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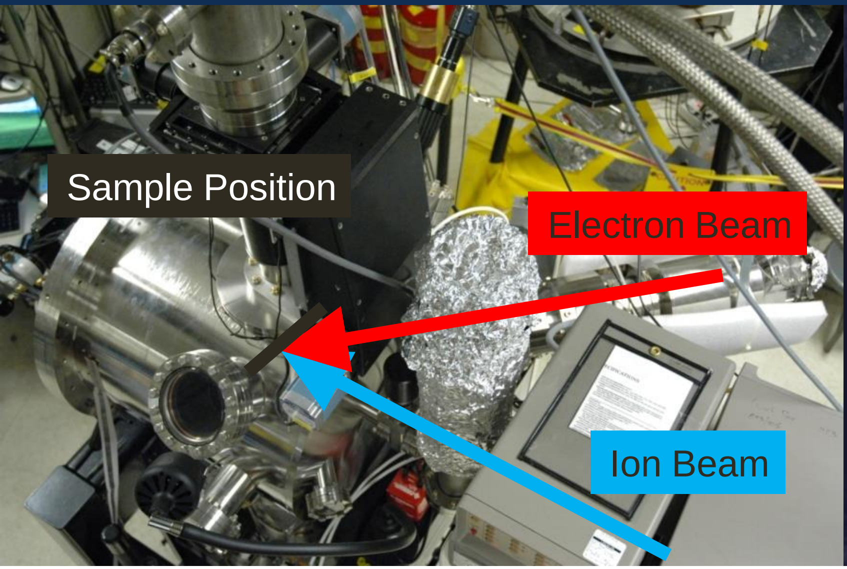

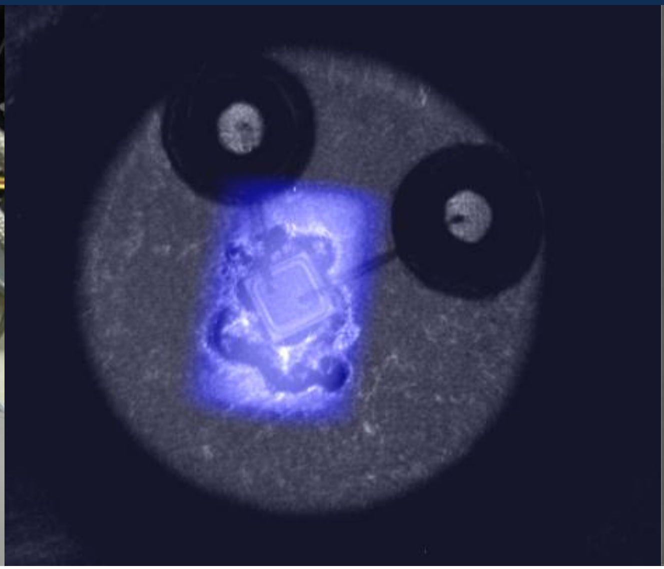

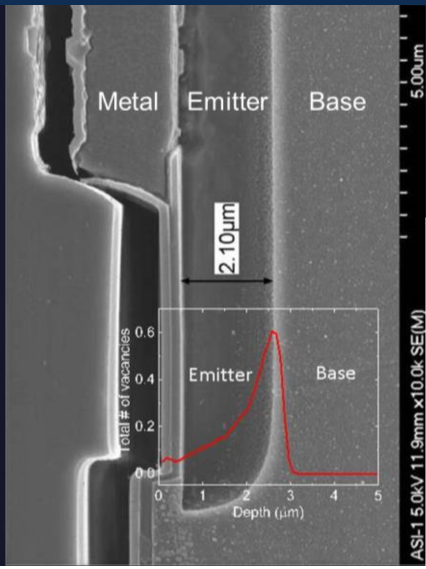

Demonstration of a <20 ns, High Flux Fast Pulsing Capability at Sandia's Ion Beam Laboratory for Hostile Relevant Threat Environment Testing

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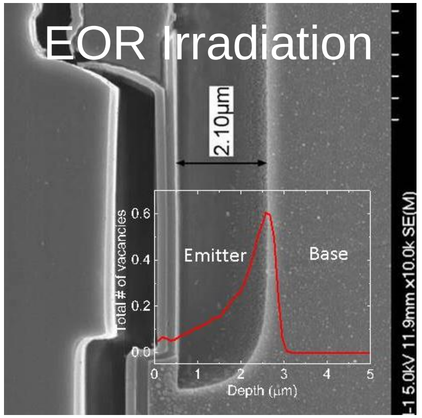
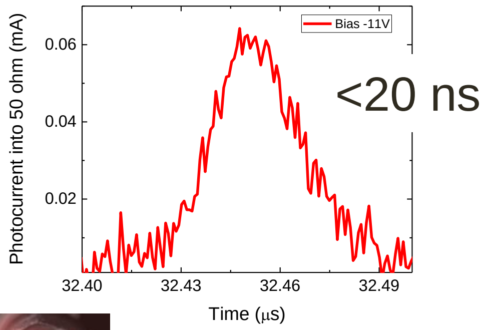
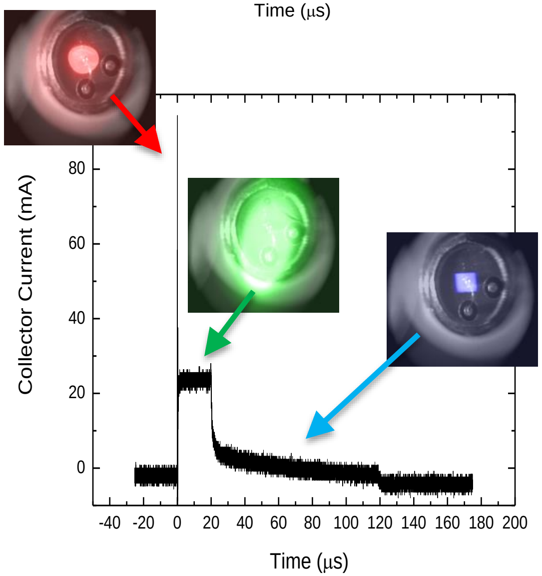
Outline

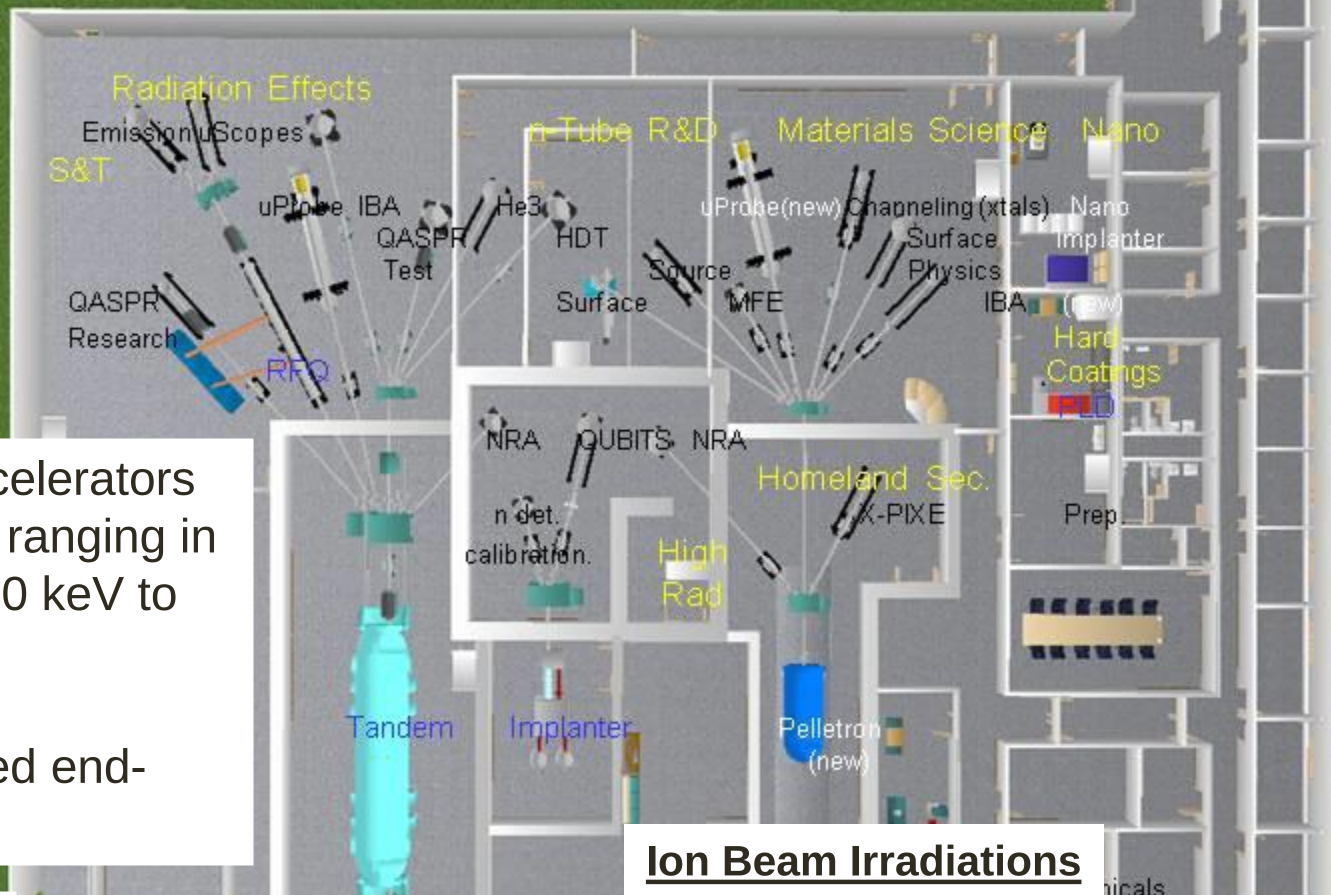
- Motivation – Radiation induced defects
- Ion vs. Neutron Displacement Damage
    - Ion-to-neutron damage equivalence
    - End-of-Range Irradiations
- Fast Pulsing Setup
    - Fluence determination (Area, Charge, Pulse)
- Simulation of the combined n+γ environment
- Summary and Outlook







