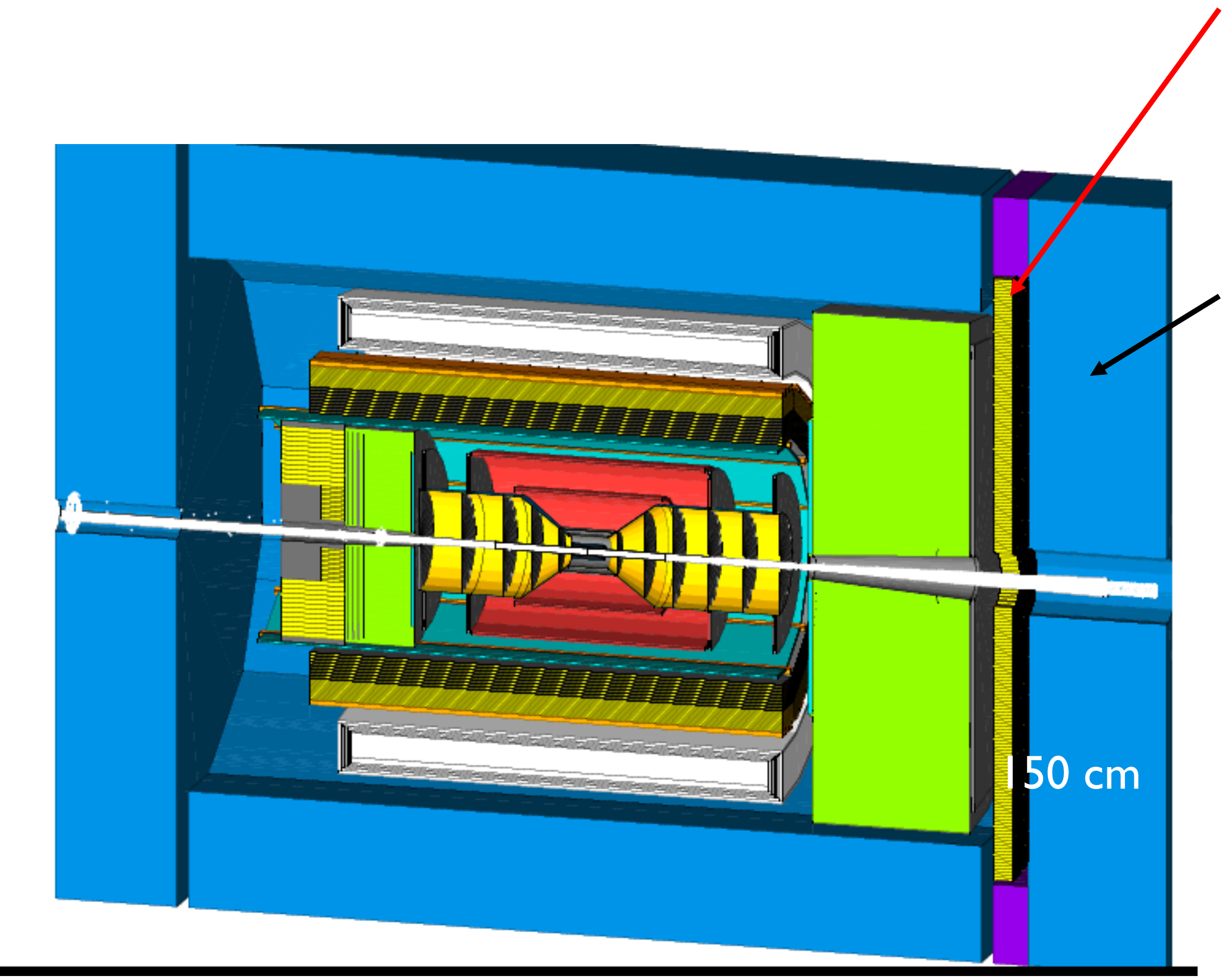
Forward Calorimetry II.

Some ideas behind conceptual design for ATHENA

O.Tsai (UCLA)



ATHENA Integrations:
IP shifted by 50 cm (Accelerator-Detector)
pRICH requires more space (Detector sybsustems)

Detector parameters in ATHENA proposal:
Ecal, WScFi 23 X0, granularity 2.5 x 2.5 cm
Number of channels ~ 26k
Coverage (R out – 230 cm)

Hcla, Fe/Sc (20/3), granularity 10 x 10 cm, longitudinal segmentation -4.
Number of readout channels ~ 5.3k
Coverage (R out – 275 cm)

CD1 Reference Detector Design

Detector Integration requires

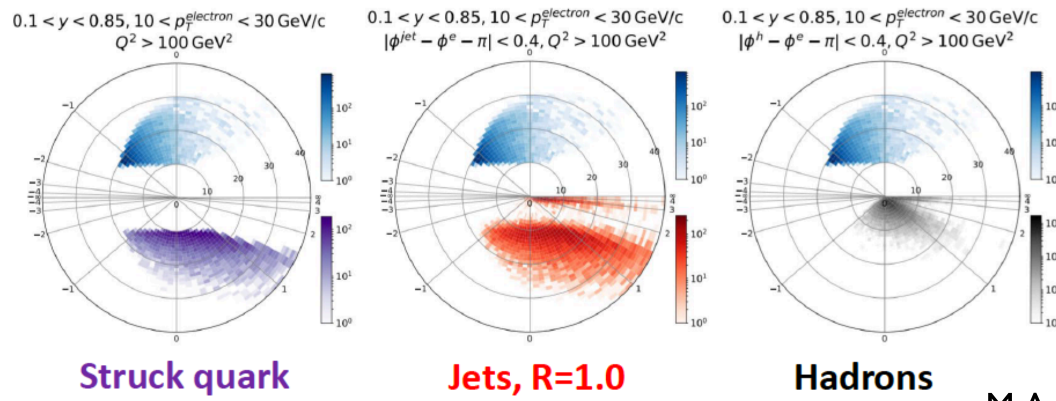
- 150 cm along Z for ~7 int. length (23 X0) EM+HAD system

Single particle performance specs (YR)

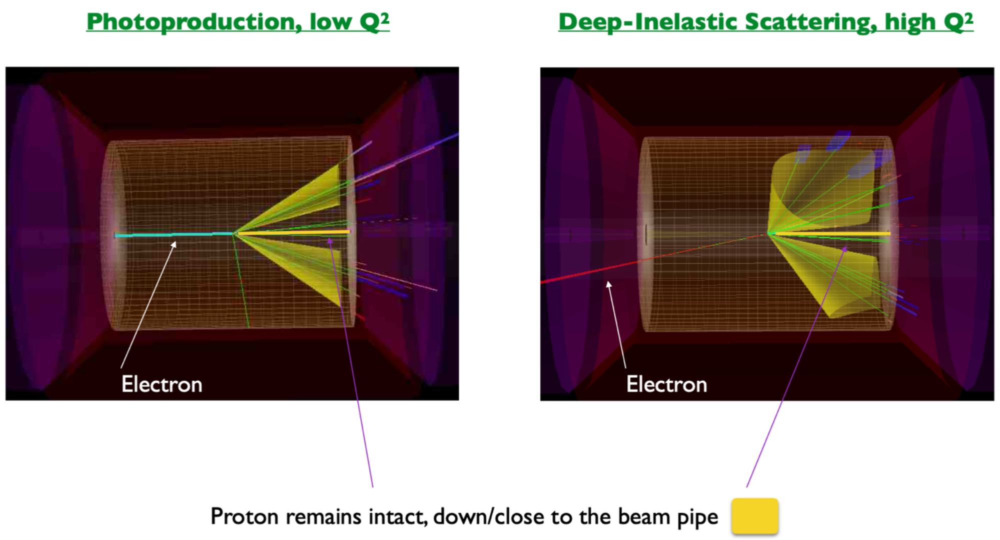
- Hadronic + EM energy resolutions.

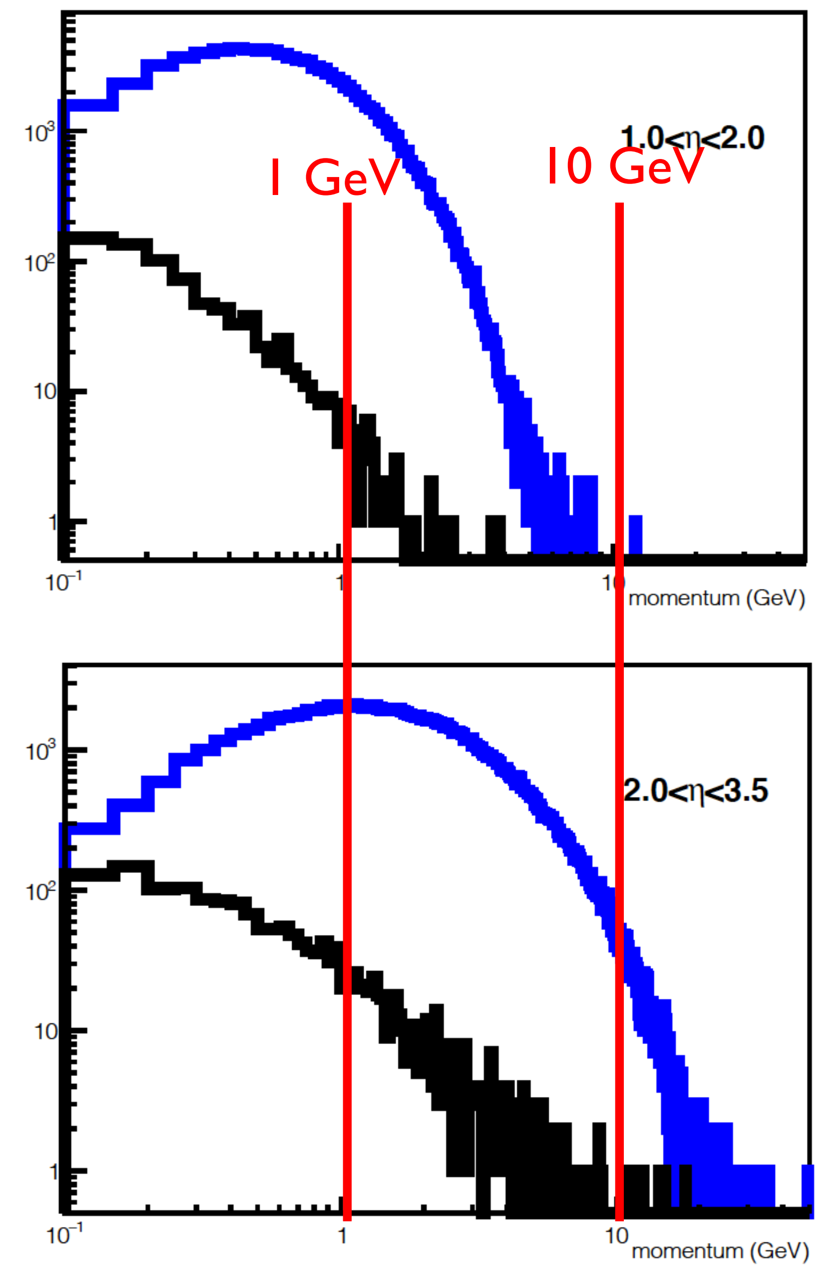
< 50%/√(E) +10% ~10%/√(E) +2%

Jets are excellent proxies for quark kinematics



M.Arratia (UCR)





