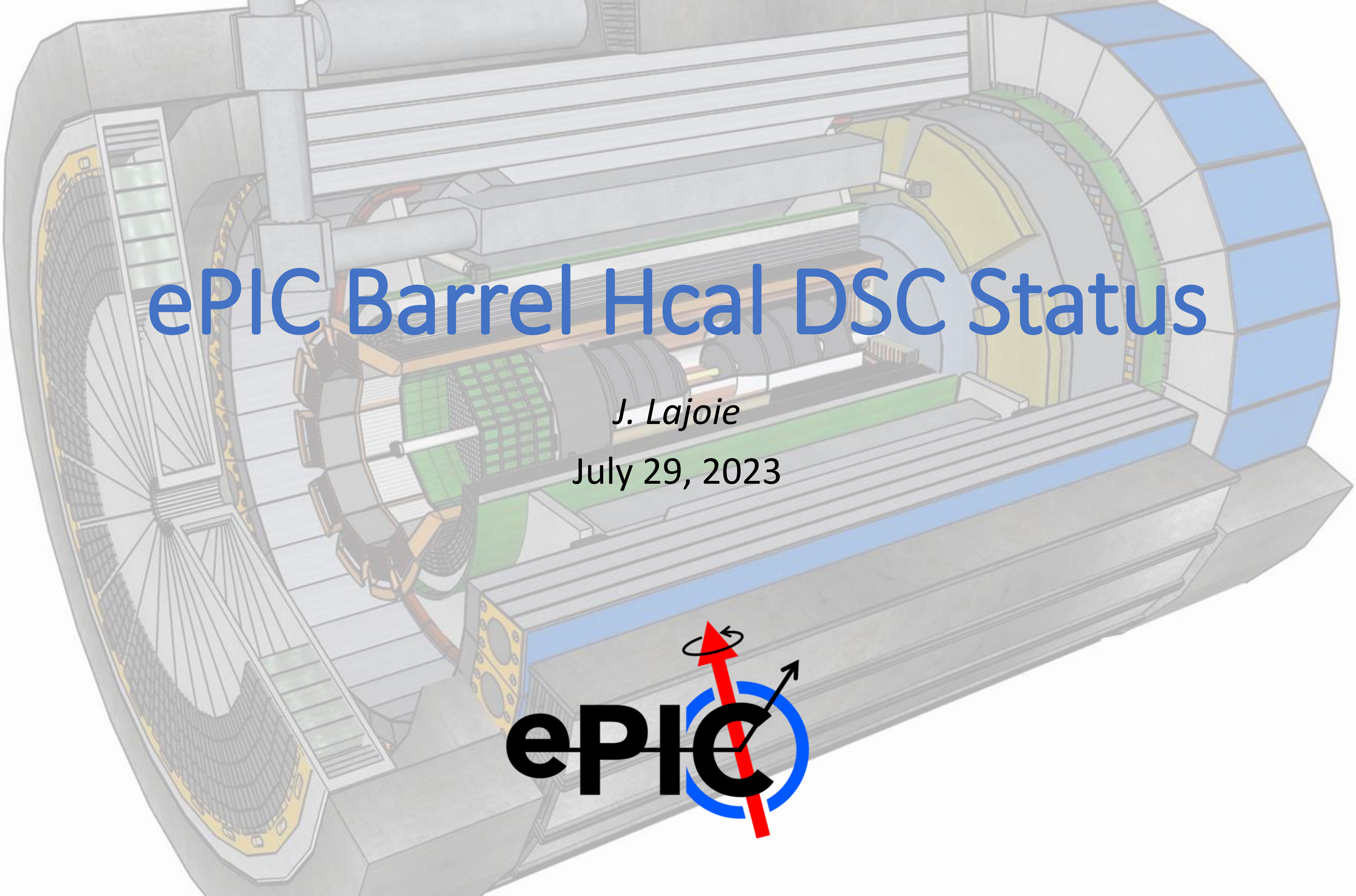


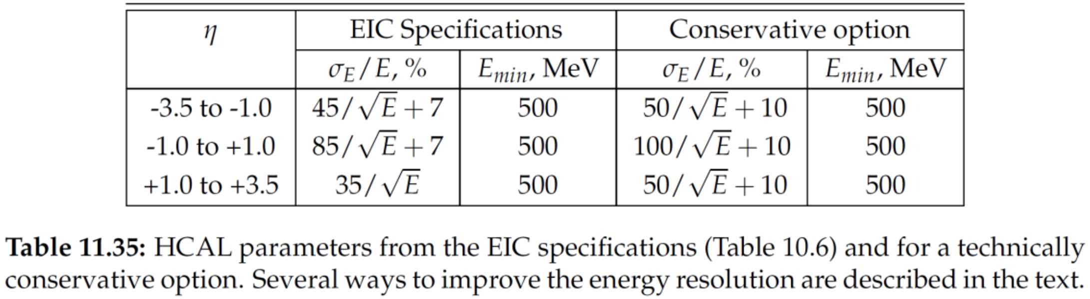
ePIC Barrel Hcal DSC Status

J. Lajoie

July 29, 2023

Introduction

EIC Yellow Report



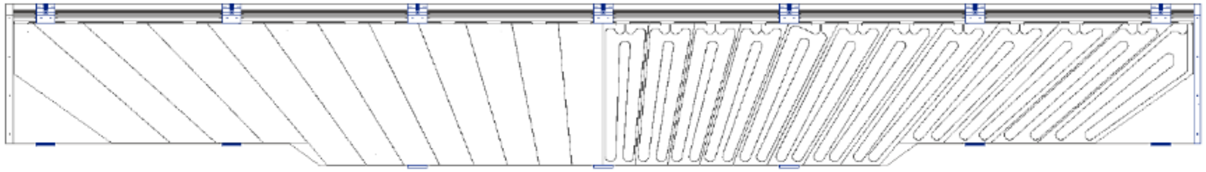
η	EIC Specifications		Conservative option	
	σ_E/E, %	E_{min}, MeV	σ_E/E, %	E_{min}, MeV
-3.5 to -1.0	$45/\sqrt{E}+7$	500	$50/\sqrt{E}+10$	500
-1.0 to +1.0	$85/\sqrt{E}+7$	500	$100/\sqrt{E}+10$	500
+1.0 to +3.5	$35/\sqrt{E}$	500	$50/\sqrt{E}+10$	500

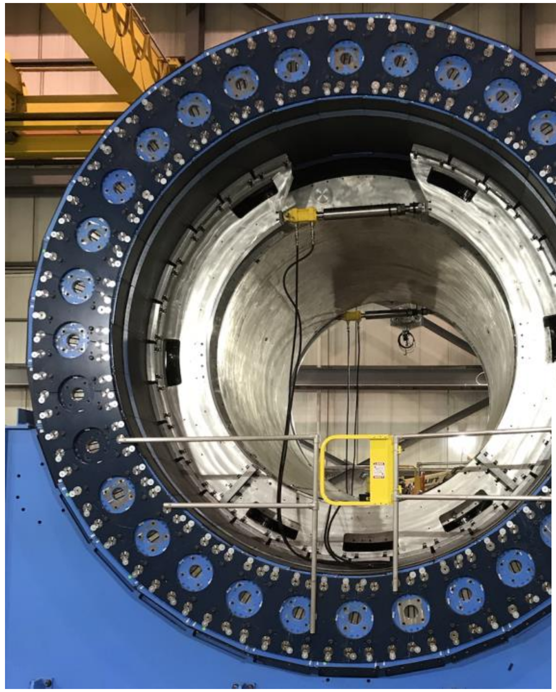
Table 11.35: HCAL parameters from the EIC specifications (Table 10.6) and for a technically conservative option. Several ways to improve the energy resolution are described in the text.

