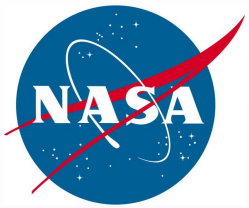
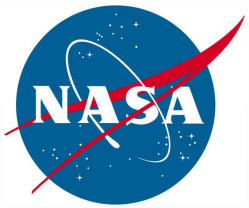


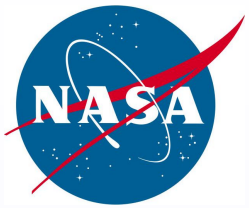

# Space Applications at NASA/GSFC Using Geant4

Bryan Fodness, *SGT Inc*
Robert Reed, *NASA/GSFC*
Thomas Jordan, *EMPC*
Jim Pickel, *PR&T*
Paul Marshall, *Consultant*
Ray Ladbury, *Orbital Science Corp*



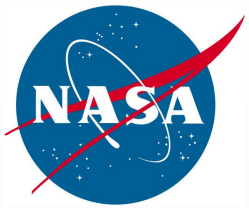

# Outline

- Introduction
- Angular Effects in Proton-Induced Single-Event Upsets
- Radiation Effects in Focal Plane Arrays
- Future Plans




# Introduction

- Why do we think Geant4 is important to NASA?
  - Need one code with these features
    - Z > 4 particle interactions
    - Tracking of all secondaries
    - CAD interface
    - Easy to simulate sensitive volume for Single Event Effects (SEE)
- Current focus is SEE
  - Single Event Upsets (SEU) in logic devices
  - Single Event Transients (SET) in FPA
- Applications for TID and DD are under review



# Angular Effects in Proton-Induced Single-Event Effects

- Dominant mechanism for SEUs can be

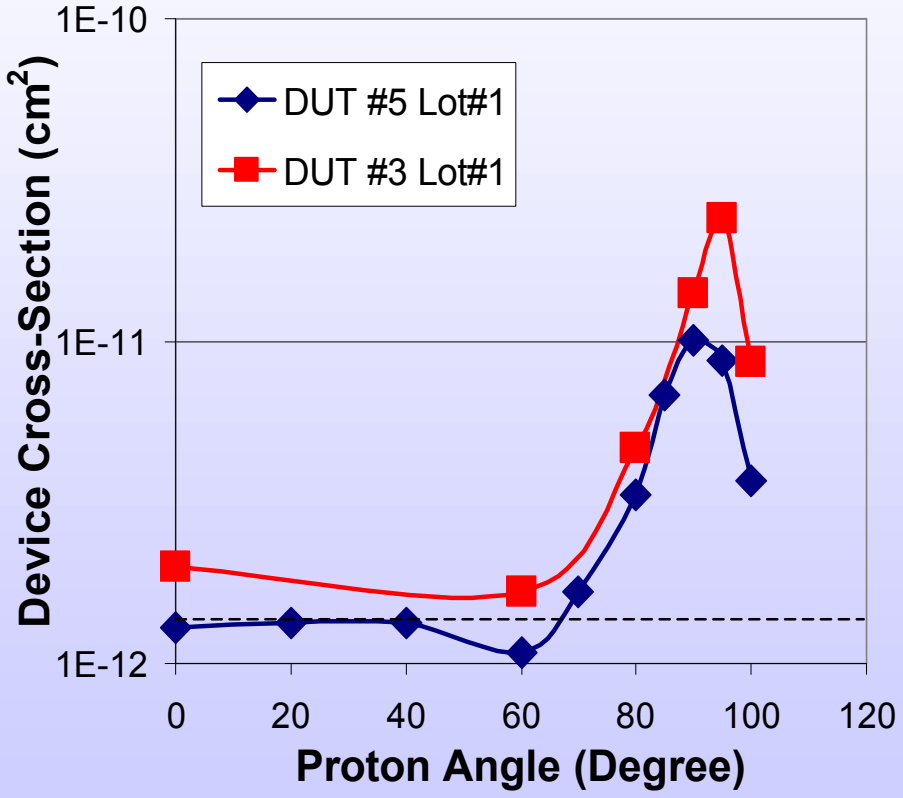
$$1 < \mathrm{LET_c(MeV \bullet cm^2/mg)} < 15$$

  - Elastic nuclear scattering
  - Spallation reactions
  - Some combination of both
- The incident proton energy will determine the dominant mechanism
- There is an angular dependence on the recoil direction
  - How does this affect an SOI/SOS device's SEU response?

