Report on W/SciFi and W/Shashlik Calorimeter R&D

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EIC R&D Committee Meeting
January 24, 2019

Status of the sPHENIX EMCAL (FYI)

- sPHENIX is moving forward at a very rapid pace. After receiving CD-1/3A approval in August 2018, considerable funds were made available for certain Long Leadtime Procurements. These include all the scintillating fibers for the entire (descoped) EMCAL and all the SiPMs for both the EMCAL and HCAL. Additional funds are also available to construct 12 complete preproduction EMCAL sectors. A CD-2/3 Review is expected in May 2019.
- Construction of the first EMCAL preproduction sector (Sector 0) is under way at UIUC and BNL.
- Analysis of the 2018 test beam data is nearly complete.

Response to the Committee's comments from the last report

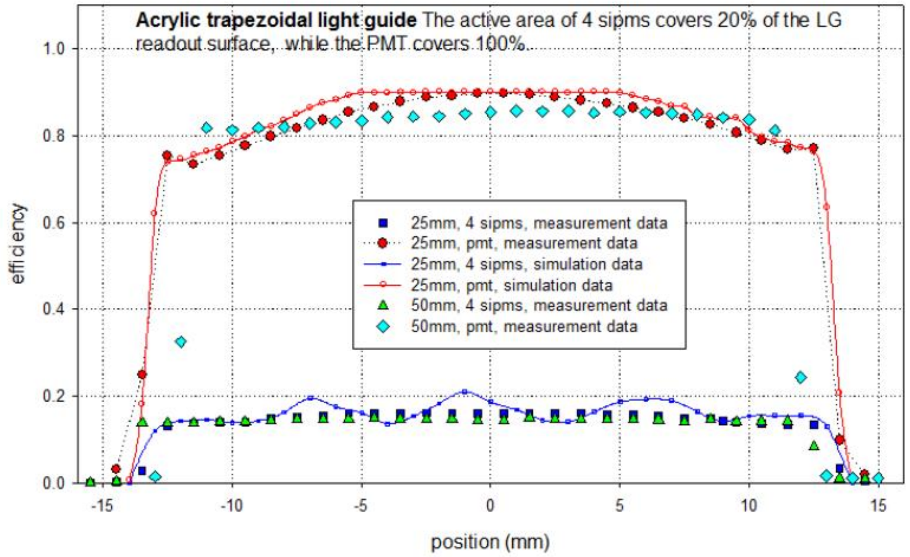
1. sPHENIX can accept this loss of resolution [due to non-uniformities] but a new EIC detector should not. Possible options going forward include tiling a larger area with SiPMs, which may well be feasible given the new development of 6mm x 6mm SiPMs and/or the ongoing decrease in SiPM price. The Committee repeats the remark from the last two reports of the need to improve the light collection uniformity via work on coupling of readout devices such as SiPMs to the fiber-tungsten matrix, and to continue study of light-guide geometry and the trade-off between radial compactness, which favors short guides, and uniformity of response, which favors long ones. Light emission from the fibers favors the addition of a diffuser between fiber and SiPM to utilize the full matrix of micro-pixels of a SiPM; space for this would need to be found also. It would also be of interest to study the timing performance that could be achieved with SiPM readout. Proposals on these subjects would be welcomed by the committee.

2. The Committee again calls for a full radiation map for a reference detector at the EIC, as also noted below under eRD14. This must include neutron dose. Selection of optical readout technology at the EIC must be informed by this

3. The Committee again encourages further analysis and dissemination of these results [radiation damage in SiPMs]. A note placing these in the context of expected radiation levels at an EIC is of interest.

