INFN Sezione di Roma Tor Vergata

DIODE

"Diamond Integrated devices fOr haDronthErapy"

Responsabile Nazionale: C. Verona

(Università di Tor Vergata – INFN-RM2)

Area di ricerca: Rivelatori, elettronica

Durata del progetto: 3 anni (2022 – 2024)

In collaborazione con

INFN LNL Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Legnaro

INFN MILANO

TIFPA

CNAO Centro Nazionale di Adroterapia Oncologica

INFN LNS

INFN Istituto Nazionale di Fisica Nucleare SEZIONE DI ROMA TRE

MedAustron

The background

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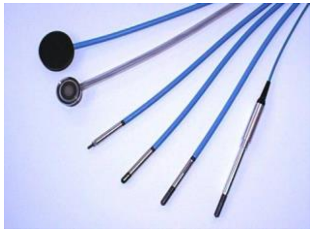
- ✓ Ionizing radiations such as photons and electrons are used in medicine, to kill malignant cells and treat different types of tumour.
- ✓ The physical quantity routinary used for Treatment Planning System (TPS) commissioning and beam quality control in a radiotherapy treatment is the absorbed dose to water, which is generally well correlated to the induced biological damage and that can be measured by several commercial dosimeters.

The <u>absorbed dose to water</u> is <u>energy per unit mass deposited in water by the radiation</u>

$$D_W = \frac{\Delta E_W}{\Delta m}$$

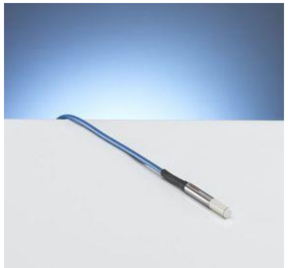
<u>Commercial dosimeters:</u>

Ionization Chambers



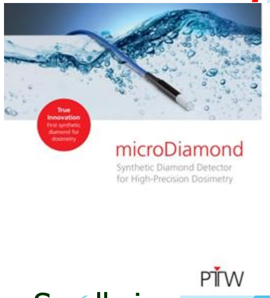
- Low sensitivity per unit volume
- Polarization effects when reducing the size
- Pressure and temperature correction needed
- Stopping power ratio correction needed (electrons)
- High voltage

Silicon diodes



- Small size
- Not "water equivalent"
- High energy dependence

Diamond Schottky diode



- Small size
- Low energy dependence
- Near tissue equivalence
- No dose rate dependency
- No bias applied

The background

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- **Hadrontherapy** is an emerging techniques which make use of high energy protons or carbon ions beams to irradiate tumors. Its main advantage is the ability to more precisely localize the delivered dose.
- Protons and carbon ions produce high local ionization density.
- Solid state dosimeters typically exhibit a strong energy dependence due to Linear Energy Transfer (LET) variation
- Radiation damage reported for silicon diode dosimeters.

