ELECTRON INDUCED SEE

R2E ANNUAL MEETING 2018

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OUTLINE

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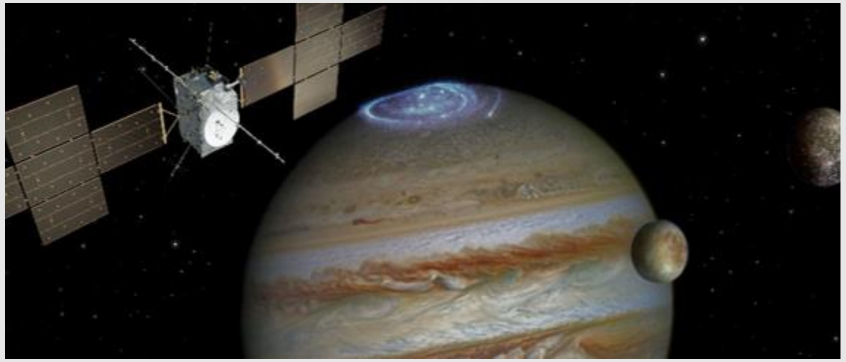
Summary
Outlook

THE HARSH JOVIAN RADIATION ENVIRONMENT



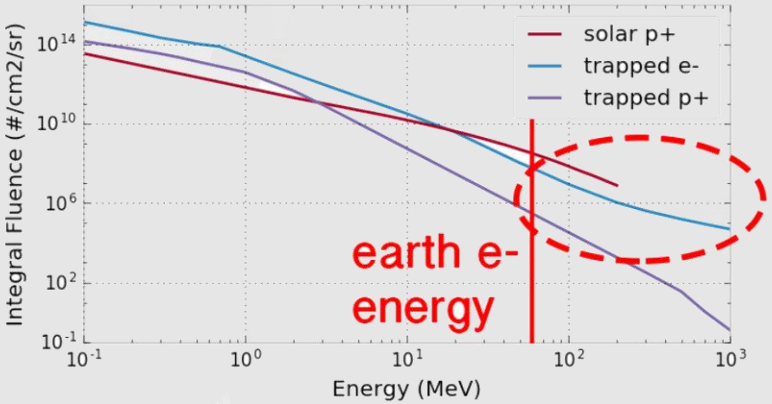
JUICE MISSION

JUICE - JUpiter ICy moons Explorer is the first large-class mission of ESA. Planned for launch in 2022 and arrival at Jupiter in 2029, it will spend at least three years making detailed observations of the giant gaseous planet Jupiter and three of its largest moons, Ganymede, Callisto and Europa.

