Shower reconstruction and FCAL2 detector calibration

Simon Taylor / JLab

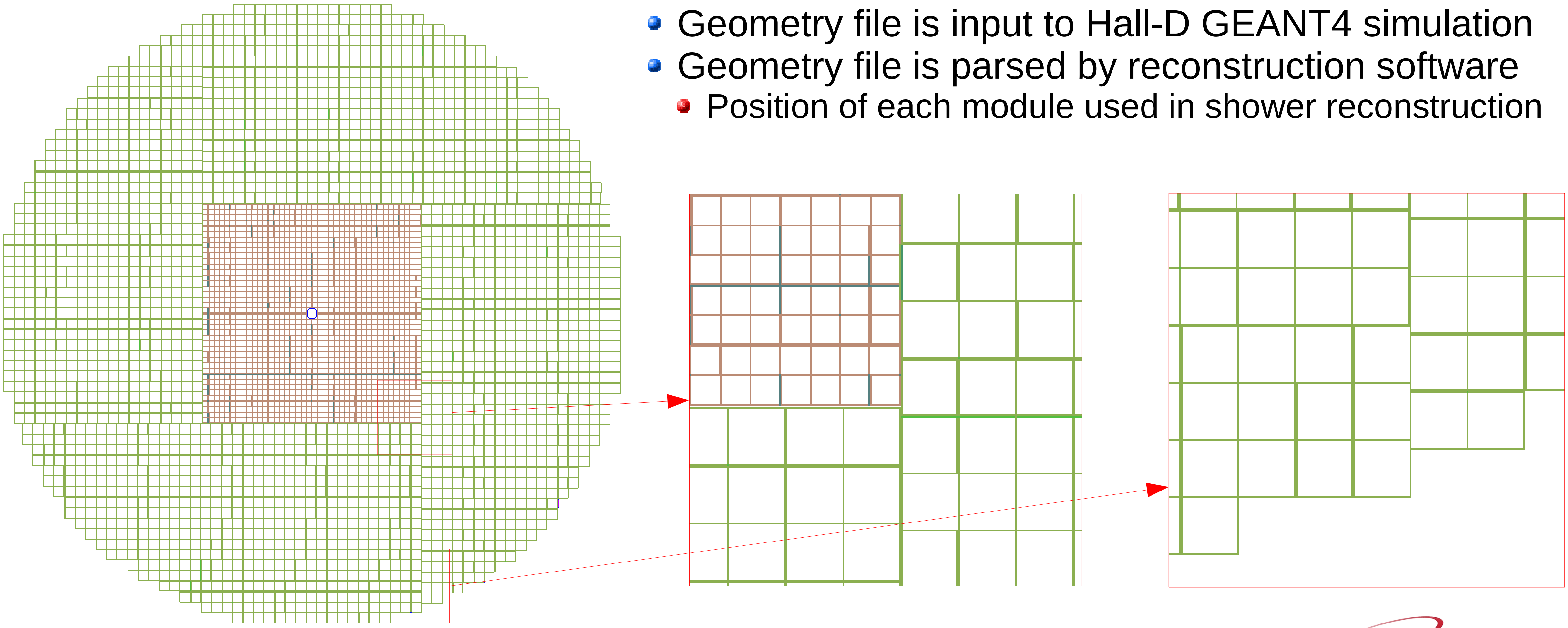
Charge 5

- Geometry
- Low level objects and factories
- Calibration constants
- Monitoring
- Shower reconstruction
- Gain calibrations

Contributions from Igal Jaegle, Drew Smith, Sasha Somov, and Zhikun Xi

Geometry specification

- Geometry specified in file stored in GlueX calibrations database (ccdb)
  - Positions of lead glass (FCAL) and lead tungstate (ECAL) modules in rows set according to survey measurements

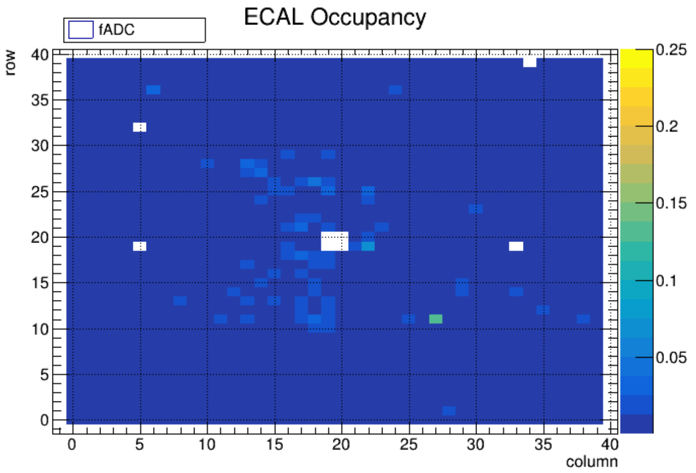


- Geometry file is input to Hall-D GEANT4 simulation
- Geometry file is parsed by reconstruction software
  - Position of each module used in shower reconstruction

Low-level objects and calibration constants

- Code to convert raw FADC data to calibrated hit data and calibration constants for FCAL blocks already in place
  - Used for all previous GlueX running
- Implemented code to convert raw FADC data for ECAL blocks into calibrated hit data in units of energy in GeV and time in ns
  - Tables for ECAL calibration constants stored in Hall-D calibrations database
    - Pedestals, gains, timing constants

Occupancy plot added to monitoring histograms



Cosmic ray events

- Calibrated hits from both FCAL and ECAL: input to shower reconstruction code

Island algorithm for shower reconstruction

- Algorithm based on Lednev, IHEP 93-153
  - Shower profile modeled by function *f(r)*
    - Lead tungstate: *d*=2.05 cm, b~0.35 cm
    - Lead glass: *d*=4.0 cm, b~0.8 cm

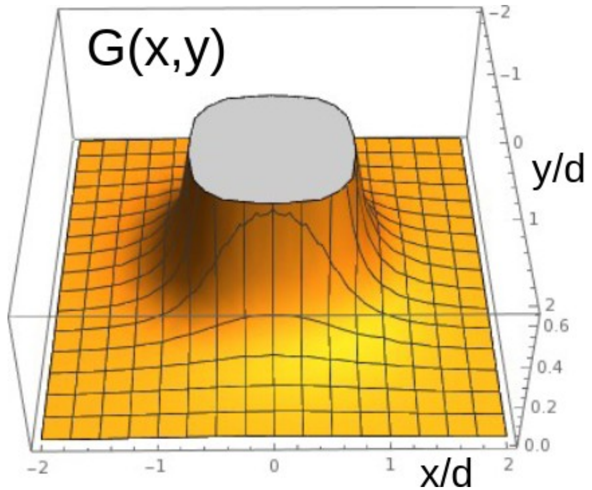
$$f(r) = \frac{ab}{2\pi}(r^2 + b^2)^{-3/2}$$

$$F(x,y) = \frac{a}{2\pi} \arctan\left(\frac{xy}{b\sqrt{b^2 + x^2 + y^2}}\right)$$

