SPES MED

Principal Investigator

Prof. Emilio Mariotti, INFN-PI.

INFN Research Units

Pisa, **Padova**, Milano, Pavia, LNL

Research Fields

Nuclear Physics, Medical Radionuclides, Cross Section Measurements, Radiation Detectors

Duration

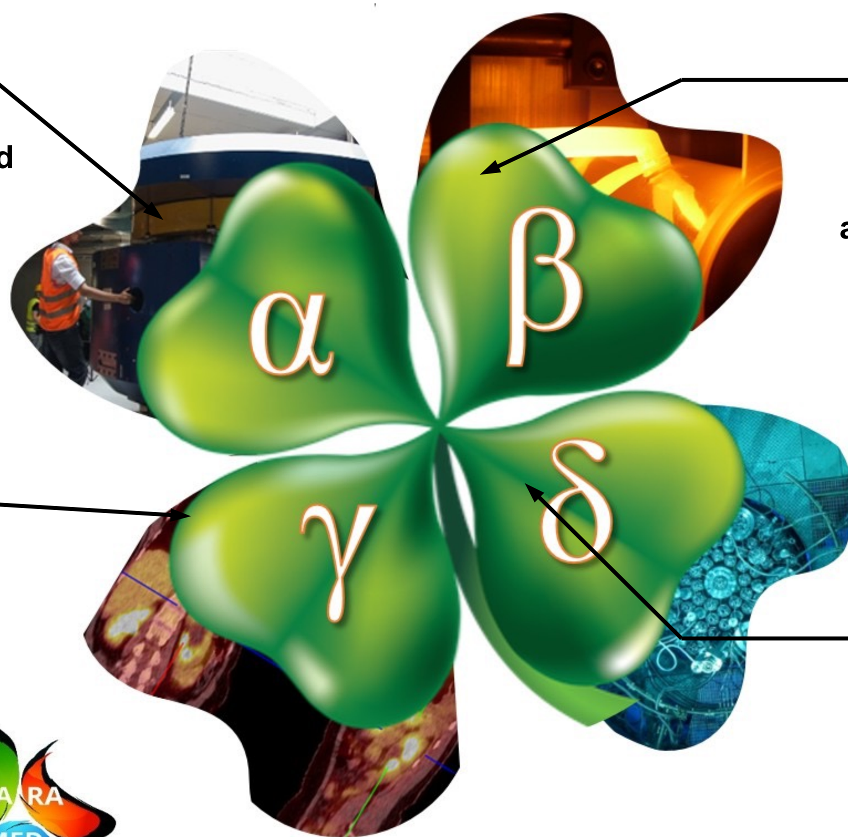
3 years.

The SPES Project

The SPES project (Selective Production of Exotic Species)

SPES-α
The cyclotron and related infrastructure

SPES-β
the ISOL facility and the acceleration of neutron-rich unstable nuclei



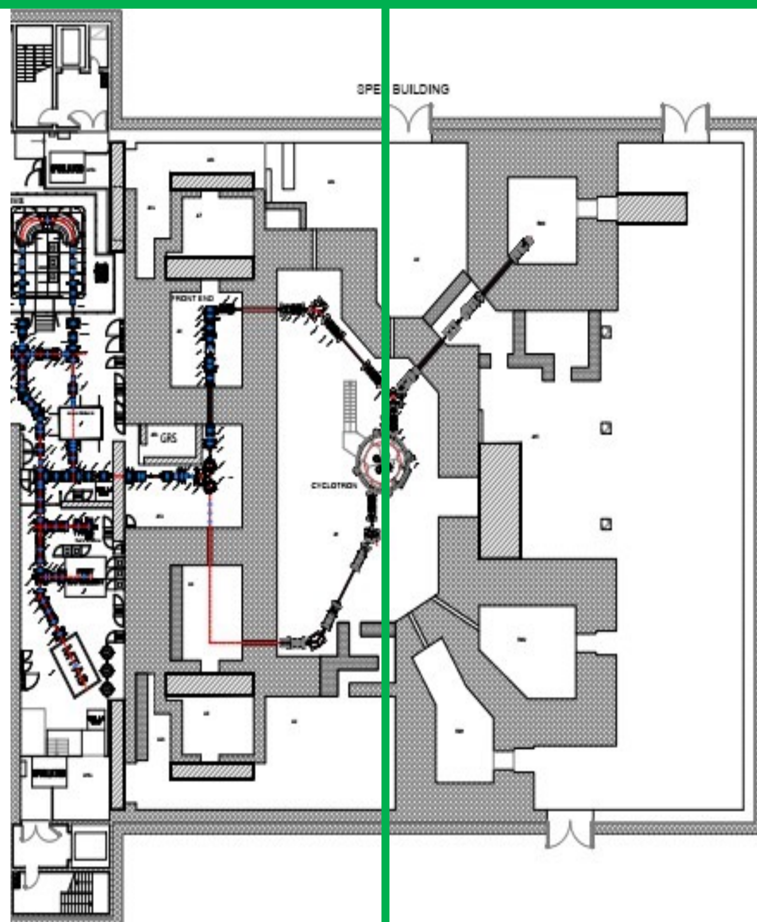
SPES-γ
The production of radionuclides for applications

