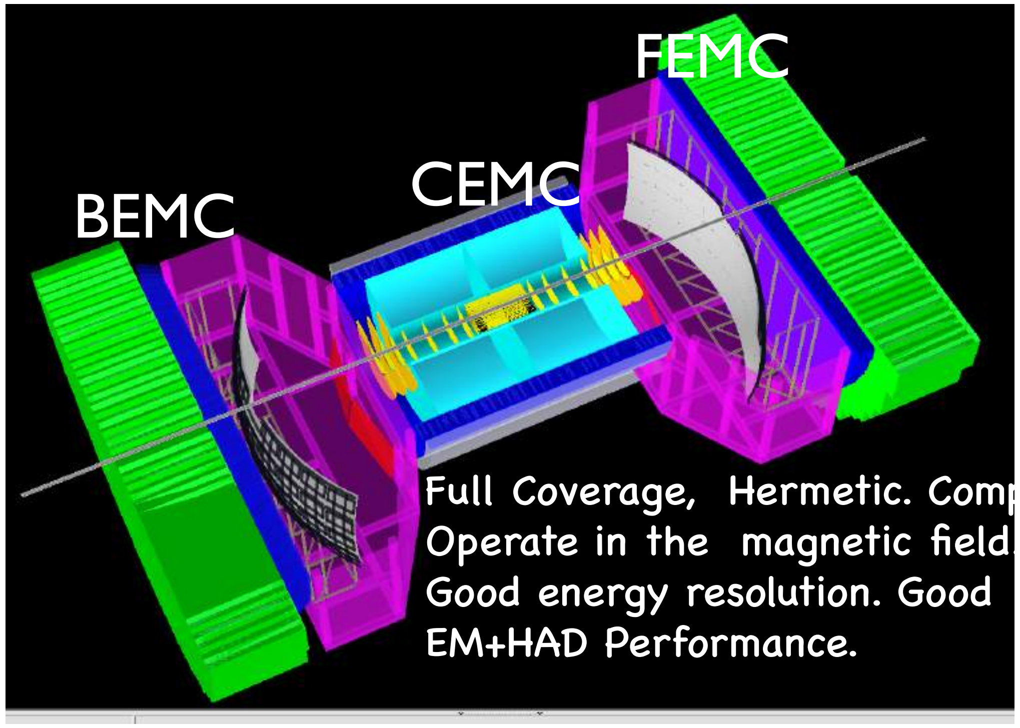
eRD1 results for sampling calorimeters for EIC

O.Tsai (UCLA)

EIC User Group Meeting, CUA 2018

Take 1. Why are we doing calorimeter R&D for a generic central detector?



Calorimetry wise, we wanted to have similar performance of H1/ZEUS in much more compact package and for a fraction of cost.

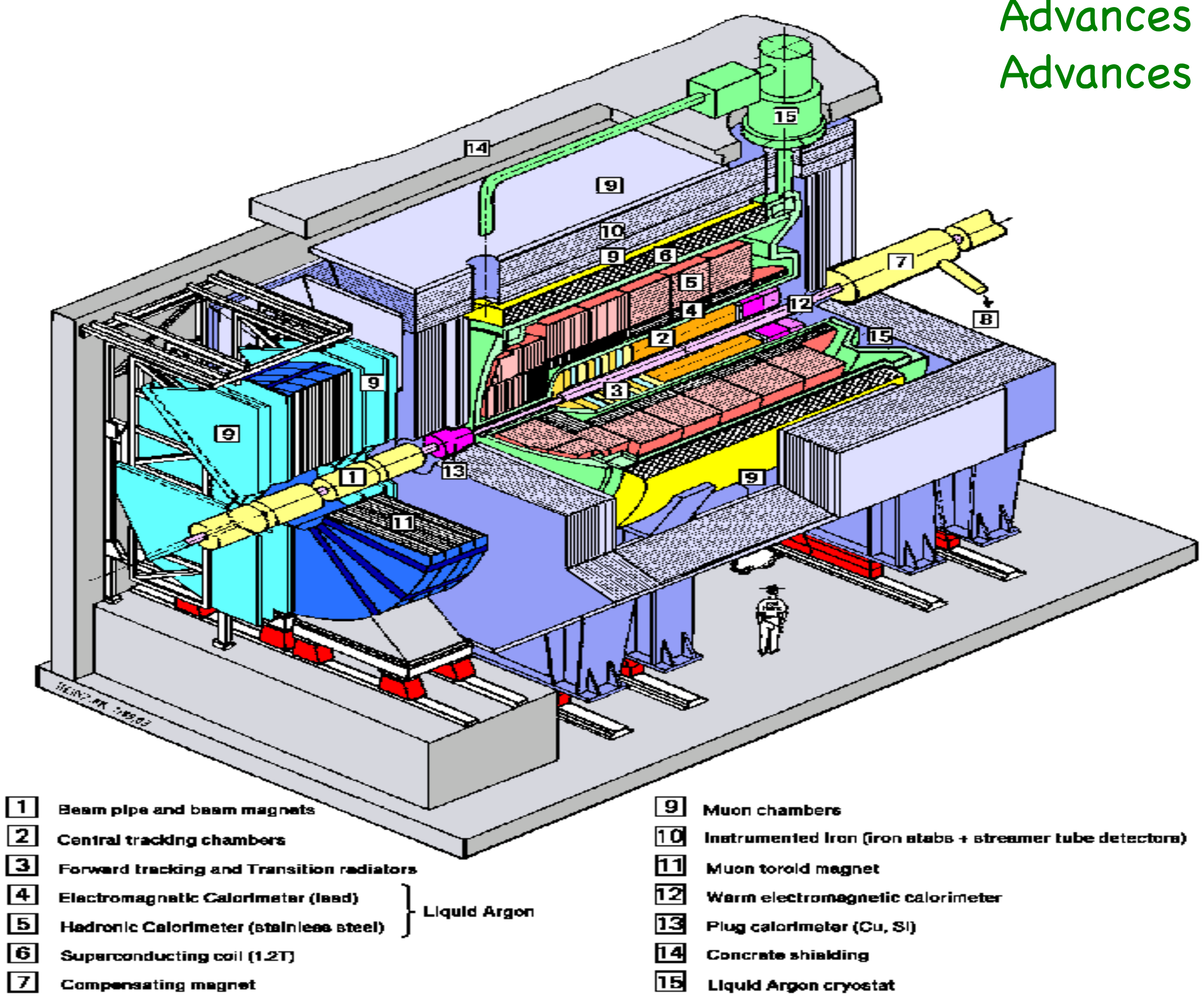
EIC Detectors ~9m long (4pi PID)

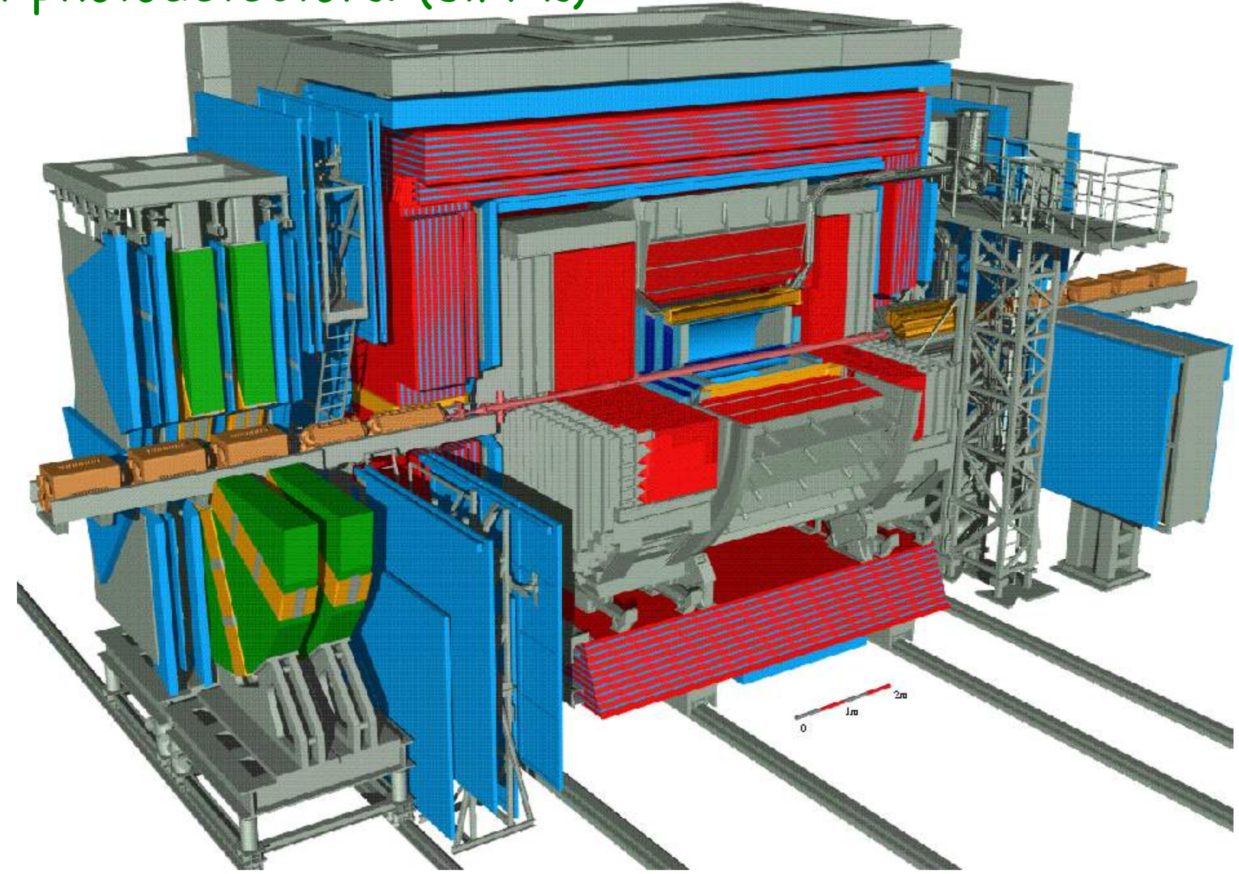
- 'Particle ID R&D Program', Silvia Dalla Torre (INFN)
- 'Quest for Particle Identification in Nuclear Physics' Elke Aschenauer (BNL)

HERA Detectors ~15 m long (no PID)

Cost of ZEUS Calorimeters ~ $90M (if I scale correctly)

Advances in micro pattern detectors.
Advances in photodetectors. (SiPMs)





Take 2. Why are we doing calorimeter R&D for a generic central detector?

https://wiki.bnl.gov/conferences/index.php/EIC_R%25D#Received_Proposals

In January 2011 Brookhaven National Laboratory, in association with Jefferson Lab and the DOE Office of Nuclear Physics, announced a generic detector R&D program to address the scientific requirements for measurements at a future Electron Ion Collider (EIC). The primary goals of this program are:

- to develop detector concepts and technologies that have particular importance for experiments in an EIC environment,

- and to help ensure that the techniques and resources for implementing these technologies are well established within the EIC user community.

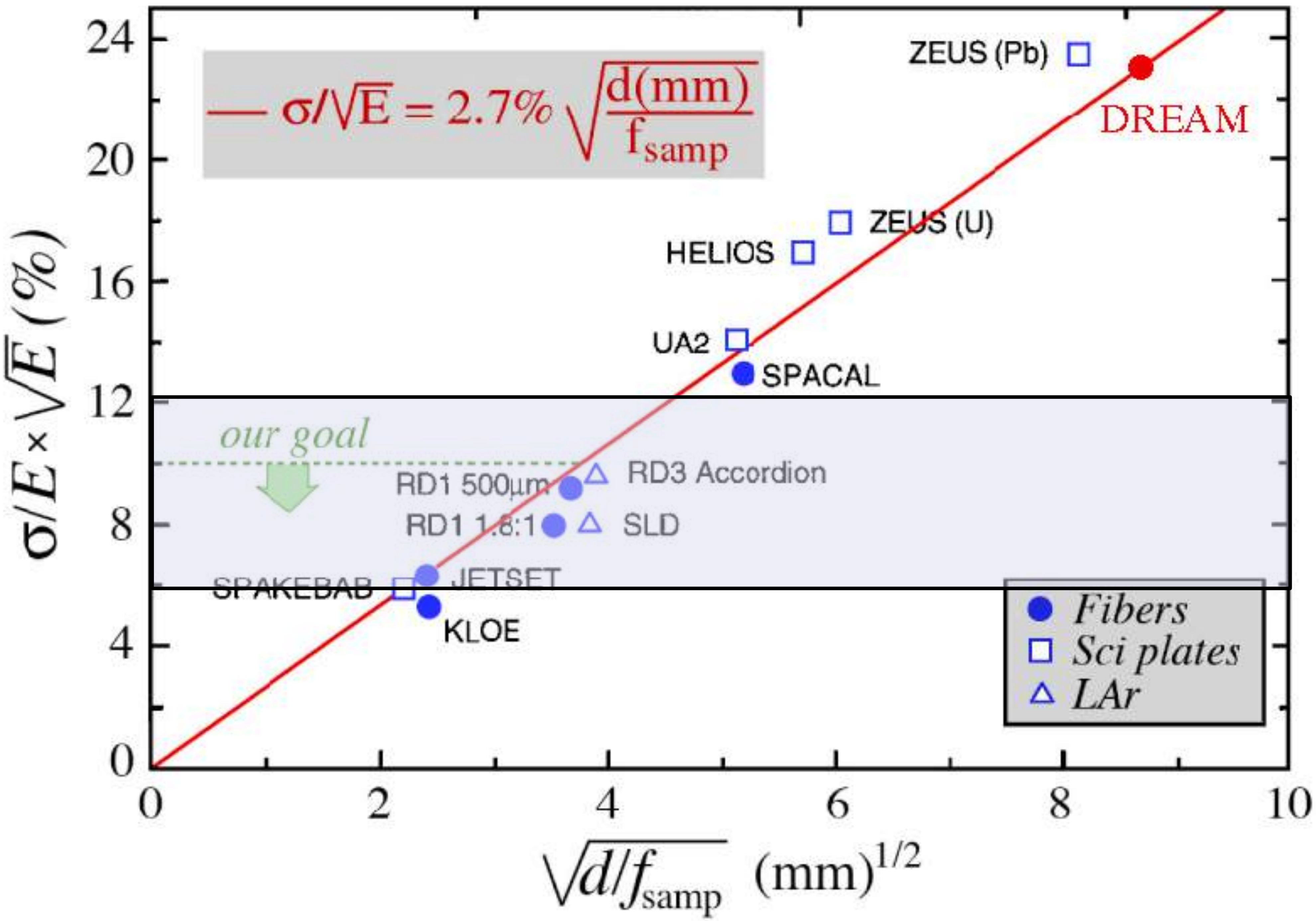
I will add:
and to help building active EIC user community.

eRD1, 2012. Motivation:

Develop ***simple, cost effective, flexible*** techniques to build ***compact*** sampling calorimeters with *good characteristics*.

- ***Simple*** – to the level that a typical university group can build it without heavy investments in "infrastructure" and workforce.
- ***Cost effective*** – fraction of the cost of crystals.
- ***Flexible*** – tunable for particular experimental requirements.

Motivation reflects experience in participating in building STAR Barrel EMC.
STAR BEMC built jointly by Universities (detector) and National labs (electronics).
At that time (1997-2003) it was largest calorimeter built by DOE Nuclear Physics.



EIC EM Sampling Calorimeters

$$\frac{\sigma_{em}}{E} = \frac{12\%}{\sqrt{E(GeV)}}$$

H1

$$\frac{\sigma_{em}}{E} = \frac{7.5\%}{\sqrt{E(GeV)}}$$

ZEUS

$$\frac{\sigma_{em}}{E} = \frac{18\%}{\sqrt{E(GeV)}} \qquad \frac{\sigma_{had}}{E} = \frac{35\%}{\sqrt{E(GeV)}}$$

- Calorimetery, Complementarity H1 and ZEUS
- Complementarity, EIC1 and EIC2?

