Experience with SiPMs for sPHENIX and future needs for EIC

Craig Woody

Brookhaven National Lab

SiPM R&D Meeting
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The sPHENIX Calorimeter Systems

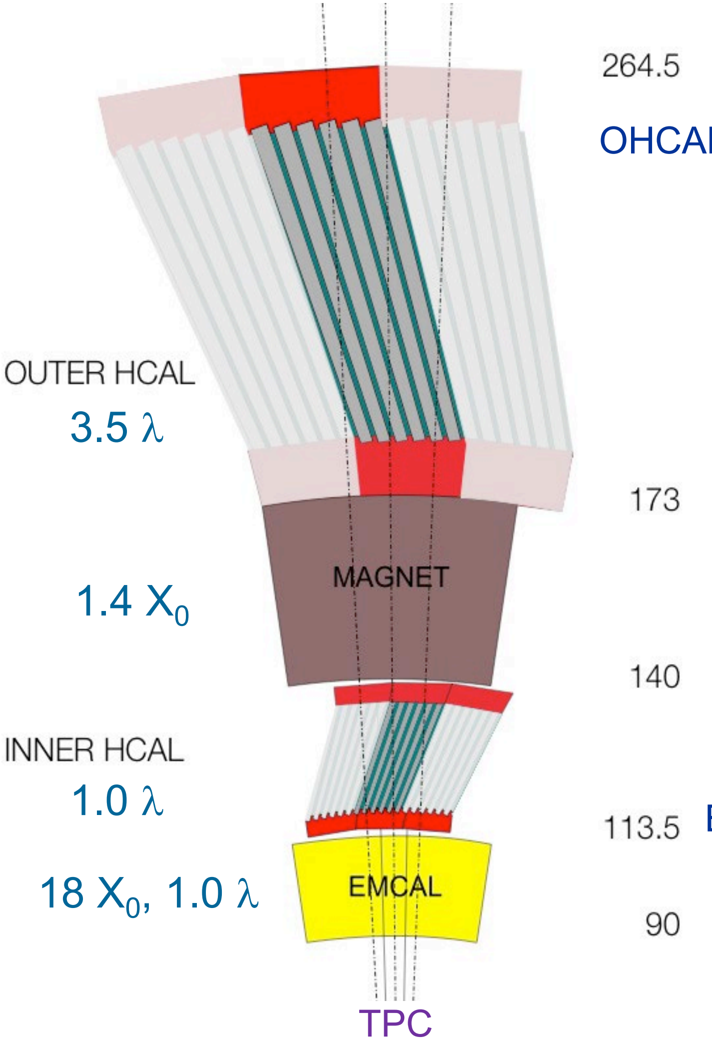
EMCAL – Tungsten SciFi SPACAL

- $\pm$ 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)

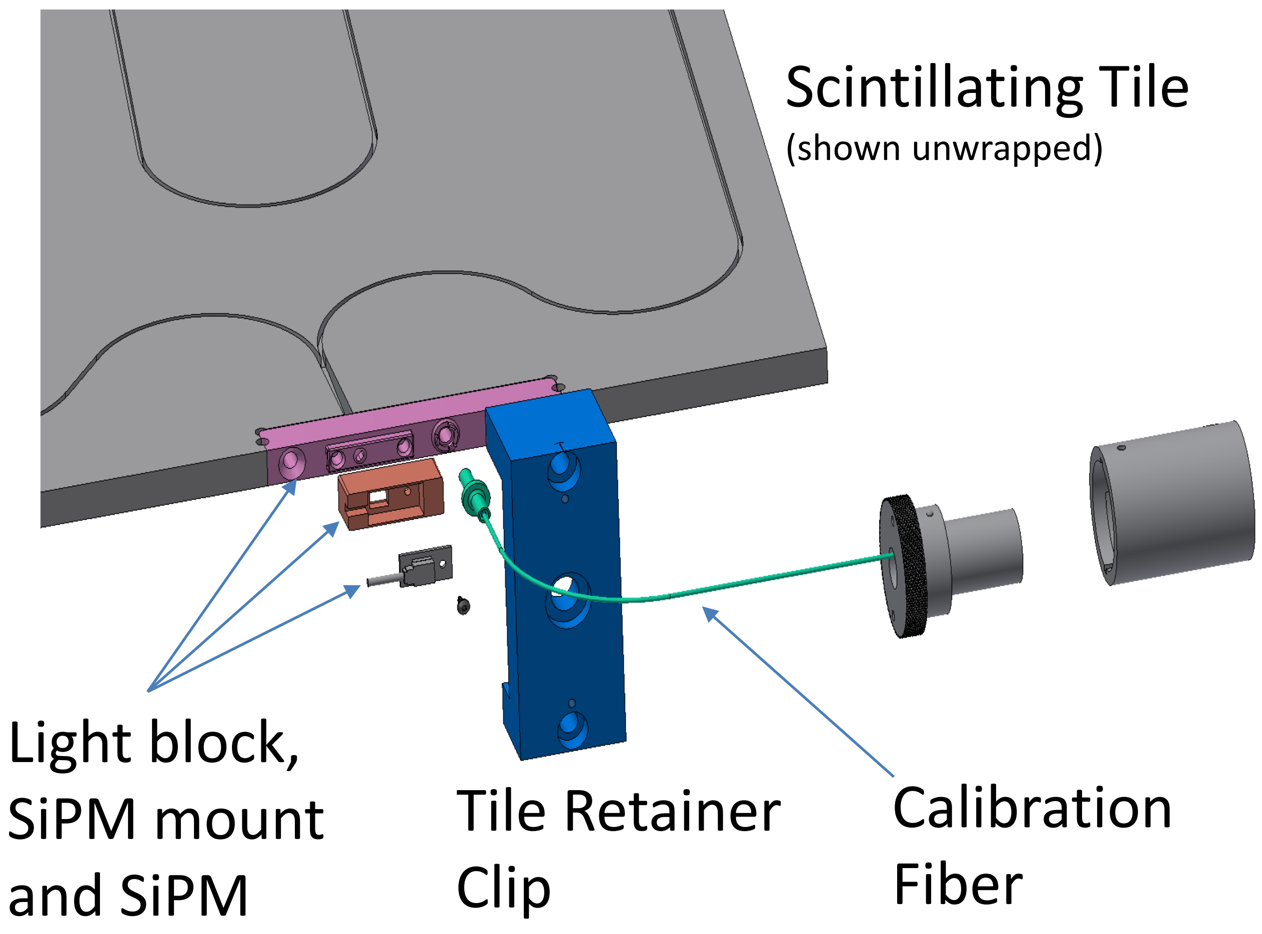
EMCAL + HCAL ~ 5.5 λ



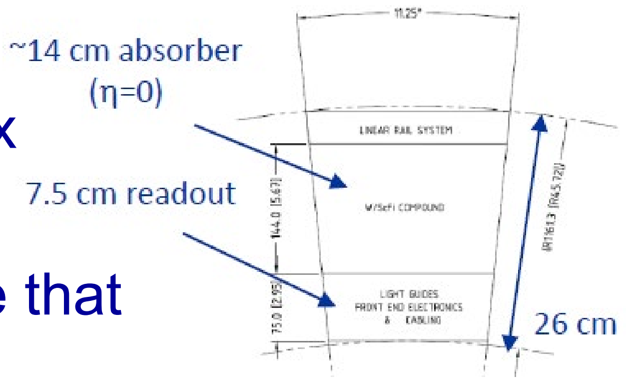
All calorimeters use same SiPM for readout
Hamamatsu S12572-015P
3x3 mm^2 15 μm pixel

