INFN Sezione di Roma Tor Vergata

DIAMIRA

DIamond-based Array for MIcrodosimetric Radiation Analysis

Responsabile Nazionale: Claudio Verona

(Università di Tor Vergata – INFN-RM2)

CNS V, Area di ricerca: Rivelatori, elettronica

Durata del progetto: 3 anni (2026 – 2028)

In collaborazione con

INFN LNS

INFN Istituto Nazionale di Fisica Nucleare SEZIONE DI ROMA TRE

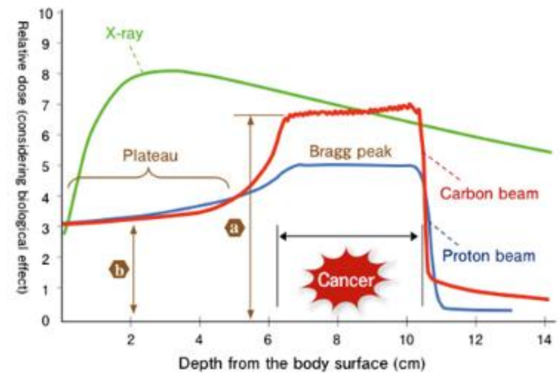
CNAO Centro Nazionale di Adroterapia Oncologica

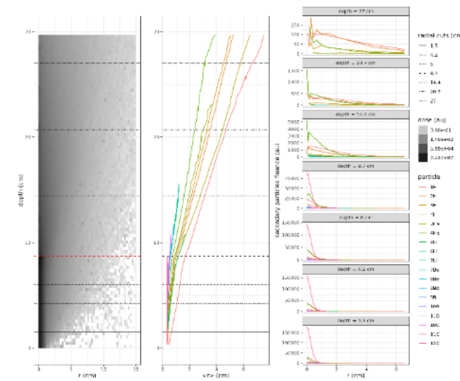
MedAustron

HIT Heidelberger Ionenstrahl-Therapiezentrum

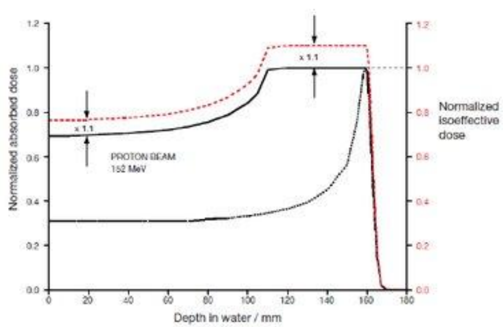
The background

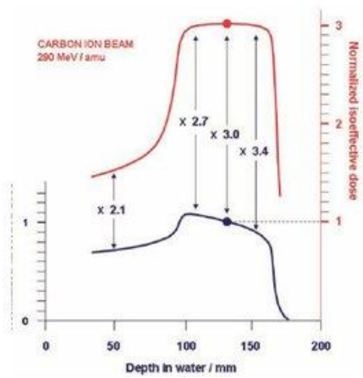
- **Hadrontherapy** is an emerging techniques which make use of high energy protons or ions beams (i.e. He, C and O) to irradiate tumors. Its main advantage is the ability to more precisely localize the delivered dose.
- Protons and ions produce high local ionization density.
- Projectile and target fragmentation produce secondary particles that contribute to dose beyond the Bragg peak and must be considered in treatment planning
- The biological effectiveness (RBE) of high LET particles can be very different from that of high energy photons (RBE > 1).



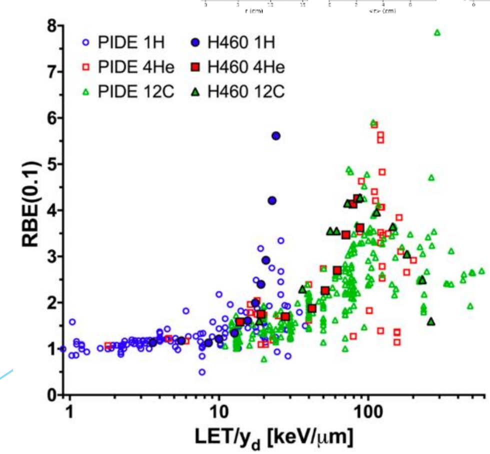


The Treatment Planning System (TPS) procedures are based on the product of the absorbed dose (dosimetry) and proper weighting factors accounting for the RBE of the radiation (radiobiology).





Effect of RBE (source: IAEA2008)



The background

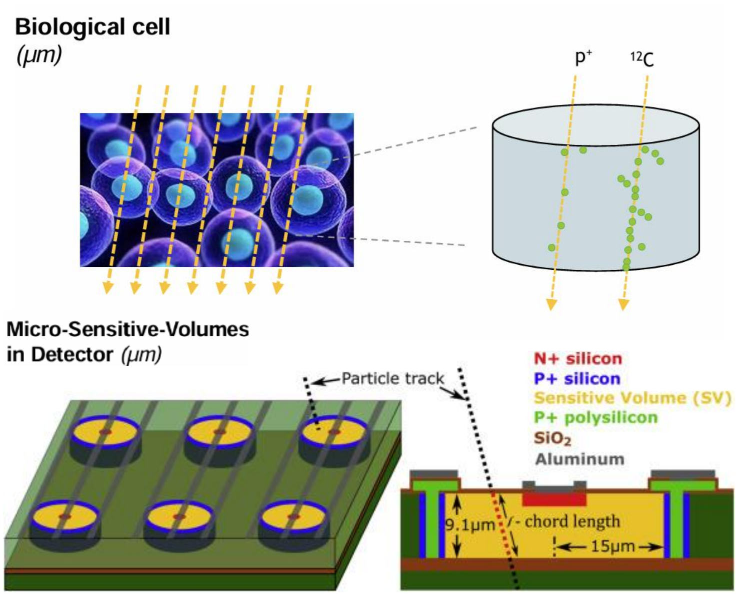
Measuring ion-beam quality: each single-event from different interaction

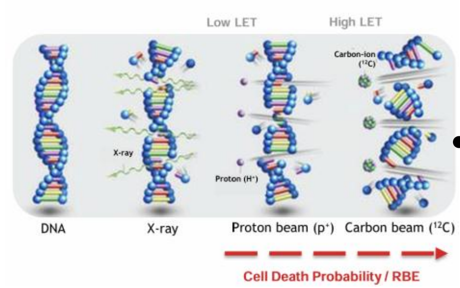
Directly measure the physical effects of fragments

