SiPM in Forward ECal.

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SiPM Final Design Review

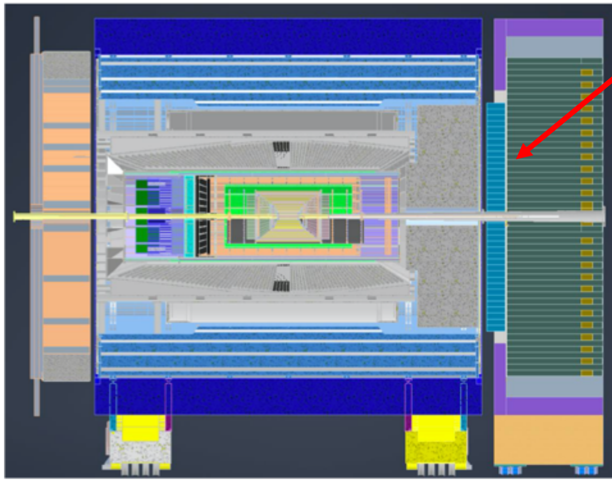
Sep 14, 2023

Electron-Ion Collider

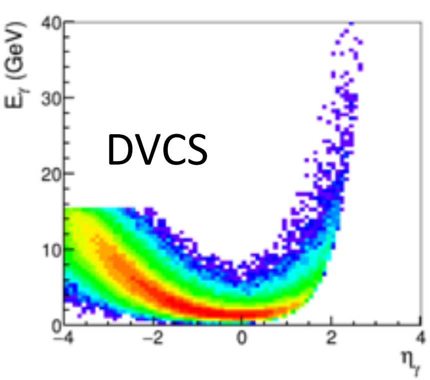
Outline

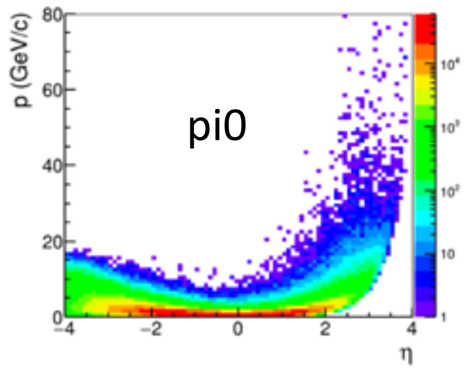
- High Level Summary of Scope.
- Dynamic Range, Active Area
- Radiation damages and effects.
- Some results from EIC R&D.
- QA, Production plan and Workforce.
- SIPM specs.
- Summary.

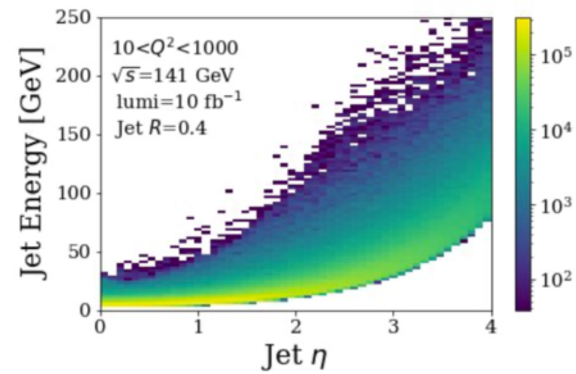
High Level Summary of Scope



- Forward ECal is part of a Hadron Endcap
- Covers pseudo rapidity range ~1.4 to 3.5 (R_{in} 30 cm, R_{out} 170 cm)*
- Integration length along Z - 30 cm (very compact)
- Number of readout channels ~16k (high granularity)
- Photosensors – SiPMs 4 per tower, ~64k total.