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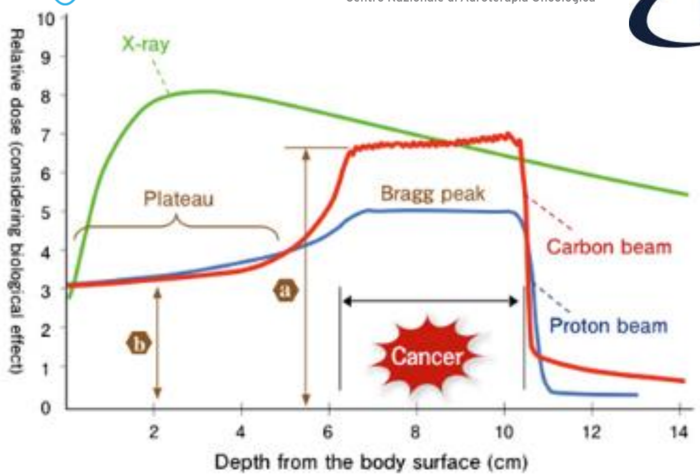
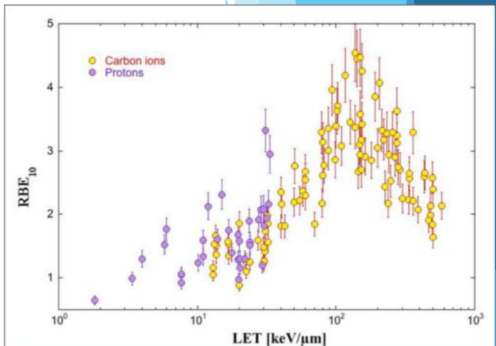
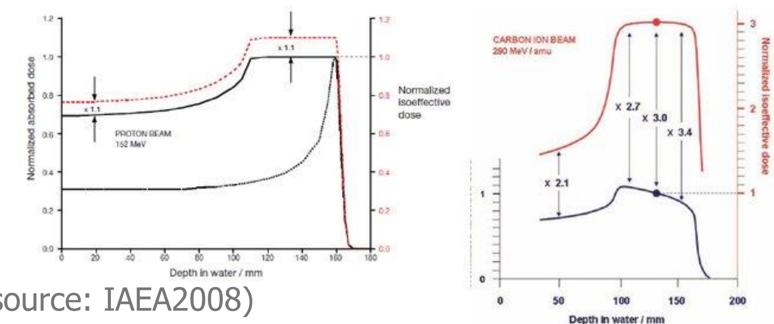




Source: Frontiers in Physics 8(2020):451

The biological effectiveness (RBE) of high LET particles can be very different from that of high energy photons (RBE > 1). The TPS procedures are based on the product of the absorbed dose (dosimetry) and proper weighting factors accounting for the RBE of the radiation (microdosimetry).

The only conventional dosimetry is not enough for a comprehensive characterization of clinical radiation.



Effect of RBE (source: IAEA2008)

The background

The use of microdosimeters has a fundamental role in the framework of cancer therapy performed with ion-beam. It allows measuring ion-beam quality

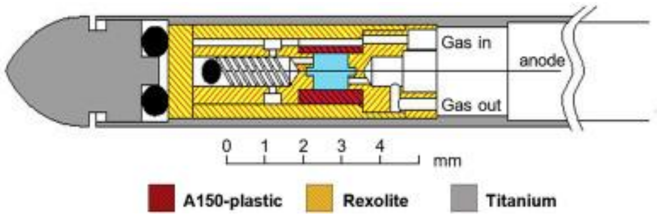
Lineal energy spectra, which describe the release of the energy to the equivalent water site.

Microdosimetric quantities: mean lineal energy values

Such parameters are correlated to the cellular damage and varies drastically at the end of particle path (high particle LET).

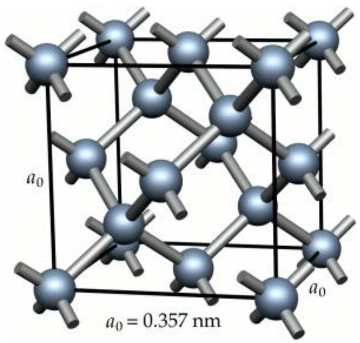
The reference microdosimeter to date is the tissue equivalent proportional gas counters (TEPCs). Microdosimetric measurements with TEPCs were proposed and demonstrated to properly assess the RBE of the radiation. However, there are several issues in the use of TEPCs in clinical practice:

- ✓ limitation in the sustainable beam current
- ✓ limited lateral spatial resolution (1 mm)
- ✓ high operation voltages.
- ✓ no practical and easy-to-use detector.



Only conventional dosimetric systems are routinely adopted for treatment plan verification and quality assurance purposes.

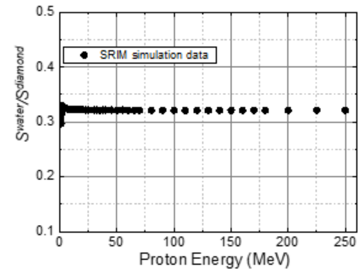
The background

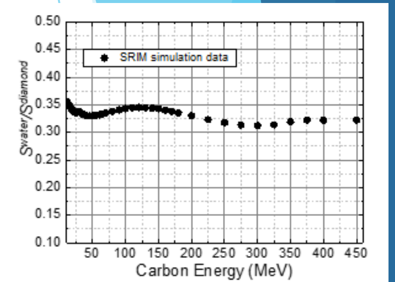


Solid-state detectors are easy to use and reasonably cheap and they have the advantage of small dimensions to cope with high-intensity beams and to allow high spatial resolution.