Total of 112,128 SiPMs
27,648 Readout Channels

sPHENIX IHCAL and OHCAL



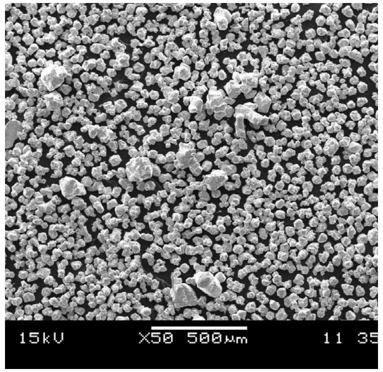
sPHENIX W/SciFi EMCAL



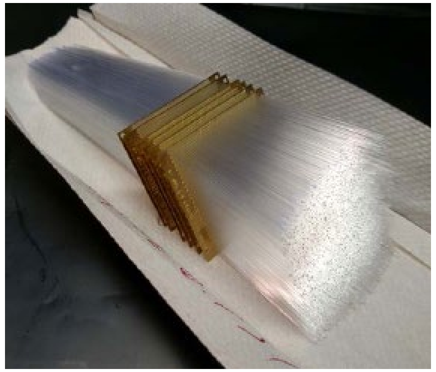
- The sPHENIX EMCAL is a W/SciFi SPACAL consisting of a matrix of tungsten powder and epoxy with embedded scintillating fibers.
- W/SciFi modules consist of 4 towers, each with its own light guide that is read out on the front with a 2x2 array of 3x3 mm^2 SiPMs.
- Hamamatsu S12572-015P with 15 μm pixels was selected in order to have large (10^4) dynamic range. However, this device was developed before deep optical trench technology for reduced after pulsing and optical cross talk.

SiPMs are susceptible to radiation and will receive a dose ~ 10^{11} n/cm^2 over the currently 3 yr lifetime of sPHENIX

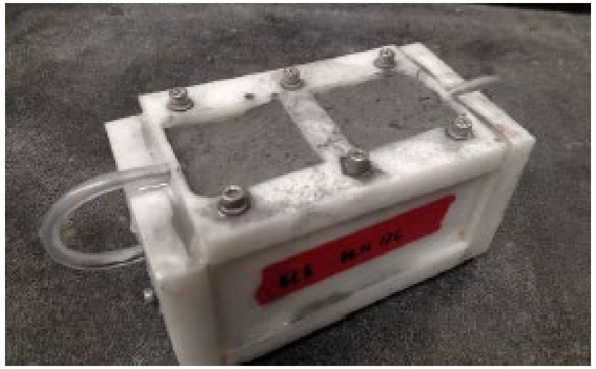
W Powder ~ 50 μm

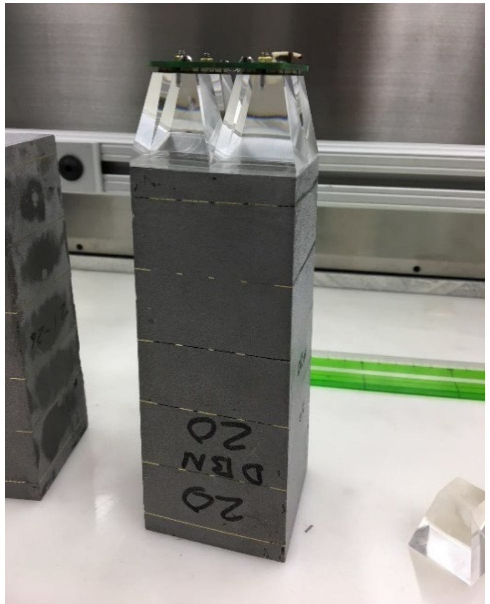


Fiber Assembly

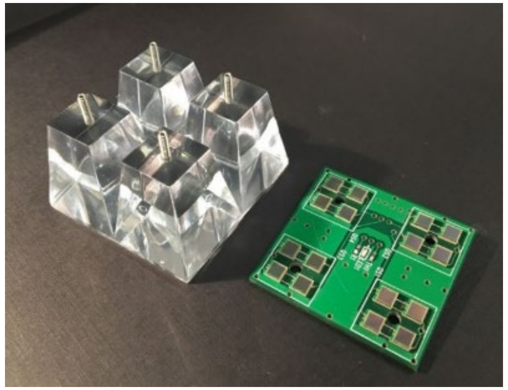


Mold with W powder, fibers + epoxy





6144 Modules (24,576 towers)



Readout with light guides and SiPMs

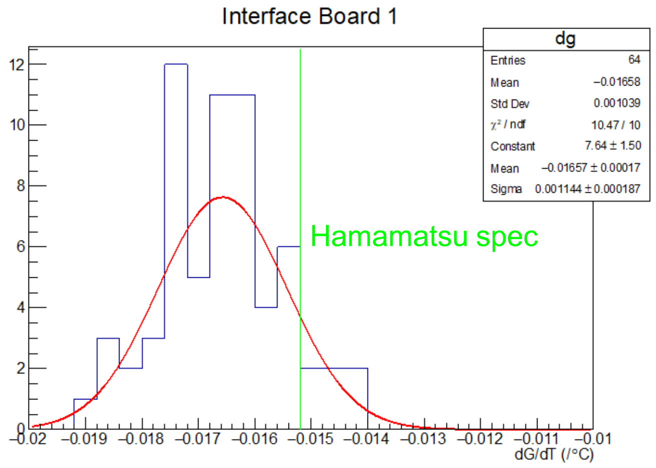
(~ 100K SiPMs)

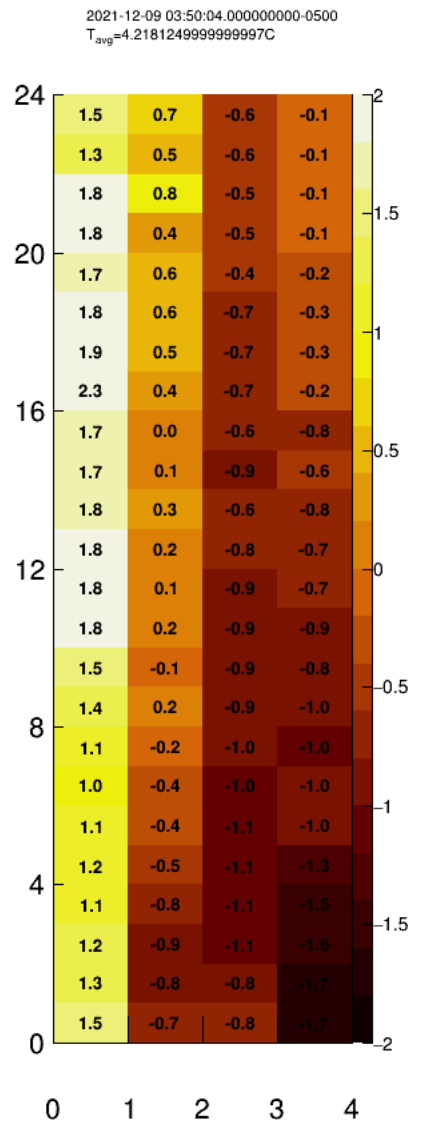
SiPM Temperature Dependence

- The gain temperature coefficient quoted by Hammamatsu on the 12572-0015P data sheet is 3.5×10^3/℃ which at V_{op} (gain 2.3×10^5) is -1.52%/℃
- We measure ~ -1.7%/℃ using our temperature probes
- We see ~ 2 ℃ temperature variation across a sector

Good temperature control and monitoring will be critical in order to maintain good energy calibration

Gain Temperature Coeff dG/T (%/℃)





J.Haggerty (BNL)

