Progress Report
EIC Sampling Calorimeter Developments

O. Tsai (UCLA) for eRD1 Consortium

- Advancing technology for W/ScFi (sPhenix)
- W Shashlyk as complimentary technology (UTFSM)
- Rad Damages of readout sensors for EIC sampling calorimeters.

sPhenix, Progress Since Last Meeting

1. Main effort was to complete the design and begin construction of a new prototype calorimeter (V2.1) consisting of 8x8 towers representing the sPHENIX calorimeter at $\eta \sim 1$

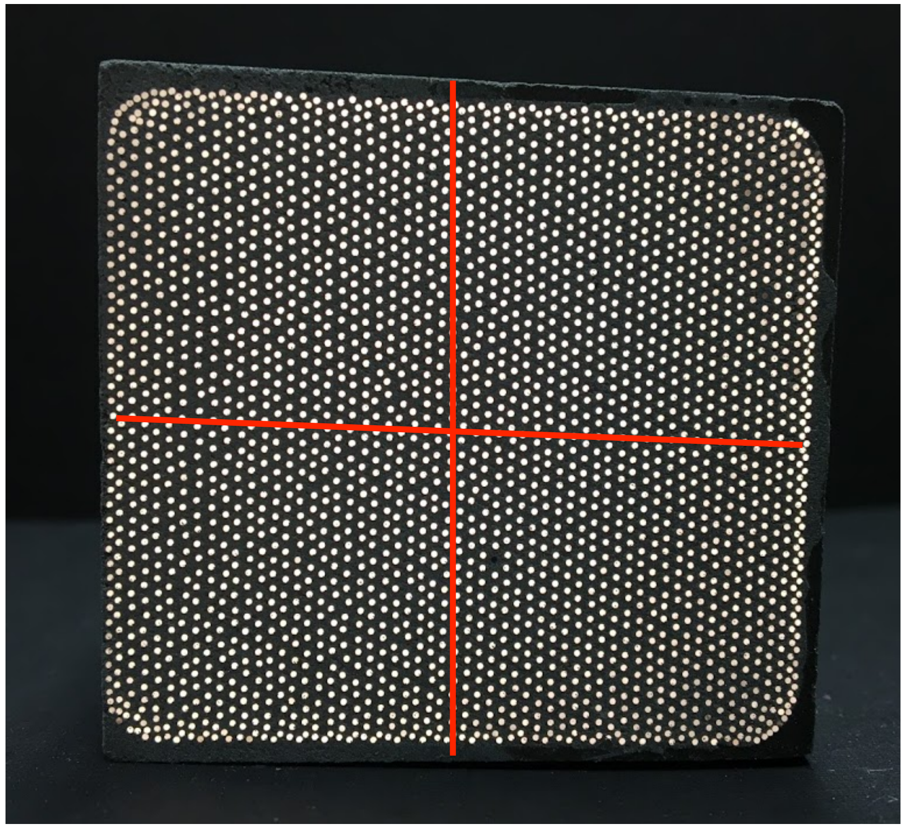
   - New improved 2D projective blocks
   - Developed QA procedure for blocks
   - New injection molded light guides
   - New method of mechanical support for blocks and external enclosure (similar to what will be used in final calorimeter)
   - New liquid cooling system for electronics
   - New readout electronics

2. Prototype is in final stages of assembly and testing at BNL and will be tested in the beam at Fermilab in Feb-Mar 2018

3. sPHENIX completed a preliminary Director's Review in August 2017 and will have a second Director's Review in March 2018, followed by an OPA CD-1 Review in May 2018.

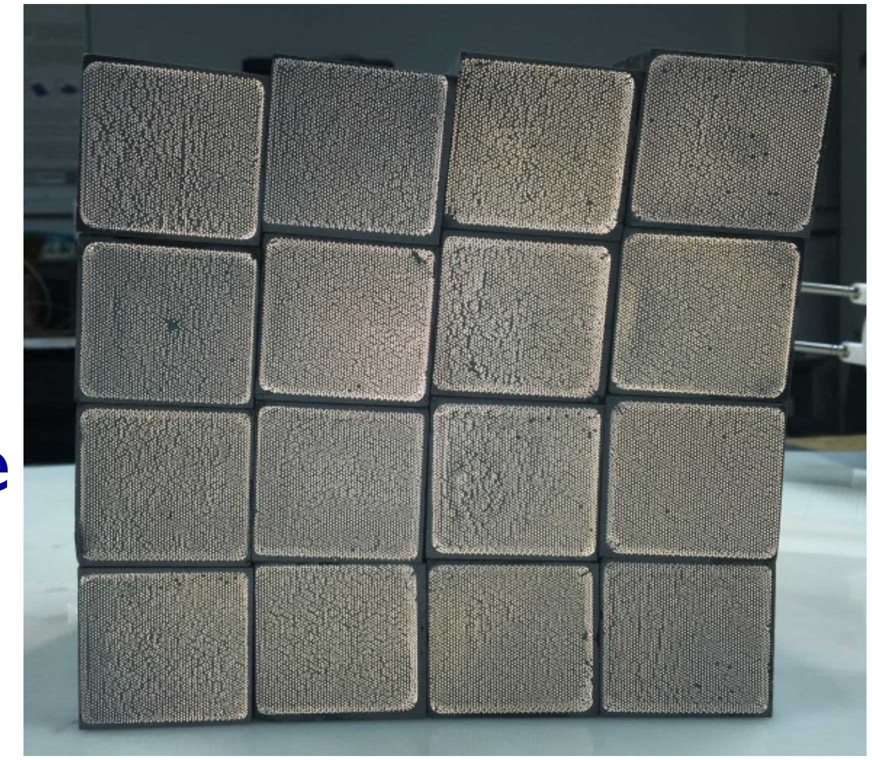
sPhenix, Blocks

Blocks are manufactured at the University of Illinois at Urbana Champaign (UIUC)

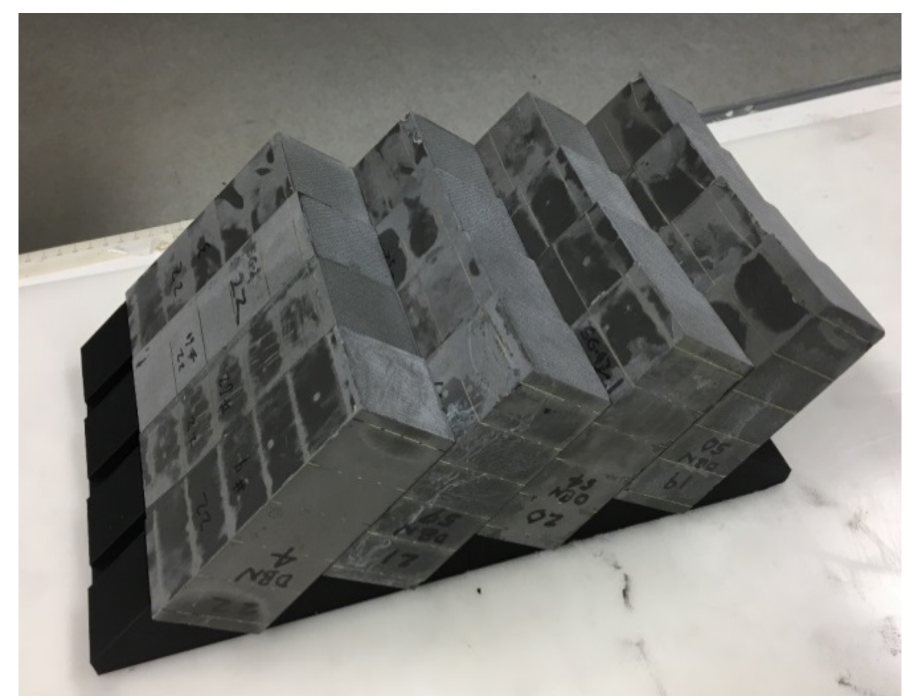


2x2 towers

2D Projective (η and ϕ)

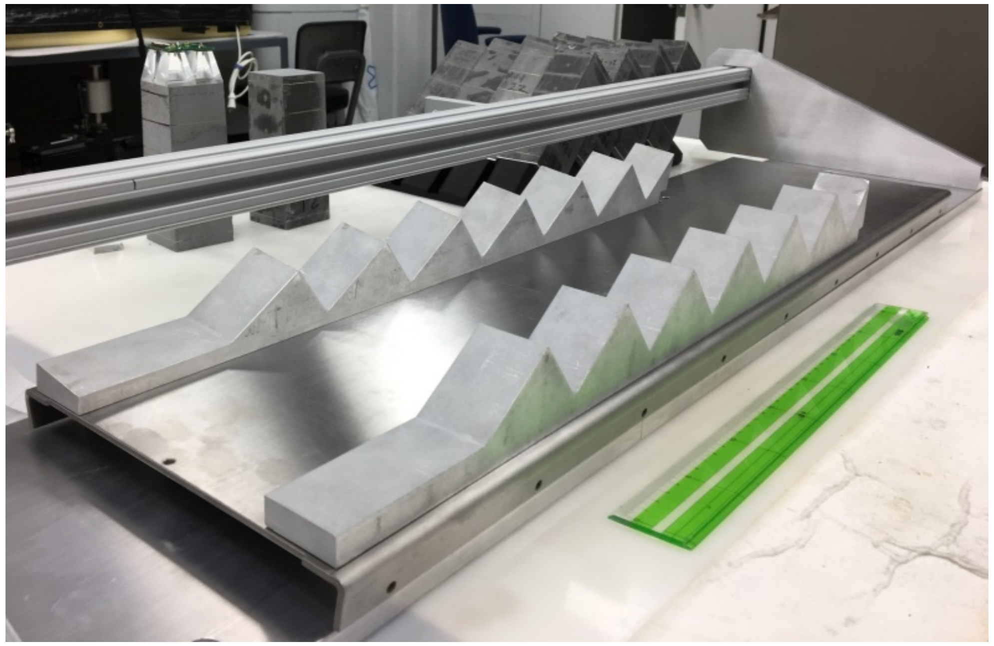


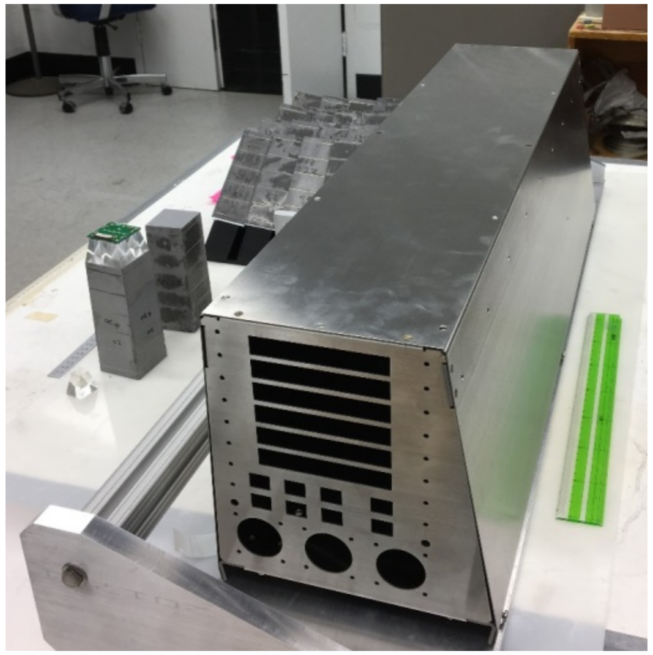
- New blocks have fibers tapered inward at readout end to improve light collection and uniformity
- Smaller border and dead material around edges
- Allows use of identical light guide for all blocks



sPhenix, Assembly of the V2.1 Prototype

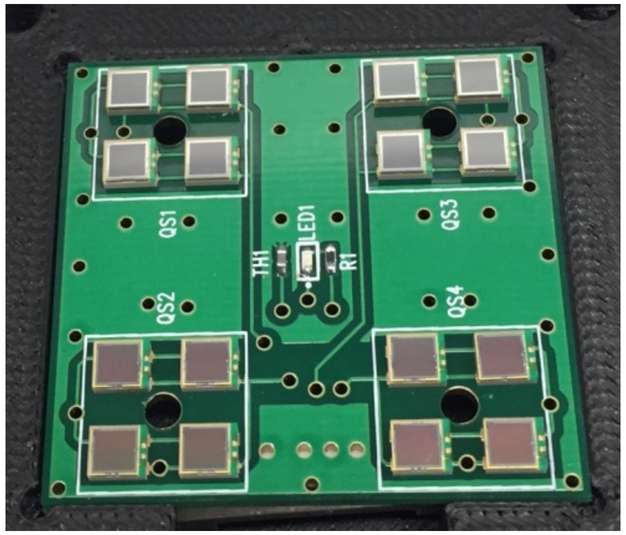
Blocks being installed onto sawtooth support

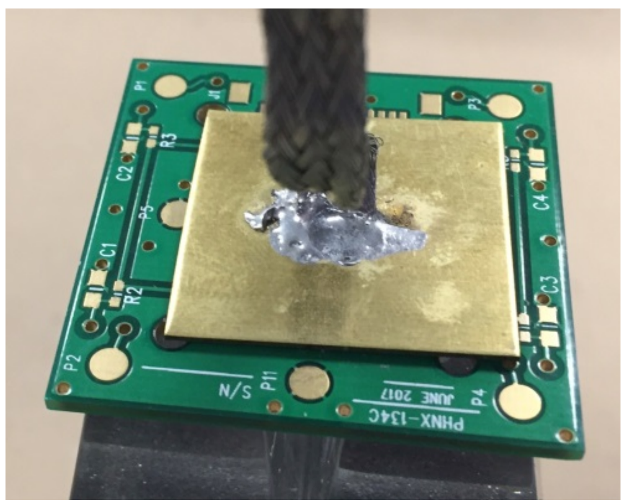




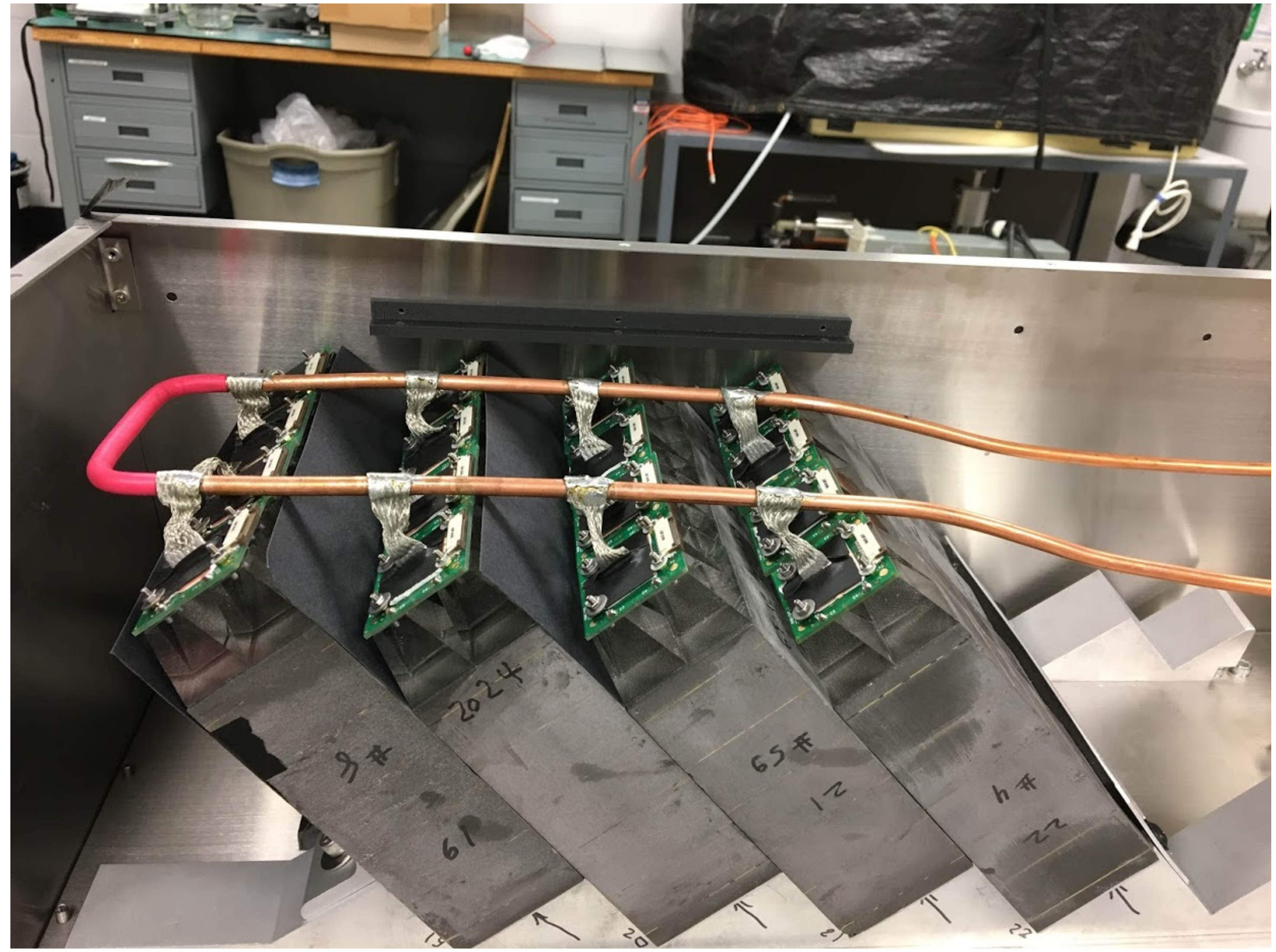
External enclosure with ports for cables and cooling

