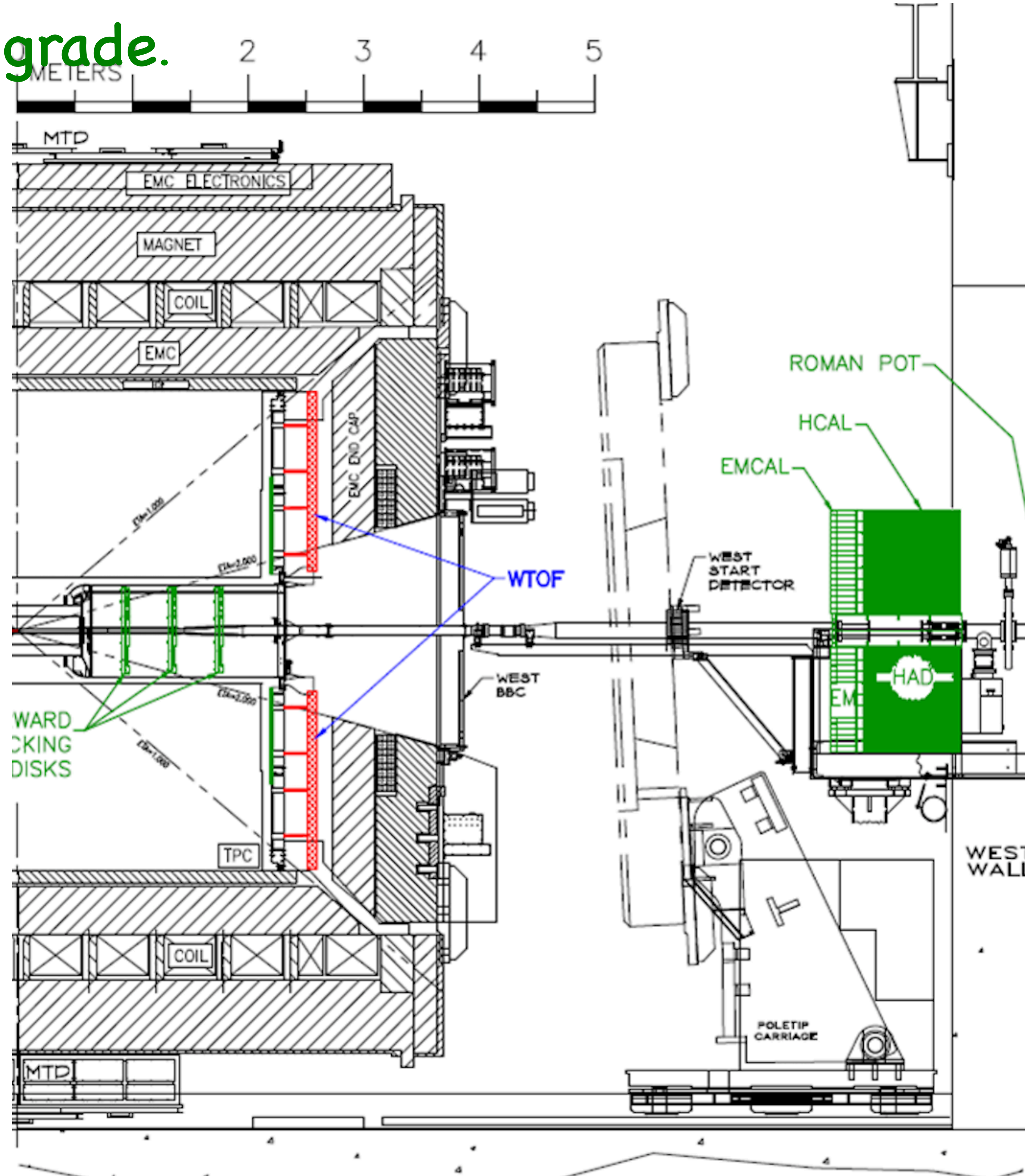
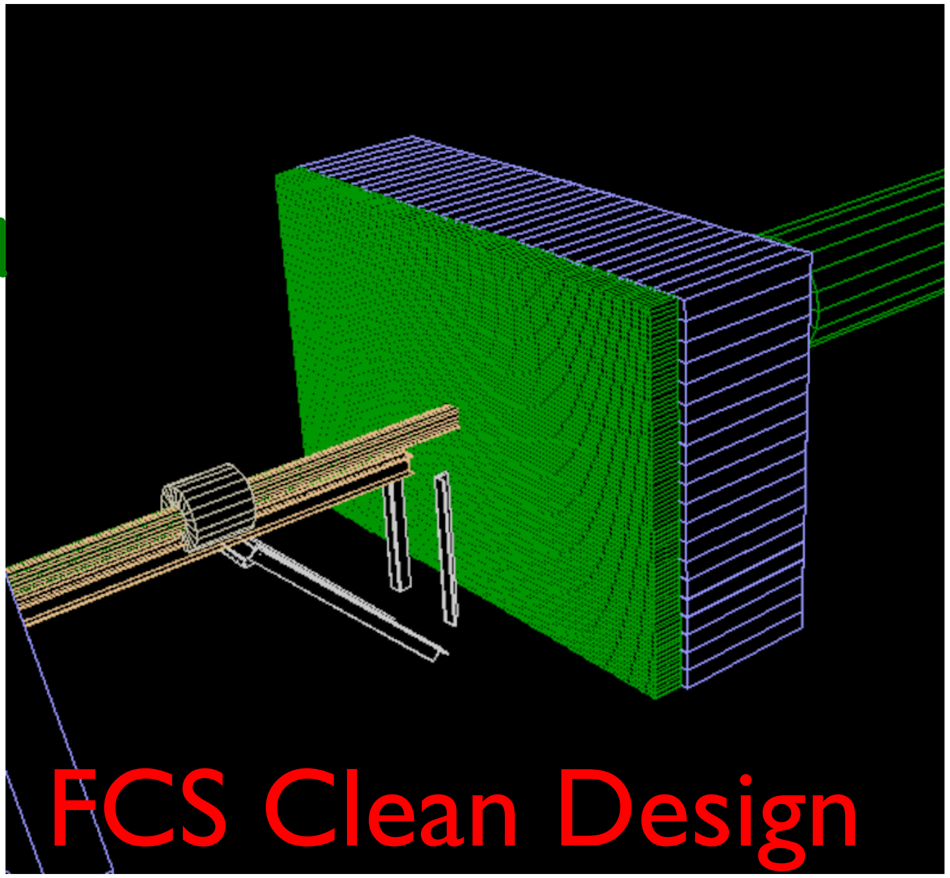
ECal and HCal design for fSTAR

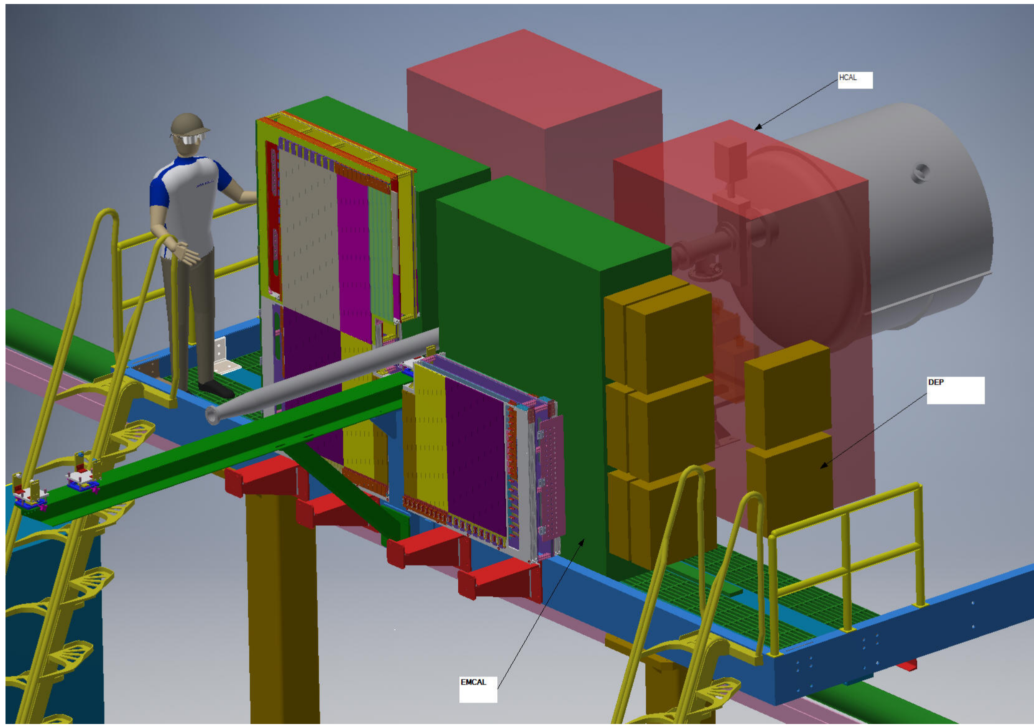
O.Tsai (UCLA)

RSC Hardware, March 9 2017

- STAR Decadal Plan
- EIC R&D, STAR Forward Upgrade (2012-2015)
- RSC Cold QCD Plan and 'Modest' forward upgrade.







FCS' Modest Upgrade

Technology for fSTAR Calorimeters. And future EIC

Compensated.
Usually share same technology
For EM and HAD sections

Non – compensated
Different technologies for
EM and HAD sections

Examples:
ZEUS, (H1)
SPACAL,
E864

Examples:
CMS,
ATLAC, LHCb,
STAR (FMS+E864)

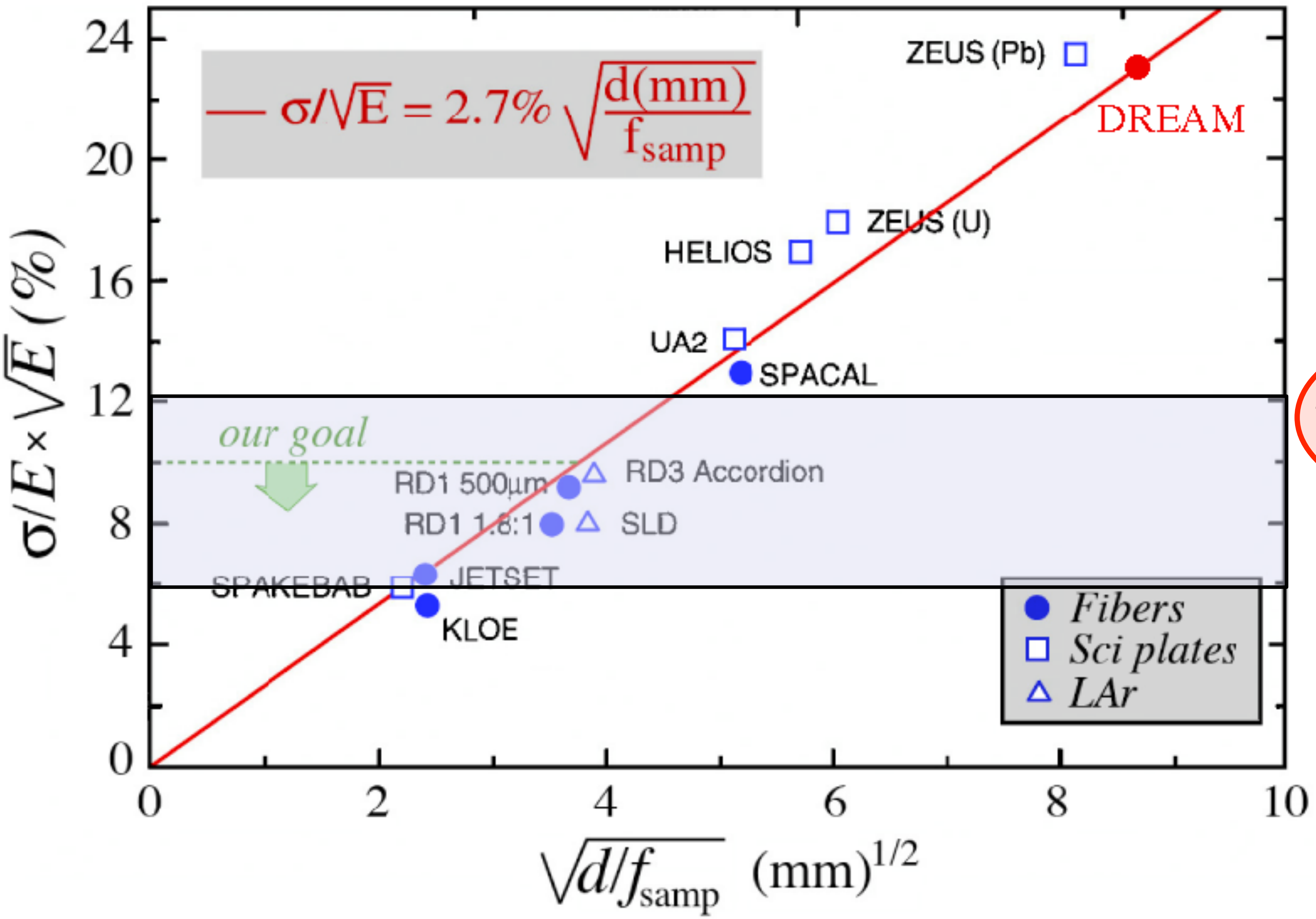
Performance:

Outstanding hadronic energy resolution,
So-so electromagnetic energy resolution.

Excellent EM energy resolution,
Poor hadronic energy resolution.

When we started to talk about STAR forward upgrade, SPACAL type was our first choice because new technique we are developing for EIC calorimetry can be used for STAR also, and thought was that W/ScFi is suitable for a large scale HCAL modules.

EIC EM Sampling Calorimeters



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

H1

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

Calorimeters:

- Full Coverage,
- Hermetic.
- Compact.
- Operate in the magnetic field.
- Fast.
- Affordable.

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

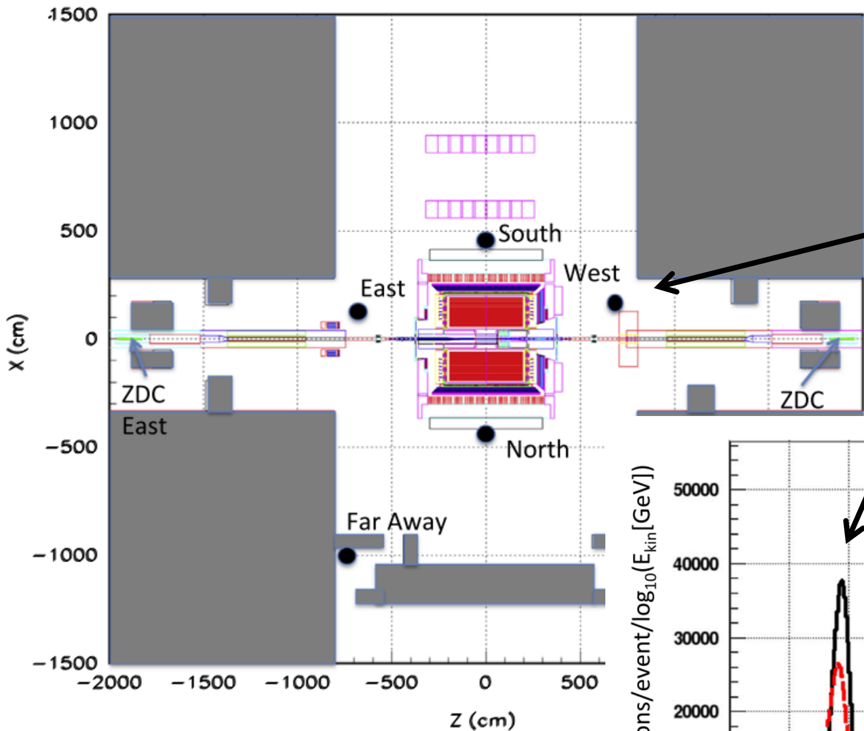
- Calorimetery, Complementarity H1 and ZEUS
- Complementarity, EIC1 and EIC2?

What shaped the design other than physics requirements?