Sandia's Ion Beam Laboratory (IBL)

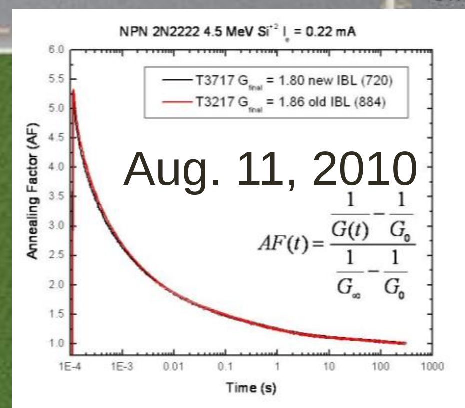


- Four main accelerators producing ion ranging in energy from 10 keV to 480 MeV
- >20 specialized end-stations

Ground Breaking

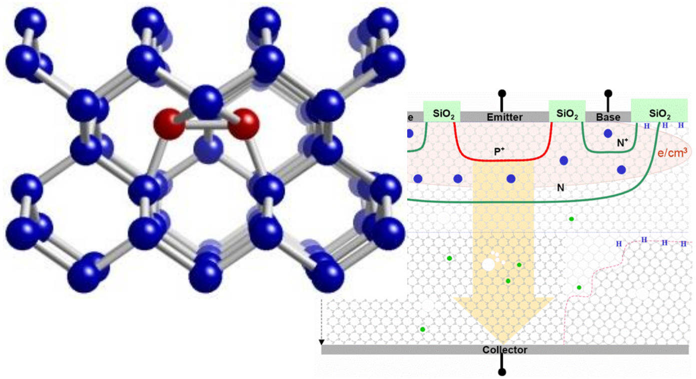
<20 months

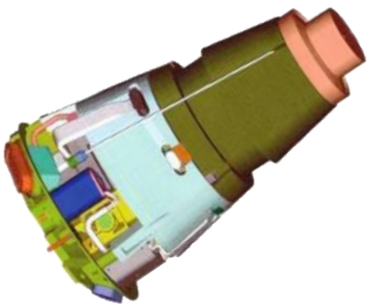
Ion Beam Irradiations



Defect Study Motivation – Displacement Damage

Radiation Induced Defects



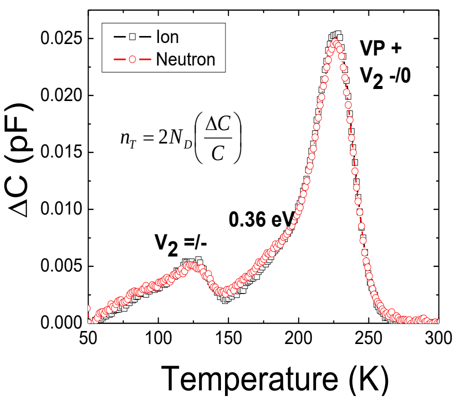


Of particular interest is early-time (<1s) gain degradation

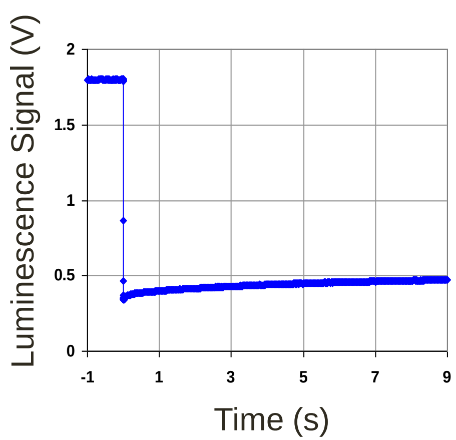
Degradation of Device/Circuit Performance

Experimental Techniques at the Ion Beam Laboratory (IBL)

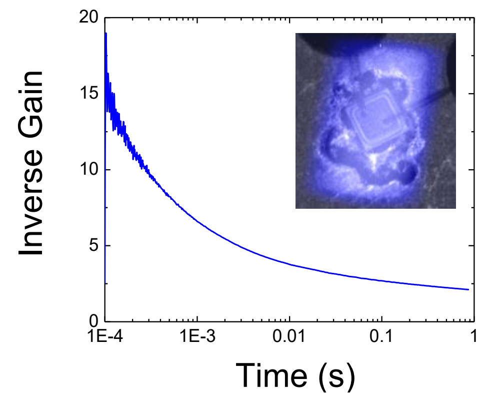
Deep-level Transient Spectroscopy (DLTS)



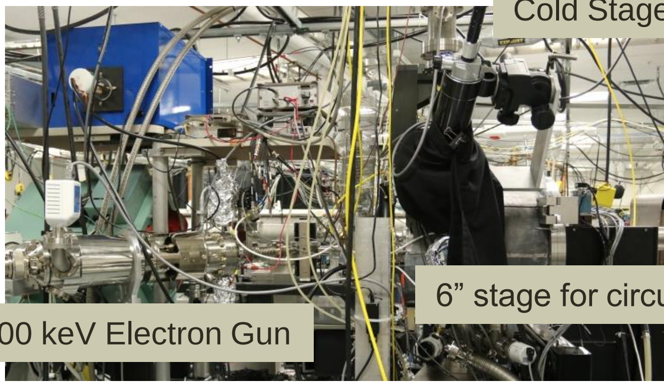
Photoluminescence

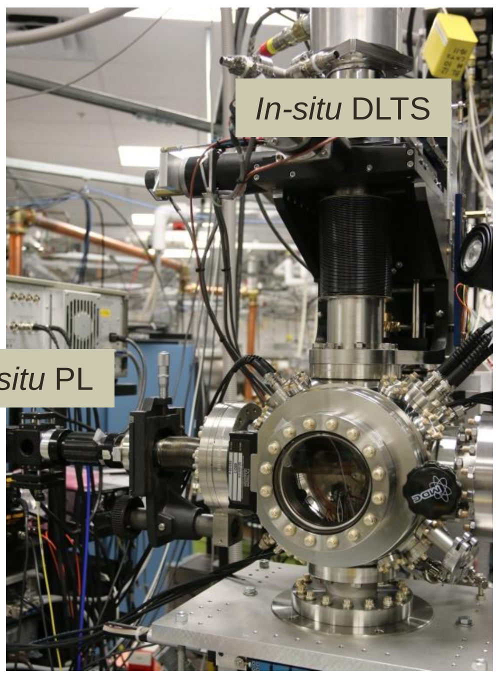


Active Gain



Ion beam irradiation for neutron and gamma simulations





Dedicated end-stations for simulating neutron and/or gamma irradiations

- Suitable for discrete device and circuit irradiations

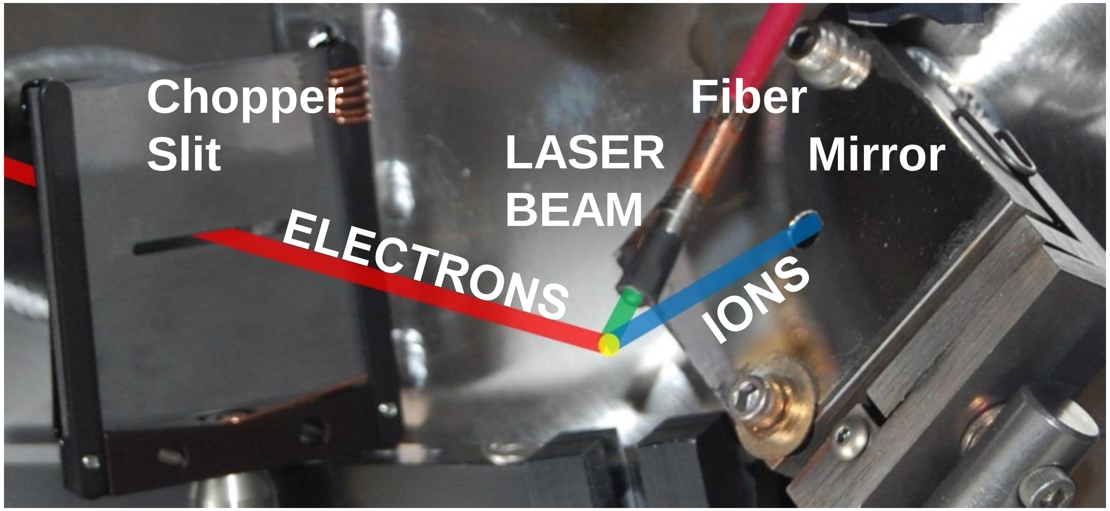
- Operates over a range of temperature from 40 to 450K

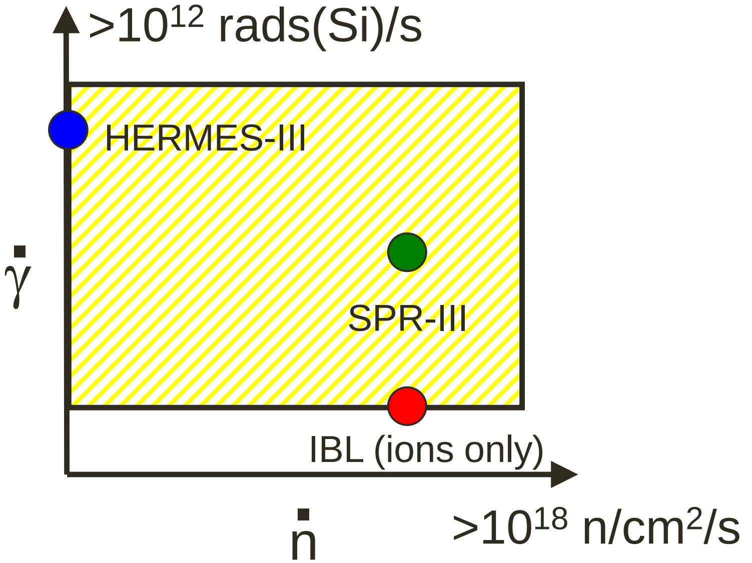
- Combines ion, electron and photon irradiations

- Specializes in electronic measurements including deep level transient spectroscopy (DLTS) and *in-situ* photoluminescence (PL)

Irradiations on GaN HEMTs, GaAs HBTs, Si BJTs, hBN, Ta_2O_x memristors, HfO_2 capacitors, InAsSb supperlattice devices, ….

