GEANT4 and MCNPX Comparison of the Treatment of Displacement Damage Mechanisms in HgCdTe

Bryan C Fodness[1], Robert A Reed[2], Thomas M Jordan[3], Christina Howe[4], Jean-Marie Lauenstein[5], Paul W Marshall[6]

1. NASA/GSFC-SGT Inc.
2. NASA/GSFC
3. EMPC
4. Vanderbilt University
5. NASA/GSFC-QSS Group
6. Consultant to NASA/GSFC

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Outline

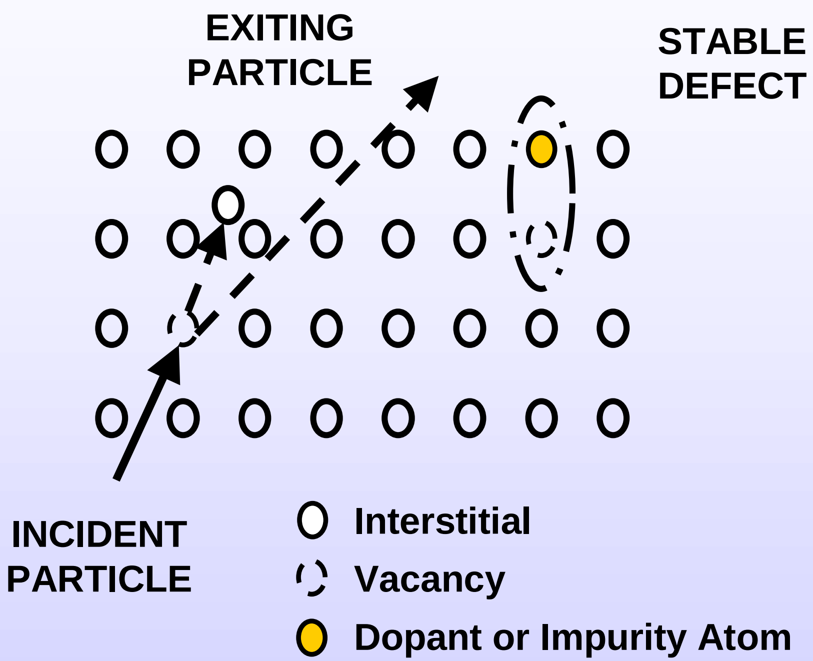
- Motivation
- Review of NIEL in Silicon
- NIEL Calculation Methodology
- Comparison of GEANT4 and MCNPX
- HgCdTe NIEL Results with Variance
- Implications for Damage in HgCdTe Detector Arrays
- Future Work

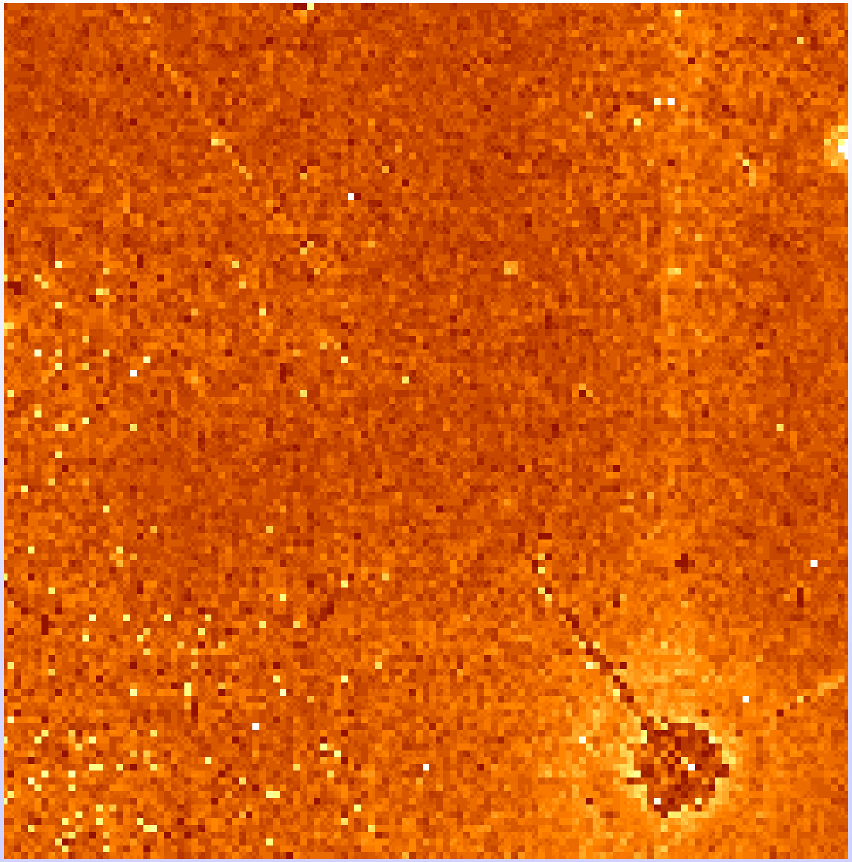
Motivation

- **Bandgap engineered materials for optical detectors**
  - HgCdTe and InSb for Infrared
  - ZnCdTe for X-Rays and Gamma Rays
- **Science missions are requiring large format pixelized IR detector systems**
  - i.e. James Webb Space Telescope
- **Recent test data in HgCdTe has shown degradation (hot pixels) at relatively low fluence**

Displacement Damage?

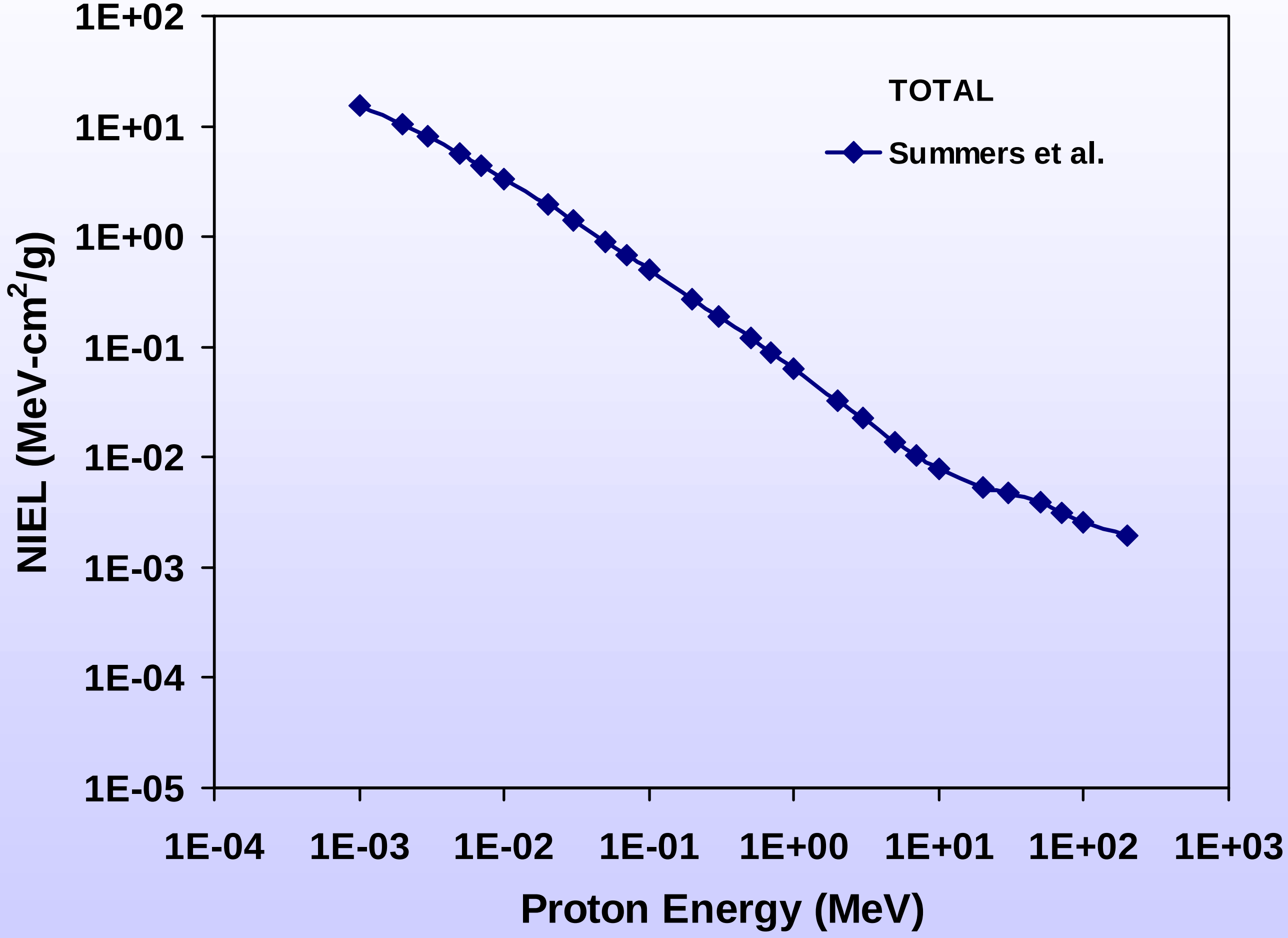
Damage Mechanism



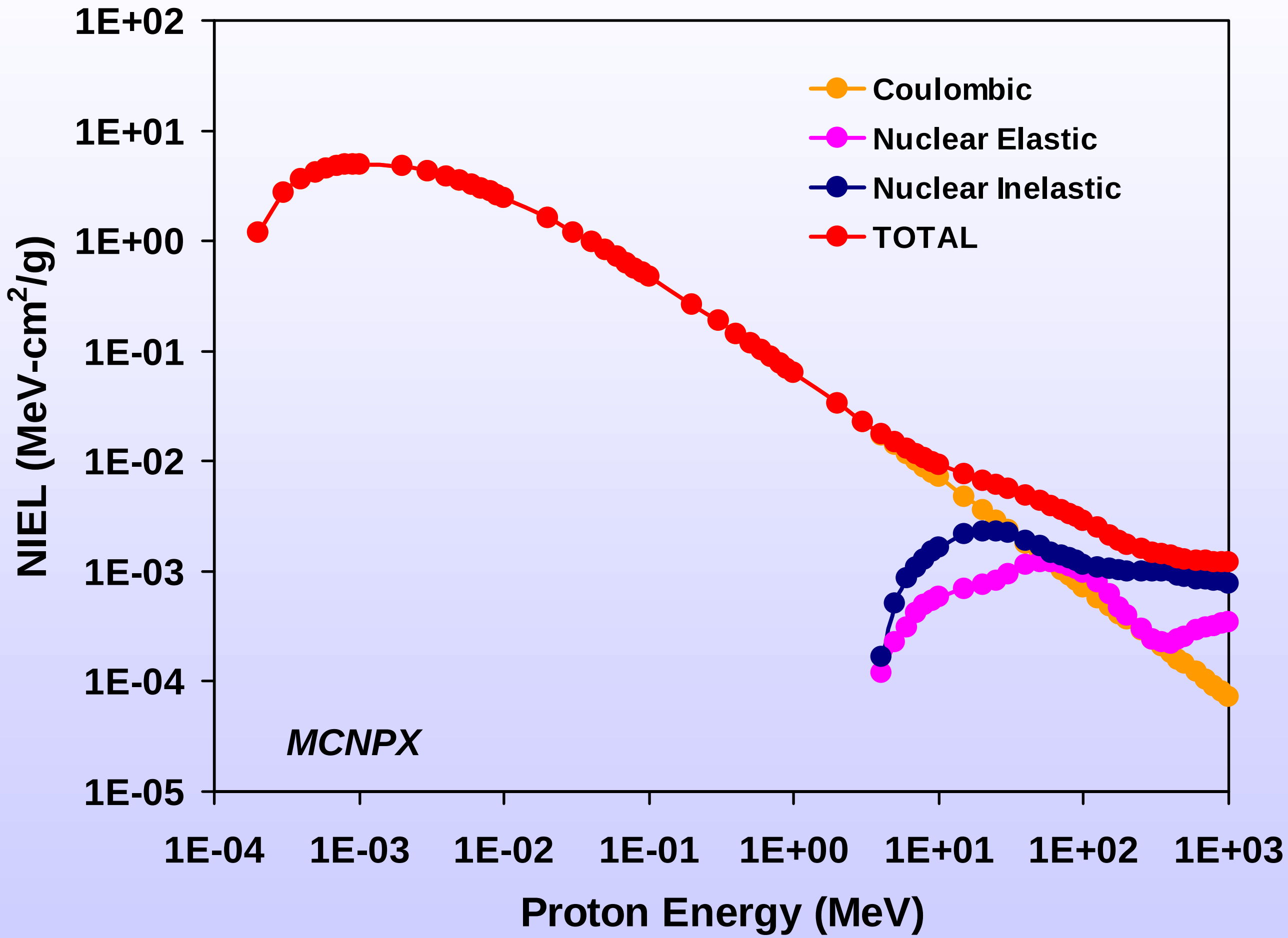


P.W. Marshall and C.J. Marshall, Notes from 1999 IEEE Nuclear and Space Radiation Effects Conference Short Course

