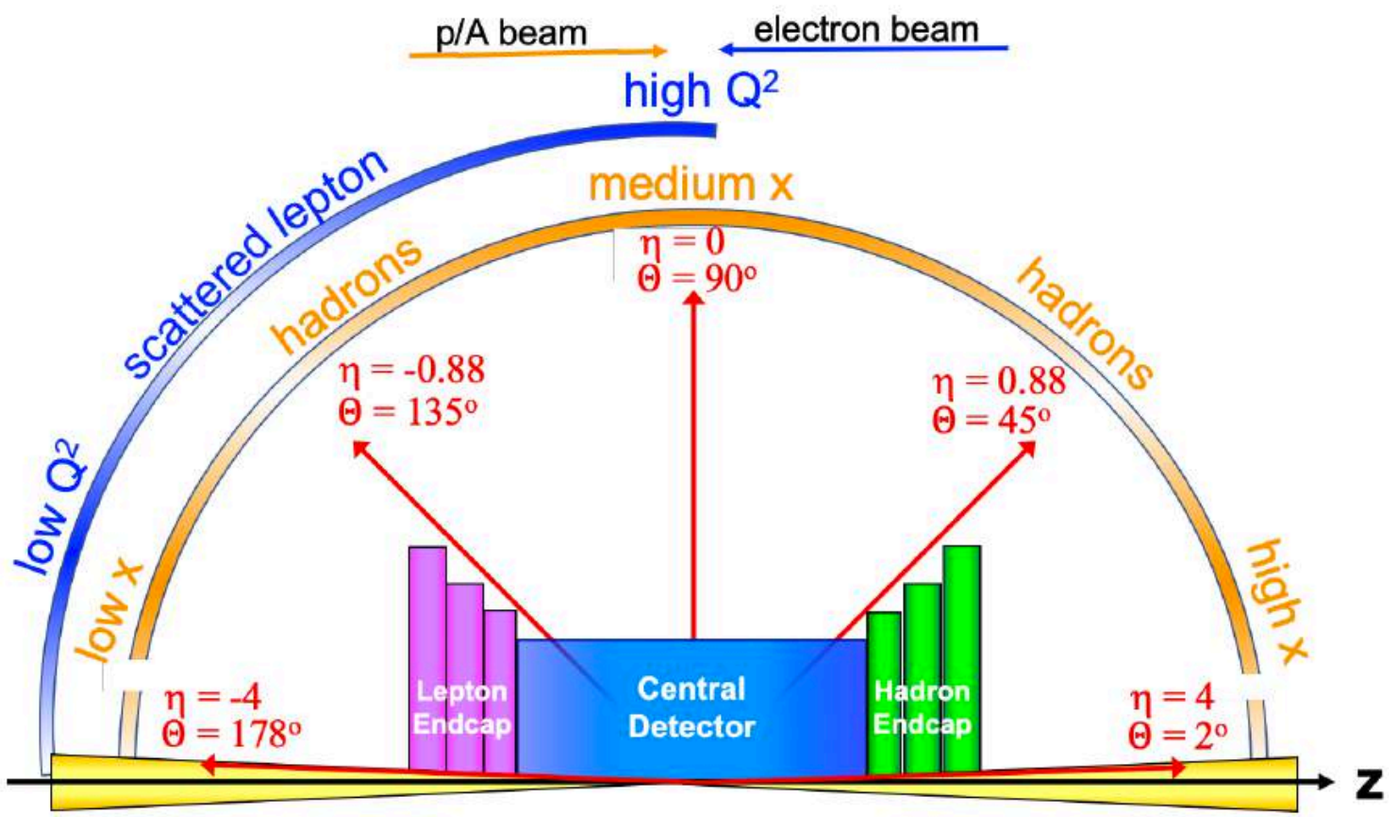
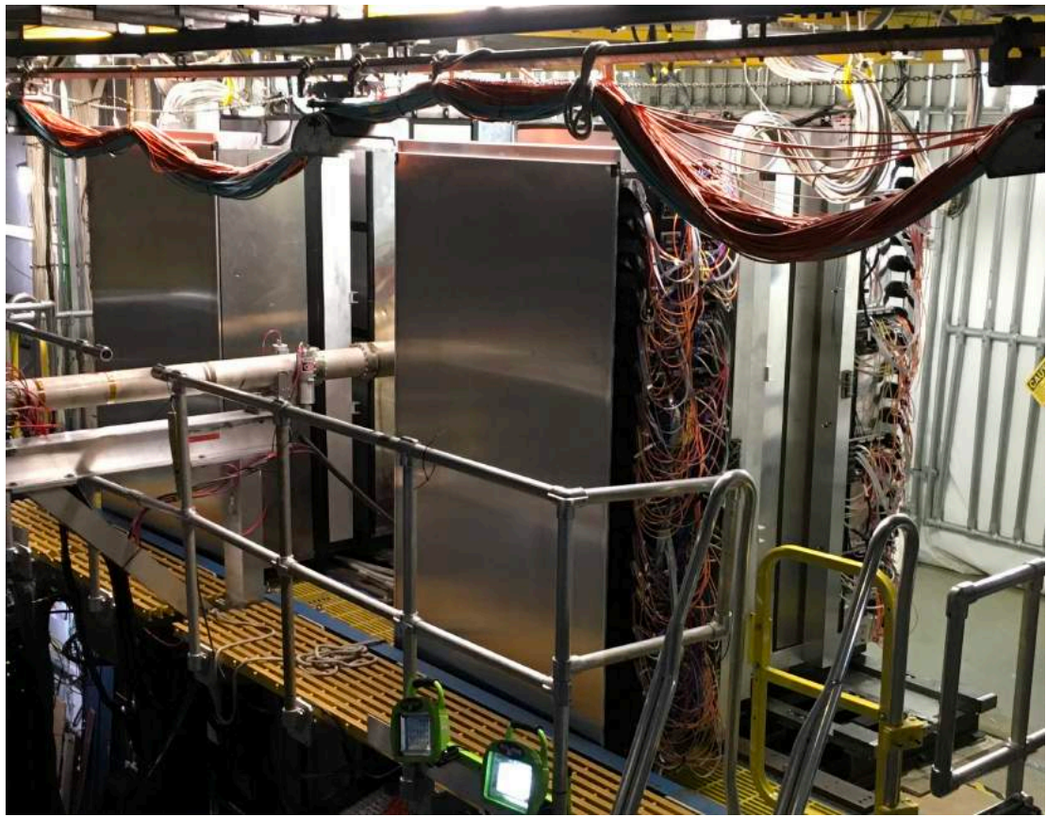
eRD1 Progress Report and proposal.

O.Tsai for (BNL, IUCF, TAMU, UCLA, UCR)



