The sPHENIX Calorimeters

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Special thanks to John Haggerty and Craig Woody for contributed slides

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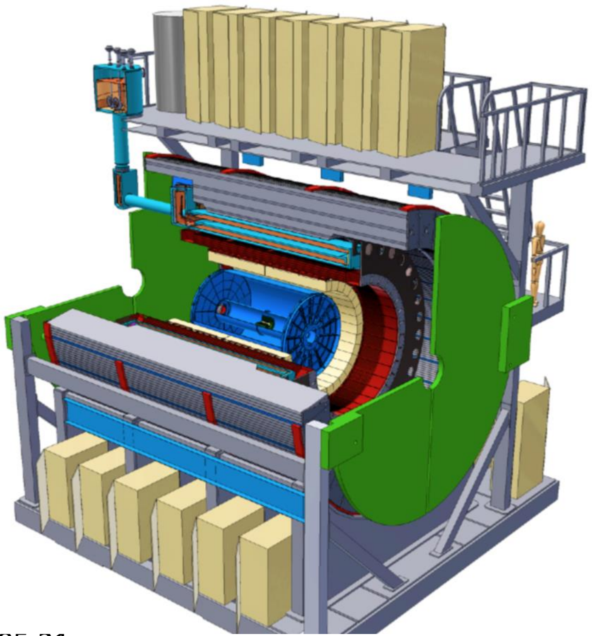
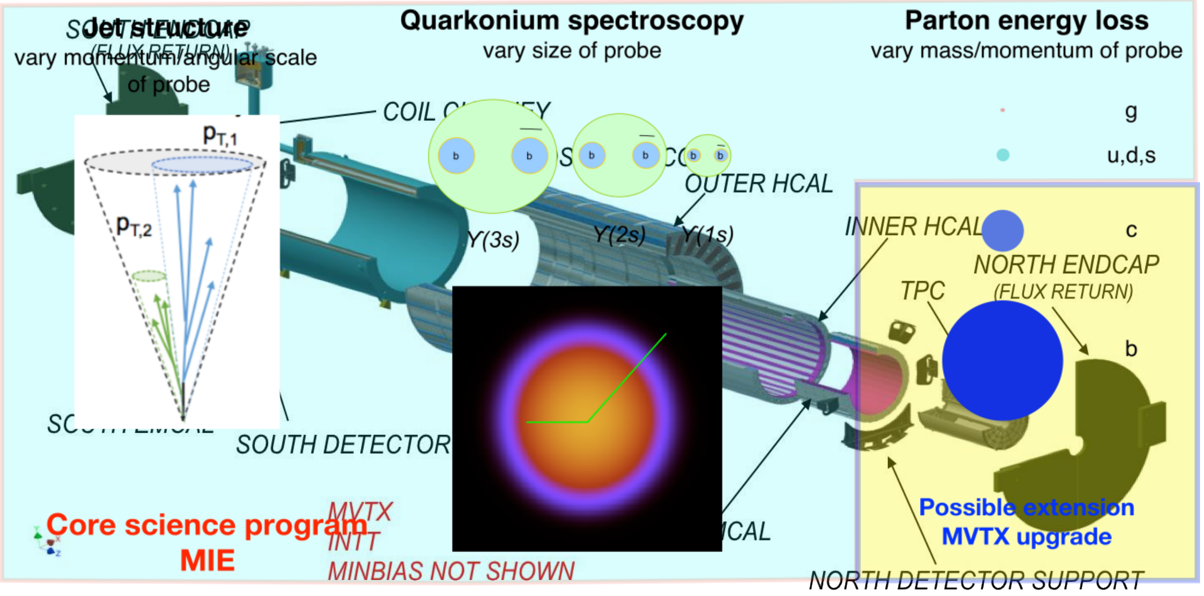
What is sPHENIX?

sPHENIX is a proposal for a major upgrade to the PHENIX detector capable of making high statistics measurements of:

- **Jets with tracking and calorimetric reconstruction**
- **Identified electromagnetic and hadronic probes of QGP**
- **Upsilon states**

G.Roland, DOE-OPE CD1/3A Review





Ultimate Performance Parameters

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Core physics goals

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Physics goal	Analysis requirement	UPP
Maximize statistics for rare probes	Accept/sample full delivered luminosity	**Data taking rate of 15kHz for Au+Au**
Precision Upsilon spectroscopy	Resolve Y(1s), Y(2s), (Y3s) states	**Upsilon(1s) mass resolution ≤ 125MeV in central Au+Au**
High jet efficiency and resolution	Full hadron and EM calorimetry Jet resolution dominated by irreducible background fluctuations	**$\sigma/\mu \leq 150\%/\sqrt{pT_{jet}}$ in central Au+Au for R=0.2 jets****
Full characterization of jet final state	High efficiency tracking for $0.2 < p_T < 40$GeV	**Tracking efficiency ≥ 90% in central Au+Au**** **Momentum resolution ≲ 10% for p_T = 40 GeV****
Control over initial parton p_T	Photon tagging with energy resolution dominated by irreducible higher order processes	**Single photon resolution ≤ 8% for p_T = 15 GeV in central Au+Au****

Calorimeter trigger

Calorimeter energy

Calorimeter Energy Id

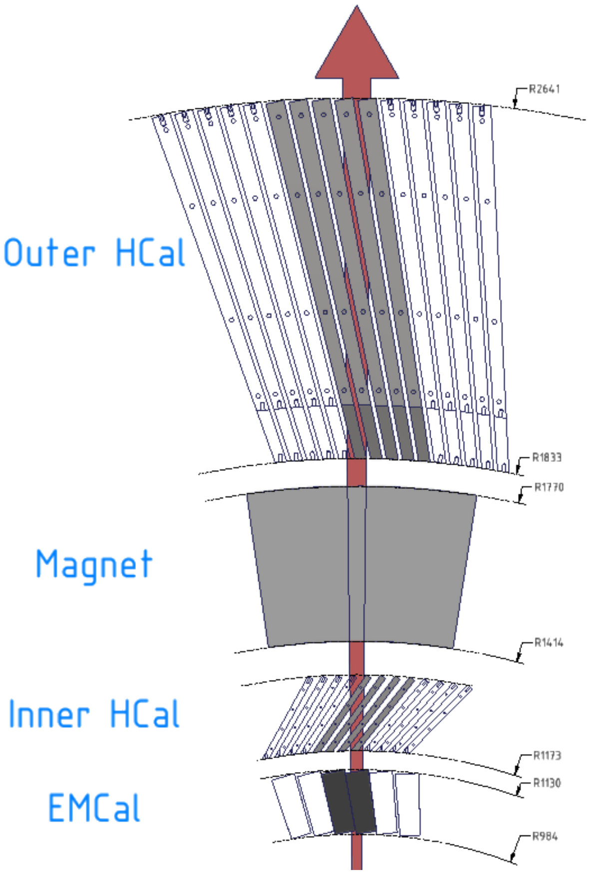
Calorimeter PId (γ/h)

