RADNEXT research: Status and objectives

Paul Leroux

KU Leuven

Content from:

Sylvain Girard, UJM St.-Etienne
Cornelia Hoehr, TRIUMF
Luigi Dilillo, Univ. Montpellier
Luis Entrena, Univ. Carlos III Madrid
Jérôme Boch, Univ. Montpellier
Vincent Goiffon, ISAE-SUPAERO
Frédéric Wrobel, Univ. Montpellier
Giuseppe Lerner, CERN
Hanne Stas, KU Leuven

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101008126

Outline

- Introducing RADNEXT
- Radiation monitors, dosimeters and beam characterization
- Standardization of system level radiation qualification methodology
- Cumulative radiation effects on electronics
- Complementary modelling tools

RADiation facility Network for the EXploration of effects for indusTry and research (RADNEXT)

RADNEXT is a H2020 INFRAIA-02-2020 infrastructure project with the main purpose of **enhancing accessibility to irradiation facilities** for research on radiation effects in electronics.

To this end, RADNEXT provides

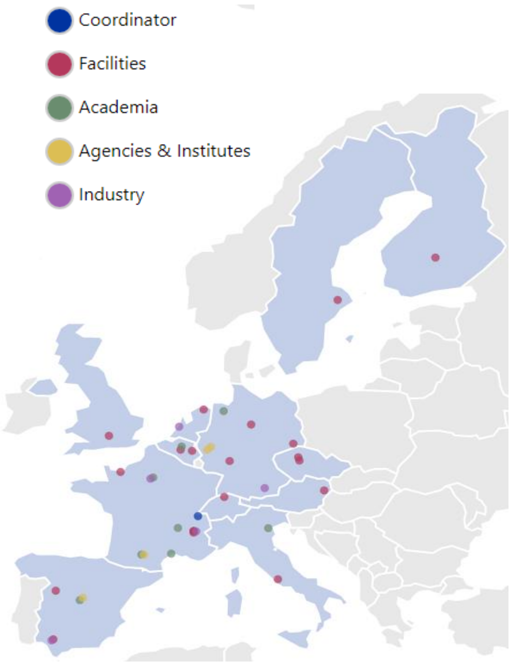
- A **network of irradiation facilities** and a structure for facility access
- **Transnational access to irradiation facilities**
- A **research program** devoted to improving radiation effects testing responding to the emerging needs of electronics component and system irradiation

TRANSNATIONAL ACCESS

- More than 6000 beam time hours are awarded (in 2021-2025) via a competitive proposal process
- Free of cost to users
- Quarterly calls for proposals (evaluated by experts)
- Both academic and industrial groups are eligible
- Types of beams: proton, neutron, heavy ion, muon, mixed-field, photon, electron

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No **101008126**

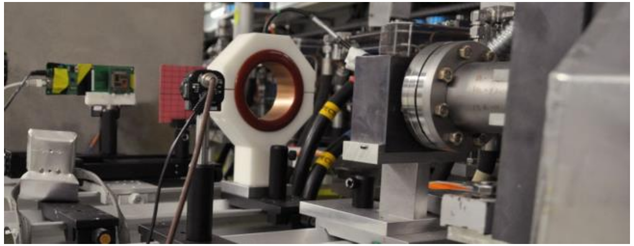
RADNEXT network

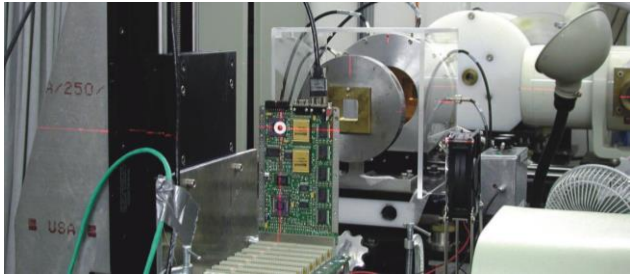


Coordinator:

Dr. Rubén García Alía

- 21 **irradiation facilities**
- 8 **academic partners** and 9 academic supporters
- 4 **agencies and research institutes**
- 5 **industrial partners** and over 20 industry supporters





