Results of STAR/EIC Test Run at FNAL.
Feb.26 - March 17, 2014

Conceptual ideas how to build EIC Barrel EM Cal.

O.Tsai (UCLA)
EIC, Calor 04/17/2014

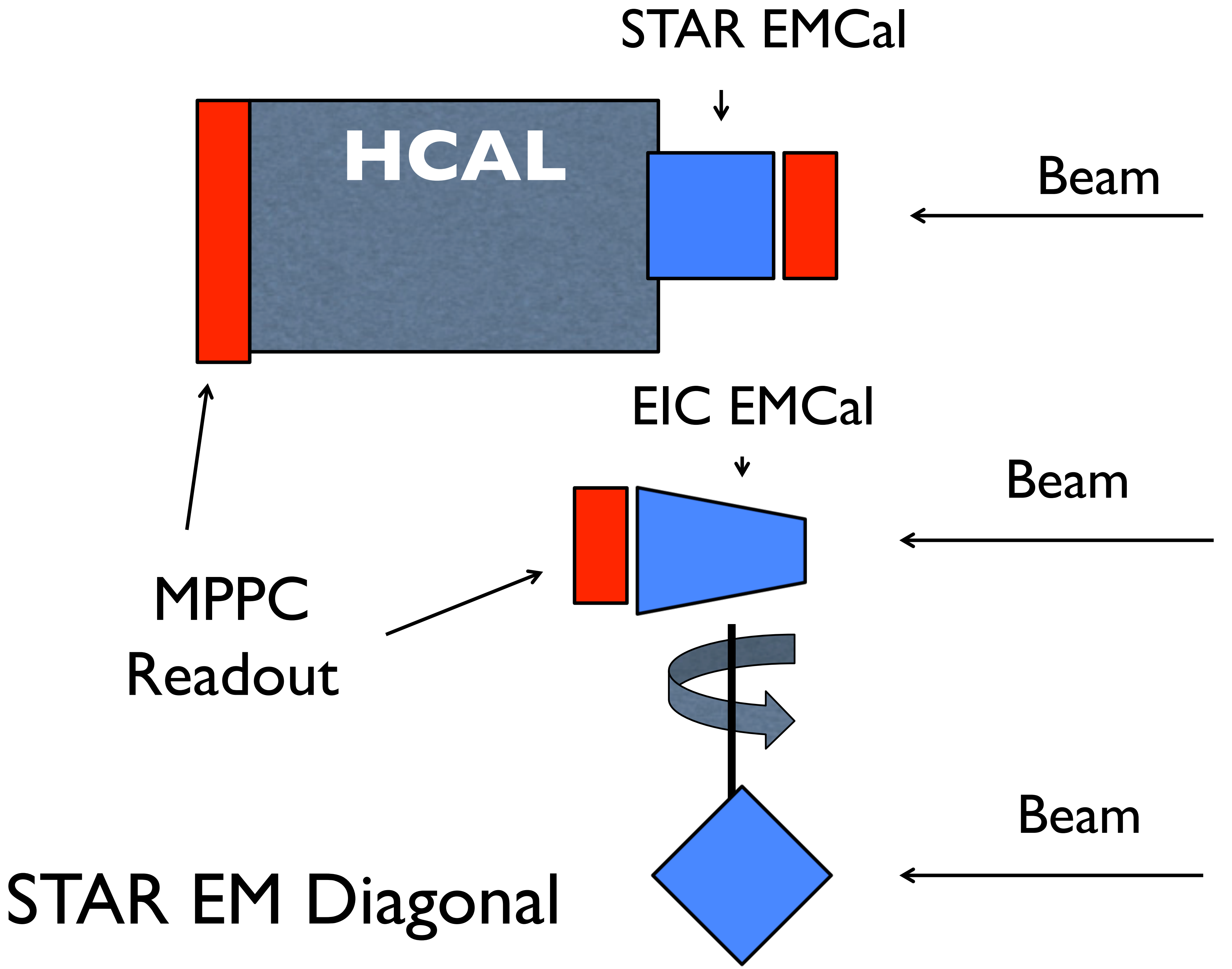
STAR FCS/EIC R&D Goals 2013/14:

- Build full scale prototype of FCS.
  - a)Verify construction technique for HCAL.
  - b) Refine construction technique for EMCal.

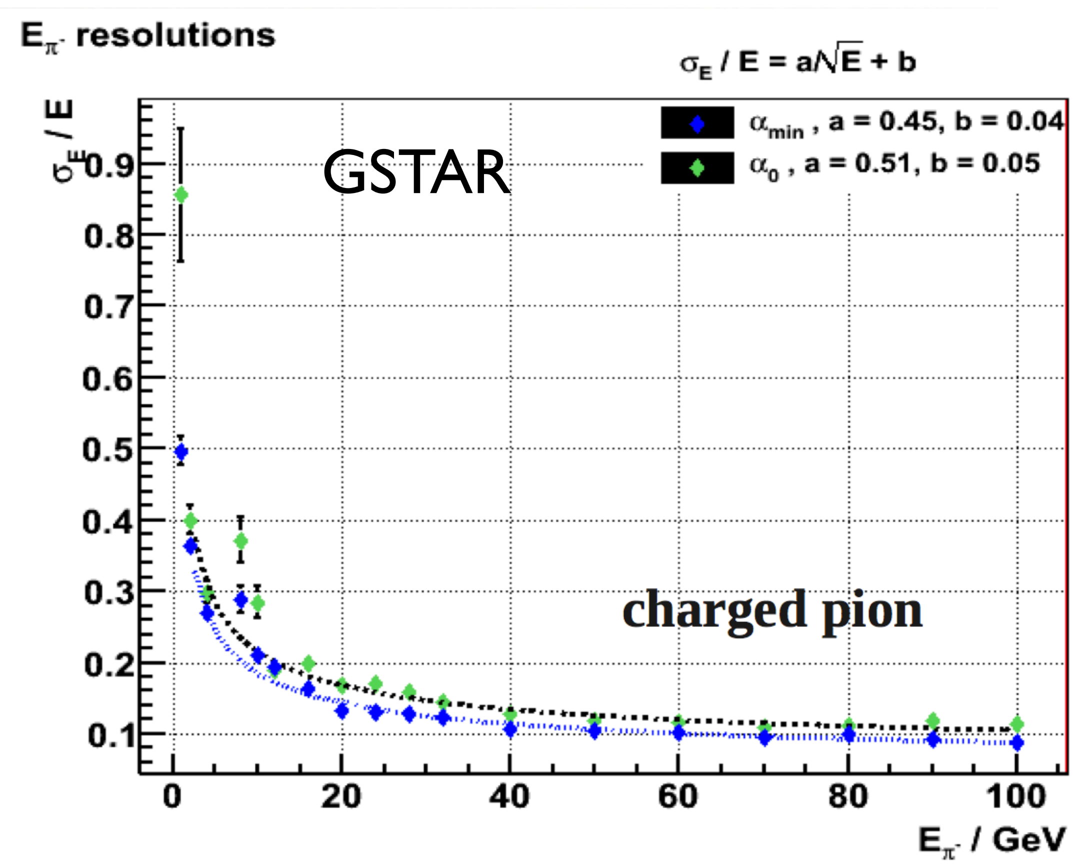
- Develop compact readout with SiPMs.
  - a) Light collection scheme.
  - b) Front End Electronics.

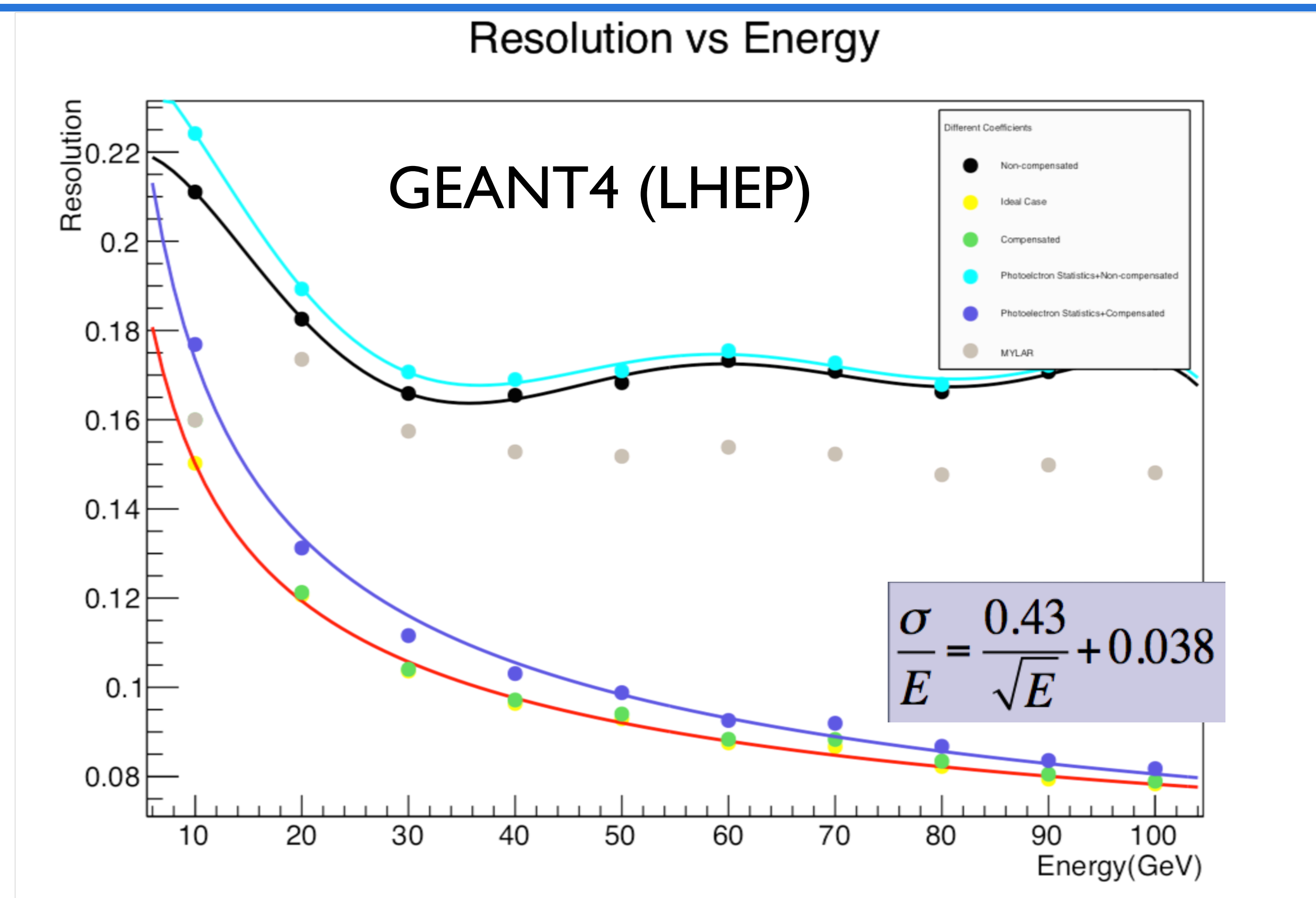
- Test system with beams at FNAL.

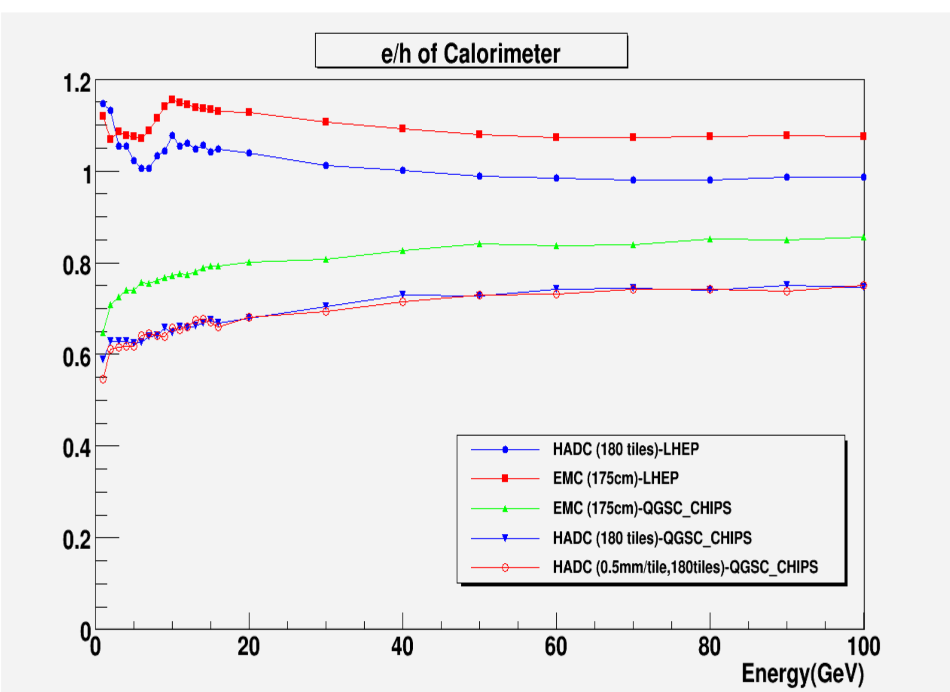
Setup on the beamline



Example, HAD Section. MC performance.

