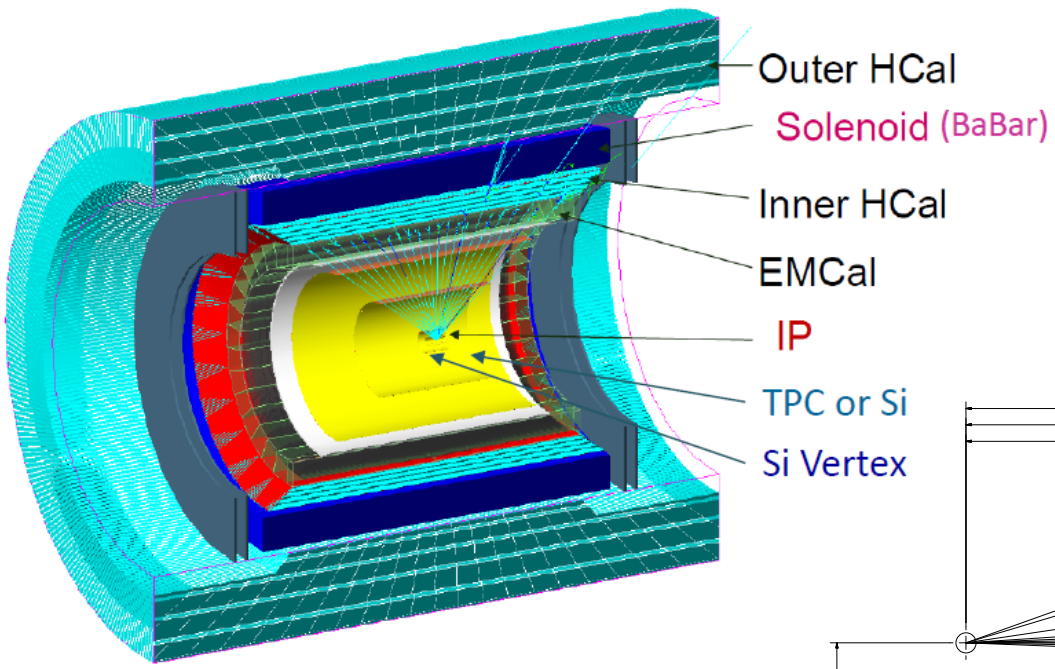
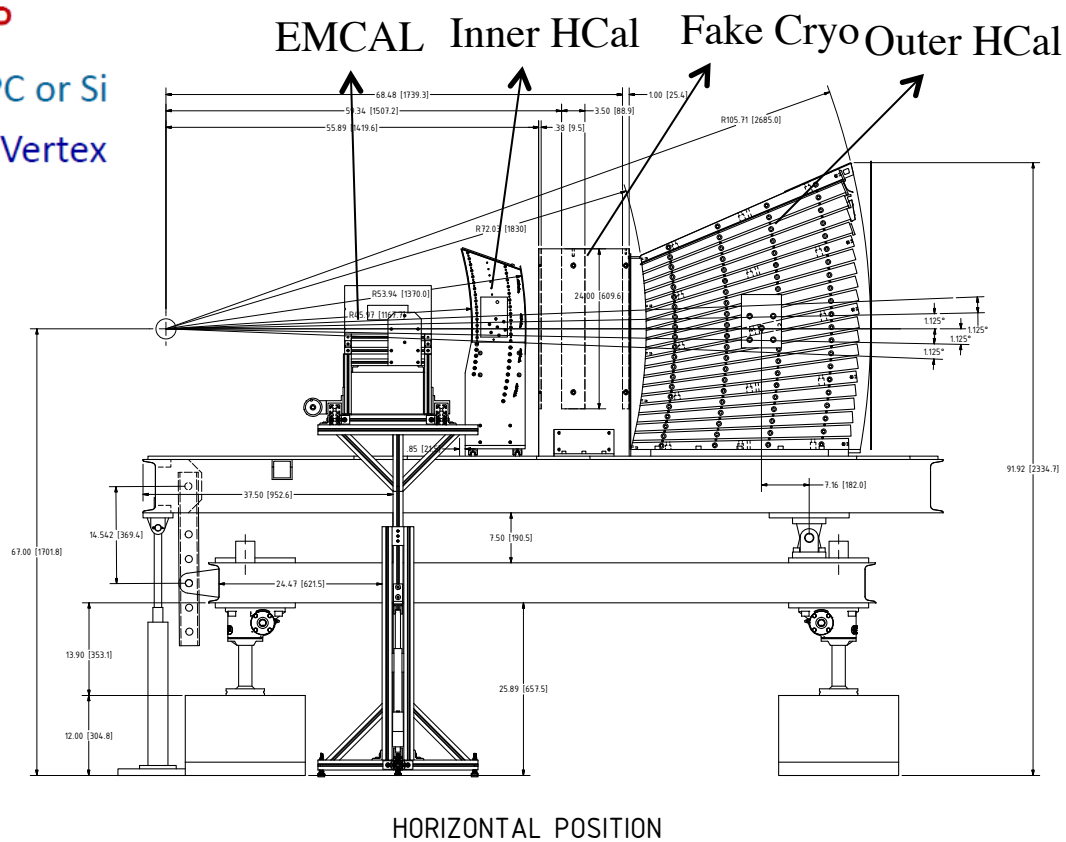
Report from Fermilab Test Beam

Abhisek Sen
Iowa State University

FNAL sPHENIX prototype



A step towards the reality from GEANT



In the month of April, 2016 we took a prototype of the sPHENIX calorimeters to Fermilab for testbeam.

Goals of the testbeam

- Test our GEANT design in real life
- Proof of principle of the calorimetry
  - Geometry
  - SiPMs
  - Bias control
  - Gain stabilization
  - Waveform digitizing
  - Readout electronics
  - Utilization of existing infrastructure for sPHENIX
- Light outputs from EMCAL and HCAL.
- Test agreement with GEANT Monte Carlo in a real calorimeter (sampling fraction, linearity, angle).
- Measure energy resolution for both calorimeters.
- Measure e/h.

R&D history

- Multiple workfests over last few years.
- First beam test of concepts for HCAL and EMCAL Feb 5-26, 2014 in T-1044 at FTBF
- Just finished second prototype test of HCAL and EMCAL beam test at Fermilab April 4-May 3, 2016
- Ongoing at BNL: Cosmic ray testing of HCAL tiles and EMCAL towers, manufacturing trials
- Third prototype test is scheduled on January 2017 at Fermilab (tentative!).
- R&D Personal:

EMCAL: Craig Woody, Sean Stoll, Anne Sickles, Vera Loggins, Jin Huang, Martin Purschke, Chris Cullen
HCAL: John Haggerty, John Lajoie, Edward Kistenev, Xiaochun He, Megan Connors, Jamie Nagle, Ron Belmont, Abhisek Sen
Electronics: Steve Boose, Sal Polizzo, Cheng-Yi Chi, Eric Mannel

T-1044

- FNAL testbeam was called T-1044 experiment.
- Prototype arrived at FNAL: April 1st 2016
- Prototype left FNAL: May 4th 2016
- 32 collaborators contributed to the test beam effort.
- Google pics:
  - https://goo.gl/photos/wJzu9KgkwbJHcdsj9
- Data at RCF:
  - /sphenix/data/data01/t1044-2016a/fnal
- Wiki page:
  - https://wiki.bnl.gov/sPHENIX/index.php/T-1044
- Detector configuration details:
  - https://docdb.sphenix.bnl.gov/cgi-bin/private/ShowDocument?docid=25

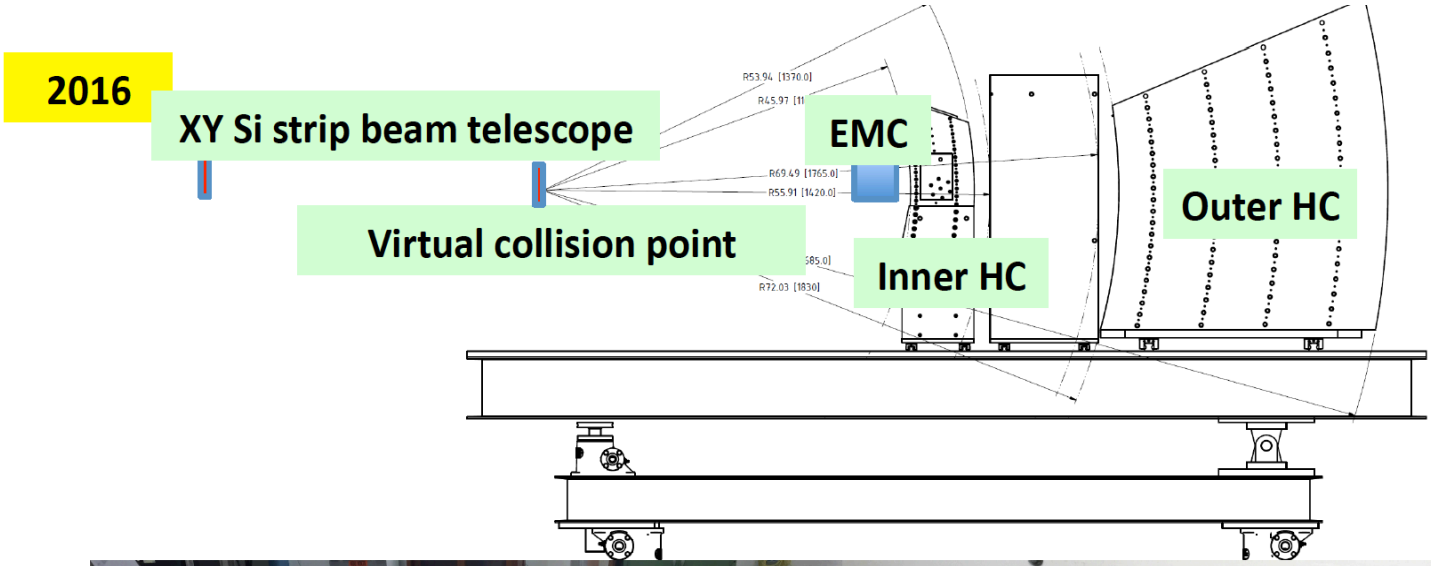
Complementary efforts:
TPC/Cerenkov prototype: T-1036 (sPHENIX/EIC)
Fast TOF/PID-Aerogel/Silicon Tracking: T-1048 (fsPHENIX/EIC)

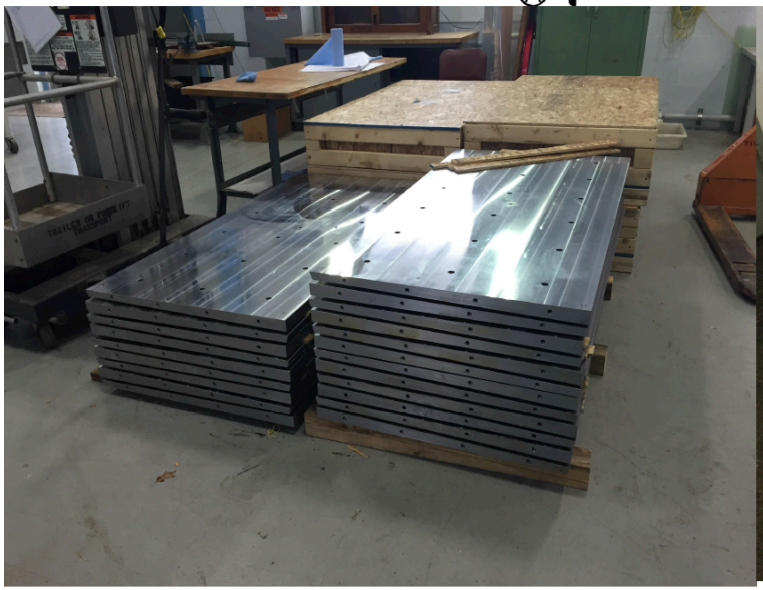
Collaborators at FNAL

John Haggerty (BNL)	Eric Mannel (BNL)
Jin Huang (BNL)	Craig Woody (BNL)
Martin Purschke (BNL)	Ed O'Brian (BNL)
Megan Connors (GSU)	Sean Stoll (BNL)
Bob Azmoun (BNL)	Abhisek Sen (ISU)
Ron Belmont (CU)	Bardia Nadim (UM)
Mickey Chiu (BNL)	Edouard Kistenev (BNL)
Xiaochun He (GSU)	Steve Boose (BNL)
Vera Loggins (UIUC)	Balazs Ujvari (UD)
Tamas Majoros (UD)	Sal Polizzo (BNL)
Murad Sarsour (GSU)	Frank Toldo (BNL)
Anne Sickles (UIUC)	Carter Biggs (BNL)
Mike Skoby (UM)	S. Vazquez-Carson (CU)
Timothy Rinn (ISU)	John Lajoie (ISU)
Achim Franz (BNL)	Ed Desmond (BNL)
Kolja Kauder (WSU)	Mike Lenz (BNL)

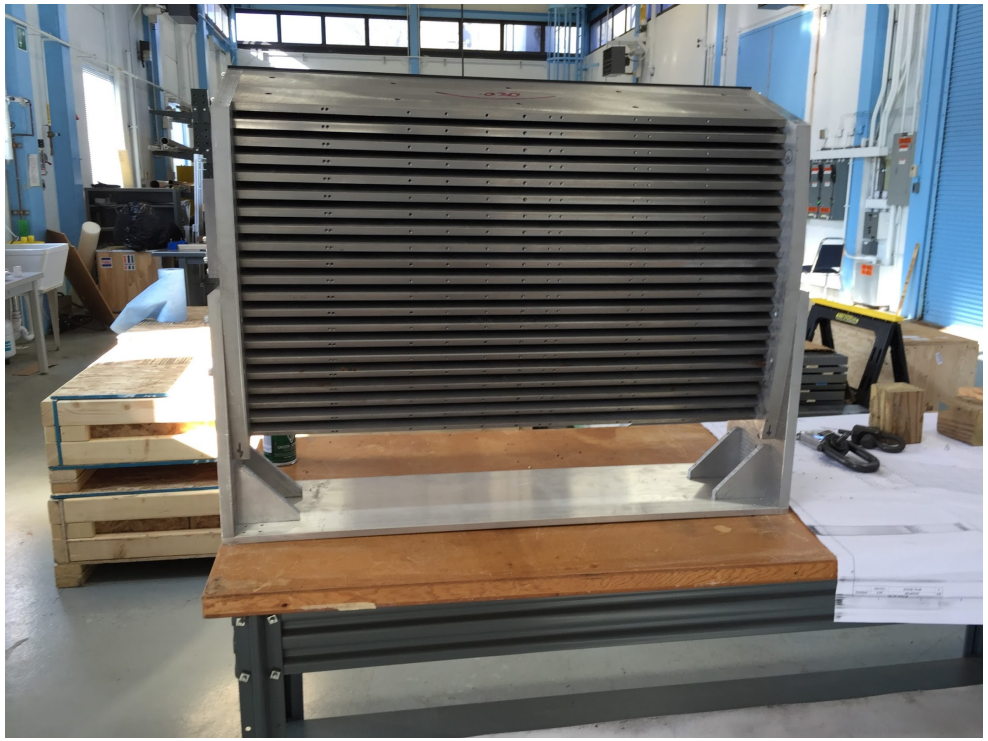
32 Collaborators
from 8 Institutions

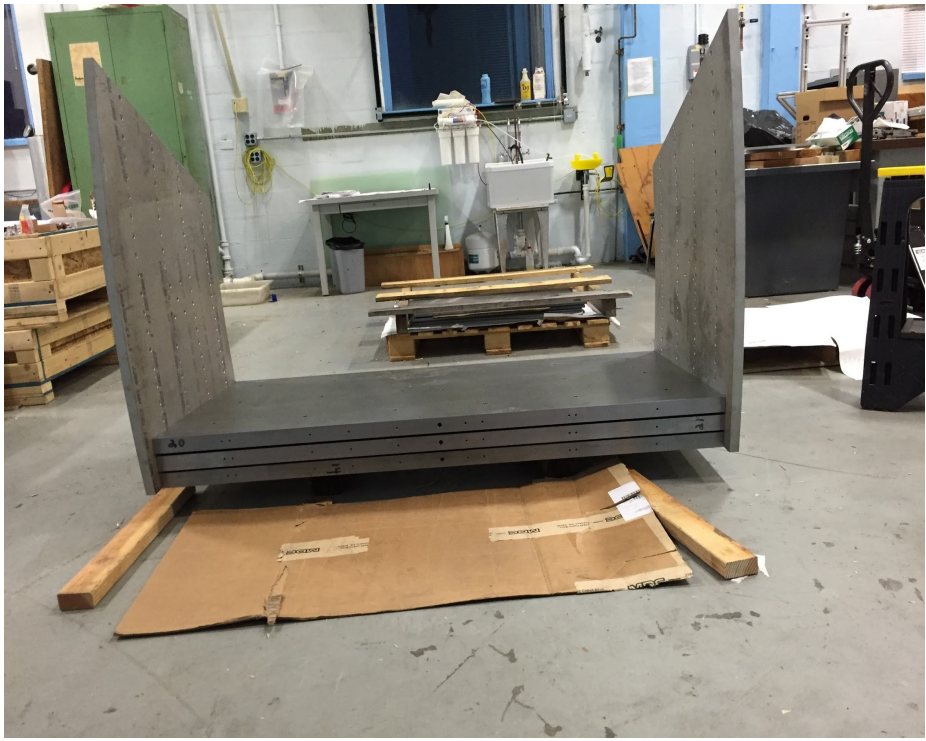
T-1044


2016
XY Si strip beam telescope
EMC
Virtual collision point
Inner HC
Outer HC
R53.94 [1370.0]
R69.49 [1765.0]
R55.91 [1420.0]
R72.03 [1830]