Small d, Small Fs (A)	Small d, Large Fs (B)	Large d, Large Fs (C)
SciFi calorimeters.	"Shashlik" type.	Tile/Fiber type.
Good energy , position resolutions. Fastest, compact, hermetic. Self_supporting. Problems are; Projectivity, high cost (1/10th of crystals). Example (H1)	Excellent energy resolution Fast Small dead areas Problems are: Low density, projectivity. Moderate cost Need external mech. support Example (KOPIO/PANDA)	Ok energy resolution Reasonably fast Very cost effective Problems are: Moderate density, large dead areas. Need external mech. Support. Example (STAR BEMC)
Rm 1.8 cm X0 0.7 cm Energy reso. ~ 10%/√(E) Density ~ 10 g/cm^3 Number of fiber/tower~ 600 (0.3 mm diameter, 0.8mm spacing)	6 cm 3.4 cm 4%/√(E) 2.5 g.cm^3 0.3 mm Pb/1.5 mm Sc 400 layers	3 cm 1.2 cm 15%/√(E) 6 g/cm^3 5mm Pb/ 5mm Sc 20 layers

eRD1 goal was to develop new technology for (A) with the price tag comparable to the cost of tile/fiber type calorimeters.

eRD1 proposal in 2011. Road map.

https://wiki.bnl.gov/conferences/images/d/d4/RD-1_RDproposal_April-2011.pdf

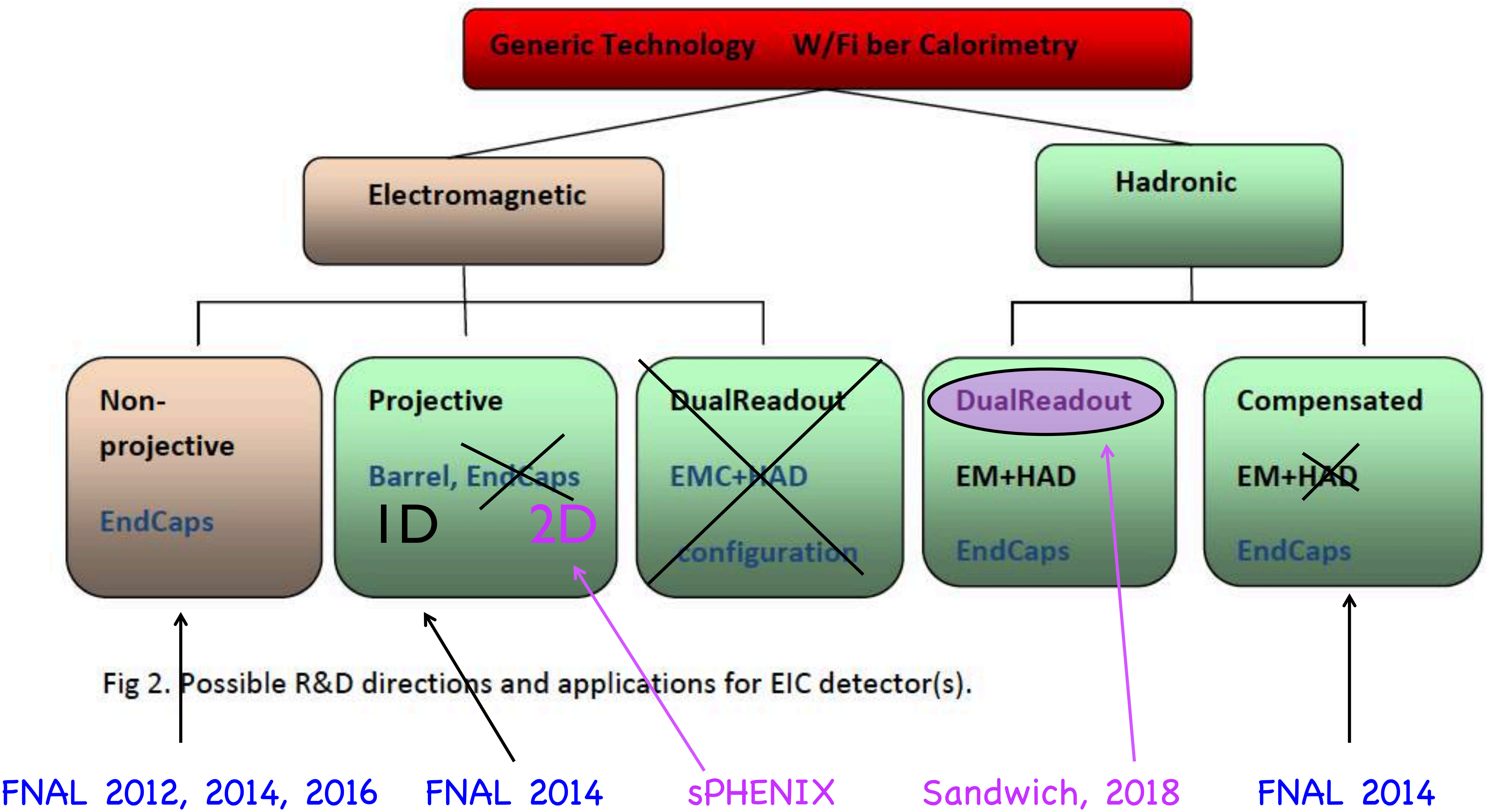
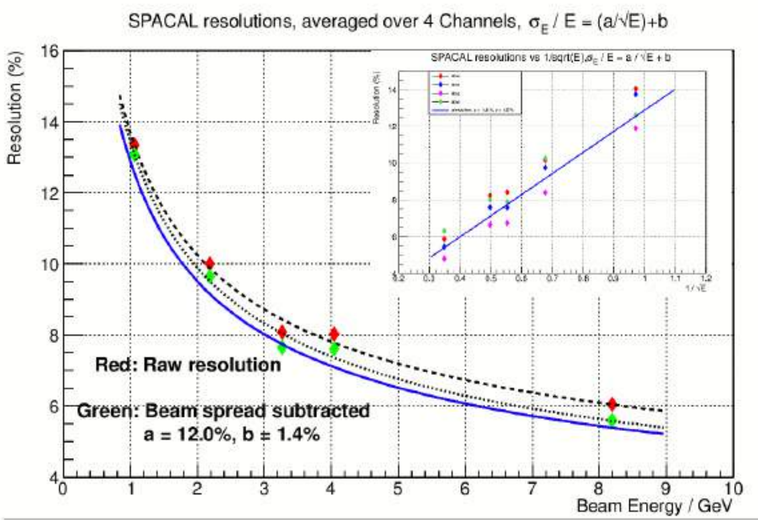
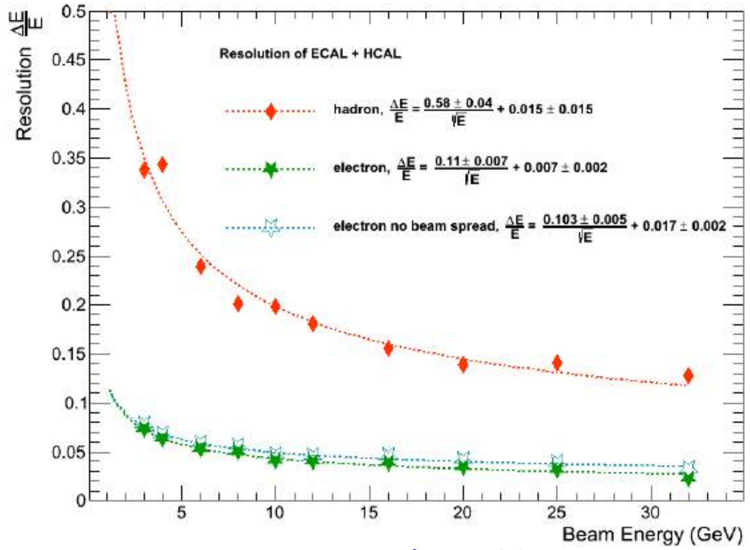


Fig 2. Possible R&D directions and applications for EIC detector(s).