Synthetic single crystal diamond is an ideal candidate material to produce microdosimeters thanks to its outstanding properties:

- ✓ near-constant ratio of stopping power with water for proton and carbon ions
- ✓ low dielectric constant
- ✓ high radiation hardness.





Diamond based- microdosimeters were proposed as Schottky diodes showing:

- ✓ High spatial resolution
- ✓ good spectroscopic properties (100% CCE, good energy resolution)
- ✓ high radiation tolerance
- ✓ good homogeneity and a well-defined confinement of the response within the active area
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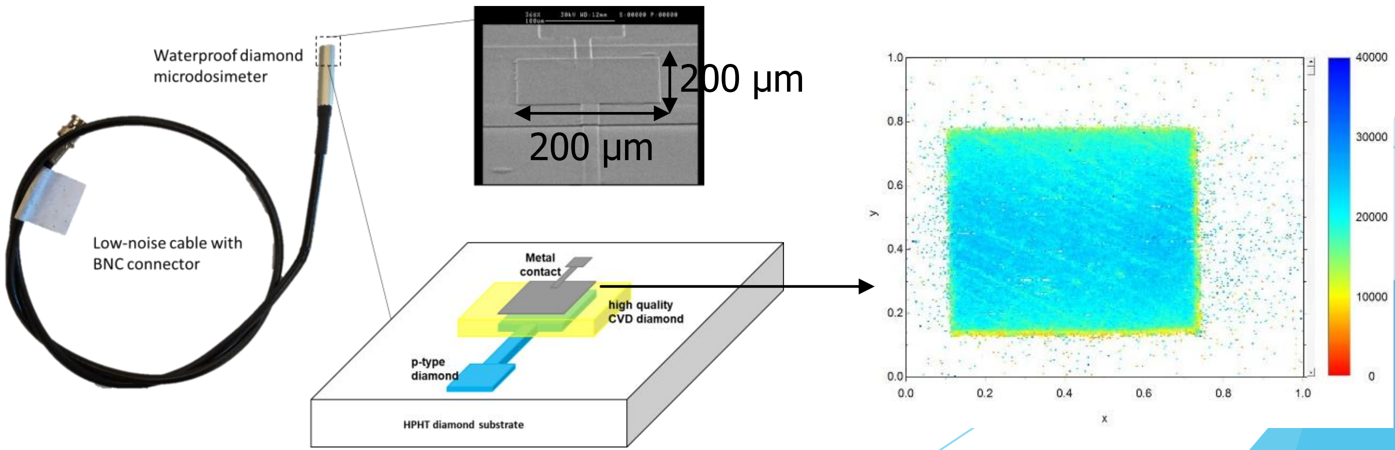

