



a toolkit for simulating radiation effects in electronics

Dávid Lucsányi

CERN, Radiation To Electronics (R2E) project



"Tools to predict Single Event Effects" event

13 December 2022



Agenda

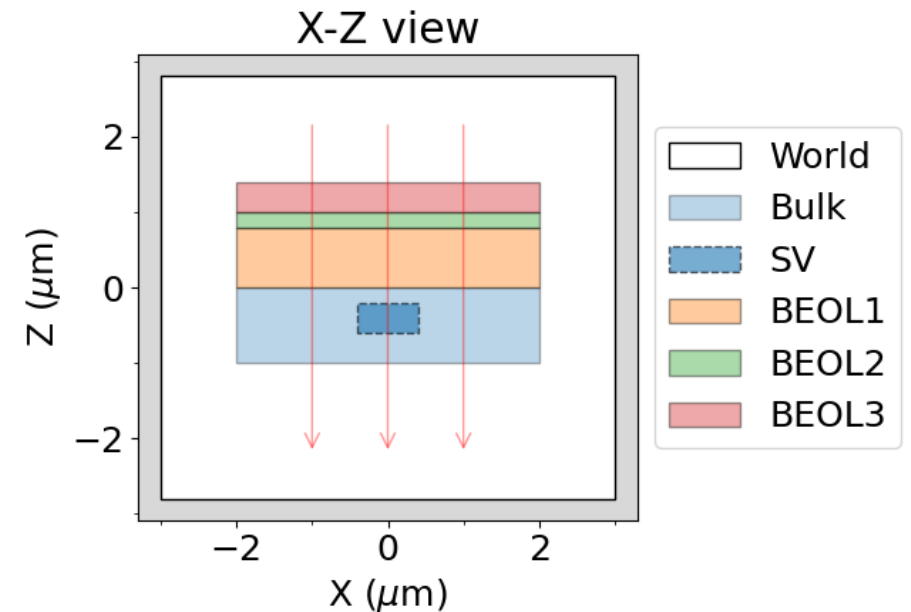


- An open-source toolkit
- Capabilities & Architecture
- Use cases
- Validation with neutrons
- Detailed scoring & neutrons
- User support & community
- Get the latest release!

An open-source toolkit



- G4SEE is a **Geant4-based Monte Carlo Single Event Effect (SEE) simulation toolkit**
- Direct and indirect **energy deposition scoring** in a micro-metric, user-defined sensitive volume \Rightarrow SEE cross-section (rate) estimation
- **Free and open-source**, available for the whole radiation effects community for a wide variety of use cases
- It is being developed in CERN Radiation To Electronics (R2E) project, but **developers, contributors and beta testers outside CERN are also welcome to join!**