Light Guide Studies in sPHENIX

July 2017 eRD1 Report

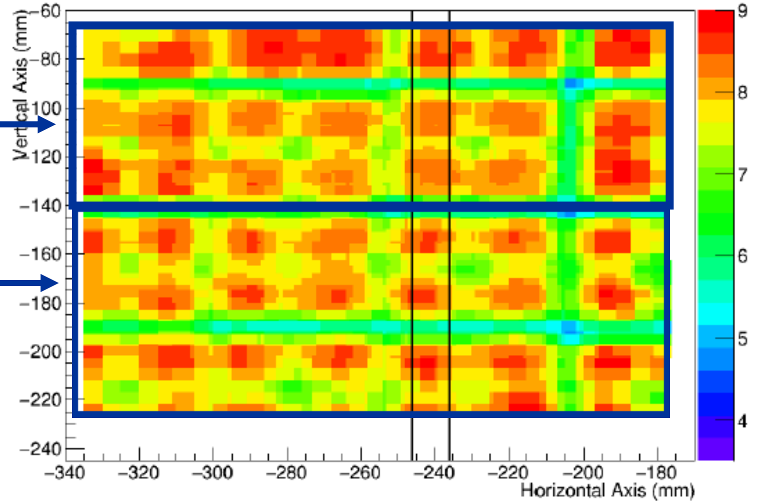


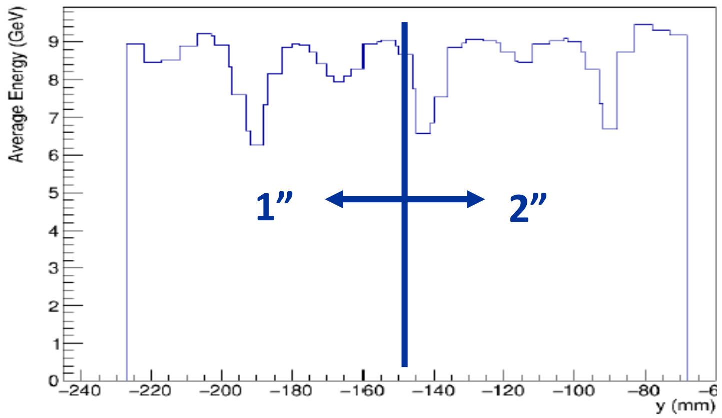
Scans with 1” and 2” light guides made in the lab

Beam test results with the V2 EMCAL prototype
Uniformity of response (8x8 towers, 0° Incidence)

2” light guides

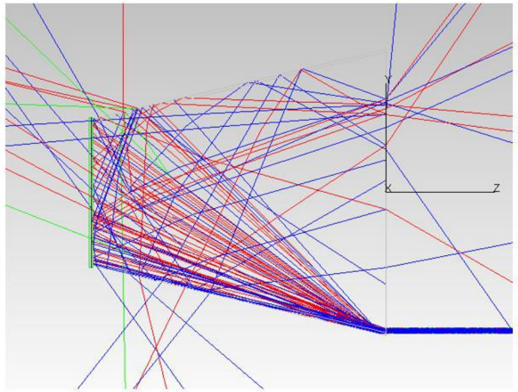
1” light guides



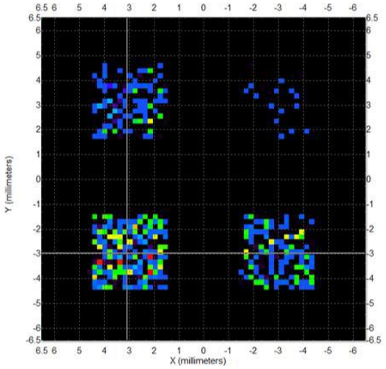


Light Guide Studies in sPHENIX

January 2018 eRD1 Report



Radiance map for fiber located in the lower left corner

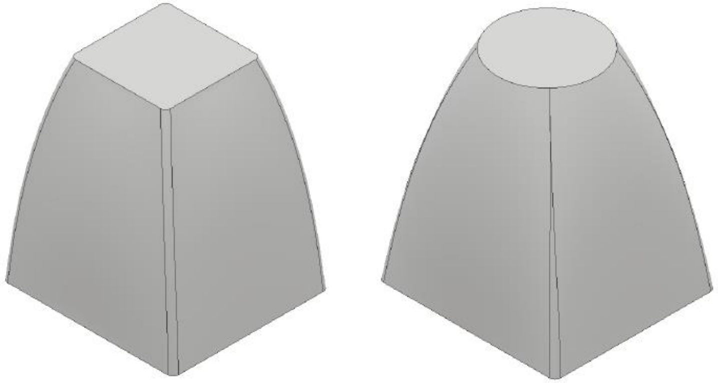


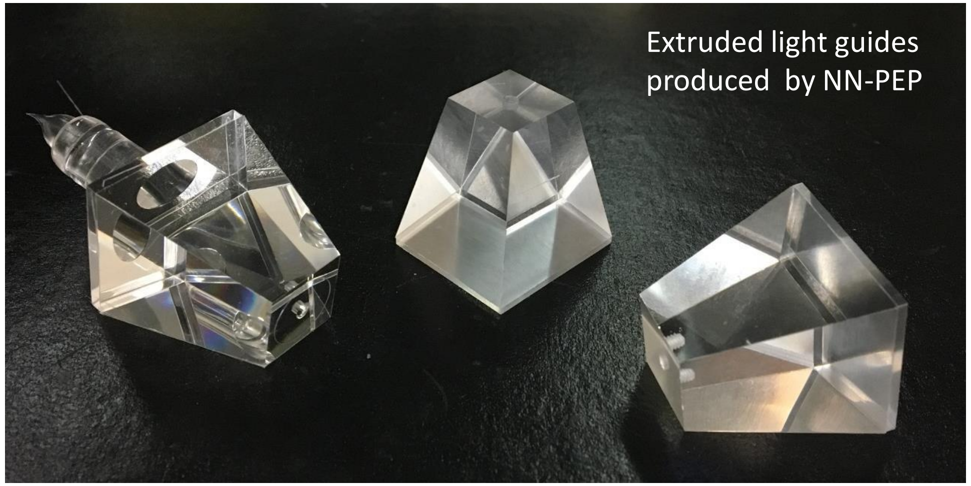
Ray tracing program (TracePro) showed that rays bounce generally only once or not at all within the light guide

In addition to simple trapezoids, we also studied Winston Cones and more complicated geometries