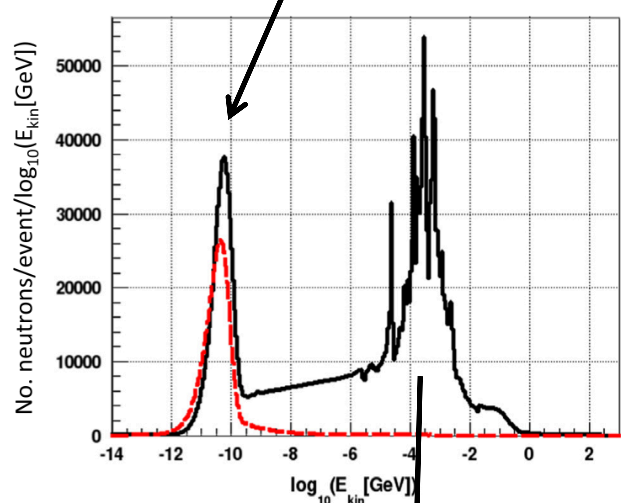
- Operational
- Mechanical Integration
- 'Modest' Uncertainties with Budget and Schedule

- Limited space. Mechanical design, Sensors
- Radiation hardness. Materials
- Neutrons. Sensors. Light Collection.
- Reconfigured for future EIC Backward. Mechanical Design
- Magnetic Field. Sensors, Mechanical Design
- Manpower (build it with students) Mechanical design
- One year construction project < $2M budget. Design

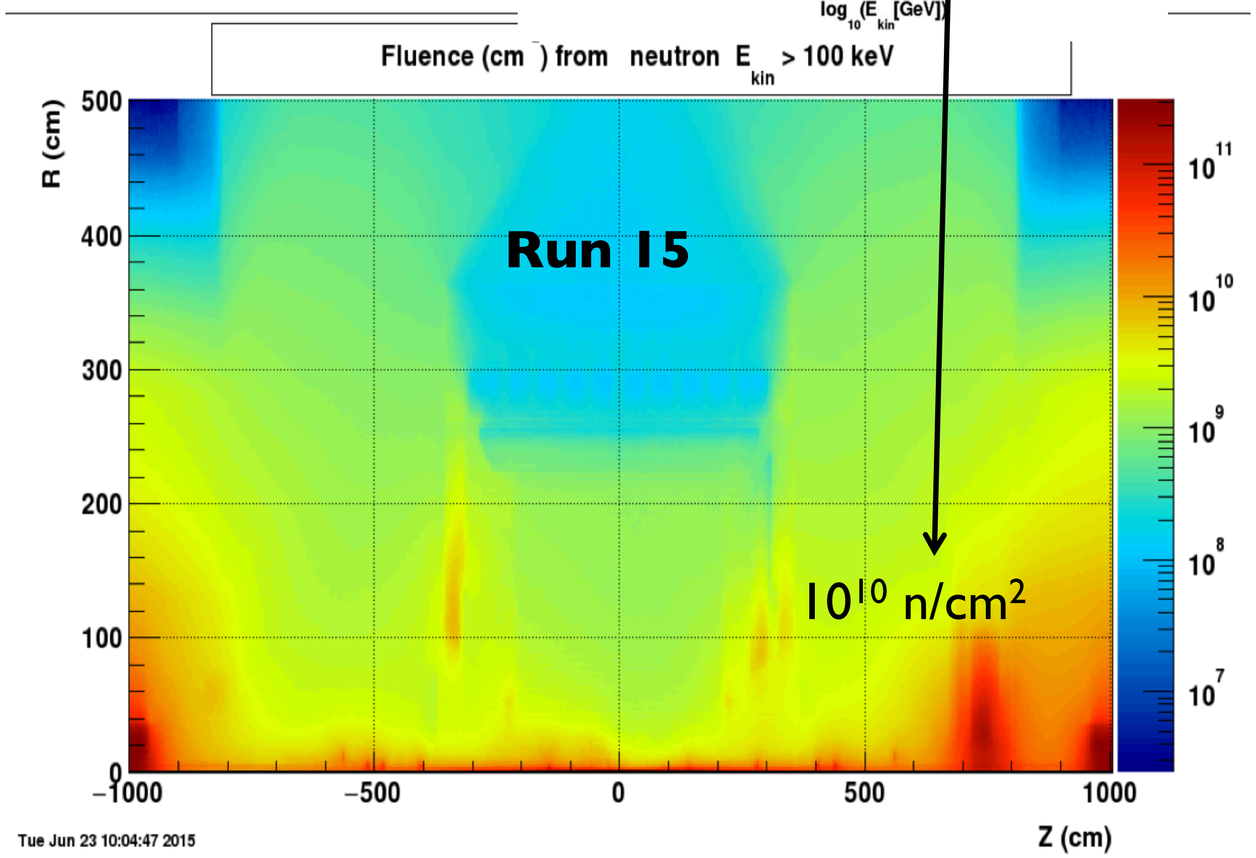
Neutron Fluxes, FPS SiPMs:



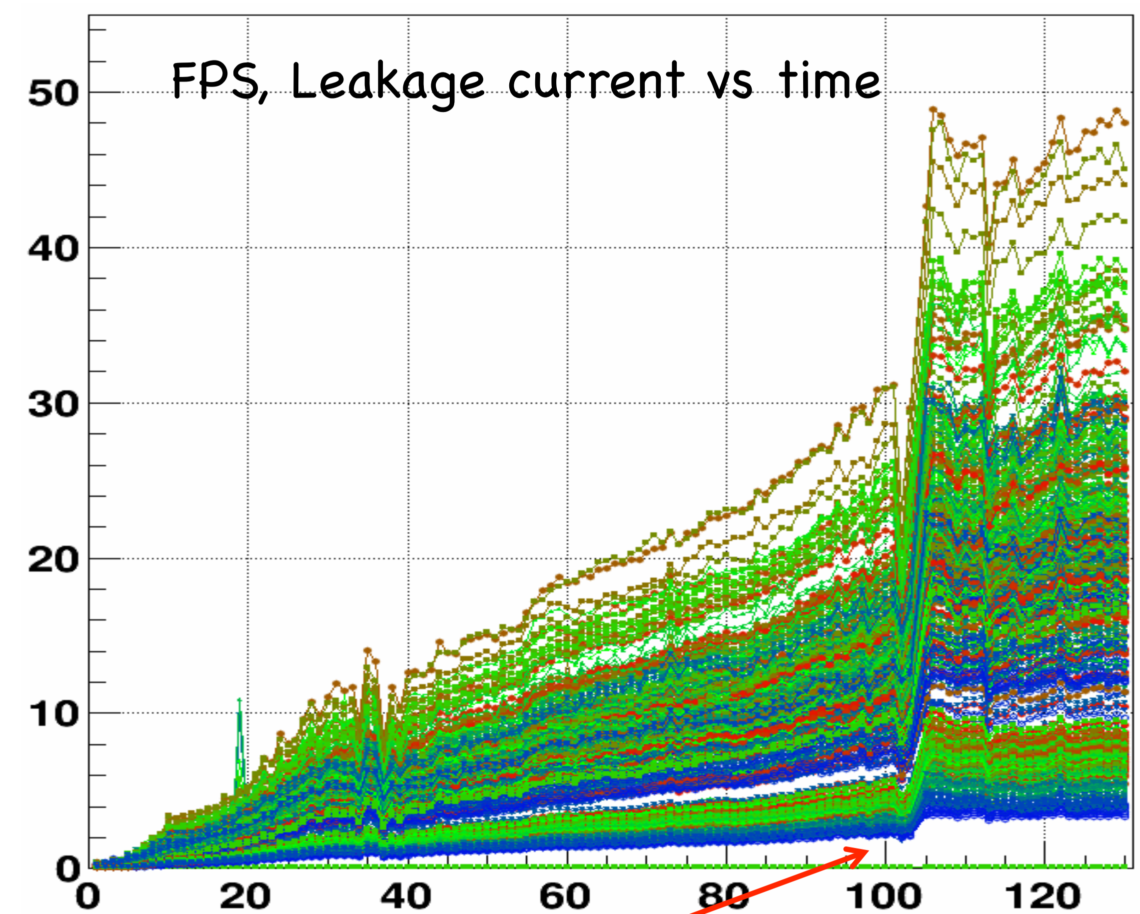
Run 13, He3 Counter. Thermal Neutrons



Y.Fisyak, et.al NIM A756



- 2015 Neutron fluencies calculated for pp, pAu, pAl for integrated delivered luminosity.
- FPS SiPMs were exposed to 10^{10} neutrons sm^{-2} according to our MC.
- MC doesn't know about beam losses, APEX or high background during steering, collimations etc., i.e. real exposure may be higher than MC gives.
- Data from TLDs still in processing.

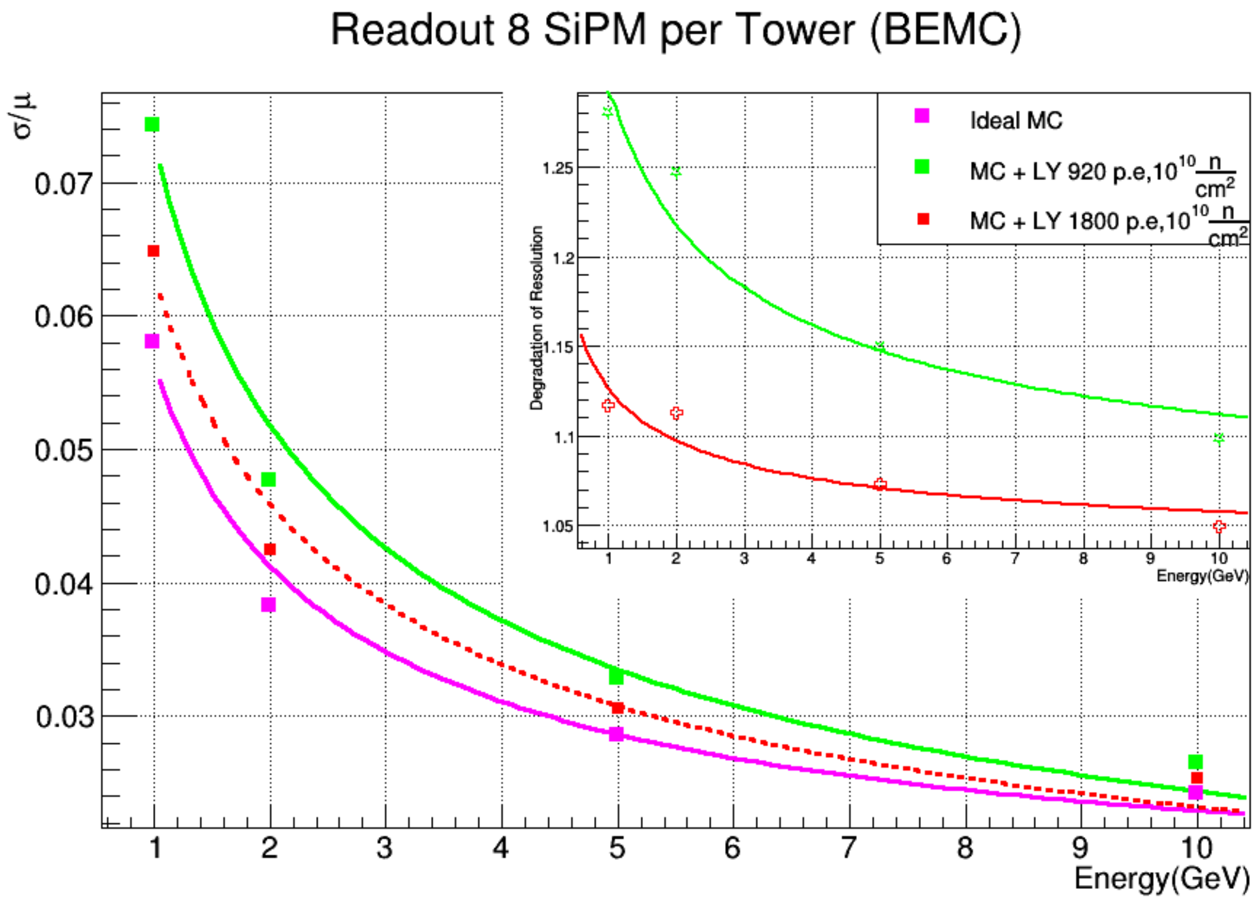


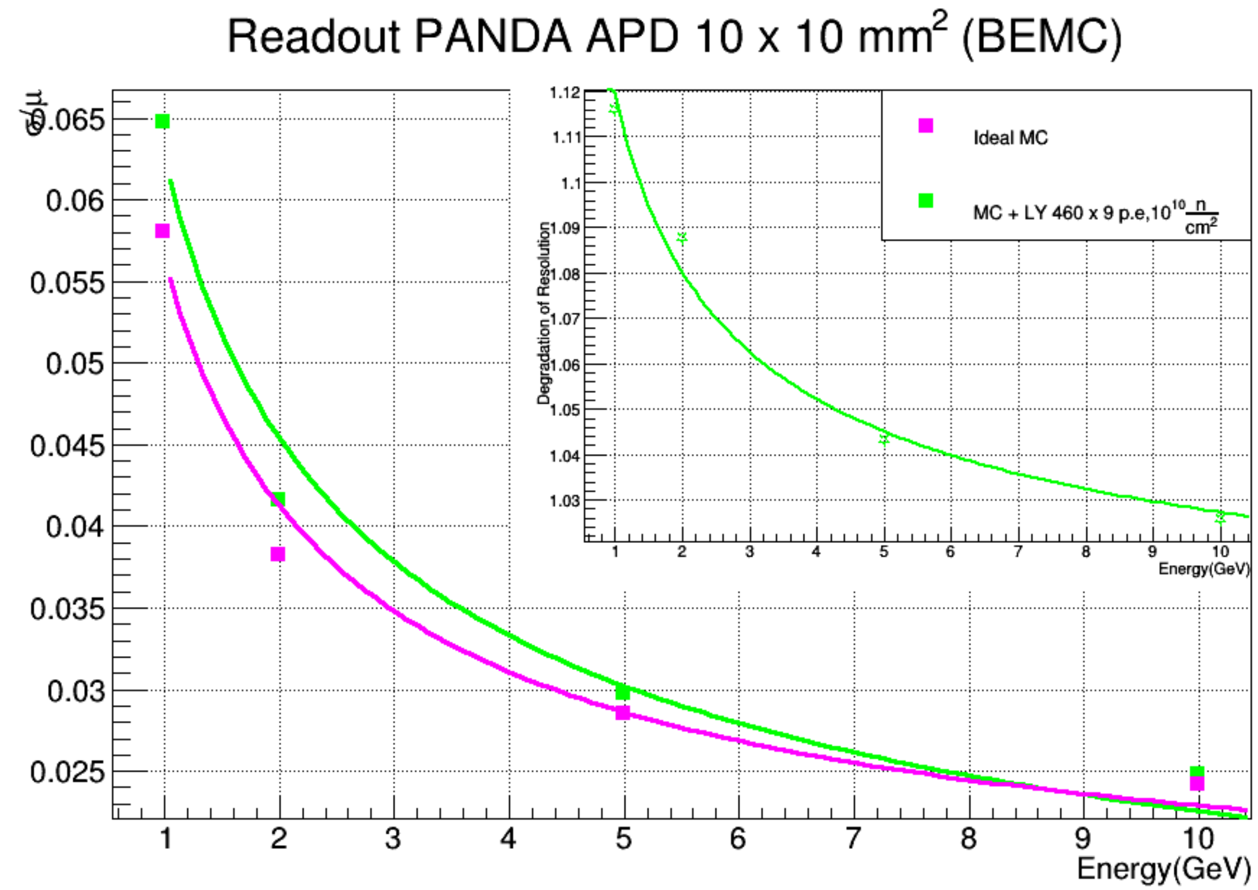
May3rd when beam blasted in WAH
~5weeks pp running worth of rad damage in 1 day

Possible schemes of improvements for 'HR' BEMC:

- Cluster 3 x 3 towers, 8 SiPMs per tower.
- **Noise after 10^{10} n/cm^2 ~ 30 p.e.**
- BEMC - Light Yield assumed ~ 460 p.e. x 2
- BEMC - Light Yiled assumed possible ~ 900 p.e. x 2

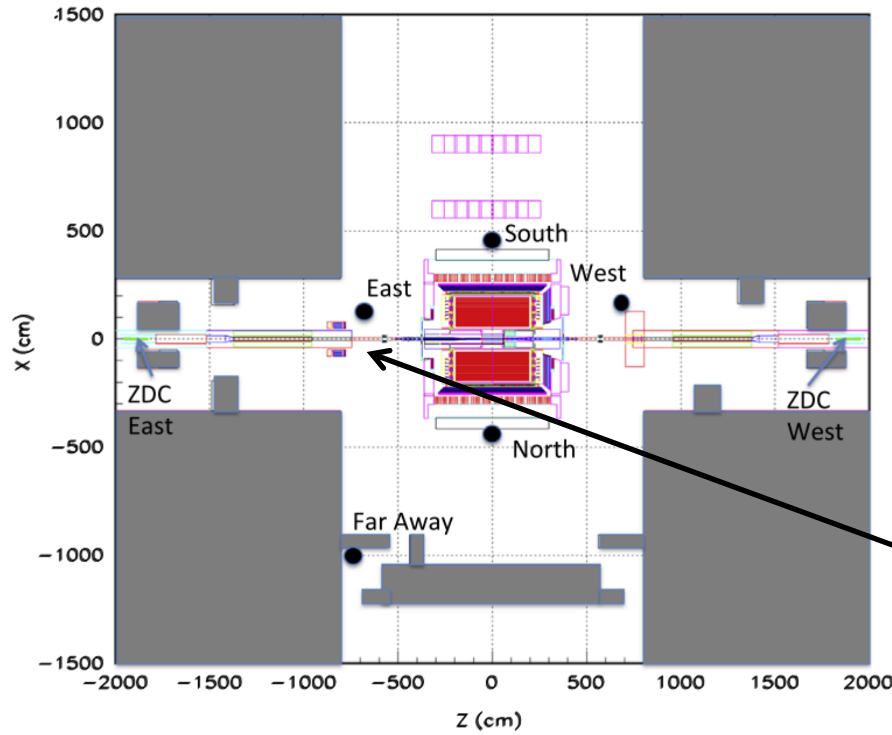
- BEMC – Light Yiled assumed ~ 460 p.e. x 9 (9 - PDE x Area of APD compare to 4 SiPMs)
- ENF – 1.4 (PANDA TDR).
- Preamp ENC – 50 p.e. (270 pF) before amplification 50 (state of the art preamp, discussed with G. Visser (IUCF))





- **EIC and for fSTAR, efficient light collection scheme important.**
- **Design should allow quick (easy) replacement of sensors.**

SiPMs and APDs in 'realistic' conditions:

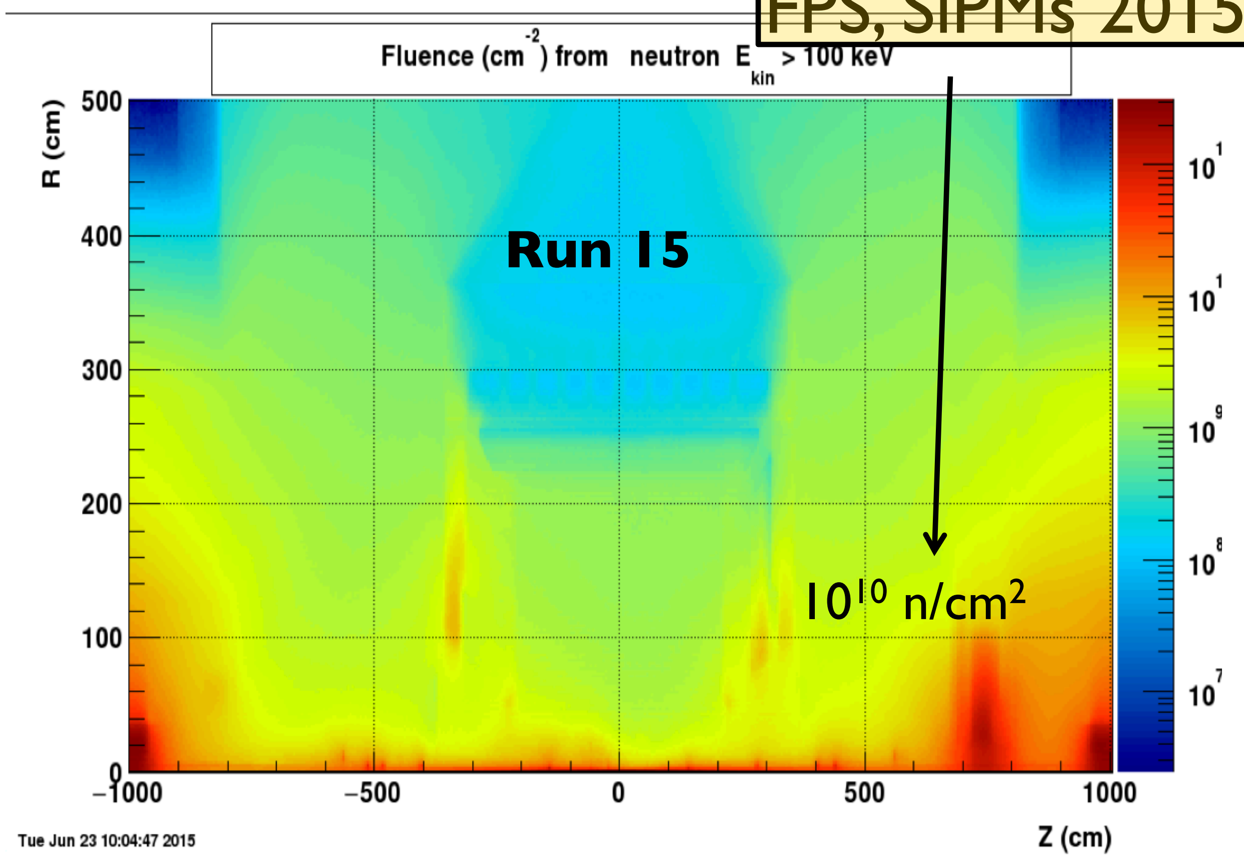


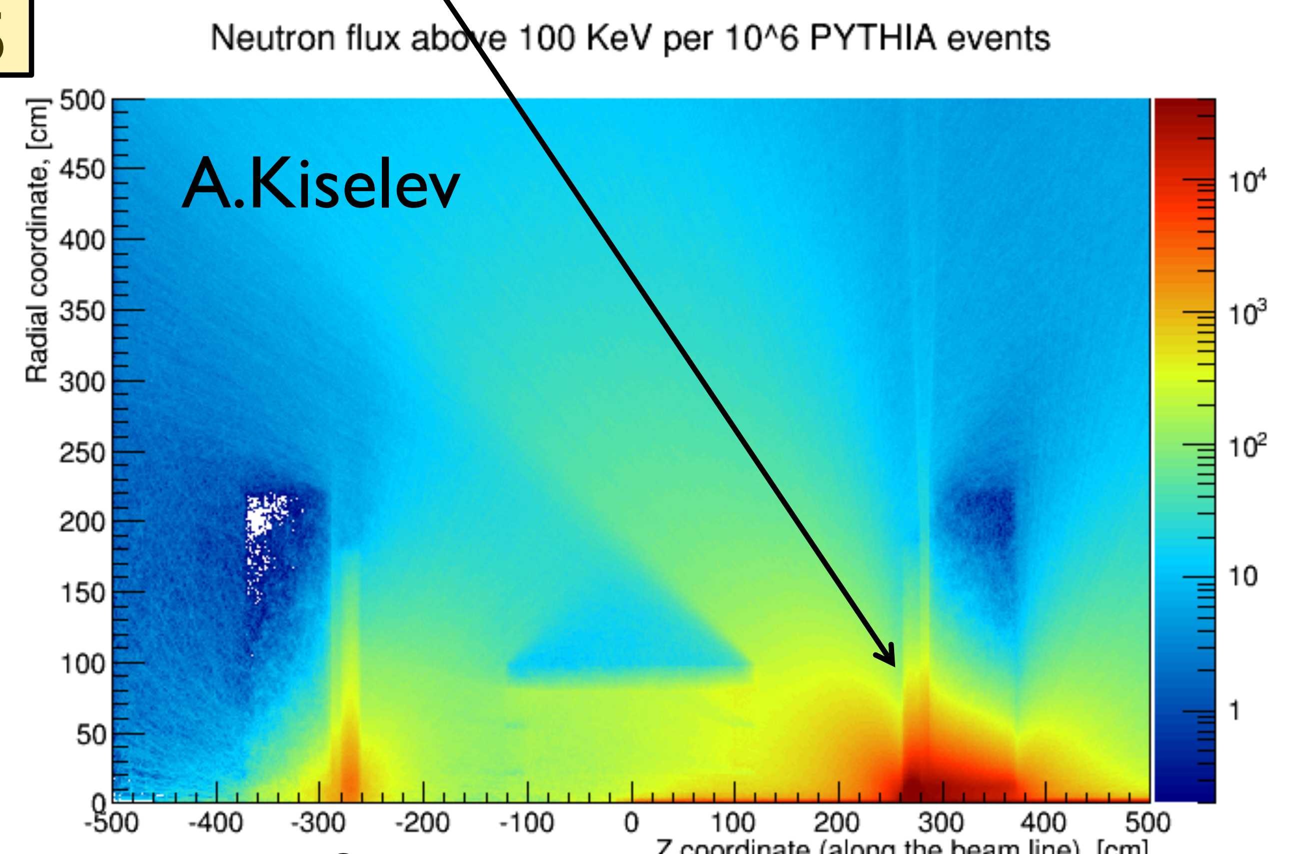
- STAR IP ideal test place for EIC. Well understood conditions (measurements in 2013 thermal neutrons, 2015 'MeV' neutrons with Forward Preshowers (FPS) SiPMs + MC).
- EICRoot tuned using STAR data.
- Conditions for FEMC in BeAST very close to one we have in STAR now.

FEMC, 2016

Y.Fisyak, et.al NIM A756

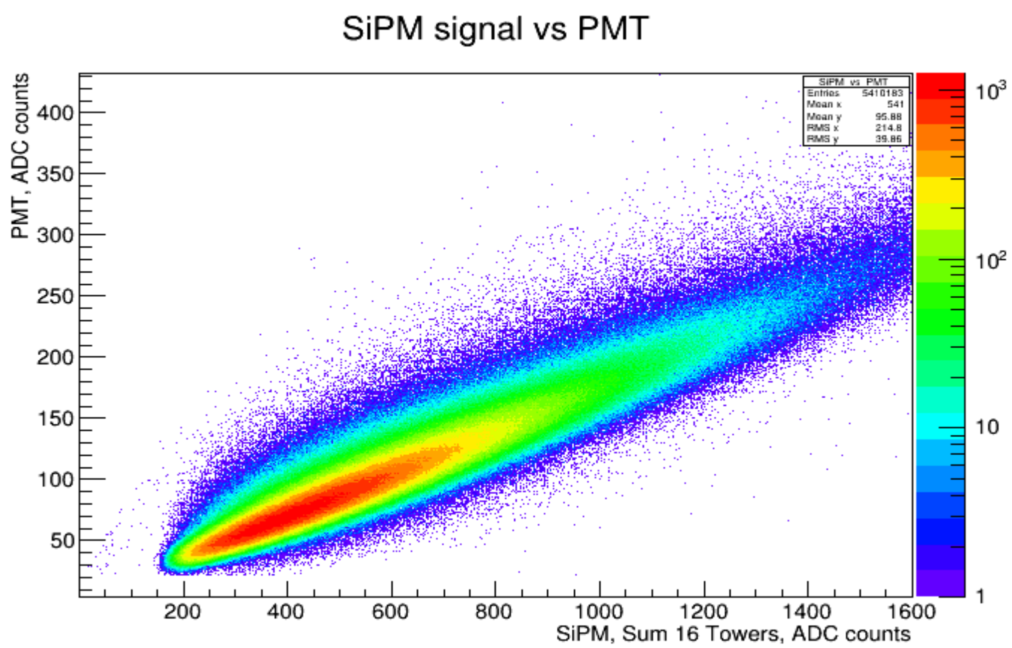
FPS, SiPMs 2015

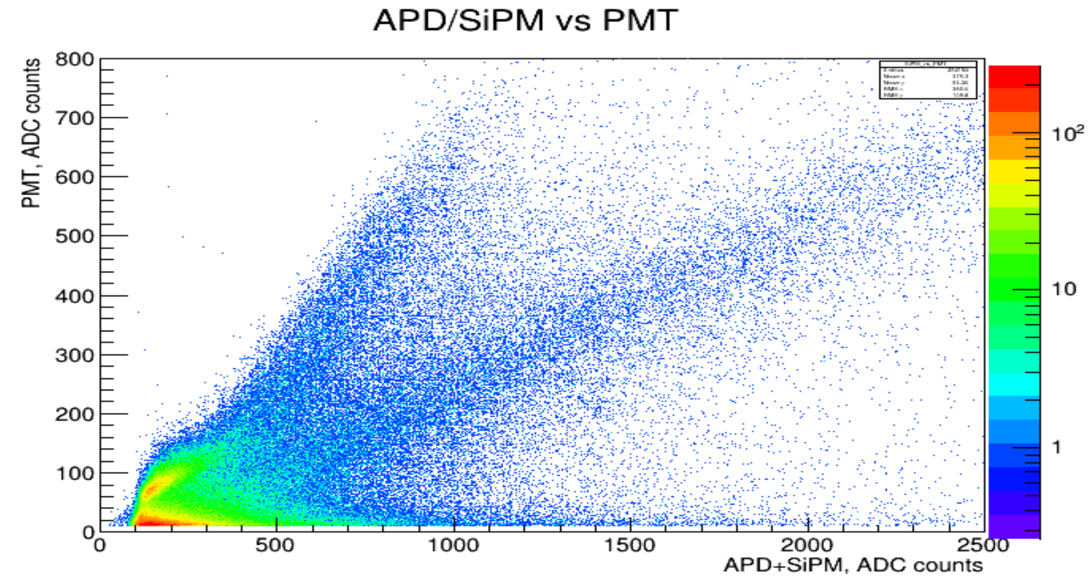


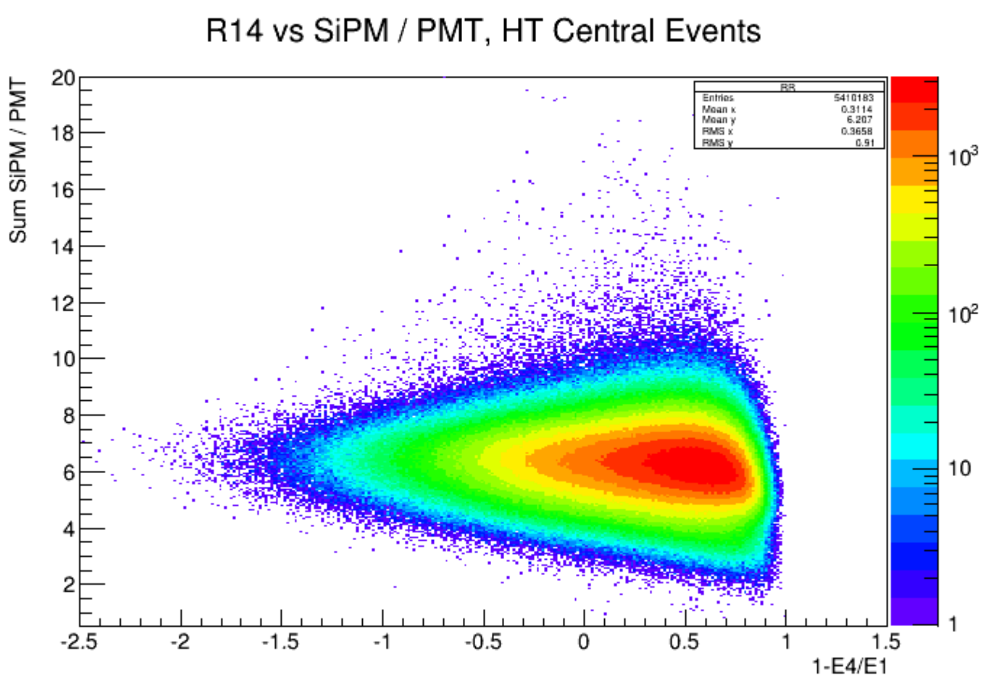


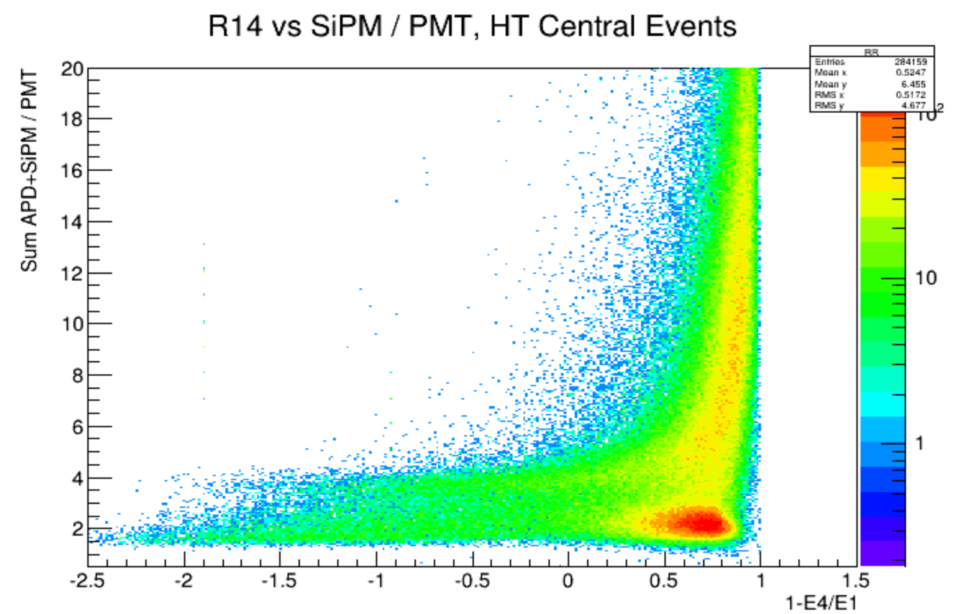
Neutron fluxes at BeAST, ep 20 x 250 GeV

FEMC, SiPMs (APDs) in 'realistic' conditions (all results are Preliminary):



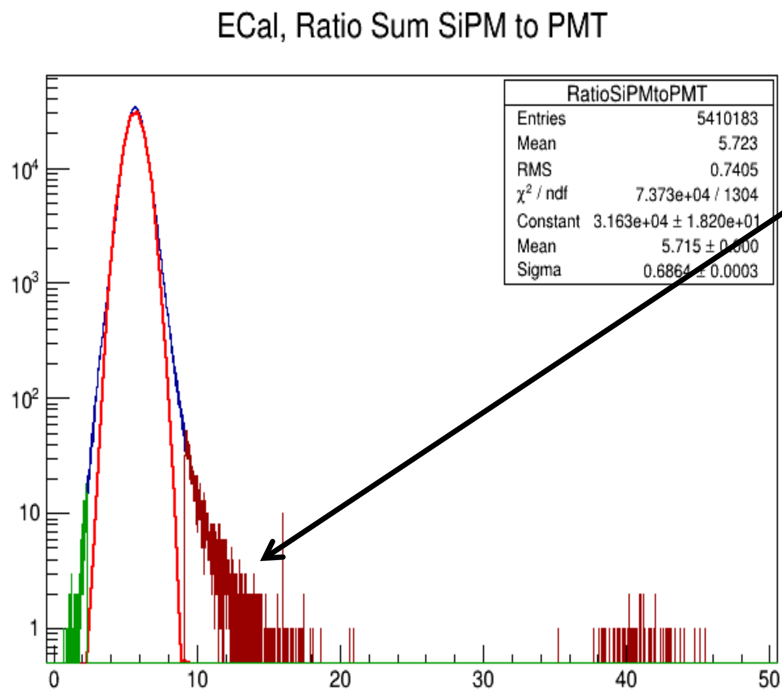




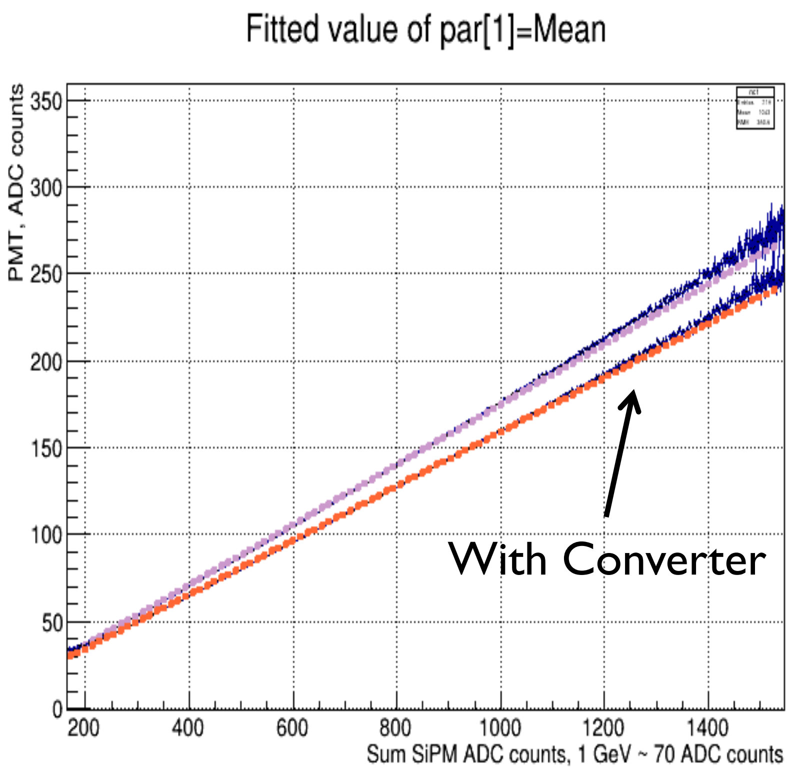


- SiPMs indeed immune to NCE
- APDs ~ 40% of High Tower Triggers are due to NCE

EIC R&D, FEMC, SiPMs in 'realistic' conditions (STAR Run16):

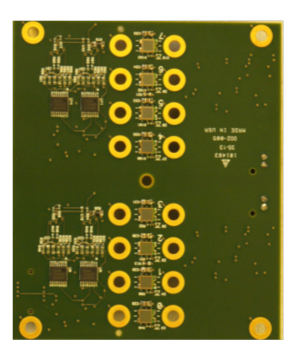


- Fraction of signals outside 5 sigma is about 4 $*10^{-4}$ for SiPM readout.
- Origin of these signals is not clear.