Contact us

radnext.web.cern.ch

radnext.network@cern.ch

linkedin.com/company/radnext

twitter.com/RADNEXT_EU

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No **101008126**

Work package structure

WP01/MGT Project management

Networking Activities

- **WP02/NA1** Communication, dissemination, exploitation and training
- **WP03/NA2** Transnational access management and harmonization
- **WP04/NA3** Roadmap and pre-design of future irradiation facilities

Joint Research Activities

- **WP05/JRA1** Radiation monitors, dosimeters and beam characterization
- **WP06/JRA2** Standardization of system level radiation qualification methodology
- **WP07/JRA3** Cumulative radiation effects on electronics
- **WP08/JRA4** Complementary modelling tools

Transnational Access

- **WP09/TA1** Neutron, muon and mixed-field spallation facilities and irradiation
- **WP10/TA2** Proton, heavy ion and alternative beams and irradiation

WP5 - Radiation monitors, dosimeters and beam characterization

Sylvain Girard, UJM
Cornelia Hoehr, TRIUMF

WP5 - Objectives and Participants

Objectives

The main objective is to render the RADNEXT facility network more accessible, standardized, homogeneous and complementary.

To achieve this, the RADNEXT facilities and user needs will be defined and matched in terms of radiation detectors, beam instrumentation and dosimetry.

Participants and Associates: (26 members in WP5 CERN e-group)

UJM CERN UniPD UO UM TRIUMF FINT UKRI

UU GANIL GSI KUL

WP5 - Workplan

- ✓ Three main technical tasks:
  - **Definition of the correlation matrix** between facility needs and monitoring solutions as well as the **definition and standardization of the relevant beam parameters**
  - **Innovative instrumentation** for optimization of R2E testing,
  - **Low-cost detectors and dosimeters** accessible to RADNEXT users.

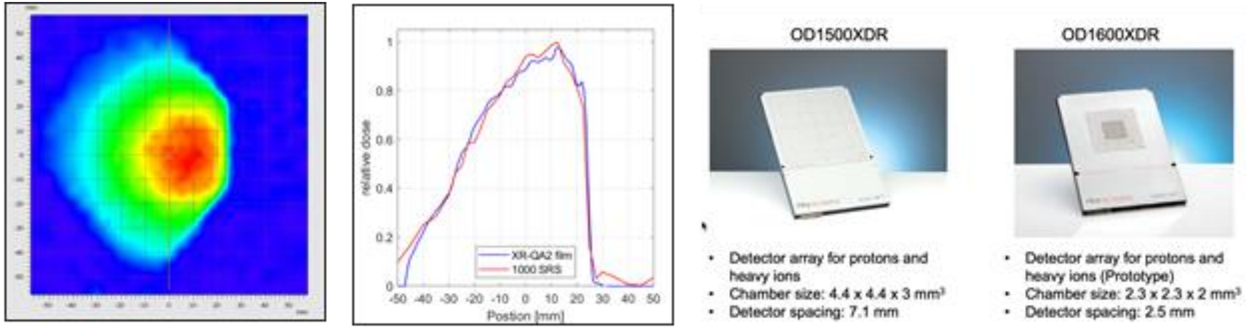
- ❑ **2 PhD Students** funded by RADNEXT initiated their PhDs in 2021
  - Andreas Pflaum (Univ. Oldenburg)
  - Luca Weninger (UJM St.-Etienne)

- ❑ Research in close collaboration with **WP7** and **WP8**

RADNEXT

Task#1: Definition of the RADNEXT facilities & users instrumentation needs, inter-laboratory comparison

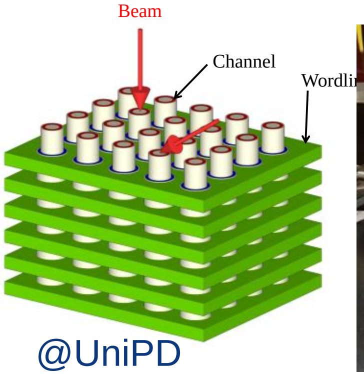
- ✓ Definition of the correlation matrix between RADNEXT facilities needs and established or innovative sensing solutions (*together with WP8-JRA4 & facility collaborators collaboration*),
- ✓ Definition and standardization of relevant beam parameters,
- ✓ Improving the comparability and accuracy of beam and dose parameters.