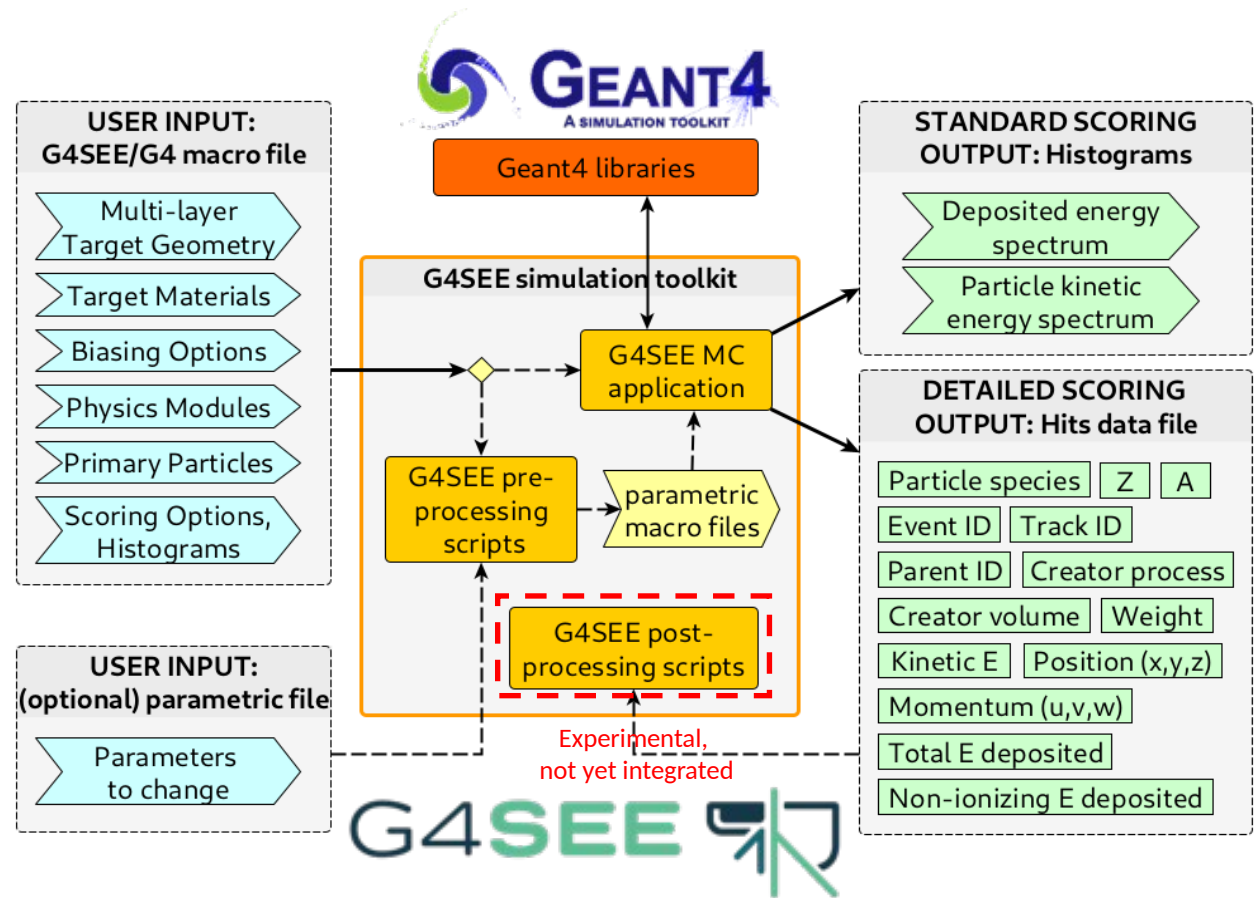


Multi-layer, micro-metric geometry used in a G4SEE simulation to obtain energy deposition in Sensitive Volume (SV) inside Bulk and below Back End Of Line (BEOL) layers

Capabilities & Architecture

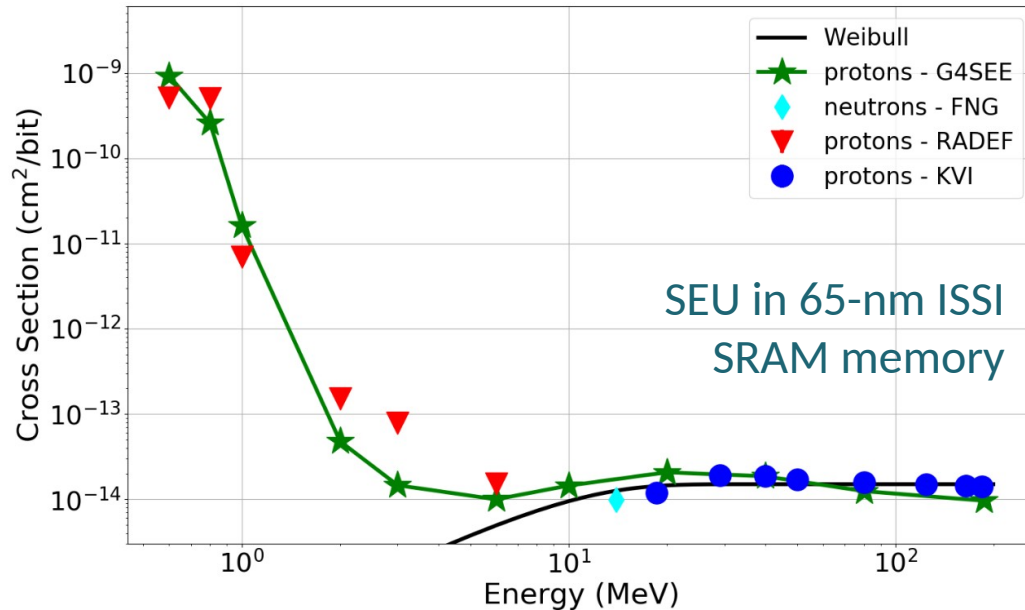


- Extracting **low-level information and quantities** relevant for SEEs, **event-by-event** and **particle-by-particle**, based on the user needs
- Primary motivation and use cases so far were **neutron and proton induced SEEs** (most relevant at CERN accelerator environments)