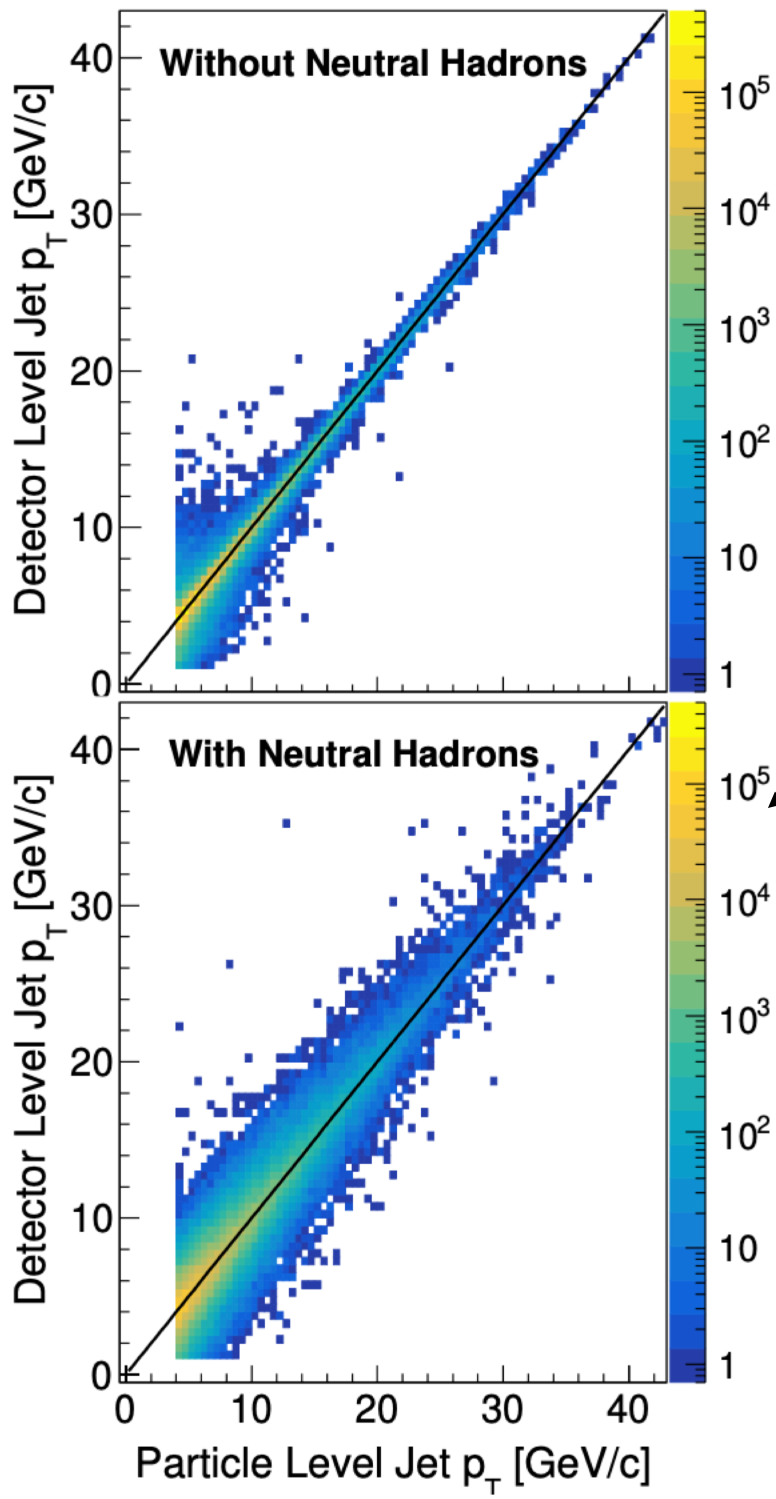
- Requirements in YR, resolution 50%/√E + 10%. 6% constant term for eta>3 is desired (Single particle)
- Desired as good as possible 35%/√E + X%. (N.B. there is no discussion in YR text to support these numbers.)
- Requires outstanding Hcal/Ecal system to achieve this.

Conditions at EIC Hadron EndCap:

- Particles Energy – low, difficult for calorimeters
- Interaction Rate – low, < 500kHz
- Occupancy - low
- Radiation Exposure - low
- Neutron Fluxes – some concern.
- Acceptance near the beam pipe is a concern.

⟷ Standard detector technologies should work fine.

Optimization of pEndCap tied to tracker, PID, and reconstruction methods



B.Page, E.Aschenauer (BNL)

- Energy flow, EM energy (EMcal) + Charge Hadrons (Tracker) + Neutral hadrons veto (EM + Hcal)
- Energy flow, EM energy (Emcal) + Charge Hadrons (Tracker) + Neutral hadrons energy (EM + Hcal)
- 'Pure' Calorimetric
- AI/ML reconstructions in case of imperfect acceptance.

Best method depends on global detector optimization. (Tracker, PID, Magnet, Cost…)

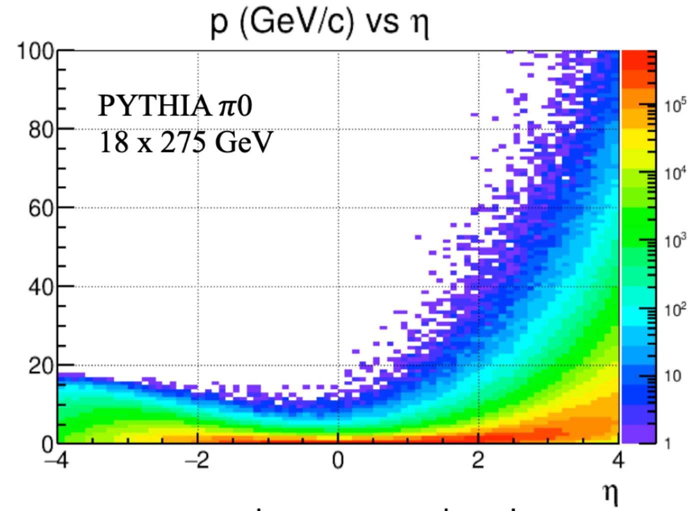
Different area of hEndCap had to be optimized differently.

For HCal 'identification of neutrals' vs measuring energy of neutrals

pECal functionality Pi0/gamma separation

See https://indico.bnl.gov/event/14906/ talk by A.Bazilevsky

YR: Fig11.80



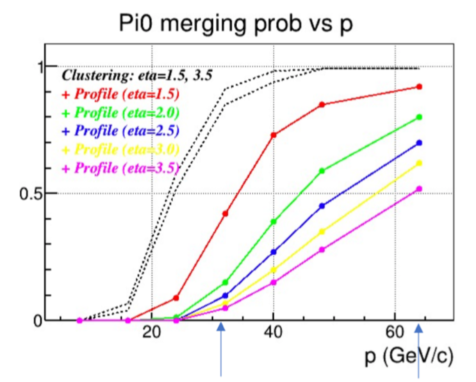
e-endcap:
up to e-beam momentum

h-endcap:
up to 50-100 GeV/c

Shower Profile Analysis

YR: Fig11.80

GEANT4:
Forward EMCal with
granularity ~0.008
(2.5×2.5 cm^2 at z=3m)



Shower Profile analysis:

$$\chi^2 = \sum \frac{(E_i^{meas} - E_i^{pred})^2}{\sigma_i^2}$$

E_i^{pred} and σ_i are f(x, y, E, $\boldsymbol{\theta}$, φ)

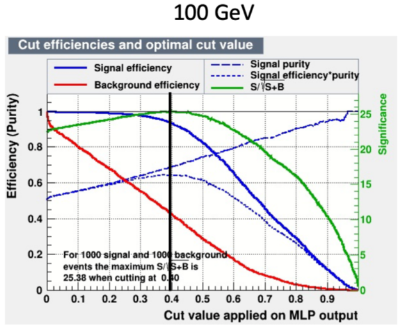
- Considerably extends the momentum range for $\pi0/\boldsymbol{\gamma}$ discrimination
- Strong dependence on rapidity (for non-projective)
- There is room for improvement …