sPhenix, V2.1 Electronics and Cooling System



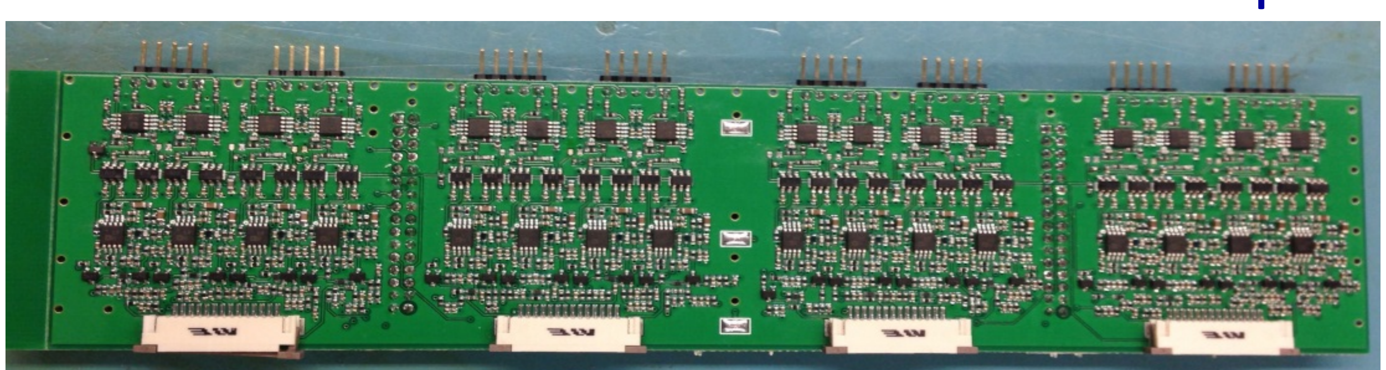


SiPM daughter board with cooling plate attached



Sixteen blocks in V2.1 prototype with SiPM daughter boards and cooling loop attached

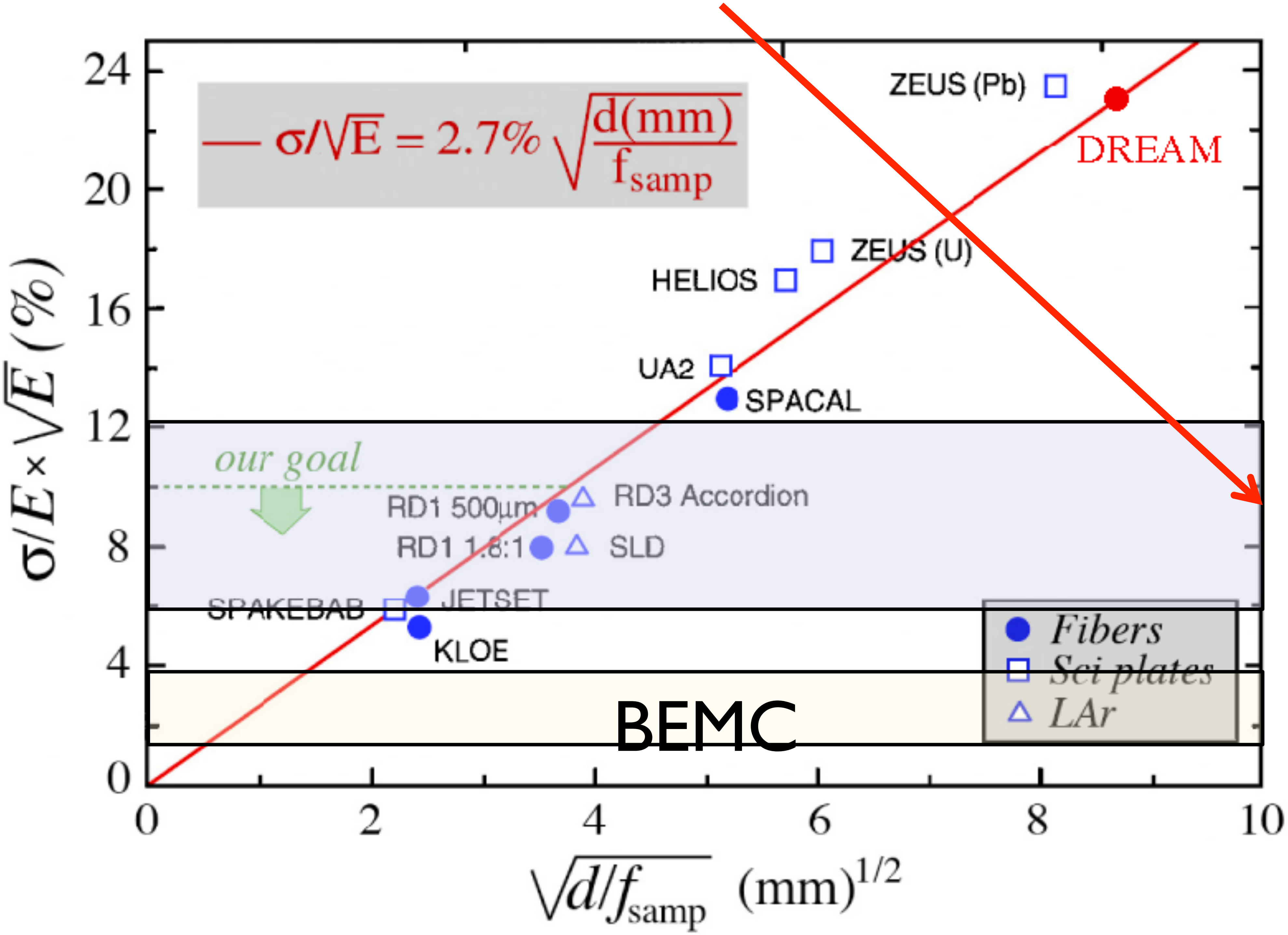
2x8 EMCal Preamp Board



W Shahslyk.
Federico Santa Maria Technical University
(UTFSM)

W Shashlyk, Complimentary Technology (Large d, Large f_{samp})

EIC EM Sampling Calorimeters



$$\frac{\sigma_{em}}{E} = \frac{12\%}{\sqrt{E(GeV)}}$$

H1

$$\frac{\sigma_{em}}{E} = \frac{7.5\%}{\sqrt{E(GeV)}}$$

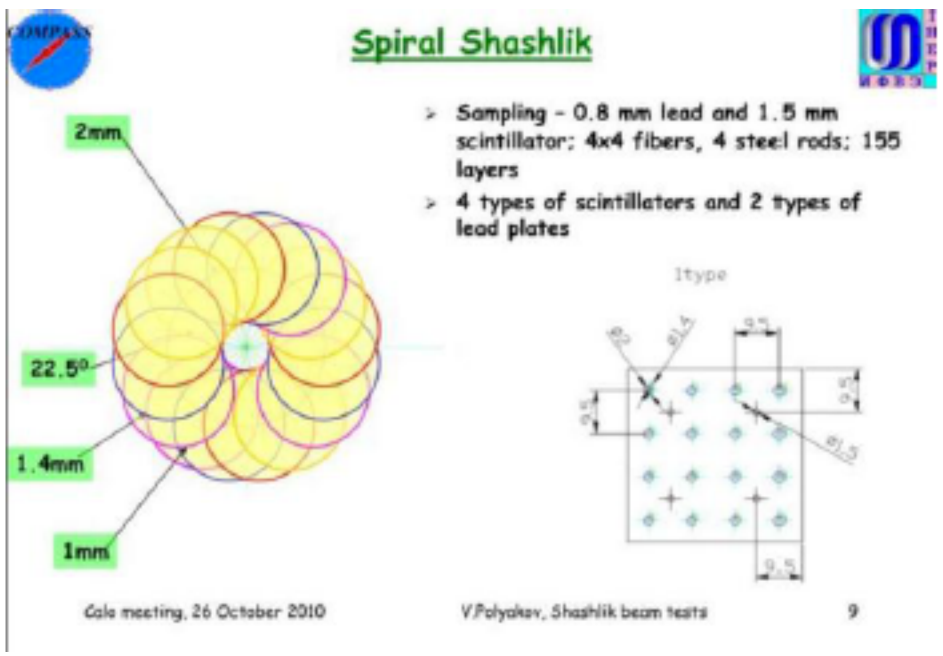
ZEUS $\frac{\sigma_{em}}{E} = \frac{18\%}{\sqrt{E(GeV)}}$ $\frac{\sigma_{had}}{E} = \frac{35\%}{\sqrt{E(GeV)}}$

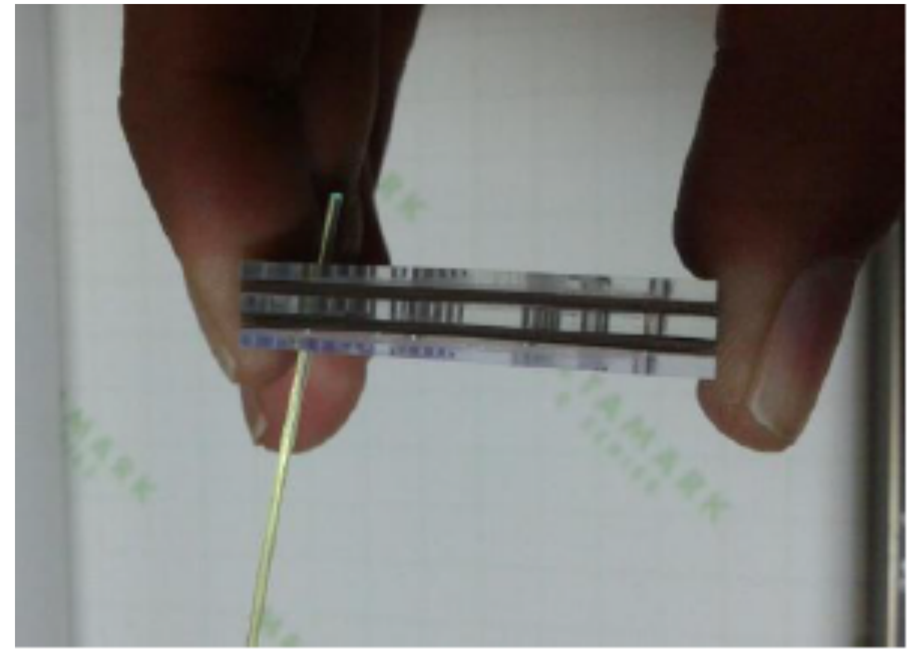
Calorimeters:

- Full Coverage,
- Hermetic.
- Compact.
- Operate in the magnetic field.
- Fast.
- Affordable.

- Calorimetery, Complementarity H1 and ZEUS
- Complementarity, EIC1 and EIC2?

W Shashlyk (Compact, 2D). UTFSM





A mechanical engineer, Eliás Rozas, works on the project

W Shashlyk (Compact, 2D). UTFSM

What was planned for this period?

- Production of a single tower technological prototype:	July-September 2017
- Production of 3x3 towers rectangular prototype:	July-December 2017
- Production of hodoscopes:	July-December 2017
- Production of read out for hodoscopes:	July-October 2017
- Production or purchase of the readout for calorimeters:	July-November 2017

What was achieved?

1. The scintillator plastic tiles for the shashlik prototype with spiral fibers with dimensions of 38 x 38 x 1.5 mm size were bought and delivered to UTFSM.
2. 900 38 x 38 x 1.5 mm W80Cu20 plates were bought and delivered in UTFSM.
3. 80WCu20 plates were covered with 70 micron thick white vinyl film (Metamark).
4. CAD/CAM design of the plates was completed
5. Drilling of holes in 300 plates is under production
6. 100 MPPCs for the calorimeter were ordered and paid for
7. We are working on the design of power supplies and read out electronics
8. The hodoscope was designed, constructed and tested during NA64 run at CERN

W Shashlyk (Compact, 2D). UTFSM

- A mechanical engineer, Eliás Rozas, works on the project (70% time) from June.
  A postdoc, Pablo Ulloa, works on the project (30% time) from July.
  An electronic engineer, Lautaro León works on electronics for the modules (30% time).
- Technicians and engineers are covered by the Detector Laboratory at UTFSM through the New Small Wheel upgrade of the ATLAS Experiment
- None of the personnel working on this project were funded through EIC R&D.

Near future:

- Test one module at CERN in May 2018
- Test one module at UTFSM.
- Continue discussions within Calorimeter consortium on most efficient use of SHASHLYK technology at EIC.

- UTFSM put significant resources to move project forward.
- Critical issue is future support from EIC R&D.

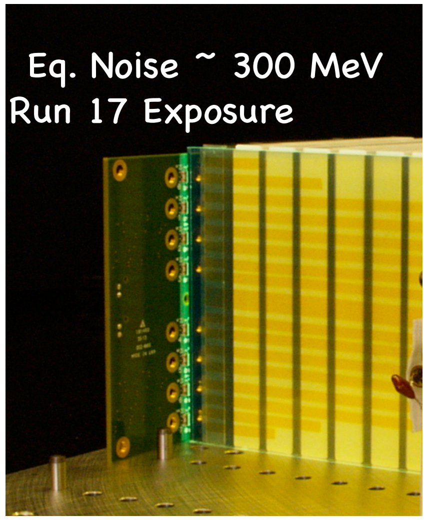
SiPMs, APDs Radiation Damages.

SiPMs/APDs , Eq. Neutrons, Light Collection Schemes…

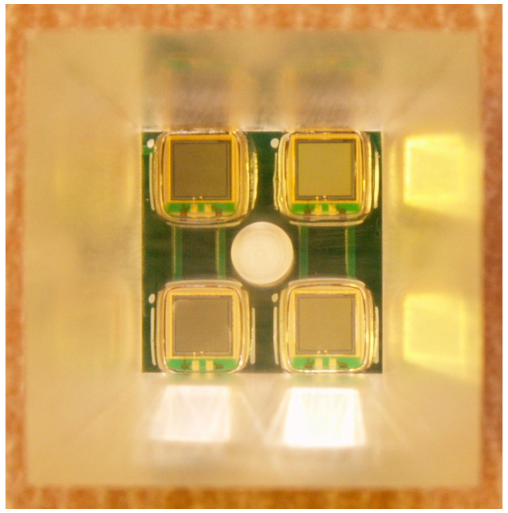
Sensor:
- Small Active Area
- Limited # pixels

Requires:
Multiple Sensors per tower

Calorimeter
- Light Collection Scheme
- Dynamic Range



Eq. Neutrons in IP
Degradation of Response
Is It Differential ?



