ILC Detector Simulation: Merged π^0 / γ Cluster Pattern Recognition

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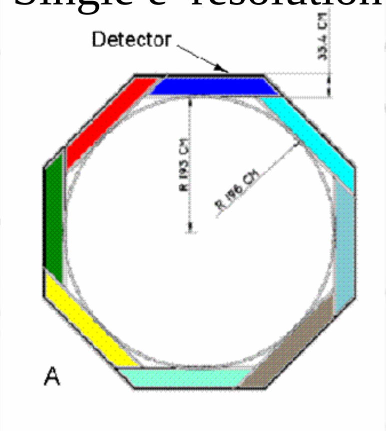
SiD Calorimeter Parallel Session

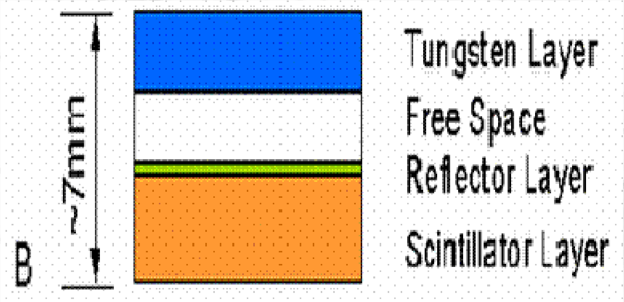
Outline

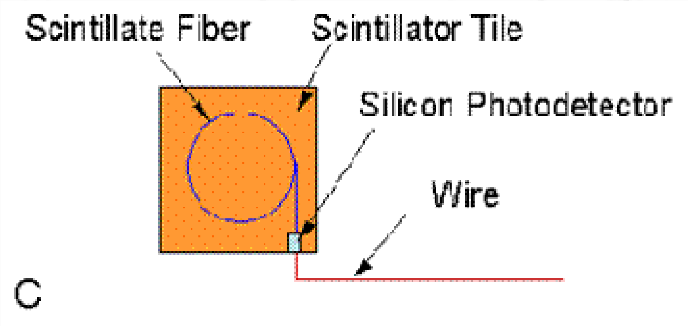
- The CU Electromagnetic Calorimeter
  - Simulations And Methodology
- Distinguishing between γ and merged π^0 Clusters
  - Motivation & Methodology
  - New Method: EM Calorimeter towers
  - Covariance Training & χ^2 Analysis
  - Results / Future Work

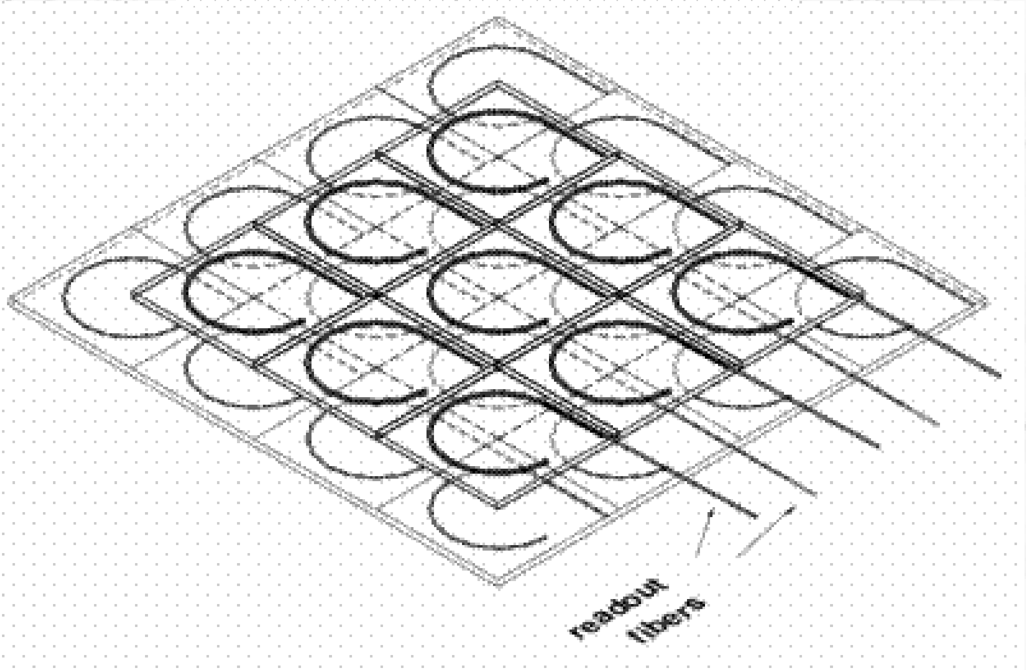
The CU EM Calorimeter

- 40 layers of Tungsten / Scintillator, 3mm Scintillator, $3/4X_0$W Tungsten
- Offset tiles in neighboring layers
- Projective Geometry
- Segmentation π / 128
- Single e^- resolution ~ 12%/$\sqrt{E}$









