SEE-U: Single Event Effect Upset modelling

Benjamin Jeanty-Ruard[1] , Laurent Artola[2], Guillaume Hubert[2], Julien Forest[1]

[1] Artenum
[2] ONERA

ruard@artenum.com

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Plan

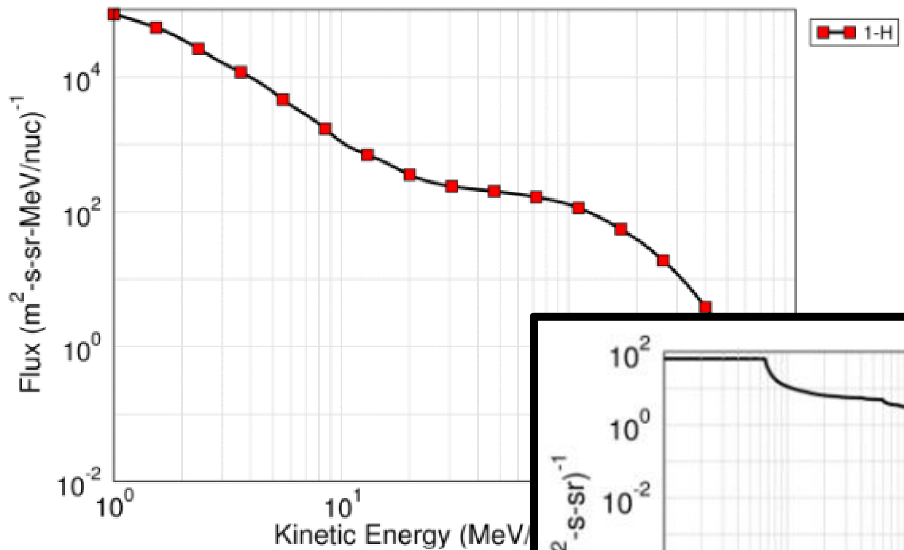
- Context: SER computation state of the art
  - Presentation
  - Limitations

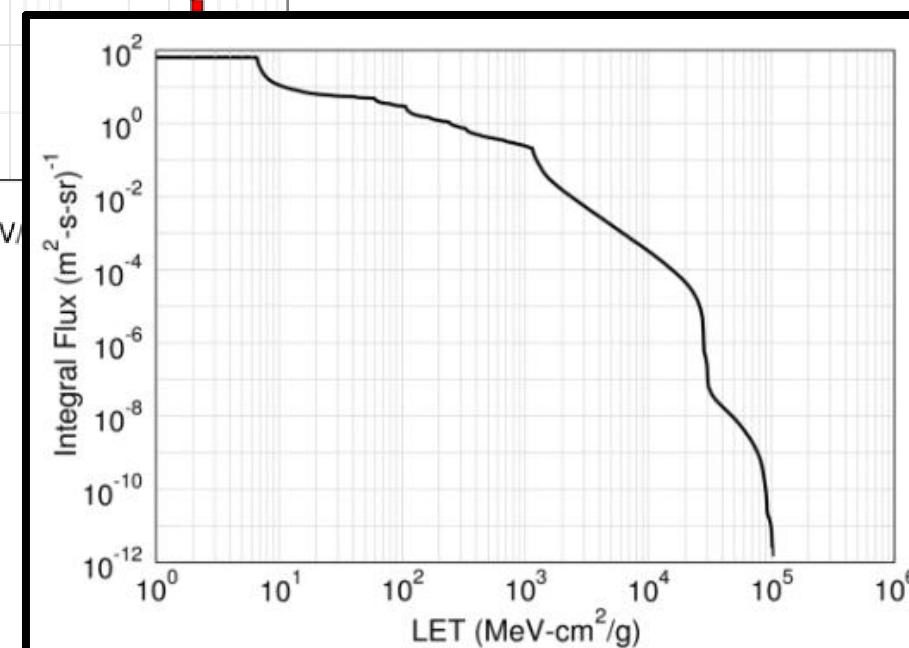
- New application: SEE-U
  - Workflow details
  - Results

Context – For both protons and heavy ions

- Compute proton/heavy ions flux after shielding
- Several tools exist: CREME96, SPENVIS, …

Orbit
↓
Environmental flux
↓
Average shielding
↓
Flux after shielding





CREME96

VANDERBILT UNIVERSITY School of Engineering

SPENVIS
The Space Environment Information System

Context – For Heavy Ions

- Get SEU cross section
  - for incident particle angle 90° with BEOL from
    - Experimental data
    - Monte-Carlo simulation
    - Weibull fit

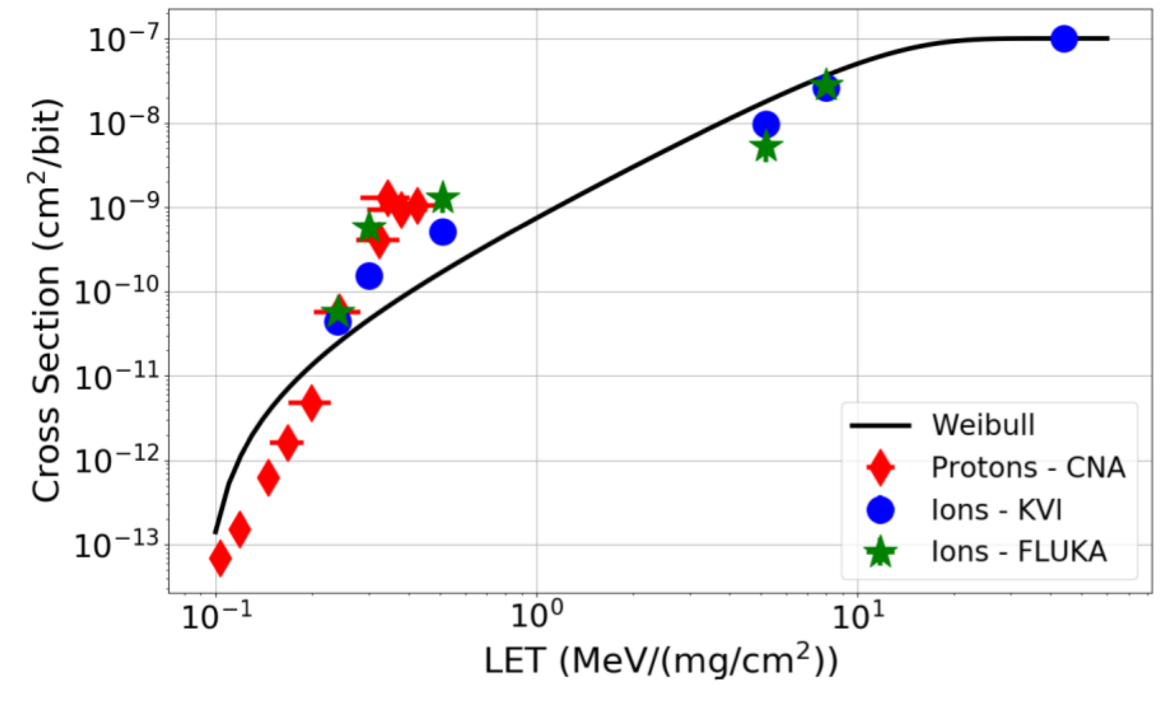


Fig. 6. LEP and HI cross sections as a function of LET for the Cypress SRAM. Weibull parameters: $\sigma_{sat} = 1 \times 10^{-7}$ cm^2/bit, LET$_0$ = 0.09 MeV/(mg/cm^2), W = 12 MeV/(mg/cm^2), and s = 1.9. The data are compared with the FLUKA simulated cross sections.