(**) to be extracted using Au+Au, p+p data and simulations, following LHC examples

Calorimetry: overview

- ***Designed around Density, Uniformity and Granularity;***
- ***Novel sampling hadronic and electromagnetic calorimetry with novel deep longitudinal segmentation***
  - "Tilted in azimuth, near pointing in rapidity" towers tungsten-scintillating fiber SPACAL EMC with ~7 mm radiation length
  - "Tilted in azimuth, near pointing in rapidity" longitudinally sectioned steel-scintillating tiles HCAL towers with light collected by embedded WLS fibers
  - Sampling fraction is allowed to smoothly vary radially
  - Common SiPM based optical readout complemented with low cost 60 MHz waveform digitizers (compact, no HV, immune to magnetic field, amplified large amplitude differentially driven signals are immune to pick up noise).

Calorimetry: Implementation



- Tilt is chosen for two neighboring towers to overlap in azimuthal space;
- It allows in principle an independent measure of longitudinal CG in every section if shower vector is at least approximately known (measured);
- Local&Global CG knowledge allows to compute shower specific sampling fraction per section and leakage energy per particle or unit of acceptance (AI assisted analyses).

Calorimeters as relate to physics

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- EMC drivers are decay electrons from Υ-family
  - Coverage: $\pm$ 1.1 in η, 2π in ϕ, ~projective in η and ϕ
  - Radiation length 7 mm, it is bout 18 X_0 deep
  - Moliere radius 23 mm (approximate tower size)
  - 2.3% sampling fraction
  - Energy Resolution: "$\sigma_E/E < 16\%/\sqrt{E}$"
  - Provide an e/h separation > 100:1 at ~5GeV/c
- Compact, works inside 1.4T magnetic field

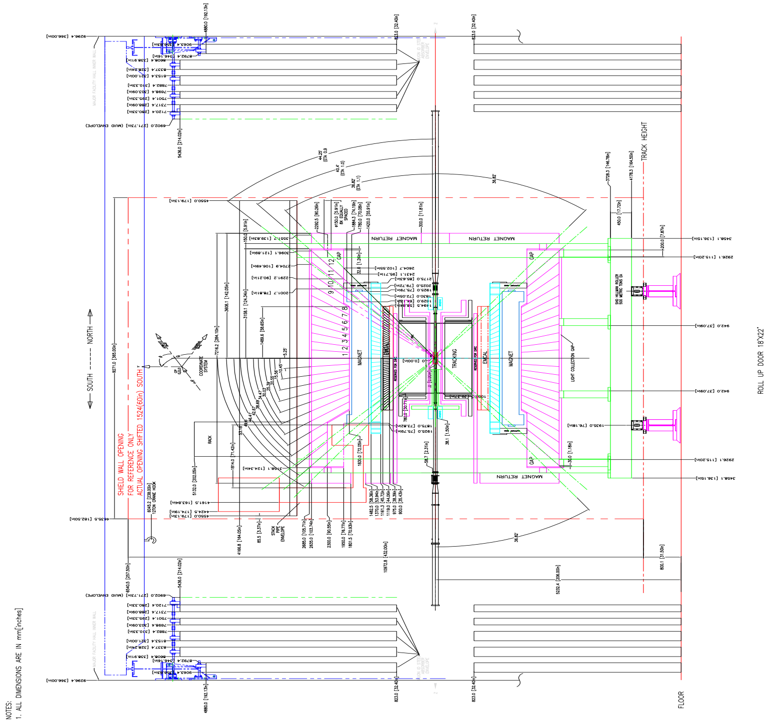
System

EMC	0.75 Labs
Hinner	0.55 Labs
Houter	3.8 Labs

95% absorption at 20GeV/c momenta

- HCAL requirements are driven by measuring jets in heavy ion collisions
  - Uniform and nearly deadzone free
  - $-1.1 < \eta < 1.1$, 2π in ϕ
  - $\Delta\eta \times \Delta\phi \sim 0.1 \times 0.1$ fits the jets with R<0.4
  - $24 \times 64 = 1536$ channels
  - Sampling fraction 2.8-3.7% (varies in depth)
- The Outer HCAL doubles as the flux return of the solenoid

