ATLAS results on QCD and quarkonia production

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Plan of the talk

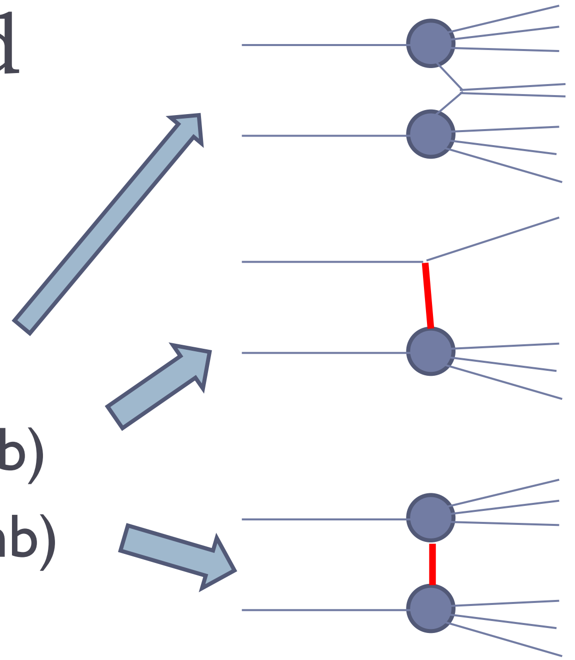
- Soft QCD:
  - Charged particle multiplicities
  - Underlying event and minimum bias
- Hard QCD:
  - Jets: production and energy scale
  - Dijet production and studies
  - Multijet production and studies
- Onia and J/Psi results
- B-physics
- Conclusion

Soft QCD

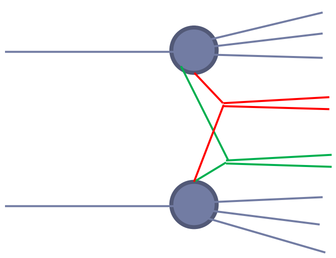
- **Soft QCD in pp-collisions:**
  - It is non-perturbative physics and has an interesting phenomenology
  - Beam remnants
  - Multiple Parton Interactions
  - Color recombination
  - ➔ all adding up to a colorless system
- An essential ingredient for precision high p_T physics
  - Causes an experimental bias such as in jet trigger and from pile up due to multiple interactions in the same bunch crossing
  - Top mass, Jet p_T energy scale, Isolation cone energy
- **Measurement done using charged particles:**
  - **Allow to control systematics and provides an inclusive measurement**

Minimum bias and underlying event

- Minimum bias at 7 TeV:
  - Non-diffractive (~50 mb)
  - + Single diffractive (~14 mb)
  - + Double diffractive (~9 mb)



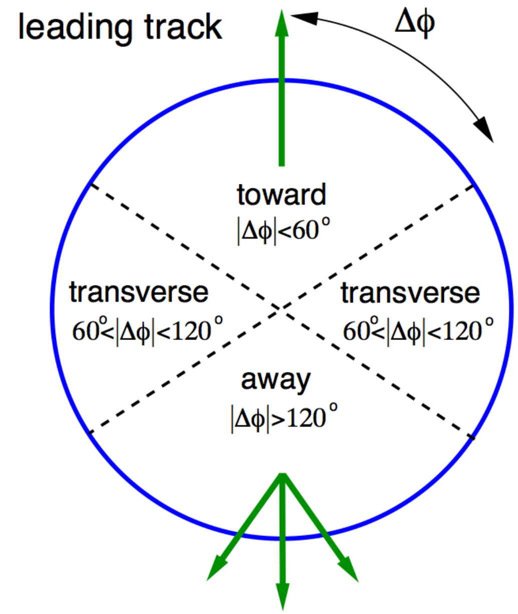
- Underlying event



Hard scatter and initial/final state ratiation
Multiple parton interactions
Beam remnants

- Soft QCD requires MC to be tuned to data

Underlying event and analysis overview



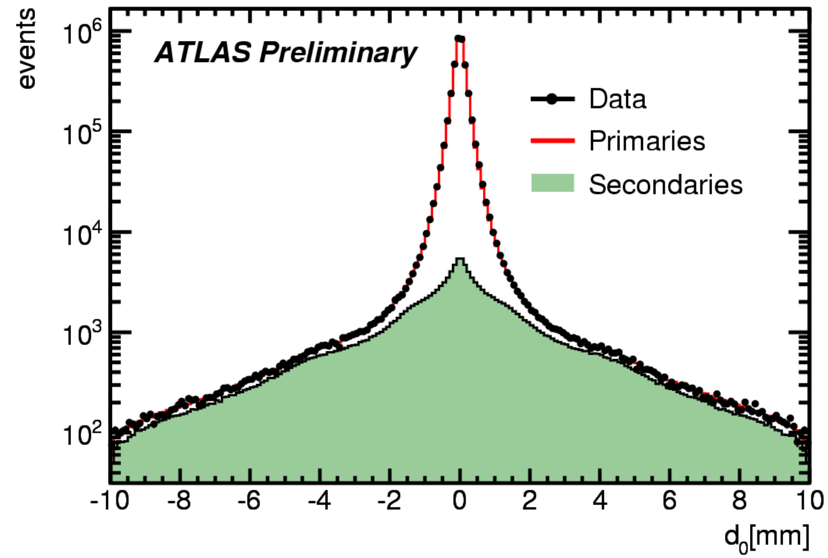
- Transverse region (to hard scattering) should be most sensitive and almost independent of energy scale
- Studied distributions:
  - Multiplicity
  - p_T distribution
  - η distribution
  - Mean pT vs. multiplicity
- Analysis overview:
  - Trigger and event selection
  - Track reconstruction and determination of efficiency
  - Unfolding from track to hadron level (using Monte Carlo)
  - No model dependent corrections (e.g. for SD contribution)
  - Compare to Monte Carlo phenomenological models based on PYTHIA – using PYTHIA to provide relative weighting of SD, DD, and ND in the MC distributions.

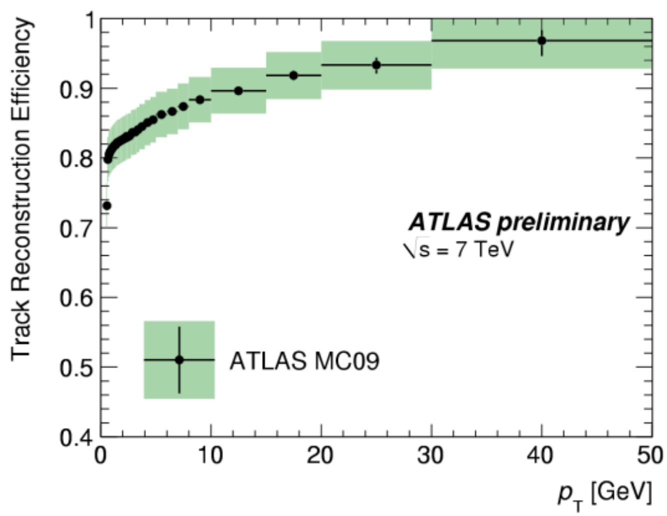
Trigger and event selection

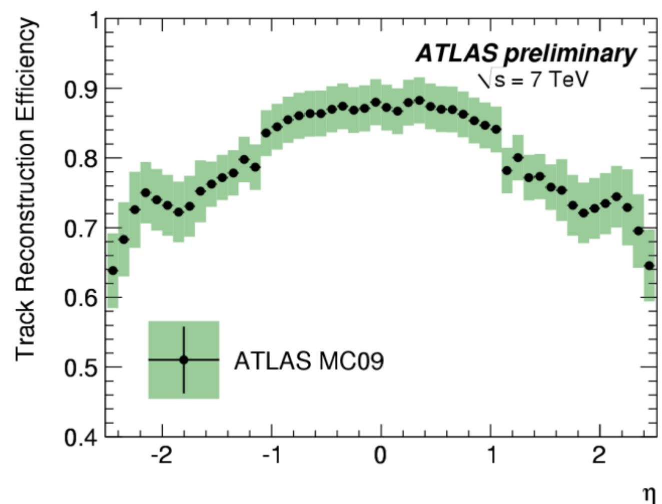
- Data:
  - ~7 nb^{-1} at $\sqrt{s}$ = 900 GeV, ~(168-190) nb^{-1} at $\sqrt{s}$ = 7 TeV
- Trigger:
  - Require ≥ 1 MBTS counter to fire on either side
  - MBTS is based on trigger scintillators at z: ±3.5m from Interaction Point (IP) cover: $2.09<|\eta|<2.82$, $2.82<|\eta|3.84$ (two rings)
  - >99.5% efficient (any track multiplicity)
- Event selection:
  - Require reconstructed vertex from ≥ 2 tracks with p_T > 100 MeV
  - No additional primary interaction
  - At least one track passing track selection cuts
- Primary track selection:
  - p_T>1 GeV (or 500 MeV), $|\eta| < 2.5$ (other tracks p_T > 500 (100) MeV)
  - Minimum 1 hit in pixel and 6 hits in SCT tracking systems
  - Transverse impact parameter $|d_0| < 1.5$mm
  - Longitudinal impact parameter $|z_0| \cdot \sin\theta < 1.5$mm

Efficiency corrections

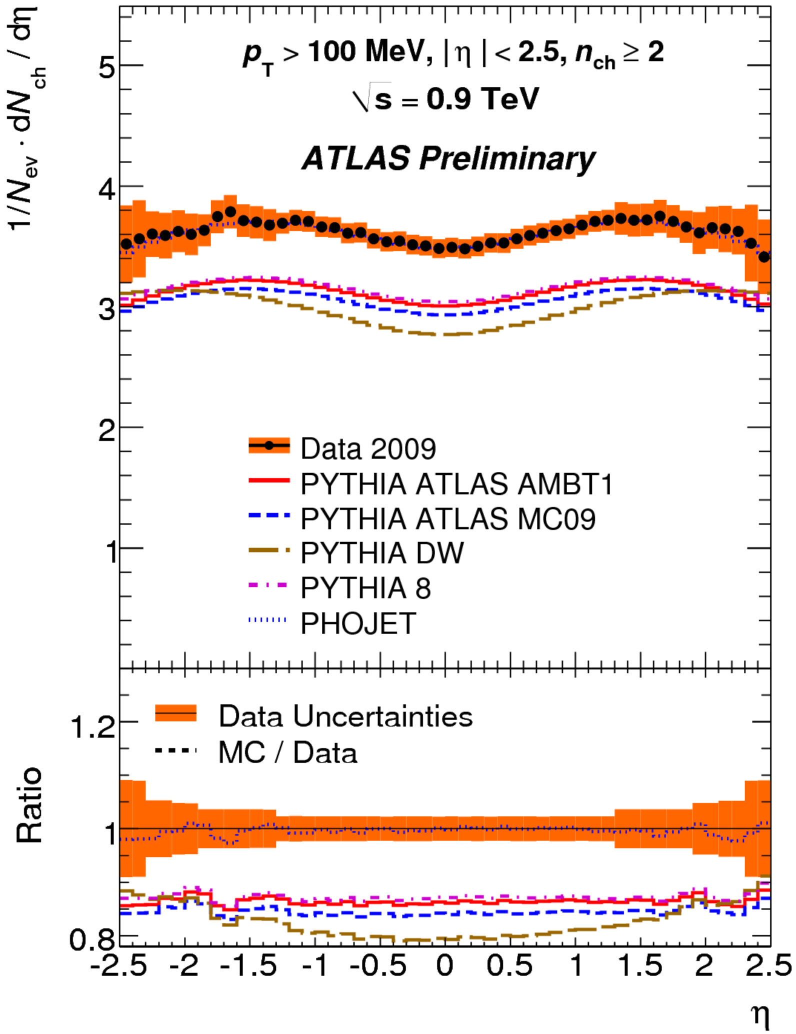
- Trigger and vertex efficiencies derived from data: > 0.995 efficient
- Tracking efficiency from MC
  - Estimate contributions from nuclear interactions, K_s, Λ, π decays
- The dominant systematic comes from knowledge of the material

