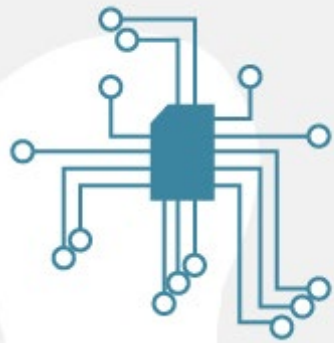




CSN5
Ricerca
Tecnologica



Istituto Nazionale di Fisica Nucleare

Consuntivi scientifici attività di gr 5 - Pavia

Consiglio di Sezione – 09 giugno 2025

Silva Bortolussi

Rivelatori

ADA_5D (Ratti)

HiDRA2 (Gaudio)

HISOL (Villa)

IONOTRACK (Grassi)

MANIFOLD (Rossella)

Fisica Medica

ARES (Ramos)

ADMIRAL (Donzella)

BIOHOT (Ballarini)

DISCOVER22 (Baiocco)

MATHER3D (Lascialfari)

NEXT_AIM (Lascialfari)

SPOC (Protti)

Fisica per i beni culturali

CHNET_MAXI (Menegolli)

Quantum

NAMASSTE (Lascialfari)

QUANTEP (Bellani)

Calcolo

GEANT4INFN (Postuma)

Attività 2024 in Sezione

ADA_5D

Avalanche Diodes Array – 5D

RL – Lodovico Ratti

Informazioni generali

Sezioni Coinvolte

- Padova
- Pavia
- Pisa
- Trento-TIFPA

FTE 2024: 3.5

Anagrafica di Pavia

Simone Giroletti	1 FTE	
Marco Grassi		0.4
FTE		
Piero Malcovati	0.3 FTE	
Lodovico Ratti		0.4
FTE		
Carla Vacchi		0.4
FTE		
Fatemeh Shojaei	1 FTE	

Goal del progetto

Obiettivi

To develop a new **LGAD based** detector capable of simultaneously measuring position, charge and time of arrival of the impinging particle – application to charge identification of individual cosmic ray elements for the next generation of space-borne experiments

Obiettivi Specifici

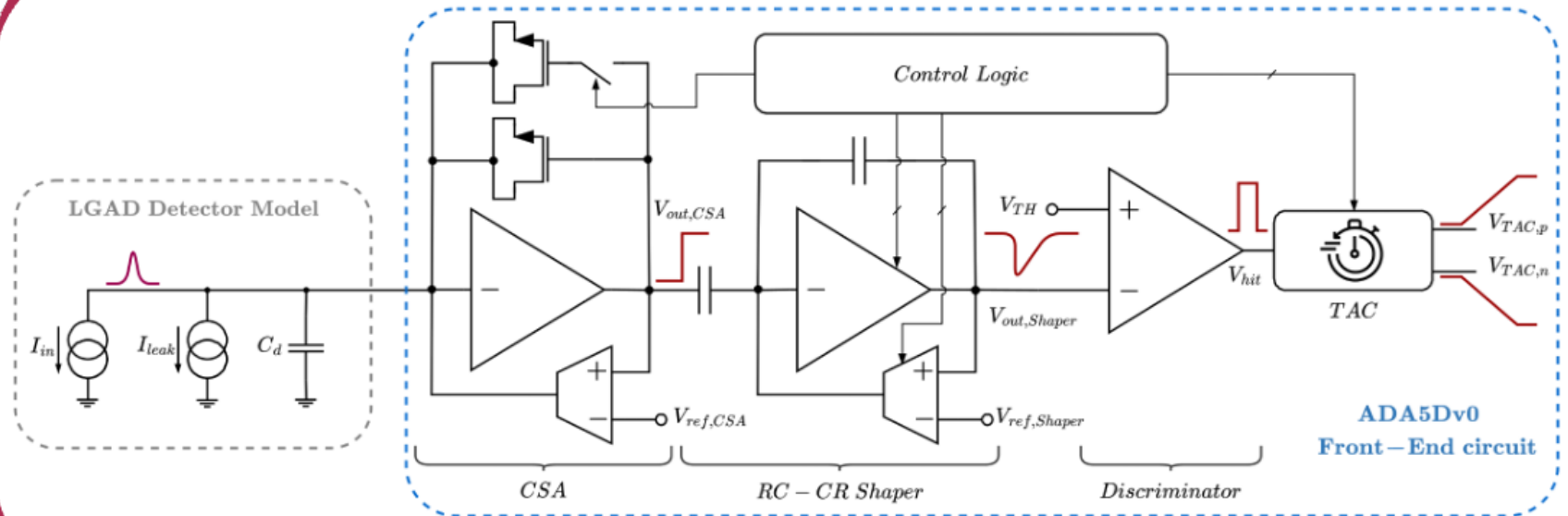
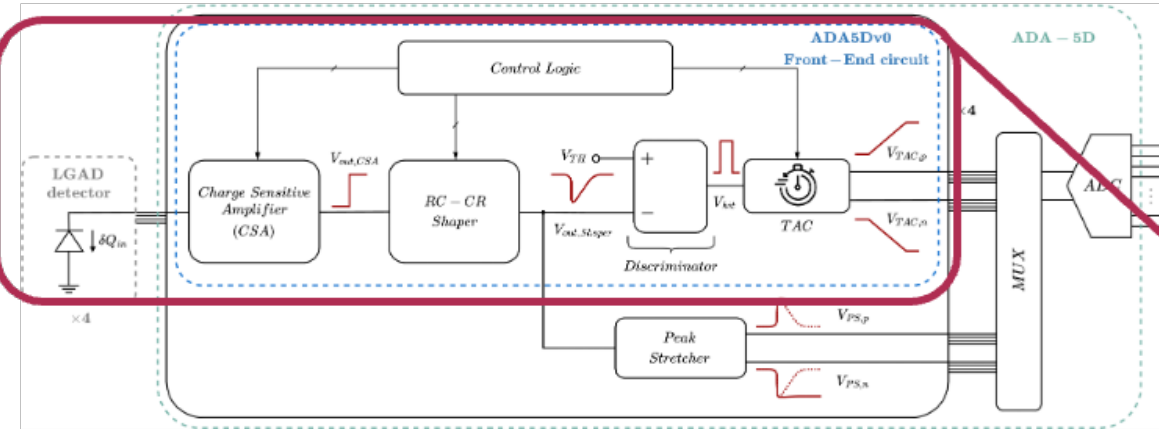
design and characterize the front-end circuit for the detector

- 2x2 array of processing channels performing preamplification, shaping and analog to digital conversion
- 65 nm CMOS technology

LGAD front-end channel

Timing branch of the ADA-5D front-end channel fabricated in a 65 nm CMOS technology and tested

- Tri-linear CSA
- RC-CR shaper
- Discriminator
- Time-to-amplitude (TAC) converter
- Slow-control logic



ADA5Dv0 Test chip

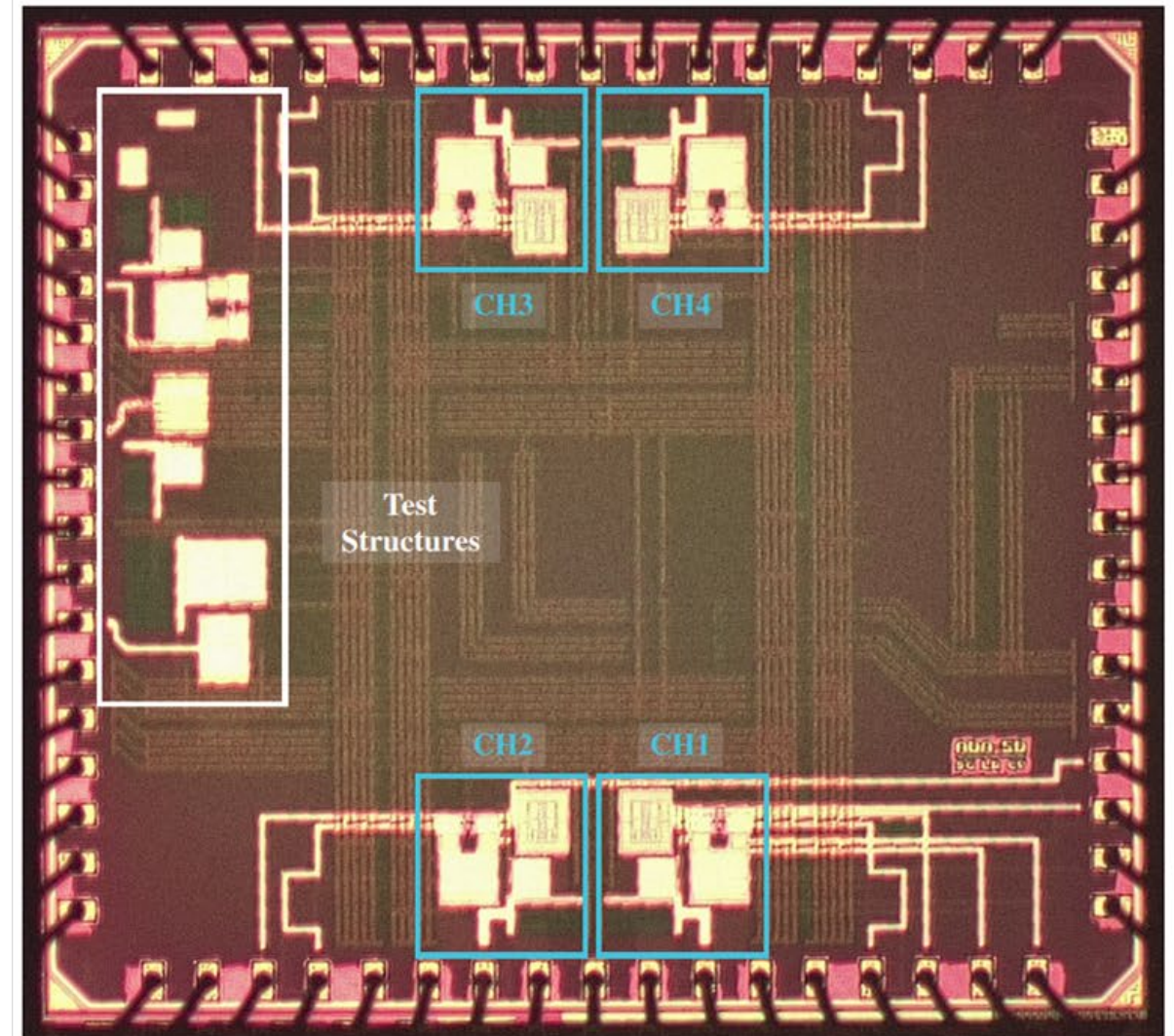
The **ADA5Dv0** chip includes:

- ❖ 4 complete front-end readout channels (CH1 – CH4) to be coupled to LGAD detectors
- ❖ Single test structures

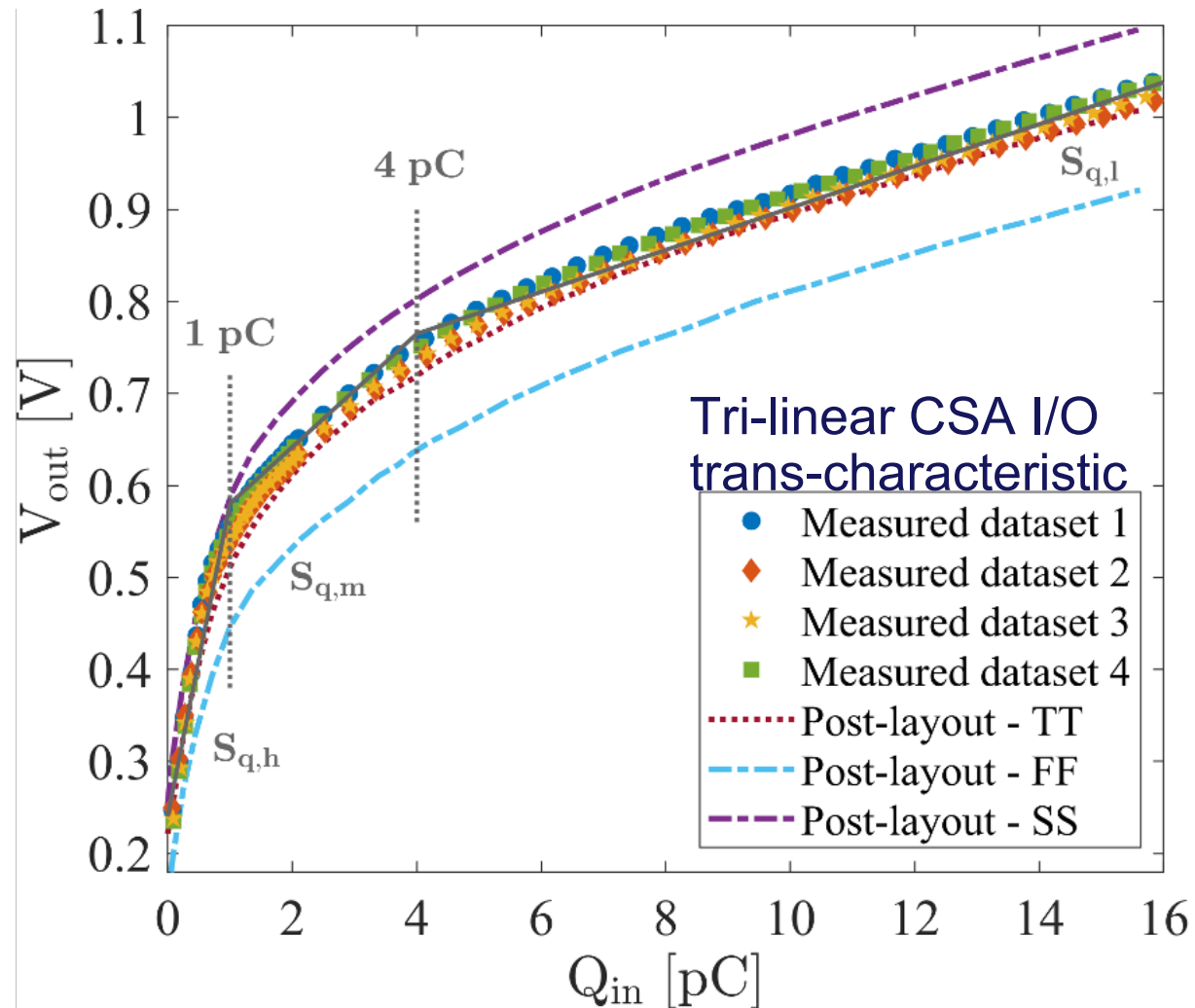
Single Test Structures

- Charge Sensitive Amplifiers with multiple dynamic signal compression features
- RC-CR Semi-Gaussian Shapers
- MOS capacitors

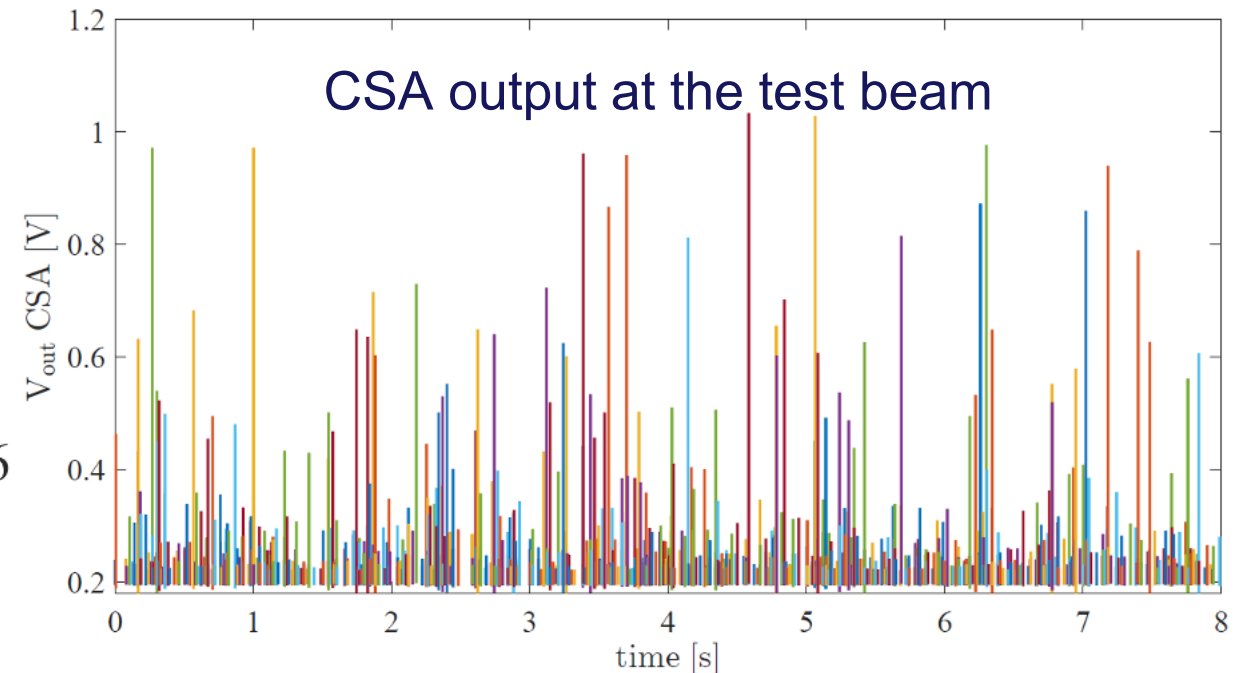
The readout channels are provided with dedicated **charge injection circuits** serving channel **calibration** and **characterization** purposes.



Result summary



- S/N > 100 (needed for having a jitter below 150 ps, as per specs)
- Main circuit parameters (CSA charge sensitivity, TAC gain, TAC jitter, ENC) close to simulation results in the nominal corner
- TAC non-linearity worse than expected from simulations - correlated with parasitic capacitive load from the test board
- Readout channel connected to an LGAD sensor and tested on a particle beam at



Tesi, congressi e pubblicazioni

S. Giroletti et al., “Analog Front-End for the Readout of LGAD-Based Particle Detectors”, *Nucl. Instrum. Methods A*, vol. 1067, article no. 169724, Oct. 2024.

S. Giroletti et al., “Modeling I-MOS Capacitor C-V Characteristic for Non-Linear Charge Sensitive Amplifiers”, *19th Conference on Ph.D Research in Microelectronics and Electronics, PRIME 2024*, Larnaca, 9 June 2024 - 12 June 2024.

S. Giroletti et al., “Pseudo-Differential Time-to-Amplitude Converter for LGAD Based Particle Detectors”, *Proceedings - 2024 IEEE International Symposium on Circuits and Systems, ISCAS 2024*, Singapore, 19 May 2024 - 22 May 2024.

S. Giroletti et al., “ADA5Dv0, an Analog Front-End Prototype for the Readout of LGAD Detectors”, *2024 IEEE Nuclear Science Symposium (NSS), Medical Imaging Conference (MIC) and Room Temperature Semiconductor Detector Conference (RTSD)*, Tampa, USA, 26 October 2024 - 2 November 2024.

Praveen Kumar Perumal, *Fast comparator based peak stretcher for amplitude measurements in an LGAD based detector system*, Master's thesis, Università di Pavia, Academic Year 2023/2024.

Matteo Porazza, *Caratterizzazione di un front-end analogico per rivelatori LGAD*, Bachelor's Thesis, Università di Pavia, Academic Year 2023/2024

HiDRA2

High-Resolution Highly Granular Dual-Readout Demonstrator

RN — Bob Ferrari - Call CSN 5

RL - Gabriella Gaudio

Informazioni generali

Sezioni Coinvolte

- Bologna
- Catania
- TIFPA
- Milano (Celoria)
- Pavia
- Pisa
- Roma I

FTE 2024: 1.15

Braghieri	Alessandro	Dipendente	Ricercatore	20%
Ferrari	Roberto	Dipendente	Dirigente di Ricerca	35%
Gaudio	Gabriella	Dipendente	Primo Ricercatore	10%
Negri	Andrea	Associato	Incarico di Ricerca scientifica	10%
Pareti	Andrea	Associato	Scientifica Dottorandi	20%
Polesello	Giacomo	Dipendente	Dirigente di Ricerca	20%

Enorme supporto dall'officina meccanica

Goal del progetto

Obiettivi generali

Costruzione di un prototipo con contenimento adronico (65x65x250 cm³) con la tecnica dual-readout per la validazione della tecnica calorimetrica e della simulazione adronica con Geant4

Obiettivi di Pavia

- Responsabilità del WP di costruzione meccanica
 - Costruzione del calorimetro e meccanica di supporto
- Responsabilità del WP di Fisica e Simulazione
 - studi di performance del calorimetro

Risultati 2024

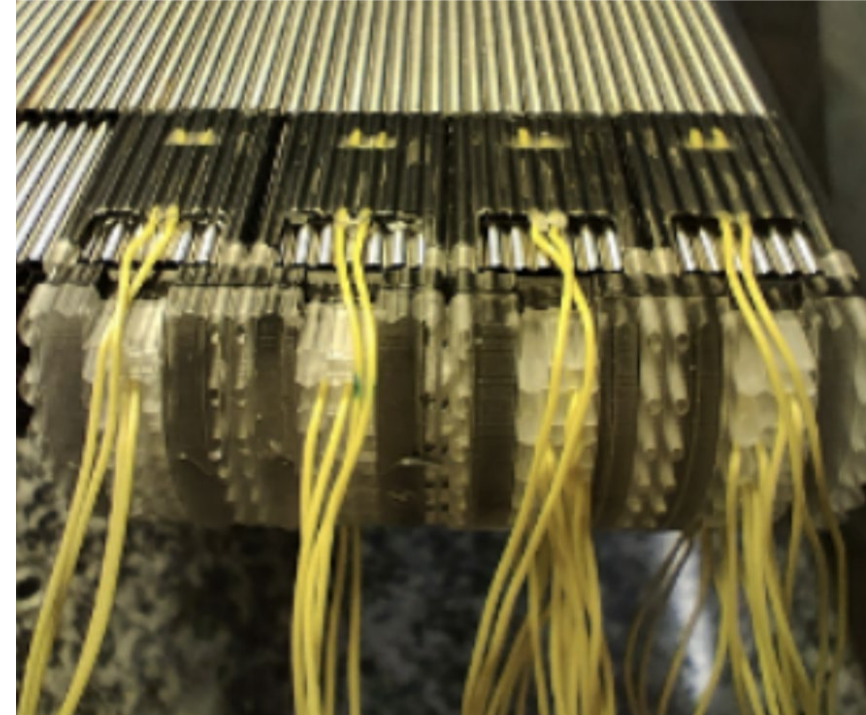
- Status of construction at present: all minimodules glued, 54/80 loaded with fibres.

*grazie (come sempre) per
l'eccellente lavoro
dell'officina meccanica*



Risultati 2024

- Status of construction at present: **all minimodules glued, 54/80 loaded with fibres.**
- The design of the **highly granular readout assembly** was finalised and tests with dummy components successfully carried on.
- A ("DRAGO") prototype with **36 minimodules** was **tested** with (electron, pion and muon) beams **at the SPS** at the end of August - beginning of September 2024, analysis is ongoing. A preliminary estimation of the electromagnetic resolution is available.
- GEANT4 HiDRa simulation implemented and hadronic resolution estimated to be about $37\%/\sqrt{E}+1\%$.



Risultati 2024 - Milestone (Pavia)

M2024.1: End of module construction and sensor integration [29.09.2024] -> 65% (based on the constructed modules)

M2024.4: Performance assessment with TB data [31.12.2024] -> 50% (Completed on partial prototypes for electromagnetic resolution, full Hidra is needed for hadronic resolution)

M2024.5: Physics performance assessment on benchmark physics processes completed. [31.12.2024] -> 70% (Full simulation of the 4π calorimeter in the DD4hep framework is completed. Beyond Standard Model benchmark models have been defined and the dependence of the discovery potential on the calorimeter performance assessed. Next step is the extraction of the expected performance figures from the new G4 simulation).

Tesi e pubblicazioni

see RD_FCC for synergie

50% HiDRa - 50% RD_FCC

HISOL

High performance ISOL systems for the production of radioactive ion beams

RL – Valerio Villa

Informazioni generali

Sezioni Coinvolte

- Pavia
- Padova
- LNL

Anagrafica di Pavia

- Valerio Villa 0.3 FTE
- Antonietta Donzella 0.1 FTE
- Alberto Girotto 1.0 FTE
- Ileana Bodini 0.1 FTE
- Diego Paderno 0.1 FTE

FTE 2024: 1.6 FTE

Goal del progetto

Obiettivi

Il progetto HISOL riguarda lo sviluppo di sistemi ISOL ad alte prestazioni per la produzione di fasci di ioni radioattivi.

Obiettivi:

Sviluppare target e sorgenti ioniche ad alte prestazioni per aumentare l'intensità e la purezza dei fasci di ioni radioattivi prodotti con la tecnica ISOL.

