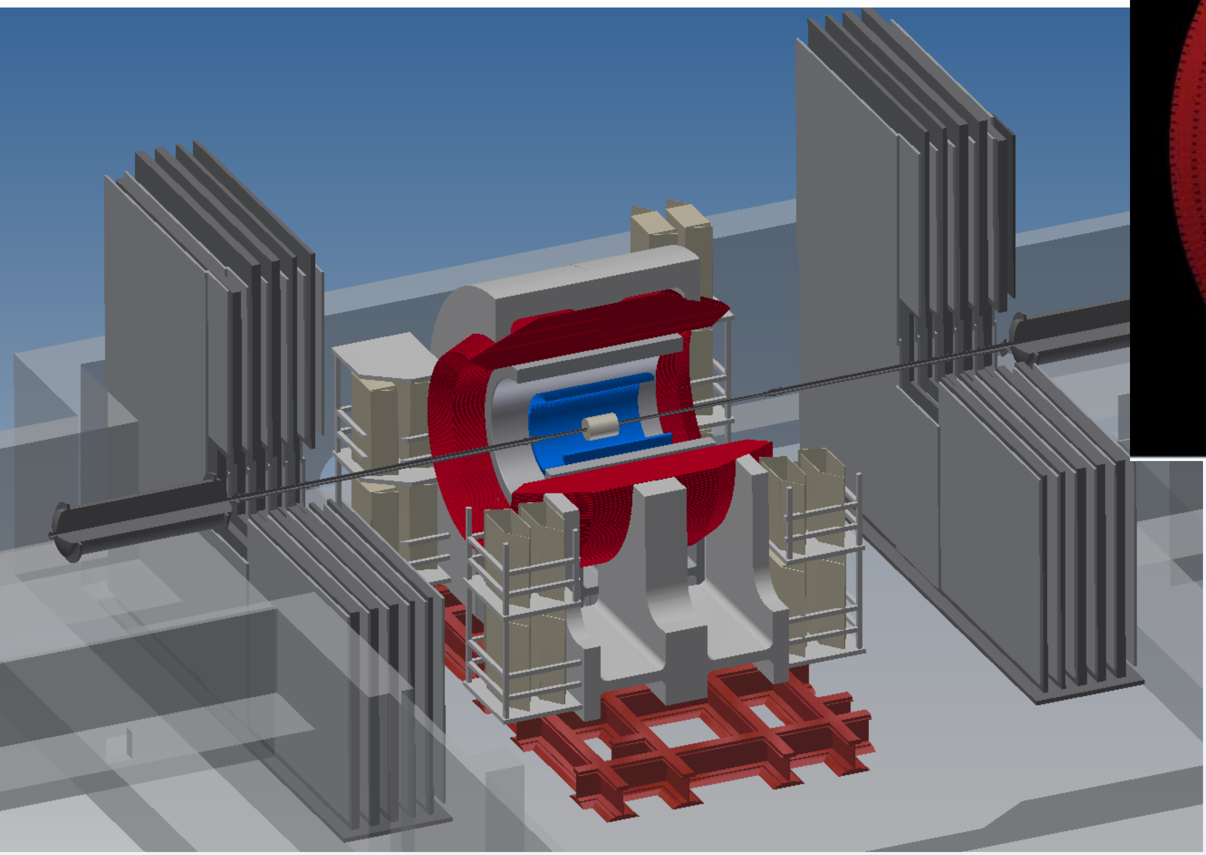
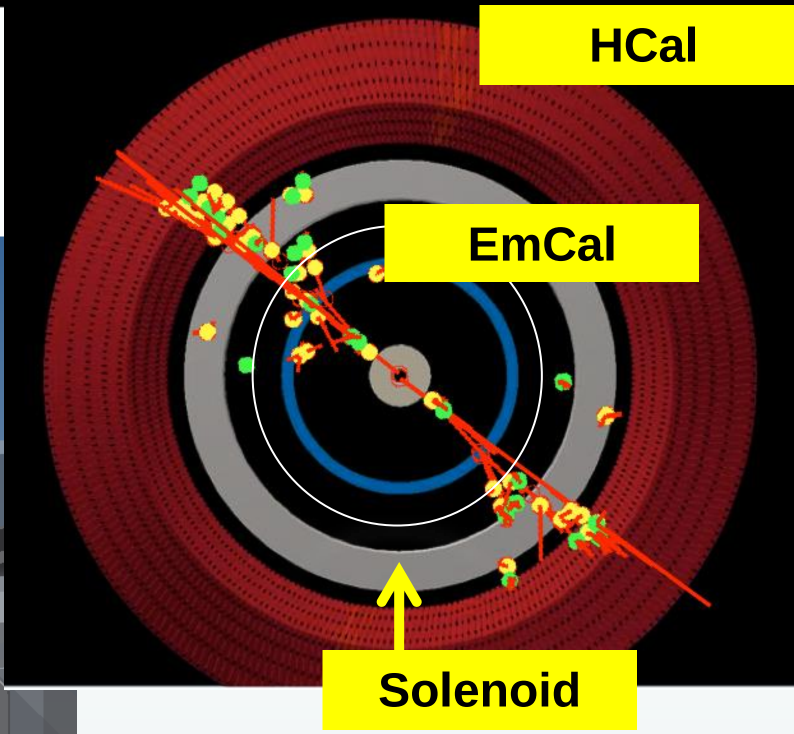
R&D on Calorimetry for sPHENIX experiment at RHIC

TIPP 2014
Amsterdam, June 6th, 2014

sPHENIX is the calorimetry based upgrade to PHENIX





Calorimeter controls in sPHENIX

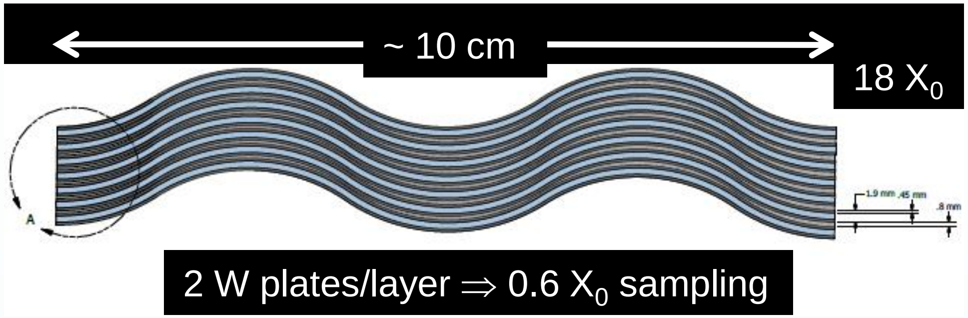
- Large solid angle coverage (± 1.1 in η, 2π in ϕ)
- Moderate energy resolution
  - EMCAL ~ 15%/$\sqrt{E}$
  - HCAL ~ 75 %/$\sqrt{E}$ (single particle), ~100 %/$\sqrt{E}$ (jet)
- Compact (for EMCAL $\Rightarrow$ small R_M, short X_0)
  - Physically small (dense) – occupies minimal space
  - High segmentation for heavy ion collisions
- Hermetic
- Projective (approximately)
- Readout works in a magnetic field
- Low cost

Technology Choices:

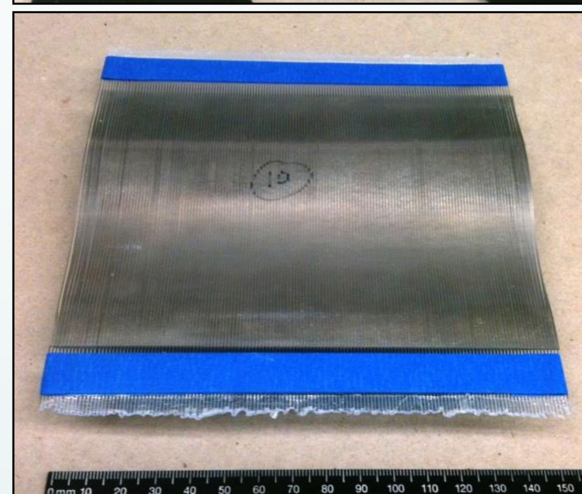
- EMCAL → Tungsten Scintillating Fiber
- HCAL → Iron Scintillating Tile with WLS Fiber
- Readout → SiPMs

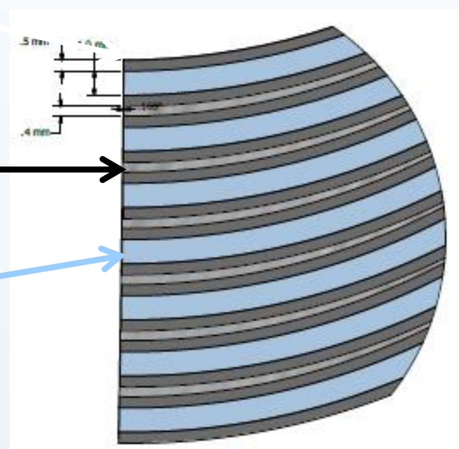
Super compact EMCal : W & SciFi

SBIR



Pure tungsten metal sheets (ρ ~ 19.3 g/cm³) Thickness: 2x1.0 mm





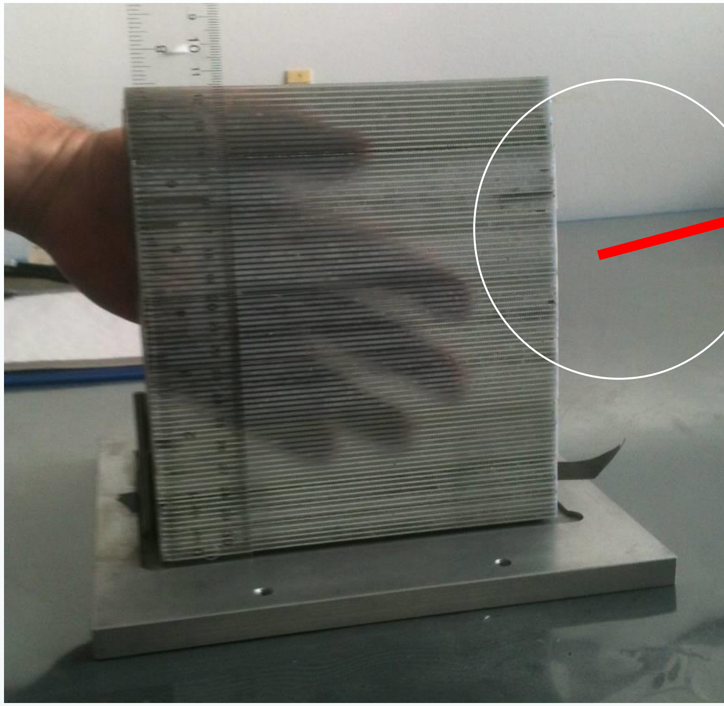
Epoxy (~ 0.1 mm)