Credits: *A. Coronetti et al. [1]*

Context – For protons

- Get SEU cross section
  - for incident particle angle 90° with BEOL from
    - Experimental data
    - Monte-Carlo simulation
  - Warning:
    - Strong effect of direct ionization
    - Peak Bragg
    - Weibull fit is not enough

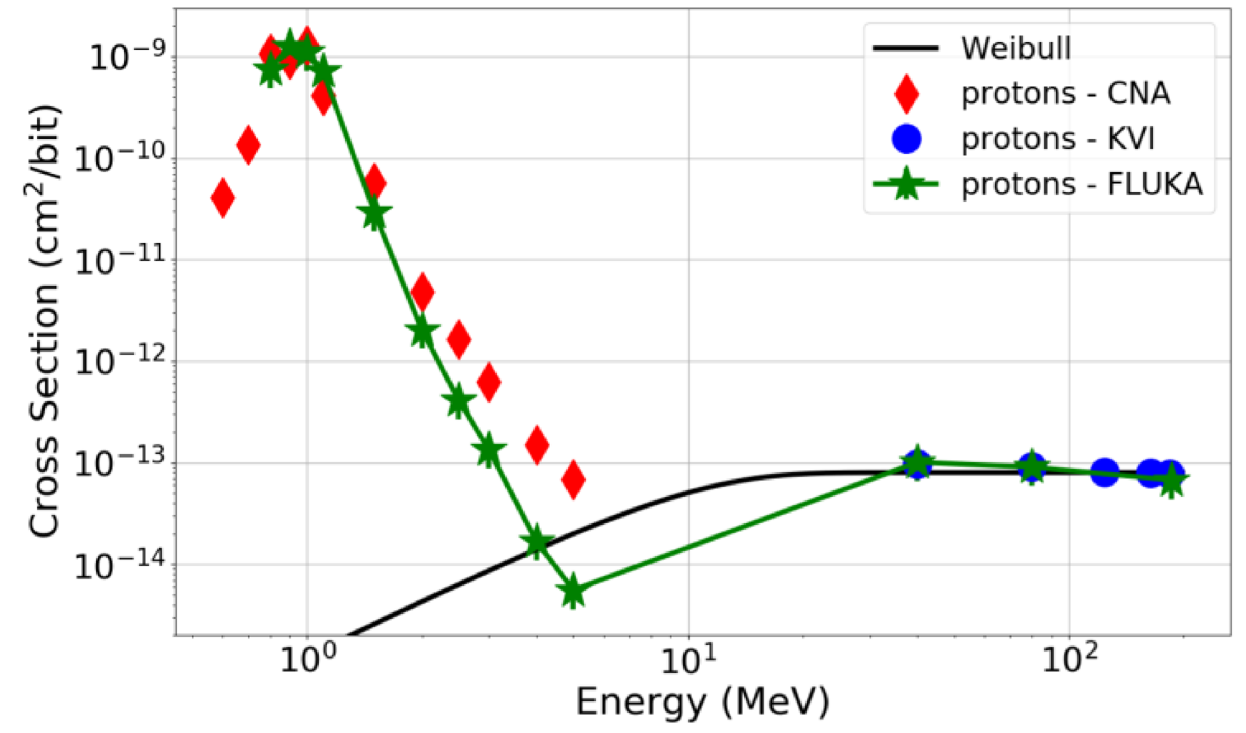


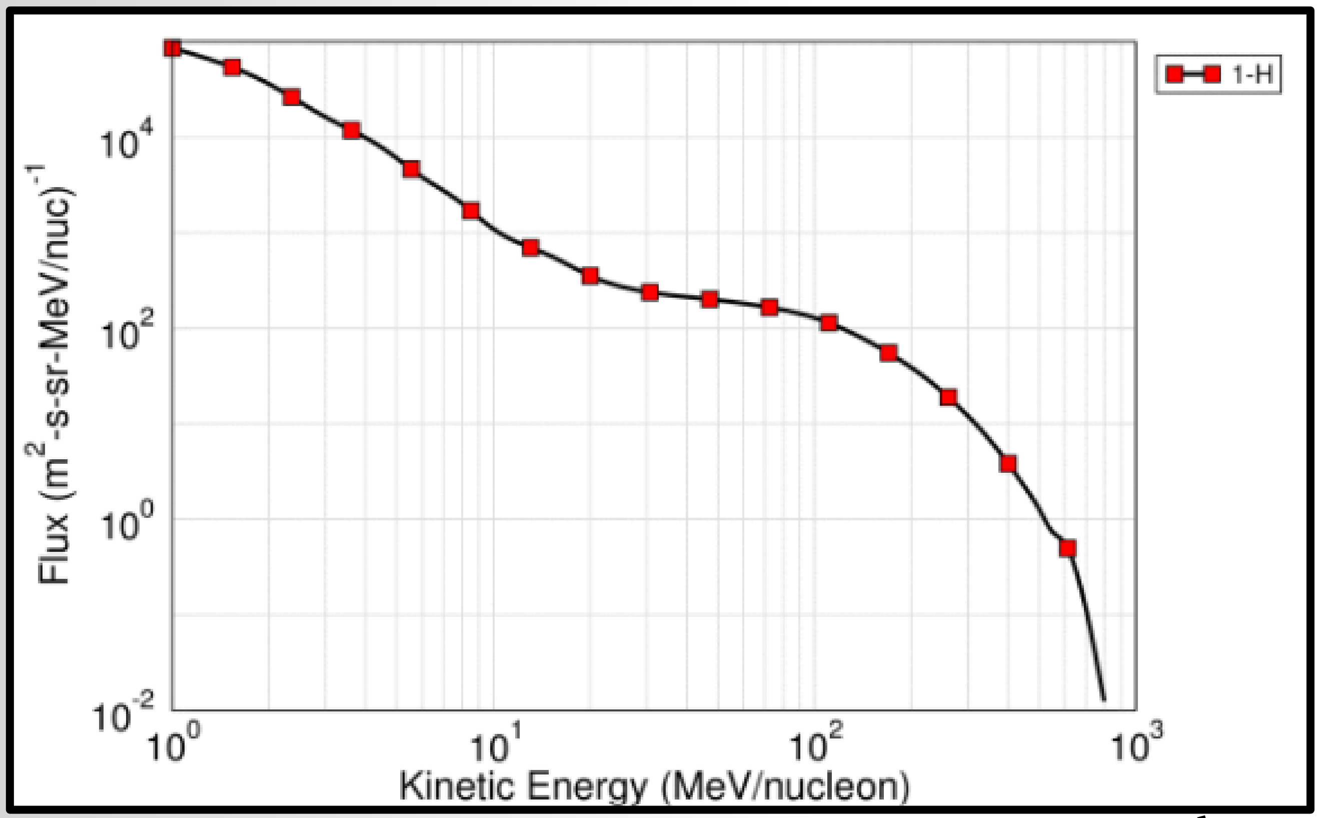
Fig. 3. Low and HEP experimental cross sections as a function of proton energy for the Cypress SRAM. The HEP data are fit with a Weibull with the following parameters: $\sigma_{\text{sat}} = 8 \times 10^{-14}$ cm^2/bit, $E_0 = 10$ MeV, $W = 0$ MeV, $s = 1.8$. The data are compared with the FLUKA simulated cross sections.

