Adaptation of GEANT4 for Single Event Simulations

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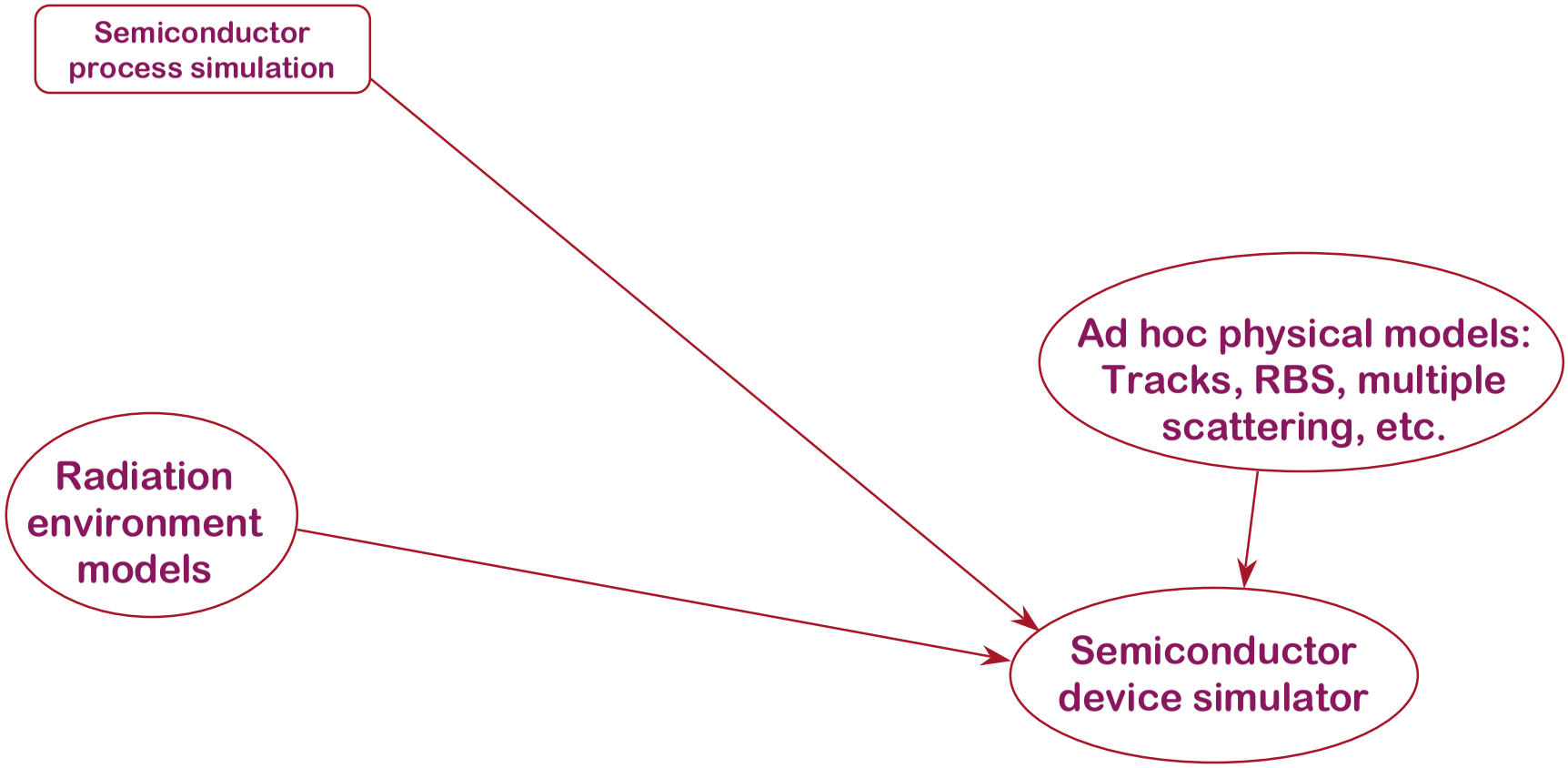
Overview

- Why use Geant4 for SEE simulation?
- What is our strategy?
- How is the strategy implemented?
- What are the results so far?
- Summary (Current)
- What is next?
- Some relevant Geant4 issues…

The way it (usually) works today



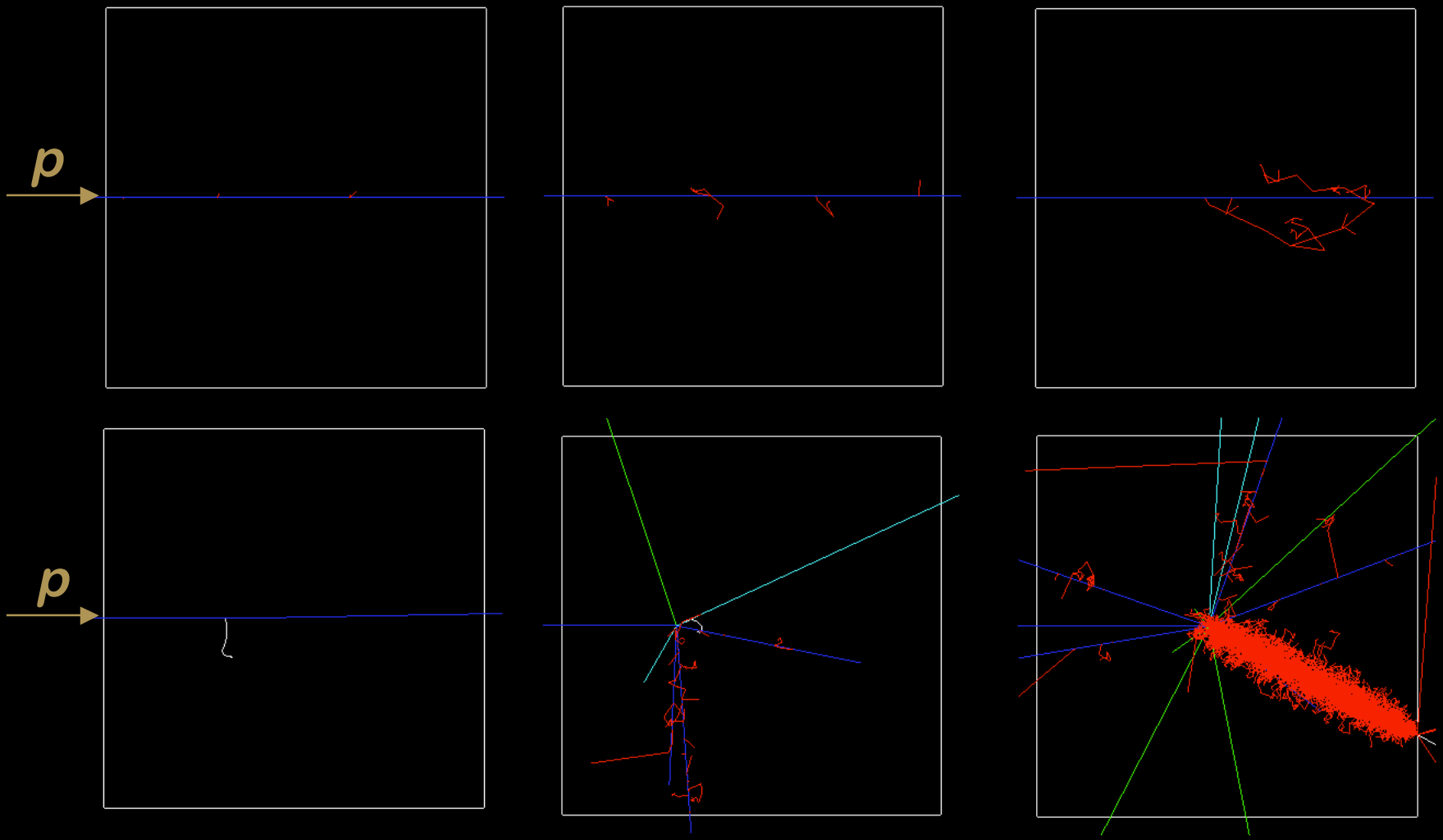
Why use GEANT4 for radiation effects in electronics?

