WP05-JRA1 Radiation monitors, dosimeters and beam characterization

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RADNEXT 3rd Annual Meeting – 10/11 June 2024
https://indico.cern.ch/event/1348465/

WP05-JRA1: Main Objective

- **define and answer** RADNEXT facilities and user needs in terms of **radiation detectors, beam instrumentation and dosimetry.**
  - **12 RADNEXT partners** involved in WP05
  - **21 members** in the CERN e-group

KUL **UU** **GANIL** **GSI**

UJM **CERN** **UniPD** **UO** **UM** **TRIUMF** **FINT** **UKRI**

WP05-JRA1: Three main technical tasks

1. **Definition of the correlation matrix between the facility needs and the established or innovative monitoring solutions** as well as the **definition and standardization of the relevant beam parameters to be monitored** across the facility network
2. **To investigate innovative instrumentation** regarding their potential high impact on facility operation and optimization of radiation to electronics testing
3. **To develop, characterize and qualify low-cost detectors and dosimeters** and have them accessible to RADNEXT users

Main objective: rendering the facility network more accessible, homogeneous and complementary

WP05-JRA1 Task 5.2 : Definition of the RADNEXT facilities & users instrumentation needs, inter-laboratory comparison

CARL VON OSSIETZKY UNIVERSITÄT OLDENBURG

- **Task Leader:** UO (Björn Poppe)
- **Participants:** *TRIUMF, UJM, UU, CERN, FINT, UnPd, Ganil, GSI, UKRI-STFC*
- **PhD student Andreas PFLAUM**

Andreas PFLAUM

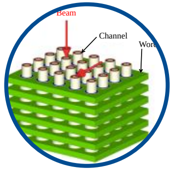
- ***5.2.1 -*** *Definition of the correlation matrix between RADNEXT facilities needs and established or innovative sensing solutions*
- ***5.2.2 -*** *Definition and Standardization of Relevant Beam Parameters*
- ***5.2.3 -*** *Improving the comparability and accuracy of beam and dose parameters*

➔ **Next talk: Recent progress by Andreas PFLAUM (UO)**

WP05-JRA1 Task 5.3 : Innovative instrumentation applied to RADNEXT facilities

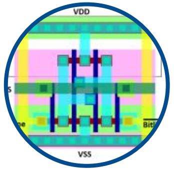
- **Task Leader:** UJM
- **Participants:** *TRIUMF, CERN, FINT, GSI, UniPD, UU, GANIL, UKRI-STFC, KUL*
- **PhD student L. Weninger UJM**

Optical Fiber-based solutions*



3D NAND Flash SEU monitor **

Characterization of neutron fields **



SRAM Dosimetry

WP05-JRA1 Task 5.3 : Fiber-based solutions

Luca WENINGER

- ✓ Neutron testing @ ENEA & TRIUMF
  - ✓ RIL-based dosimetry @ FNG/ENEA atm. Neutrons (TA)

➔ **Next talk by Luca Weninger (UJM) & official ENEA/UJM collaboration in progress**

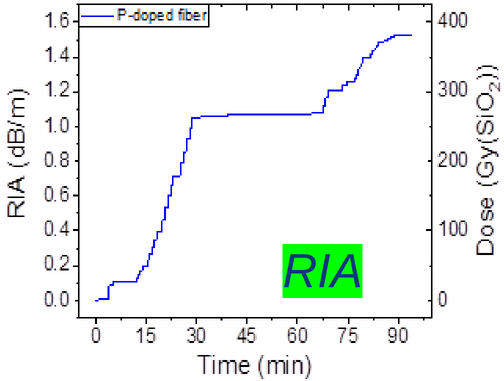
  - ✓ RIA-based dosimetry @ TRIUMF atm. Neutrons
  - ✓ RIA-based dosimetry @ FNG/ENEA 14 MeV Neutrons (TA)