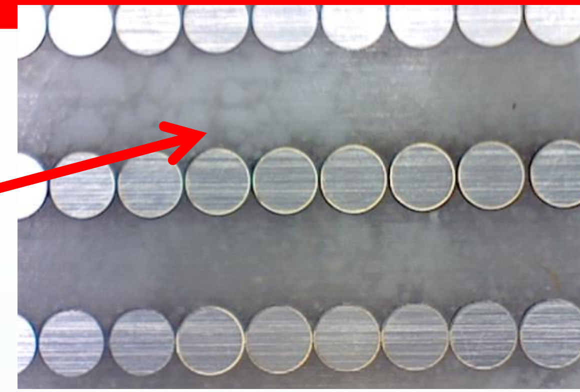
Scintillating fibers 1.0 mm

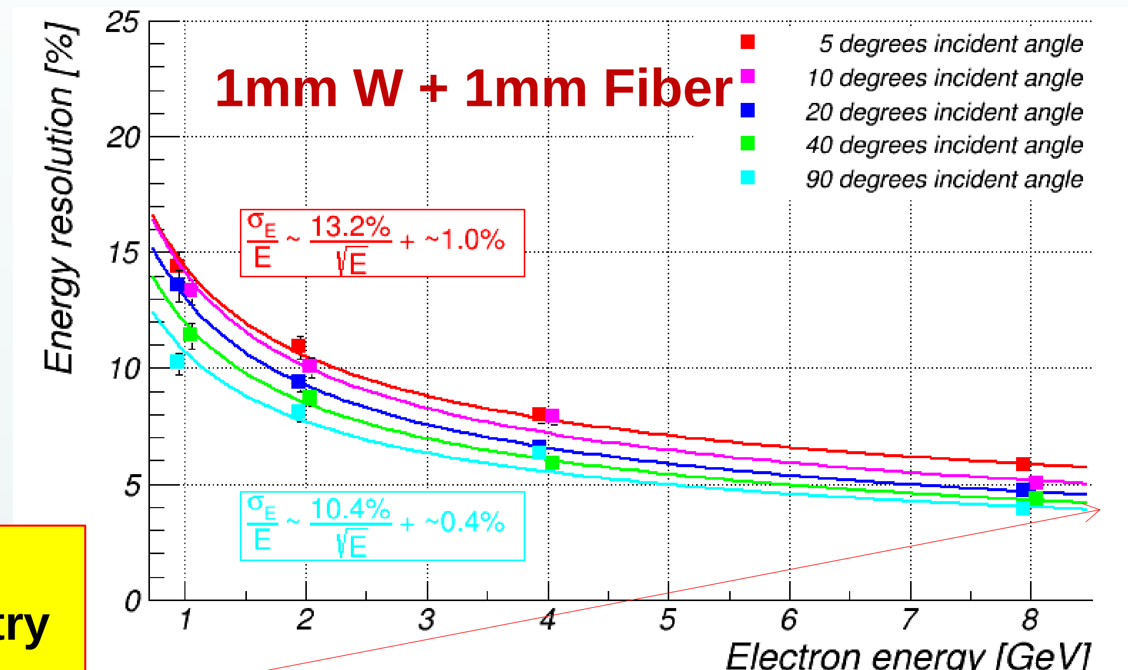
X_0 = 5.3 mm
R_M = 15.4 mm

Very ambitious, very difficult and ….. too expensive ….

Compact & Realistic W-SciFi EMCal (tilted tiles)



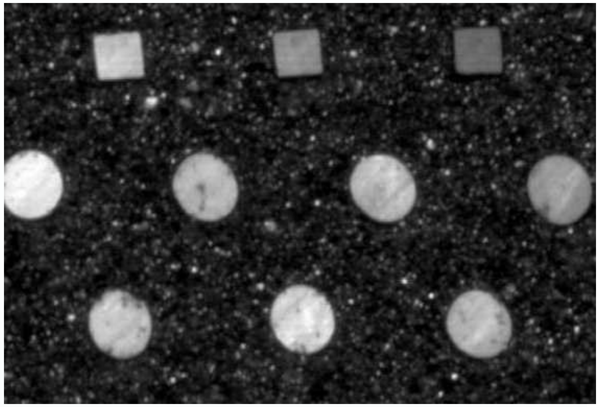


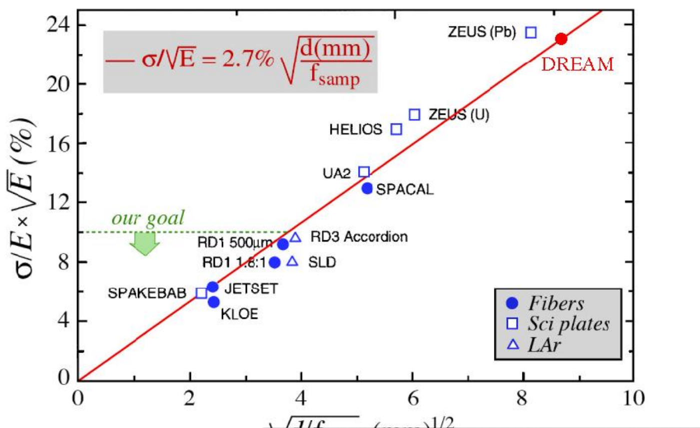


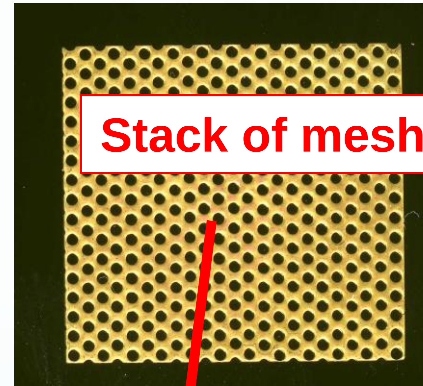
Common concern:

Implicit designed in asymmetry between along-tile and across-tile impacts->constant term

Safe bet: SciFi in W-epoxy compound



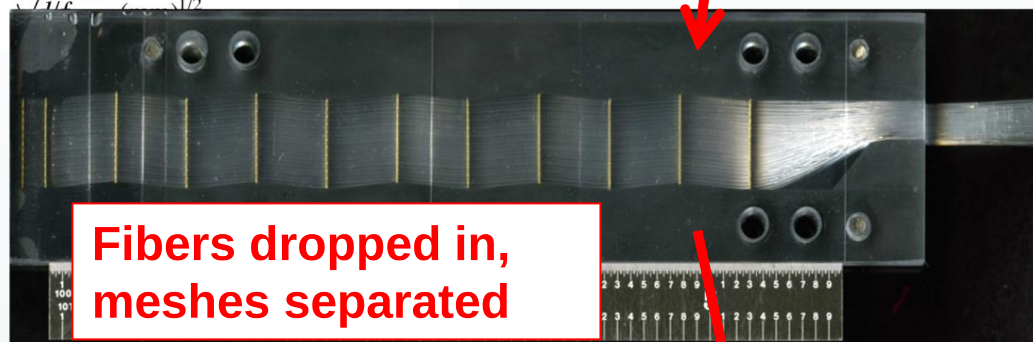




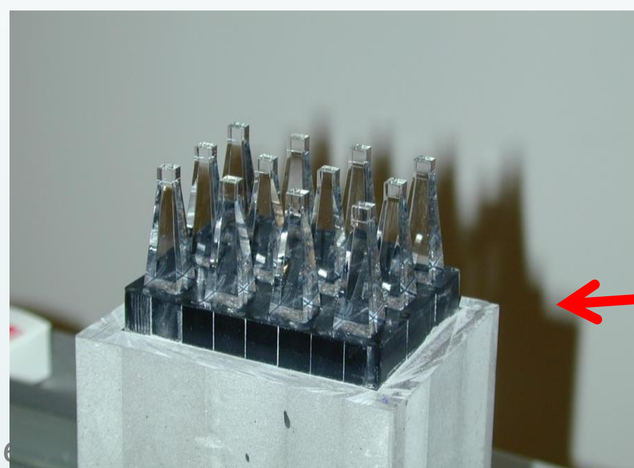
Stack of meshes

UCLA : W compound - SciFi prototype, 0.3 mm fibers, 0.8 mm spacing

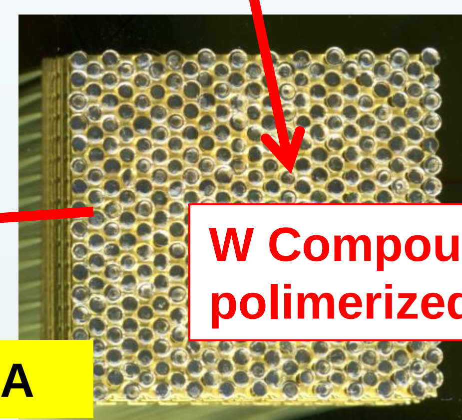
Compact: ***ρ~10.17 g/cm3, X0 ~ 7 mm, Rm ~ 2.3 cm***