sPHENIX Calorimeters by numbers

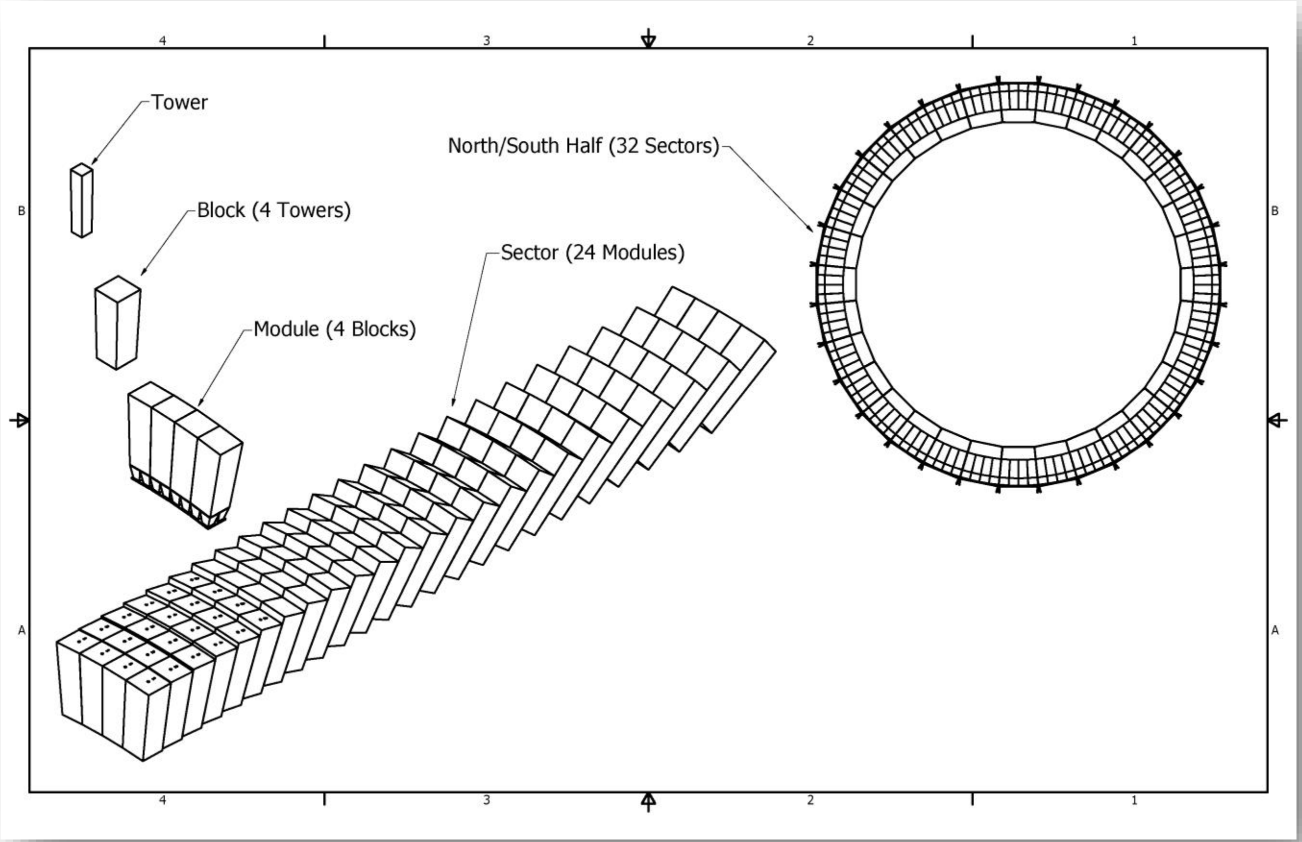


Sectors (-1.1<|η|<1.1)	32
Towers	64x24
Sc. Tiles (and SiPM's)	7680
Granularity (dη x dϕ)	~0.1x0.1

Sectors (-1.1<|η|<1.1)	32
Towers	64x24
Sc. Tiles (and SiPM's)	6144
Granularity (dη x dϕ)	~0.1x0.1

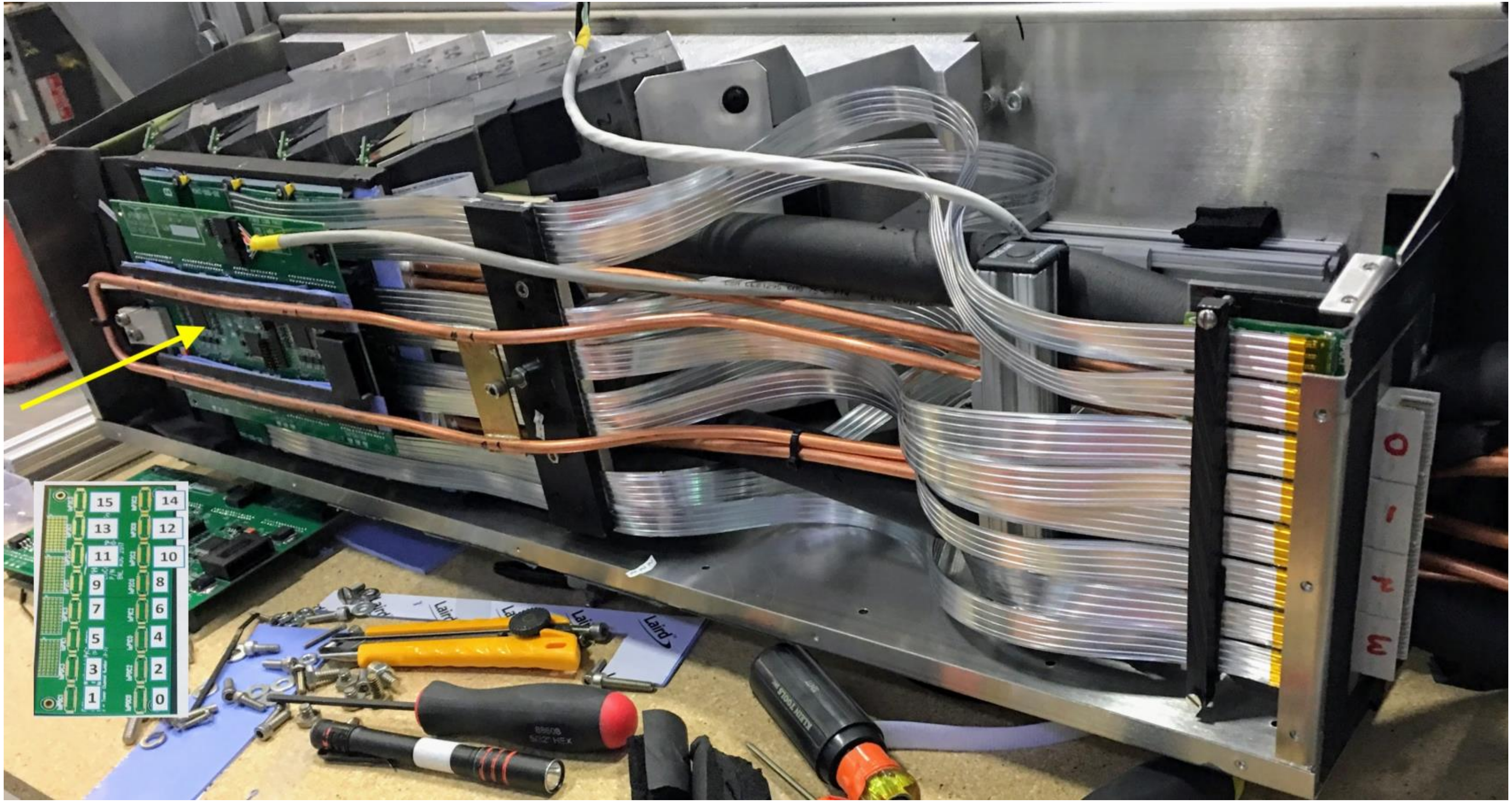
Sectors (0<|η|<1.1)	64
Towers (64x8x48)	24576
Sc. Fibers (per tower)	667
Segmentation (dη x dϕ)	~0.025x0.025
SiPM's	98304