Simulations & Methodology

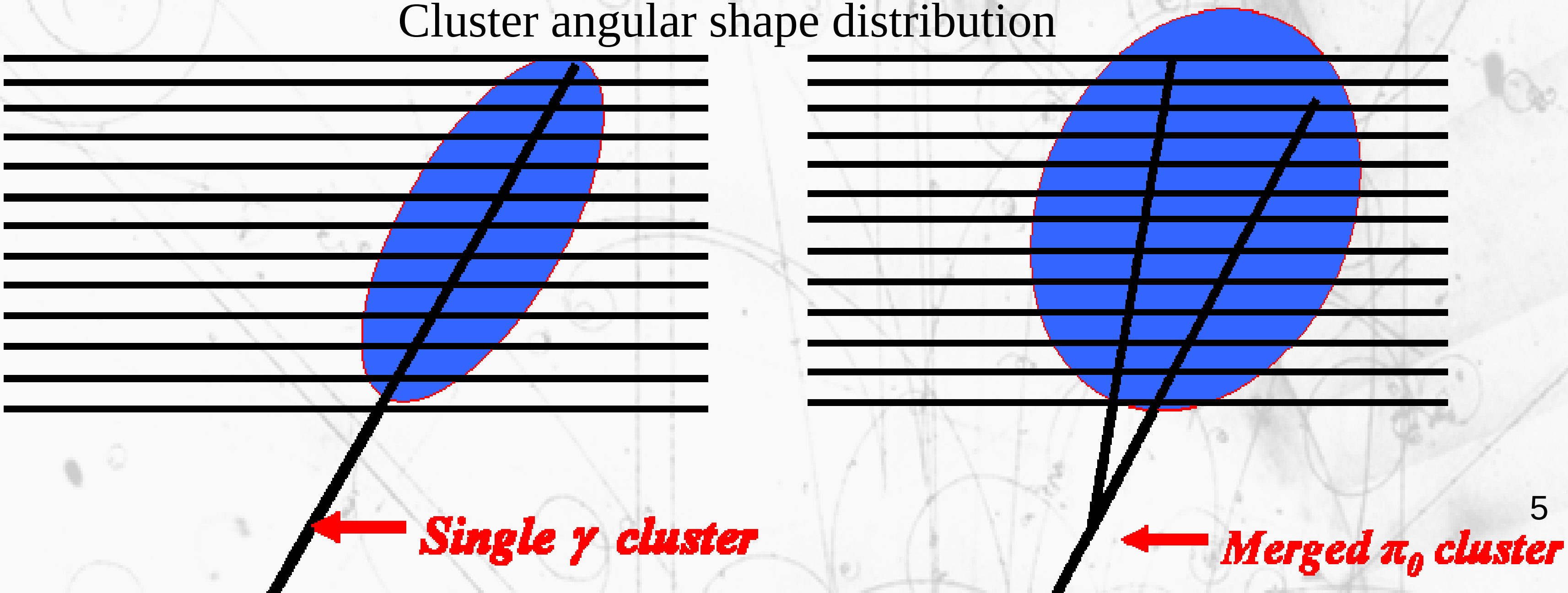
- Cluster Identification
  - A Cluster is a group of hits in any system
  - Ideally – exist only of hits from one final-state particle
  - Success – How close is the algorithm to ideal
- Motivation
  - Charged – Associated clusters with track
  - Neutrals – Only see in Calorimeters
    - Get a direction for Reconstruction (photons) (Jack Gill - Colorado)
    - Separation of Merged Clusters
- Simulation and Analysis
  - LCDG4 GUN
    - Generation of full simulation data
  - JAS 2.2.5
    - Analysis of data using hep.lcd libraries

Merged π^0 / γ Clusters

Single γ clusters vs. double γ clusters

- $\pi^0 \rightarrow 2\gamma$ (98.798 ±0.032)% $c\tau$ = 25.1nm (PDG July 2004)
- Hard to distinguish (small opening angle)
- π^0 clusters have more oblong lateral distribution
- Previously distinguished by second moment of cluster energy, tubes, cones, layering, discrete trees …