# Motivation

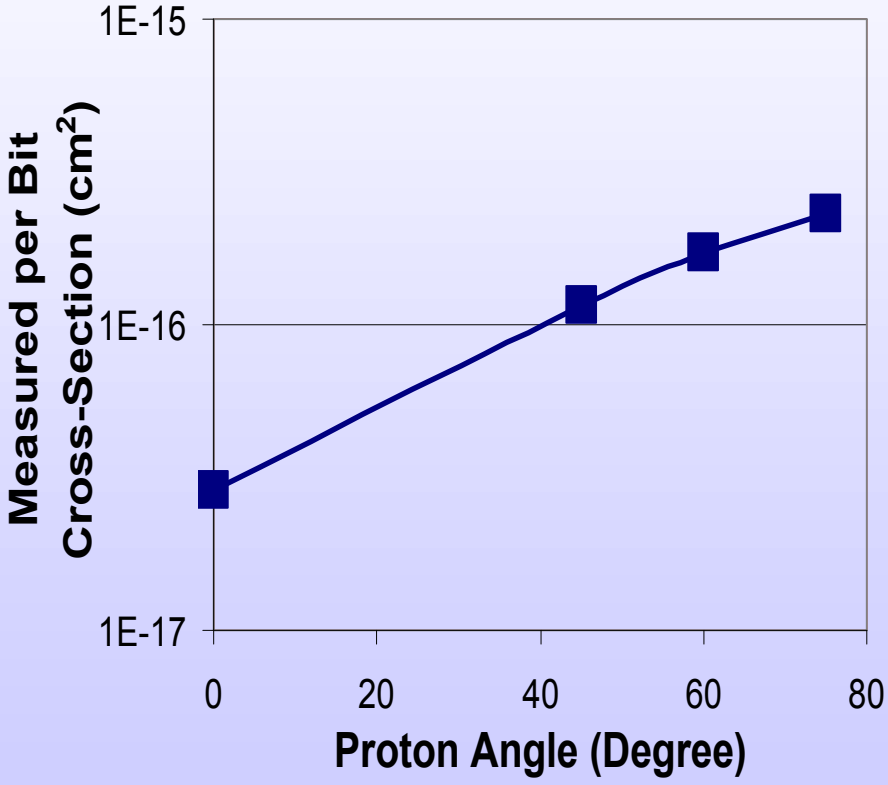
Peregrine Prescaler

SOS technology

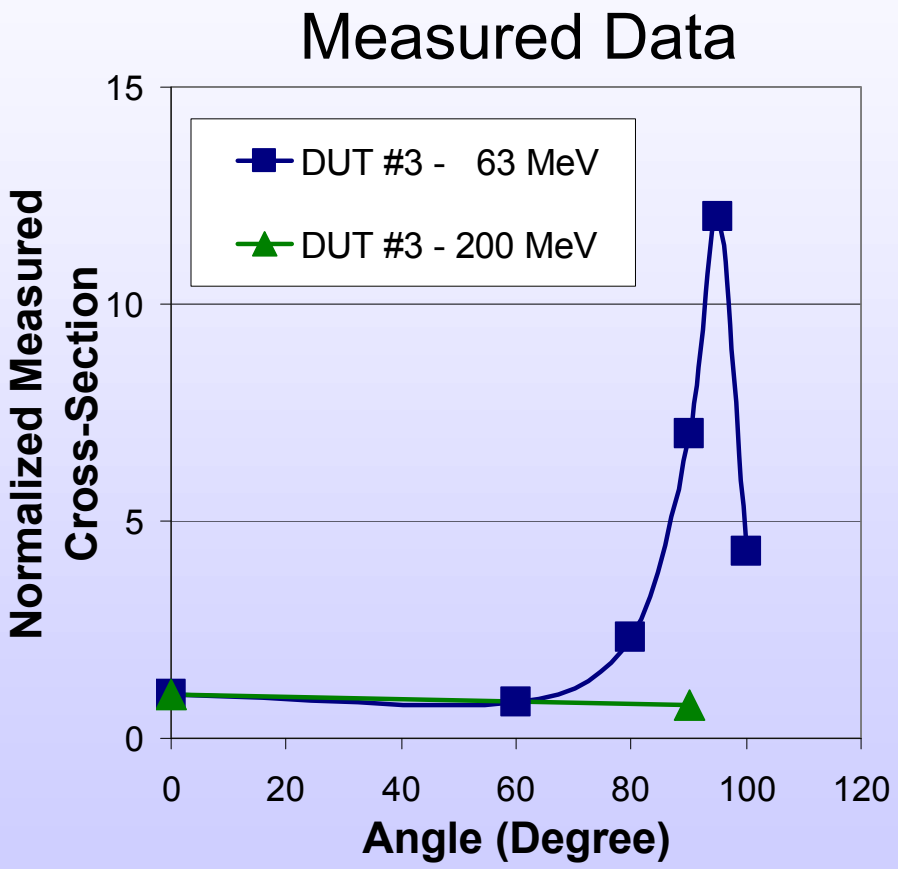


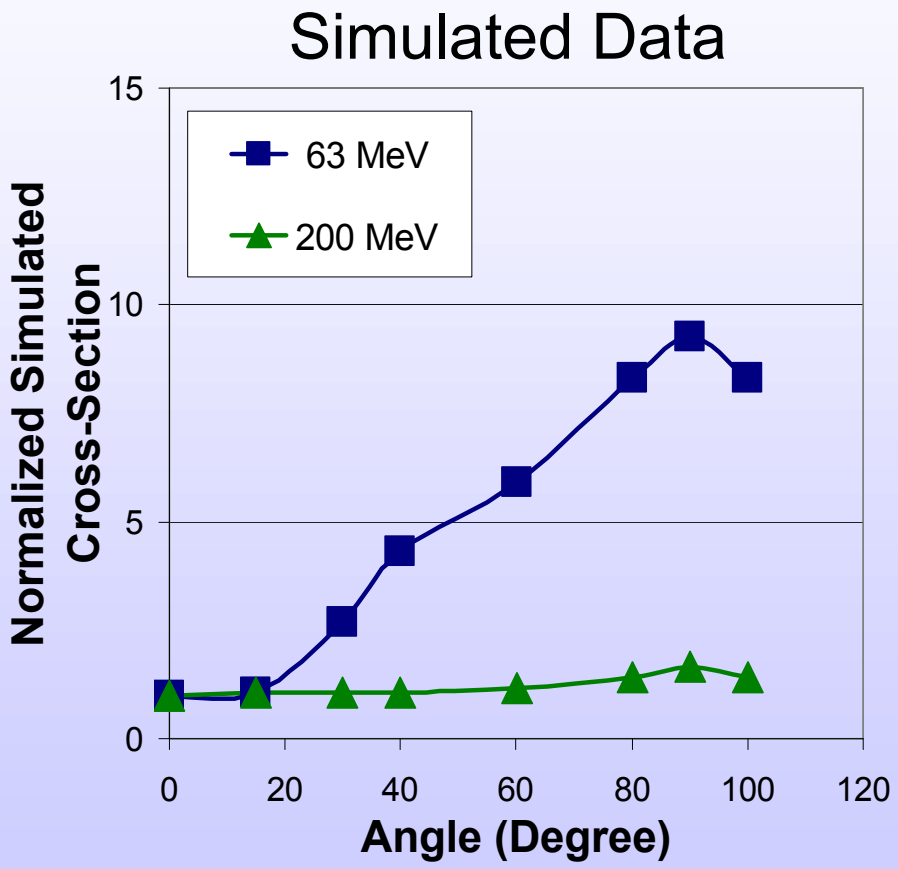

Honeywell SRAM

SOI technology



# Experimental and Modeling Results for SOS Technology



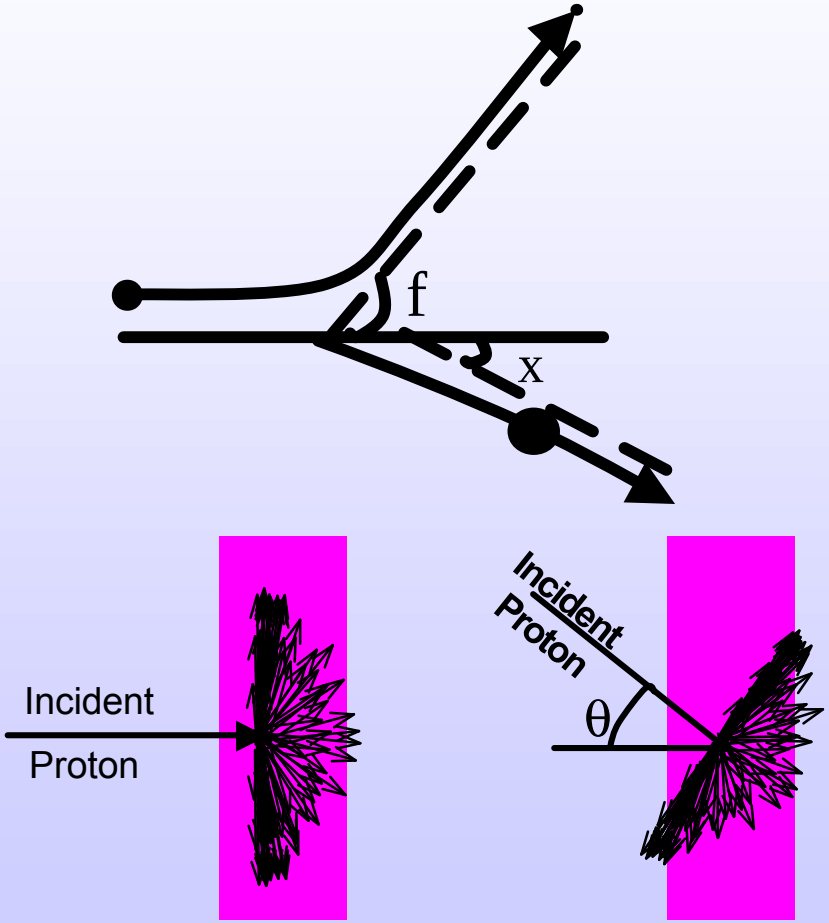
# Energy Dependence

- Spallation reaction products dominate the SEU response for proton energies > 50 MeV
- For 63 MeV protons:

  Dominant mechanism for reactions for LETs > 3 MeV•cm$^2$?

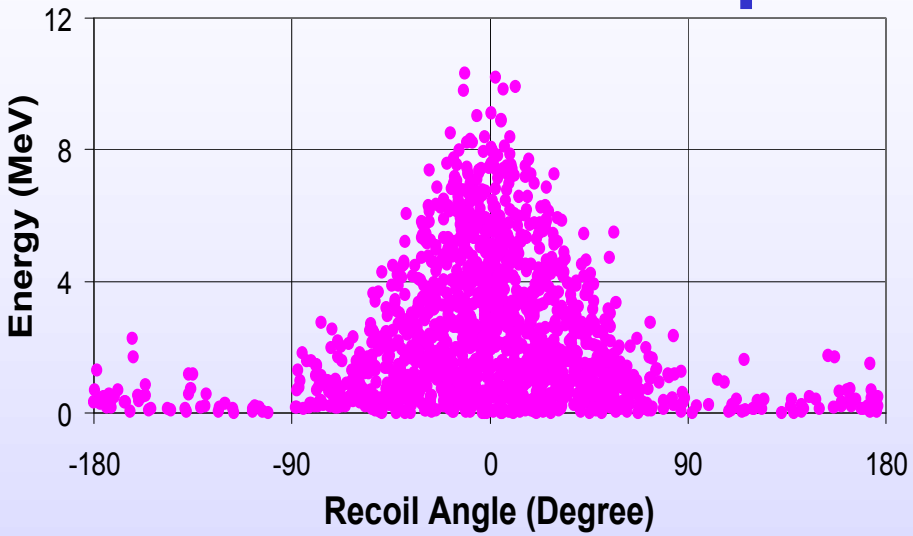
$$P_{\text{elastic scattering}} < 6\, P_{\text{spallation reaction}}$$

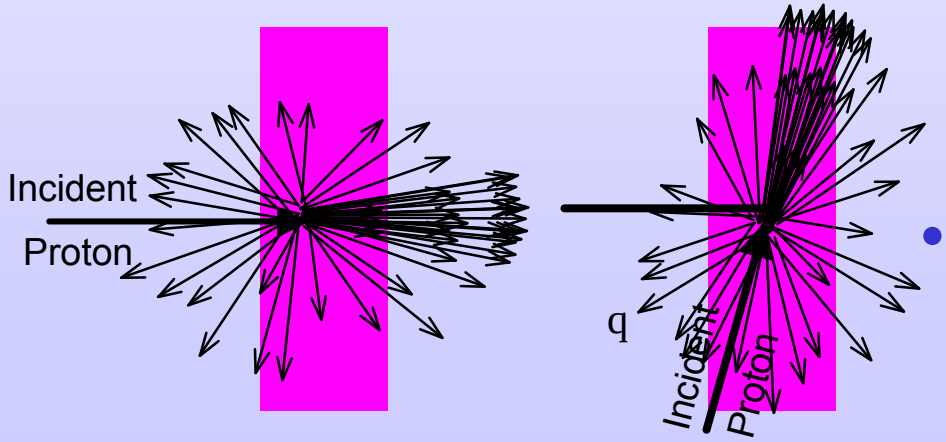
# Proton Interactions with Target Nucleus-Elastic Scattering




- Recoil pathlength decreases as angle increases
- On average, more charge is deposited when proton is normal to larger surface of SV
- **Angular dependence cannot be explained by nuclear elastic scattering**

