Heavy Ion Physics with the ATLAS Detector

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for the ATLAS Collaboration

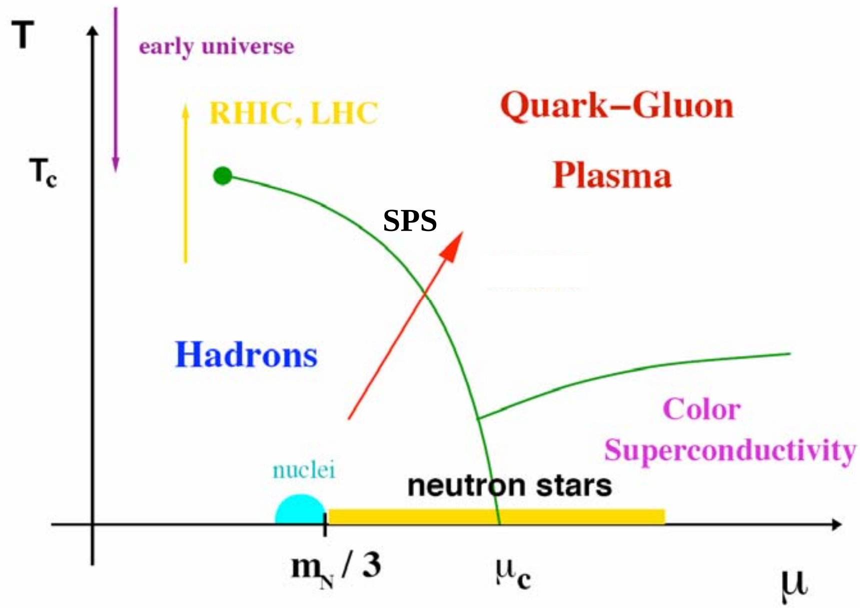
LIP

Physics at the LHC 2010, 7–12 June, DESY, Hamburg

Heavy Ion Physics

- Systematic study of a hot, dense and strongly coupled system

- Extending our understanding of QCD by studying distinct phases of matter: hadronic vs. partonic deconfined system (Plasma of Quarks and Gluons)

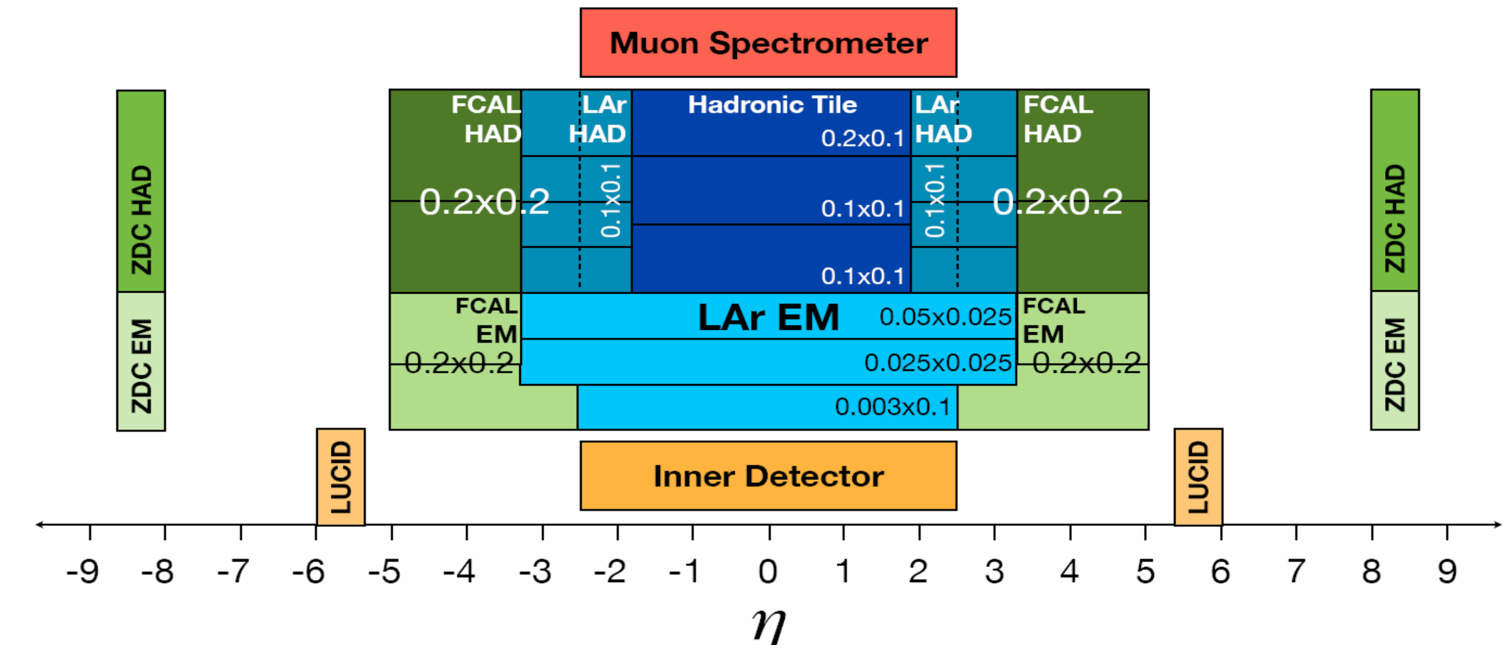


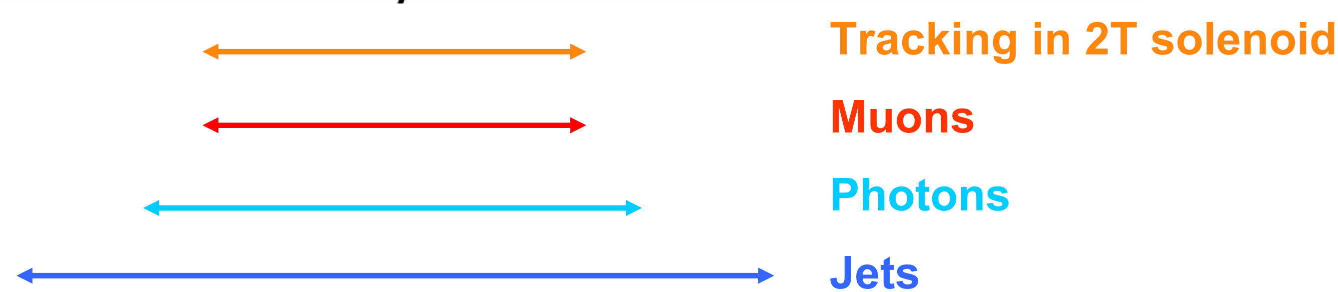
$\sqrt{s}$: 17 GeV@SPS 200 GeV@RHIC 5.5 TeV@LHC

Colliding nuclei: Pb+Pb Au+Au Pb+Pb

ATLAS Acceptance

Full azimuthal coverage





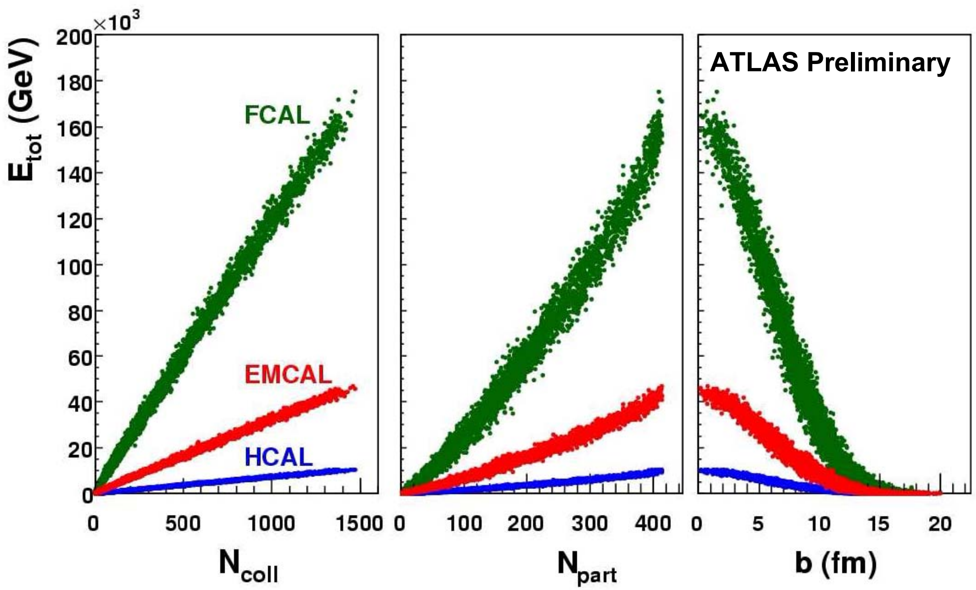
Large acceptance and precise tracking, associated to very good Trigger/DAQ capabilities, ensure a powerful Heavy Ion Program

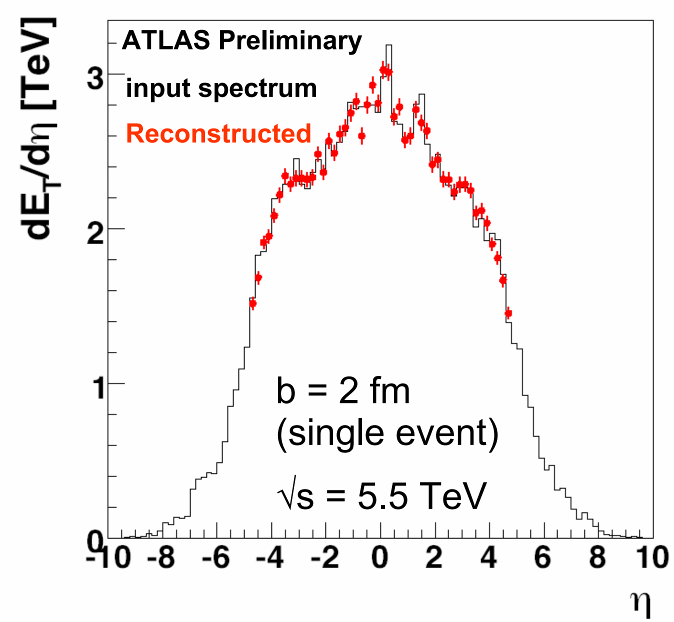
Global Observables – I

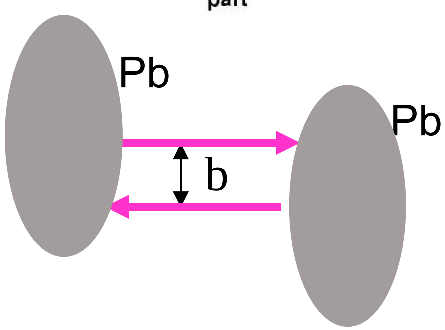
Day-1 physics

Get insight into the initial-state energy densities which control the dynamical evolution and jet quenching

