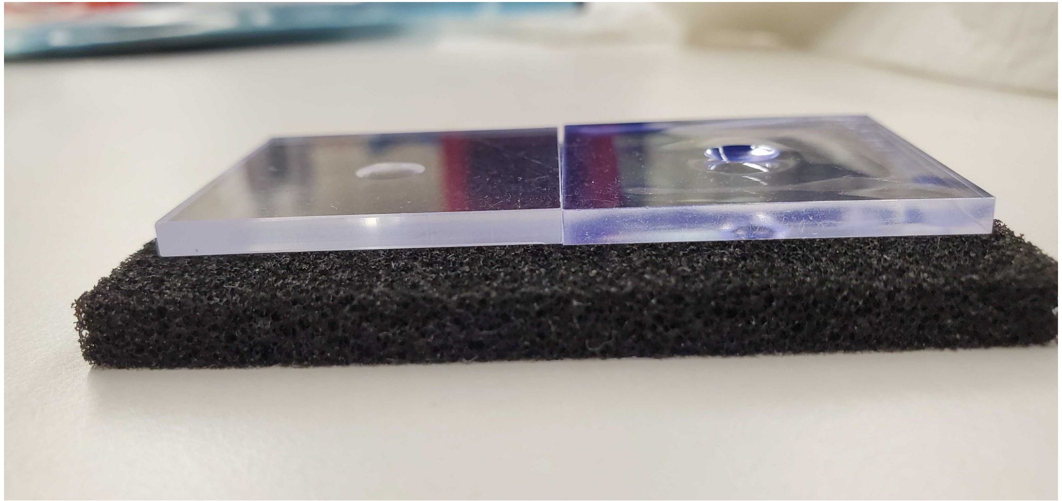
Light yield studies of SiPM-on-tile cells made with injection molding technique

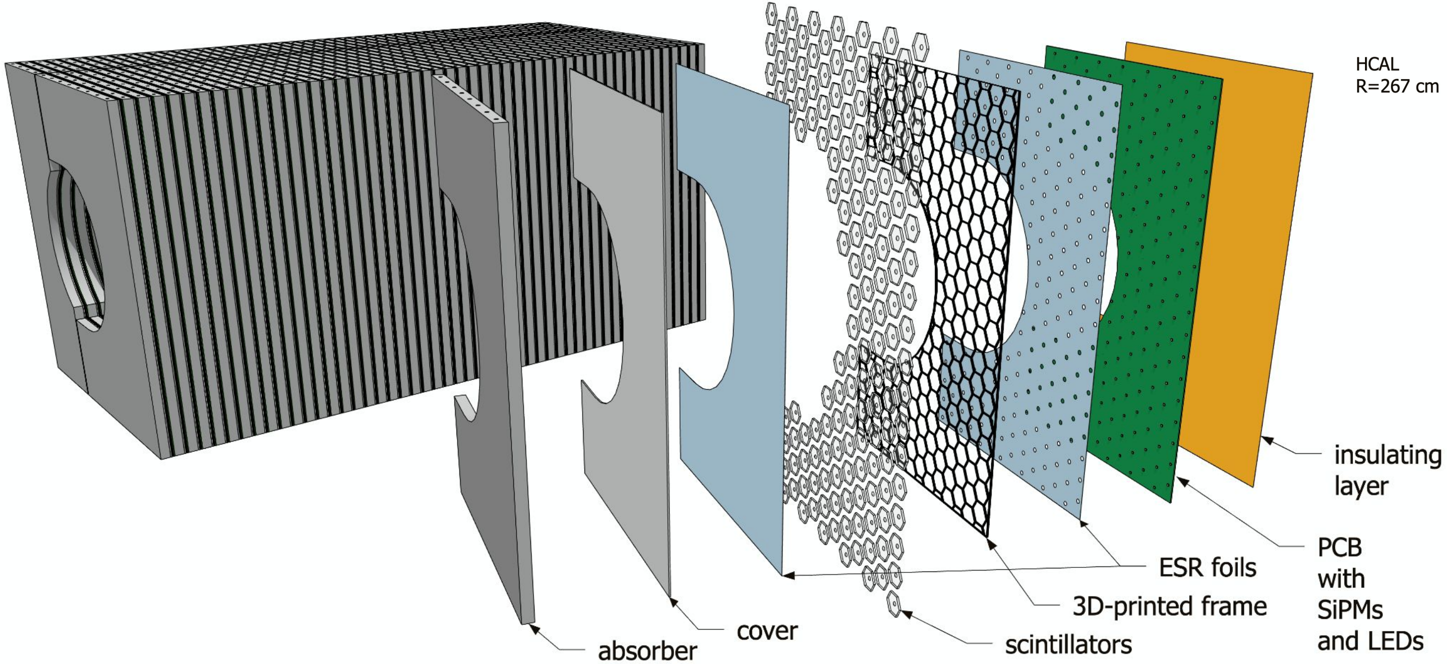
Miguel Arratia

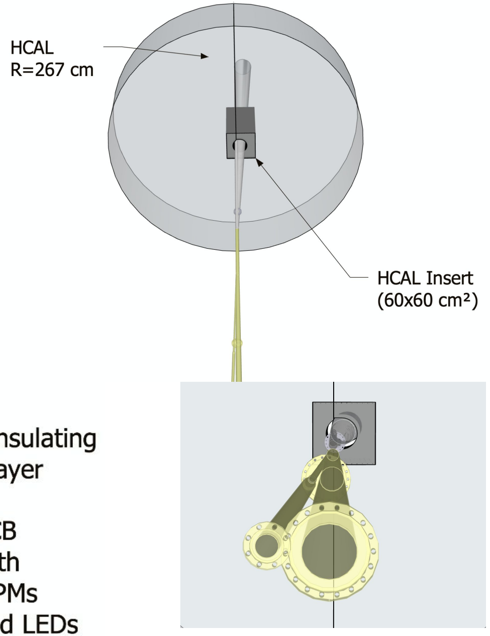
UC RIVERSIDE



The Calorimeter Insert for ePIC

More details in:
https://arxiv.org/abs/2208.05472
https://arxiv.org/abs/2302.03646





Optimal acceptance with high-granularity to cover 3<η<4 range (poor tracking)
- To improve acceptance for jets and inclusive DIS reco via event transverse-momentum
- Tag beam-induced backgrounds with topology
- To ensure SiPMs and scintillator remain easily accessible for repair/maintenance & upgrades

The ePIC Insert has a similar motivation to HERA Inserts

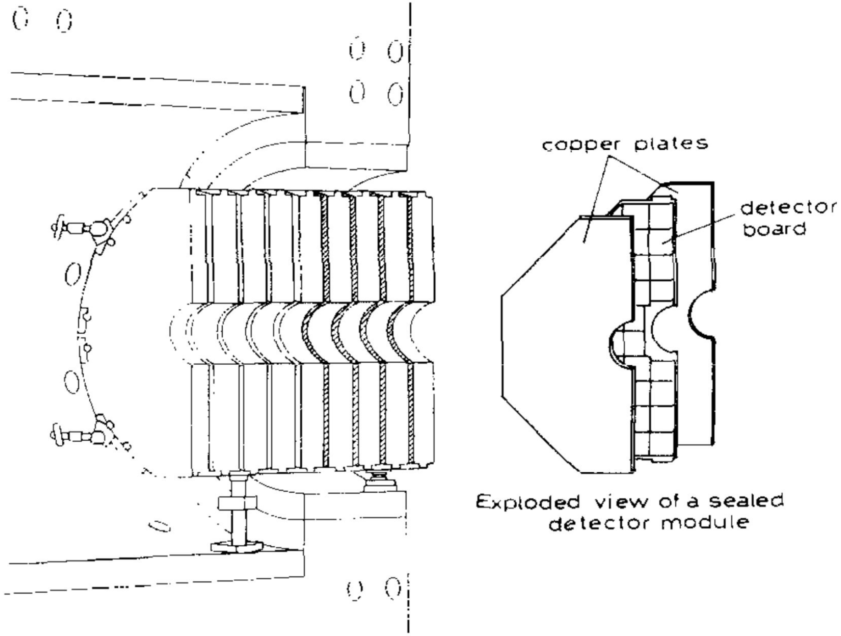


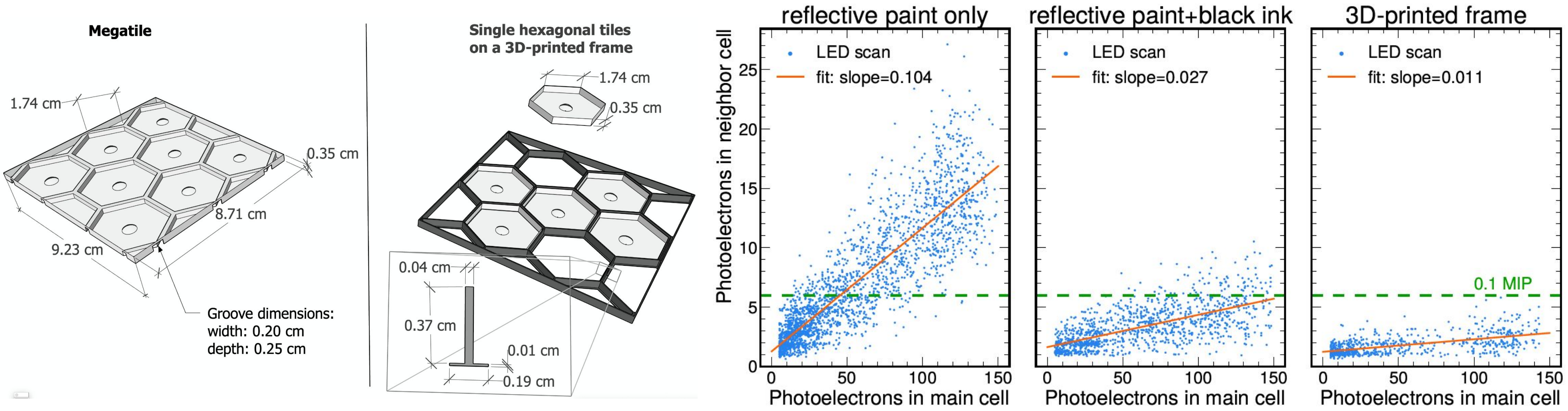
Fig. 35. Cross sectional view of the PLUG calorimeter.