Light perfectly Mixed

- Energy Resolution, term (1/E)
- Loss of Calibration Signals

Light partially Mixed

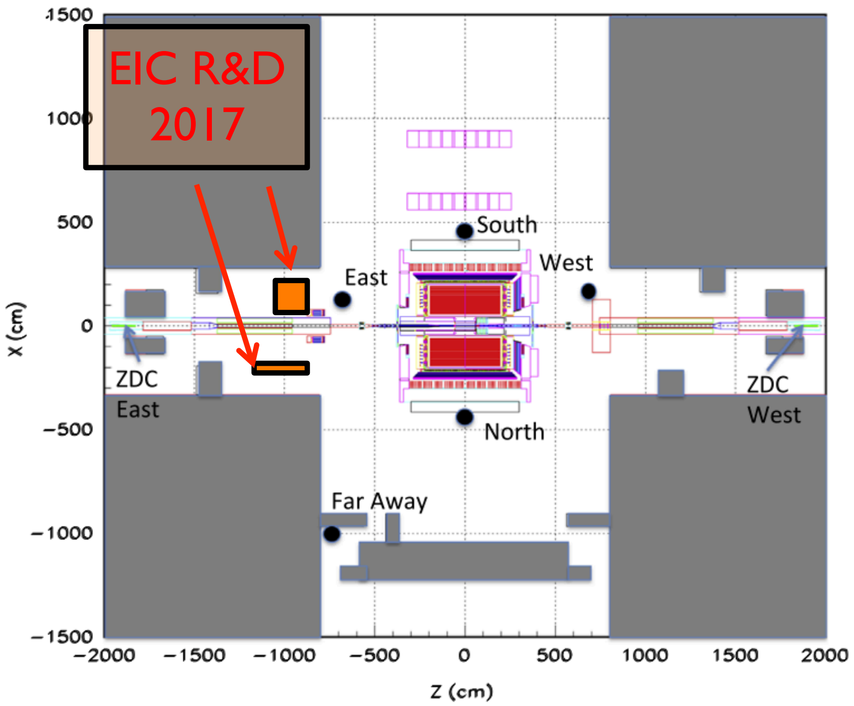
- Energy Resolution, term (1/E)
- Energy Resolution, constant term ?

- Increase LY
- Focus and Mix Light
- Minimize # sensors

Post Run 17
HCAL, Re-designed
Light collection scheme.

- Consider alternative technologies for high n flux areas.
- Consider non Si based sensors for high resolution calorimetry.

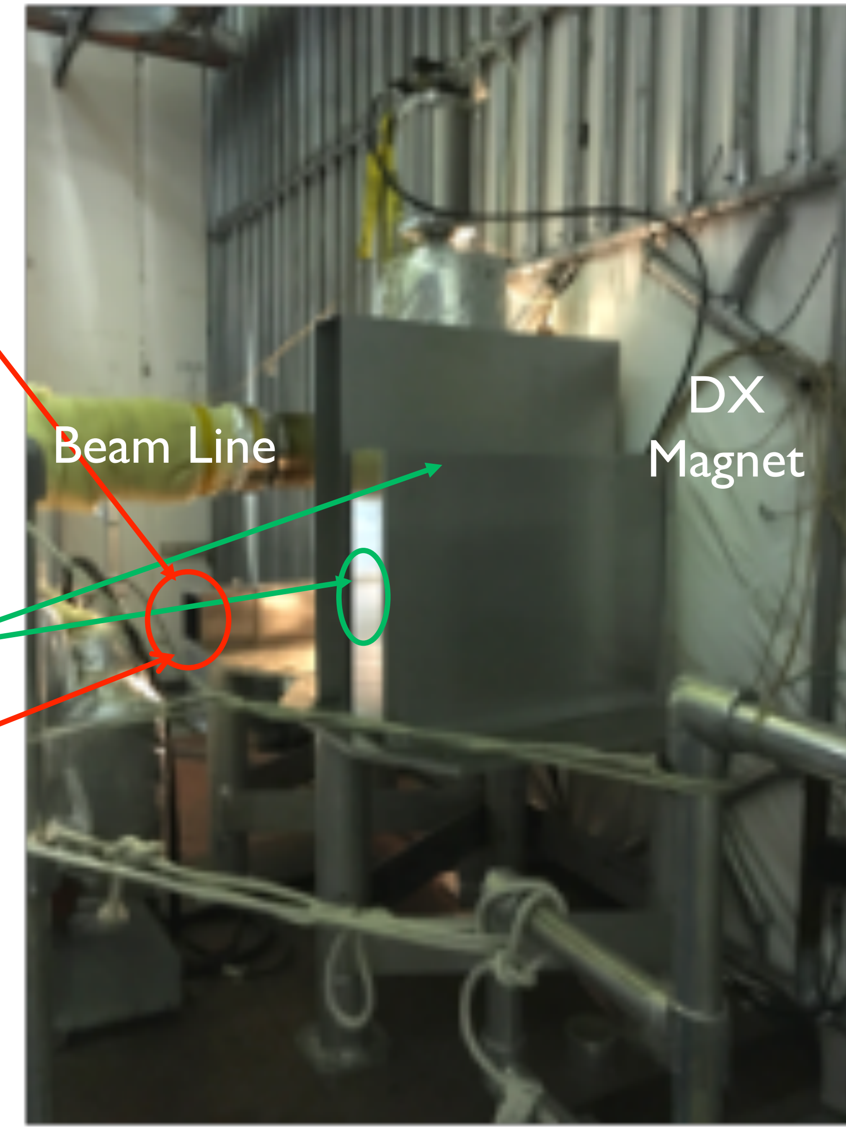
Large sample of SiPMs exposed in Run17 at RHIC STAR IP



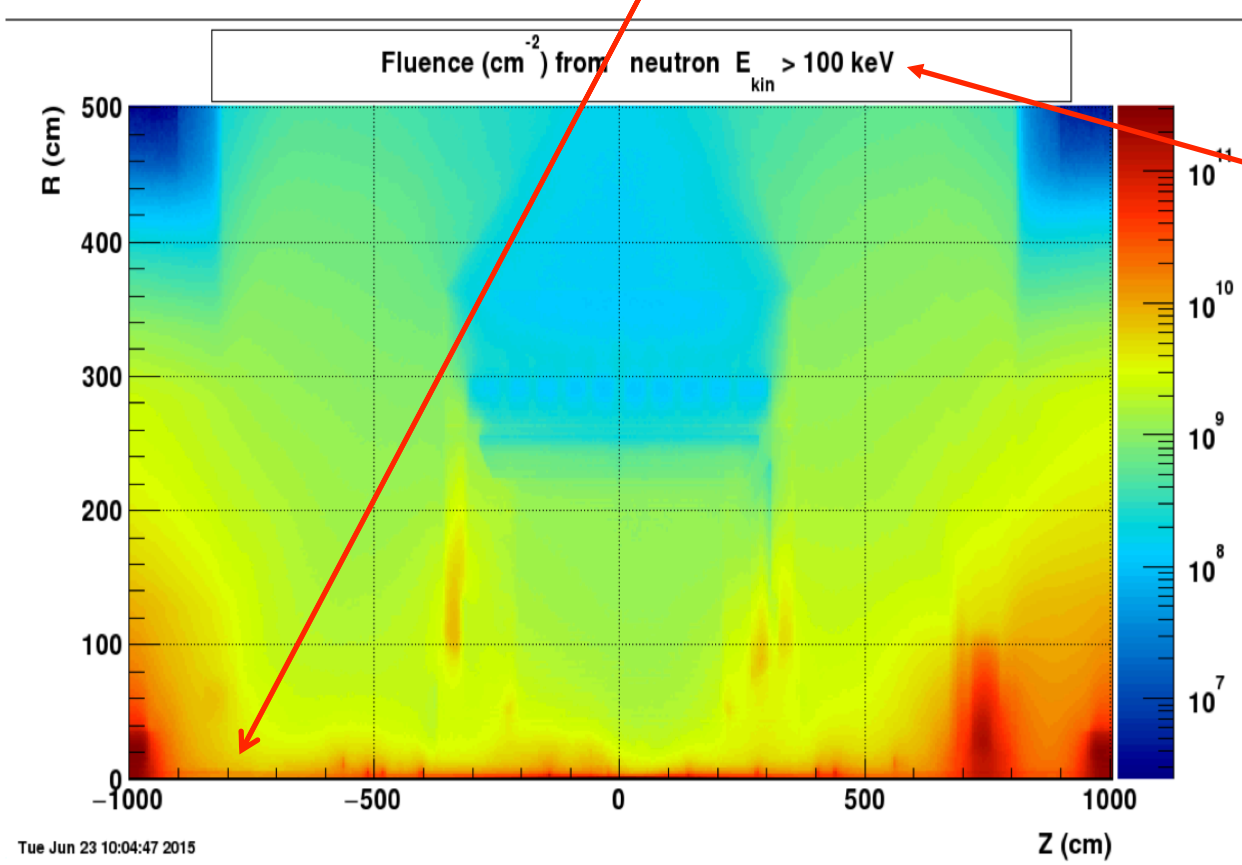
Y.Fisyak, et.al NIM A756

EIC, Run 17 STAR IP:

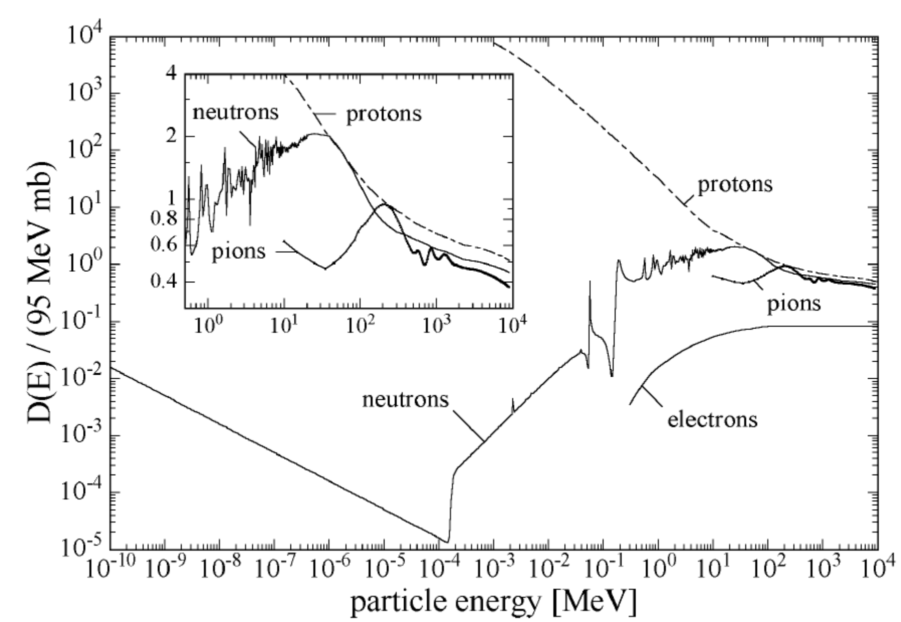
- 152 SiPM at ~135 cm (since Feb.) . All in Volume 10 x 10 x 2.5cm^3
- 26 SiPMs at ~45 cm (since April)
- APDs at ~45 cm, (since April)