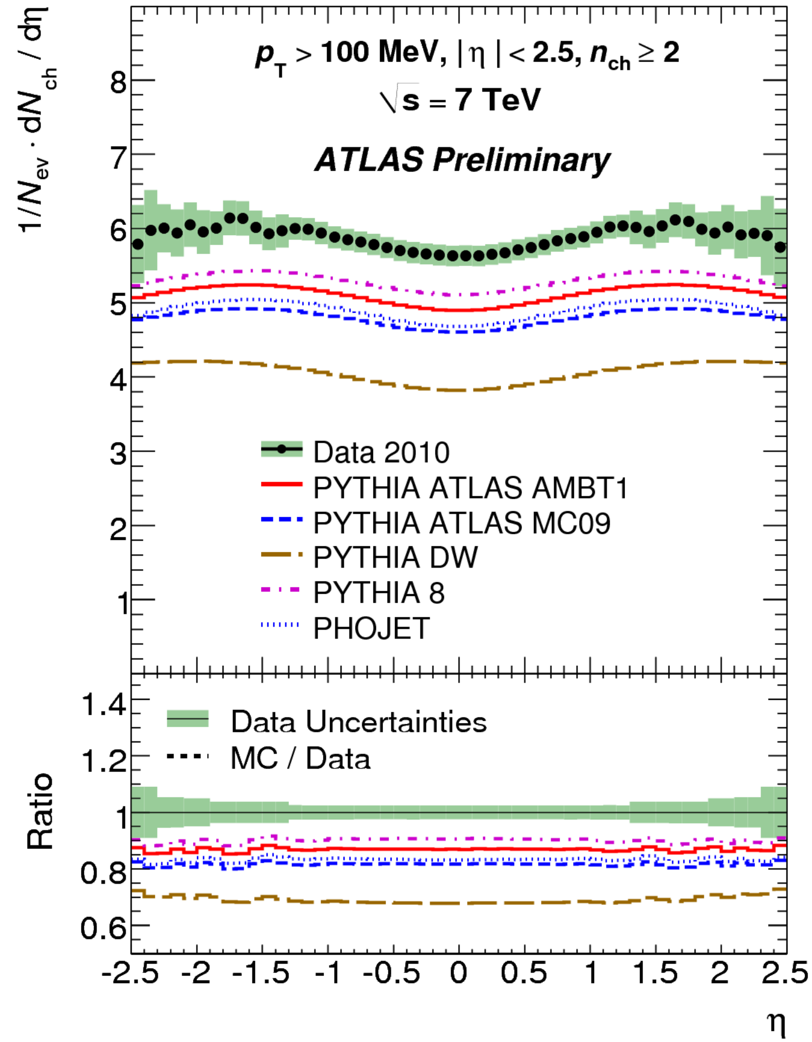






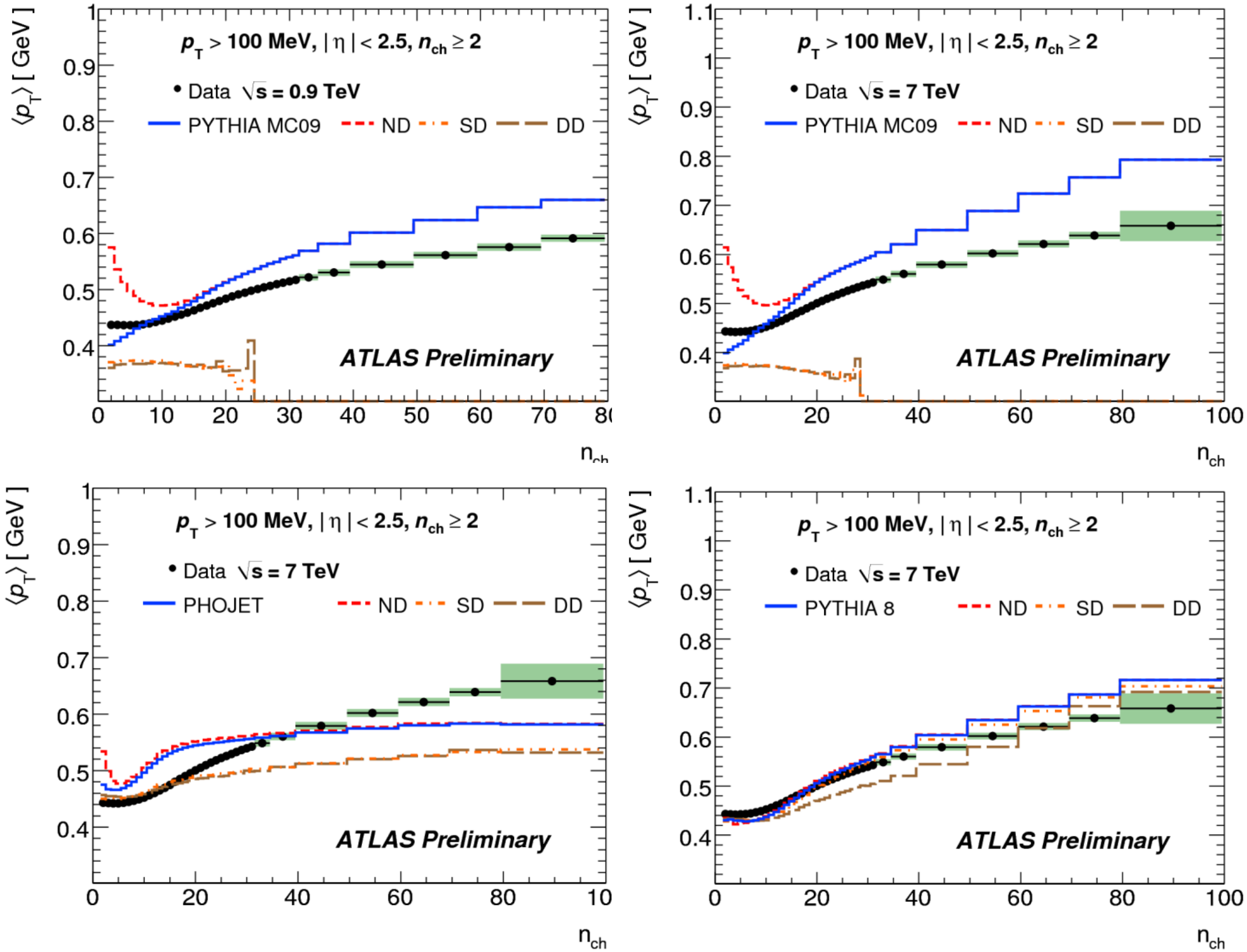
Charged particle multiplicity as a function of the pseudorapidity





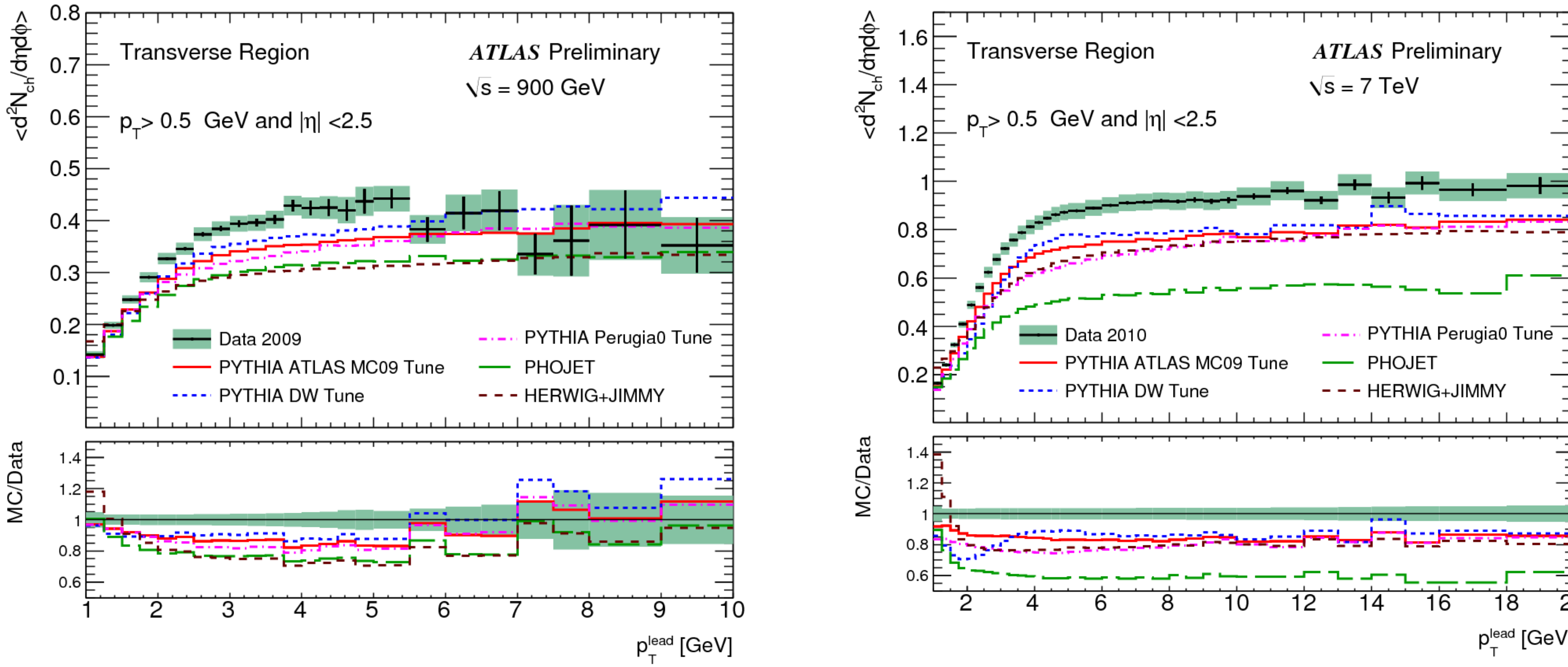
- Overall no Monte Carlo gives a “perfect” description of the data

Mean p_T as a function of charged particle multiplicity



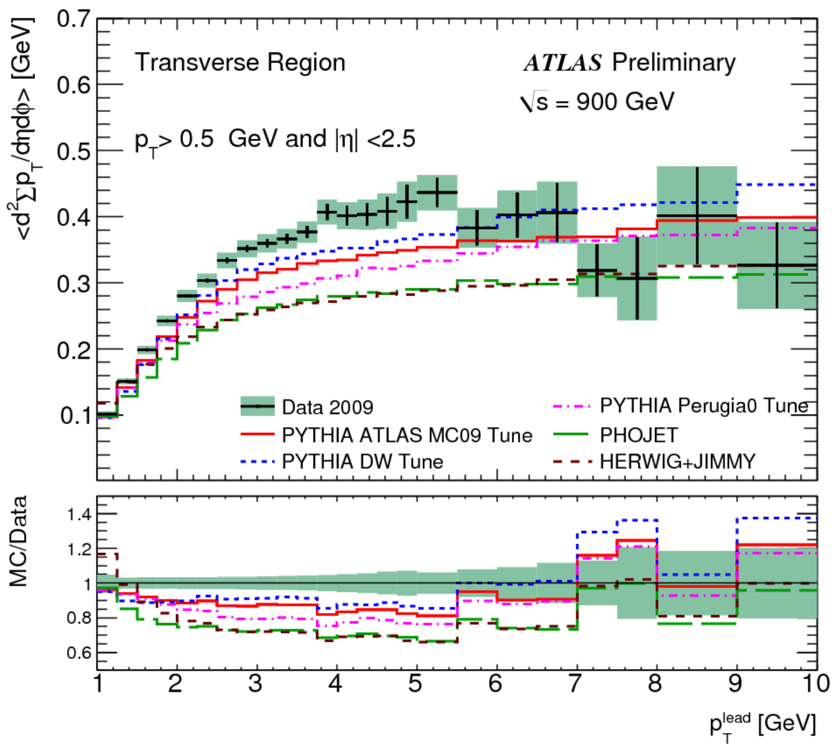
- All MC models disagree with data for high charged particle multiplicity & disagreement increases for $\sqrt{s}$ = 7 TeV

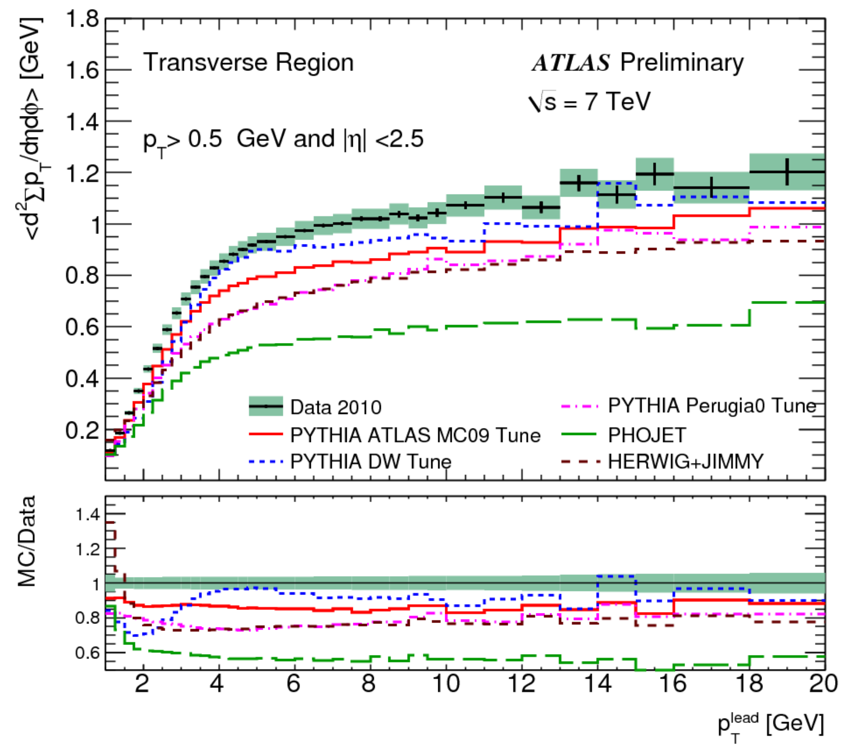
Underlying event: transverse region particle densities



- All tunes underestimate particle density by ~10-15% in the plateau region
- There is a factor of ~2 increase in activity going from √s = 900 GeV to 7 TeV; all tunes predict a comparable relative increase
- In the plateau region the measured density corresponds to ~2.5 particles per unit η at √s = 900 GeV and 5 particles per unit η at √s = 7 TeV

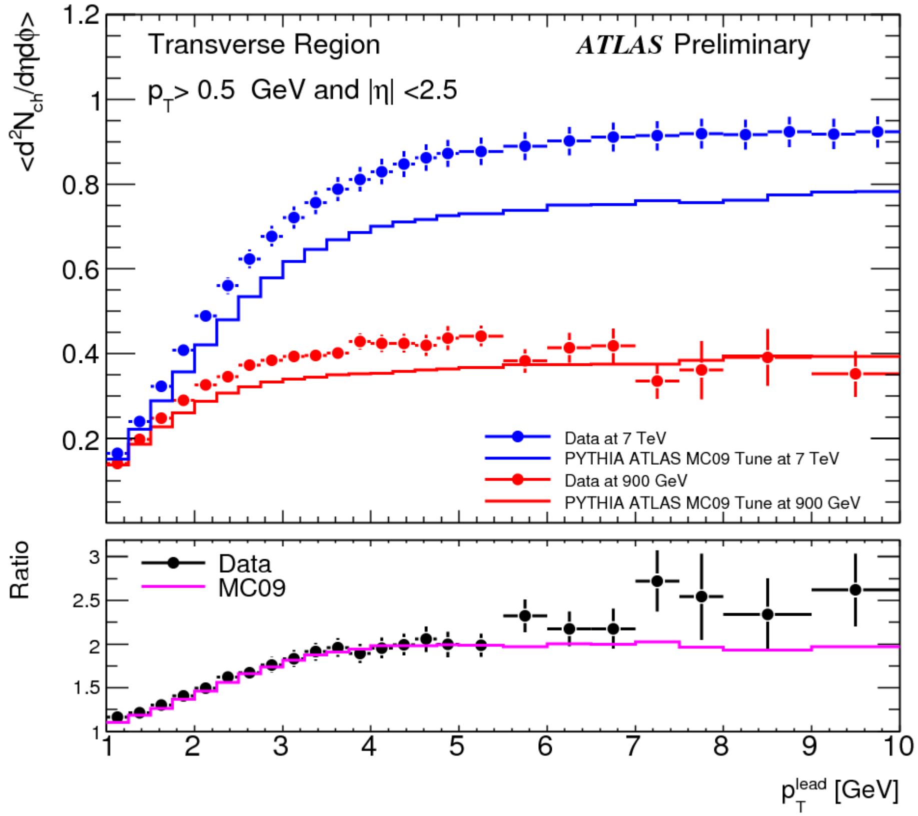
Underlying event: transverse region <Σp_T> density