*"Its main task is to **minimise the missing part of the total transverse momentum** due to hadrons emitted close to the beam pipe. In addition the energy, emitted into a narrow cone around the beam pipe can be used **to separate the proton jet** as well as **to veto beam gas and beam wall background**"*

H1 Collaboration, NIMA 386 (1997) 348-396

Motivation for injection-molded Cells for Insert

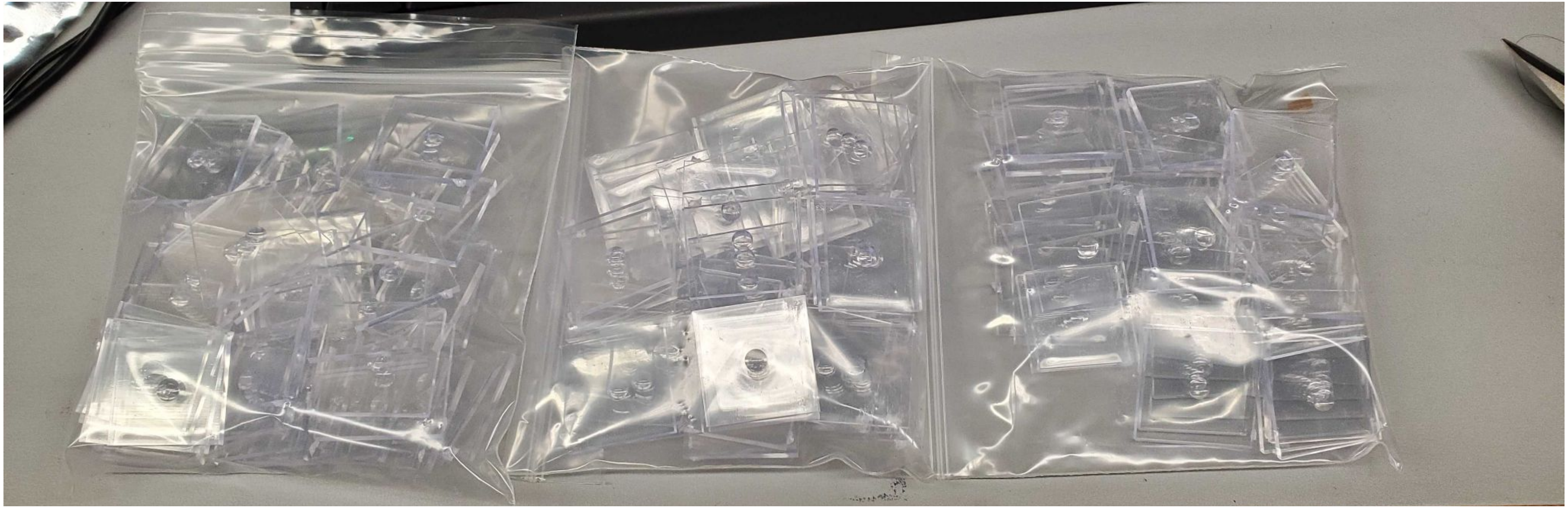
- In our most recent paper, we contrasted the "megatile" approach with an approach where separate, identical cells are placed in a plastic frame with ESR on top and bottom.
- The latter approach seems promising and is amenable to mass-production of cells with injection molding



https://arxiv.org/abs/2302.03646

Material: injected-molded cells courtesy of Fermilab

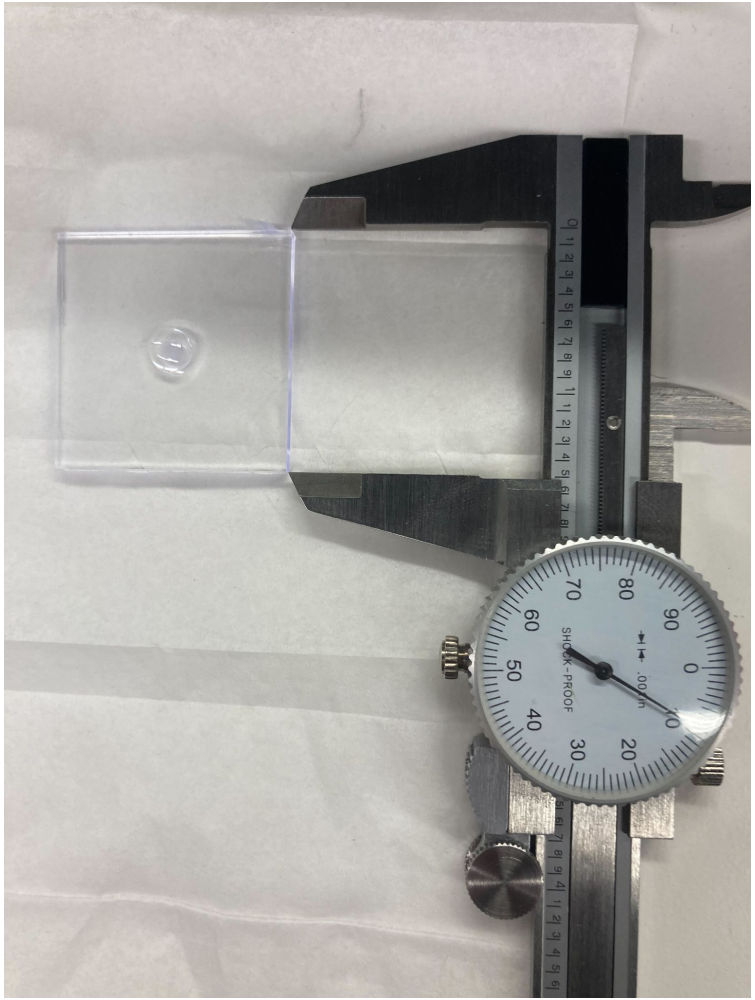
*Free as a beer. Model is ~3x3 cm2 square-ish (a couple of degree angle)



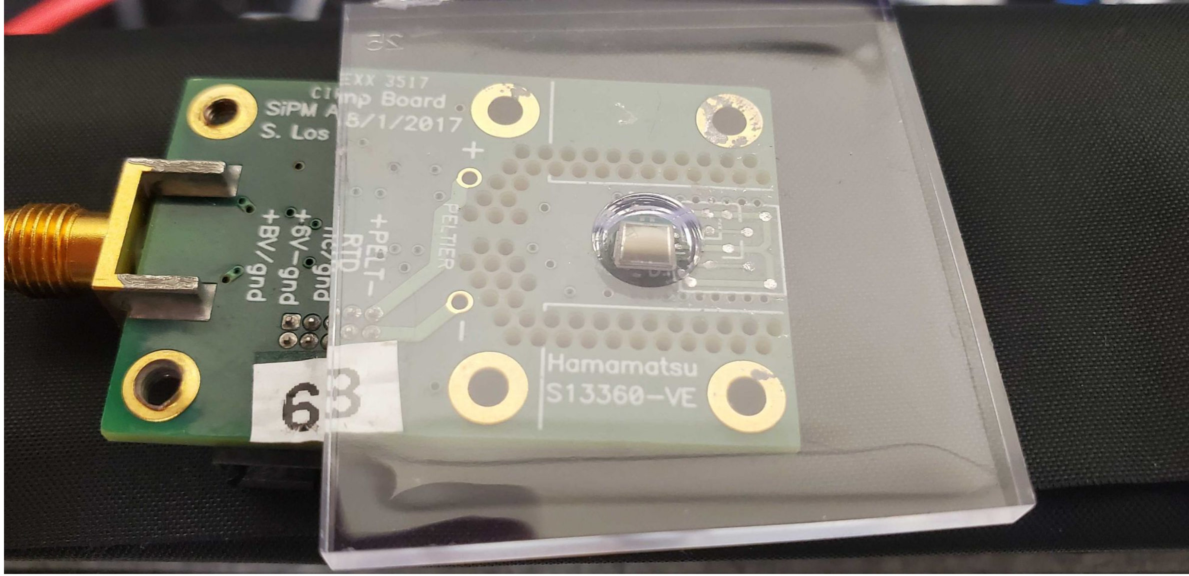
Cell dimensions

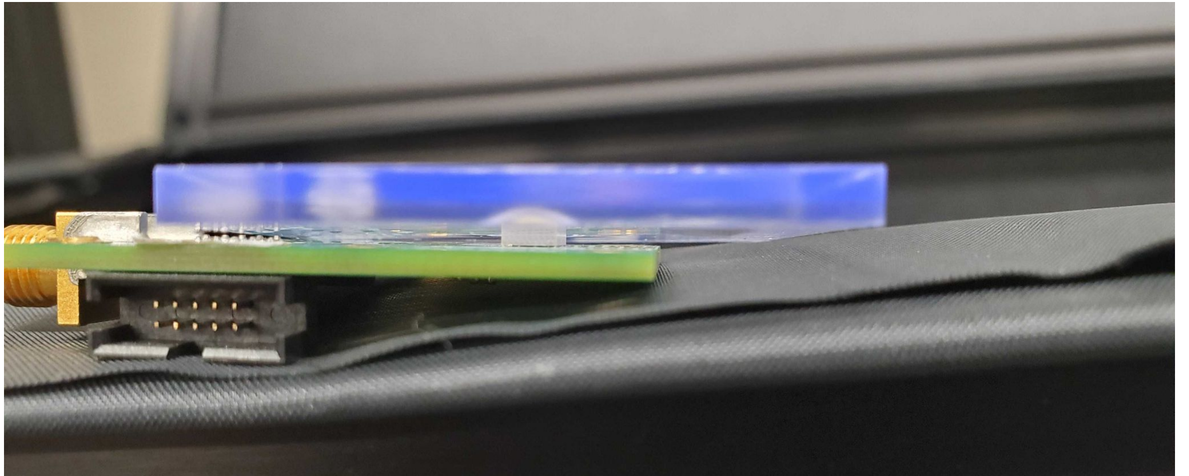
Roughly 3x3 cm2 cell.
In fact, it is not a square but has some angle (like to tessellate some big arc or something like that)

Very similar dimensions
to what we need for the Insert.