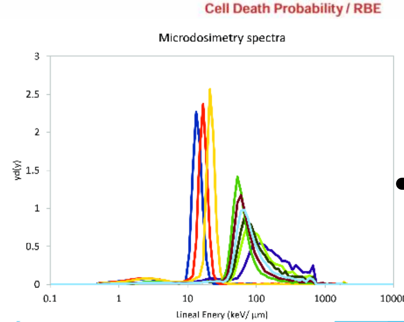
Microdosimetry

Quantities linked to biological response

Allow to study fragments' impact on radiation quality



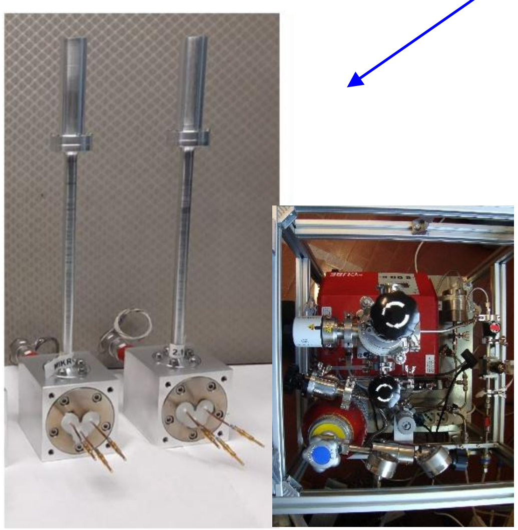


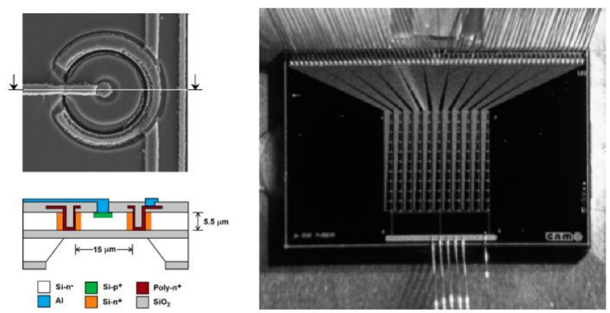


RBE

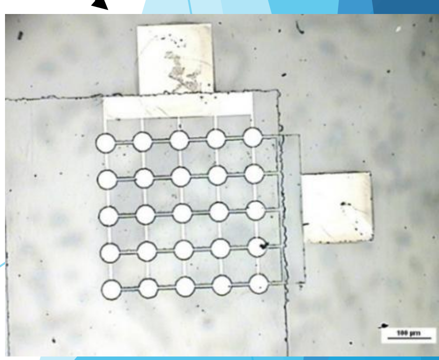
The background

Feature	TEPC (Gas)	Silicon	Diamond
Tissue equivalence	✅ OK	❌ Requires conversion	✅ OK
Spatial resolution	❌ Poor (mm scale)	✅ Excellent (micron scale)	✅ Excellent (micron scale)
Radiation hardness	✅ High	❌ Low	✅ High
High flux / pile-up	❌ limitation in the sustainable beam current	✅ High intensity	✅ High intensity
Portability	❌ Bulky, gas system, HV	✅ Compact	✅ Compact
Cost and availability	⚠️ Medium-high	✅ Widely available	⚠️ limited availability
Pixellated design	❌ No (1 pixel)	✅ yes	⚠️ limited technology





(a) (b)



The proposal

INFN
Sezione di
Roma Tor Vergata

This project aims to develop and test novel microdosimeters based on arrays of synthetic single-crystal diamond pixels, each with a cylindrical-shaped sensitive volume and independent readout. This architecture offers three main advantages:

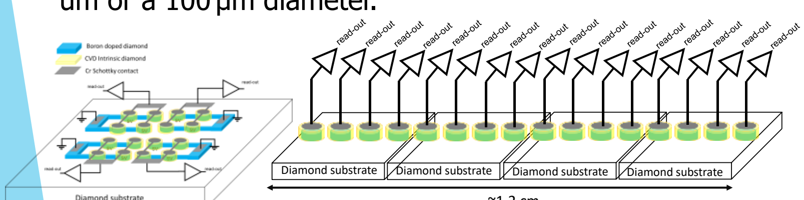
- ✓ Sensitive volumes mimicking biological cells
- ✓ High statistical accuracy within optimized acquisition times while avoiding pile-up effects;
- ✓ Spatially resolved microdosimetry, allowing mapping of particle LET and secondary fragment distributions.

Such a configuration makes the system particularly suitable for radiobiological investigations and quality assurance (QA) in clinical ion beams.

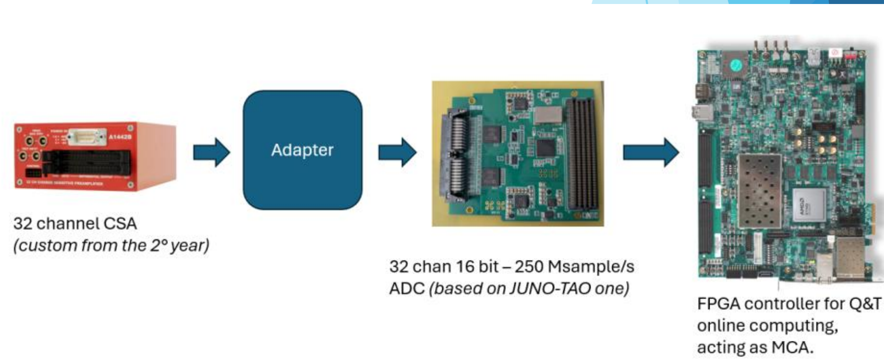
DETECTORS

1. **Microdosimeter array with scalable active area**: composed of 16 cylindrical sensors with a diameter of 10 µm, connected in groups of four in parallel.

2. **Linear microdosimeter based array**: a one-dimensional structure approximately 1 cm long, consisting of 32 individual diamond detectors, each with an active area defined by a 50 um or a 100 µm diameter.



