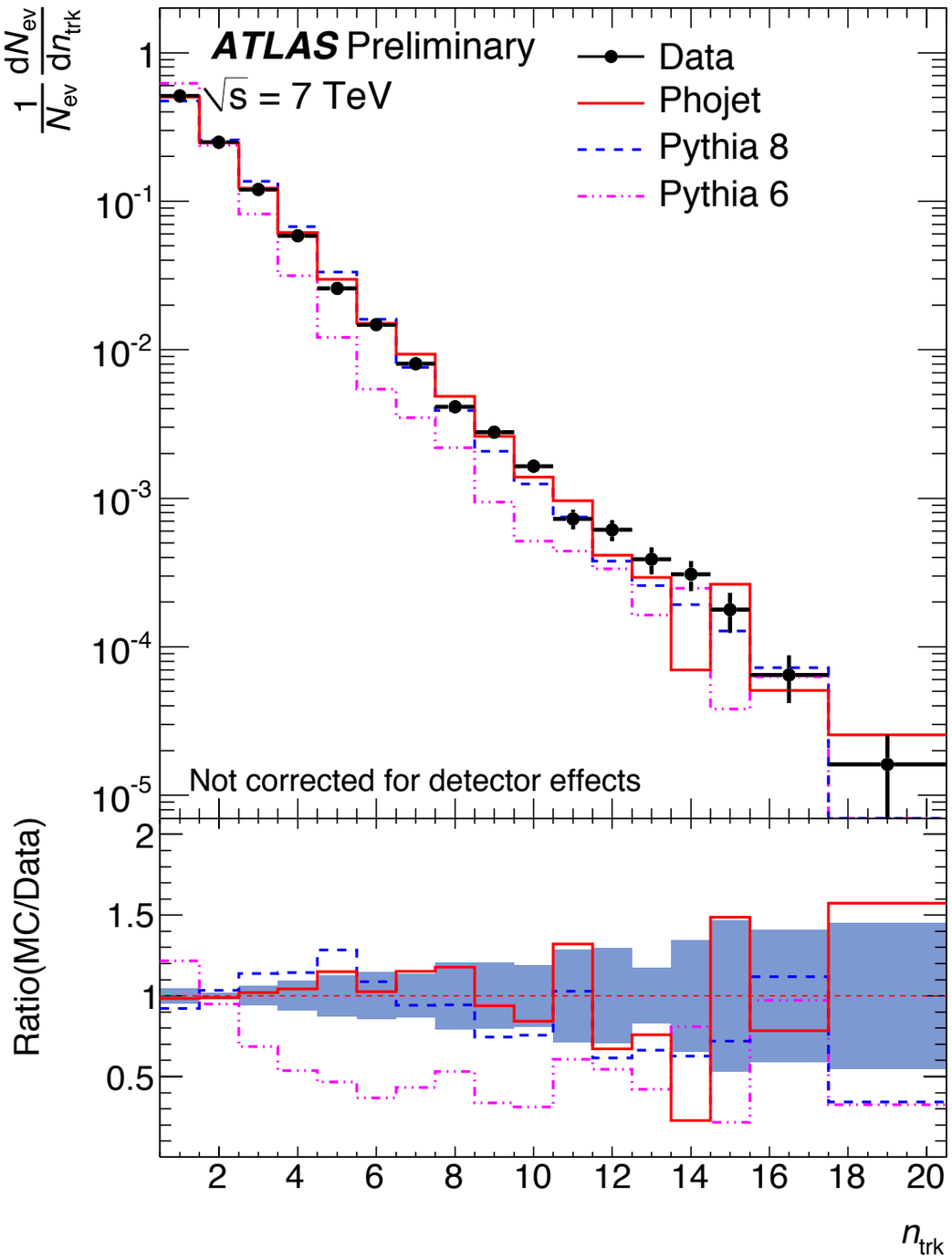


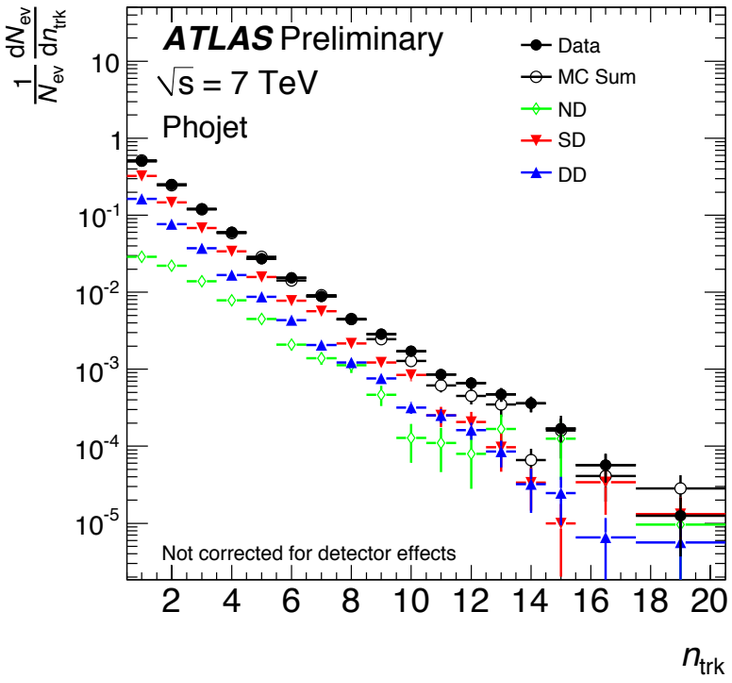
UE: $\langle p_T \rangle$ vs. N_{ch}