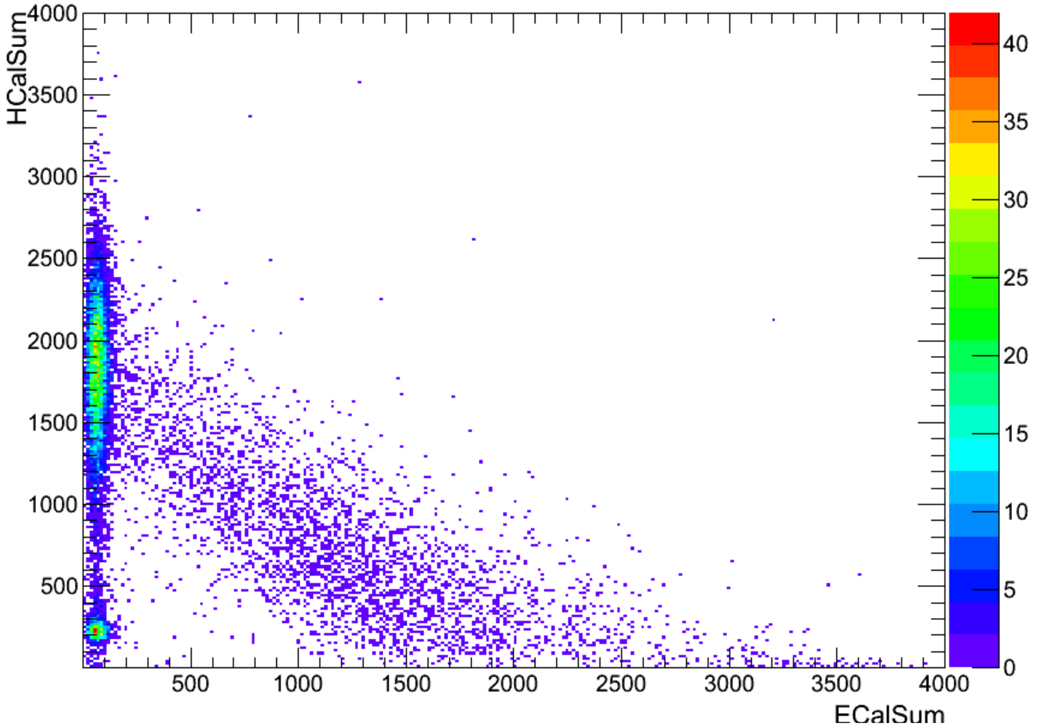


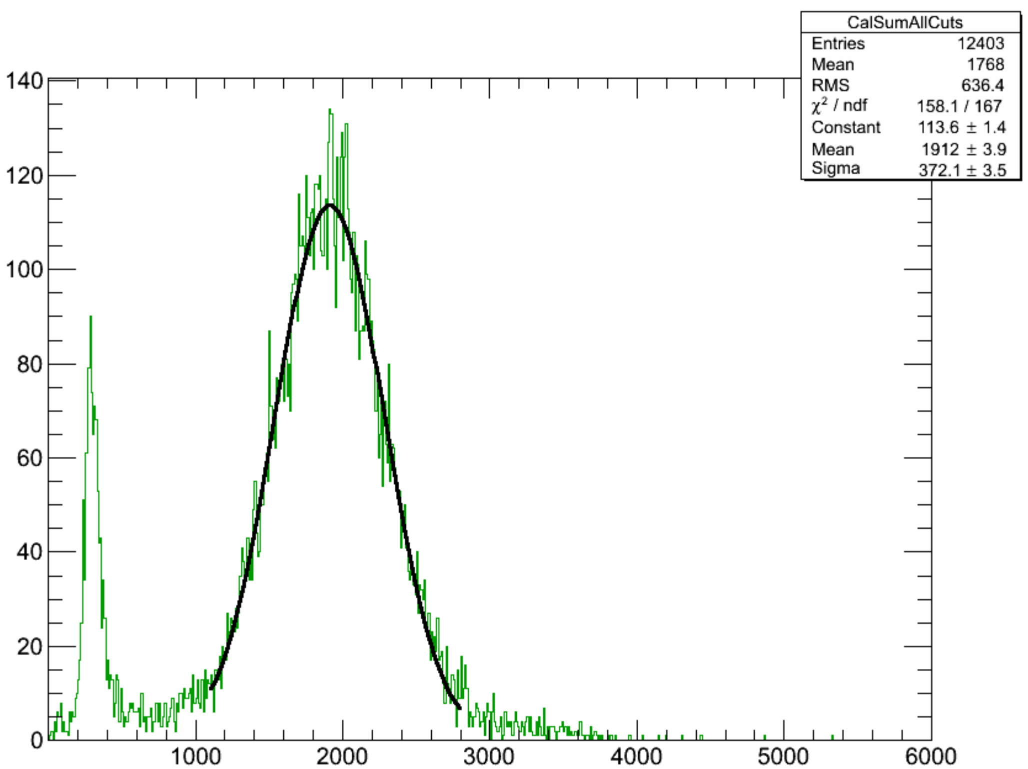




- Benchmark ZEUS Pb/Sc test beam data (longitudinal/transverse had. showers, e/h, resolution).
- HAD response hard to reproduce.
- According to GEANT EM section is overcompensated.
- **FTFP_BERT, FTFP, FTFP_EMV**
  Suggested by some people at calor2014 to try.

FCS response to hadrons. Preliminary Test Beam Results.

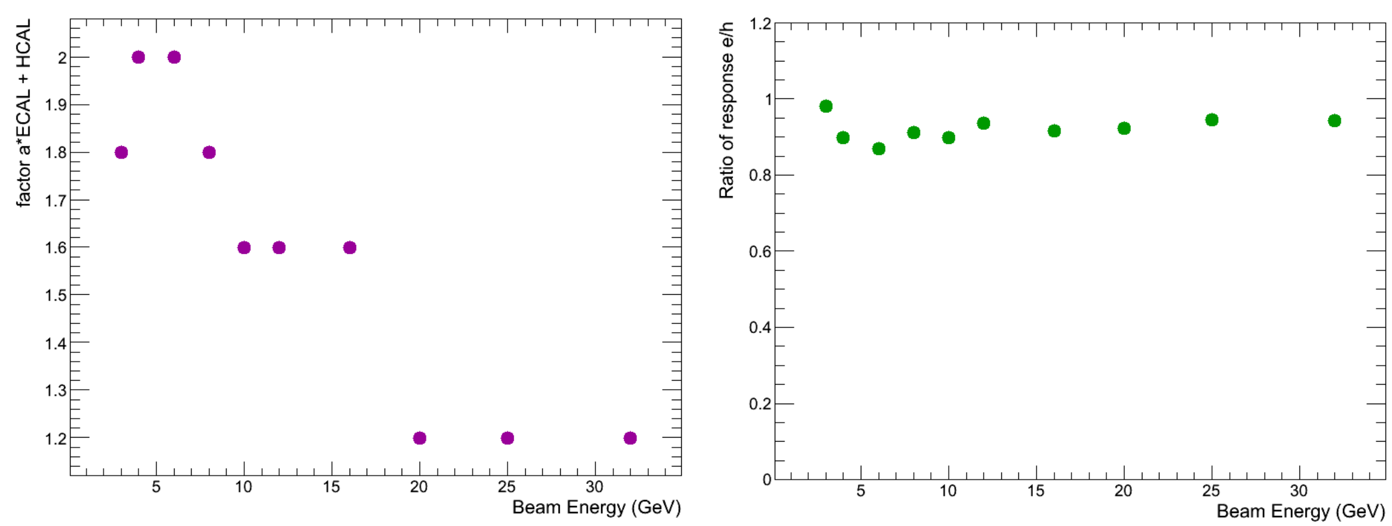




For completely compensated system one may expect that n=1 for
E(rec) = n*E(em) + E(had)

Below 10 GeV e/h deviates from 1 as was measured by ZEUS (decreases to 0.8 at 1 GeV)

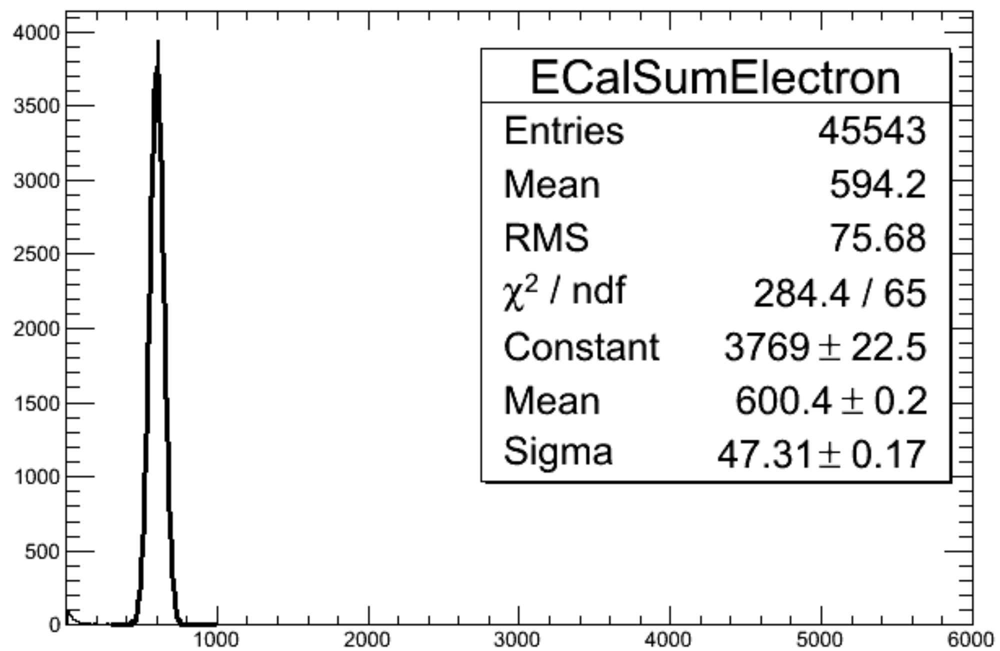
To obtain best energy resolution in FCS we found that **n** should be energy dependent both in MC and test run data.

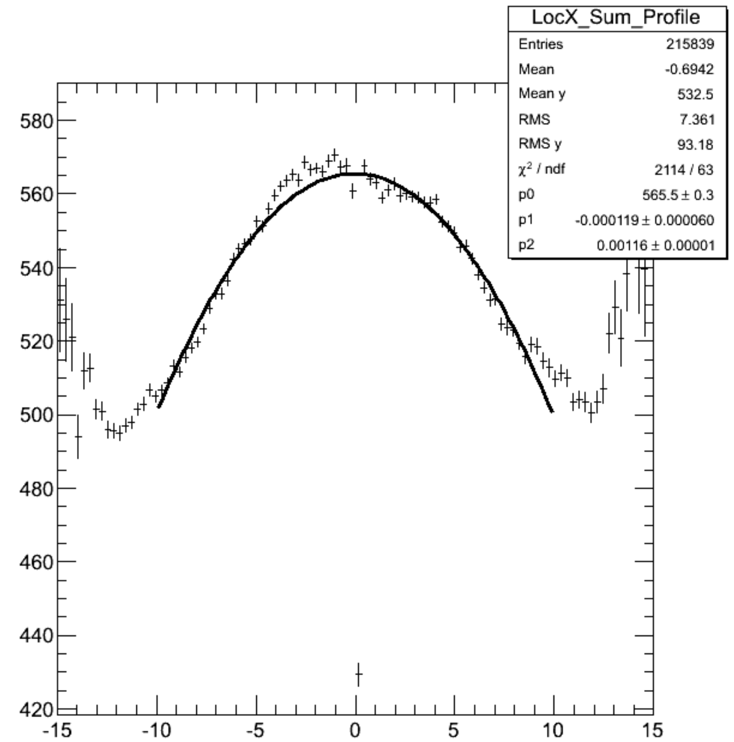


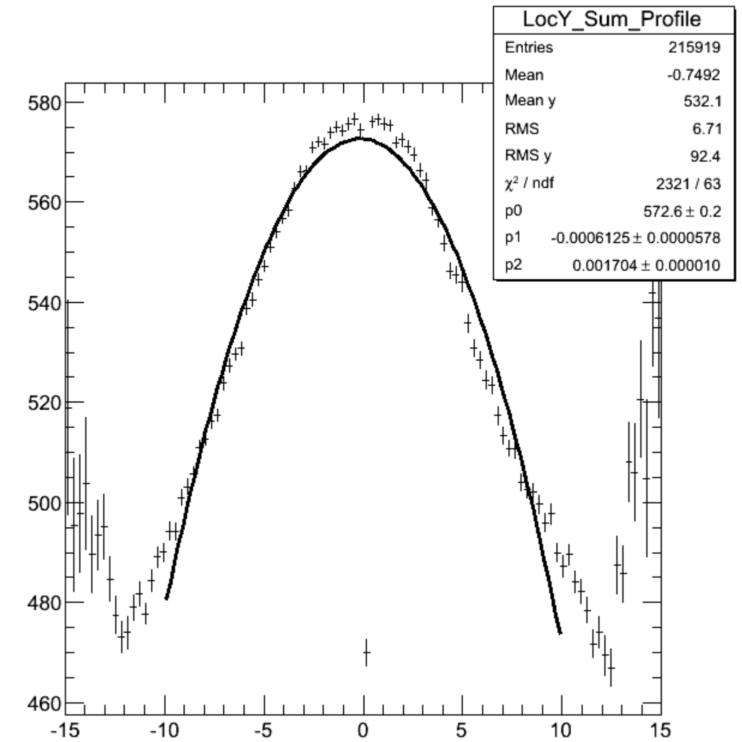
Optimal weighting factor and e/h for FCS.

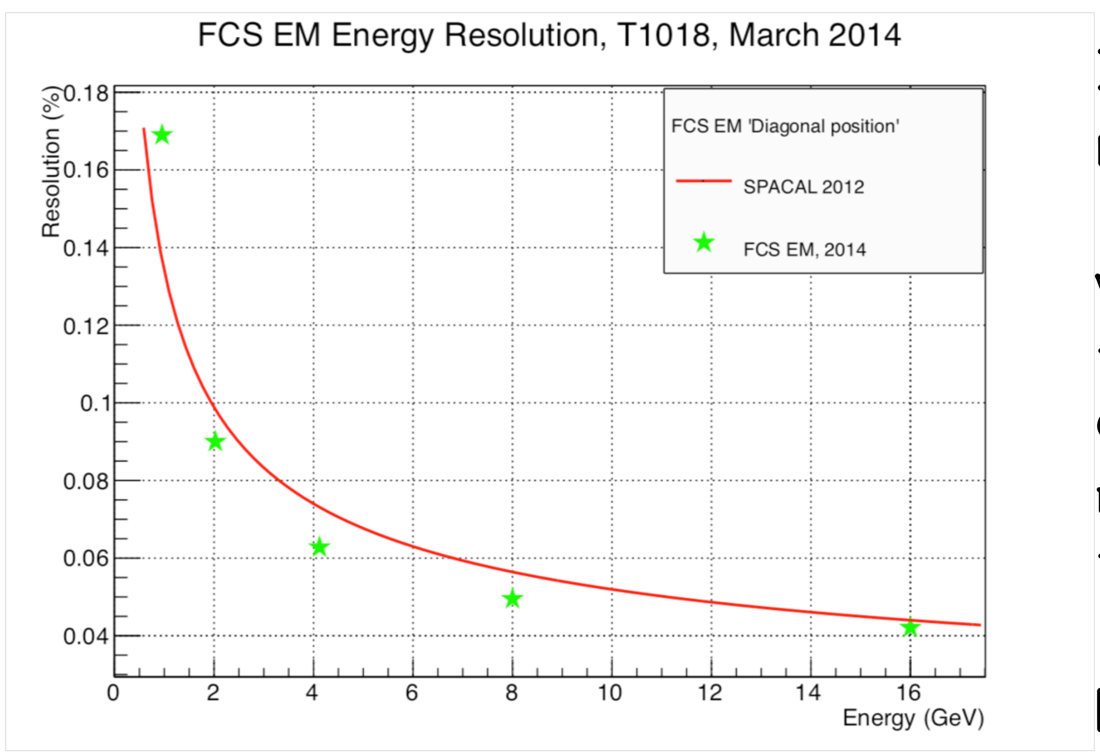
FCS response to electrons. Preliminary Test Beam Results.

