

High Energy Physics and Instrumentation with
the LHC-CERN
Física e Instrumentação de Altas Energias com
o LHC-CERN

EFEITOS DA RADIAÇÃO IONIZANTE EM
DISPOSITIVOS E COMPONENTES ELETRÔNICOS

Centro Universitário FEI, São Bernardo do Campo, Brasil

• COLLABORATION TO SEARCH A SOLUTION

- ✓ Knowledge
- ✓ Creativity
- ✓ Multidisciplinary

.....AND ALSO A LOT
OF EFFORT



Objetivos específicos relacionados ao Estudo dos Efeitos da Radiação Ionizante em Dispositivos Eletrônicos

Compreender

- os mecanismos físicos decorrentes da interação da radiação ionizante com os diferentes materiais, tecnologias e dispositivos eletrônicos
- o comportamento de dispositivos / circuitos / sistemas eletrônicos em ambientes radioativos, por meio de testes EM LABORATÓRIO E SIMULAÇÕES.

Analisar

- os diferentes dispositivos eletrônicos, caracterizando e testando através de uma plataforma específica – detectores de radiação.
- os diferentes materiais que compõem os dispositivos.

Raio X

^{60}Co

Neutrons, prótons
Íons pesados, Laser

Total Ionizing Dose is a cumulative effect caused by trapped charges in the oxide. These trapped charges modify the transistor characteristics such as threshold voltage (V_{th}), mobility, leakage current, power dissipation, etc.

Atom Displacement Damage is provoked by protons, heavy ions, electron with high energy and neutrons, which change the arrangement of atoms in the lattice, modifying electrical properties of a device.

Single Event Effects are caused by particles of high LET (Linear Energy Transfer) due to, for example, the **strike of a single ion**. They can be non-destructive, causing current or voltage peaks, changing the state of a bit, or destructive, burning the device or destroying the gate oxide in a MOSFET.

INTEGRAÇÃO ENTRE PESQUISADORES DE INSTITUIÇÕES BRASILEIRAS E INTERNACIONAIS, COOPERAÇÃO INTERDISCIPLINAR

Capacitação de RH em Projeto e Qualificação de CIs Tolerantes à Radiação
Capacitação de Recursos Humanos e Criação de Infraestrutura para Projeto, Teste e Qualificação de CIs Tolerantes à Radiação.



Temáticos FAPESP: Centro de Pesquisa e Análise de São Paulo; Física e Instrumentação de Altas Energias com o LHC-CERN; Reações nucleares com núcleos fracamente ligados ou com estrutura de cluster, radioativos e estáveis.

COLABORADORES INTERNACIONAIS



UNIVERSITÀ
DEGLI STUDI
DI PADOVA



Nuclear matrix
elements for
neutrinoless double
beta decay

High Energy Physics and Instrumentation with the LHC-CERN

Física e Instrumentação de Altas Energias com o LHC-CERN

Escola de Engenharia/EE/UFRGS

Escola Politécnica/EP/USP

Instituto de Ciência e Tecnologia de
Sorocaba/ICTS/UNESP

Instituto de Física Gleb Wataghin/IFGW/UNICAMP

Instituto de Física Armando Dias Tavares/IF/UERJ

Câmpus Experimental de São João da Boa
Vista/CESJBV/UNESP

Escola de Engenharia/EE/UFGM

Instituto de Física/IF/UFRGS

Instituto de Física/IF/UFRJ

Centro de Ciências Naturais e Humanas/CCNH/UFABC

Universidade Federal do Pampa/UNIPAMPA

Instituto de Pesquisas Energéticas e Nucleares/IPEN/SDE

Centro Universitário FEI

Czech Technical University in Prague/CTU

Brasil - Rio Grande do Sul - Porto
Alegre

Brasil - São Paulo - São Paulo

Brasil - São Paulo - Sorocaba

Brasil - São Paulo - Campinas

Brasil - Rio de Janeiro - Rio de Janeiro

Brasil - São Paulo - São João da Boa
Vista

Brasil - Minas Gerais - Belo Horizonte

Brasil - Rio Grande do Sul - Porto
Alegre

Brasil - Rio de Janeiro - Rio de Janeiro

Brasil - São Paulo - Santo André

Brasil - Rio Grande do Sul - Bagé

Brasil - São Paulo - São Paulo

**Brasil - São Paulo - São Bernardo
do Campo**

República Tcheca - Praga

GRUPO DE TRABALHO 5

Centro Universitário FEI

MARCILEI A. GUAZZELLI
ROBERTO S. S. BAGINSKI
RENATO GIACOMINI
RUDOLF THEODERICH BÜHLER
MARCO ANTONIO ASSIS DE MELO

ALEXIS CRISTIANO VILAS BÔAS
GUILHERME PARREIRA GOMES

Ana Laura Guidi
Paulo Garcia Junior
Isabel
Beatriz

NOVOS COLABORADORES SURGEM COM A DEMANDA

FEI

- ✓ LABORATÓRIO DE EFEITOS DA RADIAÇÃO IONIZANTE – LERI
 - ✓ RAIOS-X COM CALIBRAÇÃO EM DOSE
 - ✓ DIFRATÔMETRO DE RAOS X
 - ✓ PLATAFORMA DE CARACTERIZAÇÃO ELÉTRICA PXI NATIONAL
- ✓ LABORATÓRIO DE FÍSICA DAS RADIAÇÕES – LAFIR
 - ✓ ESPECTROMETRIA GAMA E FLUORESCÊNCIA DE RAIOS X POR DISPERSÃO EM ENERGIA
- ✓ LABORATÓRIO DE SIMULAÇÃO DE DISPOSITIVOS ELETRÔNICOS - TCAD
- ✓ PROBE STATION
- ✓ CARACTERIZAÇÃO SOB EFEITO DE BAIXA E ALTA TEMPERATURA
- ✓ MICROSCÓPIO DE FORÇA ATÔMICA E MICROSCÓPIO ELETRÔNICO DE VARREDURA
- ✓ LABORATÓRIO DE MATERIAIS E MECÂNICA – METALOGRAFIA

LERI – LABORATÓRIO DE EFEITOS DA RADIAÇÃO IONIZANTE

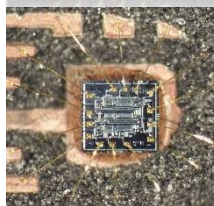
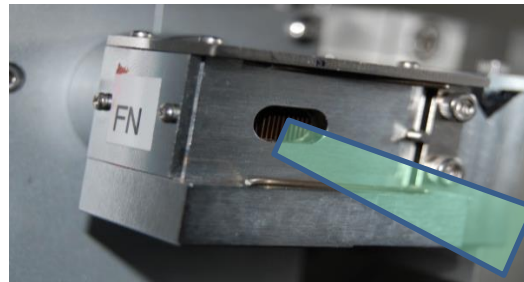
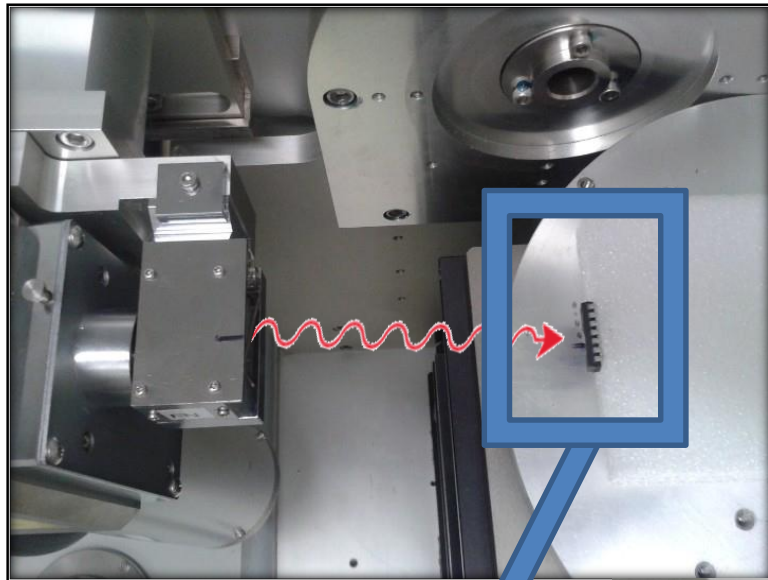
X-ray source
60 kV, 50 mA



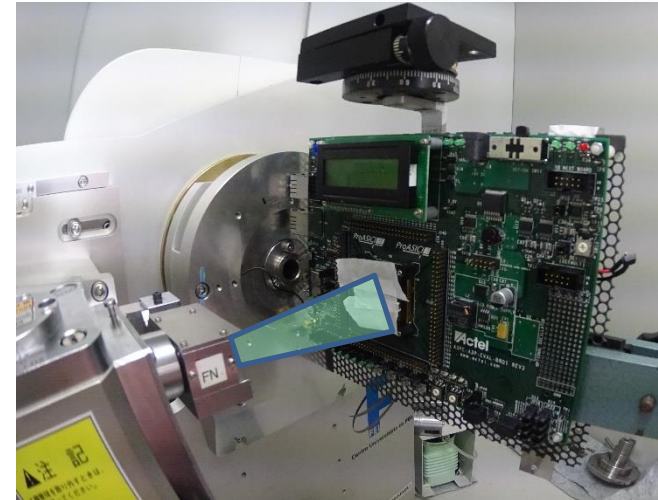
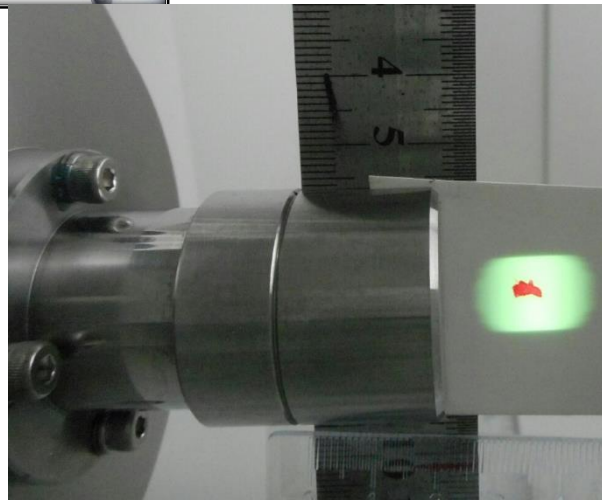
• EXPERIMENTAL SETUP

We have performed several tests on different devices, exposed to different dose rates and total ionization doses.

The total ionizing dose of radiation accumulated in the device is a function of the exposure time.