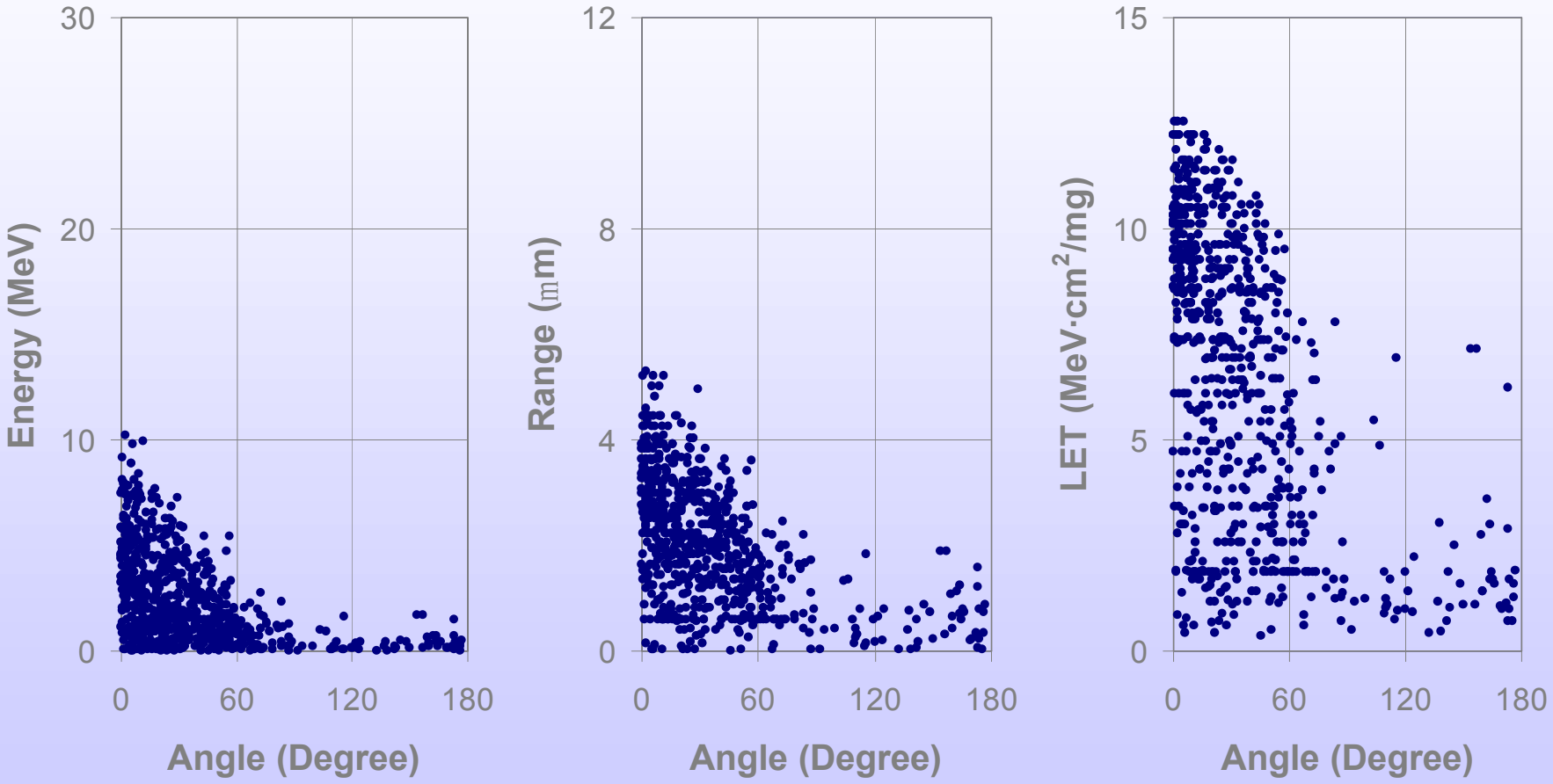
# Proton Interactions with Target Nucleus-Spallation Reactions



