VESPER Status and Outlook
CLIC workshop 2018

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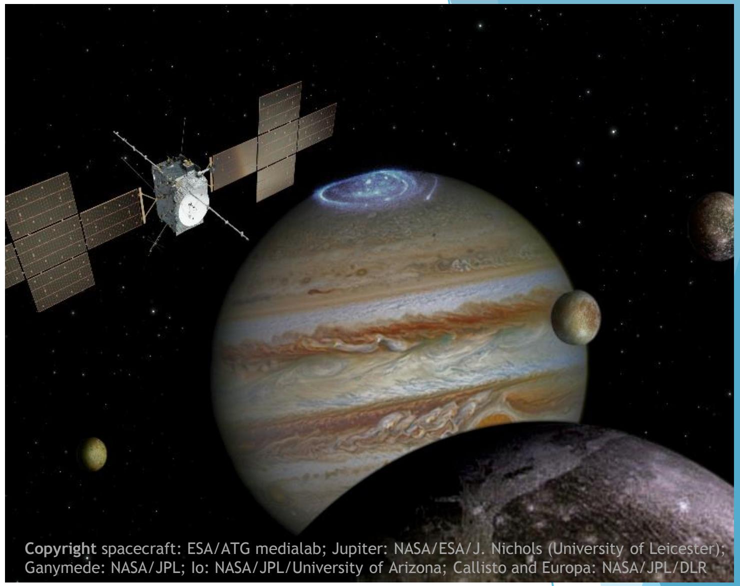
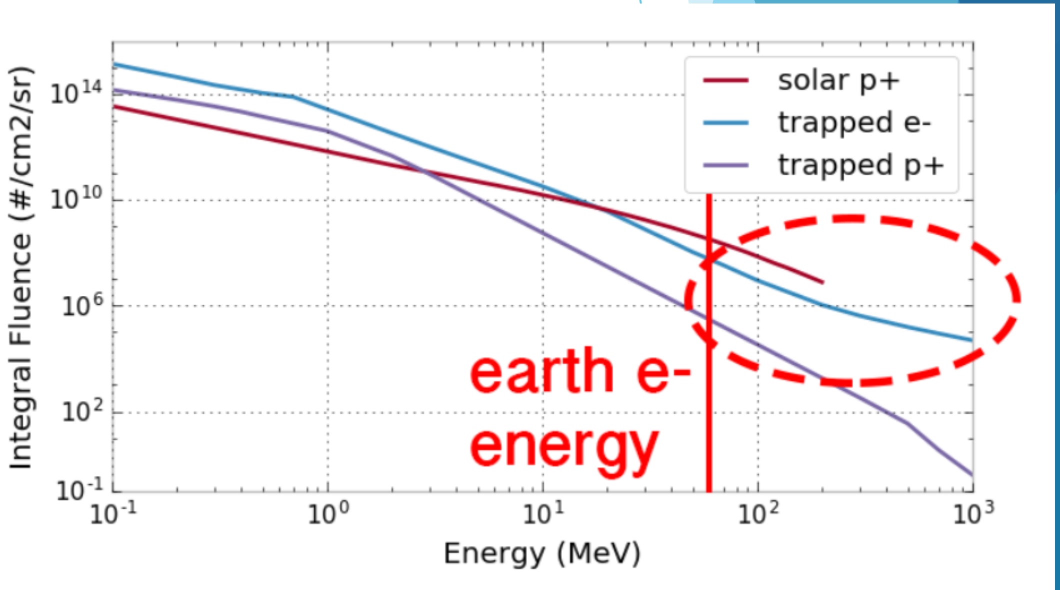
JUICE mission