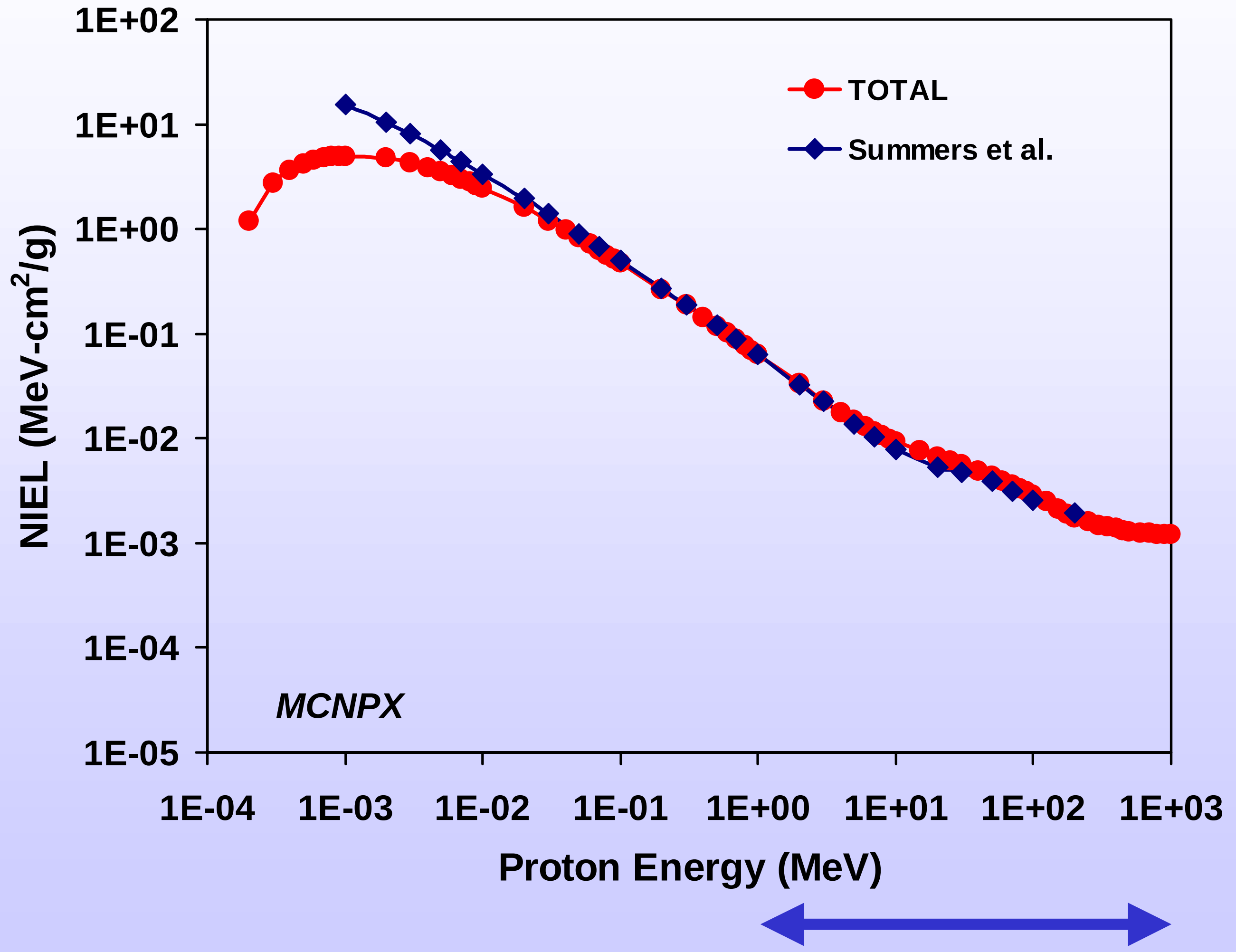
Review of NIEL in Silicon



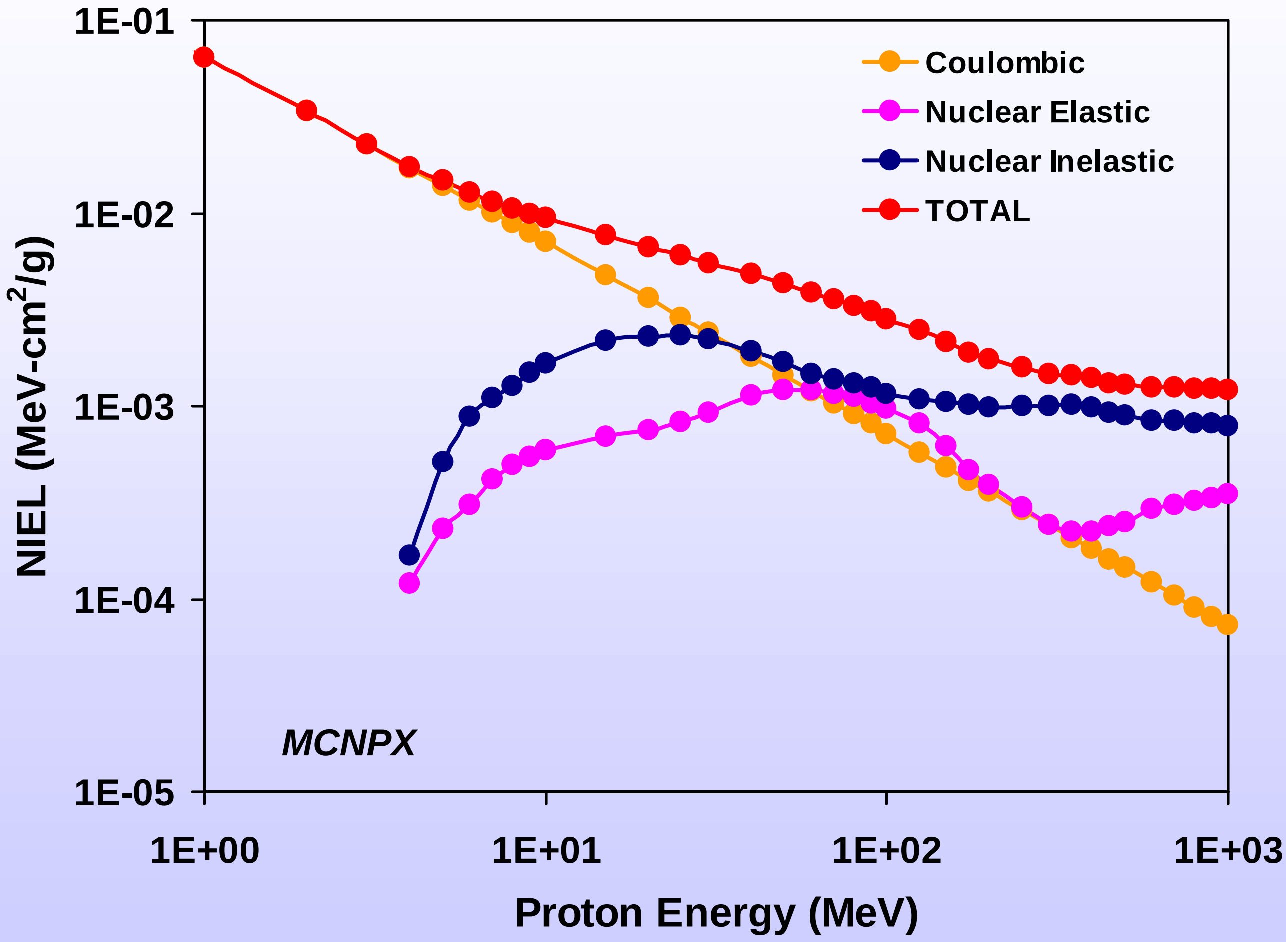
Review of NIEL in Silicon



Review of NIEL in Silicon



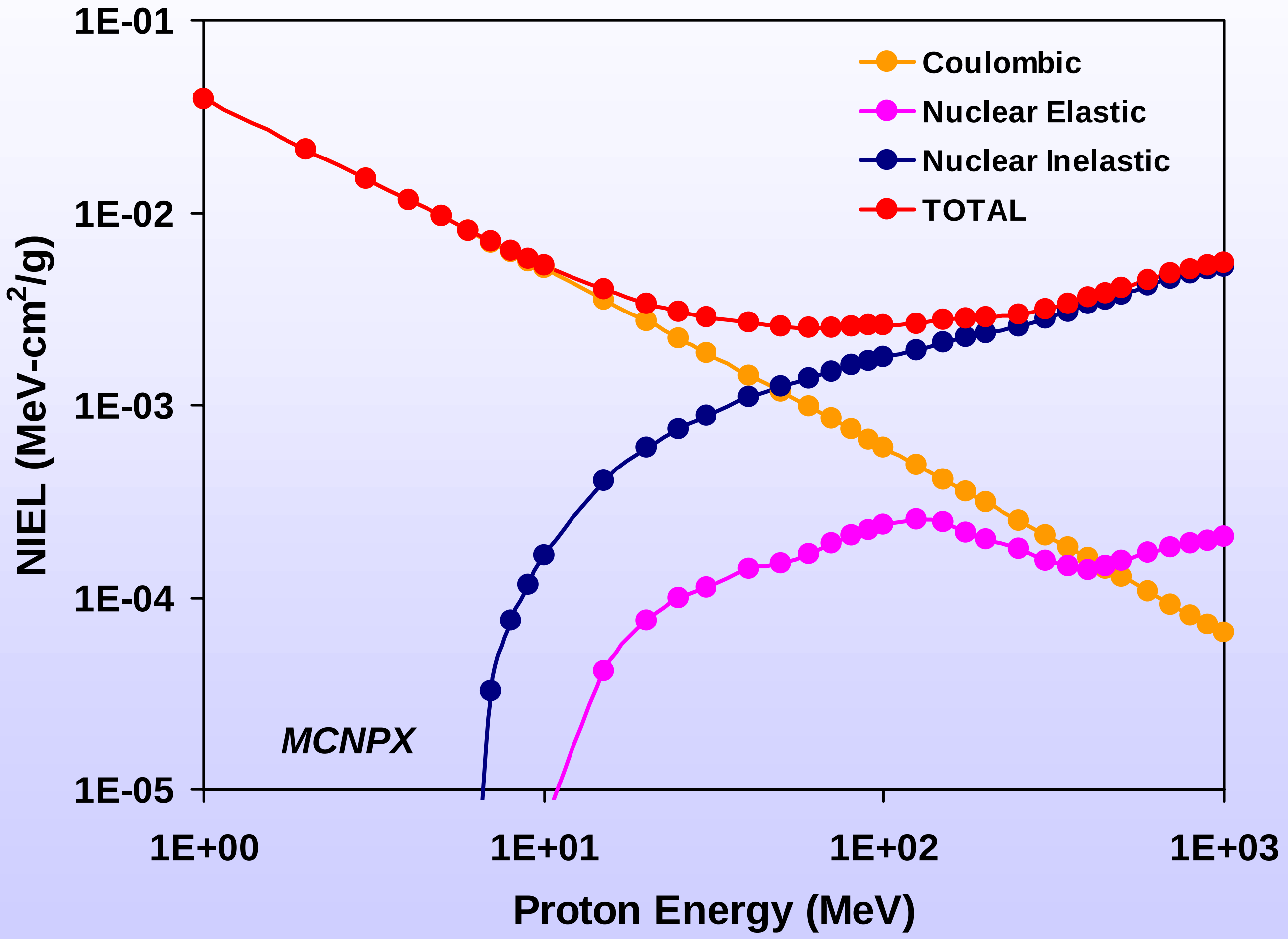
Review of NIEL in Silicon



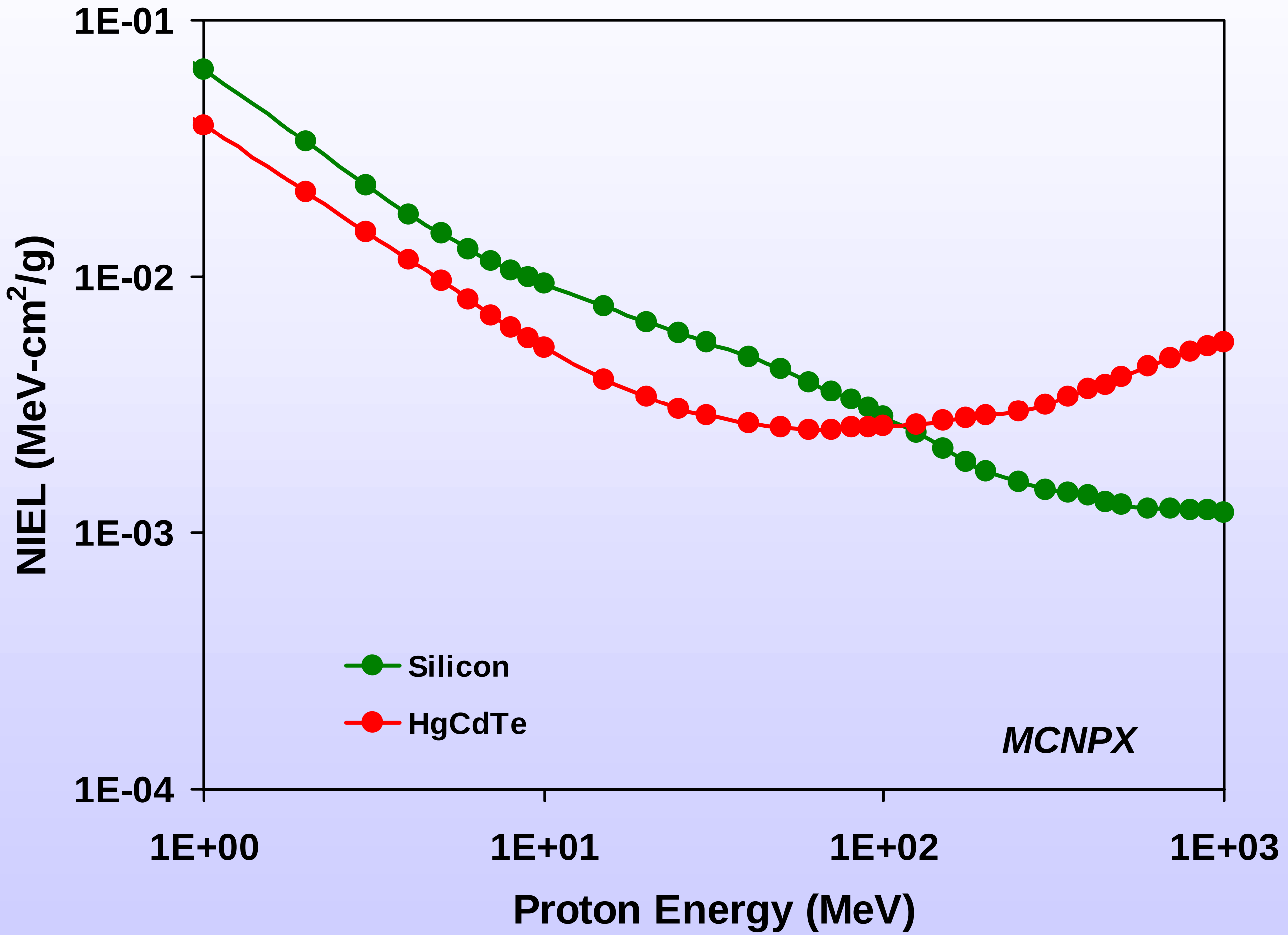
Review of NIEL Calculation Methods in Sensors

- Analytic (Burke et al. 1987)
  - Uses moment generating functions to approximate variance in damage energy spectrum
- CUPID Monte Carlo (Dale et al. 1994)