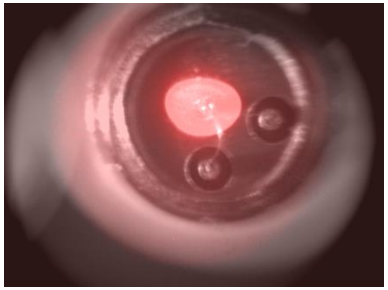
Combined n+γ Mixed Field Environment Simulator (MFES)



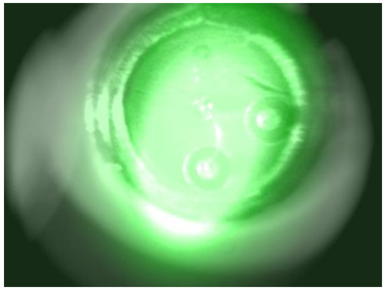


Independent control of Electron, Laser and Ion Irradiations

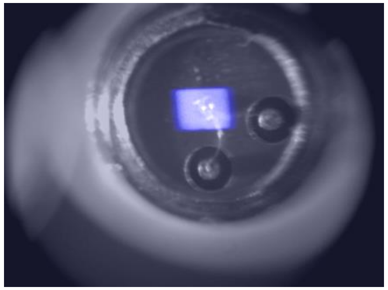
Electron Beam



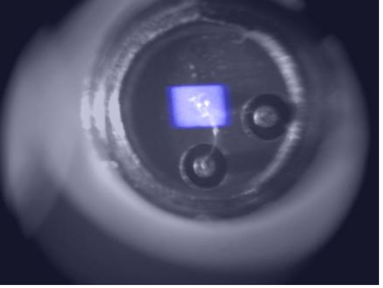
Laser Beam



Ion Beam



Combines **Ion**, **Electron** and **Laser** irradiations to produce an independently variable displacement and ionization environment for electronic device testing



Simulating Neutrons using Ion Irradiations

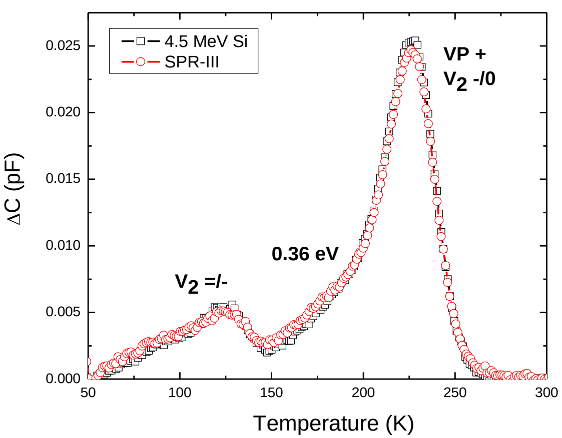
- ***Late-time gain degradation*** (Messenger-Spratt) is the same for the *tested* neutron facilities and end-of-range ion irradiations

- The ***spectra of defects*** are the same

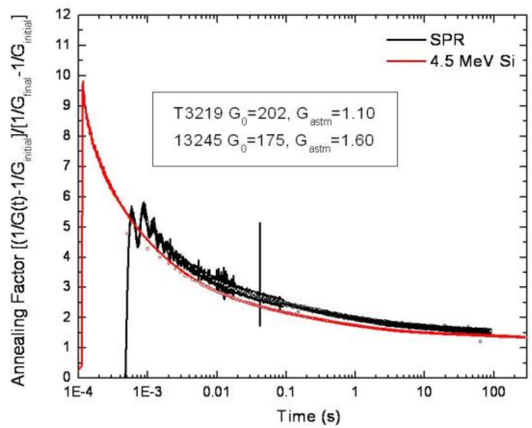
- A given ***number of defects*** produces the same late-time gain reduction

- The ***annealing kinetics*** are similar for neutron and ion irradiations

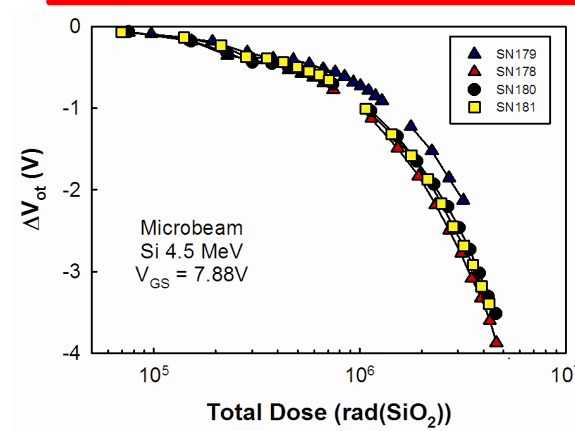
DLTS



Early-time Annealing



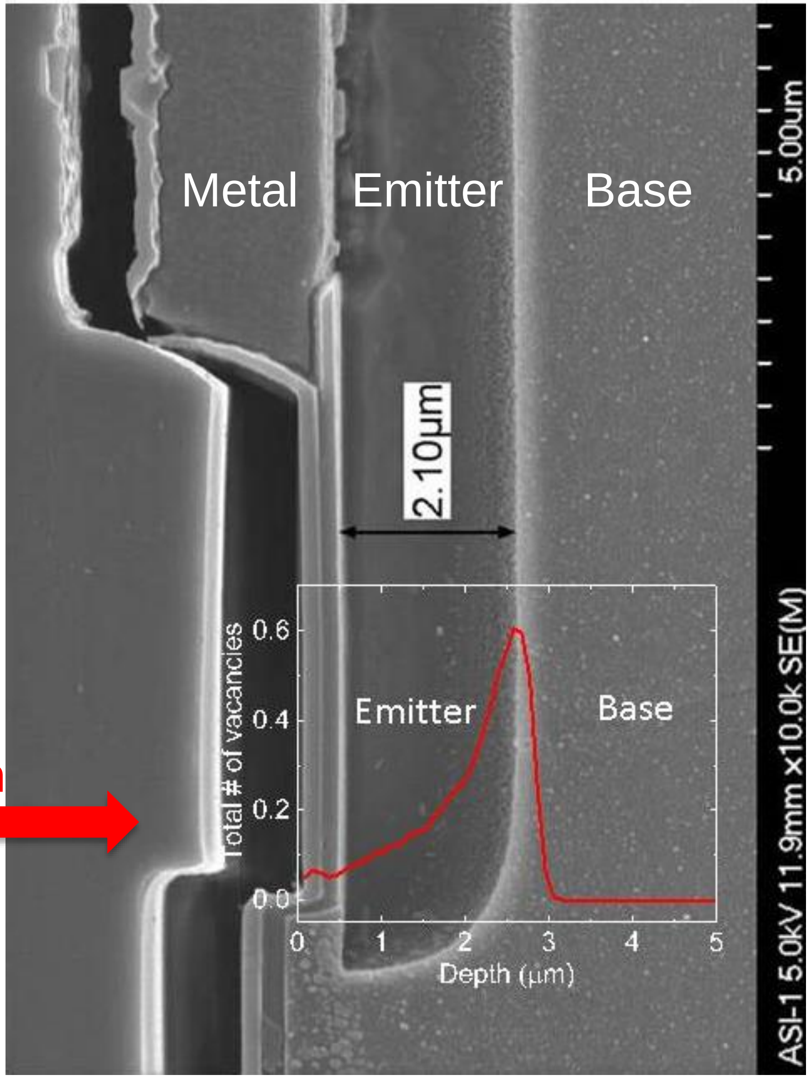
Threshold Voltage Shifts



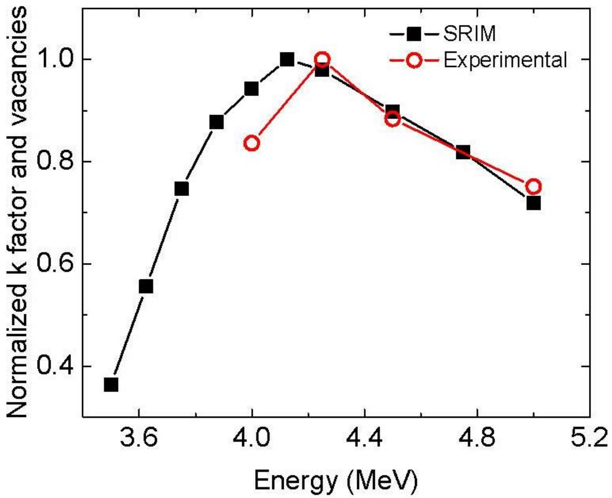
Ion-to-Neutron damage relationship is generally understood and the effect of ion beam induced ionization is secondary for high damage levels