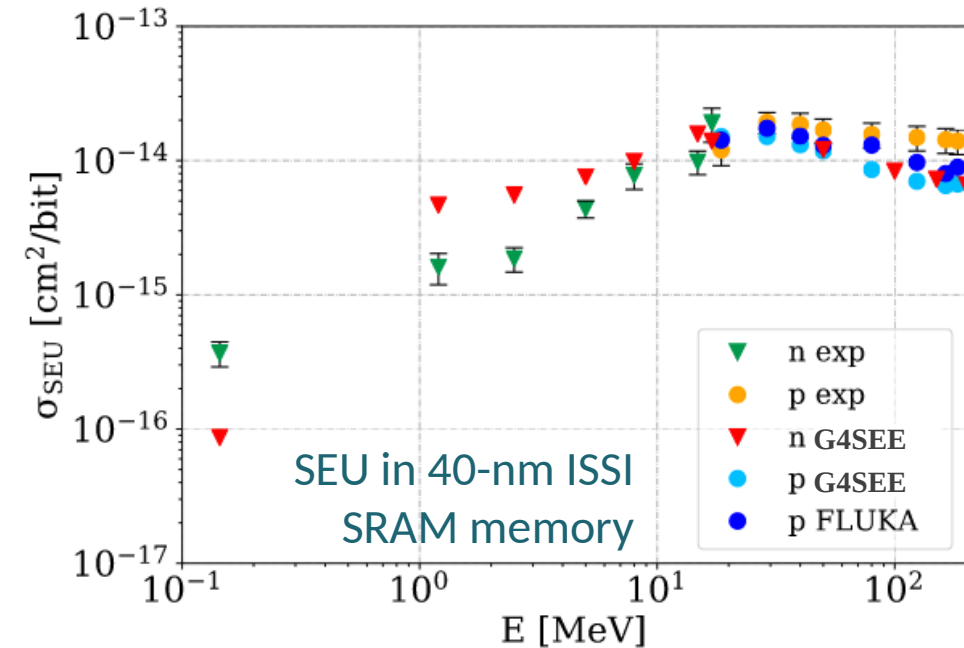


High-level architecture of the G4SEE toolkit with user inputs and outputs (ASCII files), and the two types of scoring mechanisms

Use cases



Simulated and experimental cross-section of proton induced SEUs in 65-nm ISSI SRAM as function of beam energy [1]

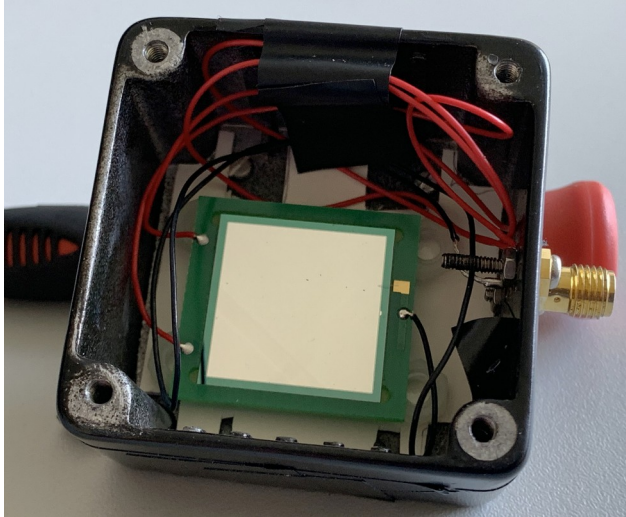


Simulated and experimental cross-section of neutron and proton induced SEUs in 40-nm ISSI SRAM as function of beam energy [2]

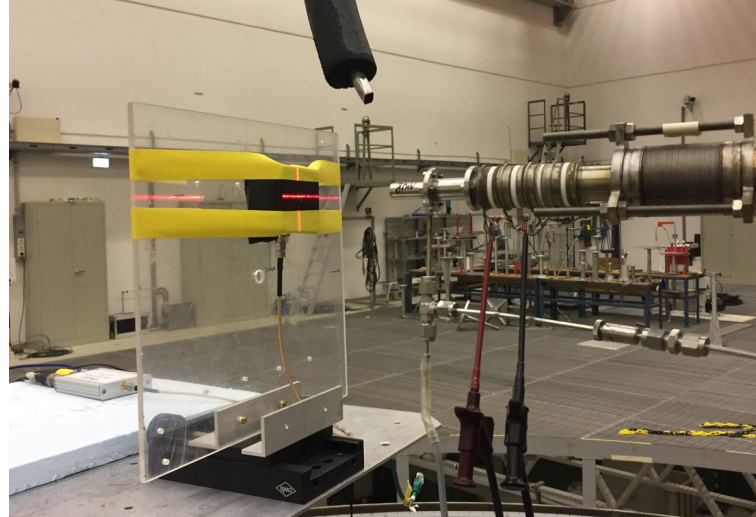
References (open-access)

- [1] Andrea Coronetti *et al.*, "Proton direct ionization upsets at tens of MeV", in *IEEE TNS*, 2022, doi.org/10.1109/TNS.2022.3207877
- [2] Matteo Cecchetto *et al.*, "0.1–10 MeV Neutron Soft Error Rate in Accelerator and Atmospheric Environments", in *IEEE TNS*, vol. 68, no. 5, May 2021, doi.org/10.1109/TNS.2021.3064666

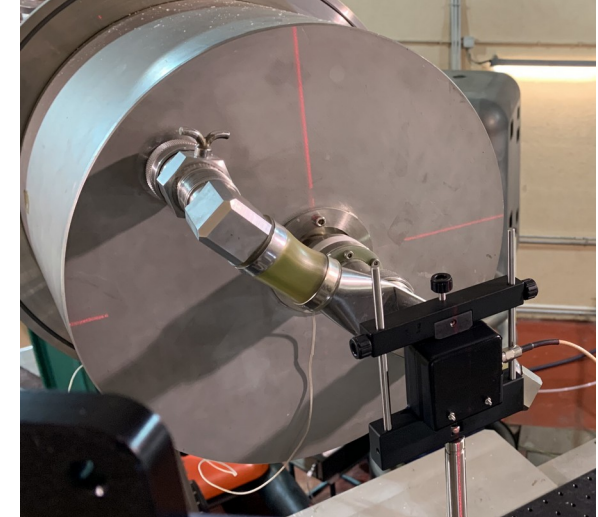
Validation with neutrons [3]



Silicon diode detector acquiring
Single Event Transient events
(2cm × 2cm × 300 μm) [3]



