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Effect of 14 MeV neutron flux on defects in Si photodiode devices

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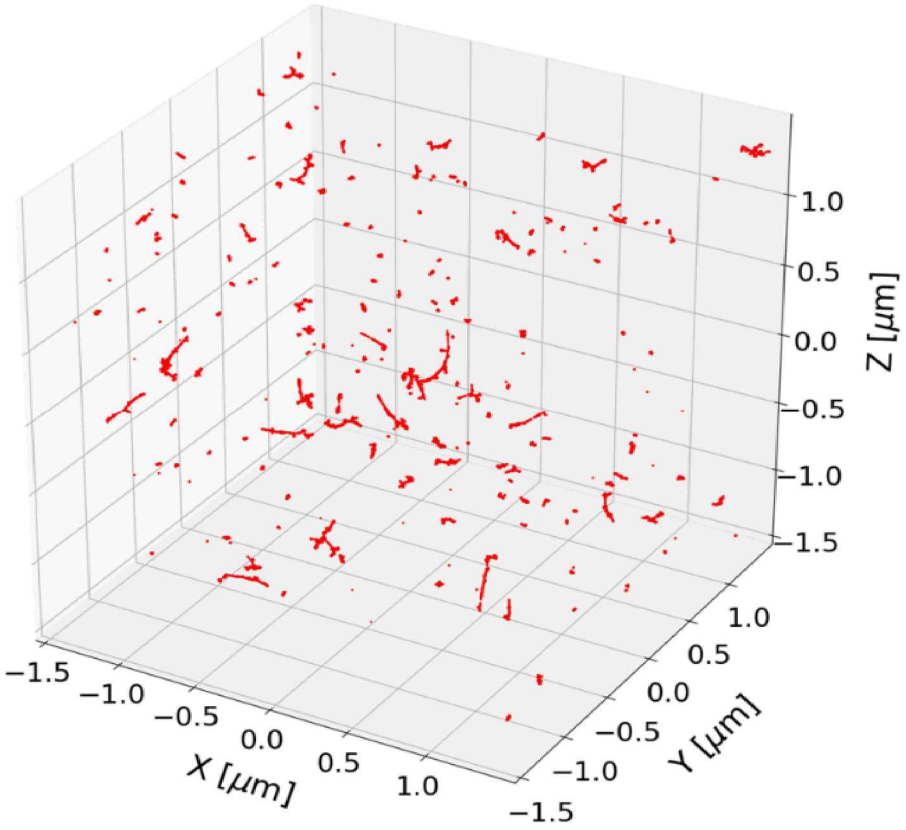
Outline

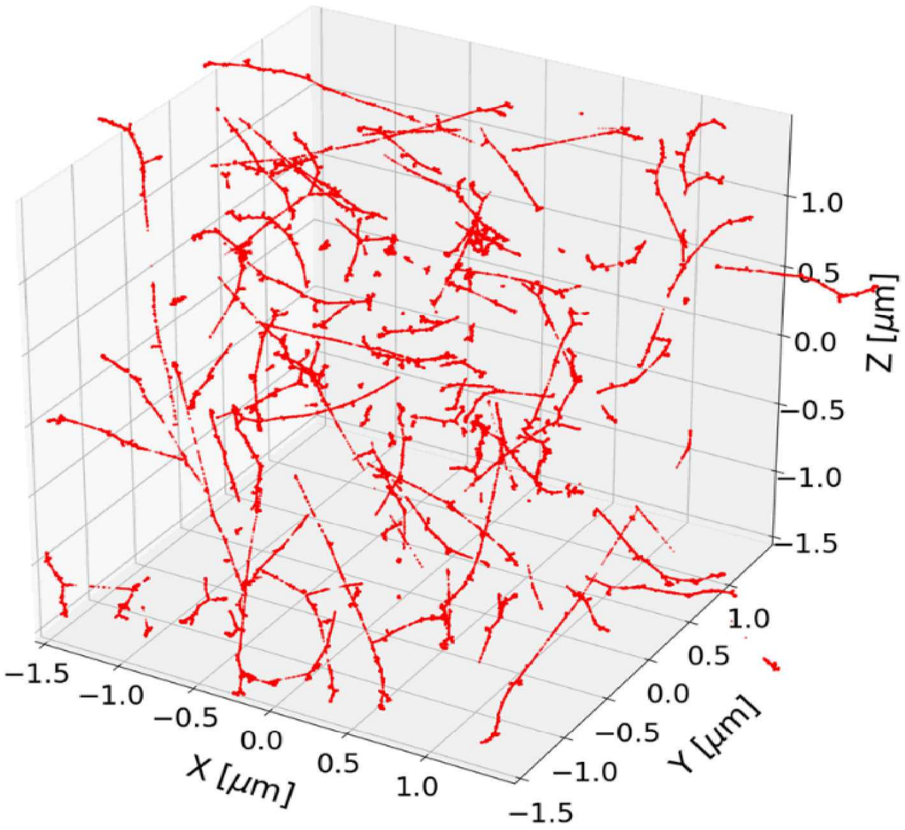
- Motivation
- 14 MeV neutron irradiation facilities
- Effect of 14 MeV neutron flux on damage factor
- Four hypothesis for damage factor difference
    1. Localized annealing during high flux shots
    2. Gamma induced annealing
    3. Down scattered neutrons during low flux irradiations
    4. electron-hole pair annealing
- Conclusions