Pi0 merging prob after MLP

Signal/Background efficiency after MLP

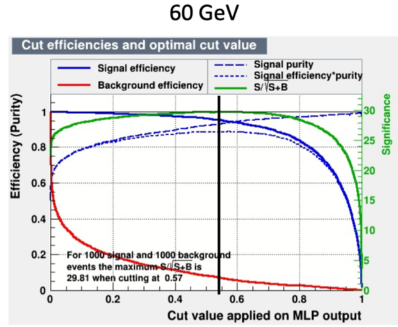
h-endcap: 2.5x2.5cm at z=3.5m, η=3

100 GeV



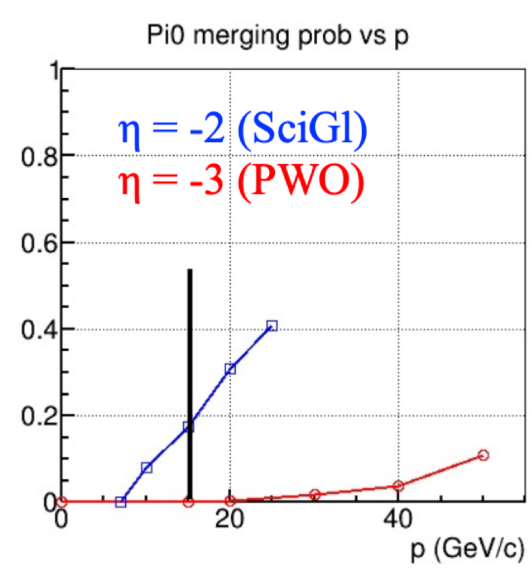
ε_{Bg} = 42% for ε_{Sg} = 95%

60 GeV

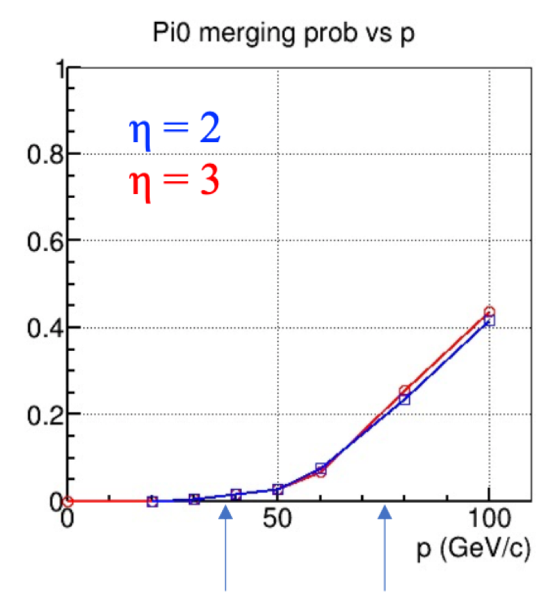


ε_{Bg} = 7% for ε_{Sg} = 95%

e-endcap:
PWO: 2x2cm at z=-2.1m
SciGl: 4x4 cm at z=-2.1m



h-endcap:
W/SciFi: 2.5x2.5cm at z=3.5m

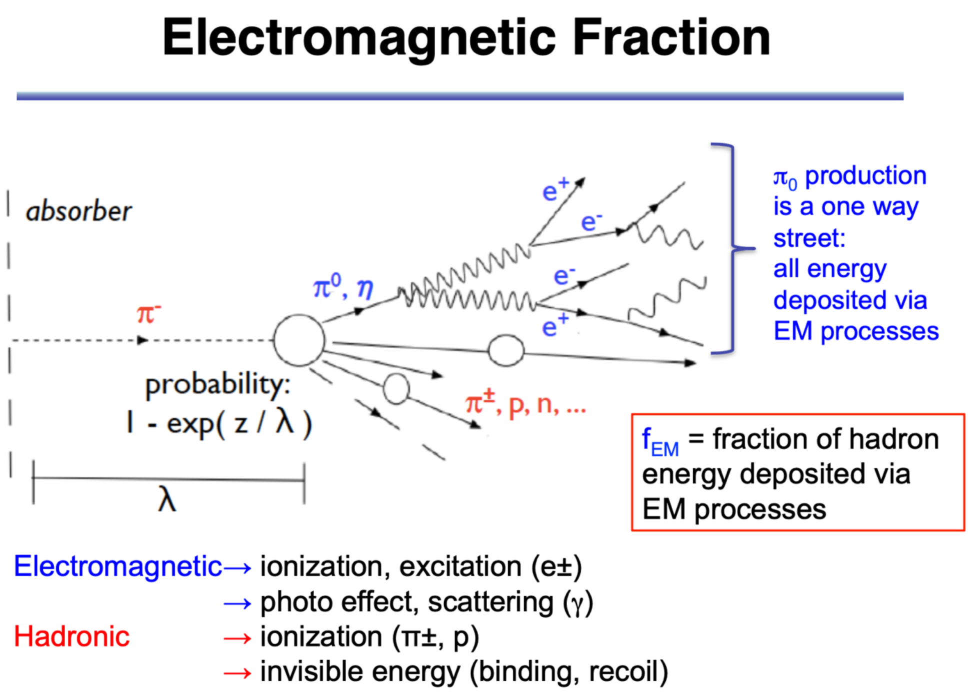


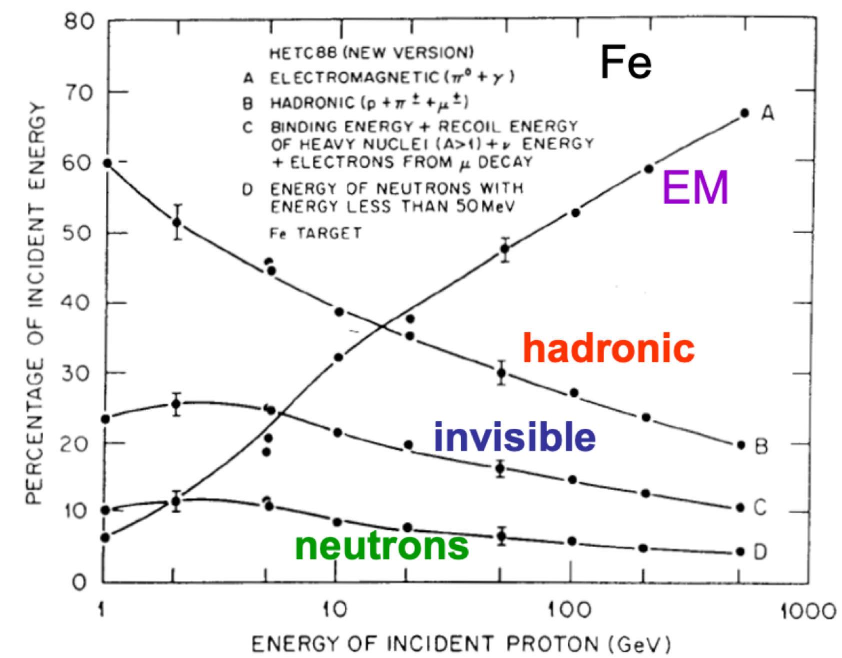
$\boldsymbol{\theta}_{min}$=1 twr $\boldsymbol{\theta}_{min}$=0.5 twr

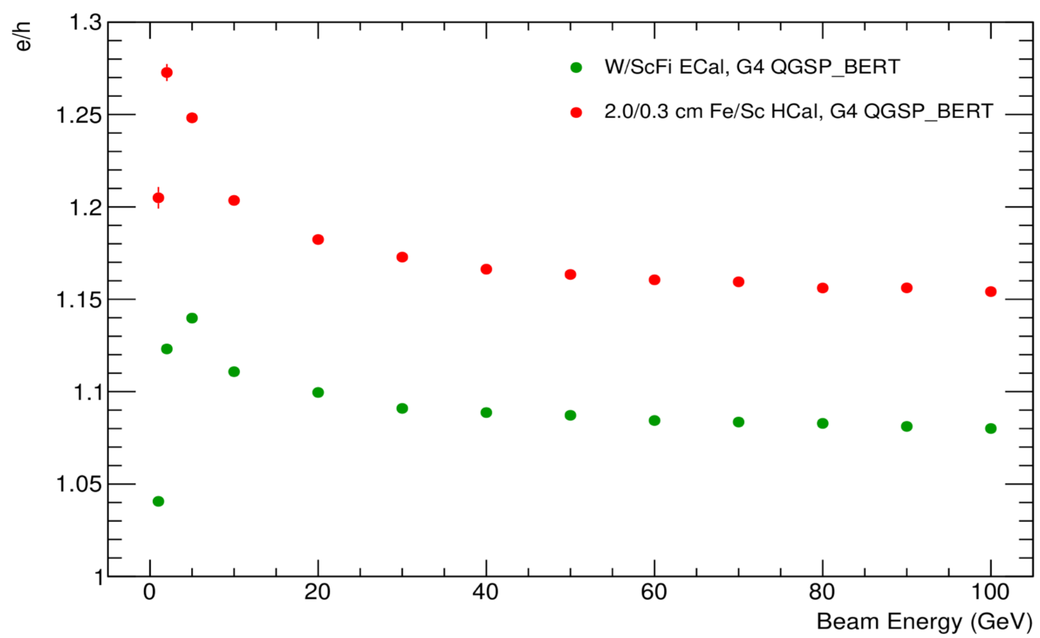
Can effectively discriminate $\boldsymbol{\gamma}/\pi0$ even when two photons are separated by 0.5 tower size

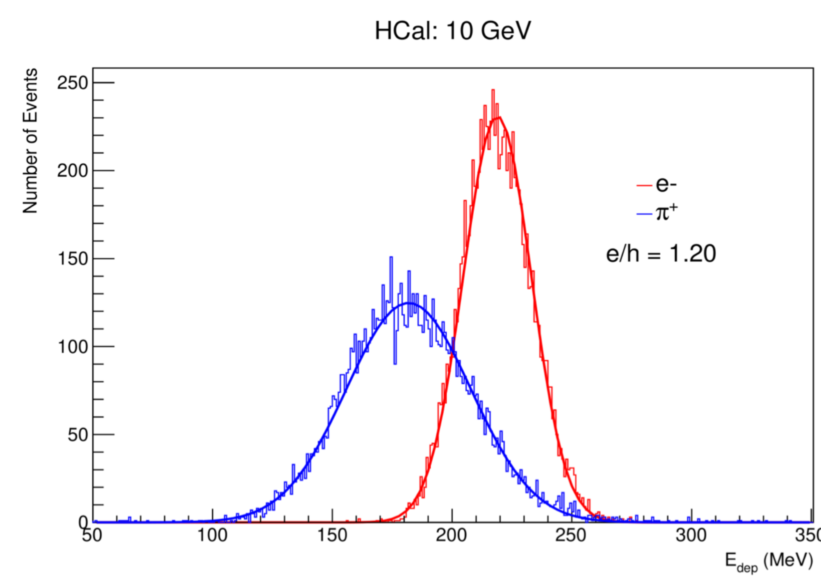
Compactness of pECal is handy.

Hadronic showers are messy…









R.Milton (UCLA)

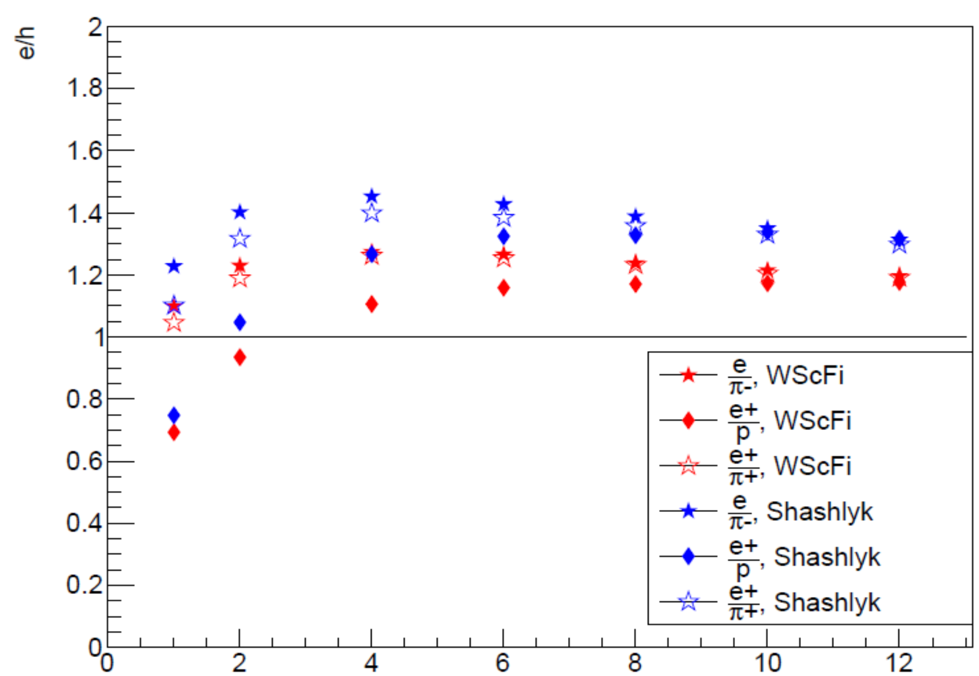
There are many complications to measure well energy of even a single hadron.
Measuring jets adds additional complications.
Many attempts to fix it one way or another:

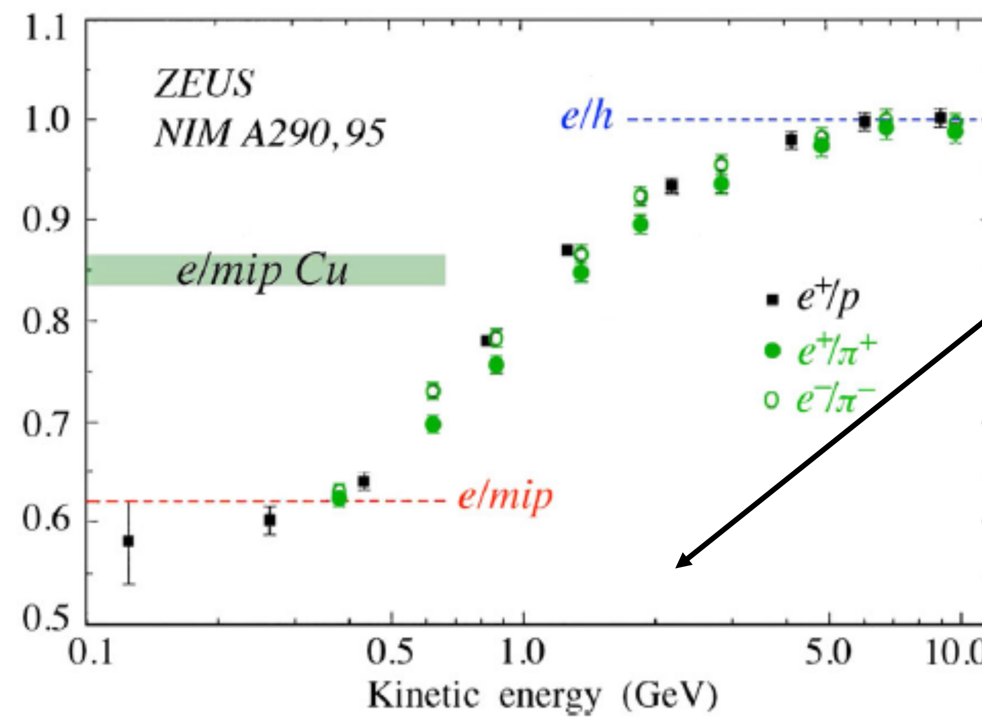
- Compensation (chemical composition and…)
- Re-weighting, (software compensation). Segmentation
- Dual Readout methods (S/C, timing)
- AI/ML

Hadron calorimeter systems. EIC energy range, complications.

