EMCAL Options for EIC

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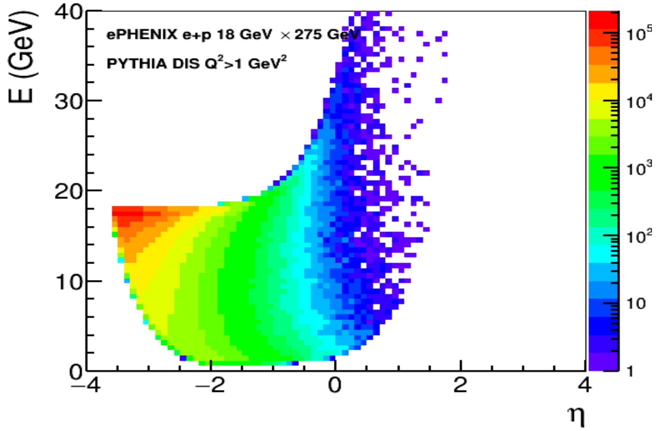
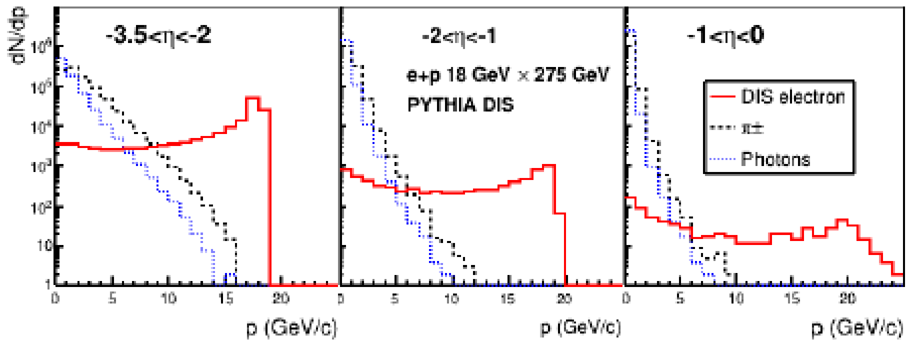
Introduction

- Numerous calorimeter options for EIC were discussed in the YR Calorimeter Working group over the course of many months. They are now summarized in the YR which gives recommendations on the different technologies for the various rapidity regions.
- This talk will focus on two sampling technologies for electromagnetic calorimetry:
  - Scintillating Fiber (SPACAL)
  - Shashlik with Pb and Tungsten absorbers

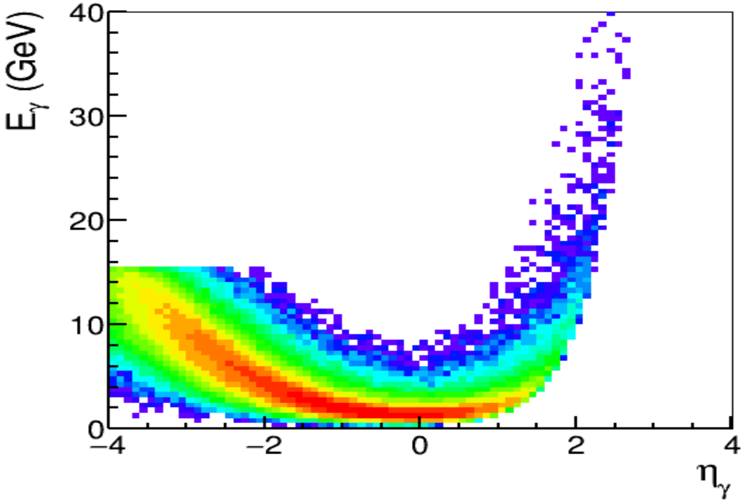
EMCAL Requirements

DIS e

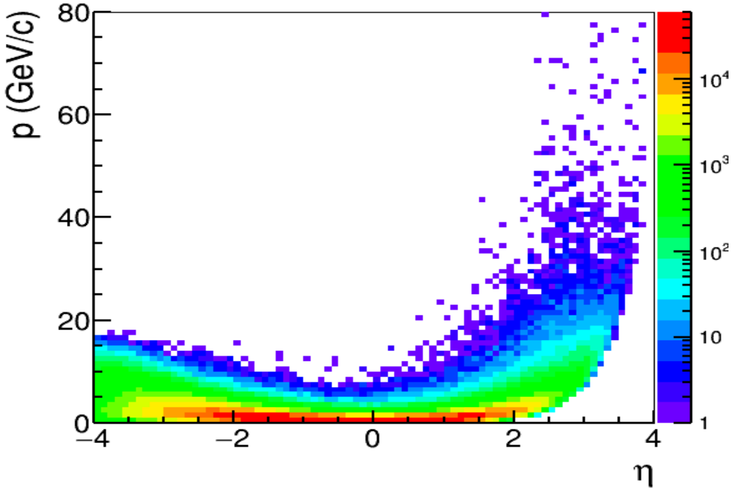




DVCS γ



SIDIS π^0s



	Backward -4 < η < -2	Backward -2 < η < -1	Barrel -1 < η < -1	Forwward 1 < η < 4	
Resolution σ_E/E	2%/√E ⊕ (1-3)%	7%/√E ⊕ (1-3)%	(10-12)%/√E ⊕ (1-3)%	(10-12)%/√E ⊕ (1-3)%	Need to measure the scattered electron with good resolution and provide e/h separation
Min E (GeV)	0.02	0.05	0.1	0.1	Require low E_{min} to measure decays
Granularity (Δθ)	< 0.02	< 0.02	< 0.025	< 0.01	γ/π^0, e/h discrimination (~ $10^{-2} - 10^{-3}$)
Space	ΔZ = 60 cm	ΔZ = 60 cm	ΔZ = 30 cm	ΔZ = 40 cm	Including all services