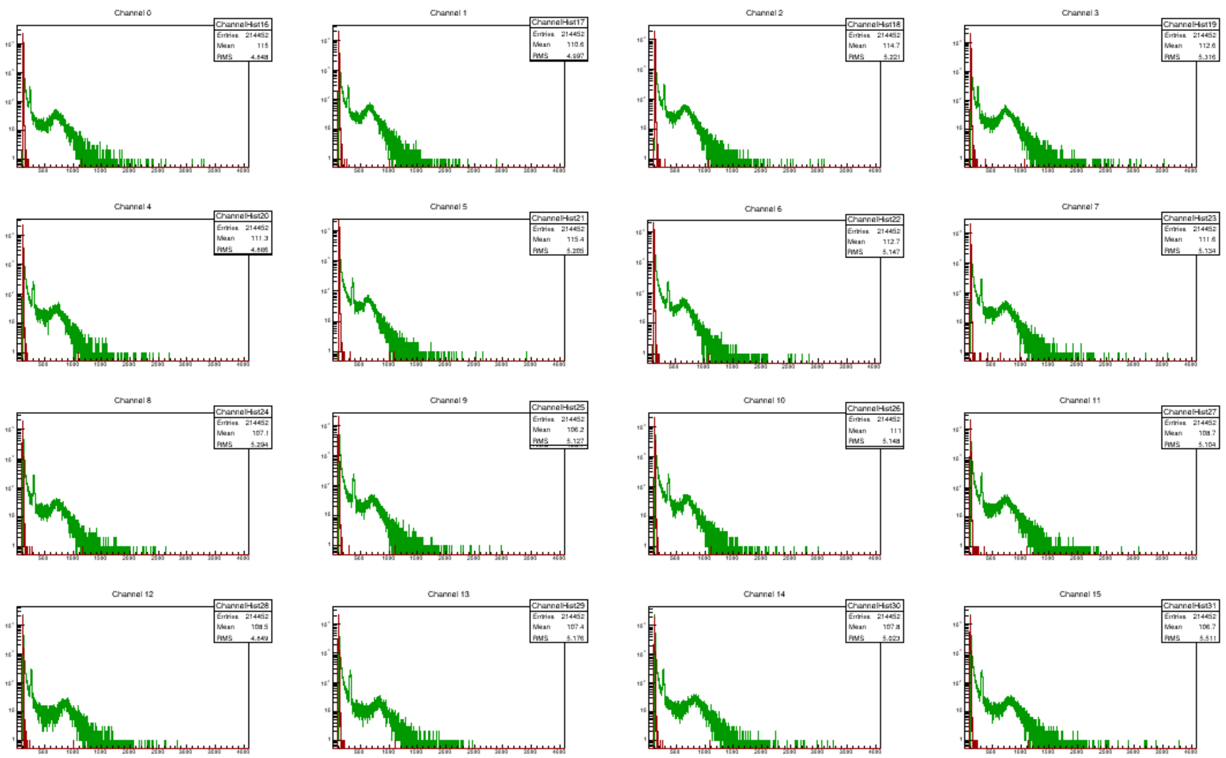
Test with $2X_0$ converter in front of SiPMs (sensitivity to 'shower' particles)

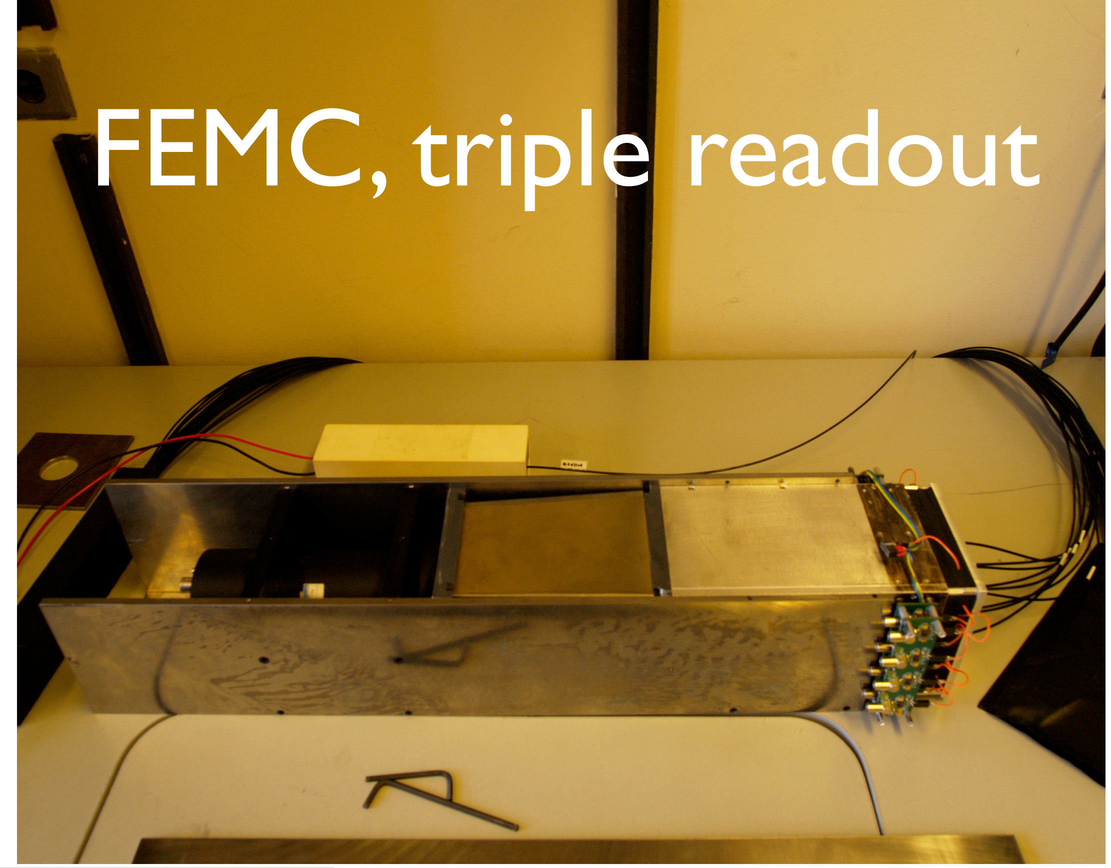
- Excess of ~ 90 pixels/GeV may be due to the same things which produces non isolated spikes in CMS, or related to CMS observation, SiPM test with neutrons for HCal upgrade?
- If true (not the artifact of light collection to PMT) this may be a problem when summing many SiPMs (especially if detector has low LY).
- Example, FEMC HAD readout, Sum 8 SiPMs. 130 pixels/GeV, Test Run 2014 at FNAL.

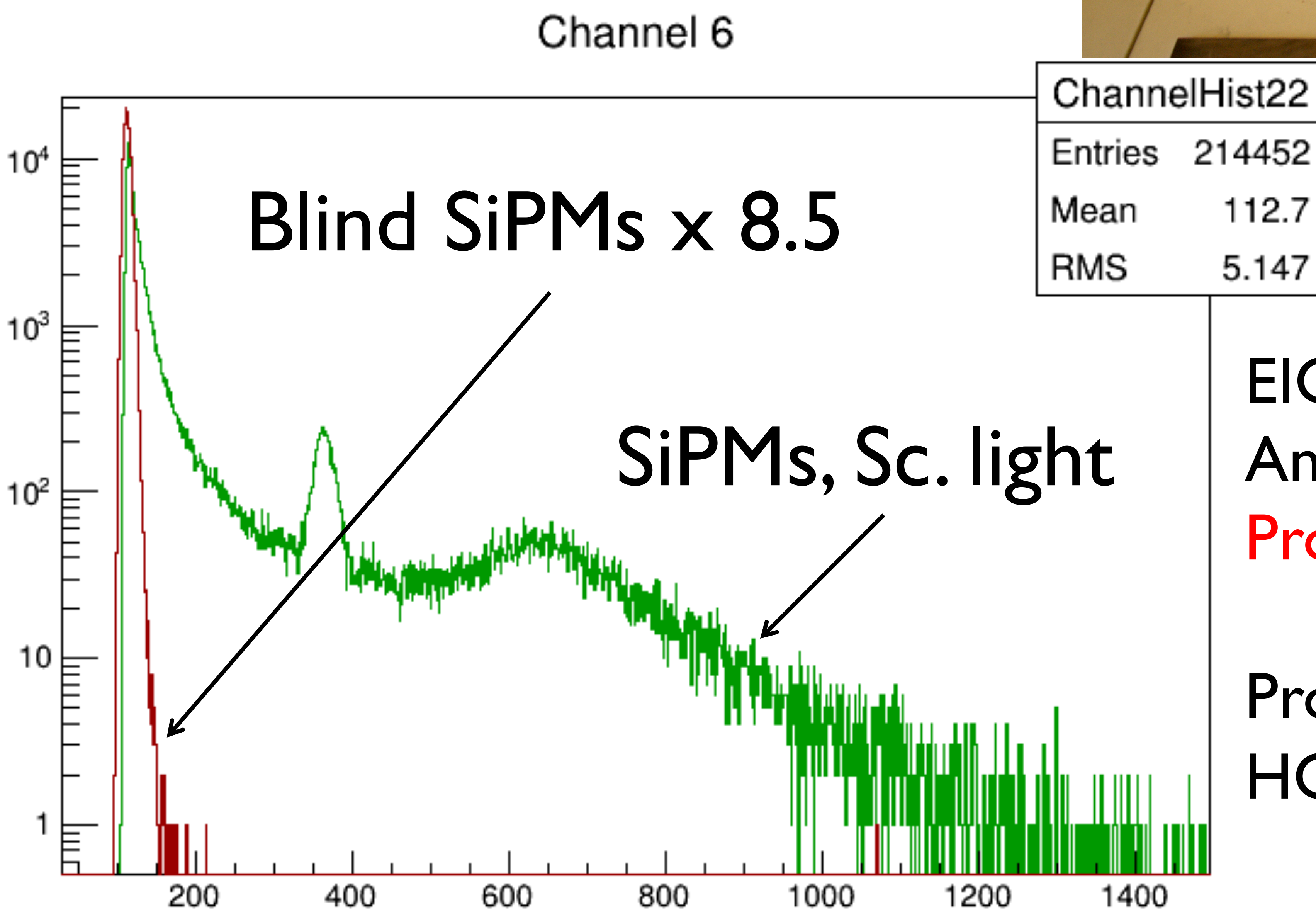


← Will this be better with two APDs ?

- APD readout will require to double number of digitizers (480 x $70 = $33,600 cost increase)



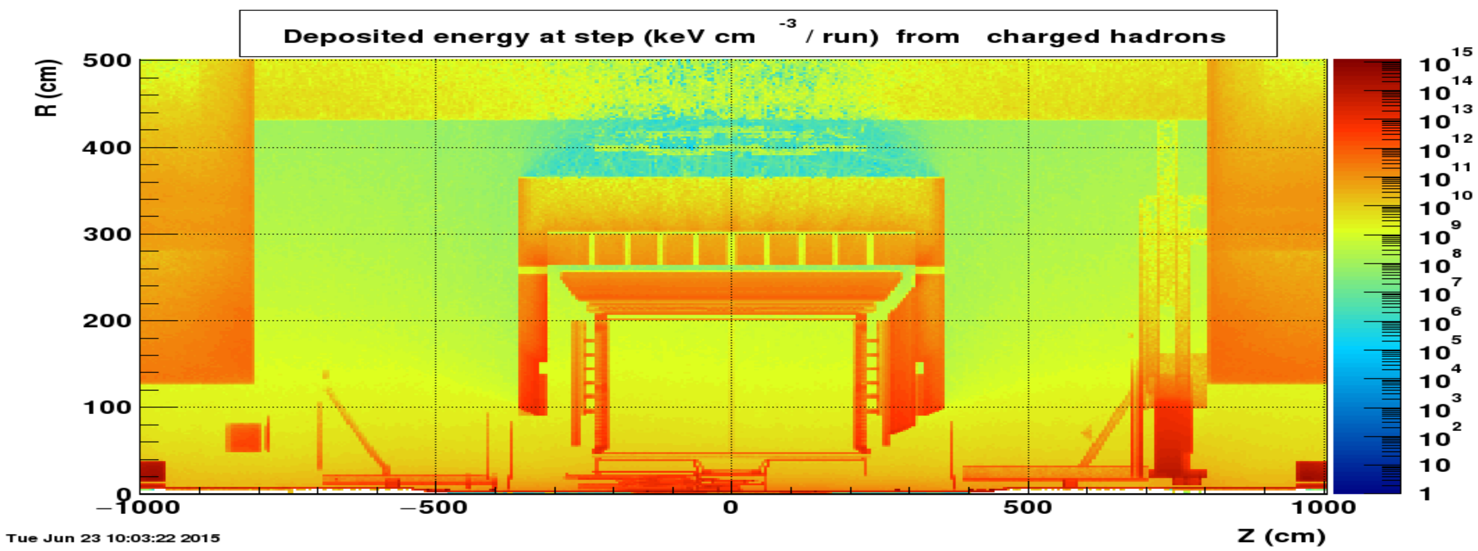


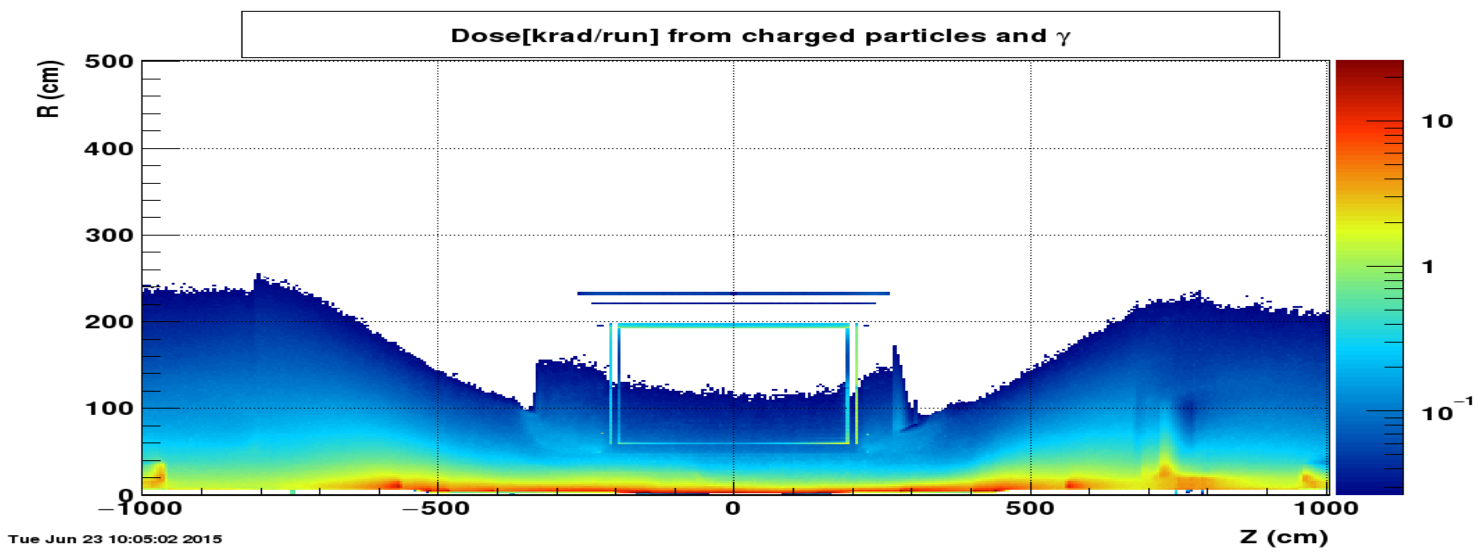


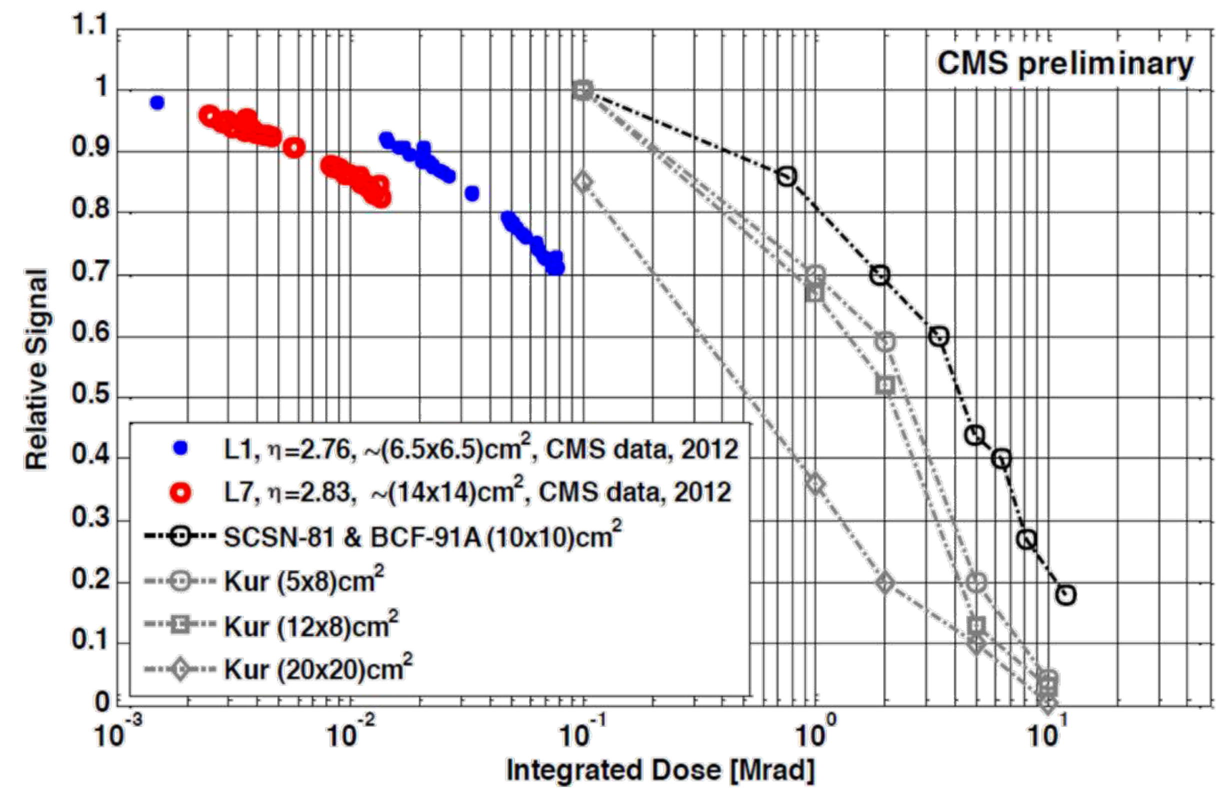
EIC R&D, Run17 STAR
Anomalous Signals in SiPMs
Probably not a problem.

Proceeded with SiPMs for HCAL.

STAR WAH environment, http://www.usatlas.bnl.gov/~fisyak/star/Flux/2015/ .