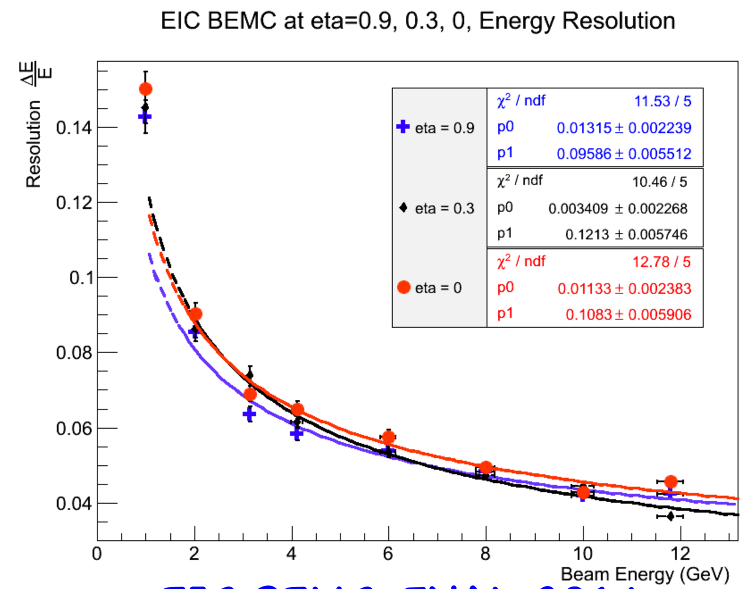
Generic R&D is a journey…



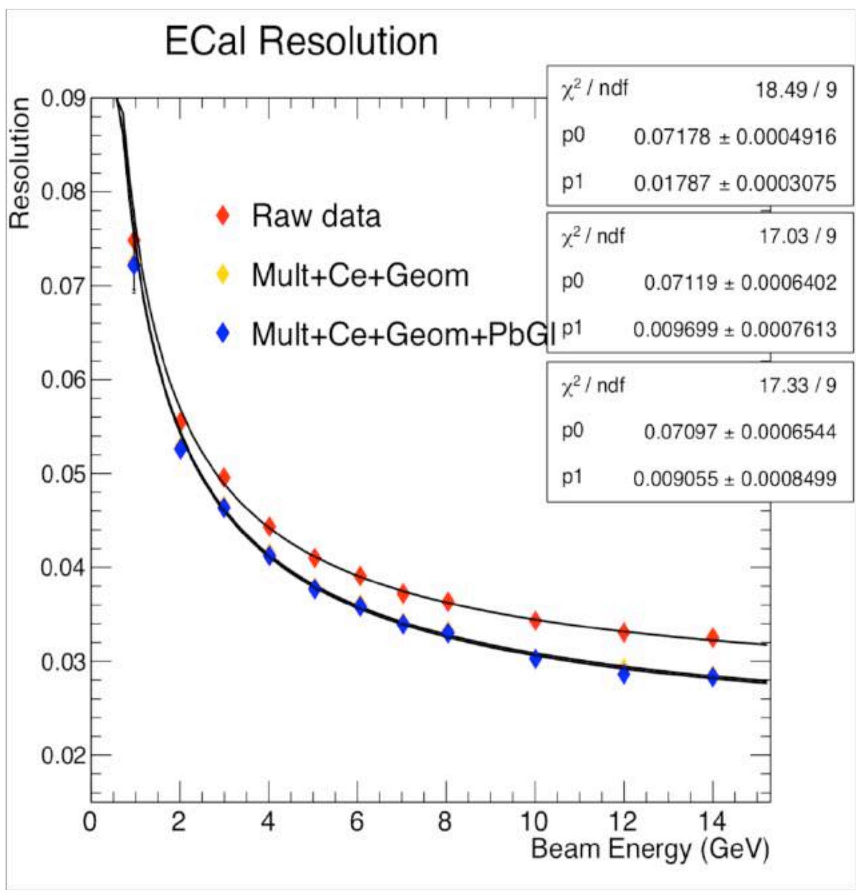
Proof of principle. FNAL 2012



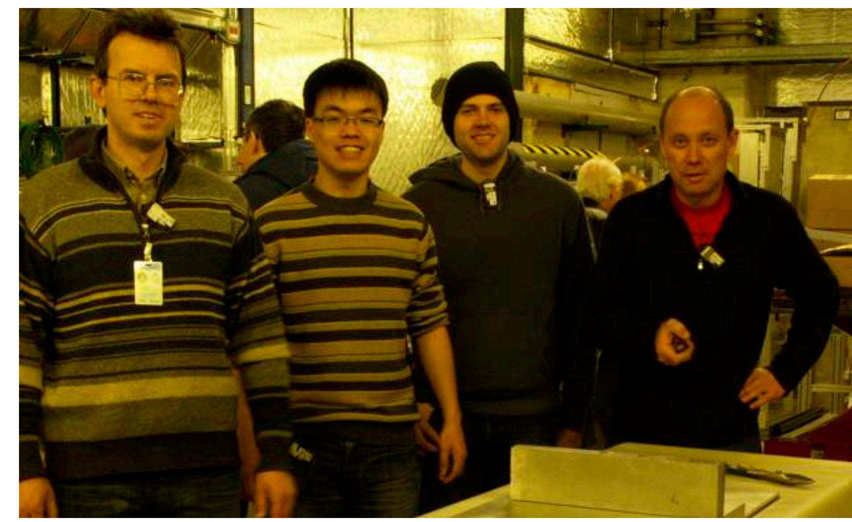
EIC Forward, FNAL 2014



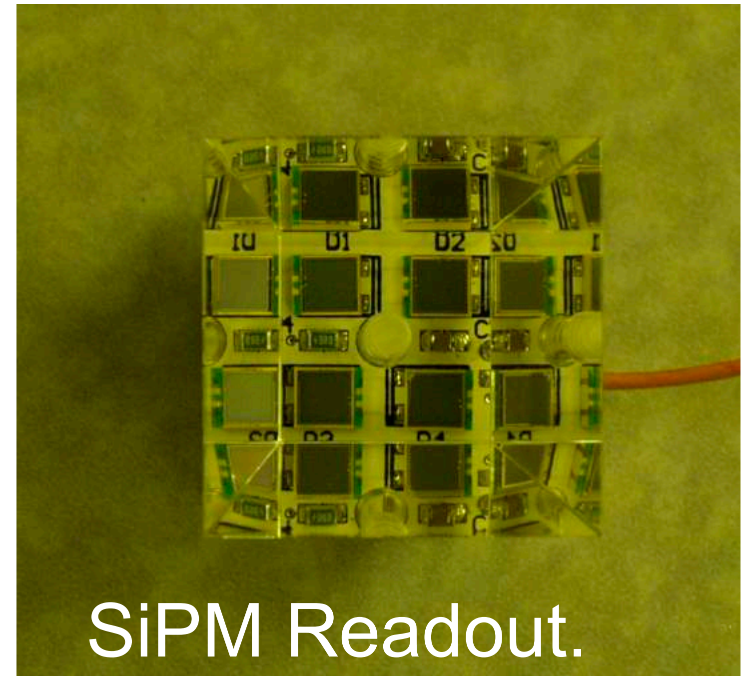
EIC BEMC, FNAL 2014

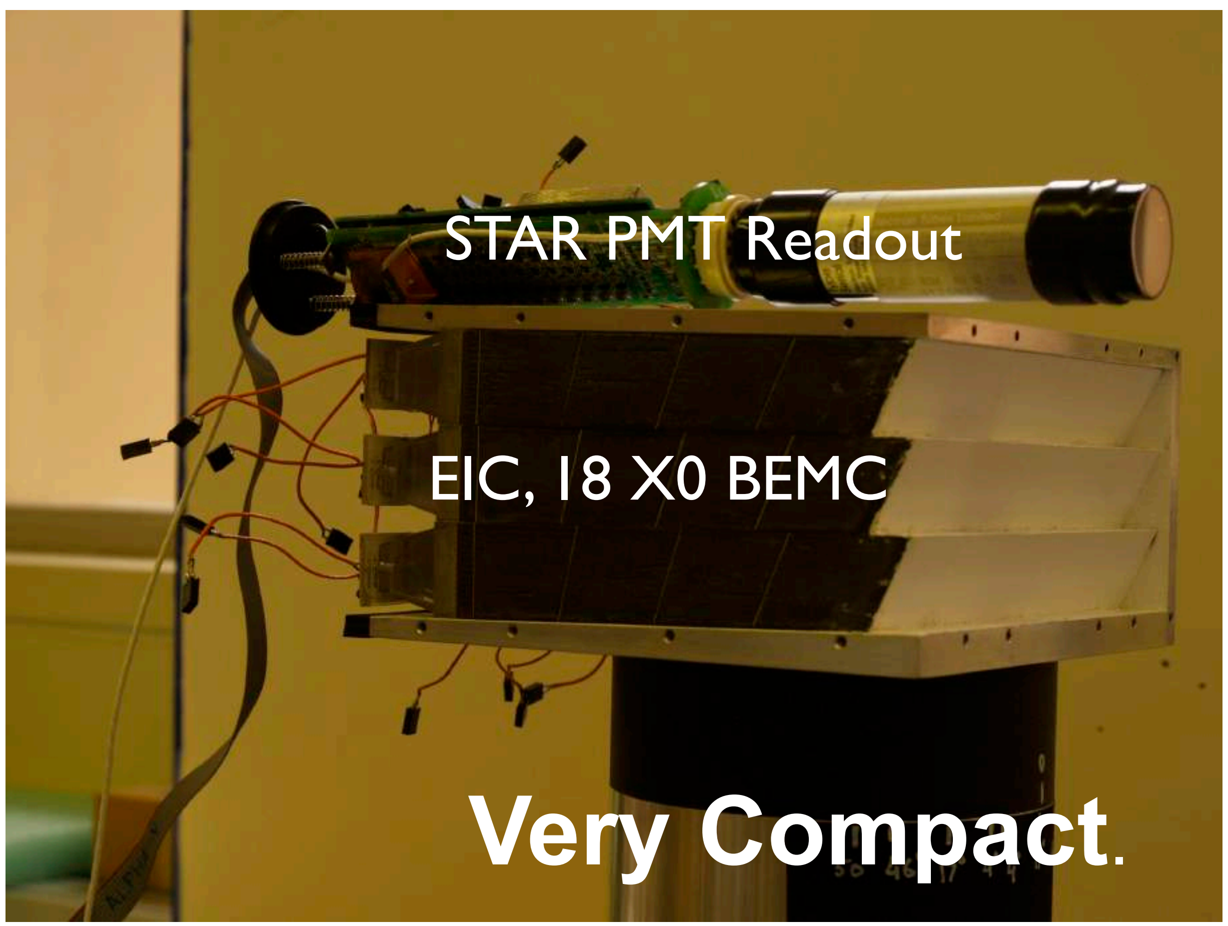


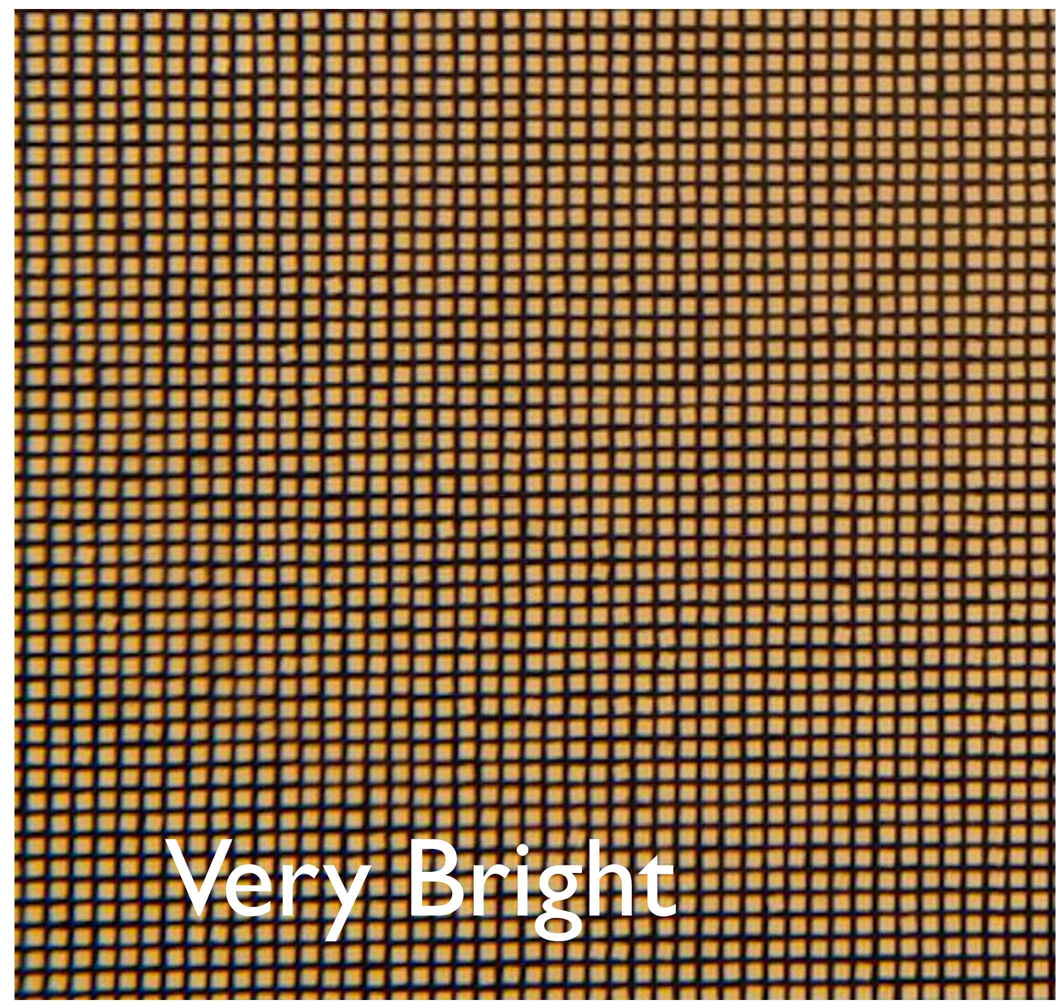
EIC Forward, FNAL 2016



Test Runs 2012 -2016

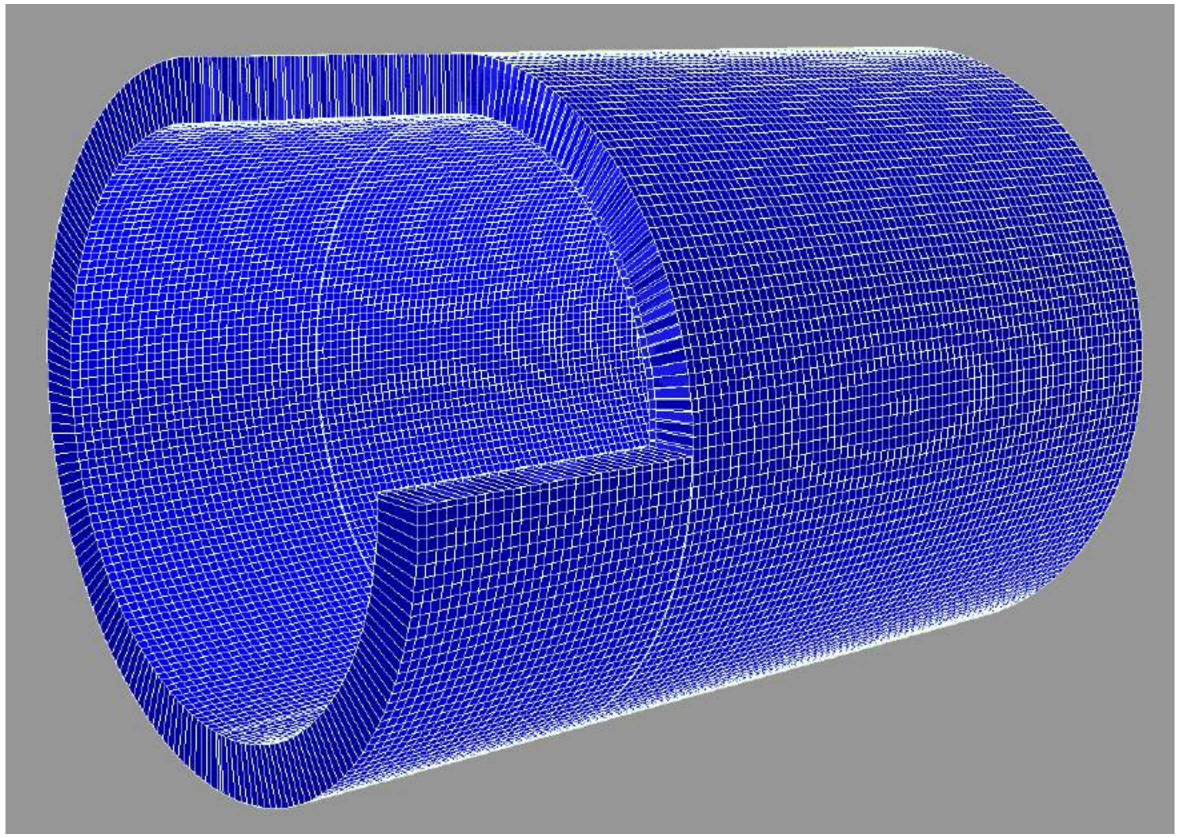


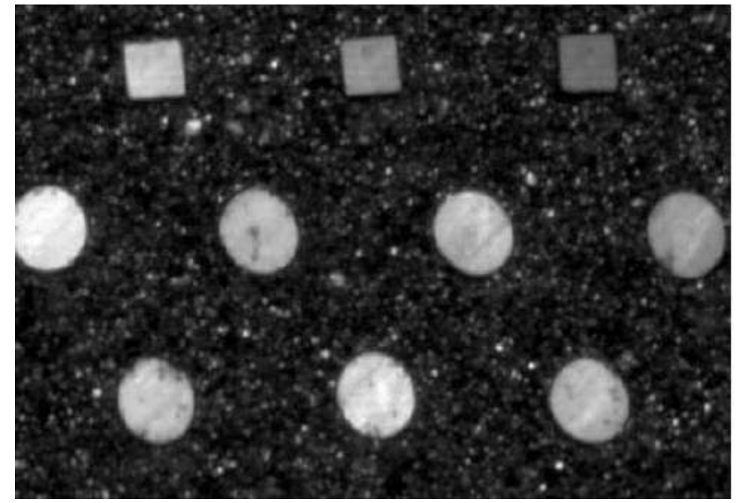




6 Different Prototypes Built to meet EIC Requirements and Tested at FNAL

Central EM Calorimeter (BEMC) for EIC.





W/ScFi Compound Mechanical properties.

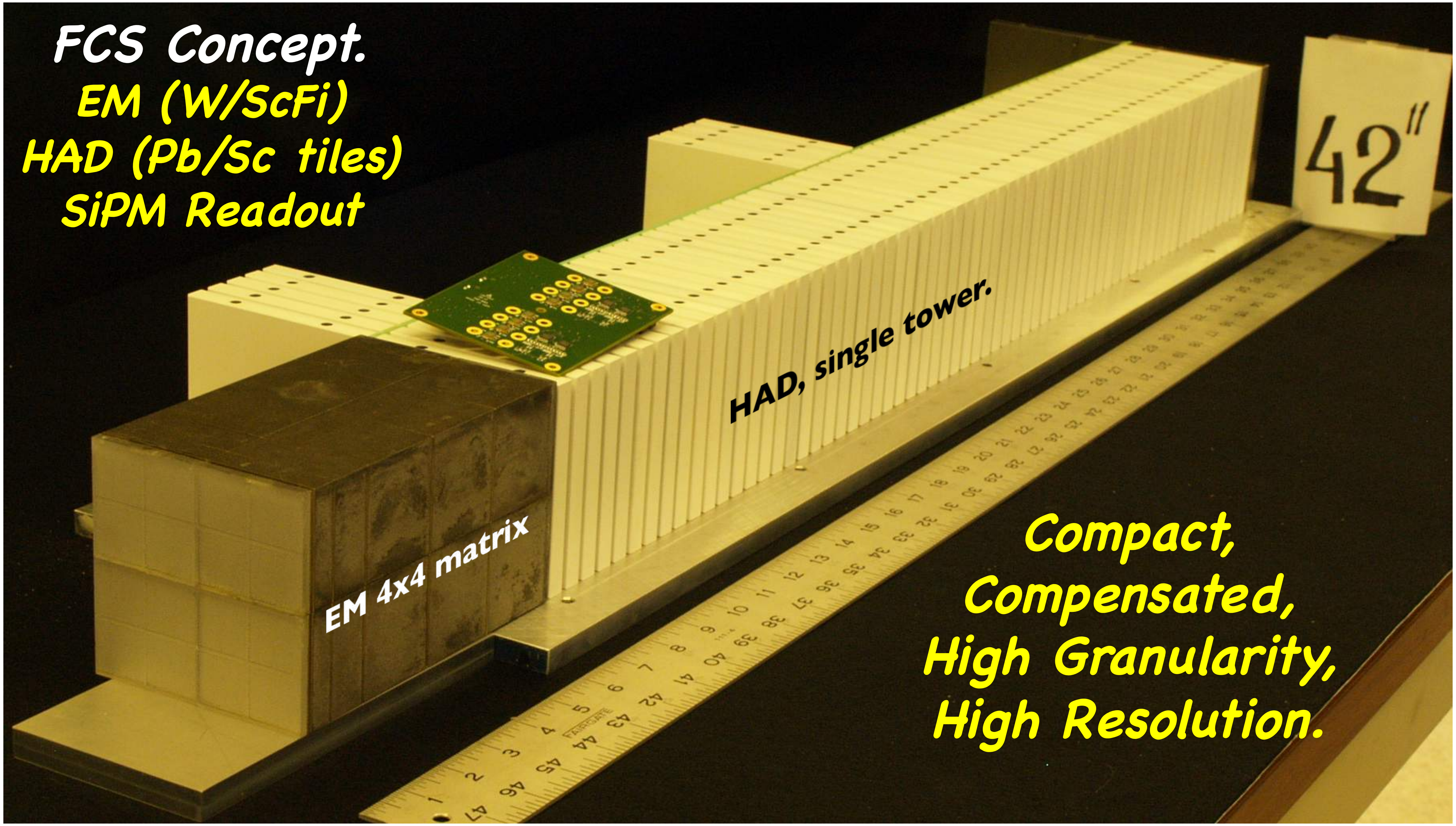
- Young's Modulus – 2 $*10^{11}$ N/m^2
- Shear Modulus – 7.5 $*$ 10^{10} N/m^2
- Bulk Modulus – 2.4 $*$ 10^{11} N/m^2

Parameters close to construction steel

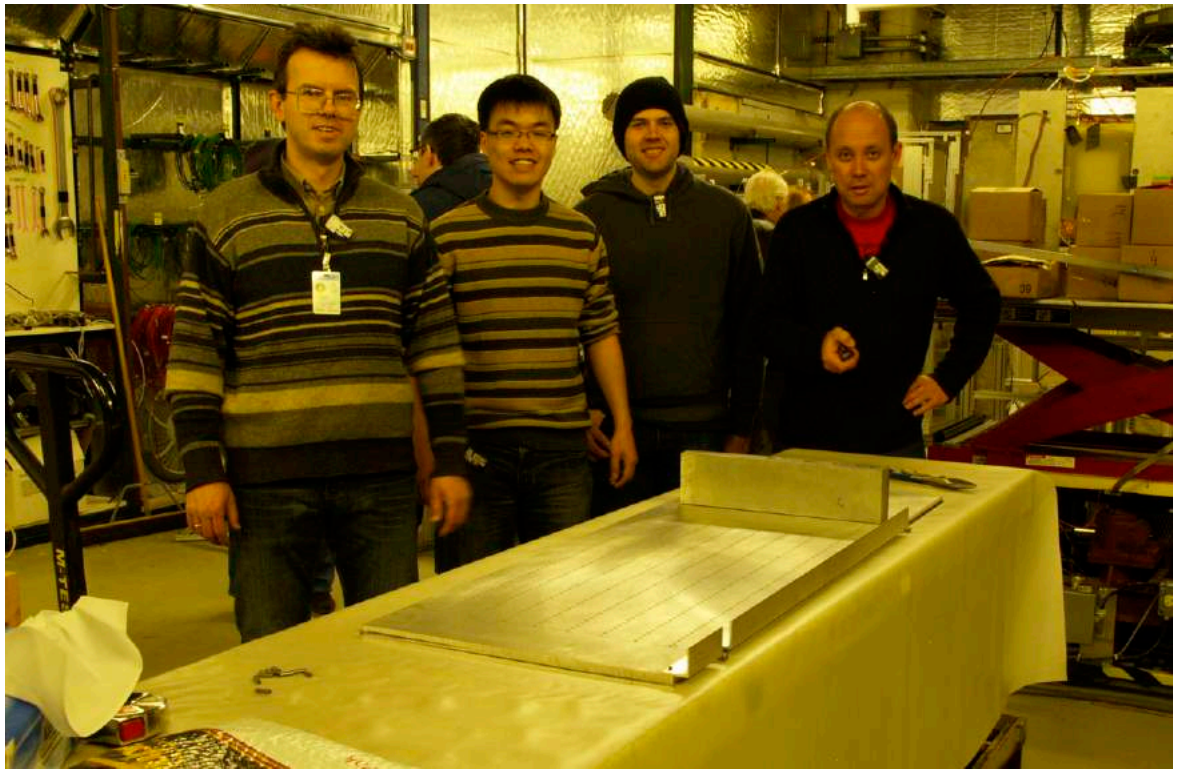
- same tungsten powder + fibers technology as FEMC,
- towers are tapered, sampling fraction along the tower depth is not constant.
- non-projective geometry; radial distance from beam line [815 .. 980]mm

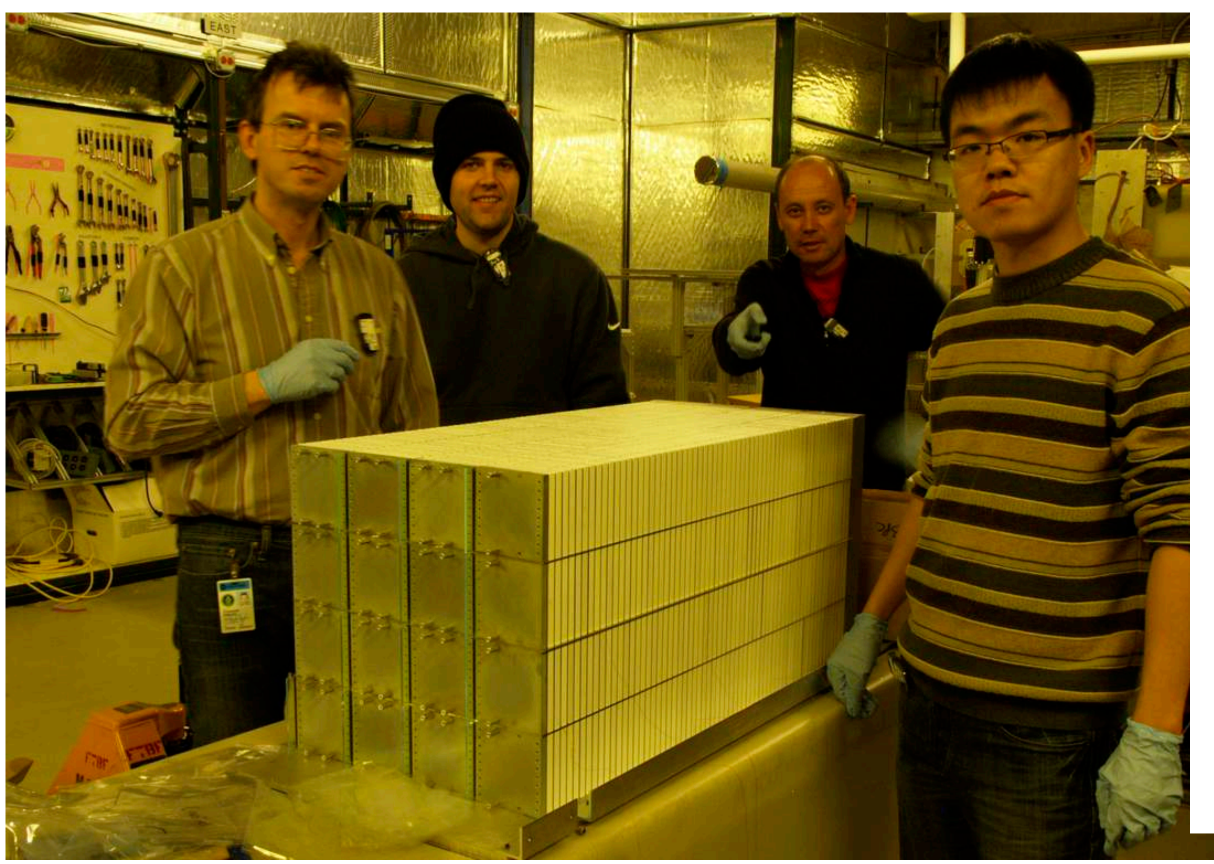
-> simulation and beam tests does not show any noticeable difference in energy resolution between straight and tapered tower calorimeters