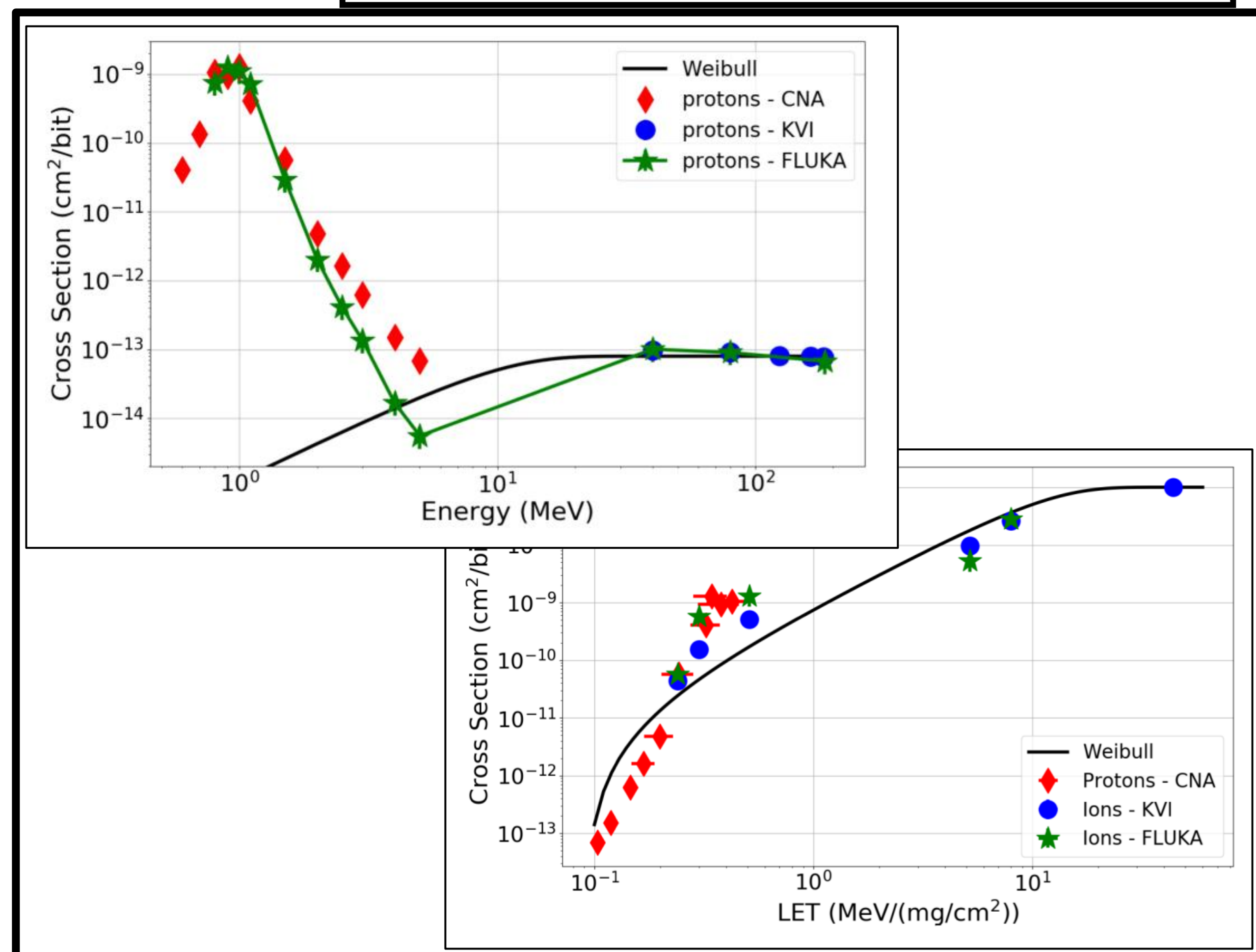
Credits: *A. Coronetti et al. [1]*

Context – For both protons and heavy ions

- SER = Convolution proton flux and SEU cross section

Credits: *A. Coronetti et al. [1]*

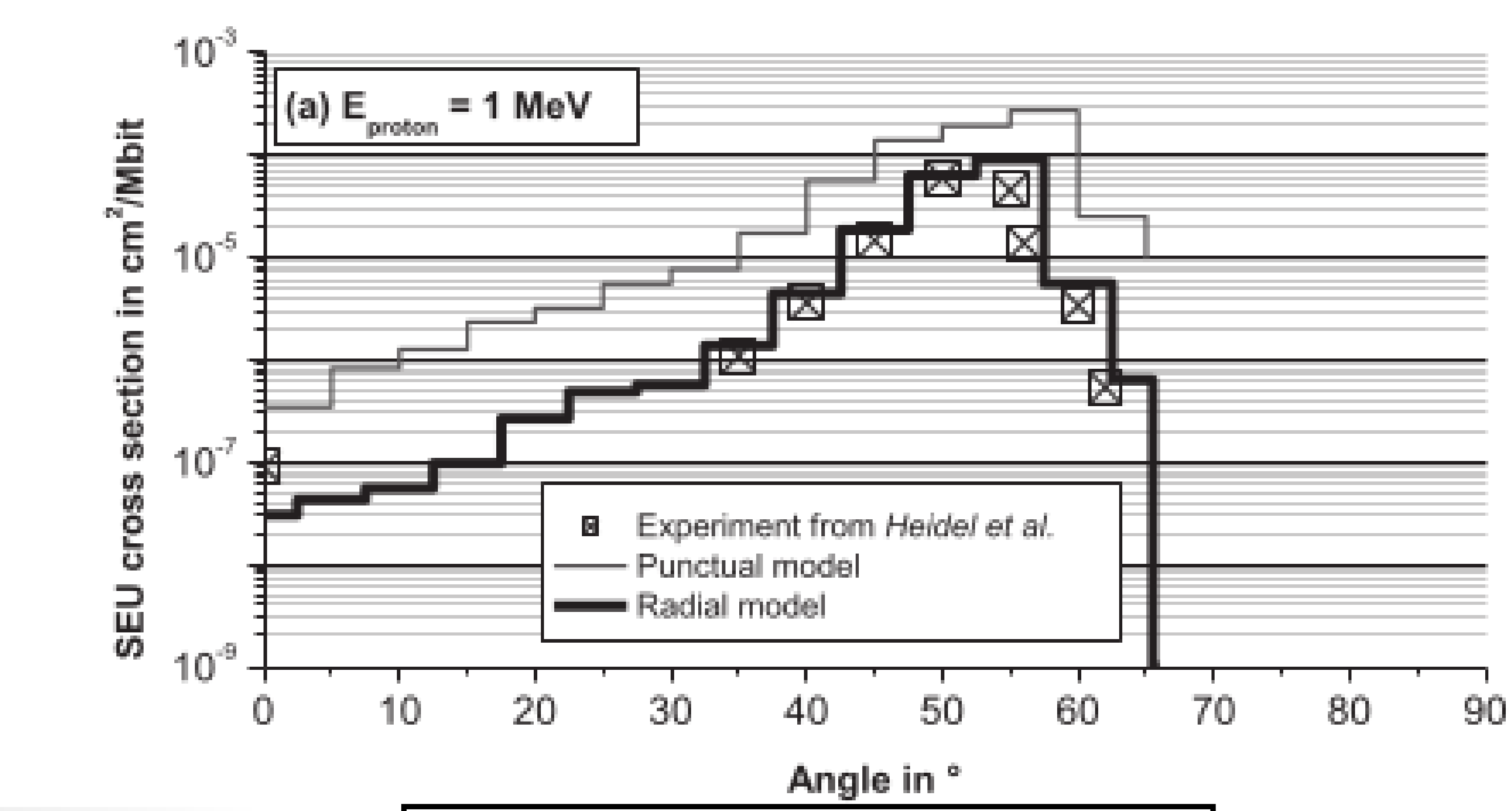




SER calculation

Context – For both protons and heavy ions

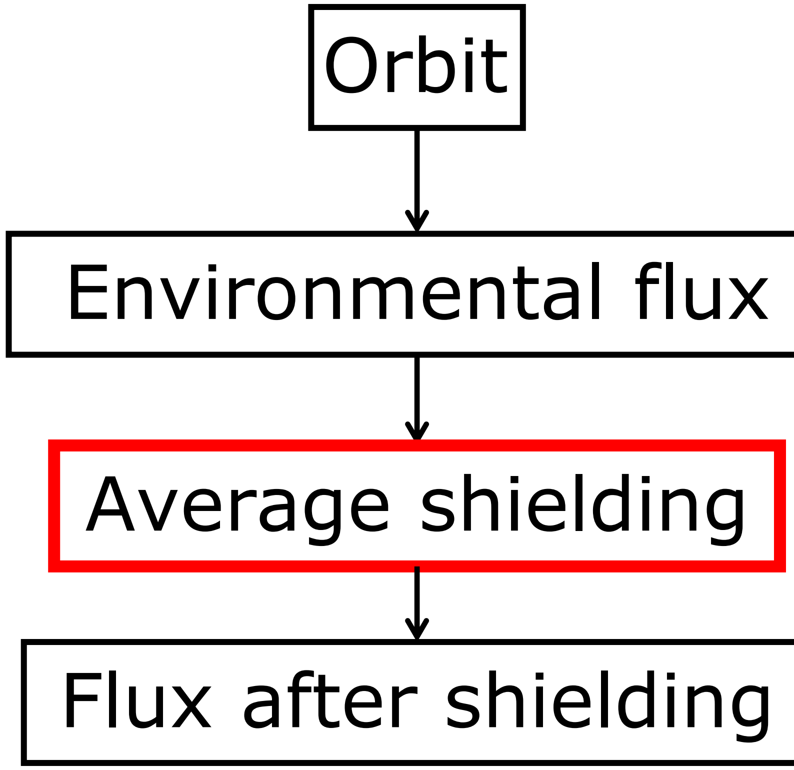
- Limitations:
  - For protons:
    - SEU cross section is the same for all incident particle angle (G. Hubert et al. [2])