DIE preparation



Homogeneity of the radiation field



X-RAY SETUP

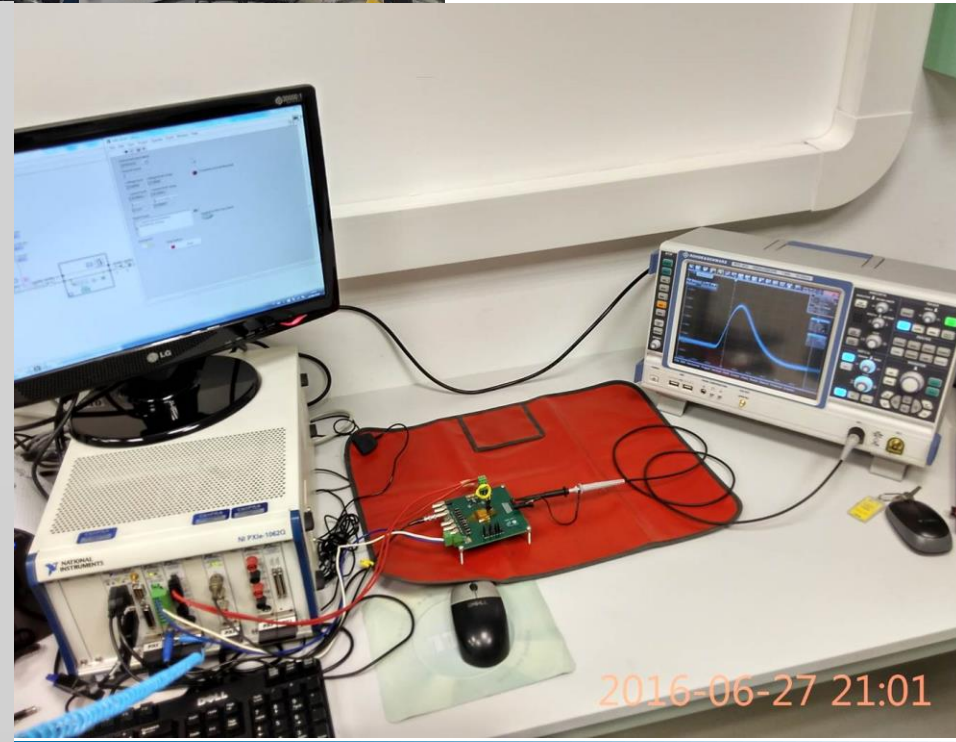
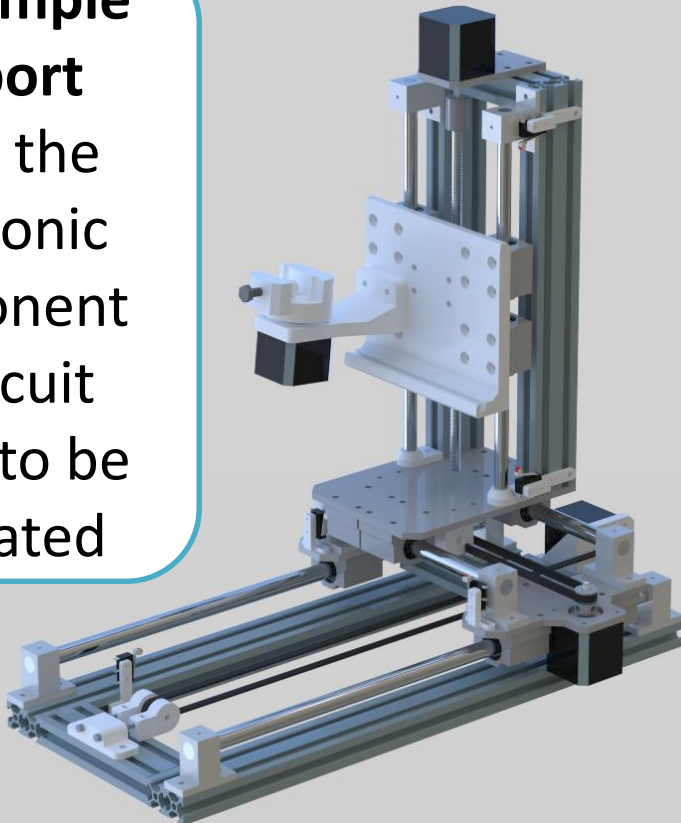
manipulador:

<https://youtu.be/e90mIBE-n0c>

medição de distância:

<https://youtu.be/WdfVwfKudqk>

The **sample support** holds the electronic component or circuit board to be irradiated

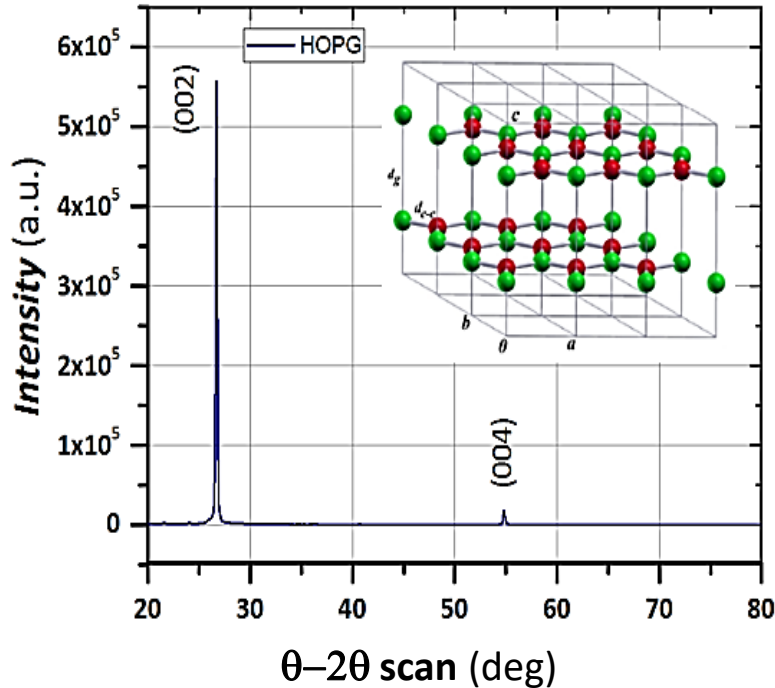


<https://youtu.be/qtmuD0IV2Ag>

MEMECHANICAL AND THERMAL PROPERTIES THAT CAN MODIFY A DEVICE'S FUNCTIONALITY

X-ray θ -2 θ Diffraction

crystallographic perfection



High degree of purity and high ordering of the atoms in the HOPG crystal lattice

HOPG not irradiated and irradiated with neutrons

Highly Ordered Pyrolytic Graphite

HOPG is a stacking of graphene sheets with a slight disorientation between each other

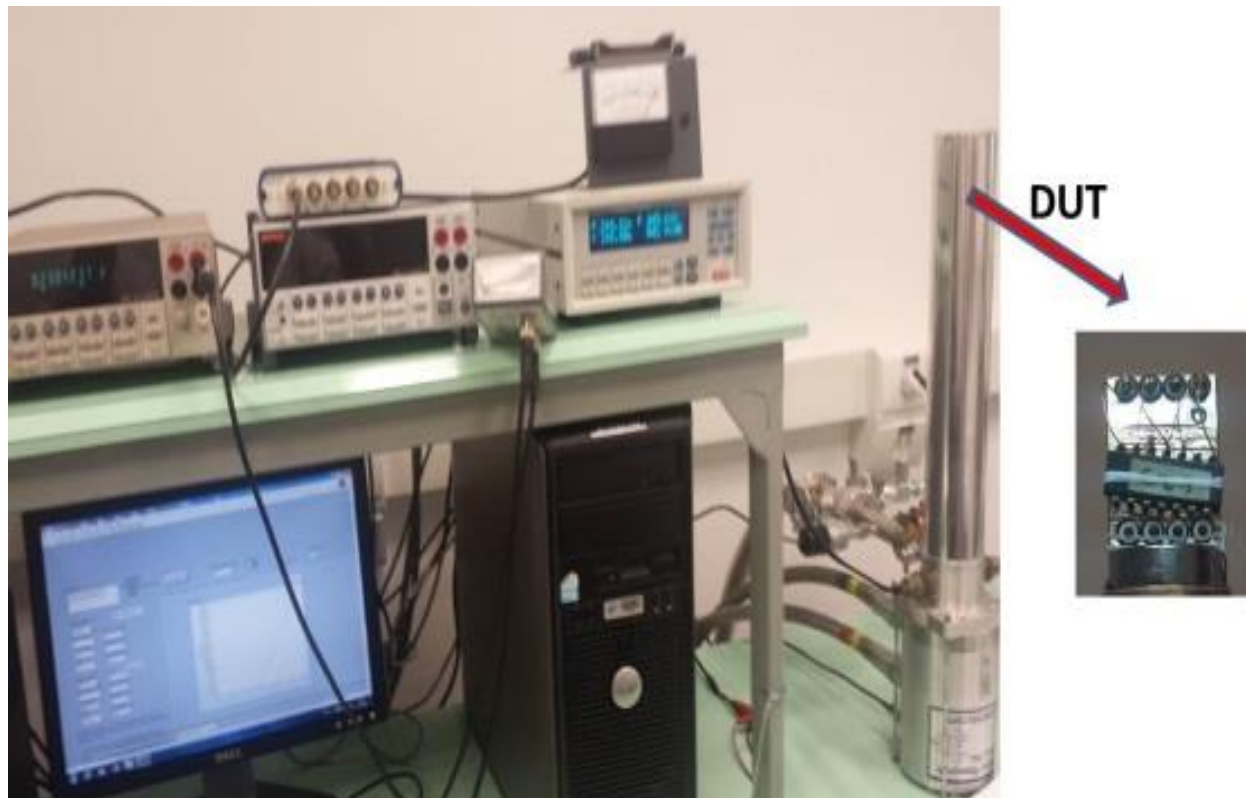
For the **HOPG** to act with thermal energy dissipation functionality **IT IS NECESSARY TO VERIFY WHETHER POSSIBLE CHANGES CAUSED BY EXPOSURE TO THE RADIATION BEAM HAVE A DIRECT OR INDIRECT INFLUENCE ON ITS THERMAL PROPERTIES.**

0.25% concentration of defects in **graphene** result in significant reduction of thermal conduction property of graphene by around **50%**"

Characterization of devices under the influence of temperature before and after radiation.

- ARS-2HW closed cycle cryocooler, equipped with a Lakeshore temperature controller.

Helium compressor and the refrigerator allow temperatures from -50°C to 70°C .



Laboratório de Microeletrônica

INFRAESTRUTURA:

1x Keysight Semiconductor
Characterization System B1500A;
2x Keythley Semiconductor
Characterization System 4200 SCS;
1x Keithley CV Unit 4200 CVU;
1x Keythley Pulse I-V System 4200 SCS;
1x Keithley CV Analyzer 590;
1x Agilent Semicondutor Parameter
Analyzer 4156C;
1x Agilent CV 4395A;
1x K-20 da MMR Technologies form low
and high temperature characterization
from 80K to 730K;
1x Cascade Microtech REL 3600;
1x Signatone S1160B;
1x vacuum pumping system

Available Softwar

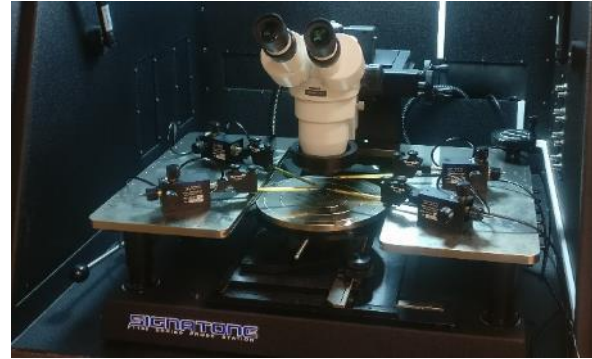
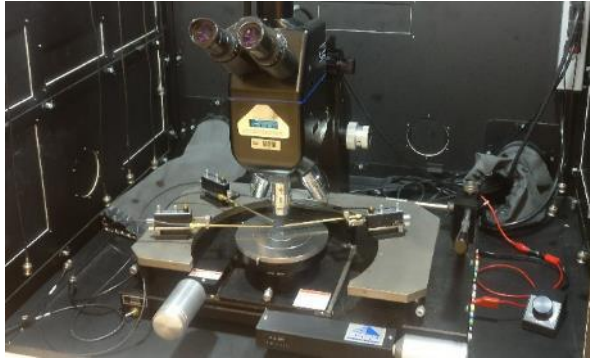
Synopsys TCAD;

Silvaco TCAD;

Cadence for layout design;

Mentor Graphics for layout design.

Laboratório de Microeletrônica

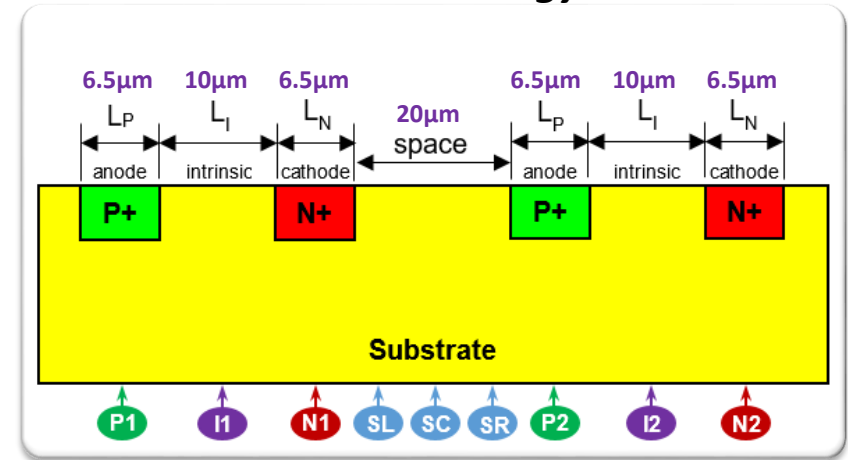


Simulações de efeitos da radiação

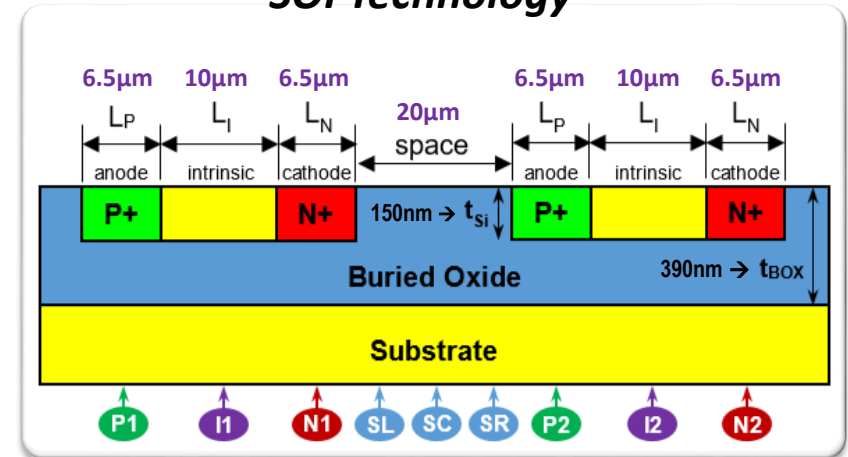
The Analyzed PIN Sensor Array

Developed in IBM BiCMOS 8HP 0.13 technology with MOSIS support

Bulk Technology



SOI Technology



Proposed Array

- $V_{cat} = 0.5 \text{ V}$ (reversely polarized)
- Anode & Substrate \rightarrow GND