For an excited system, the average response, is not, in general, the response to the average excitation.

Translation: For very small devices, all events are *single* events.

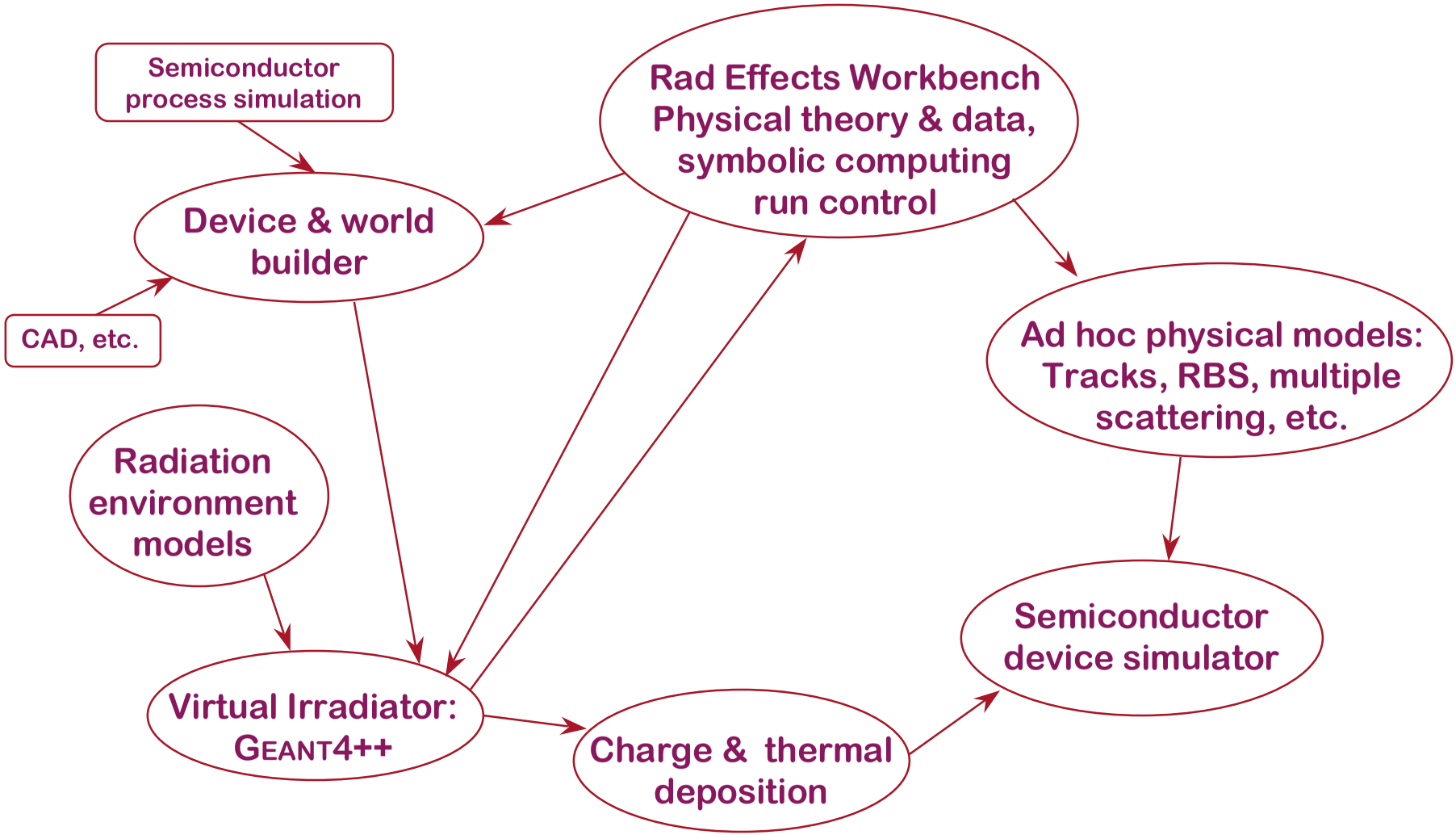