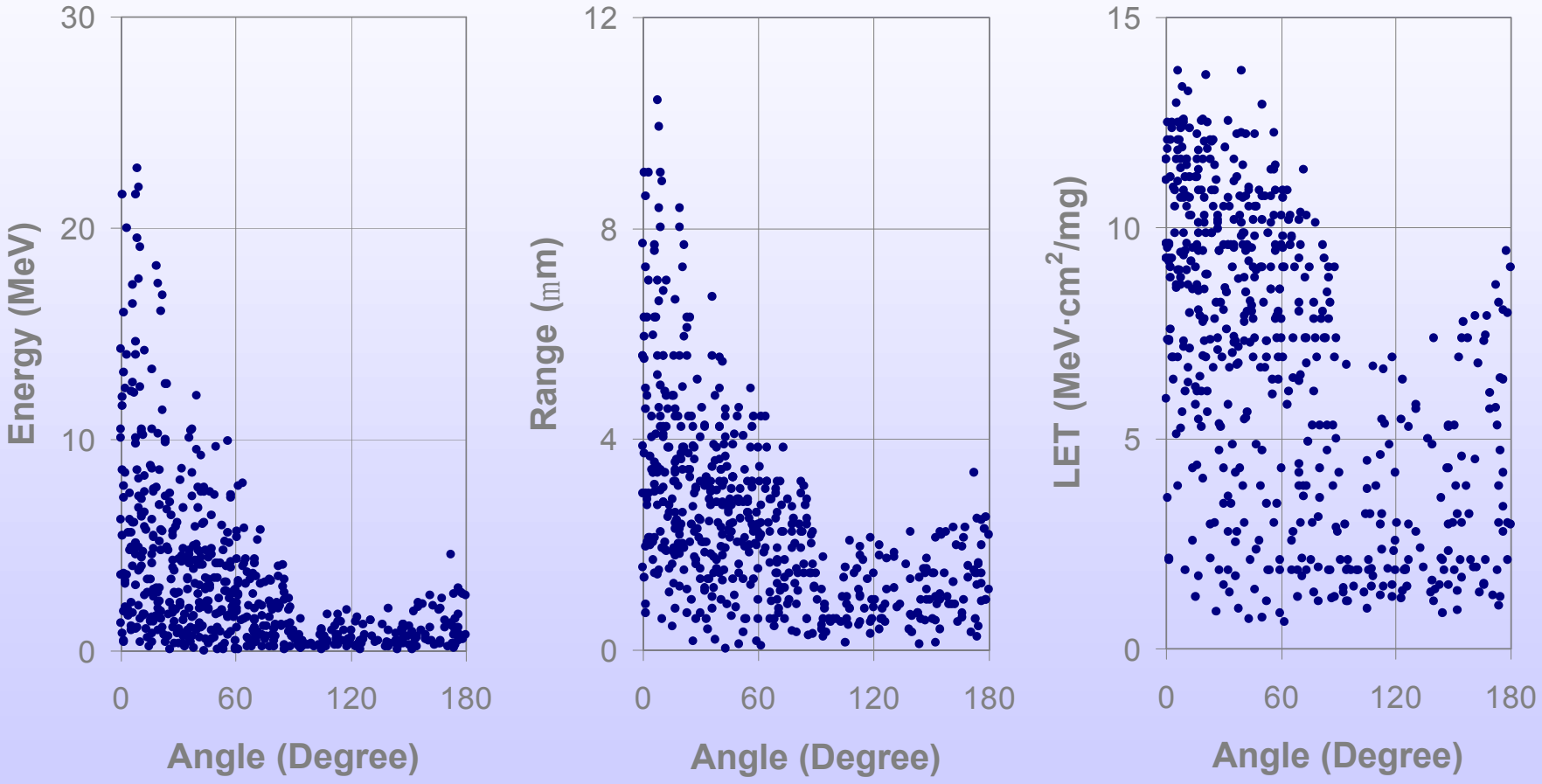




- Recoil pathlength increases as angle increases
- On average, more charge is deposited when proton is at some angle wrt to larger surface of SV
- **Spallation reaction is the mechanism**