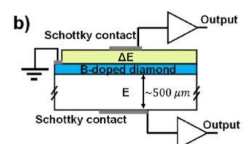
ELECTRONIC READOUT

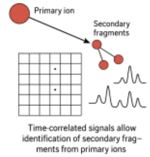


The objectives

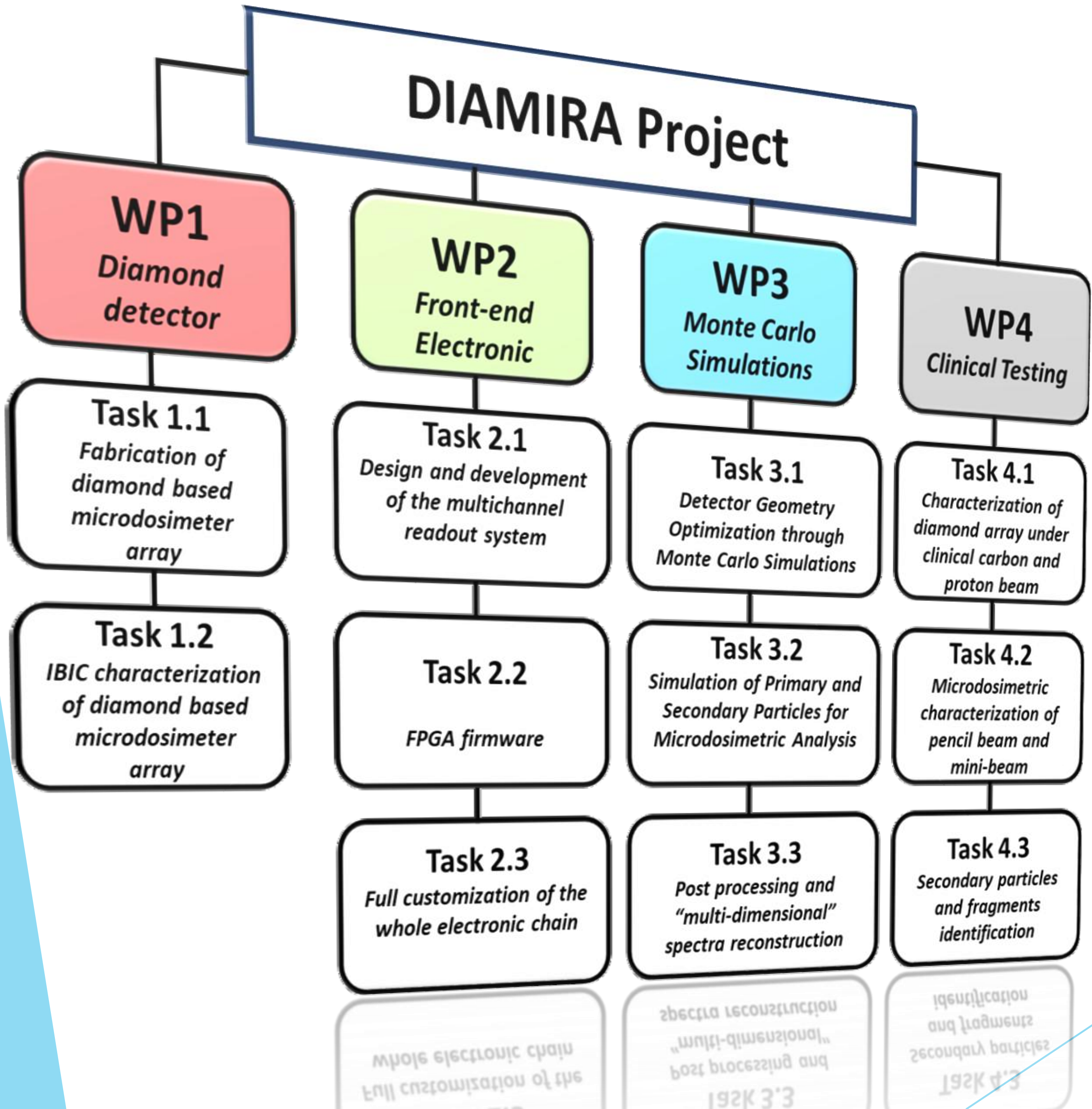
The main goal of the project are:

- ➢ Design and fabrication of pixelated Schottky diode detectors on diamond substrates using CVD deposition and optical lithography techniques refined during the DIODE project.
- ➢ Develop of individual or parallel readout electronics for flexible acquisition configurations depending on fluence conditions and spatial resolution requirements and development of an FPGA-based signal processing system that performs real-time digital filtering, baseline correction, and coincidence event recognition.
- ➢ Experimental campaigns at clinical facilities such as CNAO, MedAustron and Heidelberg to validate the detector's performance in pencil beam and minibeam fields (MIRO project).
- ➢ Identification of secondary particles and nuclear fragments produced by clinical proton and carbon ion beams in water:
  - ✓ Monolithic diamond-based ΔE–E telescope, consisting of two stacked single-crystal diamond detectors with thicknesses of 2.5 μm and 500 μm
  - ✓ Silicon based TimPix3.
  - ✓ By analyzing the time correlation of signals across multiple pixels, it is possible to distinguish isolated events from primary ions and identify correlated energy deposition events caused by secondary fragments interacting simultaneously in different parts of the detector