MOTIVATION

Harsh radiation 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



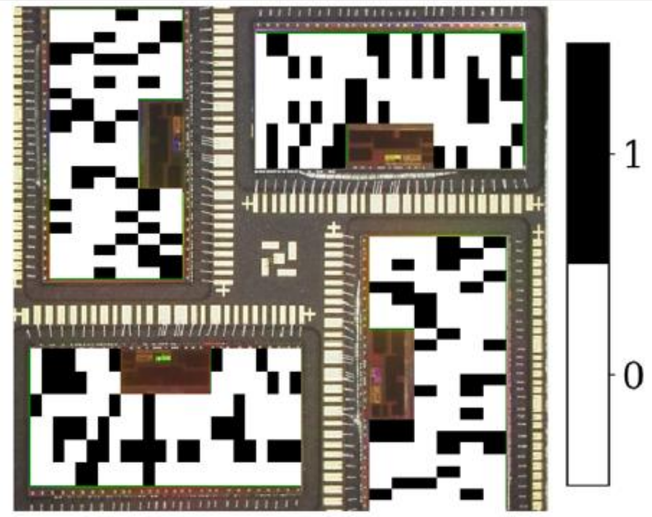
vesper

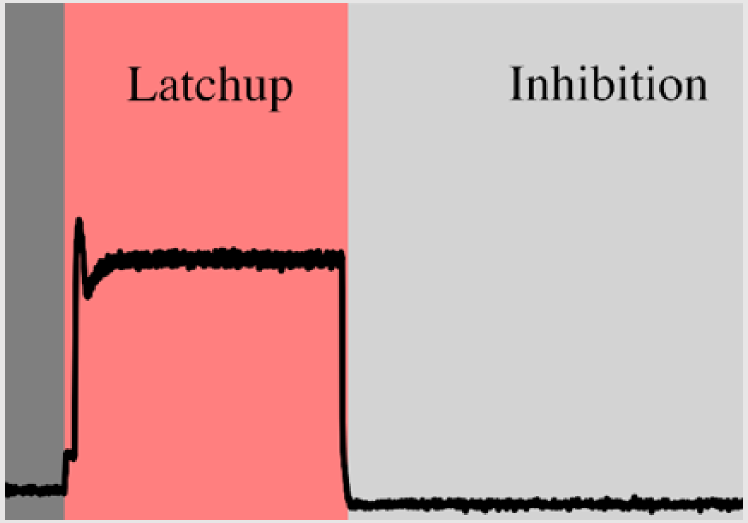
VESPER FACILITY

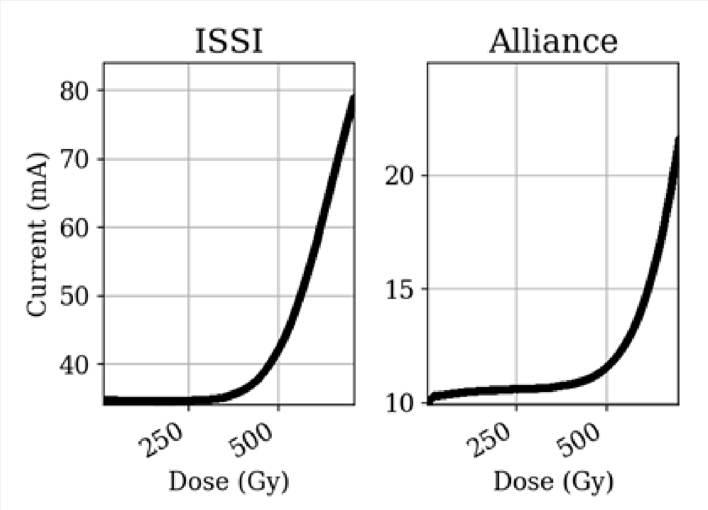
VESPER - Very energetic Electron facility for Space Planetary Exploration Missions in harsh Radiative environments. Part of a high energy electron linac line.

Main purpose test bench for general purpose radiation testing, e.g. electronics

BRIEFLY ON RADIATION EFFECTS







SINGLE EVENT UPSET

SEL Single Event Upset is caused by a single particle changing the state of a node. In case of memories – a change of 1 -> 0 or 0->1, non-detsructive

SINGLE EVENT LATCHUP

SEL Single Event Latchup is a potentially destructive event caused by a single particle, leads to a sudden increase in device current consumption, critical

CUMULATIVE EFFECTS

TID Total Ionizing Dose a cumulative dose effect, degradation of device characteristics and performance, can lead to total failure
DD Displacement Damage cumulative damage to the silicon lattice in electronic devices

ELECTRON-INDUCED SEE ARE NEW

TRADITIONALLY NOT CONSIDERED

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).