ISOLPHARM
SPES exotic beams for medicine
& LARAMED

SPES-δ
The multidisciplinary neutron sources

SPES-γ: Production of radionuclides for applications.

Production of Medical-Radio-Isotope using ISOL technique



Direct production of Medical-Radio-Isotope using the Cyclotron

SPES-MED General goals

- Perform measurements of nuclear cross sections aiming at the optimization of medical radionuclides production, also using nuclear modelling tools to find out the best irradiation conditions;
- Provide a precise measurement of the ISOL production yields originating from SiC and TiC targets;
- Compare the produced data with the existing simulation libraries and/or reaction models, with the purpose of providing an experimental benchmark useful to improve the theoretical descriptions.

SPES-MED project

Sections: Pisa, LNL, Padova, Milano and Pavia 12.7 FTE

Financial support required over the three years is 322 keuro

The SPES_MED project is lead by the National Responsible (NR) and is organised in INFN divisions lead by a Local Responsible (LR), as described below:

- **NR & LR PI**: E. Mariotti
- **LR LNL:** G. Pupillo
- **LR MI:** S. Manenti
- **LR PD:** S. Moretto
- **LR PV:** A. Gandini

WP1: L. De Dominicis and M. Colucci
WP2: P. Delogu and A. Arzenton
WP3: F. Barbaro and L.Zangrando

SPES-MED: Scientific activity planning

WP1: Nuclear cross section measurements
WP2: ISOL yield measurements
WP3: Nuclear modelling and Monte Carlo simulations

		Year 1				Year 2				Year 3			
		M3	M6	M9	M12	M15	M18	M21	M24	M27	M30	M33	M36
	WP1 - Nuclear cross-section measurements												
MS1.1	Report on cross-section measurements at SPES	→			●								
MS1.2	Report on cross-section measurements at ARRONAX	→			●								
MS1.3	Report on cross-section measurements at SPES					→			●				
MS1.4	Report on cross-section measurements at ARRONAX, CAS and i-Themba					→			●				
MS1.5	Report on cross-section measurements at SPES									→			●
MS1.6	Report on cross-section measurements at ARRONAX, CAS and i-Themba									→			●
	WP2 - ISOL yield measurements												
MS2.1	Report on testing and refinement of IRIS and tape system	→			●								
MS2.2	Report on ISOL transport and ionization efficiencies measured with stable beams	→			●								
MS2.3	Report on resonant laser studies of Mg photo-ionisation schemes	→							●				
MS2.4	Report on yield measurements of Mg-28 and optimisation of SiC targets					→			●				
MS2.5	Report on resonant laser studies of Cr and Ag photo-ionisation schemes					→							●
MS2.6	Report on yield measurements of K-43 (and possibly Cr-51 and Ag-111) and optimisation of TiC targets									→			●
	WP3 - Models and simulations												
MS3.1	Report on cross-section, yields and purity modelling for Sc-47 production	→			●								
MS3.2	Report on cross-section, yields and purity modelling for Tb radioisotopes					→			●				
MS3.3	Report on cross-section, yield and purity modelling for Cu-67 (and possibly other theranostic nuclides)									→			●
MS3.4	Report on models and simulations for target release	→			●								
MS3.5	Report on models and simulations for photo-ionisation experiments	→							●				
MS3.6	Report on Monte Carlo simulations of ISOL in-target production					→							●
→	Activity started												
●	Milestone reached												

WP1: Nuclear cross section measurements

Main Goal: The measurement of unexplored nuclear reactions leading to the production of both the radionuclide of interest and its contaminants, aims to find out the best irradiation parameters for each specific case.