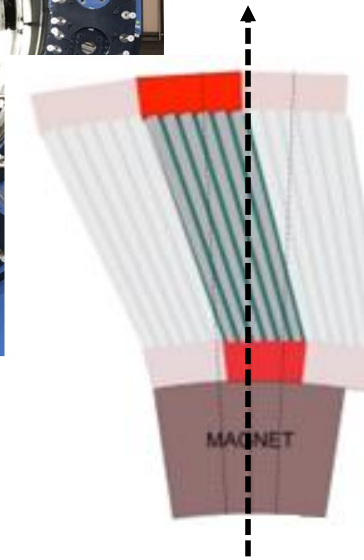
- Main goals for barrel HCAL in ePIC:
  - Precise reconstruction of jet energy
    - Jets at the EIC are relatively soft
    - Tracks + ECal will provide a better determination of jet energy than hadronic calorimetry over most of the kinematic coverage.
    - HCAL provides a measurement of neutral hadrons.
  - Secondary determination of scattered electron kinematics from hadronic remnants
  - Additional capability: Muon identification (MIP)
- ePIC will repurpose the sPHENIX barrel HCAL as a hadronic calorimeter and part of the solenoid flux return

Barrel HCAL Design

tiles in sector gap:







Assembly Detail:
5 scintillators/tower
48 towers per sector
32 sectors;
1536 channels (7680 SiPMs)

32 sectors - 1.9m inner radius, 2.6m outer radius

Titled-tile design:
10 rows of 8mm scint. tiles (24 tiles per row), 12^{o} tilt angle

Tapered 1020 steel plates ~26.1mm - ~42.4mm

Completed sector is 6.3m long, 13.5 tons

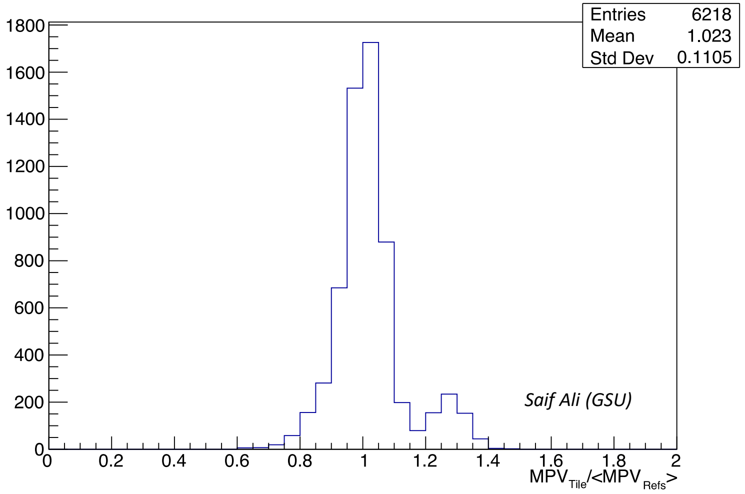
Tower preamplifiers

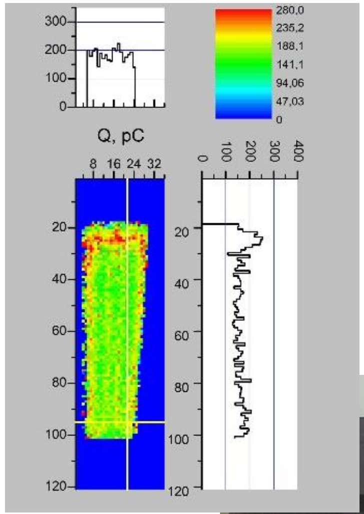
LV/Bias and slow controls.

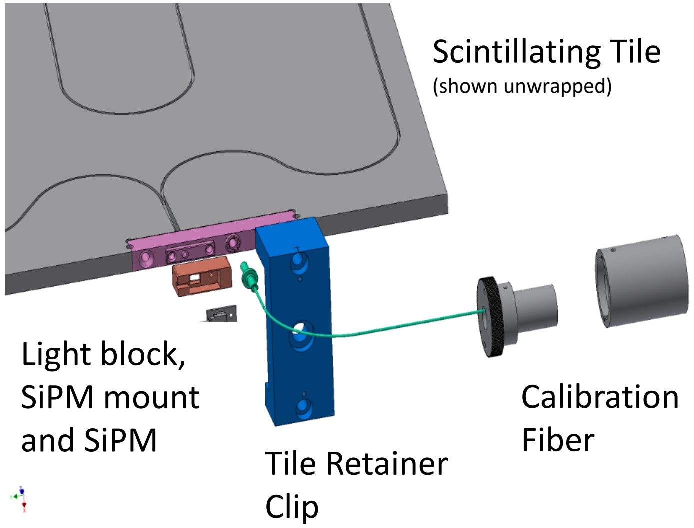
Scintillating Tiles

Scintillating tiles are integrated units manufactured by Uniplast.
Detailed cosmic ray response maps from MEPHI (Urugan telescope), integrated into sPHENIX simulations.

Extensive testing of produced tiles for unform response,
results used to sort tiles into a tower with variation <5%





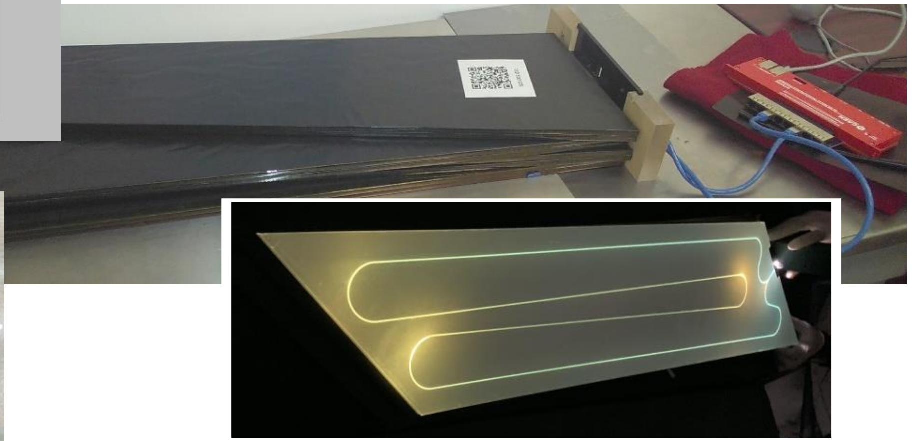


Scintillating Tile
(shown unwrapped)