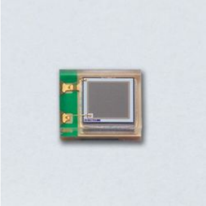
First issue we encountered:
3 mm SiPM does not quite fit the dimple.
It is not flushed with PCB.



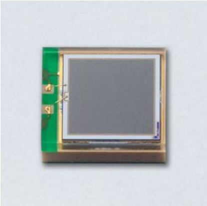


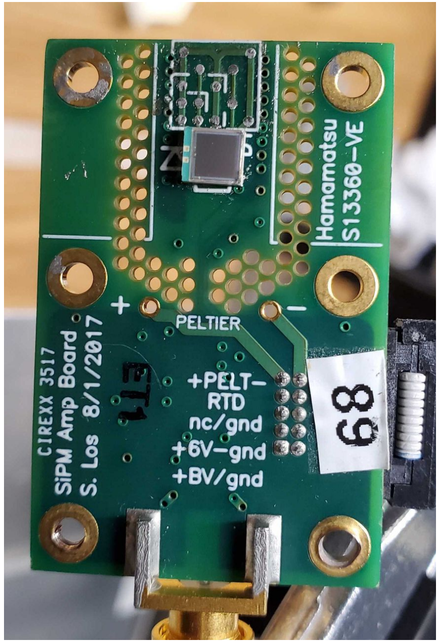
SiPMs models used

1.3 mm with 7,284 pixels
(S14160-1315PS)

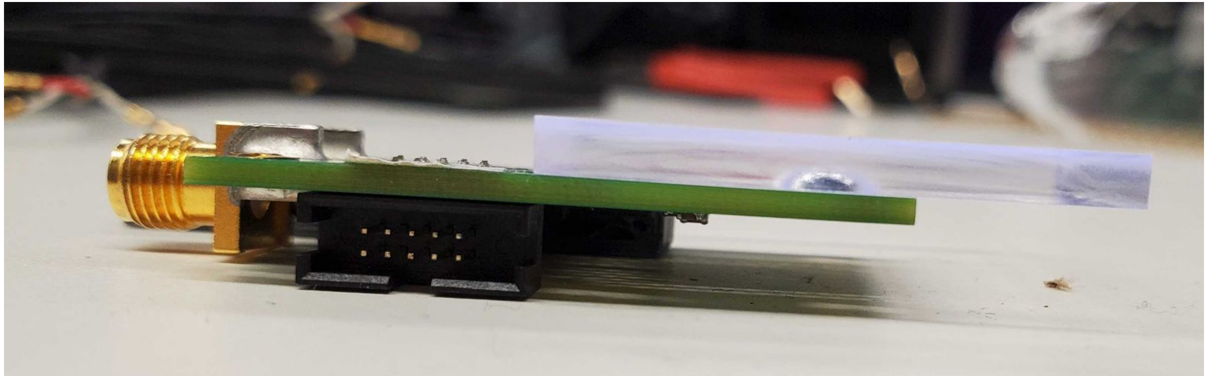


3 mm with 39,984 pixels
(S14160-3015PS)

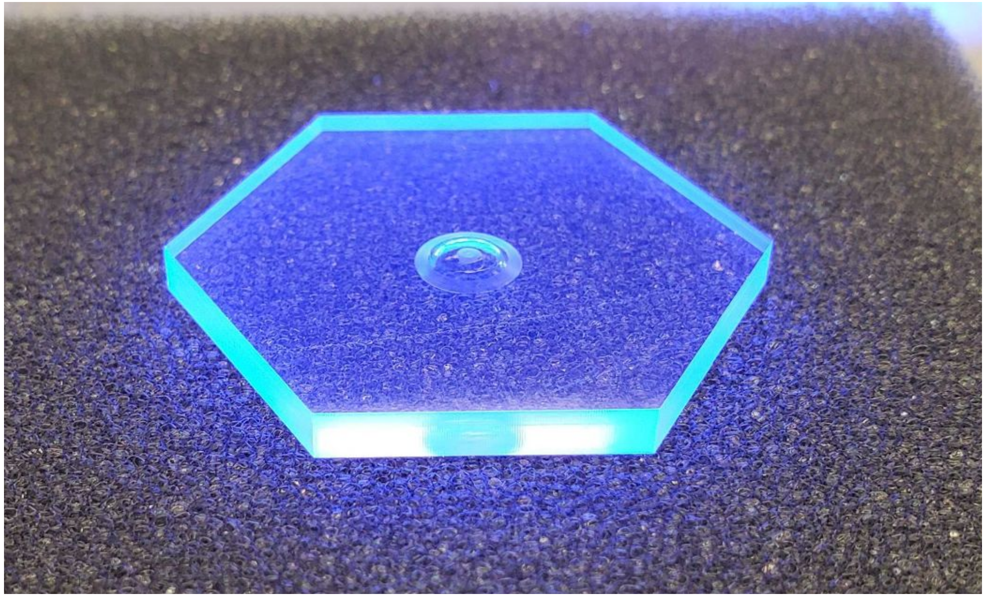




Nicely flushed with 1.3 mm SiPM

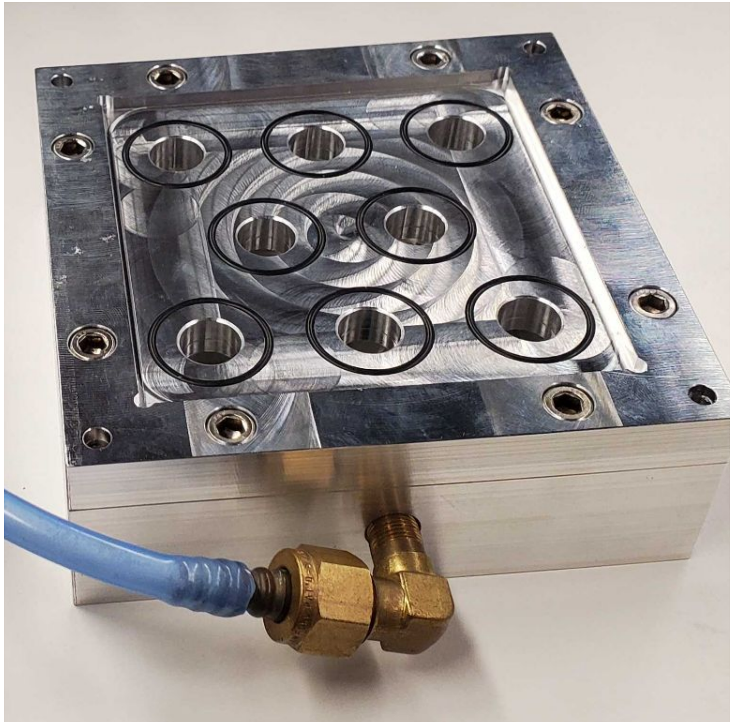


We compare injection-molded cells with cells machined at UCR from EJ-212 sheets



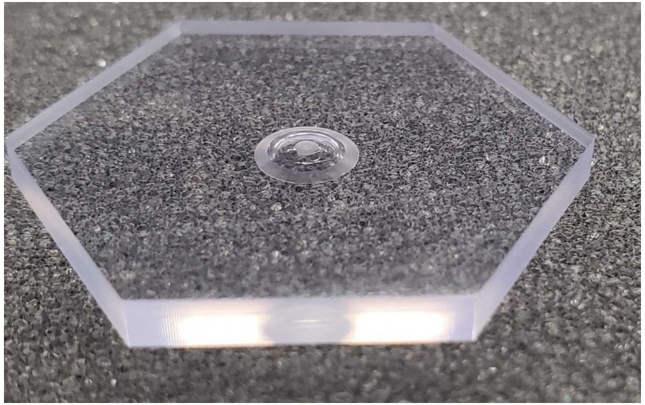
How we manufacture the cells at UCR

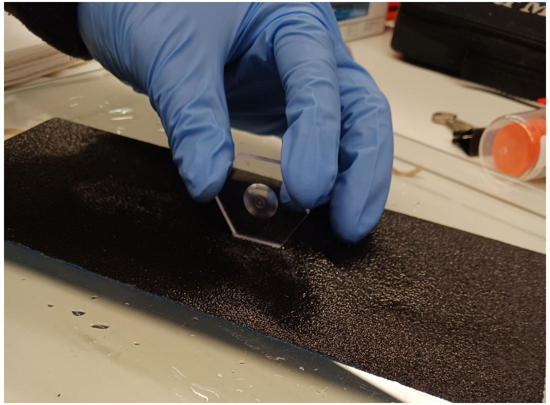
From EJ 212 raw material (square 10x10 cm2), we get ~8 small cells.
These are milled while in a custom vacuum chuck.