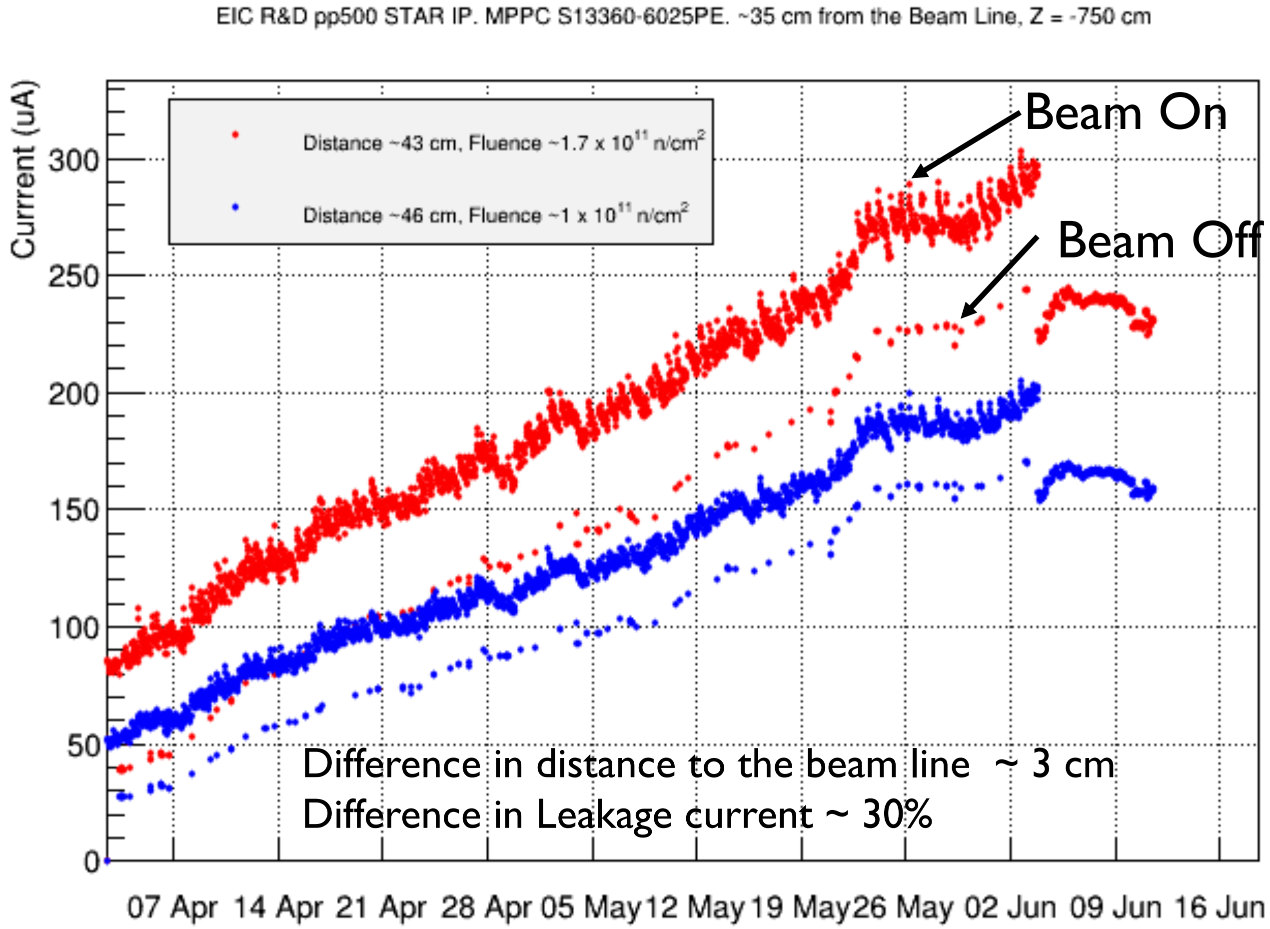
FEMC Run16, Run17

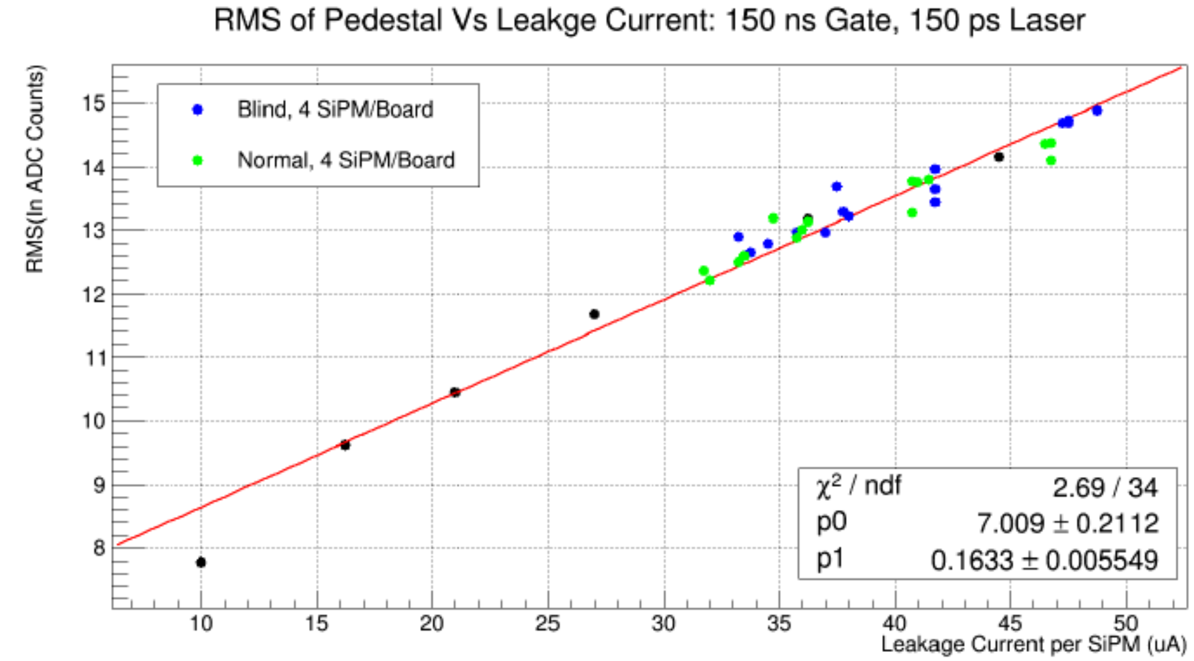


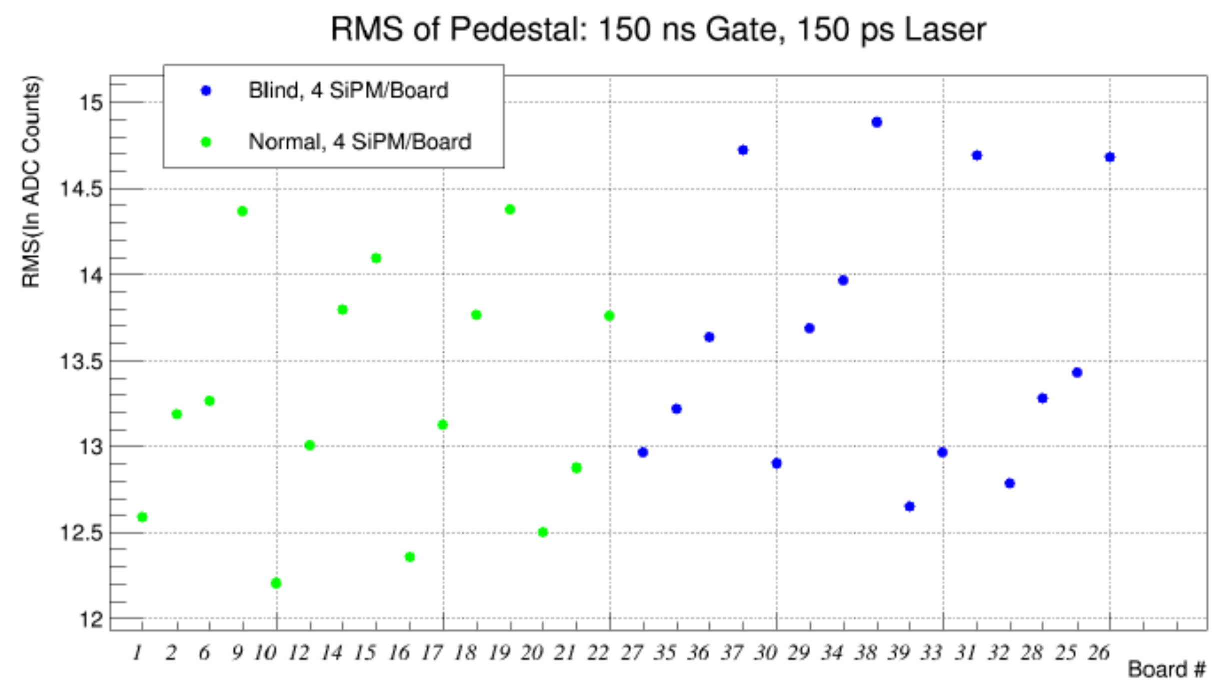
To accurately calculate damages this is probably not enough. Damage function for protons, pions etc. had to be included.



Run 17. Examples of Degradation.

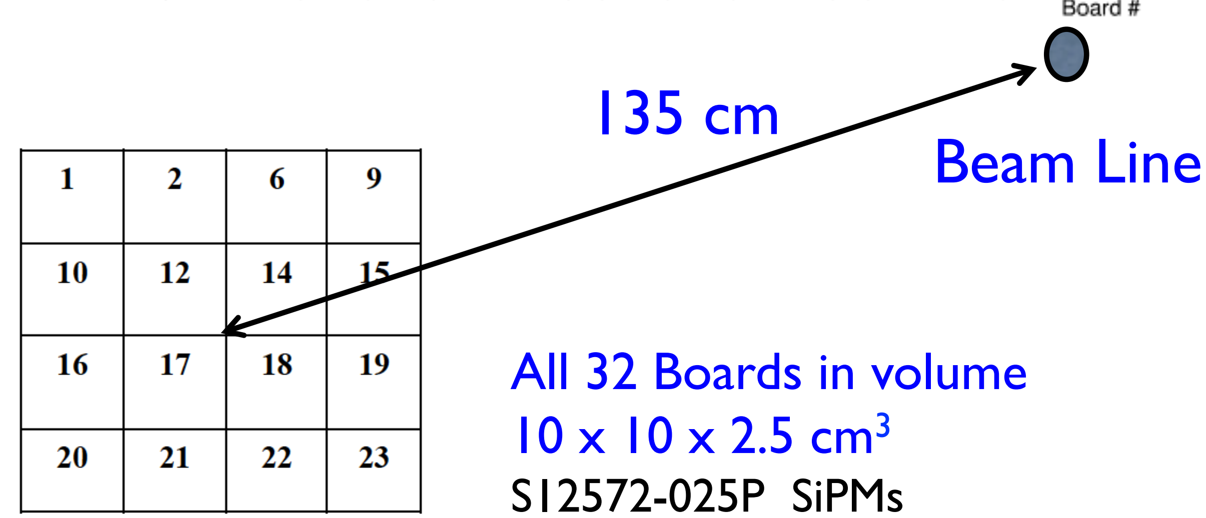






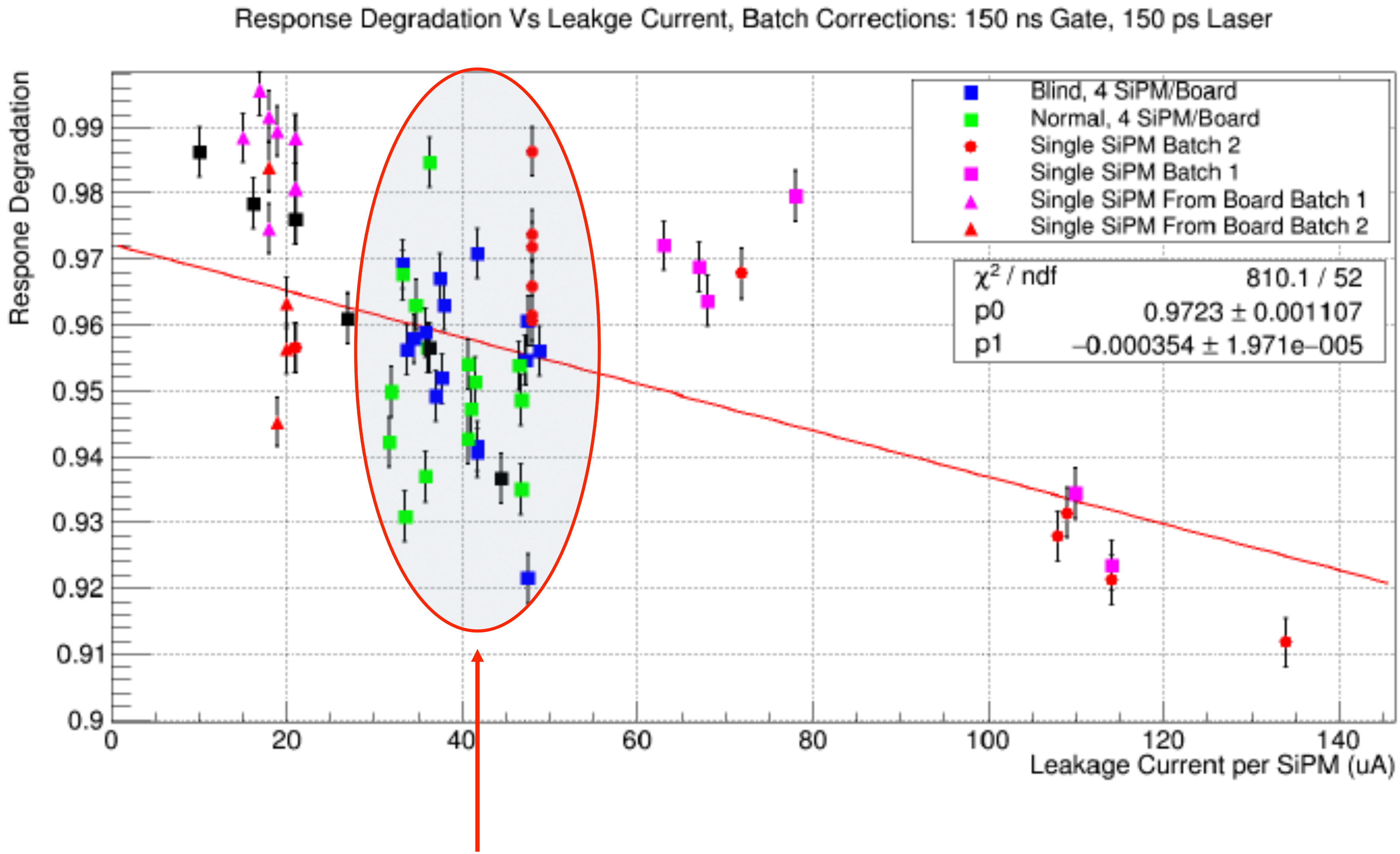
- Naive assumption that sensors are in the same conditions ("neutron gas") does not work well.
- Calorimeter is a source of background and also a shield.
- Probably need to know spectra and convolute these with damage functions.

- Yuri Fisyak were pointing to that long time ago, but it was not done. (lot of work and luck of test data).



All 32 Boards in volume
$10 \times 10 \times 2.5\ cm^3$
S12572-025P SiPMs

Degradation of response with respect to unexposed sensors.



Problem for some designs. May need monitoring for each SiPM, unless

- Light is mixed, SiPMs bunched. Still need good monitoring system but per tower.
- Or, one can claim that can calibrate/monitor from physics. (has not been looked for EIC calorimeters)

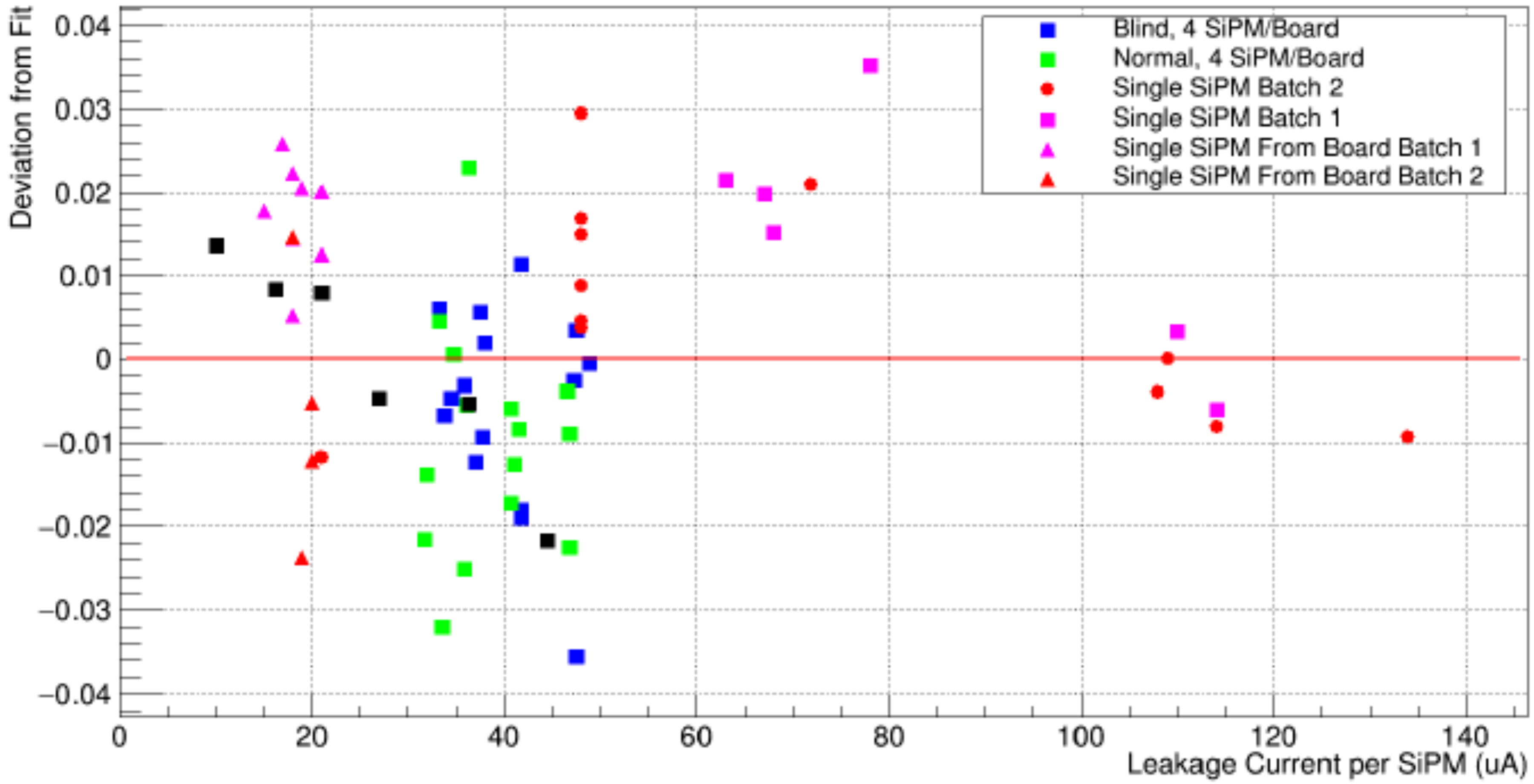
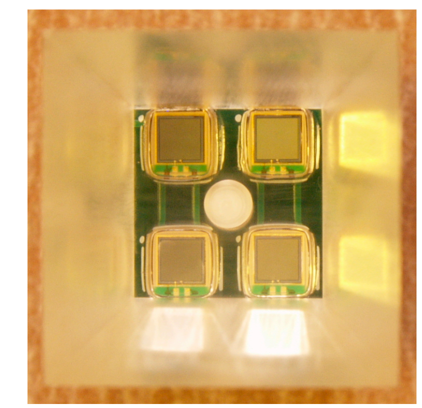


Figure 62: Deviation from fit for Leakage current versus response degradation with batch corrections. Sigma = 0.0155.