Light block,
SiPM mount
and SiPM

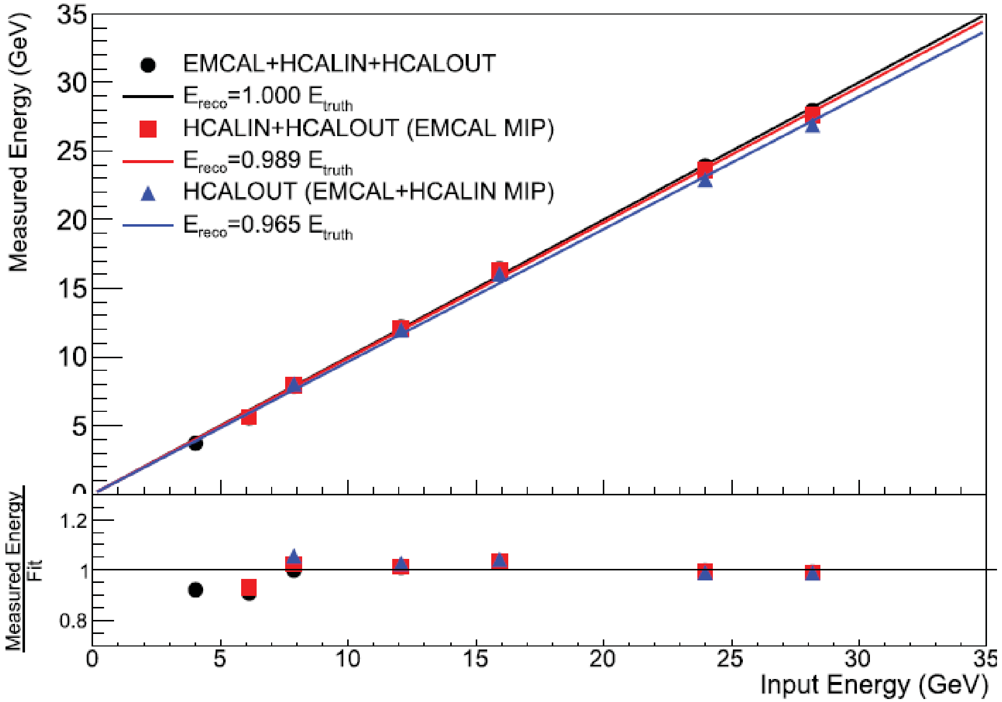
Tile Retainer
Clip

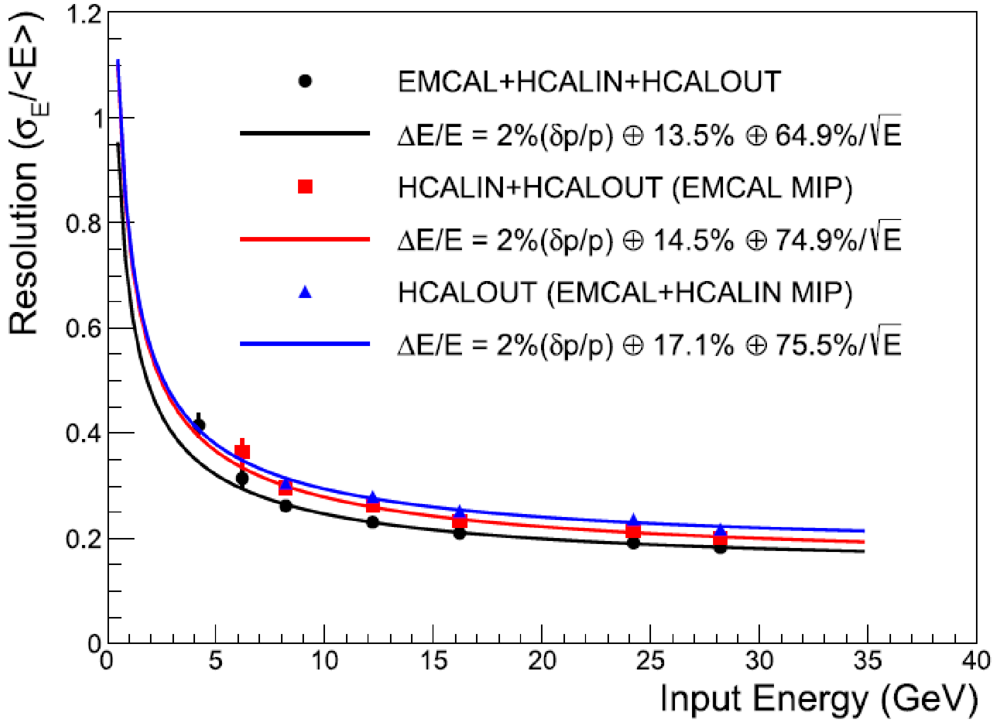
Calibration
Fiber

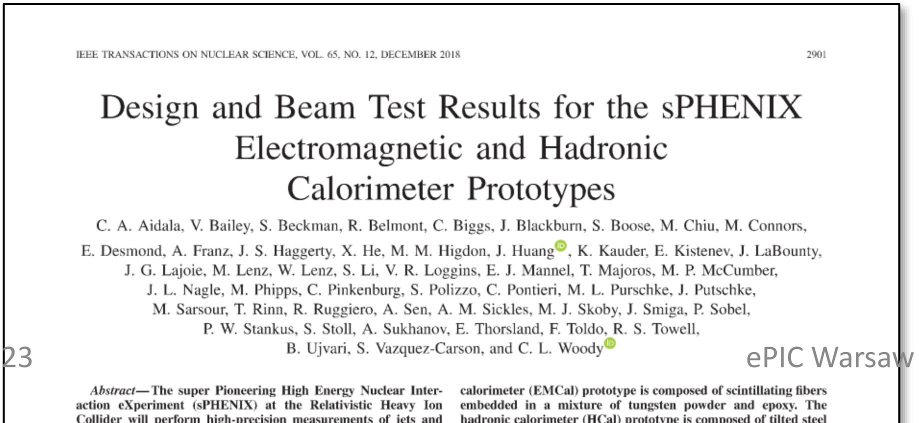


Barrel HCAL Performance (I)

sPHENIX Test Beam (T-1044)







IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 65, NO. 12, DECEMBER 2018 2901

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

C. A. Aidala, V. Bailey, S. Beckman, R. Belmont, C. Biggs, J. Blackburn, S. Boose, M. Chiu, M. Connors,
E. Desmond, A. Franz, J. S. Haggerty, X. He, M. M. Higdon, J. Huang, K. Kauder, E. Kistenev, J. LaBounty,
J. G. Lajoie, M. Lenz, W. Lenz, S. Li, V. R. Loggins, E. J. Mannel, T. Majoros, M. P. McCumber,
J. L. Nagle, M. Phipps, C. Pinkenburg, S. Polizzo, C. Pontieri, M. L. Purschke, J. Putschke,
M. Sarsour, T. Rinn, R. Ruggiero, A. Sen, A. M. Sickles, M. J. Skoby, J. Smiga, P. Sobel,
P. W. Stankus, S. Stoll, A. Sukhanov, E. Thorsland, F. Toldo, R. S. Towell,
B. Ujvari, S. Vazquez-Carson, and C. L. Woody

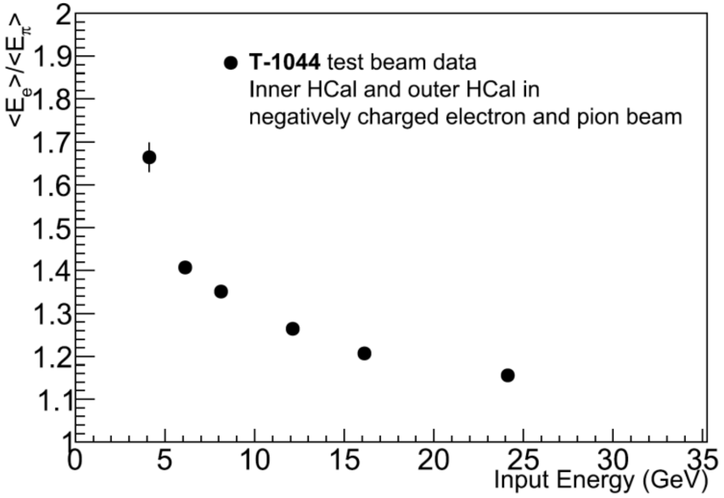
Abstract—The super Pioneering High Energy Nuclear Interaction eXperiment (sPHENIX) at the Relativistic Heavy Ion Collider will perform high-precision measurements of jets and

calorimeter (EMCal) prototype is composed of scintillating fibers embedded in a mixture of tungsten powder and epoxy. The hadronic calorimeter (HCal) prototype is composed of tilted steel

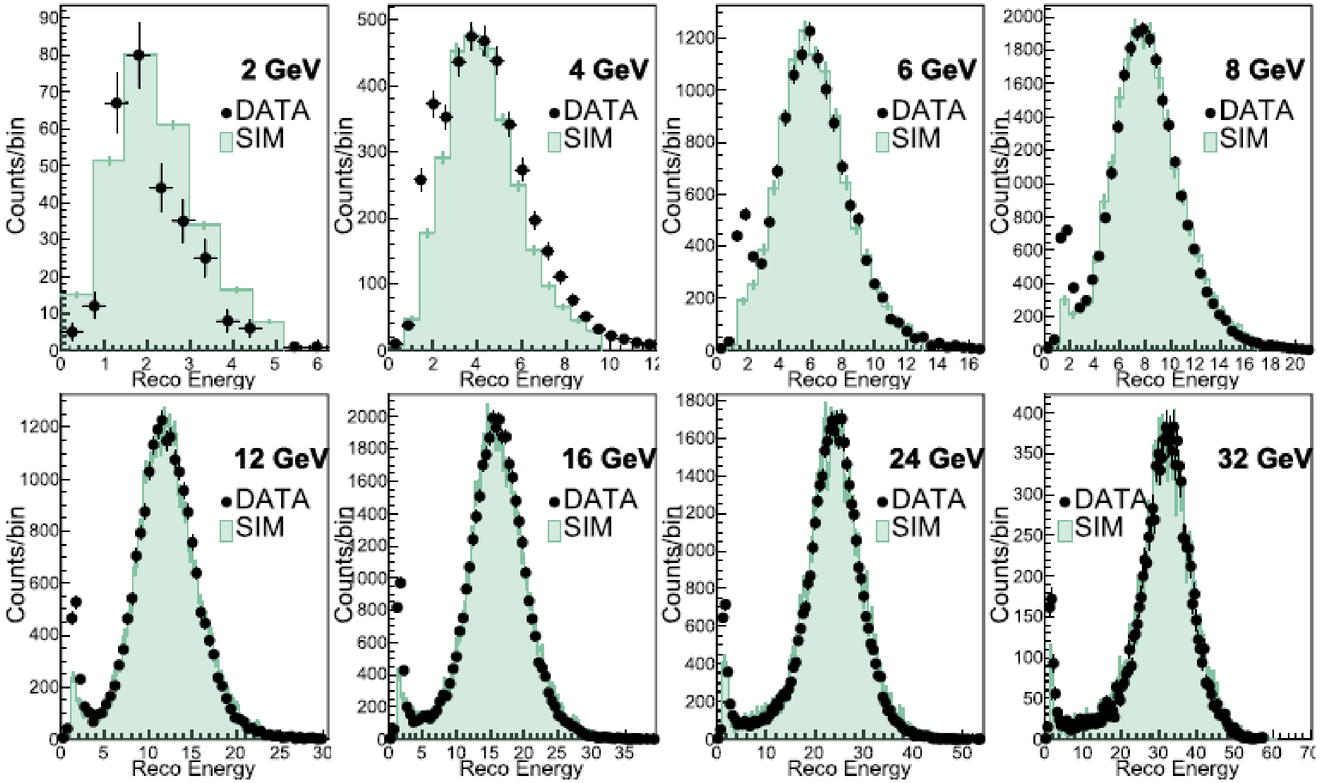
Detailed studies of performance and comparison with simulations done in test beam (T-1044).

Performance of full device will be measured in sPHENIX. We should achieve a reduced constant term due to tighter control on the scintillator variation in a tower for production sectors.