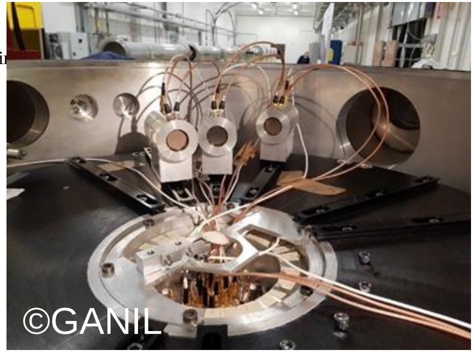


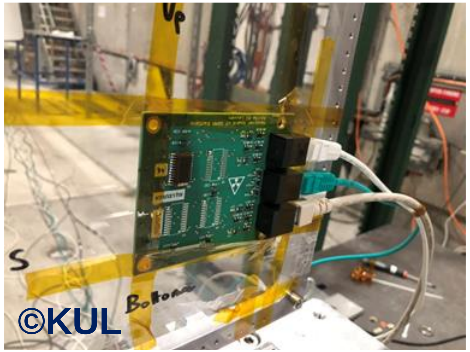
Wyrwoll et al 2020; Poppinga et al 2020 ; Kretschmer at al 2019 ; Brodbeck et al 2019

Task#2: Innovative instrumentation applied to RADNEXT facilities

- ❑ Increase maturity of various existing sensing technologies
  - ✓ **Optical Fiber**-based monitoring solutions
  - ✓ SEU monitor based on **3D NAND Flash**
  - ✓ Characterization of **Neutron Fields**
  - ✓ **SRAM-based dosimetry**







Task#3: Development of low-cost dosimetry systems accessible to RADNEXT users

- Low-cost detectors and point dosimeters

- Dosimeters based on floating gates (FG-DOS) to complement RADFETs

- A system (low-cost, open hardware/software) has been developed over the last decade for TID and NIEL measurements at CERN. This system combines RADFET and PIN diode sensors.

Fiber-based dosimeter testing at TRIUMF (Courtesy of TRIUMF)

Any question, please contact:

- Sylvain GIRARD (sylvain.girard@univ-st-etienne.fr)
- Cornelia HOEHR (choehr@triumf.ca)

WP6 - Standardization of system level radiation qualification methodology

Luigi Dilillo, Univ. Montpellier

Luis Entrena, Univ. Carlos III Madrid

WP6 - Overview

Objective

- Exploration of valid qualification procedures to be effective at system level: reduced cost and time, without compromising radiation hardness assurance level.

Tasks

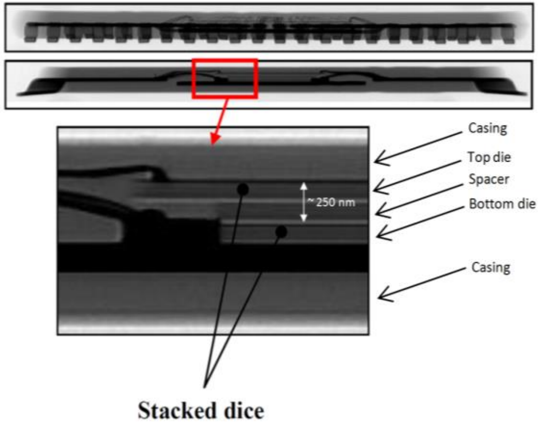
- Setup preparation and stimuli definition
- Pass/fail test
- Tests with enhanced observability

Participants and associates

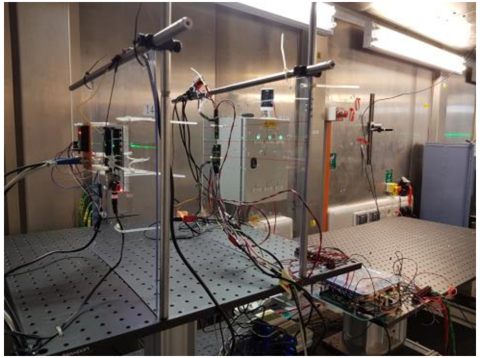
- Université de Montpellier (UM)
- Katholieke Universiteit Leuven (KUL)
- Università Carlos III (UC3M)
- European Organization for Nuclear Research (CERN)

Task 1: Setup preparation and stimuli definition

- Identification of general actions before the actual irradiation:
  - X-ray inspection of the chip
  - Use of current monitoring equipment
  - Generation of meaningful test logs
- Identification and standardization of test conditions and stimuli
- Identify a certain number of benchmark stimuli for processors and FPGAs
- Definition of a flexible and remotely operable hardware platform that supports the identified setup requirements and allows software qualification.