1-1/8" square end

1-1/8" round end



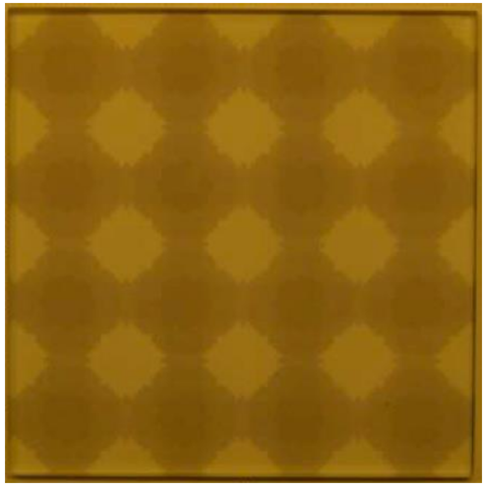


In the end, we found no design that performed significantly better than a simple trapezoid

The problem was in fabricating them in large quantities at a reasonable cost

Light Collection Studies in STAR

July 2015 eRD1 Report

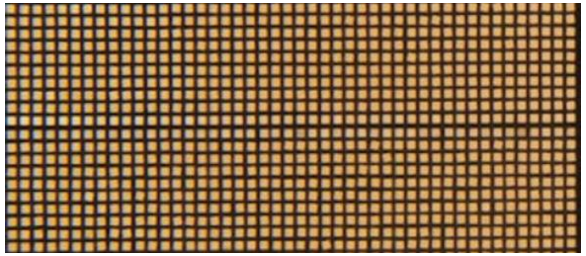


Compensating neutral density filters
Resulted in ~ 30% loss of light

Also studied compensating reflective mirrors (Jan 2016 eRD1 Report)

July 2016 eRD1 Report

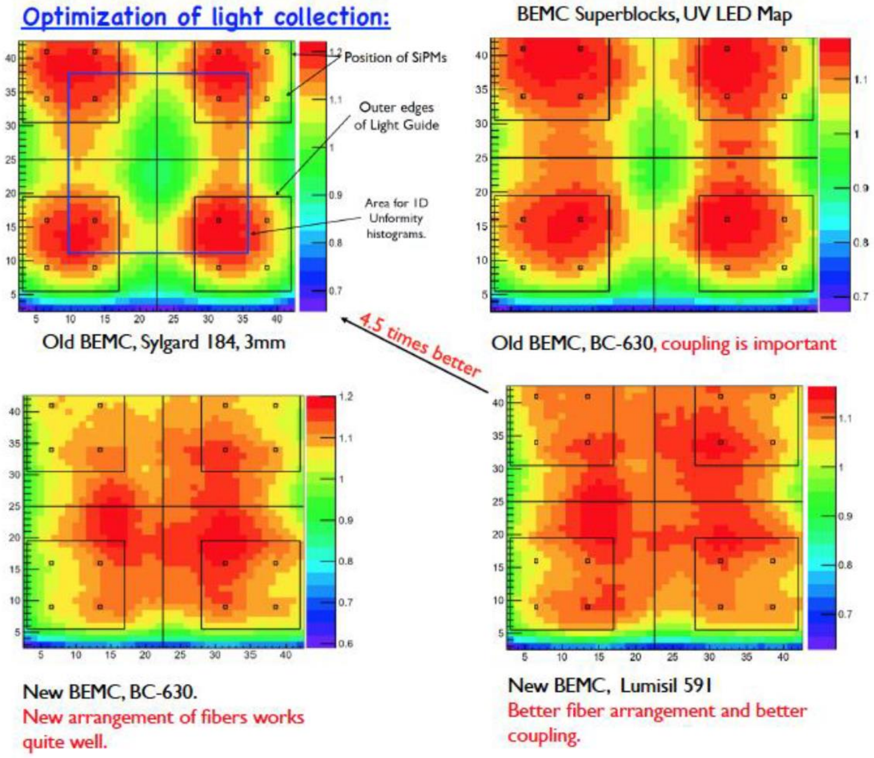
Long light guides read out with PMTs (Hi Res version)



← Square fibers vs round fibers

July 2017 eRD1 Report

Optimization of light collection with different fiber placement and optical couplings

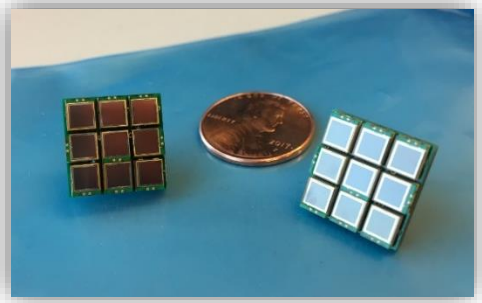


Improved uniformity when fiber ends bend in towards center of block

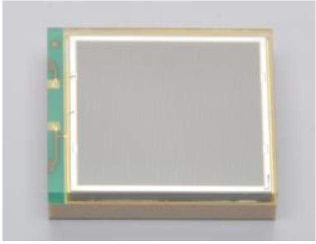
Future Directions for Improving Light Collection Uniformity

January 2018 eRD1 Report

- We are currently looking at ways of increasing the photocathode coverage with SiPM readout
  - More 3x3 mm^2 SiPMs
  - 6x6 mm^2 SiPMs
- We have studied this with PWO crystals and also plan to study this with W/SciFi blocks.