Obiettivi Specifici

- Sviluppare target ISOL in TiC e SiC con strutture regolari per massimizzare il rilascio degli isotopi
- Sviluppare componenti per sorgenti ioniche FEBIAD con geometrie complesse realizzate mediante additive manufacturing, per migliorare l'efficienza di ionizzazione, la stabilità e la riproducibilità
- Caratterizzare i materiali a temperature elevate (microstruttura, proprietà termiche, elettriche e meccaniche)
- Effettuare simulazioni multifisiche dei target e sorgenti ioniche ISOL ad alte prestazioni

Risultati 2024 – milestones (Pavia) – 1 di 3

WP1: Ottimizzazione dei target ISOL ad alte prestazioni

Risultati 2024 (Unità di Pavia - UniBS/UniPV):

- Sviluppata una procedura di ottimizzazione per target ISOL standard in SiC e TiC mediante simulazioni Monte Carlo.
- Prodotto un lotto di target ottimizzati in TiC presso LNL, in collaborazione con il progetto ISOLPHARM_CORE (PRIN 2024).
- Analisi termomeccaniche integrate in una visione multiphysics per validare le geometrie.

Prospettive HISOL_NEXT:

- Target innovativi a geometria complessa e densità graduale, realizzati con tecnologie di Additive Manufacturing.
- Simulazioni avanzate con uso di risorse HPC (High Performance Computing) per modelli multifisici computazionalmente intensivi.

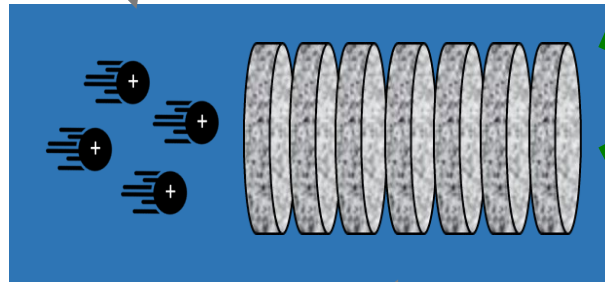
Risultati 2024 – milestones (Pavia) – 1 di 3

Monte Carlo simulations:

Particle transport and interaction with matter

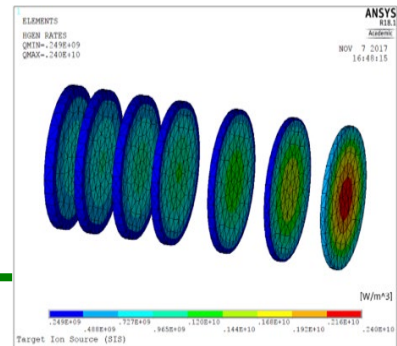


Proton Beam Properties
(energy, intensity, profile)

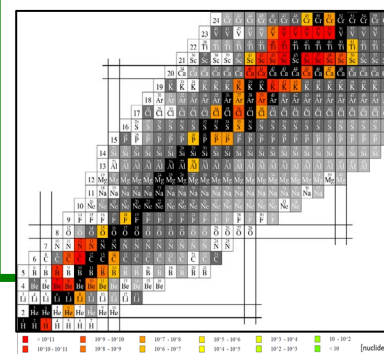


Target characteristics
(composition, geometry, density)

Power deposition



Isotope production



Multiphysics FEM simulations:
Thermal and structural analyses



Risultati 2024 – milestones (Pavia) – 2 di 3

WP2: Sorgenti ioniche ad alte prestazioni – Sviluppo e test

Contributi principali (Unità di Pavia – Alberto Girotto):

- Test della sorgente FEBIAD avanzata presso CERN e SPES (Offline/Online).
- Conduzione dei test per la produzione di fasci stabili e molecolari.

Risultati 2024:

- Incremento significativo dell'emissione termoionica con superfici AM rugose.
- Validato il ruolo della microstruttura e geometria della griglia anodica sull'efficienza di ionizzazione.



Risultati 2024 – milestones (Pavia) – 3 di 3

WP3: Componenti ausiliari ottimizzati per sorgenti e target

Attività e risultati (Unità di Pavia):

- Simulazione Monte Carlo per la copertura della camera a vuoto del target SPES.
- Identificati materiali “AM-printable” (Al-based alloys) con bassa attivazione per una maggiore sicurezza radiologica.

Sviluppi previsti:

- Estensione alle leghe Fe-, Ti-, Ni-based tramite simulazioni parallele.

Tesi, congressi e pubblicazioni

Tesi

Giroto, A. (2024). FEBIAD ion source development for advanced nuclear physics applications (Doctoral dissertation). PhD in Mechanical and Industrial Engineering, Department of Mechanical and Industrial Engineering, University of Brescia. Advisor: Prof. Valerio Villa; Co-advisors: Ph.D. Mattia Manzolaro, Ph.D. Michele Ballan. SSD: ING-IND/15. PhD Cycle XXXVII (2022–2024).

Congressi

International Conference of the Italian Association of Design Methods and Tools for Industrial Engineering – 2025 Sep 10-13 – Palermo (Italy)

Pubblicazioni

Monetti, A., Donzella, A., Ballan, M., Centofante, L., Corradetti, S., Ferrari, M., ... & Andrichetto, A. (2024). Study of the radionuclide deposition in the radioactive ion line of the Selective Production of Exotic Species (SPES) facility. *Applied Radiation and Isotopes*, 204, 111121.

Giroto, A., Ballan, M., Rebesan, P., Bodini, I., Isceri, A., Paderno, D., ... & Villa, V. (2024, September). Definition of an Experimental Method and Setup for High Temperature Deformation Measurements on FEBIAD-Type Ion Source. In *International Conference of the Italian Association of Design Methods and Tools for Industrial Engineering* (pp. 261-269). Cham: Springer Nature Switzerland.

Donzella, A., Arzenton, A., Asti, M., Bortolussi, S., Corradetti, S., D'Agostino, G., ... & Andrichetto, A. Production and characterization of the ^{111}Ag radioisotope for the development of a new generation of radiopharmaceuticals; the Italian ISOLPHARM project. (Submitted)

Bodini, I., Baronio, G., Paderno, D., Villa, V., Martinelli, P., Frizza, R., ... & Uberti, S. (2024). GPS-navigator: an advanced search engine to gather information and navigate through standards in the field of geometrical product specification. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, 18(8), 6289-6299.

IONOTRACK

Ionoacoustic Tracking and Imaging of Particle Beams

RL – Marco Grassi

Informazioni generali

Sezioni Coinvolte

- Milano - Bicocca
- Pavia
- Catania

Anagrafica di Pavia (2024): 1.25 FTE

- | | |
|-----------------------|----------|
| • Marco Grassi | 0.30 FTE |
| • Piero Malcovati | 0.25 FTE |
| • Elisabetta Moisello | 0.70 FTE |

Budget 2024

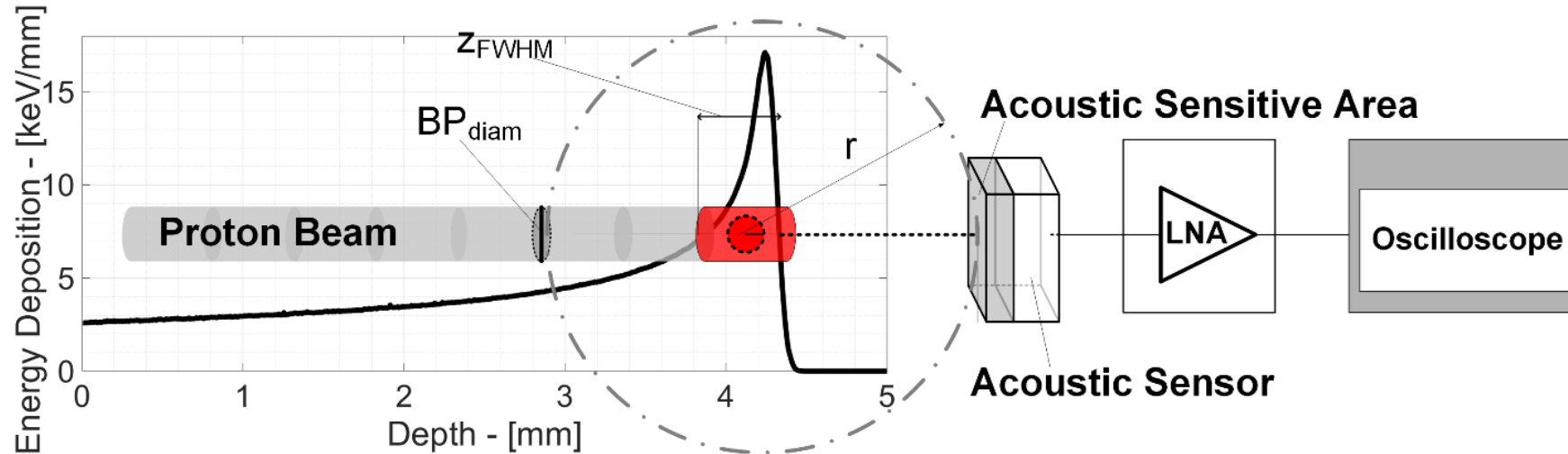
	Assegnati	Spesi	Residui	Dettagli
• Missioni:	0.0k		0.0k	0.0k
• Consumo:	1.0k		0.0k (1.0k)*	1.0k (0.0k)*
• Componenti elettronici e PCB:				0.0k (1.0k)
Totale Spesa				0.0k (1.0k)

*Durante il 2024 un problema di omonimia non ha permesso di ottenere l'autorizzazione per ordini sulla piattaforma INFN. I progetti, inoltre, non sono visualizzati correttamente. Aperto un ticket a dicembre 2024.

☐ Da quando è stato introdotto l'OTP (2025) vedo correttamente i progetti. Occorre verificare autorizzazione

Non sono state sostenute formalmente spese nell'anno 2024

Goal del progetto



Obiettivi

- Misurare fasci a dosi cliniche con precisione sub-mm e dose < 50 mGy (SoA: $\gg 1$ Gy)
- Ricavare la mappa acustica 2D della deposizione di dose e caratterizzare completamente un fascio in termini di range, energia, diametro
- Caratterizzare in real-time (latenza < 1 ms) rapide deposizioni di dose

Risultati 2024 – milestones (Pavia)

Digital Tools Setup Definition (1):

- Definizione di un flusso per la sintesi di circuiti digitali in CMOS 28 nm
- Definizione di un flusso per il place and route (layout) in CMOS 28 nm

Digital Design (2):

- Progettazione di algoritmi per il processing di segnali ionoacustici (e/o assistenza ADC)

Silicon Prototyping and testing (3):

- Assemblaggio dei circuiti digitali (+analogici e misti UniMiB) in silicon run CMOS 28 nm miniASIC
- Definizione e creazione setup per la caratterizzazione dei circuiti digitali progettati

Risultati 2024

Risultati (1): Digital Tools Setup Definition

- Definizione di script (tcl) per la sintesi circuitale dalla vista behavioural (functional) in CMOS 28nm
- Definizione di script (tcl) per la generazione del layout dal circuito sintetizzato in CMOS 28nm
- Allineamento setup dei tool circuitali (Cadence: Virtuoso) per la verifica delle viste generate
 - Stream-In, DRC, LVS (+Mentor: Calibre)
- Allineamento setup dei tool circuitali (Cadence, AMS, Spectre) per la creazione di interfacce e la simulazione delle viste generate mediante gli script definiti
 - Circuito di test realizzato ☐ Logica per la gestione di ADC SAR, SD ed incrementale (vedi obiettivi 2,3)

Risultati 2024

Risultati (2): Digital Design

- Progettazione (functional) di un circuito digitale per la gestione flessibile di un convertitore A/D
 - SAR
 - Sigma-Delta
 - Incrementale (fino al secondo ordine)
- Sintesi, Layout, Import, Verifica (DRC, LVS) del circuito digitale progettato
- ☐ Simulazione mista (2025) in vista del run finale su silicio di progetto (con UniMiB)

Risultati 2024

Risultati (3): Silicon Prototyping and Testing

Allineamento con UniMiB per possibile run su Silicio finale di progetto (catena + ADC + filtro)

- verifica studio preliminare filtro digitale FIR (functional)
- ☐ possibile run finale (con UniMiB) di progetto previsto a fine 2025
- ☐ disponibilità supporto alla caratterizzazione (ad UniMiB)

Congressi, tesi, pubblicazioni:

Tesi disponibile presso laboratorio di Sensori e Microsistemi Integrati (DIII, Via Ferrata 5):

“Design and characterization of mixed signal and digital ASIC blocks for Ionoacoustic Tracking and Imaging of Particle Beams”

DIC 2024

MANIFOLD

Multidimensional nANodevice architectures For Low-perturbation
single-ion Detection

RN – RL - Francesco Rossella

Informazioni generali

Sezioni Coinvolte

- PV
- LNL
- RM2
- LNGS

Anagrafica di Pavia

- Rossella, Francesco
- Fontana, Andrea
- Bellani, Vittorio
- Lacava, Giacomo
- Demontis, Valeria

FTE 2024: 1.7

Goal of the project

Objective

To demonstrate the low-perturbation probing of diluted ion beams, exploiting their interaction with carbon nanotube arrays, for the deterministic ion implantation in arbitrary substrates with high spatial control.

Specific Objectives

- (i) design of novel detector architectures based on carbon nanotubes
- (ii) optimization of dedicated beamline setup
- (iii) modeling of the interaction between the charged ion and the nanomaterials and of its impact on the detector response
- (iv) realization of the detectors and their electrical characterization
- (v) demonstration of their sensing functionality for diluted ion beams available at LNL

Results 2024 – Milestones

M2. Effective dielectric functions of the detectors - Unit responsible: LNGS
delivered 2024-06-29
referee evaluation 80%

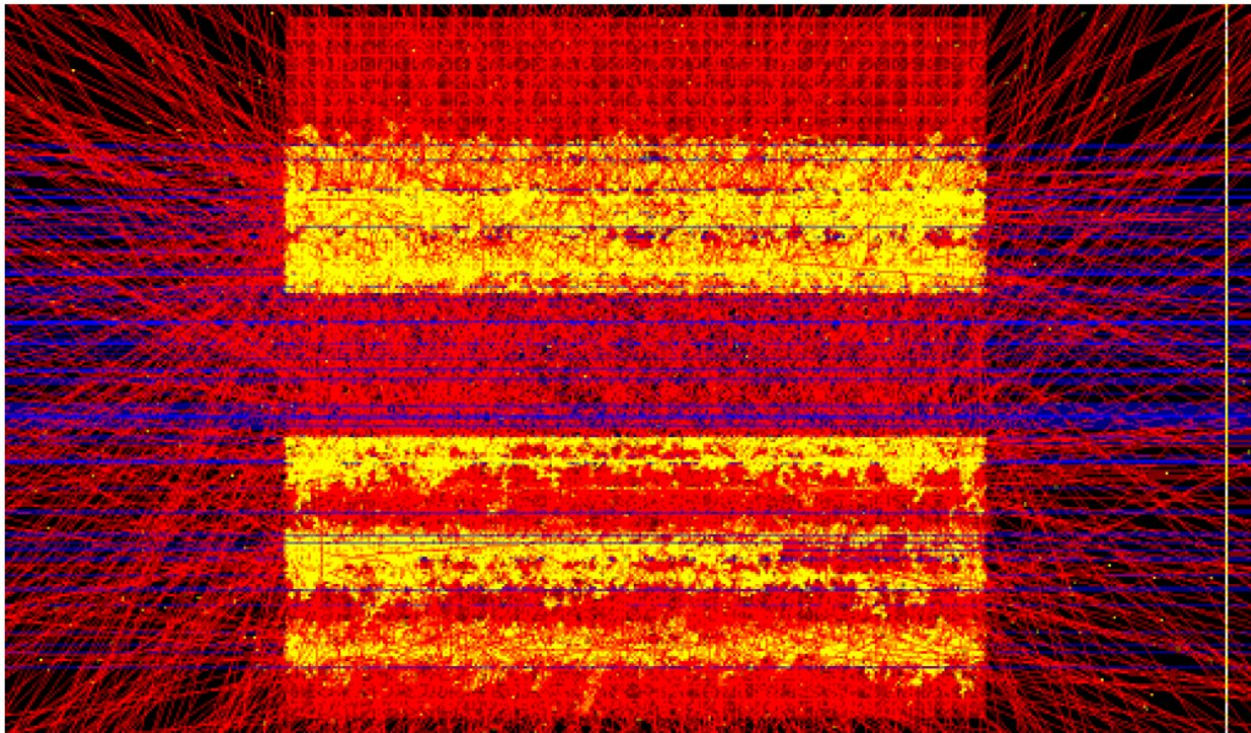
**M1. Trial architectures of multidimensional detectors - Unit responsible: PV
delivered 2024-12-31
referee evaluation 100%**

M3. Preliminary test of detector positioning inside the accelerator chamber - Unit responsible: LNL
delivered 2024-12-31
referee evaluation 100%

Simulations of the interaction ions-CNT array

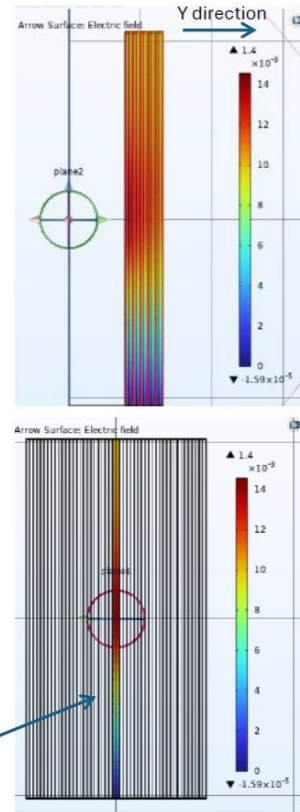
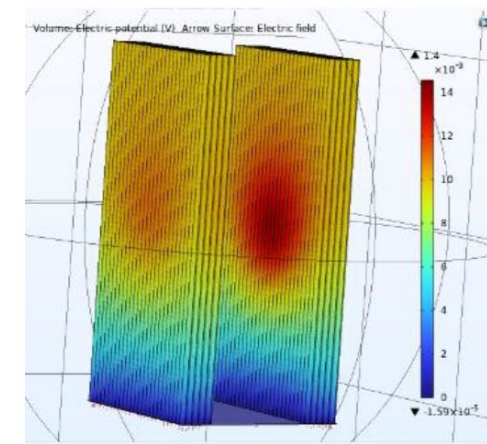
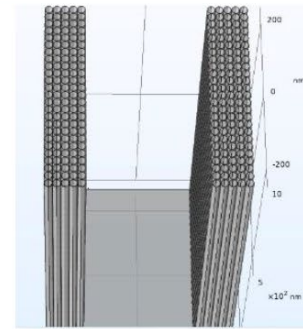
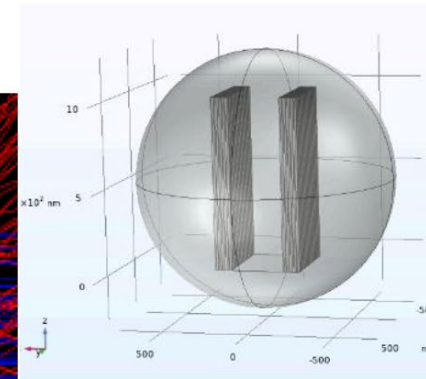
Use of **Geant4-DNA** extended to selected materials (Au, Si,C...) with the **MicroElec** library: models for solid-state electron and lattice collective processes (plasmons/phonons/surface effects).

Interaction with a SWCNT forest

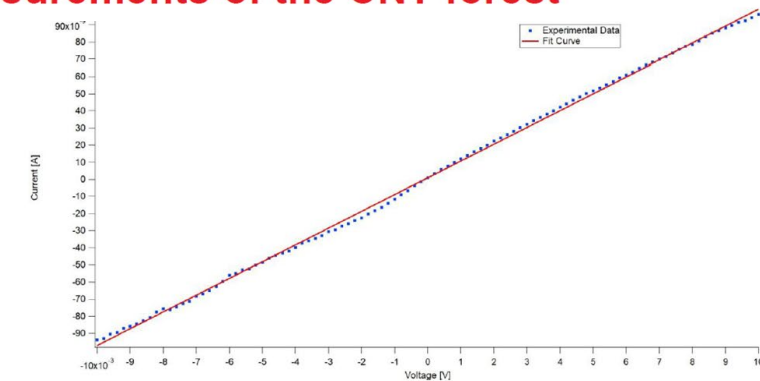


A wider trench in a 200x200 SWCNT forest hit by a gaussian proton beam with $\sigma=1\ \mu\text{m}$.

Tentative COMSOL 3D approach



Focused Ion Beam (FIB) channels milling: SEM characterization



Measured resistance	$\approx 102 \text{ K}\Omega$
Distance between pads	350 μm
Pads dimensions	50 μm X 50 μm

Talks - thesis - publications

1 x MSc Thesis: “Synthesis and characterization of metal coatings in complex structures for sub-micrometer ion beam collimation applications”, Beatrice Bonaldo, Universita' Di Padova, consaeguita 03/09/2024, relatore Valentino Rigato (LNL)

ADMIRAL

Advanced **D**osimetry **M**ethods and In-vitro **R**adiobiology of **Ag-111**
Labeled radiopharmaceuticals

RL – Antonietta Donzella

Informazioni generali

Sezioni Coinvolte:

- Pavia (UniBs, UniPv-LENA, INRiM)
- LNL (UniPd, IRCCS (RE), UniSi)
- Padova
- Bologna (UniBo)
- TIFPA (UniTn, Biotech, Cibio)
- LNS (UniCt, CAPIR)

FTE 2024: 3,4

Anagrafica di Pavia

- Donzella Antonietta (RL) UniBs 0,7 FTE
- Salvini Andrea UniPv-LENA 0,3 FTE
- Gandini Andrea UniPv-LENA 0,3 FTE
- Zelaschi Fabio UniPv-LENA 0,2 FTE
- Silva Bortolussi UniPv
0,2 FTE
- Giancarlo D'Agostino INRiM 0,5 FTE
- Marco Di Luzio INRiM
0,5 FTE
- Laura Cansolino UniPv
0,3 FTE
- Cinzia Ferrari UniPv
0,4 FTE

Goal del progetto

Obiettivi generali

ADMIRAL è finalizzato allo studio delle proprietà diagnostiche e terapeutiche di un nuovo radiofarmaco basato sul radionuclide ^{111}Ag . Il programma di ricerca si basa su quattro Task con i seguenti obiettivi:

WP1: produzione del radiofarmaco marcato con ^{111}Ag . **WP2:** costruzione di un nuovo rivelatore beta, per esperimenti in vitro su colture cellulari 2D e scaffold.

WP3: costruzione di un sistema planare per il gamma-imaging, ottimizzato per ^{111}Ag .

WP4: valutazione terapeutica in vitro del ^{111}Ag mediante esperimenti di sopravvivenza cellulare su colture tumorali sia in 2D che in scaffold 3D che imitano i tessuti cellulari, microscopia confocale e β -imaging, e sviluppo di algoritmi di dosimetria Monte Carlo a livello cellulare.

Obiettivi Specifici di Pavia

E' proseguita la **produzione di Ag-111** presso il LENA (160 MBq), con conseguente spedizione presso i laboratori autorizzati di Pavia e Catania per **misure in vitro e test clonogenici**.

La procedura di **purificazione radiochimica** del radioisotopo ^{111}Ag dal campione di ^{110}Pd arricchito ha permesso un ulteriore miglioramento di un fattore 1000 tra Ag e Pd, grazie all'uso di una seconda colonna a scambio ionico.

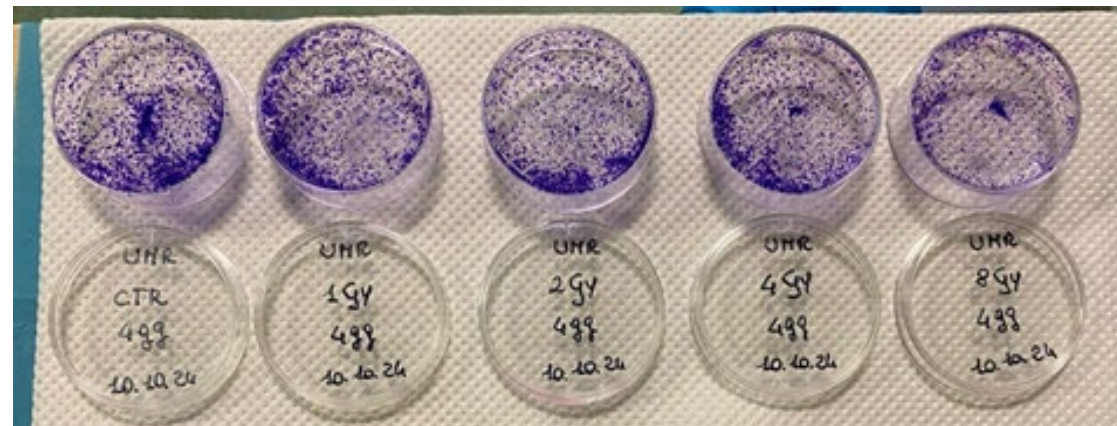
I risultati dei **calcoli Monte Carlo di dose assorbita** a livello cellulare da distribuzioni di ^{111}Ag , effettuati nel 2023, sono stati utilizzati per determinare modelli dose-risposta che correlano la dose assorbita con la frazione di sopravvivenza cellulare.