Correcting just on leakage current will increase constant term by 1.6%.



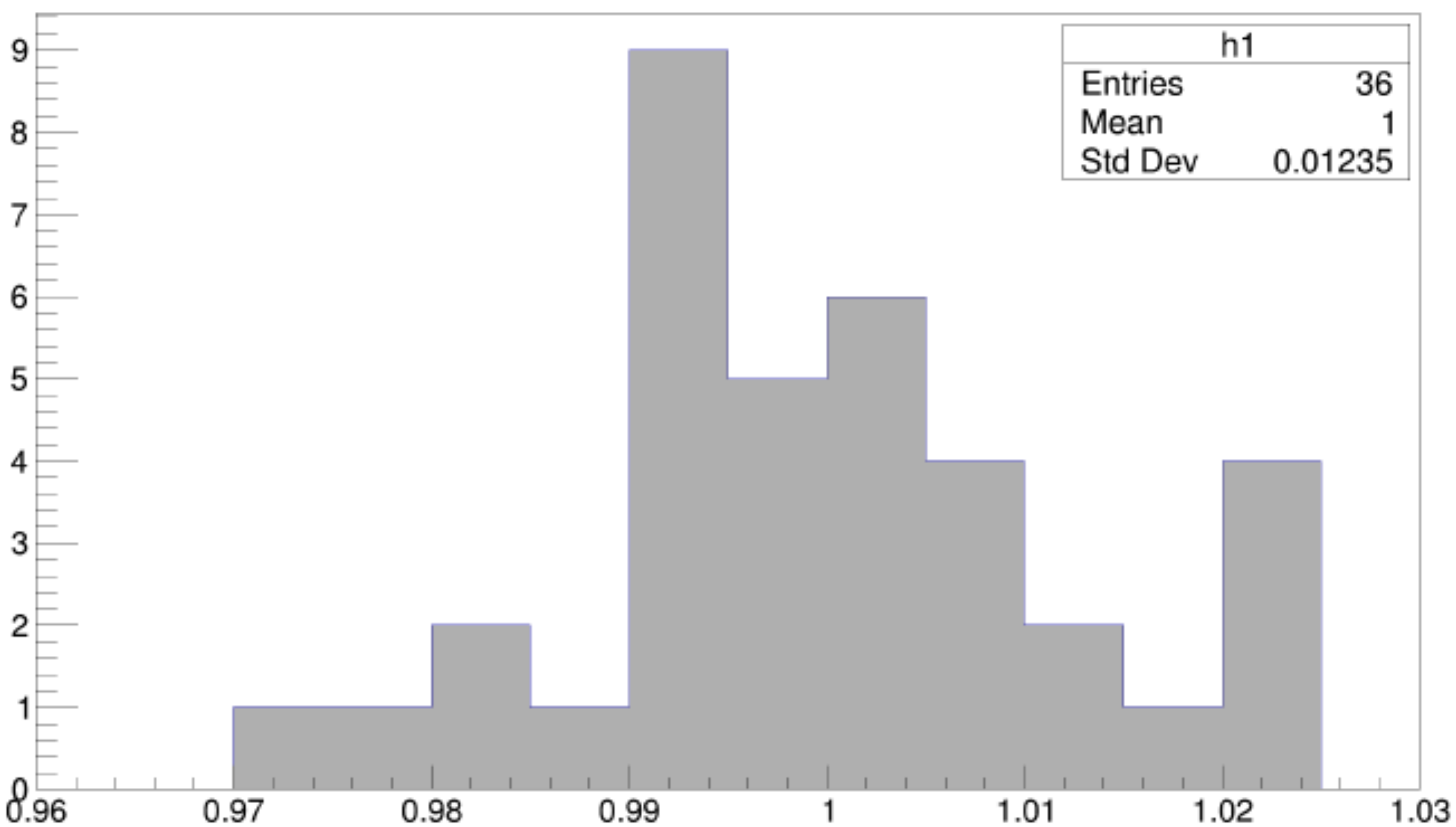
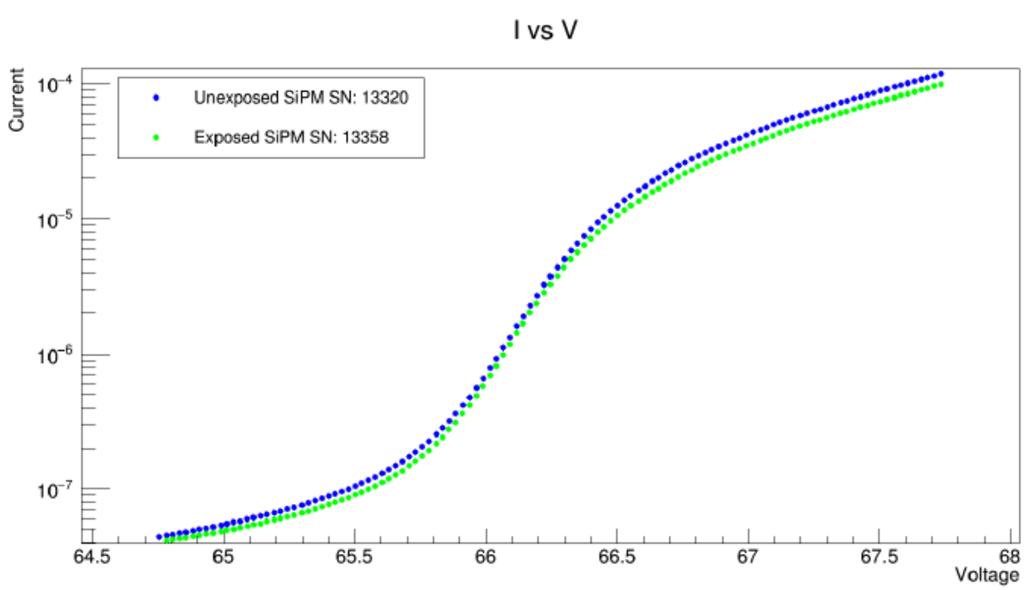


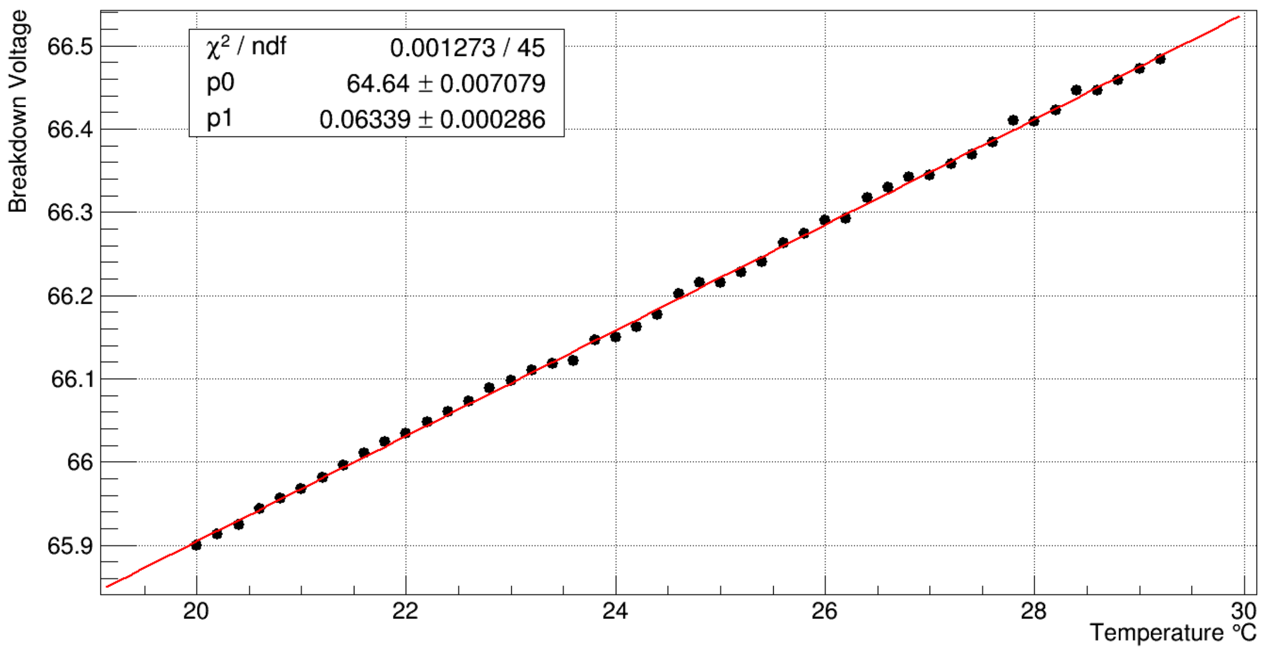
Figure 67: Differential degradation for single SiPMs

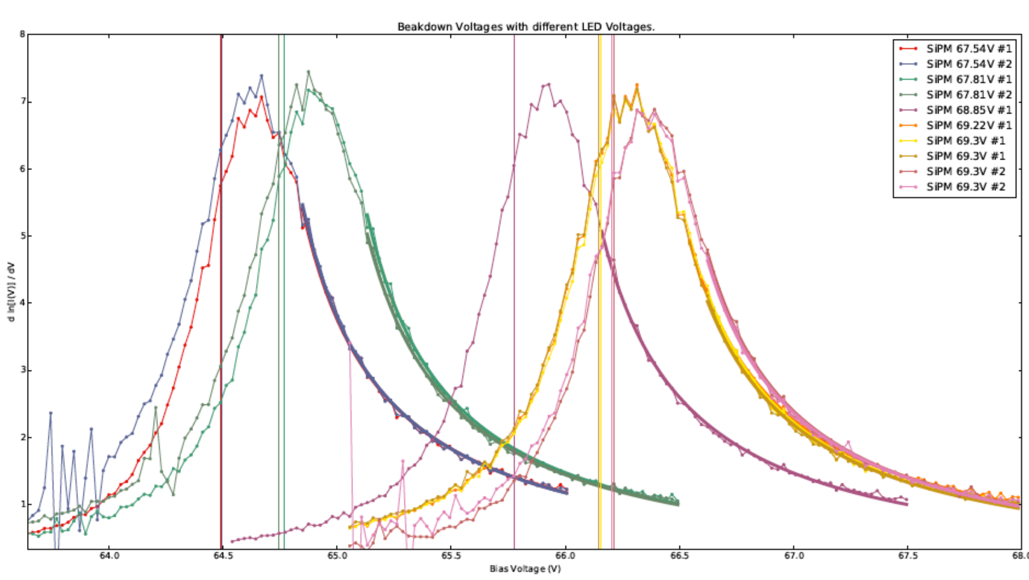
- SiPMs from a single tower degraded same way (distance between SiPMs ~ 7 mm).
- They were preselected at the beginning to have same operation voltage, (within 10 mV, using HPK data).
- Preselection should help for FEMC, BEMC or sPHENIX types of readout (in terms of keeping constant term inflated).

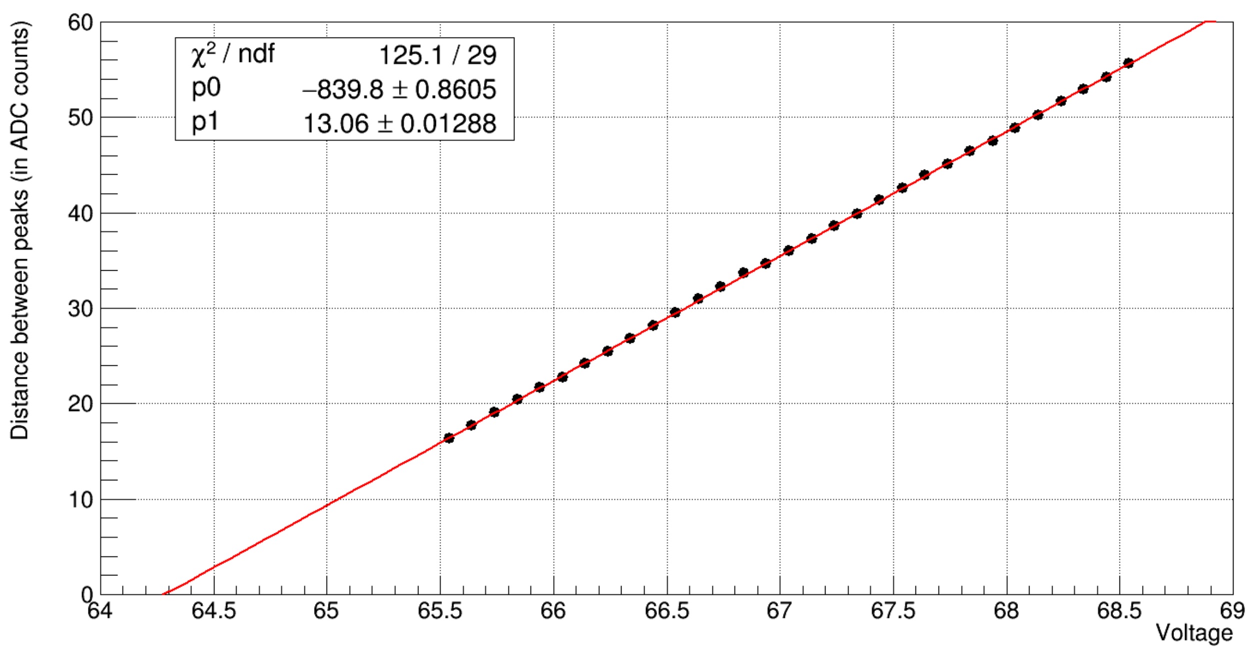
What is degrading? Gain, PDE, Junction T rises, dead pixels etc.

- Simplest thing to measure is change in Vbd (CMS reported 175 mV shift after 10^{12} n/cm^2)
- Response change by 10% correspond change in bias by ~100 mV.
- Need to extract Vbd from IV curves measured at constant illumination.
- Checked few methods, at the end settled on ILD method described in https://arxiv.org/abs/1606.05186 A.N. Otte et.al
- Checked on unexposed SiPMs with traditional (distance between peaks vs bias). Good agreement.
- Checked light intensity, time dependence. Precision is sufficient to track few% change in response.









Naive assumption that Vop – Vbd is the same for the same gain (response) specified by HPK turned out to be wrong.