Credits: *G. Hubert et al. [2]*

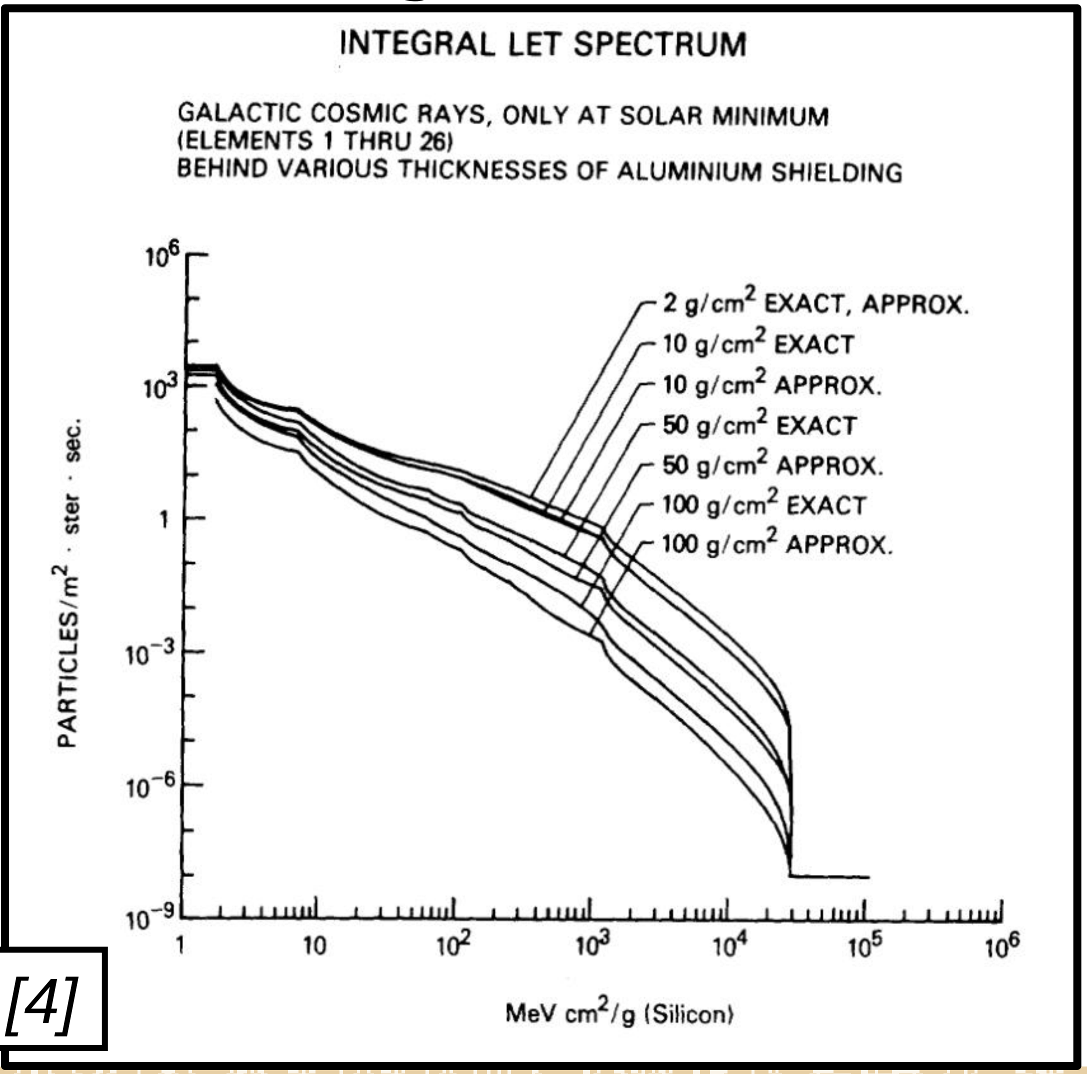
Context – For both protons and heavy ions

- Limitations:
  - For protons:
    - SEU cross section is the same for all incident particle angle (G. Hubert et al. [2])
  - For both protons and heavy ions:
    - Needs to take into account anisotropic shielding for flux after shielding



Context – For both protons and heavy ions

- Limitations:
  - For protons:
    - SEU cross section is the same for all incident particle angle (G. Hubert et al. [2])
  - For both protons and heavy ions:
    - Needs to take into account anisotropic shielding for flux after shielding
    - Validation of flux after shielding:
      - only for shielding thickness < 0.054 cm Aluminium



Credits: *J. H. Adams et al. [4]*

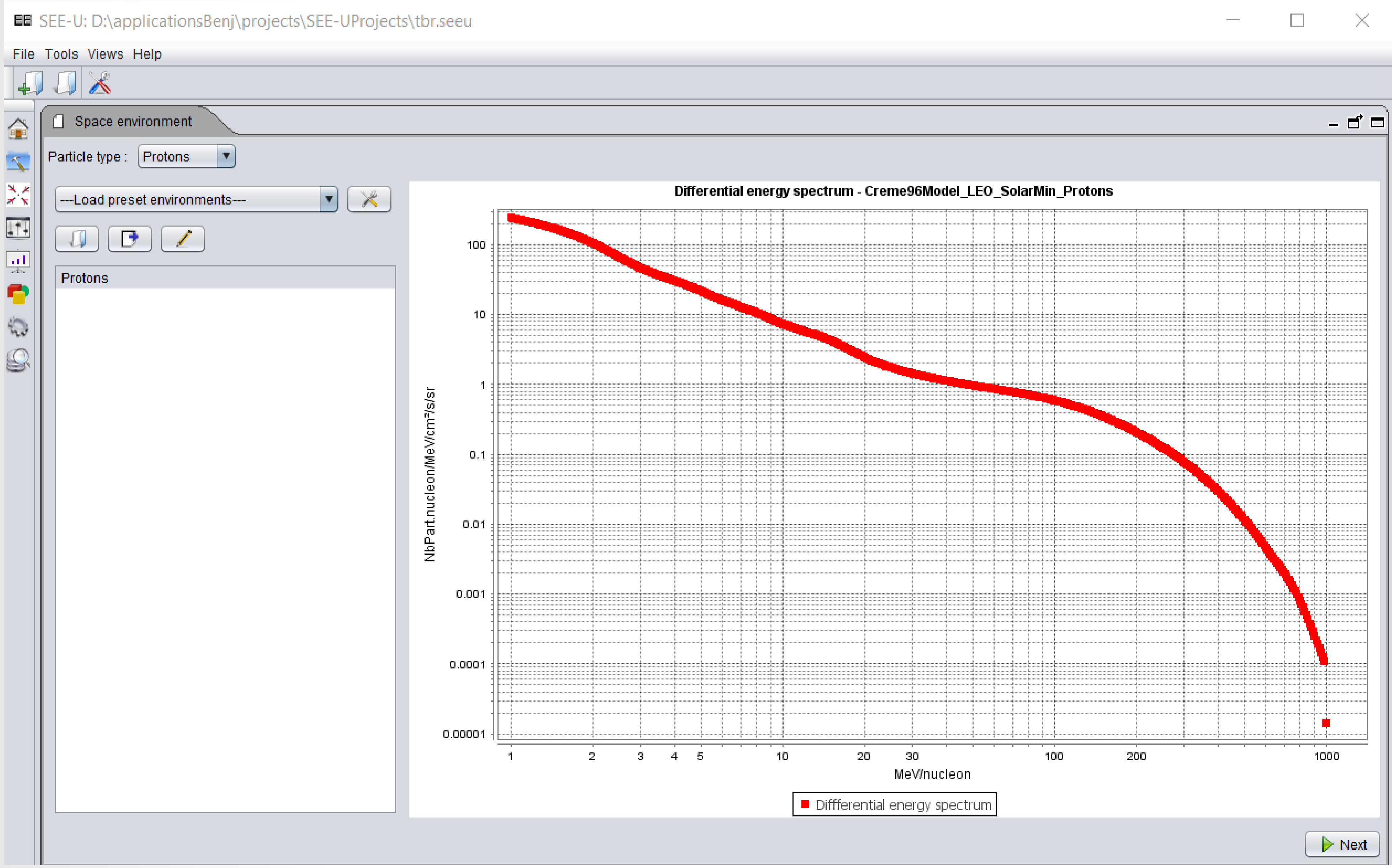
Context – For both protons and Heavy Ions