X-ray image of the 90 nm SRAM (img. LIRMM)

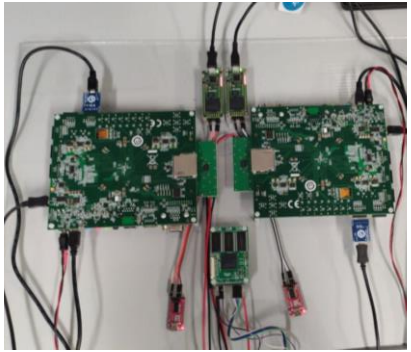


Experiment from remote in ChipIR (img. LIRMM)

Task 2: Pass/fail test

- Test of the whole system treated as **black box**
  - Unknown features and irradiation response of composing elements
  - Knowledge of resilience of whole system to a given level of radiation
  - Poor information on weakest elements and the hardware configurations that may reduce or enhance the radiation effects.

- Standardization of the pass/fail procedure to enhance the consistency and usability of the results
  - Guidelines for monitoring physical and electrical parameters
  - Limitations of pass/fail testing.



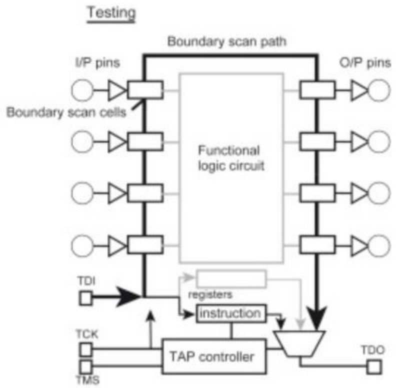
Multi-system setup for P/F test. (img. LIRMM)

Task 3: Tests with enhanced observability

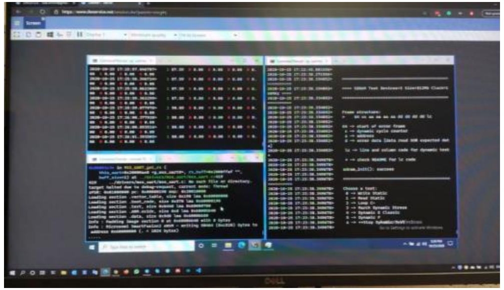
- Use of **fault injection** techniques in digital systems, based on fault simulation or emulation
  - Understanding the radiation sensitivity of the different components
  - Analysis of error propagation mechanisms
  - Preparation of irradiation campaigns to ease the interpretation of results

- Identification of techniques to increase the observability in systems on PCB (for instance Boundary Scan)

- Methods to perform effective in-depth statistical analysis of the detected errors



Example of boundary scan scheme



On-line data logs (img. LIRMM)

WP7 - Cumulative radiation effects on electronics

Jérôme Boch, Univ. Montpellier

Vincent Goiffon, ISAE-SUPAERO

WP7 - Participants

- Université de Montpellier
- ISAE-SUPAERO
- Université de Liège
- Université Jean Monnet Saint-Etienne
- ATRON

WP7 Objectives

Study of cumulative radiation effects on electronics: highly relevant both for actual applications (e.g. space, high-energy accelerators, nuclear dismantling, etc.) as well as related to by-product effects of Single Event Effects (SEE) testing.