Diode setup irradiated at
PTB Ion Accelerator Facility (PIAF) [3]



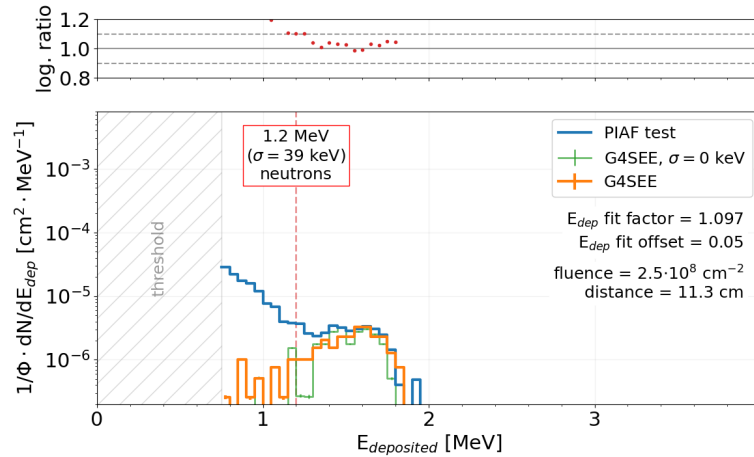
Diode setup irradiated at
Frascati Neutron Generator (FNG) [3]

Facility, Reaction	E_n (MeV)	σ_E (keV)	d (cm)	$\langle \varphi \rangle$ (cm ⁻² /s)	Φ (cm ⁻²)
PIAF, ³ H(d,n)	17	154	11.3	1.18·10 ⁵	1.11·10 ⁸
FNG, ³ H(d,n)	14.8	276	7.6	9.01·10 ⁶	2.74·10 ⁹
PIAF, ² H(d,n)	8	85	12.4	7.41·10 ⁵	3.61·10 ⁸
PIAF, ² H(d,n)	5	85	12.4	1.73·10 ⁵	2.65·10 ⁸
PIAF, ³ H(p,n)	2.5	54	11.3	4.12·10 ⁵	4.51·10 ⁸
PIAF, ³ H(p,n)	1.2	39	11.3	3.44·10 ⁵	2.48·10 ⁸

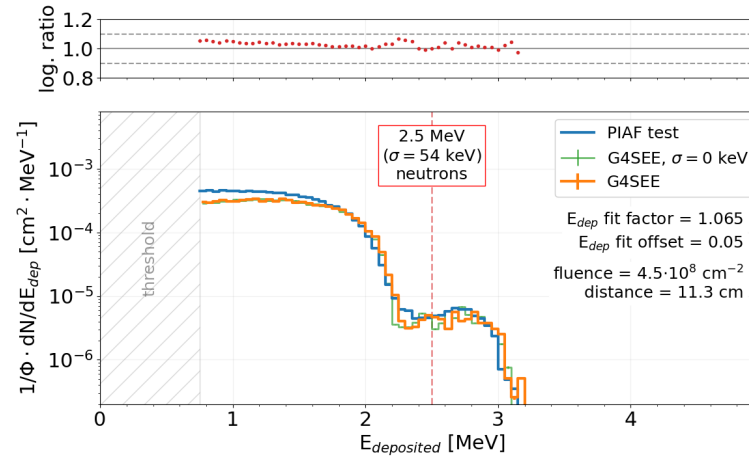
Reference (open-access)

[3] Dávid Lucsányi *et al.*, "G4SEE: A Geant4-Based Single Event Effect Simulation Toolkit and Its Validation Through Monoenergetic Neutron Measurements", in *IEEE TNS*, vol. 69, no. 3, March 2022, doi.org/10.1109/TNS.2022.3149989

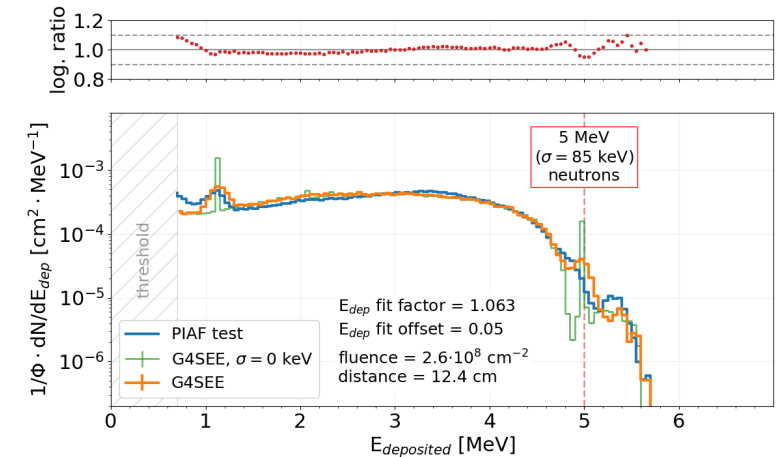
Validation with neutrons [3]