EMCAL Cooling System

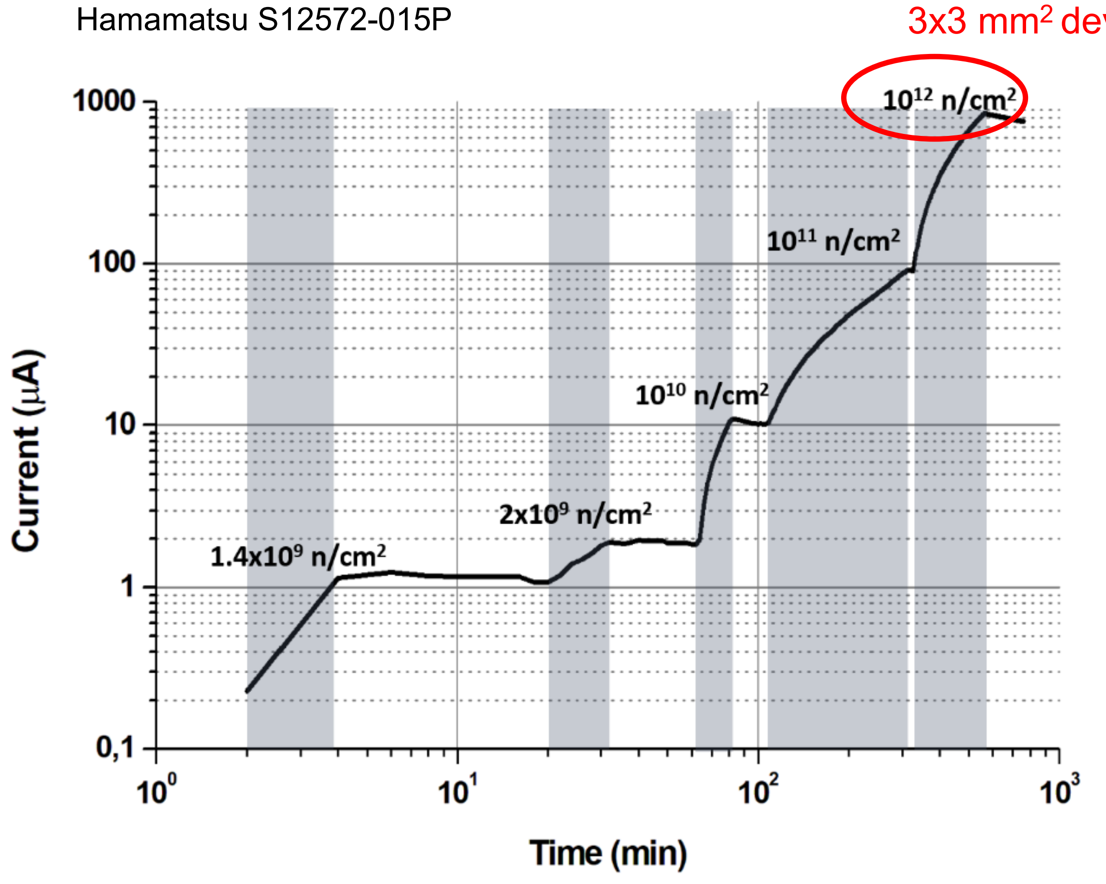
SIPM Loop
Sector 1

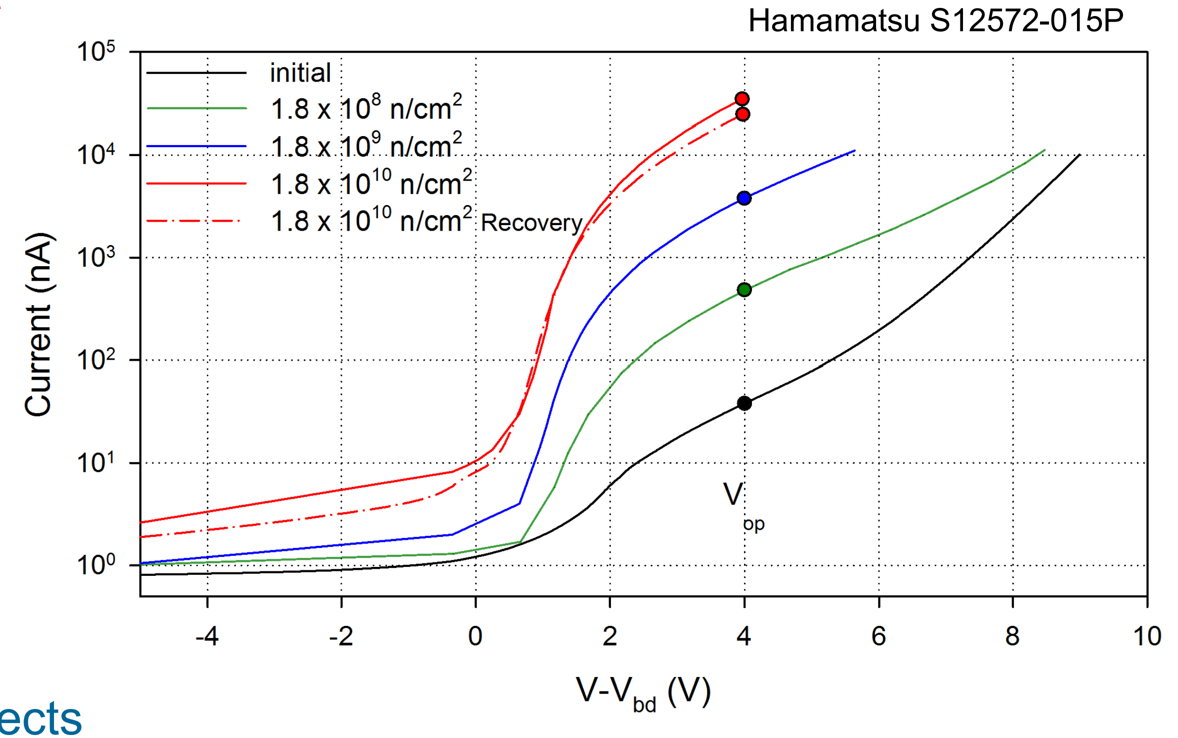
July 31, 2020 EMCAL PRR 6

Radiation Damage from Neutrons

SiPMs irradiated with neutrons up to 10^{12} n/cm^2

1 mA of current in a 3x3 mm^2 device !





Irradiations with neutrons up to ~ 17 MeV at the Atomki Cyclotron in Debrecen, Hungary

Effects

- Steady increase in current with dose
- Small increase in current below V_{op}
- Large increase at V_{op}
- Small, slow long term recovery at RT

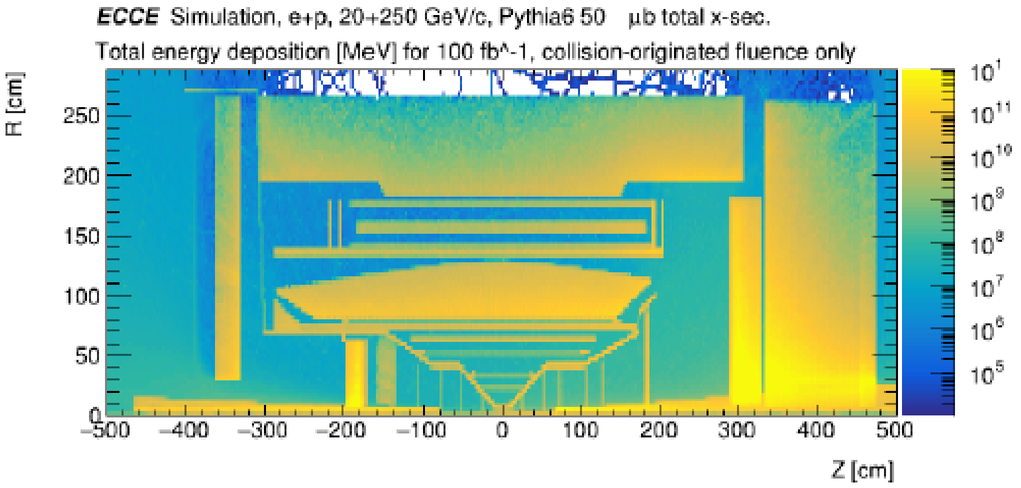
B.Biro et.al., IEEE TNS 66-7 (2019) 1833-1839

