Forward ECal Scintillation Fibers.

Oleg Tsai, UCLA/BNL

Scintillation Fibers Final Design Review

September 13, 2023

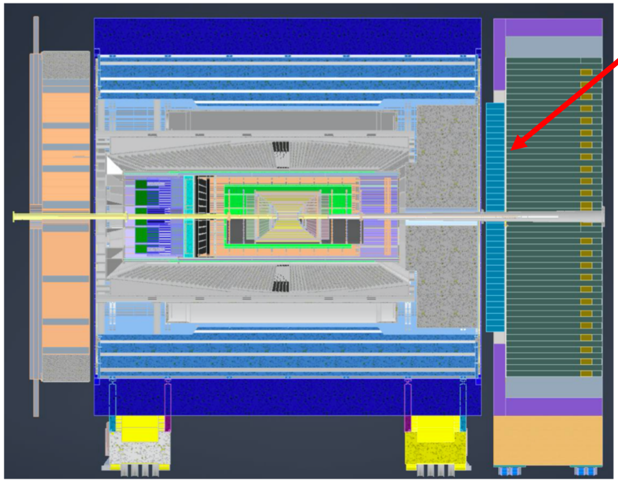
Electron-Ion Collider

BROOKHAVEN NATIONAL LABORATORY
Jefferson Lab
U.S. DEPARTMENT OF ENERGY | Office of Science

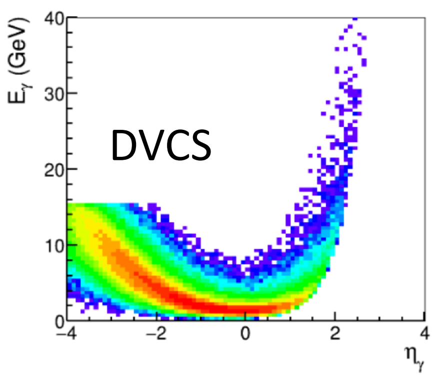
Outline

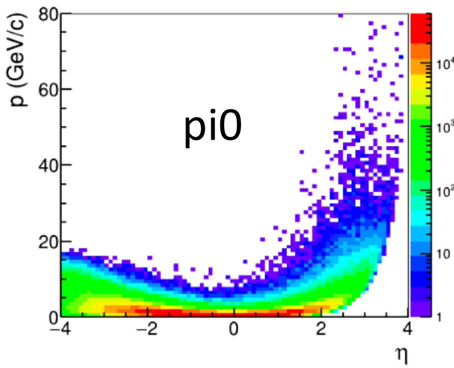
- High Level Summary of Scope.
- Basic fibers specs.
- Results from generic EIC R&D.
- Production plan and schedule.
- Fibers QA.
- Workforce.
- Summary.

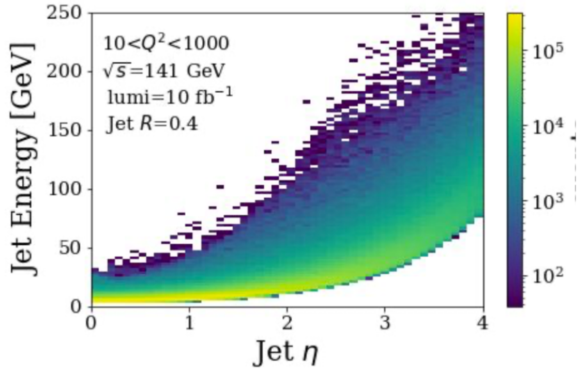
High Level Summary of Scope



- Forward ECal is part of a Hadron Endcap
- Covers pseudo rapidity range ~1.4 to 3.5 (R_{in} 30 cm, R_{out} 170 cm)*
- Integration length along Z - 30 cm
- Total weight ~ 18 tons
- Number of readout channels ~16k
- Photosensors - SiPMs



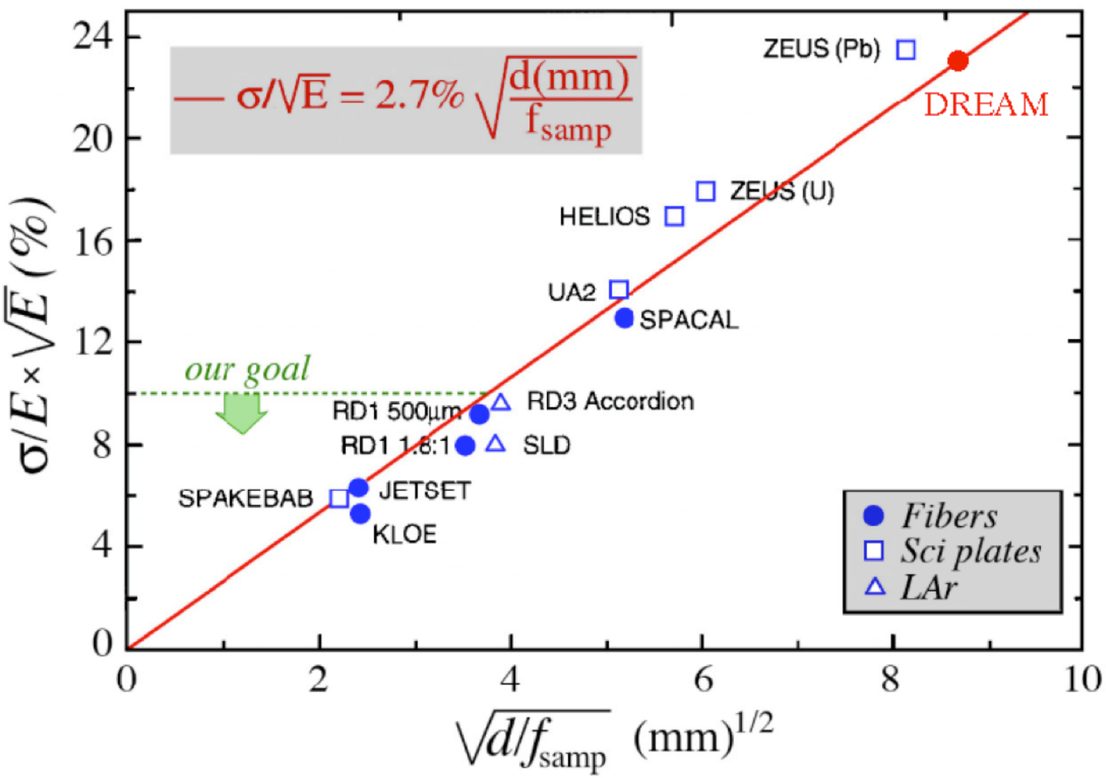




High Level Input

- Yellow Report – desired energy resolution 10%-12%/√(E) ⊕ 2%
- Yellow Report – good pi0/gamma discrimination up to ~ 50 GeV
- Optimal reconstruction of jets (ECal +Hcal (+ tracker)) (e/h ~1)
- Readout must work in magnetic field, neutron fluxes up to 10^{11} n/cm^2.
- ECal must fit in limited space. (Small X_0)

Energy resolution and compensation



1. Compensation requires small sampling fraction ~ 2 %

2. Small fiber diameter and high sampling frequency required to satisfy energy resolution from YR.

- Both fiber diameter and spacing were tuned to properties of absorber, which is mixture of W powder and epoxy to satisfy (1+2).

- Parameters were fixed since 2012 and as such been used for numerous EIC/STAR prototypes and sPHENIX barrel ECal (~25k towers)

• *EM production blocks 2012.*

Parameters:

Final Density - 10.17 g/cm³,

X_0 ~ 7 mm, R_m ~ 2.3 cm,

S_f -2% (electrons), e/h~1

Sc. Fibers -SCSF78 Ø 0.47 mm

Spacing 1 mm center-to-center.

Production Block 2x2 towers.