4 GeV Electrons







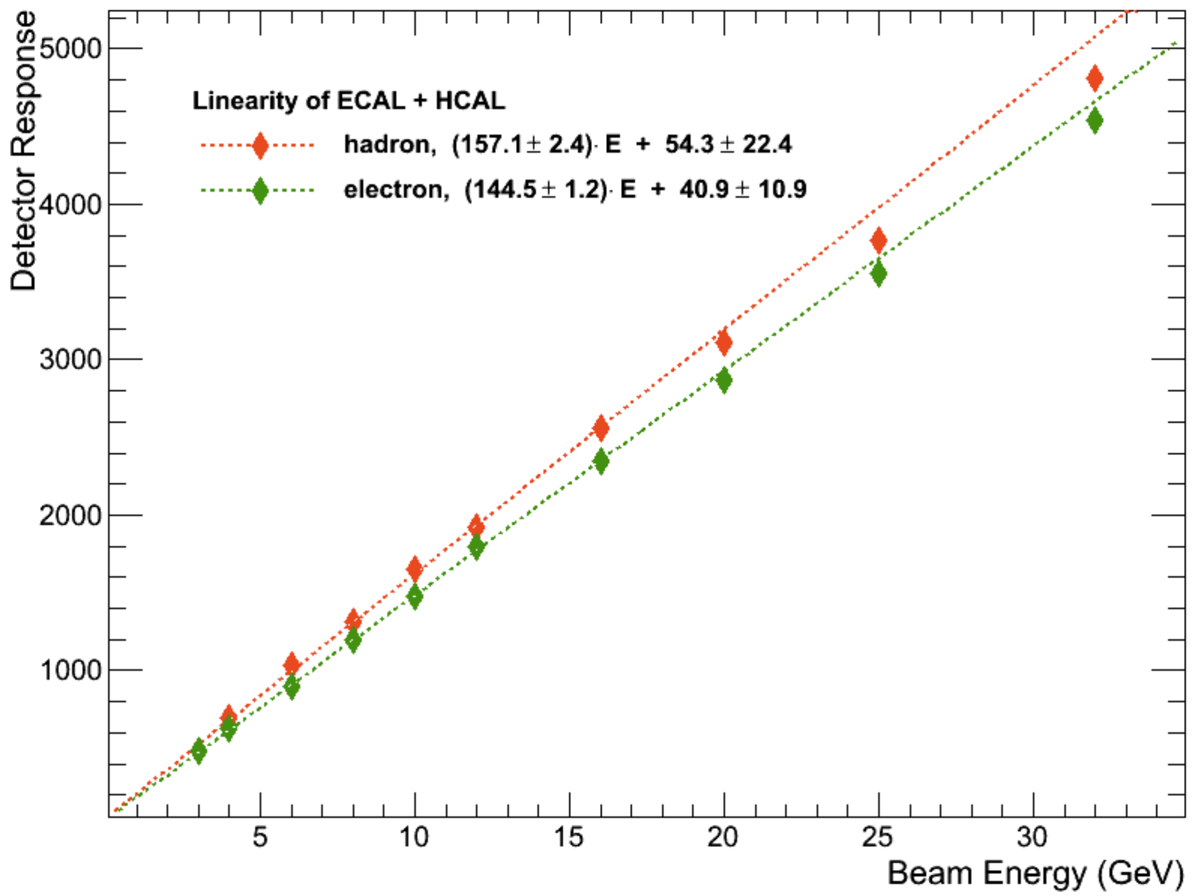


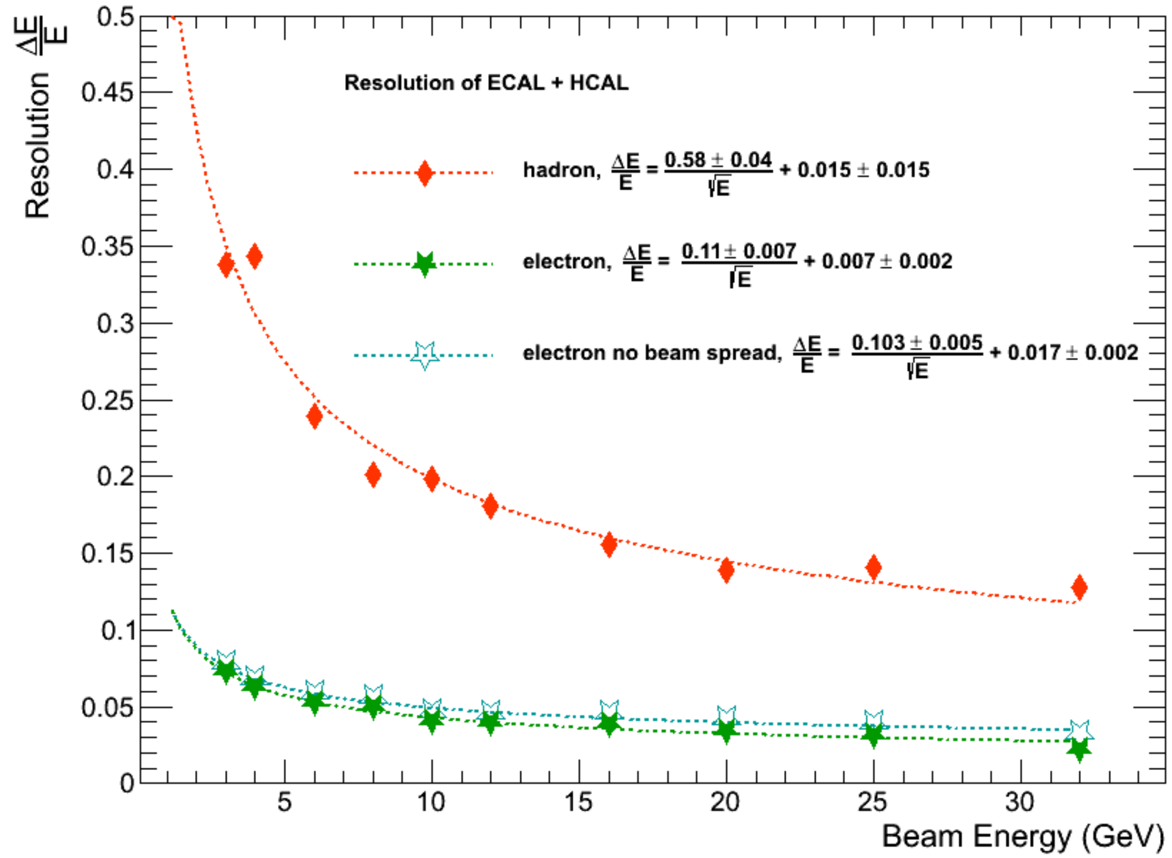
Initially had problems with ECal resolution due to non-uniformities in light collection in tower.

We measured the resolution with the detector diagonal to the beam to eliminate this effect, and later we could apply corrections during the data analysis to replicate these results with the detector face-on (imact points restricted to central part of towers, circle with diameter 14 mm) .

No need to calibrate tower by tower with the beam.

STAR FCS Performance, Test Run. Preliminary Results.



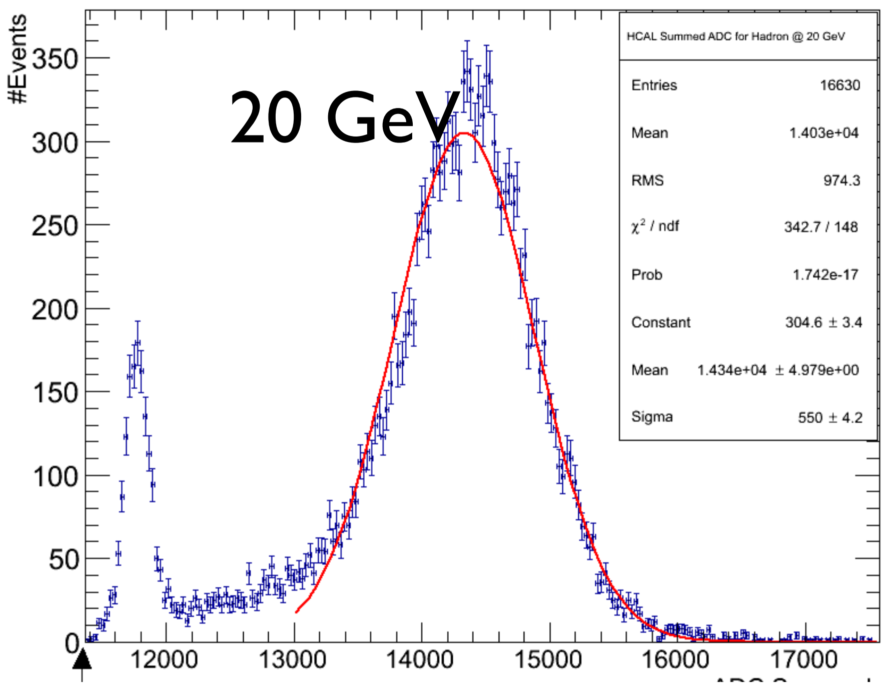


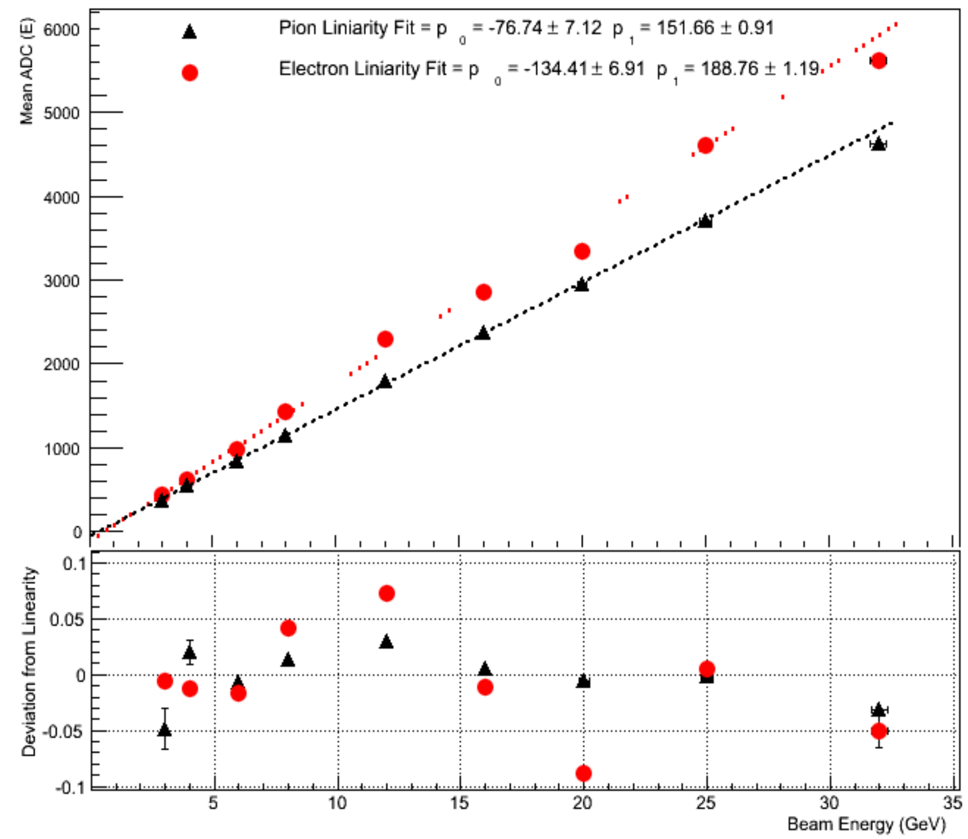
Measured the resolution of the combined ECal and HCal system for beam energies between 3 GeV and 32 GeV. Fits show hadron resolution of 58% which is close to expectations from simulation.

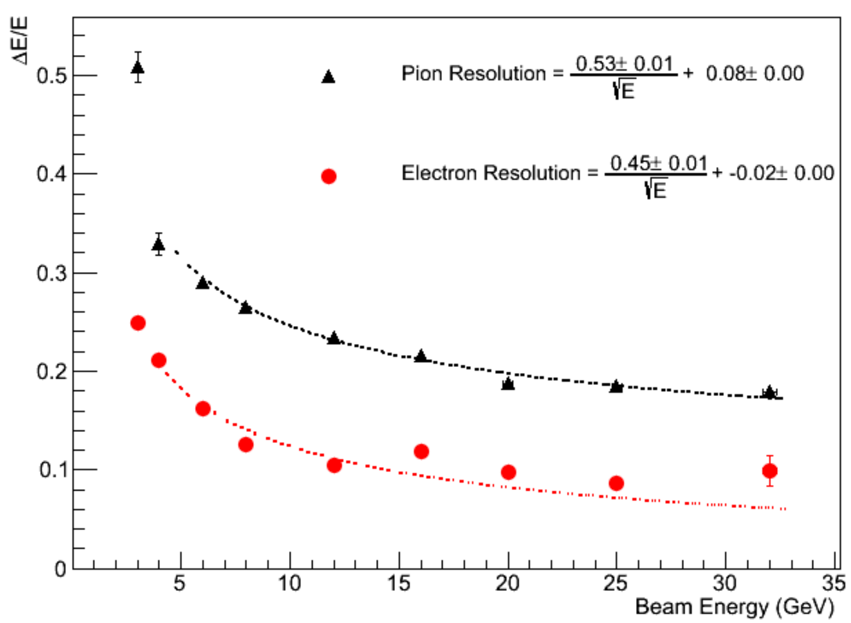
Non linearity above ~16 GeV is probably due to method of weighting fraction of the energy deposited in the EM section in the total sum.

STAR FCS Performance, Test Run. Preliminary Results.