Il lavoro è stato recentemente accettato per una pubblicazione su "Applied Radiation and

Risultati 2024 – milestones (Pavia)

(100%) Test di sopravvivenza cellulare in piastre Petri 2D

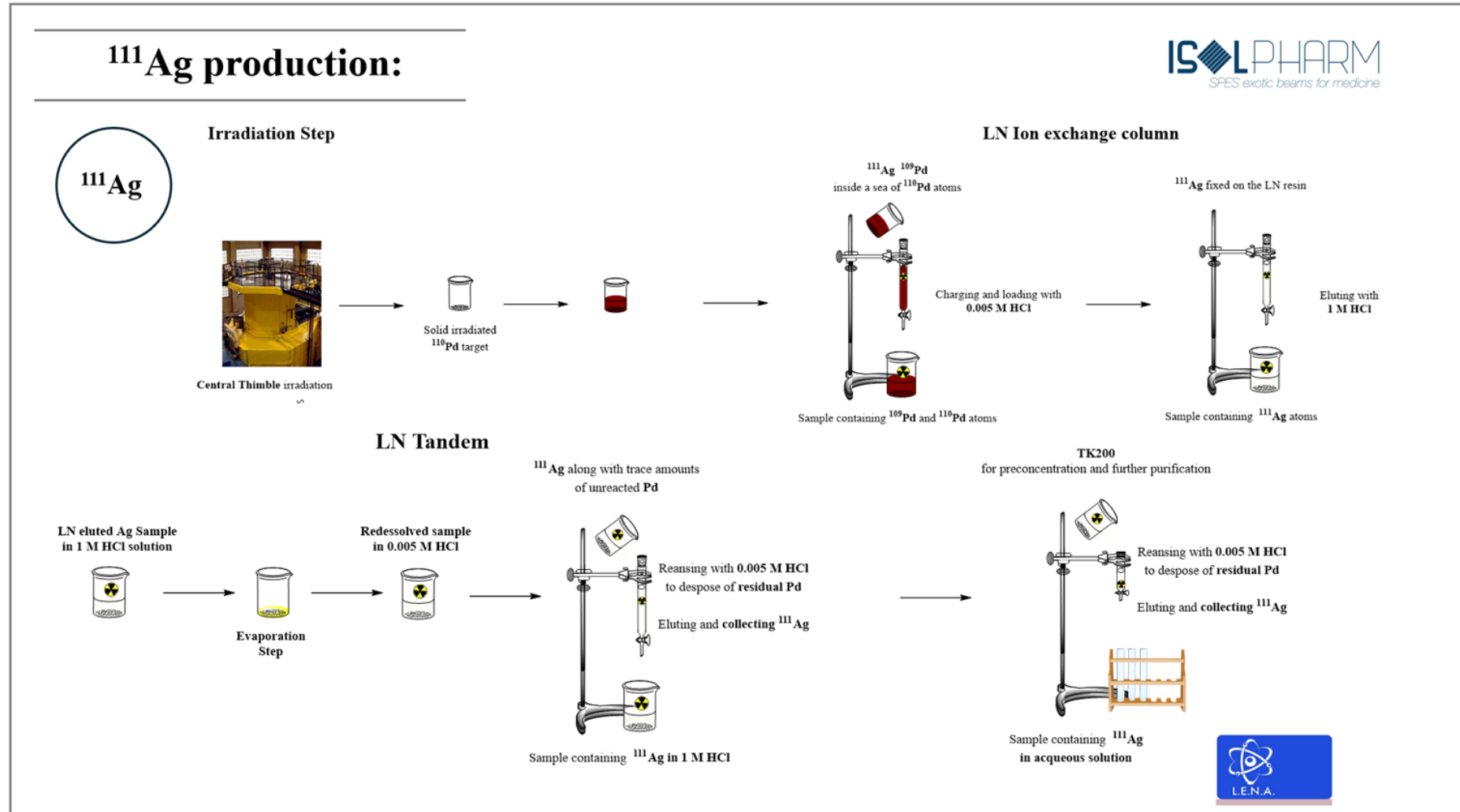
Il radioisotopo ^{111}Ag è stato somministrato alla linea cellulare tumorale UMR-106 (osteosarcoma di ratto) depositata su piastre Petri 2D, a diverse concentrazioni di attività e a diversi tempi di esposizione (4 e 10 giorni). La campagna di misura ha permesso di realizzare test preliminari sulle cellule e il saggio clonogenico per la valutazione della sopravvivenza cellulare.



Petri contenenti le cellule fissate con etanolo 70% e colorate con blu di toluidina; tempo di osservazione 4 giorni

Altri risultati 2024: doppia separazione radiochimica

Grazie a questo miglioramento nel protocollo di separazione, il rapporto Ag/Pd è migliorato di un fattore 1000. Partendo da un campione da 150 mg di palladio arricchito irraggiato nel reattore, alla fine della procedura la massa residua di palladio è di circa 50 ng.



Tesi, congressi e pubblicazioni

Pubblicazioni

D. Serafini et al., “*111Ag phantom images with Cerenkov luminescence imaging and digital autoradiography within the ISOLPHARM project*”, Appl. Radiat. Isot., 215 (2025) 111562, <https://doi.org/10.1016/j.apradiso.2024.111562>.

A. M. Pavone et al., “*Biodistribution assessment of a novel 68Ga labeled radiopharmaceutical in a cancer overexpressing CCK2R mouse model: conventional and radiomics methods for analysis*”, Life, 14(3) (2024) 409, <https://doi.org/10.3390/life14030409>

Tesi di dottorato e magistrali

A. Arzenton, “*Towards 111Ag as a medical radionuclide: from production and laser photo ionisation to cell dosimetry and radiation biophysics in the context of the ISOLPHARM project*”, PhD thesis, Università degli Studi di Siena, Dipartimento di Scienze Fisiche, della Terra e dell’Ambiente, 2024.

F. Nicente, “*Screening e sviluppo tecnologico di target di deposizione innovativi per la raccolta di radionuclidi medicali nell’ambito del progetto ISOLPHARM*”, MSc thesis, Università degli Studi di Padova, Dipartimento di Scienze del Farmaco, 2024.

Presentazioni orali a conferenze

D. Serafini, Development of a β imaging detector tailored to Ag 111 for the ISOLPHARM project, INFN2024 6th Nuclear Physics National Meeting, 26 28 February 2024, Trento (Italy).

A. Andrichetto, ISOLPHARM project: development of two preclinical imaging devices for 111Ag β and γ radiation, 10th PSMR Conference, 20 23 May 2024, Isola d’Elba (Italy).

A. Arzenton, Validation of a biophysical model for the radiobiology of radiopharmaceuticals, RAP2024 Conference, 10 12 June 2024, Granada (Spain).

D. Serafini, First ISOLPHARM preclinical studies with Ag 111 radionuclide, 110th SIF Congress, 9 13 September 2024, Bologna (Italy).

D. Chen, Simulation study of the radionuclide deposition process on the collection target in the context of the SPES facility, 110th SIF Congress, 9 13 September 2024, Bologna (Italy).

A. Donzella, Production and characterization of the 111Ag radioisotope for the development of a new generation of radiopharmaceuticals: the Italian ISOLPHARM project, ANP2024 Conference, 23 27 September 2024, Thessaloniki (Greece).

ARES

Astronauts' risks by space Radiation in future Exploration missions: simulations and experiments with the new innovative ion Source at CNAO
RN – Ricardo Ramos - Grant 5

Informazioni generali

Sezioni Coinvolte

- Pavia

FTE 2024: 2.75

Anagrafica di Pavia

- | | | | |
|---|---------------------------------|------|-----|
| - | Ricardo Ramos | 0.9 | FTE |
| - | Francesca Ballarini | 0.3 | FTE |
| - | Laura Cansolino | 0.3 | FTE |
| - | Mario Carante | 0.2 | FTE |
| - | Cinzia Ferrari | 0.4 | FTE |
| - | Marco Pullia | 0.1 | FTE |
| - | Lonardi Ornella | 0.1 | FTE |
| - | Kourkoumeli Charalampidi Athina | 0.05 | FTE |
| - | Postuma Ian | 0.2 | FTE |
| - | Vercesi Valerio | 0.2 | FTE |

Goal of the project

Objective

The main objective of ARES consists of performing simulations and experiments that will allow quantifying the risks related to space radiation exposure by reproducing as closely as possible the peculiar exposure scenarios encountered by astronauts in space.

Specific Objectives

- 1- Calculating distributions of absorbed dose and RBE for different space radiation scenarios.
- 2- Experimental characterisation and parameter optimization of the AISHa ion source.
- 3- Production and analysis of new radiobiological data in the framework of space radiation research to investigate the impact of low dose-rate in cells and tissues.

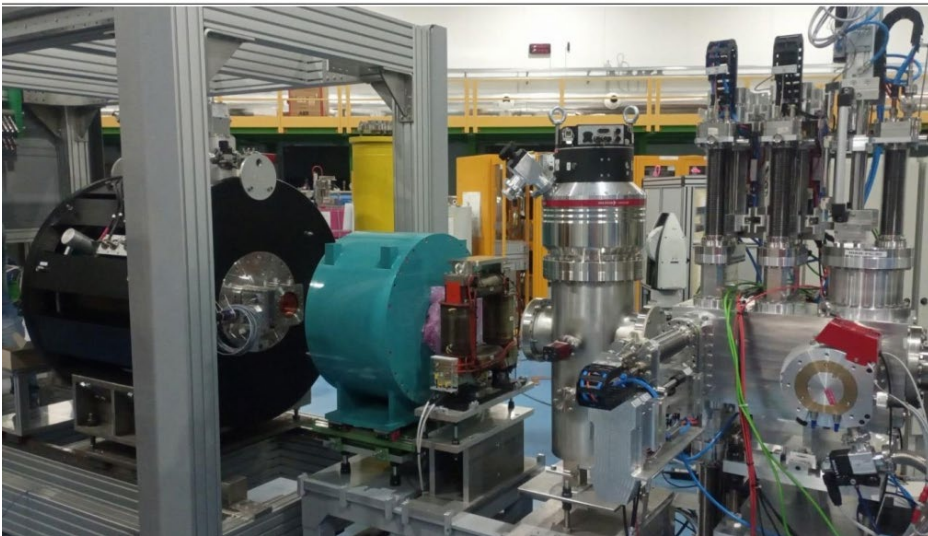
Milestones 2024

M4- Physical characterisation and optimization of the AISHa source (100%)

M5- Production of experimental radiobiological data at different dose-rates for different ion beams. The data will be produced considering both monolayer cell cultures and 3D organ models (100%)

M6- Comparison between experimental data and simulations. Up-grade of BIANCA model (100%).

Results: Participation in commissioning of AISHA -CNAO 2024 (M4)

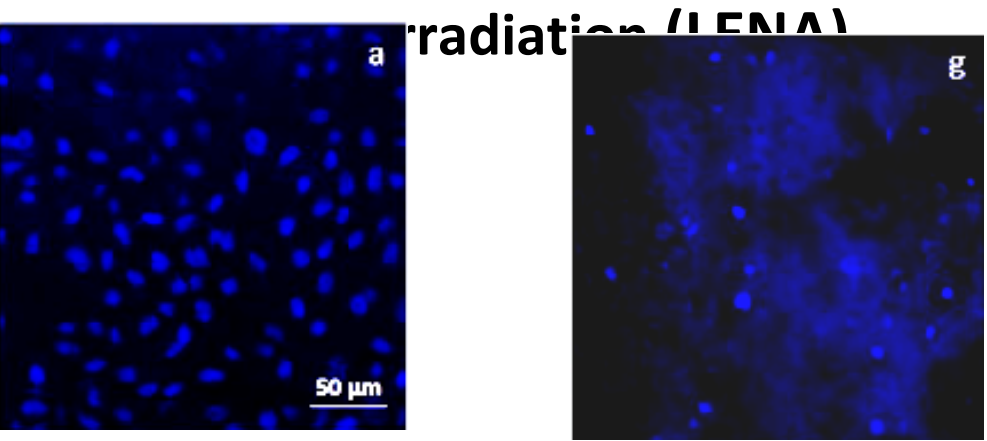
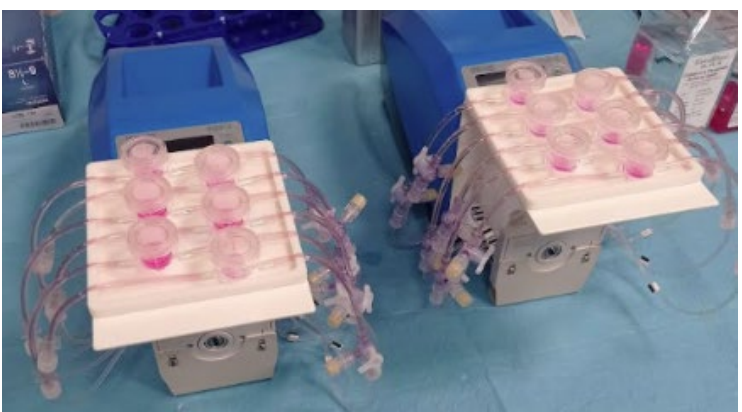


A 900uA intensity beam was produced by using 800 W of microwave power and 16 kV extraction voltage.

Results: Experimental activities and modeling (M5, M6)

3D models and Bioreactors

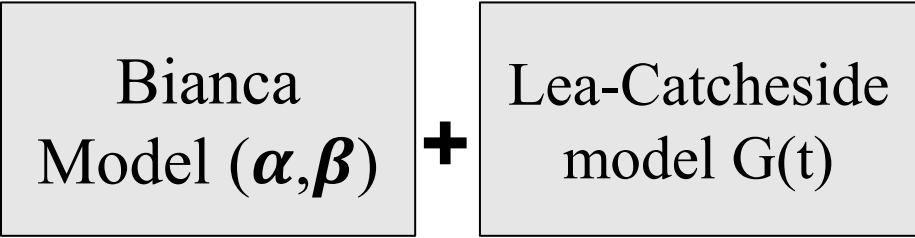
Design and implement a reproducible methodology maintaining **tissues viability and structural integrity**



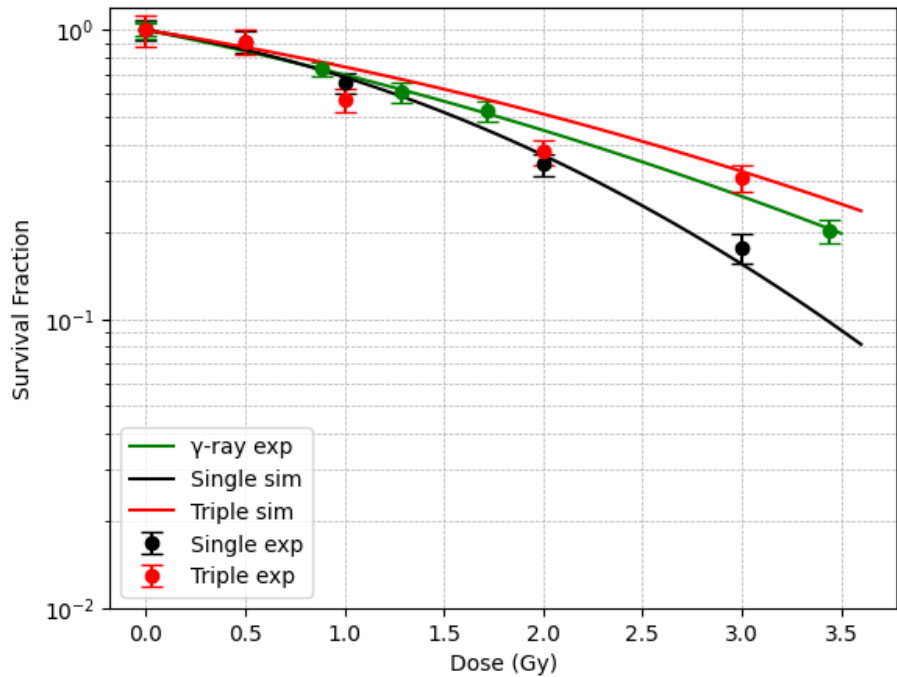
0 Gv

1 Gv

Bianca and dose-rate effects



Cells AG01522, Protons 0.7 keV/μm (CNAO)



Key Achievements of ARES project

Advanced RBE Approach:

Incorporated dependence of RBE on particle, LET, dose, and dose-rate.

Dose & RBE Modeling:

Calculated absorbed dose and variable RBE distributions for GCR/SPE sources using BIANCA-FLUKA and anthropomorphic phantoms under different shielding scenarios. New Interface BIANCA-PHITS.

New Experimental Data:

Produced new radiobiological data relevant to space radiation protection.

3D Tissue models:

Established a methodology using 3D tissue models and microfluidic bioreactors for radiation effect evaluation.

Thesis - Publications - Talks - Awards

- **2 Nuclear Engineering Master Thesis, 2 Phd Thesis (ongoing)**

- **7 publications (3 published, 2 submitted, 2 to be submitted)**

1. R. L. Ramos...& F. Ballarini ; Radiation exposure of astronauts following an intense solar particle event: analysis and comparison of doses in male and female voxel phantoms . JRadiol Prot. 2024 Oct 9;44(4).
2. R. L. Ramos... & F. Ballarini ; A method to predict space radiation biological effectiveness for non-cancer effects following intense Solar Particle Events . Life Sciences in Space Research, 41, pp . 210- 217(2024).
3. R. L. Ramos...& F. Ballarini ; A Mission to Mars: Prediction of GCR Doses and Comparison with Astronaut Dose Limits . Int . J Mol . Sci. 2023, 24, 2328.
4. E. Bernardini ...& R. L. Ramos; Astronauts' exposure to intense Solar Particle Events beyond LEO: RBE-weighted organ doses and effective doses behind different shielding materials , submitted JRP.
5. E.I. Canay...& R. L. Ramos; Incorporation of dose-rate effects into the BIANCA biophysical model and application for space radiation risk assessment, submitted LSSR
6. I. Gonella ...& R. L. Ramos; BIANCA-PHITS interface , to be submitted .
7. S. Ricci...& R. L. Ramos; Development of a Novel Methodology for Evaluating Radiation Effects Using 3D Tissue Models and Microfluidic Bioreactors , to be submitted .

- **7 oral presentations**

- **Grant of the MAECI (Ministero degli Affari Esteri e della Cooperazione Internazionale)**

- **MSc Thesis in Nuclear Engineering awarded with the 3rd place of the "Pre-Ingenieria Award" of the Argentine Center of Engineers, 2024.**

BIOHOT

BIOphysical characterization of **H**elium and **O**xygen ion
beams for hadron**T**herapy

RL – Francesca Ballarini

Informazioni generali

Sezioni Coinvolte

- Pavia (*RL Ballarini*)
- Napoli (*RN e RL Manti*)
- Roma3 (*RL Antoccia*)

FTE 2024: 2.5

Anagrafica di Pavia

- F. Ballarini (PA) 0.7 FTE
- M.P. Carante (RTDA) 0.2
- A. Facoetti (CNAO) 0.5
- A. Mairani (CNAO) 0.2
- M. Pullia (CNAO) 0.1
- A. Charalampopoulou 0.8
(dott. IUSS-CNAO)

Goal del progetto per il 2024 (Pavia)

Attività modellistica

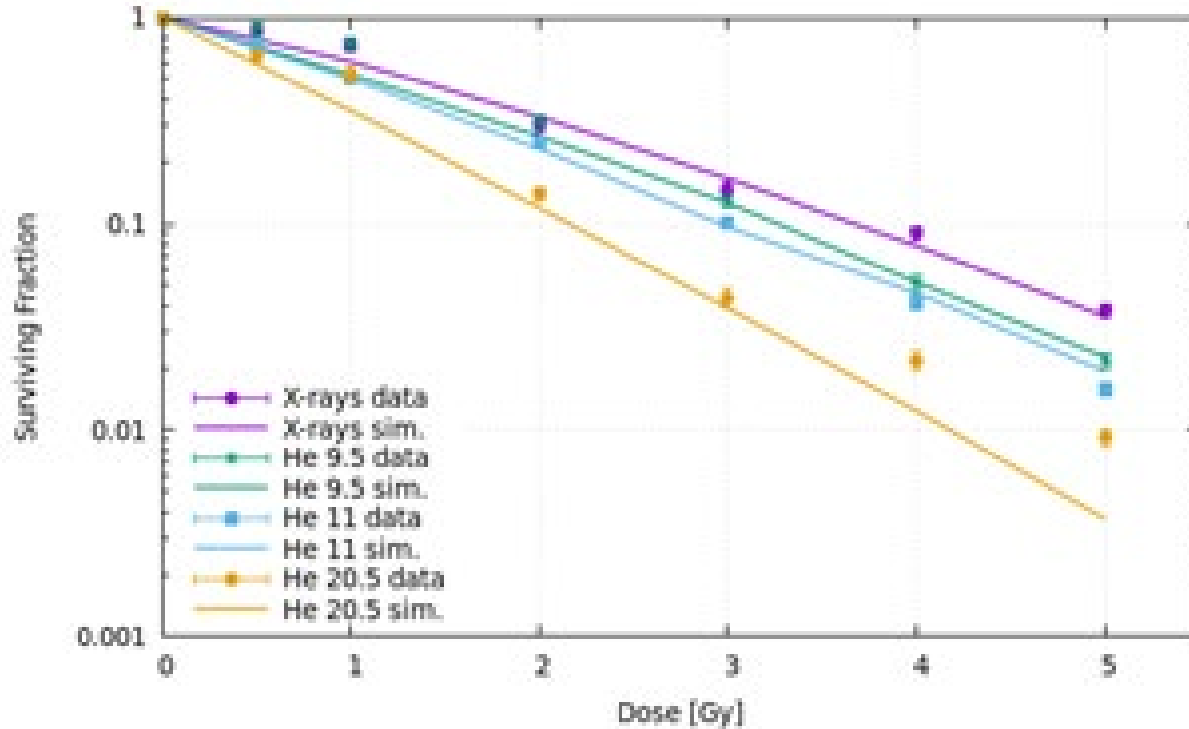
- modelling (by the BIANCA model/code) the survival of U2OS osteosarcoma cells exposed to X-rays and He-ions, and comparison with the data obtained by the experimental partners
- modelling the induction of chromosome aberrations in MRC5 non-tumoral fibroblasts, and comparison with the data obtained by the experimental partners

Attività sperimentale

assessment of cancer cell migration 24 and 48 h post-irradiation with He ions, using the “transwell migration assay” (cells were seeded in the upper chamber of a porous membrane insert and allowed to migrate toward a serum-containing medium in the lower chamber)

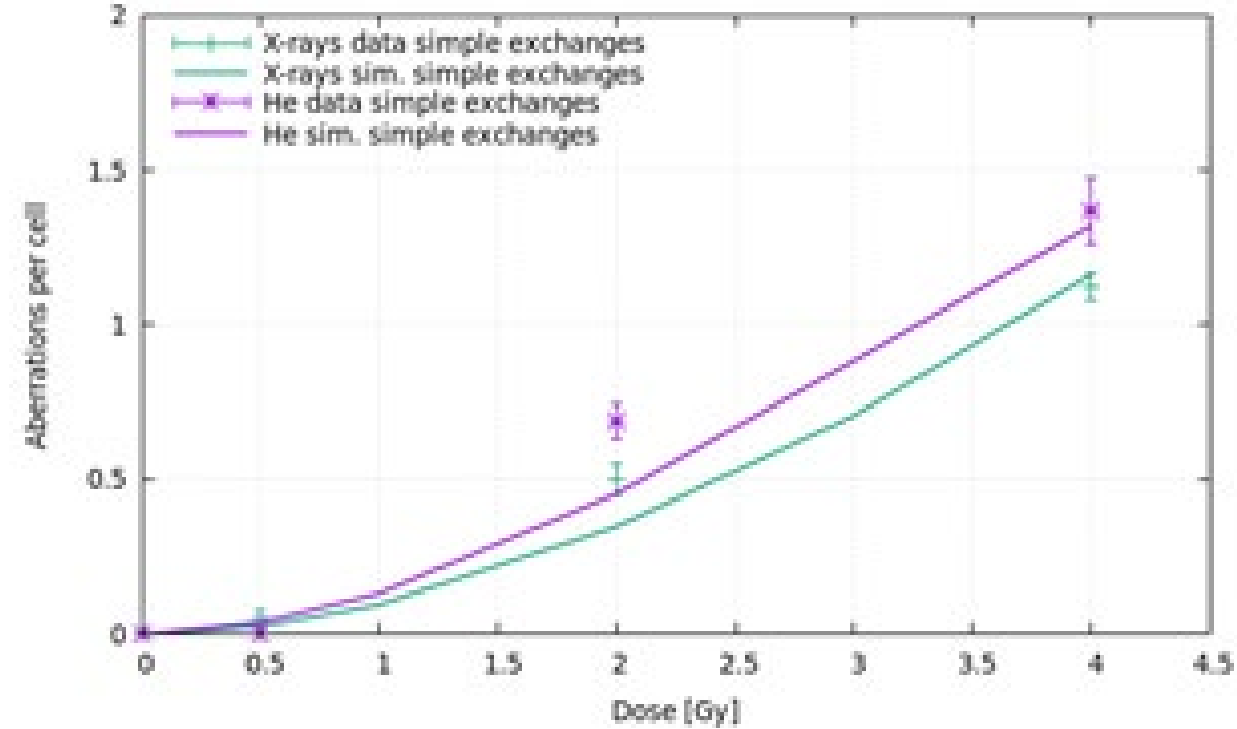
Risultati 2024 PV - modelling

survival of U2OS cells exposed to X-rays and He-ions (lines = predictions, points = data)