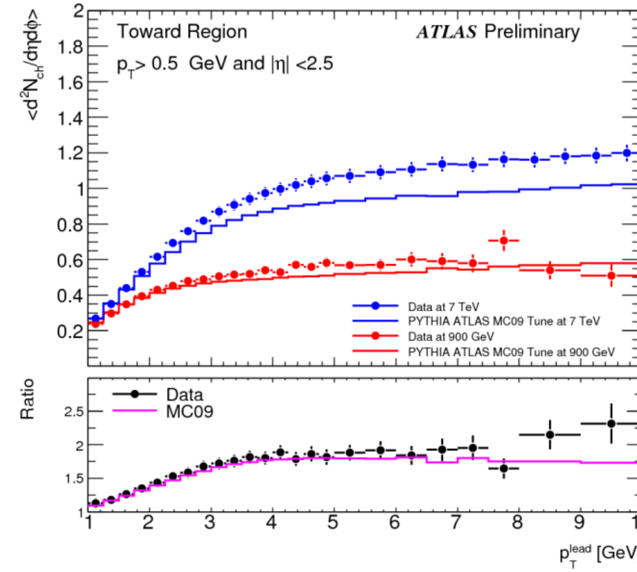


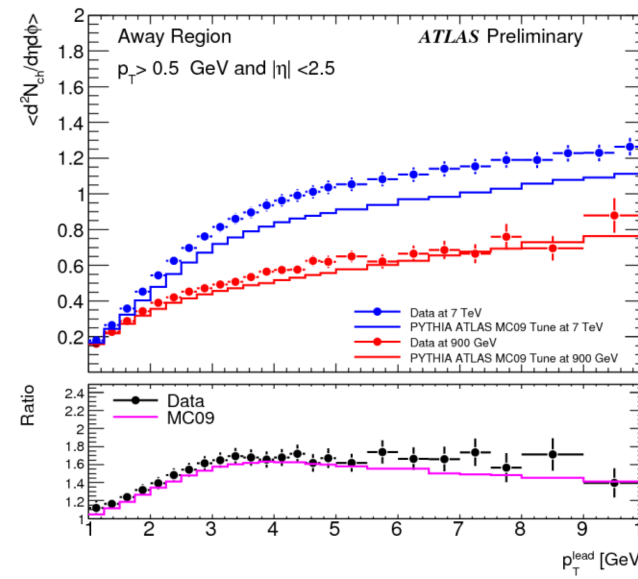


- Conclusion is similar to that for particle densities
  - all tunes underestimate the scalar sum p_T in the transverse region
  - Roughly a factor of 2 increase in sum p_T in the plateau region going from $\sqrt{s}$ = 900 GeV to 7 TeV

Underlying event particle densities by region and E_{CM}



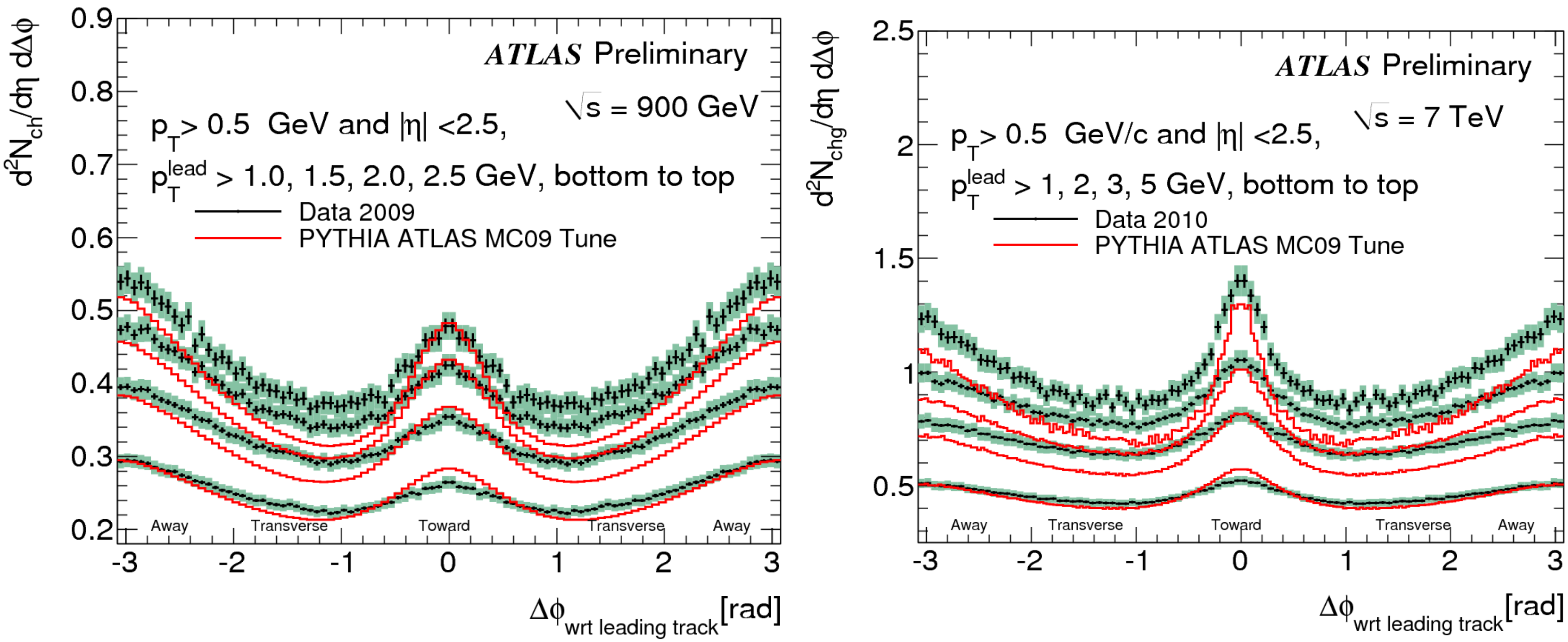




- The largest disagreement between data and is in the transverse region

Particle Density Angular Correlation

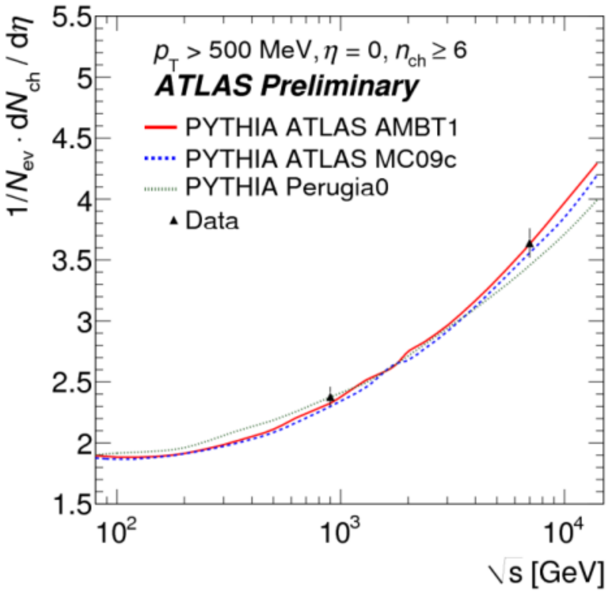
- Define the event orientation by the azimuthal angle of the track with the highest p_T
- Plots are reflected about φ=0; highest p_T track is not included

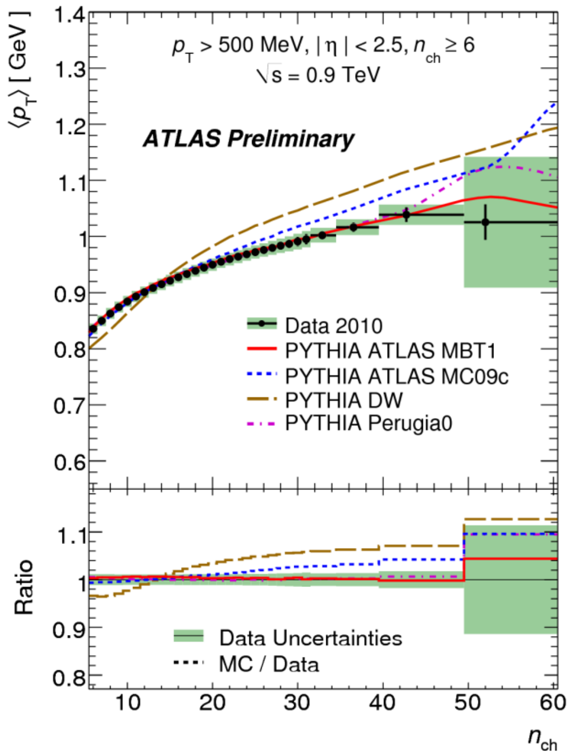


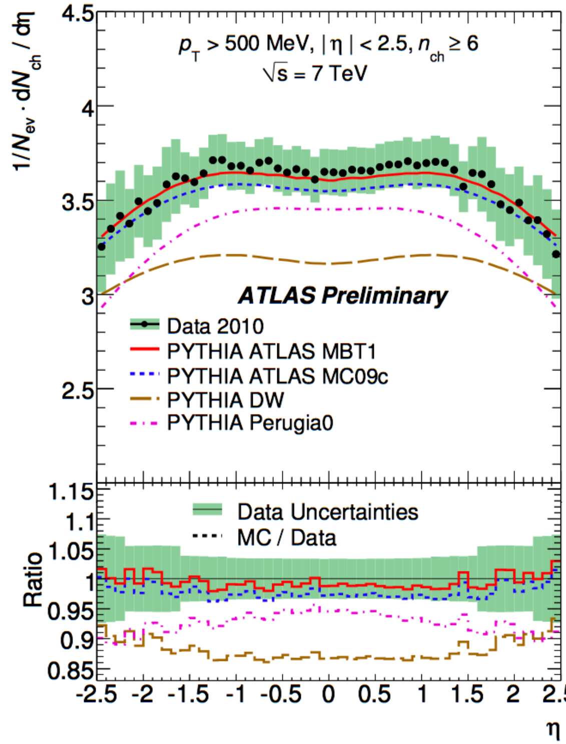
- Monte Carlo tunes only reproduce the general features
  - Disagreement in rates both in the transverse region (UE) and in the Toward and Away regions (MPI/Hard Core)

New PYTHIA tune to ATLAS minimum bias data and underlying event (AMBT1)

- **Input to Tune:**
  - **ATLAS UE data and charged particle densities at 0.9 and 7 TeV**
  - **CDF Run I & Run II: min bias, UE, Z Pt**
  - **D0 Run II dijet angular correlations**







- Tune to reduced phase space (n_{ch} ≥6) to insure no contribution from SD
- Significant improvement over pre-LHC tunes

Summary for Minbias and UE

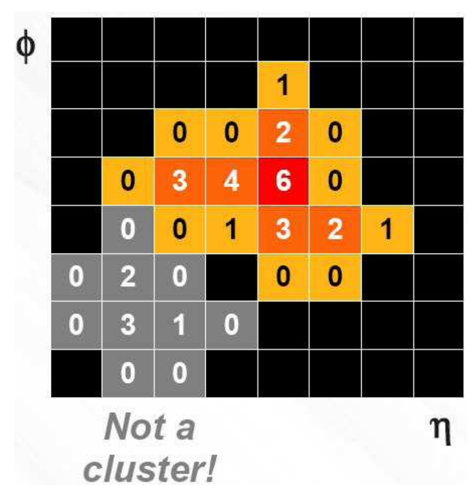
- Charged track distributions are used to study the characteristics of min bias events and compared them to phenomenological models within PYTHIA
  - $<p_T>$, N_{ch}, $<p_T>$ vs N_{ch}, $dN_{ch}/d\eta$, dN_{ch}/dp_T
  - Underlying event distributions in transverse, towards and away regions
- None of the pre-LHC tunes provided "perfect" agreement with the experimental data, though they come close to describing several kinematic distributions as well as the increase in densities with $\sqrt{s}$.
- Used these measurement to obtain a new PYTHIA tune. This does a good job of describing the experimental data (*though still has problems with parts of the underlying event)*

Hard QCD

- Jet reconstruction and triggering
- Measurements of jet production and differential cross sections
- Measurements of dijet and multijet production
- Search for new particles in dijets
- Azimuthal decorrelations in dijet events

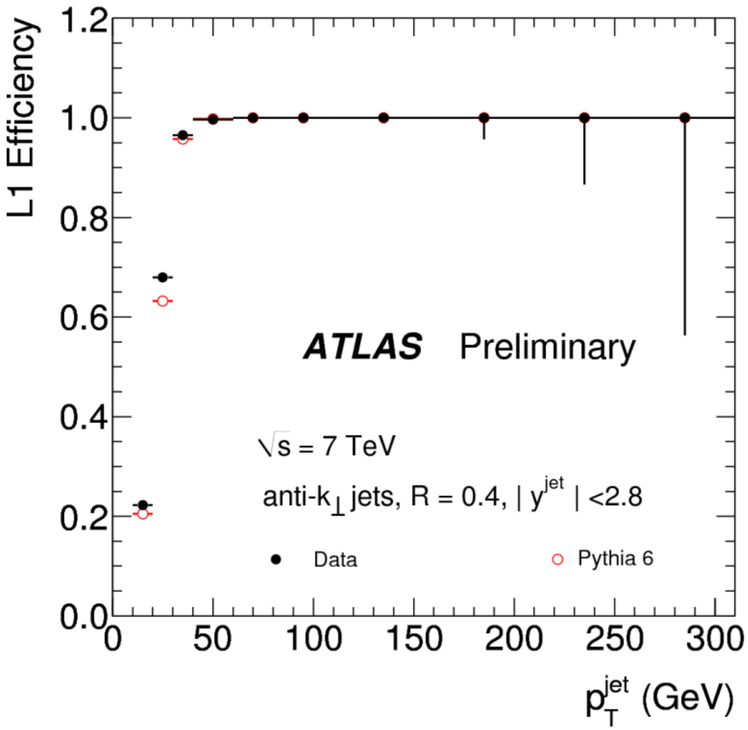
Jet production @ $\sqrt{s}$ = 7 TeV

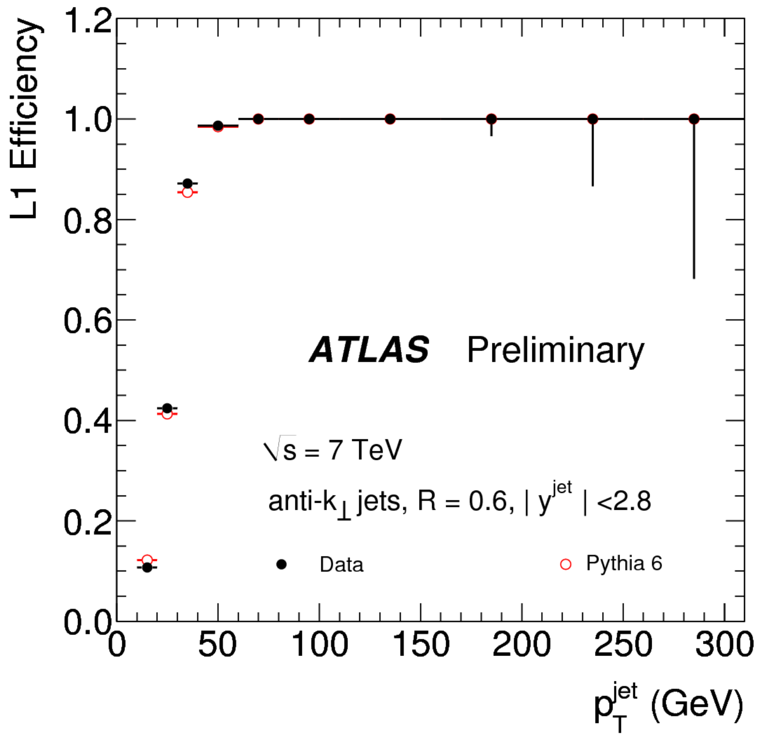
- Data sets of proton-proton collisions at 7 TeV center-of-mass-energy:
  - March/July 2010, integrated luminosity from 1 to 315 nb^{-1}
- Jet reconstruction: topological clusters as input to anti-k_T jet algorithm:
  - Infrared- and collinear-safe jet clustering algorithm around hard objects producing geometrically well defined cone-like jets (experimentally friendly)
  - Resolution parameter R=0.6 or R=0.4
  - TopoCluster algorithm:
    - Seeded by calorimeter cells with energy deposit $E_{cell} > 4 \times$ noise
    - Then neighbouring cells with $E_{cell} > 2 \times$ noise iteratively added
    - Then all nearest neighbours around cluster to accumulate shower tail