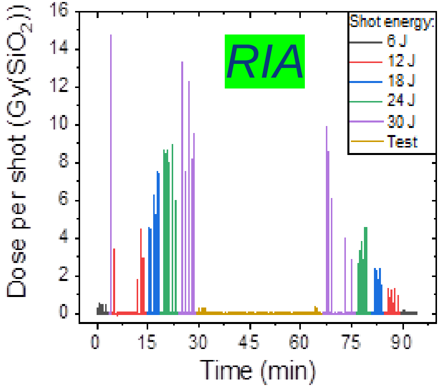
- ✓ Low-energy Proton testing @ CLPU (TA)
  - ✓ Joint UJM-CERN-ELI-CLPU experiment

- ✓ Distributed sensing: radiation detection along one optical fiber

WP05-JRA1 Task 5.3 : RIA/RIL Fiber-based dosimetry

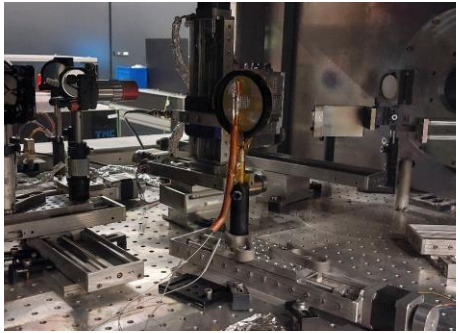
- **Teaser CLPU Results**

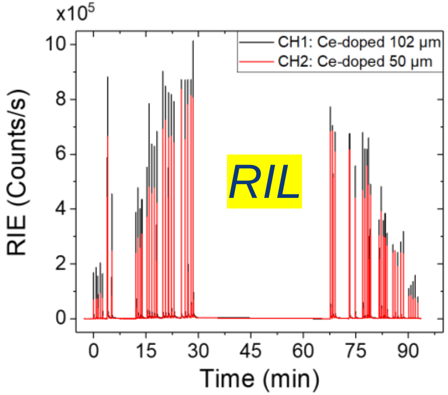




- *These tests reveal the high potential of fibers to monitor low* ***energy proton flux*** *associated with PW lasers in a* ***EMP-rich environment***

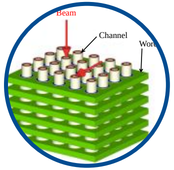
- *RIA-FOD gives* ***absolute dose values*** *on a larger zone while RIL-FOD gives dose rates on a smaller zone . Ideas to optimize the detectors*



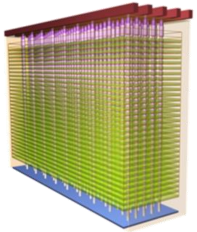


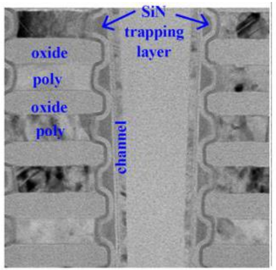
Future: to be done if TA (CHARM?, CNA?, ENEA?)

WP05-JRA1 Task 5.3 : 3D NAND Flash SEU monitor (Work by UniPD)



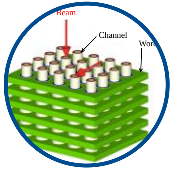
- Ionizing radiation causes a **threshold voltage shift (ΔV_{th})** in Flash cells and this shift can be exploited to realize a **particle detector/ radiation dosimeter**
- 3D NAND Flash devices offer many advantages as an ionizing particle detector, compared to other memories
  - ΔV_{th} can be extracted, in addition to the number of errors
  - **Non-volatility**: low power, no data loss with SEFIs, passive detectors, etc…
  - Capability of tracking particles in **three dimensions**, higher precision in determining the beam features, discrimination of errors due to radiation from other errors
- 3D NAND Flash exploit either FG cells (conductive polysilicon Floating Gate cells) or RG (replacement gate) technology using Charge Trap (CT) cells



