Application of p-i-n Photodiodes to Charged Particle Fluence Measurements Beyond 10^{15} 1-MeV-neutron-equivalent/cm^2

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Introduction

- Some detectors planned for use in the HL-LHC will need to operate at fluences 20x the LHC specifications or higher
- Techniques described in this study seek to extend the linear regime of forward voltage versus fluence for real time measurements
  - This will facilitate radiation campaigns involving new particle tracking detectors where the goal is optimal operation at high fluences

See full details of the study here:

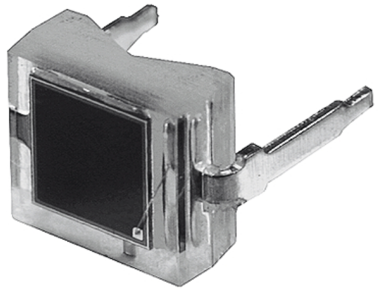
M.R. Hoeferkamp, et al., NIMA 890 (2018) 108-111, https://doi.org/10.1016/j.nima.2018.02.070

And here:

P. Palni, et al., NIMA 735 (2014) 213–217 http://dx.doi.org/10.1016/j.nima.2013.09.037

p-i-n Diodes

- The LHC Radiation Monitoring System (RadMon)* was developed to monitor and measure radiation levels in order to avert equipment failures
- Several device types were characterized and found to be appropriate for use as radiation monitors**
- The commercially available OSRAM BPW34F p-i-n diodes have been used in this study and have the following characteristics:
  - Fabricated with n-type silicon of resistivity approximately 2.5 kΩ-cm
  - Base length of ~ 210 μm and cross section of 2.65 mm^2
  - Sensitive only to damage produce by fast hadrons (E > 100 keV). Almost insensitive to photons.



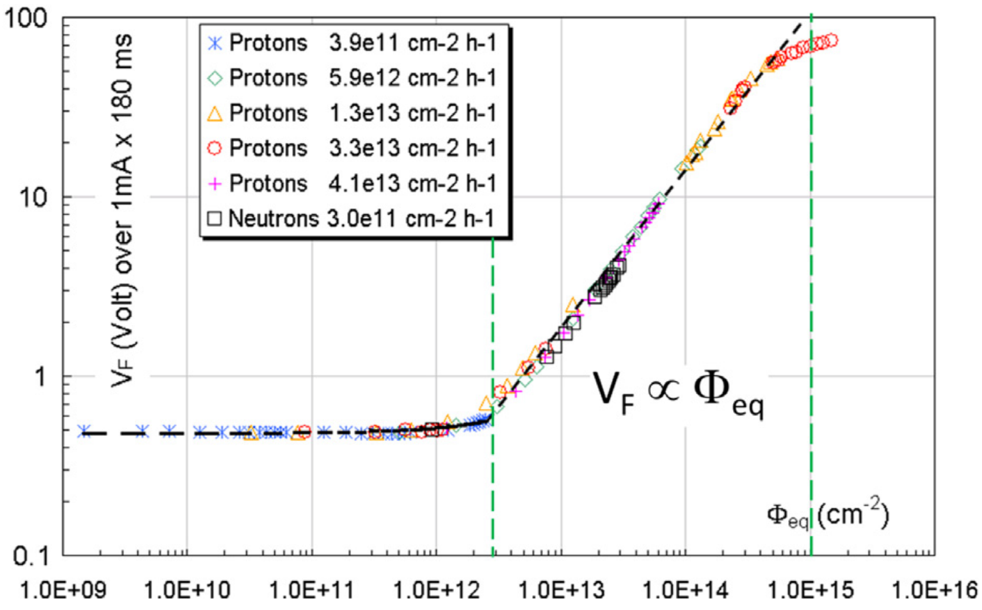
OSRAM BPW34F p-i-n Diode

* G. Spiezia, et al., The LHC Radiation Monitoring System - RadMon, PoS RD11, 2011, p. 024.