The proposal

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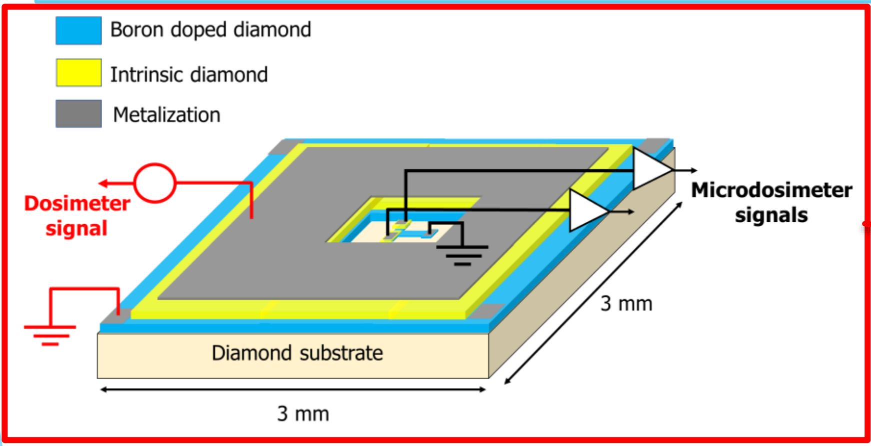
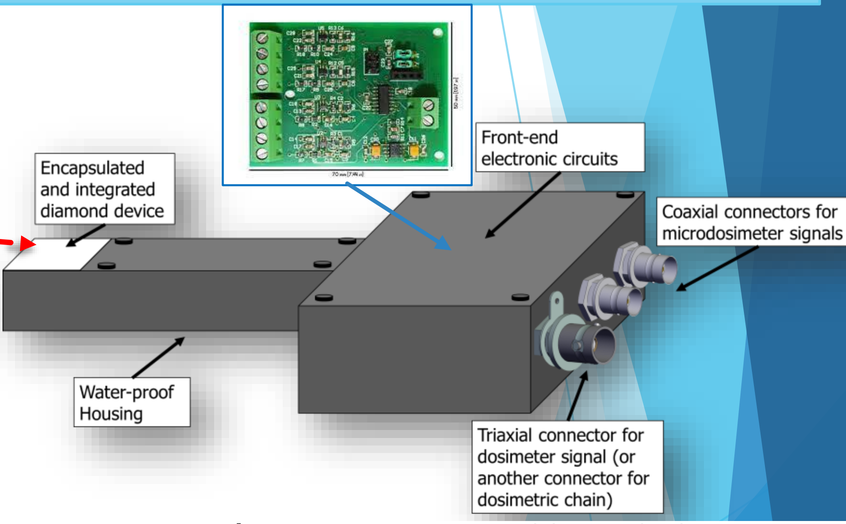
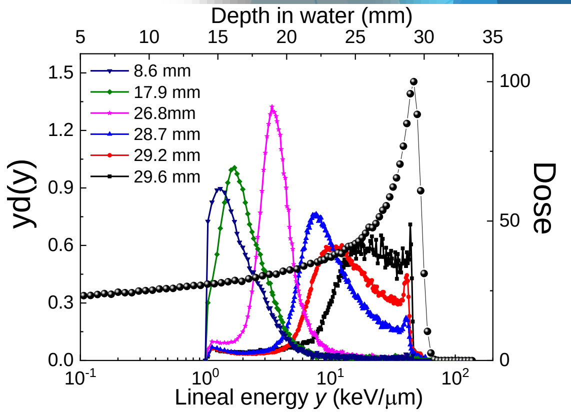
The aim of the proposed project is the development and characterization of a novel detection system based on synthetic single crystal diamond able to simultaneously perform dosimetric (current integration measure) and microdosimetric (single particle energy deposition measure) characterization of clinical hadron beams.





Advantages

- ✓ The simultaneous measurements of dosimetric and microdosimetric data would allow a fast and exhaustive beam characterization and quality assurance in hadrontherapy centres.
- ✓ Reduction of the experimental uncertainties such as those associated with the detector positioning.
- ✓ Dosimetric information will be used to compensate the distortions at the lowest part of the microdosimetric spectrum due to the unavoidable electromagnetic noise.



The objectives

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The main goal of the project are:

- the development of novel diamond technology methods to realize different integrated devices, *i.e.* diamond dosimeter and few diamond microdosimeters, on the same diamond substrate, 3 x 3 mm^2 in size, combining chemical vapour deposition and photolithography techniques. Such diamond devices, featured by different area, thickness and shape, will be realized in a Schottky diode configuration (p-type diamond/intrinsic diamond/metal contact).

- the development of a dedicated front-end electronic circuits both for dosimetric and microdosimetric signals and placed very close to the diamond detector to minimize the noise and to achieve a compact device. The integration of dosimeteric and micro-dosimeteric electronic chains is a relevant goal of the experiment.

- the realization of a water-proof prototype (diamond devices + front-end electronic circuits)

- the detailed simulation of the device with Monte Carlo approach. The simulation will include both the dosimetric and the microdosimetric parts of the device.

