Heavy Ion Physics with the ATLAS Detector at the LHC

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Hot Topics in Heavy Ion Physics at LHC

	SPS		RHIC		LHC
	Pb+Pb	→	Au+Au	→	Pb+Pb
$\sqrt{s_{NN}}$:	*17.3 GeV*		*200 GeV*		*5500 GeV*

- **Global observables (N_{ch}, E_T, *elliptic flow*):**
  - **Dynamics of hot and dense medium (perfect fluid)**
  - **Properties of initial state (energy/gluon density)**
- **High energy photons and jets:**
  - **In-medium energy loss processes**
- **Quarkonia:**
  - **QCD deconfinement**
  - **Color screening**
- **…**

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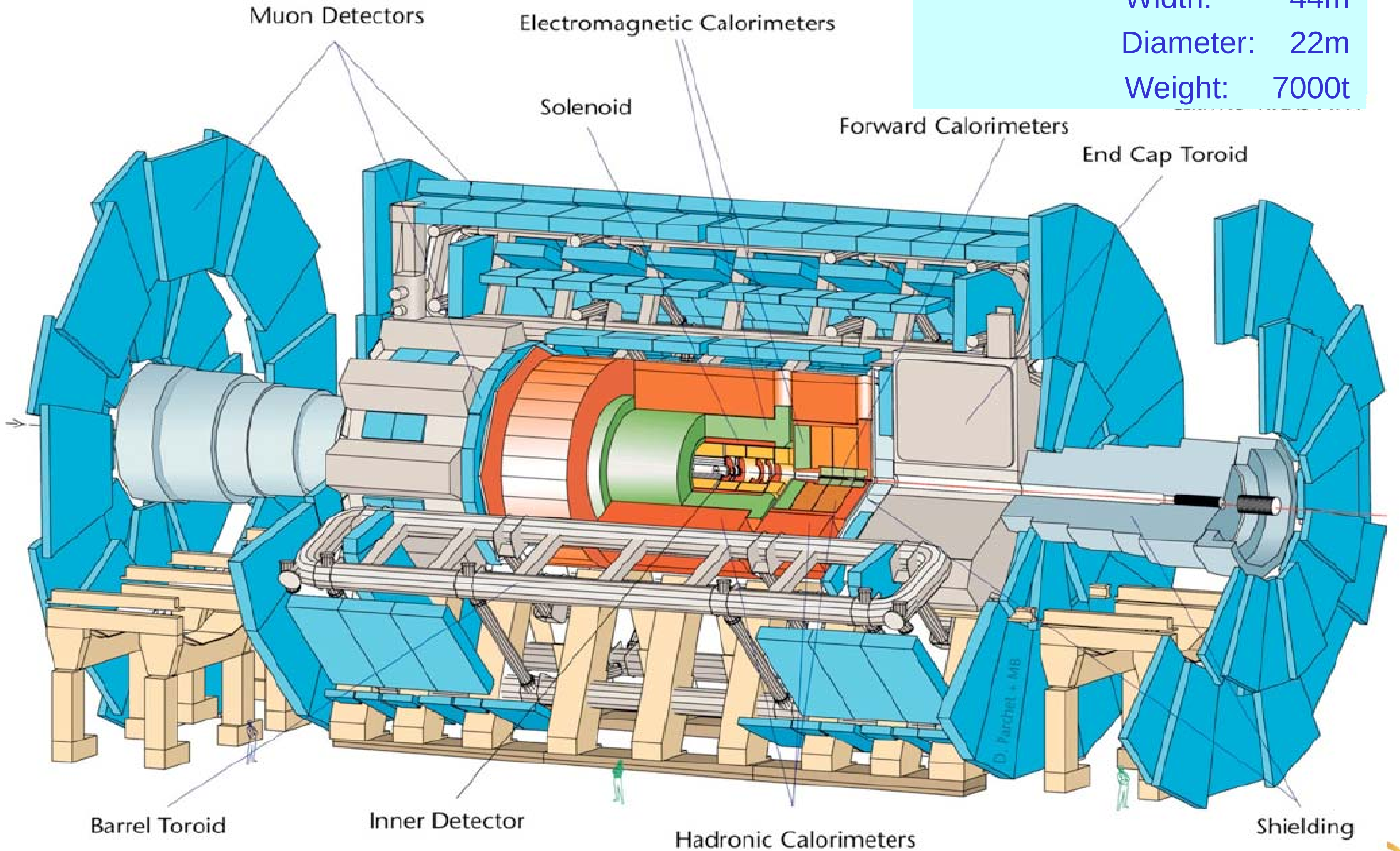
The ATLAS Detector

Detector parameters:

Width:	44m
Diameter:	22m
Weight:	7000t

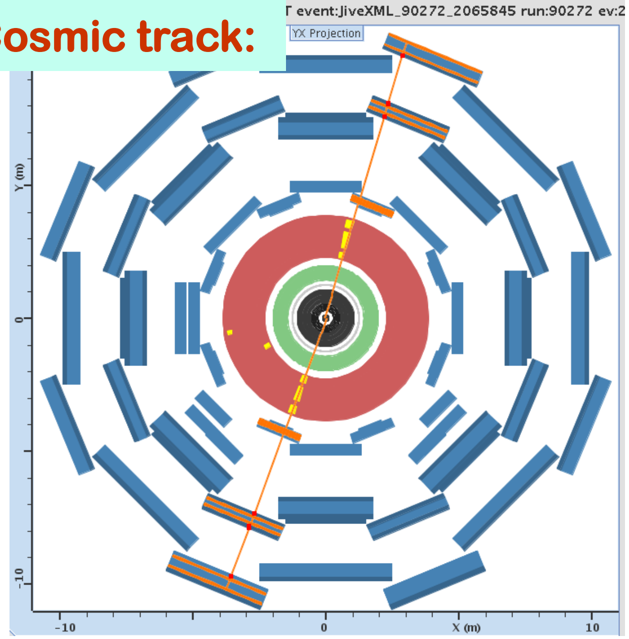


Inner tracker, EM and hadronic calorimeters, muon spectrometer

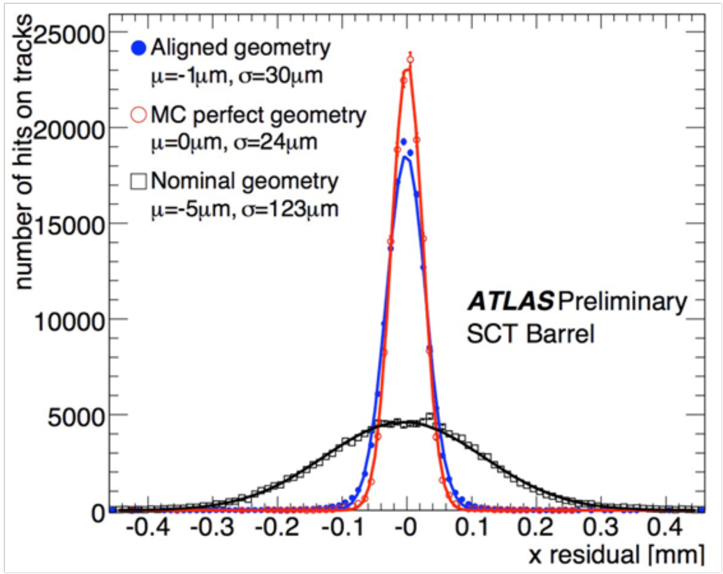
ATLAS Performance & Experience in 2008

- **First single beam events (2008-Sep-10)**
- **Combined Cosmic Run (2008-Oct-Dec):**
  - **300 M cosmic events collected**
  - **Very few dead channels (~1%)**
  - **Well understood noise**
  - **Progress on alignment and calibration**