Motivation

ACRR



14 MeV



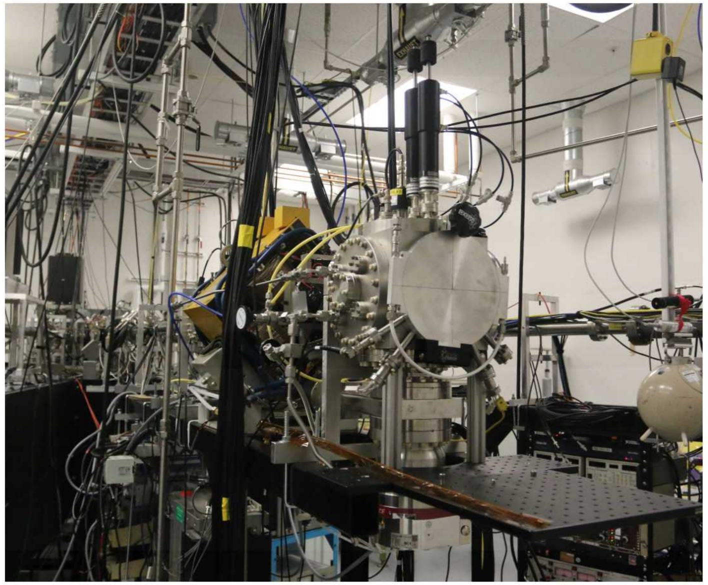
- Pulsed vs steady state irradiations (effect of flux)
- Understanding of neutron energy spectrum
- Understanding rapid annealing after neutron burst
- Neutron single event effects

- Damage effects are different for 1 MeV vs 14 MeV

Do we get the same damage with 14 MeV neutron steady state runs and short pulse irradiations?

Irradiation Facilities – 14MeV neutron

IBL-14 MeV n/SNL

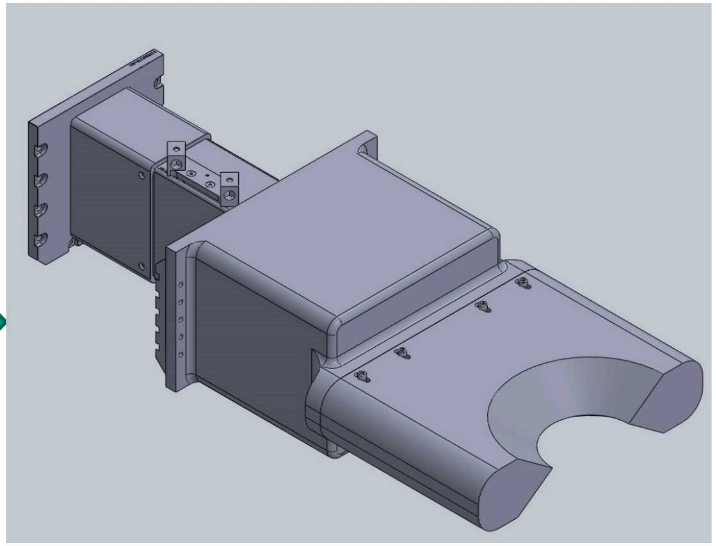


- Target: Use of deuterium beam on tritium target
- Pulse length: 1 week-long steady irradiation
- Flux ~ $5x10^6$ n/cm^2/s

OMEGA/LLE

- Target: Hoppe-type glass DT(10)SiO2, Type B
- Pulse length: Multiple 125 ps-long shots
- Flux ~ $7x10^{20}$ n/cm^2/s