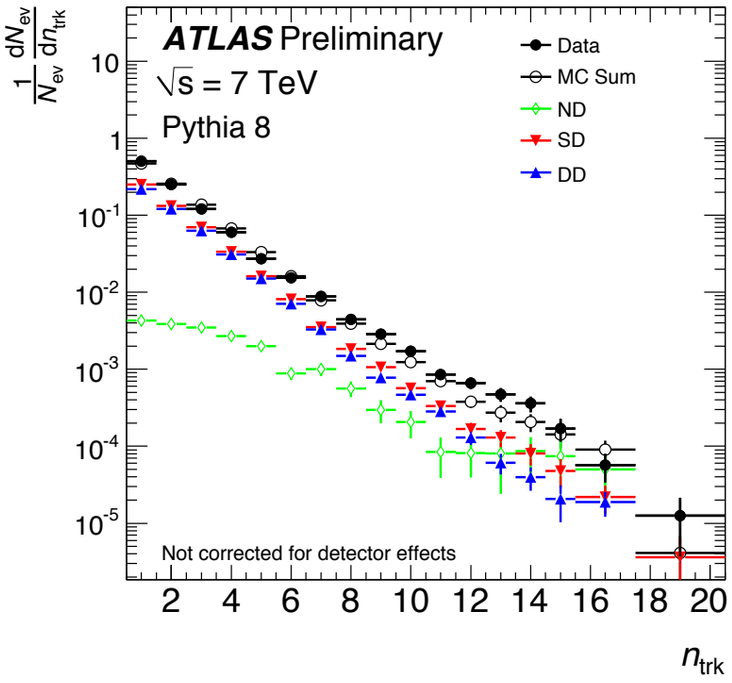


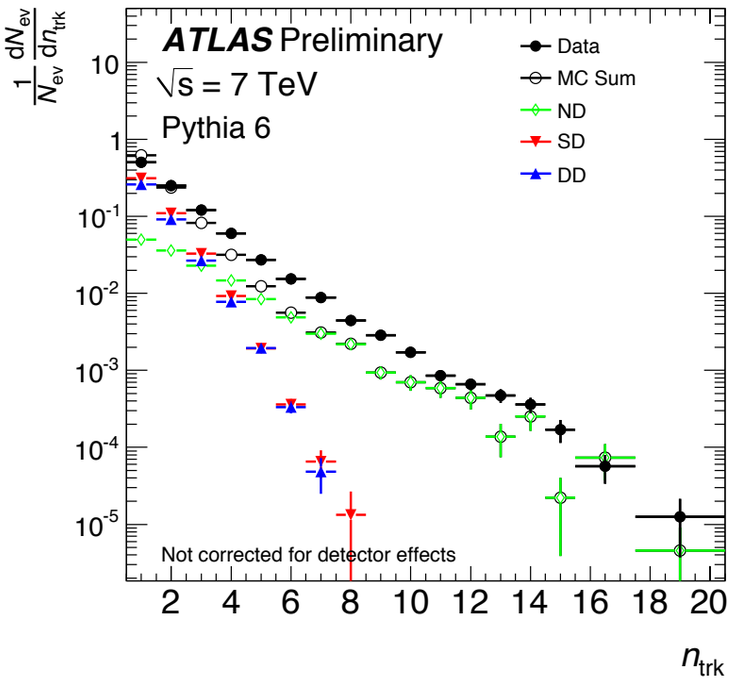


Diffraction: N_{ch}