- Two main tasks:
  - Effects of TID (Total Ionizing Dose)
  - Effects of TNID (Total Non-Ionizing Dose)

- Main objectives
  - understand the physical mechanisms behind the damage
  - propose test methodologies for electronic components and systems

RAD NEXT

WP7: Task 1: Study of TID effect

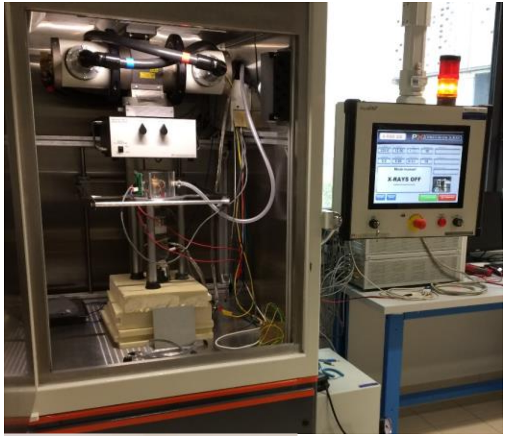
Areas of work to be studied:

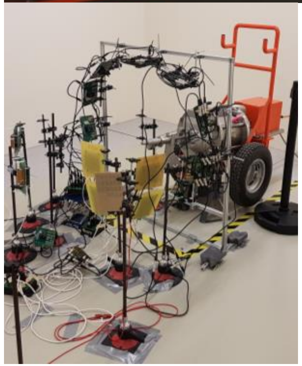
- Experimental investigation of X-ray facilities and simulation
- Comparison of component and system degradation between X-ray and ^{60}Co
- Specific study on the charge yield

⇒ Experimental data at component and system level

⇒ X-ray testing methodology

⇒ Inputs for system level qualification (WP6) and links with WP5 and WP8





Source: UM

WP7: Task 1: Study of TID effect

- SubTask1.1: How to perform a TID test with X-ray facilities
  - How to modify the energy spectrum: choices of energy, filters; dosimetry, … .
  - Simulation of the X-ray facilities with Geant4
  - different X-ray facilities (UM, UJM, ISAE and ATRON 3.5 MeV e^- accelerator with X-ray target)
- SubTask1.2: Comparison of component and system degradation between X-ray and ^{60}Co.
  - Based on dosimeters (RADFET, FGDOS) and in link with WP5
  - Based on electronic components or systems and in link with WP6
- SubTask1.3: A specific study on the charge yield.
  - This study will be executed in order to increase our knowledge on the initial recombination.
  - Different facilities (^{60}Co, X-ray, electrons, protons), temperature (50K to 400K) and bias configurations.

=> Main outcome: Guidelines and recommendations for TID testing.

RAD NEXT

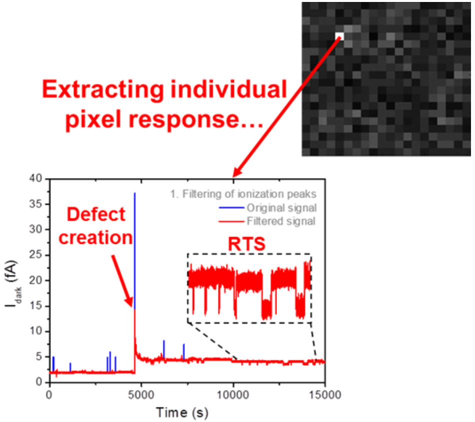
WP7: Task 2: Study of TNID effects

Areas of work to be studied:

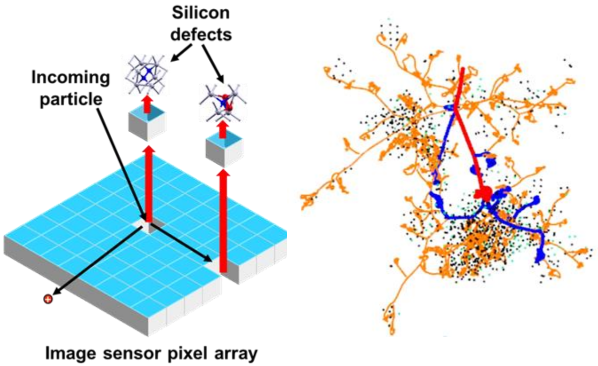
- Influence of irradiation conditions (biasing, particle type and flux) on the average leakage current degradation of silicon diodes
- More detailed study on the statistics of displacement damage by the use of image sensors and pixel arrays
- Comparison to existing models to clarify their validity range

⇒ Guidelines for TNID tests for the different fields of application encountered in RADNEXT

⇒ Inputs for system level qualification (WP6)



Courtesy of M. Raine (CEA DAM)