Fibers dropped in, meshes separated



Readout ready towers



W Compound polimerized

Pictures from O.Tsai, UCLA

More about HCal

Physics requirements

- Containment up to 60 GeV hadrons
- Hermeticity, uniformity & projectivity
- Energy resolution ≤ 100%/√E
- Full azimuthal coverage for |η|<1.
- Granularity to allow correlated

jet-jet and γ-jet measurements

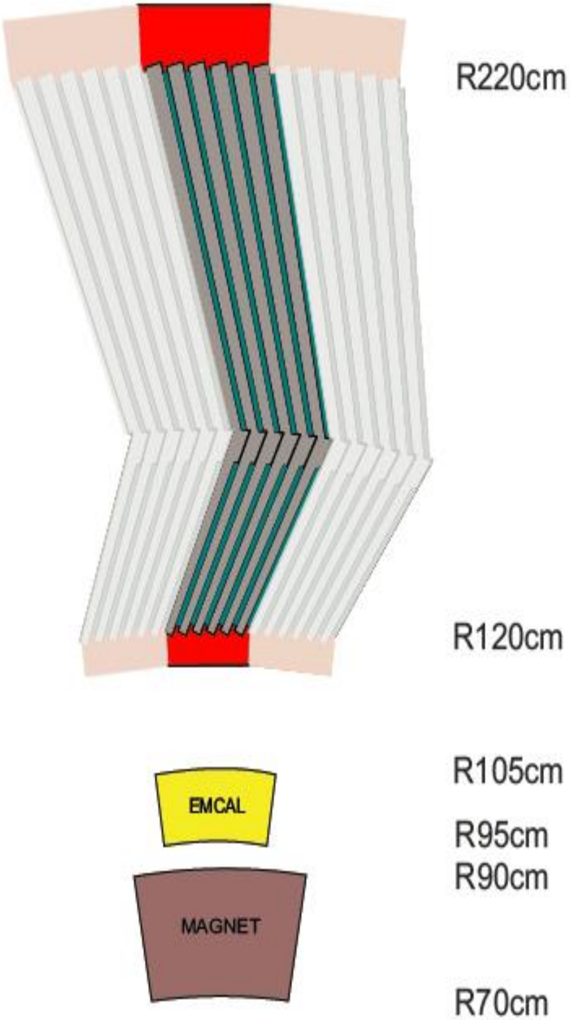
Design goals

- Simple to construct
- Simple to collect and digitize signals
- Use well established technologies
- Readout electronics identical to EMCAL
- Serves as flux return for solenoid

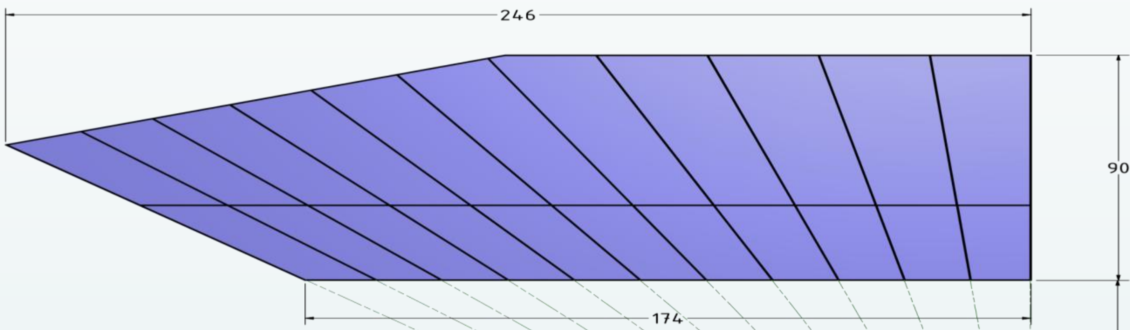
PHENIX (BNL)
BNL (Physics, CAD, …)
INR (Moscow, Russia)
CSU (Boulder, Colorado)
GSU (Atlanta, Florida)

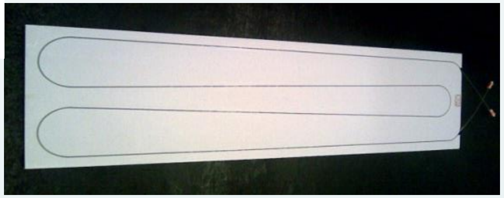
Uniplast (Vladimir, Russia)

Hcal: Concept 2012

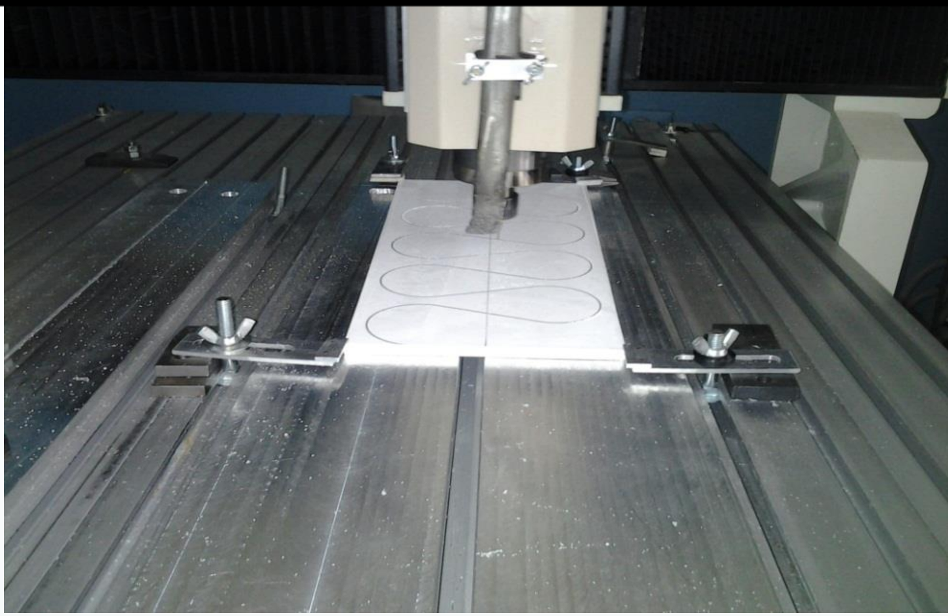


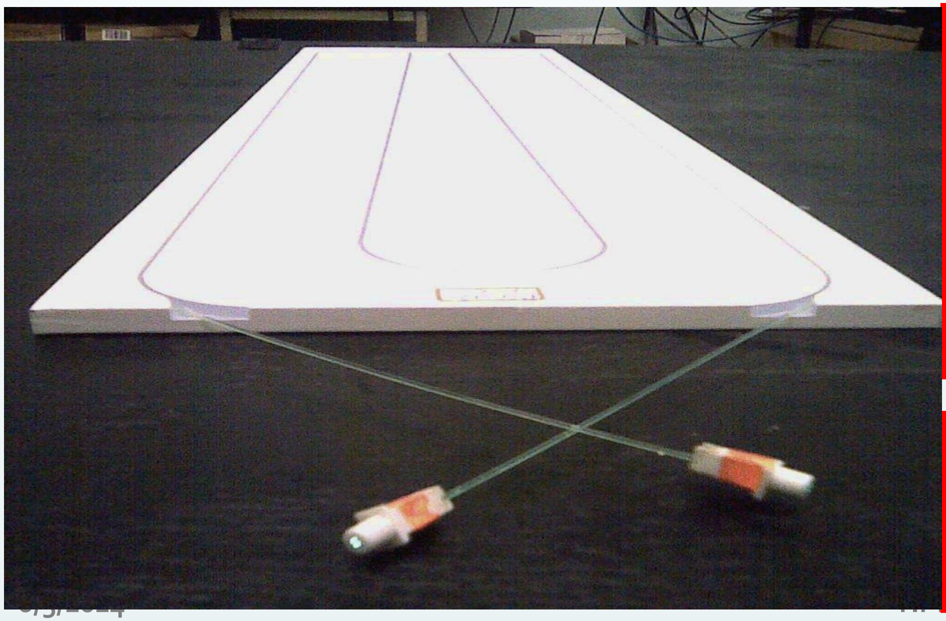
- Sampling Fe-Scintillating tile calorimeter
- Sampling cells (layers of Fe and scintillator extending along the beam line) tilted at a small angle to developing shower core
- Self-supporting, dead area free,
- Longitudinally segmented to avoid channeling and to minimize sampling fraction variations;





Light collection: patterning & containment

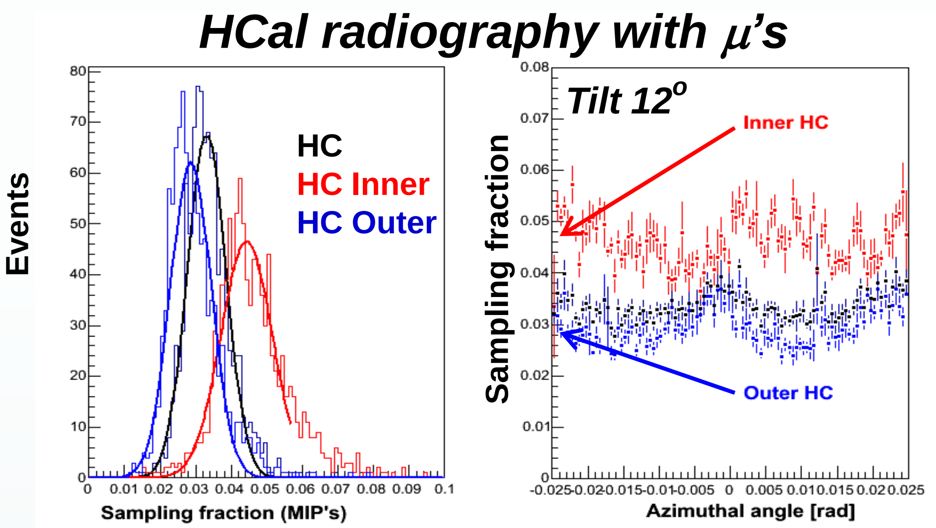


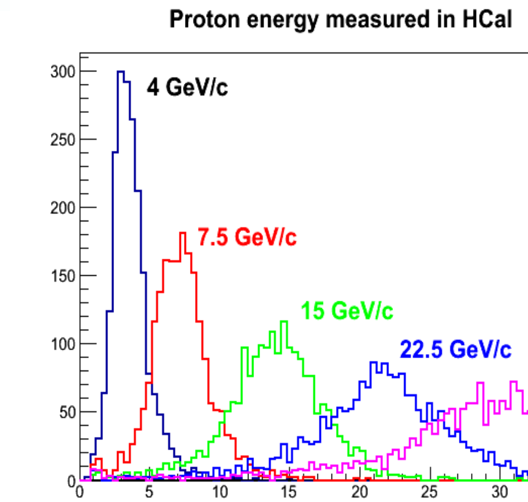


Design rules:
- -**Minimum bending diameter of 55mm;**
- -**Maximum point-to-fiber distance of 27mm**
- -**WLS fibers uncut**