√s = 5.5 TeV



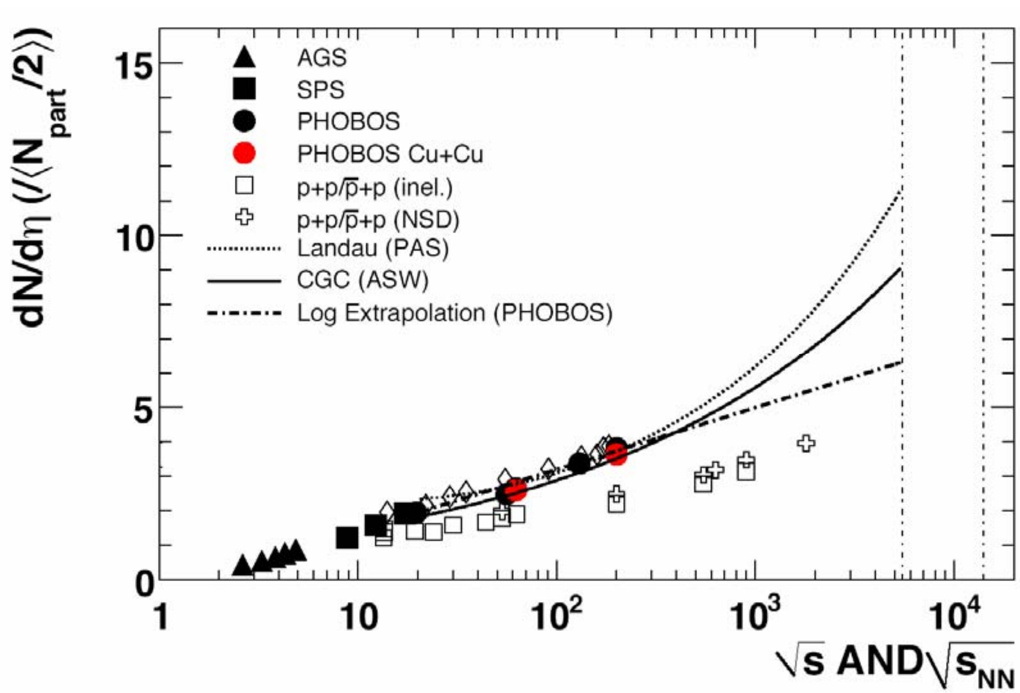




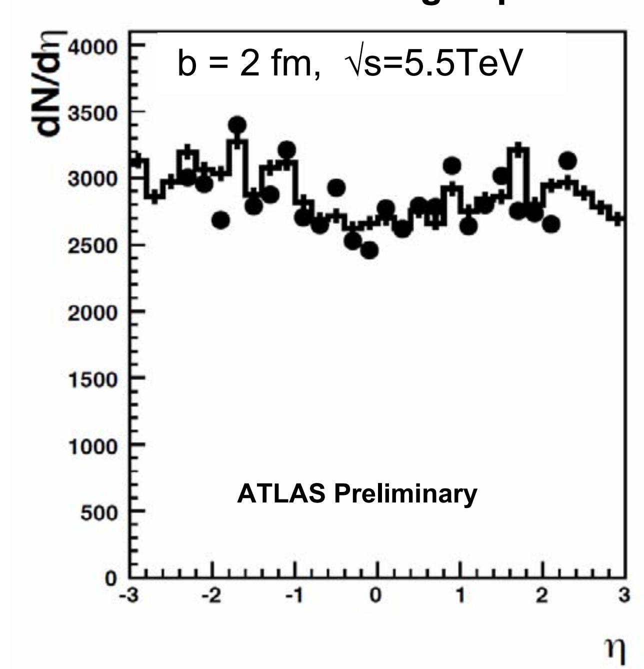
Global Observables – II

Day-1 physics

Inclusive particle production predictions for LHC

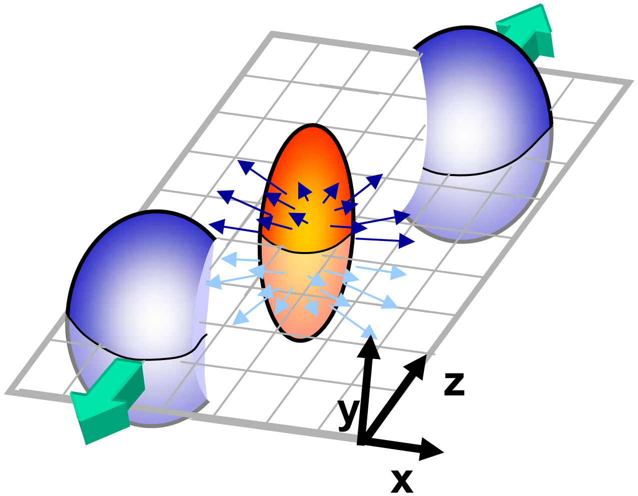


Reconstructed charged particles



Within a few days of LHC Pb+Pb running entire classes of models may be excluded

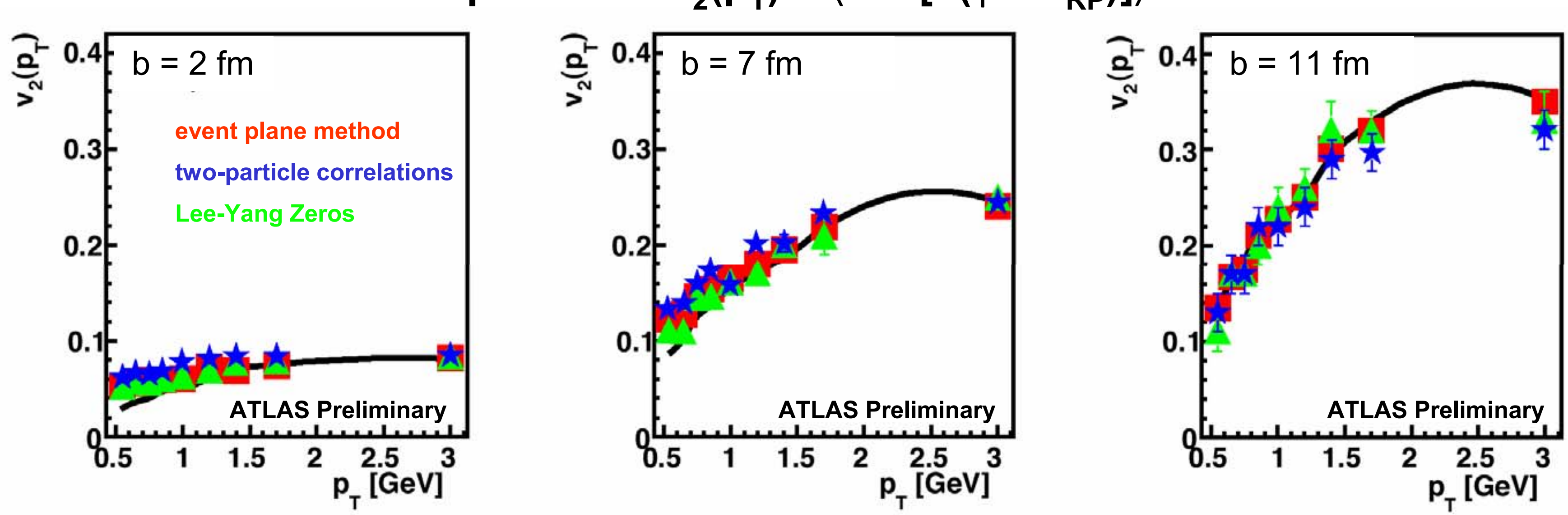
Global Observables – III



Anisotropic spatial collective motion leads to an elliptical asymmetry in the momentum space

$$E\frac{d^3N}{dp^3} = \frac{1}{2\pi}\frac{d^2N}{dp_T^2dy}\left(1+2\sum_{n=1}^{\infty}v_n(p_T,y)\cos[n(\phi-\Phi_{RP})]\right)$$