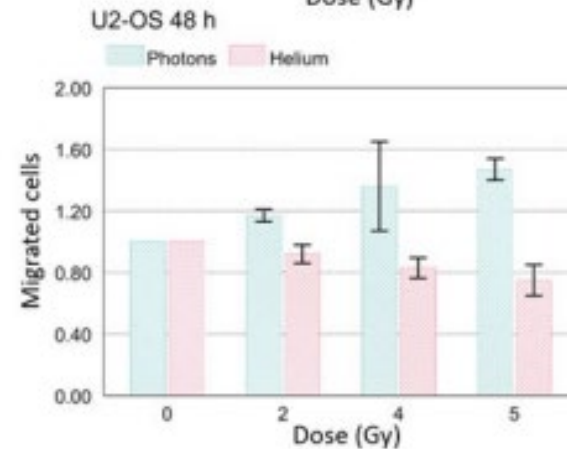
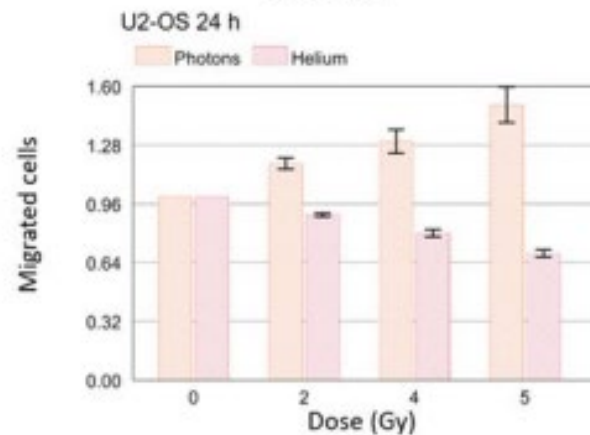
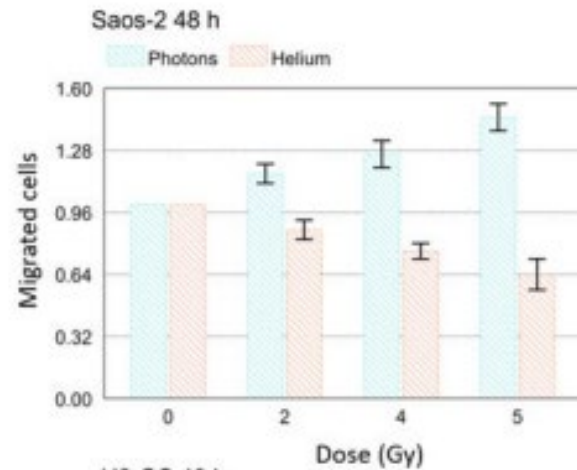
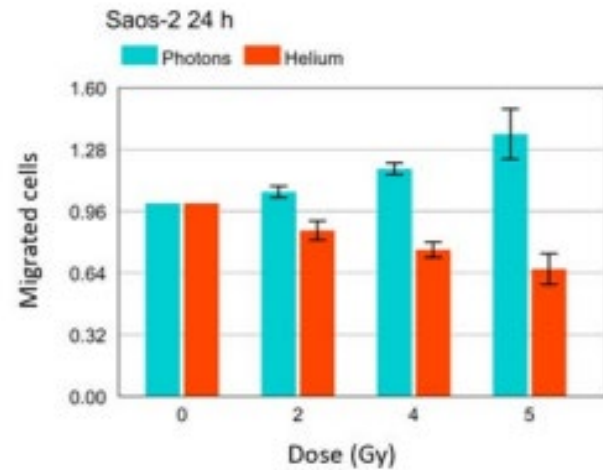
calculated RBE for the three He-ion positions: 1.03, 1.14, 1.56 (exp. values: 1.10 ± 0.16 , 1.22 ± 0.17 , 1.60 ± 0.20).

chromosome aberrations in MRC5 cells exposed to X-rays and He-ions (lines=predictions, points = data)



comment: the agreement between predictions and data allowed validating the extension of BIANCA to model the induction of cell death in U2OS cells and chromosome aberrations in MRC5 cells

Risultati 2024 PV - experiments



comment: the exposure of both SAOS-2 and U2OS osteosarcoma cells to He ions (mid-SOBP) resulted in a significant, dose-dependent reduction in the cell migratory capacity. This effect is in stark contrast with the enhanced migration observed following photon irradiation

Tesi, pubblicazioni e congressi (PV)

Tesi:

MSc in Physics, “Development of a mechanistic model for the prediction of Normal Tissue Complication Probability in cancer hadrontherapy”, University of Pavia. Candidate: Alice Casali; Supervisors: M. Carante, F. Ballarini; date of discussion: 19/04/2024

Articoli:

- M Carante, R Ramos, F Ballarini, *Radiation damage in biomolecules and cells 3.0*. International Journal of Molecular Sciences (Open Access), Volume 25, Issue 12, June 2024, 6368
- A Casali, R Ramos, F Ballarini, M Carante, *Prediction of normal tissue complication probability for rat spinal cord tolerance following ion irradiations*. Phys. Med. Biol. Vol 69, Issue 2421, Dec 2024, 245012

Congressi

- M Carante, *Probability for ion irradiation can be accurately predicted by a new biophysical approach*. 62nd PTCOG annual conference, Singapore, 10-15 June 2024.
- LM Valeriano, *The Photon Isoeffective Dose Model in Proton Therapy*. 62nd PTCOG annual conference, Singapore, 10-15 June 2024.
- S González, *Does including the dependence of the biological effect on the energy of charged particles in photon equivalent dose models significantly affect dosimetry in BNCT?* 20th ICNCT, Krakov, Poland, 24-28 June 2024.
- A Casali, *Previsioni di probabilità di complicanze nei tessuti sani (NTCP) sul midollo spinale di ratti in seguito a irraggiamento con ioni*. XXI Congresso Nazionale della Società Italiana per le Ricerche sulle Radiazioni (SIRR), October 2024, Pavia, Italy
- R Ramos, *The impact of including the dependence of the biological effect on energy of charged particles in BNCT dosimetry calculations: the extended photon isoeffective model*. XXI Congresso Nazionale della Società Italiana per le Ricerche sulle Radiazioni (SIRR), October 2024, Pavia, Italy
- A. Charalampopoulou, *3D tumour spheroids: new aspects as a radiobiological model for the assessment of cell survival and tumour invasiveness in response to irradiation*. 48th European Radiation Research Society Meeting, September 2024, Aveiro, Portugal
- A. Charalampopoulou, *Sferoidi tumorali 3D: nuovi aspetti come modello radiobiologico per la valutazione della sopravvivenza e dell'invasività tumorale in risposta alle radiazioni*. XXI Congresso Nazionale della Società Italiana per le Ricerche sulle Radiazioni (SIRR), October 2024, Pavia, Italy

DISCOVER22

**DNA Damage and Immune System COoperation in VEry low
Radiation environment (2022)**

RL – Giorgio Baiocco

Informazioni generali

Sezioni Coinvolte:

Roma 3 (RN)
Roma 1
LNGS
LNL
Pavia

Durata del progetto:
2023-2025

FTE 2024 sezione PV : 2.0

Anagrafica di Pavia 2024:

Giorgio Baiocco		PA
100		
Isabella Guardamagna	tecnico lab	50
Leonardo Lonati	AdR	50

Goal del progetto

Obiettivi

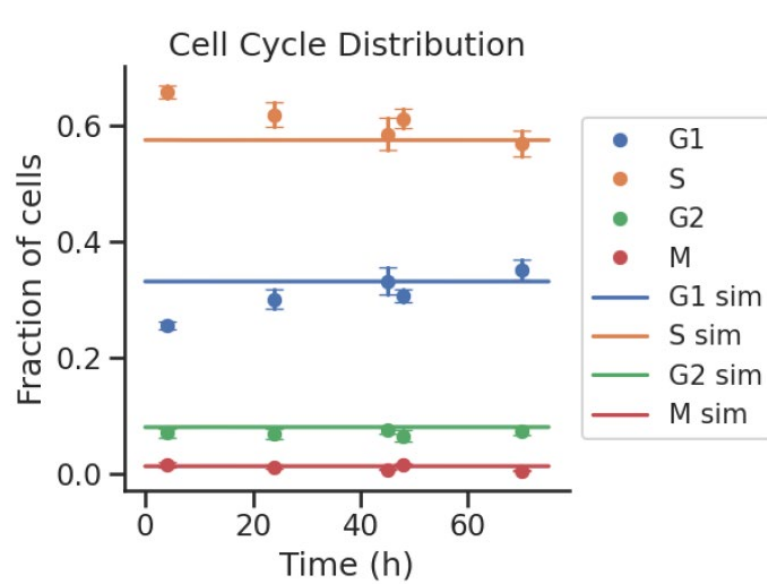
- To investigate whether a **low dose (< natural background) radiation environment** influences:
 - the **innate immune response** following **radiation-induced DNA damage**
 - the **differentiation** of immature immune cells to **in specialised immune system's cells**
 - **Gene-expression** of genes involved in the **immune response** using **Drosophila Melanogaster** as an *in vivo* organismal model
- To characterize the radiation field in the underground LNGS Lab by means of **microdosimetric measurements**
- To develop a **biophysical model** of a human cell population proliferating in the underground LNGS Lab and subject to radiation-induced DNA damages.

Obiettivi specifici

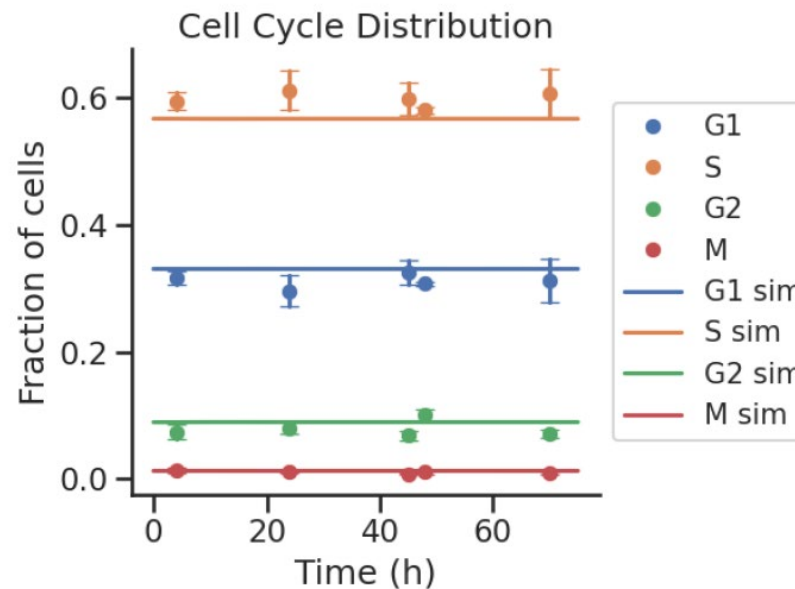
INFN-Pavia unit is in charge of:

- The development of the **biophysical model** to study the influence of the **low-dose radiation environment** in mechanisms activated by **DNA damage response** with the chosen *in vitro* cell line (HaCaT cells)
- Data analysis for the study of how the radiation environment influences ***in vitro* differentiation of immune cells**

Risultati 2024 – milestones (Pavia)

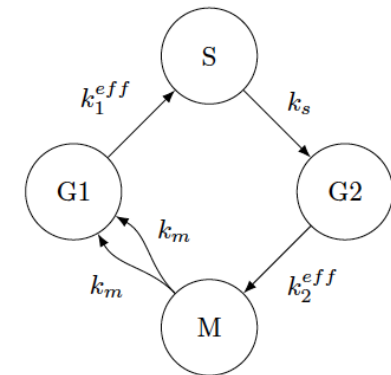


RRE



LRE

$$\begin{aligned}\frac{dG_1(t)}{dt} &= 2k_M M(t) - k_1^{eff}(t, d)G_1(t) \\ \frac{dS(t)}{dt} &= k_1^{eff}(t, d)G_1(t) - k_S S(t) \\ \frac{dG_2(t)}{dt} &= k_S S(t) - k_2^{eff}(t, d)G_2(t) \\ \frac{dM(t)}{dt} &= k_2^{eff}(t, d)G_2(t) - k_M M(t)\end{aligned}$$

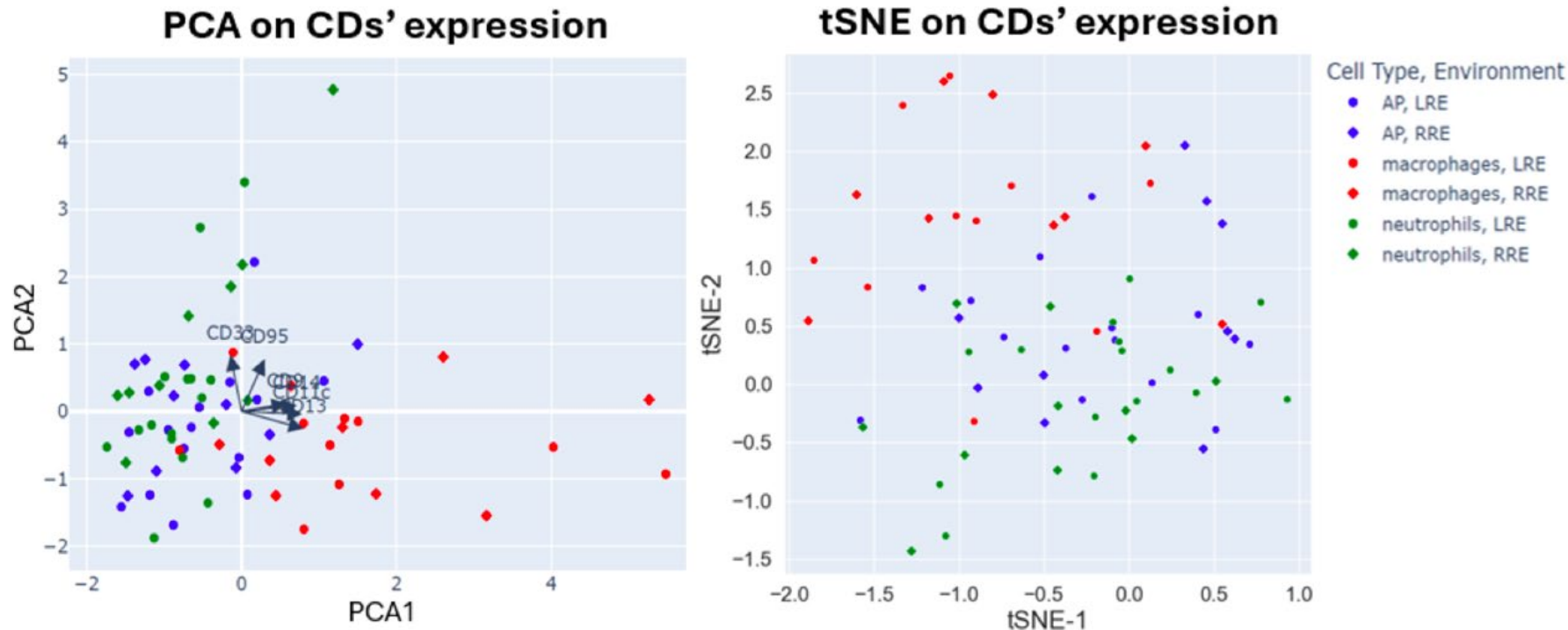


•MILESTONE: Report on cell-cycle model validation for LRE and RRE - **RAGGIUNTA**

Modello computazionale di ciclo cellulare sviluppato e adattato per riprodurre la percentuale di cellule nelle varie fasi del ciclo in condizioni di crescita nei due ambiente di radiazione (*RRE*, *Reference Radiation Environment*, laboratorio esterno, e *LRE*, *Low Radiation Environment*, laboratorio underground @LNGS).

Il modello è nella fase finale di adattamento per la riproduzione della perturbazione del ciclo nelle due popolazioni cellulari (raccolta dati completata, trasferta Lonati @LNGS e Roma3 e misure presso il RadBioPhys Lab - UniPv) e induzione di micronuclei (dati Roma3) a seguito di irraggiamento con *challenging* dose.

Risultati 2024 – milestones (Pavia)



- **MILESTONE:** Analisi dati sull'effetto sul differenziamento di cellule del sistema immunitario a seconda dell'ambiente di radiazione (dati da Roma1) - **a fine PROGETTO**

Approcci con *Principal Component Analysis* e tSNE testati sui dati ricevuti (parziali) di espressione dei CD, con capacità di discriminazione tra tipi cellulari (principalmente identificazione della popolazione di macrofagi) ma NON tra ambienti di radiazione RRE e LRE. Le analisi verranno finalizzate sul pacchetto dati completo di Roma1, che includerà test di funzionalità delle diverse popolazioni cellulari nelle varie condizioni.

Tesi, congressi e pubblicazioni

Intervento a congresso:

Giorgio Baiocco, *DISCOVER22 radiobiology project at Laboratori Nazionali del Gran Sasso*, RRS 2024 15-18 September 2024 Tucson (US) (Invited speaker) Oral presentation

Tesi:

E. Agulló Roca, *M.Sc. Biomedical Physics, UniPv* - in corso

MATHER3D

MAgnetic hyperthermia and hadron THERapy applied to 3D
cellular scaffolds

RN –Alessandro Lascialfari

Informazioni generali

Sezioni Coinvolte

- Pavia
- Milano
- Firenze (da 2024)

FTE 2024:

PV (7 persone – 2 FTE)

MI (10 persone – 3.4 FTE)

Anagrafica di Pavia

• Alessandro Lascialfari	0.30 FTE
• Francesca Brero	0.20 FTE
• Angelica Facoetti	0.40 FTE
• Marta Filibian	0.20 FTE
• Margherita Porru	0.50 FTE
• Marco Giuseppe Pullia	0.10 FTE
• Agnese Robustelli Test	0.30 FTE

Collaboratori esterni

Firenze

Fondazione CNAO Pavia

Fondazione Maugeri

Università di Pavia/IRCCS S. Matteo

Goal del progetto

Obiettivi

- **Terapia anti-tumorale (pancreas): studio della azione combinata** di Adroterapia (HT) e Ipertermia (Hyp) e/o Ipertermia magnetica (MFH)
- **Focus su scaffolds tridimensionali (3D) contenenti cellule BxPC3 pancreatiche**, trattate con protoni/ioni carbonio+ MFN/Hyp oppure fotoni + MFH/Hyp

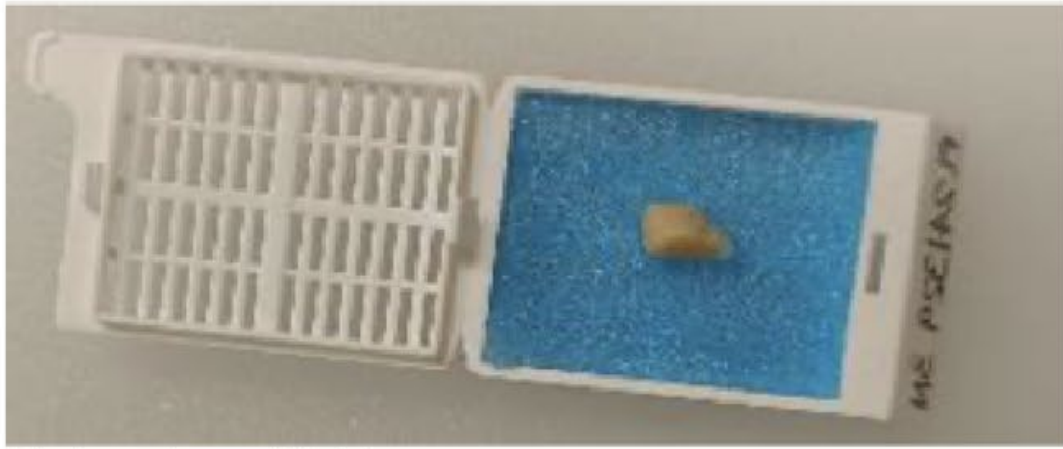
Obiettivi Specifici

- Nanoparticelle magnetiche: sintesi, caratterizzazione e ottimizzazione
- Scaffolds 3D: scaffolds seeding e uptake delle nanoparticelle
- Trattamento combinato
- Valutazione efficacia del trattamento tramite analisi istologica

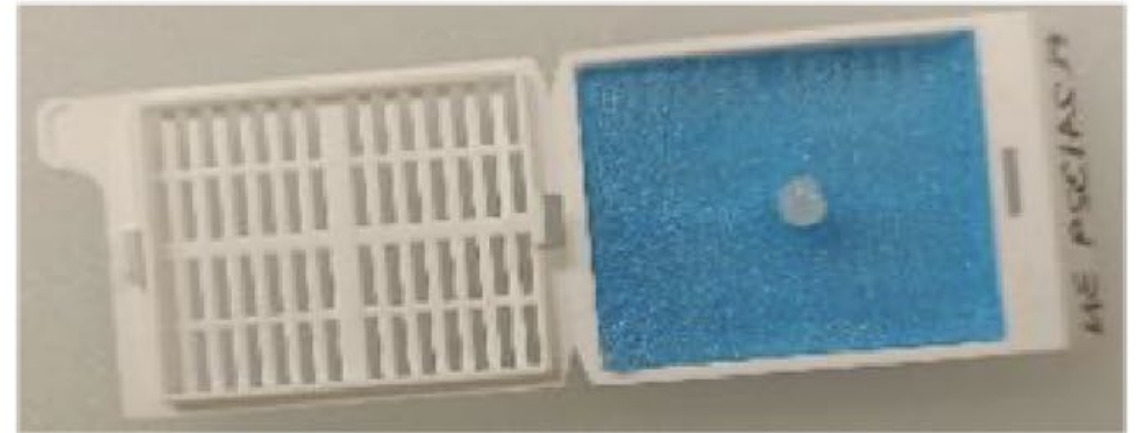
Obiettivi di Pavia

- Caratterizzazione NMR e ipertermica
- Esperimenti presso CNAO
- Quantificazione dell'uptake cellulare
- Scaffolds seeding
- Collaborazione con le altre unità

Preparation of synthetic and natural scaffolds (PV, FI)



Natural scaffold



Synthetic scaffold

Fig. 2: Macroscopic appearance of natural and synthetic scaffolds.

Proton/photon irradiation plus hyperthermia on 3D scaffolds (PV)

- **Proton Irradiation on January 21, 2024 and July 21, 2024:**
Natural scaffolds seeded with BxPc-3 cells were used at doses of 0, 2, and 4 Gy under the following conditions:
 - NO nanoparticles, NO hyperthermia
 - YES nanoparticles, NO hyperthermia
 - YES nanoparticles, YES hyperthermia

For each condition, scaffolds were fixed at 48 hours and 15 days after irradiation, in order to perform treatment efficiency evaluation, through histological evaluation.

- **Proton Irradiation on October 7, 2024 and Photon Irradiation on November 15, 2024:**
Natural and synthetic scaffolds seeded with BxPc-3 cells were used at doses of 0 and 4 Gy under the following conditions:
 - NO nanoparticles, NO hyperthermia
 - YES nanoparticles, NO hyperthermia
 - YES nanoparticles, YES hyperthermia

Each scaffold was fixed 15 days after irradiation, in order to perform treatment efficiency evaluation, through histological evaluation.

Histological and immunohistochemical evaluation of scaffolds seeded with BxPC3 cells (MI)

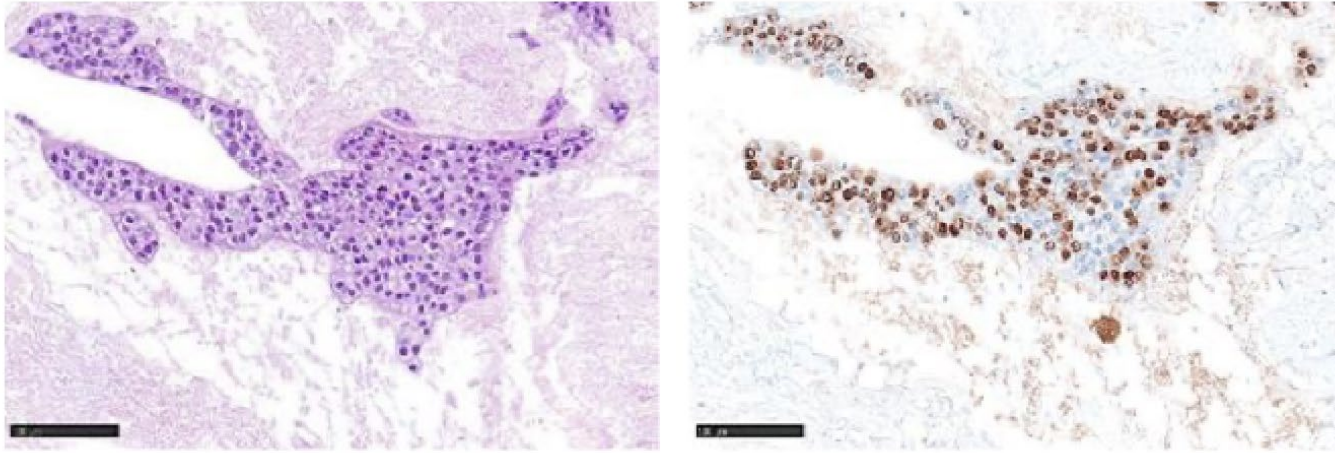


Fig. 3. Proton Irradiation on July 21, 2024 - Representative images of a decellularized swine liver scaffold colonized by BxPc-3 cells without magnetite nanoparticles, no irradiation, and no hyperthermia (48h, 0Gy, NO NP, NO HYP). Presence of proliferating cells positive to Ki67 immunostaining (brown cells).