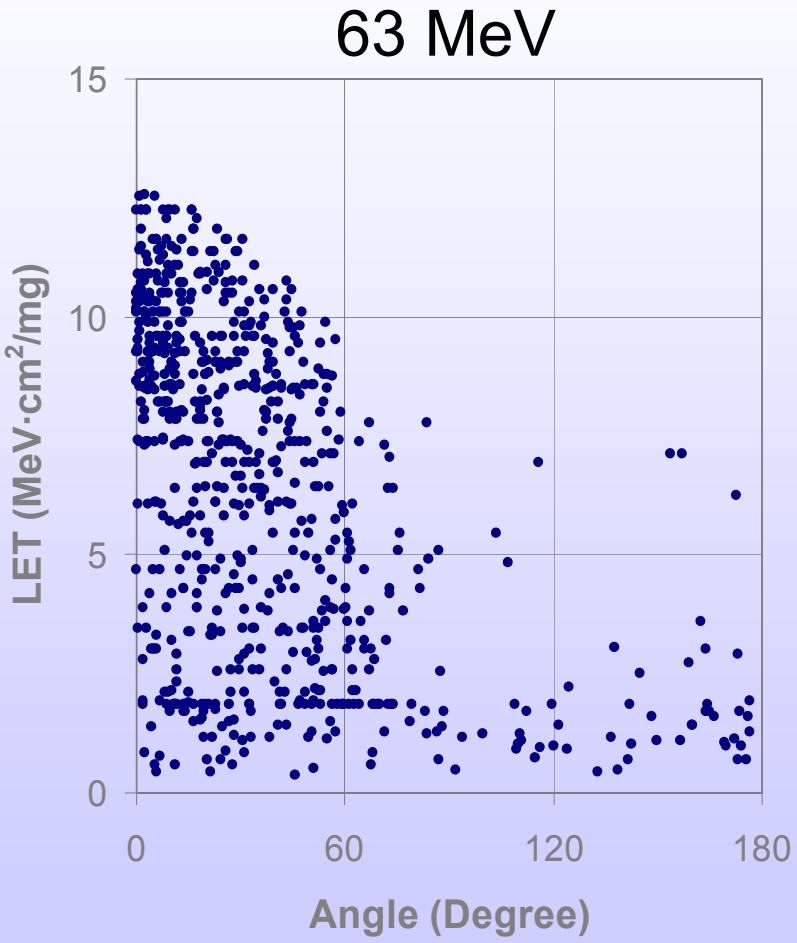
# 63 MeV Inelastic Recoils in Si

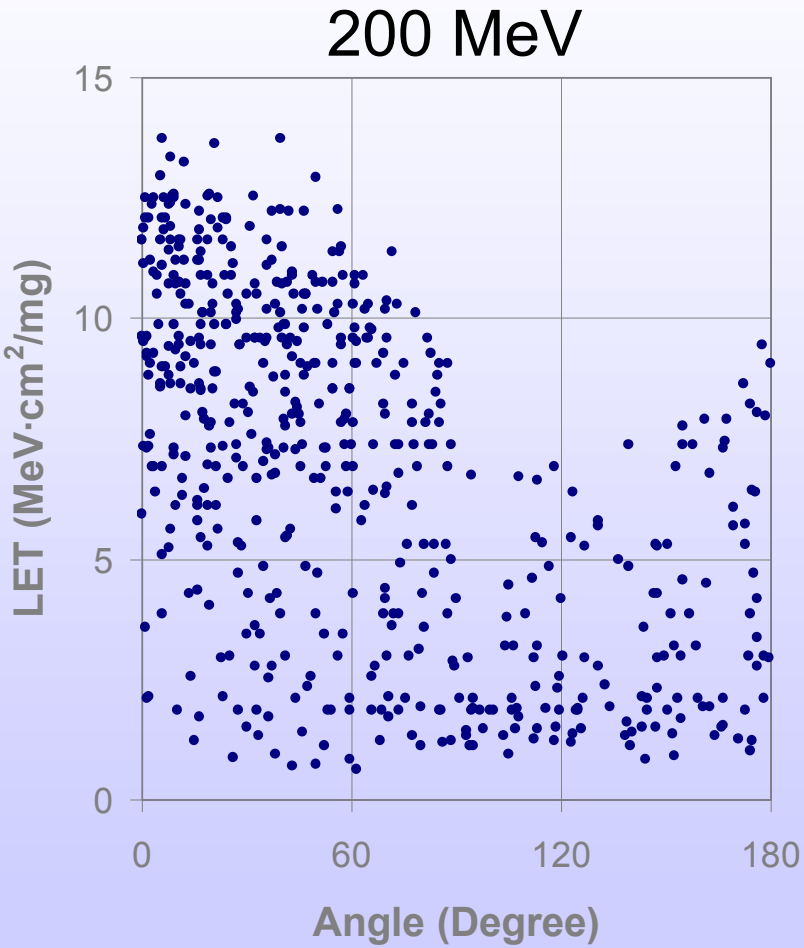


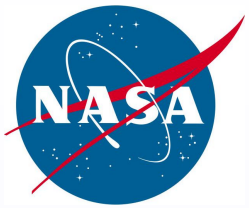
# 200 MeV Inelastic Recoils in Si



# Energy Dependence

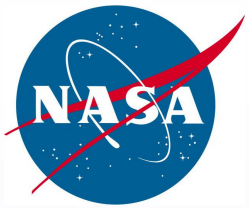





# Conclusions (#1) and Future Plans

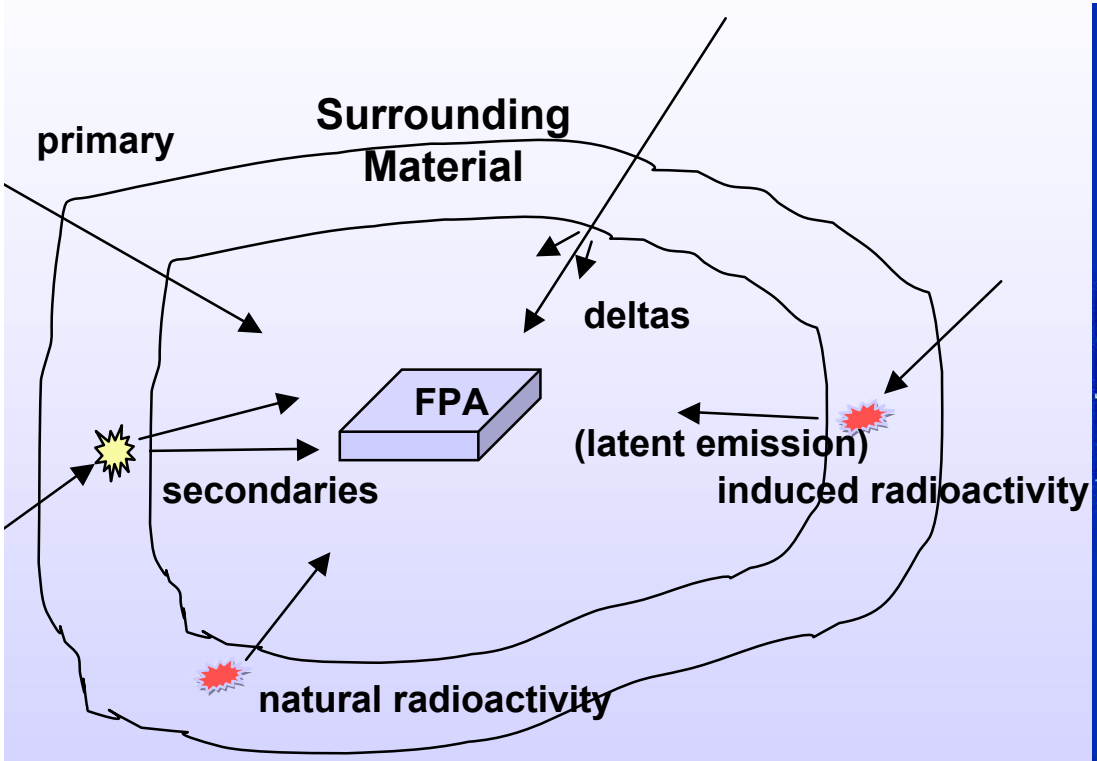
- Geant4 provided the physics simulation to uncover the basic mechanism for SEU in thin SOI/SOS technologies
- Plans to develop Geant4 SEE simulations
  - Incorporation of sensitive volume model
  - Incorporation of a charge collection model for proton induced events for complex transistor structures

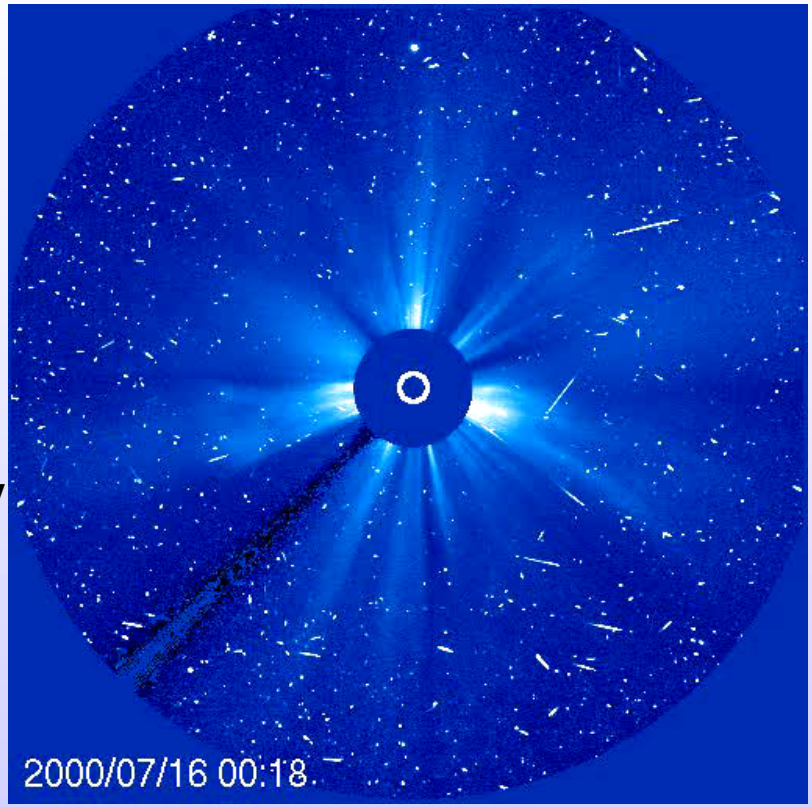



# Simulation of Radiation Effects for James Webb Space Telescope

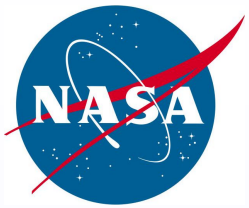
- Goal is to predict Focal Plane Array (FPA) response to incident particles (protons, heavy ions, electrons) with high fidelity
  - Charge contamination on a pixel-by-pixel basis
- Source term is external radiation environment and transport through material surrounding FPA
  - L2 environment is predominantly galactic cosmic rays and solar particles