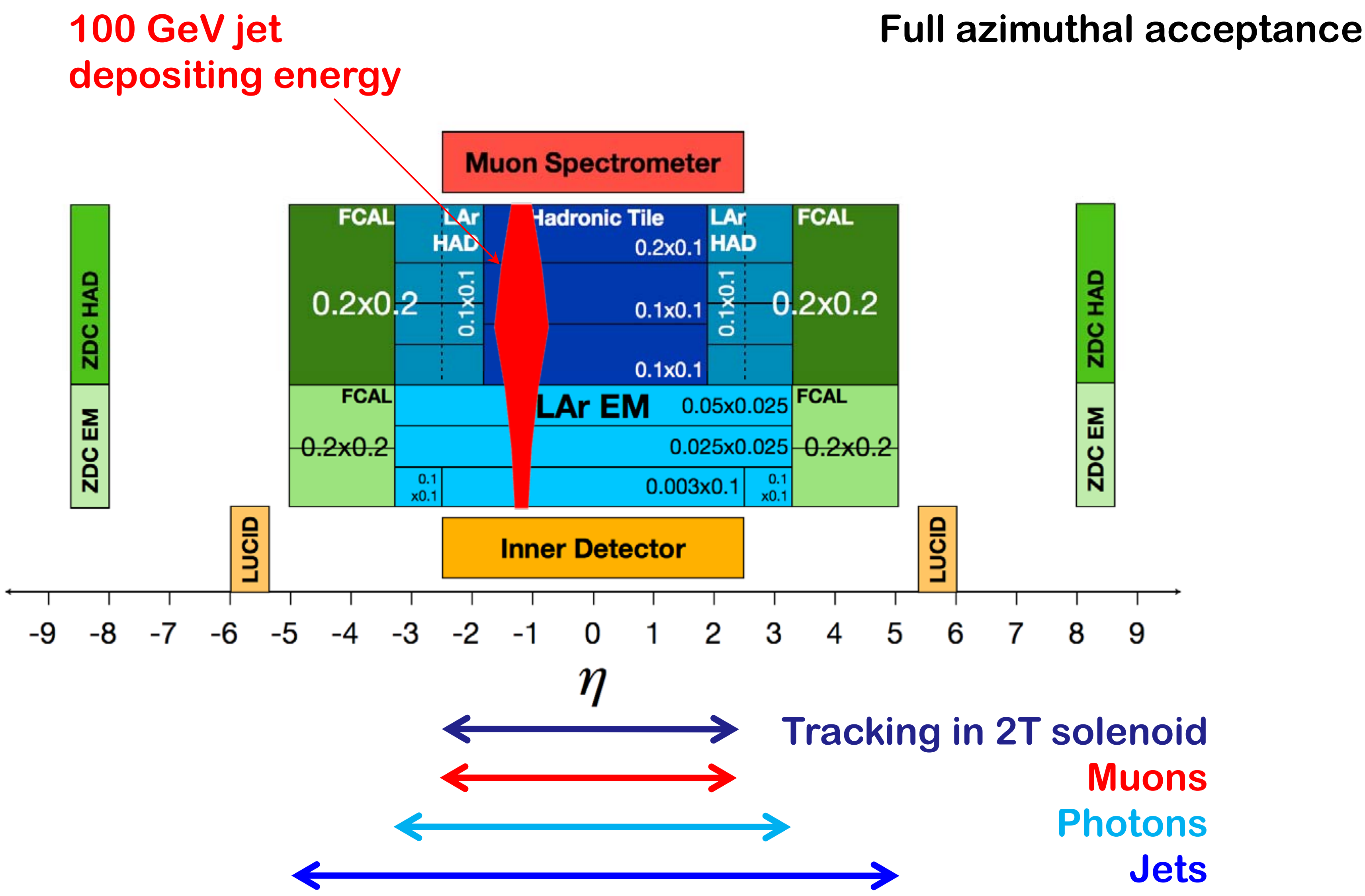
Cosmic track:



ATLAS is well prepared for first p+p in 2009 and for Pb+Pb collisions at the end of 2010



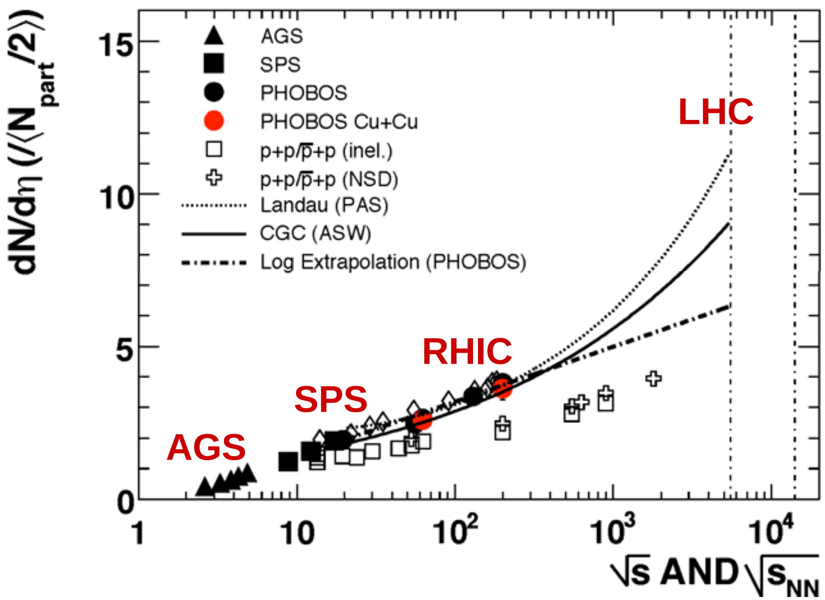
Overview of ATLAS Acceptance



Charged Particle Multiplicity

$dN_{ch}/d\eta$ in Pb+Pb at LHC Energy

J. Phys. G 35, 104151 (2008)

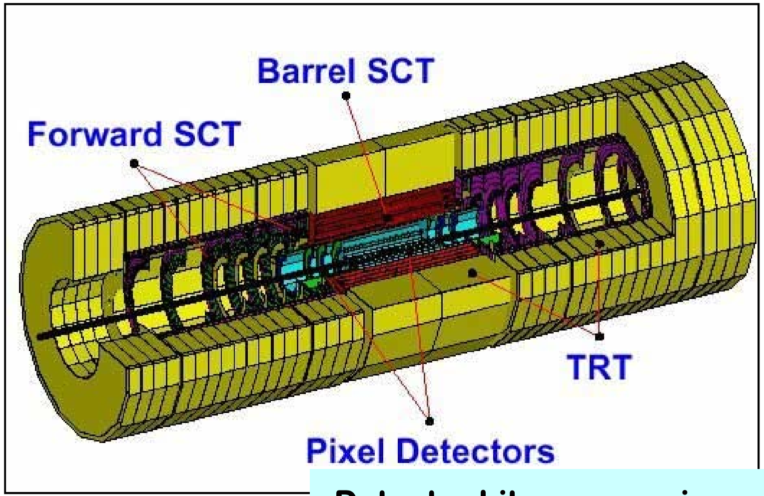


N_{part} - number of participating/wounded nucleons in AA collision

Day-one measurement:

- **Constrain model predictions**

ATLAS Inner Detector

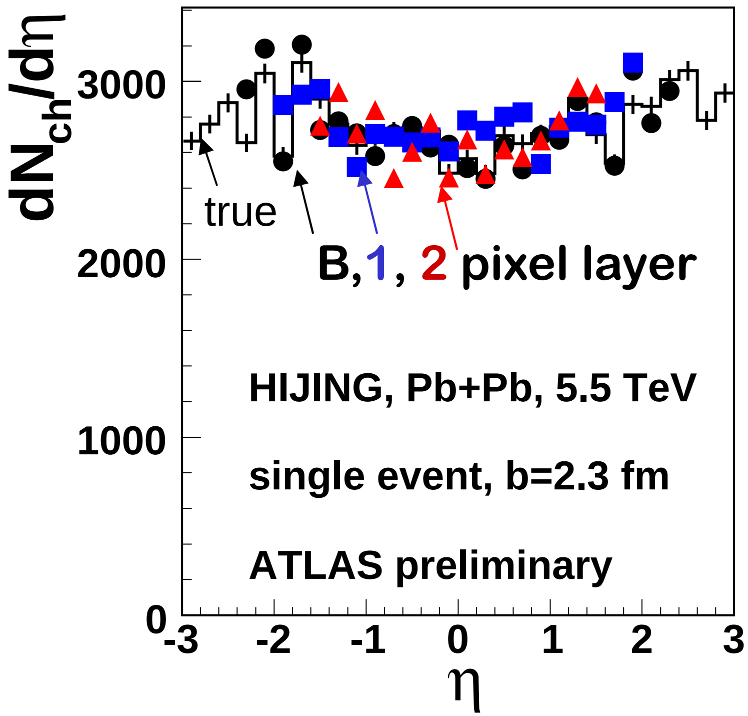


Detector hit occupancies:
(Pb+Pb, 5.5 TeV, b < 1 fm):
Pixels < 1%
SCT < 15%

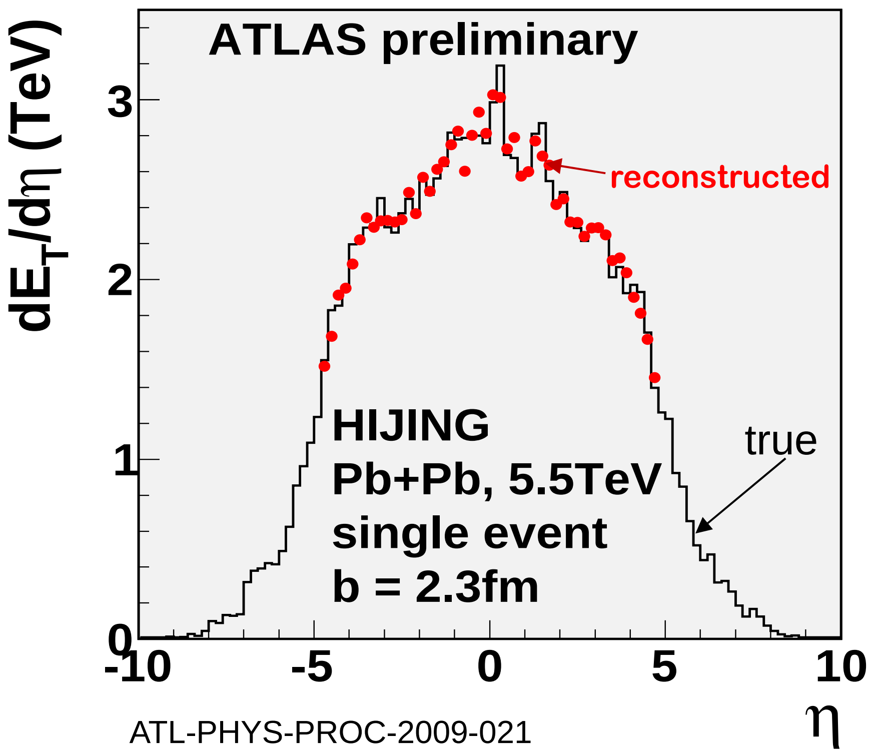
$dN_{ch}/d\eta$ - Measurements of position of hits in Inner Detector