End-of-Range (EOR) Irradiations

Ion beam



- Device: Microsemi 2N2907 pnp BJT
- Target base-emitter (BE) junction



- EOR conditions for different ion species:

He: 850 keV
O: 3.75 MeV
Si: 4.25 MeV
Au: 11 MeV

} Device dependent

End-of-range ion irradiations target the BE junction → maximum damage

Late-Time Gain Comparison

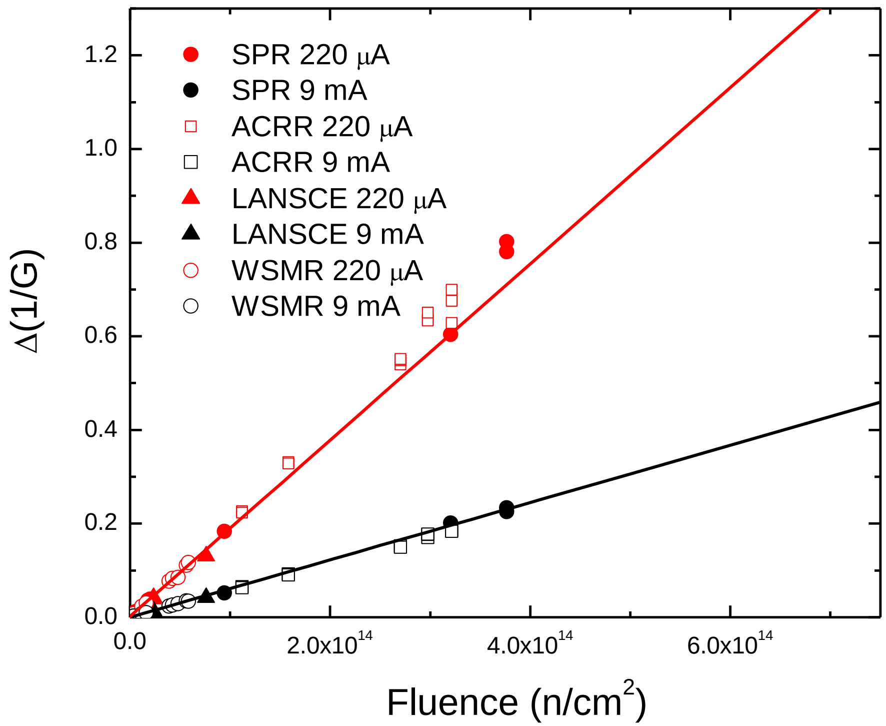
- Displacement damage follows the Messenger-Spratt equation:

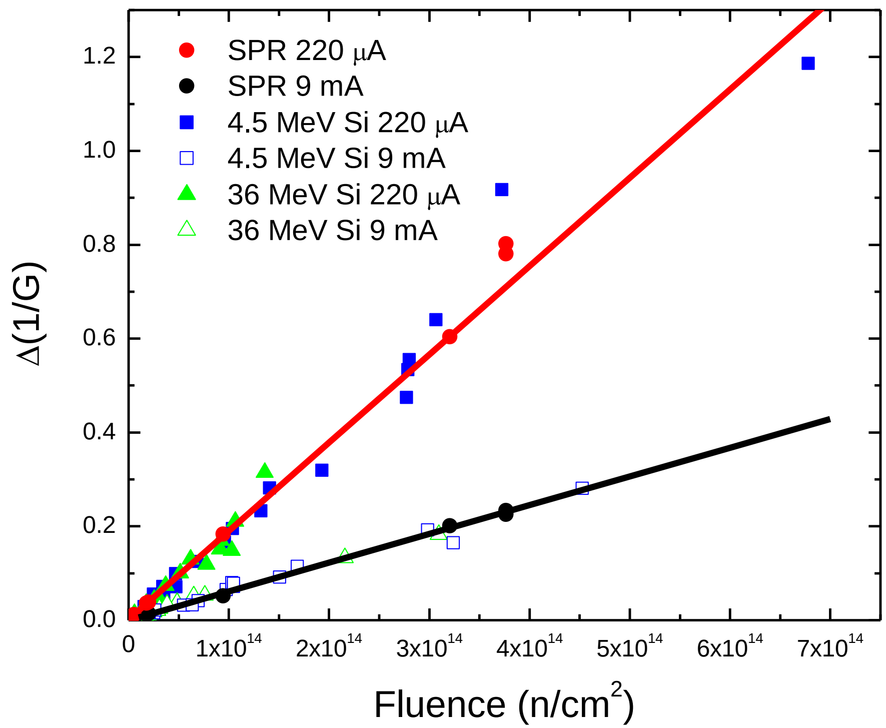
$$\frac{1}{G_\infty} - \frac{1}{G_0} = k \cdot \Phi$$

Damage Constant

- Scale ion fluence to 1 MeV Neutron Equivalent Fluence using:

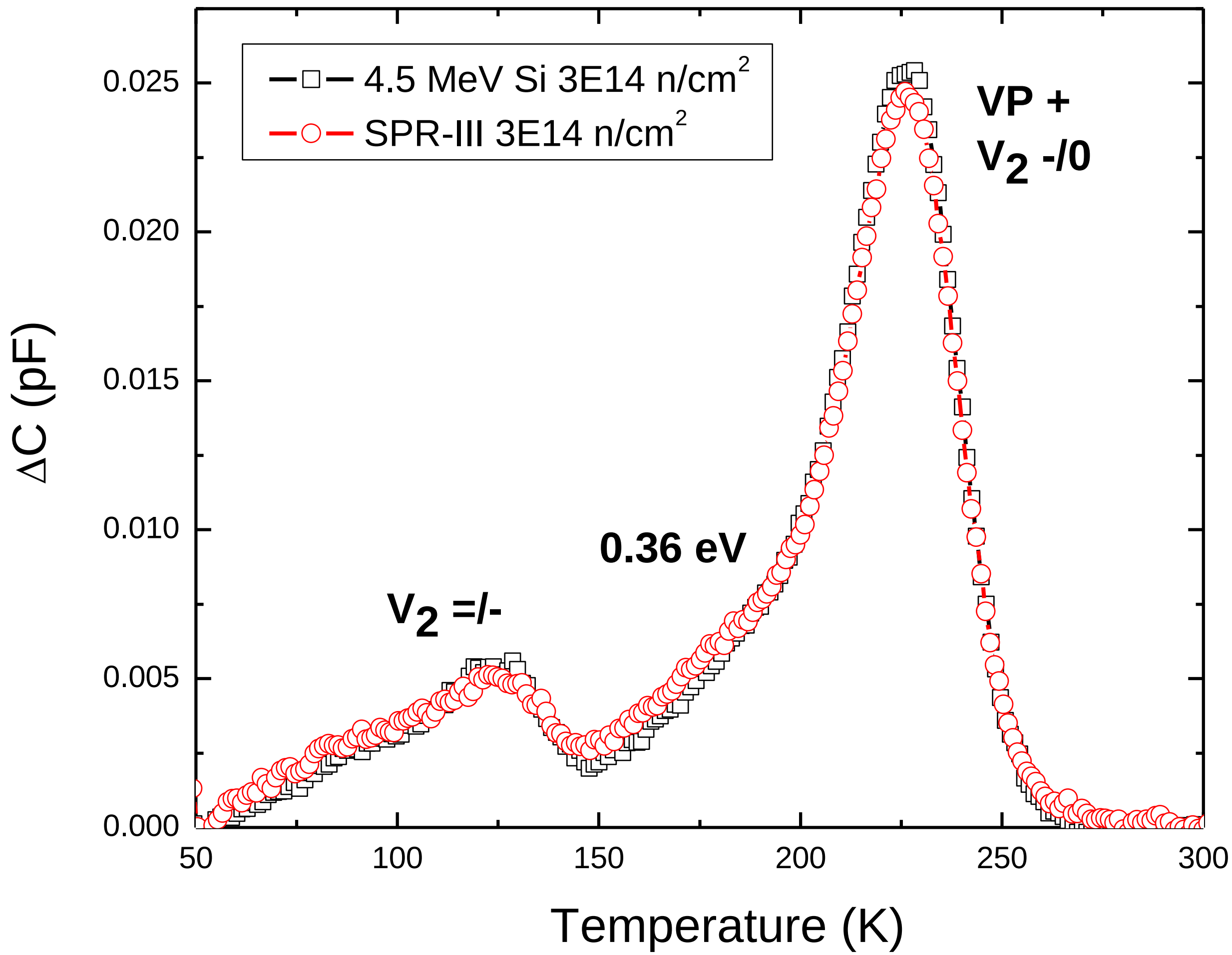
$$\Phi_{neutron} = \frac{k}{k_n} \cdot \Phi_{ion}$$





Late-time gain degradation (Messenger-Spratt) is the same for the *tested* neutron facilities and end-of-range ion irradiations