NIF/LLNL



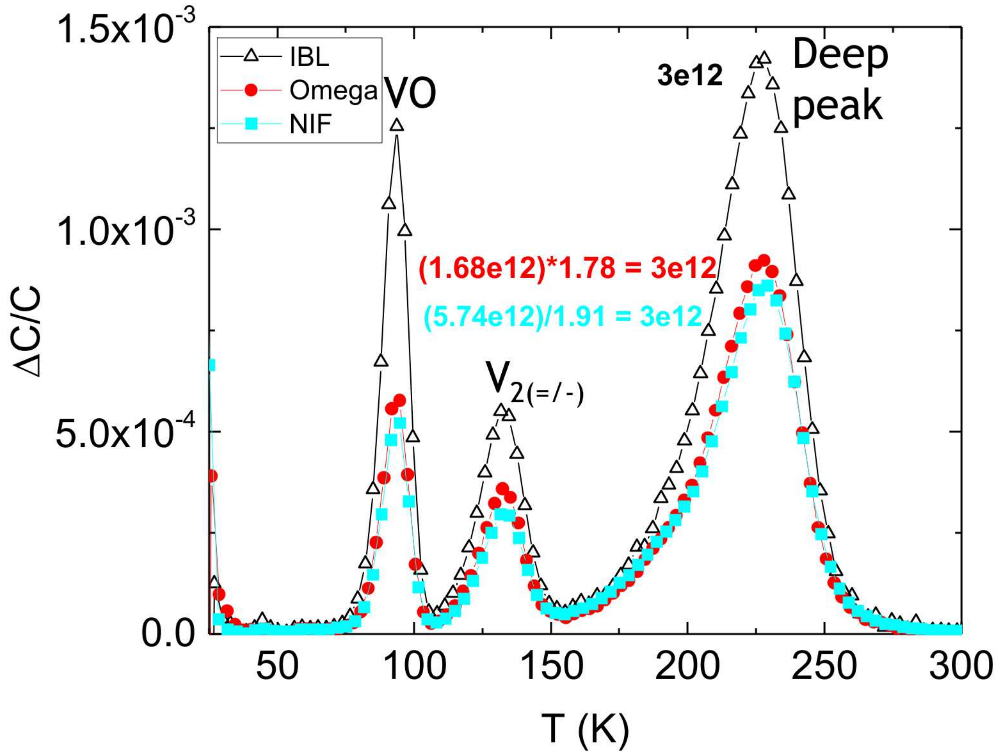
- Target: HSC plastic polar direct drive DT target
- Pulse length: 300 ps-long single shot
- Flux ~ $2x10^{22}$ n/cm^2/s

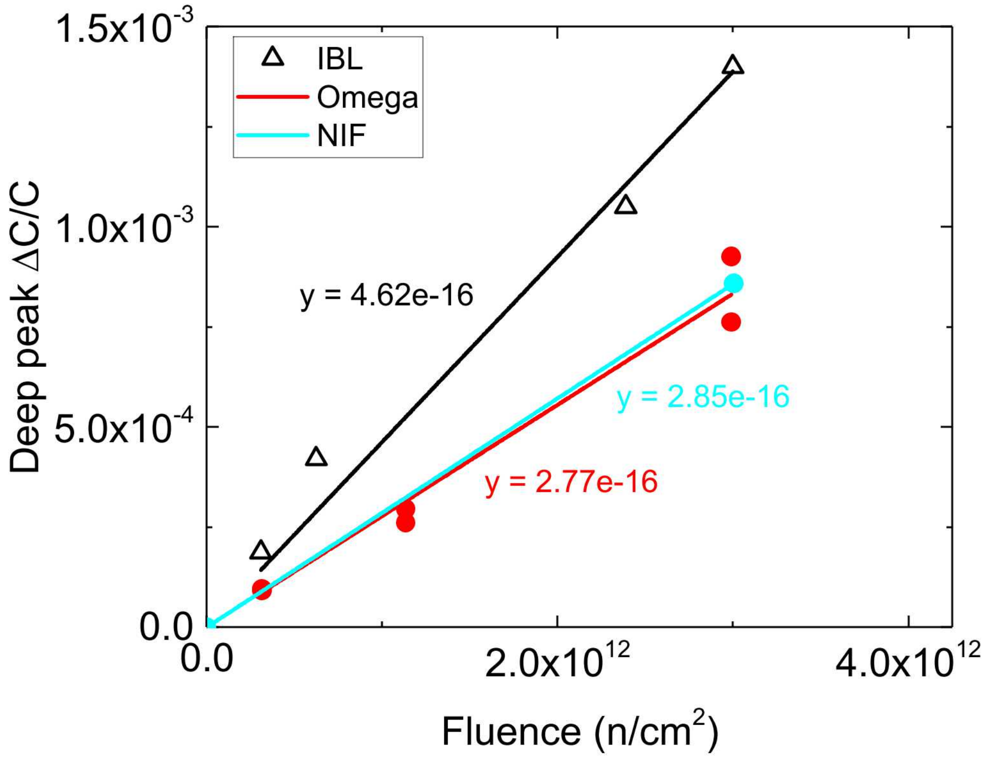
16 orders of magnitude in flux per shot (for roughly the same fluence)

Explored the effect of 16 orders of magnitude difference in neutron flux using 3 different facilities

Effect of 14 MeV neutron flux on defect spectrum

Deep Level Transient Spectroscopy (DLTS)





- DLTS peak amplitude ∝ to the # of defects
- Same type of defects produced by all facilities