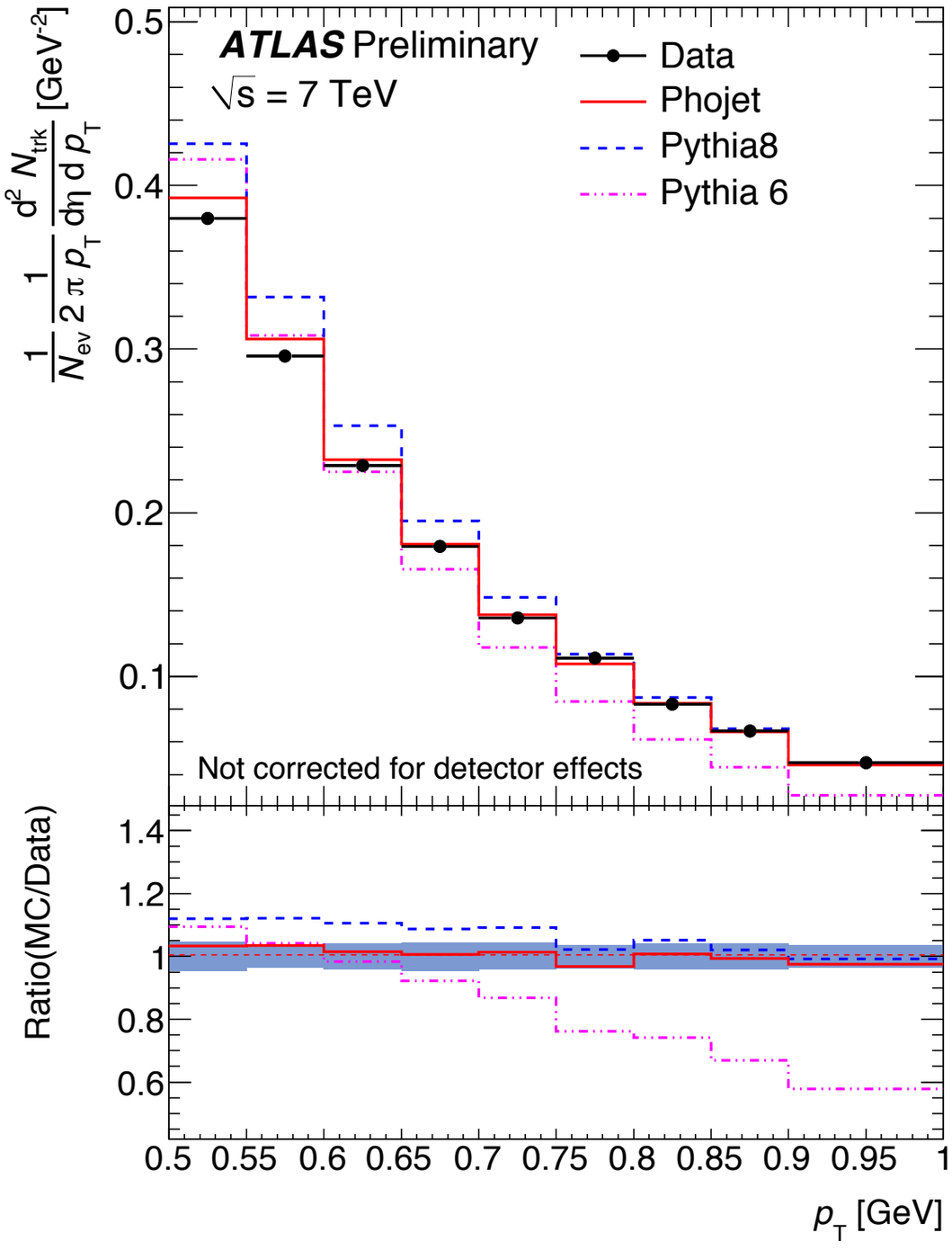


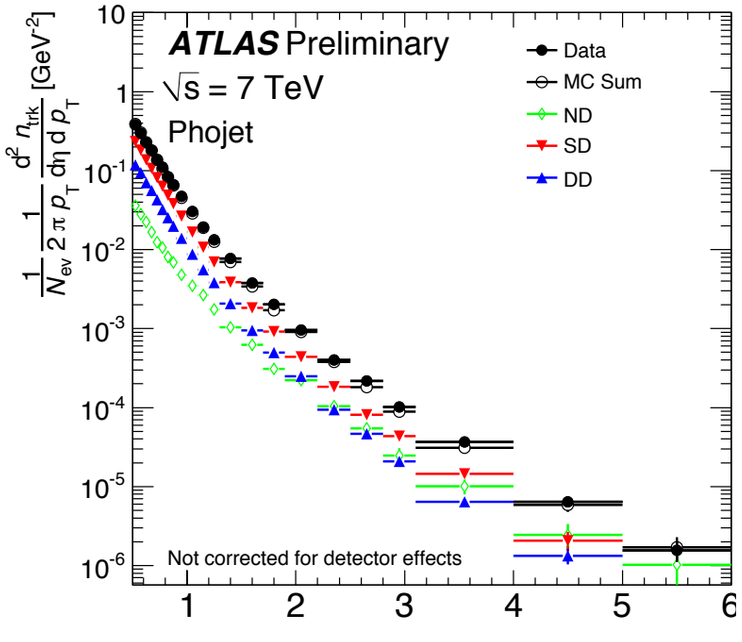


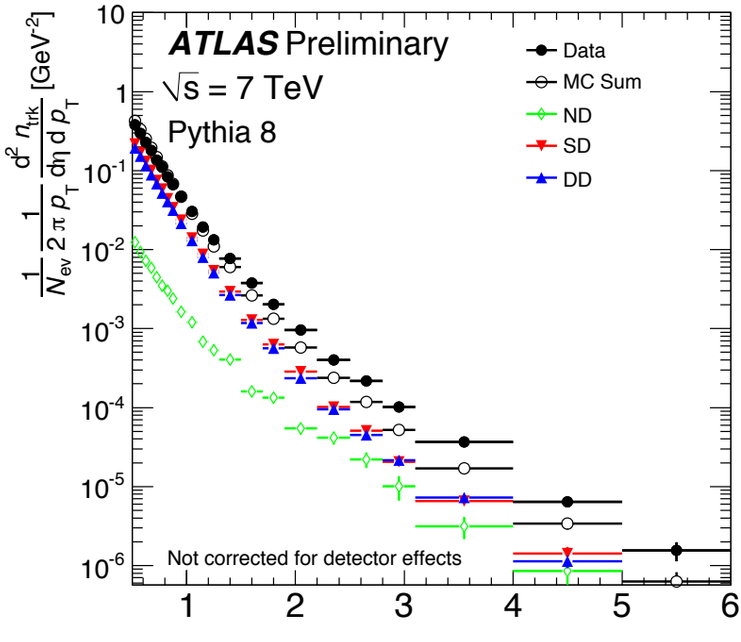