Numerical Simulation's Comparison Study

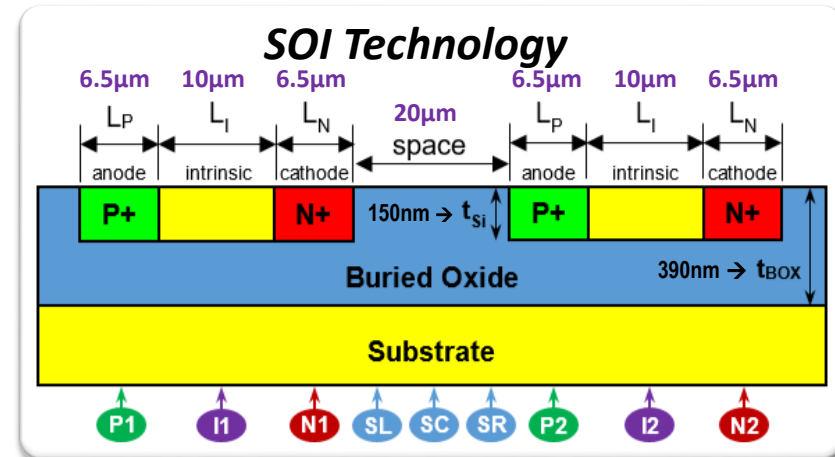
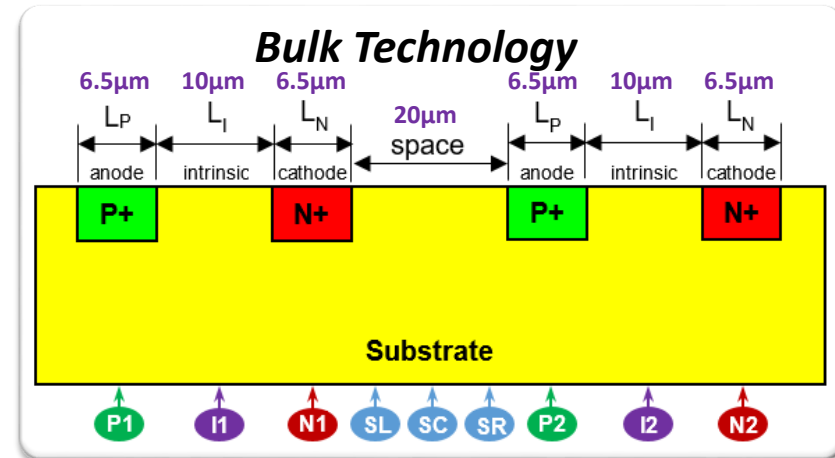
Simulações de efeitos da radiação

Pre-radiation model's characteristics:

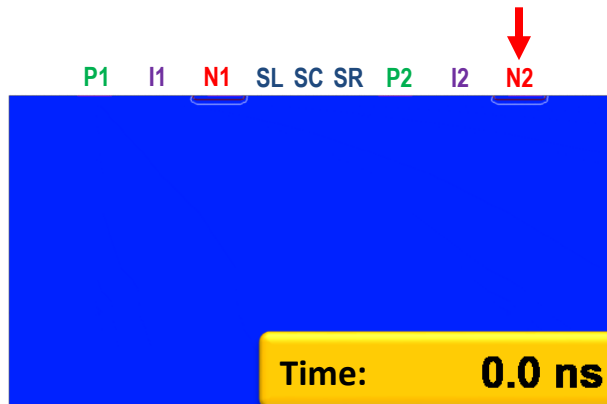
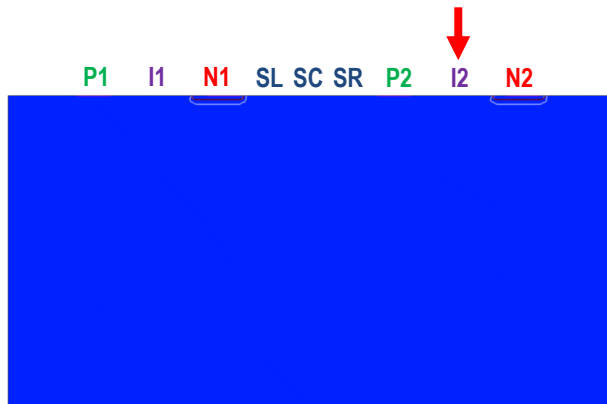
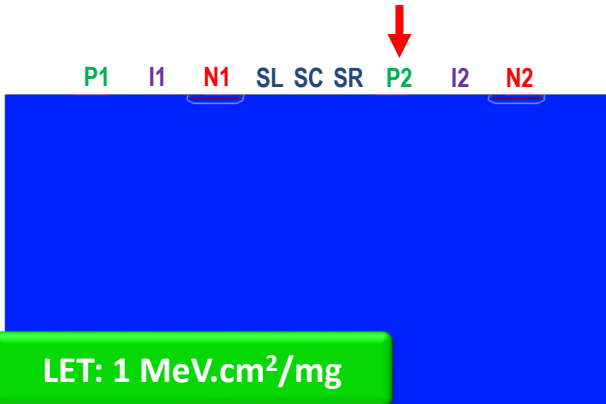
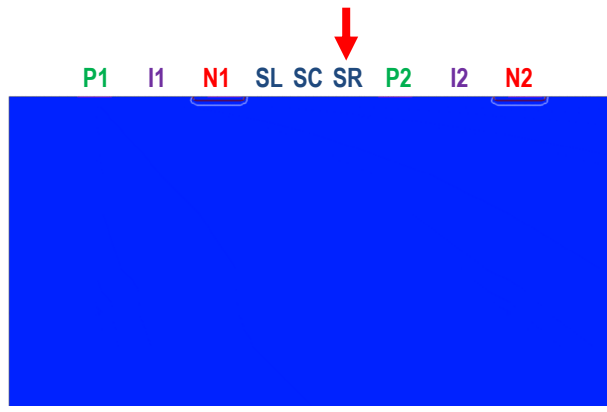
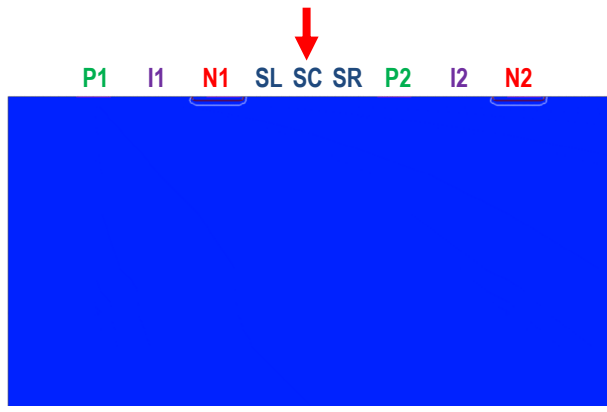
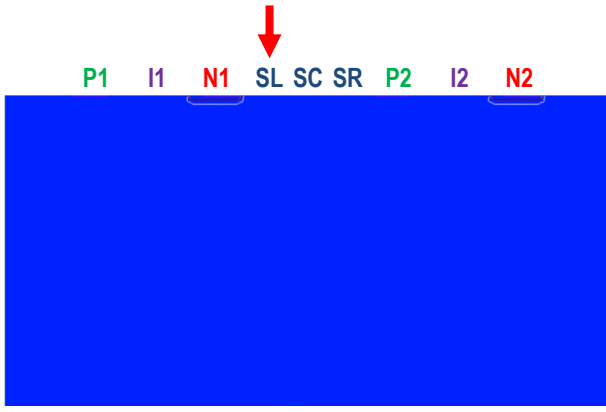
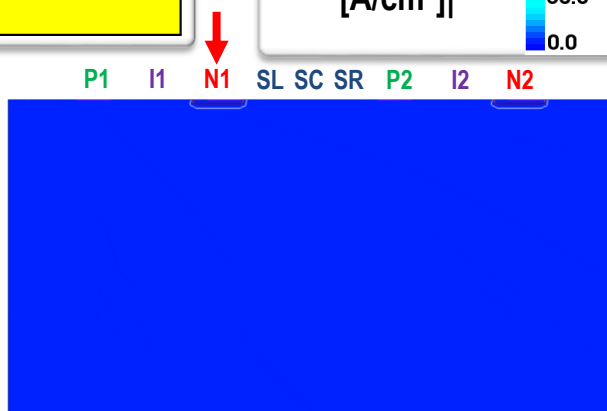
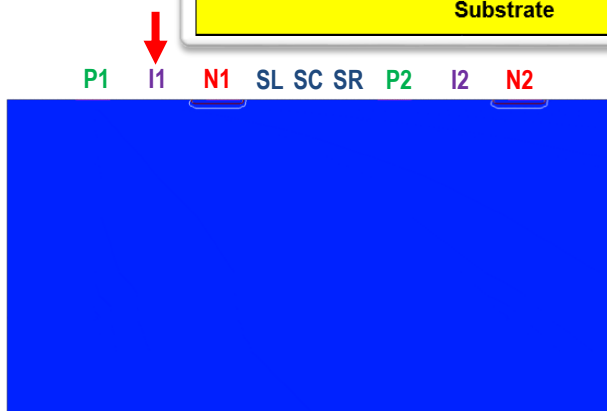
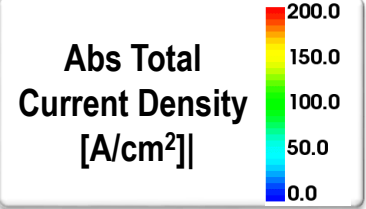
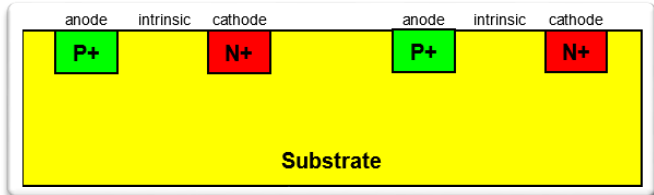
- PIN dimensions match experimental devices
- Mobility and carrier's lifetime parameters adjusted with experimental data

SEE Parameters:

- Heavy-Ion LET = 1 and 10 MeV.cm²/mg
- Strikes vertically at specified positions
- Strike time: $t^* = 1.0$ ns
- Total transient time: 2.0 μ s