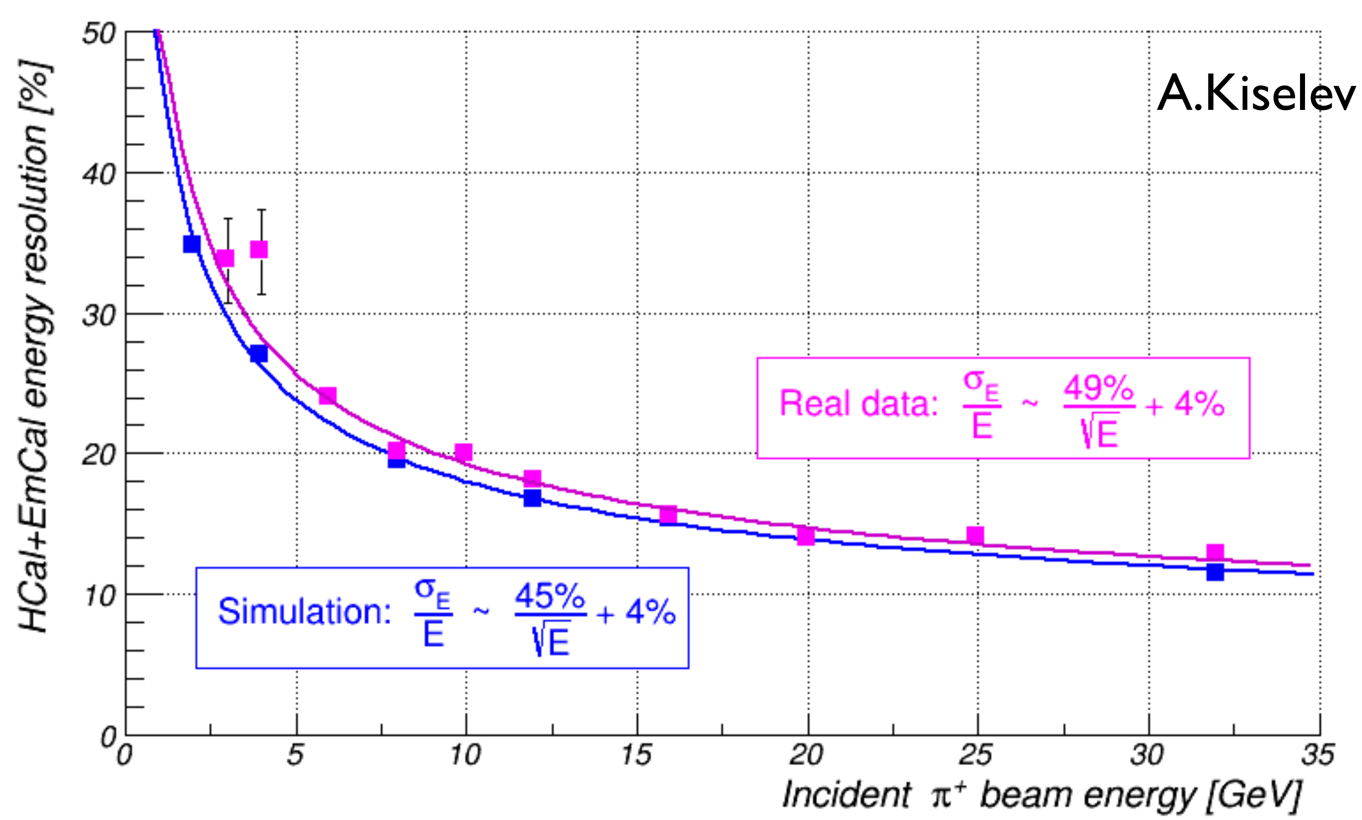
STAR Forward, EIC Forward. Combine H1/ZEUS



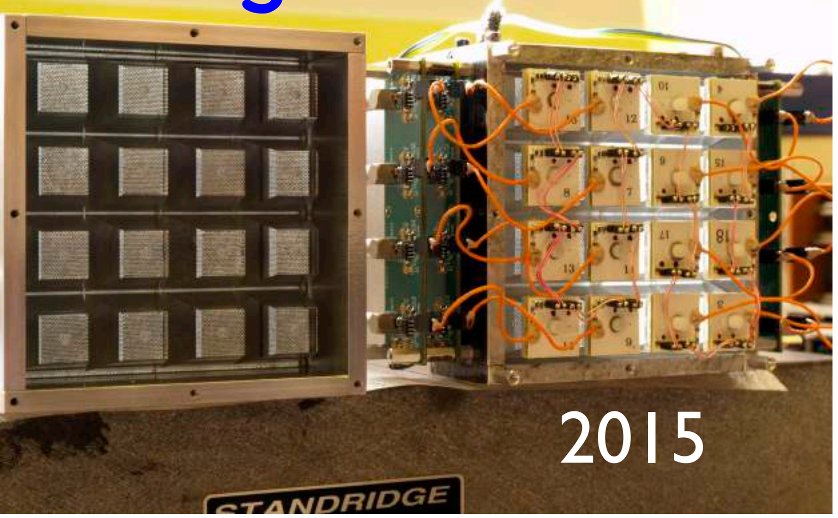
Assembling HCal Onsite. Feb 26, 2014. FNAL







High Resolution Sampling BEMC, 2016 R&D.



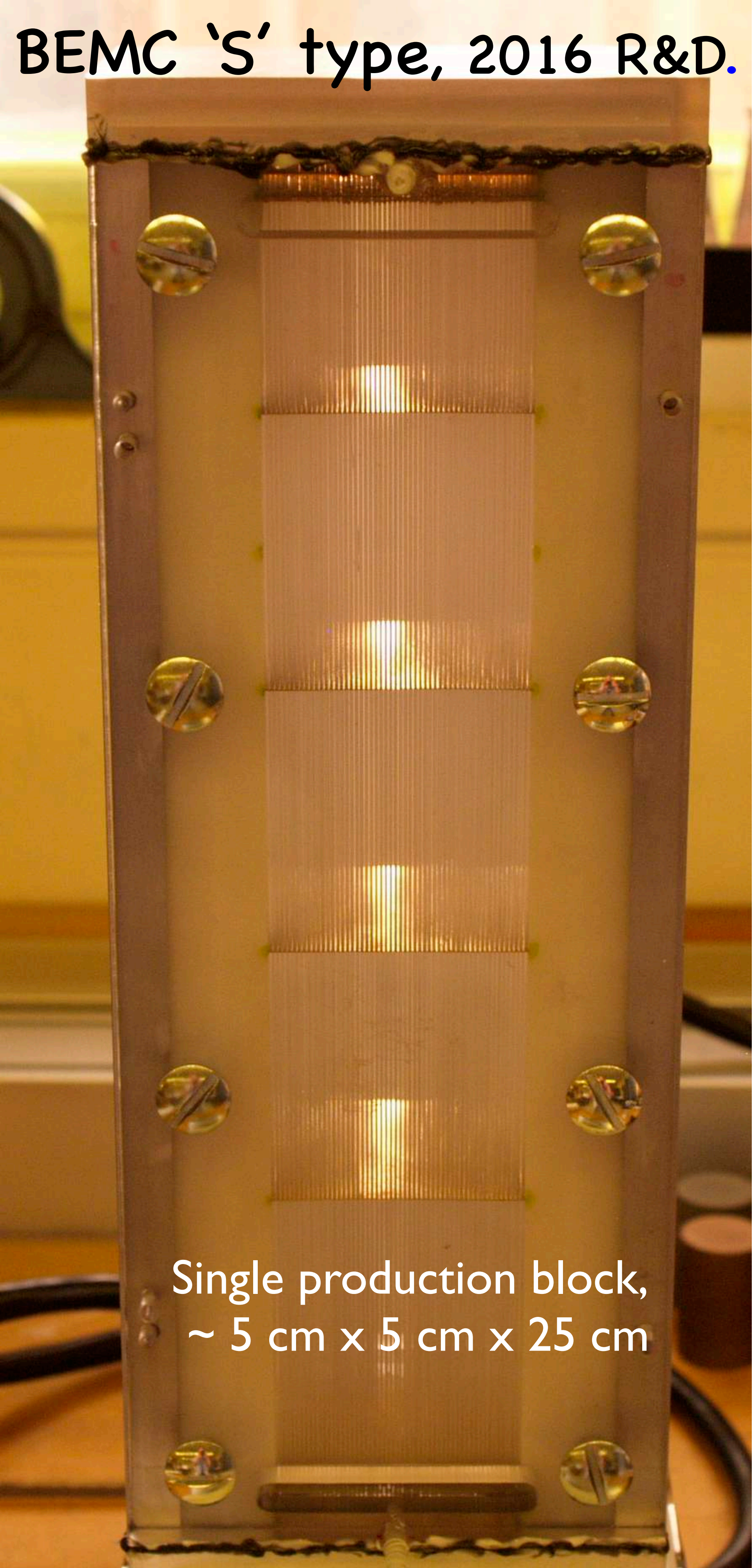
'is W/ScFi technology still feasible towards high-resolution calorimeters with future development?' (After 2015 Test Run)

Potential problems with the first 'O' HR prototype in 2015:

- homogeneity of the composite absorber
- consistency of the sampling frequency with thin fibers
- damage at the end of the fibers due to machining
- efficiency of light collection with compact readout.

In 2016 we proposed to build an additional 'S' prototype which did not have complications with the homogeneity of absorber and consistency of sampling frequency. This prototype consisted of thicker, square fibers and an absorber of 100% W-powder.

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



Why to try square scintillation fibers?

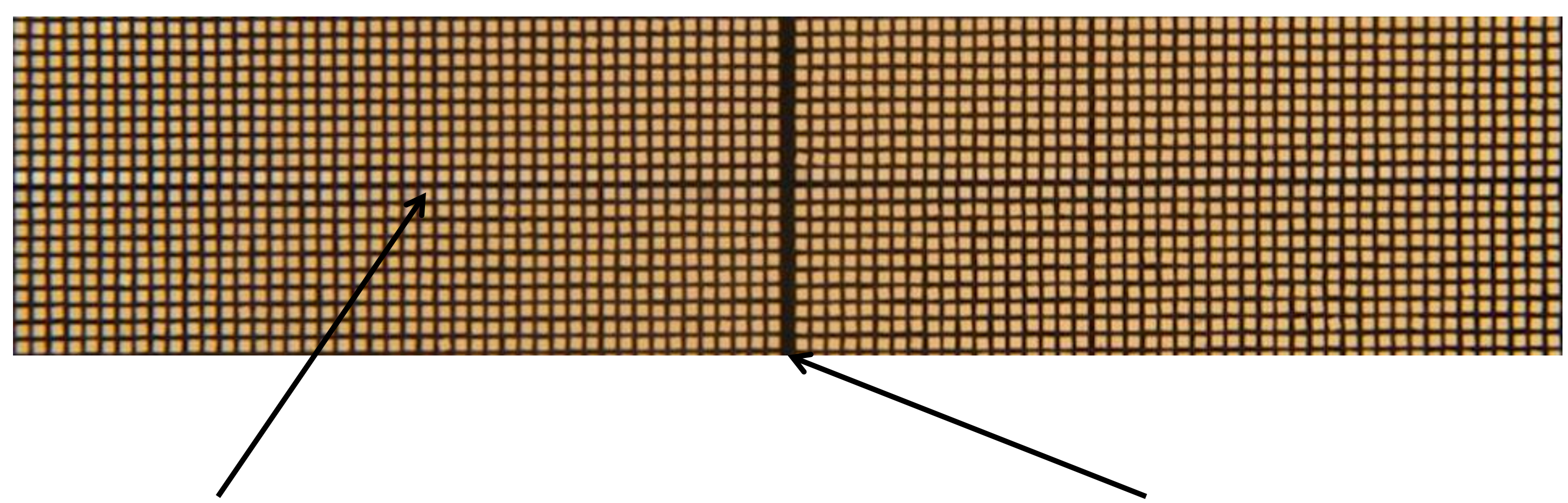
No ScFi calorimeters in the past were built with square fibers.

Pros:

- better light yield (according to Kuraray ~ 30% better trapping efficiency compared to round fibers, which is particularly interesting for compact light collection scheme)
- internal structure of the detector can be made more homogeneous
- easier to preserve sampling fraction and frequency within and between superblocks (glued from four production blocks).
- larger surface area for a given volume

Cons:

- more expensive
- more difficult to feed through the set of screens

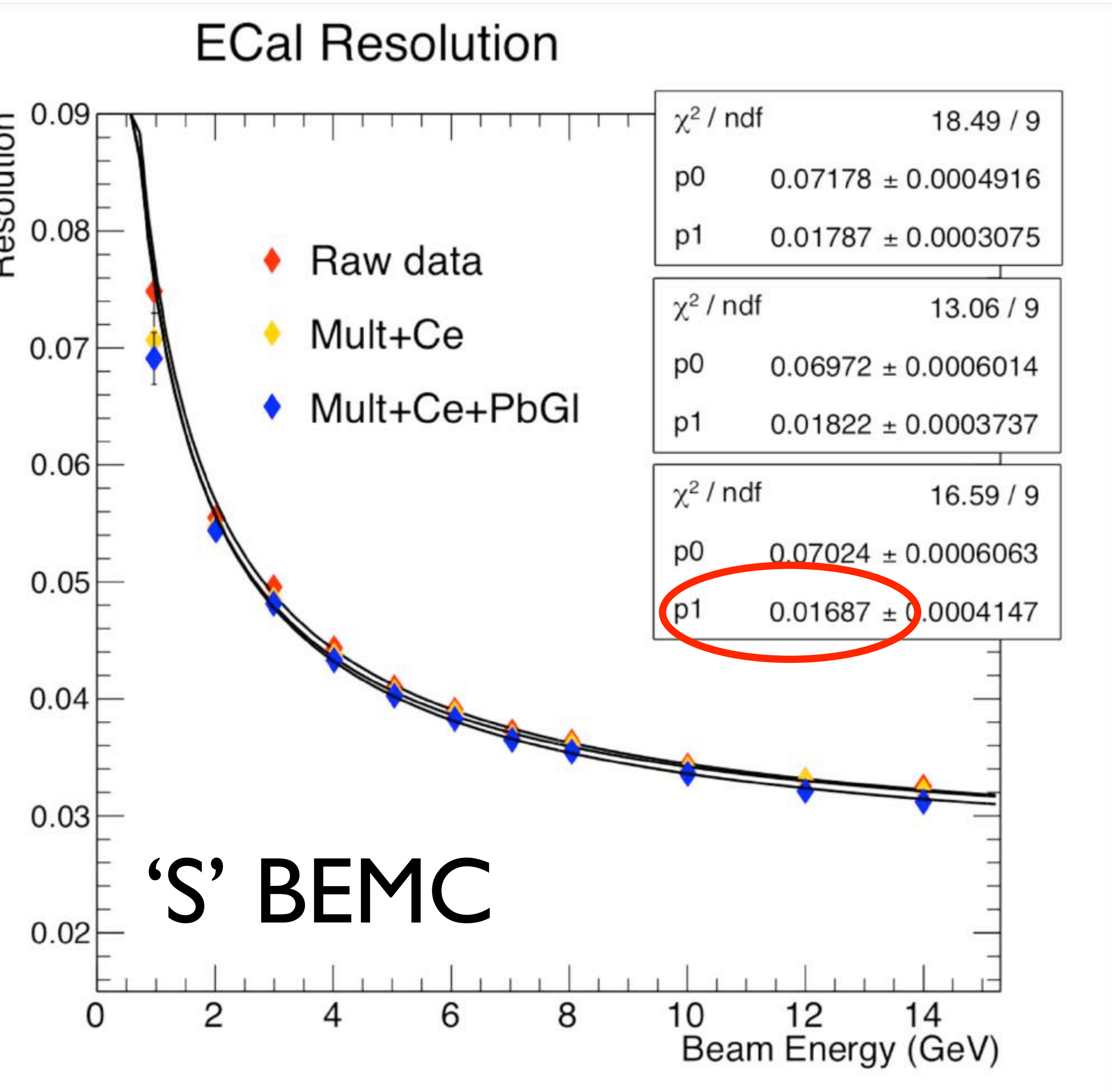


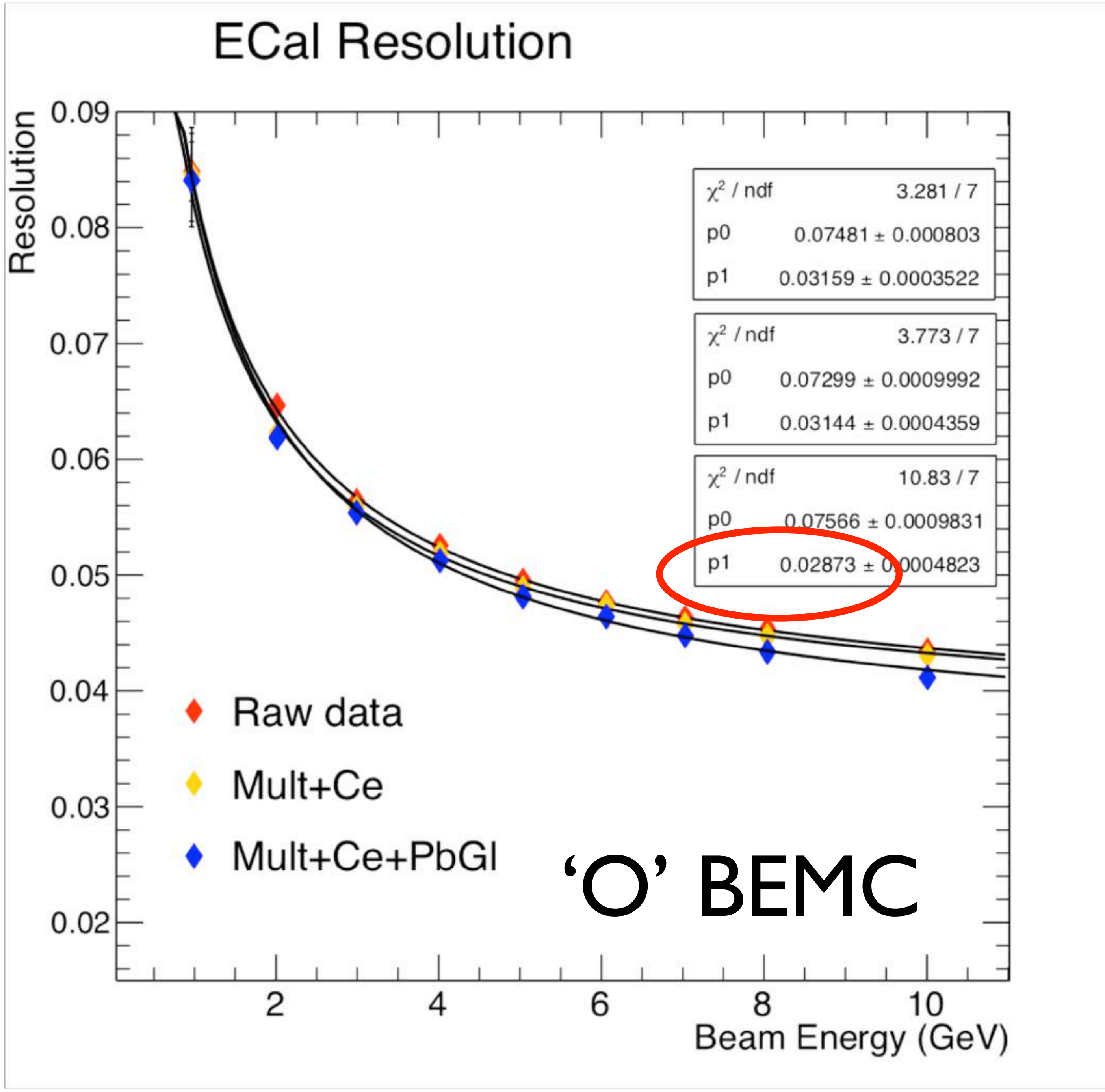
Joint between two production blocks

Joint between two doublets (‘Crack’)