Details:

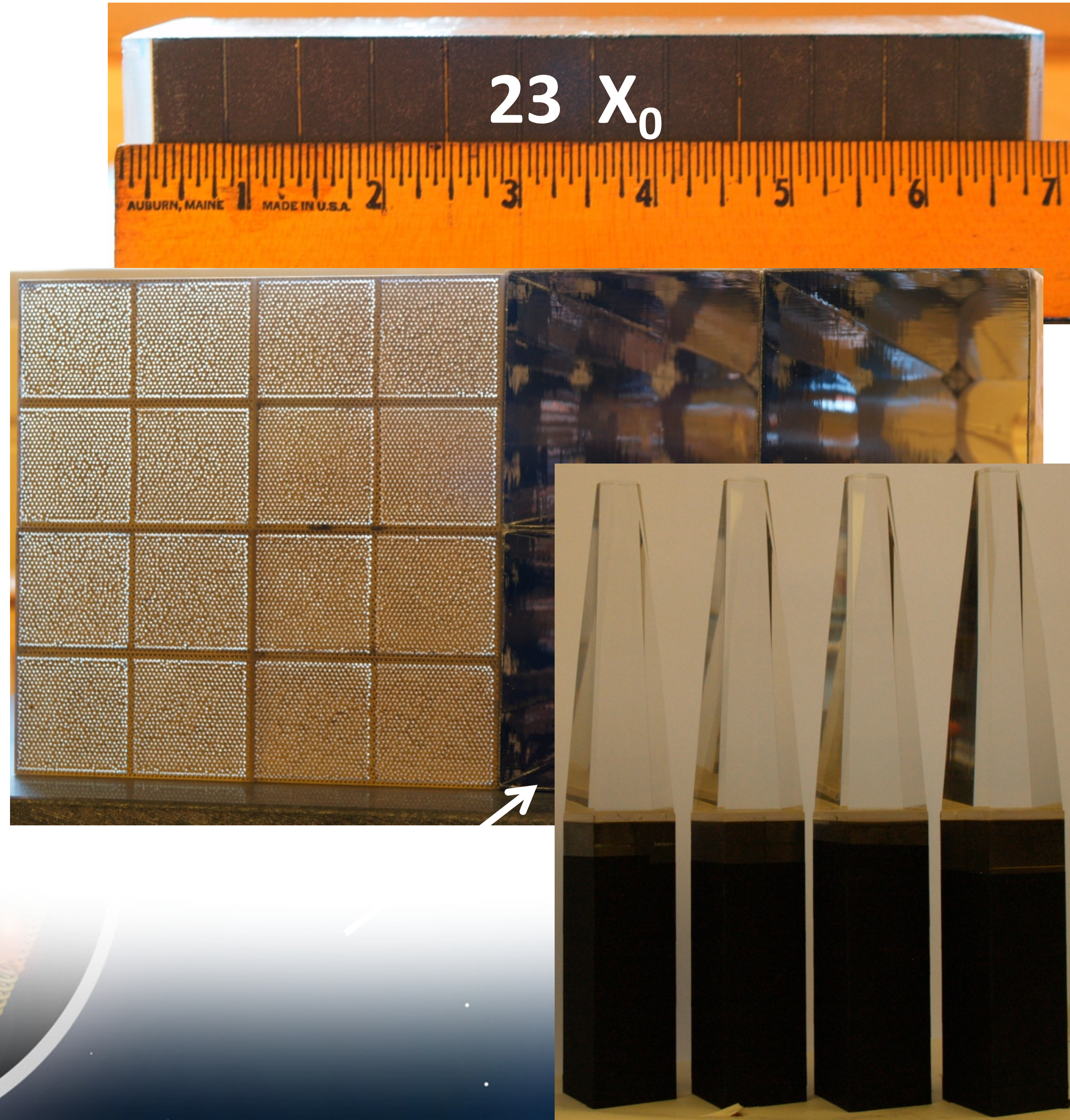
Dimensions 16.6 × 5.33 ×5.33 cm³

Weight of supermodules (4567, 4651, 4627,4630 g.)

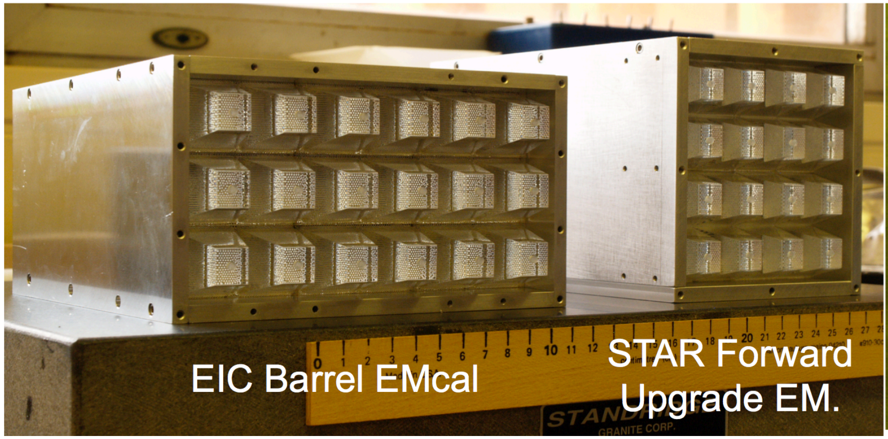
Number of fibers -3120

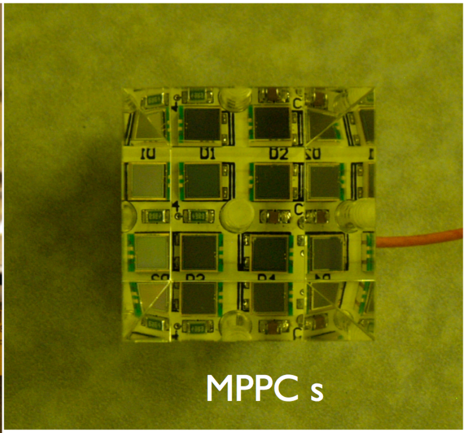
Resolution ~12%/√E

Compact, compensated good energy resolution as required for EIC in YR.

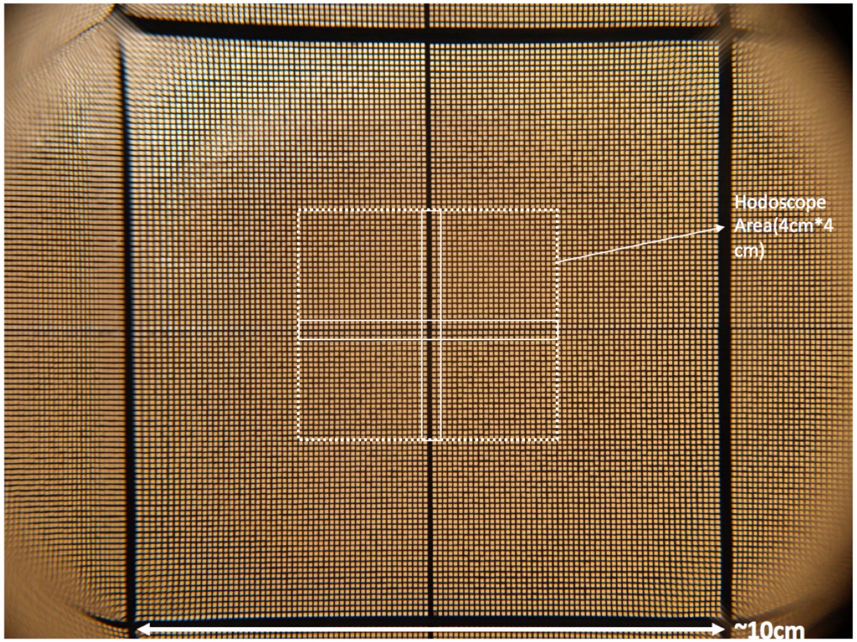


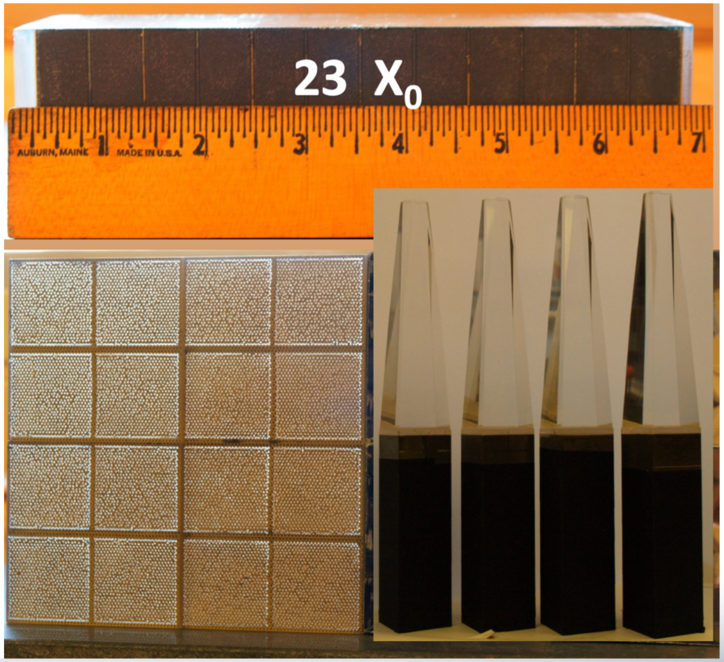
Highlights from generic EIC R&D.