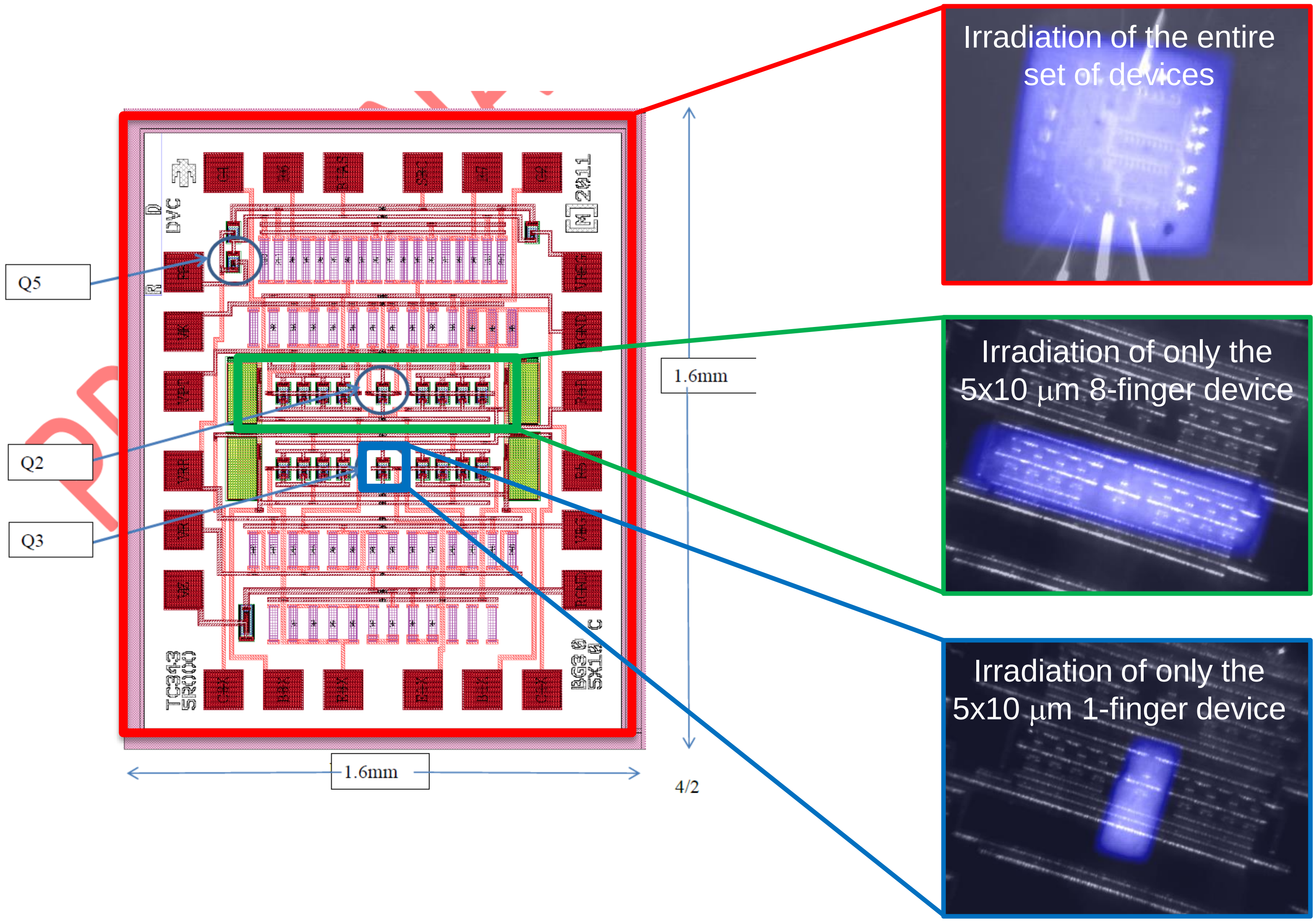
Spectra of Defects: Ions and Neutrons



- DLTS peak amplitude proportional to number of traps
- Temperature scale provides a means to determine emission energy of the defect
- DLTS spectra of the base region of a PNP device.
- Probes the N-type area of the devices most closely associated with the BE junction.

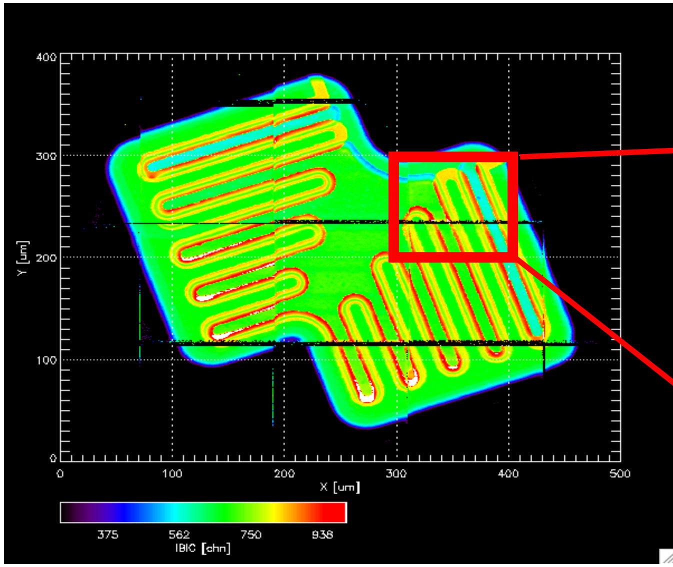
The *spectra of defects* are the same under EOR ion and neutron irradiation

Range of Beam Spot Sizes

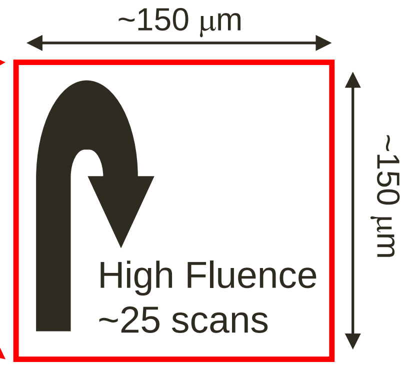


Board beam to microbeam irradiations spot sizes from ~5x5 mm^2 to 1x1 μm^2

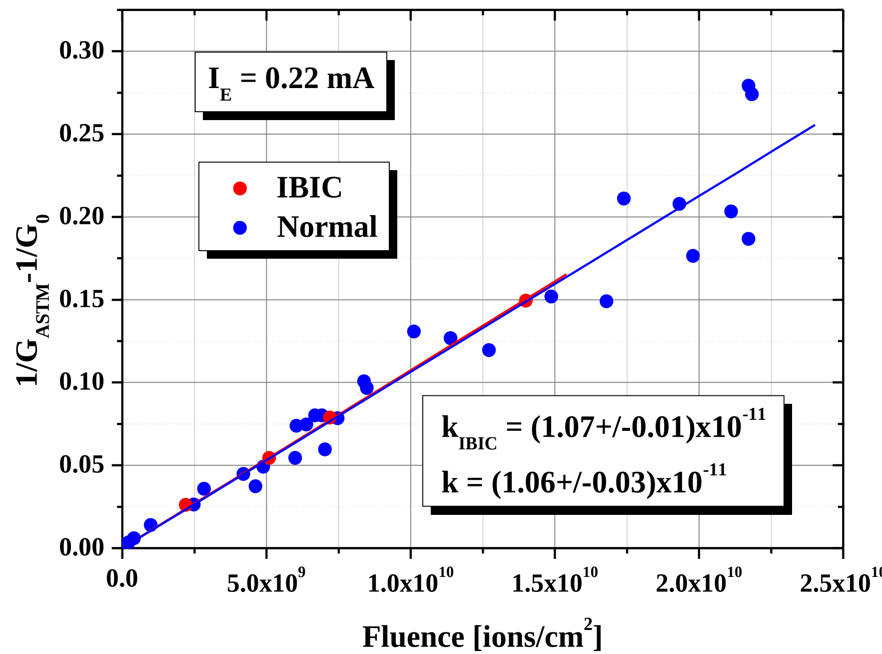
Range of Pulse Lengths



• Raster ~1 μm 36 MeV Si beam over a ~ 150 x 150 μm^2 area

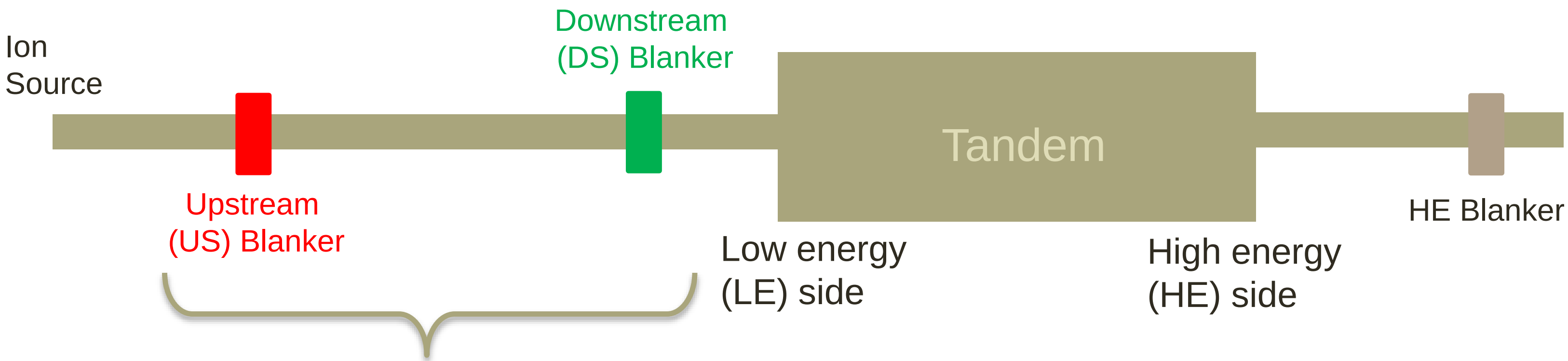


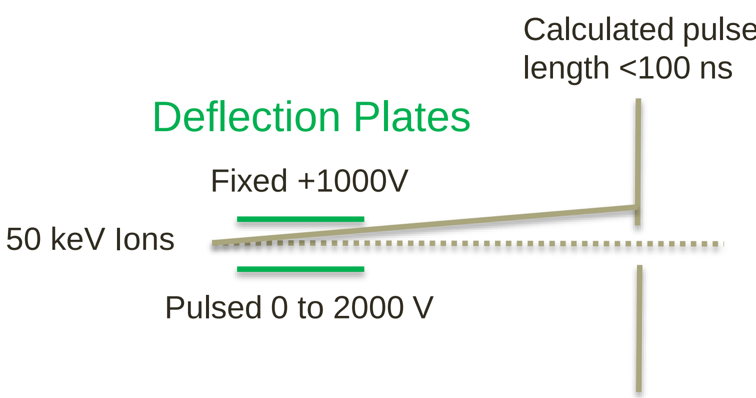
Range of pulse lengths from 2 μs to DC produce the Messenger-Spratt slope