→ <u>High flux</u> facilities resulted in <u>less defects</u>

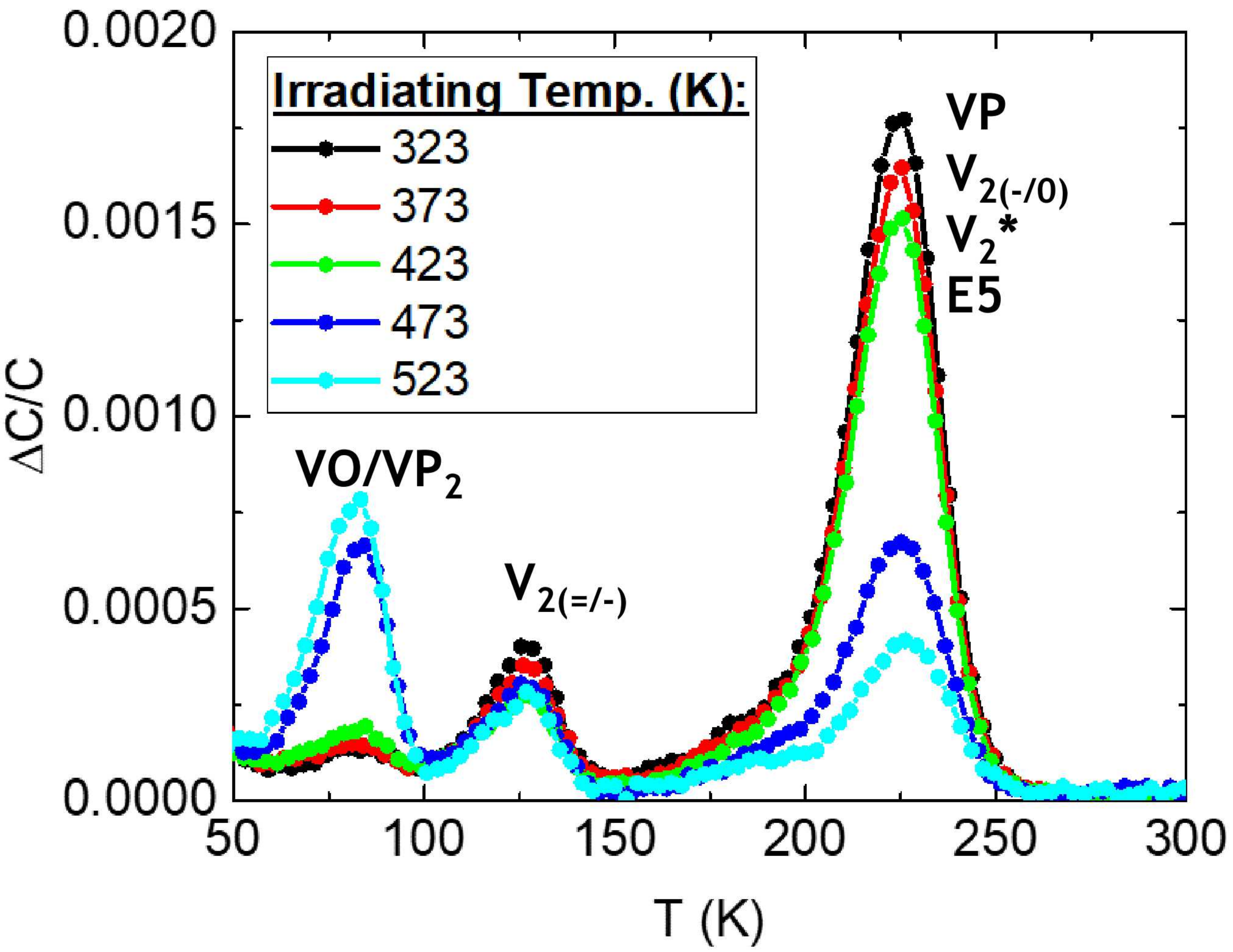
60% difference in damage factor

Low neutron flux irradiations produced a 60% larger damage factor than high flux irradiations

