Heavy Ion Physics Prospects from the ATLAS Detector at the LHC

Nathan Grau

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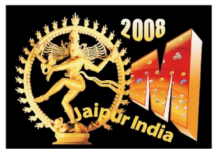
for the ATLAS Collaboration

COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK



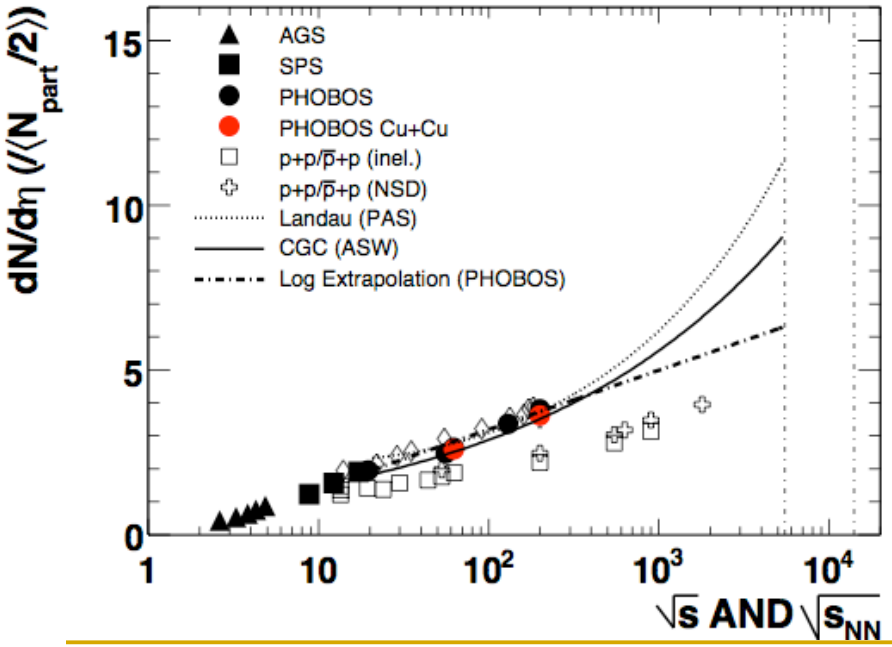
Heavy Ion Collision Evolution

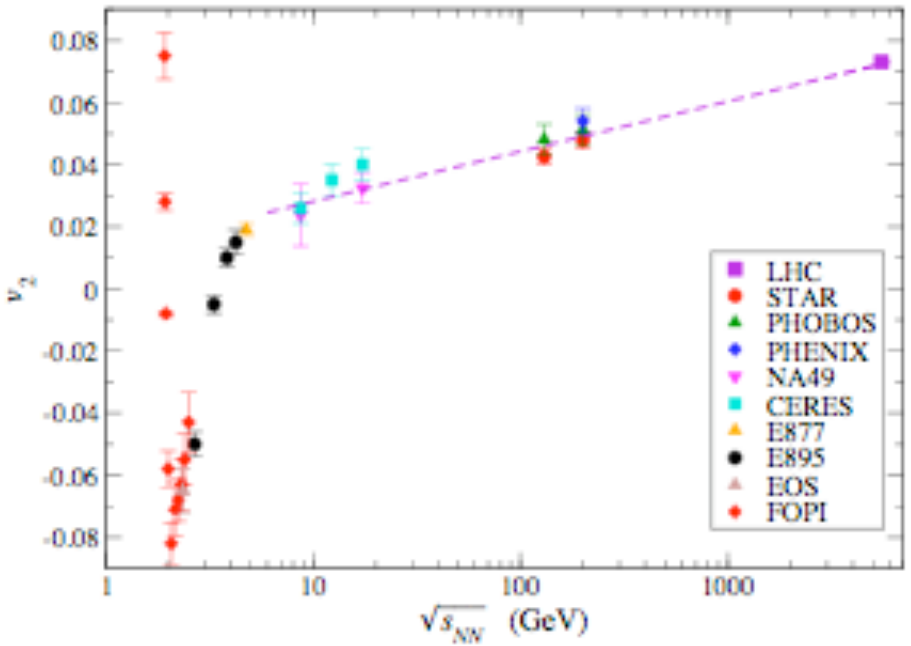
	Experimental Observable	Theoretical Tools	Physics
Nuclear PDFs	**Particle multiplicities, monojets**	Color Glass Condensate (Parton Saturation)	**High-density pQCD**
Hard Processes	Jets, Photons, Heavy Quarks & Onia, Z&W	pQCD	**QCD in medium**
(non-) Ideal Hydrodynamics	$\frac{d^3N}{d\eta d\phi dp_T}$	3+1D Hydro Initial conditions	**Equation of State (Degrees of Freedom)**
Hadron Freezeout	**Particle yields, correlations, fluctuations**	Statistical models, Cluster models	**Hadronization**

- Goal: understand all aspects HI collision evolution
- RHIC and SPS brought new insights and questions

The Bulk Physics Questions

- "Day-1" Measurements
  - Is the CGC important at mid-rapidity at the LHC?
  - How perfect is the "perfect fluid"?
- See P. Steinberg Session XXI (17:50) and B. Toczek poster P15

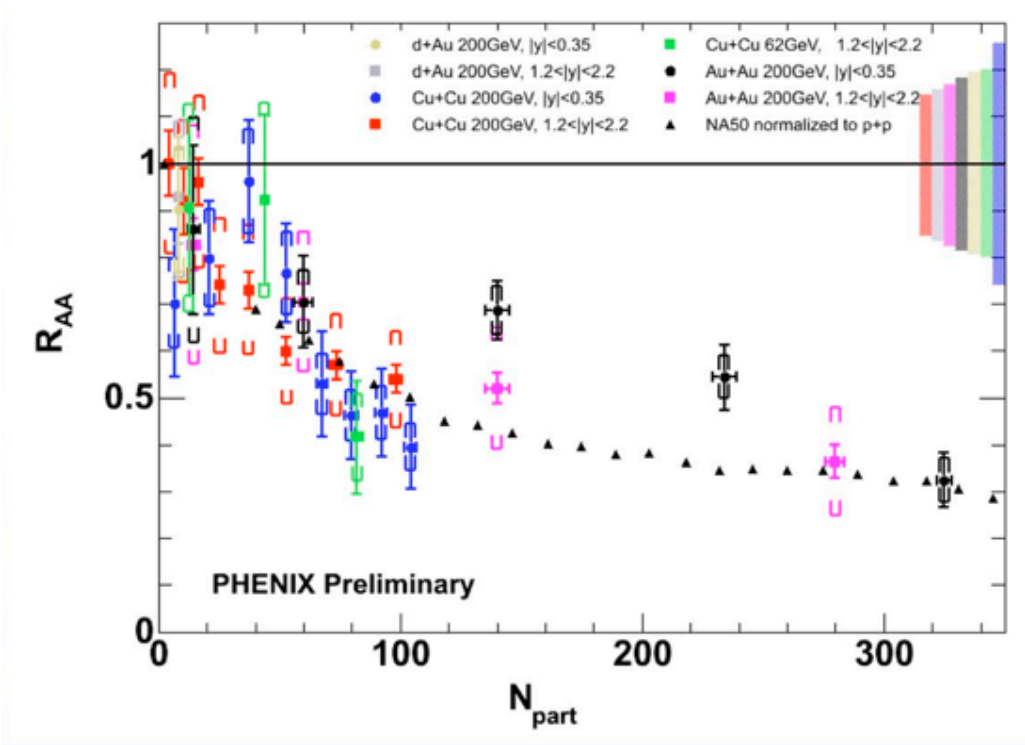




Heavy Flavor Questions

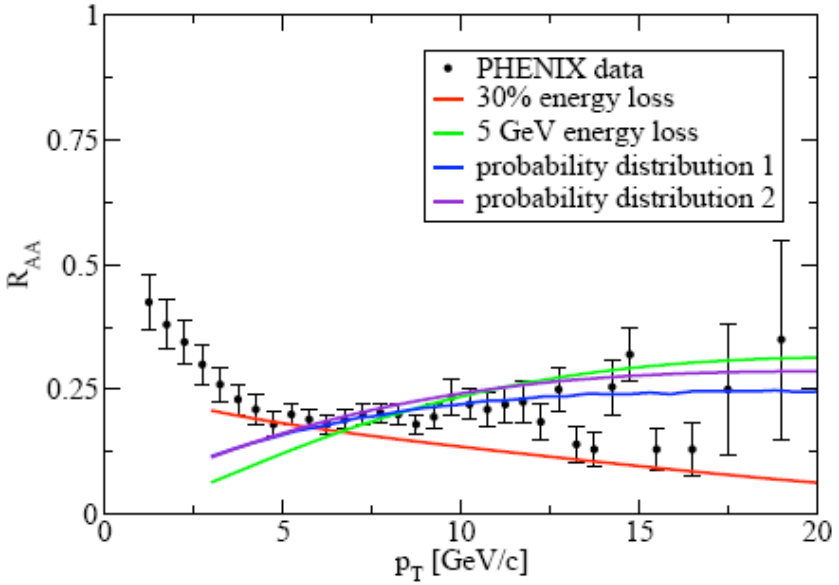
- Meaurements of quarkonia, b-jets, etc.
  - Will Upsilon states be more conclusive about color screening than Psi states?
  - Why are heavy flavors as suppressed as light flavors?
- See talk by A. Lebedev Session XX (14:00)

J/ψ R_{AA} SPS & RHIC



Jet Physics Question

- How are jets quenched?
  - Single particle suppression sensitive only to integral of energy loss



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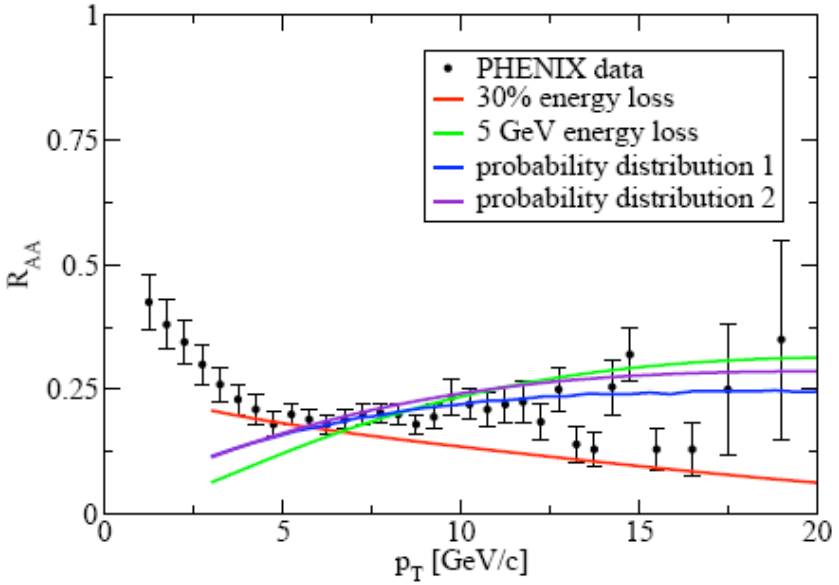
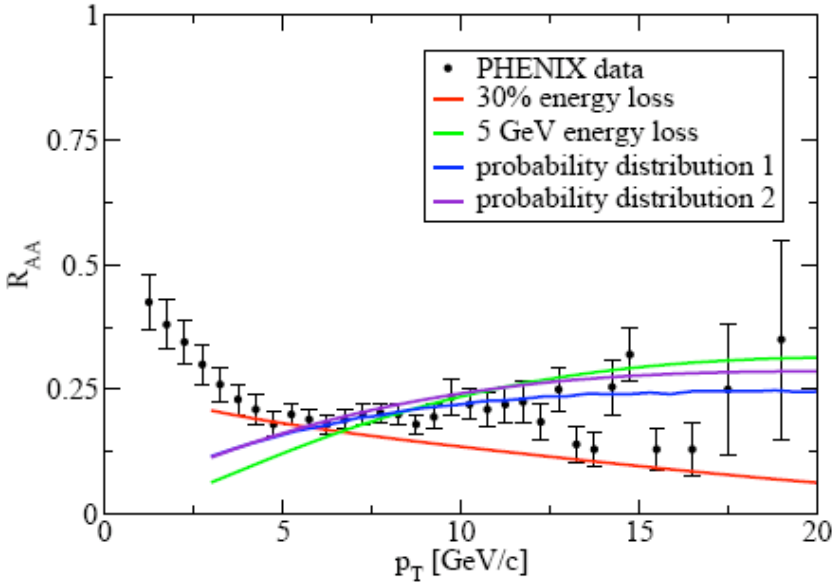
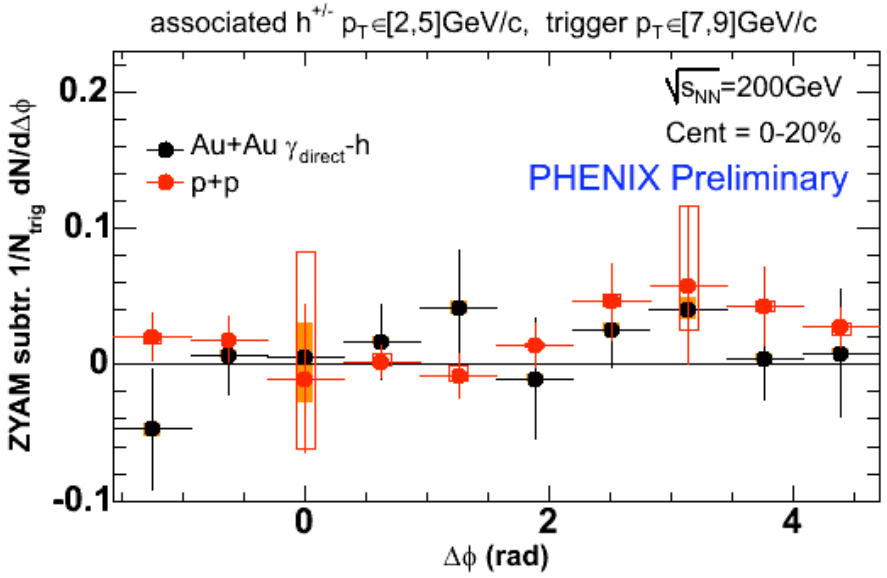


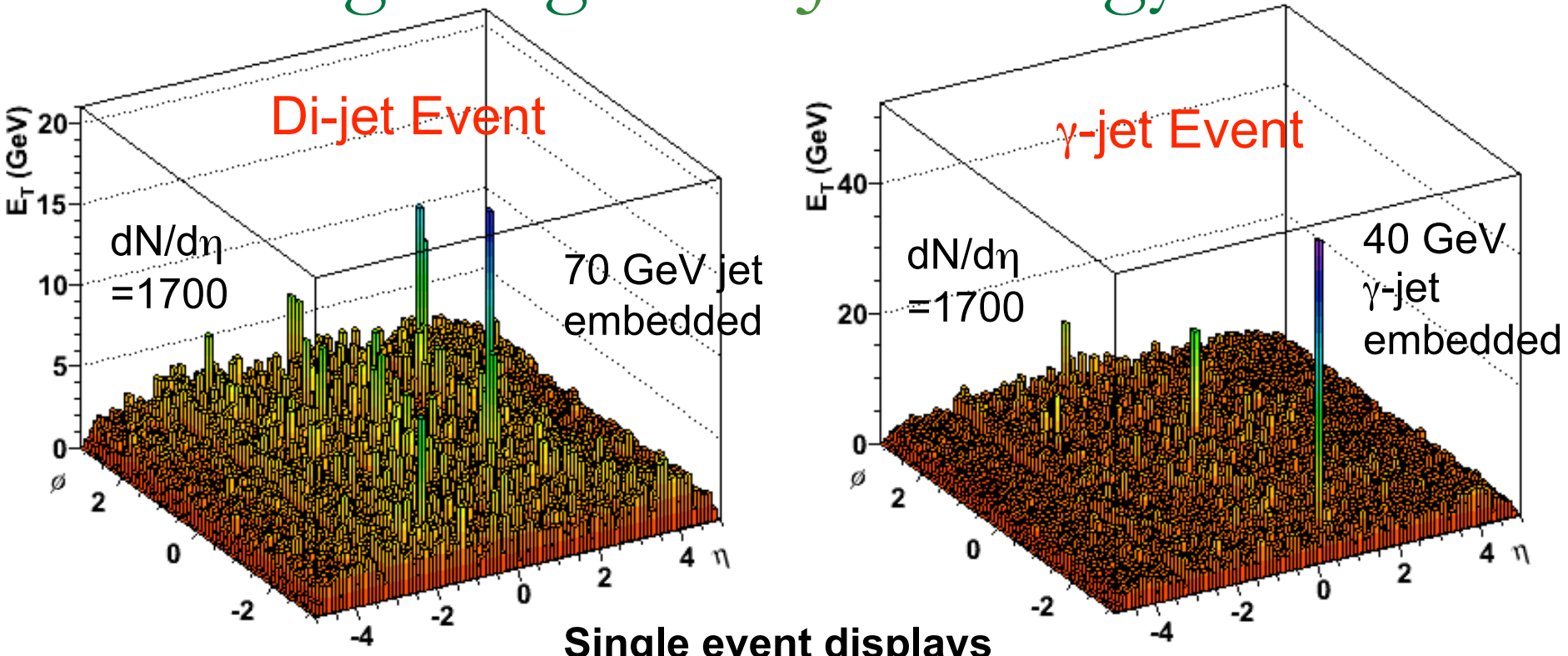
Jet Physics Question

- How are jets quenched?
  - Single particle suppression sensitive only to integral of energy loss
  - Di-hadron correlations suffer from ΔE bias
  - Gamma+hadron suffers from statistics (D(z))