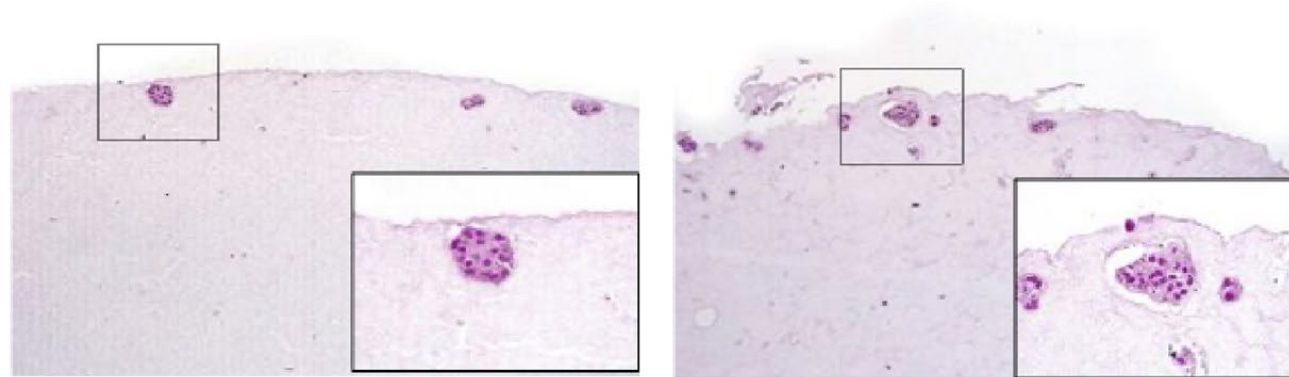


Fig. 4. Photon irradiation on November 15, 2024 - Representative images of synthetic scaffolds with few cells in the form of clusters in the matrix at the periphery of the scaffold.

Tesi, congressi e pubblicazioni

Margherita Porru

–**POSTER** “Iron Oxide-Based MNPs: Shape, Size and Coating Effect on their Hyperthermic and ^1H -NMR Relaxation Properties”, VIII Italian Conference on Magnetism MAGNET2024, Milano, 7-9 Febbraio 2024

–**POSTER** “Manganese and Zinc Doping of Iron-Oxide Magnetic Nanoparticles: Their Role in Relaxometric and Hyperthermic Properties”, ICM2024, Bologna, 30 Giugno -5 Luglio 2024

–**ORAL** “Zinc and manganese doped iron oxide magnetic nanoparticles: effect on the ^1H -NMR relaxometric properties”, 51st National Congress on Magnetic Resonance, Firenze, 4-6 Settembre 2024

–**ORAL** “Proprietà rilassometriche di nanoparticelle magnetiche a base Fe_3O_4 : effetto del doping con Zn^{2+} e Mn^{2+} ”, 110° Congresso Nazionale della Società Italiana di Fisica, Bologna, 9-13 Settembre 2024

–**POSTER** “Iron-Oxide Magnetic Nanoparticles: Manganese and Zinc Doping Effects on Relaxometric Properties”, 14th International Conference on the Scientific and Clinical Applications of Magnetic Carriers, Barcellona, 17-21 Giugno 2024

Francesca Brero

ORAL “Effetto di forma e dimensione sulle proprietà rilassometriche e ipertermiche di nanoparticelle magnetiche”, 110° Congresso Nazionale della Società Italiana di Fisica, Bologna, 9-13 Settembre 2024 **ORAL** “OPTIMIZATION OF IRON OXIDE MAGNETIC NANOPARTICLES FOR ENHANCED MRI CONTRAST AND HYPERTHERMIA TREATMENT”, 51st National Congress on Magnetic Resonance, Firenze, 4-6 Settembre 2024

POSTER “Influence of Shape, Size, and Coating on the Efficiency of Iron-Oxide Magnetic Nanoparticles as Magnetic Resonance Imaging Contrast Agents and Hyperthermic Agents”

International Conference on Magnetism - ICM2024, Bologna, 30 Giugno -5 Luglio 2024

POSTER “Exploring the Impact of Shape, Size, and Coating on the Efficacy of Iron-Oxide Nanoparticles in Magnetic Resonance Imaging and Hyperthermia”, 14th International Conference on the Scientific and Clinical Applications of Magnetic Carriers, Barcellona, 17-21 Giugno 2024

POSTER “Magnetic Hyperthermia and Hadron Therapy Applied to 3D Cellular Scaffolds”

VIII Italian Conference on Magnetism MAGNET2024, Milano, 7-9 Febbraio 2024

Alessandro Lascialfari

ORAL “Magnetic nanoparticles for magnetic resonance imaging”

Workshop “Exploring diagnostic probes and procedures beyond Gd(III) for MRI applications, Alessandria, 31/05/2024

NEXT_AIM

NEXT_Artificial Intelligence in Medicine

RL – Alessandro Lascialfari

Informazioni generali

Sezioni Coinvolte

- Pisa (RN – A. Retico)
- Bari
- Bologna
- Cagliari
- Catania
- Ferrara
- Firenze
- Genova
- LNS
- Milano
- Napoli
- Padova
- Pavia

Anagrafica di Pavia (2024)

Ballante Elena	0.2	
Barzaghi Leonardo	0.3	
Brero Francesca - postdoc	0.2	
Cabini Raffaella	0.3	
Figini Silvia, PO	0.2	
Filibian Marta – tecnico D	0.1	
Lascialfari Alessandro-PO	0.15	RL
Negri Andrea-PA	0.1	
Porru Margherita – PhD	0.1	
Postuma Ian-postdoc	0.2	
Protti Nicoletta-RTDB	0.1	
Robustelli Test Agnese - PhD	0.2	

FTE 2024: 2

Goal del progetto

Obiettivi generali

Development of robust and explainable Artificial Intelligence (AI) algorithms and their validation on realistic cases in the medical field.

Indeed, a wide variety of AI-based algorithms have already been developed to analyze medical images and data. Their potential to improve clinical workflows has not yet been fully realized due to:

- Lack of robustness or generalizability of the models
- Lack of transparency.

Obiettivi di Pavia

- Continuation of the study on COVID-19 (lung).
- Deep Learning to quantify fat fraction and water T2 value in facio-scapulo-humeral muscular dystrophy, to observe the disease progression (Mondino).
- Study of lung tumors (BlueSky, S. Matteo): radiomic features vs treatments.
- MRI+CT on the lung: comparison between different software and between MRI and CT.
- Instructions on available software resources and their usage.
- Instructions for the release of the software package.

Non-Invasive Lung Cancer Characterization Through Radiomics and Deep Learning Techniques

Agnese Robustelli Test

MRI-driven expression
assessment of PD-L1 in
lung cancer



Bridging Scales: A
Radiomics-Based
Comparison Between CT
and Micro-CT Modalities



CT-Based Radiomics for
Subtype Classification
in Non-Small Cell Lung
Cancer



CONCLUSIONS

Limitations

- Small dataset size
- Mono-centric nature

! Common for lung MRI

Lung investigation gold standard = CT

Next steps:
Test on bigger dataset

Conclusions

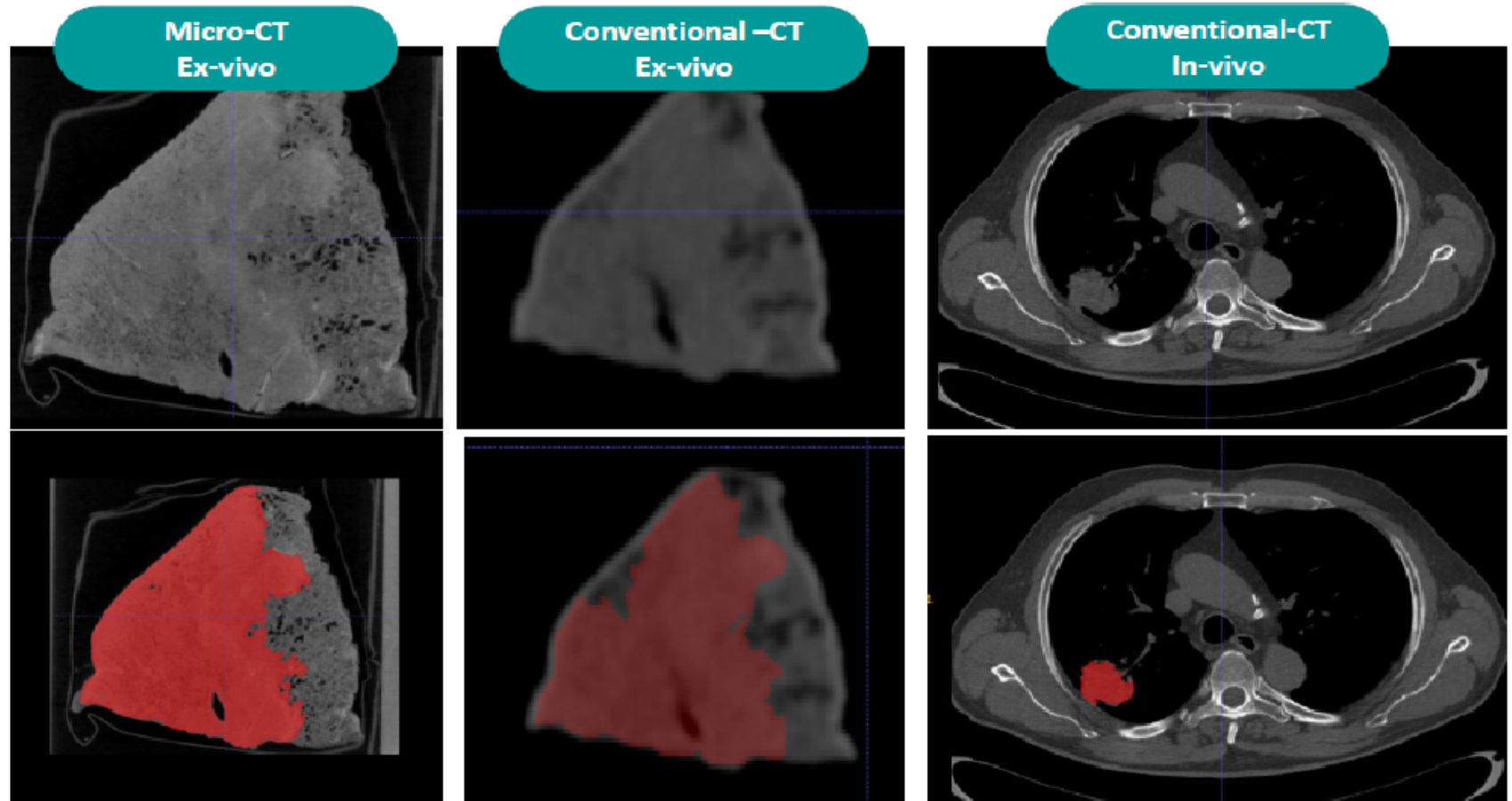
- Non-invasive pipeline to assess PD-L1 expression in NSCLC patients
- Good discriminative power (AUCs range [0.72; 0.92])
- IVIM-pf features = most stable input
- Mixed approach = beneficial
- Concordance among different classifiers

Bridging Scales: A Radiomics-Based Comparison Between CT and Micro-CT Modalities

Goal

Address the challenge of **translating microscopic-level information about the extracellular matrix into clinically relevant imaging features**, assessing whether microCT can bridge the gap between pathology and conventional CT imaging.

A total of 60 CT images were acquired using 3 different imaging modalities.

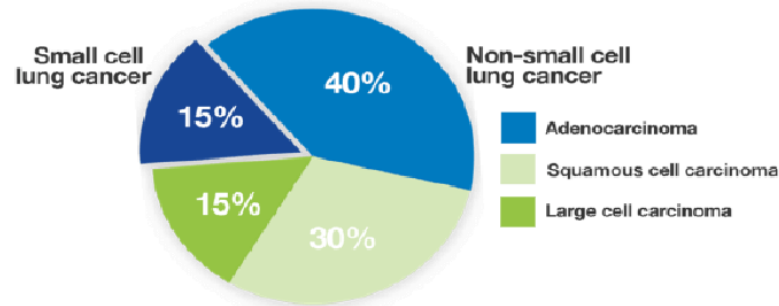


In progress.....

CT-Based Radiomics for Subtype Classification in Non-Small Cell Lung Cancer

Why ?

Lung adenocarcinoma (ADK) and lung squamous cell carcinoma (SCC) are the two most common subtypes of lung cancer. Previously, they were categorized into one histological subtype known as non-small cell lung cancer (NSCLC) and often treated similarly. However, increasing evidence suggested that ADK and SCC should be classified and treated as different cancers.



Goal

Identify the histological subtype of NSCLC (ADK vs SCC) through the analysis of CT images

Reduce the need for invasive biopsies

CONCLUSIONS

Limitations

Small dataset size → shallow NN
Noisy data → harmonization scanner-based

Next steps:

- Data augmentation
- Pre-trained NN

Conclusions

- Train-test: AUC = 0.74
- Cross-validation AUC = 0.71
- Comparable to previous study addressing the same goal with a similar dataset size

Deep learning classification of lung cancer histology using CT images

Tafadzwa L. Chavuzwa^{1,2}, Ahmed Heshiv, Yixen Xia, Andrea Shafer, Nancy Diaz, Michael Lanuti, David C. Christiani, Raymond H. Mak & Huo J. W. L. Aerts^{1,2}

Radiomics for Classification of Lung Cancer Histological Subtypes Based on Nonenhanced Computed Tomography

Linling E¹, Lin Lu², Li Li³, Hao Yang⁴, Lawrence H Schwartz⁴, Binsheng Zhao⁴

Lung cancer histology classification from CT images based on radiomics and deep learning models

Panagiotis Marentakis¹, Pantelis Karalaskos¹, Vassilis Kouloulas², Nikolaos Kolekis², Stylianos Argentos², Nikolaos Oikonomopoulos², Constantinos Loukas³

Tesi, congressi e pubblicazioni

PUBBLICAZIONI 2024

- 1) "Fast deep learning reconstruction techniques for preclinical magnetic resonance fingerprinting", R. F. Cabini, L. Barzaghi, D. Cicolari, P. Arosio, S. Carrazza, S. Figini, M. Filibian, A. Gazzano, R. Krause, M. Mariani, M. Peviani, A. Pichiecchio, D. U. Pizzagalli, A. Lascialfari, NMR in Biomedicine 37, e5028 (2024), <https://doi.org/10.1002/nbm.5028>
- 2) "Myo-regressor Deep Informed Neural NetWOrk (Myo-DINO) for fast MR parameters mapping in neuromuscular disorders", Leonardo Barzaghi, Francesca Brero, Raffaella Fiamma Cabini, Matteo Paoletti, Mauro Monforte, Francesca Lizzi, Francesco Santini, Xeni Deligianni, Niels Bergsland, Sabrina Ravaglia, Lorenzo Cavagna, Luca Diamanti, Chiara Bonizzoni, Alessandro Lascialfari, Silvia Figini, Enzo Ricci, Ian Postuma, Anna Pichiecchio, Computer Methods and Programs in Biomedicine 256, 108399 (2024)
- 3) "CT and MRI radiomic features of lung cancer (NSCLC): comparison and software consistency" Chandra Bortolotto, Alessandra Pinto, Francesca Brero, Gaia Messana, Raffaella Fiamma Cabini, Ian Postuma, Agnese Robustelli Test, Giulia Maria Stella, Giulia Galli, Manuel Mariani, Silvia Figini, Alessandro Lascialfari, Andrea Riccardo Filippi, Olivia Maria Bottinelli and Lorenzo Preda, European Radiology Experimental 8, 71 (2024)
- 4) "A Multi-input Deep Learning Model to Classify COVID-19 Pneumonia Severity from Imaging and Clinical Data", Francesca Lizzi, Francesca Brero, Maria Evelina Fantacci, Alessandro Lascialfari, Gianfranco Paternò, Ian Postuma, Piernicola Oliva, Camilla Scapicchio & Alessandra Retico, Bioinformatics and Biomedical Engineering 14849, 237 (2024), https://doi.org/10.1007/978-3-031-64636-2_180

Agnese Robustelli Test

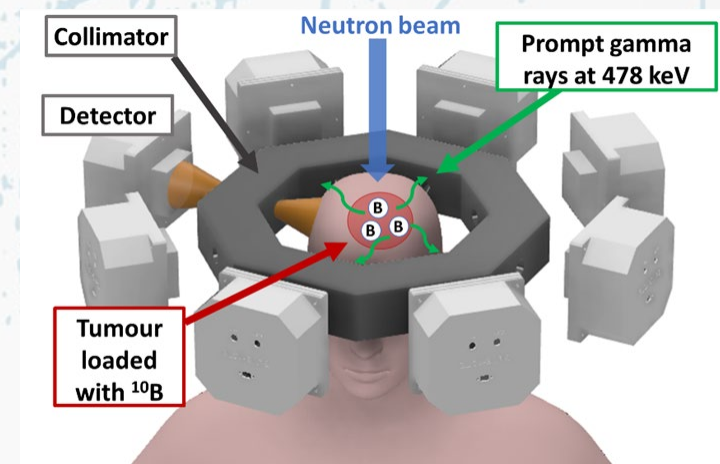
- ORAL** "Combining Radiomics and Machine Learning to assess PD-L1 expression from Magnetic Resonance Imaging acquisitions of lung cancer patient"
RSS International Conference 2024, Brighton, 2-5 Settembre 2024
- ORAL** "A combined Radiomics and Machine Learning approach to Magnetic Resonance Imaging for a quantification of PD-L1 expression in lung cancer"
110° Congresso Nazionale della Società Italiana di Fisica, Bologna, 9-13 Settembre 2024
- POSTER** "Magnetic Resonance Imaging and Machine Learning: a potential combined tool to quantify PD-L1 expression in lung cancer"
ESMRMB, Barcelona, 2-5 Ottobre 2024
- POSTER** "Investigating the Aging Brain by Combining Radiomics and Diffusion MR"
ESMRMB, Barcelona, 2-5 Ottobre 2024
- ORAL** "Combining Radiomics and Diffusion-MR to investigate the aging brain: a preliminary study"
International Conference on Magnetism - ICM2024, Bologna, 30 Giugno -5 Luglio 2024
- ORAL** "Combining Radiomics and Diffusion-MR to unveil the ageing brain"
next_AIM workshop on XAI techniques for medical data analysis, Bari, 16-18 Ottobre 2024
Francesca Brero
- ORAL** "Introduction to Magnetic Resonance Imaging"
Prima edizione hackathon advanced artificial intelligence@inf (ai_inf), Padova, 27 Novembre 2024
- ORAL** "Radiomics and AI techniques: selected experimental results on medical images"
SPOKE 8- HPC- Annual meeting – Online, 18 Dicembre 2024
- ORAL** "Radiomics and AI techniques: selected experimental results on medical images of lung cancer, neurological diseases and COVID-19"
Incontro Plenario ICSC Spoke 8, Cineca, Bologna, 24 Giugno 2024
Alessandro Lascialfari
- ORAL** "Tecniche di Intelligenza Artificiale applicate alla medicina"
Convegno "A lezione di ricerca", IRCCS San Matteo, Pavia, 11/04/2024
- ORAL** "Fundamentals of Radiomics and Machine Learning in Medical Images"
Convegno del Collegio Ghislieri "Artificial Intelligence in Biologia e Medicina", Pavia, 09/05/2024
- ORAL** "Artificial Intelligence techniques applied to Medical Imaging"
Convegno del Collegio Borromeo "Al nuova scienza e nuovo umanesimo? Governare l'evoluzione", Pavia, 11/05/2024
- ORAL** "Fisica e fisica biomedica : "ricerca, percorsi e opportunità"
Progetto Orientamento Consapevole - PNRR, Liceo scientifico "Copernico", Pavia, 14/05/2024

SPOC



– SPECT for Online boron dose verification in bnCT

RN – RL - Nicoletta Protti



Informazioni generali

Sezioni Coinvolte

- Pavia
- Milano
- Bari

Anagrafica di Pavia

N.Protti (RL) 50%

V.Pascali (PhD) 100%

FTE 2024: 1.5

Goal of the project

Objective

Sviluppo di un sistema SPECT dedicato per la dose verification in tempo reale in BNCT (tramite il fotone da 478 keV emesso nel 94% delle reazioni di cattura neutronica del B10).

Prototipi basati su cristalli di $\text{LaBr}_3(\text{Ce}+\text{Sr})$ accoppiati a SiPM, collimatori channel edge pinhole, schermi dedicati per limitare l'attivazione neutronica di rivelatori ed ELETTRONICA.

Specific Objectives

1. Completamento della validazione della sorgente di neutroni tipo AB-BNCT presso la High Flux Accelerator-Driven Neutron Facility, Università di Birmingham
2. Affiancamento del gruppo del Politecnico Milano, per simulazioni in FLUKA della stanza di irraggiamento presso la facility di Birmingham in previsione di una prima campagna di misure
3. Prosecuzione dei test del primo prototipo presso il fascio della PGNAa del LENA;
4. Appoggio alla pianificazione e implementazione di misure preliminari presso una facility clinica accelerator-based (NUANS-JP).

Results 2024

Santini, Caracciolo, Grisoni, Ferri, Bortot, Borghi, Pola, Agosteo, Pascali, Protti, Mazzucconi, *Monte Carlo simulation of a SPECT real time dose monitoring system for BNCT: response at the LENA reactor, under revision IEEE Transaction on Radiation and Plasma Medical Science*

OUTCOMES

- 1) FLUKA model of LENA PGNAAC used to carry out preliminary SPECT-BNCT measurements: simulated results validated against experimental data
- 2) Further improvements in the simulated imaging system proved its capability of distinguishing two separate boronated vials (approximately 1 cm apart)

FUTURE PERSPECTIVES

- 1) New measurements on further increased detecting system and collimation/shield structure as preparatory campaigns for measurements to be performed at BNCT clinical neutron sources.

Results 2024

Caracciolo, Mazzucconi, Ferri, Grisoni, Ghisio, Piroddi, Borghi, Carminati, Agosteo, Tsuchida, Nishitani, Ichikawa, Uritani, Altieri, Protti, Fiorini, *Prompt gamma-ray imaging in realistic background condition of a boron neutron capture therapy facility*, published in Sci.Rep.2025

OUTCOMES

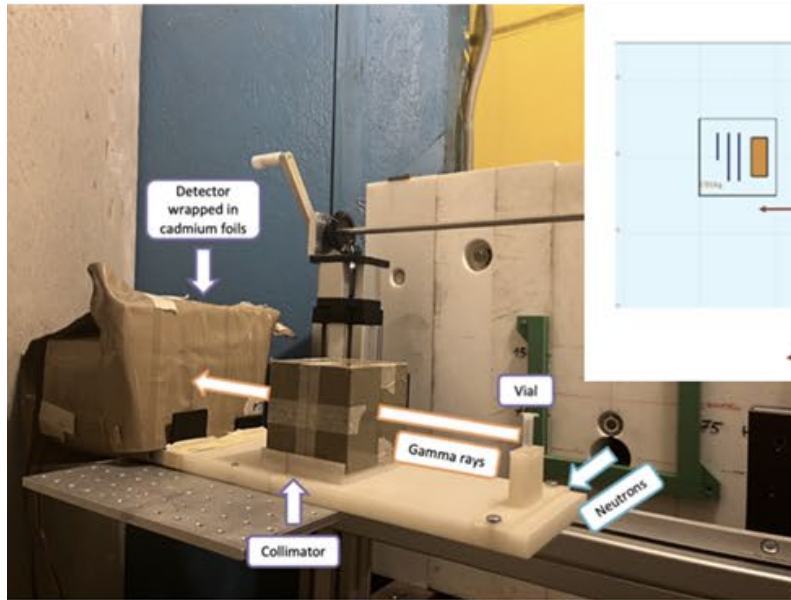
- 1) The detector is able to detect B10 concentrations as low as approximately 1850 ppm with a neutron flux of about 10^7 n/cm²s
- 2) It has the ability to map 1 cm displacements and distinguish different B10 concentrations within a single measurements

FUTURE PERSPECTIVES

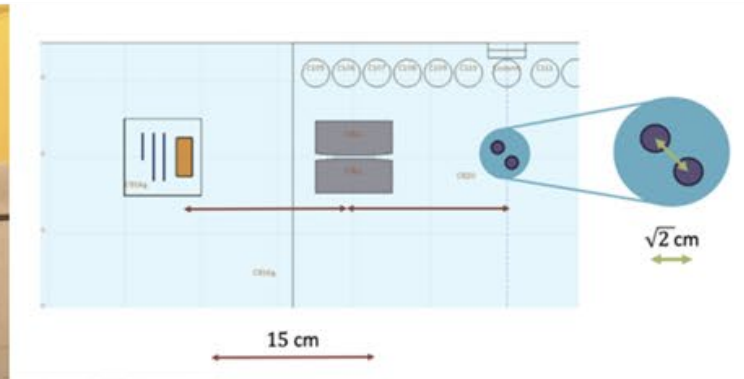
- 1) Improvements in shielding (ideally should completely eliminate the 478 keV background, having compact dimensions)
- 2) New measurements increasing neutron flux and diminishing B10 content in the vials.

