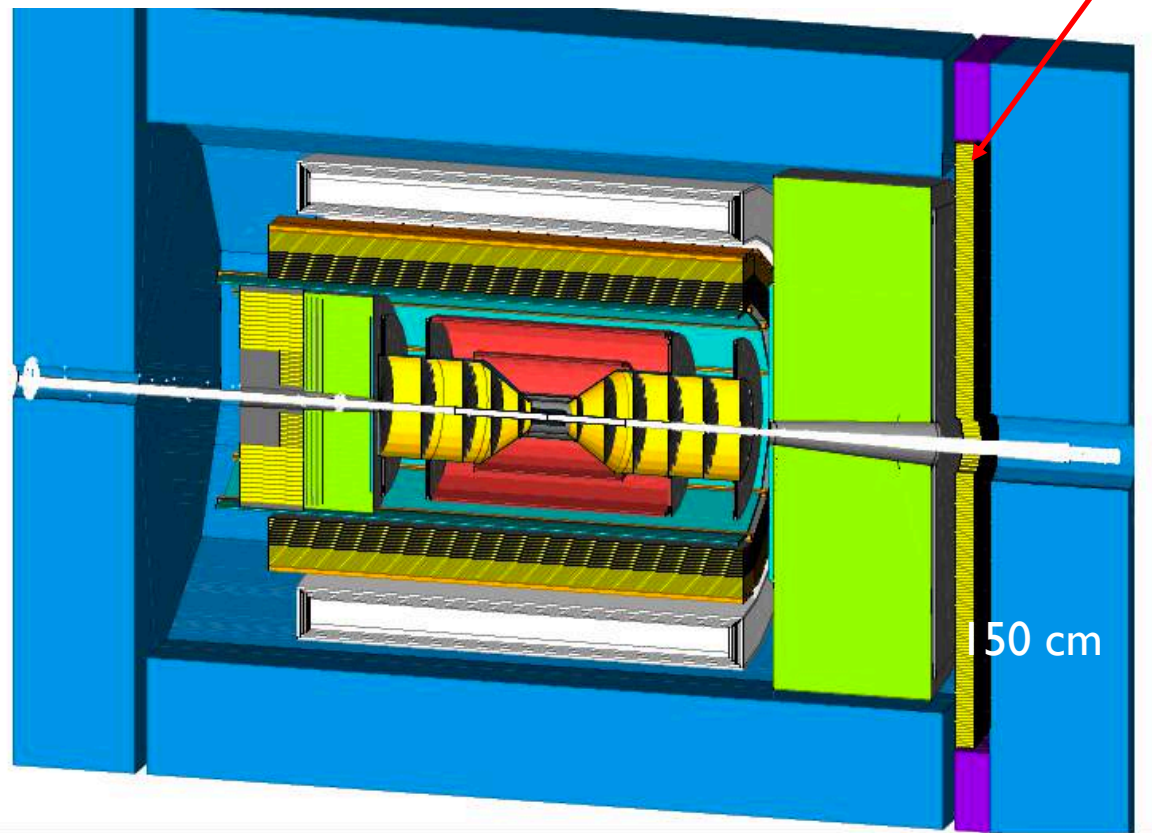


# pECal in ATHENA. Details

O.Tsai (UCLA) Fudan, Shandon University, Tsinghua, South China Normal University,  
UCLA, IUCF, BNL eRD106 (WScFI)



## Integration Envelope:

Length along Z - 30 cm (back side of ecal is at 380 cm from IP), R out -230 cm

## Integration envelope sub-division:

- WScFi length - 17 cm ( 23 X0)
- Light Guides - 2.5 cm
- Readout (FEE+LED+Cooling) - 10 cm

## Nomenclature:

- Tower -  $2.5 \times 2.5 \text{ cm}^2$
- Production Block -  $2 \times 2$  towers
- Installation Unit - superblock  $4 \times 4$  towers

## Photosensors:

4 HPK S13360-6050PE per tower

Costed for 26600 towers (6650 production blocks)

ATHENA Integrations:

IP shifted by 50 cm (Accelerator-Detector)

pRICH requires more space (Detector subsystems)



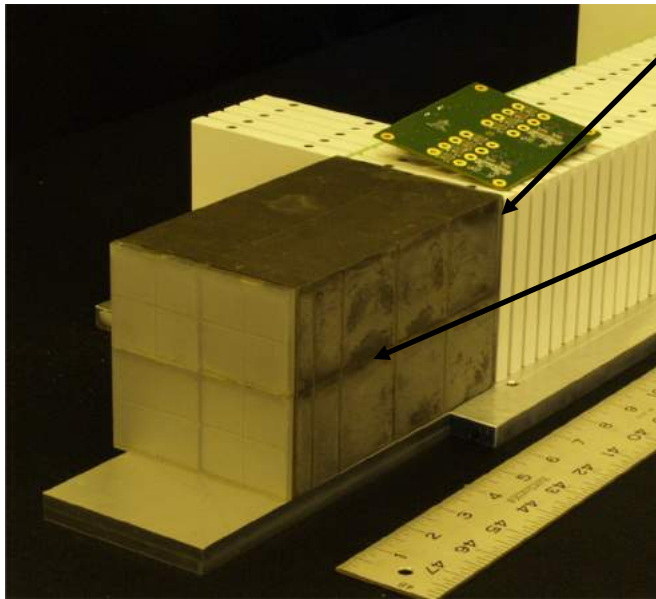
## Cost drivers (ATHENA dimensions)

- Scintillating fibers – \$1.87M (Quoted, KURARAY)
- W powder - \$1.38M (sPHENIX, price in China)
- SiPMs - \$2.44M (Quoted)
- Electronics - \$1.33M (Direct scaling from STAR FCS)
- Labor - \$4.1M (\$1.98M to project) (mostly historical)

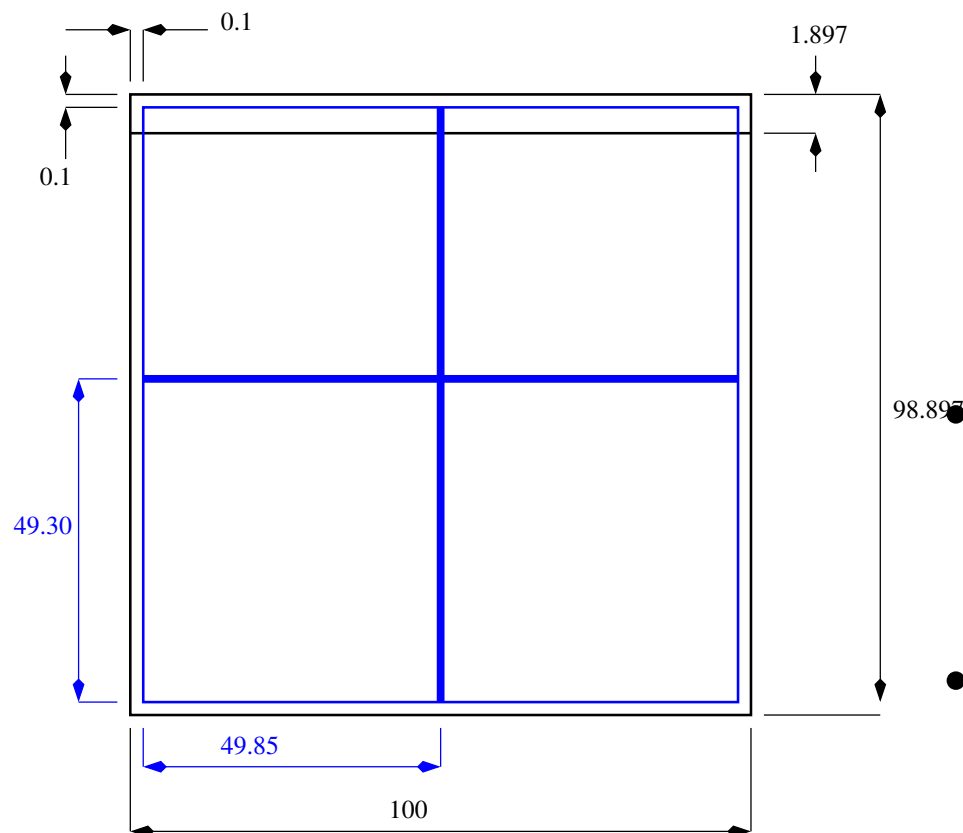
Total: ~\$12.7M (using project templates)



## Integration with HCal



- First absorber plate of Hcal is a 'strong back' for ECal
- Installation block glued to that plate prior assembly of Hcal.
- Installation of ECal goes along with assembly of Hcal, i.e. layer by layer as it was done for STAR FCS. First absorber blocks of Hcal bolted to each other.
- Installation gaps 0.2 mm seemingly easy to achieve (production tolerances of ECal and tolerances for Hcal assembly, which were verified with STAR FCS ( 2m high, 30 t, better than 0.1 mm tolerances achieved)
- ECal is self supporting, in current version there is no pressure from one ecal installation block to another.
- Mechanical properties of compound is close to construction steel.