EMCAL sector design



- 64 sectors (32+32)
- 90 < r < 116 cm
- 1.7 m long
- 450 kg/sector
- Read out on inner radius

EMCAL V2.1 assembled



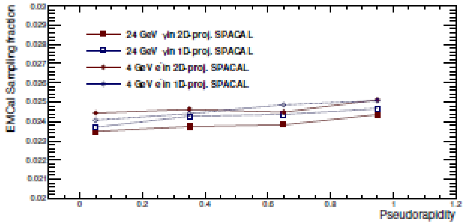
EMCAL Absorber Blocks (*)

Active media

- Matrix of tungsten powder and epoxy with embedded scintillating fibers
- Density ~ 9-10 g/cm^3
- X_0 ~ 7 mm (18 X_0 total), R_M ~ 2.3 cm

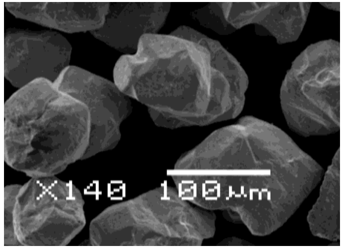
Scintillating fibers

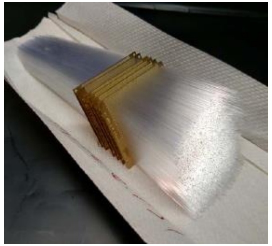
- Diameter: 0.47 mm, Spacing: 1 mm
- Sampling Fraction ~ 2 % and *changes with rapidty*



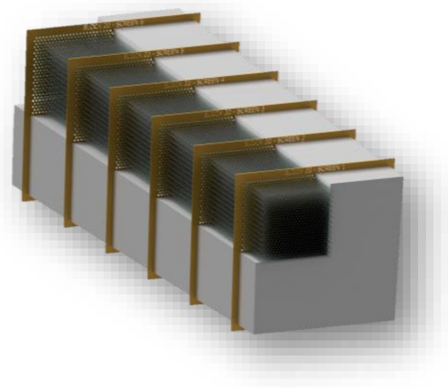
(*) E.C.Dukes et al, in CALOR 1992 Proceedings, p 655

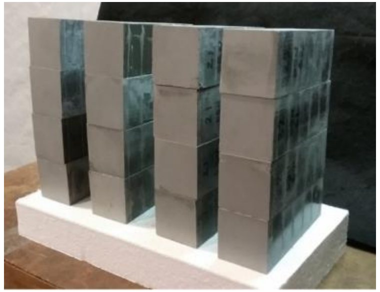
100 Mesh tungsten powder





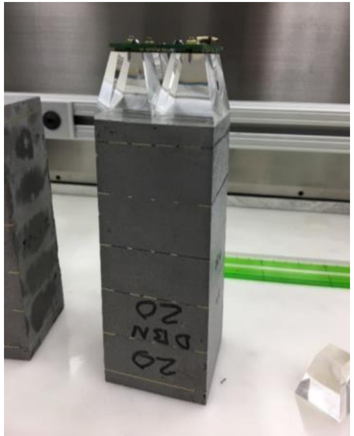
Mesh screens & Sc fibers

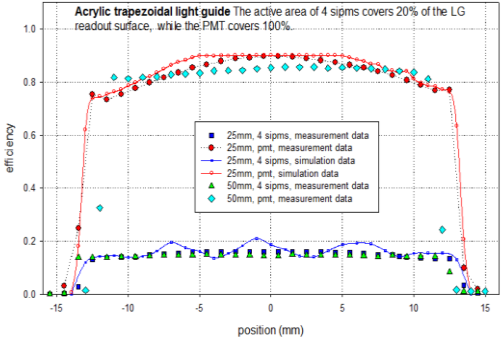


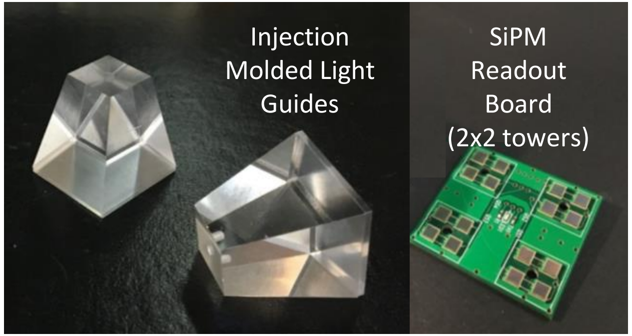


Light Collection and Readout

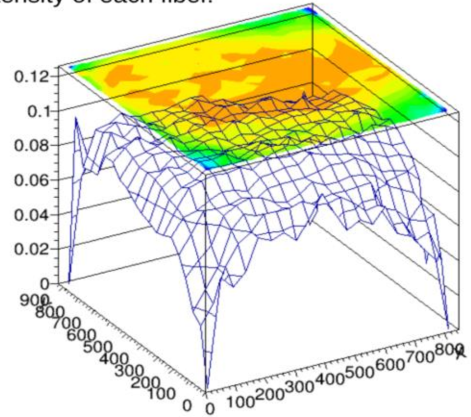
Blocks are read out in individual towers using optical light guides and SiPMs







I is the intensity of each fiber.