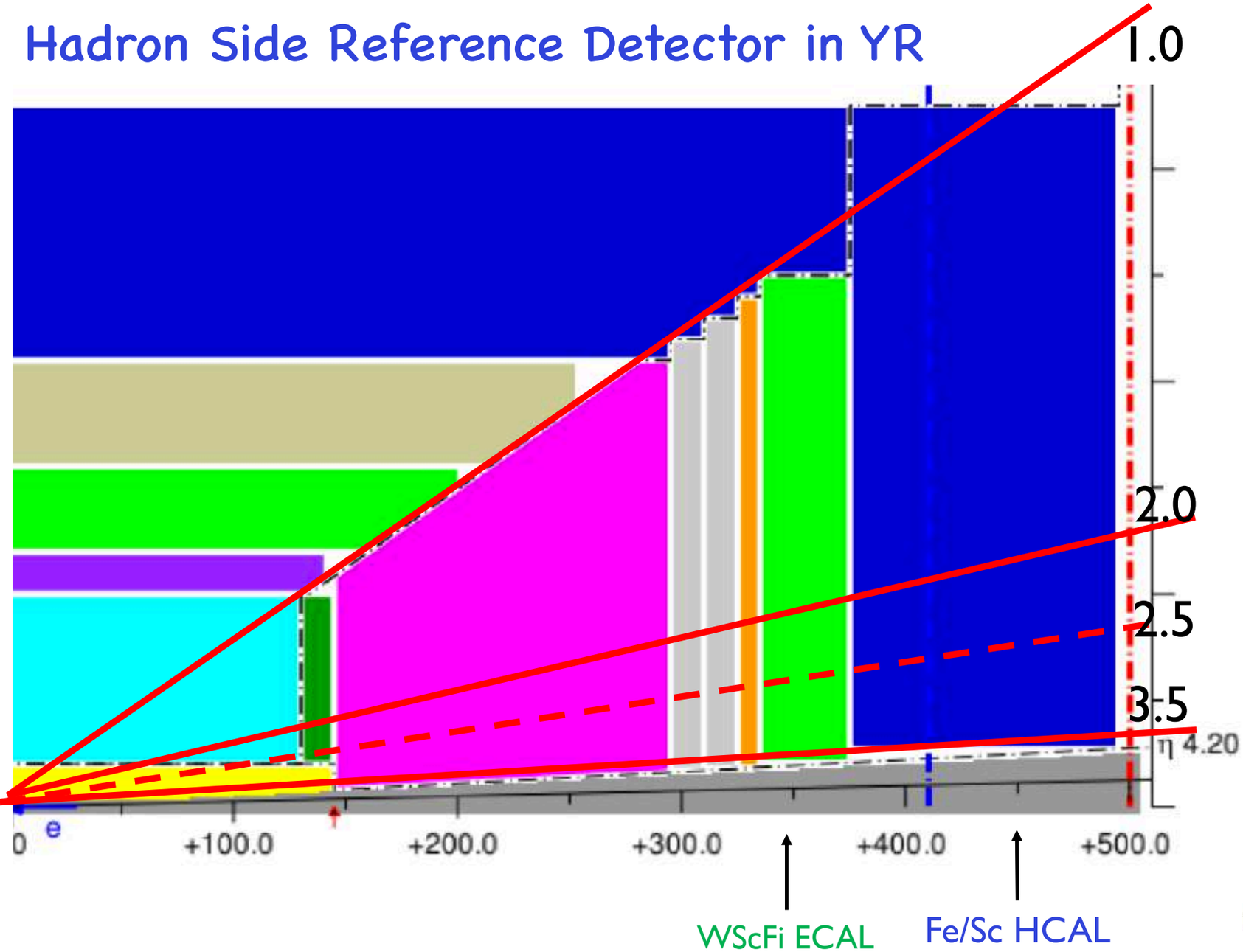


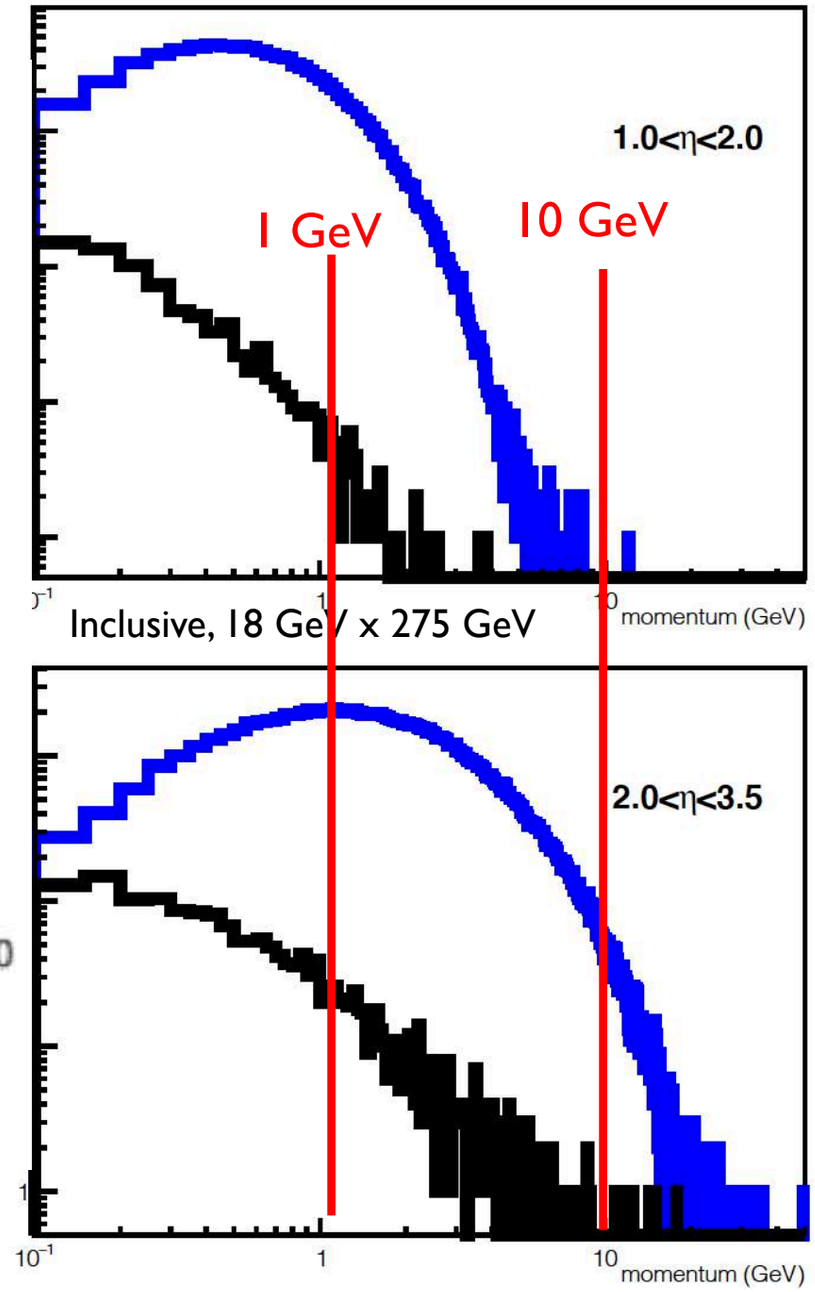
- Optimization of forward calorimeters system for EIC
- Construction of STAR Forward Calorimeter System

Synergy between STAR FCS and EIC Calorimetry R&D lead to:

- development of EIC reference detector concept and technologies.
- helped to ensure these technologies are now well established within EIC user community.

Hadron Side Reference Detector in YR





- Requirements in YR, resolution 50%/√E + 10%. 6% constant term for eta>3 is desired

Conditions at EIC Hadron EndCap:

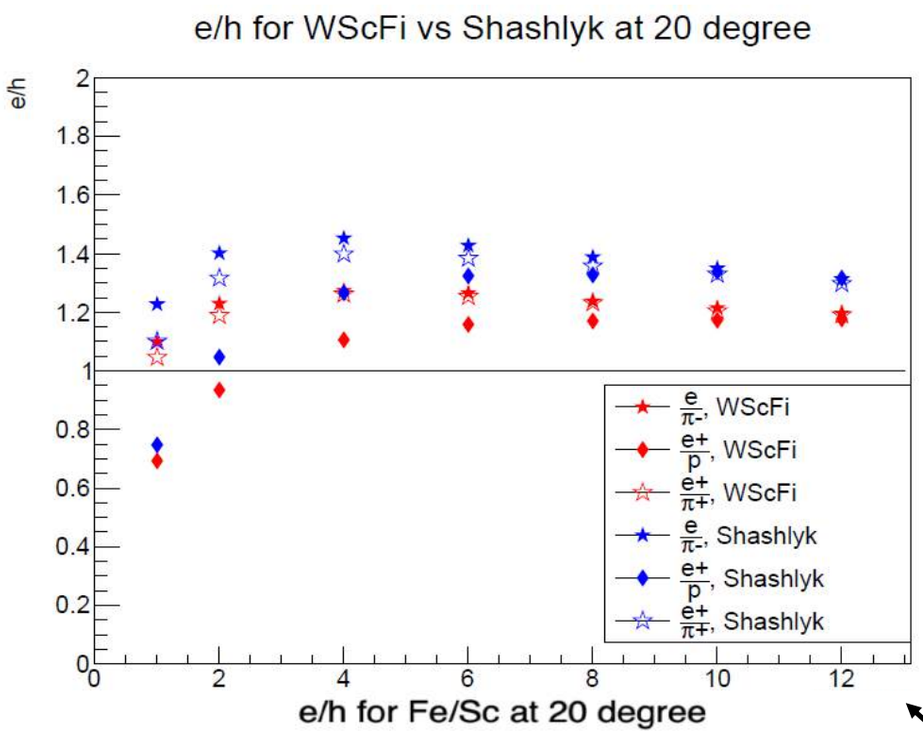
- Particles Energy – low, difficult for calorimeters
- Interaction Rate – low, < 500kHz
- Occupancy – low
- Radiation Exposure – low
- Neutron Fluxes – some concern.

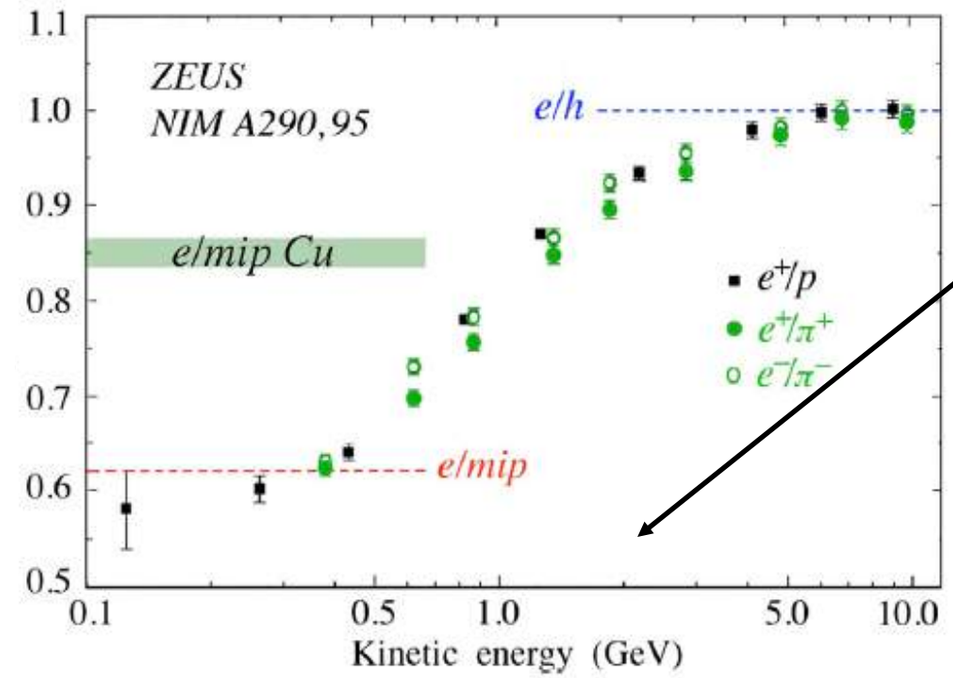
⟷ Standard detector technologies should work fine.

Hadron calorimeter systems. Challenges.

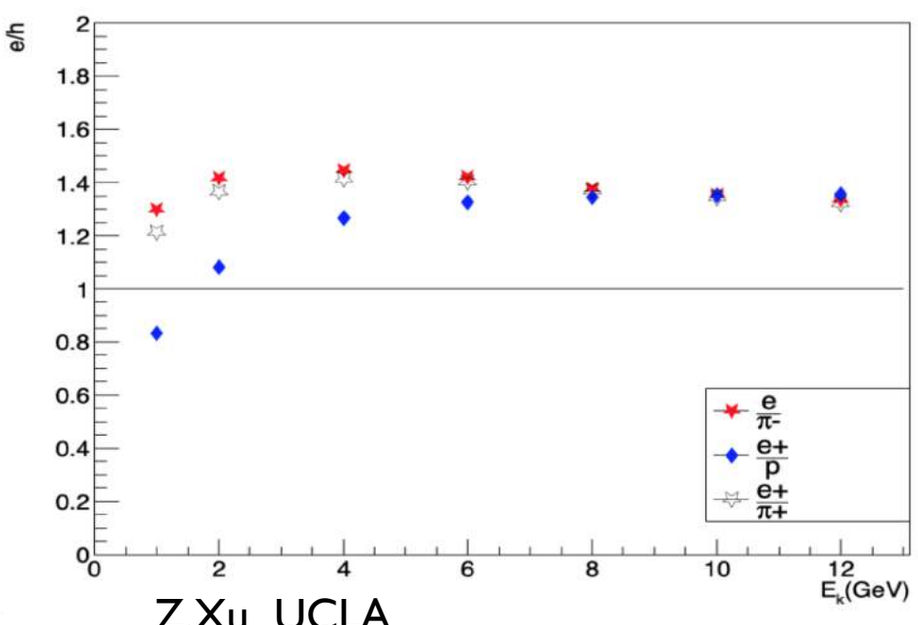
- $e/h \neq 1$
- $e/h_ecal \neq e/h_hcal$
- $e/h = f(E)$
- $e/p \neq e/\pi$
- $f_{em} = 0.11 \ln[E(GeV)]$

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

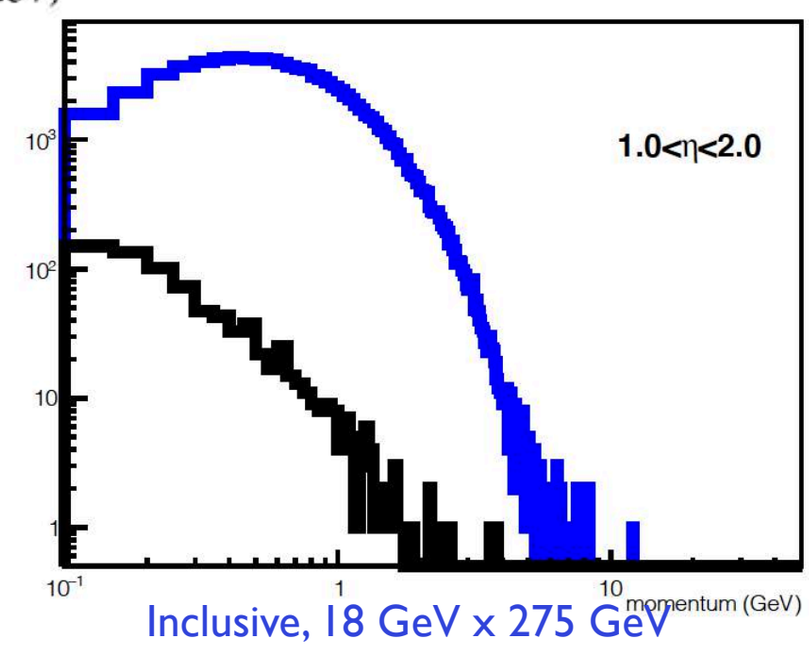




EIC Calorimetry need measurements In this energy range.