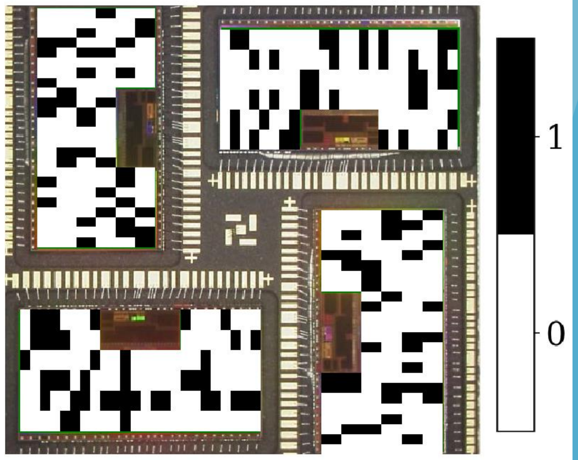
- ESA mission to Jupiter - JUICE (JUpiter ICy moon Explorer)
  - Objectives – Study the Jovian system
  - Jupiter, Europa, Ganymede and Callisto
- VESPER Motivation - Energetic particle environment
  - Magnetically trapped charged particles, solar protons and galactic cosmic rays
  - Main contribution to dose: high-energy trapped electrons
  - Secondary radiation generated by the interaction of the environment with the spacecraft

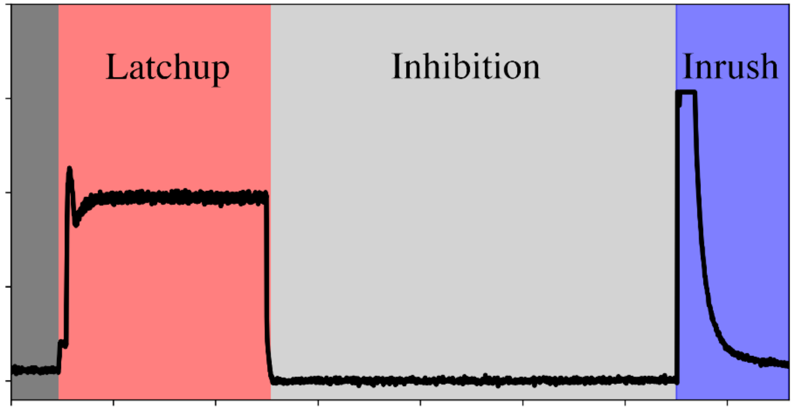




Brief intro to Radiation Effects on Electronics

- Single Event Effects (SEEs) caused by single particles
  - Single Event Upset (SEU) → single bit-flip
  - Single Event Latchup (SEL) →
    - abnormal current in device due to parasitic bipolar (npn, pnp) structure triggering
- Cumulative effects generating progressive degradation of component
  - Total Ionizing Dose (TID)
  - Displacement Damage