— Glue Joint between EMcal blocks is 0.1 mm thick

EMcal block external dimensions are 49.85 x 49.30

HCal tower external dimensions are 100 x 98.897

Clearance gap between edges of EMcal and Hcal towers is 0.1mm

**N.B. Gaps, Dead areas in modular calorimeters and resolution.**



# WScFi technology key points:

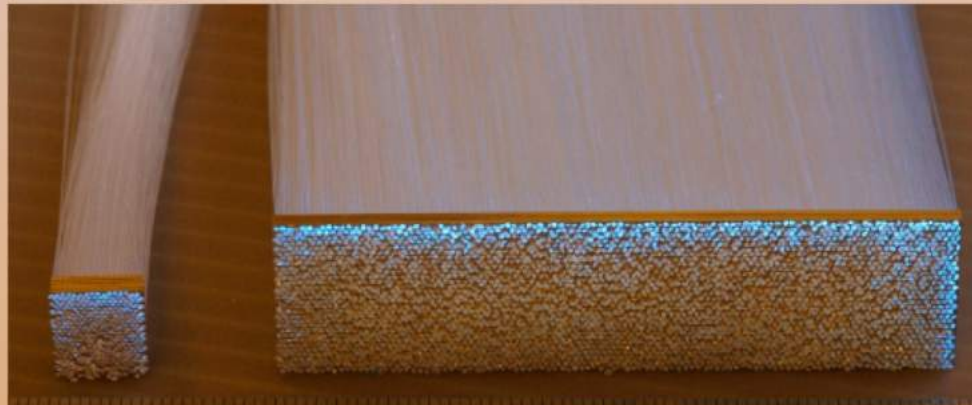
- WScFi is a unique technology allowing to achieve  $e/h \sim 1$  and at the same time keep em energy resolution at  $\sim 10\%/\sqrt{E} + 2\%$ , no other known technology for EMcals can achieve this.
- WScFi technology is unique allowing to build detectors with different configurations (SPACAL, 1D SPACAL, 2D SPACAL, Optical Accordeon) eRDI, sPHENIX
- WScFi technology allows to build very high density (compact) calorimeters.
- WScFi method is very simple requires only few components to build detector free from dead areas.
- Very simple mechanical integration (with Hcal and readout).
- Performance, cost and risk are well understood due to almost 10 years long R&D and sPHENIX construction
- Technology is simple and can be easily transferred (US, China), has minimal requirements on infrastructure at production site.
- R&D plan was submitted (pending now) eRDI06 to address uniformity of light collection with compact readout.

Fudan, Shandong University, Tsinghua, South China Normal University, UCLA, IUCF, BNL  
eRDI06 (WScFi)

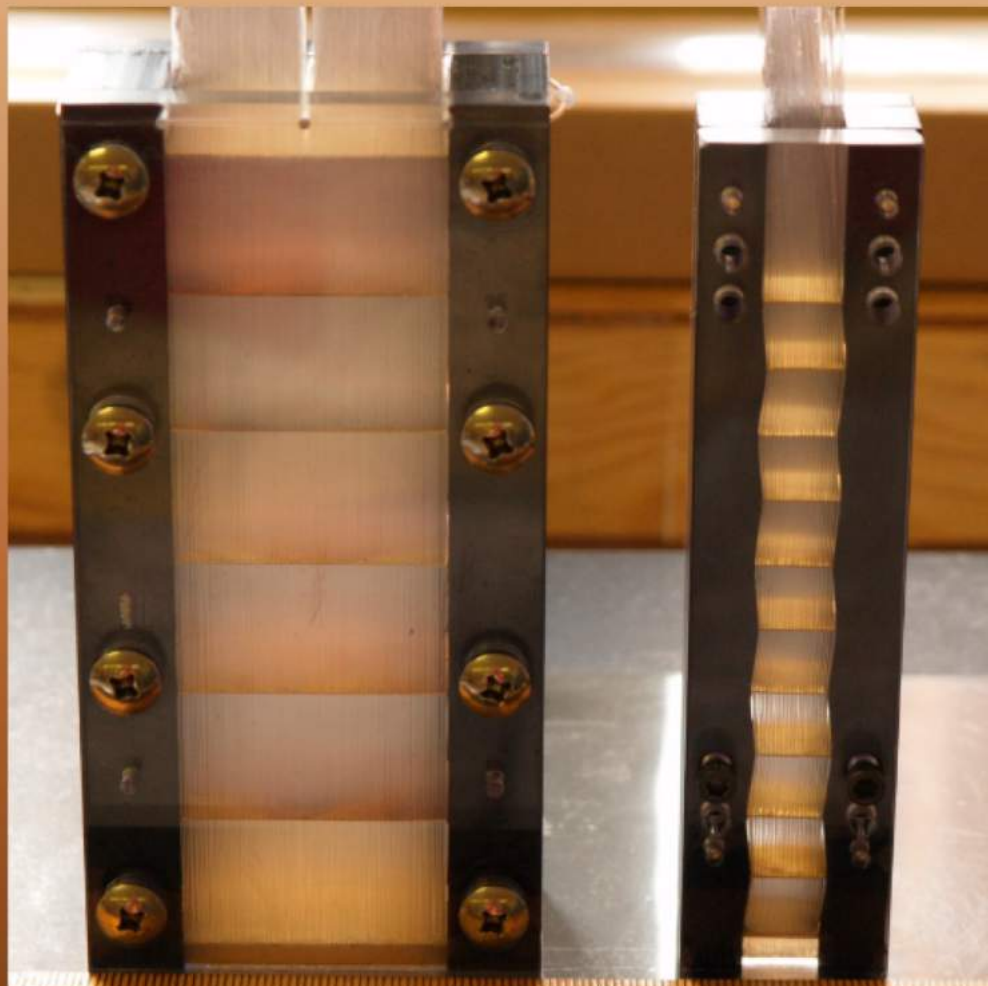


## ***Construction steps:***

- 1. Put fibers in set of screens.*
- 2. Spread meshes and put assemblies in container.*
- 3. Epoxy both ends (photodetector and mirror end)*
- 4. Fill container with W powder.*
- 5. Replace air in detector with epoxy.*



sPHENIX dropped this



- First prototypes 2011, spacordion and spacal types
- [https://wiki.bnl.gov/conferences/images/d/d4/RD-I\\_RDproposal\\_April-2011.pdf](https://wiki.bnl.gov/conferences/images/d/d4/RD-I_RDproposal_April-2011.pdf)



# Technology 2. Important measurements, LY, homogeneity transvers and longitudinal to separate effects due to readout and properties of VVScFi compound

## Parameters:

Final Density -  $10.17 \text{ g/cm}^3$ ,  
 $X_0 \sim 7 \text{ mm}$ ,  $R_m \sim 2.3 \text{ cm}$ ,  
 $S_f$  -2% (electrons),  
Sc. Fibers -SCSF78  
 $\varnothing 0.47 \text{ mm}$   
Spacing 1 mm center-to-center.

Supermodule 2x2 towers.

## Details:

Dimensions  $16.6 \times 5.33 \times 5.33 \text{ cm}^3$   
Weight of supermodules (4567, 4651,  
4627,4630 g.)  
Number of fibers -3120

