

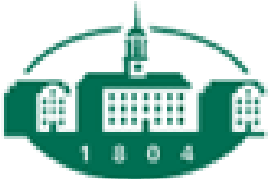
# SiPM and FEB Discussion Items

Justin Frantz (Ohio University)

ePIC EEEMcal Readout Mtg

06/19/2024

Happy Juneteenth -- Forgot, might've canceled,  
but it was too late. But we do have important  
business to discuss



# Initial SiPM Choice Discussion

- Carlos willing to buy all 25 channels-worth siPM's for their Orsay prototype.
- Final thoughts on which siPM model they should buy...
- First let's run through our document on this made by Tanja
- Gerard slide

# SiPM Selection for the Beam Test in October/November 2024

## Pixel Size

- ❑ Originally, the idea was to use 10um SiPMs as EIC data are mainly taken at GeV scale where linearity (constant term) is more important than photostatistics. However, note that in EIC we have to detect the shower down to 100 MeV (5 MeV/block)
- ❑ It would be good to understand the nonlinearity even before combining SiPMs into an array. **Can we compensate for nonlinearity?**
- ❑ Radiation hardness – see analysis of the recent irradiation test data

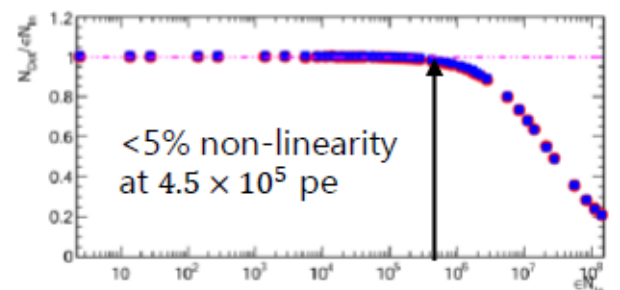
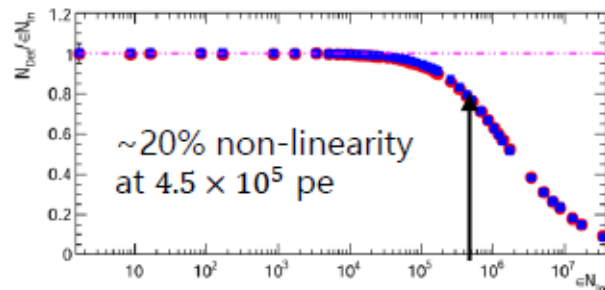
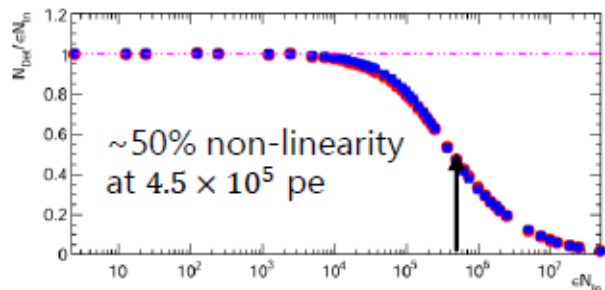
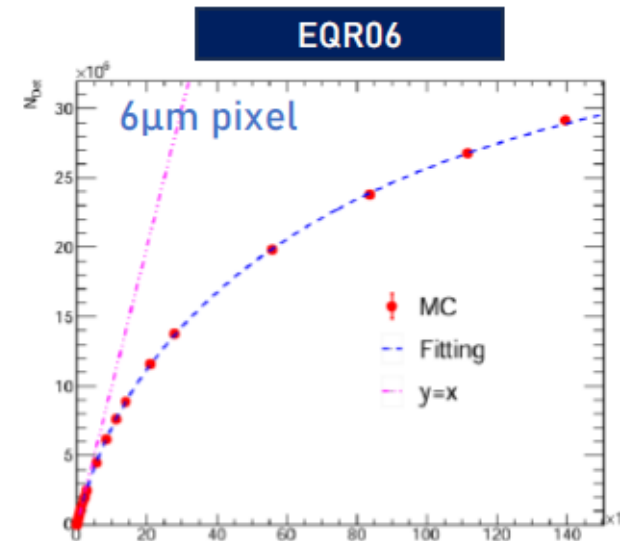
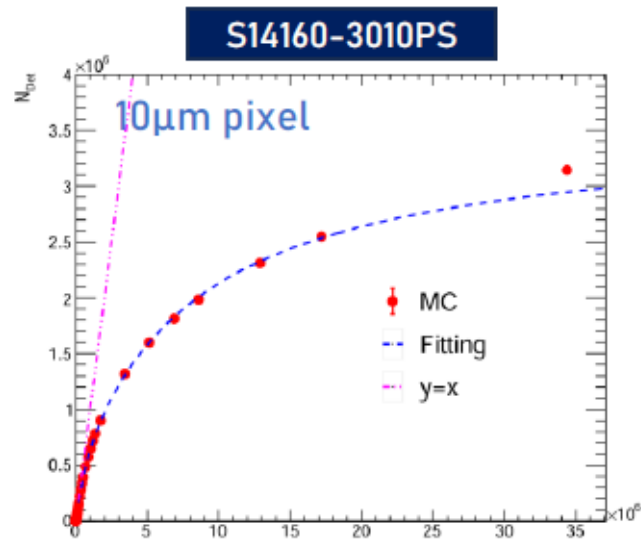
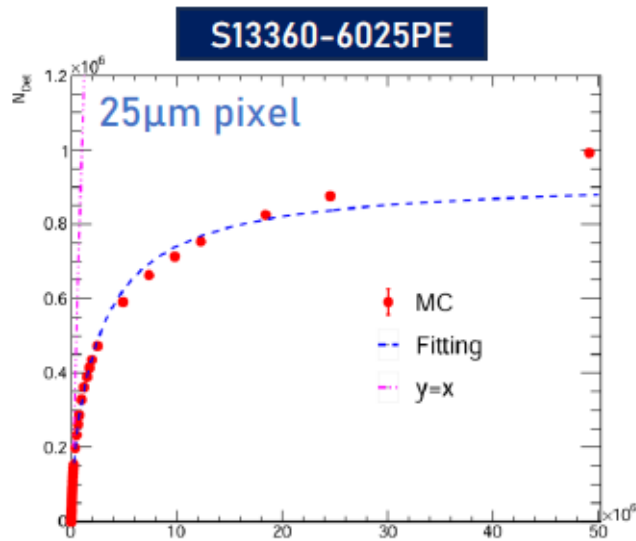
Topic	10um	15um
PDE at 420 nm (%)	17	<b>32</b>
Number of cells	89984	39984
Activated sites/SiPM	907	1588
INL at 15 GeV 100% coupling efficiency	<b>0.5%</b>	2.0%
Total activated cells	14506	25204
Resolution (bit)	14	15
INL at 15 GeV 20% coupling efficiency	<b>0.10%</b>	0.40%
Total activated cells	2913	5163
Resolution (bit)	12	13
Radiation Hardness	TBD	TBD