elliptic flow: $v_2(p_T) \equiv \langle\cos[2(\phi - \Phi_{RP})]\rangle$

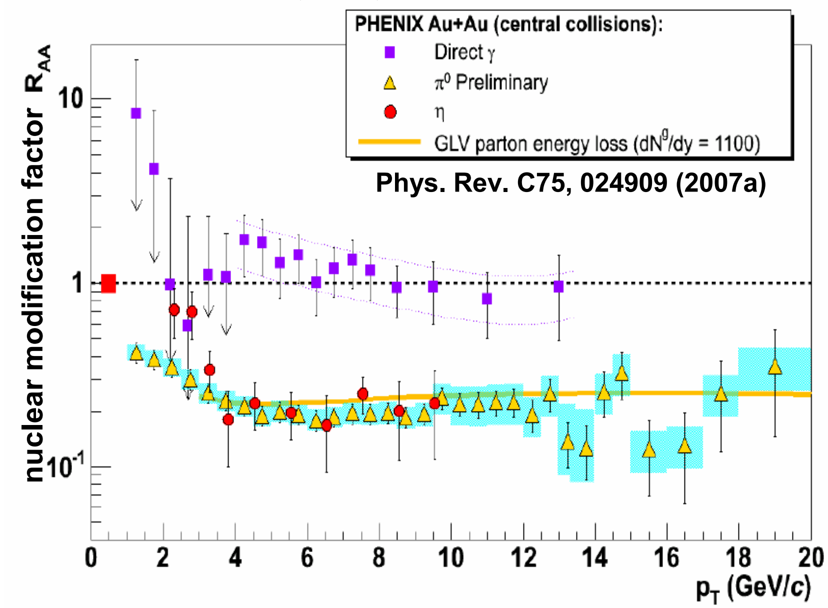


Lee-Yang Zeros method less sensitive to non-flow effects

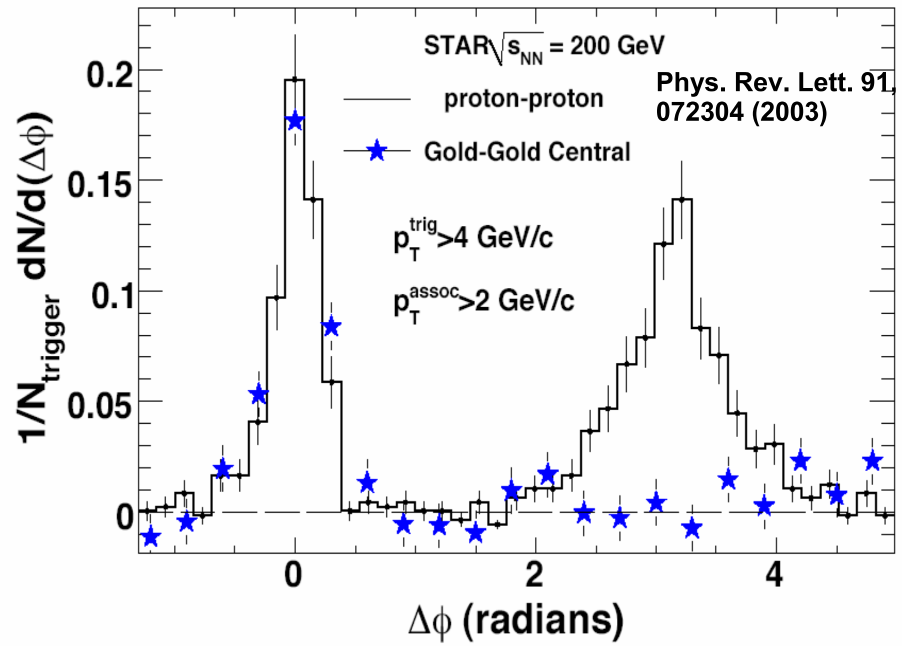
Jet Production in Pb+Pb Collisions

Hard processes probe the very earliest phase of the collisions. One of the most hot topics of the LHC Heavy Ion Program will be the jet quenching measurements.

$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{dN/dp_T \,|_{AA}}{dN/dp_T \,|_{pp}}$$



correlations between trigger particle and associated charged hadrons

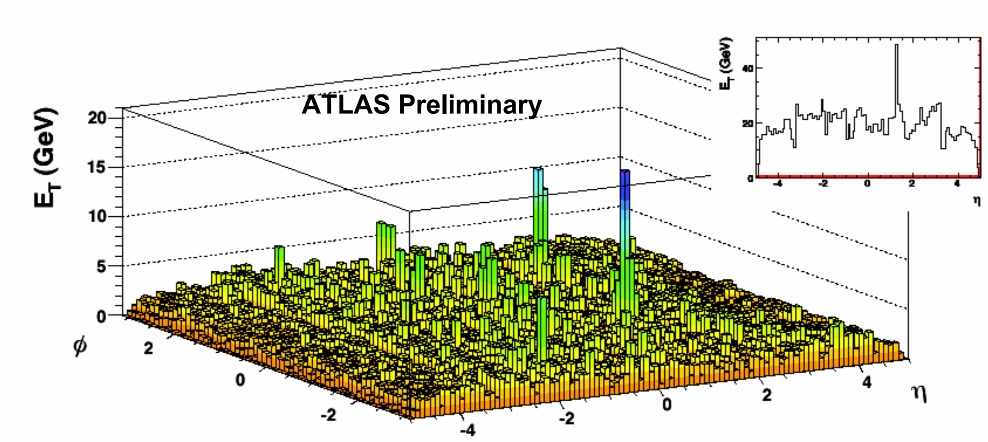


Neutral hadrons suppressed by a factor of 5

Recoil jets suppressed in central Au+Au collisions

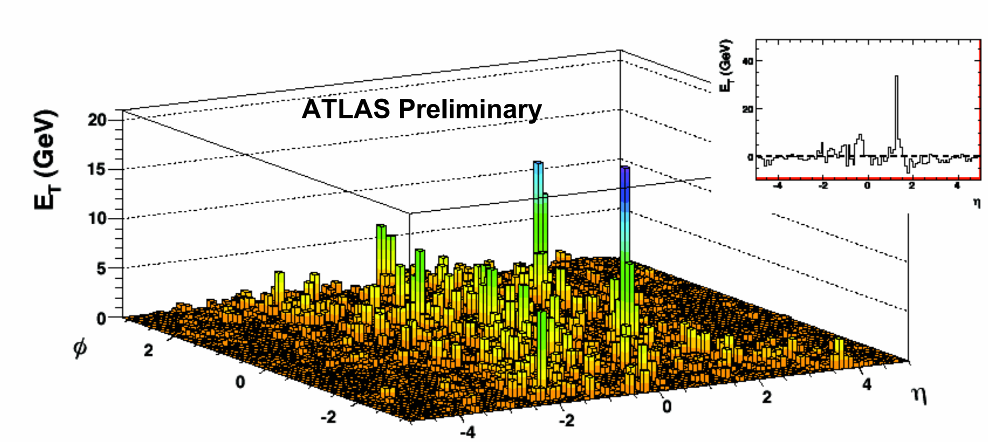
Jet Reconstruction – I

Challenging in the heavy ion environment, but the large acceptance of the ATLAS calorimeters allows full jet reconstruction



PYTHIA di-jets embedded in HIJING central event

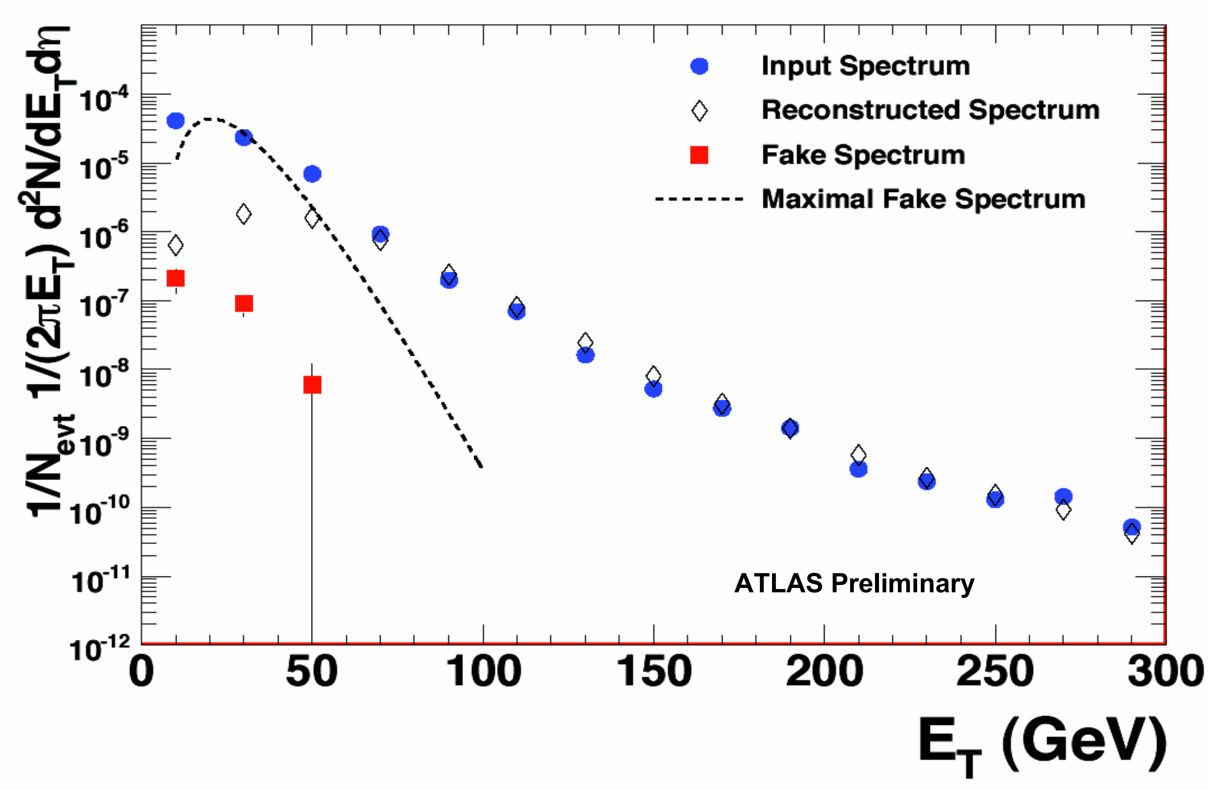
- **without quenching**
- **limit $Q^2 < 100$ GeV^2 (no HIJING jets)**



Underlying event subtraction by removing the E_T average from the seeded jet signal

Seeded cone jets, $\Delta \mathbf{R} = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < \mathbf{0.4}$

Jet Reconstruction – II



Seeded cone jets,

$\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < 0.4$

No Q^2 cut in HIJING

At 70 GeV (for b = 2 fm):