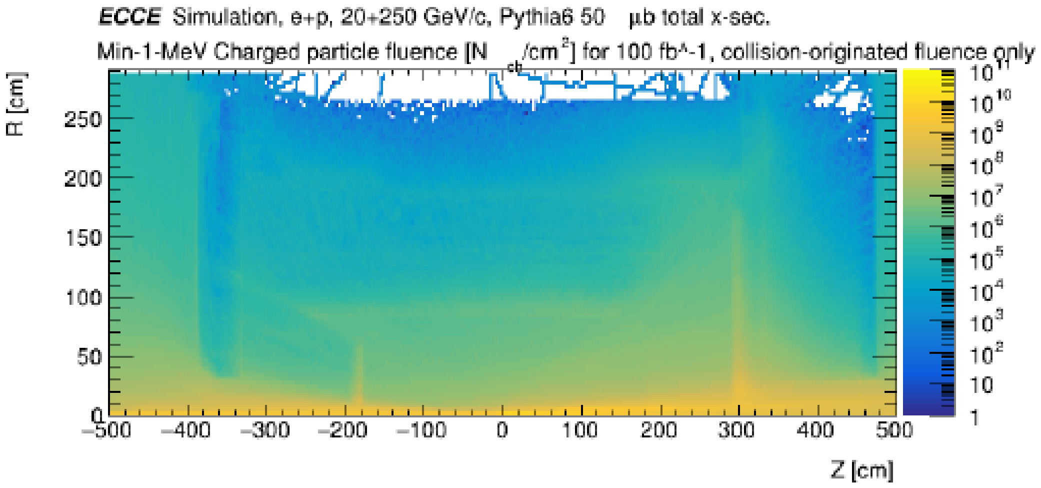
ECCE Response to Question T6 from the DPAP Committee:

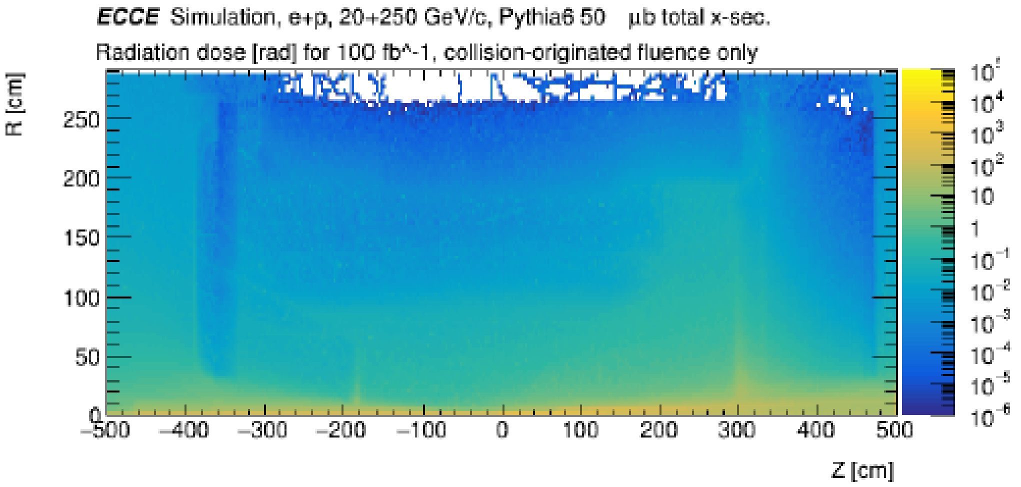
Jin Huang (BNL)

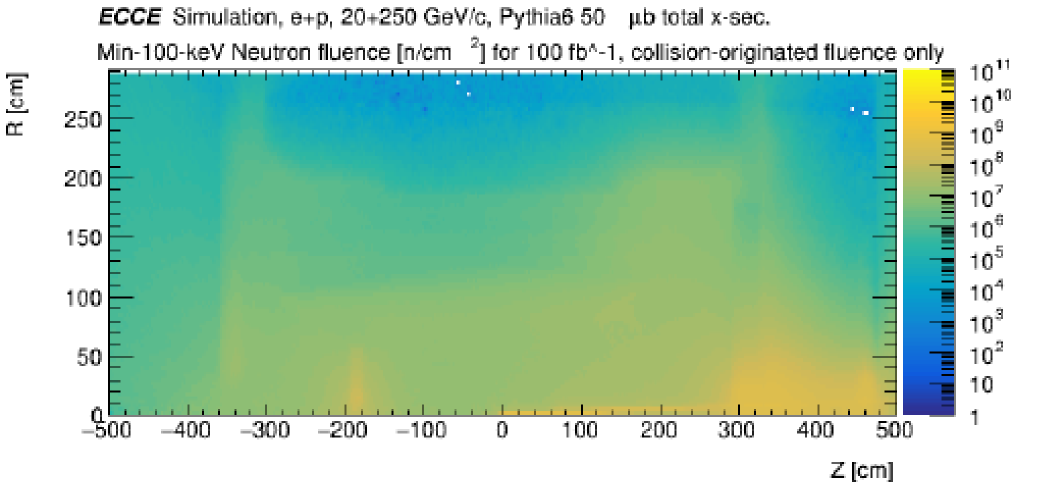
How will radiation damage of detector components affect physics performance, including forward and backward instrumentation? Please provide a map of the radiation field in the detector.

- Beam collision radiation: based on Pythia6 50ub total inelastic x-section tuned for EIC





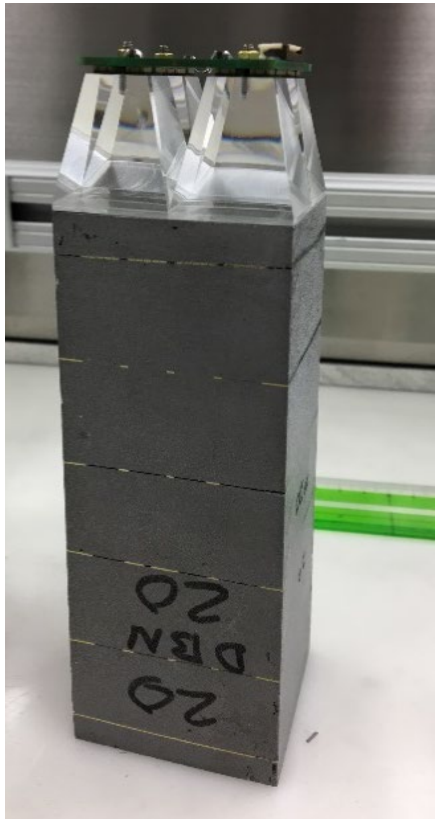




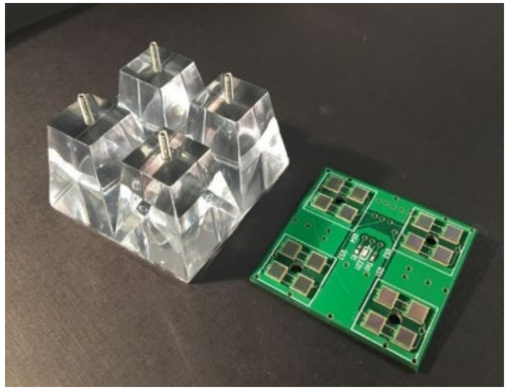
Future Developments for W/SciFi Calorimetry

We believe we can improve the light output, energy resolution and uniformity of response of the sPHENIX calorimeter by increasing the photocathode coverage for the readout of the absorber blocks.