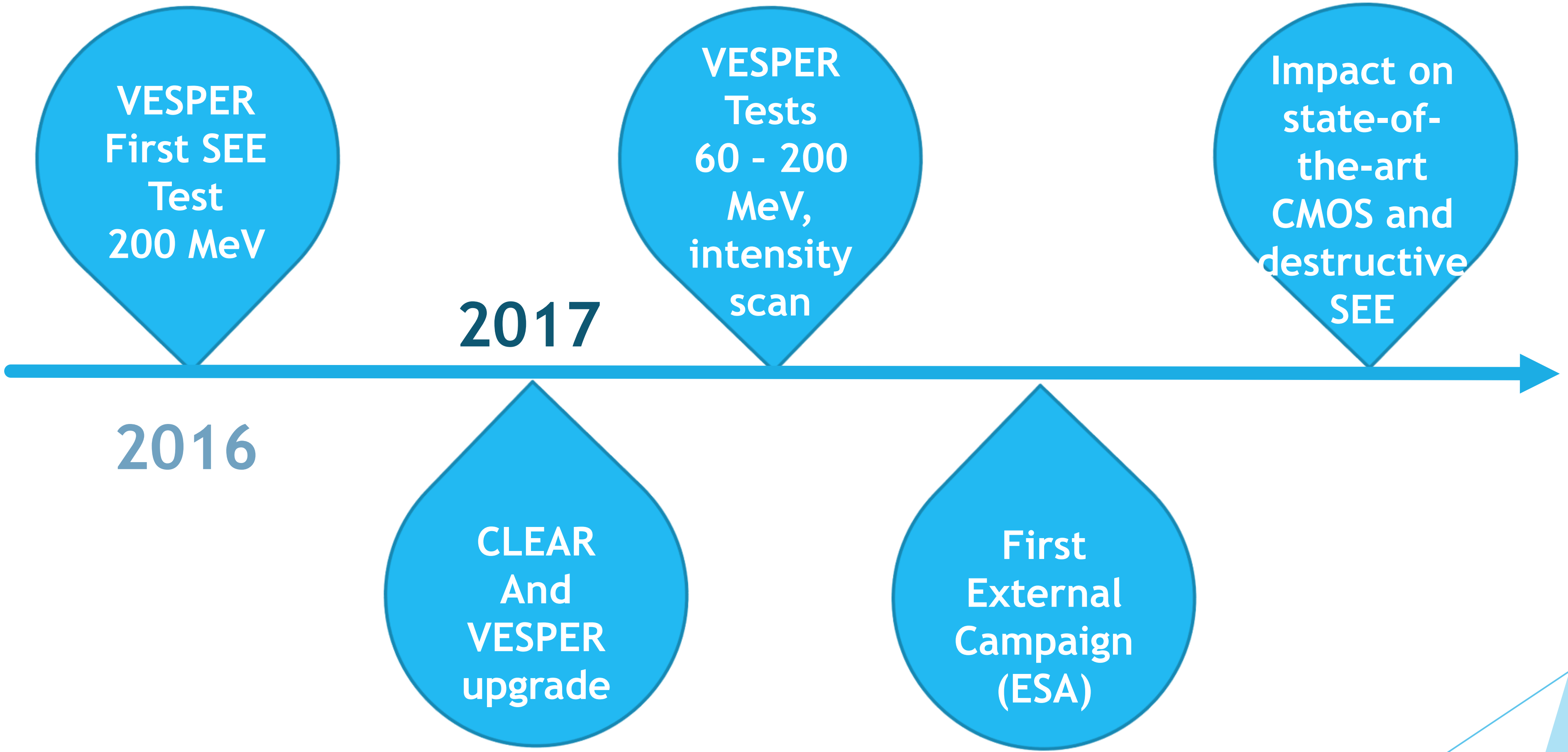
Why are electrons relevant to SEEs?

- Traditionally, electrons have been neglected as a source of SEEs due to their relatively low LET (e.g. compared to ions), very low nuclear reaction probability, and/or low relative flux and energy in operational scenarios (e.g. Earth trapped electron belts)
- Recent studies (2013+) show that single electrons are capable of inducing SEEs; active research topic in terms of (i) underlying physical mechanisms and (ii) implications on qualification approaches

Where are these effects relevant?

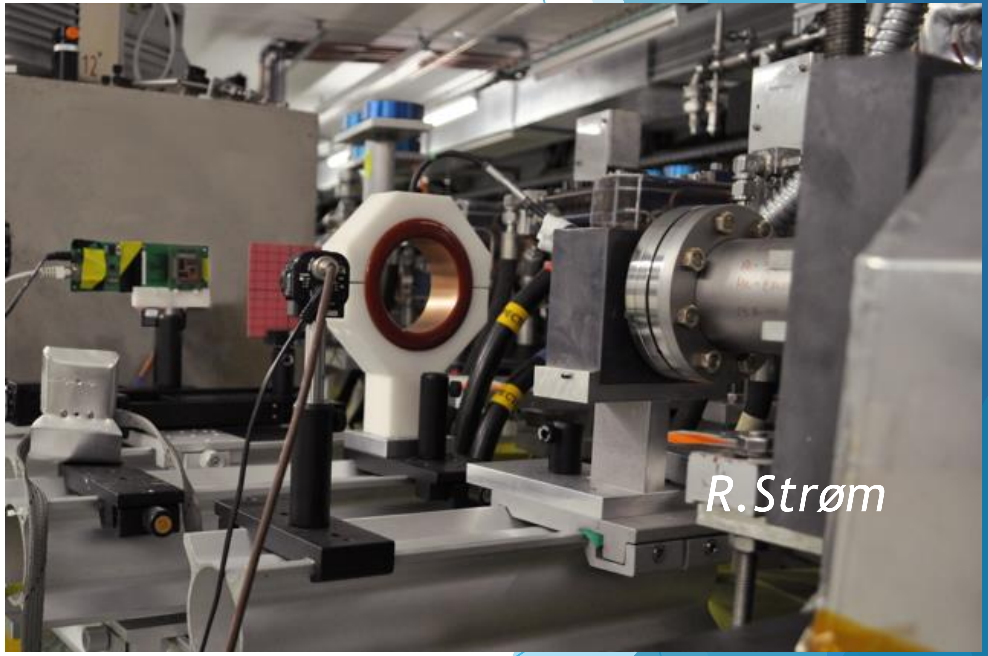
- Spacecraft near Jupiter where the trapped electron energies can reach up to hundreds of MeV
- Delta-ray electrons from high energy protons and heavy ions in cosmic rays and high-energy accelerators
- Electro-magnetic contribution to damage /degradation of electronics/detectors in high-energy physics experiments
- High-energy electron LINACs