Detector Matrix YR - Calorimetry

Crystals & Glasses

SciFi & Shashlik EMCAL

Backward $-4.0 < \eta < -1.0$

Central $-1.0 < \eta < 1.0$

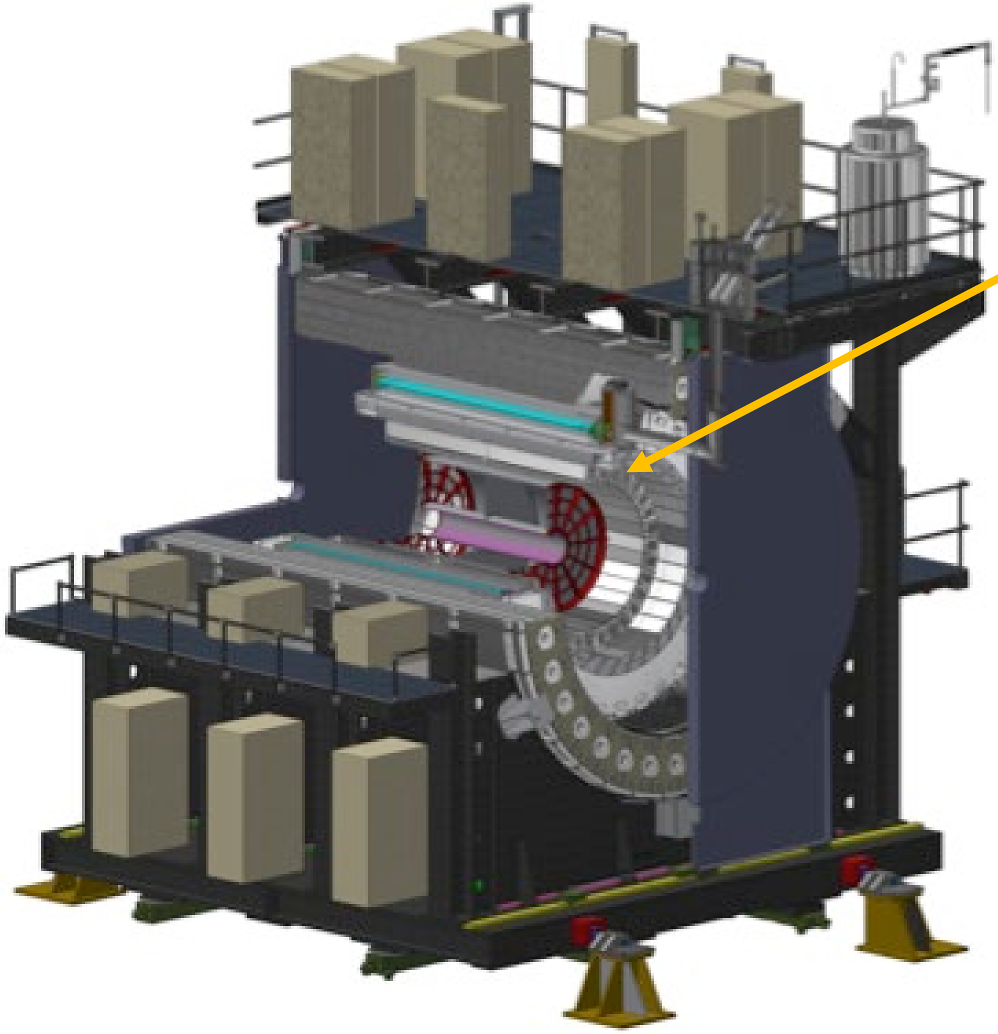
Forward $1.0 < \eta < 4.5$

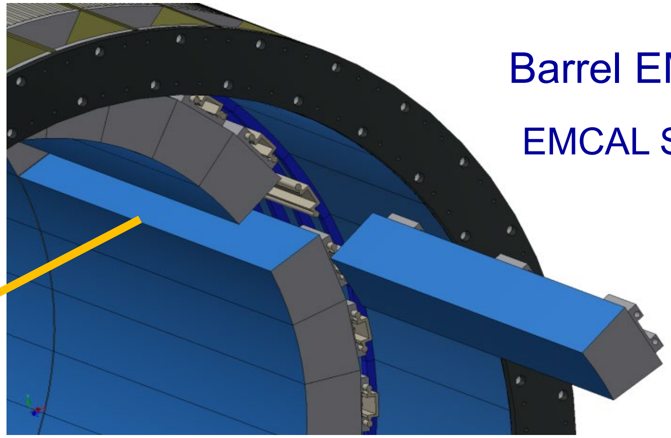
η	Nomenclature			Electrons and Photons: Resolution σ_E/E	PID	min E	π/K/p: p-Range (GeV/c)	Separati	HCAL: Resolution σ_E/E	Energy
-4.5 to -4.0	↓ p/A	Auxiliary Detectors	Instrumentation to separate charged particles from photons	2%/√E(+1-3%)		50 MeV				
-4.0 to -3.5						50 MeV			~50%/√E + 6%	
-3.5 to -3.0			Backward Detector		π suppression up to 1:1E-4	50 MeV	≤ 7 GeV/c	≥ 3 σ	~45%/√E+6%	~500 MeV
-3.0 to -2.5						50 MeV				
-2.5 to -2.0				2%/√E(+1-3%)		50 MeV				
-2.0 to -1.5				7%/√E(+1-3%)		50 MeV				
-1.5 to -1.0				7%/√E(+1-3%)		50 MeV				
-1.0 to -0.5		Central Detector	Barrel	(10-12)%/√E(+1-3%)		50 MeV	≤ 10 GeV/c		~85%/√E+7%	
-0.5 to 0.0						50 MeV			~85%/√E+7%	
0.0 to 0.5						50 MeV			~85%/√E+7%	
0.5 to 1.0						50 MeV	≤ 15 GeV/c		~85%/√E+7%	
1.0 to 1.5			Forward Detectors		3σ e/π	50 MeV	≤ 30 GeV/c		35%/√E	
1.5 to 2.0						50 MeV	≤ 50 GeV/c			
2.0 to 2.5						50 MeV				
2.5 to 3.0						50 MeV	≤ 30 GeV/c			
3.0 to 3.5						50 MeV	≤ 45 GeV/c			
3.5 to 4.0	↑ e	Auxiliary Detectors	Instrumentation to separate charged particles from photons			50 MeV				
4.0 to 4.5						50 MeV				
4.5 to 5.0			Neutron Detection	4.5%/√E for photon energy > 20 GeV	<= 3 cm granularity	50 MeV			35%/√E (goal), <50%/√E (acceptable)*, 3mrad/√E (goal)	

SciFi and Shashlik Technologies

- Both technologies are very mature and have been used by a number of experiments.
- The energy resolution can be tuned by changing the sampling fraction and/or the sampling frequency.
- The absorber (e.g., W, Pb) can be selected to optimize the desired properties of the calorimeter (e.g., cost, compactness, degree of compensation w/HCAL,...). *Note: For EM calorimetry, the ability to use W absorbers in various forms allows for compact designs which utilize less space which is a prime consideration for EIC.*
- The readout in both cases can be done on the ends of the calorimeter (either the front or the back or both) which allows a variety of different geometrical configurations.