Barrel HCAL Performance (II)

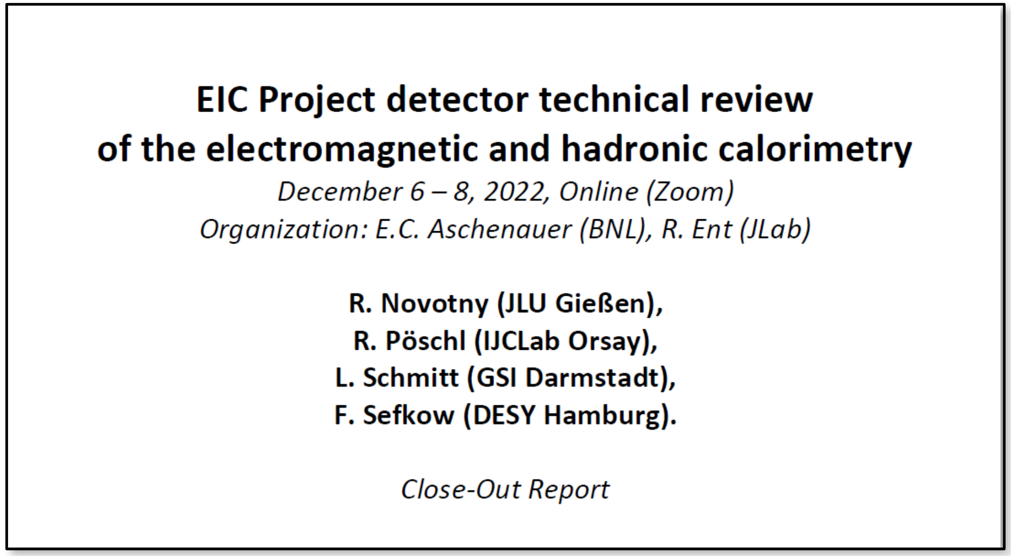


$<E_e>/<E_\pi>$ in data for standalone HCAL



Comparison of standalone HCAL lineshape data/MC

HCal Review Recommendations



EIC Project detector technical review
of the electromagnetic and hadronic calorimetry
December 6 – 8, 2022, Online (Zoom)
Organization: E.C. Aschenauer (BNL), R. Ent (JLab)

R. Novotny (JLU Gießen),
R. Pöschl (IJCLab Orsay),
L. Schmitt (GSI Darmstadt),
F. Sefkow (DESY Hamburg).

Close-Out Report

Barrel HCal

- **Findings**
  The ePIC Barrel HCal will reuse the existing system from sPHENIX consisting of iron layers acting as magnetic flux return and absorber interleaved by layers of scintillating tiles for the shower sampling. The existing tiles will be equipped with new SiPMs as readout. A detailed tile map exists from tests at MEPHI. It is considered to use the HGCROC ASIC in an emulated streaming mode as frontend electronics. The layers are arranged in tilted wedges to avoid showers passing through straight gaps.
- **Comments/Concerns**
  Control of inhomogeneities of the tiles is important to understand the calorimeter response. One should consider using one HGCROC channel per tile to have also longitudinal shower information, as this can be easily achieved with the highly integrated readout. This will allow to distinguish shower from MIP(μ). A concern is the possibly different systematics for positive and negative particles due to the chirality of setup with the inclined wedges.
- **Recommendations**
  R7. Re-map tiles to fully control inhomogeneities.

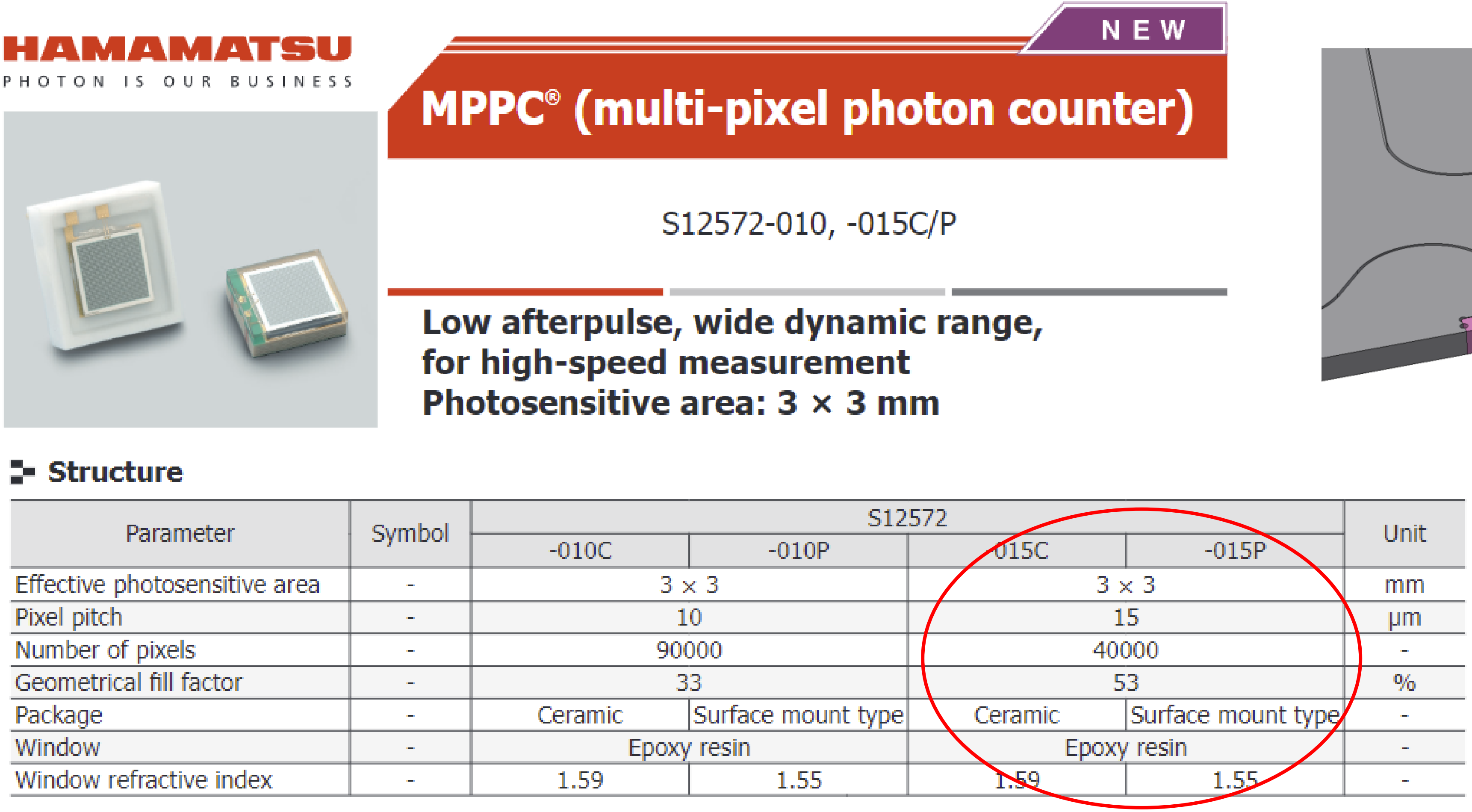
  R8. Exploit advantages of HGCROC to have longitudinal information (see comments).

  R9. Once full physics simulations are available, study particle flow performance of ECAL-Coil-HCAL configuration for jets and muon ID.

Barrel HCAL Refurbishment Plans

- SPHENIX barrel HCAL disassembly
  - In sPHENIX the barrel HCAL currently has 100% live towers
- Refurbish outer HCAL sectors:
  - Do not anticipate significant radiation damage to scintillator
  - Plan to replace SiPMs and readout electronics
    - Will require removal of scintillating tiles.
    - Modify sectors as needed (tapped holes)
    - Re-measure tile cosmics PR
    - Opportunity to replace/repair scintillating tiles if necessary
    - Piggy-back on H2GCROC3 development for LFHCAL
      - Dual-range ADC/TOT very helpful for MIPs
    - Replace slow controls boards as well (LED, etc)
  - Repeat sector-level cosmics calibration

Scintillating Tile SiPM’s



HAMAMATSU
PHOTON IS OUR BUSINESS

NEW

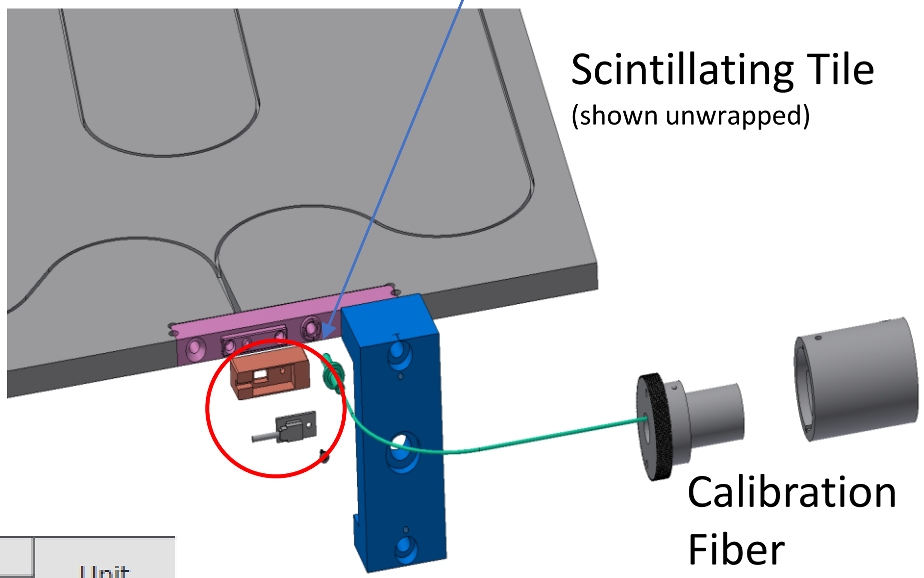
MPPC® (multi-pixel photon counter)

