eRD1 Report on Calorimeter R&D for EIC

- W/SciFi & W/Shashlik Calorimetry - C. Woody (BNL)
- Crystals & Scintillating Glasses - C. Munoz-Camacho (Orsay)
- W/SciFi EMCAL & Fe/Scint HCAL - O.Tsai (UCLA)

EIC R&D Committee and Detector Advisory Committee Meeting
March 25, 2021

Detector Matrix YR - Calorimetry

Crystals & Glasses

SciFi & Shashlik

HCAL

η	Nomenclature			Electrons and Photons			π/K/p		HCAL	
				Resolution σ_E/E	PID	min E	p-Range (GeV/c)	Separati	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		Central Detector	Backward Detector			50 MeV	≤ 7 GeV/c	≥ 3 σ	~45%/√E+6%	~500 MeV
-3.0 to -2.5					π suppression up to 1:1E-4	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			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)	

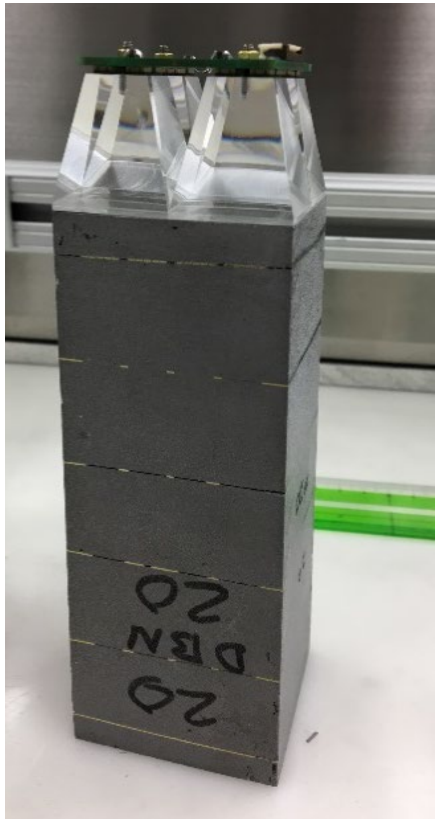
Development of W/SciFi Calorimetry for EIC

- W/SciFi technology based on a W powder/epoxy matrix with embedded scintillating fibers was developed in eRD1.
- Began with early prototype work in 2012 at UCLA and was later developed by BNL and UIUC for the sPHENIX Barrel EMCAL.
- Shown to provide an energy resolution ~ 12-15%/$\sqrt{E} \oplus$ 3% using SiPM readout and 6-7%/$\sqrt{E} \oplus$ ~ 2% using a PMT readout.
- The technology for mass production of absorber blocks was developed for sPHENIX which now has the capability for producing over 60 blocks per week. These blocks are 2D projective (η and ϕ) which are no more difficult or costly to produce that non projective blocks.
- Technology is ready to be utilized for future EIC detectors if needed.

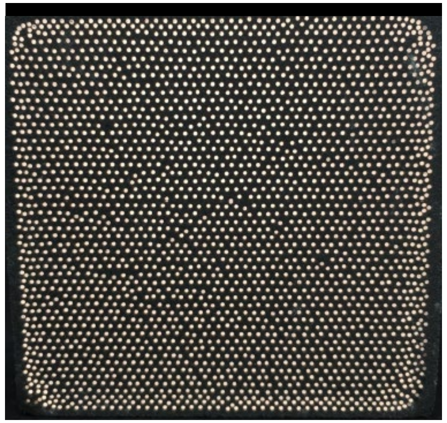
Future Developments for W/SciFi Calorimetry

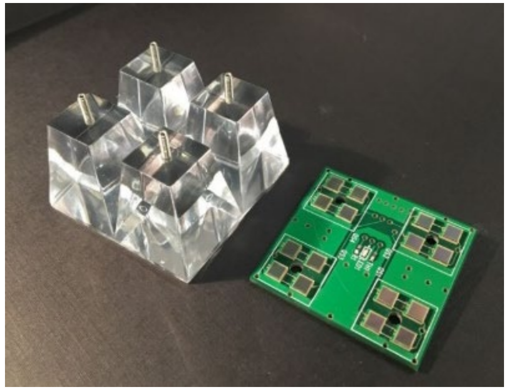
We believe we can improve the light output, energy resolution and uniformity of response of the sPHENIX calorimeter by increasing the photocathode coverage for the readout of the absorber blocks.

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



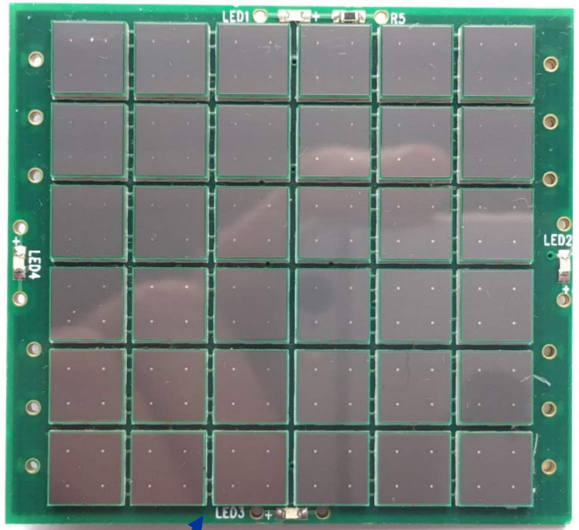
Readout end of block





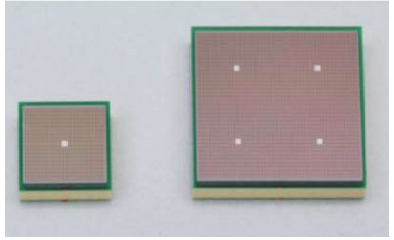
Two possible ways to increase photocathode coverage:

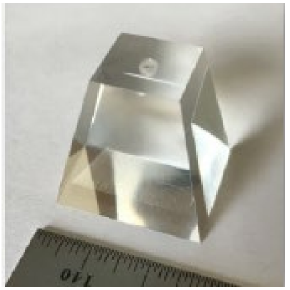
- Keep existing light guides and replace 2x2 array of 3x3 mm^2 SiPMs with four 6x6 mm^2
- Remove or cut down existing light guides and cover entire readout end of block with a 6x6 array of 6x6 mm^2 SiPMs.

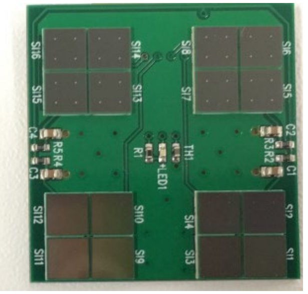


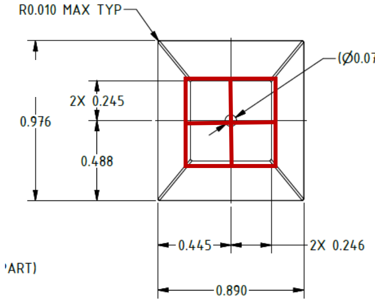
Note small gaps

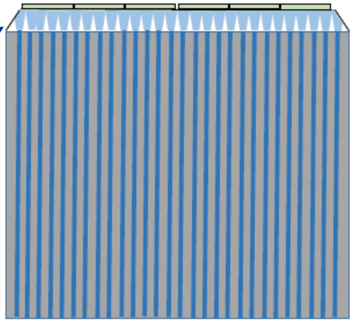
Hamamatsu S13360 6x6 mm^2 SiPM with TSVs (50 μm pixels)









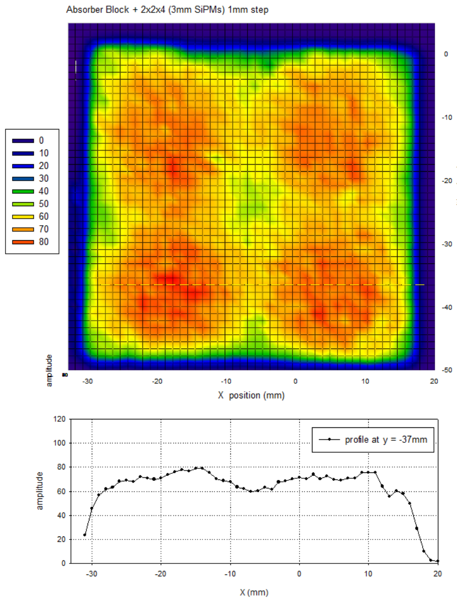


Short light guide covering entire block

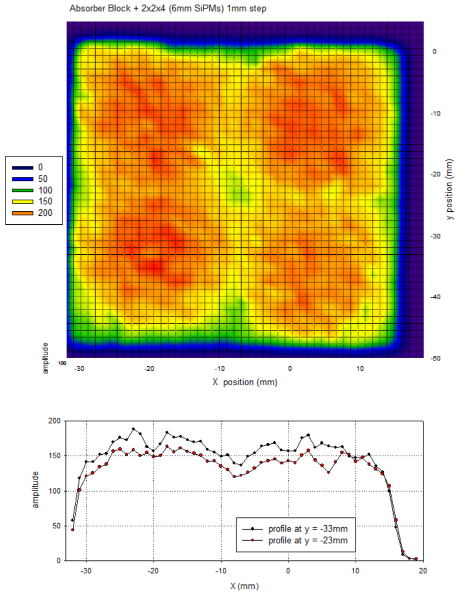
Tests with 6x6 mm^2 SiPMs

Scan of absorber block with UV LED exciting fibers from opposite end of the block read out on the front with light guides and SiPMs

Standard sPHENIX 1”light guides

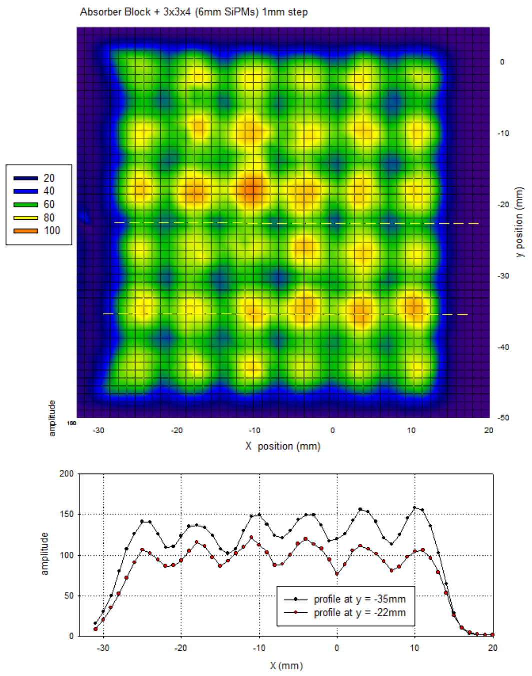


2x2 arrays of
3x3 mm^2 SiPMs



2x2 arrays of
6x6 mm^2 SiPMs

4 mm thick lucite light guide



6x6 array of 6x6 mm^2 SiPMs

Note: SiPM gains are not balanced

Conclusion: 3x3 mm^2 SiPMs already do a good job as far as uniformity but p.e. yield would be greatly increased with 6x6 mm^2 SiPMs.

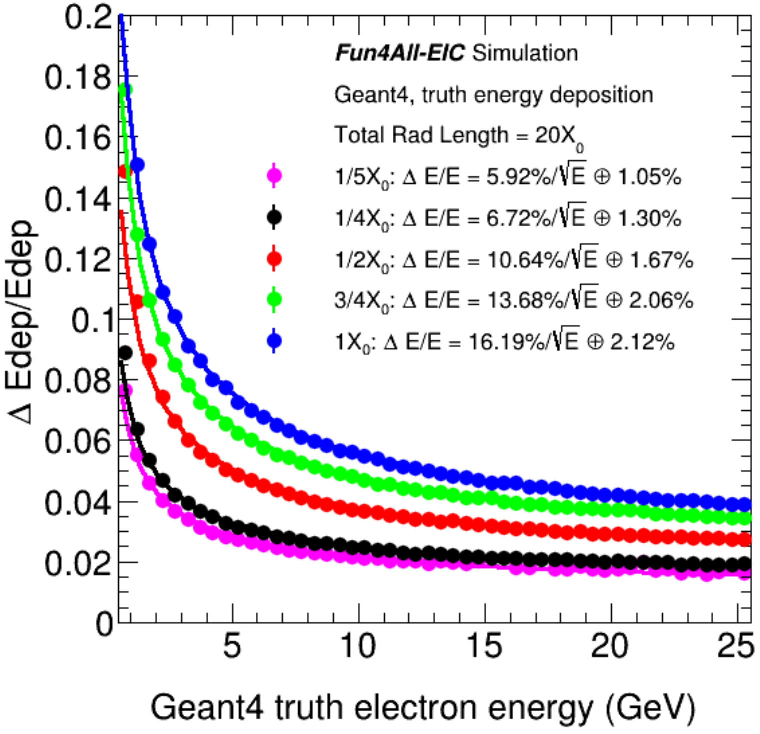
Conclusion: Light guide needs to be longer and SiPMs need to be arranged w/o gaps.