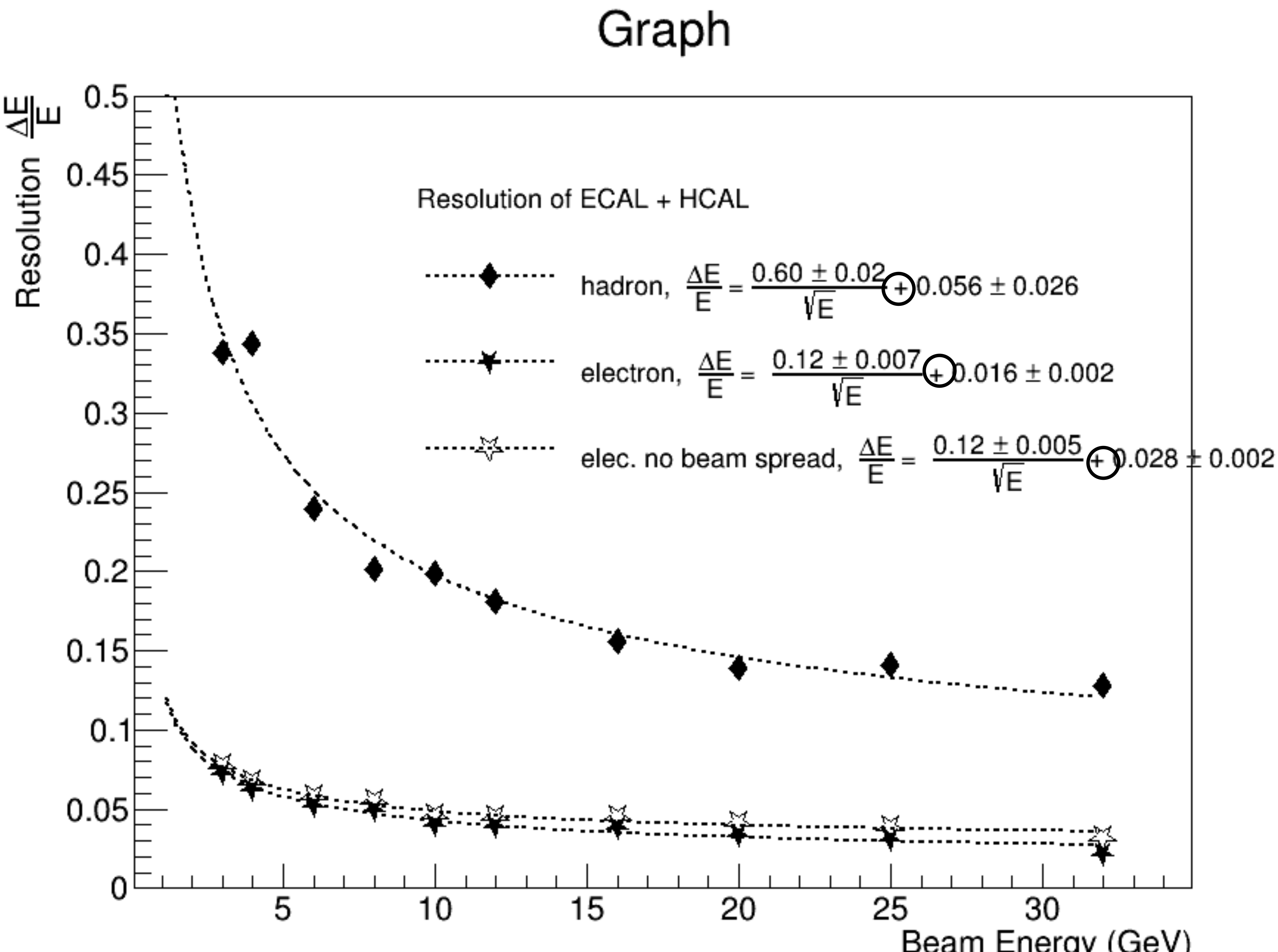
Rad damages probably not a big concern.

Scintillator ~ 100 Rad per Run

But, all scintillators are different. Rad damages in scintillator is very complicated question, has to be tested!

FCS Constant Term, FNAL 2014

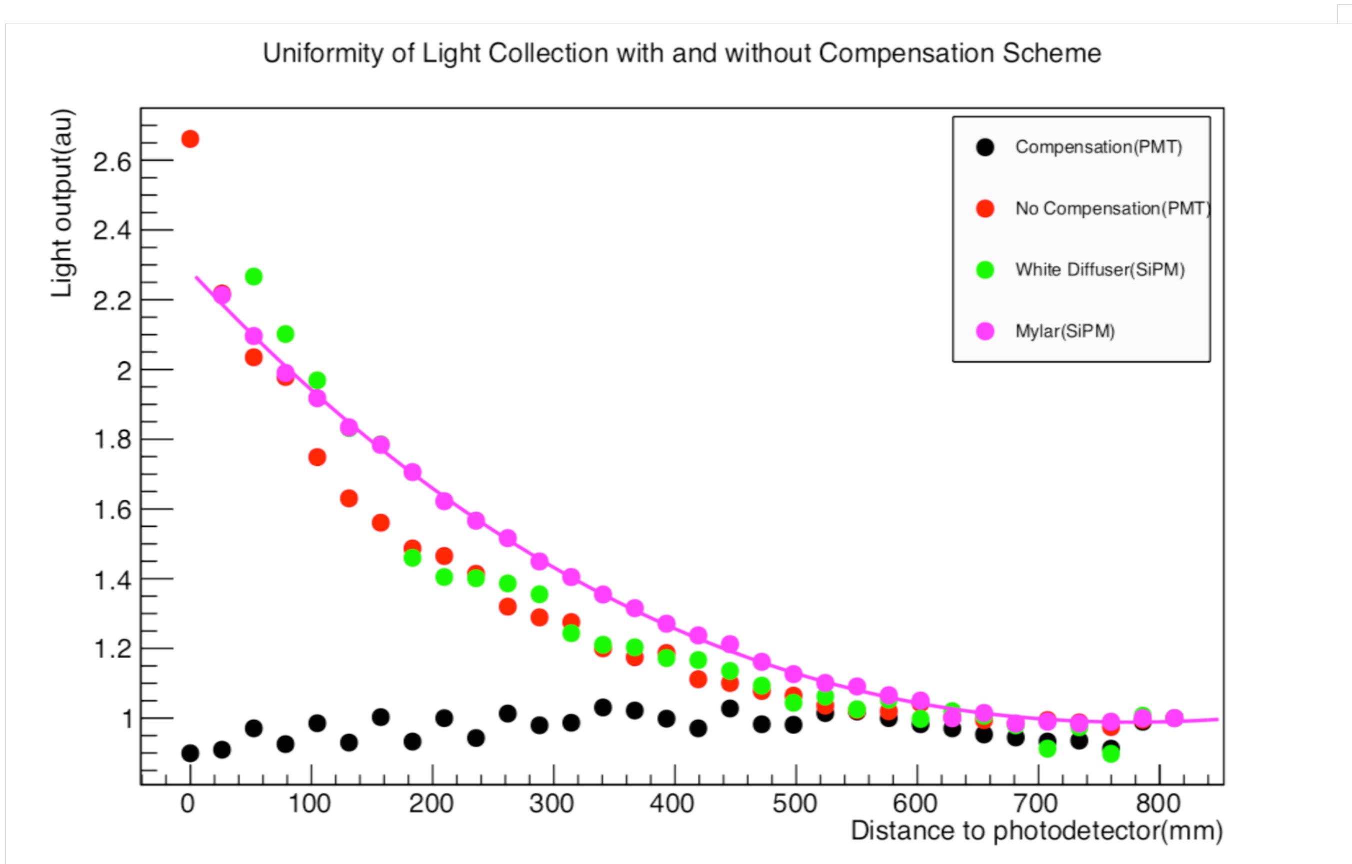
Advantages of compensated system

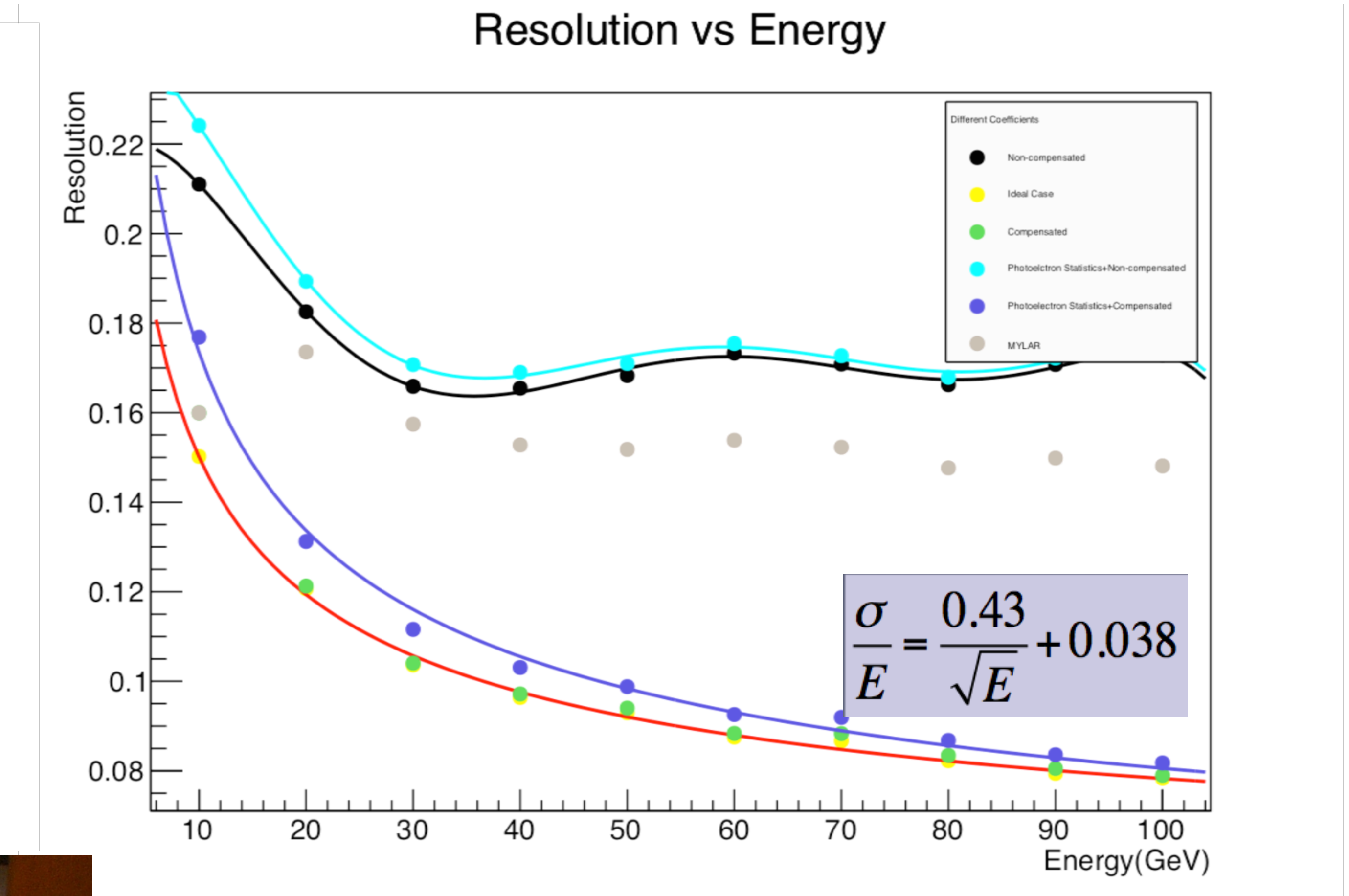


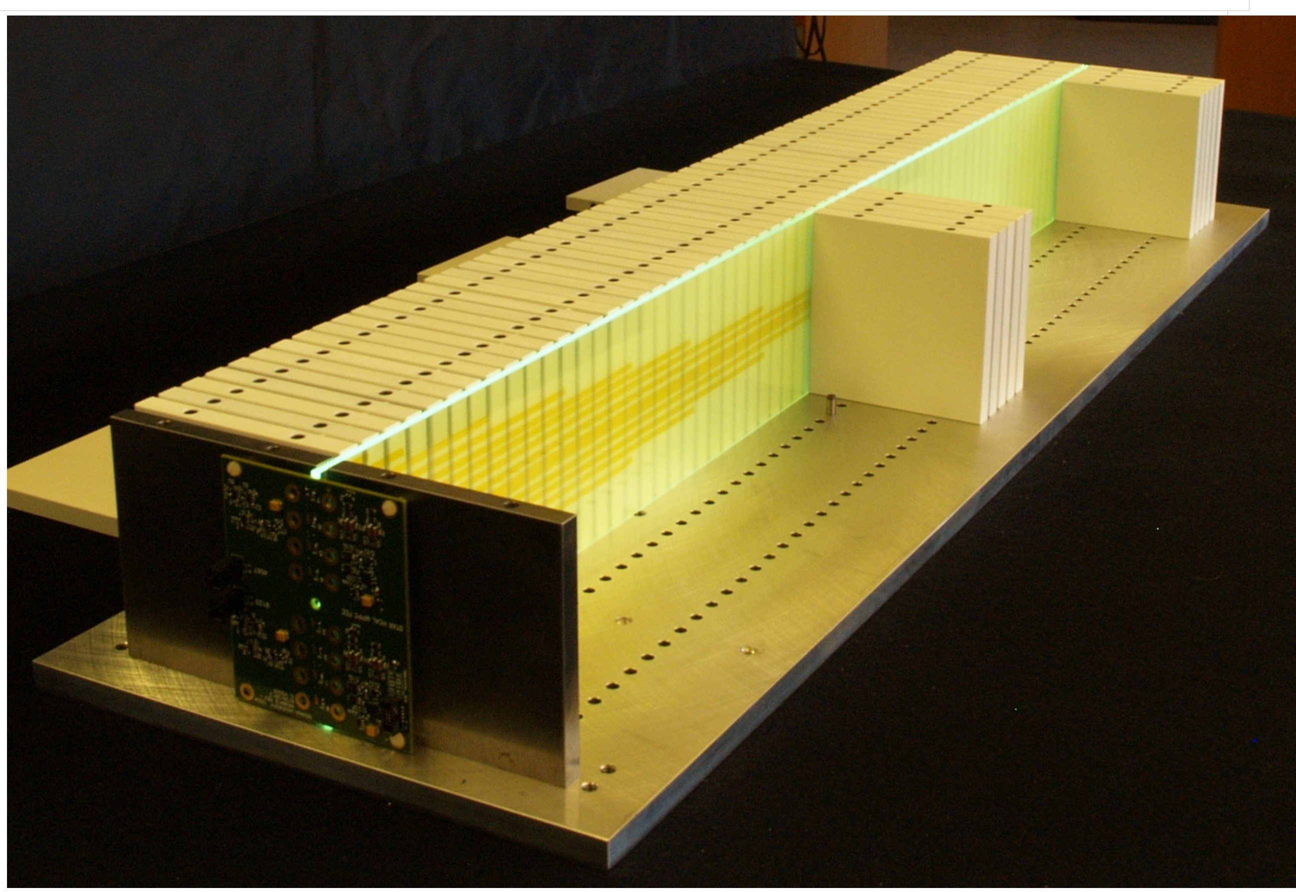
Imperfections:

- Thick steel plate between EM and HAD sections
- Leakages transverse and longitudinal