Efficiency ~ 70%

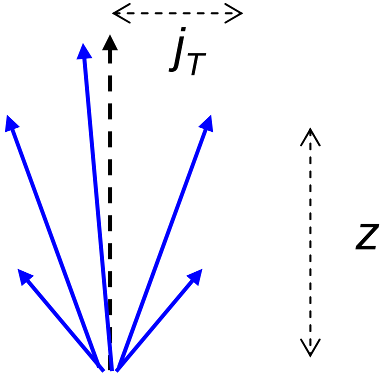
B/B+S < 1%

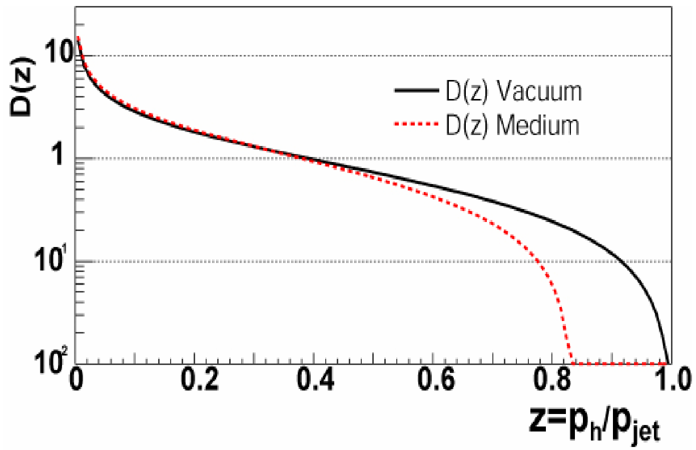
$\Delta E_T/E_T$ ~ 25%

Reconstructed spectrum not corrected for efficiency and energy resolution

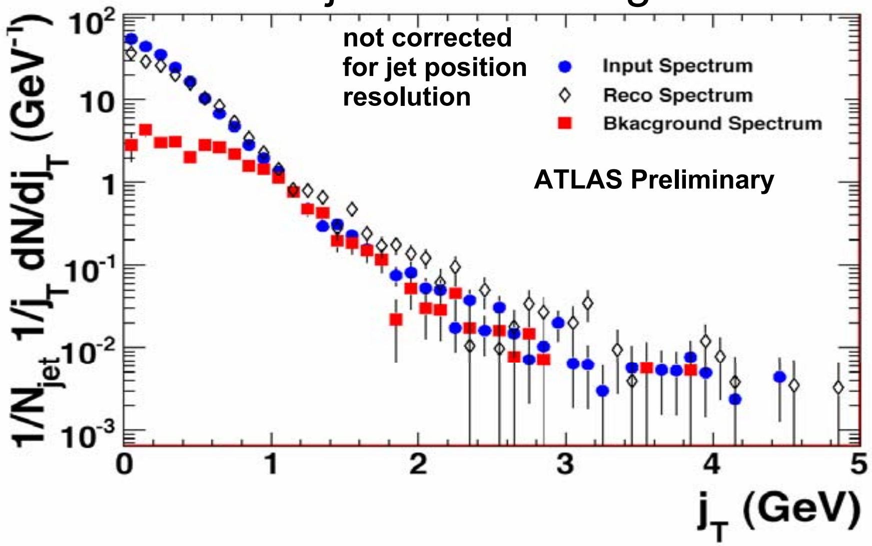
Dashed line represents the absolute fake jet rate from pure HIJING events prior to background jet rejection

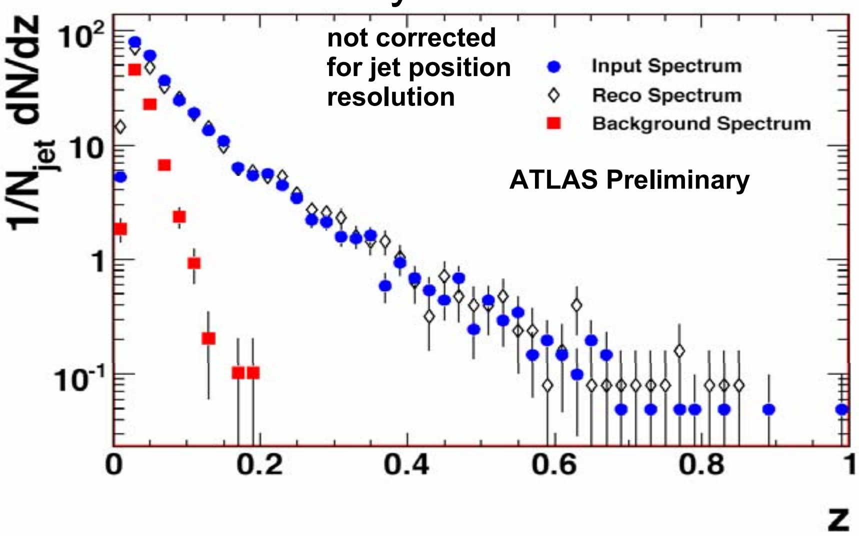
Jet Fragmentation





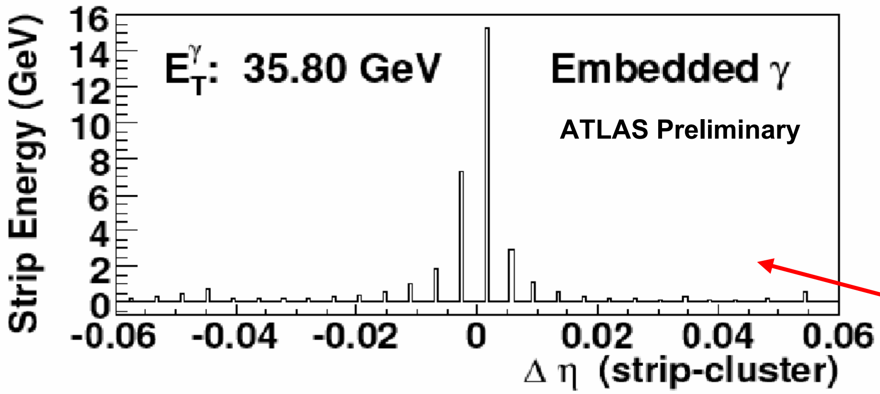
reconstructed distributions of j_T and z for p_T > 2 GeV tracks matched to 70 GeV jets after background subtraction and efficiency correction

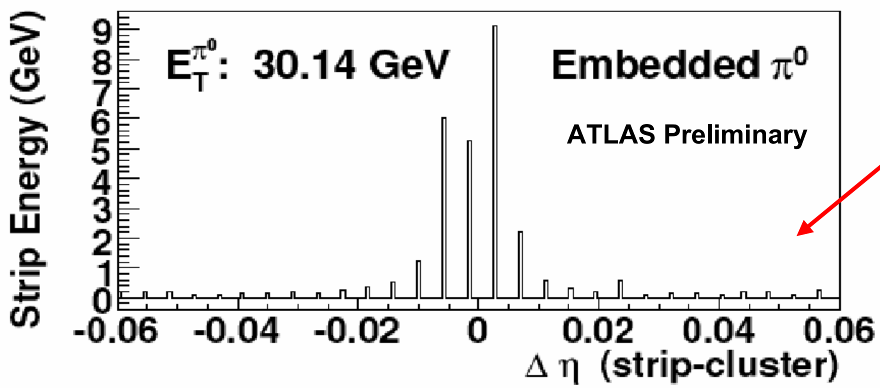


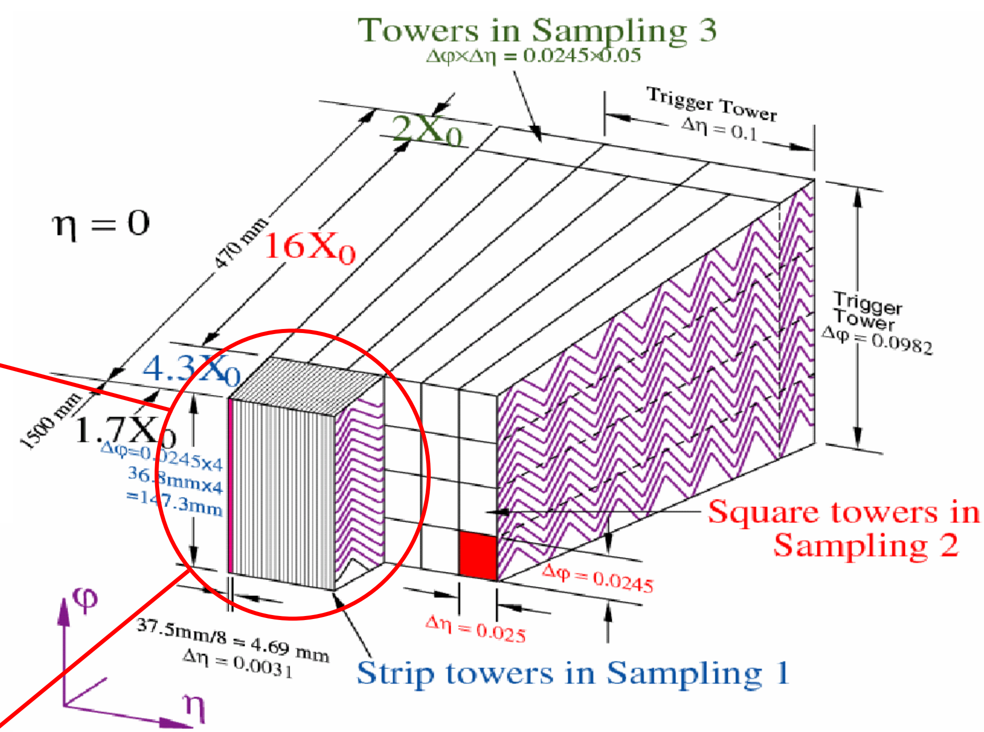


Good agreement between reco and input spectra

Photon Identification







Excellent capabilities for direct γ measurements and rejection of π^0, η over a broad η, ϕ range.

Crucial for jet energy scale in Pb+Pb.