Cluster angular shape distribution

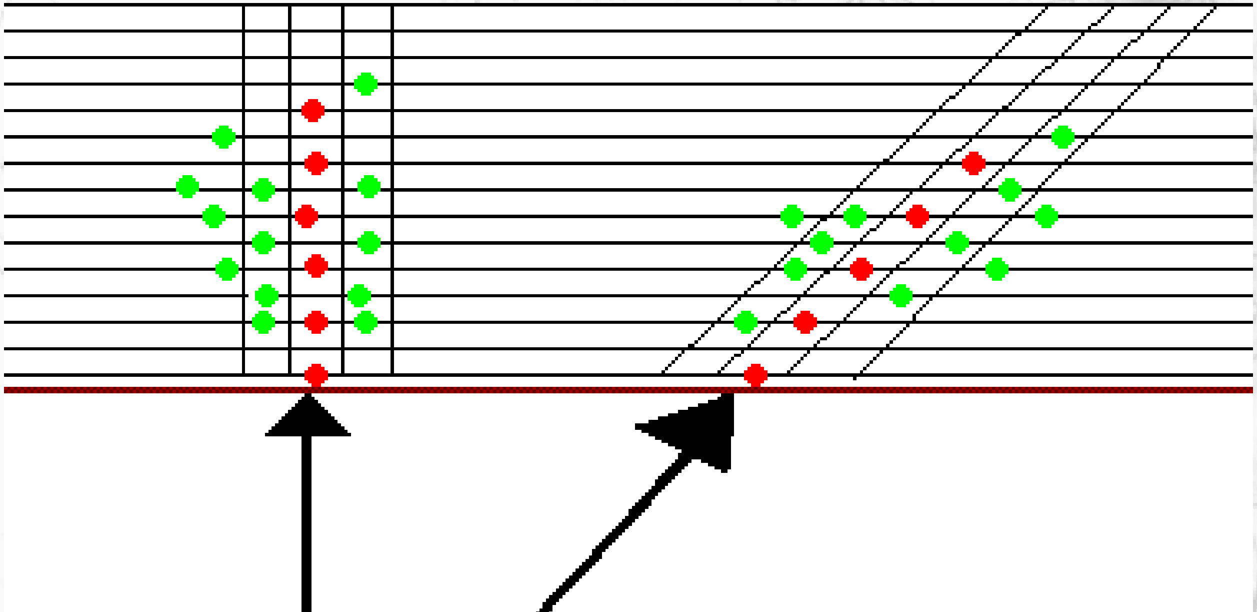


Pattern Recognition in Cluster Separation: A New Approach

- Separating γ's from Merged π^0's
  - Using ECal design to our advantage
  - Projective geometry & non-offset tiles make simpler (for now)
- Use Covariance training to generate χ^2 confidence values
  - Create (3x3) matrices of tower energy distribution
  - Center element chosen to be max energy tower
  - Use single γ events to train a covariance matrix (A)
    - Incident γ angle is random
    - 1–10 GeV 100 γ events (2100 for 10GeV), 15 GeV 1000 γ events
    - $A = \Sigma(x_i * x_j) / Nevt$
  - Generate χ^2 confidence values for π^0 events
    - Based on trained matrix (A) & π^0 events
    - Generate an Event Covariance matrix (E), Trace gives χ^2
    - $E = \langle (x_i - A_i)*(x_j - A_j) \rangle$
    - $\chi 2 = Tr(A^{-1}*E)$
  - Statistically decide what caused cluster (π^0 or single/double γ)