SEVERAL RECENT STUDIES SHOW IMPORTANCE

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

IMPORTANCE FOR SPACE

Spacecraft near **Jupiter** where the trapped electron energies can reach up to hundreds of MeV

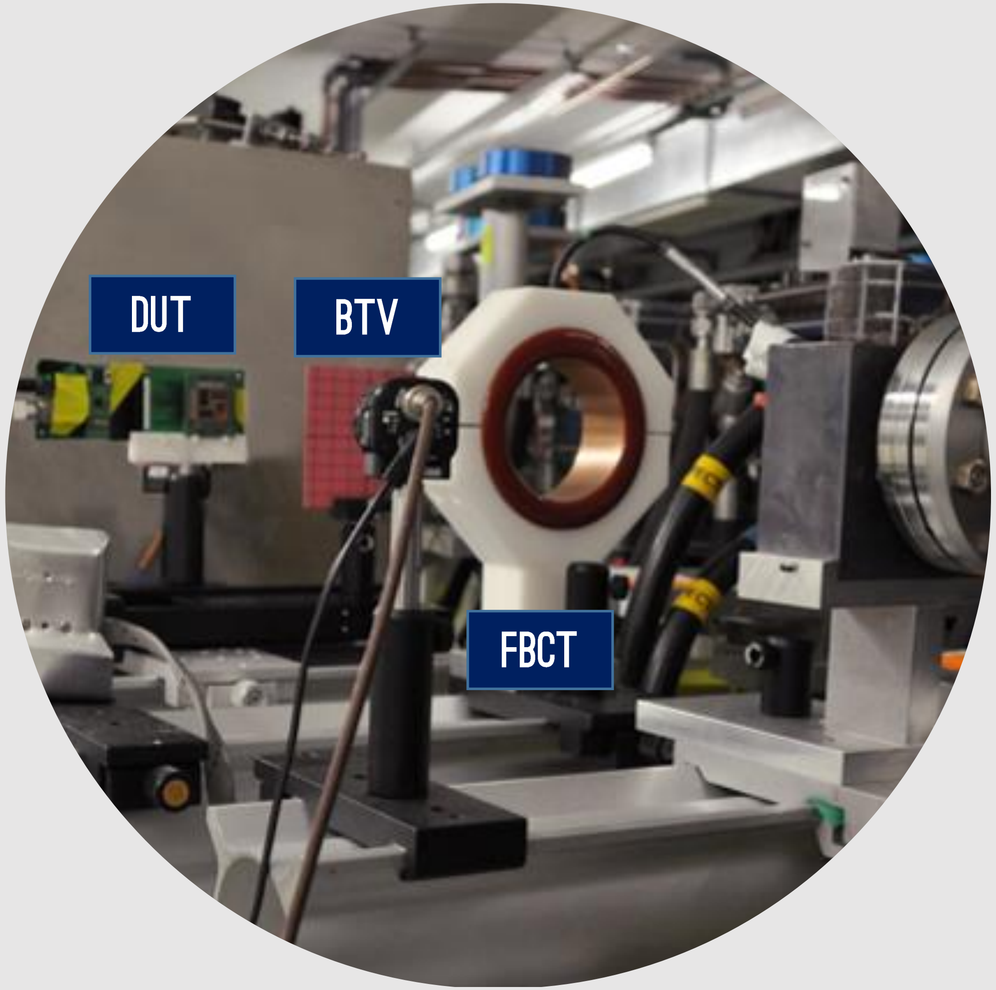
Delta-ray electrons from high energy protons and heavy ions in cosmic rays and high-energy accelerators

IMPORTANCE FOR HIGH-ENERGY PHYSICS EXPERIMENTS

Electro-magnetic contribution to damage /degradation of electronics/detectors in high-energy physics experiments

High-energy electron **linear accelerators**

VESPER FACILITY FOR ELECTRON TESTING AT CERN



OVERVIEW

Main application of the test bench is that of characterizing electronic components for the operation in a Jovian environment

Beam monitoring using the **FBCT (fast beam current transformer)**, **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**

Typical beam parameters – pulse charge 1 – 15 pC, Flux 7×10^6 - 1×10^8, dose rate 2 mGy/s - 31.6 mGy/s

FIRST ELECTRON SEE IN 250 NM TECH.

