Risk assessment of SEE due to high energy electrons during the JUICE mission

N. Sukhaseum, A. Varotsou, B. Vandevelde and C. Boatella-Polo
Presented by J. Guillermin

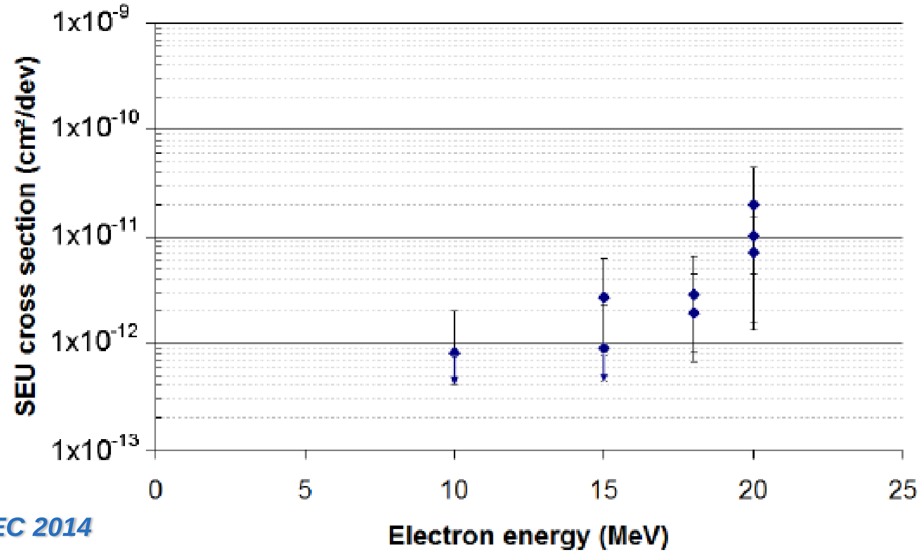
Final Presentation Days 2023 – ESA ESTEC – 29/06/2023

esa *contract ref. AO/1-8191/15/NL/KML*

- Introduction & Context
- Devices Under Test
- Test facility selection
- Test results
- Environments & SEE risk assessment
- Conclusion

Introduction & context

- SEE risk assessment for space projects
  - Particle beam testing
    - Heavy ions
    - High energy protons
  - SEE rate calculations
    - Mission environment (GCR, trapped protons, solar particles)
    - OMERE, SPENVIS, CREME…
- Previous studies demonstrated potential SEE sensitivity
  - Low energy protons (Direct Ionization)
  - Electrons

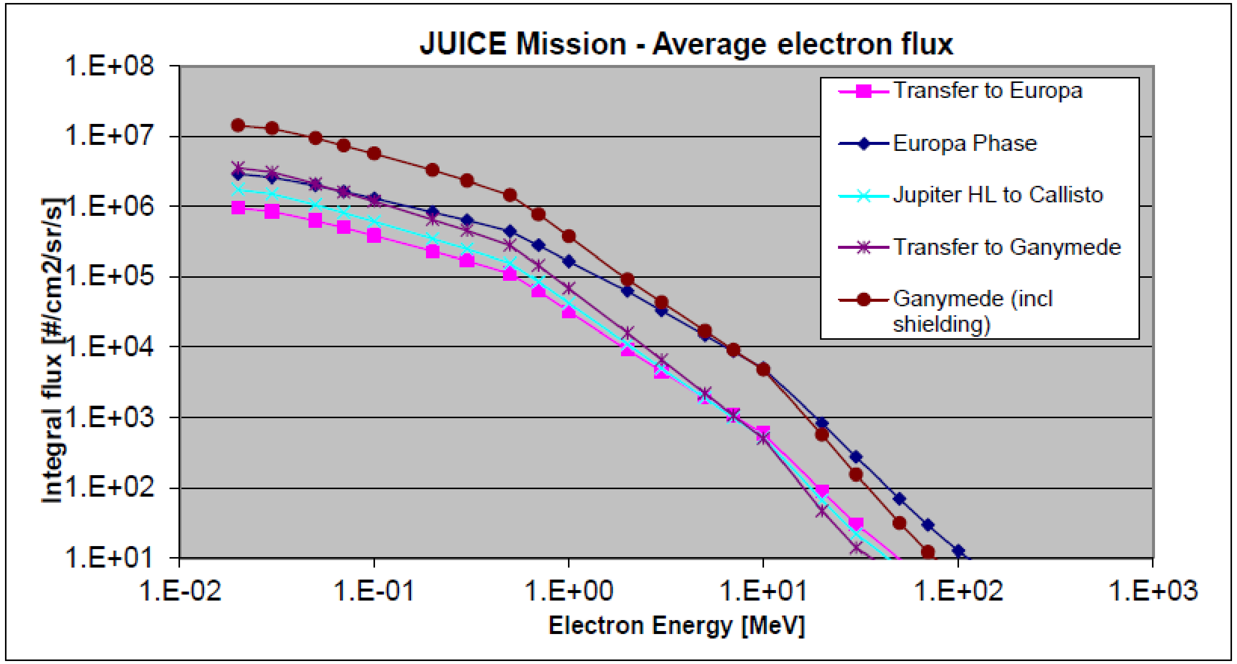


A. Samaras et al. NSREC 2014

Introduction & context

- JUICE mission

  - ➢ Significant high energy electron fluxes
    - o Up to 100 MeV
  - ➢ SEE electron risk has to be investigated



JUICE environment specification iss. 5.3

- Purpose of the study
  - ➢ Measure experimentally all SEE contributions
  - ➢ Standard and “new” effects
  - ➢ On the same devices
  - ➢ Calculate the corresponding SEE rates
  - ➢ Put in evidence the predominant contributions & discuss the risk

- First results presented at FP Days 2017

Devices Under Test

- Criteria for device selection
  - SRAM technology memory for SEU testing
    - Basic technology and event type
  - High integration level (below 45 nm tech. node)
    - Potentially sensitive to electrons and low energy protons
  - Can be put under operation with significant distance between control board and device under test
    - High energy electron and proton tests
  - Can be delidded
    - Heavy ions and low energy proton tests
  - Commercially available

Reference	Artix 7 XC7A35T-1CPG236C	R1QBA7218ABG-22IB0	Spartan 6 XC6SLX9-TQFP144
Manufacturer	Xilinx	Renesas	Xilinx
Function	SRAM based FPGA	DDR SRAM	SRAM based FPGA
Package	CPG236	165FBGA	TQFP144
Technology	28nm	45nm	45nm

Devices Under Test

- Artix 7 Xilinx FPGA
  - High integration scale (28nm)

- R1QBA7218A Renesas memory
  - Commercially available 45nm SRAM memory
  - High frequency synchronous device
  - Frequency operation can be reduced via internal PLL desabling…

- Spartan 6 Xilinx FPGA
  - Electron and low energy protons sensitivity already demonstrated
  - ESA/CNES collaboration
    - Test-bed developed by TRAD for the CNES on previous studies and shared for this project
    - Test results shared by the ESA with the CNES

Test Facility Selection

- Many tests to be performed…

- Heavy ions and high energy protons
  - Existing & adapted facilities in Europe

- Low energy protons
  - Proton direct ionization tests already performed at European facilities
    - CNA (Centro Nacional de Aceleradores, Spain)
    - RADEF (RADiation Effects Facility, Finland)