Gaining Insight on Jet Energy Loss

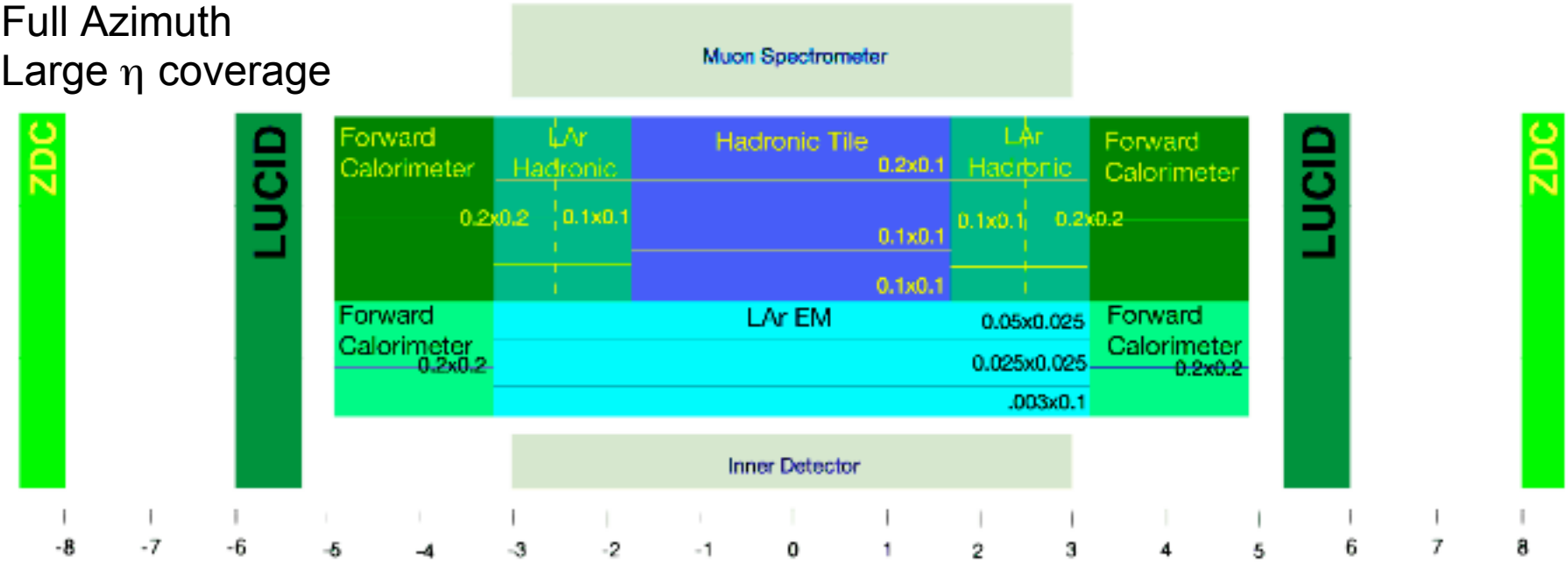


Single event displays
of 0.1x0.1 towers in calorimeter

- Measure jets and γ+jets in large acceptance calorimeter

The ATLAS Detector

Full Azimuth
Large η coverage



- Calorimeters
  - Longitudinally segmented (x3 in EM and HAD)
  - Fine η strip ($\Delta\eta$~0.003) in front segment of EMCal
    - Separate γ and π^0 below 70 GeV
  - Ideal for jet and photon measurements

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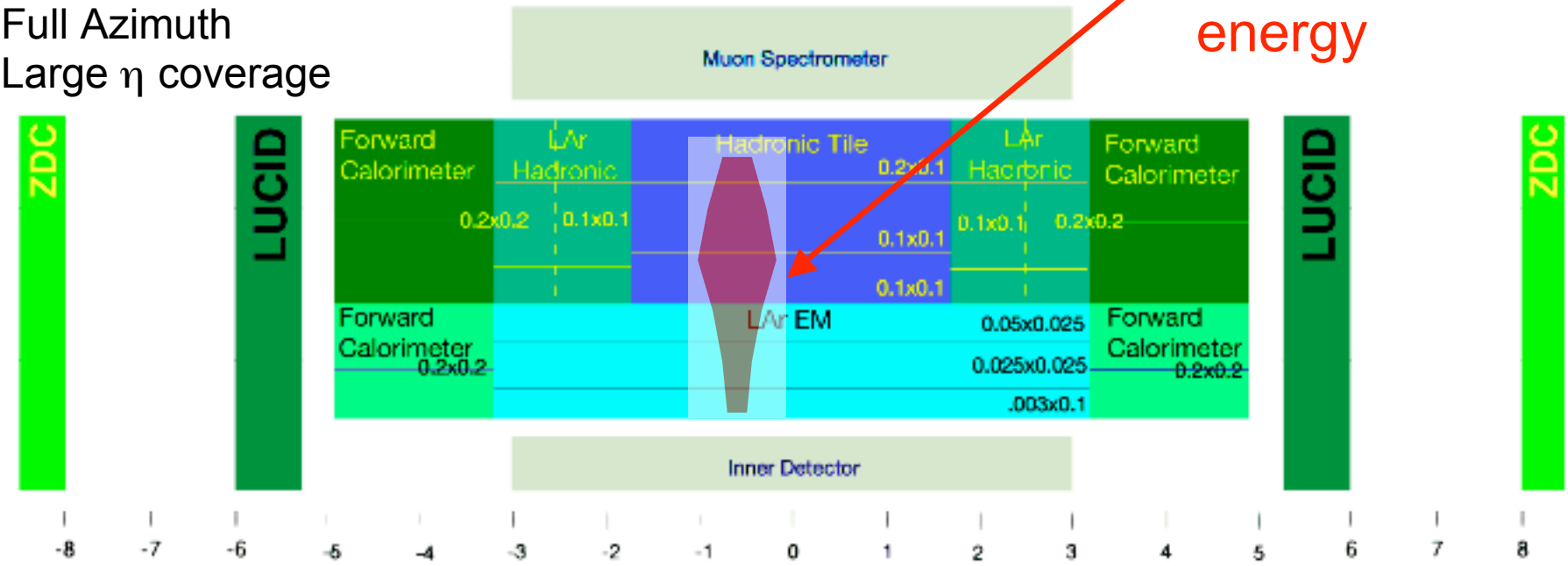

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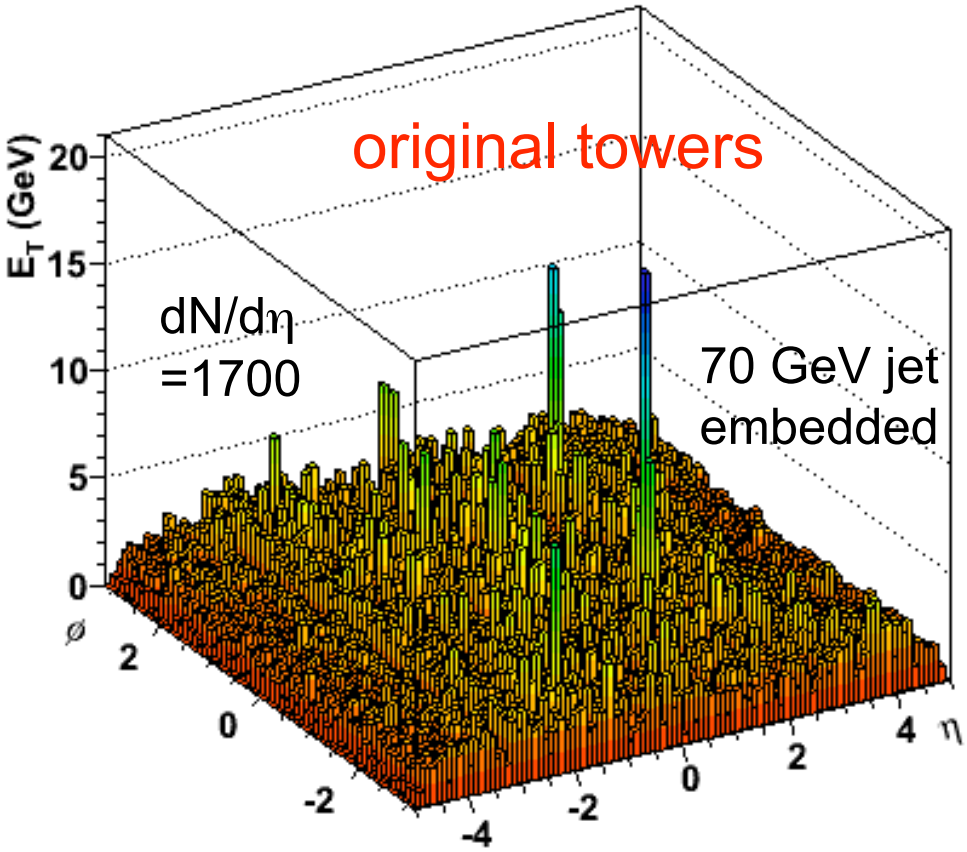
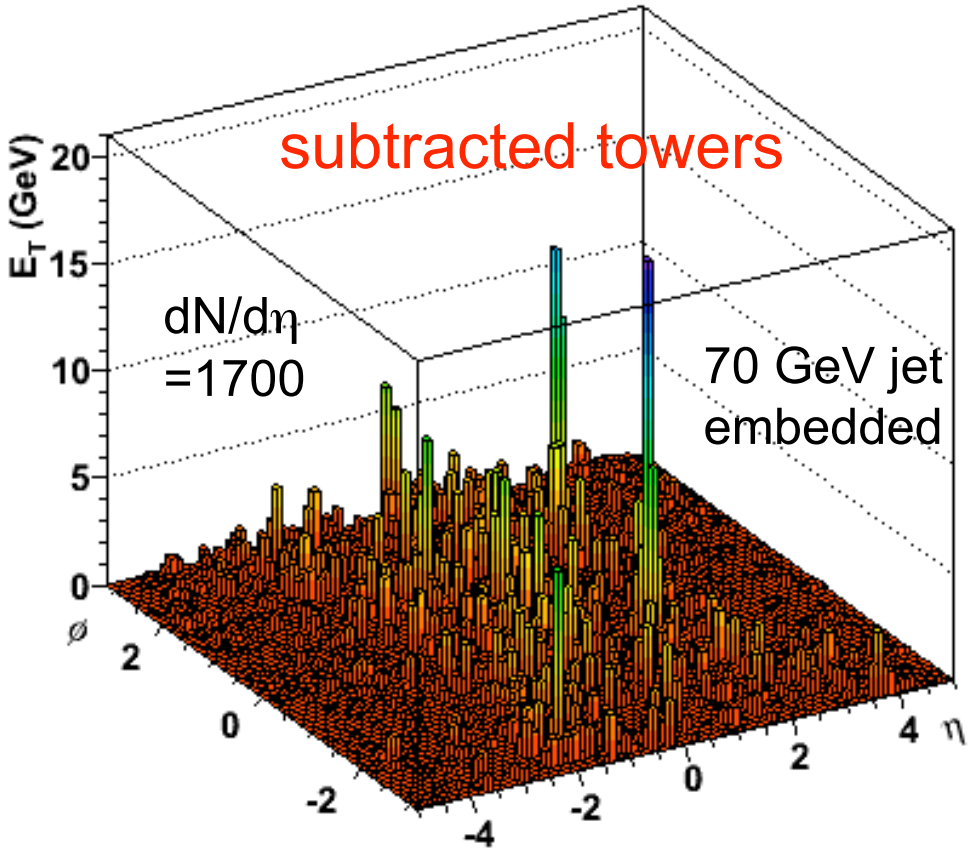
Jet Reconstruction in HI Events

- Embed pythia dijet events in HIJING
  - Without quenching
  - Limit $Q^2<100\ GeV^2$
    - i.e. no HIJING jets
- Compare results to jet reconstruction on pythia
  - Same approach as in 14 TeV p+p analysis



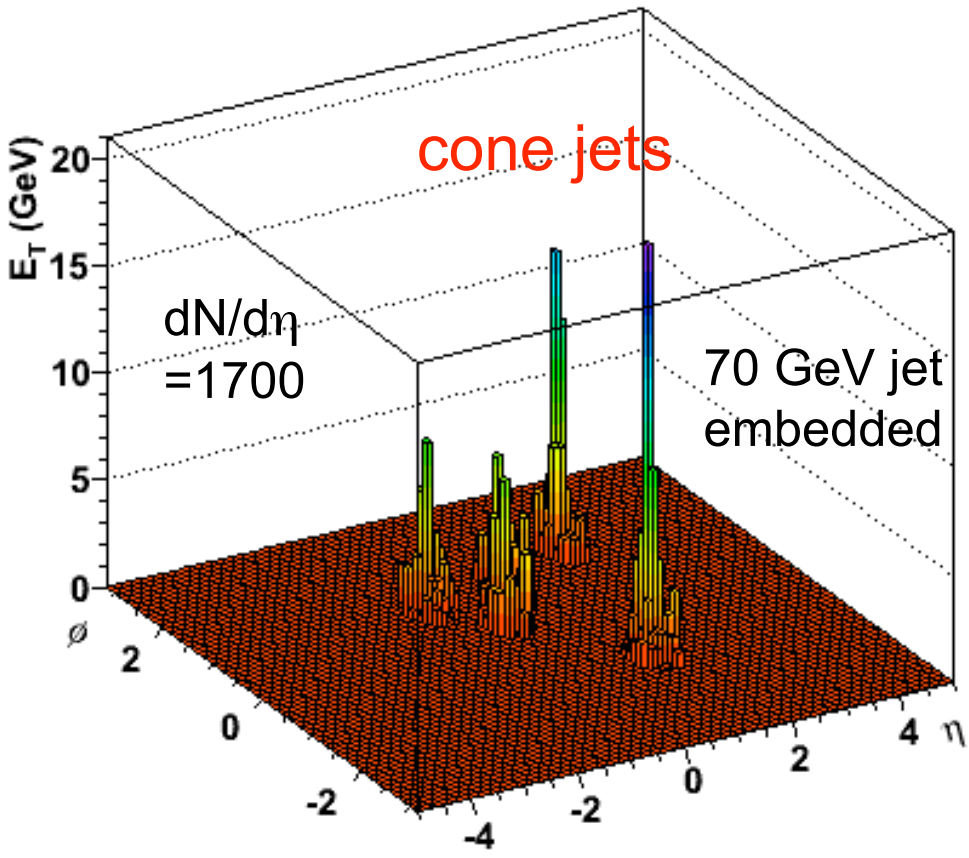
Jet Reconstruction in HI Events: Cone Jet

- In HI events subtract the underlying event by removing η-dependent average E_T

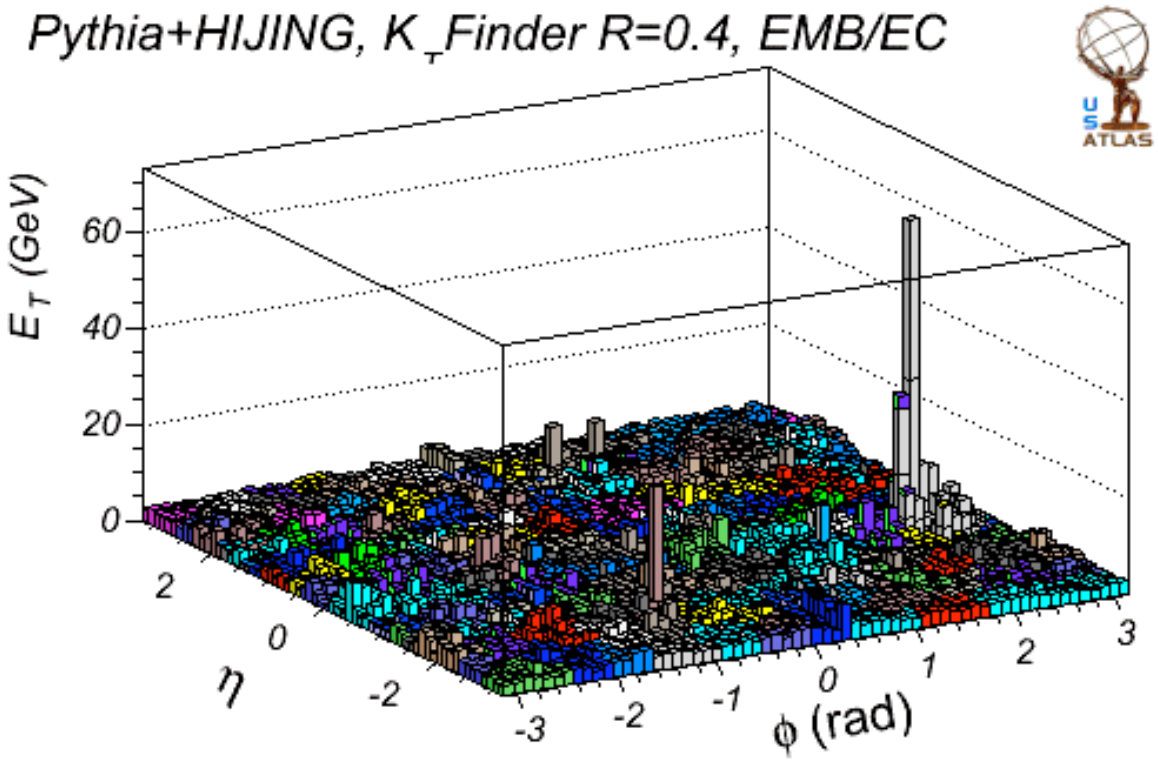


Jet Reconstruction in HI Events: Cone Jet

- Cone jet reconstruction
  - Cluster towers within a radius of R=0.4 around 5 GeV seed towers
  - Iterates on jet position until convergence or excluded