Methodology



INFN Sezione di Roma Tor Vergata

Resp: **C. Verona**

INFN Istituto Nazionale di Fisica Nucleare Sezione di Roma Tre

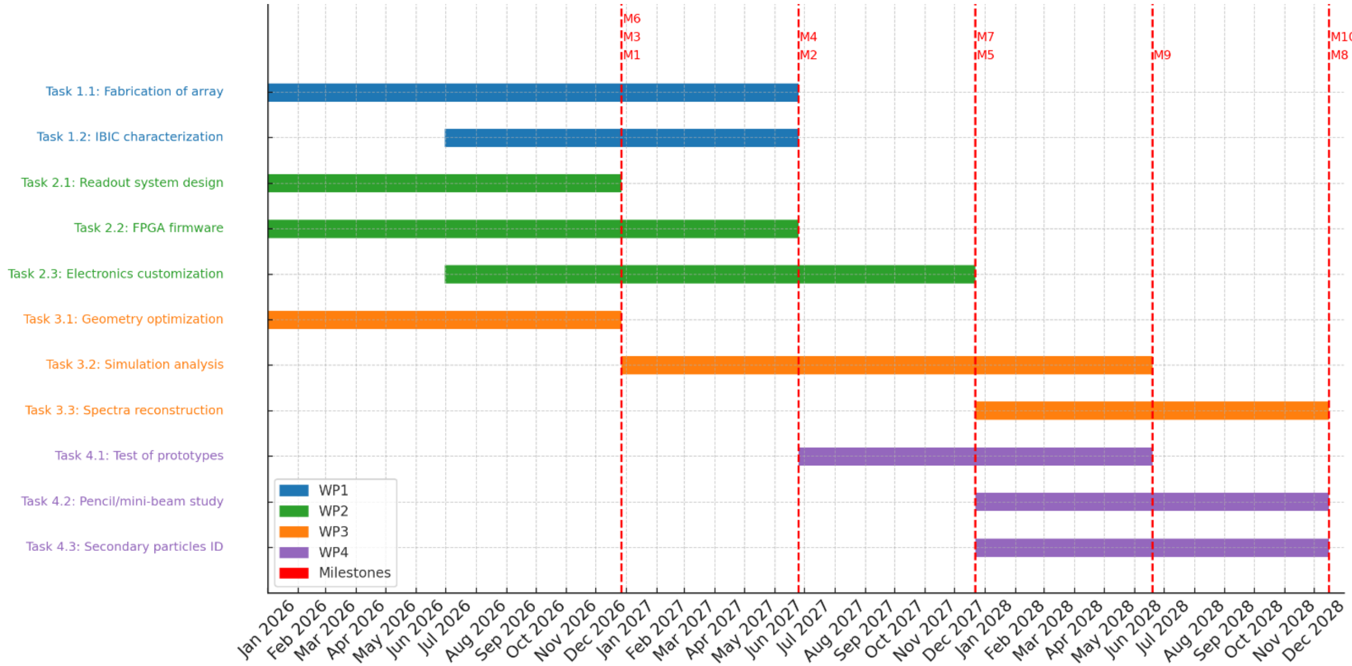
Resp: **A. Fabbri**

INFN LNS

Resp: **P. Cirrone**

Methodology

INFN Sezione di Roma Tor Vergata



Gantt project

Year 1	Detector and electronics design; fabrication of pixelated prototype; Monte Carlo evaluations for the definition of the detectors main characteristics
Year 2	Electronic Readout custom and integration, laboratory testing; IBIC and calibration; Monte Carlo simulations of the final detector and preliminary comparisons with experimental data; preliminary beam test.
Year 3	Full clinical testing; data analysis; comparison with Monte Carlo simulations; publication and dissemination.

Milestones

WP1	**M1:** Completion of lithographically patterned diamond pixel arrays	Month 12
	M2: IBIC characterization and Laboratory validation	Month 18
WP2	**M3:** Multichannel readout system	Month 12
	M4: Full development of FPGA Firmware	Month 18
	M5: Customization of electronic chain	Month 24
WP3	**M6:** Monte Carlo simulation of the detector and definition of its physical and geometrical characteristics in the experimental conditions	Month 12
	M7: Monte Carlo simulations to define key conditions, extract parameters, and compare with experimental data.	Month 36
	M8: Report on the study for the reconstruction of coincidence spectra	Month 36
WP4	**M9:** Characterization of the prototypes under clinical proton and carbon ion beam	Month 30
	M10: Clinical testing to identify fragments/secondary particles with PBS and proton minibeam	Month 36

Anagrafica

INFN Sezione di Roma Tor Vergata

INFN-Roma2

Name	Title	FTE
Claudio Verona	Associated professor	0.5
Gianluca Verona Rinati	Full professor	0.4
Marco Marinelli	Full professor	0.3
Enrico Milani	Full professor	0.2
Angelo Raso	PhD student	0.5
Benoist Grau	PhD student	0.6
		2.5

INFN-Roma3

Name	Title	FTE
Andrea Fabbri	Technologist	0.2
Andrea Attili	Researcher	0.1
Lucrezia Bianchi	PhD student	0.3
Marco Ruggeri	Post doc	0.5
Luca Tortora	Associato	0.2
		1.3

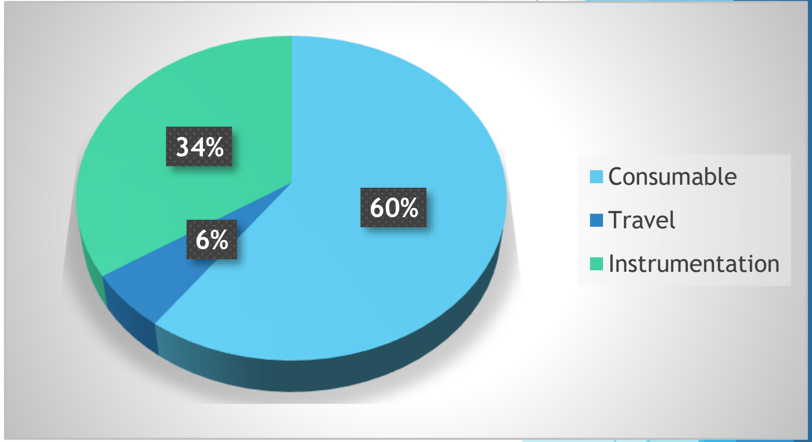
INFN-LNS

Name	Title	FTE
Giada Petringa	Tecnologo	0.5
Pablo Cirrone	Primo Ricercatore	0.2
Giacomo Candiano	Associato	0.5
Arjmand Sahar	Post doc	0.4
Alma Kurmanova	Post doc	0.5
Mariacristina Guarrera	Post doc	0.5
		2.8

Budget

DIAMIRA costs are break down into the following categories: Consumables, Instrumentation and Travels. The budget for each year is reported in Table

Cost category	ITEM	I year	II year	III year	Total	UNIT	WP
Consumable	20 Single crystal diamond substrates	5.5 k€	5.5k€		11 k€	Roma2	1
	Photolithography Masks	2.5k€	1.5k€		4 k€	Roma2	1
	Consumable for photolithography technology	1 k€			1 k€	Roma2	1
	Gas ultrapure and evaporation material	1.5 k€	1 k€		2.5 k€	Roma2	1
	Scheda ADC	4 k€	4 k€		8 k€	Roma3	2
	Scheda Adapter	2 k€			2k€	Roma3	2
	CSA + Adapter		5 k€		5k€	Roma3	2
	Radiocromic films			2k€	2k€	LNS	4
	Support realization for detector irradiation		2k€		2k€	LNS	4
	Manufacturing of mechanical components		2k€		2k€	Roma2	4
	TOTAL CONSUMABLE				39.5k€		
Instrumentation	CAEN A1442 (32 channel)	4 k€			4 k€	Roma3	2
	Motorized XY Translation Stage	6 k€			6 k€	Roma2	1
	Controller FPGA	4 k€			4 k€	Roma3	2
	Low Noise HV	1.5 k€			1.5 k€	Roma3	2
	workstation for local data analysis and visualization	4 k€			4 k€	Roma3	3
	TOTAL INSTRUMENTATION				19.5 k€		
Travel	IBIC Experiment from Rome	2 k€	2 k€		4 k€	Roma2e 3	4
	Heidelberg from Rome			4 k€	4 k€	Roma2e 3	4
	MedAustron from Rome			4 k€	4 k€	Roma2e 3	4
	CNAO from Rome		1 k€	2 k€	3 k€	Roma2e 3	4
	IBIC Experiment from Catania	2 k€	2.5 k€		4.5 k€	LNS	4
	Heidelberg from Catania			3 k€	3 k€	LNS	4
	MedAustron from Catania			3 k€	3 k€	LNS	4
	CNAO from Catania		2 k€	2 k€	4 k€	LNS	4
	TOTAL TRAVELS				29.5 k€		
	TOTALS	40k€	28.5k€	20 k€	88.5k€		