Note: lowest energy at DESY Oct/Nov. test may be 1 GeV

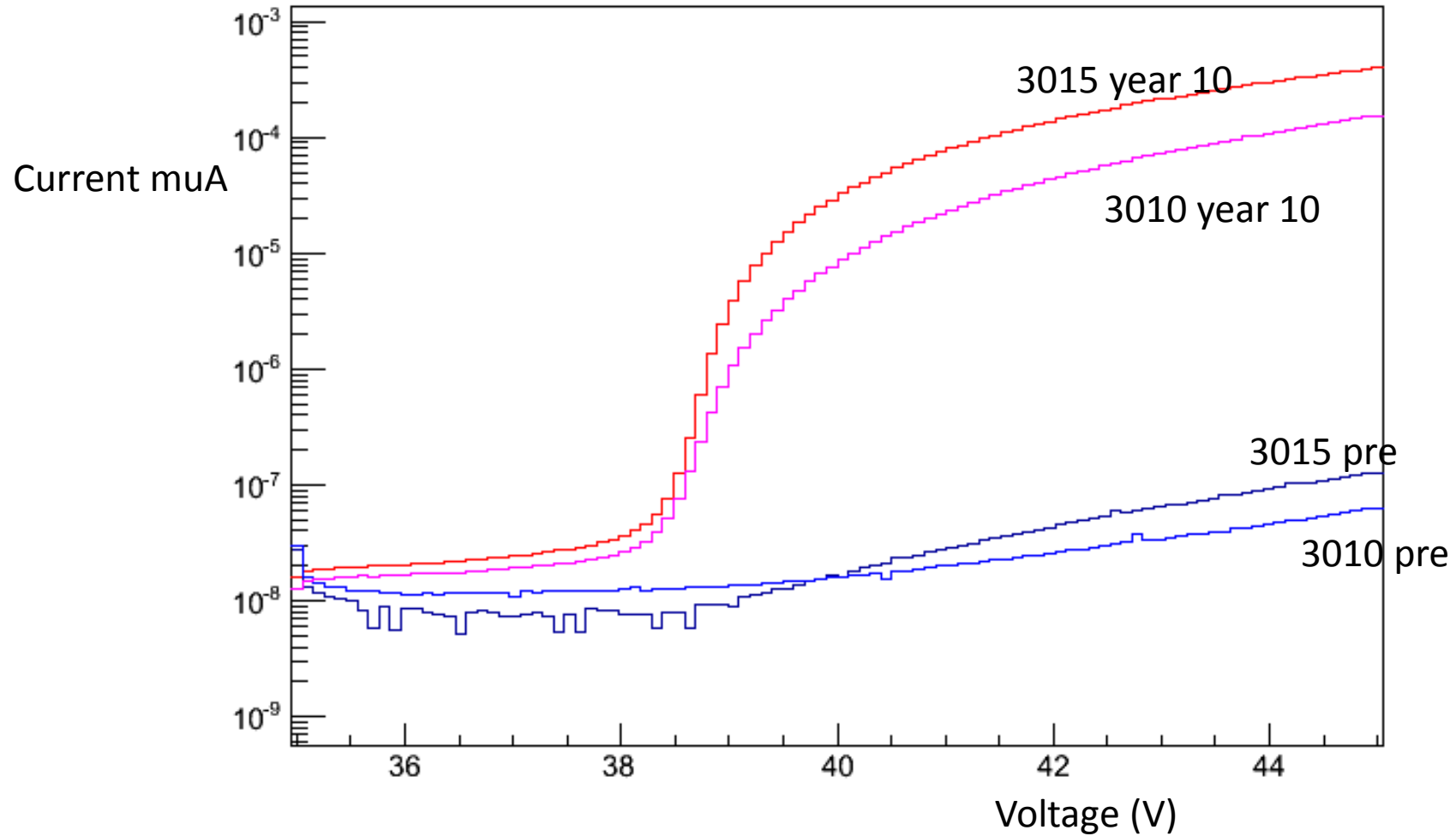
**In general, a beam test with the different SiPM options would be best, but lead times for procurements may require an earlier decision**

# Linearity in Presentation at CALOR2024

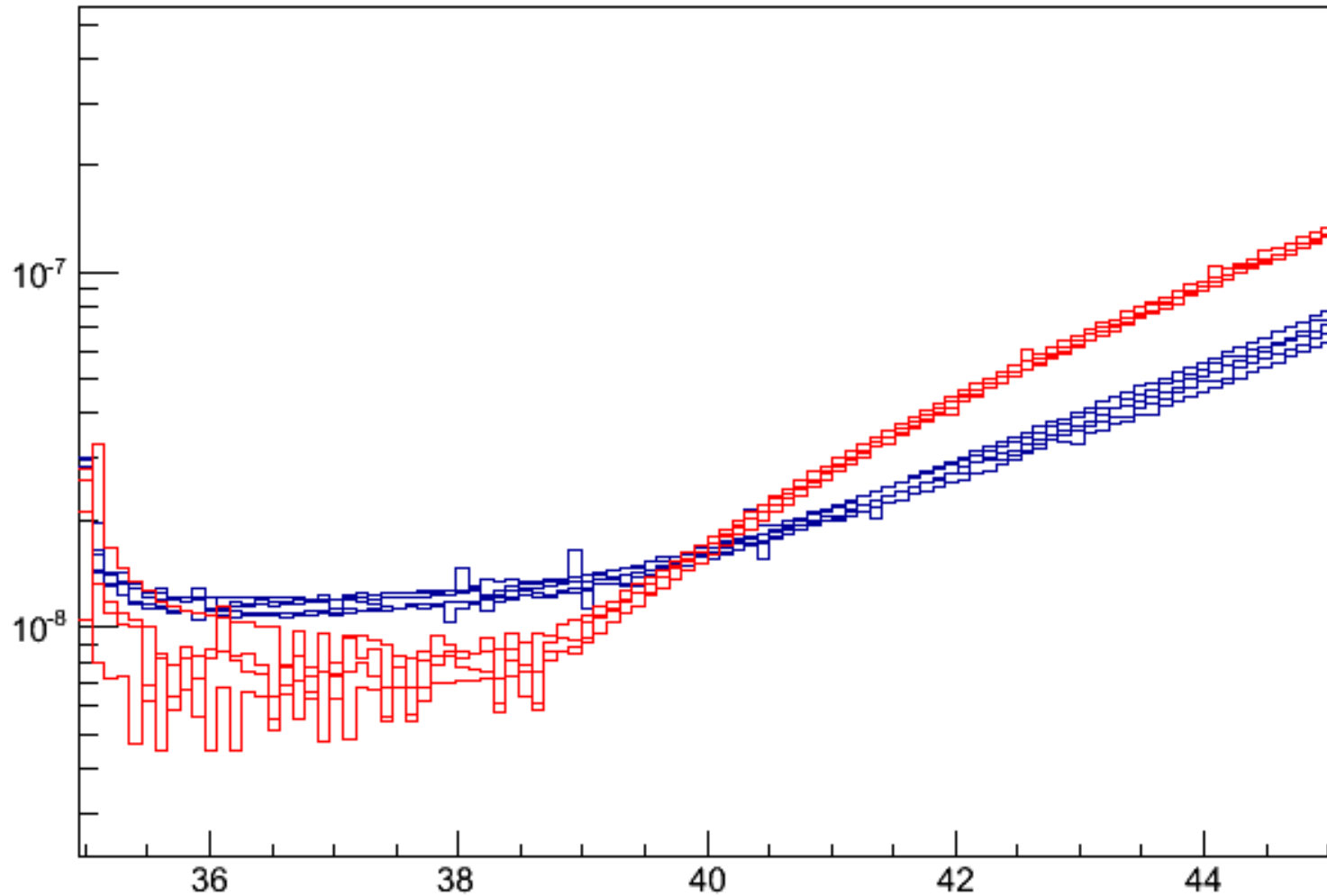
- <https://indico.cern.ch/event/1339557/contributions/5898510/>
- After more careful look, w/ Gerard, conclude linearity of 15 vs 10 should indeed be slightly worse w/ 15um, but highly and similarly correctable w/ simulation for both cases → for now no advantage therefore 10 um
- Higher power consumption - take 10 um pixels out of the running?
- Noise expected to be higher?