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

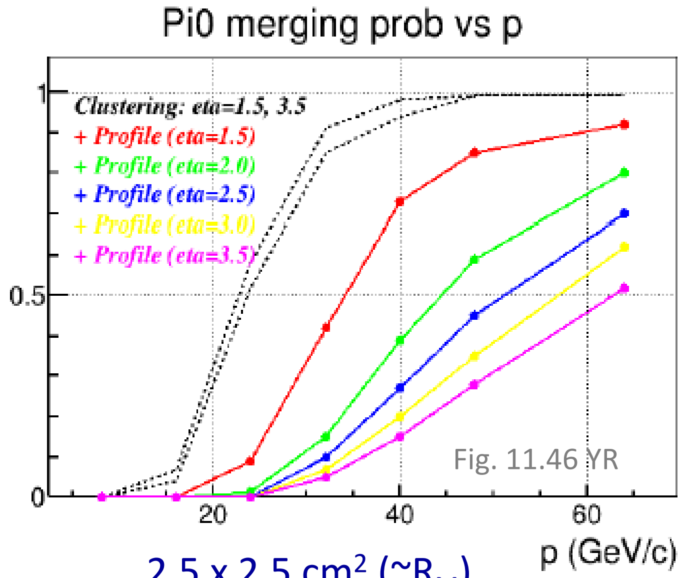
Energy resolution vs sampling fraction
20 X0 total length (L ~ 30 cm w/readout)



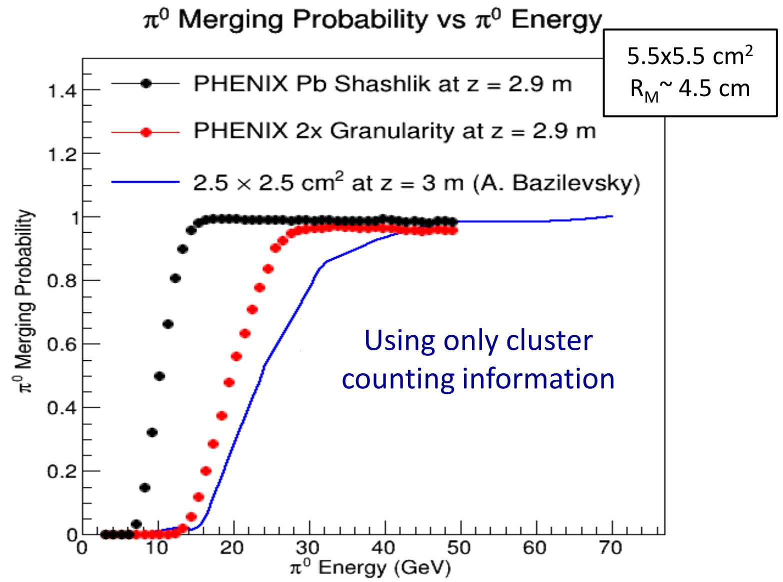
Require fine segmentation and small R_M to resolve γ/π^0 at high momentum

Comparison of the PHENIX Pb shashlik with a compact shashlik

Non projective geometry



2.5 x 2.5 cm² (~R_M)



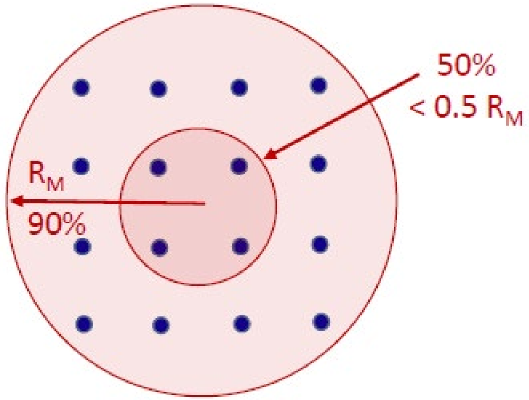
Note:

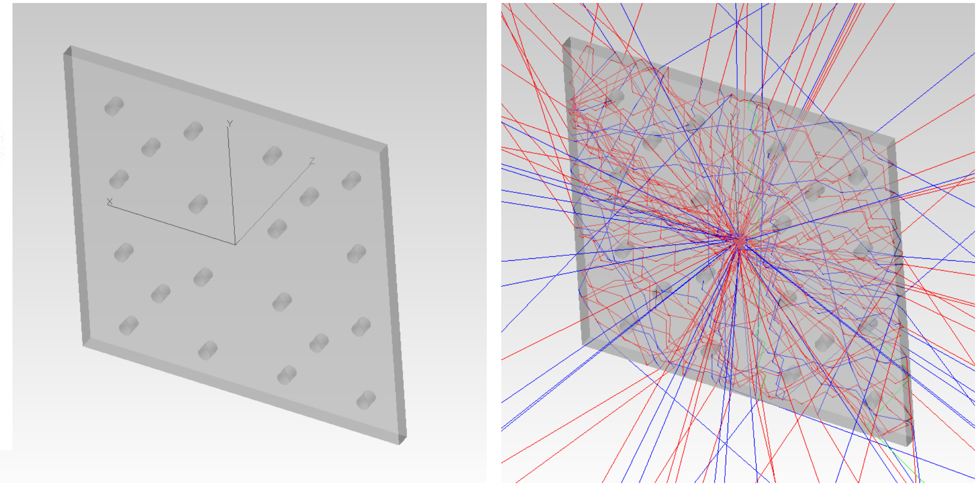
- Projective geometry will improve separation, particularly in the η ~ 1-3 region
- Can also achieve γ/π^0 separation using a preshower detector

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

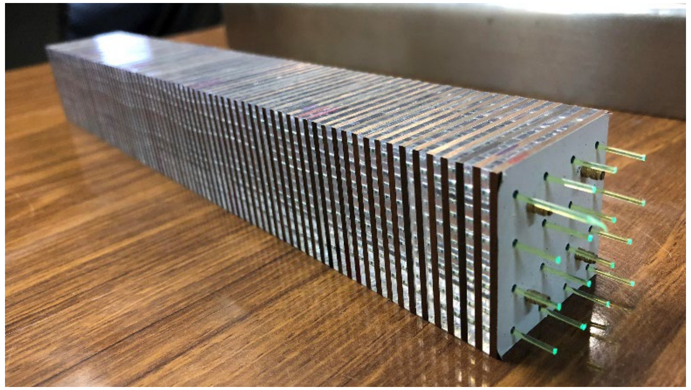
- Non-uniformities of light collection within a tile will cause a position dependence. However, this can in principle be corrected for using lab measurements and ray tracing can produce a light collection map for each fiber.

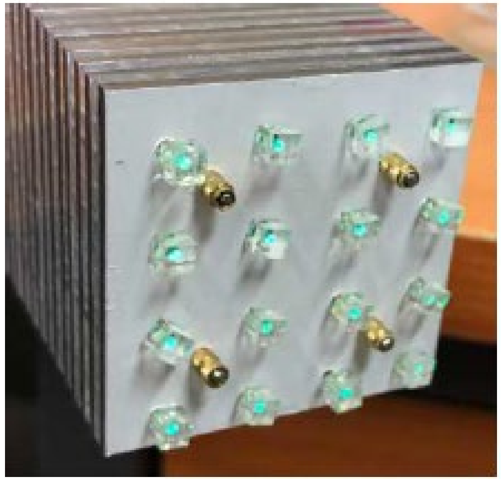
Prototype W/Shashlik EMCAL

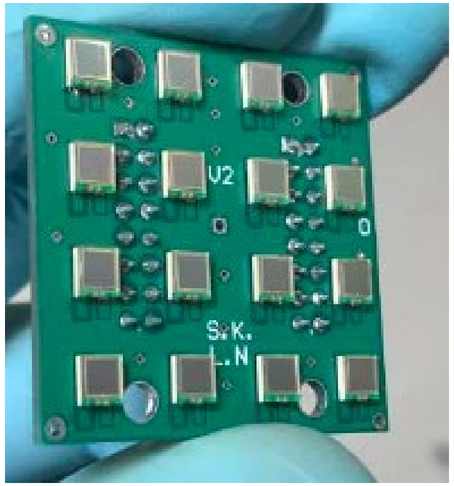
Originally designed for the NA64 Experiment at CERN (not optimized for EIC)

Andres Bello University
Santiago, Chile

- Absorber plates are a W(80%)/Cu(20%) alloy that is easily machinable
  ρ = 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

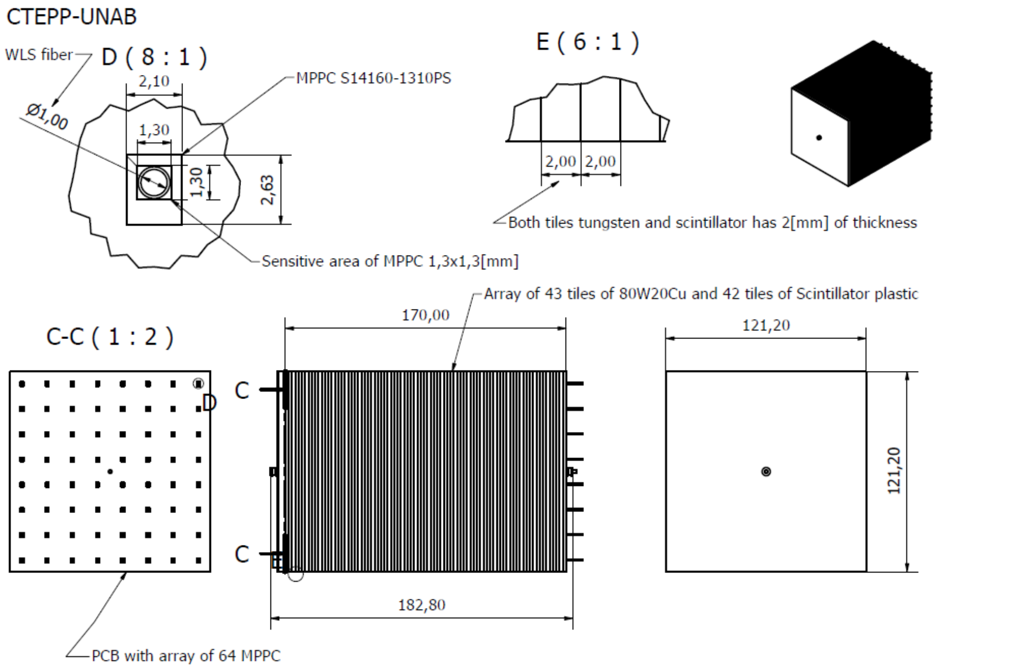

Hamamatsu S14160-3015P


3x3 module prototype

Future Plans

Build a new larger W/Shashlik prototype that is better optimized for EIC

- Larger module size (~ 12 x 12 cm^2) ⇒ fewer boundaries
- Choose sampling fraction/sampling frequency for desired resolution (~ 6-12 %/√E)
- Optimize absorber/scintillator material and thicknesses
- Investigate manufacturing techniques for plates & tiles
- Choose WLS fiber spacing to optimize light collection efficiency and uniformity
- Choose total length to minimize back leakage in our energy range
- Use smaller SiPMs (~ 1-2 mm) to read out each fiber (⇒ minimize cost)
- Construct 4 modules and arrange them in a close packed 2x2 array with minimal gap boundaries



Preliminary W/Shashlik Module Design (UNAB)

Further design will require simulations to determine and optimize the performance parameters.

Summary

- Both W/SciFi and W/Shashlik calorimeters can satisfy the calorimetry requirements for EIC over a wide range of rapidities.
- The W/SciFi technology developed for sPHENIX is now fully developed for mass production of 2D projective modules at a very high rate and at an affordable cost. However, we believe this technology can still be improved to provide better energy resolution and performance for EIC.
- The technology for producing shashlik calorimeters is also mature, but the possibility to now read out every fiber using low cost SiPMs provides a new opportunity to improve its performance.
- While a compact W shashlik provides several important advantages over Pb, it also offers new challenges in terms of design and construction that need to be investigated.
- To fully develop and study a new W shashlik design for EIC (TDR) will require ~ 2 years of R&D and would cost ~ $200-$300K.
- Both of these efforts are severely limited by the lack of manpower, particularly at BNL where the sPHENIX group is currently fully committed to the construction of the sPHENIX EMCAL and HCAL. *Both efforts would benefit significantly from the addition of new collaborators and by having a dedicated postdoc and/or graduate students.*

Backups

eRD1 Consortium

Collaborators

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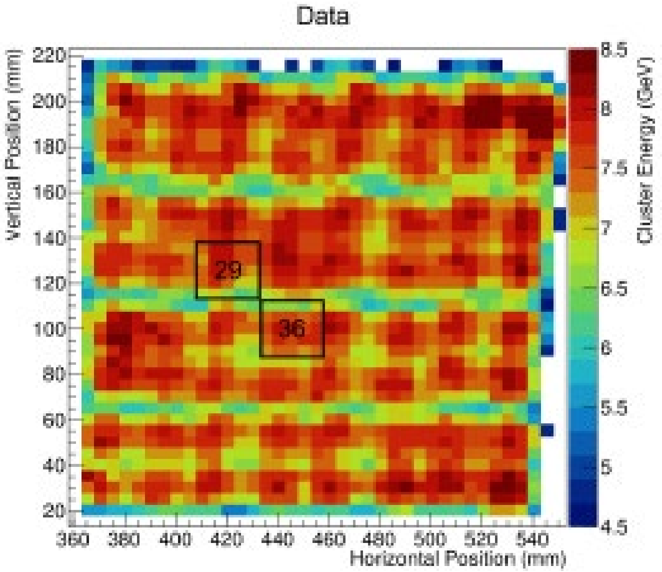
AANL, Armenia

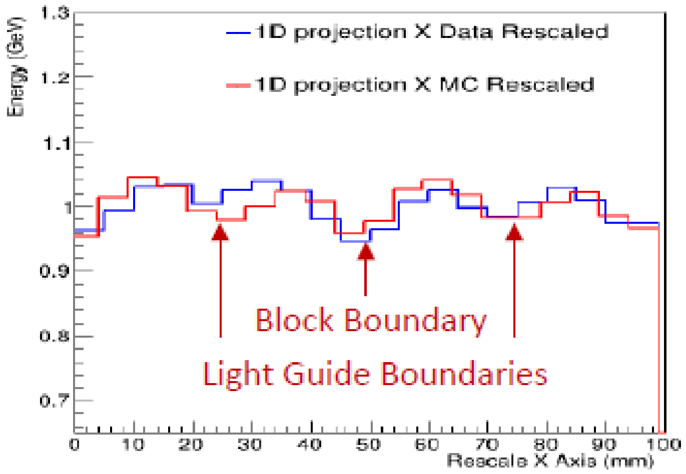
18 Groups/Institutions
~ 70 Individuals

Uniformity of W/SciFi - Effect on Energy Response

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

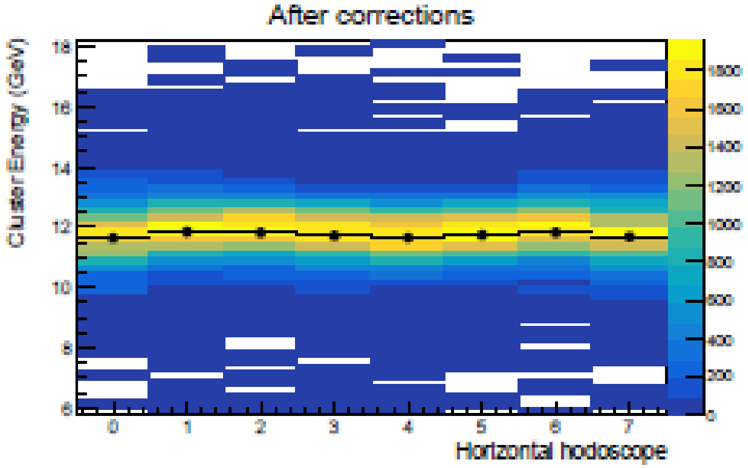
Uniformity of response over 8x8 towers with 8 GeV electrons (Test Beam Data)