Unit	WP participation	Consumable	Travel	Instrumentation	Total
INFN-Roma2	1	10.5 k€	1 k€	6 k€	17.5 k€
INFN-Roma3	2	6 k€	1 k€	13.5 k€	20.5k€
INFN-LNS	3	0 k€	2 k€	0 k€	2 k€
TOTAL					40 k€

Budget for each unit in 2026, including cost breakdown and WP participation

HEARTBEAT Project

INFN Sezione di Roma Tor Vergata

Project title: Hadrontherapy with hElium and protons as Advanced Radiotherapy Treatment for BrEAst Tumors

Acronym: HEARTBEAT

Proposed duration: 3 years

Field of the research: Interdisciplinary

PI: Prof. Lorenzo Manti

Participating units: LNL, LNS, NA, PV, RM2, and RM3

PURPOSE:

✓ Evaluate proton therapy (PT) as an alternative to CRT for breast cancer treatment.

✓ Explore helium-4 (^4He) hadron therapy (HT) for its potential biological and dosimetric advantages.

METHODS

Radiobiology

- Test on BC cell lines (MCF-7, MDA-MB-231) with varying radiosensitivities. Measure cell death, DNA repair, and response to novel anti-metastatic drugs.
- Assess cardiac toxicity in human cardiac microvascular endothelial cells (HMVEC-C).
- Evaluate secondary cancer risk via chromosomal aberration analysis in MCF10A epithelial cells.

Biophysical modeling

- Develop and parameterize radiobiological models predicting clinically relevant endpoints.
- Simulate normal-tissue effects under different treatment modalities.

Microdosimetry

- Quantify energy deposition at subcellular scales (1–25 µm) using gas and solid-state detectors.
- Correlate microdosimetric parameters with observed biological outcomes.

OUTCOMES

- Fills a critical pre-clinical research gap in advanced breast cancer radiotherapy.
- Compares PT and ^4He HT for tumor control efficiency and cardiac sparing.
- Potentially leads to improved clinical planning with reduced cardiac toxicity and better patient outcomes.

FTE and Budget

INFN Sezione di Roma Tor Vergata

MICRODOSIMETRY	M7: Characterization and comparison of the three microdosimeters under proton and 4He (or 12C) ion Microdosimetry irradiation	12
	M8:Microdosimetric characterization of the clinical proton beam using all involved detectors. The characterization includes both in-field regions, corresponding to depths within the SOBP overlapping with the tumor volume, and out-of-field regions, to assess the impact on surrounding healthy tissue	24
	M9: Microdosimetric characterization of the clinical 4He beam using all involved detectors. The characterization includes both in-field regions, corresponding to depths within the SOBP overlapping with the tumor volume, and out-of-field regions, to assess the impact on surrounding healthy tissues.	36

Project Milestones

FTE

Marco Marinelli	PO RM2	30%	RM2
Enrico Milani	PO RM2	30%	RM2
Angela Maria Raso	Dottorando	20%	RM2
Claudio Verona (Res. Loc.)	PA RM2	20%	RM2
Gianluca Verona Rinati	PO RM2	10%	RM2

BUDGET

Capitolo	Descrizione	Parziali (k€)		Totale (k€)	
		Richieste	SJ	Richieste	SJ
consumo	Consumable for realization and experimental test (set-up) of diamond microdosimeter for proton beam.	1.50	0.00	1.5	0
missioni	3 keuro sono destinati a coprire le spese di missione previste per quattro turni di misura presso CNAO (due nel primo semestre e due nel secondo).	3.00	0.00	3	0
Totale				4.5	0

GAP Project

INFN Sezione di Roma Tor Vergata

Genomic Adjusted Particle-therapy
Durata proposta: 3 years
Area di ricerca: Interdisciplinare
PI: Prof. Francesco Giuseppe Cordoni

Participating units:
LNL, TIFPA, TO, PV, RM2, and CT

PURPOSE

- Investigate how protons and carbon ions, influence gene expression in both healthy and tumor tissues.
- Develop a predictive framework for Genomic-Adjusted Particle Therapy (GAP) to enable personalized treatment based on individual genomic profiles.

METHODOLOGY

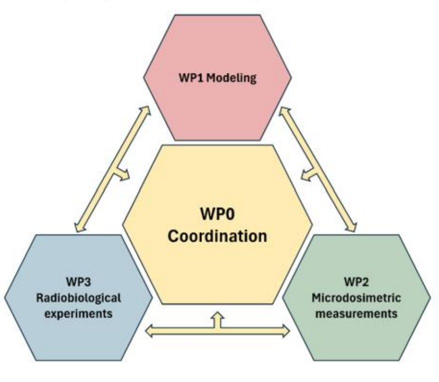
- ✓ **Radiobiology**: 2D cultures, 3D spheroids, and co-cultures of healthy and cancerous cells. Irradiation with protons and carbon ions at Trento Proton Therapy Center and CNAO.

Post-irradiation analyses:

Next-Generation Sequencing (NGS) and immunofluorescence to monitor gene expression and cellular phenotype.

Study of **extracellular vesicle** production.

- ✓ **Microdosimetry**: Radiation fields characterized at micron scale using novel INFN-developed detectors.
- ✓ **Computational analysis**: advanced statistical techniques to link gene expression with biological endpoints and inform predictive modeling.



OUTCOMES

- ✓ Identification of radiation quality-specific gene expression signatures.
- ✓ Establishment of a methodology to integrate genomic data into radiobiological modeling.