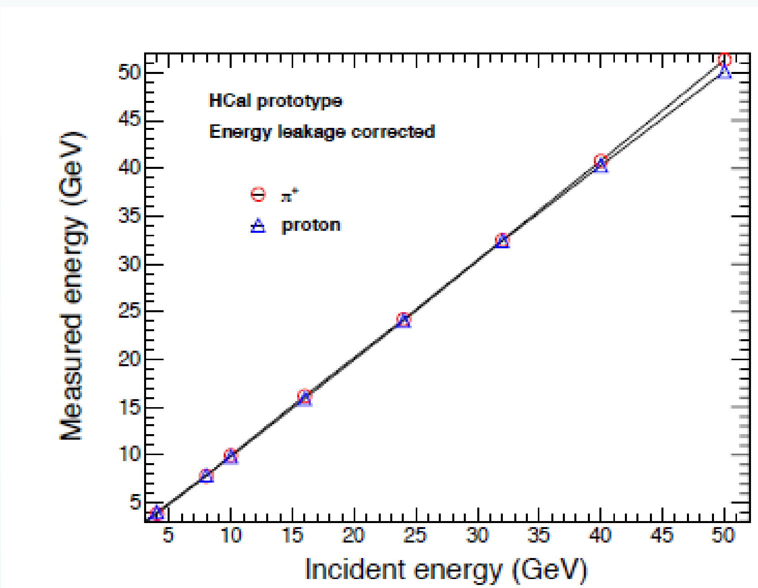
Response uniformity measurements with cosmic muons and source were made at INR and in Boulder, Colorado

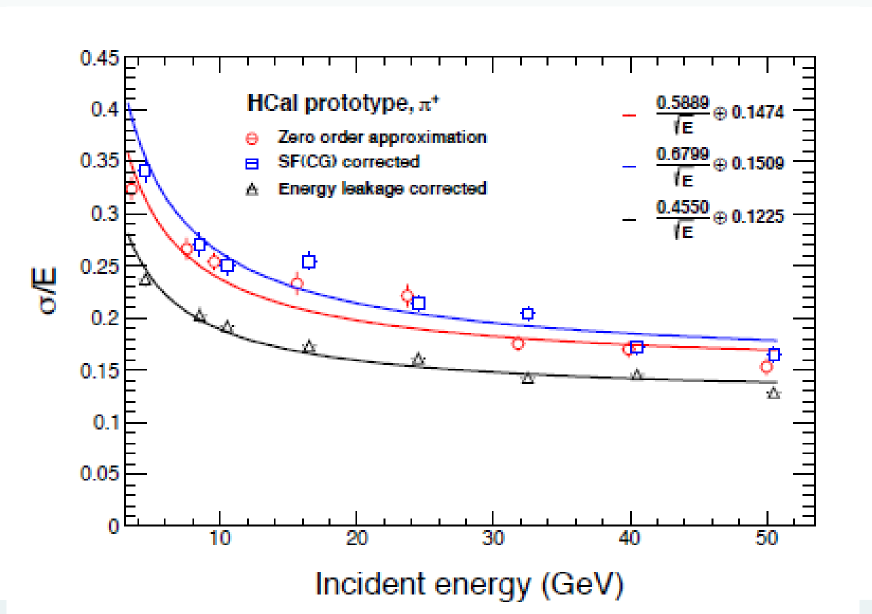
Hcal: expectations (G4) 2012



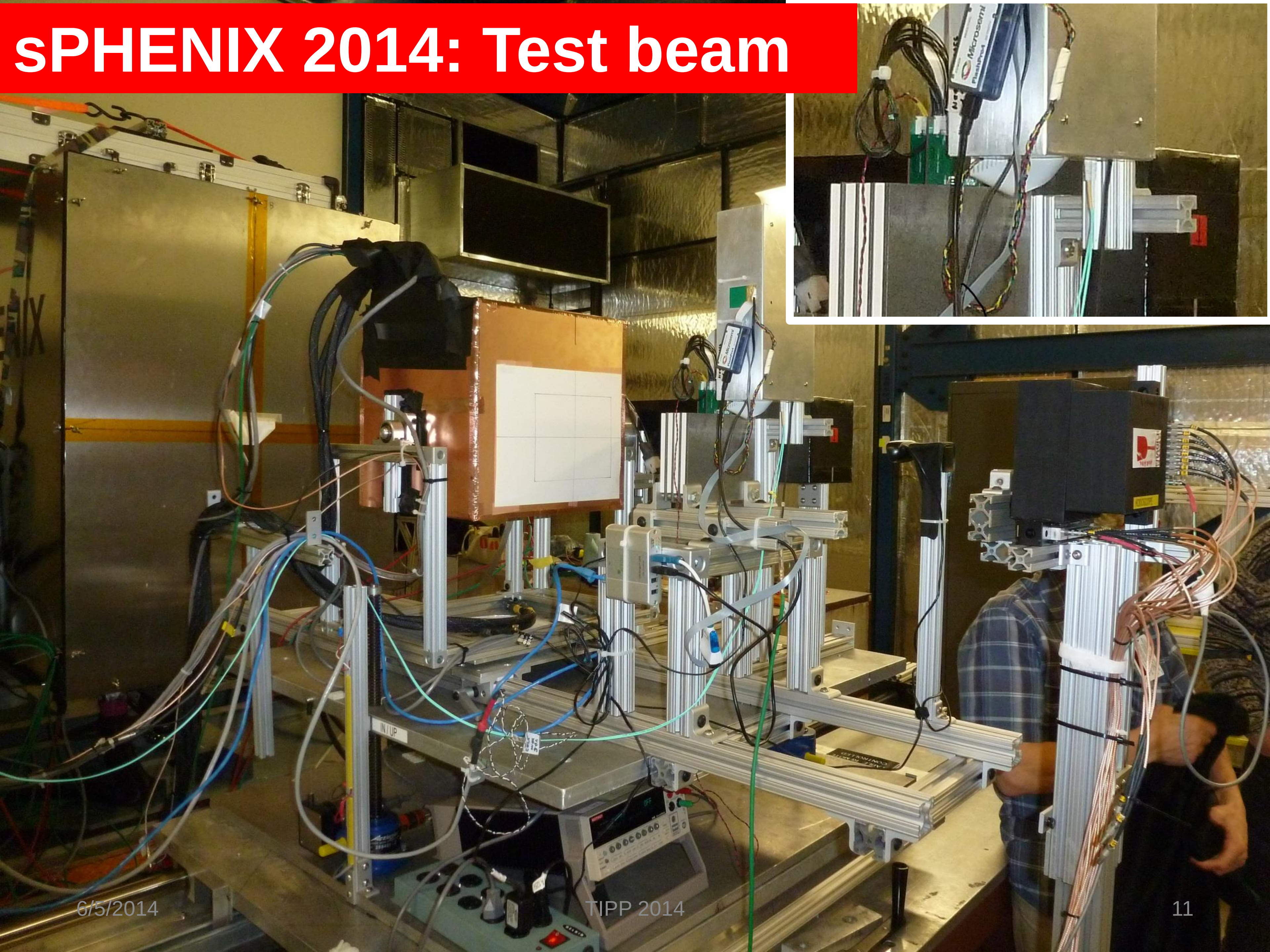


Simulation effort has continued since the submission of the proposal to refine the design and optimize analysis software