  - Tracks individual particle reactions
  - Calculates the damage energy directly
- Hybrid (Jun et al. 2003)
  - Coulombic using Analytic
  - Nuclear Reactions using Monte Carlo (MCNPX)
- Our work extends the Hybrid approach to include variance of NIEL in HgCdTe

NIEL in $Hg_{(1-x)}Cd_xTe$, x=0.3

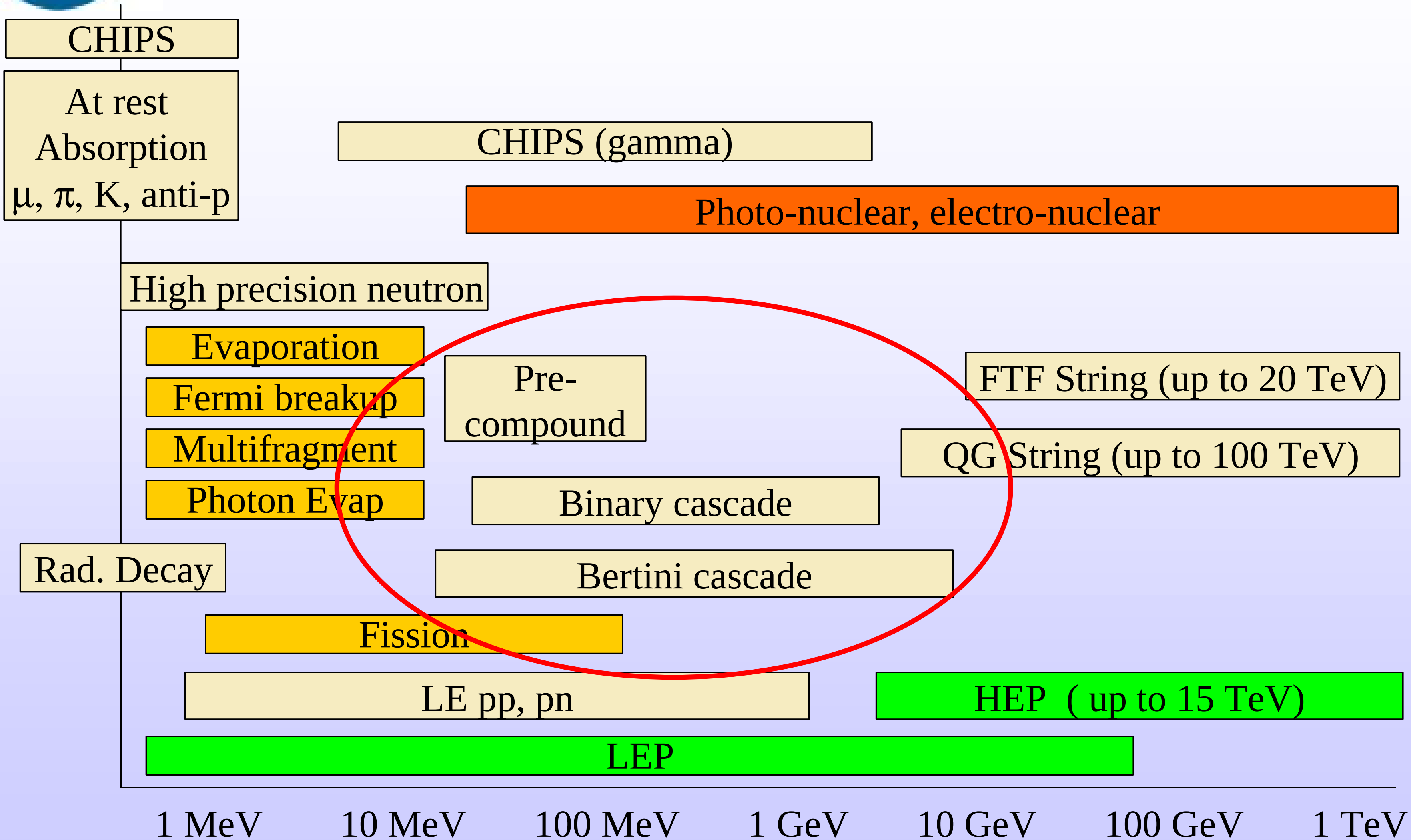


HgCdTe vs. Si



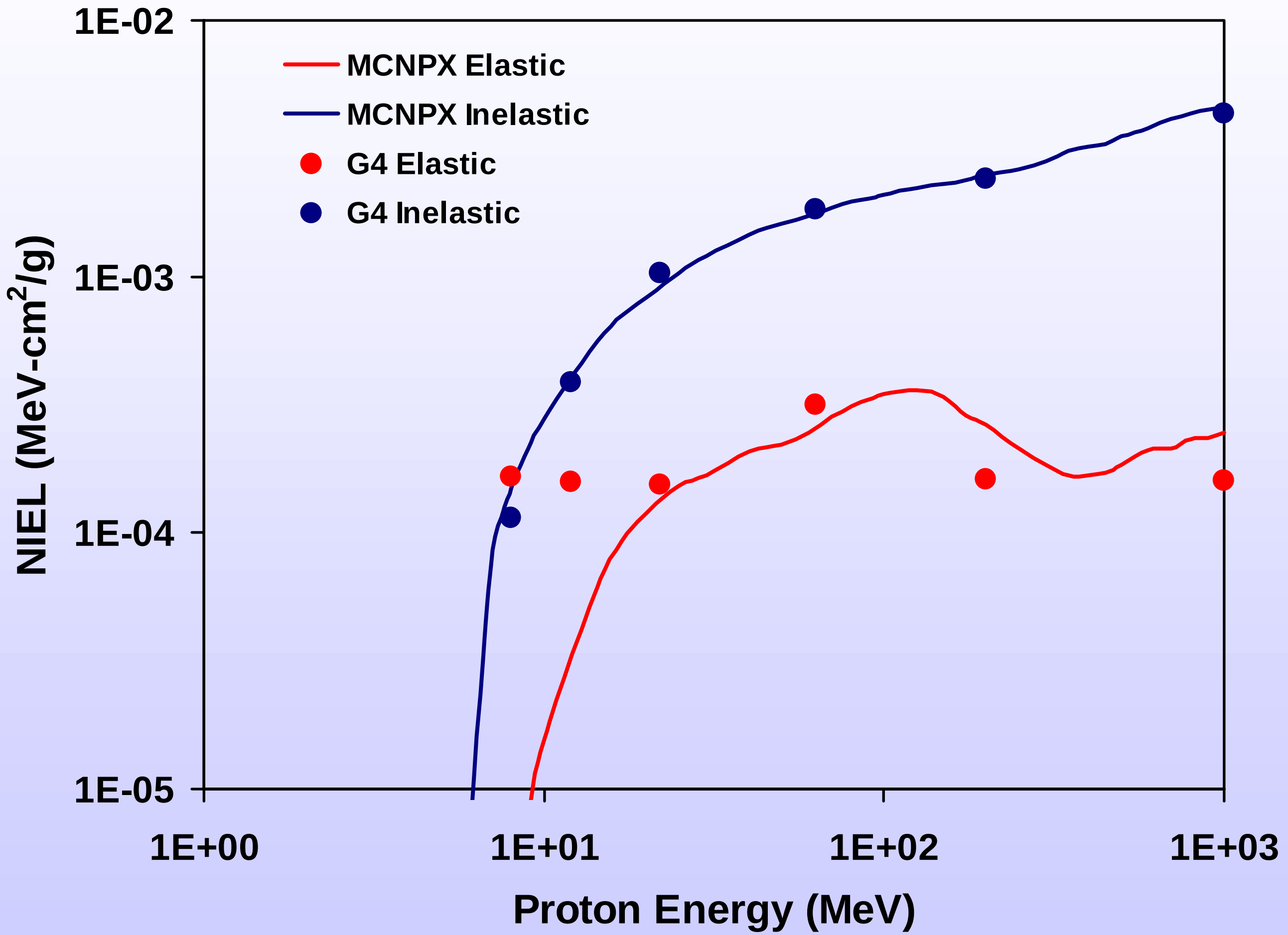
1E-01
1E-02
1E-03
1E-04
NIEL (MeV-cm2/g)
1E+00
1E+01
1E+02
1E+03
Proton Energy (MeV)
Silicon
HgCdTe
MCNPX