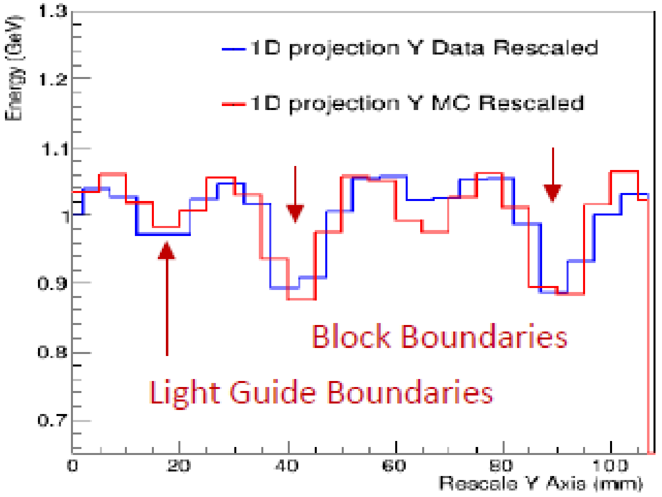




X axis projection

Uniformity after position dependent correction



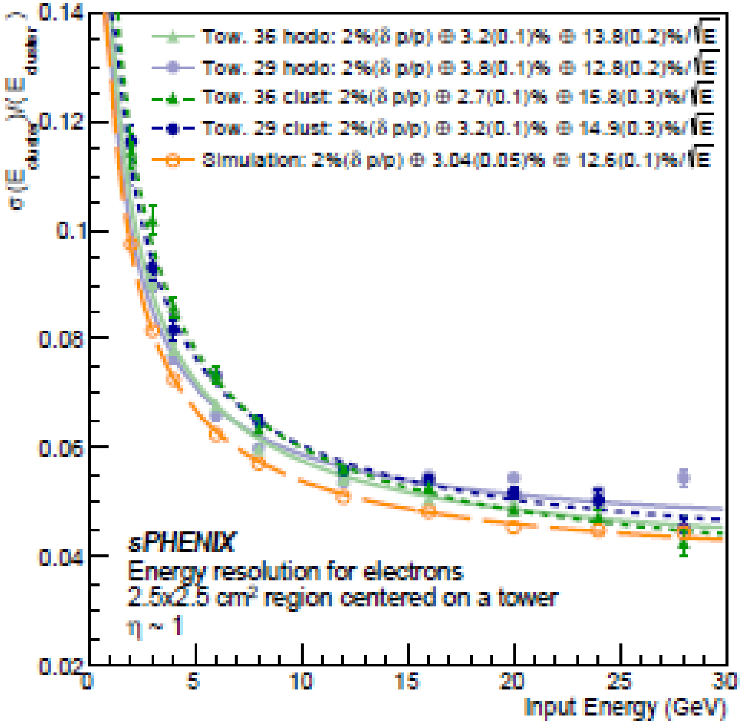


Y axis projection

Energy Resolution

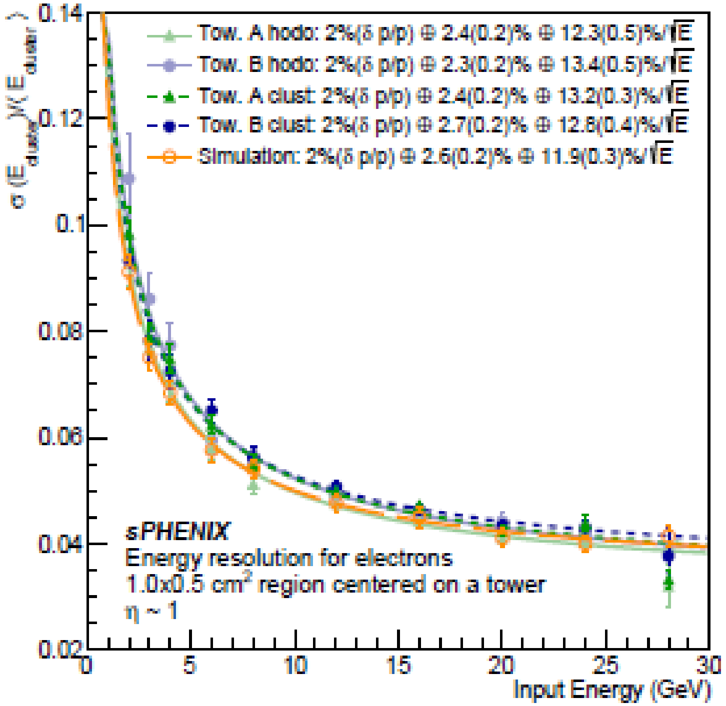
Energy resolution after position dependent correction

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



Resolution ~ (13-15)%/√E ⊕ 3%

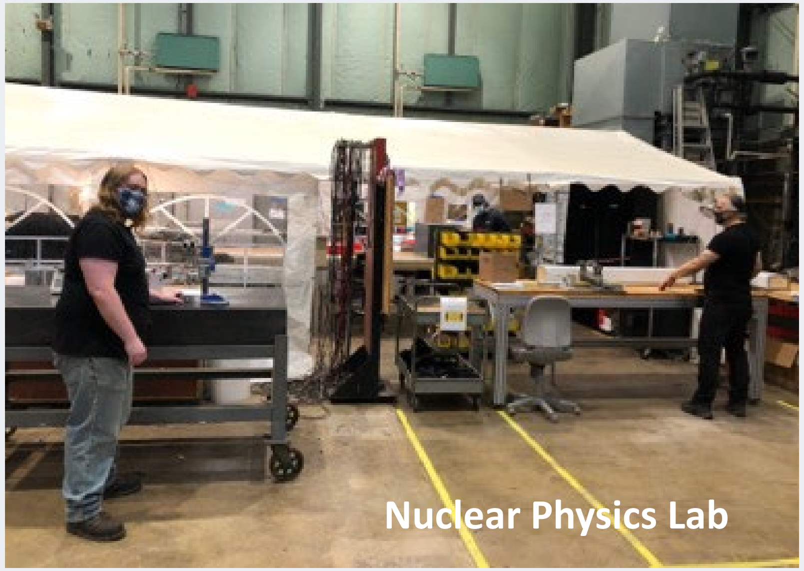
Beam covering a 1.0 x 0.5 cm^2 area centered on a tower

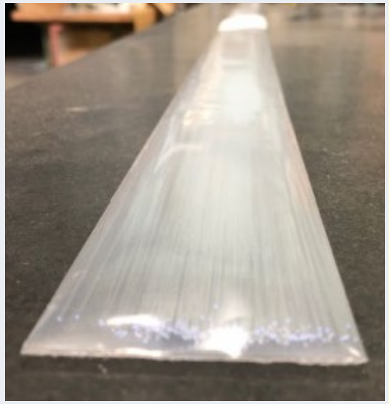


Resolution ~ (12-13)%/√E ⊕ 2.5%

sPHENIX EMCAL Under Construction (Completion - Jan 2022)

Block Production at UIUC (also Fudan U - Shanghai)



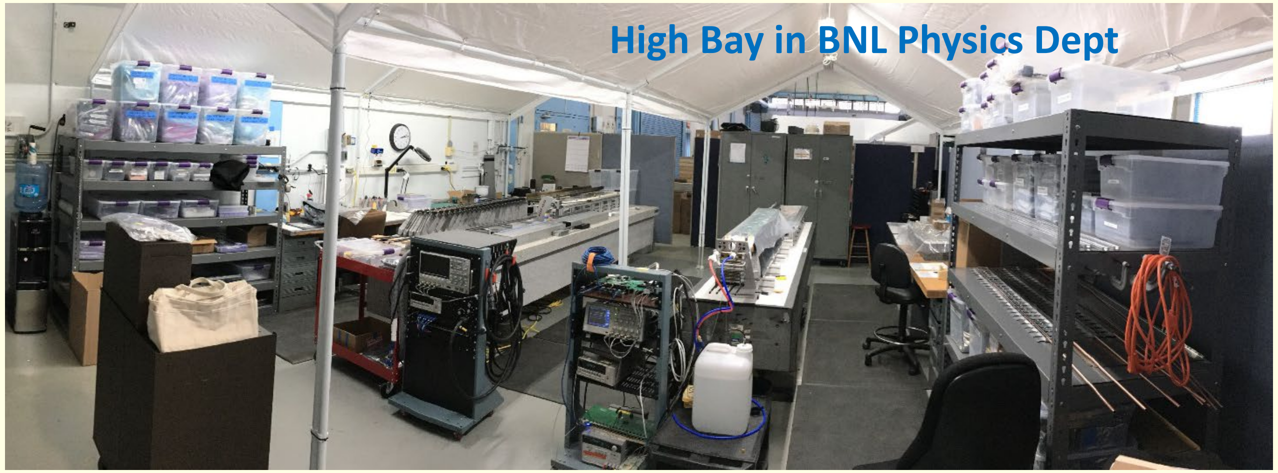


2600 km of fiber
665 kg of epoxy
88 m^2 of screens

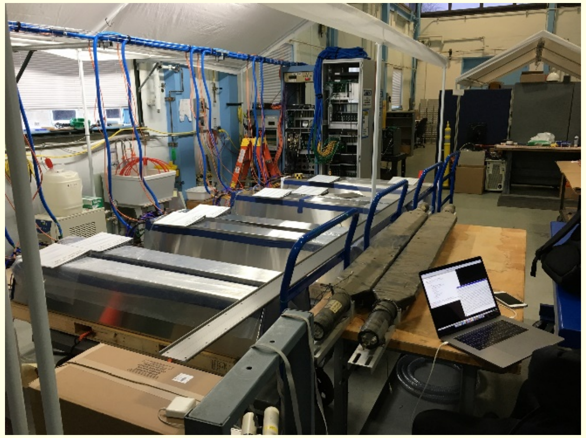
20 Tons of W powder

Blocks awaiting removal from molds

Module and Sector Production at BNL



Modules being glued into sectors



Sector Burn-in and Testing

Crystals & Scintillating Glasses

C. Munoz-Camacho (Orsay)

Homogeneous EM Calorimeter R&D for EIC

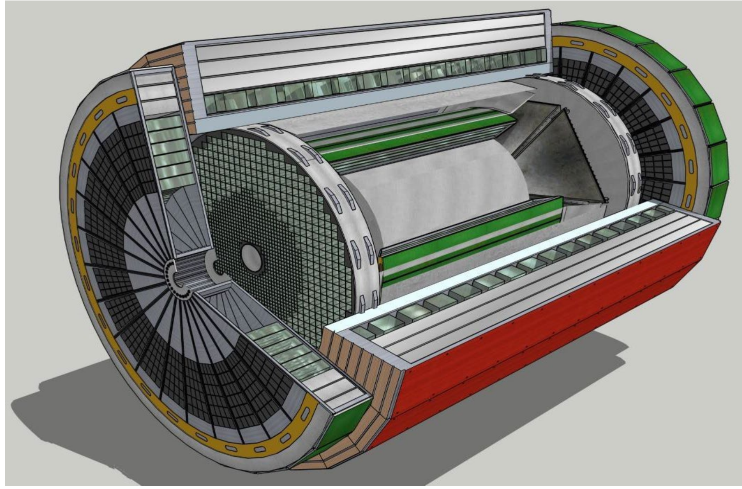
(part of eRD1)

S. Ali, M. Battaglieri, V. Berdnikov, J. Bettane, M. Bondi, A. Celentano, J. Crafts, D.Damenova, R. DeVita, C. Fanelli, T. Horn, G. Hull, M. Josselin, J. Paez Chavez, I.L. Pegg, M. Purschke, L.Marsicano, C. Munoz-Camacho, P. Musico, H. Mkrtchyan, E. Nguyen, M.Osipenko, E. Rindel, M. Ripani, H. San, A. Somov, S. Stoll, V. Tadevosyan, M.Taiuti, R. Trotta, C. Walton, R. Wang, C. Woody, R-Y. Zhu

A.I. Alikhanyan National Science Laboratory/Yerevan, Catholic University of America, The Vitreous State Laboratory, Institut de Physique Nucleaire d'Orsay/France, Jefferson Laboratory, Brookhaven National Laboratory, Caltech, MIT

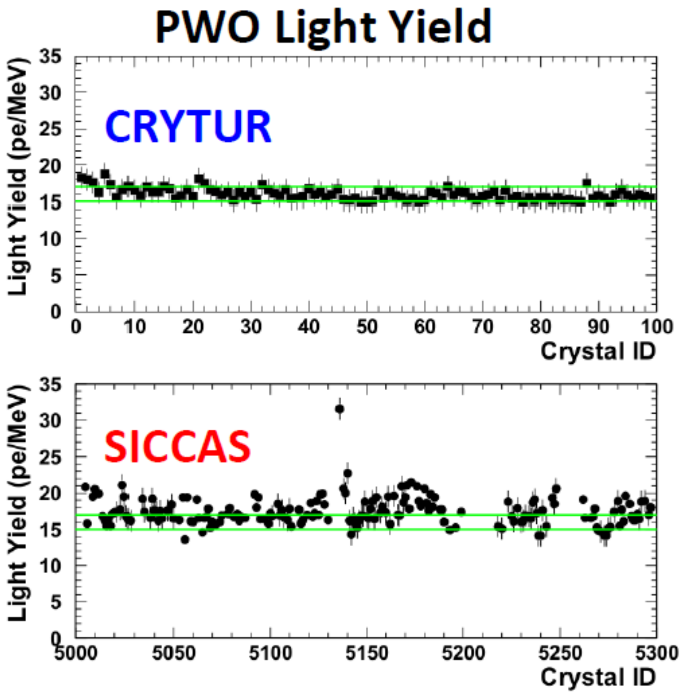
Outline

- $PbWO_4$ crystals for high resolution e-endcap EM calorimeter (R&D largely completed)
- SciGlass for cost effective high resolution EM calorimeter (short-term – about 1 year – R&D needed)
- SCGlass for potential improvement of hadron calorimetry (medium-term – about 3 years – R&D needed)



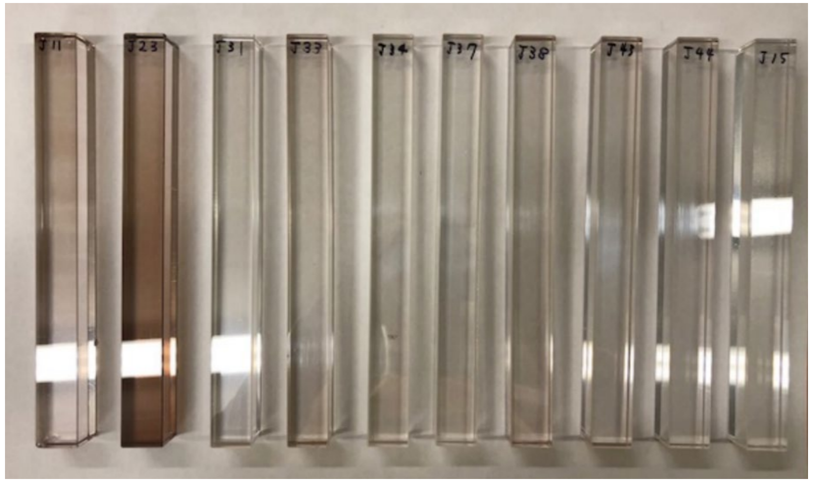
$PbWO_4$ (PWO) crystals: manufacturers

- ❑ Up to 2010 – PWO-II production at BTCP, Russia
  - ➢ Missing funding -> bankruptcy of BTCO
- ❑ Limited availability of reliable SICCAS (China) crystals that would be compatible with experiment requirements
  - ➢ ~900 produced for JLab projects since 2017 – Q&A concerns, 30-40% rejection
- ❑ 2014 – restart of high-quality PWO-II production at CRYTUR, Czech Republic
  - ➢ ~900 produced for JLab projects since 2018 at rate of ~20-30 crystals /month
- ❑ Cost of PWO crystals (\$15-25/cm^3)



