SiPMs Radiation Tests
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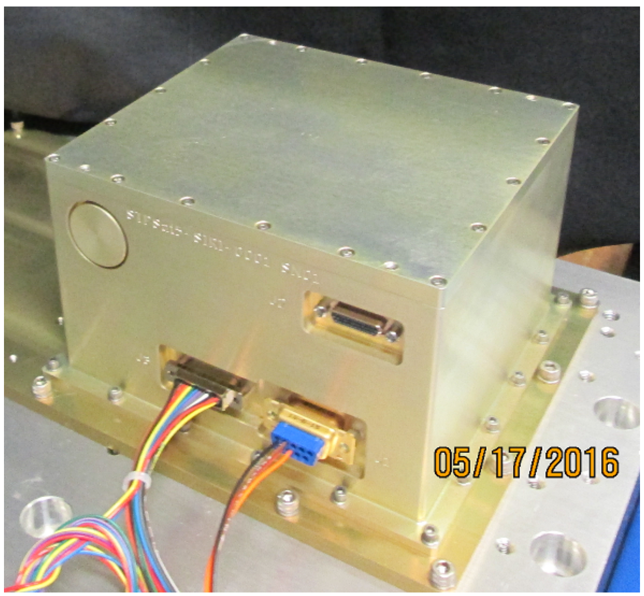
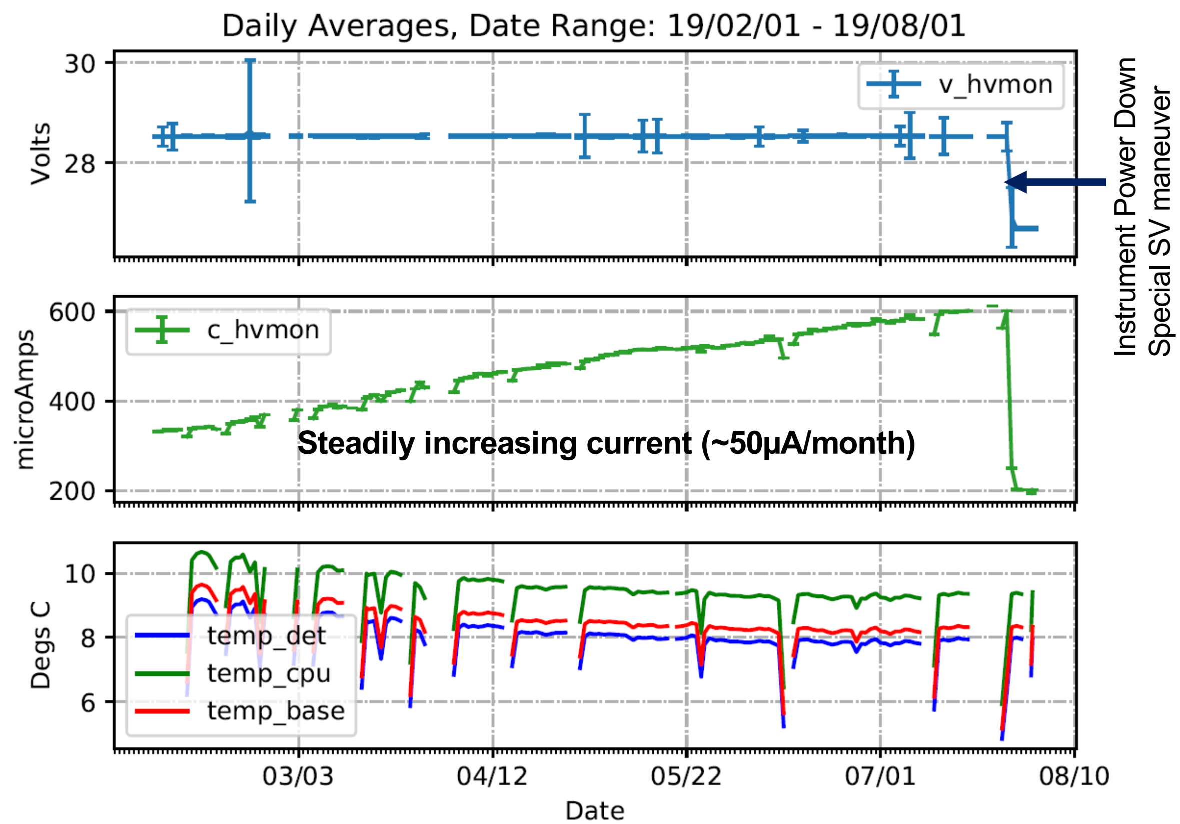
Motivation for Test