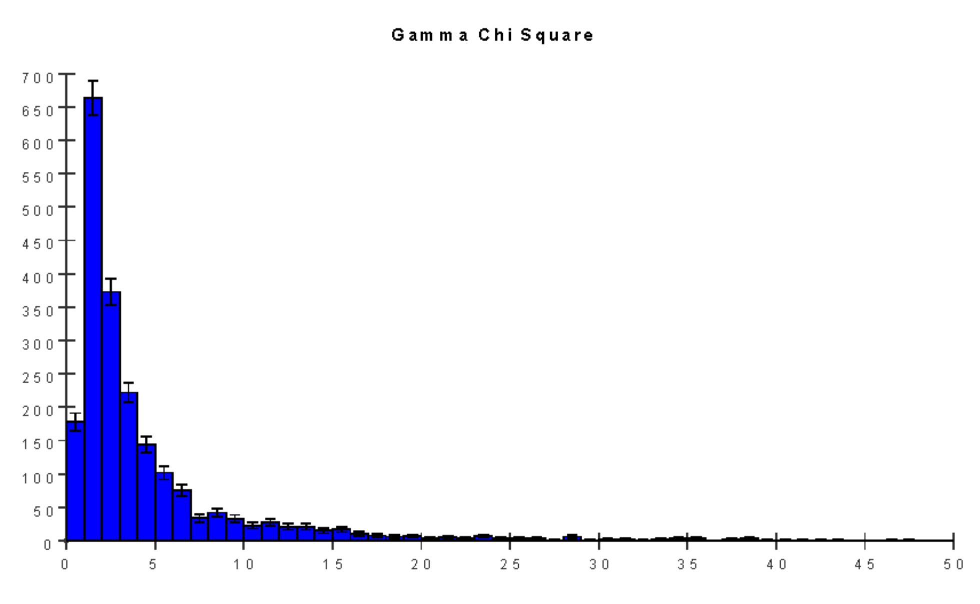
Cluster Separation Methodology

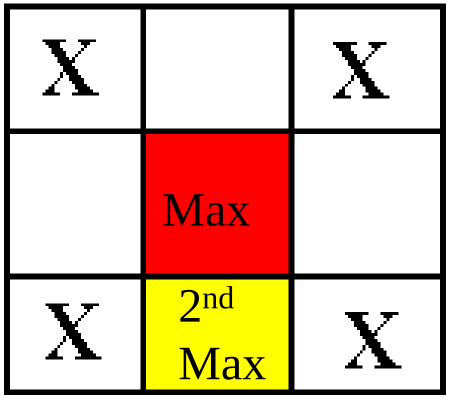
- Incident γ angle random LCDG4
- Projective Geometry
- Selection of greatest energy tower
- Count hits from every other layer
  - Offset tile effect

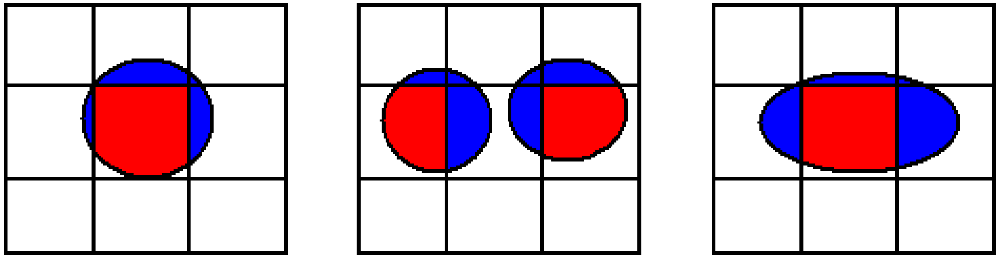


Cluster Separation Methodology II

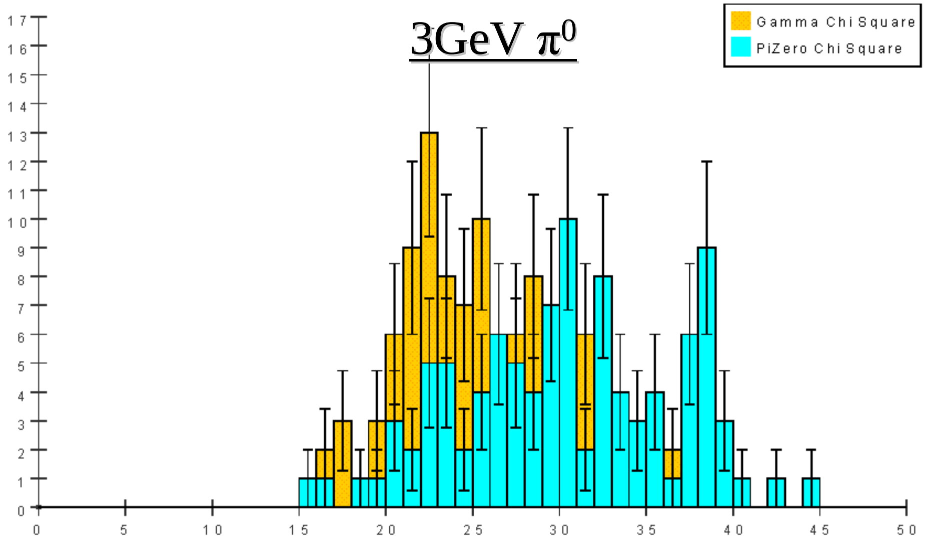
- Maximum energy tower = central matrix element
- Second Max. rotated to $A_{3,2}$
- Covariance Matrix = 9*9 reduced to 5*5
  - 9*9 noninvertible due to 0 hits in corner towers



