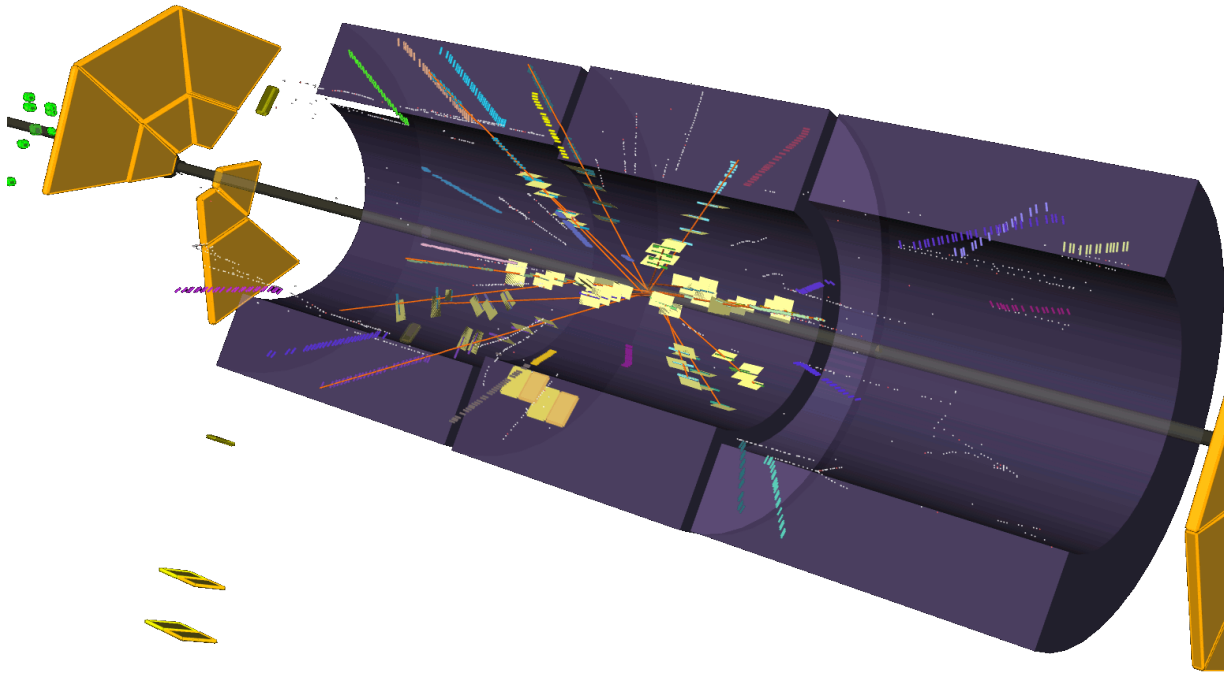
Minimum bias and soft QCD ATLAS Results @ 0.9 and 7 TeV



Roberto Di Nardo

University & INFN Roma Tor Vergata,

On behalf of the ATLAS Collaboration

LC10 Workshop, INFN LNF - 1 December 2010

Introduction

- ATLAS at LHC is a general purpose experiment:
  - Main physics goal are: Higgs Boson searches, SUSY, new Heavy Bosons, extradimension…
- At the LHC start, in a low luminosity regime, the properties of Minimum Bias events have been investigated, since they are crucial for understanding high-p_T physics.
- Moreover, the study of identified particle is important from the physics point of view, but also to evaluate the tracking performance and calibrate the detector.
  - Tuning MC generators
  - Compare the production in proton-proton and Heavy Ion collision
  - Tracking reconstruction and efficiency, momentum scale
  - Secondary vertexing and tracking for long-lived particles
  - dE/dx validation
  - Alignment

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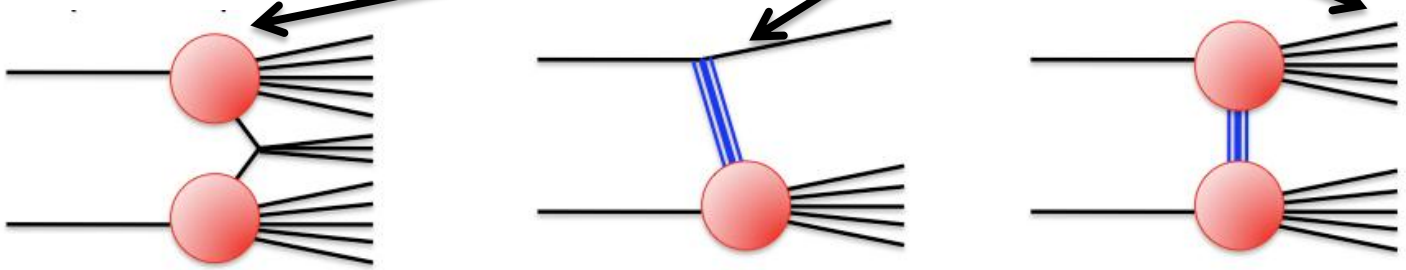
Minimum Bias Events

$$\sigma_{tot} = \sigma_{EL} + \sigma_{ND} + \sigma_{SD} + \sigma_{DD}$$



Non-Diffractive (~50 mb) @7TeV

Single-Diffractive (~14 mb) @7TeV

Double-Diffractive (~9 mb) @7TeV

- Soft QCD processes are unavoidable background to all collider observables (in particular jet cross-section, missing energy, isolation cuts...)
- Not well understood since non-perturbative physics is involved.
- Soft QCD distributions have to be used to test the phenomenological models and "tune" the Monte-Carlo event generators to give the best description of the data.
  - Visible effect in the tuning also at high-p_T (e.g. colour reconnection)

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Outline

- The ATLAS experiment and the Inner Detector
- Reconstruction of known particles in Minimum Bias Events
- Charged particle multiplicity spectra
- Underlying event measurement
- Angular correlations between charged particles
  - New observable to probe different MB physics models

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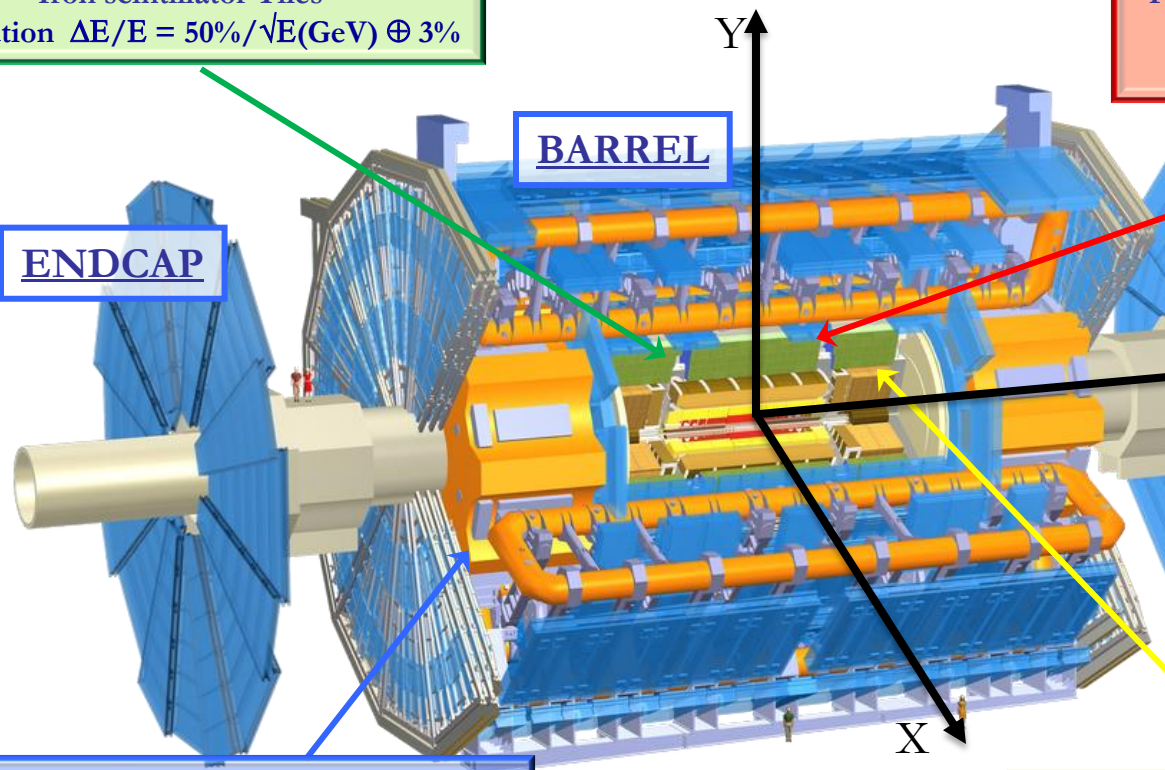
The ATLAS Experiment

ADRONIC CALORIMETER:
Iron scintillator Tiles
Resolution $\Delta E/E = 50\%/\sqrt{E(GeV)} \oplus 3\%$

INNER TRACKER:
PIXEL (σ_R=10μm), SCT (σ_R=17μm), TRT (σ_R=50μm), in 2T soleinodal magnetic field



Diameter = 22 m
Lenght= 46 m

MUON SPECTROMETER:
3 Toroidal magnetic fiield(1 barrel,2 endcap)
MDT, RPC nel barrel
MDT, TGC , CSC endcap

EM CALORIMETER:
Alternate layers Pb-LAr
Resolution $\Delta E/E = 10\%/\sqrt{E(GeV)} \oplus$
$\oplus 0.5\%/E\ (GeV) \oplus 0.7\%$

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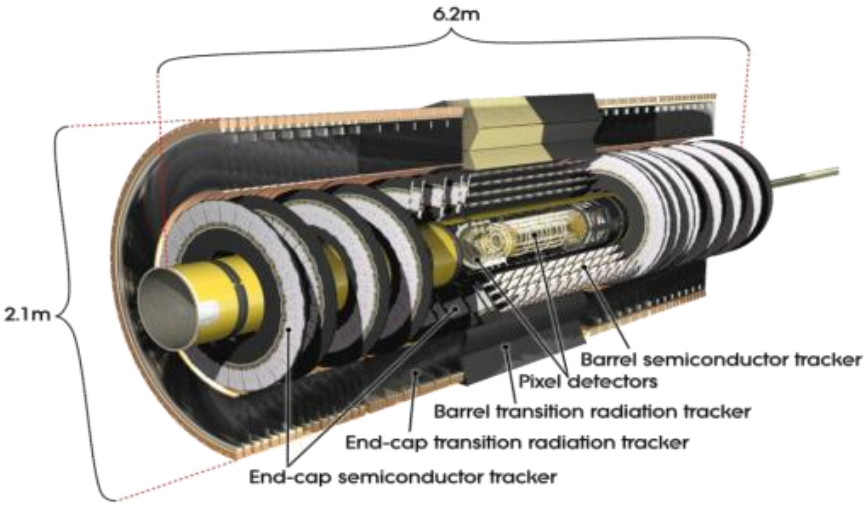
Inner Detector and MB trigger