** Sensor Catalogue for Radiation Monitoring, https://ep-dep-dt.web.cern.ch/irradiation-facilities/radmon

Forward Voltage ∝ Fluence

- Forward voltage across the diode has been shown to increase linearly with fluence when supplied with a constant forward current*
- The linearity range has been observed to extend from about 2×10^{12} to about 2×10^{14} 1-MeV-neutron-equivalent (neq)/cm^2
- Our goal is to extend this range beyond 10^{15}

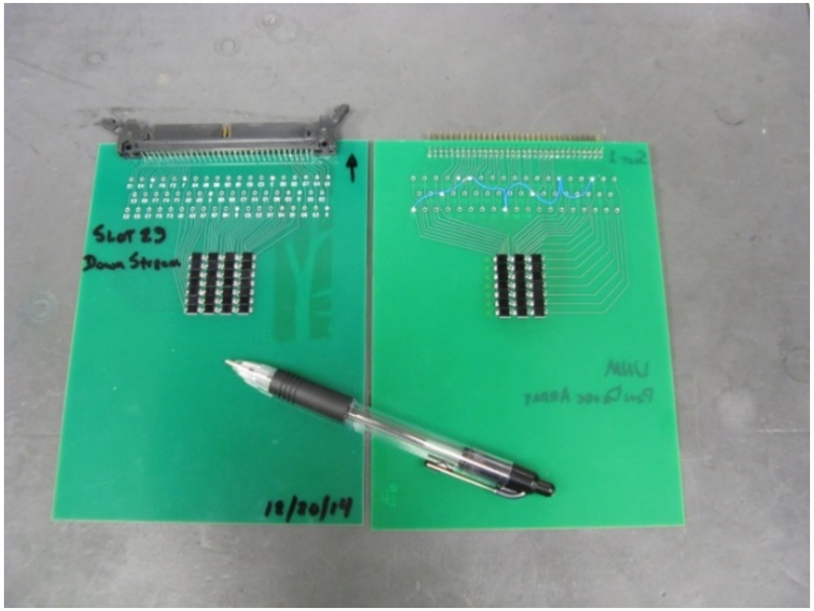


* F. Ravotti, Development and Characterization of Radiation Monitoring Sensors for the High Energy Physics Experiments of the CERN LHC Accelerator, Dissertation, Université Montpellier II, 2006 (PhD Dissertation), pp.123–124.

Diode Array

- An assembly of 49 diodes, arranged as a 7 × 7 matrix, has been used for real-time monitoring of the fluence applied by a charged particle beam to a target
- The pitch between diode centers is 3.8 mm and the resolution is 1.1 mm