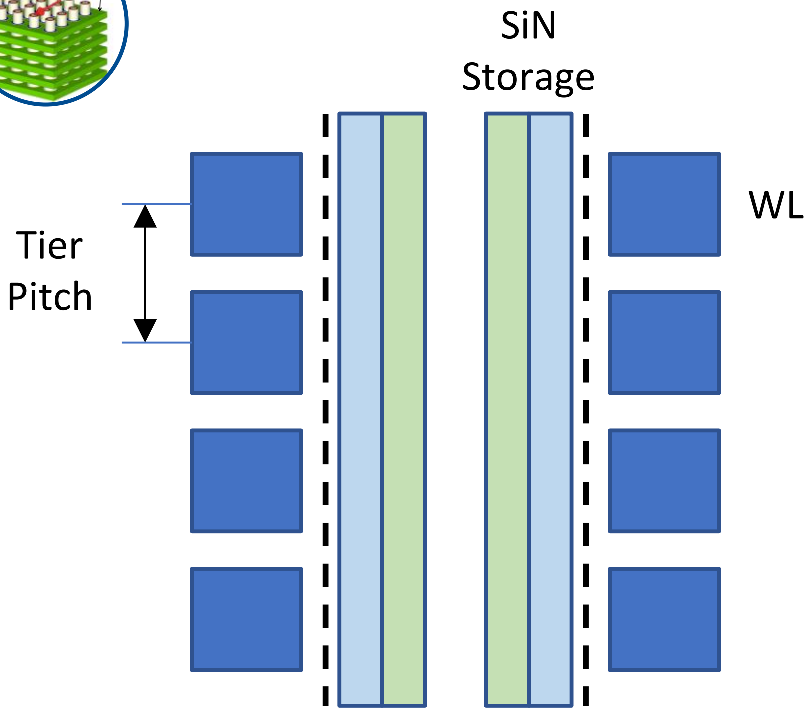


The purpose is to explore the **feasibility of a high-LET particle detector based on 3D NAND Flash CT memories**

WP05-JRA1 Task 5.3 : 3D NAND Flash SEU monitor (Work by UniPD)

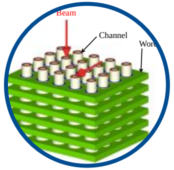


Scaling of 3D NAND Flash

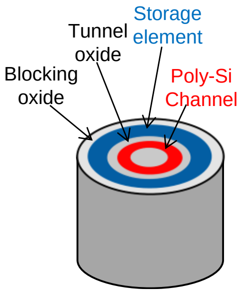


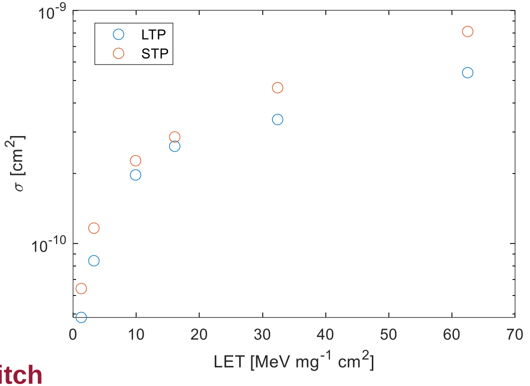
- Two possible approaches to **increase the density** of 3D Flash array
  1) Act on xy plane: reduction of the cell feature size
  2) Act in z-direction: increase the number of stacked layers (preferred strategy, minimizes the technological and electrical issues associated with taller pillars)
- The trend is to reduce the tier pitch (i.e. distance between adjacent WLs)
- **Tier pitch scaling** leads to higher electric fields between adjacent cells and therefore stronger disturbs
- The impact of tier pitch scaling on cell array radiation sensitivity needs to be addressed