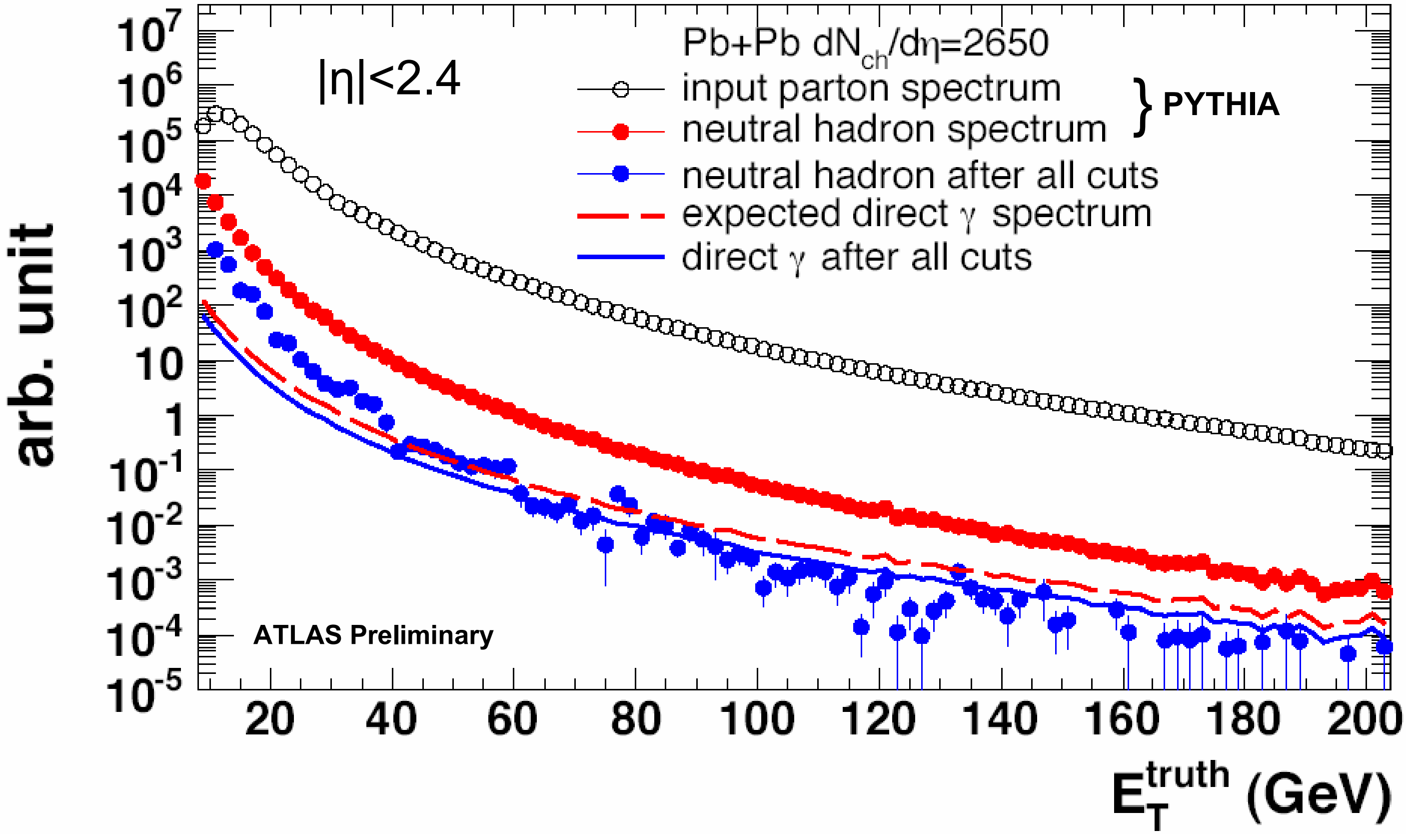
Longitudinal segmentation: (unique strength of ATLAS)

- **3 layers for $|\eta| < 2.4$**
- **first strip layer: $\Delta\eta = 0.003$**

$\sigma_E/E = 10\%/\sqrt{E} \oplus 24.5\%/E \oplus 0.7\%$

Linearity < 0.5% up to 300 GeV

Direct Photons Identification Performance



Above 60 GeV the neutral hadron spectrum falls below direct γ

For 100 GeV photons: S/B ~ 1 (R_{AA}= 1, worst case); S/B ~ 5 (R_{AA}= 1/5, as observed at RHIC)

Rates estimated: 200k at E_T > 30 GeV, 10 k at E_T > 70 GeV (if R_{AA} = 1/5) and for one month of LHC run of 0.5 nb^{-1} and $\sqrt{s}$=5.5 TeV.

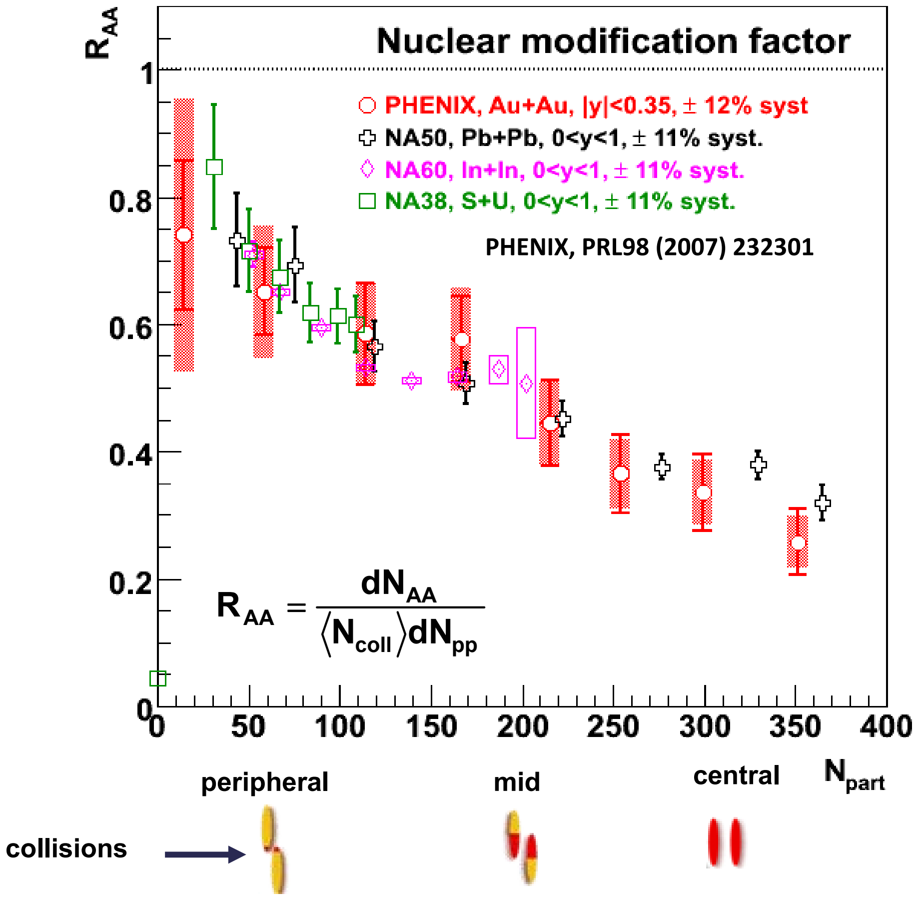
Quarkonia Studies

Quarkonia suppression is predicted by lattice QCD calculations

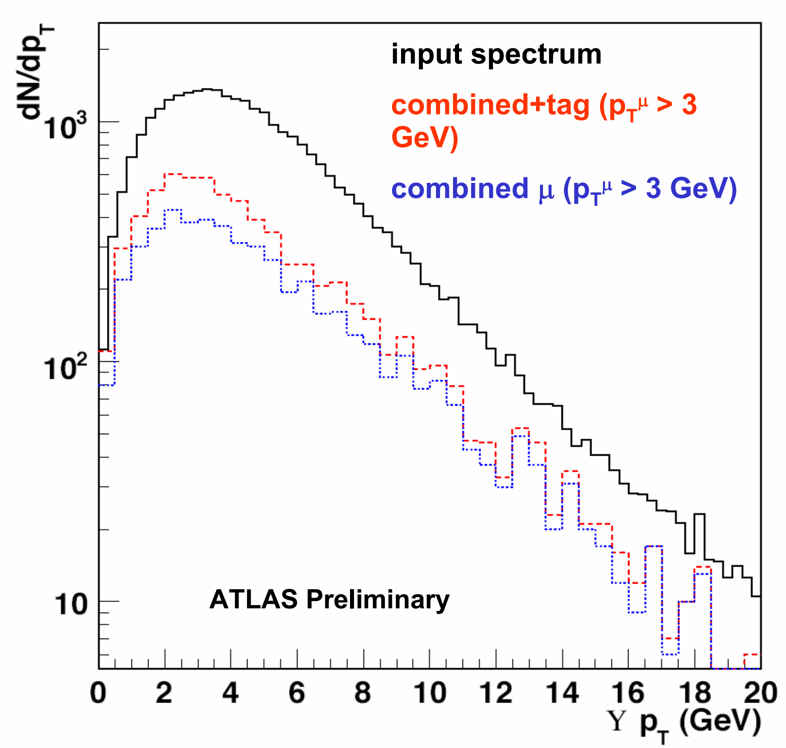
State	χ_c	ψ'	J/ψ	Υ'	χ_b	Υ
T_{dis}	$\leq T_c$	$\leq T_c$	$1.2T_c$	$1.2T_c$	$1.3T_c$	$2T_c$