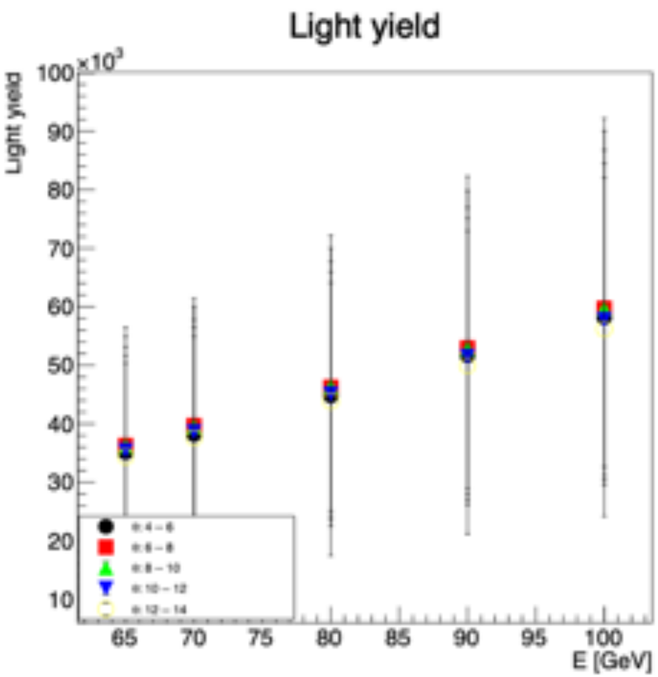
High Level Input

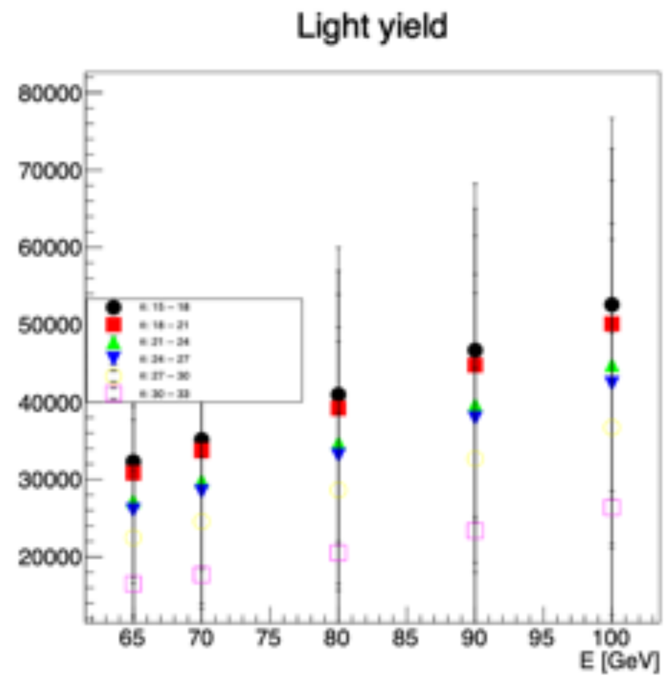
- Yellow Report – desired energy resolution 10%-12%/√(E) ⊕ 2%
- Yellow Report – good pi0/gamma discrimination up to ~ 50 GeV
- Optimal reconstruction of jets (ECal +Hcal (+ tracker))
- Readout must work in magnetic field, neutron fluxes up to 10^{11} n/cm^2.
- ECal must fit in limited space. (compact readout)

Dynamic Range

- Yellow Report requirement – energy range 0.1 GeV – 100 GeV

1. min energy in a single tower 15 MeV – max energy in a single tower ~ 90 GeV
2. Assuming Light Yield ~ 1000 p.e./GeV (next slides)
3. Signal range (pixels) 15 – 90 x 10^3





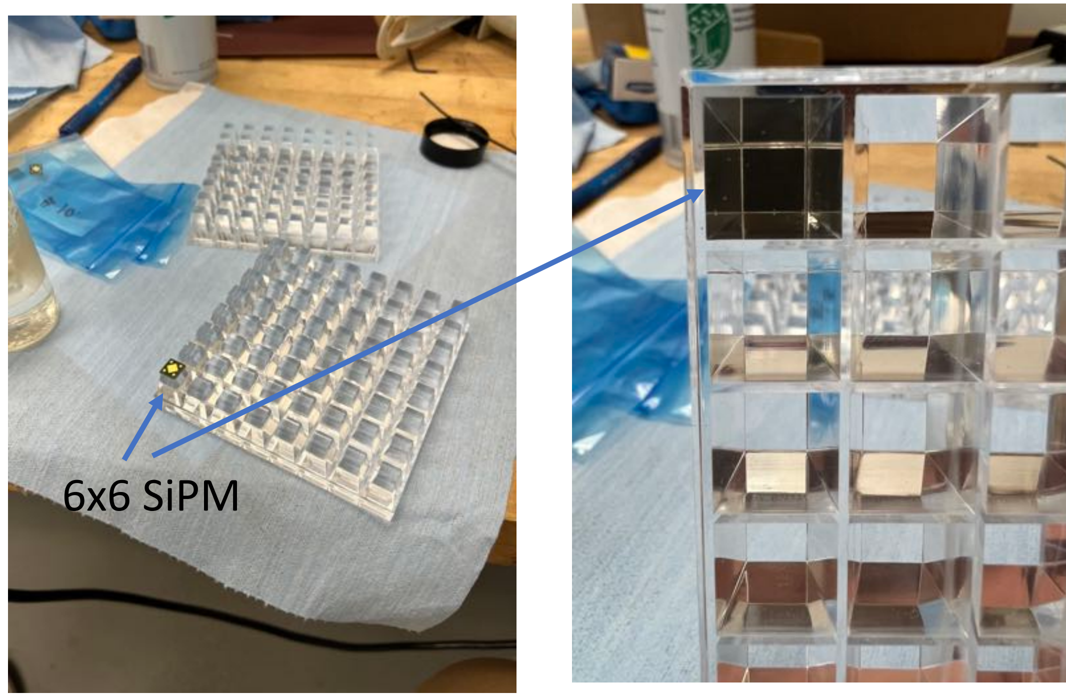
Pixel size 15 um
four 6x6 mm SiPMs per tower