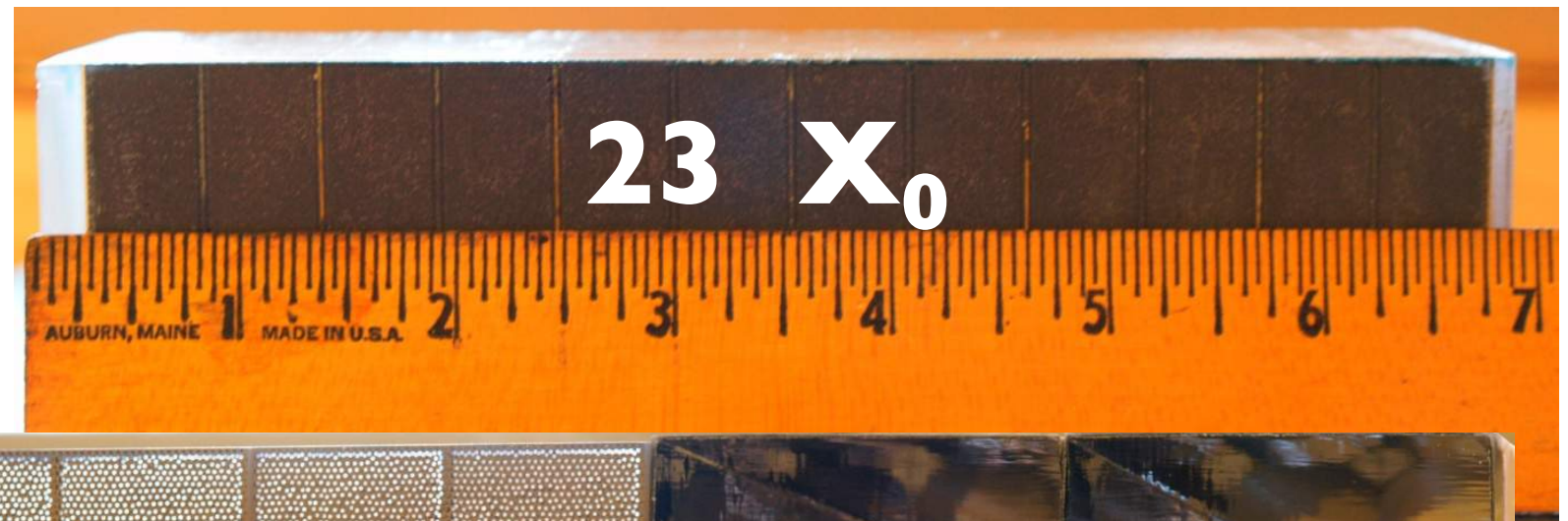
Resolution  $\sim 12\%/ \sqrt{E}$

Light yield 2000 p.e./GeV



**SiPM Readout  
Possible.**

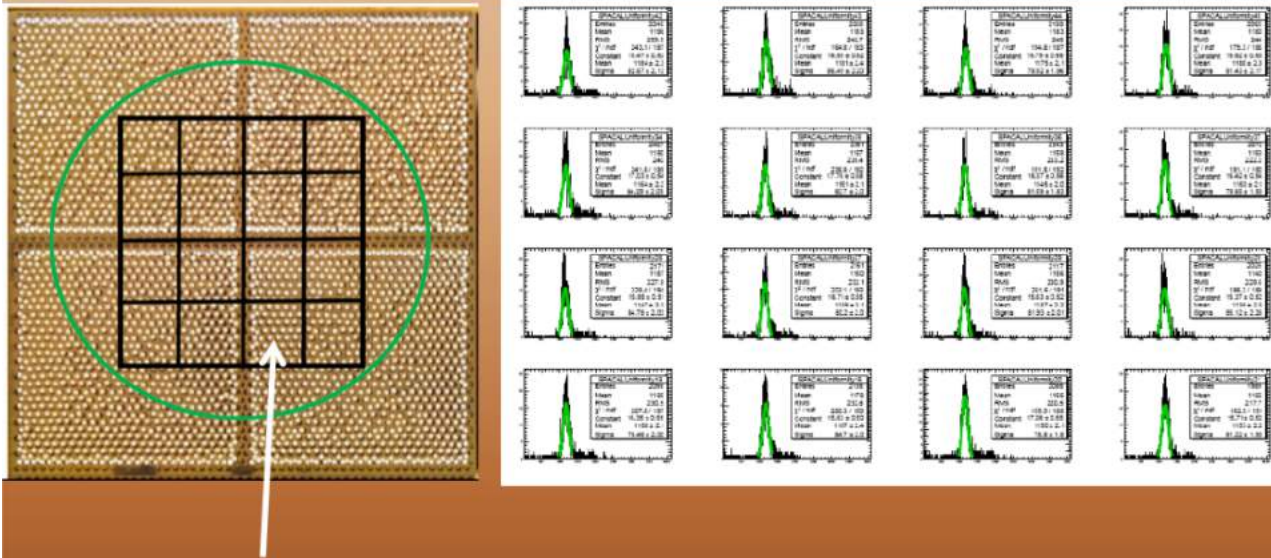
RD1 Collaboration, EIC R&D  
Proof of principle, Jan 2012  
Test Run at FNAL T1018





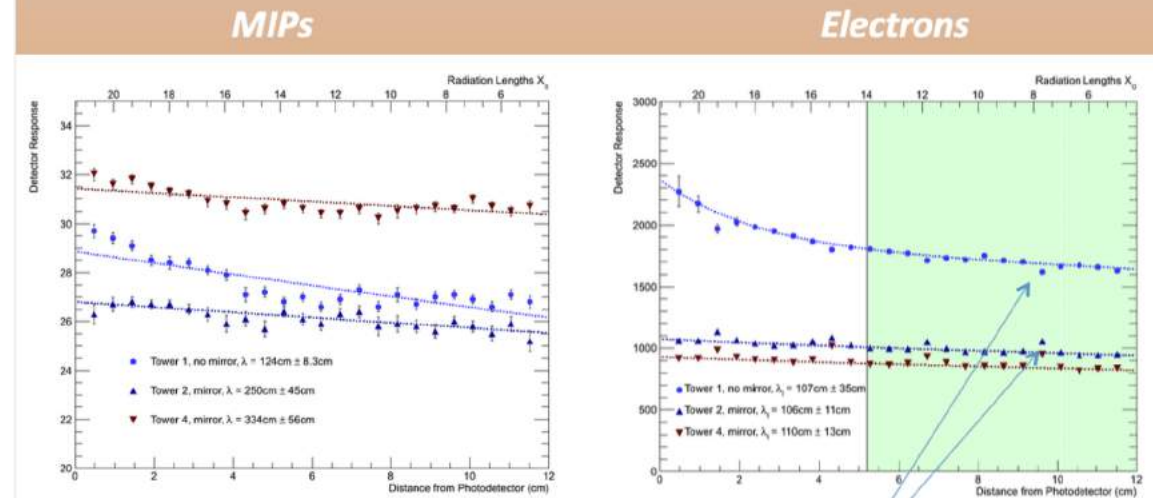
# Technology 2. Important measurements, LY, homogeneity transvers and longitudinal

## Uniformity of response across the tower. Test Run. 4 GeV electrons.



Each square is 4.8 mm x 4.8 mm, selected by Sc. hodoscope.  
Uniformity of SPACAL response is 1.4%

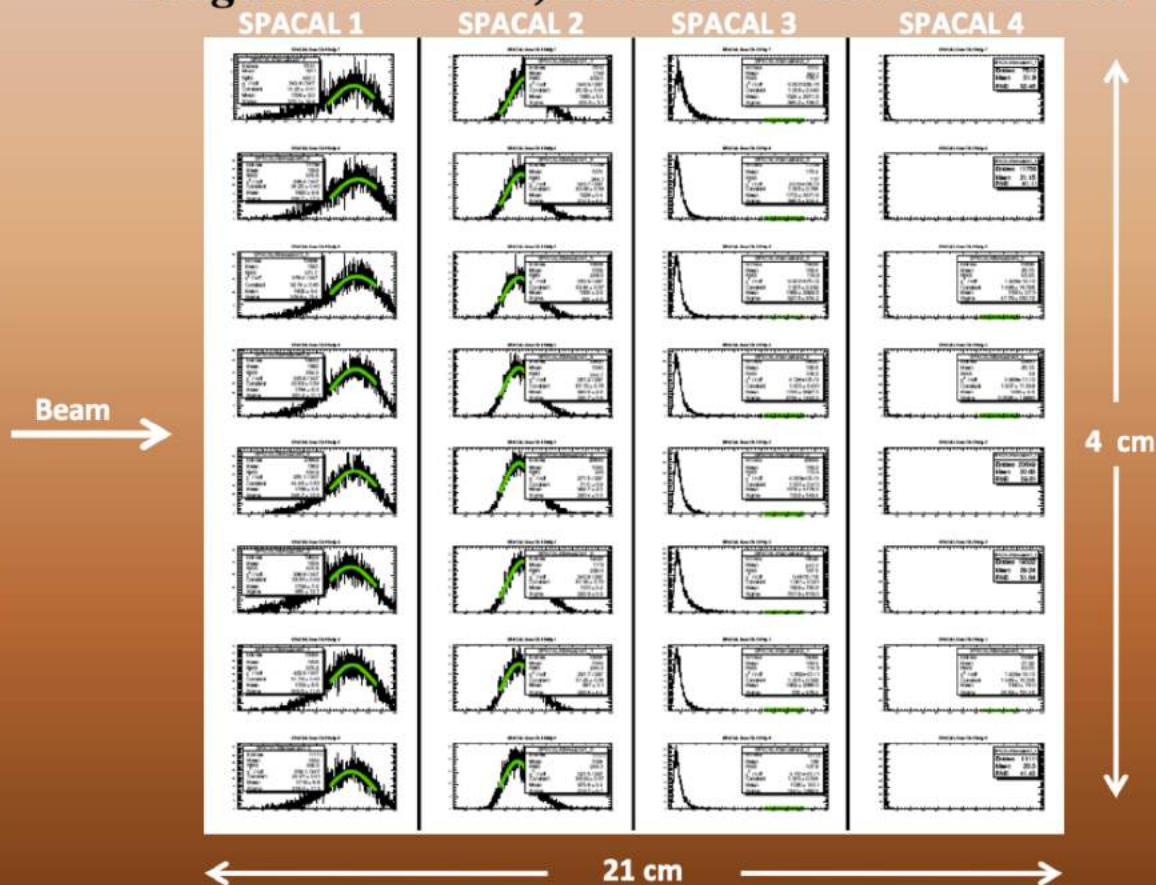
## Attenuation lengths and uniformity along the towers.



300 mkm brass meshes.

1. Typical attenuation length for 0.5 mm fibers (no damage due to packing).
2. Non-uniformities inside the towers is ~ 5% in the most important region from 5-14  $X_0$ .
3. Attenuation length measured with electrons is ~ 3 times shorter compare to one measured with MIPs. <- That was not planned!
4. SPACORDION attenuation length is ~50% of SPACAL, as well as light yield. Do Not use very thin fibers (0.33 mm in SPACORDION vs 0.47 in SPACAL).

## Longitudinal Scans, Electrons 8 GeV and MIPs.

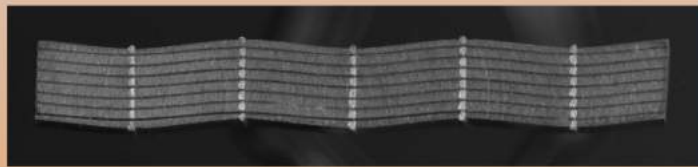


Excellent homogeneity of WScFi compound confirmed in test run.

Prior to that density was measured by cutting blocks.

Some concerns of working with thin scintillation fibers.





Wiggle or not is a question. However for some applications where channeling is an issue this will help.