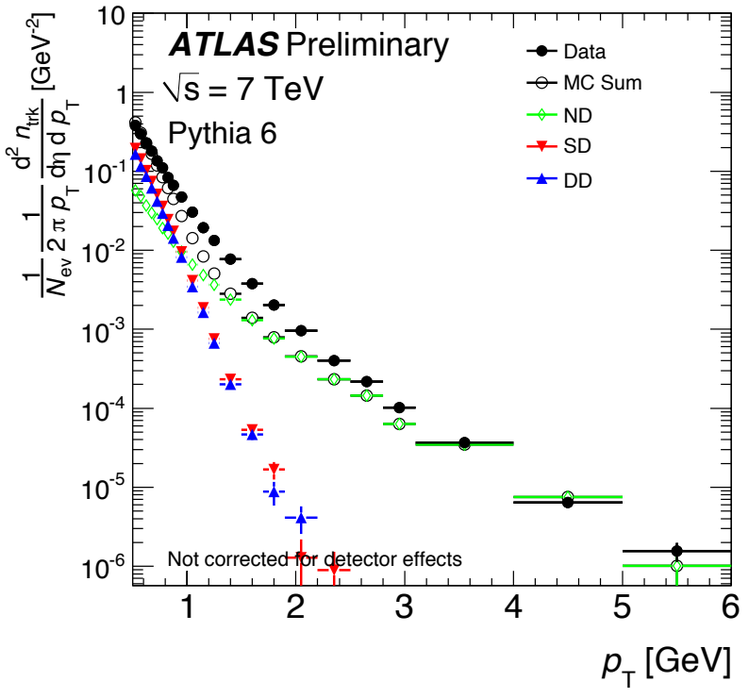


Diffraction: p_T Spectrum









Diffraction: $\Delta\eta$