R&D Studies of a Lead-Scintillating Fiber Calorimeter as a STAR Forward Detector

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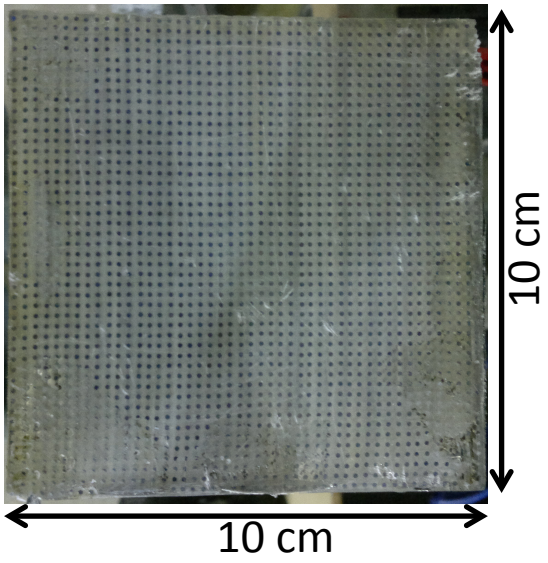
(for FCal group at STAR)

Outline

- Physics and R&D goals
- Pixelizing the existing cells to improve resolution
- Results from Fermilab Test Beam Facility-T1064
- Prototype at STAR in Run-14
- Conclusions
- Outlook: Proposed annular geometry at STAR



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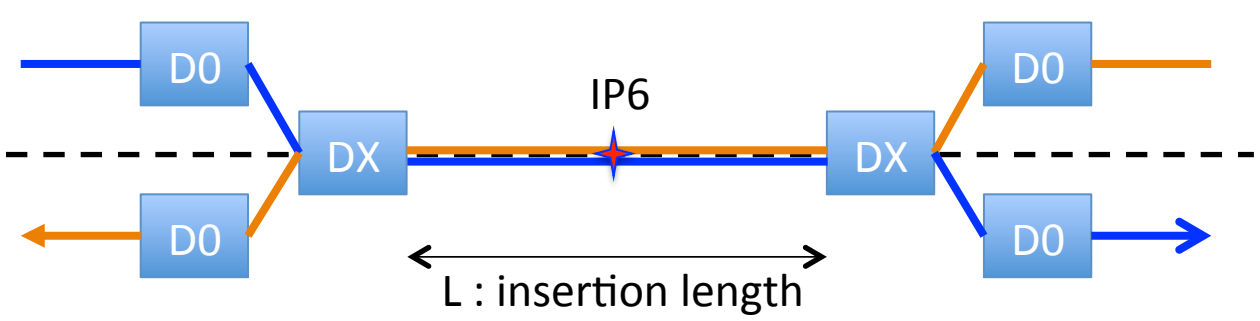
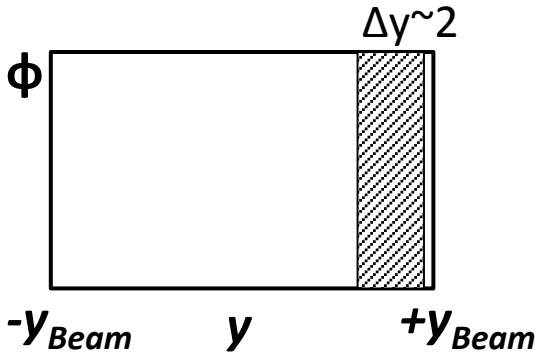
STAR

Physics Motivations

- Improve limited <u>forward</u> instrumentation





- RHIC has large insertion lengths
- Measurement of large X_F particle production is feasible
- Sufficient *pT*

Physics Motivations

- Improve limited forward instrumentation
- Proton structure
  - Drell Yan
  - Dijets

A_nDY :Perpendicularly polarized p+p

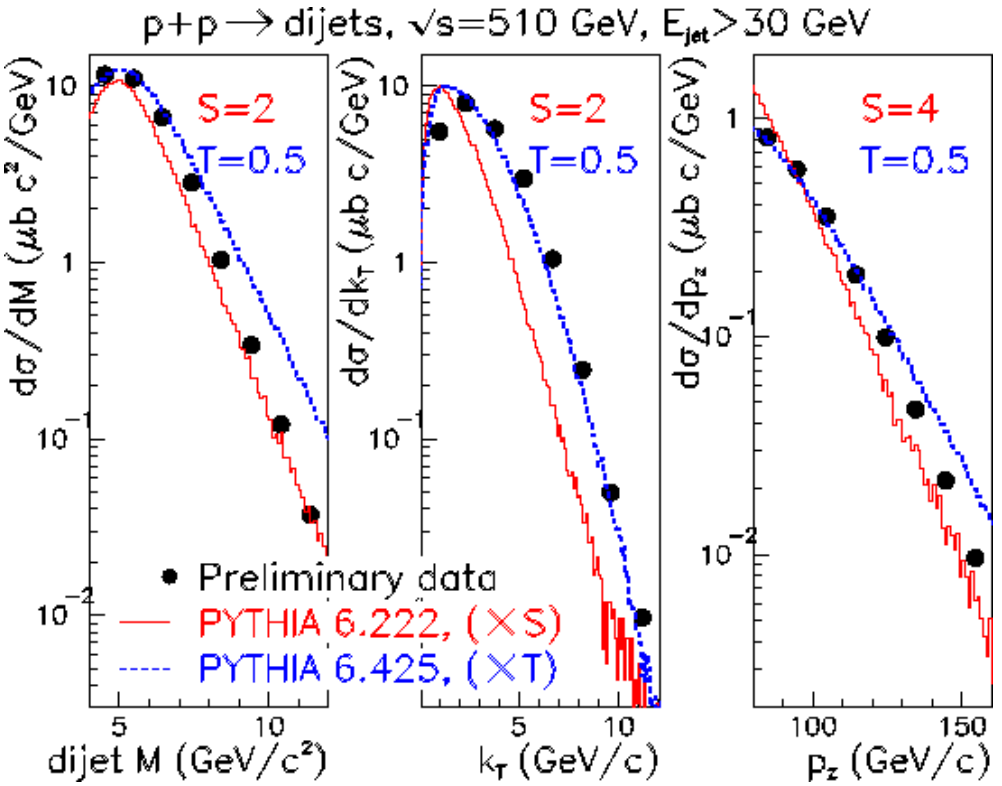
STAR : Spin rotators

=> +/- Helicity proton beam

=> Gluon polarization

=> Low-X measurements

$$A_{LL} \propto \frac{\Delta g}{g}$$



- Dijet cross sections as functions of dijet mass (M)
- Dijet momentum imbalance (kT)
- Dijet longitudinal momentum (pz)

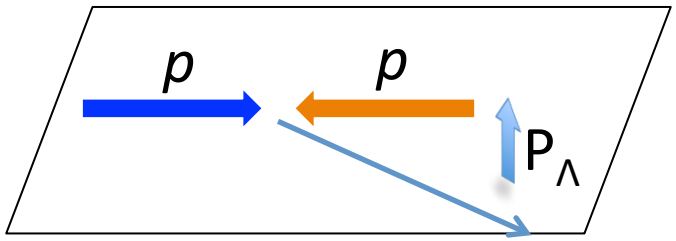
arXiv:1308.4705

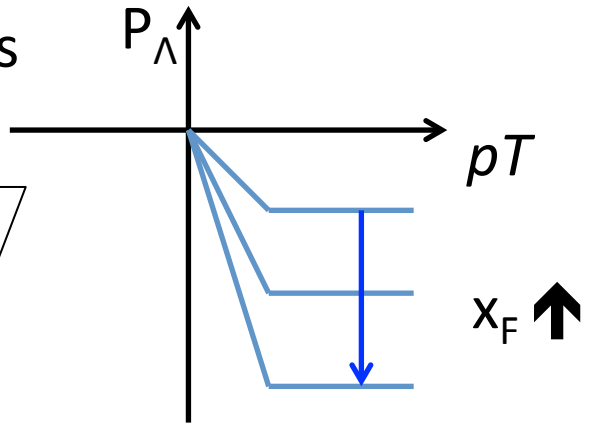
Physics Motivations

- Improve limited forward instrumentation
- Proton structure
  - Drell Yan
  - Dijets
- Heavy-ion collision
  - Event plane detector for all energies
    - Strong flow at large η ➔ Better event plane resolution
    - Large η gap ➔ Smaller non flow contribution to flow analysis