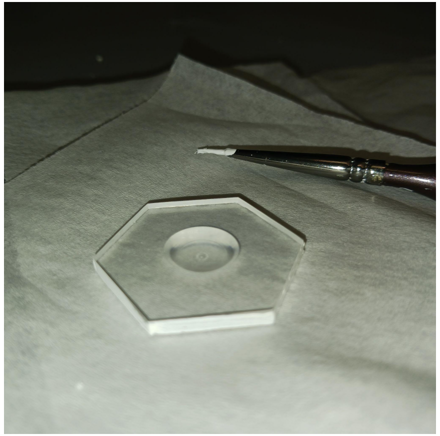


Polishing & Painting

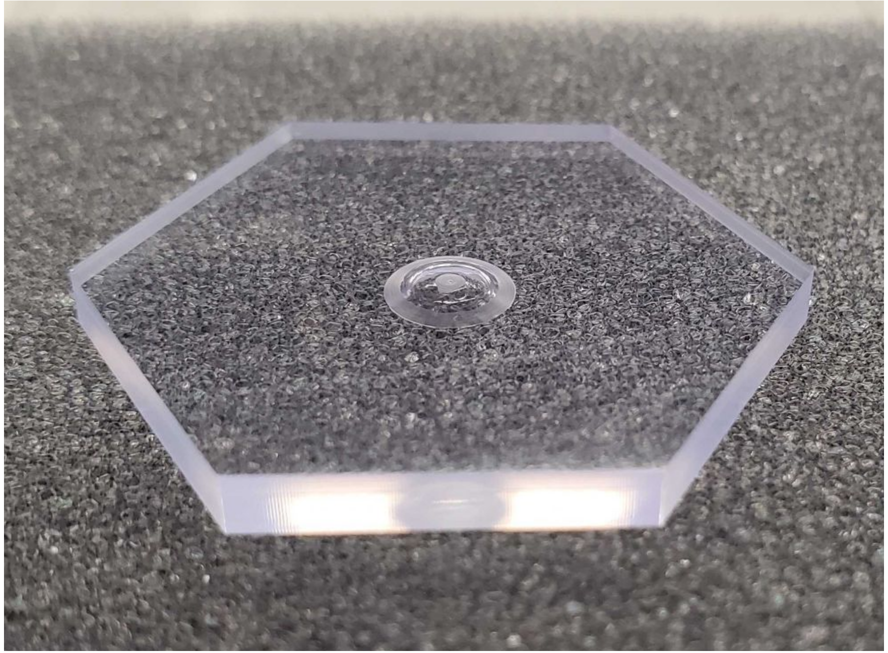
Edges & dimple are hand polished,
Edges painted with Saint-Gobain BC-621 paint

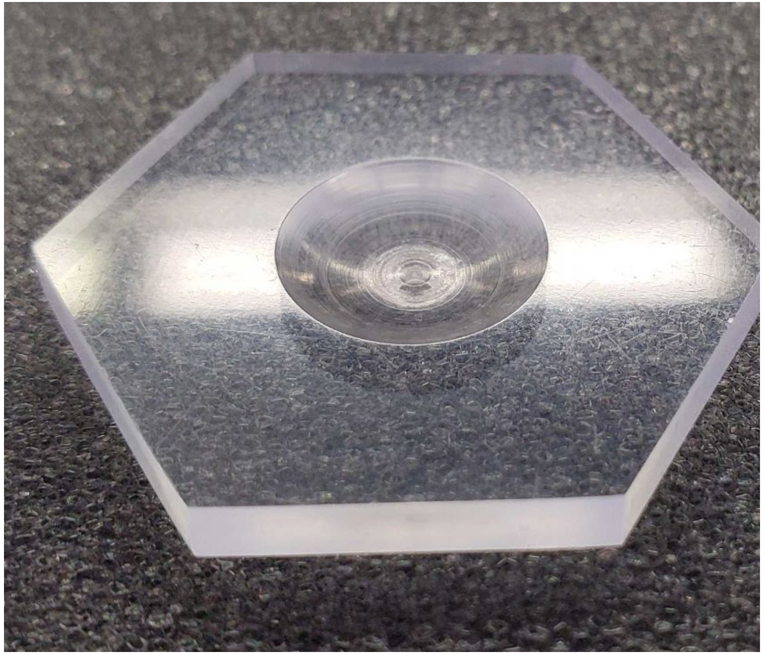




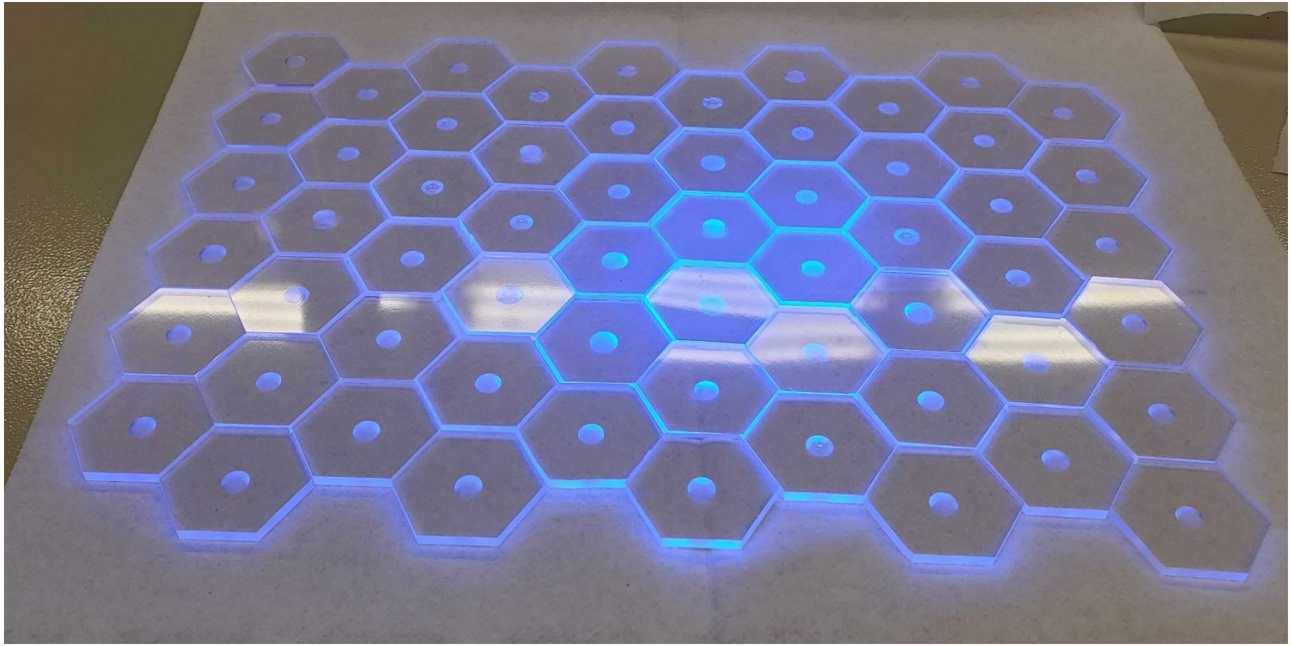


Hexagonal cells with small and large dimple (for 1.3 mm and 3 mm SiPM)





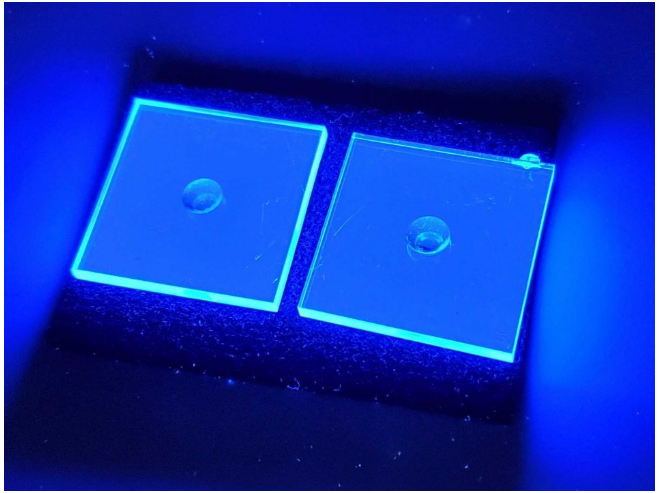
Production, QA, and characterization steps

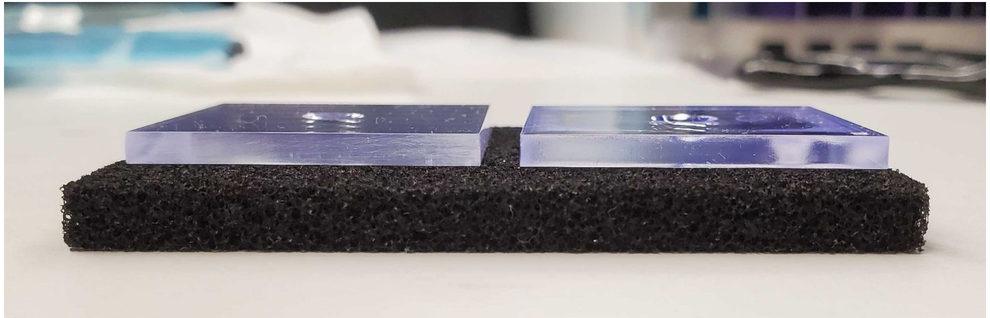


We have been working to refine the production process (machining)
QA and characterization (cosmic rays and Sr-90).
We have achieved >95% yield for high-quality cells
for a total corresponding to ~1-2%l of full-insert size

UCR-made (left) cell and FNAL injected molded cell (right)