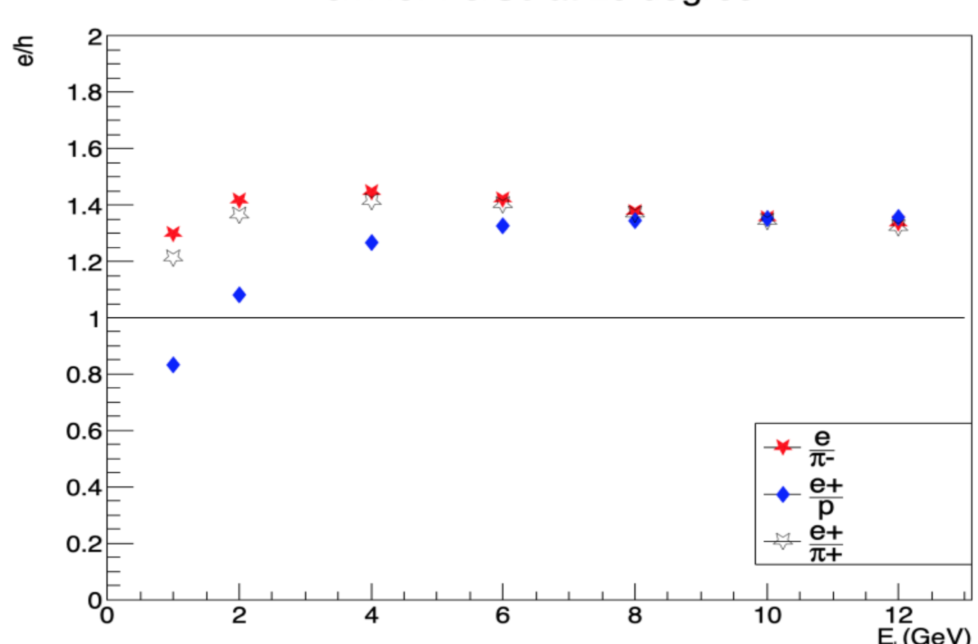
- $e/h \neq 1$
- $e/h\_ecal \neq e/h\_hcal$
- $e/h = f(E)$
- $e/p \neq e/\pi$
- $f_{em} = 0.11 \ln[E(GeV)]$

Jet energy resolution is always poorer than for a single hadron. Despite ~ 20% of jet energy (em) measured very accurately by Ecal.

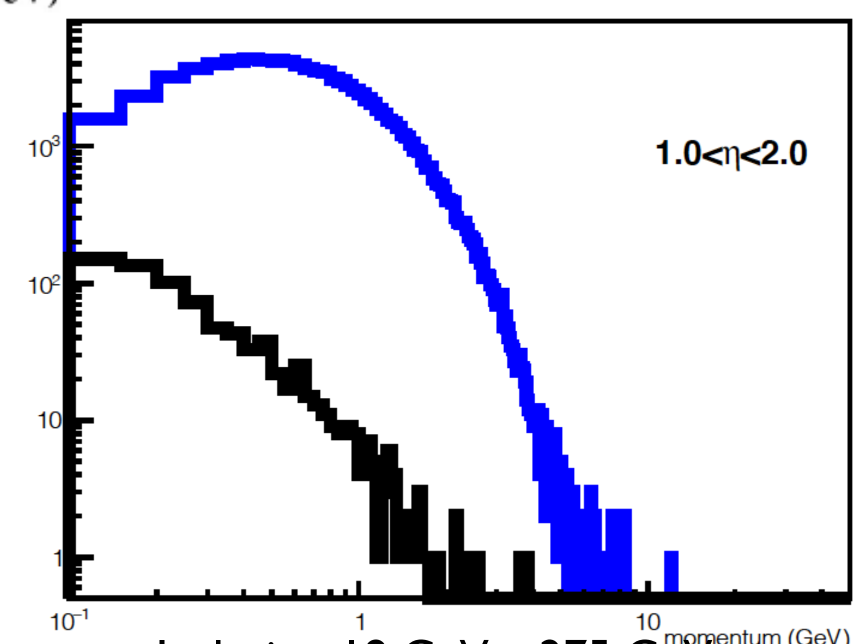




EIC Calorimetry need measurements In this energy range.

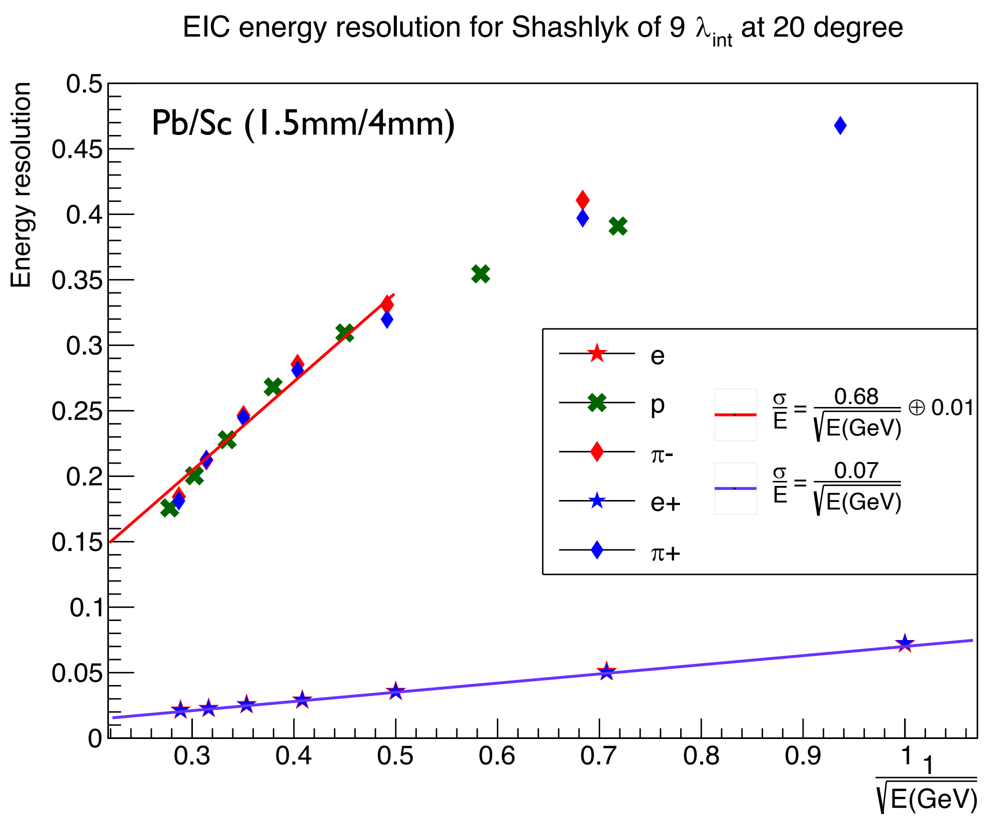


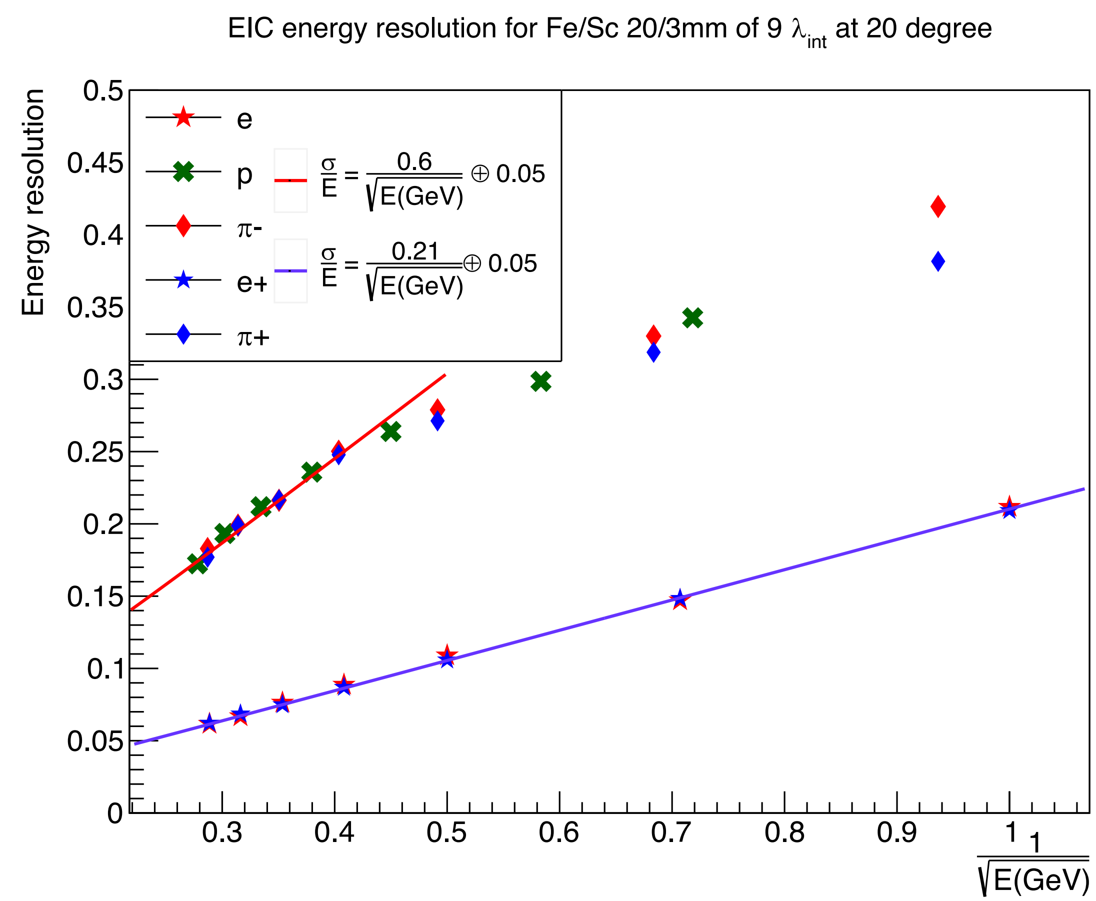
- ZEUS are experimental results
- eRD1 – GEANT4 with physics list validated for LHC (FTFP_BERT_HP).
- Validation of MC can be done only using experimental data form detector with correct chemical composition.