DBN 60

Light guide focuses light onto four 3x3 mm^2 SiPMs

- Phase space matching between tower and 4 SiPMs is < 6.4%
- Short light guide is a poor mixer
- Photostatistics gives ~ 500 p.e./GeV

$\Rightarrow$ ~ 4.5%/√E contribution to energy resolution
$\Rightarrow$ 0.5 pixels/MeV (each SiPM has 40K pixels)

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Standalone EMC Performance

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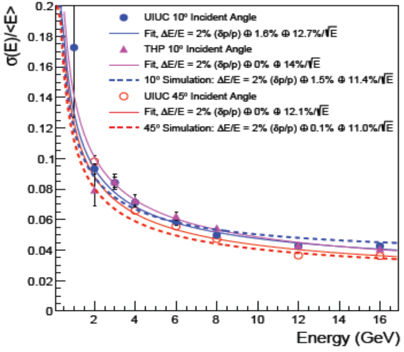
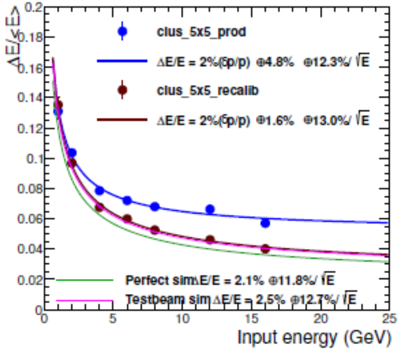
2016

Beam Centered on a single tower

2017

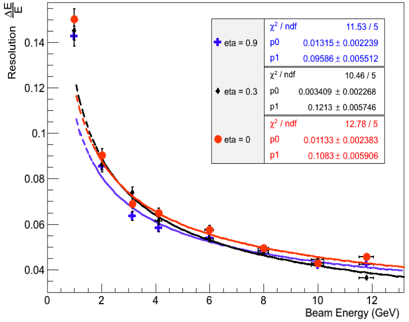


1D Projective (η = 0)



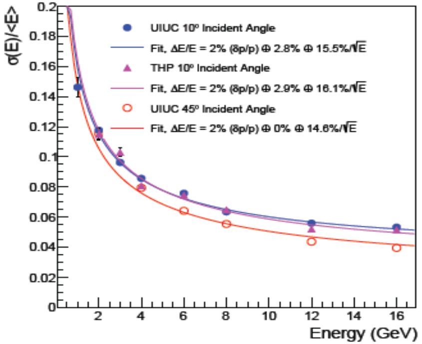
2D Projective (η ~ 0.9)

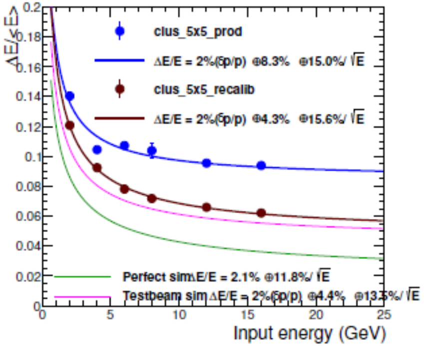
2014 - UCLA



1D Projective (η = 0, 0.3, 0.9)

O.Tsai (2014)





Beam spread over more than one block

Inner HCAL

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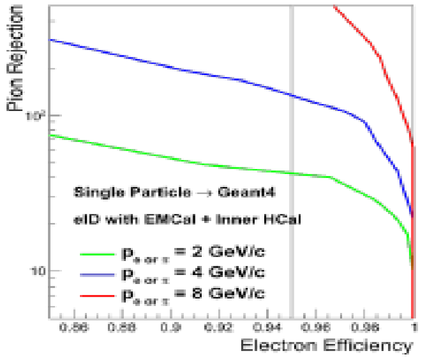
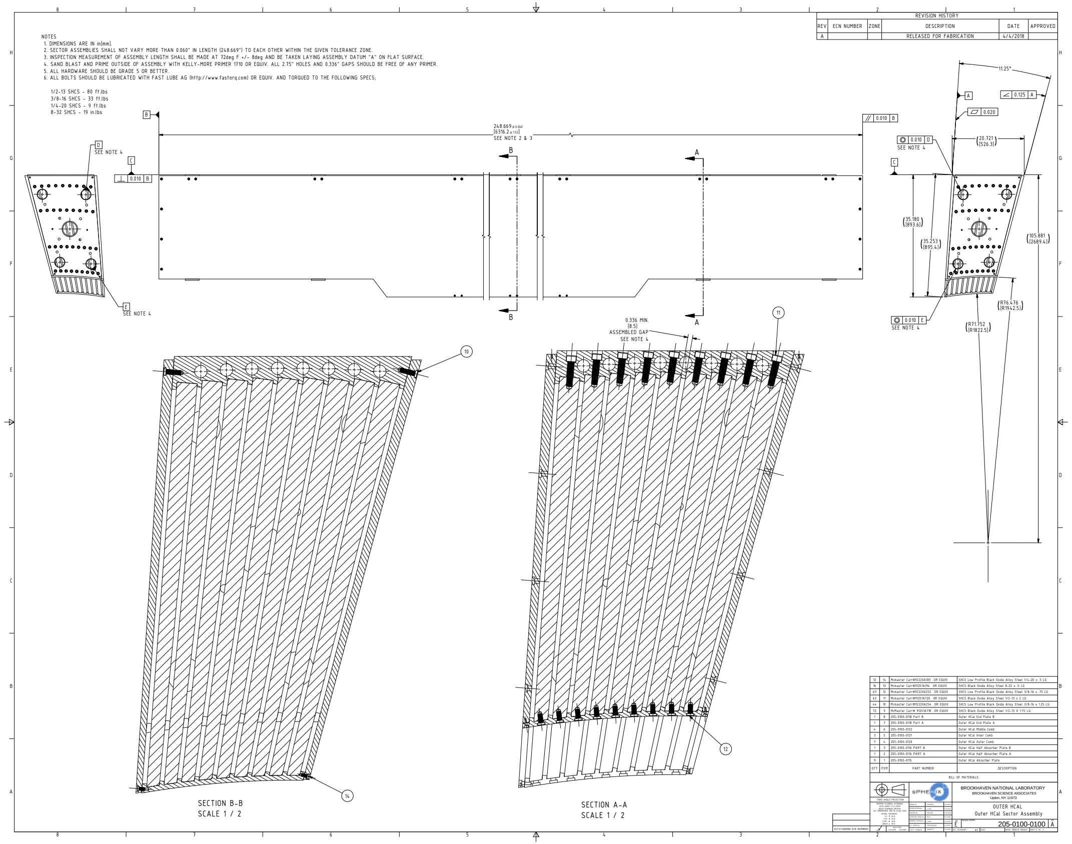
- **Nonmagnetic**
- **0.7 Labs of Flat Stainless or Cu plates**
- **4 tiles per tower**
- **Part of Hcal but also serves a leakage section to EMCal (neutral hadron rejection in photon sample). Has sampling fraction comparable to EMC.**
- **has been descoped in the DOE-funded detector (sPHENIX hopes to recover it as in-kind contribution as time goes by) and replaced by support structure**