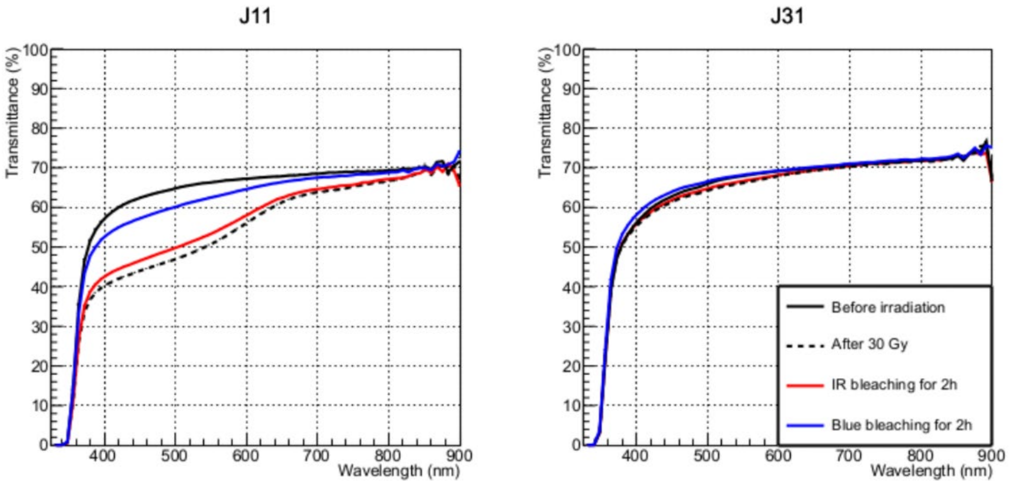
PWO: radiation hardness

^{60}Co source irradiation



SICASS: 0.5 MRad

Crytur: 1 MRad

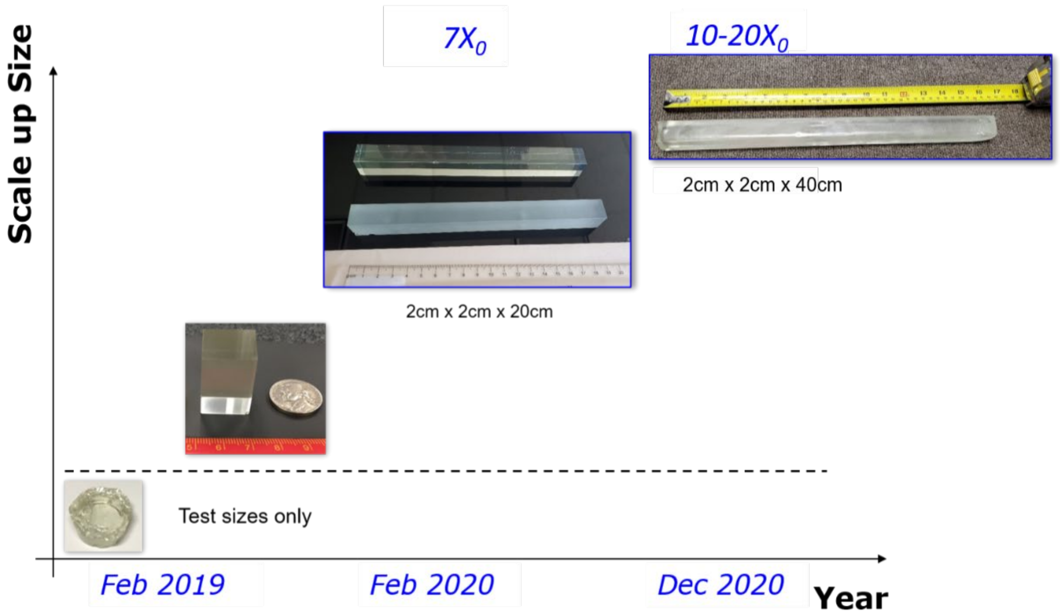


Nucl. Instrum. Meth. A956 (2020) 163375. ArXiv: 1911.11577

Glass Scintillator - SciGlass

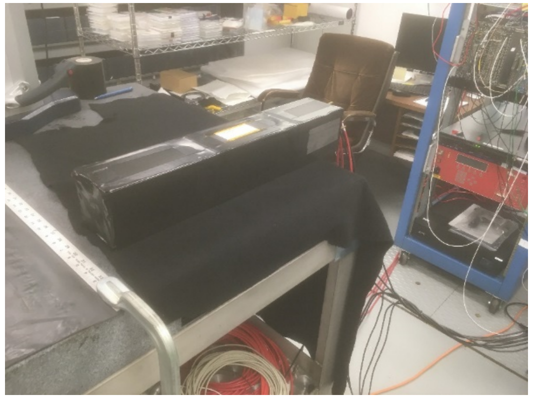
SCINTILEX

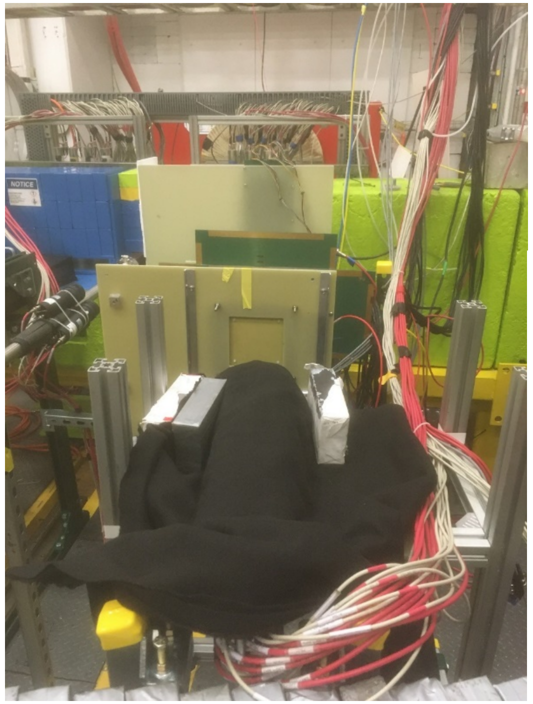
- SciGlass is a radiation hard material optimized to provide characteristics similar to or better than PbWO4.
  - Fabrication is expected to be cheaper, faster, and more flexible than PbWO4 crystals.
- SciGlass is being developed by Scintilex, LLC in collaboration with the Vitreous State Laboratory at CUA.



- Tremendous progress has been made in the formulation and production of SciGlass that improves properties and solves the issue of macro defects.
- Scintilex has demonstrated a successful scaleup method and can now reliably produce glass samples of sizes up to ~10 radiation lengths.
- R&D needed: demonstrate scale up to block sizes ≥15 X0. Investigate the consistency of product quality over many repetitions of bar production

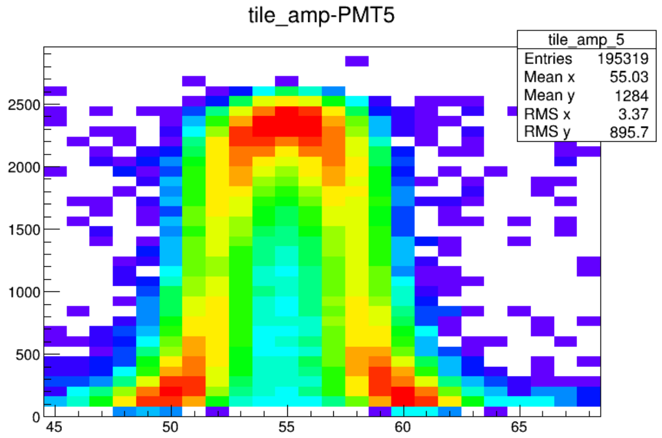
Prototype tests - status

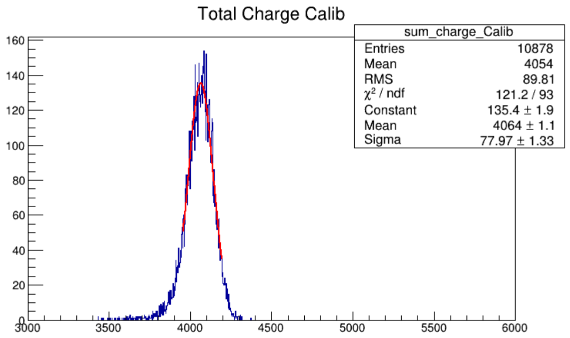




- ✔ ❑ Instrument two 3x3 SiPM and PMT based prototypes to test scintillator materials and test/optimize the entire readout: preamps, fADC and streaming DAQ system
- ✔ ❑ Establish baseline performance with PMT based PWO prototype and standard RO – performed a few test runs
- X ❑ Tests in Hall D with 8 production configurations

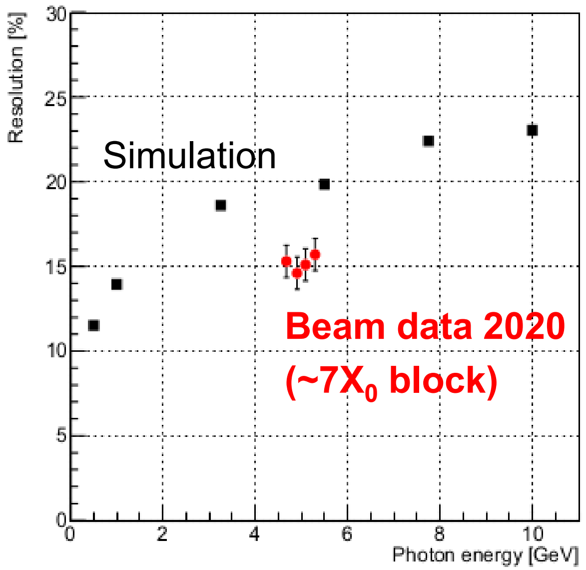
Covid-19 closures of labs and universities

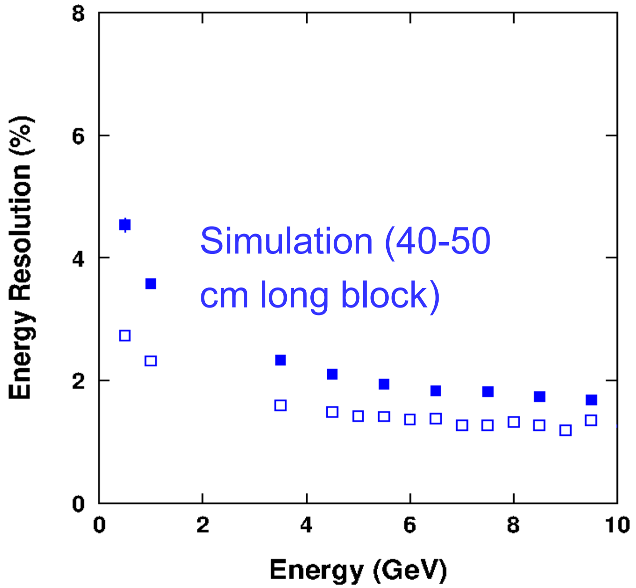




Energy resolution ~1.9% for ~4GeV lepton

SciGlass – Prototype tests





- ❑ Test with 2cm x 2cm x 20cm (~$7X_0$) SciGlass blocks: the preliminary results show an energy resolution of ~15% for a 5.2 GeV particle energy.
  - The slightly better performance observed in the experiment is due to the difference in composition/density of the SciGlass and the base composition

- ❑ Simulations combined with initial beam tests at photon energies of 4-5 GeV suggest that high resolution competitive with PbWO4 can be reached for ≥15 X0.

- ❑ R&D needed: carry out prototype beam test program with to establish SciGlass characteristics

Radiation Hardness – initial tests complete

SCINTILEX

EM irradiation:

- ~1 MeV Co-60
- 160 keV Xray

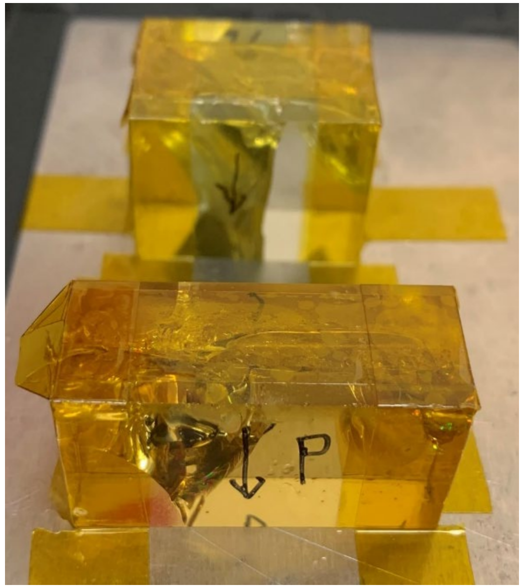
Before irradiation

After 2min 160KeV Xray at >3k Gy/min

Hadron irradiation:

- 40 MeV protons

Photograph taken immediately after irradiation. No visual evidence of radiation damage (don't get fooled by the yellow Kapton tape)



Fluence: 2E15 p/cm^2

Fluence: 1E15 p/cm^2

- ❑ G, T, SC, EC series are EM radiation hard
- ❑ G, SC series are radiation hard under hadron irradiation

SciGlass Scale-up and production

SCINTILEX

- ✓ Control of process chemistry and material properties
  - glass composition optimization and process modifications to improve uniformity and prevent the formation of bubbles and inclusions

- ✓ Demonstrate basic production processes from a few centimeters up to 2 cm x 2 cm x 20 cm polished bars

- ❑ Extend demonstration of basic production processes up to (2-4) cm x (2-4) cm x 40 cm polished bars (~20 X_0) – first block produced in December 2020 ✓

Essential: SBIR/STTR Phase 2 (submitted proposal for 2021/22)

- ❑ Investigate the consistency of product quality over many repetitions of bar production in order to assess the statistical distributions of key properties

- ❑ Identify and understand the process parameters that affect these distributions and develop and implement process controls to ensure that the variations of these properties remain within acceptable ranges

- ❑ Selection and optimization of process features that are best suited to the projected production rates that are likely to be required

➢ **SciGlass STTR Phase 2 was submitted – CSGlass STTR Phase 1 was awarded!**

SciGlass development timeline estimate

The approximate timeline for completing the SciGlass R&D is about one year assuming R&D funds are available. The goal is to be ready for a day-1 detector. SciGlass could also be available for future detector upgrades.
The estimated cost is $66.5k, which was approved in July 2020, but the funds have not yet been received.