GEANT4? A Simulation Toolkit…

S. Agostinelli et al. "Geant4 – a simulation toolkit, " Nucl. Instr. Meth. A506 (2003) 250.

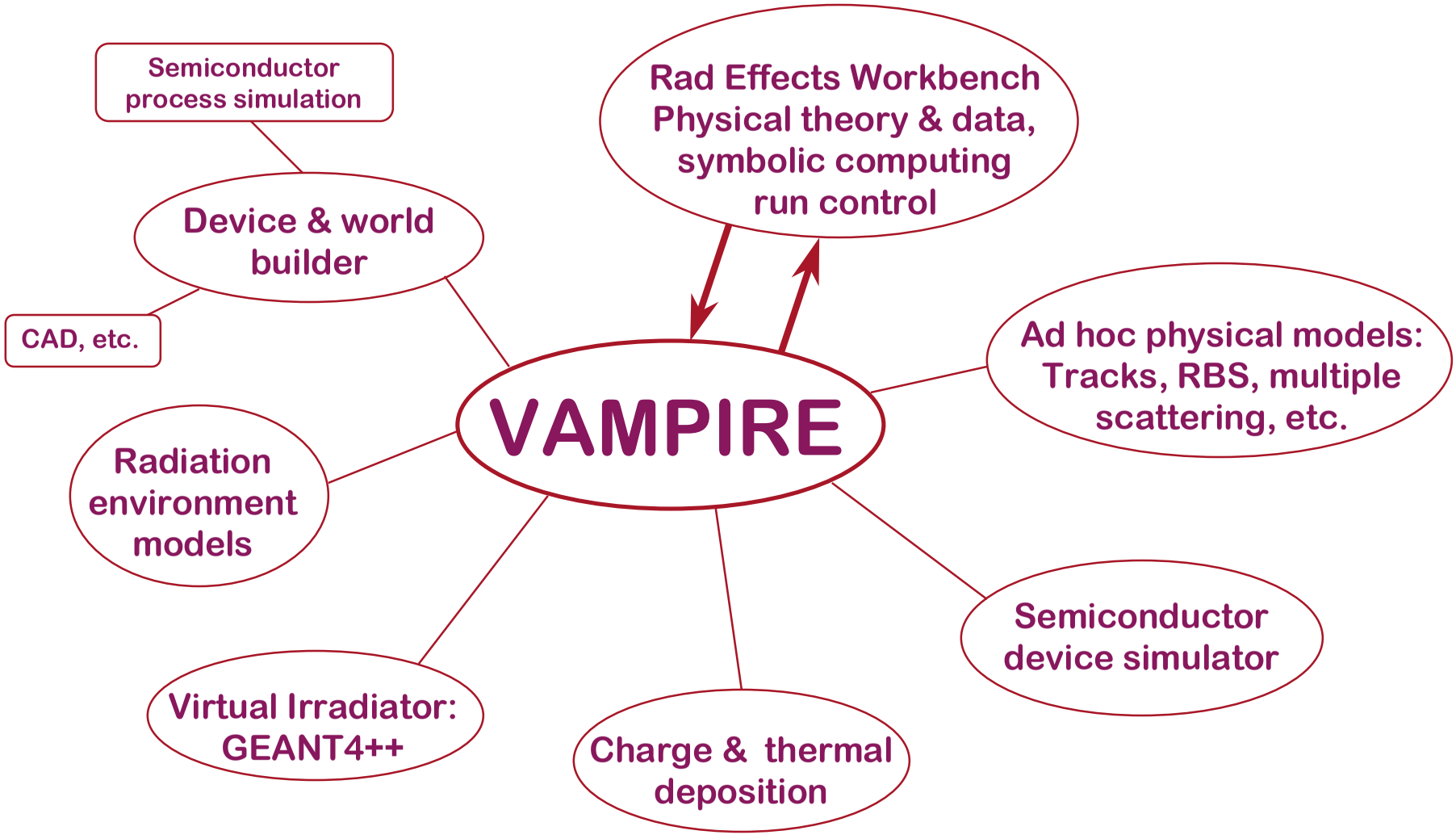


100 MeV protons →5 μm Si

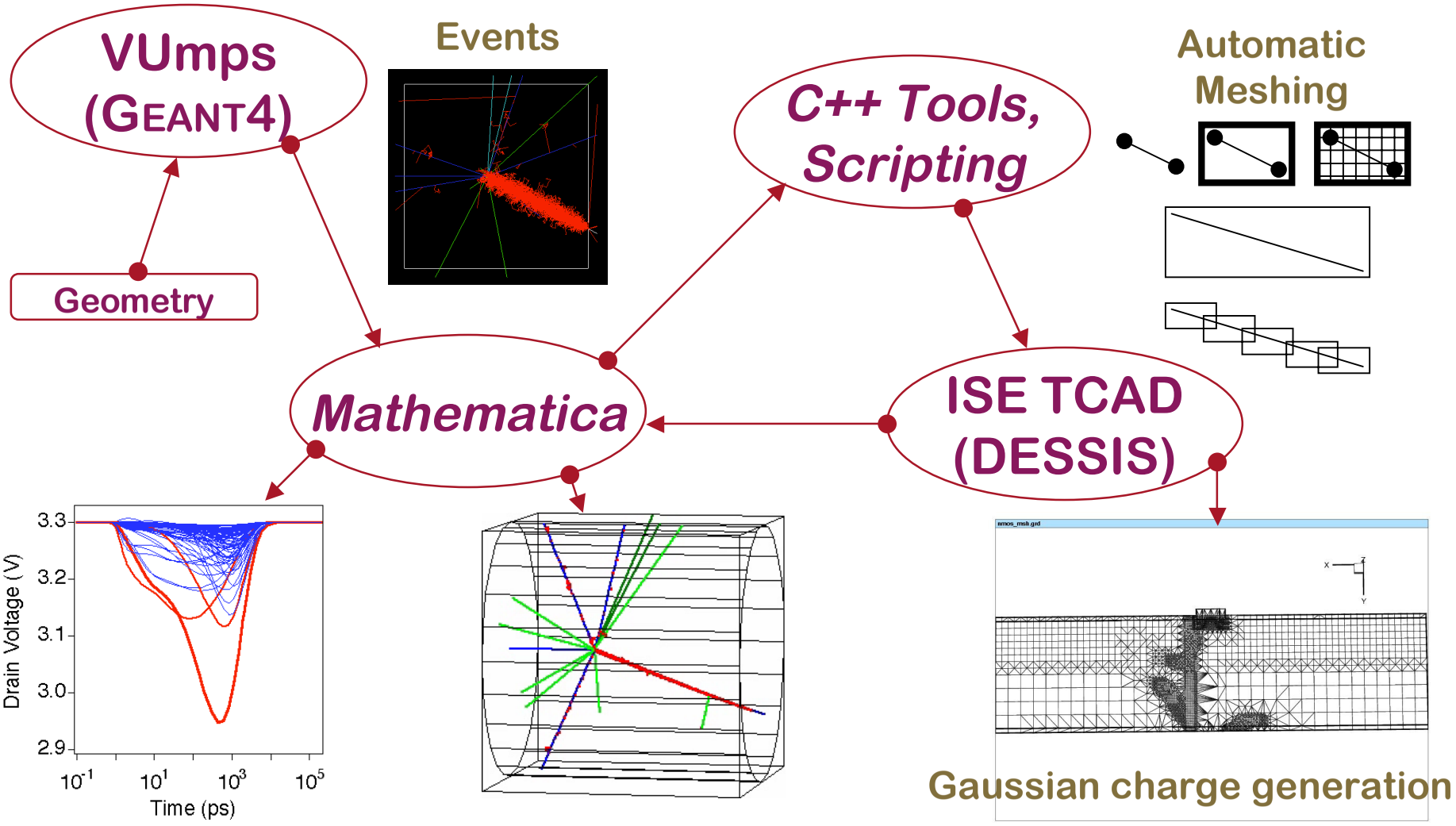