- Covers $|\eta|<2.5$ with 3 subdetectors
- Pixel detector (Silicon Modules)
  - 1774 modules, ~80 M channels
  - Resolutions: ~10 μm (rφ) – ~115 μm (rz)
- SCT detector (Silicon Strip)
  - 4088 modules, ~6.3 M channels
  - Resolutions ~ 17 μm (rφ) – ~580 μm (rz)
- TRT detector (straw drift tubes, $|\eta|<2$)
  - 176 modules, ~0.4 M channels
  - Intrinsic tube resolution ~130 μm (rφ)
  - $e^{+/-}$PID by detection of transition radiation γ

Minimum Bias Trigger Scintillator (MBTS)

- Inside the endcap calorimeters
- 3.6m from interaction point
- Coverage $2.1<|\eta|<3.8$ in 2 disks

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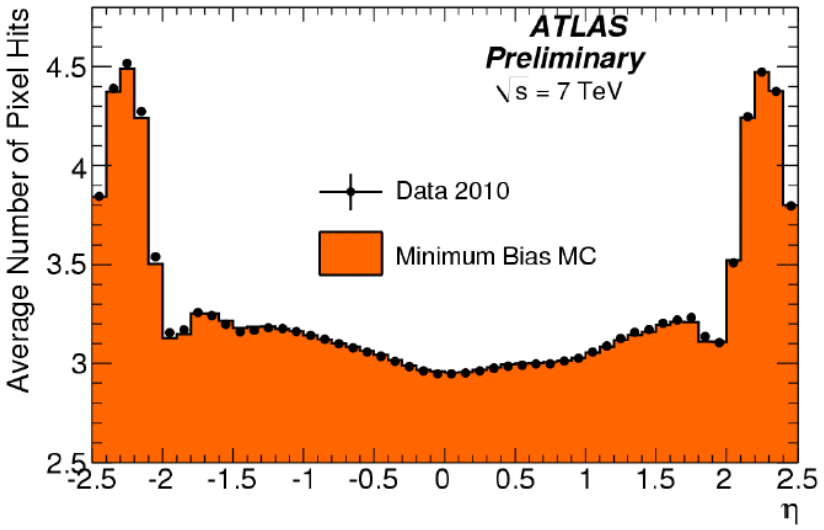
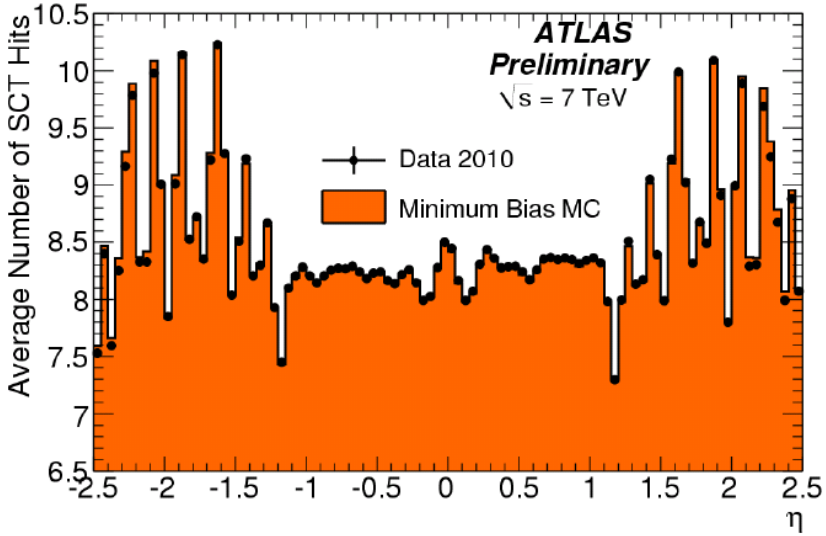
Detector performances

- Good data/MC agreement in the comparison of the average number of silicon hits on track





- Uncertainty in the detector material description in simulation→ largest systematic uncertainties in the measurement
  - 10 % material uncertainty reflects into 3% difference in the efficiency

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Known particle reconstruction

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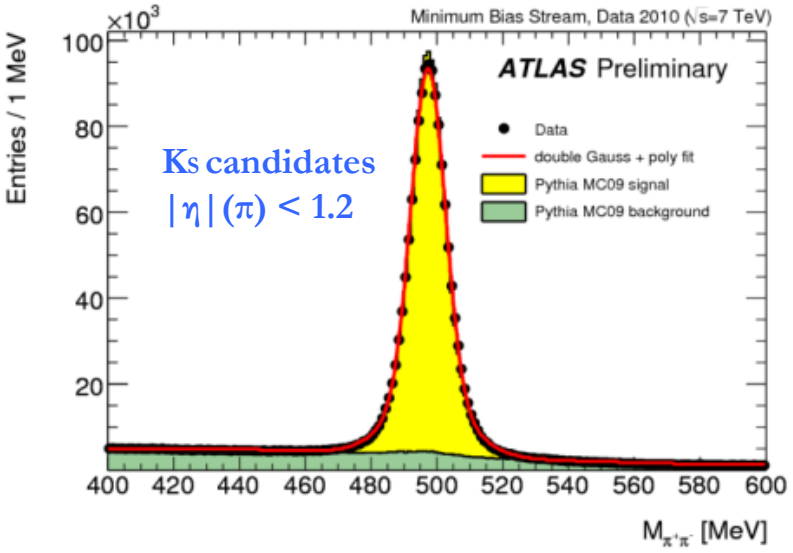
K^0_s and Λ^0 reconstruction

- ~190 μb^{-1} of 7 TeV minimum-bias collision data compared with non-diffractive minimum bias simulation (Pythia ATLAS MC09 tune)
- MC signal and background adjusted separately to match signal/background ratio in data
- Pre-selection: tracks with opposite charge, p_T>100MeV , at least 2 silicon hit (Pixel +SCT)

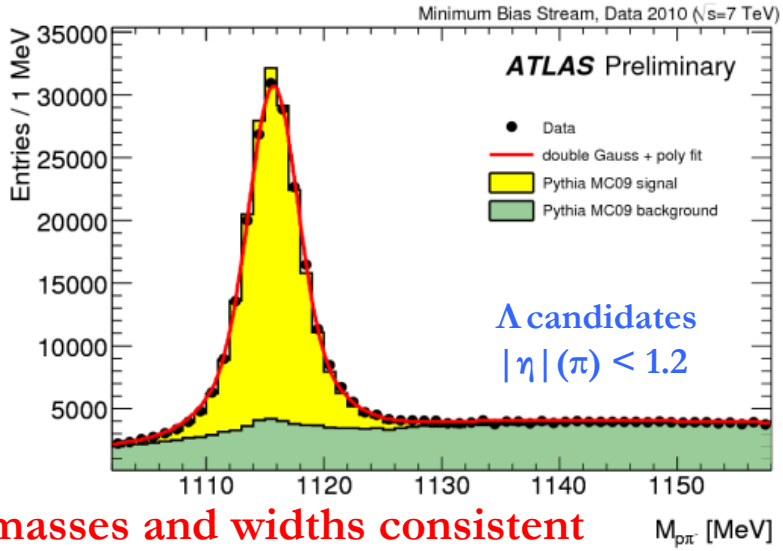
$K^0_s \rightarrow \pi^+\pi^-$ ($c\tau$=2.7cm, BF~69%)

- Transverse Flight Distance > 4 mm
- $Cos(\theta_k)$> 0.999
  - Angle between momentum and flight direction



$\Lambda \rightarrow p^+\pi^-$ + c.c.($c\tau$=7.9cm, BF~64%)

- Flight Distance > 30 mm
- $Cos(\theta_k)$> 0.9998



Fitted masses and widths consistent with MC and PDG mass values

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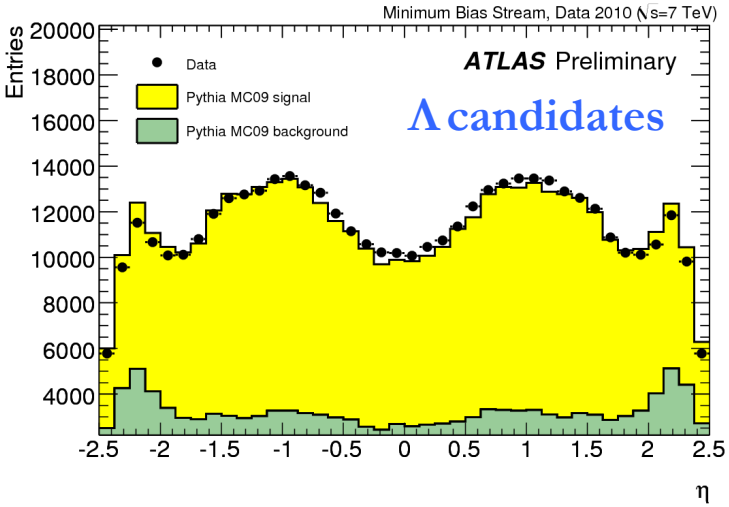
η for K^0_s , Λ and $\bar{\Lambda}$ candidates

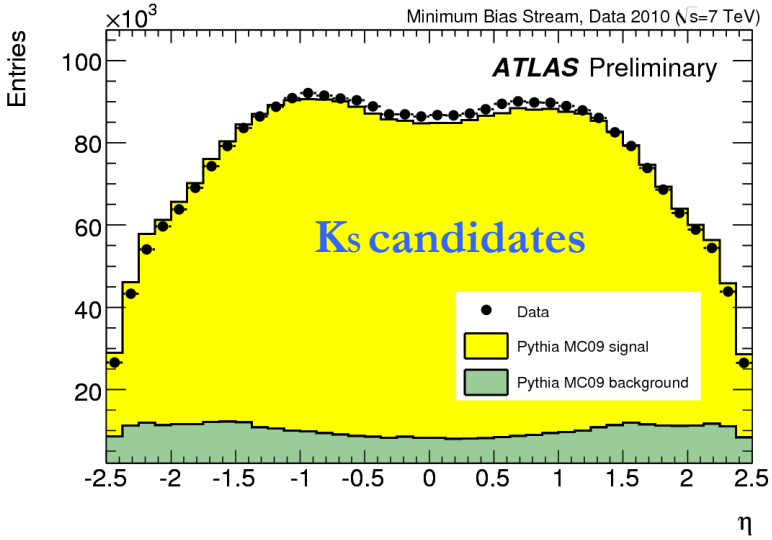
- No Correction for detector effect applied