Results 2024

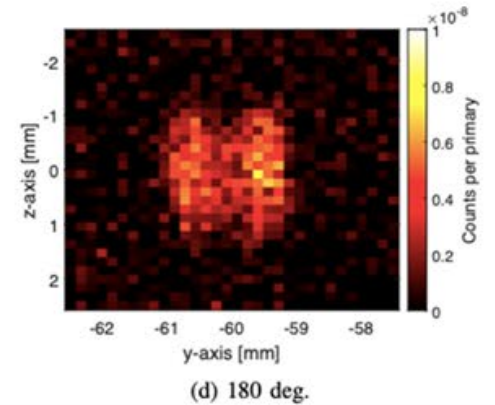
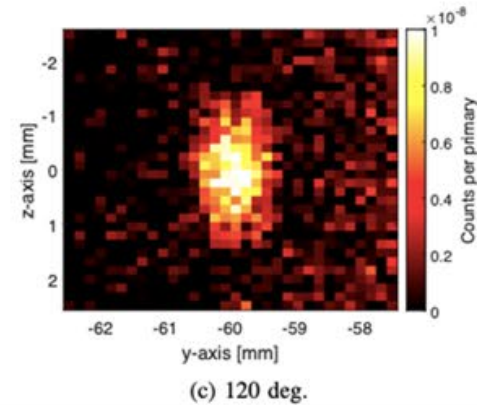
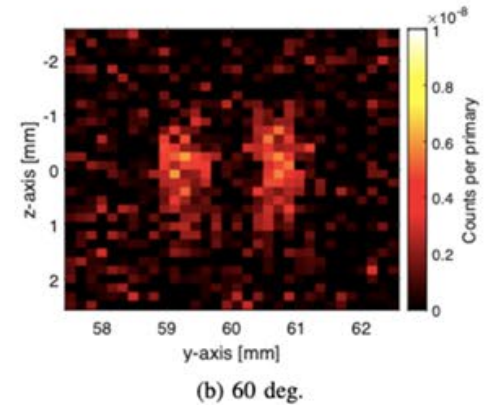
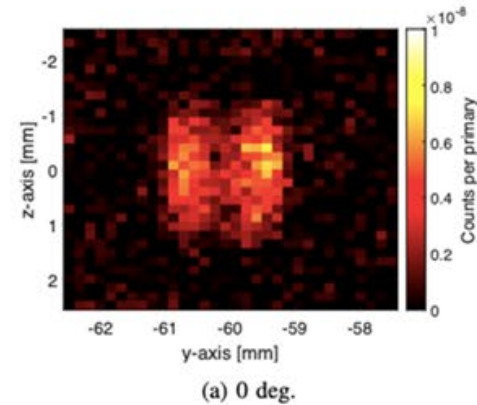
IMAGING SIMULATION @LENA IN 2024



experimental setup at PGNAA-LENA,
 6×10^6 n/cm²s at 250kW.



Scheme of the tomographic set up; the system was rotated counterclockwise with respect to the vials.

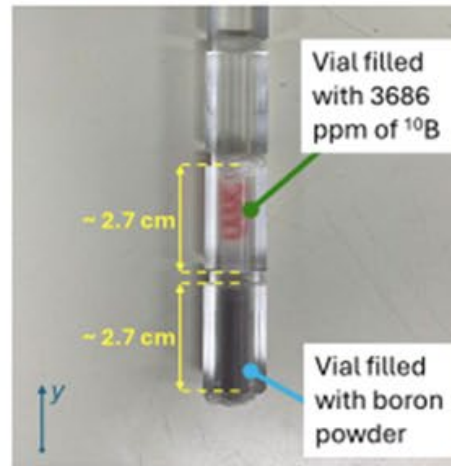


simulated images with tomographic set up

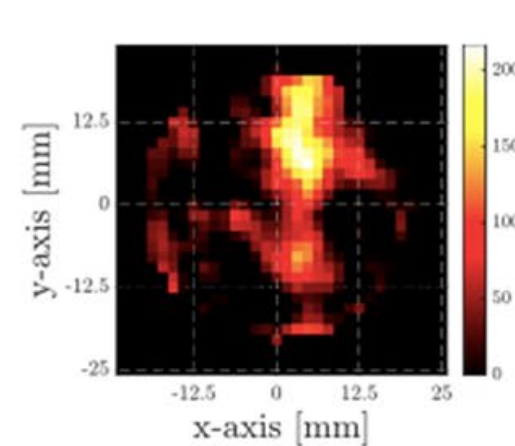
Results 2024

Study 2:

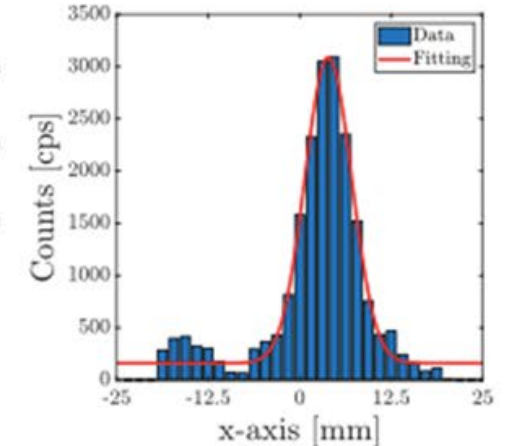
Imaging of the boronated vials
(several configuration, here reported the most complex scenario investigated)



(a) Picture of the sample.



(b) Image of 3686 ppm + B powder.



(c) 1D Hist. of 3686 ppm + B powder.

TEST OF MEASURING AND IMAGING CAPABILITIES @NUANS clinical facility IN 2024; experimental conditions s.t. 10^7 n/cm²s

Talks - thesis - publications

Caracciolo, Mazzucconi, Ferri, Grisoni, Ghisio, Piroddi, Borghi, Carminati, Agosteo, Tsuchida, Nishitani, Ichikawa, Uritani, Altieri, Protti, Fiorini, *Prompt gamma-ray imaging in realistic background condition of a boron neutron capture therapy facility*, published in Sci.Rep.2025

Santini, Caracciolo, Grisoni, Ferri, Bortot, Borghi, Pola, Agosteo, Pascali, Protti, Mazzucconi, *Monte Carlo simulation of a SPECT real time dose monitoring system for BNCT: response at the LENA reactor*, under revision IEEE Transaction on Radiation and Plasma Medical Science

CHNET_MAXI

Muonic Atom X-ray and prompt gamma spectroscopy for
Isotopic analysis for cultural heritage

RL – Alessandro Menegolli

Informazioni generali

Sezioni Coinvolte

- Pavia
- Milano Bicocca
- Cagliari (gruppo di Sassari)

FTE 2024: 6.5

Anagrafica di Pavia

- | | |
|------------------------|---------|
| • Alessandro Menegolli | 0.2 FTE |
| • Daniele Alloni | 0.3 FTE |
| • Andrea Gandini | 0.5 FTE |
| • Riccardo Rossini | 0.2 FTE |
| • Antonio de Bari | 0.1 FTE |
| • Fabio Zelaschi | 0.2 FTE |

Goal del progetto

Obiettivi

- Misura dei rapporti isotopici (RI) (in particolare del piombo): potente strumento per la determinazione della provenienza di manufatti antichi. Al momento le tecniche utilizzate in ambito archeometrico sono tutte di tipo distruttivo.
- Obiettivo: studio, tramite irraggiamento di targhette di materiale arricchito negli isotopi 204-206-207-208 del Pb, di tutte le possibili figure di merito:
 - “shift” isomerico dei raggi X muonici del Piombo.
 - le reazioni gamma “prompt” a seguito di cattura muonica semplice o con emissione di neutroni.
 - Radionuclidi attivati aventi tempi di dimezzamento e emissioni gamma caratteristici.
- Si utilizza la tecnica della spettroscopia X di atomi

Obiettivi Specifici

- Realizzazione di un monitor di fascio per la centratura dei campioni archeometrici (**main task Pavia**).
- Realizzazione di un sistema di rivelazione dei raggi X e gamma compatto, con scintillatori e SiPM.
- Realizzazione di un DAQ per gli array di rivelatori (HPGe, scintillatori) installati al Port 4 di ISIS.
- Implementazione di un codice Monte Carlo e stima sensibilità degli array di HpGe.
- Primi test dei setup a LENA, CNAO e infine ISIS.

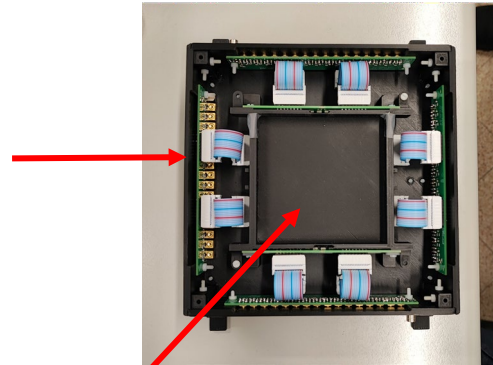
*Ultimo anno di sigla: test finale previsto
ad ISIS a Ottobre 2025*

Risultati 2024 – milestones (Pavia)

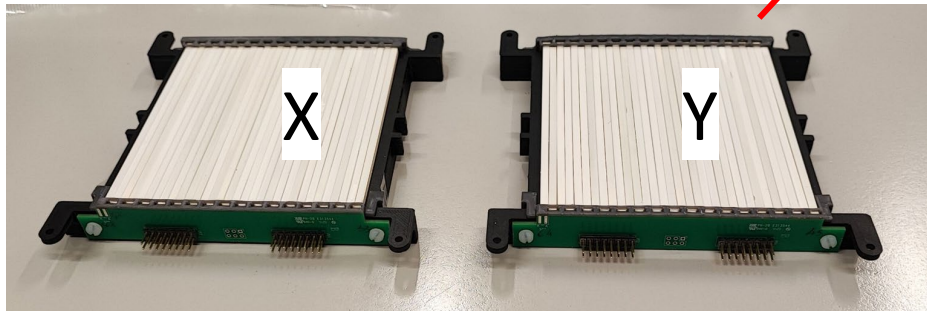
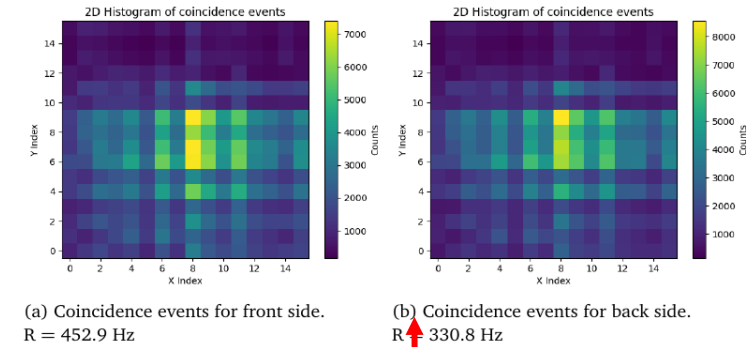
- **Item principale di Pavia:** realizzazione del monitor di fascio di CHNet_MAXI basato su 32+32 fibre scintillanti (sezione 3mm^2) lette da SiPM, in modalità odoscopio (X/Y). Lavori 2023-2024: assemblaggio finale del monitor di fascio (fibre + PCB + case).
- Lavori 2024 (DAQ): test del rivelatore con sorgenti presso INFN MiB e su fascio di protoni a CNAO.



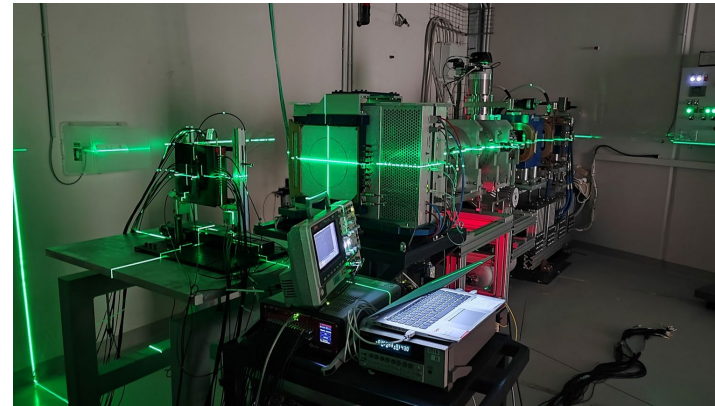
Schede SiPM e connettori: M.C. Prata



Detector pronto!
(Meccanica: INFN-MiB)



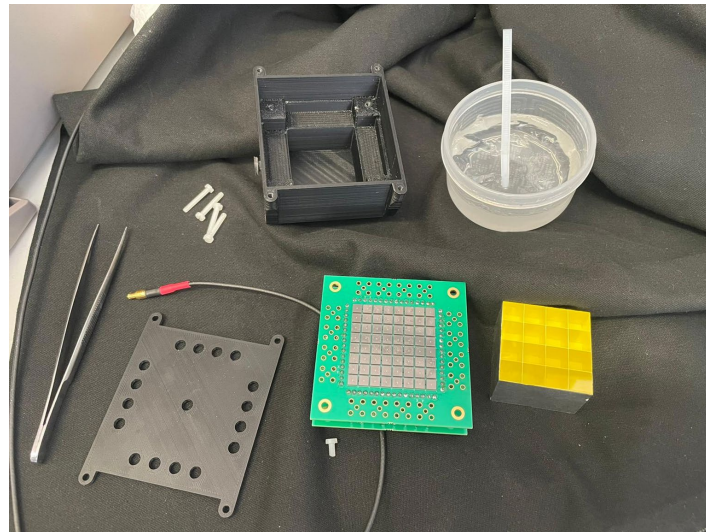
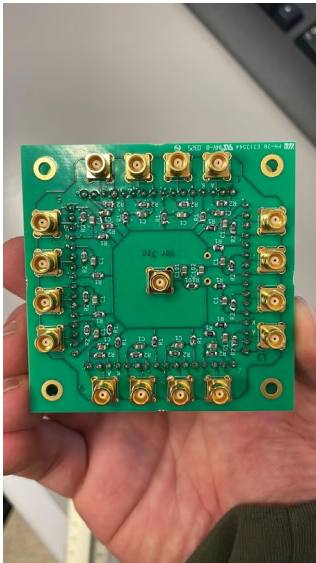
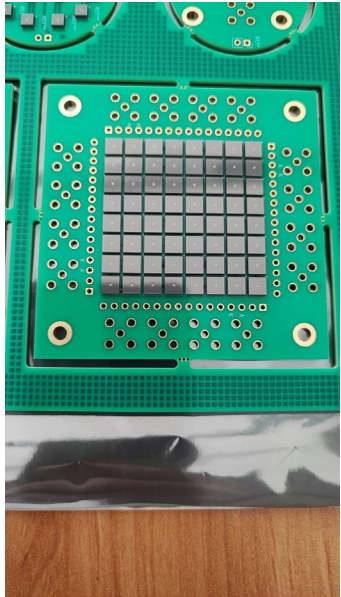
Piani di fibre: Scienze della Terra Unipv + MiB



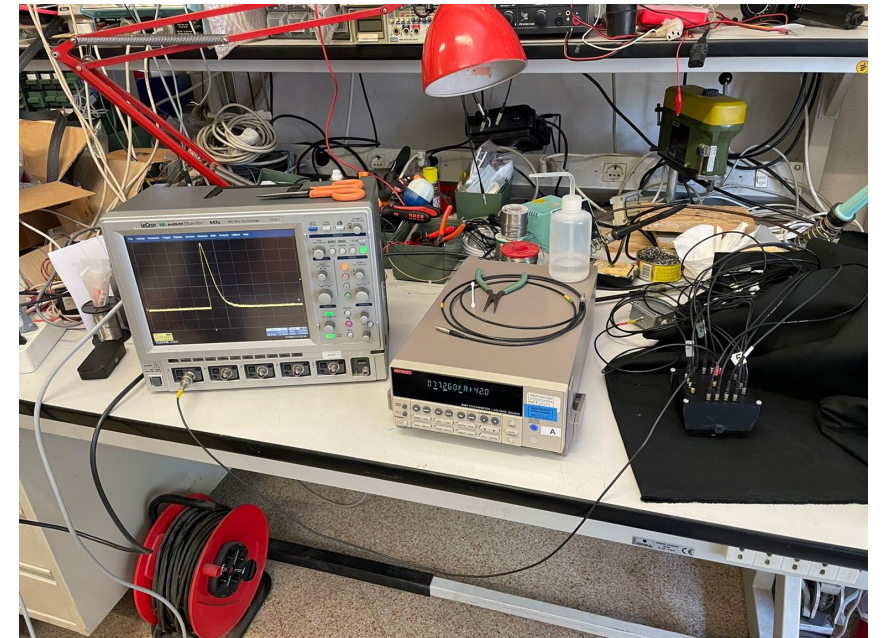
2 Luglio 2024: Test detector e DAQ a CNAO.
(A. Menegolli, R. Rossini + L. Malliolo, laureanda triennale)

Risultati 2024 – milestones (Pavia)

- **Item secondario Pavia #1:** realizzazione dell'elettronica (SiPM, PCB) per la lettura dei segnali dei rivelatori a scintillazione (CLLB, GAGG) di CHNet_MAXI.

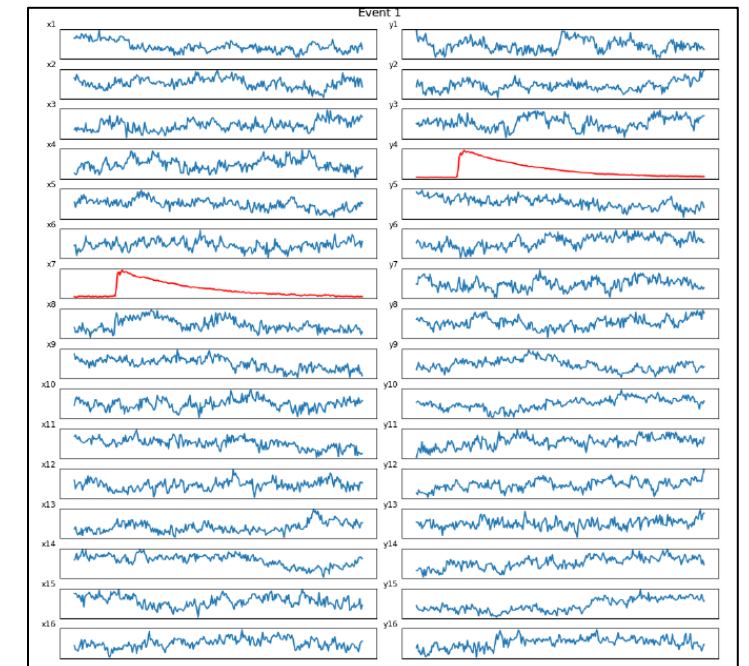
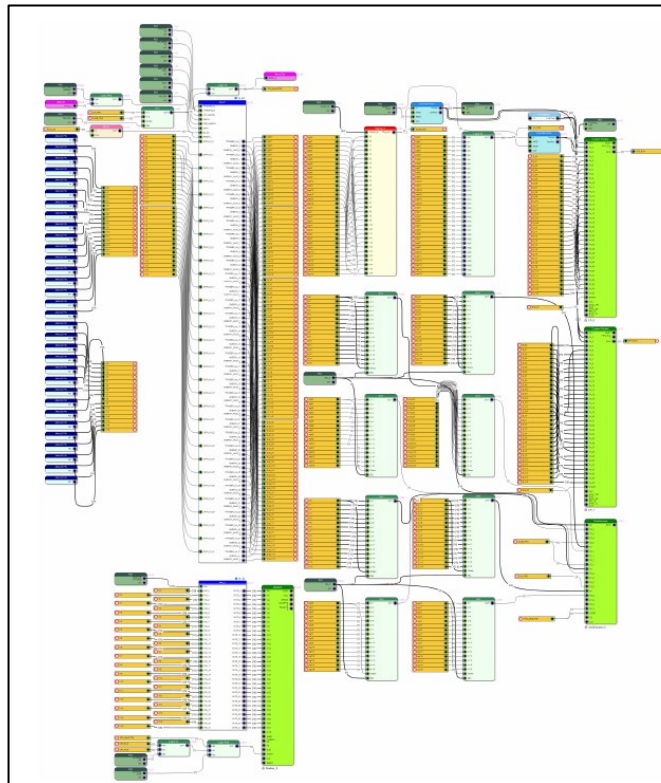
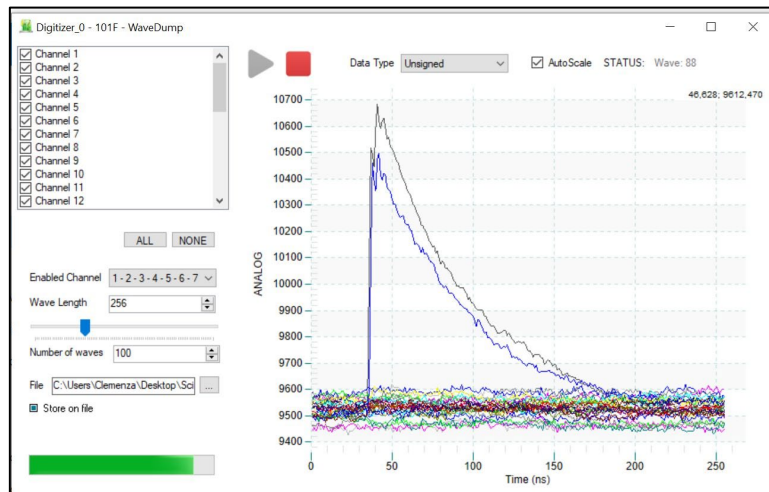


Schede SiPM e connettori per GAGG detector + assemblaggio e test:
M.C. Prata + INFN MiB



Risultati 2024 – milestones (Pavia)

- **Item secondario Pavia #1:** realizzazione dell'elettronica (SiPM, PCB) per la lettura dei segnali dei rivelatori a scintillazione (CLLB, GAGG) di CHNet_MAXI.
- **Item secondario Pavia #2:** gestione DAQ CHNet_MAXI, basata su Open-FPGA desktop digitizers CAEN, programmati tramite SciCompiler.



Schema DAQ - SciCompiler ed esempi di
forme d'onda del beam monitor
(L. Malliolio e R. Rossini)

Congressi, tesi, pubblicazioni

- R. Rossini et al. *“A muon beam monitor for the CHNet-MAXI experiment at the RIKEN-RAL laboratory”*, Nucl. Instr. Meth. **A1069**, 169824 (2024). <https://doi.org/10.1016/j.nima.2024.169824>
- Tesi di laurea triennale di L. Malliolio (Febbraio 2025): *“DAQ system for the CHNet-MAXI muon beam monitor”*

NAMASSTE

NAno**M**agnets for quantum **S**ensing and Data **S**Torag**E**

RL – Alessandro Lascialfari

Informazioni generali

Sezioni Coinvolte:

- Pavia
- Bologna
- Firenze
- Milano

Anagrafica di Pavia (2023):

- | | |
|--|------|
| • RL- Alessandro Lascialfari – PO | 0.15 |
| • Francesca Brero – Postdoc | 0.2 |
| • Elio Giroletti – Membro Senior INFN | 0 |
| • Margherita Porru – PhD Student | 0.3 |
| • Agnese Robustelli Test – PhD Student | 0.3 |
| • Marta Filibian – Tecnico D | 0.1 |

FTE 2024 - PV: 1.05

Goals del progetto

Obiettivi generali

Studio di nanomagneti molecolari (MNMs) (magneti a singola molecola (SMMs) ed a singolo ione (SIMs)) per:

- (i) l'uso di SMMs come **sensori quantistici** ad alta sensibilità per la rivelazione di particelle con interazioni caratterizzate da rilascio di bassa energia, fino a 10^{-3} eV;
- (ii) la determinazione, nei SIMs, del legame tra proprietà chimico-fisiche e magnetiche, per la sintesi di nuovi SIMs ancora più performanti di quelli attualmente esistenti per il loro utilizzo come **memorie magnetiche per l'immagazzinamento di dati**.

Finalità più specifiche:

- (i) **Sintesi** di MNMs
- (ii) **Caratterizzazione magnetica** e della dinamica di spin in MNMs con magnetometria SQUID, NMR, EPR, μ^+ SR
- (iii) Studio, con misure SQUID ed NMR, su per la **rivelazione di effetti legati all'irraggiamento con particelle alfa e beta**
- (iv) Sviluppo di **modelli teorici** legati alla dinamica di spin in SIMs ed alle interazioni in SMMs irraggiati.