Physics Motivations

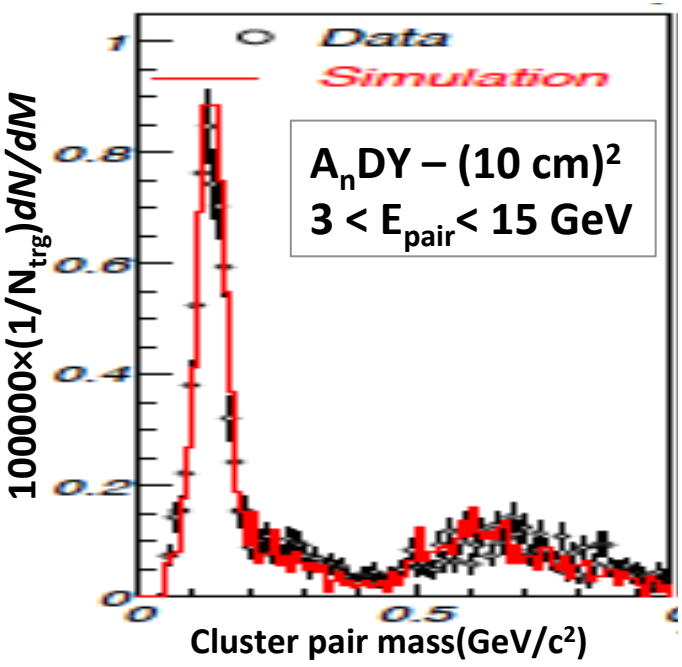
- Improve limited forward instrumentation
- Proton structure
  - Drell Yan
  - Dijets
- Heavy-ion collision
  - Event plane detector for all energies
  - Centrality selection
  - Long range near side rapidity correlation
  - Forward jets in asymmetric HI collisions
  - Induced Λ polarization

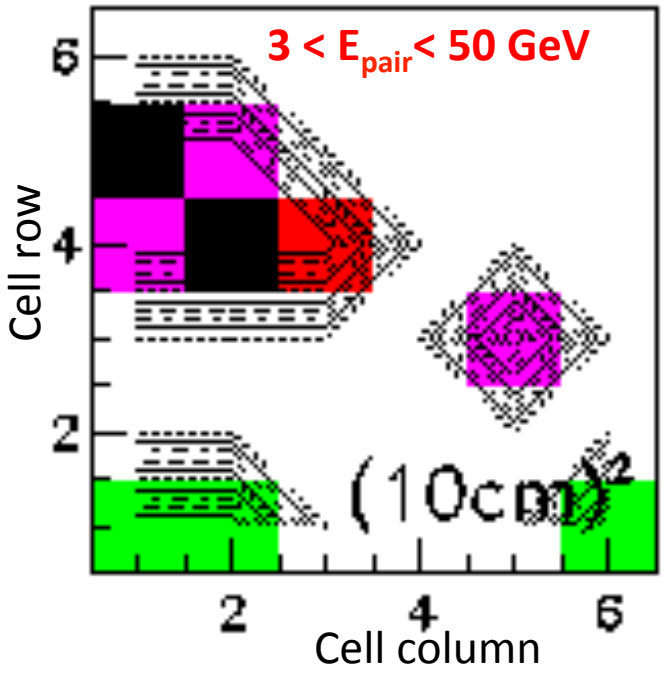




Goals of R&D project

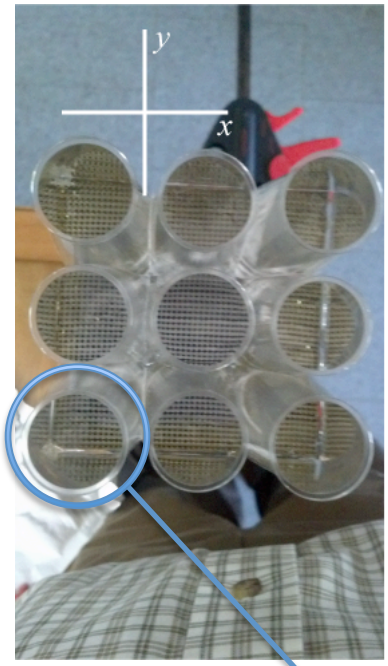
- Does increasing transverse resolution allow reconstruction of neutral pions at higher energies?
  - Reconstructing pions -> Tool to calibrate FCal
- Can we discriminate incident hadrons (e.g. π, *K*,..) from electromagnetic particle (e.g. ϒ, e^+,e^-,…) showers?

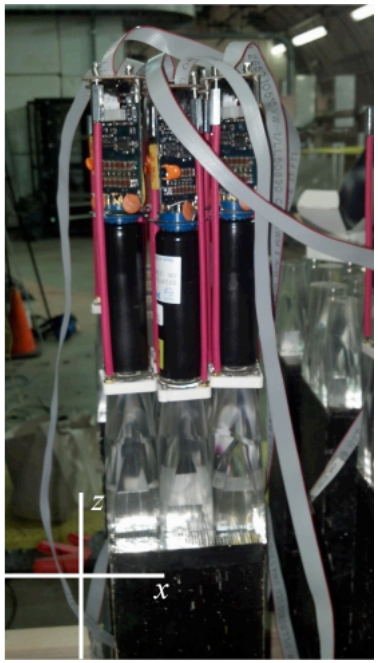


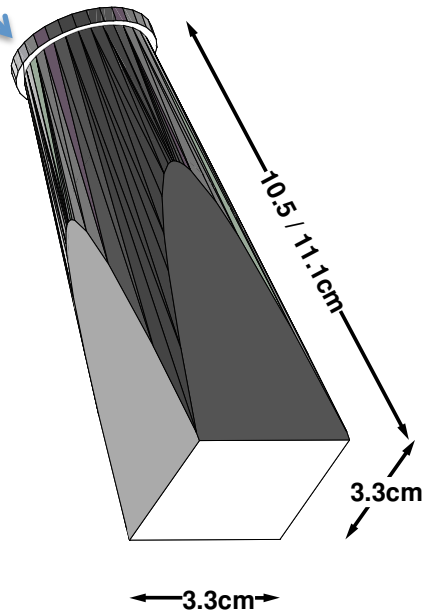


arXiv:1304.1454

Pixelizing AGS-E864 cells

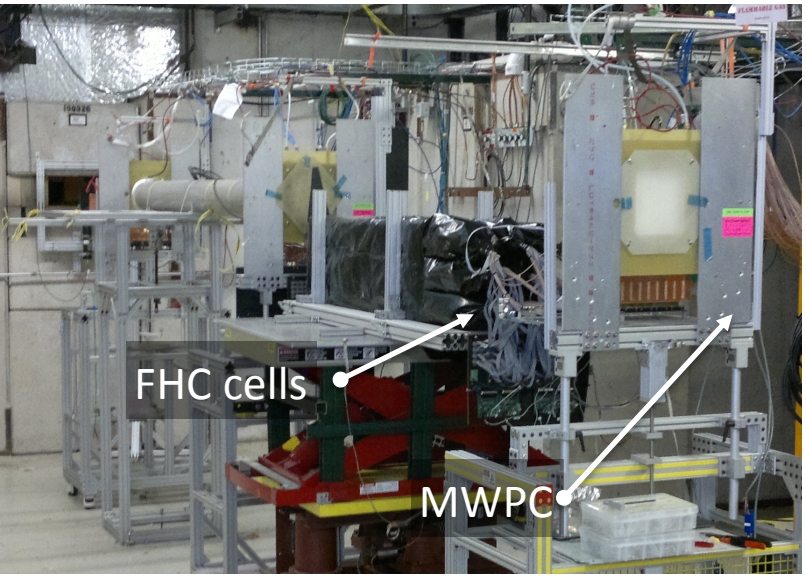




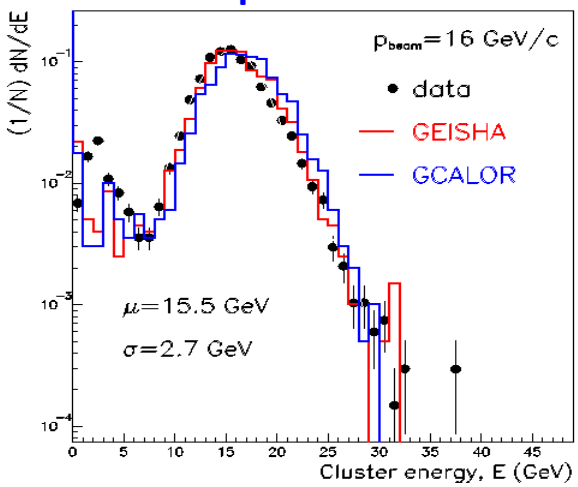


- Transverse resolution is increased by pixelizing
  - $(10\ cm)^2$ cells ➔ 3×3 array of $(3.3\ cm)^2$ cells
  - Specially designed totally internal reflective optically isolated light guides
  - xp2972 photomultiplier tubes
- Existing FMS detector electronics with STAR triggers for data collection