VESPER 2017 milestones



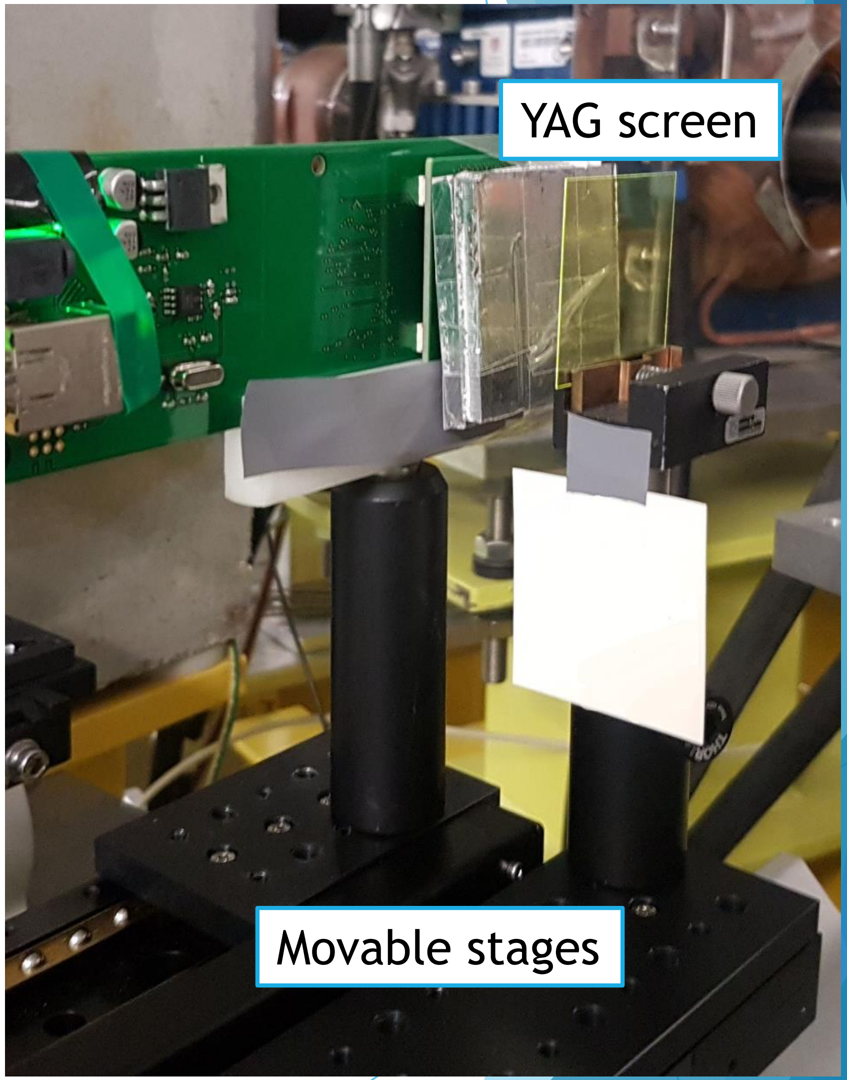
VESPER Overview

- Very energetic Electron facility for Space Planetary Exploration Missions in harsh Radiative environments
- Test bench for general purpose radiation testing, e.g. electronics
- Part of high energy electron beamline CLEAR experimental linear electron accelerator
- Main application of the test bench is that of characterizing electronic components for the operation in a Jovian environment
- Beam monitoring using the FBCT, BTV screens and radiochromic films
- Calibration of the facility using RadFET, the ESA SEU monitor and gold activation measurements
- Facility can operate with laser driven beam and without – dark current