$(3\text{mm})^2$ ,  $15\ \mu\text{m}$  pixel vs  $10\ \mu\text{m}$



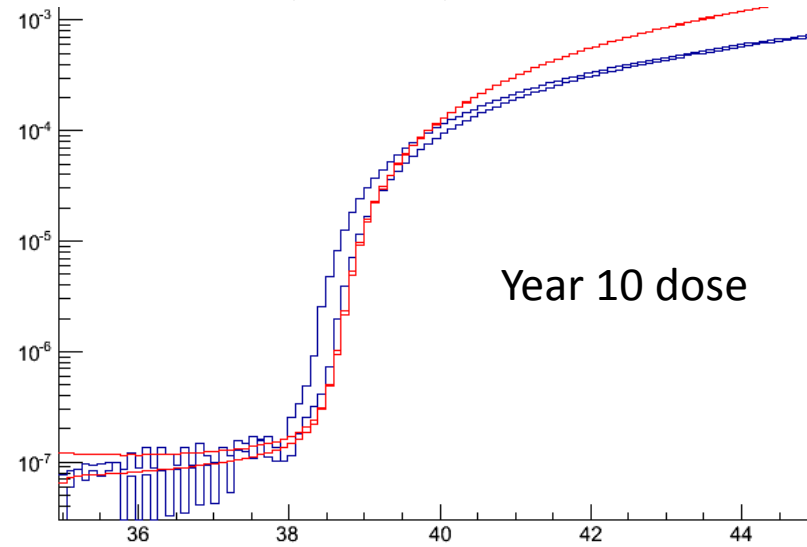
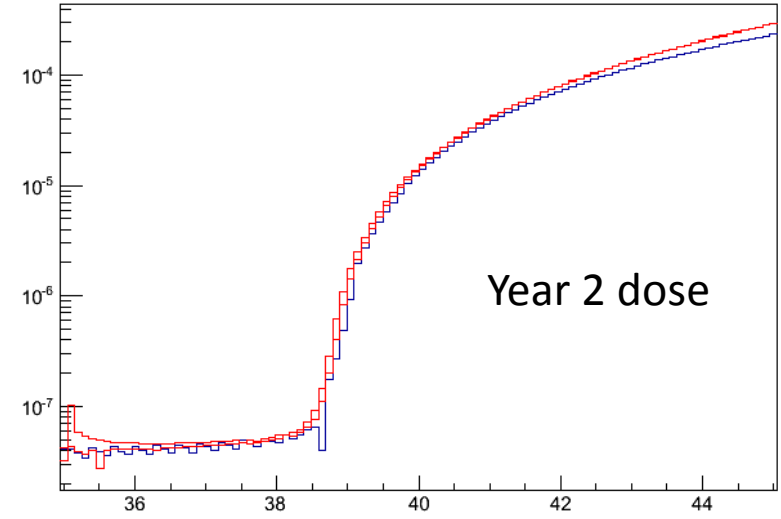
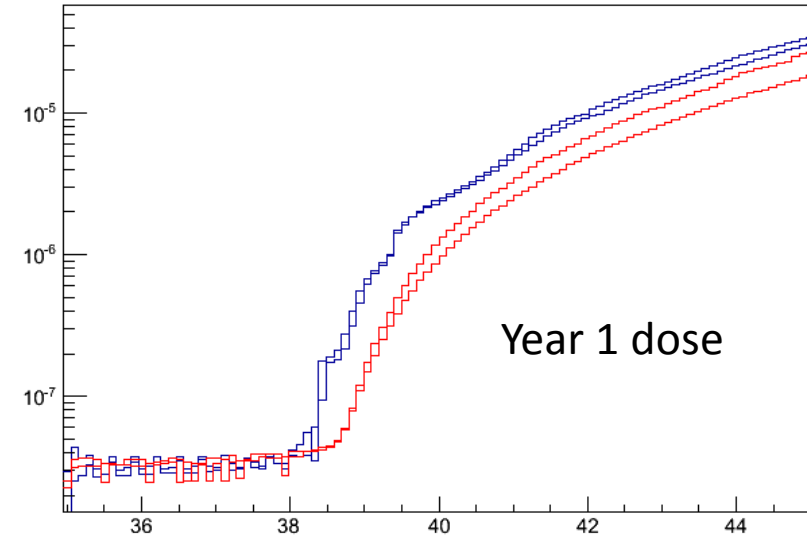
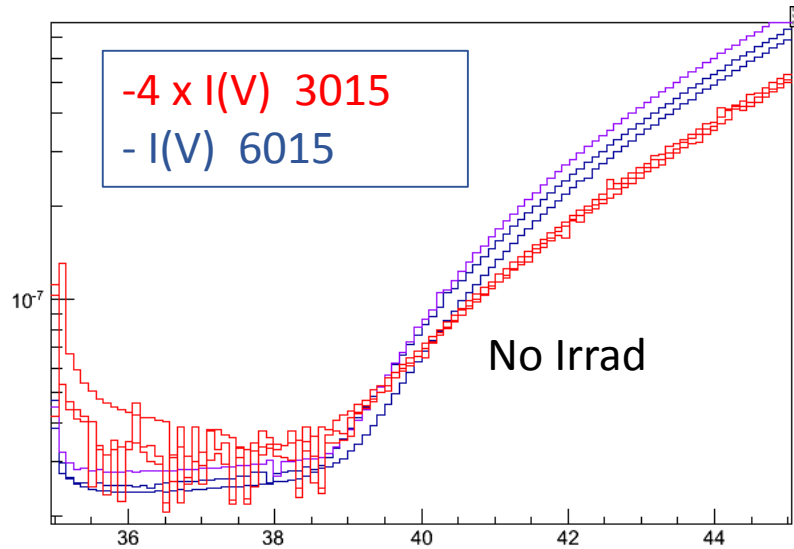
$(3\text{mm})^2$ ,  $15\ \mu\text{m}$  pixel vs  $10\ \mu\text{m}$  No Irradiation  
variation of different units



# 4 x 3015 vs 6015

$$I_D \approx q \cdot DCR \cdot gain \cdot (1 + CT + AP)$$

- According to this equation I got from a Broadcom siPM guide, gain and Vop are given on the spec sheets as the same, and q should be too. So  $I_{\text{dark}}$  proxy for DCR's?
- Empirically,  $I(V)_{6015} \approx 4 \cdot I(V)_{3015} \rightarrow$  some evolution of the agreement w/ dose?



# SiPM Selection for the Beam Test in October/November 2024

## Device Size

- ❑ Originally, the idea was to use larger SiPMs as this was thought to be easier for making a SiPM matrix and possibly more cost effective – current knowledge

Topic	3 mm x 3mm	6mm x 6mm
Anode Capacitance	<b>530 pF</b>	2500 pF → combining into array further increases capacitance
Array config	4x4 -possibility for more fine grained readout -possibility for more surface area (20 siPM vs 16)	2x2
Cost (per siPM)	base \$53; 100 ch: \$19	base \$125/SiPM 100 ch: \$65
Radiation Hardness	TBC	TBC

- ❑ Radiation hardness – based on information from Hamamatsu no major differences are expected. See analysis from the recent irradiation test for results from the measurement.

**In general, a beam test with the different SiPM options would be best, but lead times for procurements may require an earlier decision**



# Cost

- Re-checking with Hama about original estimates for full production quantities prices since current price differences/discount levels disagree somewhat with those original estimates (email on next slide → the costs sent before were estimates not formal quotes).

**From:** Ardavan Ghassemi <AGhassemi@hamamatsu.com>

**Sent:** Friday, December 22, 2023 11:51 AM

**To:** Frantz, Justin <frantz@ohio.edu>

**Cc:** rosijreed@lehigh.edu <rosijreed@lehigh.edu>; Larry Isenhower <ldi00a@acu.edu>

**Subject:** RE: different addresses / quote targets Re: thanks! + others? Re: [External] Ohio University QUO-48648-Q7G2X1 CRM:0401093

Hi Justin,

Thanks for your email. The quotes for yourself and Rosi were just emailed so you'd be able to proceed. For Larry's quote, it'd need to wait until after the holidays (2nd week of January) at the earliest if he'd like to buy -6010PS or -6015PS parts.

However, if Larry chooses to buy -3010PS or -3015PS parts, he could do so today by calling our CSR dept. at 917-947-7199 even without a formal quote.

To answer your questions about the larger purchase quantities and max. variation of Vop options, please find our proposal in bold text below; please note that "pcs" refers to product units and Vop is defined as Vbreakdown + X whose value is noted on each product's datasheet.

**S14160-6015PS: Qty. 12 - 16 kpcs**

- Reel packing with a Vop selection (+/-0.1V per reel, Packing quantity: 500 pcs/reel)
- Unit price: \$27

**S14160-3015PS: Qty. 50 – 65 kpcs**

- Reel packing with a Vop selection (+/-0.1V per reel, Packing quantity: 1k pcs/reel)
- Unit price: \$11

I hope you find the above info helpful. Don't hesitate to let me know if you have any further questions.