- Energy within a single block:

$$G(x,y) = F\left(x + \frac{d}{2}, y + \frac{d}{2}\right) - F\left(x - \frac{d}{2}, y + \frac{d}{2}\right) - F\left(x + \frac{d}{2}, y - \frac{d}{2}\right) + F\left(x - \frac{d}{2}, y - \frac{d}{2}\right)$$

- Look for peaks within cluster of adjacent ECAL/FCAL hits
- Fit with *G(x,y)* to find center (x_c,y_c) for each peak ⇒ photon shower

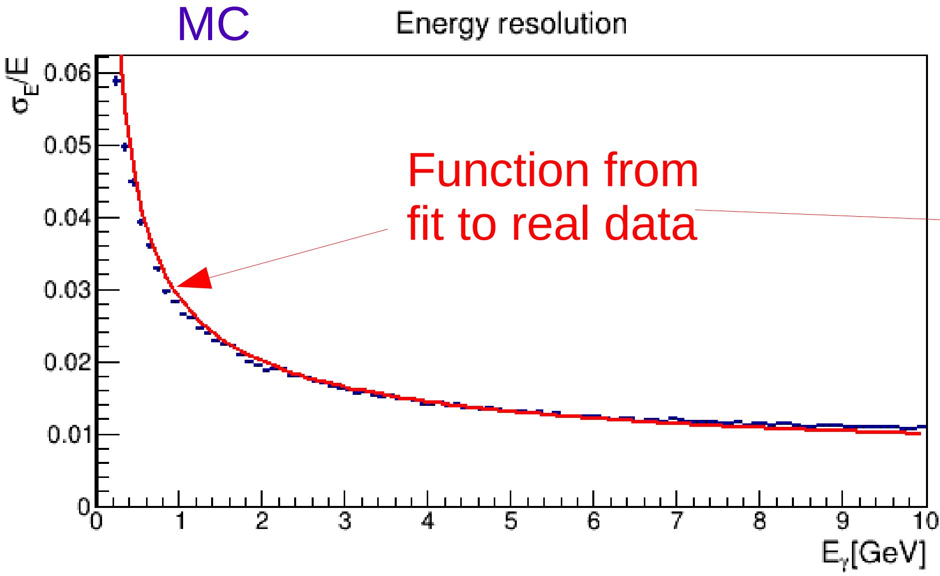


Jefferson Lab

Simulation of single photon events in ECAL

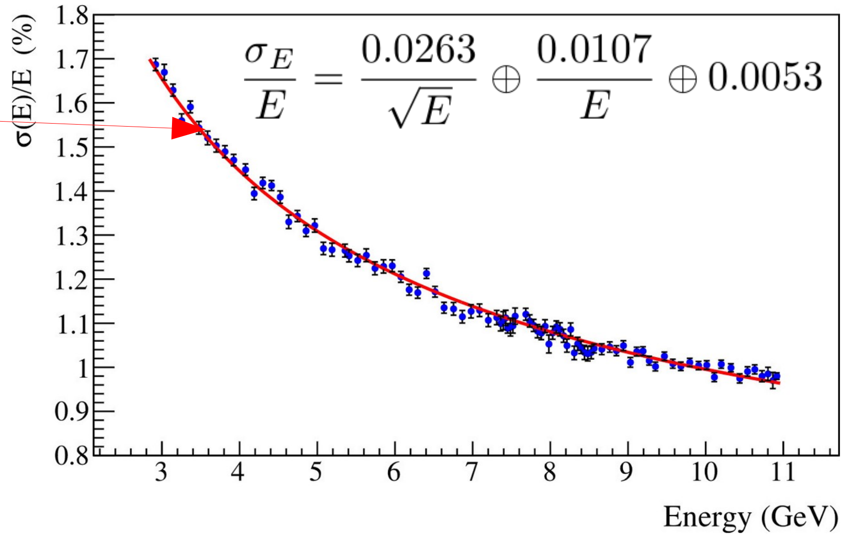
- Simulated photons at θ=2.5° coming from target region
  - E_γ=0-10 GeV
  - Reconstructed energy = sum over all blocks within a cluster

MC



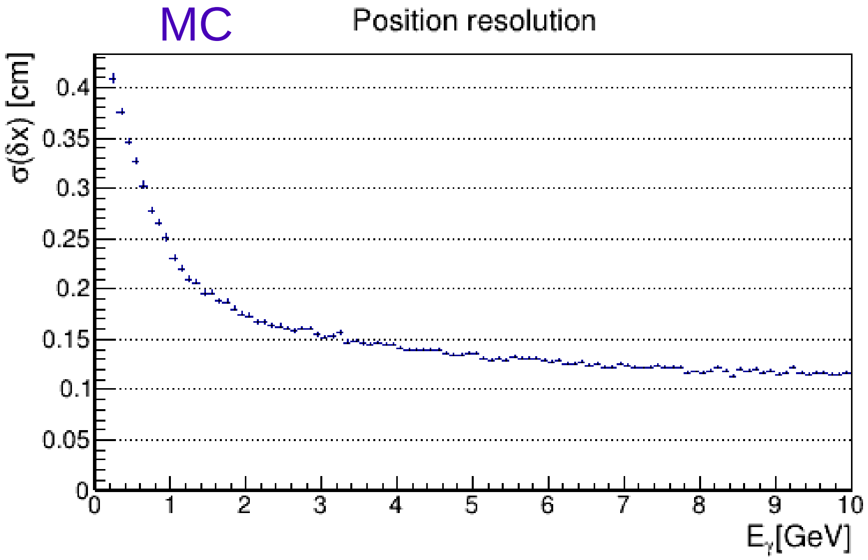
Measurements from Hall-D beam data

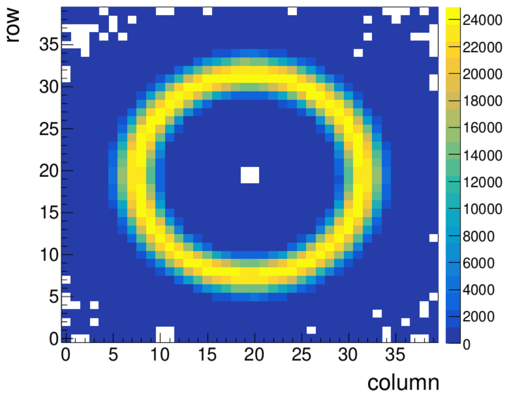
A. Asaturyan, et al. NIM A 1013 (2021) 165683