Matching dimensions and dimple size & geometry

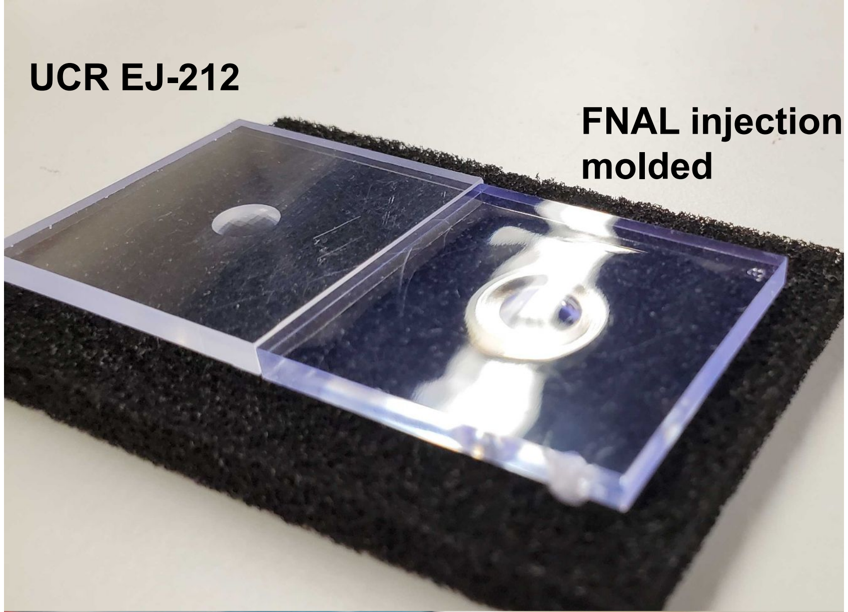


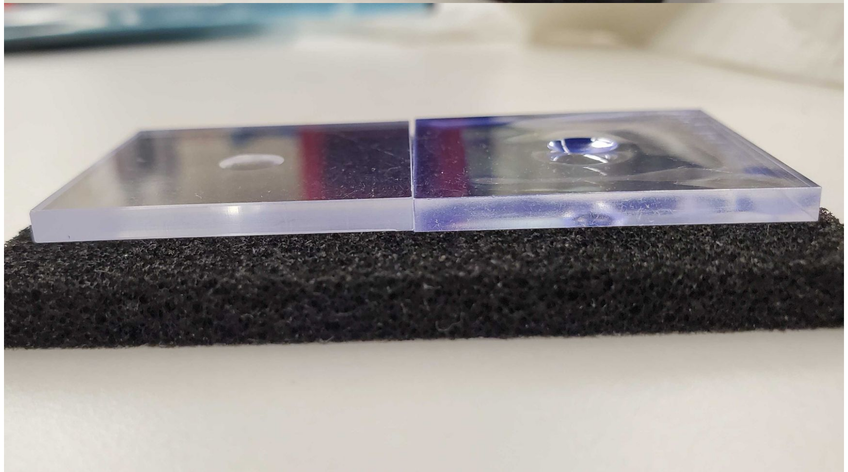


Non-flatness?

FNAL cells look less flat, which might make them more prone to air gaps

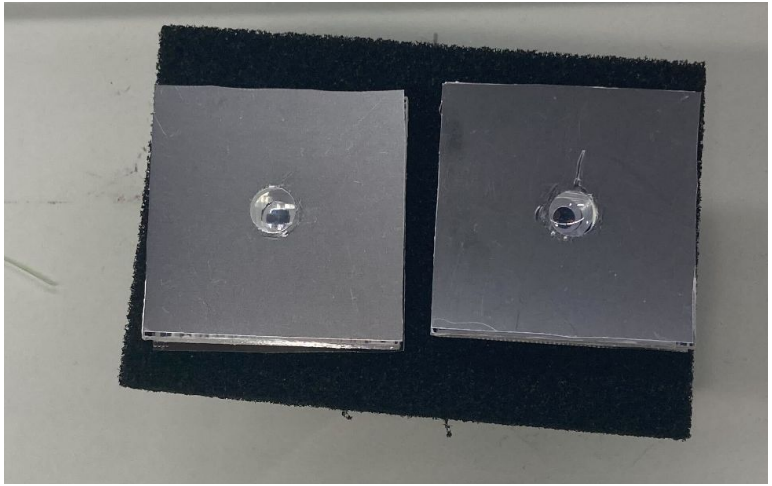
Future measurements with CMM would be informative





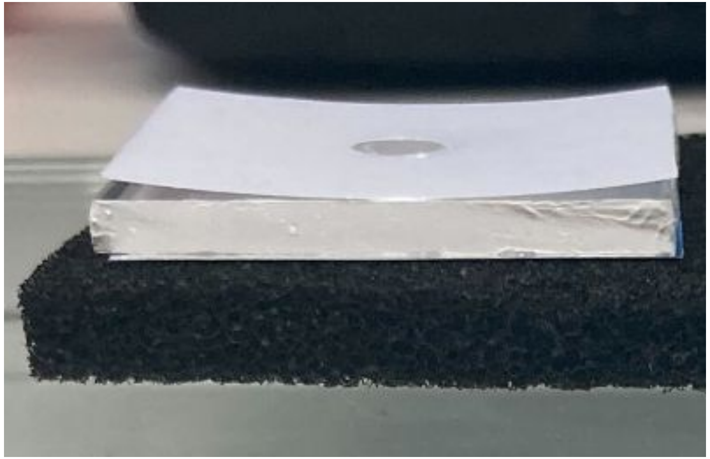
Both UCR and FNAL cells get same treatment

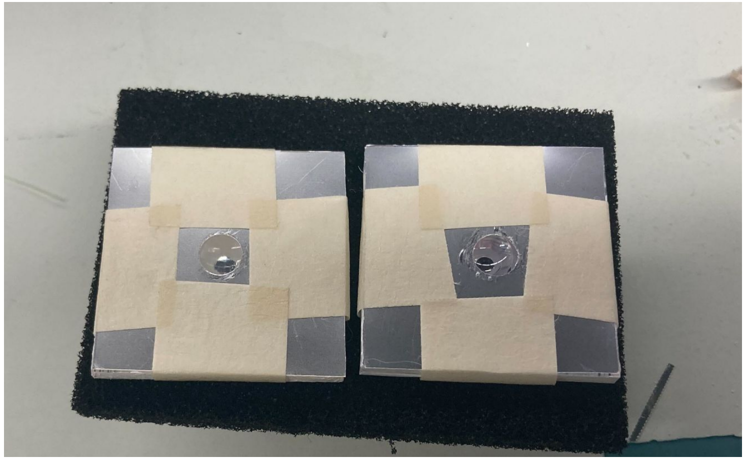
Edges painted



ESR foil top and bottom

ESR foil tends to bend itself

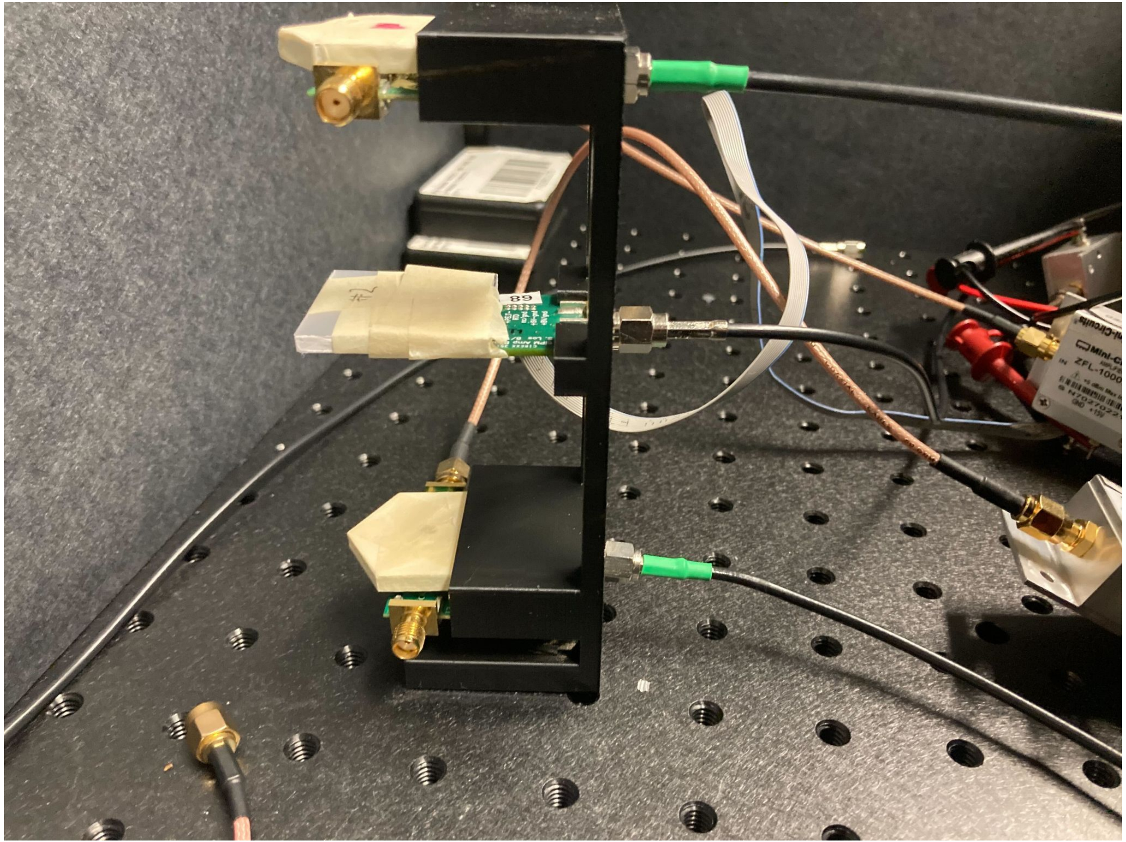




For individual-cell testing we use tape to hold it.