BEAM CHARACTERIZATION

RadFET, gold foils and radiosensitive films were used to determine the real beam intensity, effort was put into the logging and analysis of beam characteristics

SEU TESTING

ESA SEU monitor (SRAM 250nm technology) was irradiated with 200 MeV electrons. Large amounts of statistic were gathered over long runs over nights/weekends

SHIELDING EFFECT

5mm of aluminium was placed in front of the ESA SEU monitor. A **factor 6** increase of the SEU cross-section was observed

FLUKA MODELLING

Energy deposition simulations and secondary particle simulation, gold foil simulation

RADECS 2016

ARTICLE

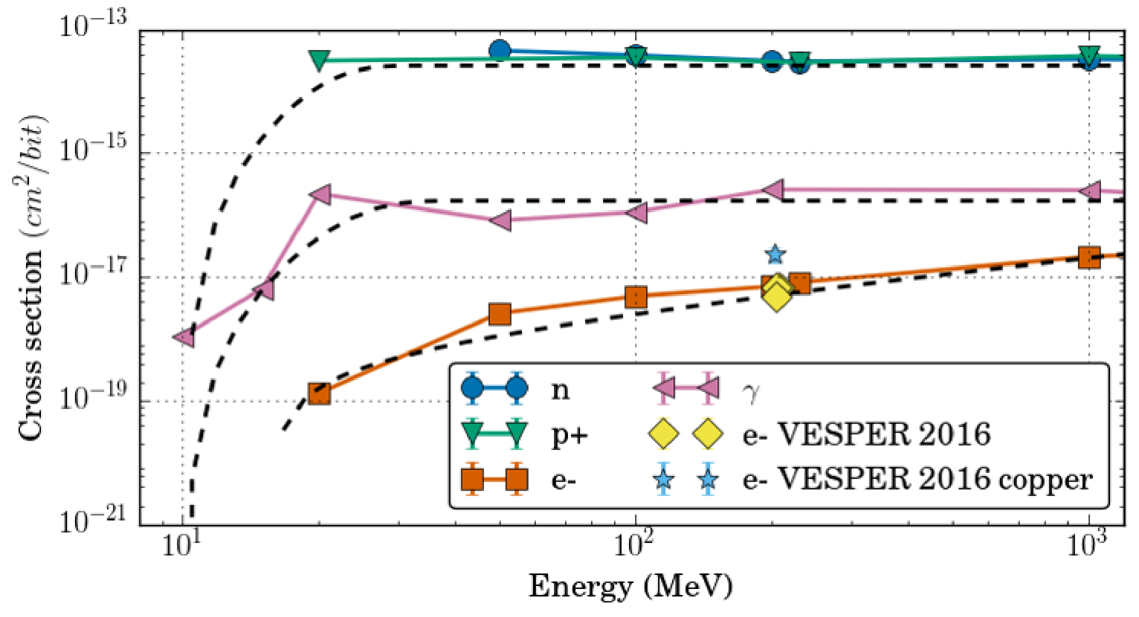
High-energy electron included SEUs in 0.25 um technology compatible with FLUKA simulated value for **electro-nuclear process**

SEU 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

A FEW WORDS ON FLUKA MODELLING



WHAT IS FLUKA

FLUKA is a particle physics MonteCarlo simulation package.

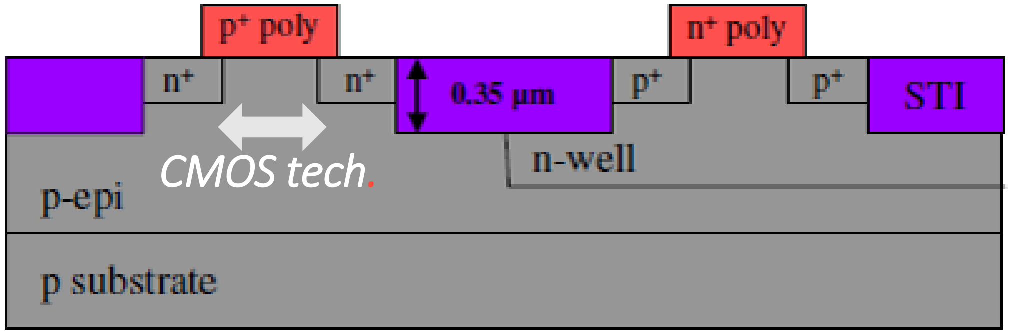
MODELLING SECONDARY RADIATION

Simulation of interaction of beam with different elements in the beamline that create secondary particles through the interaction with the beam (e.g. vacuum window)