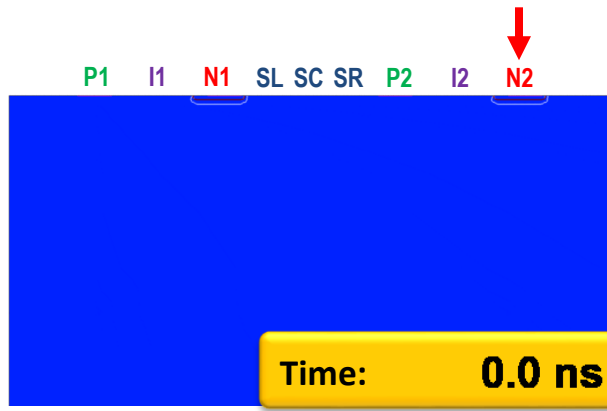
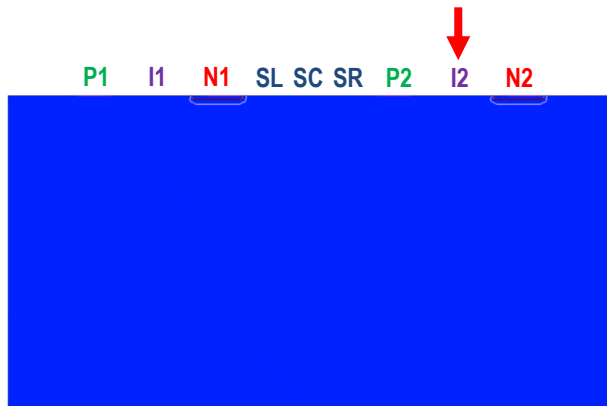
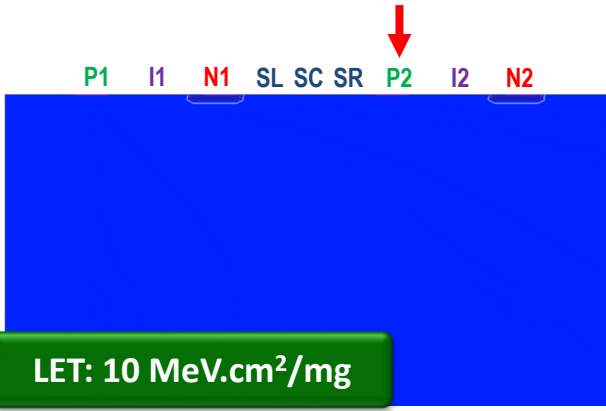
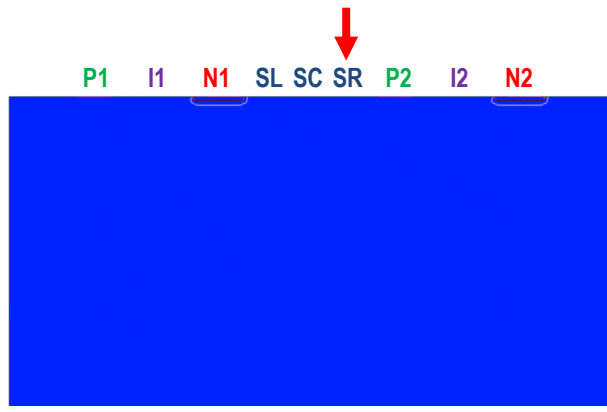
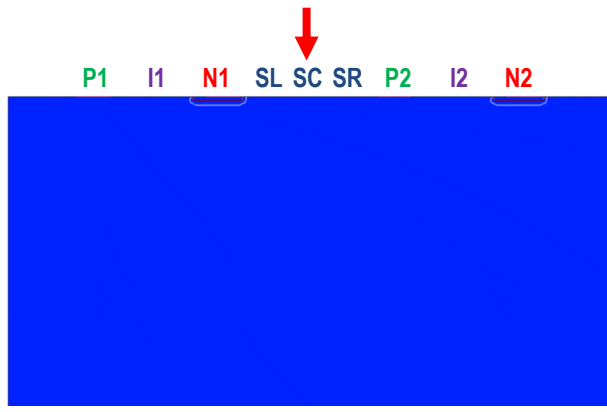
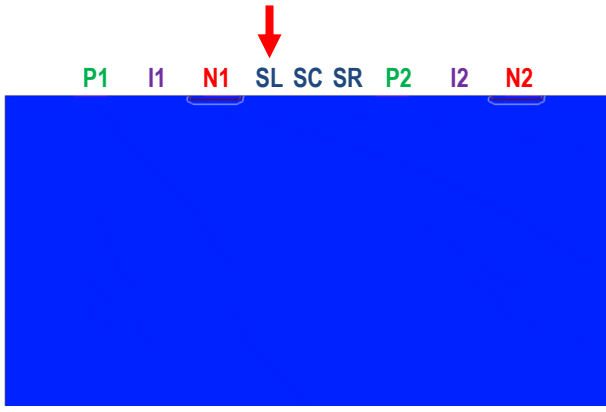
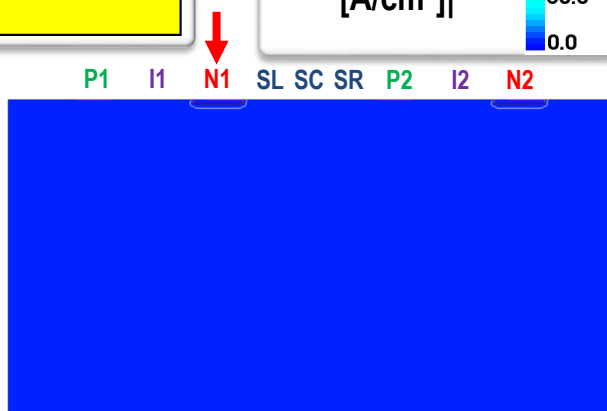
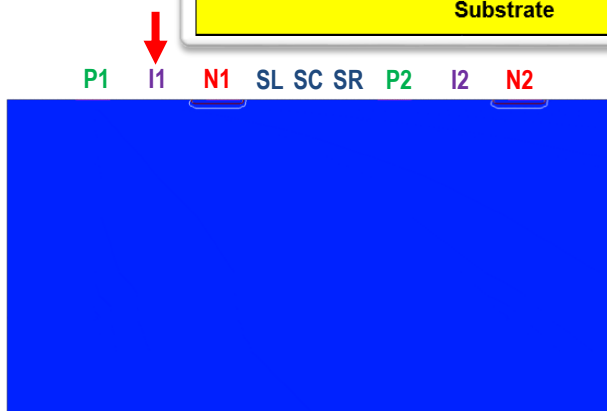
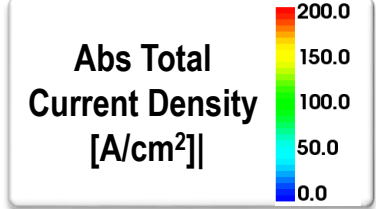
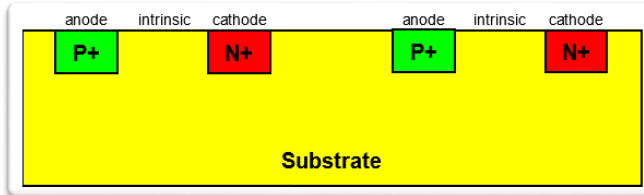


**Numerical Simulation's
Comparison Study**



LET: 1 MeV.cm²/mg

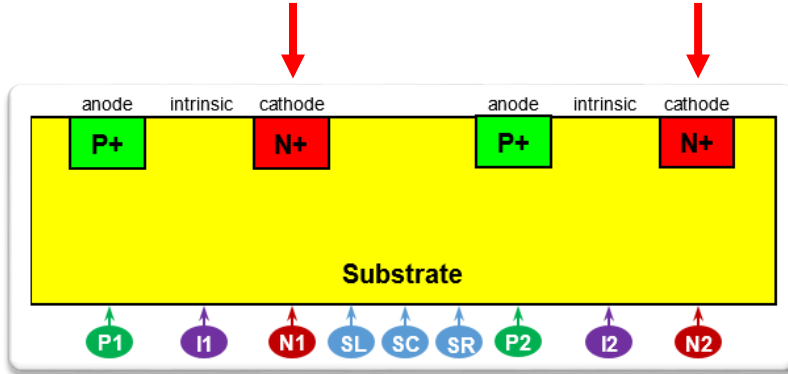
Time: 0.0 ns



LET: 10 MeV.cm²/mg

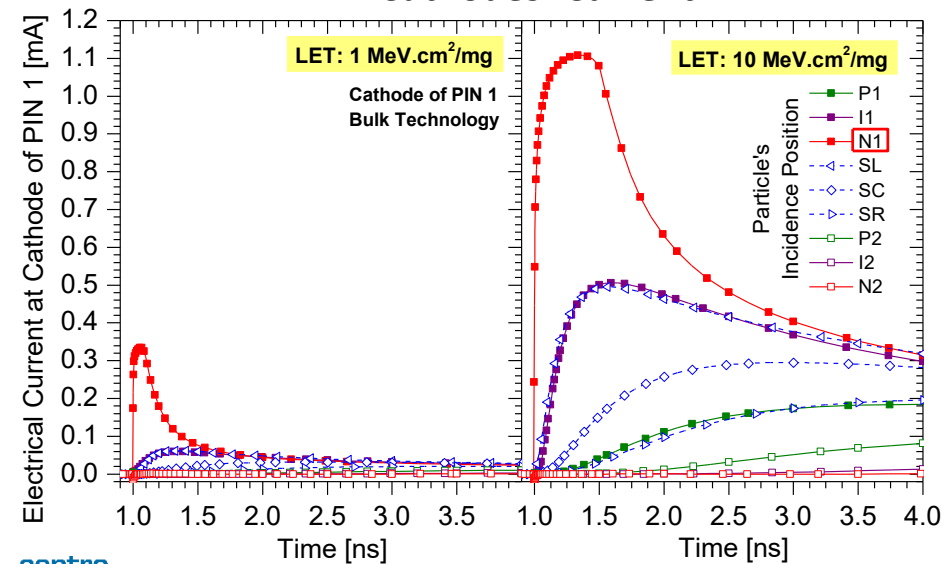
Time: 0.0 ns

Simulações de efeitos da radiação

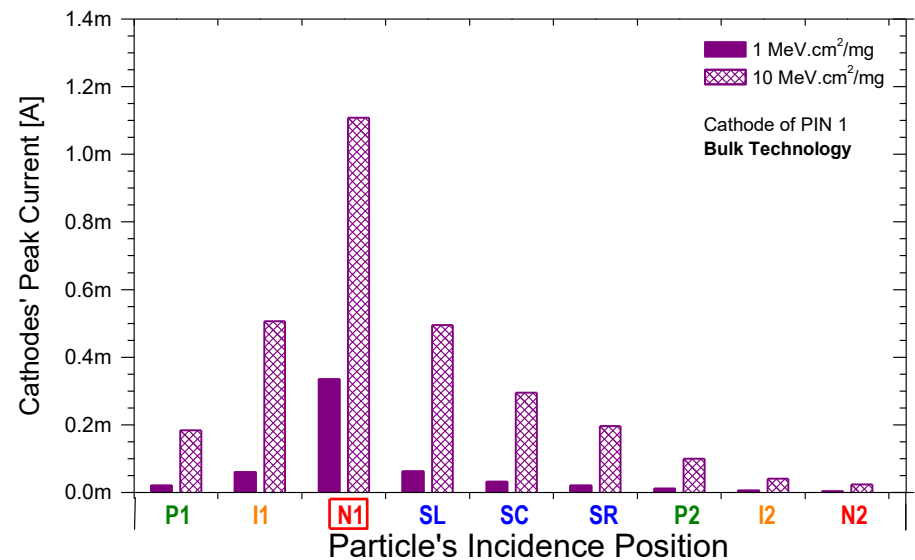


- Generated e-h pairs forms a “funnel” that distorts the depletion layer;
- Prompt current component (drift) produces the peak;
- Remaining e-h creates the delayed current component (diffuse).