- SIRI-1 instrument was in orbit from Dec. 2018 –Dec. 2019 (~12months)
- Primary mission - study the harsh radiation environment's effect on a the scintillator material (SrI_2:Eu) and SiPM readout technology.
- Sun synchronous orbit at 600 km.
- Current increase in SIRI-1 ~50 uA per month





Spacecraft had issues (randomly go in to safehold)

Test Objectives

- Objective: Quantify radiation effects on a variety of SiPMs
- Focused on the current issue
- Measurements made at the UC Davis Cyclotron
- Targets were irradiated at with 64 MeV proton beam
- SiPM Products Tested
  - SensL
  - KETEK
  - Hamamatsu
  - FBK (AdvanSiD) One of the few groups working on rad tolerant SiPMs (High-energy colliders).
- Exploring potentially better options in for future mission.
  - GARI-1&2
  - SIRI-3
  - Glowbug
  - AMEGO (Calorimeter)

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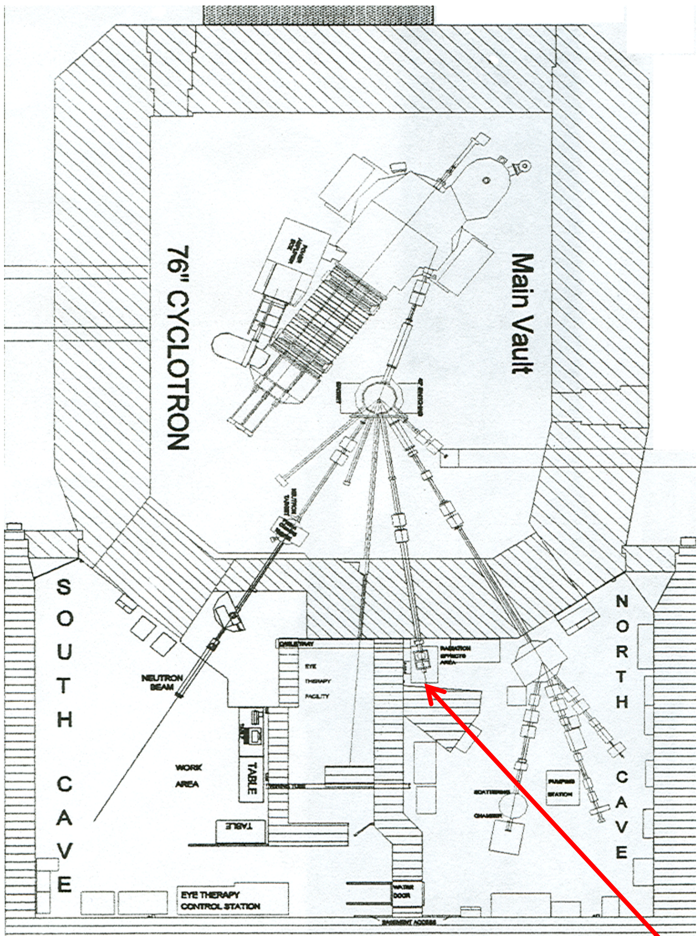
Test Information

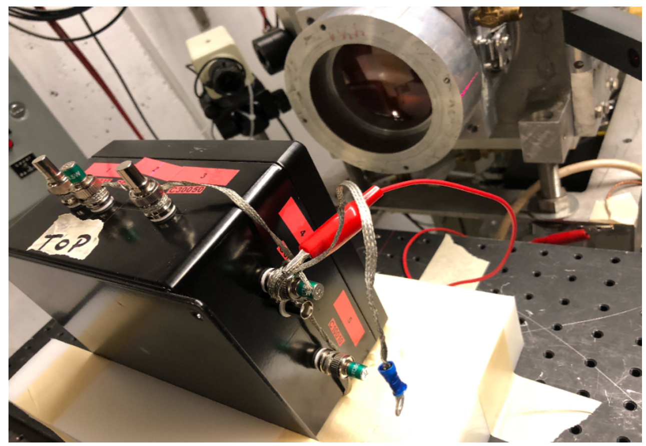
- Test were conducted at the UC Davis Cyclotron in Davis California using a 64 MeV proton beam with a diameter of 6cm.
- Allotted ½ a day of beam time to complete measurements.
- SiPMs mounted in two tests boxes (See next slide for FBK box).
  - DUTs required to be enclosed in ~6 cm diameter of uniform beam.
  - SensL J-Series SiPMs (60035) have shown good reproducibility in the past and we used these as a way to validate dose across measurements
- Test boxes were irradiated and the current as function of voltage was measured between each irradiation.
- Irradiation times were around 5 mins, beam current was adjusted higher as we asked for larger fluence to keep this to a minimum.
- To efficiently use our beam time, one box would be undergoing irradiation while the other test box was being measured.