- Need more accurate tools: new tools called SEE-U
- Engineering tool easy to use
- Open source
  - First release December 2022
- Compute SER for any mission:
  - Environment flux
  - Spacecraft geometry
  - Device position in the Spacecraft geometry

- Successfully solved identified limitations:
  - SEU cross section:
    - incident particle angles dependency
    - Model all particle-matter interactions:
      - direct proton ionization
      - nuclear reactions…
  - Manage anisotropic shielding for flux after shielding
  - Flux after shielding valid for any shielding thickness

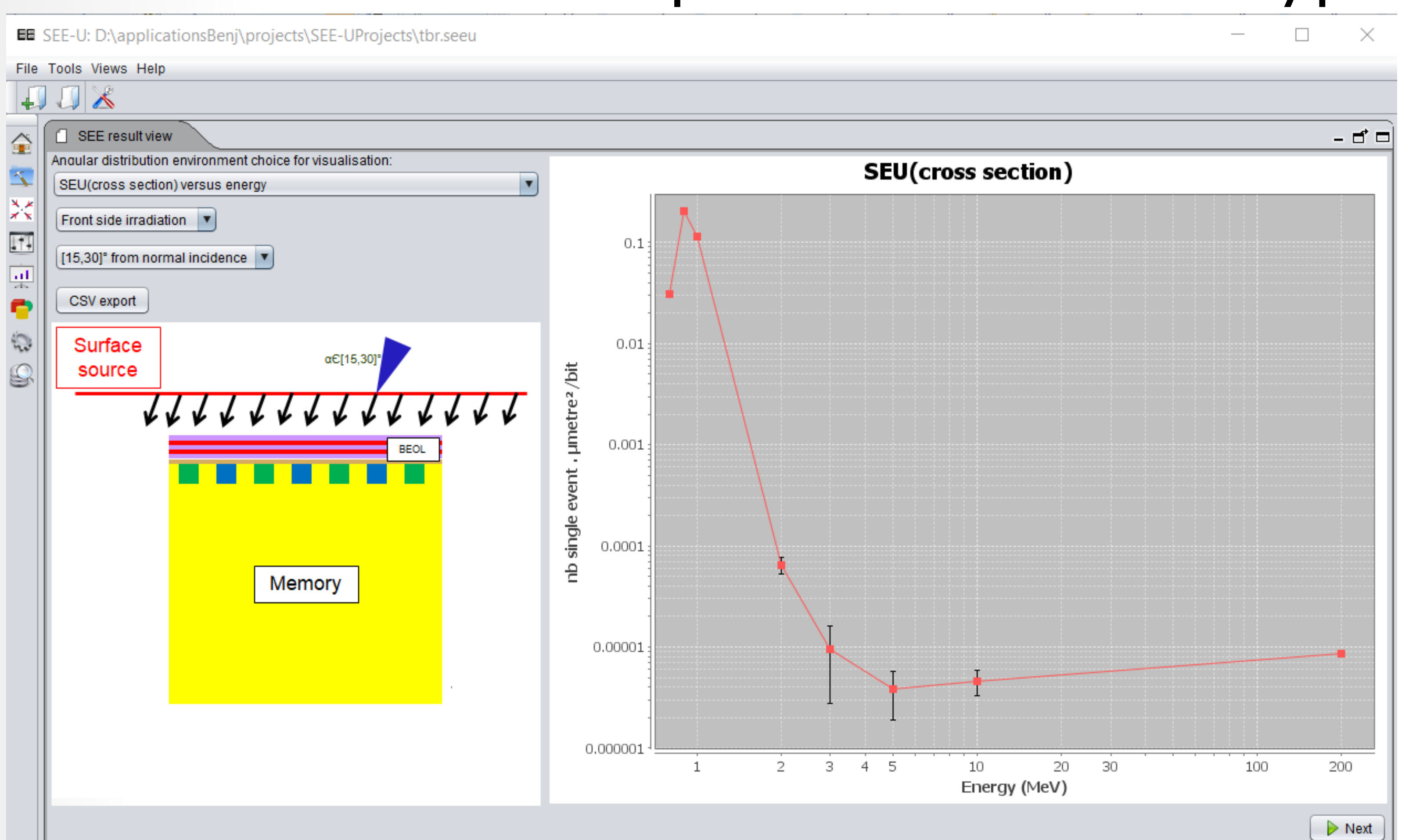
SEE-U presentation – For both protons and Heavy Ions

- Compute environment flux with CREME96 online tools/SPENVIS:
  - Choose orbit
  - Compute environment for both proton and heavy ions flux
- Example: protons flux for LEO



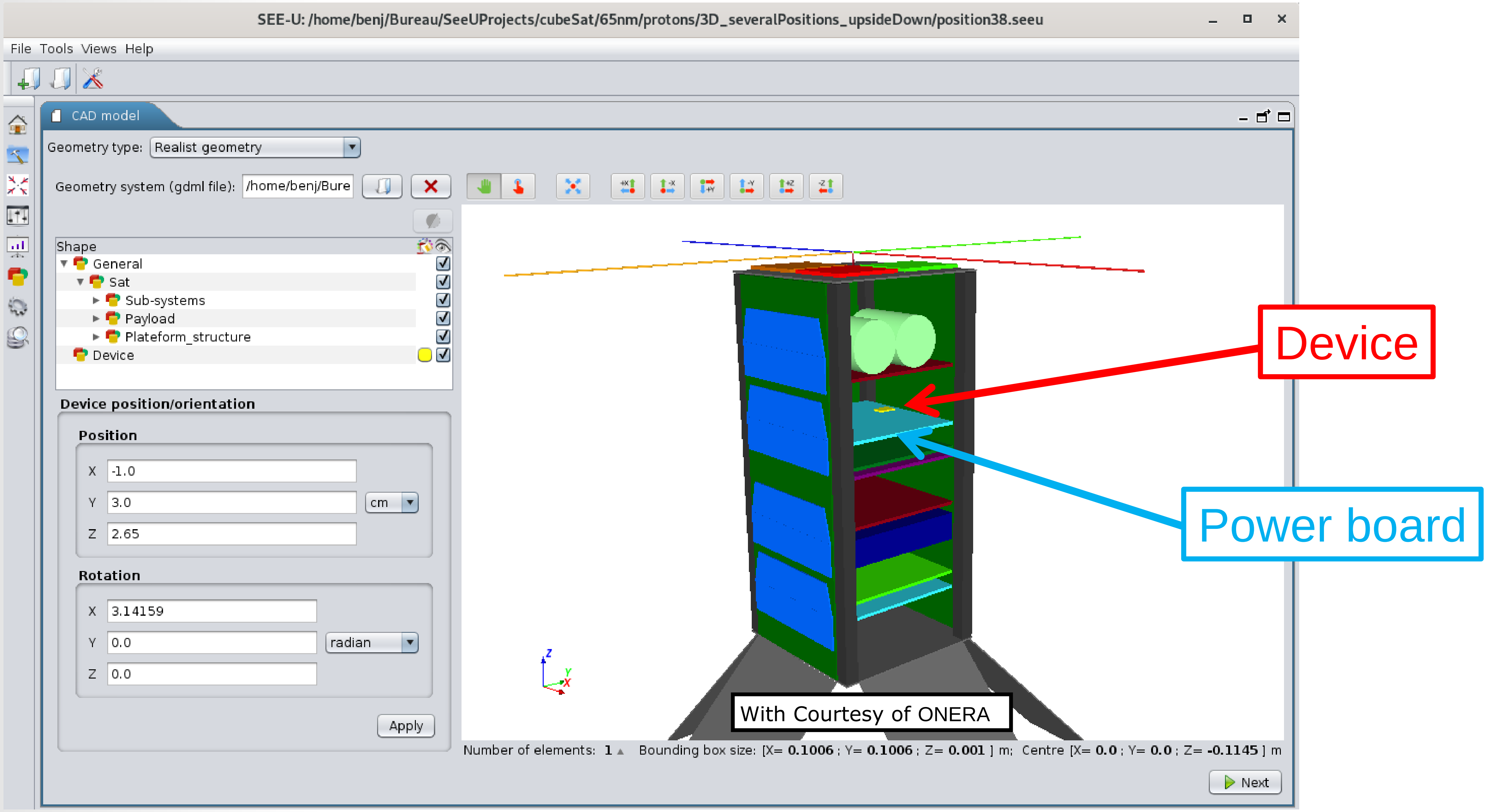
SEE-U presentation – For both protons and Heavy Ions