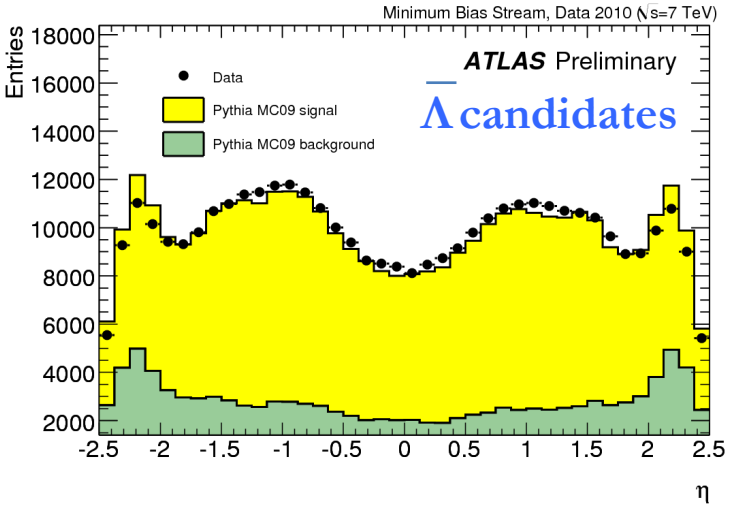
Candidates definitions

- $|M(K_s)-M(K_{PDG})| < 20$ MeV
- $|M(\Lambda)-M(\Lambda_{PDG})| < 7$ MeV

- MC consistent with data within 10%







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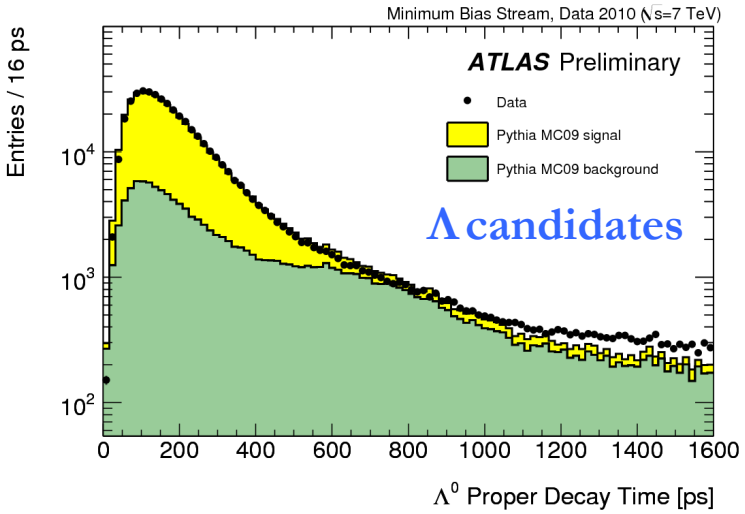
Proper decay time for K^0_s , Λ and $\bar{\Lambda}$

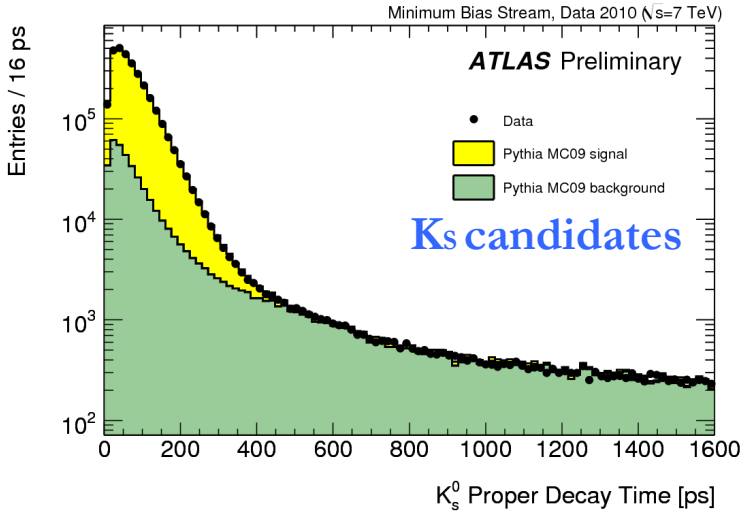
- No Correction for detector effect applied

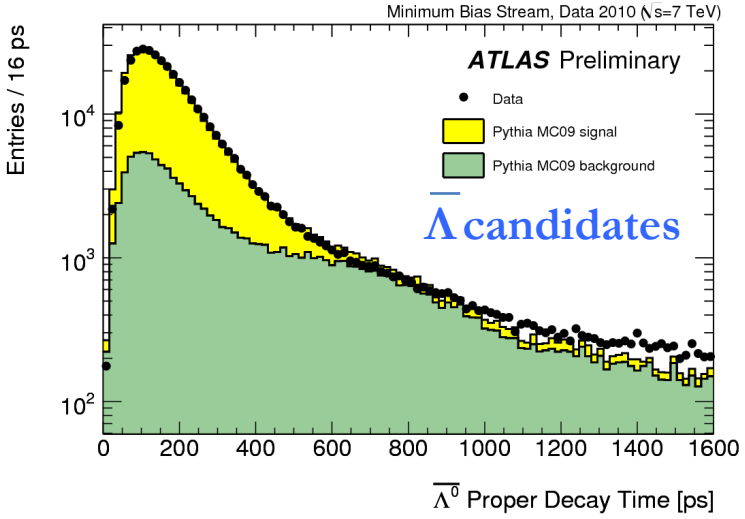
Candidates definitions

- $|M(K_s)-M(K_{PDG})|<20$ MeV
- $|M(\Lambda)-M(\Lambda_{PDG})|<7$ MeV

- MC in good agreement with data
  - Worts in background dominated region for Λ and $\bar{\Lambda}$







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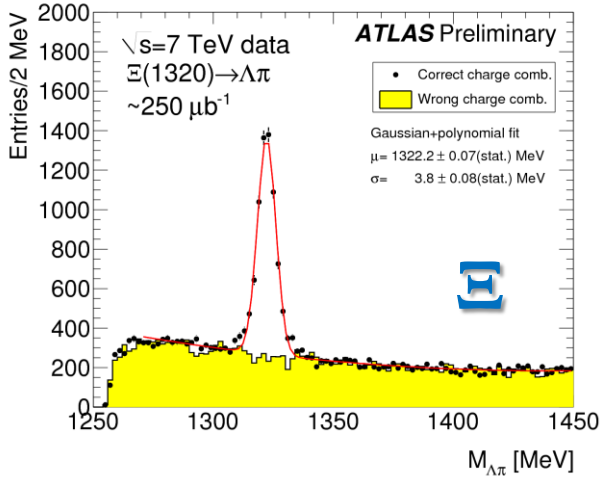
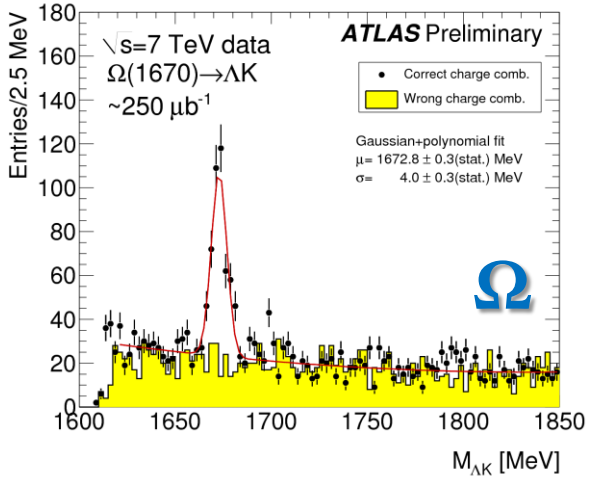
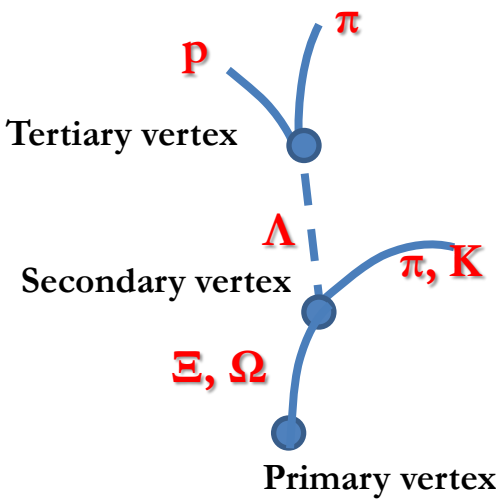
Not only K^0_s and Λ

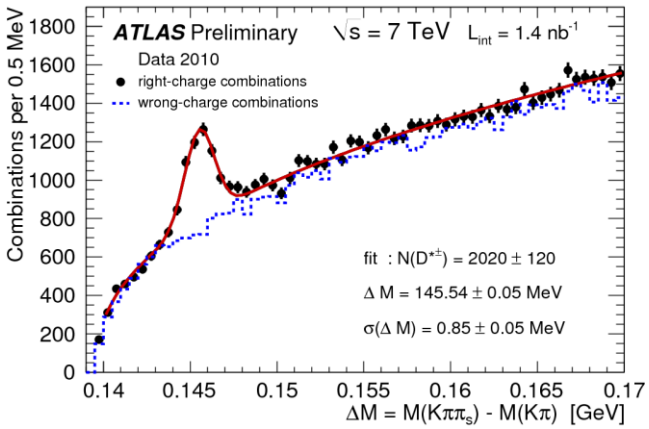
$\Xi^- \rightarrow \Lambda\pi^-$ + c.c. and $\Omega^- \rightarrow \Lambda K^-$ + c.c.

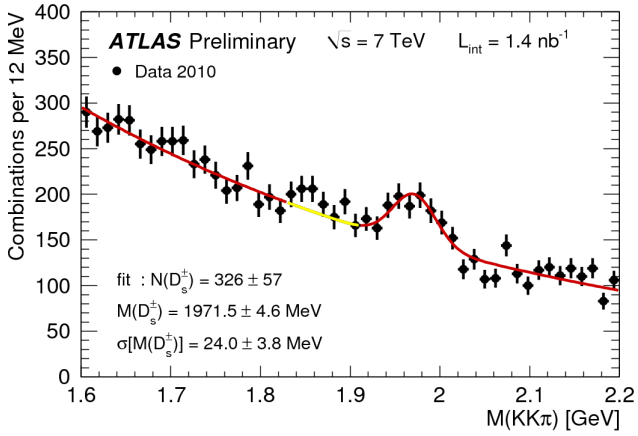






$D^{*+} \rightarrow D^0 (K^-\pi^+)\pi_s^+$ + c.c. and $D_s^+ \rightarrow \Phi(K^+K^-)\,\pi^+$





Fitted masses and widths consistent with MC and PDG mass values

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Charged particle multiplicity spectra

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Dataset and Event Selection

The Datasets:

- $\sqrt{s}$=0.9 TeV (~7 μb-1): 360k events, 4.5M tracks
- $\sqrt{s}$=7 TeV (~190 μb-1): 10M events, 210M tracks

The Event Selection:

- MBTS single-cell trigger in coincidence with the BPTX (beam pickup)
- 1 Vertex reconstructed
  - 2 tracks + Beam Spot
  - No pileup (seconadry vtx with >3 tracks)

Most inclusive

- ≥2 good tracks
- p_T > 100 MeV ; $|\eta| \leq 2.5$
- Additional tracking algorithm at low p_T

Negligible diffractive contribution

- ≥6 good tracks
- p_T > 500 MeV ; $|\eta| \leq 2.5$
- Additional tracking algorithm at low p_T

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Correction procedure

- Event-wise correction for trigger and vertex efficiencies

$$w_{ev}\left(n_{sel}^{BS}\right)=\frac{1}{\varepsilon_{trig}\left(n_{sel}^{BS}\right)}\cdot\frac{1}{\varepsilon_{vertex}\left(n_{sel}^{BS}\right)}$$

n_{sel}^{BS}: number of tracks; cuts as close to final selection as possible without a vertex

- Track-wise correction (e.g. tracking efficiency)

$$w_{ev}\left(p_T,\eta\right)=\frac{1}{\varepsilon_{trk}\left(p_T,\eta\right)}\cdot\left(1-f_{Sec}\left(p_T,\eta\right)\right)\cdot\left(1-f_{okr}\left(p_T,\eta\right)\right)$$