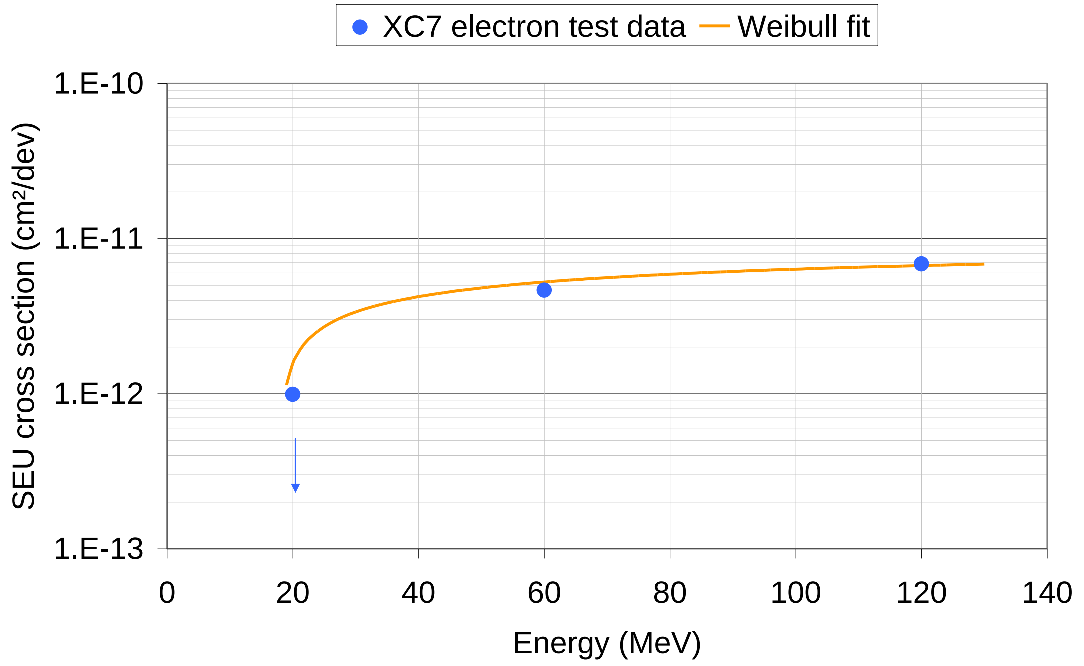
- Electrons
  - Several existing facility, different beam maturity levels…
  - Has to be related to electron SEE experimental problems
    - Total dose deposition

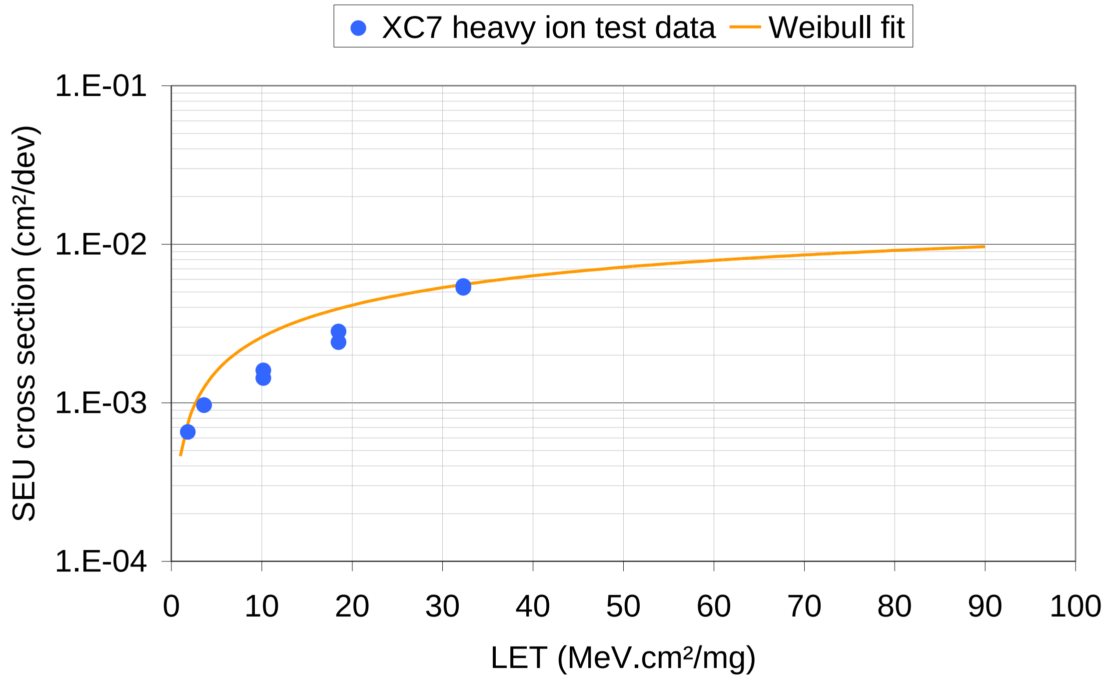
Test Facility Selection

- Heavy Ions → RADEF (Radiation Effects Facility – Finland)
  → UCL (Université Catholique de Louvain – Belgium)
- High energy protons → PSI (Paul Scherrer Institut – Switzerland).
- Low energy Protons → CNA (Centro Nacional de Aceleradores – Spain)
- Low energy Electrons → NPL (National Physical Laboratory – UK)
  - E < 20 MeV
- High energy Electrons → CERN (Vesper facility)
  - E : 60 MeV ; 120 MeV

Test results – Electrons & HI

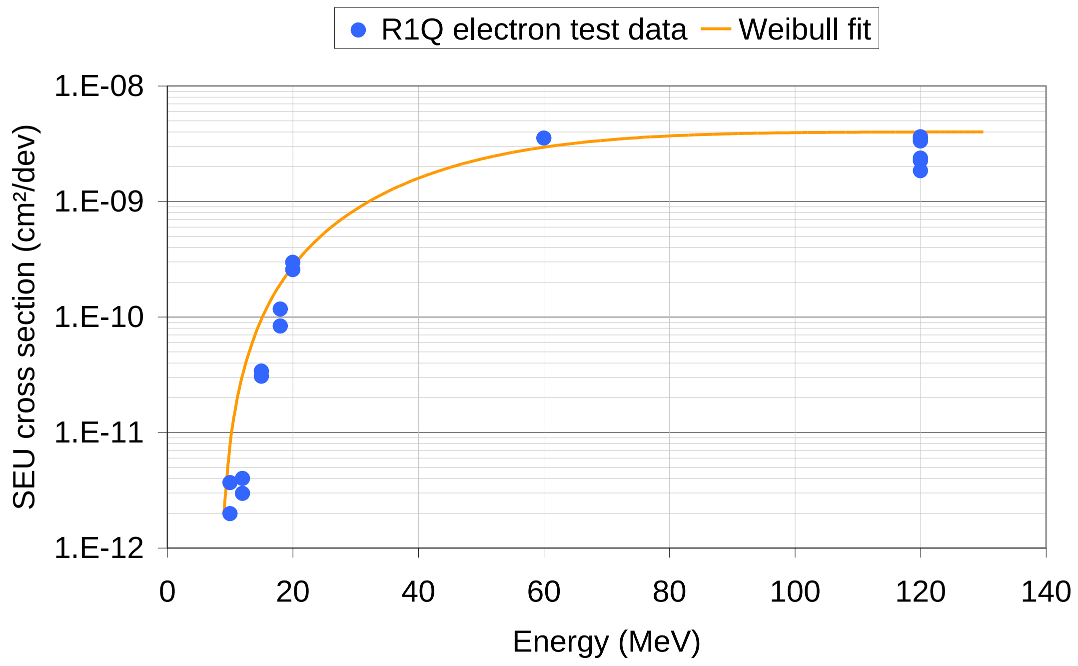
- Artix-7 FPGA
  - ➢ Electrons
    - ○ Very few events, from 20 MeV
  - ➢ Heavy Ions
    - ○ SEU Lth<1.8 MeV.cm²/mg
    - ○ SET and SEFI observed at low LET
    - ○ No MBU or SEL under heavy ions up to 32 MeV.cm²/mg