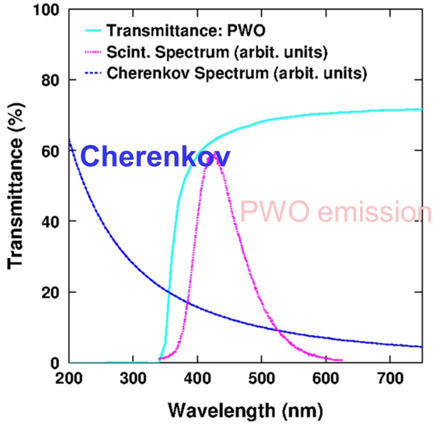
Item	Task	FY20				FY21				FY22				FY23		
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
Fabrication	Composition optimization															
	Characterization															
	Scale up and demo 4x4x40cm^3															
	Show uniformity and reproducibility															
	Fabrication process optimization															
	Performance tests with prototype															
	Process design verification to scale up															
	Large scale production study															
Simulations	Prototype															
	Design options															
	Cost/performance optimization															
Prototype	Base version															
	Initial commissioning															
	Upgrade and commissioning															
Beam test	Beam test															
	Data analysis															

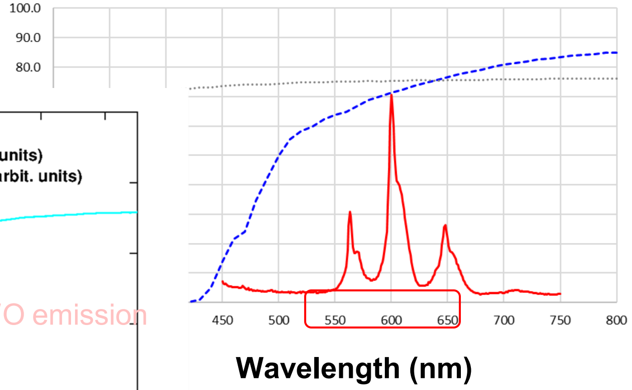
CherenkovScintillation (CS) Glass

- ❑ CSGlass could be of interest for precision hadron calorimetry with dual readout, where Cherenkov and Scintillation light are detected in the same detector

- ❑ CSGlass is derived from SciGlass and expected to be similarly resistant to EM and hadron irradiation up to 100 Gy and 1015 n/cm2

- ❑ R&D needed: demonstration of CSGlass with sufficient UV transparency for Cherenkov light collection, clear separation of Cherenkov and Scintillation light of sufficient intensity (slow scintillation, > 500 nm beneficial), low cost, and characterization of CSGlass in the lab and with test beam R&D prototypes.

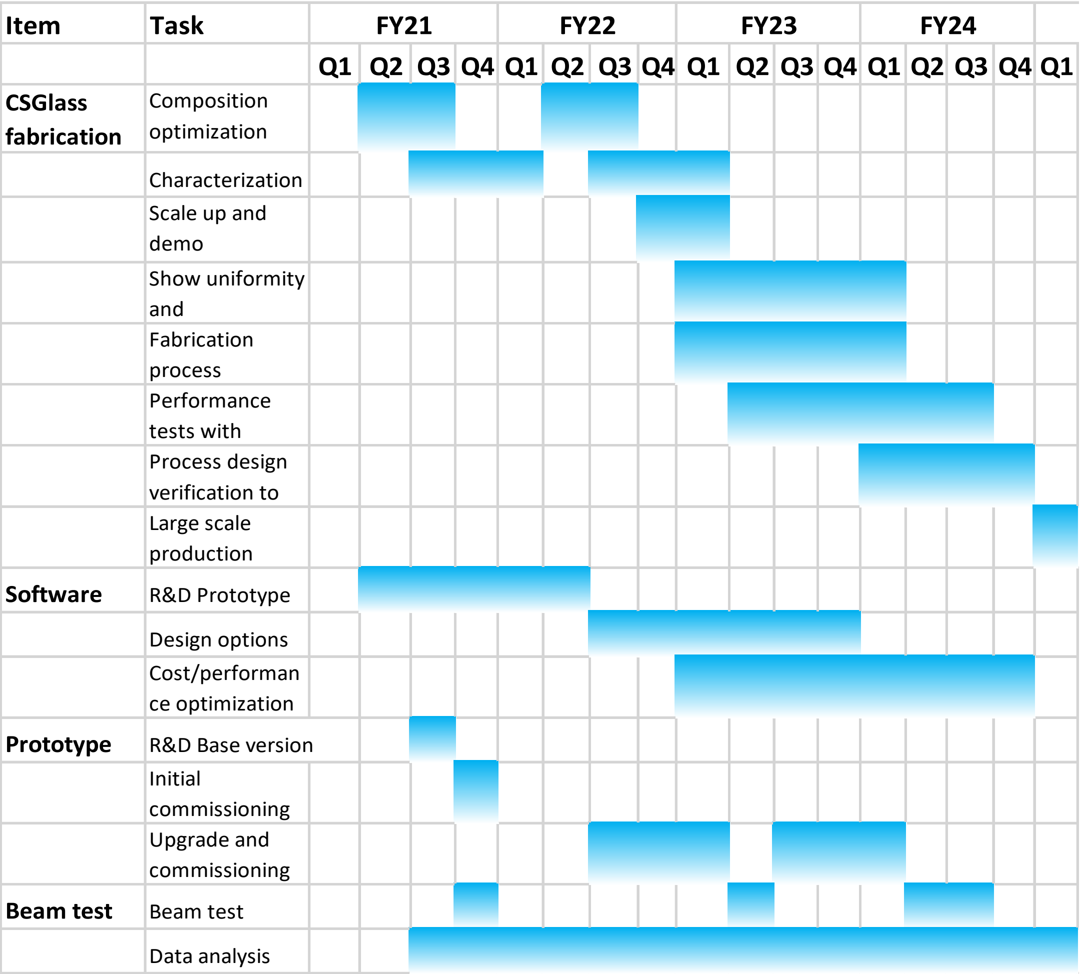




Very high-density compared to nominal, emits at >550nm, good LY

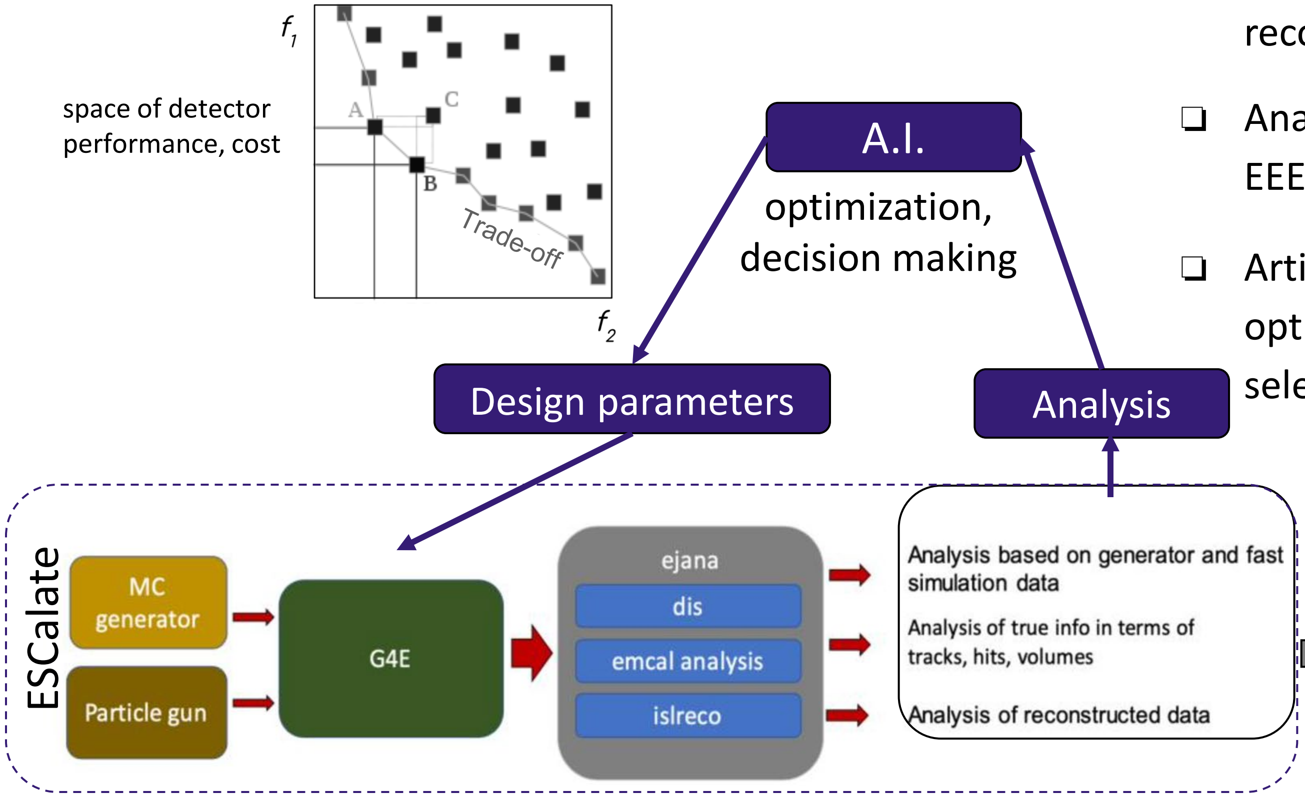
CSGlass development timeline estimate

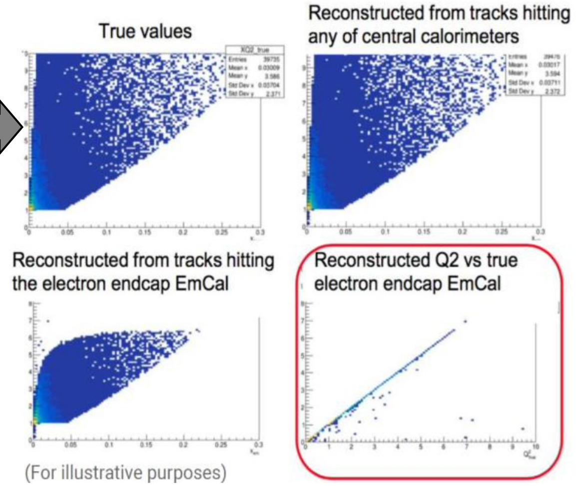
The approximate timeline for completing the CSGlass R&D is around three years assuming R&D funds are available. CSGlass could be ready for future detector upgrades. The estimated cost for this R&D is $60k/year for three years.



Other activities: simulations to further optimize material & configuration

- GEANT4 simulation including geometry, readout digitization, and reconstruction algorithms
- Analysis plugins for studies of the EEEMCal performance
- Artificial Intelligence Framework to optimize crystal/glass material selection in the shared rapidity region





Conclusion and outlook

- The anticipated technology for the EM calorimeter of the electron endcap (PWO+SciGlass) is mature and will be ready for day 1

  Remaining tasks: SciGlass scale-up and scale production
  Beam tests with prototypes

- CSGlass for hadron calorimetry still requires some R&D (about 3 years, with and estimated cost of $60k/year)

  This could be available for future EIC detector upgrades

Long-term goal:

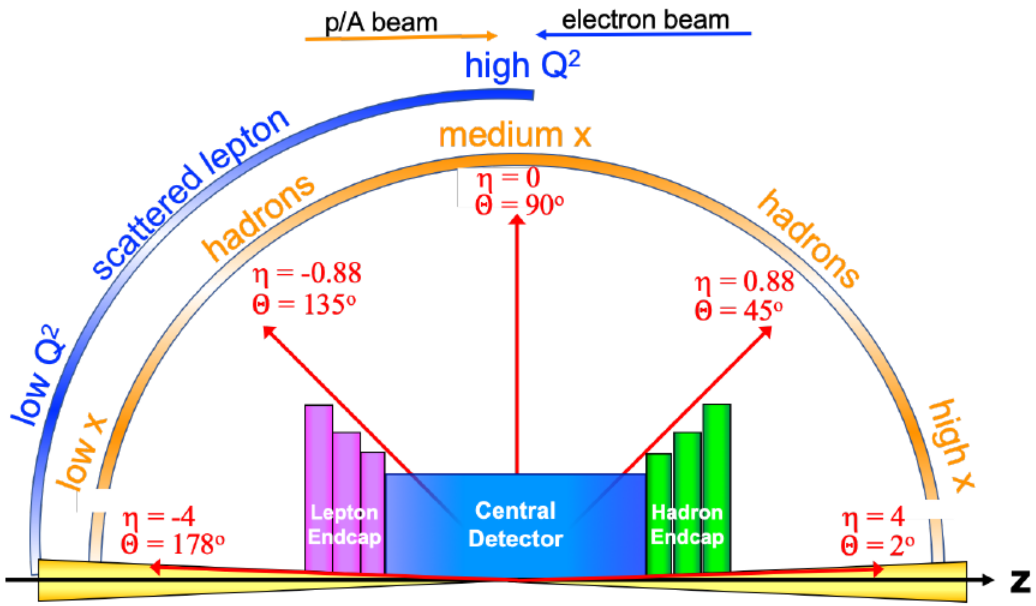
- Our collaboration would like to construct the electron endcap EM calorimeter (PWO/SciGlass)
- An Expression of Interest (EEEMCal) was submitted by *CUA, FIU, MIT, U. of Kentucky, Lehigh U, Chalres U./Prague* & international institutions *IJCLab-Orsay, AANL-Armenia*

W/SciFi EMCAL & Fe/Scint HCAL

O.Tsai (UCLA)

eRD1 Progress Report and proposal.