Four hypothesis for damage factor difference

1. Localized heating
2. Gamma rays-induced annealing
3. Down scattered neutrons
4. Electron-hole pair annealing

I. Rise of temperature during high flux irradiations



Ion irradiations on Si BJTs

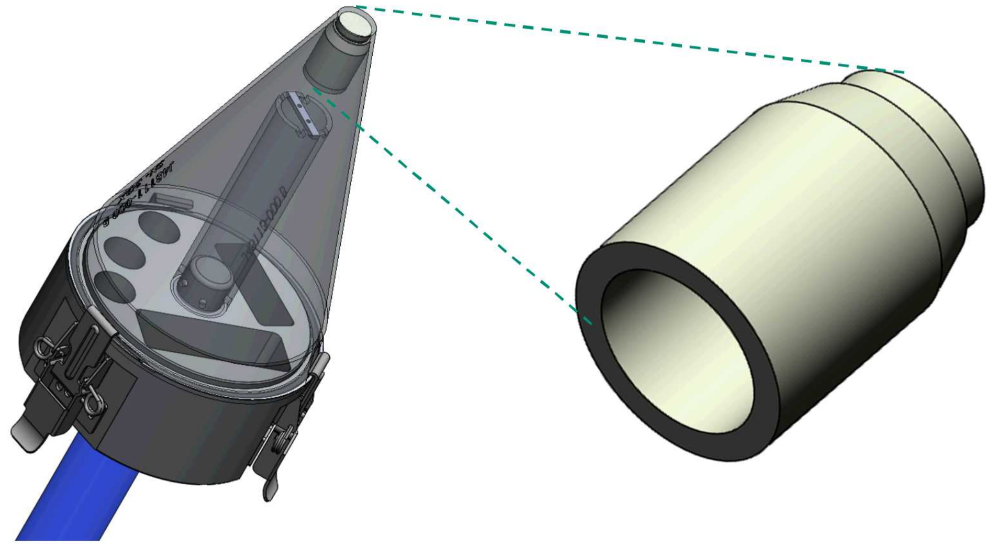
- Irradiations performed with fixed fluence
- In-situ annealing irradiations show:
  - Decrease of deep peak
  - Increase of VO/VP2 peak
- Neutron irradiations are similar to 300 K irradiations
- This temperature effect was shown by Svensson

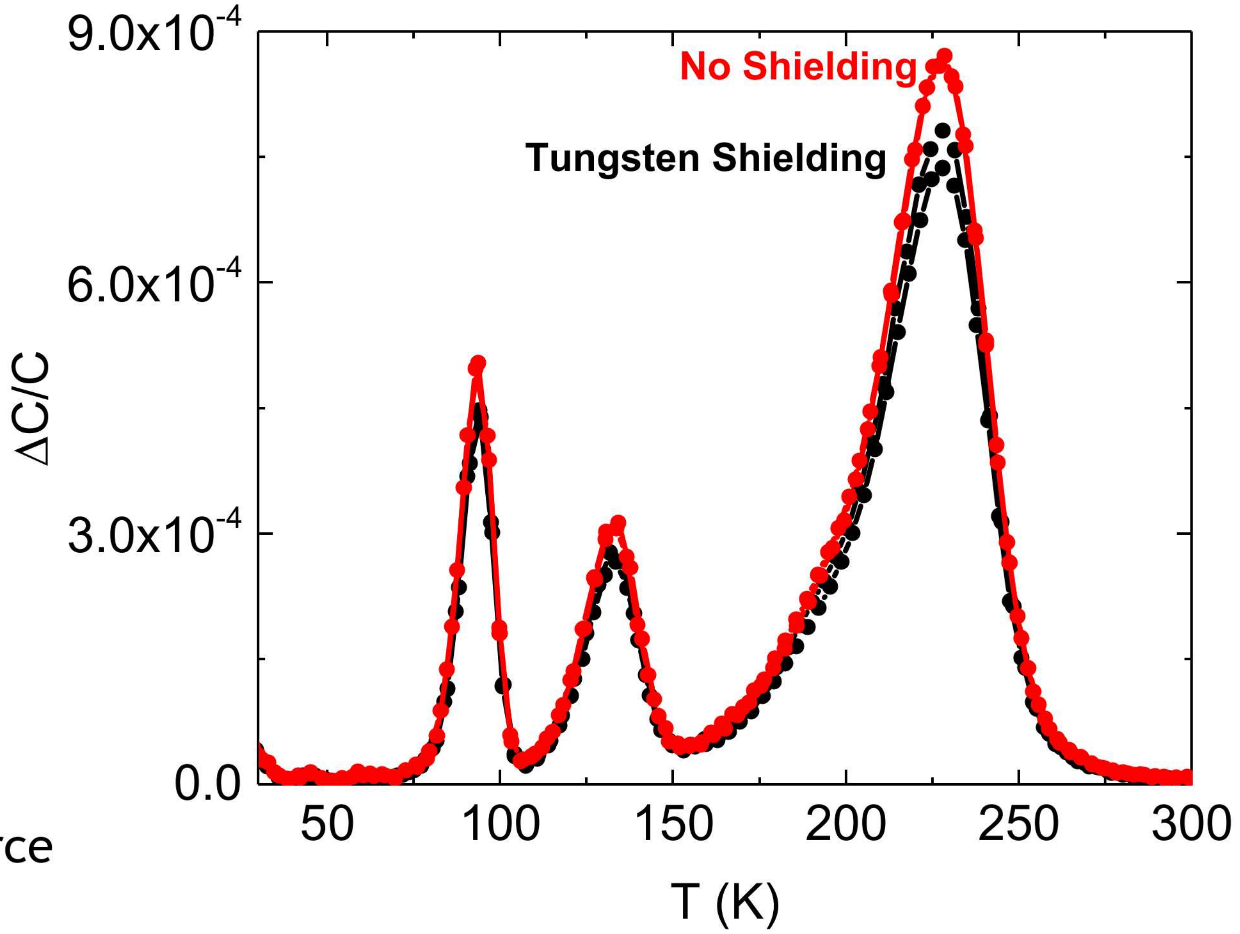
Temperature rise during ion irradiations show a decrease of the deep peak and an increase of the VO/VP_2 peak → not observed in high flux neutron irradiations