RADNEXT

WP7: Task 2: Study of TNID effects

- SubTask2.1: Comparison of TNID effects on “ideal” silicon diodes
  - Selection of an “ideal” silicon PN junction (mm^2-cm^2 scale)
  - Comparison of irradiation conditions on TNID induced **mean dark current** increase
  - Envisaged experimental parameters to explore: particle type (p+, n0, e- and possibly γ), energy, flux and biasing conditions
  - Comparison with existing prediction models and clarification of their validity domain
  - Point defect VS clustered defect discussion
- SubTask2.2: Study of the TNID effects statistics in microvolumes (μm^2 scale)
  - Selection of a pixel array to push the previous comparison to the µm scale
  - Comparison of TNID induced **dark current distributions and statistics** at the µm scale
  - Depending on SubTask2.1 conclusion ➔ selection of a few irradiation parameters to explore
  - Improvement of existing statistical models of TNID effects in silicon microvolumes

=> Main Outcome: Guidelines for TNID testing.

RAD NEXT

WP8 - Complementary modelling tools

Frédéric Wrobel, Univ. Montpellier
Giuseppe Lerner, CERN

WP8 - Objectives and Participants

Objectives

Develop and apply tools and approaches for modelling radiation effects on electronics + comparison against experimental results.

These require a multi-physics approach, at radiation-matter interaction, semiconductor physics, circuit level and even facility level.

Participants and associates

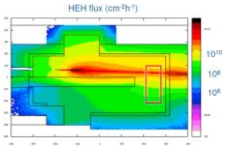
- Université de Montpellier
- CERN
- GSI
- ELI

GSI Helmholtzzentrum für Schwerionenforschung GmbH

eli beamlines

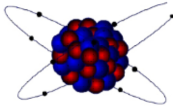
Multi physics / multi scale simulations

Radiative environment



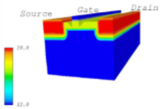
Natural environment, beam facilities (FLUKA)

Particle-matter interaction



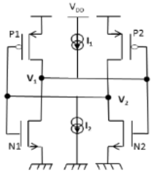
FLUKA, DHORIN

Electrons and holes transport trapping and detrapping



Ecorce, PredicSEE

Effect on the cell (SET, SEU …)