Fraction of tracks out of kinematic range

Fraction of secondaries

- Takes in to account secondary contamination and tracks out of kinematic range
  - e.g. Track p_T<100 MeV but particle p_T>100 MeV
- N_{ch} and p_T both corrected using a Bayesian unfolding
- $\langle p_T \rangle$ vs n_{ch} → bin-by-bin correction of average p_T and the n_{ch} migration

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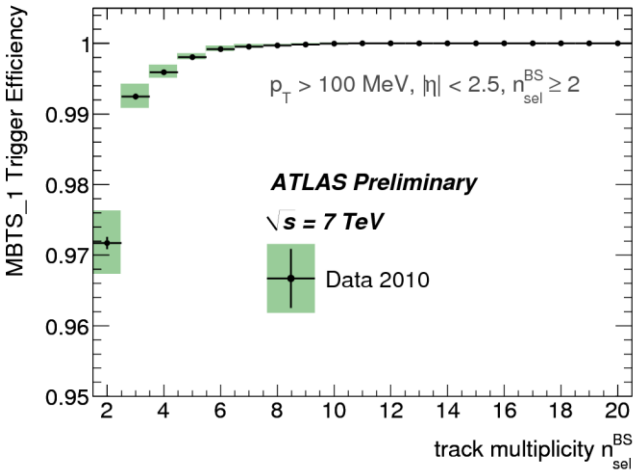
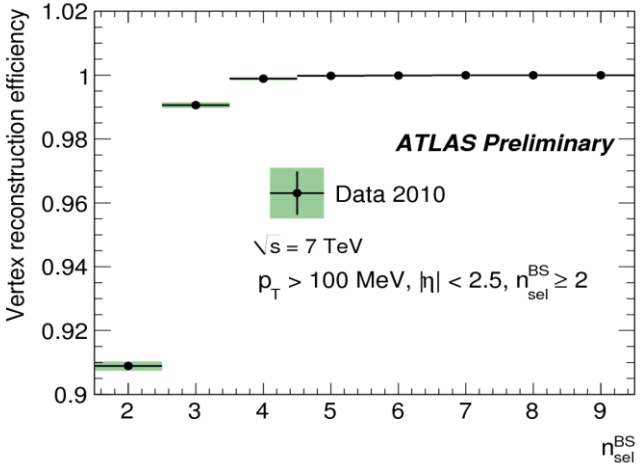
Efficiencies

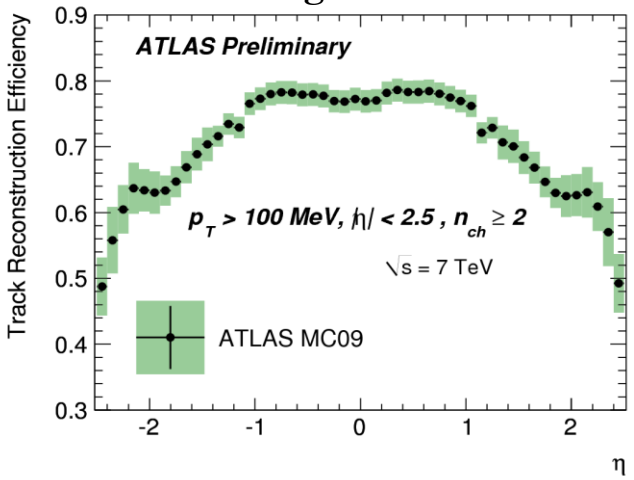
ε_{trig} **Trigger efficiency** from data using orthogonal trigger

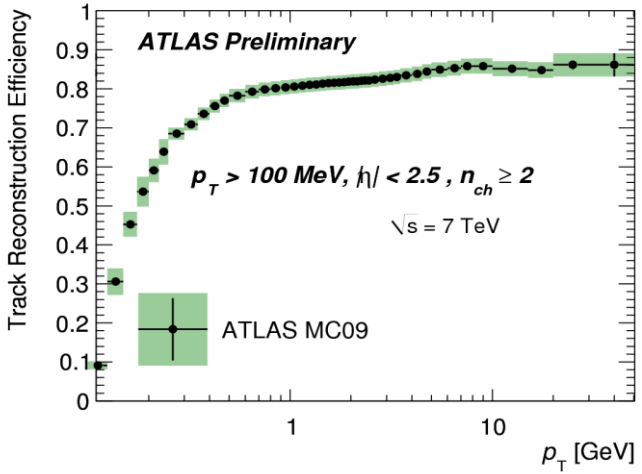


ε_{vtx} **Vertex efficiency** measured from data



ε_{trk} **Tracking efficiency** from MC – systematic dominated by knowledge of material budget





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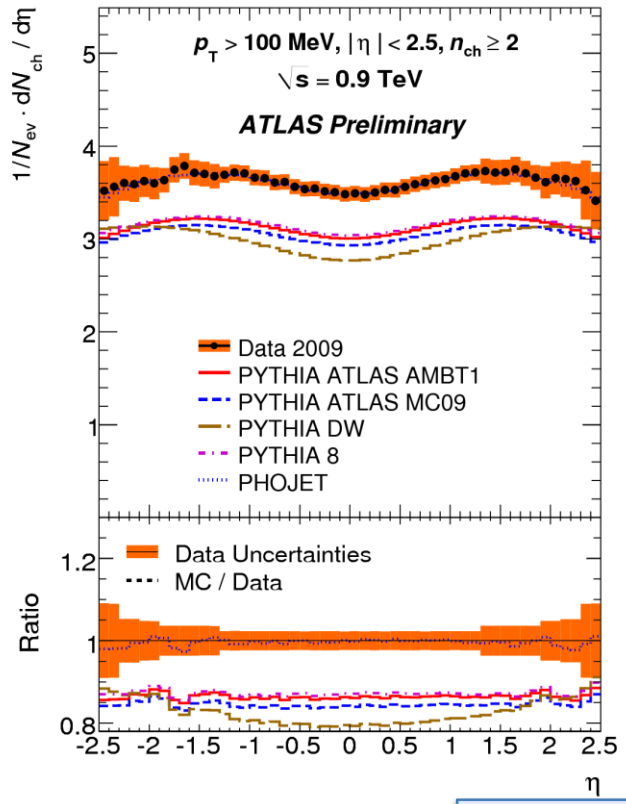
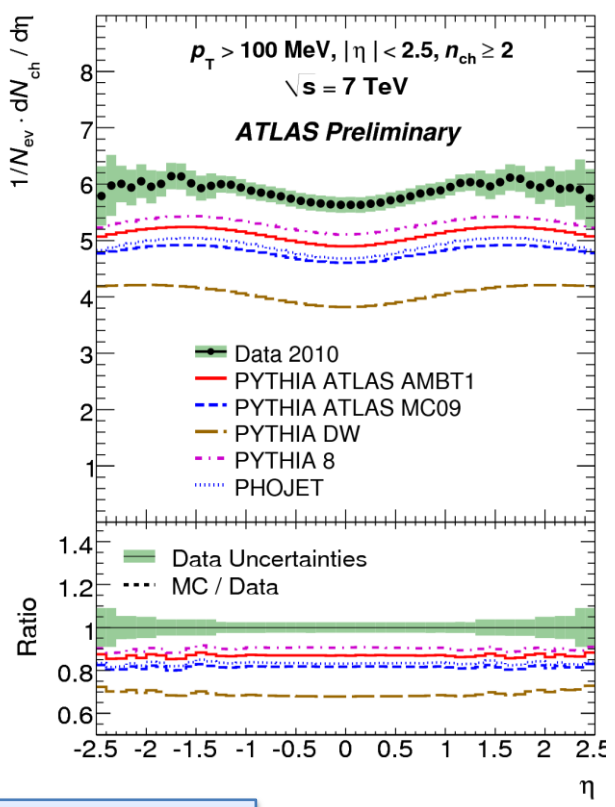
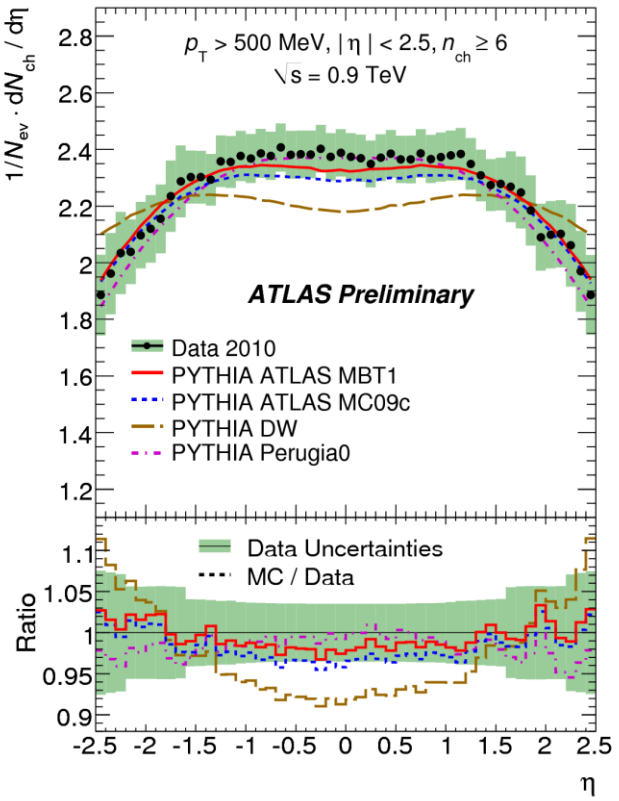
$1/N_{ev} dN_{ch}/d\eta$

- Different models differ in normalization but the shape are almost similar
  - Track multiplicity underestimated.
  - Very little shape variation between models
- $n_{ch} \geq 6$, pT>500MeV measurement used in AMBT1 tune