S12572-010, -015C/P

Low afterpulse, wide dynamic range, for high-speed measurement
Photosensitive area: 3 × 3 mm

Structure

Parameter	Symbol	S12572				Unit
		-010C	-010P	-015C	-015P	
Effective photosensitive area	-	3 × 3		3 × 3		mm
Pixel pitch	-	10		15		μm
Number of pixels	-	90000		40000		-
Geometrical fill factor	-	33		53		%
Package	-	Ceramic	Surface mount type	Ceramic	Surface mount type	-
Window	-	Epoxy resin		Epoxy resin		-
Window refractive index	-	1.59	1.55	1.59	1.55	-



Light block, SiPM mount and SiPM (S12572-015P-02) 7680 total

Scintillating Tile
(shown unwrapped)

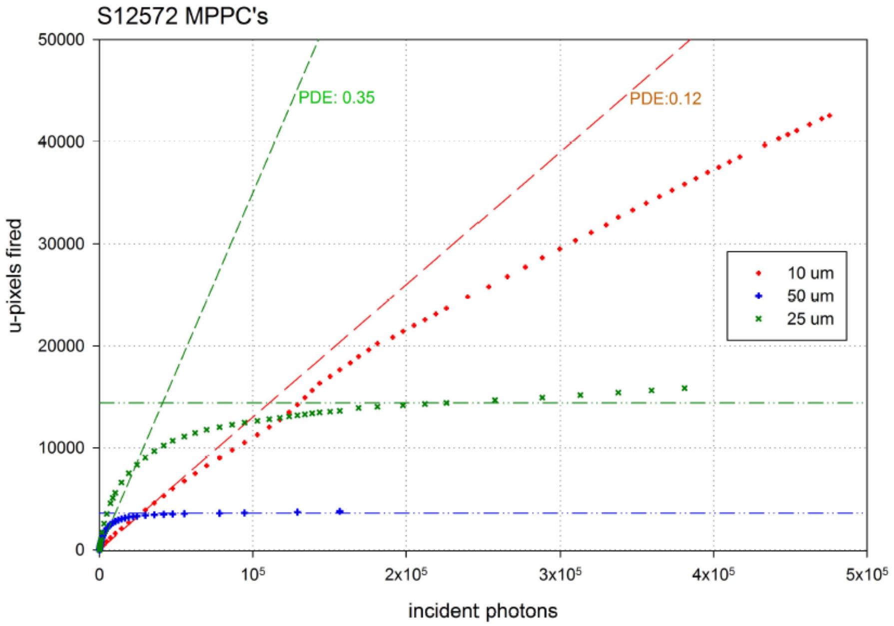
Calibration Fiber

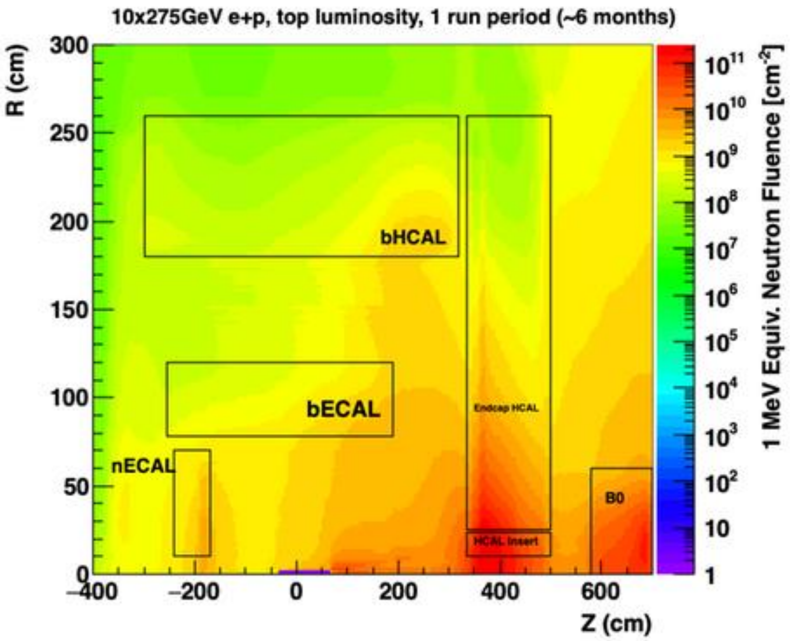
Tile Retainer Clip

SiPM Specifications

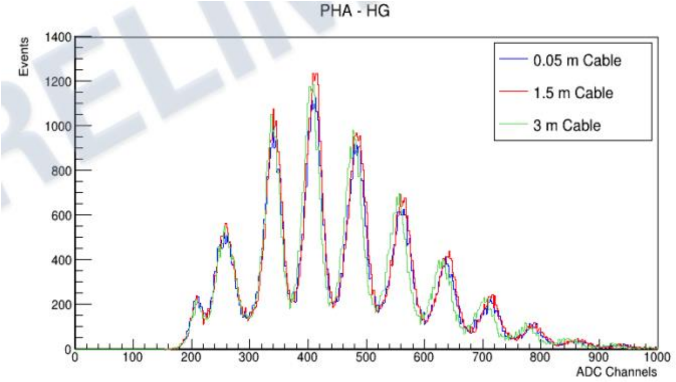
- What is the dynamic range one needs to cover?
  - sPHENIX planned on 25 MeV – 50 GeV per tower (5 scintillator tiles) @200 GeV
    - 5 MeV – 10 GeV per tile, or 1 – 2000 (2.5 – 5000) pixels @ 200 (500) PE/GeV
    - Look at 18x275 GeV jets at η ~ 1 to verify range, suspect OK
- What is the impact of radiation damage of the SiPMs on your system?
  - Expected to be negligible, at outer radius of detector. No degradation anticipated in 3 years of sPHENIX operation (HI).
  - Expected dose in ePIC two orders of magnitude below where serious issues show up, need to understand implications of lower dose on MIP
    - Expect this is not a problem with HGCROC dual range ADC/TOT
- What specs have you already determined and how? What needs still be determined
  - Based on existing design, we have a fixed physical package (3x3mm)
  - Designed for 40000 pixels @ 15μm. Reduced pixel count might work but needs study
- How do your SiPM specs impact the readout electronics, especially the FEEs.
  - Plan to use HGCROC, piggy-back on ORNL HGCROC development for LFHCAL
- Identified Hamamatsu S14160-3015PS as potential replacement