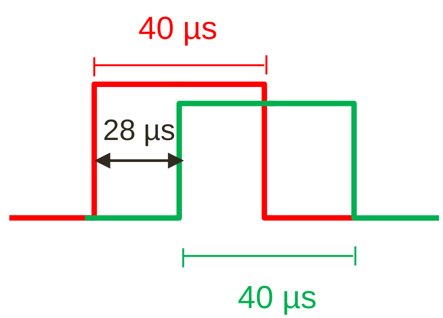


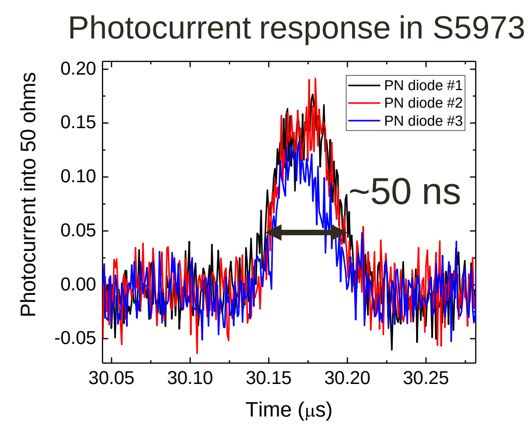
How to push down to shorter pulses and measure the fluence?

Fast Pulsing – Modification to the Low Energy Side









Key question – how to measure the fluence?

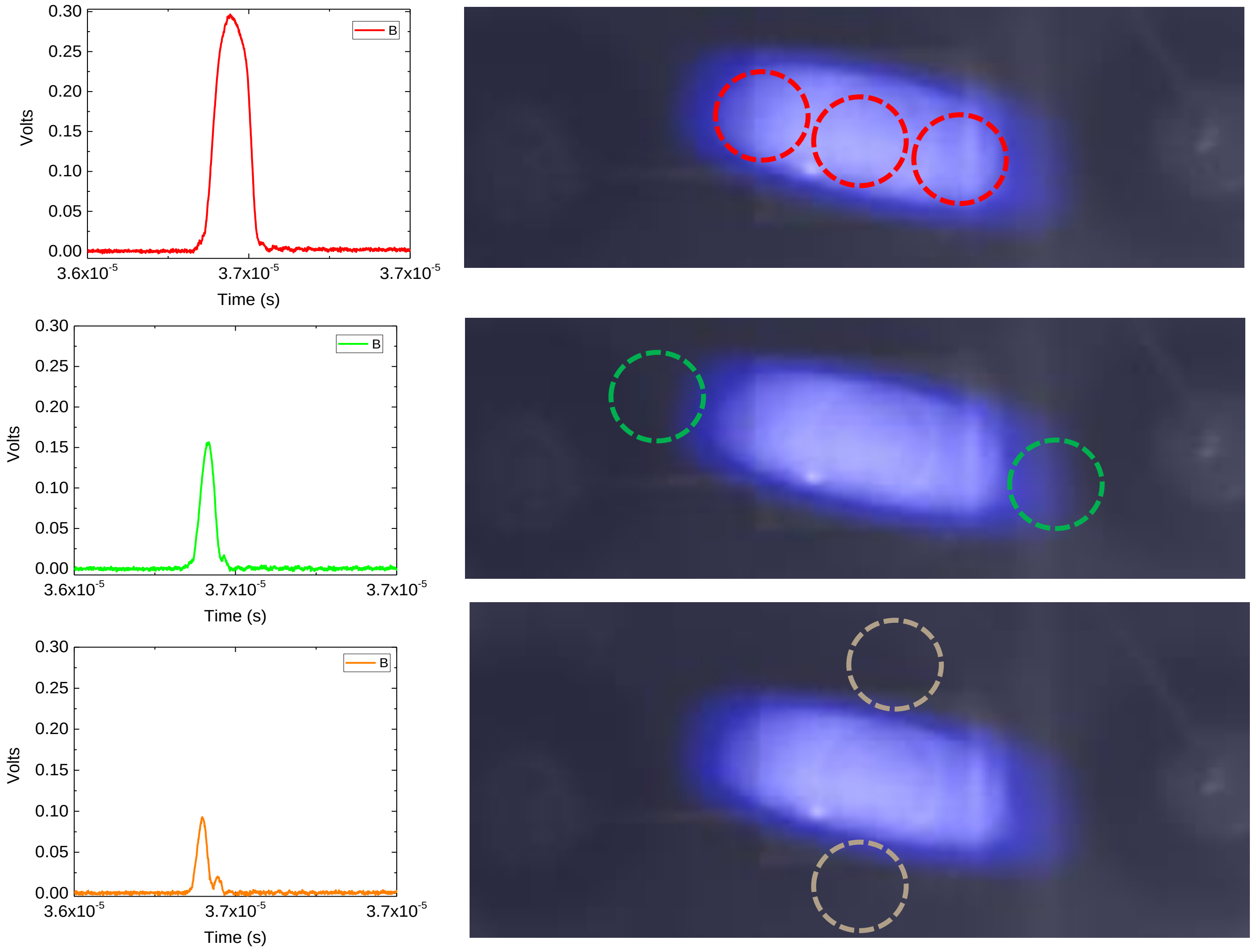
1.) Area – P47 imaging not sensitive enough

2.) Charge – electrometer not fast enough

3.) Pulse length – device response limited by parasitic capacitance

Fast Pulsing – Determining the beam area

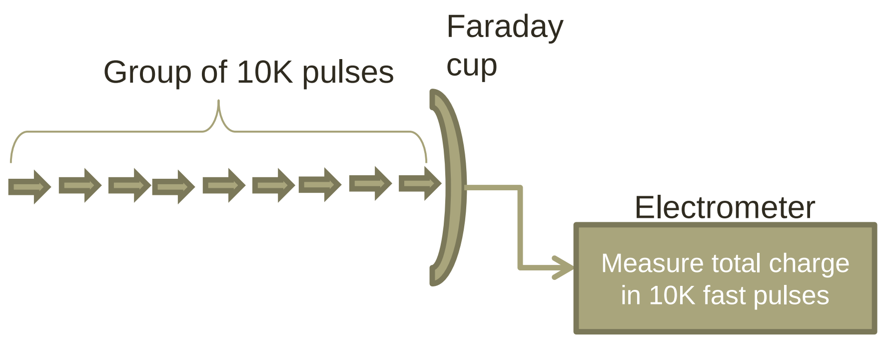
→ Normal P47 and Watec camera not sensitive enough to capture fast pulse

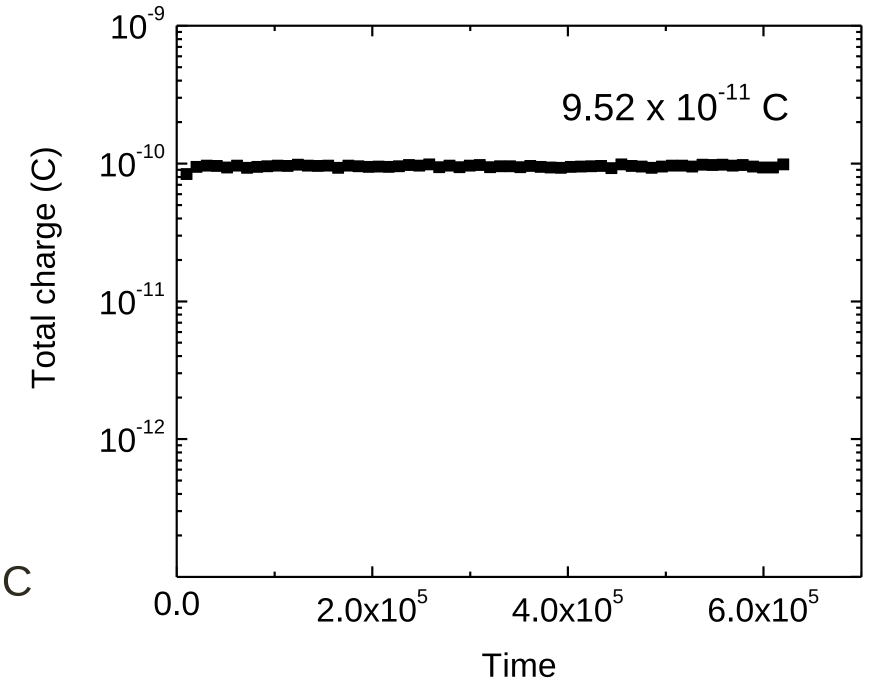


Use long pulse imaging and fast pulse photocurrent to map out area

Fast Pulsing – Measuring the charge

→ Single shot charge measurement not sensitive or fast enough to capture fast pulse





Charge per fast pulse = $\frac{total\ charge}{\#\ of\ pulses}$ = 9.52 x 10^{-15} C