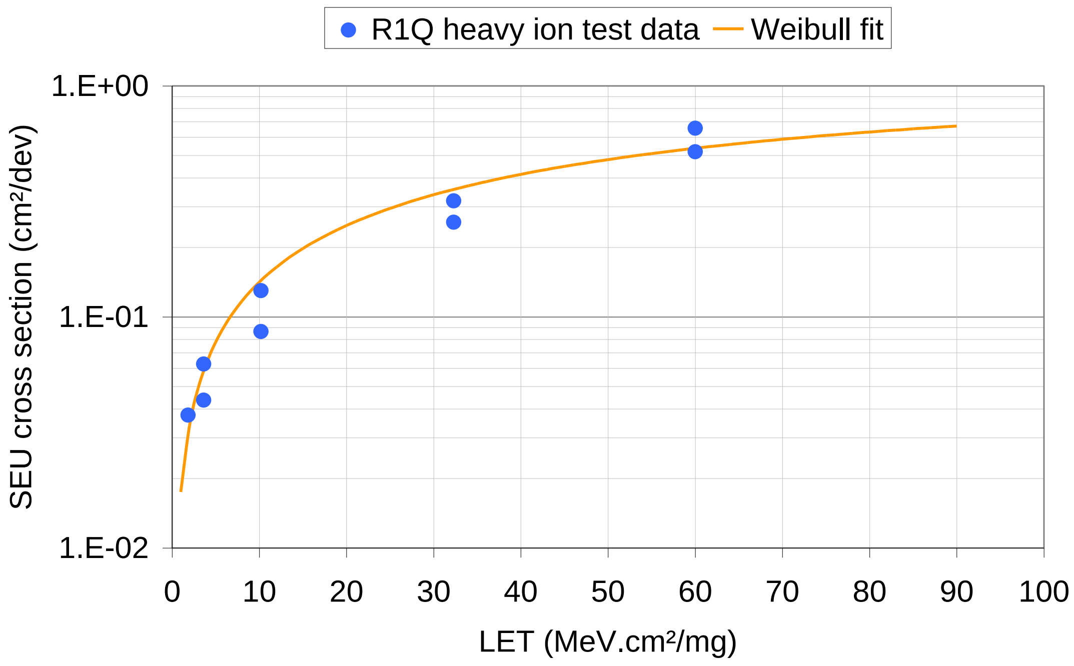




Test results – Electrons & HI

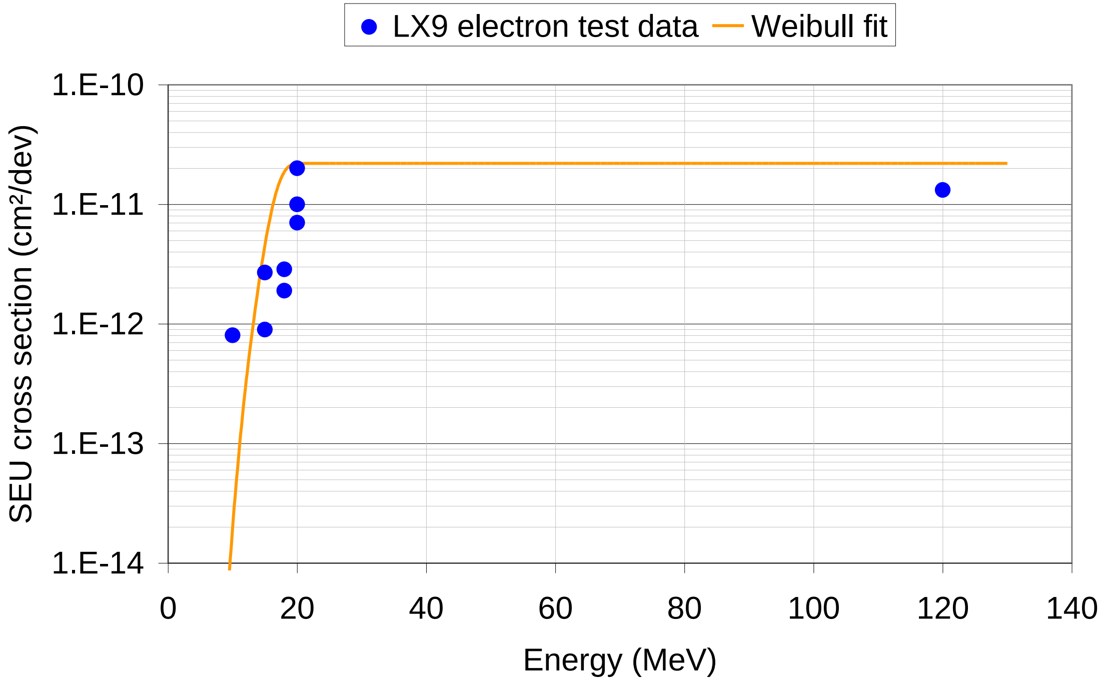
- Renesas sync. SRAM memory
  - ➢ Electrons
    - ○ Interesting sensitivity
    - ○ SEU Eth < 10 MeV
  - ➢ Heavy ions
    - ○ SEU Lth<1.8 MeV.cm²/mg
    - ○ MBU Lth<1.8 MeV.cm²/mg
    - ○ No SEFI or SEL up to 60 MeV.cm²/mg