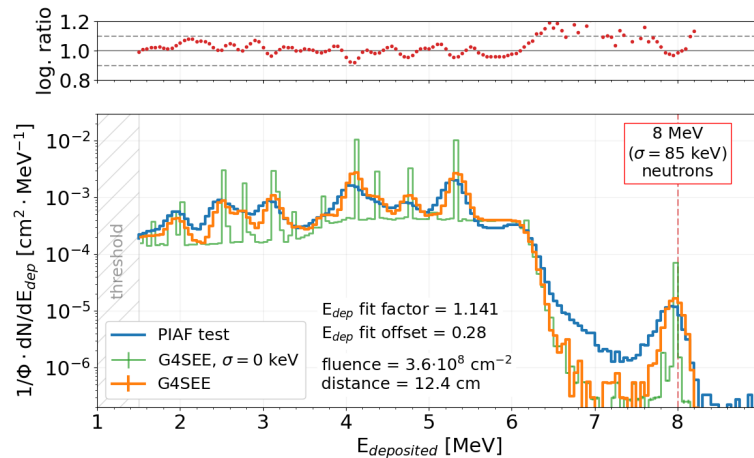
1.2 MeV



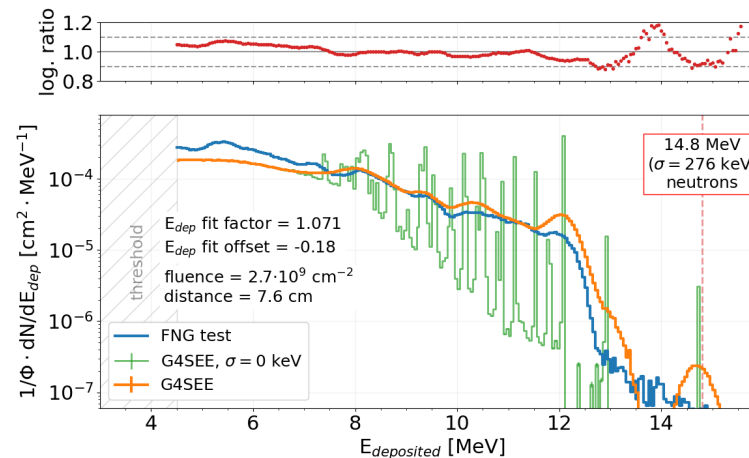
2.5 MeV



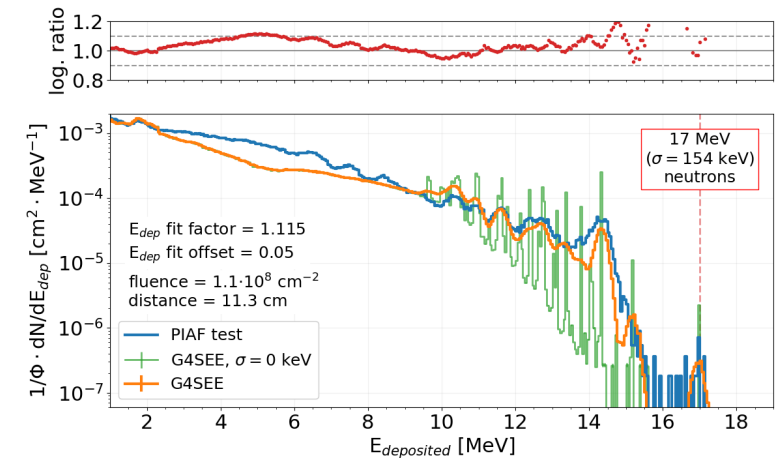
5 MeV



8 MeV



14.8 MeV



17 MeV