~160K 15 um pixels per 6x6 SiPM,
~25% occupancy.

Signal range in a single fECal tower vs pseudorapidity. ePIC full simulation.
https://indico.bnl.gov/event/18437/contributions/73244/attachments/46022/77786/main.pdf

Active photosensor area

- Four 6 mm x 6 mm SiPMs per tower required to achieve Light Yield ~ 1000 p.e./GeV at low overvoltage* to have good S/N (explained in rad damages slide)



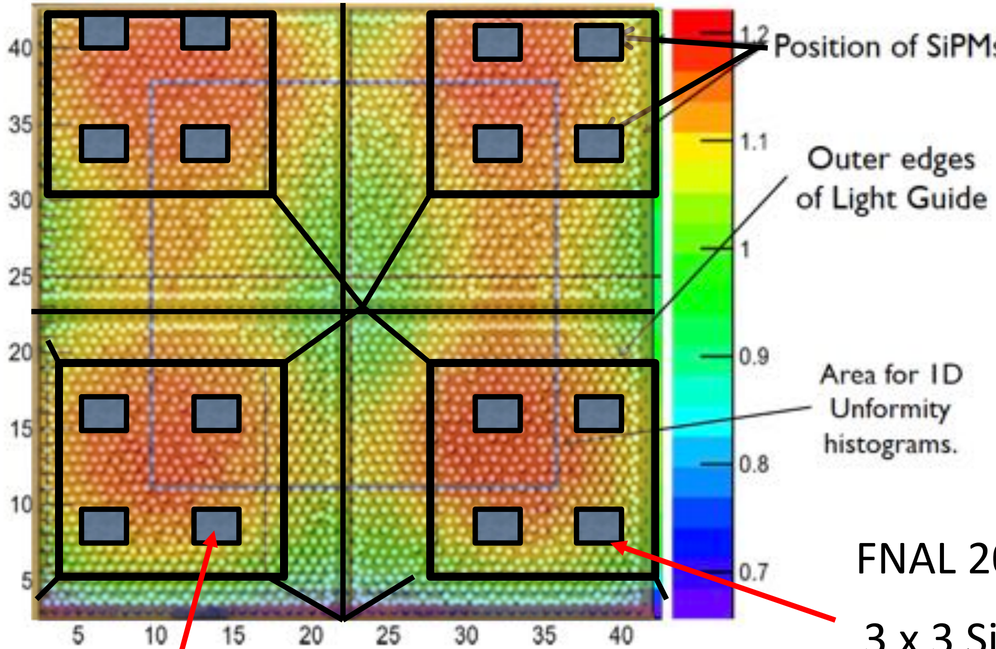
- New light guides – one per SiPM.
- Geometrical, 85% light collection efficiency, compared to 21%

Active photosensor area

Compact scheme (short light guide with four 3x3 SiPMs, which only partially covering output area of light guide) especially prone to be non-uniform.

6 x 6 mm² and re-designed light guides and pre-bunched sc. fibers aims to improve uniformity of light collection by ~ 4-5 times.