gata







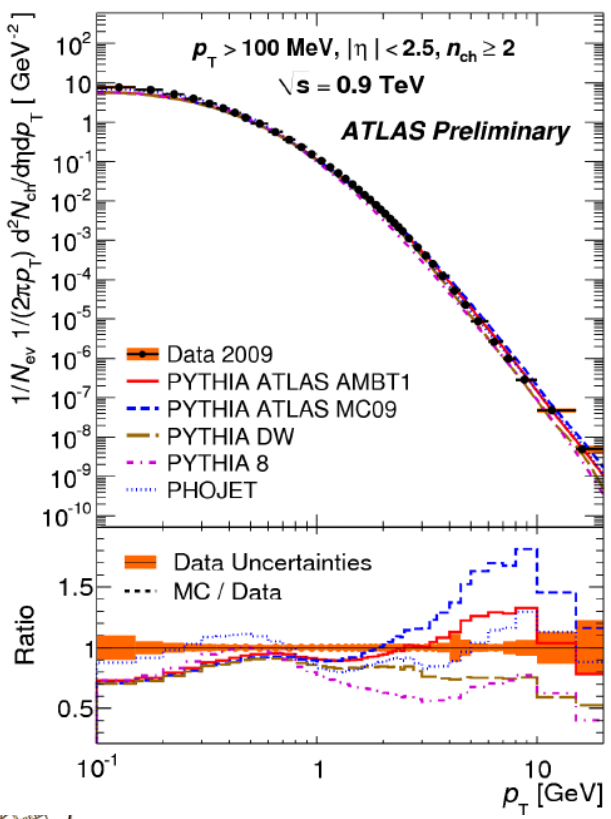
$n_{ch} \geq 2$, p_T>100MeV

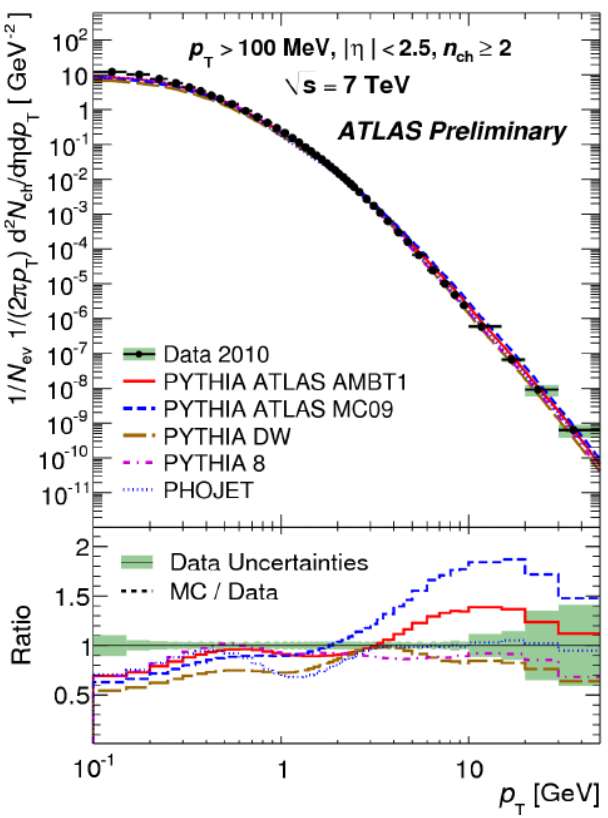
$n_{ch} \geq 6$, p_T>500MeV

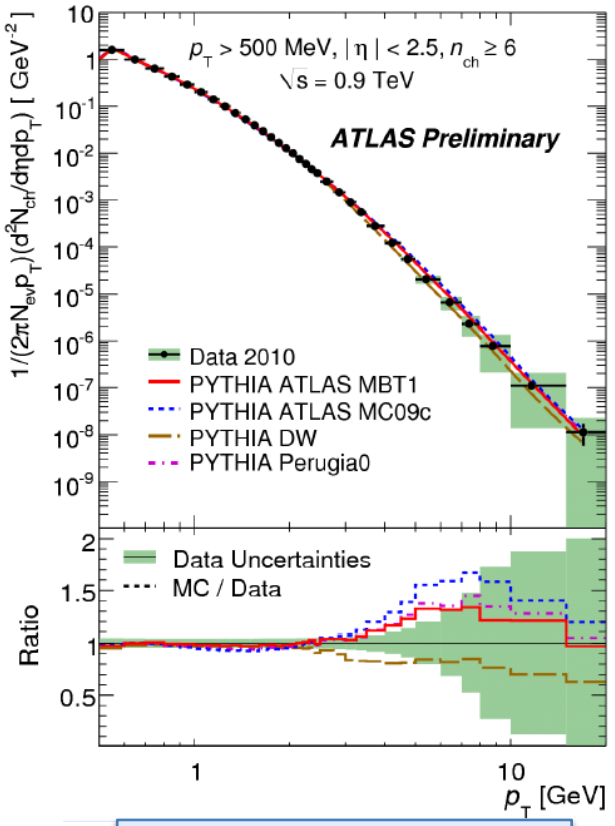
$1/(2\pi p_T)1/N_{ev}d^2N_{ch}/d\eta dp_T$

- Measurement spans 10 orders of magnitude
- Large disagreement at low p_T and high p_T
- Improvement at medium p_T for AMBT1 tune

rgata







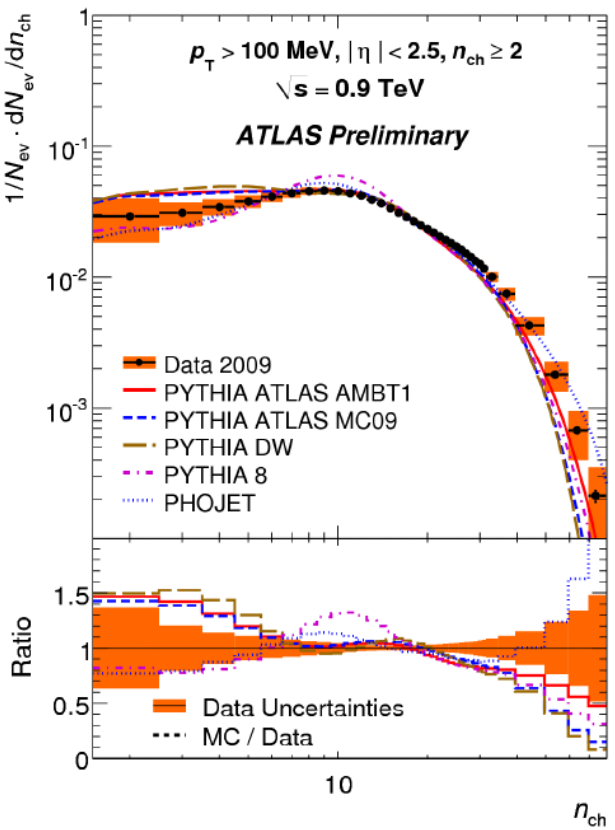
$n_{ch}\geq 2$, p_T>100MeV

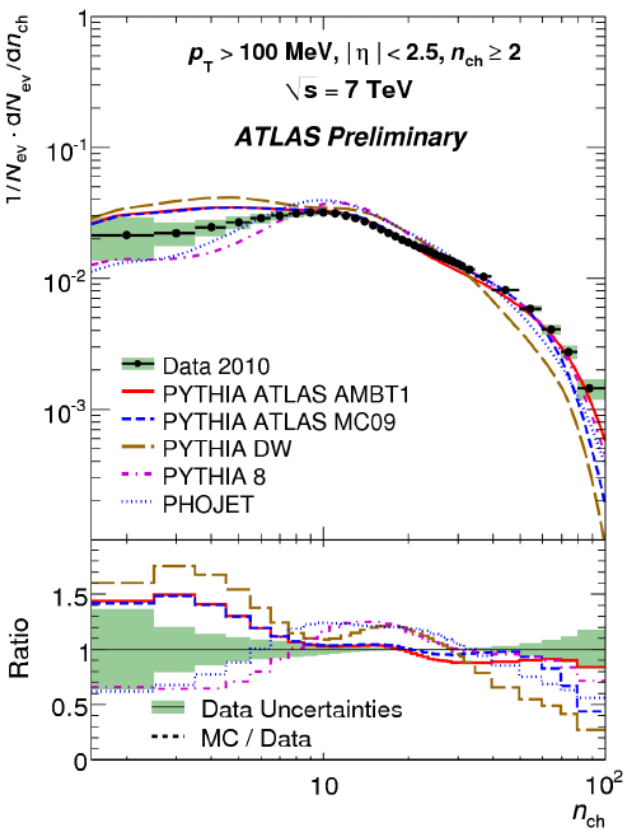
$N_{ch}\geq 6$, p_T>500MeV

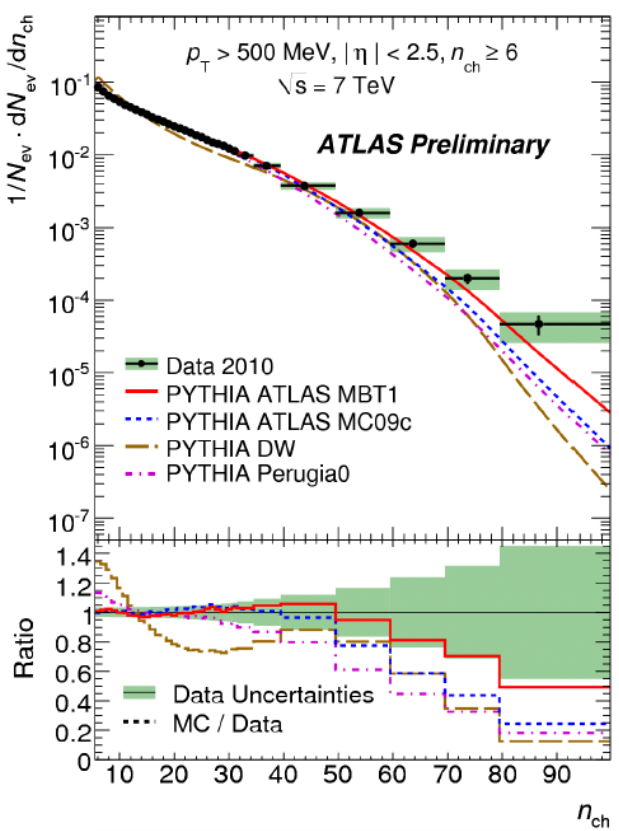
$1/N_{ev}dN_{ev}/dN_{ch}$

- The low n_{ch} region not well modeled by any MC
  - large contribution from diffraction
- The peak at 10 particles well described by AMBT1