Global Pb+Pb Event Characteristics

Charged Particle Multiplicity
(Si Hit Counting Method)



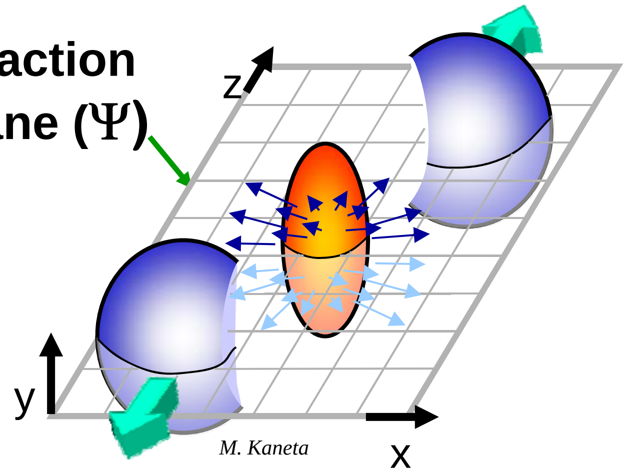
Transverse Energy Flow
(Calorimeter Cells)

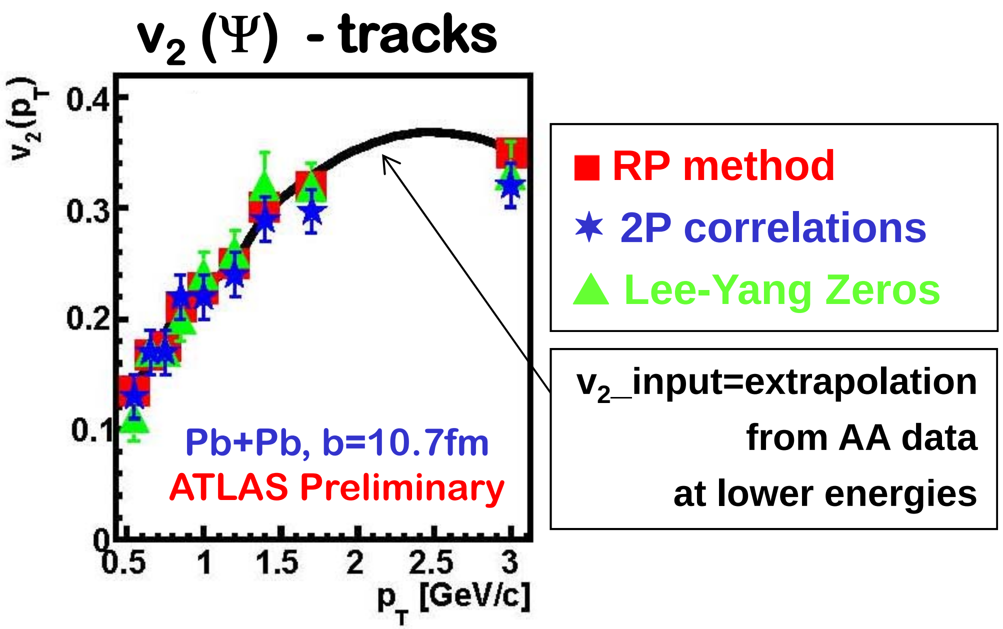


ATLAS provides good estimate of event-by-event multiplicity and total transverse energy

Azimutal Anisotropy of Produced Particles

Strongly interacting QGP





- Pressure gradients lead to azimuthal anisotropy

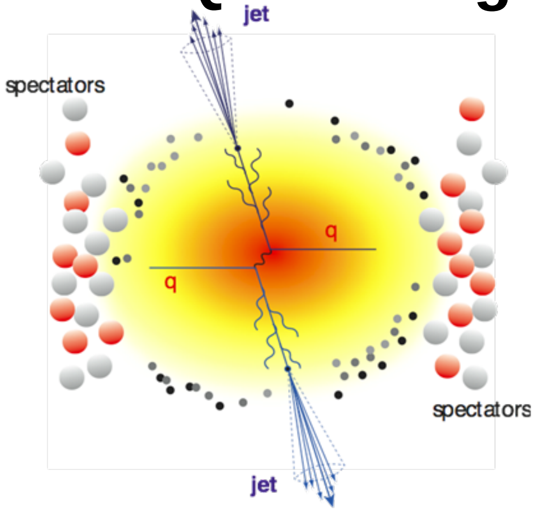
- Input v_2 is well reproduced
- Different methods control non-flow effects

v_2 – *elliptic flow*

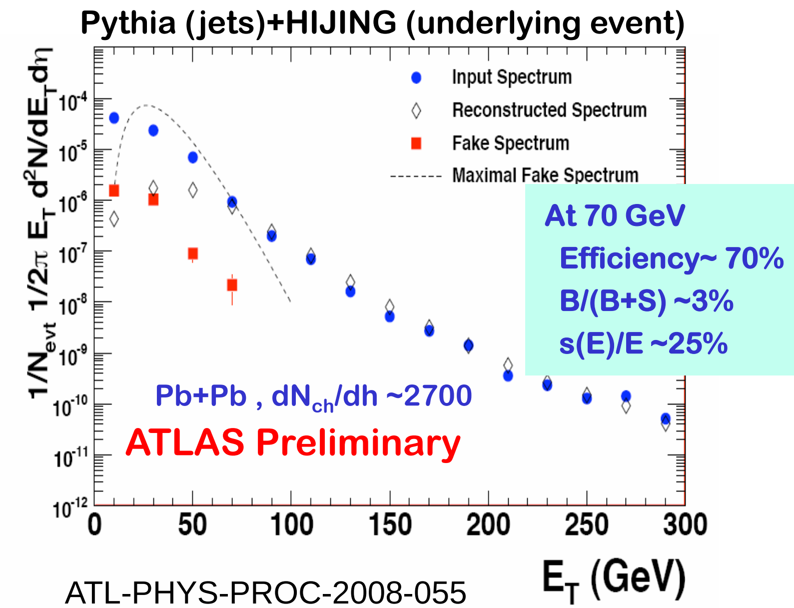
$$dN/d(\phi-\Psi_0) = N_0\,(1 + 2v_1 \cos(\phi-\Psi_0) + 2\mathbf{v_2} \cos(2(\phi-\Psi_0)) + \dots)$$

Jet Measurement

Jet Quenching



Jet Spectrum



- **At RHIC mostly leading particle measurements**
- **At LHC jets will be ideal probe to study parton energy loss effects**
- **~20 million jets of E_T>50 GeV in one month of Pb+Pb (5.5 TeV) run at nominal luminosity (0.5 nb^{-1})**

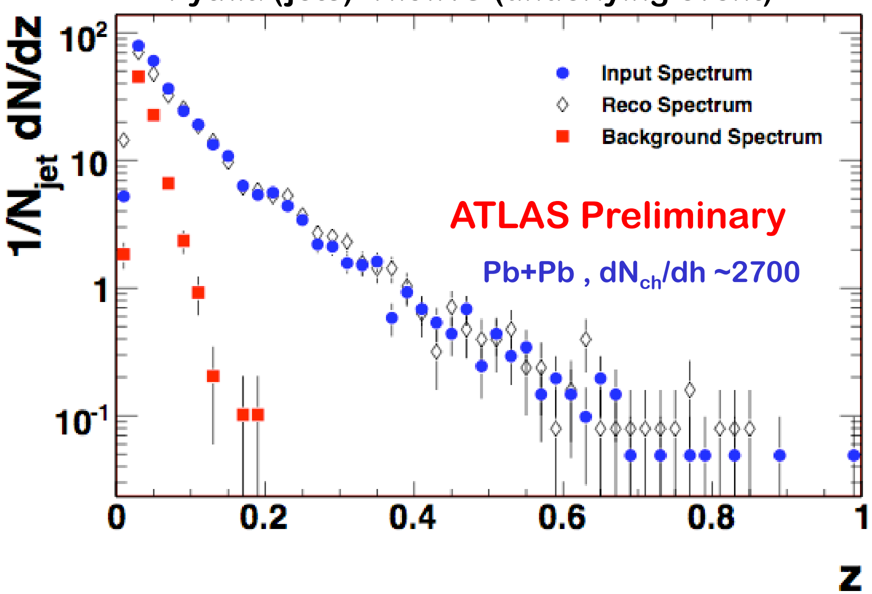
(no efficiency and energy resolution corrections)

Reconstructed cone (R=0.4) jet spectrum matches input yield above 80 GeV

Jet Fragmentation Function

Fragmentation function, D(z), modified by in-medium energy loss

Pythia (jets)+HIJING (underlying event)