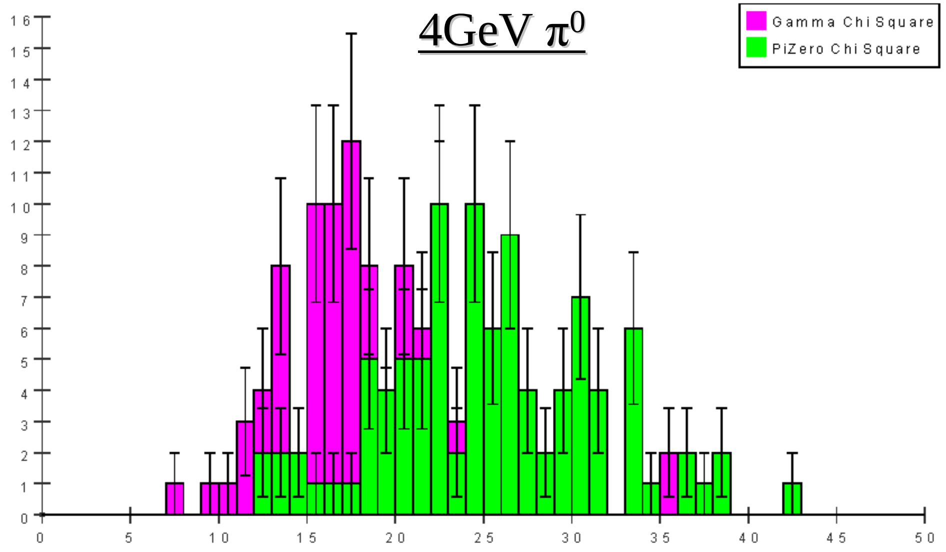




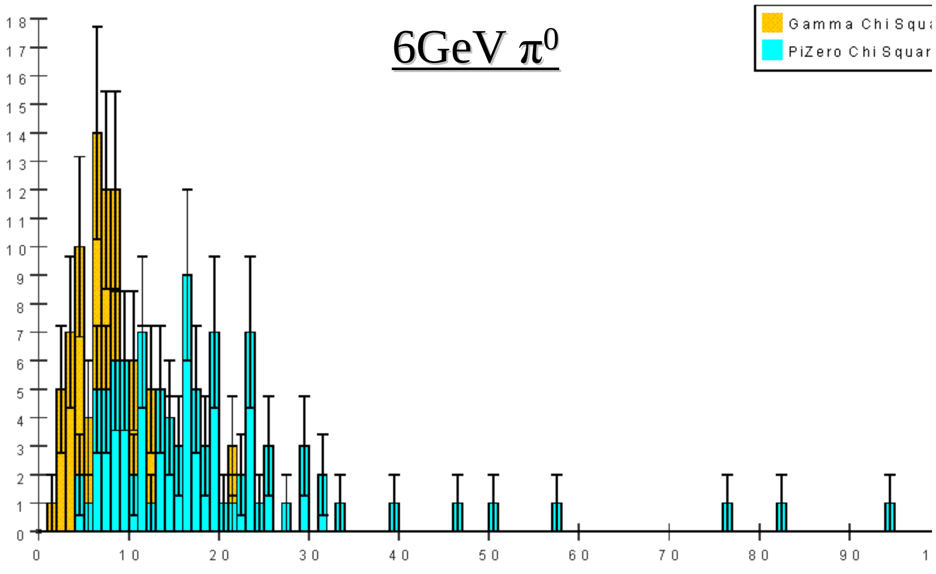
Results



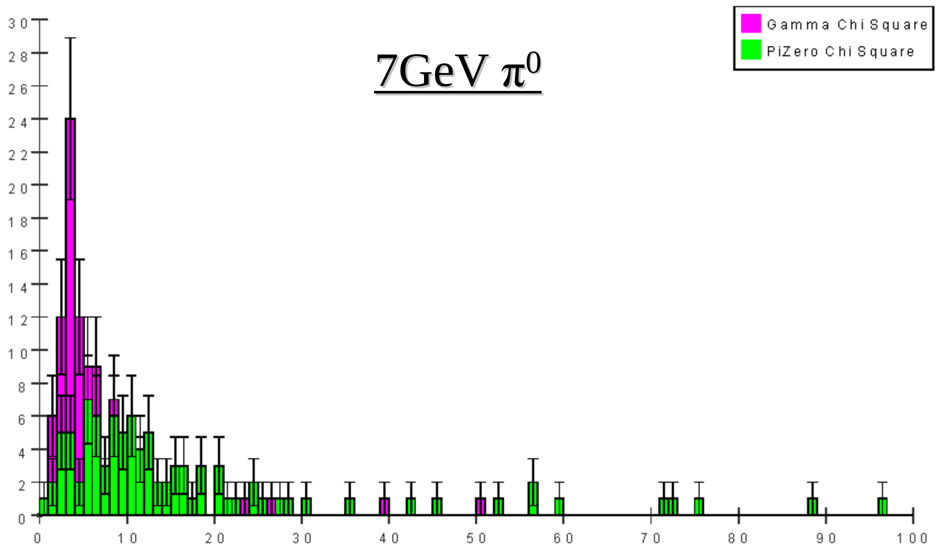
3GeV π^0
Gamma Chi Square
PiZero Chi Square