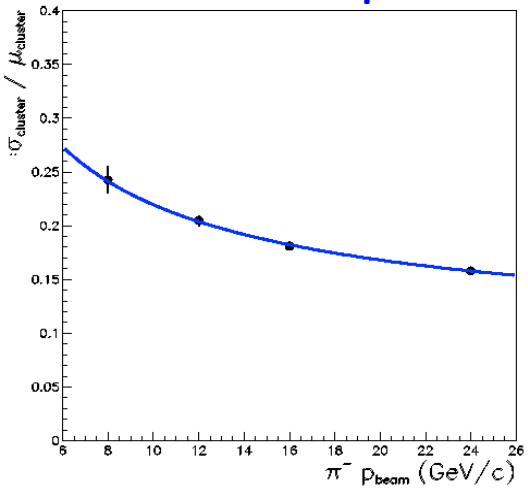
Results from Fermilab Test Beam Facility-T1064



Cluster energy distribution of center pixel for π⁻ beam



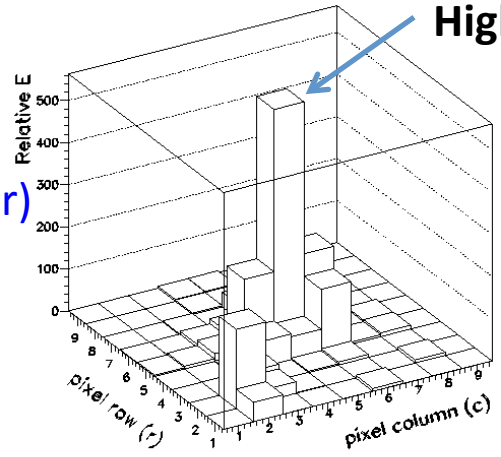
Cluster energy resolution for π⁻ on central pixel



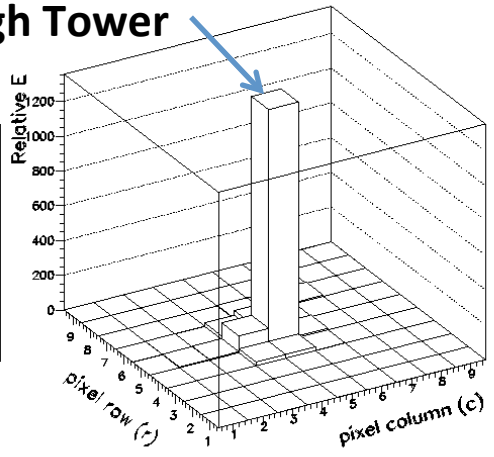
- 1 GeV (π,*K*,*p*) to 120 GeV *p* (resolution <3%)
- Cerenkov Detector (Particle Identification)
- MWPC Tracking System (Beam profile, trigger)

- 3×3 Cells (9×9 pixel) were used
- Studied shower shapes of e⁻ & π⁻ at beam momenta : 8, 12, 16, 24 GeV/c
- Simulations shows **good** agreement with data
- **Shows clean separation between e⁻ & π⁻ shower shapes**

High Tower



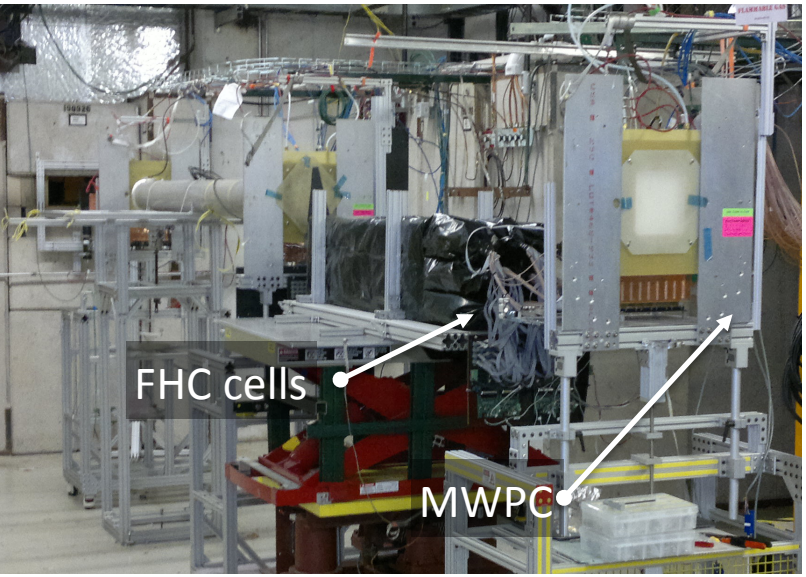
π⁻ 16 GeV/c



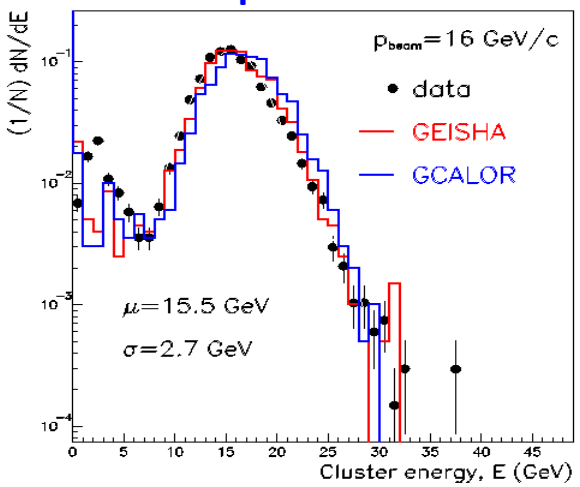
e⁻ 16 GeV/c

http://ppd.fnal.gov/ftbf/

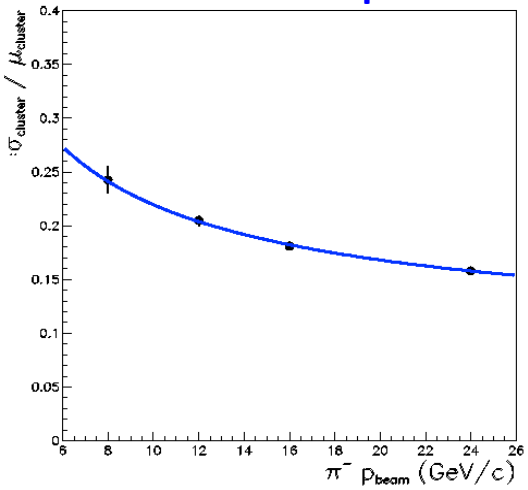
Results from Fermilab Test Beam Facility-T1064



