Status and New Results for the sPHENIX Calorimeter Systems

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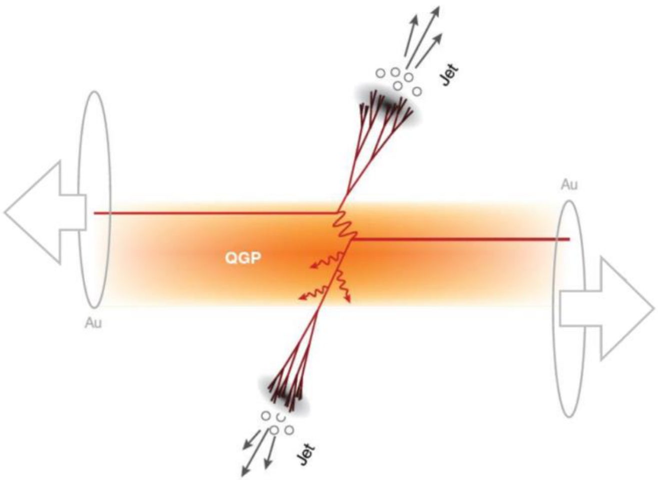
The sPHENIX Experiment

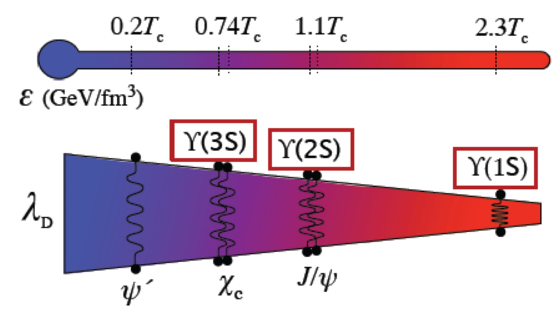
- Major upgrade to the PHENIX Experiment at RHIC
  New collaboration: currently sPHENIX ($\rightarrow$ new name ?)
- Primary purpose is to measure jets and heavy quarkonia in heavy ion collisions
  - Measure total energy using calorimetry (including hadronic – first HCAL at central η at RHIC)
  - Good solid angle coverage ($|\eta|< 1$, $\Delta\phi=2\pi$)
  - Measure Υ to σ_M~ 100 MeV
- Provide a basis for a future Day 1 detector for eRHIC (Brookhaven's version of the Electron Ion Collider)
  - Study nucleon structure and QCD in nuclei over a broad range of x and Q^2 using deep inelastic polarized ep and eA collisions

The Physics of sPHENIX

Goal: To study the QGP over a broad range of temperature and length scales, particularly in the region of T ~ T_c where the coupling is strongest, and study its evolution from an initial high temperature state, through its transition by cooling and expansion, to a state of normal hadronic matter

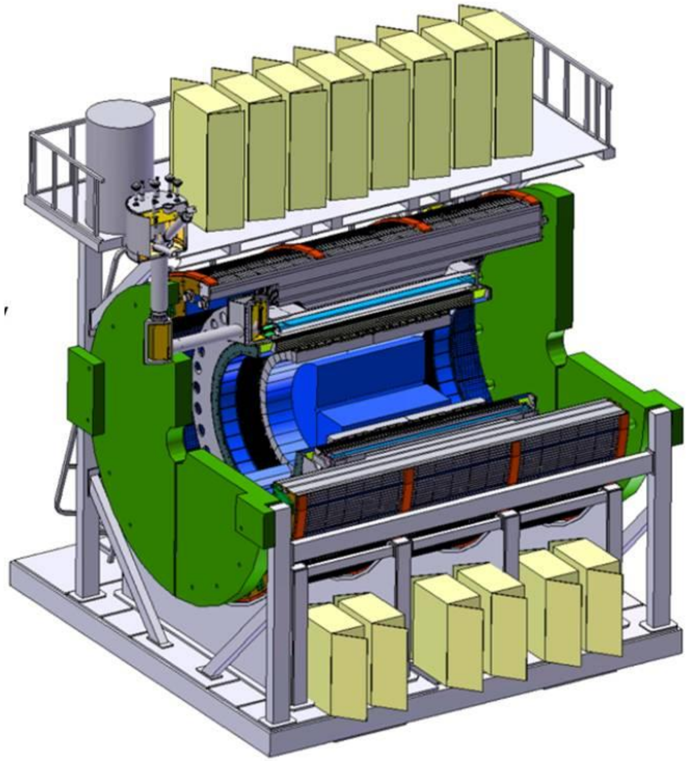
- At RHIC energies, partons interact in the QGP for a long time and over a large length scale at T ~ T_c
- Use jets as a probe to measure the energy loss of partons traversing the QGP
- Study the production of heavy quarkonia (ϒ's) in heavy ion collisions to study color screening at different length scales