p+p

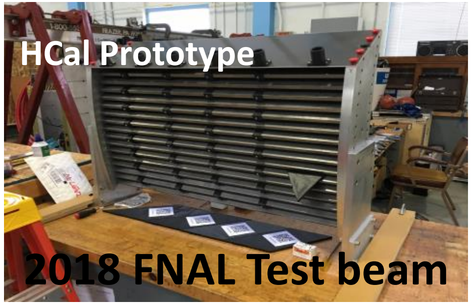


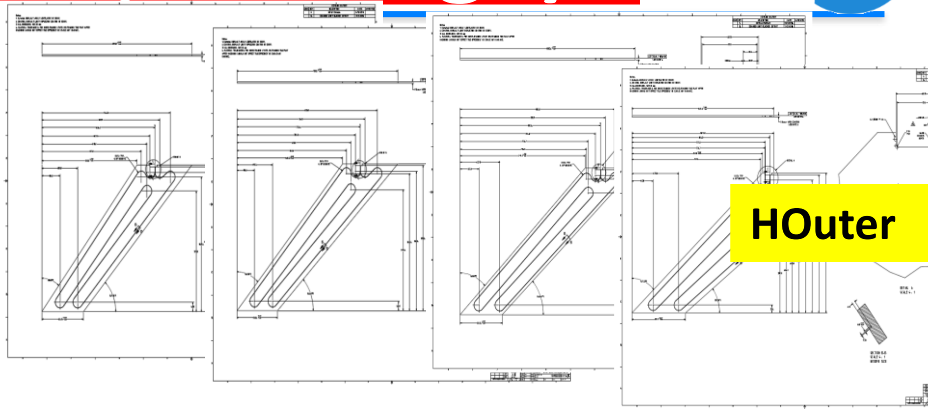
Outer HCAL

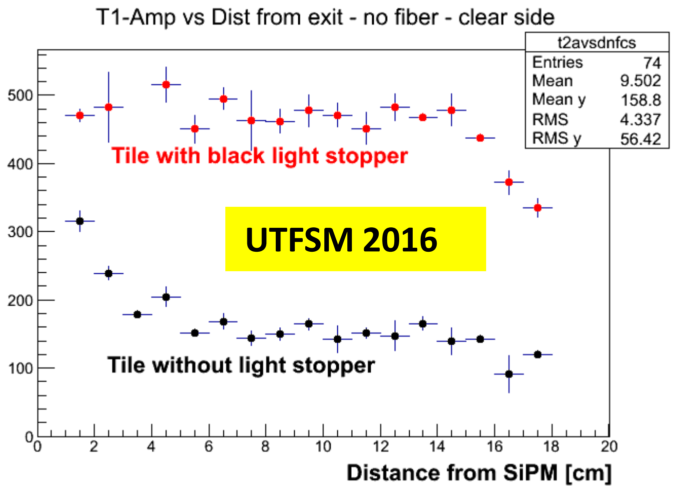


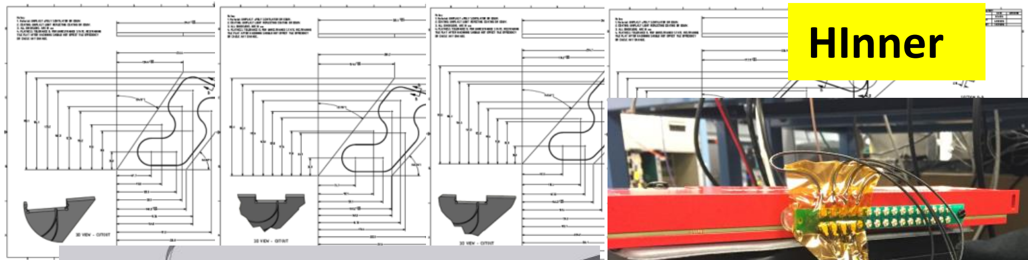
- 32 sectors. Each:
  - **1.9 m < r < 2.6 m**
  - **6.3 m long**
  - **13.5 tons**

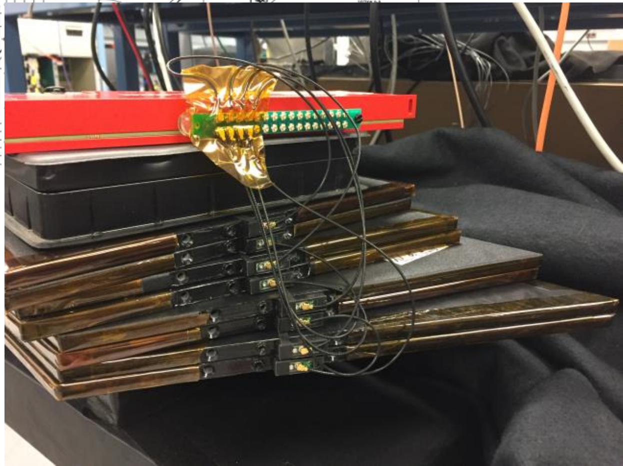
HCal Tiles 2018 (12 small/ 12 large)