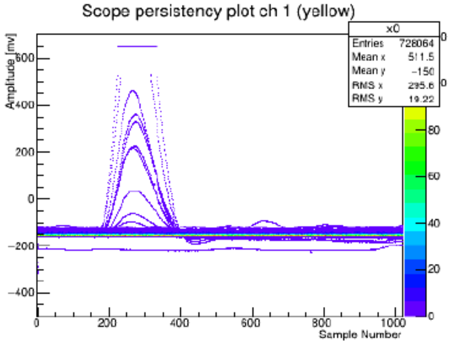


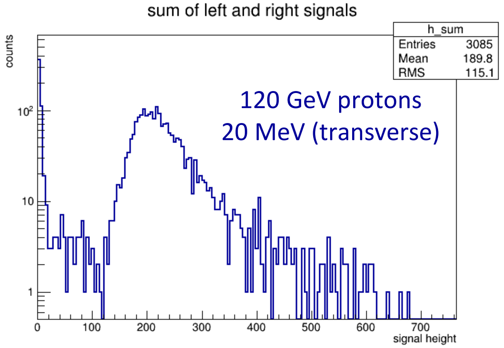
3x3 array of 3x3 mm^2 S12572 MPPCs

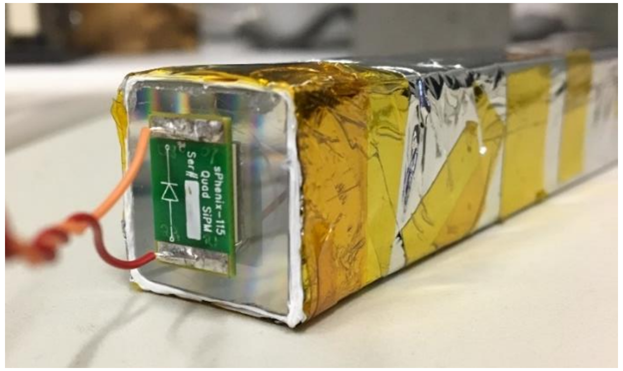


6x6 mm^2 S13360-6025PE MPPC

PWO







3x3 array mounted on PWO crystal

PWO crystal with 3x3 array of SiPMs on each end tested in the test beam at Fermilab in March 2018
Preliminary results by M. Purschke (not in report)

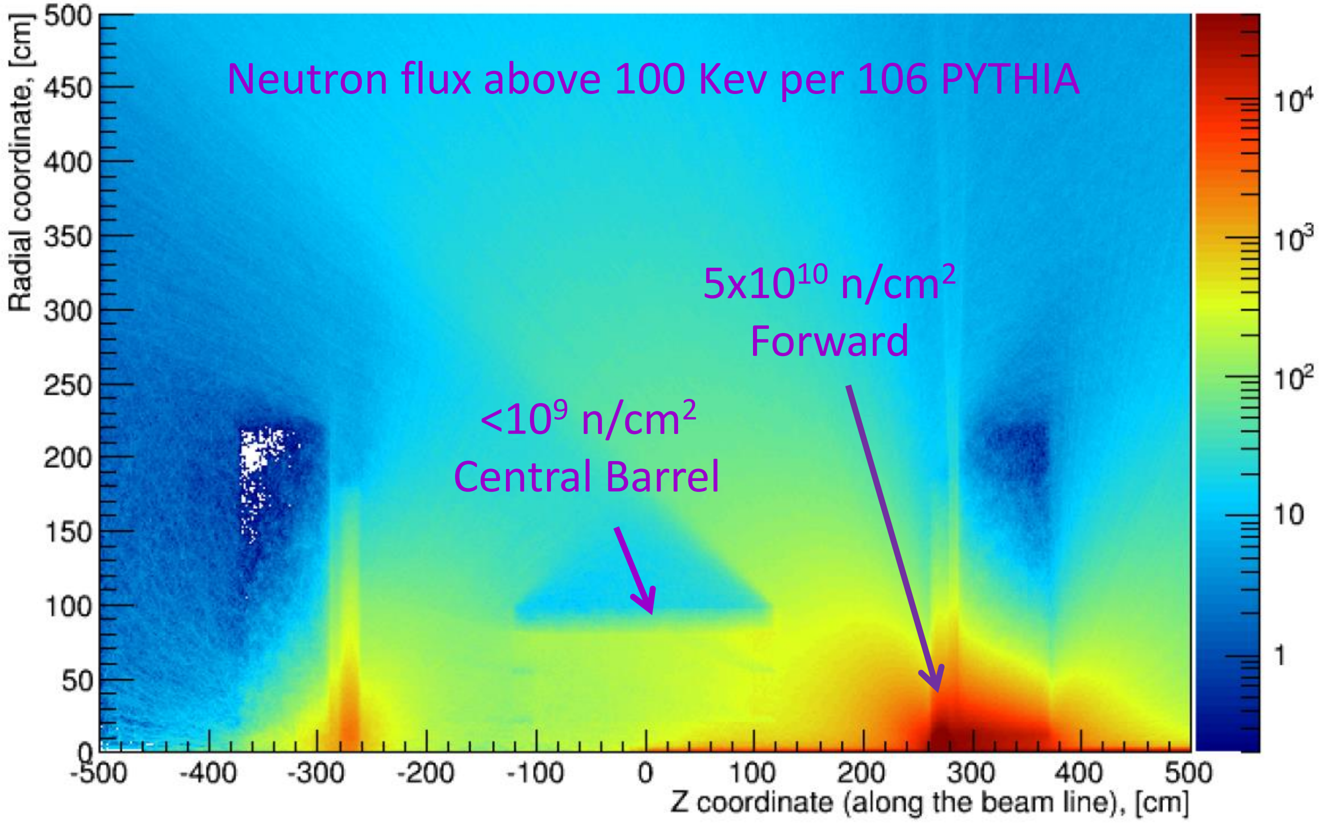
This seems like the best option for improving the light collection uniformity within a block or crystal. However, there will still be non-uniformities at the block/crystal boundaries.