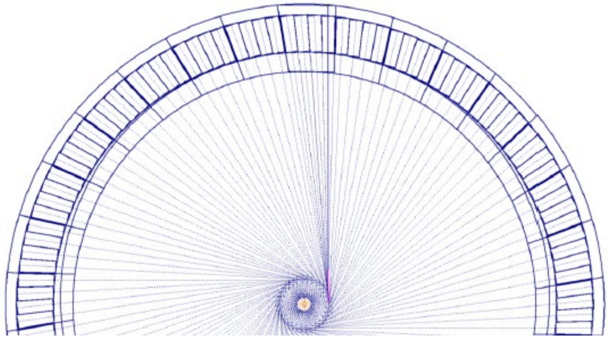
sPHENIX W/SciFi EMCAL



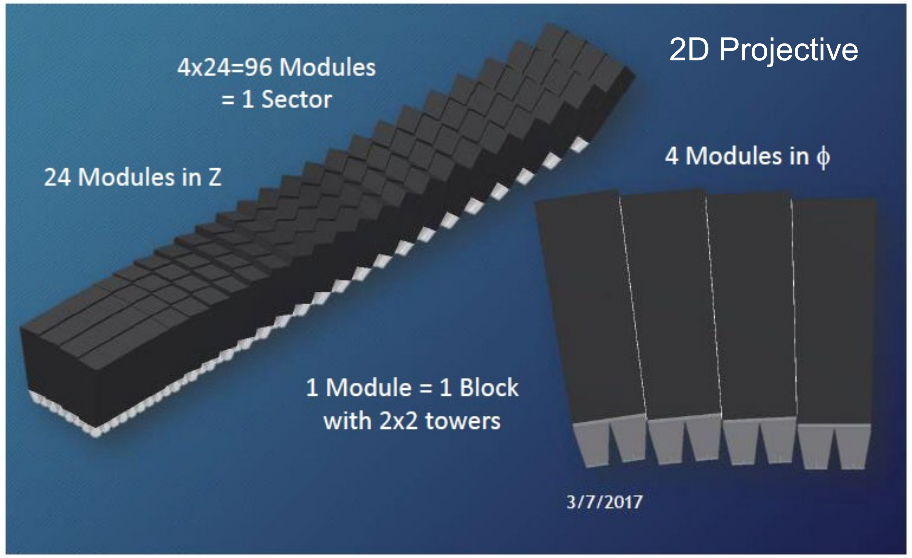


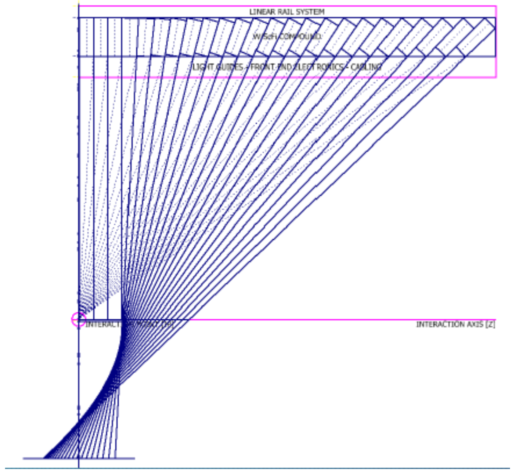
Barrel EMCAL

EMCAL Sector



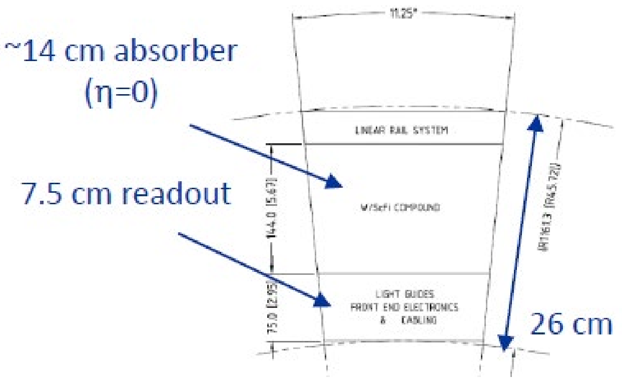
$2(\pm\eta) \times 32\ (\phi) = 64$ Sectors





Sectors and blocks are approximately projective and tilted in η and ϕ

sPHENIX W/SciFi EMCAL



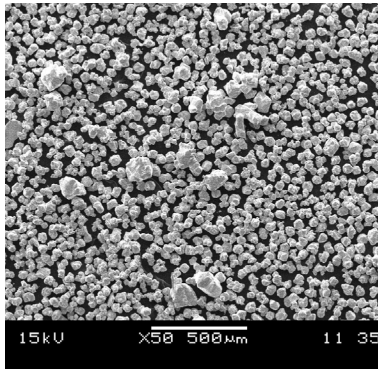
- The sPHENIX EMCAL is a W/SciFi SPACAL consisting of a matrix of tungsten powder and epoxy with embedded scintillating fibers
  - 0.47 mm dia. fibers, spacing 1 mm, SF ~ 2%
  - Density ~ 9.0 g/cm^3, X0 = ~ 7 mm, ~ 20 X0 total, R_M ~ 2.3 cm
- W/SciFi modules consist of 4 towers, each with its own light guide that is read out on the front with a 2x2 array of 3x3 mm^2 SiPMs (Hamamatsu S12572-015P)

SiPMs are susceptible to radiation and will receive a dose ~ 10^{11} n/cm^2 over the currently 3 yr lifetime of sPHENIX

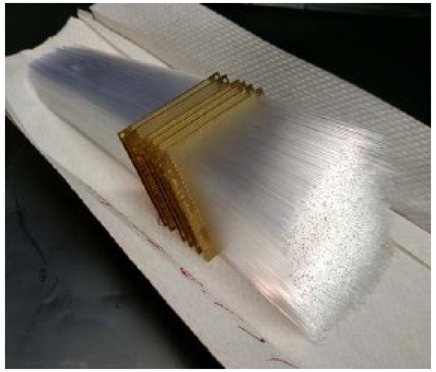
Modules will be re-instrumented with new SiPMs for EIC