G4 Hadronic Models



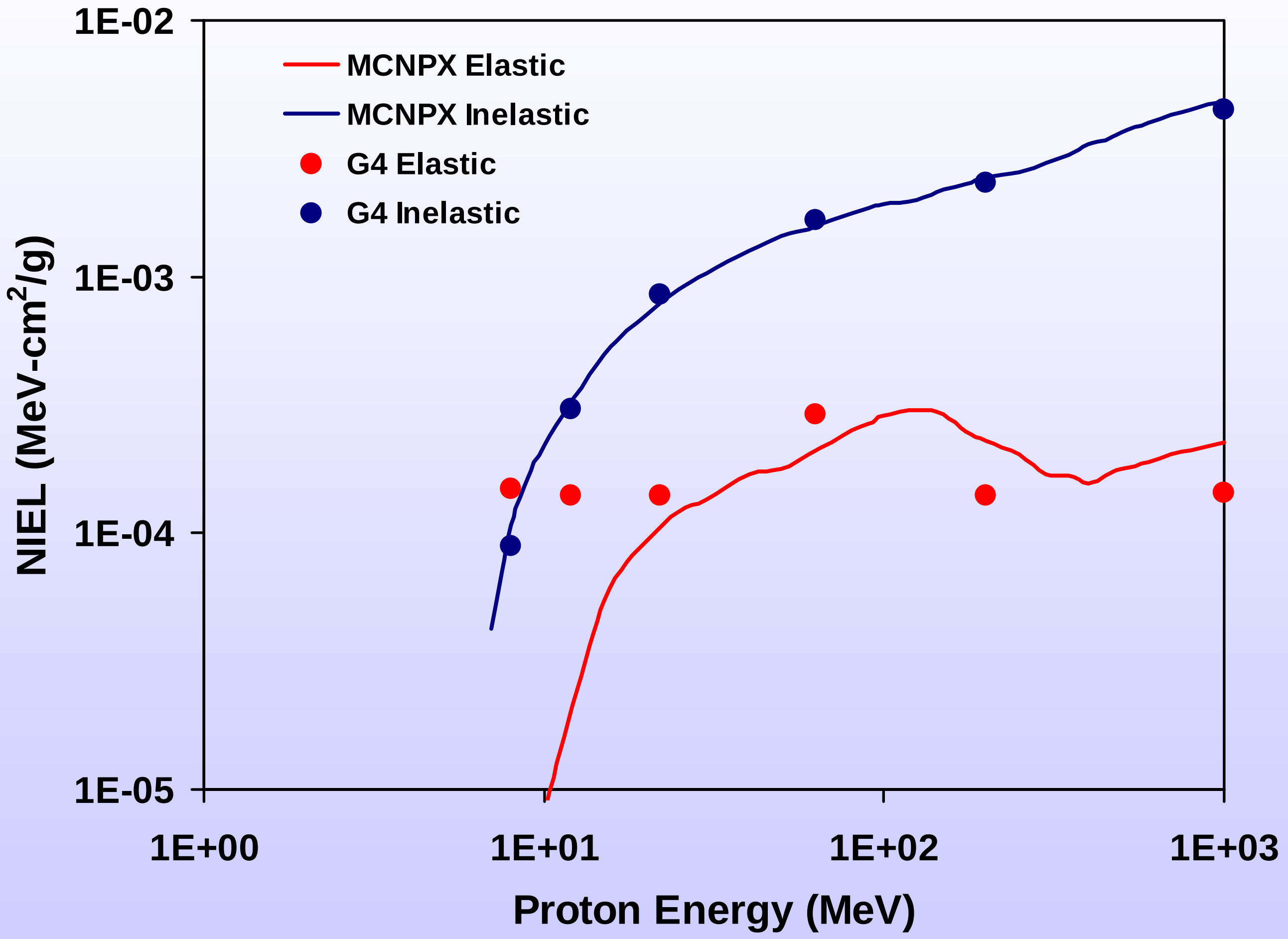
D. Wright 2004

Comparison for Cadmium
Bertini Cascade

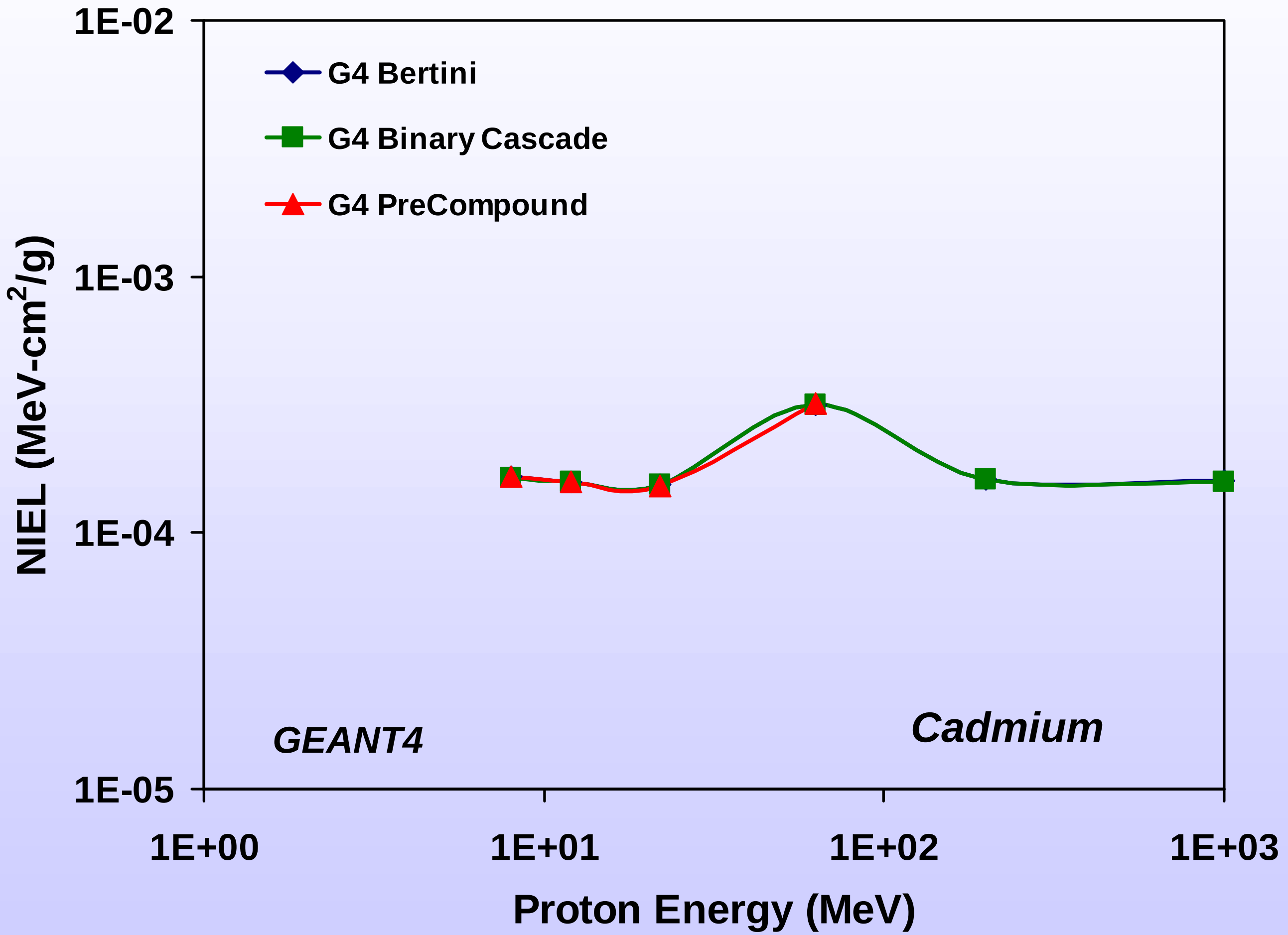


Comparison for Tellurium

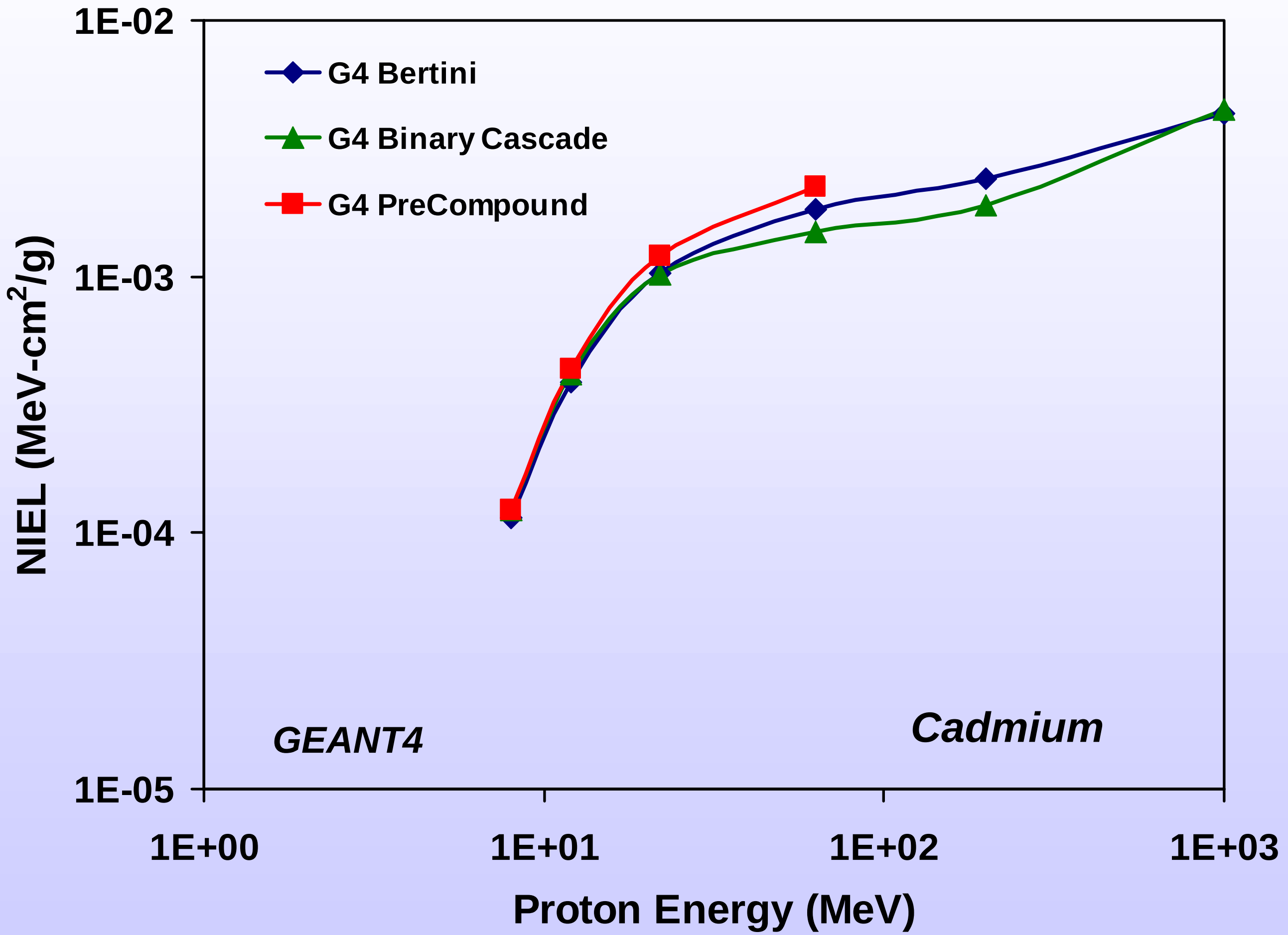
Bertini Cascade



G4 Models-Nuclear Elastic