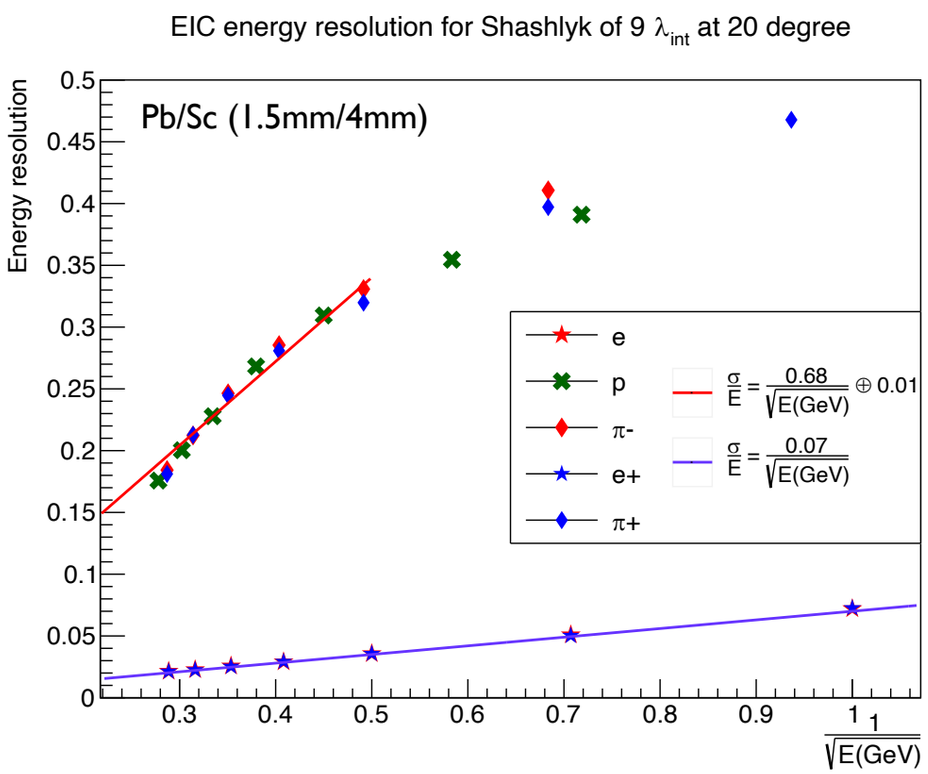
- ZEUS are experimental results
- eRD1 – GEANT4 with physics list validated for LHC.
- Validation of MC can be done only using experimental data form detector with correct chemical composition.

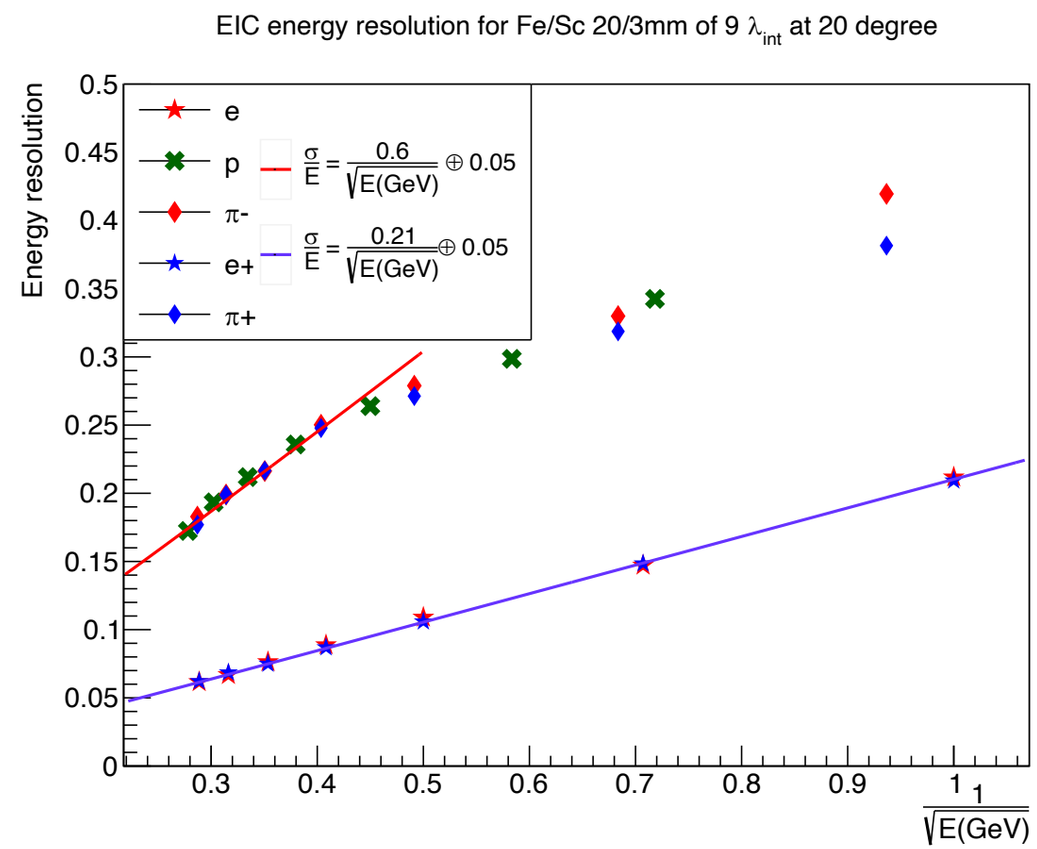


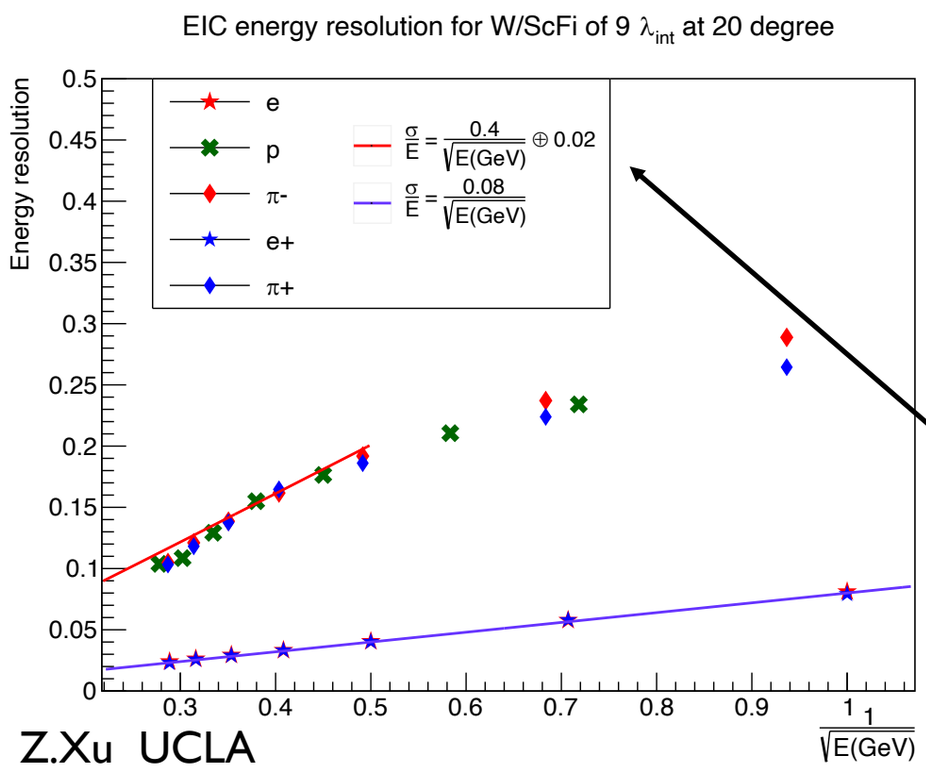
Inclusive, 18 GeV x 275 GeV

Z.Xu UCLA

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







Z.Xu UCLA

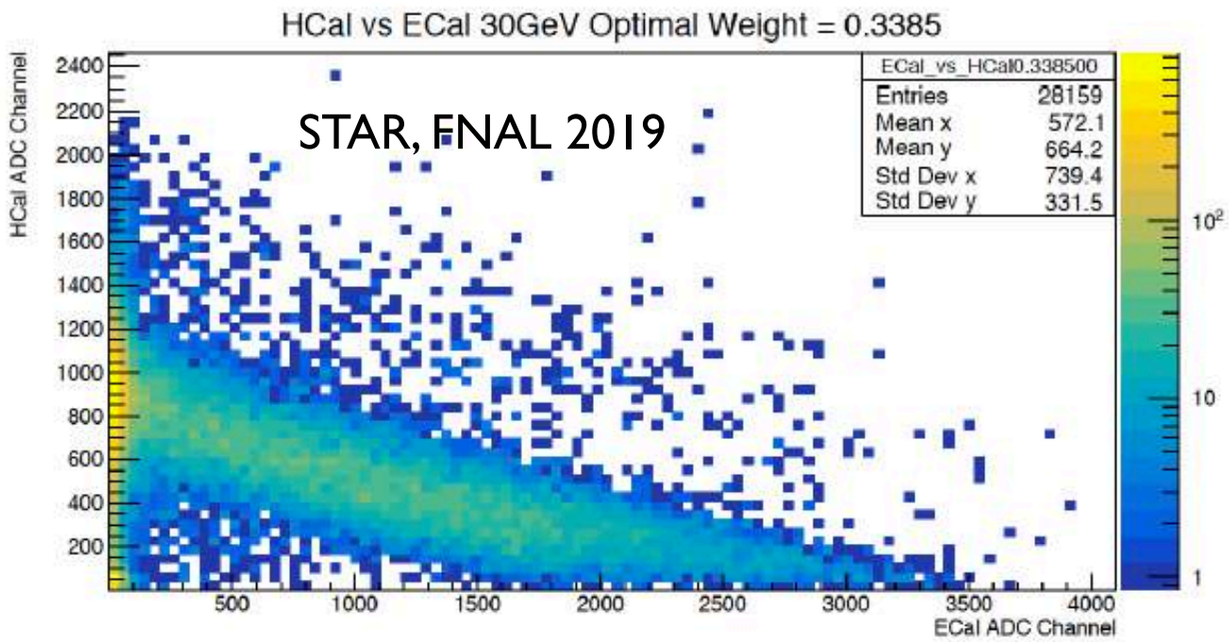
Hypothetical variant, 9 interaction lengths long calorimeters. Same structure for Ecal and Hcal sections. Three different technologies:

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

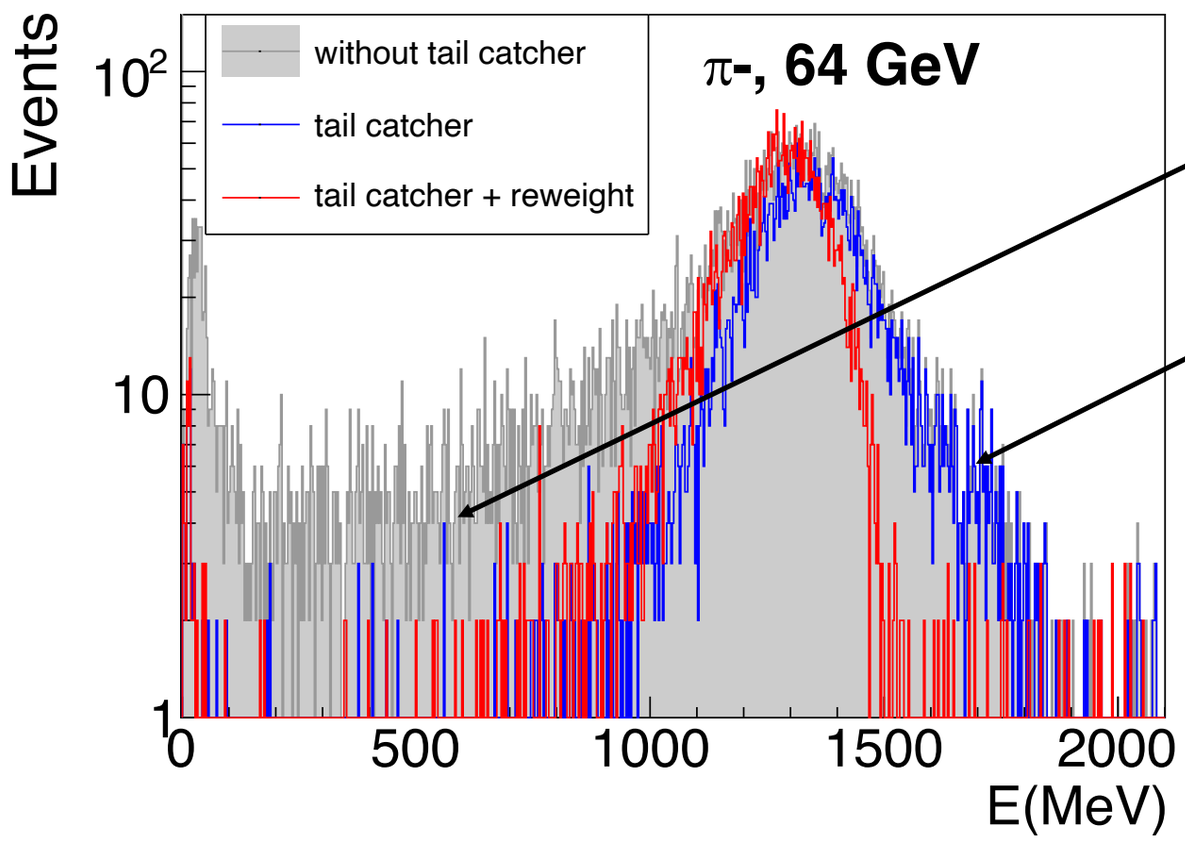
Proper detector composition required for good hadronic resolution. I.e. desired to keep e/h as close as practically possible to 1.

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

Realistic Configurations, i.e. binary systems Em + HAD.



- E_t= w*E_em+E_had
- Cut on tail catcher
- 'Shower Shape'
- Re-weighting Hcal towers. $E'_i = E(1 - \frac{C}{E_{tot}} E_i)$



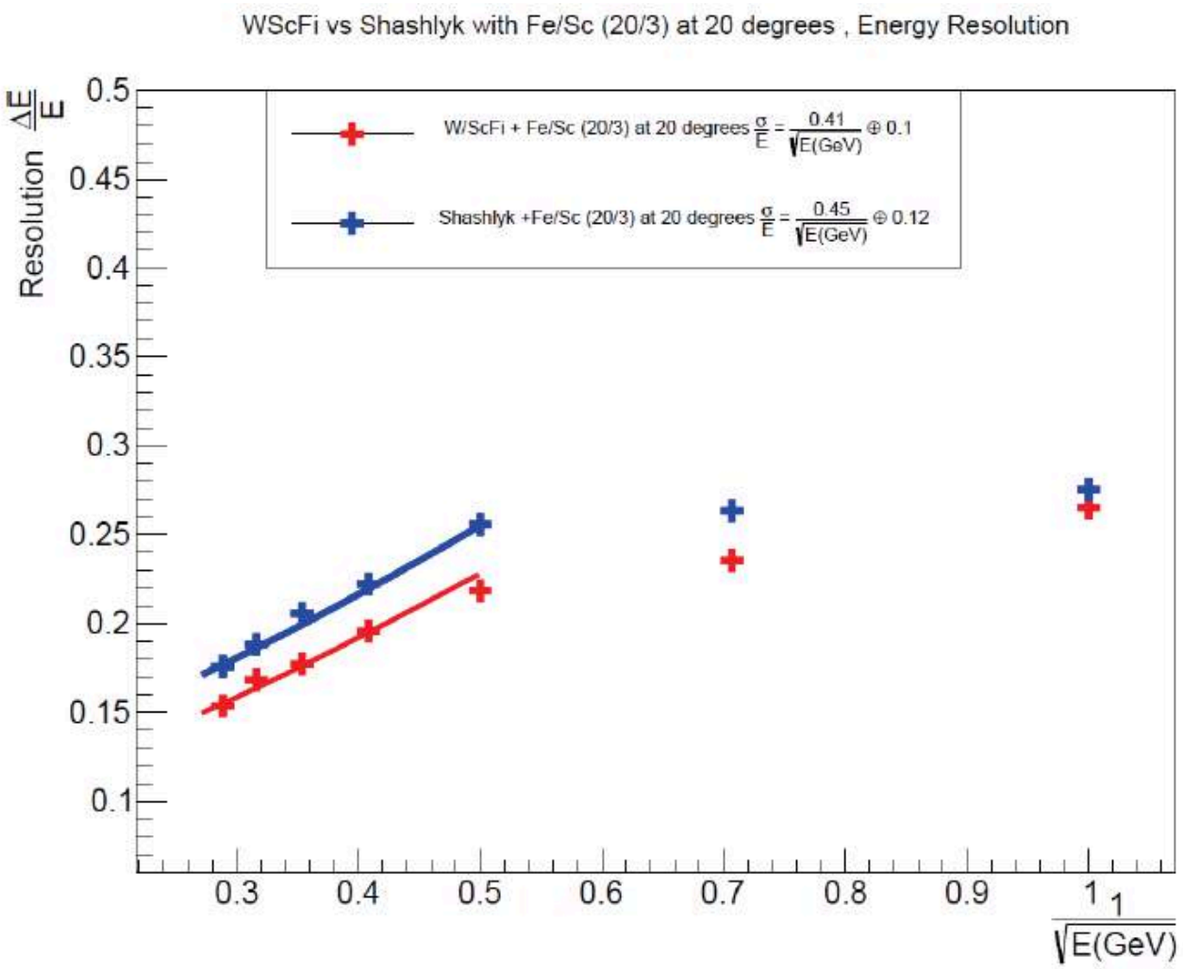
Tail catcher, handle to controls leakages.

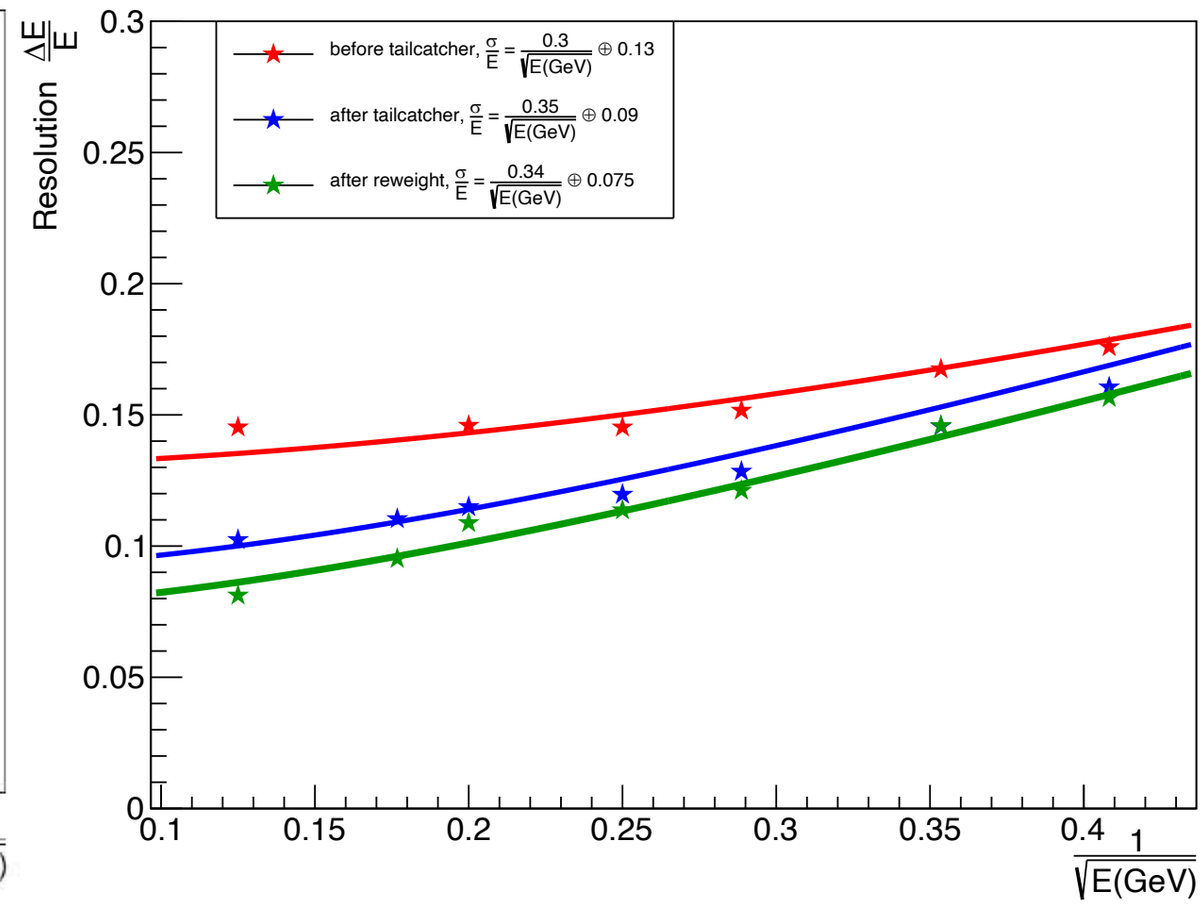
Re-weighting Hcal towers helps to deal with abnormally high f_{em} events.