  - Shower position: (x_c,y_c) determined from fit over cluster hits using shower shape model

MC



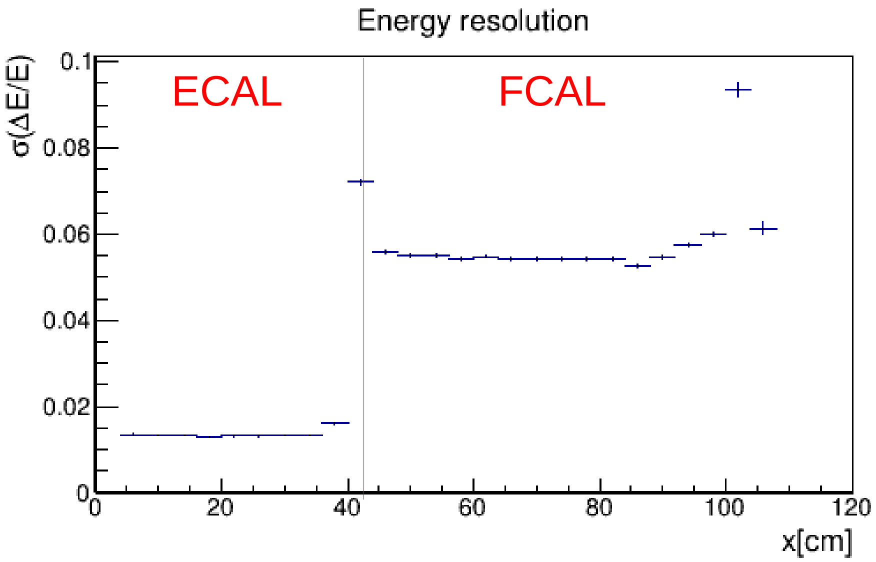


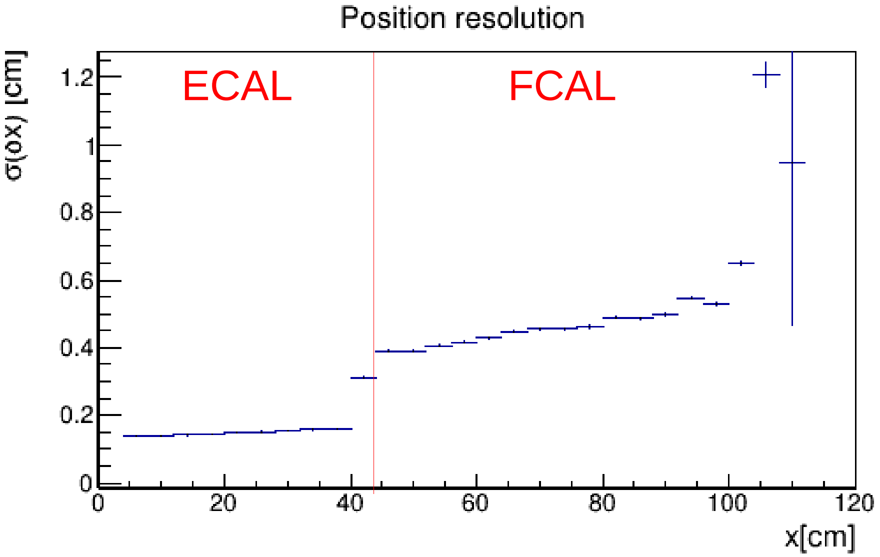
MC hit distribution

Jefferson Lab

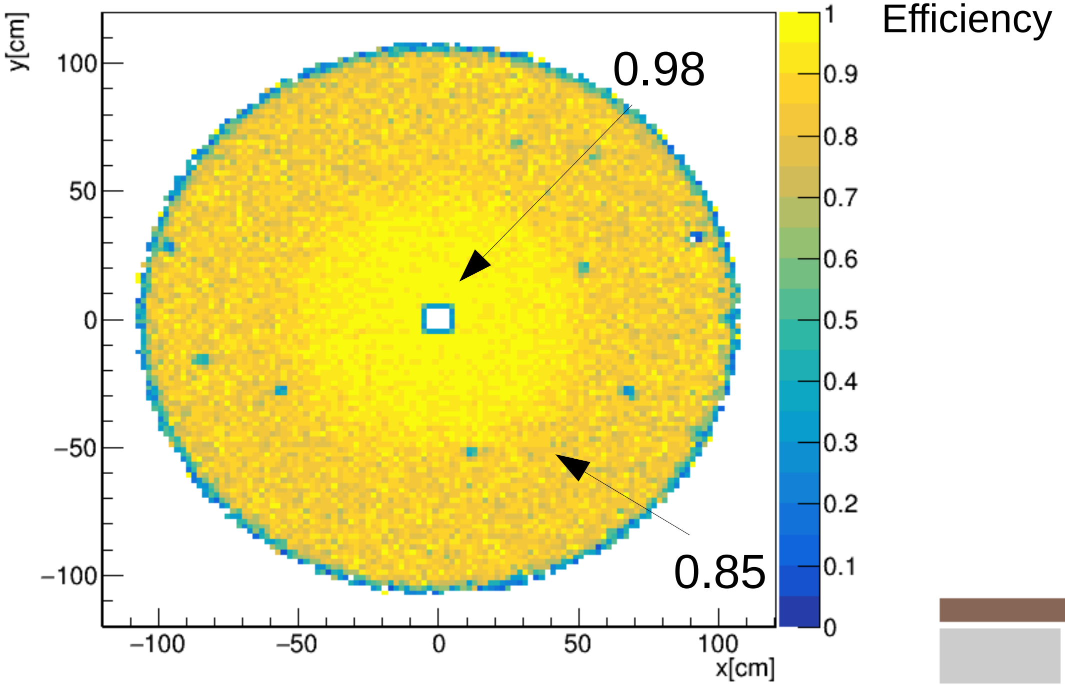
Efficiency and resolution as a function of position