FTE and Budget

INFN Sezione di Roma Tor Vergata

TASK and Deliverable for WP2

Task	Deliverable	Description	When	Who
T2.1 TPTC measurements	D2.1.1	MUSICA and mini-TEPC (4MiCA) measurements	1-12 m	INFN-LNL
	D2.1.2	DIODE measurements	1-12m	INFN-RM
	M2.1	Measurements at TPTC completed	12m	INFN-LNL - INFN-RM
T2.2 CNAO measurements	D2.2.1	miniTEPC (4MiCA) measurements	12-24 m	INFN-LNL
	D2.2.2	DIODE measurements	12-24 m	INFN-RM
	M2.2	Measurements at CNAO completed	24m	INFN-LNL - INFN-RM

FTE

INFN - RM		
Name	**Età anagrafica**	**FTE**
Claudio Verona	44	0.2
Gianluca Verona Rinati		0.2
Marco Marinelli		0.3
Enrico Milani		0.2
Angelo Maria Raso		0.2
		Total = 1.1

BUDGET

Capitolo	Descrizione	Parziali (k€)		Totale (k€)	
		Richieste	SJ	Richieste	SJ
consumo	Acquisto di materiale di consumo e assemblaggio per costruzione del set-up sperimentale a Trento	1.50	0.00	1.5	0
missioni	3 turni di misure a Trento per due persone	3.00	0.00	3	0
Totale				4.5	0

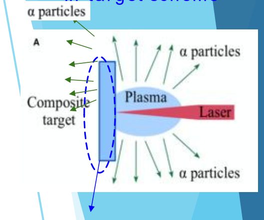
FUSION Project

INFN Sezione di Roma Tor Vergata

FUsion StudIes of prOton boron Neutronless reaction in laser-generated plasma

$11B + p \rightarrow 3\alpha + 8.7\ MeV$

In-target scheme



- Boron (natural or 11B) enriched target on silicon substrate
- NB targets

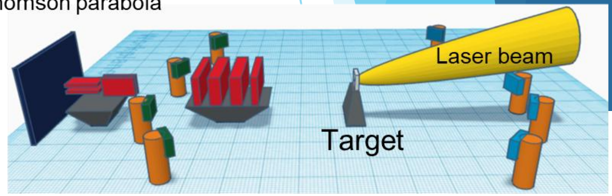
Responsabile Nazionale: G.A.P. Cirrone (LNS) and F. Consoli (ENEA)
Durata proposta: tre anni (2023-2025)

Area di ricerca: Acceleratori e multidisciplinare

INFN sections: Catania, Lecce, LNS, LNGS, Milano, Roma2, Torino, TIFPA, Bologna, Firenze

Ion detectors in TOF configuration (CR39, diamonds, ICs)

Thomson parabola

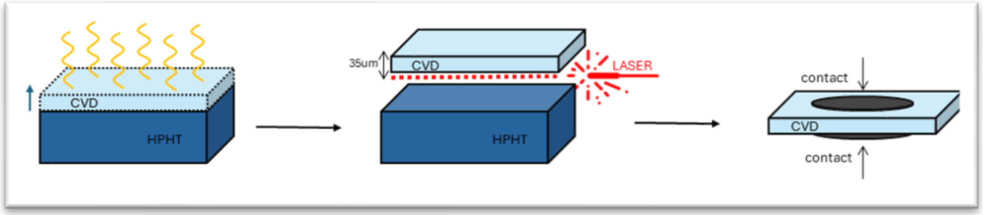


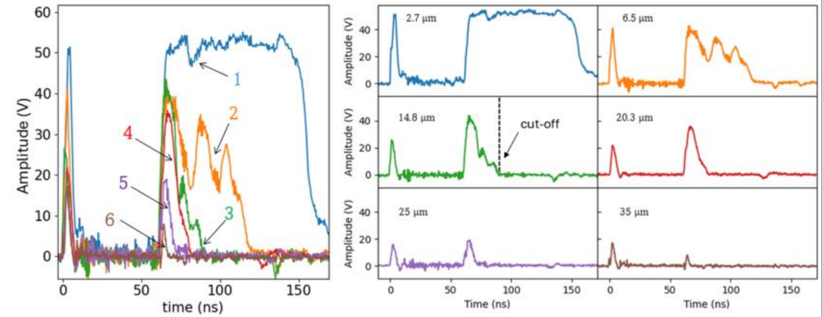
FUSION goals are:

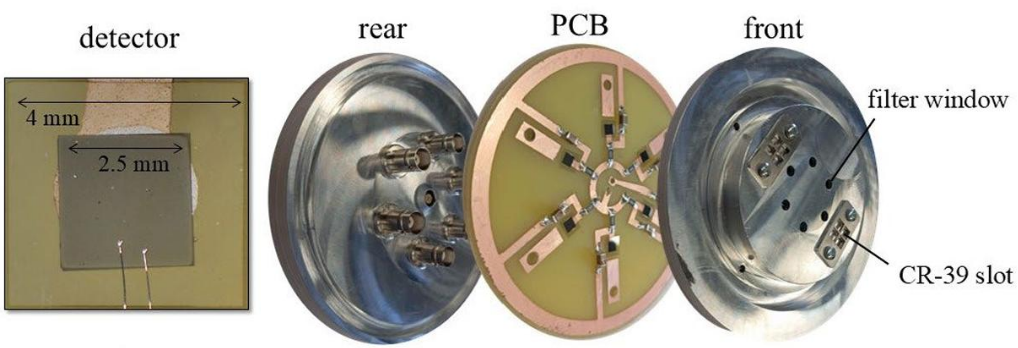
1. The maximisation of the $p^{11}B$ reaction rate in plasma (WP1). This will be done by studying the interaction of laser systems with targets of different materials and configurations that will be developed (WP3) and optimized with both Particle in Cell (PIC) and hydrodynamic simulations.
2. The development of innovative diagnostic (WP5) able to estimate the $p^{11}B$ reaction rate by looking at alphas products or protons, and investigating reaction channels where neutrons are produced. The diagnostic shall also operate in real-time.
3. The understanding of the physics laying at the basis of the observed $p^{11}B$ reaction rate. This will be done by studying the interaction of protons and alphas by conventional accelerators in a borated expanding plasma (WP2)