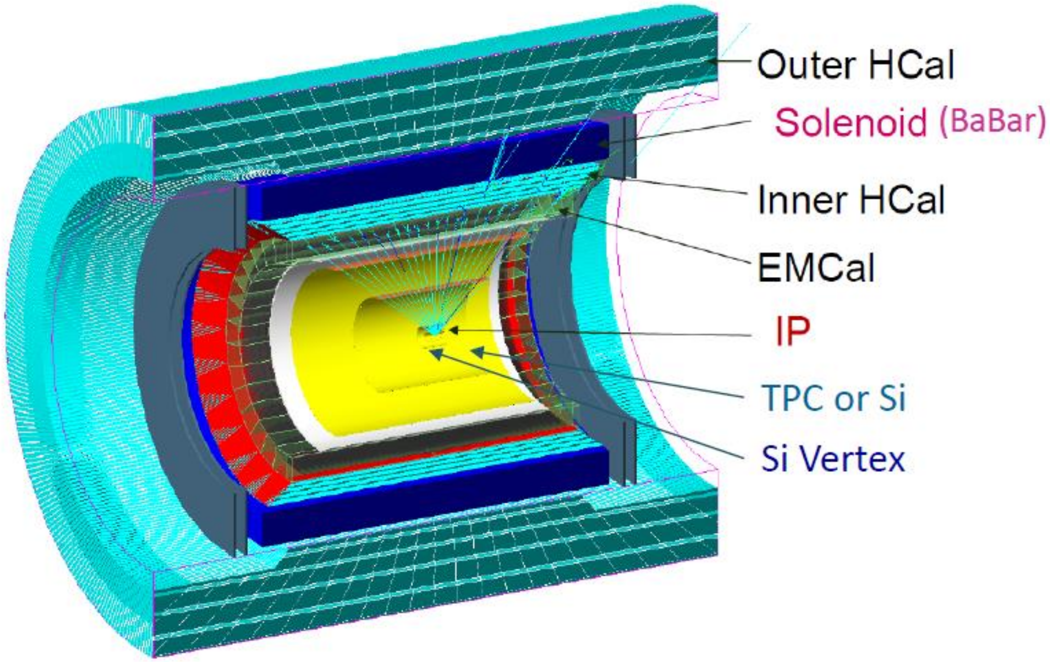




The sPHENIX Experiment

A solenoid spectrometer based around the BaBar magnet





Two new calorimeter systems: Electromagnetic and Hadronic

Coverage: ± 1.1 in η, 2π in ϕ

Central Tracker: Si + TPC

The sPHENIX Calorimeter Systems

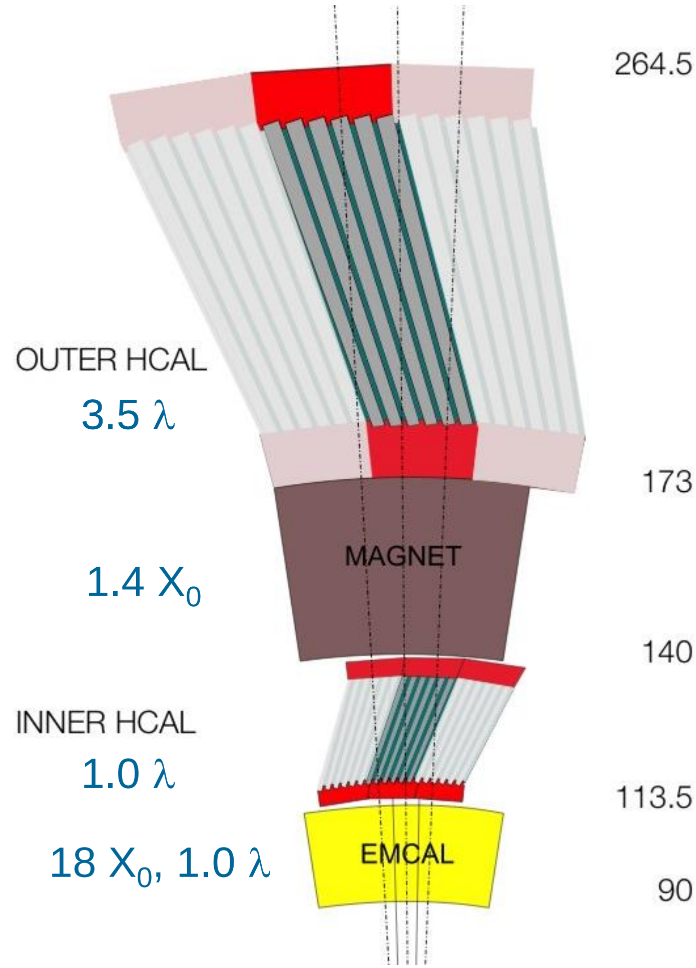
EMCAL – Tungsten SciFi SPACAL

- ± 1.1 in η, 2π in ϕ
- $\Delta\eta \times \Delta\varphi \approx 0.025 \times 0.025$
- 96x256 = 24576 readout channels
- $\sigma_E/E < 15\%/\sqrt{E}$

HCAL – Steel plates + scintillating tiles with WLS fiber readout

- Plates oriented parallel to beam
- Iron serves as flux return
- Plates are tilted to avoid channeling
- Two longitudinal sections (~ 4.5 λ)
  - Inner HCAL inside magnet
  - Outer HCAL outside magnet
- $\Delta\eta \times \Delta\varphi \approx 0.1 \times 0.1$
- 2x24x64 = 3072 readout channels
- $\sigma_E/E < 100\%/\sqrt{E}$ (single particle)

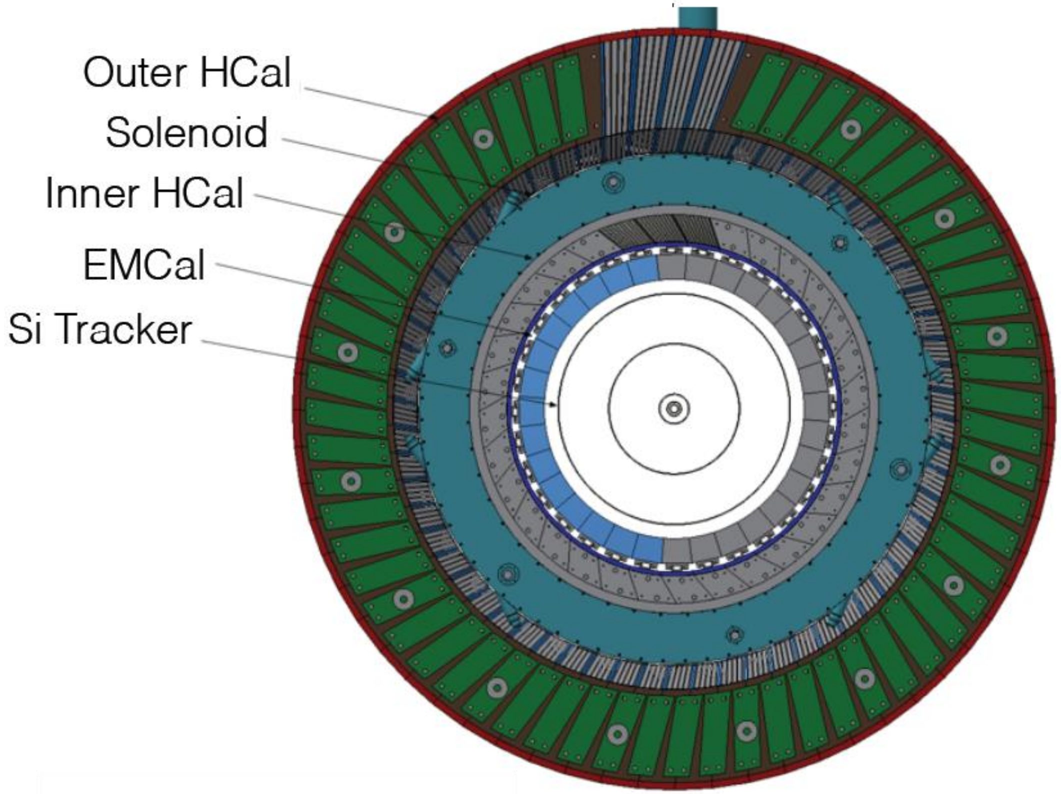
Both EMCAL and HCAL read out with SiPMs

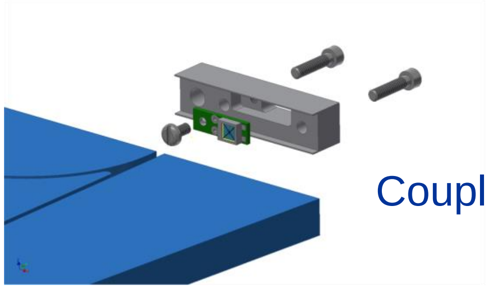


EMCAL + HCAL ~ 5.5 λ

Hadronic Calorimeters

Tilted Steel Plates with Scintillating tiles and WLS fiber readout

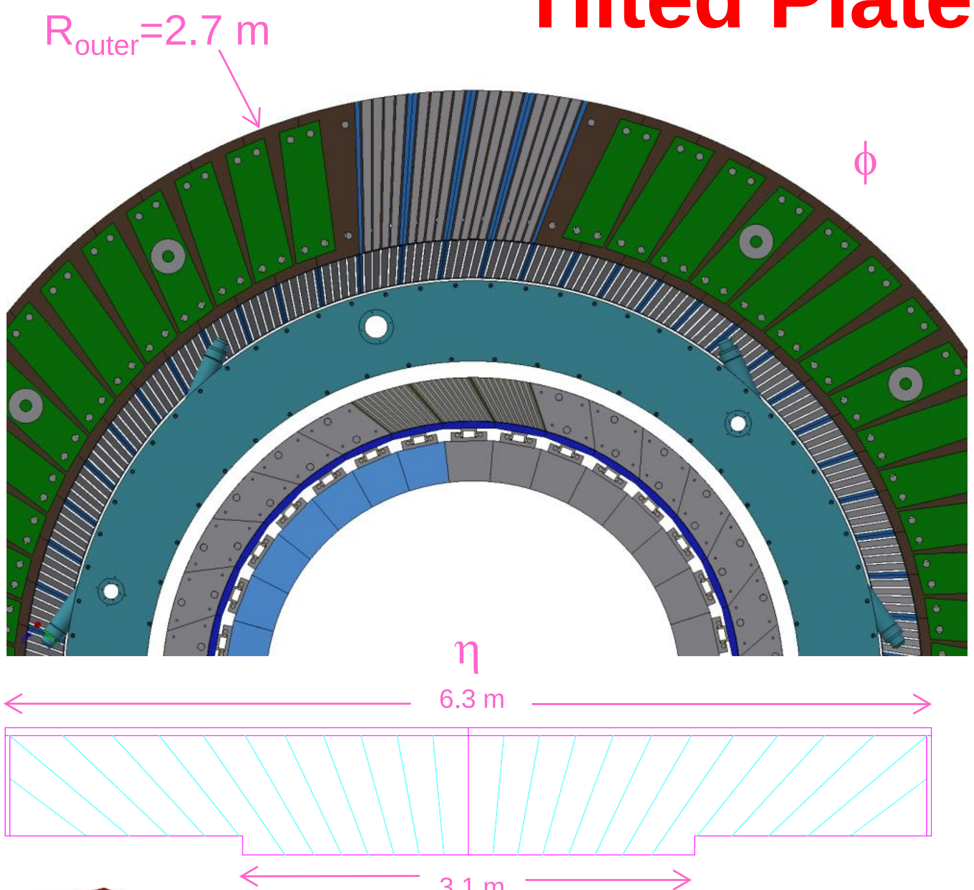




Coupler to SiPM

- 7 mm polystyrene scintillator with 1 mm embedded WLS fiber (similar to T2K)
- 5 tiles, each with its own SiPM, summed together in ϕ to form a tower