Z.Xu UCLA

WScFi, ECAl

Cut on tail catcher + re-weighting Hcal towers





Z.Xu (UCLA)

At lower energies (EndCap eta range 1- 2) stochastic term almost always will dominate.

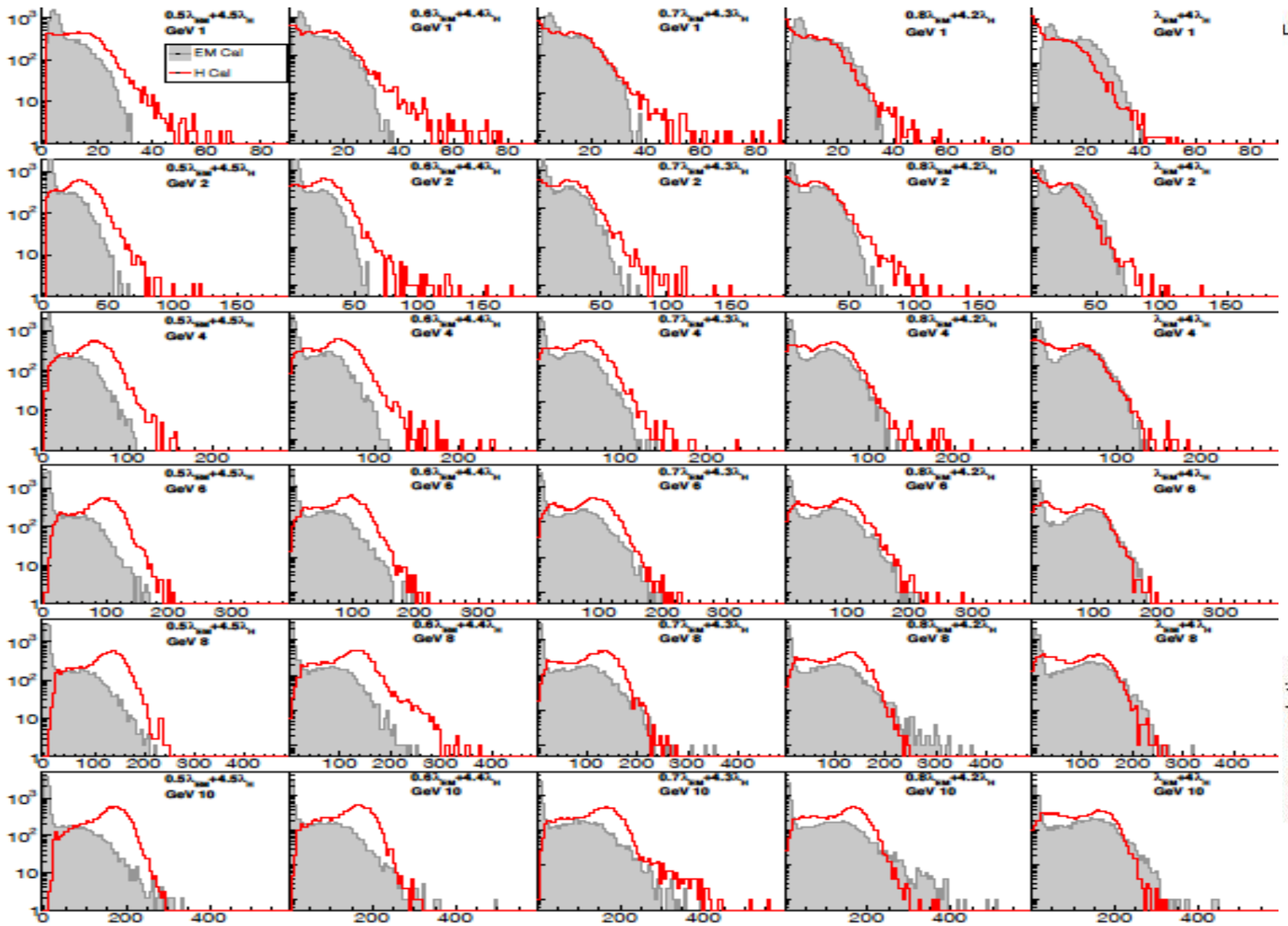
N.B. no cuts on tail-catcher or re-weighting was applied here.

WScFI 23 X0 vs SHASHLYK 18X0
(both depth and better e/h plays role)

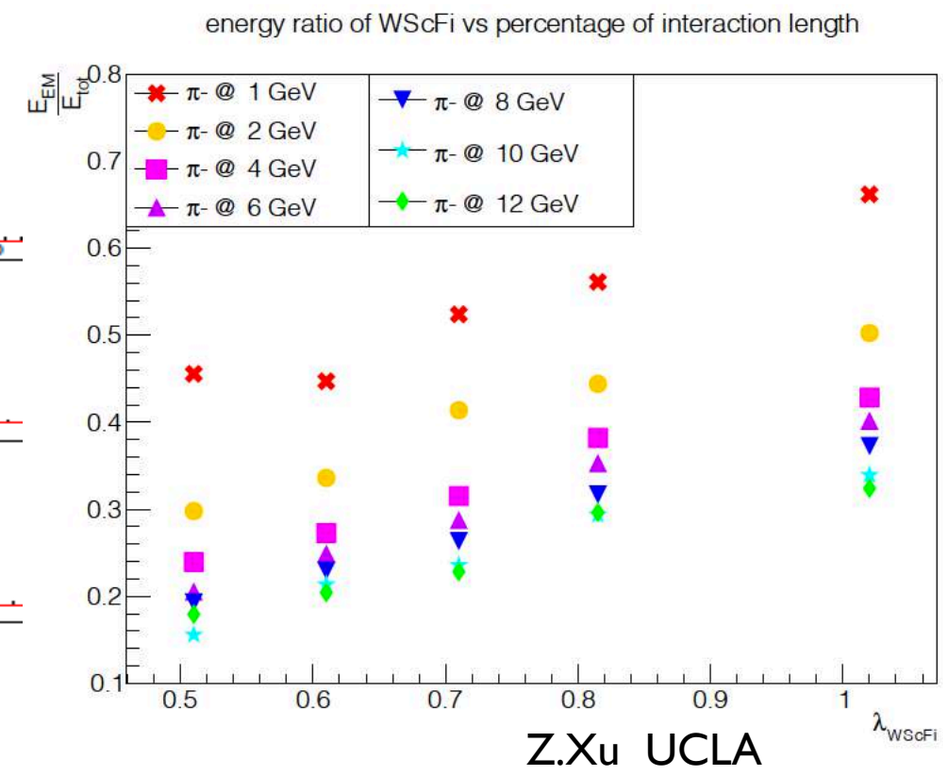
At higher energies (EndCap eta range 2- 3) constant term start to dominate.

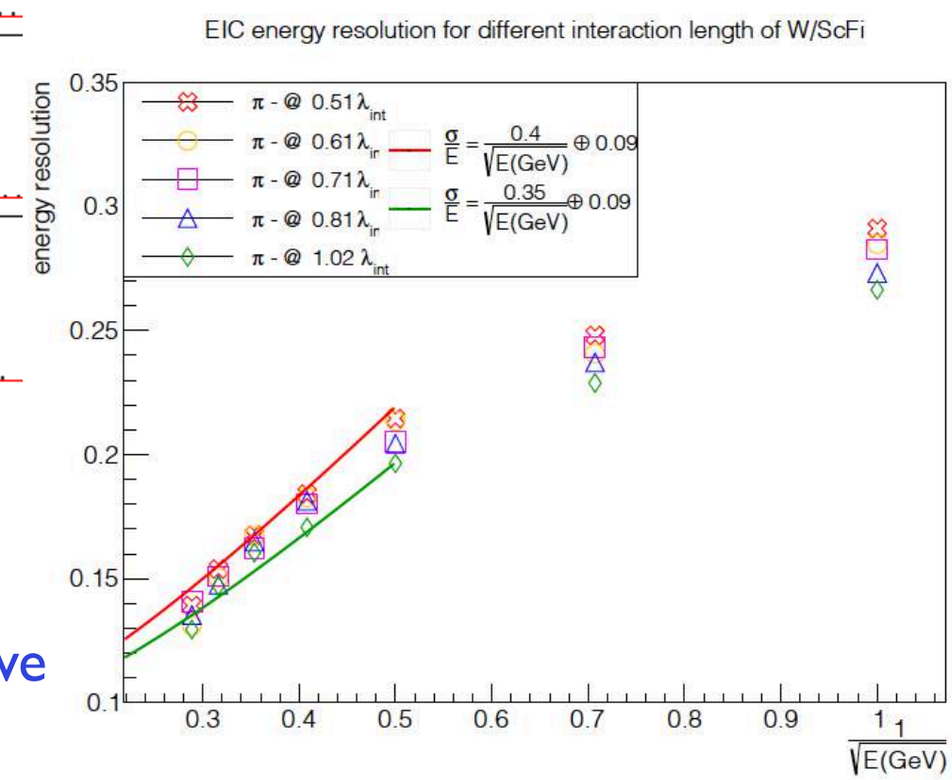
With cuts on tail-catcher and re-weighting subset of events can be measured quite well according to MC.

Does deeper Ecal helps to reconstruct low energy hadrons?



Increased depth of ECal



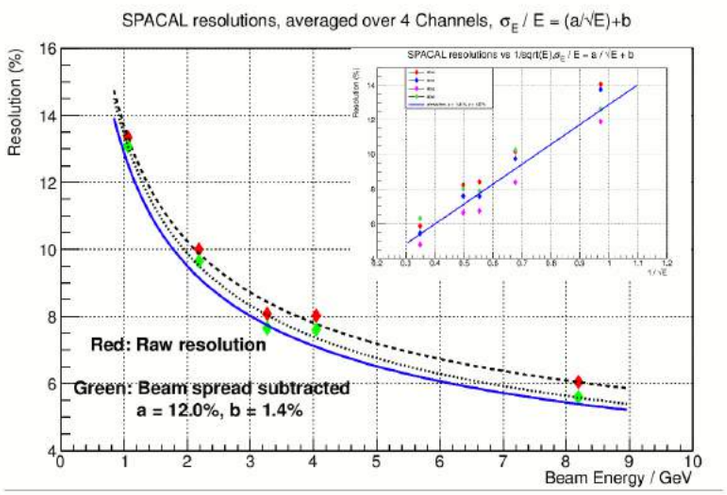


Increased depth of Ecal does help a bit to improve energy resolution of the system for low energy hadrons. Assuming we have good PID, additional e/h (TRD etc.,) you can do that.