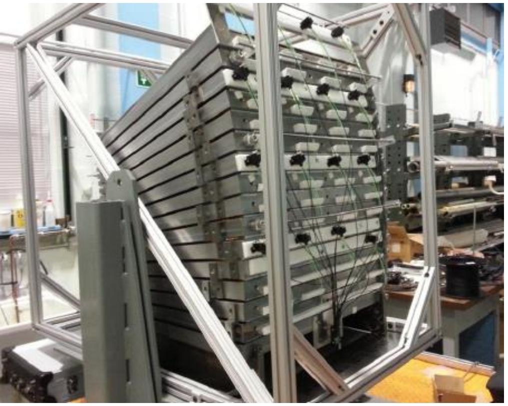


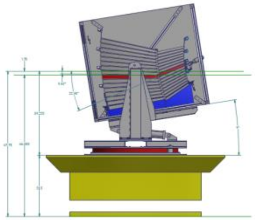


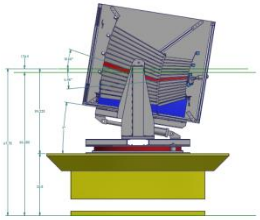
sPHENIX 2014: Test beam

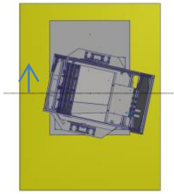


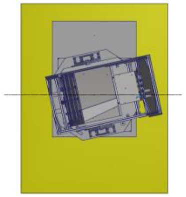
Inside the boxes

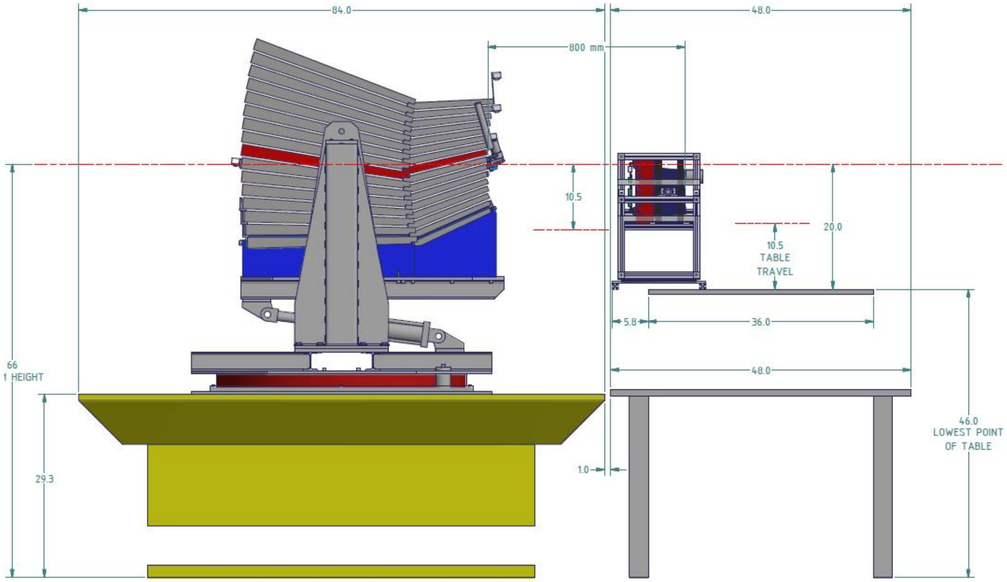


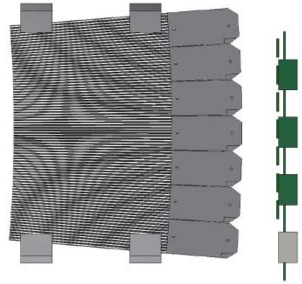


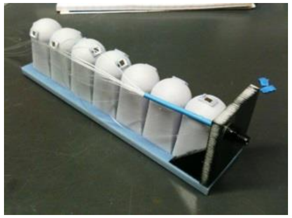


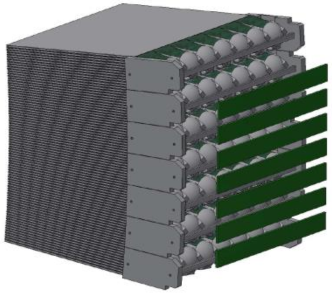






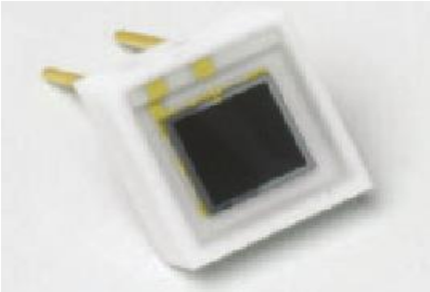






Beam

MPPC based optical readout



MPPC 3x3 (S10363-33-025)
Sensitive area: 3x3 mm^2
Number of pixels: 14400
Fill factor: 30.8%

EMCal

Fibers:

Kuraray SCSF7, 1mm diameter, double clad;

Sampling fraction: %;

Single MPPC per tower of 20x20 mm2;

Light collection:

Air domes ~3cm tall;

Average efficiency = 4.7% (compare to area ratio of 1.3%);

Nonuniformity (Max/Min ratio) of 1.7;

Light yield:

3900 p.e./GeV of energy deposited in calorimeter measured with calibrated phototube;

180 p.e./GeV of energy deposited in calorimeter with MPPC's and collection efficiency of 4.7%

Hcal

Scintillator:

extruded, polystyrene based (PTP+POPOP) tiles;

chemically developed reflective coating for light containment; wrapped with Aluminized miler and protective plastic wrap;

Fibers:

Kuraray Y11 single clad, 1mm OD;

Sampling Fraction: 2.5-5%

Single MPPC per Tower

Light yield (photoelectrons per MIP per fiber):

F. Ends: 11.9 – 12.9 ;   F.Total 24.8 (tile center)

F. Ends: 12.9 – 14.4;   F.Total 27.3 (far from MPPC)

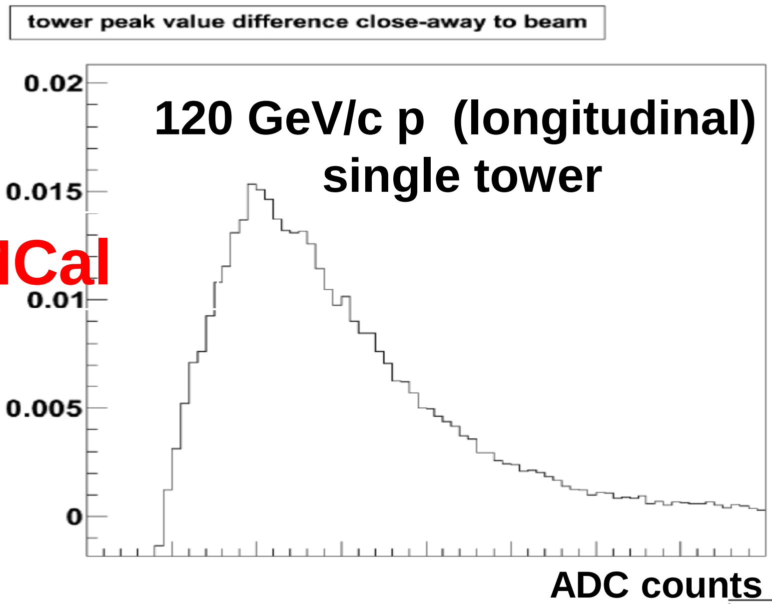
F. Ends 11.3 – 12.8 ;   F.Total 24.1 (close to MPPC)

4 sc. Tiles, 8 fiber ends bundled to point towards single MPPC. Air gap about 10 mm.

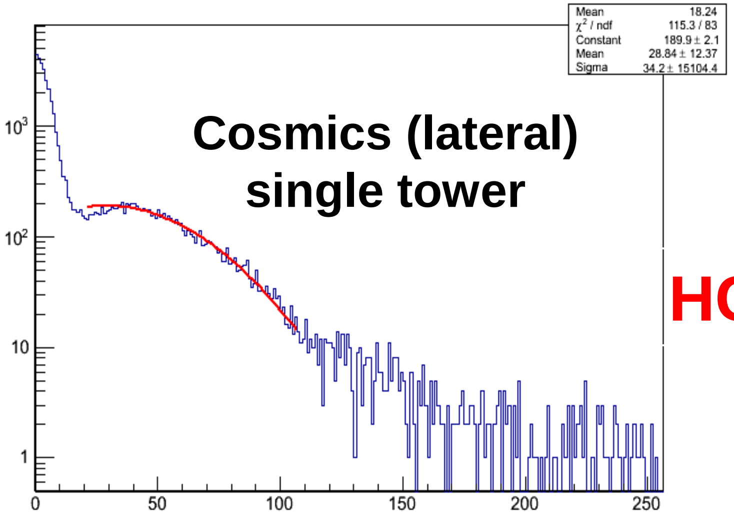
Test beam: Calibration

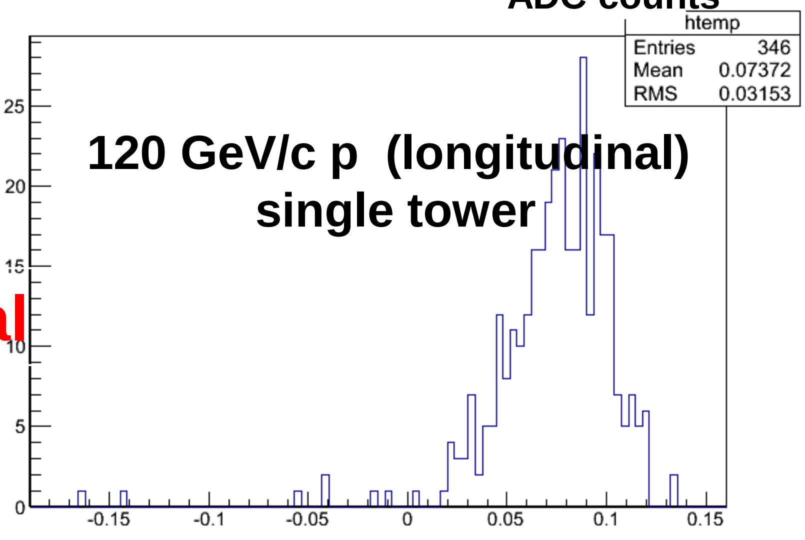
Both detectors are calibrated combining highest momentum beam data (protons at 120 GeV/c) with cosmic muon exposure (important for Hcal towers on the detector edges).