4GeV π^0
Gamma Chi Square
PiZero Chi Square

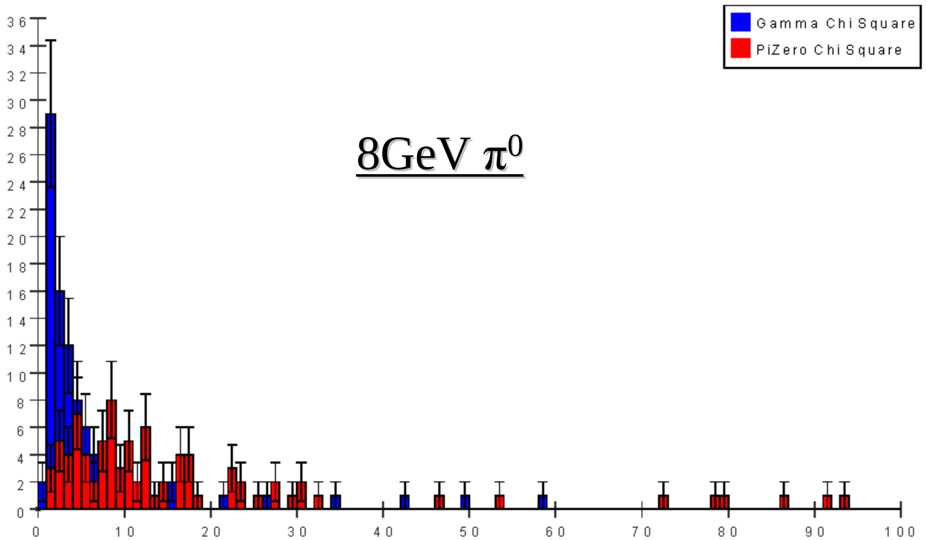


6GeV π^0
Gamma Chi Squa
PiZero Chi Squar

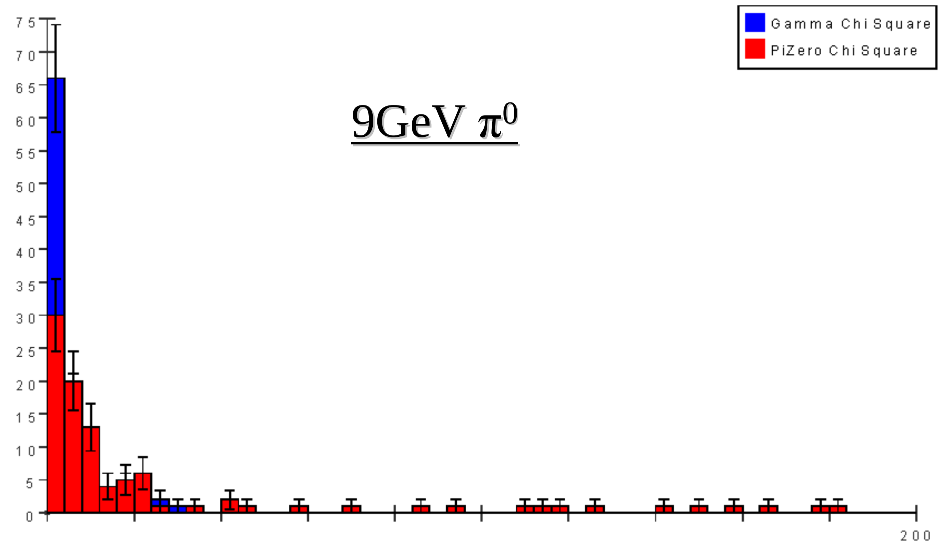


7GeV π^0
Gamma Chi Square
PiZero Chi Square

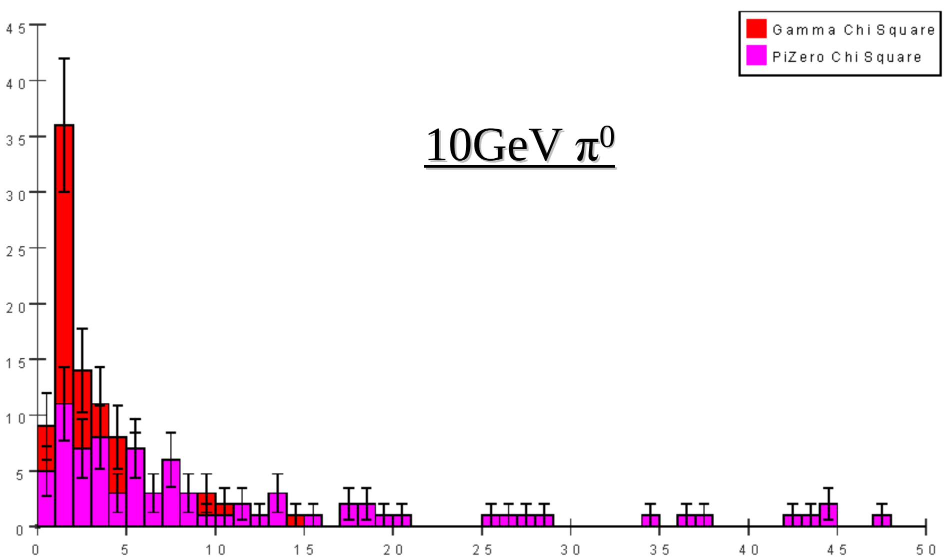
Results II