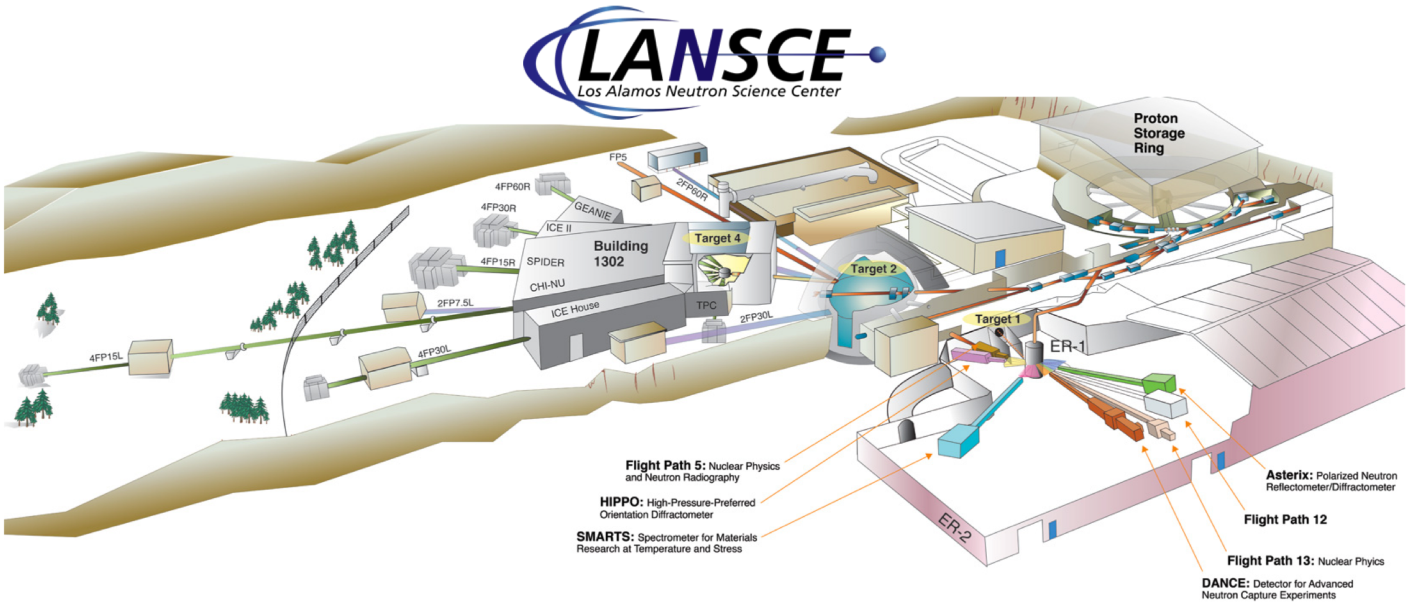
Diode Array



Picture of two boards, showing the front and back sides of a typical array

Measurement Strategy

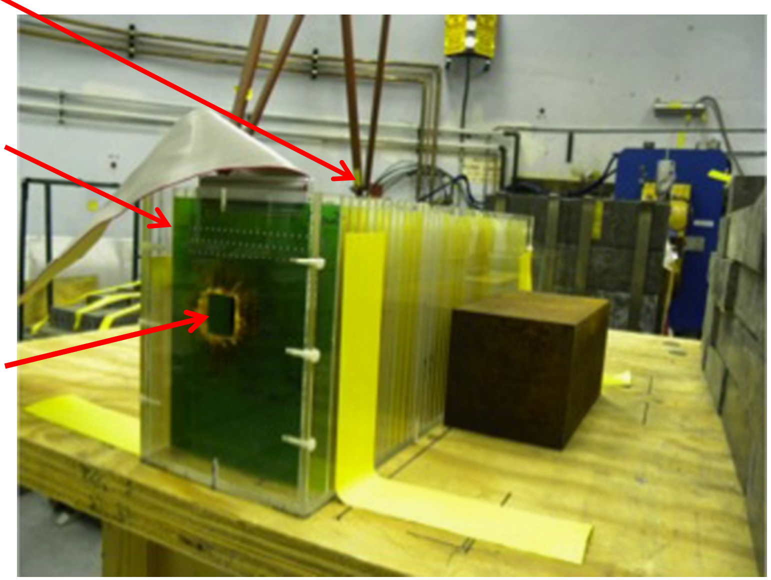
- The diodes are irradiated at the Los Alamos Neutron Science Center (LANSCE) up to fluences of 3.8×10^{15} neq/cm^2 with an 800 MeV proton beam
- In parallel, aluminum dosimeters are irradiated to the same fluences as the diodes
- After the irradiation, the sensors are stored in a freezer to minimize annealing effects



Experimental Setup

- In the image on the right, the experimental setup at LANSCE is shown
- Many samples are irradiated along the beam line
- Real-time forward voltage measurements are made with the diode array including transverse plane spatial resolution
- The aluminum foil activation is used to calibrate the diode response to fluence