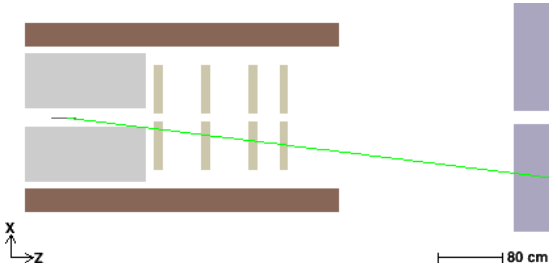
- Simulated 3 GeV photons at φ=0°





- Simulated 3 GeV photons over all φ
  - Required reconstruction of single shower
  - Used map of FCAL block efficiencies for old GlueX data
  - Drop of efficiency radially due to conversions in material





Event sources and calibration procedures

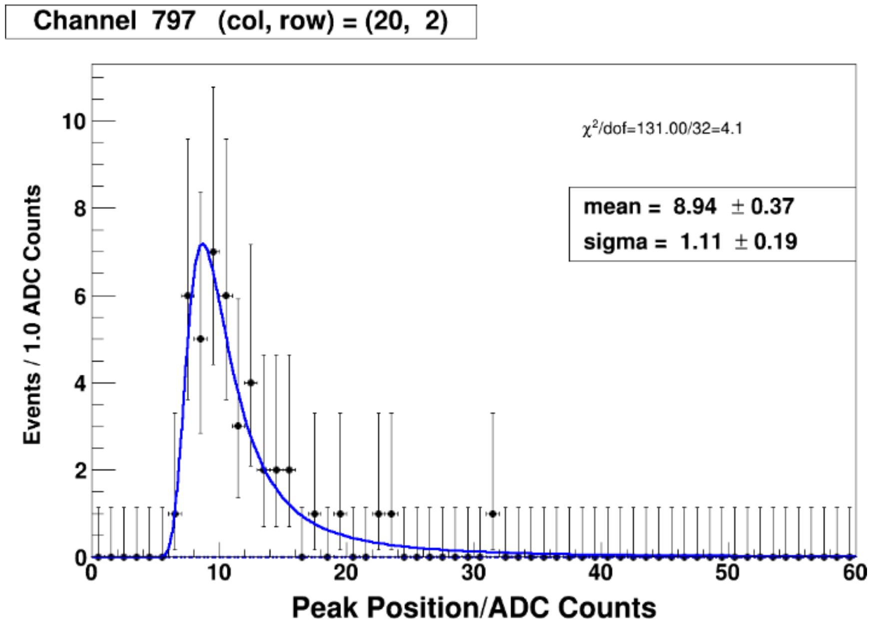
- Cosmic rays
  - Use to set preliminary HV for each channel

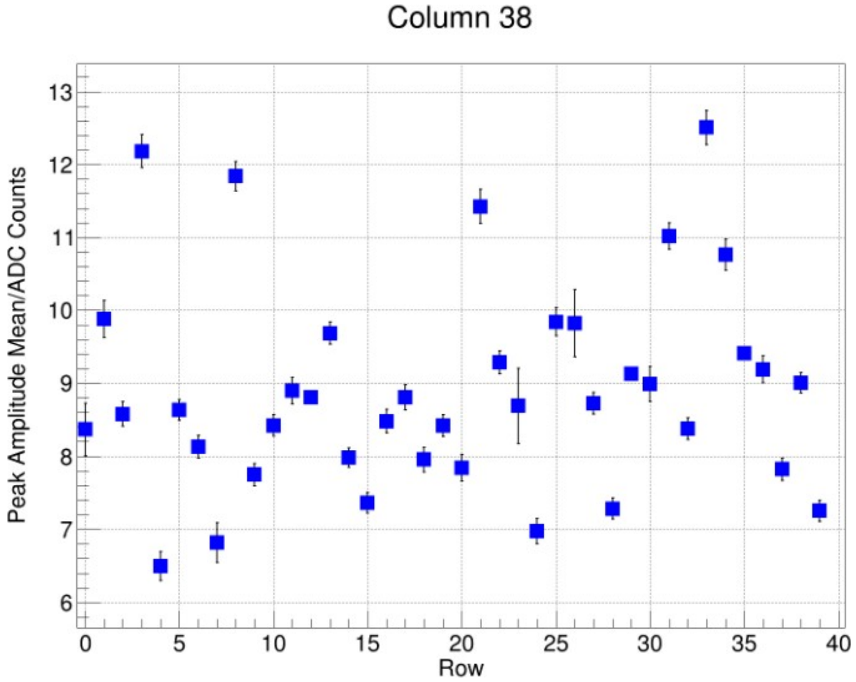
- Compton events
  - Usable for ECAL region only
  - Need photon beam, during commissioning period
  - High cross section
  - Refine HV settings near beam line
  - Needed for trigger

- π^0 events
  - Cover ECAL and FCAL
  - Need photon beam
  - Refine HV settings for trigger during commissioning period
  - Iterate to find software gain calibrations
    - 2-3 days data taking + 1 day for analysis
  - Calibrate throughout running period

Cosmic ray events

- Look for muons passing through the ECAL volume
- Fit peak positions with Landau distribution convoluted with a Gaussian
- Set HV on each channel to line peak positions up: Peak=A(HV)$^{\alpha}$, α=8