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

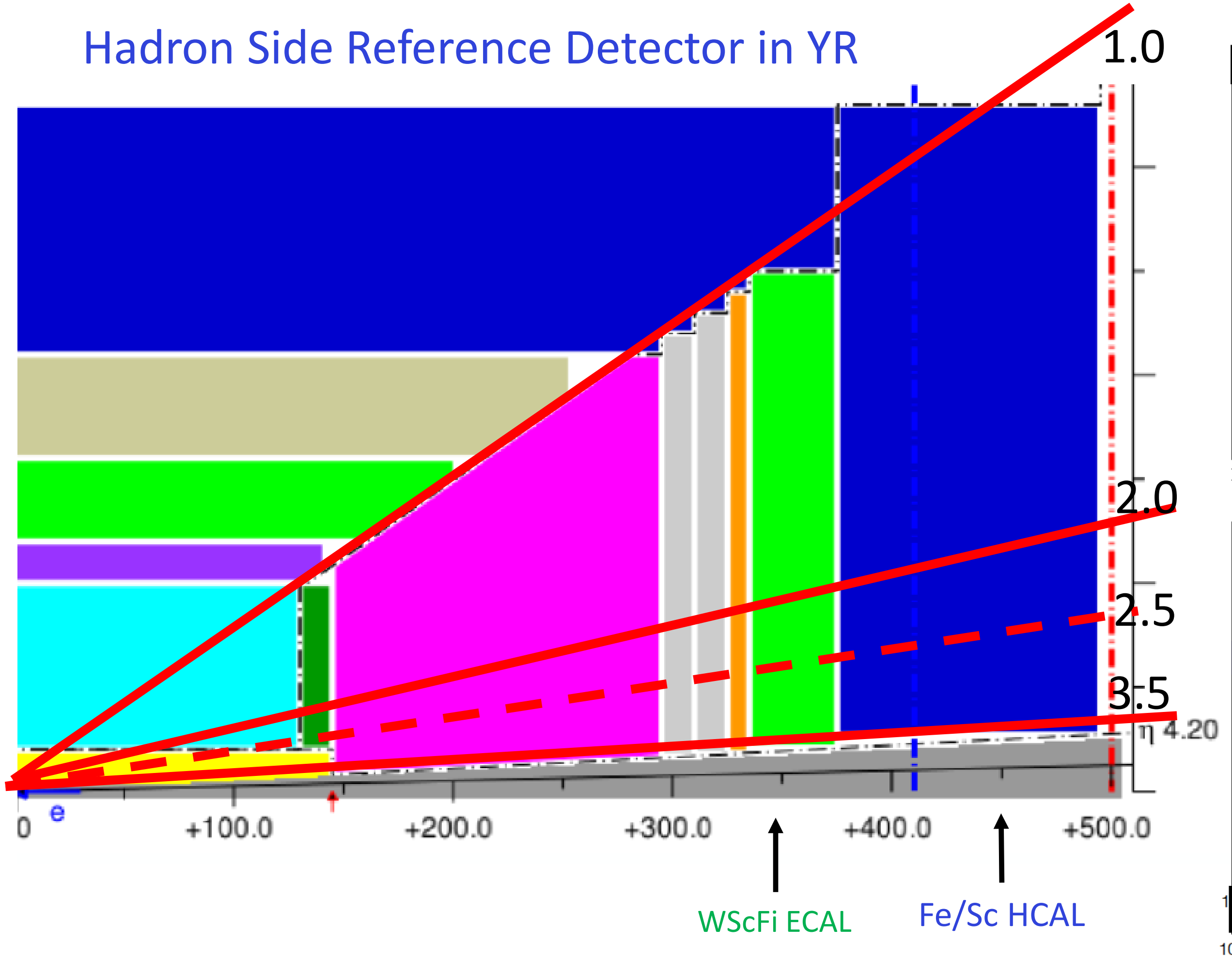


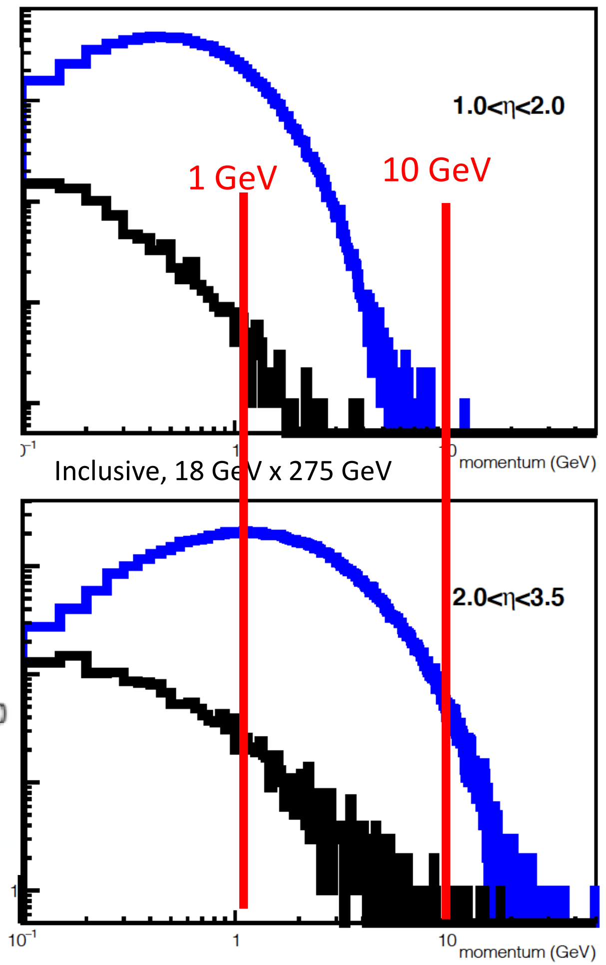
- Optimization of forward calorimeters system for EIC
- Construction of STAR Forward Calorimeter System

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.

⟷

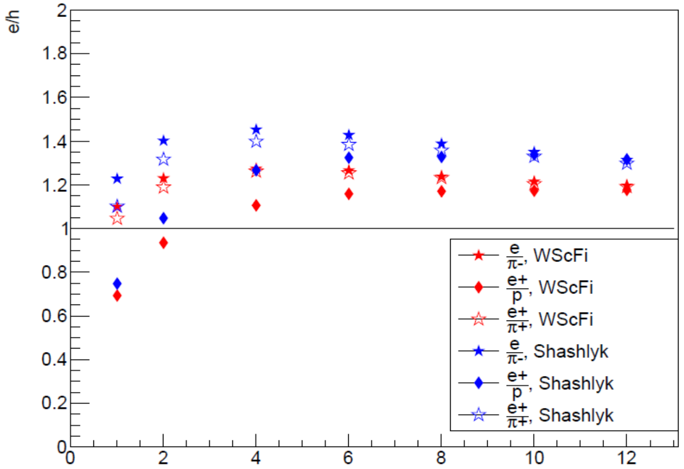
Standard detector technologies should work fine.

Hadron calorimeter systems. Challenges.

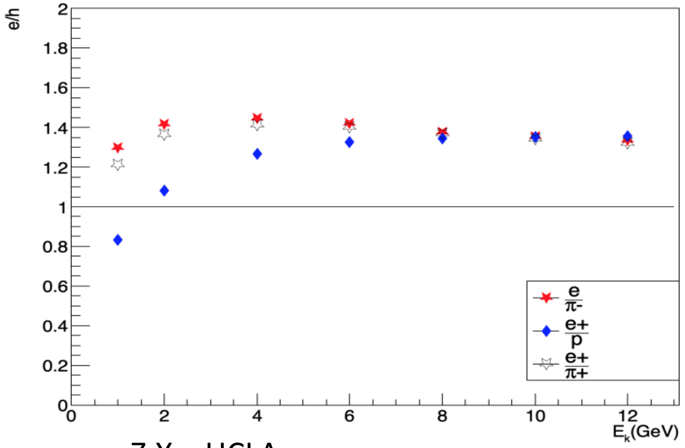
- $e/h \neq 1$
- $e/h\_ecal \neq e/h\_hcal$
- $e/h = f(E)$
- $e/p \neq e/\pi$
- $f_{em} = 0.11 \ln[E(GeV)]$

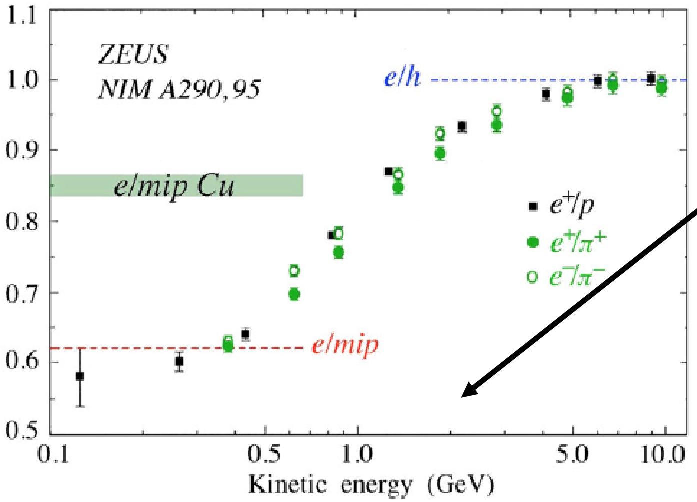
Jet energy resolution is always poorer than for a single hadron.
Despite ~ 20% of jet energy (em) measured very accurately by Ecal.

e/h for WScFi vs Shashlyk at 20 degree



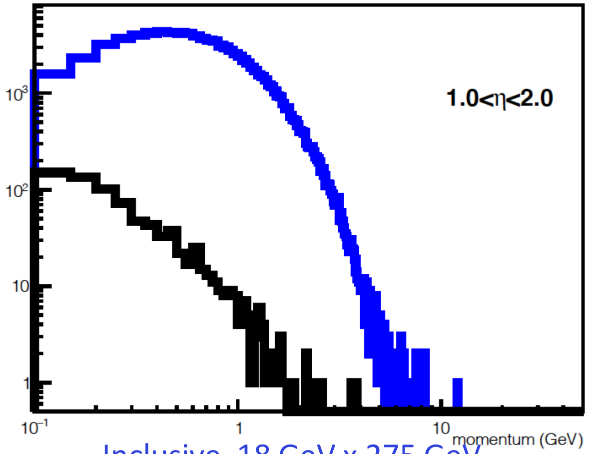
e/h for Fe/Sc at 20 degree





EIC Calorimetry need measurements
In this energy range.

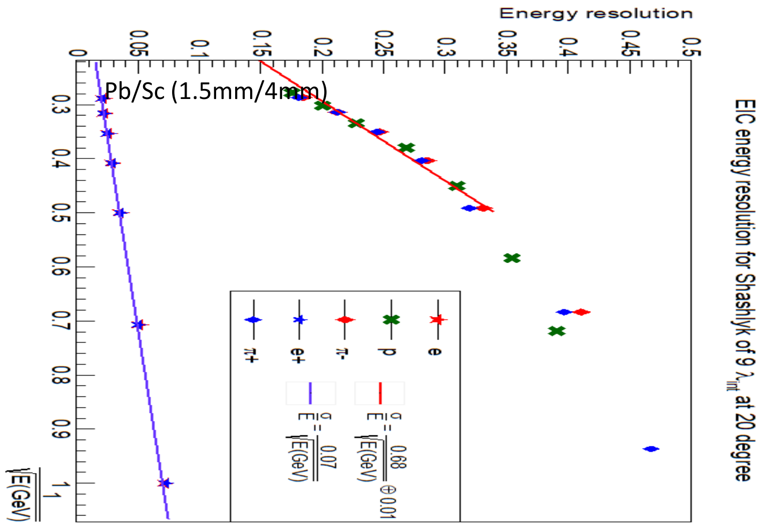
- ZEUS are experimental results
- eRD1 – GEANT4 with physics list validated for LHC.
- Validation of MC can be done only using experimental data form detector with correct chemical composition.

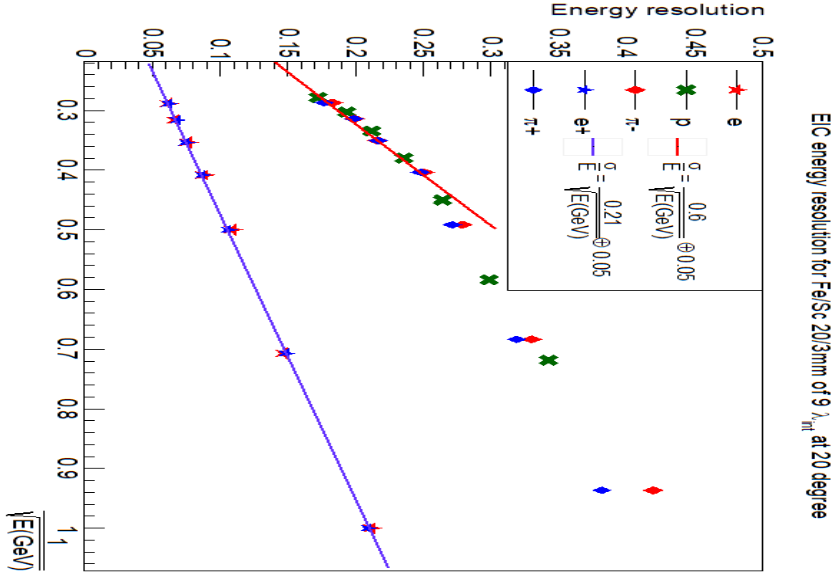


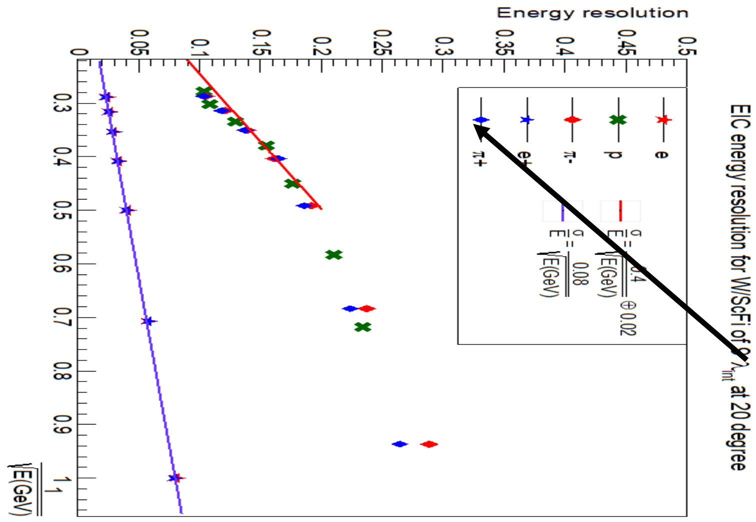
Inclusive, 18 GeV x 275 GeV

Z.Xu UCLA

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







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

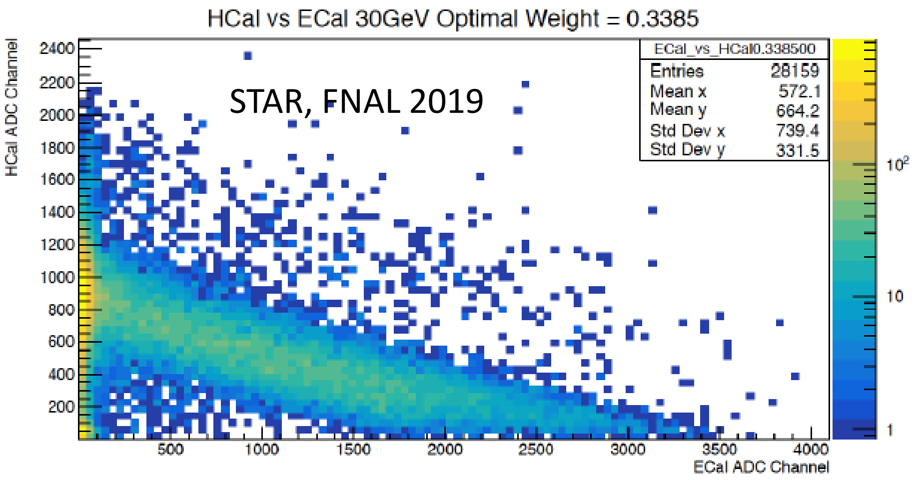
- SHASHLYK (Phenix, STAR Forward)
- WScFi (STAR Forward 2014)
- Fe/Sc (STAR Forward 2020)