Performance of EM + HAD compare to HAD only

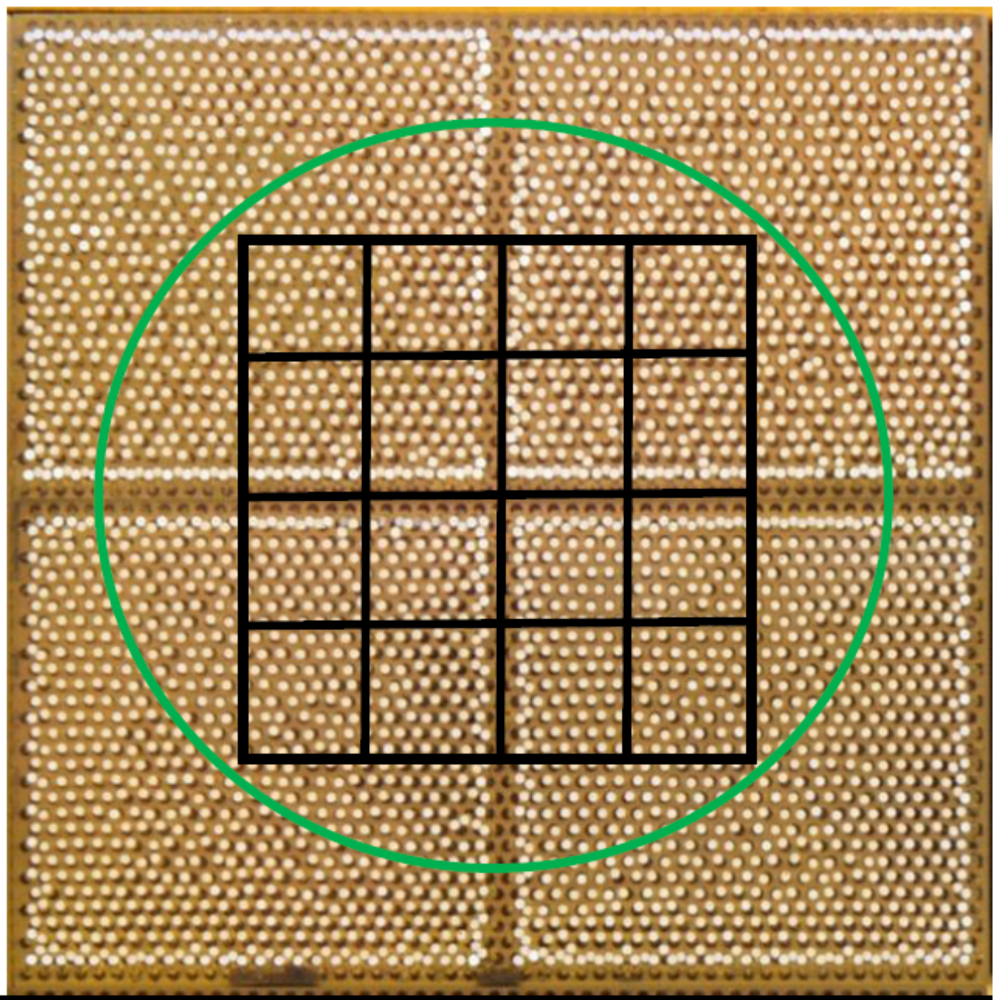


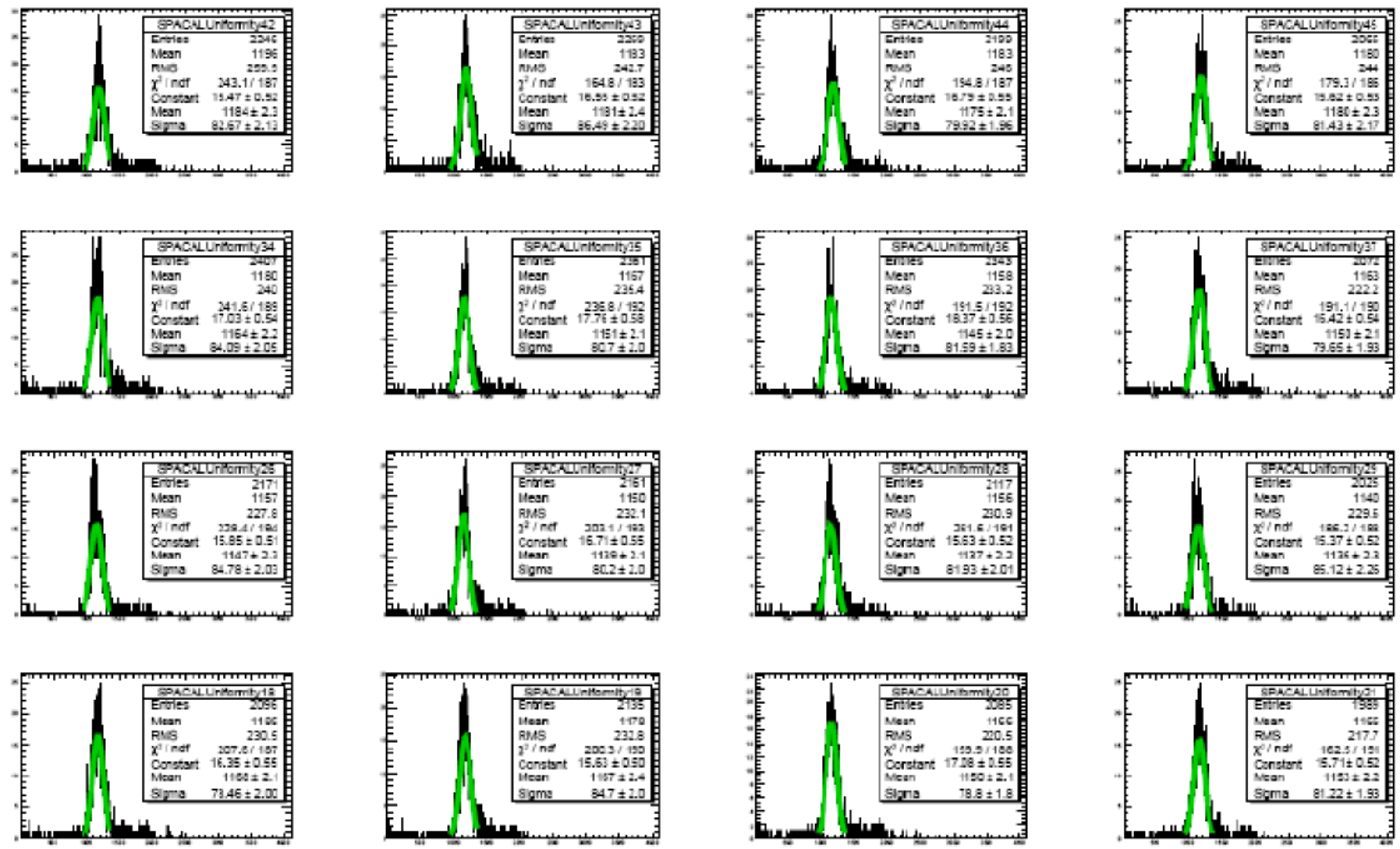




- e/h is > 1, most likely due leakages.
- e/MIP is the same as ZEUS measured.
- Response to hadrons at first order is linear (compare to EM+HAD scheme)
- Energy resolutions pretty much as was expected.

Uniformity of EMcal across the surface.

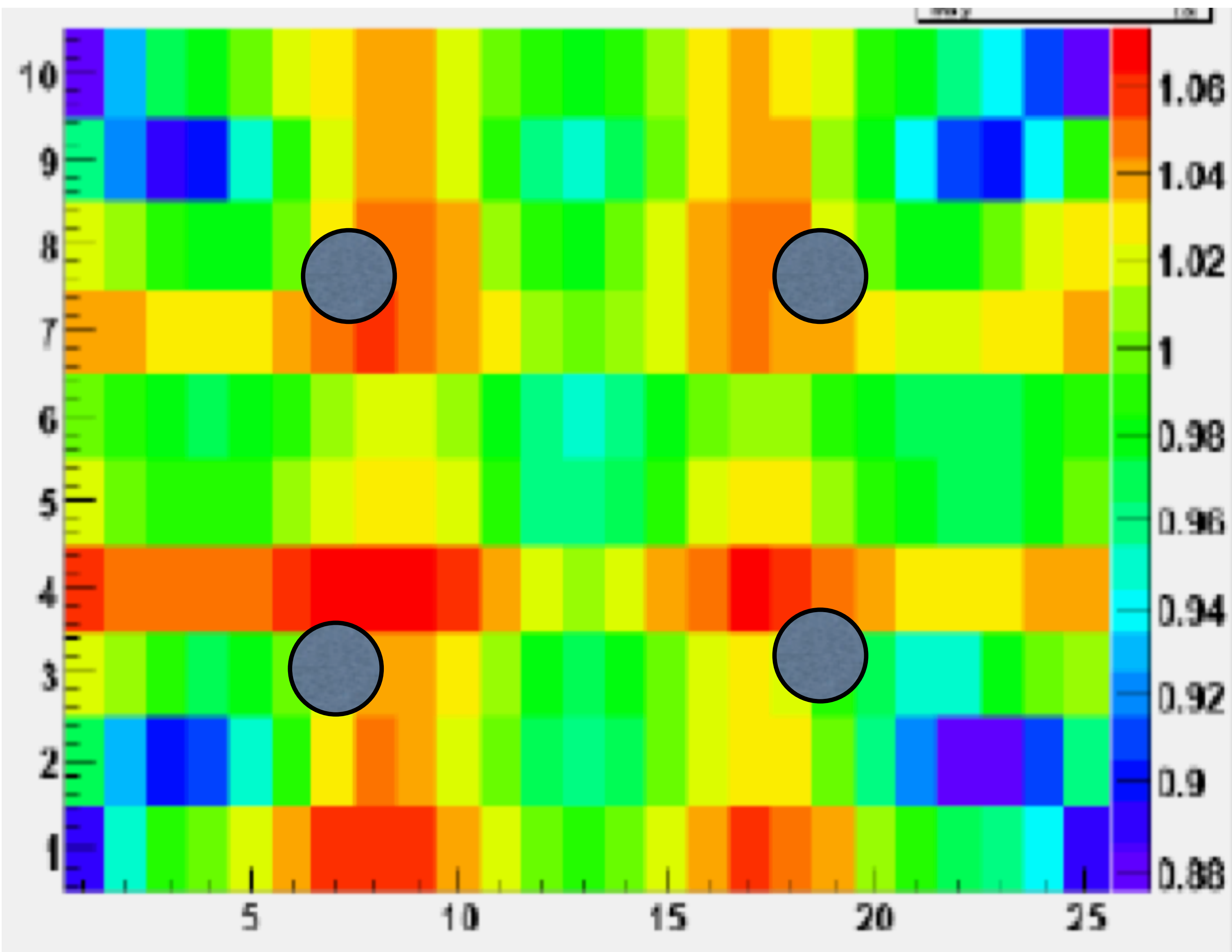




Each square is 4.8 mm x 4.8 mm, selected by Sc. hodoscope.
Uniformity of SPACAL response is 1.4%
Test Run 2012. Light collection with 7" long light mixer.

Light collection scheme, EM prototypes.
(a) Non-uniformity.

- It was expected that we'll need to iterate light collection scheme after the test run. But it was not clear how. It depends on absolute light yield.
- That was explained in our EIC R&D proposal (Dec. 2013). Funds for this iteration was requested and received from EIC R&D for FY2014.



Example of a scan with a single Sc. fiber across the face of the light guide with four SiPMs readout.

Difference between hottest and coldest spots is about 20%.

Now we know, that with the light yield of 400 p.e./ GeV for STAR EM prototype as was measured at FNAL we can create a simple mask which will be glued between fibers and light guide to make response flat.

Light Collection. (b) Absolute light yield.

EM prototype for STAR had back side of towers painted with white diffusive paint Bicron BC-620 (instead of having mirror over there).

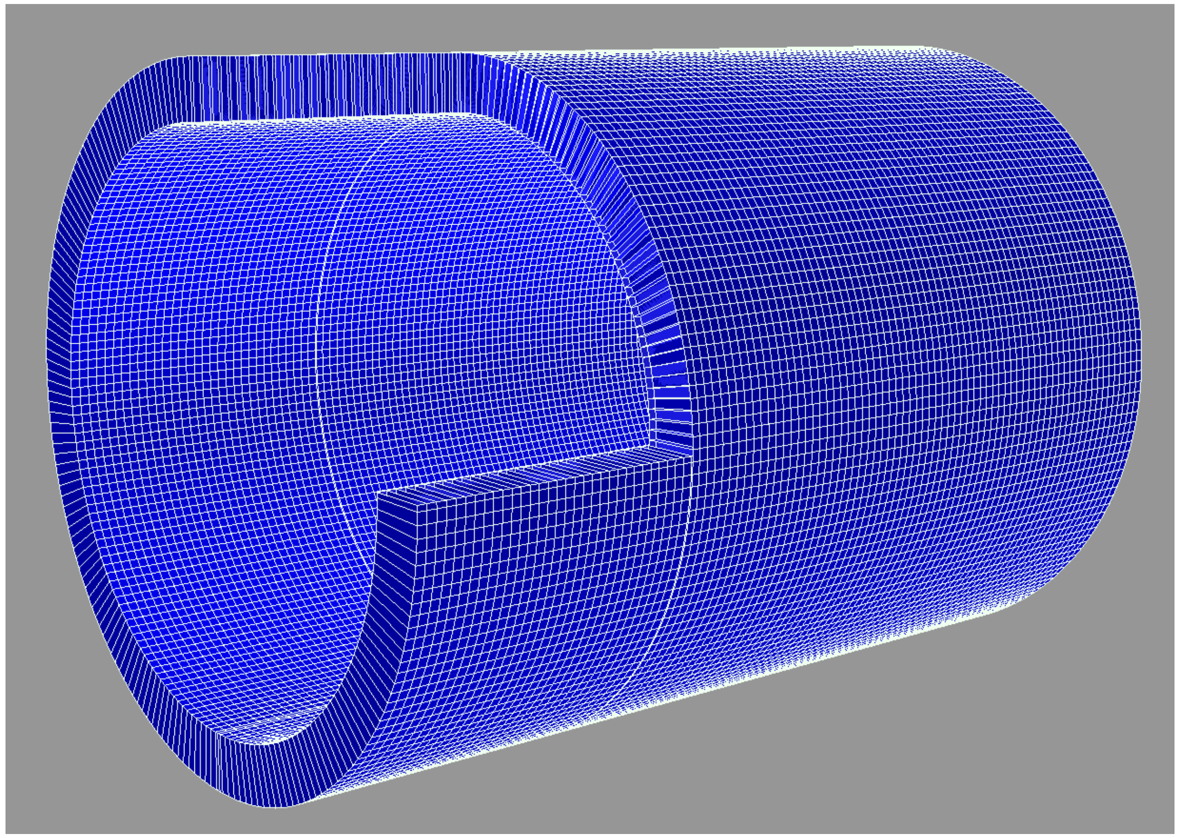
We knew that good mirror can add ~70% of light (Test run in 2012), however there are reason not to do that. Perfect mirror will cost a lot. Technology wise it is in principle trivial, but on practice usage of mirror can create huge headache.

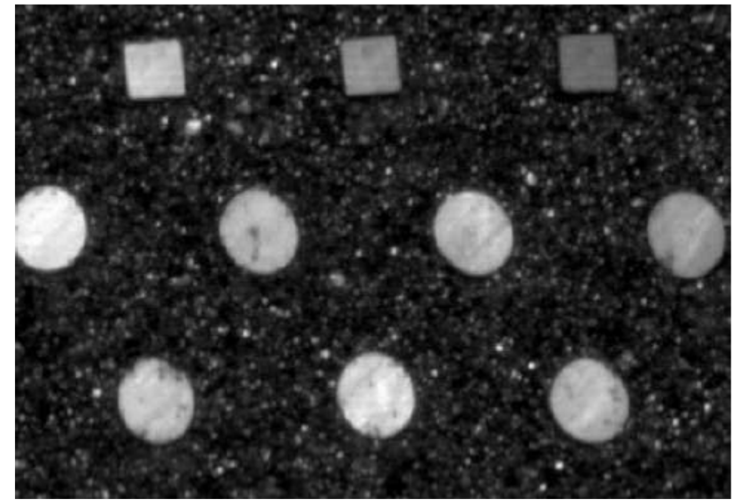
Small deviations from perfection can easily happen during production and then one need to worry about protection and long term effects.

With new Hamamatsu sensors we don't need any types of reflector at the backside. This significantly simplifies:

a) Production process
b) Mechanics of super modules

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

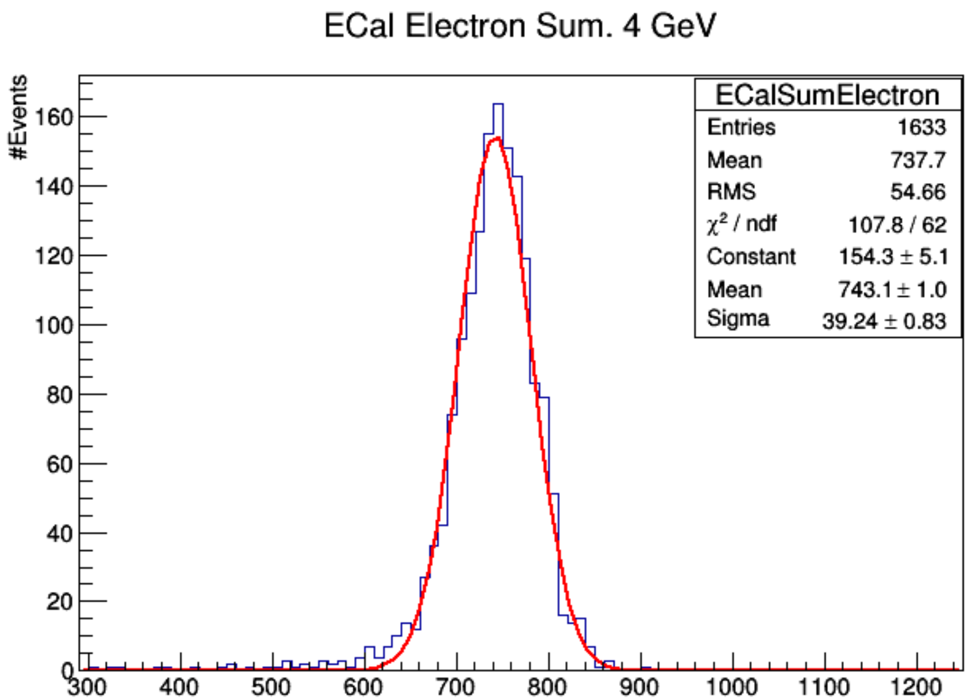
Parameters close to construction steel

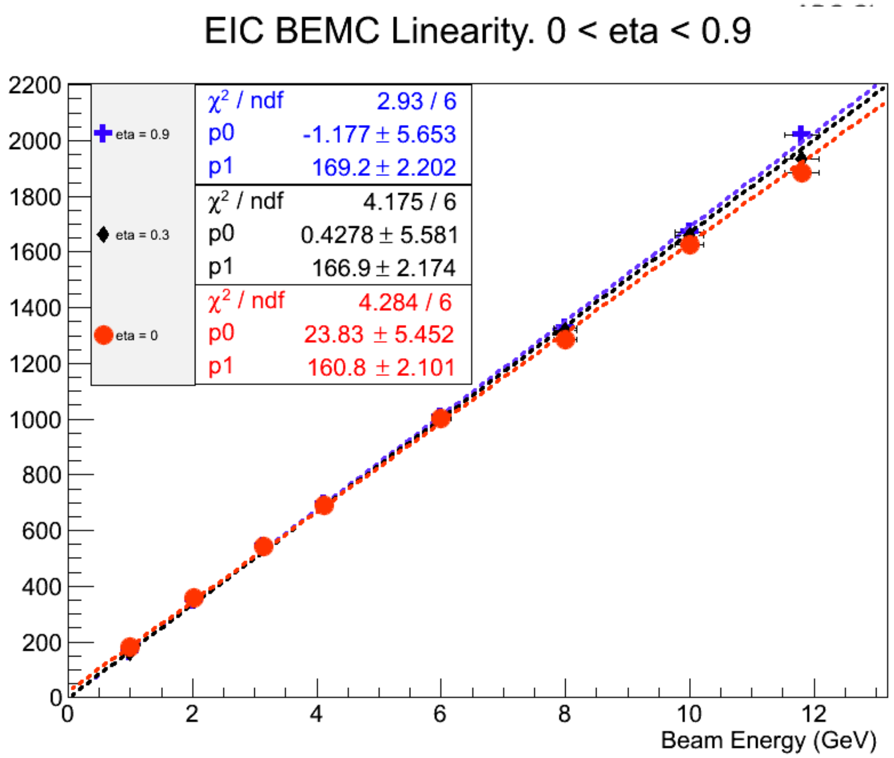
- same tungsten powder + fibers technology as FEMC,
- towers are tapered, sampling fraction along the tower depth is not constant.
- non-projective geometry; radial distance from beam line [815 .. 980]mm

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

EIC BEMC, prototype performance at FNAL. Preliminary Results.

