G4SEE

a toolkit for simulating radiation effects in electronics

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CERN, Radiation To Electronics (R2E) project

"Tools to predict Single Event Effects" event

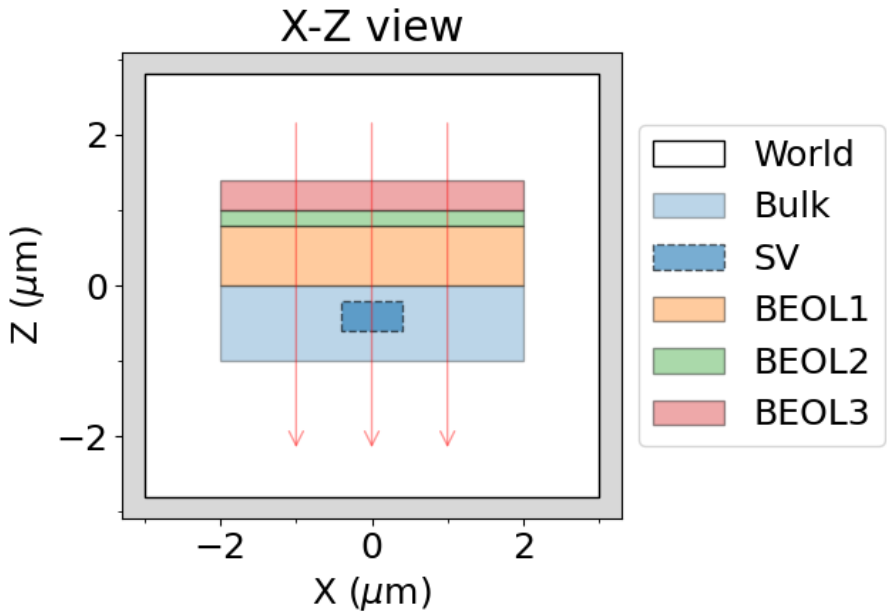
13 December 2022

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

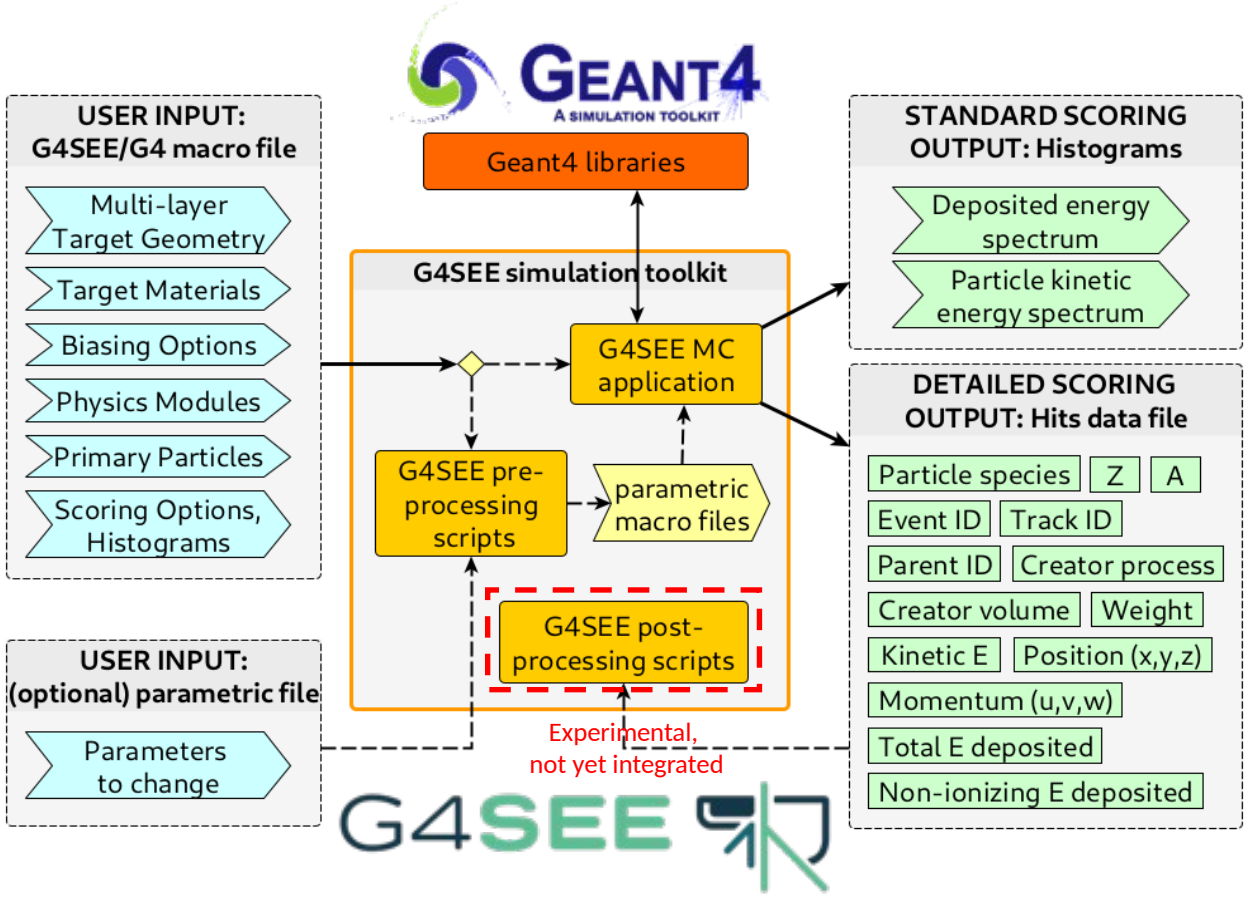
- G4SEE is a **Geant4**-based **Monte Carlo Single Event Effect** (SEE) simulation **toolkit**
- Direct and indirect **energy deposition scoring** in a micro-metric, user-defined sensitive volume ⇒ SEE cross-section (rate) estimation
- **Free and open-source**, available for the whole radiation effects 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