6144 Modules (24,576 towers)

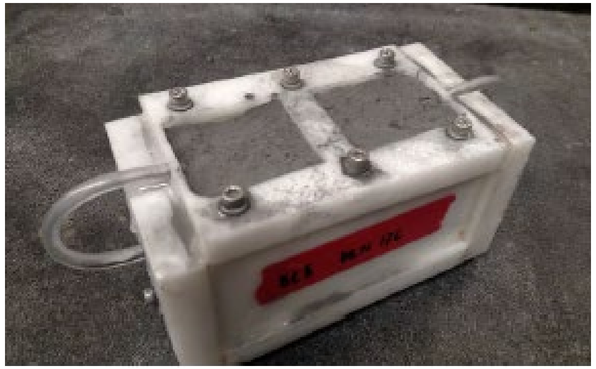
W Powder ~ 50 µm

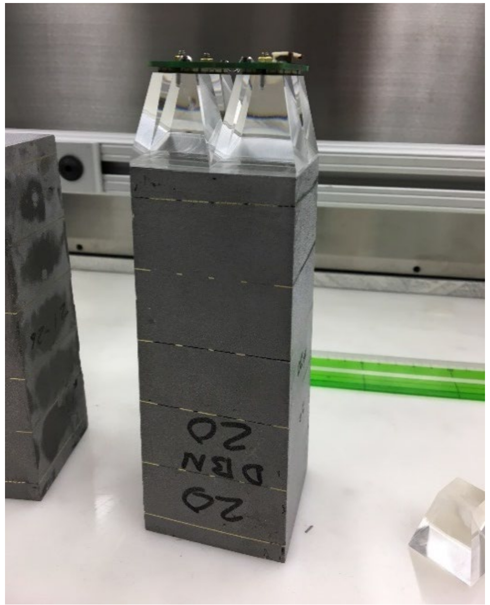


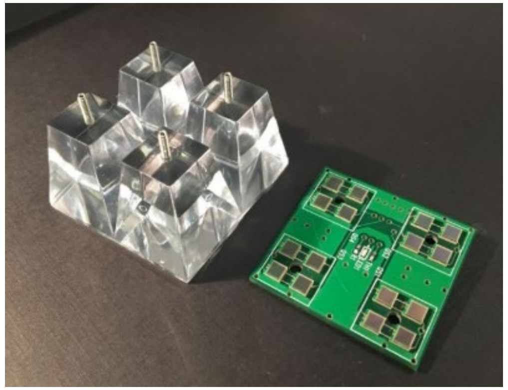
Fiber Assembly



Mold with W powder, fibers + epoxy







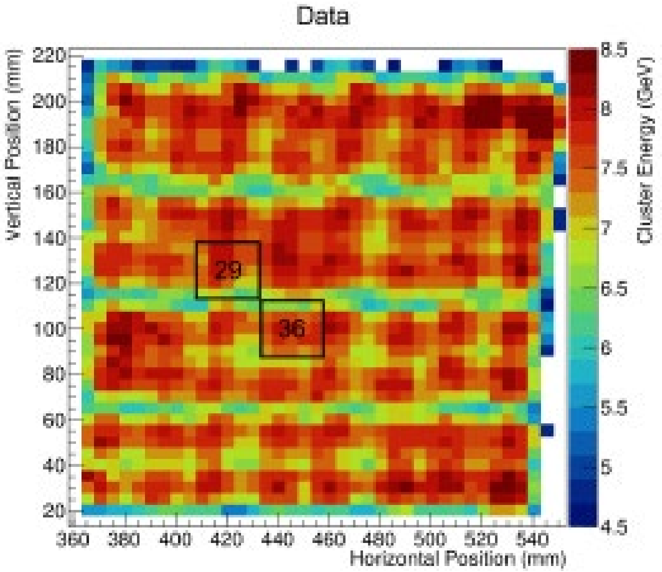
Readout with light guides and SiPMs

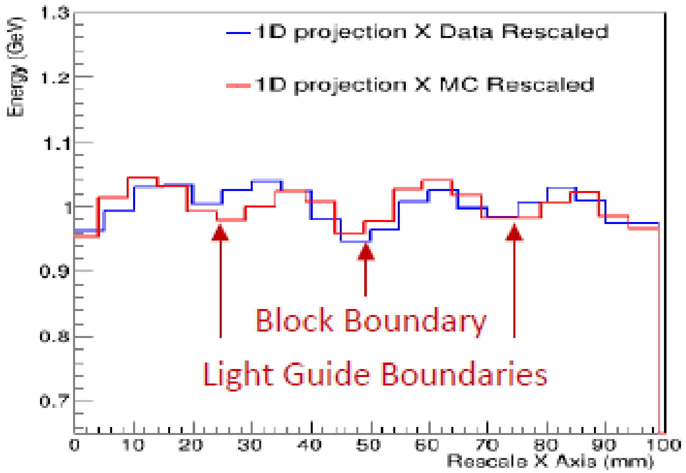
(~ 100K SiPMs)

Uniformity of W/SciFi - Effect on Energy Response

Non-uniformities are inherent in the design and contribute to the energy resolution

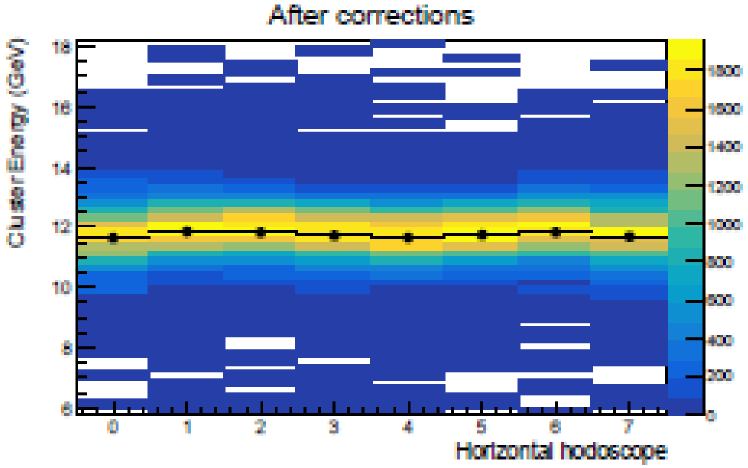
Uniformity of response over 8x8 towers with 8 GeV electrons (Test Beam Data)

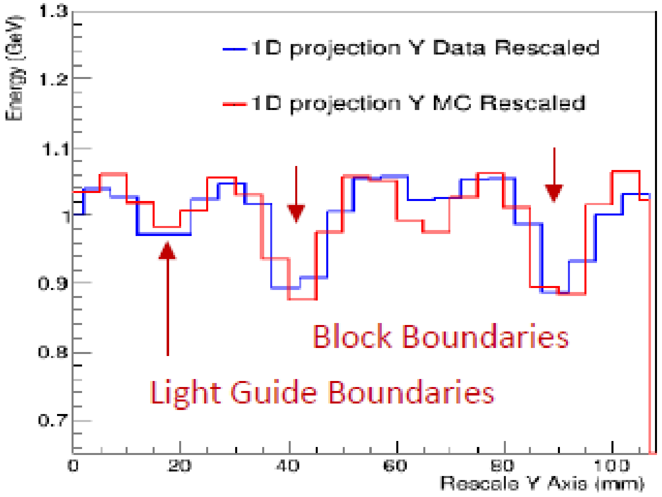




X axis projection

Uniformity after position dependent correction



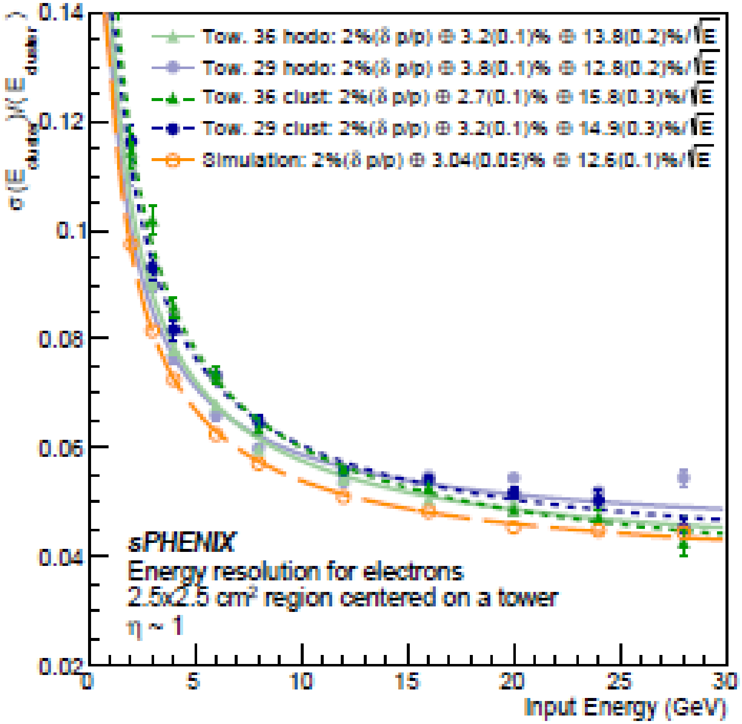


Y axis projection

Energy Resolution

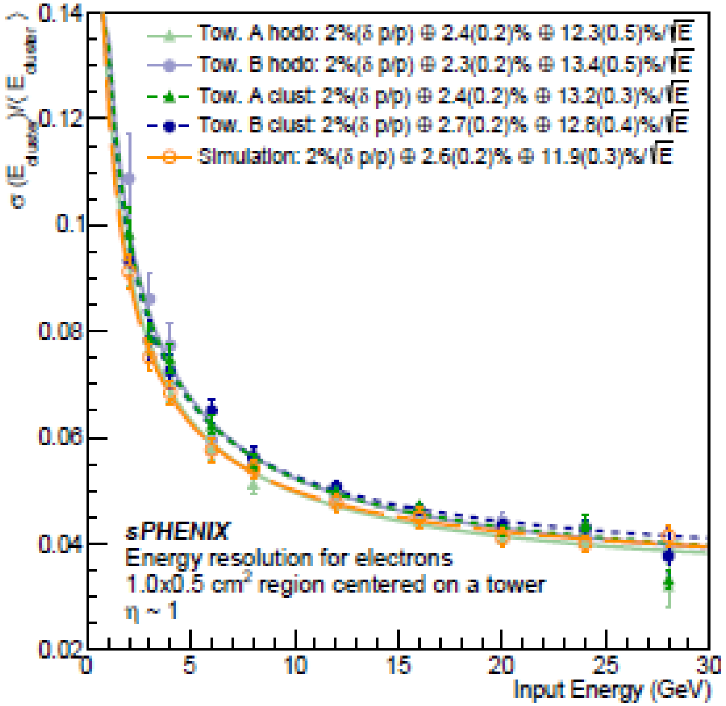
Energy resolution after position dependent correction