Cluster energy distribution of center pixel for π⁻ beam



Cluster energy resolution for π⁻ on central pixel



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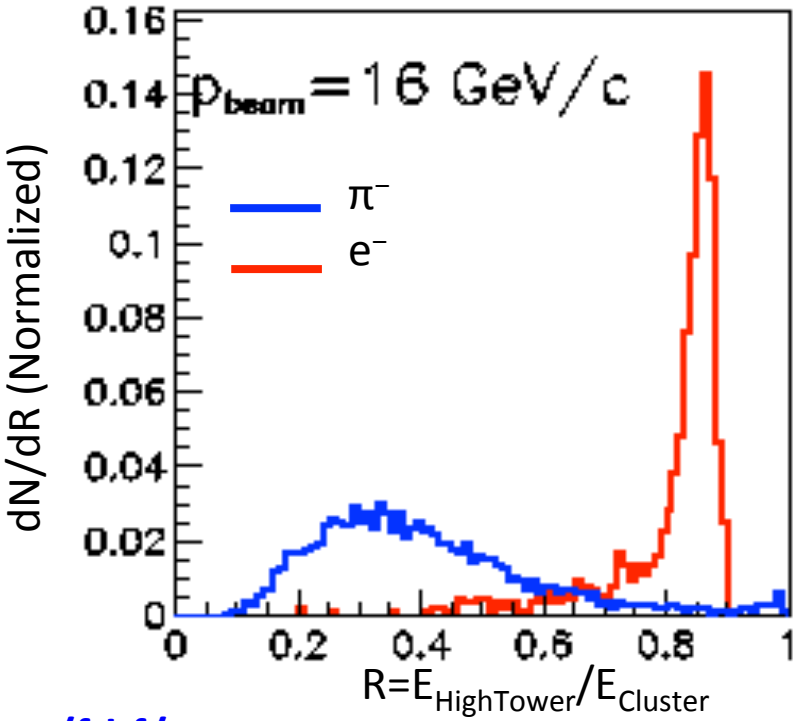
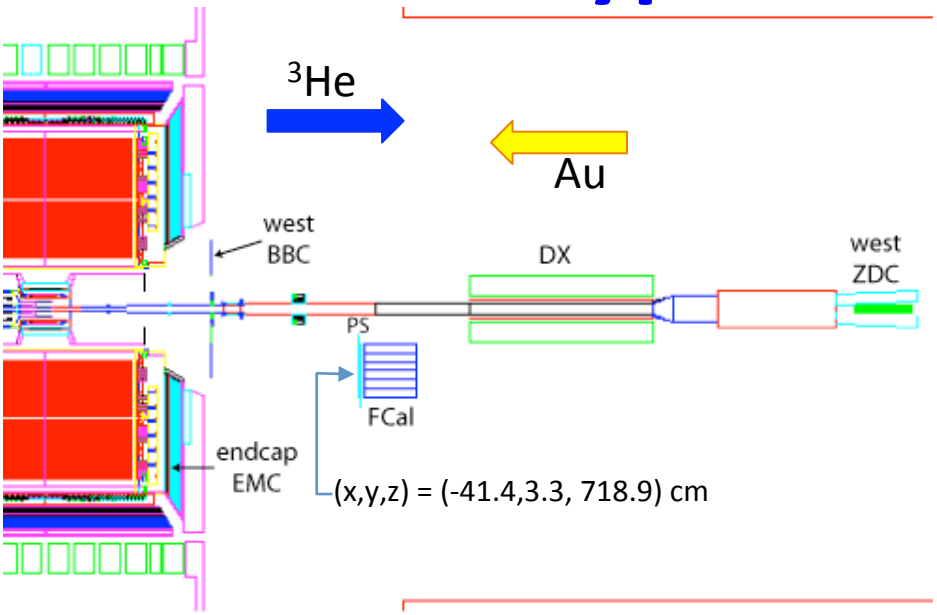
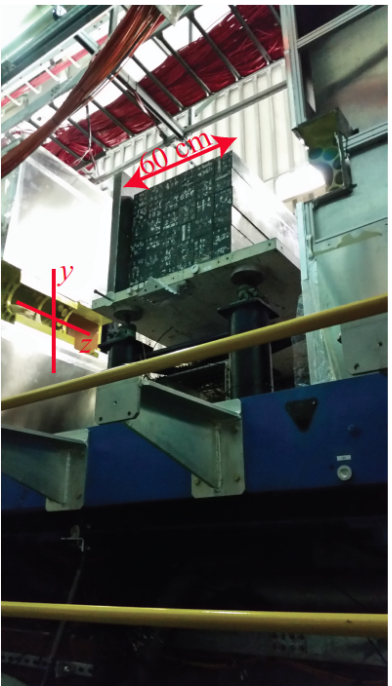


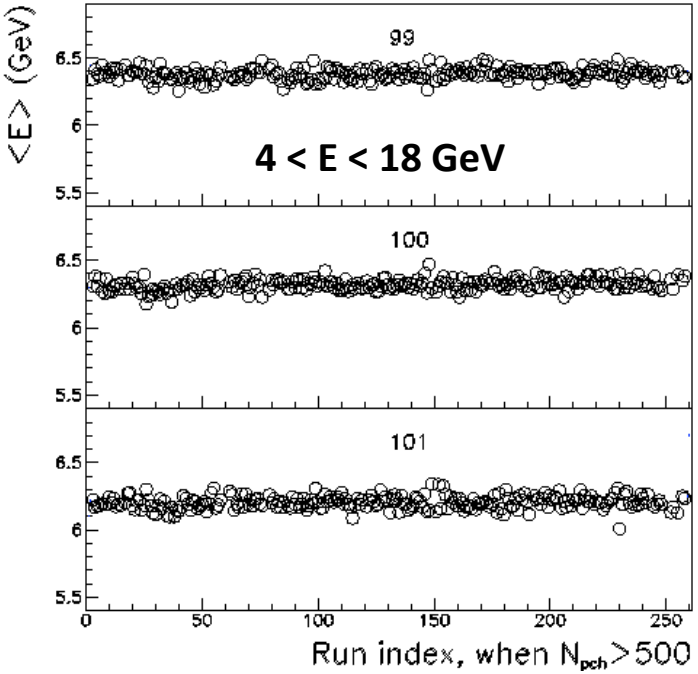
http://ppd.fnal.gov/ftbf/

2014 Prototype at STAR



- 6×6 array of cells (18×18 pixel) were mounted on the North-West side of STAR
- Best transverse resolution in forward direction
  - Granularity
  - Hadronic response
  - Large rapidity window



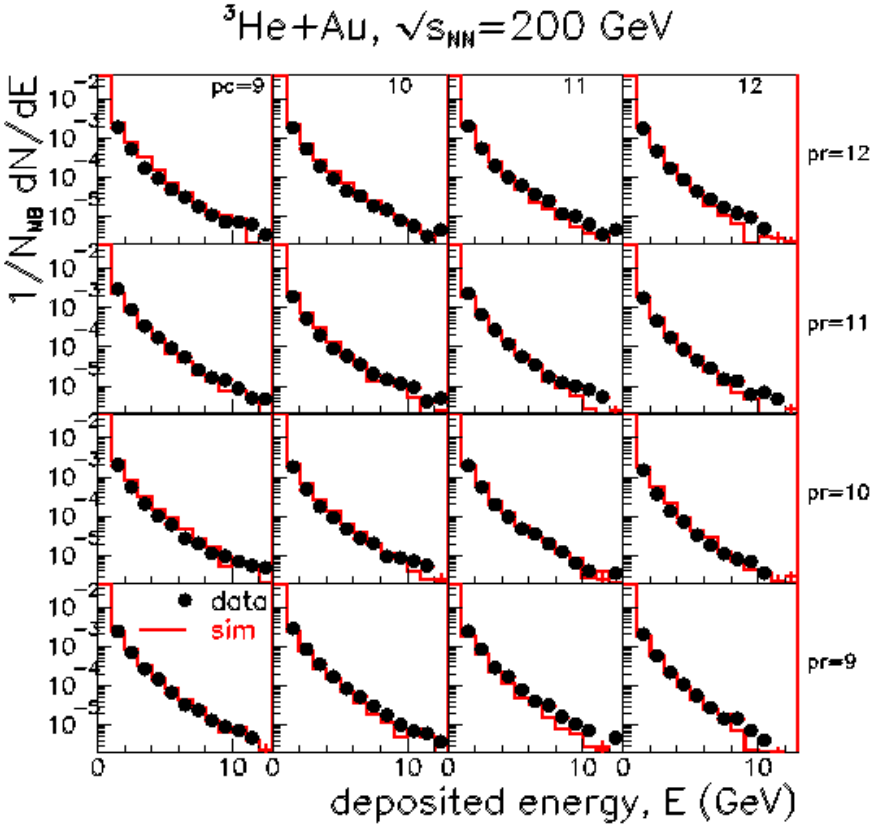


- $\sqrt{s_{NN}}$ = 200 GeV Au+Au collisions for commissioning
- $\sqrt{s_{NN}}$ = 200 GeV ^{3}He+Au collisions for calibration and analysis
- Average energy deposition per run shows stable response throughout the operation

Luminosity of ^{3}He+Au ≈ 25 pb^{-1} of p+p

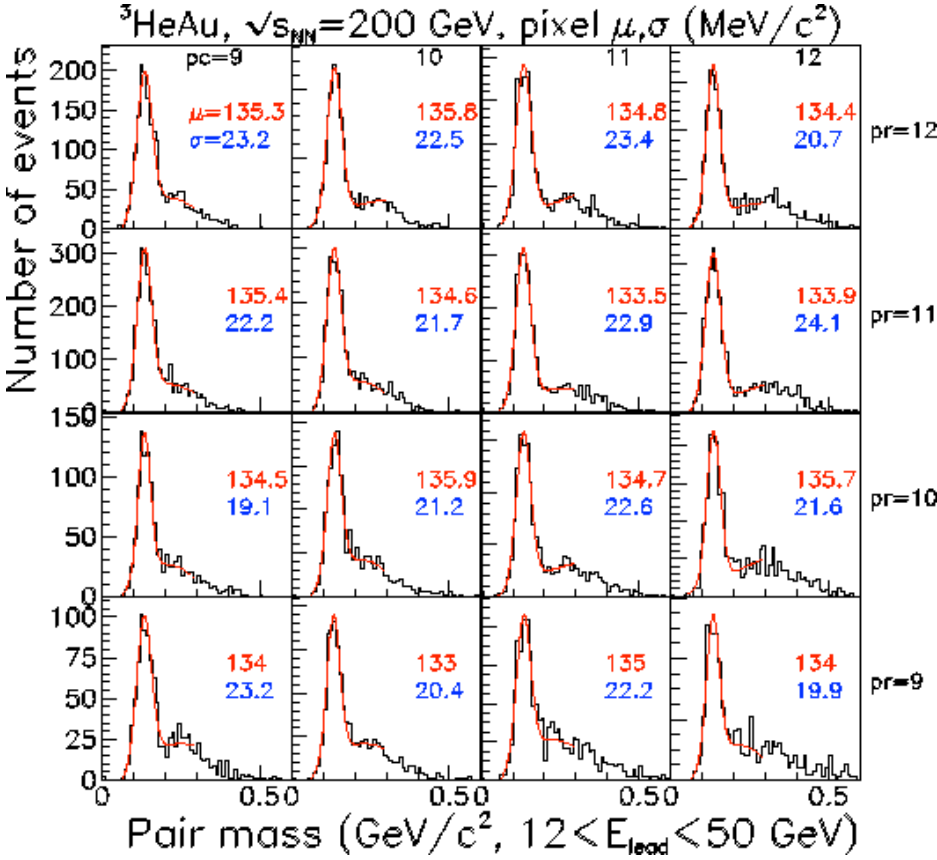
Calibration – Relative calibration of pixel