2. Defect annealing by Gamma rays

Hypothesis: Omega and NIF produce a gamma environment that could introduce annealing

Test hypothesis at Omega by fielding devices with and without Tungsten shield





Very small difference observed in the DLTS spectra due to shield thickness (0.69 cm) moving devices away from source

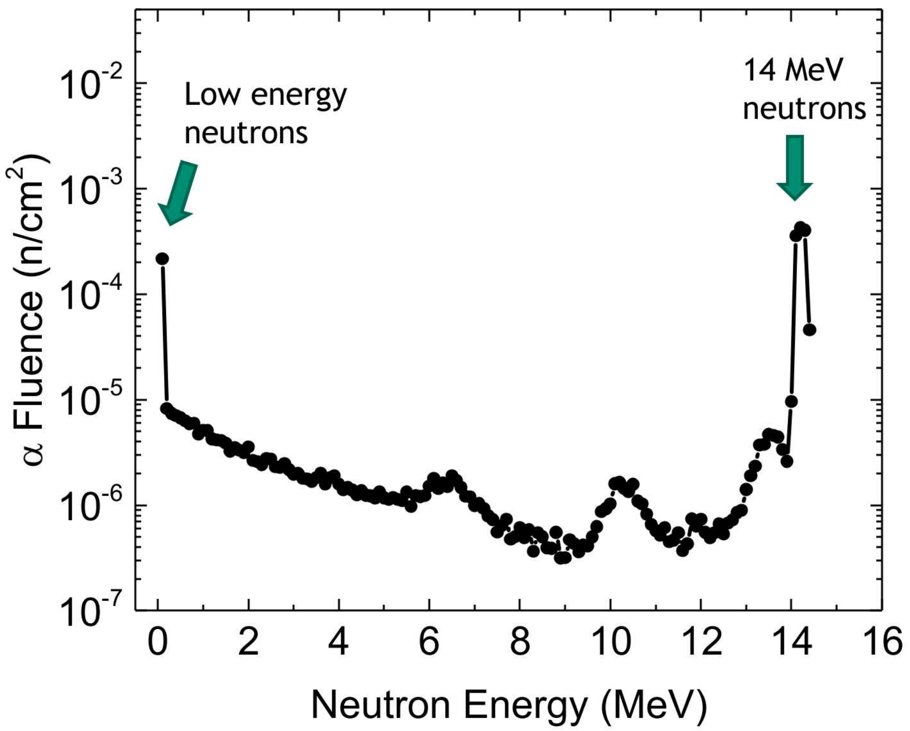
$$\frac{No\ Shield_{Fluence}}{Shield_{fluence}} = 1.17 \qquad \frac{No\ Shield_{Deep\ peak\ height}}{Shield_{Deep\ peak\ height}} = 1.16$$

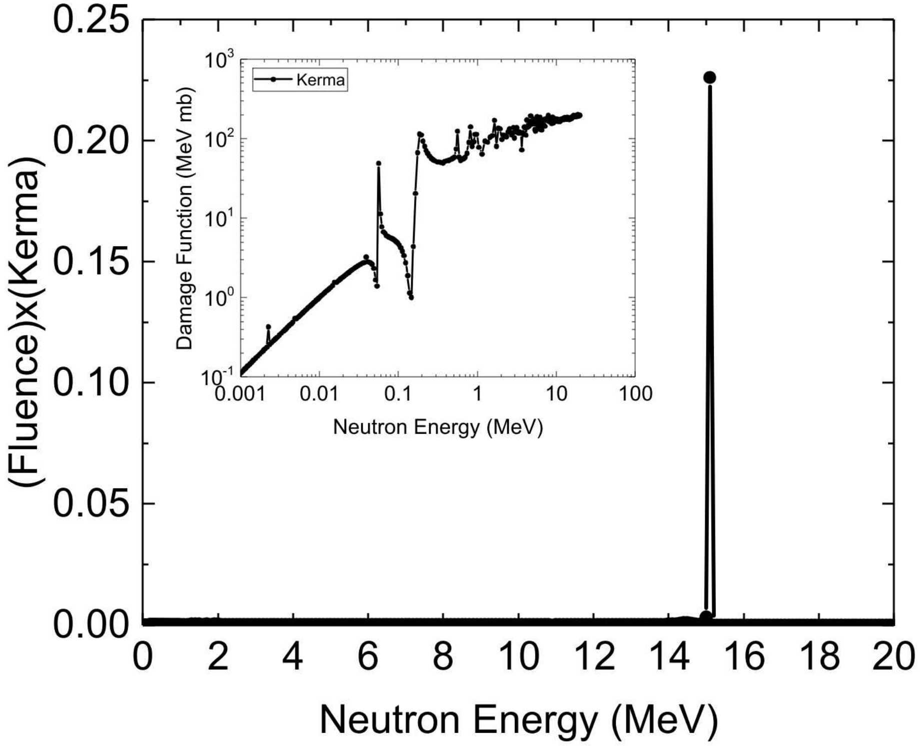
Gamma rays-induced annealing can not account for 60% damage factor difference