gata





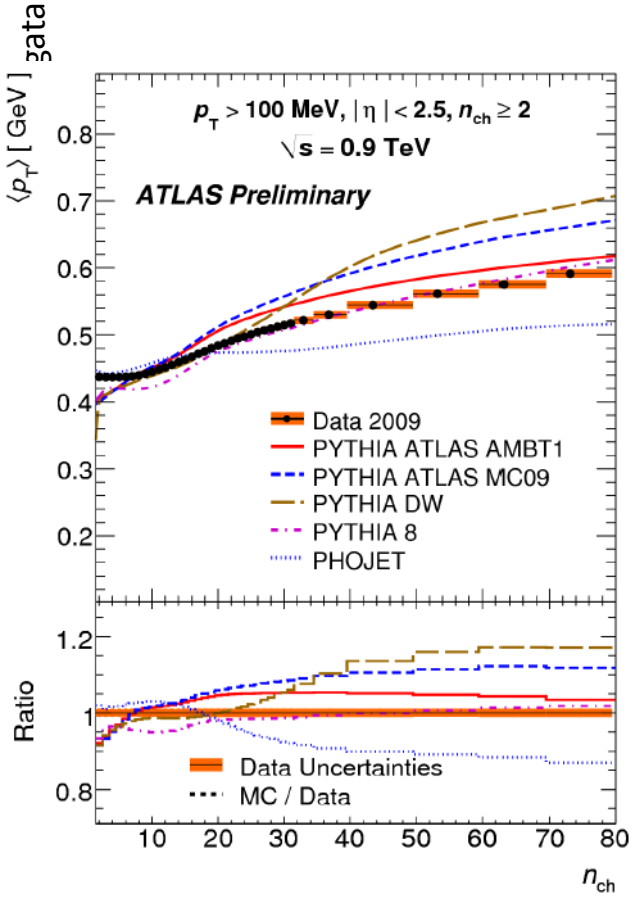


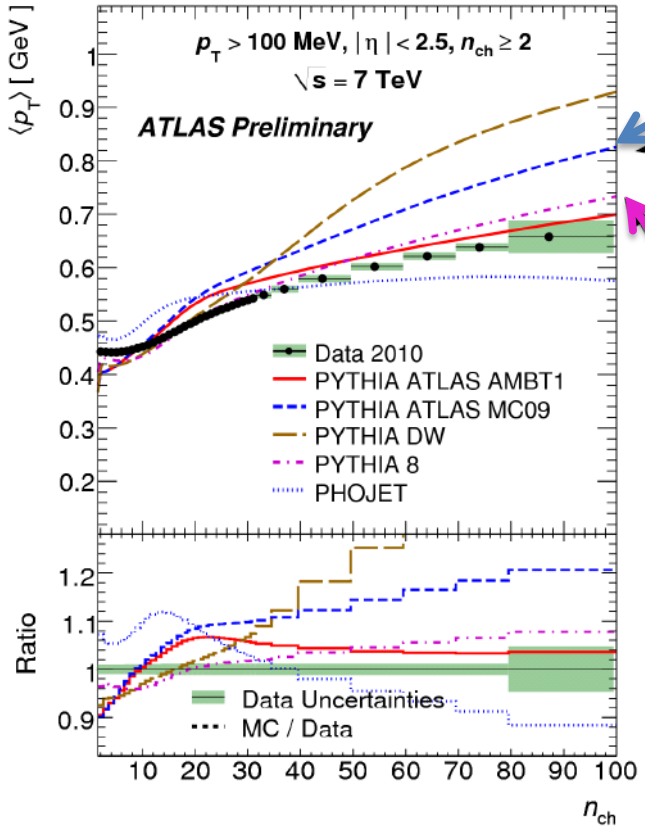
$n_{ch} \geq 2$, $p_T > 100$MeV

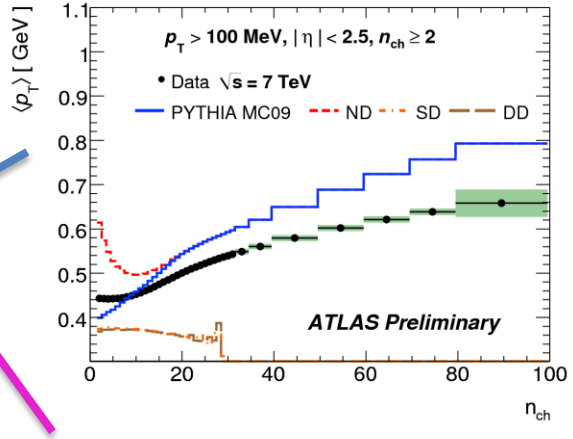
$N_{ch} \geq 6$, $p_T > 500$MeV

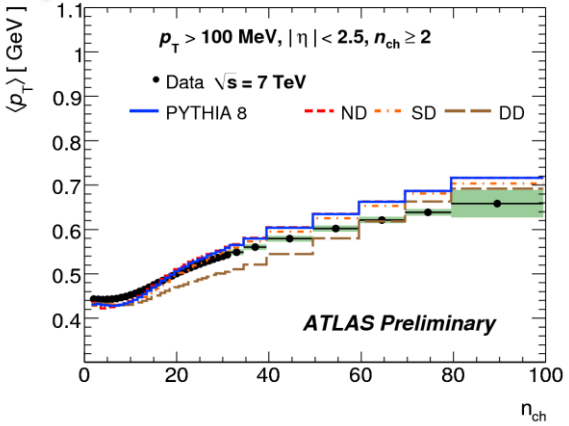
$< p_T >$ vs N_{ch}

- Best description from AMBT1 and Pythia8
- Shape at high p_T well modelled
- High sensitivity of the low n_{ch} shape linked to the different ND,SD,DD fractions









Pythia6 – softer spectrum at low nch – too large diffractive component?

$n_{ch} \geq 2$, $p_T > 100$MeV

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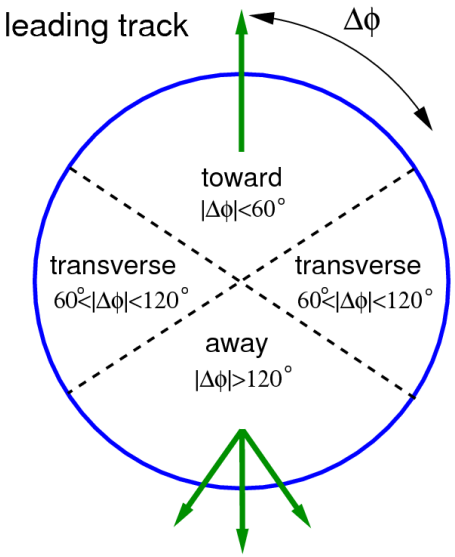
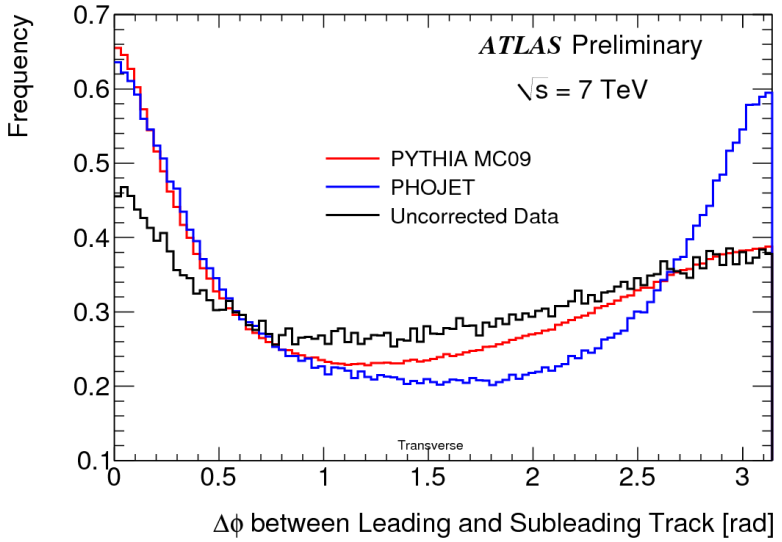
Underlying event

Underlying event

- "Underlying Event": everything else in addition the hard scattering process
  - MPI, ISR-FSR contributions, beam-beam remnants
- The sentive region to the UE is the one perpendicular to the hard scattering (transverse region) – Used the leading track to identify the leading jet
  - $60° < |\Delta\varphi| < 120°$
- same correction for trigger, vertex and tracking efficiency as in the Minimum Bias





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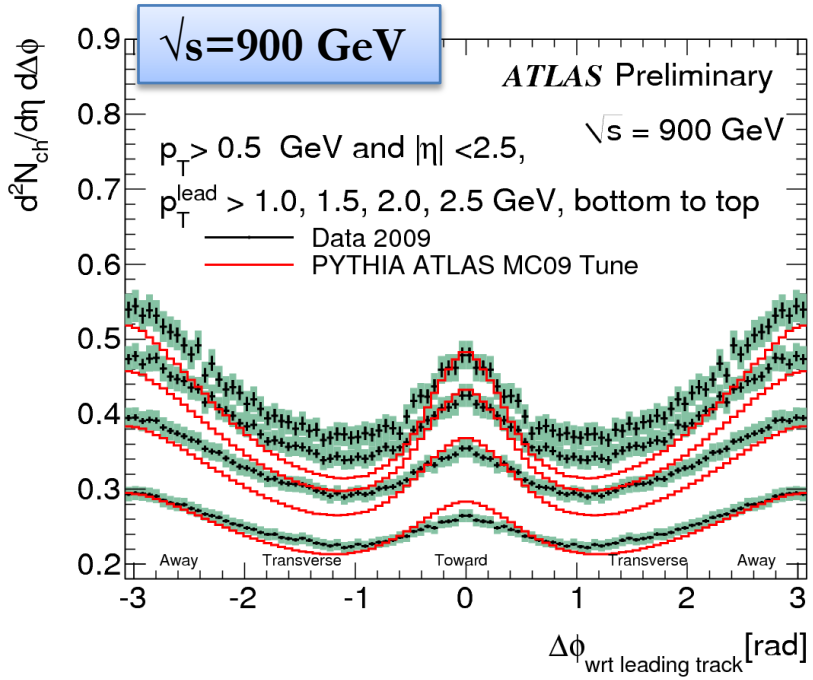
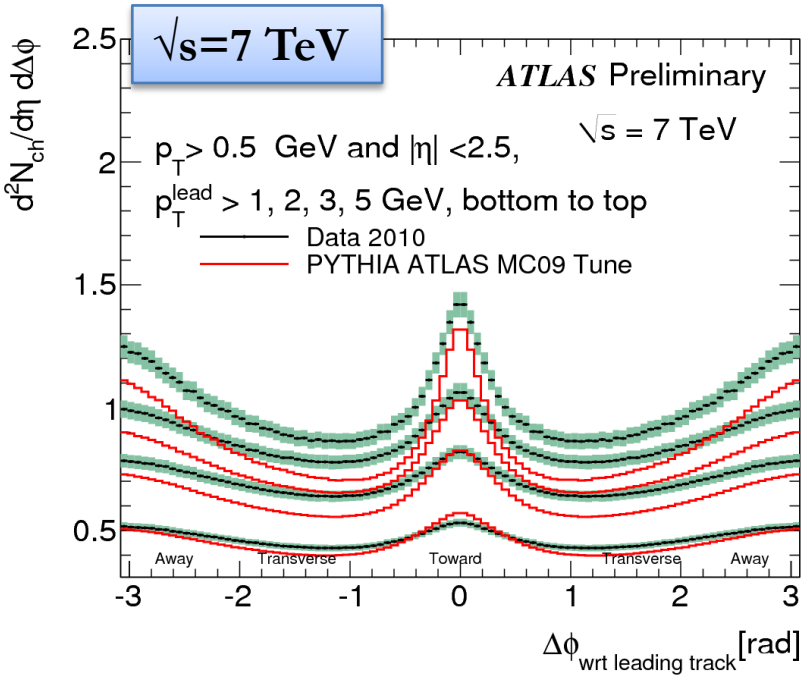
Angular distributions vs p_T^{lead}

- Charged particle number density for tracks other than the leading track
  - plot reflected wrt $\Delta\varphi=0$
  - Jet-like shape (higher tracks population in the toward and the away region)is much evident for harder leading tracks