- Relative gain correction factors for each pixel are corrected in two steps
- 1st approximation
  - Relative calibration of pixel by comparing the slope from dN/dE distributions from data and simulation



Calibration – Relative calibration of pixel

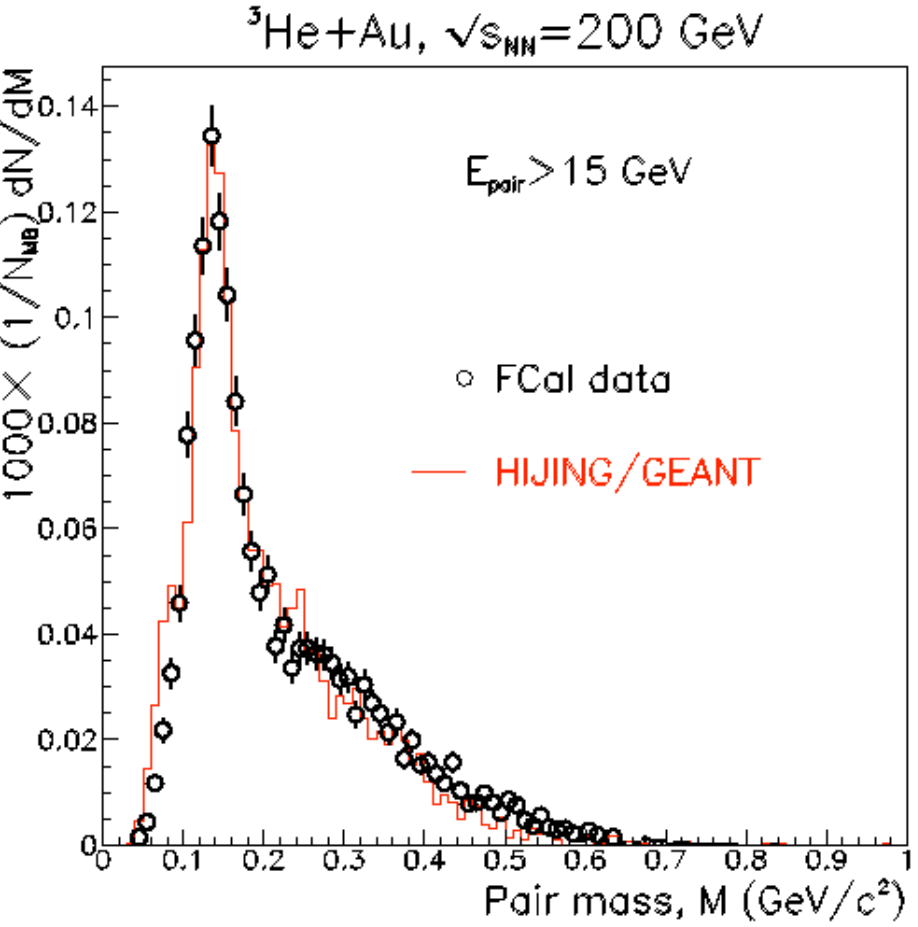
- Relative gain correction factors for each pixel are corrected in two steps
- 1st approximation
  - Relative calibration of pixel by comparing the slope from dN/dE distributions from data and simulation
- 2nd approximation - relative energy scale of pixels
  - Invariant mass of reconstructed cluster pair; high tower is associated to the pixel
  - Iterate until cluster pair mass converge to π^0 mass
- Further, energy dependent correction is also applied for pair mass



Fitted Gaussian centroid (μ) in red
Fitted Gaussian sigma (σ) in blue

$$g_i^{n+1} = \frac{g_i^n m_\pi}{\mu_i^n}$$

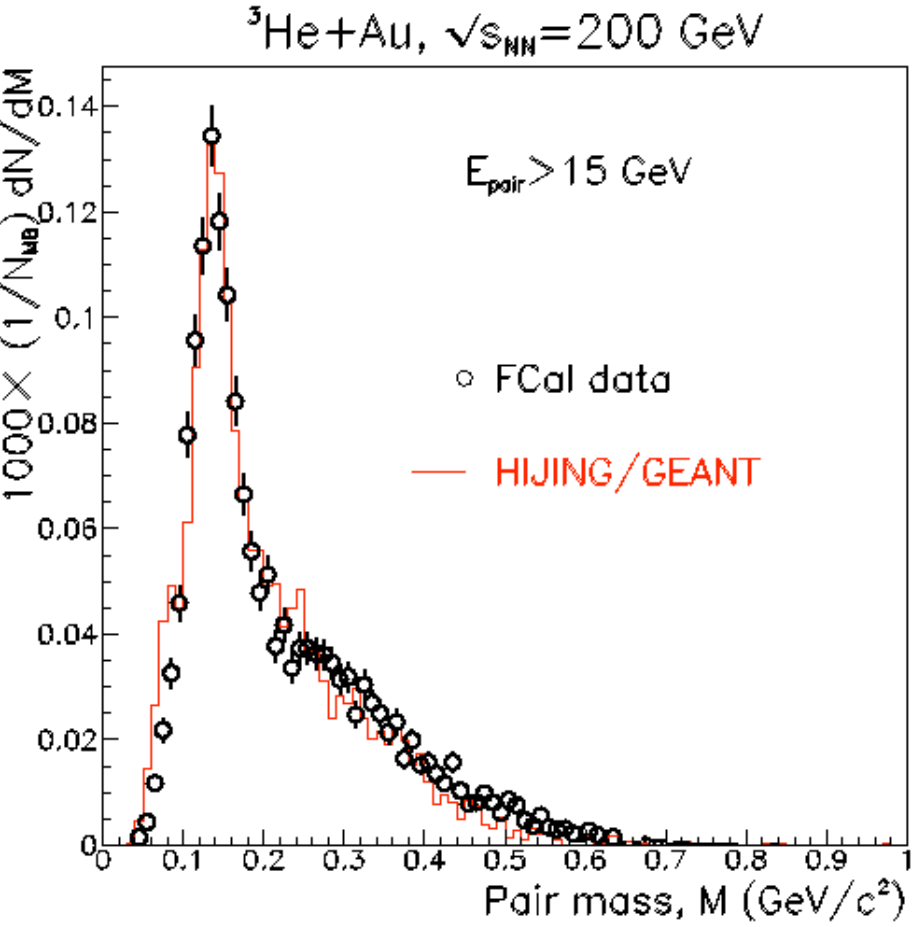
Data vs. Simulation

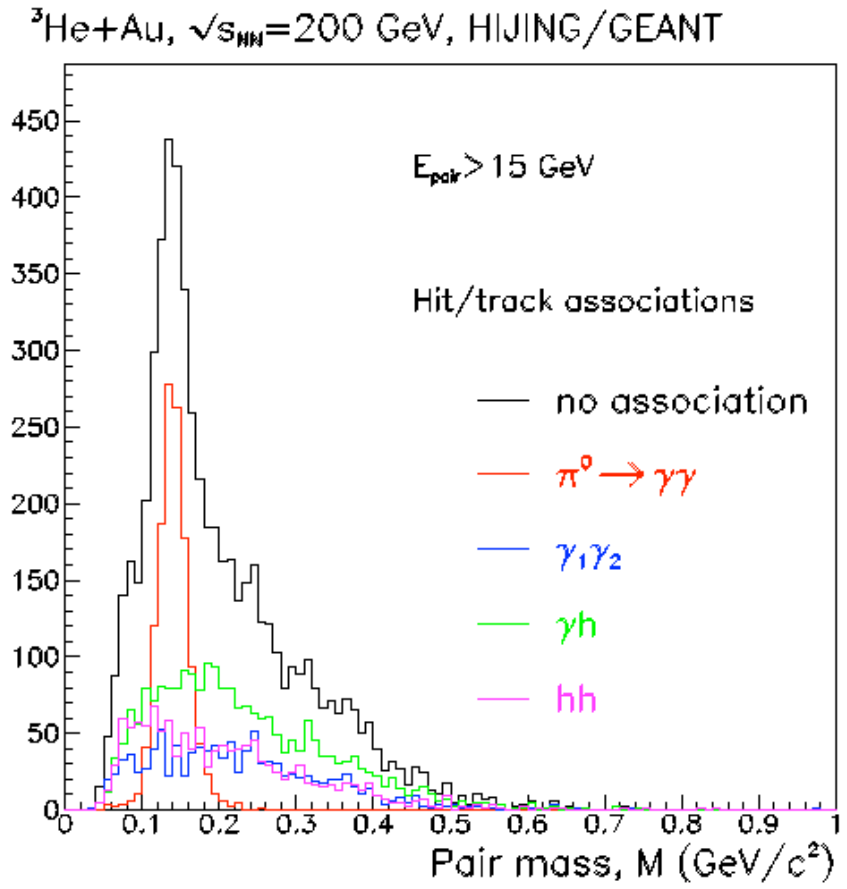


- Invariant mass of good cluster pairs from data vs. Simulation
  - Assumed clusters are from π^0 decay daughters
  - But, clusters may arise from non photons
- Vertical axis scaled by minimum-bias events