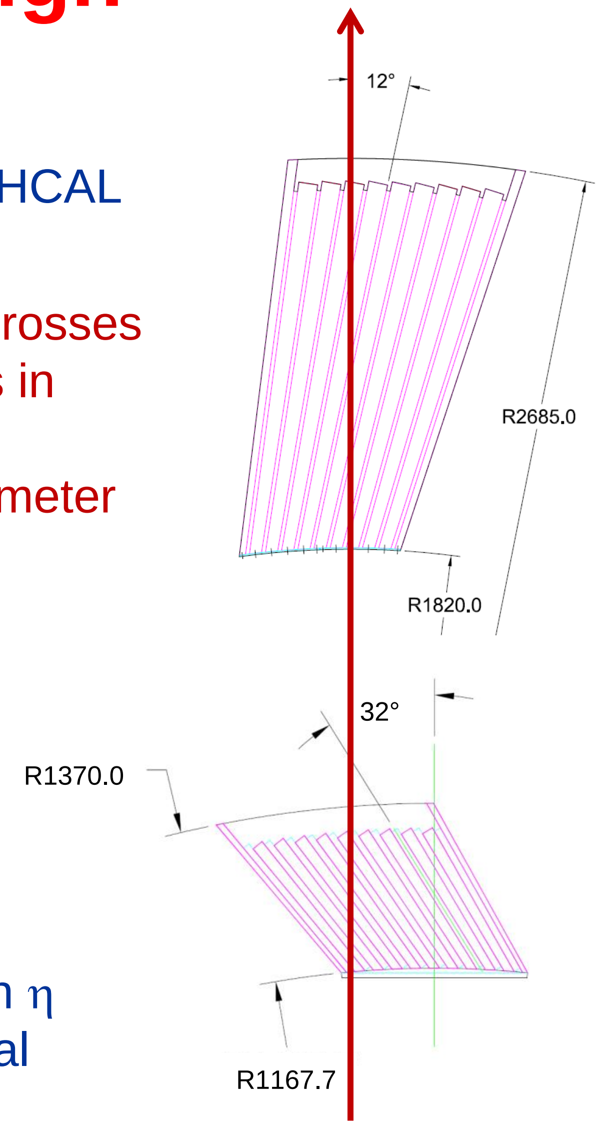
Tilted Plate Design



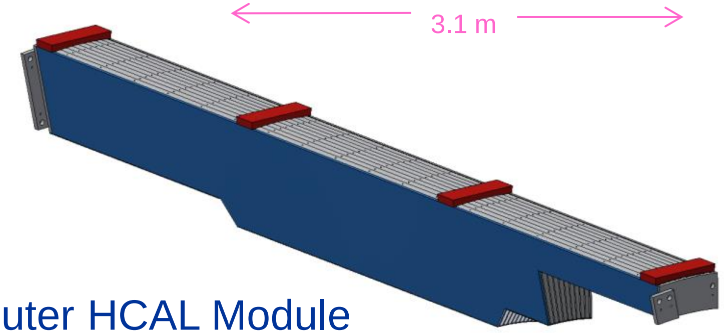
Outer HCAL

MIP crosses 4 tiles in each calorimeter

Inner



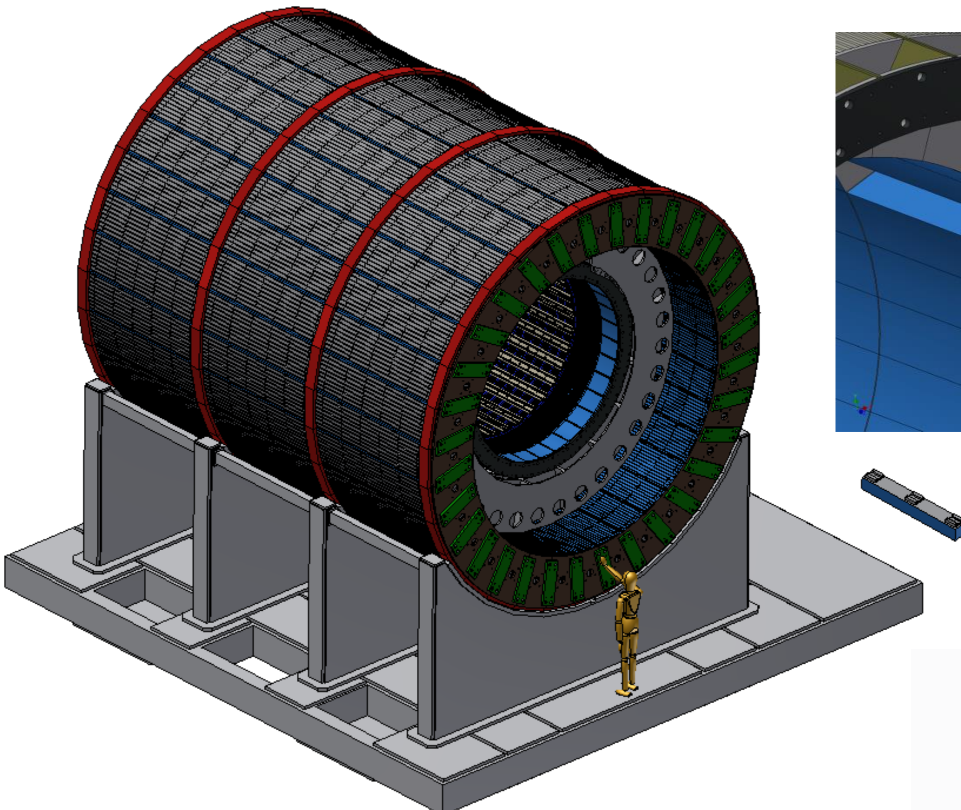
64 towers in ϕ
2x12 modules in η
3072 towers total



Outer HCAL Module (13.5 tons)

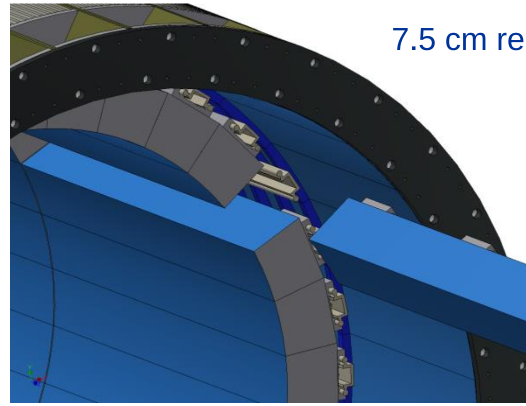
Sampling fraction changes with depth (~25%)

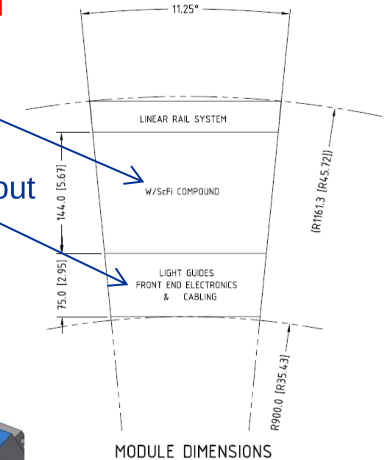
EMCAL Mechanical Design



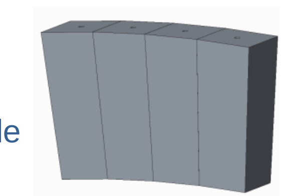
14 cm absorber (η=0)