G4 Models-Nuclear Inelastic



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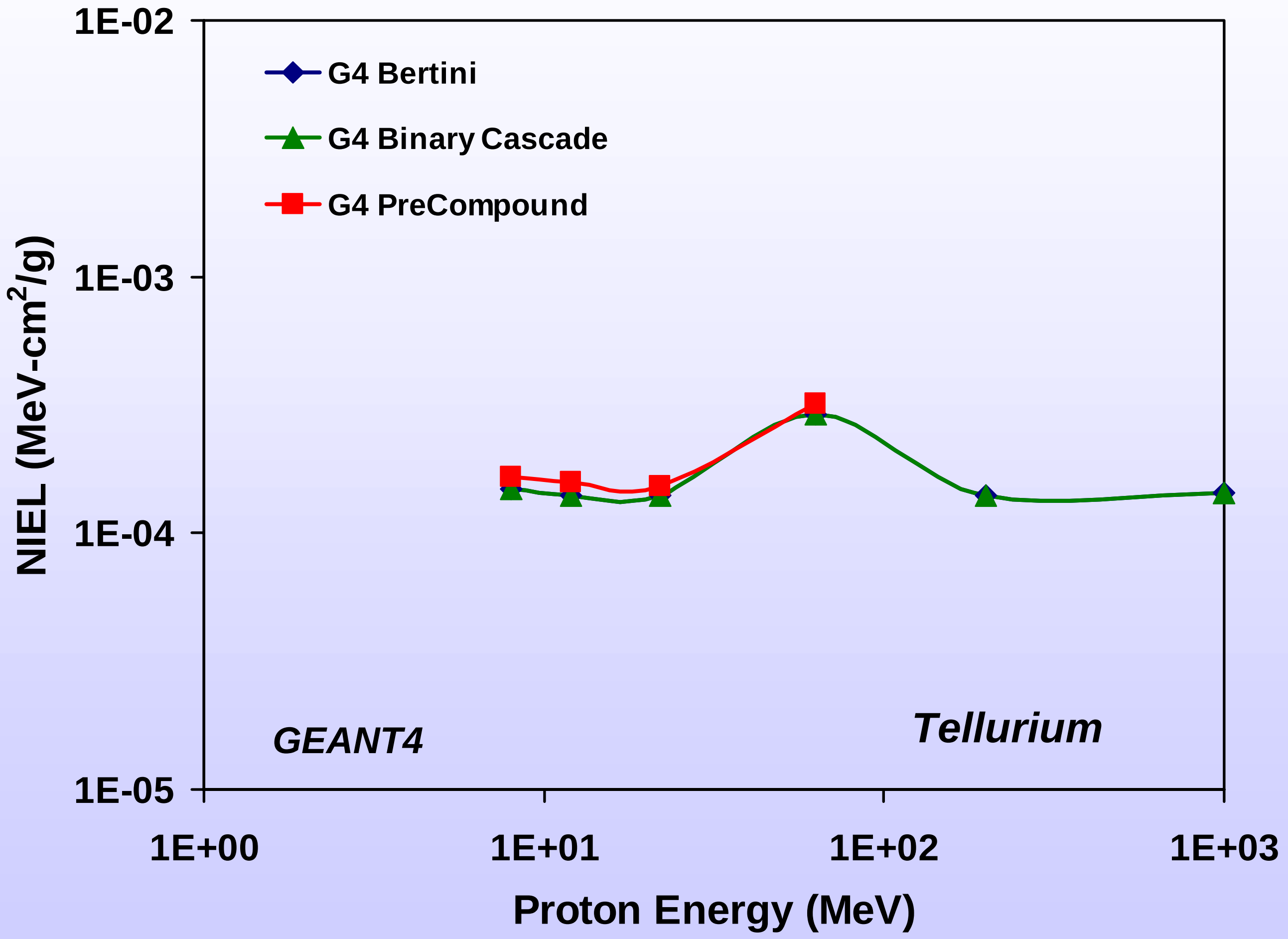

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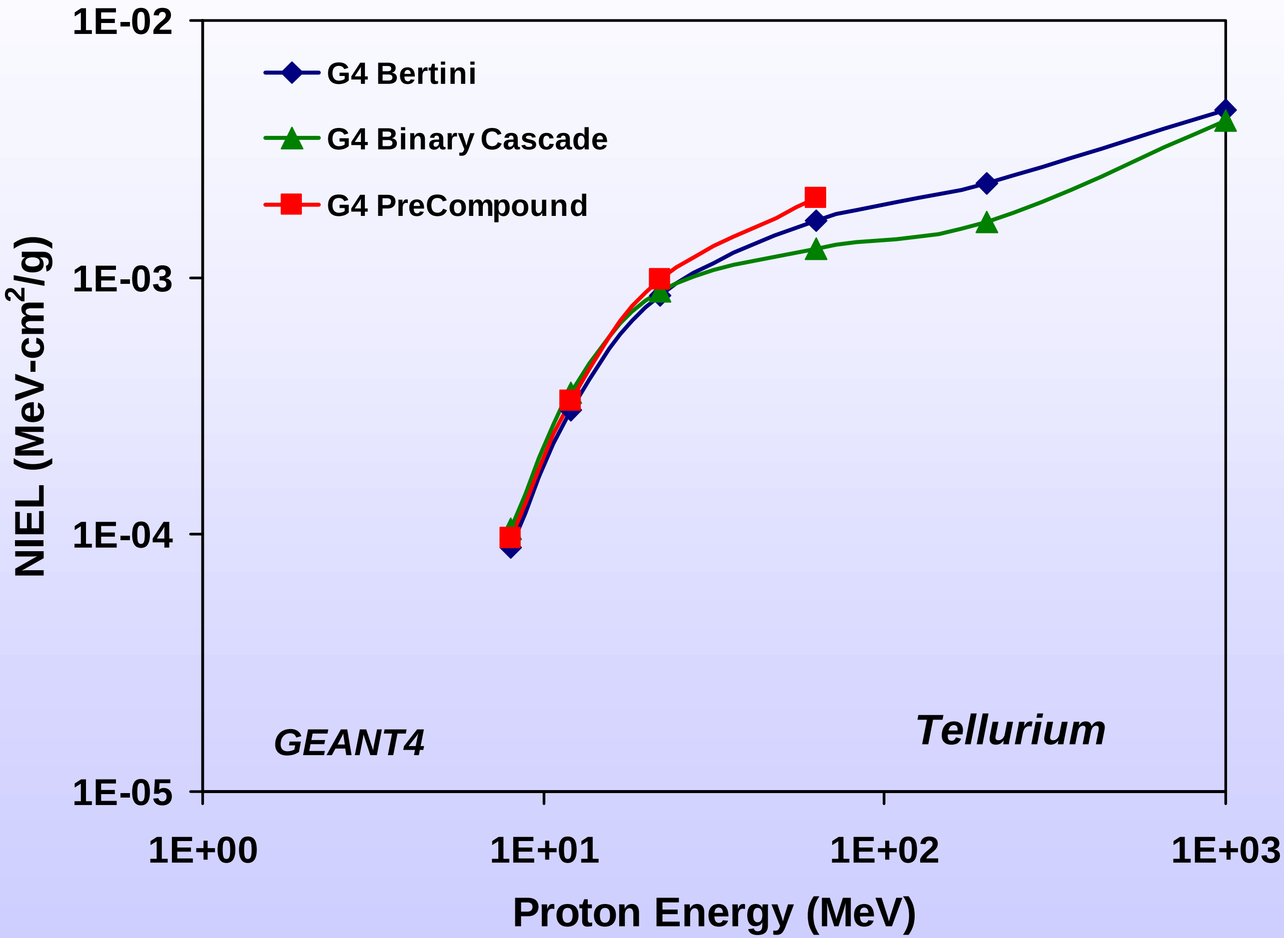
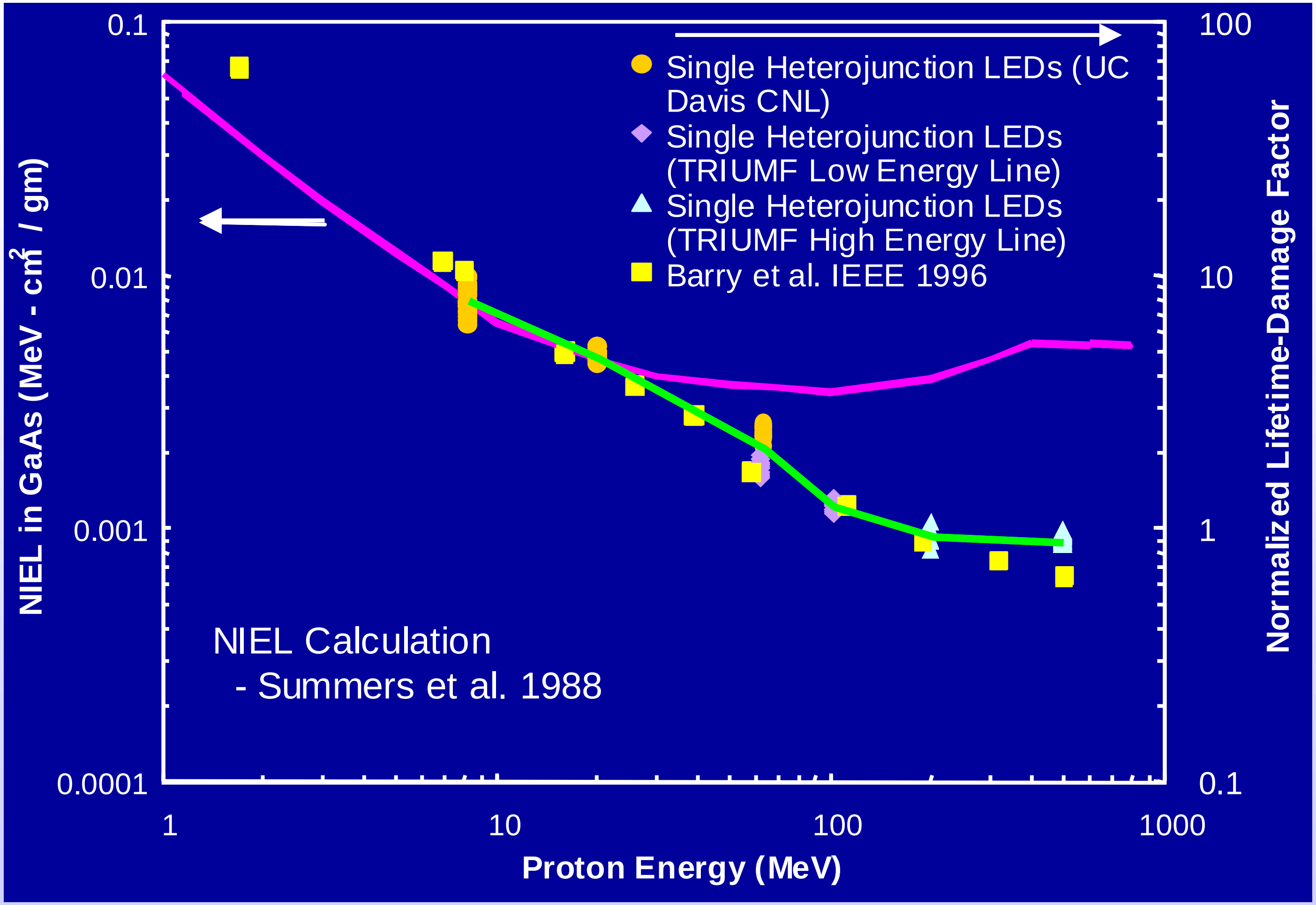