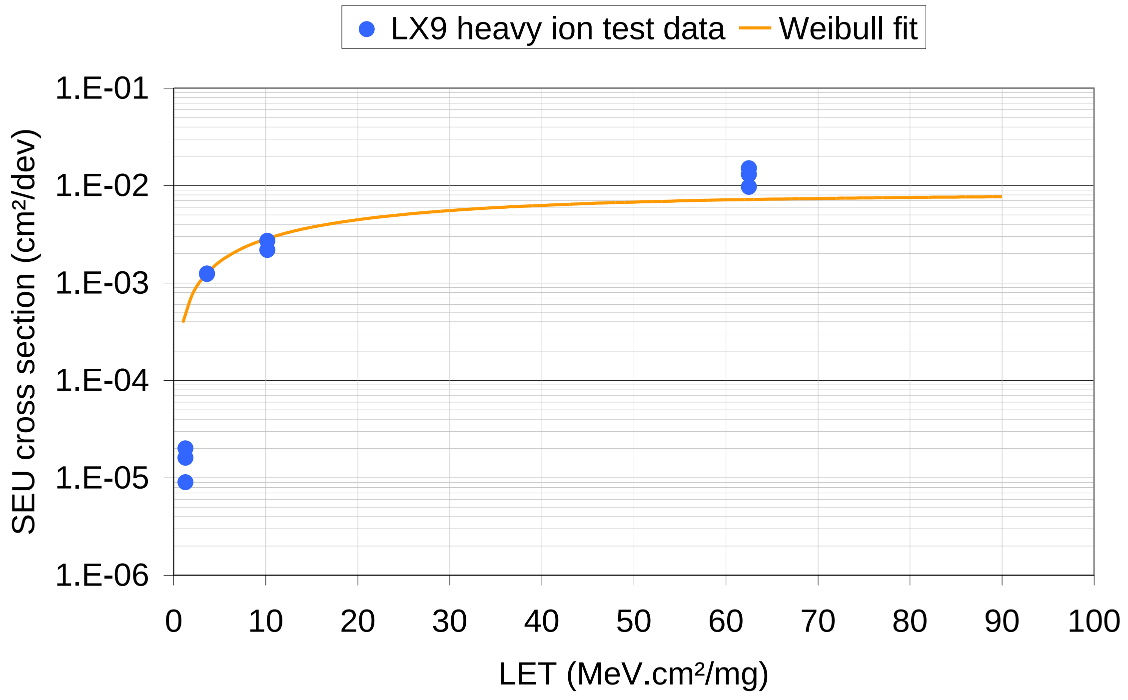




Test results – Electrons & HI

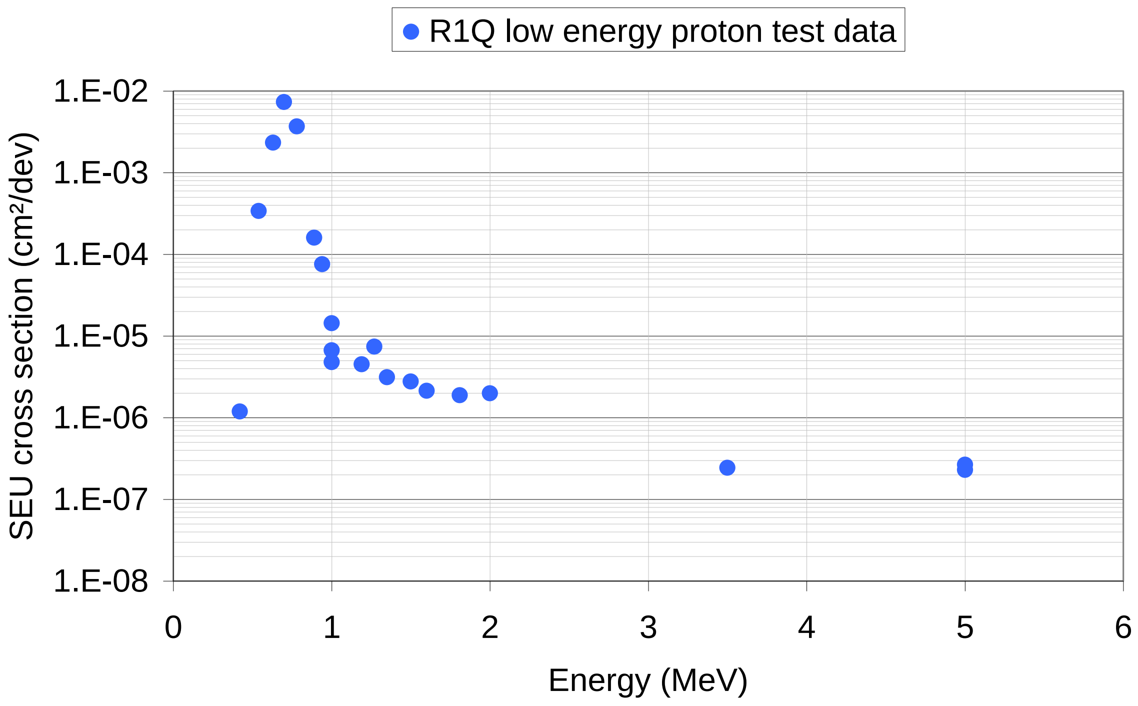
- Spartan 6 FPGA
  - ➢ Electrons
    - SEU Eth < 10 MeV
  - ➢ Heavy Ions
    - SEU Lth<3.6 MeV.cm²/mg
    - SEFI Lth<3.6 MeV.cm²/mg