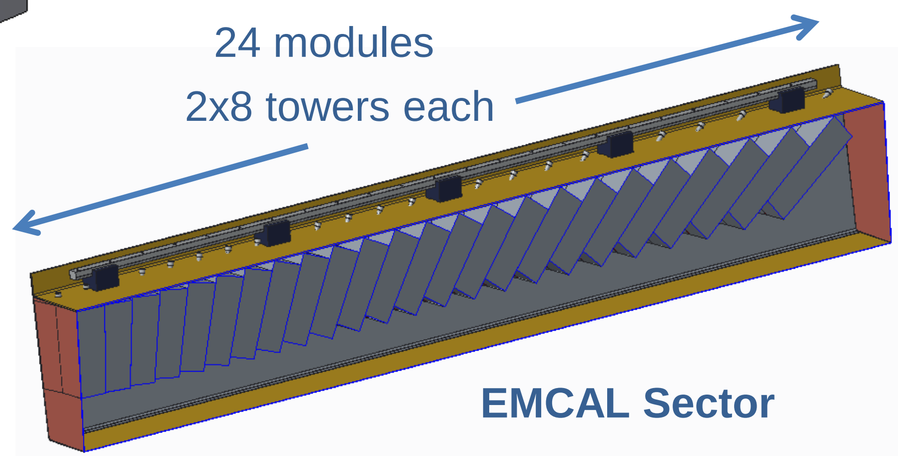
7.5 cm readout





Four 2x2 tower blocks = 1 module





2($\pm\eta$) x 32 (ϕ) = 64 Sectors

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

~25K towers total

EMCAL

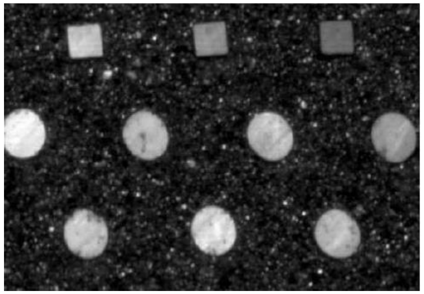
W/SciFi SPACAL (originally developed by Oleg Tsai at UCLA)

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

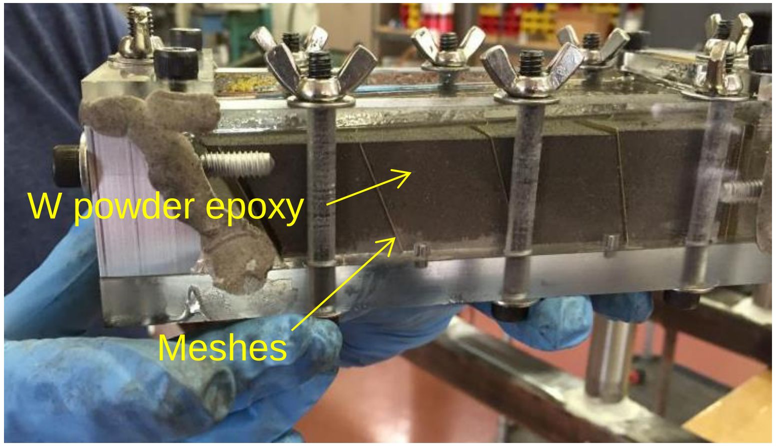
Tungsten HEAVY Powder, Inc.



Scintillating fibers (Kuraray SCSF78)

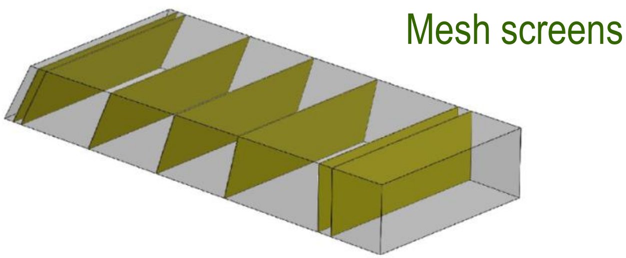
- Diameter: 0.47 mm, Spacing: 1 mm
- Sampling Fraction ~ 2.3 %

- 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

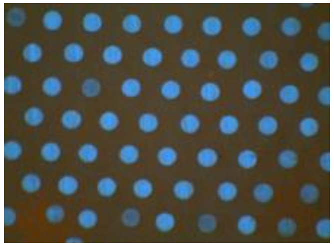


W/SciFi Modules

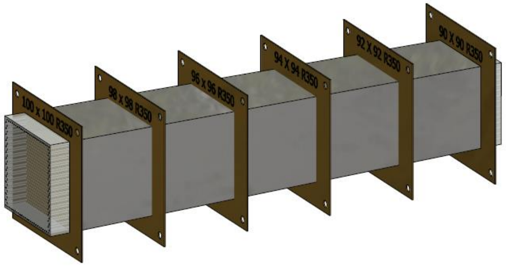
1D Projective



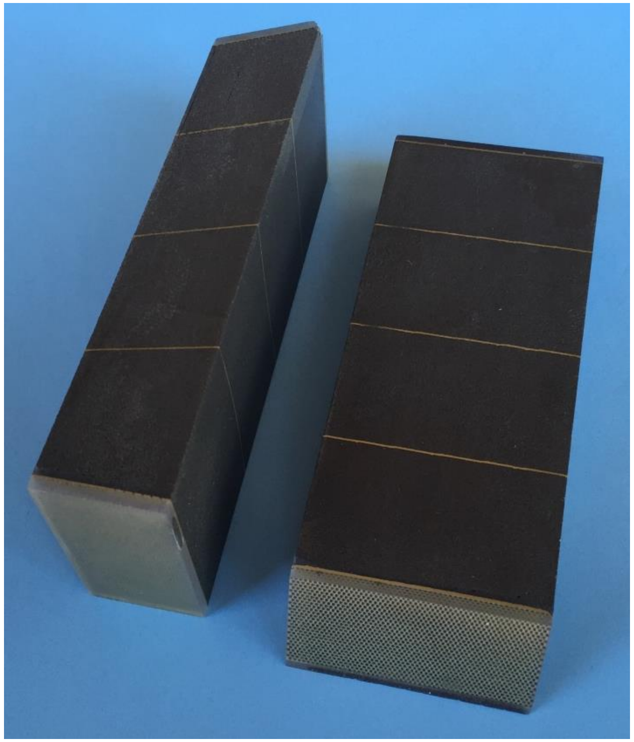
Fiber ends are finished by with fly cutting

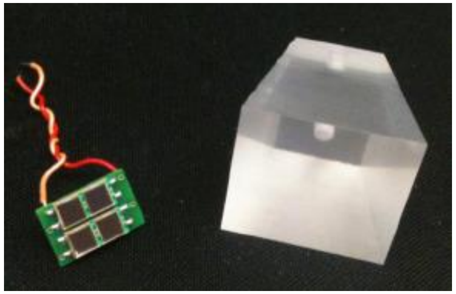


2D Projective

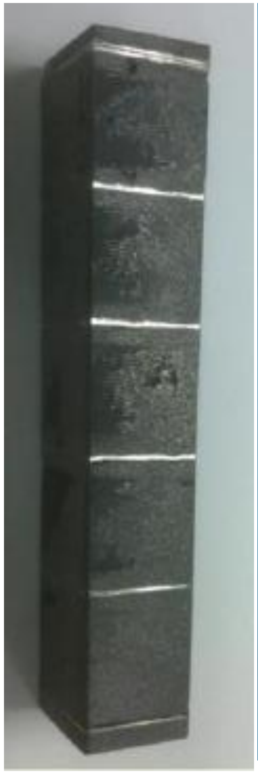


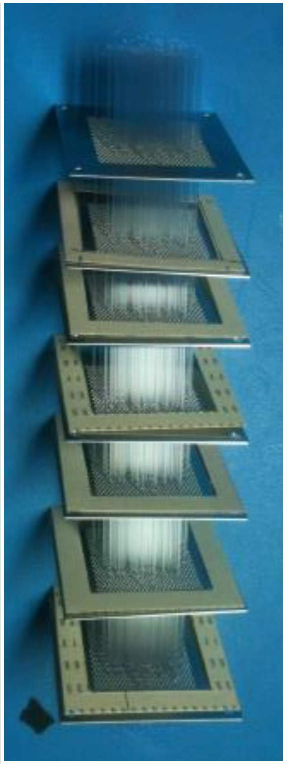
Produced at UCLA, BNL, UIUC and THP





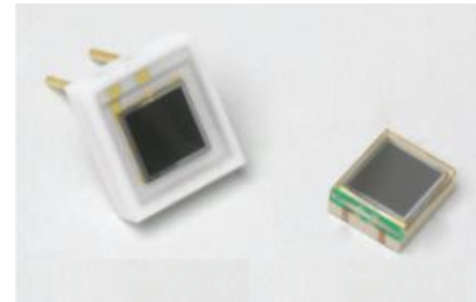
Light guides and SiPMs are attached to module ends to form towers