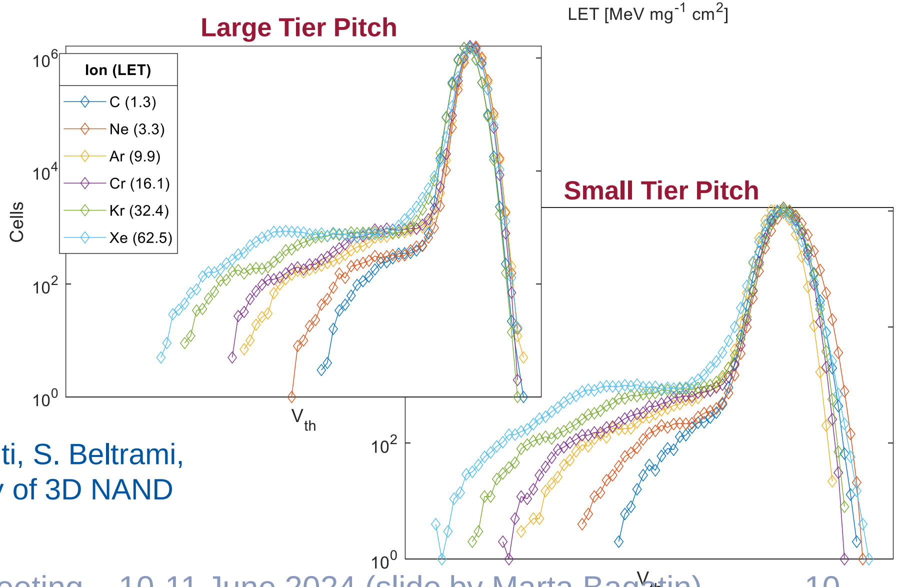
WP05-JRA1 Task 5.3 : Impact of Tier Pitch on SEE Sensitivity of 3D NAND Flash



- SEE sensitivity of Large Tier Pitch (LTP) and Small Tier Pitch (STP) cells was compared
- The cross sections show an increase more than proportional to the reduction in tier pitch
- The threshold voltage distributions show similar trends
- The increase in sensitivity has been attributed to the reduction of stored charge, increased cell-to-cell electric fields, and increased variability in V_{th}



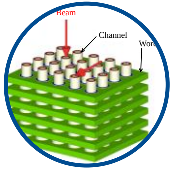




M. Bagatin, S. Gerardin, A. Paccagnella, A. Benvenuti, S. Beltrami, “Impact of Tier Pitch Scaling on Heavy-ion Sensitivity of 3D NAND Flash Memories,” Trans. Nucl. Sci. 2024

WP05-JRA1 Task 5.3 : 3D NAND Flash SEU monitor (Work by UniPD)