Different WScFi prototypes were tested at FNAL from 2012-2016.

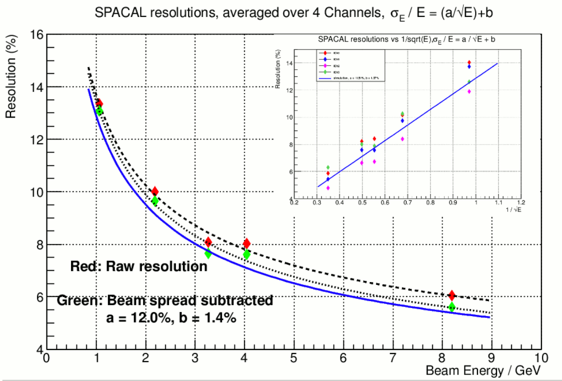




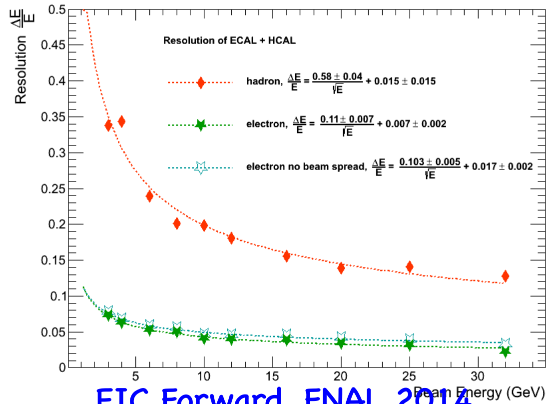
CALOR 2012, J.Phys.: Conf. Ser. 404 012023
CALOR 2014, J. Phys.: Conf. Ser. 587 012053

Highlights from generic EIC R&D.

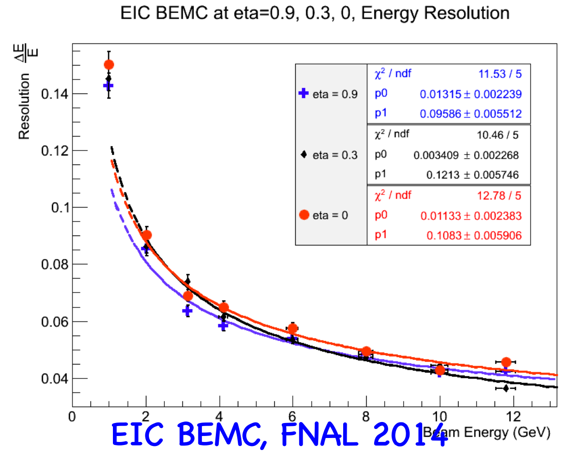
All EIC ECal prototypes meet YR requirements



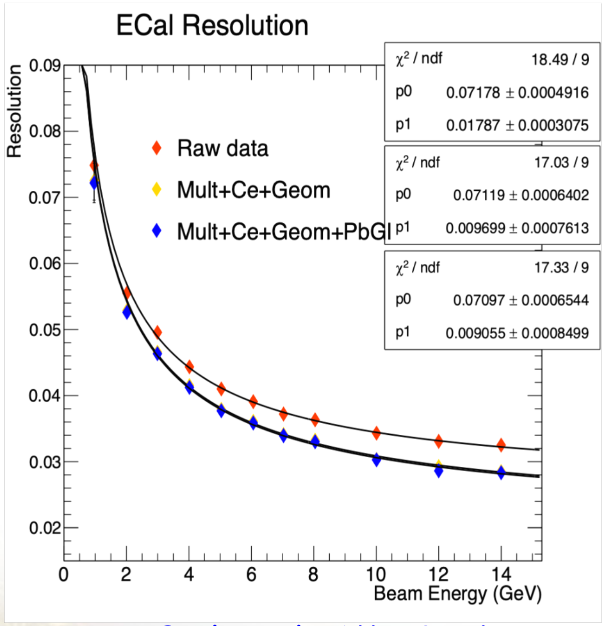
Proof of principle, FNAL 2012



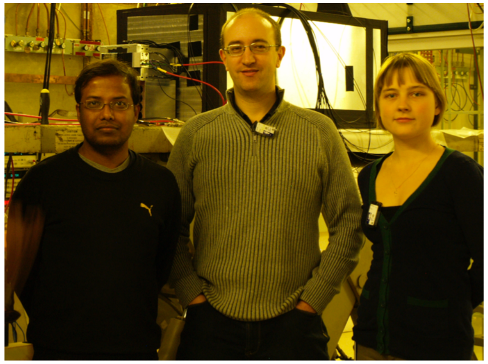
EIC Forward, FNAL 2014

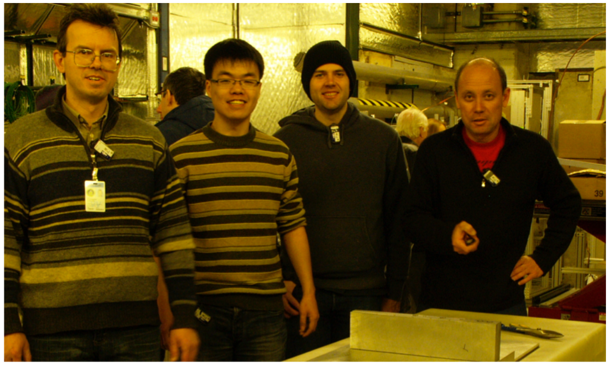


EIC BEMC, FNAL 2014



EIC Backward, FNAL 2016





Test Runs 2012 -2016

Scintillating Fibers. Light Yield specs.

Yellow Report requirement – fECal energy range 0.1 GeV – 100 GeV ->

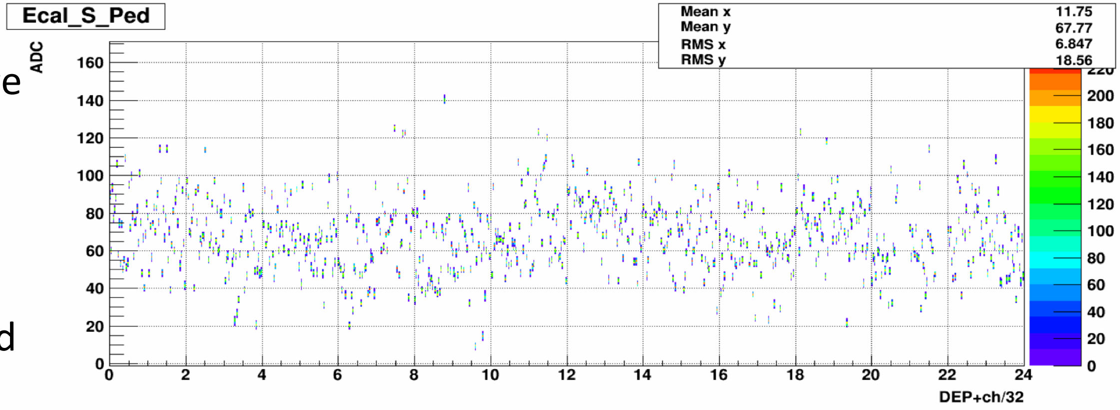
min energy in a single tower 15 MeV ->

noise due to degradation of SiPMs should be ~5 MeV (3 sigma below min energy) ->

require sufficient light yield > 1000 p.e../ GeV ->

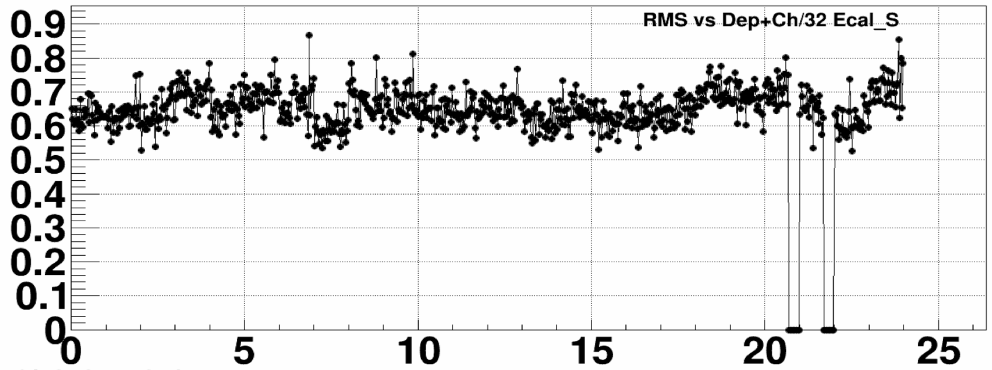
required light yield from fibers ~ 8000 photons/MeV