18 Tapered towers for inner radius ~ 120 cm.

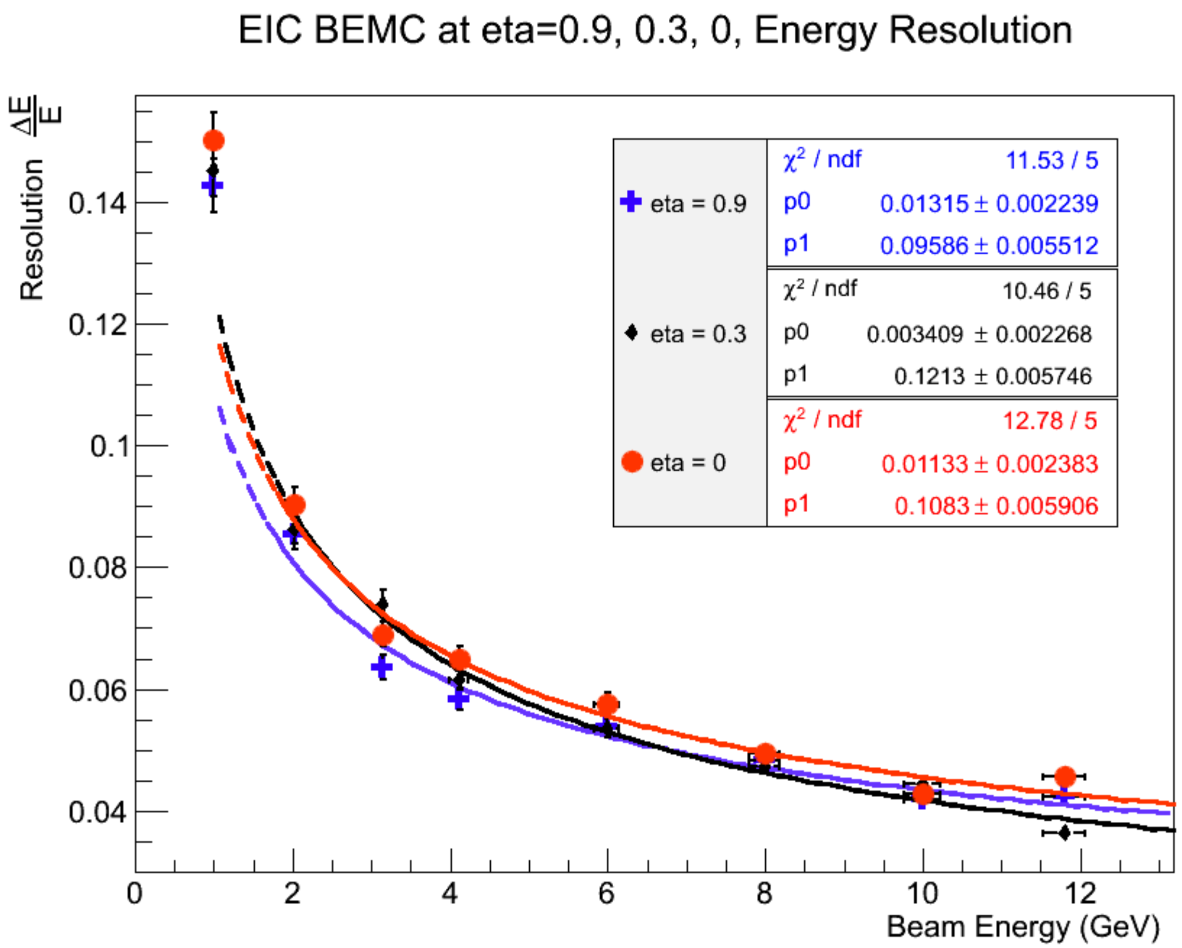




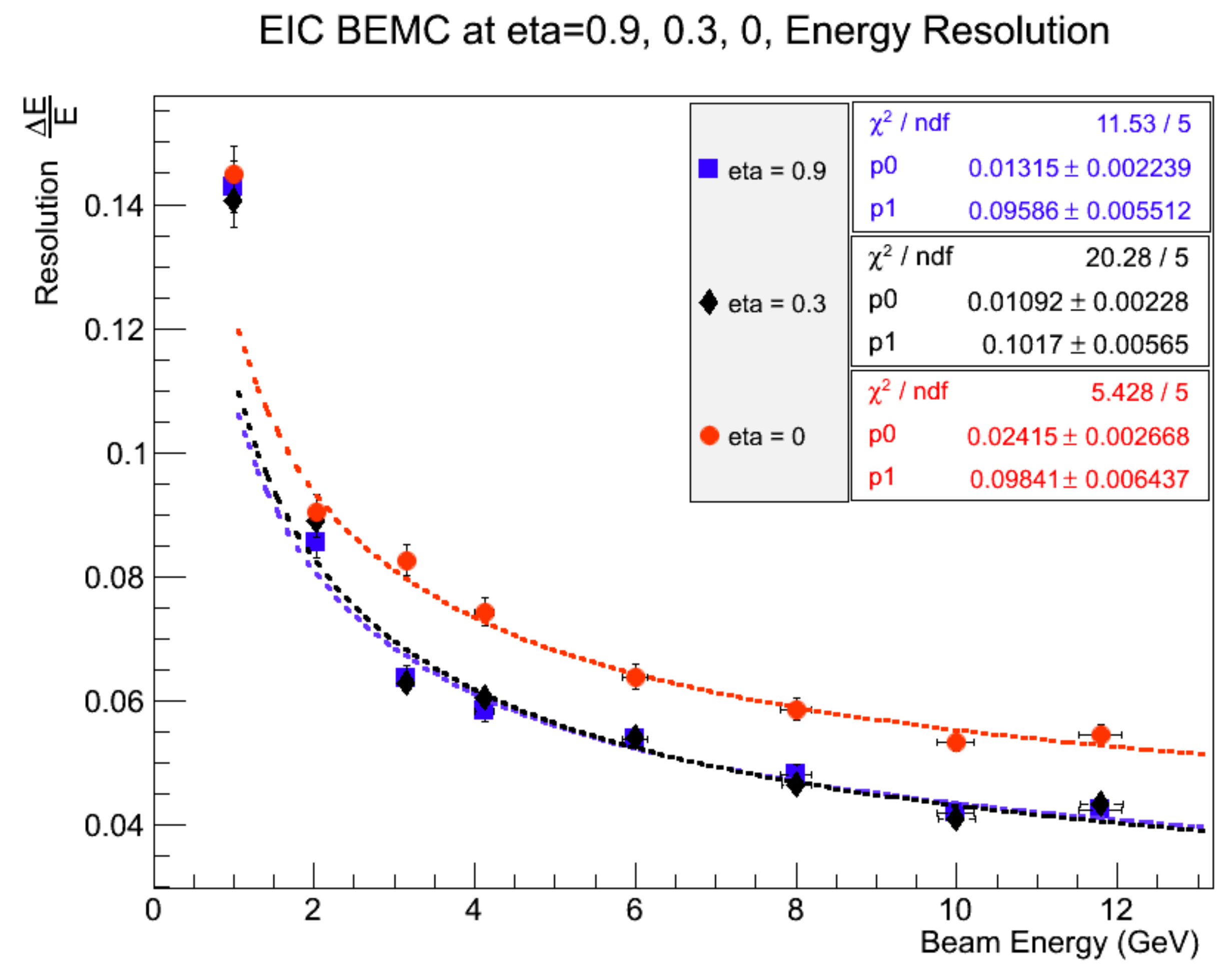
- Tower by tower calibration with the beam not required.
- Limited size of the prototype, and light collection non-uniformities required to limit impact points on Y within +- 5 mm.
- Small dependence of response vs. incident angle.
- Light yield measured for different configurations of light collection scheme: 430, 530 and 600 p.e./GeV

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.

FCS EM and BEMC, prototype performance at FNAL Summary.

- Good Energy resolution for both STAR and EIC prototypes.
- Good light yield. Sufficient to introduce masks between light guides and fibers to make uniform light collection.
- No difference in performance for readout with MPPCs upstream or downstream of calorimeters.
- No need to calibrate individual EM towers with the beam, homogeneity is very good.
- No need for a mirror or diffusive reflector on the back side for final EM calorimeters.
- Very weak dependence of response vs. impact angle for EIC BEMC.

What is next for FCS and EIC BEMC ?

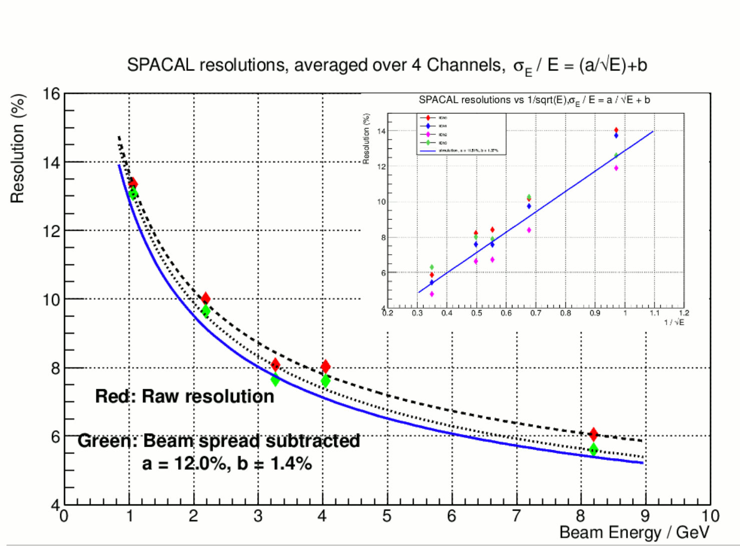
FCS concept was validated. Performance of prototype is close to what was expected (even for things like response to hadrons and light collection non-uniformity in ECal). This test run is the end of the FCS R&D stage.

There is a list of small things (except electronics) in my logbook that need to be refined. The biggest is to improve uniformity of light collection. We plan to do this during this summer for EIC R&D.

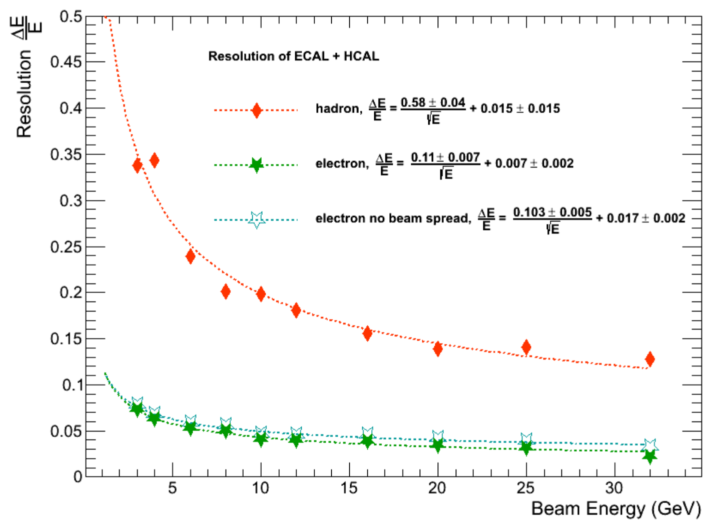
The front end electronics concept need to be re-evaluated.

For EIC BEMC we need to move readout upfront of the modules. If time permit a new EIC BEMC prototype will be constructed this summer and tested within a year with beams.

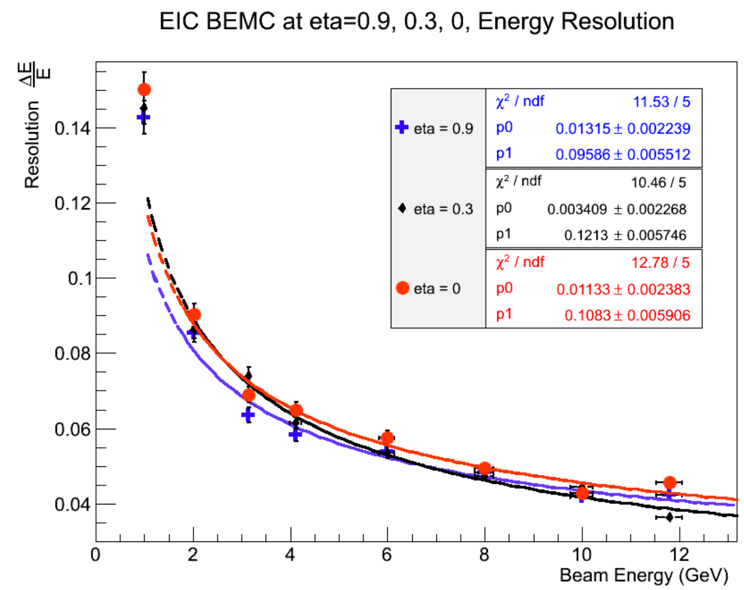
Let's keep filling the bottom plot !