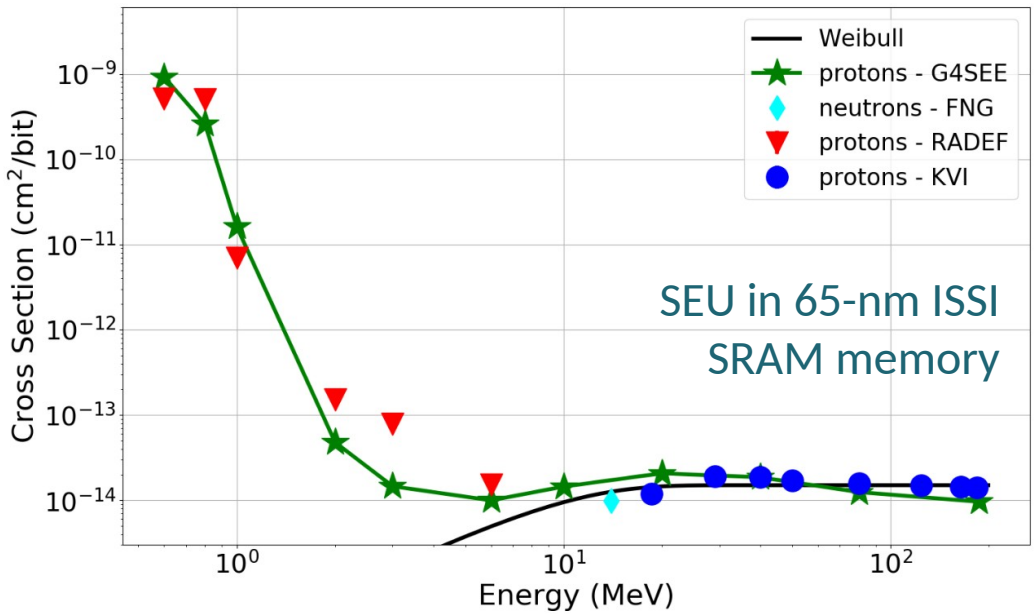
Capabilities & Architecture

- 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)