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

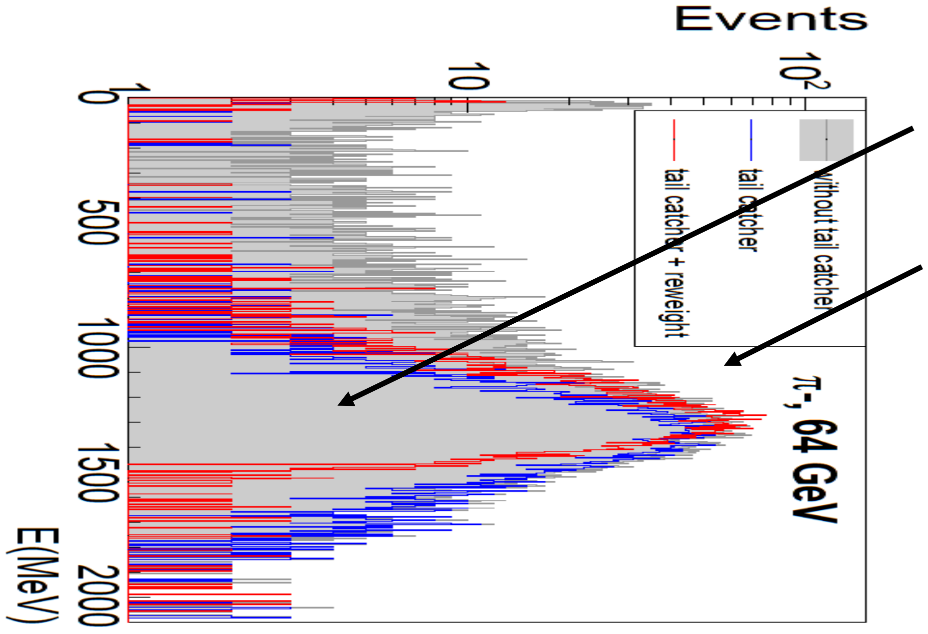
N.B. these are MC not an experimental results.

Z.Xu UCLA

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. $E_i' = E(1 - \frac{C}{E_{tot}} E_i)$



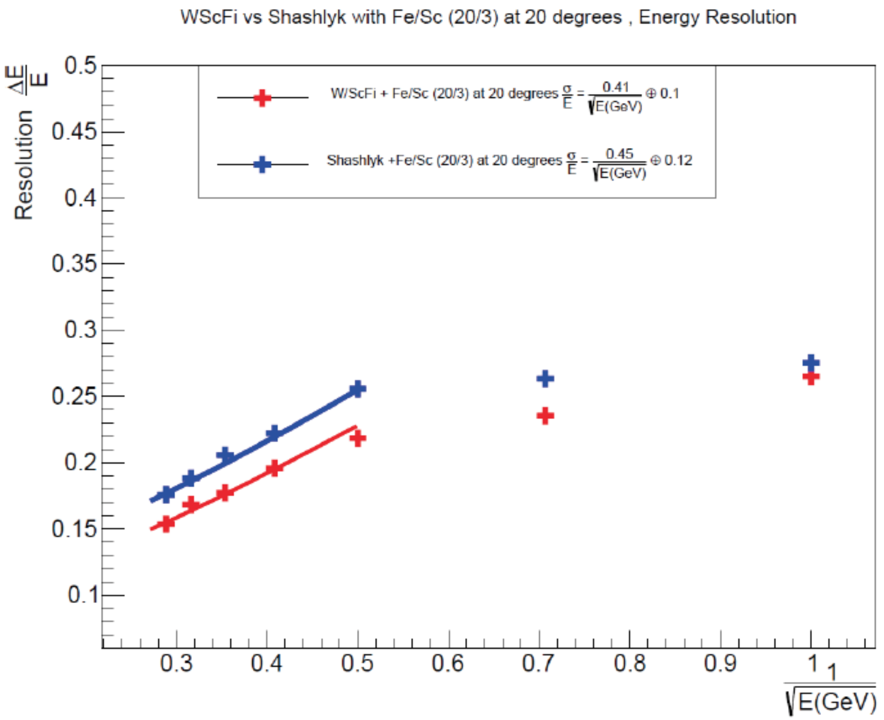
Tail catcher, handle to controls leakages.

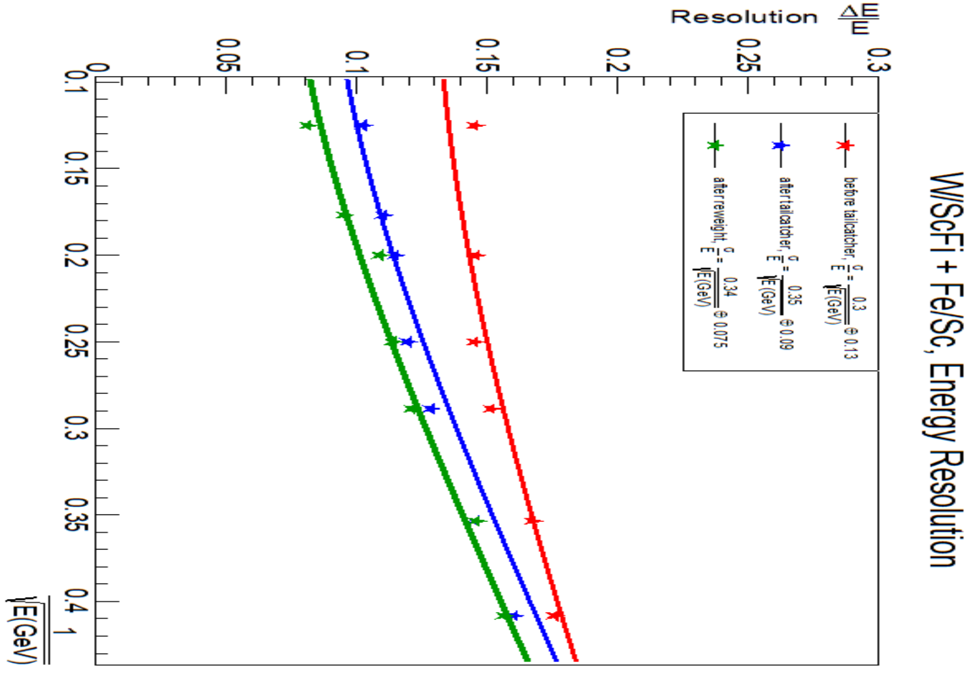
Re-weighting Hcal towers helps to deal with abnormally high f_{em} events.

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.

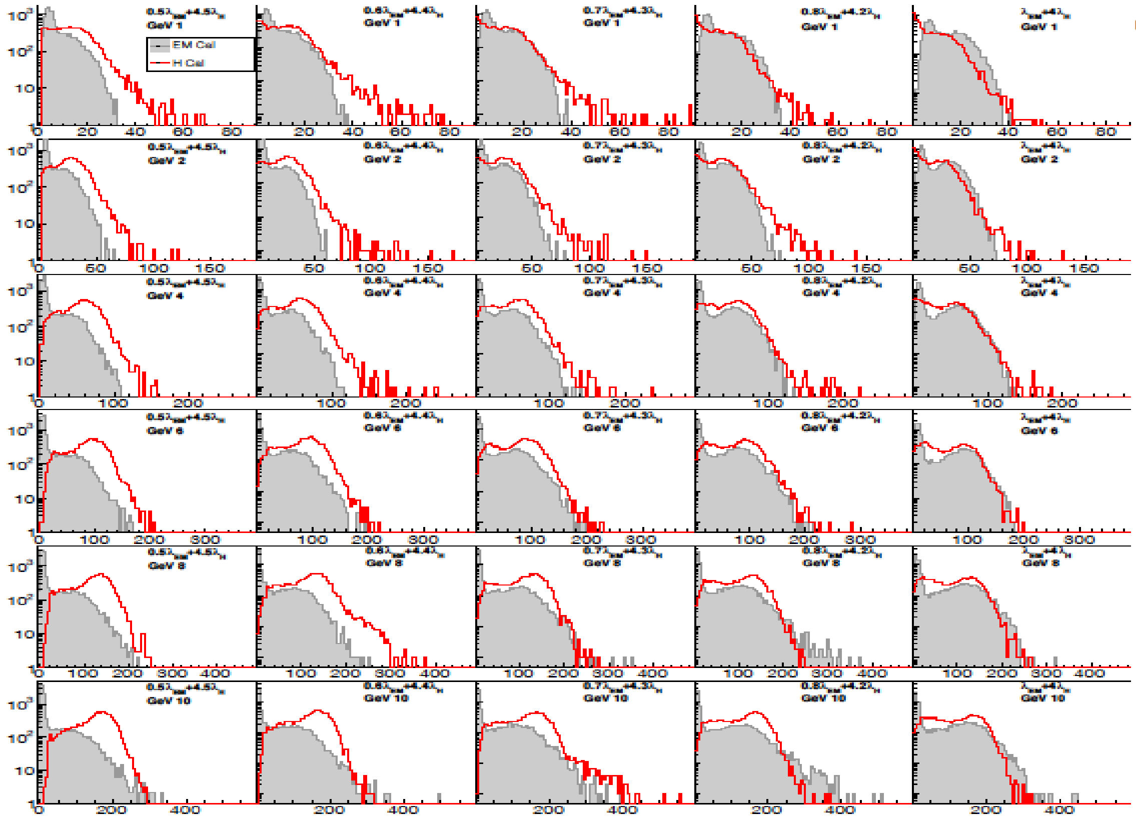
N.B. no cuts on tail-catcher or re-weighting was applied here.

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

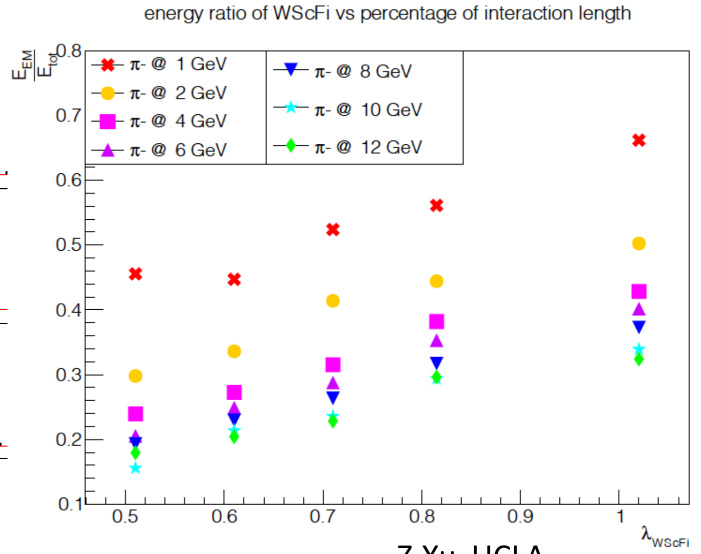
At higher energies (EndCap eta range 2- 3) constant term start to dominate.

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

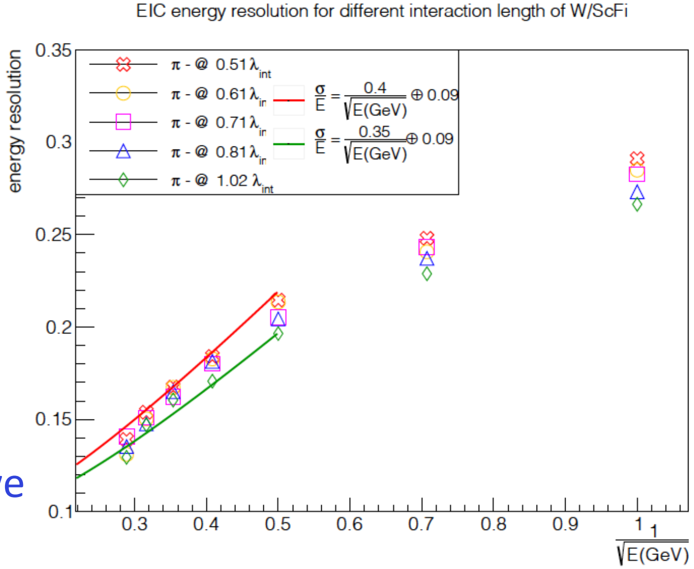
Does deeper Ecal helps to reconstruct low energy hadrons?



Increased depth of ECal



Z.Xu UCLA

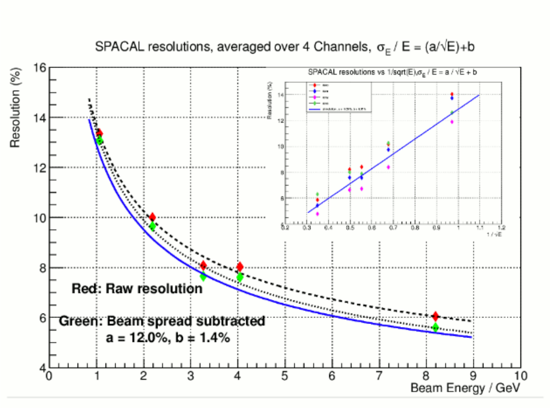


Increased depth of Ecal does help a bit to improve energy resolution of the system for low energy hadrons. Assuming we have good PID, additional e/h (TRD etc.,) you can do that.

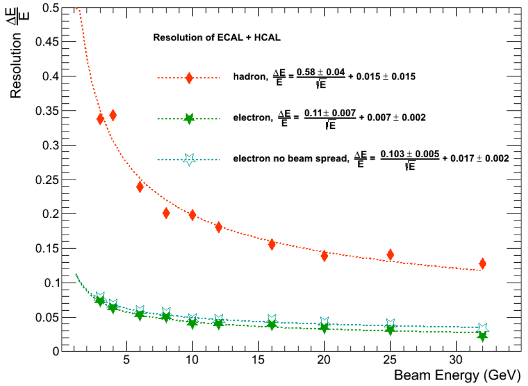
Reference EIC Hadron EndCap studies summary:

- 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.