The LANSCE Irradiation Hall

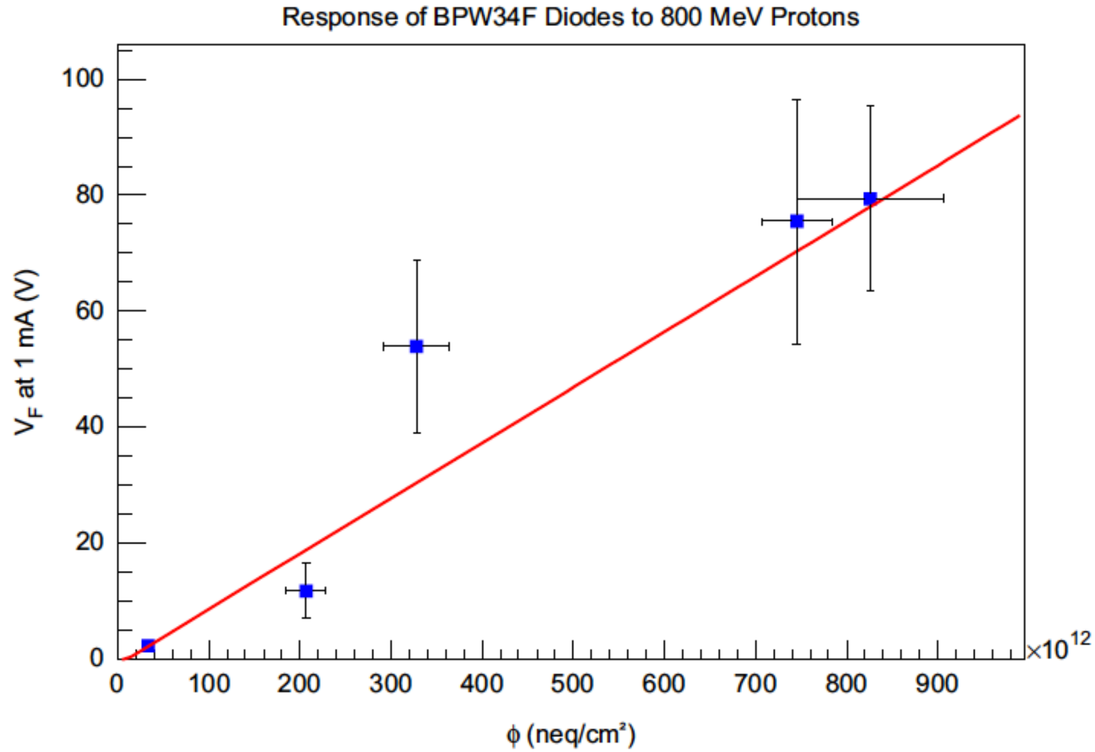


Measurements

- Back at the lab at UNM, optimization of the diode measurements is done.
- Diodes are temporarily brought to room temperature with the use of a thermal chamber
- Current is applied to the sensors in the diode arrays individually
- A circuit is used to modulate the pulse-width of the source current.
- This setup allows for a variety of combinations of measurement conditions.