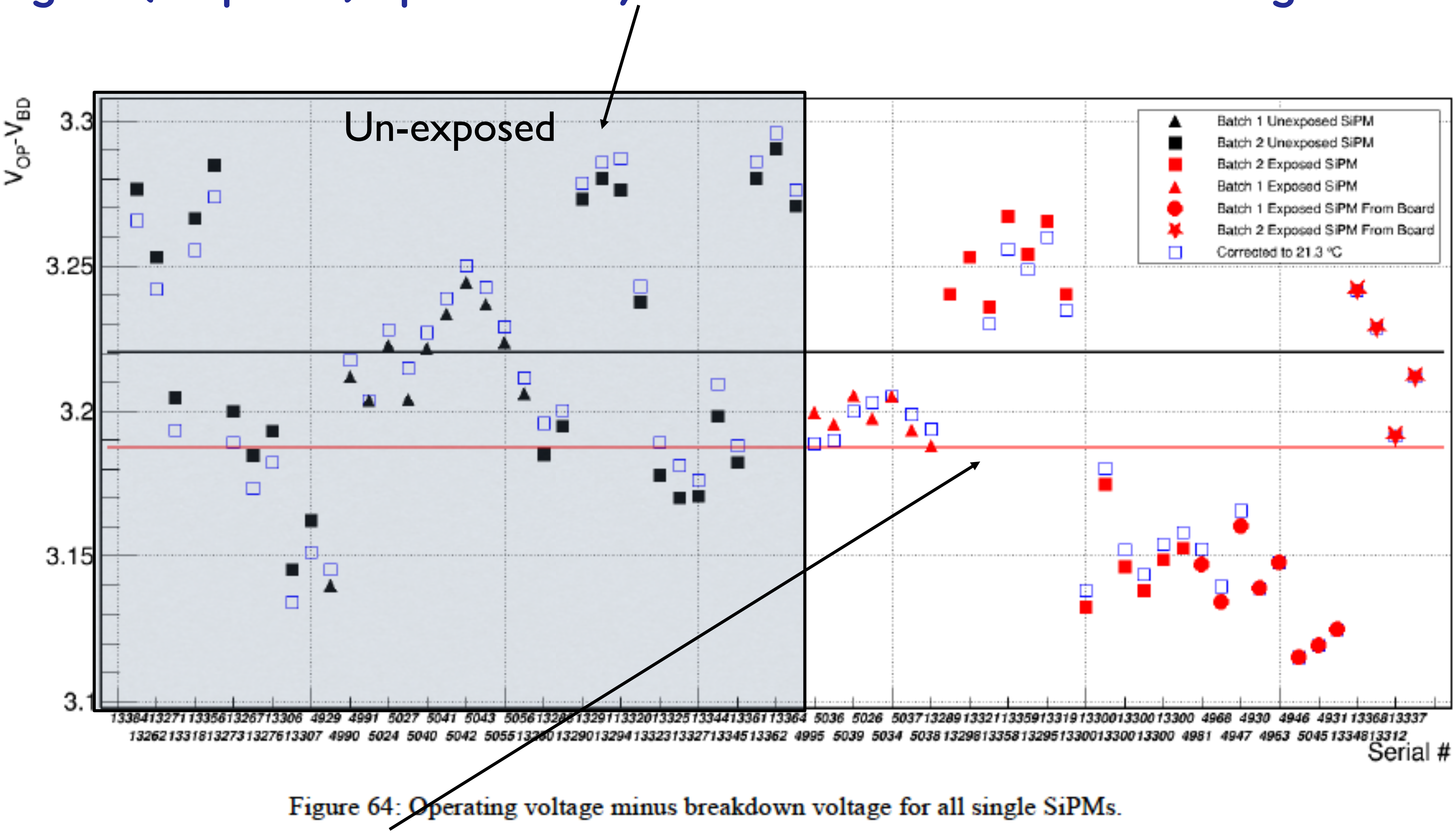
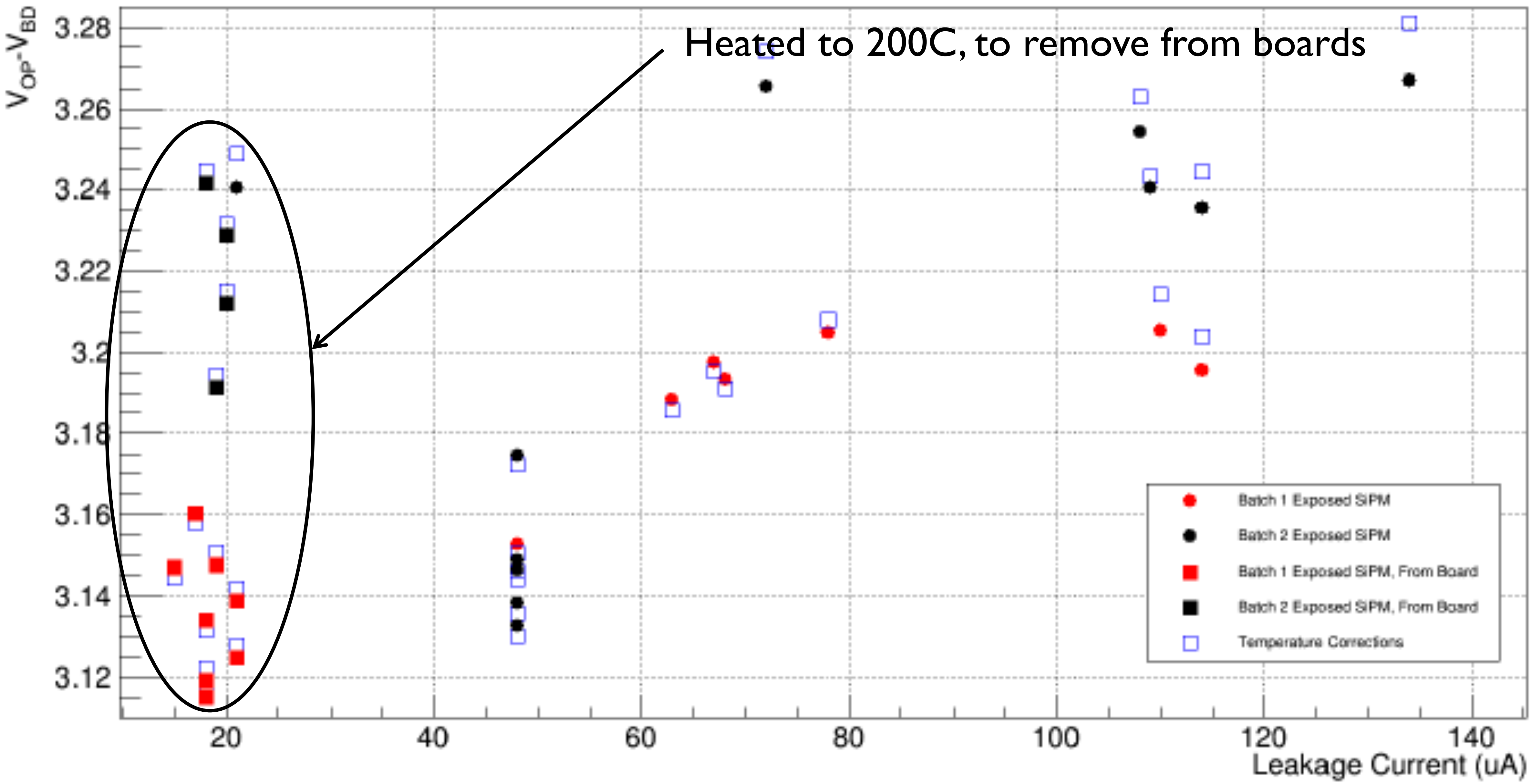


Figure 64: Operating voltage minus breakdown voltage for all single SiPMs.

- Average 30 mV shift for exposed sensors is plausible, but
- Not super convincing.



- No clear dependence from leakage current.
- No correlations with initial parameters (Vop, Dark Current, Serial #).
- Later high rate tests and results of measuring Vbd with different illumination level (I up to few x 100 uA) suggested that rising T in junction probably is not a root problem.

So far, safe approach is to think:

- SiPMs at EIC conditions will degrade.
- Each SiPM is 'unique' and will degrade differently.

Defence

- Choice of calorimeter design, which can amplify or play down problems related to degradations due to exposure, see slide 12.
- Good monitoring system.

Additional Efforts required.

- Reliable calculation of degradation will require more work than we did so far, that had also include such things as machine background.
- Calibration/monitoring in situ from physics.

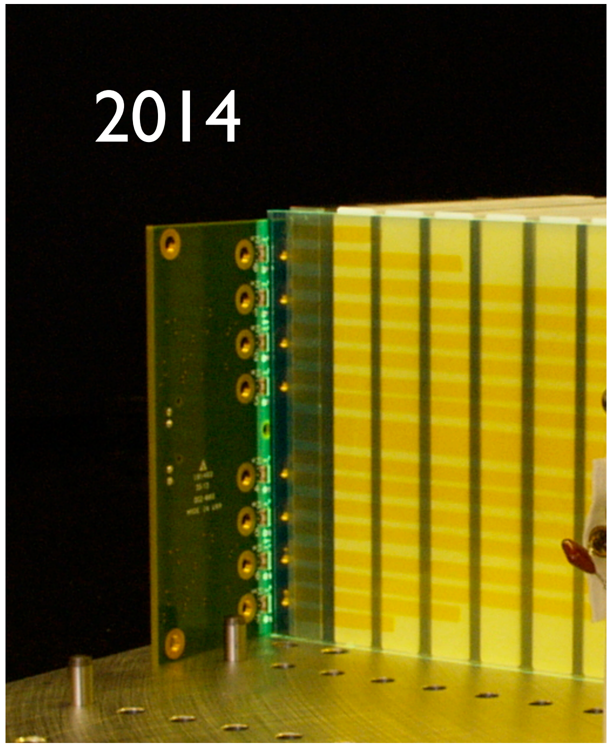
To Be Continued

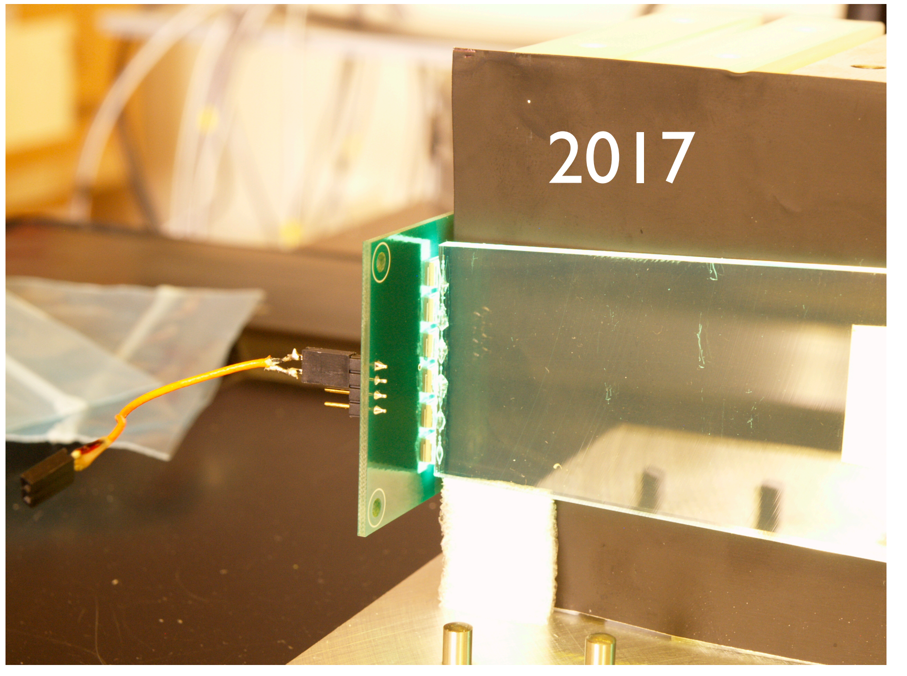
- These results are by-product of other measurements we did with these setups in Run17.
- Obviously, having fully characterised sensors before exposure will help to pin down things like change in Vbd.
- Will tape characterised sensors to the beam pipe during Run18.
- Investigate 'active' annealing schemes.

Backup Slides

Extra Slides, if we'll have time.

Re-designed, cheaper version of Hcal (Mixed Light, Increased LY, Decreased # of SiPMs)





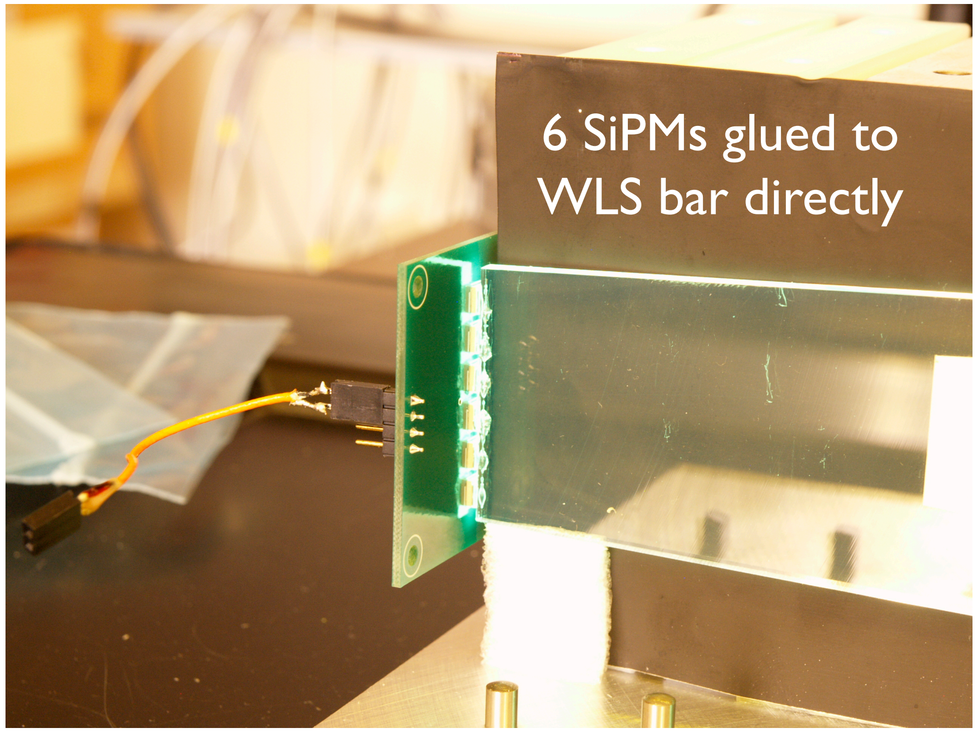
- Compared S8664-55 APDs with S12572-025P SiPMs. Exposed (Run17) and unexposed sensors.
- Found better S/N with SiPM readout version.
- With CMS/PANDA type APD sensors, performance may be close to what observed with SiPMs.

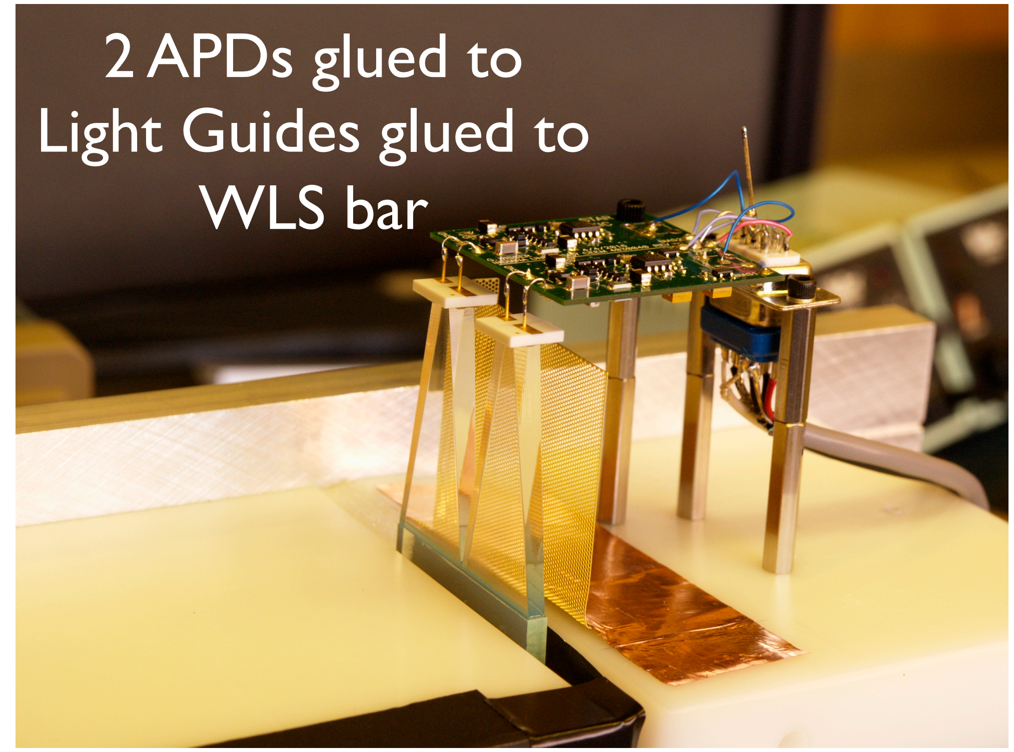
Light Collection Scheme for updated HCAL compare to HCAL version of2014:

- In 2014 we had 64 tiles (total thickness 160 mm), LY was 130 p.e./GeV with 8 SiPMs per tower.
- In 2017, there are 35 tiles (total thickness 105 mm), LY is ~ 270 p.e./MIP (MC, MIP is close to 1 GeV) with 6 SiPMs per tower.
- Light Collection efficiency significantly improved due to taper in WLS (focusing) and removing of compensation filter between Sc. Tiles and WLS bar which we had in 2014.