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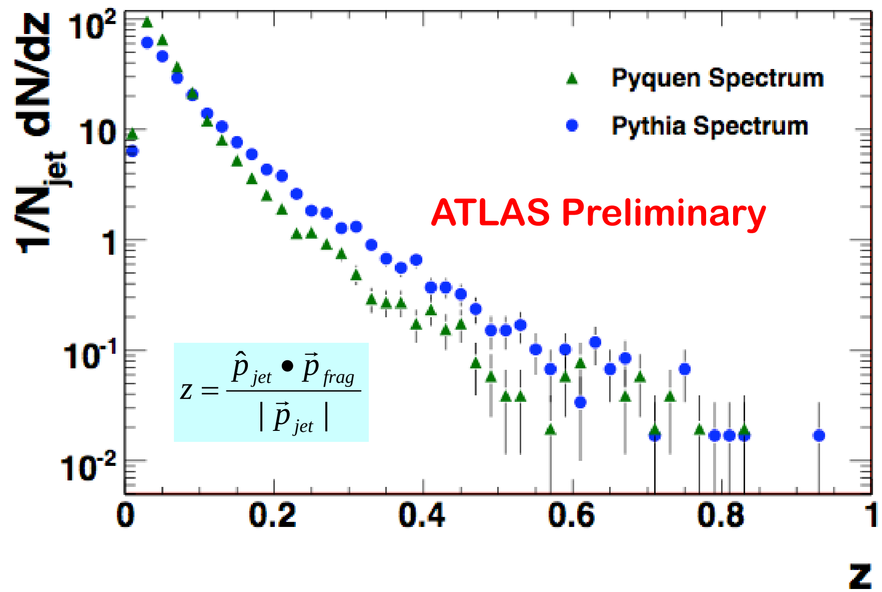
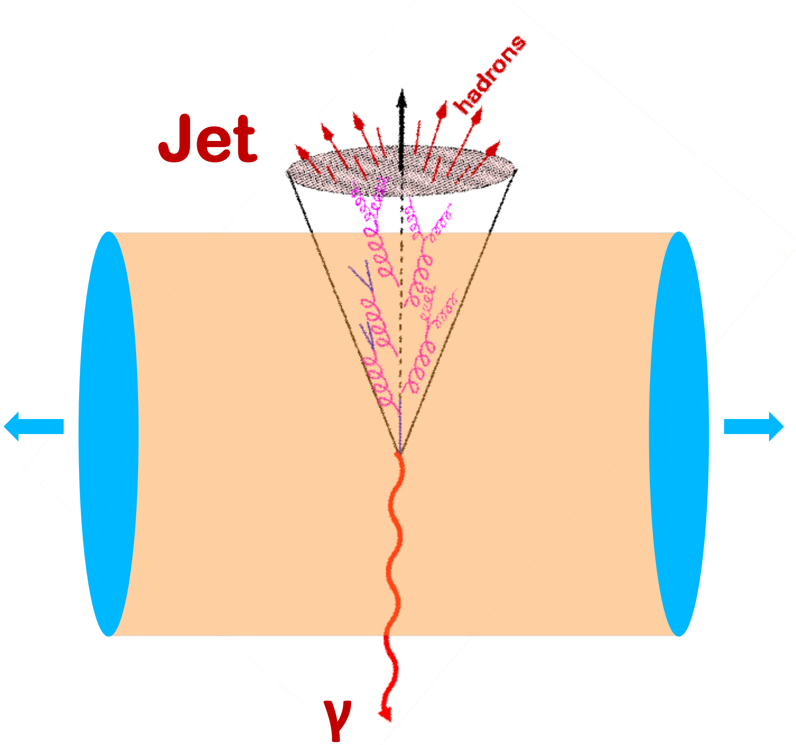


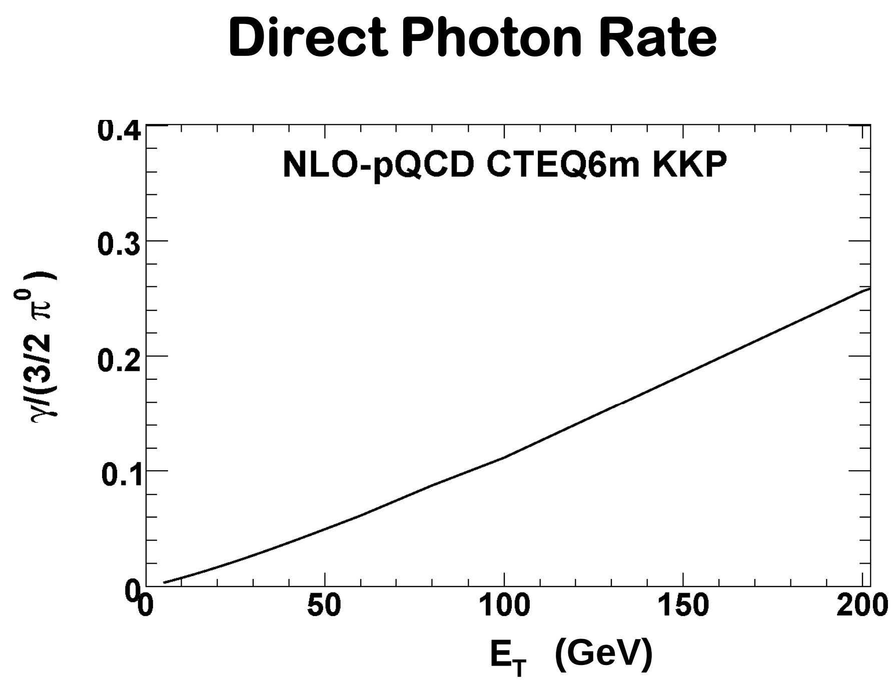
- Input D(z) is well reproduced
- Reconstruction of tracks (p_T > 2 GeV) matching cone jets

Jet quenching suppresses yield of high p_T particles

ATLAS is sensitive to modifications of D(z) due to energy loss effects

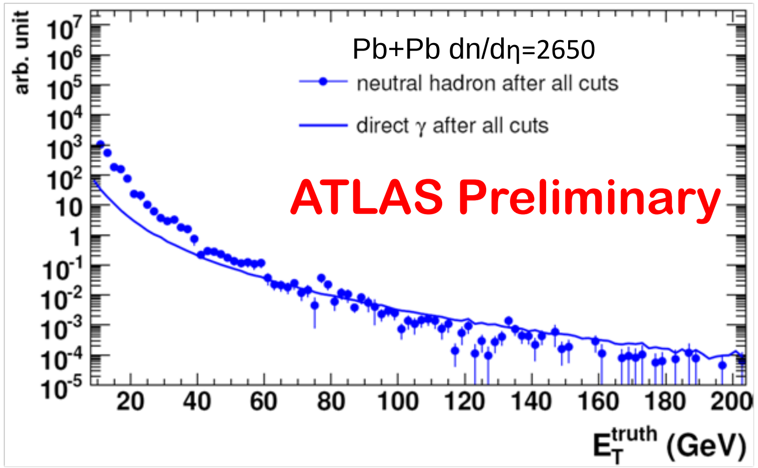
γ-jet





- γ - tagged jets at LHC (5.5 TeV, PbPb) are a <u>direct</u> handle on jet energy loss process in QGP
- ~200k γ's of E_T>30 GeV in standard Pb+Pb run (0.5 nb^{-1})

