Validation of GEANT4 p+Si Nuclear Reaction Cross-Sections and Implications for SEU Rate Evaluations

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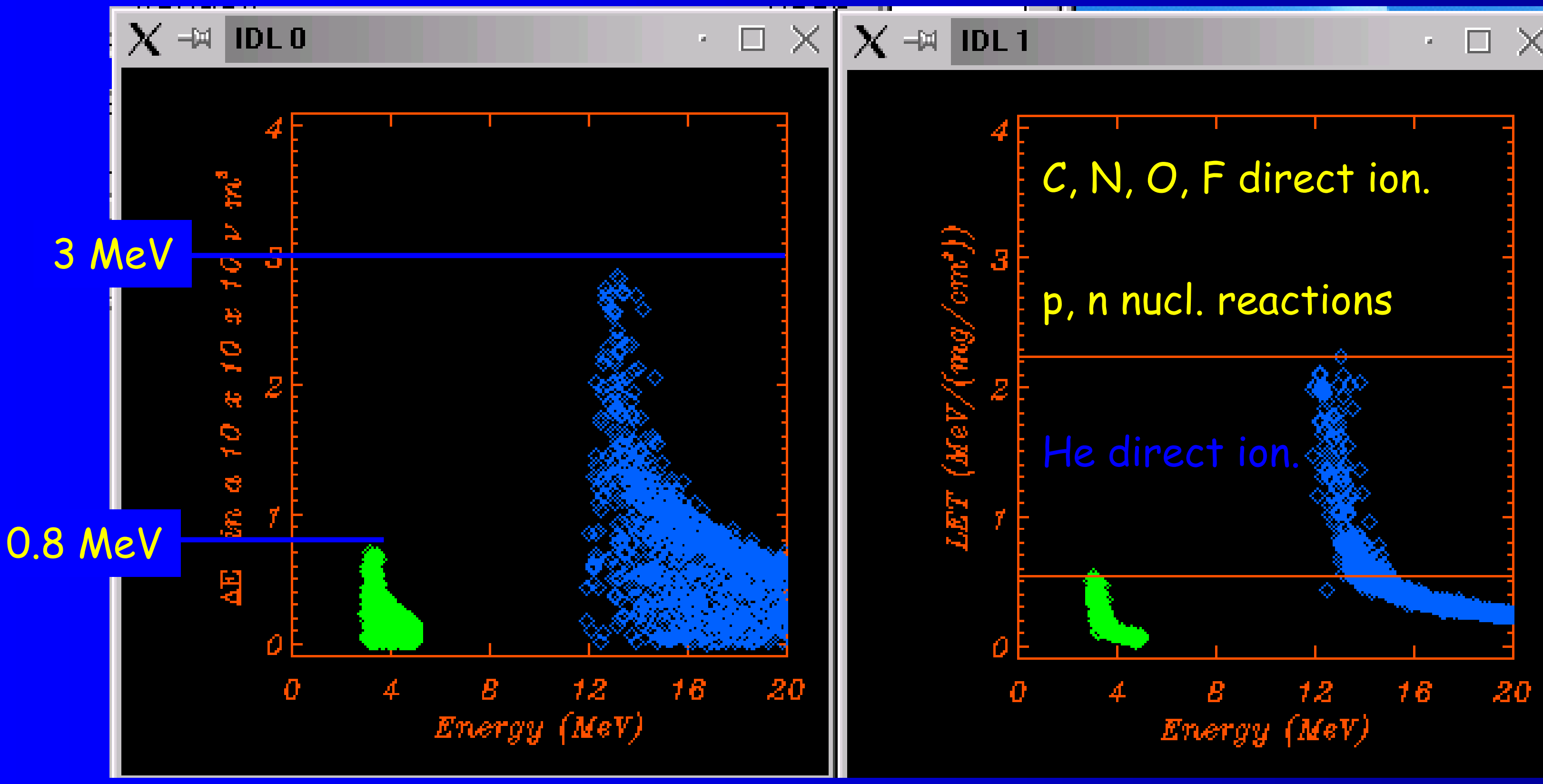
Contents:

Motivation

Given a well characterized (sensitive volume, critical charge,…) digital electronic device:

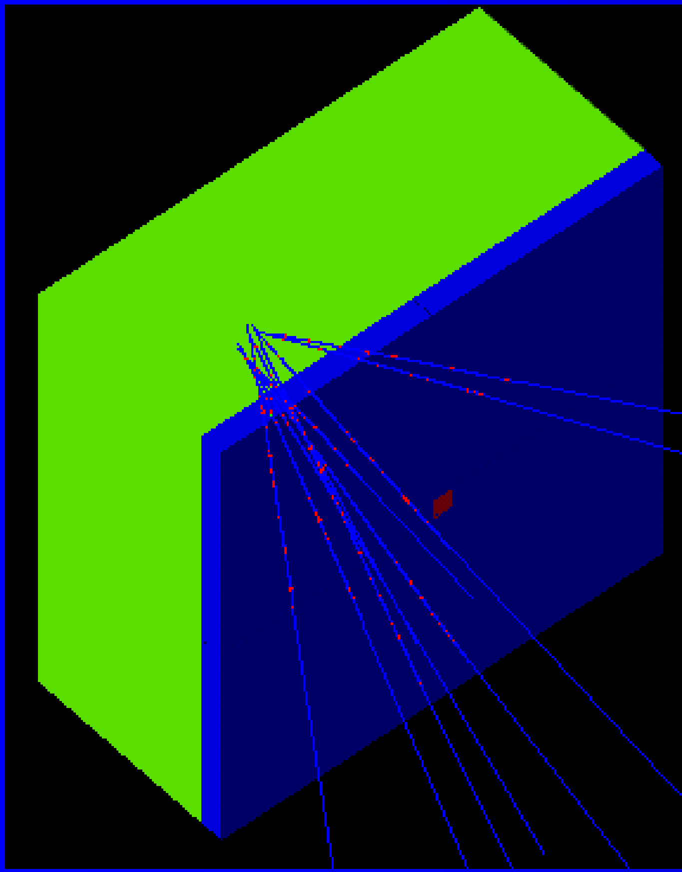
- ❑ Which secondary ions (or nuclear reactions) are involved in production of proton induced SEU?
- ❑ Do their fluxes exceed their primary counterpart in space (trapped, CR,…)?
- ❑ Is GEANT4 a valid tool to help answering these questions?

Energy loss in a 10x10x10 μm^3 sensitive volume



Many validations already performed by comparison with experimental data, SRIM, GEANT3,…

Proton induced nuclear reaction in Si



Validation of GEANT4 QSGP-BIC Physics list

	Secondary production cross-section (mb) at 100 MeV										
	p	d	t	He		C	N	O	F		Si
ICRU63	951	68	8	144						…	
GEANT4	963	15	2	138		2	68	14	1		724

Ok for p and He, but what goes wrong with d and t and what does this imply on corresponding heavy residues?

Does the proton induced SEU rate outnumber cumulated contribution from:

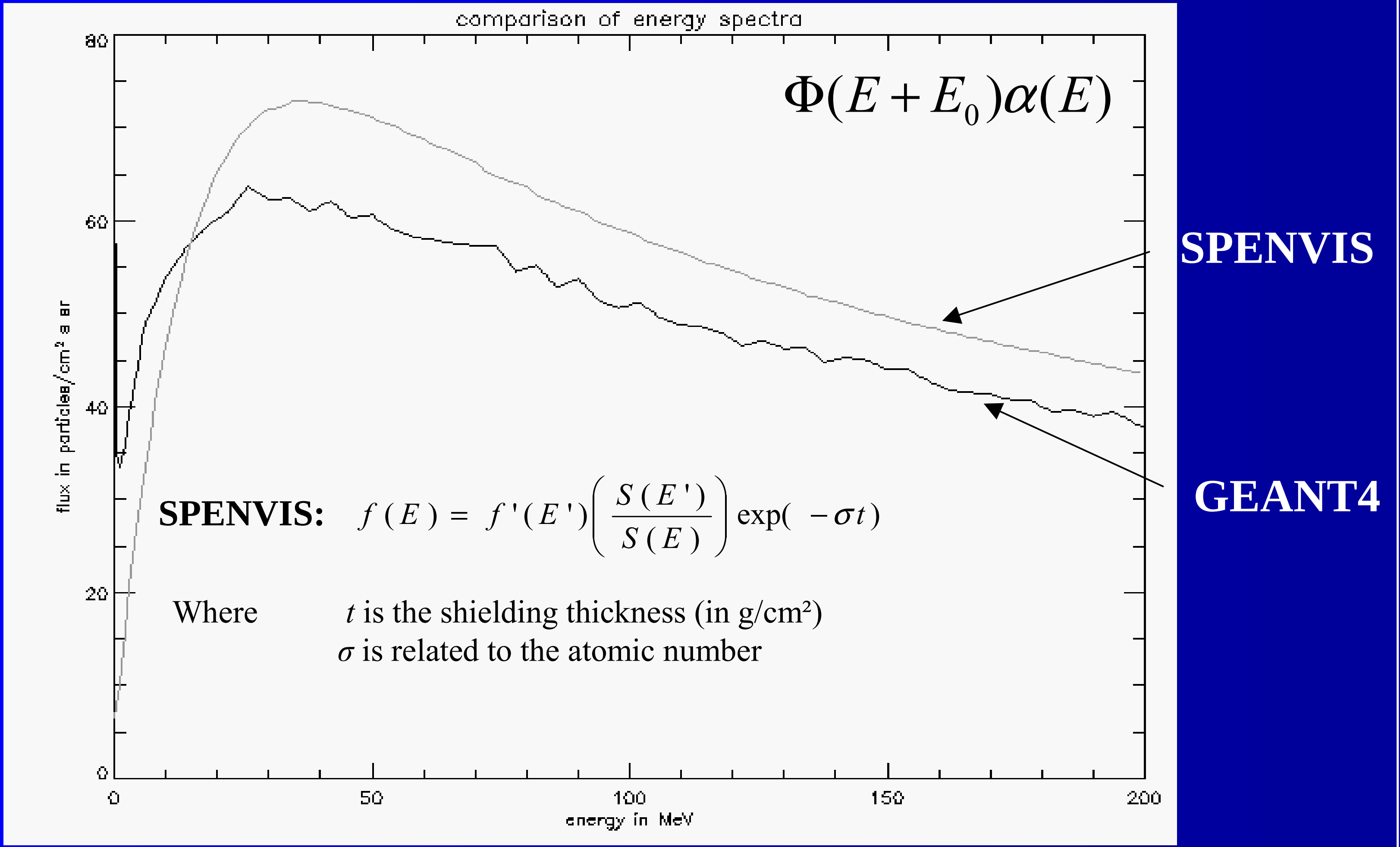
- the heaviest light ion: He?
- the lightest heavy ions?
- secondary neutrons?

Basic SEU rate calculations

$$R = K \int \sigma(E)\Phi(E+E_0)\alpha(E)dE$$

R is the SEU rate ($s^{-1}bit^{-1}$)
σ is the SEU cross section (cm^2/bit)
Φ is the particle differential flux ($cm^{-2}s^{-1}sr^{-1}MeV^{-1}$)
α is the transfer function
K is the solid angle (2π or 4π depending on shielding)