Projections for 10 ^{11} n/cm^2 exposure.
Dark current ~ 14 uA/ mm^2 @ 2V overvoltage
(as measured at STAR FCS)



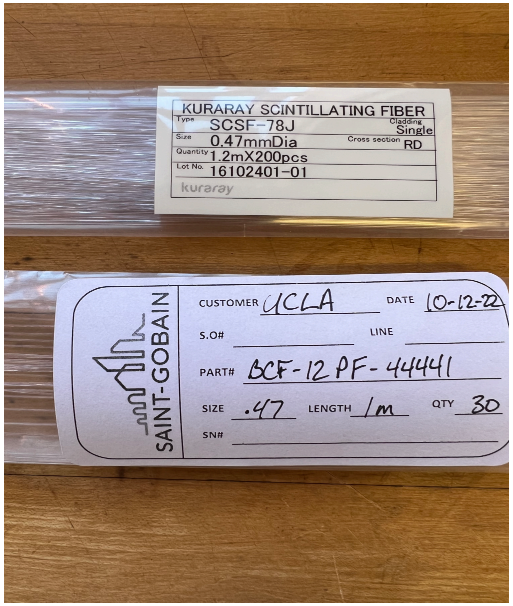
Two effects:

1. Noise
2. Degradation of response due to localized heating of avalanche region (dark current)



fECal expected highest noise ~6 MeV (requirements on min. energy 15 MeV).
Scaled from FCS operated in similar conditions to fECal and close LY.

Scintillating Fibers. Potential vendors.

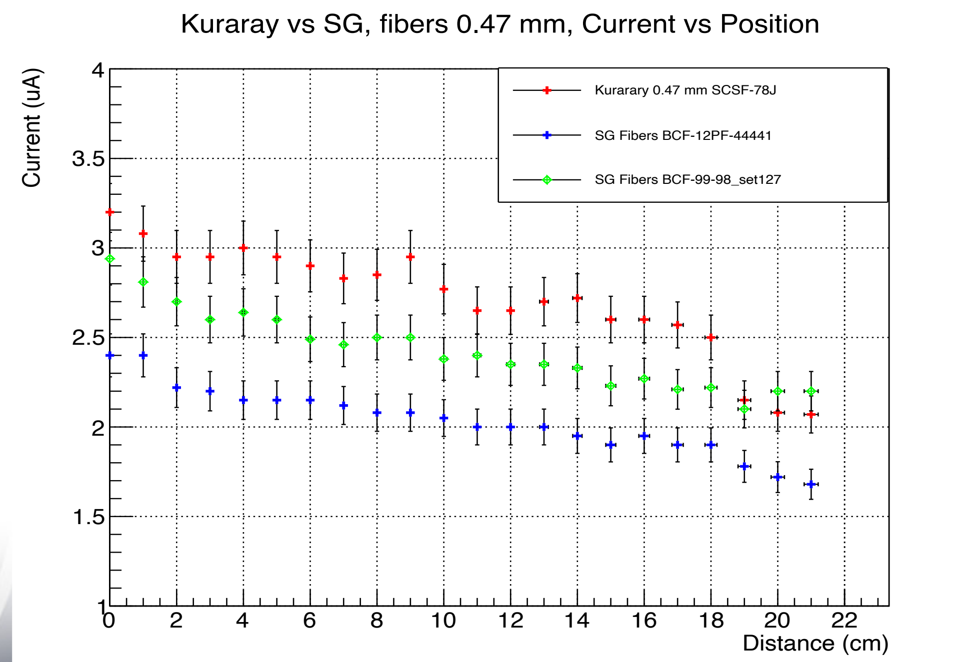


Extensive communications with KURARAY and SAINT-GOBAIN (now it is SGC/Luxium Solutions) since 2012.

Both companies are very interested to bid on fibers. (Production of 0.47 mm fibers poses no problem for either of them)

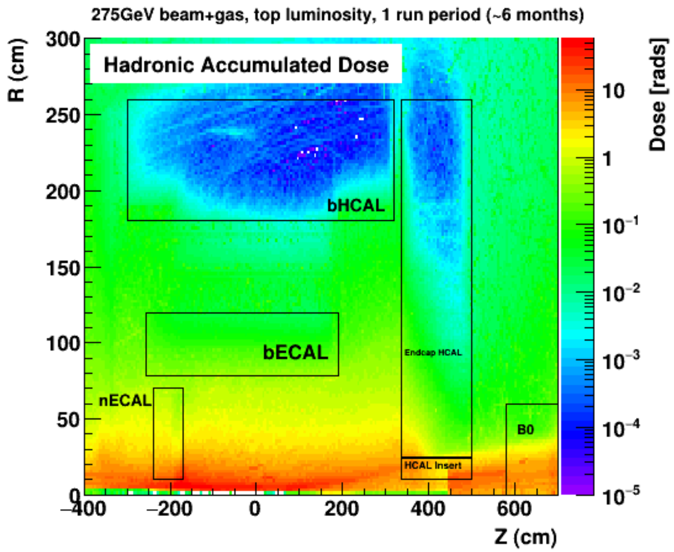
SG was notified (a year and half ago) that LY from their fibers is about 30% lower than KURARAY (~ 10000 photons/MeV).

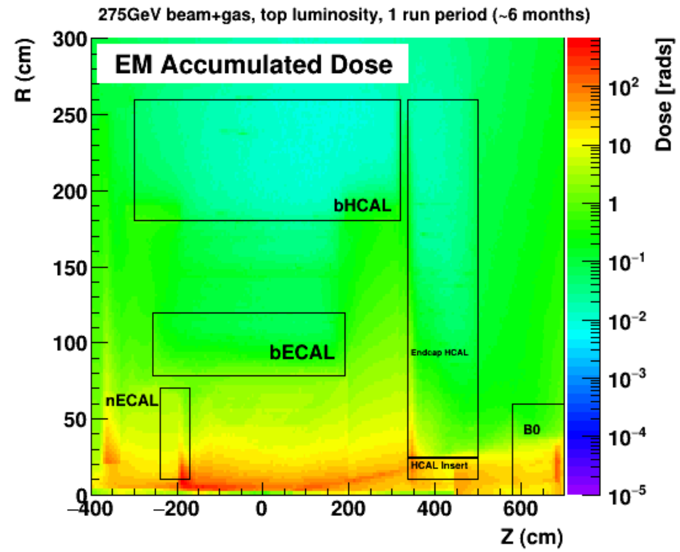
- Luxium (SG) worked on improved version of Sc fibers for EIC (same raw components, not to trigger irradiation tests)
- Second test batch from Luxium shows LY close to KURARY



- EIC prototypes built with both Kurarary and Bicron fibers.
- sPHENIX used Saint Gobain (Bicron, now Luxium) fibers

Scintillating Fibers. Radiation damages.