Performance of Direct γ Measurement



Background: neutral hadrons after cuts

Signal: direct γ after cuts

Photon reconstruction cuts suppress background

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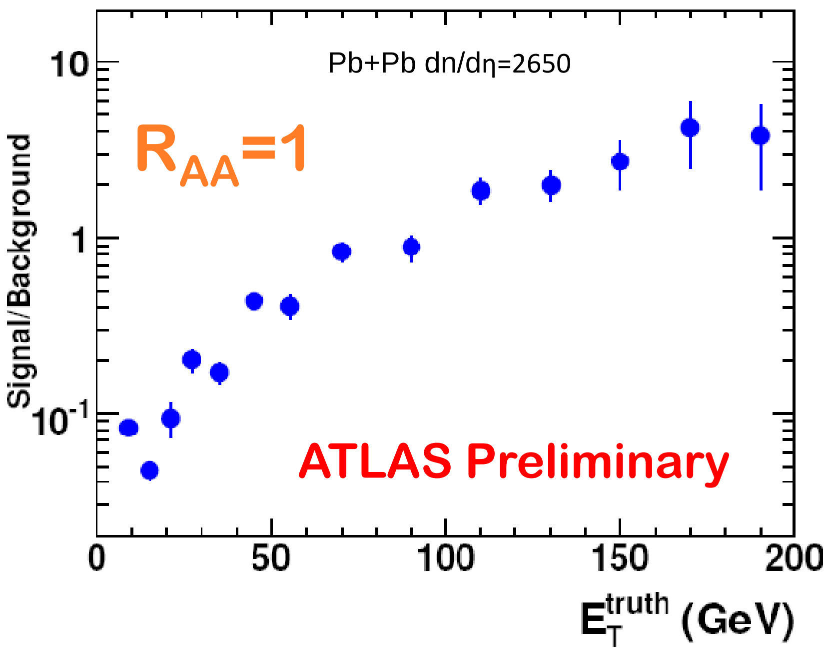
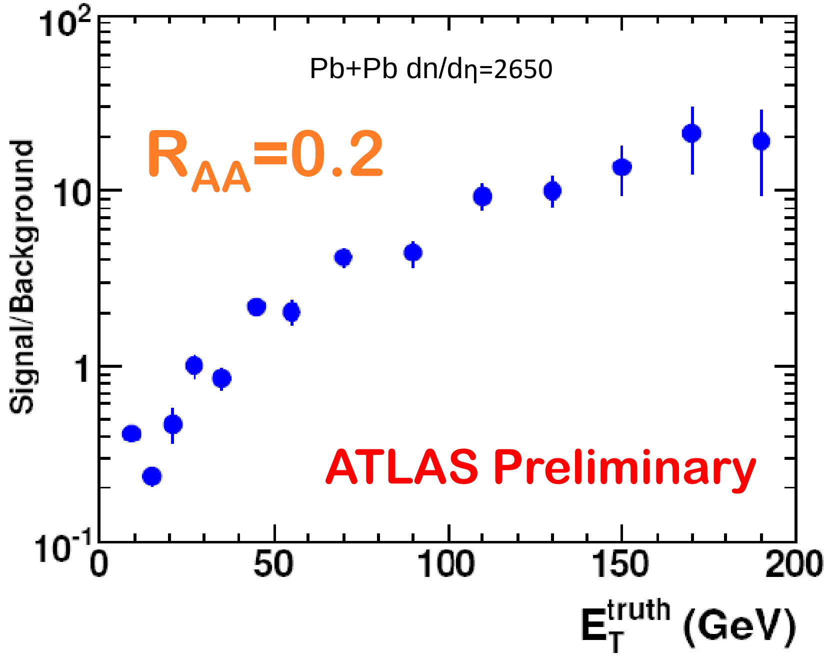
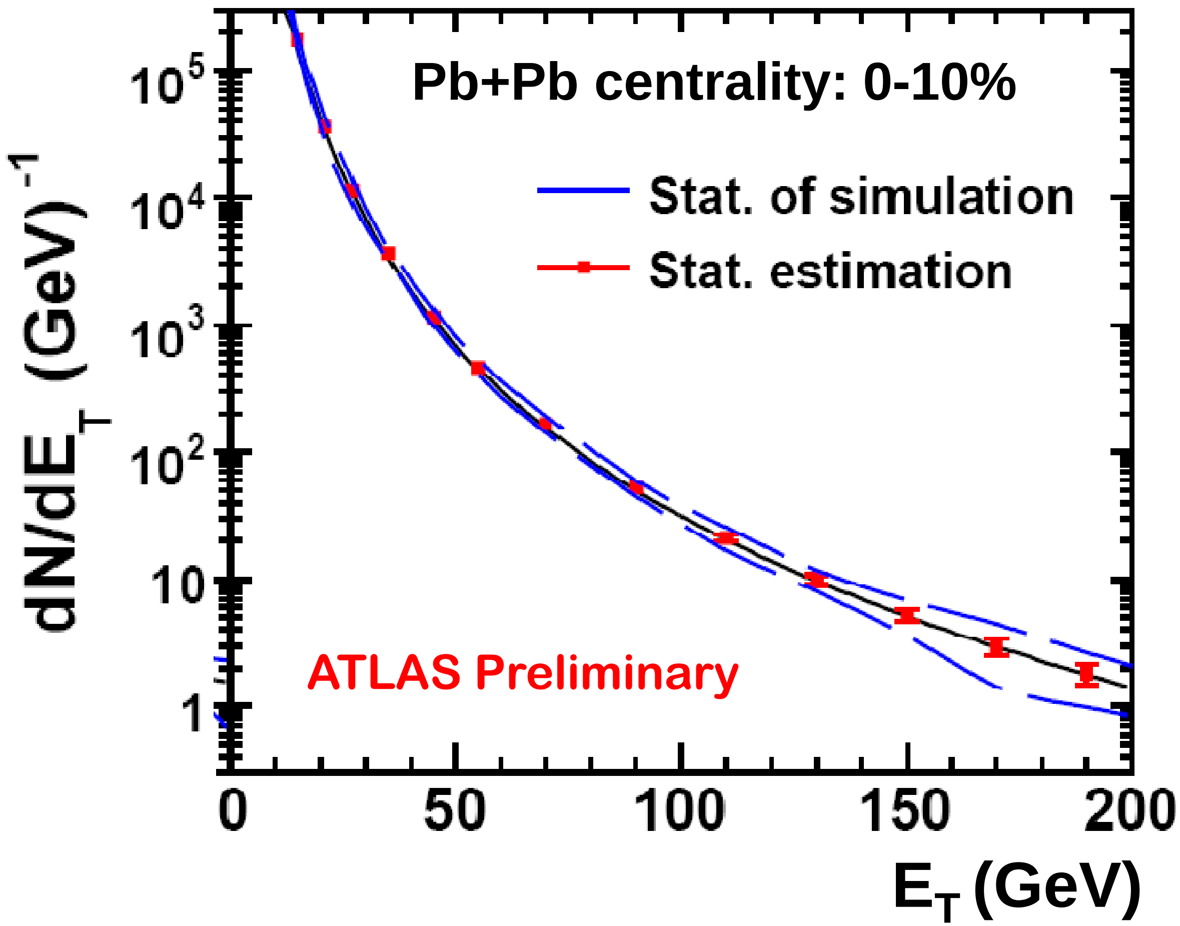




Direct γ Spectrum in Central Pb+Pb (5.5TeV) Collisions



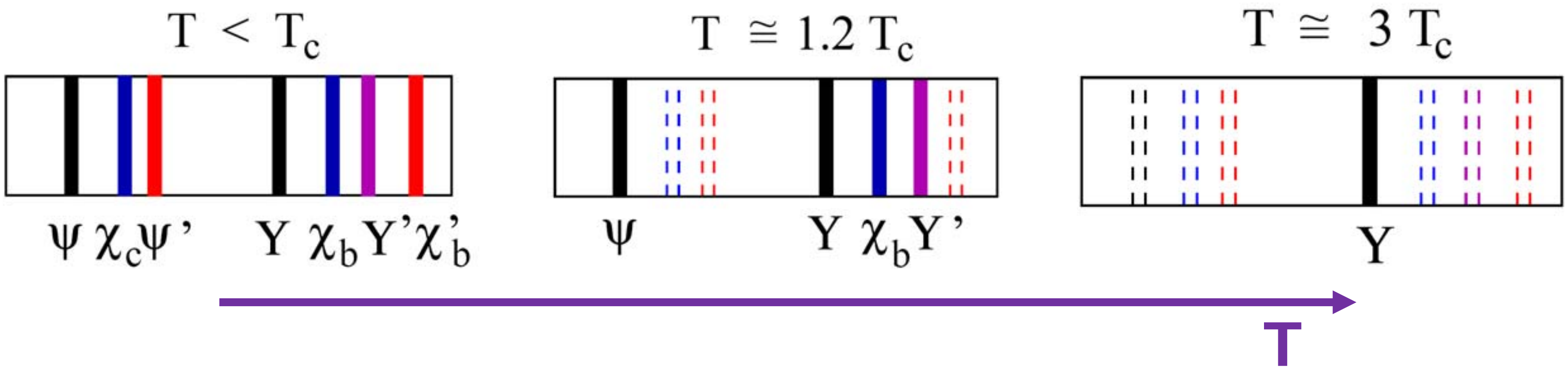
- Standard LHC Pb+Pb run (0.5 nb^{-1})

Quarkonia Suppression

Color screening in QGP prevents formation of various quarkonia states

- Color screening length < Size of resonance
- Color screening length decreases with T