Beam covering a 2.5 x 2.5 cm^2 area centered on a tower



Resolution ~ (13-15)%/√E ⊕ 3%

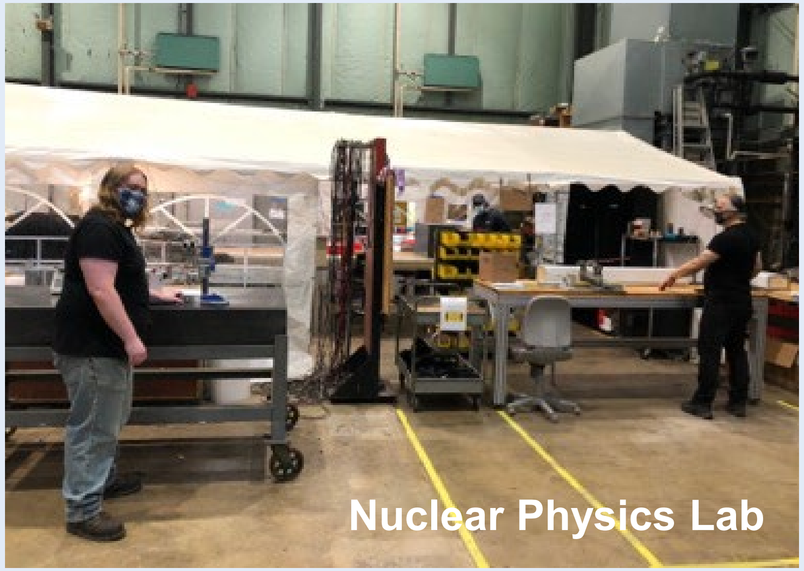
Beam covering a 1.0 x 0.5 cm^2 area centered on a tower

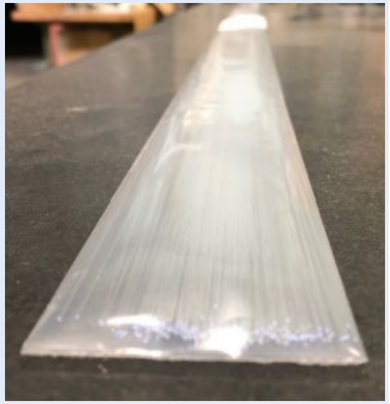


Resolution ~ (12-13)%/√E ⊕ 2.5%

sPHENIX EMCAL Under Construction (Completion - Jan 2022)

Block Production at UIUC (also Fudan U - Shanghai)



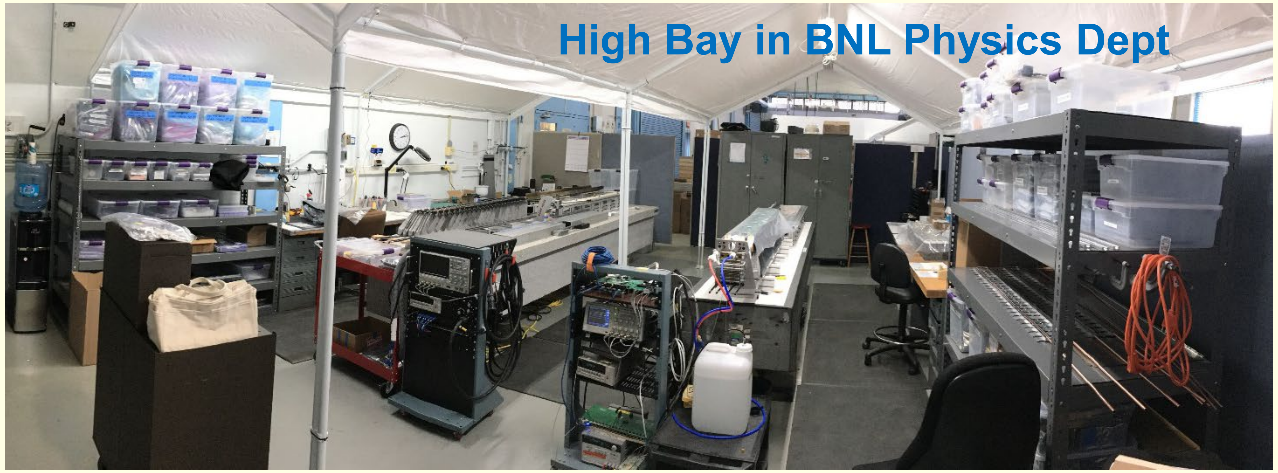


2600 km of fiber
665 kg of epoxy
88 m^2 of screens

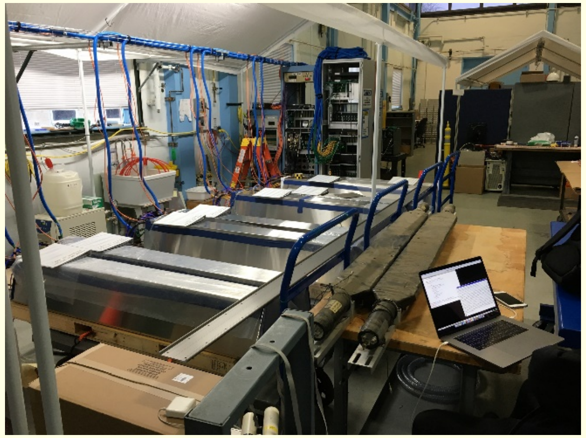
20 Tons of W powder

Blocks awaiting removal from molds

Module and Sector Production at BNL



Modules being glued into sectors

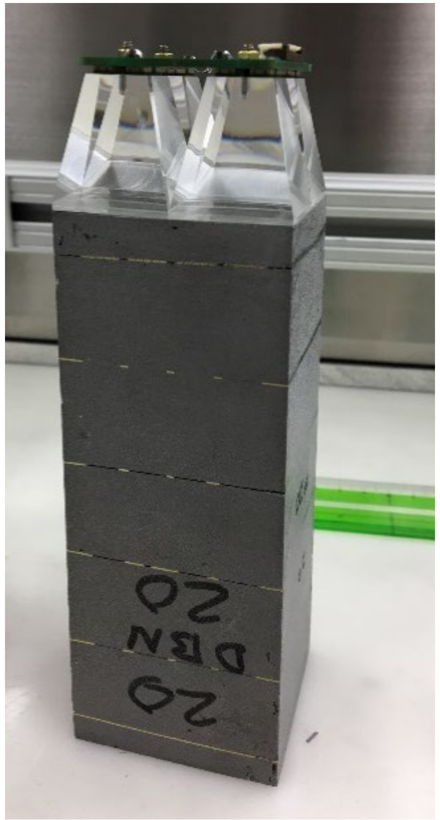


Sector Burn-in and Testing

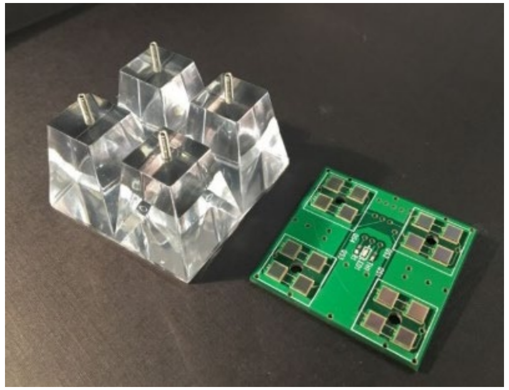
Future Developments for W/SciFi Calorimetry

We believe we can improve the light output, energy resolution and uniformity of response of the sPHENIX calorimeter by increasing the photocathode coverage for the readout of the absorber blocks.