WP1: NUCLEAR REACTION OF INTERESTS

The main nuclear reactions of interest are listed below:

- $^{49}Ti(d,x)^{47}Sc$ up to 30 MeV, in collaboration with the ARRONAX facility (LNL team, 1 year);
- $^{68}Zn,^{70}Zn(p,x)^{67}Cu,^{64}Cu$ for proton beams with energy higher than 70 MeV, in collaboration with the I-Themba facility (LNL team, 1 and 2 year);
- $^{70}Zn(p,x)^{67}Cu,^{64}Cu$ in the energy range 25-50 MeV at SPES (LNL team, 3 year);
- $^{159}Tb(p,5n)^{155}Dy \rightarrow ^{155}Tb$ up to 70 MeV at SPES, also in the framework of the PRIN PNRR 2022 entitled “APHRODITE-155” and focused on ^{155}Tb production (LNL and MI team, 1 year);
- $^{nat}Eu(a,x)^{155}Tb$ in the energy range 10-30 MeV in collaboration with ARRONAX facility (1 year) and with Czech Nuclear Physics Institute CAS (1 and 2 year) (MI team);
- $^{nat}Gd(p,x)^{152},^{149}Tb$ in the energy range 40-70 MeV at SPES (LNL and MI team, 2 and 3 year) and at energies up to 200 MeV in collaboration with i-Themba facility (LNL and MI team, 2 and 3 year);
- $^{nat}Gd(a,x)152,^{155}Tb$ in the energy range 10-70 MeV in collaboration with ARRONAX facility (MI team, 1 and 2 year) and CAS (MI team, 2 and 3 year).

WP2: ISOL PRODUCTION YIELD MEASUREMENTS

Main Goal:
measure the ISOL production yield of relevant medical radionuclides and acquire in-depth understanding of the elements that can increase their production.

WP2: ISOL PRODUCTION YIELD MEASUREMENTS

This measurements will help to establish the yield database of the SPES facility, in particular:

- silicon carbide (SiC) targets, for the production of 28Mg;
- titanium carbide (TiC) targets, for the production of ^{43}K and, possibly, ^{51}Cr.

Further measurements will then allow to determine, for each element of interest, the two main factors affecting the global ISOL production yield, explicitly:

- the SPES target release efficiency;
- the best ion source technology and its efficiency.

ISOL PRODUCTION YIELD MEASUREMENTS @SPES_MED Padova

Based on the results attained before, SPES_MED intends to investigate further the dependence of isotope yields on experimental set-up and target characteristics with a novel detection system and the first exotic beams run by SPES.

The yield measurements will be realised with a dedicated spectroscopic system.

High Purity Germanium (HPGe) detector and more flexible inorganic scintillator detectors like LaBr3 and Lanthanum BromoChloride (LBC).

The selected detection system will be applied to quantify the activity of the produced radionuclides collected by the collection target handling station IRIS.

WP3: Nuclear modelling and Monte Carlo simulations

Main Goal

simulate high-purity radionuclide production for medical applications through nuclear reactions and examine different models for the nuclear reaction mechanisms analysis.

Cross Sections studies

- compute cross sections using nuclear reaction codes TALYS and/or EMPIRE
- optimize irradiation parameters
- compare simulation outcomes with experimental results
- Focus on contaminants' impact, dosimetric assessment (interdisciplinary)

In-Target production analysis

- employ Monte Carlo codes (MCNP, PHITS, FLUKA, Geant4) to simulate nuclear interactions
- interface these codes with nuclide evolution programs to simulate radioisotope formation and decay over time

Modeling and Monte Carlo Simulations @SPES_MED Padova

simulate **high-purity radionuclide** production for **medical applications** through **nuclear reactions**

examine different models for nuclear-reaction mechanisms analysis

studies on various radiological aspects (dosimetric impact, activation, etc)

Plan WP3 Padova

Production study of the theranostic 47Sc radionuclide ~2025
Subsequent investigations following the idea of a bilayer target, natV/enriched 50Ti,whose patent has been deposited in 2023 (L Canton, F Barbaro et al.). Improvement of optimization methods, based on genetic algorithms, for refining the reproduction of cross section data, relevant for production studies. Study of production routes using uncommon beams (d, α, he3, t).

The Terbium family: application on 155Tb, 152Tb productions ~2026
Investigations in collaboration with the team responsible for the target manufacture. Focus on the target thickness and calibration of irradiation parameters for thick-target 155Tb production at hospital cyclotrons. Model study of the Dy-Tb generator production method, which can be exploited at full energy of the SPES cyclotron.
Explorative study of 152Tb production with enriched Gd targets at SPES cyclotron

~2027:
Study 67Cu production and other promising radionuclides

PLAN & NEEDS

PLAN

To adapt the platform's computing capabilities to the specific requirements of SPES_MED (integration of TALYS, PHITS, etc)

Utilize the CloudVeneto ecosystem (CaaS and cloud resources) to create a scalable computing infrastructure

Needs

2 TB storage, 200 CPU/cores, 800GB RAM.

Request of 12k Eu contribution for a dedicated server to be integrated in CloudVeneto/INFN-Cloud infrastructure and managed by CloudVeneto administration team.