Test Run 2016 FNAL, May 4-11:

Minimal set of cuts

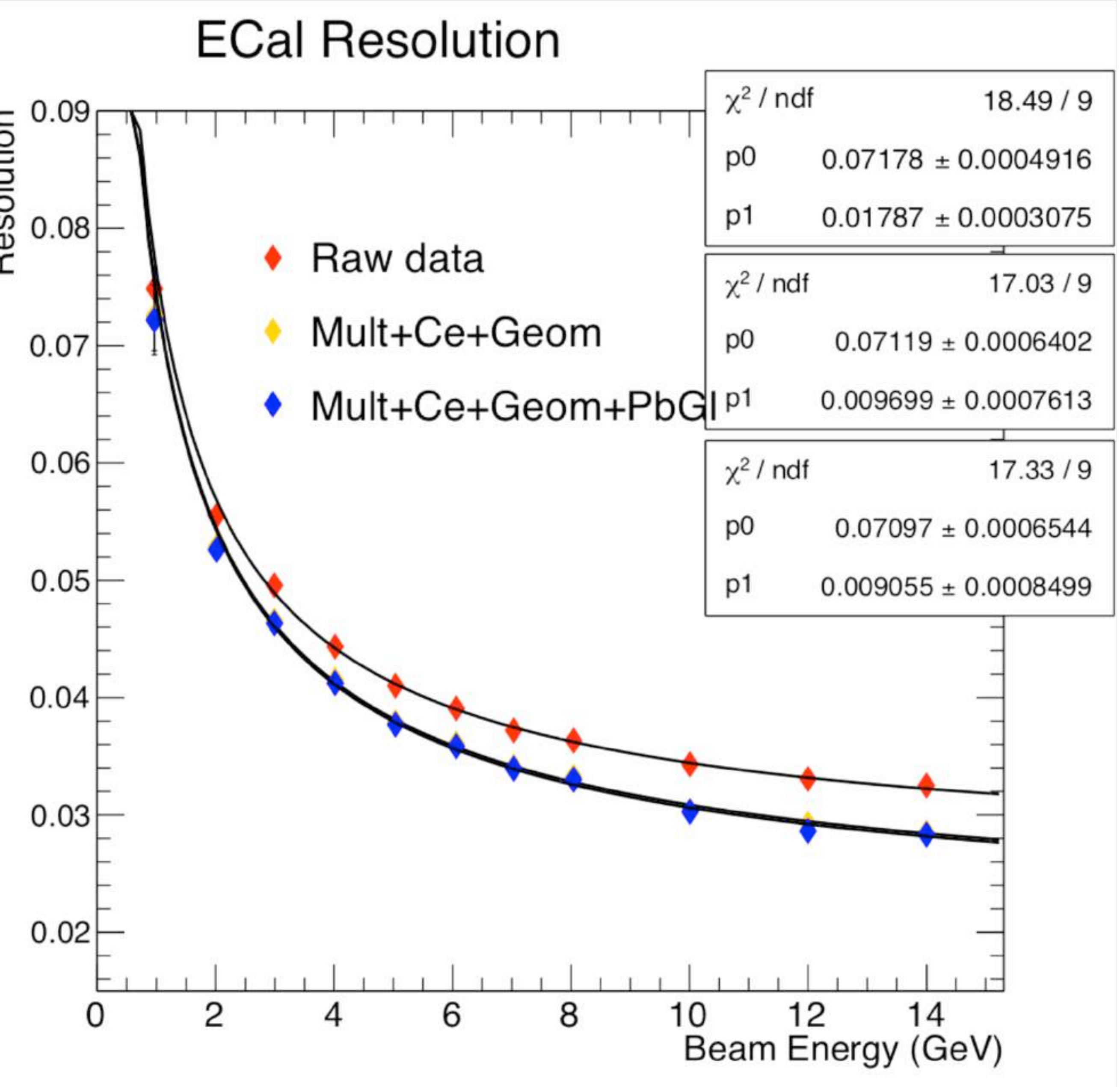


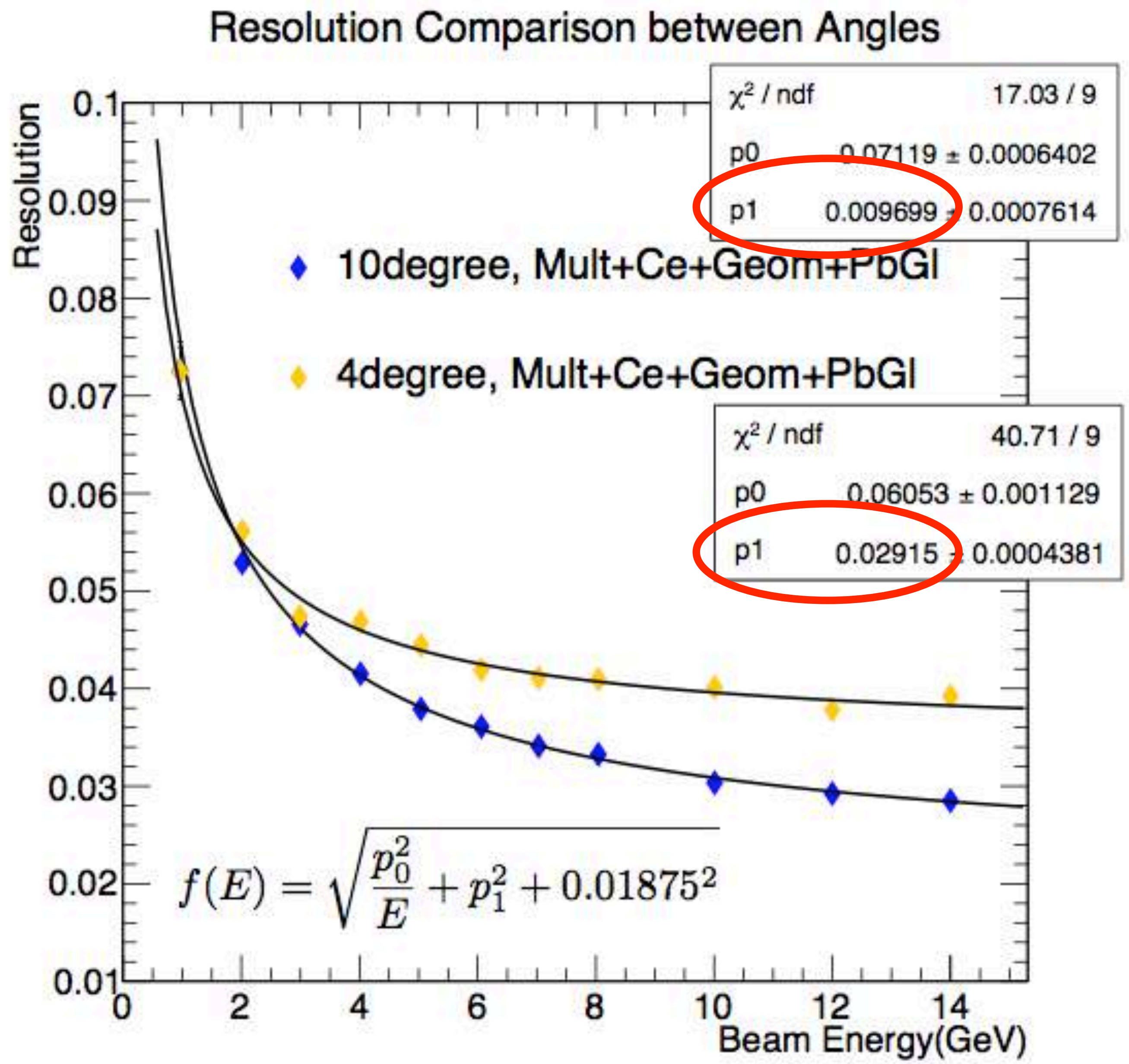


- 'S' has about 20% better resolution at 1 GeV
- 'S' constant term 1.7% compare to 2.9% for 'O'
- 'S' Light Yield ~ 5000 p.e./GeV, 'O' LY – 3500 p.e./GeV

Mult – one hit in Sc. Hodoscope, Ce – electrons ID using Cherenkov, PbGl – veto on hits in the PbGl

Test Run 2016 FNAL, May 4-11: ‘S’ BEMC, and Projectivity





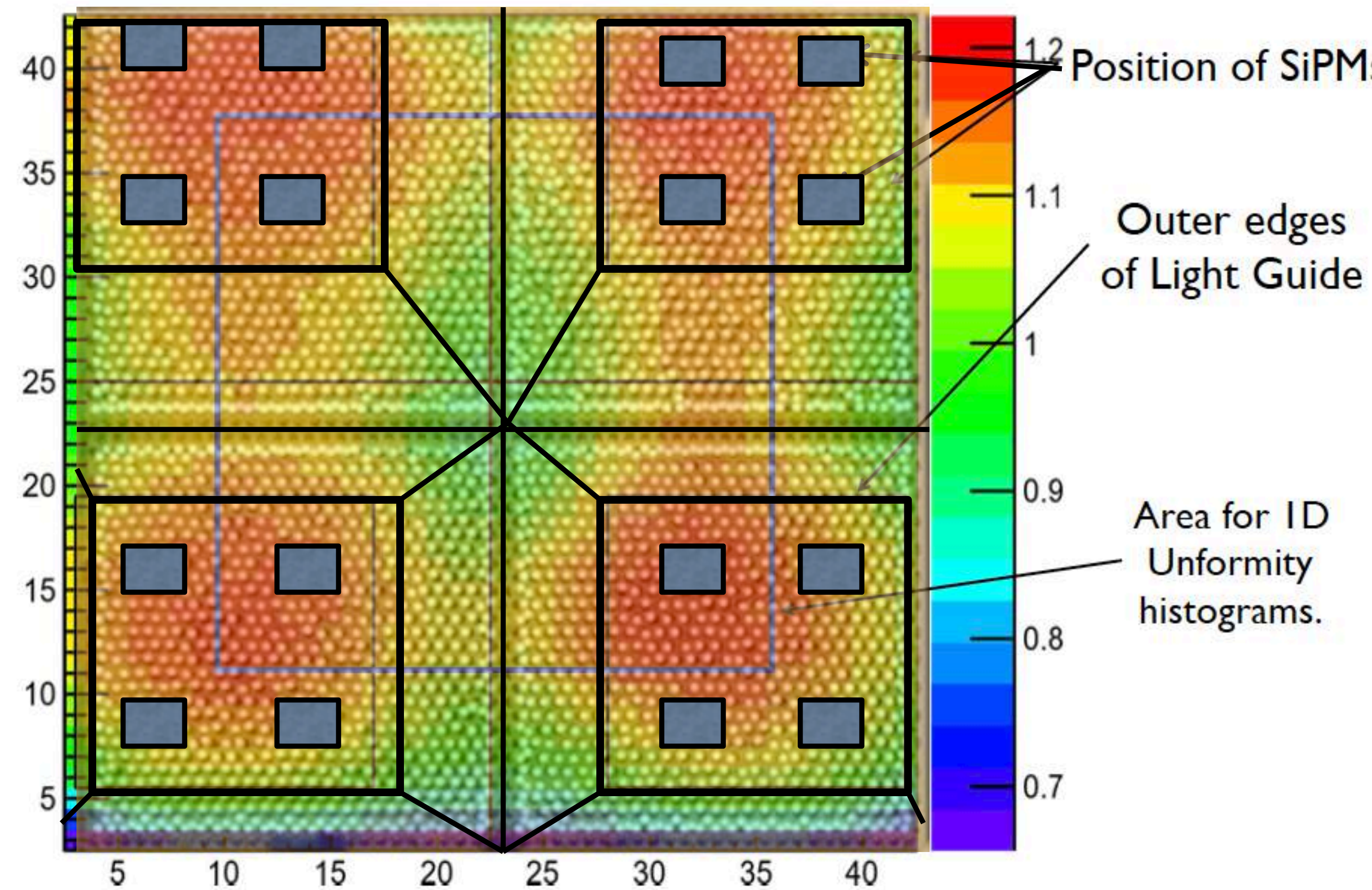
Excluding hits within +-2.5 mm within crack. Non-projective dead area.

- 1% constant term at 10 degrees.
- 2.9% constant term at 4 degrees.

- A similar analysis was made for the ‘O’ prototype. With the same ‘Geom’ cut used for ‘S’ detector, the constant term is about 2.6% at 10 degrees. The only explanation for this is that the combination of composite absorber and thin fibers does prevented us from keeping the sampling fraction within production blocks sufficiently uniform.

Optimization of light collection:

BEMC Superblock 2 x 2 towers, 4 SiPMs / tower, UV LED Map



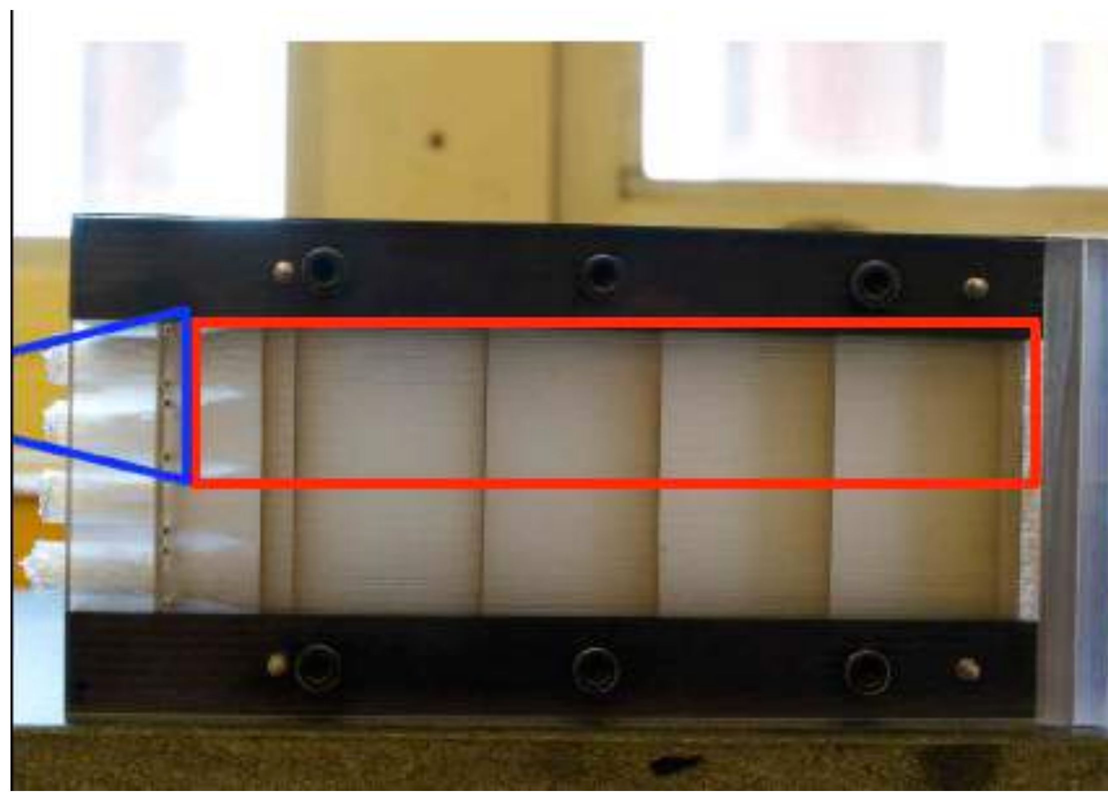
Compact scheme (short light guide with 4 SiPMs, which only partially covering output area of light guide) especially prone to be non-uniform.

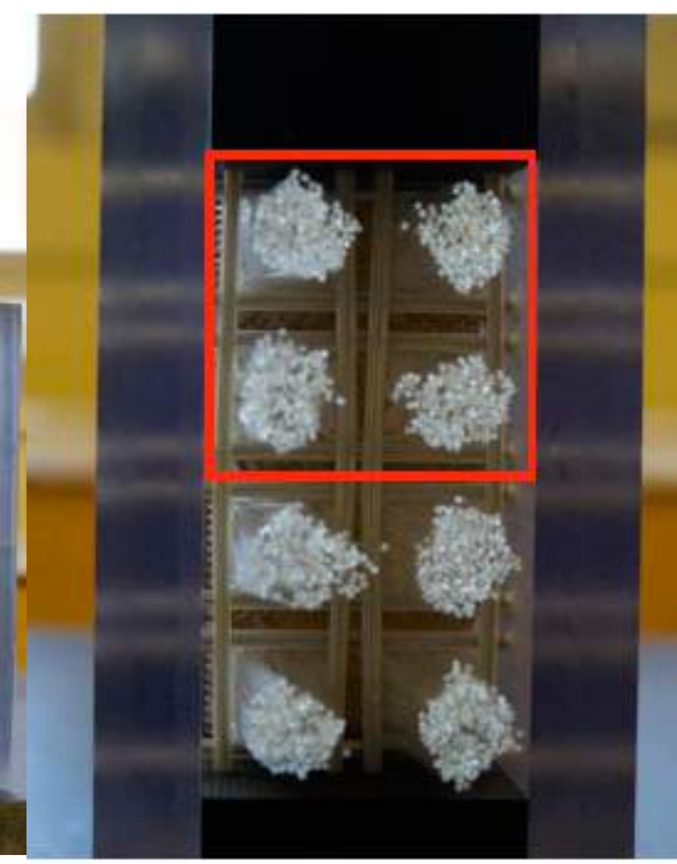
Solutions we tried in the past:

1. Compensation Filter between fibers and light guide. Loss about 30% of light (test run 2015). Will not work for FEMC.

2. Compensation with gradient reflector from the back side of the superblock. Practicality issues.

New Approach. Introduce controlled angular irregularities in fibers within tower, so that fibers in the corners and in the middle of the tower provide same LY.