- different densities and different angular distributions between data and MC

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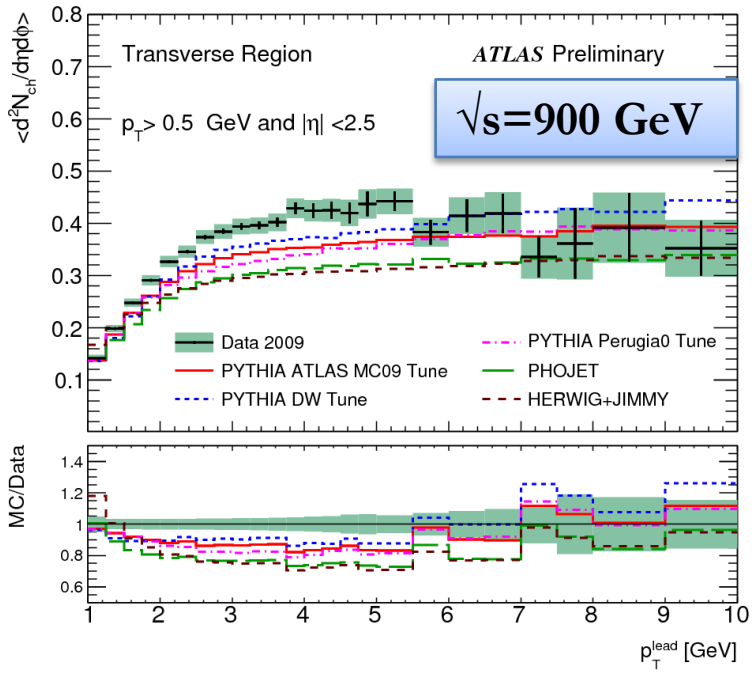
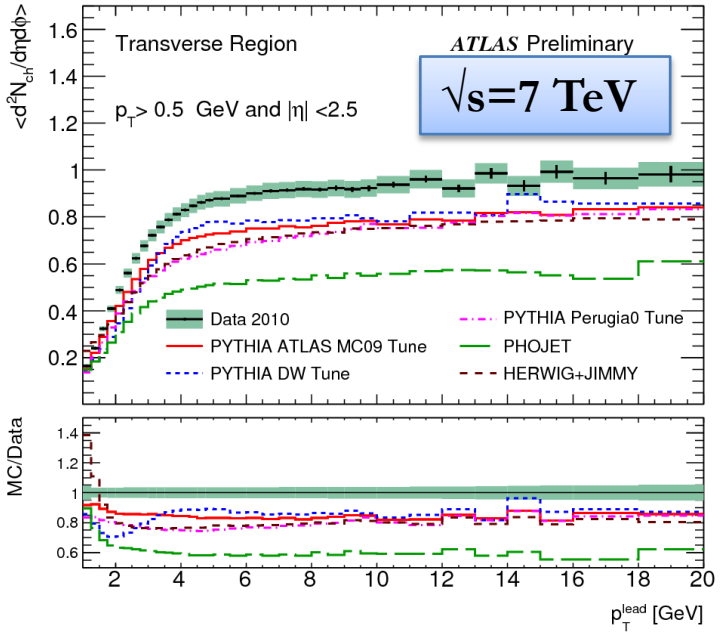
Mulitplicity

➢Density of cherged particle (p_T>500MeV $|\eta|$<2.5) as function of the leading track p_T in the transverse region increase of a factor 2 form 900 GeV to 7 TeV .





➢Plateau value is a factor 2 larger as seen in the Minimum Bias events (due to the high p_T track selection effect: more momentum exchange and lack of diffractive contributions in events with p_T^{lead} in plateau region)

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Angular Correlations

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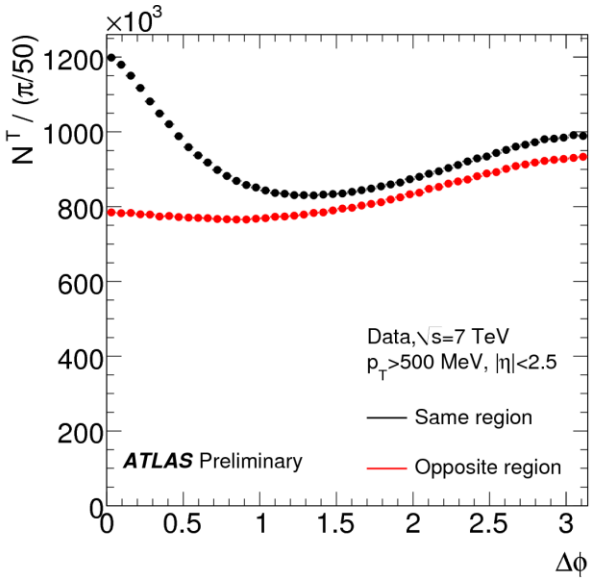
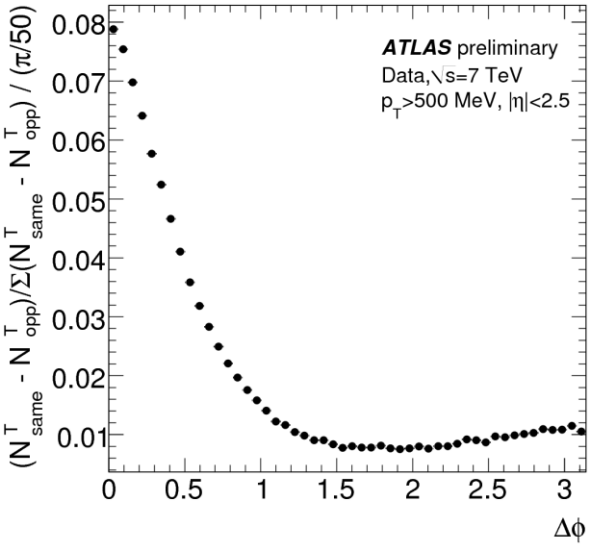
Angular correlations

- **ΔΦ = difference of the azimuthal angle between the p_T-leading track and all the other non leading tracks in the event**
- **Studied the "Toward" and "Away" components (width and weight of the "Toward" and "Away" peaks) – variable sensible to differences between models**
  - **This variable has been measured in the same and in the opposite regions with respect to the leading one (in η)**



More particles produced in the same region



"same minus opposite " ΔΦ normalized

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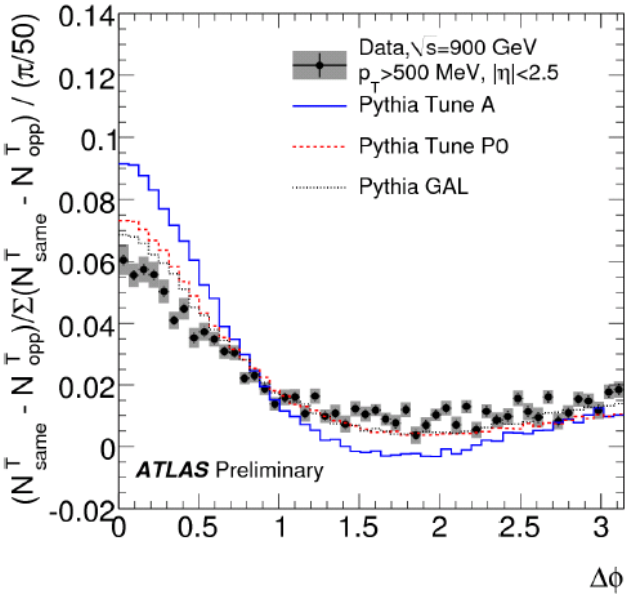
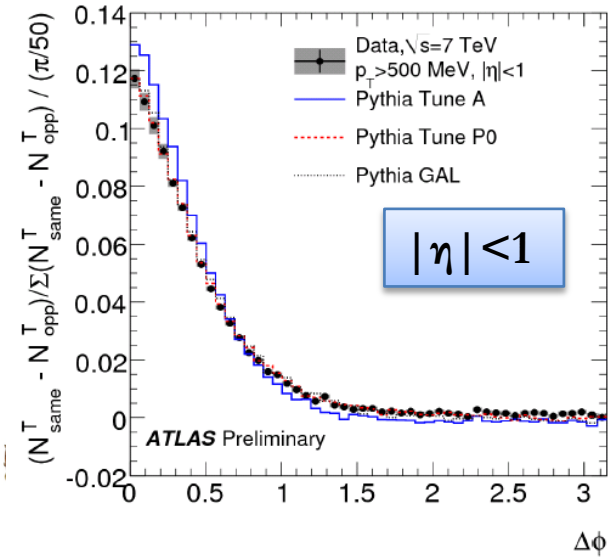
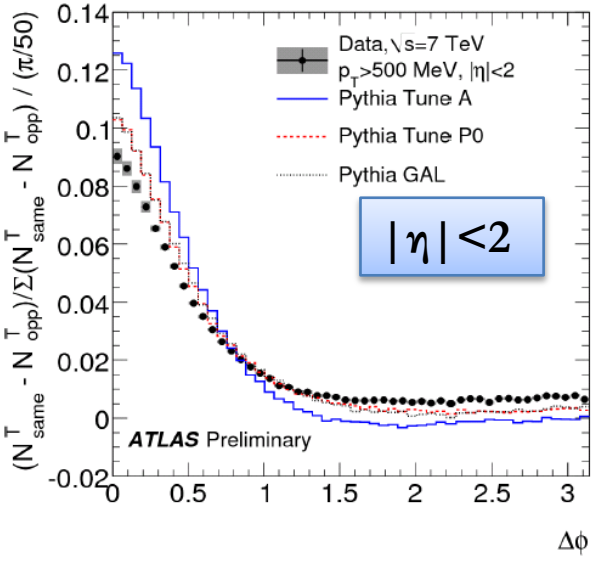
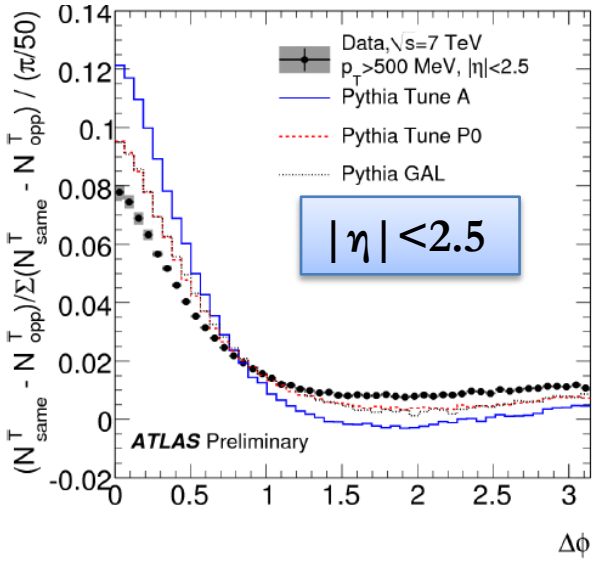
The Δφ crest shape

- Good consistency in central pseudorapidity region $|\eta|<1$
- Considering also the forward regions comes out that models poorly constrained at forward direction where reach of previous experiments limited
- Same discrepancy observed @ 0.9 TeV



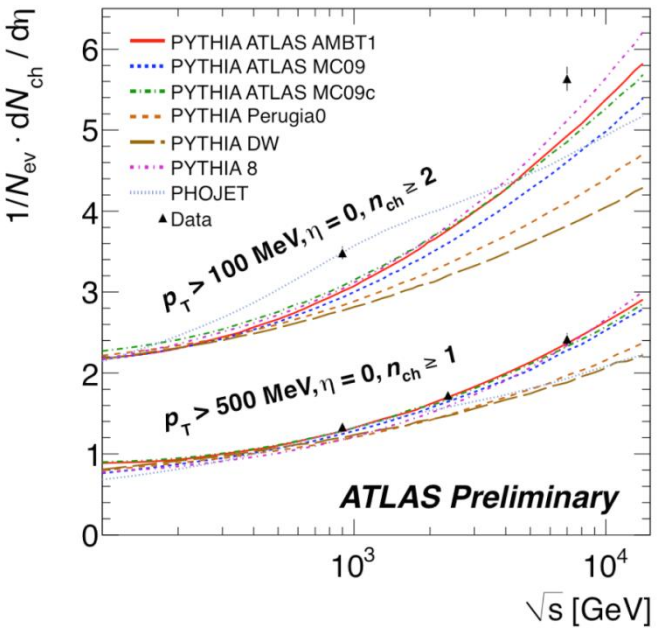






Conclusions

- Spectra of charged particle measured from 100 MeV @ 0.9, 2.36 and 7 TeV
  - no model dependent correction applied (well-defined phase-space and no correction back to a particular component (e.g. NSD))
  - p_T>100 MeV
    - Models underestimate the particle multiplicity
  - p_T>500 MeV
    - Good description of the data by AMBT1