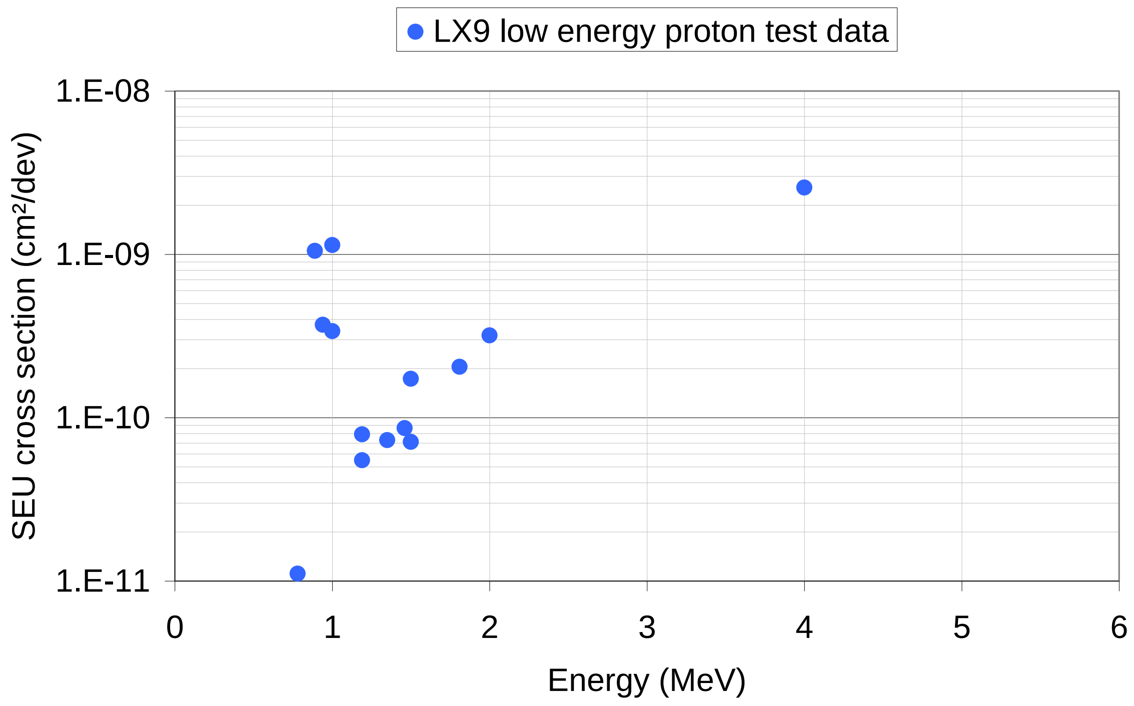




Test results - Protons

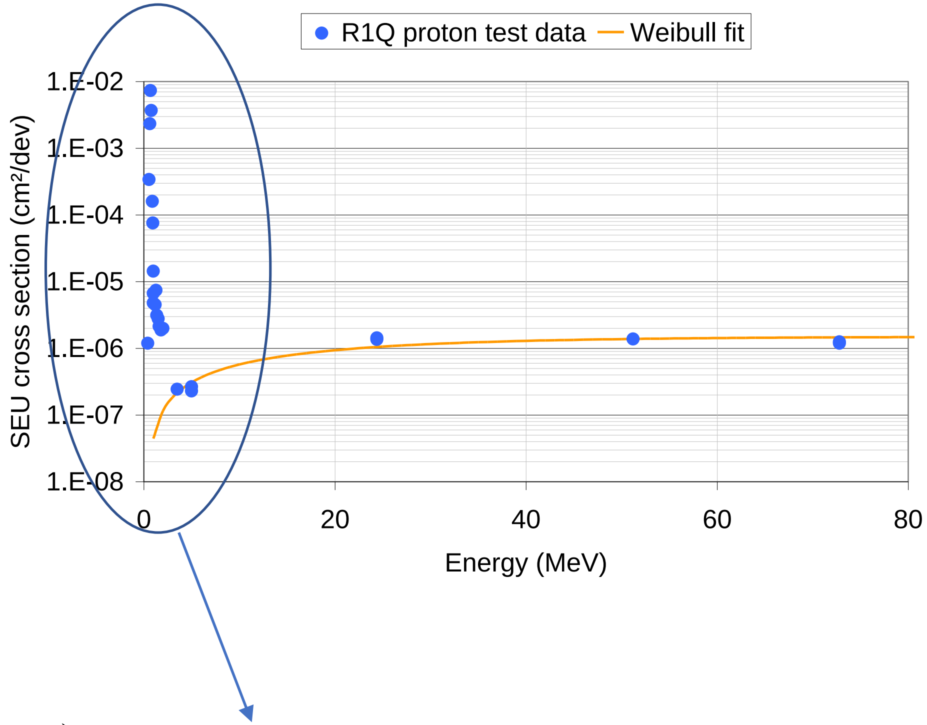
- Low energy protons
  - Renesas memory → very sensitive to proton direct ionization
  - Spartan 6 → limited sensitivity to proton direct ionization
  - Artix 7 → not sensitive to low energy protons



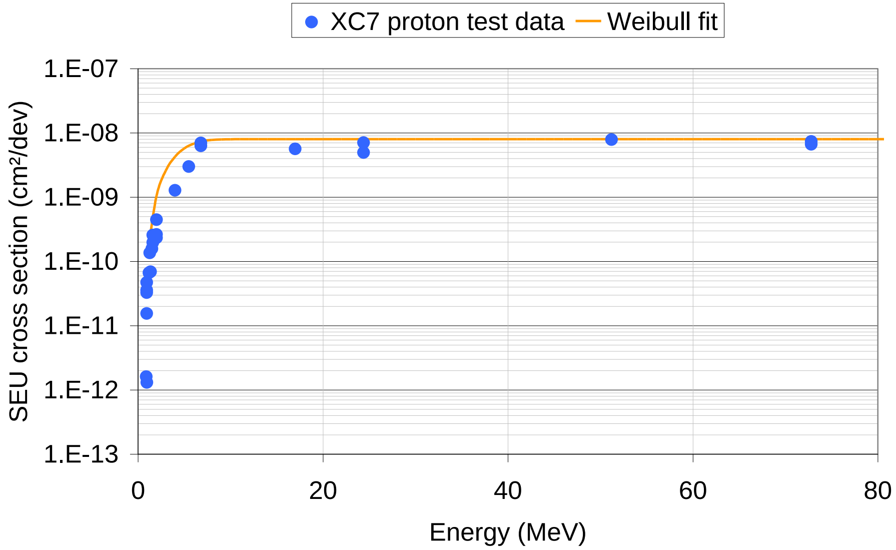


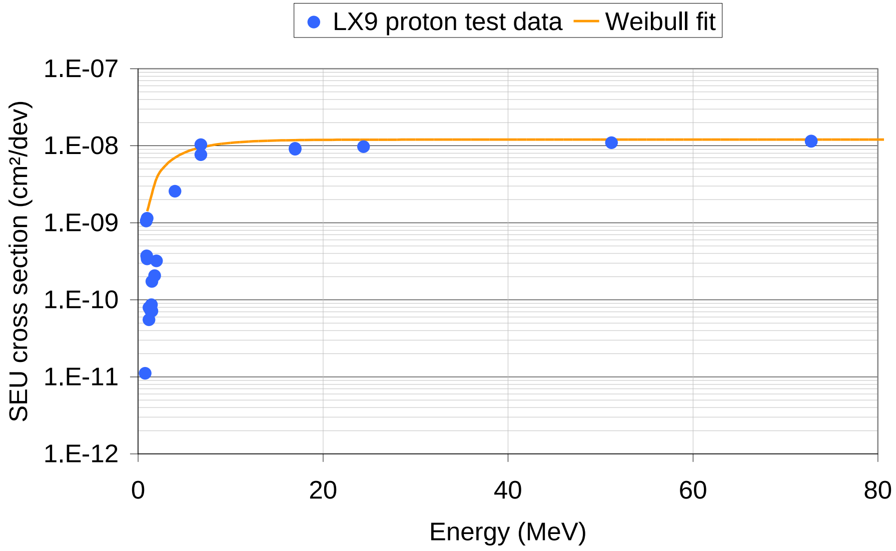
Proton test results

- High energy protons



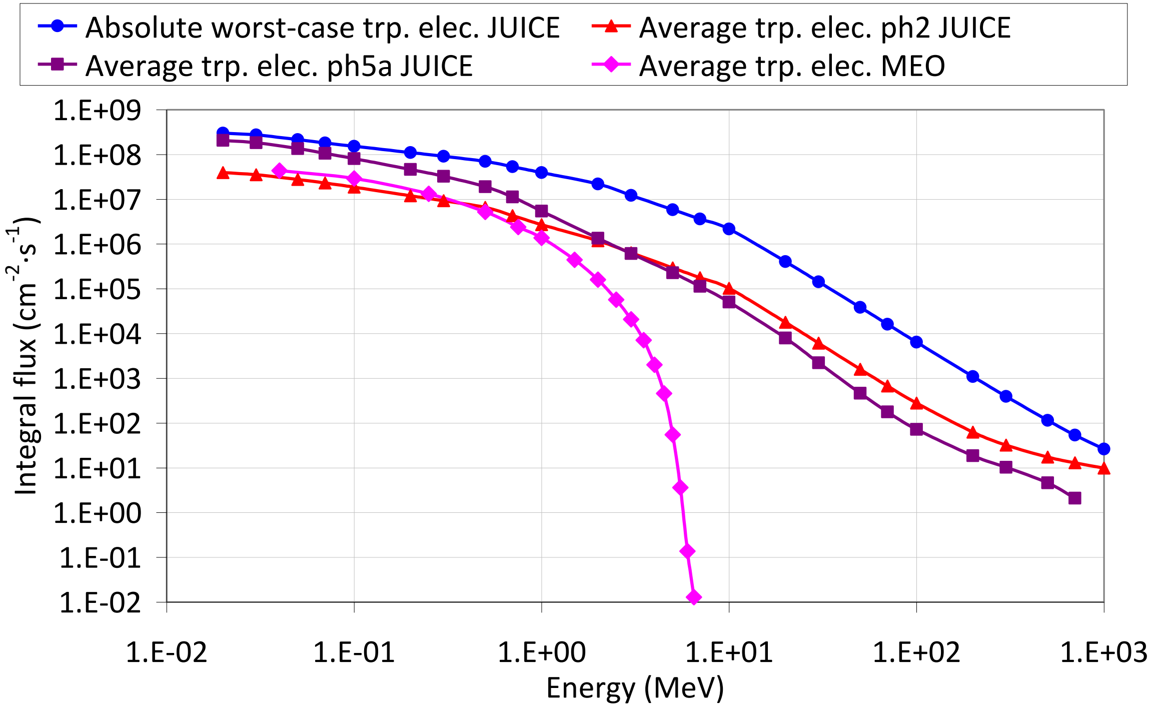
➢ Critical sensitivity to PDI foreseen for Renesas memory