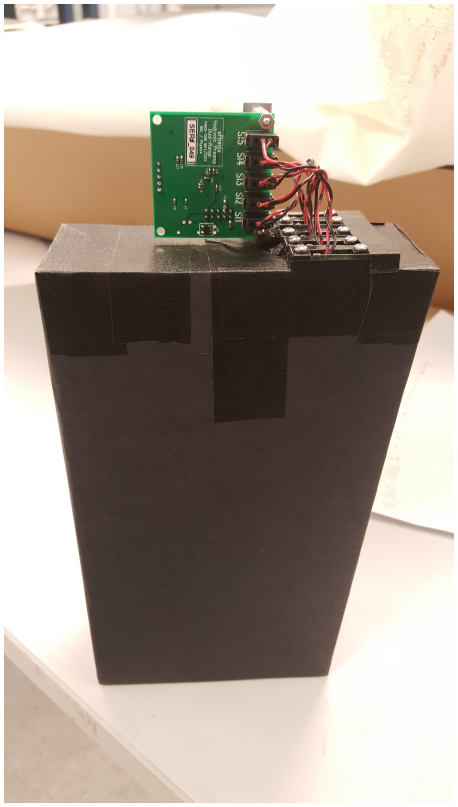
T-1044



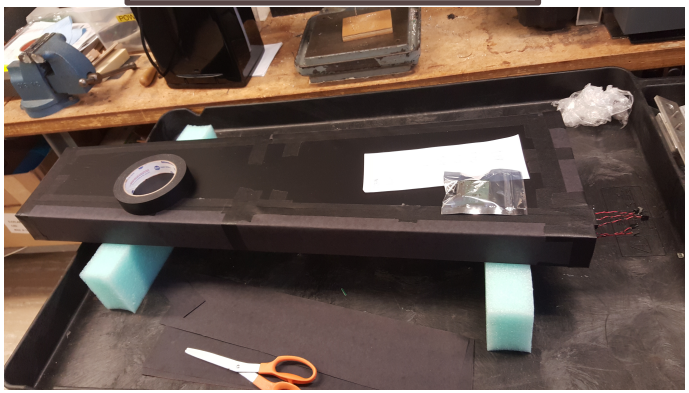


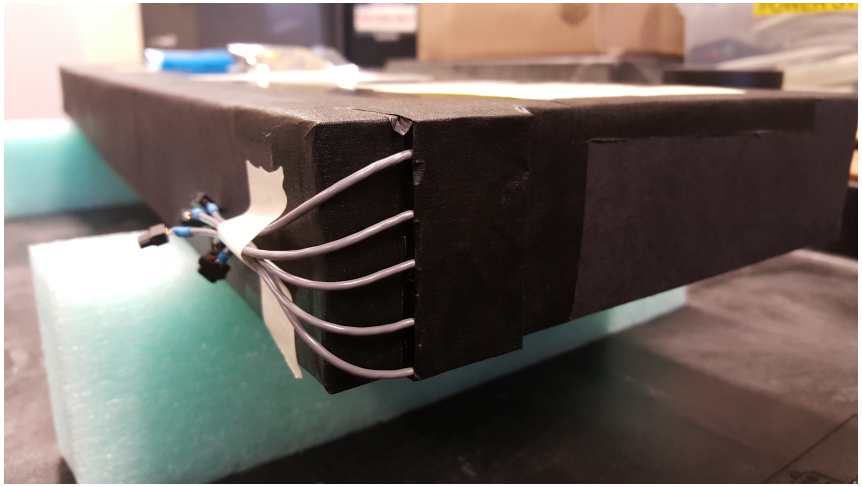
T-1044

Inner Hcal Tower



Outer Hcal Tower





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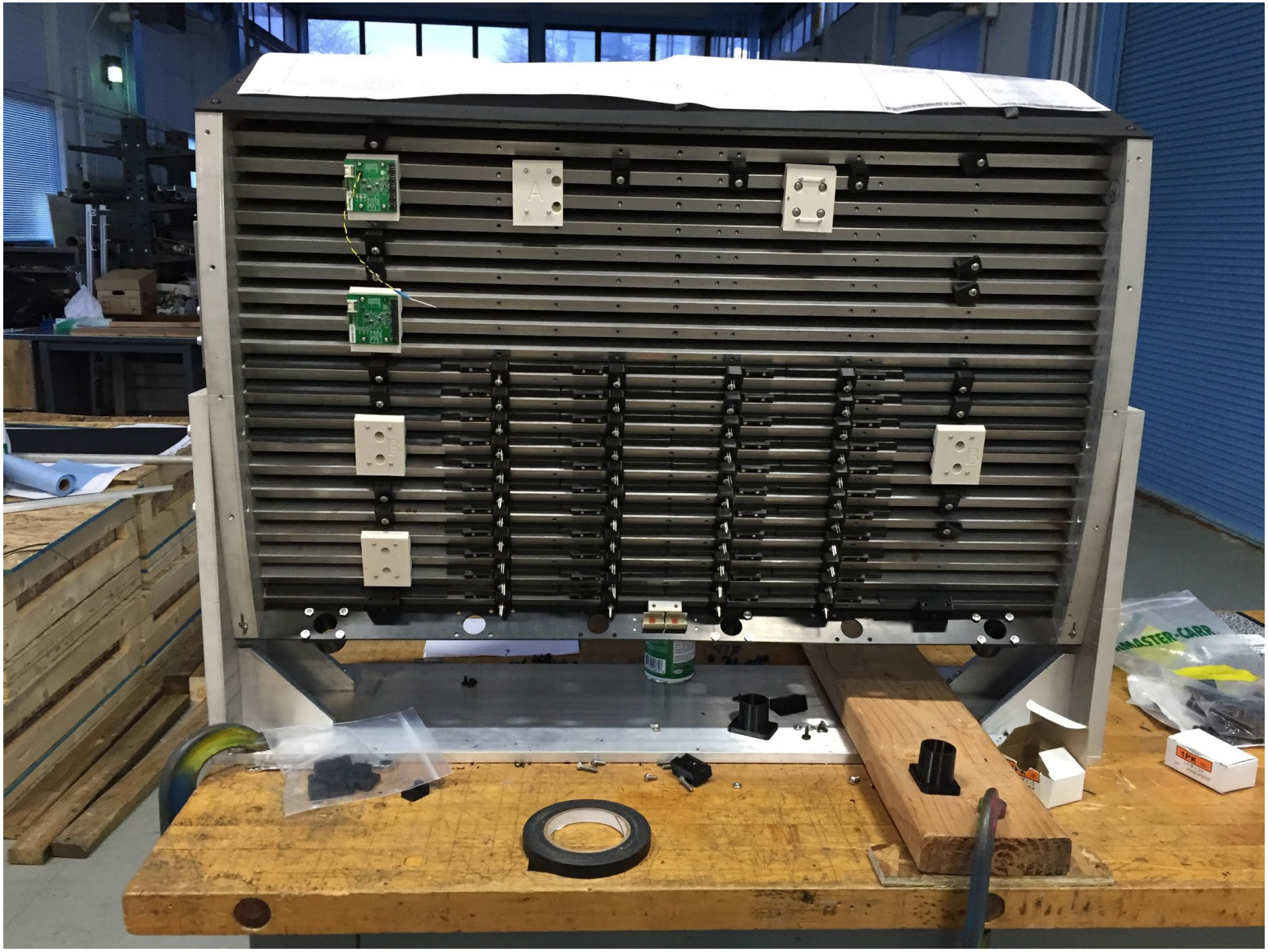
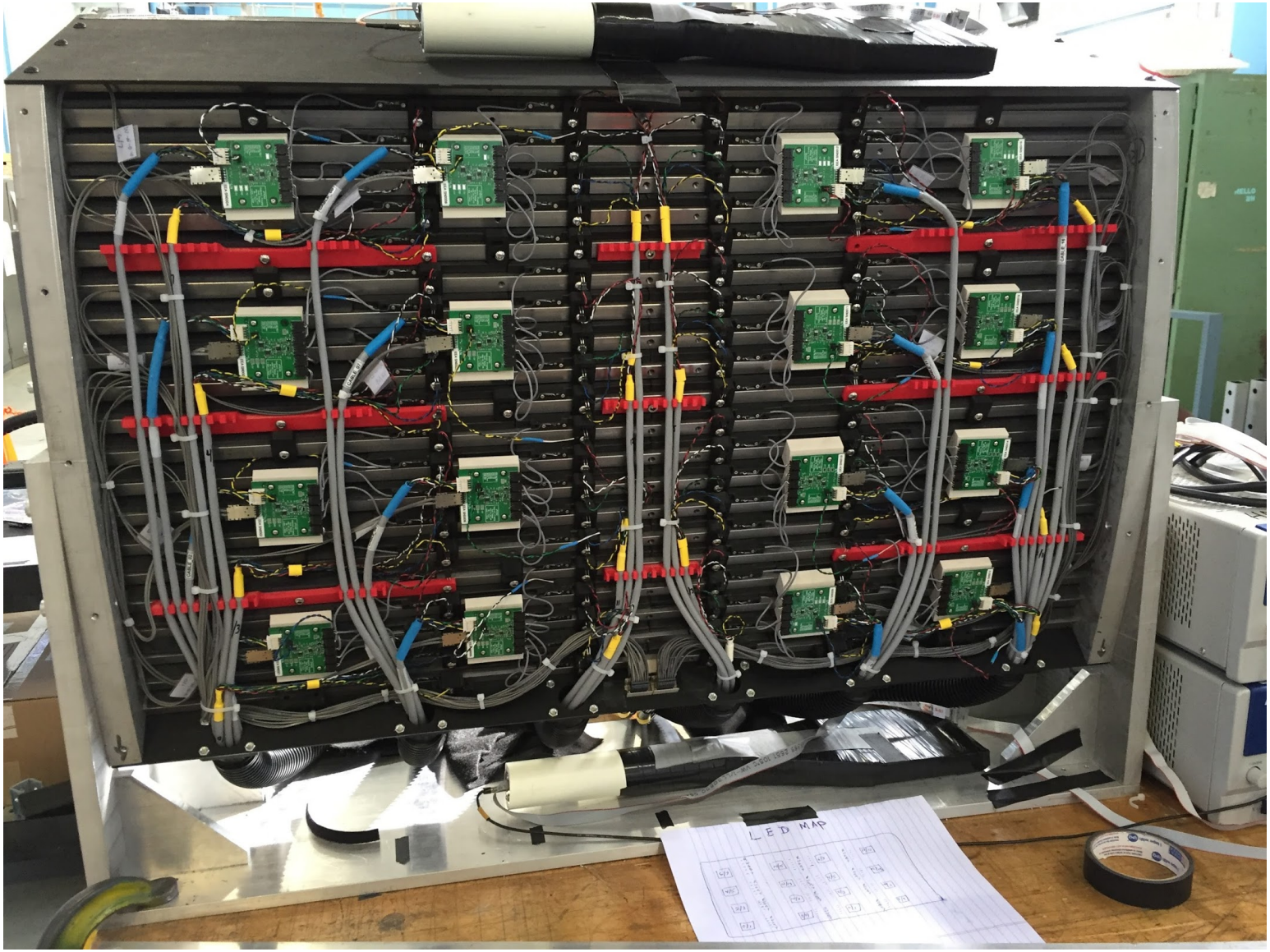


T-1044

T-1044



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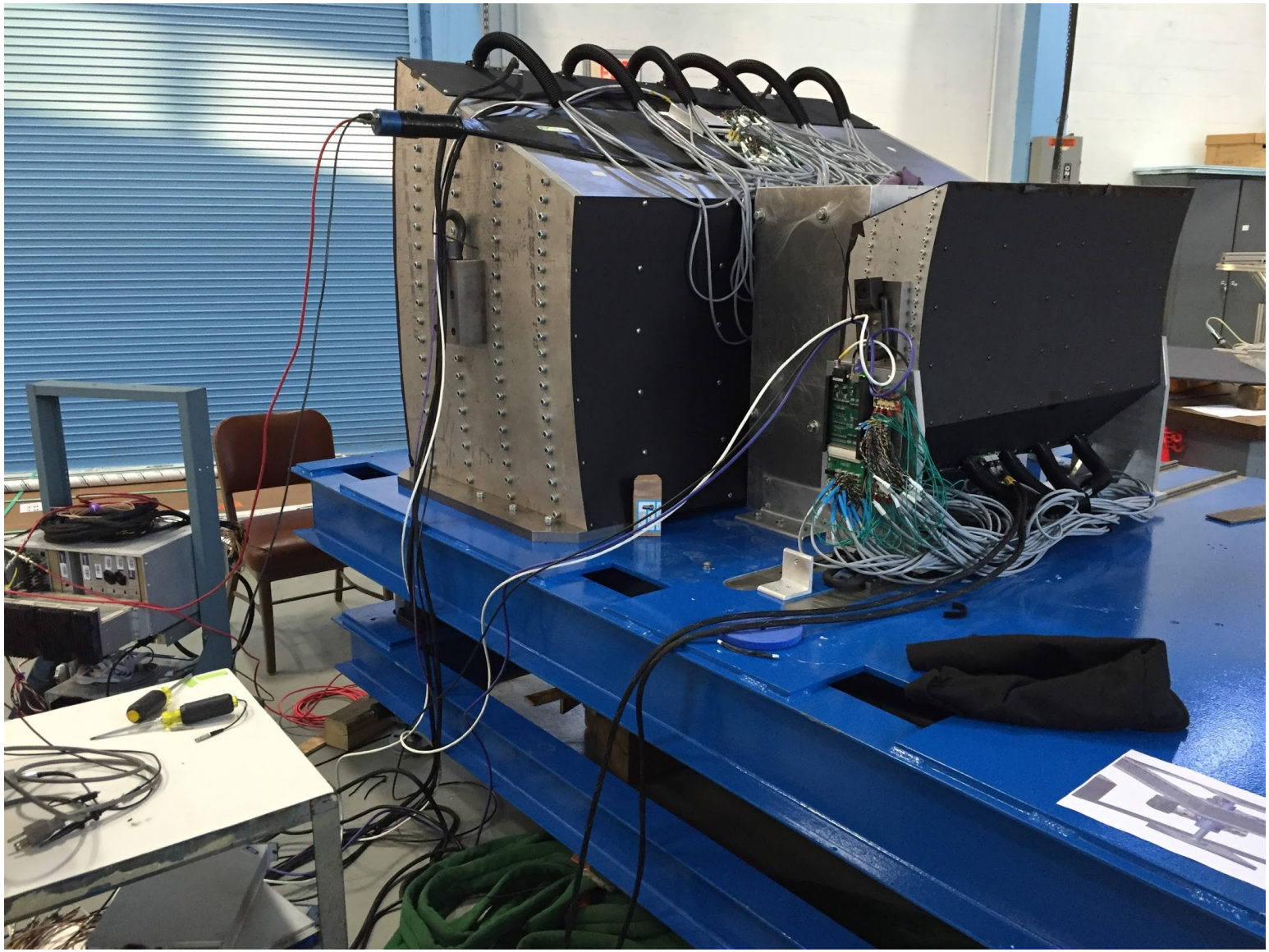

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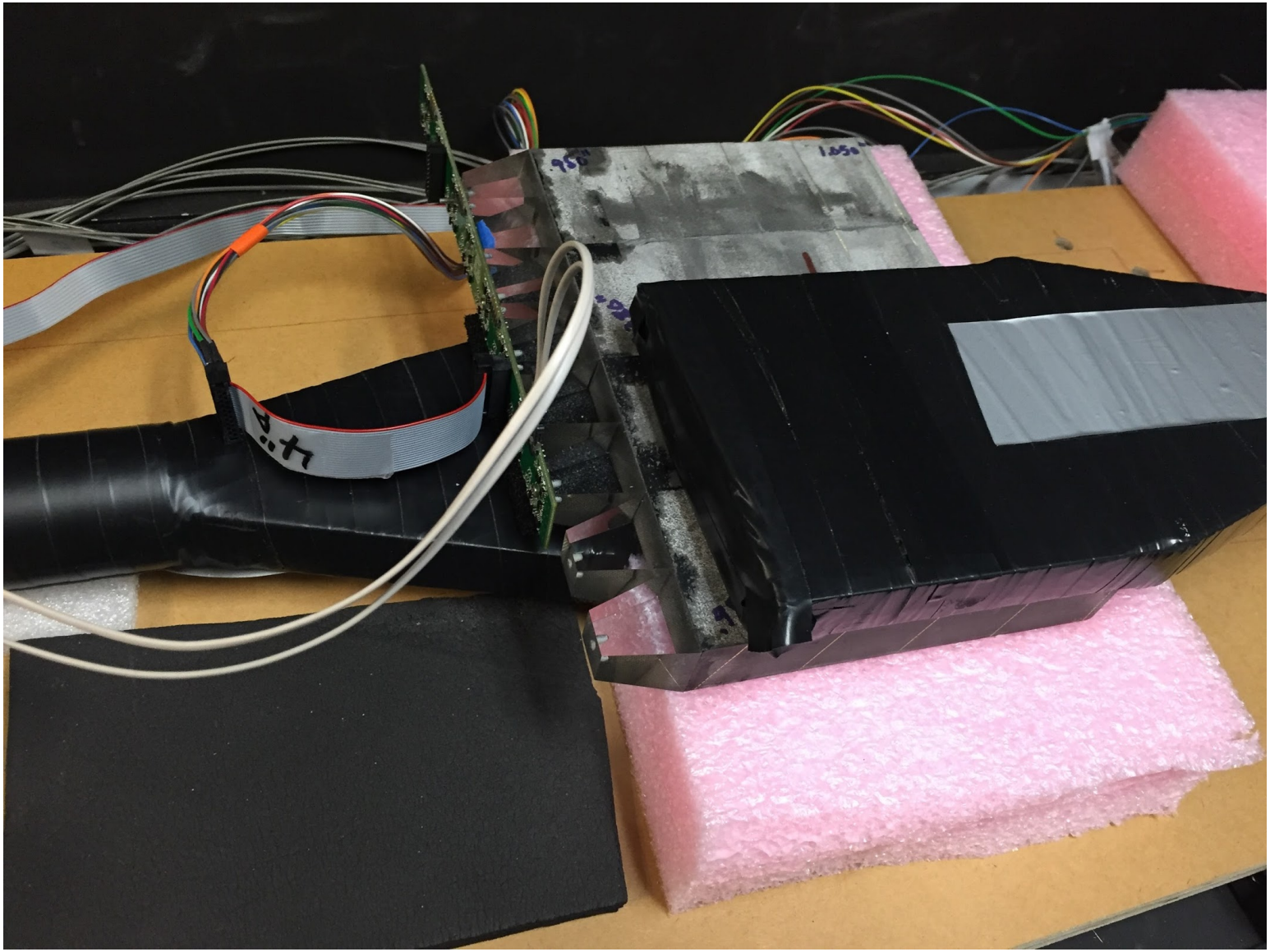