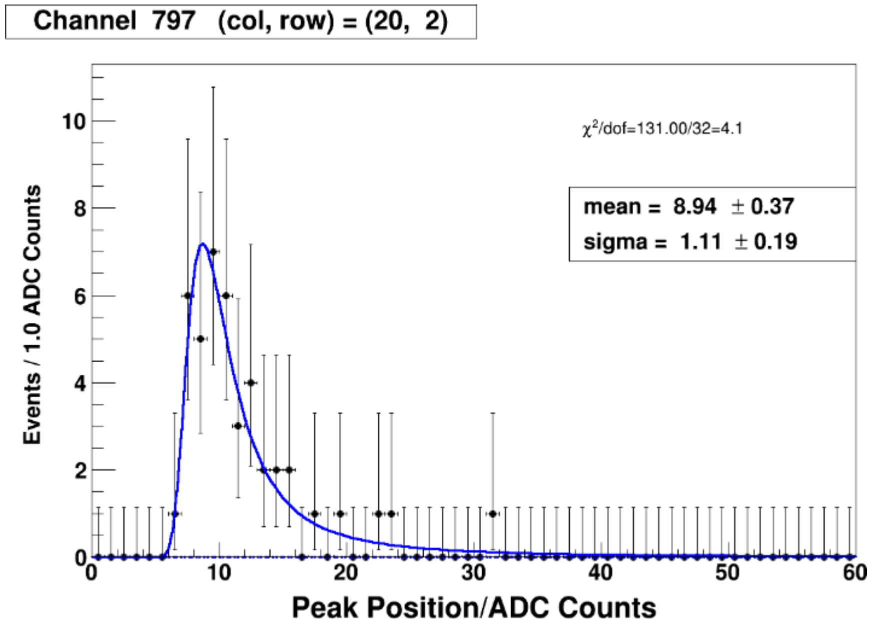
Zhikun Xi

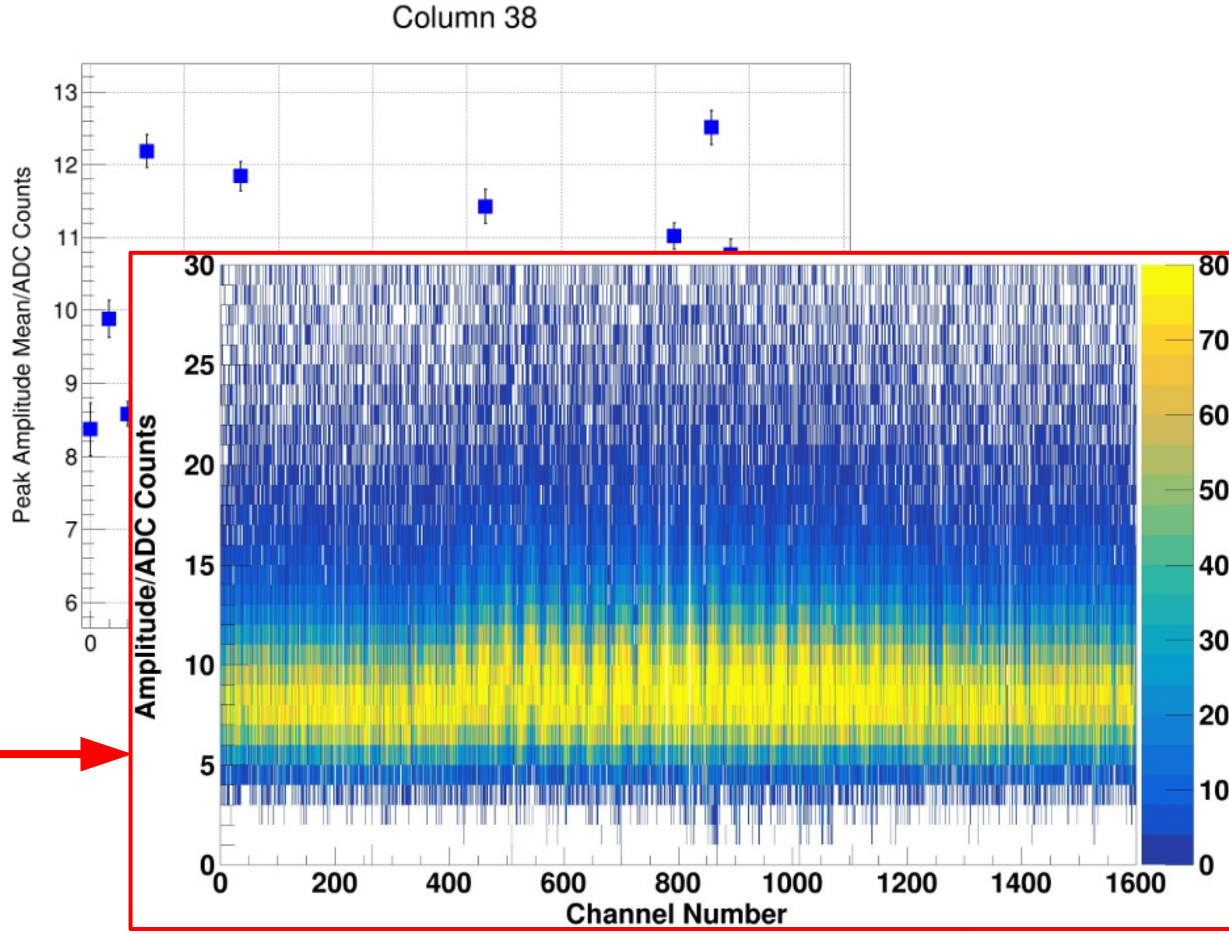
- Procedure has been iterated twice

Jefferson Lab

Cosmic ray events

- Look for muons passing through the ECAL volume
- Fit peak positions with Landau distribution convoluted with a Gaussian
- Set HV on each channel to line peak positions up: Peak=A(HV)$^{\alpha}$, α=8