FCS Constant Term

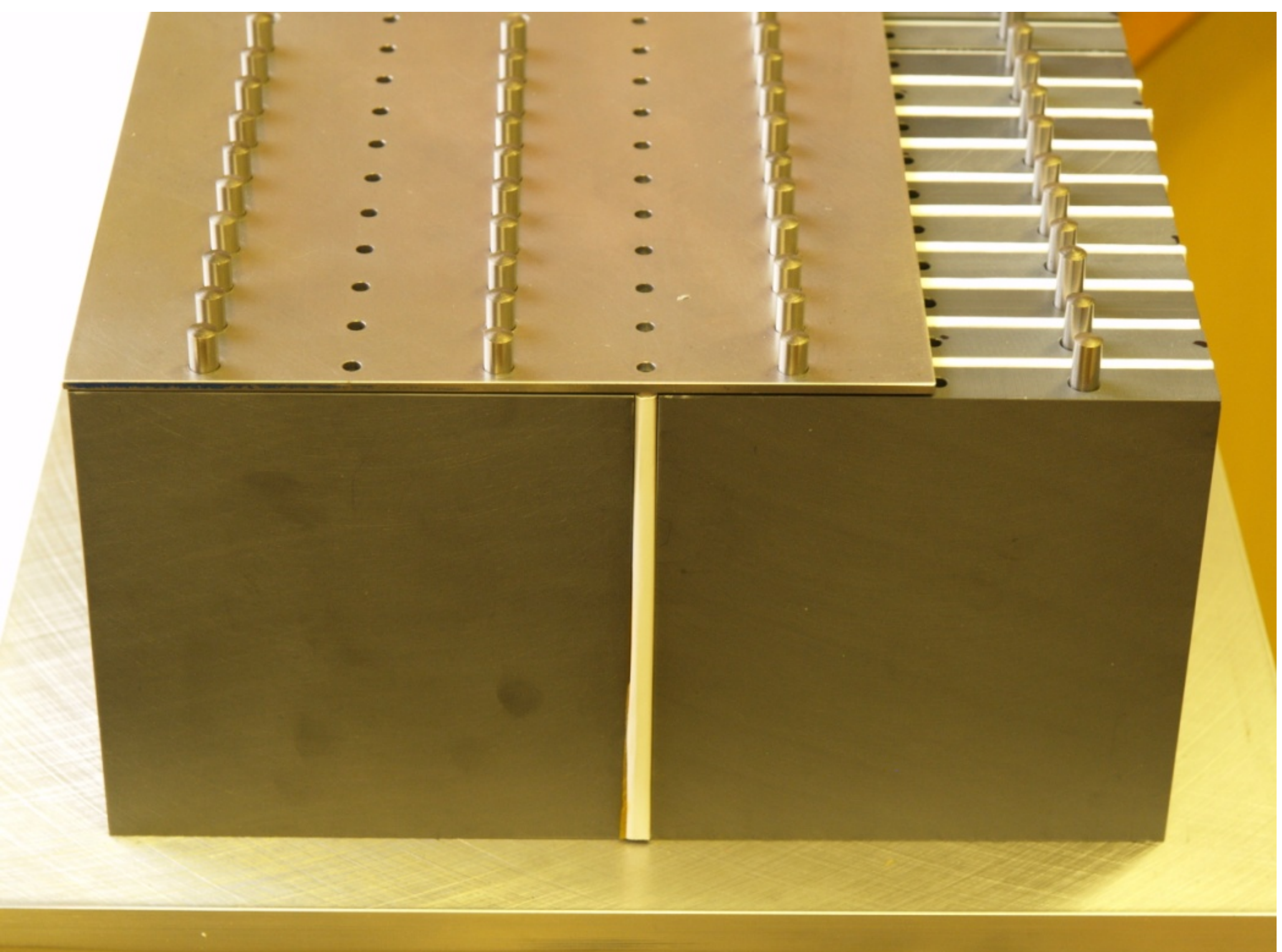


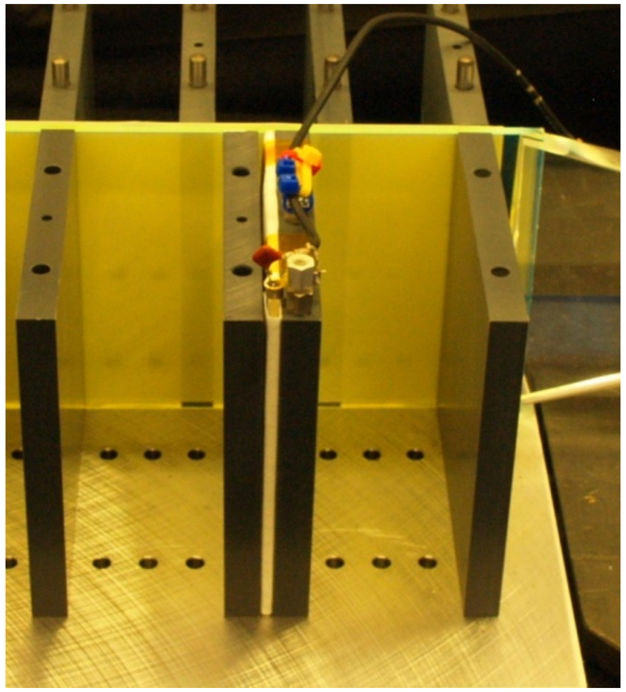




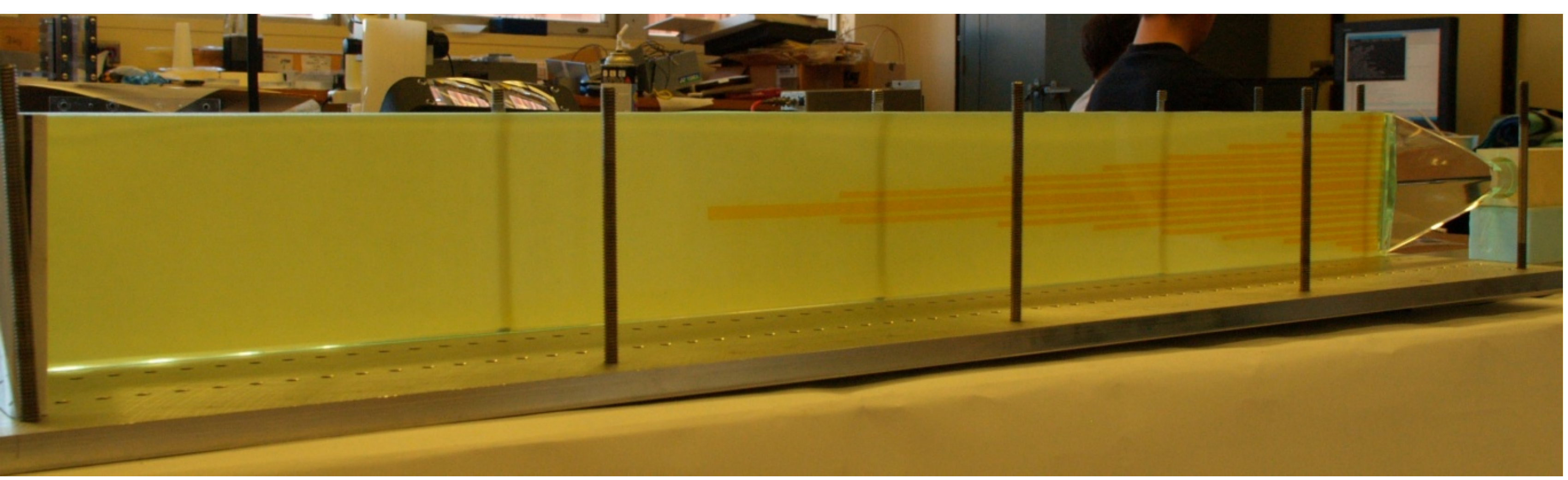
Uniform and Efficient light collection is very important. It is very easy to end up with constant term at 15% or so.

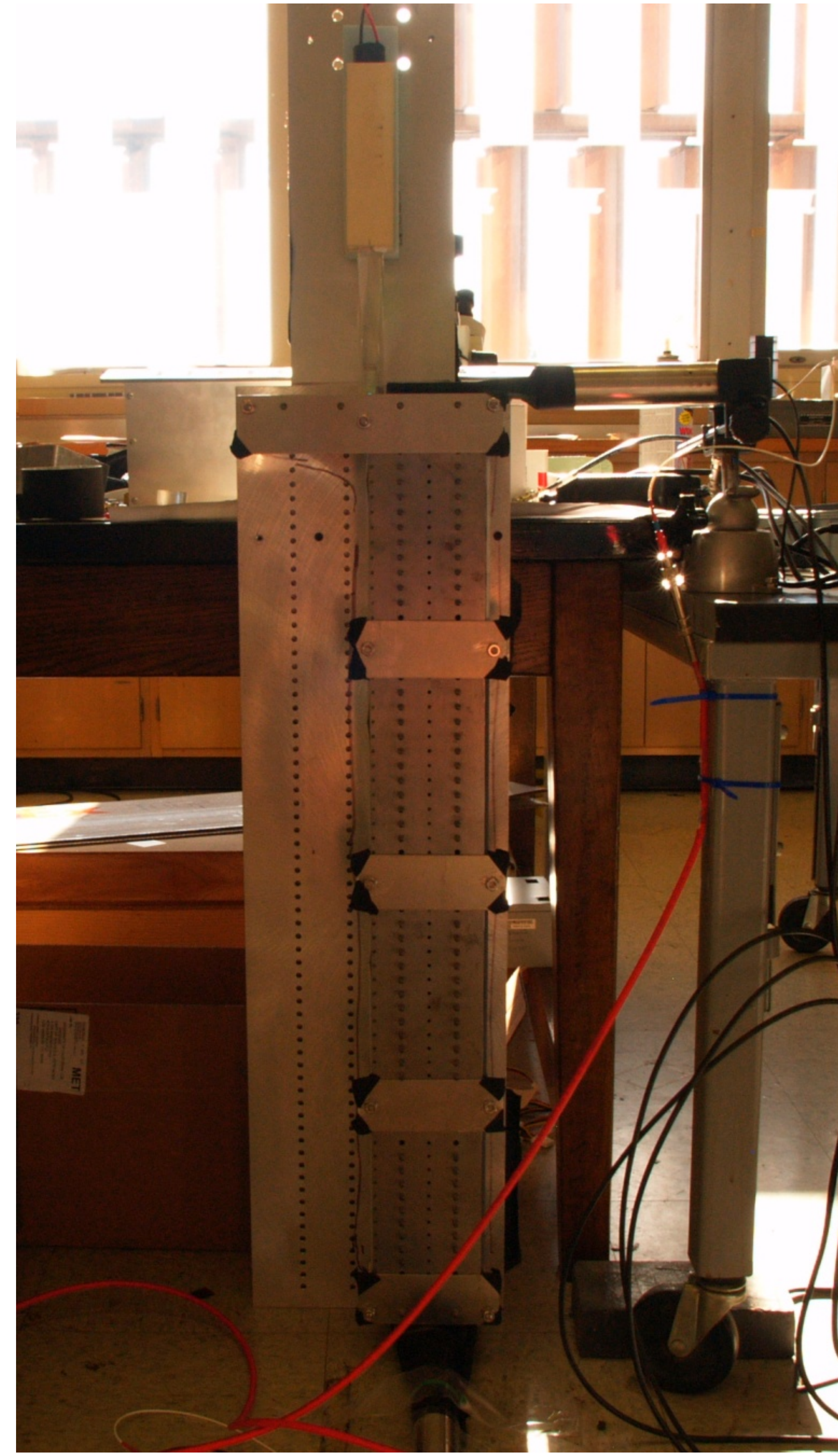
LEGO style construction(mechanics): Master Plates, Absorber Plates, Scintillation plates, WLS Plates.





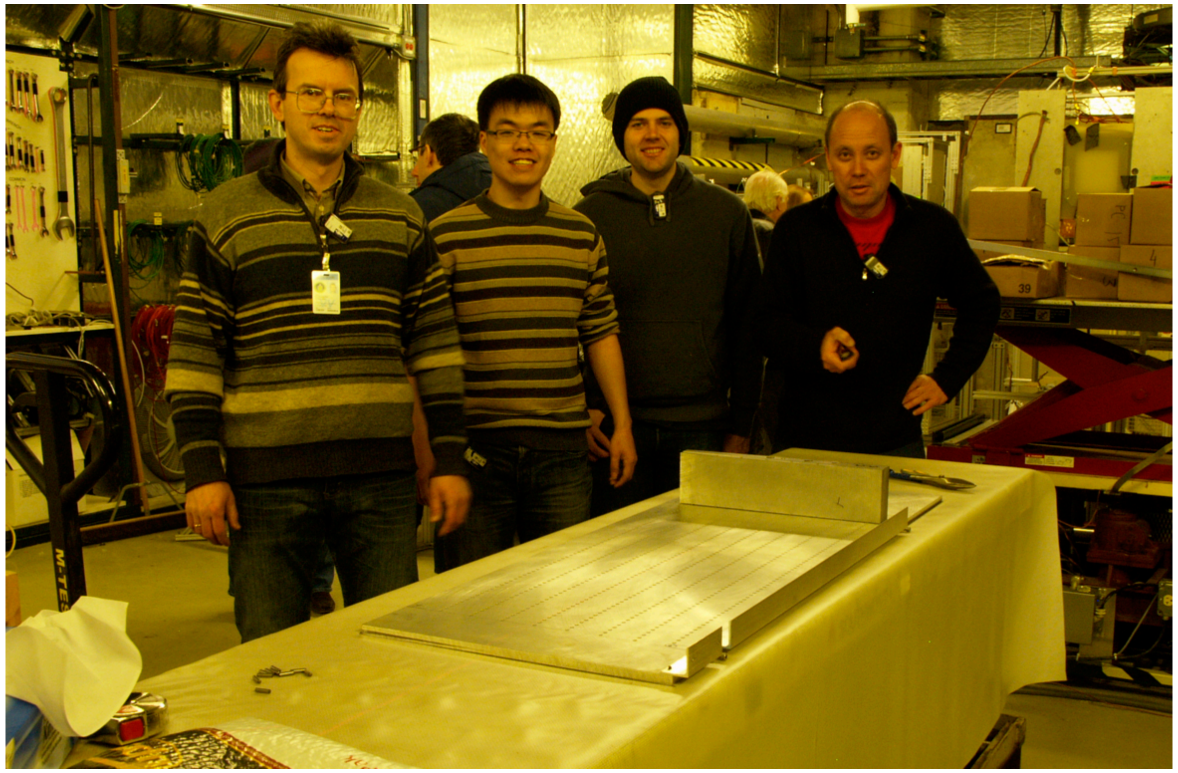
Uniformity and Compensation Measurements



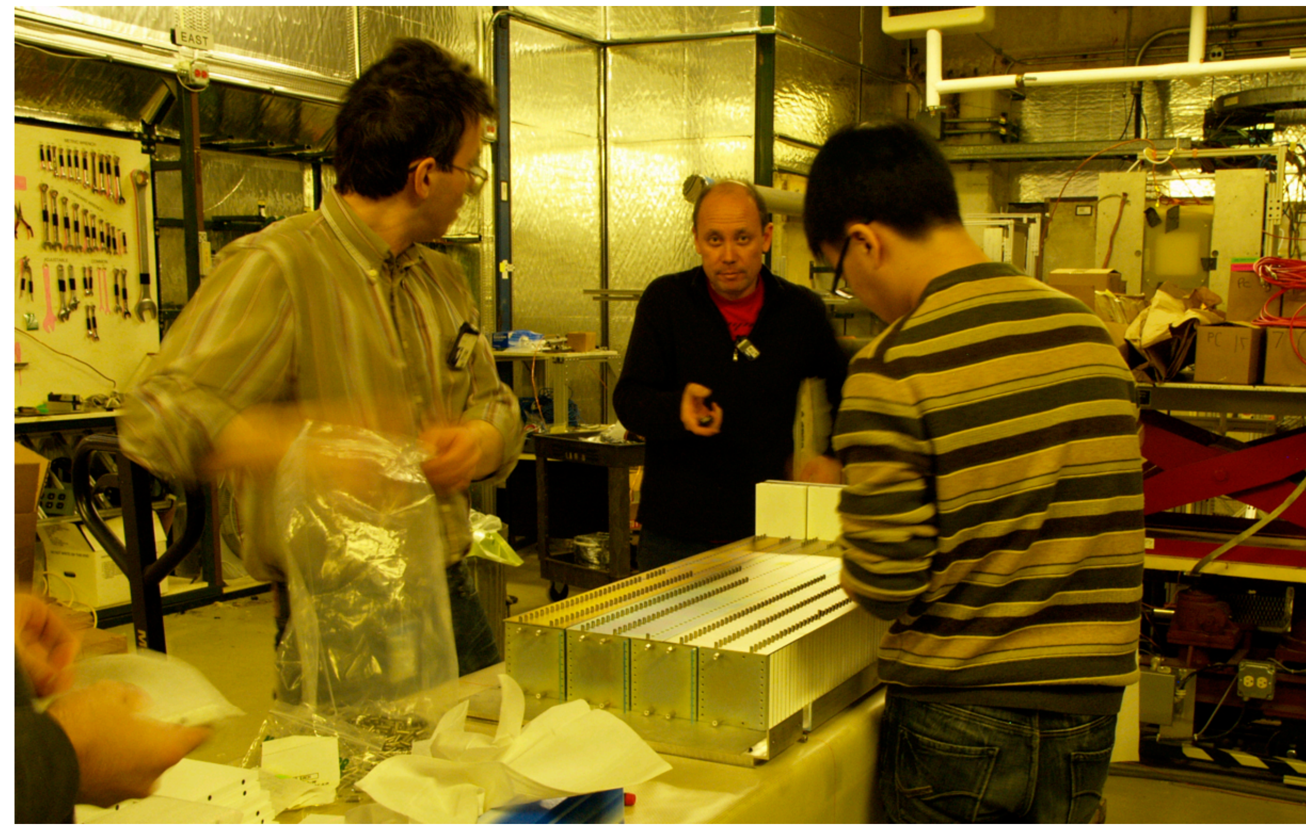


Absolute Light Yield Measurements

Assembling HCal Onsite. Feb 26, 2014. FNAL

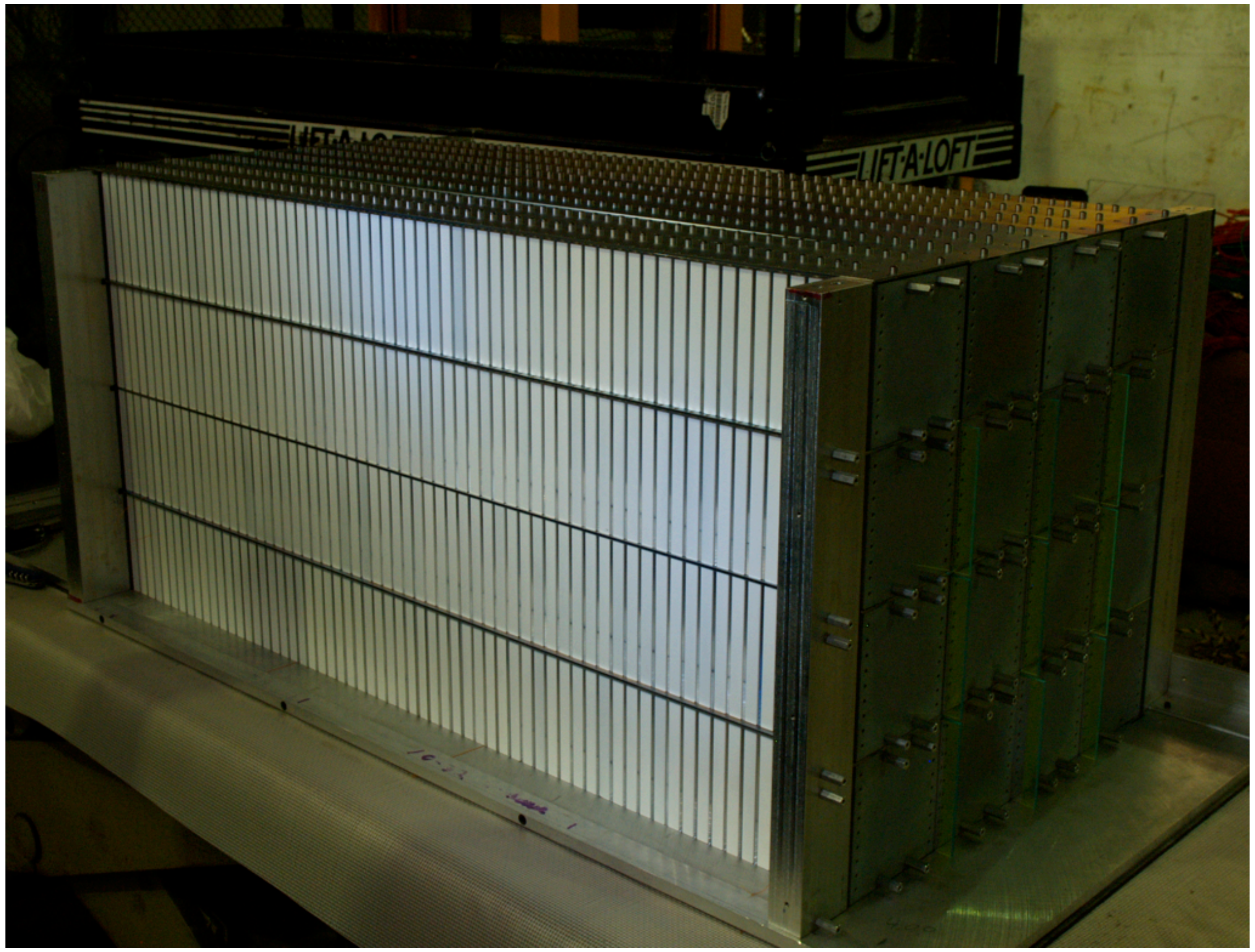


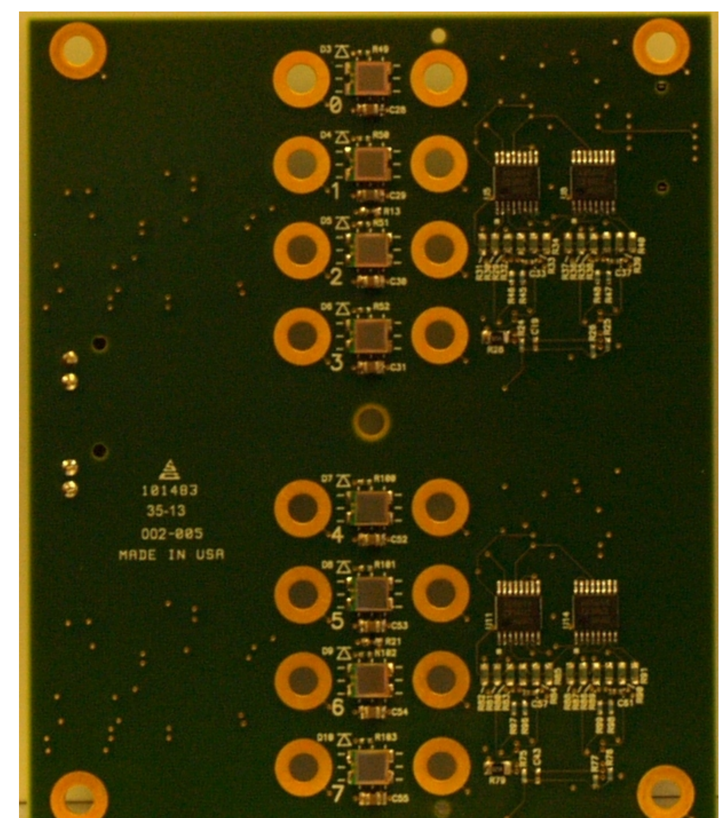
After two hours first layer done.