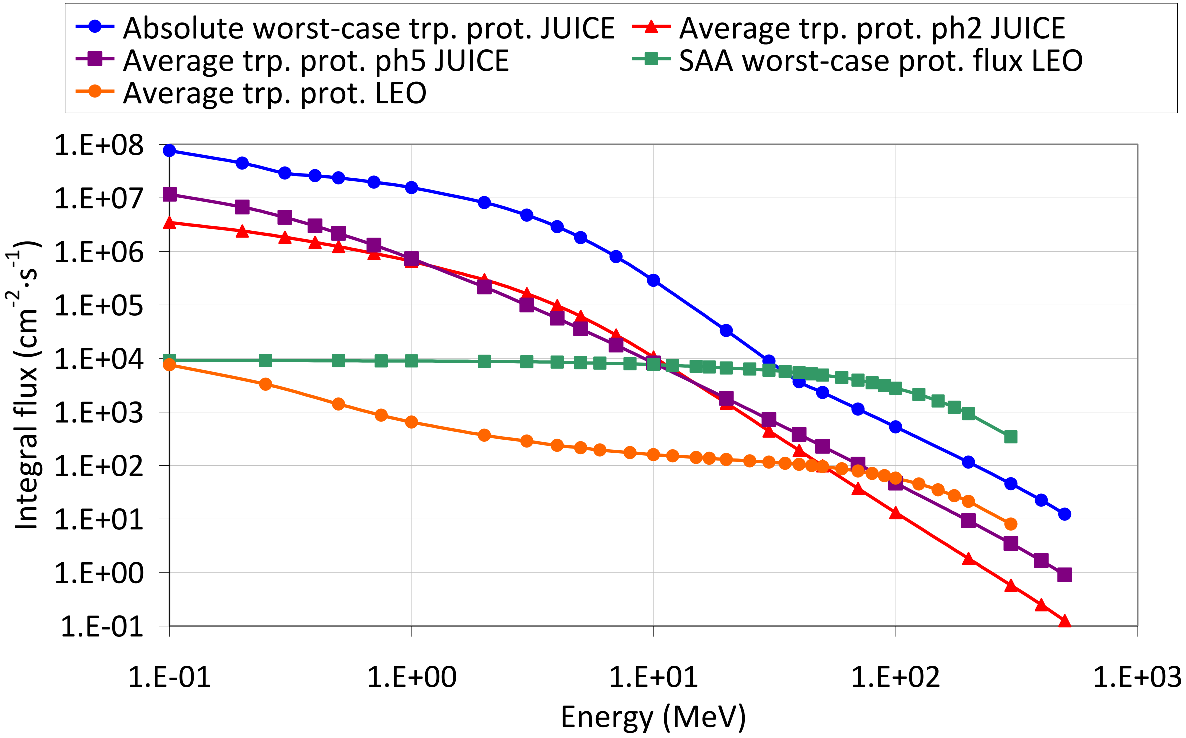


Risk assessment in various environments

- JUICE environment
  - ➢ Harsh environment for trapped particles



Trapped electron fluxes for JUICE and for a Middle Earth Orbit.



Trapped proton fluxes for JUICE and for a Low Earth Orbit.

Risk assessment in various environments

- JUICE environment from specification
    - average trapped electron and proton fluxes for the mission phases 2 (Europa) and 5a (Ganymede)
    - worst-case trapped electron and proton fluxes
    - solar protons spectrum
    - heavy ion LET spectrum

- LEO (alt. 800 km, incl. 98°) with OMERE
    - Average fluxes
    - Worst-case flux in SAA (alt. 805.48 km, long. -30.7°, lat. -30.42°, E > 30 MeV)

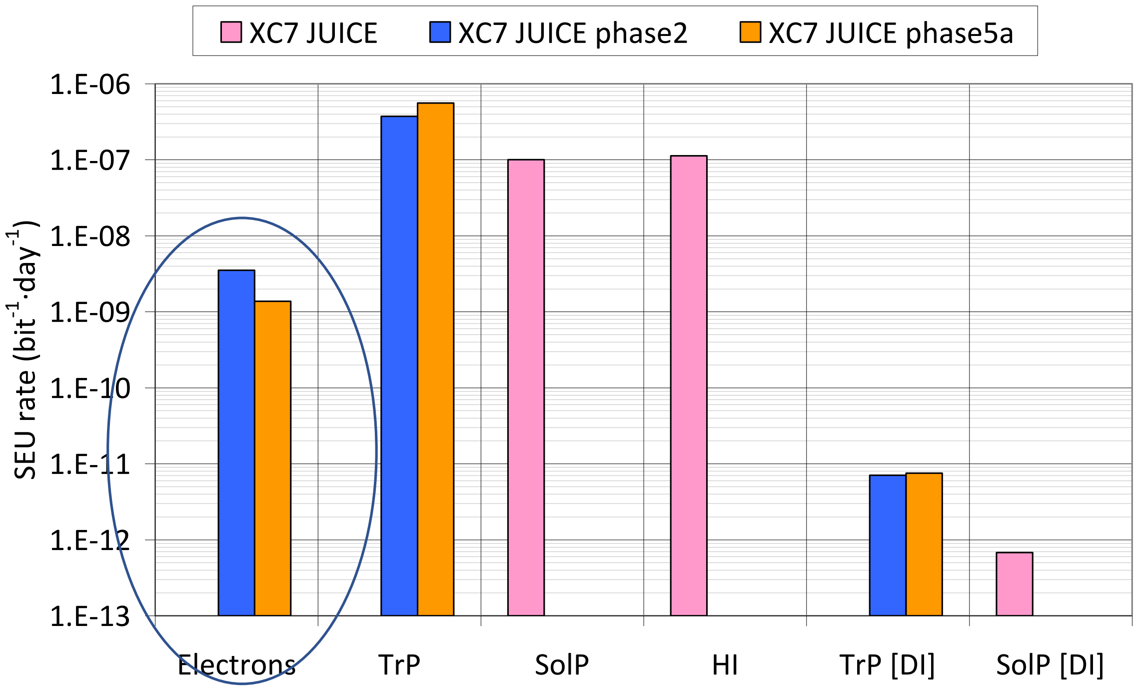
- GEO (alt. 35780 km) with OMERE
    - Average fluxes