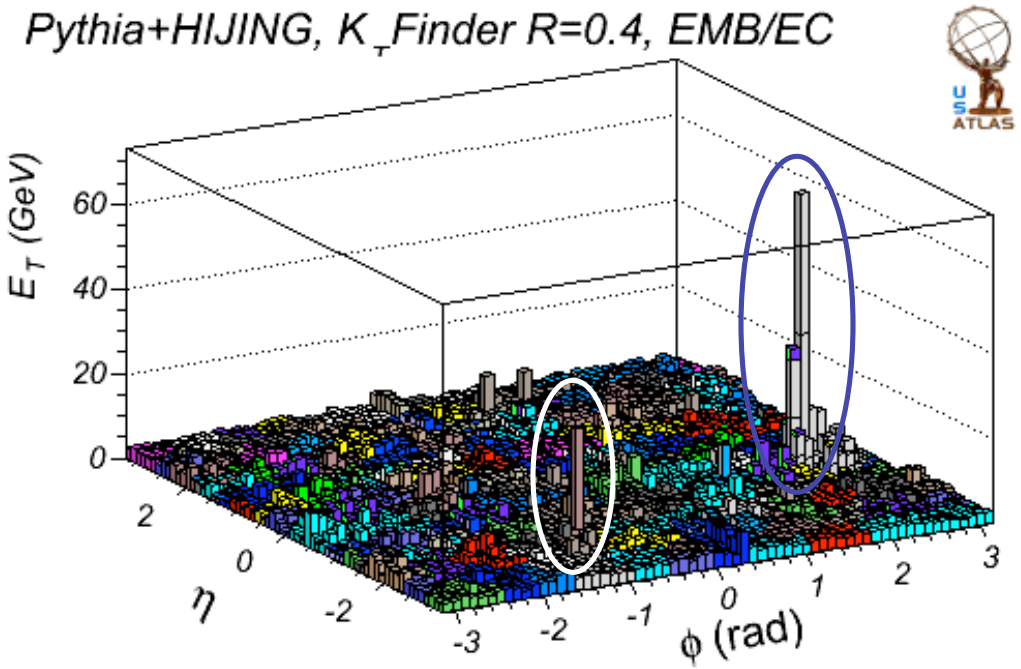
Jet Reconstruction in HI Events: Fast-k_T

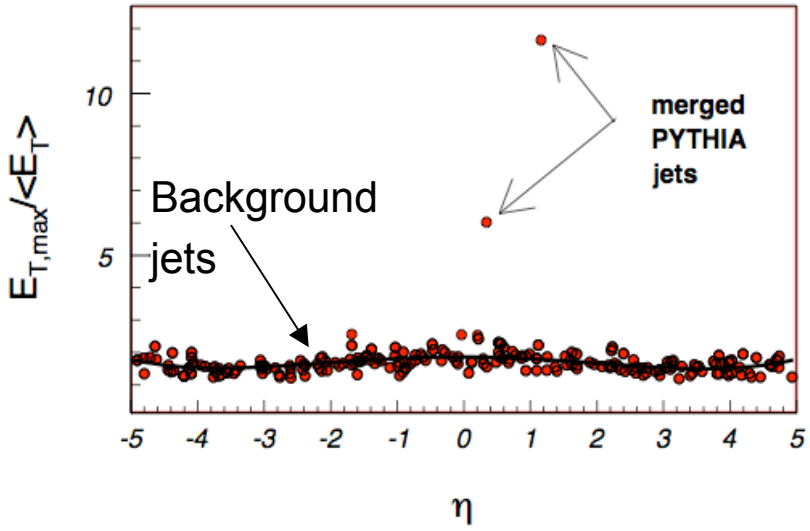


Each color is a jet defined by the algorithm

- Fast-k_T algorithm
  - Infrared-safe
  - reconstruct jet back through the fragmentation chain
- No background subtraction
  - background clustered into jet defined by algorithm

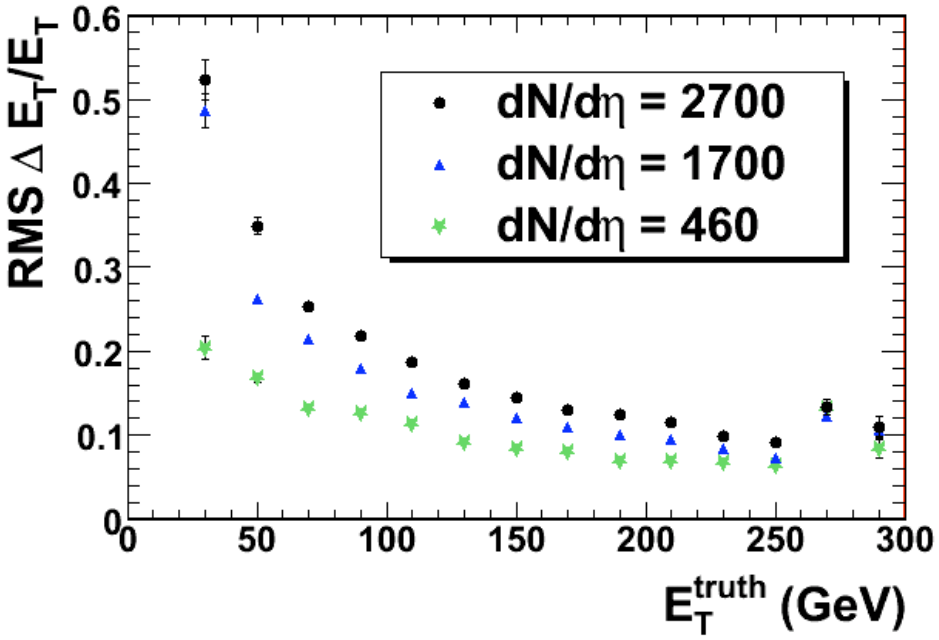
Jet Reconstruction in HI Events: Fast-k_T

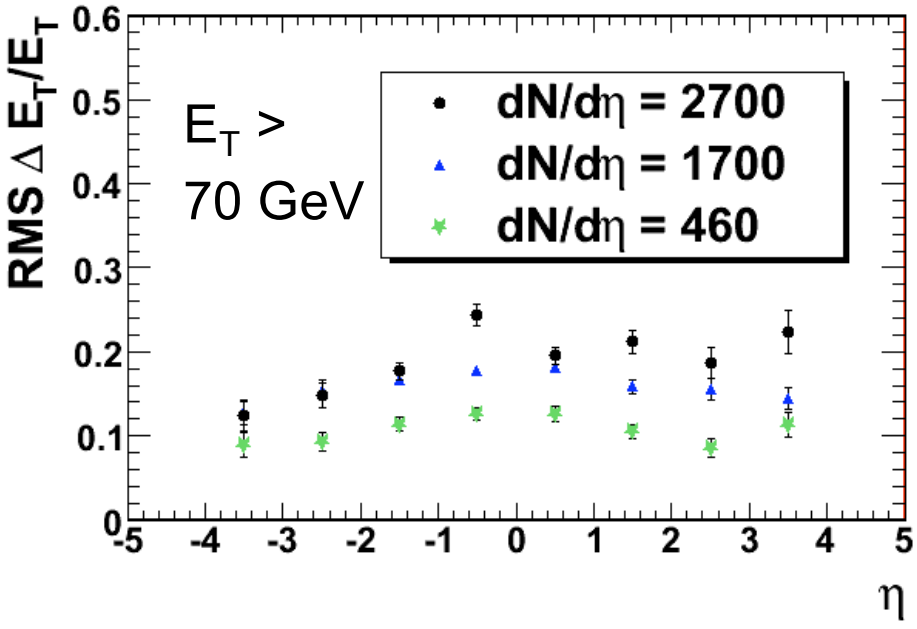




- Discrimination variables distinguish real and background jets event-by-event
  - e.g. Maximum/Average Tower E_T

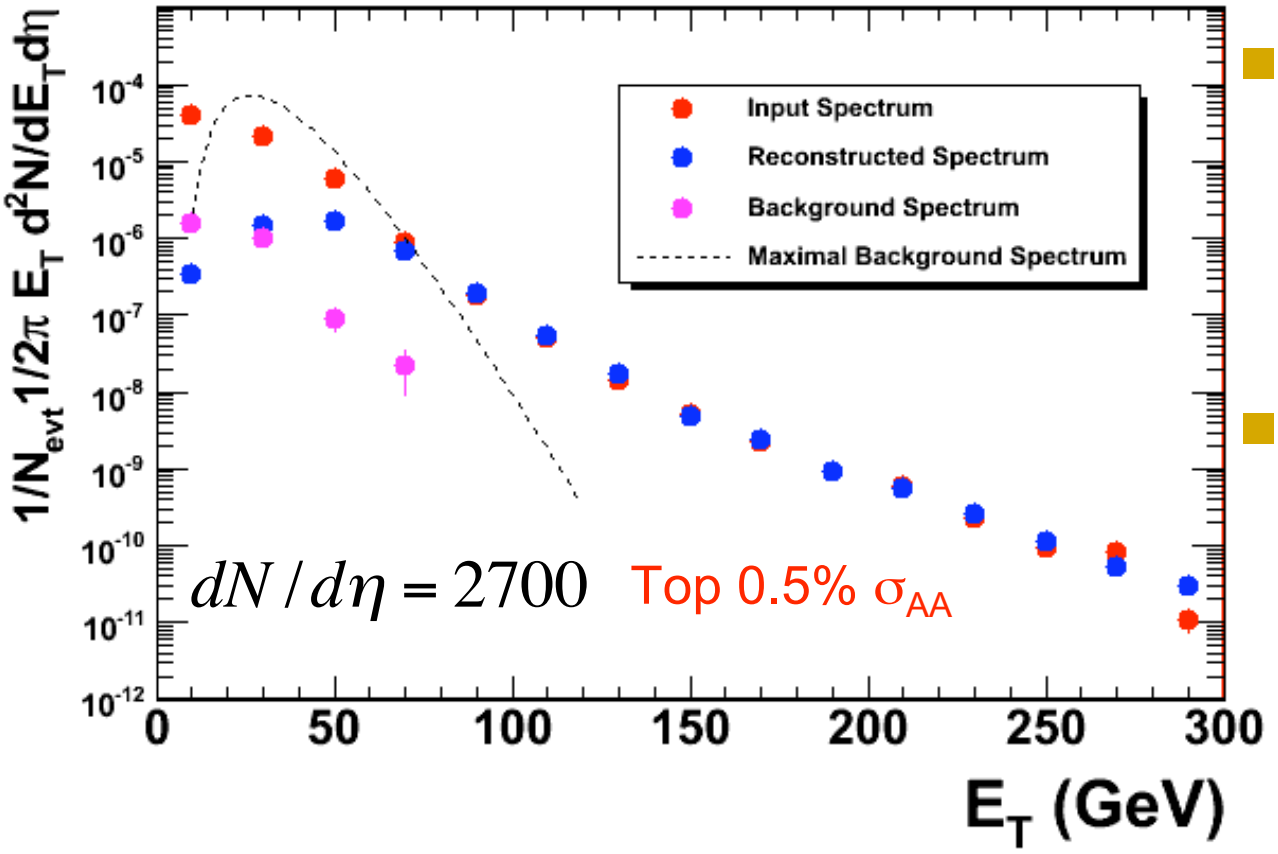
Jet Performance: E_T Resolutions





- Energy resolution improves with decreasing multiplicity
- Some improvement with increasing η
  - Large tower size, smaller event background

Inclusive Jet Reconstruction

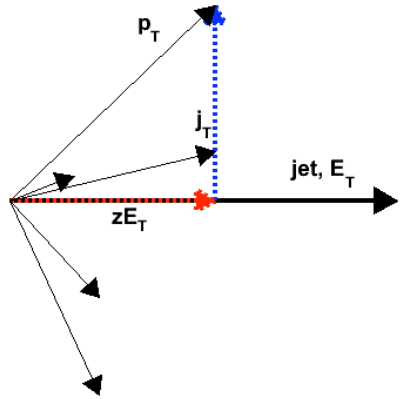


- Suppression of background jets using shape analysis
- For 70 GeV jets at $dN/d\eta$ = 2700
  - ε = 70%
  - B/(S+B) = 3%
  - $\sigma_{\Delta Et/Et}$ = 25%

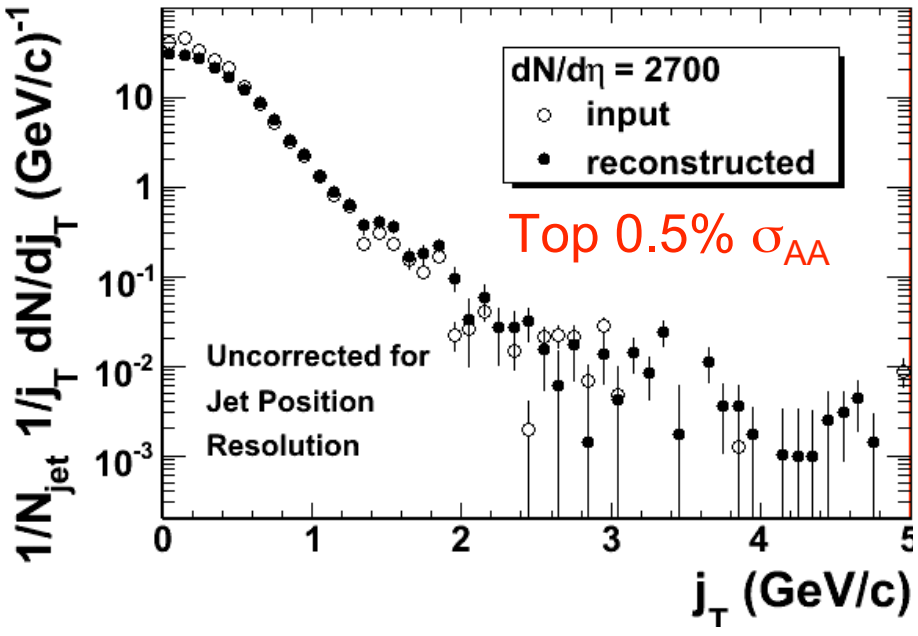
Reconstructed spectra not corrected for efficiency and energy resolution.