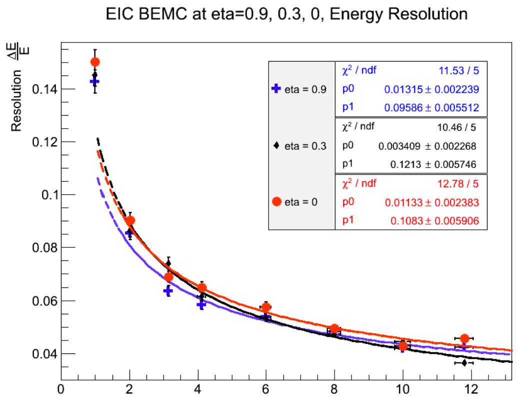
Transition to targeted R&D…



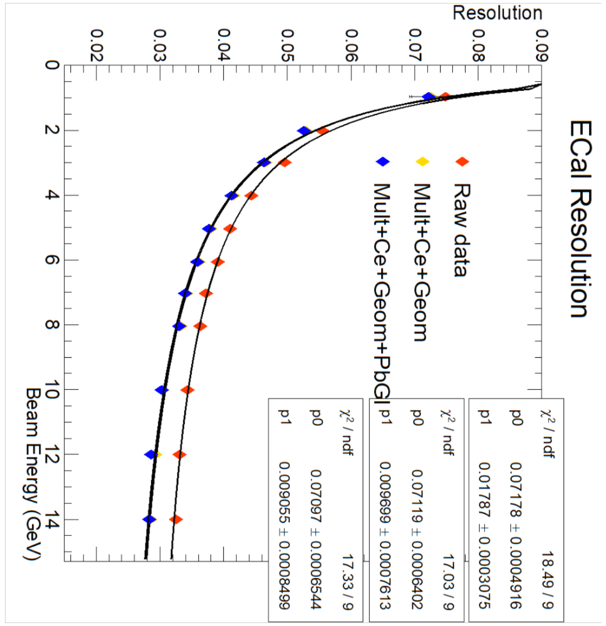
Proof of principle. FNAL 2012



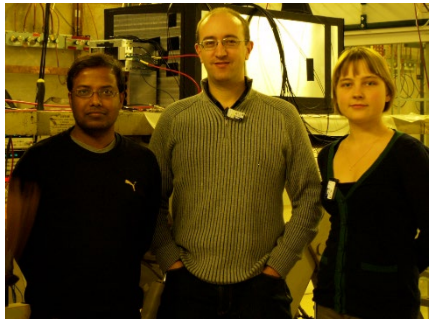
EIC Forward, FNAL 2014

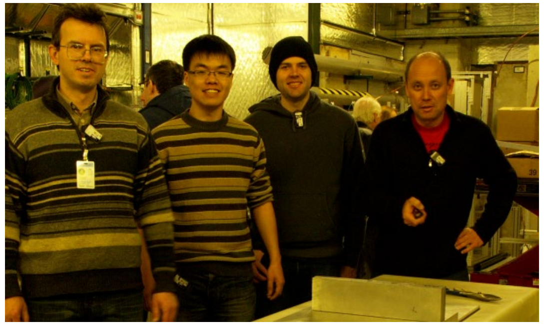


EIC BEMC, FNAL 2014



EIC Forward, FNAL 2016



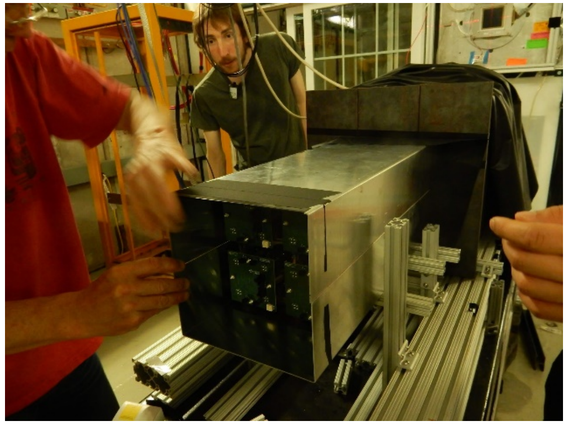


Test Runs 2012 -2016

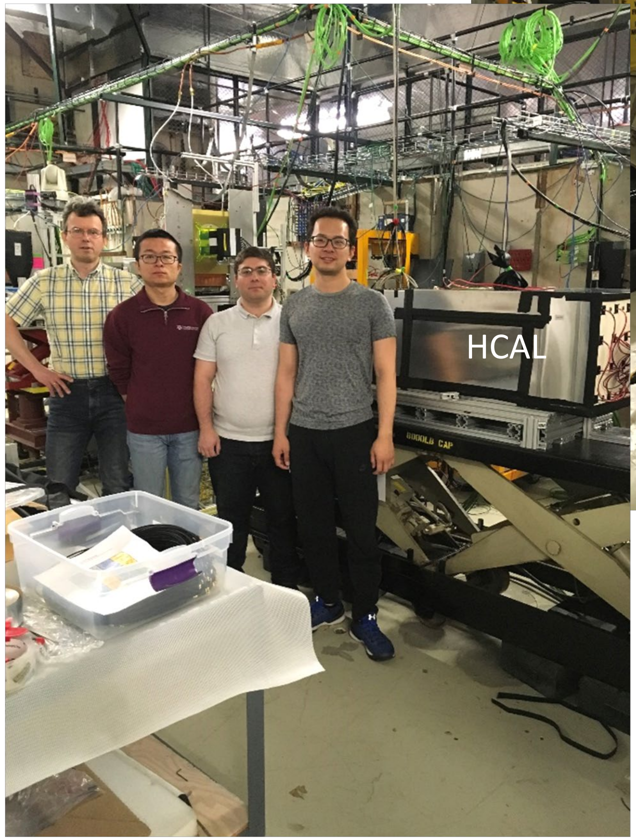
STAR Forward Calorimeter

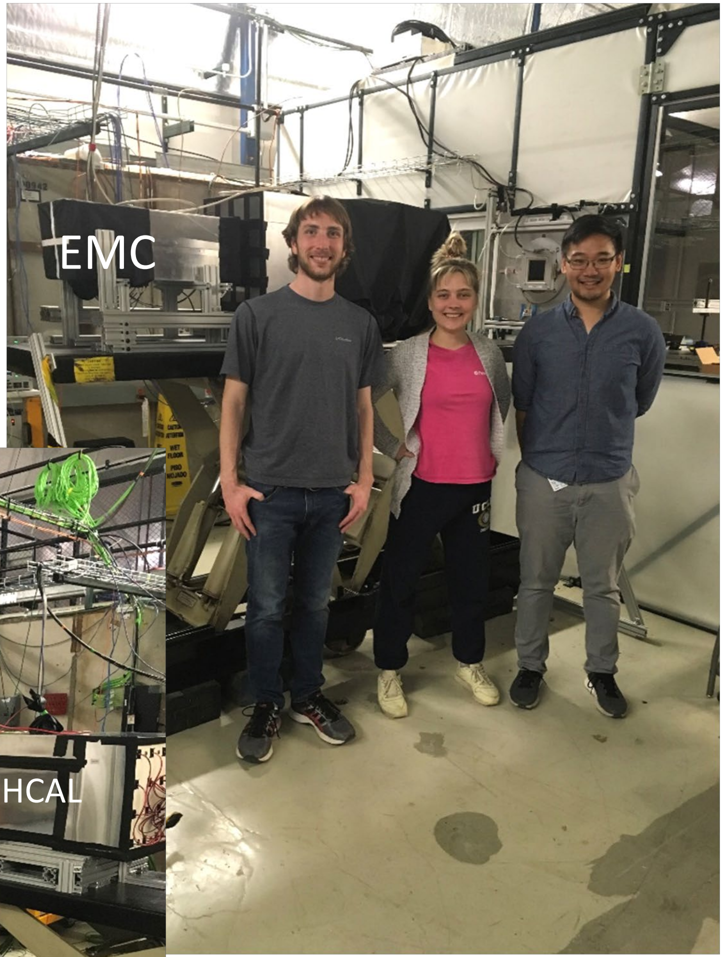
FNAL Test Beam, 2019

4x4 Ecal, 4x4 HCal



A.Kiselev (BNL)
T. Lin (TAMU)
D. Kapukchyan (UCR)
D. Chen (UCR)
G. Visser (IUCF)
O. Tsai (UCLA)



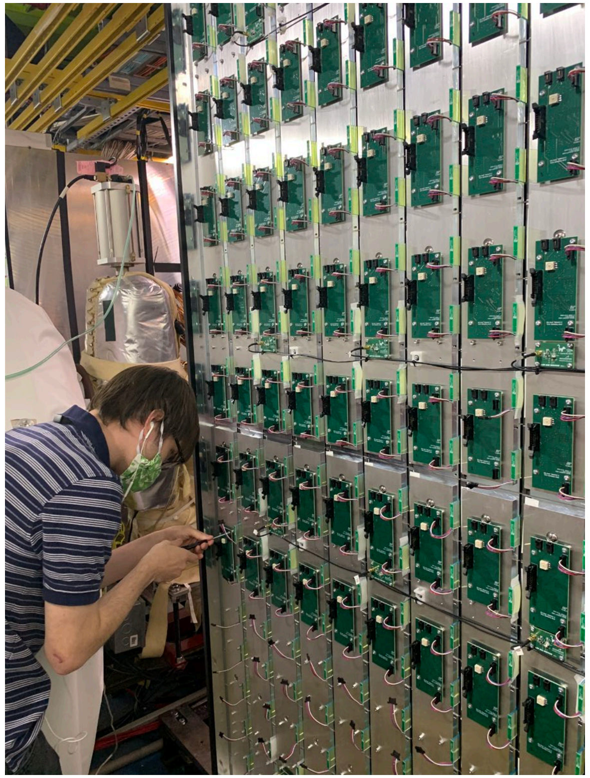


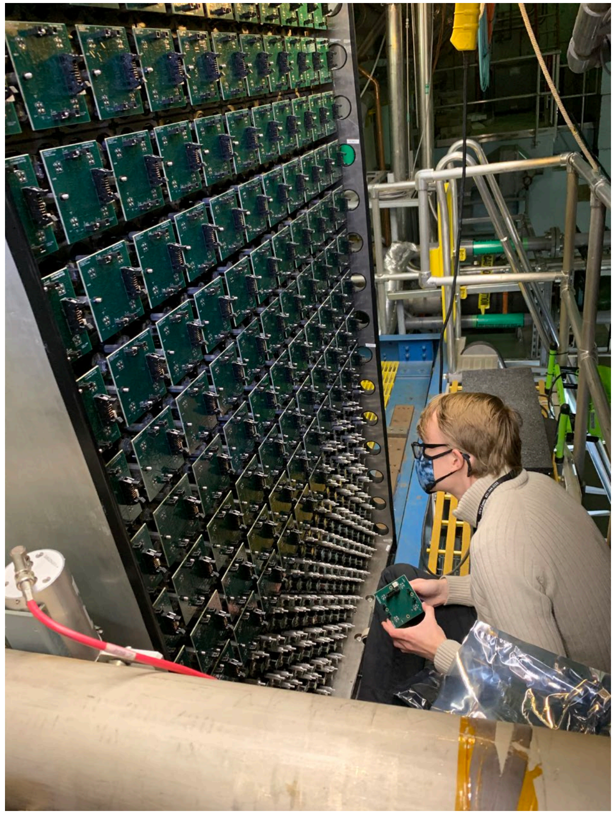
D. Neff (UCLA)
M.Sergeeva (UCLA)
B. Chan (UCLA)

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

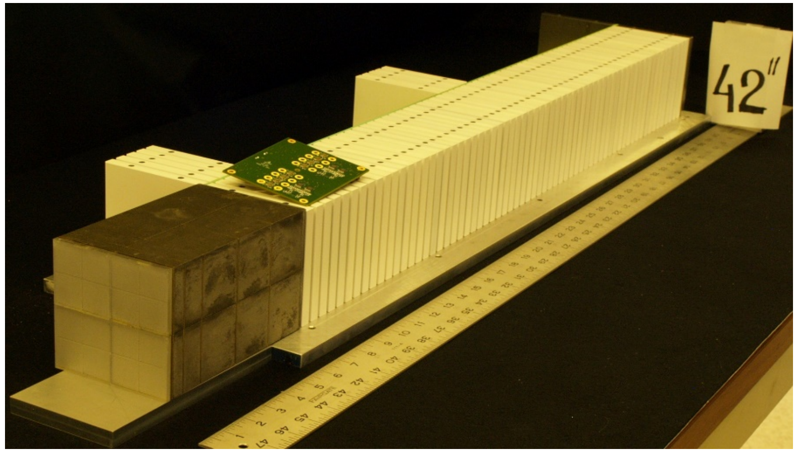
BNL Newsroom
https://www.bnl.gov/newsroom/news.php?a=217681

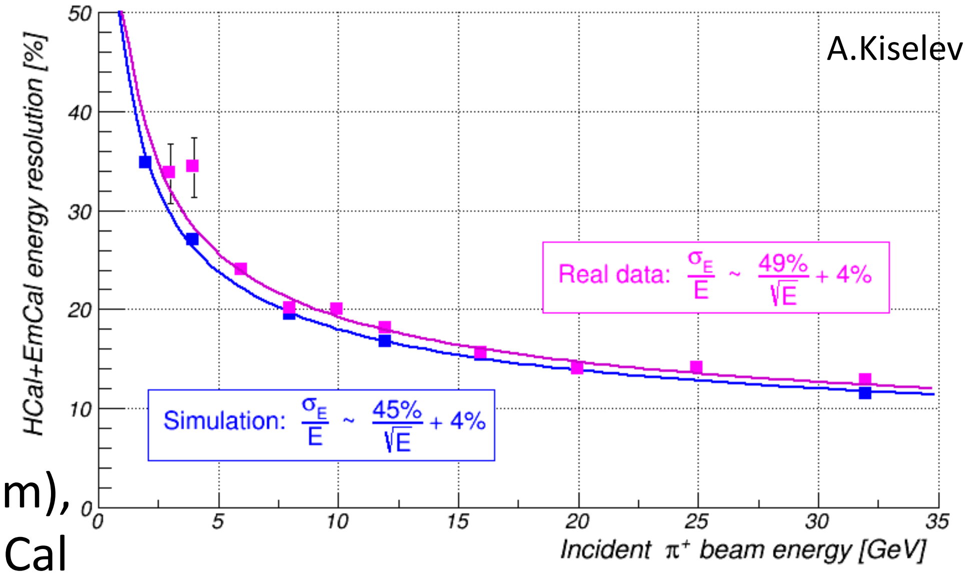
FCS Successful Construction Project.

- 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).