Average many fast pulses to determine the charge (number of ions) in each pulse

Fast Pulsing – Measuring the pulse length

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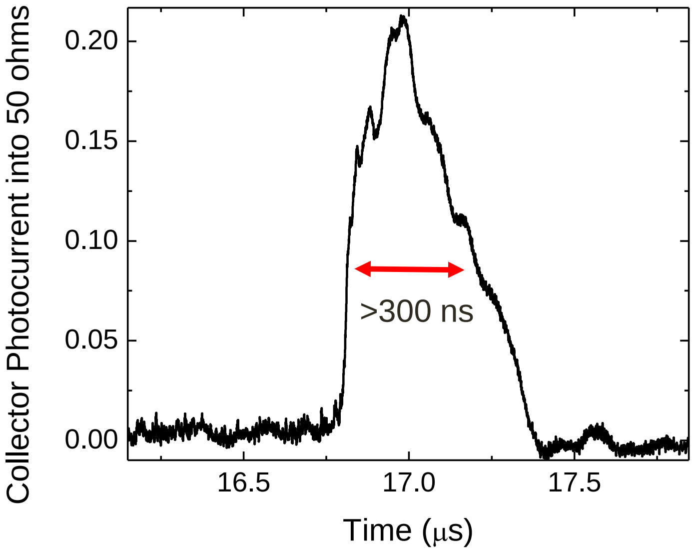
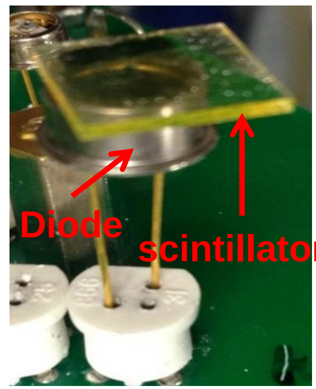
→ Device response time is limited by e-h pair diffusion in a Si BJT

Si BJT

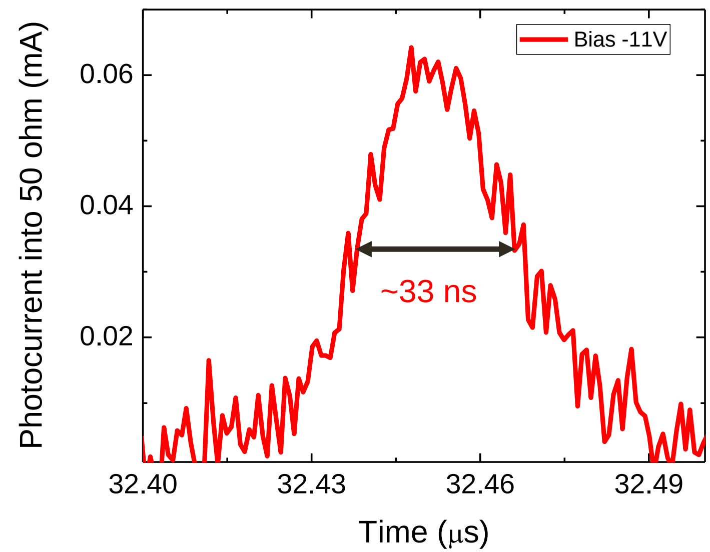


- Transistor pulse length: >300 ns

- We irradiated scintillator with 25 MeV O^{5+} using fast pulse setup
- Light emitted by scintillator (BC430) creates e-h pairs in pin diode

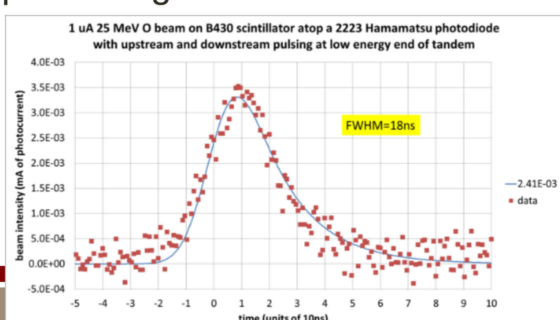


BC403 + S1223



- Measured pulse length = 33 ns
- Scintillator decay time: 17 ns

Convoluting beam pulse (Gaussian) function for the and exponential decay of the BC430 scintillator to determine the pulse length



Measure the pulse length to be 18 ns

Fast Pulsing – Maximum Flux

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Neutrons (SPR-III)

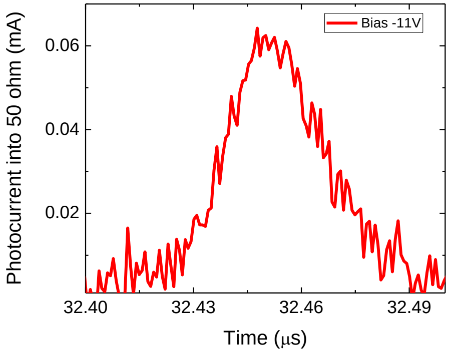
Flux$_{neutron}$ >3x10^{18} n/cm^2/s

Other neutron facilities:

LANSCE ~1x10^{19} n/cm^2/s

ACRR ~1x10^{16} n/cm^2/s

EOR Ions (4.25 MeV Si^{2+})