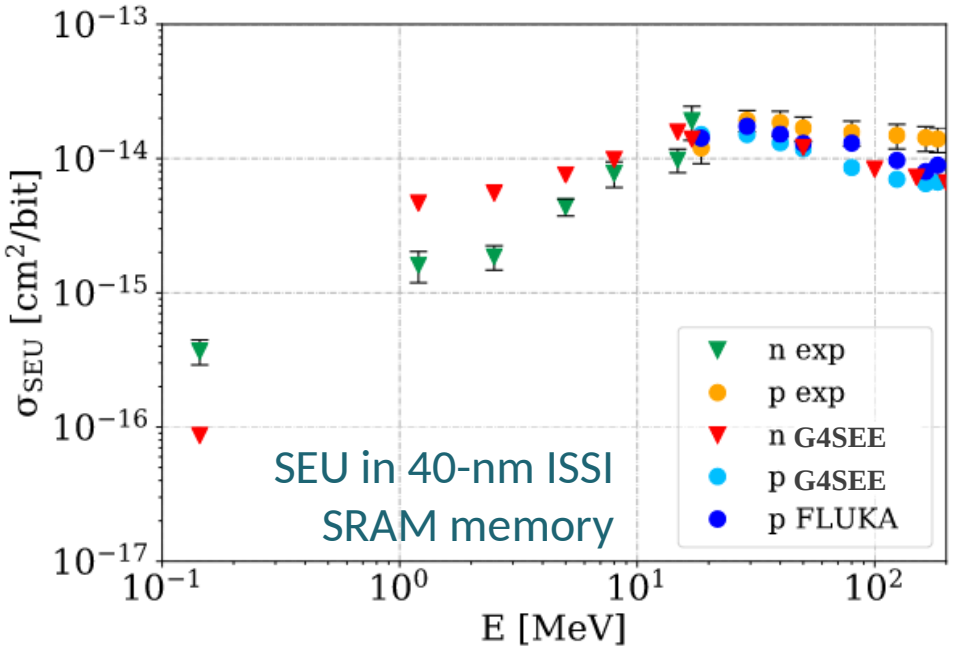


High-level architecture of the G4SSE toolkit with user inputs and outputs (ASCII files), and the two types of scoring mechanisms

Use cases



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



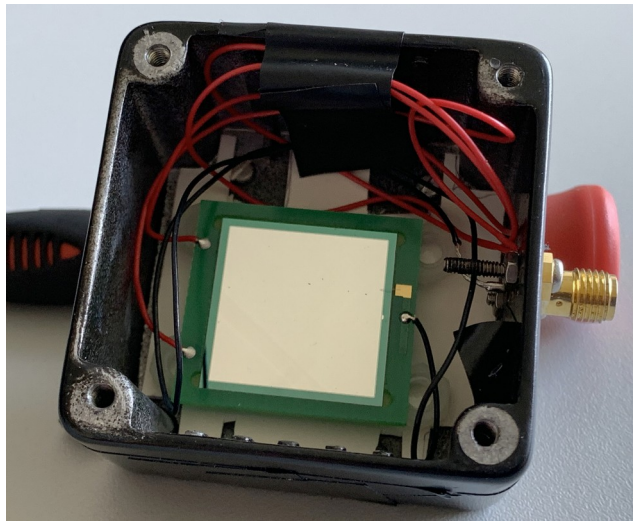
Simulated and experimental cross-section of neutron and proton induced SEUs in 40-nm ISSI SRAM as function of beam energy [2]

References (open-access)

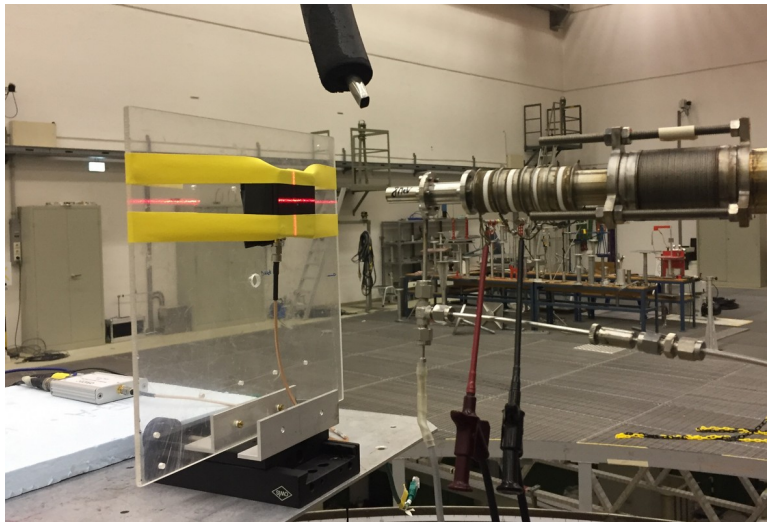
[1] Andrea Coronetti *et al.*, "Proton direct ionization upsets at tens of MeV", in *IEEE TNS*, 2022, doi.org/10.1109/TNS.2022.3207877