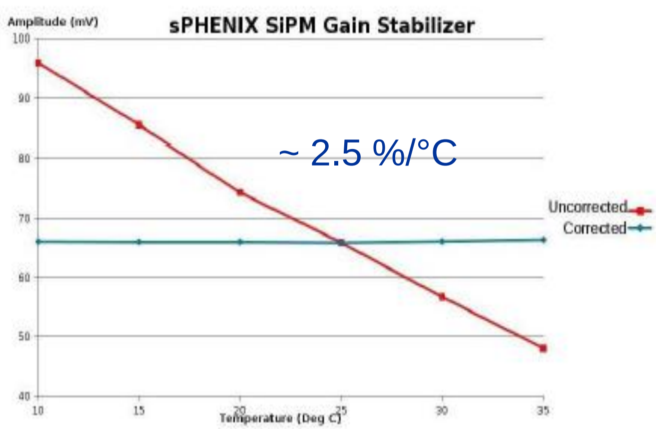


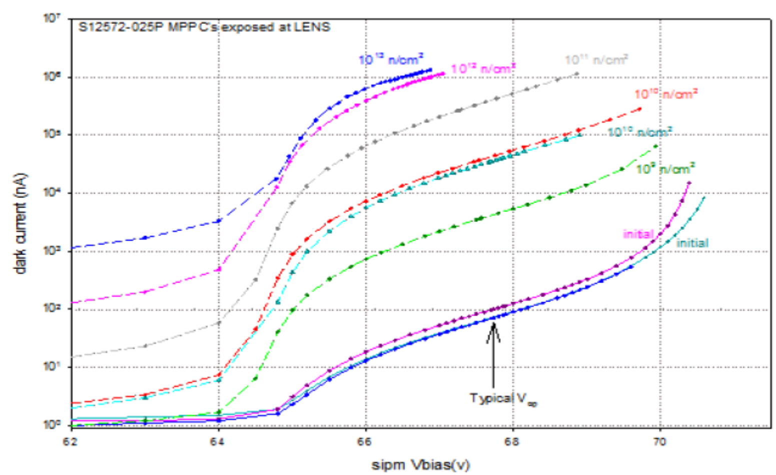
Silicon Photomultiplier Readout

- Common SiPM used for EMCAL and both HCALs (Hamamatsu S12572-015P)
- Gain ~ 2×10^5, PDE = 25%
- Dynamic range > 10^4
  15 μm pixel device $\rightarrow$ 40K pixels
- Need ~ 115K total (100K EMCAL, 15K HCAL)
- Read out with dual gain preamp + 60 MHz digitizer
- Cooling required for EMCAL
- Readout will employ gain stabilization with temperature
- Concerns about radiation damage from neutrons