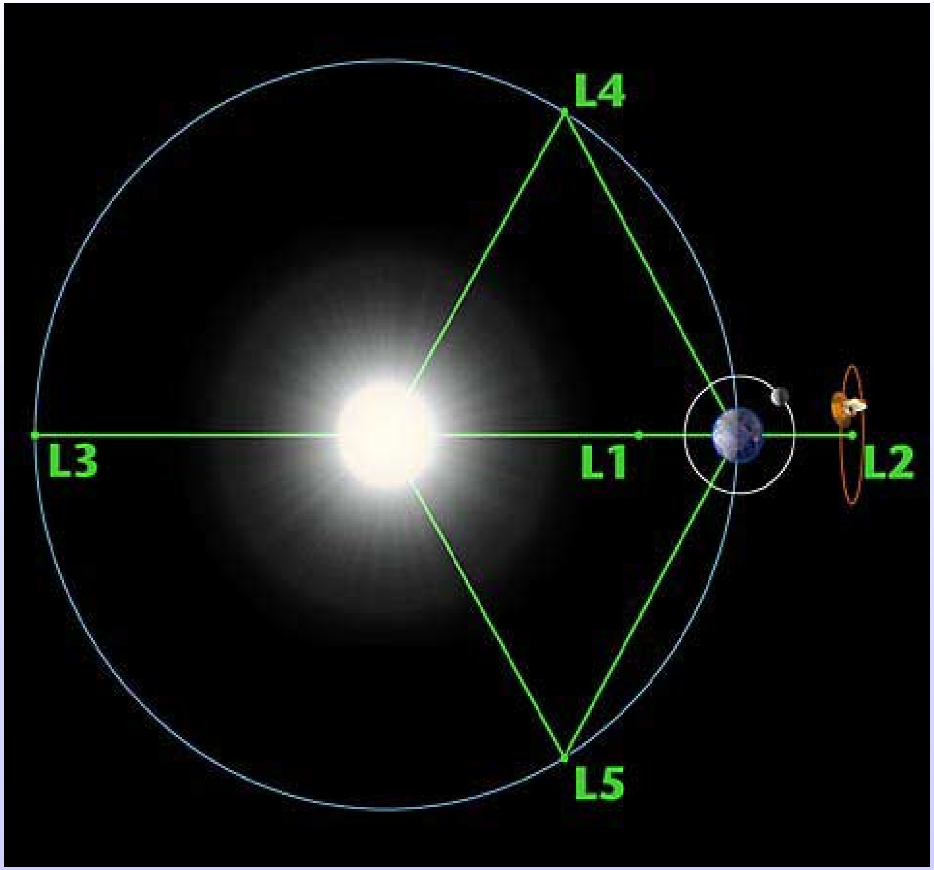
NIEL in GaAs (A Little History)

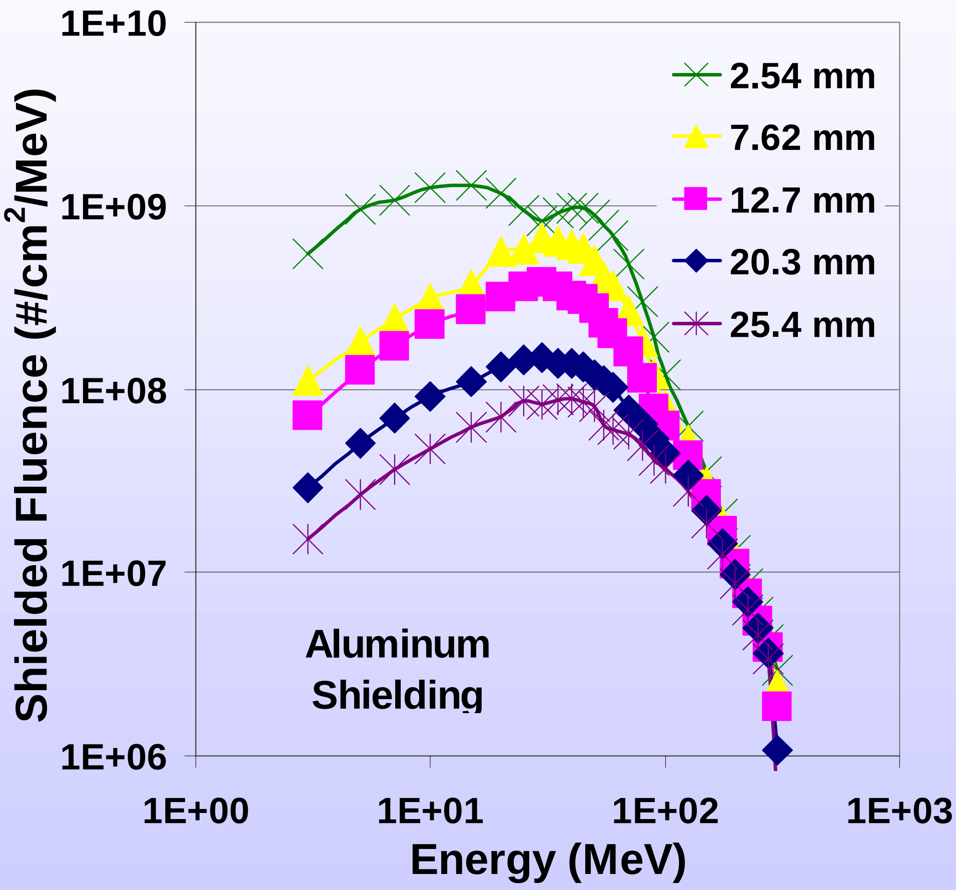


Device Response Does Not Always Follow NIEL!

JWST Mission: Proton Environment

Dominated by Solar Protons

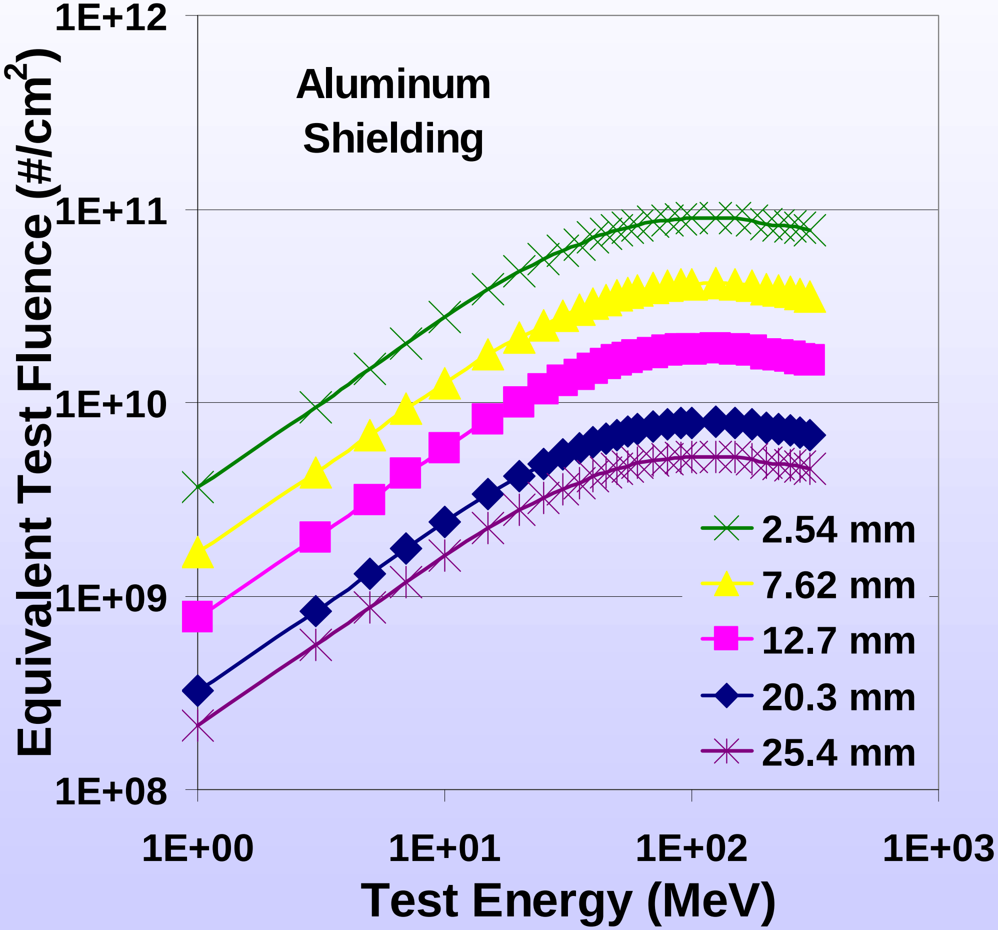




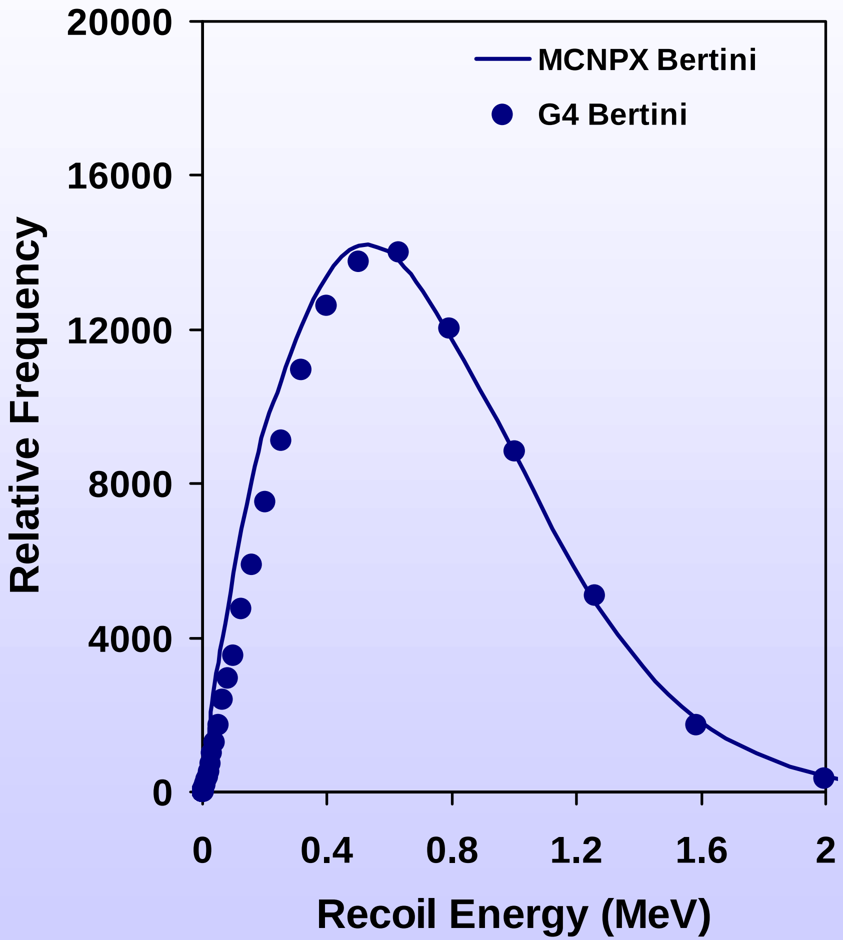
Equivalent Test Fluence Issues

$$\Phi_{eq}\left(E_T\right)=\frac{\int S_{NIEL}\frac{d\Phi}{dE}dE}{S_{NIEL}\left(E_T\right)}$$

- **Assumes the average damage follows NIEL**
- **Microdosimetry is energy dependent!**