Irradiation Information



Map of UC Cyclotron Facilities.

Sample Irradiation Beam Port



Test box in front of beam port. Laser alignment used to center target on beam. SiPMs ground during irradiation.

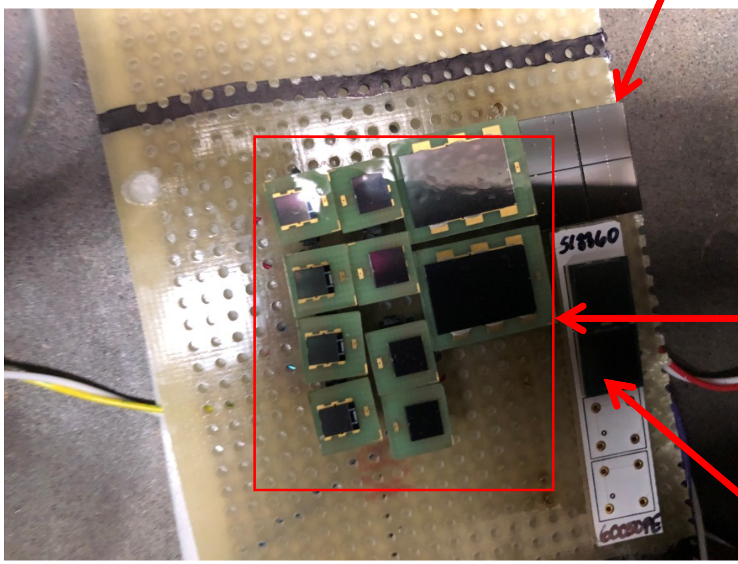
Fluence	Cum. Fluence
0	
2.60E+06	2.60E+06
2.57E+06	5.18E+06
4.99E+06	7.56E+06
1.01E+07	1.51E+07
2.00E+07	3.01E+07
3.98E+07	5.98E+07
8.02E+07	1.20E+08
1.59E+08	2.40E+08
3.19E+08	4.78E+08
6.43E+08	9.62E+08
1.28E+09	1.92E+09
2.56E+09	3.84E+09
5.10E+09	7.66E+09
1.02E+10	1.53E+10
2.04E+10	3.06E+10