Transfert of isotropic p flux through an 8 mm thick Al shielding

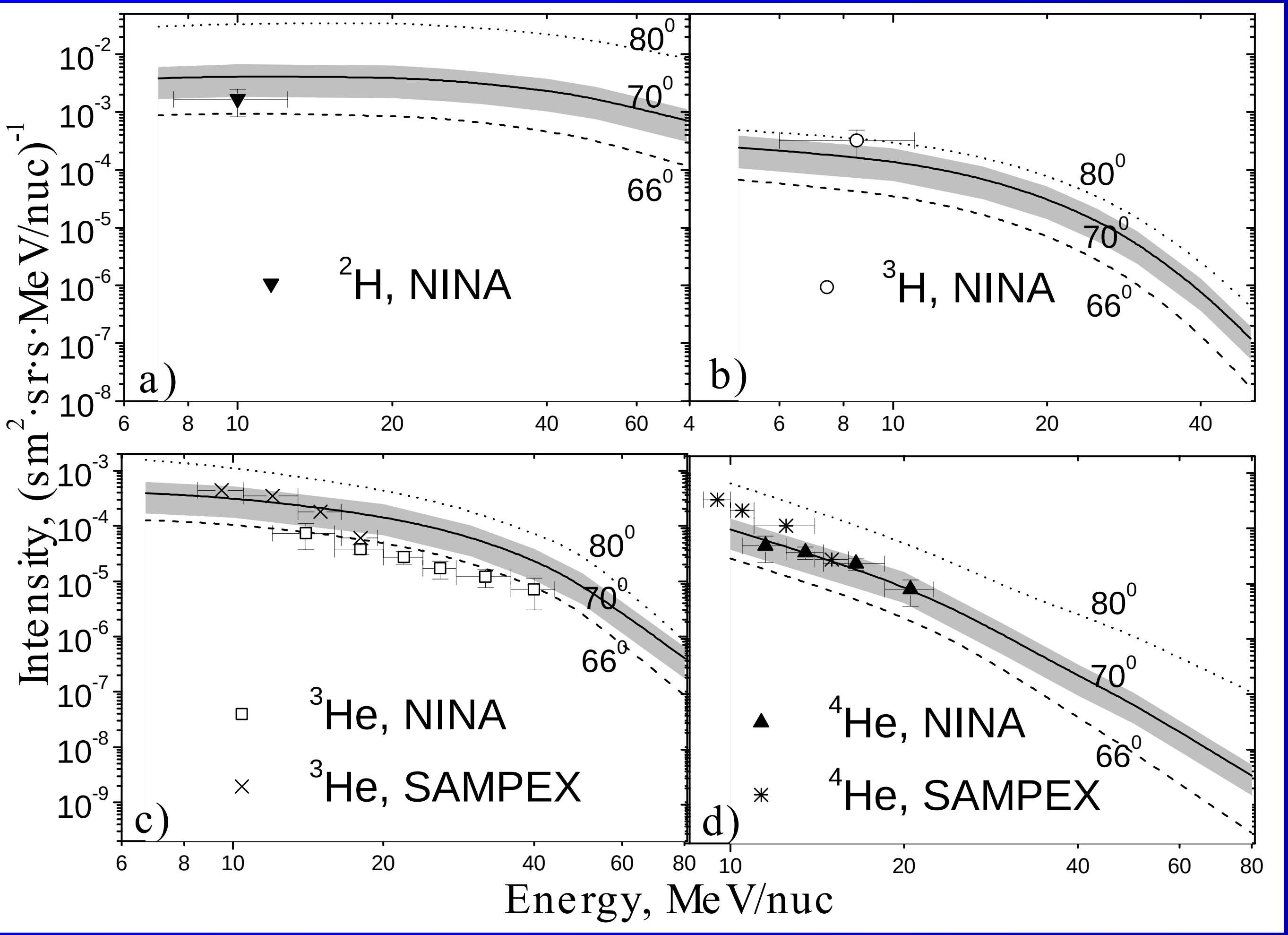


Rate of SEUs induced by He through direct ionization

SV dimension (μm)	Ec (MeV)	$\sigma_{pSEUmax}$ (cm²)	Bendel Parameter A	SEU Rate for typical flux of p (bit⁻¹ s⁻¹)	$\sigma_{alphaSEU}$ direct (cm²) (GEANT4)	Threshold flux behind 8 mm Al (cm⁻² s⁻¹ sr⁻¹)	Threshold differential flux at 168 MeV in space (γ=1) (cm⁻² s⁻¹ sr⁻¹ MeV⁻¹)
10x10x10	0.1	2E-11	19.4	7E-10	2E-4	6E-7	9E-10
	0.5	2E-11	19.4	7E-10	3E-5	4E-6	1E-10
	1.0	2E-11	19.4	7E-10	7E-6	2E-5	3E-11
	1.5	2E-11	19.4	7E-10	3E-6	4E-5	1E-11
1x1x1	0.1	2E-14	31.7	5E-13	3E-8	3E-6	1E-13