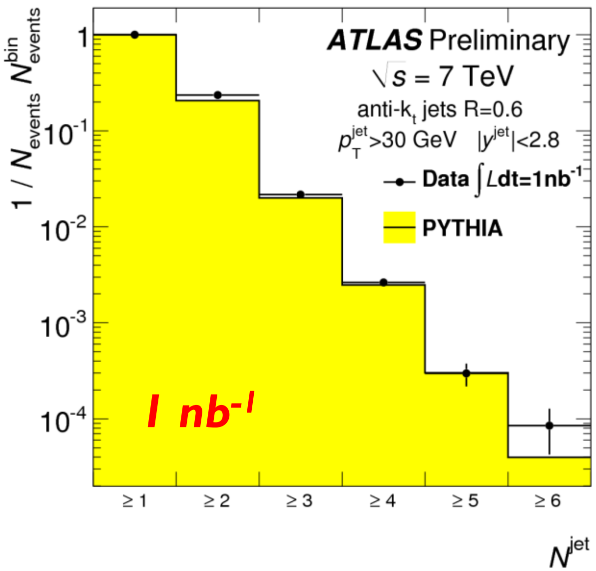
Jet trigger efficiency

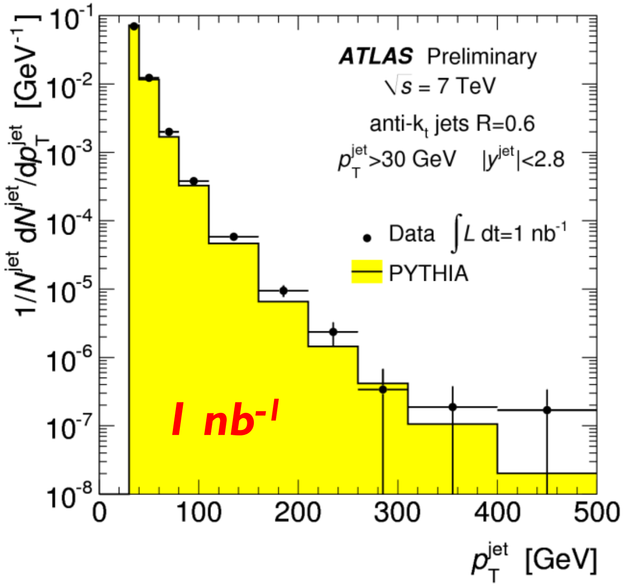
- Events accepted either by the system of minimum-bias trigger scintillators (MBTS, 2%) or the calorimeter trigger (98%).
- Jet trigger is based on the selection of jets according to their transverse energy, E_T. For p_T>60GeV and $|\eta|$<2.8, the trigger efficiency is above 99%.

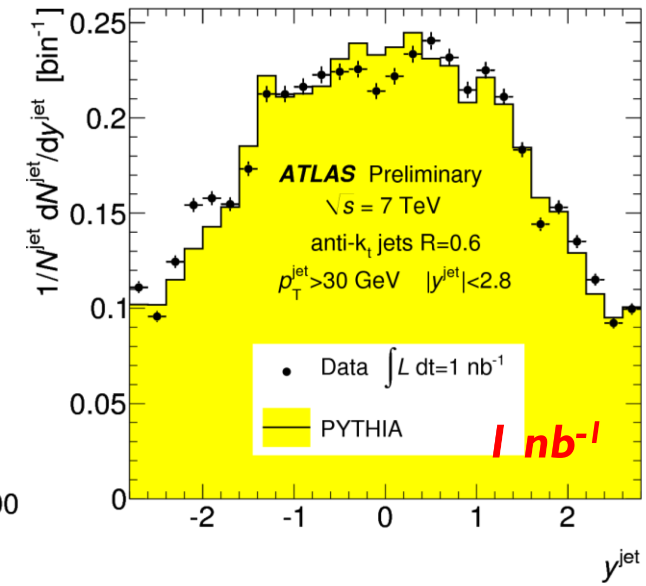


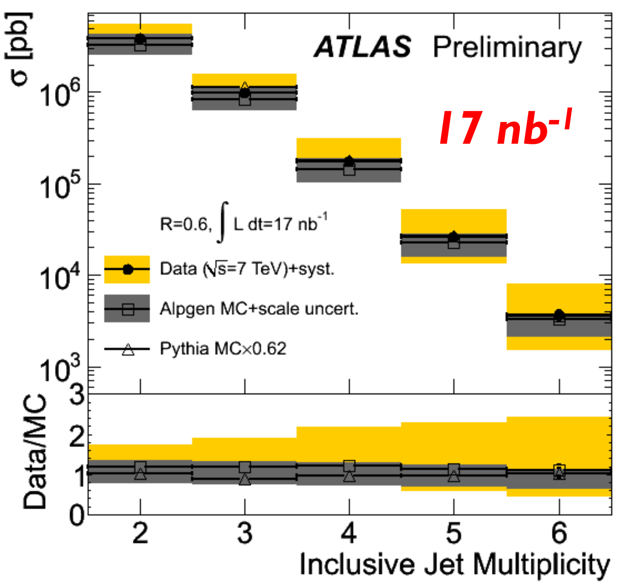


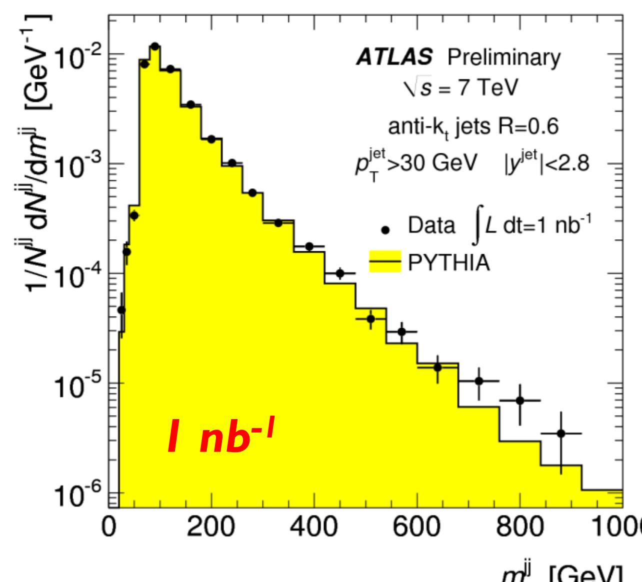
Jet kinematical distributions





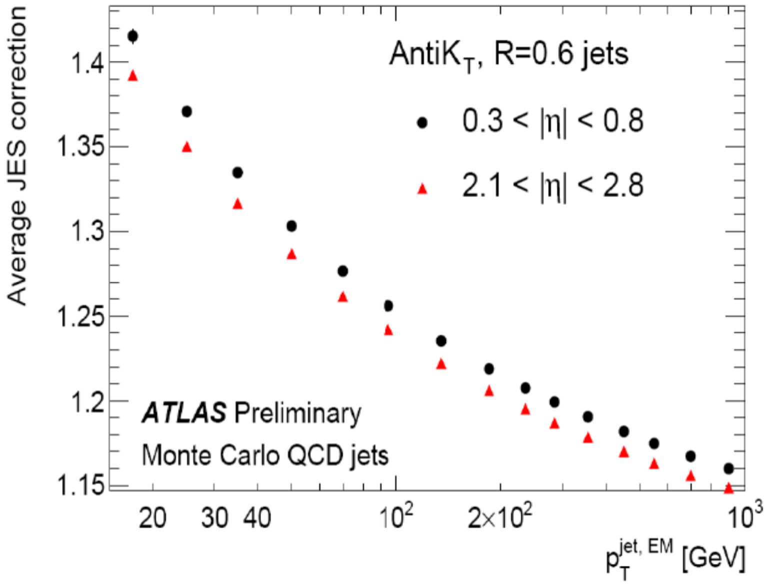




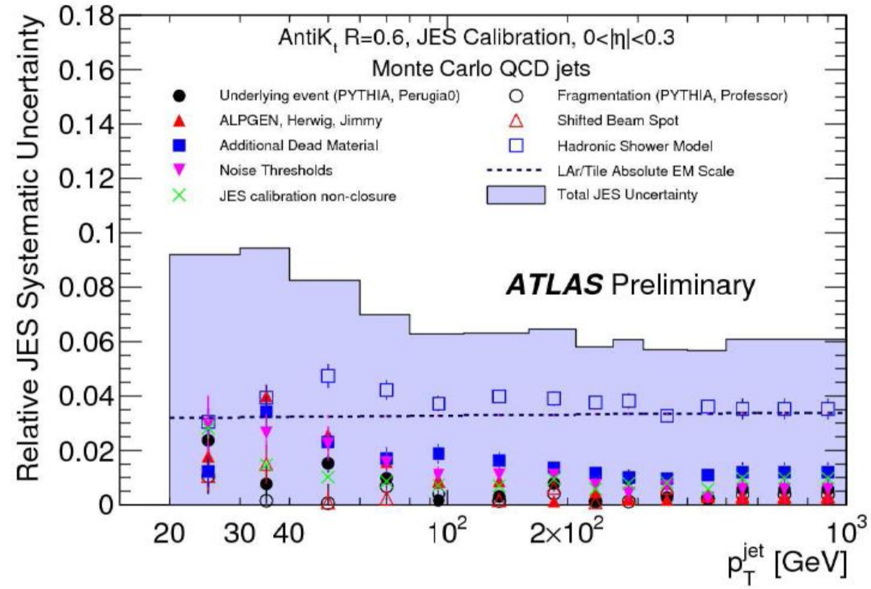


Jet Energy Scale and uncertainties

Calibration factors C (p_T, η) from MC:



JES uncertainty for central/forward jets obtained from MC:



- Dominant contributions:
  - Detector geometry
  - Noise description
  - Hadronic shower model
  - + additional 2% from pile-up
- Cross checked by single particle response

Summary for anti-k_T jets R=0.6:

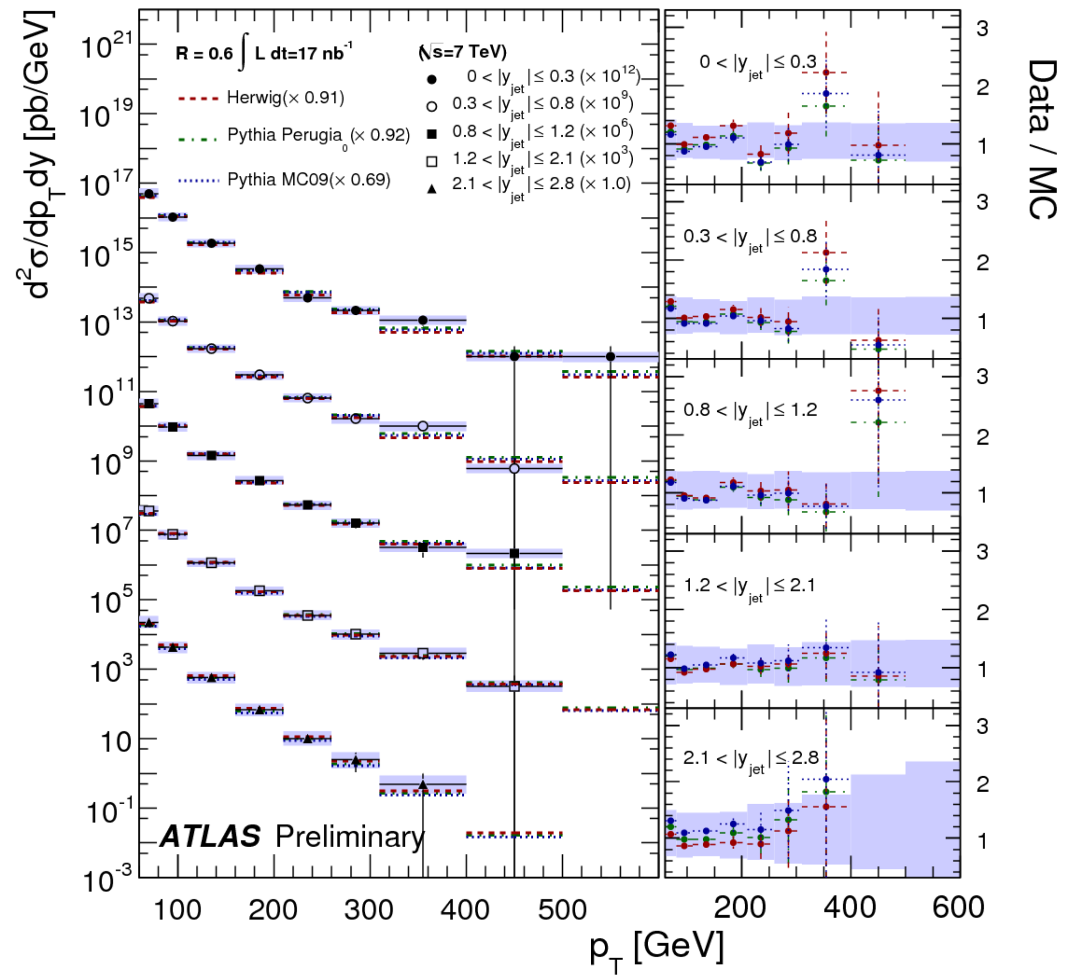
η region	Maximum relative JES Uncertainty	
	p_T^{jet} >20 GeV	p_T^{jet} >60 GeV
$0 < \|\eta\| < 0.3$	9.4%	6.9%
$0.3 < \|\eta\| < 0.8$	9.4%	6.8%
$0.8 < \|\eta\| < 1.2$	9.3%	7.0%
$1.2 < \|\eta\| < 2.1$	9.5%	6.9%
$2.1 < \|\eta\| < 2.8$	10%	7.6%