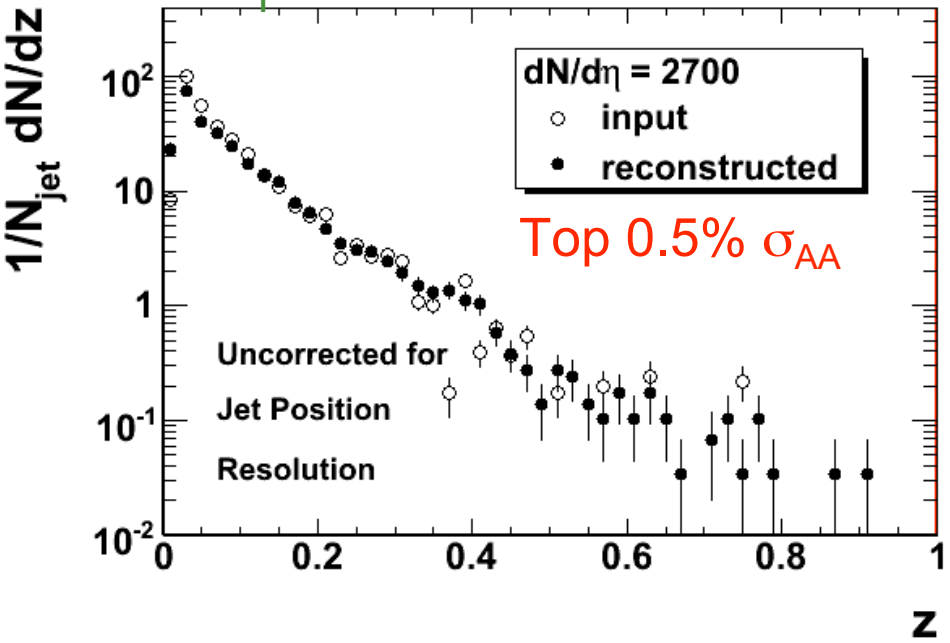
Jet Fragmentation

- Project tracks to calorimeter, match to jets
- Discriminate between energy-loss models
  - Few hard vs. many soft gluons
- See Poster P215 (165) by M. Spousta



E_T > 70 GeV

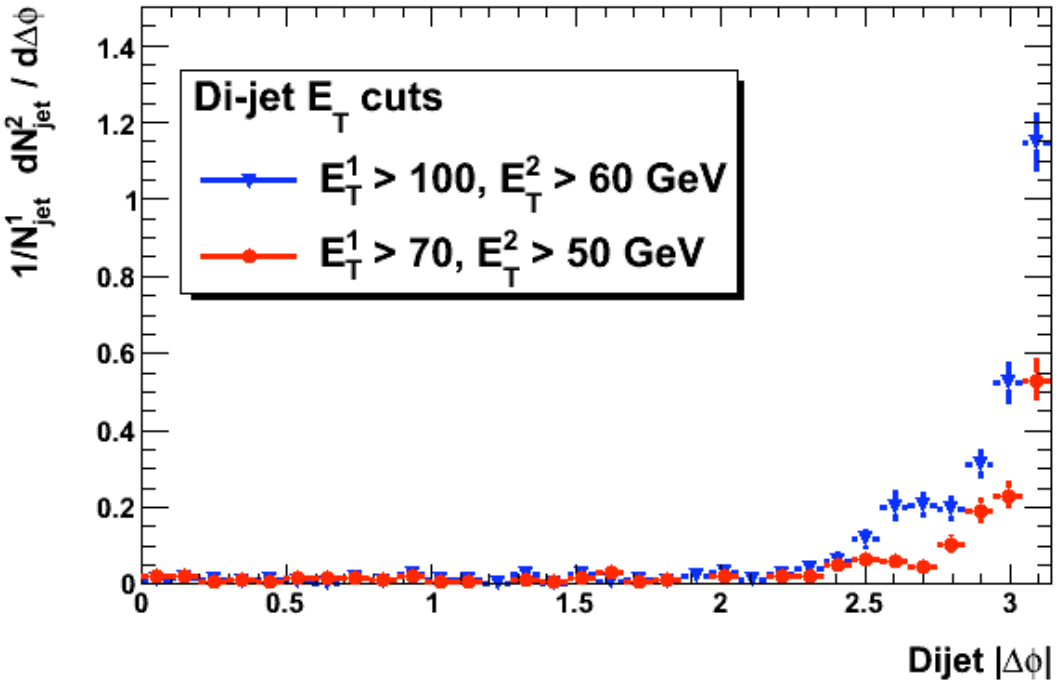




Di-Jet Cone Reconstruction

- Large acceptance + high resolution = di-jet studies
- Large signal evident with little background
  - Given a jet >100 GeV, 60% probability to detect the associated > 60 GeV jet

$dN/d\eta = 2700$ Top 0.5% σ_{AA}



Uncorrected for efficiency and resolution

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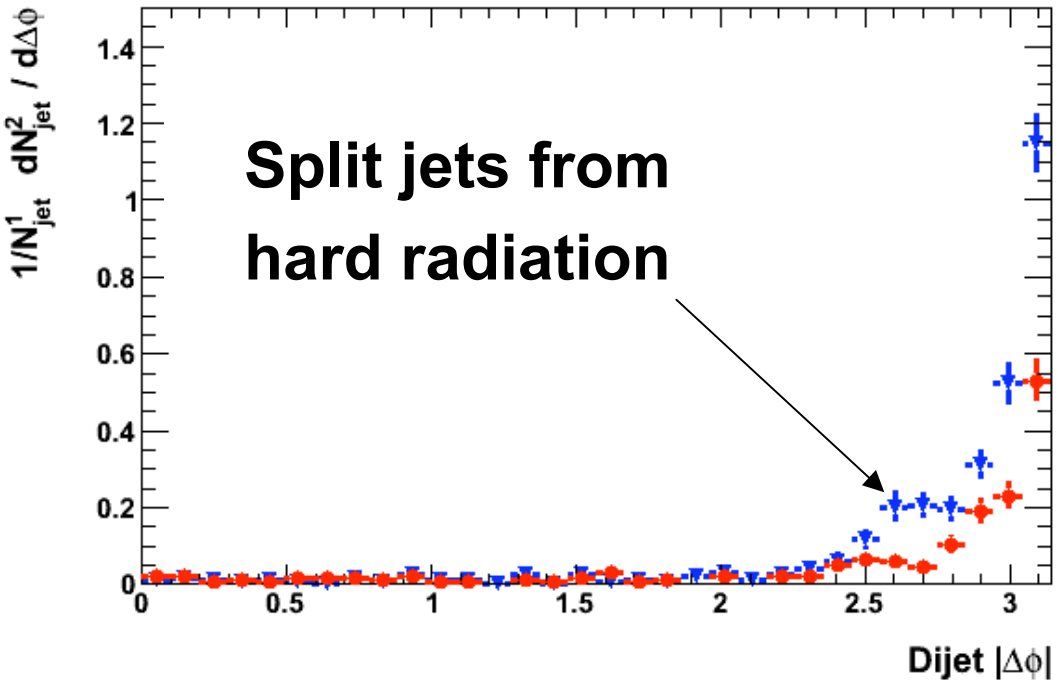
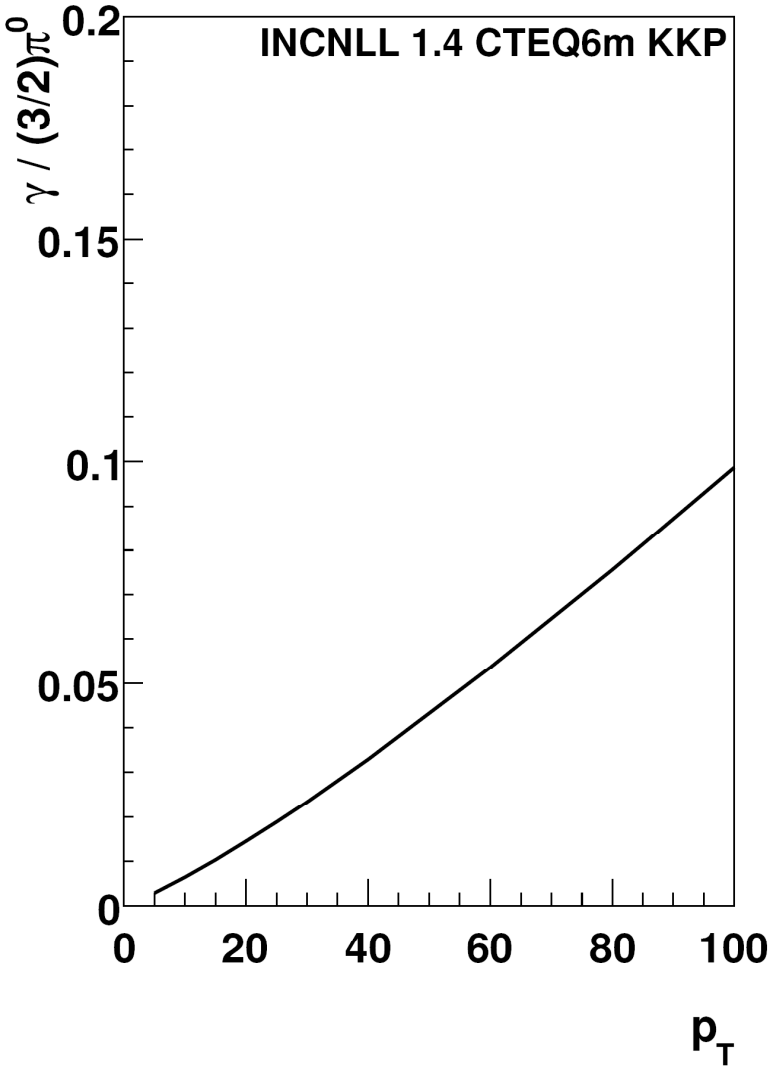


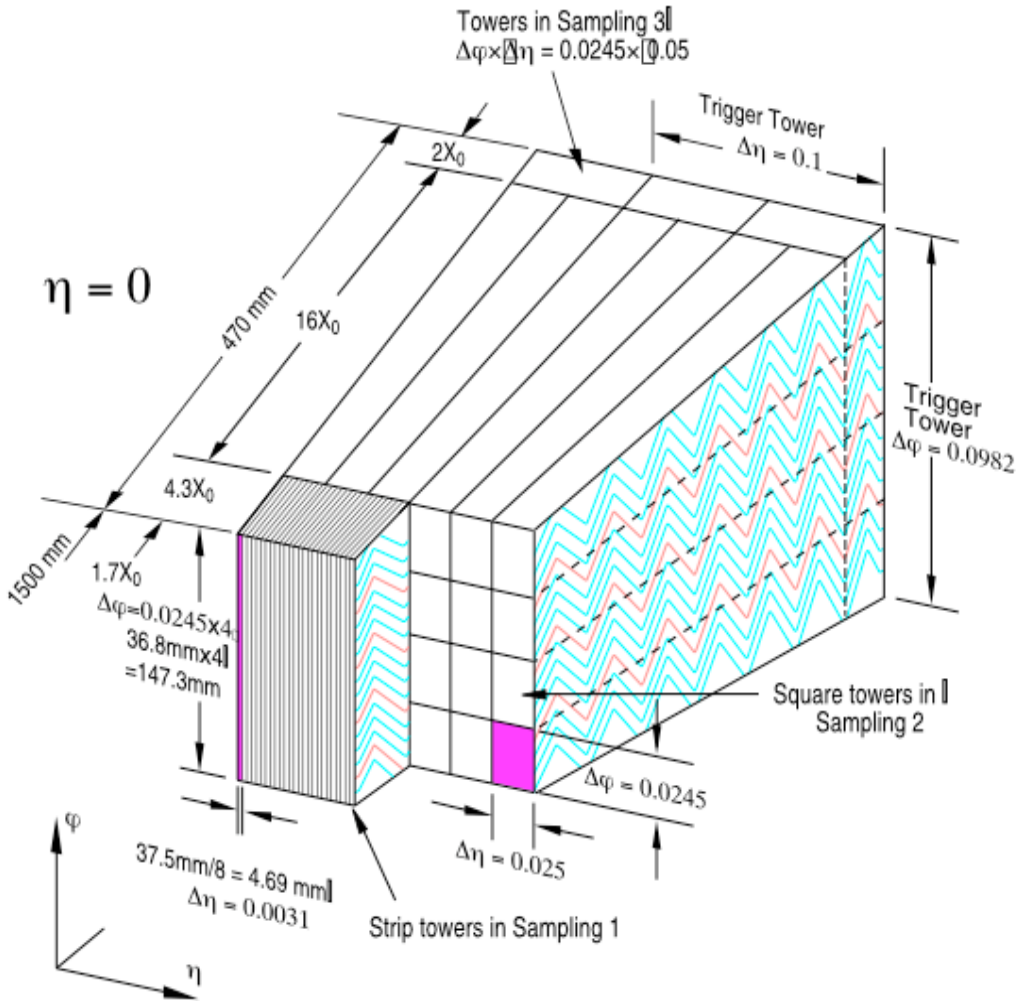
Uncorrected for efficiency and resolution

γ+jet Measurements

- γ-jet more direct measure of D(z)
- Large background from hadronic decay
  - From NLO pQCD expect S/B 1/20 - 1/10
- For details of what follows see poster P160 by M. Baker



Strip Layer of EMCal



- Designed to measure

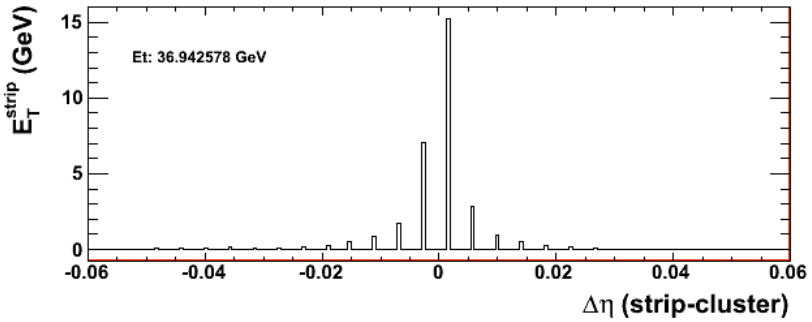
  $H \rightarrow \gamma\gamma$

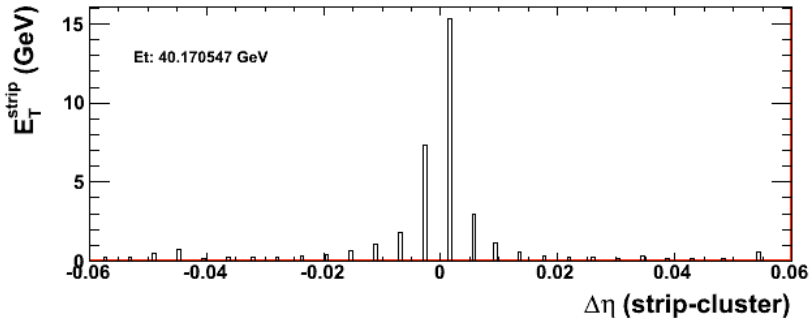
  and rejecting di-jets
- γ and π^0 separation for E_T<70 GeV
- Front layer: strips
  - Typically 0.003x0.1 in $\Delta\eta \times \Delta\phi$
  - Over $|\eta|$<2.5

Single Particles Detection with Strips

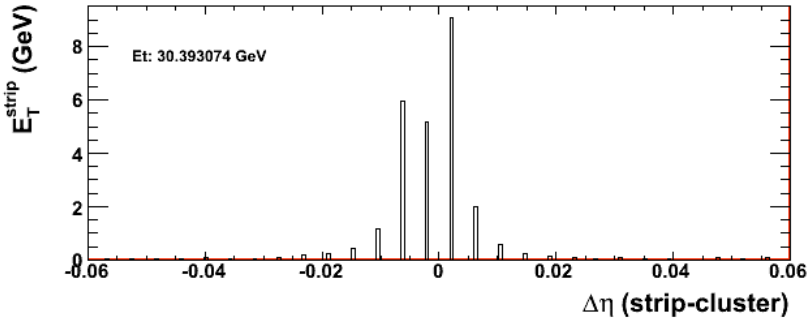
Single particle | **Embedded**

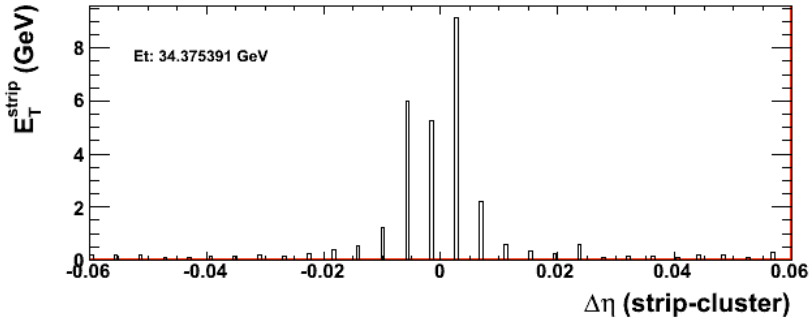
photon





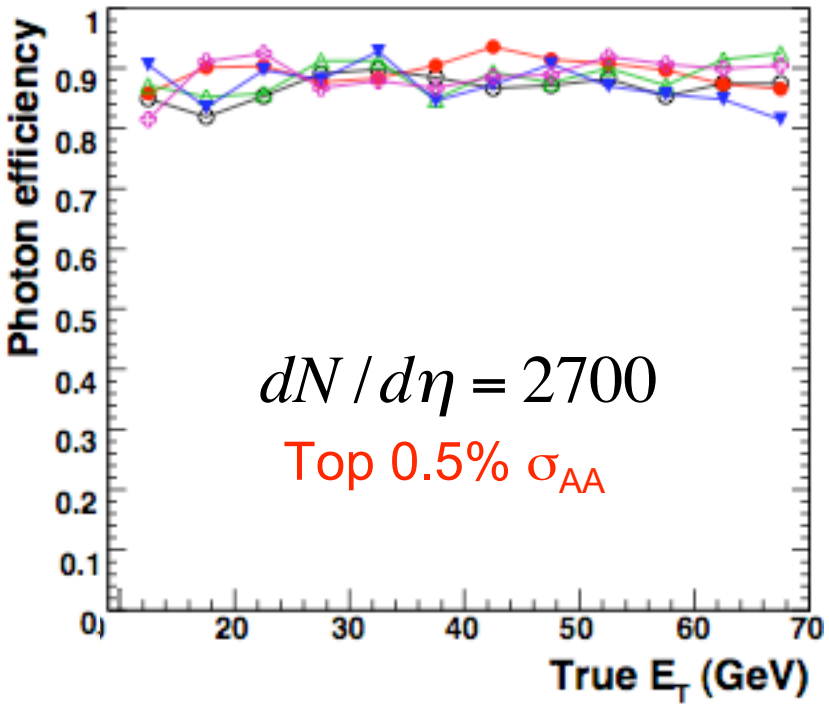
π^0

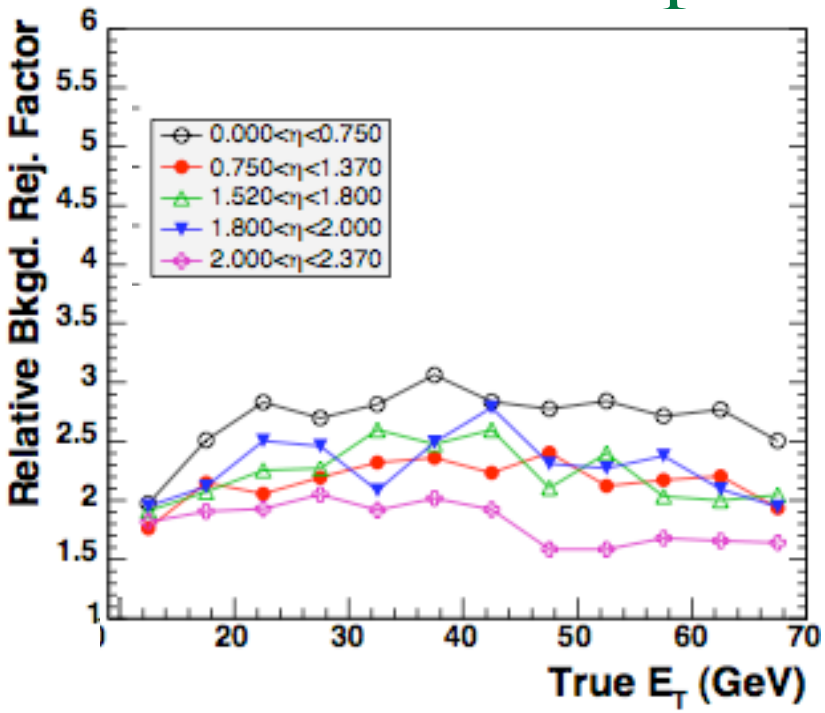




- Single particles embedded in dN/dη = 2700 (99.5% σ_{AA})
- Low occupancy from background in strips even in high multiplicity
- 3 GeV additional energy in the cluster energy due to the background