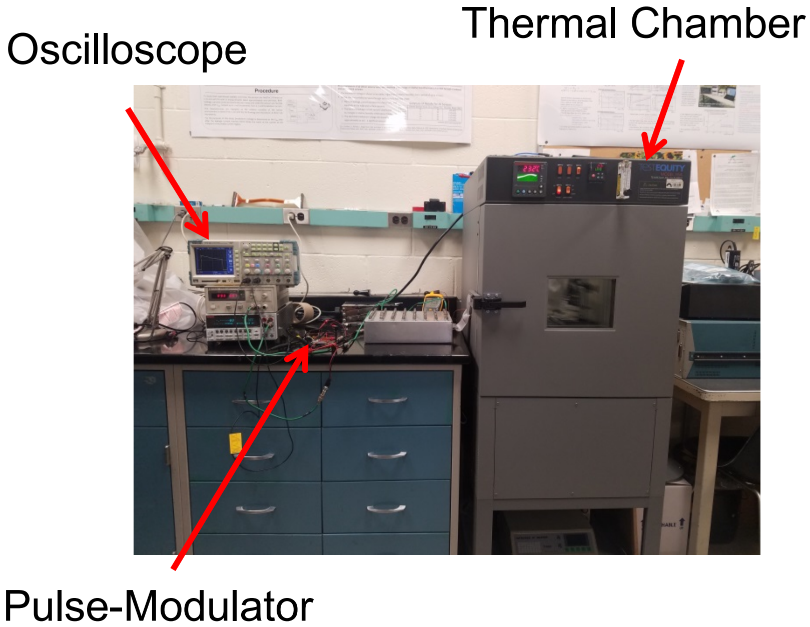
Calibration Plot

- The aluminum foils are analyzed with a gamma spectrometer and the decay of Na-22 is used to obtain the fluence
- In the figure here is shown the calibration plot of forward voltage of the diode array at 1 mA versus fluence.
- The linear coefficient of the fitted line is $9.558 \pm 1.536 \times 10^{-14}$ neq/cm^2 for the 800 MeV proton beam

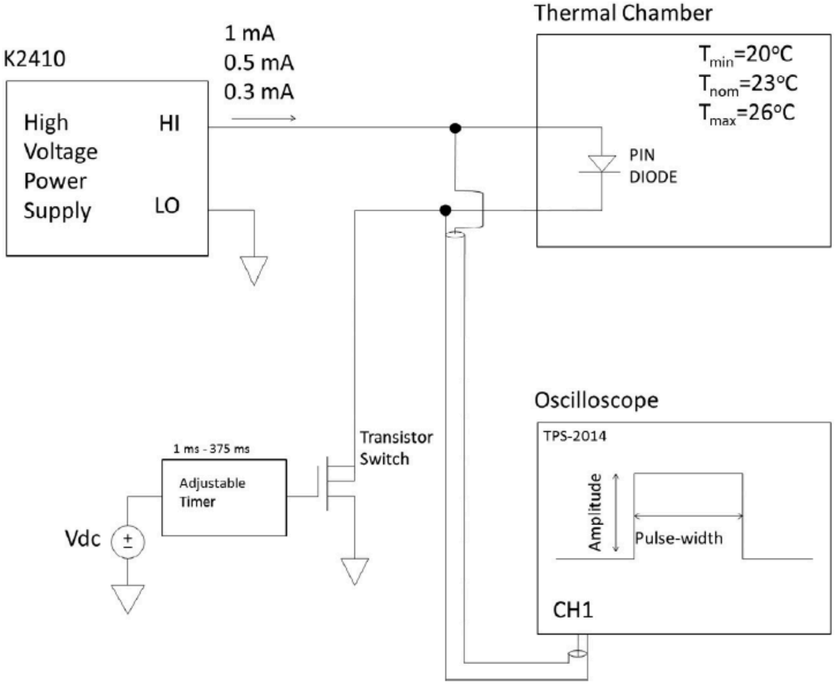


Measurement Setup

- The measurement setup is described in the diagram below
  - Pulse width can be varied with the adjustable timer
  - Magnitude of the pulsed forward current can be set with the high voltage power supply
  - Diode temperature is controlled with a thermal chamber
  - Measurement is made with an oscilloscope