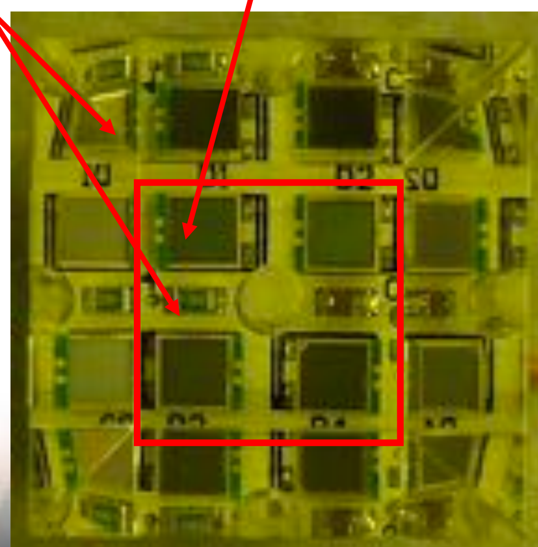
WScFi Superblock 2 x 2 towers, 4 SiPMs / tower, UV LED Map



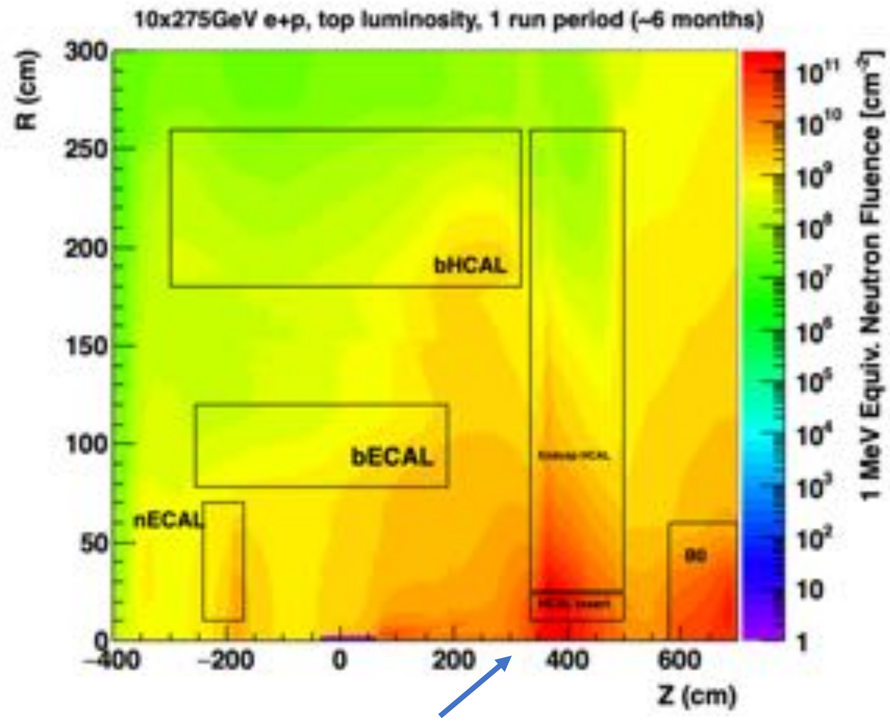
FNAL 2014

3 x 3 SiPMs

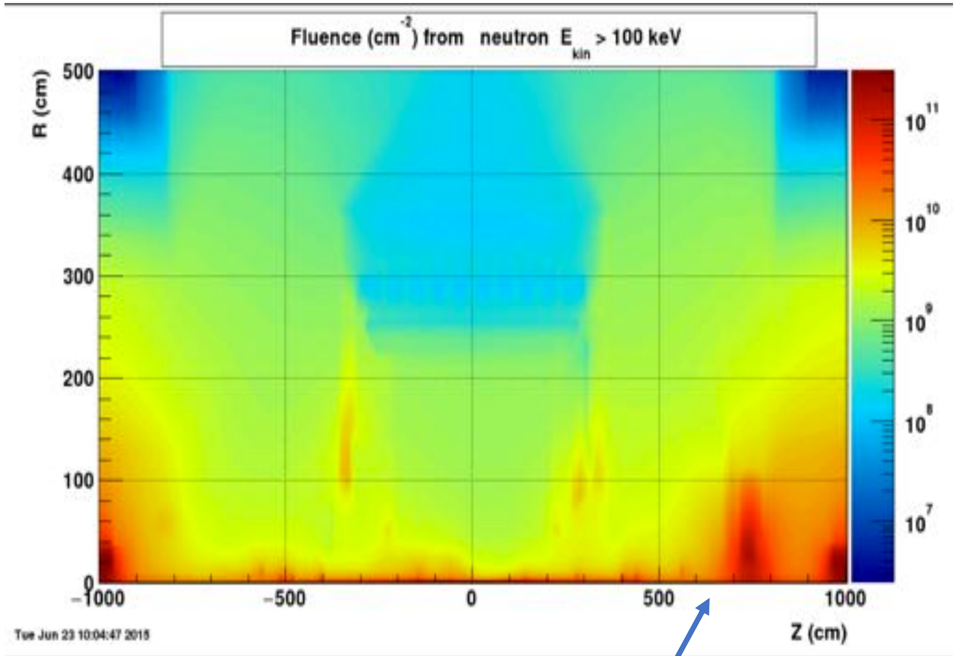
Losses



Radiation Damages and effects on performance of SiPMs



ePIC, fECal



STAR pp 500, Forward Calorimeter System (FCS). n fluxes measured, MC validated Y.Fisyak et.al. NIM A V756, 2014