From sPHENIX TDR



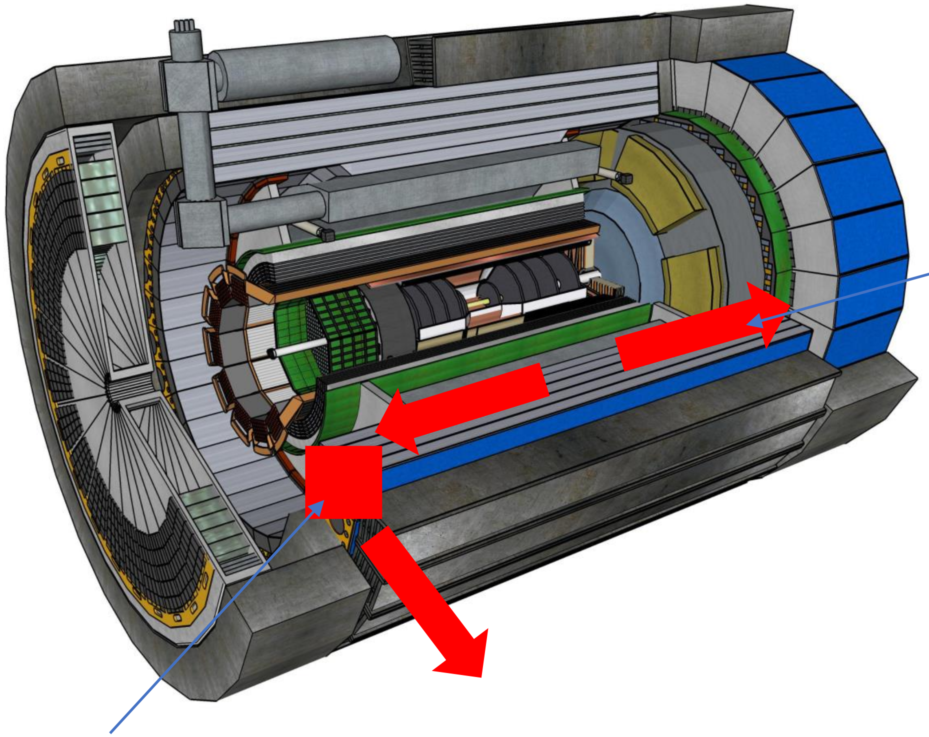


Readout Chain



Energy loss along a cable with remote SiPM

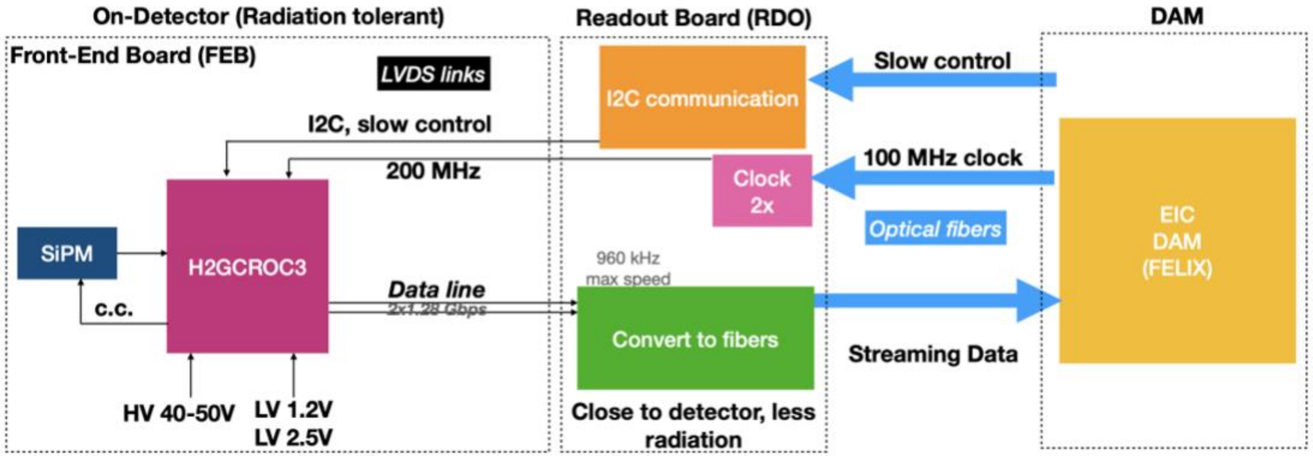
One sector -> 8 H2GCROC3 boards. Cable SiPM's out to end of barrel HCAL to keep accessible for maintenance.



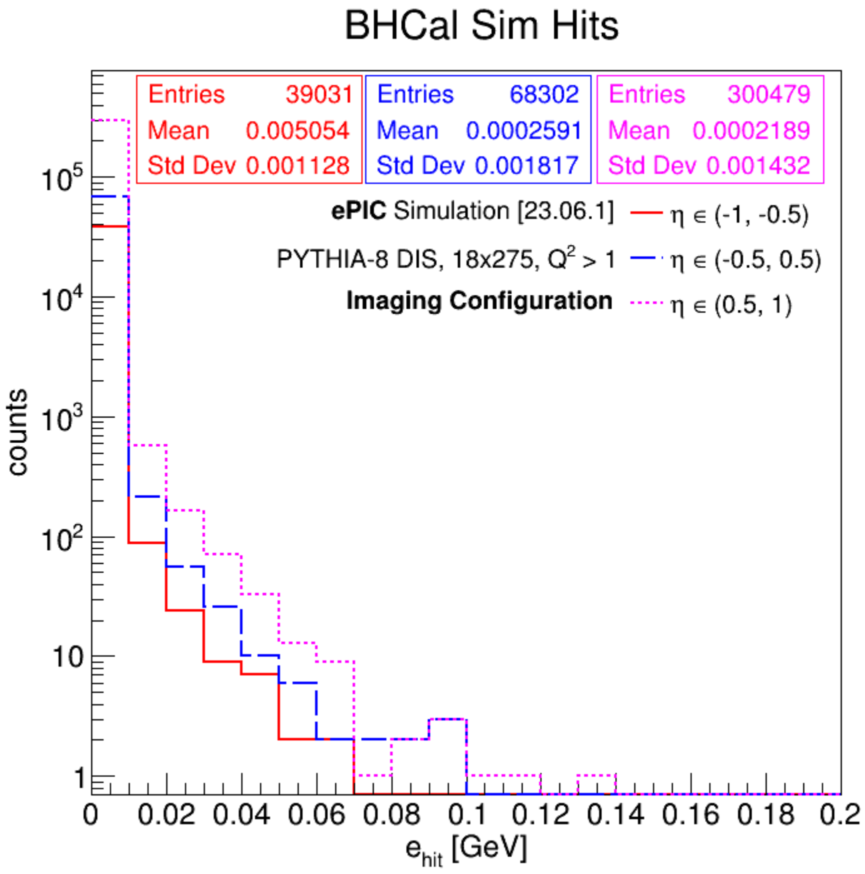
μcoax cables ~3m

H2GCROC3 + RDO

LFHCal readout hierarchy (after the upgrade)



Readout Requirements



This is the distribution of energy deposited in the scintillating tiles (*visible* energy) in an ePIC simulation of 18x275 GeV DIS events (10k events total). The regions are split in rapidity, and the higher overall energy deposition at positive rapidity is visible. (Derek Anderson, ISU.)

0.3 GeV of *visible* energy corresponds to ~1300 SiPM pixels firing (using sPHENIX calibration and new SiPM).

ePIC plans to use the Hamamatsu S14160-3015PS SiPM, operated at ~3.6x10^5 gain (about 4V over breakdown, or ~42V). The terminal capacitance of the S14160-3015PS is 530pF at V_{op}. Therefore, the junction capacitance is

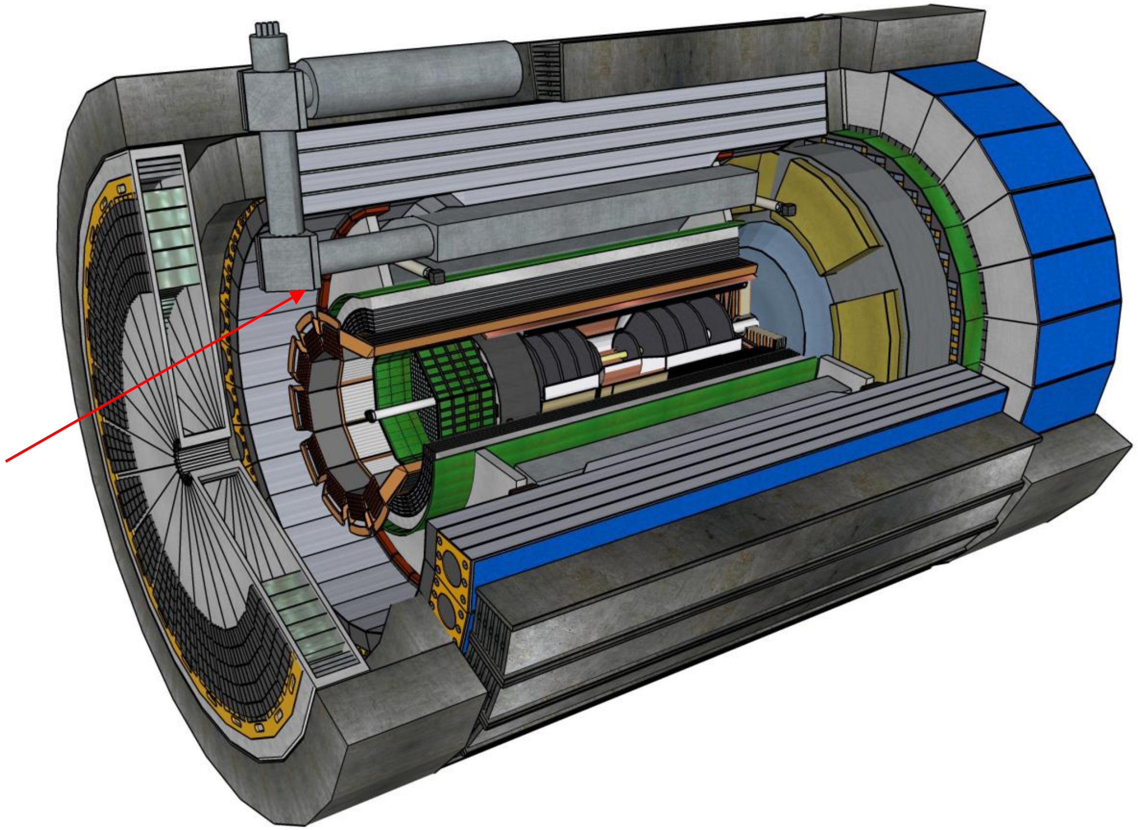
$$C_J = \frac{C_T}{N_{pix}} = \frac{530pF}{39984} = 13\text{fF}$$

This gives a single pixel charge output of $Q = C_J \Delta V$ = 13fF x 4V = 52fC

Combined with the dynamic range of fired pixels (26-1300) this means the charge range we would see is 1.5 – 68 pC. Of course, we would want more resolution in the lower range from the HGCROC ADC and then resolution at higher amplitudes from the TOT.