EMCal

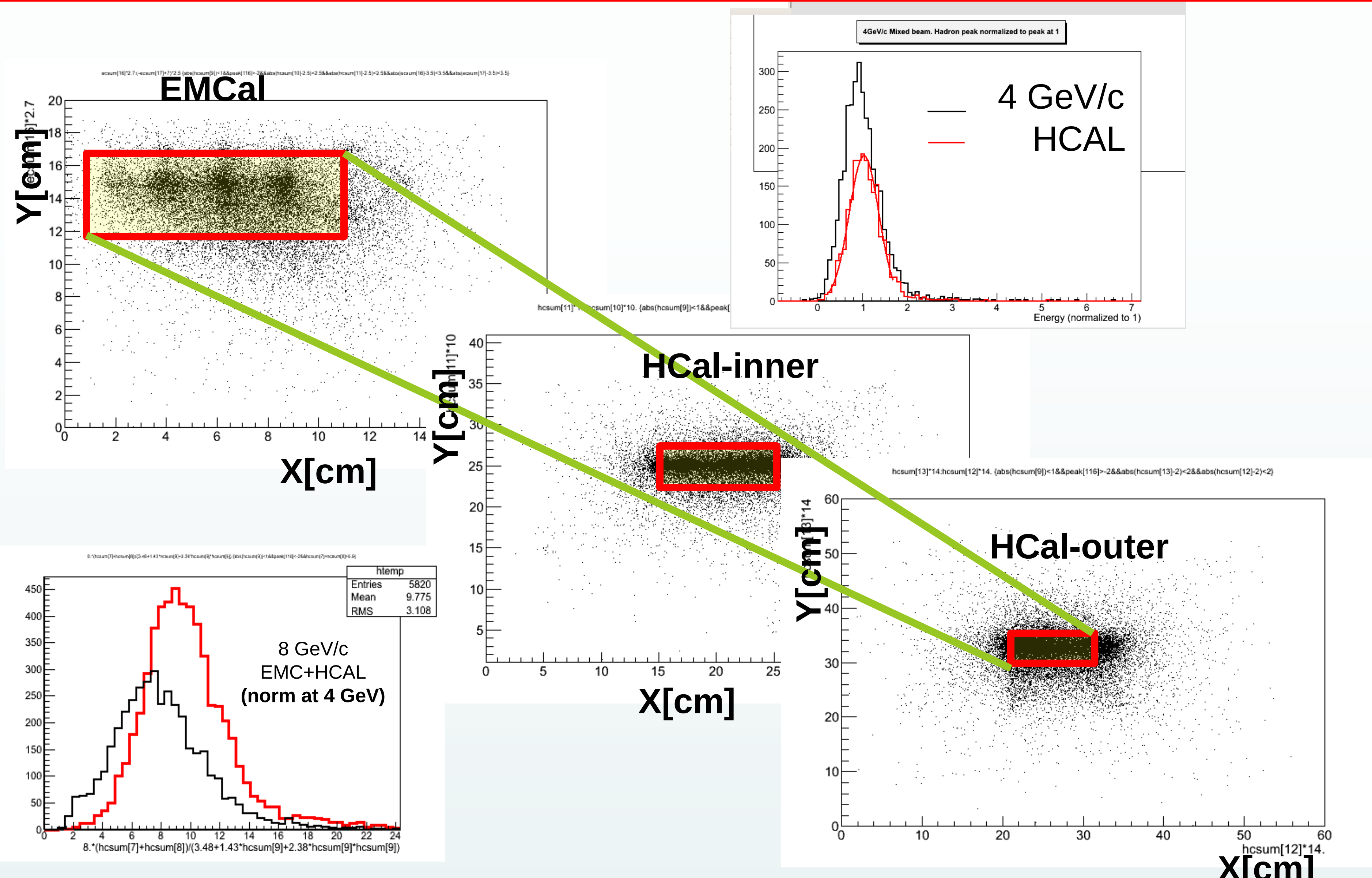


HCal



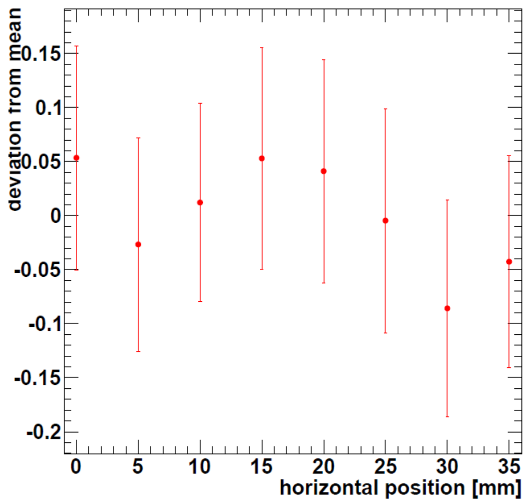


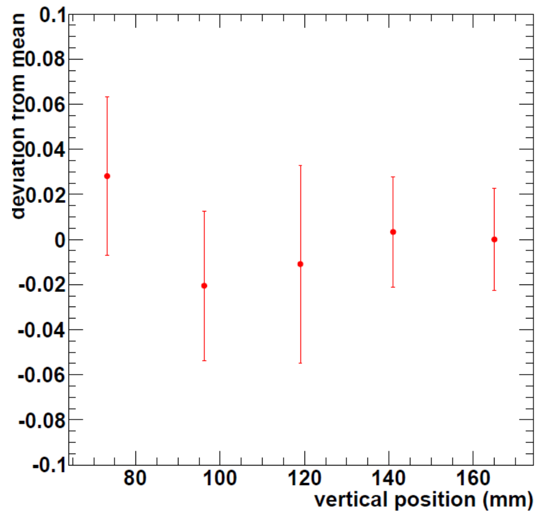
System at a glance

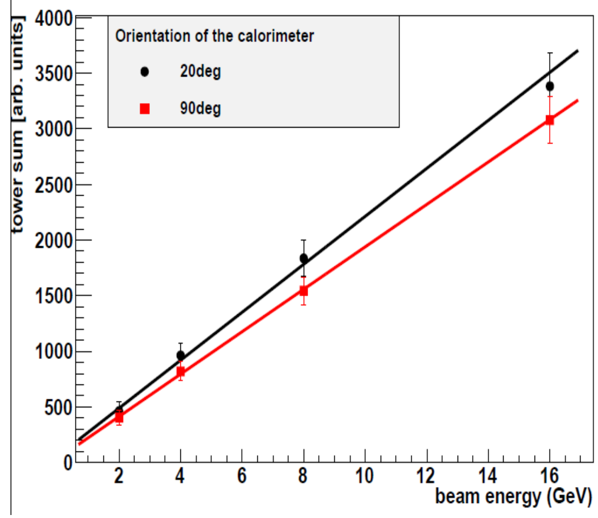


ECal – W-SciFi compound is baseline technology

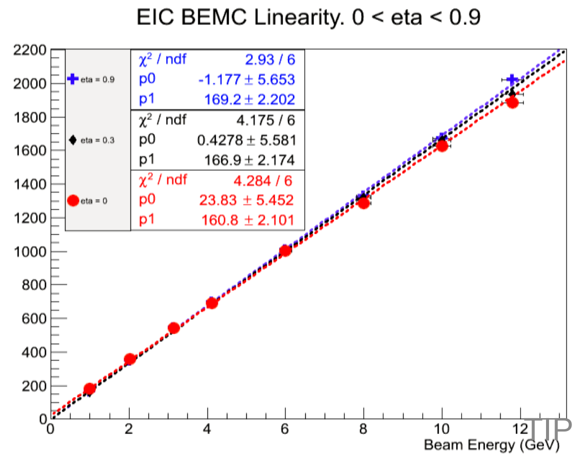
BNL: tilted flat tiles W-SciFi EMC prototype