Latest Results and Publications

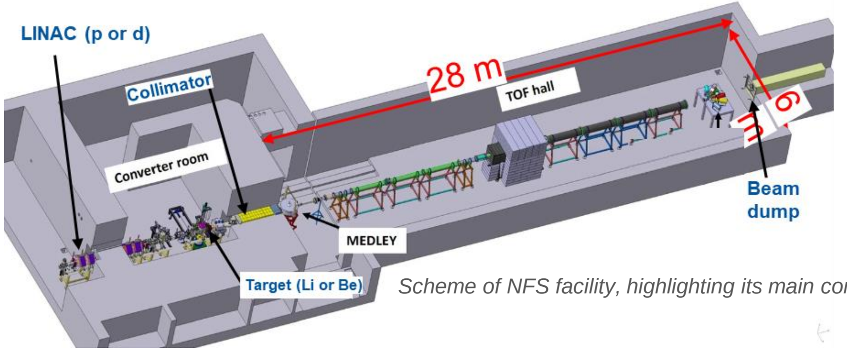


- Impact of Tier Pitch Scaling on **single event effect sensitivity** of 3D NAND Flash memories
  - M. Bagatin, S. Gerardin, A. Paccagnella, A. Benvenuti, S. Beltrami, “Impact of Tier Pitch Scaling on Heavy-ion Sensitivity of 3D NAND Flash Memories,” presented at RADECS 2023, Toulouse, France, Sept. 2023
  - M. Bagatin, S. Gerardin, A. Paccagnella, A. Benvenuti, S. Beltrami, “Impact of Tier Pitch Scaling on Heavy-ion Sensitivity of 3D NAND Flash Memories,” Trans. Nucl. Sci. 2024
- Impact of Tier Pitch Scaling on **total ionizing dose sensitivity** of 3D NAND Flash memories
  - M. Bagatin, S. Beltrami, A. Paccagnella, S. Gerardin, “Total-Dose Induced Threshold Voltage Shift Dependence on Tier Pitch in 3D NAND Flash Memories,” to be presented at NSREC 2024, Ottawa, Canada, July 2024
- **Future** work
  - Study of interaction between heavy ions and TID
  - TCAD simulations

WP05-JRA1 Task 5.3 : Characterization of neutron fields at NFS white neutron beam (Work by UU and GANIL)

- **Neutrons for Science (NFS) at GANIL (France) is a new neutron facility**, operating since 2019, with a 20 meter long flight path.
- White spectrum neutron beam extends,from ~1 to ~ 40 MeV neutrons, and is produced by 40-MeV deuterons hitting on a 9-mm thick Beryllium target.

- **Experimental setup**: The Medley setup, formerly used at the old TSL facility (Uppsala, Sweden) with quasi monoenergetic neutron beams. **Medley was transferred to NFS in 2021 and reconfigured to work with white neutron beams**.



Scheme of NFS facility, highlighting its main components.

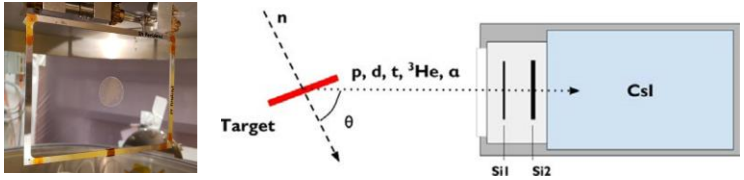
The Medley setup consists of a chamber with 8 telescopes, placed at 20° intervals, able to detect and identify light ions.

Medley setup with target installed.

It is also being used in other experiments to measure double-differential cross-sections of light-ion production in neutron-induced reactions.

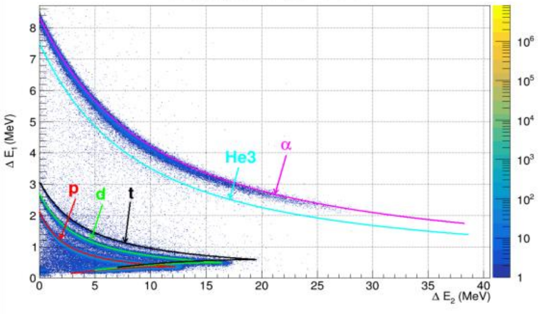
WP05-JRA1 Task 5.3 : Characterization of neutron fields at NFS white neutron beam (Work by UU and GANIL)

Each of the 8 telescopes is equipped with two Si (SSBD) detectors with different thicknesses and one scintillation detector, allowing to use the **ΔE-ΔE-E technique to identify light ions (p, d, t, ^{3}He, α)**.



The CH_2 target installed in Medley (left), and the working principle of a telescope (right).

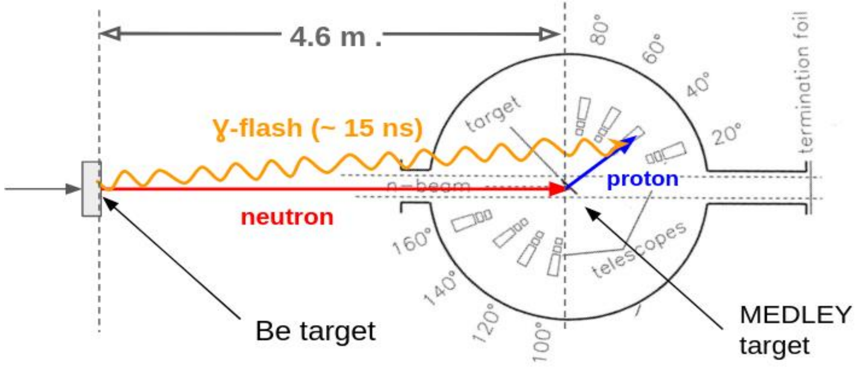
Thanks to the good energy resolution of the setup, it is **possible to discriminate between individual H and He isotopes**.