Synergy between EIC R&D and STAR Forward Upgrade, since 2014 tests and use of SiPMs to readout STAR detectors in forward region. Conditions in terms of exposure very similar. -> projections for ePICs.

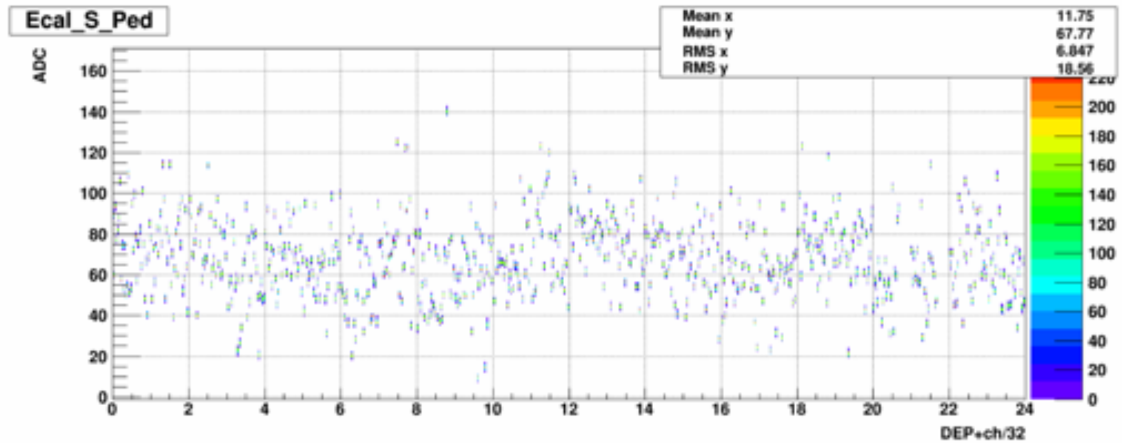
Radiation Damages and effects on performance of SiPMs

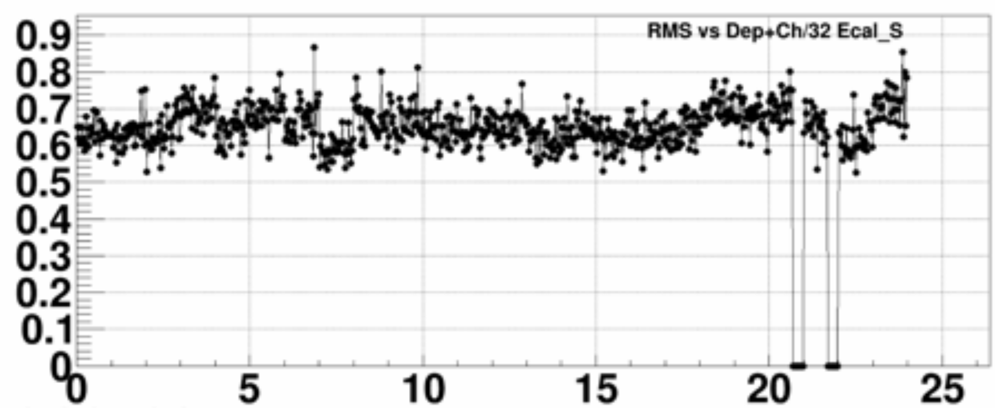
Projections for 10^{11} n/cm^2 exposure. Dark current ~ 14 uA/ mm^2 @ 2V overvoltage (as measured at STAR FCS)

Two effects:

1. Noise
2. Degradation of response due to localized heating of avalanche region (dark current)

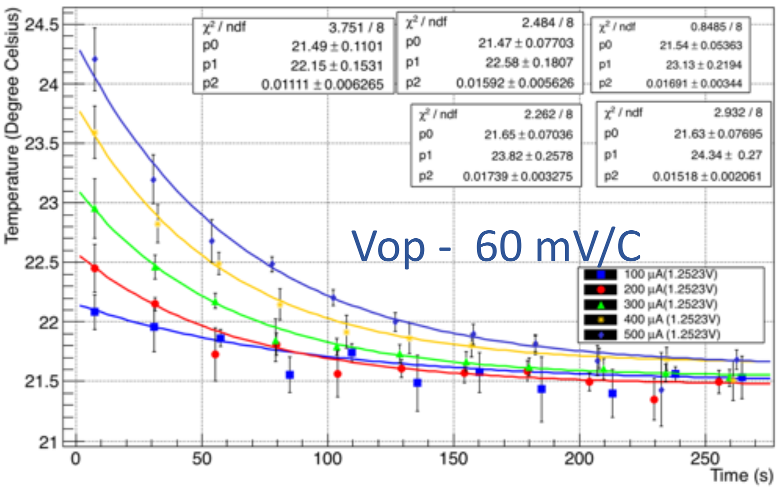
fECal expected highest noise 6 MeV (requirements on min. energy 15 MeV). Scaled from FCS.

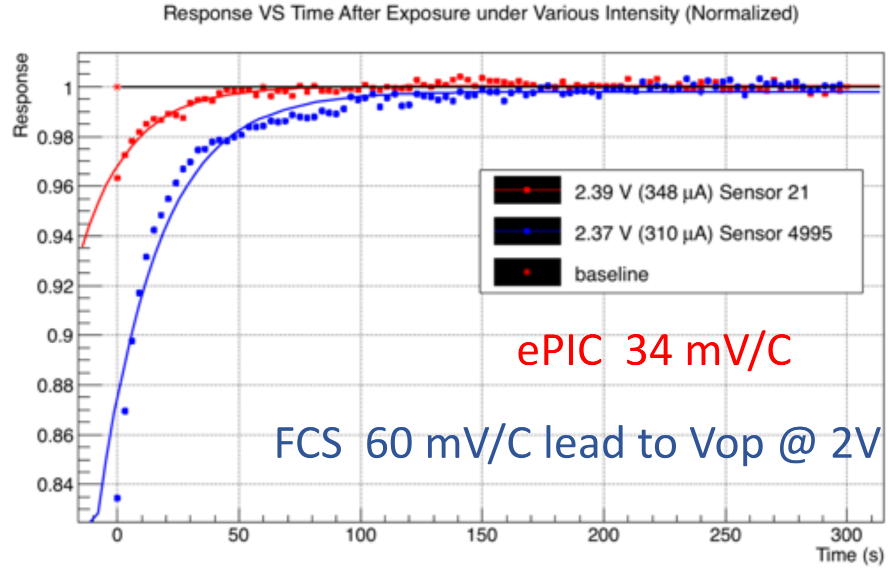


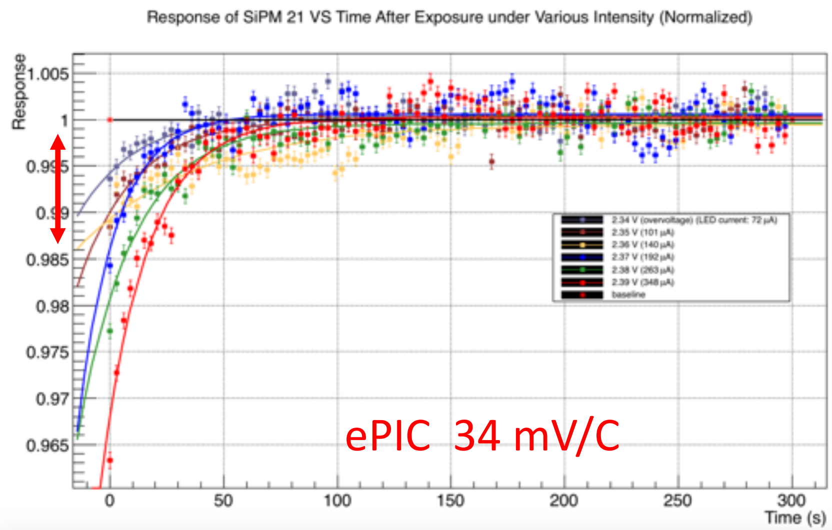


Noise 3 MeV, STAR FCS after ~ 10^{11} n/cm^2

Radiation Damages and effects on performance of SiPMs (past EIC + STAR R&D)







Combination of leakage current (due to radiation damages) and signal current from calorimeter light heats junction of the sensors, which leads to increase in Vbd, which leads to degradation of response.