Detailed scoring & neutrons

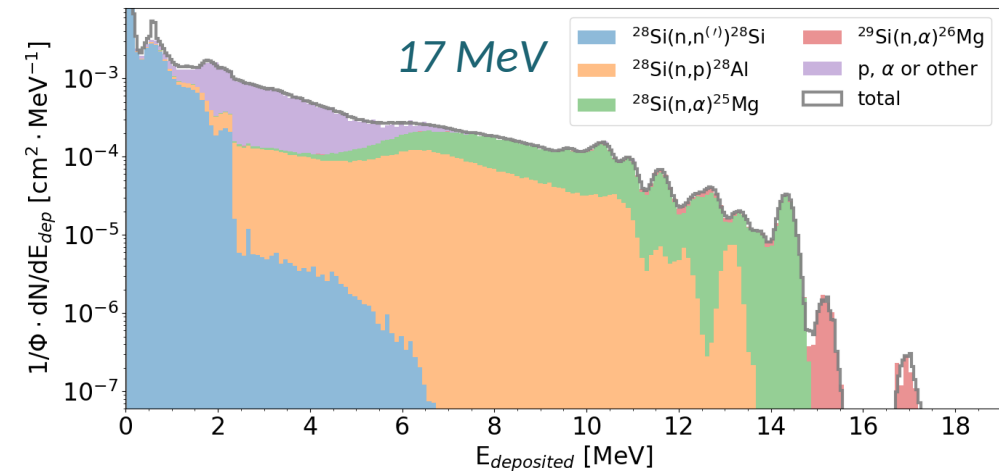
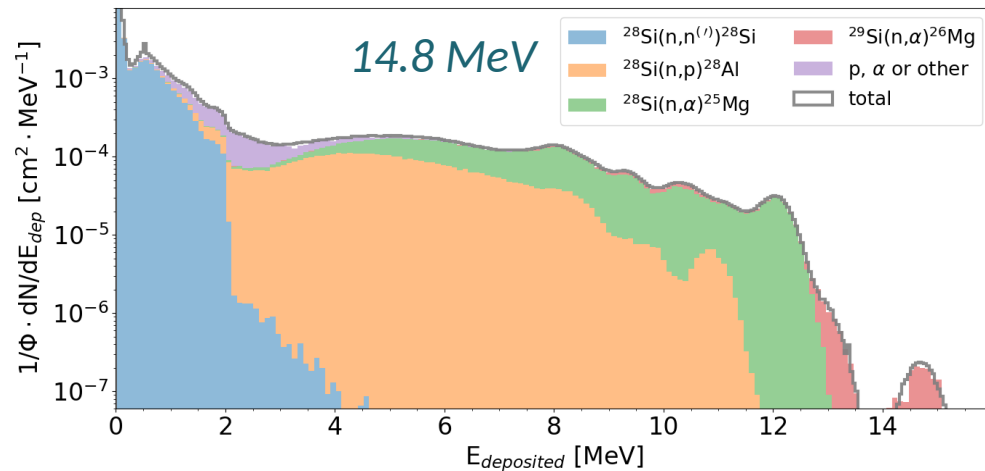
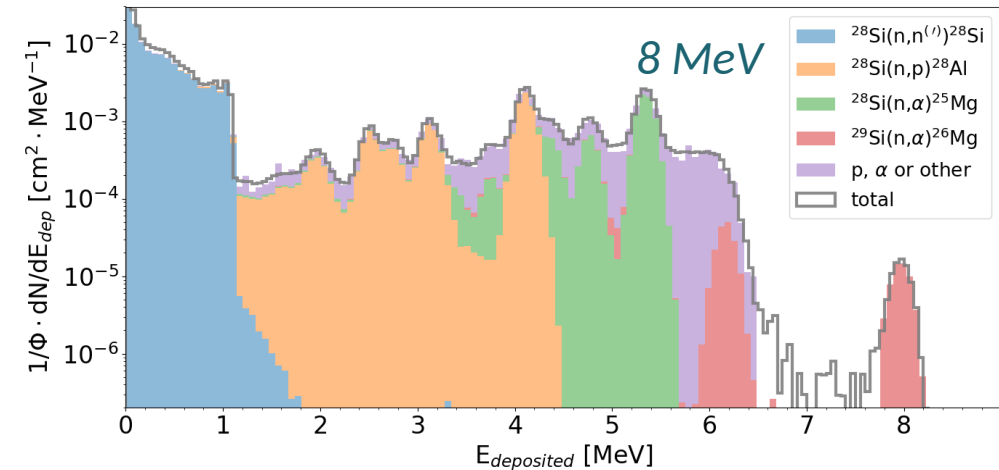
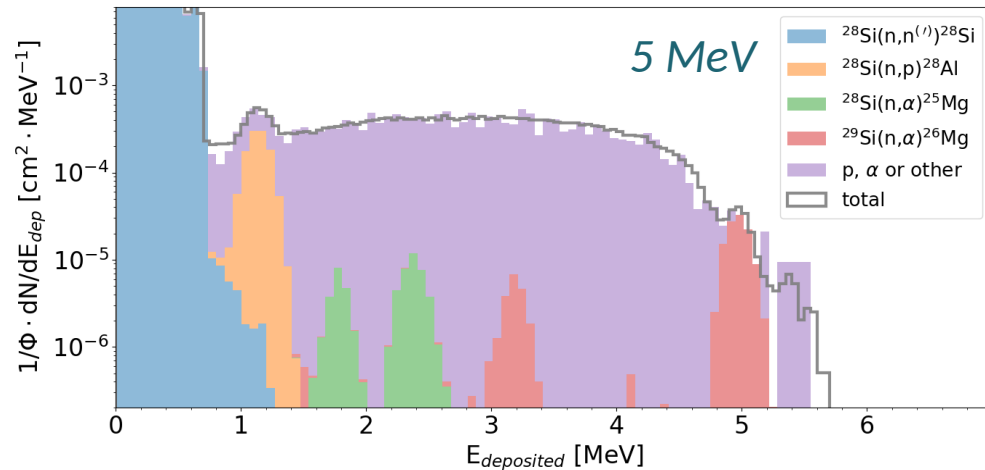