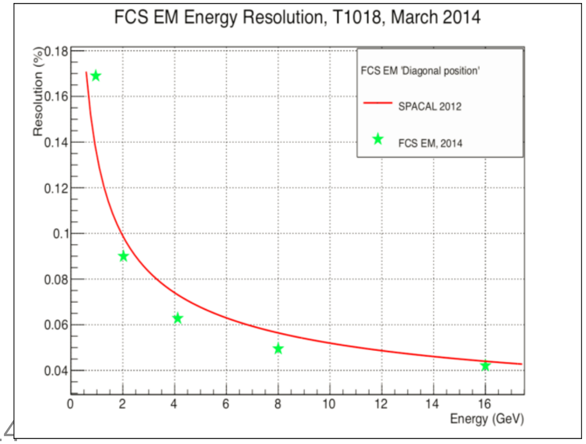




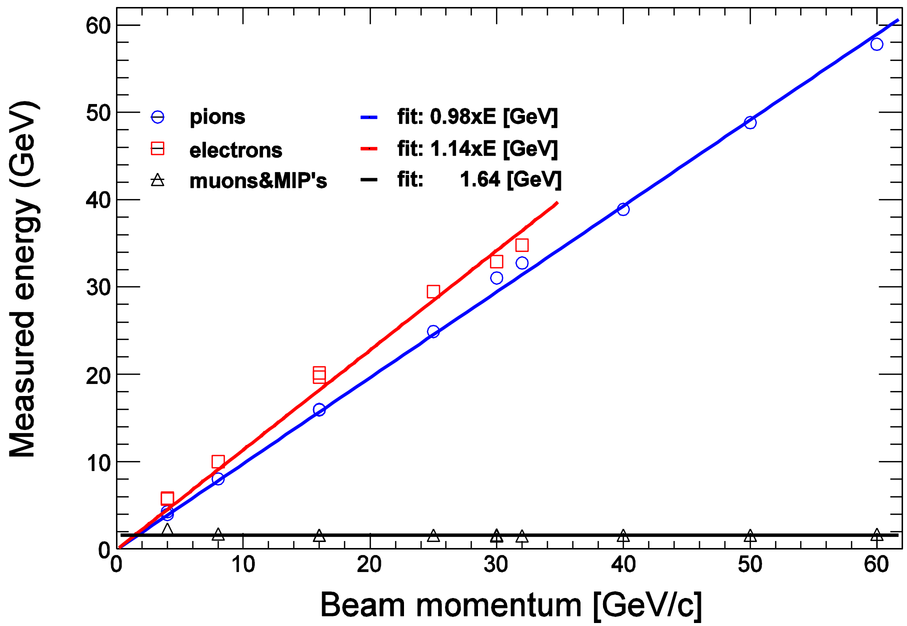


UCLA : W-epoxy compound SciFi prototype





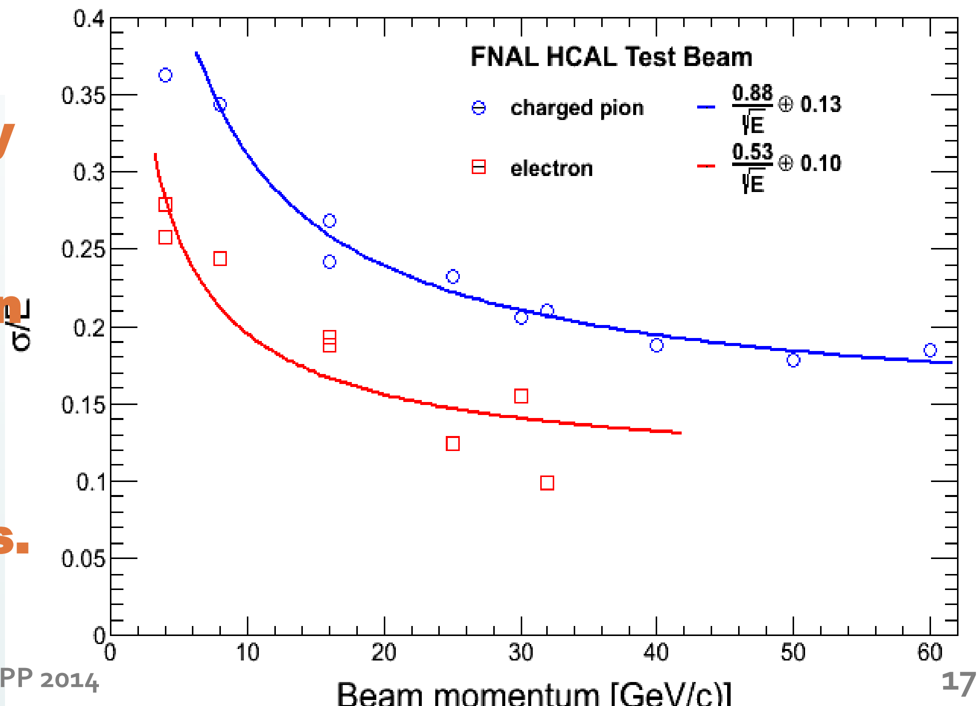
Hcal: Performance at a glance



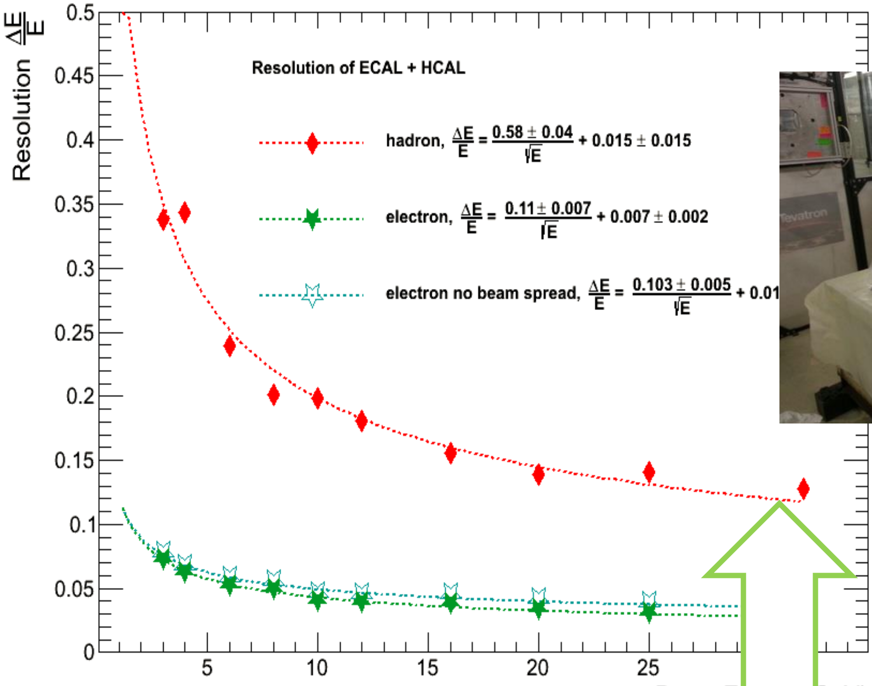
$e/\pi = 1.17$

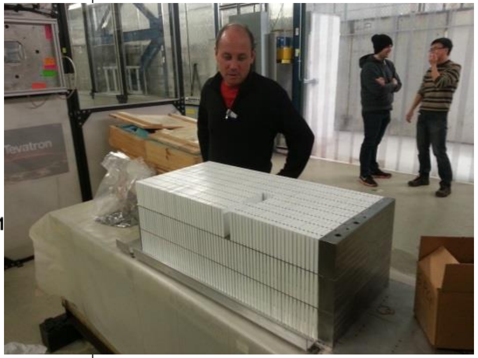
$e/\mu = 0.77$

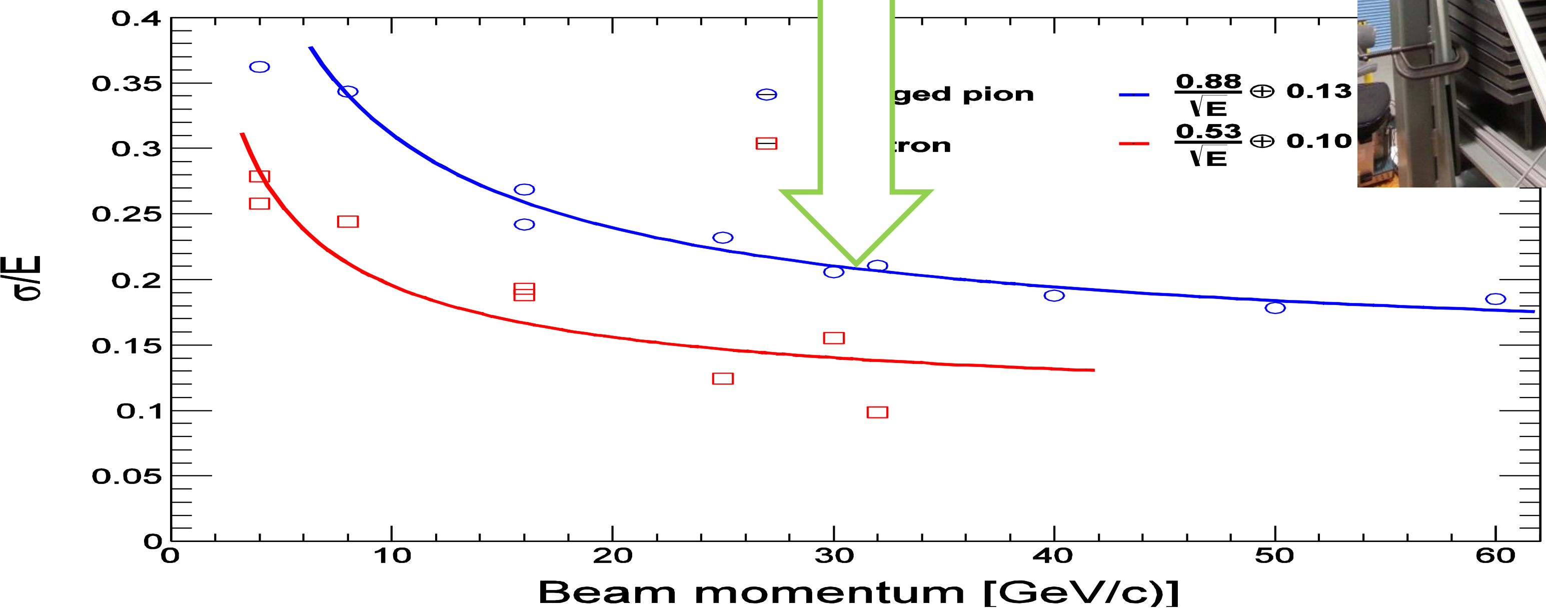
- Linear everywhere in the energy range tested;
- In the energy range of sPHENIX (below 50GeV) energy resolution is dominated by stochastic fluctuations) ;
- Constant term will be reduced with LCG dependent corrections.



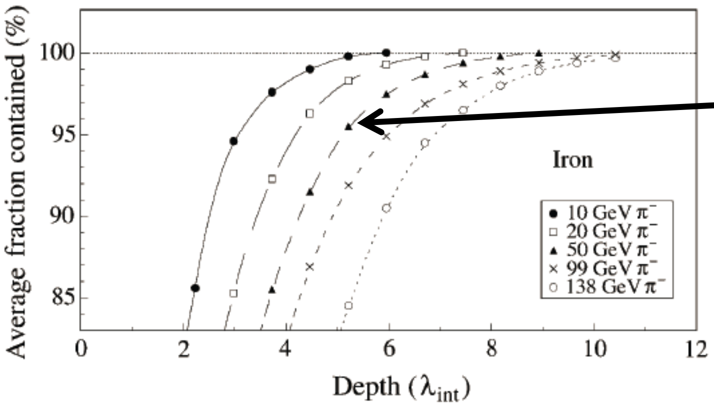
HCal vs HCal


Resolution $\frac{\Delta E}{E}$
Resolution of ECAL + HCAL
hadron, $\frac{\Delta E}{E} = \frac{0.58 \pm 0.04}{\sqrt{E}} + 0.015 \pm 0.015$
electron, $\frac{\Delta E}{E} = \frac{0.11 \pm 0.007}{\sqrt{E}} + 0.007 \pm 0.002$
electron no beam spread, $\frac{\Delta E}{E} = \frac{0.103 \pm 0.005}{\sqrt{E}}$ + 0.01
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
5
10
15
20
25