[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

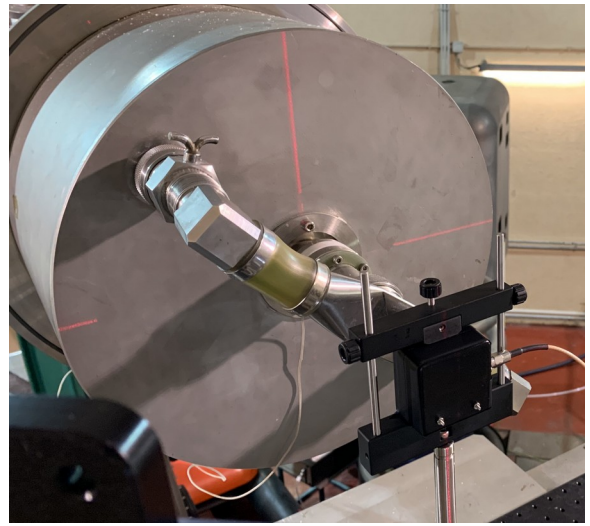
Validation with neutrons [3]



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



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



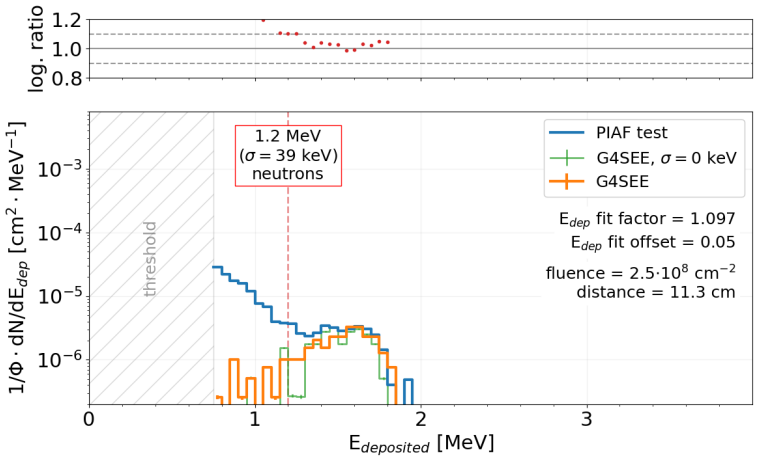
Diode setup irradiated at Frascati Neutron Generator (FNG) [3]

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	$1.18 \cdot 10^5$	$1.11 \cdot 10^8$
FNG, ^{3}H(d,n)	14.8	276	7.6	$9.01 \cdot 10^6$	$2.74 \cdot 10^9$
PIAF, ^{2}H(d,n)	8	85	12.4	$7.41 \cdot 10^5$	$3.61 \cdot 10^8$
PIAF, ^{2}H(d,n)	5	85	12.4	$1.73 \cdot 10^5$	$2.65 \cdot 10^8$
PIAF, ^{3}H(p,n)	2.5	54	11.3	$4.12 \cdot 10^5$	$4.51 \cdot 10^8$
PIAF, ^{3}H(p,n)	1.2	39	11.3	$3.44 \cdot 10^5$	$2.48 \cdot 10^8$

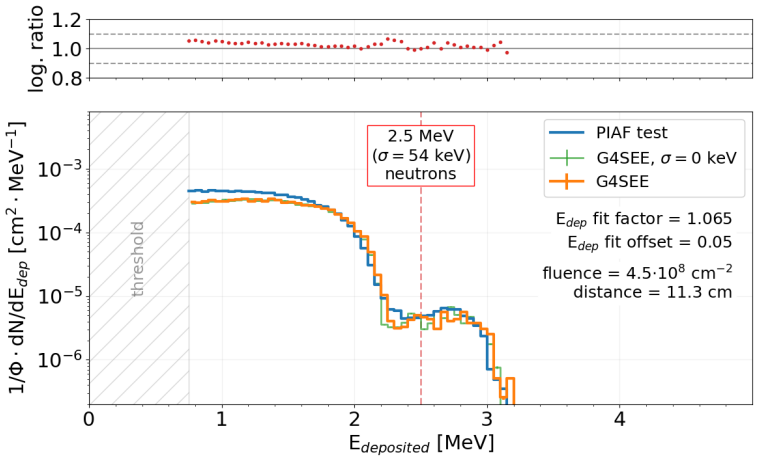
Reference (open-access)