In mass-testing and for prototype and full-sized Insert we hold them flat with 3D printed frame sandwich

Cosmic-ray setup

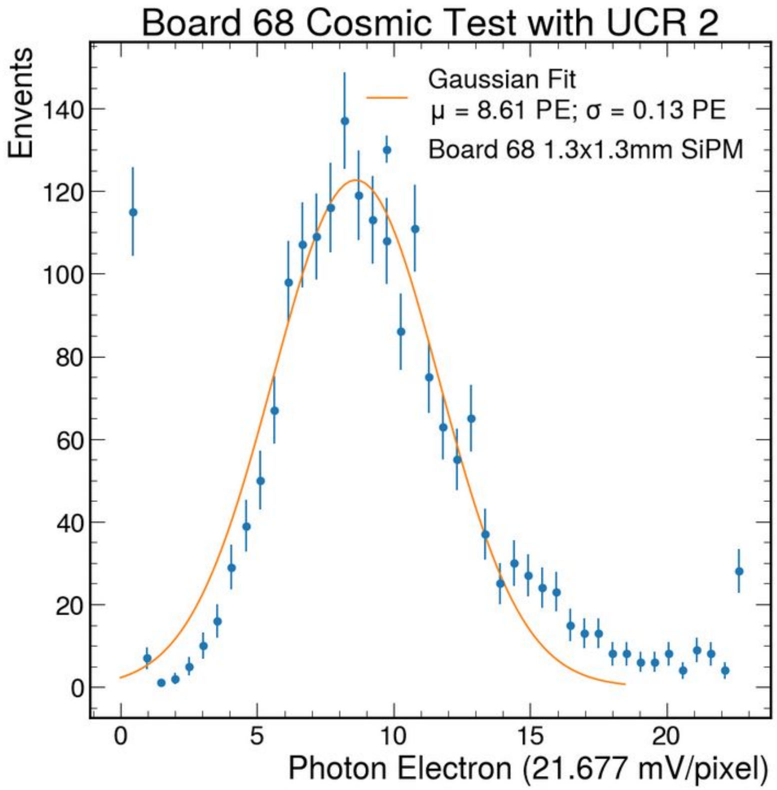


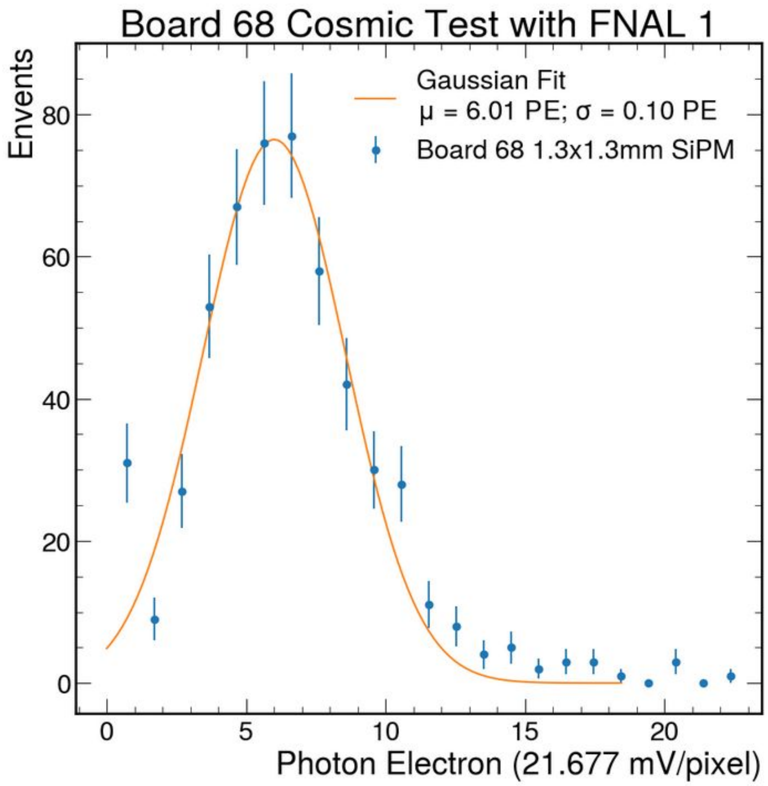
Single-cell testing setup
Full-waveform readout (DRS4) and pre-amp board + external amplifier

Multi-cell testing being developed as well with CITIROC 1A (FERS-5200)

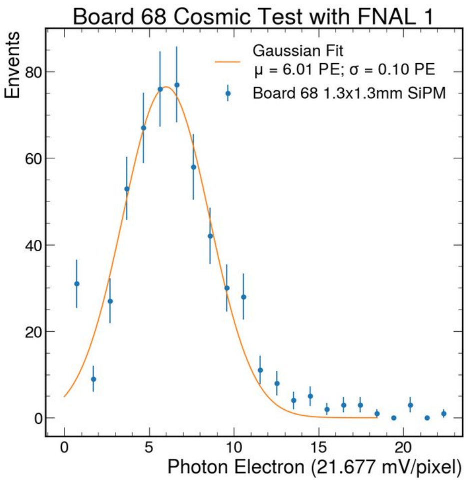
SiPM calibrated and operated at +2V bias
(details in backup)

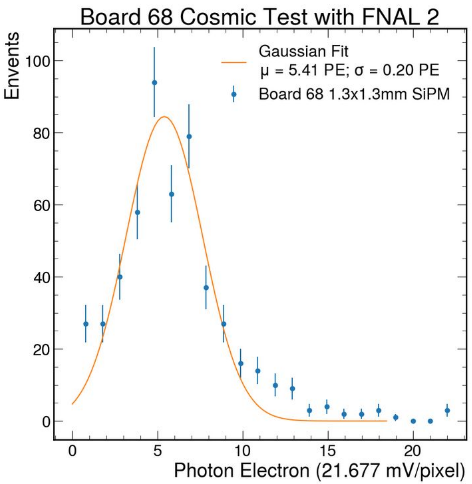
Example Landau distributions for UCR (left), FNAL (right)