σ/E
ged pion
ron
$\frac{0.88}{\sqrt{E}} \oplus 0.13$
$\frac{0.53}{\sqrt{E}} \oplus 0.10$
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
10
20
30
40
50
60
Beam momentum [GeV/c)]

SF variations & energy leakage



R.Wigmans, Scientifica Acta 2, 1, 18-55 (2008)

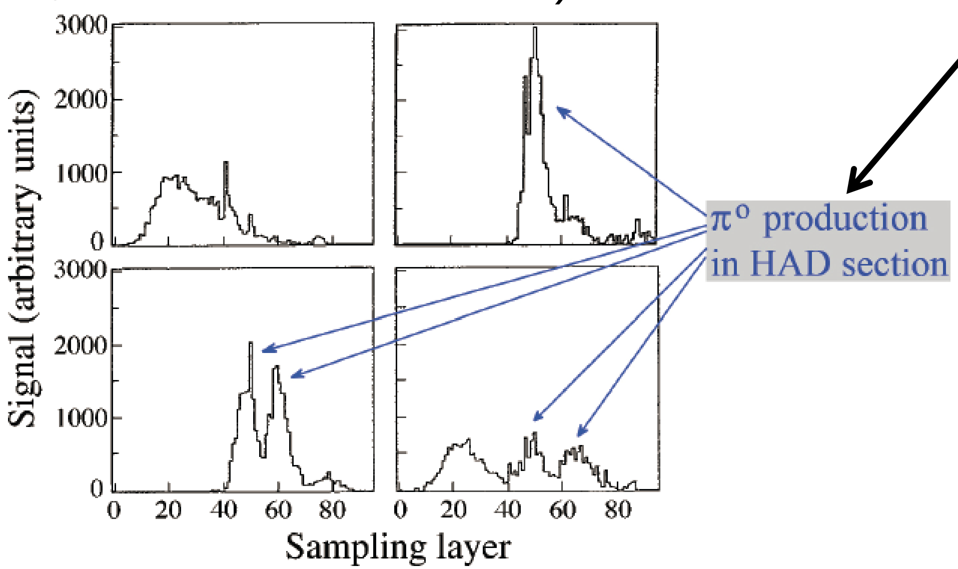


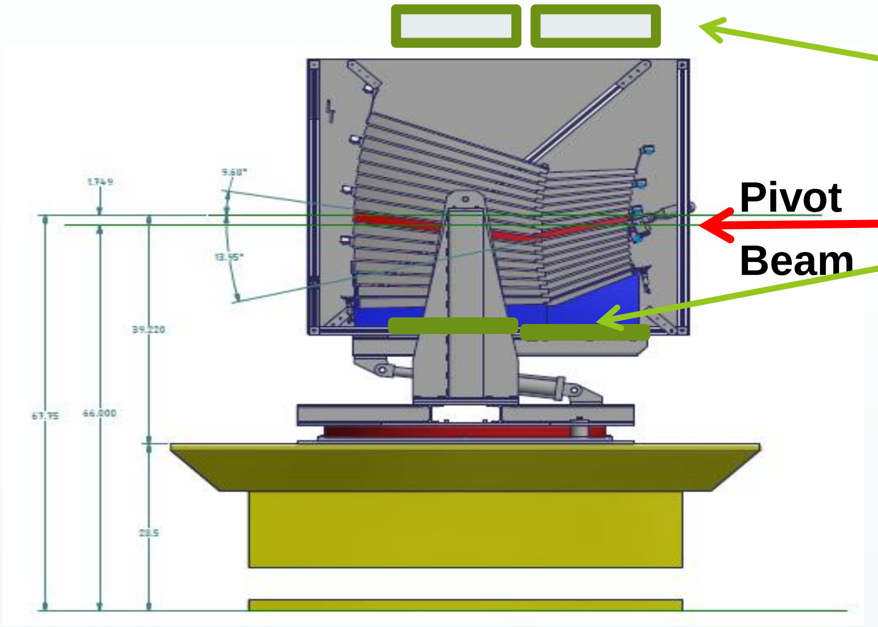
Fig. 7: Longitudinal profiles for 4 different showers induced by 270 GeV pions in a lead/iron/plastic-scintillator calorimeter [5].

Tested prototype is only 5 Labs deep. Energy leakage exceeds 5% for energies above 30GeV contributing comparably to constant term in energy resolution.

In the calorimeter section with depth dependent sampling fraction the fluctuations in the shower profile may lead to overestimates to upstream energy and underestimates to downstream energy. The asymmetry estimator (E1-E2)/(E1+E2) then becomes neither linear nor unambiguous function of LCG.

Measuring LCG and correcting leakage and shower fluctuations needs better constrained data (EMC or third longitudinal segment) , minimizing the scale of SF variations (optimization to segment boundaries) and corrections. We are working on it.

Constant term and tilt plates geometry

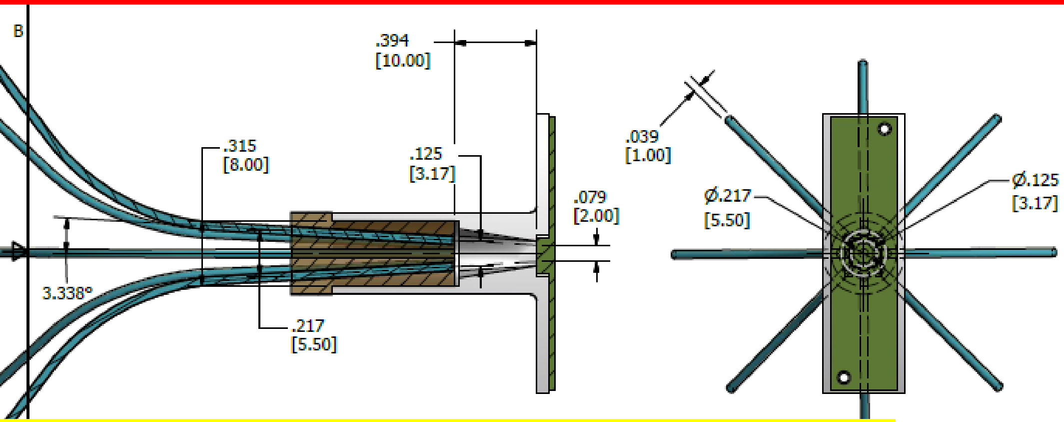


Plates in the HCal are tilted at an angle chosen to keep the number of scintillating tiles crossed by geantino independent of azimuth. In the prototype the sampling fraction:

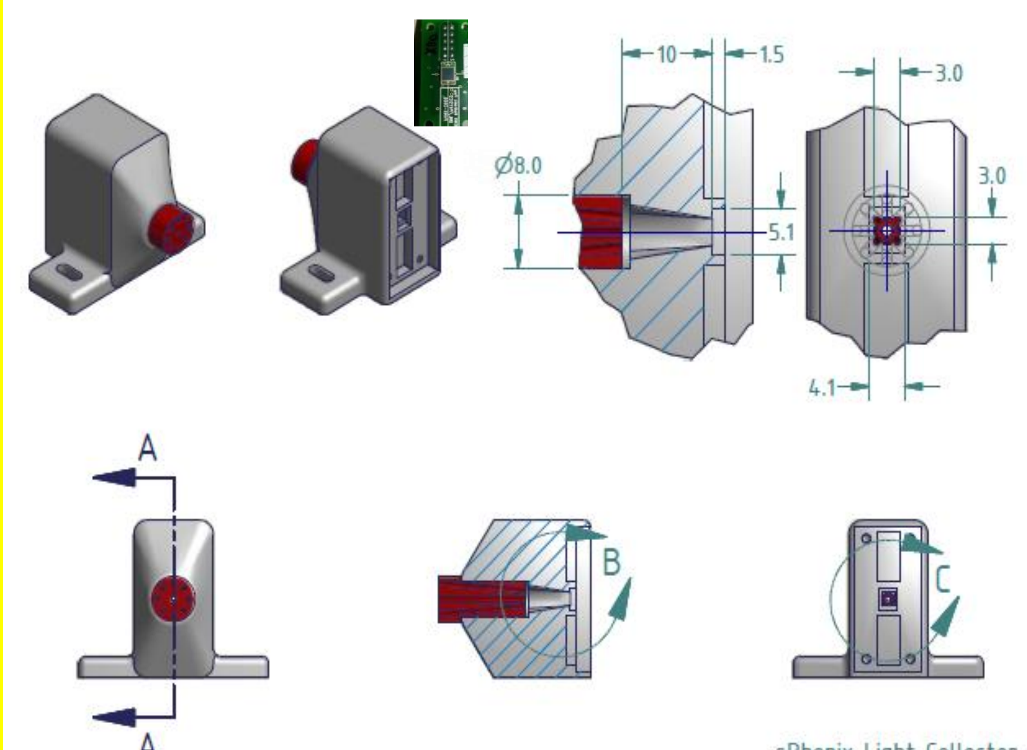
- drops by x1.4 towards outside due to increases in Fe plate thickness;
- varies by ~15% azimuthally with the angle between radius and scintillating tile at crossings;

Two effects are mutually compensating and tunable using the light collection controls. We are working on it.

Constant term and consistency of light collection



- 3D printing is neither precise, nor repeatable;
- Parts need further machining to match;
- Surface reflectivity inside cavity is unknown.;
- Air gap coupling is plainly not practical when light yield and consistency are essential. We are looking into one SiPPM per tile solution.



Summary

- **The calorimeters for sPHENIX are conceived to be intrinsically uniform devices with minimal dead-areas and fit to build in industry;**

-**Prototype calorimeters are built and tested with e's & hadrons at FNAL.** ***Test beam data is now compared with simulation;***

- Conclusions and observations based upon test beam performance of the 2012 concept prototype calorimeters are currently used to predict and optimize EMC&HCal system performance in 2014 geometry built around preexisting BaBar superconducting solenoid;

- Plans are for upgraded prototypes in the test beam in 2015.