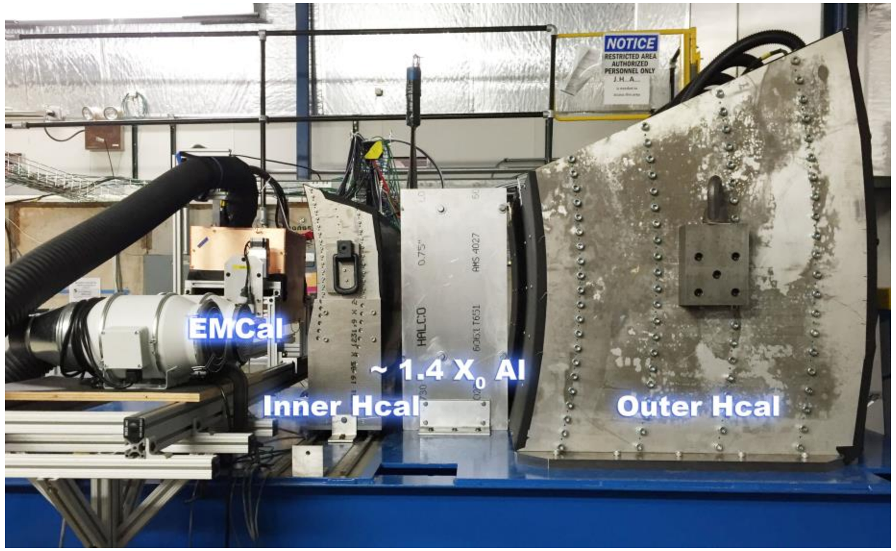
The H2GCROC3 expected range is 1-16pC (ADC), 16-320pC (TOT)

Other Items



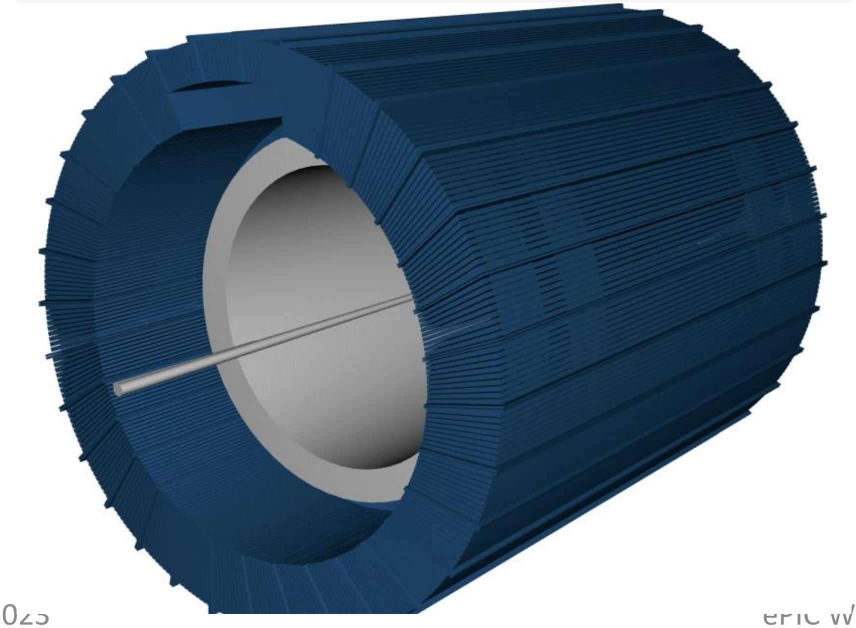
- No need to modify chimney sectors for ePIC cryo:
  - MARCO stack sits within existing cutout in three HCAL sectors, phase separator outside

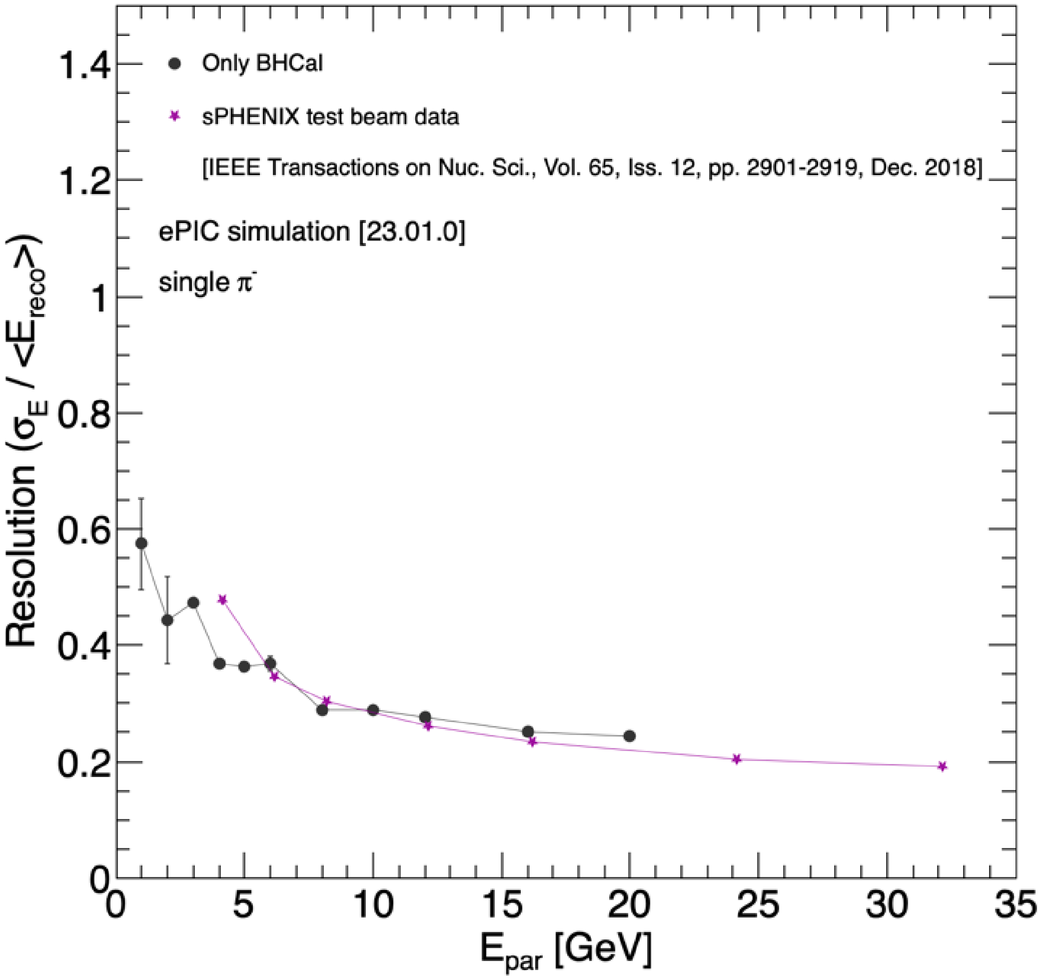
- sPHENIX test beam setup available for electronics development
  - Test beam w/H2GCROC3 electronics ~2026



Simulation Status | Implementation

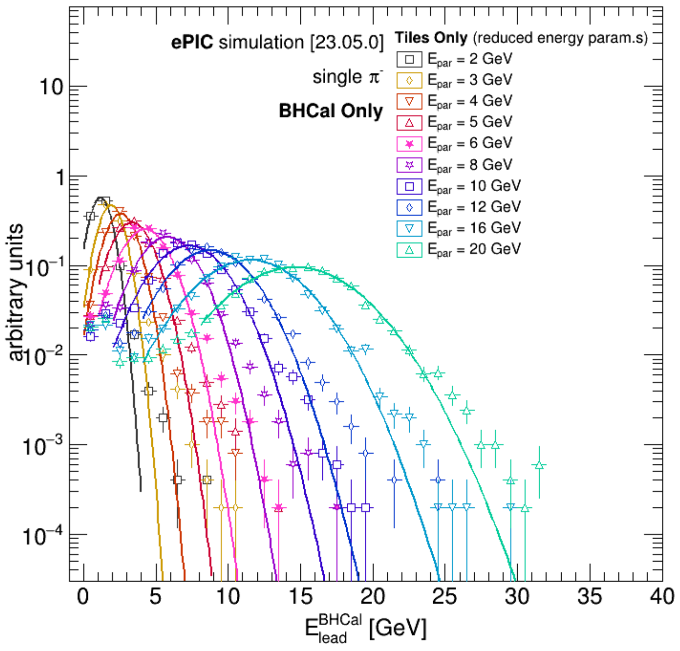
- Geometry fully implemented from tessellated 3D solids
  - Plates and tiles only
  - Issues with spurious overlaps solved (vecgeom)
  - Can/should be easily be expanded to included endplates, dogbones, large end rings
  - Performance matches sPHENIX test beam