QUOTES AND REQUESTS @SPES-MED PADOVA

No requests for mechanical and electronic workshops

BUDGET PER YEAR

INFN Padova				
Equipment (inv)	12	0	0	12
Consumables	1	1	1	3
Travels	6	6	6	18
Publications	2	2	2	6
TOTAL PD	**21**	**9**	**9**	**39**

FTE @SPES-MED PADOVA

PADOVA GROUP

PD			
Name	**Expertise – Activity in the project**	**WP**	**FTE**
Sandra Moretto (PD local resp.)	Experimental physicist, associate professor	2	0.5
Marcello Lunardon	Experimental physicist, associate professor	2	0.2
Lisa Zangrando	Technologist	3	0.2
Daiyuan Chen	Physics PhD student at Padova University	2,3	1
Luciano Canton	Theoretical physicist, researcher	3	0.2
Laura De Nardo	Experimental physicist, researcher	3	0.2
Francesca Barbaro	Physicist	3	0.2
Yuliia Lashko	Theoretical physicist	3	0.1
Total PD FTE			2.6

ROLES AND RESPONSIBILITIES:
WP3 Leaders: Francesca Barbaro, Lisa Zangrando
Local Responsible PD: Sandra Moretto

Conclusions

- The SPES_MED collaboration accumulates data and expertise for the gamma phase of SPES.
- It assists in the commissioning of the LARAMED and ISOLPHARM lines.
- It improves spectroscopy models.
- It gathers novel experimental data.
- It fortifies the collaboration among nuclear physicists with a focus on medical applications.

Additionally, it fosters innovation and interdisciplinary research in nuclear and medical sciences.

BACKUP

The SPES_MED project

The SPES_MED project is lead by the National Responsible (NR) and is organised in INFN divisions lead by a Local Responsible (LR), as described below:

- **NR & LR PI**: E. Mariotti
- **LR LNL:** G. Pupillo
- **LR MI:** S. Manenti
- **LR PD:** S. Moretto
- **LR PV:** A. Gandini

WP1: L. De Dominicis and M. Colucci
WP2: P. Delogu and A. Arzenton
WP3: F. Barbaro and L.Zangrando

FTE

PI			
Name	**Expertise – Activity in the project**	**WP**	**FTE**
Emilio Mariotti (National and PI local resp.)	Experimental physicist, associate professor	2	0.8
Pasquale Delogu	Experimental physicist, associate professor	2	0.2
Alen Khanbekyan	Experimental physicist, researcher	2	0.2
Total PI FTE			1.2

LNL			
Name	**Expertise – Activity in the project**	**WP**	**FTE**
Gaia Pupillo (LNL local resp.)	Experimental physicist	1	0.5
Liliana Mou	Tecnhologist	1	0.3
Juan Esposito	Technology executive	1	0.2
Sara Cisternino	Technologist	1	0.2
Lucia De Dominicis	Experimental physicist	1	0.5
Daniele Scarpa	Electronical engineer, technologist	2	0.1
Alberto Andrighetto	Technology executive	2	0.2
Alberto Arzenton	Physicist	2,3	0.5
Davide Serafini	Physics PhD student at Siena University	2,3	1.0
Aurora Leso	Physics PhD student at Ferrara University	2,3	1.0
Omorjit Singh Khwairakpam	Experimental physicist, Post-Doc	2	0.1
Total LNL FTE			4.6