Radiation Map – Neutron Fluences

January 2016 eRD1 Report

Neutron Fluxes in BeAST ep 20x250 GeV

Simulation by A. Kiselev



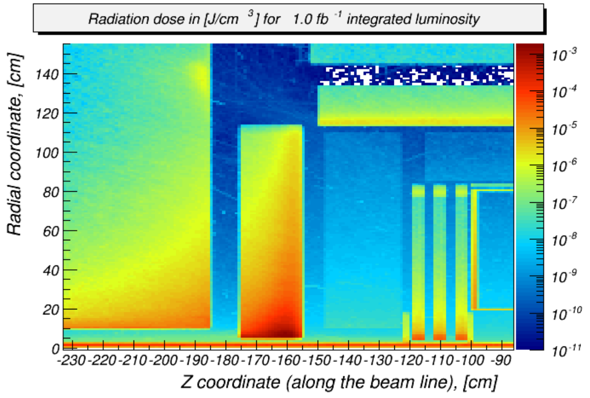
At EIC design luminosity (L ~ 10^{33} $cm^{-2}s^{-1}$) the fluence in the region of the Forward EMCAL would be ~ 5 x 10^{10} n/cm^2 after 100 days of running

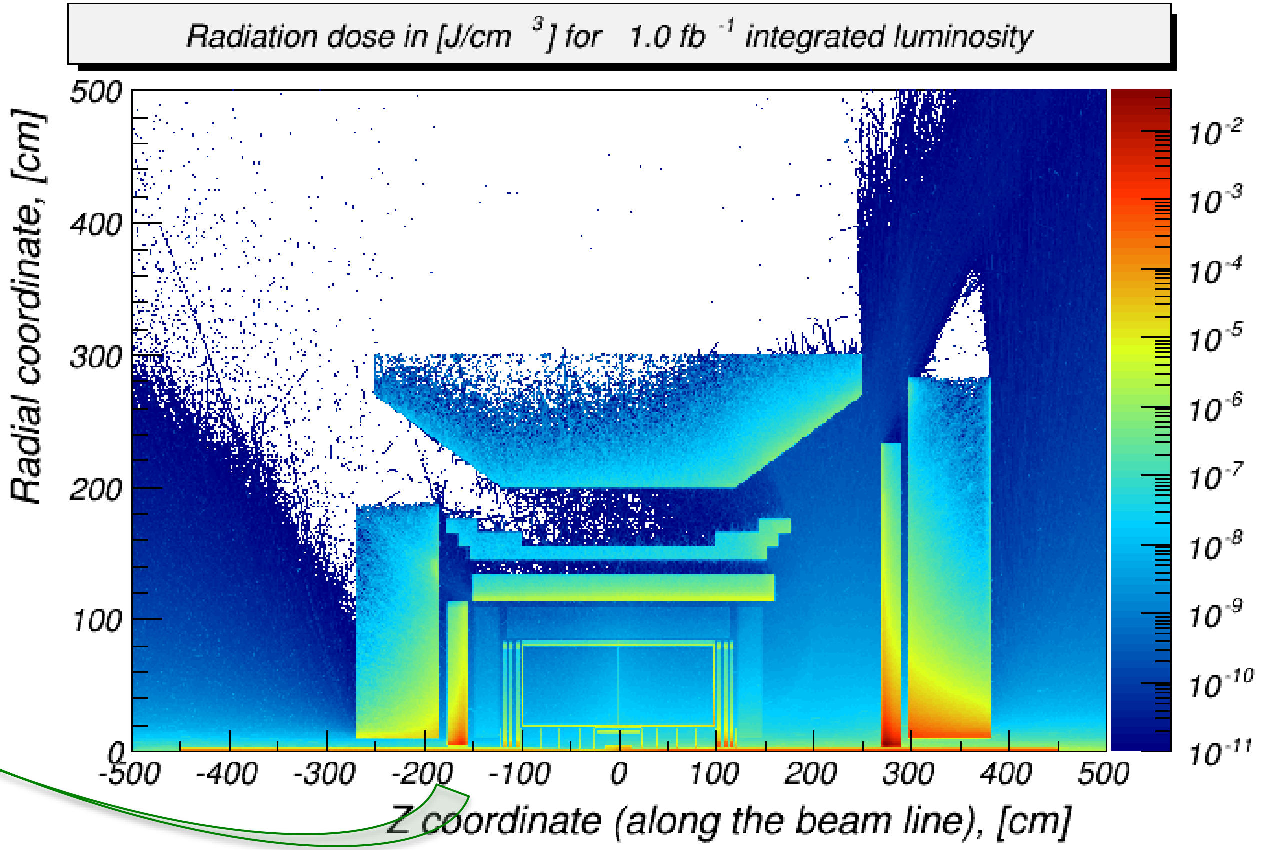
Fluences are 1-2 orders of magnitude lower at the location of the Central EMCAL