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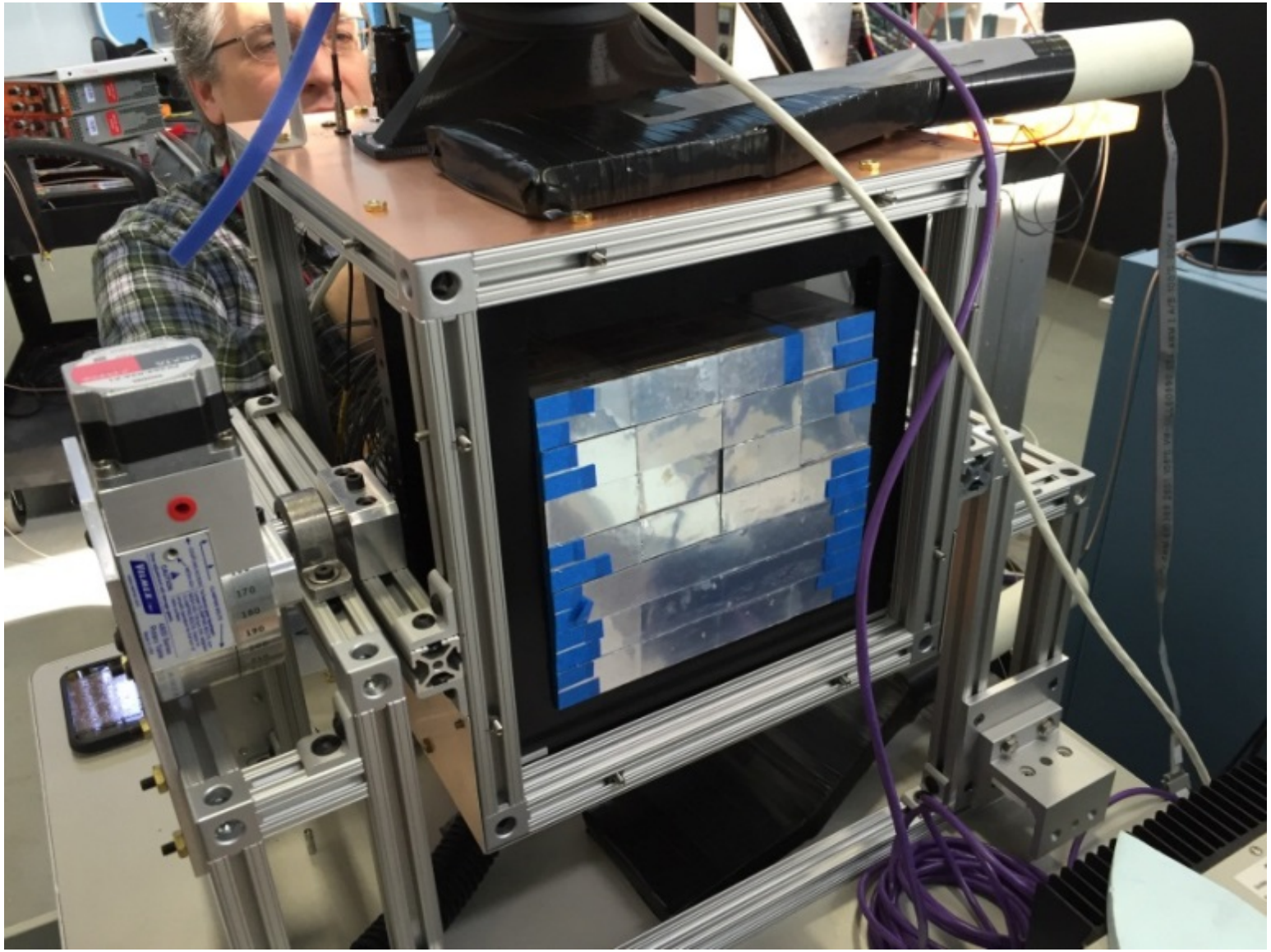

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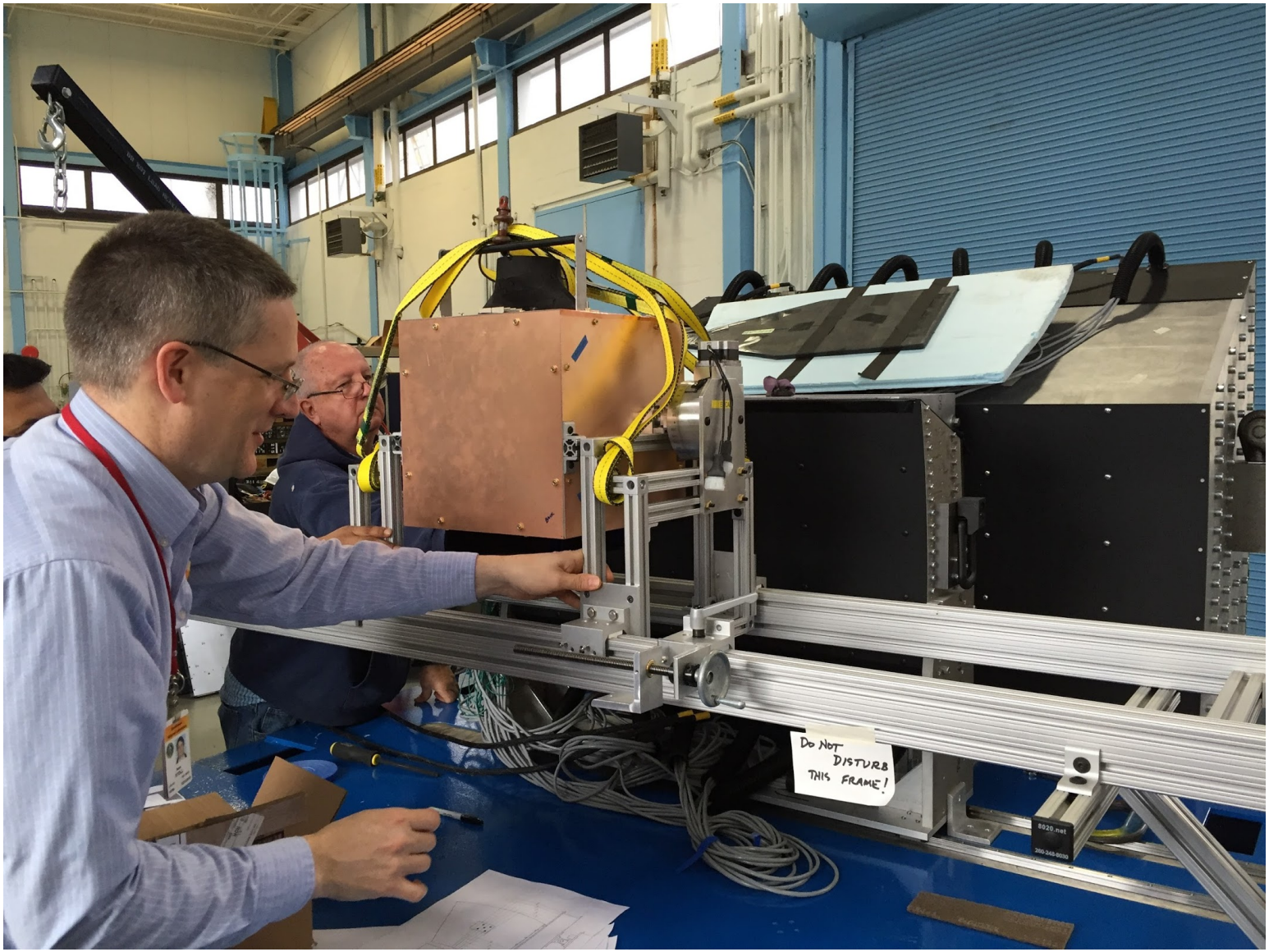


T-1044

T-1044

T-1044

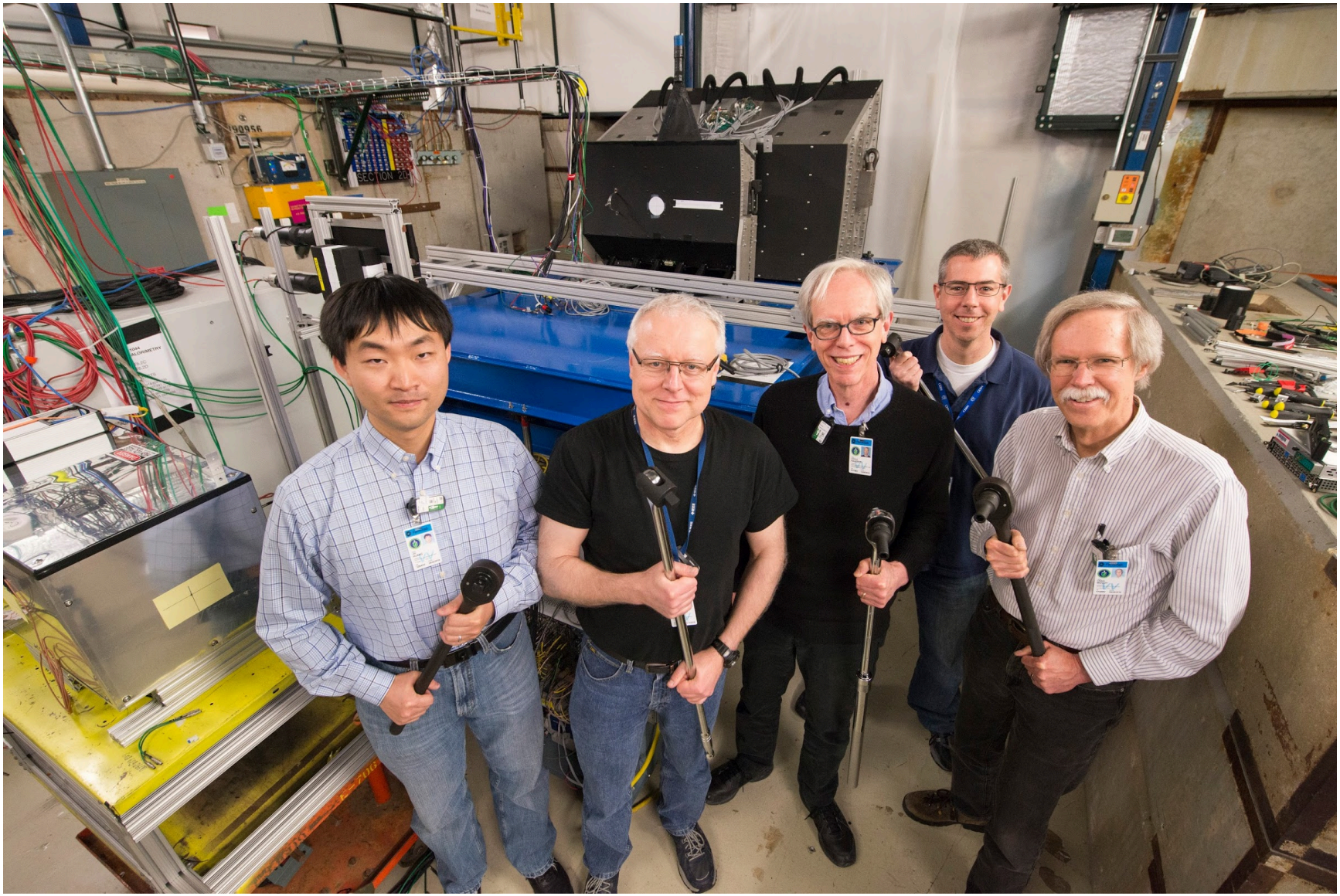
T-1044

Status
Energy: -8 GeV
Mode: Low E Pion
MT6SC2
538 Cnts
MT6SC3
5097 Cnts
MT6SC4
0 Cnts
2800 Cnts
0 Cnts
4 Sec
sPHENIX IHCAL Monitor
Status:
Running
Run number:
2038
sPHENIX OHCAL Monitor
Status:
Running
Run number:
2038
sPHENIX EMCAL Monitor
Status:
Running
Run number:
2038
DELL

T-1044

T-1044

T-1044



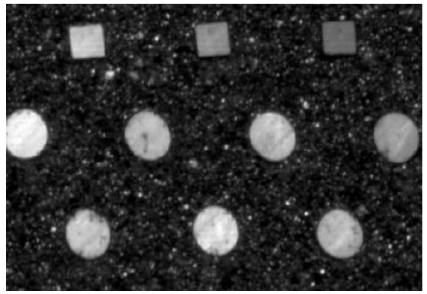
EMCAL

W/SciFi SPACAL (originally developed by Oleg Tsai at UCLA)

Absorber

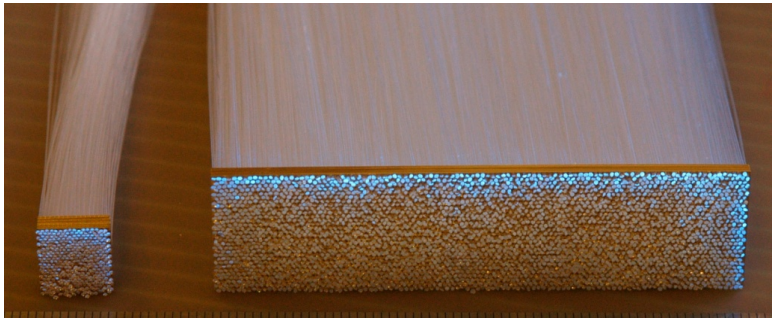
- Matrix of tungsten powder and epoxy with embedded scintillating fibers
- Density ~ 10 g/cm^3
- X_0 ~ 7 mm (18 X_0 total), R_M ~ 2.3 cm
- Energy resolution ~ 12%/$\sqrt{E}$

Powder supplier



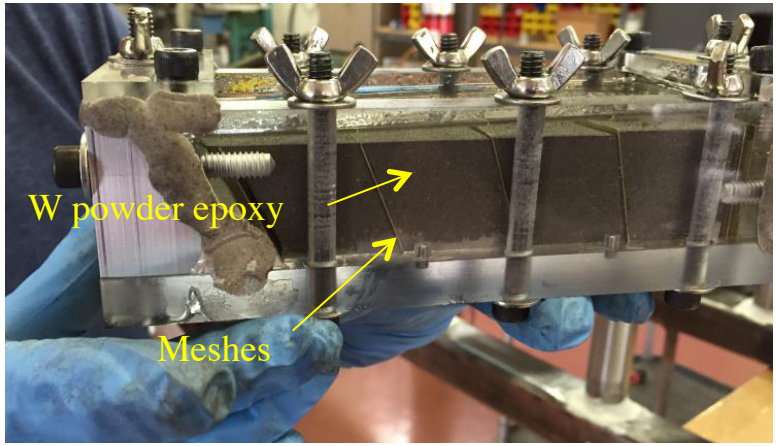
Scintillating fibers (Kuraray SCSF78)

- Diameter: 0.47 mm, Spacing: 1 mm
- Sampling Fraction ~ 2.3 %



- Modules are formed by pouring tungsten powder and epoxy into a mold containing an array of scintillating fibers

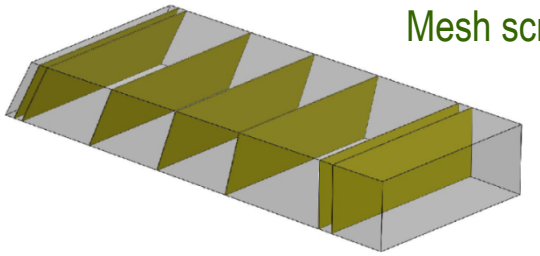
- Fibers are held in position with metal meshes spaced along the module