FTE

PD			
Name	**Expertise – Activity in the project**	**WP**	**FTE**
Sandra Moretto (PD local resp.)	Experimental physicist, associate professor	2	0.5
Marcello Lunardon	Experimental physicist, associate professor	2	0.2
Lisa Zangrando	Technologist	3	0.2
Daiyuan Chen	Physics PhD student at Padova University	2,3	1.0
Luciano Canton	Theoretical physicist, researcher	3	0.2
Laura De Nardo	Experimental physicist, researcher	3	0.2
Francesca Barbaro	Physicist	3	0.3
Yuliia Lashko	Theoretical physicist	3	0.3
Total PD FTE			2.9
MI			
Name	**Expertise – Activity in the project**	**WP**	**FTE**
Simone Manenti (MI local resp.)	Experimental physicist	1	0.5
Flavia Maria Groppi Garlandini	Experimental physicist, associate professor	1	0.4
Michele Colucci	Experimental physicist	1	0.3
Elisa Persico	Experimental physicist	1	0.5
Total MI FTE			1.7
PV			
Name	**Expertise – Activity in the project**	**WP**	**FTE**
Andrea Gandini (PV local resp.)	Chemist, technologist	2	0.5
Antonietta Donzella	Monte Carlo simulation, technologist	3	0.2
Giancarlo D'Agostino	Metrologist, researcher	2	0.3
Marco Di Luzio	Metrologist, researcher	2	0.3
Giorgio Grosso	Chemist, Post-Graduate	2	1.0
Total PV FTE			2.3
Total project FTE			12.7

Gantt and Milestones

		Year 1				Year 2				Year 3			
		M3	M6	M9	M12	M15	M18	M21	M24	M27	M30	M33	M36
	WP1 - Nuclear cross-section measurements												
MS1.1	Report on cross-section measurements at SPES	→			●								
MS1.2	Report on cross-section measurements at ARRONAX	→			●								
MS1.3	Report on cross-section measurements at SPES					→			●				
MS1.4	Report on cross-section measurements at ARRONAX, CAS and i-Themba					→			●				
MS1.5	Report on cross-section measurements at SPES									→			●
MS1.6	Report on cross-section measurements at ARRONAX, CAS and i-Themba									→			●
	WP2 - ISOL yield measurements												
MS2.1	Report on testing and refinement of IRIS and tape system	→			●								
MS2.2	Report on ISOL transport and ionization efficiencies measured with stable beams	→			●								
MS2.3	Report on resonant laser studies of Mg photo-ionisation schemes	→							●				
MS2.4	Report on yield measurements of Mg-28 and optimisation of SiC targets					→			●				
MS2.5	Report on resonant laser studies of Cr and Ag photo-ionisation schemes					→							●
MS2.6	Report on yield measurements of K-43 (and possibly Cr-51 and Ag-111) and optimisation of TiC targets									→			●
	WP3 - Models and simulations												
MS3.1	Report on cross-section, yields and purity modelling for Sc-47 production	→			●								
MS3.2	Report on cross-section, yields and purity modelling for Tb radioisotopes					→			●				
MS3.3	Report on cross-section, yield and purity modelling for Cu-67 (and possibly other theranostic nuclides)									→			●
MS3.4	Report on models and simulations for target release	→			●								
MS3.5	Report on models and simulations for photo-ionisation experiments	→							●				
MS3.6	Report on Monte Carlo simulations of ISOL in-target production					→							●
→	Activity started												
●	Milestone reached												

Budget (per WP)

		Year 1 [k€]	Year 2 [k€]	Year 3 [k€]	Total [k€]
	WP1 - Nuclear cross-section measurements (LNL, MI)				
EQUIPMENT (INV)	Electrodeposition system - LNL	3	0	0	3
CONSUMABLES	Enriched material (Zn-70, Zn-68) and custom clearance - LNL	20	0	0	20
	Consumables for experiments - LNL	4	4	4	12
	Targets and custom clearance - MI	20	5	0	25
	Maintenance - MI	2	2	2	6
	Radioactive transport - MI	8.5	8.5	8	25
TRAVELS	Travels for experimental activity and meetings - LNL	12	21	6	39
	Travels for experimental activity - MI	13.5	18.5	21	53
PUBLICATIONS	Publication fees - LNL	5	5	5	15
	Publication fees - MI	3	3	3	9
	TOTAL WP1	**91**	**67**	**49**	**207**
	WP2 - ISOL yield measurements (PI, LNL, PV, PD)				
EQUIPMENT (INV)	Computing machines - PI	3	0	0	3
	Computing machines - LNL	3	0	0	3
	Sigmatek modules - LNL	11	0	0	11
	Bosch profiles and accessories - LNL	3	0	0	3
	RS components - LNL	2	0	0	2
	Platform for IRIS maintenance - LNL	3	0	0	3
	Optical micrometer for INRiM - PV	6	0	0	6
CONSUMABLES	Laboratory equipment - PI	2	2	2	6
	Electrical components for IRIS - LNL	1	0	0	1
	Consumables for experiments - PD	1	1	1	3
TRAVELS	Travels for experimental activity and meetings - PI	2	5	5	12
	Travels for experimental activity and meetings - LNL	3	3	3	9
	Travels for experimental activity and meetings - PV	3	4	4	11
	Travels for experimental activity and meetings - PD	3	3	3	9
PUBLICATIONS	Publication fees - LNL	0	3	3	6
	TOTAL WP2	**46**	**21**	**21**	**88**
	WP3 - Models and simulations (PD, PV)				
EQUIPMENT (INV)	CloudVeneto server - PD (and PV)	12	0	0	12
TRAVELS	Travels for meetings and exchange collaborations - PD	3	3	3	9
PUBLICATIONS	Publication fees - PD	2	2	2	6
	TOTAL WP3	**17**	**5**	**5**	**27**
	TOTAL BUDGET	**154**	**93**	**75**	**322**