- characterization of the developed prototype in clinical operating conditions with proton and carbon ion beams and comparison with standard dosimetric and microdosimetric systems: PTW ionisation chambers and a mini-TEPC from LNL.

Methodology

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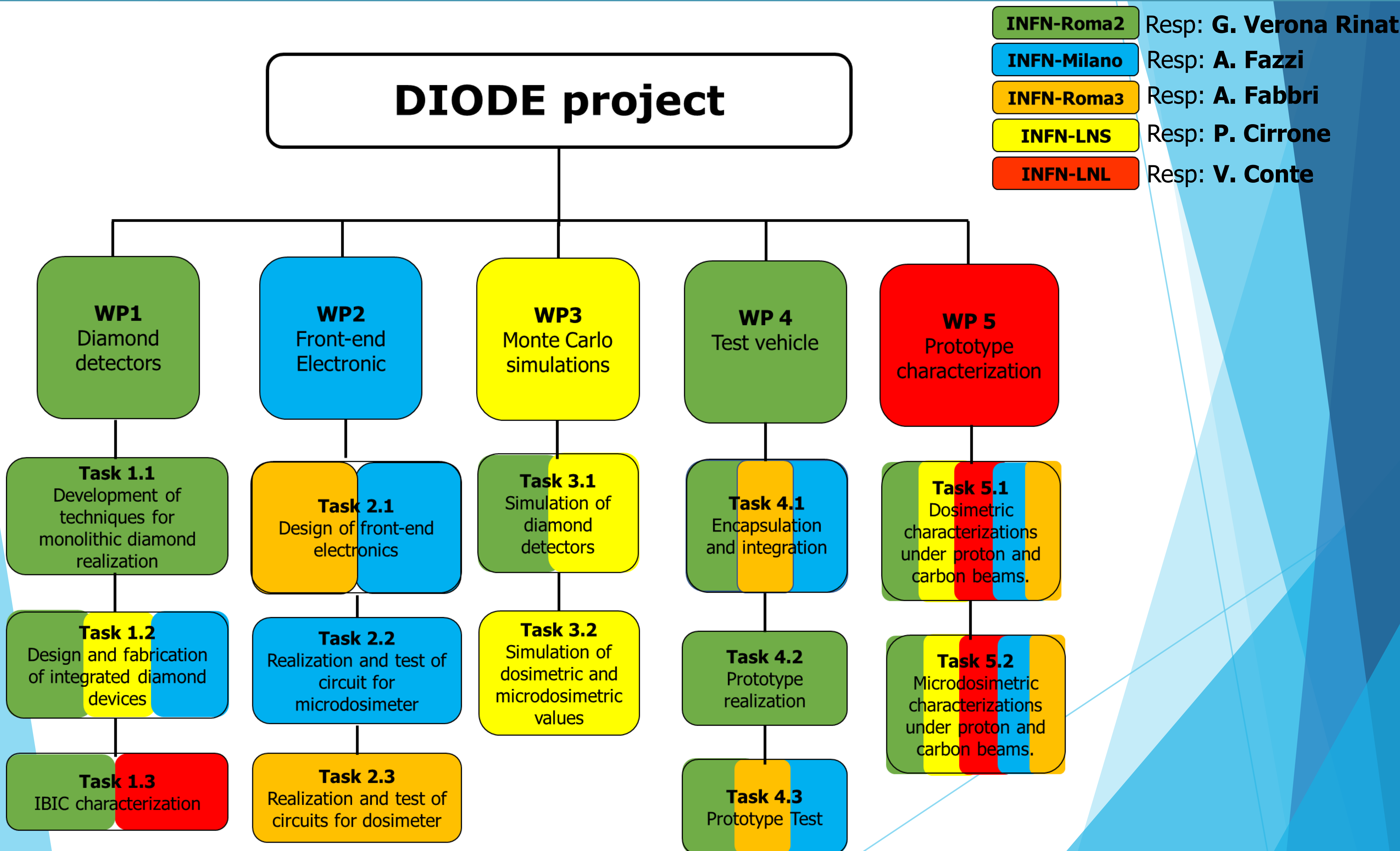
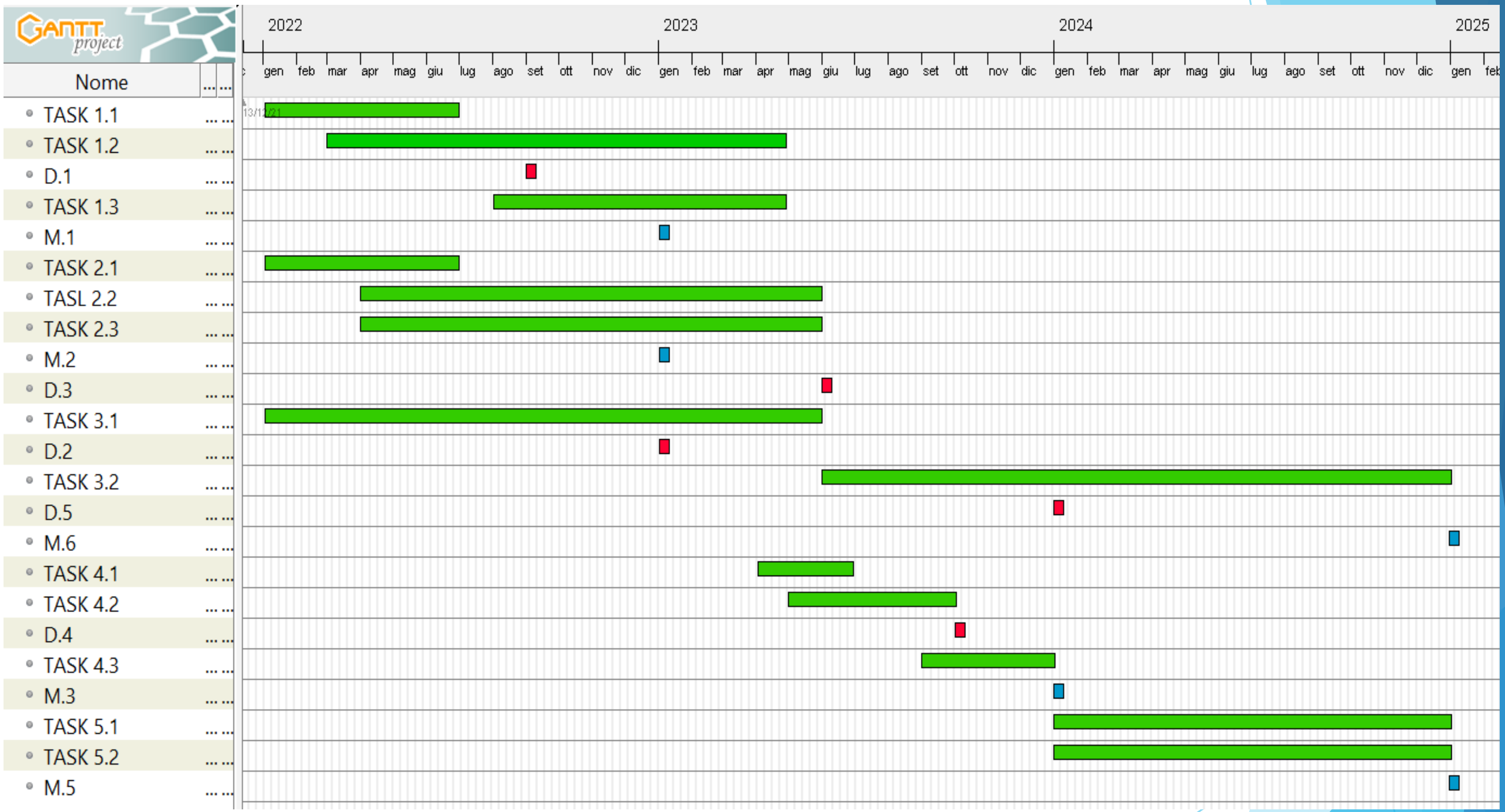