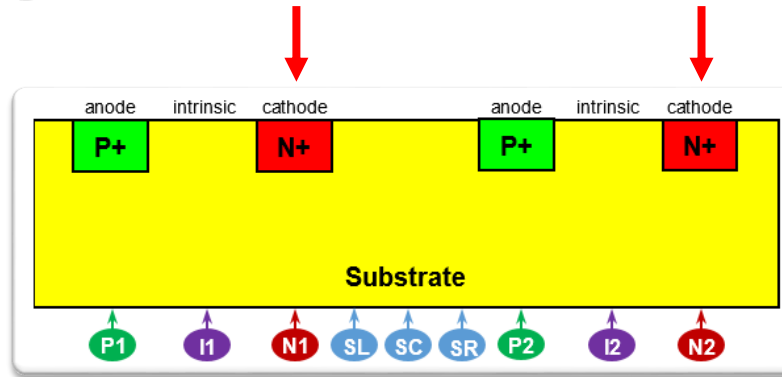
PIN 1 Cathodes' Current



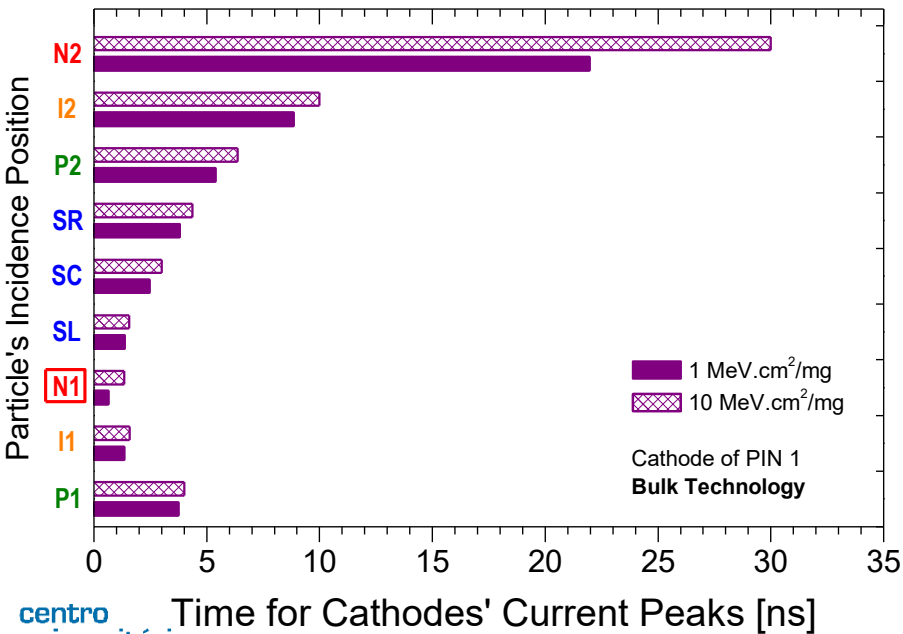
PIN 1 Cathodes' Peak Current



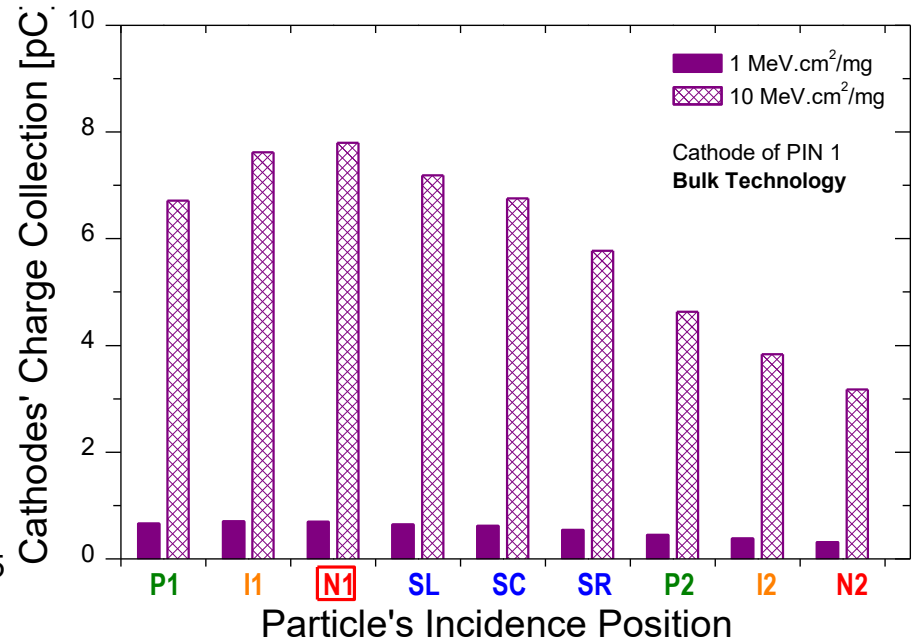
Simulações de efeitos da radiação



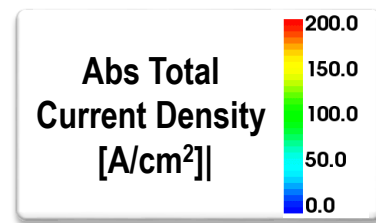
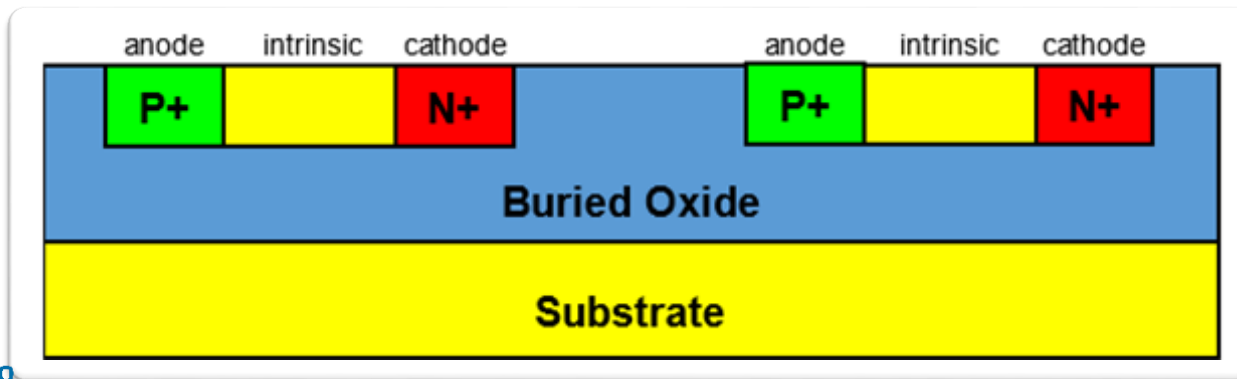
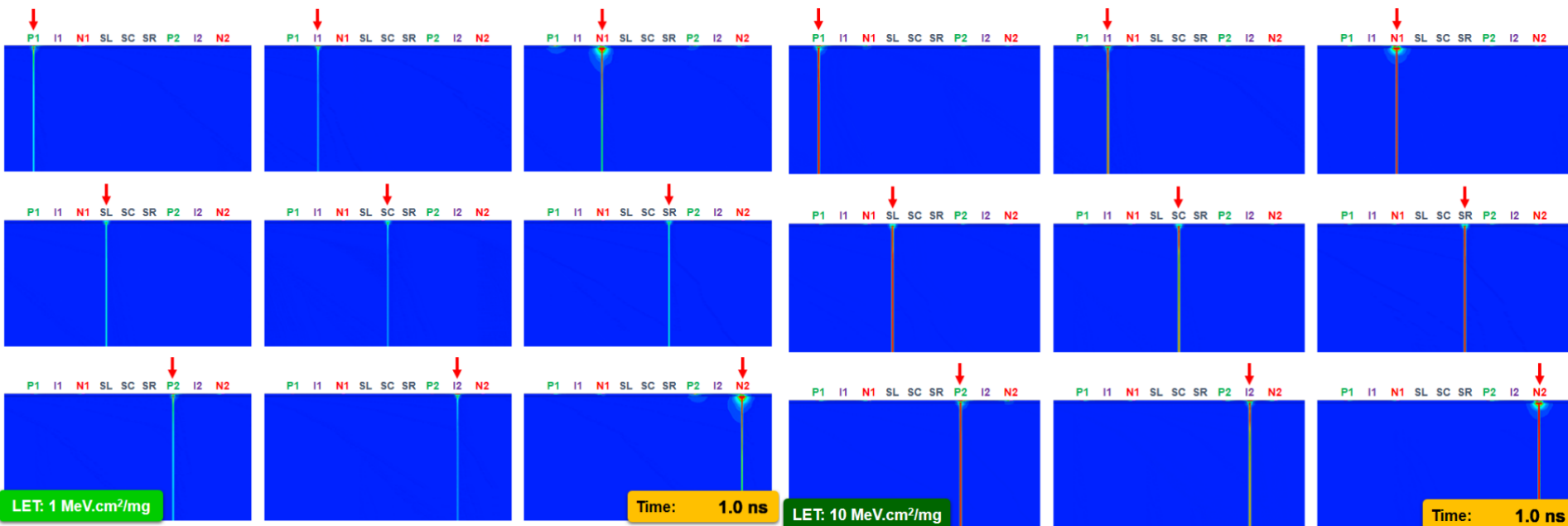
PIN 1 Time for Peak Current



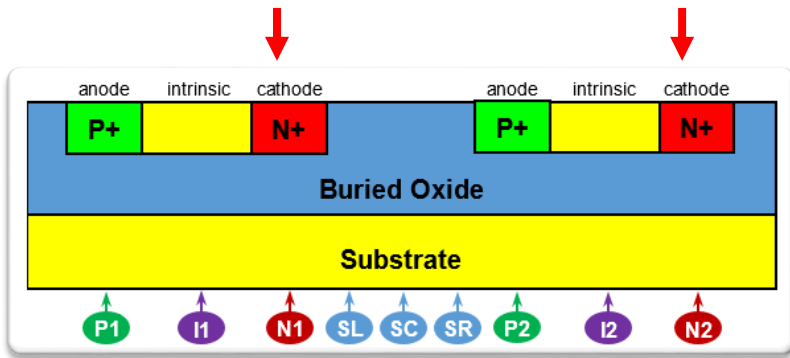
Charge Collected at PIN 1' Cathode



SOI Technology

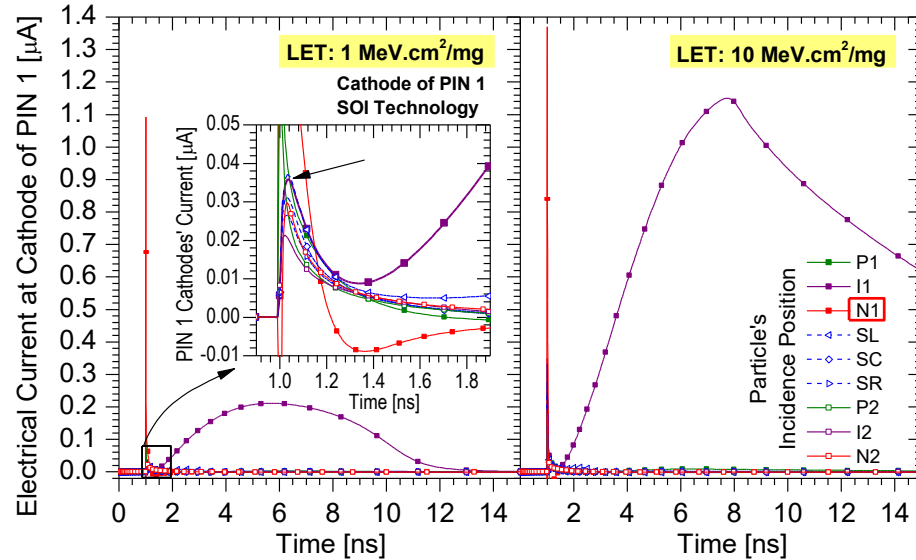


SOI Technology

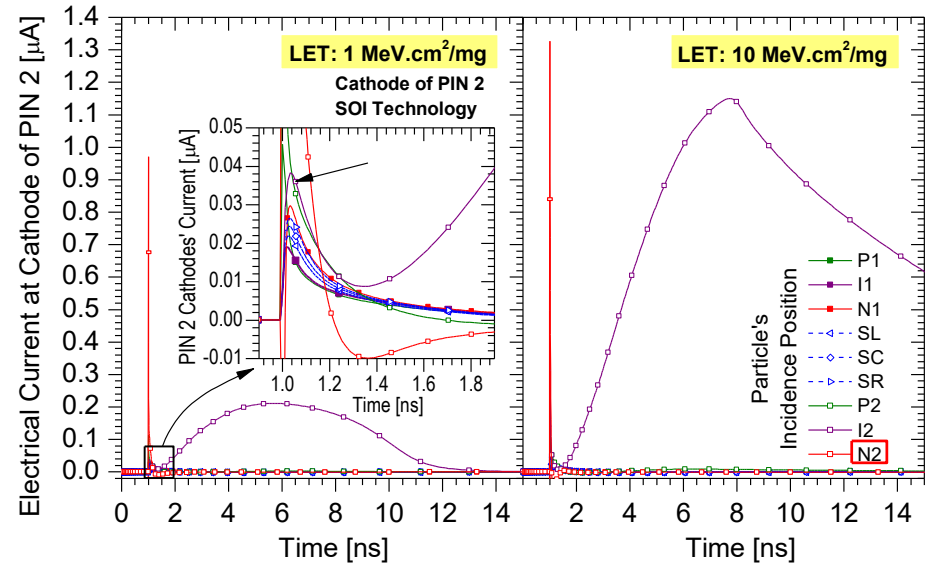


2 peaks: 1st about 1 ns wide;
2nd when the particle hits I1 and I2.