Fluence in protons/cm^2

Test Box Design

SensL 2x2 J-Series (60035)_b

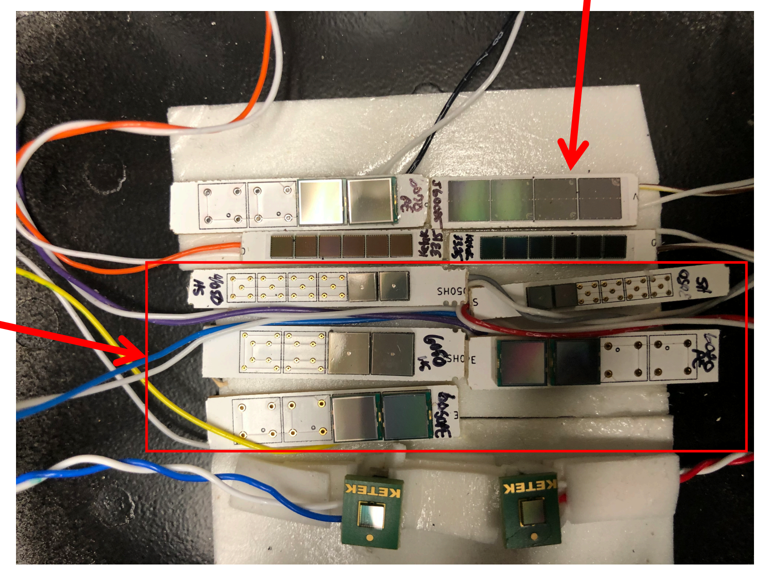
SensL 2x2 J-Series (60035)_a



FBK SiPMs

Hamamatsu

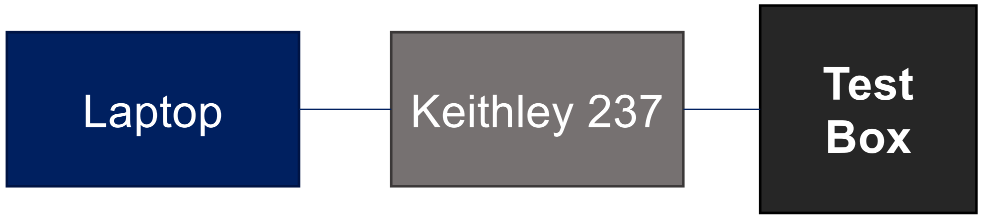
Test Box #2 Contents



KETEK

Test Box #1 Contents

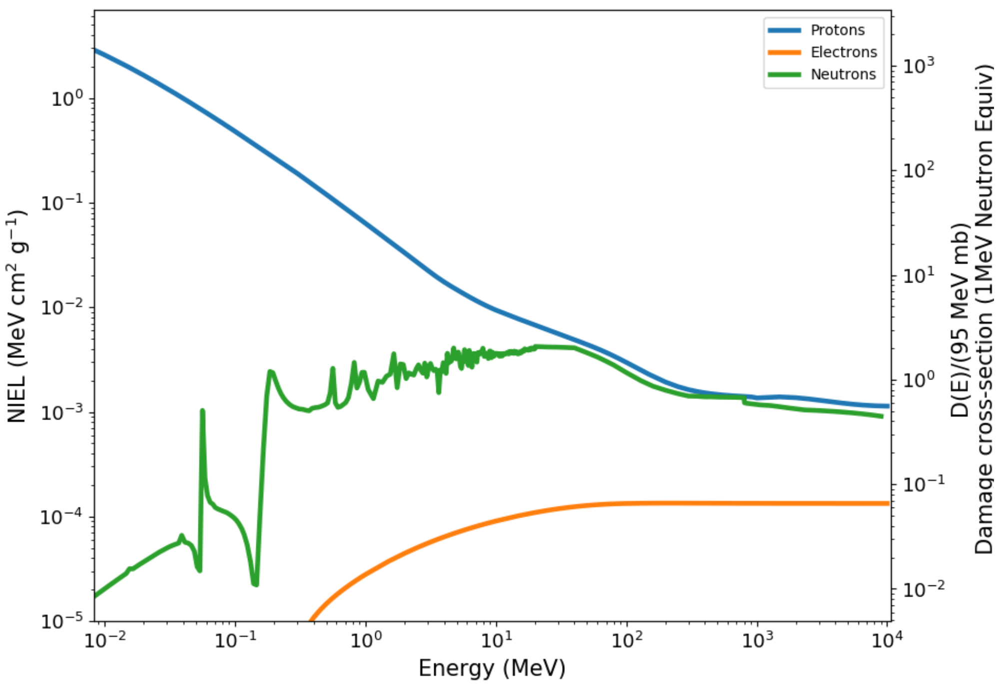
IV Measurement Setup



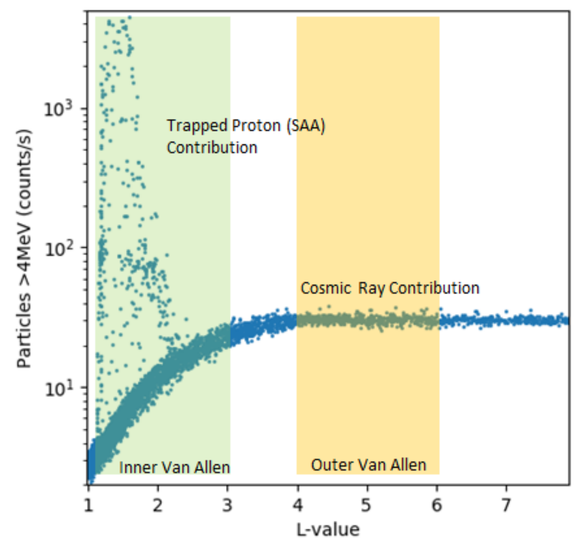
Electronics Setup

- Laptop commands Keithley 237 to cycle through a range of voltages specific for each SiPM type @ 0.5V resolution
- Voltage ranges varied for each SiPM type, but typical the overvoltages ranged between (-1V to 6V)
- Overvoltage here is defined as the $V_o = V_{bias} - V_{breakdown}$
- Currents varied orders of magnitude throughout the test (1uA to 100mA).
- Keithley current resolution is set by the scale (in this case the maximum current).
- Scanned predefined voltage range over 4 current scales (0.1mA, 1mA, 10mA, 100mA) resolution~7nA at the lowest scale

Some Theory

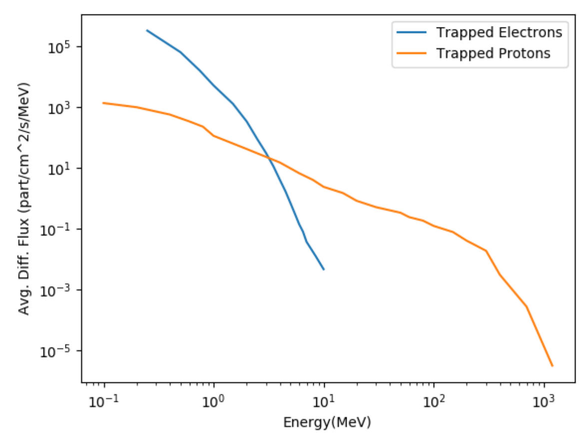


Non-ionizing energy loss as a function of energy for three particle types.