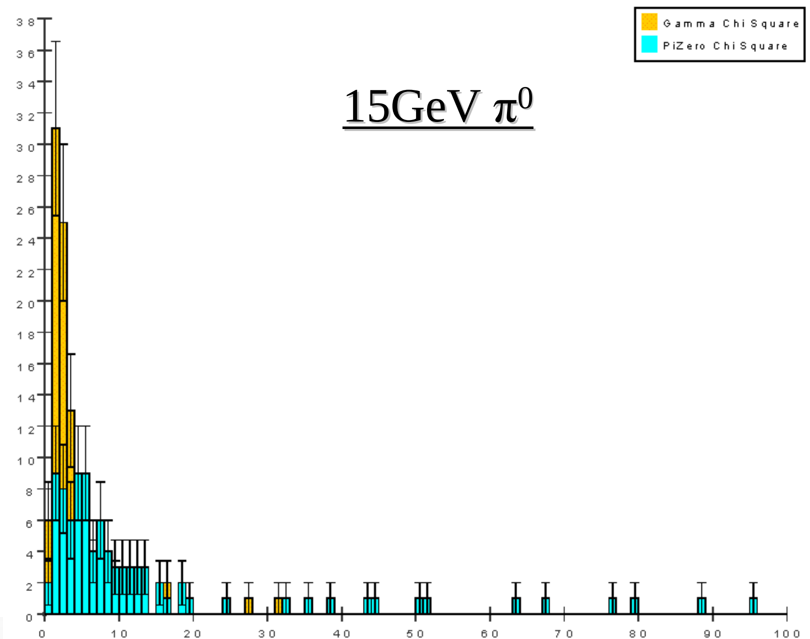
Gamma Chi Square
PiZero Chi Square
8GeV π^0



Gamma Chi Square
PiZero Chi Square
9GeV π^0



Gamma Chi Square
PiZero Chi Square
10GeV π^0



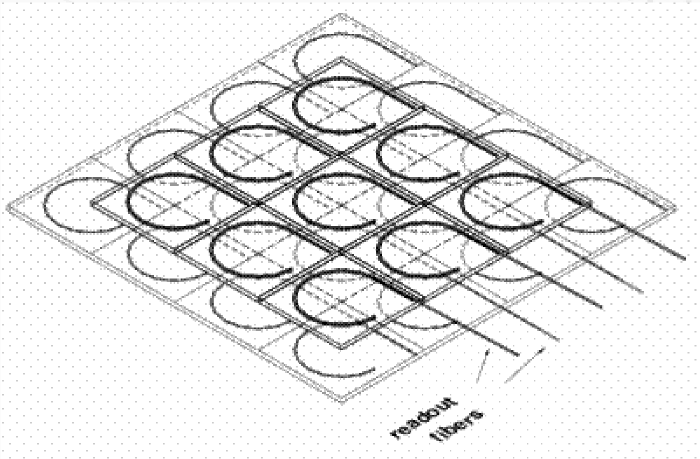
Gamma Chi Square
PiZero Chi Square
15GeV π^0