Obiettivi di Pavia

- (i) **Misure NMR e SQUID** per la caratterizzazione dei SIMs con lo studio delle loro proprietà magnetiche statiche e della dinamica di spin
- (ii) Misure NMR e SQUID sui SMMs per la **rivelazione di effetti legati all'irraggiamento con particelle alfa e beta** su questi sistemi
- (iii) Collaborazione con l'Unità di Milano per le **misure μ^+ SR** per la caratterizzazione della dinamica di spin nei SIMs
- (iv) **Coordinamento delle attività** del progetto e collaborazione con le altre unità di Firenze e Milano

Results NAMASSTE project: 0. Setup of experimental protocol

Experimental setup :

- (i) Materials synthesis and characterization*
- (ii) Radiation sources (α, β, γ) and sample holders*
- (iii) Techniques :*
 - (a) ac and DC SQUID magnetometry
 - (b) wide-band solid-state Nuclear Magnetic/Quadrupole Resonance (NMR/NQR)
 - (c) Muon Spin Relaxation (MuSR)
 - (d) CW Electron Paramagnetic Resonance (EPR)

Advantage of techniques' complementarity :

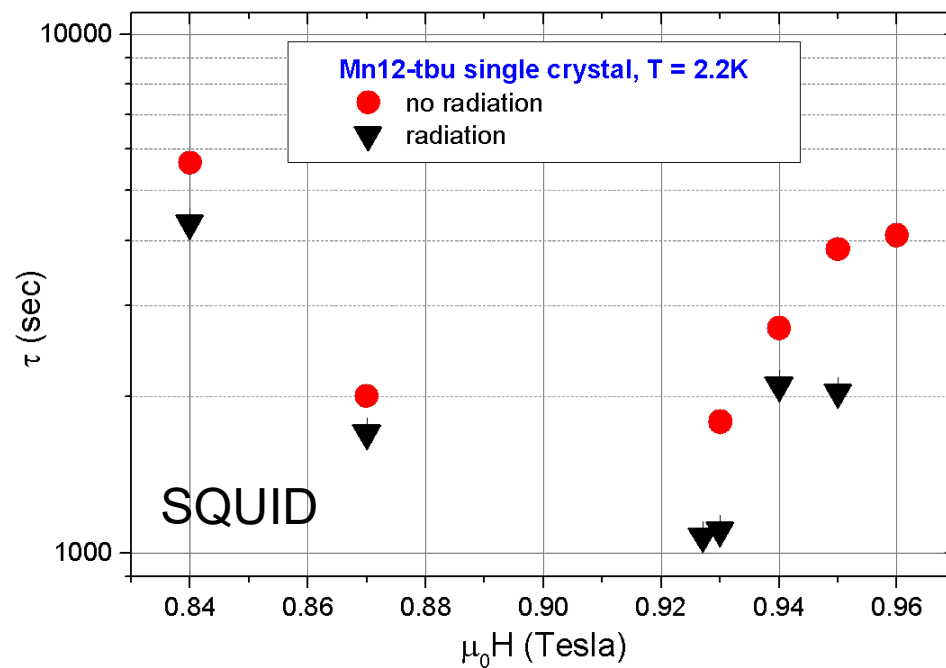
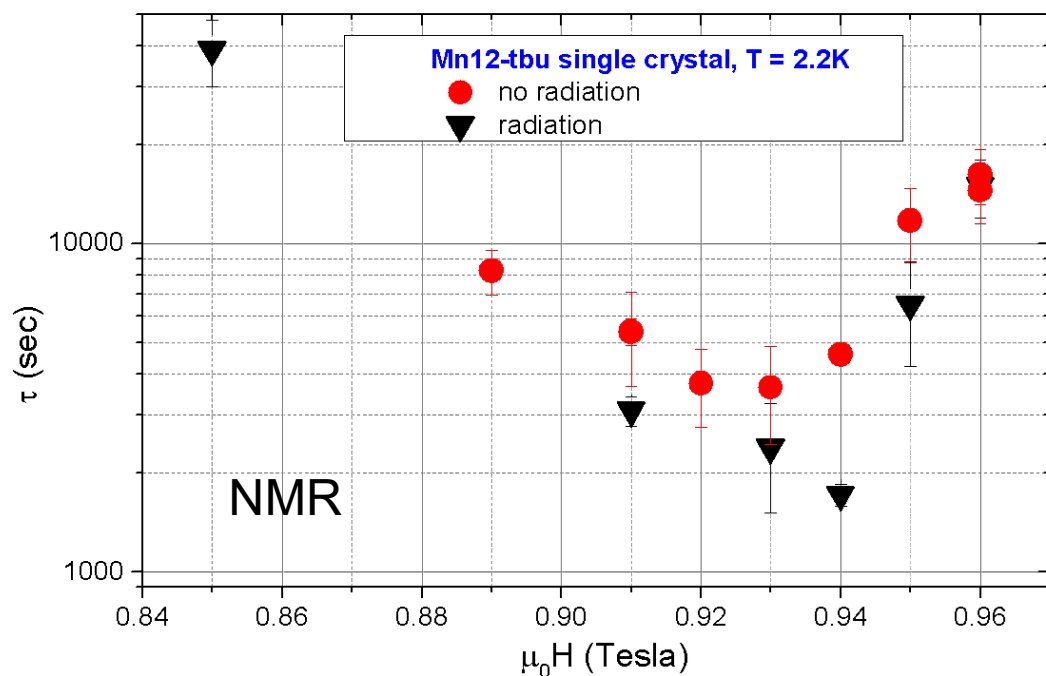
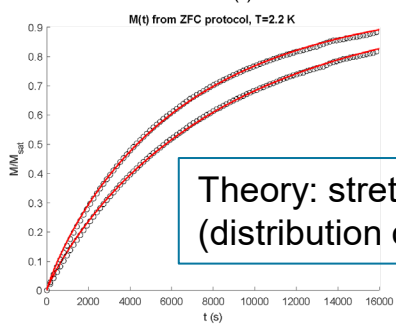
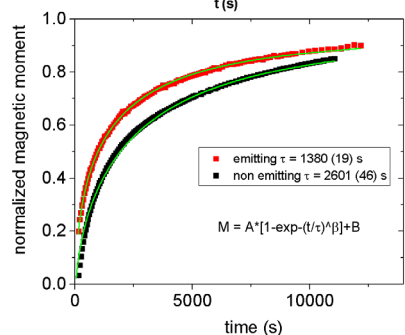
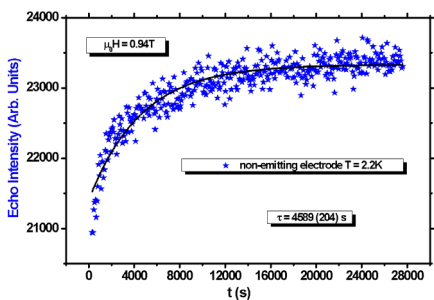
wide frequency range (10^{-1} - 10^{11} Hz)

⇒ allows to determine the system spin dynamics

Results NAMASSTE project: I. sensing by SQUID and NMR

Quantum sensing with Mn12-tbu :

- **Difference in magnetization** relaxation **with and without** impinging radiation (same bckg)
- Revealed by SQUID and NMR
- **Model** under development : local small thermal effect or structural deformation

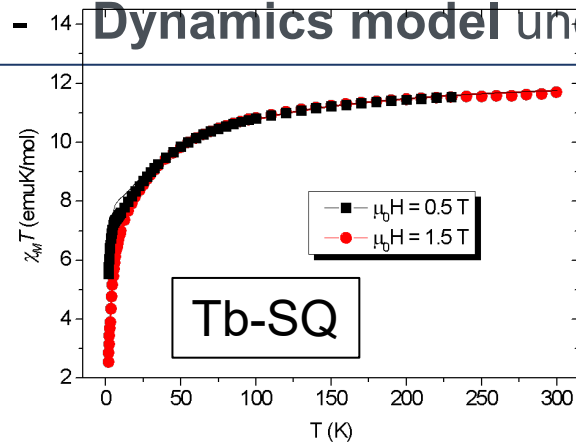


- ~ per minute : 0.2 α particles, 4 β particles, 50-100 γ particles
- Detectability limit : to be studied (e.g. better than 10^{-12} Tesla)

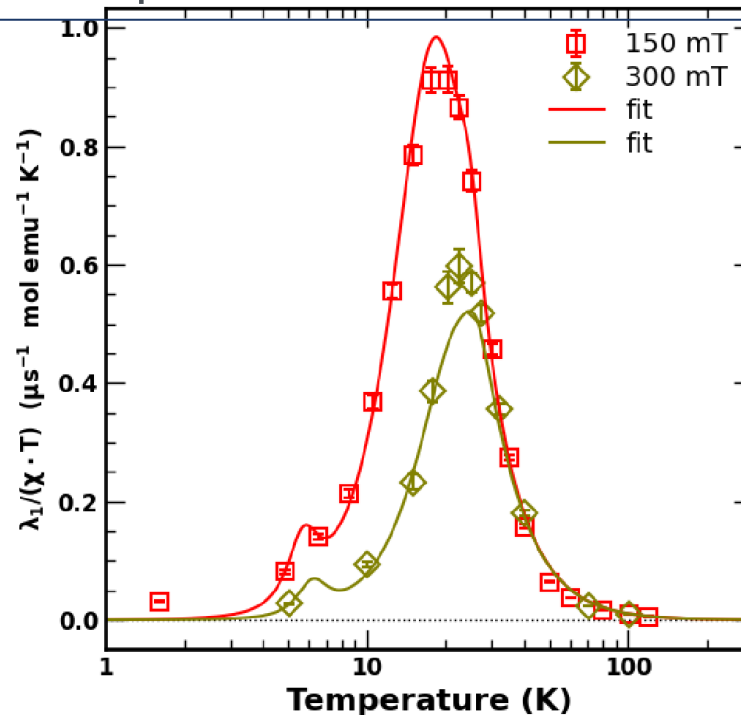
Results NAMASSTE project: II. relaxation by ac χ , NMR, muSR

Mechanisms of M relaxation in Ln-SQ and Ln-trp rare-earth SIMs :

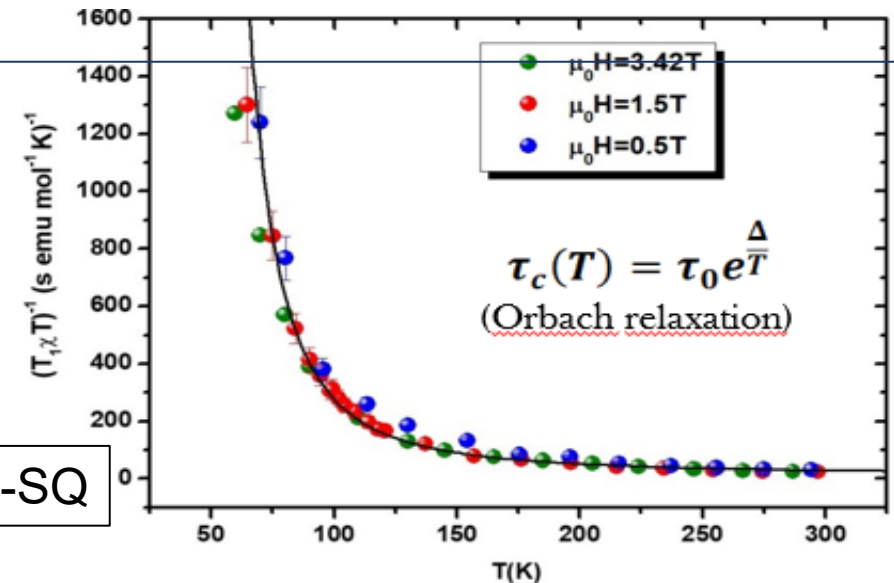
- **DC susceptibility χ** : Hamiltonian and energy levels
- **muSR +ac susceptibility** : different relaxation mechanisms depending on T and H - *direct, Raman, Orbach*
- **Relaxation time** : ac χ reveals first energy gap, **NMR** reveals higher excited levels
- **Dynamics model** under development



	$ J_z \gamma_B $	Spin orientation	Energy (cm^{-1})	Energy (K)
E0	6	antiparallel	0	0
E1	6	parallel	36	52
E2	5	antiparallel	231	332
E3	5	parallel	267	384
E4	4	antiparallel	420	604
E5	4	parallel	456	656
E6	3	antiparallel	567	816
E7	3	parallel	603	868
E8	2	antiparallel	672	967
E9	2	parallel	708	1019
E10	1	antiparallel	735	1058
E11	0	antiparallel	756	1088
E12	1	parallel	771	1109
E13	0	parallel	792	1140



Tb-SQ



BPP law : $(T_1 \chi T)^{-1} = A \frac{2\tau_c(T)}{1 + \tau_c^2(T) \omega_L^2}$ (3 components for muSR)

NMR: Fit of the peak right-side $1/T_1$ data ($\tau_c(T) \omega_L \ll 1$)

$$(T_1 \chi T)^{-1} = A_2 \tau_c(T) = A_2 \tau_0 e^{\frac{\Delta}{T}} \quad (\tau_c(T) = \tau_0 e^{\frac{\Delta}{T}})$$

2 works in progress, Phys. Rev. B, to be submitted

Tesi, congressi e pubblicazioni

- 2 lavori in preparazione
- **Poster GIDRM 2024** : Spin Dynamics in Rare-Earth Ions nanomagnets studied by NMR, M. Mariani, A. Lascialfari, M. Filibian, I. Villa, M. Porru, L. Sorace, M. Fittipaldi, G. Latino, A. Rettori, F. Cinti, A. Cini, F. A. Rusnati, P. Arosio, F. Orsini, F. Brero, E. Giroletti, D. Redigolo, C. Cialdai, P. Santini, G. Poneti
- **Talk ICM 2024** : «Magnetic Properties and Spin Dynamics in Rare – Earth Ions coupled with semiquinones: a NMR investigation”, M. Mariani, A. Lascialfari, M. Filibian, I. Villa, M. Porru, L. Sorace, M. Fittipaldi, G. Latino, A. Rettori, F. Cinti, A. Cini, F. A. Rusnati, P. Arosio, F. Orsini, F. Brero, E. Giroletti, D. Redigolo, C. Cialdai, P. Santini, G. Poneti
- **Poster ICM 2024**, “Magnetic techniques for quantum sensing using single molecule magnets”, M. Mariani, P. Arosio, F. Brero, G. L. Celardo, A. Cini, M. Fittipaldi, E. Giroletti, A. Lascialfari, G. Latino, F. Orsini, S. Sanna, F. Santanni, P. Santini, L. Sorace

QUANTEP

Quantum Technology Experimental Platforms

RL – Vittorio Bellani

Informazioni generali

Sezioni Coinvolte:

INFN LNL, MI, PG,
PI, PV, RM2, SA, TO

FTE 2025- PV: 2.9

Anagrafica di Pavia:

- Bellani Vittorio
- Boffelli Massimo
- Fontana Andrea
- Lacava Cosimo
- Rossella Francesco
- Vitali Valerio

Goals del progetto

Obiettivi generali:

The QUANTEP project develops integrated quantum photonic devices using a 220 nm SOI CMOS process with advanced methods like ion implantation and nanomaterial deposition. Key goals include a linear optics C-NOT gate, single-photon sources, and a $\text{Bi}_2\text{Se}_3/\text{n-Si}$ detector. Using 2D materials and nanowires, it enables dynamic photon polarization control, with full on-chip integration targeting telecom applications.

Obiettivi di Pavia:

A new atomic-scale microscopy system supports the development of silicon waveguides with nanowires and graphene for quantum photonics, focusing on polarization control. The project implements graphene-hBN twisted 2D materials to create advanced quantum photonic and electronic devices, enhancing quantum state manipulation and enabling scalable, tunable technologies integrated with existing photonic platforms.

Risultati 2024/25 – Milestones (Pavia)

Guida d'onda GD1, grating coupler punto 1

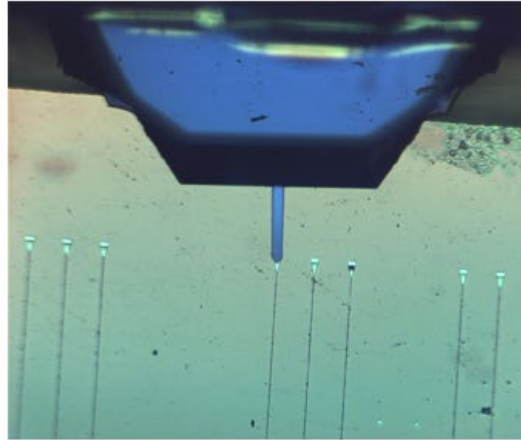
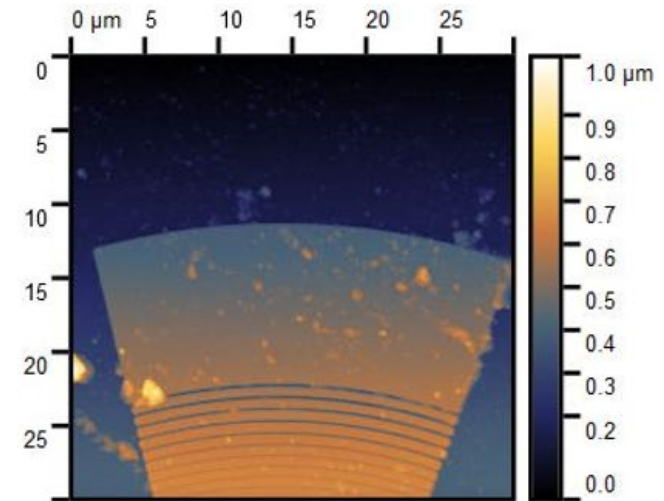


Immagine AFM



Guida d'onda GD2, grating coupler punto 2

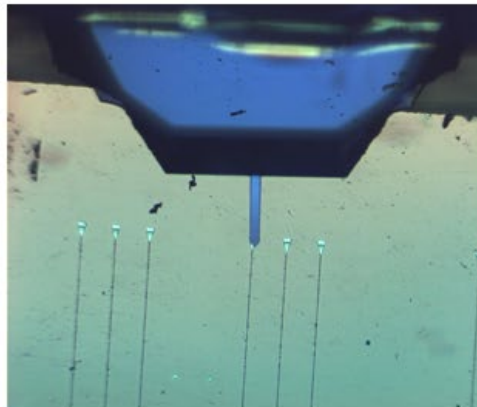
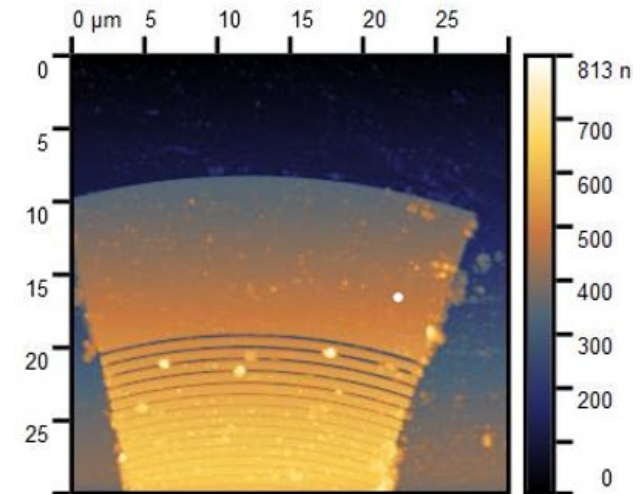


Immagine AFM



Risultati 2024/25 – Milestones (Pavia)

Guida d'onda con capping, punto A

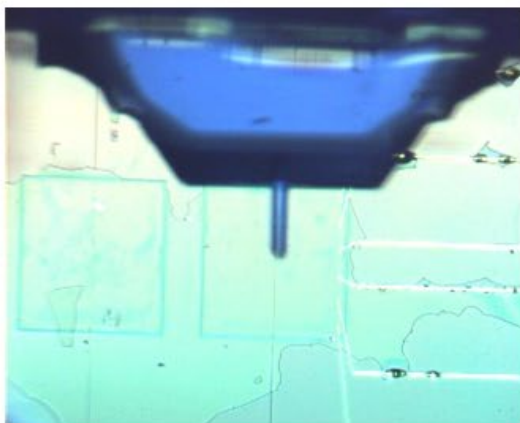
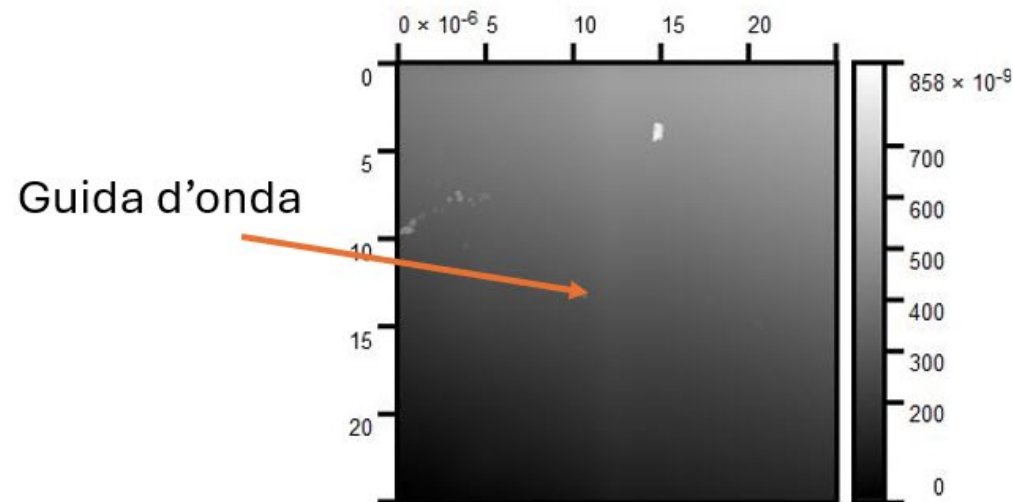