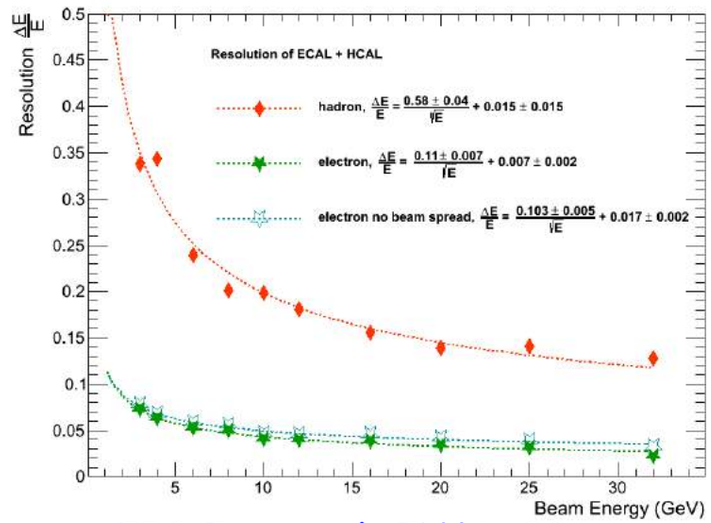
Reference EIC Hadron EndCap studies summary:

- There are some tricks which may help improve resolution of reference hadron endcap system, may be by 20%, without escalating the cost.
- It is little to no room to improve e/h for Fe/Sc section.
- WScFi, e/h good as it is (may be improved a little, but need experimental data).
- Tail catcher will allow to control leakages from the back. (Easy to integrate).
- Dead material between Ecal and Hcal is not an issue, because it is not needed.
- Different Instrumental effects, like light collection non-uniformities in hcal section has little effect on resolution, checked with gSTAR.
- With cut on tail catcher and re-weighting Hcal towers GEANT4 resolution looks very good with stochastic term at ~35% and constant term at ~7% (N.B. efficiency, fit).
- Need to think a bit more about increasing depth of Ecal – that may be important for Barrel, due to magnet coils between Ecal and Hcal.