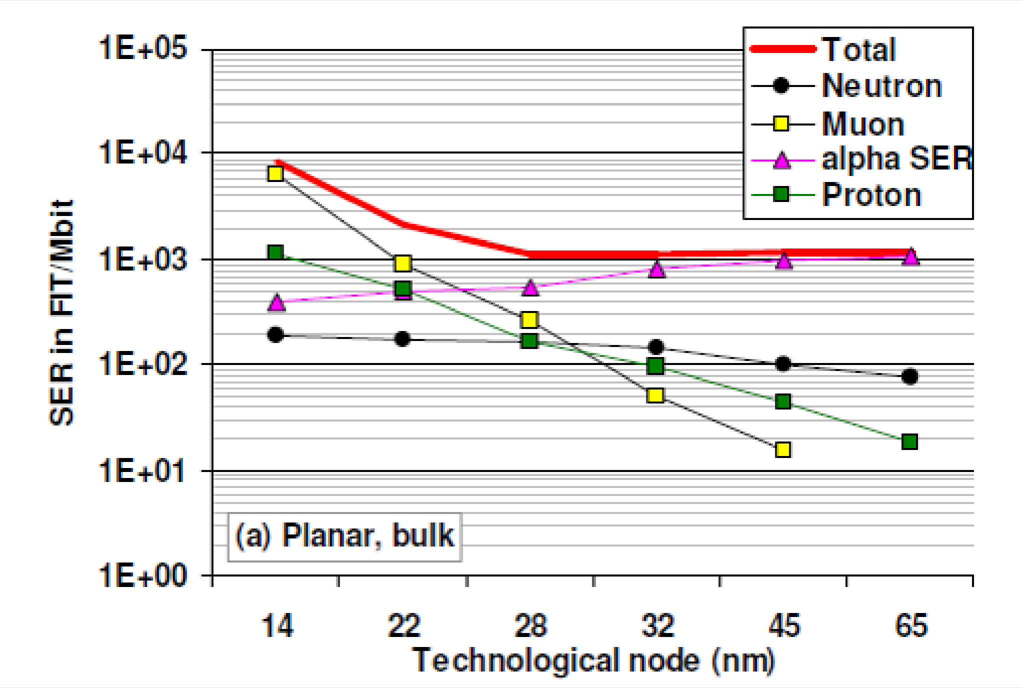
ENERGY DEPOSITION SIMULATION

Event-by-event energy deposition scoring focusing on indirect energy deposition through nuclear interactions

A BRIEF NOTE ON TECHNOLOGY SCALING



(a) Bulk planar MOS transistor



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

CMOS

CMOS technology integration represented by minimum distance between source and drain in basic transistor – **gate width**

SEU CROSS-SECTION

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

TECHNOLOGIES USED

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

A RANGE OF ELECTRON ENERGIES TESTED

ENERGY SCAN

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

IMPACT OF TECHNOLOGY NODE

Tests with **two different device generations** show a higher sensitivity for more integrated devices. The 28nm technology roughly a magnitude higher cross-section than 250nm technology

TESTS AT MEDICAL LINAC

Complementary tests at lower energy in **medical LINAC** facility adapted to electronics testing (RADEF – Jyvaskyla, Finland)