event	particle	weight	Z	A	track	parent	E_kin	process	volume	E_dep	counts
377	alpha	1.055e-03	2	4	2	1	3.8826e+00	b(neutronInelastic)	Sensitive	2.5712e-02	1
377	Mg25	1.055e-03	12	25	3	1	1.5530e+00	b(neutronInelastic)	Sensitive	2.4899e-02	1
377	g(e-)	nan	0	0	-1	nan	nan	ionIoni	Sensitive	5.4009e-03	5
490	neutron	1.053e-03	0	1	2	1	5.9415e+00	b(neutronInelastic)	Sensitive	0	1
490	Si28	1.053e-03	14	28	3	1	3.4732e-01	b(neutronInelastic)	Sensitive	1.2955e-01	1
490	gamma	1.053e-03	0	0	4	1	1.7778e+00	b(neutronInelastic)	Sensitive	0	1
732	O16	1.069e-03	8	16	2	1	1.0890e+00	b(hadElastic)	Oxide	1.3268e-01	1
914	gamma	1.057e-03	0	0	4	1	4.8919e+00	b(neutronInelastic)	Bulk	0	1
914	gamma	1.057e-03	0	0	5	1	1.7790e+00	b(neutronInelastic)	Bulk	0	1
1212	neutron	1.077e-03	0	1	2	1	5.2899e+00	b(neutronInelastic)	Bulk	0	1
1257	O16	1.048e-03	8	16	3	1	1.2290e-01	b(neutronInelastic)	Oxide	9.4224e-02	1
1342	neutron	1.072e-03	0	1	2	1	3.9277e-01	b(neutronInelastic)	Sensitive	0	1
1342	gamma	1.072e-03	0	0	3	1	5.1945e+00	b(neutronInelastic)	Sensitive	0	1
1342	gamma	1.072e-03	0	0	4	1	1.4963e+00	b(neutronInelastic)	Sensitive	0	1
1342	gamma	1.072e-03	0	0	5	1	4.7253e-01	b(neutronInelastic)	Sensitive	0	1
1342	Si30	1.072e-03	14	30	6	1	3.3550e-01	b(neutronInelastic)	Sensitive	1.3925e-01	1
1428	O16	1.050e-03	8	16	3	1	5.6249e-02	b(neutronInelastic)	Oxide	4.4397e-02	1
1536	Si28	1.066e-03	14	28	2	1	4.7965e-02	b(hadElastic)	Sensitive	4.7965e-02	1
1565	Al28	1.067e-03	13	28	3	1	4.7900e-01	b(neutronInelastic)	Bulk	1.6775e-01	1
1605	neutron	1.053e-03	0	1	2	1	6.0902e+00	b(neutronInelastic)	Sensitive	0	1
1605	Si28	1.053e-03	14	28	3	1	2.3035e-01	b(neutronInelastic)	Sensitive	1.2189e-01	1
1605	gamma	1.053e-03	0	0	4	1	1.7730e+00	b(neutronInelastic)	Sensitive	0	1
1984	neutron	1.055e-03	0	1	2	1	6.0284e+00	b(neutronInelastic)	Sensitive	0	1
1984	Si28	1.055e-03	14	28	3	1	2.0772e-01	b(neutronInelastic)	Sensitive	1.6477e-01	1
1984	gamma	1.055e-03	0	0	4	1	1.7703e+00	b(neutronInelastic)	Sensitive	0	1
1993	Si28	1.054e-03	14	28	3	1	3.6548e-01	b(neutronInelastic)	Bulk	1.9489e-01	1
1993	gamma	1.054e-03	0	0	4	1	3.2000e+00	b(neutronInelastic)	Bulk	0	1
1993	gamma	1.054e-03	0	0	5	1	1.7790e+00	b(neutronInelastic)	Bulk	0	1
1993	g(gamma)	nan	0	0	-1	nan	nan	b(neutronInelastic)	Bulk	0	1
2044	Si28	1.072e-03	14	28	2	1	7.3092e-02	b(hadElastic)	Bulk	0	1
2176	proton	1.066e-03	1	1	2	1	3.3008e+00	b(neutronInelastic)	Sensitive	4.8202e-03	1
2176	Al28	1.066e-03	13	28	3	1	7.5380e-01	b(neutronInelastic)	Sensitive	4.1540e-02	1
2176	g(gamma)	nan	0	0	-1	nan	nan	b(neutronInelastic)	Sensitive	0	1
2559	proton	1.063e-03	1	1	2	1	2.6926e+00	b(neutronInelastic)	Sensitive	2.4314e-03	1
2559	Al28	1.063e-03	13	28	3	1	3.8967e-01	b(neutronInelastic)	Sensitive	8.7722e-02	1
2559	gamma	1.063e-03	0	0	4	1	9.8268e-01	b(neutronInelastic)	Sensitive	0	1
2559	g(e-)	nan	0	0	-1	nan	nan	hIoni	Sensitive	3.9645e-03	3
2559	g(gamma)	nan	0	0	-2	nan	nan	b(neutronInelastic)	Sensitive	0	1

The detailed scoring output file containing information of individual particles (or groups of e^- , e^+ and γ particles) scored inside the sensitive volume.

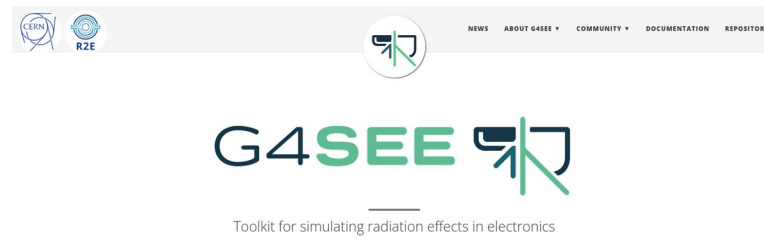
Further processing and analysis needed (such a post-processing python script will be added to a future G4SEE release).