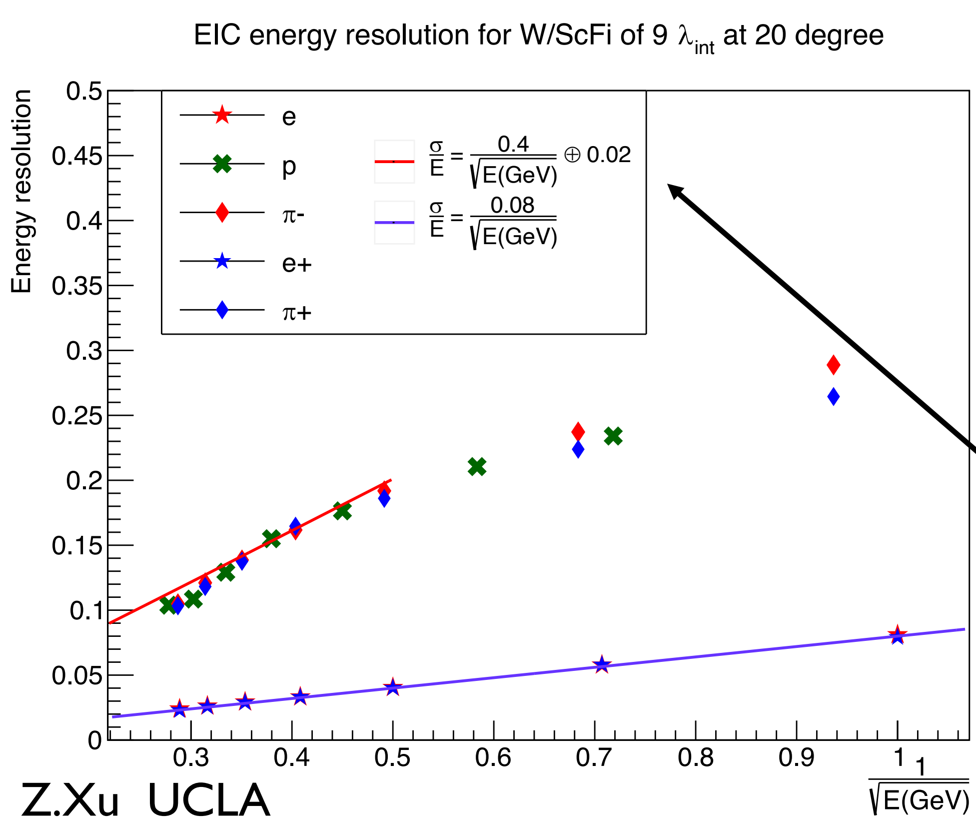


Inclusive, 18 GeV x 275 GeV

How important to tune e/h value? Hypothetical Configurations.







Z.Xu UCLA

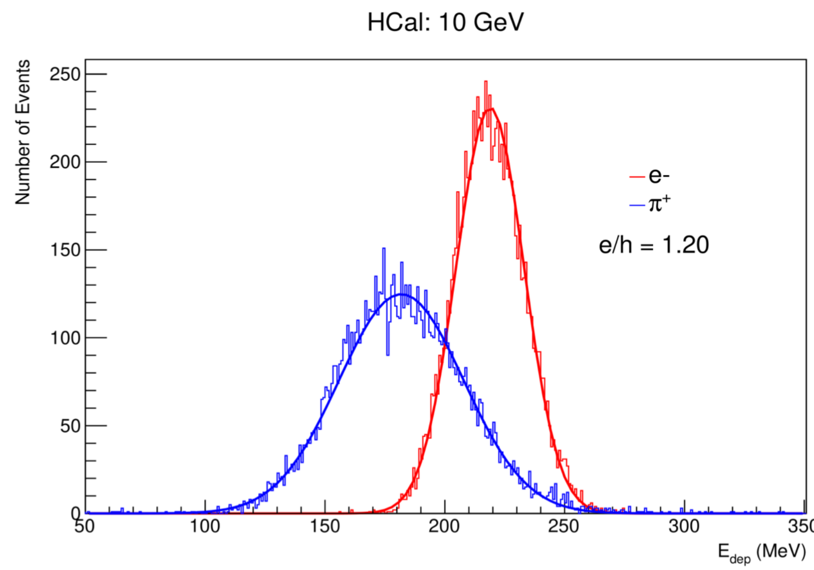
Hypothetical variant, 9 interaction lengths long calorimeters. Same structure for Ecal and Hcal sections. Three different technologies:

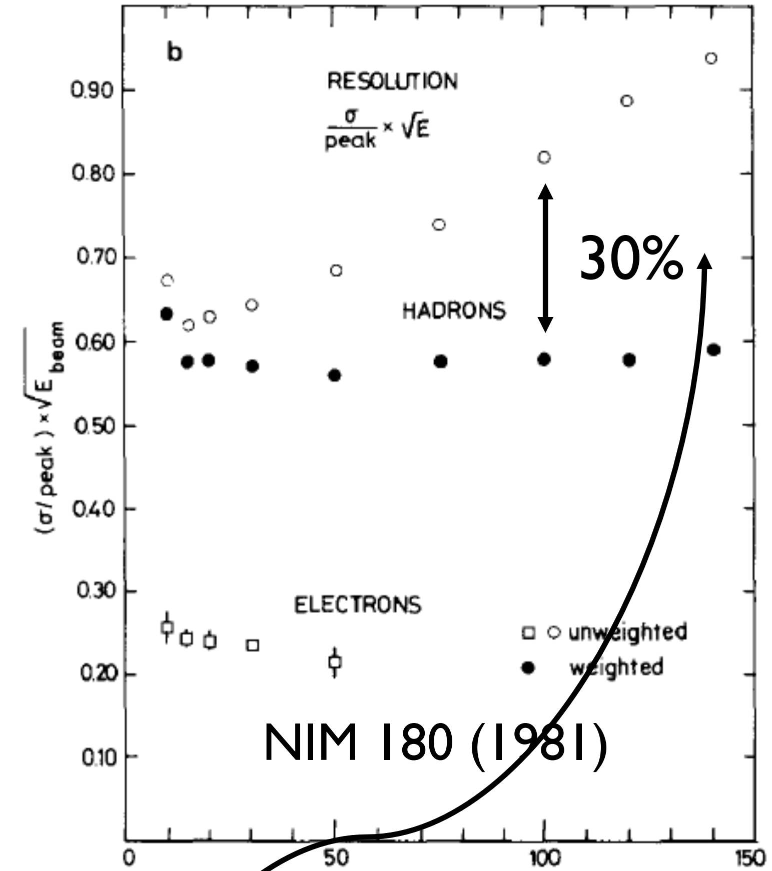
- SHASHLYK (Phenix, STAR Forward)
- WScFi (STAR Forward 2014) – compensated
- Fe/Sc (STAR Forward 2020)

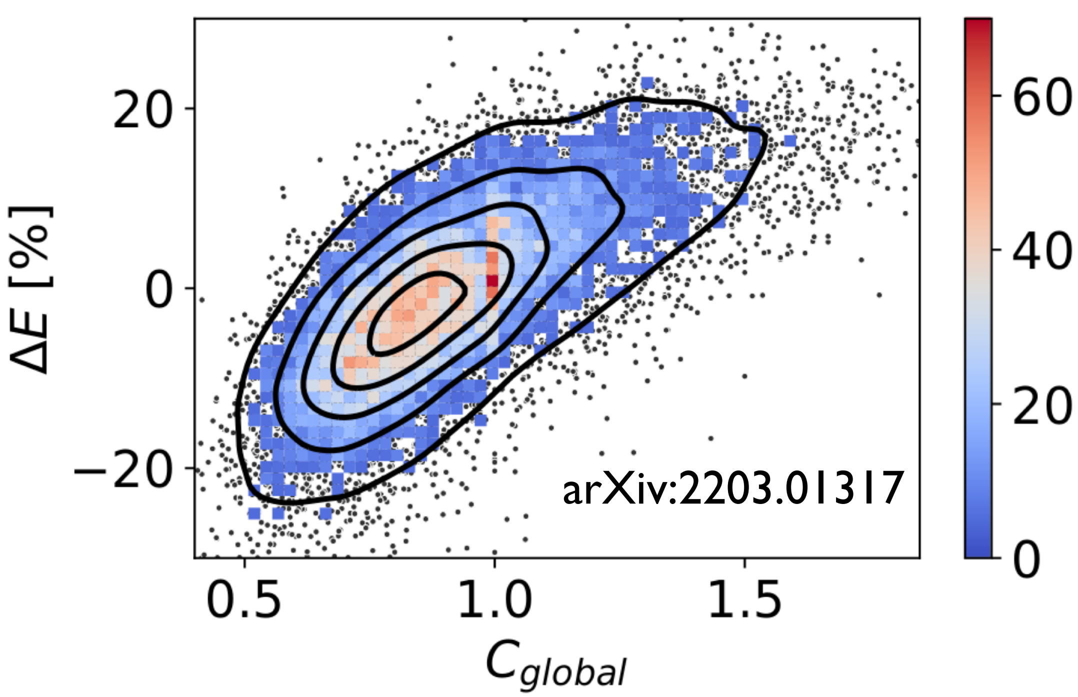
Proper detector composition required for good hadronic resolution. I.e. desired to keep e/h as close as practically possible to 1.

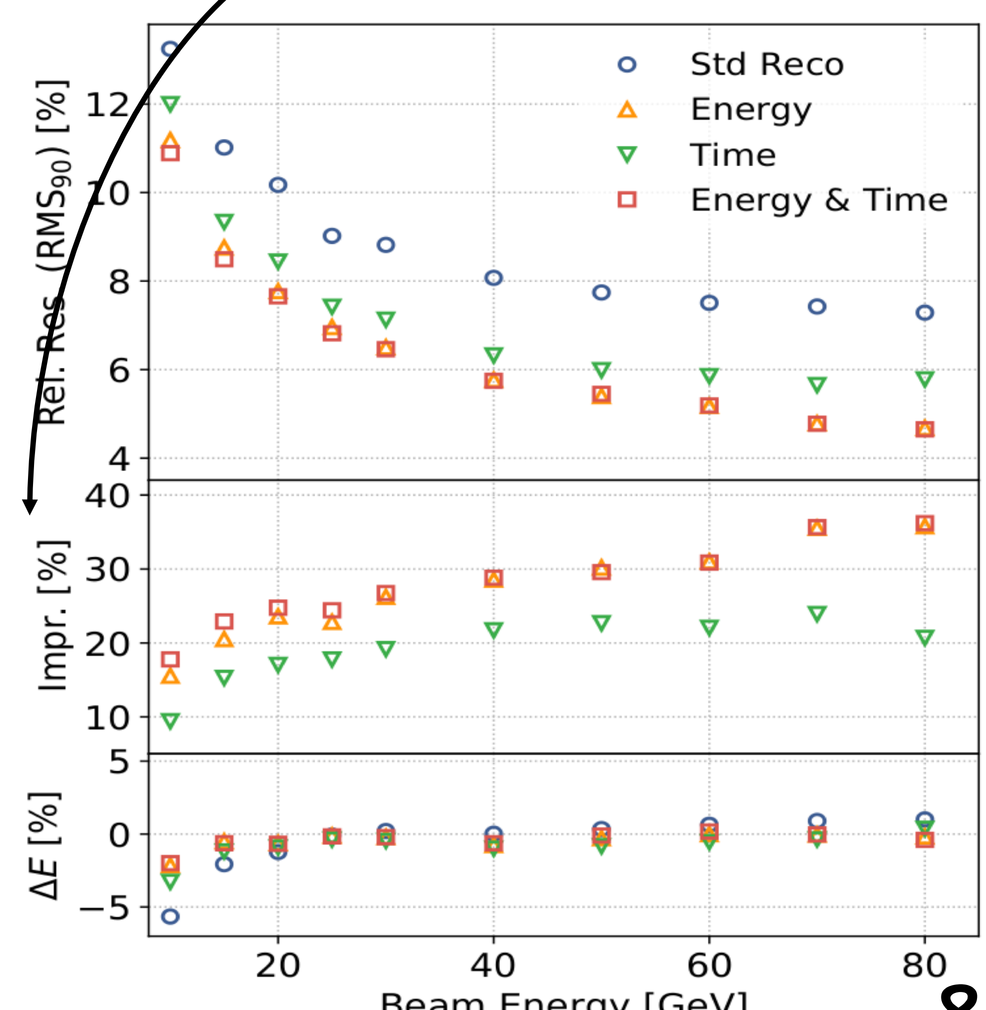
N.B. these are MC not an experimental results.