Ionizing Radiation Doses

The (primary) quantity: E_{sum} = “a sum of dE/dx”/”cell volume” for N events

Simulation by A. Kiselev (Nov 2017)
Not in Report





-> crystal EmCal: up to ~$2 \cdot 10^{-3}$ J/cm^3 per fb^{-1} (close to beam line)

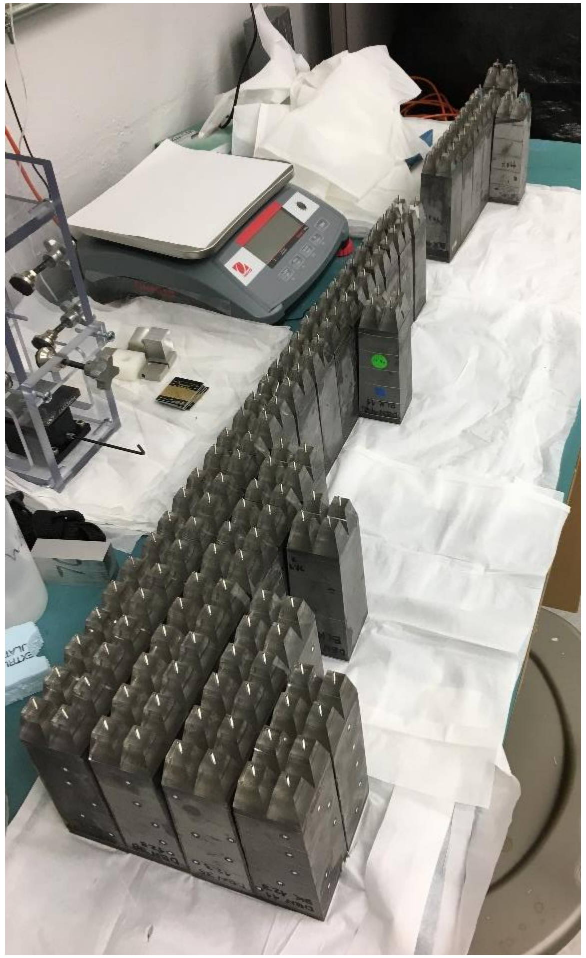
1 rad = 0.01 Gy & [Gy] = [J/kg] & PWO density ~8g/cm^3 -> ~250 rad/year (at “nominal” luminosity ~10^{33} cm^{-2} s^{-1})

Update on the Status of the sPHENIX W/SciFi EMCAL

- Blocks for Sector 0 are being produced at UIUC.
- 36/96 blocks have been shipped to BNL and are in the process of having reflectors, light guides and SiPM readout boards installed.
- Mechanical parts for Sector 0 are being produced at SBU and at an outside vendor.
- Expect assembly to begin in April 2019.
- Blocks for the large rapidity part of the calorimeter are now being planned to be built in China.