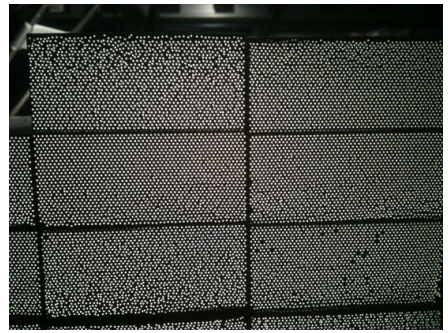
w/SciFi Modules

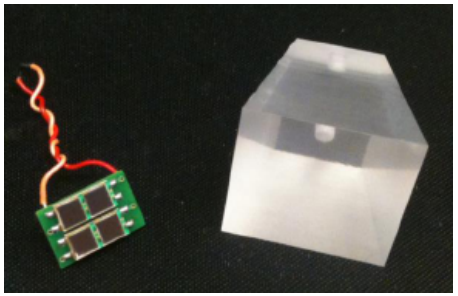
1D Projective

Mesh screens

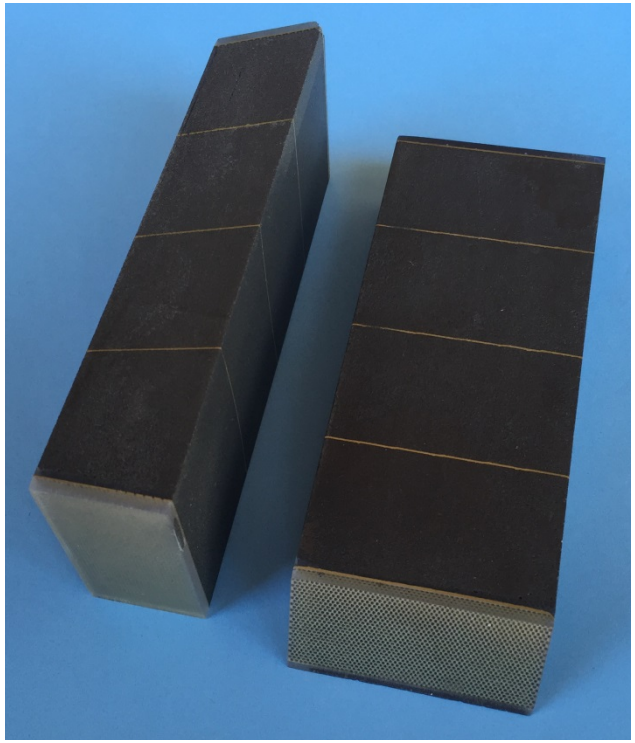


Fiber ends are finished by with fly cutting

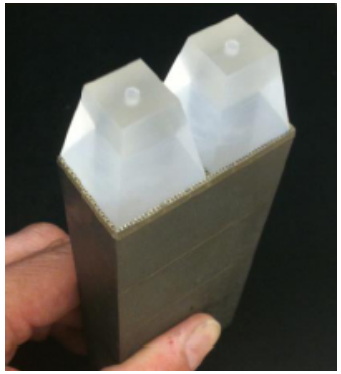




Produced at UCLA, BNL, UIUC and THP



Light guides and SiPMs are attached to module ends to form towers



8x8 array of towers

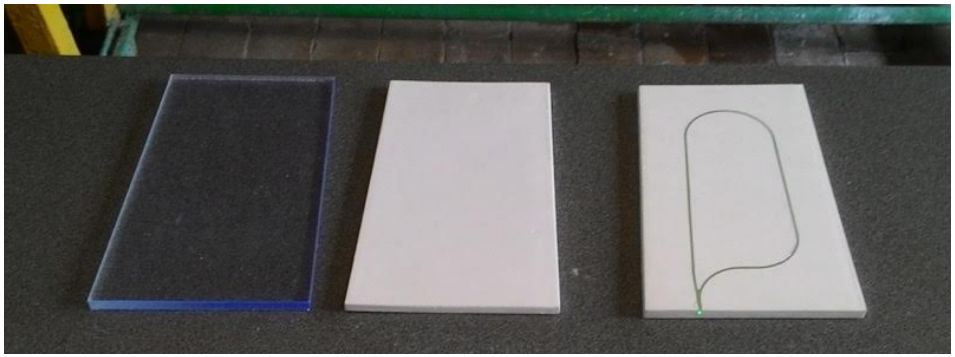
THP 10.2	THP 10.5	THP 8.5	THP 8.5	THP 9.0	THP 9.0	THP 9.8	THP 9.8
THP 9.7	THP 9.7	THP 10.0	THP 10.0	THP 10.0	THP 10.0	THP 9.9	THP 9.9
THP 9.2	THP 9.2	THP 9.8	THP 9.8	THP 9.3	THP 9.3	THP 10.1	THP 10.1
UIUC 9.6	UIUC 9.6	UIUC 9.4	UIUC 9.4	THP 10.1	THP 10.1	THP 9.6	THP 9.6
UIUC 9.5	UIUC 9.5	UIUC 9.5	UIUC 9.5	THP 9.3	THP 9.3	THP 9.3	THP 9.3
UIUC 9.4	UIUC 9.4	UIUC 9.4	UIUC 9.4	UIUC 9.4	UIUC 9.4	UIUC 9.6	UIUC 9.6
UIUC 9.2	UIUC 9.2	UIUC 9.6	UIUC 9.6	UIUC 9.3	UIUC 9.3	UIUC 9.3	UIUC 9.3
UIUC 9.5	UIUC 9.5	UIUC 9.6	UIUC 9.6	UIUC 9.3	UIUC 9.3	UIUC 9.2	UIUC 9.2

Density varied from ~ 8.5 – 10 g/cm^3

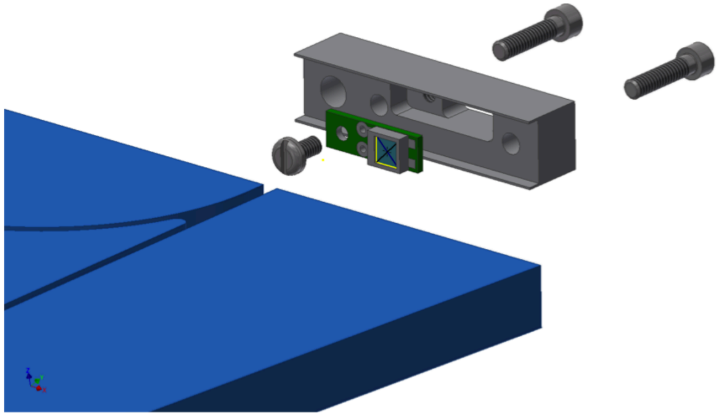
Half of the absorber blocks were manufactured at THP and half at UIUC

HCAL tile preparation

Inner HCAL tiles <SF> = 6.7%



Coupling of the fiber to the SIPM



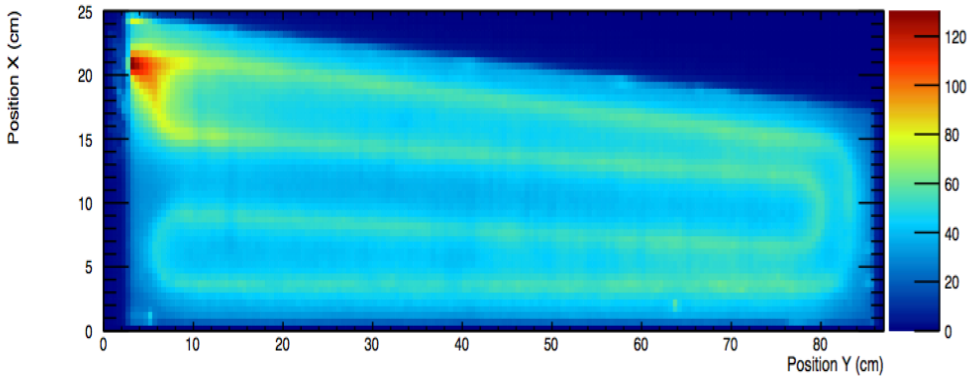
Outer HCAL tiles <SF> = 3.5%

Polystyrene scintillating tiles (7 mm) with WLS fiber (1 mm) in groove. One SiPM reads out both ends of fiber. SiPMs from 5 tiles summed together to form one tower

Sampling fraction changes with depth (~25%)

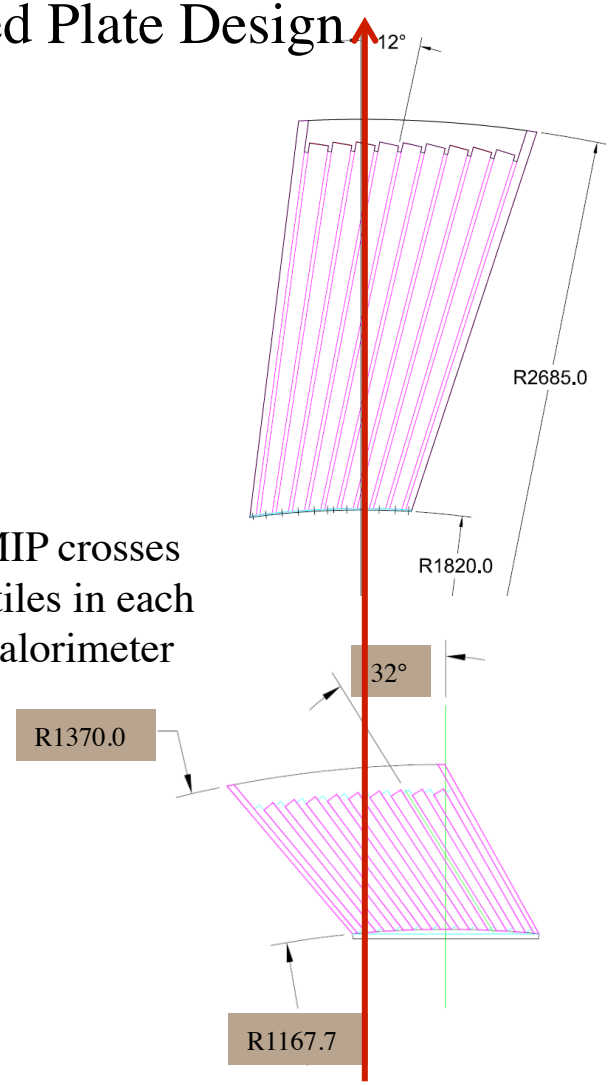
HCAL Prototype

Tile response map with LEDs



Outer HCAL prototype with assembled steel plates and readout electronics

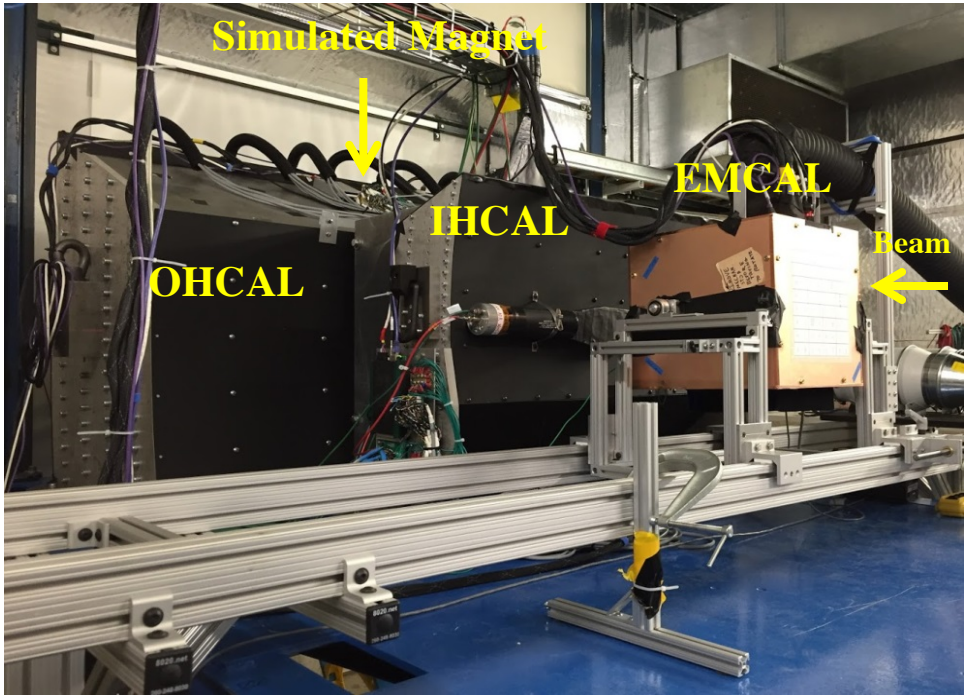
Tilted Plate Design

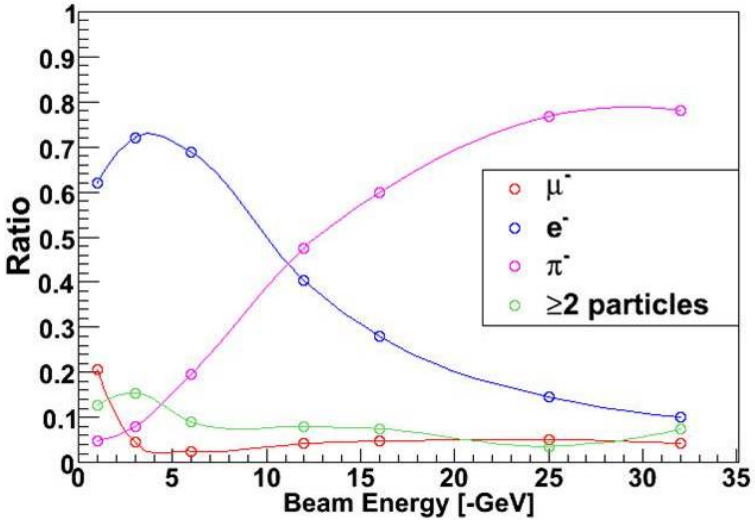


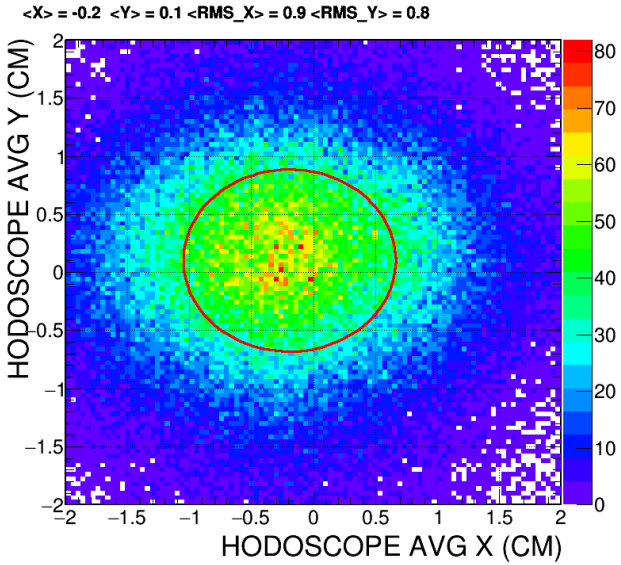
MIP crosses 4 tiles in each calorimeter

Test setup at Fermilab

All three prototype calorimeters in the beam line at Fermilab



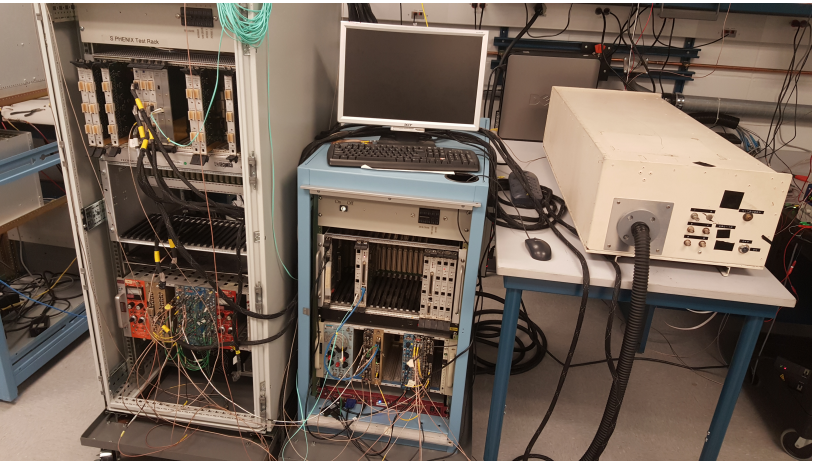


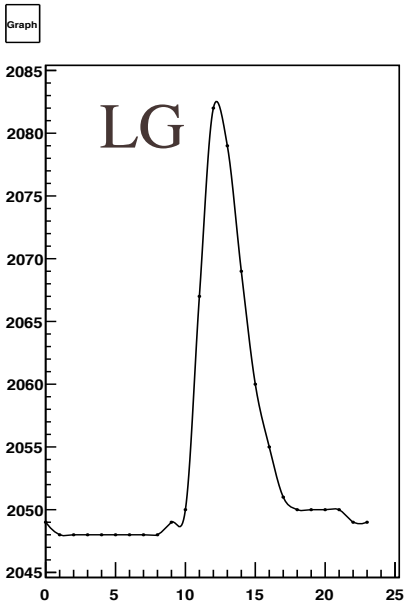


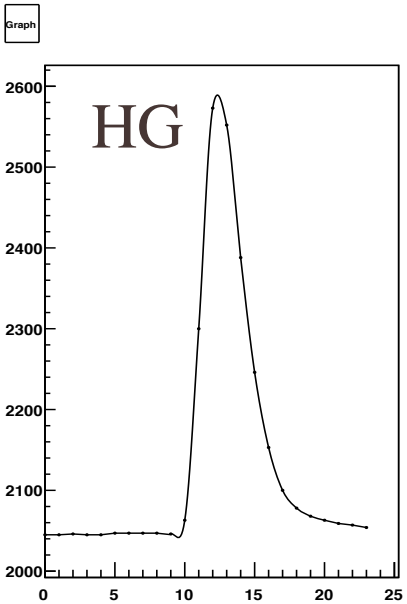
Three calorimeters in their sPHENIX configuration

Some measurements were with EMCAL upstream.
Measured at three tilt angle positions (0, ± 4.5°).

Electronics







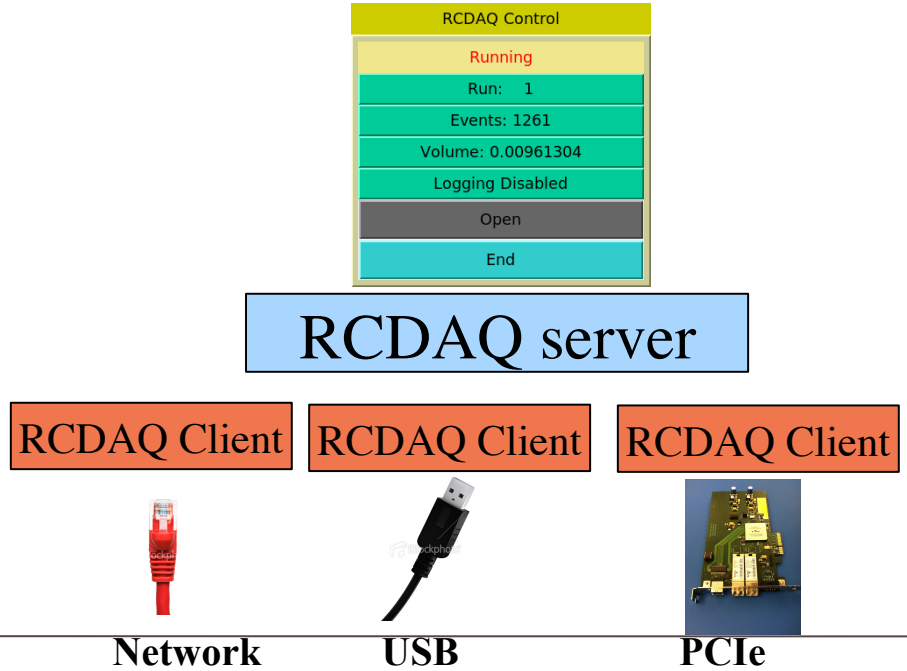
HBD design

- 60 MHz sampling frequency.
- 12 bit ADC.
- 48 channels per board.
- Collects 24 samples.
- Each sample ~16ns, total ~400ns.