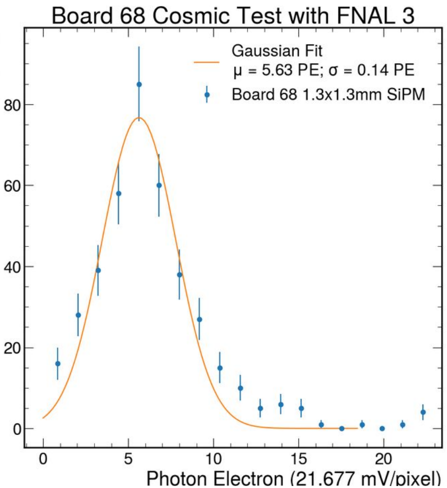


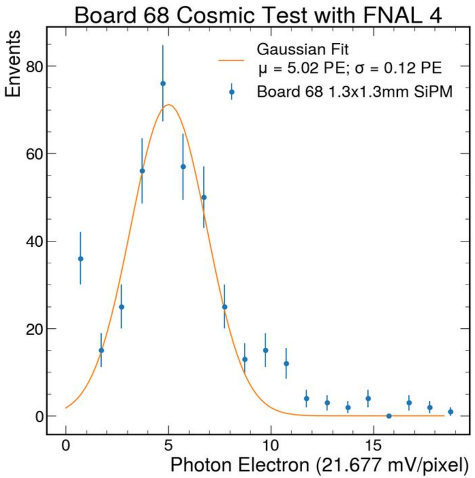


Four FNAL cells

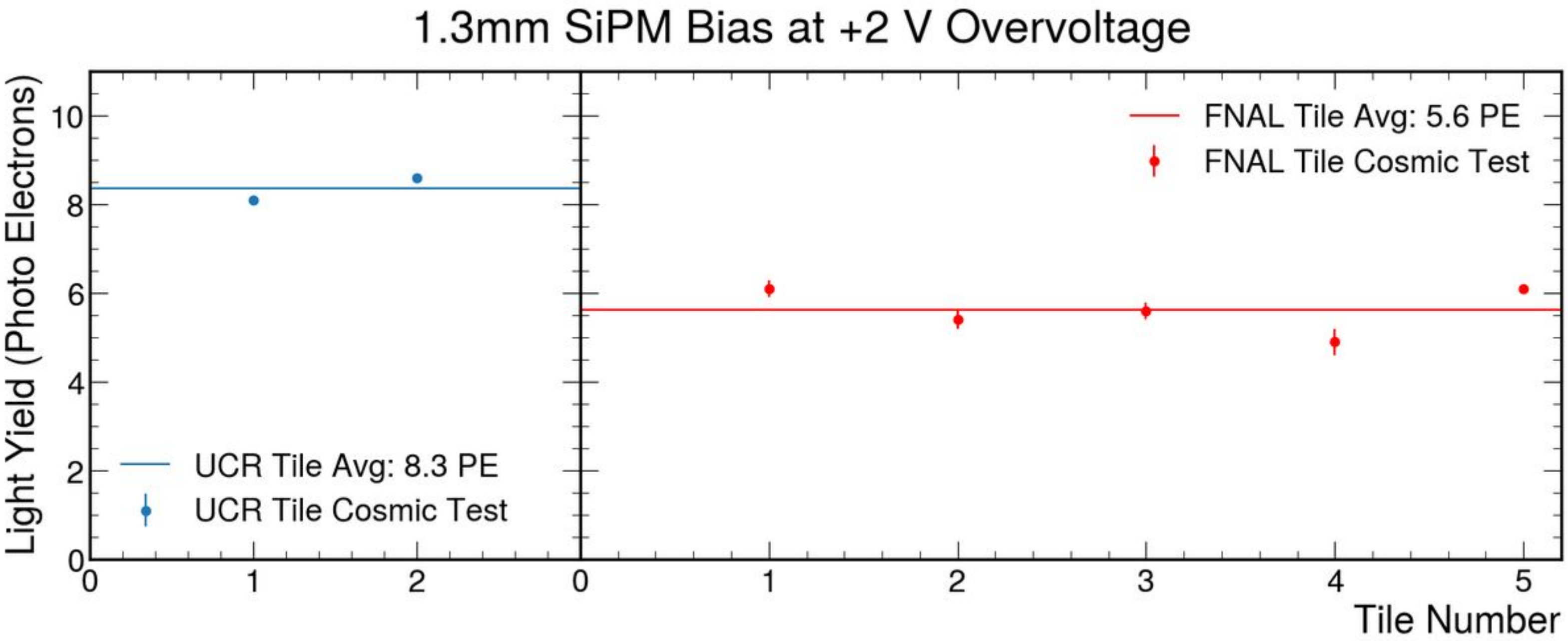








Light yield comparison for UCR and FNAL cells

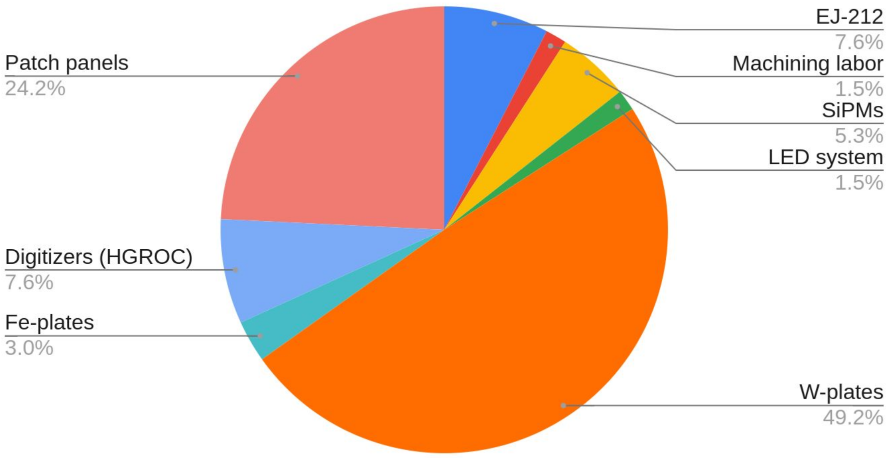


FNAL cells yield ~33% less light than machined EJ-212 cells
(under same wrapping conditions, with 1.3 mm SiPM at +2V)

Pro/Cons for Insert

Note: Insert is small, only few thousand cells

Scintillator & labor aren't cost drivers



EJ tiles machined

Pros:

+33% higher light yield !!

-Flat with high mechanical tolerance

Cons:

- Requires machining and polishing of edges and dimple

FNAL injection molded

Pros:

- Reduced cost of material & labor

-Avoids need for polishing & painting

Cons:

-Lower light yield, with 0.5 MIP at ~2.5 photons !!

-Reduced flatness ??

Can we decide?

We need more information to tell. In particular, we need to consider:

- We should aim to operate at a cell threshold of 0.5 MIP (based on CALICE studies), or lower.
- We should be able to withstand signal-to-noise ***after* radiation damage expected at Insert region**
- We need to optimize operating voltage. Currently we follow STAR HCAL operation of +2V (similar radiation fluence).
- Noise is exponentially distributed, so small increases in light yield (increasing threshold) can have huge impact

Next step: a SiPM irradiation test!

Planning in advanced stage at 88'' cyclotron with 50 MeV proton beam

To be led by Dr. Barak Schmookler
+ army of students

Aim at providing a comprehensive reference for damage and annealing for the SiPMs models that we will use in ePIC calorimeters.

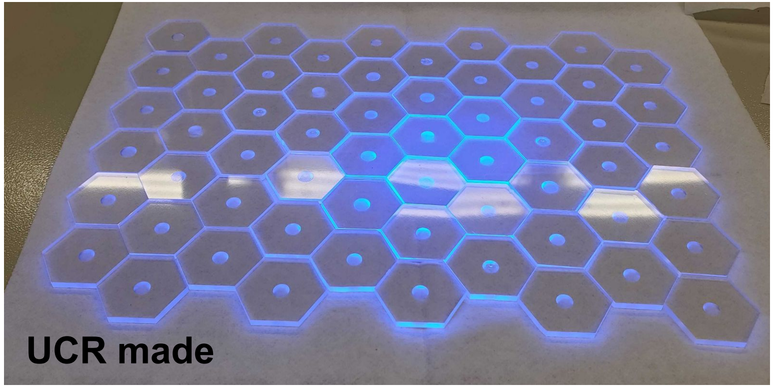
Info to include realistic noise in future simulation campaigns

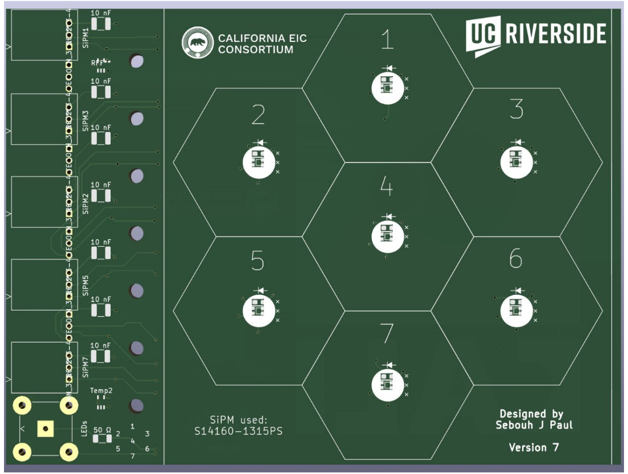
BASE
BERKELEY
ACCELERATOR
SPACE
EFFECTS

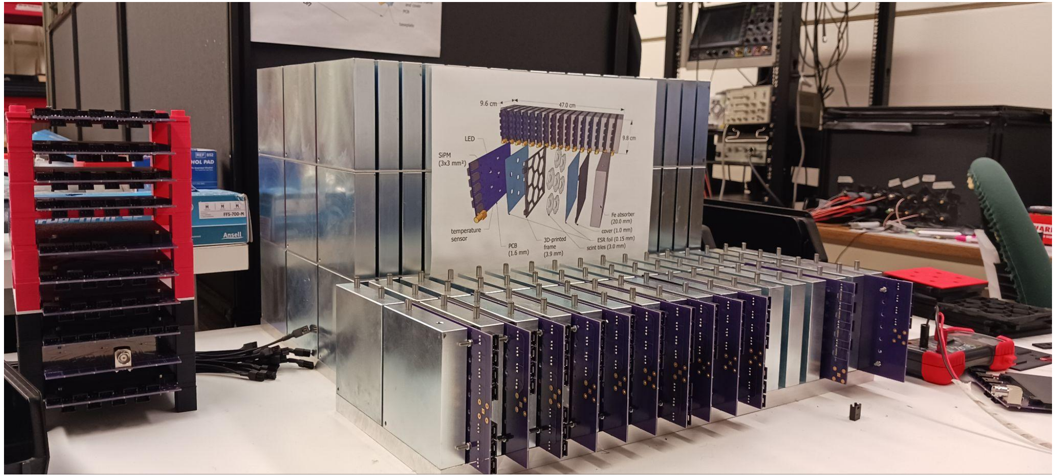
CALIFORNIA EIC
CONSORTIUM

Update on planned next steps for the Insert

We will use both UCR-made cells and FNAL cells to instrument our Insert Prototype







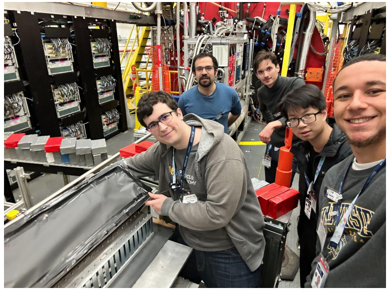
Next steps for Insert prototype testing

2023

Jefferson Lab

Already done a "warm up" test with 40 channels in Hall-D In January 23

Plan second beam test with 128 channel ECAL-size prototype
To be lead by Dr. Sebouh Paul (JLab EIC Fellow)



2023

BERKELEY LAB

SiPM irradiation testing @88" cyclotron

(within months)
To be led by Dr. Barak Schmookler

2023

Fermilab

Together with UCLA's W/SciFi ECAL

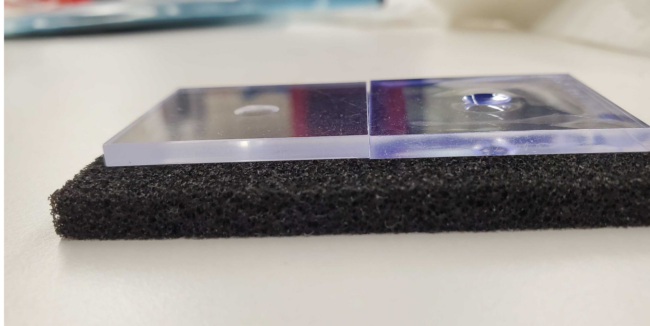
2024

Brookhaven National Laboratory

East-side of STAR near beam pipe.
Operate parasitically during 200 GeV pp run

Aim at having a few hundred channels prototype, or roughly ~O(10)% of full-size Insert

To be led by
Dr. Weibin Zhang



Summary

- We have measured injection-molded SiPM-on-tile cells for Insert.
- Cosmics yield 33% less light than machined EJ-212
- Average MIP of 5.6 photons with 1.3 mm SiPM at +2V.

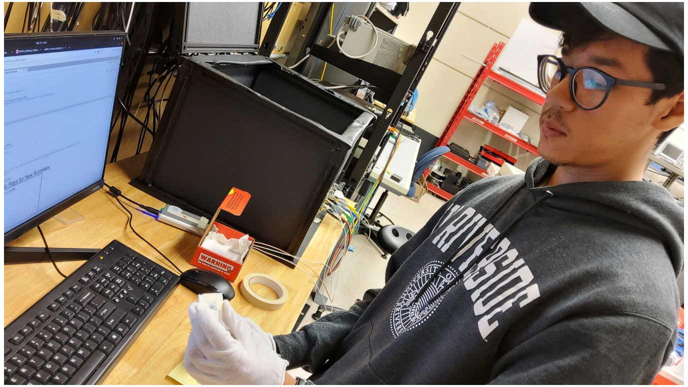
-> Our initial studies suggest that machined EJ-212 might be better option for calorimeter Insert.