UNM Lab Equipment

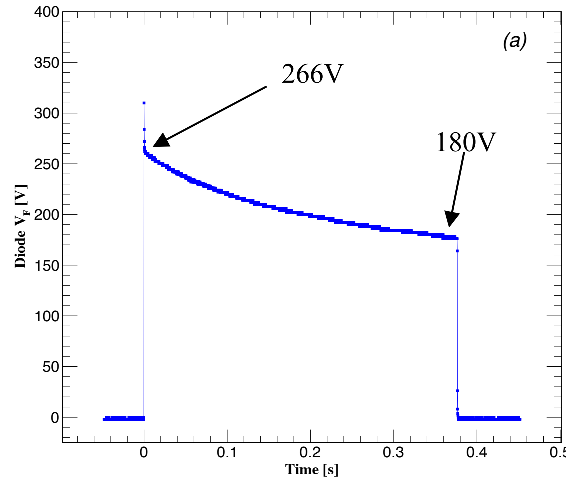


Measurement Diagram

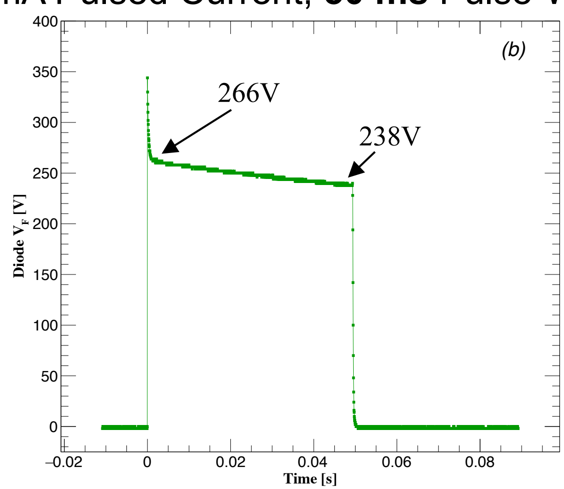
Various Pulse Widths

- A decrease in amplitude is observed with increasing pulse width
- Accuracy of the measurement is compromised with larger pulse widths so the shortest achievable width is used

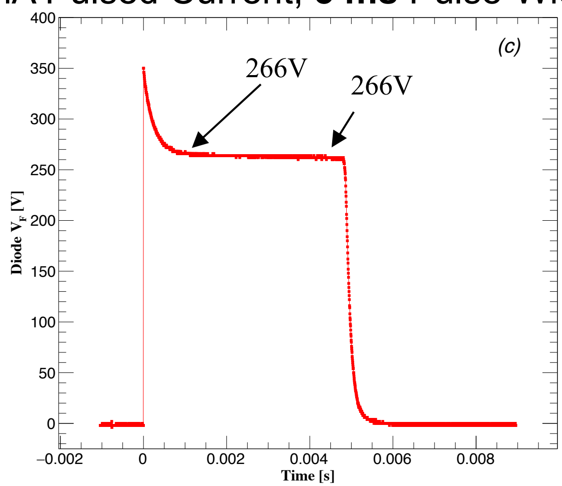
1 mA Pulsed Current, **373 ms** Pulse-Width