# Ionizing Particle Impacts to FPA



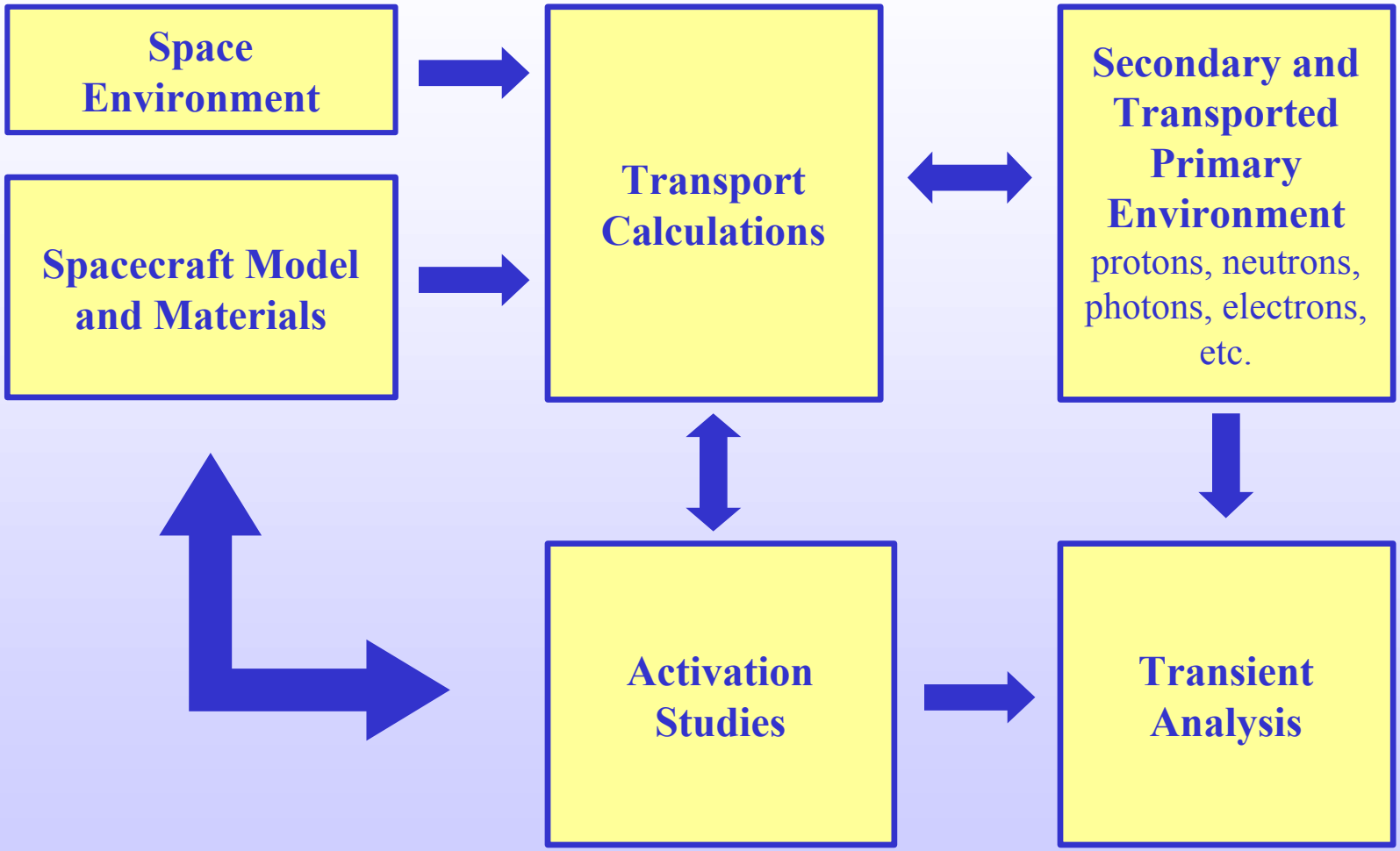

Note that secondaries and delta electrons are time coincident with primary and have limited range




# Need Accurate Estimate of Transients

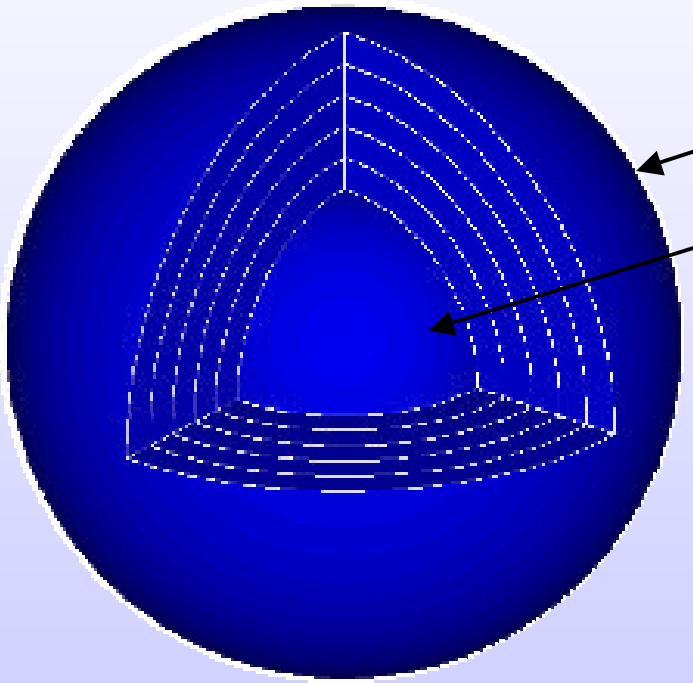
- Most primary and secondary particles can add to the noise floor (goal is 3-10 $e^-$)
- Ionization energies for 5 μm HgCdTe and InSb detector material is on order of 1 eV/e-h pair
- Pathlengths are on order of 10 μm
  - Need only 3 to 10 e-h pairs/μm
  - Note that a 1 GeV proton in HgCdTe will create 1160 e-h pairs/μm