Kind Regards

# SiPM Selection for the Beam Test in October/November 2024

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**In general, a beam test with the different SiPM options would be best, but lead times for procurements may require an earlier decision**

# Other items

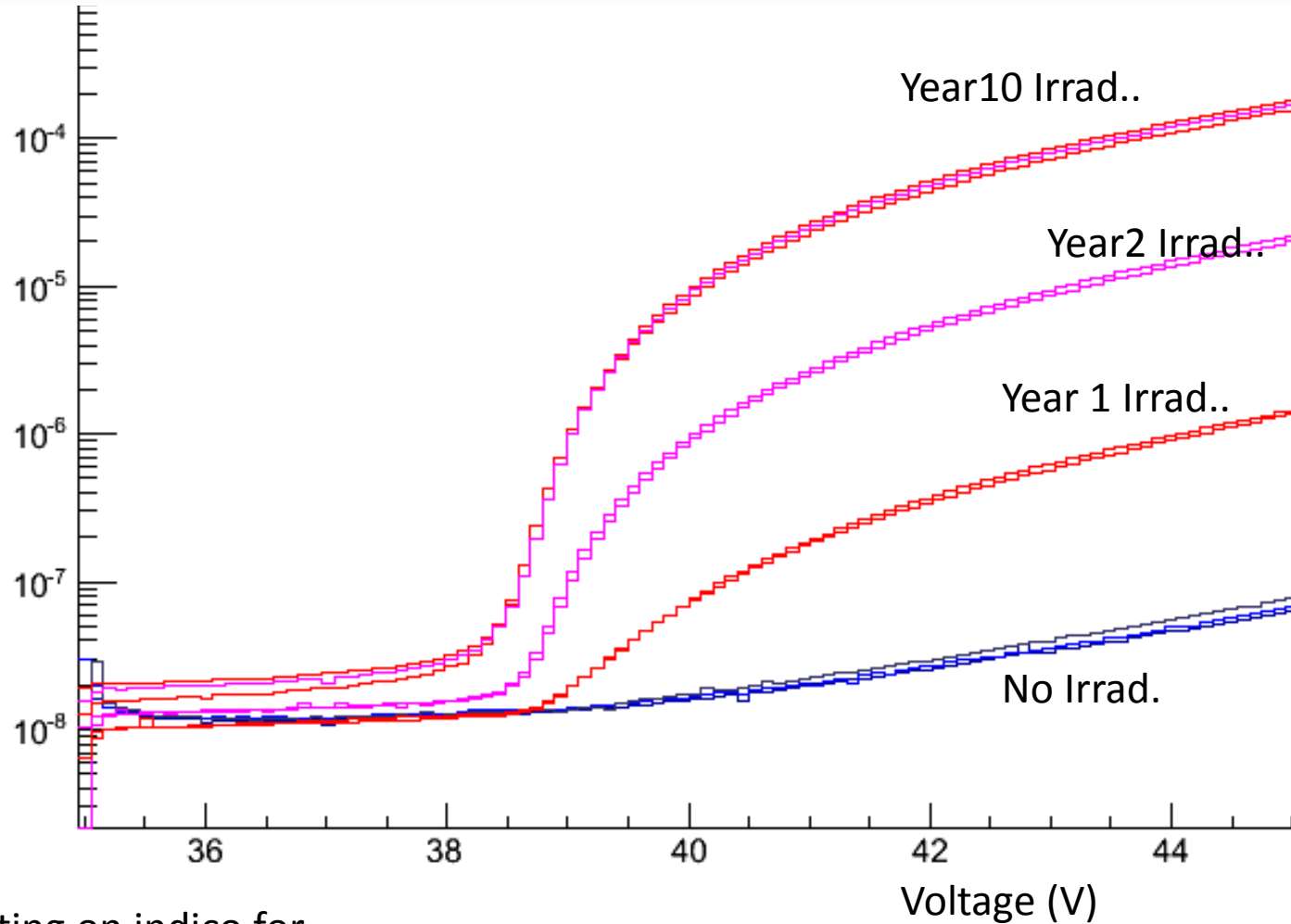
- Flash ADC's