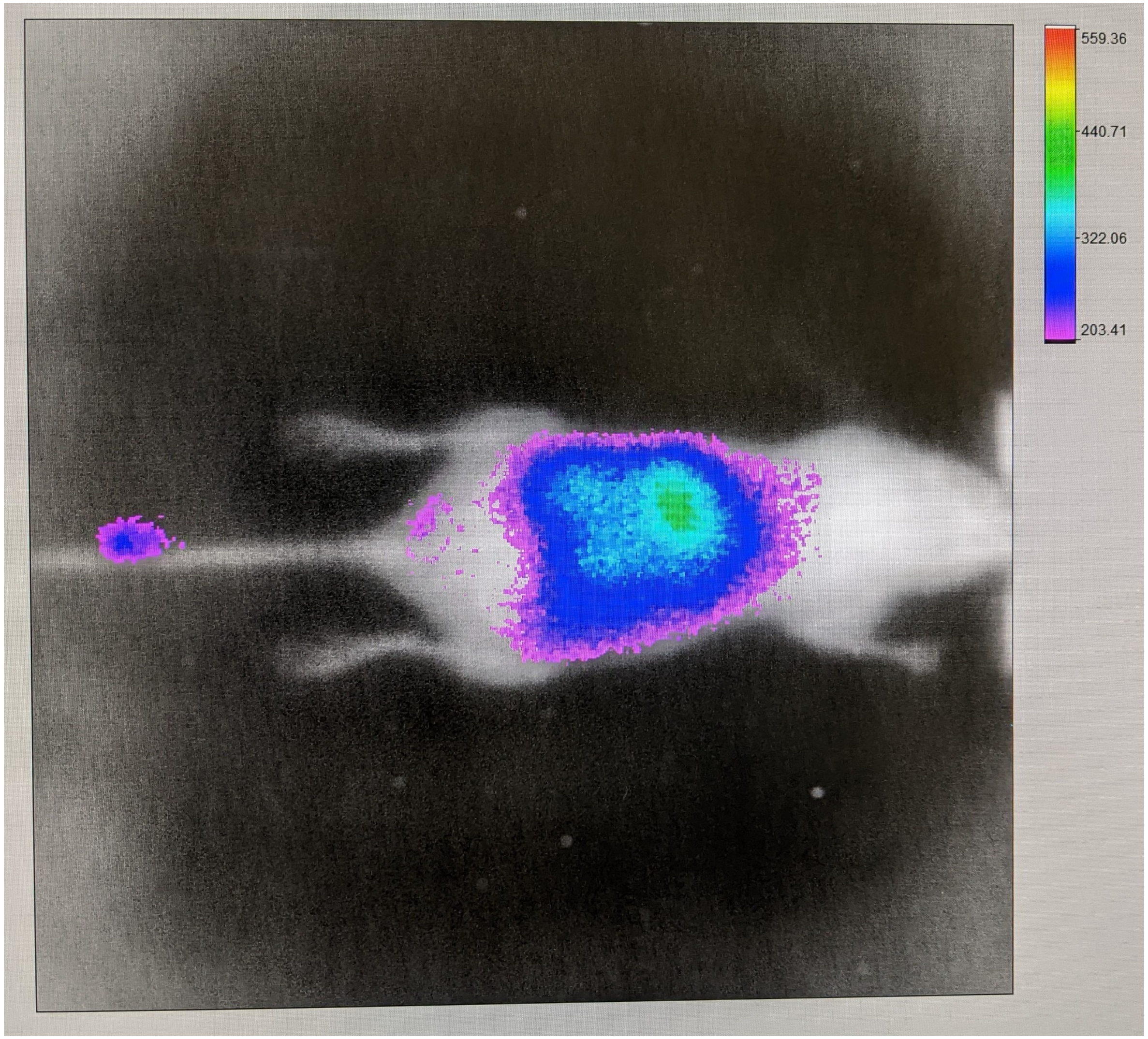
Budget (per year)