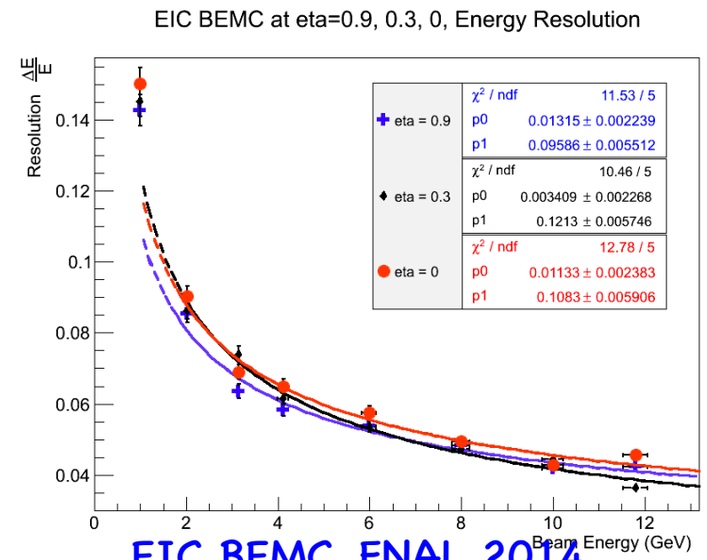
Transition to targeted R&D…



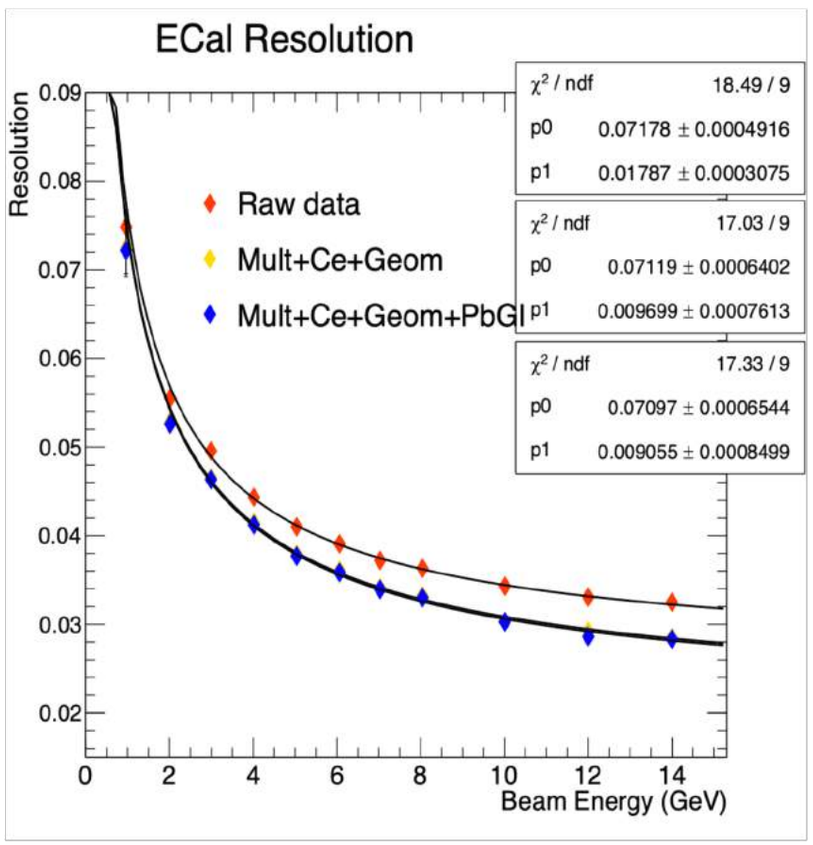
Proof of principle. FNAL 2012



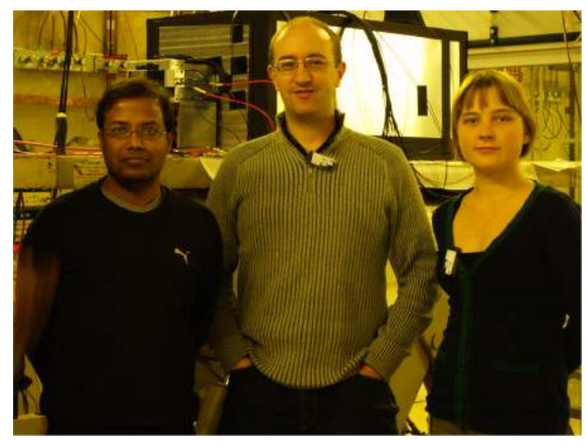
EIC Forward, FNAL 2014

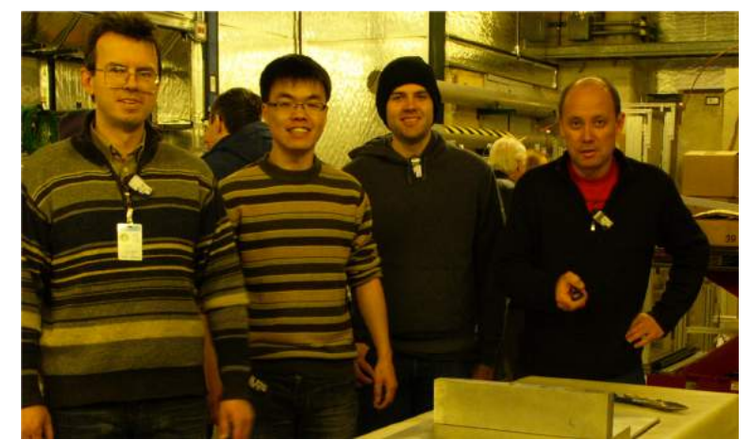


EIC BEMC, FNAL 2014



EIC Forward, FNAL 2016



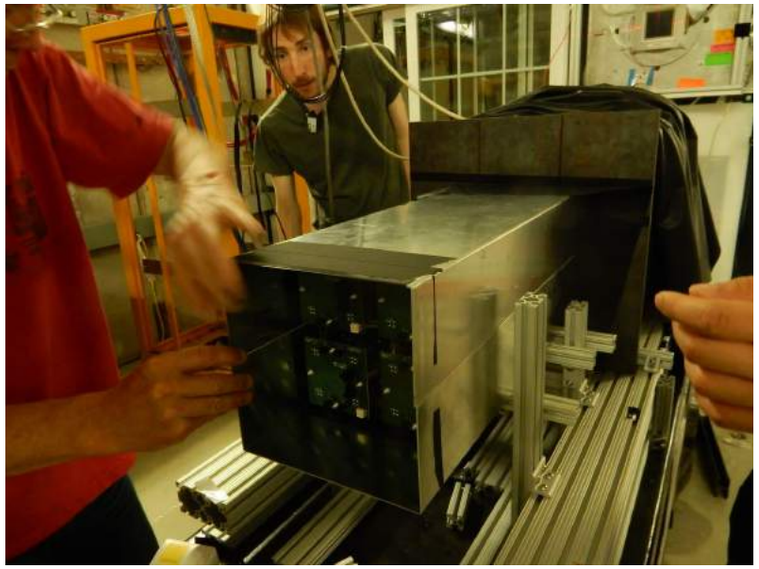


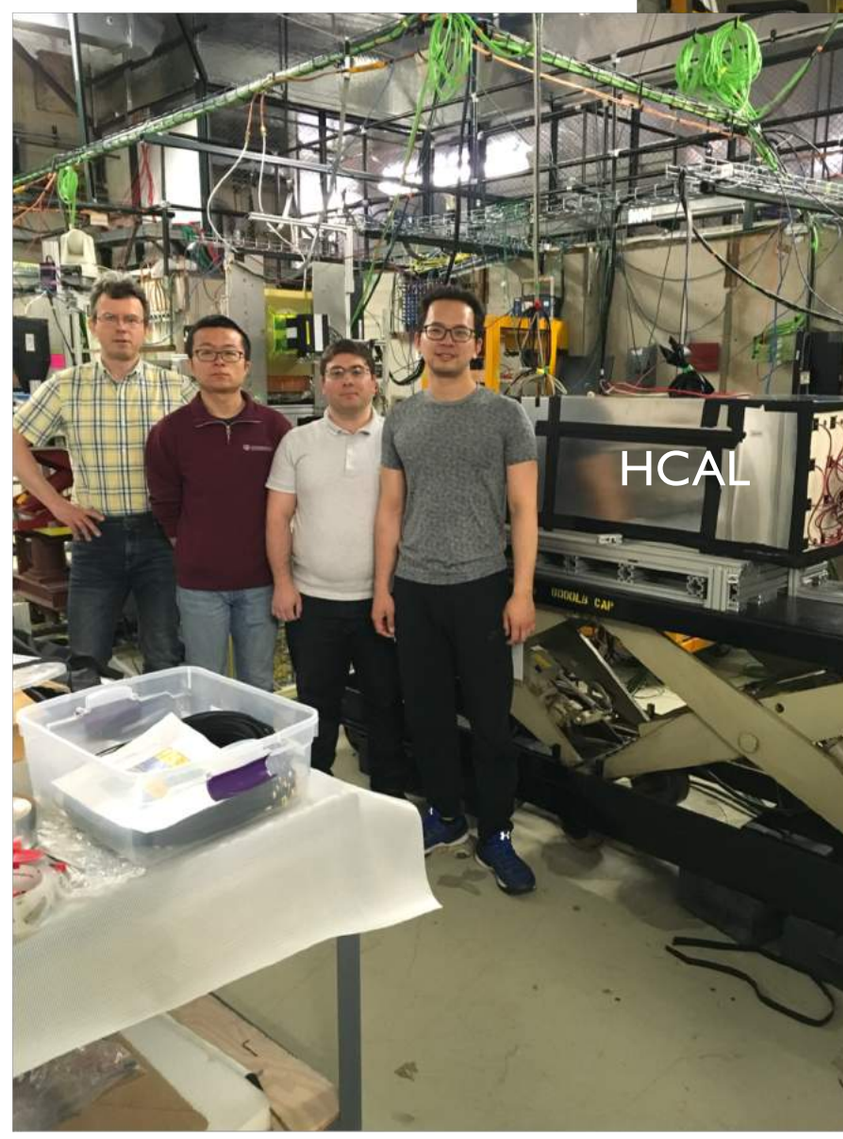
Test Runs 2012 -2016

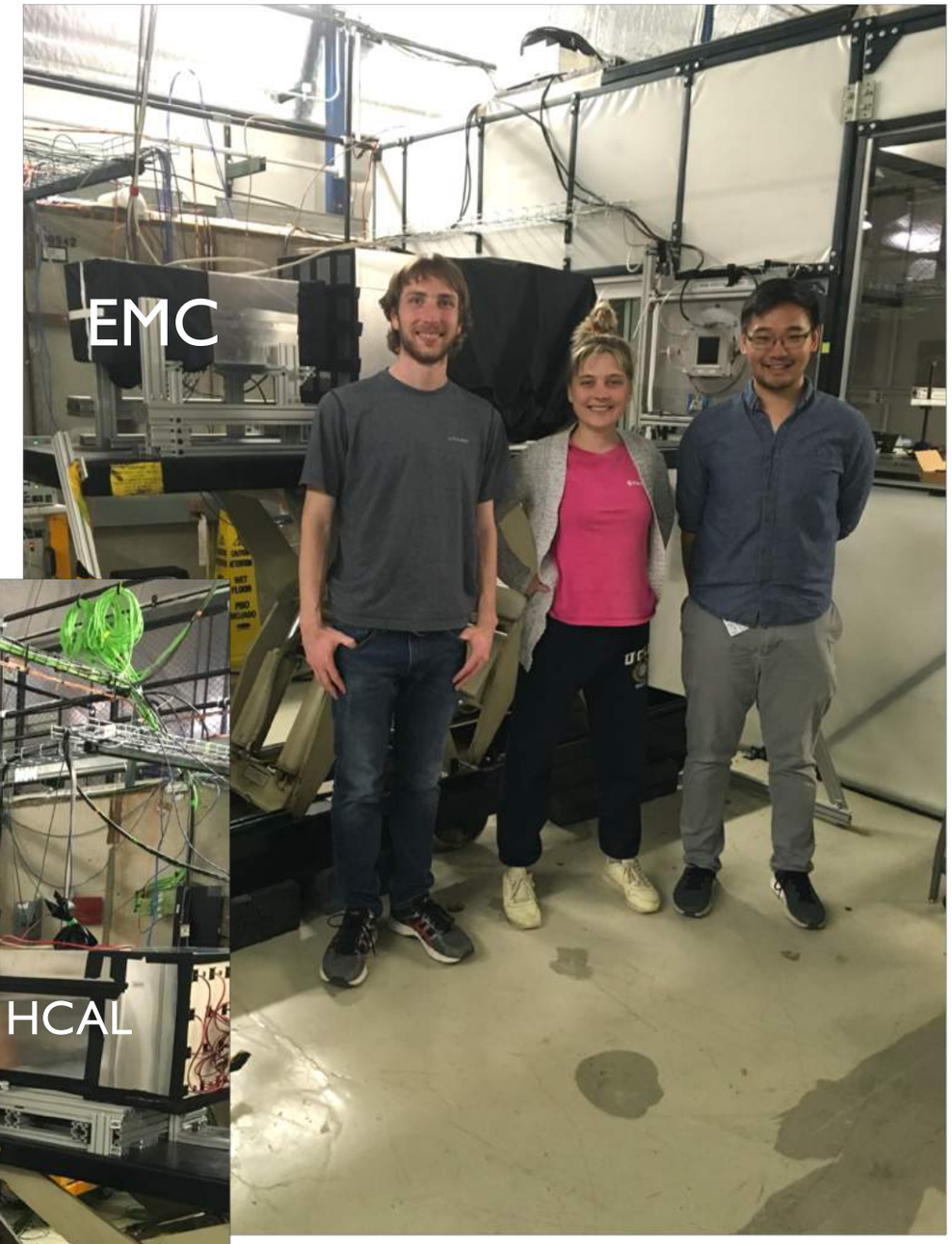
STAR Forward Calorimeter

FNAL Test Beam, 2019

4x4 Ecal, 4x4 HCal







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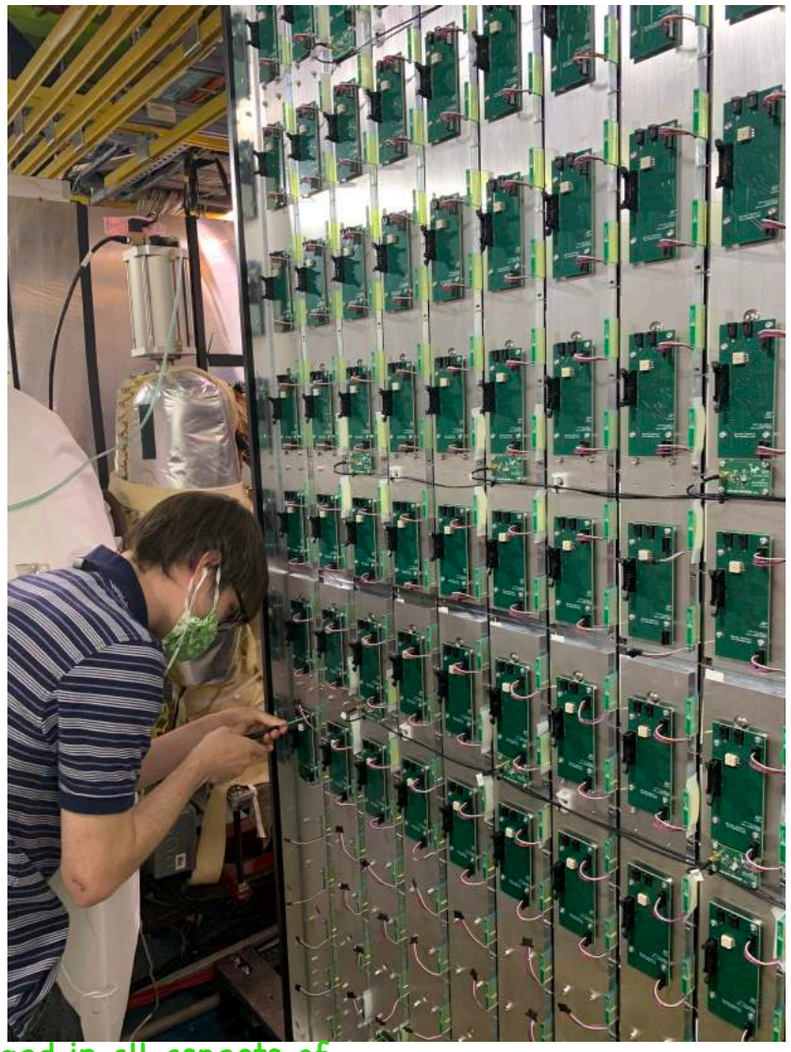
G. Visser (IUCF)
O. Tsai (UCLA)

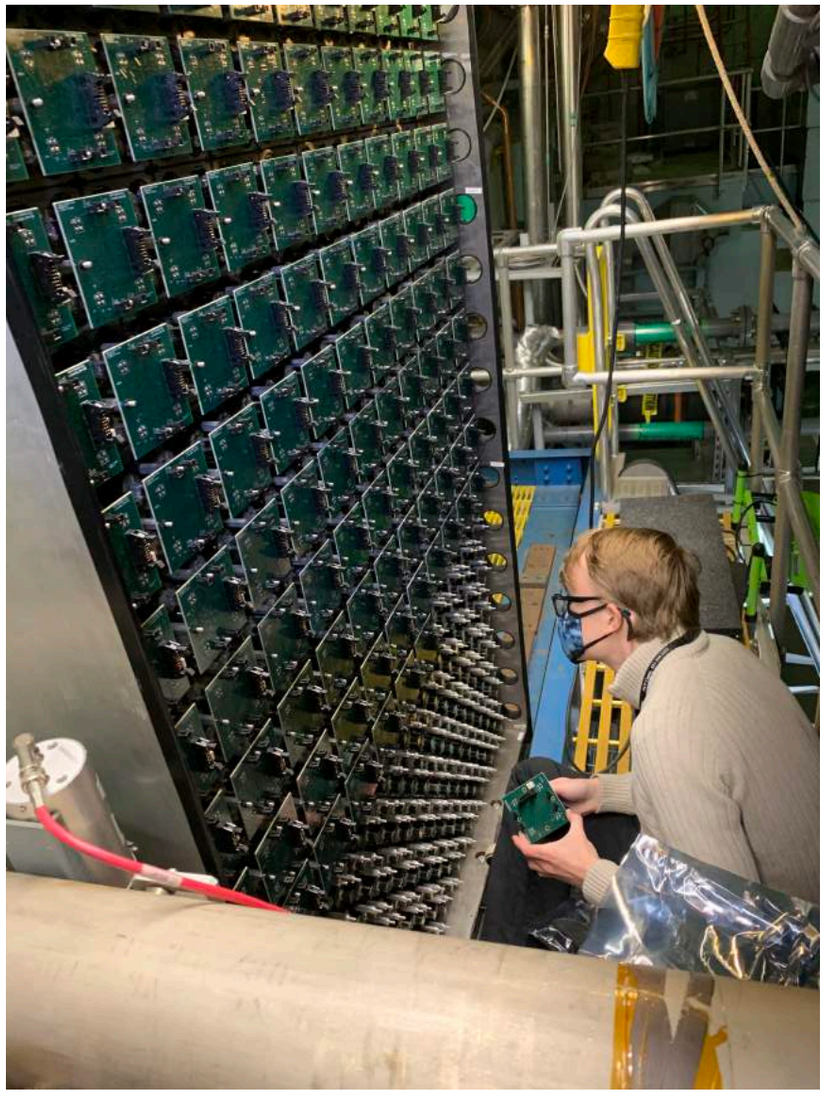
D. Neff (UCLA)
M.Sergeeva (UCLA)
B. Chan (UCLA)

STAR Forward Calorimeter System (FCS), 2020

Forward Calorimeter System (FCS)

- ECal – 1496 channels ~ 8 tons
- HCal – 520 channels ~ 30 tons.
- SiPM Readout Bias ~ 67V
- New digitizers + Trigger FPGA = DEP boards





STAR Collaborators,
Members of UC EIC Consortia
Assembling FCS in Dec. 2020, BNL

Large group of STAR collaborators actively engaged in all aspects of the project: ACU, BNL, UCLA, UCR, Indiana University CEEM, UKU, OSU, Rutgers U., Temple U., Texas A&M U., Valparaiso U.