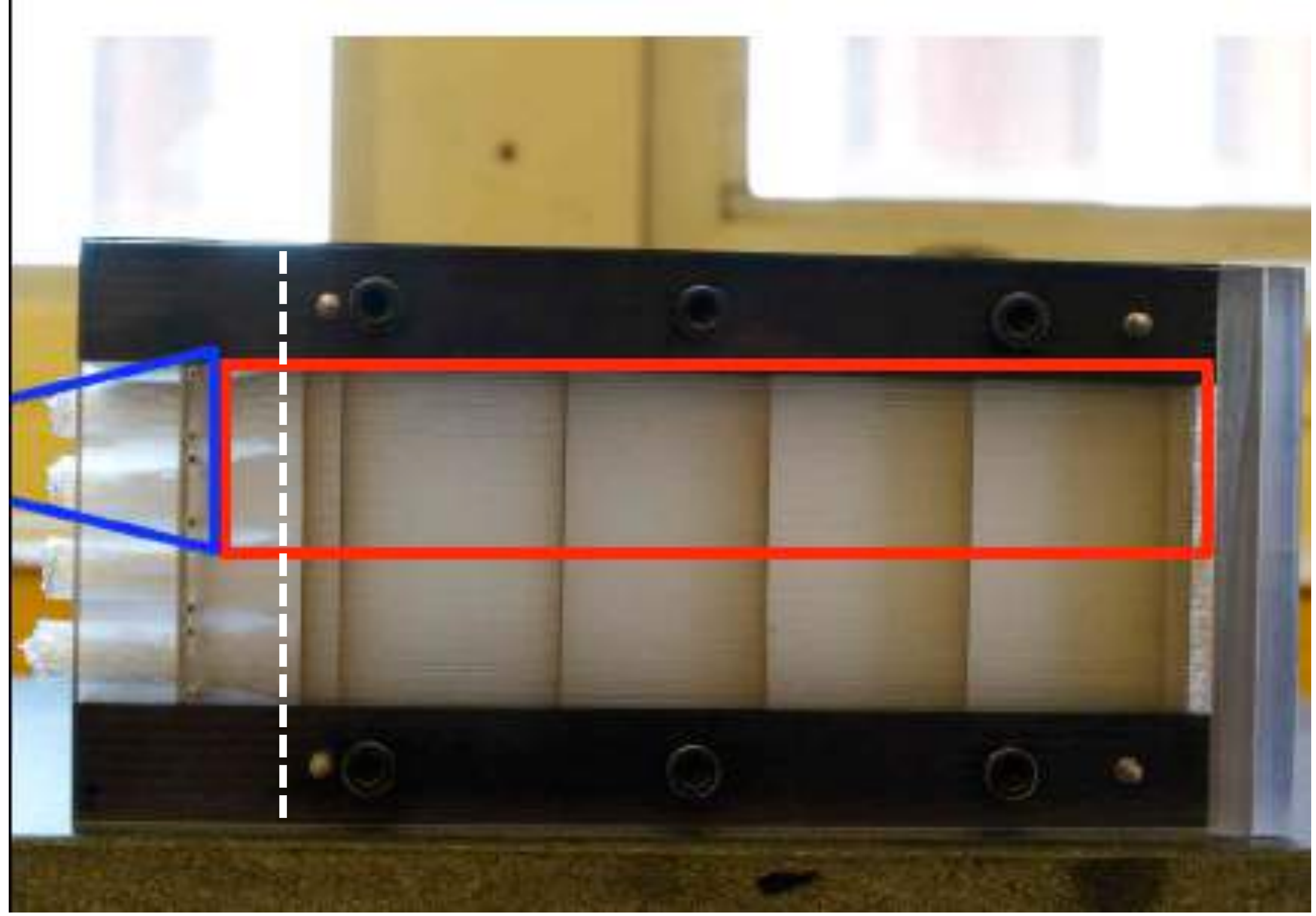


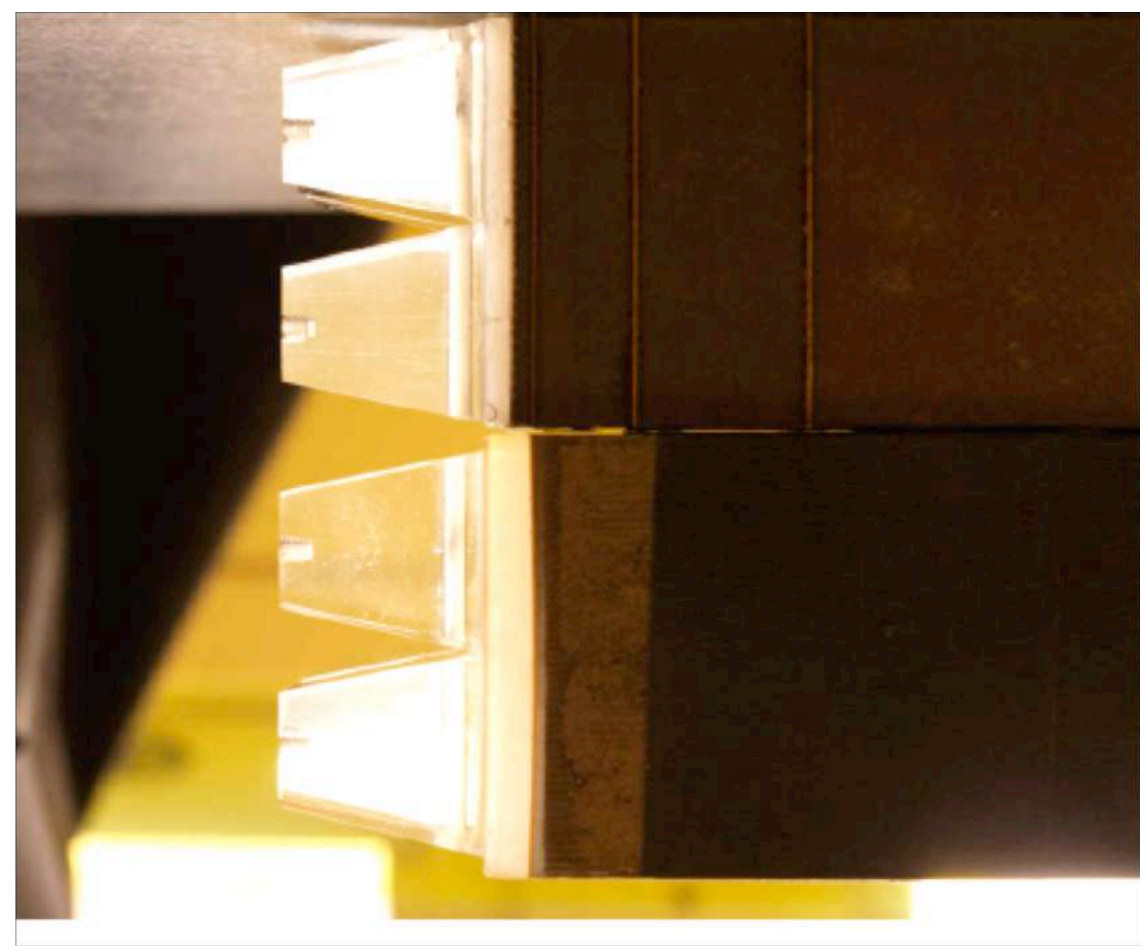
In 2014 we dropped development of 'bunched fiber' configuration for two reasons:

1. Introduction of volume in tower with 100% sampling fraction.
2. Practical issues; four independent light guides, mechanical mounting of FEEs to towers.

However, if one need to change angles of fibers only, then cut can be done close to the last mesh and one can use the same single light guide as in previous versions.

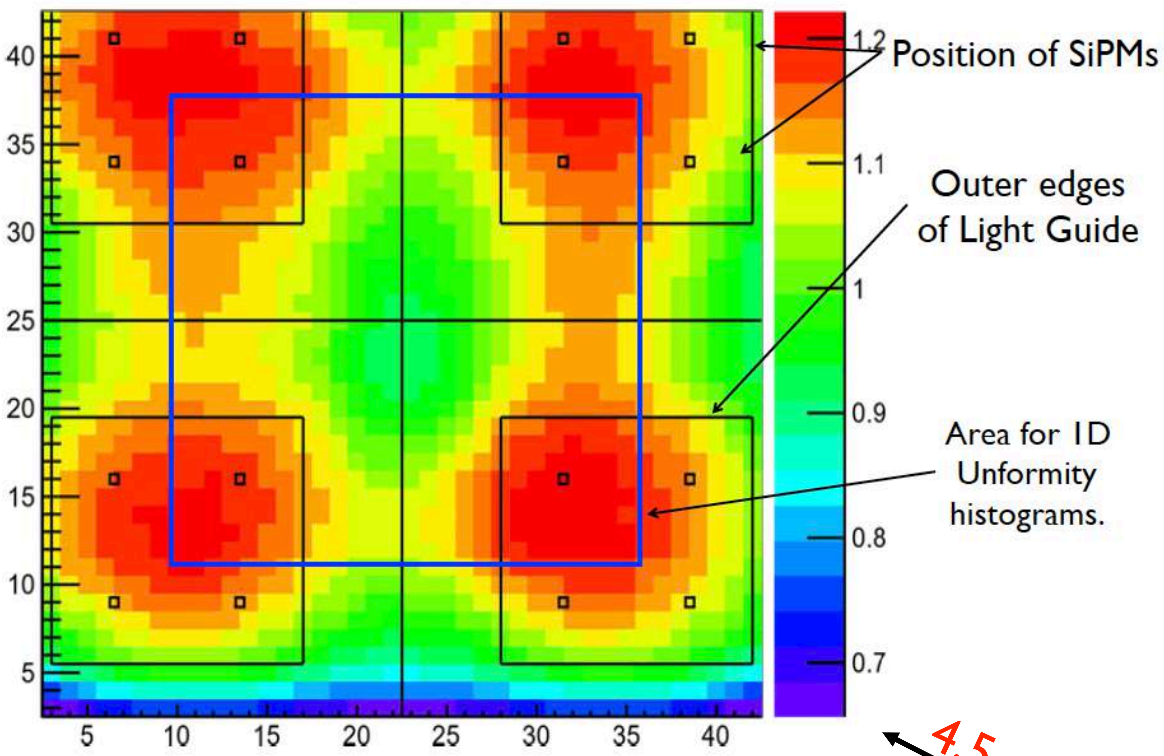
The last mesh has larger diameter holes to allow bending of fibers.



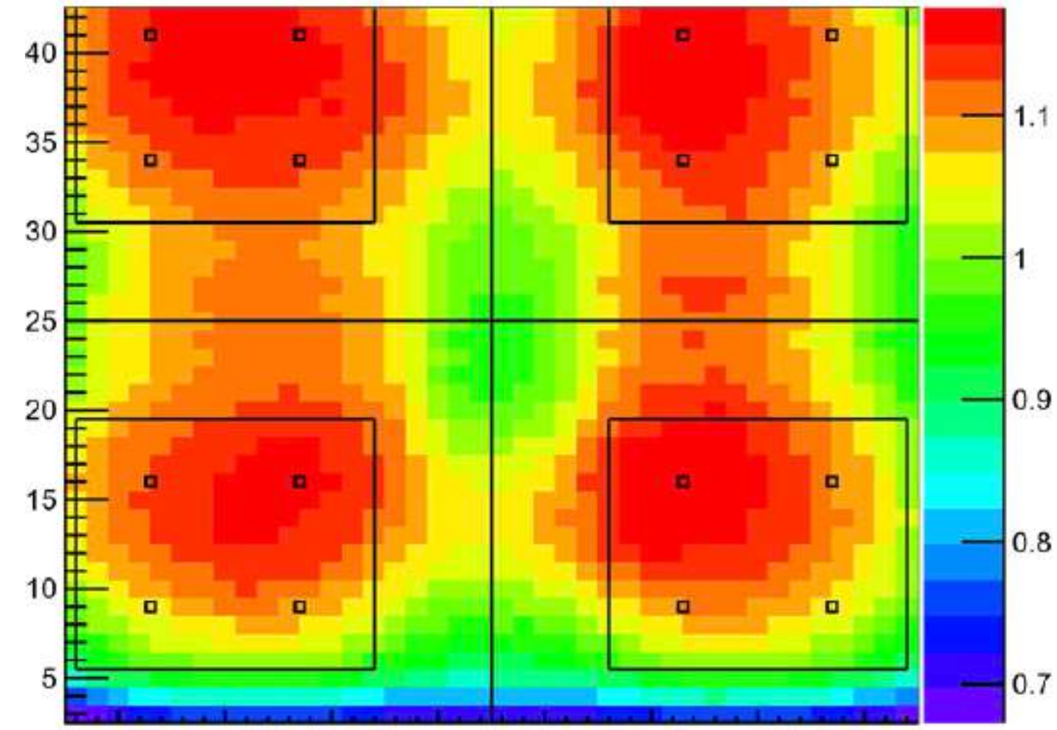


Optimization of light collection:

BEMC Superblocks, UV LED Map

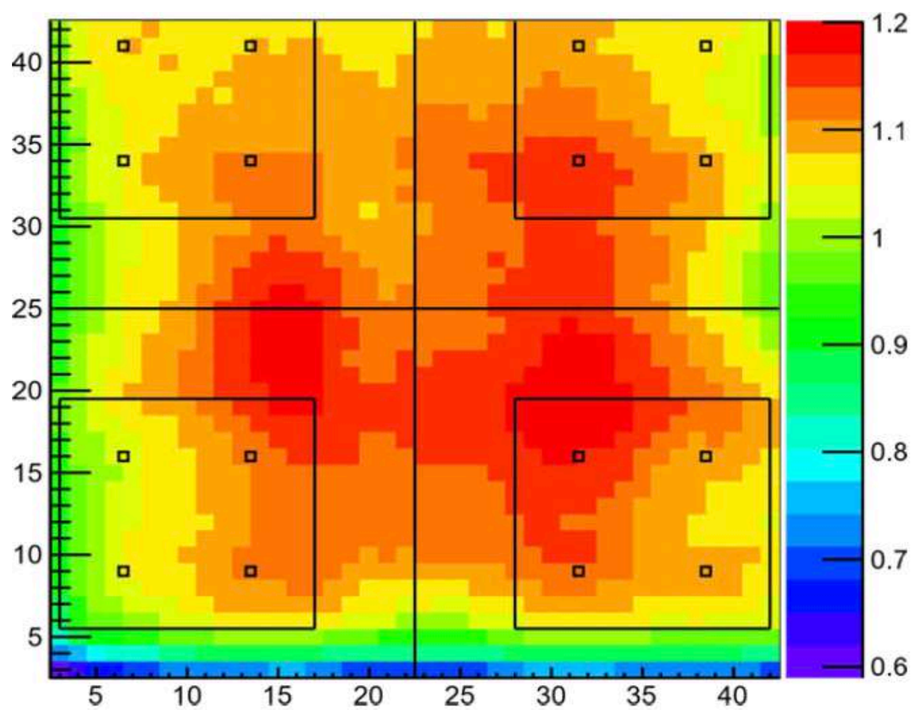


Old BEMC, Sylgard 184, 3mm

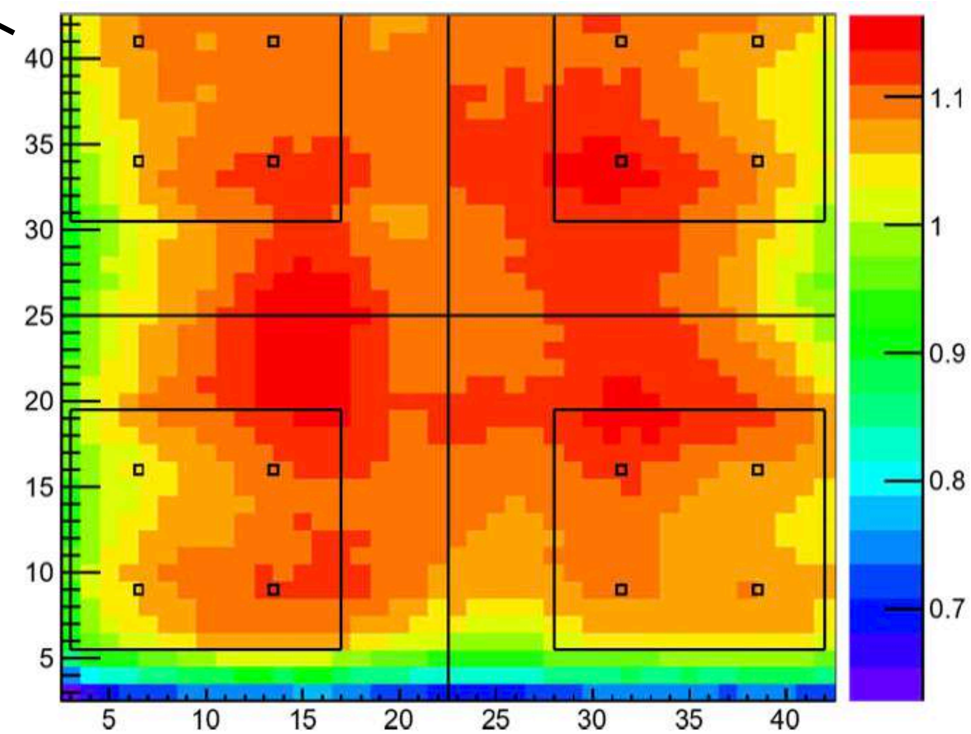


Old BEMC, BC-630, coupling is important

4.5 times better

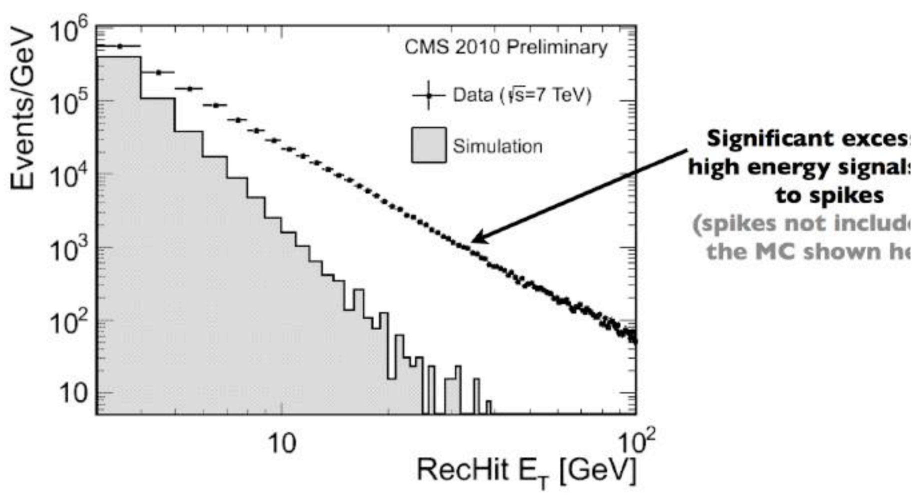


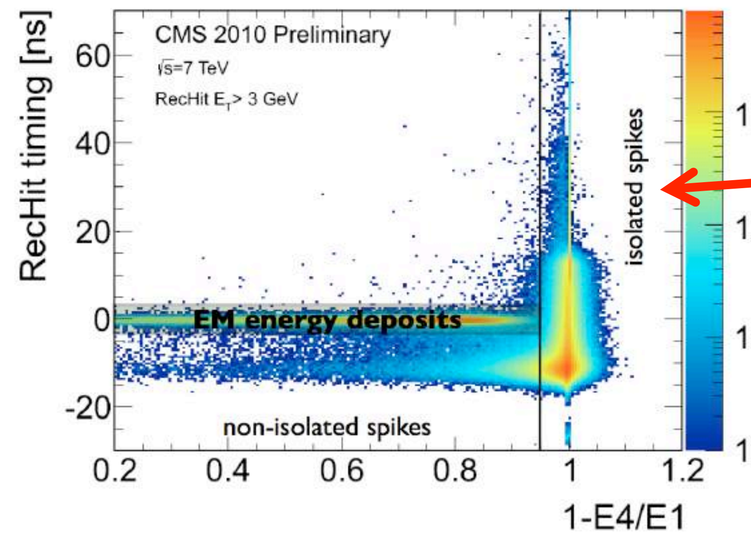
New BEMC, BC-630.
New arrangement of fibers works quite well.