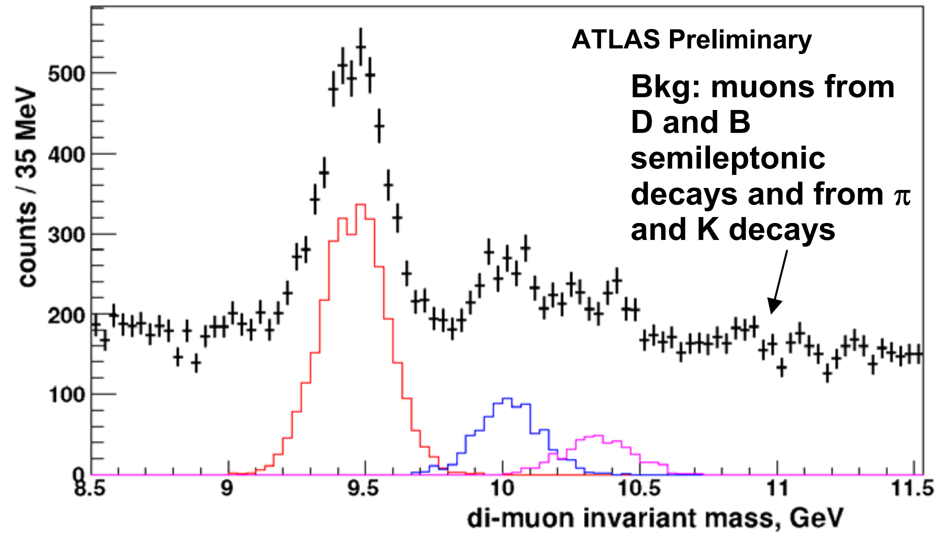
J/ψ anomalous suppression by Debye colour screening (Matsui and Satz, 1986)

→ One of the most striking signatures for the QGP formation



Υ → μ⁺μ⁻ Reconstruction

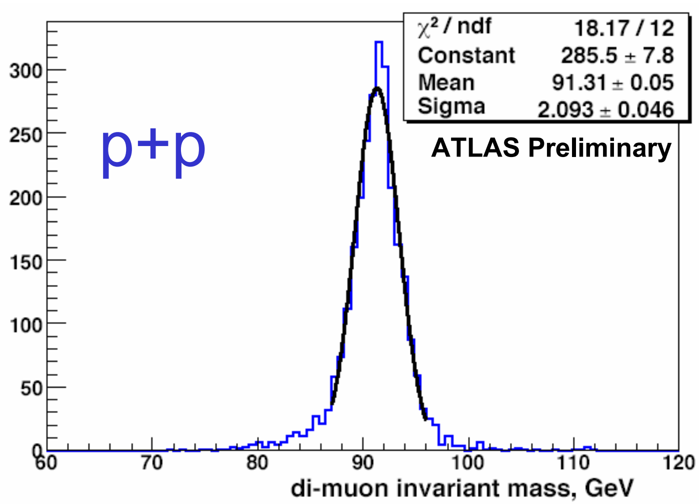


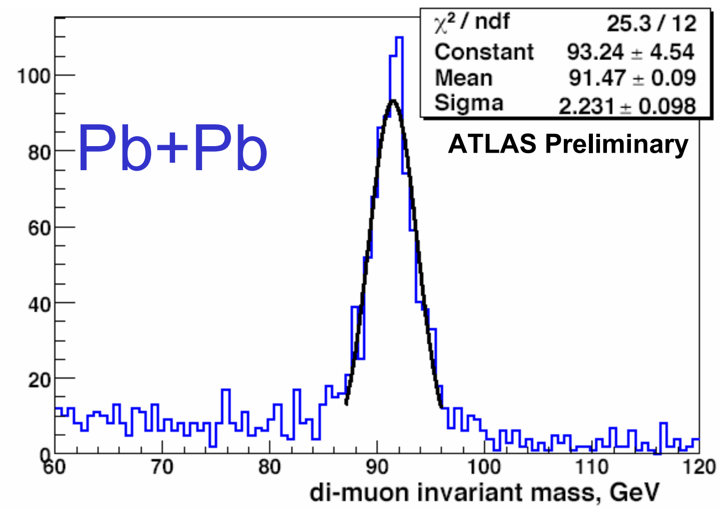


Estimated rates for one month LHC run of 0.5 nb^{-1} and $\sqrt{s}$=5.5 TeV

	$\|\eta\| < 1$	$\|\eta\| < 1.5$	$\|\eta\| < 2.5$
Acceptance x efficiency	6.0% 3.6%	10.8% 6.8%	23.2% 17.2%
Mass resolution	147 MeV	162 MeV	182 MeV
Rate/month	9100 5500	16400 10300	35200 26100

Z measurements





Mass resolution weakly affected by the high-multiplicity of the heavy ion environment (within 1σ difference)

Acceptance x Efficiency	**60%**
Mass Resolution	**2.2 GeV**
Rate/year	**8000**

Estimated rate for one month LHC run of 0.5 nb^{-1} and using NLO pQCD rapidity distributions

Good prospects for Z–Jet correlations studies

Heavy Ions Run in 2010

Parameter	Nominal	2010
Beam energy/nucleon [TeV]	2.76	1.38
Peak luminosity [$cm^{-2}s^{-1}$]	10^{27}	10^{25} — $2x10^{25}$
Interaction rate	7.7 kHz	80 — 160 Hz
# bunches	592	62
Bunch spacing [ns]	100	1350

Trigger plans for 2010

- For Pb+Pb collisions, at nominal luminosity, the expected interaction rate is 7.7 kHz, a factor of 10 smaller than LVL1 bandwith (75 kHz)
  - ✓ No rejection at LVL1; HLT in transparent mode

4 trigger signatures: Minbias, Jet, Muon

UPC (Ultra-Peripheral Collisions; not covered in this talk) planned

Summary

High potential of the ATLAS experiment to carry on the Heavy Ion Program of the LHC

Excellent capabilities to explore many A+A observables:

- Bulk variables as $dN_{ch}/d\eta$, $dE_T/d\eta$ and $v_2(p_T)$
- Inclusive jets and direct photons
- di–jet (γ–jet and Z–jet) correlations
- Quarkonia states

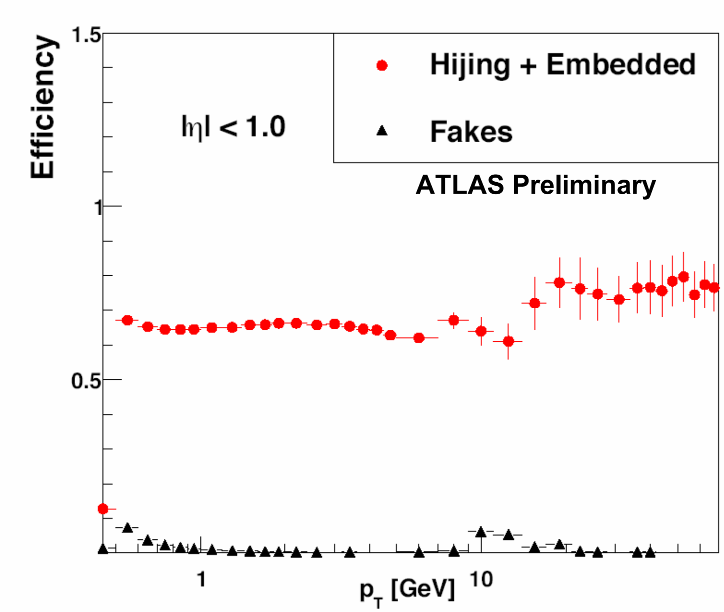
p+p data will be used as a reference for Pb+Pb

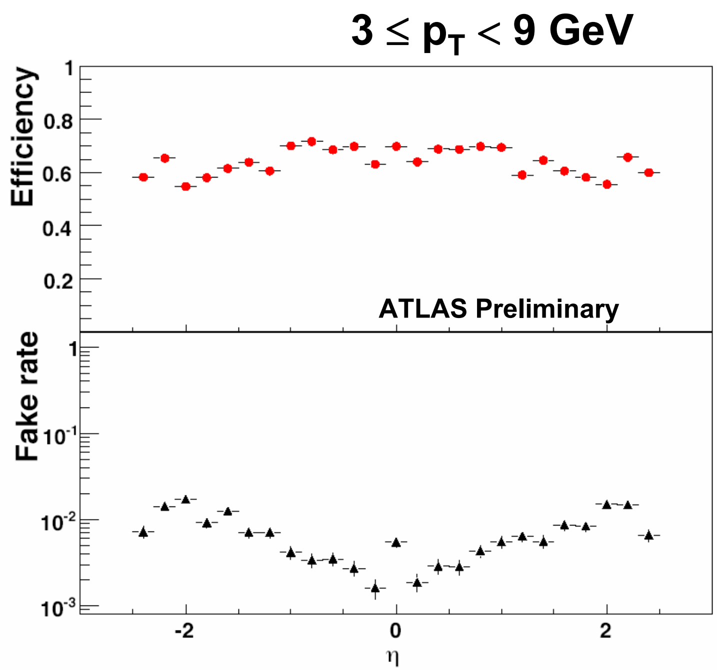
Not covered in this talk (but promising):

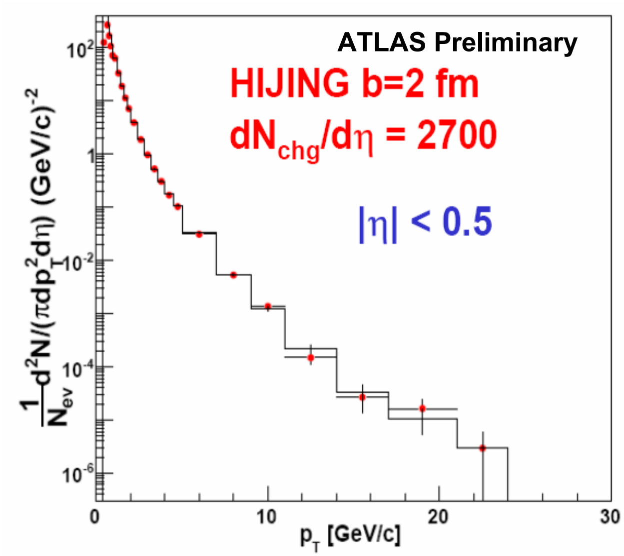
- Heavy flavour jets
- Zero Degree Calorimeters in the HI program
  - ✓ Ultra–Peripheral Collisions
  - ✓ Low-x physics