# Backup

# From UC Davis: 6015 ( (6mm)<sup>2</sup>, 15 $\mu\text{m}$ pixel)

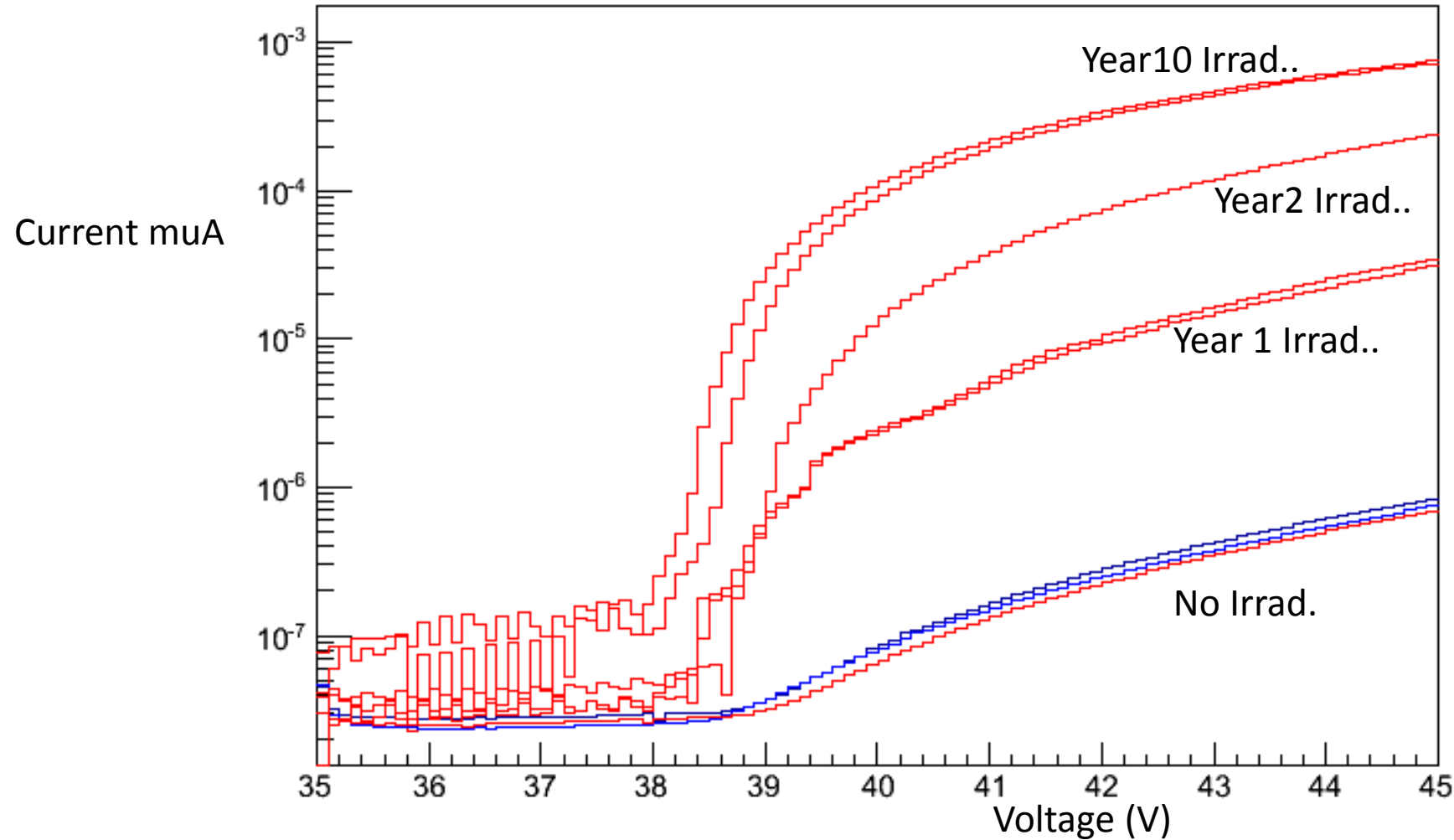
quick first  
look

Current  $\mu\text{A}$

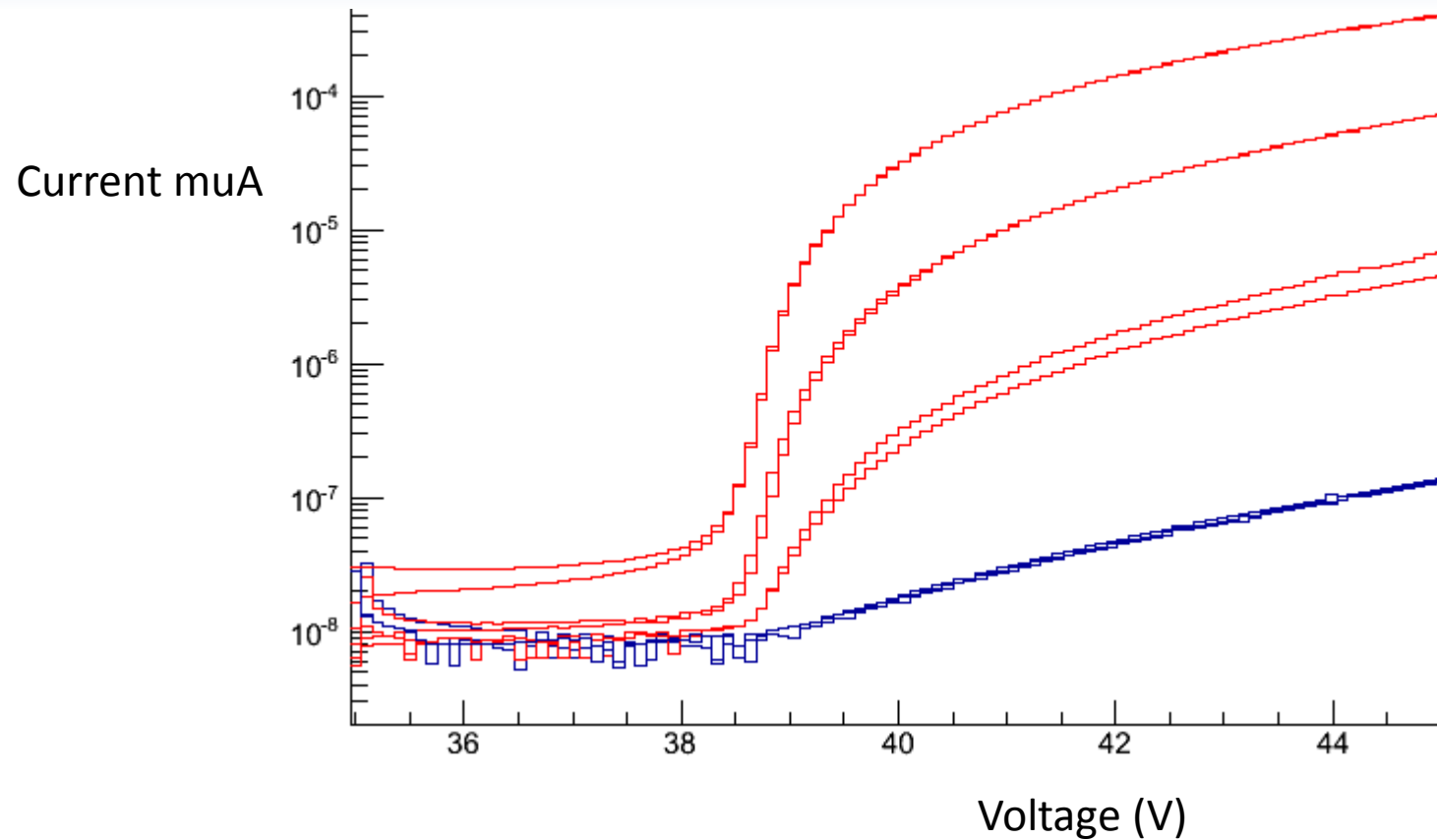


See last readout meeting on indico for  
more detailed info about radiation doses

3010 ( (3mm)<sup>2</sup>, 10  $\mu\text{m}$  pixel)

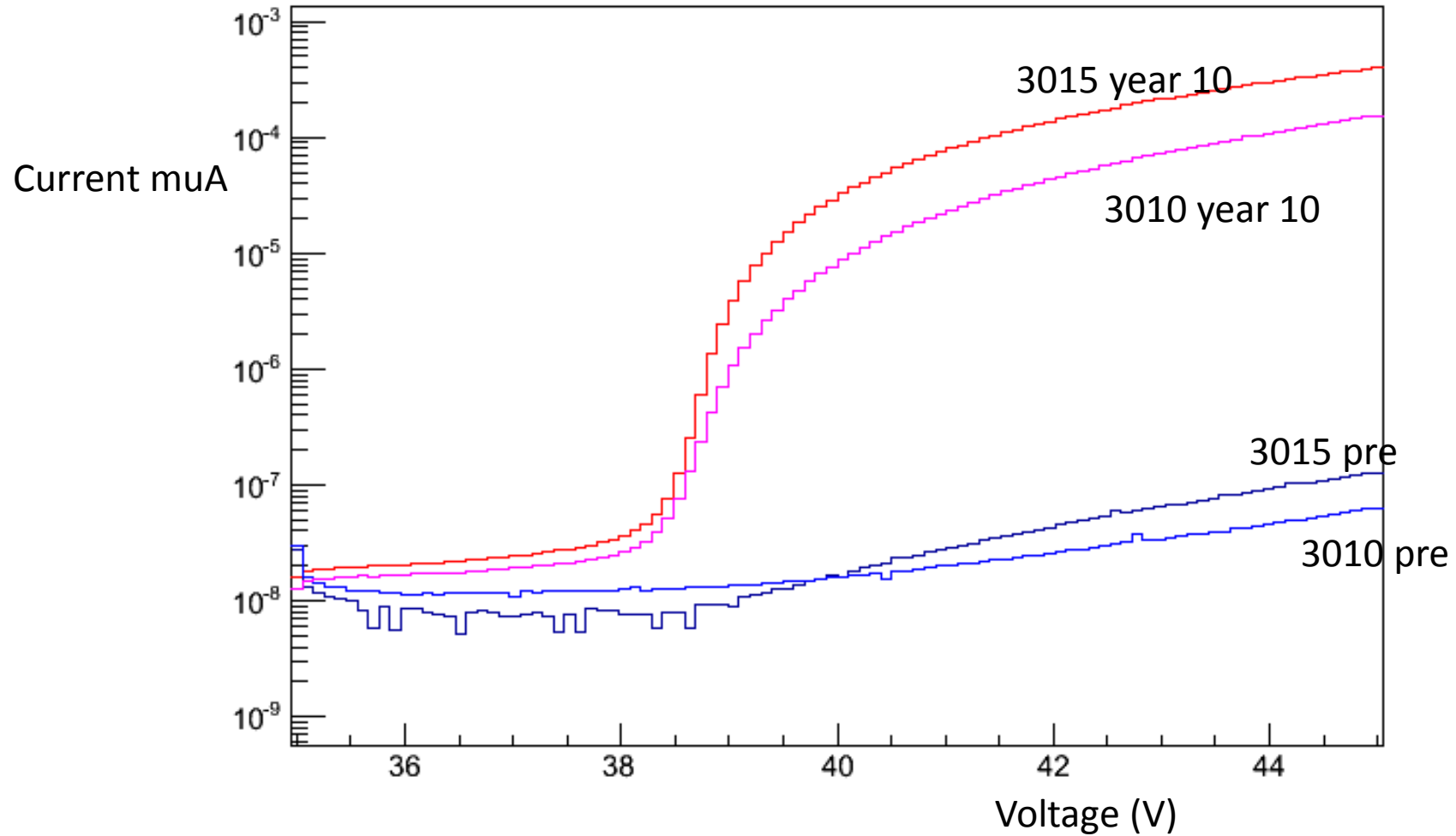


3015 ( (3mm)<sup>2</sup>, 10  $\mu m$  pixel)