Strategy? The Virtual Rad Lab



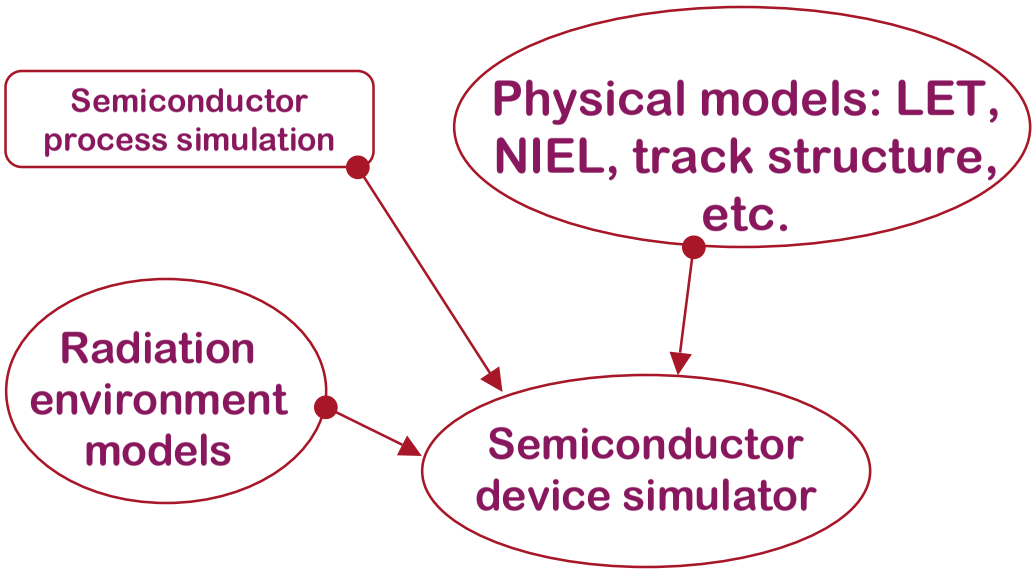
The Virtual Radiation Effects Lab

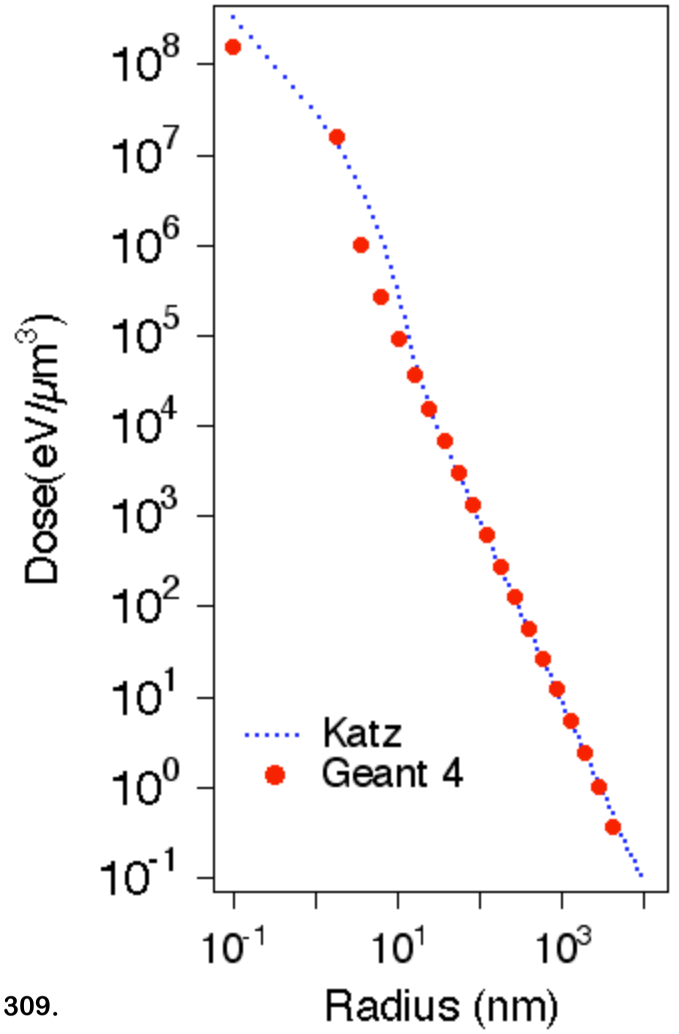


Implementation? How it works…