Particle identification (PID) process. Experimental data for C with simulations superposed.

For each event, the **energy of the incoming neutron** is deduced from the **time-of-flight technique**, using the time signal of the proton detection in the telescope, and the radiofrequency signal of the accelerator.

Scheme exemplifying the Time of flight (ToF) technique used on Medley.

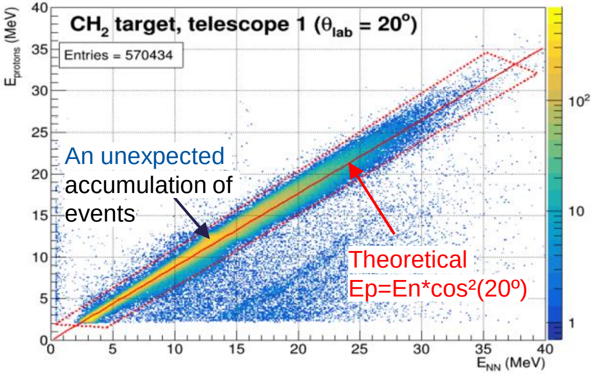


- By measuring the kinetic energy of the proton with the telescope, it is possible to properly correct for the time used by the proton to reach the telescope:

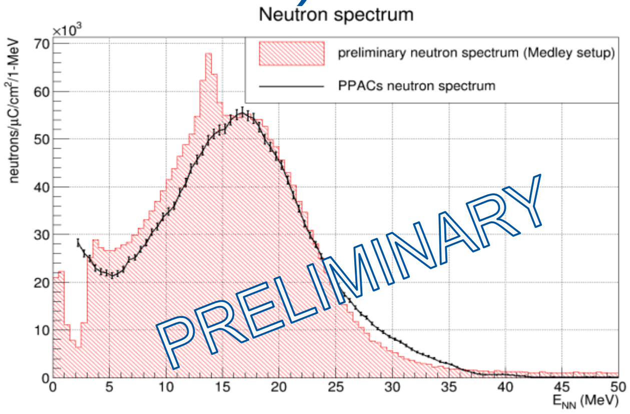
$ToF_{NEUTRON} = TOF_{MEASURED} - ToF_{PROTON}(E_{proton})$

WP05-JRA1 Task 5.3 : Characterization of neutron fields at NFS white neutron beam (Work by UU and GANIL)

- By **measuring the protons elastically scattered in a hydrogen-rich sample exposed to the neutron beam**, **it is possible to reconstruct the neutron spectral flux** by using the well-known neutron-proton elastic scattering cross section.
- A Polyester sample (CH_2) was used, in addition to a natural carbon sample (C) to subtract the contribution from neutron reactions in C.
- **For each event**, the energy of the backscattered proton is measured by a telescope and the energy of the incoming neutron, is deduced from the time-of-flight technique.



- There is an **unexpected accumulation of events** in the punch-through energy region **(around 13 MeV for protons),** probably related to the detector performance. Work is in progress to suppress it in the analysis.



Comparison between neutron spectral flux from Medley and PPACs.

Conclusions:

- The **preliminary neutron spectral flux** at NFS has been measured and agrees with the value obtained from an external parallel plate avalanche chamber (PPAC) monitor.
- The **analysis is ongoing** to improve the suppression of the non-physical peak near 15 MeV, which corresponds to the punch-through region of the second Silicon in the telescope.
- **Energy loss corrections have not been implemented yet**, which will shift the spectrum towards higher energies.