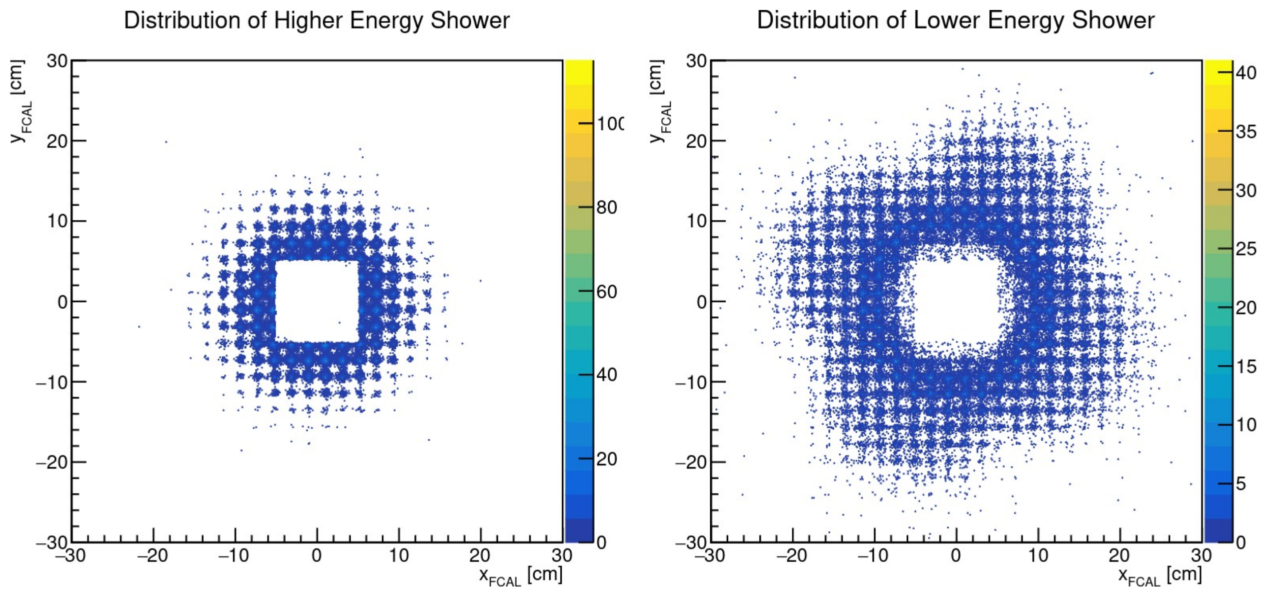
- Procedure has been iterated twice

Compton events

- Hardware gain calibration refinement with beam using Compton scattering off atomic electrons: $\gamma + e \rightarrow \gamma' + e'$
- Simulation of 2-arm Compton events
  - Events generated according to LO (Klein-Nishina) cross section
  - $E\gamma$ = 3 GeV incident beam energy
  - Select events with 2 reconstructed showers
    - $E_{1,2} > 200$ MeV
    - $0.85 < (E_1+E_2)/E_\gamma < 1.15$
- Considering also using 1-arm events
  - Increased angular coverage
  - … but also increased background
  - Calibrate detector using ratio of measured energy to calculated energy

$$E'_\gamma = \frac{E_\gamma}{1 + \frac{E_\gamma}{m_e}(1 - \cos\theta_\gamma)}$$

Coverage of 2-arm events

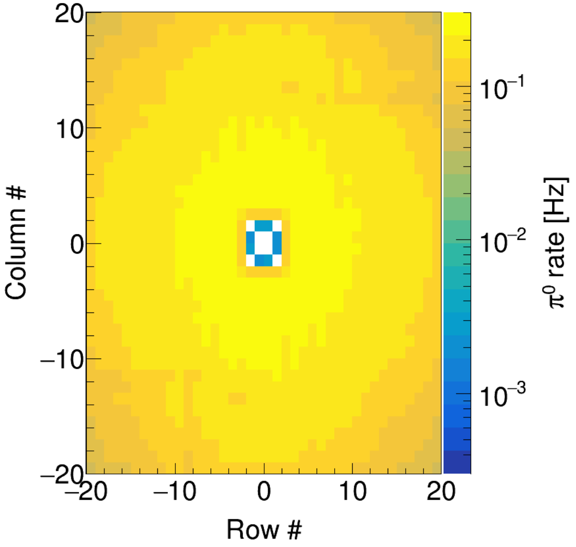


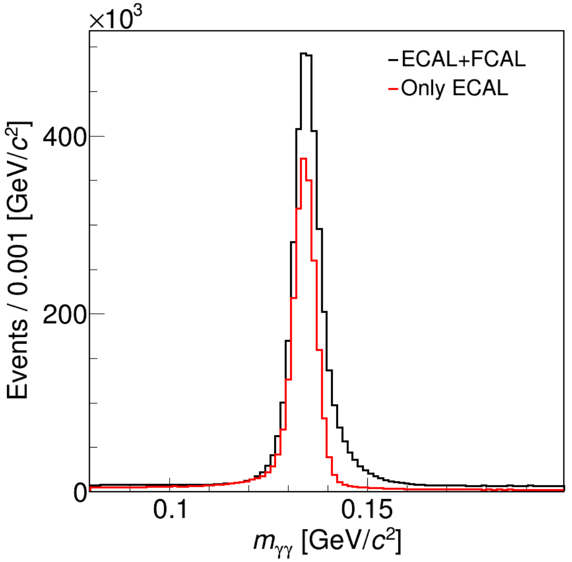
Drew Smith

Software gain calibration using π^0 events

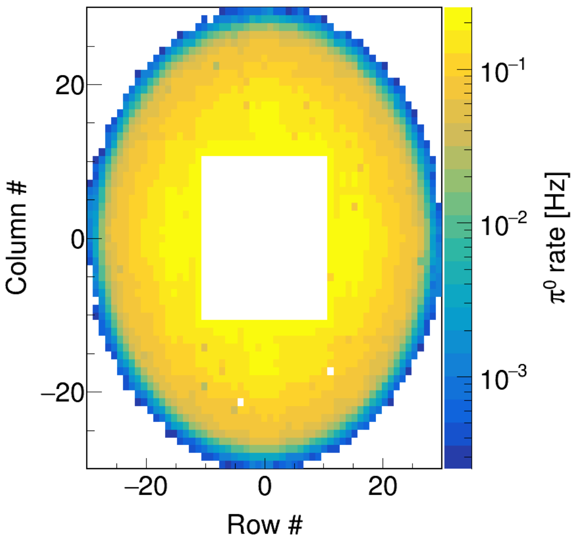
- Use well-known mass (m_{π^0}=0.135 GeV) of π^0 mesons ⇒ software gain calibration
  - Decay: $\pi^0 \to \gamma_1\gamma_2$, $m_{\gamma1,\gamma2} = \sqrt{2E_{\gamma1}E_{\gamma2}(1 - cos\theta_{1,2})}$
  - Procedure demonstrated to work for old FCAL-I
  - Apply calibration procedure separately for FCAL and ECAL regions
- Generated $\gamma p \to p\pi^0\pi^0$ events with realistic mass and angular distributions