=> Data and Simulation are in good agreement

Data vs. Simulation



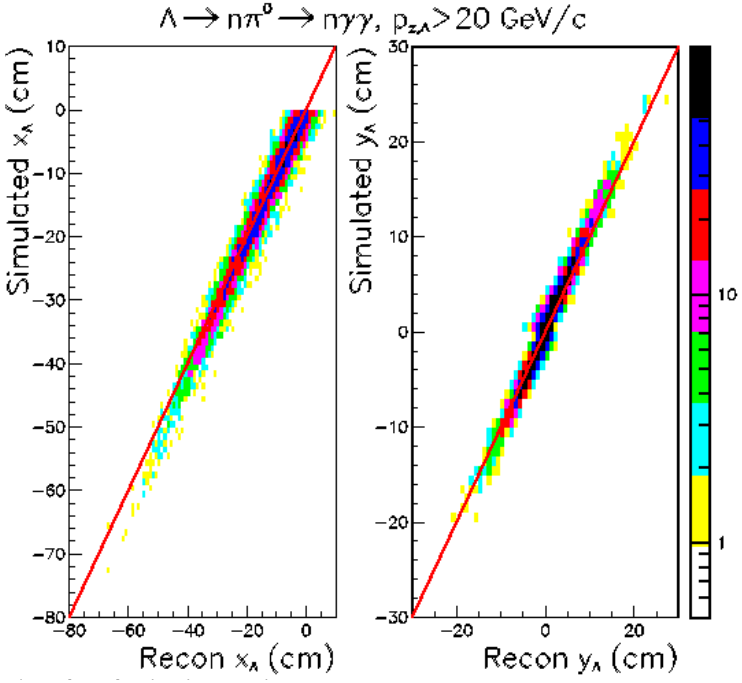


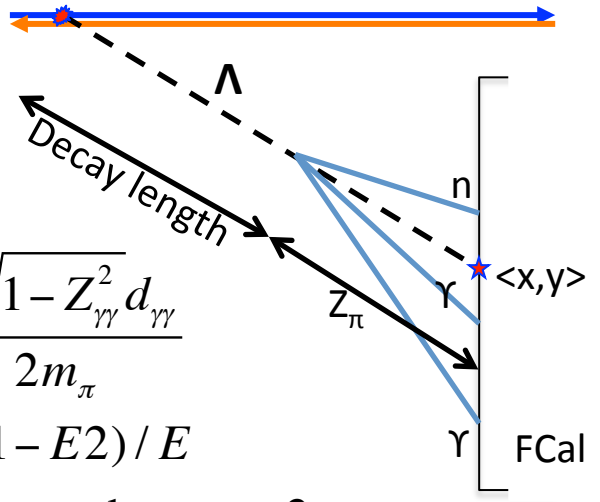
- Hits/Clusters were identified using associated particles in simulation
- Dominant background is when one cluster is a photon and the other is a hadron
  - Can be effectively reduced by good pre-shower detector and additional e/h discrimination from FCal

Lambda reconstruction - Ongoing

- PYTHIA events
- <x,y> are Λ impact point, from energy weighted average of n, ϒ, ϒ measured positions
- Y-axis : PYTHIA decay vertex
- X-axis : PYTHIA decay vertex is reconstructed including FCal acceptance and efficiencies
- Require two photons and neutron to make distinct clusters

=> The Λ decay vertex can be reconstructed from n, ϒ, ϒ measurements in FCal





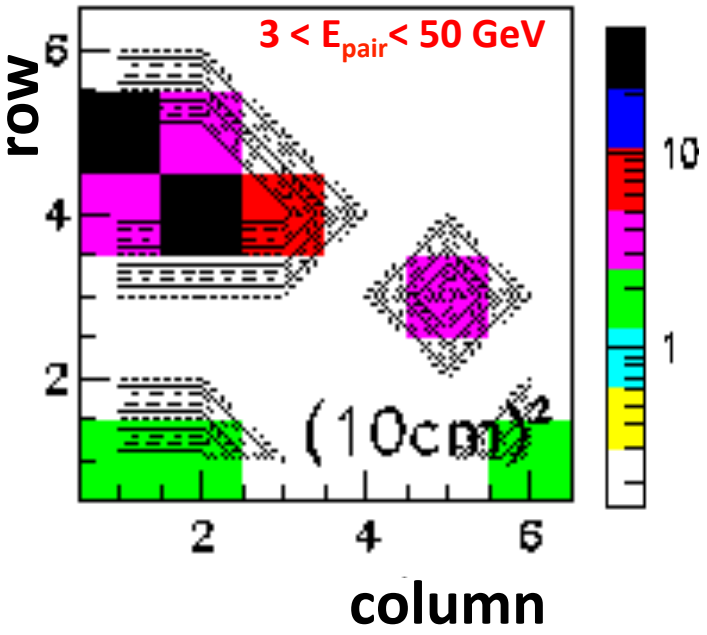
$$Z_\pi = \frac{E\sqrt{1 - Z_{\gamma\gamma}^2}\, d_{\gamma\gamma}}{2m_\pi}$$

$$Z\gamma\gamma = (E1 - E2)/E$$

$$d\gamma\gamma = \text{distance between } 2\gamma \text{ in FCal}$$

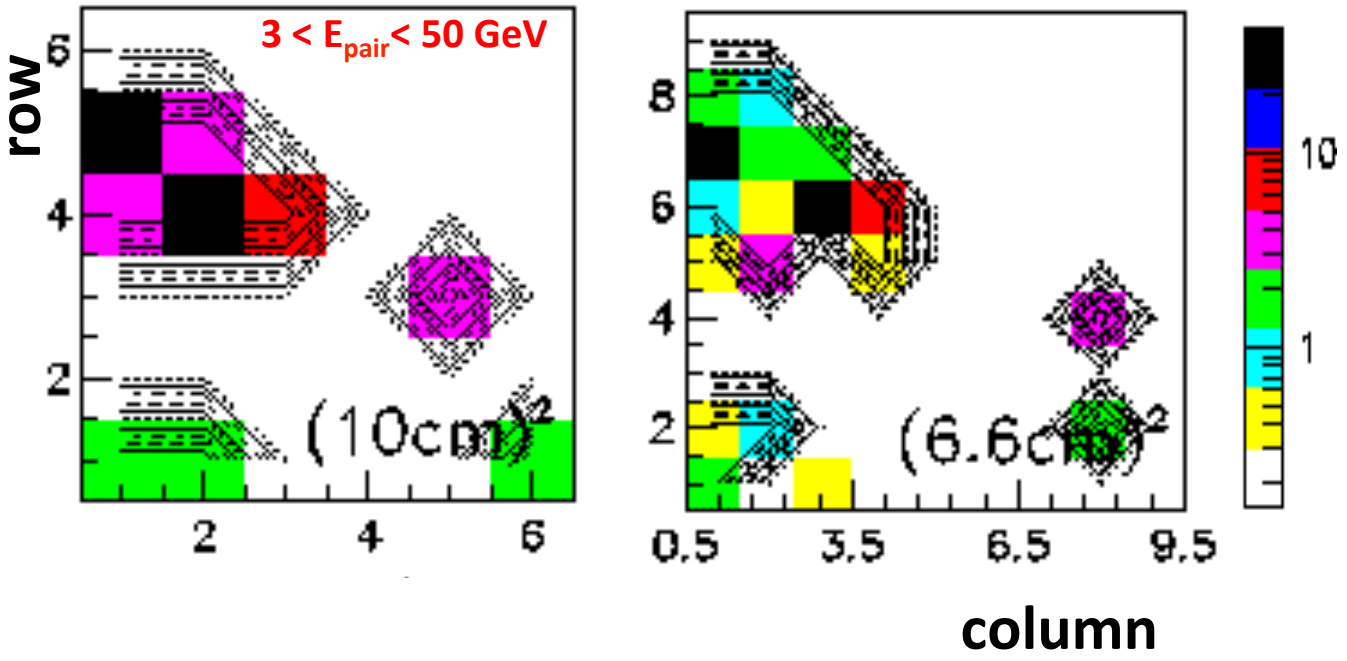
Conclusions

- Pixelizing E864 cells allows reconstruction of neutral pions to higher energy up to ≈50 GeV