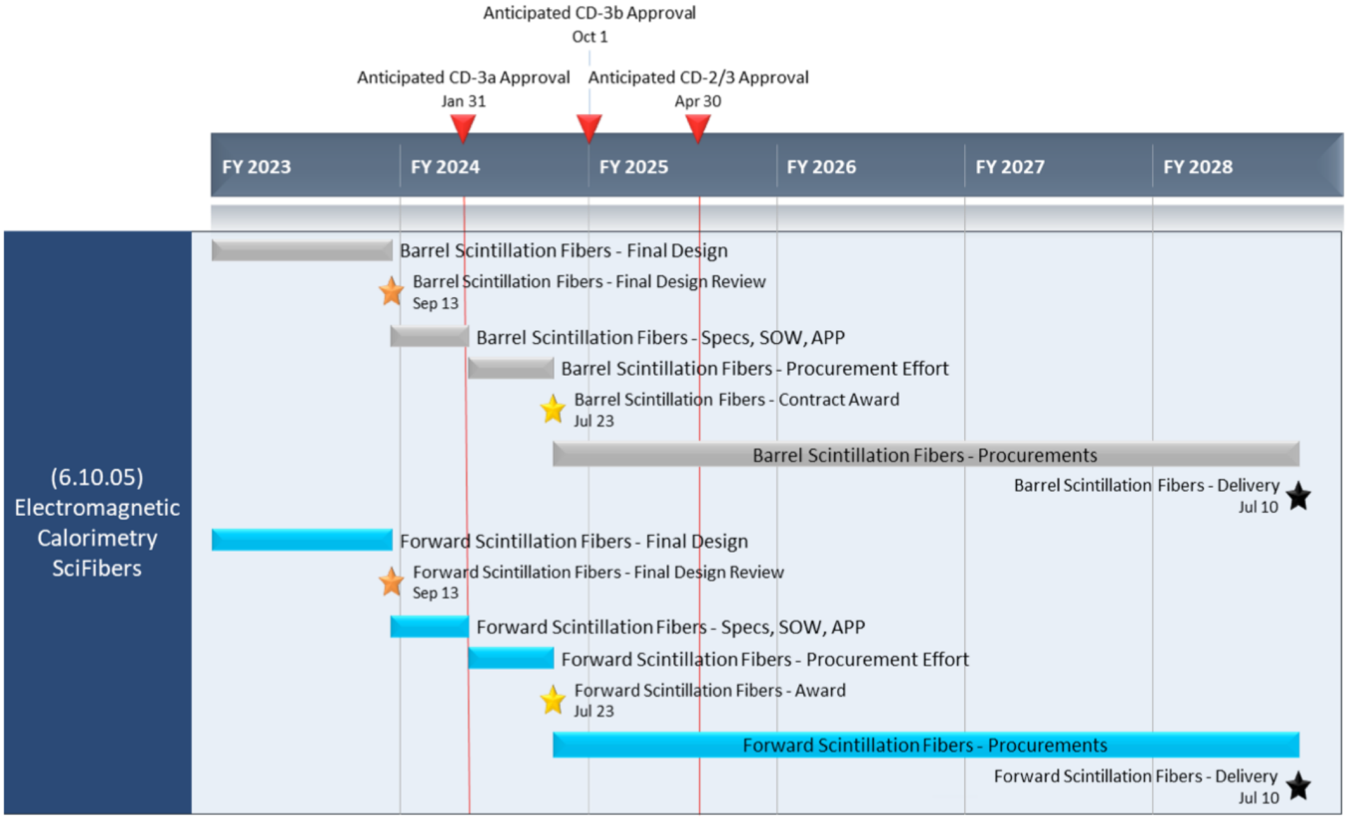


Divide by 100
To account for
sc. fibers
sampling
fraction

- Accumulated dose in fECal fibers is < hundred of Rads in 10 years.
- Degradation of transparency of polystyrene base or degradation of fluors is not a concern.
- Similar fibers were/are in use in experiments with ~five orders of magnitude higher doses (LHCb tracker).
- Because we have no concerns and since vendors in any case have no ability to perform irradiation tests and measurements we did not list radiation hardness as a requirement for fECAl.

K. Hara et al. Radiation hardness and mechanical durability of kuraray optical fibers NIM A411 (1998) 31

Production Plan



- Rump up production – 6 month
- Production – 3 years
- Installation 6 months

Enough schedule float.

Specs finalized:	Now
Final Design Review:	Now
Contract award:	Summer 2024
Material delivery:	Summer 2024 – Summer 2028

Fibers QA

Assumptions. Vendor acquire raw materials (base, fluor, cladding) in sufficiently large quantities to produce a single batch of fibers. (i.e. same material and stable production conditions for a reasonably large batch, as a standard practice).

- Vendor assure attenuation length and diameter of fibers as specified.
- Vendor keeps record of used materials and production parameters.
- Vendor keeps witness samples of materials for each production batch.

Upon delivery of batch standard QA procedures on samples:

1. Visual inspection (cleanliness, damages during transportation/handling)
2. Diameter variations
3. Attenuation length (UV excitation)
4. Relative (to a reference sample) light yield (Sr90)

- Sampling frequency during production ramp-up ~ 20% of spools, later ~5%
- Acceptance of delivery in two-four weeks upon receiving shipment.
- Results of QA will be kept in common database with all other parameters of production fECal blocks.

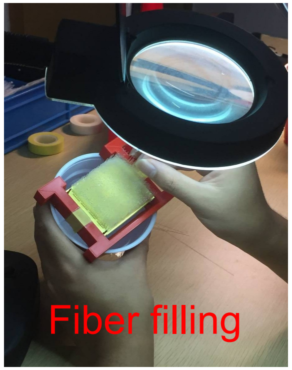
ES&H

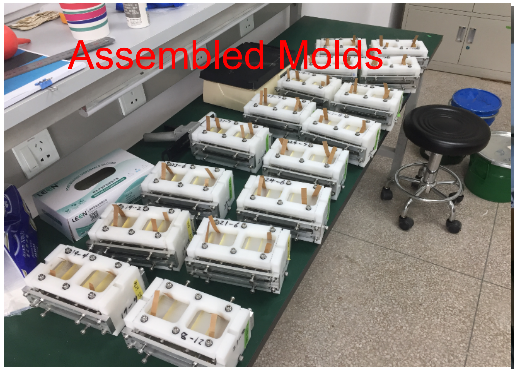
- Scintillating fibers are flammable materials.
- The total mass of fibers is quite large 0.5 tons.
- Fibers will be processed/stored at two sites.
- Adequate safety measures have to be followed to store large volumes of fibers. Storage and processing areas should be equipped with proper fire extinguishing systems.

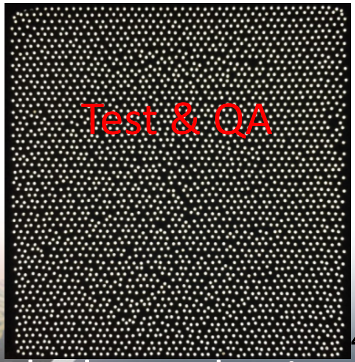
Workforce

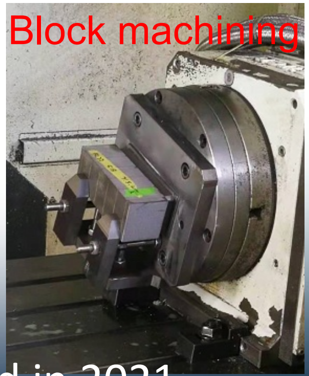
- Chinese Universities Consortia (Fudan University, Shandong University, Tsinghua University)
- University of California EIC Consortium (UCLA, UCR)
- Indiana University
- BNL

Groups has extensive expertise and capabilities in executing large scale project in high energy and nuclear physics experiments around the world. (RHIC, JLab, CERN, Super KEKB).









WScFI Blocks production in FUDAN for sPHENIX finished in 2021

Sc. Fibers Specs

1. Single clad fibers, round crossection
2. diameter 0.47 mm
3. diameter variation +- 2%
4. cladding thickness 3% of diameter
5. attenuation length for blue light >3 m
6. peak emission 450 nm
7. light yield > 8000 photons/MeV
8. batch-to-batch variation in LY 10%
9. scintillation decay time < 3ns
10. delivered in cans ~ 1m long, or spools, or both
11. total length 3000 km
12. delivery schedule - 3 years

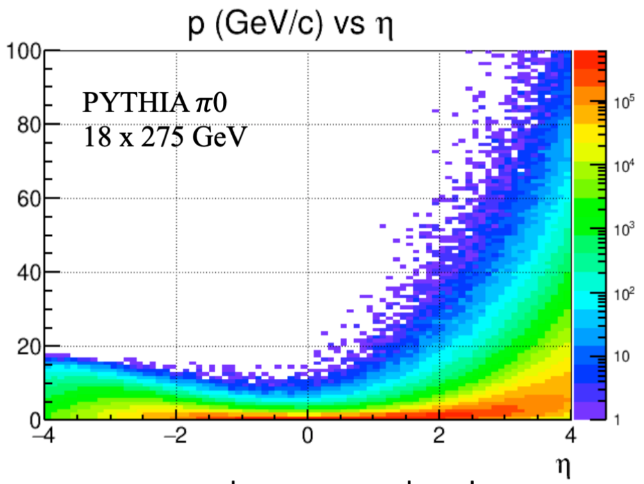
Summary

- Specs for scintillating fibers are well defined.
- Design of forward ECal is based on mature technology and is well advanced.
- Numerous test runs demonstrated all required parameters of fECal will be reached with proposed technology.
- Workforce is experienced in executing large scale projects (including recently built forward calorimetry systems for STAR and participating in sPHENIX WScFi barrel Ecal construction).
- QA procedures are well established.