Light output from fibers is very uniform but light collection efficiency is low (~ 6 %)



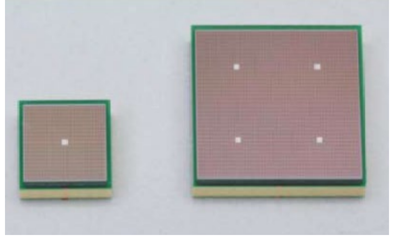
Readout end of block

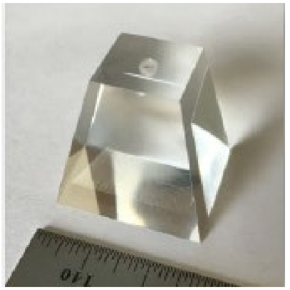


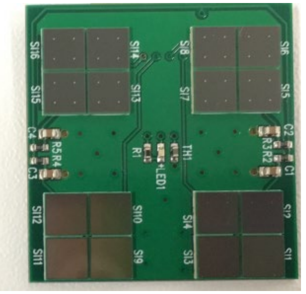
Two possible ways to increase photocathode coverage:

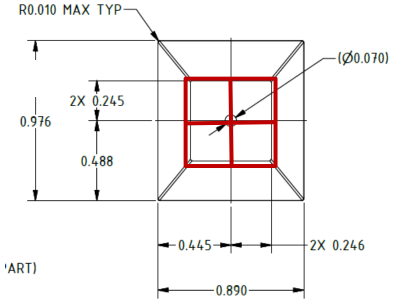
- Keep existing light guides and replace 2x2 array of 3x3 mm^2 SiPMs with four 6x6 mm^2
- Remove or cut down existing light guides and cover entire readout end of block with a 6x6 array of 6x6 mm^2 SiPMs.

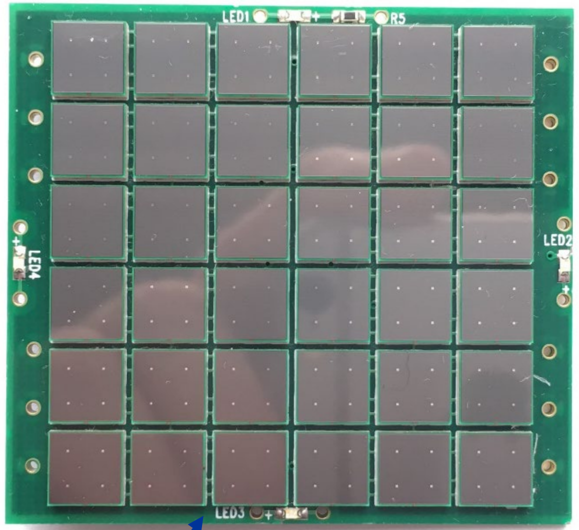
Hamamatsu S13360 6x6 mm^2 SiPM with TSVs (50 μm pixels)





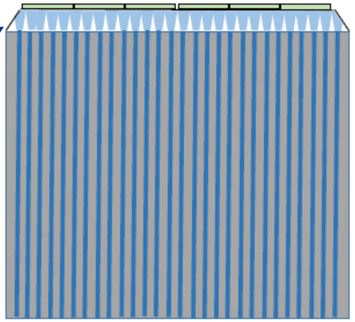






Note small gaps

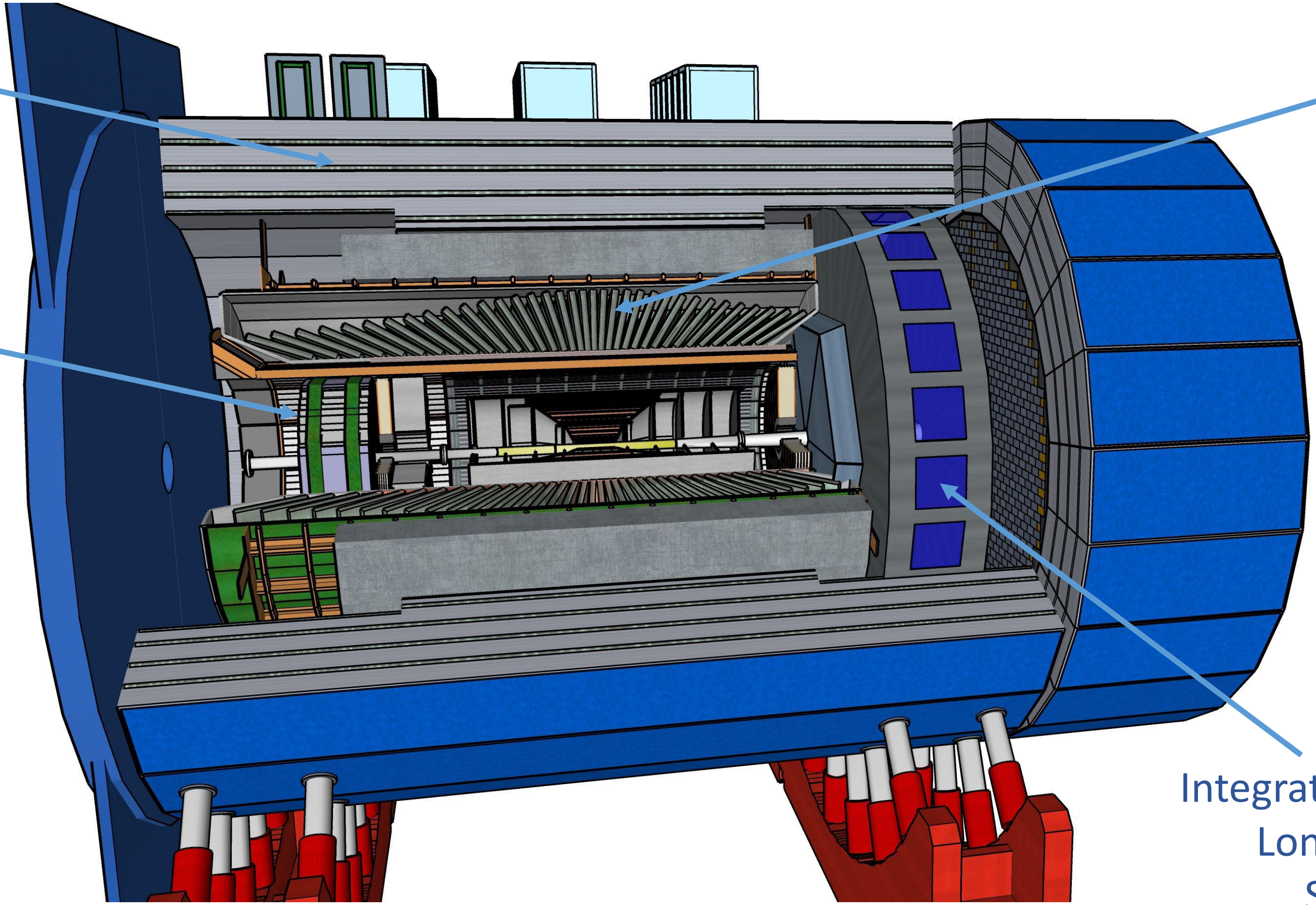
Short light guide covering entire block



ECCE Calorimeter Systems

Barrel HCAL
Reuse of sPHENIX
OHCAL and new IHCAL

Electron Endcap
EMCAL
PWO + SciGlass Blocks



Barrel EMCAL
SciGlass Blocks
8960 Towers

Hadron Endcap
Integrated Pb-Shashlik EMCAL and
Longitudinally Segmented
Steel-Tungsten HCAL

SiPM requirements for EEEMCAL

T.Horn CUA/JLAB

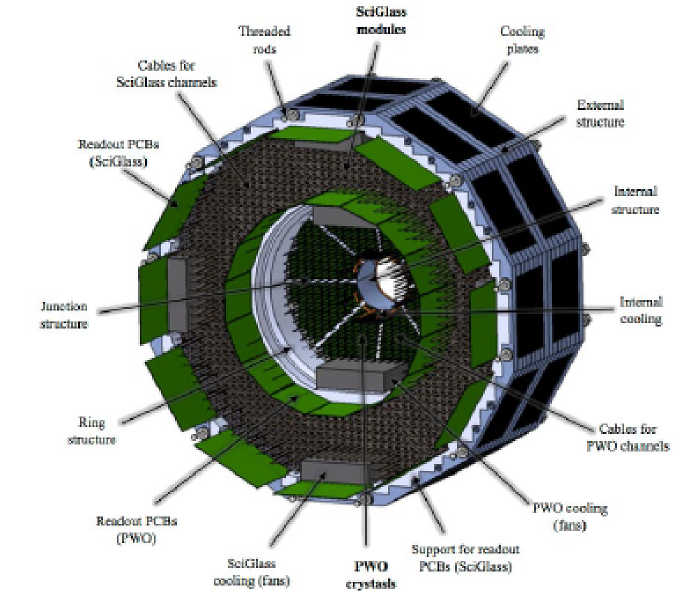


Figure 1. Overview of the EEEMCAL design

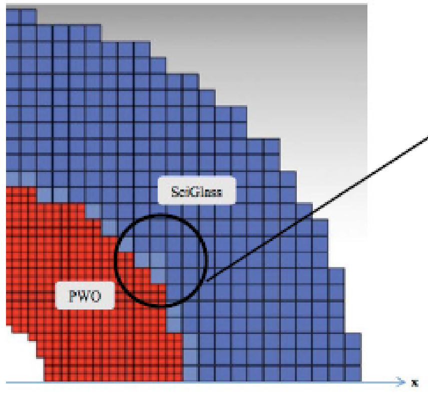


Figure 2. Distribution of the modules (quarter)