- Track based underlying event measurements have been performed by ATLAS
  - None of the current models can decribe accurately all the UE measurement
  - Can be used as input to improve de models

- Angular correlations: new osservable sensible to differents models
  - Can be used to improve the tunings

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References

Reconstruction of known particle @ 7 TeV

K^0_s and Λ^0 reconstruction	ATLAS-CONF-2010-033
Xi, Omega, K*(890)	ATLAS-CONF-2010-032
D* mesons reconstruction	ATLAS-CONF-2010-034

Inclusive charged particle spectra @ 0.9 and 7 TeV

pT>100 MeV, Nch>1, $\|\eta\|$<2.5	ATLAS-CONF-2010-046
pT>500 MeV, Nch>9, $\|\eta\|$<2.5	Phys. Lett. B 688, 1, ATLAS-CONF-2010-024
	ATLAS-CONF-2010-047 (2.36 TeV)
pT>500 MeV, Nch>6, $\|\eta\|$<2.5	ATLAS-CONF-2010-031

(diffraction suppressed sample, used to derive AMBT1)

Underlying event using tracks

ATLAS-CONF-2010-081

Angular correlation between charged particles

-Measurements probing event topologies @ 0.9 and 7TeV (pT>500 MeV)

ATLAS-CONF-2010-082

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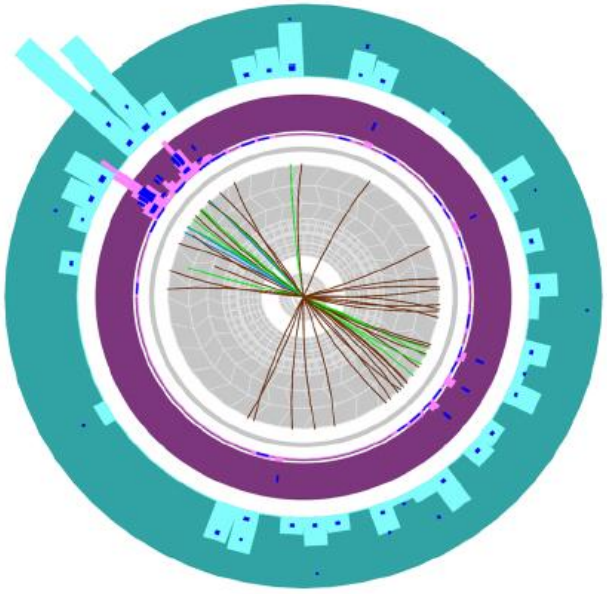
Extra

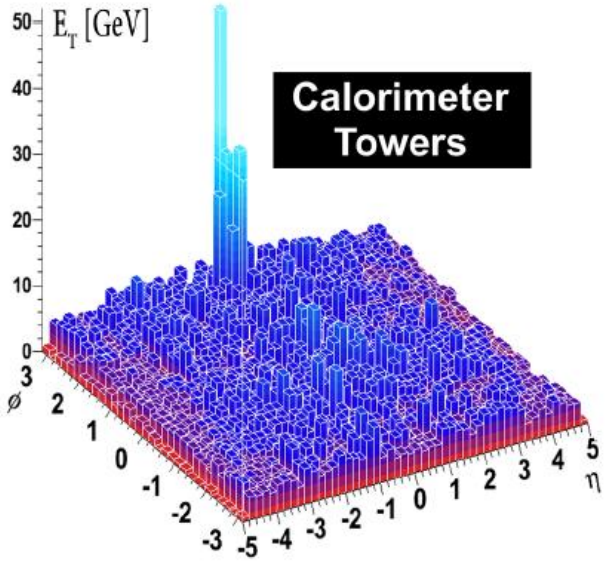
ATLAS HI hot results

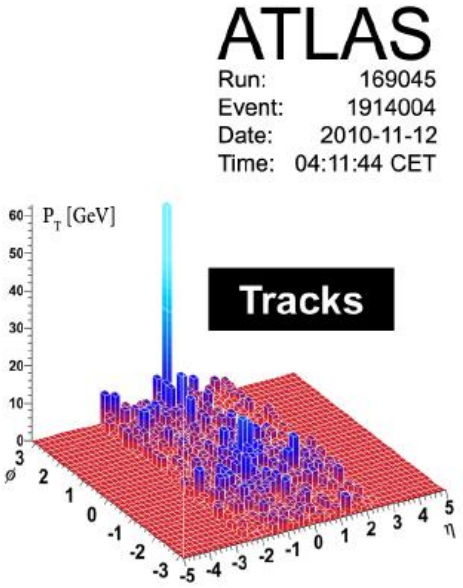
- The LHC heavy ion program – Pb-Pb collisions → opportunity to study jet quenching at much higher jet energies than achieved at RHIC.
- Data taken since the beginning of November , $\sqrt{s_{NN}}$= 2.76 TeV – 1.7 μb^{-1} of data used
- At this energy, NLO calulation predict high rate of jets above 100GeV in $|\eta|<4.5$
- Focus on the balance between pair of jets with highest E_T and $\Delta\varphi$ separation $|\varphi 1 - \varphi 2| > \pi/2$
- Jet Enegy unbalance studied in terms of asymmetry

$$A_J = \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}}, \Delta\phi > \frac{\pi}{2}$$

E_{T1}>100GeV, E_{T2} >25 GeV







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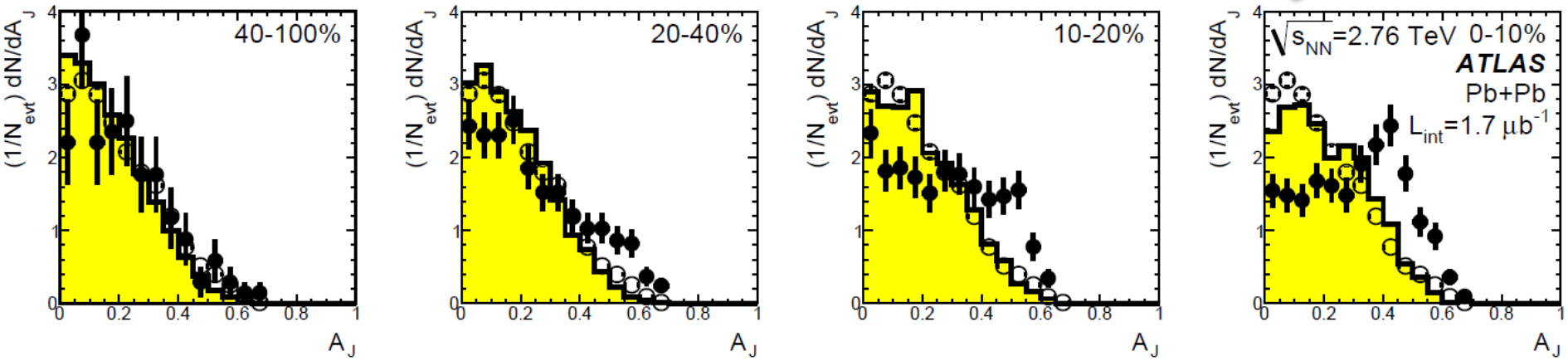
ATLAS HI hot results

- Dijet events are expected to have A_J near zero
  - Deviations from gluon radiation falling outside the jet cone and instrumental effects.

CENTRALITY



Histogram: MC (PYTHIA+HIJING) | open points: 7 TeV pp data | filled: Pb-Pb data

- Dijet asymmetry obserbed in PbPb data and not in p-p collisions
- May point to an interpretation in terms of strong jet energy loss in a hot, dense medium

Backup

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Tunings

- The basic components of Pythia that require tuning are the descriptions of:
  - Final state radiation and hadronisation,
  - Initial state radiation and primordial kT ,
  - Underlying event, beam remnants, colour reconnection, and
  - Energy scaling.

- Perugia0
  - PYTHIA Tune based on Minimum bias results from CDF and UA5. No UE data used
  - CTEQ5L parton distribution functions used
- DW
  - PYTHIA Tune that use CDF UE and Drell-Yan data (no Min Bias Data)
- ATLAS MC09
  - PYTHIA Tune based on CDF Minnimum Bias and UE Measurements (RUN I and II) plus the D0 results on dijet angular correlations

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ATLAS data in AMBT1

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

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Tevatron data in AMBT1

CDF Run I underlying event in dijet events[13] (leading jet analysis)

- N_{ch} density vs leading jet p_T (transverse), JET20
- N_{ch} density vs leading jet p_T (toward), JET20
- N_{ch} density vs leading jet p_T (away), JET20
- $\sum p_T$ density vs leading jet p_T (transverse), JET20
- $\sum p_T$ density vs leading jet p_T (toward), JET20
- $\sum p_T$ density vs leading jet p_T (away), JET20
- N_{ch} density vs leading jet p_T (transverse), min bias
- N_{ch} density vs leading jet p_T (toward), min bias
- N_{ch} density vs leading jet p_T (away), min bias
- $\sum p_T$ density vs leading jet p_T (transverse), min bias
- $\sum p_T$ density vs leading jet p_T (toward), min bias
- $\sum p_T$ density vs leading jet p_T (away), min bias
- p_T distribution (transverse), leading $p_T > 5$ GeV
- p_T distribution (transverse), leading $p_T > 30$ GeV

CDF Run I underlying event in MIN/MAX-cones[14] ("MIN-MAX" analysis)

- $\langle p_T^{max} \rangle$ vs. E_T^{lead}, $\sqrt{s} = 1800$ GeV
- $\langle p_T^{min} \rangle$ vs. E_T^{lead}, $\sqrt{s} = 1800$ GeV
- $\langle p_T^{diff} \rangle$ vs. E_T^{lead}, $\sqrt{s} = 1800$ GeV
- $\langle N_{max} \rangle$ vs. E_T^{lead}, $\sqrt{s} = 1800$ GeV
- $\langle N_{min} \rangle$ vs. E_T^{lead}, $\sqrt{s} = 1800$ GeV
- Swiss Cheese p_T^{sum} vs. E_T^{lead} (2 jets), $\sqrt{s} = 1800$ GeV
- $\langle p_T^{max} \rangle$ vs. E_T^{lead}, $\sqrt{s} = 630$ GeV
- $\langle p_T^{min} \rangle$ vs. E_T^{lead}, $\sqrt{s} = 630$ GeV
- $\langle p_T^{diff} \rangle$ vs. E_T^{lead}, $\sqrt{s} = 630$ GeV
- Swiss Cheese p_T^{sum} vs. E_T^{lead} (2 jets), $\sqrt{s} = 630$ GeV

D0 Run II dijet angular correlations[15]

- Dijet azimuthal angle, $p_T^{max} \in [75, 100]$ GeV
- Dijet azimuthal angle, $p_T^{max} \in [100, 130]$ GeV
- Dijet azimuthal angle, $p_T^{max} \in [130, 180]$ GeV
- Dijet azimuthal angle, $p_T^{max} > 180$ GeV

CDF Run II minimum bias[16]

- $\langle p_T \rangle$ of charged particles vs. N_{ch}, $\sqrt{s} = 1960$ GeV

CDF Run I Z p_T[17]

- $\frac{d\sigma}{dp_T^Z}$, $\sqrt{s} = 1800$ GeV

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