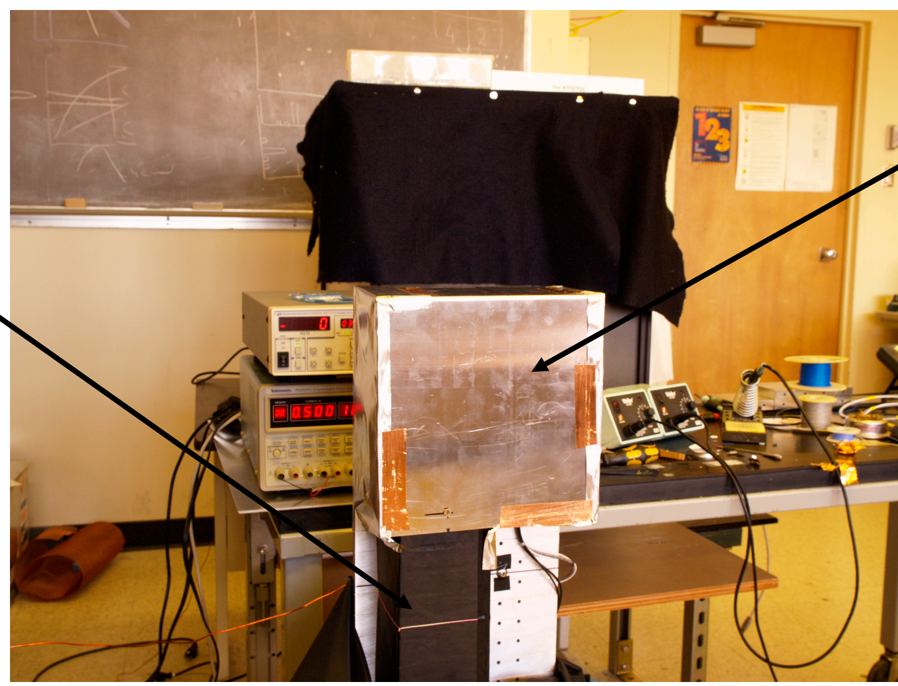
For sampling calorimeters at EIC.
Stick with SiPM readout, simpler and cheaper implementation.

Setup

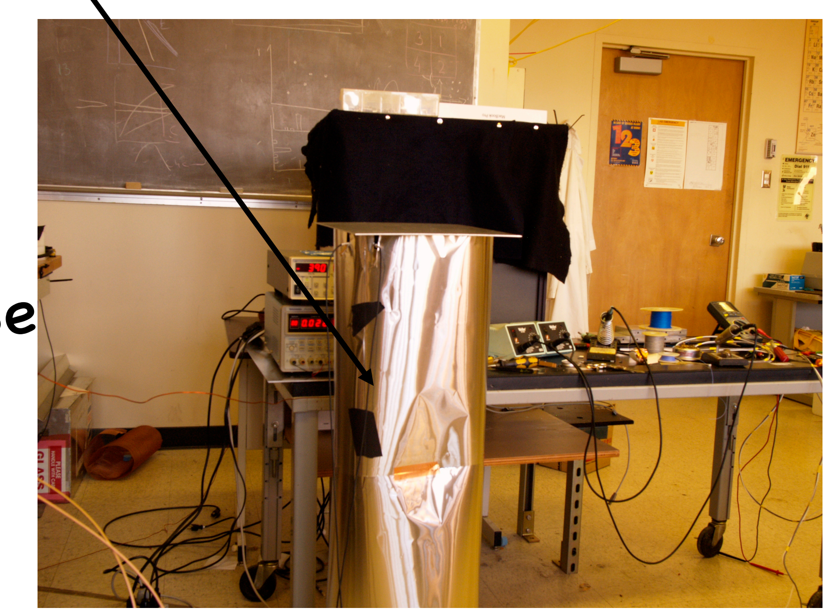




Hcal Tower

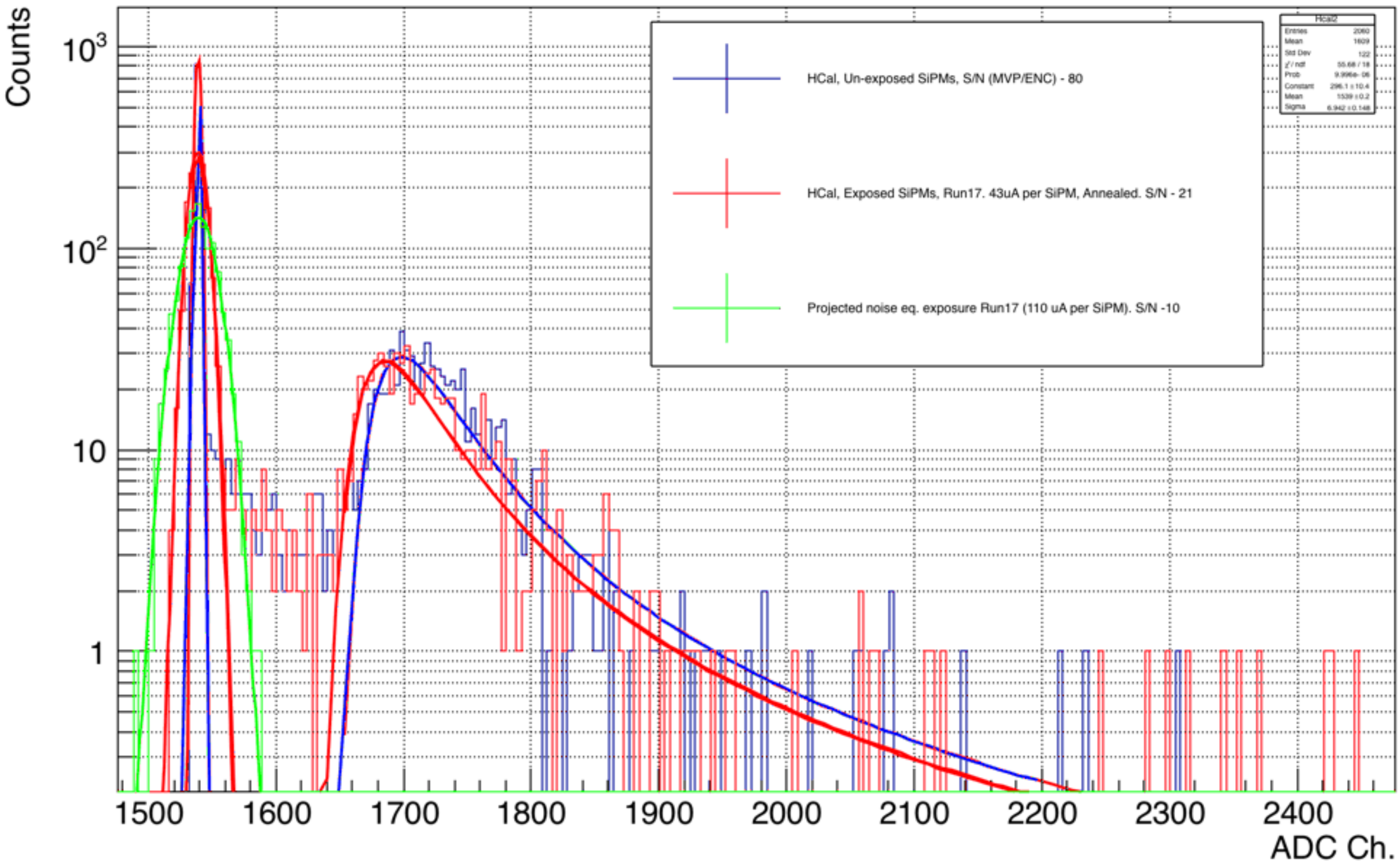


Shielding



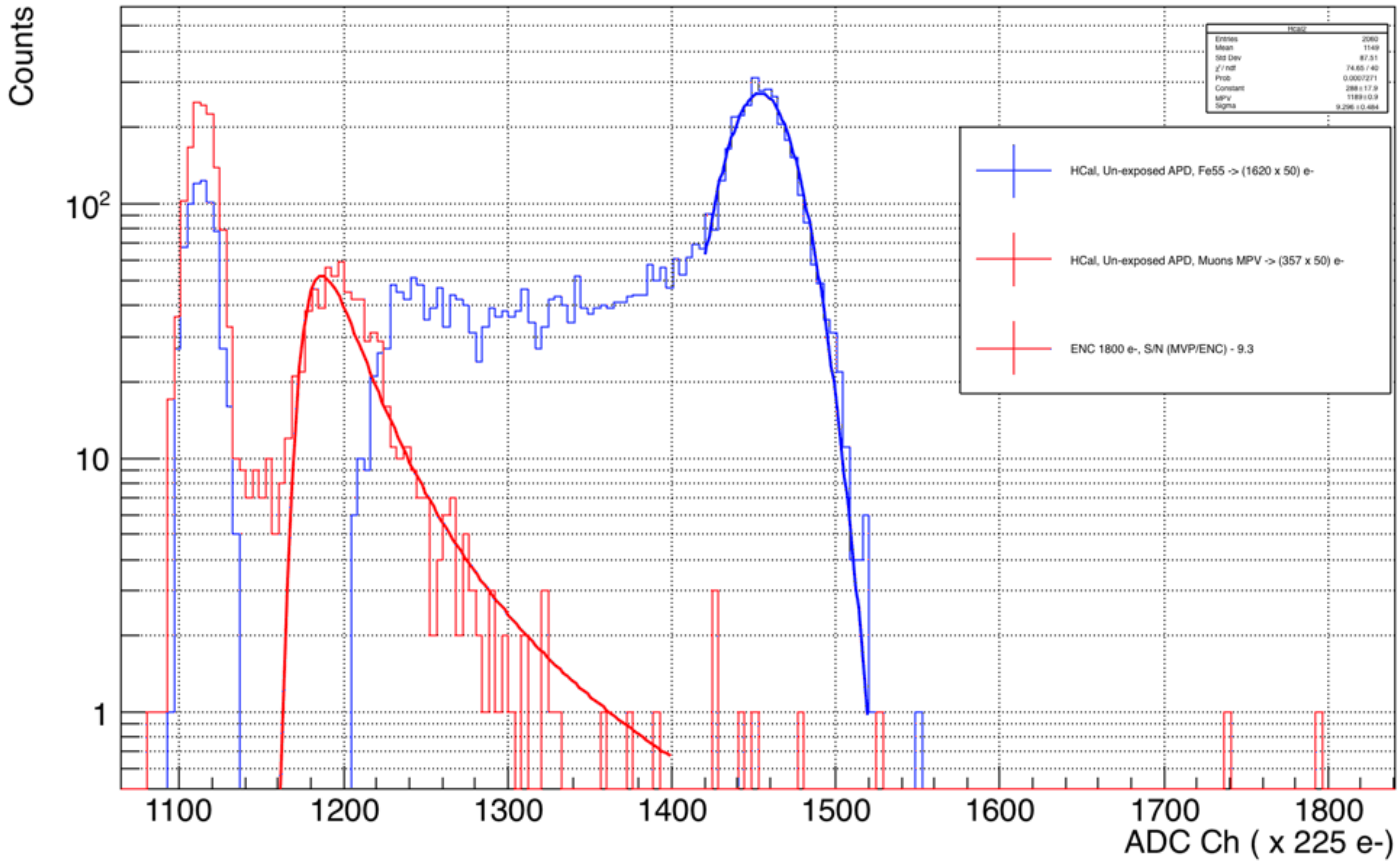
APDs readout required 'extensive' shielding to handle noise pickup. Essentially it was a double Farady cage, which was not required for SiPMs version of readout.

HCal, Muons with Exposed and Un-exposed SiPMs



Shift in MIP peak position may be due to mis-alignment of readout board during gluing to WLS , or degradation of SiPMs response after exposure as reported earlier. S/N somewhat arbitrary, i.e S means MPV for Landau. N – sigma of pedestal peak. (Excess noise due to degradation of SiPMs ~ 100 MeV/tower)

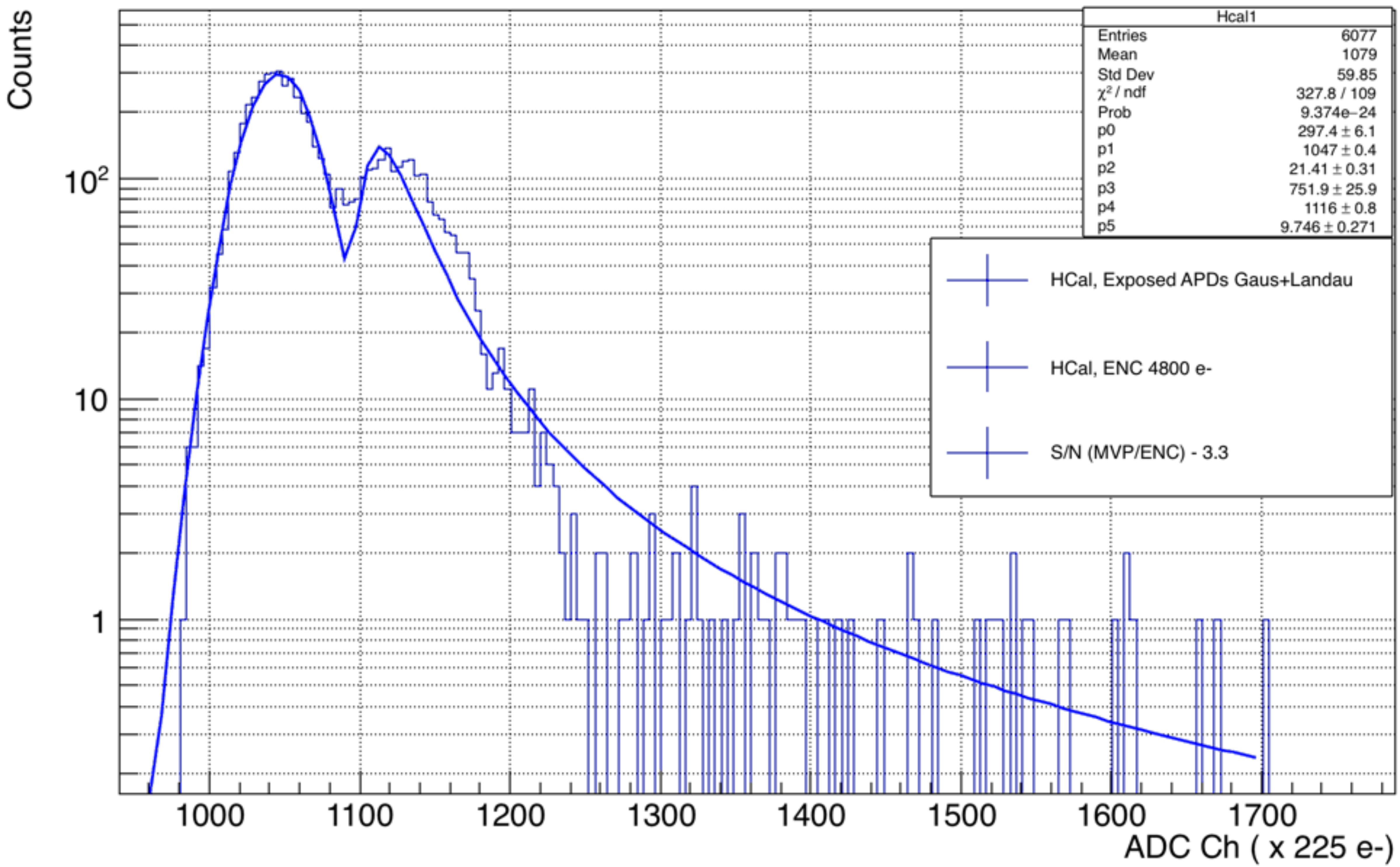
HCal, Muons with Un-exposed APDs (per APD)



- Calibrated with Fe55, 1620 primary e- from 5.9 keV
- For un-exposed APDs, ENC is 1800 e-
- S/N is about the same as for exposed SiPMs

With modified APDs (14 x 3 mm^2, coupled directly to WLS), potentially S/N may reach 20 or so. But, this depends on shaping time for preamp.