Backup

Tracking



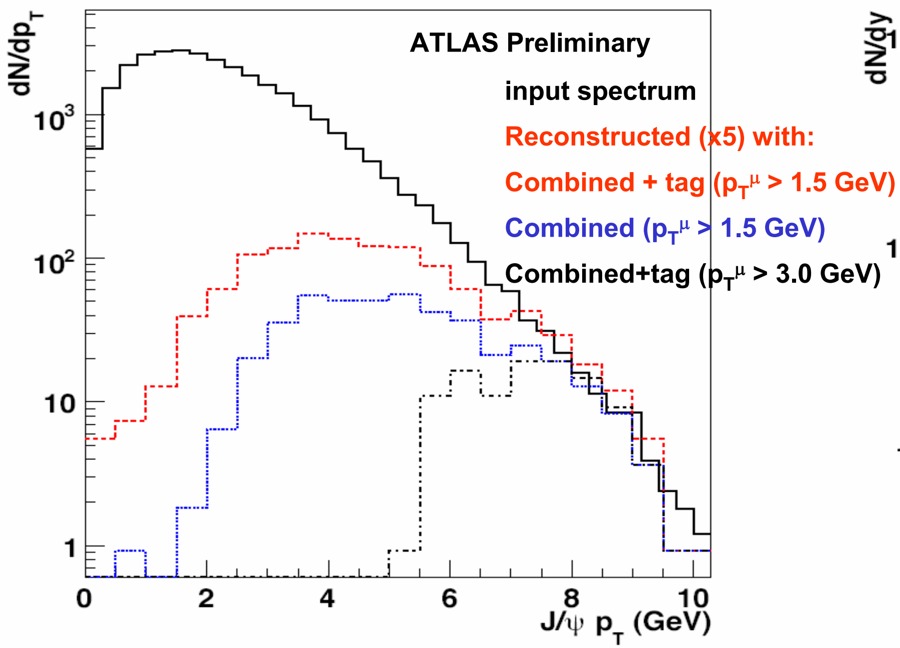


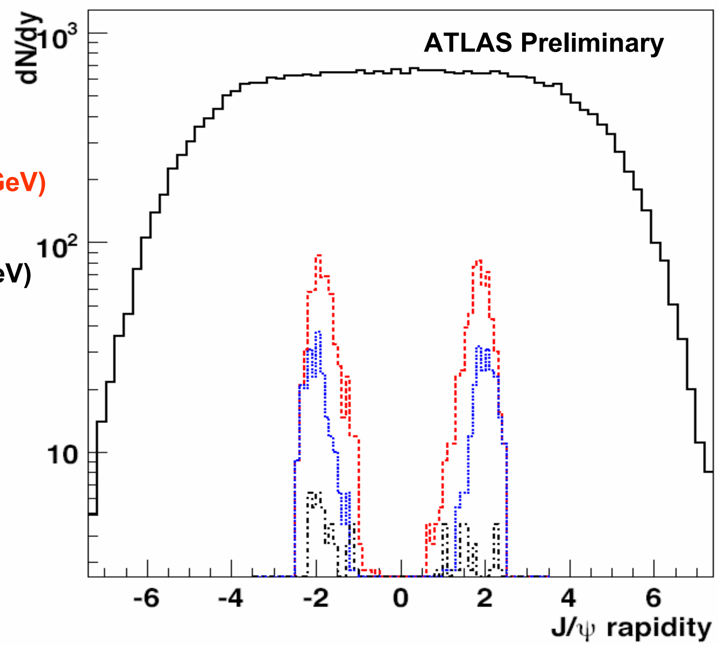


Good agreement

$J/\psi \to \mu^+\mu^-$ Reconstruction

Important study to establish connection with SPS and RHIC results





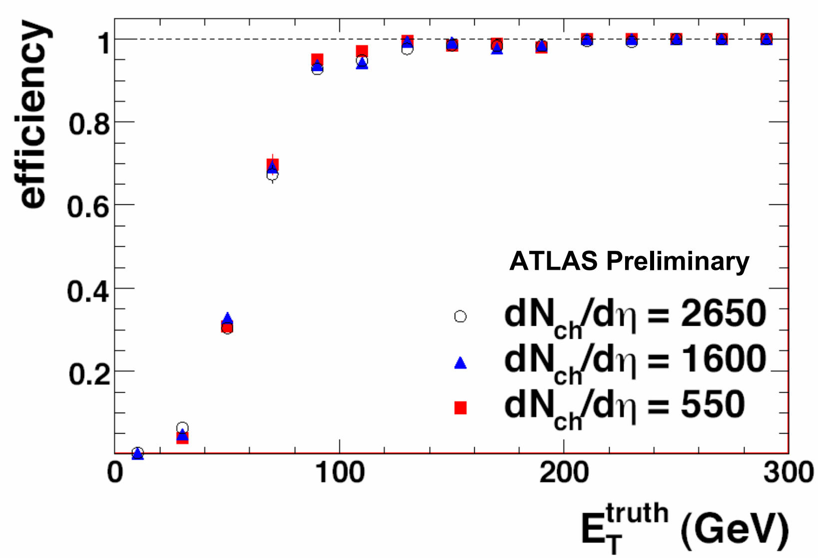
A low p_T trigger, based on φ information from μ-trigger chambers, is under study (worse bkg, better rate and significance)

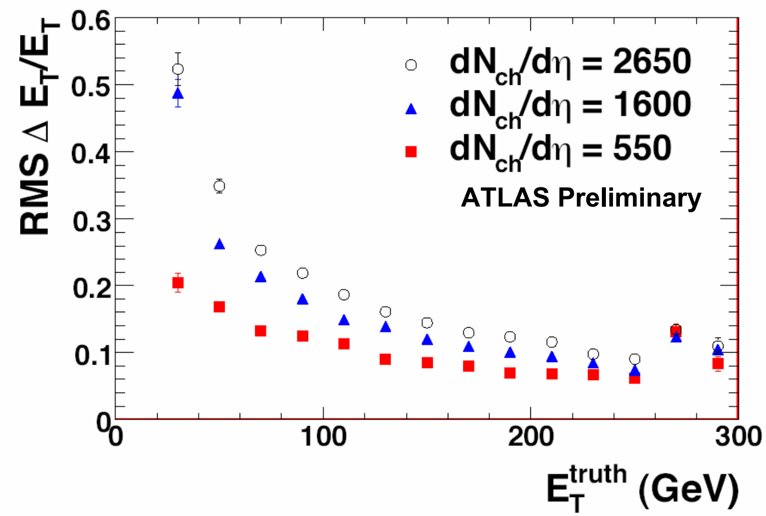
Estimated rates for one month LHC run of 0.5 nb^{-1} and $\sqrt{s}$=5.5 TeV

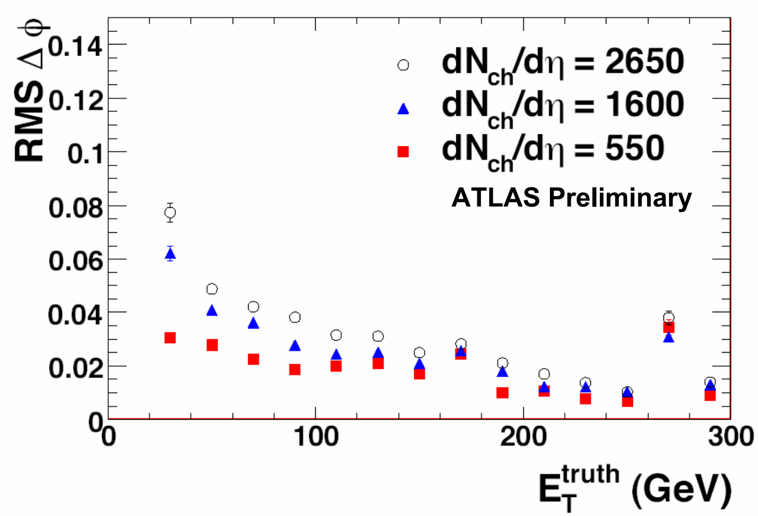
	p_T^μ > 3 GeV	p_T^μ > 1.5 GeV
Acceptance x efficiency	0.075% 0.051%	0.785% 0.301%
Mass resol.	69 MeV	81 MeV
$S/\sqrt{S+B}$	74 66	158 111
Rate/month	19000 13000	192000 74000

Jet Reconstruction Performance

reconstruction efficiency, E_T and ϕ-position resolutions for 3 multiplicity ranges