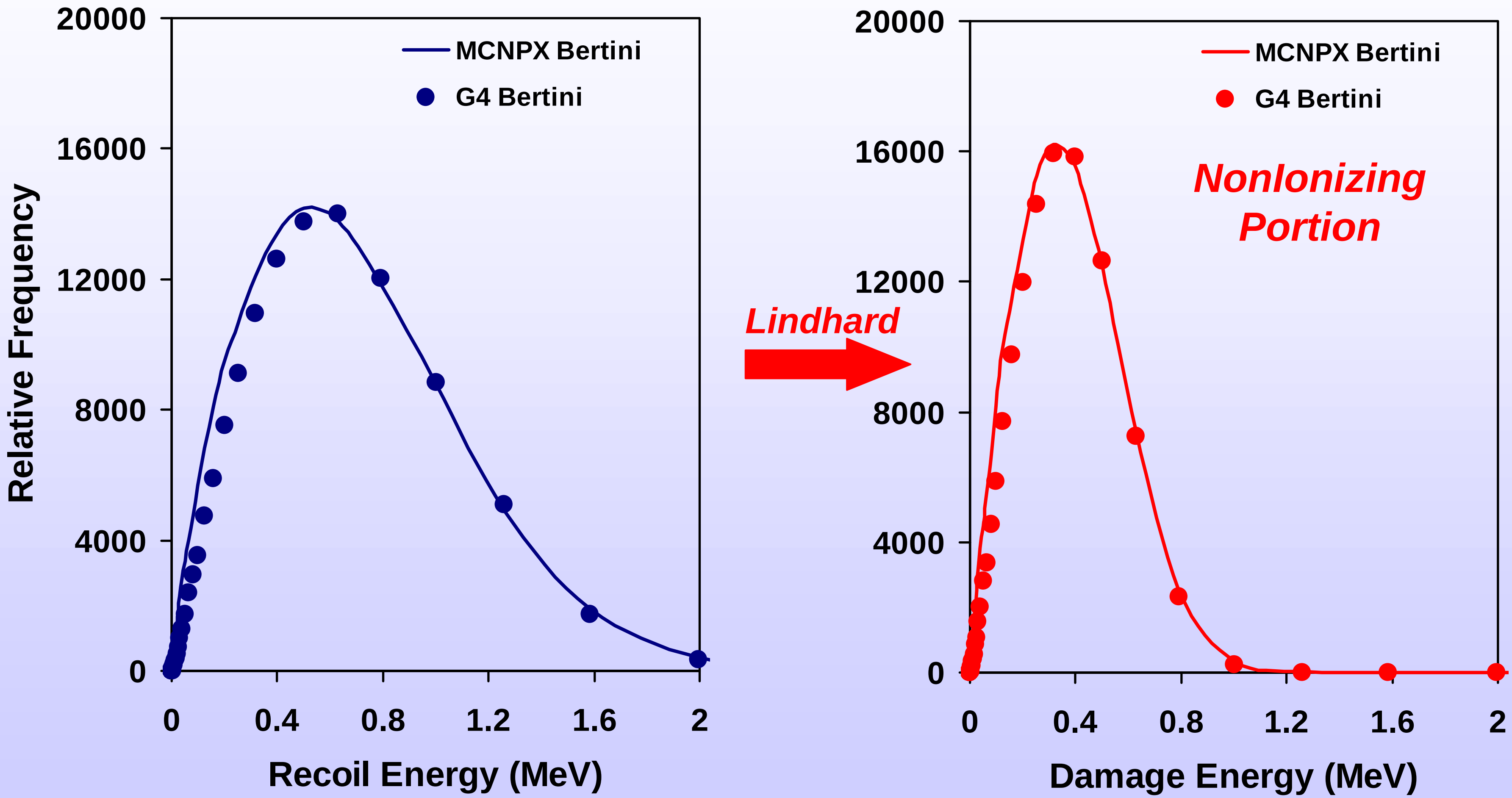


Inelastic Recoil/Damage Energy



- **63 MeV protons in HgCdTe**
- **Energy histogram including all reaction products**
- **The recoil energy is part ionizing and part nonionizing**

Inelastic Recoil/Damage Energy



Lindhard Partition Function

$$L(T) = \frac{1}{1 + F_L\left(3.4008\varepsilon^{1/6} + 0.40244\varepsilon^{3/4} + \varepsilon\right)}$$

$$T = recoil\ energy\ (eV)$$

$$\varepsilon = \frac{T}{E_L}$$

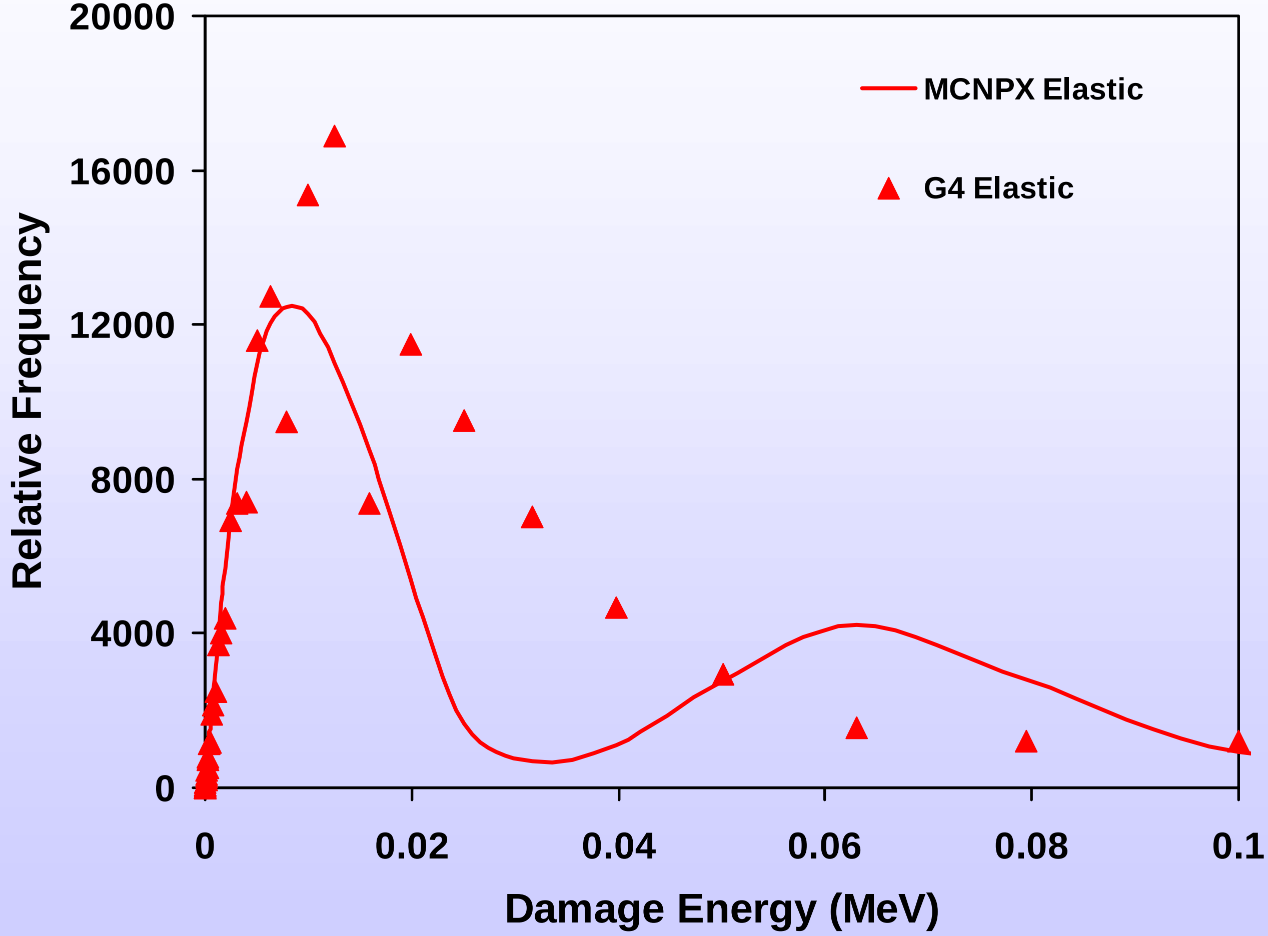
$$E_L = 30.724 Z_R Z_L \left(Z_R^{2/3} + Z_L^{2/3}\right)^{1/2} \frac{A_R + A_L}{A_L}$$

$$F_L = \frac{0.0793 Z_R^{2/3} Z_L^{1/2} \left(A_R + A_L\right)^{3/2}}{\left(Z_R^{2/3} + Z_L^{2/3}\right)^{3/4} A_R^{3/2} A_L^{1/2}}$$

I. Jun 2003

Implications in HgCdTe Detectors

Damage Energy Distribution



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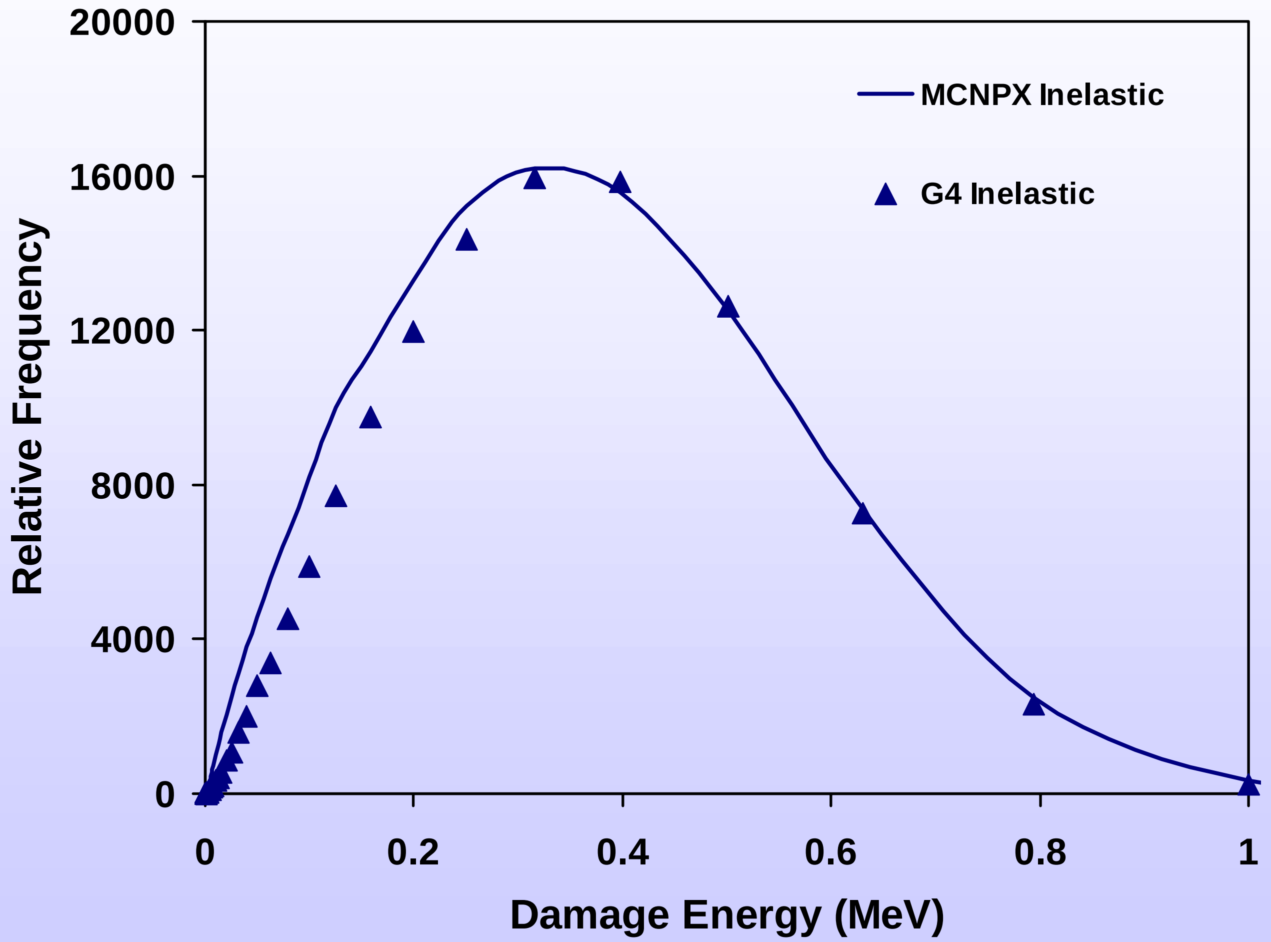