3. Down scattered neutrons

Hypothesis: Down scattered neutrons are not being counted in low flux irradiations

- IBL 14 MeV neutron fluence is determined via associated particle detection and activation foils



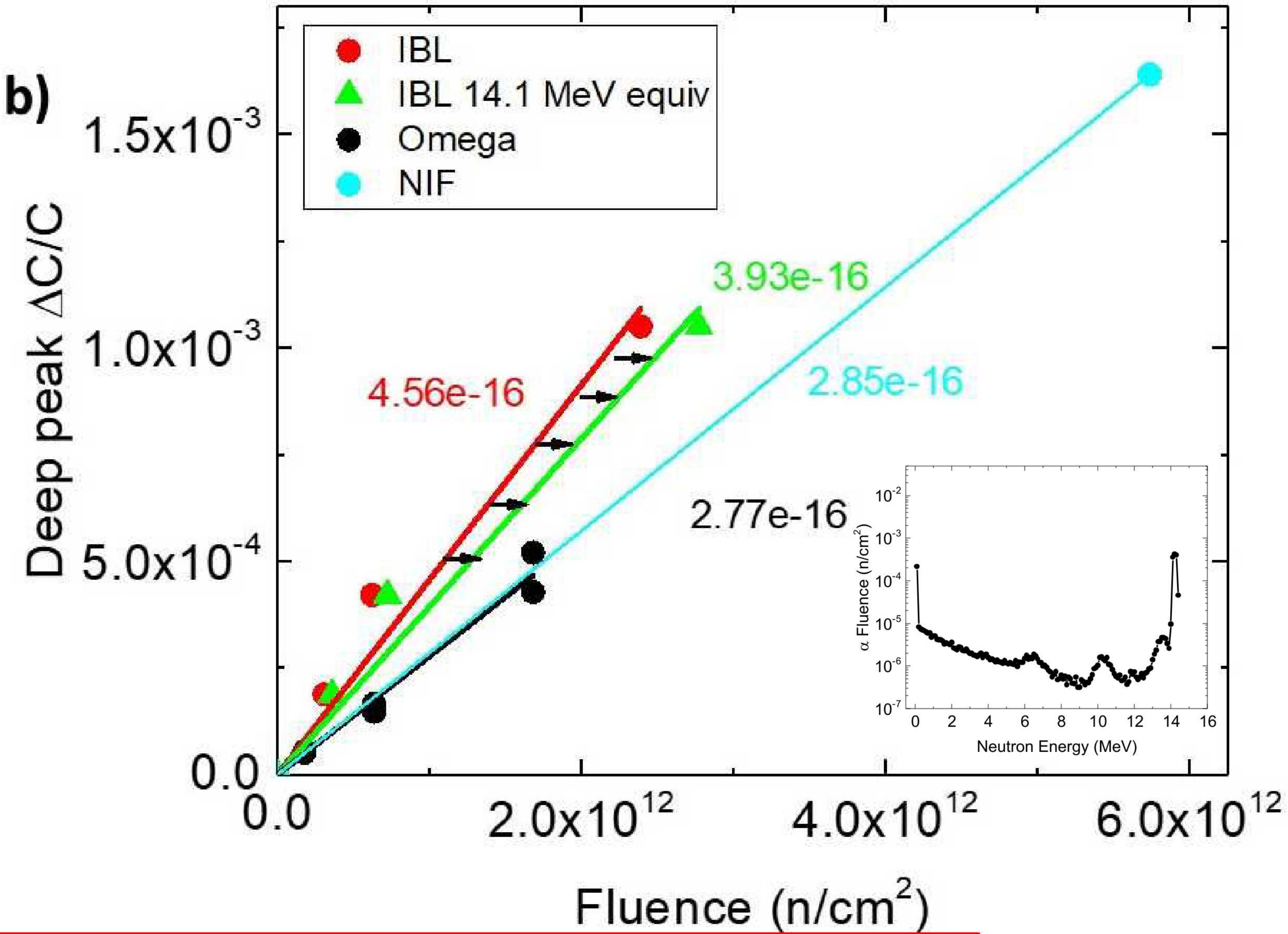


MCNP shows there is a low energy neutron component in the neutron energy spectra at IBL – 14 MeV n beamline