Light output from fibers is very uniform but light collection efficiency is low (~ 6 %)



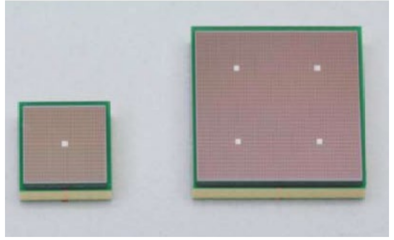
Readout end of block

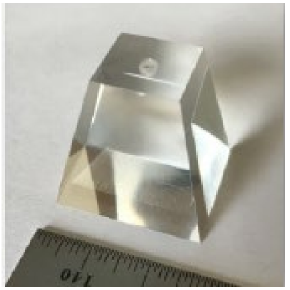


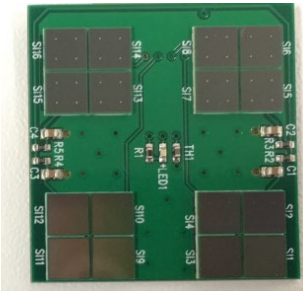
Two possible ways to increase photocathode coverage:

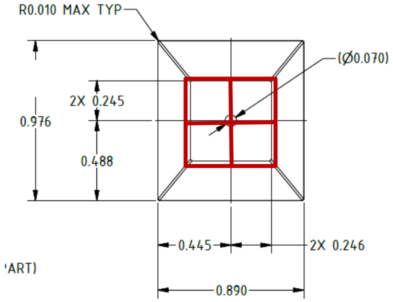
- Keep existing light guides and replace 2x2 array of 3x3 mm^2 SiPMs with four 6x6 mm^2
- Remove or cut down existing light guides and cover entire readout end of block with a 6x6 array of 6x6 mm^2 SiPMs.

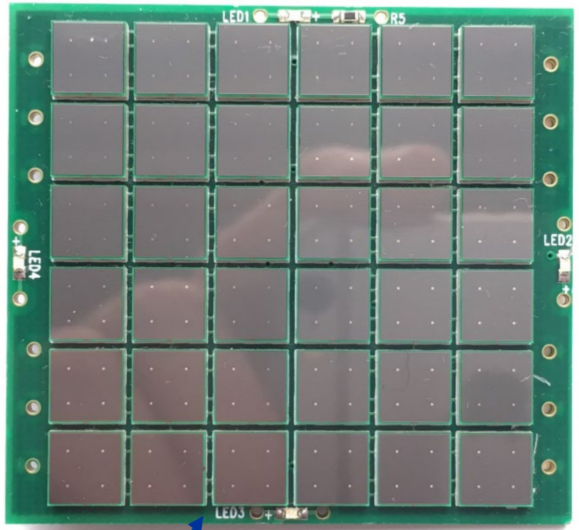
Hamamatsu S13360 6x6 mm^2 SiPM with TSVs (50 μm pixels)





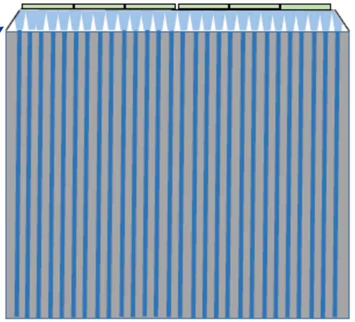






Note small gaps

Short light guide covering entire block

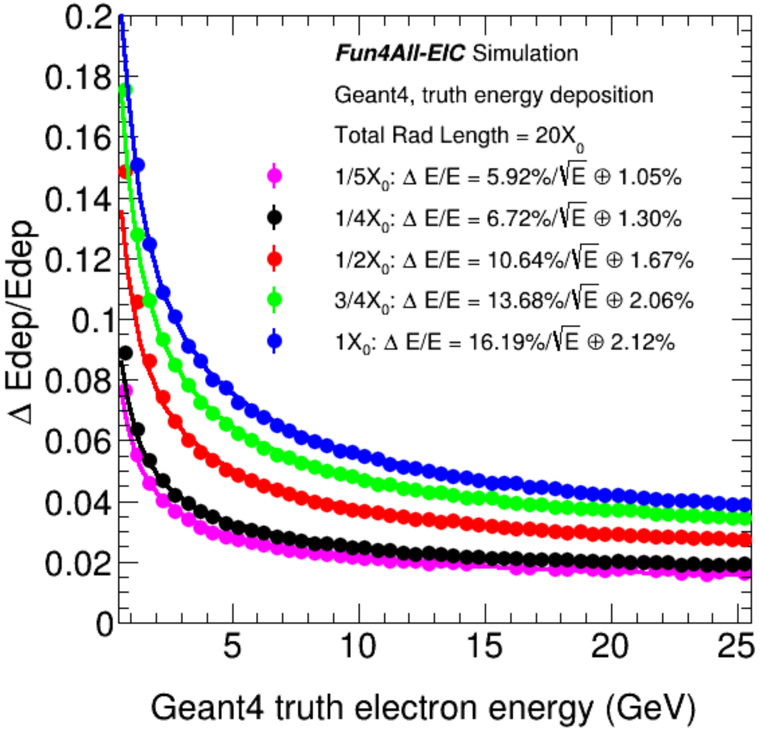


W/Shashlik Calorimetry for EIC

- Shashlik calorimetry was listed as one of the possible technologies for EIC over a wide range of rapidities ($-2.0 < \eta < 4.0$)
- Shashlik calorimetry is a mature technology but most shashlik calorimeters that have been built so far have used Pb as the absorber.
- However, using W as an absorber has several advantages:
  - For the same total X0, a W shashlik calorimeter will occupy less space, either longitudinally along the beam direction or radially in the central barrel.
  - The R_M of W is much smaller than for Pb and the showers will be much smaller and therefore have less overlap with neighboring showers.
    (Improves γ/π^0 separation and e/h separation)
- Using W as an absorber also has some disadvantages:
  - W is more expensive and harder to machine.
  - It is more difficult and costly to make a shashlik calorimeter projective.

EMCAL Shashlik Calorimetry – Pb vs W

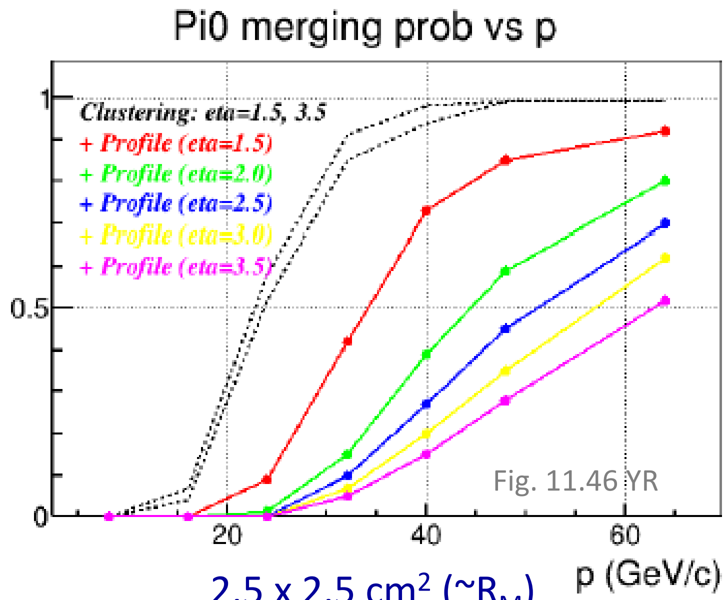
Energy resolution vs sampling fraction
20 X0 total length (L ~ 30 cm w/readout)