WBS of the project

Methodology



Gantt project

Anagrafica

INFN Sezione di Roma Tor Vergata

INFN-Roma2

Name	Title	FTE
Claudio Verona	RTD_B	0.7
Gianluca Verona Rinati	Associated professor	0.5
Marco Marinelli	Full professor	0.3
Enrico Milani	Full professor	0.3
XXXXXX	PhD student	0.8
		2.6

INFN-Milano

Name	Title	FTE
Alberto Fazzi	Associated professor	0.3
Stefano Agosteo	Full professor	0.2
Davide Bortot	RTD_A	0.3
Davide Mazzucconi	Post doc	0.4
Giovanni d'Angelo	Technical	0.4
		1.6

INFN-Roma3

Name	Title	FTE
Andrea Fabbri	Technologist	0.2
Andrea De Iacovo	Researcher	0.4
Lorenzo Colace	Full professor	0.5
XXXX	Post doc	0.6
		1.7

INFN-LNS

Name	Title	FTE
Giada Petringa	Post doc, INFN and ELI-Beamllines	0.1
Pablo Cirrone	Senior researcher, INFN-LNS	0.1
Roberto catalano	Post doc, INFN-LNS	0.2
Serena Fattori	INFN-LNS	0.2
Pietro Falcignia	RTD_B University of Catania	0.2
Michele Costa	Technologist, INFN-LNS	0.3
		1.1

INFN-LNL

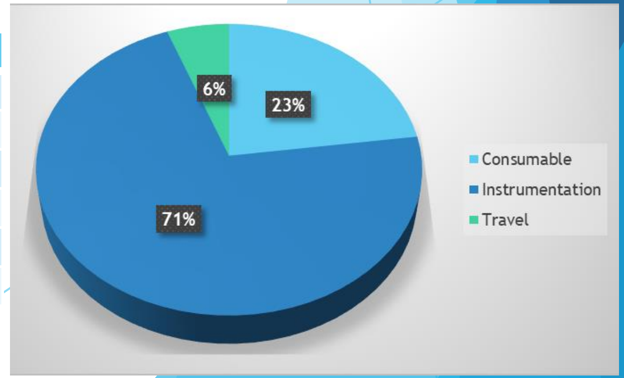
Name	Title	FTE
Valeria Conte	Technologist	0.1
Chiara La Tessa	Associated professor	0.1
		0.2

Budget

DIODE costs are break down into the following categories: Consumables, Instrumentation and Travels. The budget for each year is reported in Table for INFN-Roma2.

Cost category	**ITEM**	**I year**	**II year**	**III year**	**Total**	**UNIT**	**WP**
Consumable							
	Diamond substrates	5 k€			5 k€	Roma2	1
	Photolithography mask	1 k€	1 k€		2 k€	Roma2	1
	consumable for CVD reactors and metalization	1 k€	1 k€		2 k€	Roma2	1
	Prototype realization and assembly		2 k€		2 k€	Roma2	1
	TOTAL CONSUMABLE	7 k€	4 k€		**11 k€**		
Instrumentation							
	Mask Aligner	25 k€			25 k€	Roma2	1
	TOTAL INSTRUMENTATION	25 k€			**25 k€**		
Travel							
	Experimental activity at LNL, TPT and CNAO	2 k€	2 k€	6 k€	10 k€	Roma2	1, 4 and 5
	TOTAL TRAVELS	2 k€	2 k€	6 k€	**10 k€**		
	TOTALS	**34 k€**	**6 k€**	**6 k€**	**46 k€**		

Unit	WP participation	Consumable	Travel	Instrumentation	Total
INFN-Roma2	1	7 k€	2 k€	25 k€	34 k€
INFN-Milano	2	6 k€	2 k€	5.5 k€	13.5 k€
LNS-INFN	3		3 k€	4 k€	7 k€
LNL-INFN	1	1 k€			1 k€
INFN-Roma3	2	6 k€	4 k€		10 k€
TOTAL					65.5 K€



Budget for each unit in 2022, including cost breakdown and WP participation