Inclusive jet cross section

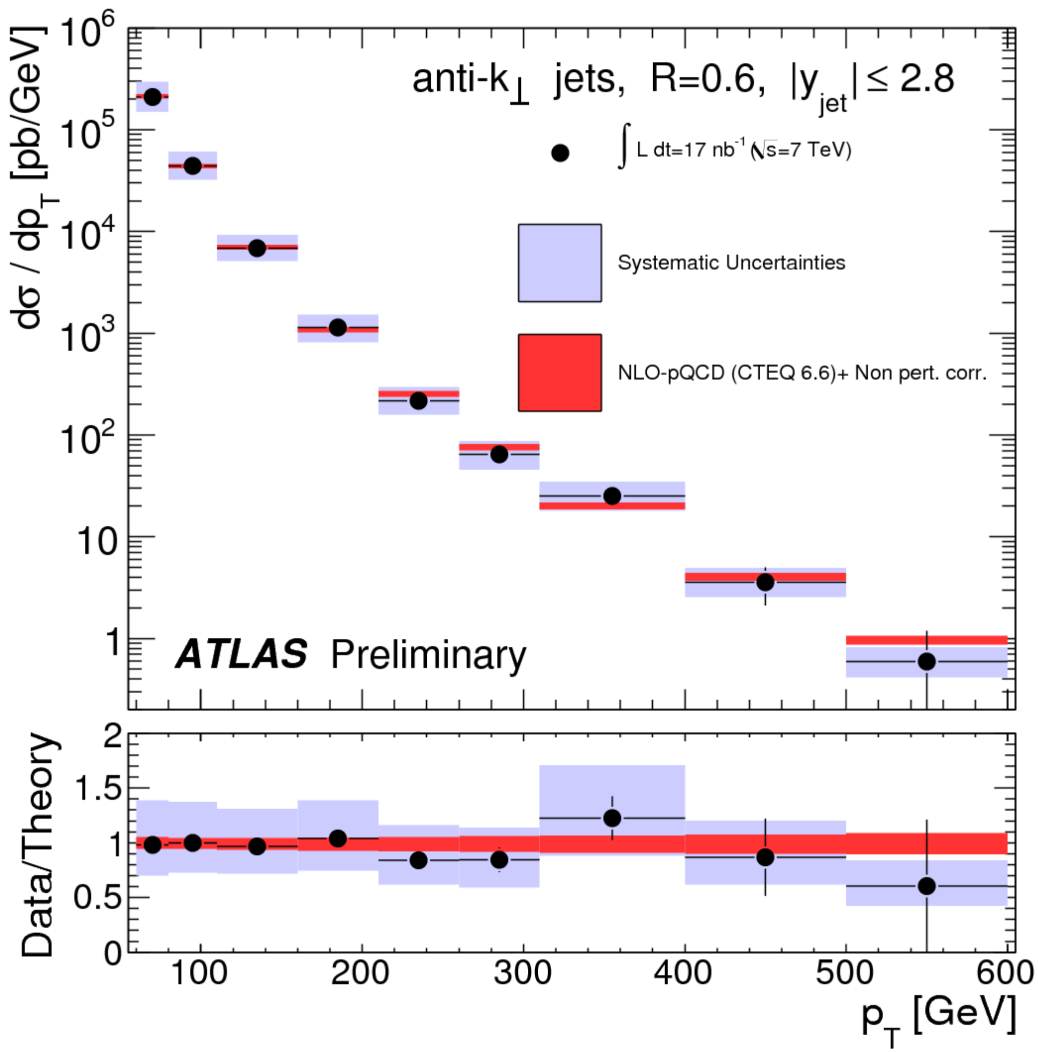
- Systematics: JES, jet resolution, pile-up
- 11% luminosity uncertainty (not included)
- Theory uncertainty: renormalization & factorisation scales, PDFs, α_s and effects from soft QCD modelling
- Bin-by-bin data correction: correction factor from ratio of MC truth to simulation applied to data in each bin

  ➔ Corrections < 20%

Jet cross section in p_T:

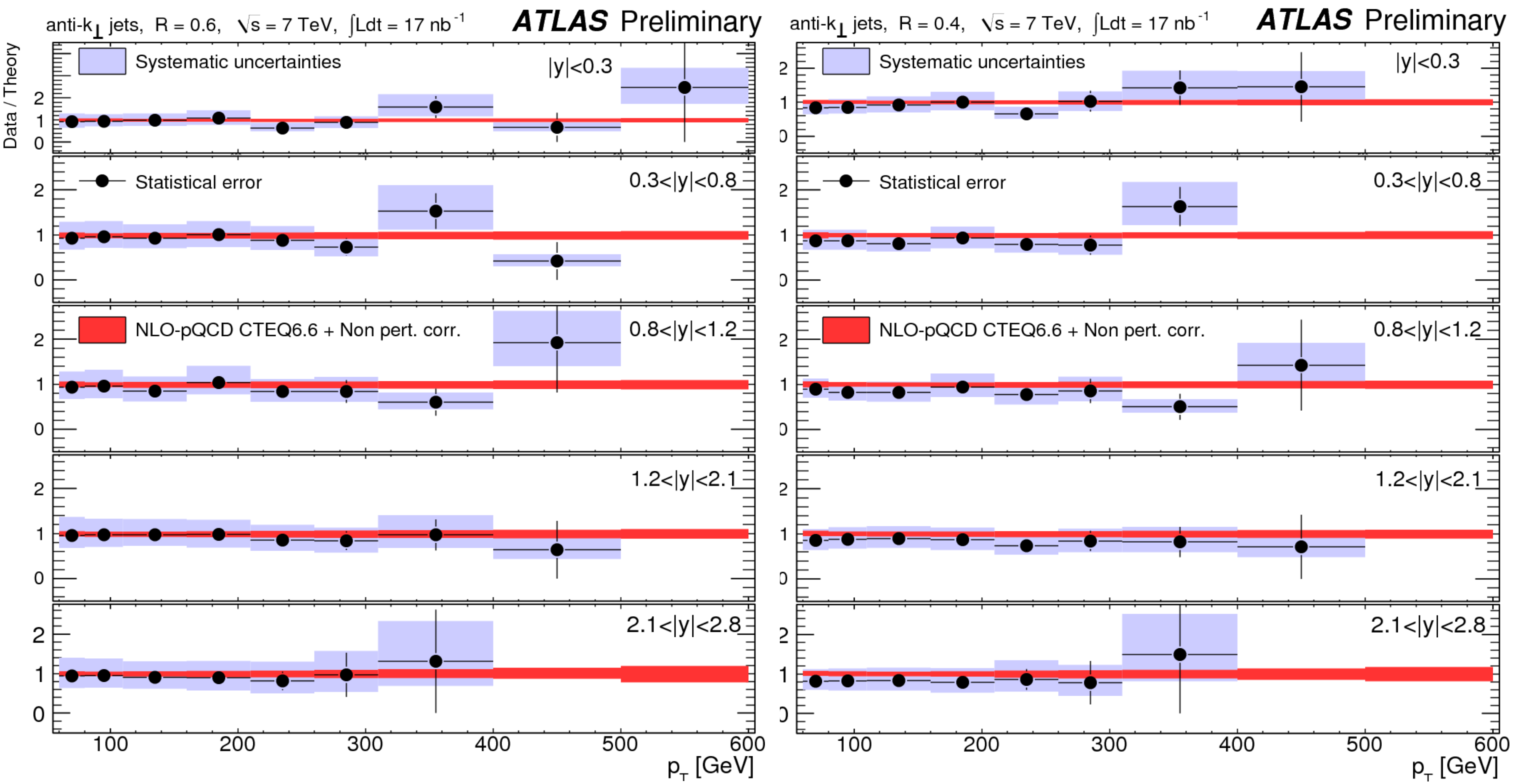


Single inclusive jet cross section



- p_T reach up to 600 GeV, similar to latest Tevatron measurements
- Data and theory are consistent
- Uncertainty in data larger than in theory
- Dominated by jet energy scale

Single inclusive jet cross section

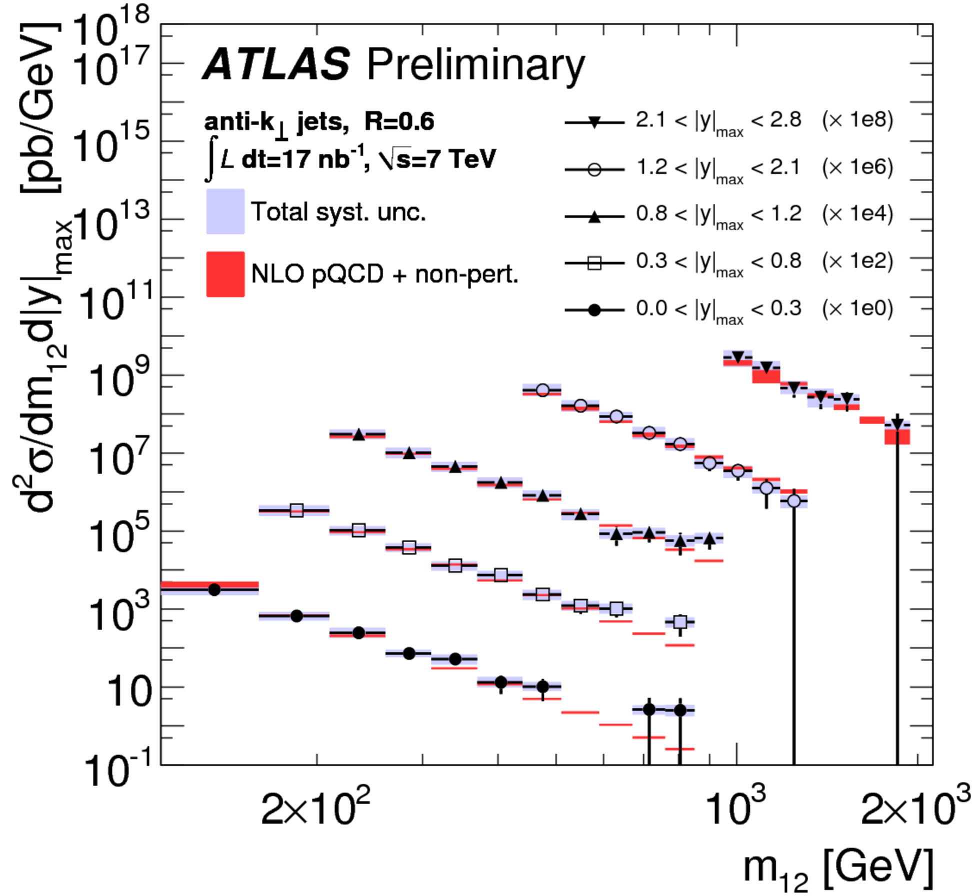


- Data and theory are consistent in all repidity regions. R-dependence (~cone size) will be important handle on non-perturbative corrections

Dijet cross section for as function of $M_{1,2}$ in rapidity bins

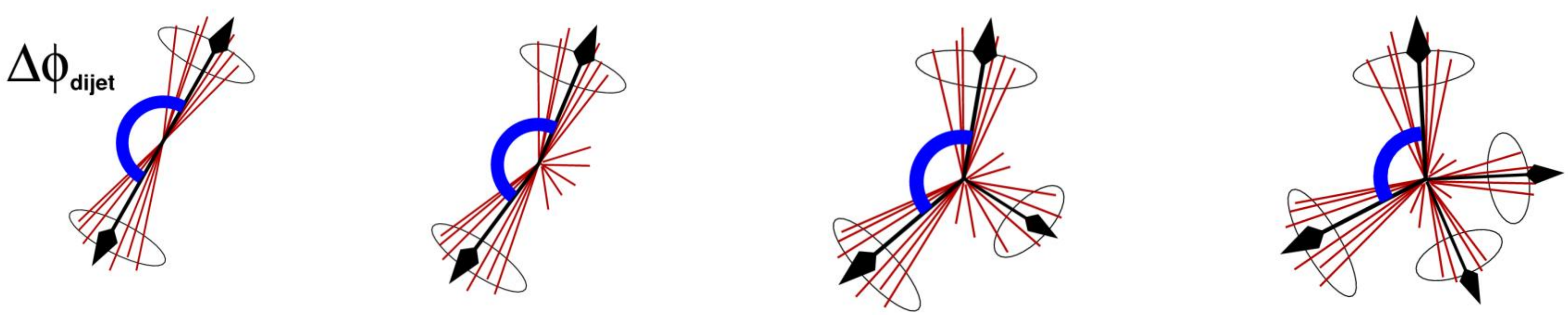
- $M_{1,2}$ is invariant mass of first two leading jets with $p_T(1) > 60$ GeV, $p_T(2) > 30$ GeV.
- Dijet masses up to ~ 2 TeV.
- Overtaking Tevatron analysis in mass reach.
- Data and theory consistent in all rapidity regions.