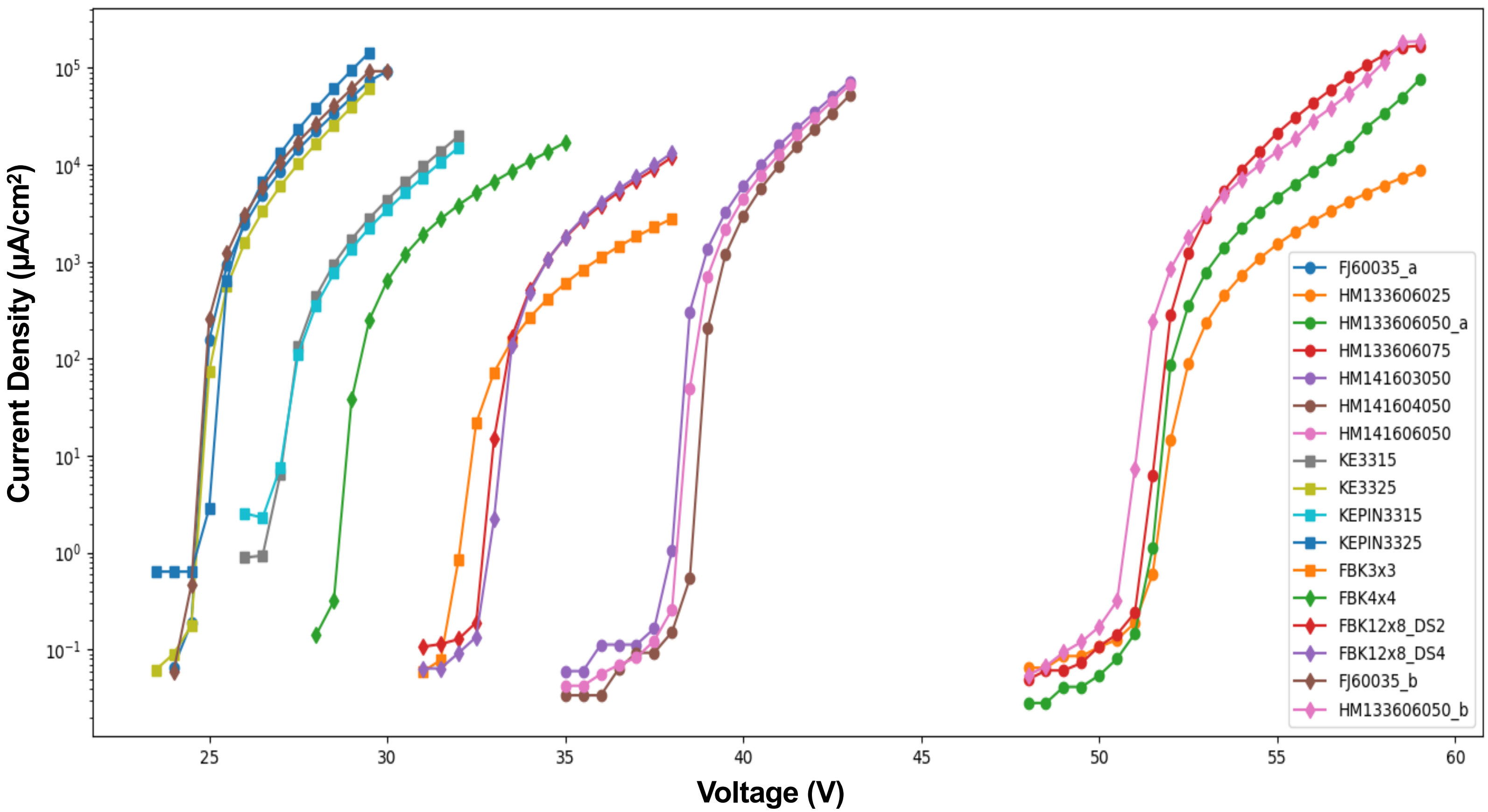
Plot shows the counts/sec of the overflow bin (>4 MeV)

- The effects we are interested in are a result of the Non Ionizing Energy Loss (NIEL) of the incident particle.
- Well studied phenomena, especially in silicon detectors.
- SIRI's sun synchronous orbit encounter trapped protons, trapped electrons, and cosmic rays.
- For us the bulk of the damage is from trapped protons when transiting the SAA.