Area → XXx10^{-2} cm^2

Charge per pulse → 2.5x10^{-14} C

Pulse length → <20 ns

Flux$_{ion}$ → 2.3x10^{14} ions/cm^2/s

$$\Phi_{neutron} = \frac{k}{k_n} \cdot \Phi_{ion}$$

k_{ion} = 3.2ex10^{-10}

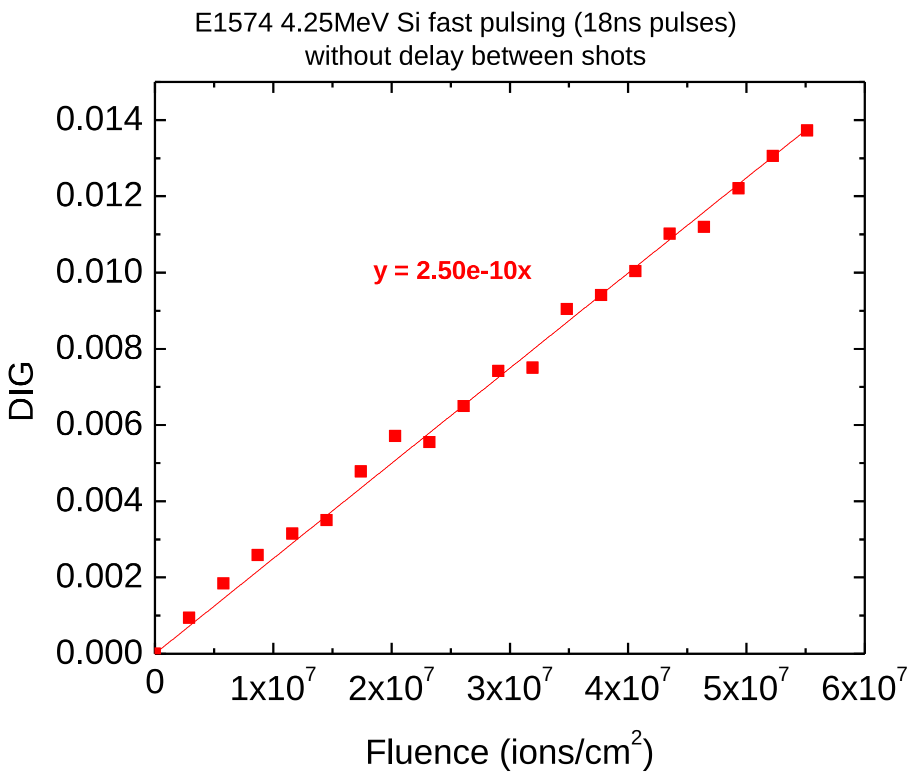
$k_{neutron}$ = 2.8x10^{-15}

Flux$_{neutron}$ >3x10^{19} n/cm^2/s

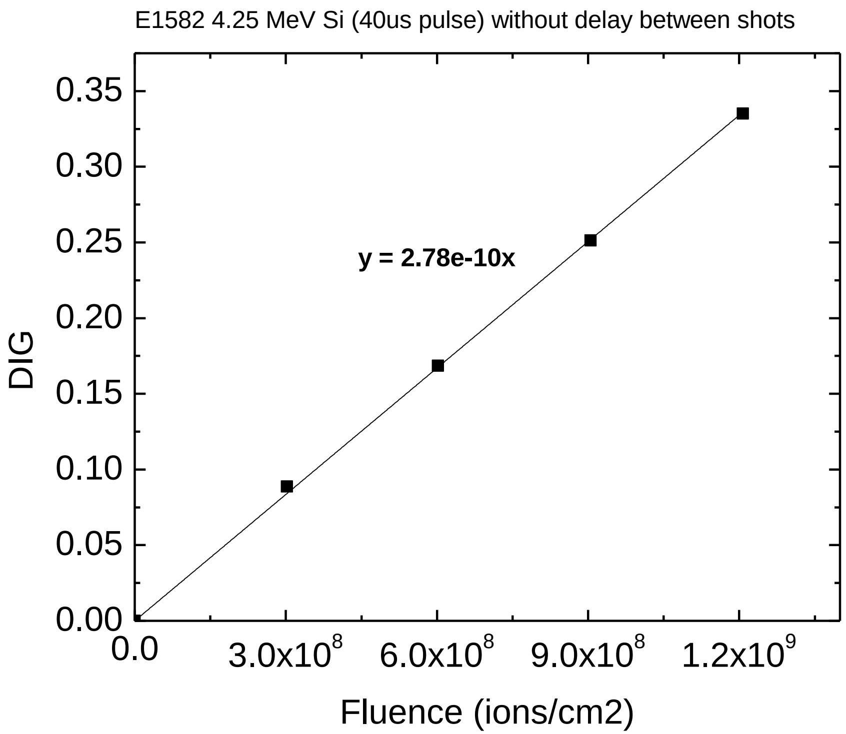
We obtained ~10x more flux than SPR-III

Messenger-Spratt k-factor: Fast vs. Long Pulsing

Fast pulses, no delay



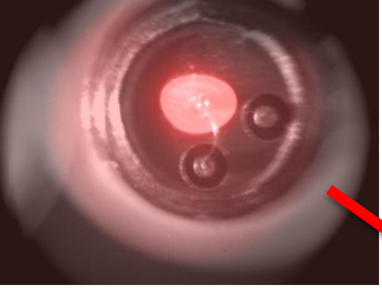
Long pulses, no delay

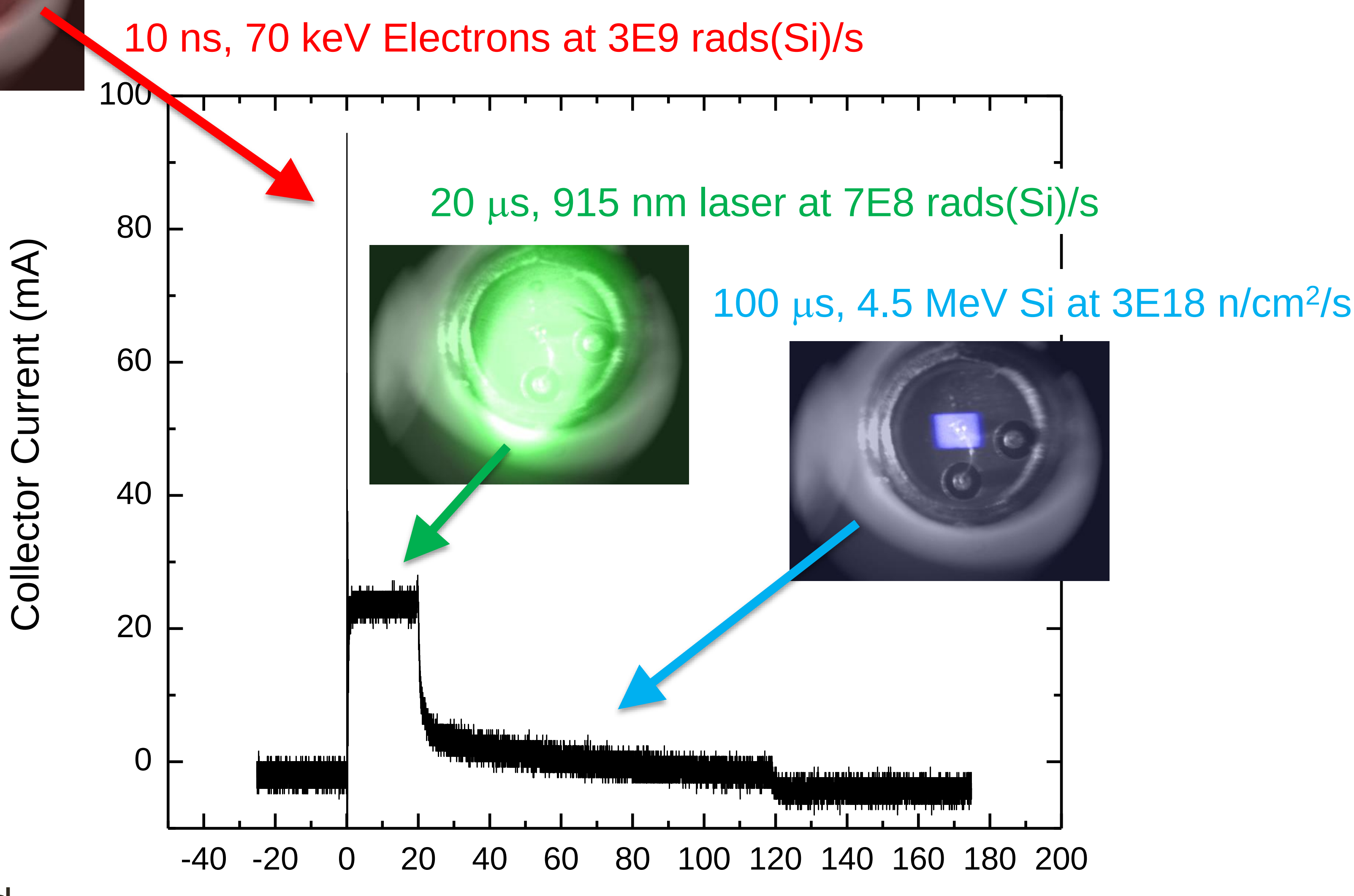


<10% difference in k-factor between fast and long pulses

→ Exploring the effect of temperature, can we extract an energy scale of the annealing

Our first combined n+γ simulations





E, B ground,
Unbiased C current

OUO

More to come!

Simulating Hostile-Relevant Radiation Conditions

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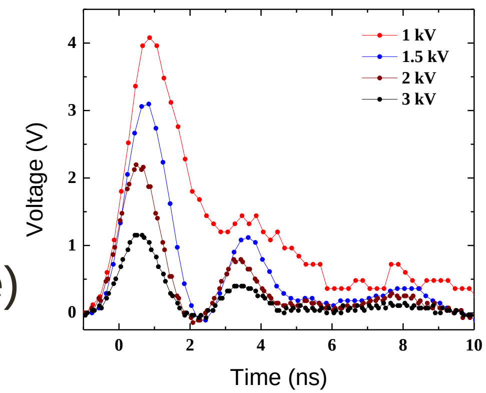
Prompt Gamma (Photocurrent)

Fast Pulse of Electrons – (1 to 4 mm^2)

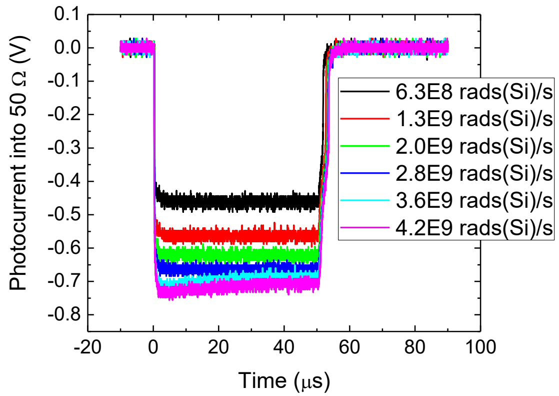
- Variable Pulse lengths 1-100 ns, 2μs to DC
- Dose rates $>10^{12}$ rads(Si)/s
- Hermes-III Simulator (low energy, small volume)



Sustained Gamma (Photocurrent)

Laser Pulse – (12 mm^2)

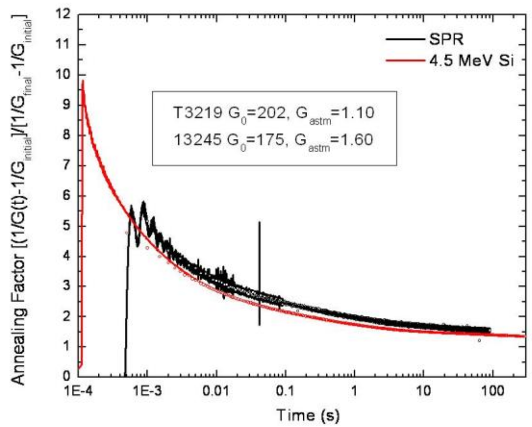
- Variable Pulse length up to 10's of μs FWHM
- Dose rates up to 10^9 rads(Si)/s
- Little Mountain LINAC Simulator



Neutron (Displacement Damage)

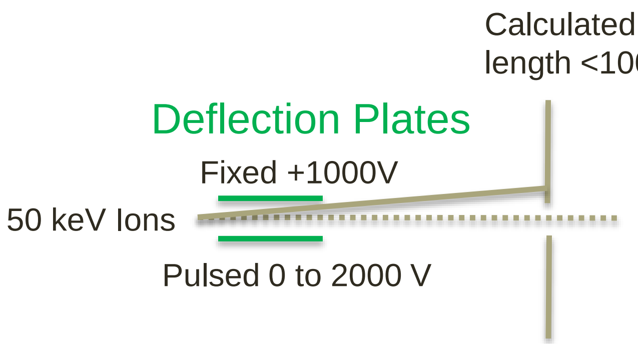
Pulse of Heavy Ions – (as large as 16 mm^2)

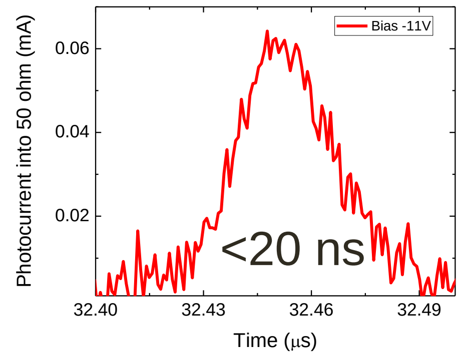
- Variable Pulse length 20 ns to DC
- Dose rates ~10^7 rads(Si)/s
- SPR-III Simulator $>10^{19}$ 1 MeV equ n/cm^2/s

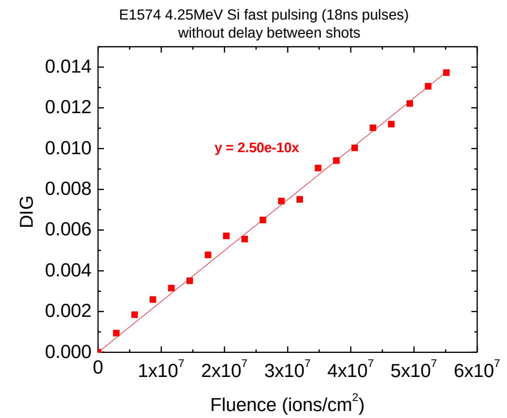


Summary and Outlook

- Demonstrated a <20 ns fast pulsing capability with high flux







- Ion-to-neutron equivalence is still a work in progress

  → Role of ion mass in DLTS and single ion gain degradation reponse