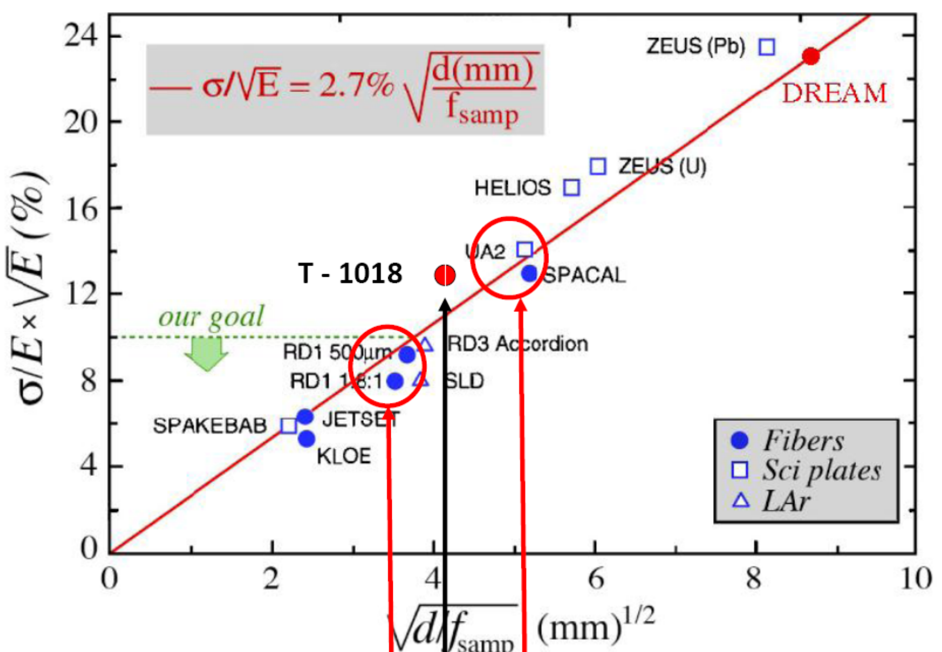
Proof of principle.



STAR FCS



EIC BEMC



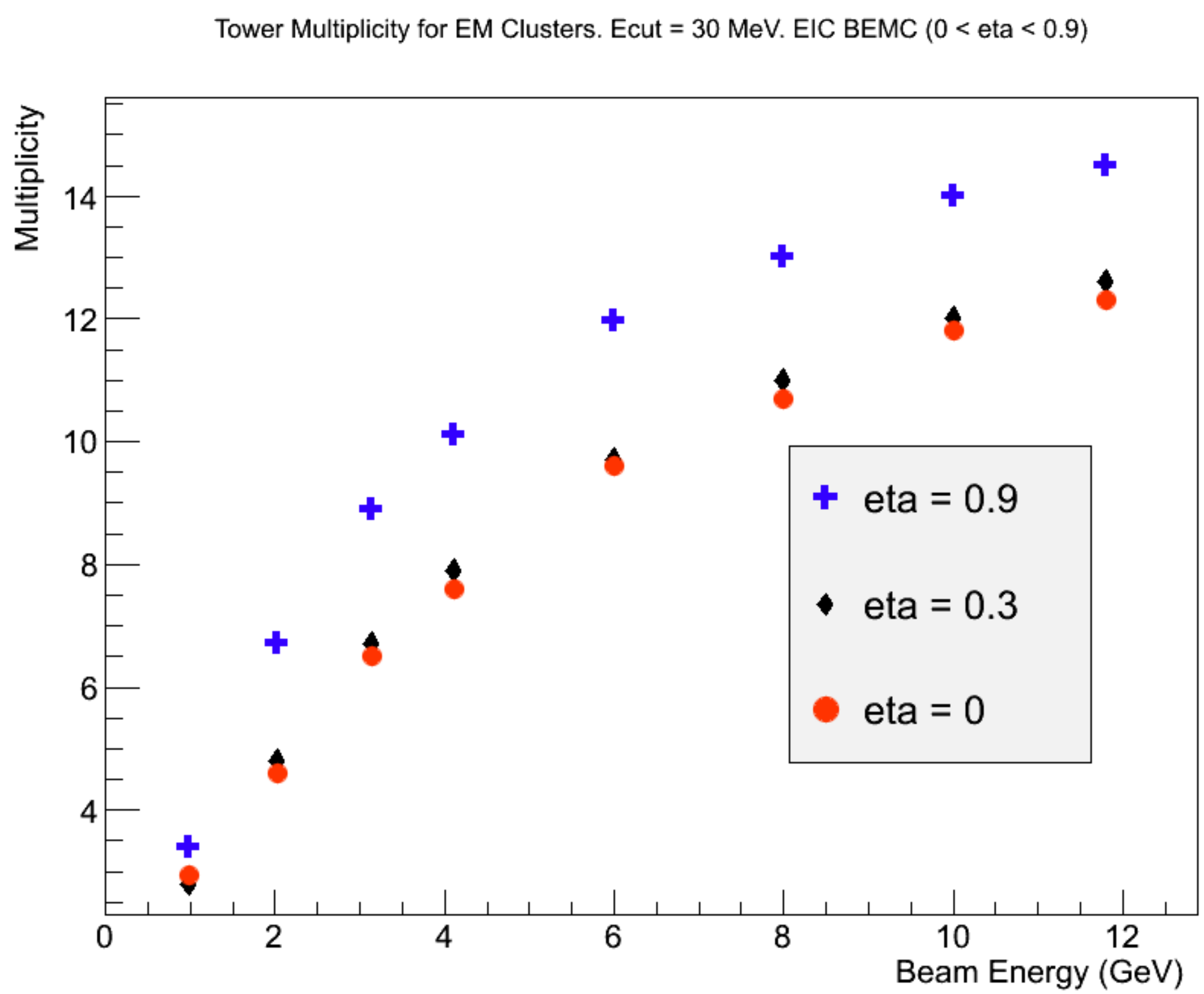
T-1018 "proof-of-principle", 2012

T-10XX (STAR FC), 2013

T-10xx (EIC BEMC), 2014

Thank You !

BEMC, prototype performance at FNAL

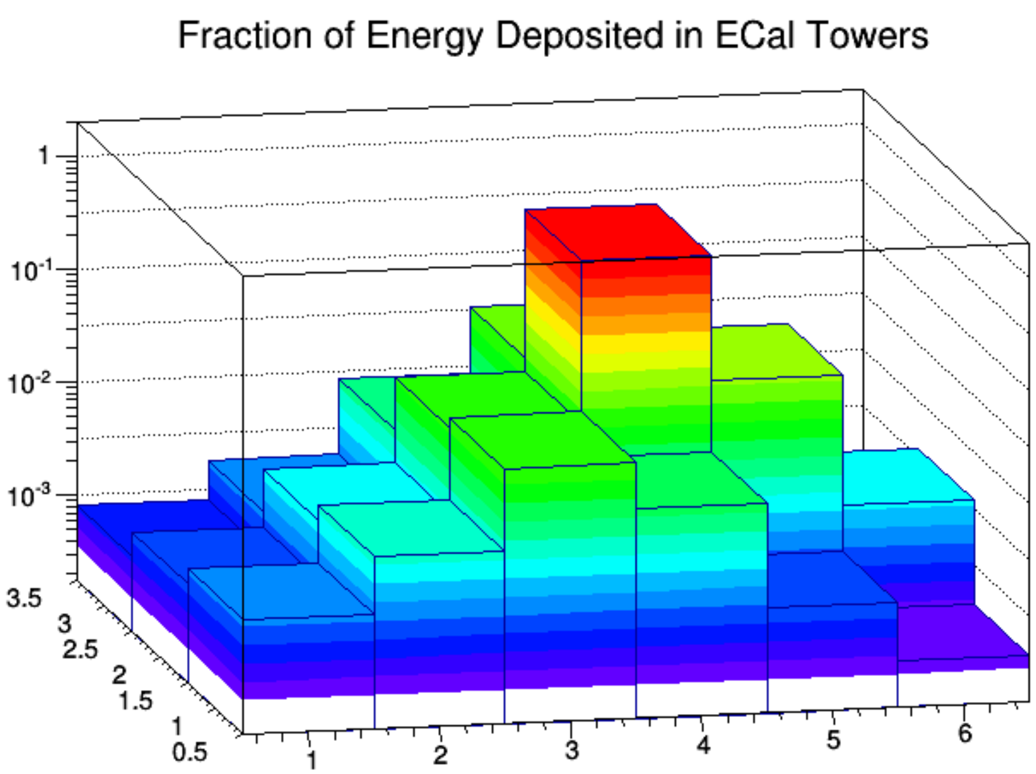


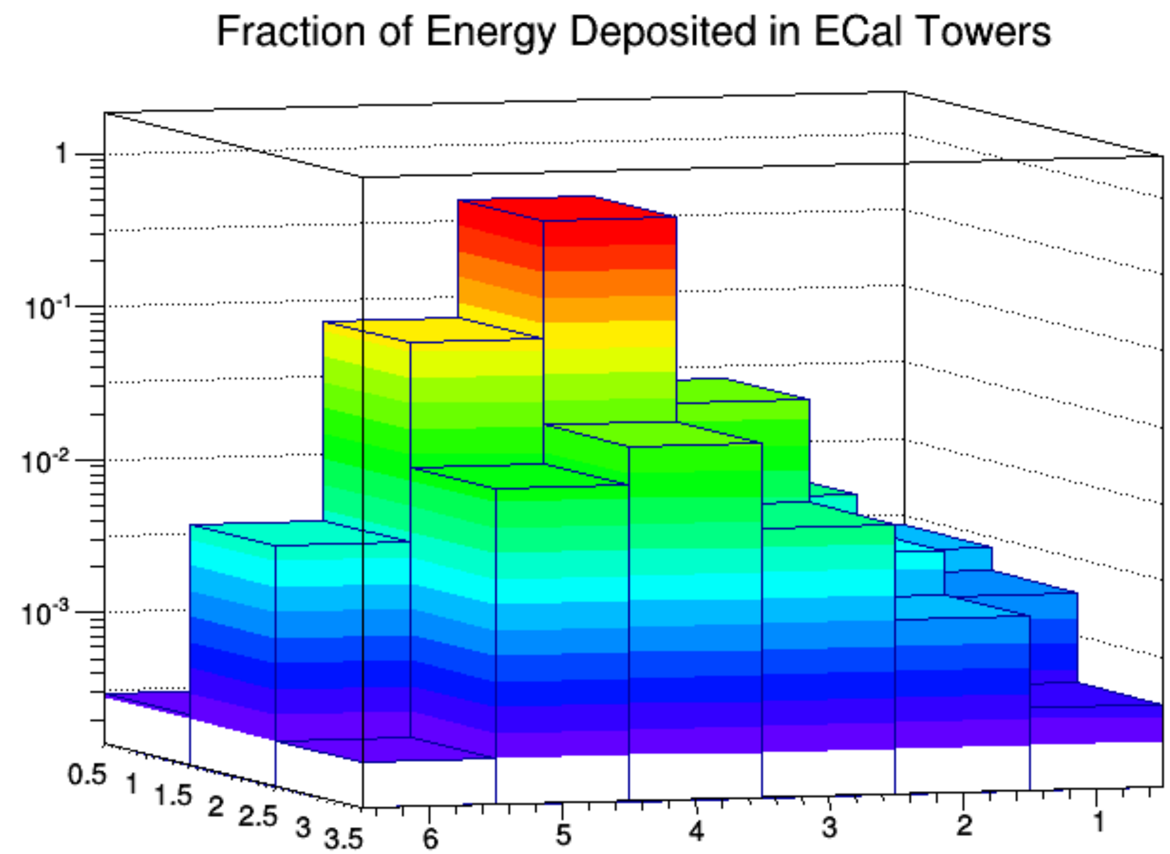
Electronics noise (sigma) during tests was about 13 MeV.

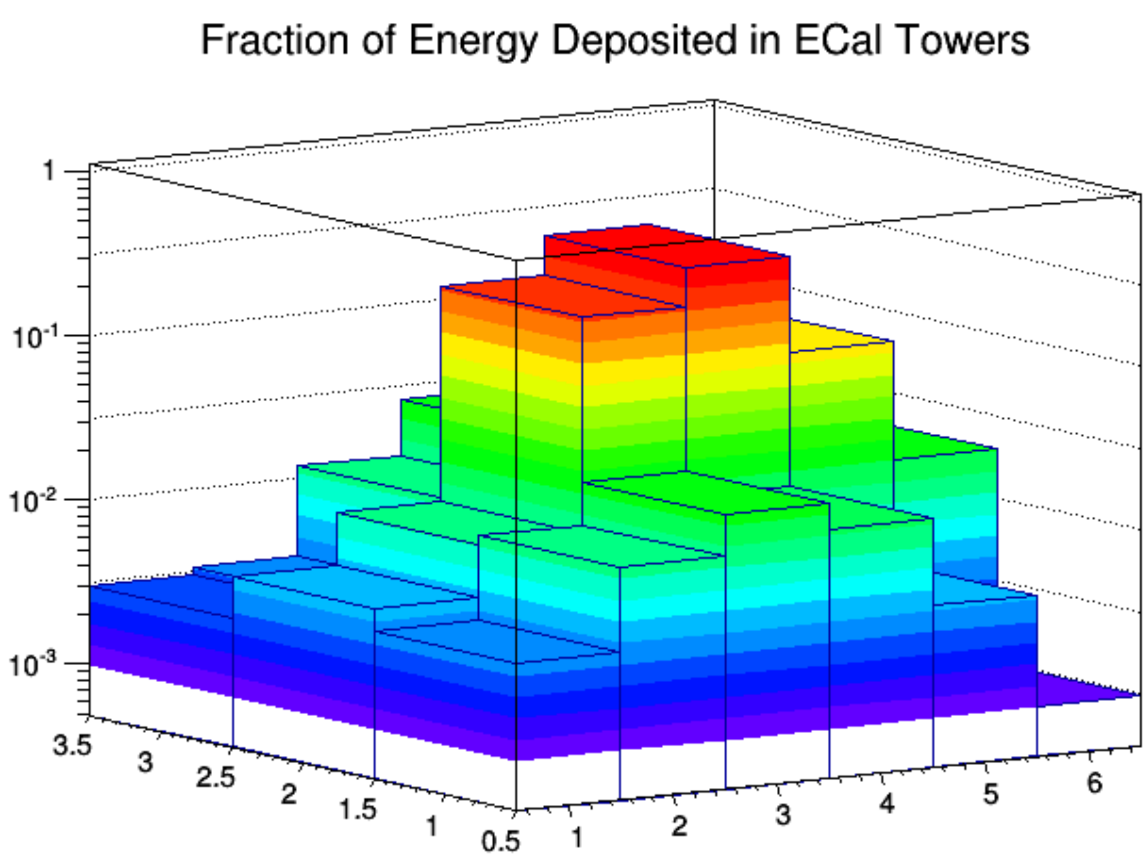
Multiplicity is defined as number of towers with energy depostion above 3 sigma.

Not an issue for EIC.