Spice

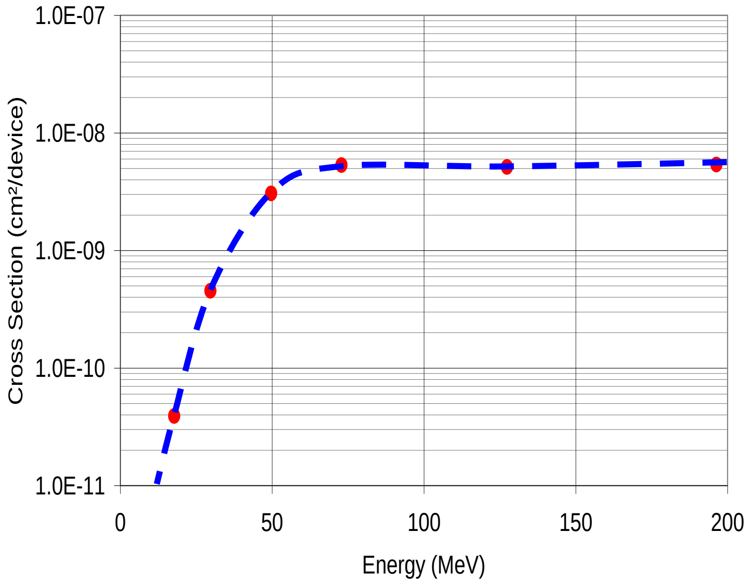
Effect on the system

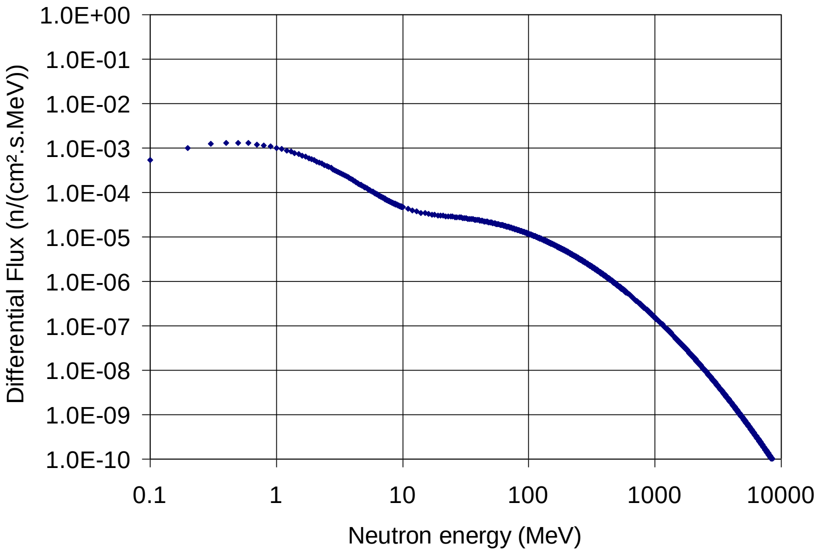
WP8 – structure of tasks

- Task 8.1: Coordination (UM, CERN, GSI, ELI)
- Task 8.2: Impact of low energy particles on SEU rate prediction (UM)
- Task 8.3: Circuit level modelling (UM)
- Task 8.4: Facility modelling (CERN, GSI, ELI)
- Task 8.5: Dose Effect with ECORCE (UM)
- Task 8.6: Integration of SEE event-by-event scoring in FLUKA (CERN)

Example 1: Impact of low energy particles on SEU rate prediction

NEUTRON CASE





When neutron energy decreases :

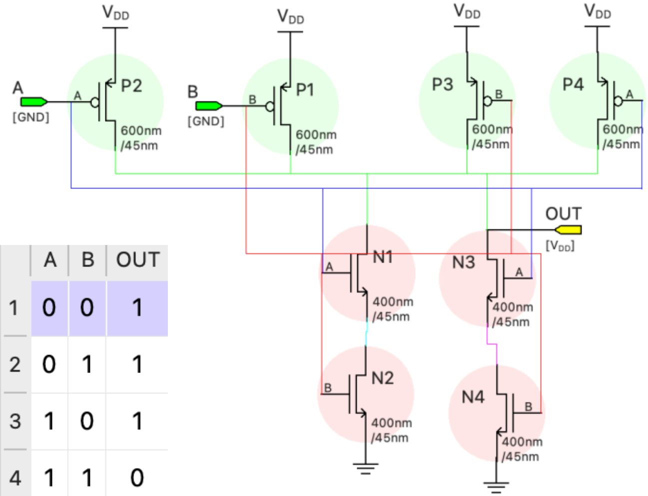
- Device sensitivity decreases
- Neutron flux increases

Need to investigate low energy range because device sensitivity increases with shrinking

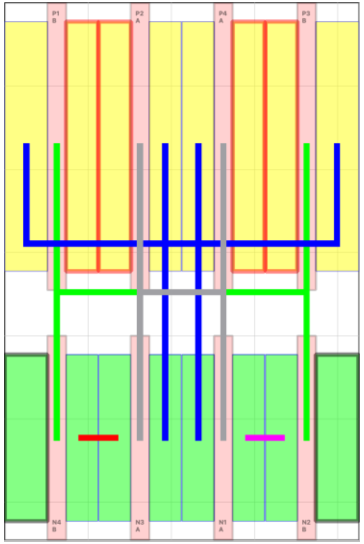
RADNEXT

Example 2: Circuit level modelling with PredicSEE

- Impact on the sensitivity of digital circuits considering:
  - different transistor layout design approaches (i.e., sizing, placement, folding…);
  - the implications of the input stimuli (i.e., sensitive area, driving capability,…).



	A	B	OUT
1	0	0	1
2	0	1	1
3	1	0	1
4	1	1	0



Example 3: Integration of SEE capabilities in FLUKA Monte Carlo code (CERN)

- FLUKA is a general-purpose Monte Carlo code able to describe the transport and interaction of any radiation type in complex geometries

- The aim of this task is to render FLUKA usable and accessible to the radiation effects community:
  - Simple engineer tool
  - Scoring
  - Adapted interface

- A FLUKA course will be organized during the 3rd year of the project

Thank you!