Result: Radial Track Structure

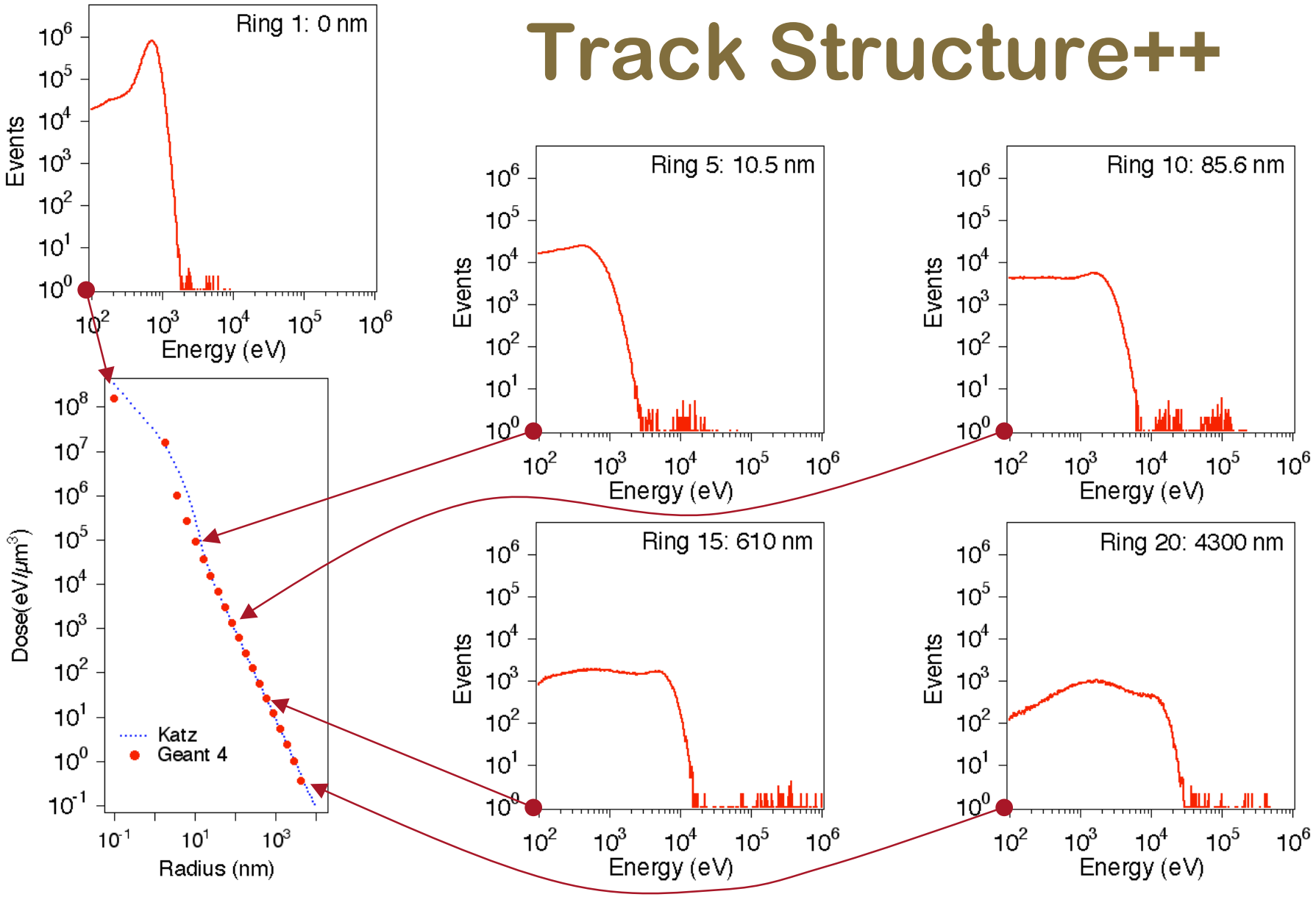




100 MeV protons in Si

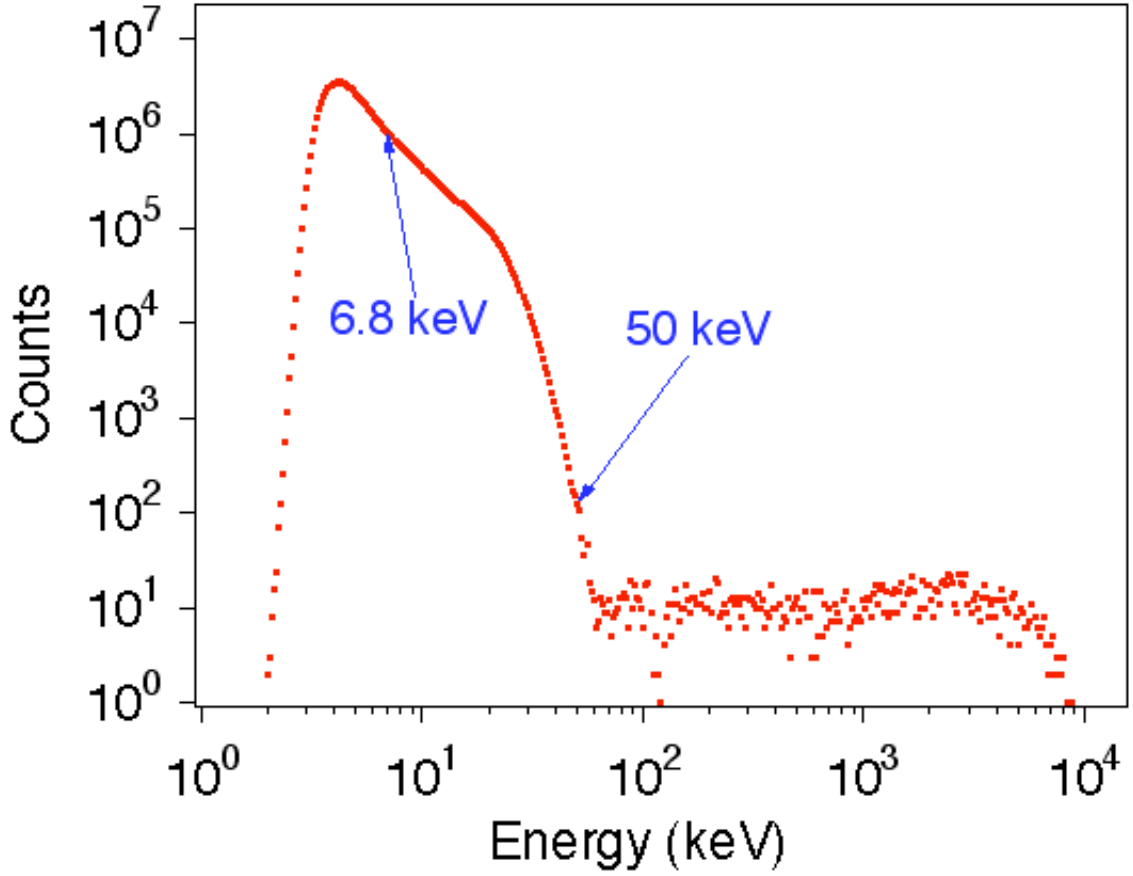
M. P. R. Waligórski, R. N. Hamm & R. Katz, Nucl. Tracks Radiat. Meas. 11 (1986) 309.