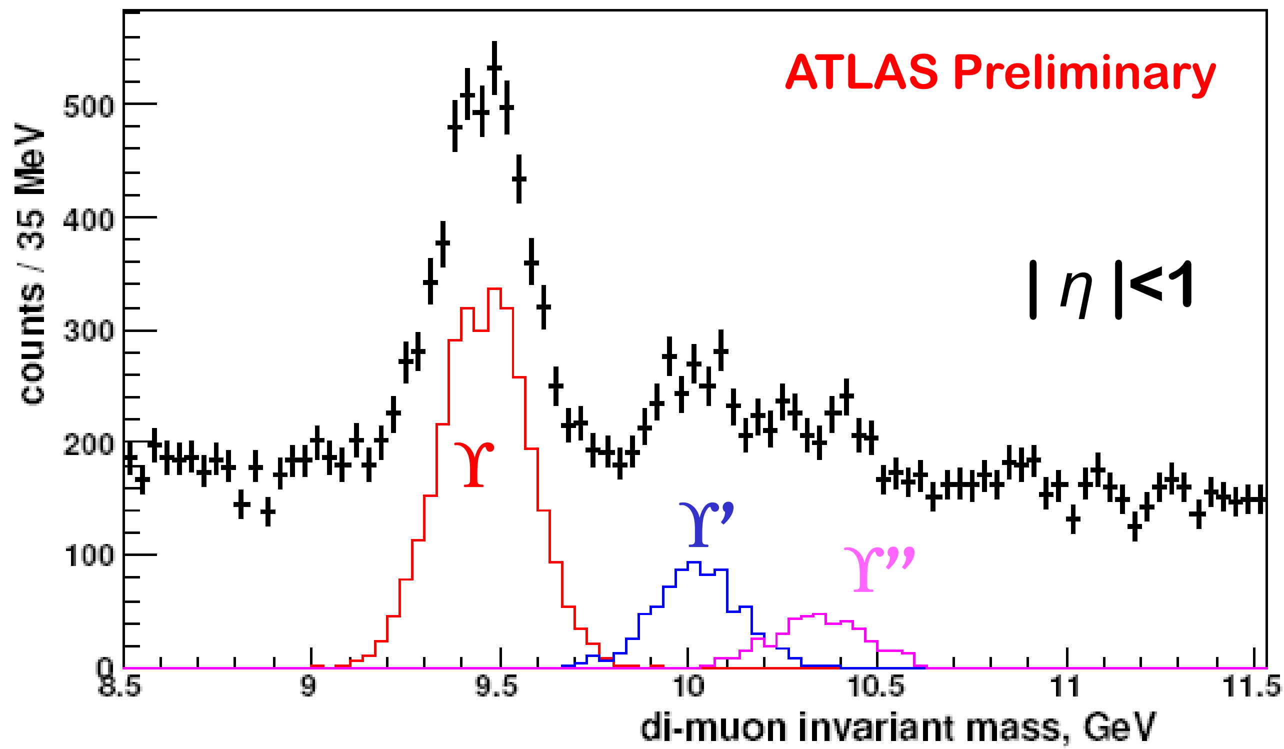
Nucl.Phys.A783,p.249,2007



Important to measure ϒ(1s) and ϒ(2s) separately in Pb+Pb collisions

Di-muon Invariant Mass Distribution

J. Phys. G: Nucl. Part. Phys. 35 (2008) 104143



Background muons:
- Charm decays
- Beauty decays
- Hadron decays
- Hadron punch-through

Statistical errors

Mass Resolution (~120 MeV) sufficient the separate various ϒ states

~19k ϒ in standard Pb+Pb (5.5 TeV) run (0.5 nb^{-1})

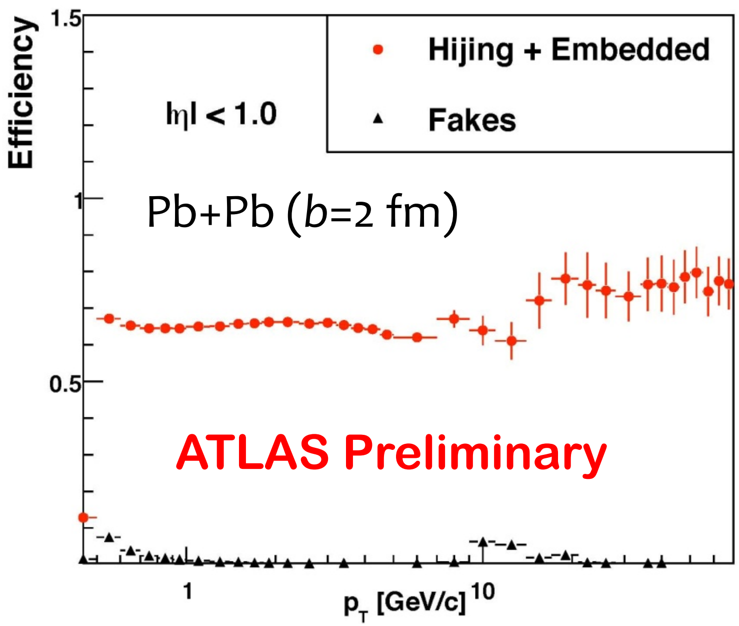
Summary

- **High potential of the ATLAS experiment to study heavy ion physics**
  - **Large acceptance and fine granularity of tracking and calorimeter systems**

- **ATLAS has excellent capability to explore many AA observables, including:**
  - **Bulk variables**
  - **Inclusive jets & direct γ**
  - **Quarkonia states (J/Ψ, Υ)**
  - **Low-x physics from ZDC**
  - **Jet-jet, γ-jet, Z-jet correlations**
  - **Ultra-peripheral collisions**
  - **Heavy quarks (c, b)**
  - **…**

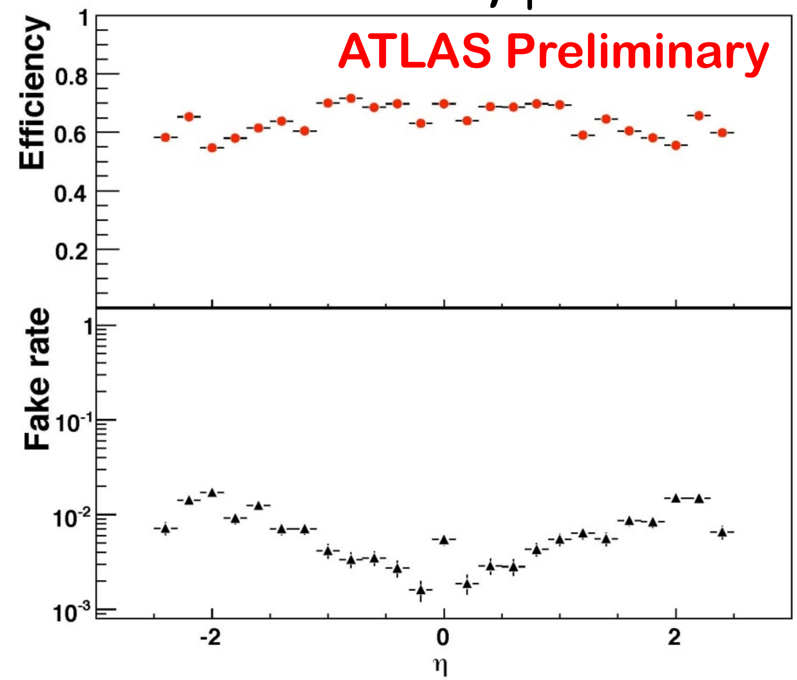
- **p+p data will be used as a reference for Pb+Pb collisions and allow to test different methods in AA analyses**

Tracking



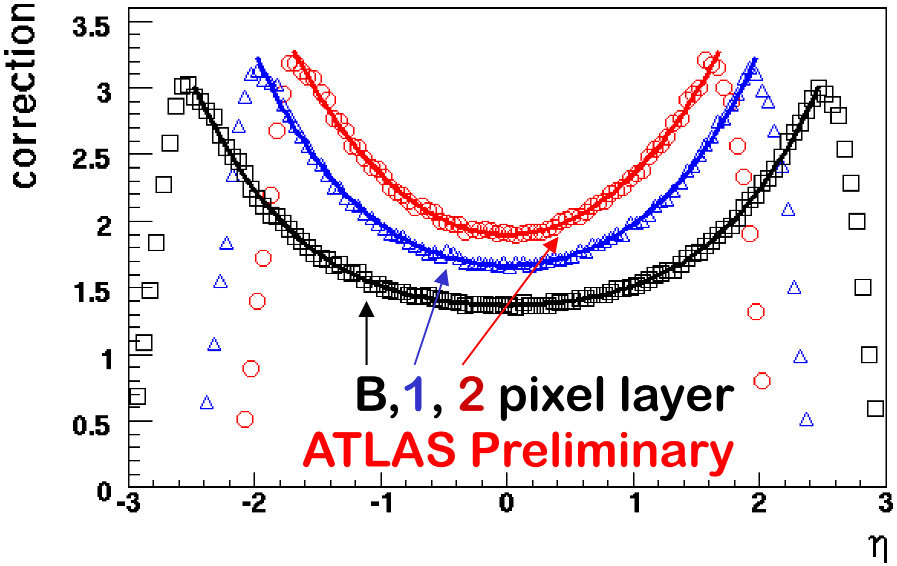
Acceptable efficiency of about 70%, negligible fake rate above 1 GeV/c