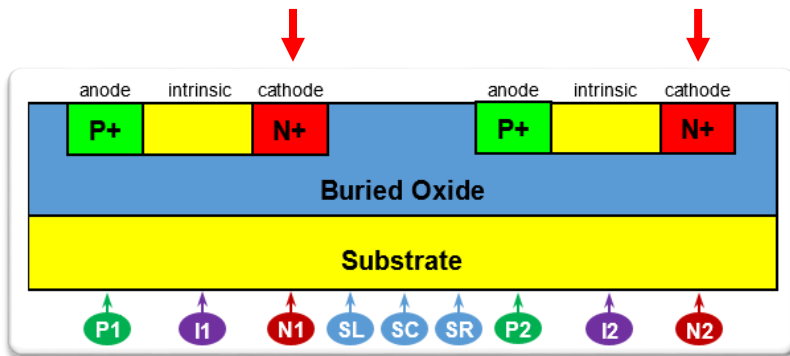
PIN 1 Cathodes' Current



PIN 2 Cathodes' Current

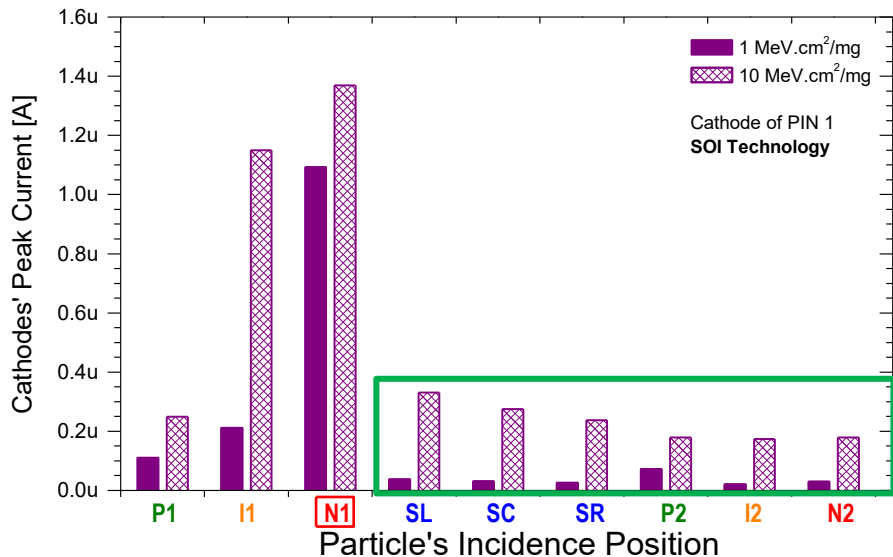


SOI Technology

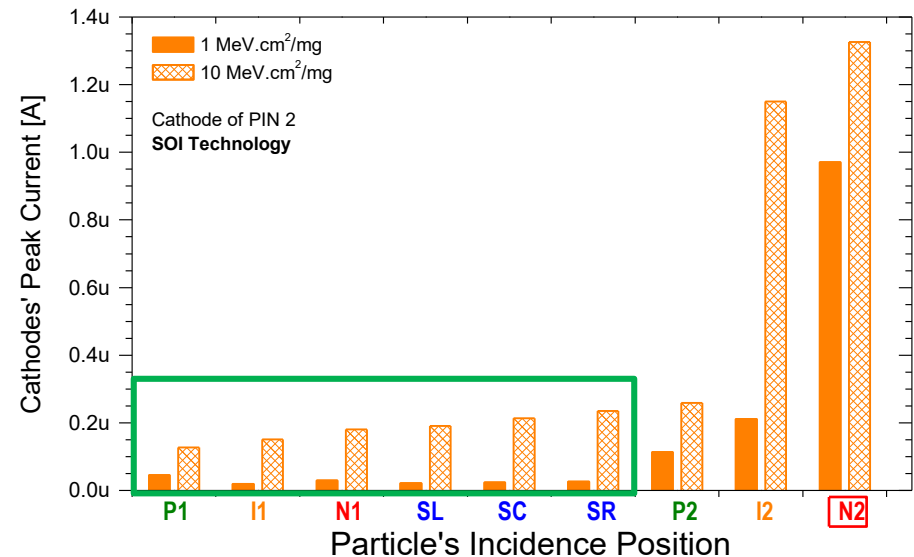


- For I1 and I2, 2nd peak was considered;
- The radius of detection is limited to its own active region*;
- Small current can be detected in the nearby diodes (generated substrate charges).

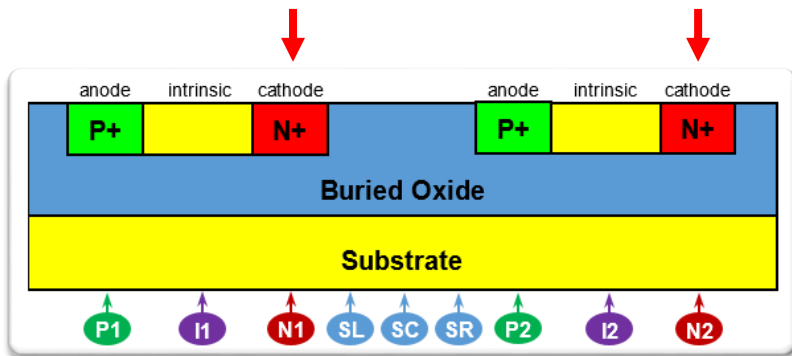
PIN 1 Cathodes' Peak Current



PIN 2 Cathodes' Peak Current

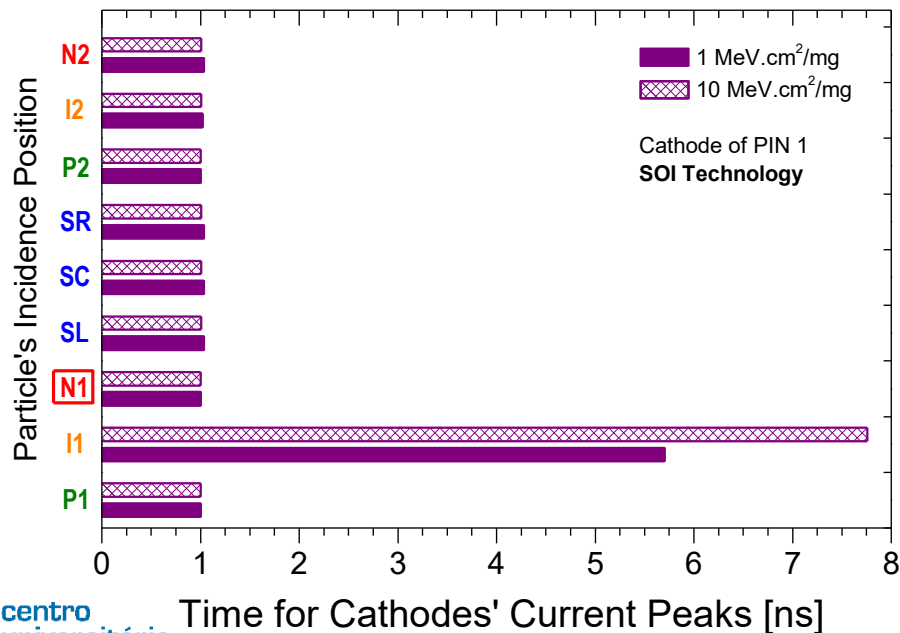


SOI Technology

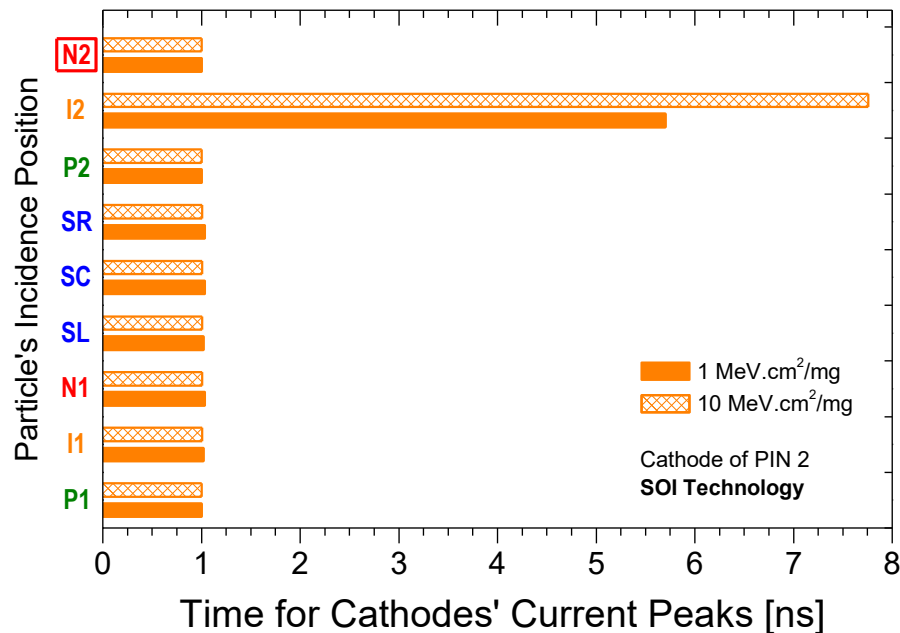


- The delay is virtually the same in nearby PINs;
- 1st peak has the same delay as others (another reason for choosing second peak).

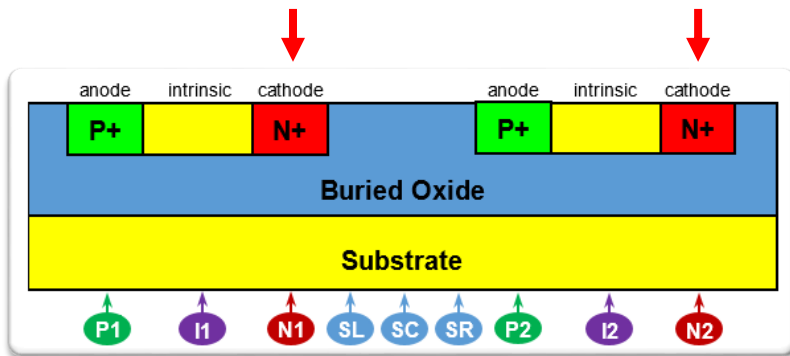
PIN 1 Time for Peak Current



PIN 2 Time for Peak Current

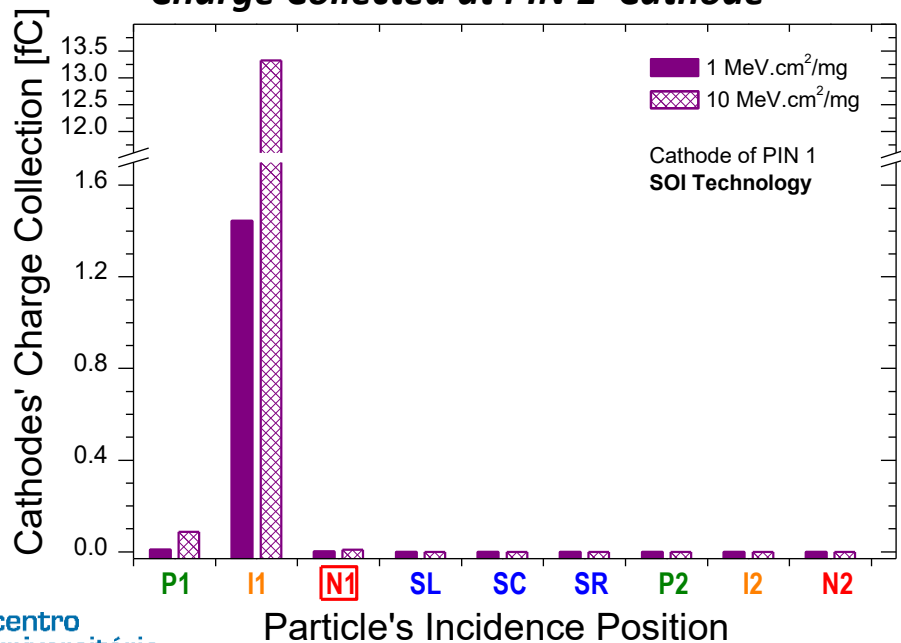


SOI Technology

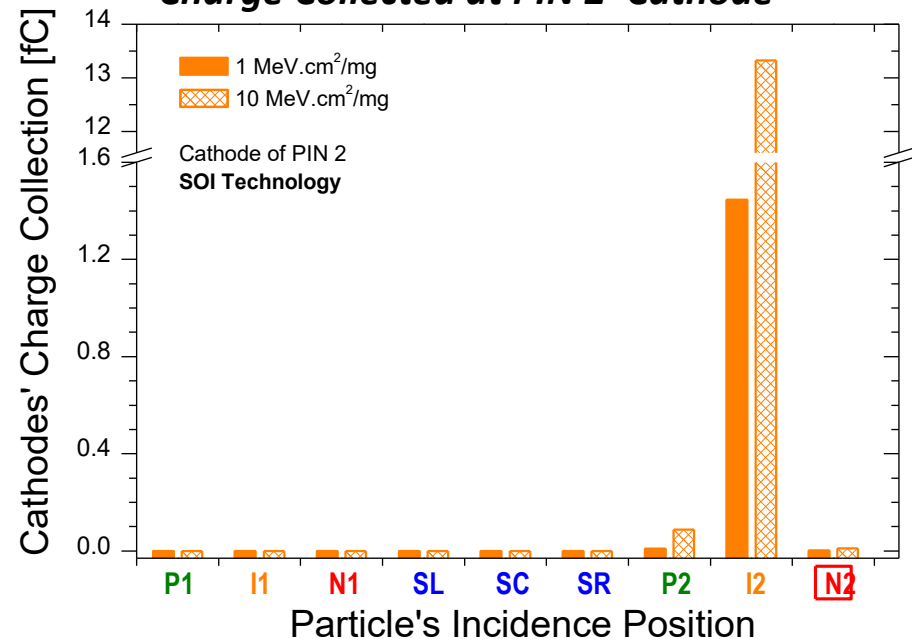


- ~ 5 x lower than bulk in the I1 and I2 regions;
- Remaining regions return almost constant values, near tens of zC (10^{-21} C);
- Impractical to be read by standard equipment.