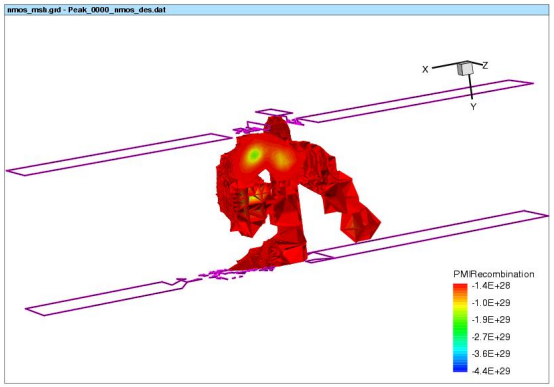
Track Structure++

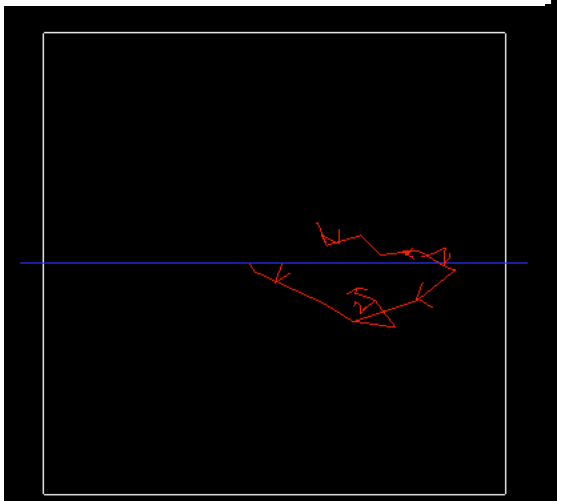


Result: MOS transistor response to energetic δ-ray events

Supply = 3.3 V R_L = 200 kΩ Biased off

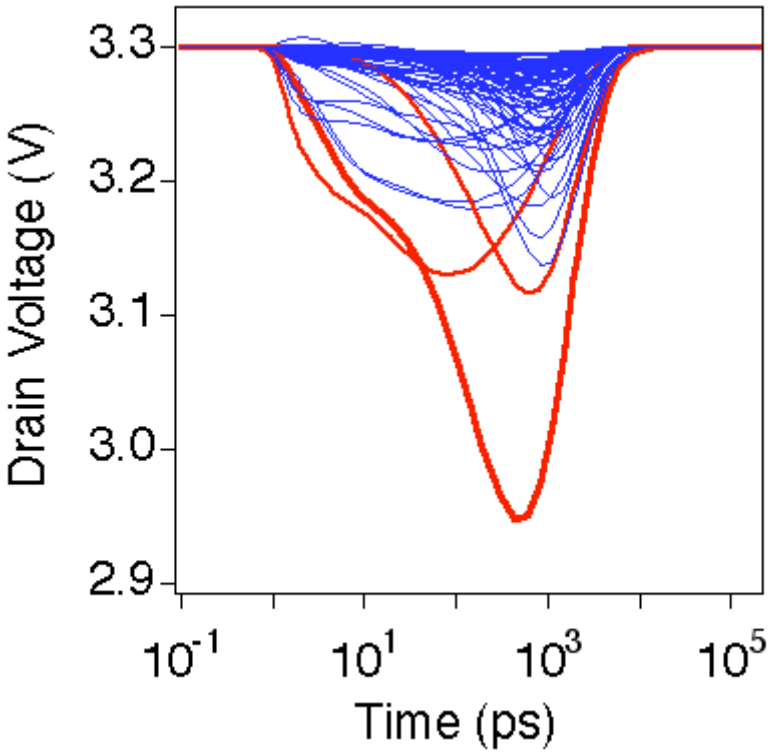




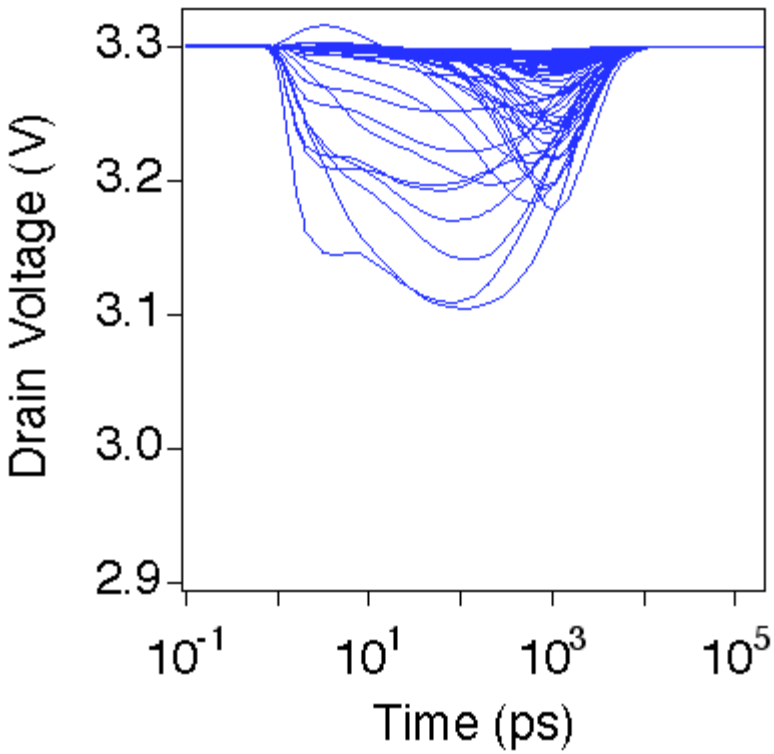