Mitigation against He needed if this flux level exceed

What we know about trapped He in space…



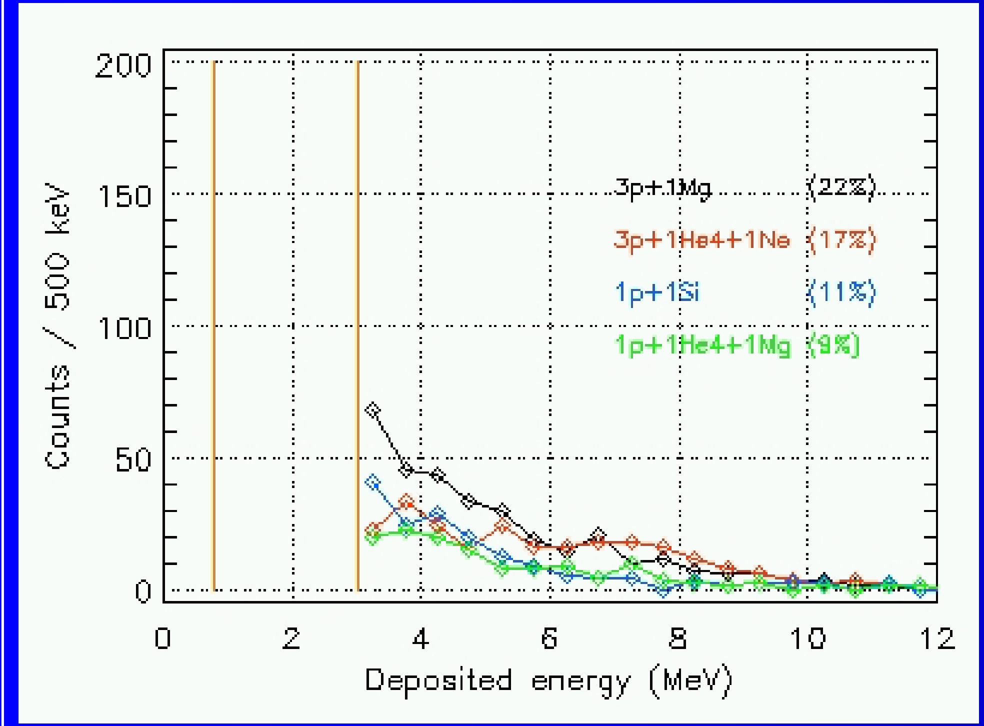
Calculated fluxes of trapped nuclei: ^{2}H (a), ^{3}H (b), ^{3}He (c), ^{4}He (d) resulting from the interaction of proton with atmospheric helium and oxygen. Each picture shows three curves. The dotted show the pitch angle range measured in NINA experiment.
The middle curve corresponds to the measured average pitch angle. The gray area shows the uncertainties propagated from those in double differential cross-sections of proton interaction with oxygen target. The data of SAMPEX and NINA experiments are also shown.

Another example: the procedure may be generalized

Consider a cubic 10x10x10 μm^3 sensitive volume, having a critical energy Ec = 3 MeV

More than 50% of p induced SEU from nuclear reaction products (+ Si recoils) come from the reactions shown in the Fig. below (provided QGSP-BIC is completely validated)

No SEU from direct ionization by protons nor α – particles is expected.



The maximum energy deposited by protons in such SV is ~0.8 MeV: Major contribution to the critical energy deposited comes from secondary Mg, Ne, or Si ions.

Unless a device is properly shielded against primary sources of these ions, evaluations of SEU rates should take them into account even if their absolute fluxes are low! In fact their efficiency to produce SEU by direct ionization is not modulated by 'cross-section'.

Summary

- GEANT4 allows evaluation of ion contribution to SEU rate produced by direct ionization;
- For assumed device characteristics, limits on He ion flux have been set (beyond which that ion may dominate SEU rates);
- Some (preliminary) He flux measurements indicate that these limits may be reached in space;
- However, there is no guaranty for the existence of the devices such as those involved in our assumptions.