Hamamatsu S12572-015P
3x3 mm^3 MPPC

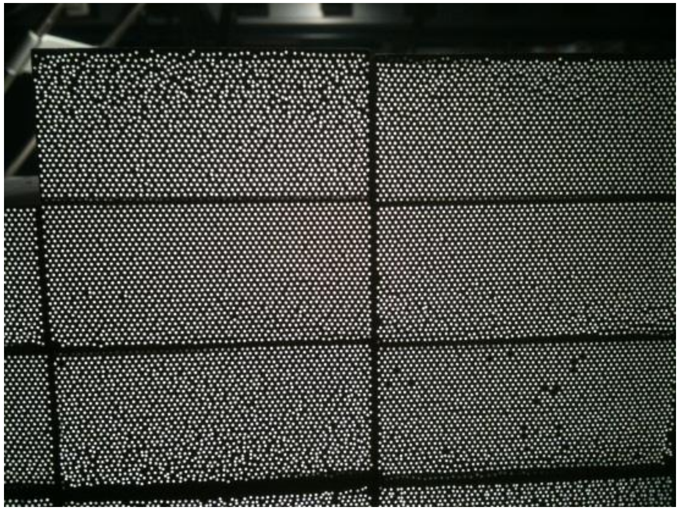




Expected neutron flux at RHIC ~ 10^{10} n/cm^2 per RHIC run

EMCAL Prototype

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

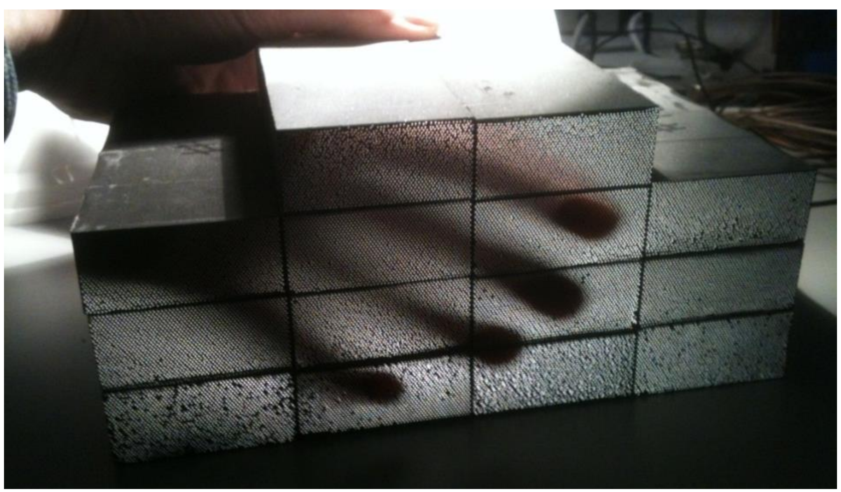


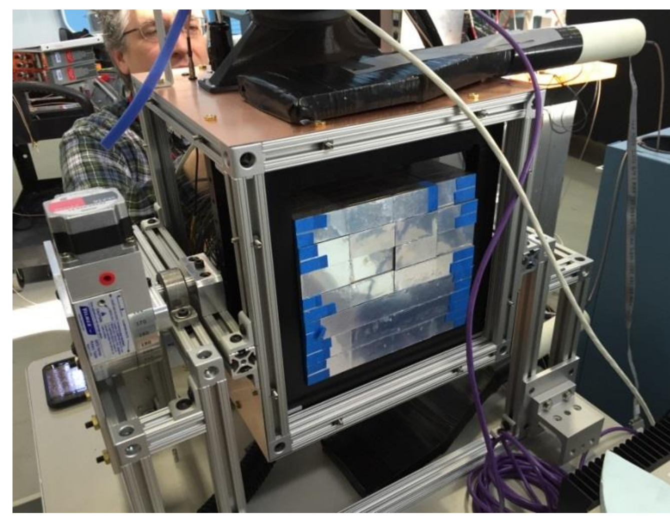
Density varied from ~ 8.5 – 10 g/cm^3

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





HCAL prototypes

Inner and Outer HCAL prototypes each consist of 4 x 4 towers

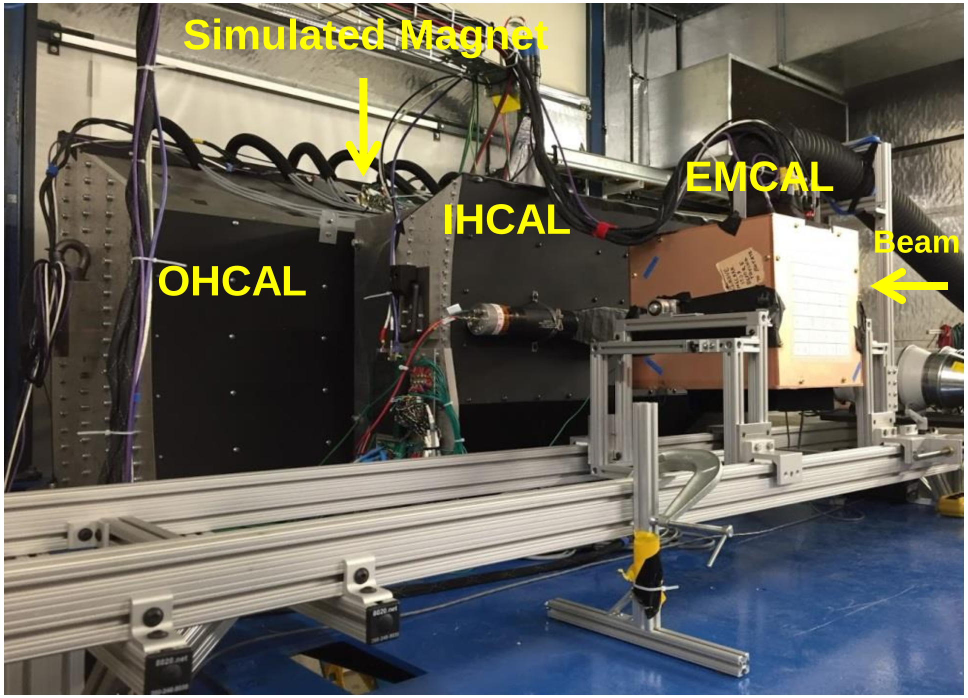
- Inner: ~ 1x1 m^2, 25 x 25 cm^2 towers
- Outer: ~ 1.5m^2, 35 x 35 cm^2 towers

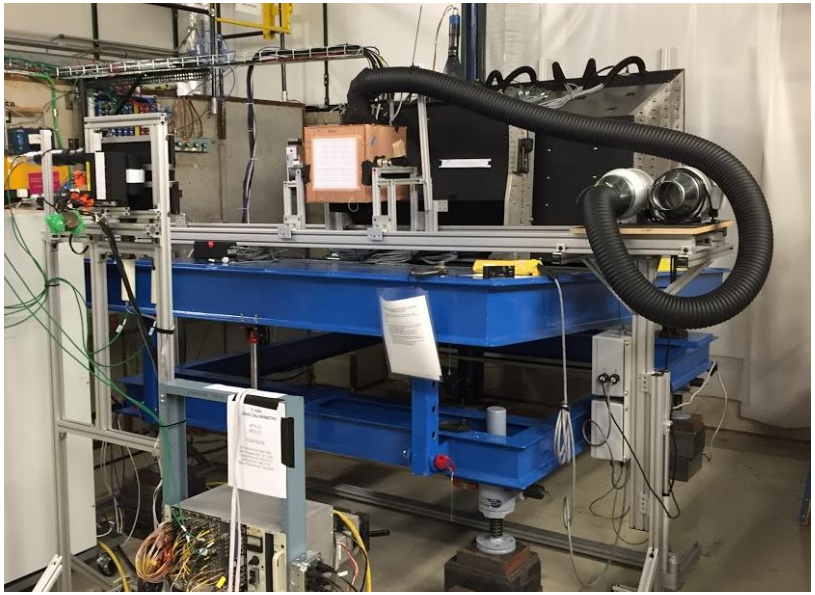
Outer HCAL prototype with assembled steel plates

Scintillating tiles with WLS fiber in groove. One SiPM reads out both ends of fiber.

Test Setup at Fermilab

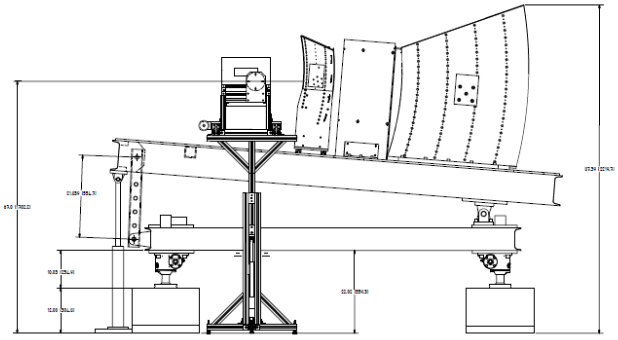
All three prototype calorimeters in the beam line at Fermilab





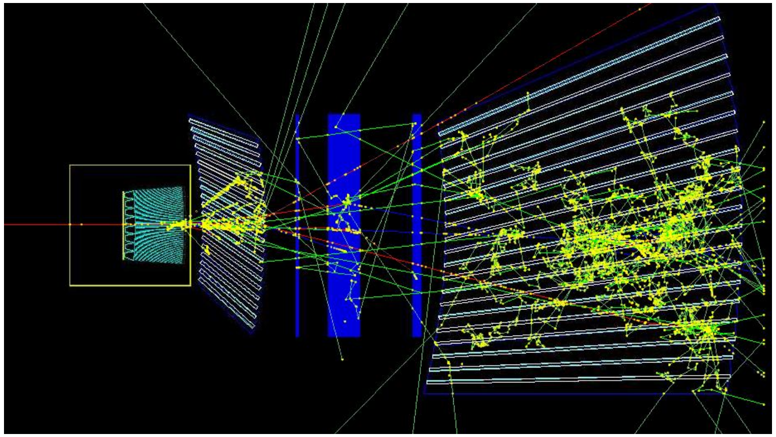
Three calorimeters in their sPHENIX configuration

Measured at three tilt angle positions (0, ± 4.5°)

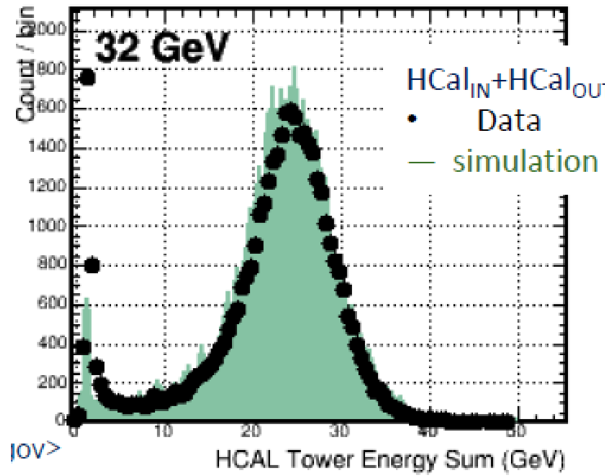


Simulations

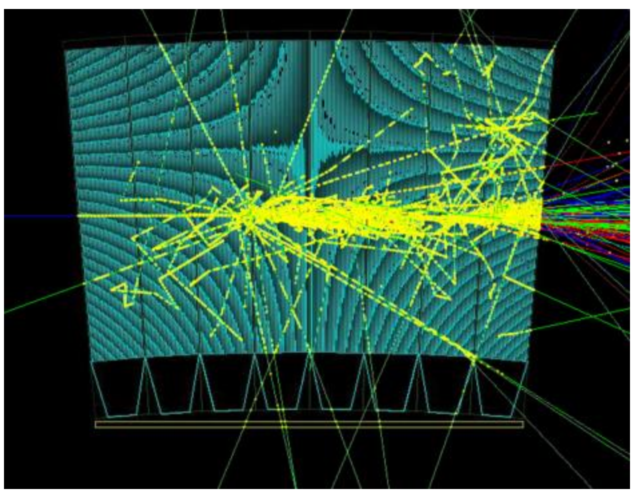
Entire test beam setup was simulated in GEANT4