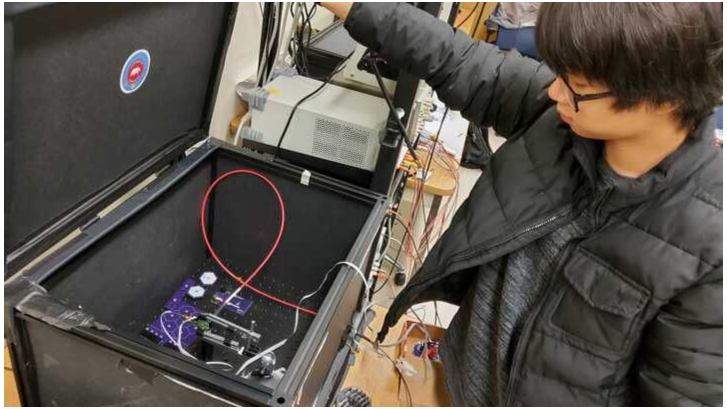
Future steps: quantify signal-to-noise ratio after irradiation expected for Insert region; optimize operating voltage. Tests planned at LBNL

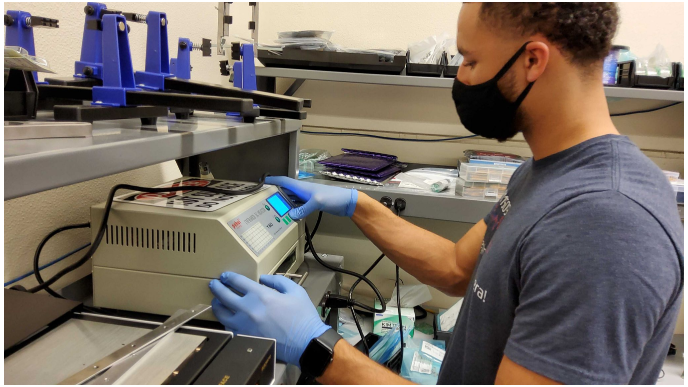
These test are meant to concretize design, minimize risk, produce realistic cost estimates, and build up production capabilities.

Credit to the strong team that made this study possible

SiPM soldering, SiPM testing, SiPM calibration, cell 3D modelling, chuck modelling, cell polishing, cell painting, cell wrapping, mounting cosmic ray setup, mounting Sr-90 setup, implement DAQ and associated software, waveform analysis algorithms, light-yield data analysis, systematic studies.





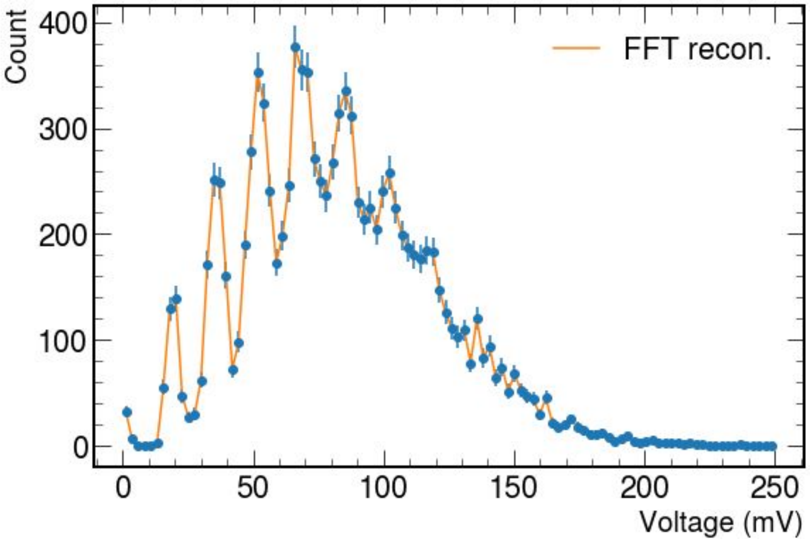


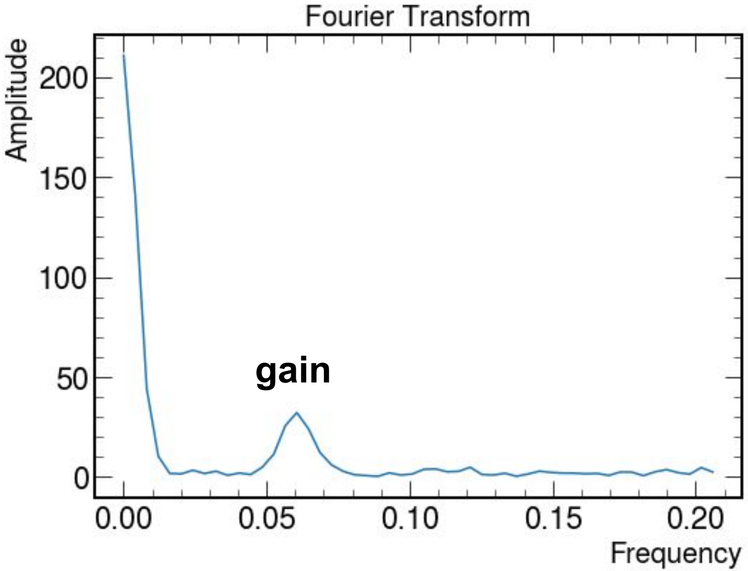
Backup

SiPM gain calibration

Low-intensity pulses yield finger spectrum.

FFT to spectrum yields gain (pixel-to-photoelectron)

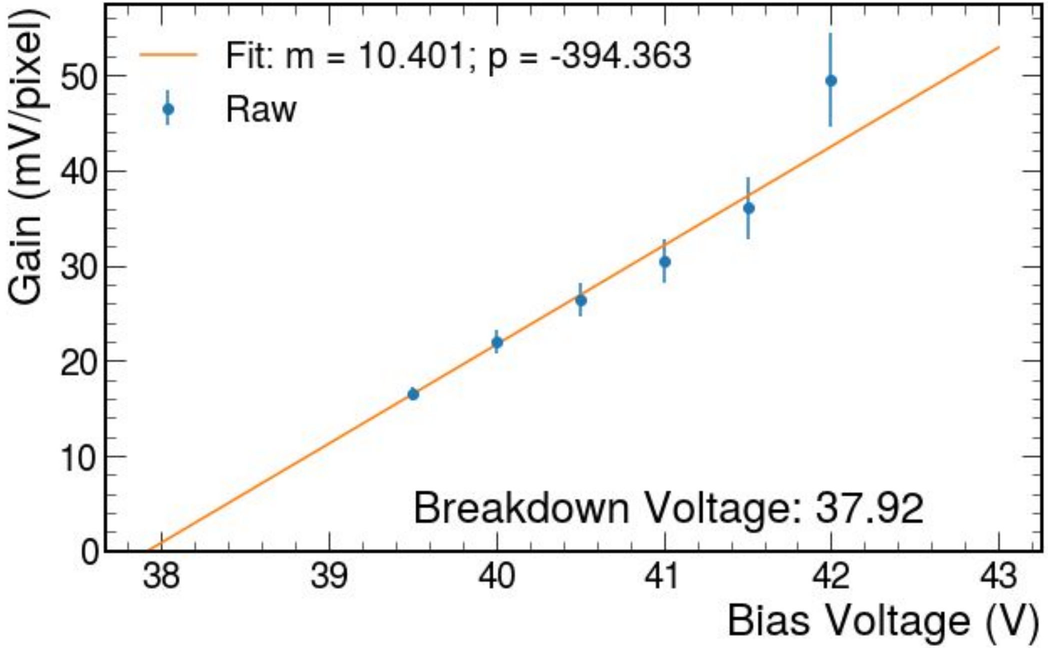




SiPM breakdown voltage

Gain vs voltage curve yields estimate for breakdown voltage.

SiPM operated at +2V



Cost estimates

Hardware (~50% W, 50% Fe)	k$USD
Absorber plate (W)	325
Absorber plate (Fe)	20
Scintillator plates (EJ-212)	50
SiPMs (14160-3015PS)	35
LED monitoring system	10
Supplies	10
Electronics (4k channels)	
Digitizers (HGROC)	50
Patch panels/LV	160
Total hardware + electronics:	**660**

*All info either from direct quote, or from info from ATHENA proposal

Quotation

Quote To: Miguel Arratia
University of California, Riverside
Riverside, CA 92521
United States

Quote Number:	22048			**Contact:**	
Quote Date:	10/25/2022	**Expires:**	11/24/2022	**Inquiry:**	
Customer:	UCR			**Terms:**	25% due at order placement
Salesman:	In House Sales			**Phone:**	310-825-3124
Ship Via:	United Parcel Service			**FAX:**	

Estimated lead time for all 100: 16 weeks

Quote is for Manufacturing only. Freight charges to be invoiced to customer at time of shipment.

Pricing is subject to change based on timing of order and price of raw material at time of order.

Item	Part Number Description	Revision	Quantity	Price
1	UCR PRELIM PLATE Plate, A36 Steel, .625 x 23.523 x 11.811, holes on two ends, semi-circle cutout		100	$415.000 /EA
			Total:	***$41,500.00***

Notes & Instructions

TUNGSTEN HEAVY ALLOY - ASTM B777 CLASS 1 - ET90
0.602" X 11.65" X 23.52" - CUT TO SHAPE WITH MACHINED HOLES PER SKETCH.
NO DRAWING NUMBER OR TITLE ON SKETCH
****
BUDGETARY QUOTE

Line	Qty	UM	Elmet Part#	Description	Price
001	100.0000	EA	ETOFAB-1	FPWHA-0.602" PER SKETCH	$7,500.0000
				Total for Quote	