After 8 hours they told me "next time let undergrads do that".

Hadronic Calorimeter Prototype at FNAL

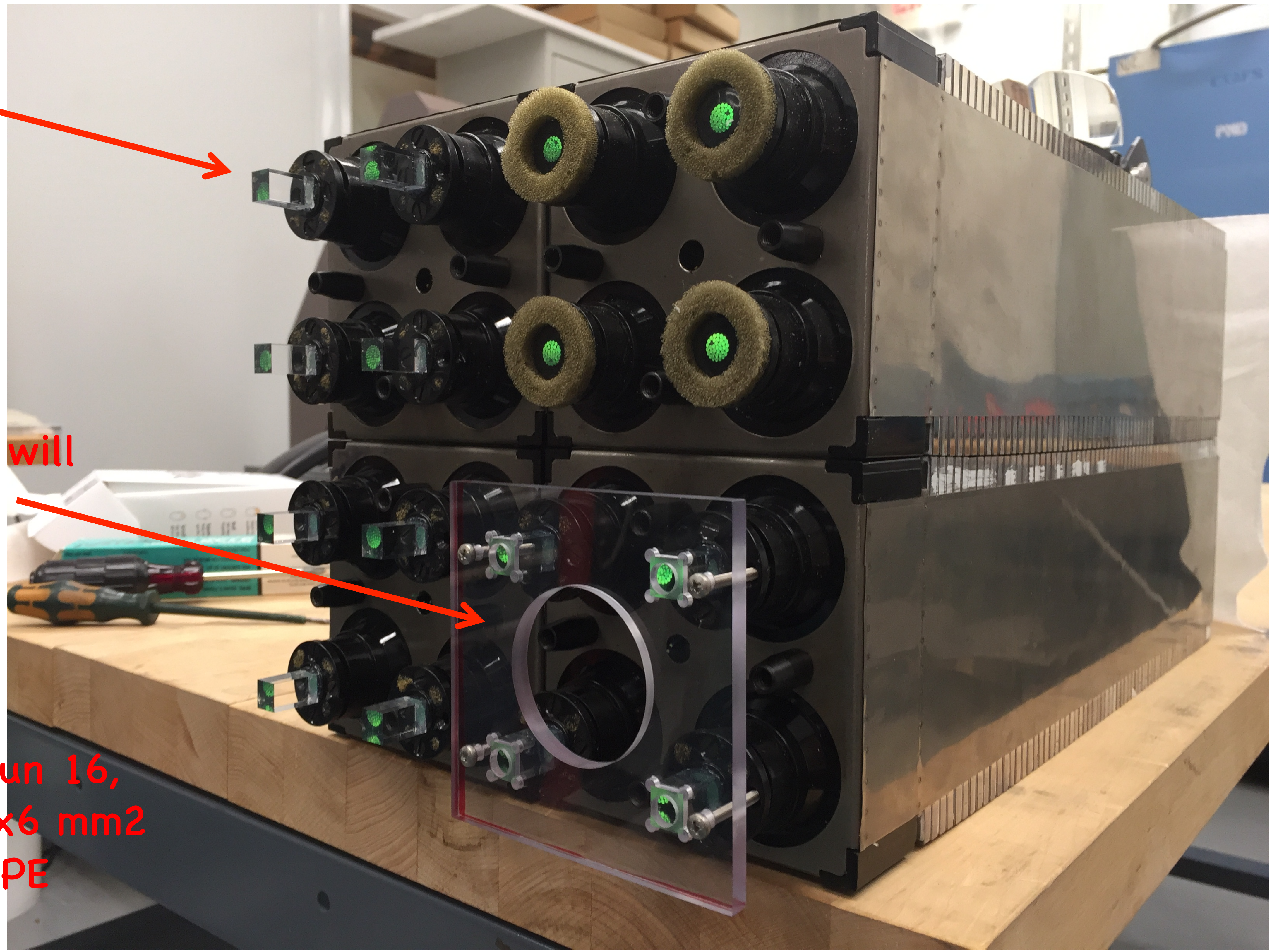




- HCal is ~4 interaction lengths Pb/scintillator.
- Readout is from Hamamatsu S10931-025p SiPMs attached to wavelength shifting plates which run the length of the detector.
- 16 individual towers.
- Total Volume 0.4 m x 0.4 m x 0.8 m

- Back to Modesty. (R^3 = Reuse, Reduce, Relax)
- PHENIX EMcal, trivial modifications.

Light Mixers



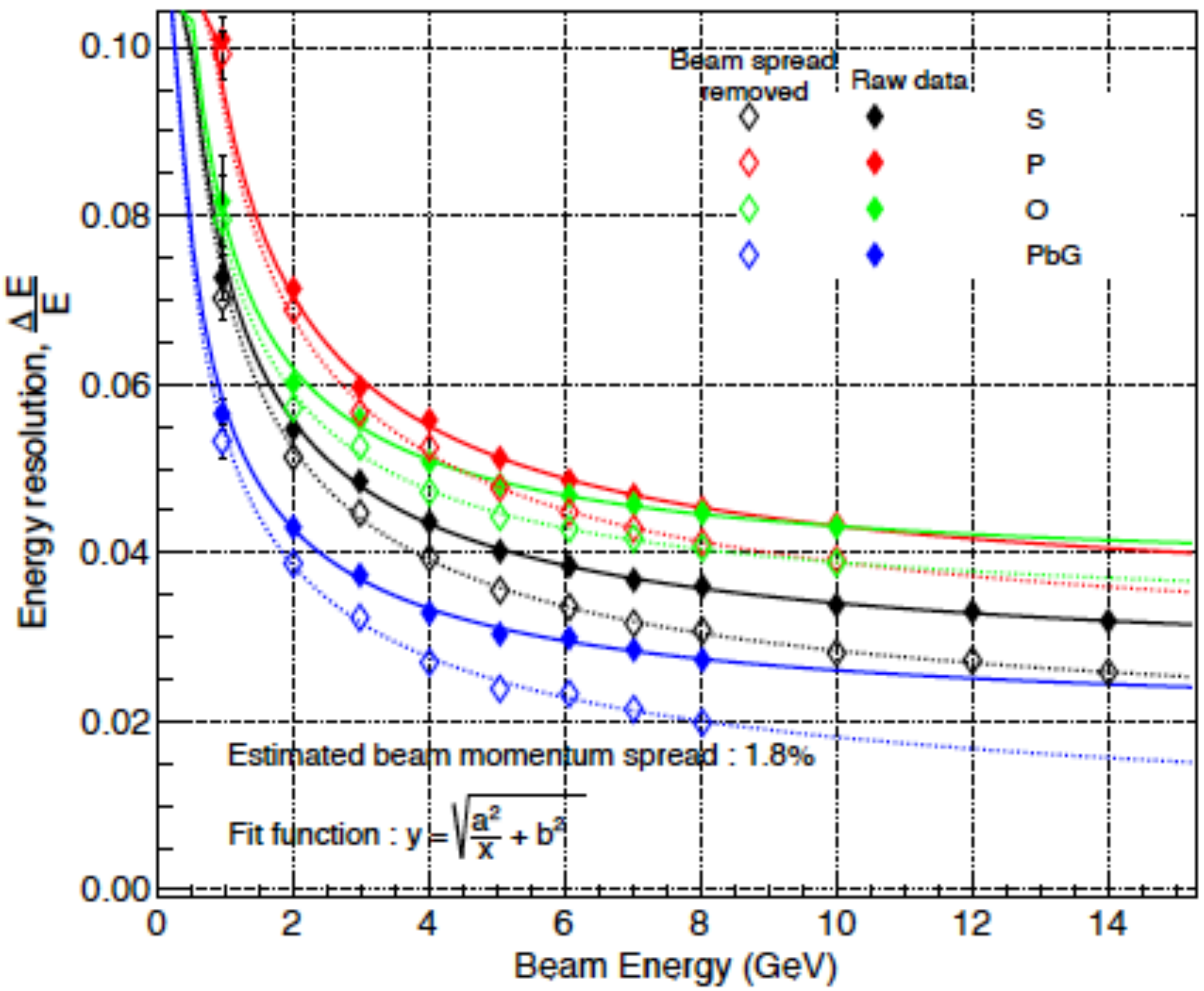
Gerard's FEEs will here

Sensors for Run 16,
Hamamatsu 6x6 mm2
S13360-6025PE

20 SiPMs at UCLA

PHENIX Shashlyk. Tested at FNAL in 2016, parasitic to EIC R&D HR

Light yield with PMT ~ 1000 p.e., quite large constant term 2.7%



Detector		χ^2 / ndf	a (in %)	b (in %)
S	solid	12.45 / 9	6.99 ± 0.06	2.59 ± 0.02
	dashed	14.75 / 9	6.99 ± 0.05	1.79 ± 0.03
P	solid	17.95 / 7	8.82 ± 0.09	3.30 ± 0.04
	dashed	19.31 / 7	8.82 ± 0.09	2.72 ± 0.05
O	solid	14.24 / 7	7.04 ± 0.10	3.70 ± 0.03
	dashed	15.75 / 7	7.04 ± 0.09	3.19 ± 0.04
PbG	solid	26.3 / 6	5.40 ± 0.07	1.97 ± 0.04
	dashed	38.93 / 6	5.39 ± 0.06	0.62 ± 0.09

Fe/Sc Hcal, example NIM 180 (1981) 429-439. (H.Abramovich et.al. A.Para)

0.6 x 0.6 x 2 m^3 (total absorption !), Fe/Sc (25/5 mm)

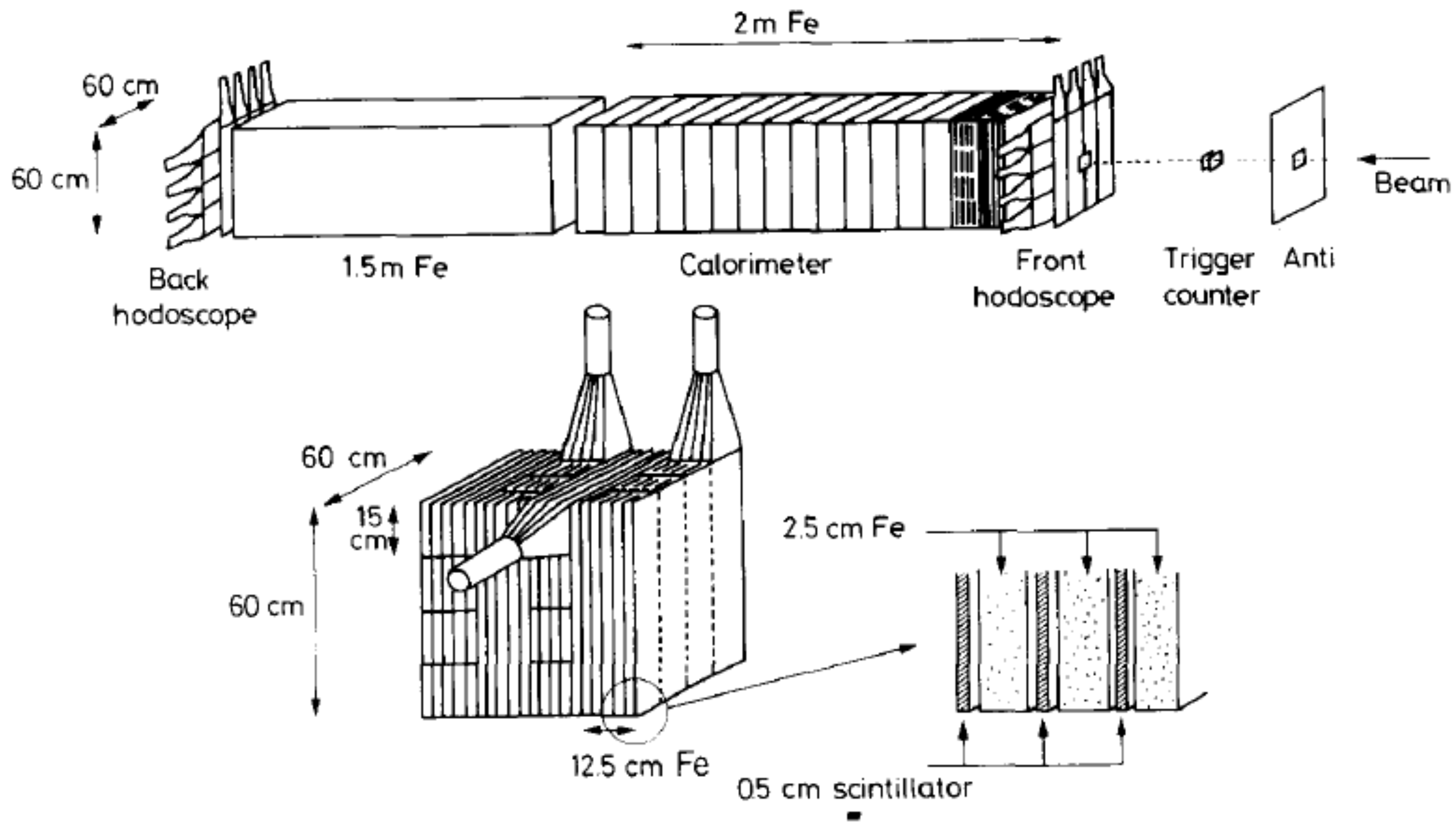
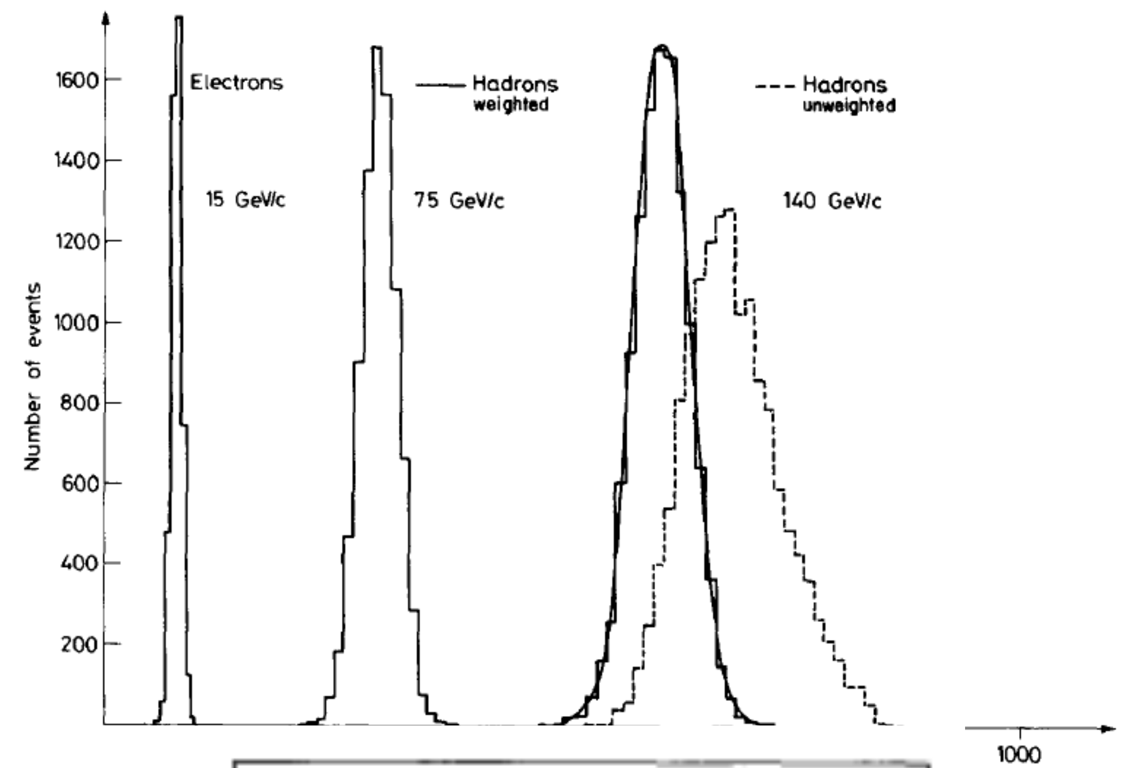
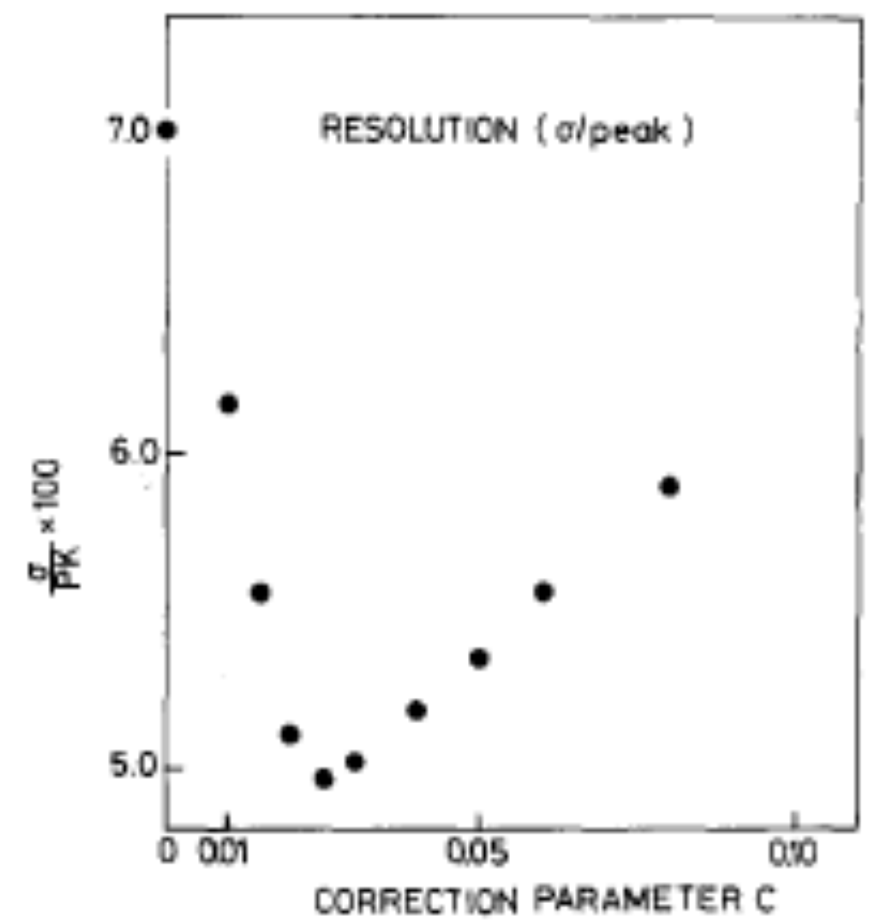


Fig. 1. The test calorimeter and the detailed structure of a module.