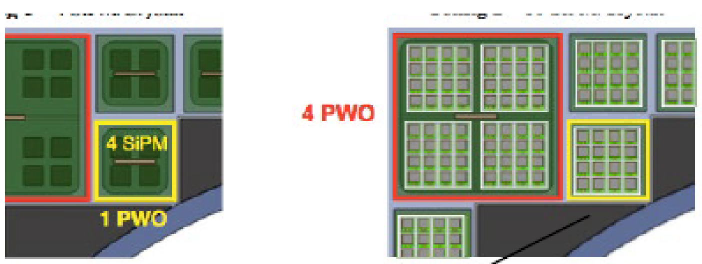
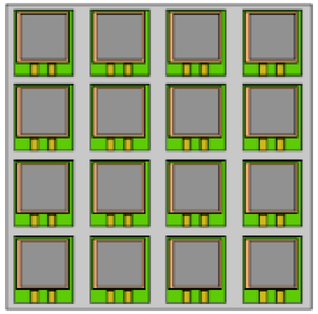


Figure 17. Number of SiPm per crystal (first layer in yellow)

PWO: surface 2x2 cm^2
Glass: surface 4x4 cm^2



S14160-3010PS/-3015PS

Figure 15. Dimensions and assembly of S14160-3010PS/-3015PS Hamamatsu SiPMs

- Linearity is critical in full dynamic range, up to 20 GeV
- One 6x6 mm^2 SiPM per crystal showed loss in calorimeter performance compared to PMT RO
- Configuration with 3x3 mm^2 SiPM required 16 preamps ----> cooling issue, electronics cost
- PWO EEEMCAL need ~12um pixel pitch SiPMs with 6x6 mm^2 dimension. Customize matrix 2x2(?)
- Glass part will need SiPMs with bigger pixel pitch (15-50)um and good photon detection efficiency (PDE). Final number strongly depends on exact technology, e.g., SciGlass vs LeadGlass.
- Glass surface is four times bigger ---> use of light guides (potential light loss) versus big sensitive surface matrix of SiPMs.

ECCE Hadron Endcap Calorimeter

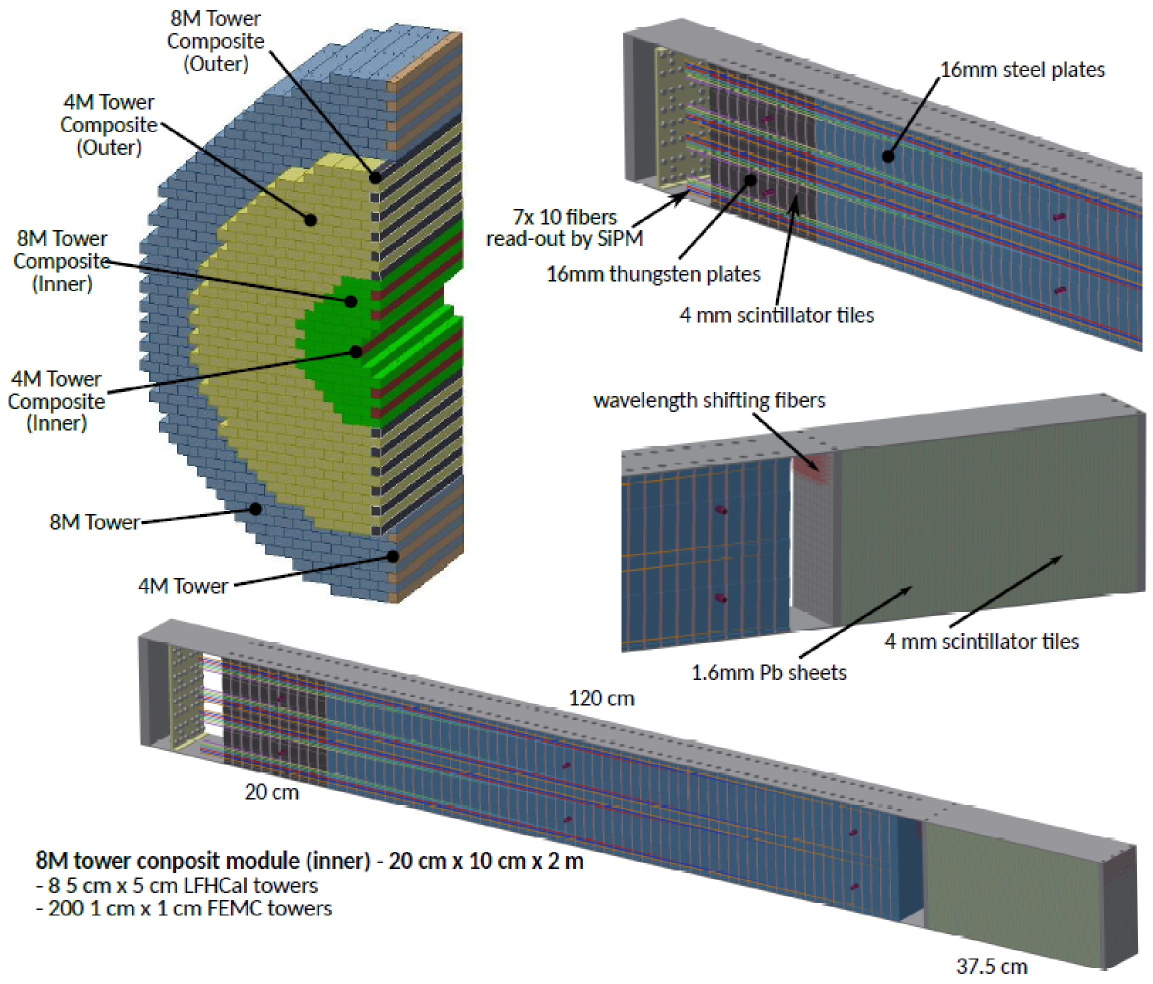


Figure 13: Design pictures of the forward calorimeter assembly (left), stacking concept (middle top), 8-tower module design (middle bottom) and single scintillator plate for 8 tower module with embedded wavelength shifting fibers and steel absorber plate (right).