Photon Identification: Shower Shape

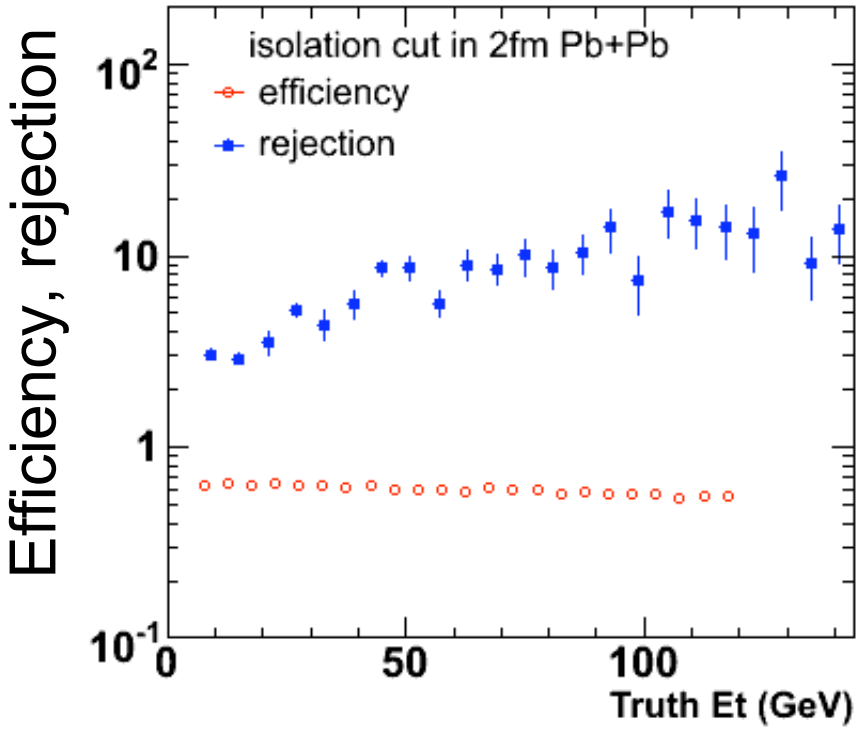


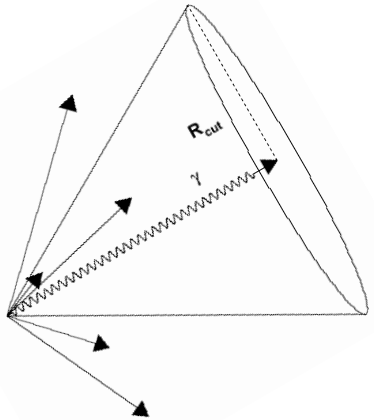


- Apply cuts based on energy deposition in strip layer
- For an efficiency of 80-90%, 1.5-3 in background rejection
- Additional advantage: Allows statistical subtraction of background without isolation!

Photon Identification: Isolation

$dN/d\eta = 2700$ Top 0.5% σ_{AA}

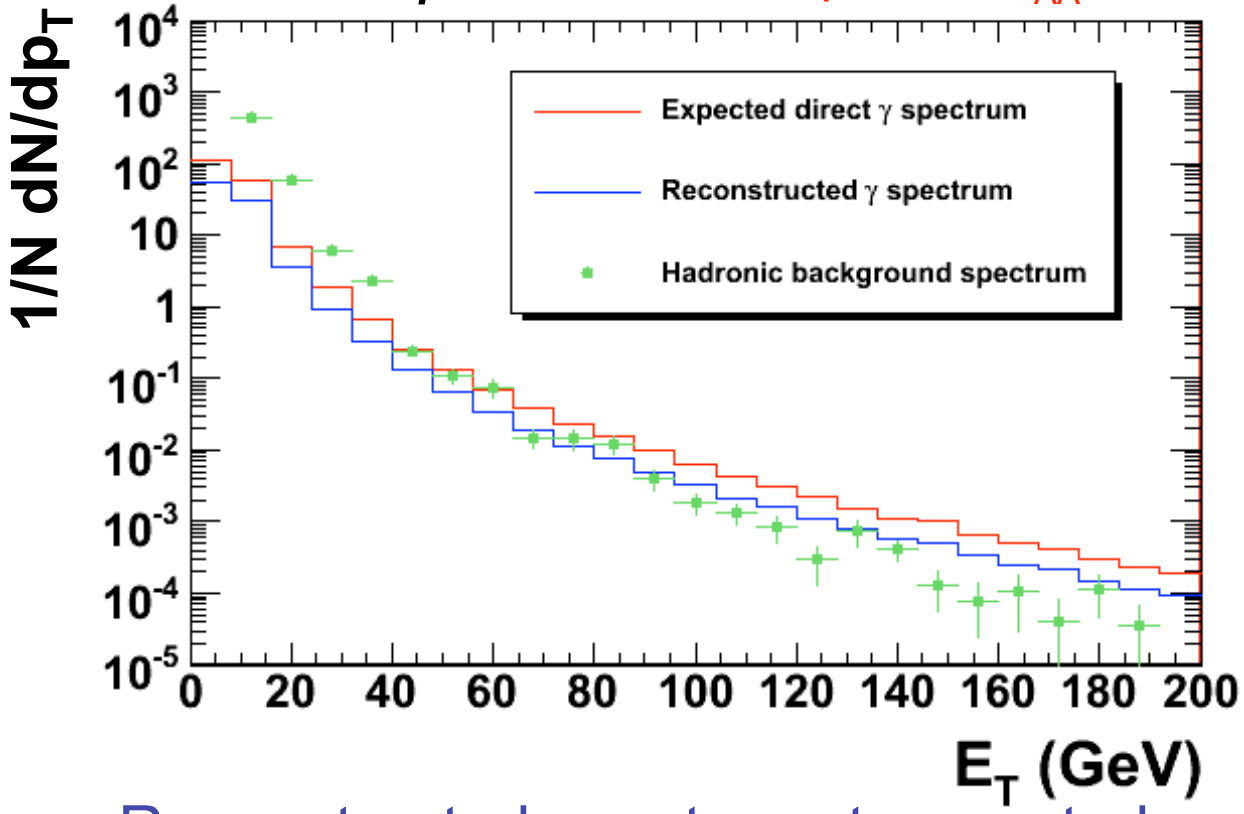




- Isolation requirement
  - R=0.2, track p_T< 2.5 GeV
  - R=0.2, Σtower E_T< 31 GeV
- Cuts chosen so ε>50% with highest rejection

Direct Photon Spectrum

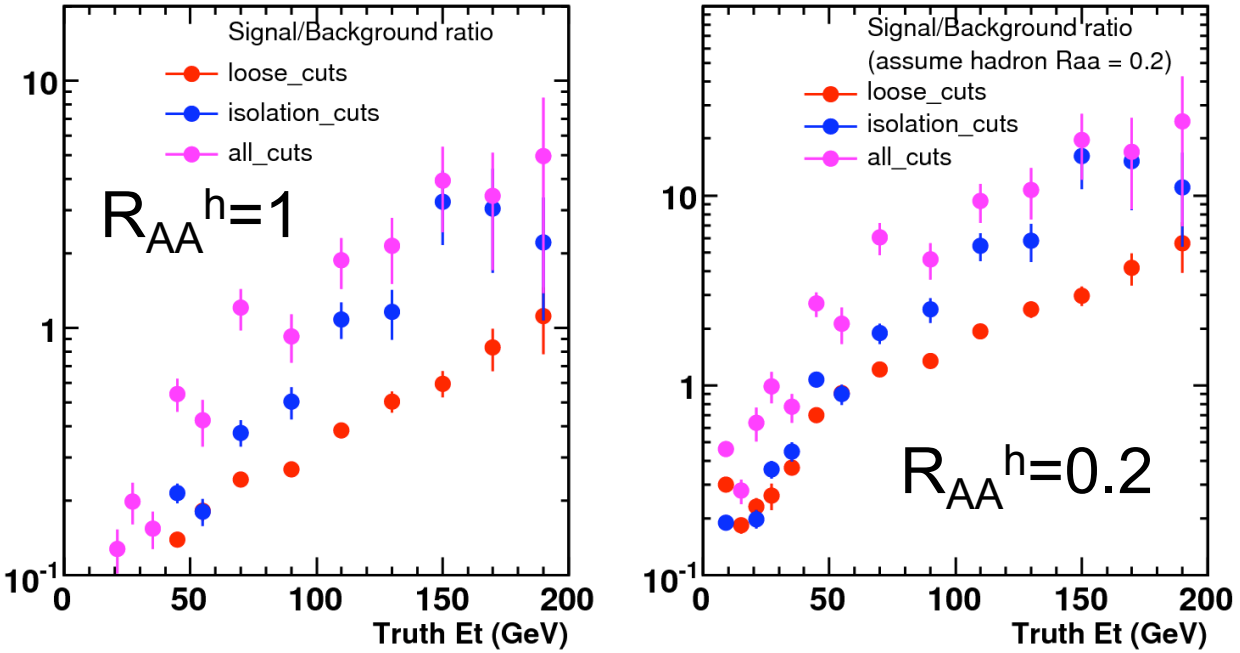
$dN/d\eta = 2700$ Top 0.5% σ_{AA}



- Resulting spectrum from combining shape and isolation cuts
- ε ~ 50-60%
- Assuming $R_{AA}^{h}/R_{AA}^{\gamma} = 1$

Reconstructed spectra not corrected for efficiency and energy resolution.

Identified Photon S/B



- Recall from NLO pQCD S/B = 1/20-1/10
- If $R_{AA}^{h}/R_{AA}^{\gamma}$~0.2, S/B>1 for E_T>30 GeV

Direct Photon Rates

- Given
  - NLO pQCD rates
  - Reconstruction efficiency of 50-60%
  - R_{AA}^{h}~0.2 @ 30 GeV
  - 3 weeks/year running at 100% uptime
- We expect to measure 7000 direct photons/LHC year above 30 GeV with S/B>1
  - Large rates because of E_T reach and η coverage

Summary

- ATLAS will study a broad spectrum of physics topics but will excel at jet and photon measurements
- Jets
  - Able to reconstruct jets in a large kinematical range, E_T > 40 GeV and $|\eta|<5$
  - Will perform key fragmentation measurements
    - j_T, D(z), shapes
  - Large acceptance allows multi-jet studies
- Photons
  - Able to isolate and measure photons in a large kinematical range, E_T > 10 GeV and $|\eta|<2.5$
  - Unique calorimeter design allows additional rejection beyond isolation and provides a direct measure of the background with high statistics

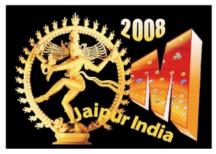
ATLAS Heavy Ion Working Group

A. Ajitanand[10], A. Angerami[3], G. Atoian[11], M. Baker[1], P. Chung[10], B. Cole[3], R. Debbe[1], A. Denisov[5], J. Dolejsi[2], N. Grau[3], J. Hill[7], W. Holzmann[3], V. Issakov[11], J. Jia[10], H. Kasper[11], R. Lacey[10], A. Lebedev[7], M. Leltchouk[3], P. Nevski[1], R. Nouicer[1], A. Olszewski[6], A. Poblaguev[11], V. Pozdnyakov[8], M. Rosati[7], L. Rosselet[4], M. Spousta[2], P. Steinberg[1], H. Takai[1], S. Timoshenko[9], B. Toczek[6], A. Trzupek[6], F. Videbaek[1], S. White[1], B. Wosiek[6], K. Wozniak[6], M. Zeller[11]

ATLAS Talks
A. Lebedev Session XX (14:00)
P. Steinberg Session XXI (17:50)
ATLAS Posters
P15 B. Toczek
P219 M. Spousta
P160 M. Baker

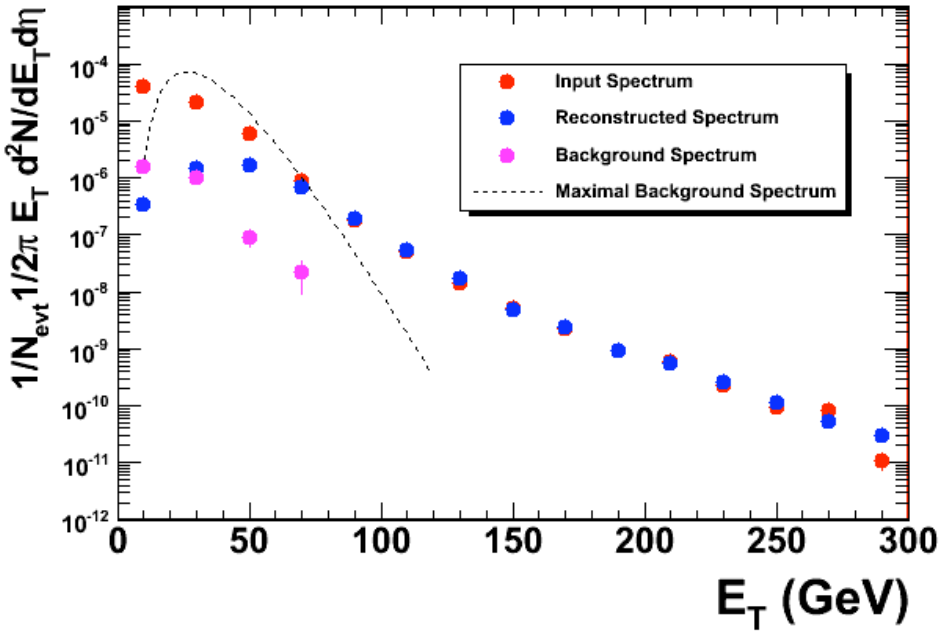
1 Brookhaven National Laboratory, USA
2 Charles University, Prague
3 Columbia University, Nevis Laboratories, USA
4 University of Geneva, Switzerland
5 IHEP, Russia
6 IFJ PAN, Krakow, Poland
7 Iowa State University, USA
8 JINR, Dubna, Russia
9 MePHI, Moscow, Russia
10 Chemistry Department, Stony Brook University, USA
11 Yale University, USA