EMCAL had gain switchable.
HCAL has both high and low gains.
Inner HCAL: high/low ratio=32
Outer HCAL: high/low ratio=16

RCDAQ

- Developed by Martin Purschke
- Built-in support for online monitoring
- Being used at PHENIX, FermiLab, Medical Imaging groups, CERN RD51, EIC R&D groups, ATLAS
- Ideal data acquisition not only read your detector but records everything: HV, temperature, configuration files, etc

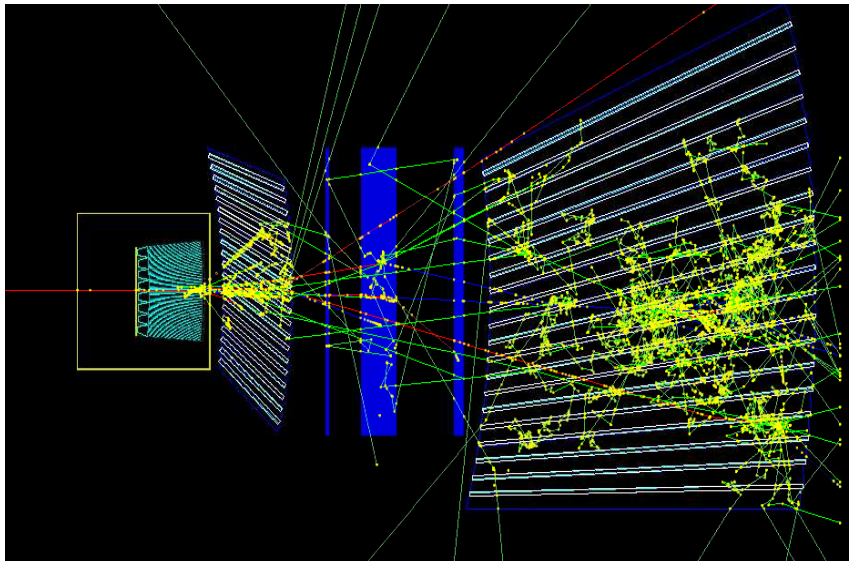


It is scalable and can be controlled from anywhere.

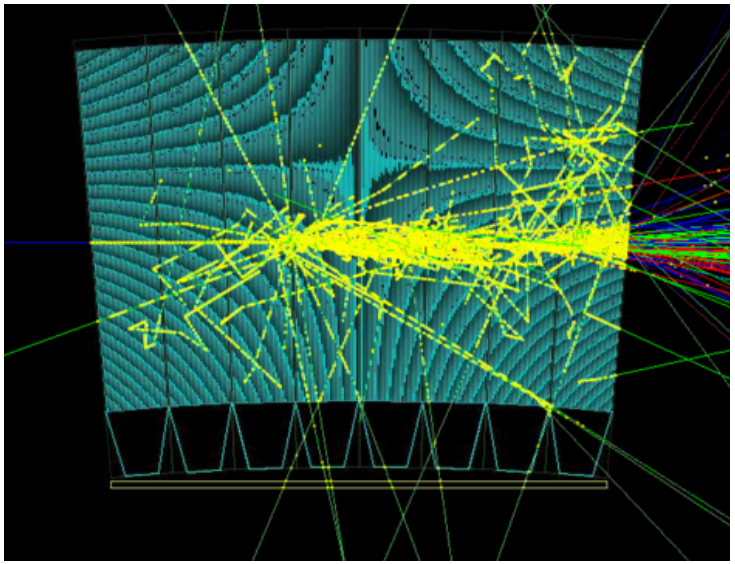
Results

Simulations

Entire test beam setup was simulated in GEANT4



Hadronic shower in 3 calorimeters

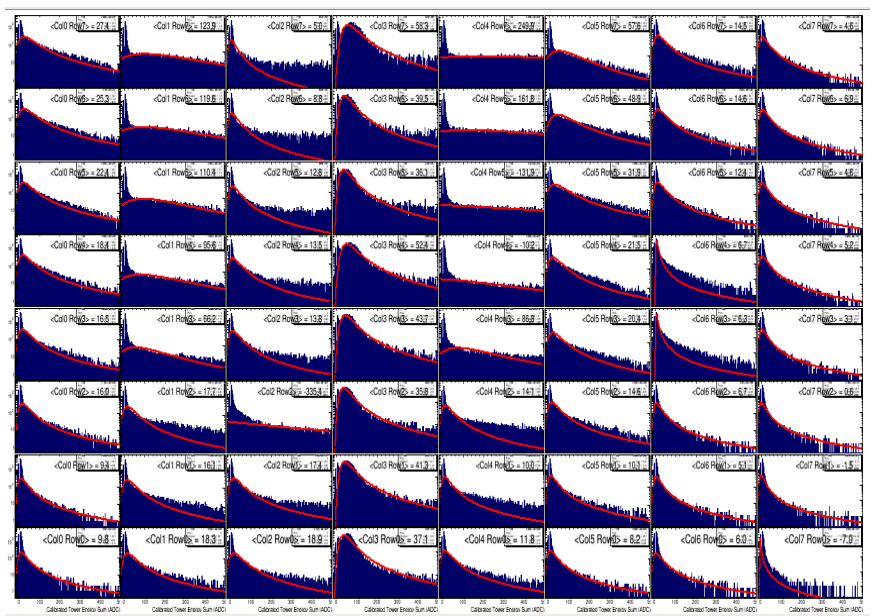


Hadron entering EMCAL in “nose down” position

Calibrations

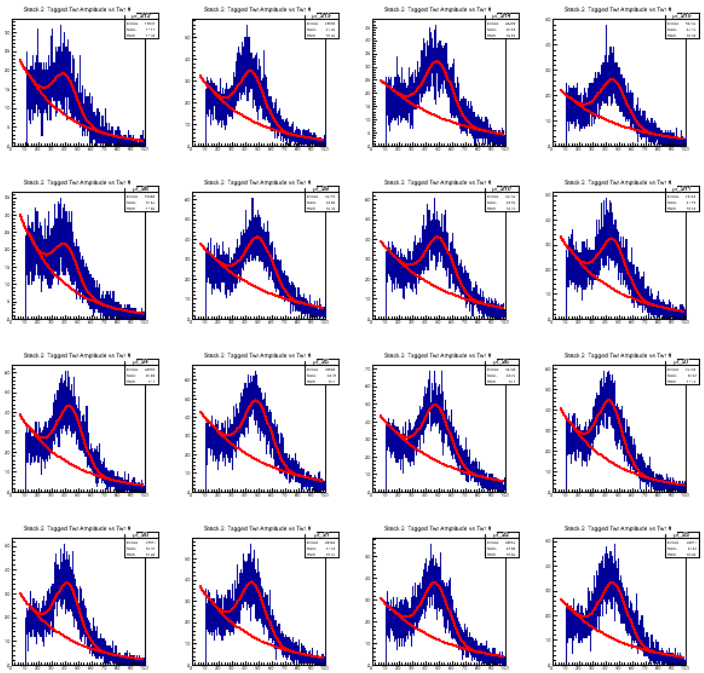
MIP peaks in each detector used to equalize response for each tower and set approximate energy scale

EMCAL calibration done with 120 GeV p's Detector in "nose down" position
Beam passes through 8 towers at a time
Edep ~ 30 MeV per tower
Preamps set to x16 higher gain



Beam

HCAL calibration done with cosmic μ's
Edep ~ 750 Mev/1 GeV (Inner/Outer)
Inner & Outer HCAL done simultaneously
(self triggering w/x16 higher gain)

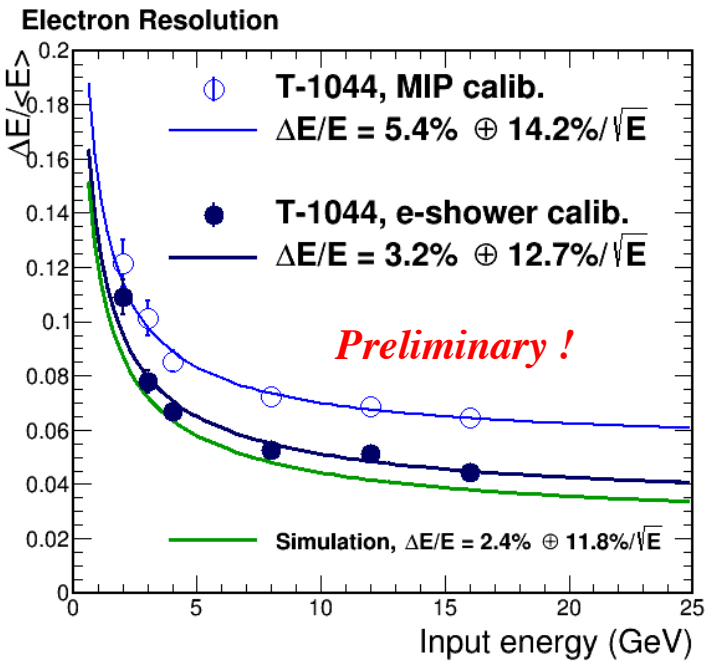


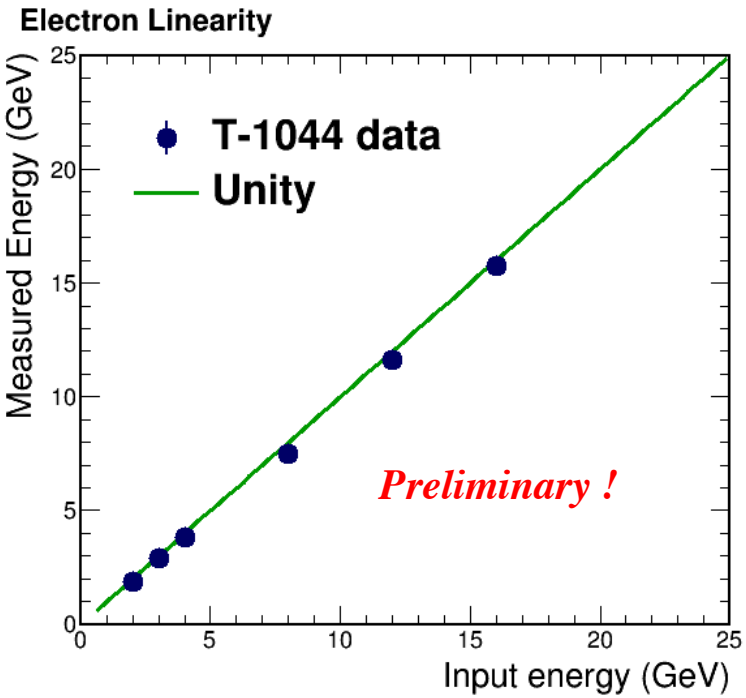
Example of Outer HCAL calibration with cosmic muons

EMCAL Energy Resolution and Linearity

Electrons selected using beam Cherenkovs
(Also require hodoscope hit + no veto hit)

Beam momentum spread of ~ 2% ***not*** unfolded

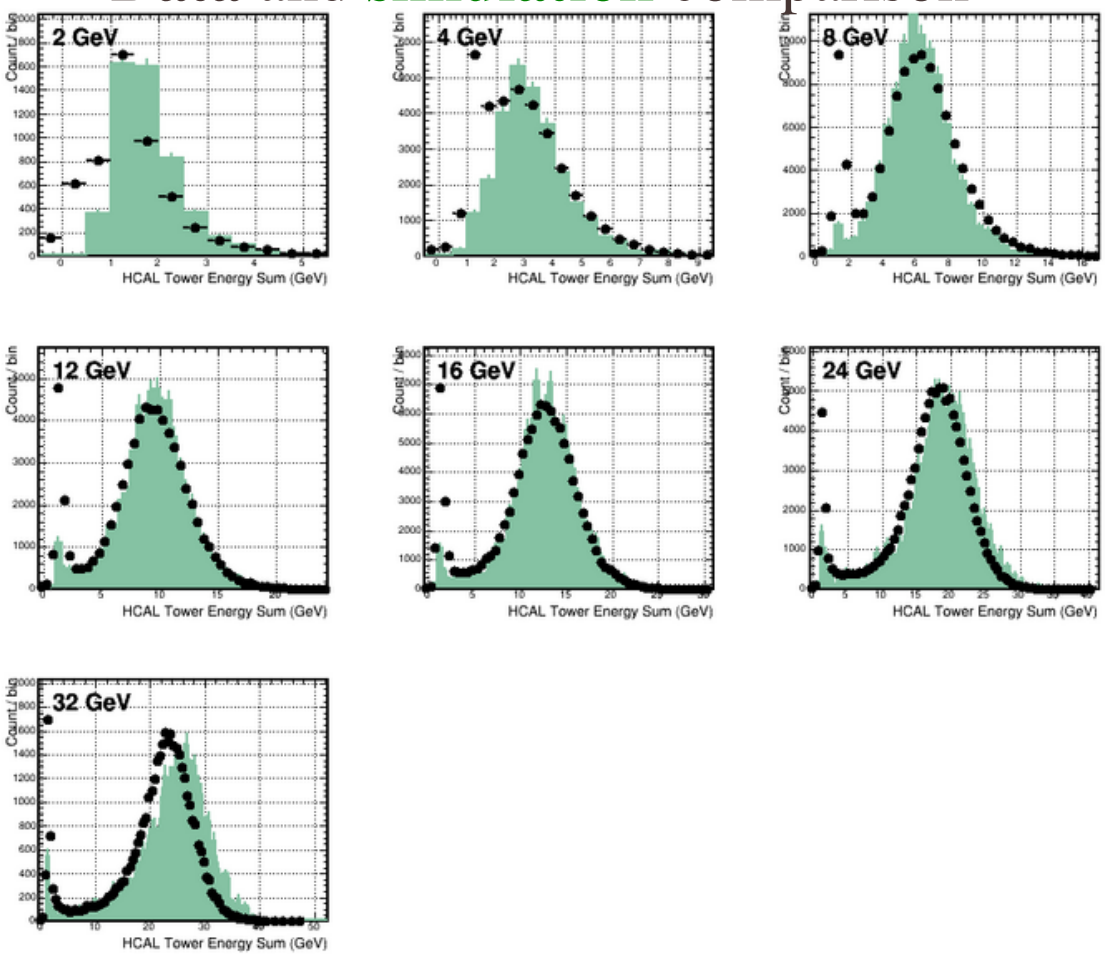


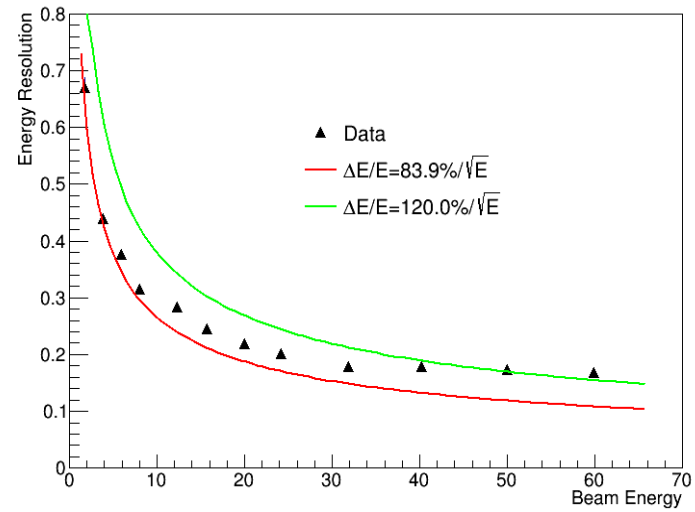


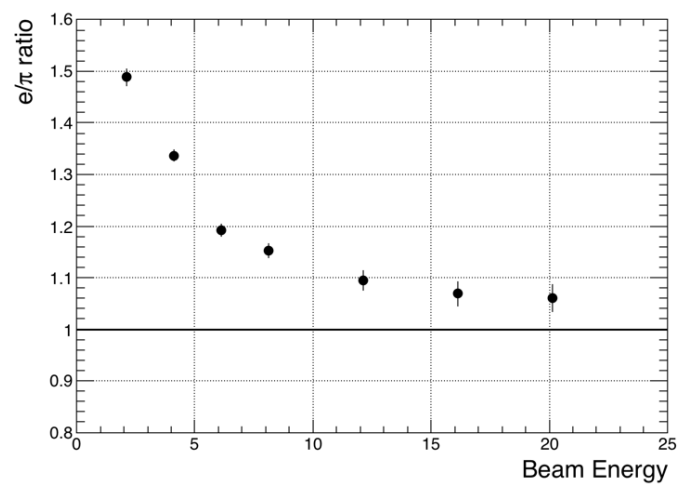
First pass MIP calibration already meets our design goal
Improvement using optimized tower to tower calibration using electron showers