Charge Collected at PIN 1' Cathode



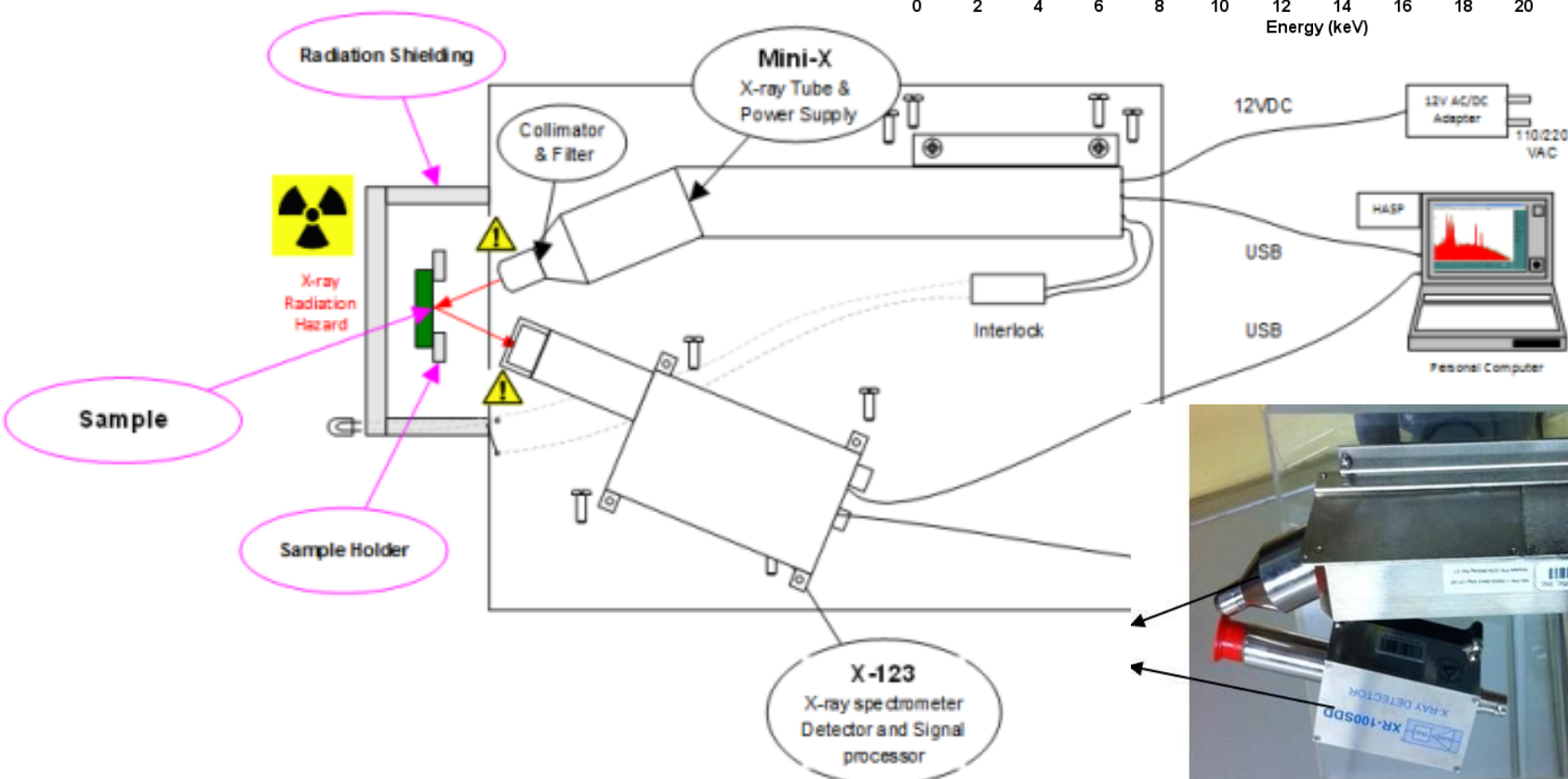
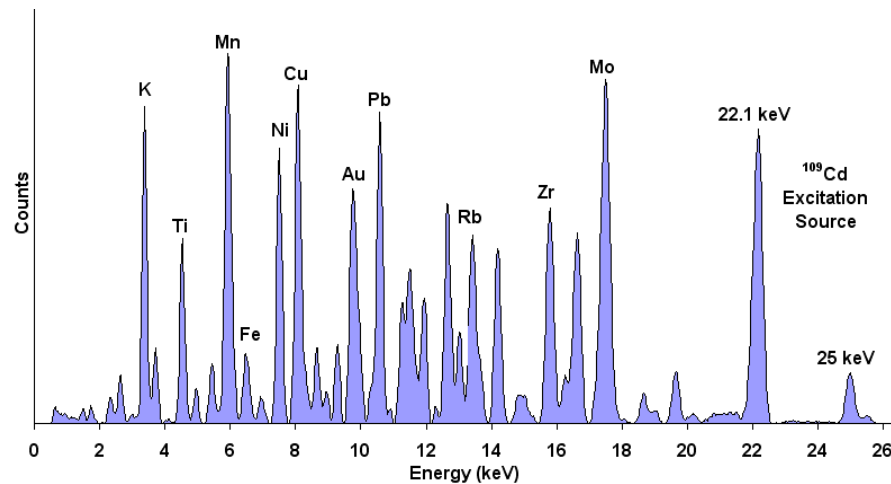
Charge Collected at PIN 2' Cathode



• LAFIR – LABORATÓRIO FÍSICA DAS RADIAÇÕES

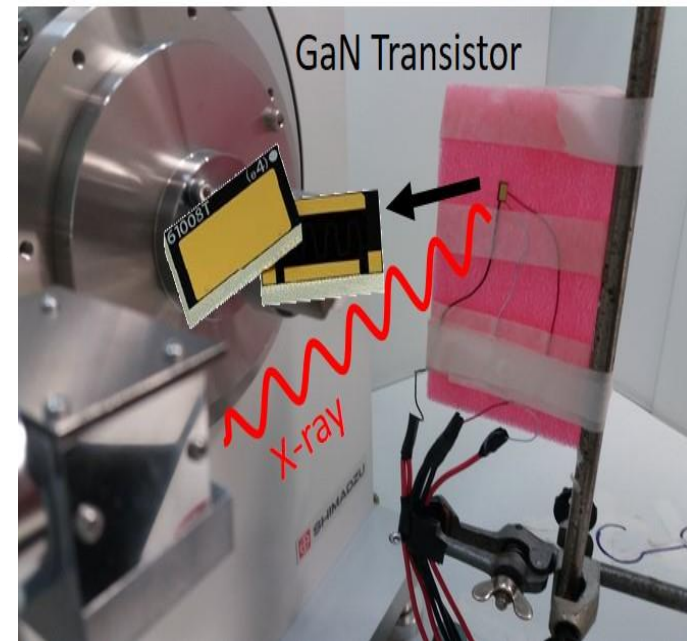
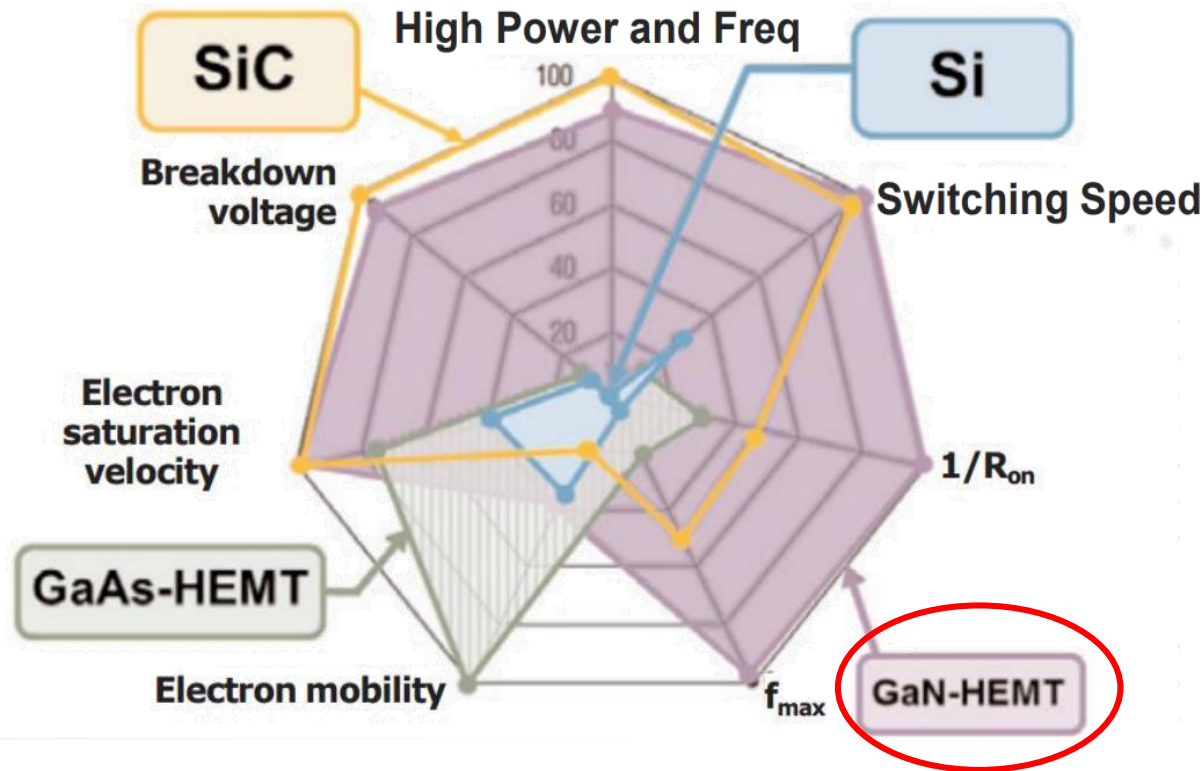
Energy Dispersive X-ray Fluorescence (EDXRF)

X-ray Fluorescence techniques used for elemental analysis applications.

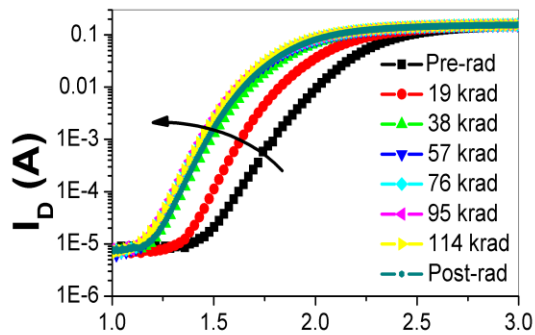


DEVICES AND NEW TECHNOLOGIES

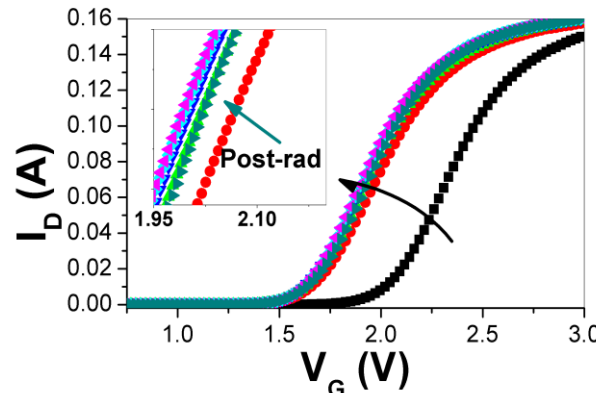
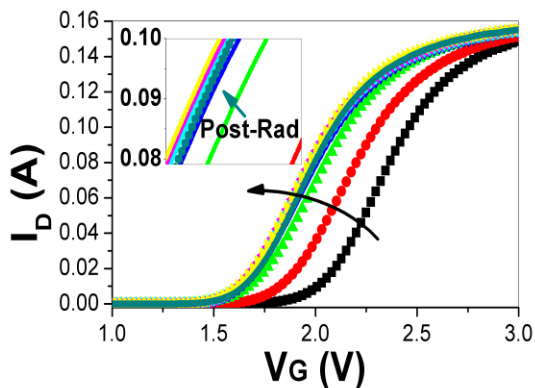
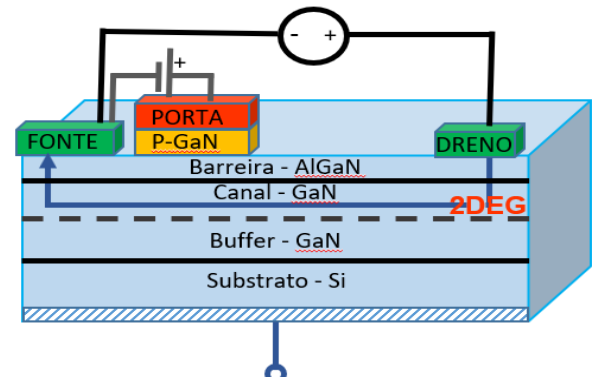
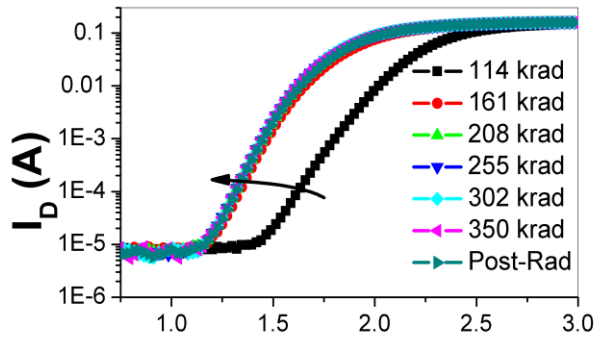
TECHNOLOGY COMPARISON: SI (MORE TRADITIONAL), SiC, GaAs, **GaN**
THE NEWEST TECHNOLOGY IN THIS AREA!