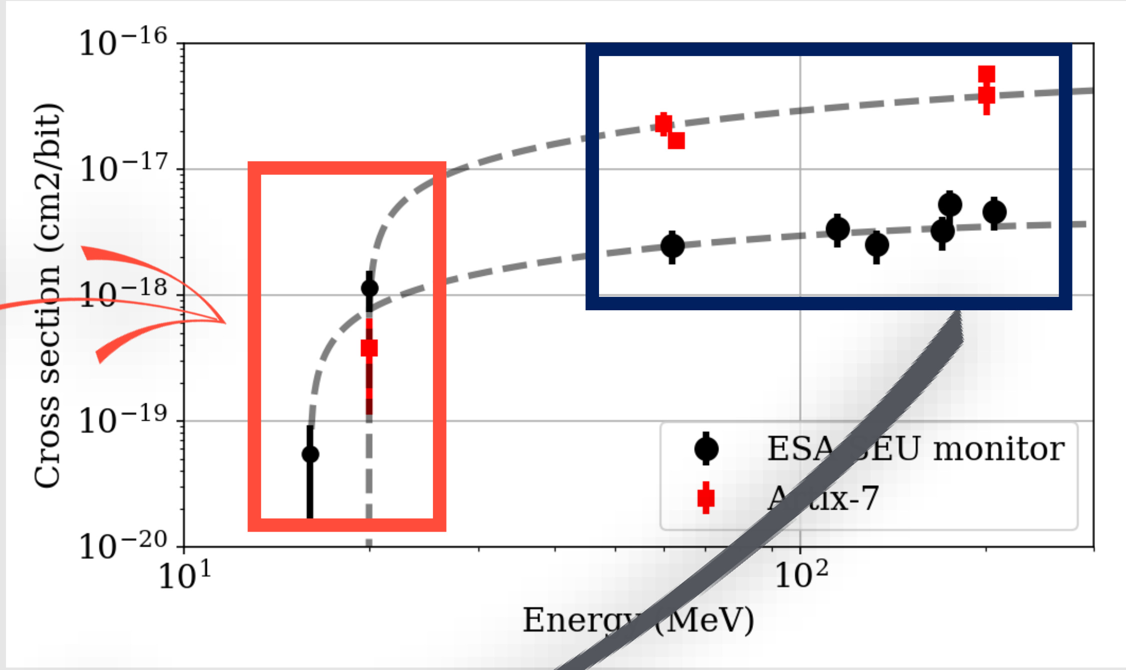
Important for SEU threshold determination; 20MeV not sufficient to reproduce saturation value

EFFECT OF SCALING

Proton cross section (indirect energy deposition) decreases by factor 3 from 0.25um (black) to 28nm (red). Same trend would be expected for electro-nuclear dominated process – however, 28nm electron SEU bit cross section **is factor 10 larger**

RADECS 2017

CONCLUSION



FIRST DESTRUCTIVE ELECTRON EFFECTS

SRAM MEMORIES

Tests from **60 MeV** to **200 MeV** at VESPER. Cross-section remains constant with the change of flux, excluding prompt dose effects. Alliance, ISSI and Brilliance were tested, ~200 nm technology node

IMPACT OF TID

Increase in standby current -> TID. Tests at Co60 facility confirm the effect is due to TID. No change in XS, however results were discarded