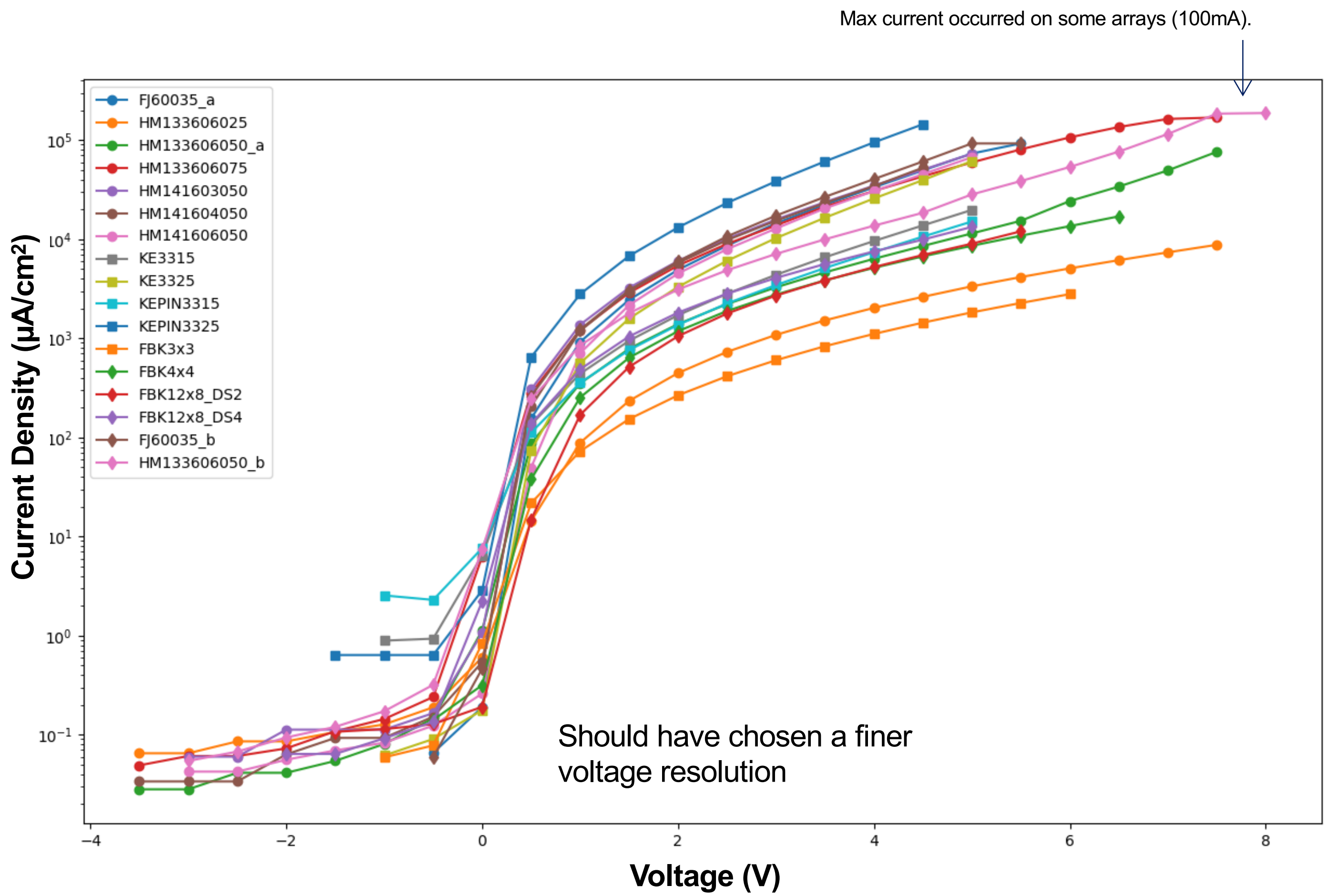
AE9 and AP9 predicted average differential fluxes for both trapped electrons and protons. Latitude, longitude, and altitude data from the month of April 2019 was used as the input ephemeris file for the model.

Comparing different SiPMs



IV curves for the various SiPMs at one fluence (3.06E+10 p/cm^2) plotted as a function of voltage.
Doesn't really show much since they all have different breakdown voltages.
Need to plot them versus overvoltage.