- Software compensation.
- Re-weighting cells with high f_em
- CALICE, H1 (UCR)
- Segmentation









- C_{global} = num. hits with E_{dep}> 5 MIP / num. hits with E_{dep} > avg. hit energy
- Then reconstruct the energy using $E_{reco} = E_{hits} \cdot (a + b\, C_{global} + c\, C_{global}^2)$

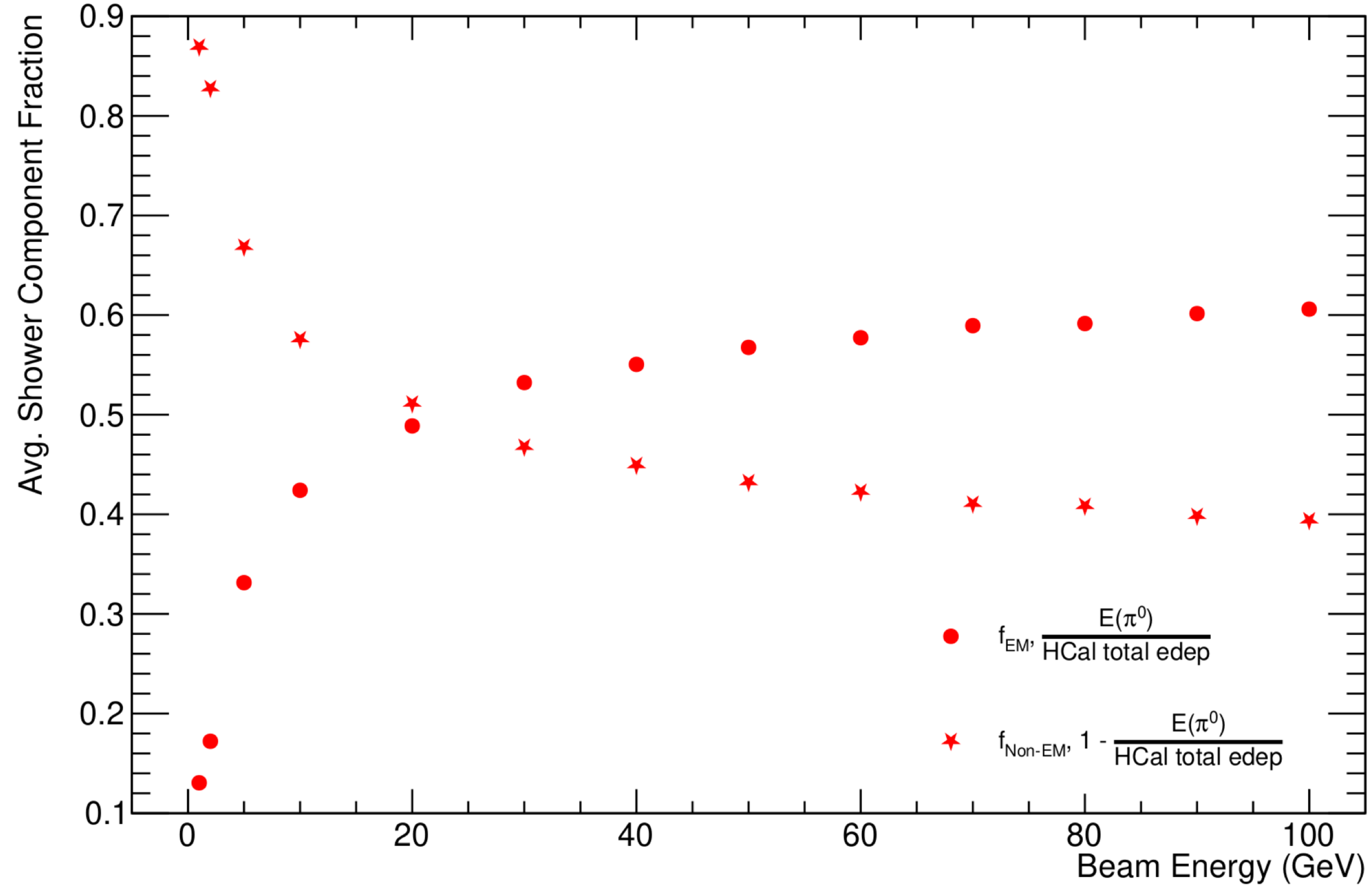
~30% improvements in resolution at high energy

- Software compensation.
- Re-weighting cells with high f_em
- Segmentation

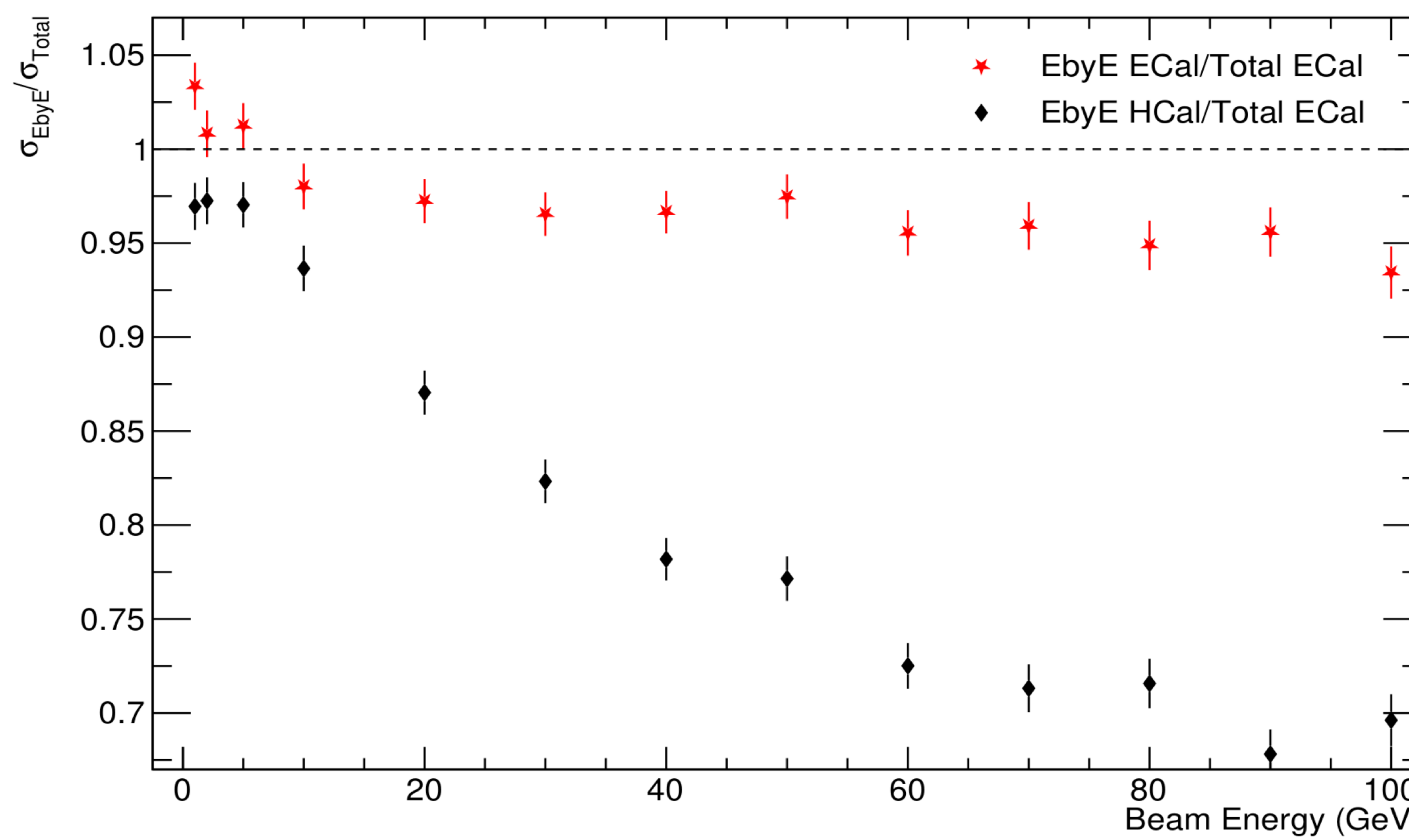
f_em small at low energies ‘software compensation’ helps only at higher energies

pEcal is compensated, re-weighting as expected did not help.

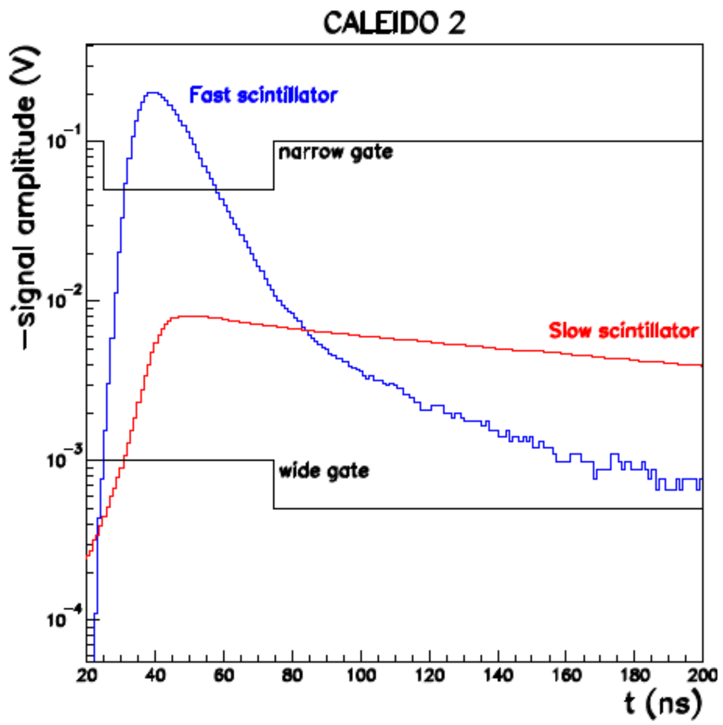
pHcal re-weighting of entire tower (no segmentation) gives ~ same improvement (30%) in energy resolution as in CALICE.