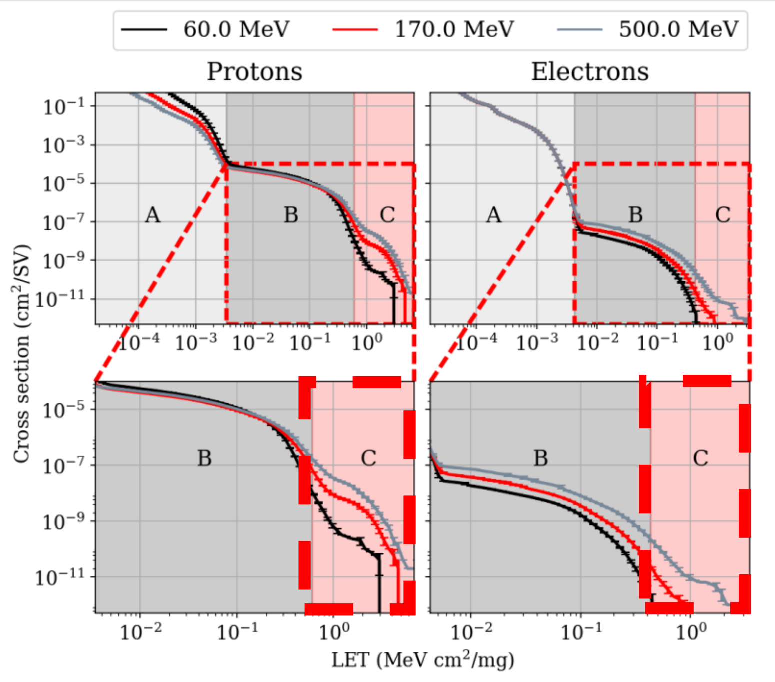
FLUKA RECOIL MODELLING

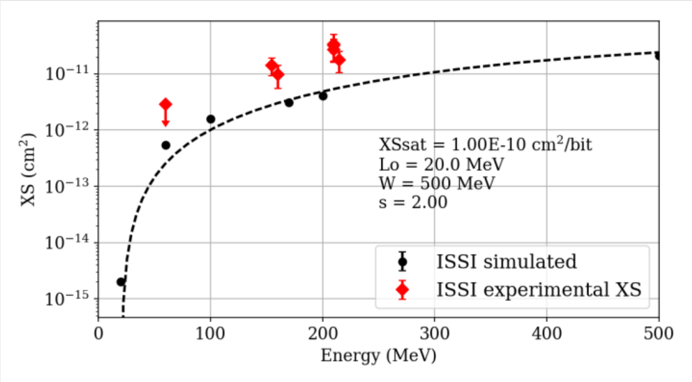
Photons and electrons are also capable of producing these high-LET fragments up to ~40 MeV cm2/mg. Similar to protons, highest LET recoils have to be considered