Dijet mass cross section:



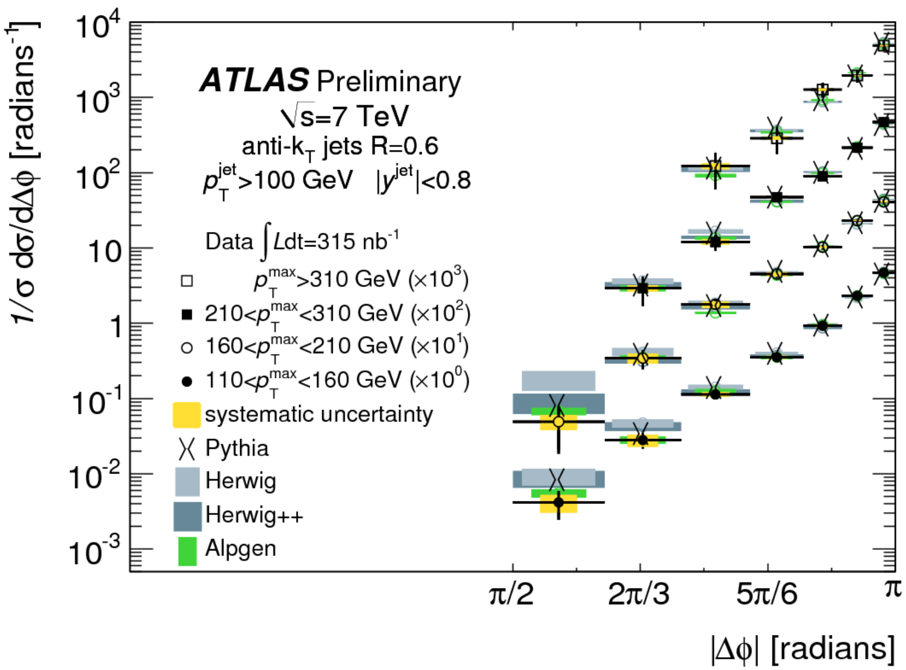
Azimuthal decorrelations in dijet events ($315\ nb^{-1}$)

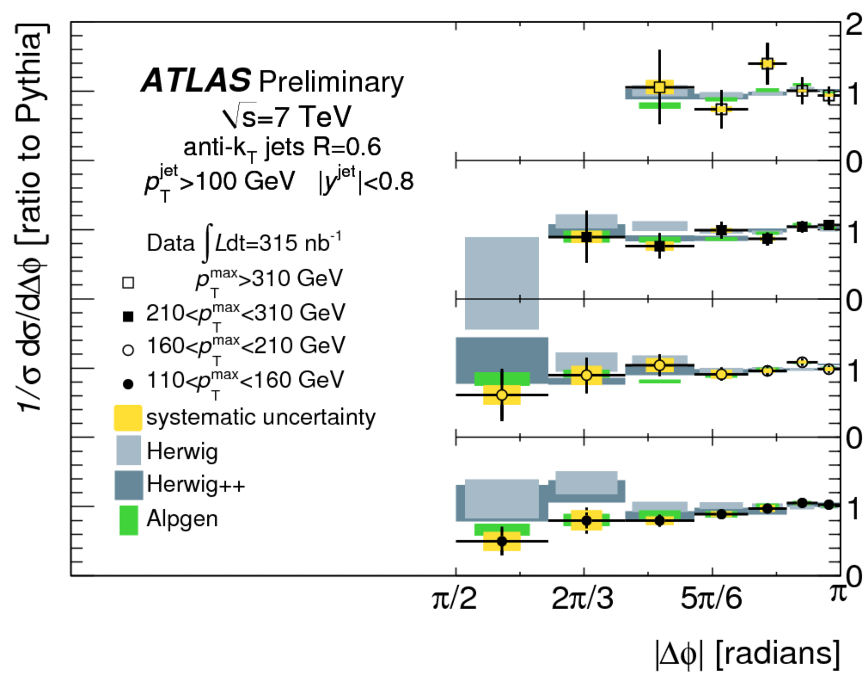
- QCD predicts how the azimuthal angle with respect to the beam axis (φ) between the two most energetic partons changes when additional radiation is produced.
- Dijet production at Leading Order results in two jets with equal p_T and correlated azimuthal angles such that the azimuthal angle between them, $\Delta\varphi$, is equal to π.
- The addition of soft radiation causes small azimuthal decorrelations with $\Delta\varphi \sim \pi$, whereas $\Delta\varphi << \pi$ is evidence of additional hard radiation:



Azimuthal decorrelations in dijet events (cont.)

- Differential cross section and ratio (in 4 regions) based on the pT of the leading jet, in compare with MC:

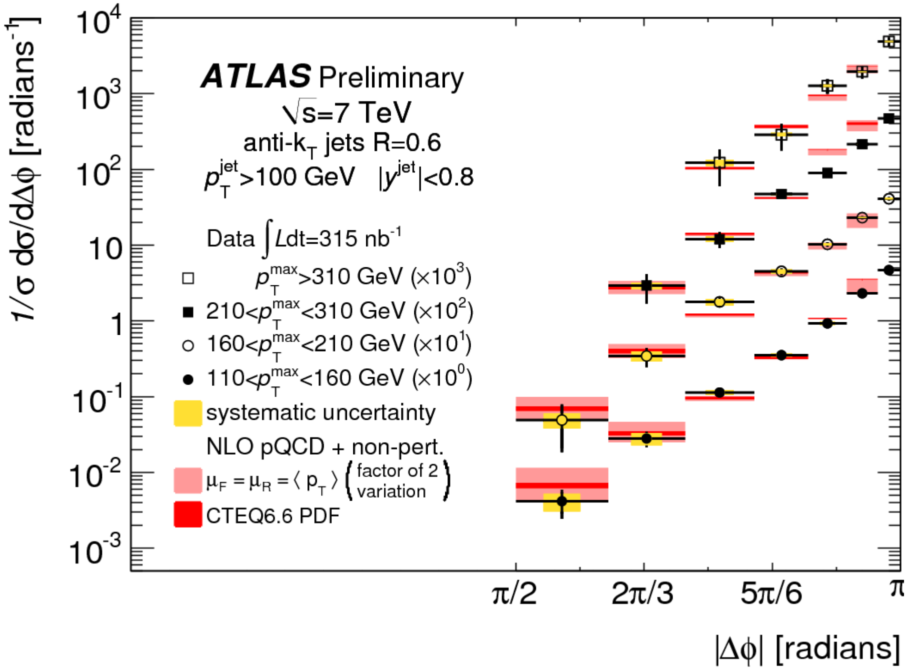


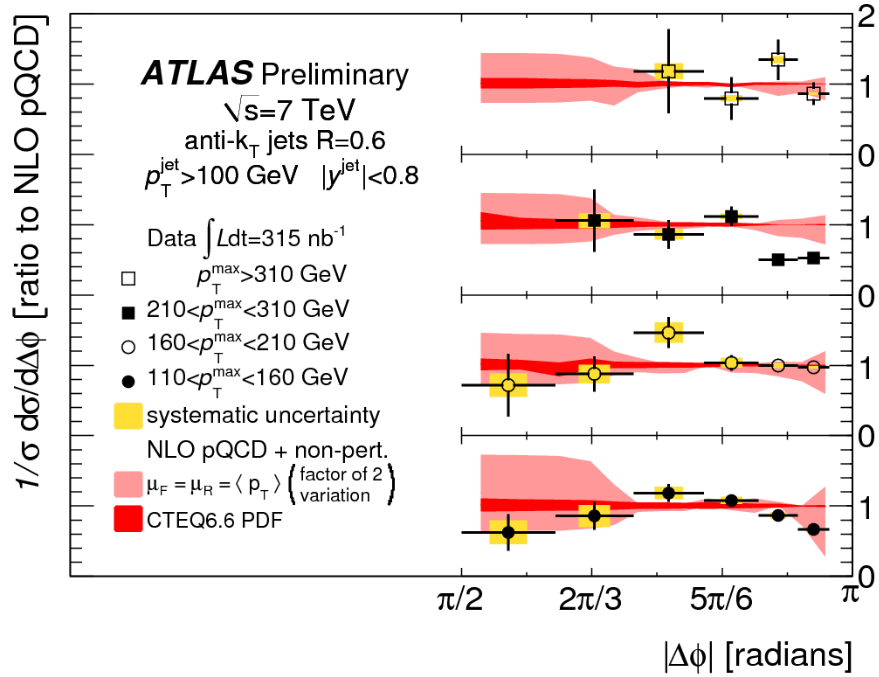


Good MC agreement

Azimuthal decorrelations in dijet events (cont.)

- Differential cross section and ratio (in 4 regions) based on the pT of the leading jet, in compare with NLO pQCD predictions :

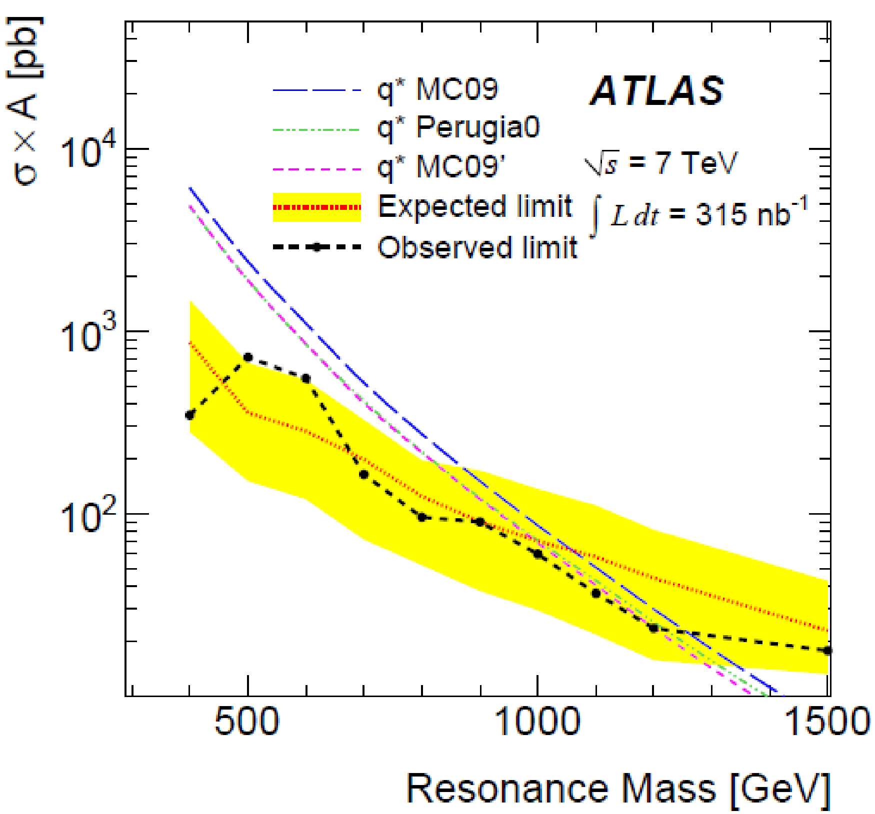


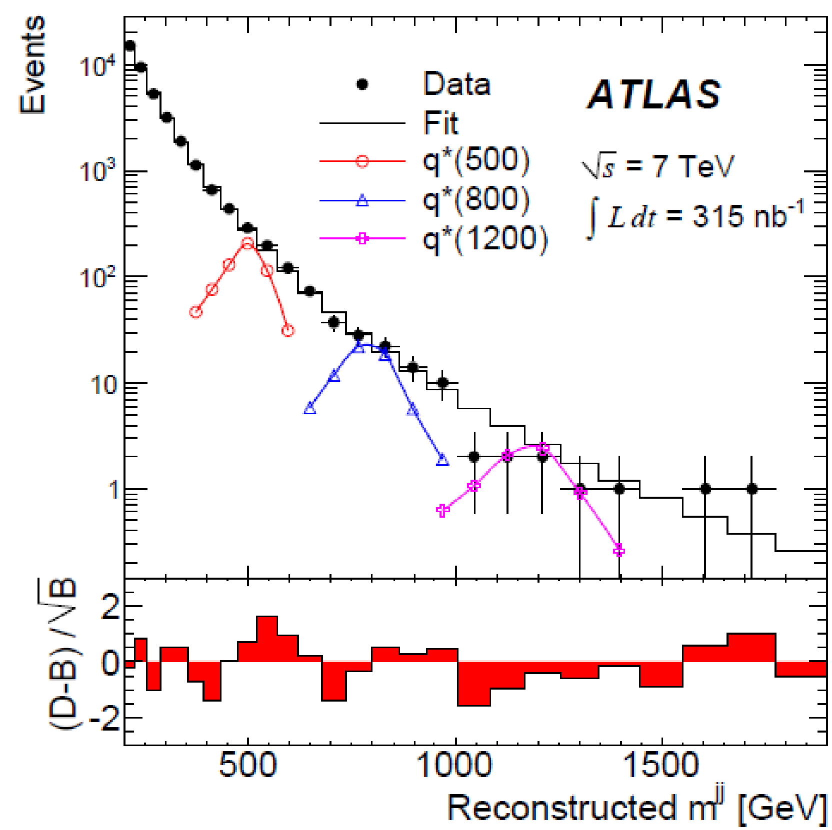


Again, good MC agreement

Search for new particles decaying in dijets

- Sensitive for possible new states in dijet resonances: excited quarks q*, Z', W', graviton and others
- Tevatron exclusion for q*: $260 < m_{q*} < 870$ *GeV* @ *95% CL*
- *New ATLAS limit:* $400 < m_{q*} < 1290$ *GeV* @ *95% CL* (more details here: http://arxiv.org/abs/1008.2461, paper submitted to PRL)





Summary for hard QCD

- Atlas has observed first events beyond $p_{T,jet}$ ~ 1 TeV and beyond $M_{1,2}$ ~ 2.5 TeV
- Based on the first data Atlas has measured the single inclusive jet cross section for 60< $p_{T,jet}$ <600 GeV and $|y| < 2.8$ using the anti-k_T jet clustering algorithm with R=0.4 and R=0.6
- Dijet cross sections have been measured as a function of the dijet mass and the scattering angle
- New limit is set for q* mass
- The data are consistent with a NLO QCD theory calculation
- Theory uncertainty about 10% (PDF and scale)
- Data uncertainty about 30-40% (driven by jet energy scale)
- Good calorimeter understanding and large data set will allow to reduce jet energy scale uncertainty