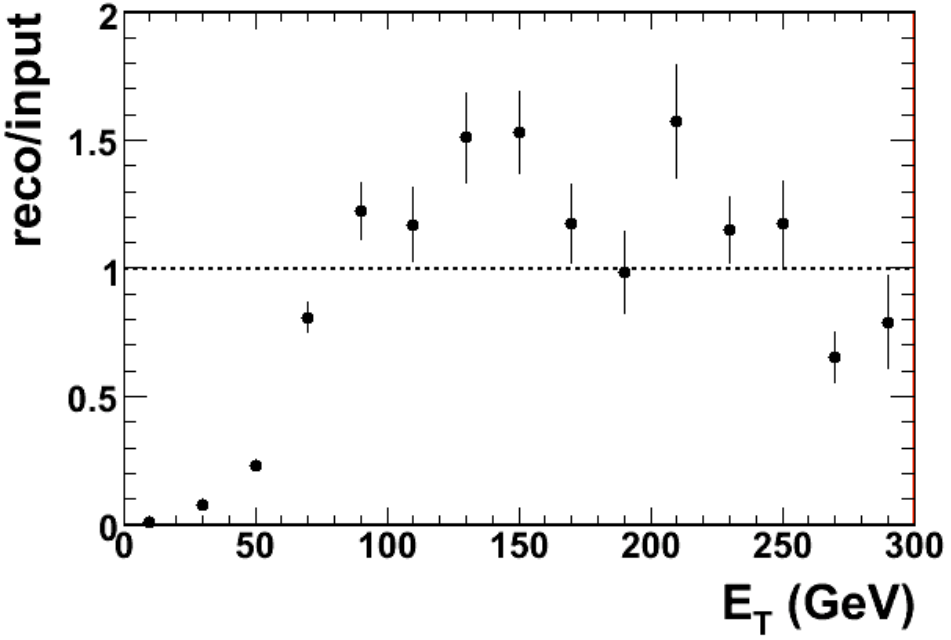
Backup Slides



Raw Jet R_{AA}

$dN/d\eta = 2700$ Top 0.5% σ_{AA}

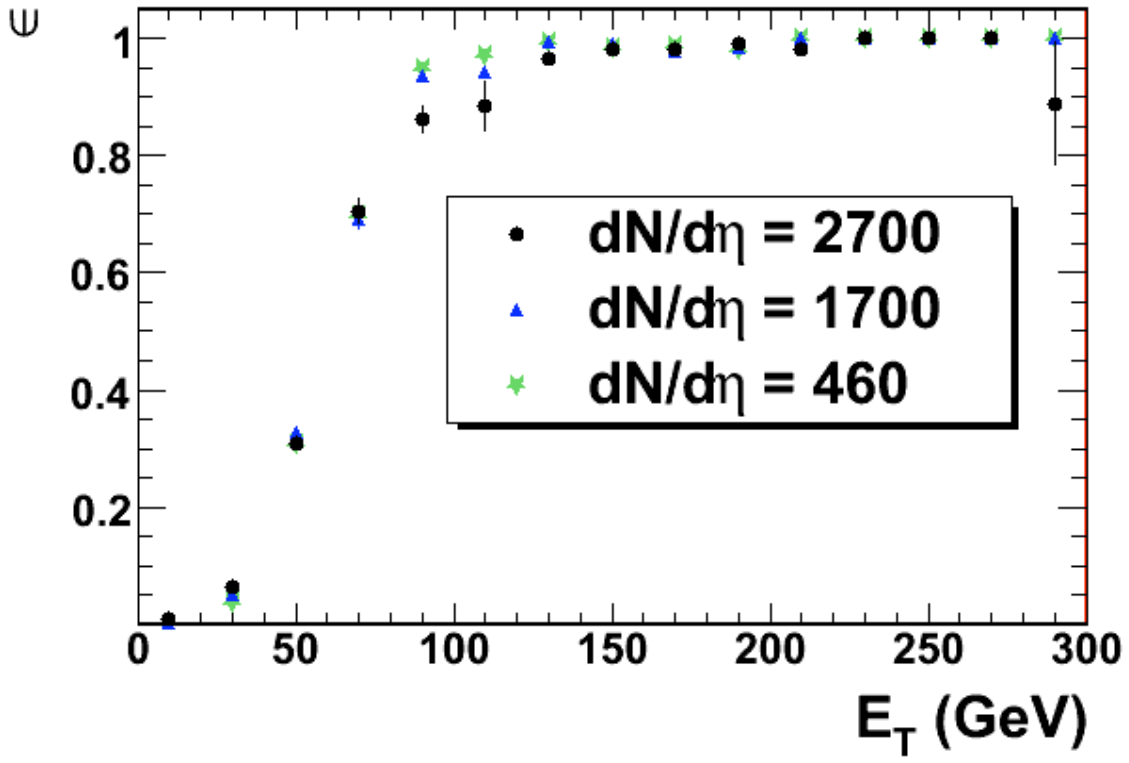




- "Raw" Jet R_{AA} before correction for efficiency and energy resolution correction

Cone Jet Reconstruction Performance

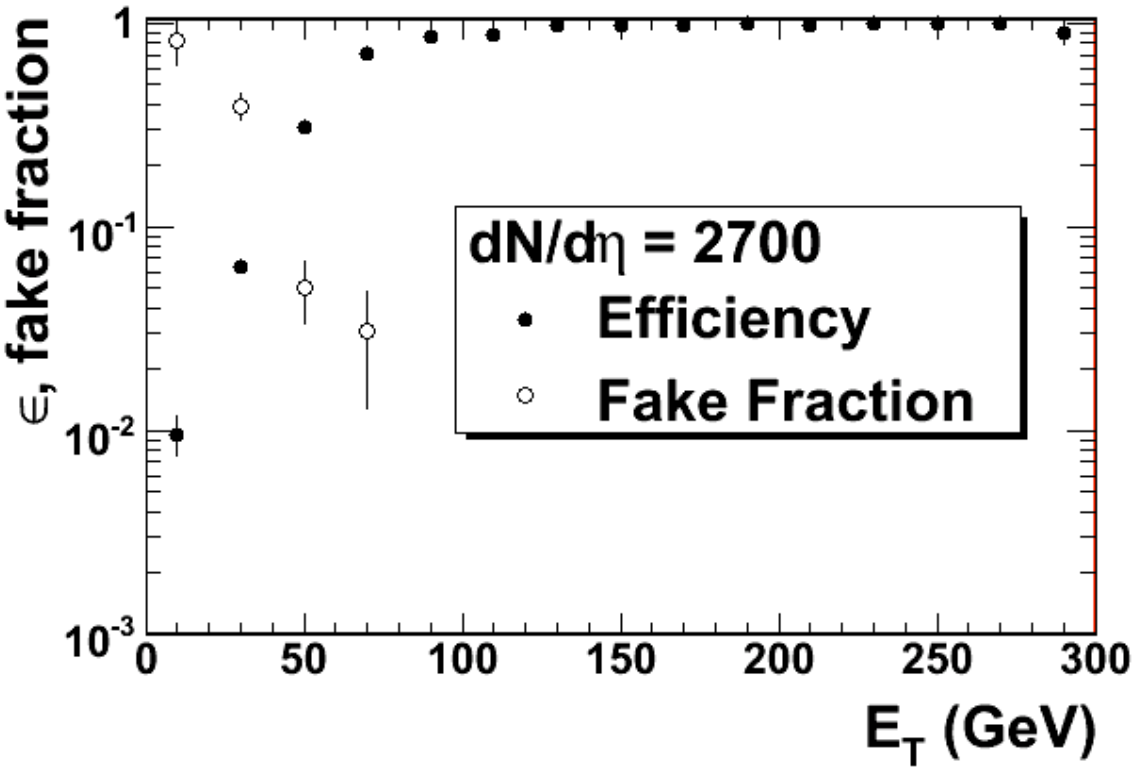
- 70% efficiency at 70 GeV for large range of dN/dη



Cone Jet Reconstruction Performance

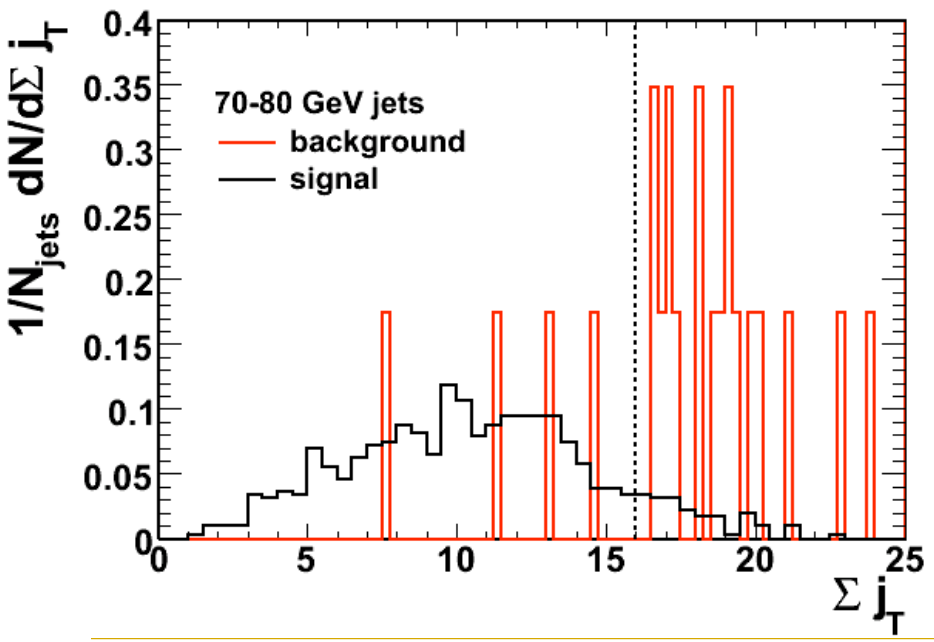
- 70% efficiency at 70 GeV for large range of dN/dη
- 3% fake fraction at 70 GeV for large dN/dη

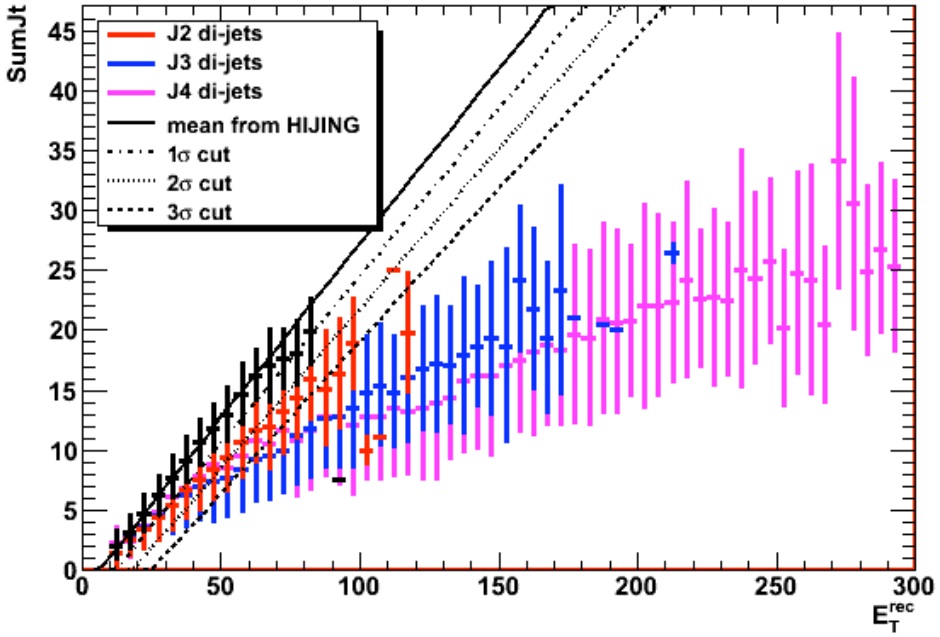
Removal of physical background based on shape analysis.



Shape Discrimination

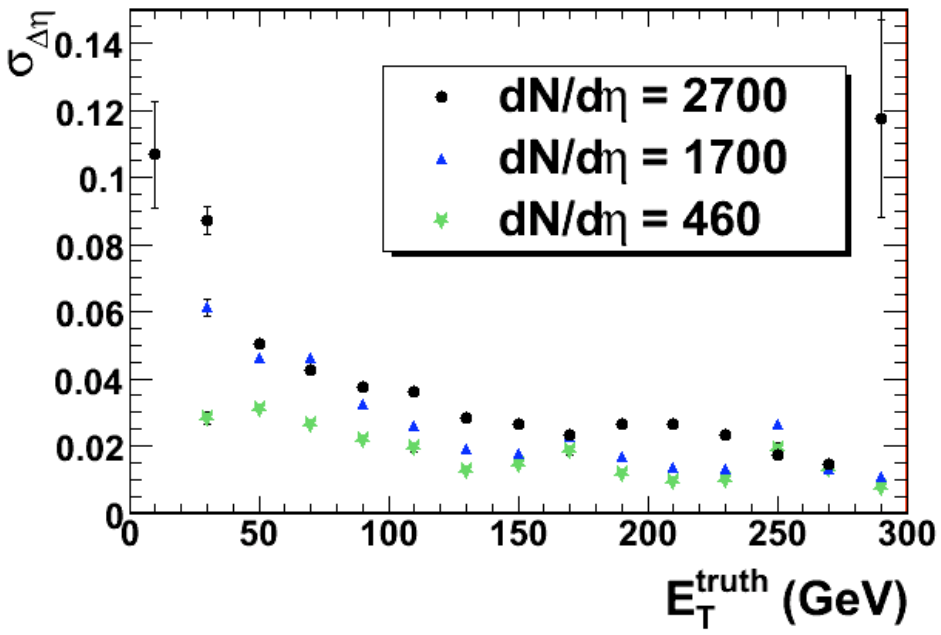
- Define SumJt as $\sum j_T = \sum_{cells} E_{T,cell} \sin R_{cell}$
- Clear separation between background and embedded jets

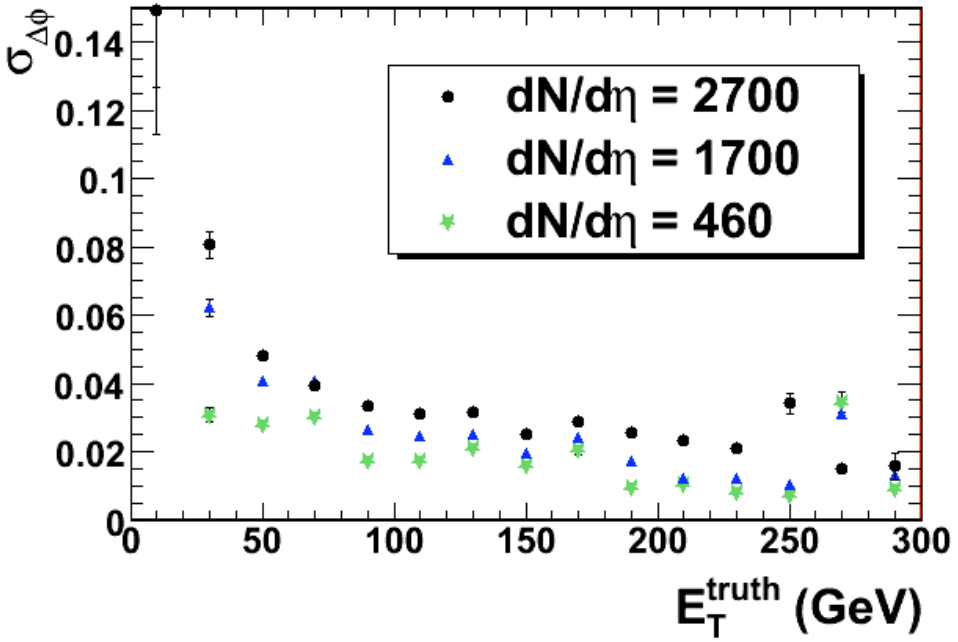




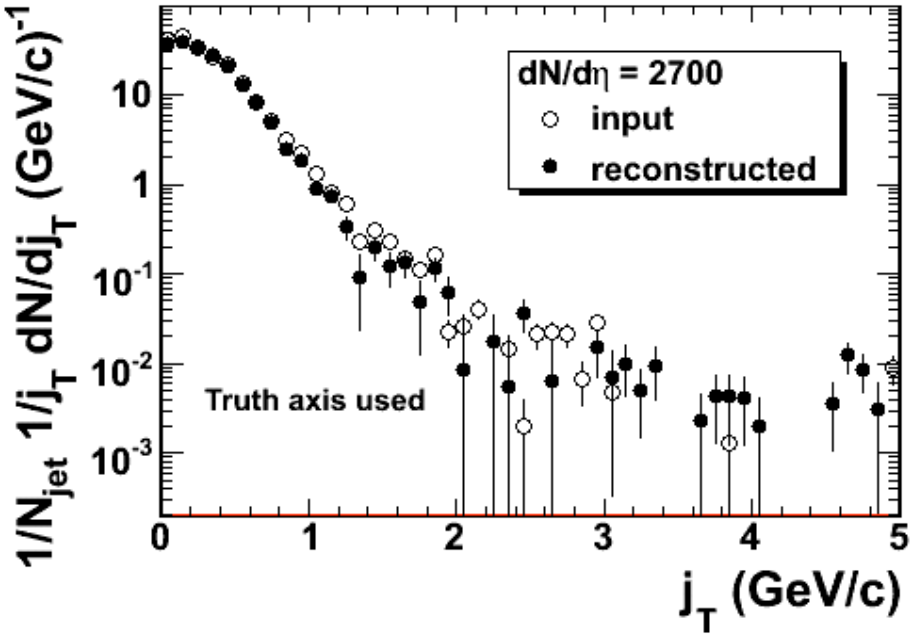
Cone Jet Reconstruction Performance: Position Resolution