[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

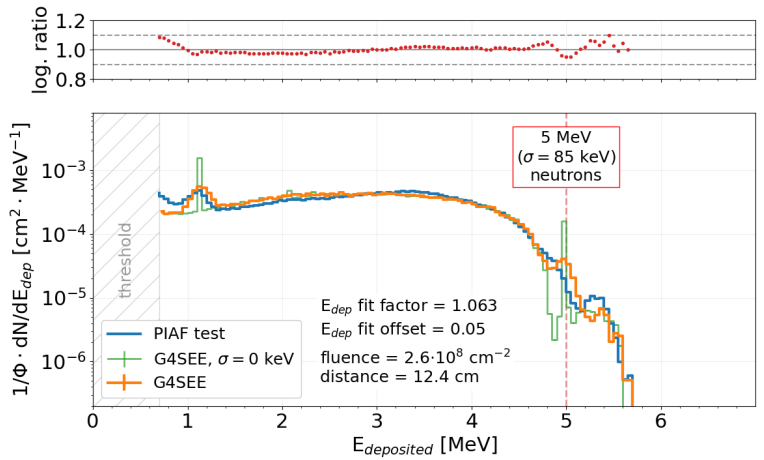
Validation with neutrons [3]



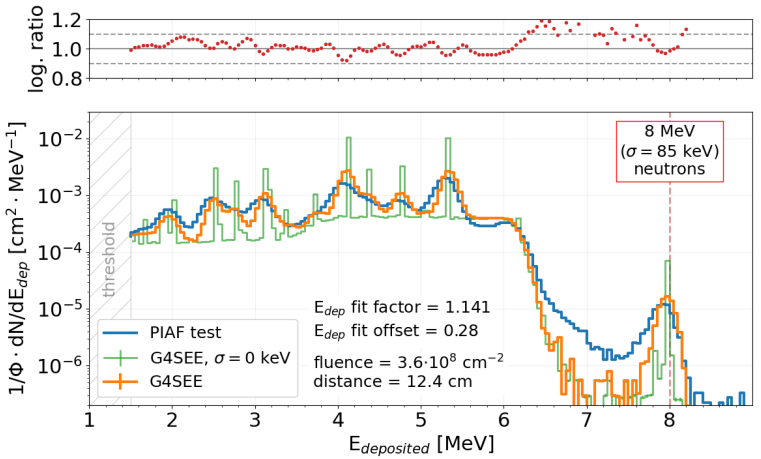
1.2 MeV



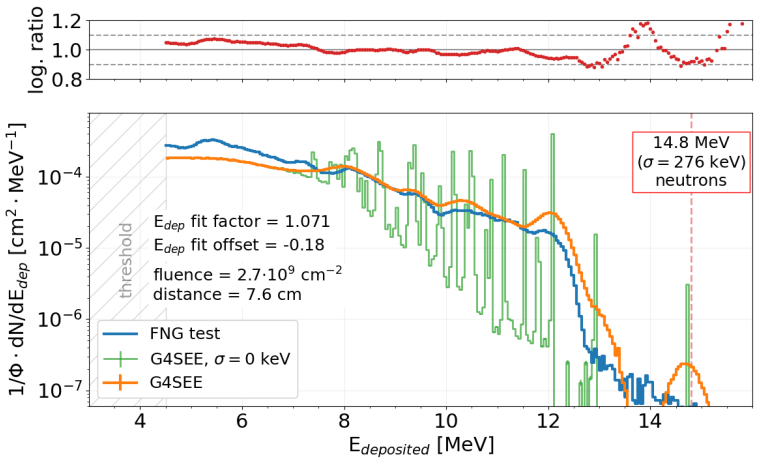