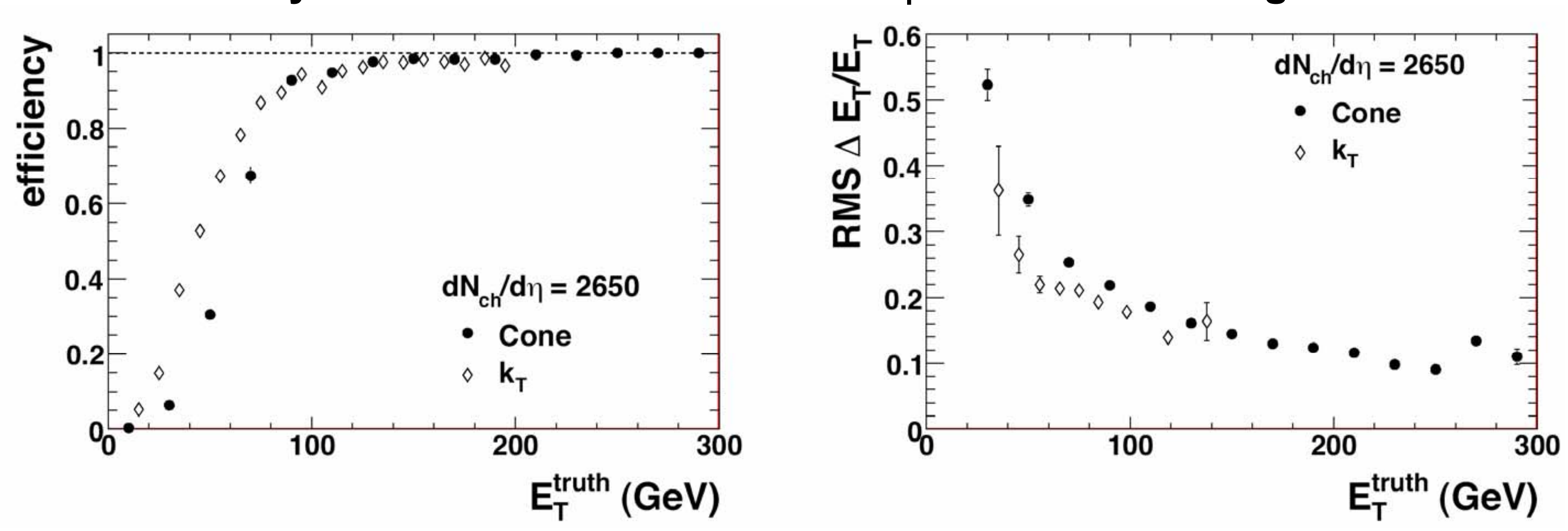






Jet Reconstruction Performance

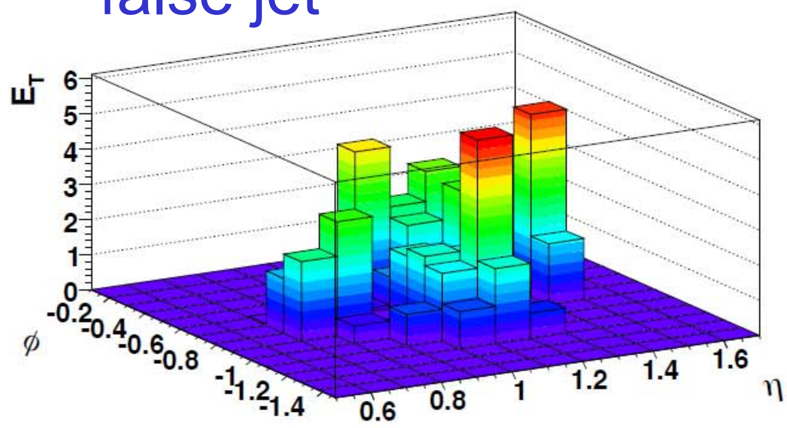
efficiency and resolution for cone and k_T reconstruction algorithms



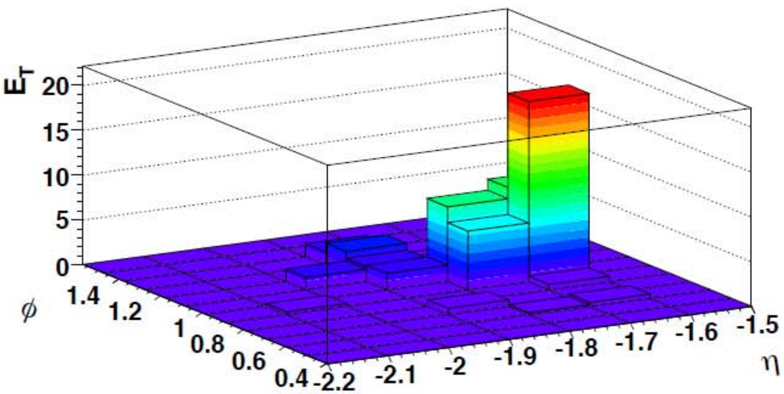
Anti-k_T algorithm under study; promising.

Jet Fakes Rejection

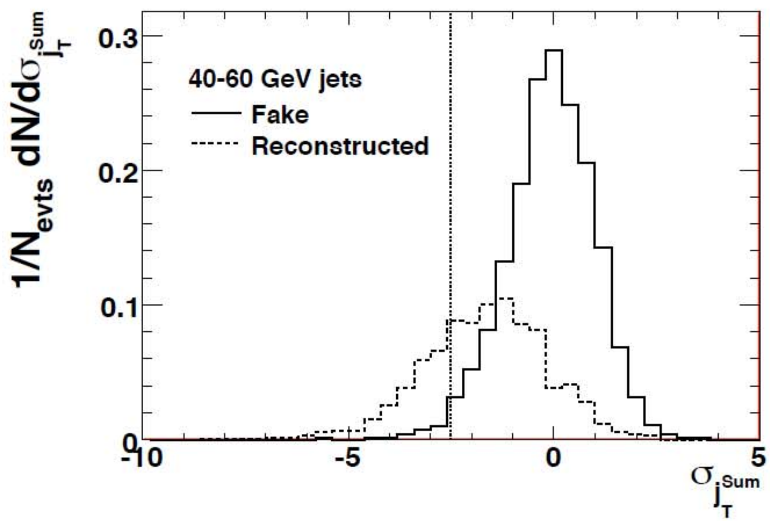
false jet

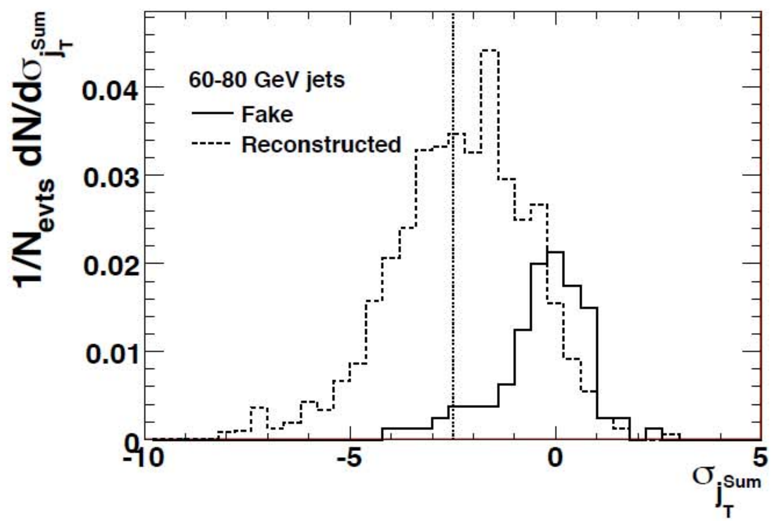


real jet



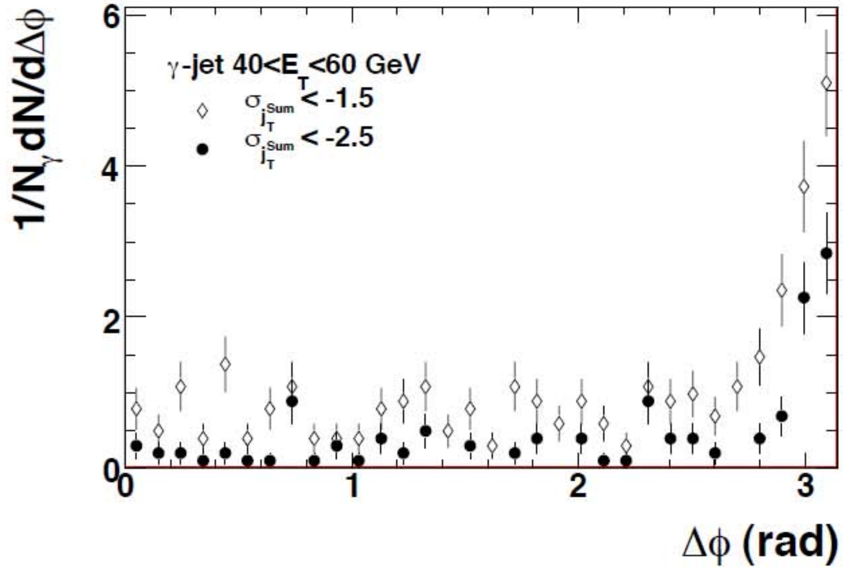
$$j_T^{Sum} = \sum_{cell} E_T^{cell} \sin R_{cell}, \qquad \sigma_{j_T^{Sum}} = \frac{j_T^{Sum}(E_T) - \langle j_T^{Sum} \rangle (E_T)}{\sigma(E_T)}$$

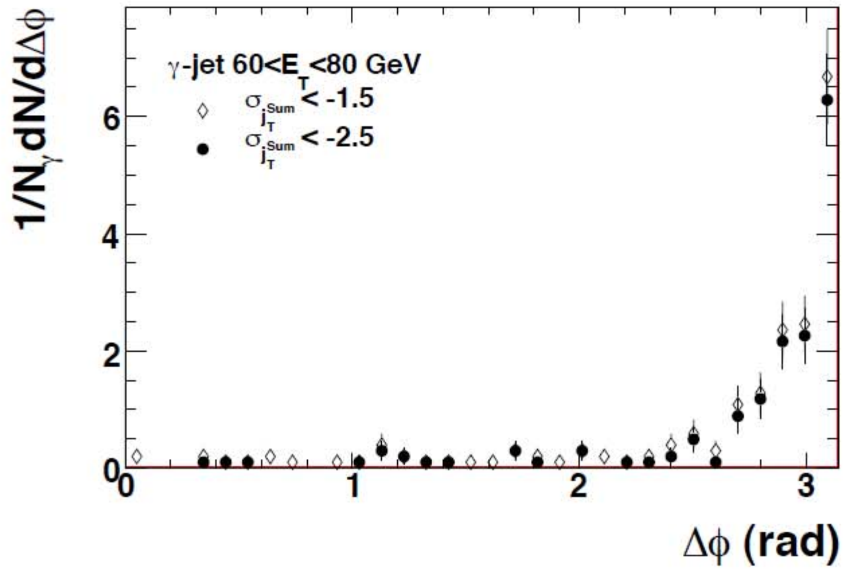




γ–jet Correlations

Δφ correlations for γ–jet pairs





Two different fake rejection cuts:

Open symbols – loose

Close symbols – tight

Jet Rates in 2010

Assuming:

- **1/20 nominal luminosity ($25\ \mu b^{-1}$/year)**
- **100% trigger efficiency**

~4000 jets @ 100 GeV/c

~200 jets @ 200 GeV/c