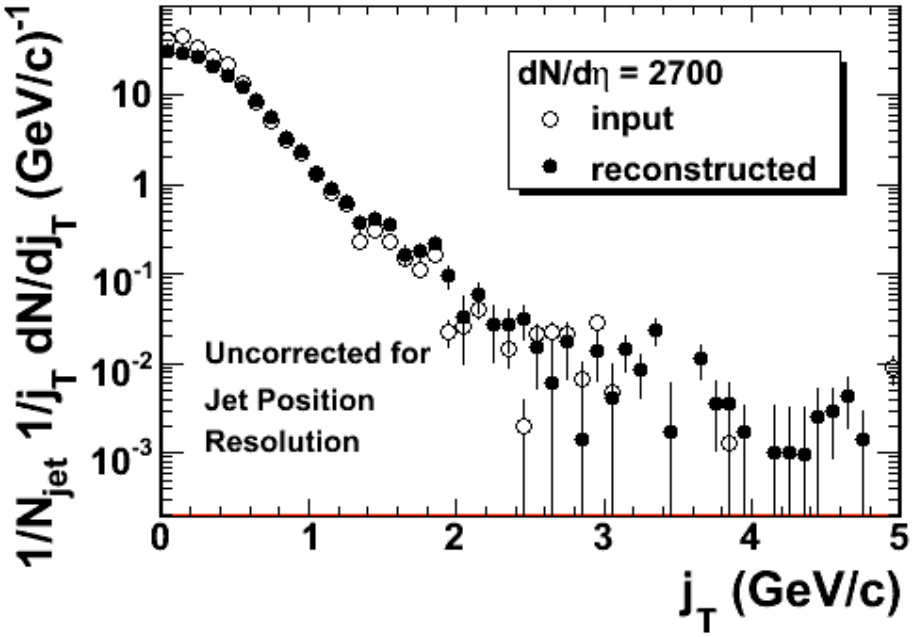
- Excellent position resolution over large range of E_T and $dN/d\eta$





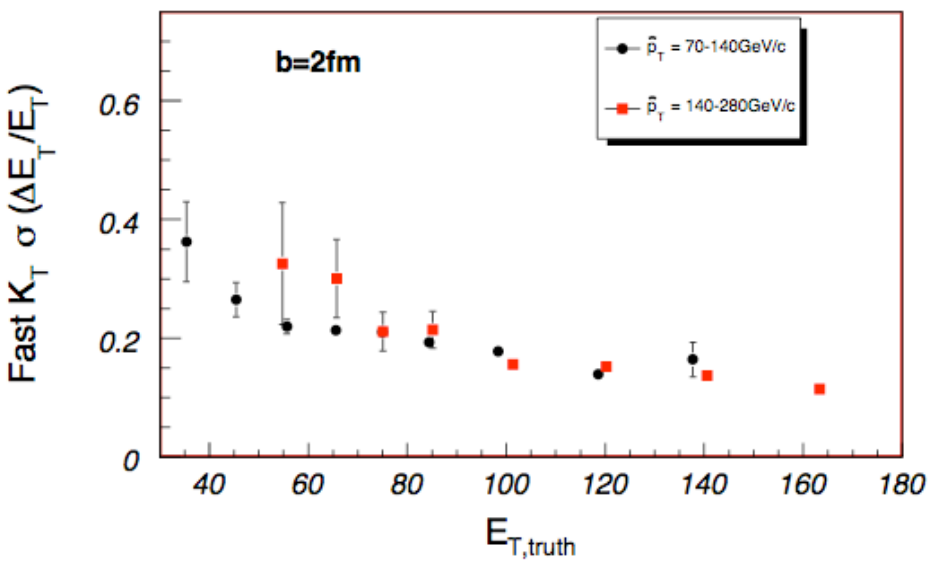
j_T with Truth Jet Axis

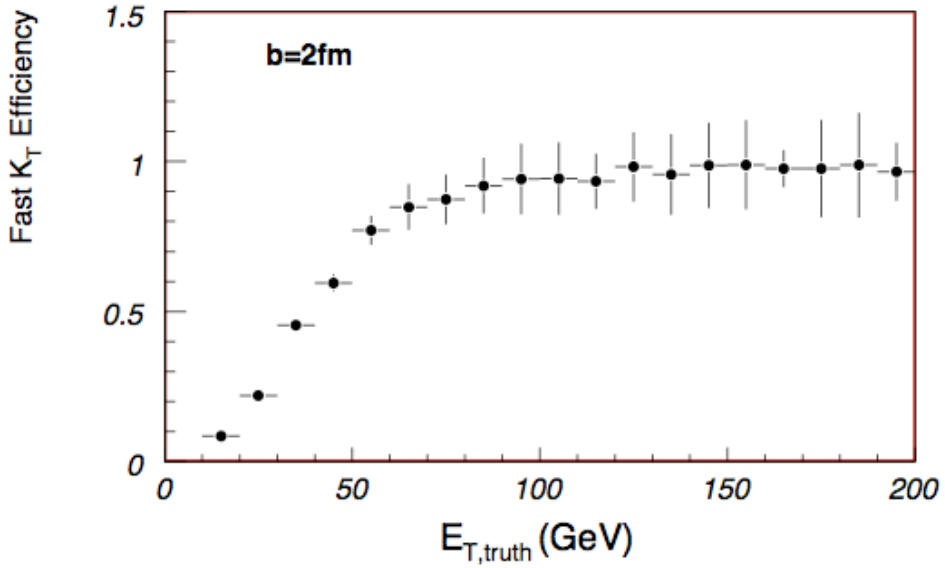




- Left: j_T with truth axis
- Right: j_T with reconstructed axis
- Difference due entirely to jet position resolution

Fast-k_T Performance

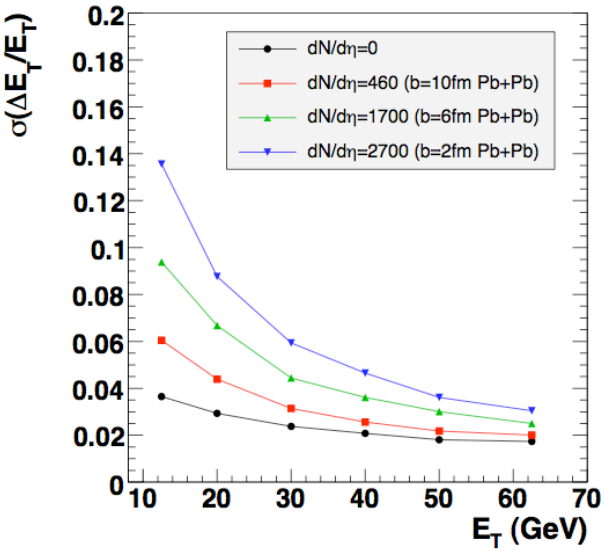


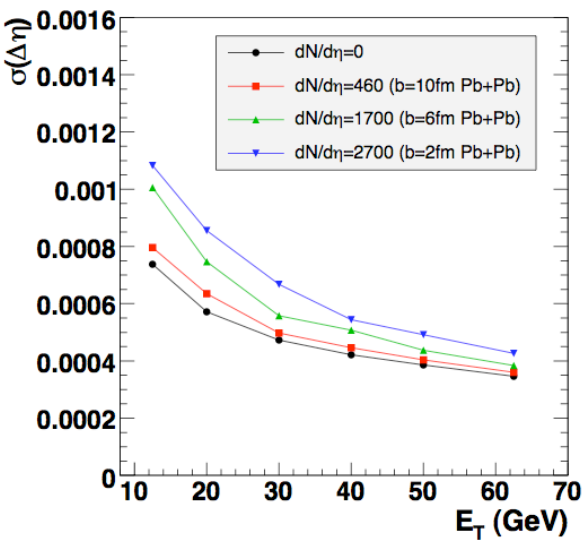


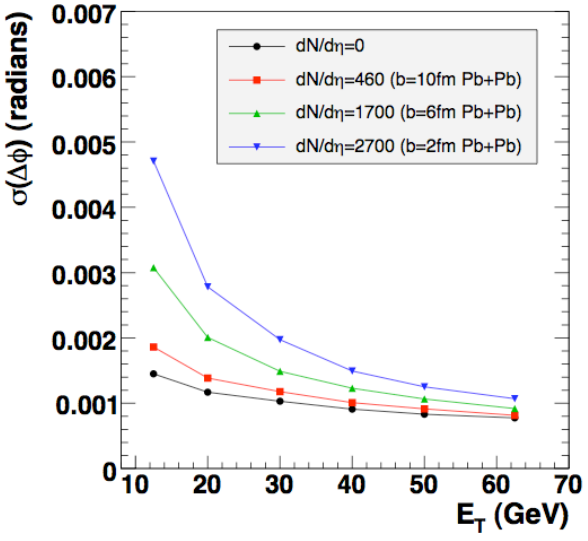
- Energy resolution and efficiency from Fast-k_T jet reconstruction
  - Similar results to the cone jet reconstruction

Photon Cluster Reconstruction

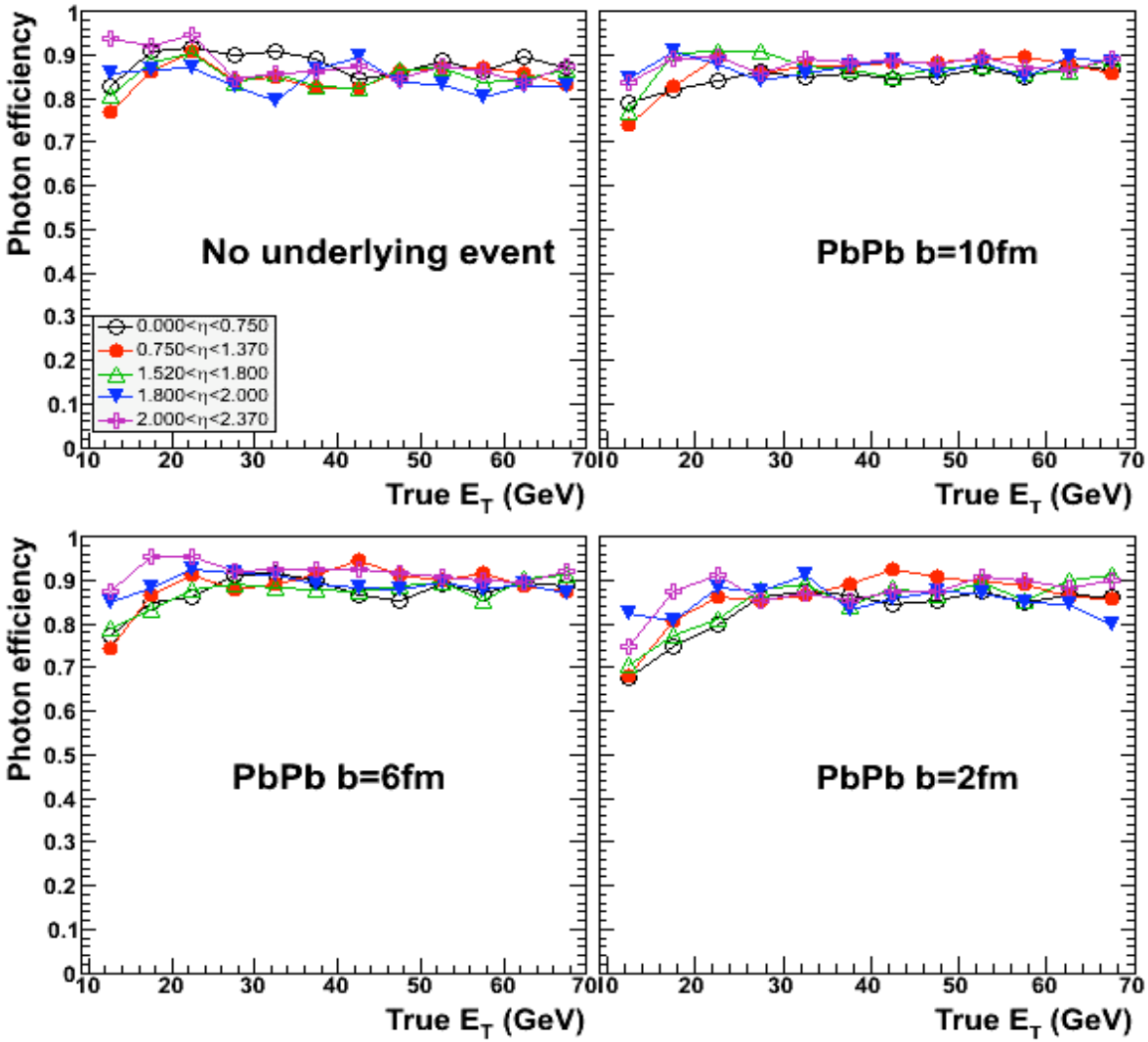
- Excellent energy and position resolution on cluster reconstruction, even at large dN/dη
- From ***unmodified*** ATLAS p+p cluster reconstruction algorithm.





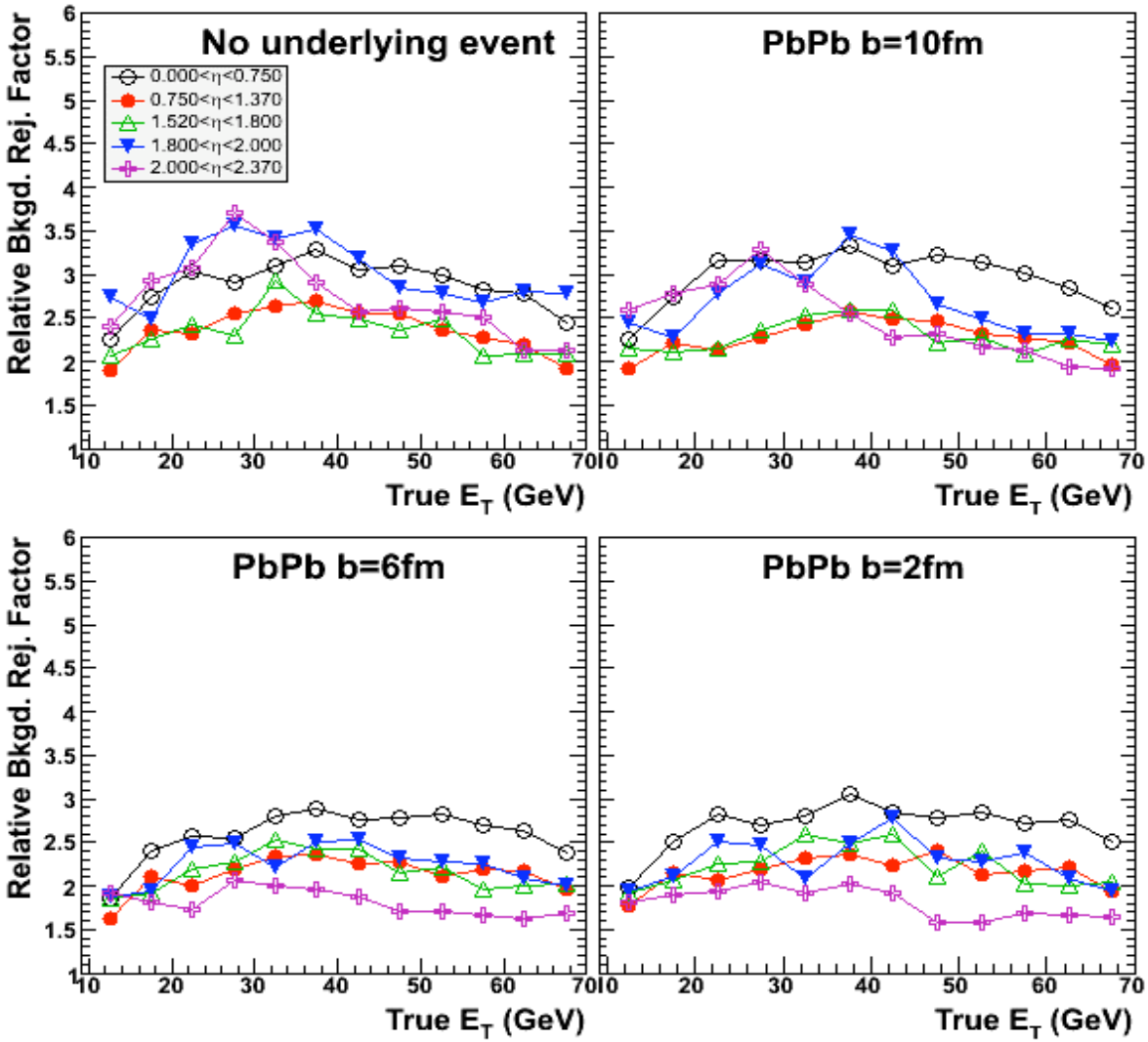


Photon Efficiency from Shape Cuts



- Efficiency from loose strip cuts for different HIJING backgrounds

Relative Rejection from Shape Cuts



- Relative background rejection from loose strip cuts for different HIJING backgrounds