3. What is the effect of the down scattered neutrons on the damage?

Down scatter neutrons contribute an extra 16% damage

Down scattered have a small effect

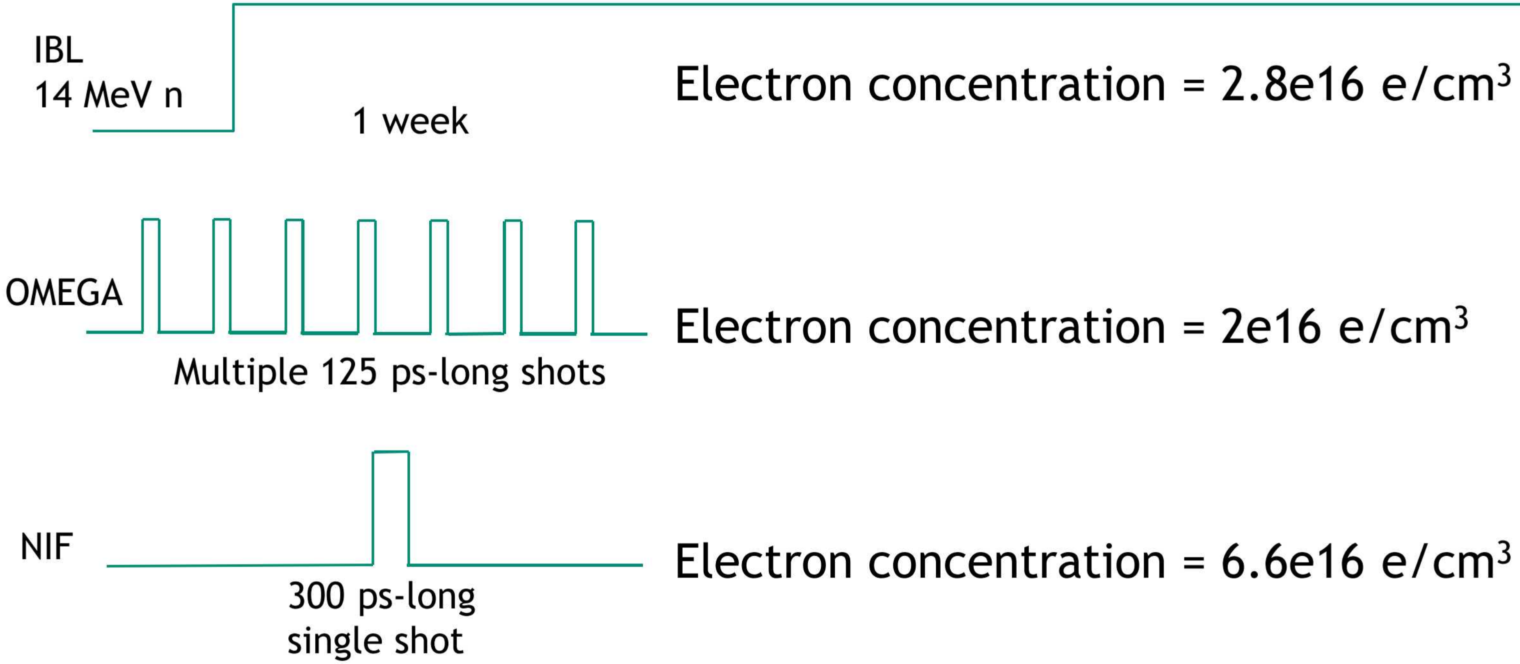


Down scattered neutrons do not account for the 60% difference in damage factor

4. Electron-hole pair concentration in NIF and OMEGA

Are the short-pulse environments in NIF/OMEGA producing a large concentration of e-h pairs which are annealing out defects?

14 MeV neutrons deposit up to >80% of the energy into ionization.



- Carrier concentration during short pulses at Omega and NIF is very high relative to doping level

- Localized annealing due to high e-h pair concentration in very period of time

- DLTS signature does not change during current Injection annealing

High carrier concentration during high flux irradiations might result in defect annealing

Conclusions

- Low neutron flux irradiations at IBL produce more damage than high flux shots at OMEGA and NIF

Hypothesis:

~~1. Localized heating~~

~~2. Gamma rays-induced annealing~~

~~3. Down scattered neutrons~~

4. Electron-hole pair annealing

  - High carrier concentration during high flux shots anneal out neutron damage as it is being created
  - Under investigation
  - Designed experiments to probe this