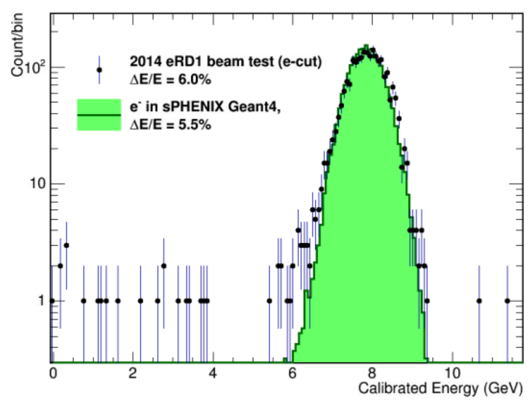


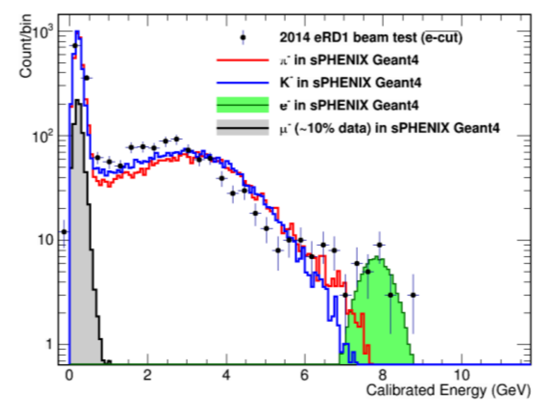
Hadronic shower in 3 calorimeters



Comparison of IHCAL+ OHCAL line shape with simulation







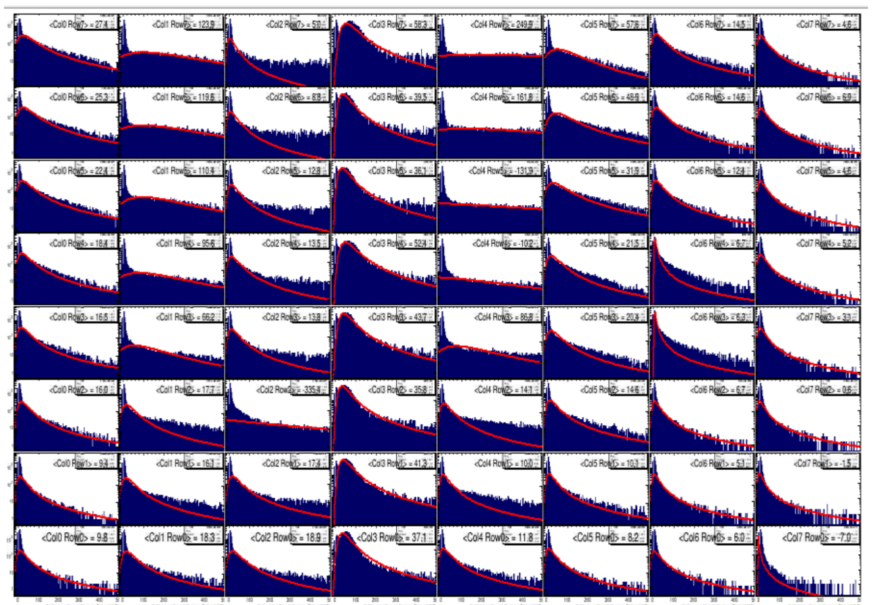
Comparison of EM and hadronic showers in with eR1 test beam data

Hadron entering EMCAL in “Nose Down” position

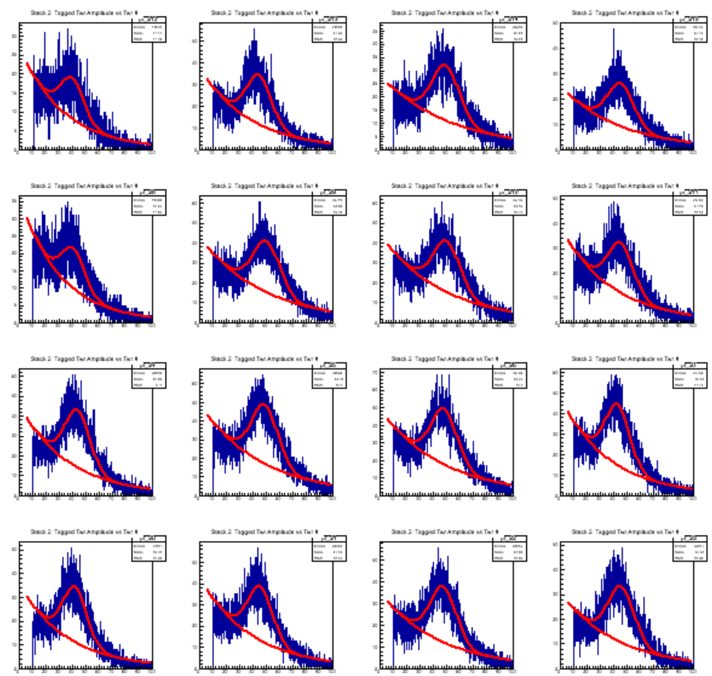
Calibrations

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



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)