VESPER 2017 Upgrades

- The test bench was equipped with 2 movable stages for paralell testing
- A more sensitive scintillating YAG screen was installed. Allows online beam monitoring down to a few pC/pulse
- Beam energy can now be varied down to 60 MeV and up to 200 MeV

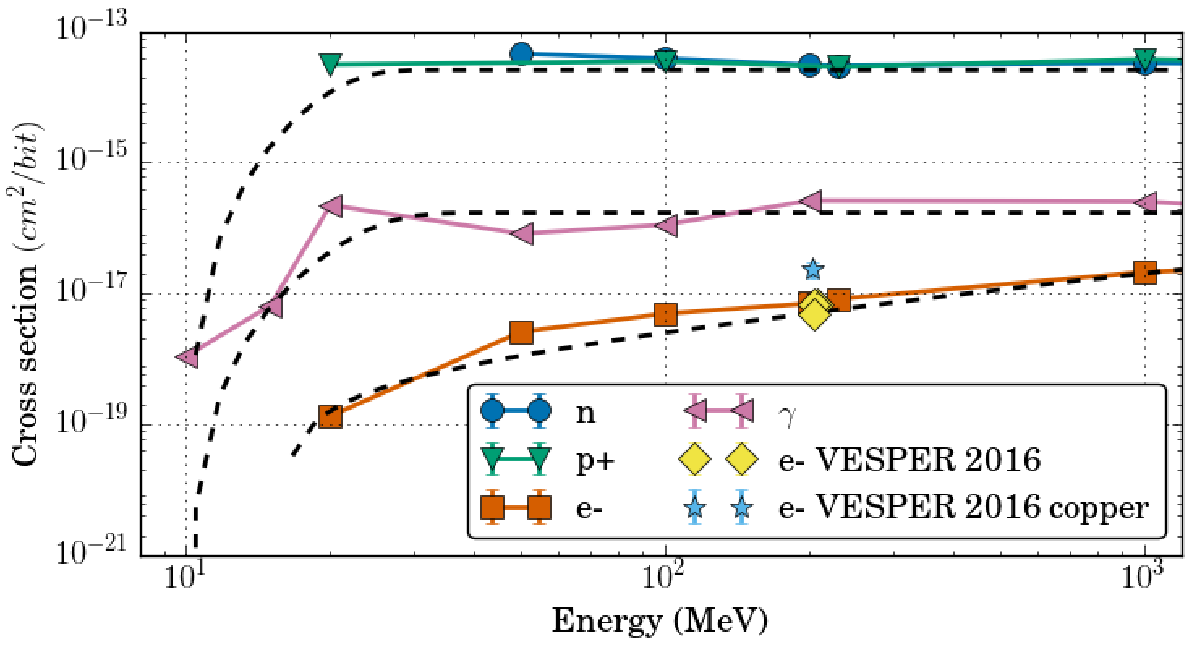


VESPER 2016

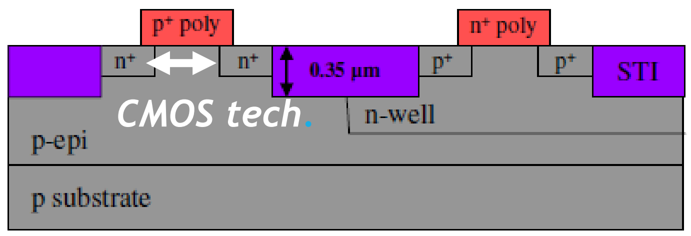
- First tests at 200 MeV, beam characterization
- Detector used is the ESA SEU reference monitor
  - 4 SRAM memories on a single board, 0.25 um technology node
  - Monitors ”bit-flips”, including physical location
- To evaluate shielding effect: test with 5mm copper – increase of Single Event Cross-section by factor 5
- Main takeaways:
  - High-energy electron included SEUs in 0.25 um technology compatible with simulated value for electro-nuclear process; cross sections roughly 3 orders of magnitude lower than for hadrons
  - Strong impact of bremsstrahlung photons on SEU probability through photo-nuclear processes
  - Secondary neutrons are also considered but have a negligible contribution with respect to photons