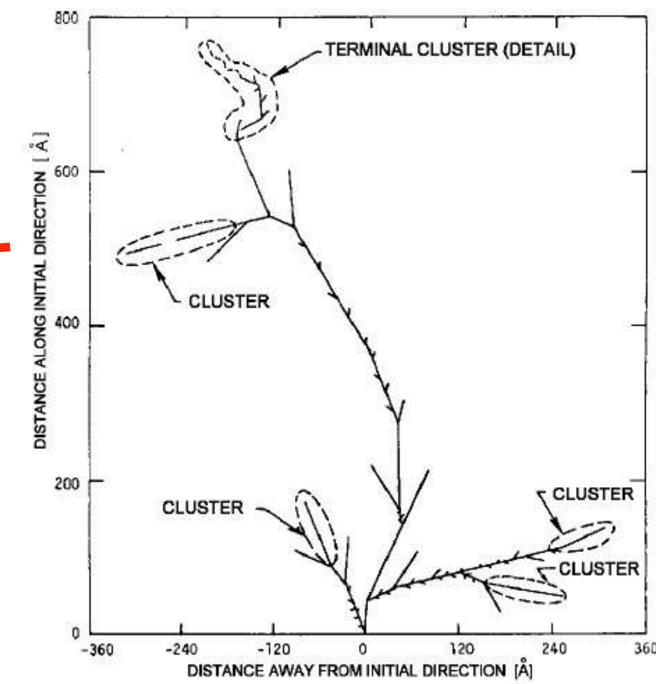


New BEMC, Lumisil 591
Better fiber arrangement and better coupling.

Critical Tests SiPMs and APDs in 'realistic' conditions:



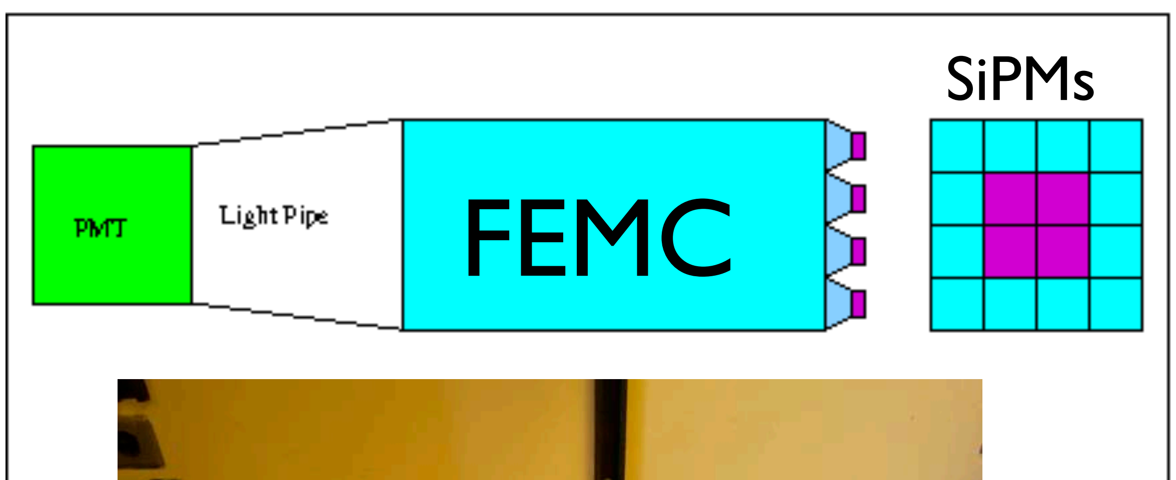


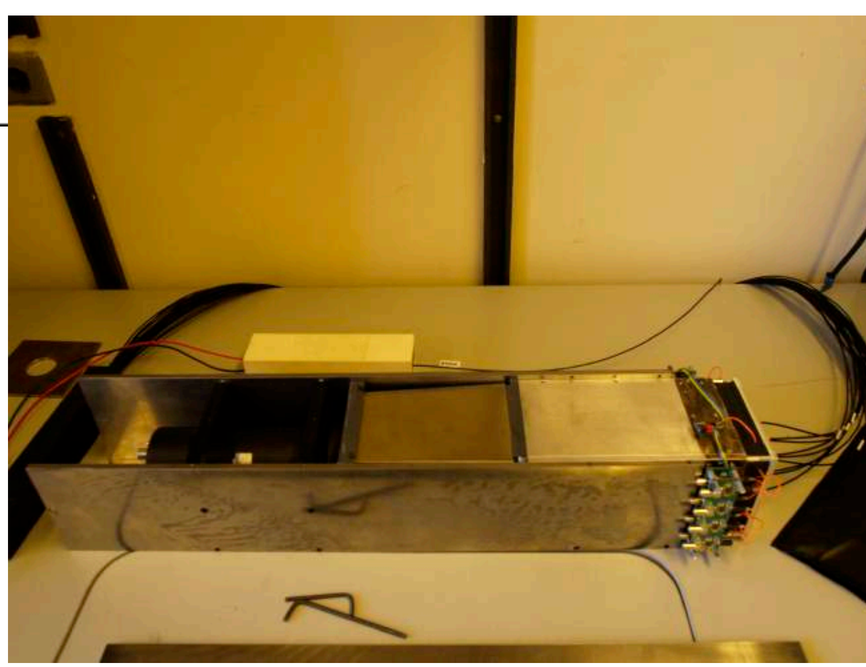


- You can't catch this in the test runs. Need collider environments.
- CMS and PANDA didn't know about this until LHC started and trigger system got choked!
- SiPMs in principle should be immune to Nuclear Counting Effects, but what about non-isolated spikes?

50 keV, PKA

- Large signal in APD,
- One pixel fired in SiPM

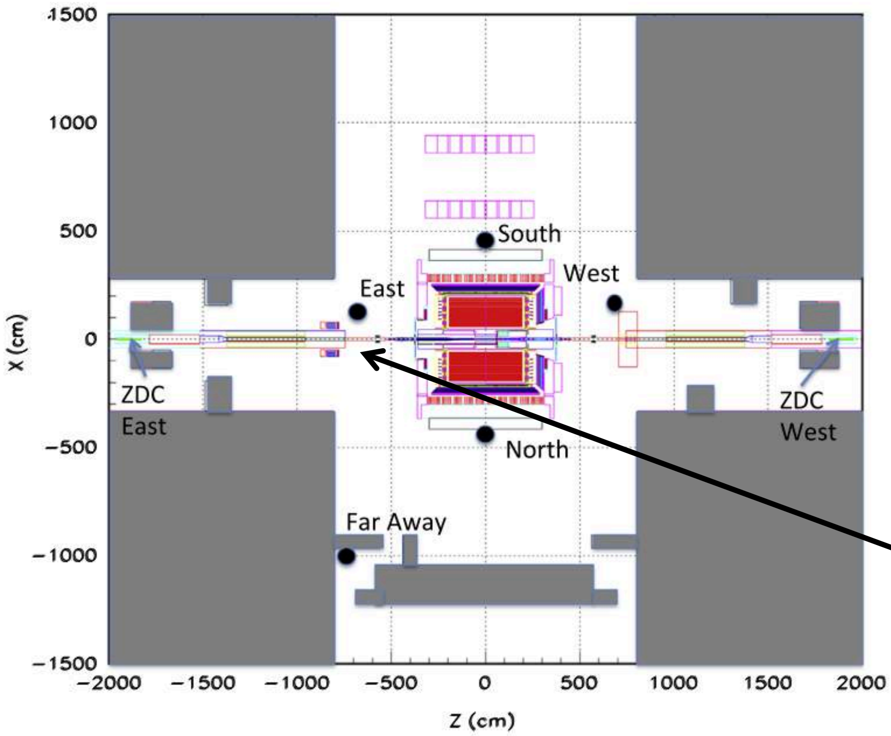




Test at STAR IP during Run16:

- FEMC equipped with dual readout to compare response of SiPMs (APDs) to PMT.
- High Tower (HT) Trigger for four central towers (range 4 – 2 GeV).
- Installed at the East Side of the STAR Detector about 1 meter away from the beam pipe.
- SiPM HT. data set taken during AuAu run.
- APDs HT. data set taken during dAu run. Gap in data taking is due to test run at FNAL.

SiPMs and APDs in 'realistic' conditions:

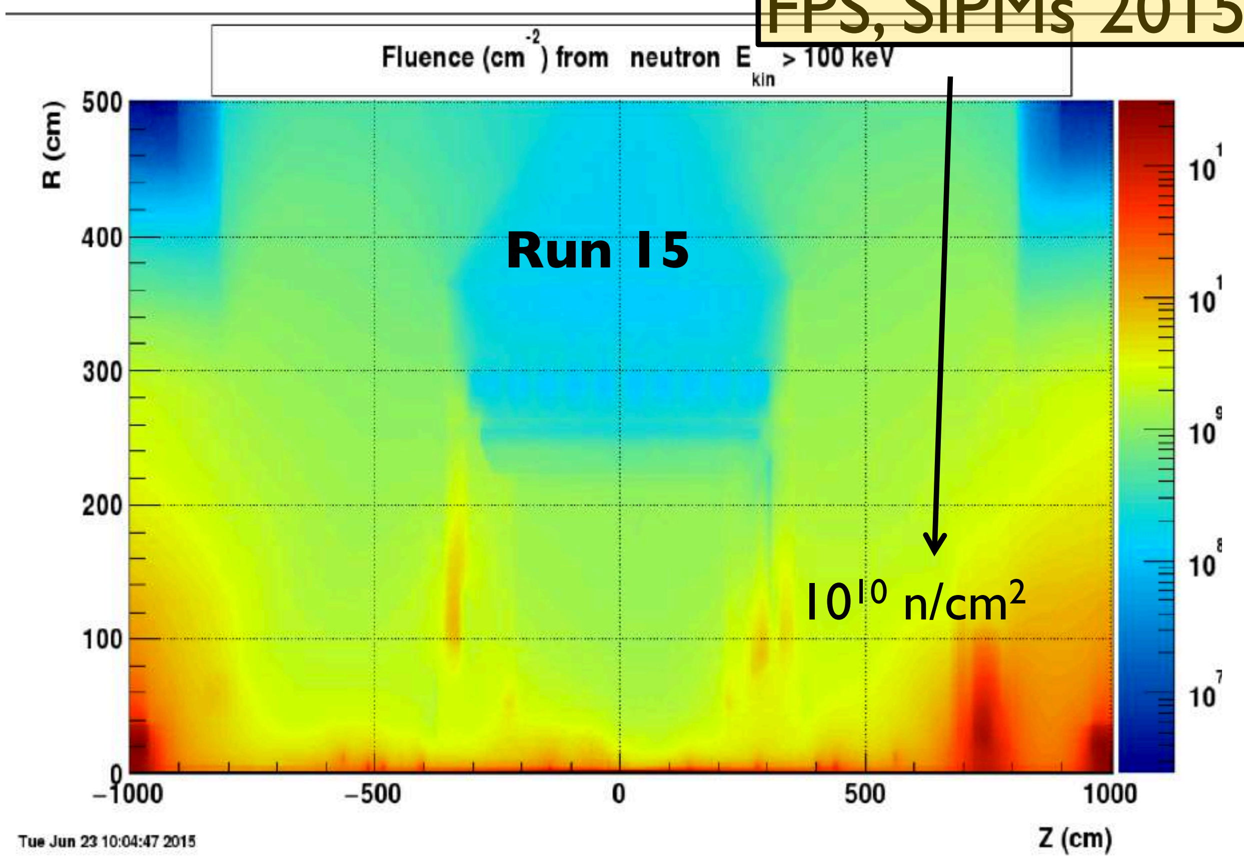


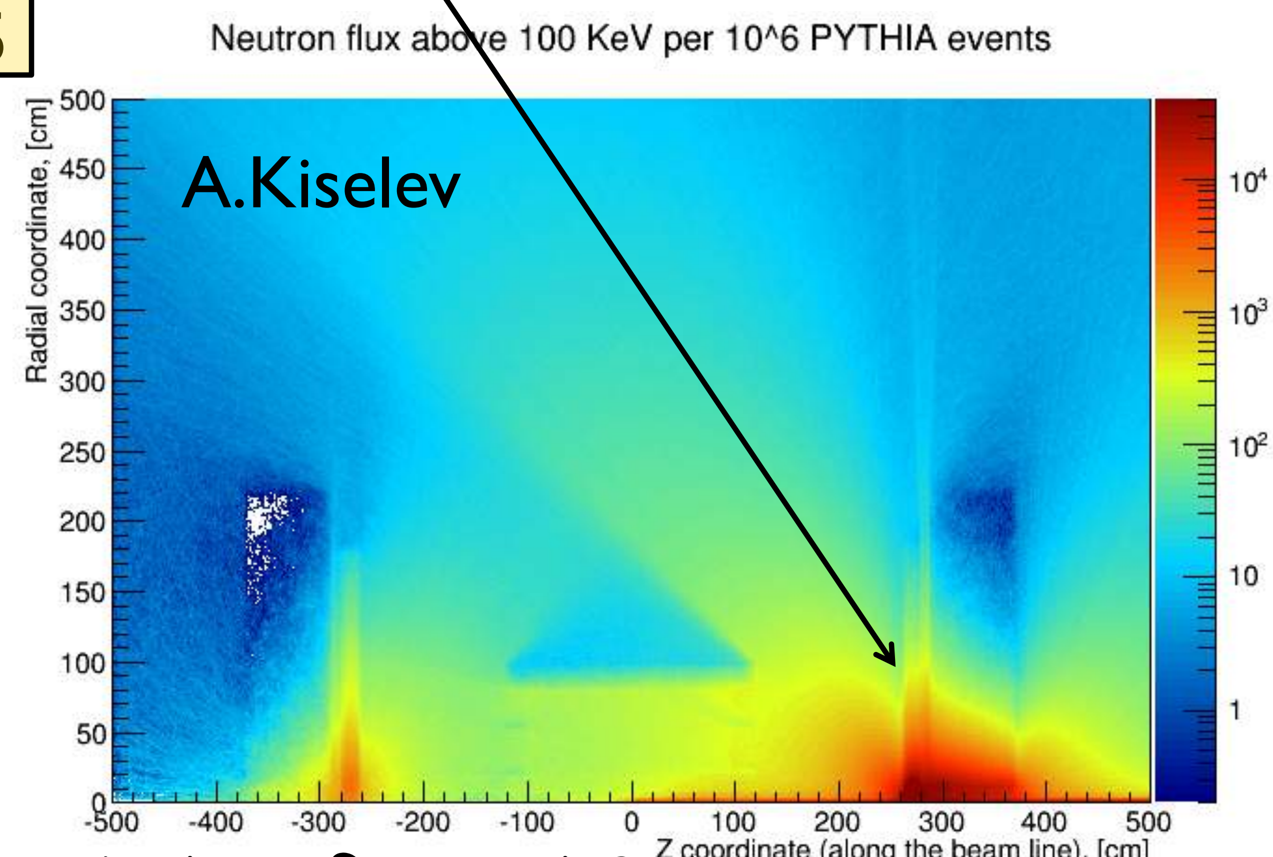
- STAR IP ideal test place for EIC. Well understood conditions (measurements in 2013 thermal neutrons, 2015 'MeV' neutrons with Forward Preshowers (FPS) SiPMs + MC).
- EICRoot tuned using STAR data.
- Conditions for FEMC in BeAST very close to one we have in STAR now.