Detailed scoring & neutrons

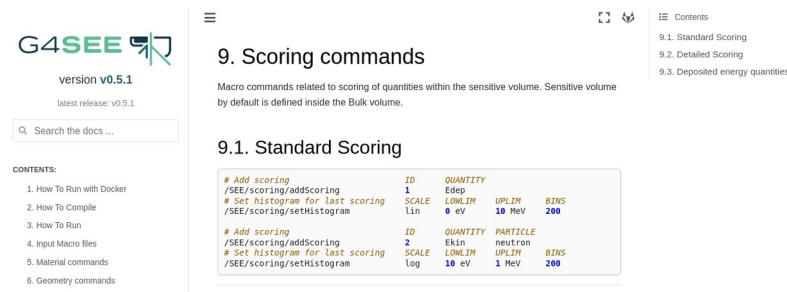


Contribution of the most frequent nuclear reactions to energy deposition distributions by monoenergetic neutrons in Si diode detector [3]

User support & community



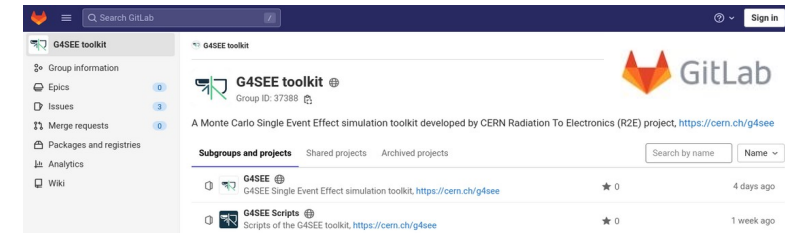
Website: g4see.web.cern.ch



Documentation: g4see-docs.web.cern.ch

Feature Requests Suggestions and discussions regarding potential new features of G4SEE.	3	# Welcome to G4SEE Discourse Sep '21	1
Issues Report issues, propose fixes and find help.	4	Scoring Elements rather than Isotopes Feature Requests · scoring, feature-request	1 10d
News & Announcements New releases, upcoming events, collaboration partners & projects.	1	How does biasNonPrimariesToo command work? Issues · biasing, g4see	2 1 Nov
Uncategorized Topics that don't need a category, or don't fit into any other	1	Plotting multiple histograms Issues · post-processing, scripts	1 21 Oct

Community forum: g4see-forum.web.cern.ch



GitLab repositories: gitlab.cern.ch/g4see

IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 69, NO. 3, MARCH 2022

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G4SEE: A Geant4-Based Single Event Effect Simulation Toolkit and Its Validation Through Monoenergetic Neutron Measurements

Dávid Lucsányi[✉], Rubén García Alfá[✉], Member, IEEE, Kacper Bilko[✉], Matteo Cecchetto[✉], Salvatore Fiore[✉], Member, IEEE, and Elisa Pirovano[✉]

Abstract—A single-event effect (SEE) simulation toolkit has been developed at CERN for the whole radiation effects community and released as an open-source code. It has been validated by comparing the simulated energy deposition of inelastic inter-

to the overall SEU rate [8], as well as the π^\pm SEE cross section and its impact on a mixed-field environment [9]. The primary MC tool used so far for such simulations was FLUKA [10],

Paper published in IEEE TNS: [DOI link](#)

9:00 AM → 9:50 AM

Introduction to G4SEE: a toolkit for simulating radiation effects in electronics I






🕒 50m 📍 503/1-001 - Council Chamber

G4SEE, a novel Geant4-based Monte Carlo simulation toolkit is being developed at CERN for the radiation effects community, and released as a free and open-source code. It has been already demonstrated and validated experimentally by measurements of inelastic energy deposition single events of monoenergetic neutrons below 20 MeV. These two hands-on lectures will give an introduction on how to use the G4SEE toolkit in simple, but real-life scenarios to simulate, analyse and better understand the nuclear physics of Single Event Effects induced by neutrons and protons in microelectronic structures.

G4SEE website: <https://cern.ch/g4see>

Speaker: David Lucsányi (CERN)

SERESSA 2022



Lectures at SERESSA 2022: [Indico page](#)

Get the latest release!



- Options to run G4SEE toolkit on your computer:

- A) Cloning [CERN GitLab repositories](#) and building it from source (*Geant4 needed*)

-- OR --

- B) Using Docker** (*recommended*)



- After [Docker installation](#), pull the latest, **G4SEE v0.5.1** Docker image



- Run a Docker container based on latest G4SEE image (*with shared folder*)

CLI commands to run on host computer to start a G4SEE Docker container

```
$ docker pull gitlab-registry.cern.ch/g4see/g4see:v0.5.1_G4-11.0.3
$
$ docker run -it -h g4see -v /host/path/to/shared_folder:/home
    gitlab-registry.cern.ch/g4see/g4see:v0.5.1_G4-11.0.3
root@g4see:/home#
```

Share a folder between host
and Docker container!

Thank you for your attention!

Questions?

If you have further questions, or you are interested in contributing or testing the G4SEE toolkit, please contact us!

g4see.toolkit@cern.ch