FLUKA SEE simulations

- *Modelling on SEU sensitive region and surrounding materials (e.g. metallization)*
- *Simulation of interaction of beam with different elements (e.g. vacuum window)*
- *Event-by-event energy deposition scoring focusing on indirect energy deposition through nuclear interactions*

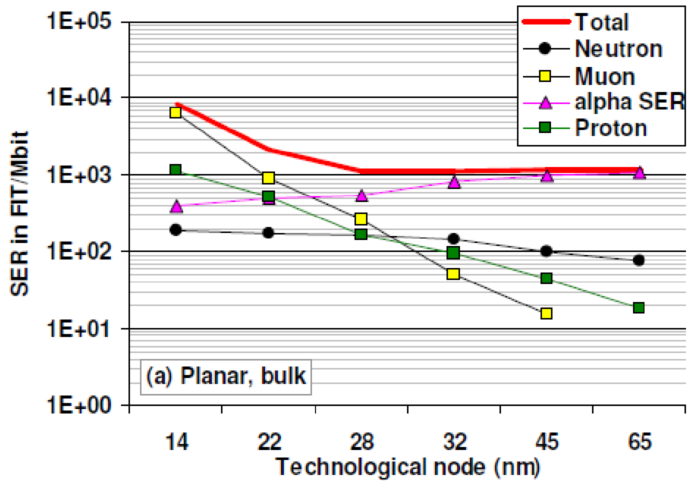


Small parenthesis: impact of scaling



(a) Bulk planar MOS transistor

G. Hubert, Integration, the VLSI Journal (2015)

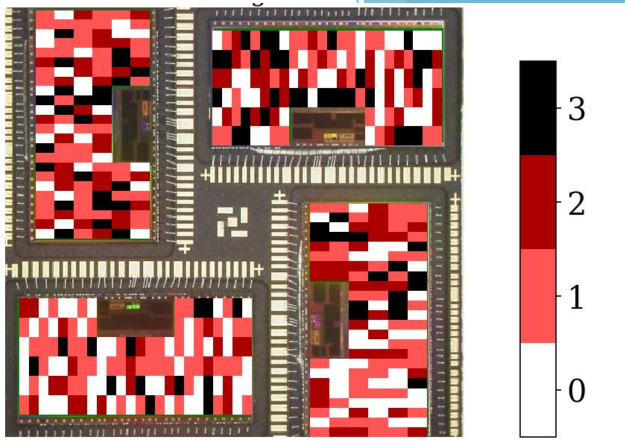


- CMOS technology integration represented by minimum distance between source and drain in basic transistor
- For indirect energy deposition (i.e. through nuclear interaction such as neutrons in the graph above) the SEU cross section per bit is expected to be roughly constant with integration due to compensation of lower critical charge and smaller sensitive volume
- The SEU rate per chip increases due to larger number of bits in highly integrated parts
- VESPER tests: SEUs in 0.25um (250nm) and 28 nm technologies