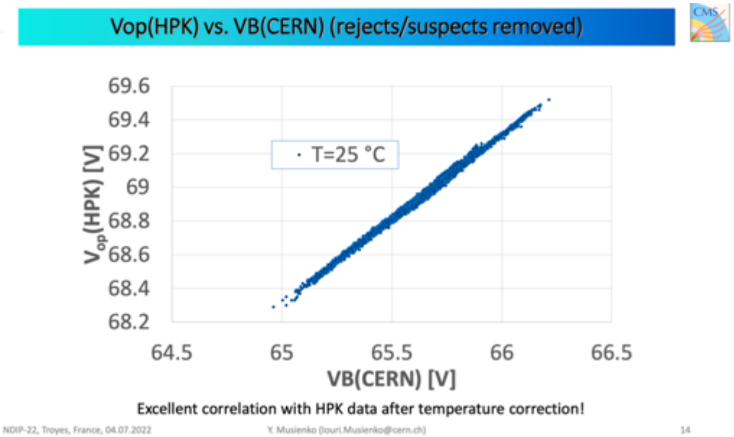
Differential degradation (variation from sensors to sensors) probably is due to different overvoltage required to achieve same response.

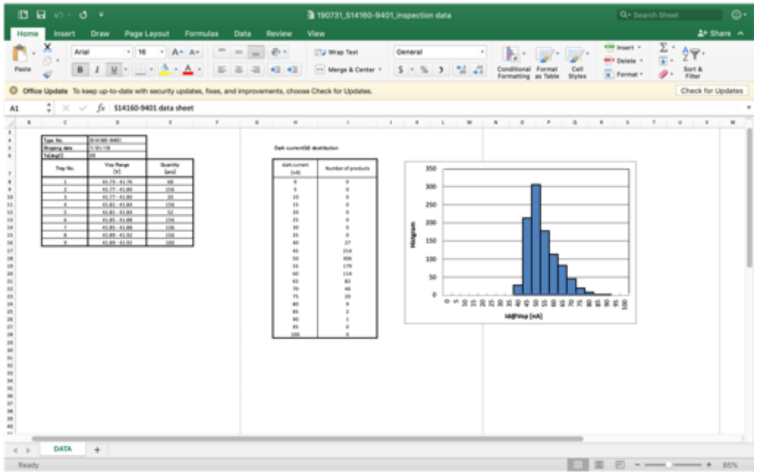
Temperature dependence of Vop < 40 mV/C is sufficient for fECal to keep response degradation < 1%.

Ordering SiPMs

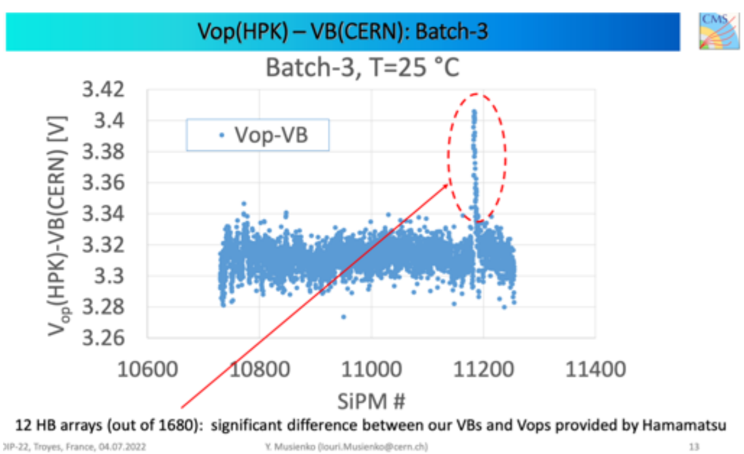
- STAR FCS, sPHENIX barrel ecal ordered ~ 110 k S12572-025P with a requirement HPK sort SiPMs on Vop+- 20 mV, grouping x4 per tray.
- Reason was to eliminate handling of individual chips before SiPM currying board assembled (reliability). SiPMs mounted to bards from HPK trays.
- For fECal, in addition, requirements on constant term is very stringent. There are many factors. Sorting of SiPMs by HPK same way it was done for FCS is the easiest way to make contribution from SiPM Vop variation negligibly small to constant term in energy resolution.
- HPK data on Vop highly reliable, confirmed by GLUEX, STAR, sPHENIX, CMS calorimeters constructions. (next slide)