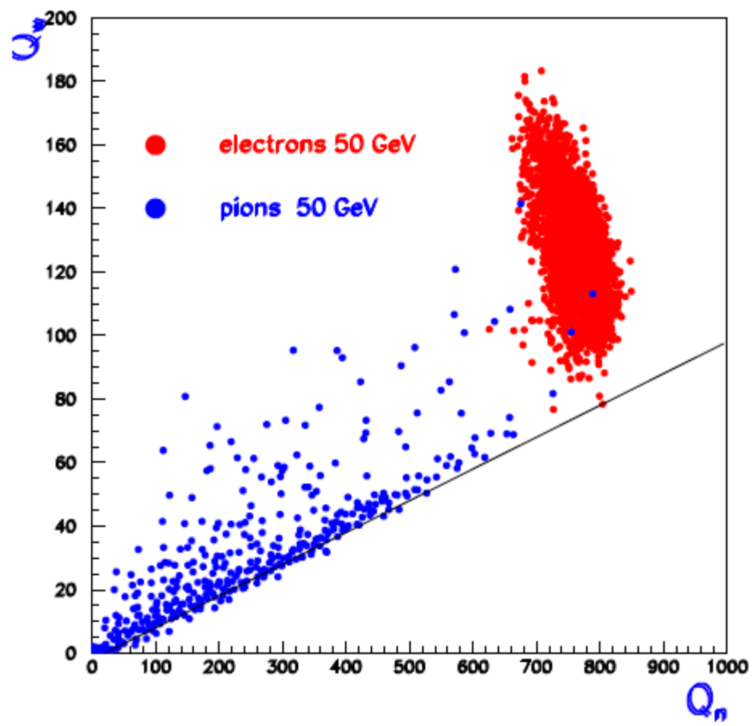


R.Milton (UCLA)



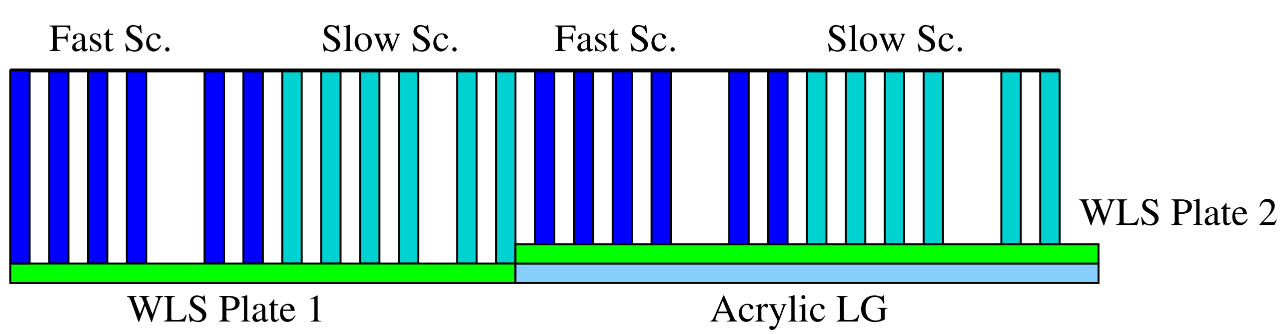
- Segmentation





Use CALEIDO 2 (SHASHLYK EMcal) method with two types of scintillator in calorimeter stack.

EJ-212 2.4 ns decay time
EJ-240 240 ns decay time

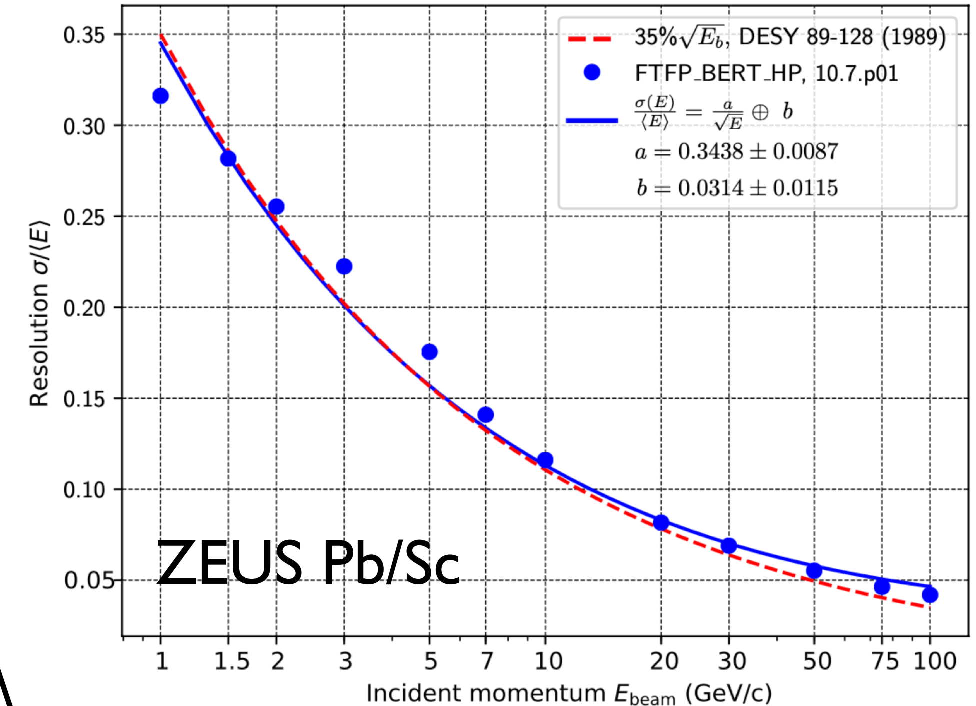


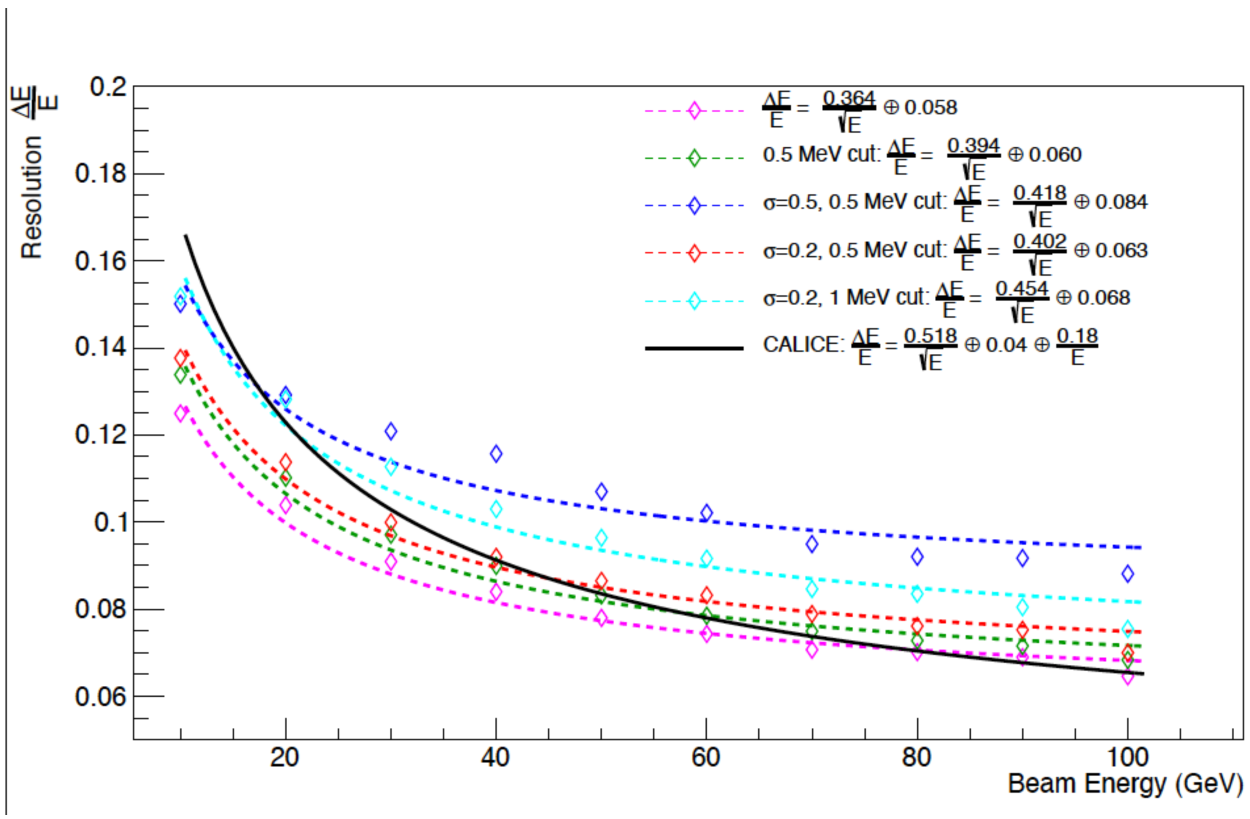
Concept of HCal Tower. Two Independent readout Channels –> four sections.

Practical implementation seems simple, not that different from STAR FCS.

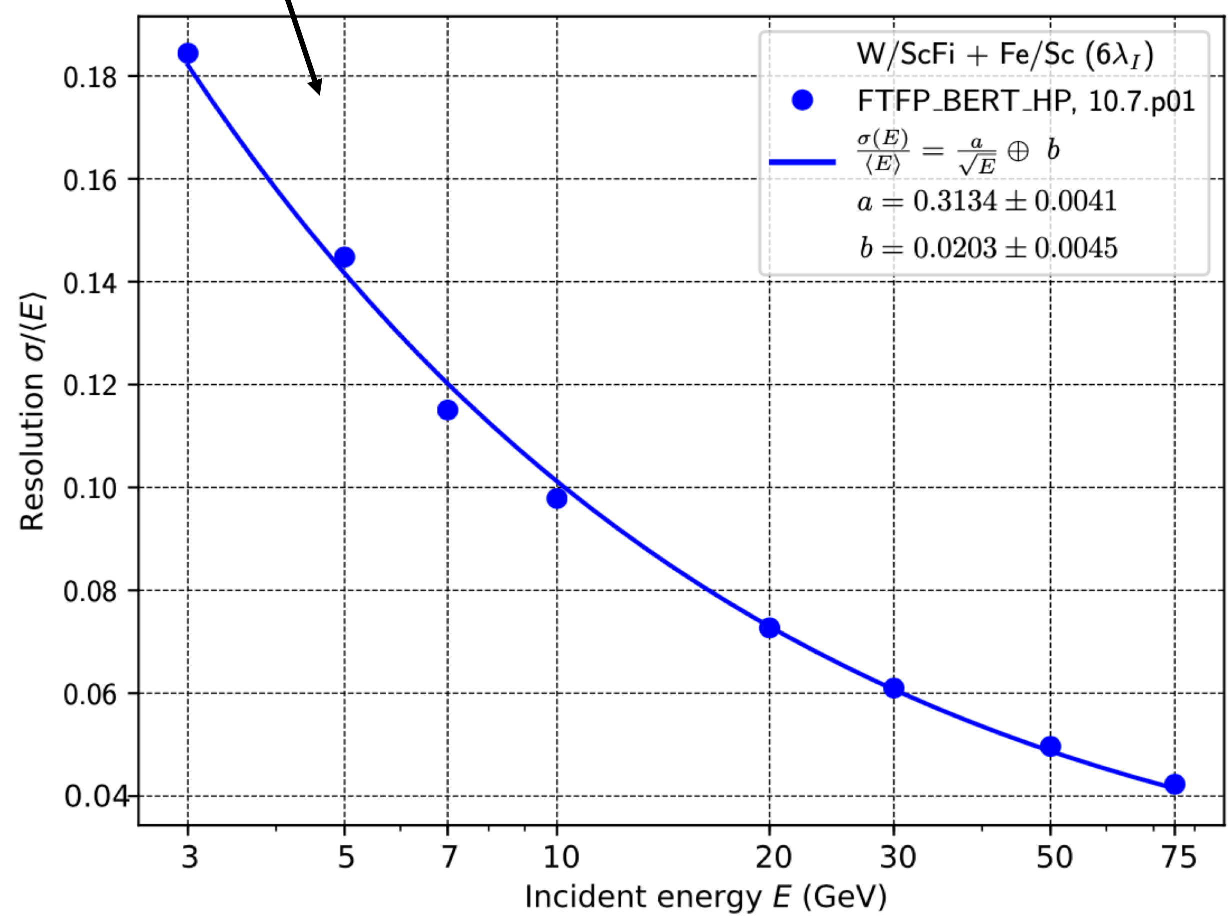
MC results should be taken with a grain of salt…