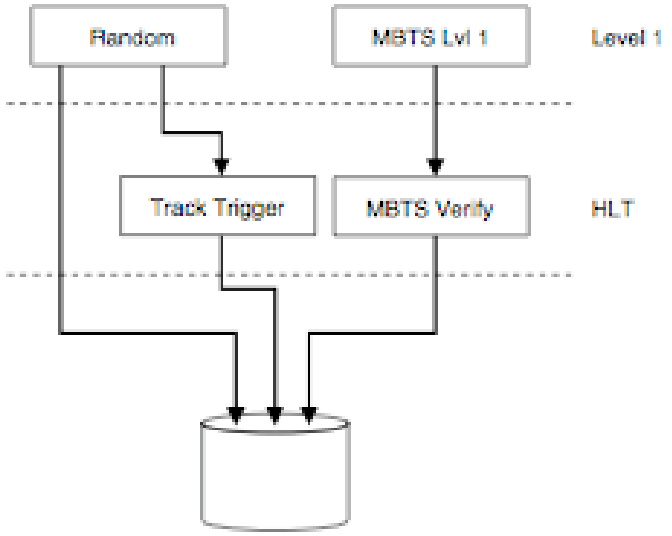
Trigger & Event Selection

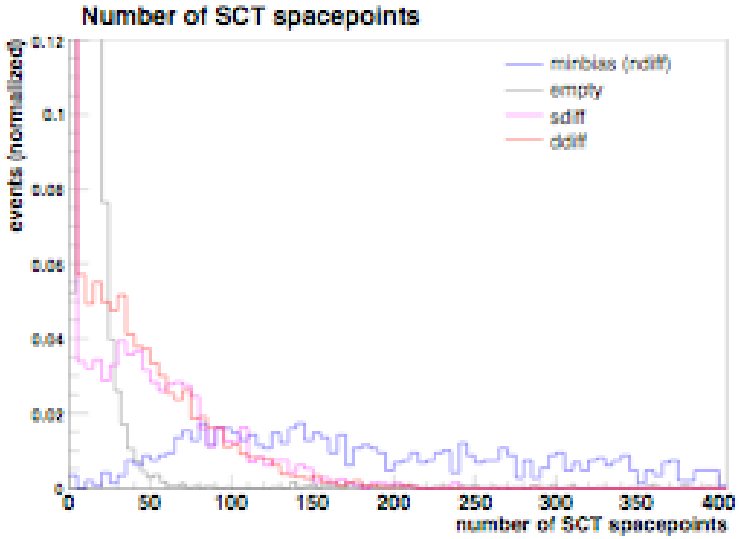
P. Steinberg

Session XXI

17:00

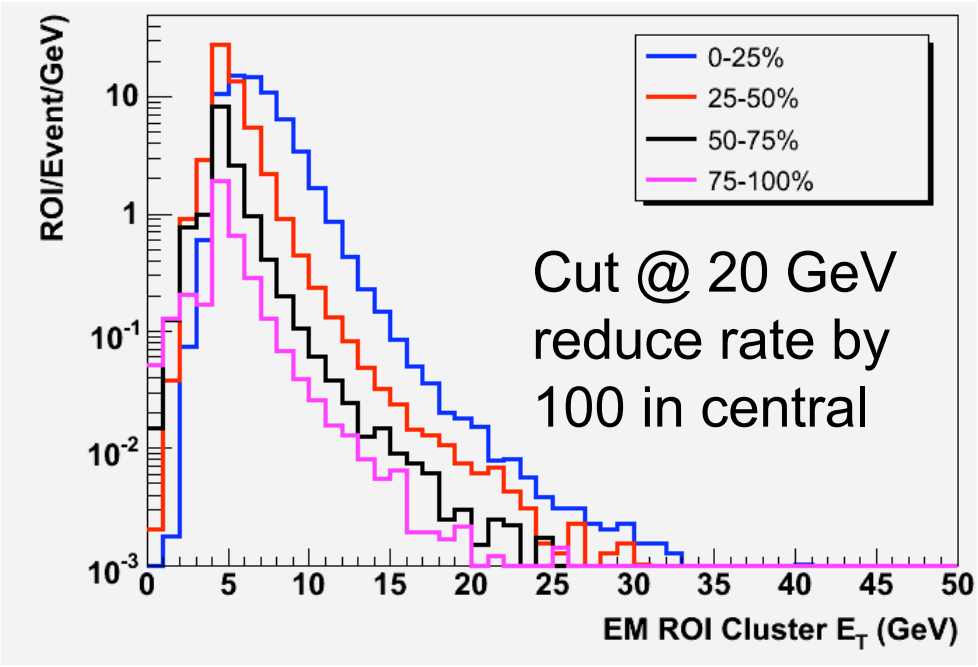
- **Heavy ion triggering schemes being developed in tandem with minimum-bias p+p effort**
- **Day-1 triggering strategies**
  - Random + space-point cut + track trigger - minimal bias, while rejecting empty events (less useful beyond day-1 A+A)
  - Minimum Bias Trigger Scintillators - installed at 2.12<|η|<3.85 (very useful - limited scintillator lifetime)
- **Calorimeter event trigger limited by readout noise**
  - With thresholding, can reliably trigger on 85% of total inelastic cross section

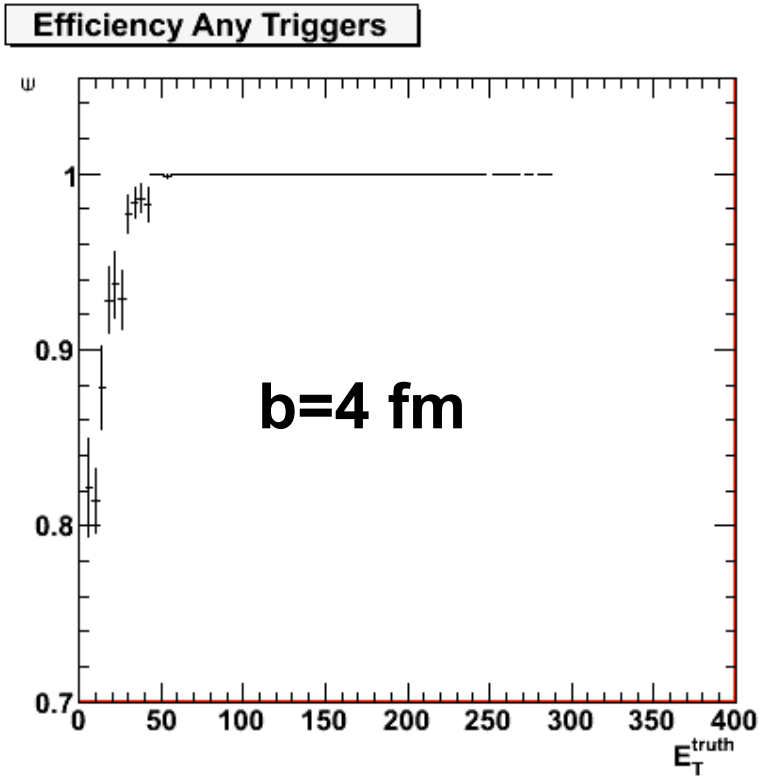




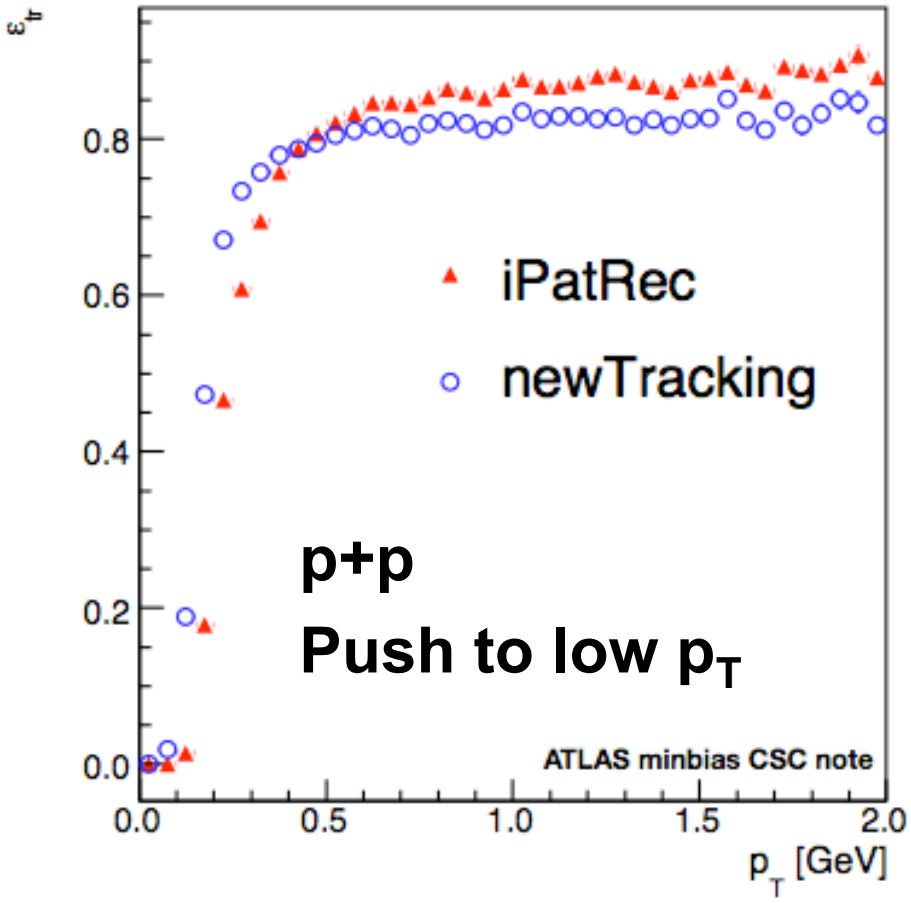
Jet and Photon Triggering

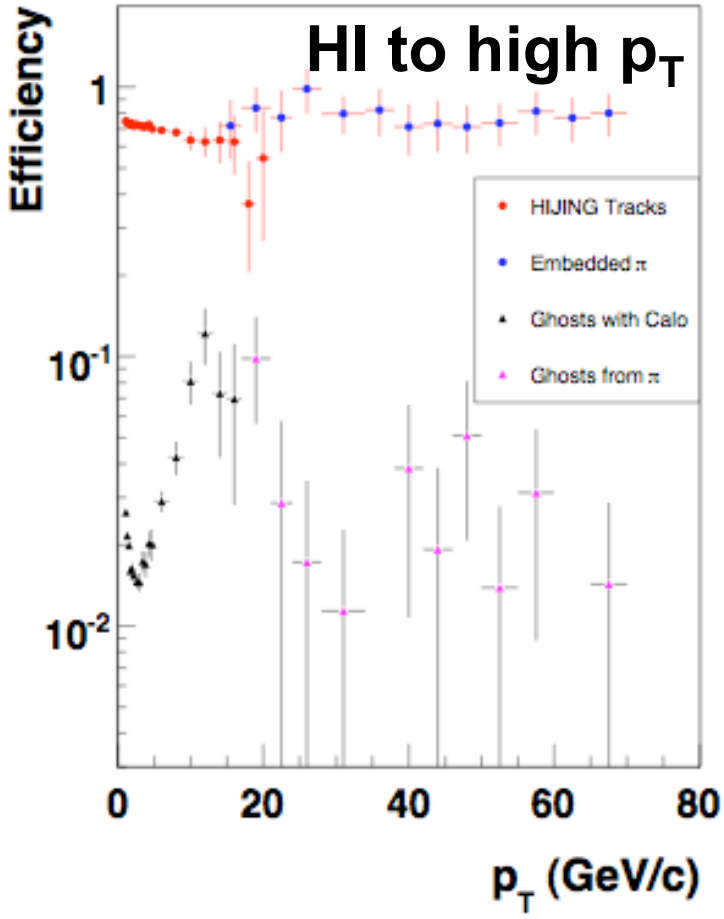
- No rejection needed at Level-1 but Region of Intrest (ROI) helpful for Level-2/3





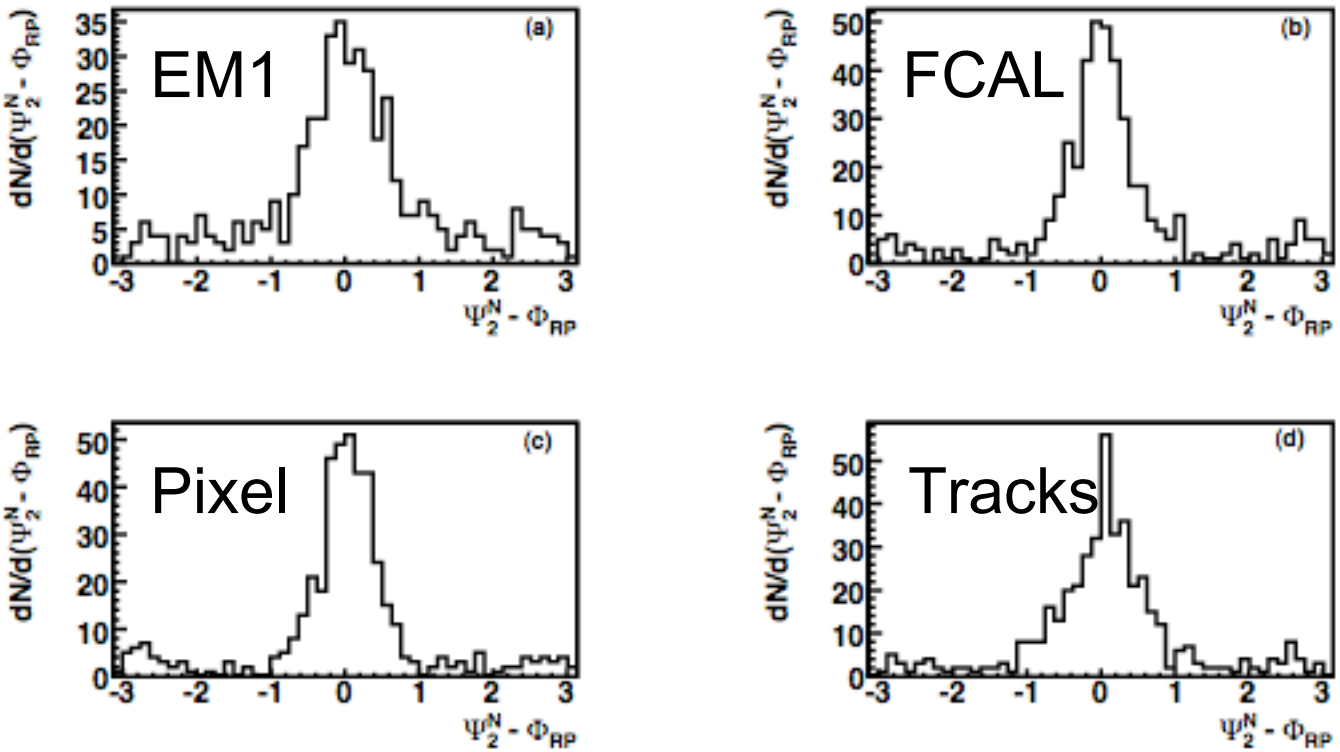
Tracking efficiency: Low to High p_T





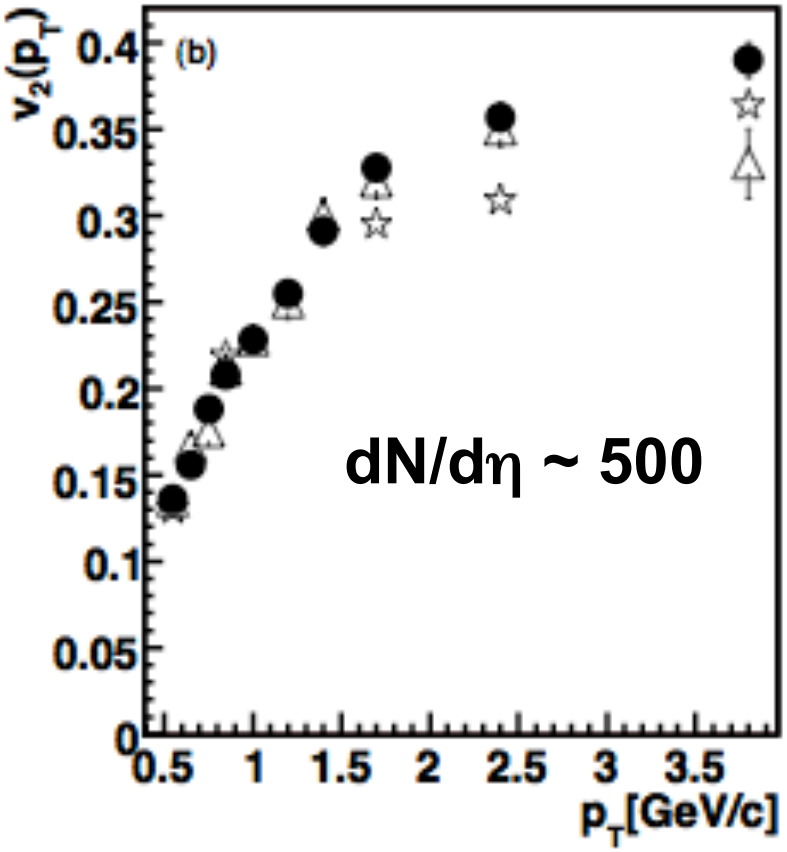
Reaction Plane Resolution

Correlation with true RP



- Several methods to measure reaction plane
- RP resolution > 0.7

v_2 From Calorimeter/Tracks



- Circles - generated v_2
- Triangles - v_2 from RP method
- Stars - v_2 from two-particle correlations