WP05-JRA1 Task 5.4 : Development of low-cost dosimetry systems accessible to RADNEXT users

- **Task Leader:** CERN
- **Participants:** UJM, UM, UO

Main research was applied to low-cost SRAM dosimetry with progress on the following axes (to be detailed in future meetings):

- Application of SRAM neutron monitoring solution to a high-energy electron linac medical environment
- In-orbit SRAM monitor data collection (mainly on CELESTA)
- MCU detection for flux and LET monitoring of heavy ion beams
- SEE cross-calibration data for heavy ion facilities
- Laser versus heavy ion SEU cross section comparison

Deliverables

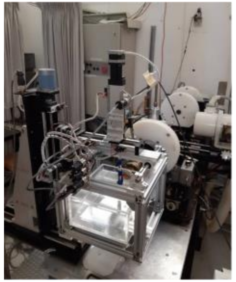
Status	ID	Title	Deadline	Responsible (s)
TBD	D5.1	**Book of Knowledge, M38** *Definition and Standardization of Relevant Beam Parameters* ***[Milestone 5.1]***	31/07/2024	UO
TBD	D5.2	**Report, M40** *Potential of SEU monitor based on 3D NAND Flash memories for R2E*	30/09/2024	UniPD
TBD	D5.3	**Prototype, M44** *Prototypes of Fiber-based dosimeter and Low cost RadMON detector* ***[Milestone 5.2]***	31/01/2025	UJM/CERN
TBD	D5.4	**Report, M46** *Characterization of neutron fields at the NFS facility*	31/03/2025	UU

Scientific publication and communications

Title	Journal	DOI	Open Access
Radiation Monitoring with Radiosensitive Pure-Silica Core Ultra-Low Loss Optical Fiber	IEEE TNS	10.1109/TNS.2024.3380999	YES
Calibration in the Visible and Infrared Domains of Multimode Phosphosilicate Optical Fibers for Dosimetry Applications	IEEE TNS	10.1109/TNS.2023.3252941	NO (available on HAL)
Gamma Ray Effects on Multi-Colored Commercial Light-Emitting Diodes at MGy Level	MDPI Electronics	https://doi.org/10.3390/electronics12010081	YES
Distributed Optical Fiber-Based Radiation Detection Using an Ultra-Low-Loss Optical Fiber	MDPI Radiation	doi: 10.3390/radiation4020013	YES
Impact of Tier Pitch Scaling on Heavy-ion Sensitivity of 3D NAND Flash Memories	IEEE TNS	10.1109/TNS.2024.3355939	No (not on TNS)

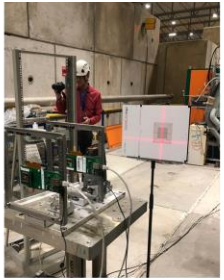
Scientific publication and communications

Title	Conference or others	If proceedings, DOI:	Open Access
Calibration in the Visible and Infrared Domains of Multimode Phosphosilicate Optical Fibers for Dosimetry Applications	RADECS 2022	10.1109/TNS.2023.3252941	YES
Calibration in the Visible and Infrared Domains of Multimode Phosphosilicate Optical Fibers for Dosimetry Applications	RADECS 2023	10.1109/TNS.2023.3252941	NO (available on HAL)
Impact of Tier Pitch Scaling on Heavy-ion Sensitivity of 3D NAND Flash Memories	RADECS 2023	10.1109/TNS.2024.3355939	No (not on TNS)
Total-Dose Induced Threshold Voltage Shift Dependence on Tier Pitch in 3D NAND Flash Memories	NSREC 2024	To be presented	N/A
14 MeV and Atmospheric Neutron Monitoring Through Optical Fiber Dosimeters	NSREC 2024	To be presented	N/A



TRIUMF Facility – Fiber testing

Medley chamber @ NFS facility



CERN North Area, 2D ion chamber detector

Thanks for your attention!

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4. HOEHR, Cornelia (TRIUMF)
5. TARRÍO, Diego (UU)
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7. POPPE, Björn (UO)
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9. WROBEL, Frédéric (UM) WPL WP8-JRA3
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