- Validation for high Z absorbers looks fine
- (J.Adam, A. Jentsch (BNL), earlier studies with Pb/Sc hcal eRD1/STAR)
- With Fe absorber we can't reproduce CALICE results well…

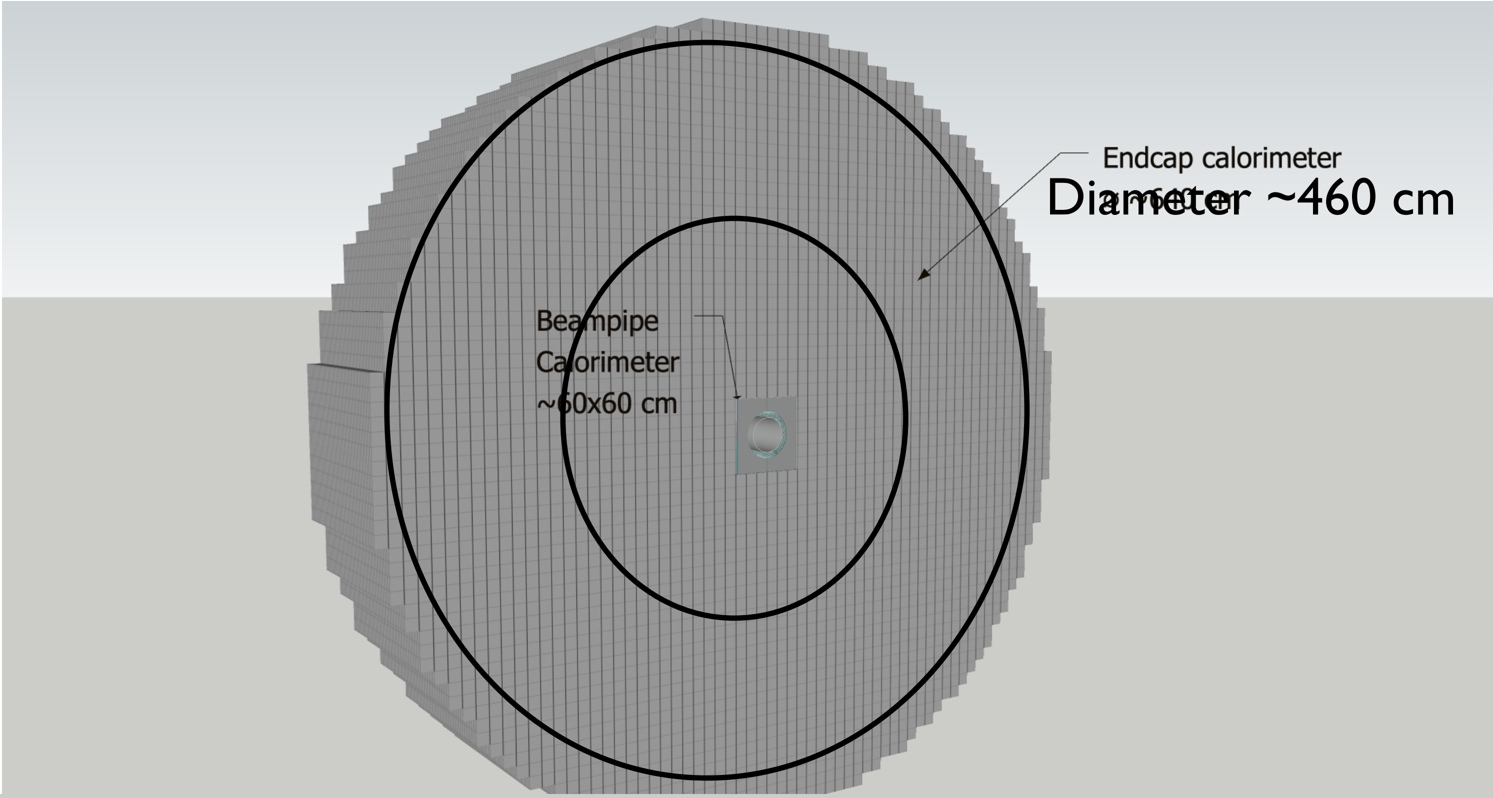


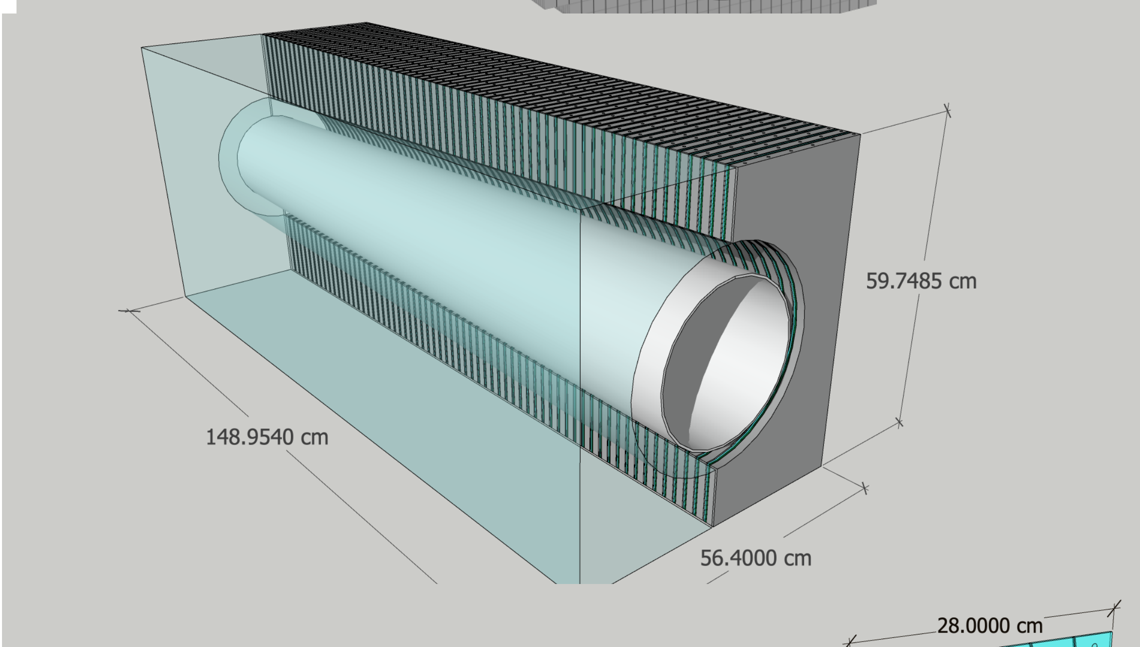


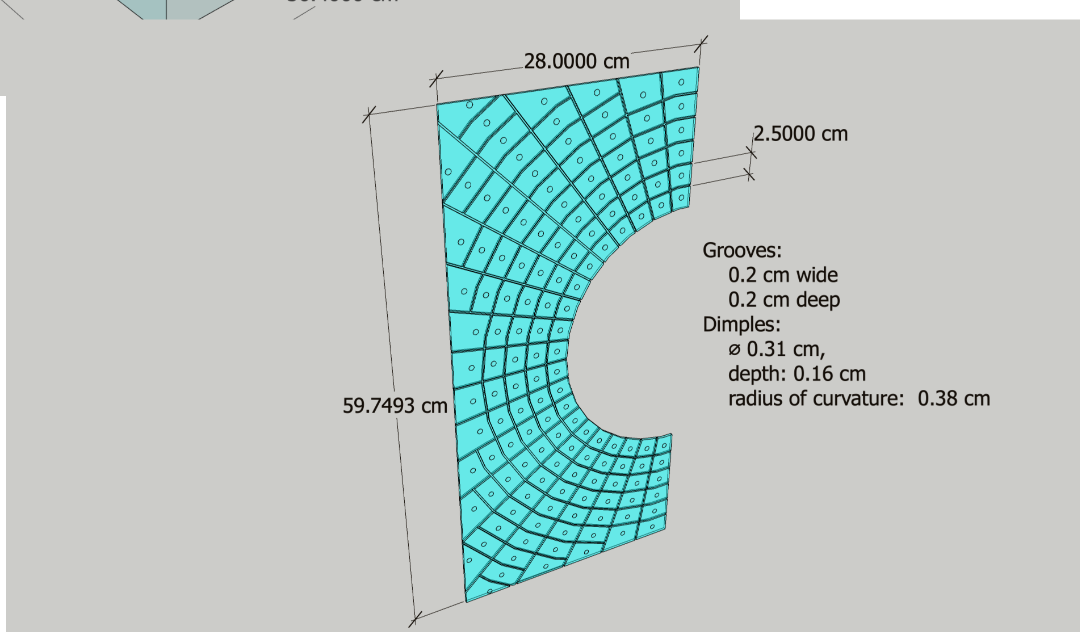
Fe/Sc, CALICE Model R.Milton (UCLA)



J.Adam (BNL)







M.Arratia (UCR)

Post proposal investigations are in progress:

Role of segmentation in different parts of pEndCap.

- Outer – 'PID for neutrals'?
- Central – software compensation?

Away from the beampipe subject of global detector optimization.

Insert around beam pipe

- High density, high granularity (spread of showers, leaks into beampipe)
- High granularity - recovery of acceptance.

Conclusions:

- Conceptual design of pEndCap for ATHENA meets specs (MC).

- Design is based on proven, effective technologies:

WScFi – sPHENIX – finished construction in 2022
Fe/Sc – STAR Forward HCal – finished construction in 2021, 510 GeV pp 2022

- R&D plan was submitted (pended now) eRD106/107

Fudan, Shandon University, Tsinghua, South China Normal University, UCLA, IUCF, BNL – eRD106 (WScFI) ACU, BNL, IUCF, Rutgers,UCR, UCLA, Valpo –eRD107 (Hcal)

- Optimization of pEndCap is in progress, driven and supported by UC EIC consortia (UCR, UCLA)

Workfest at UCR, April 2022. Optimization of pEndCap.UC EIC consortia members.
Photo by Miguel Arratia.

We are looking forward for interesting detailed discussion ahead of us!