SEE risk assessment

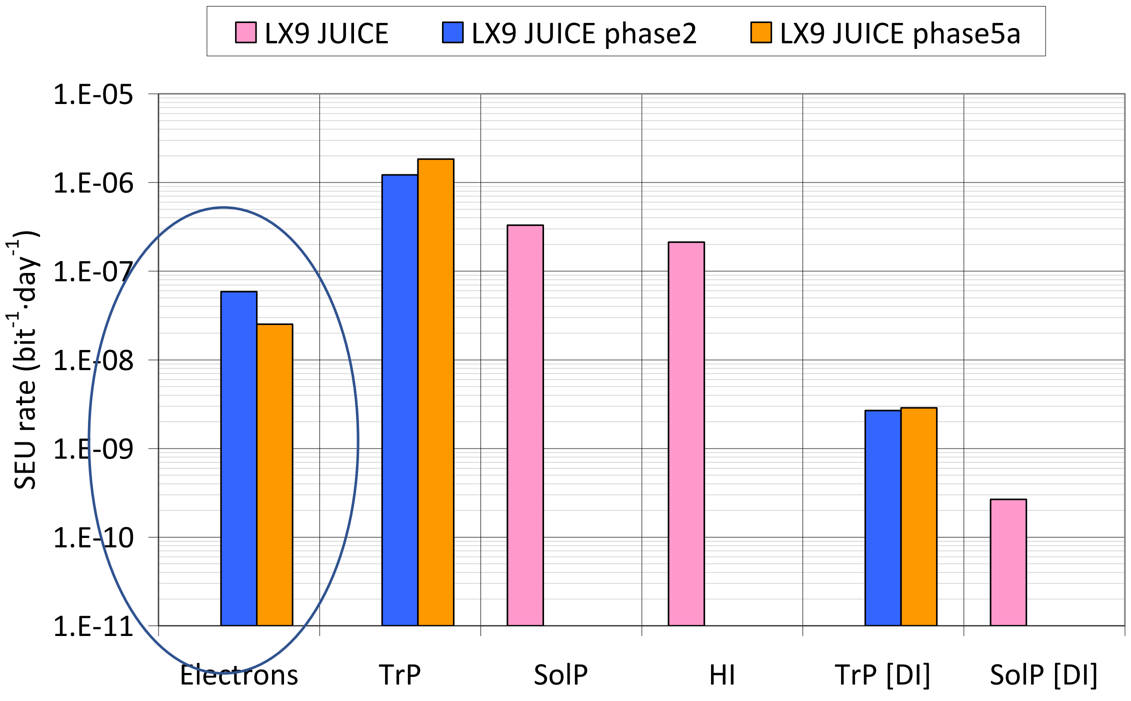
- Calculation of SEE rates for all the contributions with OMERE
  - Heavy ions (RPP method)
  - High energy protons (Indirect Ionization)
  - Low Energy protons (Direct Ionization)
    - Computed from methodology proposed in prevous studies
      - *SUKHASEUM, N., SAMARAS, A., GOUYET, L., et al. "A Calculation Method for Proton Direct Ionization Induced SEU Rate from Experimental Data: Application to a Commercial 45nm FPGA." NSREC, 2014.*
      - *GUILLERMIN, J., SUKHASEUM, N., POURROUQUET, P., et al. "Worst-Case Proton Contribution to the Direct Ionization SEU rate" RADECS 2017.*
  - Electrons
    - Same method as for protons : $SEU - Rate = \int_{E_0}^{\infty} \phi(E)\sigma(E)dE$ *A. Samaras et al. NSREC 2014*
  - Isotropic shielding of 1 g/cm²
    - (even Juice thicker)

SEE risk assessment

- JUICE environment
  - ➢ Protons contribution is dominant



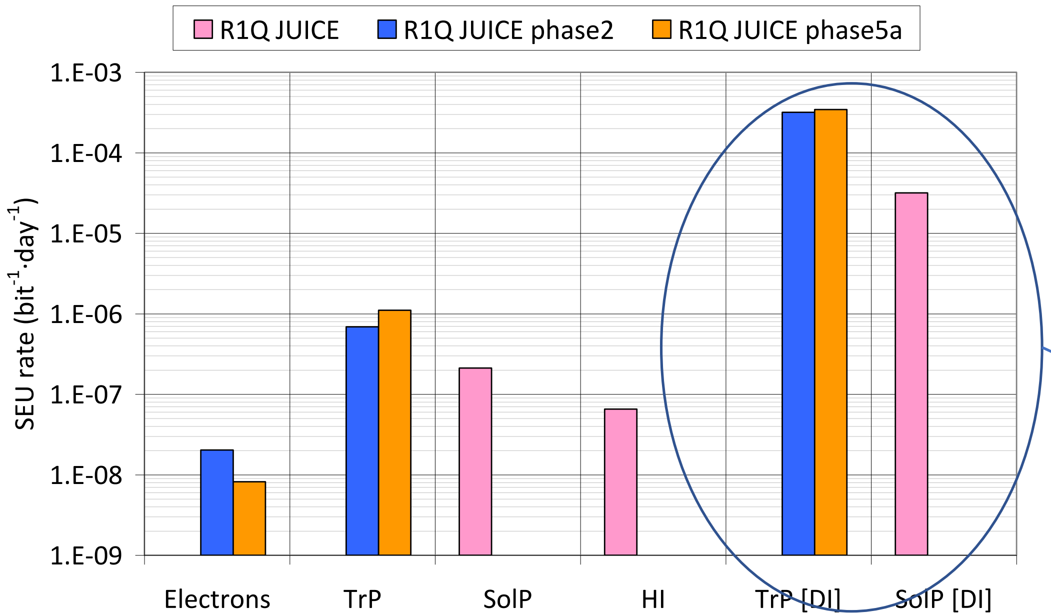
XC7A35T SEU rates for the JUICE mission



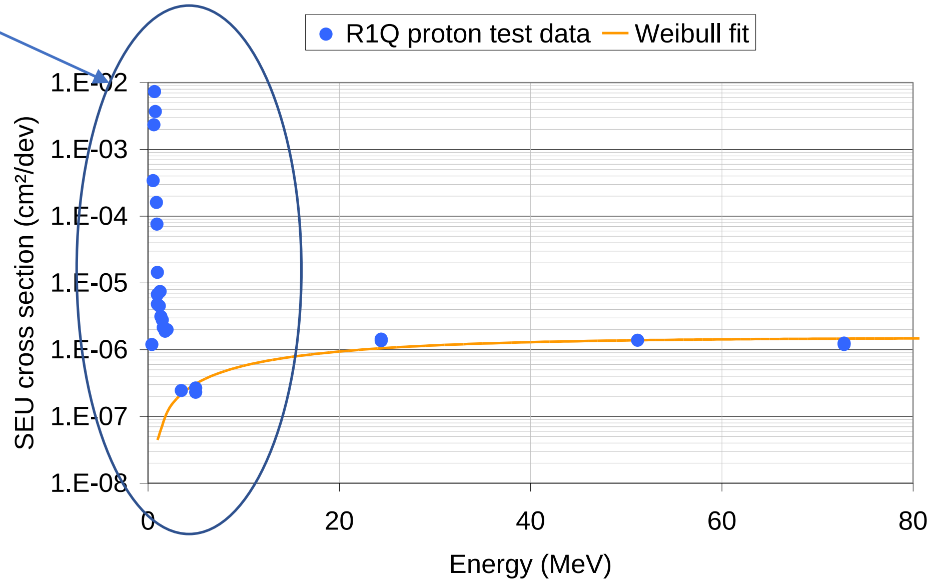
XC6SLX9 SEU rates for the JUICE mission.