SiPM readout board being tested with LED and fiber

36 blocks for Sector 0 with reflectors and light guides installed

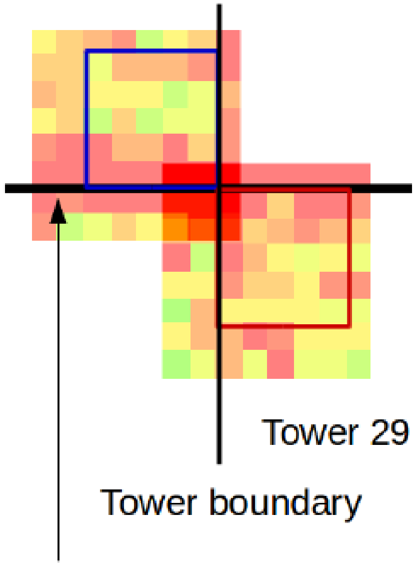


Preliminary Analysis of the 2018 Test Beam Data

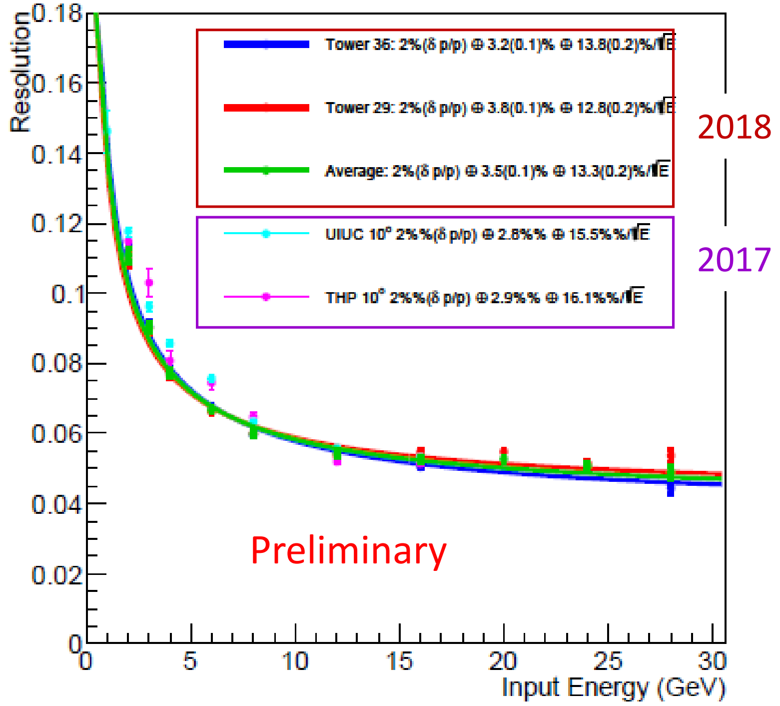
- V2.1 EMCAL prototype (8x8 array of towers of 2D blocks representing η~1)
- Detector was tilted by ~ 6° in η and ~ 8° in ϕ
- Measured with beam centered over two different tower positions
- 8x8 hodoscope with 5 mm wide fingers used to measure beam position in X & Y
- Data analyzed with a 5x5 hodoscope cut that included both light guide and block boundaries
- Measured energies were corrected using hodoscope position

Significant improvement seen relative to 2017 data, particularly at lower energies

Average energy resolution: 13.3%/√E ⊕ 3.5% including block and tower boundaries



Energy Resolution



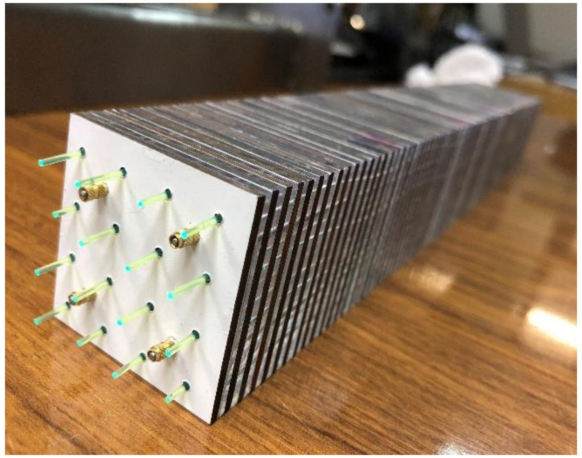
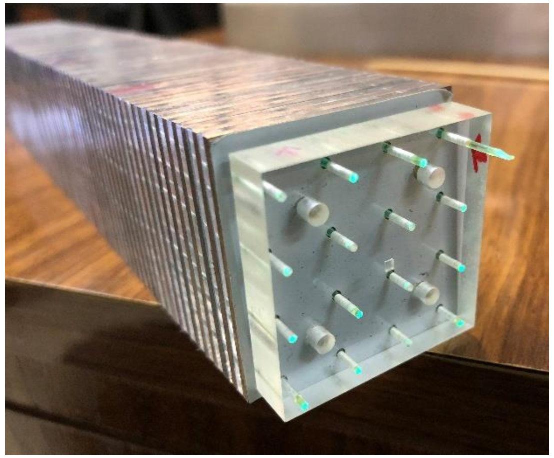
Publications

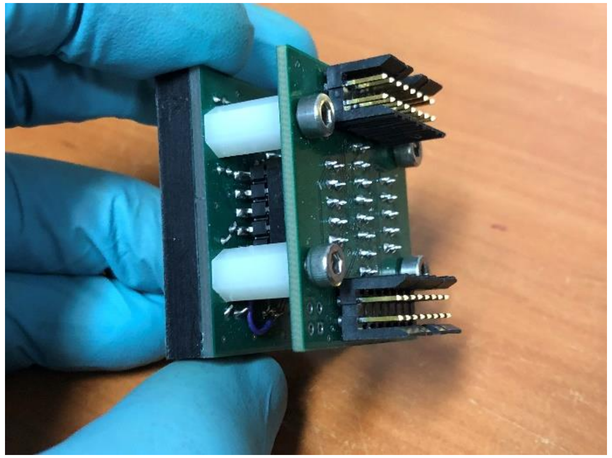
- C.Aidala et.al., “Design and Beam Test Results for the sPHENIX Electromagnetic and Hadronic Prototypes”, IEEE Trans. Nucl. Sci. 65 (2018) 2901-2919.

- B.Biro et.al., “A Comparison of the Effects of Neutron and Gamma Radiation in Silicon Photomultipliers “, submitted to the IEEE Trans. Nucl. Sci. in September 2018.
  - First review was received in October 2018
  - New revised version resubmitted in January 2019.

Status of R&D on W/Shashlik Calorimetry

Main goal since the last meeting was to complete the first W/Cu shashlik module at UTFSM. This has now been completed.