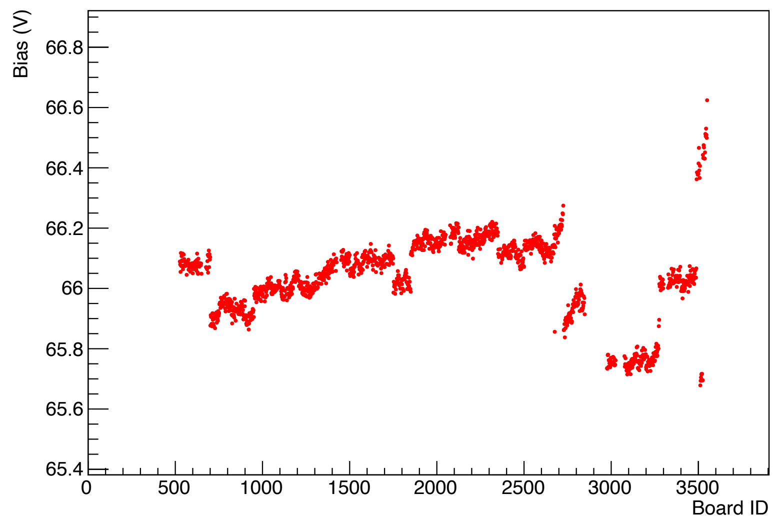
Ordering SiPMs cont.





STAR FCS ECal SiPM Boards





STAR FCS SiPM Board calibration data
Good correlation with HPK data.

Some facts working with SiPMs

STAR FCS – out of ~2100 assembled SiPM boards for ECal and HCal:

- no testing of individual SiPMs
- rejected during calibrations – 0
- one board failed immediately after installation on detector, likely bad soldering.
- failed during two years of operation – 0

Similar stats for GLUEX and CMS HCal (per verbal communications).

During ~ 10 years long R&D for STAR and EIC we did not run into a single bad SiPM from HPK.

For fECal we suggest to order minimal amount of SiPMs beyond needed on the detector, these will be used for 'first article' large area fECal prototype, which will be tested in FY2025.

Production plan, QA, manpower.

- Following STAR FCS path, we will use same approach to produce and test/calibrate SiPM boards for fECAL
- Boards will be made at UCLA electronics shop (STAR FCS), or in industry (like sPHENIX).
- QA/calibration. Semi-automated test stand to measure IV for each board -> derive Vop (same as for FCS). IV scan is a simple, reliable test. As was demonstrated by CMS it may help to identify SiPM board which may fail after ‘extreme’ irradiation (Y. Musienko)
- All QA/calibrations will be performed by members of UC EIC consortium (UCLA, UCR).

Specs for SiPMs for fECal.

	Parameter	Specs	Notes
1	Active area	6 mm x 6 mm	Dynamic range, Unformity of Light Collection
2	Pixel Size	15 um or 20 um	Dynamic Range
3	Package type	Surface mount	Compactness
4	Peak Sensitivity	Max PDE at ~ 450 nm	Matching Sc fibers spectra
5	PDE	>30%	@ 3V overvoltage, Vop due to radiatic
6	Gain	~$2x 10^5$	@ 3V overvoltage
7	DCR	< 3000 kcps	@ 25C, 0.5 PE threshold, @3V overvol
8	Temperature coefficient of Vop	< 40 mV/C	Uniformity of Light Collection
9	Direct crosstalk probability	< 1%	Radiation, dark current
10	Terminal capacity	< 2nF	Front End electronics
11	Packing granularity	Multiple of 4 per tray	Uniformity of light collection
12	Vop variation within a tray	+/- 0.02V	Uniformity of light collection

Summary

- Specs for SiPMs for fECal are well defined.
- Effects of radiation damages are well understood during ~ 10 years of R&Ds and operation of calorimeters readout with SiPMs at STAR. Aided by GLUEX, sPHENIX and CMS experiences.
- Production plan and QA will follow well established protocols used for STAR FCS.
- Workforce is experienced in executing large scale projects (including recently built forward calorimetry systems for STAR).
- Participating Institutions has extensive capabilities to carry large scale construction projects.

Backup Slides