1 mA Pulsed Current, **50 ms** Pulse-Width

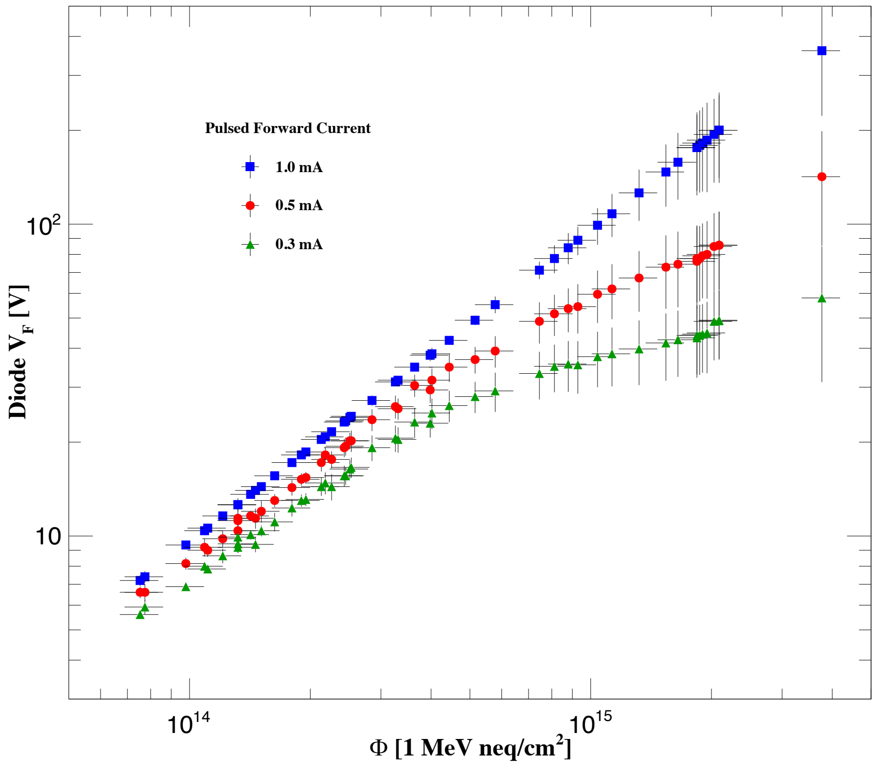


1 mA Pulsed Current, **5 ms** Pulse-Width



Forward Current Magnitude

- Diode forward voltage as a function of applied fluence, for three choices (1.0 mA, 0.5 mA, and 0.3 mA) of forward current amplitude are shown in the figure
- The fluences are independently measured using gamma spectrometry of the aluminum dosimeters
- A linear relationship is realized for 1.0 mA of forward current amplitude up to ~4 × 10^{15} neq/cm^2



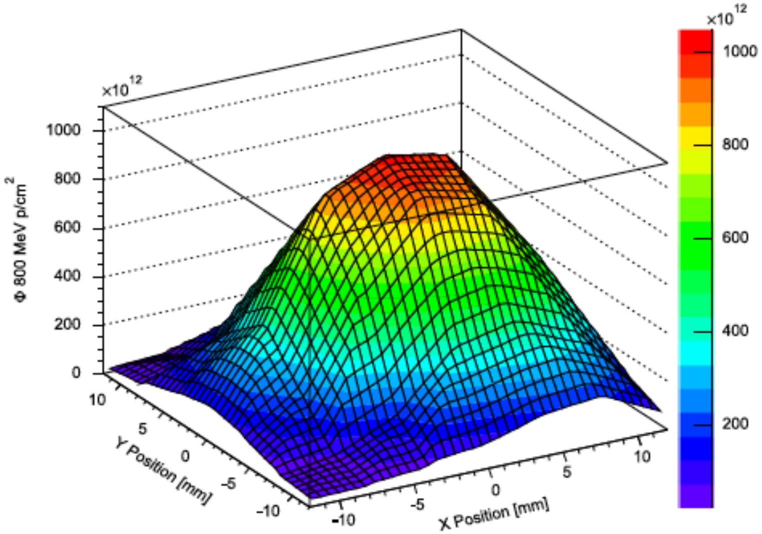
Uncertainty

- The forward voltage error is calculated by the combined uncertainties related to temperature variation during the irradiation process, current pulse width, and source meter precision.
- The applied fluence error is determined from the uncertainty deriving from counting statistics on calibration foils in a gamma spectrometer

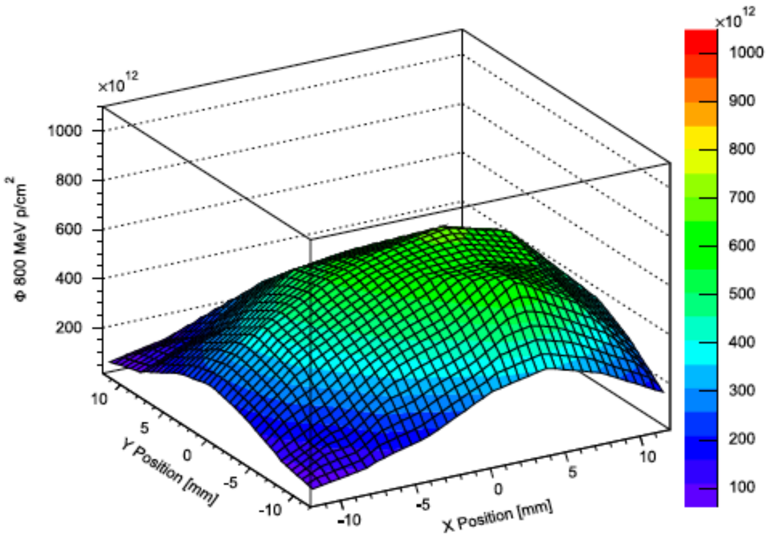
Proton Beam Profile

- Beam profile measured using two diode arrays - one upstream on the proton beam line and other downstream