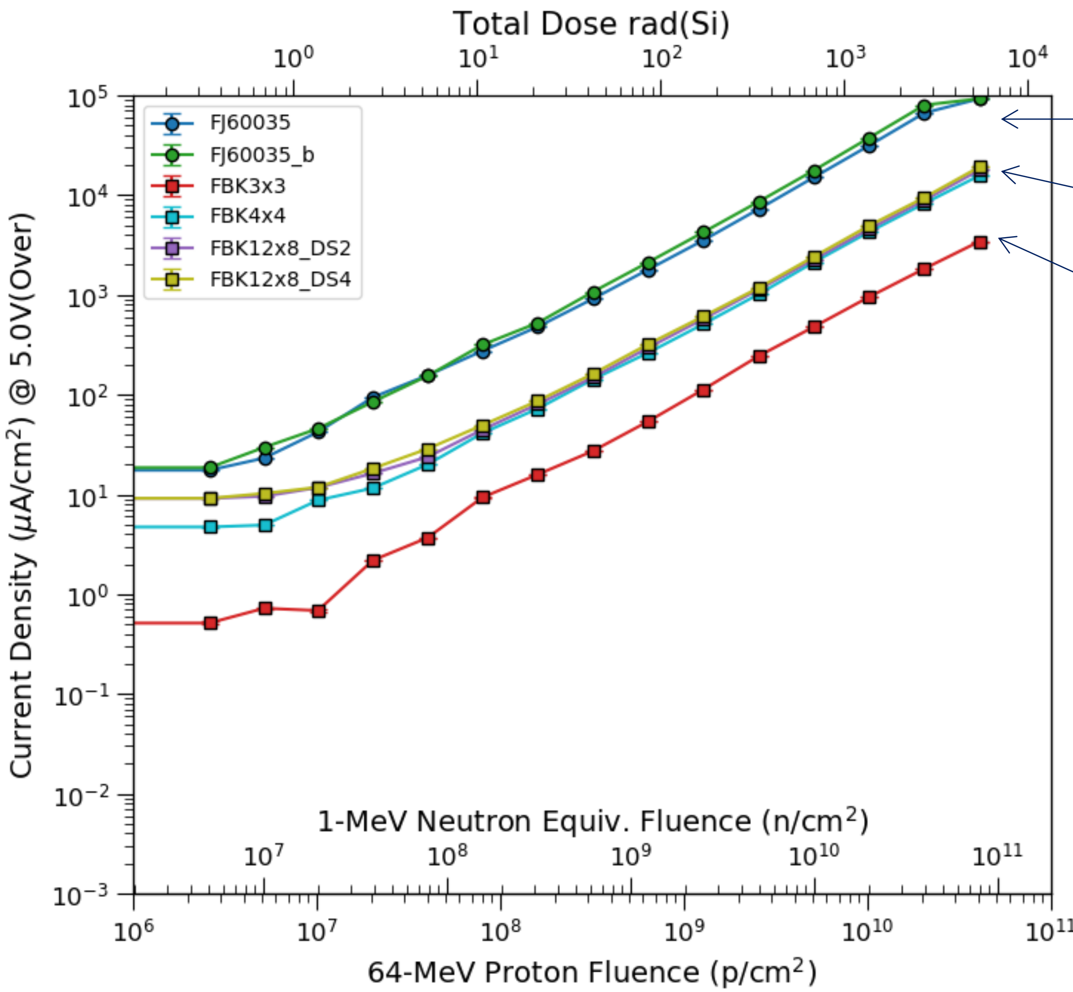
Plotted as a Function of Overvoltage



Note: Here we only compare current density as a function of fluence at a specific overvoltage between different manufacturers. From a radiation detector standpoint other factors are important as well, such as gain, noise level, shifts in the break down voltage, general performance….

IV curves for various SiPMs at one fluence (3.06E+10 p/cm^2) plotted as a function of voltage
Next step would be to line them up according to over voltage (= bias – breakdown voltage).
Allows for some comparison (not a perfect comparison)

FBK vs SensL



2x2-6mm x 6mm SensL J-series 35μm
From Box#1 and Box#2 (hit maximum current on last measurement)