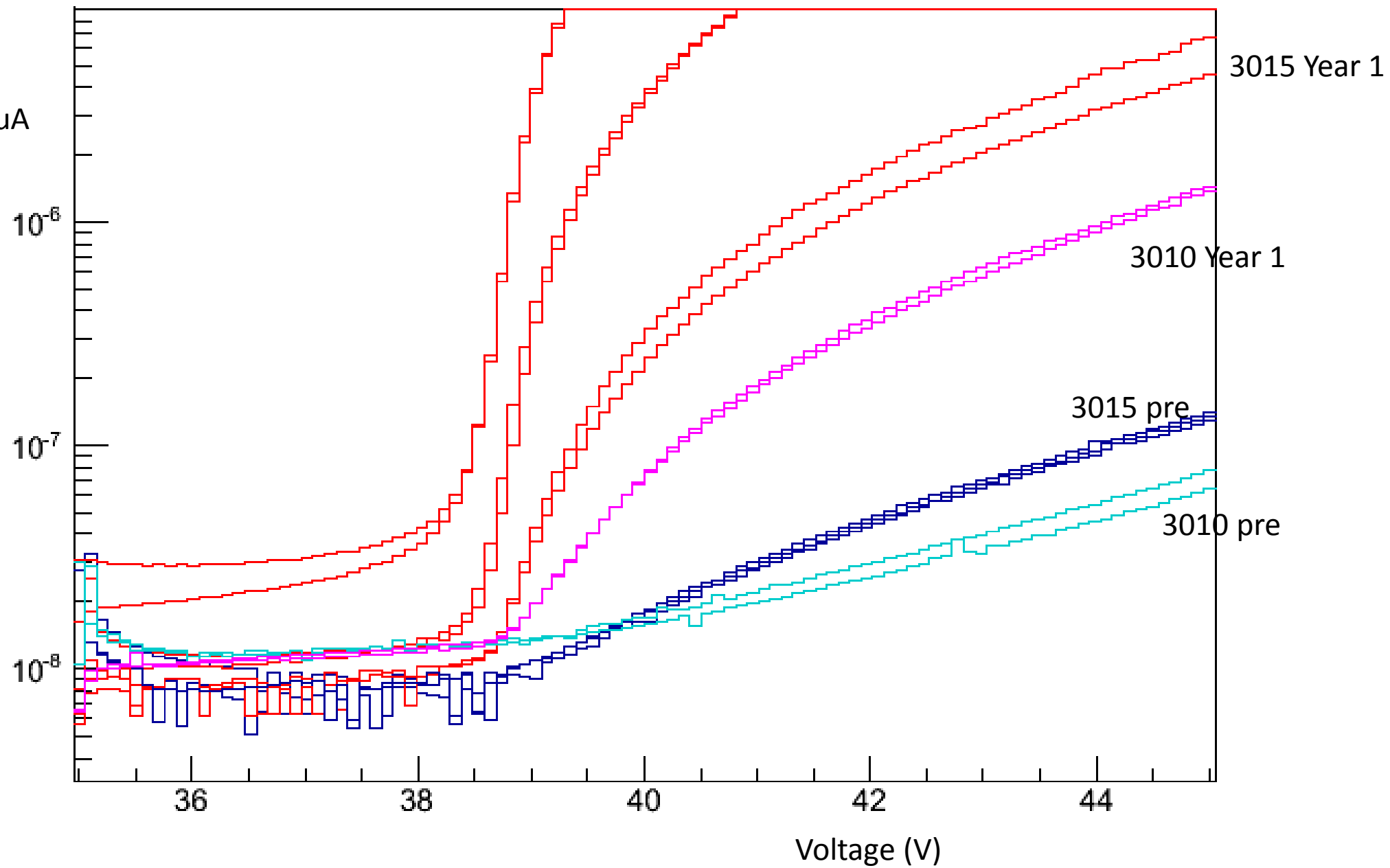




$(3\text{mm})^2$ ,  $15\ \mu\text{m}$  pixel vs  $10\ \mu\text{m}$

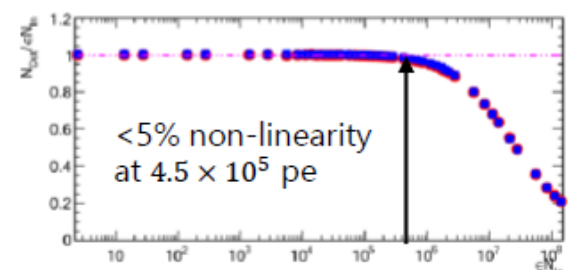
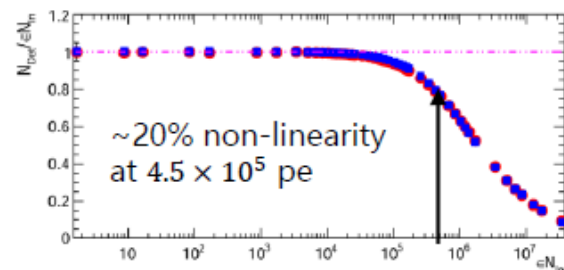
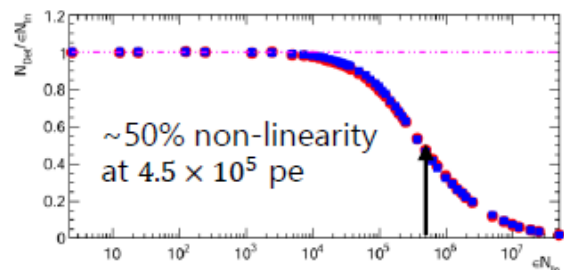
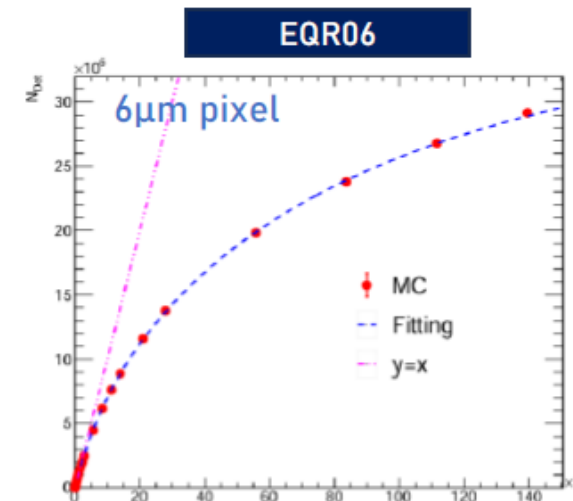
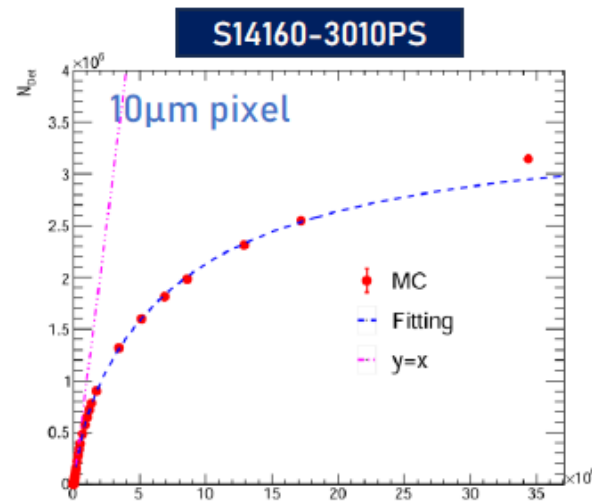
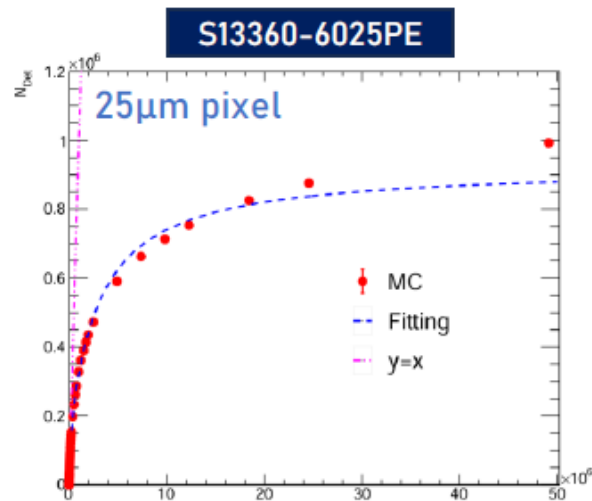