Backup Slides

ePIC first campaign. Pi0/gamma

YR: Fig11.80



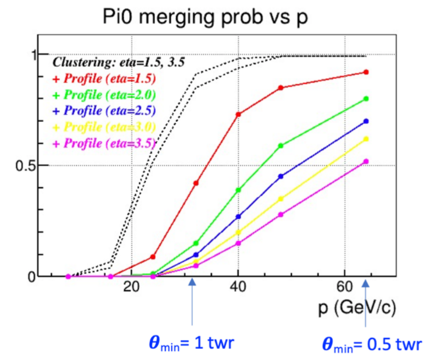
e-endcap:
up to e-beam momentum

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 cm² at z=3m)

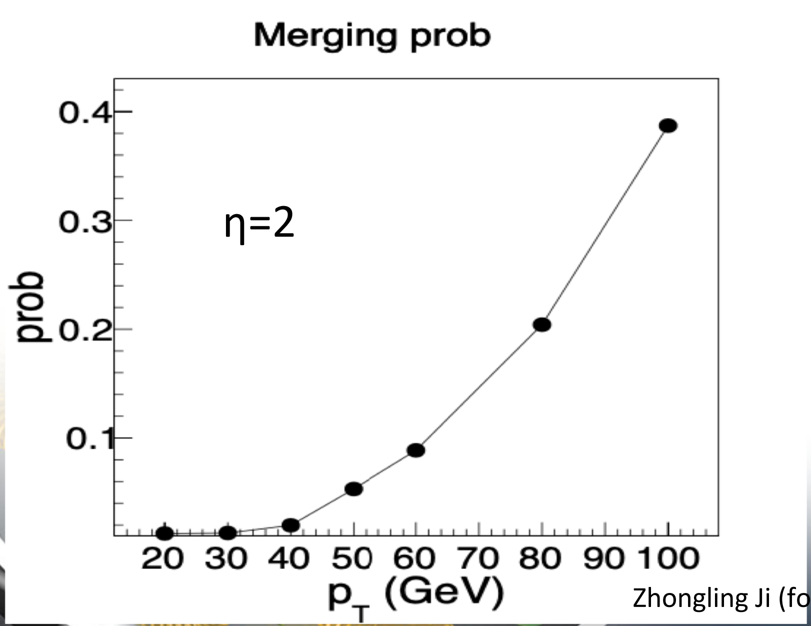


Shower Profile analysis:

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

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 …



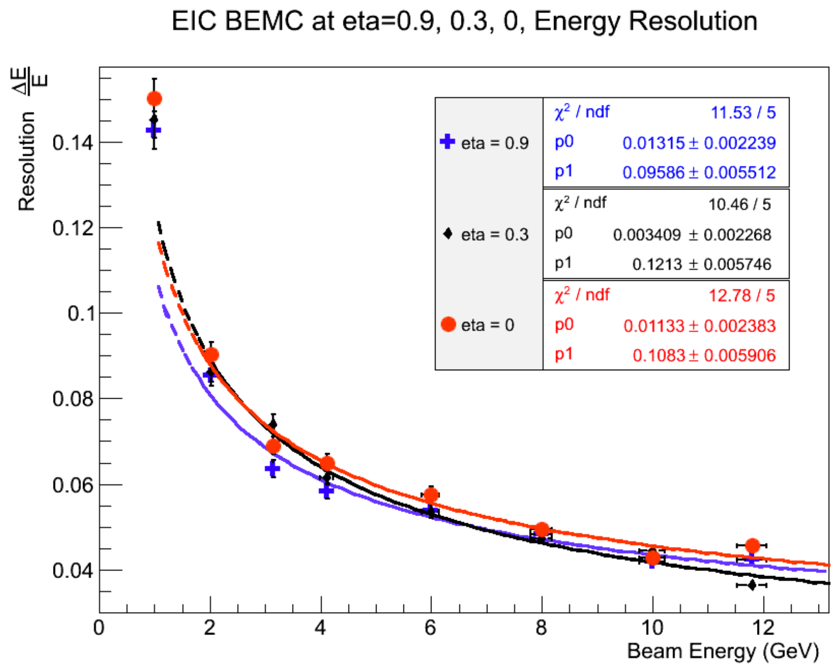
Zhongling Ji (for ePIC geometry)

pi0 merging probability after ML with transverse shower profile.
ePIC simulations.

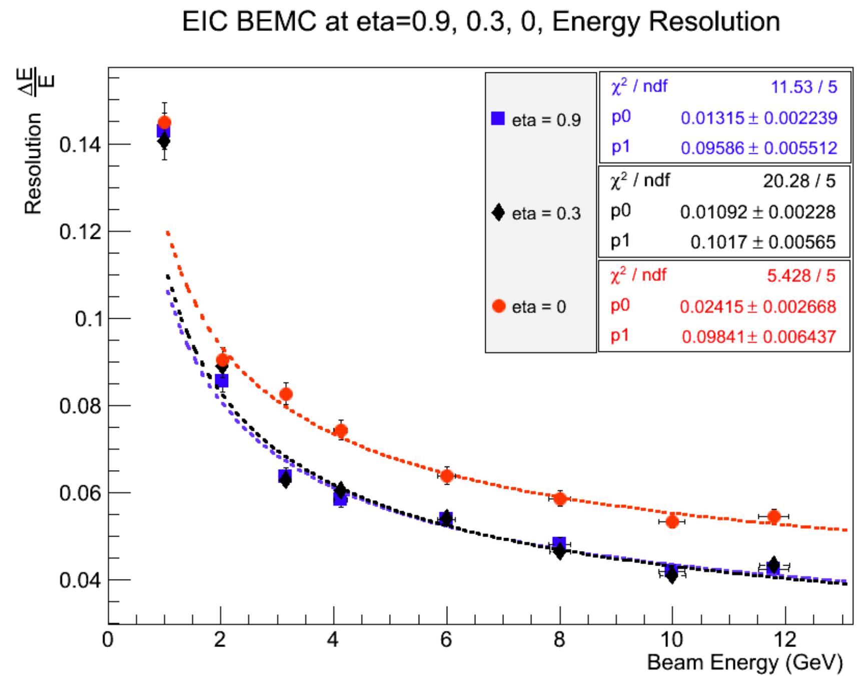
Meet desired performance for forward ECal.

EIC BEMC, prototype performance at FNAL. Preliminary Results.

ESR glued with silicone.



BC-620, painted at FNAL.



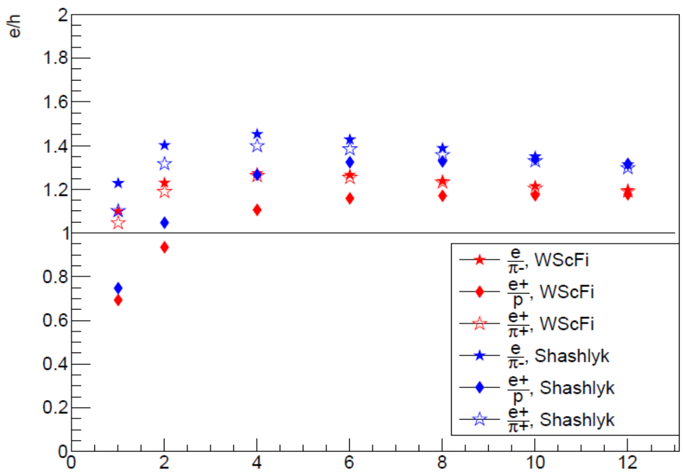
About the same energy resolution for 430 p.e./GeV and 530 p.e./GeV. In both cases at shallow impact angles it becomes better

Sample of results from simulations.