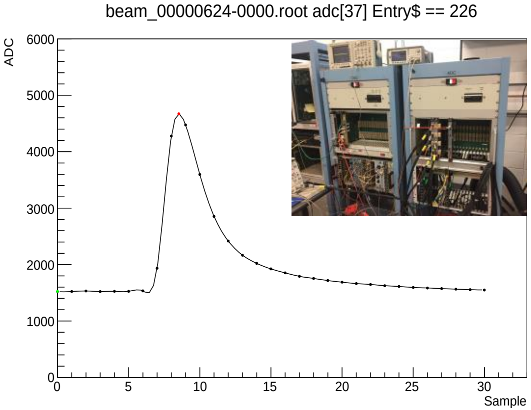


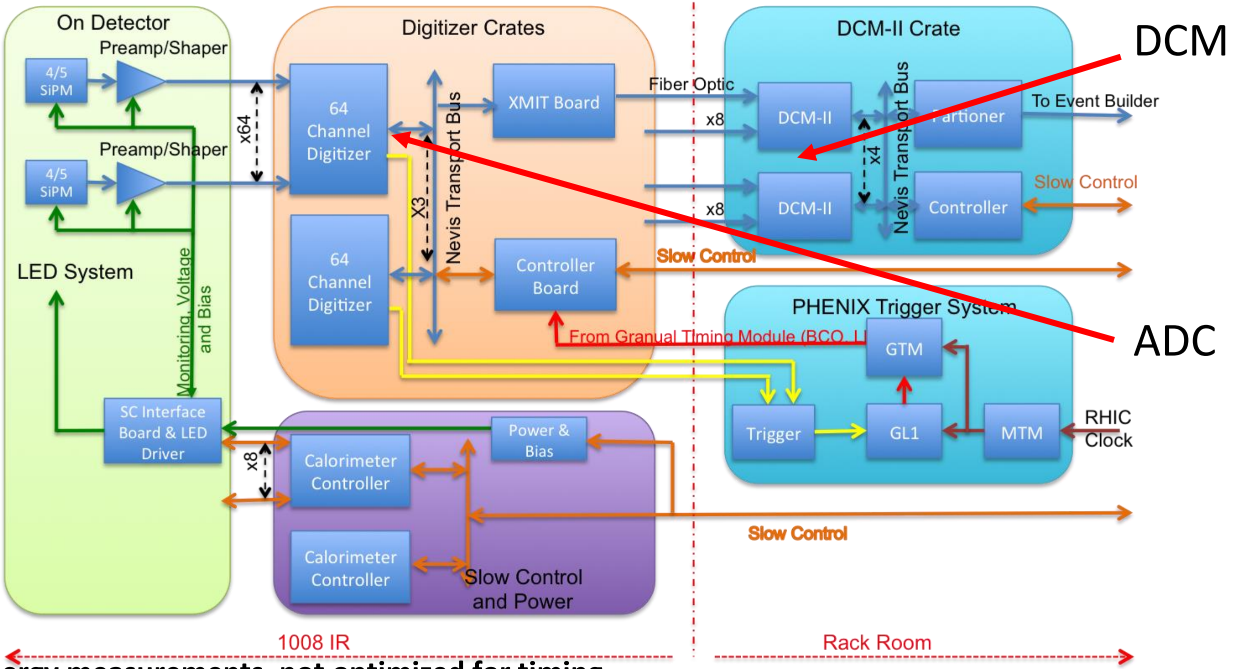






Calorimeter electronics





- **60 MHz FADC – sufficient for energy measurements, not optimized for timing**
- **Base line restoration in two crossings**
- **14 bit waveform digitizers**
- **Digital trigger data available on every crossing**
- **Transmit 192 channels in <40 µs**

Calorimeters in the test beam

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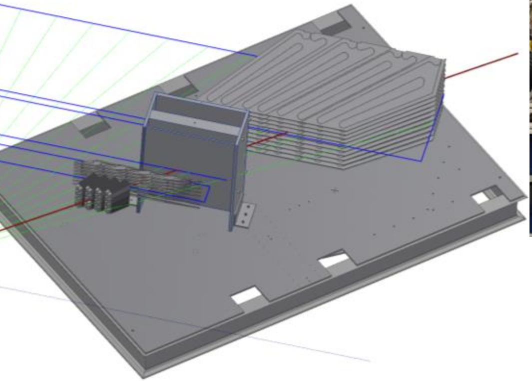
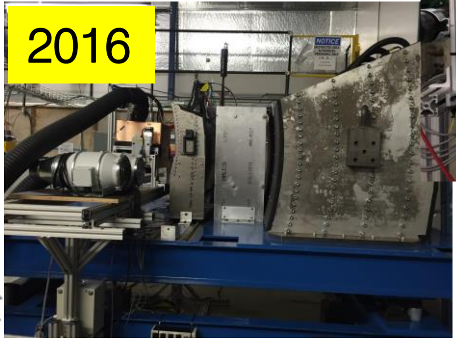
History

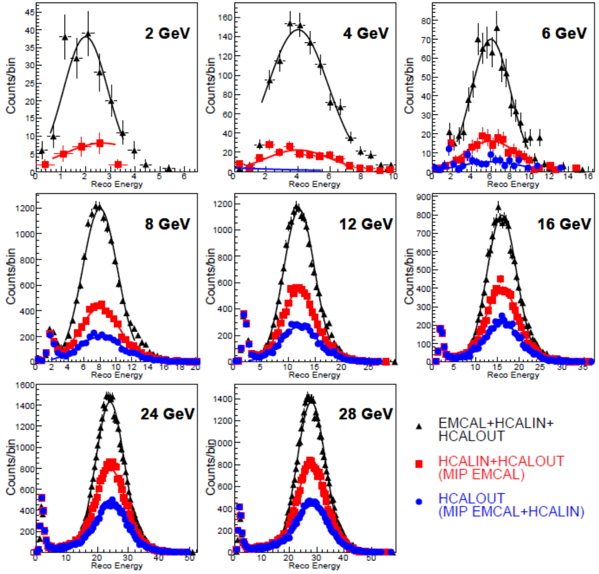
2/2014	**Proof of principle**
2/2016	**System at η~0**
2/2017	**System at η~0.9**
2/2018	**System at η~0.9.**
	"Production" components