Current  $\mu\text{A}$



# Linearity in Presentations at CALOR2024

- Olivier pointed to some slides
- Initial non-linearity worse with 6mm pixel, but better able to be corrected?
- <https://indico.cern.ch/event/1339557/contributions/5898510/>
- **Also one with beam tests , but non-linearity w/ 6mm models there was due to leakage?**
- <https://indico.cern.ch/event/1339557/contributions/5898480/>



# Price Options Immediate Funds Needed

- Assume Sasha Bazilevsky Mechanism/Process gets needed funds for remaining needs, such as adapter board fab/assembly in late Aug/Sept timeframe
- Order siPM's ASAP
  - 3mm<sup>2</sup> siPM's came faster last time, still should be time to get in time, for 6015, order needs made ~now based on December order fulfillment times
- Costs: [10vs 15 mum always same]
  - 3mm : \$53/siPM, discount 100 unit: \$42/siPM, discount 300 \$19/siPM
  - 6mm \$125/siPM, discount 100 unit \$65/siPM
- discount level needs single buyer
- Some Options
  - Option 1) Single group buyer \$6500 – 100 6015 siPMs , \$7600 3015 500 siPM ALL new 25 channels worth
  - Other options : reuse some/all ones in hand, including some irradiated – maybe place on edges – expect some annealing – perhaps even baking could accelerate? 12-13 channels worth need ~12 more
  - Option 2) Many groups contribute, minimum, probably 3mm, around \$5500 (6mm is more expensive but similar)
  - Option 3) Many groups contribute, get more, probably 3mm, around \$8000- \$12K)
  - Option 4) Two groups contribute to get ~100 3mm's each 2 x 2980 = 6000

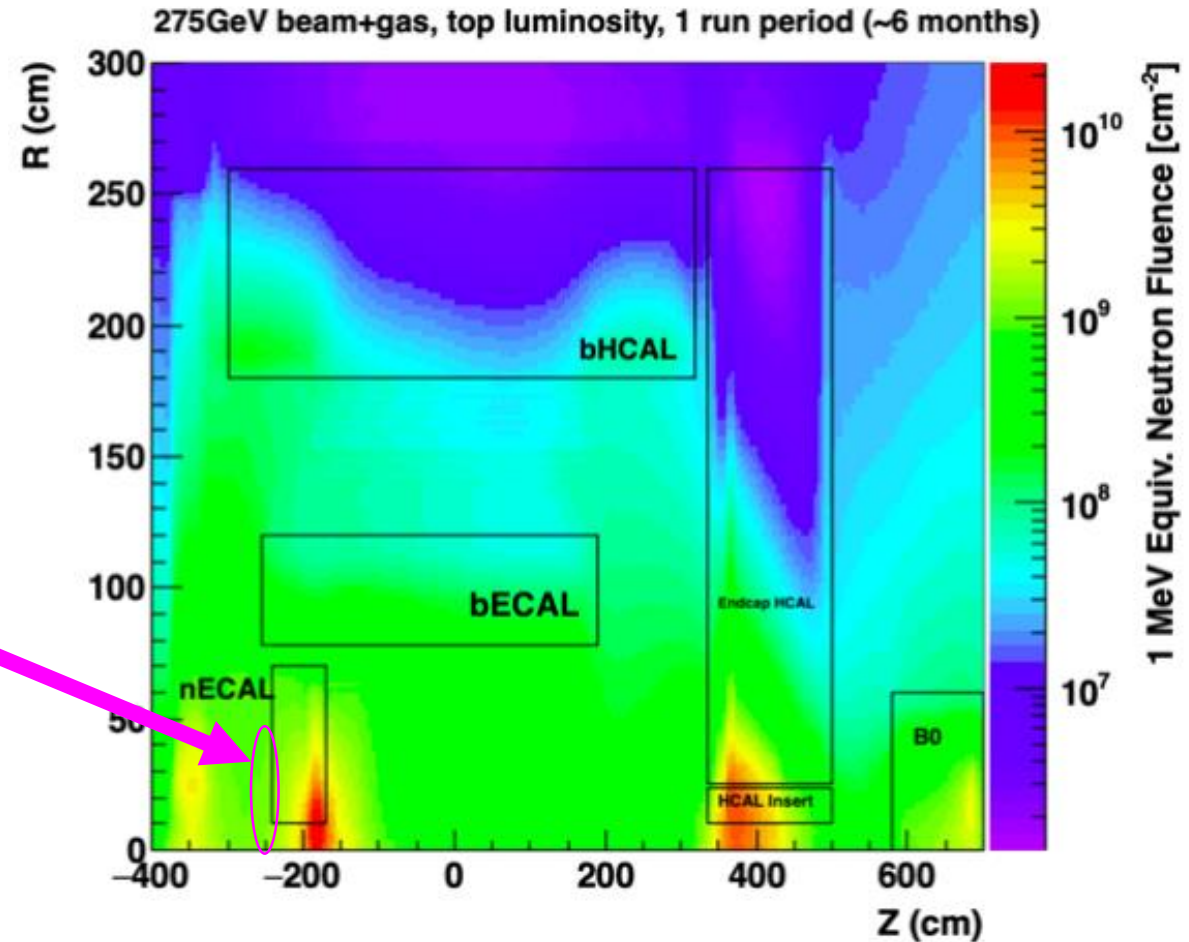
# FEB Decision

- Status Carlos/HGCroc – should be ready by October beam test time
- Gerard not sure, but probably can't have everything ready: can other engineering help get more in time?
- Can generic Flash ADC tell us enough info anyway, work on getting that set up over summer?
  - Carlo's can provide board for this, but would want help developing the solution.
  - Work needs to be done by other group (ie in US probably)
- FUNDS FROM FERNANDO FOR FLASH

# Backup

# siPM's Irradiation Plan: Ingredients

- Also after carefully looking at [https://wiki.bnl.gov/EPIC/index.php?title=Radiation Doses](https://wiki.bnl.gov/EPIC/index.php?title=Radiation_Doses) Carlos and I arrived at  $8 \times 10^9$  n/cm<sup>2</sup> for the inner most channels per standard year.
- $8 \times 10^{10}$  for 10 years
- In first year, expect half design lumi :  $4 \times 10^9$



# siPM's Irradiation Plan: Ingredients

- First one point, UC Davis (Proton) Beam Energy 60 MeV
- Can provide in different fluxes (see next slide)
- Using this plot Gerard sent for conversion to MeV Equiv Neutron flux

308

A. Akkerman et al. / Radiation Physics and Chemistry 62 (2000)

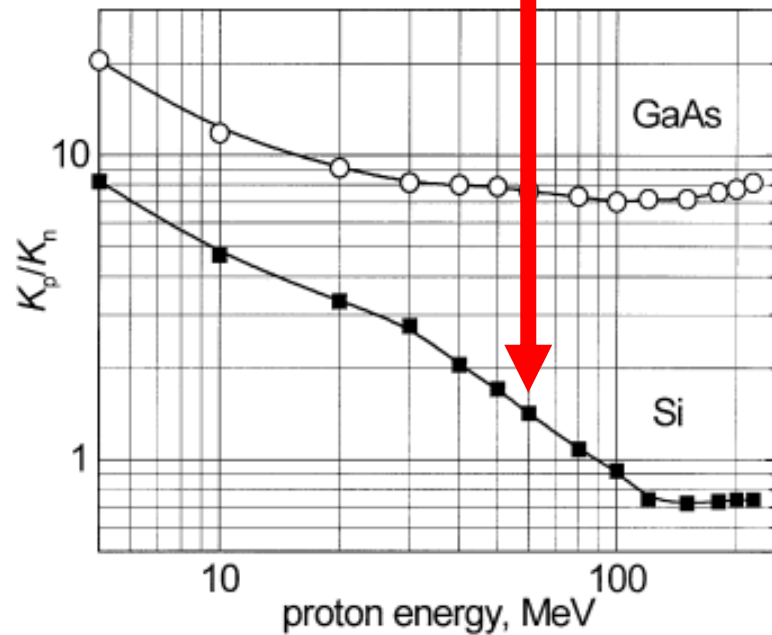


Fig. 6. The relative damage,  $K_p/K_n$ , as a function of proton energy where  $K_n$  is taken for 1 MeV neutrons.