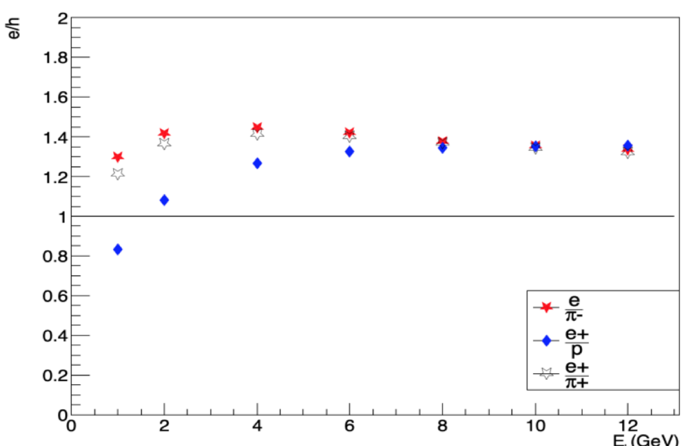
- e/h $\neq 1$
- e/h_ecal $\neq$ e/h_hcal
- e/h = f(E)
- e/p $\neq$ e/π
- f_{em}= 0.11 ln[E(GeV)]

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

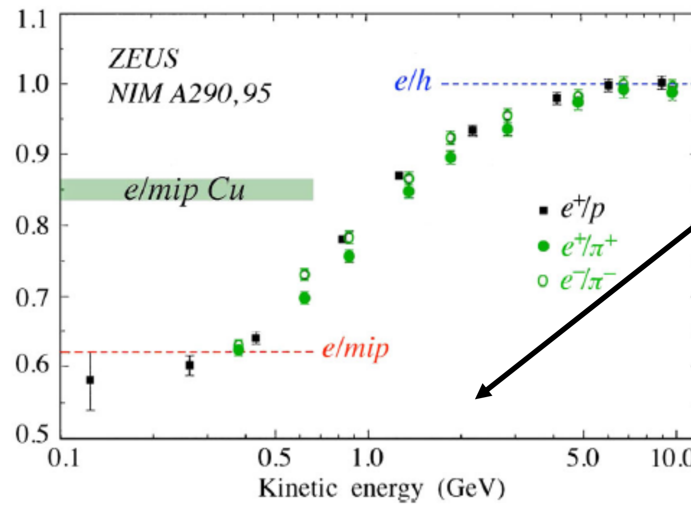
e/h for WScFi vs Shashlyk at 20 degree



e/h for Fe/Sc at 20 degree

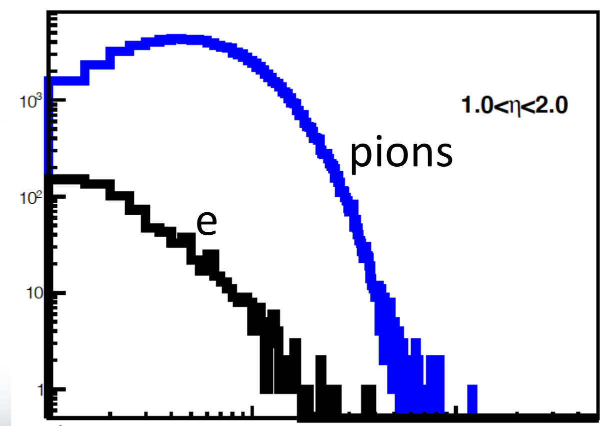


Z.Xu UCLA



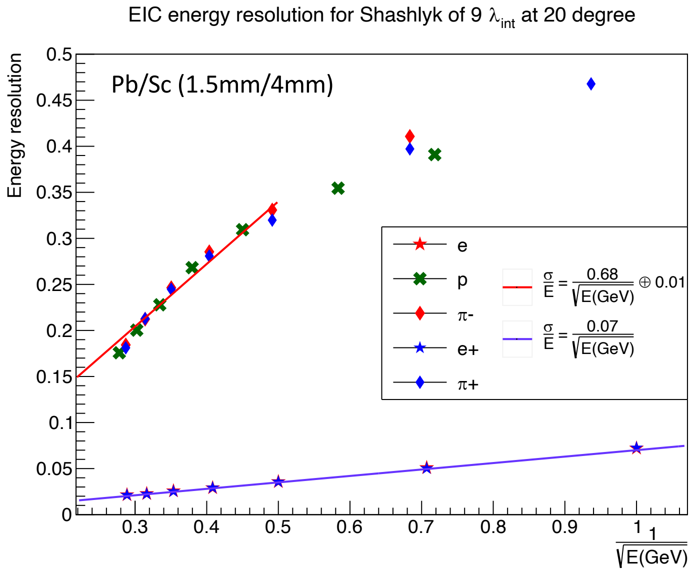
EIC Calorimetry need measurements
In this energy range.

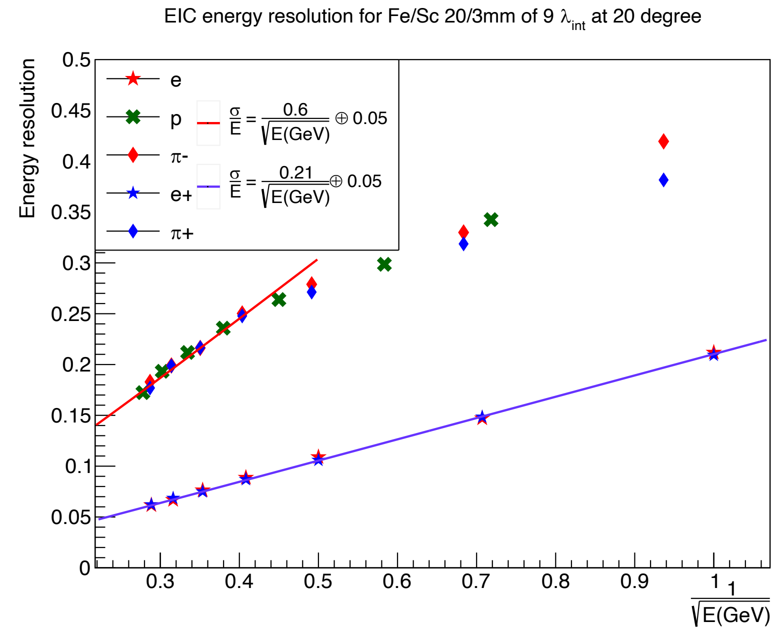
- ZEUS are experimental results
- eRD1 – GEANT4 with physics list validated for LHC (FTFP_BERT_HP).
- Validation of MC can be done only using experimental data form detector with correct chemical composition.