Conclusions

- Pixelizing E864 cells allows reconstruction of neutral pions to higher energy up to ~50 GeV



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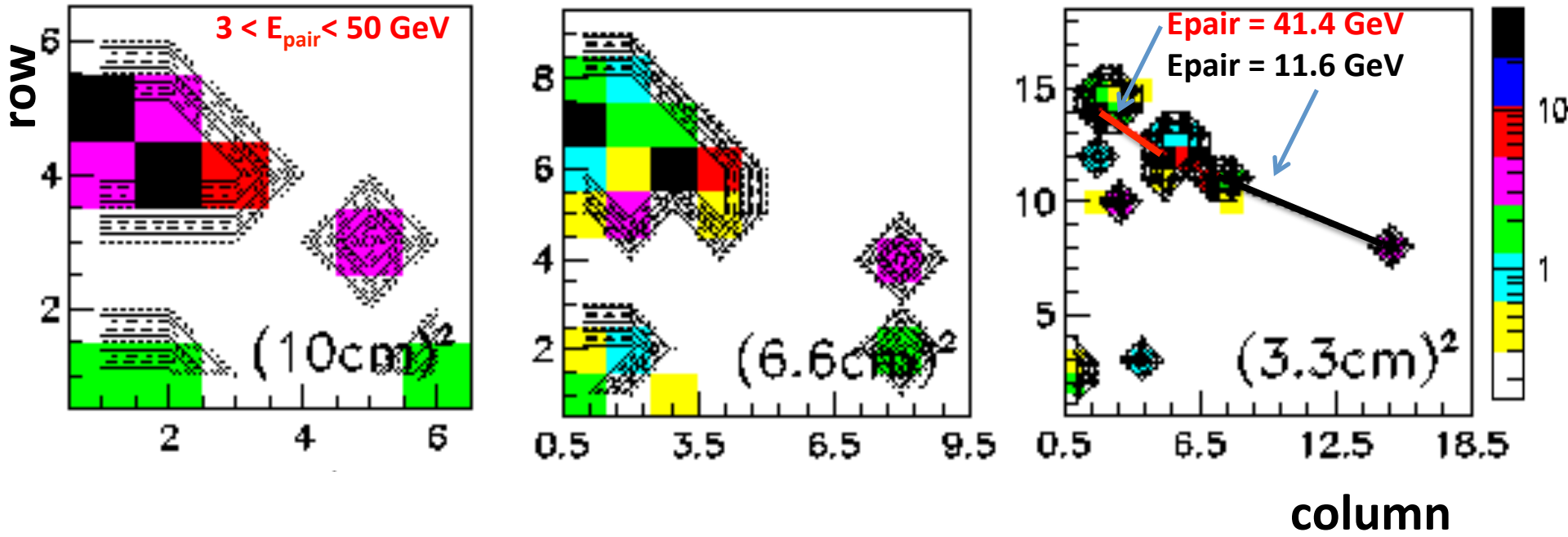
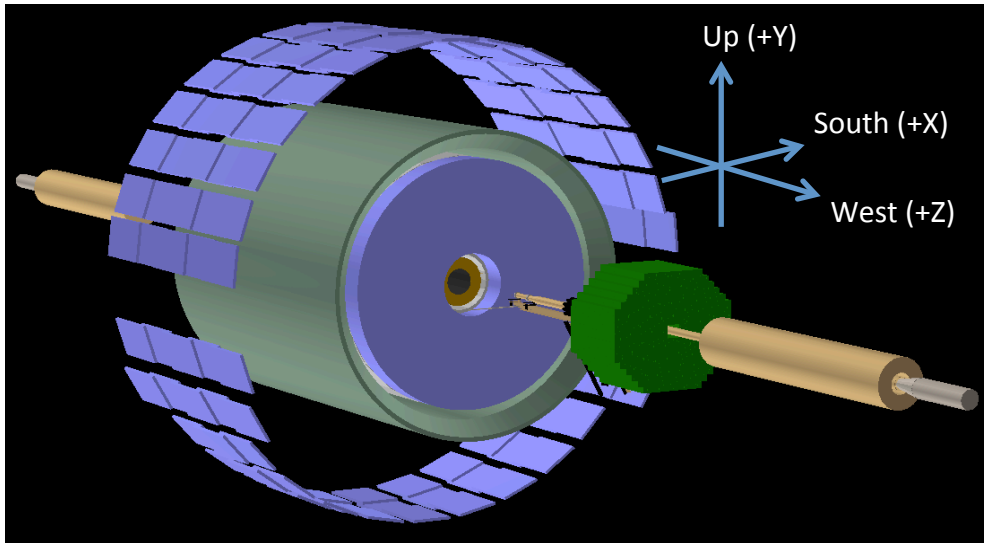


Conclusions

- Pixelizing E864 cells allows reconstruction of neutral pions to higher energy up to ~50 GeV
- Hadronic shower shapes can be distinguished from EM showers with greater than 90% confidence
- FCal was stable through ^{3}He+Au collision
- Radiation Hardness - no energy re-calibration required over duration of ^{3}He+Au running
- Material in-between interaction point and FCal is sufficiently modeled by Geant

Outlook :Proposed Annular Geometry at STAR



- 18×18 by array (316 cells,2844 pixel)
- $0 \leq \phi \leq 2\pi$ azimuth coverage
- $2.7 \leq \eta \leq 4.5$ rapidity coverage

=>Best resolution in forward direction

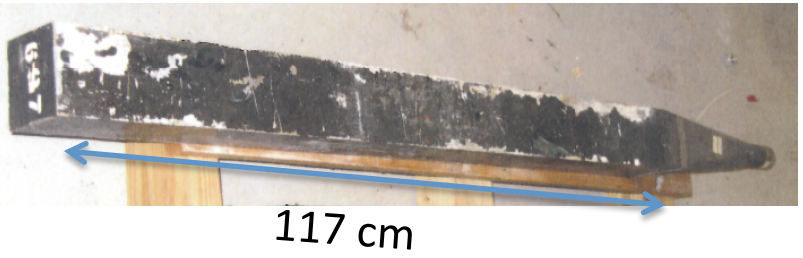
- Enables di-jets for low-x measurements
- Enables event plane for pA and AA collisions & Centrality selection
- Enables long range correlations over $-1.1 > \eta > 4.5$
- Combined with tracking detectors (e.g. FGT,FPS) physics goals can be extended with unique beam energy range provided by RHIC

  (Drell-Yan, Baryon Stopping, Flow measurements,…)

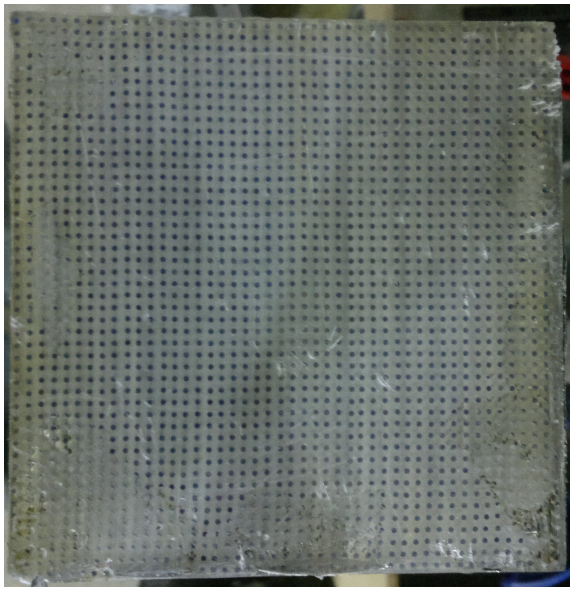
Significantly improve forward ($X_F > 0.1$) instrumentation at STAR

Backup

The AGS-E864 lead-scintillating fiber hadronic calorimeter



- Independent measurement of masses of produced particles
- Cell size :$(10\ cm)^2 \times 117\ cm$
- Showering material is lead
- Energy deposition is measured by 47×47 array of scintillating plastic fibers(Spaghetti-type)
- 1st repurpose – Phenix & Phobos
- 2nd repurpose - A_nDY
- **3rd repurposing at STAR**