BEMC, prototype performance at FNAL

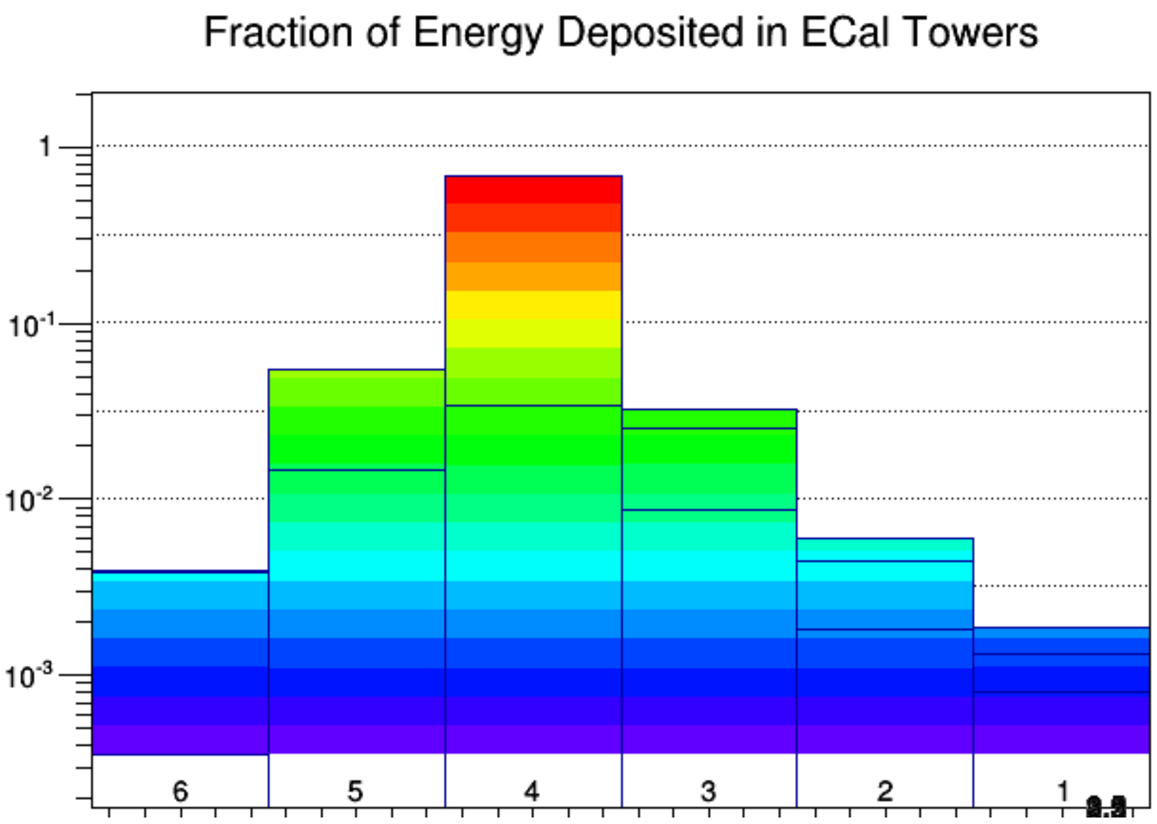


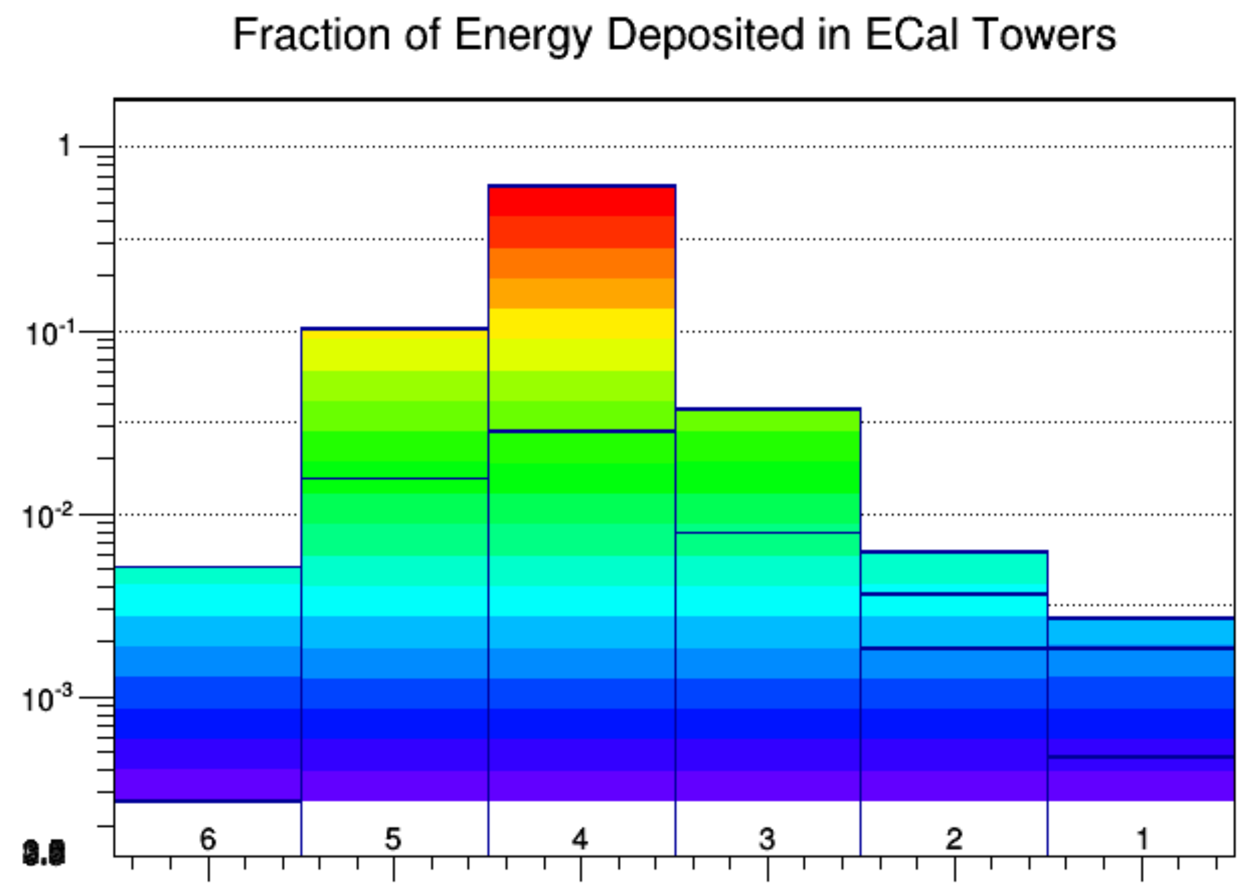


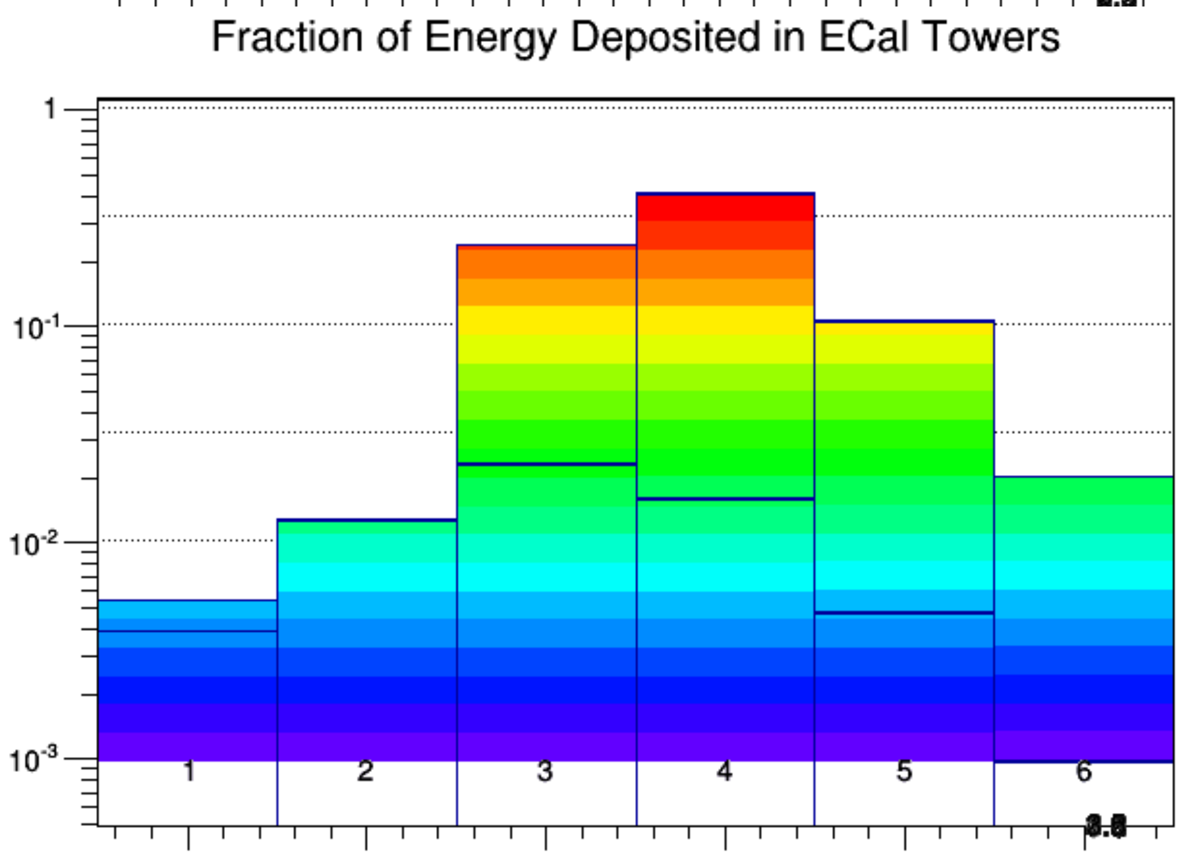


Shower Shapes for eta = 0, 03, 0.9

BEMC, prototype performance at FNAL



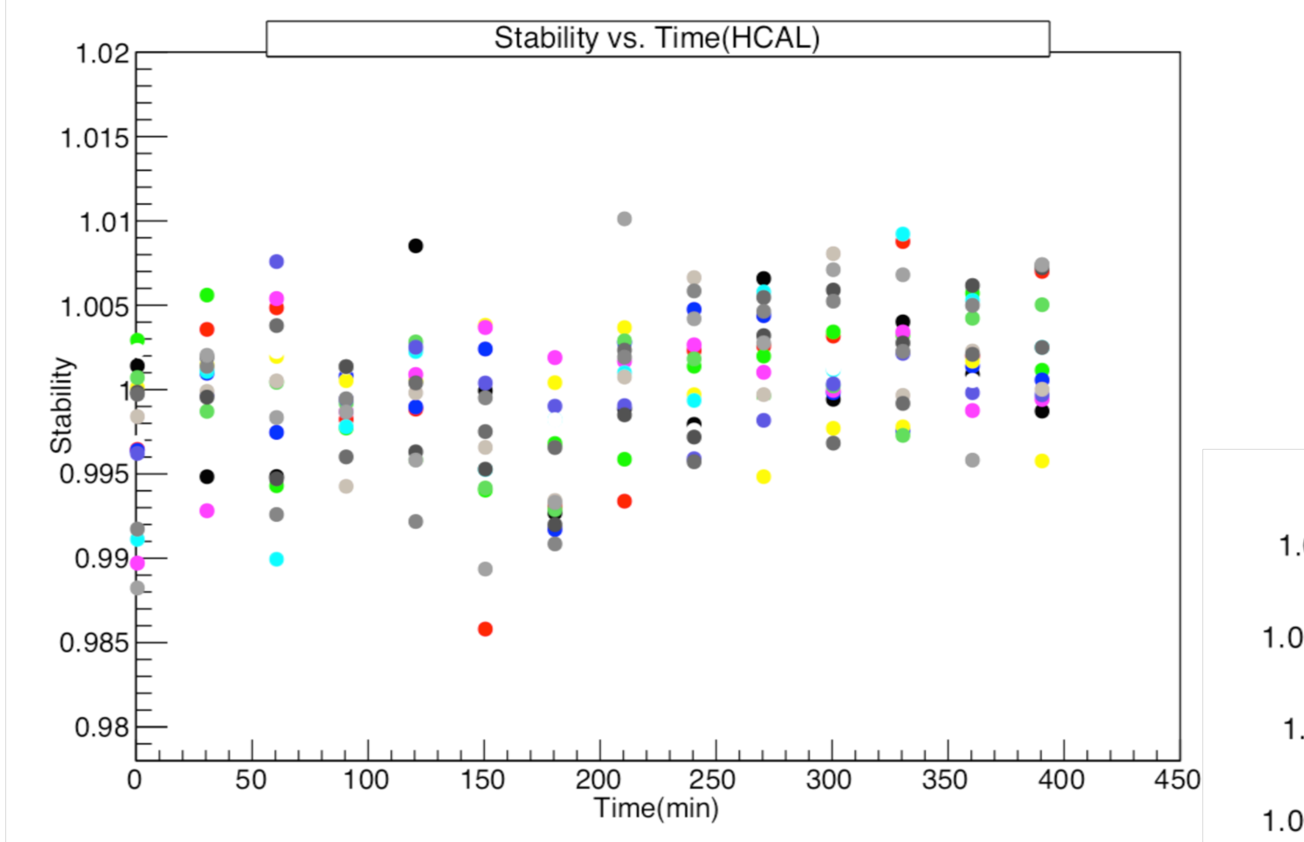




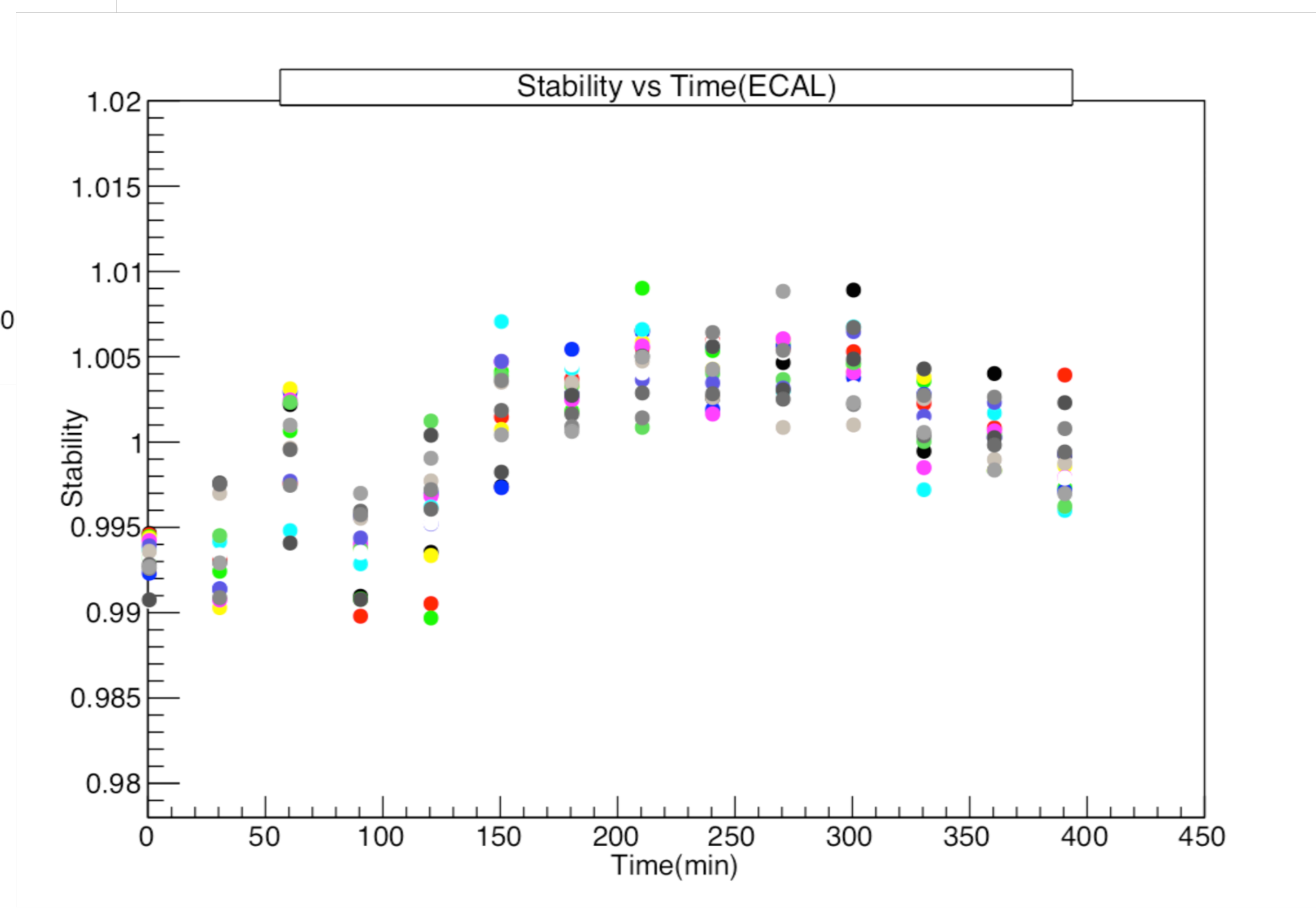
Shower Shapes for eta = 0, 03, 0.9

BEMC, prototype FEE performance at FNAL

HCAL FEE



EMCal FEE



FEE can be really simple,
For STAR we will reconsider design

Backup Slides

BEMC Design. General Comments.