ECCE Hadron Endcap Calorimeter

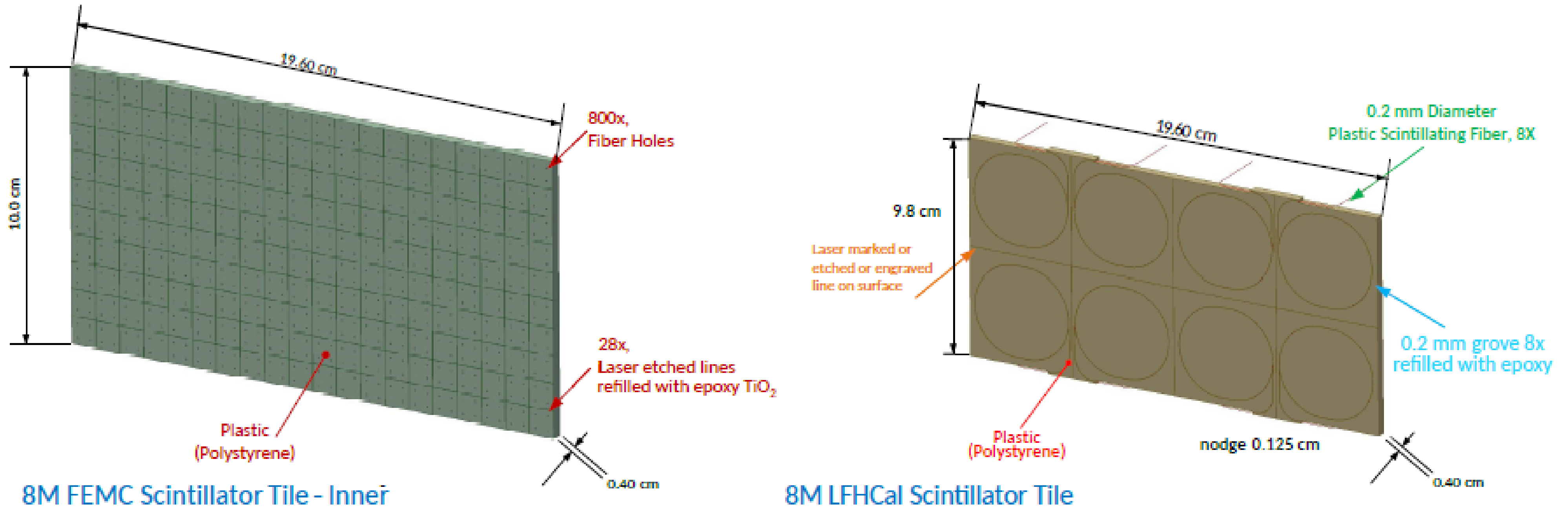


Figure 12: Scintillator plate designs for a 8M module in the FEMC (left) and LFHCAL (right).

0.5 mm WLS fibers spaced ~ 1x1 cm^2 grid each read out with its own SiPM

53,600 Readout Channels

WLS fibers embedded in scintillating tile read out with small SiPMs (9-16 mm^2 area)

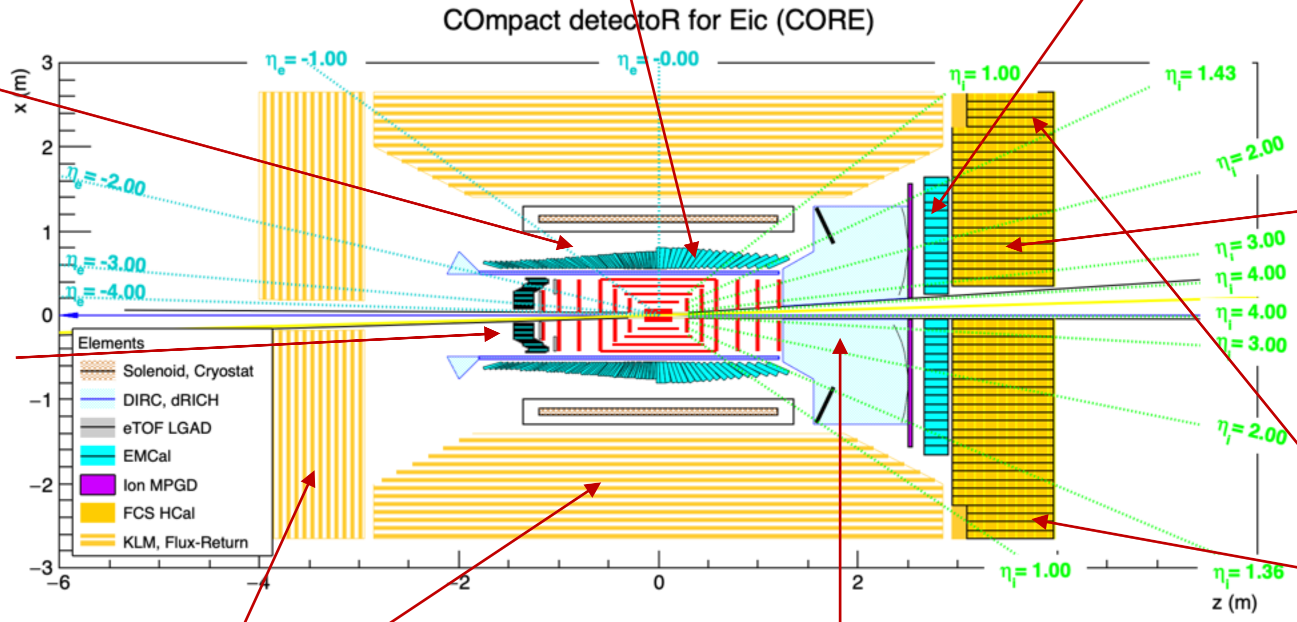
63,280 Readout Channels

CORE – SiPM overview

Projective PbWO$_4$ Emcal (10,812 crystals)

Projective W-shaslik Emcal (780 modules)

Non-projective W-shaslik Emcal (962 modules)



Hcal: 1,602 new Fe/Sci modules

Non-projective PbWO$_4$ Emcal (1,432 crystals)

Hcal, outer rings: 520 re-used STAR FCS modules

Neutral hadron and muon ID detector (KLM)