Stack of seventy 38 x 38 x 1.5 mm W80Cu20 absorber plates and 1.5 mm scintillator plates

Readout consists of 16 WLS fibers each read out with its own SiPM

Reading out each SiPM separately will allow one to study the position dependence of the light collection within a module and in principle correct for it.
This will be done at UTFSM using LEDs and cosmic rays.

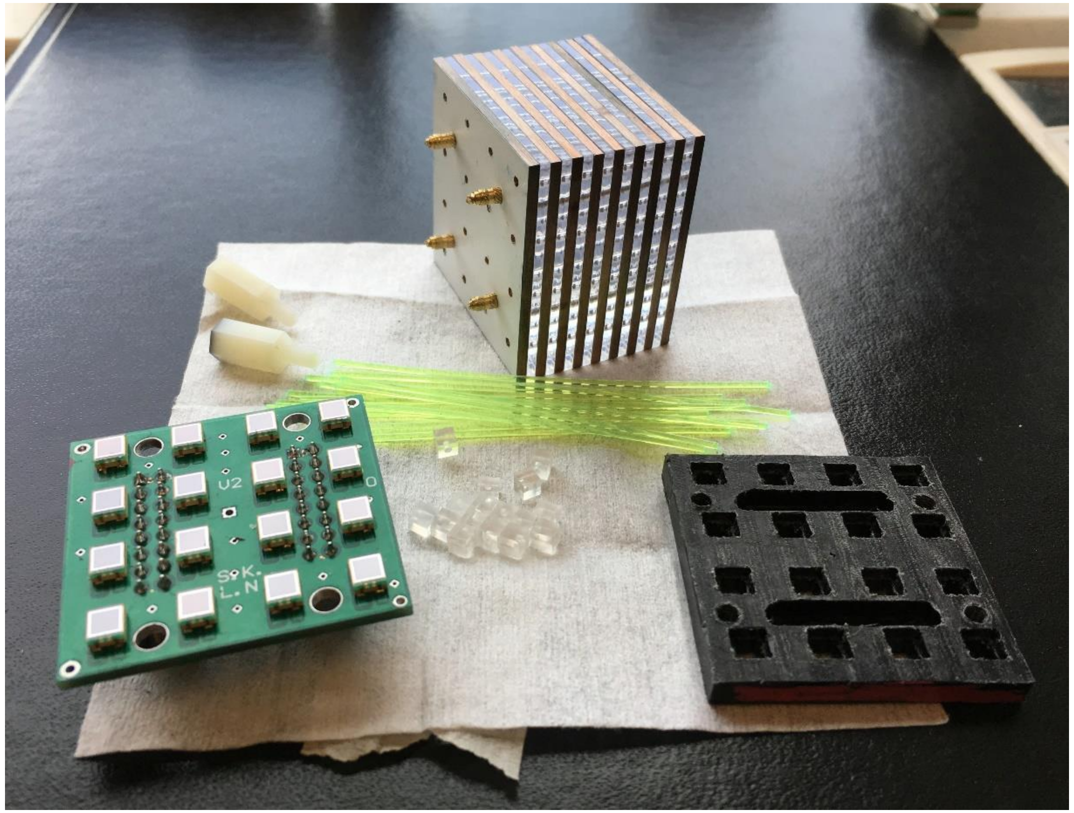
The hope is that this will lead to better overall uniformity in energy response.

Additional Studies on Light Collection

A set of calorimeter components was sent to from UTFSM to BNL for additional studies on light collection.

These will be used to do detailed studies of the light collection within the absorber stack using lasers, LEDs and radioactive sources in the lab.

Will also test with new 3x3 mm^2 15 μm pixel SiPMs from Hamamatsu and KETEK.



- Short stack of absorber and scintillator plates
- WLS fibers
- Acrylic light mixers
- SiPM readout board and mounting plate

Plan for the next 6 Months

- Test the first completed module at UTFSM with LEDs and cosmic rays. This will be done using readout electronics at UTFSM.
  - Overall light output (Npe/MeV)
  - Initial energy calibration that can be correlated with LED response
  - Initial results on uniformity
  - Initial results on timing
- Study light collection of scintillator stack in the lab at BNL and correlate with UTFSM tests
- Send first module to BNL and repeat some of the tests using the sPHENIX readout electronics
- Begin construction of an additional 5 modules to be used in a future beam test.
- Begin looking at old PHENIX Pb/Scint modules to compare with new W/Scint modules

Summary

- The sPHENIX EMCAL is now well under way towards becoming a construction project. A tremendous amount was learned about the benefits and limitations of the W/SciFi design during the course of this project and in conjunction with our EIC R&D. The design has now been developed into a full scale production effort.
- A new effort to study a W/Shashlik design has now begun (thanks to the support by this Committee !) and we will hopefully learn much more about its performance for EIC.
- Studies of the expected radiation levels at EIC have also begun and some preliminary results exist. However, much more needs to be done to obtain realistic estimates of neutron and ionizing radiation doses expected (including backgrounds).
- Studies of radiation damage in SiPMs continue (as will be reported by Oleg)