### Instrumental effects: channelling in fiber calorimeters

- Sampling fraction for em showers: 2%
- Electrons entering the calorimeter at  $0^\circ$  exactly at the position of a fiber loose very little energy in the early stages of the shower development and can cause longitudinal leakage
- Shower particles escaping from the back traverse a region where there is no more Pb, the fibers are bundled and the sampling fraction is almost 100%

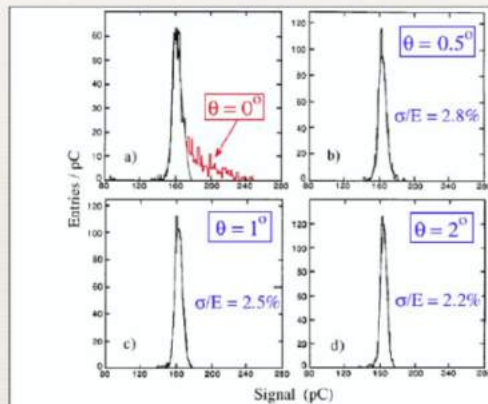


FIG. 4.22. Signal distributions for 40 GeV electron showers measured with the RD1 0.5 mm fiber calorimeter, for different angles between the particle  $z$  direction and the fiber [Rad 94a].

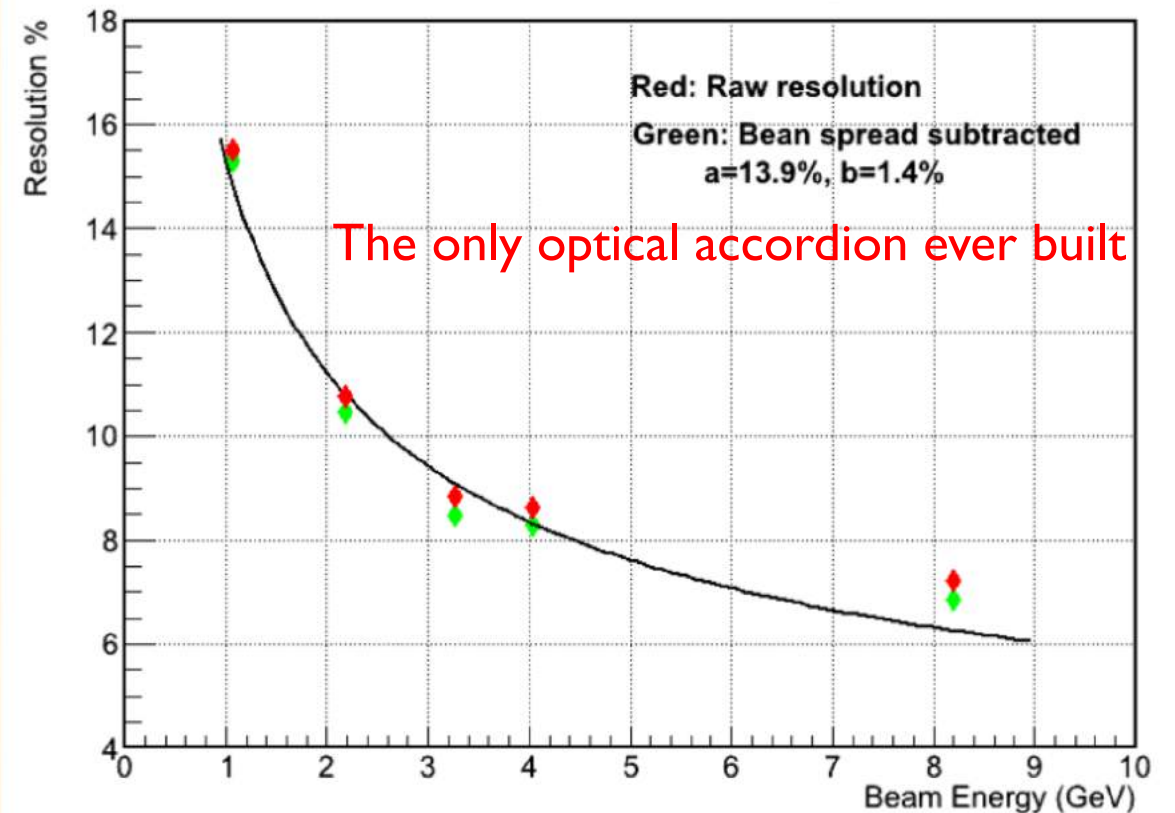
From M.Livan "The art of Calorimetry, Lecture IV"

Plus:  
Increased sampling frequency for given number of fibers.

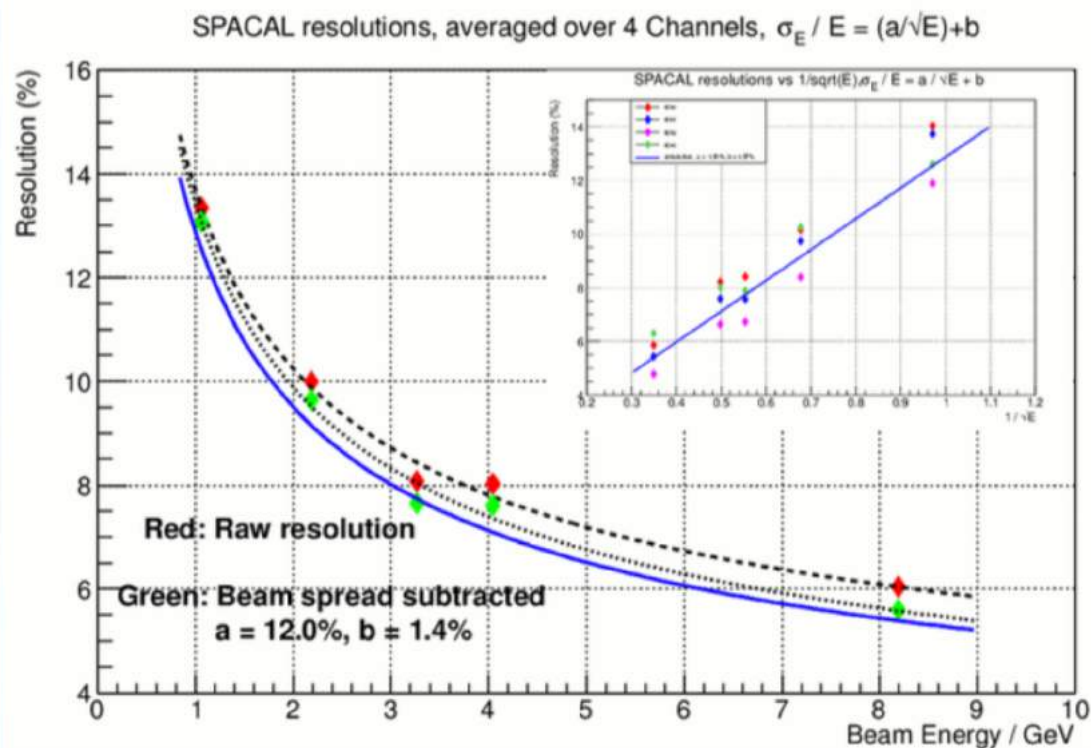
More fibers will contribute to a signal, thus fiber-to-fiber variations will be diminished.

Minus: It is reasonably easy to wiggle 370 fibers of 0.33 mm diameter, more than that will be a problem.

Spacordion resolution, 3x3 channel sum,  $\sigma_E/E = (a/\sqrt{E})+b$



- [https://wiki.bnl.gov/conferences/images/d/d4/RD-I\\_RDproposal\\_April-2011.pdf](https://wiki.bnl.gov/conferences/images/d/d4/RD-I_RDproposal_April-2011.pdf)



Good agreement with MC  
(spacordion geometry was not implemented)