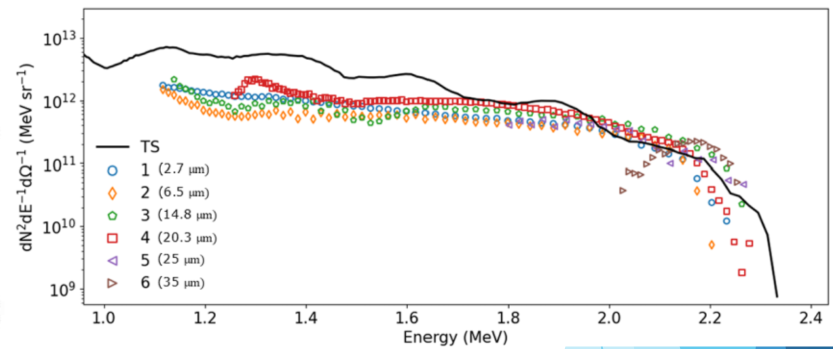
Activity INFN-RM2

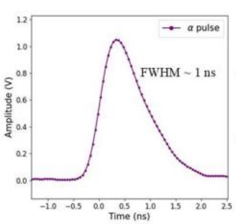
The Time-of-Flights Diamond Array was successfully employed for the study and characterization of the pB11 fusion reaction in plasma during the experimental campaing at PALS facility