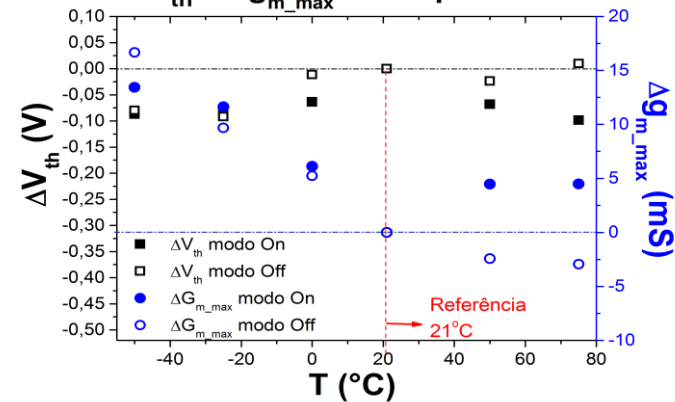
$I_D \times V_G$ - 1st Step - Mode Off



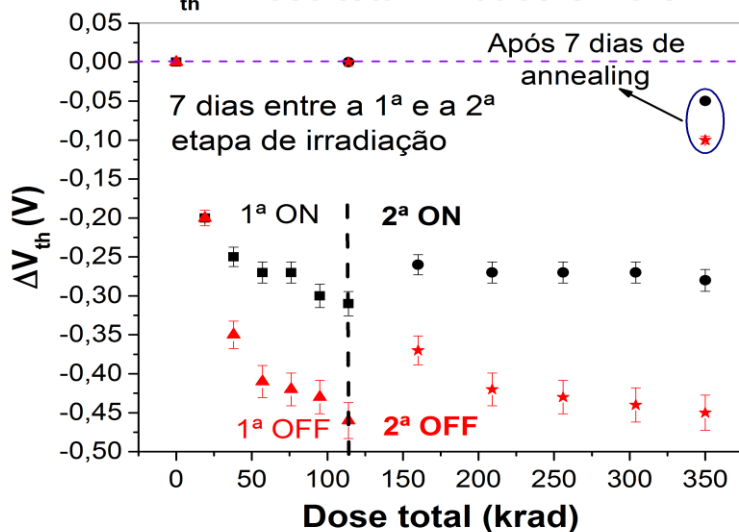
$I_D \times V_G$ - 2nd Step - Mode Off



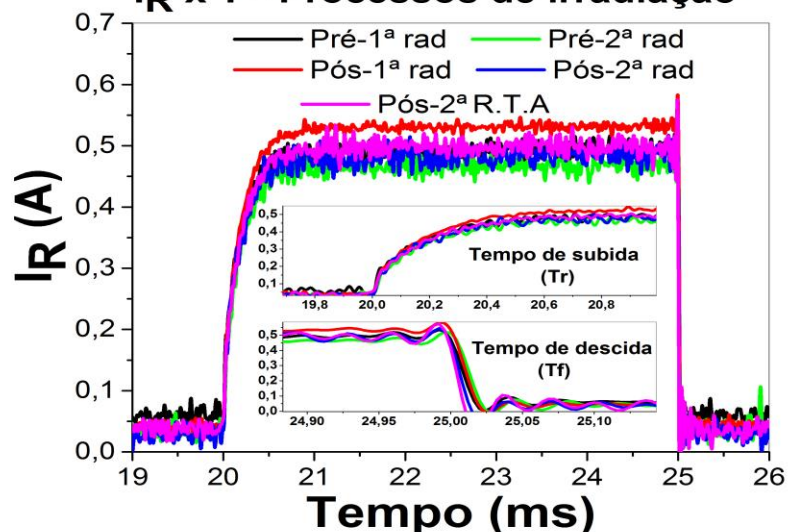
ΔV_{th} e Δg_{m_max} x Temperatura



ΔV_{th} x Dose total - Modos ON e OFF



$I_R \times T$ - Processos de irradiação

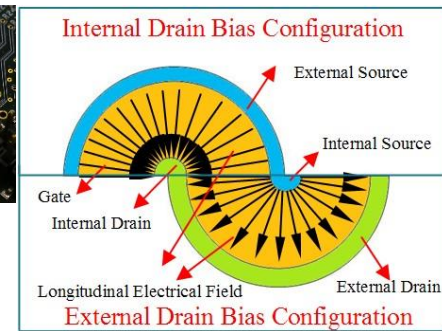
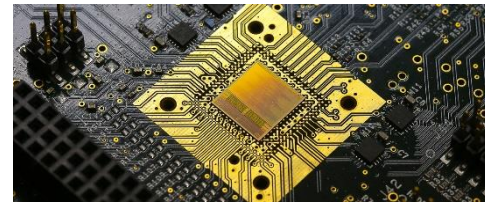


RESEARCHES

COTS: Commercial off-the-shelf devices on reliable designs for space, medical and high energy physics applications. Usually a COTS have a lower cost, easy acquisition and more technical resources than radiation-hardened devices.



ASICs: Application-specific integrated circuits. It is an integrated circuit (IC) customized for a particular use, rather than intended for general-purpose use.

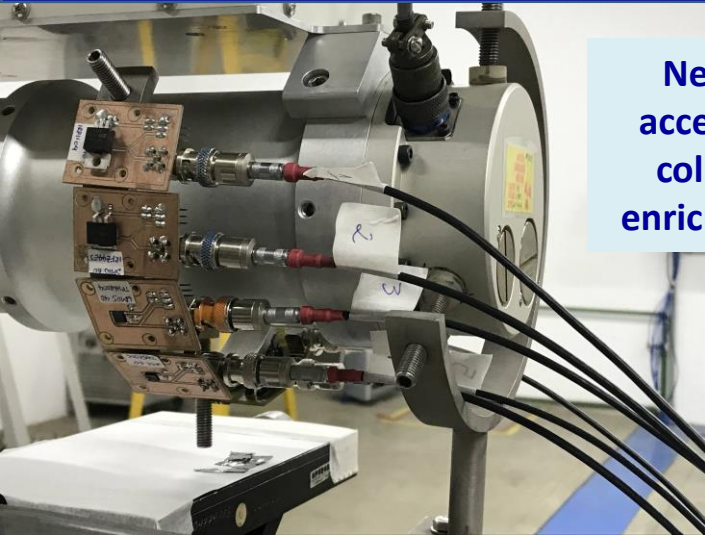


RAD-HARD DEVICES

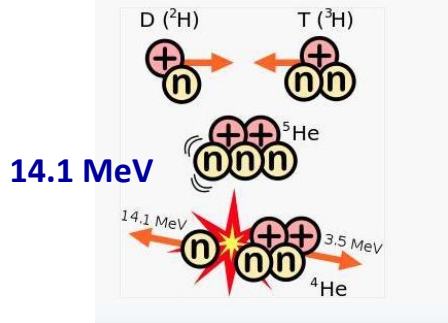
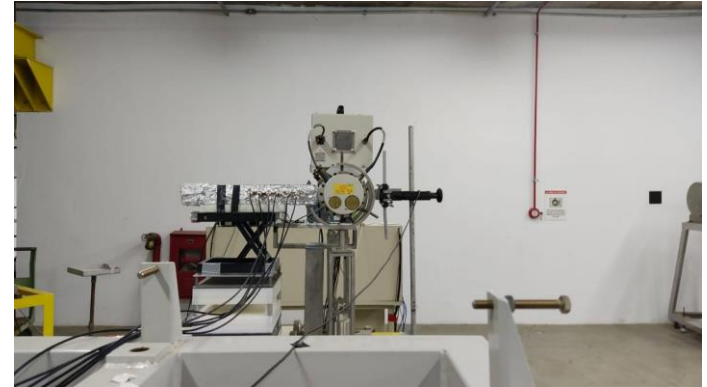
Integrity of HOPG sheets used as heat sink in nuclear reaction
Radiation effects on electronic devices

NEUTRON 14 MeV

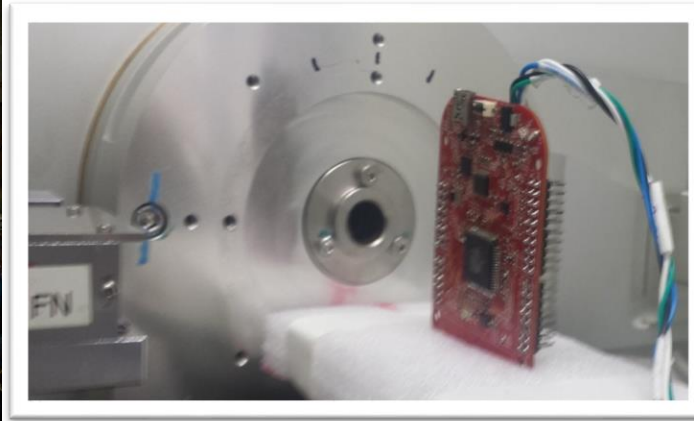
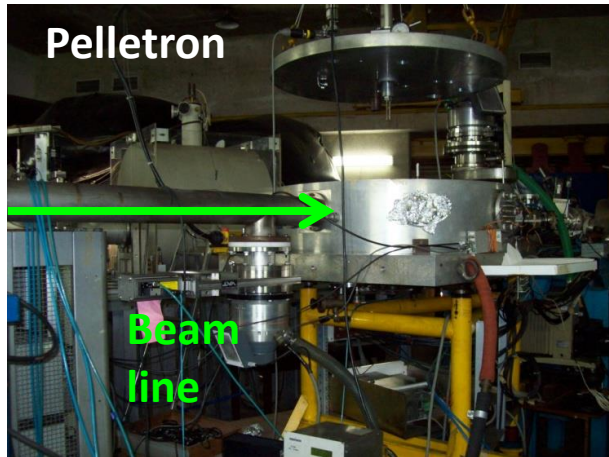
THE EXPERIMENT



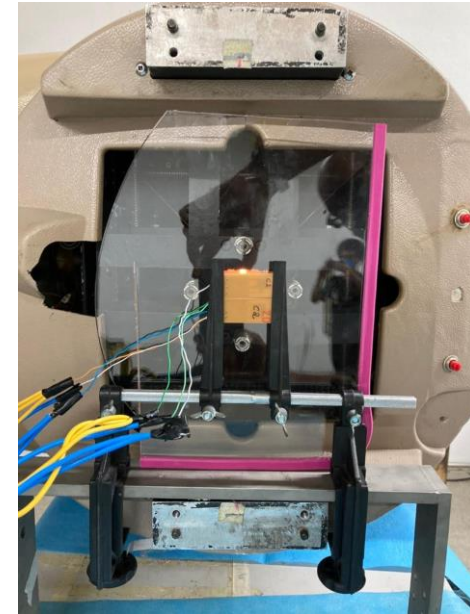
Neutron generator:
accelerated deuterons
collide with Tritium-
enriched titanium target



EXPERIMENTOS



Co-60



OBRIGADA



Centro Universitário FEI, São Bernardo do Campo, Brasil