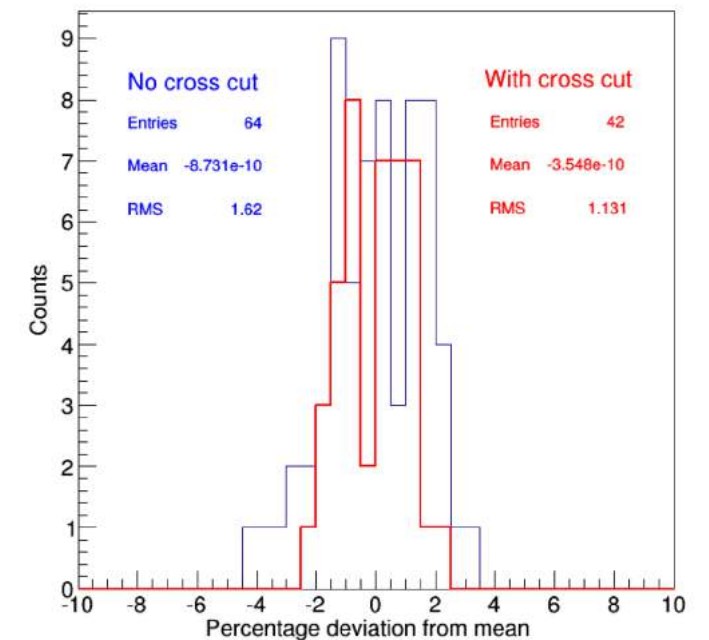
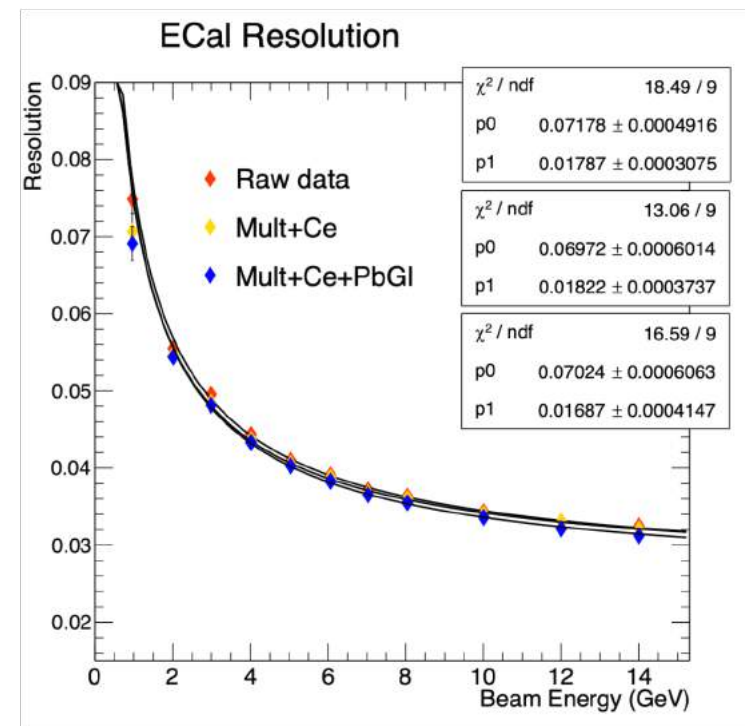
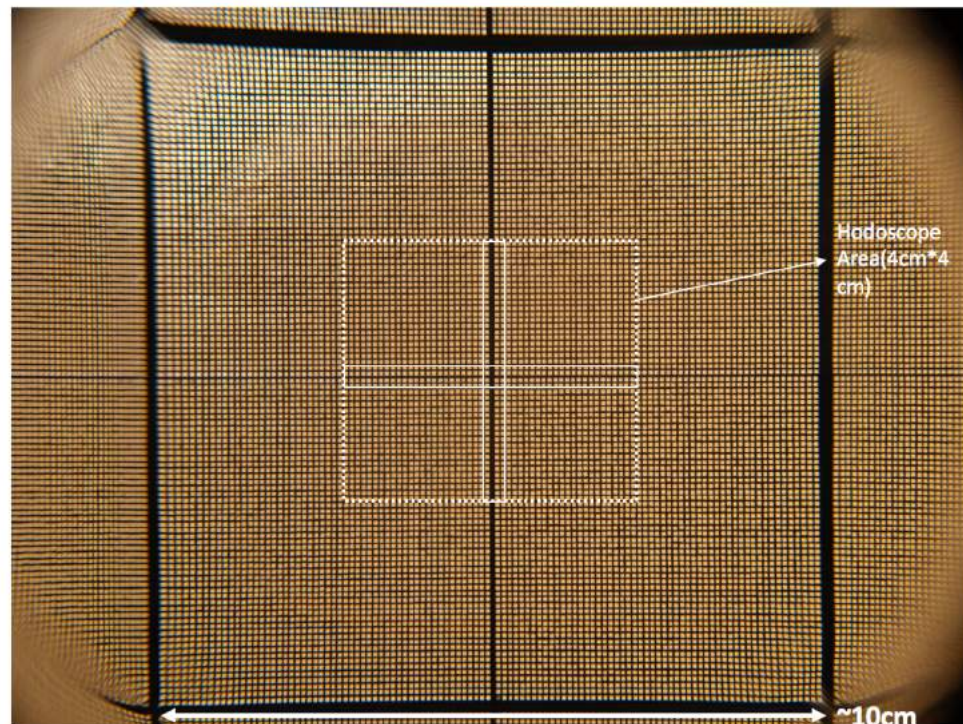
# Technology 2 Examples



SPACAL and ID,  
FNAL 2014

SiPM Readout

CALOR 2012, J.Phys.: Conf. Ser. 404 012023  
CALOR 2014, J. Phys.: Conf. Ser. 587 012053



FNAL 2016. High resolution, square fibers, constant term



# Optimization of light collection (2016):

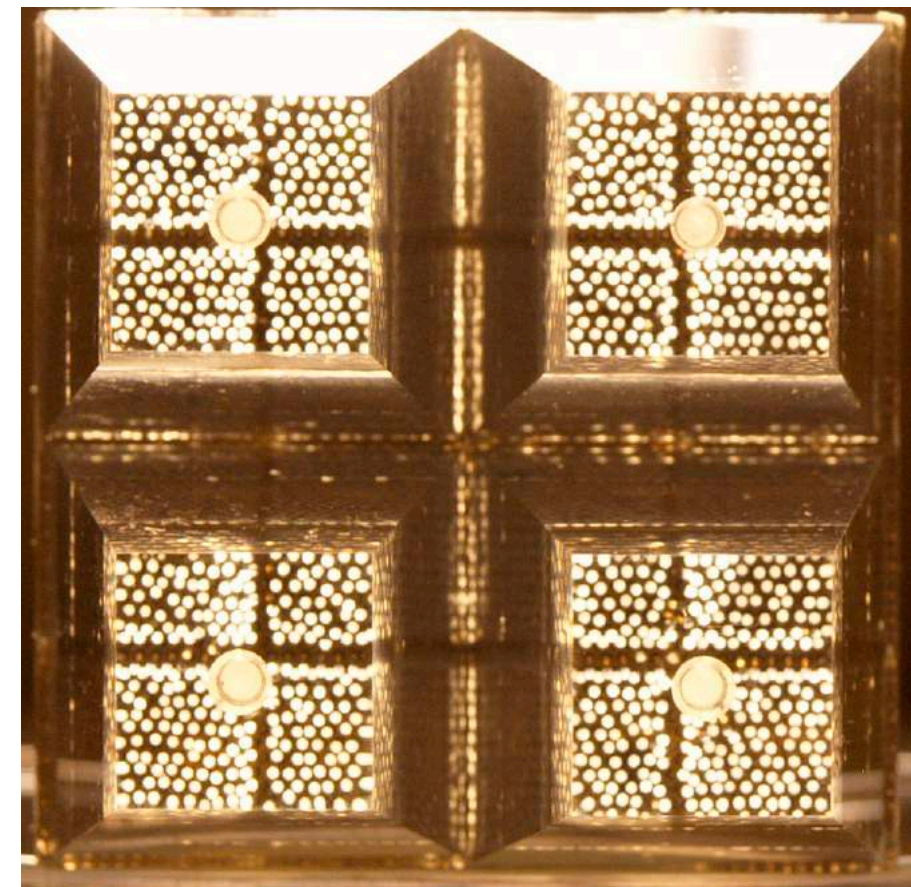
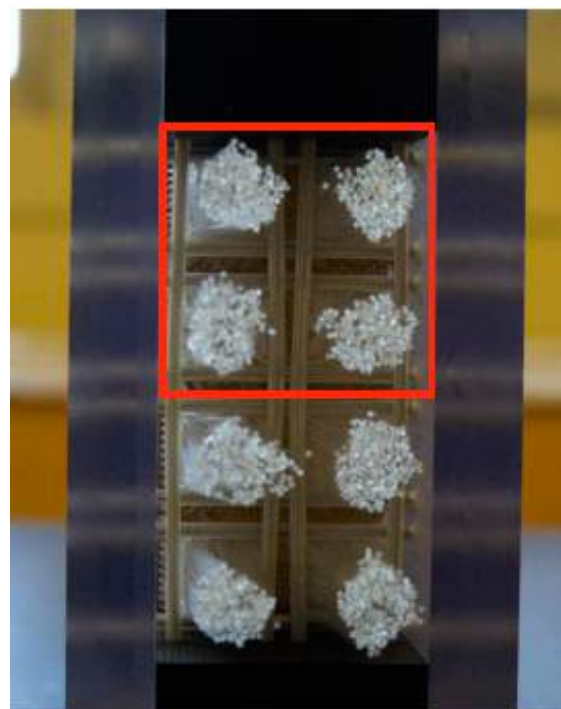
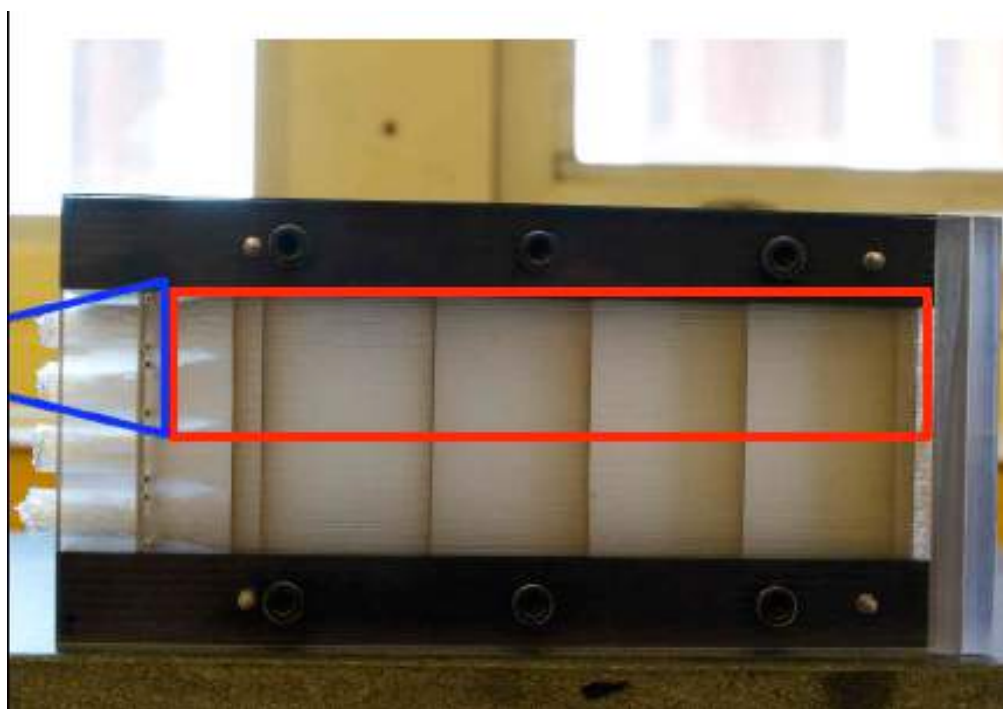
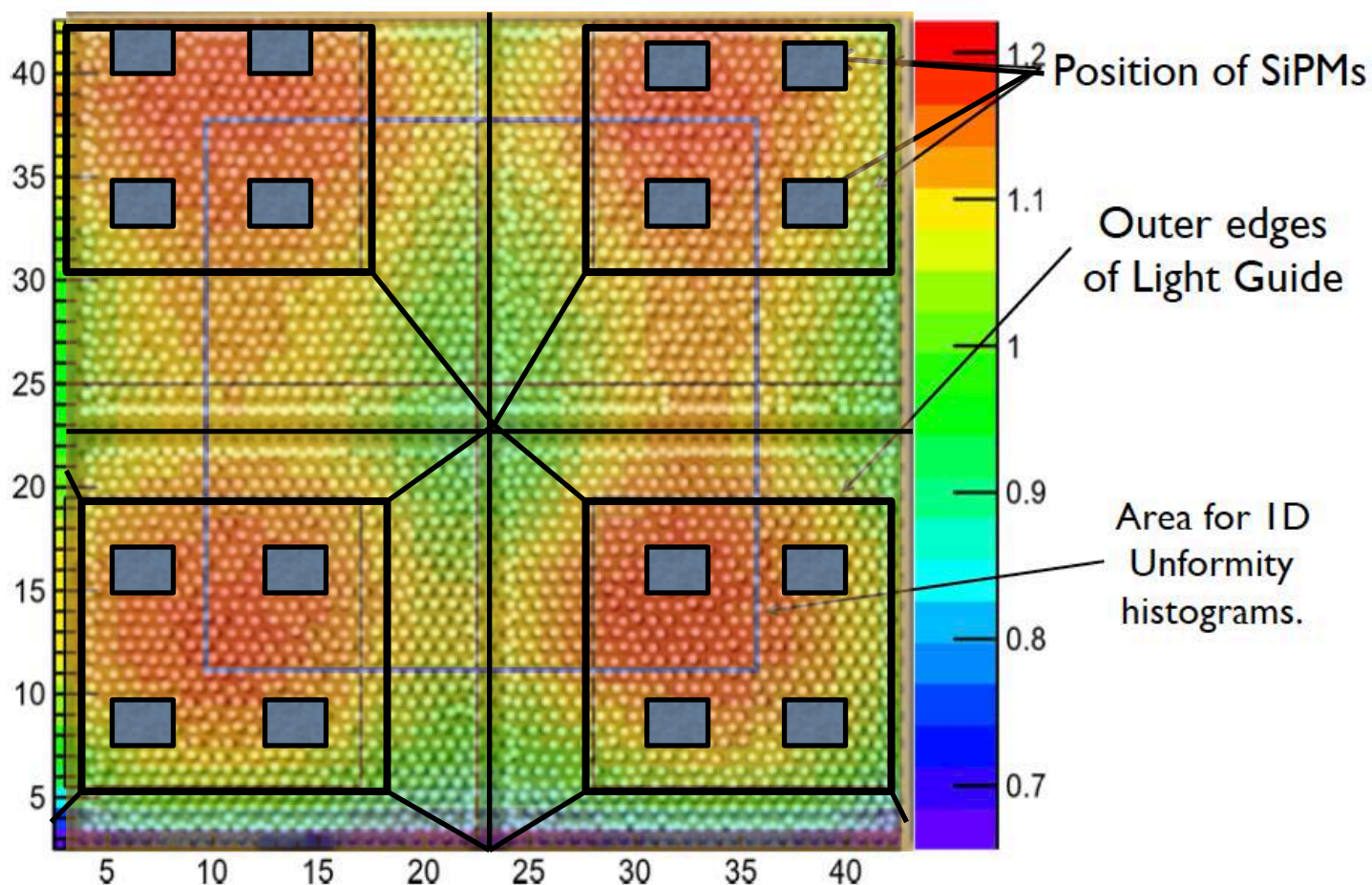
BEMC Superblock 2 x 2 towers, 4 SiPMs / tower, UV LED Map