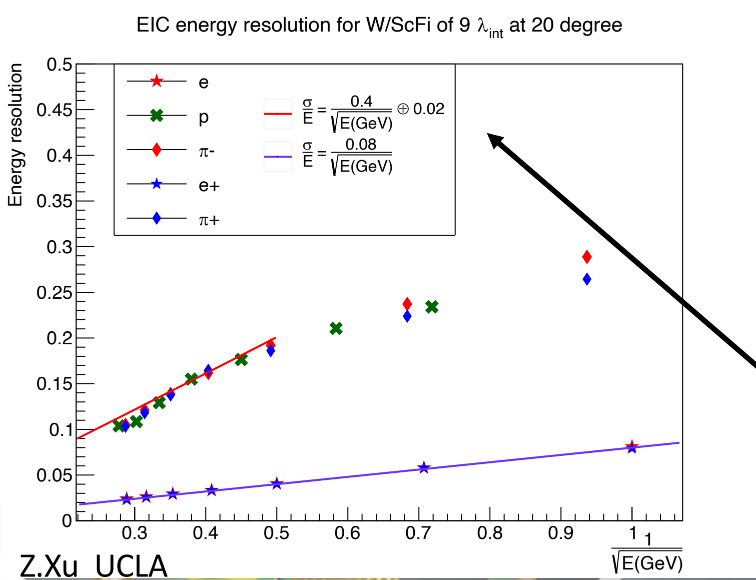


Inclusive, 18 GeV x 275 GeV

Sample of results from simulations. pECal, e/h







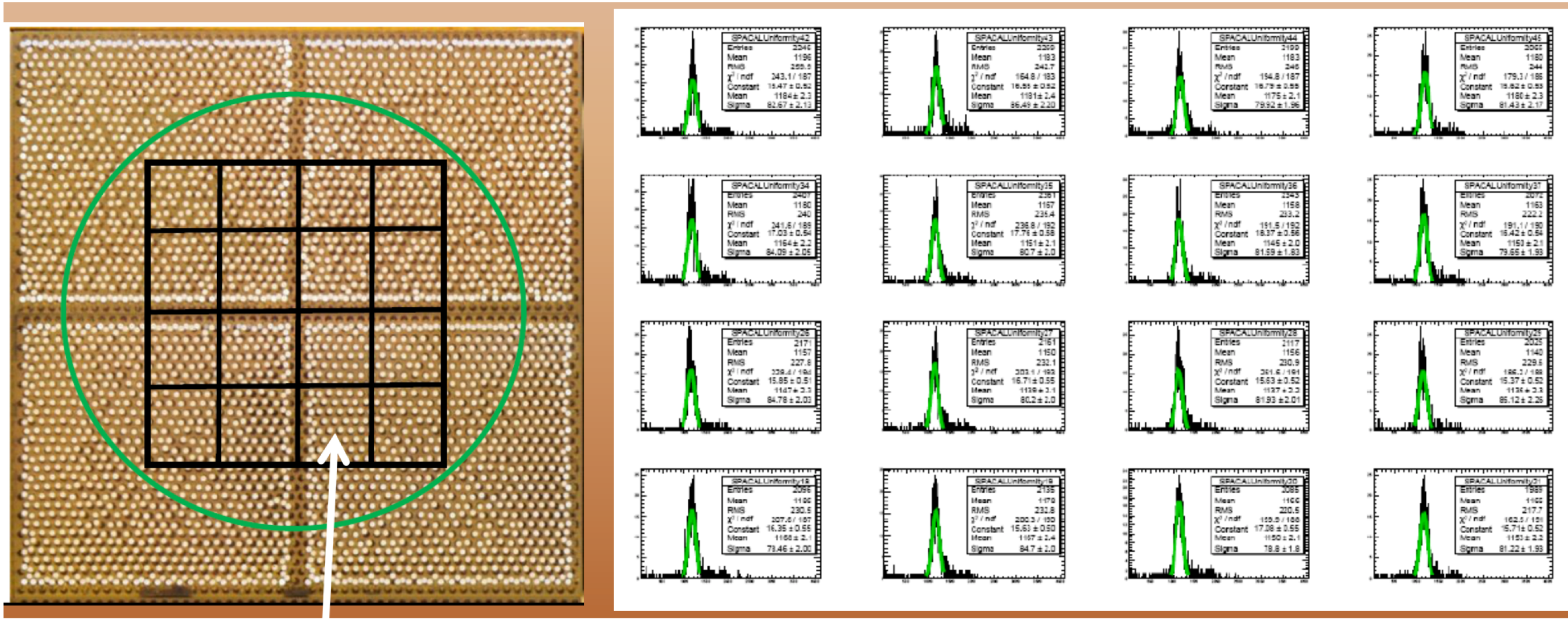
Hypothetical variant, 9 interaction lengths long calorimeters. Same structure for Ecal and Hcal sections. Three different technologies:

- 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.

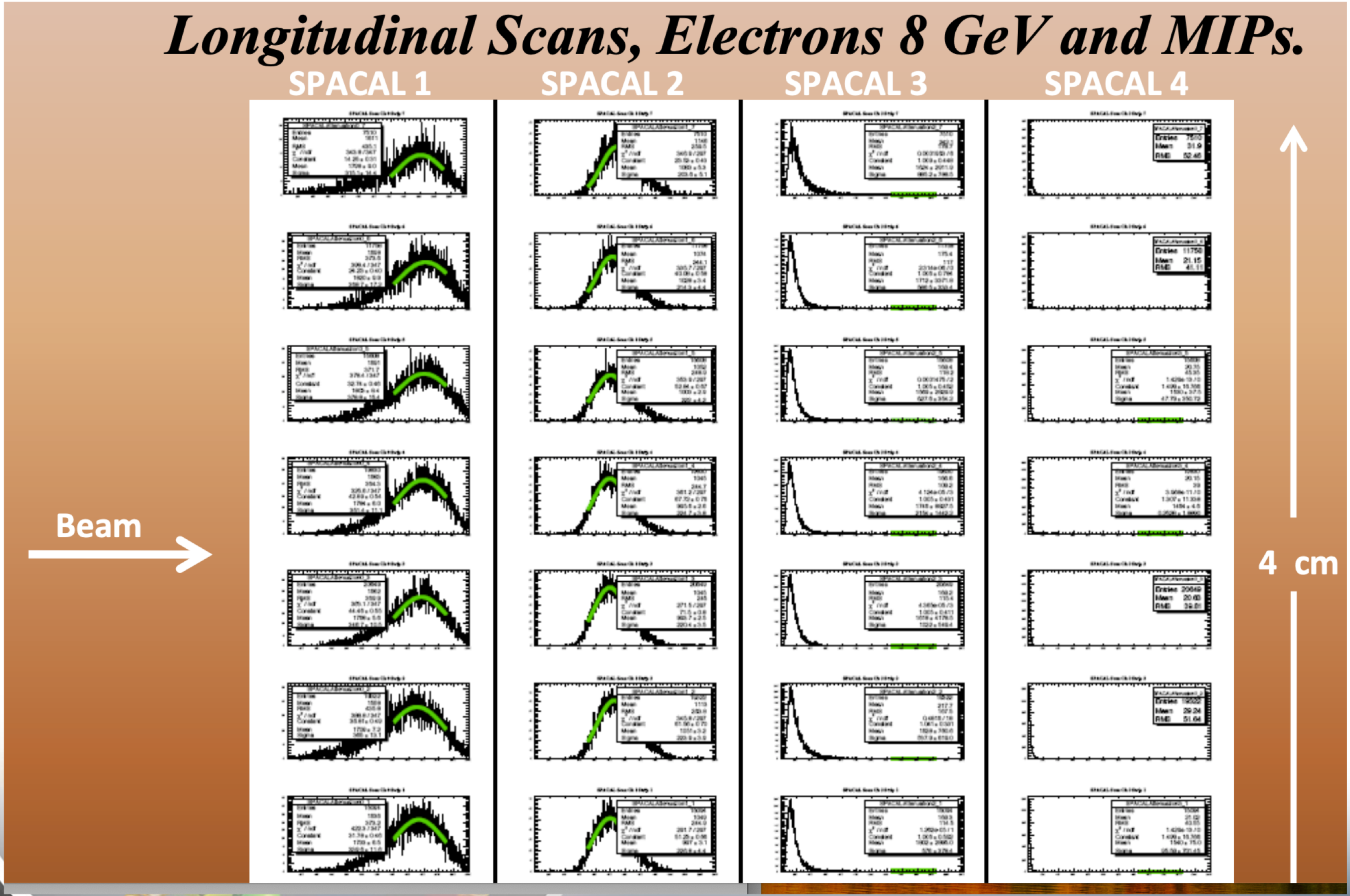
N.B. these are MC not an experimental results.

Results from generic EIC R&D. FNAL Test Run 2012



Beam position selected by hodoscope ~ 5 mm x 5 mm
Non-uniformity of response is 1.4% for a single 5 cm x 5 cm production block.
~ 1.4% may be a limit for a constant term for forward ECla (ideal readout with long light guides) which allows to meet KPR (2%). (N.B. measurements done at ~3 degrees impact angle, non-uniformities greatly reduced at large impact angles in forward ePIC Ecal)

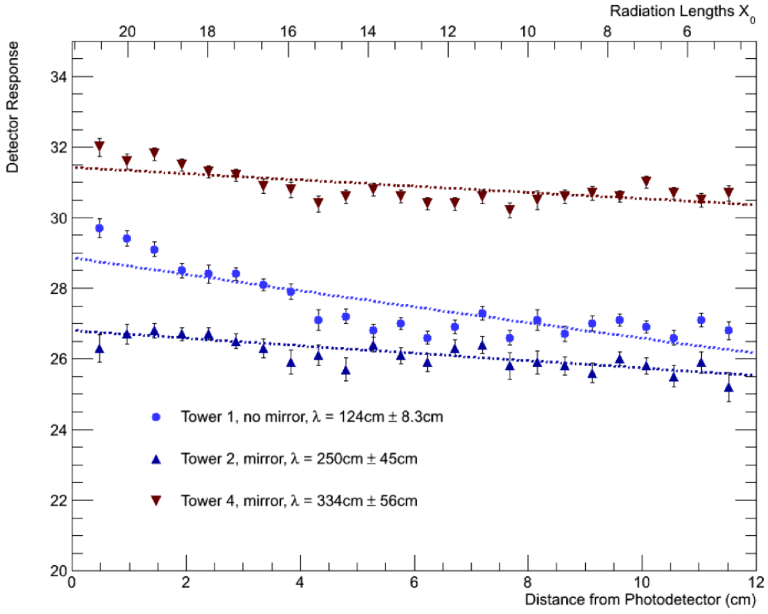
FNAL Test Run 2012



FNAL Test Run 2012

- ***Attenuation lengths and uniformity along the towers.***

MIPs



Electrons