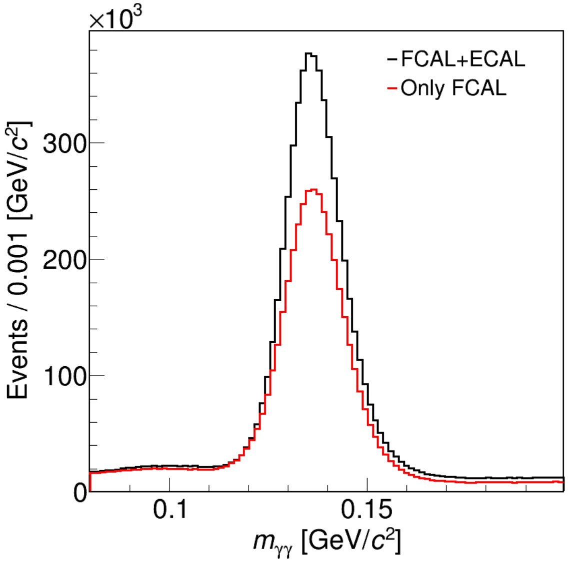
At least one π^0 in ECAL





At least one π^0 in FCAL





Igal Jaegle

Corresponds to ~3 hrs of data taking

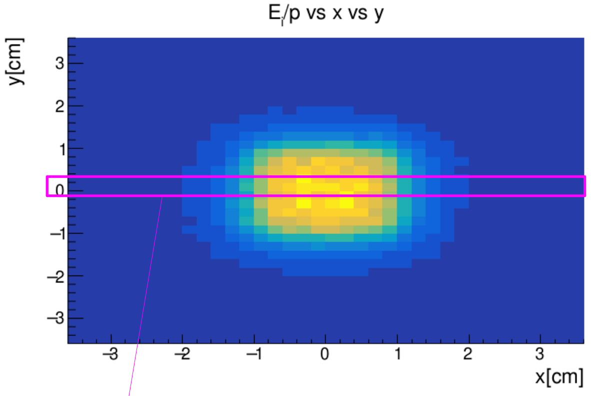
Summary

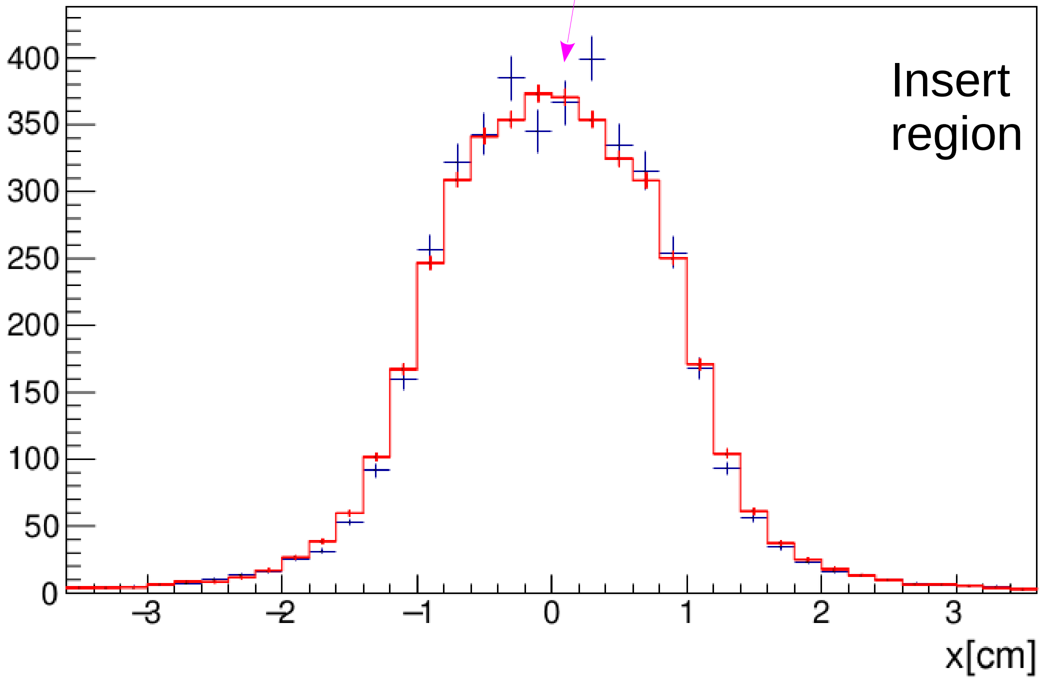
- Geometry for FCAL-II implemented
- Code for handling low-level objects in place
- Tables for calibration constants in Hall-D database
- Shower reconstruction code ready to go
- Gain calibration procedures have been developed
  - Cosmic ray procedure has been used
  - Calibration using events with π^0s well-established procedure

Backup

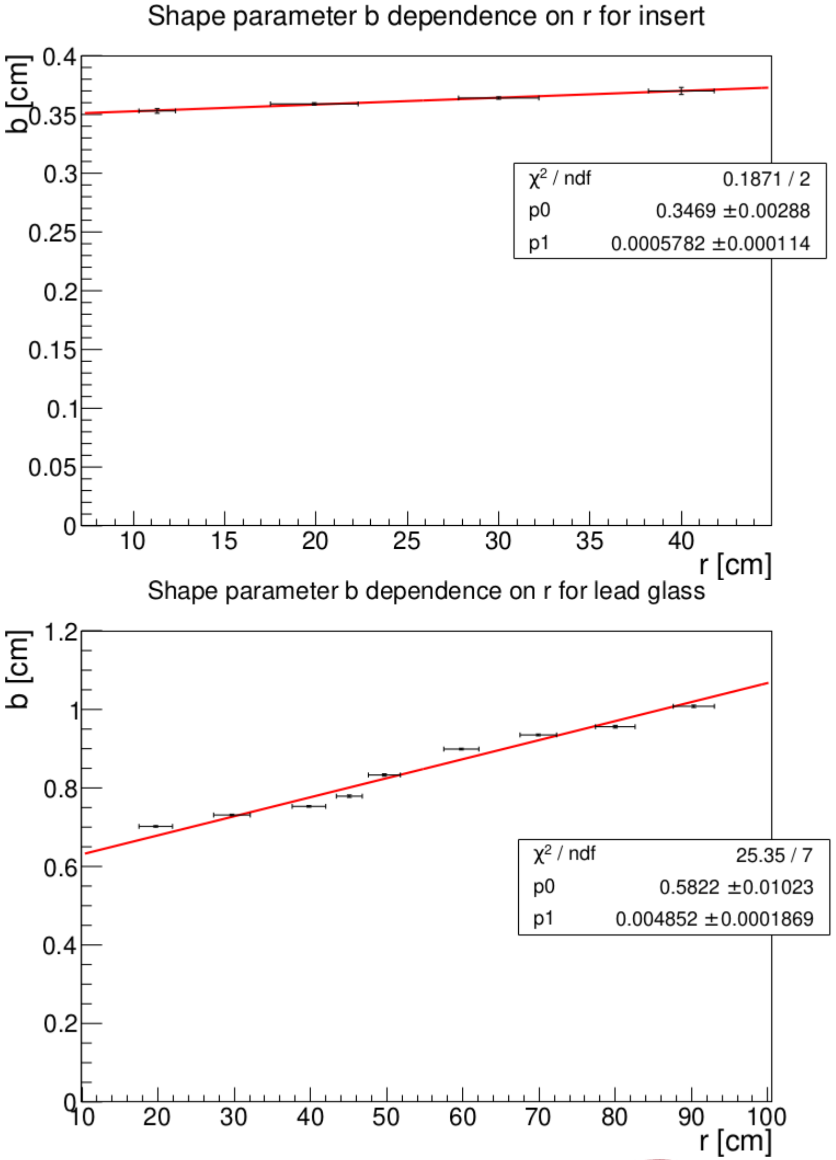
Shower shape parameter *b*

- Model for shower shape agrees with simulated hit distributions in ECAL and FCAL