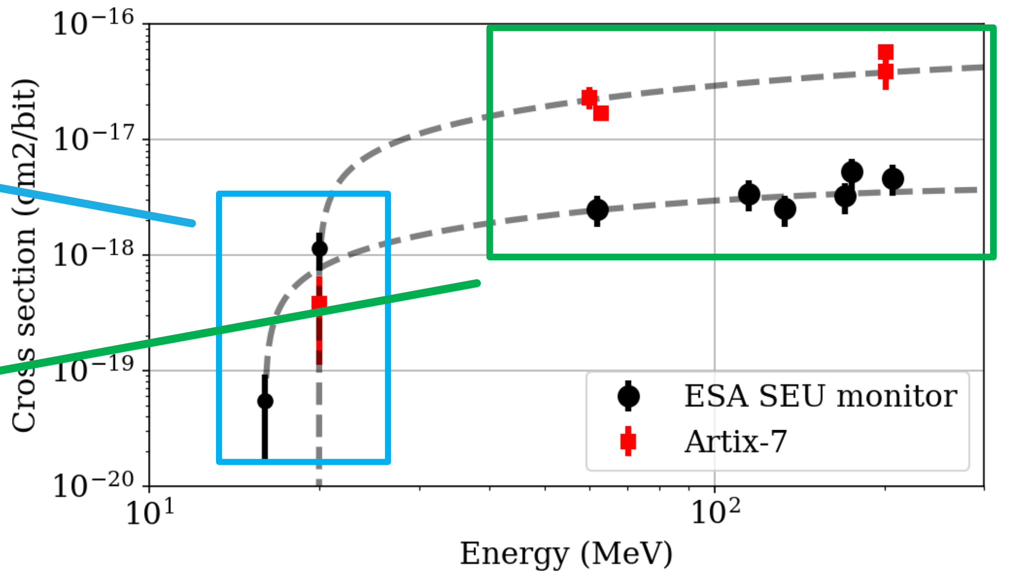
VESPER 2017

- Tests from 60 MeV to 200 MeV at VESPER
- Shown dependency of cross-section with energy
- Cross-section remains constant with the change of flux, excluding prompt dose effects
- Tests with two different device generations show a higher sensitivity for more integrated devices

- *Complementary tests at lower energy in medical CLINAC facility adapted to electronics testing (RADEF - Jyvaskyla, Finland)*
- *Important for SEU threshold determination; 20MeV not sufficient to reproduce saturation value*
- *Proton cross section (indirect energy deposition) decreases by factor 3 from 0.25um (black) to 28nm (red) [see scaling considerations in previous slide]*
- *Same trend would be expected for electro-nuclear dominated process – however, 28nm electron SEU bit cross section is factor 10 larger*



175 MeV, 8 pC/pulse

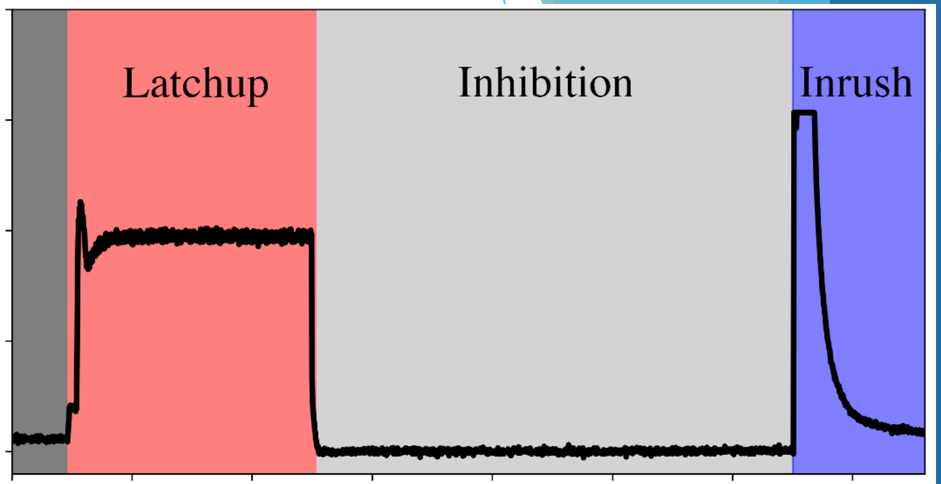


[M. Tali et al, 2018 IEEE TNS (submitted)]

Other possible physical mechanism such as elastic silicon recoils? Under investigation