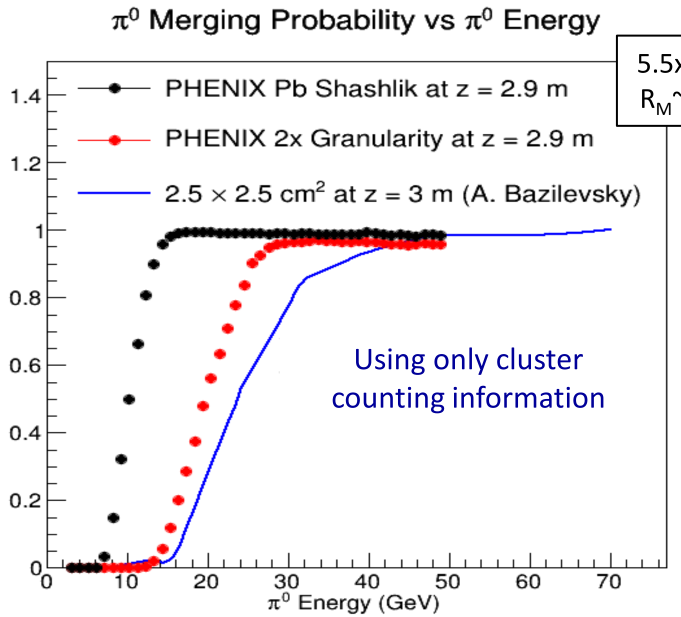
W Shashlik

Require fine segmentation and small R_M to resolve γ/π^0 at high momentum

Non projective geometry



2.5×2.5 cm^2 (~R_M)



5.5x5.5 cm^2
R_M~ 4.5 cm

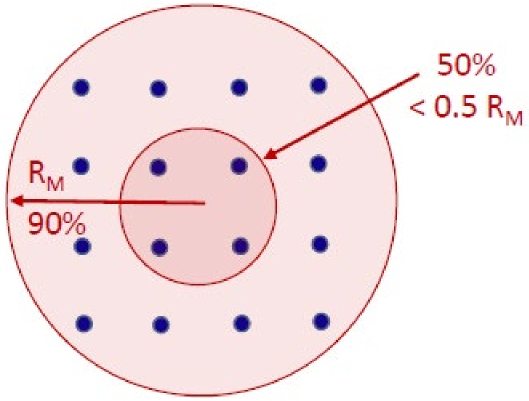
Note:

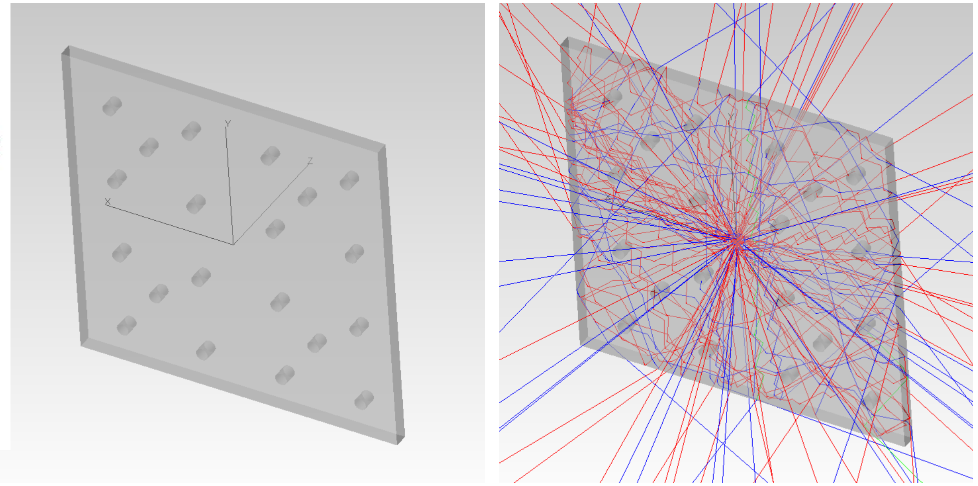
- Projective geometry will improve separation, particularly in the η ~ 1-3 region
- Can also achieve γ/π^0 separation using a preshower detector

Improving Shashlik Spatial Resolution

- The availability of low cost SiPMs allows the possibility of reading out *each fiber individually.* This allows determining the shower position even within a Moliere radius.

A compact shashlik may also offer the possibility of improving the position dependence due to the short light path to the WLS fibers.





Ray tracing withing a scintillation tile

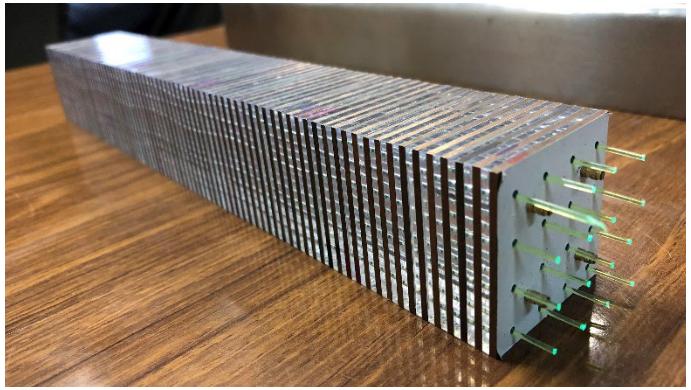
- Non-uniformities of light collection within a tile will cause a position dependence. However, this can in principle be corrected for using lab measurements and ray tracing can produce a light collection map for each fiber.

Prototype W/Shashlik EMCAL

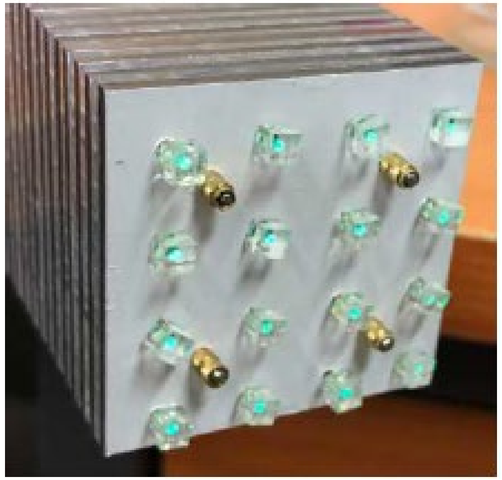
Originally designed for the NA64 Experiment at CERN (not optimized for EIC)

Andres Bello University
Santiago, Chile

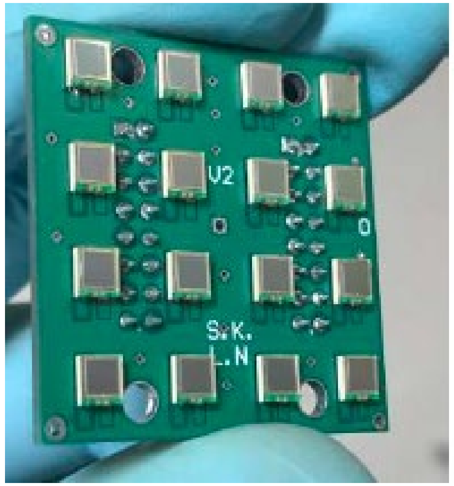
- Absorber plates are a W(80%)/Cu(20%) alloy that is easily machinable
  $\rho = 17.2\ g/cm^3$, X0 = 4.1 mm, 38 x 38 x 1.58 mm^3
- Scintillating tiles: 38 x 38 x 1.63 mm^3 injection molded polystyrene (Uniplast, Russia).
- 1 mm dia WLS fibers spaced on a 9.5 x 9.5 mm^2 grid
- 80 sampling layers, X0 = 8.5 mm, Total ~ 31 X0 (27 cm), R_M ~ 2.5 cm
- Each fiber read out with 3x3 mm^2 SiPMs