Upstream on Beam Line



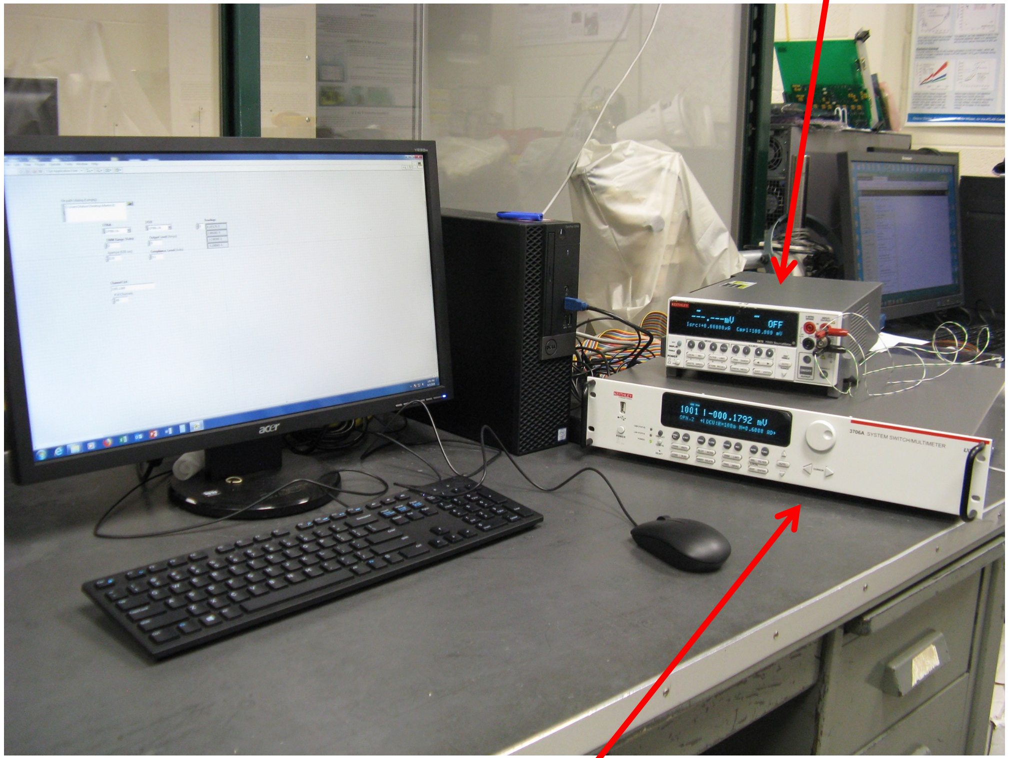
Downstream on Beam Line



New Test Stand

- New test stand to readout the diodes which has the ability to adjust stimulus current and measurement pulse width

Keithley 2410 SourceMeter



Keithley 3706A Switch System
Keithley 3724 FET Mux Card

Conclusions

- Real-time fluence measurements can be made at fluences up to a factor of 20 times greater than previously reported by minimizing the applied pulse width and selecting an optimized forward current amplitude to suppress uncertainty
- These measurements can be performed with photodiode components that are familiar and commercially produced
- A test stand to read the diode voltages out directly, with the ability to vary the current stimulus and measurement duration, in real time during the irradiation has been developed
- The new usable linear range spans 2×10^{12} to 4×10^{15} neq/cm^2