2.5 MeV



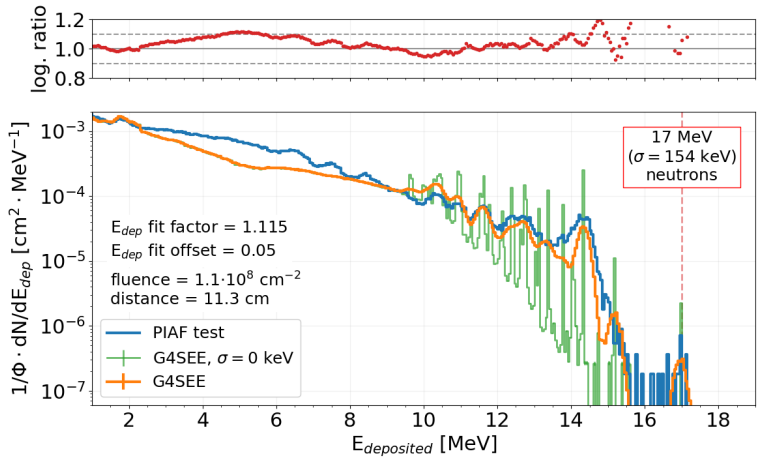
5 MeV



8 MeV



14.8 MeV



17 MeV

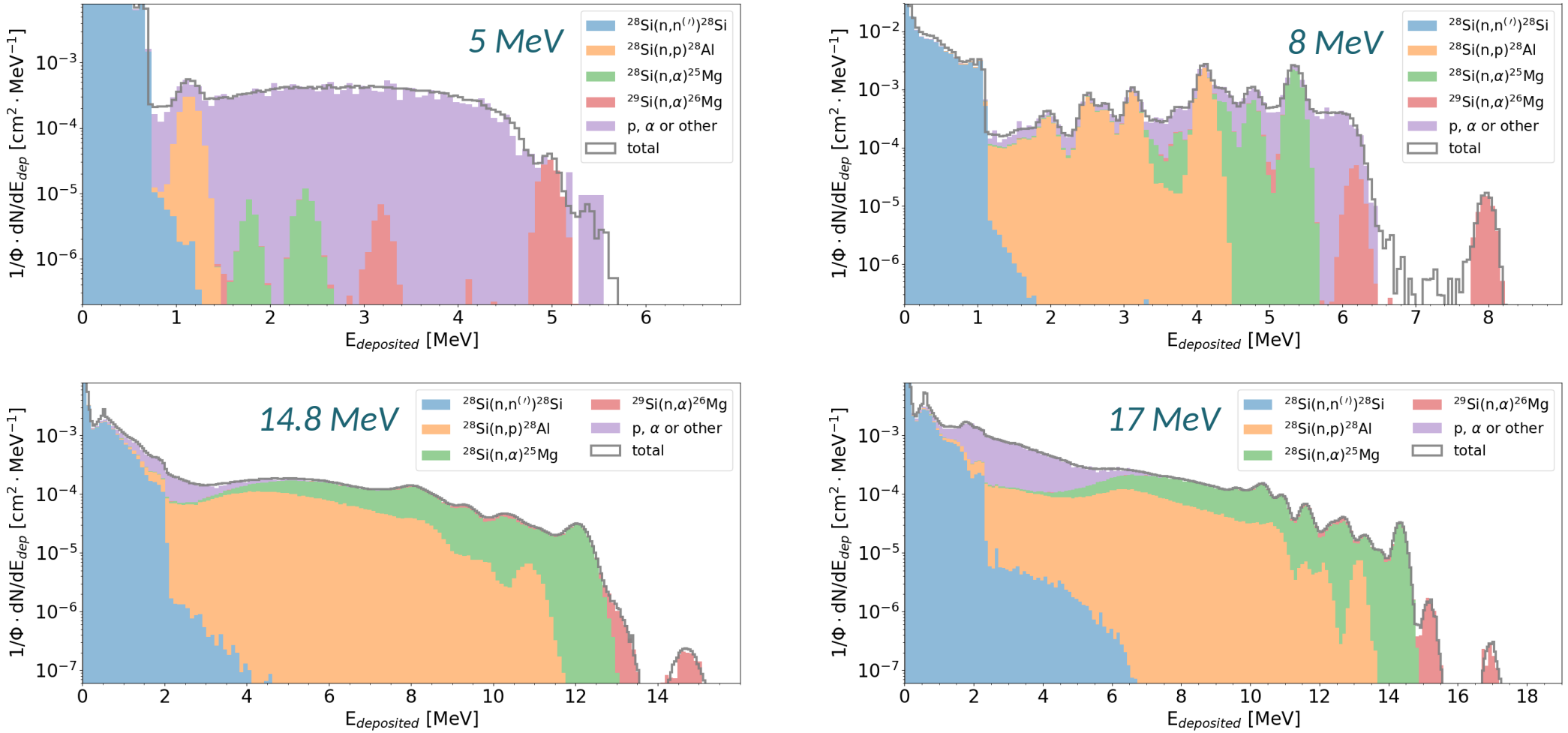
Detailed scoring & neutrons

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).