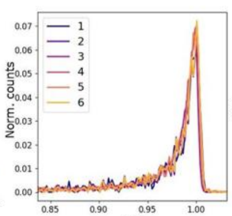


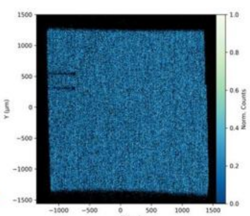


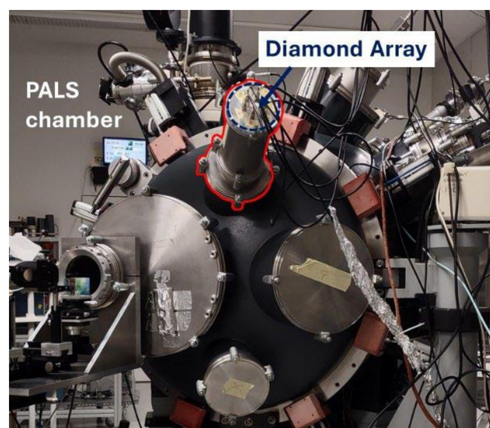


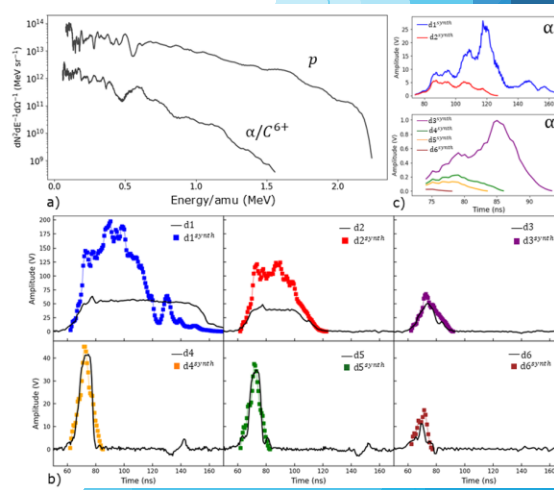






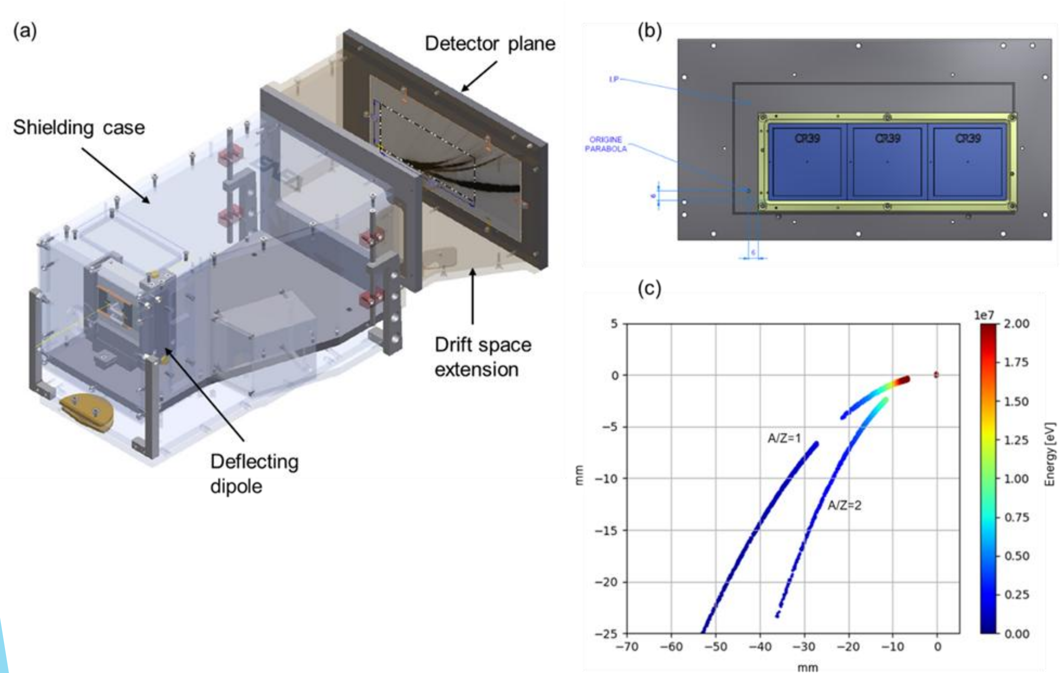




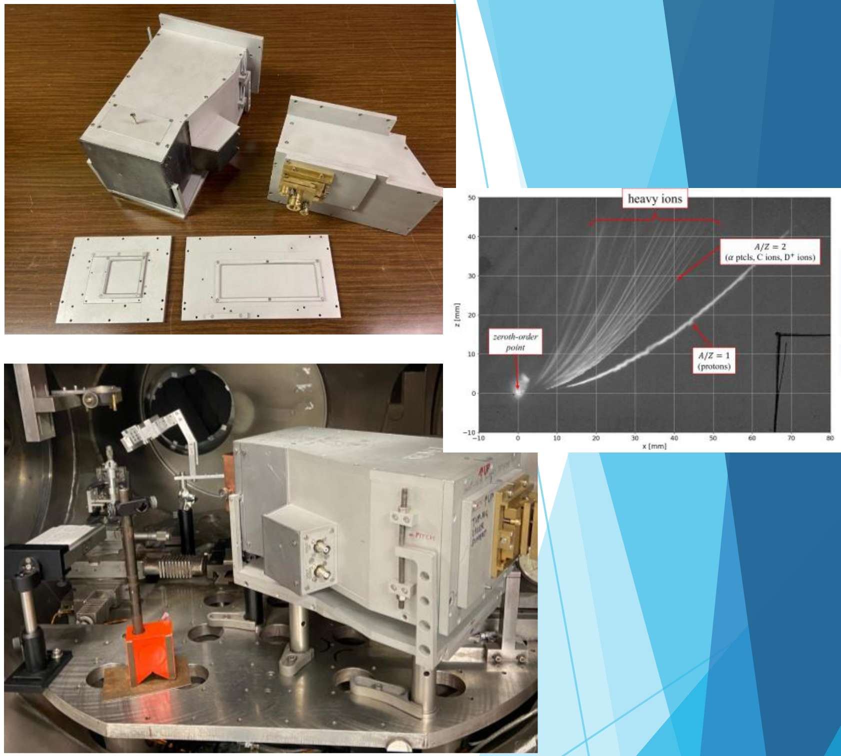


Activity INFN-RM2

INFN Sezione di Roma Tor Vergata



- Schematic design of the alpha particle detection device. (b) Improved design of the detector plane, allowing the use of a CR39 array. (c) Parabolic traces of the deflected ions, computed by a particle tracking simulation, at the end of the drift space after the deflecting dipole (i.e. at the position of the particle detector of the device).



- Main body of the spectrometer (top left), extension of the drift space for adaptable detector positioning (top right) and interchangeable detector planes for implementing single or multiple CR-39 detectors (bottom).

Activity INFN-RM2

INFN Sezione di Roma Tor Vergata

For the PALS campaign, CH foam + Si-H-B substrate targets have been realized and tested.

The targets were constituted by a steel washer with an outer diameter of 1 cm and an inner diameter between 300 and 400 μm.

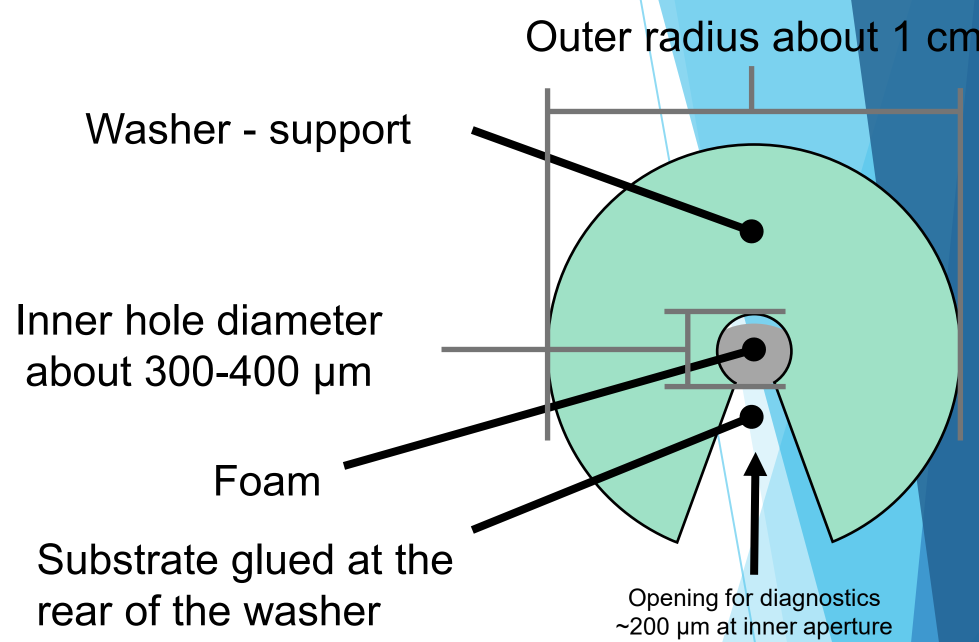
The inner opening of the washer was filled of a plastic foam with a pore size smaller than 1 μm.

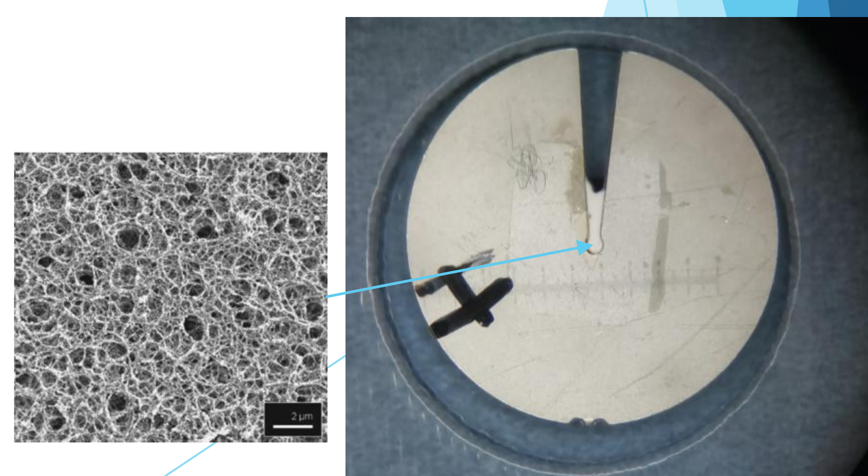
A substrate made of a Si wafer enriched with H and B was attached to the back of the target.

The main laser beam was intended to come from the foam side, to exploit the ability of the foam to enhance laser absorption.

The foam densities achieved during manufacturing was of 100 and 50 mg/cm^3, slightly too high for the optimal functioning of the laser-foam interaction.

New foam targets are recently realized with lower foam density, closer to 10 mg/cm^3.





Activity, FTE and Budget

INFN Sezione di Roma Tor Vergata

Planned Activities in the FUSION Project:

•A new experiment on proton-boron fusion has been scheduled at the PALS facility, to take place over four weeks between November and December 2025.

•The experiment will test:

- The targets selected during the first experimental campaign.
- The diagnostics developed within the project, including the newly designed TP diagnostic.
- New investigation techniques aimed at improving data and alpha fusion yield assessment.

•The year 2026 will be dedicated to:

- Data analysis from the PALS experiment.
- Preparation of scientific publications and presentations at international conferences.

•Final experimental testing at Singletron (CT) of the chopper system developed in WP2 will also be completed during this phase.

No BUDGET for 2026 for RM2

FTE

Cognome	nome	FTE
Alonzo	Massimo	0,3
Cipriani	Mattia	0,4
Consoli	Fabrizio	0,5
Milani	Enrico	0,1
Raso	Angelo Maria	0,1
Scisciò	Massimiliano	0,3
Verona	Claudio	0,1
Verona Rinati	Gianluca	0,1
		1,9