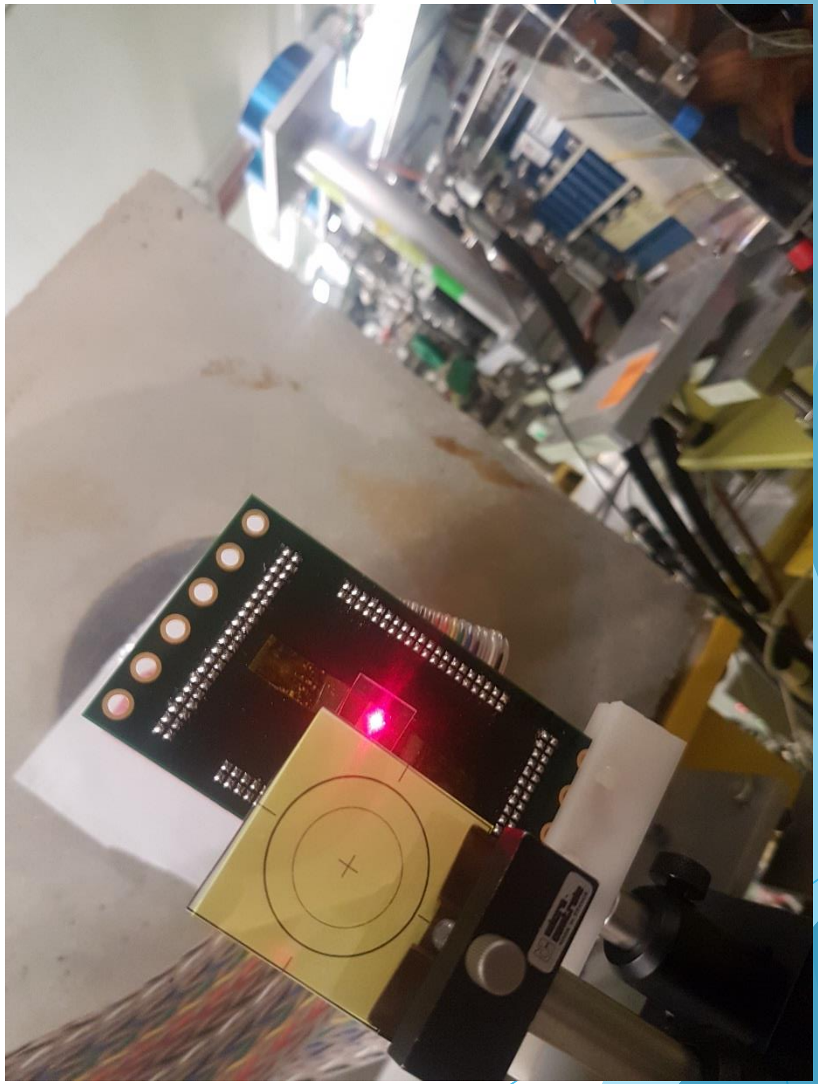
Destructive Event Experiment

- To demonstrate that electrons can cause destructive events
- Experiment run late 2017
- A set of memories sensitive to the latchup effect were irradiated
- Preliminary results:
  - First experimental result showing potentially destructive events caused by electrons!



External Campaign

- In collaboration with ESA and TRAD
- The tests were driven by the JUICE mission
- Irradiation campaign over 3 days
- The users were very satisfied with the test
- The strength of the CLEAR beamline compared to other similar facilities
  - Higher energies (with respect to medical LINACs) → saturation energy for SEUs
  - Higher flux with respect to other high-energy research LINACs → lower testing time
- Further proposal from ESA and IROC to test more integrated technologies (16 nm FinFET), planned for March 2018



Conclusion & Outlook

Conclusions

- An array of different devices were tested, different effects were evaluated
- Due to the possibility to run experiments during the night and during the weekend, an impressive total number of testing time could be accumulated
  - Useful for effects with a very low cross-section, requiring large fluence
- Large sensitivity (by factor 10) for more integrated technolgy – to be further investigated
- Preliminarily – a first time a destrucitve effect caused by electrons was shown

Outlook

- VESPER test bench is unique due to the energy range, the high fluxes and the possiblity to run very long irradiations with a dark current beam
- Further research on destructive SEEs and SEU dependence with technology node
- A second external campain already planned – March 2018
- As an application for the laser driven beam – other single event effects (latchups, burnout, displacement damage)
- The interest from external parties is still there – JUICE mission is the one of the main drivers