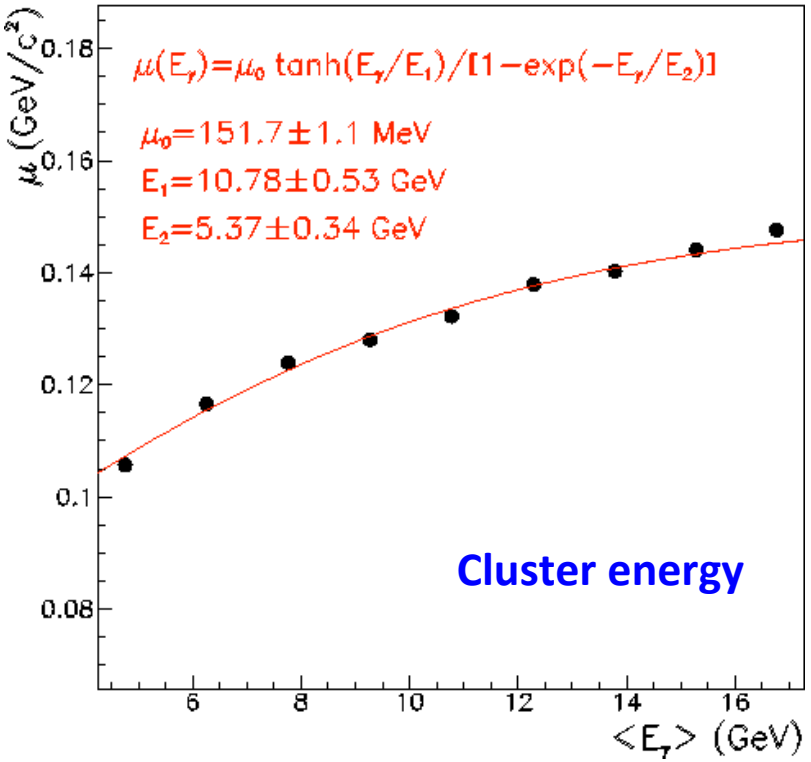


Hadronic resolution : 34/√E %

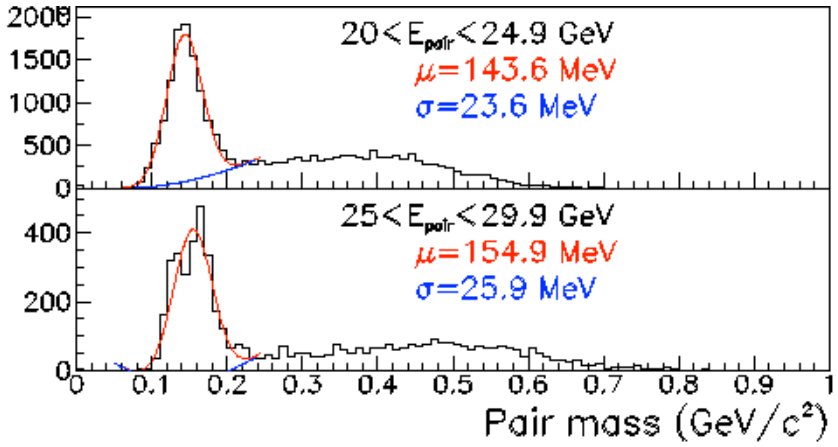
*T.A. Armstrong, et al. NIM **406** (1998) 227*

Calibration – Energy Dependence

- Energy dependence (non-linearity) between cluster and the incident particle that created the cluster
- Dominated by thresholds (e.g.: ADC, cluster finder)
- π^0 mass as a function of leading photon energy



Pair mass before E correction



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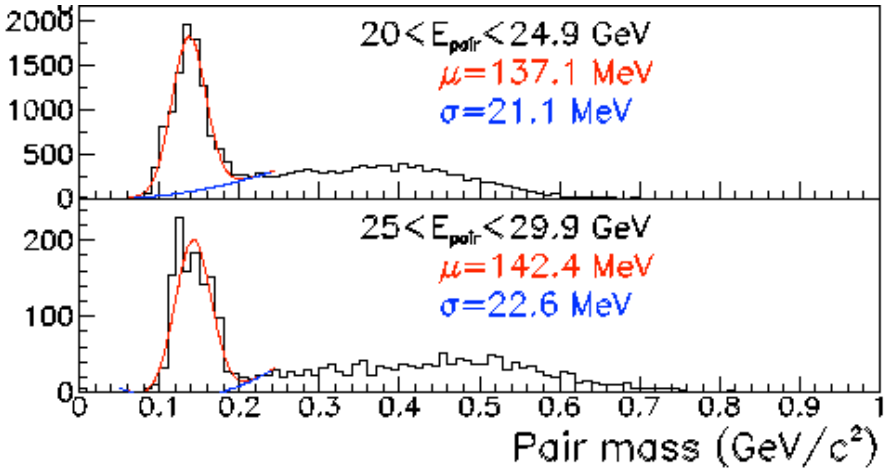
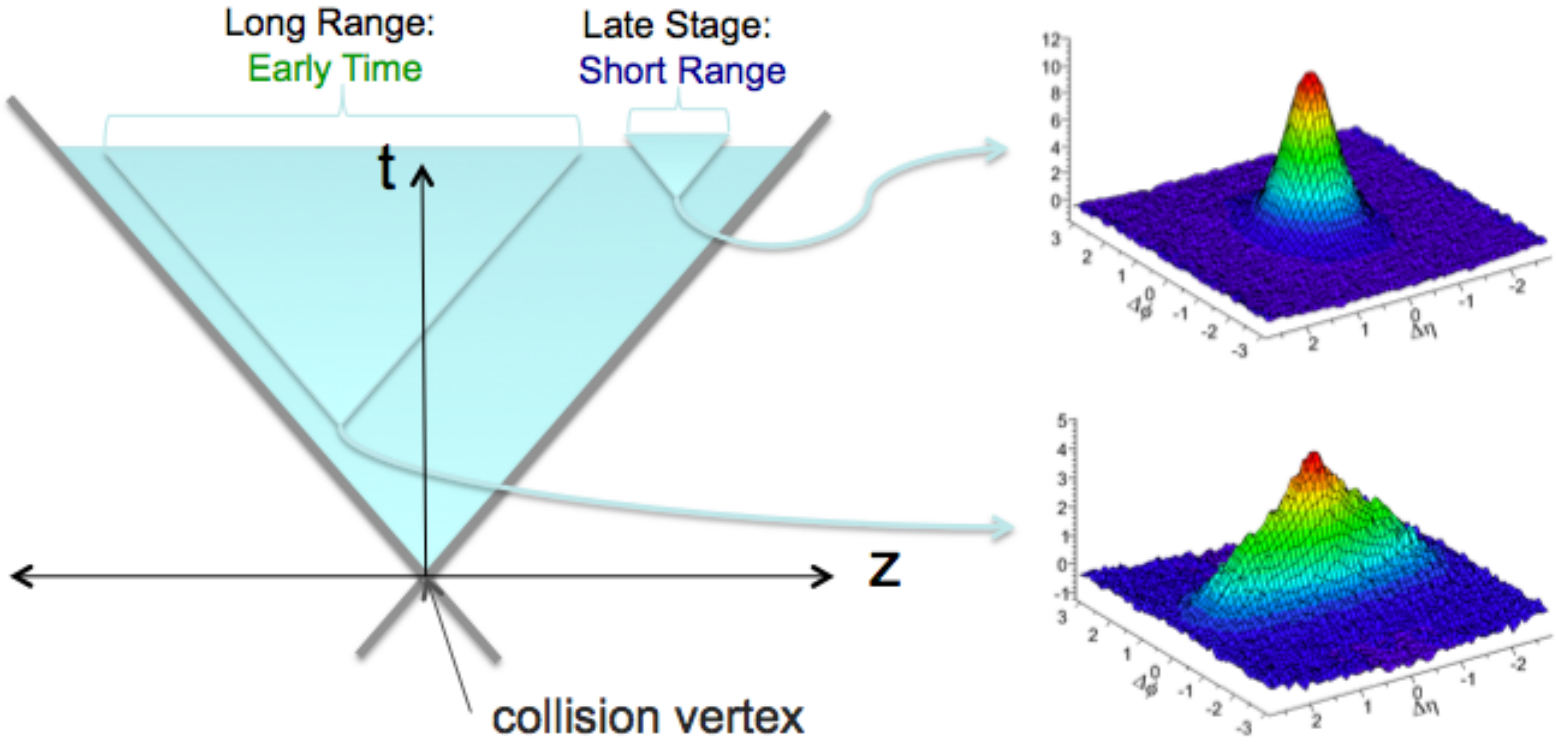


Long range near side rapidity correlation



Forward jets in asymmetric HI collisions