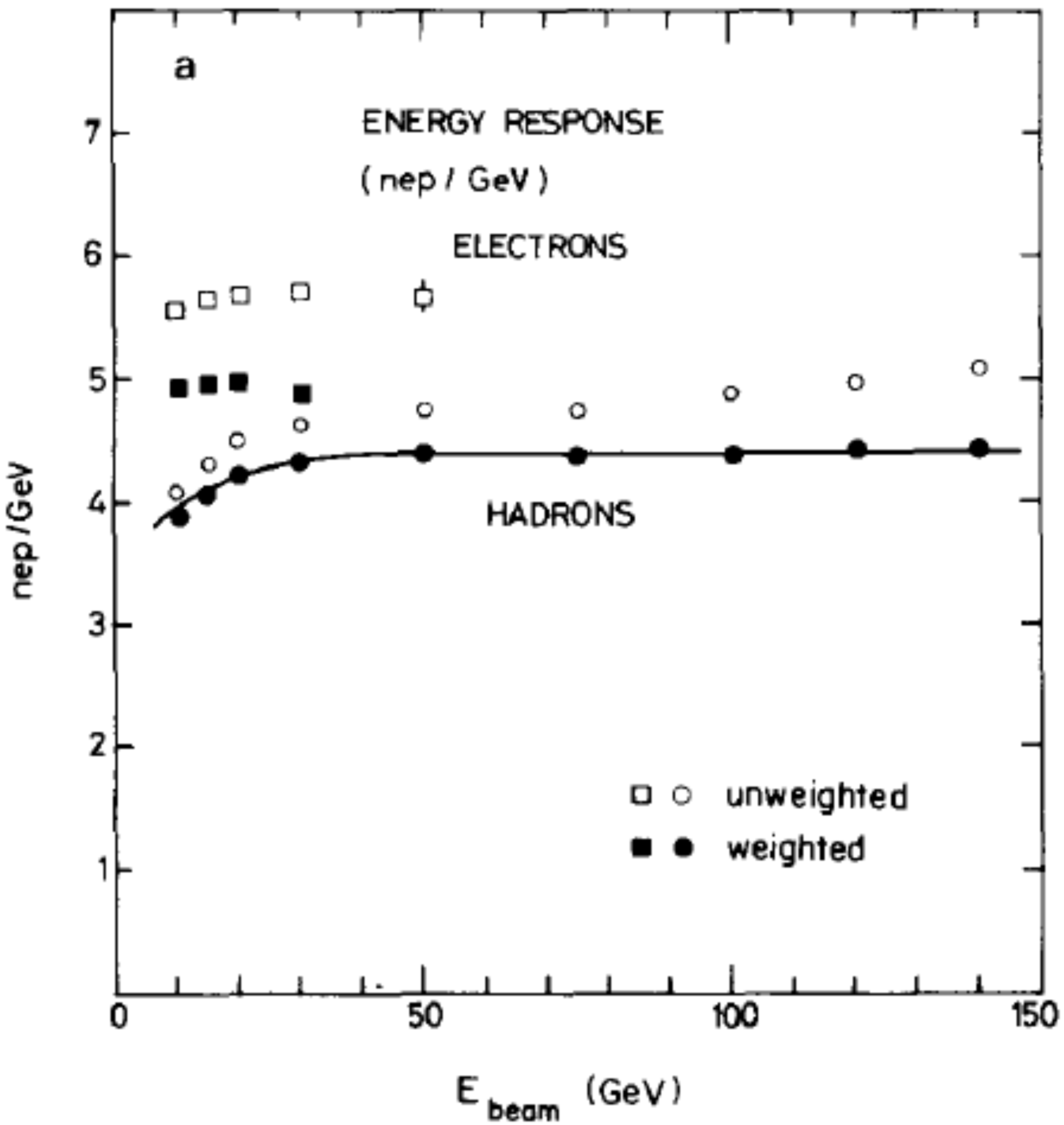


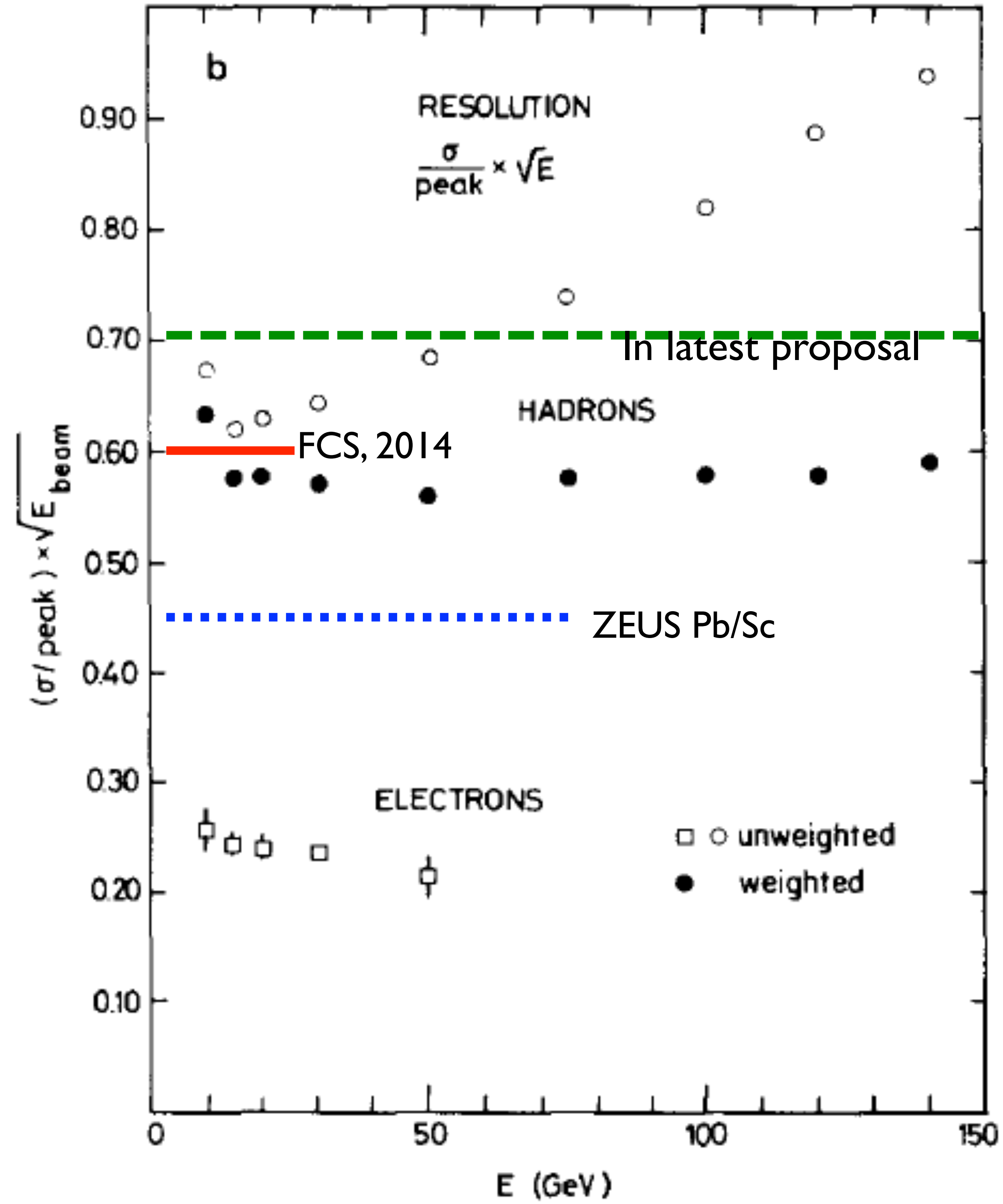
Replace compensated Pb/Sc with non-compensated cheap Fe/Sc

- Re-weight every cell to account for excessive f_e
- $E_i' = E_i(1 - C/\mathrm{sqrt}(E_{total})E_i)$
- Cell size 15 x 15 cm^2, not optimized.

Fe/Sc Hcal, example NIM 180 (1981) 429-439.

0.6 x 0.6 x 2 m^3 (total absorption), Fe/Sc (25/5 mm)





Non linear response and cell weighting to get resolution.

Sampling for Fe/Sc Hcal for FCS'.

Length limited to 90 cm, can fit 38 layers (23.5 mm each)
38 layers Fe/Sc (20/3 mm). Total int. length 4.5 + (0.56 Shahslyk)

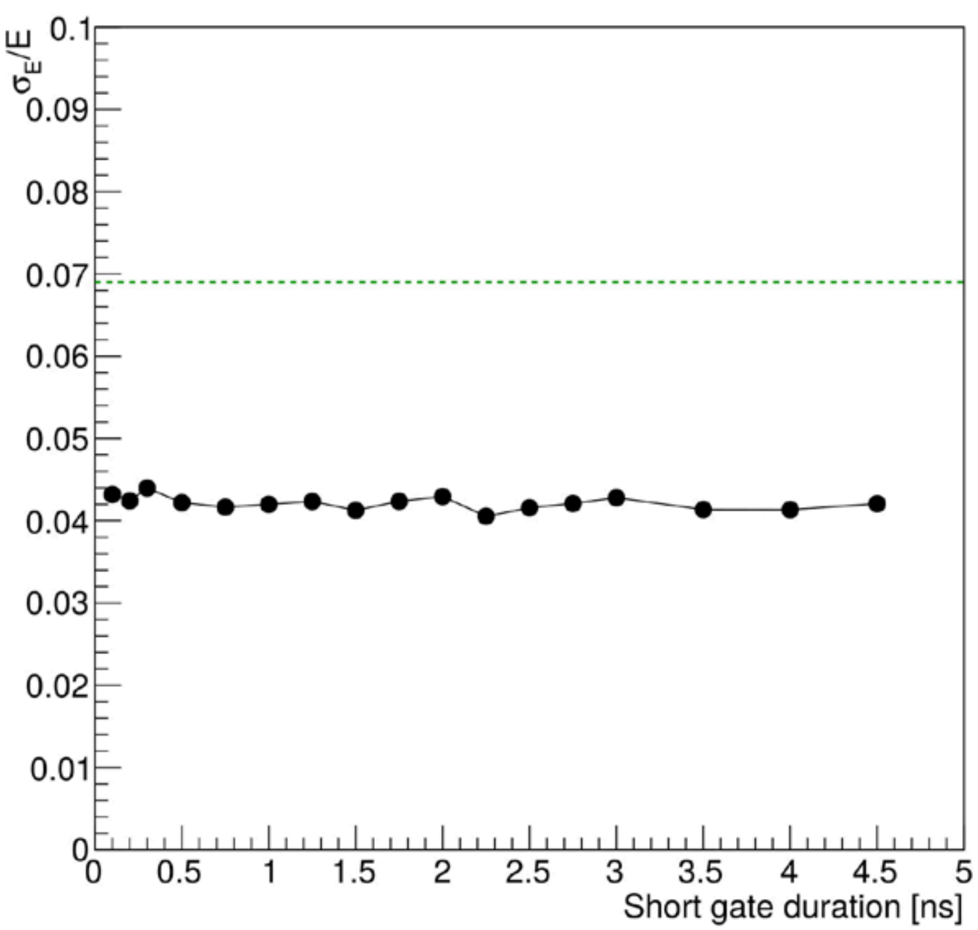
Longitudinal leak ~ 5% at 100 GeV, probably will dominate single hadron resolution. Jet resolution will suffer more because of non-linearity, non-compensation.

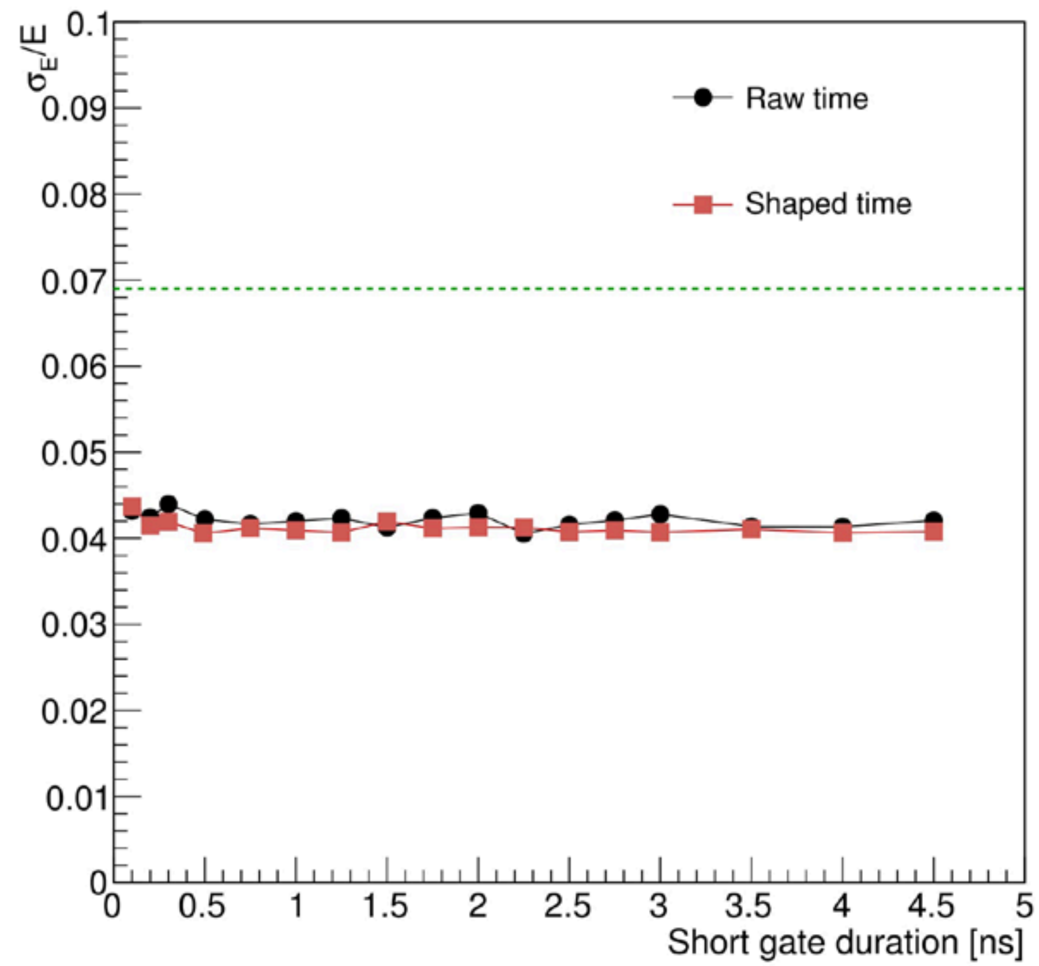
Compare to original FCS:
+ A bit longer, no need for thick front plate in front which worked as anchor for the whole structure (dead layer between EM and HAD sections).
+ Smaller number of layers (cost for machining)
+ Fe is more cost effective
+ Cheaper painting
+- light yield? (114 mm vs 157, but thicker Sc plates can compensate some Need clear MIP for calibrations, same as it was for FCS)

Need MC. Not a small task. Even simplest single hadron reconstruction will require weighting EM + re-weighting HAD cells for linearity and good resolution, this is price for non-compensation. Calibration is another complication.

Fe/Sc Hcal Joint R&D for FCS' and EIC.

May be interesting R&D to use full DEP functionality. Use timing (short/long gate) to correct for fluctuations in f_{em}.





20 mm Fe + 5 mm LuAG (decay time 40 ns)
Talk by A. Para at CPAD, Oct 10. 2016
'Space-time evolution of hadron showers and its use in hadron calorimetry'

See Talk by Alexander.

Moving Forward.

PHENIX Emcal at STAR IP Run 17:
- FEE + DEP (Talk by Gerard V.)
- Sc. Rad damages

FCS' Milestones

Major milestones to realize FCS for Run 21 are listed below:

- 01/2021 Start Commissioning of FCS.
- 08/2020 Start Assembly of FCS at WAH.
- 08/2019 Start Procurements (absorber and scintillation plates, electronics components, etc.).
- 06/2019 Production Readiness Review.
- 01/2019 Final Design Report and Review.
- 09/2018 Technical Design Report.

FCS' Milestones

- Test of small scale, sixteen channels of EM prototype equipped with first iteration of FEE and DEP at STAR during RHIC Run17 (06/2017).
- Investigate potential degradation of Shashlyk EM modules near the Beam Pipe, exposure of passive EM stack at STAR during Run17 (06/2017).
- Finalize choice of readout sensors for HCAL by 03/2017.
- Optimize Light collection for HCAL by 08/2017.
- Produce final design of FEEs for EM section by 06/2017.
- Produce next iteration of DEP by 12/2017.
- Produce 64 channel readout electronics for EM by 12/2017.
- Assemble 64 channels EM prototype for Run 18 by 01/2018.
- Test of 64 channels EM prototype during Run 18 including HT functionality integrated with STAR DAQ and Trigger. (Need manpower)
- Design and produce prototype of HCAL FEE by 02/2018.
- Start production of final FCS prototype (64 ch. EMcal + 16 Ch. HCAL) by 03/2018
- Test one HCAL tower in final configuration with the first version of FEEs and DEP at STAR during Run 18 (06/2018).
- Final design and production of sixteen HCAL FEEs by 06/2018.
- Beam test and calibration of full scale FCS prototype at FNAL by 12/2018.
- Operate full scale FCS prototype at STAR during Run 19 fully integrated with STAR DAQ and Trigger. (Single spin run, need well understood detector at Day 1)

For Discussion

1. From the start (2012) very efficient joint R&D (STAR Forward and EIC)

2. New interesting ideas how to potentially dramatically improve energy resolution in Hcals.

3. Tough budget situation for EIC R&D. 2017 is the end of eRD1, small continuing efforts with Hcal at STAR IP during 2018.

4. Need for high resolution Hcal for EIC forward spectators.

5. Can we form new calor collaboration to address (2) primarily for EIC, but also for fSTAR and fsPHENIX. One of the outcome of this workshop?

6. If (5) in place - move forward and prepare new proposal for next EIC R&D meeting (July 2017) ?

Will require lot of MC. We already indicated at last EIC meeting that such proposal may materialized (need to be justified, physics benefits of improving hcal resolution in BCAL).