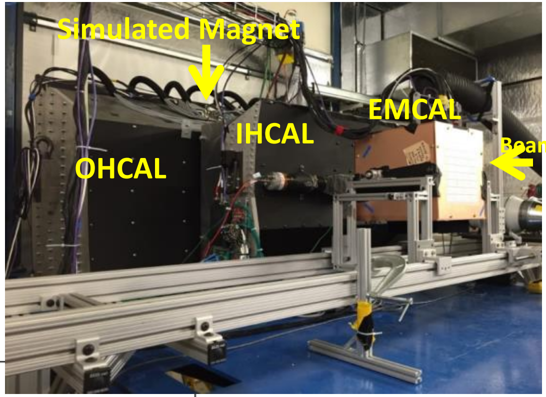


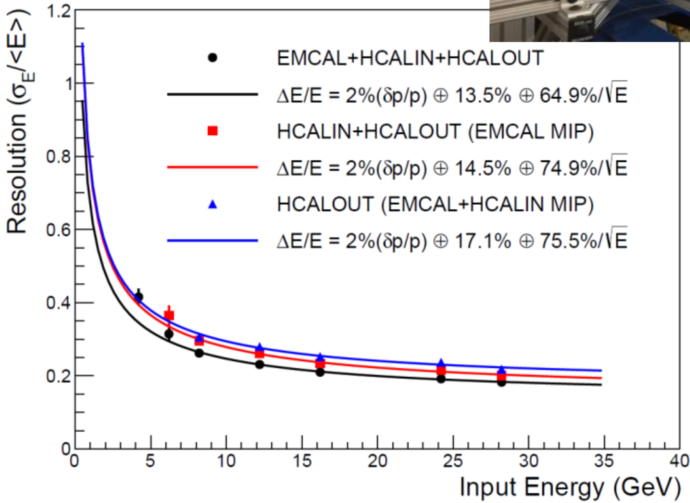
sPHENIX Calorimeter Performance

2014 – 2016 – 2017



In all cases, the combined system meets the sPHENIX spec!





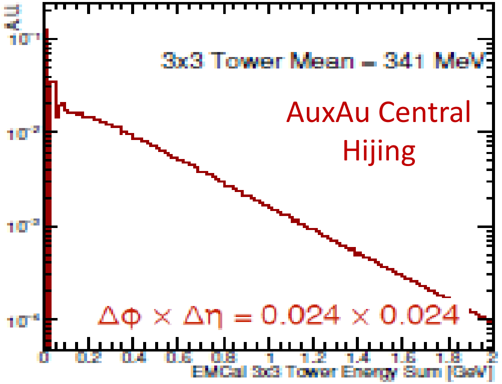
Calorimeters and sPHENIX Physics

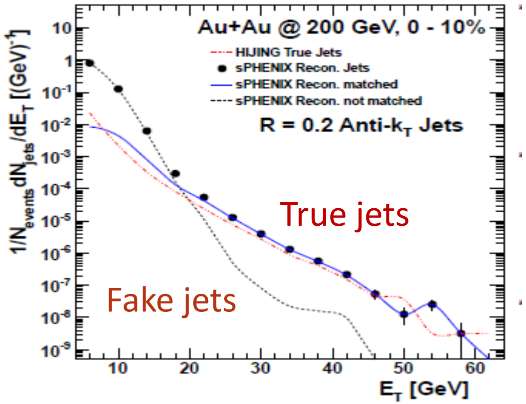
Jet measurements

- Measure the EM component of the jet energy along with HCAL
- Requirements on energy resolution and segmentation are determined mainly by the underlying event

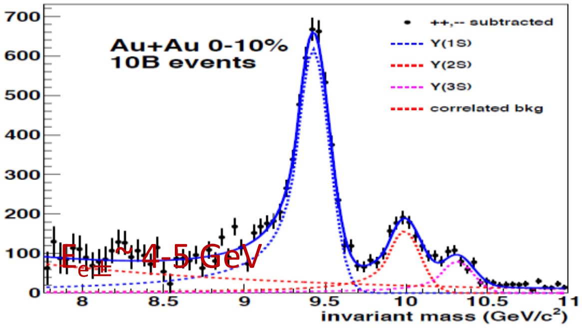
For a 5 GeV electron from ϒ decay
$16\%/\sqrt{E} \Rightarrow \sim 340$ MeV

True jets begin to dominate fake jets for $p_T > 20$ GeV/c



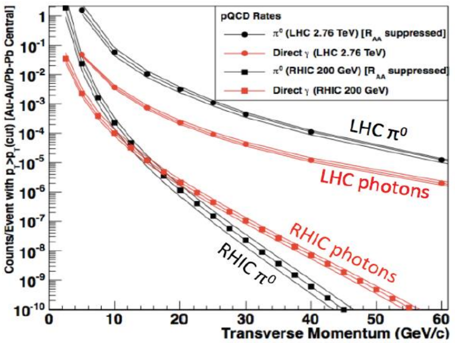


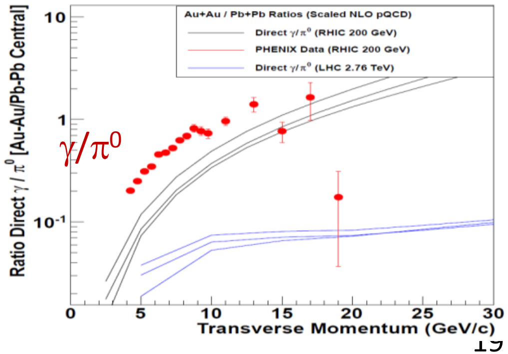
ϒ measurements



Provide electron id (e:h > 100:1)

γ-jet and direct photon measurements





Tag and measure photons for $p_T > 20$ GeV

Summary

sPHENIX is building deeply segmented longitudinally and laterally near pointing calorimeters optimized for jet extraction and characterization, electron identification and photon measurements at RHIC in the pT range free of underlying event effects in Heavy Ion Collisions.

The Calorimeters are nearly dead space free, have several novel features including deep longitudinal segmentation and intentional overlaps between neighbor towers in azimuthal space allowing enhanced shower shape measurement, control of the energy leakage from the system and event by event compensation for shower fluctuations in detector with sampling fraction inversely dependent on the depth in calorimeter.

The design was validated in beam tests of prototype sPHENIX electromagnetic and hadronic calorimeters from 2014 until 2018 (latest run was finished on May 18th).

Mapping tile response