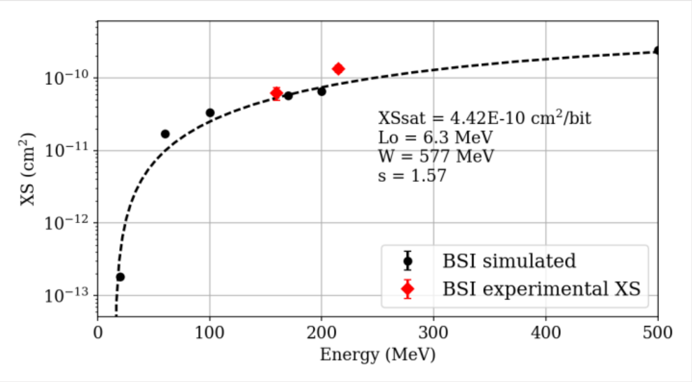
GEOMETRY SENSITIVITY

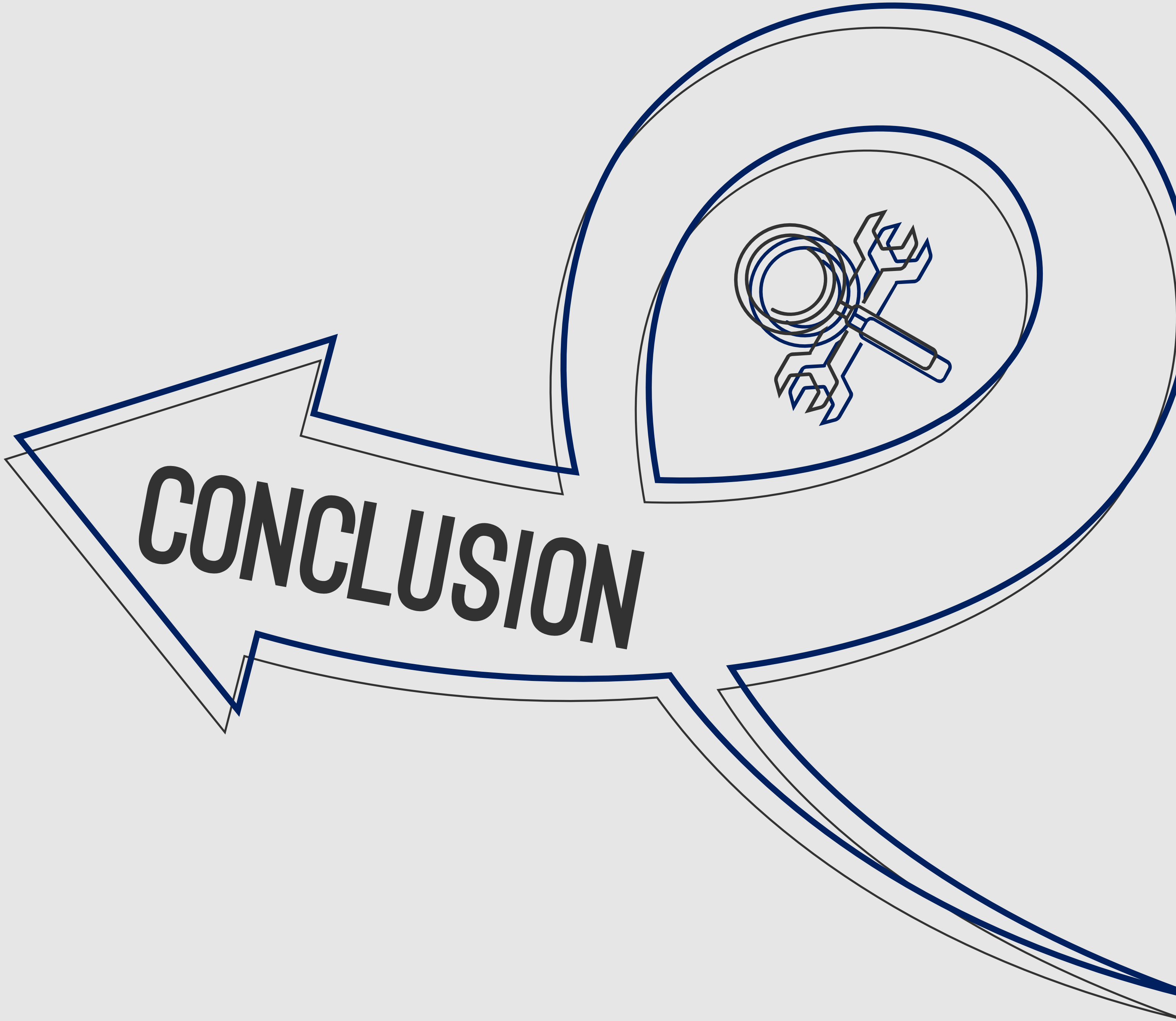
The XS has a good agreement with the FLUKA modelling results. The same geometry was used for all memories, thickness of the SV has a large impact on the XS, hence the slight offset

NSREC 2018 CONCLUSION









CONCLUSION

An array of different device generations were tested, both destructive and non-destructive 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

Not decreased sensitivity for more integrated technology – to be further investigated

A first time a destructive effect caused by electrons was shown

Relevance for the high-energy field with the technologies becoming more integrated

STILL WORK TO BE DONE

First proof of electron induced SEE in larger technology nodes. First tests providing a more complete picture with test from 20 – 200 MeV.

Further research on destructive SEEs and SEU dependence with technology node. Main contributor at different tech. nodes and energies to be investigated

First potentially destructive single event effects observed. Different effects still observable with the dark current beam - SEB

There are still other possible application for the **laser driven beam** – other destructive single event effects (displacement damage)

THANK YOU!