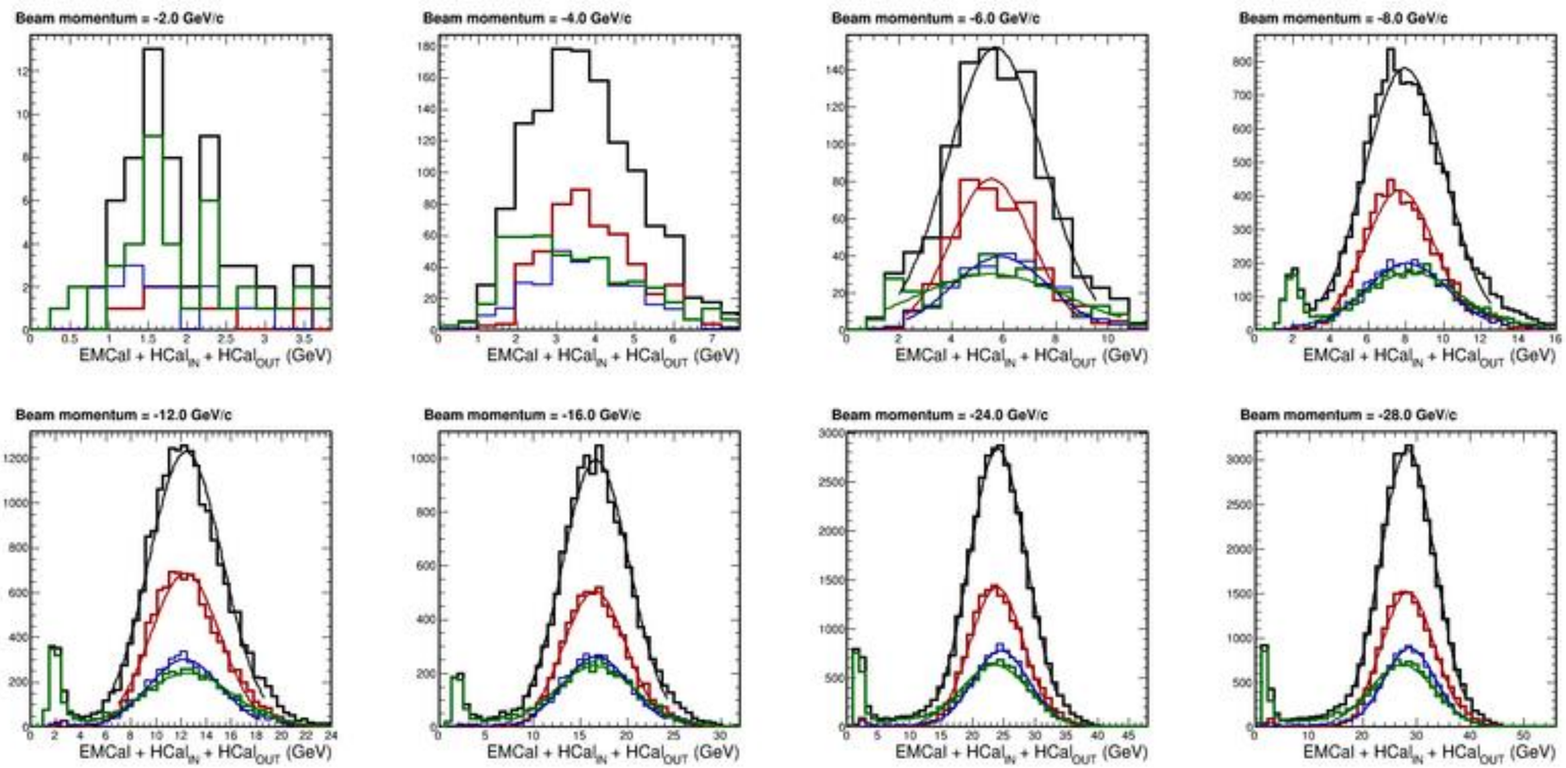


Example of Outer HCAL calibration with cosmic muons

Setting the Energy Scale

Calibration with hadron showers selected using beam Cherenkovs

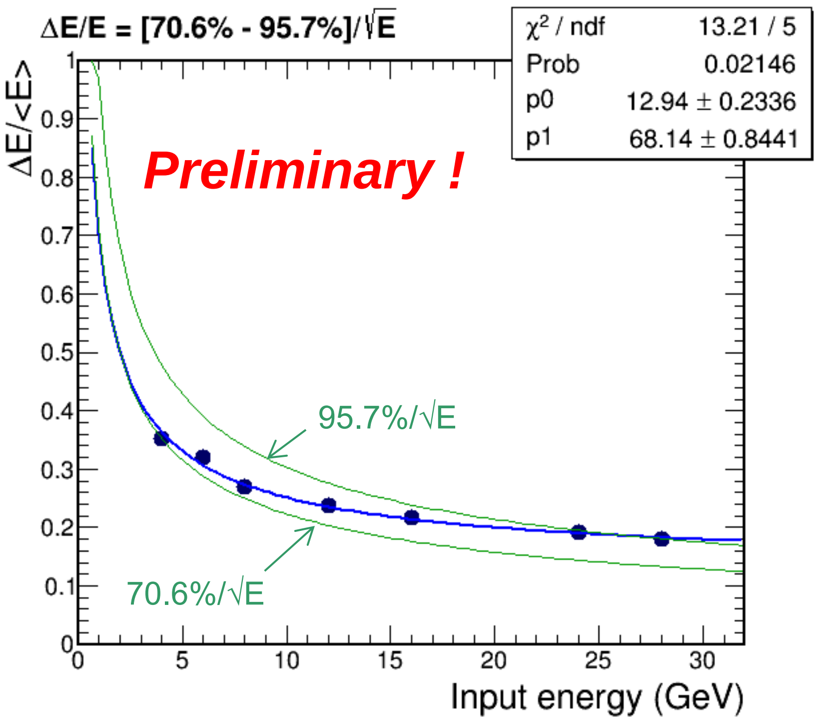
(Addition requirements: 4x4 cm^2 hodoscope hit, no veto hit)

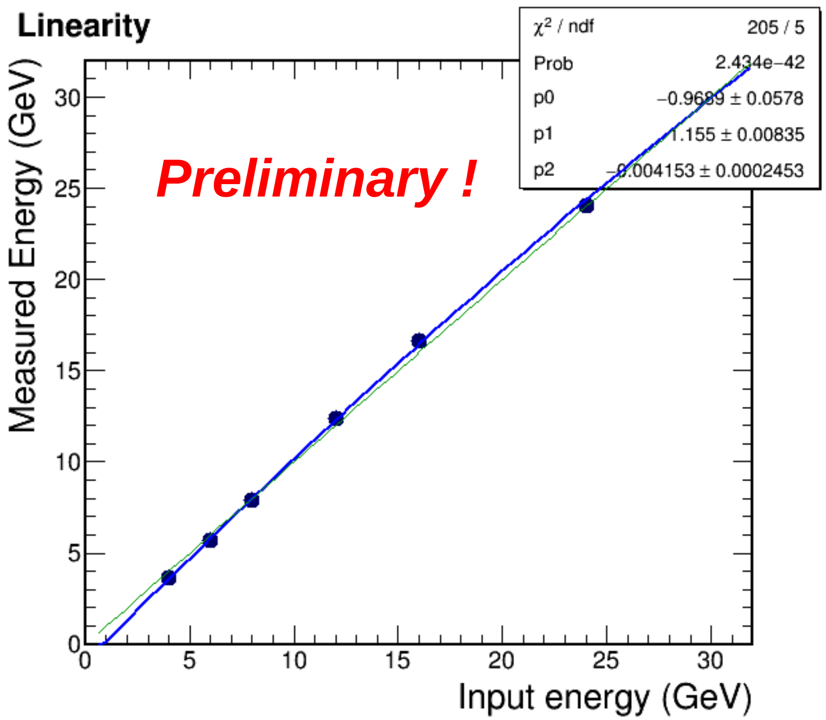


Red: Shower starts in EMCAL
Blue: MIP in EMCAL. Shower starts in Inner HCAL
Green: MIP in EMCAL and Inner HCAL. Shower starts in Outer HCAL
Black: Sum of all showers

Sets energy scale for adding energies from all three calorimeters

Combined EMCAL + HCAL Energy Resolution and Linearity





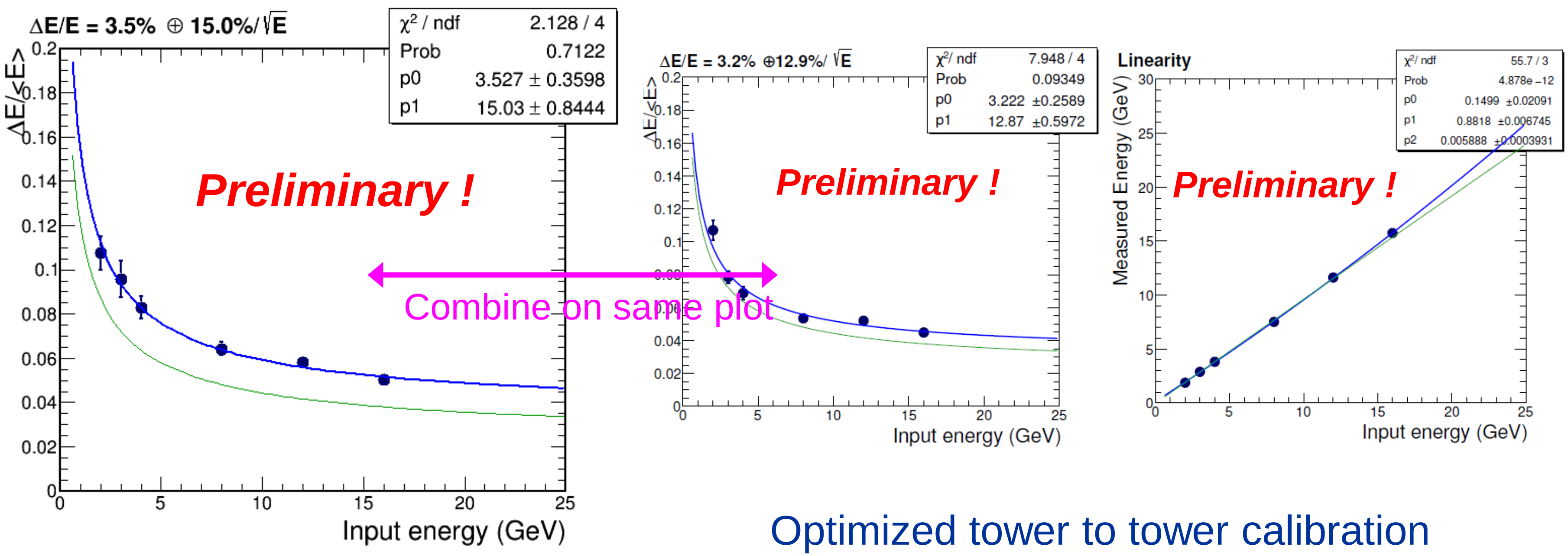
- Combined energy resolution meets our design goal of < 100%/√E
- Actual fit gives 68%/√E ⊕ 12.9%
- Constant term is first pass on tower to tower calibration and will certainly improve with further analysis

EMCAL Energy Resolution and Linearity

Electrons selected using beam Cherenkovs

(Also require hodoscope hit + no veto hit)

Beam momentum spread of ~ 3% ***not*** unfolded



Optimized tower to tower calibration using electron showers

First pass MIP calibration

Already meets our design goal

Summary

- A major new detector, currently called sPHENIX, is being proposed for RHIC.
- Purpose is to do a systematic study of the QGP around the region of the critical temperature using full calorimetry measurements of jets at central rapidity and a high resolution measurement of the three upsilon states
- The calorimeter system will consist of a compact W/SciFi EMCAL and 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 indicated that all three detectors will meet the design goals of the new experiment
- Be on the lookout soon for some exciting new results !