HCAL Muons, Run 17 Exposed APDs

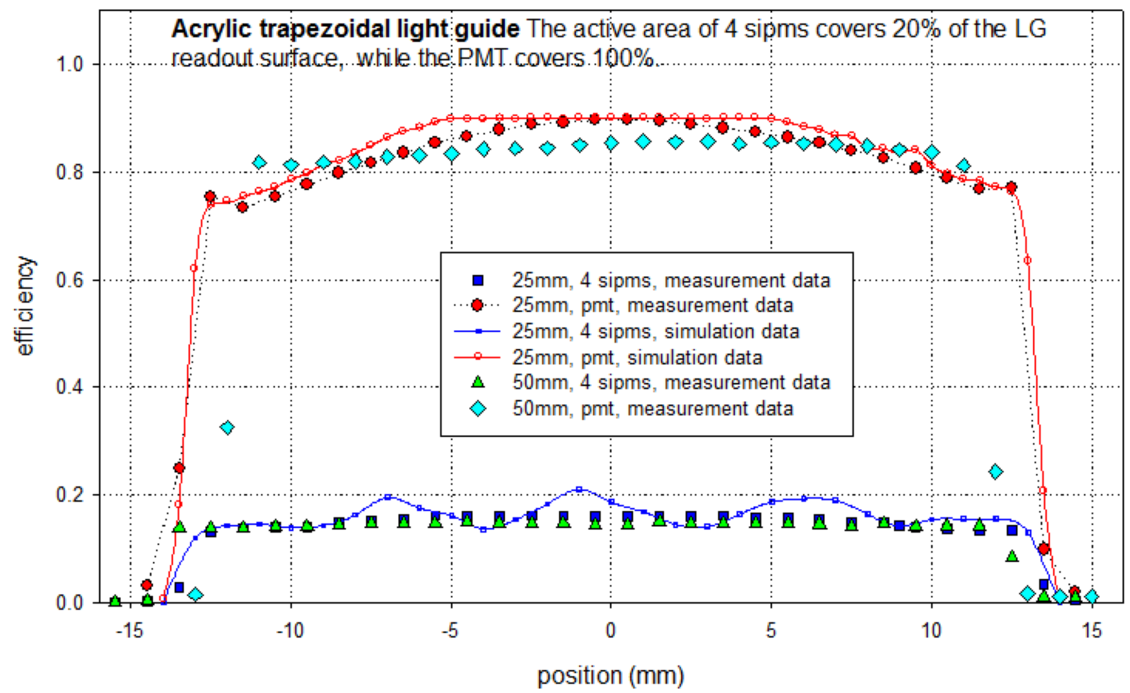


- Significantly degraded performance.
- Modification of APDs to CMS/PANDA type will improve noise, as perimeter groove significantly cuts surface leakage current.
- Potentially S/N may reach to what we have with SiPMs., with optimized sensors.

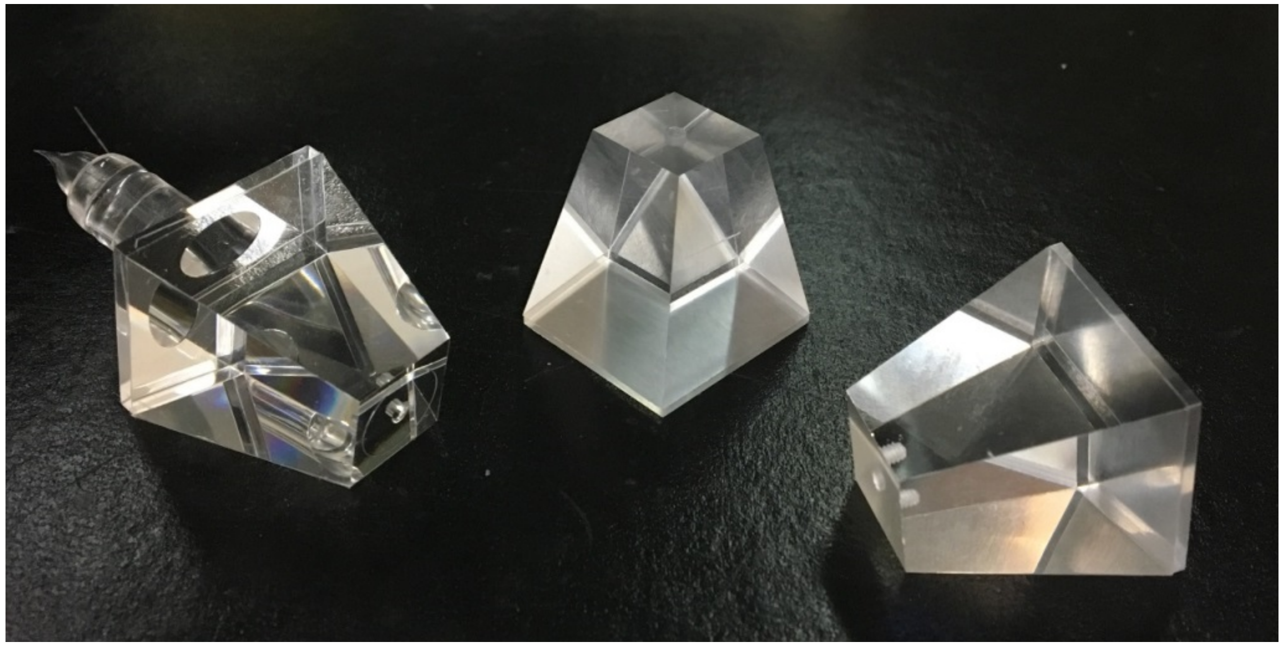
Light Guides

Need to achieve good uniformity in a very short light (1") guide due to space constraints inside sPHENIX magnet and find a cost effective way for manufacturing 25K of them.

Solution was an injection molded light guide with an optical quality mold

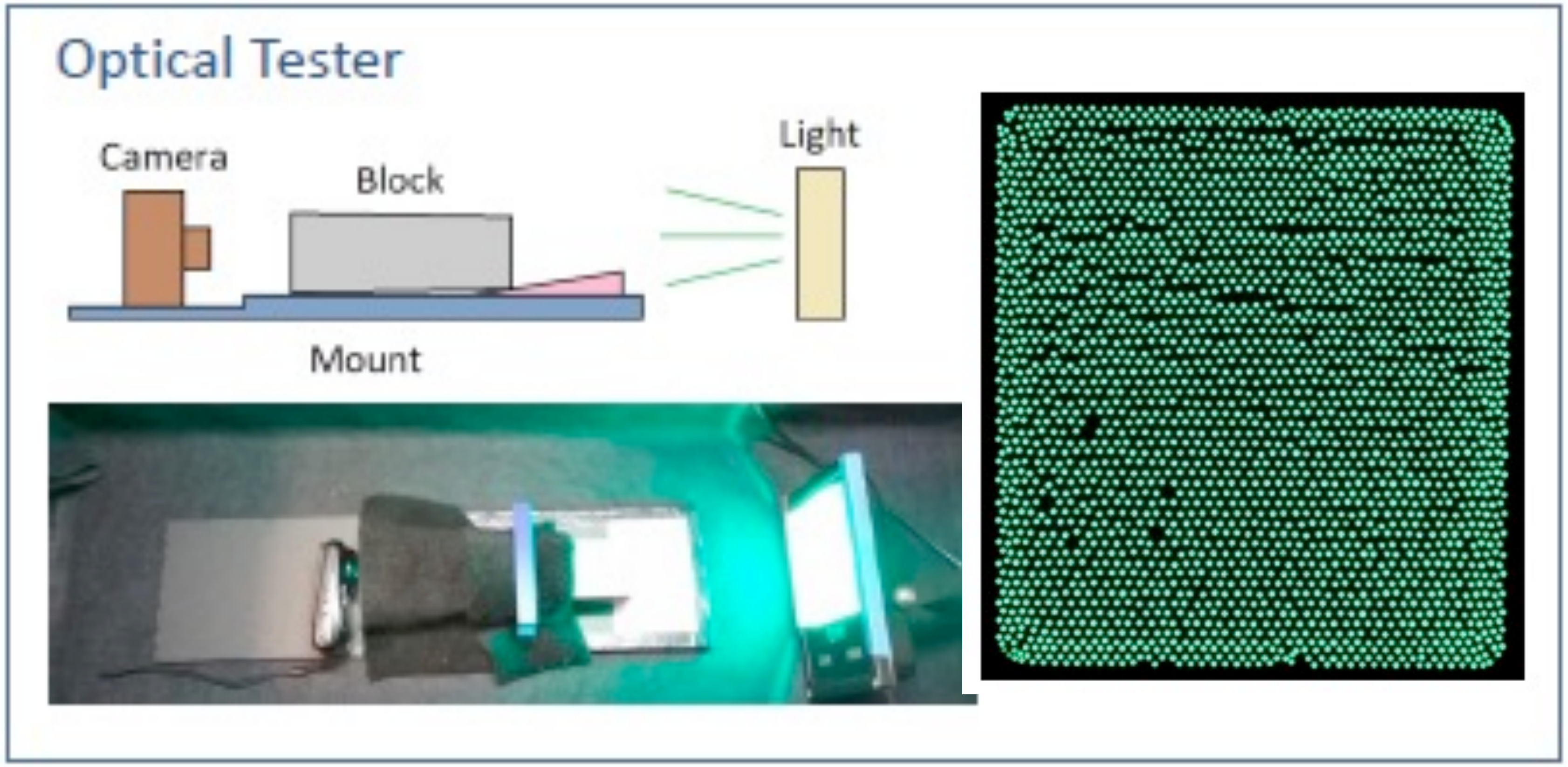


Simple trapezoidal light guide gave best overall results in terms of light collection efficiency and uniformity and was the simplest to manufacture



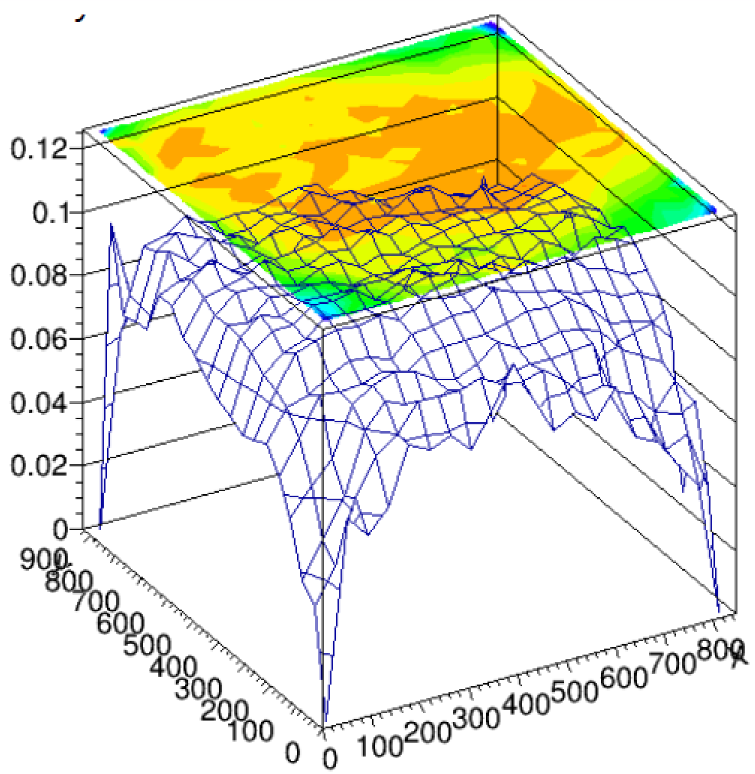
Injection molded light guides manufactured by NN, Inc. (Precision Engineering Products) in Providence, RI

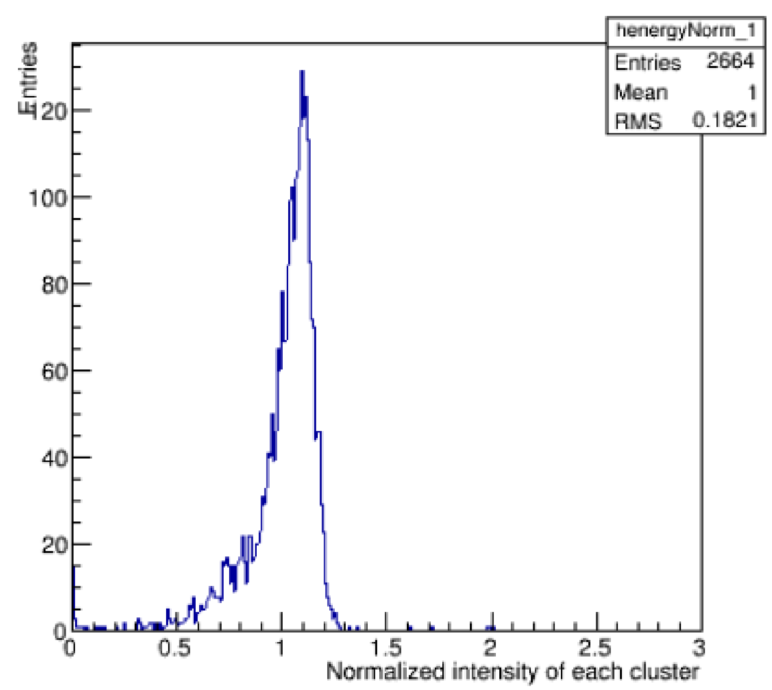
Quality Assurance Testing of Blocks. Work in progress.



Optical scanner measures light transmission of each fiber in a block

Determines the number of fibers with light output above certain threshold and compares to a reference





Density (> 9.5 g/cm^3) and mechanical tolerances (typ ± . 010”) are also checked

sPHENIX, Publications in 2017-2018

- "Design and Beam Test Results for the sPHENIX Electromagnetic and Hadronic Calorimeter Prototypes", revised after its first review and resubmitted to IEEE TNS in September 2017. Currently waiting final review and approval for publication.
- "Test Beam Results and Status of the sPHENIX Calorimeter System", submitted to the Conference Record for the 2017 IEEE NSS/MIC in November 2017 (talk given by M.Connors at conference)
- "Light Collection Efficiency and Uniformity of Light Guides for the sPHENIX Electromagnetic Calorimeter", submitted to the Conference Record for the 2017 IEEE NSS/MIC in November 2017 (talk given by S.Stoll at conference).
- "Design and Performance of the Readout Electronics for the sPHENIX Calorimeters", submitted to the Conference Record for the 2017 IEEE NSS/MIC in November 2017 (talk given by E.Mannel at conference).
- "Results of the Effects of Neutron and Gamma Ray Irradiation on Silicon Photomultipliers", is currently in preparation and will be submitted to IEEE TNS in early 2018.