- Compute SEU cross section based on G. Hubert et al. [3]
  - Particle incident angle dependency
  - Matter-particle several physic models like for example:
    - Direct ionization of protons
    - Nuclear reaction for protons and Heavy Ions
  - Model already validated in publication by G. Hubert et al. [3]
- Example: SEU cross section computed for 65 nm Cypress SRAM type 16MBits



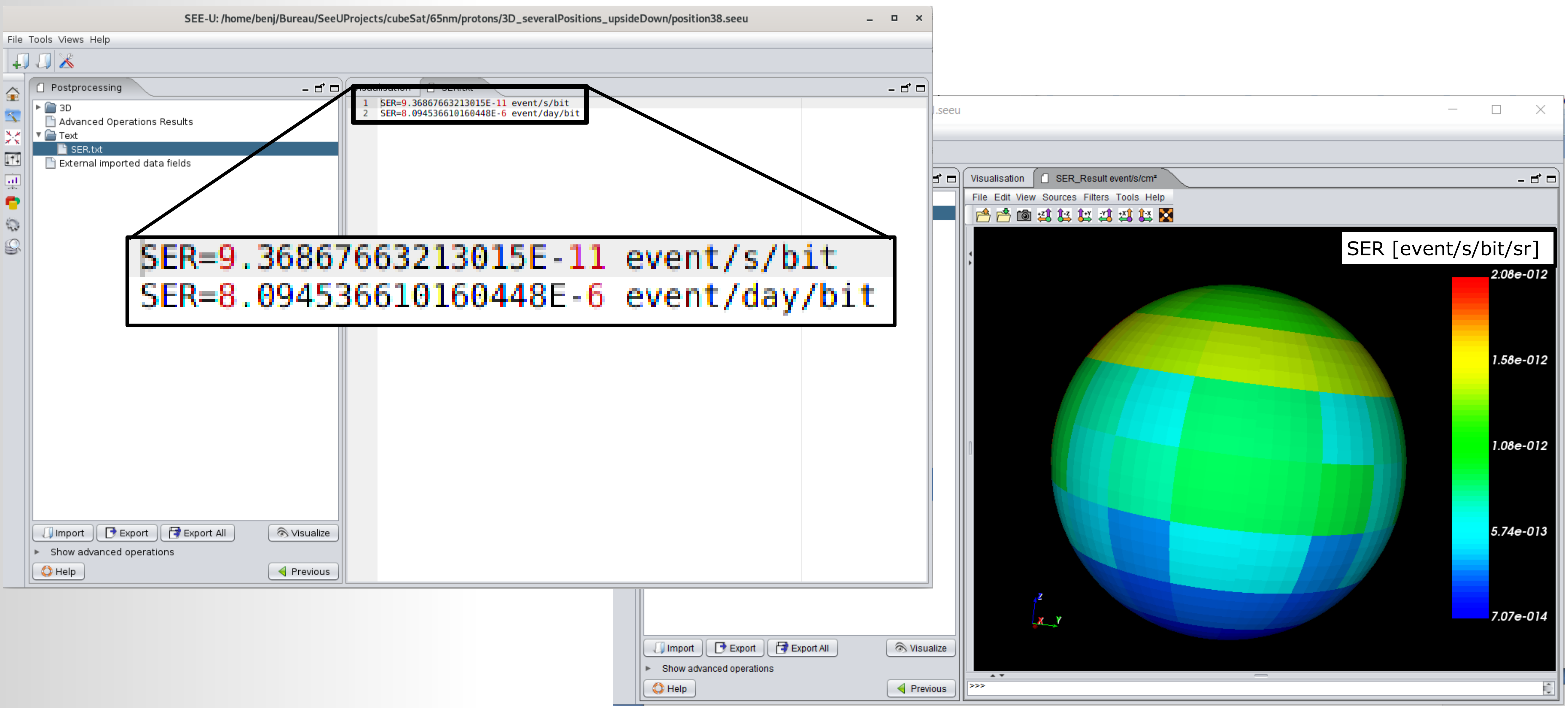
SEE-U presentation – For both protons and Heavy Ions

- Choose 3D CAD model and position/orientation of device
- Anisotropic shielding is computed
- Example: SER for several positions/orientations on power board



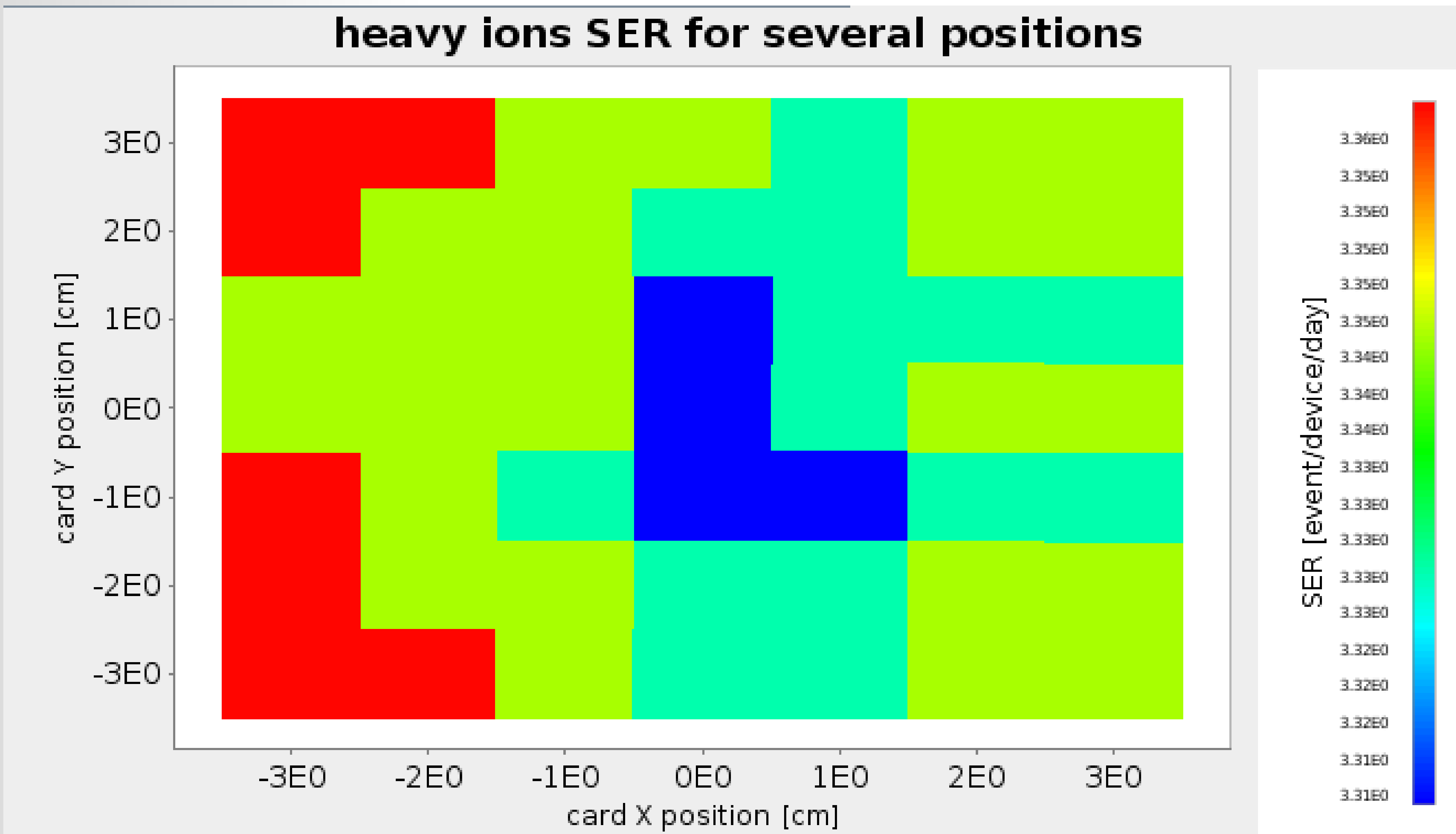
SEE-U presentation – For both protons and Heavy Ions