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:

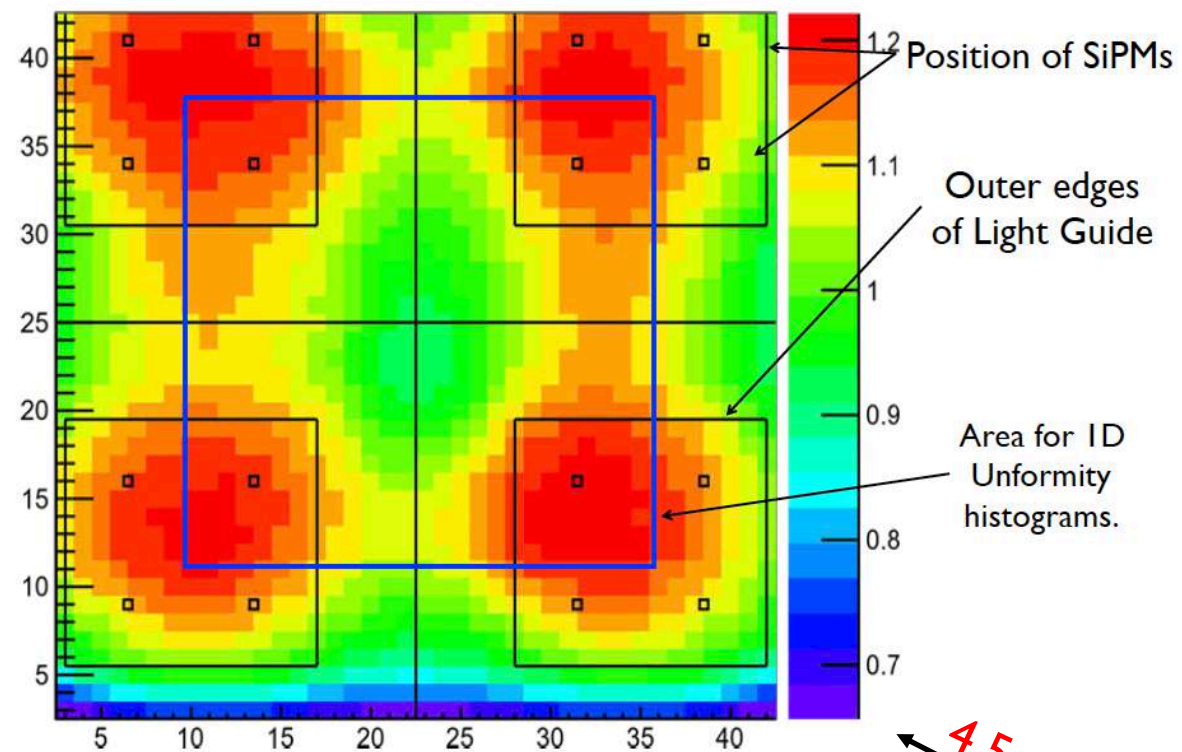
1. Compensation Filter between fibers and light guide. **Loss about 30% of light** (test run 2015). Will not work for FEMC.
2. Compensation with gradient reflector from the back side of the superblock.  
**Practicality issues.**