HCAL energy resolution and linearity

Data and **simulation** comparison





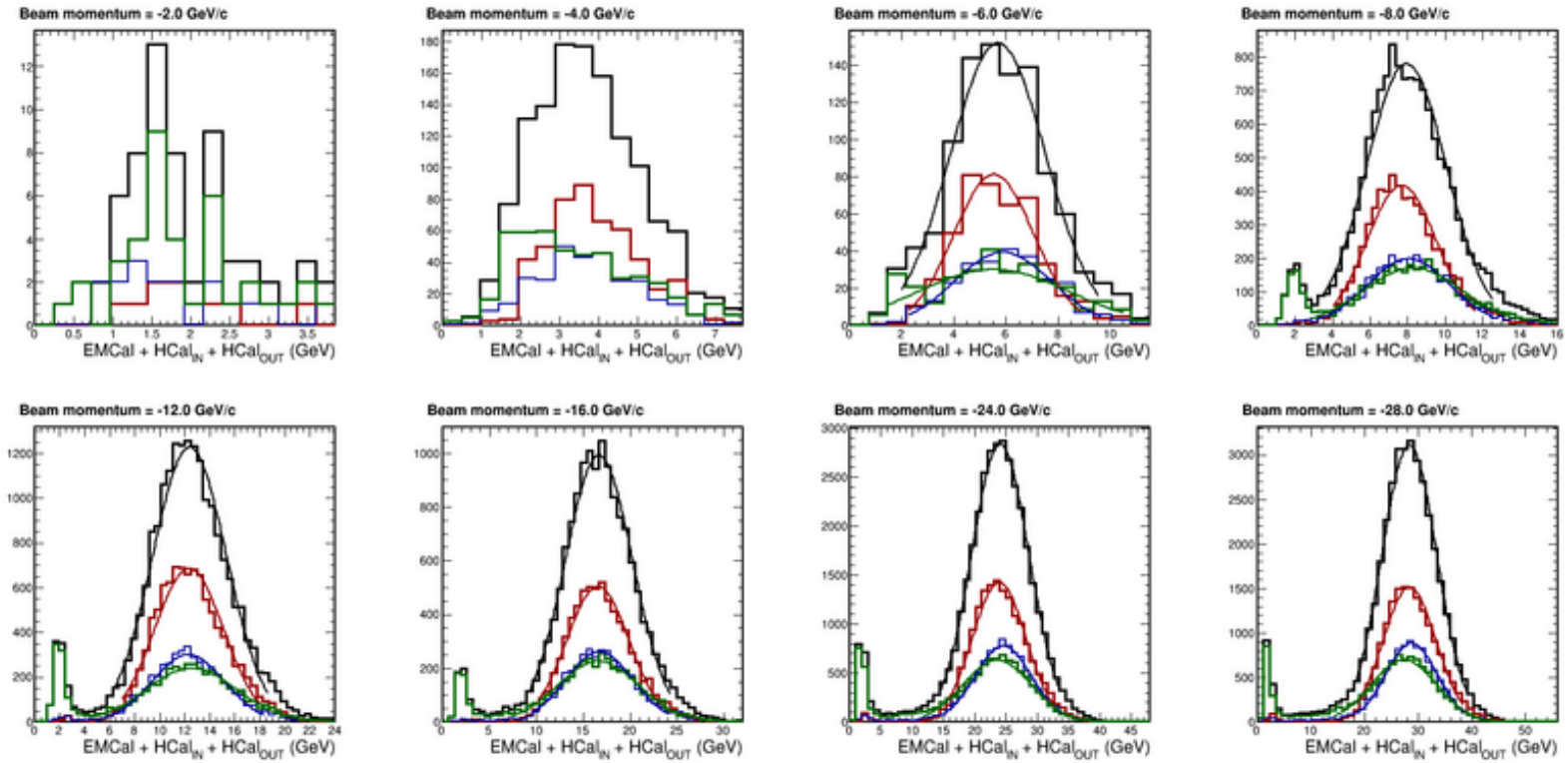


- Calibration done using cosmic mips
- Final calibration is still work in progress.

Combining EMCAL + HCAL Energy

Calibration with hadron showers selected using beam Cherenkovs

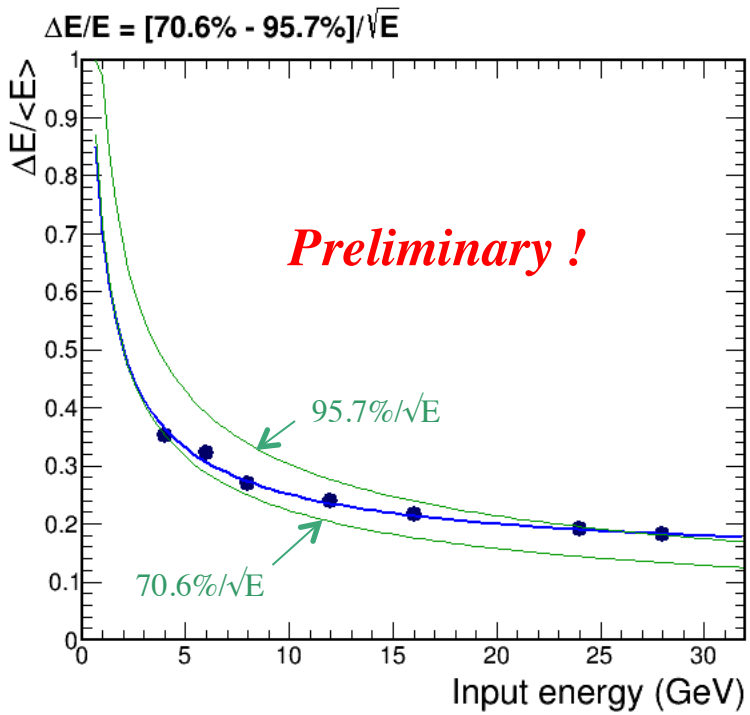
(Addition requirements: 4x4 cm^2 hodoscope hit, no veto hit)

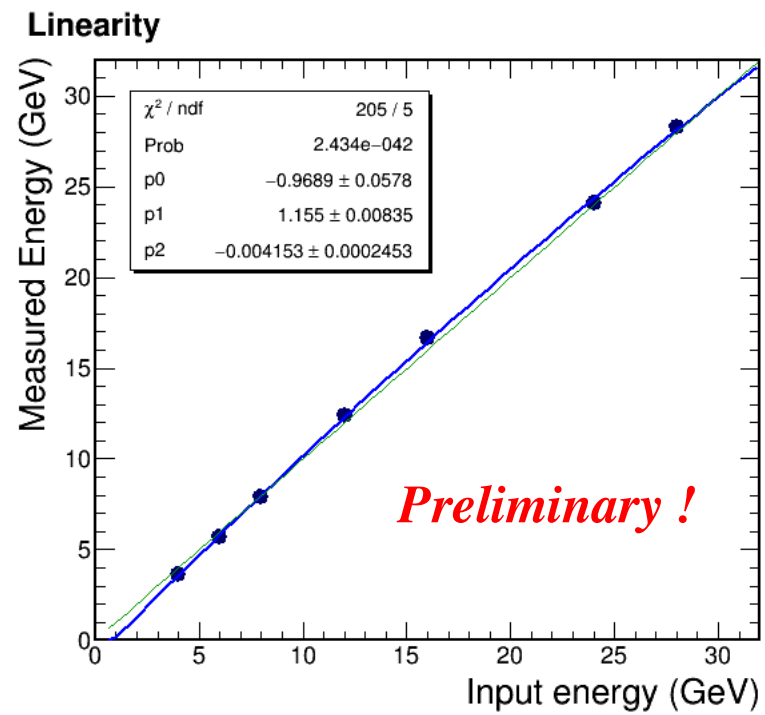


Red: Shower starts in EMCAL
Blue: MIP in EMCAL. Shower starts in Inner HCAL
Green: MIP in EMCAL and Inner HCAL. Shower starts in Outer HCAL
Black: Sum of all showers

Sets energy scale for adding energies from all three calorimeters

Combined EMCAL + HCAL Energy Resolution and Linearity





- Two component fit gives **~ 70-80 %/√E ⊕ ~ 10-15 %**
- Calibration done using cosmic mips
- Final calibration is still work in progress, but first results already show that we are able to meet our design goal < 100%/√E

Technical paper in preparation

https://wiki.bnl.gov/sPHENIX/index.php/T-1044_publication

Publication timeline: Oct, 2016
Intended journal: NIM or IEEE

Beam Test Results for the sPHENIX Electromagnetic and Hadronic Calorimeter Prototypes.

R. Belmont[b], C. Biggs[a], S. Boose[a], M. Chiu[a], M. Connors[d], E. Desmond[a], A. Franz[a], J. Haggerty[a], X. He[d], J. Huang[a], K. Kauder[h], E. Kistenev[a], M. Lenz[a], J. Lajoie[e], V. Loggins[f], T. Majoros[c], E. Mannel[a], E. O'Brien[a], M. Phipps[f], C. Pinkenburg[a], S. Polizzo[a], M. Purschke[a], M. Sarsour[d], T. Rinn[e], A. Sen[e], A. Sickles[f], M. Skoby[g], S. Stoll[a], F. Toldo[a], B. Ujvari[c], S. Vazquez-Carson[b], C. Woody[a]

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Abstract

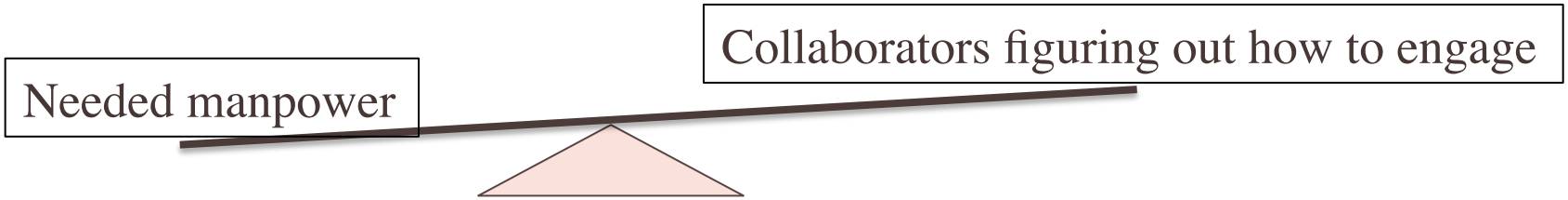
sPHENIX is a proposed new experiment at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory designed to probe the properties of the quark-gluon plasma (qgp) using jets. The new sPHENIX detector is based on the former BaBar 1.5 T superconducting solenoid and consists of a tracking system, electromagnetic and hadronic calorimetery covering 2π in azimuth and $-1 \leq \eta \leq 1$ in pseudorapidity.

This article describes the sPHENIX Electromagnetic and Hadronic Calorimeter prototype detectors and associated readout electornics and their performance in tests conducted at the Fermilab Test Beam Facility as part of experiment T-1044 in the spring of 2016.

Keywords: RHIC, sPHENIX, Electromagnetic Calorimetery, Hadronic Calorimetery, SpaCal, SiPM, Prototypes

1. Introduction [Megan] - Comment go to both emcal and hcal list.
2. Prototype Electromagntic Calorimeter [Vera] - Comment go to emcal list
    1. Overview
    2. Block construction [Vera]
    3. Light collection [Sean]
    4. Assembly and support [Sean]
3. Prototype Hadronic Calorimeter [Abhisek] - Comment go to hcal list
    1. Overview
    2. Tile construction - [Ed K.]
    3. Tile testing - [Ron]
    4. Absorber and assembly - [TBD]
    5. Tilt - [Abhisek]
4. Readout electronics and DAQ - [Ron] - Comment go to electronics list
    1. SiPM - [Sean?]
    2. Pre-amp - [Steve]
    3. Slow control - [Steve]
    4. ADC - [Chi]
    5. RCDQA - [Martin]
5. Simulation - [Jin]
    1. Framework - [Chris]
    2. EMCal - [Jin]
    3. HCal - [Chris, Murad]
6. Test beam - [Ron] - Comment go to emcal + HCal list
    1. Overview
    2. Setup
    3. Beam study (PbGl) - [Vera]
7. Results (see #Target plots) - [Megan]
8. Conclusion

Testbeam workfest



- Learn about sPHENIX testbeam data, hardware and software.
- (Tentative!) Next beam test is January, 2017 (Note that Quark Matter is in Chicago Feb 5-11, 2017)

- Task list for next beamtest:
  - High rapidity test
  - 2-D projective EMCAL
  - Rebuild inner HCAL with flat steel plates
  - Newly designed outer HCAL tiles
  - Next generation digitizers
  - Test calorimeter with 4 tiles per tower
  - Real-time control of temperature compensation.

We are expecting to organize a workfest in July, 2016 (tentative!).

Summary

- The sPHENIX calorimeter system will consist of a compact W/SciFi EMCAL and a steel plate scintillating tile hadronic calorimeter divided in two sections.

- Prototypes of all three calorimeters have been built and tested in a month long test beam run at Fermilab which just ended.

- A large collection of data was taken and is currently being analyzed but the preliminary analysis results indicate that all three detectors will meet the design goals of the new experiment.

- Be on the lookout soon for some exciting new results !

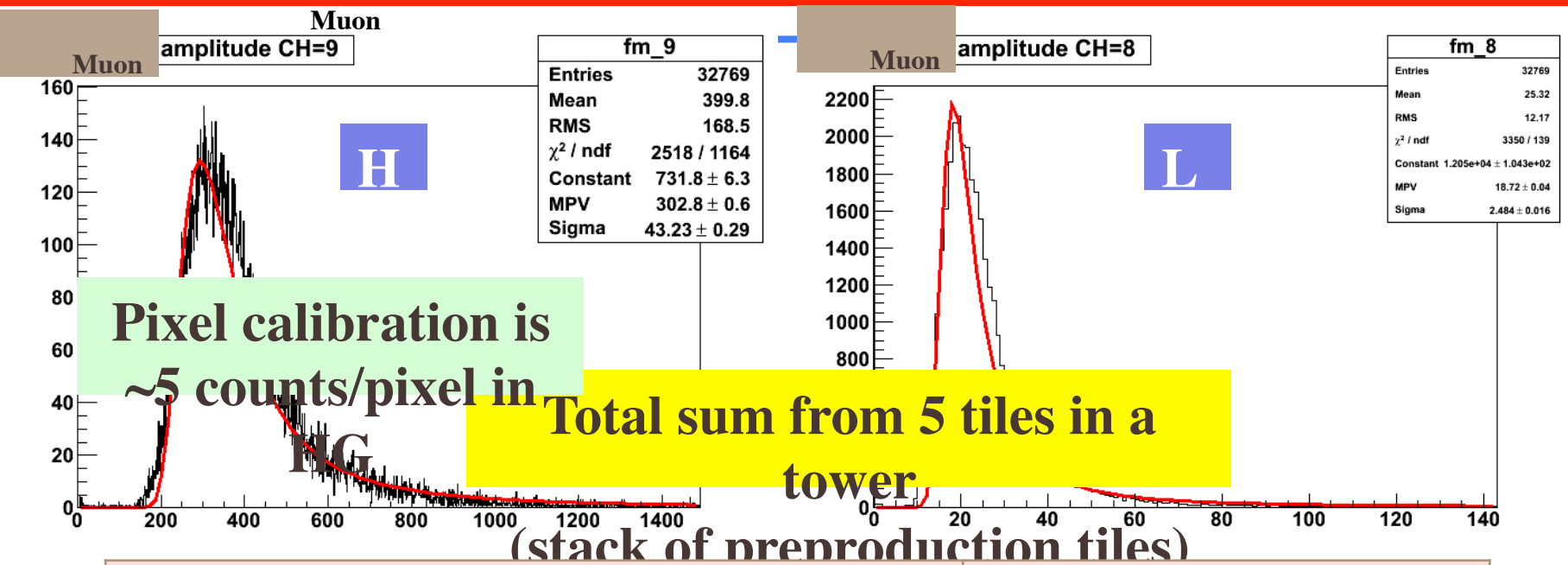
Special thanks to FNAL and Mtest. Mandy Rominsky, Todd Nebel, Ewa Skup, Leo Bellantoni

BACKUP

The sPHENIX detector concept

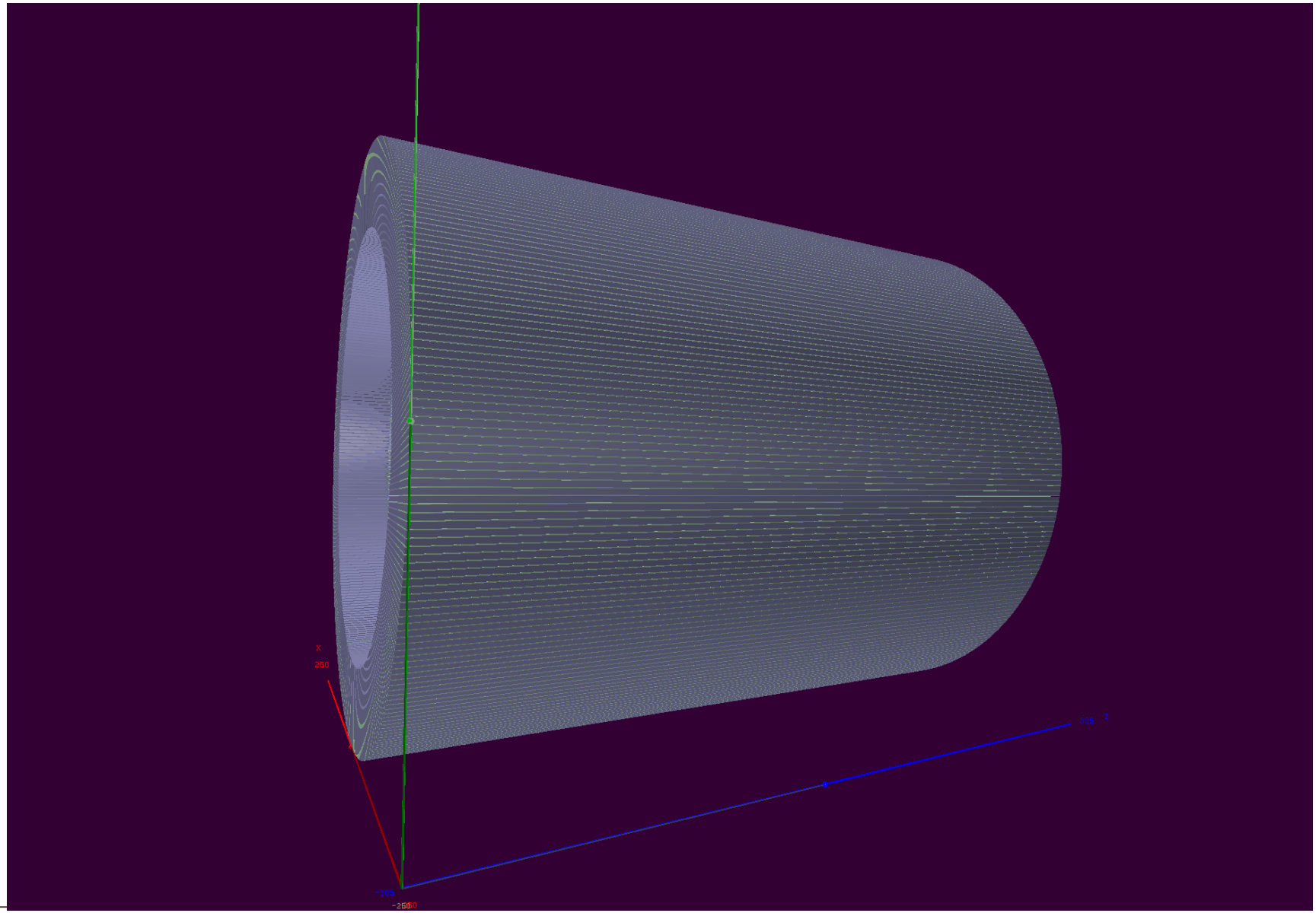
- **Uniform acceptance** $|\eta|<1.1$ and $0<\varphi<2\pi$
- **Superconducting solenoid** enabling high resolution tracking
- Compact **electromagnetic calorimeter** allowing fine segmentation at a small radius
- **Hadronic calorimeter** doubling as flux return
- **Solid state photodetectors** that work in a magnetic field, have low cost, do not require high voltage, are physically small
- **Common readout electronics** in the calorimeters
- **15 kHz recorded** in A+A allows for large unbiased data sample
- **High resolution tracking** within an 80 cm radius
- Utilization of infrastructure in an **existing experimental hall** (cranes, rails, beam pipe, power, network…)