# Block Diagram Showing Approach



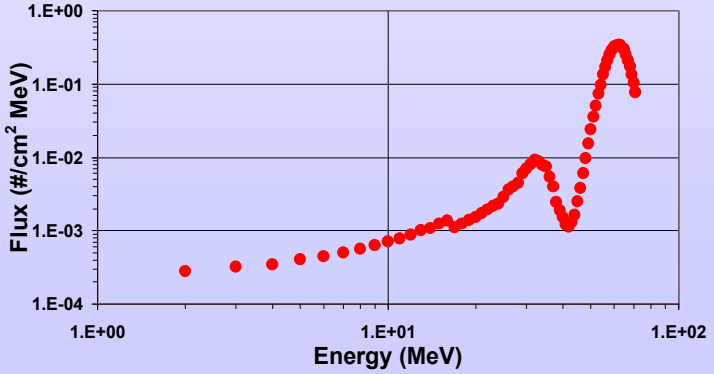
# Transport Calculations

- Material Studies
  - Perform simulations for secondary environment

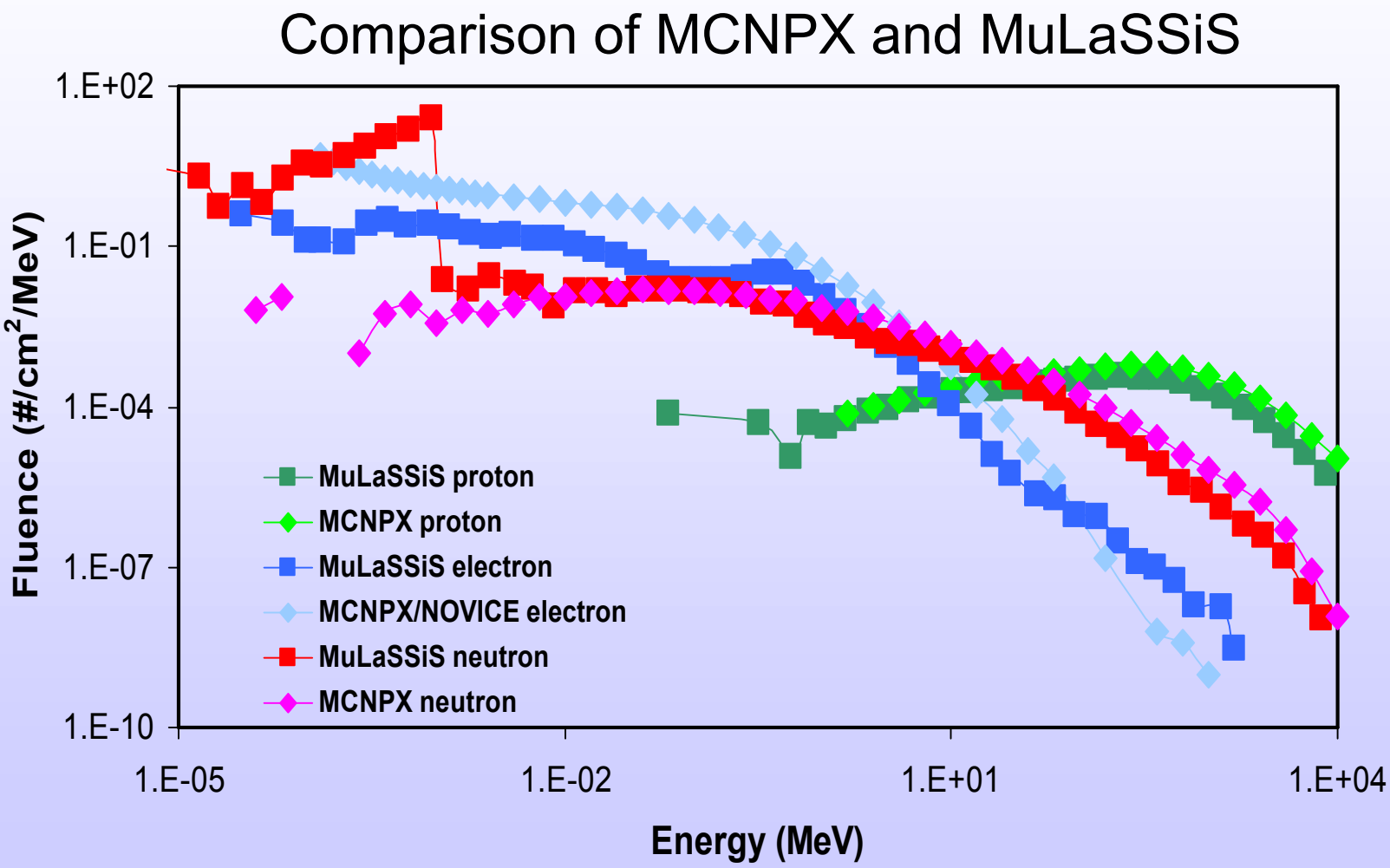


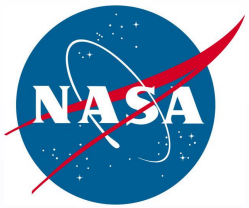

2.5 cm Hollow Sphere
($R_{in}$=1.25cm, $R_{out}$=2.5cm)

GCR Min Proton Spectrum



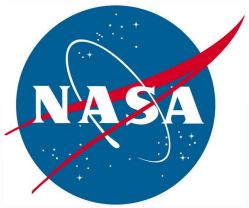
# Secondary Environment






# Activation Studies

- Proton and neutron fluxes along with reaction cross-sections for spacecraft materials determine number of activated nuclei




# Transient Analysis

- Supply location, trajectory, particle type, energy, and temporal information for every particle incident on FPA
- FPA model will use these inputs to calculate the transient rate for relevant environments, configurations and conditions

# Conclusions (#2) and Future Efforts

- We are currently focused on determining the frequency of occurrence, magnitude, and pulse width distributions of radiation induced transients in infrared FPAs used on JWST
- Purpose of transport studies is to provide reliable estimates of transported primary and secondary environment as input to:
  - Contamination and activation analysis
  - Transient analysis