**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.



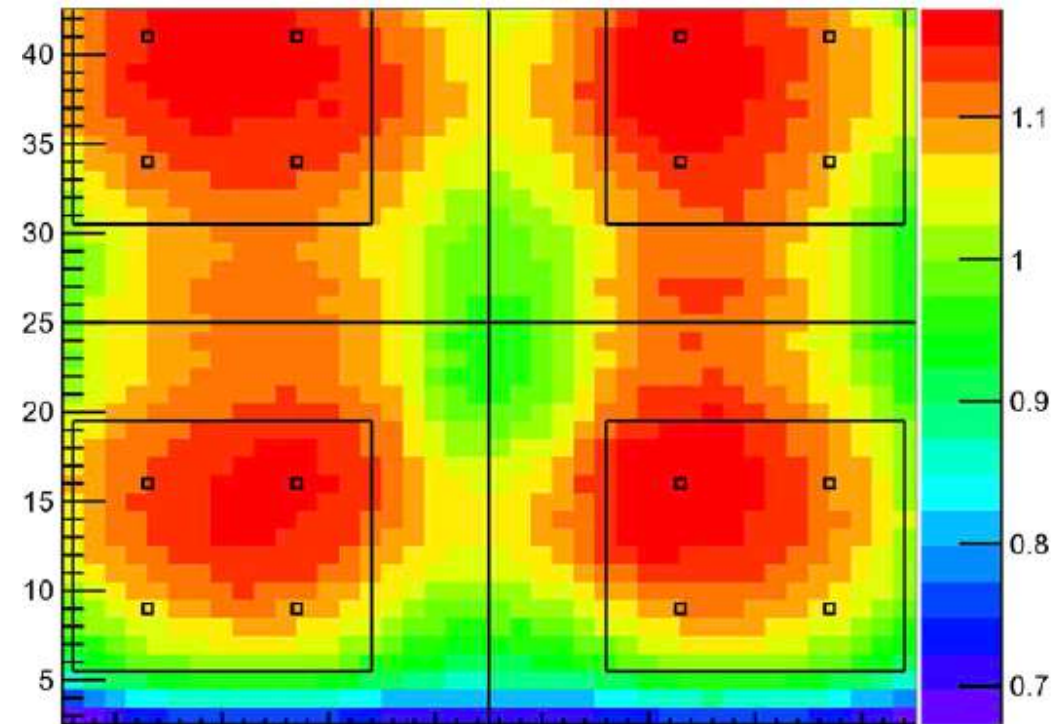


## Optimization of light collection:

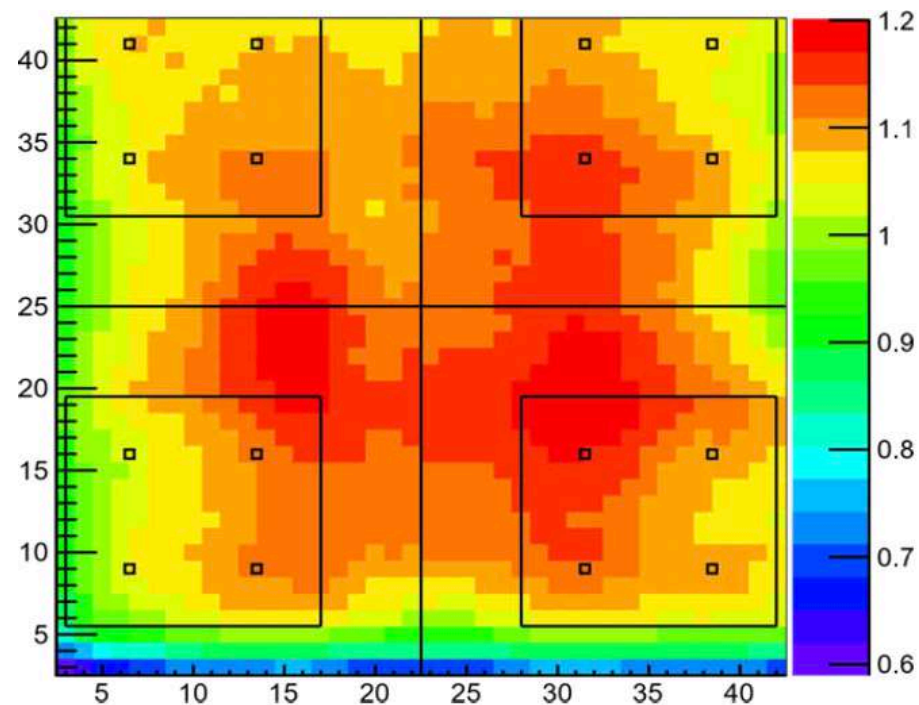


Old BEMC, Sylgard 184, 3mm

## BEMC Superblocks, UV LED Map

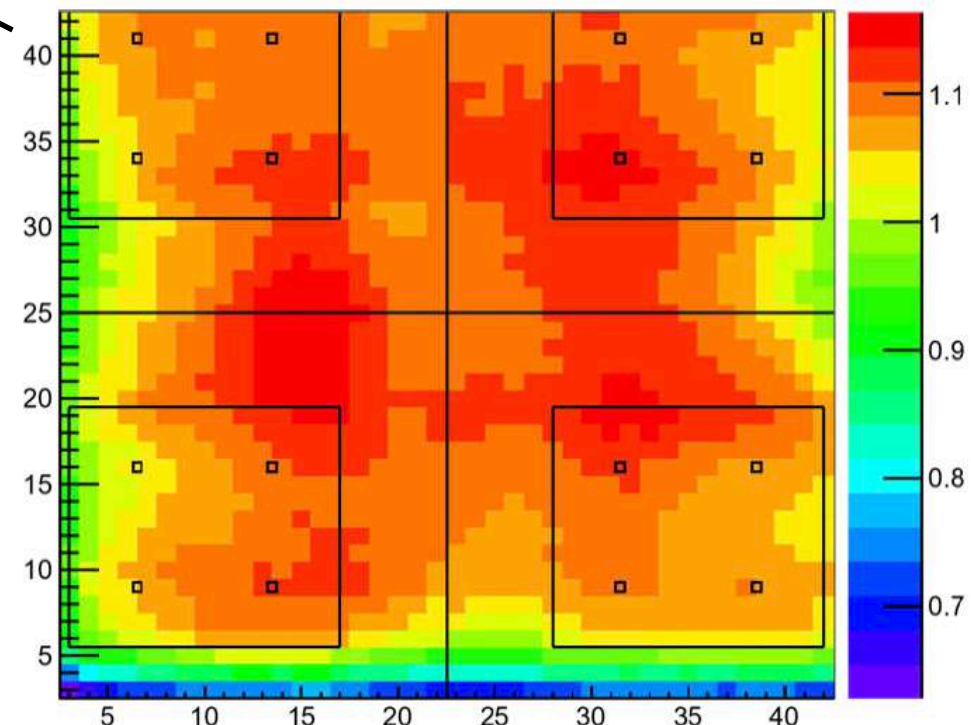


Old BEMC, BC-630, coupling is important



New BEMC, BC-630.

New arrangement of fibers works quite well.

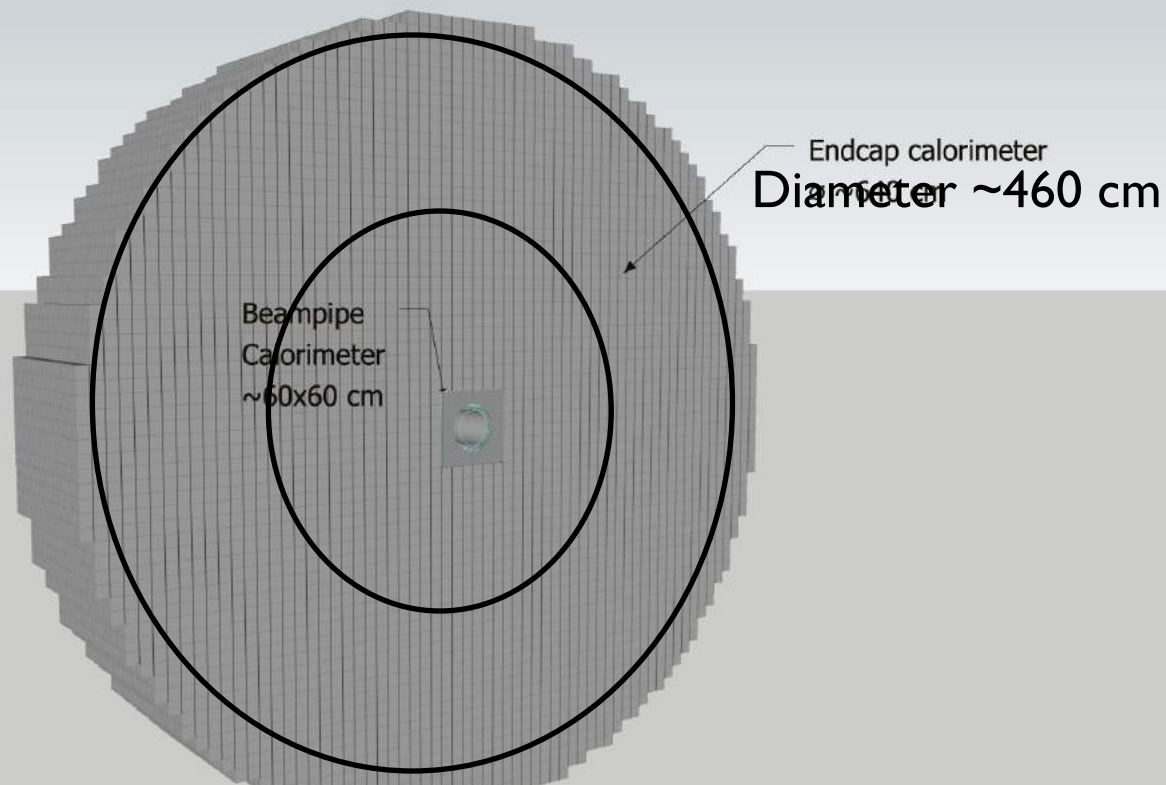


New BEMC, Lumisil 59I

Better fiber arrangement and better coupling.