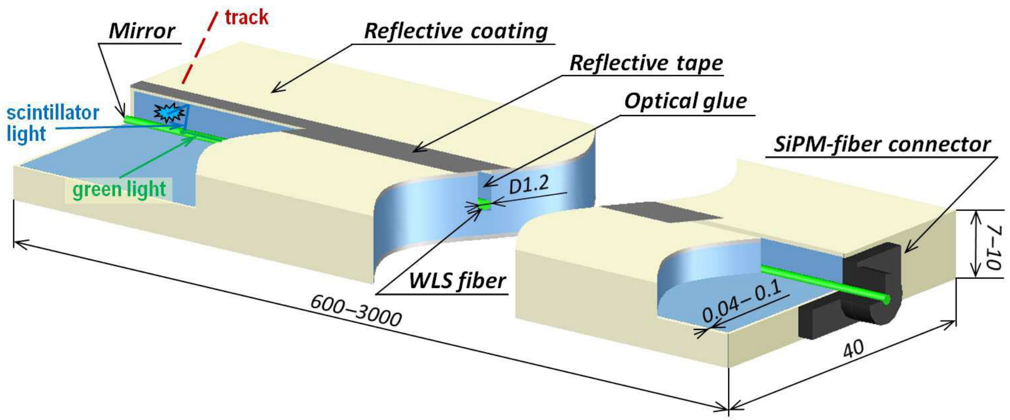
38k channels

Dual-radiator RICH

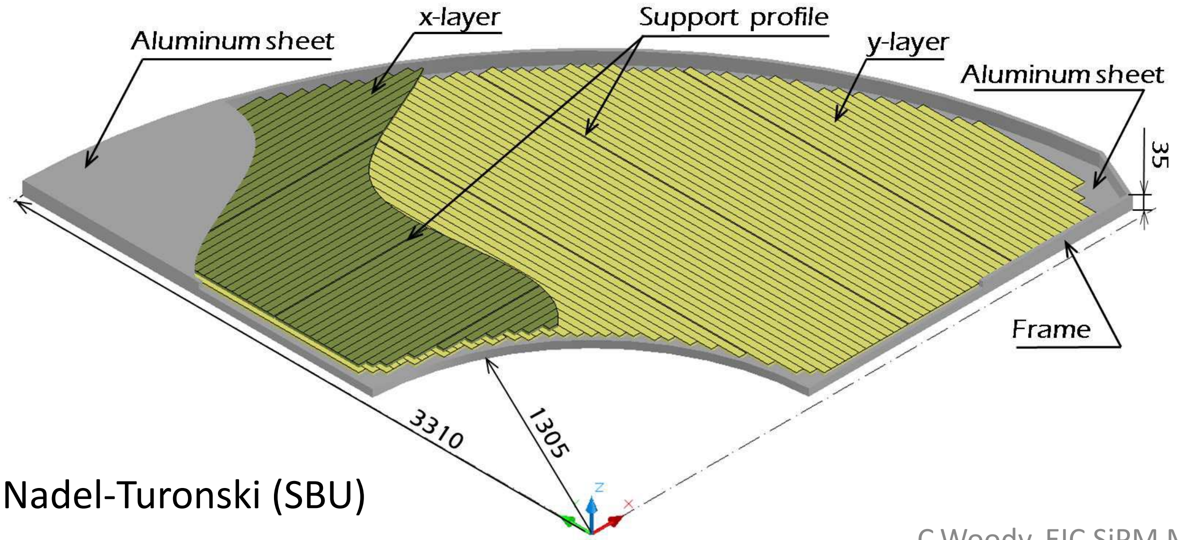
18k channels
6k per sector

P. Nadel-Turonski (SBU)

KLM

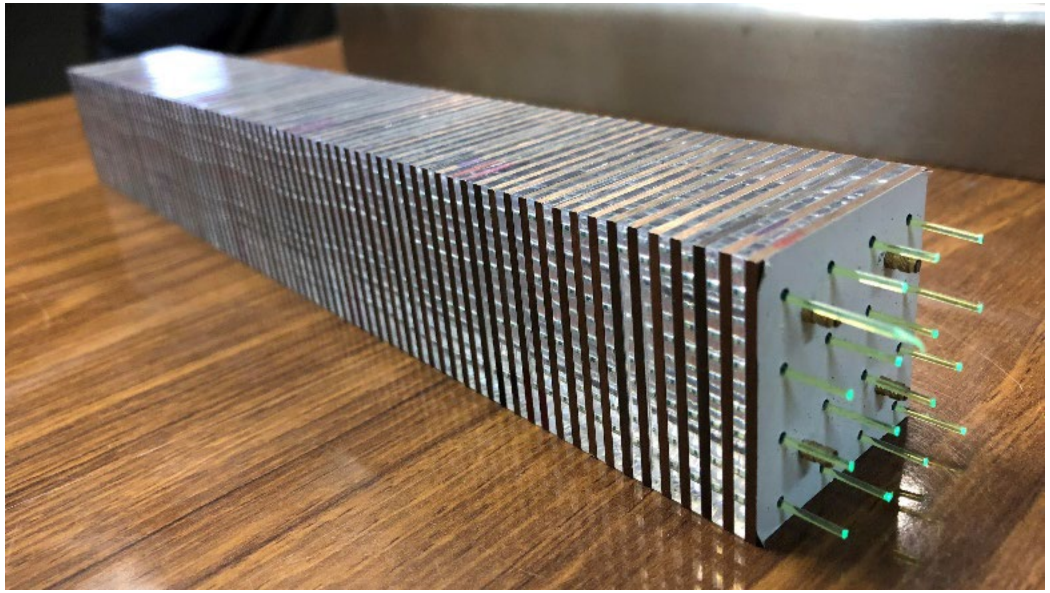


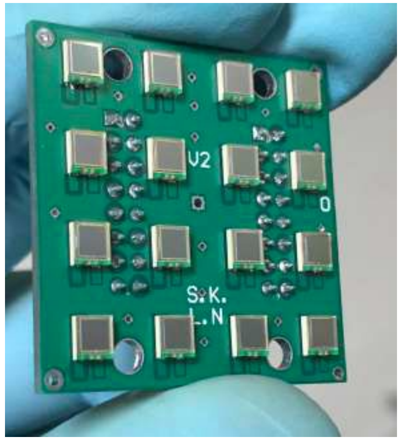
T. Aushev *et al.* arXiv:1406.3267v3 (2015)

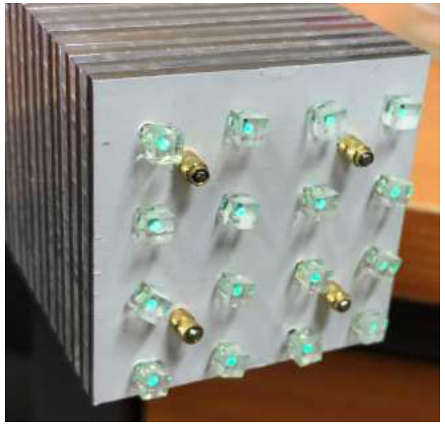


P. Nadel-Turonski (SBU)

W-shashlyk



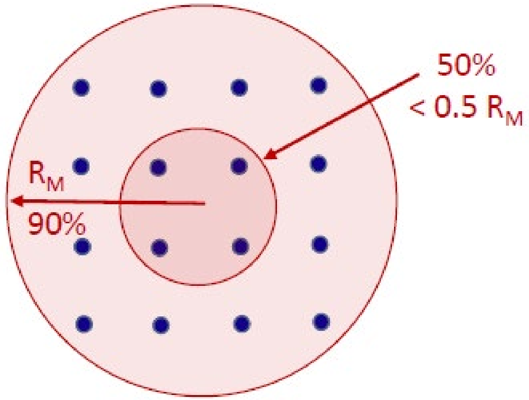


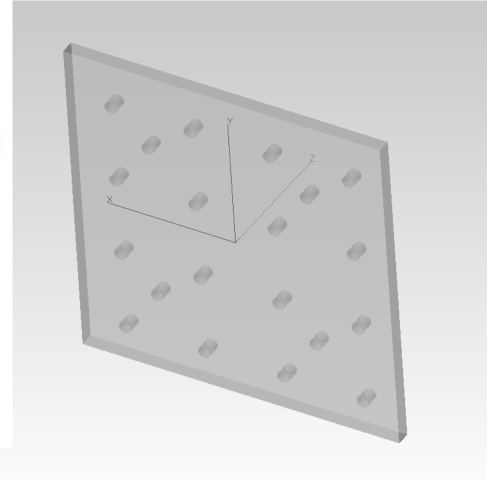


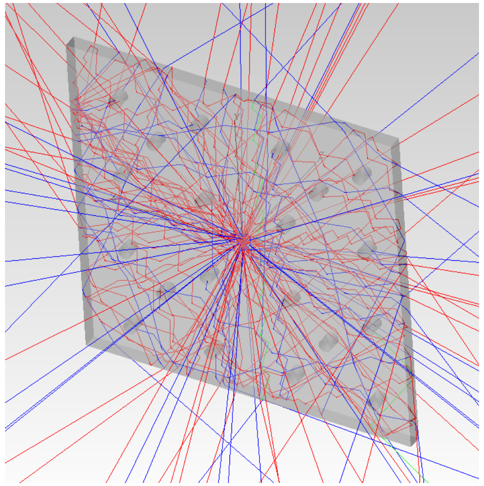
Improving Shashlik Spatial Resolution

- The availability of low cost SiPMs allows the possibility of reading out *each fiber individually.* This allows determining the shower position even within a Moliere radius.

A compact shashlik may also offer the possibility of improving the position dependence due to the short light path to the WLS fibers.







Ray tracing withing a scintillation tile

- Non-uniformities of light collection within a tile will cause a position dependence. However, this can in principle be corrected for using lab measurements and ray tracing can produce a light collection map for each fiber.

R&D Issues for SiPMs

- Need for large area ($\geqq$ 6 x 6 mm^2) SiPMs with small pixel size (10-15 μm) at low cost. *Issue for manufacturers.*
- Shashlik calorimeters will have high segmentation with an individual readout for each fiber. This will require low-cost small area (~ 2 x 2 mm^2) SiPMs with small pixel size. *However, due to high channel count, cost of readout electronics will be an issue.*
- While radiation exposures at EIC are expected to be much less than at LHC or in RHIC HI running, devices with less susceptibility to radiation damage (particularly neutrons) would enhance long term stability and performance.
- SiPMs with less temperature dependence would also improve long term stability and performance.
- Lower noise would be extremely beneficial for RICH applications.