Drain Voltage Pulses

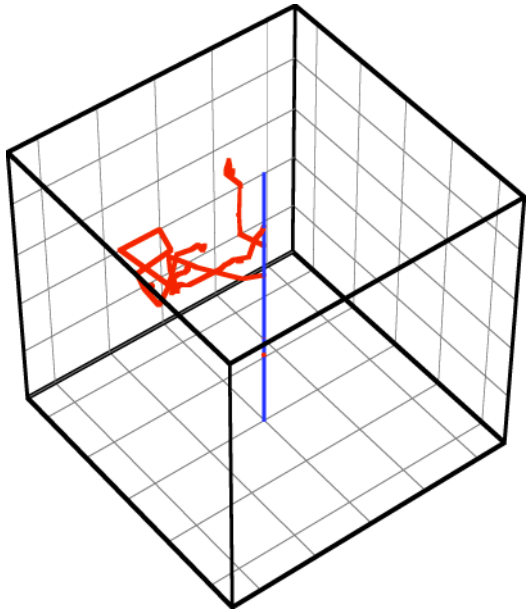
100 MeV protons



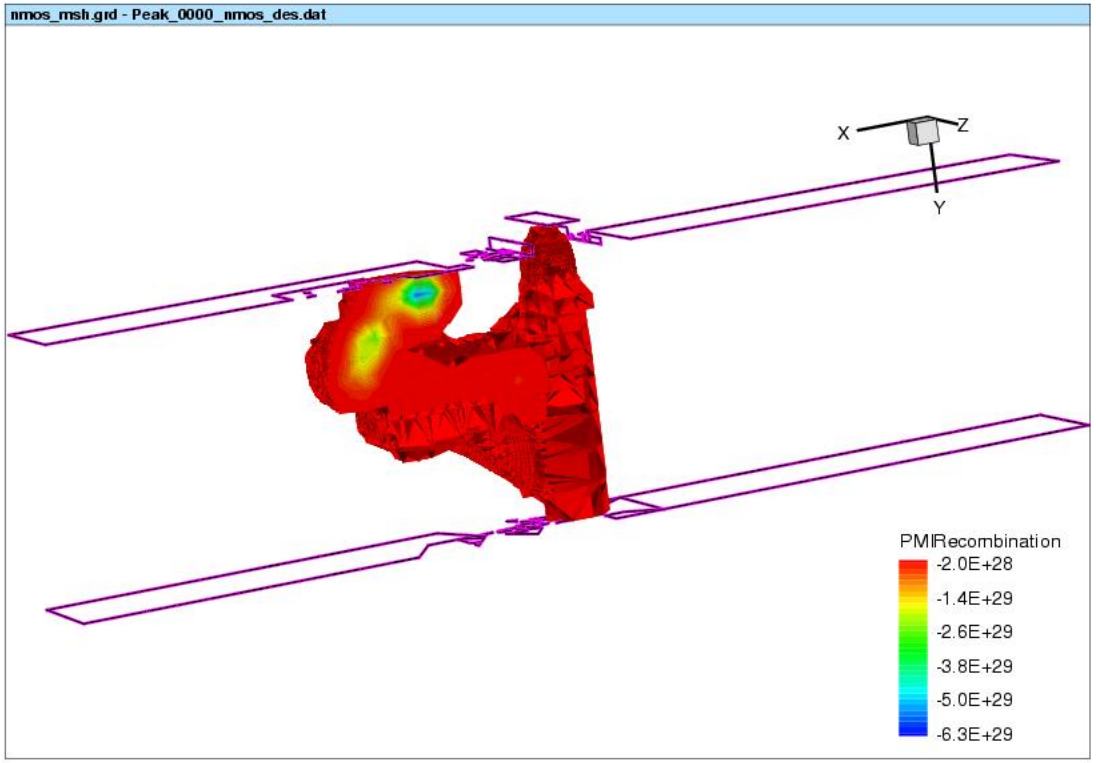
200 MeV protons



The largest event : ≈10% V_{DS}



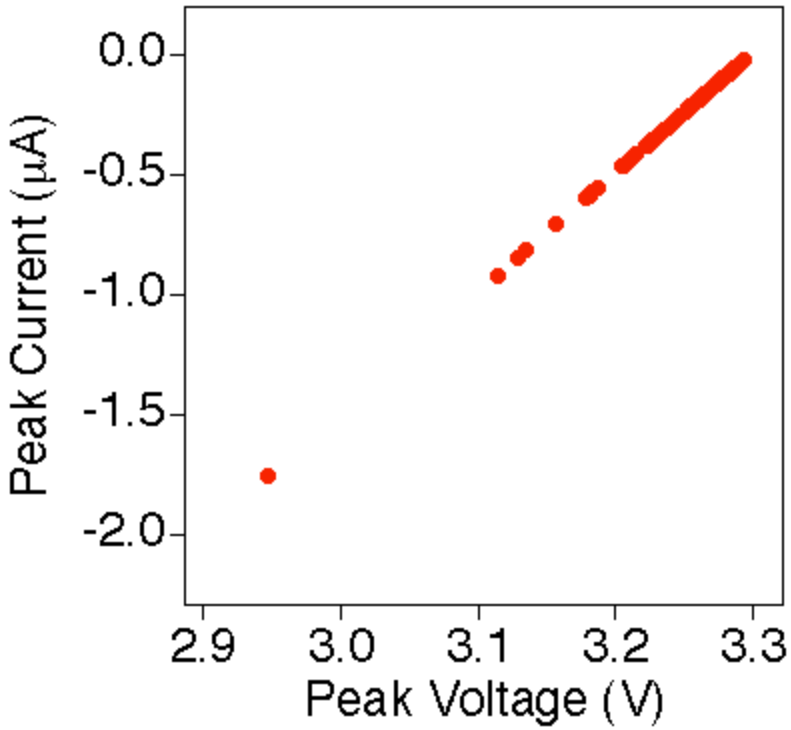
Particle Trajectories
Incident proton: blue
Electrons: red