- Shape parameter depends on radius (for photons coming from target region)



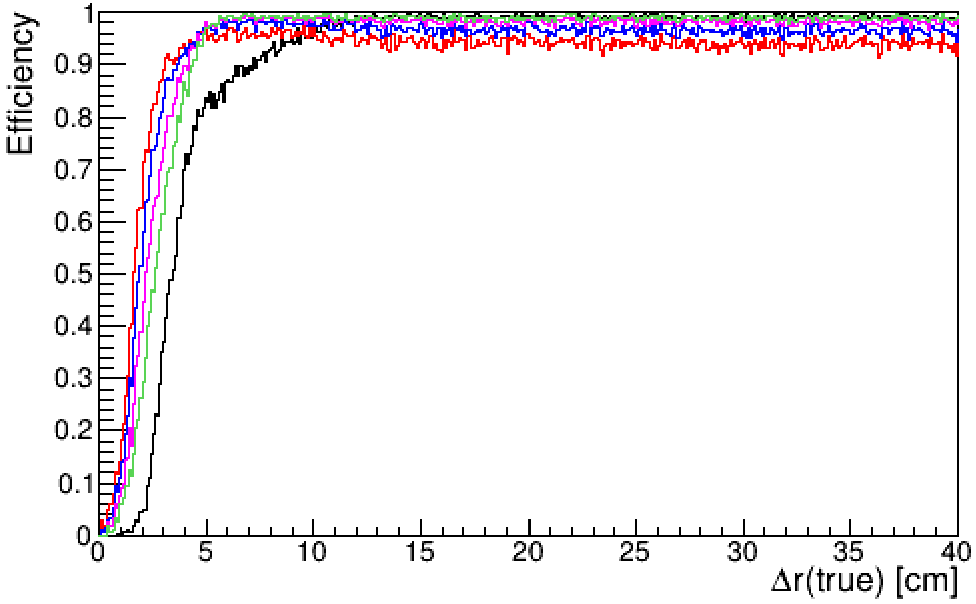
Two cluster separation

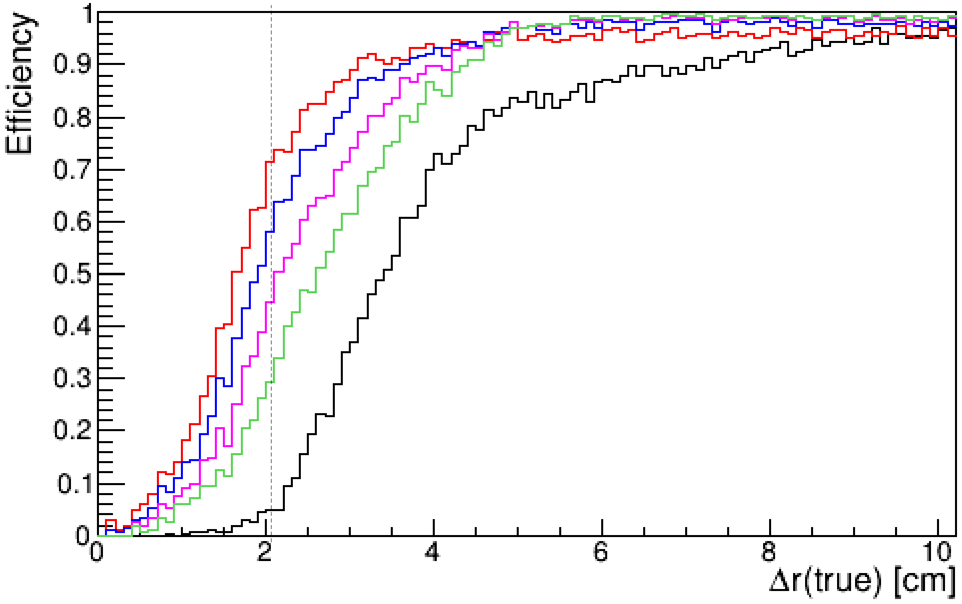
- Threw 2 photons towards ECAL from center of target, varying angular separation and energy balance with $E_1+E_2=5$ GeV
- Count number of times reconstruct 2 photons in ECAL
- Island algorithm (IA): cluster splitting controlled by χ^2 margin parameter: $(\chi^2/ndf)_{Nshower+1}$ + margin < $(\chi^2/ndf)_{Nshower}$

IA: χ^2 margin=2.5
IA: χ^2 margin=5
IA: χ^2 margin=10
IA: χ^2 margin=20
Old FCAL-I algorithm

θ=3° (Insert)

$E_{threshold}$=0.2 GeV





Δr = separation between photon shower positions

Gain calibration using π^0 events

- Procedure has already been used to calibrate old FCAL-I
  - Iterative procedure
- Use well-known mass (m_{π^0}=0.135 GeV) of π^0 mesons to do final software gain calibration
  - Two photons emerge from target region after decay: $\pi^0 \rightarrow \gamma_1\gamma_2$
  - $E_{\gamma1}$, $E_{\gamma2}$: individual shower energies
  - $\theta_{1,2}$ = angle between showers

$$m_{\gamma1,\gamma2} = \sqrt{2E_{\gamma1}E_{\gamma2}(1 - cos\theta_{1,2})}$$

- Define ratio used to determine corrected gains:

$$f_E^2 = \frac{m^2_{\pi^o}}{m^2_{\gamma1,\gamma2}} = \frac{E^o_{\gamma1}E^o_{\gamma2}}{E_{\gamma1}E_{\gamma2}} = \frac{gain^o_{\gamma1} \times gain^o_{\gamma2}}{gain_{\gamma1} \times gain_{\gamma2}}$$

- $$f_E^2 = \frac{1}{N} \sum_{k\ \ is\ \ fixed} G_k G_i = \frac{G_k}{N} \sum_{k\ \ is\ \ fixed} G_i \approx G_k \times 1$$
  - For a fixed central detector of a cluster, looping over all the other clusters
- Correct (software) gain: $gain^o = gain \times \frac{m^2_{\pi^o}}{m^2_{\gamma1,\gamma2}}$

In practice, for better convergence we use $gain^o = gain \times \frac{m_{\pi^o}}{m_{\gamma1,\gamma2}}$