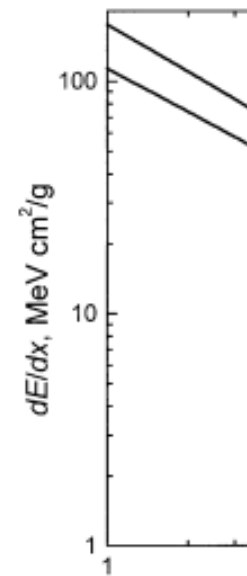


Fig. 7. The stopping power for GaAs as a function of proton energy (2000).

Assume 1.5 MeV/p as 60 MeV proton to MeV Neutron flux conversion factor



# siPM's Irradiation Plan - Proposal

Beam Flux (cm <sup>-2</sup> s <sup>-1</sup> )	Time (seconds)	Total Fluence (cm <sup>-2</sup> )	MeV n equiv fluence	Number of SiPMs/board
1.00E+08	540	5.40E+10	8.10E+10	Whole board of 20-3015 sipms
1.00E+08	540	5.40E+10	8.10E+10	3 S14160-3010PS (3mm, 10um pitch)
1.00E+08	540	5.40E+10	8.10E+10	2 S14160-3015PS (3mm, 15um pitch)
1.00E+08	540	5.40E+10	8.10E+10	2 S14160-6015 (6mm, 15um pitch)
1.00E+07	540	5.40E+09	8.10E+09	3 S14160-3010PS (3mm, 10um pitch)
1.00E+07	540	5.40E+09	8.10E+09	2 S14160-3015PS (3mm, 15um pitch)
1.00E+07	540	5.40E+09	8.10E+09	2 S14160-6015 (6mm, 15um pitch)
1.00E+07	35	3.50E+08	5.25E+08	2 S14160-3010PS (3mm, 10um pitch)
1.00E+07	35	3.50E+08	5.25E+08	2 S14160-3015PS (3mm, 15um pitch)
1.00E+07	35	3.50E+08	5.25E+08	2 S14160-6015 (6mm, 15um pitch)
as carlos suggests if we can retest this last bunch, and then re-irradiate, then shoot for longer on these to make 4e10?				

# “Initial Guess” Decision for Impending siPM

- Purchase (not) voted for 3015
- Funds may limit : 3mm models 1.6-2 times more expensive
  - They are ~1.65 times more expensive for same surface area
  - They are ~2 x times more expensive since we can/want to include 4 more siPMs on top of 16 equivalent, 25% more
- Any further ideas on how to make this decision – irradiation testing should tell us something?

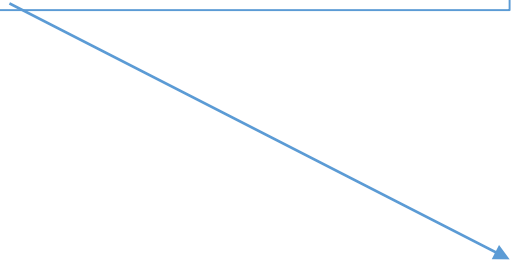
# Ultimate Decision for siPM choices

- What goes into this decision:
  - Linearity (not really as much a concern? all should be linear enough after correction)
  - Noise characteristics around 5 MeV threshold most important
- Can we get information from NPS on expected light yield, etc...?
- Test benches being set up at Ohio, Lehigh, already at ACU –
  - Can test with sources, cosmics, LED crystals no crystals

# List of Needed Performance Parameters

- **Energy Resolution** (cluster)  $2.5\%/\sqrt{E} + 1\%$ 
  - **Earlier 2023**  $1\% + 2.5\%/\sqrt{E} [+ 1\%/E ?]$
- **Spatial resolution:**  $1 + 3\%/\sqrt{E}$
- **Linearity** : correctable to 0.5%
- **Threshold (single tower)** :  $\sim 5$  MeV [[Bazilevsky studies](#)]
- **Dynamic Range:** Tower level 2-5 MeV to  $\sim 15$  GeV (x 7500-3000) (Cluster level -20-100 MeV – 20 GeV)
  - (assume  $\geq 1-3$  ADCU per 5 MeV – which is threshold target.)
  - In pC :  $\sim 10$  pC to 30-75 nC [?]- per channel : (min 10 pC from summer epic calo questionnaire document answer of “10-10000 pC”)
  - ADC : 14bit [?]
- **Rate Capability** : 20-100 kHz (highest [eta?] channels): Dominated by beam backgrounds, to be confirmed by further studies

This 20 is an old number?  
YR: 50 MeV, later studies 100 MeV OK



# List of Needed Performance Parameters

- **Waveform/timing:** All three of the below TBD
- *Timing resolution* : identify bunch crossing  $\sim 10$  ns -- [can assume  $\geq 2$  tower measurements if needed  $\rightarrow 14$  ns?]
- *Peak Time, N\_samples* :  $\geq 3-5$  in Peak + 2 pre-pedestal?
- *Sampling rate* : determined by above 40-80 MSPS
- 
- **Noise Requirements** TBD by timing/resolution requirements: Pre-raddamage : DCR  $\leq 3-10$  MHz Dark Current:  $\leq 1.4$  microAmps [Gerard's fEcal siPM presentation] Post-rad-damage

# List of Needed Performance Parameters

- **Temperature/ Heating :**
- ***Temperature Sensitivity of siPM's*** - (Confirmation) tests of this would be good w/ w/o rad damage etc... look for opportunity
- ***Temperature Stability Requirement*** - tied to previous, later studies?
- ***Power consumption / Heating*** Pre-amp location [on adapter or preferably on IU adc board w/ 60 cm cable] - will be tested by Gerard IU.
  - TBTtested with Dark current increase from Irradiation tests

# Adapter Boards

- **Designs :**
- Larry: Updated (finished?) designs for 4x4 6010 and 6010 independent readout[details on ind] [also 6015?] adapter boards]
- We currently don't have board designs for 3mmx3mm models? Can we again start with the 3x3 = 9 siPM boards (made for previous prototype testings)
- For sooner tests if siPM's delayed can we make a customized board for say four 3mm sipm - usefl?
- **Production of Testing Adapter Boards:**
- How much? Can Gerard/someone make cheap test boards?

# Gerard recent studies for fEcal w/ 6015 siPM's

- Gerard presented study for fEcal Readout [last week at Calo mtg](#):
  - Parts can be applied almost directly or done similarly for us to us?
- LED testing for 4 6015 siPM's on test adapter board - different pre-amp expectation than for us?
- Different dynamic range need (15 MeV threshold – 100 GeV) different light yield conversions
- Showed behavior of near threshold (for fEcal 15 MeV- ~20 pixel) and higher pulse and digitization characteristics
  - 13.5 pixel RMS 4.5 w/ simulated 100  $\mu$ A dark current rad damage RMS @ 13 is **18**
  - Timing resolution: assuming 14bit ADC digi-noise 39MSPS sampling need 5 ADCI pulses to achieve bunch crossing 10 ns resolution



# Testing Proposals (who does them next slide?)

- Repeat Gerard's last tests on all (other) siPM's models
  - mostly same stuff done , but for other siPM models (too much work?) x 3
  - Independent readout of 6015 board? + 1 or x2
  - do we need to better characterize the LED for PDE do we want cosmics/crystals?
    - Need calibrated comparison (e.g. PMT) setup – at least for cosmics?
- Not covered so far but to be added
  - same tests : sim rad damage → real rad damage – repeat same tests?
  - Timing resolution is a pure sim study, can be done by anyone – To be improved by real pulse shape [pulse shape can be adjusted by design of adapter board,etc.]



[https://wiki.jlab.org/cuawiki/index.php/OVERVIEW\\_OF\\_SPECIFICATIONS](https://wiki.jlab.org/cuawiki/index.php/OVERVIEW_OF_SPECIFICATIONS)