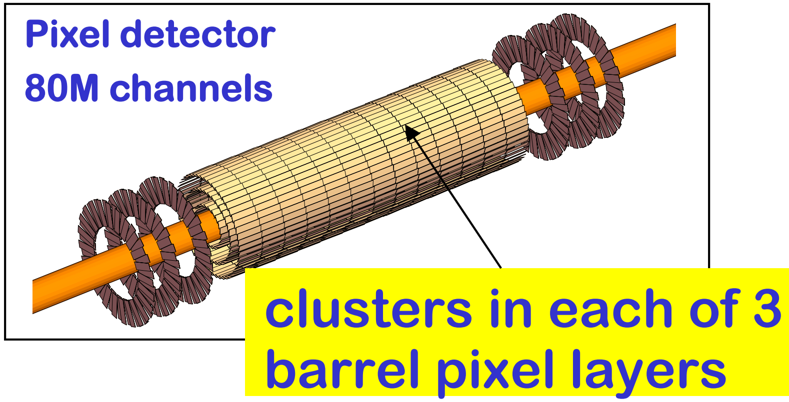
tracks with 3 < p_T < 8 GeV



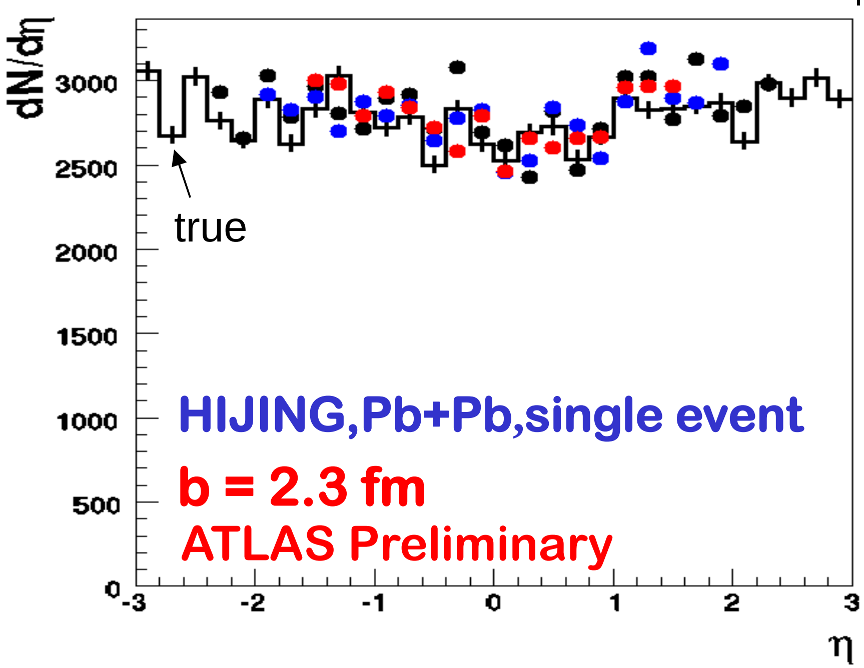
Negligible dependence on η

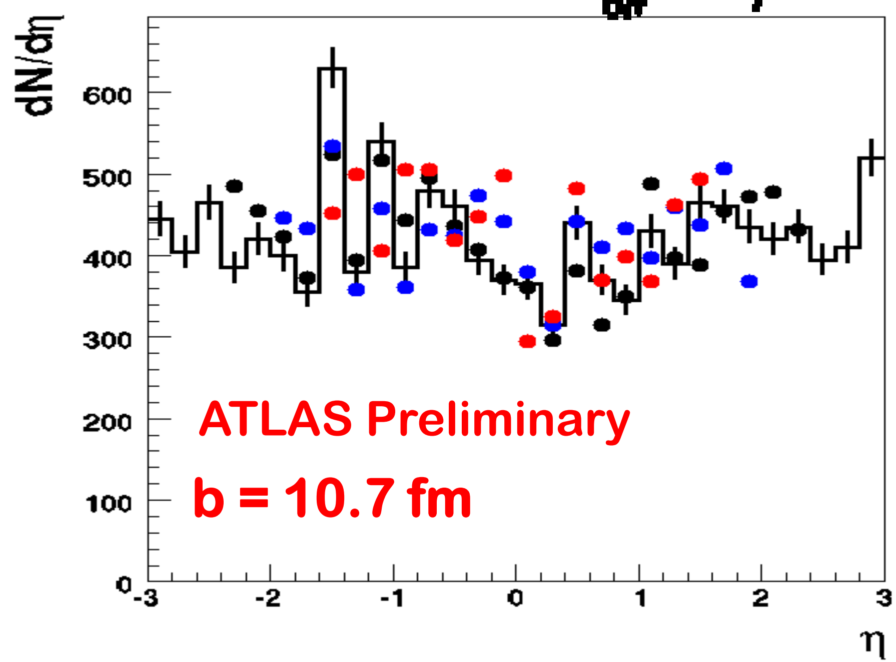
Multiplicity from Si Hit Counting





$$\text{correction} = \frac{\langle dN_{clus}/d\eta \rangle}{\langle dN_{ch}/d\eta \rangle}$$

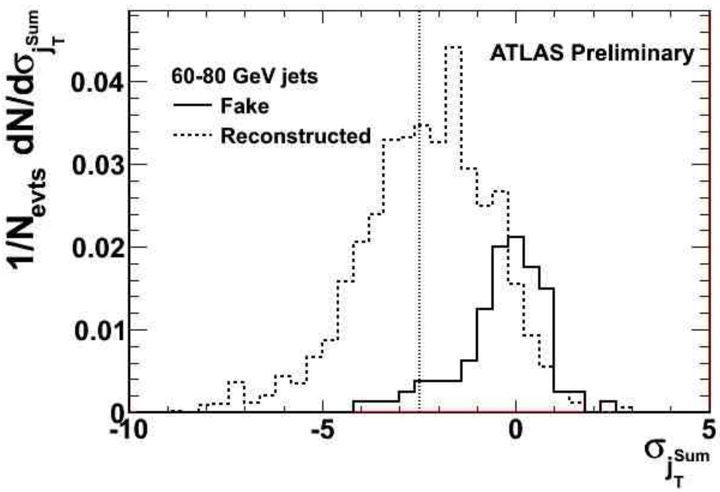


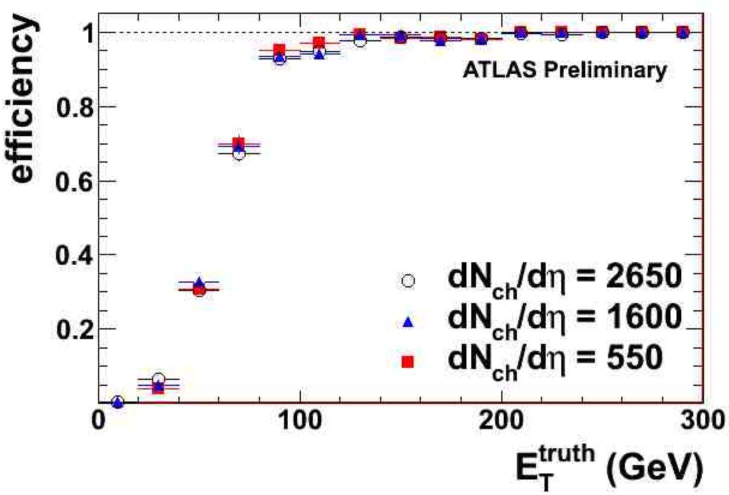


Performance of Cone Jet Algorithm

$$j_T^{Sum} = \sum_{cell} E_T^{cell} \sin R_{cell}$$

$$\sigma_{j_T^{Sum}} = \frac{j_T^{Sum}(E_T) - \langle j_T^{Sum}\rangle (E_T)}{\sigma(E_T)}$$





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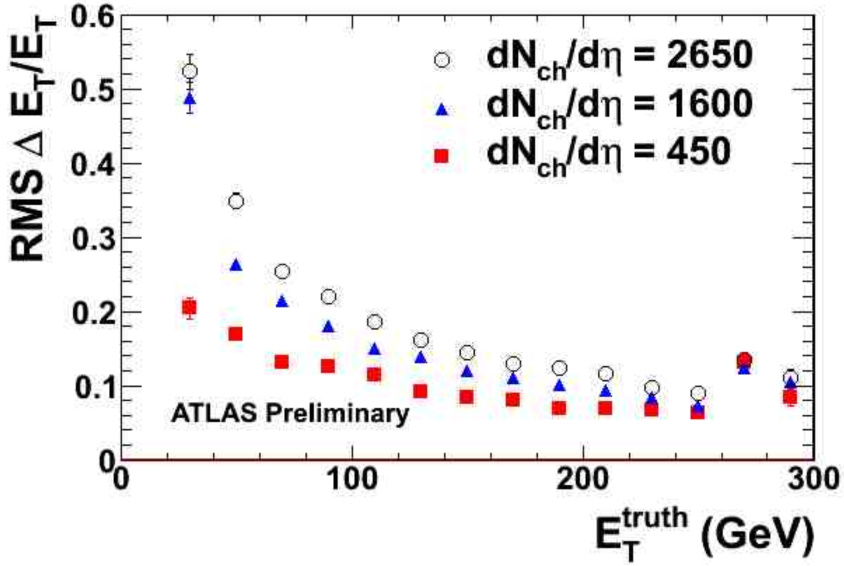
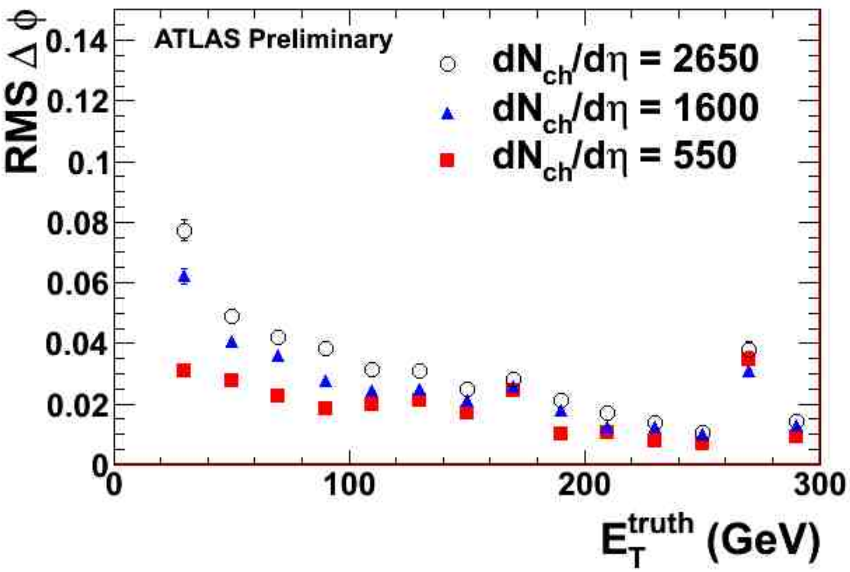
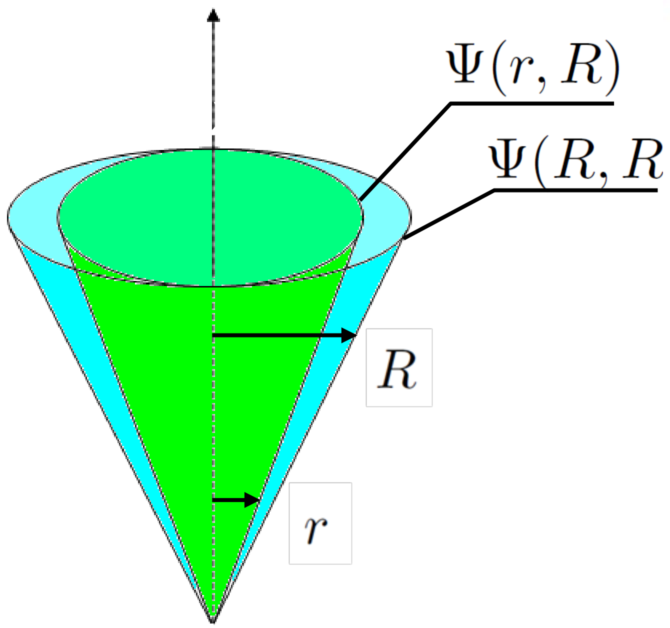