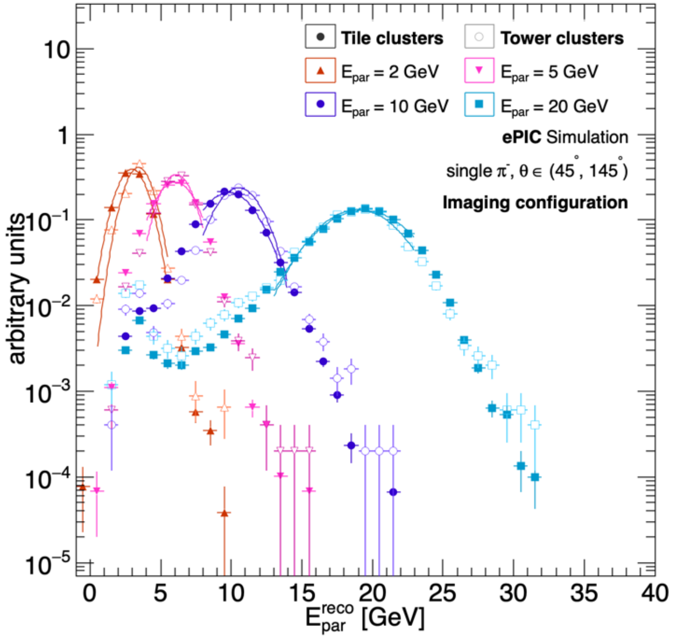




Simulation Status | Ongoing

See talk by Derek Anderson
(Early Career Workshop)





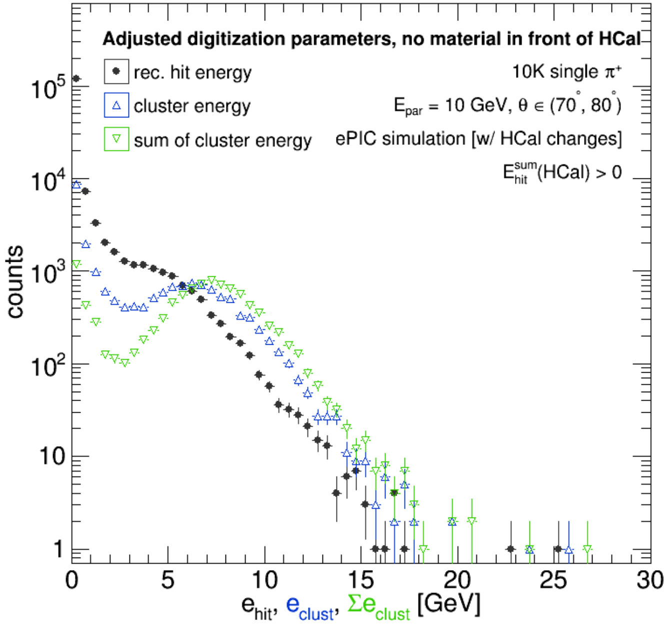
- **Transitioned to reading out tiles rather than towers**
  - Now studying impact on energy resolution
  - Need to revise clustering parameters

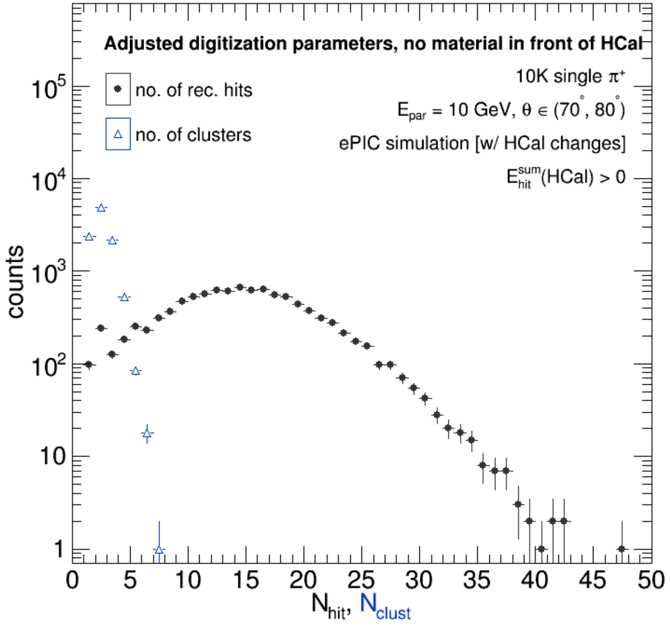
- **Above:** comparison of tile-based BHCal clusters **(closed markers)** vs. tower-based clusters **(open markers)** from March study
  - **Left:** Raw cluster energies
  - **Center:** calibrated energies (ML)
  - **Right:** extracted energy resolutions

Simulation Status | Near-Term Plans

See talk by Derek Anderson (Early Career Workshop)

- **Expanding ML Calibration Studies**
  - More thorough study of hyperparameters
  - Expanding ML techniques used
    - ☞ e.g. ML-driven cluster splitting
- **Extending performance studies with Brian Page**
  - More thorough study of BHCal energy reconstruction
  - Study its impact on JES/JER
  - And evaluate if it aids muon identification
- **Implementing EICrecon benchmarks**
  - **Right:** representative (but ancient) plots for possible benchmarks

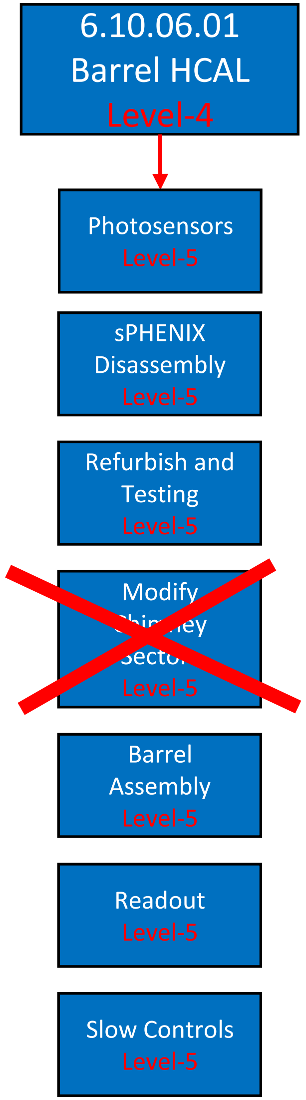




Barrel HCAL
Work Packages

DSC Institutions:

ISU
Georgia State
Rutgers
Lehigh U.
Baruch College
ORNL (HGCROC)



6.10.06.01
Barrel HCAL
Level-4

Photosensors
Level-5

sPHENIX Disassembly
Level-5

BNL Engineer?

Refurbish and Testing
Level-5

~~Modify Chimney Sector~~
~~Level-5~~

May not be required

Barrel Assembly
Level-5

BNL Engineer?

Readout
Level-5

(One work package for all HGCROC calorimeters?)

Slow Controls
Level-5

Summary

- ePIC plans to refurbish the sPHENIX HCAL
  - Replace SiPM’s on tiles
  - Upgrade electronics (readout and slow controls)
  - Expected performance meets EIC requirements

- DSC forming slowly
  - Expect to ramp up activity after sPHENIX run
  - Partner with ORNL on H2GCROC3 (ePIROC) development
  - Develop slow controls (through RDO)
  - Optimize clustering with single tiles
  - Test muon identification algorithms


BACK UP

sPHENIX sees ~16000 pixels per GeV of *visible* energy in the scintillator (per Jin Huang, 7/21/22 email and 2016 sPHENIX test beam).

16000 pixels/GeV/5 scintillators = 3200 pixels/GeV (ePIC)

So 0.3 GeV of *visible* energy corresponds to ~960 SiPM pixels firing. As we know already, we are not using anything like the full range of the 40k pixels in the SiPM, so linearity issues with the SiPM should not be a concern.

At the other end of the spectrum, a MIP muon loses about ~1GeV in traversing the HCAL from inner to outer radius. This corresponds to:

1 GeV * 0.03 * 3200 pixels/GeV = ~96 pixels/5 slats ~ 20 pixels/slat

So – the dynamic range in fired pixels we want in ePIC is in the range of ~20-1000 pixels.

sPHENIX used the Hamamatsu S12572-015P-02 SiPM, operated at ~10^5 gain (about 3V over breakdown, or ~68V). The terminal capacitance of the S12572-015P-02 is 320pF at V_{op}. Therefore, the junction capacitance is

$C_J = \frac{C_T}{N_{pix}} = \frac{320pF}{40000}$ =8fF

This gives a single pixel charge output of $Q = C_J \Delta V$= 8fF x 3V = 24fC

ePIC plans to use the Hamamatsu S14160-3015PS SiPM, operated at ~$3.6\text{x}10^5$ gain (about 4V over breakdown, or ~42V). The terminal capacitance of the S14160-3015PS is 530pF at V_{op}. Therefore, the junction capacitance is

$C_J = \frac{C_T}{N_{pix}} = \frac{530pF}{39984} =$ 13fF

This gives a single pixel charge output of $Q = C_J \Delta V$= 13fF x 4V = 52fC

Combined with the dynamic range of fired pixels (20-1000) this means the charge range we would see is 1 – 52 pC. Of course, we would want more resolution in the lower range from the HGCROC ADC and then resolution at higher amplitudes from the TOT.

The amplifier will saturate at 10pC, or ~200 pixels.