Quarkonia production

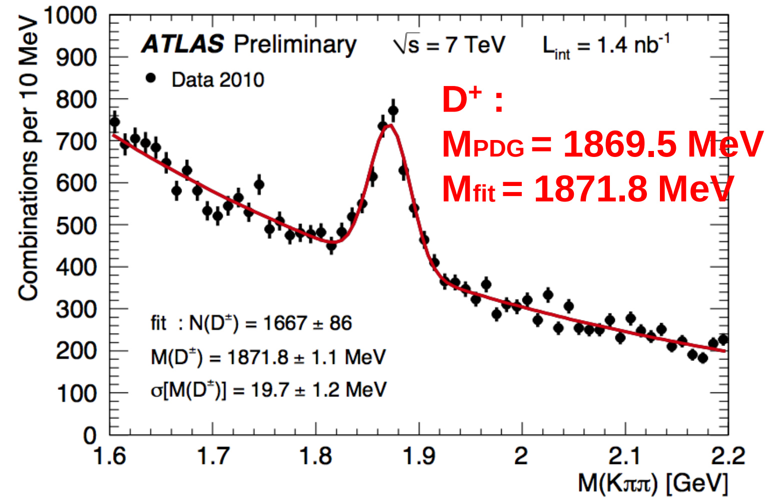
- Trigger strategy
- Open charm results
- J/ ψ production and performance
- B-physics plans

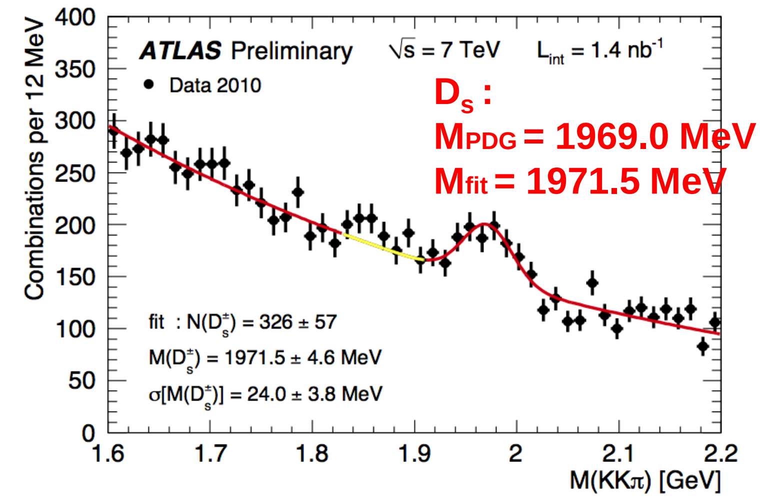
Trigger strategy for Onia and B-physics

- During the start-up period ($L<10^{28}cm^{-2}s^{-1}$) use minimum bias trigger (MBTS, >99.5% efficient for any track multiplicity, not prescaled)
- For $L\sim10^{28}cm^{-2}s^{-1}$, MBTS based High Level muon trigger ➔ study L1 muon efficiency (look for muon reconstructed at the Muon Spectrometer)
- For $L\sim10^{29}cm^{-2}s^{-1}$, L1 Muon trigger ➔ study dedicated B-triggers' efficiency (no requirement on muon p_T)
- For $L\sim10^{30}cm^{-2}s^{-1}$ and more the dedicated non-prescaled B-triggers are now in effect

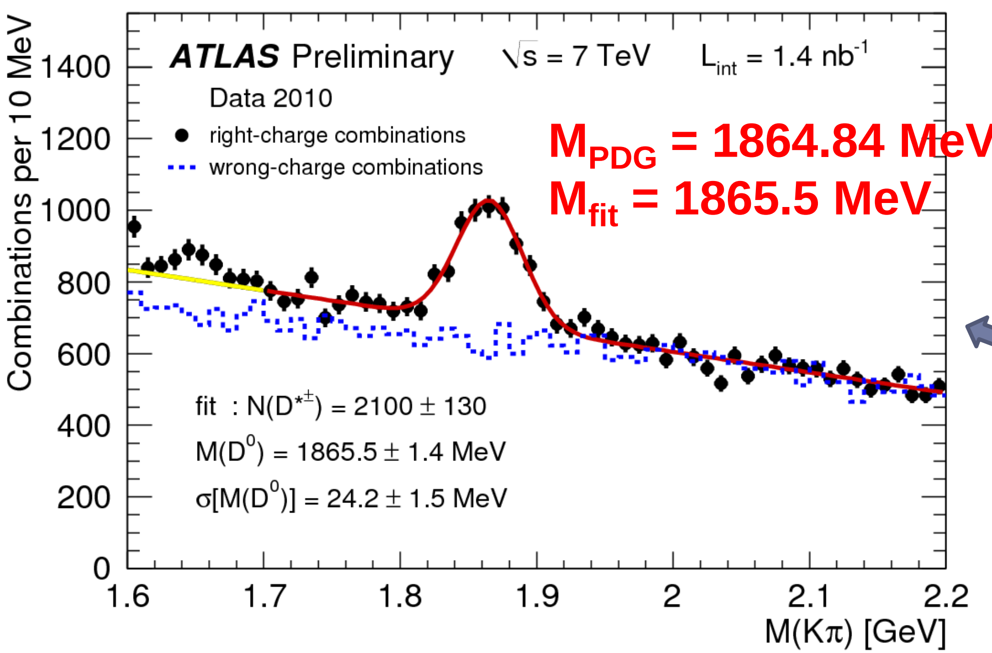
Observation of open charm in minimum bias events: $D^{*\pm} \rightarrow (K^-\pi^+)\pi_s^\pm$, $D^+ \rightarrow K^-\pi^+\pi^+$, $D_s^\pm \rightarrow \varphi(K^+K^-)\pi^\pm$

- Inclusive measurements for open charm production is feasible with the first data using D*
- Events with D* accompanied by a muon can provide a measurement of the bb/cc fraction: D*μ from b and c decays (++/--)/(+-)





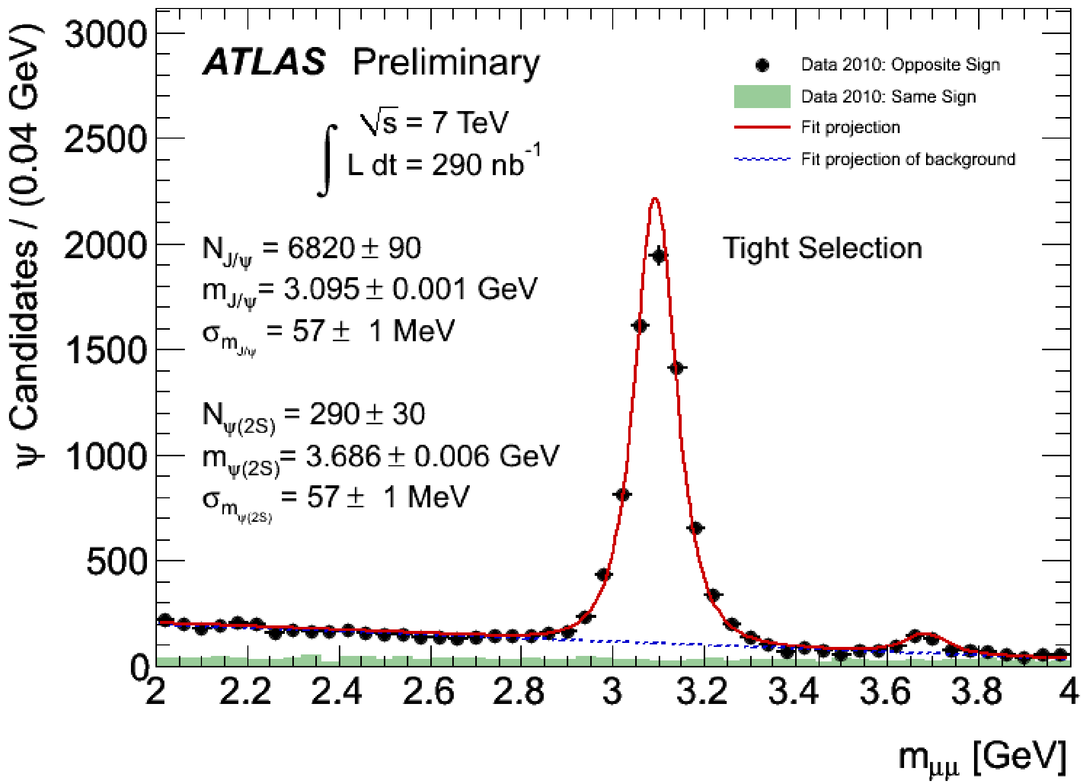
D* satisfying 1.83<M(Kπ)<1.90 GeV



Reconstruct D* from $D^0\pi$ decays
p_T (K, π) > 1 GeV
p_T of soft pions > 0.25 GeV
Positive decay length
ΔM (Kππ)-(Kπ) > 140 MeV

J/ψ candidate reconstruction

- Clear J/ψ peak visible above background
- $p_{T\mu 1}$>2.5 GeV, $p_{T\mu 2}$>4 GeV, $|\eta_\mu|$<2.7,
- Background dominated by fake muons, decays in flight, heavy flavour decays
- Unbinned maximum likelihood fit used to fit background and signal in data/MC



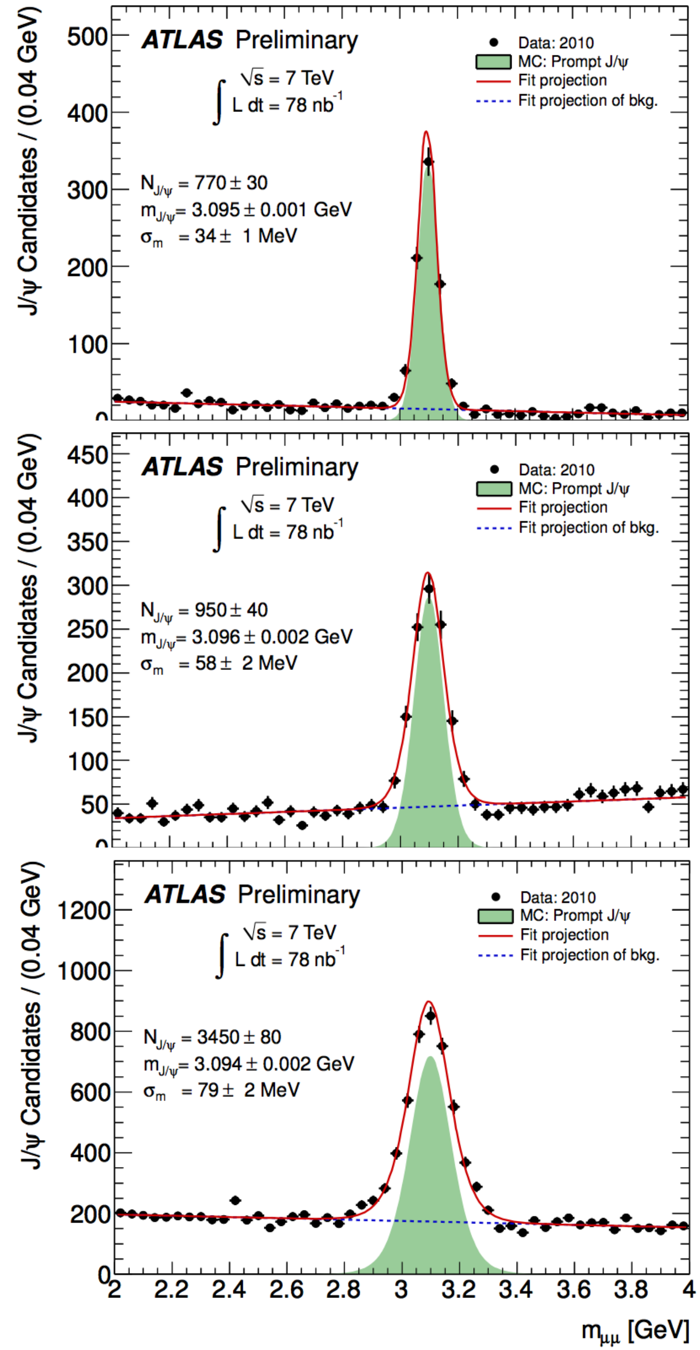
Mass and resolution in good agreement with PDG and MC

$M(J/\psi)_{PDG}$ = 3.097 GeV
$M(J/\psi)_{data}$ = 3.095 0.001 GeV

J/ψ candidate performance

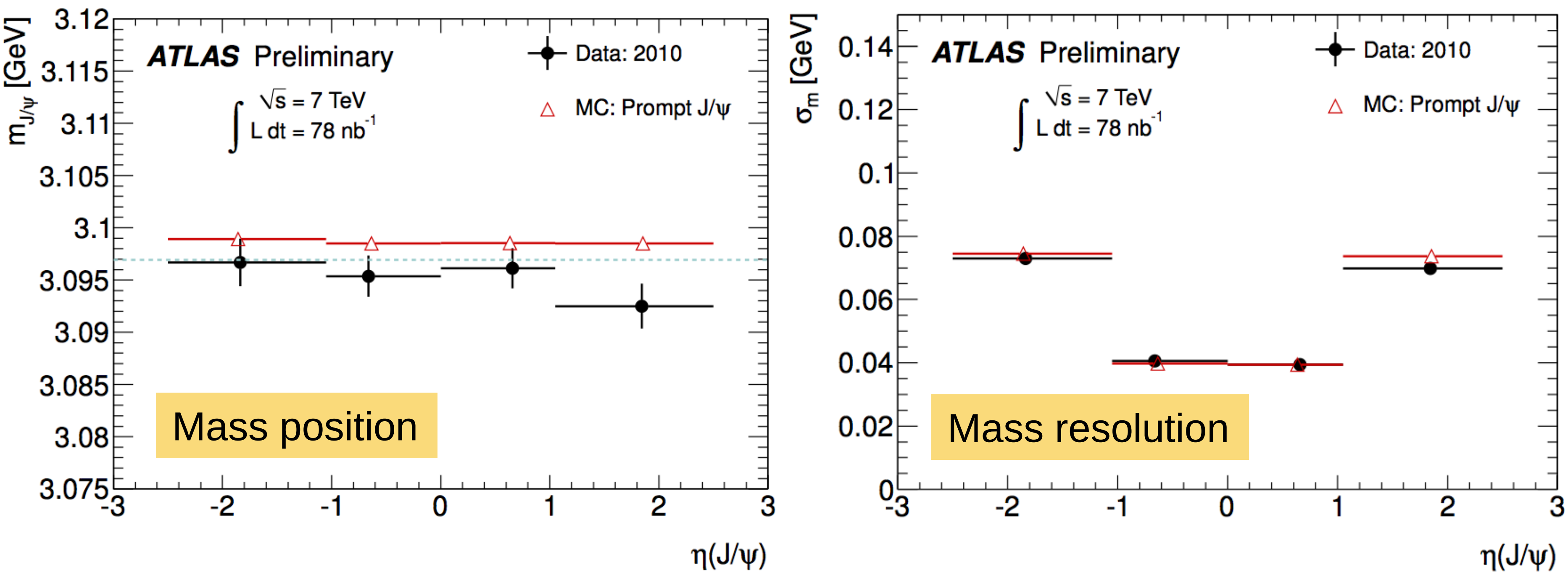
- J/ψ mass resolution dependent on muon η (as per MC predictions) due to detector resolution, material and magnetic field effects
- Divide J/ψ candidates into three categories:
  - Both muons in barrel (|η|<1.05) (BB)
  - Both muons in endcap (1.05<|η|<2.5) (EE)
  - One muon in barrel, one in endcap (EB)
- Again good agreement with MC predictions is observed