Immagine AFM



Guida d'onda con capping, punto B, grating coupler

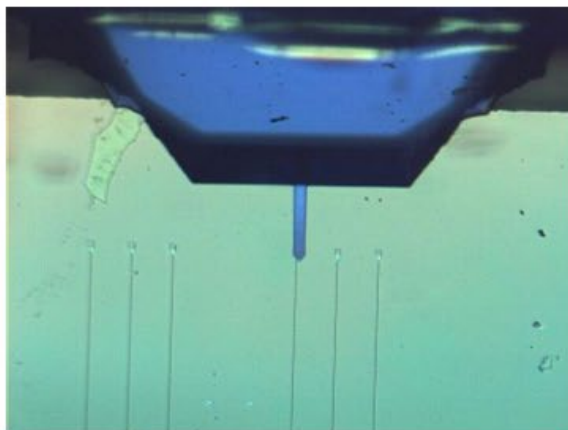
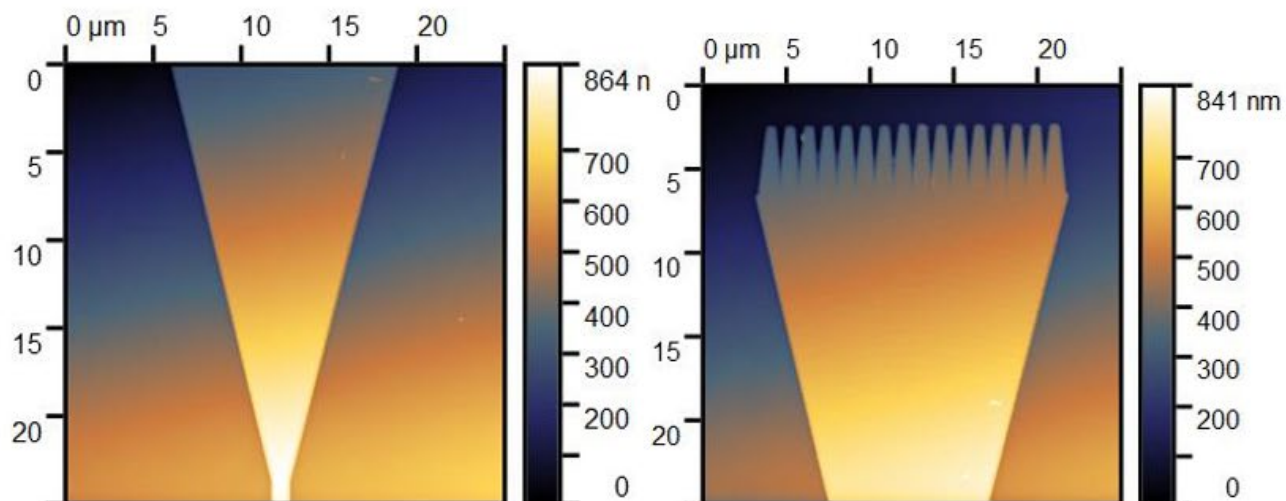
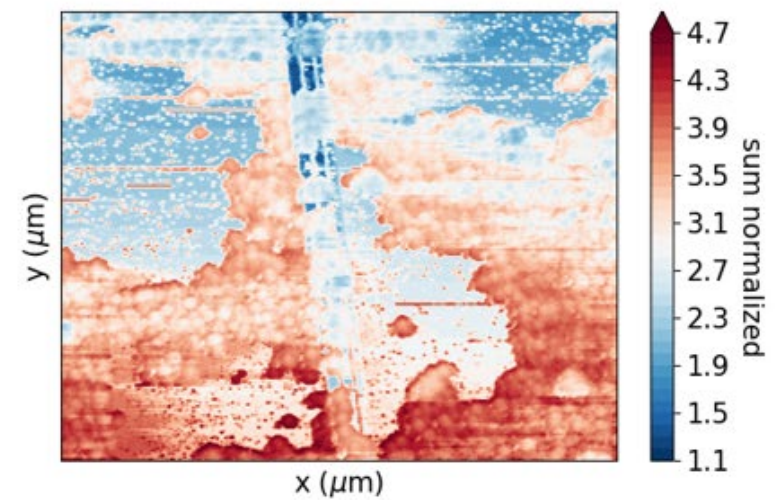
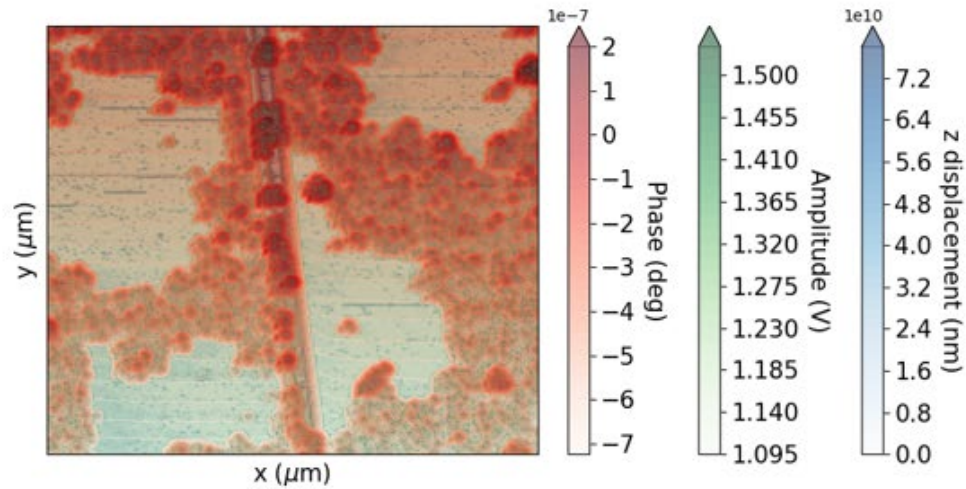
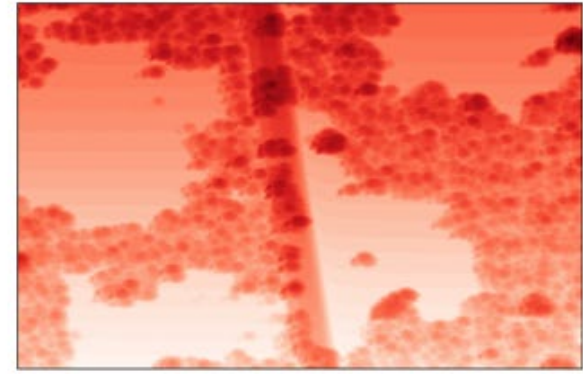
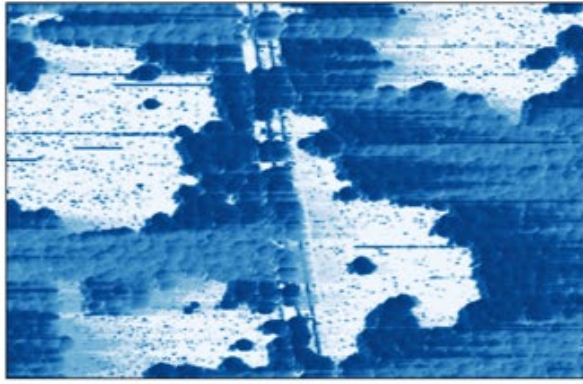


Immagine AFM



Risultati 2024/25 – Milestones (Pavia)



Immagini in falsi colori del campione con nanowires in cui sembra di vedere delle
eferette/nanowires (blue-topografia, verde-ampiezza, rosso-fase)

Publicazioni

- *Integrated photonic passive building blocks on silicon-on-insulator platform*, F. Amanti et al. Photonics 11, 494 (2024).
- *Spin-Resolved Magneto-Tunneling and Giant Anisotropic g-Factor in Broken Gap InAs-GaSb Core–Shell Nanowires*, V. Clericò et al., Nano Letters 24, 790 (2024).
- *Hybrid Integrated Silicon Photonics Based on Nanomaterials*, D. Prete et al., Photonics 11, 418 (2024).
- *Quantum Information with Integrated Photonics*, P. Piergentili et al., Applied Sciences 14, 387 (2024).
- *Composite fermions and parton wavefunctions in twisted graphene on hexagonal boron nitride*, The European Physical Journal Plus 139, 1 (2024).
- *Gate-Switchable Molecular Diffusion on a Graphene Field-Effect Transistor*, F. Liou et al., ACS nano 18, 24262 (2024).



RL – Ian Postuma

Informazioni generali

Sezioni Coinvolte

• CT,	• MI
• LNS	• PG
• FE	• PV
• LNS	• Roma1

FTE 2024:

Nazionale	16.57
Pavia	3

Anagrafica di Pavia

Laura Cansolino	0.10
Mario Pietro Carante	0.20
Alice Casali	1.00
Alessandro Colombi	1.00
Setareh Fatemi	* 0.25
Andrea Fontana	0.20
Ian Postuma	0.25

* in sinergia con ANTHEM

Goal of the project

Objective

Si propone il **coordinamento a livello nazionale** dei contributi INFN alla manutenzione, validazione e **sviluppo di Geant4**, codice strategico per l'Ente vista la sua ampia diffusione. L'obiettivo è duplice: garantire, in **sinergia con la Collaborazione Geant4**, la **manutenzione e validazione** delle componenti già seguite da INFN, e **sviluppare nuovi modelli** originali di fisica e esempi applicativi. I modelli descriveranno l'interazione coerente di fotoni e particelle cariche con materiali cristallini e amorfi, e le interazioni di elettroni con i gas atmosferici, oltre a nuovi esempi per la fisica medica. Geant4INFN proseguirà inoltre il contributo al gruppo G4-Med per la validazione in ambito medico.

Specific Objectives

La Sezione di Pavia contribuisce al progetto Geant4INFN con attività focalizzate su simulazioni per la **Boron Neutron Capture Therapy** (BNCT), sviluppo e **validazione di modelli Geant4-DNA** con dati sperimentali del reattore LENA, e progettazione di microdosimetri innovativi. Collabora inoltre alla modellizzazione di sorgenti per terapie avanzate, come la brachiterapia con placche ^{106}Ru . In ambito computazionale, sviluppa algoritmi di Intelligenza Artificiale per emulare simulazioni Monte Carlo e ricostruire distribuzioni di dose. Ha curato infine l'organizzazione della Geant4 School 2024, rafforzando il ruolo formativo e divulgativo del progetto.

Results 2024 – Milestones PV

31/12/2024 - Validazione del primo set di dati nella stima del DSB e SSB. In corso, 80%

31/12/2024 - Primo set di dati da irraggiamento BNCT da usare con Geant4-DNA. In corso, 50% (Sinergia con PNRR ANTHEM Pilot 4.9 WP4 e GIOCONDA)

31/12/2024 - Definizione sorgente BNCT da (p,n) su Be a partire da dati sperimentali su una targhetta spessa di Be per la reazione con 5 MeV di protoni. Completato, 100%

Coupling Geant4 - BIANCA

Goal: Development of a Geant4 - BIANCA interface for the prediction of α and β values in case of mixed field with active beam irradiation.

- **BIANCA**: Biophysical model for the prediction of cell survival for each particle type and LET value in monochromatic irradiations.

$$\alpha = \frac{\sum_{i=1}^n \sum_{j=1}^m \alpha_{i,j} D_{i,j}}{\sum_{i=1}^n \sum_{j=1}^m D_{i,j}}$$

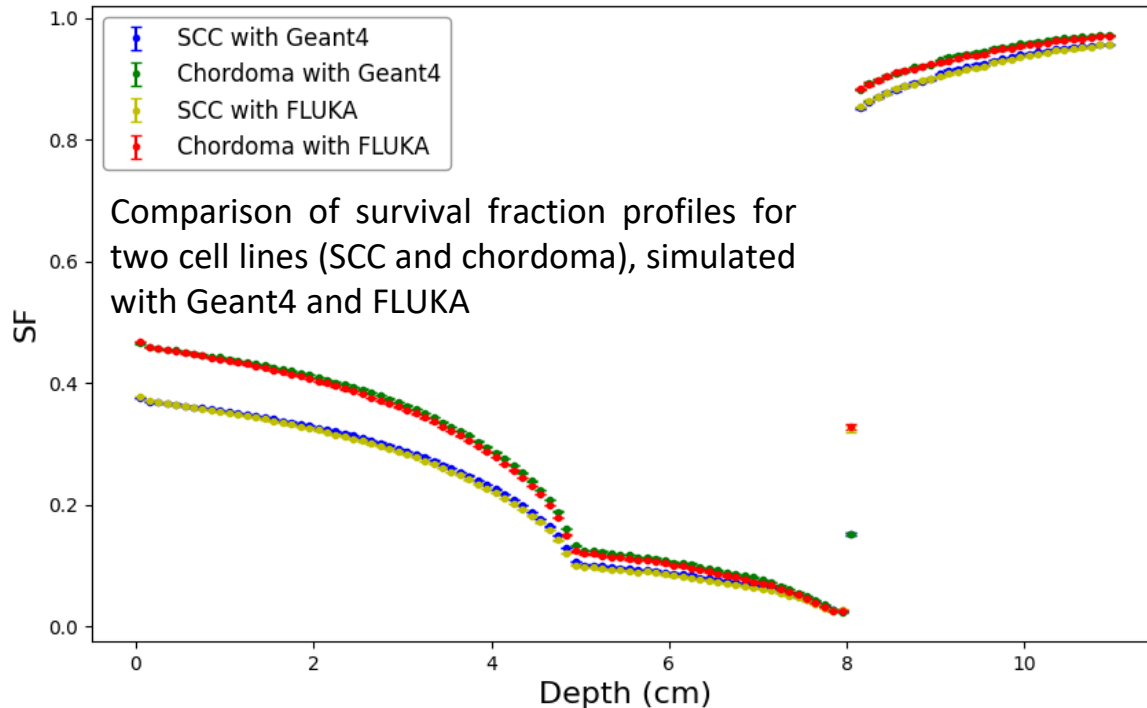
i : particle type

j : energy value

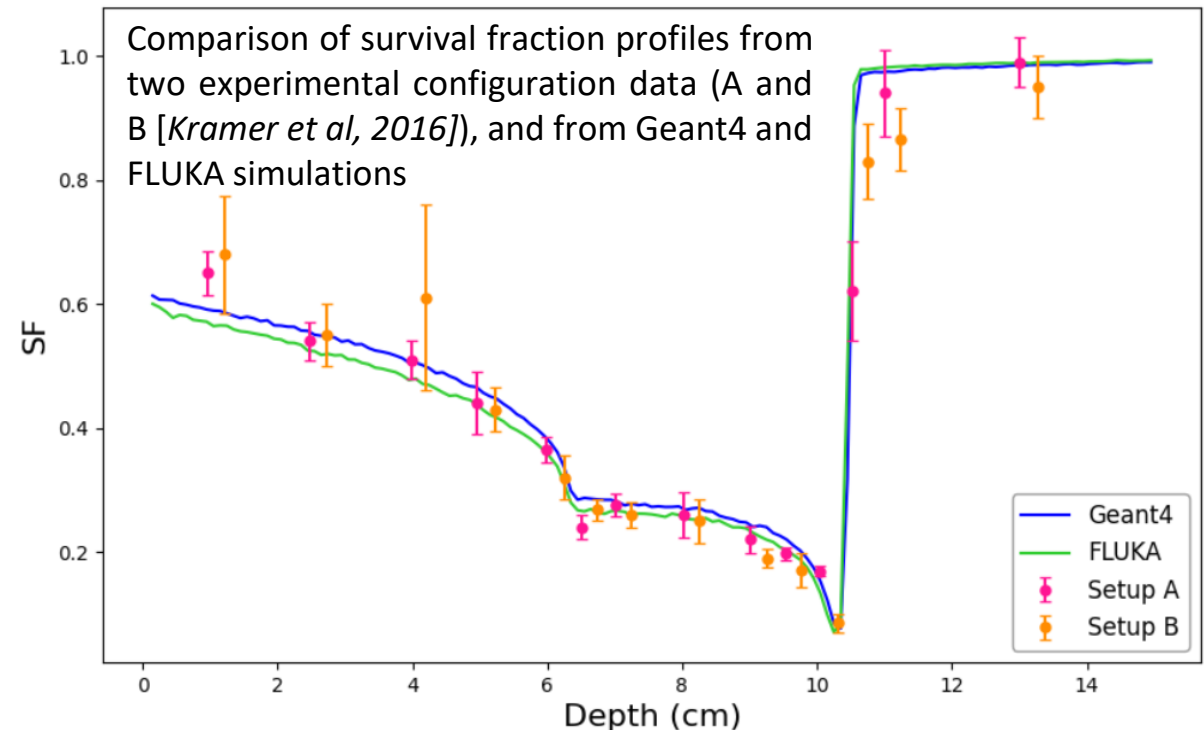
$$\beta = \left(\frac{\sum_{i=1}^n \sum_{j=1}^m \sqrt{\beta_{i,j}} D_{i,j}}{\sum_{i=1}^n \sum_{j=1}^m D_{i,j}} \right)^2$$

Validation with the previous FLUKA-BIANCA interface

SOBP of CARBON IONS from 5 cm to 8 cm



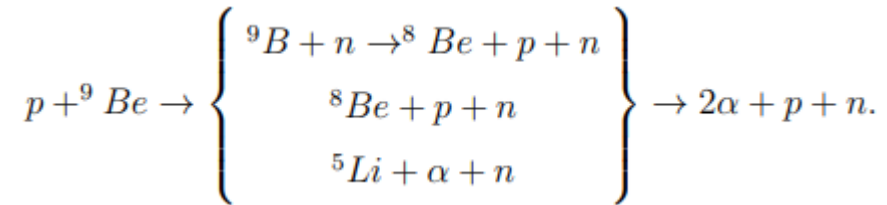
HELIUM IONS



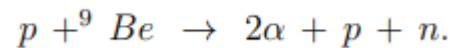
Modeling of the reaction ${}^9\text{Be}(p,x)$ in Geant4

Analogy with $p+{}^7\text{Li}$, but more complex case: many reaction channels.

- Intermediate states:

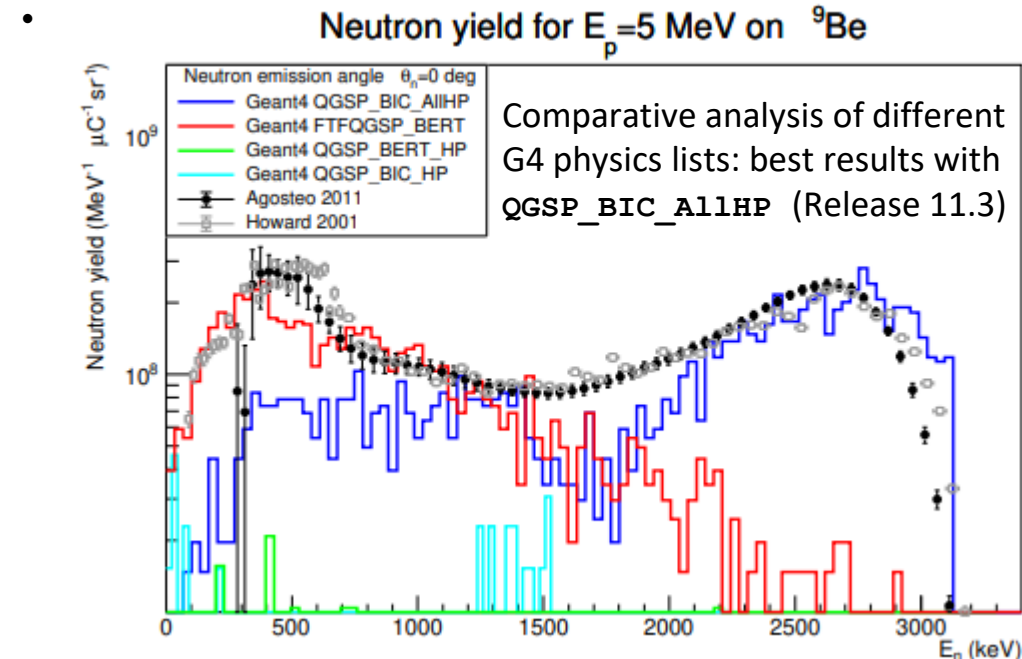


- Direct production:



Channel	Reaction products	Threshold (keV)
(p,n)	${}^9\text{B} + n_0$	2057.4
	${}^9\text{B}^* + n_1$	3924.6
	${}^9\text{B}^* + n_2$	4663.9
	${}^9\text{B}^* + n_N$	ϵ_N
(p,p'n)	${}^8\text{Be} + p + n$	1850.8
(p,p'αn)	${}^4\text{He} + \alpha + p + n$	1748.7
(p,αn)	${}^5\text{Li} + \alpha + n$	3930.0

Double differential yield:
$$\frac{d^2 N}{dE_n d\Omega} = \frac{f_{\text{Be}} N_0}{eA} \cdot \frac{\frac{d\sigma}{d\Omega_{\text{cm}}} \cdot \frac{d\Omega_{\text{cm}}}{d\Omega} \frac{dE_p}{dE_n}}{-\frac{1}{\rho} \frac{dE_p}{dx}}$$



- Missing contribution of (p,p'n) channel to total yield:

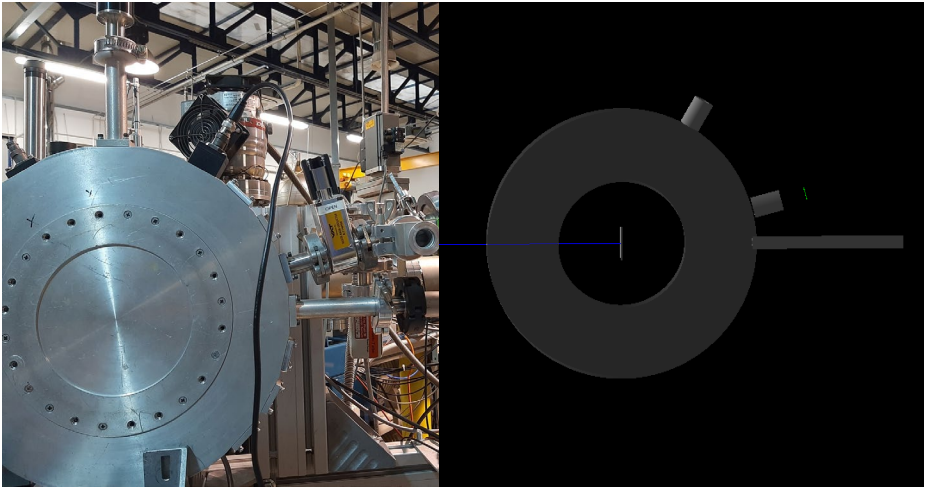
$$\left\{ \begin{array}{l} k = \frac{f_{\text{Be}} N_0}{eA} \\ X' = \frac{d\sigma}{d\Omega_{\text{cm}}} \\ J = \frac{d\Omega_{\text{cm}}}{d\Omega_{\text{lab}}} \frac{dE_p}{dE_n} \\ S = -\frac{1}{\rho} \frac{dE_p}{dx} \end{array} \right. \quad Y'' = k \cdot \frac{X' \cdot J}{S}$$

$$Y''_{\text{tot}} = Y''_{p,n} + Y''_{p,p'n} + Y''_{p,p'\alpha n} + Y''_{p,\alpha n}$$

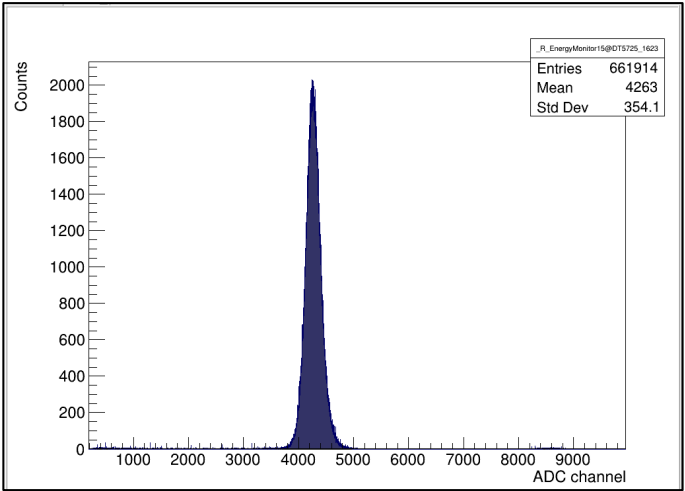
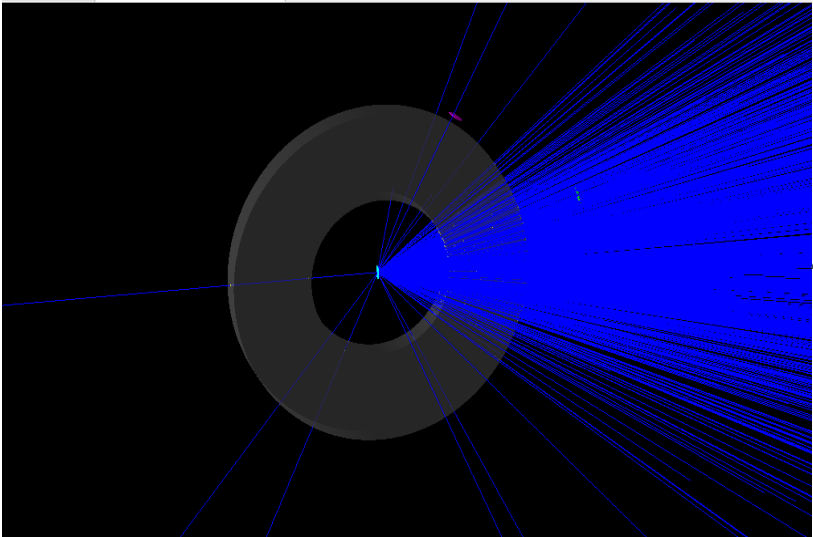
Goal: detailed evaluation of its contribution with new model.

Geant4-DNA for BNCT irradiation data set and DNA damage validation

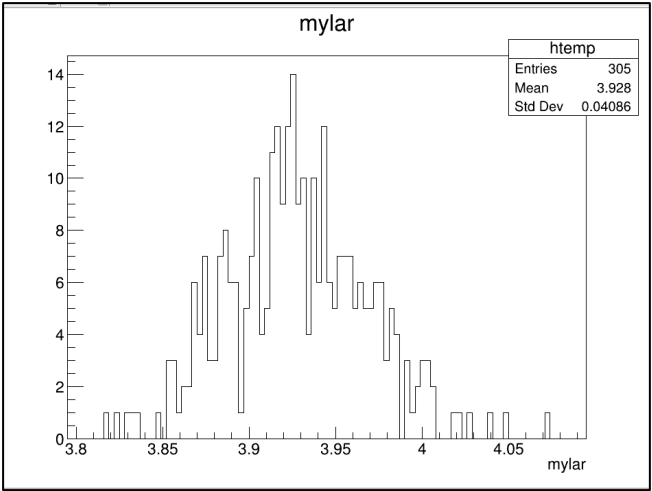
Vanvitelli CIRCE-lab biophysics beam line design/reproduction.



p and Li beam simulations



Energy spectra validation



DNA damage evaluation

Particles	Type of Primaries	GEANT4-DNA DSB
Li 840 keV	E spectrum	4.31 (1 PPM)
a 1470 keV	mono energetic	8.32 (1 PPM)
p 583 keV	E spectrum	23.6163 (N 3% in tissue)
combined DSBs		19.906

GEANT4 School with focus on medical Physics

XI International Geant4 School

14–19 Jan 2024
University of Pavia, Physics Department
Europe/Rome timezone



Overview

Timetable

Contribution List

Registration

Organizing committee

Venue and Accommodations

Sponsors

Contact

✉ [mariopietro.carante@un...](mailto:mariopietro.carante@unipv.it)

✉ ian.postuma@pv.infn.it

Welcome to the One-Week School on Geant4 with focus on medical physics applications and Geant4_DNA

We are delighted to invite you to the One-Week School on Geant4 with focus on the medical applications of nuclear physics, to be held in the historic city of Pavia, Italy, and organized jointly by the University of Pavia, the Section of Pavia and the Laboratori Nazionali del Sud (LNS) of the Istituto Nazionale di Fisica Nucleare (INFN). This educational event is aimed at exploring the advancements of the Geant4 toolkit in the field of medical physics with special lectures dedicated to Geant4_DNA, for the first time in Italy.

44 partecipanti

3 PhD di Pavia

8 MsC di Pavia

13 studenti
internazionali