Very efficient construction method.

HCal was assembled in tight place during COVID in just 20 days!

From generic R&D and YR to targeted R&D.

- Technologies for WScFi and Fe/Sc (construction method) are well established and spread in community (STAR and sPHENIX). Developed during generic EIC detector R&D.

- Performance of reference detector Hadron EndCap is very good on paper. Well exceed requirements of YR.

What we need to do before CD2 (Jan. 2023)?

- A full scale prototype WScFi + Fe/Sc with transverse size 0.6m x 0.6m, with integrated tail catcher for hadron endcap.
  a) HCAL part is IP independent.
  b) HCAL part is endcap independent (e or h side)
- A test beam or two (FTBF at FNAL may be OK, BNL A2 will be nice to revive)

Timescale is doable. Construction of prototype will take 1 or 1.5 years, cost ~ $300k
There are few small R&D topics which has to be finished (light collection efficiency and such) these are already funded by EIC generic detector R&D (Funds for FY2020 have not been received yet).

Thanks!

Backup Slides

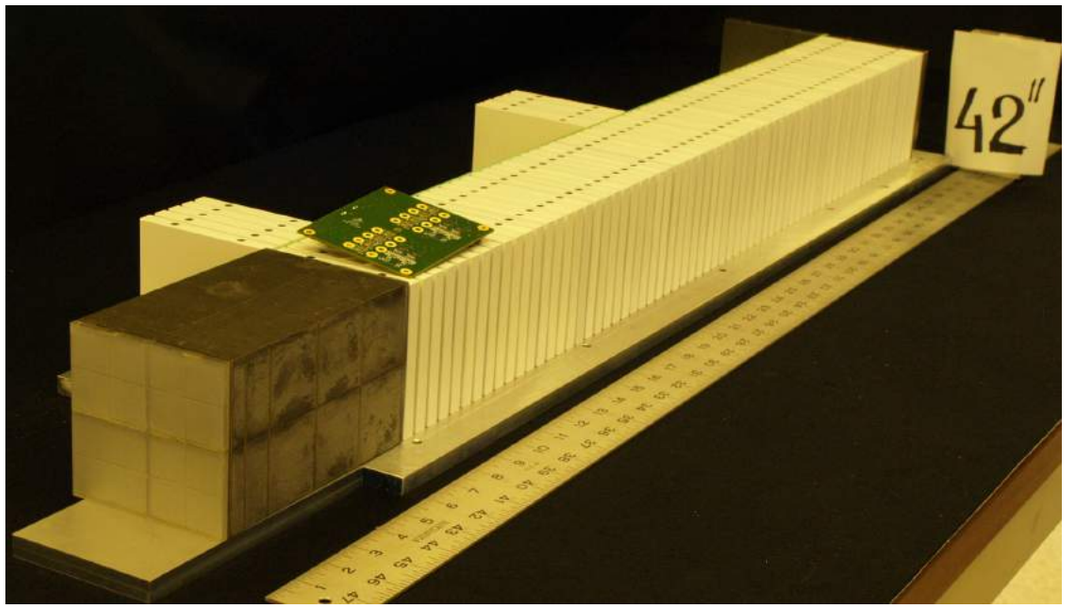
BNL Newsroom
https://www.bnl.gov/newsroom/news.php?a=217681

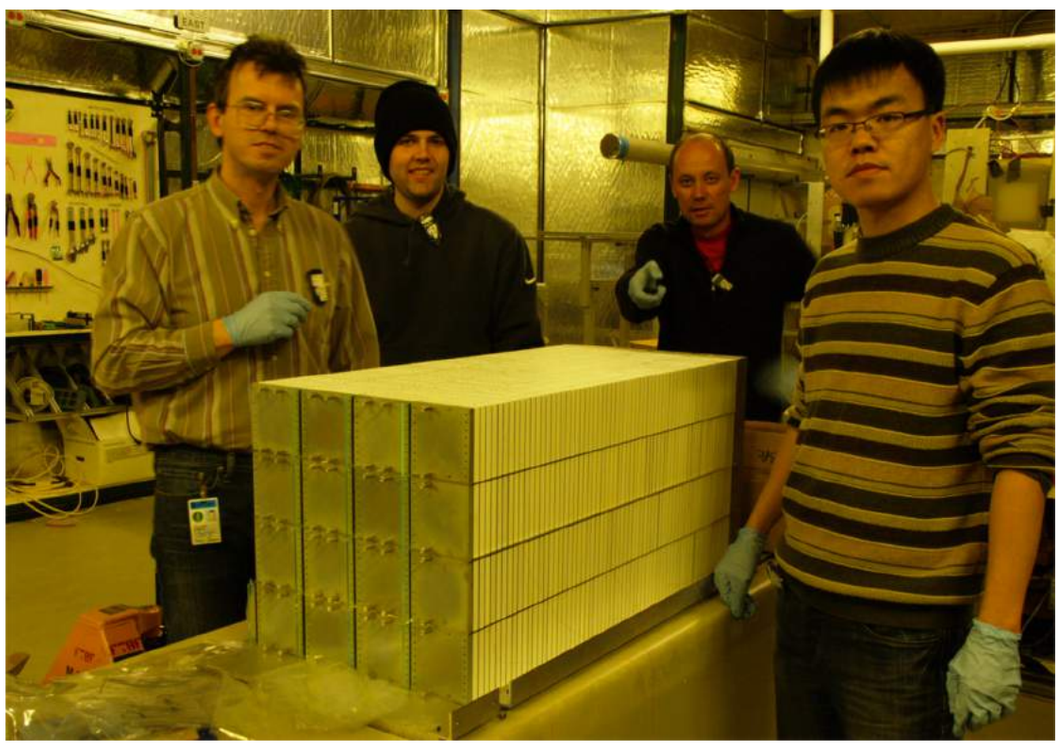
FCS Successful Construction Project.

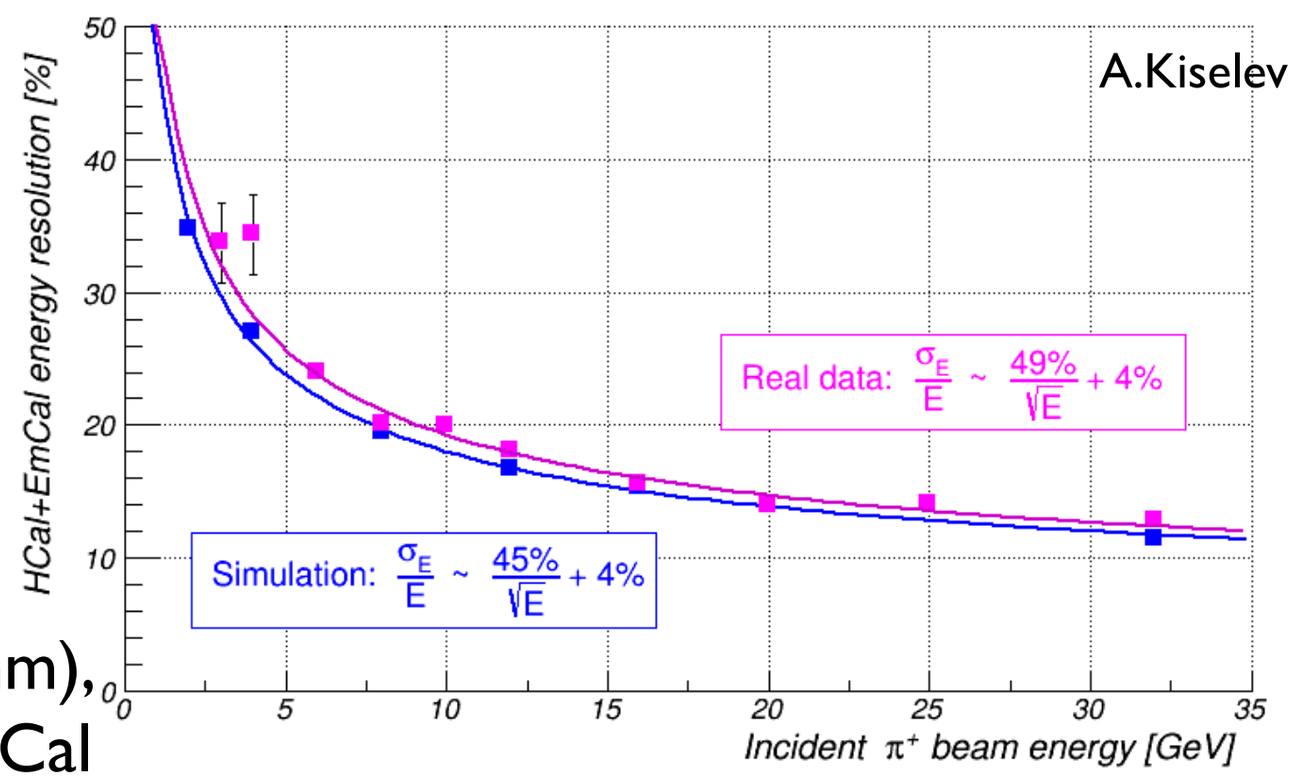
- Performance
- Cost
- Space
- Workforce
- Ability to stage construction and installation by design

Large group of STAR collaborators actively engaged in all aspects of the project: ACU, BNL, UCLA, UCR, Indiana University CEEM, UKU, OSU, Rutgers U., Temple U., Texas A&M U., Valparaiso U.

Assembling HCal Onsite. Feb 26, 2014. FNAL







23X0 WScFi + 63 layers Pb/Sc (10/2.5mm),
5cm Thick Fe plate between Ecal and HCal

Assesment eRD1 (UCLA lead sub-projects):

- Experimental proof of feasibility of W/ScFi technology for very compact sampling electromagnetic calorimeters with energy resolutions varying from (7%-12%)/sqrt(E) for stochastic and (1-2)% for constant term. Several designs of prototype calorimeter utilizing the W/ScFi technology were built and tested with beams at FNAL during 2012-2016 period.

- Demonstration of new effective construction technology for sampling hadron calorimeters with good energy resolution. Two prototypes were built and tested at FNAL in 2014, 2019. A 30 ton HCal for the STAR Forward Calorimeter System was constructed in 2020 using this innovative technology.

- Multi-year studies of SiPM characteristics in beam conditions close to those expected at high luminosity EIC. Notably, during Run 2017 at RHIC with 500 GeV pp data, our observation led to new understanding of mechanism responsible for the degradation of SiPMs responses after exposure to neutrons and ionization particles.

- Development of compact readout schemes using SiPMs for W/ScFi and Shashlyk type calorimeters (e.g., the STAR Forward Calorimeter System using SHASHLYK EMCal ~ 1500 channels instrumented in 2020) and WLS/SiPM for HCals (STAR Forward HCal 520 channels).