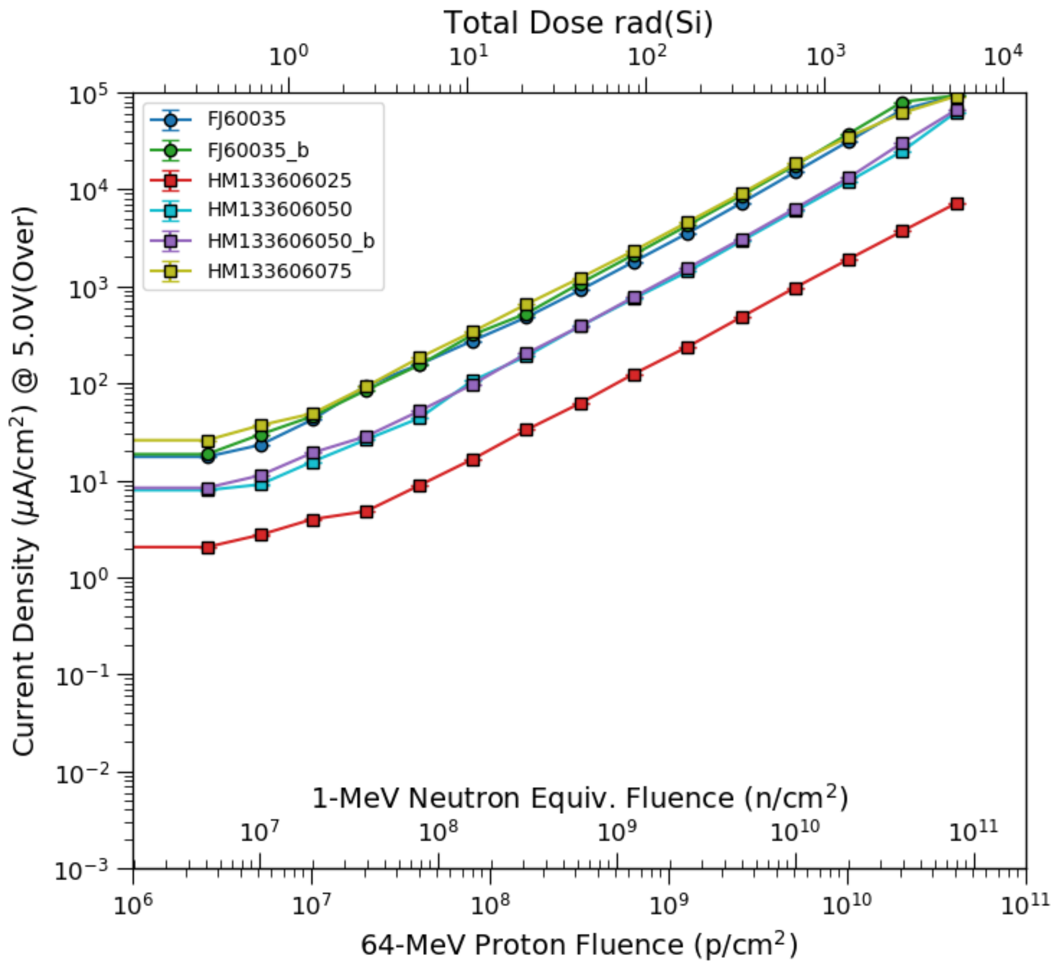
4x1 4mm x 4mm 35 μm FBK
1x1 12mm x 8mm 35 μm FBK DS2 & DS4

4x1 3mm x 3mm 15 μm FBK

Note: As we have seen in the past from other manufactures, smaller cell size amongst comparable designs show less susceptibility from a current standpoint.

Plot of Current Density as a function of fluence(dose). Current is normalized by the active area (Note: we are considering active area to be the photosensitive area.)

Hamamatsu vs SensL



Note: As we have seen in the past from other manufactures, smaller cell size amongst comparable designs show less susceptibility from a current standpoint.

Plot of Current Density as a function of fluence(dose). Current is normalized by the active area (Note: we are considering active area to be the photosensitive area.)

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Conclusion

- Other factors effected by the radiation damage may be more important.
  - Degradation in energy resolution, gain shifting, increase baseline noise level
  - Did not see these to any large degree with SIRI.
  - Like to see some better controlled experiments on the ground that quantify these additional parameters.
  - Number of other SiPM properties not all that important to our work, but are important to other experimenters.
- Bulk of the damage in our case is from the trapped protons in the SAA.
  - Scenarios with SiPMs are exposed to large fluxes of trapped electrons.
  - Interplanetary, concerned with cosmic-rays
- Mitigation for us has largely been focused on the current issue.
  - Shielding (from the back)
  - Lower voltage if possible.
  - Smaller microcell SiPMs when possible.
  - Rad tolerant SiPMs ??? (We are exploring FBK options).
  - Or just use a bigger power supply (obviously other engineering limitations there)
- Its difficult to say one is necessarily better than the other since factors such as the increase in gain per voltage step is important as well.