- SER computation from:
  - Anisotropic flux after shielding for each incident particle angle
  - SEU cross section with incident particle angle dependency
- Quick simulation (CPU time < 3 minutes on standard laptop)



SER calculation for Heavy Ions

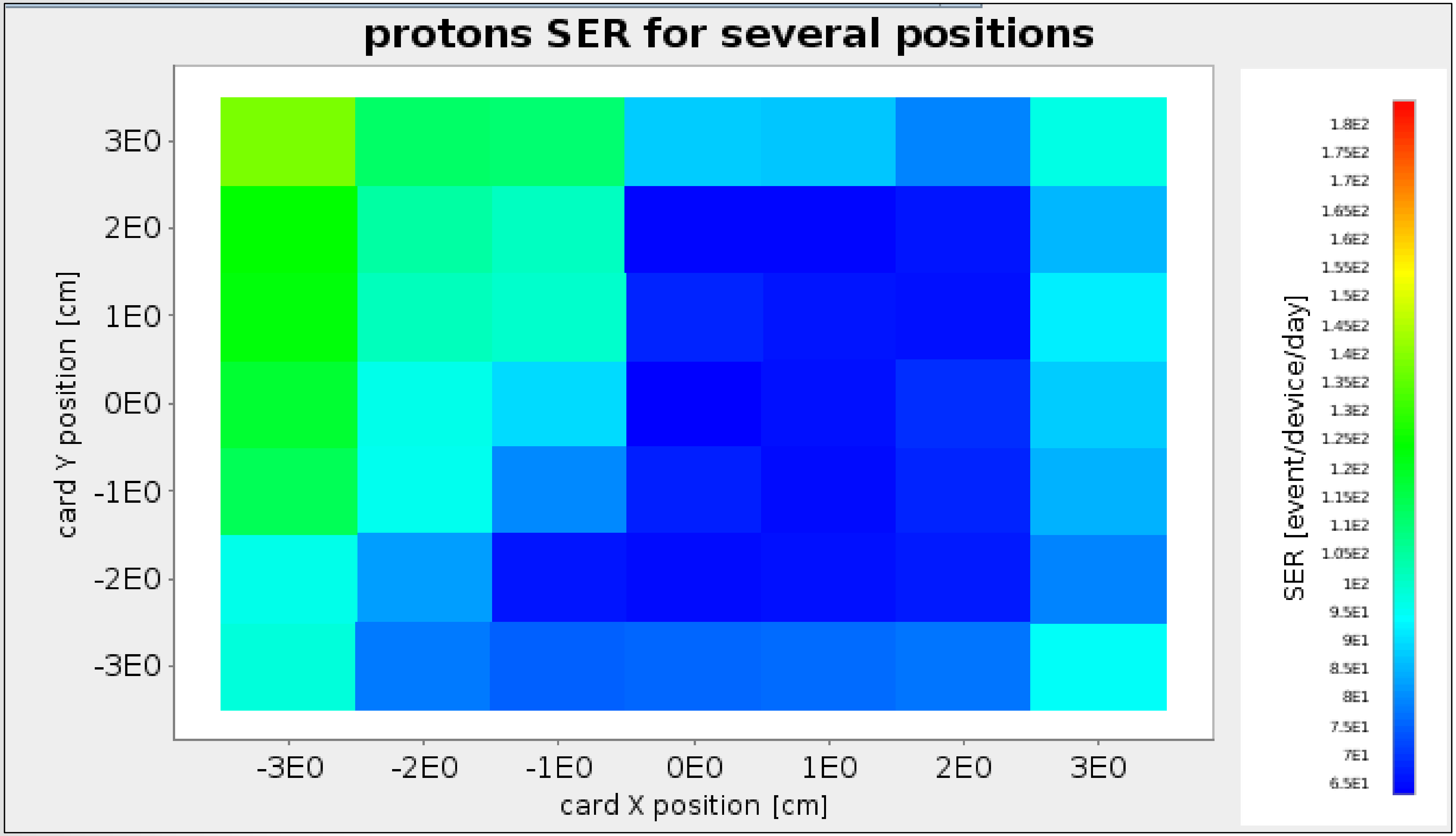
- SER values for heavy ions between [3.31; 3.36] event/device/day



SER calculation for Protons

- SER values for protons between
  - [63; 138] event/device/day BEOL toward +z direction