eRD I06



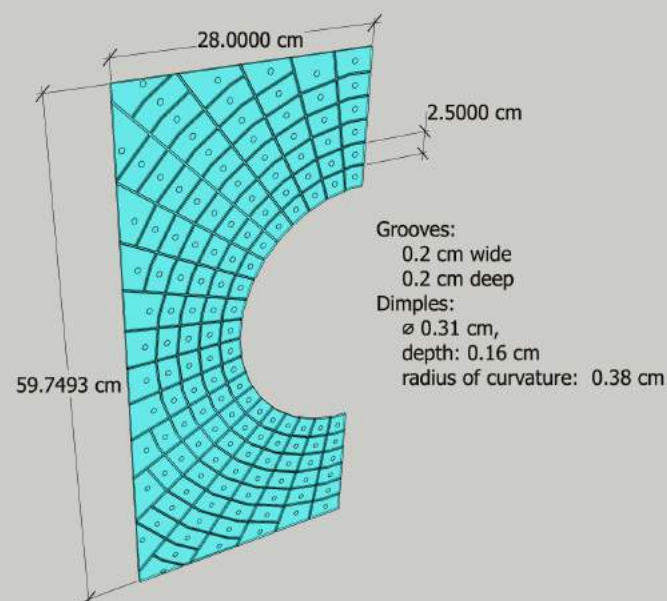
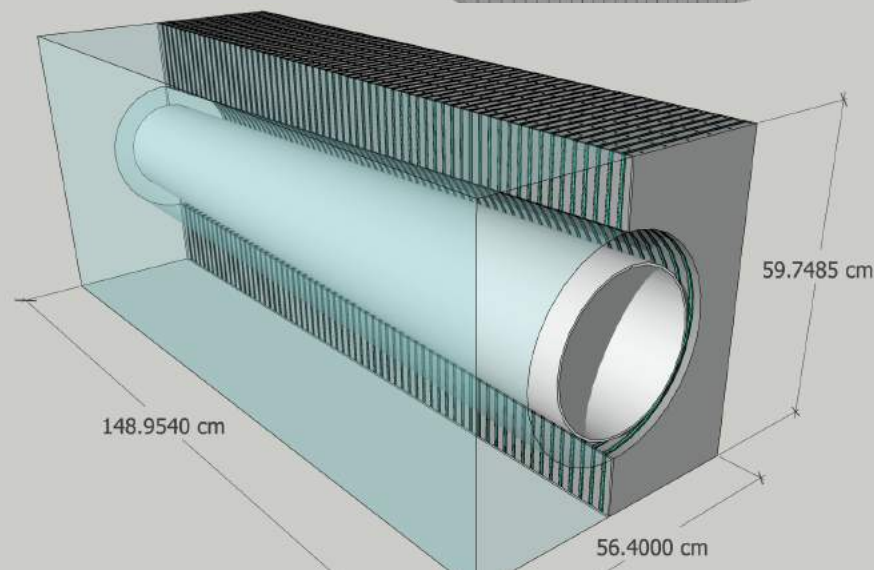


Post proposal 'optimization' of pECal directions under discussion:

Outer area Ecal segmentation?  
Reduction of readout channels?

Insert around beam pipe  
Highest density, i.e. lower sampling fraction, thinner fibers, accordion?

Readout – moving ADC to FEEs pros/cons.



M.Arratia (UCR)



# Summary:

- WScFi is a unique and mature technology.
- Lots of know how accumulated in EIC community during last ten years, eRDI and construction of sPHENIX.
- pECAL build with this technology meet YR requirements.
- Performance, cost, risks are well understood.
- Design, and integration of pECAL looks very simple.
- Small developments are still needed to improve light collection.
- Discussions on readout scheme is needed, i.e. pushing ADCs to FEEs ?



# Backup

## *Prototypes. Spacordion. Not There Yet!*

2011 construction



*SPACORDION was the first prototype. We build it using technique we developed in the past. Each tower were glued from four subassemblies. Then all 16 towers were glued to a single matrix. The fibers were bundled at the end.*

*Main problem with this approach is: matching four pieces to make a single tower. It was quite labor extensive process.*

*Not that Simple.*

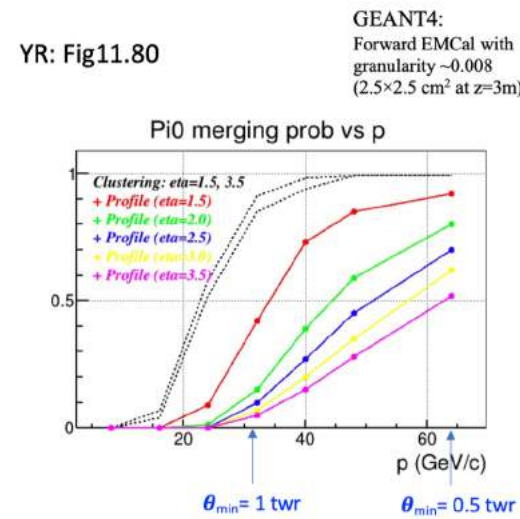
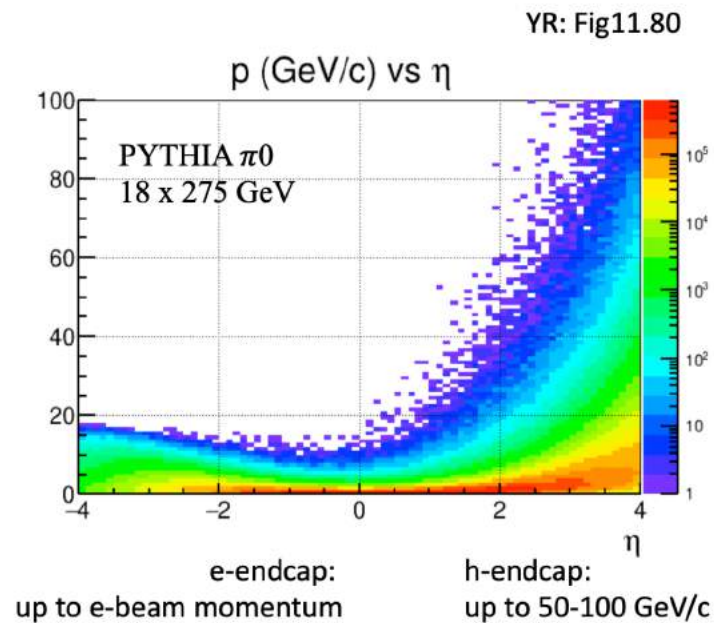
*So, we refine technique for second prototype.*



# pECal functionality Pi0/gamma separation

See <https://indico.bnl.gov/event/14906/> talk by A.Bazilevsky

## Shower Profile Analysis



Shower Profile analysis:

$$\chi^2 = \sum \frac{(E_i^{\text{meas}} - E_i^{\text{pred}})^2}{\sigma_i^2}$$

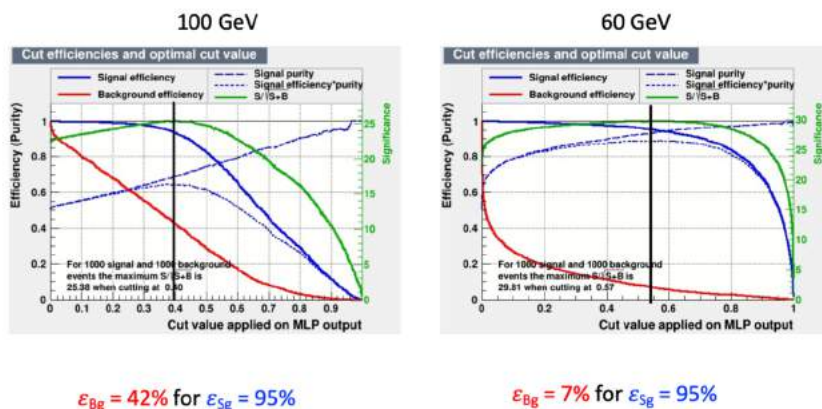
$E_i^{\text{pred}}$  and  $\sigma_i$  are  $f(x, y, E, \theta, \varphi)$

- Considerably extends the momentum range for  $\pi^0/\gamma$  discrimination
- Strong dependence on rapidity (for non-projective)
- There is room for improvement ...

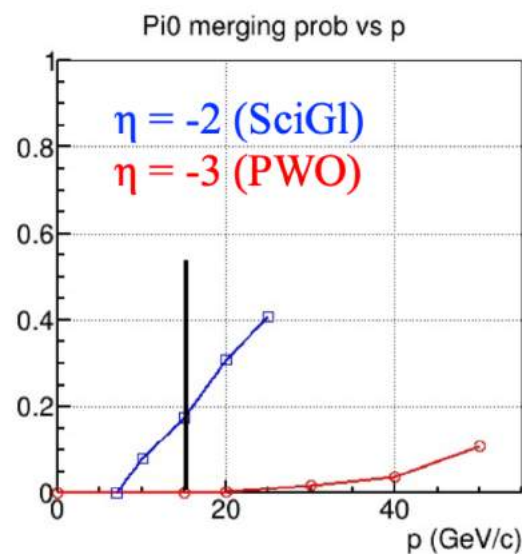
## Pi0 merging prob after MLP

Signal/Background efficiency after MLP

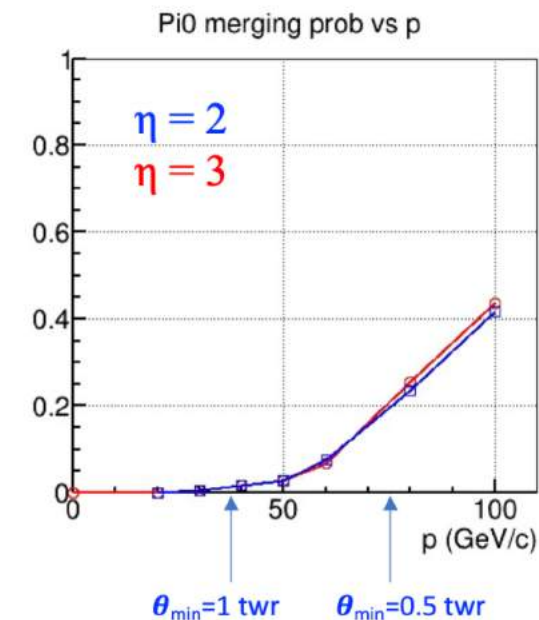
h-endcap: 2.5x2.5cm at z=3.5m,  $\eta=3$



e-endcap:  
**PWO**: 2x2cm at z=-2.1m  
**SciGl**: 4x4 cm at z=-2.1m



h-endcap:  
**W/SciFi**: 2.5x2.5cm at z=3.5m



Can effectively discriminate  $\gamma/\pi^0$  even when two photons are separated by 0.5 tower size

Compactness of pECal is handy.