WLS fibers pass through stack in a slight spiral pattern to improve light collection uniformity and reduce dead areas



Each fiber coupled to small lucite light mixer



Hamamatsu S14160-3015P

3x3 module prototype

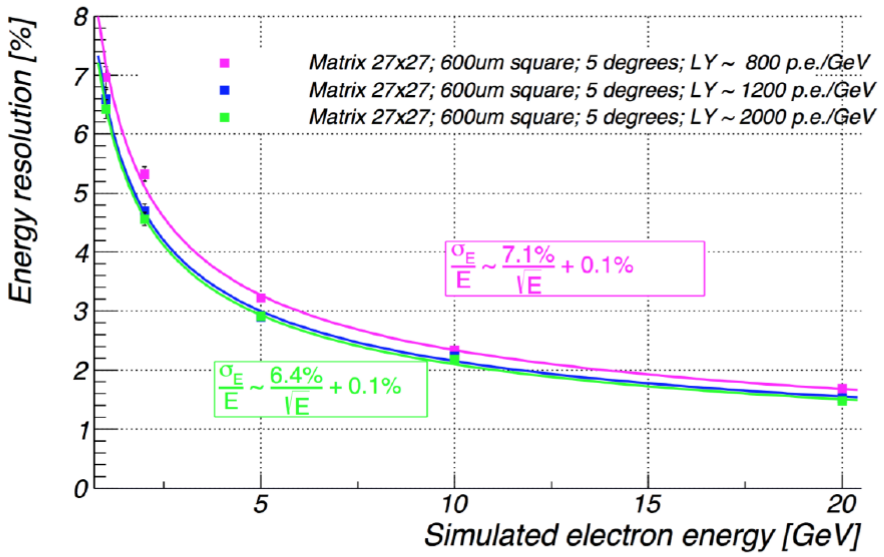
Summary & Conclusions

- Scintillating fiber and shashlik calorimeters have been used in many experiments over many years. Both are very mature technologies that could be used over almost the entire rapidity range of interest at EIC.
- Both designs offer the ability to tune their parameters to match the various physics, space and performance requirements for each application.
- Although both technologies are mature, there are still significant improvements that can be made by using them in new designs utilizing new materials and components that are available today.

Backup

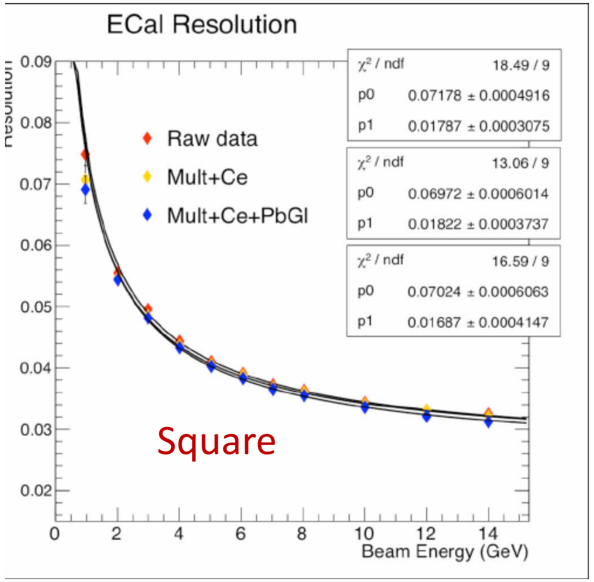
HiRes W/SciFi

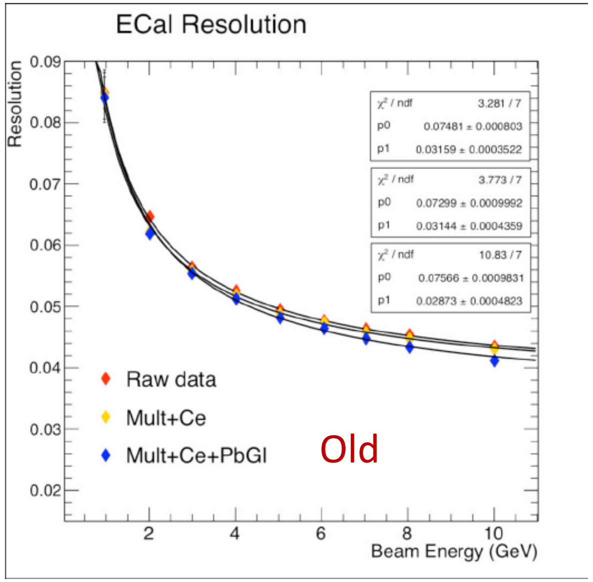
eRD1 Report Jan 2016



Detector	Fibers SCSF 78	Absorber	Sampling Frequency	Composition by weight	Number of fibers in superblock
"Old" High sampling frequency	Round, 0.4mm	75% W 25% Sn	0.671 mm Staggered Pattern	W -0.665 Sn – 0.222 Sc – 0.057 Epoxy- 0.056	25112 Damaged 3
"Square" High sampling fraction	Square, 0.59 x 0.59 mm[2]	100% W	0.904 mm Square Pattern	W – 0.858 Sc- 0.075 Epoxy- 0.067	11664 Damaged 0

O.Tsai (UCLA)





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PHENIX Shashlik

Designed for heavy ion collisions
5.535 x 5.535 cm^2 towers $\Rightarrow$ $\Delta\eta$ =0.01, $\Delta\phi$ = 0.01 at R = 5 m
X0 = 2.1 cm, R_M ~ 4.5 cm
Total absorber depth = 37.5 cm (18 X0, 0.85 λ_{int})

3888 modules $\Rightarrow$ 15,552 towers total

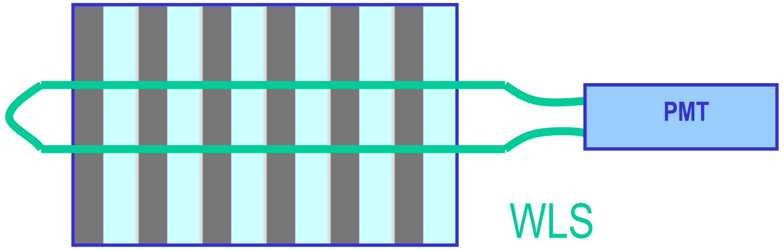
Resolutions

$$\frac{\sigma_E}{E} = \frac{8.1\%}{\sqrt{E}} \oplus 2.1\% \qquad \sigma_x = \frac{5.7\ (mm)}{\sqrt{E}} \oplus 1.55\ (mm)$$

$$\sigma_t \sim 200ps$$

1500 modules now deployed in STAR FCS w/ SiPM readout

Pb (1.5 mm) Scint (4 mm) 66 layers (18 X_0)



WLS

Light Yield ~ 1.5 p.e./MeV