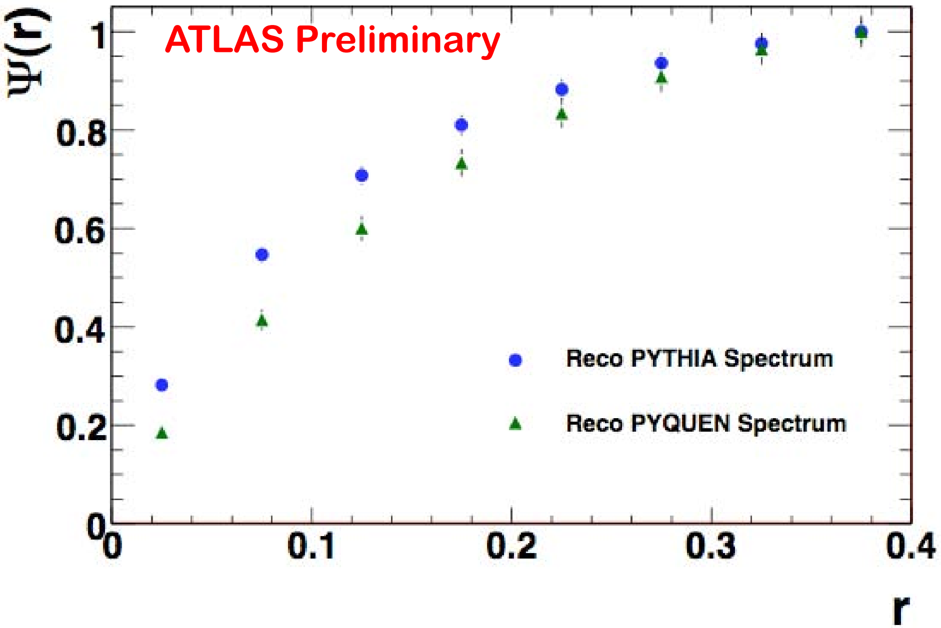


Jet Shapes

Jet shape can be modified by in medium energy loss



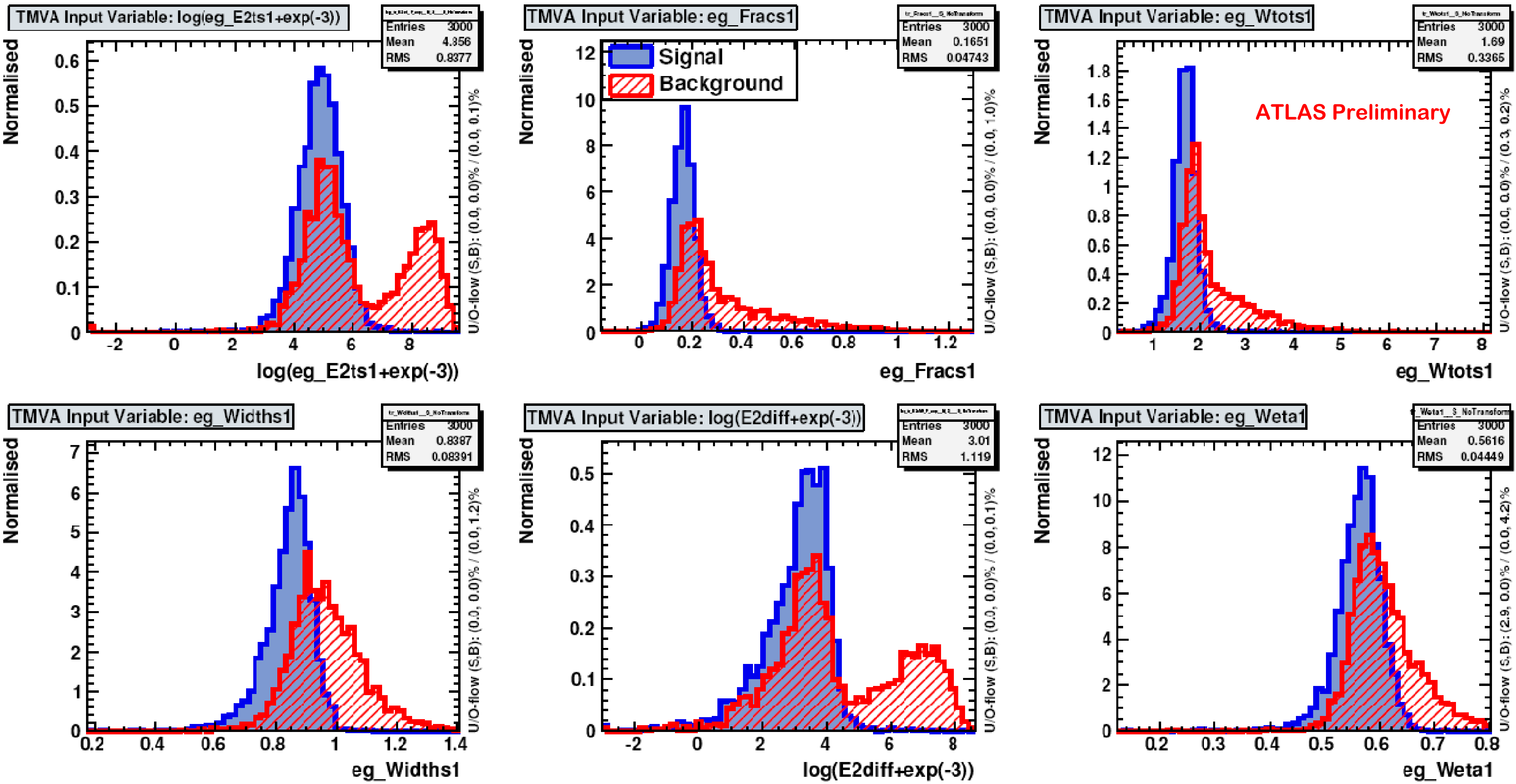
$$\Psi(r, R=0.4) = \frac{\int_0^r E_T(\rho)\mathrm{d}\rho}{\int_0^R E_T(\rho)\mathrm{d}\rho}$$



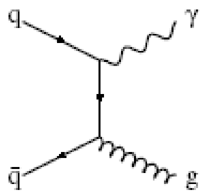
- Relative energy transfer from jet center to jet periphery due to energy loss effects
- Jet quenching modifications well within experimental sensitivity

Six cut variables

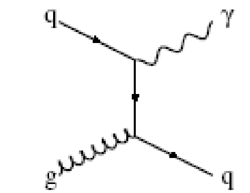
$|\eta|<0.75$, 45 GeV$<E_T<$ 70 GeV



Direct γ

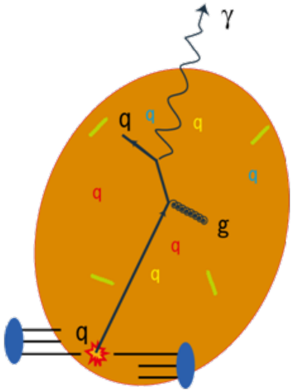


Annihilation



Compton Scattering

Hard scattered partons interact with thermal partons in matter



Isolation cut details

ATLAS Preliminary	$dN/d\eta = 2700$	$dN/d\eta = 1700$
Track-based cut	$0.02 < R < 0.2$ $p_T < 2.5$ [GeV]	$0.02 < R < 0.25$ $p_T < 2.5$ [GeV]
Energy-based cut	$R < 0.2$ $\sum E_T < 31 + 0.025 E_\gamma$ [GeV]	$R < 0.2$ $\sum E_T < 17.2 + 0.025 E_\gamma$ [GeV]
Efficiency	0.60	0.70
Absolute rejection at 50 GeV	8	10

	$dN/d\eta = 460$	p+p
Track-based cut	$0.02 < R < 0.35$ $p_T < 2.0$ [GeV]	$0.02 < R < 0.5$ $p_T < 1$ [GeV]
Energy-based cut	$R < 0.2$ $\sum E_T < 5.6 + 0.025 E_\gamma$ [GeV]	$R < 0.2$ $\sum E_T < 0.9 + 0.025 E_\gamma$ [GeV]
Efficiency	0.70	0.91
Absolute rejection at 50 GeV	14	16

Direct γ Performance