Test Bench 2015: Running Conditions

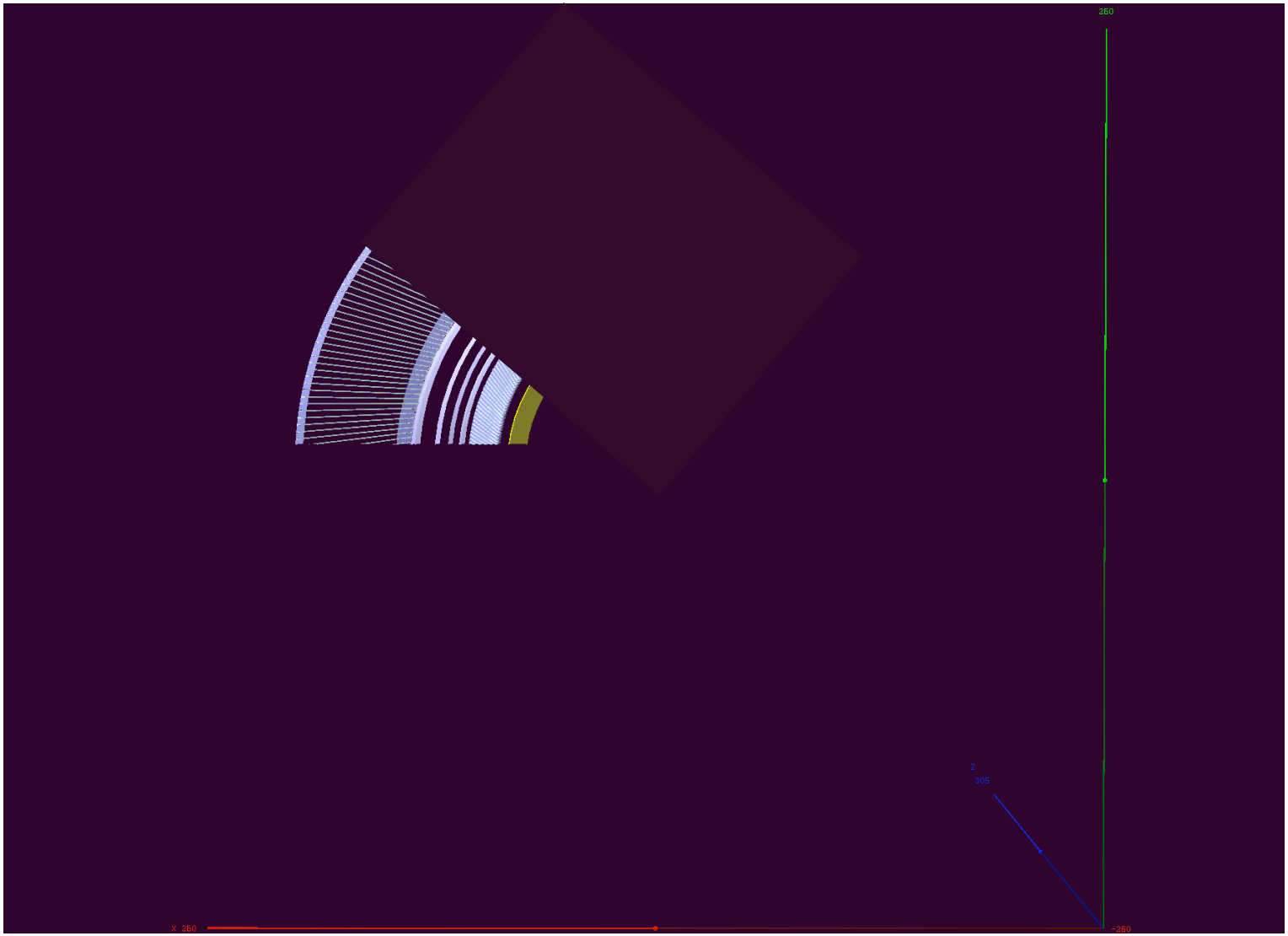


Muon crossing tower at 90deg	7 MeV
Sampling Fraction	3%
Visible energy	~230 MeV
Test Bench Least Count (High/Low Gains)	0.8/12.3 MeV/ADC count
Dynamic Range (1V unipolar pulse)	1.6GeV / 26GeV

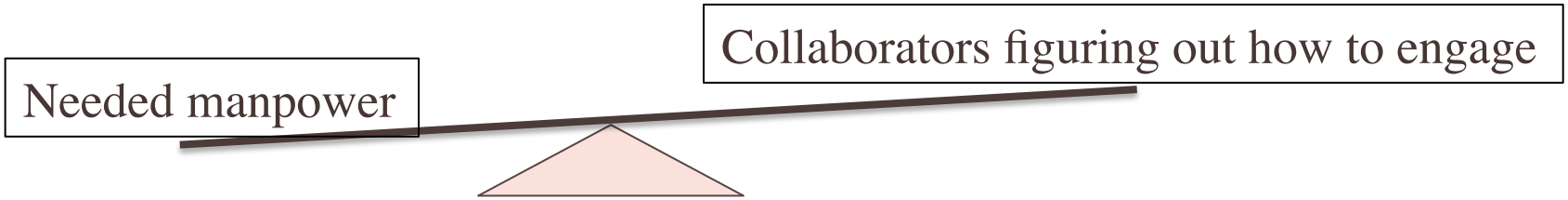
sPHENIX Calorimeters



sPHENIX calorimeters



Testbeam workshop

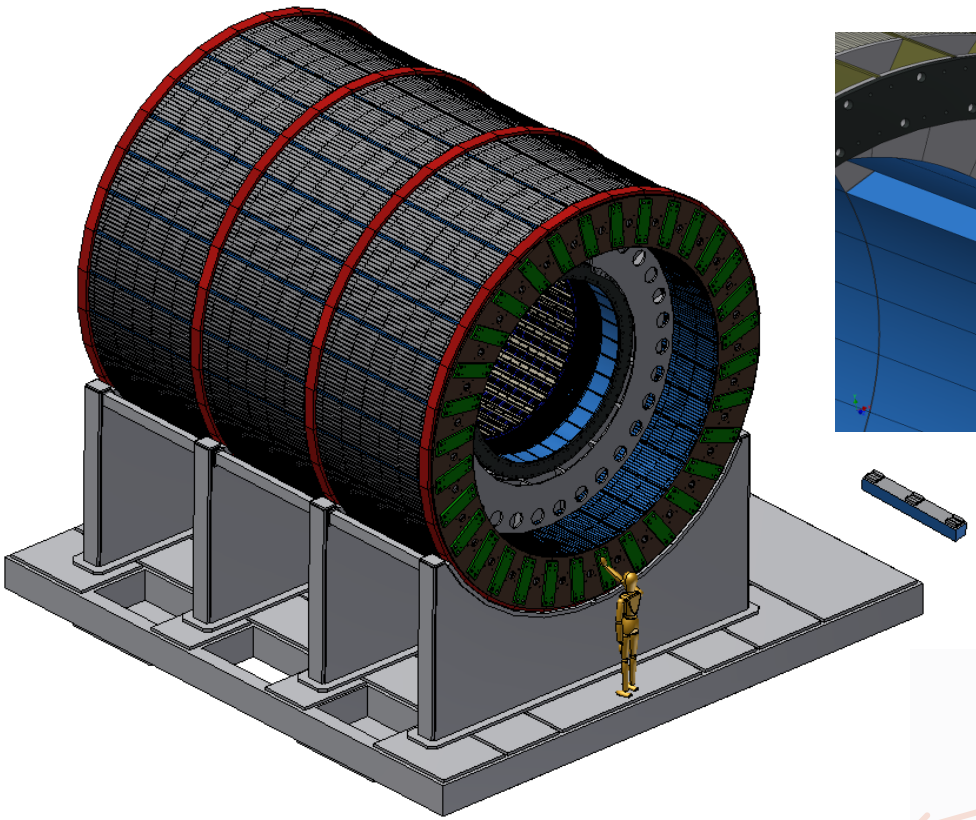


- Learn about sPHENIX testbeam data, hardware and software.
- (Tentative!) Next beam test is January, 2017 (Note that Quark Matter is in Chicago Feb 5-11, 2017)

- Needed manpower:
  - Both calorimeters have depth dependent sampling fraction and that needs more study and characterization both in single particle, jet, and embedded jet events.
  - We need studies of real world effects (missing fibers, low light production, variability in light output of tiles, dead sensors, miscalibration)

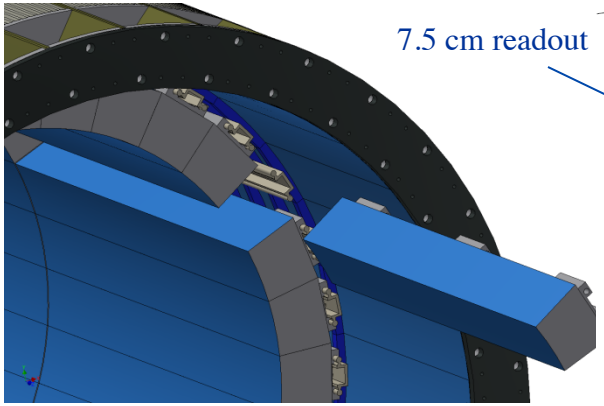
We are expecting to organize a workshop in July, 2016 (tentative!).

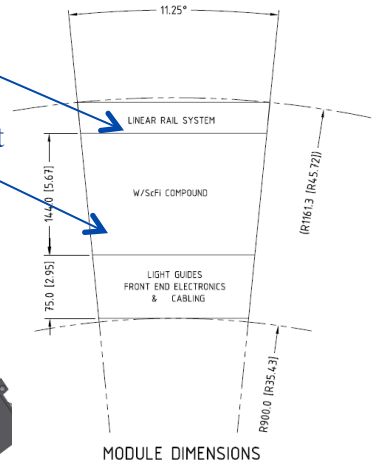
EMCAL Mechanical Design



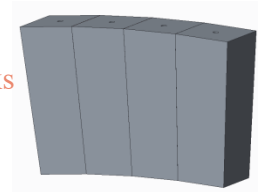
14 cm absorber (η=0)

7.5 cm readout



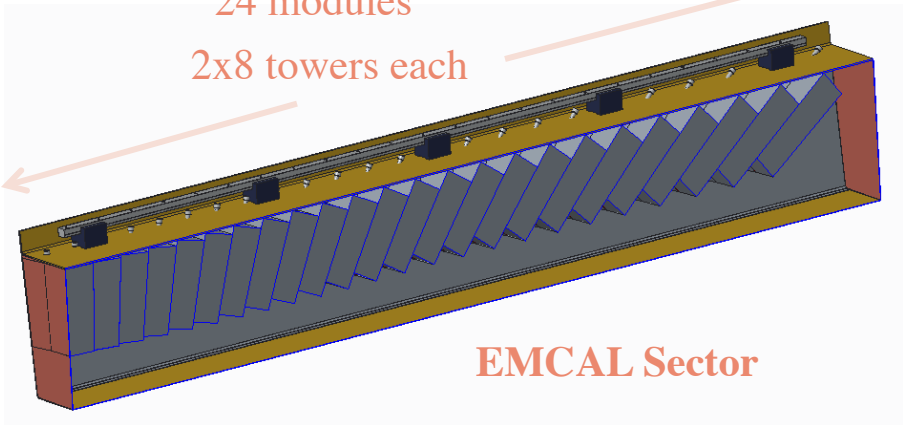


Four 2x2 tower blocks
= 1 module



24 modules

2x8 towers each



EMCAL Sector

2(±η) x 32 (ϕ) = 64 Sectors

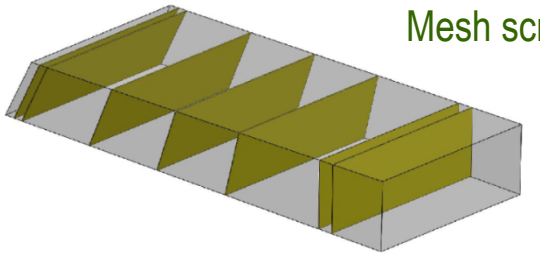
24 modules per sector
2x8 towers per module
384 towers per sector
Sector weight ~ 950 lb