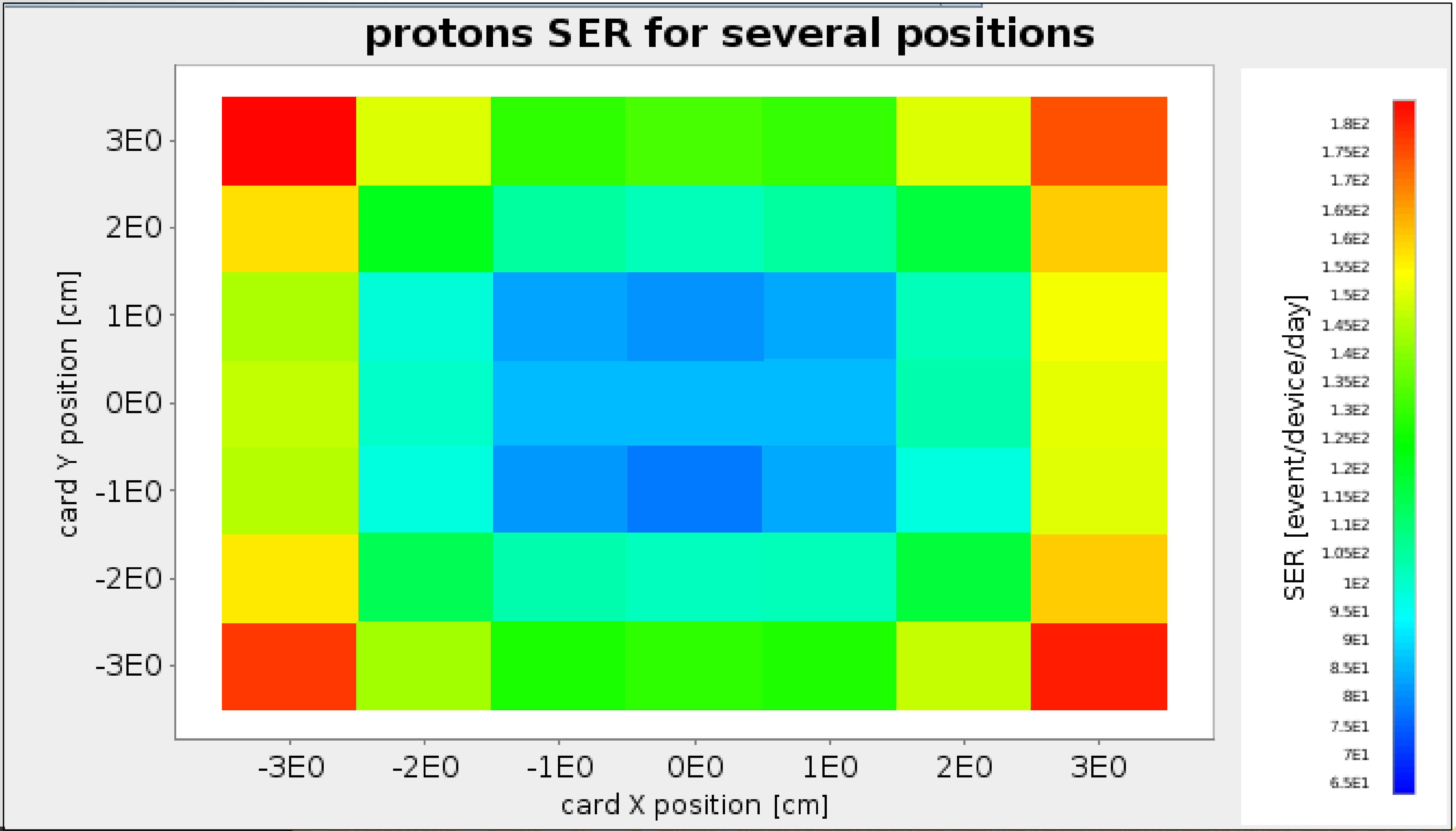
BEOL toward +z direction



SER calculation for Protons

- SER values for protons between
  - [78; 184] event/device/day BEOL toward -z direction

BEOL toward -z direction



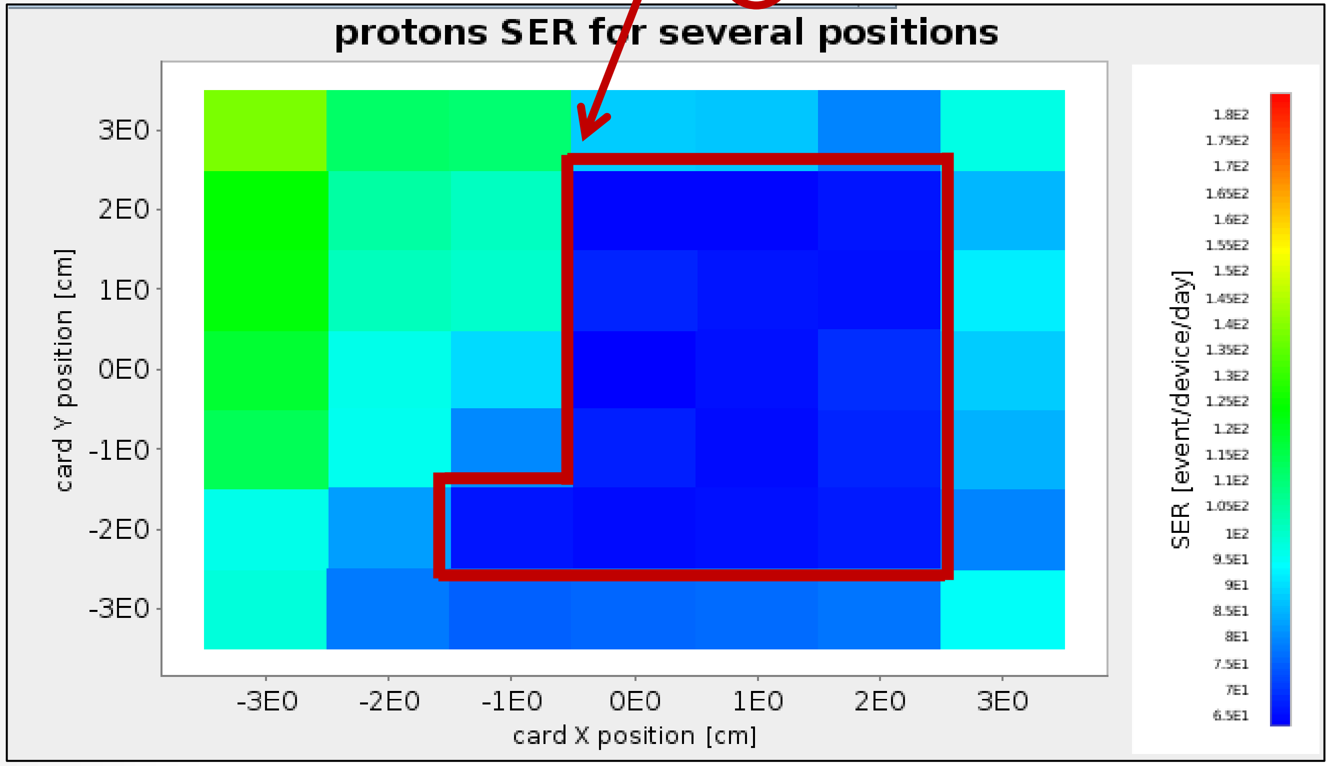
SER calculation

- In our case, SER from protons is at least 20 times higher than SER for Heavy Ions:
  - Heavy Ions: SER between [**3.31; 3.36**] event/device/day
  - Protons SER [event/device/day] between:
    - [**63**; 138] with BEOL toward +z direction
    - [78; 184] with BEOL toward -z direction

Worst position SER = 187 event/device/day

Best position and orientation => **SER = 66 event/device/day**

BEOL toward +z direction



Conclusion

- SEE-U: New simulation tool
  - Easy-to use engineering tool
  - Compute SER for protons and heavy ions
  - Quick results for any environment and geometry
  - SEU cross section taking into account:
    - incident particle angle
    - Matter particle interactions models: nuclear reaction, direct ionization, …
  - Take into account realist 3D CAD model
  - Easily optimize position/orientation of device in the spacecraft

- A new open source software
- Available through Space Suite website:
  - www.space-suite.com/see-u
  - http://support.spis-services.eu/Register
  - http://support.spis-services.eu/software/see-u

References

[1] *A. Coronetti et al. [1], "Assessment of Proton Direct Ionization for the Radiation Hardness Assurance of Deep Submicron SRAMs Used in Space Applications," in IEEE Transactions on Nuclear Science, vol. 68, no. 5, pp. 937-948, May 2021, doi: 10.1109/TNS.2021.3061209.*
[2] *G. Hubert, P. Li Cavoli, C. Federico, L. Artola and J. Busto, "Effect of the Radial Ionization Profile of Proton on SEU Sensitivity of Nanoscale SRAMs," IEEE Trans. Nucl. Sci., vol. 62, no. 6, pp. 2837-2845, 2015, doi: 10.1109/TNS.2015.2496238*
[3] *G. Hubert, S. Duzellier, C. Inguimbert, C. Boatella-Polo, F. Bezerra and R. Ecoffet, "Operational SER Calculations on the SAC-C Orbit Using the Multi-Scales Single Event Phenomena Predictive Platform (MUSCA SEP3)", IEEE Trans. Nucl. Sci., vol. 56, n° 6, pp. 3032 – 3042, 2010, doi: 10.1109/TNS.2009.2034148*
[4] *J. H. Adams, "The Variability of Single Event Upset Rates in the Natural Environment," in IEEE Transactions on Nuclear Science, vol. 30, no. 6, pp. 4475-4480, Dec. 1983, doi: 10.1109/TNS.1983.4333157.*

Questions?

ruard@artenum.com