	BB	EB	EE
$M_{J/\psi}$ (GeV)	3.095±0.001	3.096±0.002	3.094±0.002
σ_M (MeV)	34±1	58±2	79±2
N_{sig}	770±30	950±40	3450±80
$N_{bkg}(\pm 3\sigma)$	80±10	410±20	2050±60
Scale factor	1.12±0.04	1.21±0.05	1.18±0.03

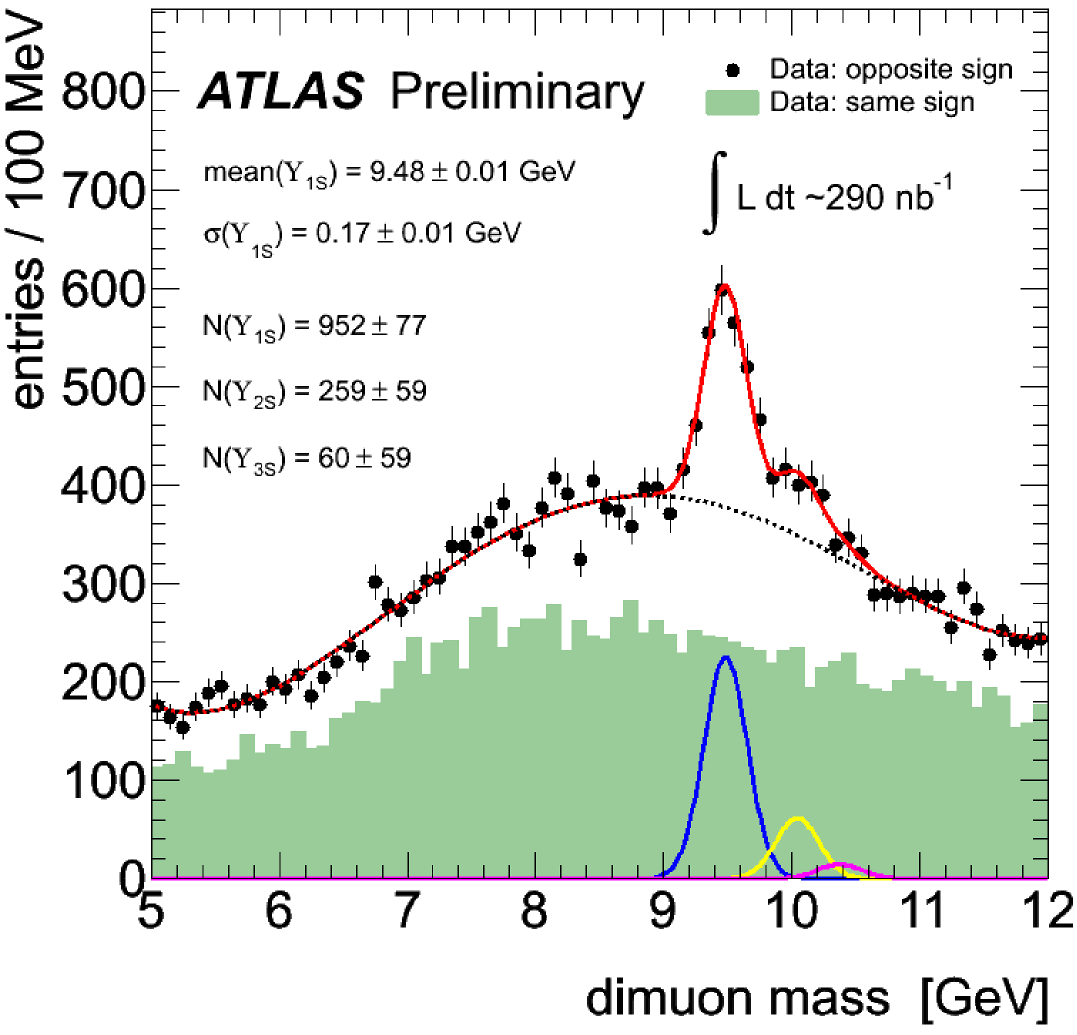


J/ψ performance – mass shifts and resolution

- Use J/ψ mass shift and resolution to study the detector and reconstruction: misalignment, magnetic field distortion, material mapping issues, algorithm performance problems



Υ(1s,2s,3s)→μμ candidates



Level1 muon trigger with no p_T cut

Cuts on muons:
2.5 and 4 GeV

Open charm and Onia summary

- Signals from $D^{*\pm}$, $D^{\pm}$ and $D_s^{\pm}$ observed by the ATLAS detector with 1.4 nb^{-1} integrated luminosity
  - Signal yields: $D^{*\pm}$ (2020±120); $D^{\pm}$(1667±86); $D_s^{\pm}$(326±57)
  - Good agreement with PDG in reconstructed mass position
- J/ψ signal has been observed
  - Excellent agreement with MC predictions and PDG mass position
  - Now have enough statistics (6820±90) in peak with 290 nb^{-1} data for performance studies
- Studies of these particles show tracking, vertexing and muon system working well, and in line with expectation
- Expect to be making first ratio and differential production cross-section measurements shortly, with a strong program of measurements into the charmonium production mechanism to follow

ATLAS B-physics program

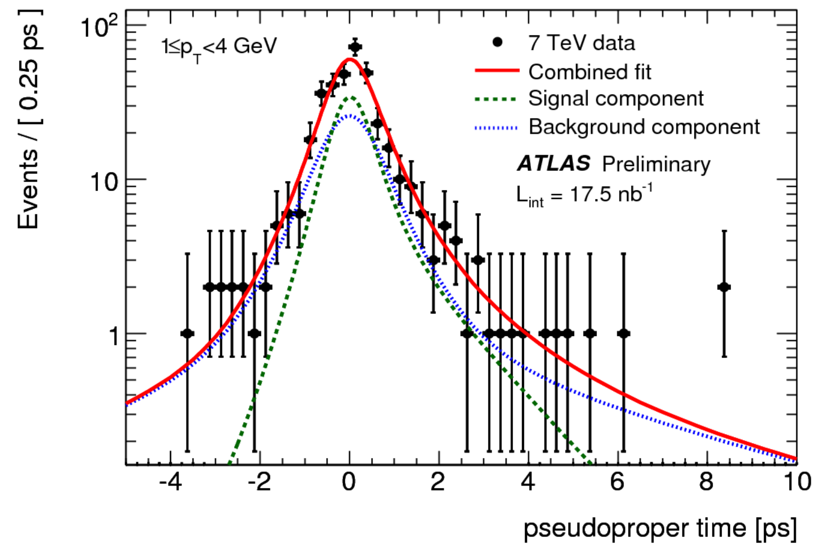
- From now to 10 pb^{-1} : $B^+ \rightarrow J/\psi(\mu\mu)K^+$ decay. Reference channel for many analyses. Measure total and differential cross section
- 1fb^{-1} : $B_s \rightarrow J/\psi\phi$ decay. Study of weak mixing phase ϕ_s (small in SM, may be increased by BSM processes)
- 10fb^{-1} and more: $B_s \rightarrow \mu\mu$ decay. FCNC, suppressed in SM, sensitive to New Physics through new particles in loops.

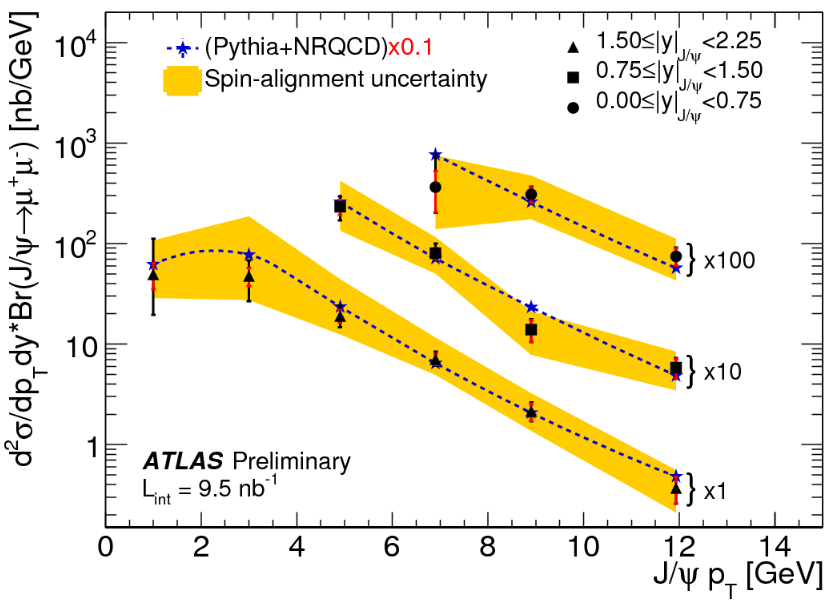
Thank you!

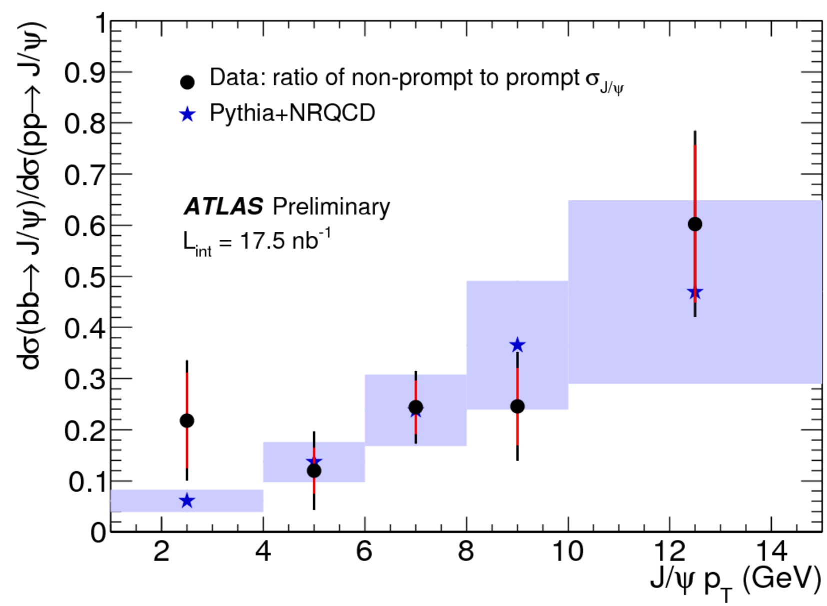
Backup

J/ψ cross section and ratio non-prompt/prompt

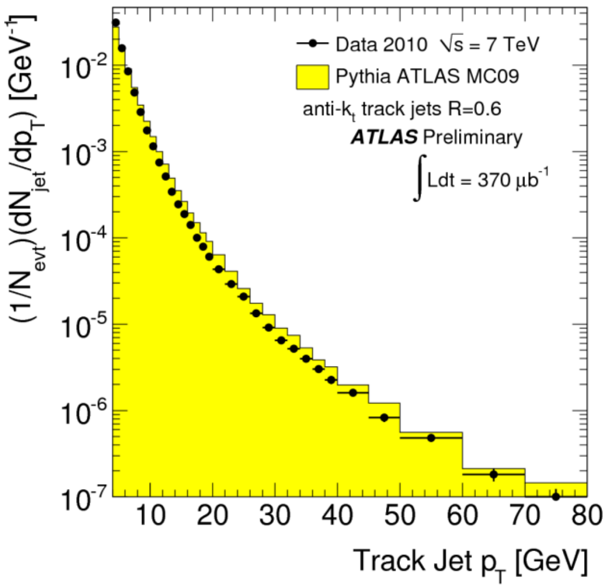
- D.-d. Inclusive cross section is measured,
  - $0<p_T<15$GeV, $|y|<2.25$
- The absolute cross section prediction from the Monte Carlo is an order of magnitude higher than the data; shape predictions are in a good agreement with MC
- Ratio J/ψ(bb)/ J/ψ(pp) is measured
- For average y=1.85, the s.-d. cross section:
  - $d\sigma/dy \times Br(J/\Psi \to \mu\mu)(250^{+130}_{-80})$ nb

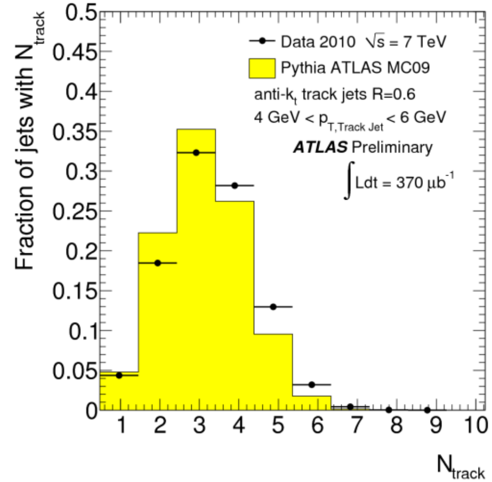


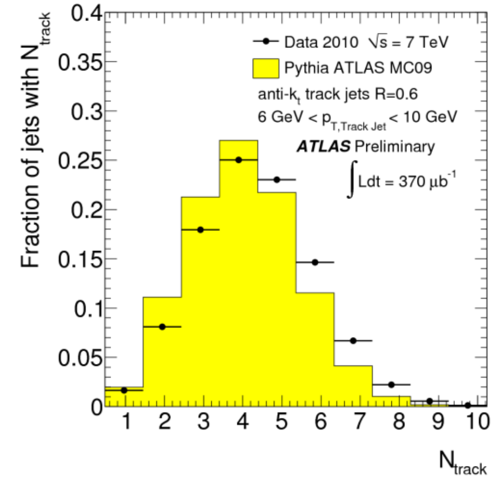




Jet tracks p_T distribution and multiplicity







Multiplicities for p_T region (4 – 80) GeV