FEMC, 2016

Y.Fisyak, et.al NIM A756

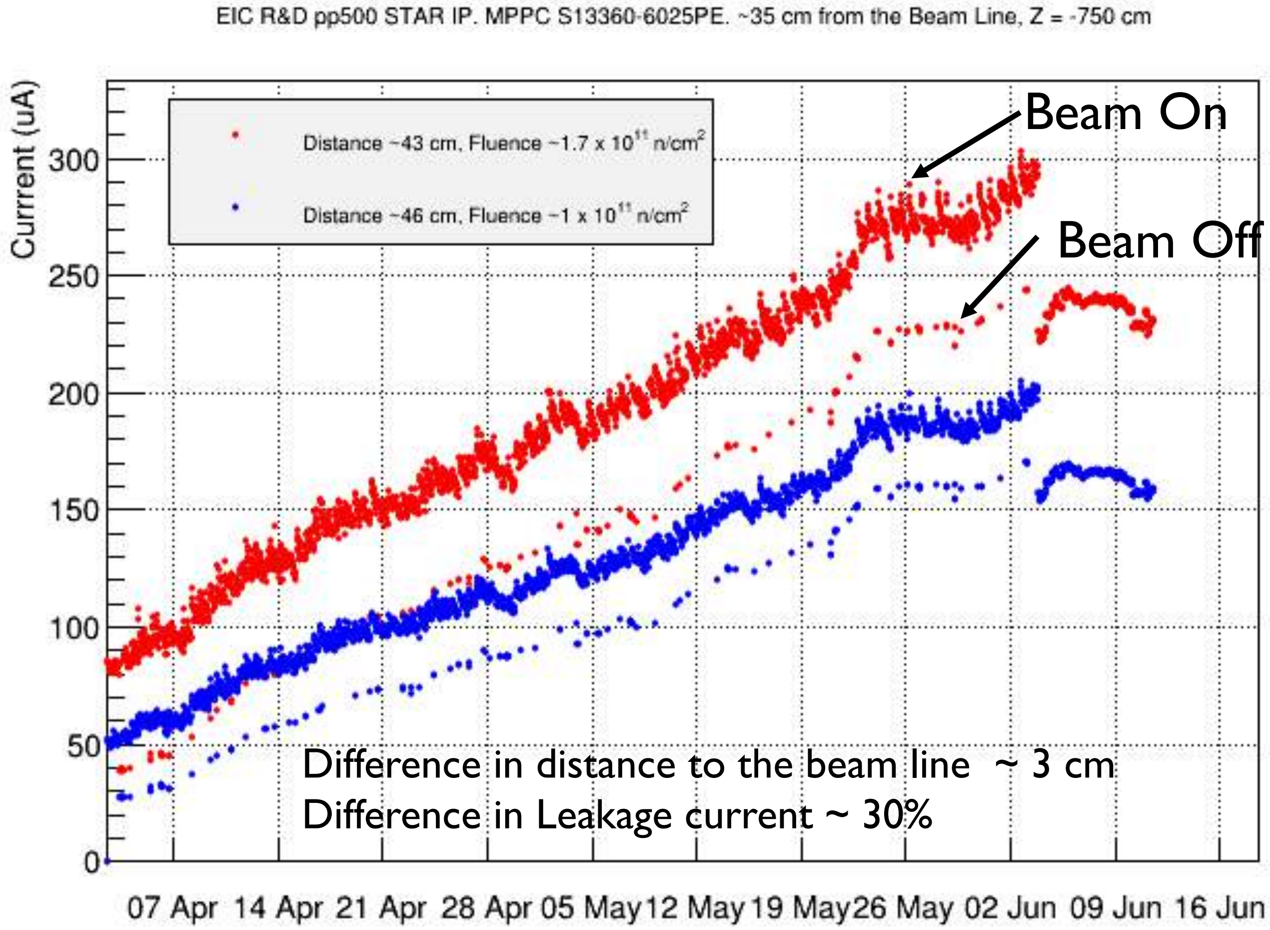
FPS, SiPMs 2015

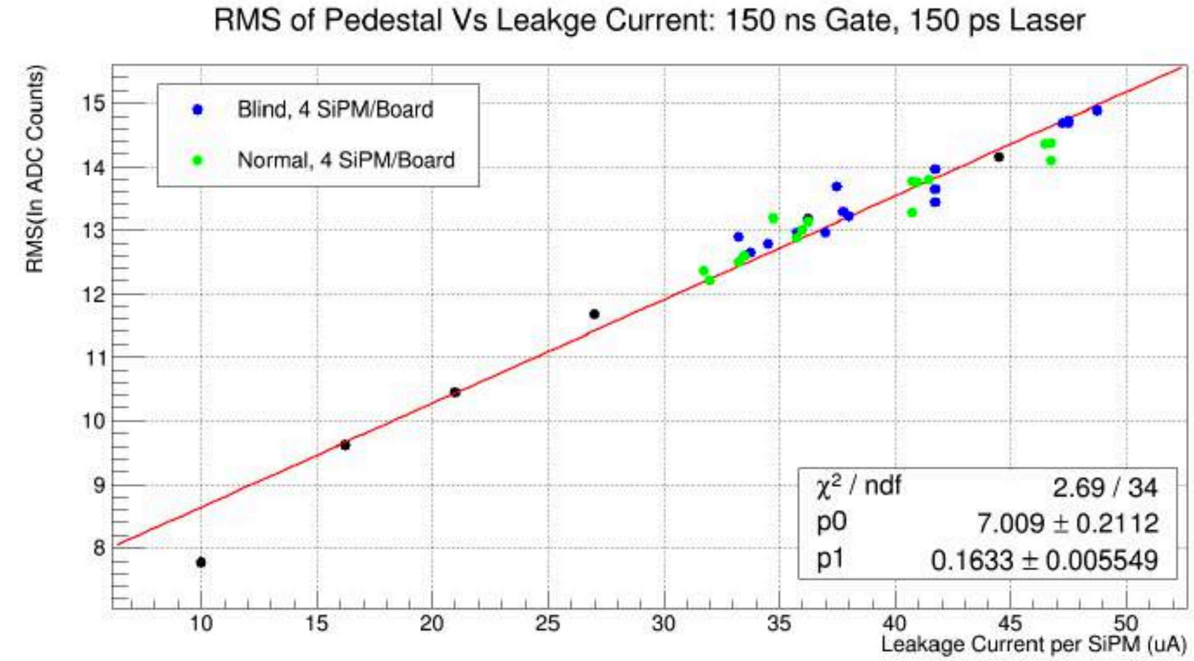


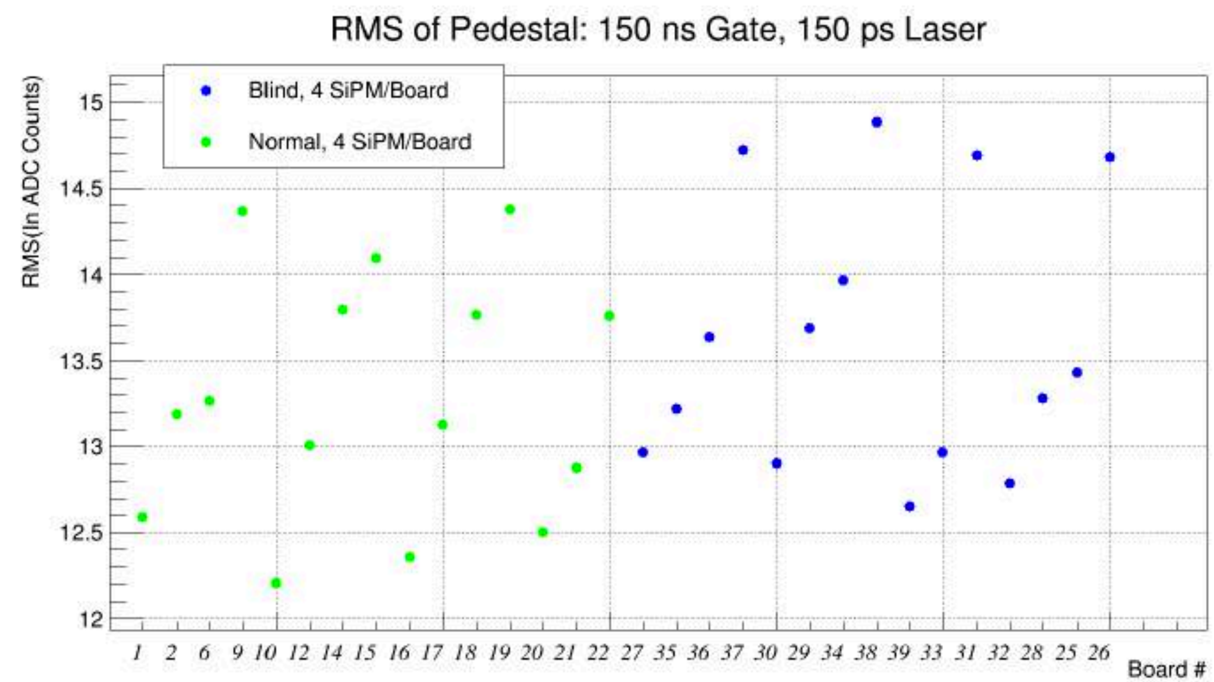


Neutron fluxes at BeAST, ep 20 x 250 GeV

Run 17. Examples of Degradation.

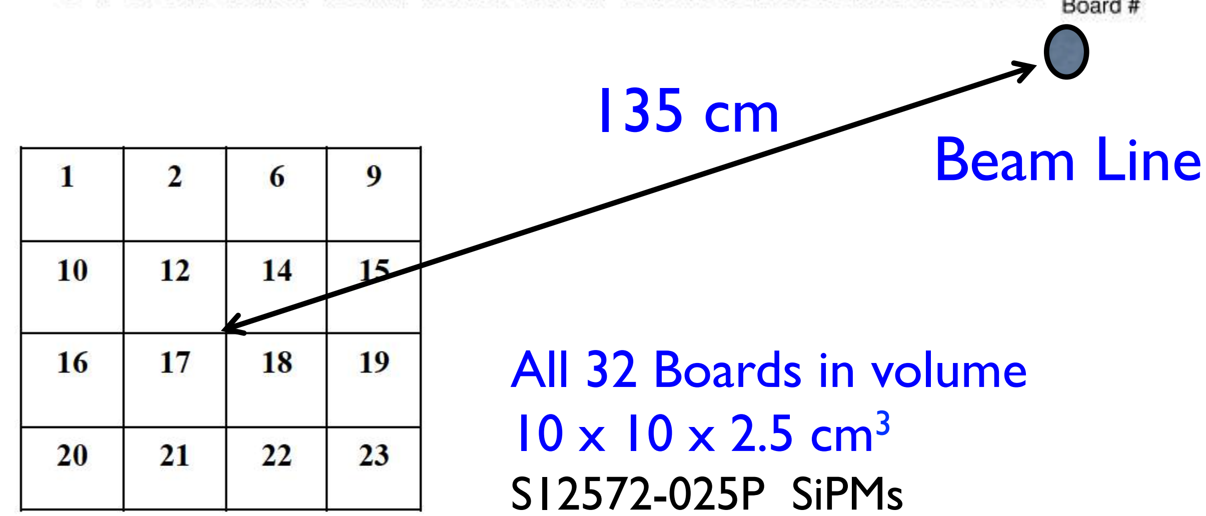






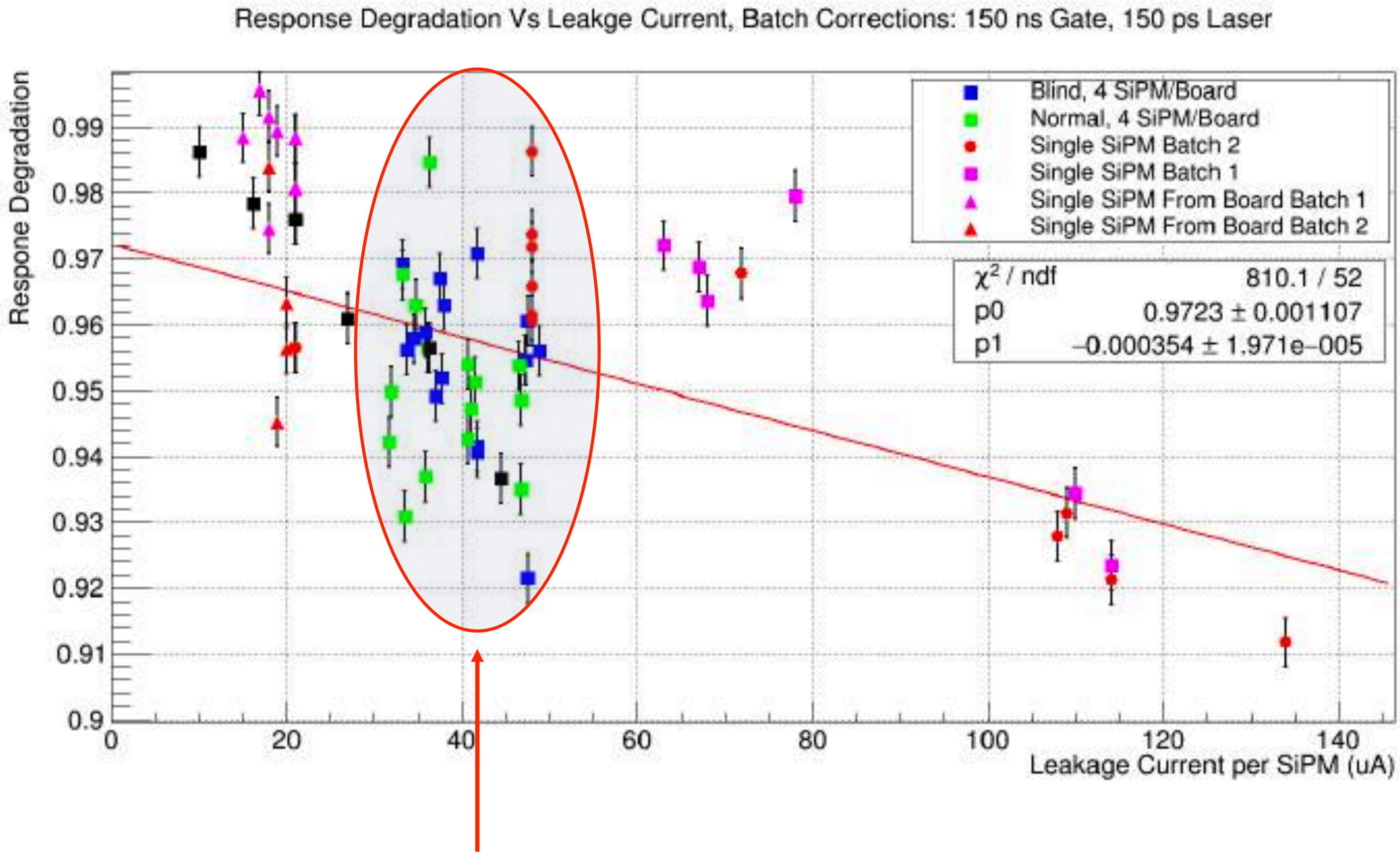
- Naive assumption that sensors are in the same conditions ("neutron gas") does not work well.
- Calorimeter is a source of background and also a shield.
- Probably need to know spectra and convolute these with damage functions.

- Yuri Fisyak were pointing to that long time ago, but it was not done. (lot of work and luck of test data).



All 32 Boards in volume
10 x 10 x 2.5 cm^3
S12572-025P SiPMs

Degradation of response with respect to unexposed sensors.



Problem for some designs. May need monitoring for each SiPM, unless

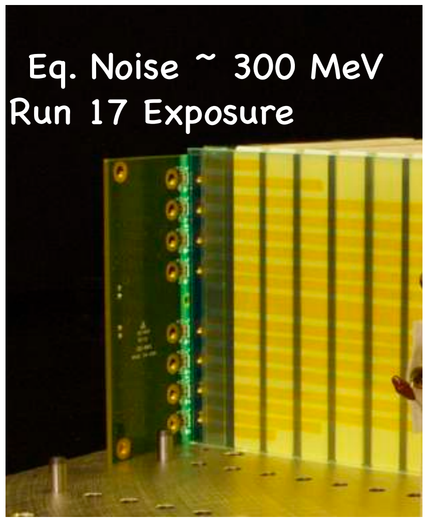
- Light is mixed, SiPMs bunched. Still need good monitoring system but per tower.
- Or, one can claim that can calibrate/monitor from physics. (has not been looked for EIC calorimeters)

SiPMs/APDs , Eq. Neutrons, Light Collection Schemes…

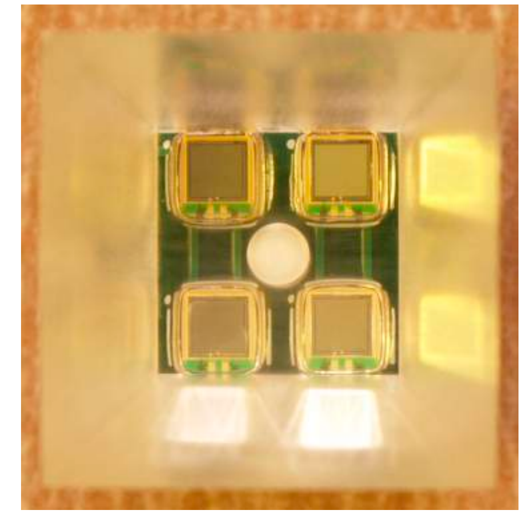
Sensor:
- Small Active Area
- Limited # pixels

Requires:
Multiple Sensors per tower

Calorimeter
- Light Collection Scheme
- Dynamic Range



Eq. Neutrons in IP
Degradation of Response
Is It Differential ?



Light perfectly Mixed

- Energy Resolution, term (1/E)
- Loss of Calibration Signals

Light partially Mixed

- Energy Resolution, term (1/E)
- Energy Resolution, constant term ?

- Increase LY
- Focus and Mix Light
- Minimize # sensors

Post Run 17
HCAL, Re-designed
Light collection scheme.

- Consider alternative technologies for high n flux areas.
- Consider non Si based sensors for high resolution calorimetry.

So far, safe approach is to think:

- SiPMs at EIC conditions will degrade.
- Each SiPM is 'unique' and will degrade differently.

Defence

- Choice of calorimeter design, which can amplify or play down problems related to degradations due to exposure, see slide 12.
- Good monitoring system.

Additional Efforts required.

- Reliable calculation of degradation will require more work than we did so far, that had also include such things as machine background.
- Calibration/monitoring in situ from physics.

  - SiPM R&D will continue.
  - New sensors and sensors exposed during Run 18 at STAR IP are being characterized now at UCLA.

Summary of developments and next steps:

- W/ScFi R&D pretty much finished. sPHENIX adopted this technology for barrel Emcal (UIUC is leading construction project).
- W/ScFi technology for Emcal for Hadron EndCap is ready for construction.
- W/ScFi for barrel (non-projective), like to revisit readout scheme.
- Compensated binary scheme EM+HCAL were tested and seemed to be good enough back in 2014.
- Electron EndCap. Shashlyk technology may be a good candidate. Emphasis should be placed on improving constant term.
- Potential of dual readout schemes (timing) had to be understood. Non-compensated HCAL for Hadron Endcap with good resolution.
- Photodetectors (SiPMs) R&D will continue.