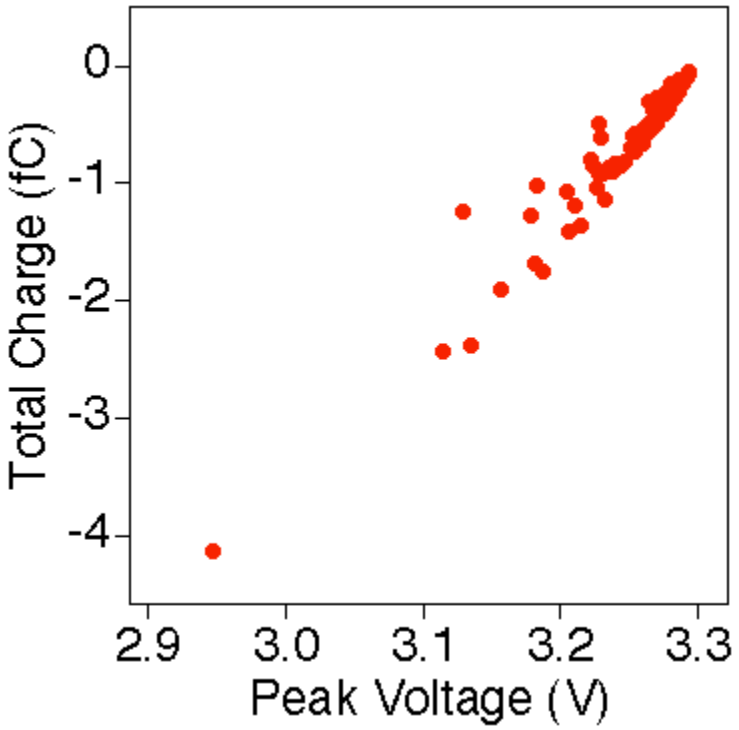
Energy in the transistor: 44.7 keV

Consistency Checks

Derivative = R_L = 200 kΩ

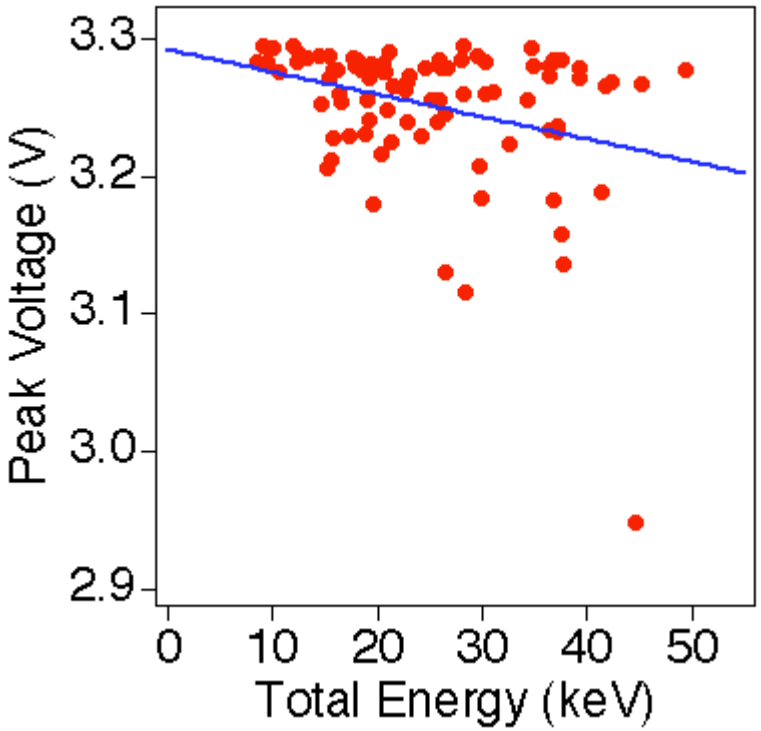


Pulse shape variability!

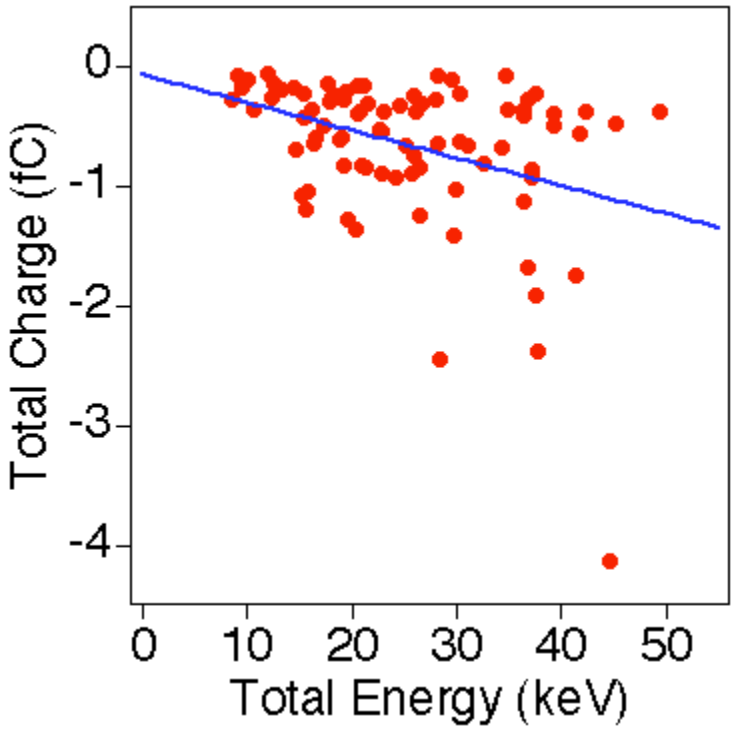


Pulse amplitude vs. event energy

Minimum V_{DS} & fit



Integrated I_D & fit



Note the dispersion!

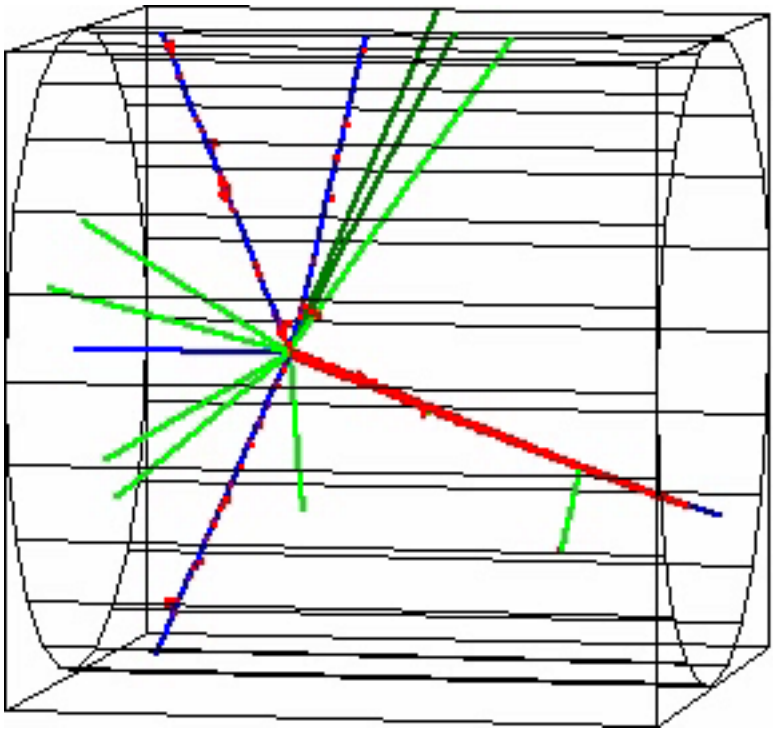
Summary

- The basic framework for ensemble simulation of single events is in place and tested.
- The methodology has been demonstrated by application to low-probability, high-energy, discrete δ-ray events.
- Development is continuing…

What's next?

300 MeV p ⇒ 5 μm Si

ΔE ≈ 18 MeV



Code: Red = e^-; Blue = + ion; Green = n, γ, etc.

- Realistic geometry
- Proton nuclear reactions
- Screened Coulomb scattering
- Heavy-ion nuclear reactions
- Validation
- Statistical studies
- Practical circuits
- Upset cross sections

Geant4 Issues

- Flexible, automated geometry interface…
- General: A complete and verified physics engine with all energy deposition mechanisms and various ions up to perhaps 20+ GeV/u…
- Specific: Screened (low energy) Rutherford collisions with secondary particle tracking, hadronic reactions for cosmic rays such as ^{12}C, ^{16}O, ^{56}Fe, etc.
- Lengths handled down to the few nm range…
- Integration into a larger system or systems…
- Eventually: physics models at sub-μm scale…