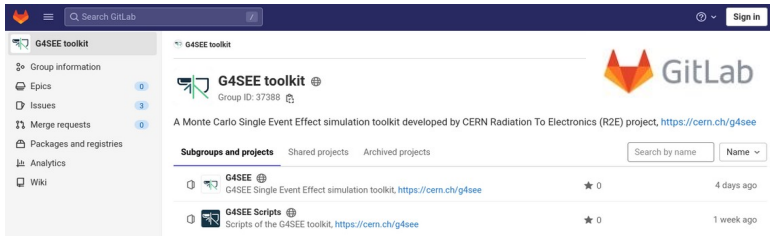
Detailed scoring & neutrons



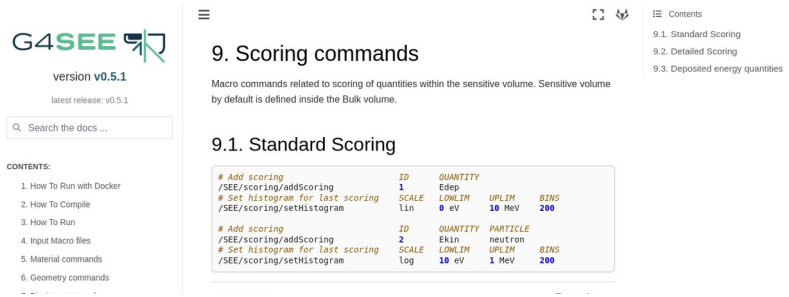
Contribution of the most frequent nuclear reactions to energy deposition distributions by monoenergetic neutrons in Si diode detector [3]

User support & community

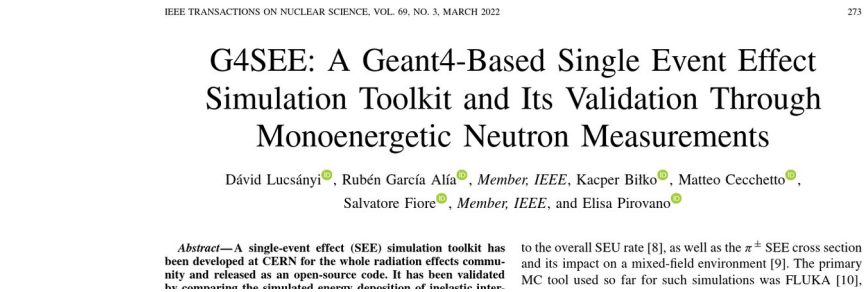
Website: g4see.web.cern.ch



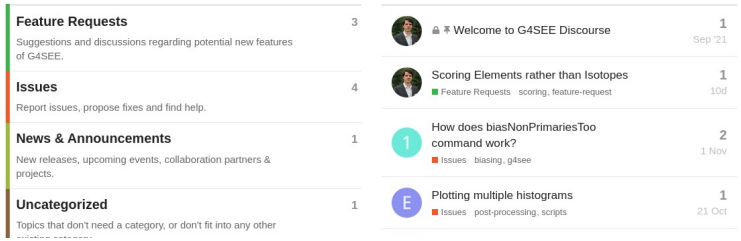
GitLab repositories: gitlab.cern.ch/g4see



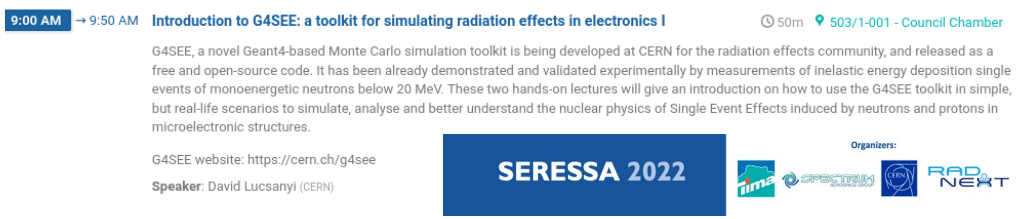
Documentation: g4see-docs.web.cern.ch



Paper published in IEEE TNS: [DOI link]



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



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