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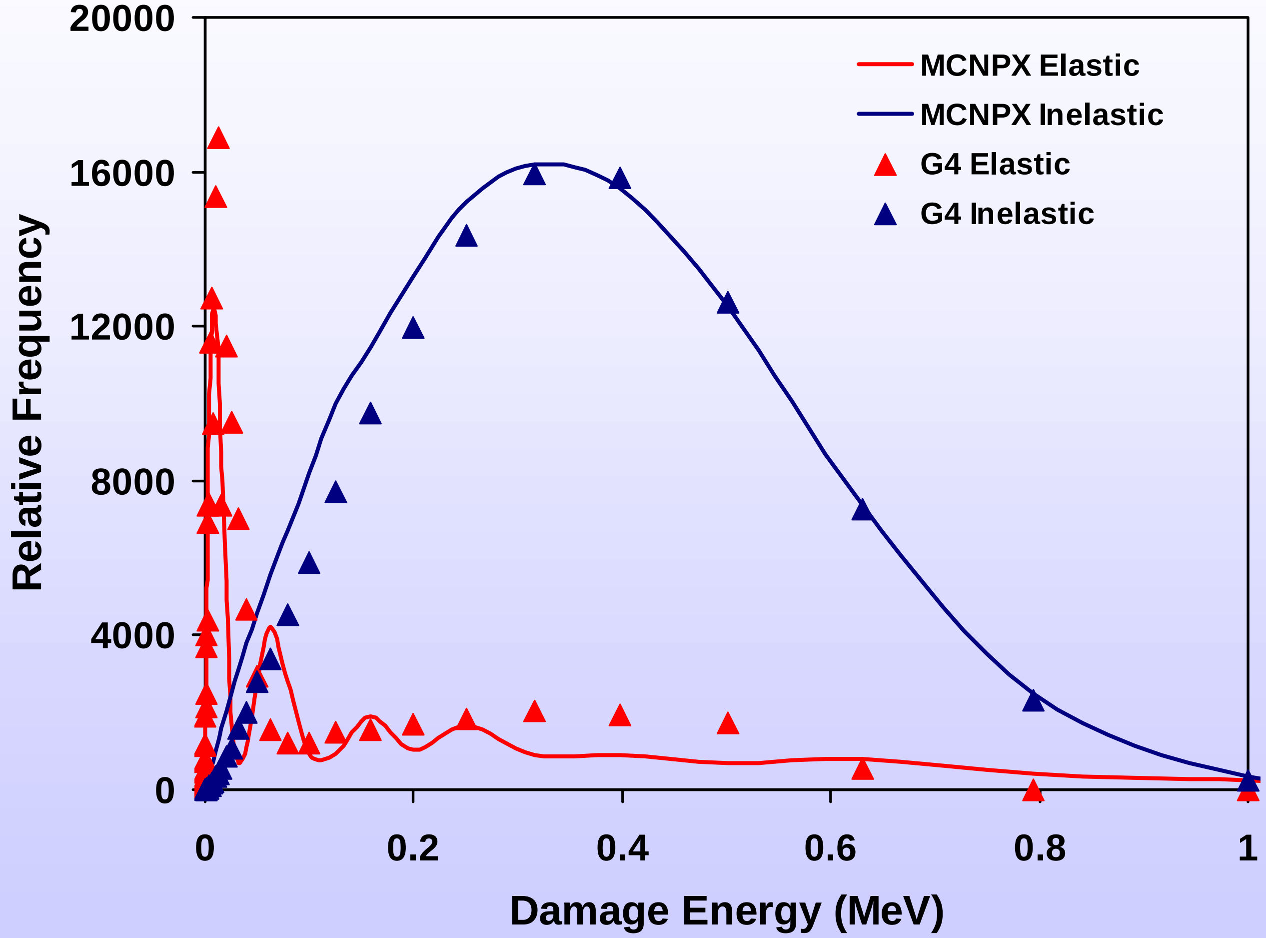

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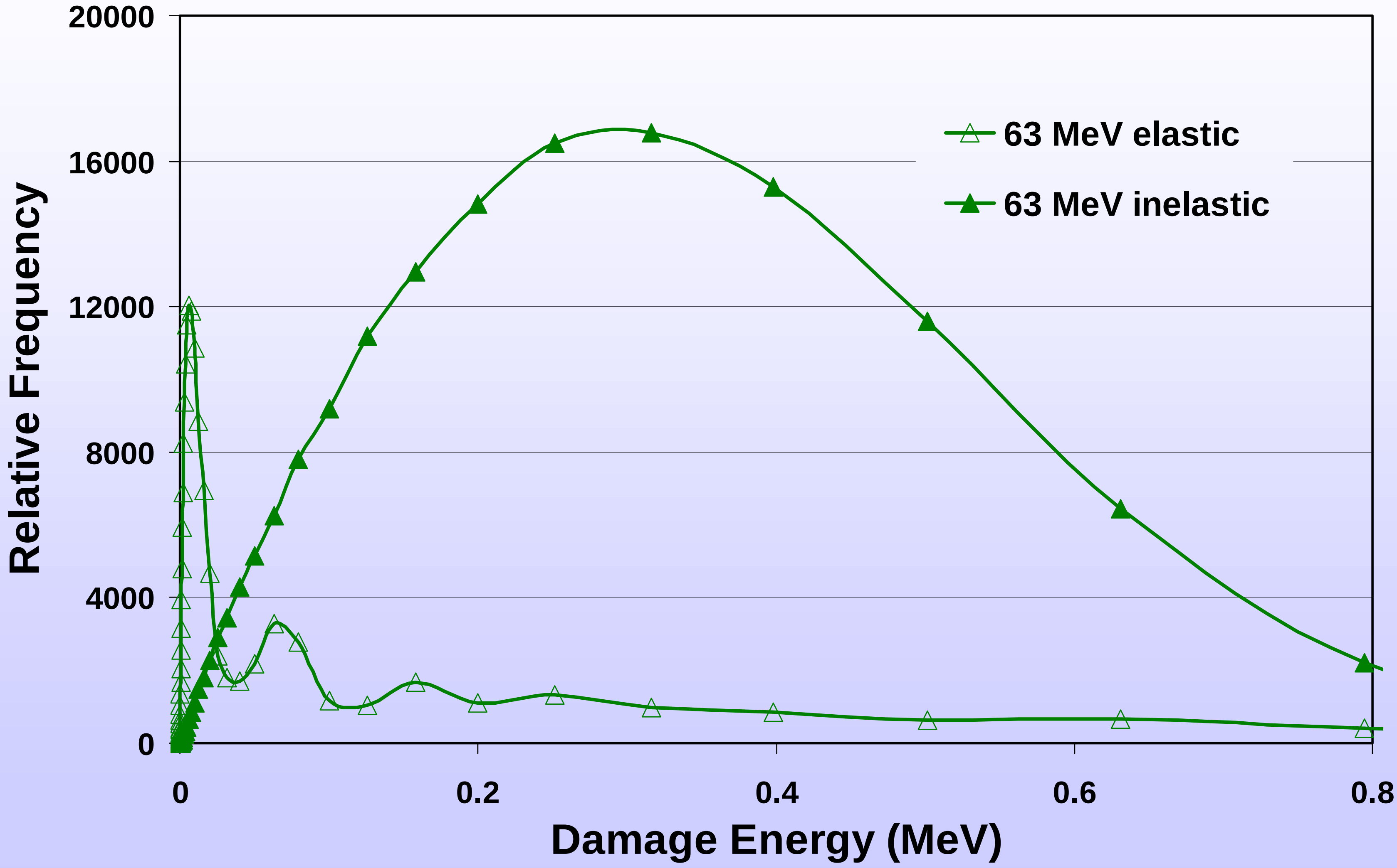
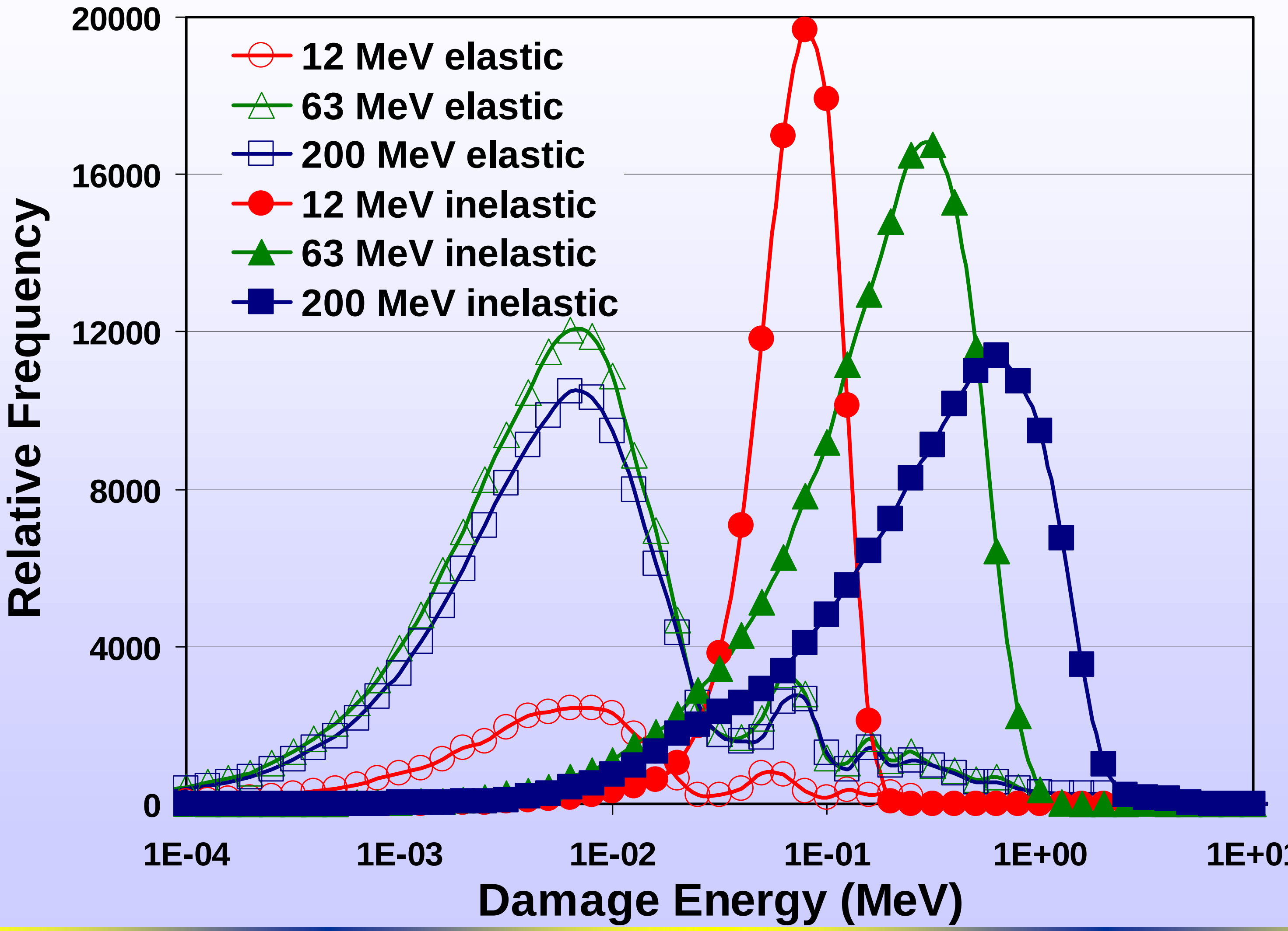


Damage Distributions in HgCdTe



Conclusion

- Calculated NIEL for short, mid, and longwave HgCdTe material compositions
  - Readily extendable to other materials and compositions
- Demonstrated technique to assess recoil spectrum behavior
  - Captured and analyzed full recoil spectra details
  - Revealed importance of damage mechanisms
- Showed importance of damage energy distribution in high Z materials
- Future work will provide comparisons of measured array damage