~25K towers total

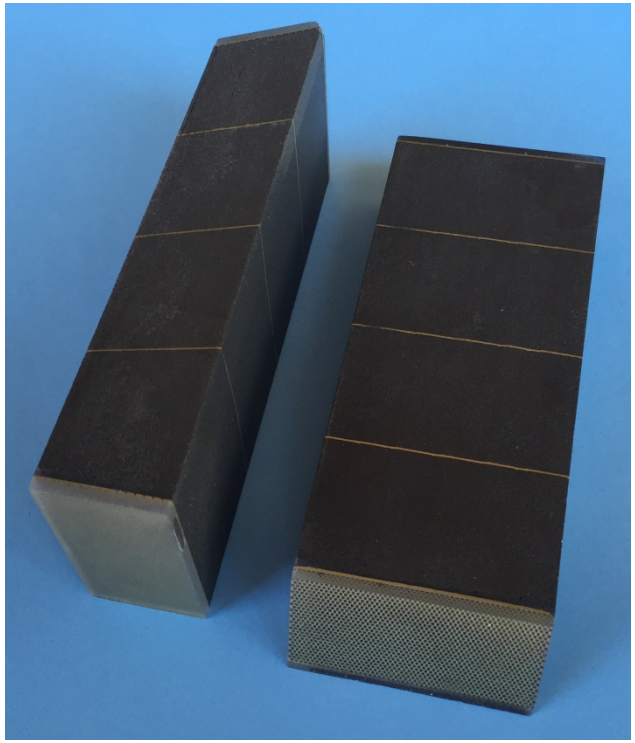
w/SciFi Modules

1D Projective

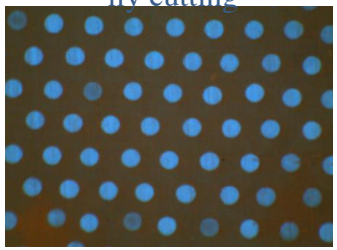
Mesh screens

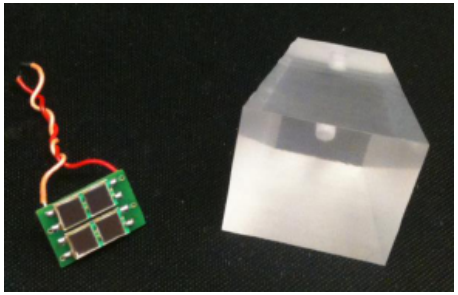


Produced at UCLA, BNL, UIUC and THP

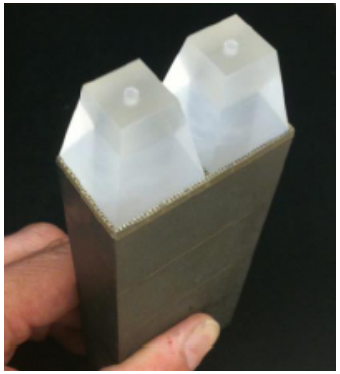


Fiber ends are finished by with fly cutting



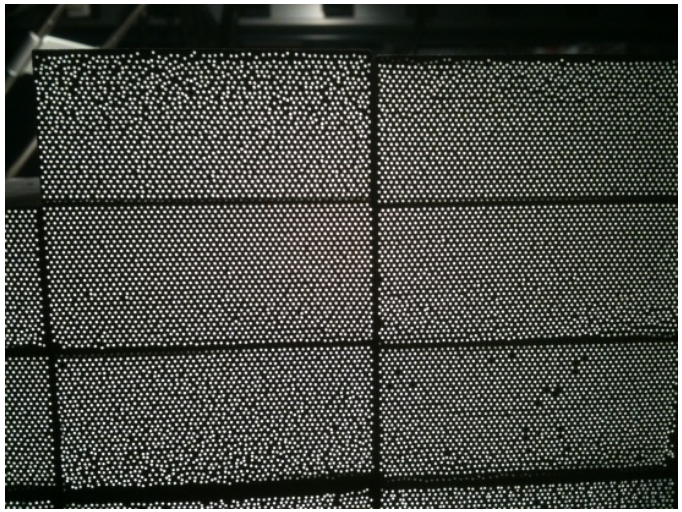


Light guides and SiPMs are attached to module ends to form towers



EMCAL Prototype

Half of the absorber blocks were manufactured at THP and half at UIUC

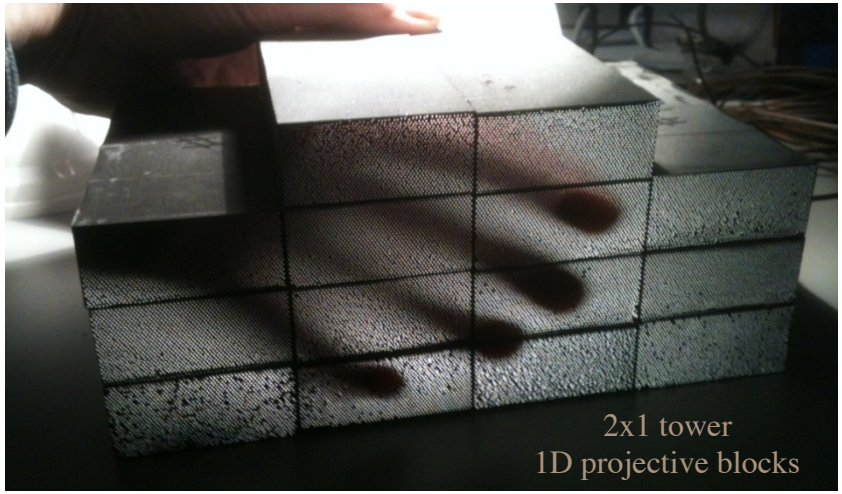


Density varied from ~ 8.5 – 10 g/cm^3

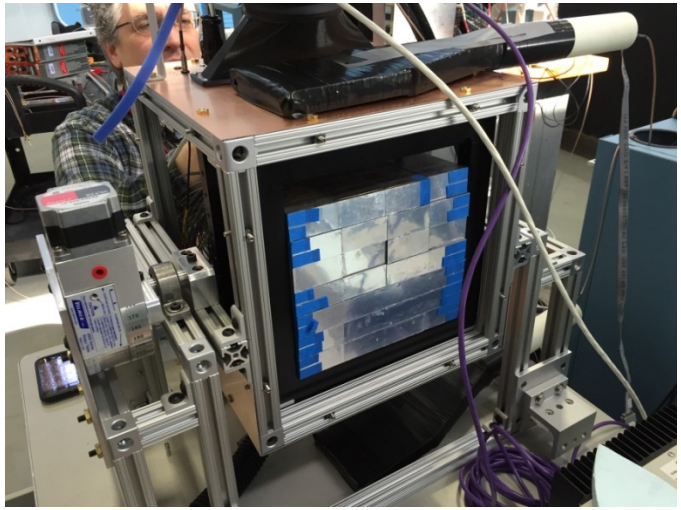
Slight fiber misalignment at one end but can be easily corrected in the future

8x8 array of towers

THP 10.2	THP 10.5	THP 8.5	THP 8.5	THP 9.0	THP 9.0	THP 9.8	THP 9.8
THP 9.7	THP 9.7	THP 10.0	THP 10.0	THP 10.0	THP 10.0	THP 9.9	THP 9.9
THP 9.2	THP 9.2	THP 9.8	THP 9.8	THP 9.3	THP 9.3	THP 10.1	THP 10.1
UIUC 9.6	UIUC 9.6	UIUC 9.4	UIUC 9.4	THP 10.1	THP 10.1	THP 9.6	THP 9.6
UIUC 9.5	UIUC 9.5	UIUC 9.5	UIUC 9.5	THP 9.3	THP 9.3	THP 9.3	THP 9.3
UIUC 9.4	UIUC 9.4	UIUC 9.4	UIUC 9.4	UIUC 9.4	UIUC 9.4	UIUC 9.6	UIUC 9.6
UIUC 9.2	UIUC 9.2	UIUC 9.6	UIUC 9.6	UIUC 9.3	UIUC 9.3	UIUC 9.3	UIUC 9.3
UIUC 9.5	UIUC 9.5	UIUC 9.6	UIUC 9.6	UIUC 9.3	UIUC 9.3	UIUC 9.2	UIUC 9.2

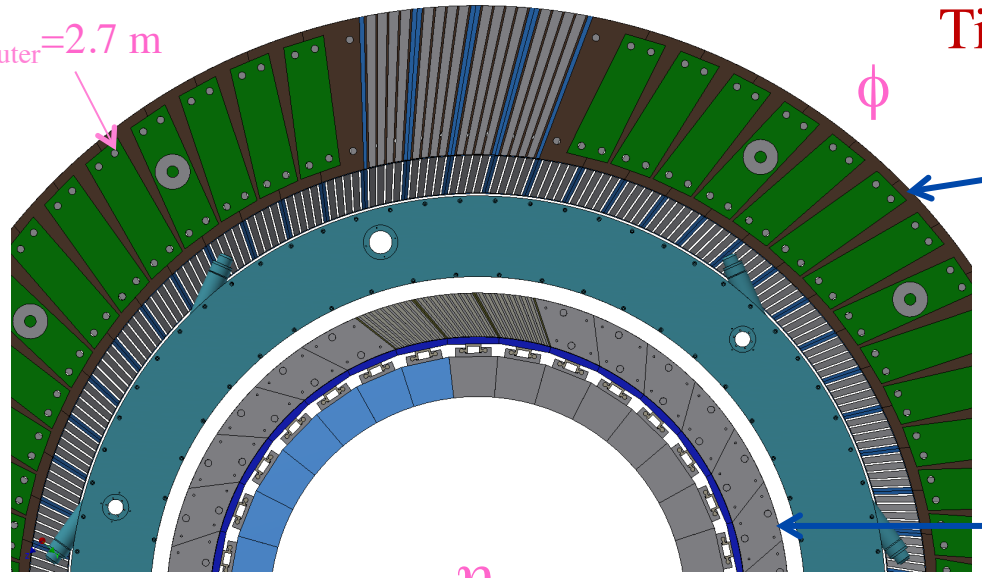


2x1 tower
1D projective blocks



Hadronic Calorimeter

R_{outer}=2.7 m



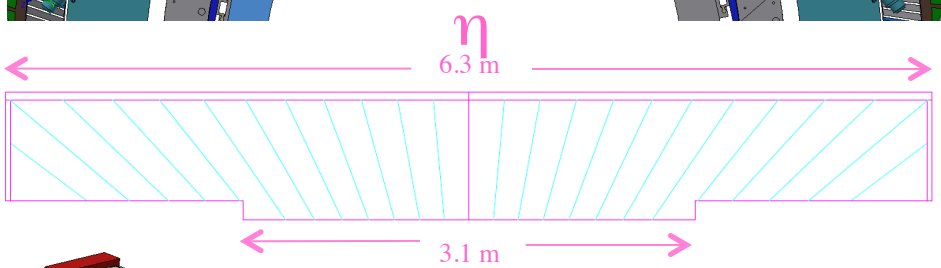
Tilted Plate Design

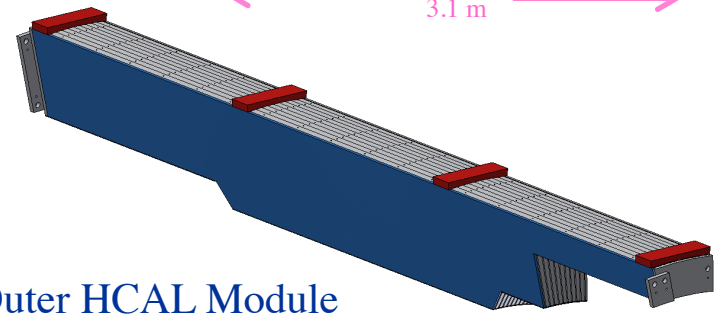
ϕ

Outer HCA L
64 modules in ϕ
<SF> = 3.5%

MIP crosses
4 tiles in each
calorimeter

Inner HCAL
32 modules in ϕ
<SF> = 6.7%

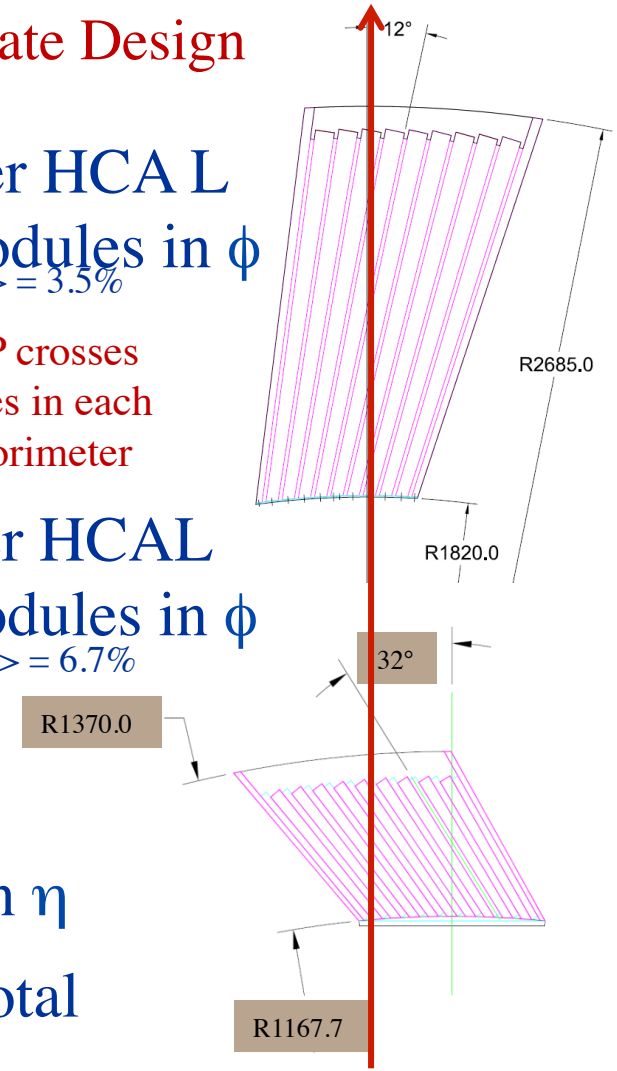




Outer HCAL Module
(13.5 tons)

2x12 towers in η

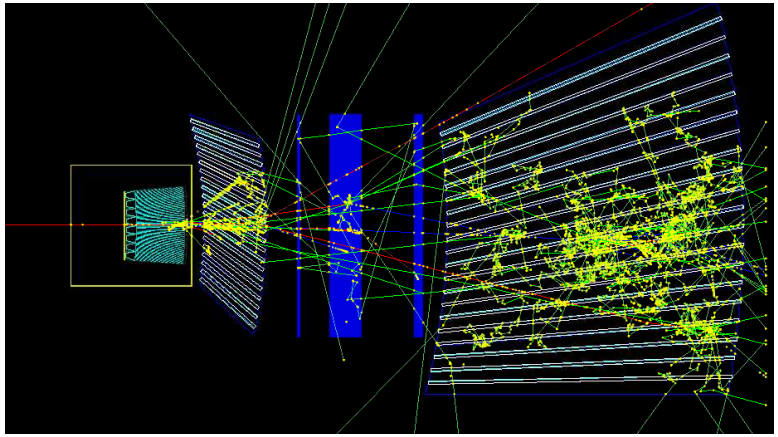
3072 towers total



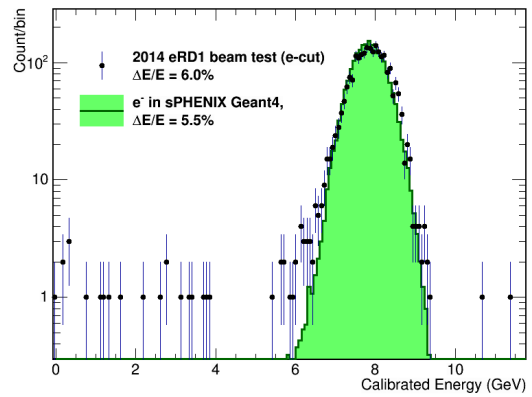
Sampling fraction changes with depth (~25%)

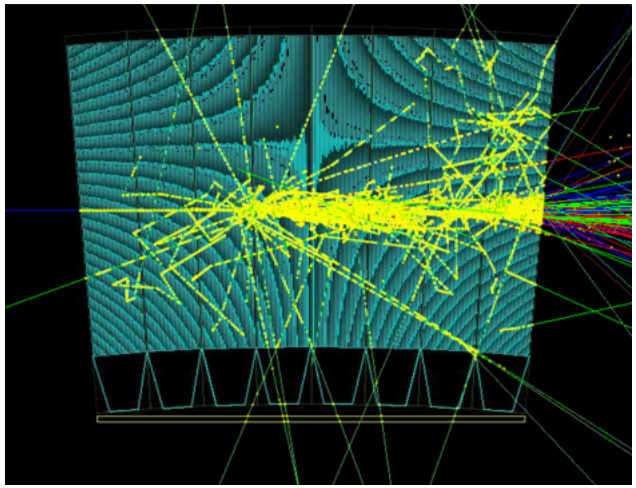
Simulations

Entire test beam setup was simulated in GEANT4

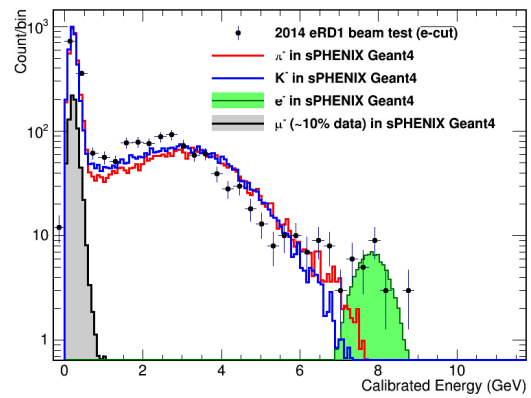


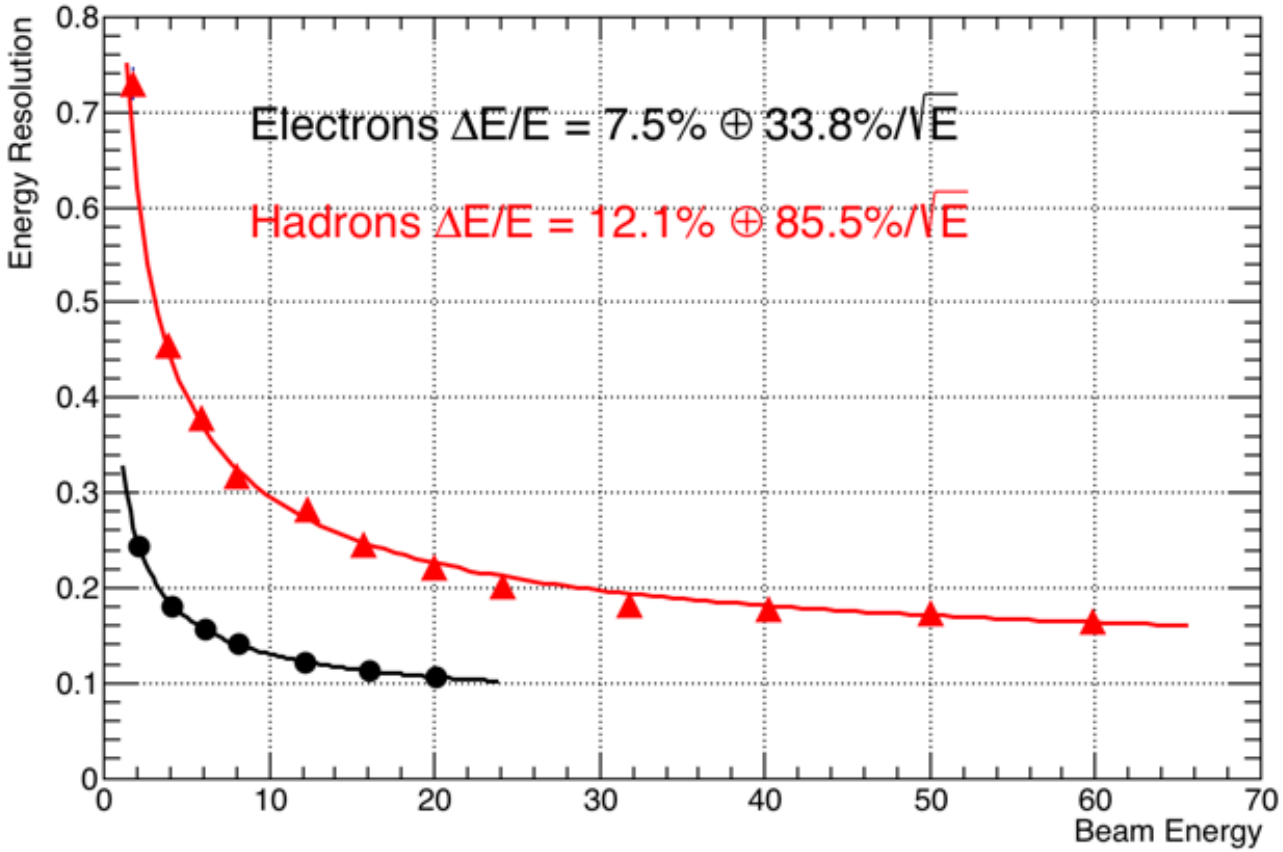
Hadronic shower in 3 calorimeters





Hadron entering EMCAL in “nose down” position



Comparison of EM and hadronic showers in EMCAL prototype with eR1 test beam data

HCAL only resolution