SEE risk assessment

- JUICE environment



R1QBA7218ABG SEU rates for the JUICE mission



SEE risk assessement

- Concerning proton Direct Ionization phenomenon
  - Considered approach for estimating contribution is wort case
  - shielding considered is thinner than the real protection provided by the JUICE spacecraft

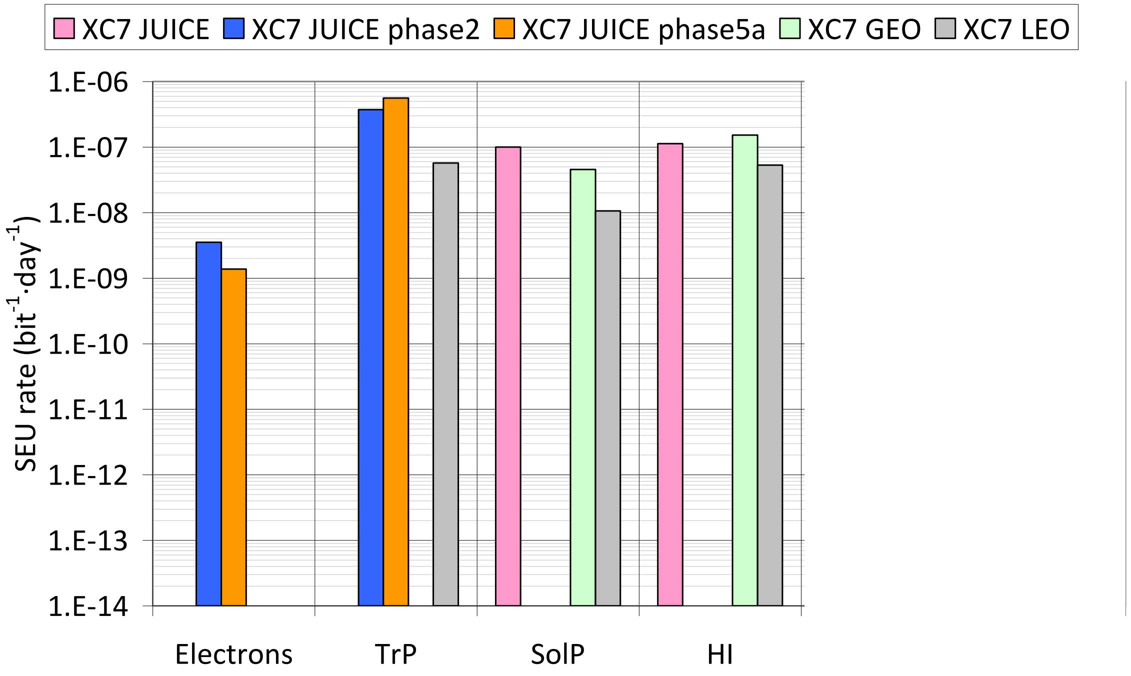
- Without PDI, electron contribution estimated for JUICE environment remains “weak”

	XC6SLX9	R1QBA7218	XC7A35T
Trapped electrons	3.3 %	2.0 %	0.6 %
Trapped protons	67.3 %	69.9 %	63.4 %
Averaged solar protons	17.9 %	21.5 %	17.3 %
Heavy ions	11.6 %	6.6 %	18.7 %

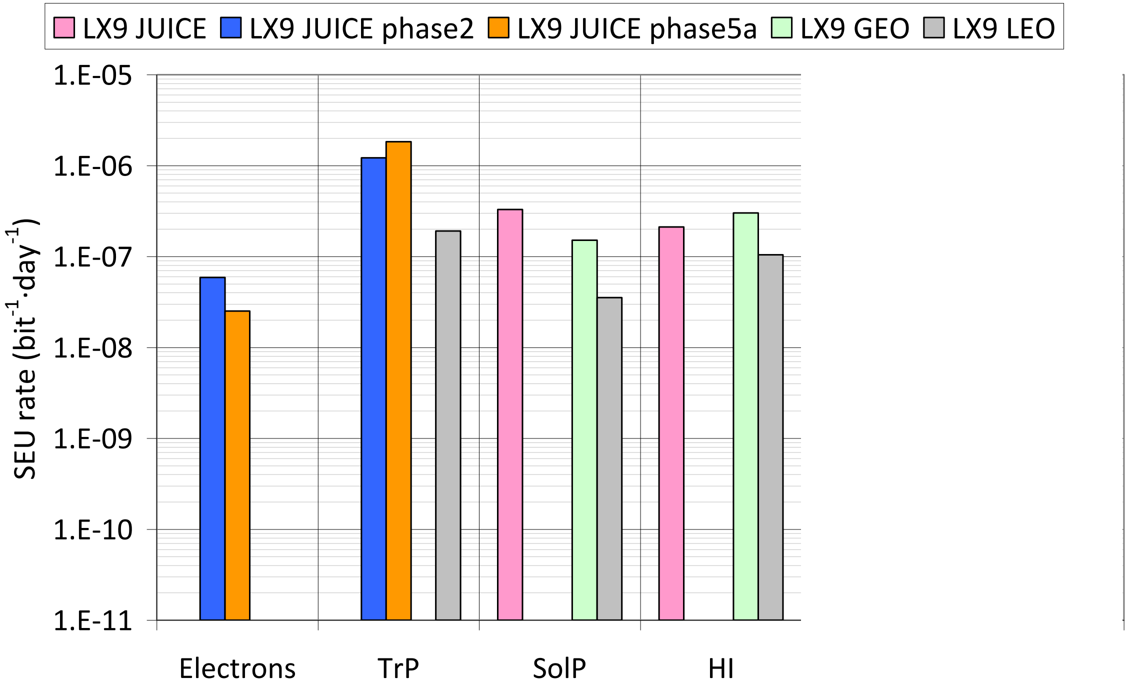
Percentage of the SEU rate per device for the JUICE mission (without proton direct ionization)

SEE risk assessment

- Comparison with terrestrial environments
  - ➢ Except Proton Direct Ionization
  - ➢ Electrons → no higher risk compared to terrestrial environments



Comparison between the XC7A35T SEU rates for the JUICE, LEO and GEO missions



Comparison between the XC6SLX9 SEU rates for the JUICE, LEO and GEO missions

Conclusion

- Complete characterization of different parts
  - 3 different devices & 3 test-beds
  - 6 test facilities / many data collected
- Out of 3 selected devices → interesting sensitivity
  - All sensitive to electrons
- Main conclusions from this work
  - electron sensitivity → lead to a non-negligible contribution in the JUICE environment (but weak)
  - electron contribution → never predominant compared to other environment sources
  - electron sensitivity → does not lead to a higher risk in the JUICE environment than the risk due to proton / HI in typical Earth environments
  - main contribution of trapped particles → mainly protons / potential sensitivity to direct ionization

- Work published at RADECS 2018 : "Risk Assessment of Electron Induced SEE during the JUICE Mission"

N. Sukhaseum[1]; B. Vandevelde[1]; L. Salvy[1]; G. Augustin[1]; A. Varotsou[1]; N. Chatry[1]; M. Tali[2]; F. Bezerra[3]: R. Ecoffet[3]; C. Boatella Polo[4] ([1]TRAD / [2]University of Jyväskylä / [3]CNES / [4]ESA)

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