Assuming we choose W/ScFi technology for barrel EMCal and we'll need to build new collider detector in few years, starting tomorrow.

What are the main concerns?

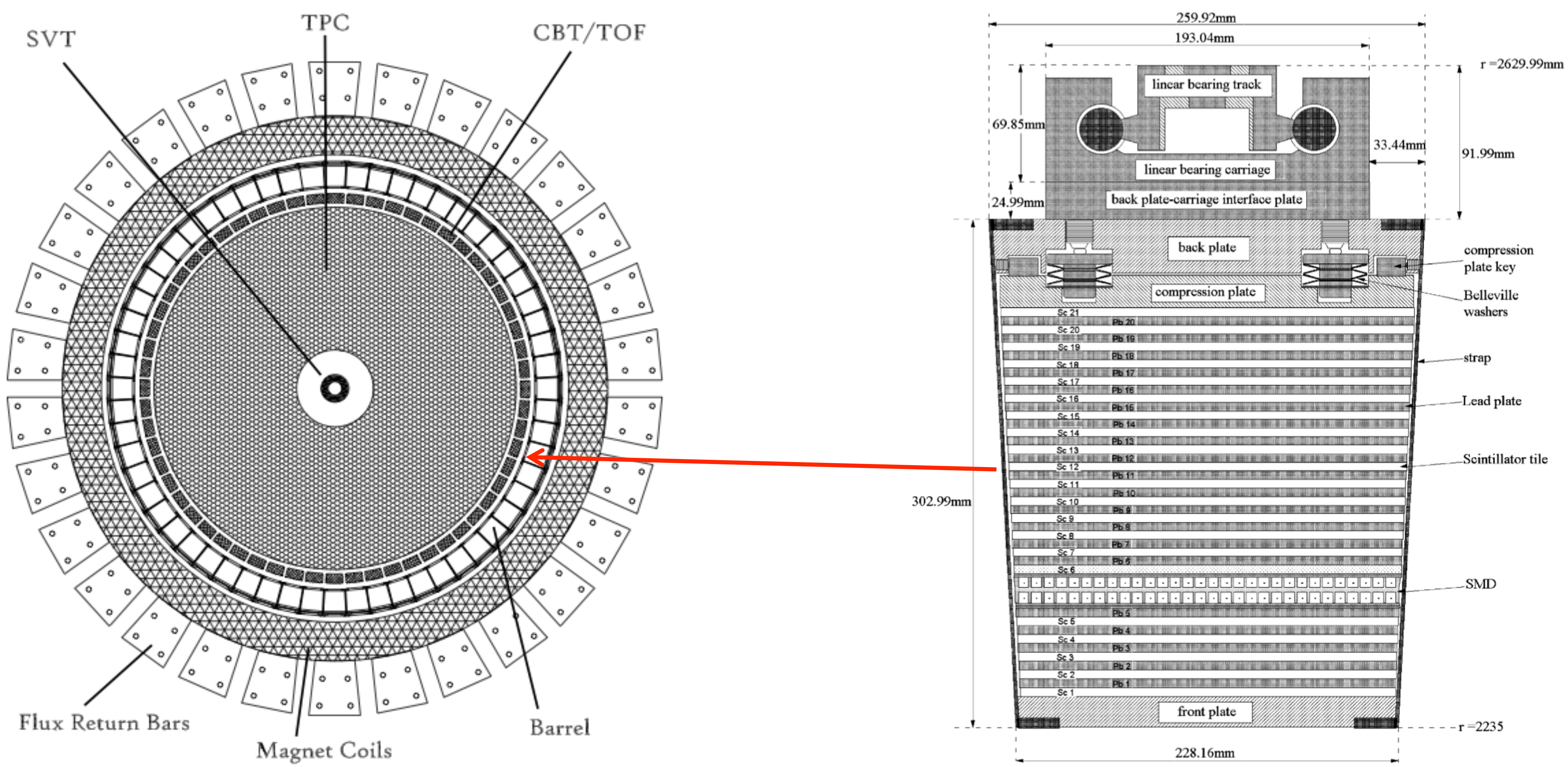
- Schedule Risk is Very High for the whole detector.
- Technical risk is high for EMCal, but probably quickly can be reduced to tolerable level.
- Schedule risk for EMCal is especially high because of knowhow technology which is not industrialized (common problem for STAR and PHENIX).

BEMC Design. Conceptual Requirements (apart from physics requirements)

- Design should be free from deep integration with the rest of the detector.
- Design should be free from deep integration within BEMC subsystem.
- Design should allow scalability.
- Design should implement proven techniques and ideas as much as possible.
- Design should fit overall strategy of BNL regarding contributed manpower, funding profiles etc.

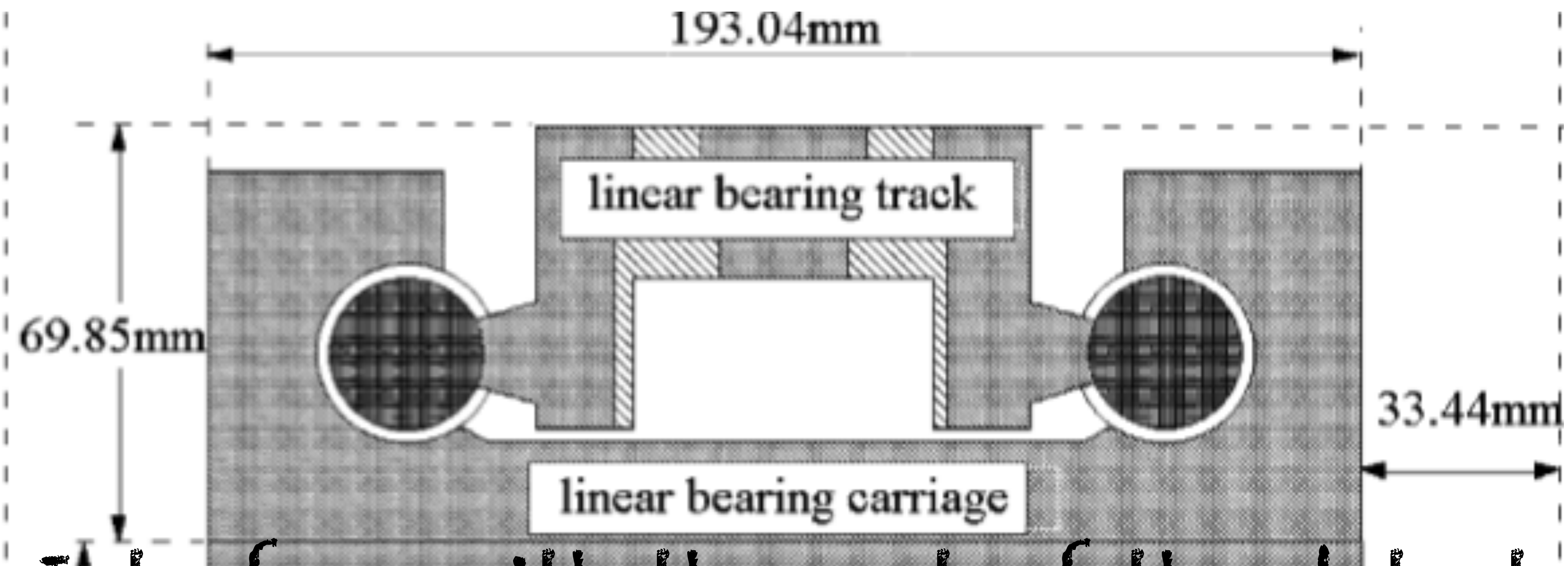
BEMC Design. Possible Implementation.

- W/ScFi technology fit well to these conceptual design requirements.
- These requirements also remind me how we designed and build STAR Barrel EMC.



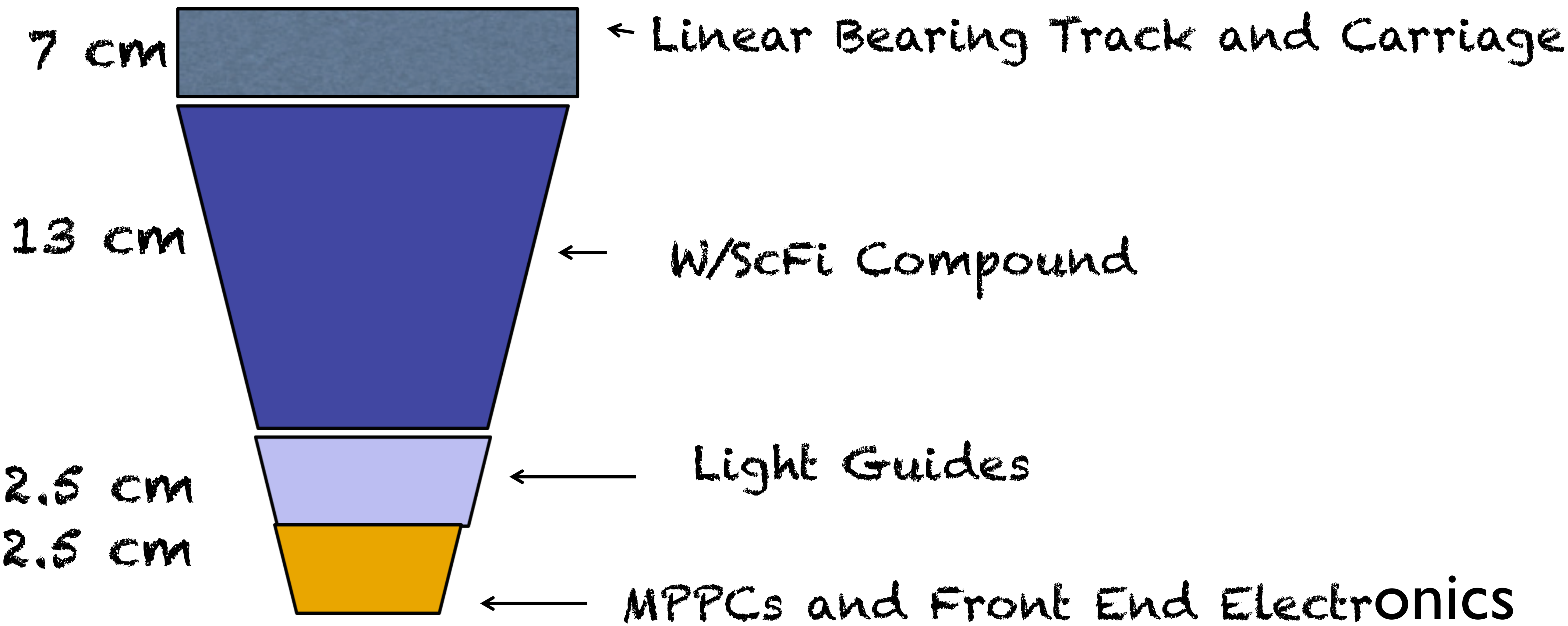
120 BEMC Modules

BEMC Design. Possible Implementation.



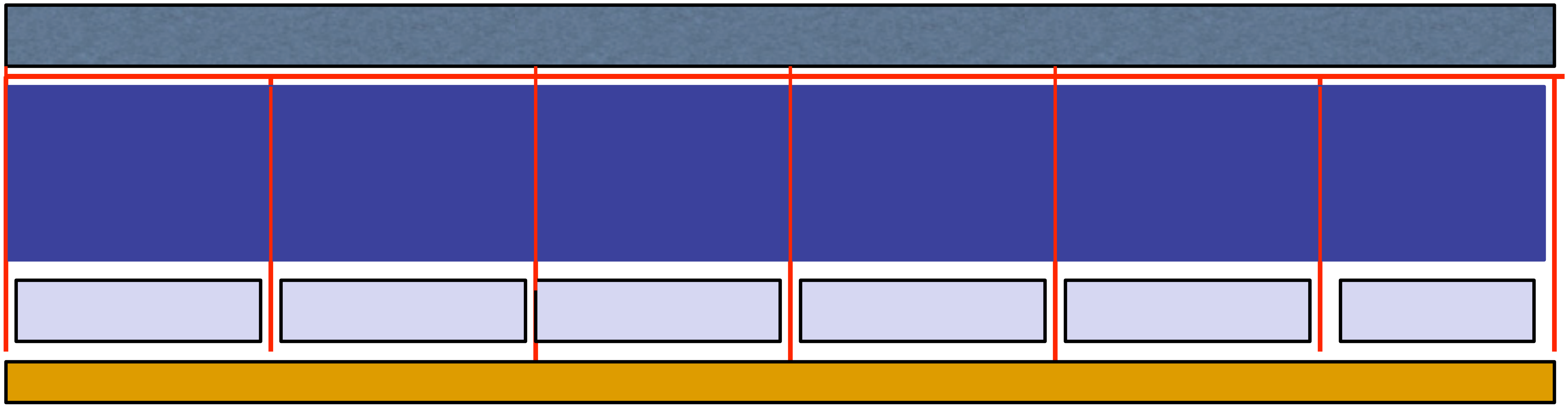
- Interface with the rest of the detector Linear bearing tracks attached to tail catcher.
- Proven method of installation, STAR.

BEMC Design. Possible Implementation. Radial Envelopes



Total ~ 25 cm for 18 X_0 deep EMCal

BEMC Design. Possible Implementation. Cross Section of a module.



- W/ScFi Superblocks glued directly to carriage
- Red lines - Thin metal Sheets attached to carriage
  two purposes:
  1. increase gluing surface to keep superblocks
  2. provide mechanical support for Front End Electronics and light tight cover cup.

This I believe is possible because we dont need any sort of mirror or reflector at the back side of the W/ScFi block.

Rough idea how much mechanics will cost.

List of materials and cost estimates EIC BEMC.
This is covers production of ~ 1520 W/ScFi super modules.
Each has 16 towers. Each tower 2.5 cm x 2.5 cm x 18 X0.

R_{in} = 96.5 cm, R_{out} = 110 cm, L = 247 cm
V=2168480 cm^3, Mass ~22 tons

Absorber 22 tons @ $89/kg = $1.958M		Quote, THP
Fibers 3625 km @ $0.42/m = $1.52M		Quote, Kuraray
Light Guides 24320 @ $1.00 = $25k		Guess
Epoxy 1764 lb @ $52/lb = $92k		Quote, Epotek
Meshes 12160 * $7.4 = $90k		Quote, PhotoFab (scaled)
Molding Forms fabrication	$30k	Educated Guess
Supplies	$20k	Guess
Shipping	$	
Labor 14 FTE tech		
Labor 2 FTE machinist		

Labor Total $1.5m Guess

Materials $3.775M
Labor $1.5M