Conclusions/Next Steps

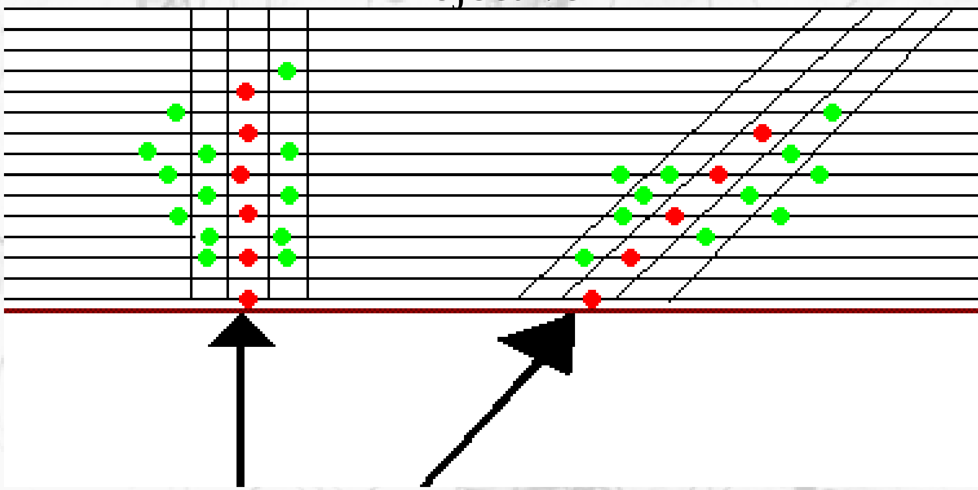
- Still very preliminary – Work in progress
- Efficiency calculations are needed
- Code improvement – First attempt
- 3*3 matrix of towers may be too small for variability among clusters

Future Work

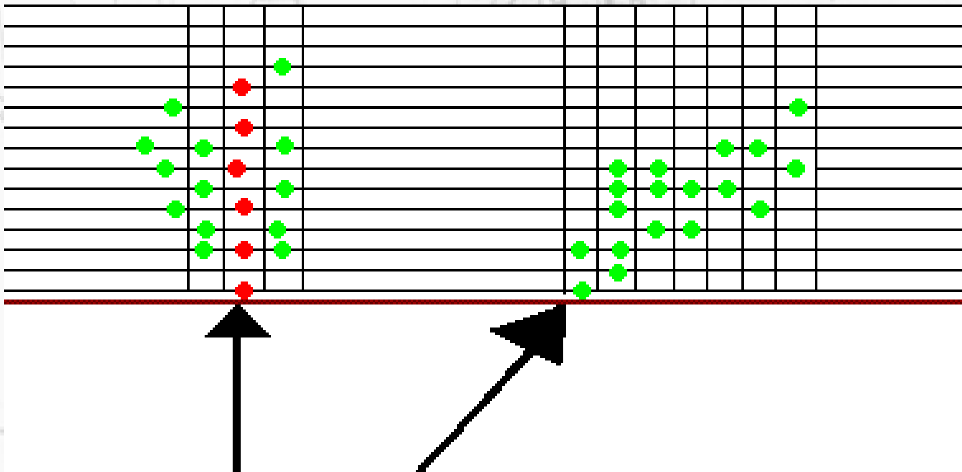
- Analyze for >15GeV photons
- Offset Geometry
  - What is meant by neighboring tile?
    - Break tiles into quadrants?
  - How is a tower defined?
    - Currently: alternating layers based on max E deposited
- Non-projective Geometry
  - Hits distributed across several towers



Projective



Non-Projective



References / Acknowledgements

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- University of Colorado:
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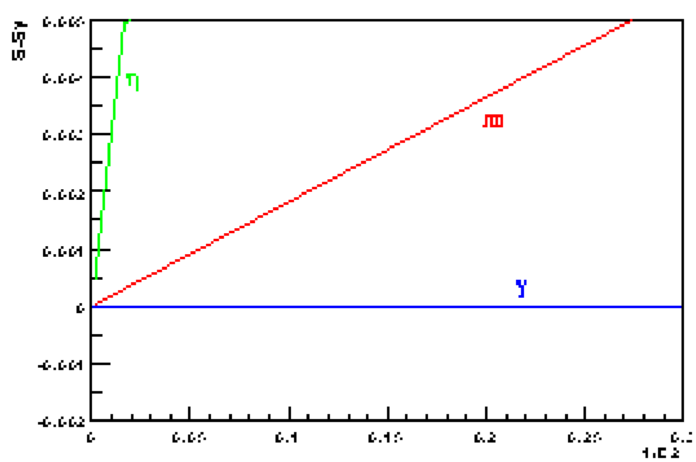
  - Jack Gill
- University of Kansas:
  - Graham Wilson

::Extra Slides::

Cluster Separation (Angular Method) D. Dujmic 2002

- Invariant Mass Reconstruction for $\pi^0 \rightarrow 2\gamma$:
  - $M^2 = 2E_1E_2(1 - \cos\Delta\alpha_{1,2})$: $\Delta\alpha_{1,2}$ is the opening angle
  - $M^2 = E^2(S_{\pi 0} - S_\gamma)$: Based on shape of cluster
  - $S = 1/E\ \Sigma\ E_i\ \Delta\theta_i^2$: Second moment of the Cluster
  - θ_i = angular distance from center of cluster
  - S_γ determined a priori by individual photon data
  - Can separate by Second moment proportional to mass squared



Second moment versus inverse momentum squared