	Year 1	Year 2	Year 3	Total
	[k€]	[k€]	[k€]	[k€]
INFN Pisa				
Equipment (inv)	3	0	0	3
Consumables	2	2	2	6
Travels	2	5	5	12
TOTAL PI	**7**	**7**	**7**	**21**
INFN LNL				
Equipment (inv)	25	0	0	25
Consumables	25	4	4	33
Travels	15	24	9	48
Publications	5	8	8	21
TOTAL LNL	**70**	**36**	**21**	**127**
INFN Padova				
Equipment (inv)	12	0	0	12
Consumables	1	1	1	3
Travels	6	6	6	18
Publications	2	2	2	6
TOTAL PD	**21**	**9**	**9**	**39**
INFN Milano				
Equipment (inv)	0	0	0	0
Consumables	30.5	15.5	10	56
Travels	13.5	18.5	21	53
Publications	3	3	3	9
TOTAL MI	**47**	**37**	**34**	**118**
INFN Pavia				
Equipment (inv)	6	0	0	6
Consumables	0	0	0	0
Travels	3	4	4	11
TOTAL PV	**9**	**4**	**4**	**17**

Conclusioni

- La collaborazione SPES_MED porta a raccogliere dati e competenze per la fase gamma di SPES
- Dà un contributo nella messa in funzione della linee LARAMED e ISOLPHARM
- Permette un miglioramento dei modelli di spettroscopia
- Raccoglie dati sperimentali inediti
- Rafforza la collaborazione di fisici nucleari interessati anche alle applicazioni mediche

Grazie per l’attenzione!



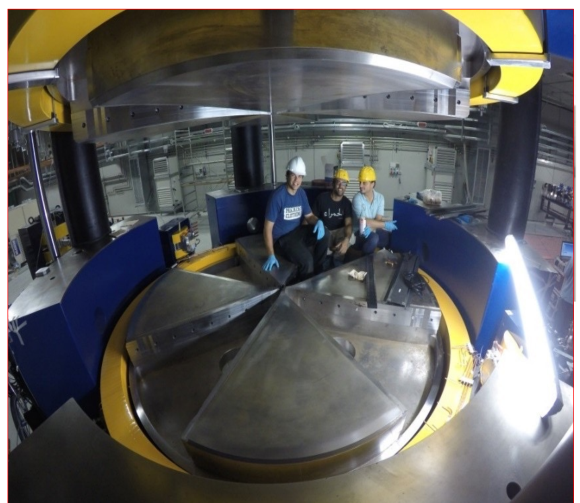
SPES-α: Acquisition of the cyclotron and construction of the infrastructure

High Power Cyclotron:

Several application at LNL

✓ Fundamental Research:

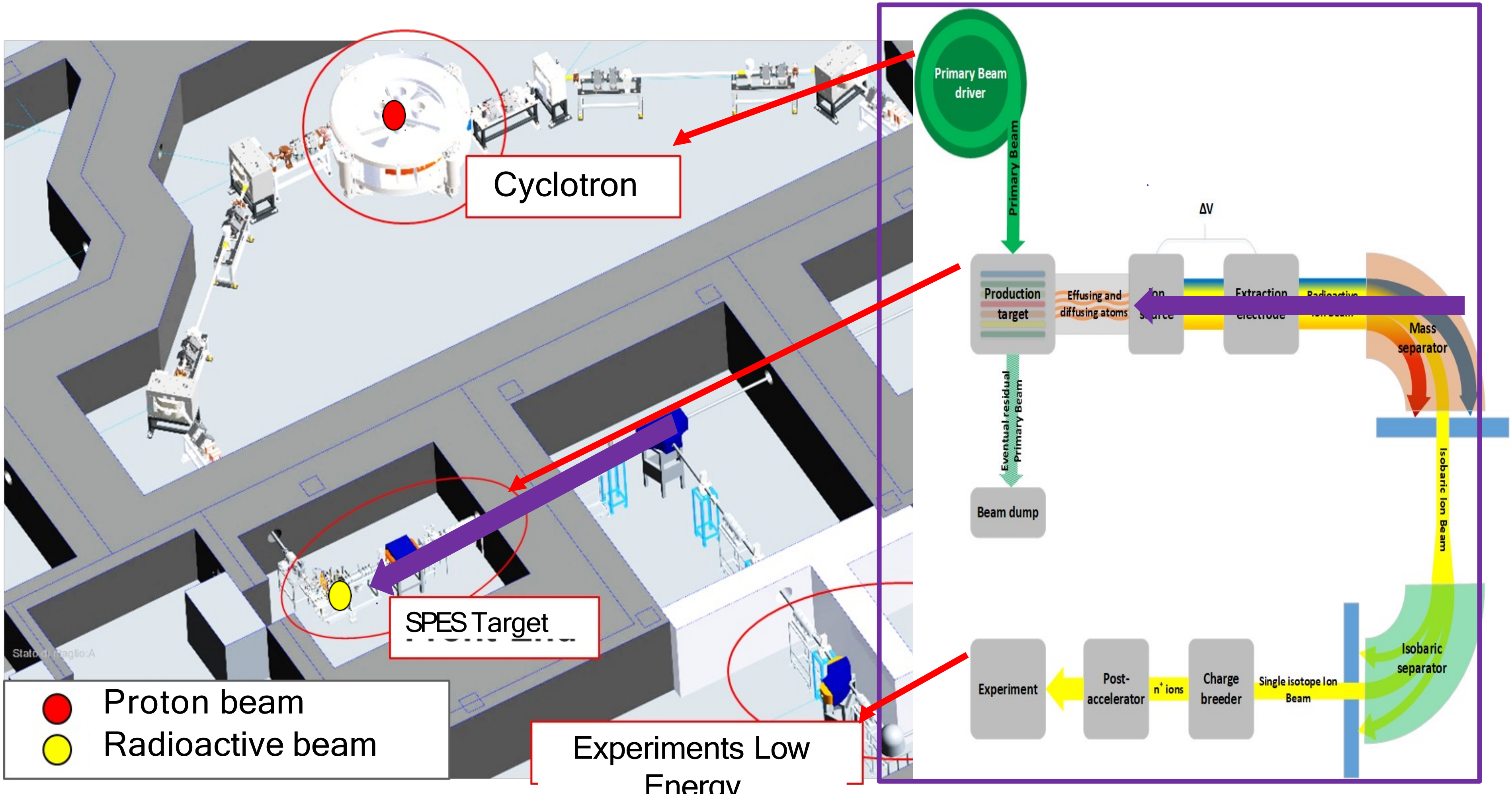
✓ Applied Research



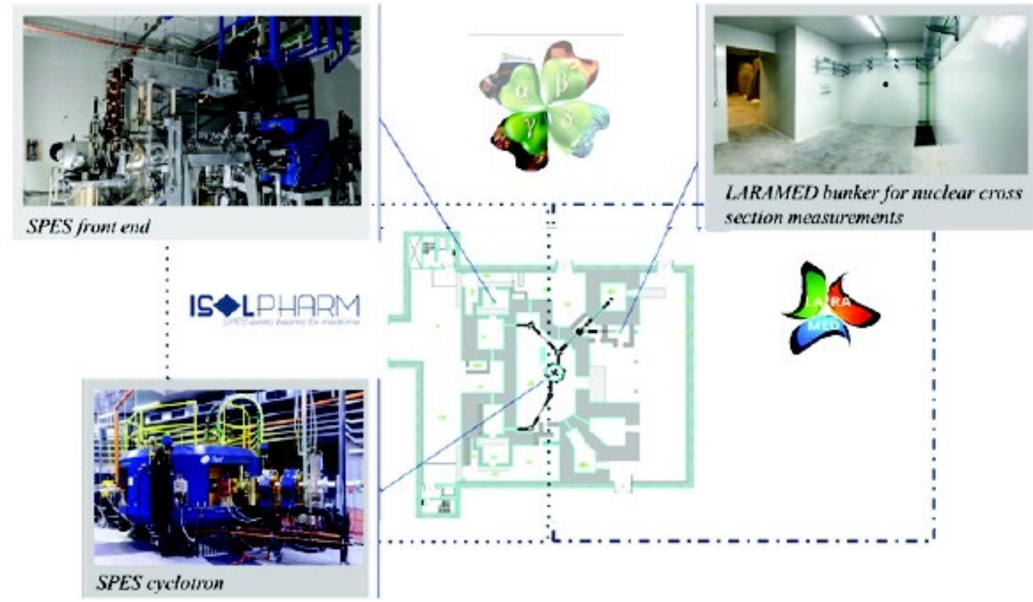
Main Parameters	
Accelerator type	Cyclotron AVF with 4 sectors, Resistive Magnet
Particle	Protons (H^- accelerated)
Energy range	35-70 MeV
Max Current Intensity	700 μA (variable within the range 1μA-700μA)
Extraction	Dual stripping extraction
Max Magnetic Field	1.6 T (Bo = 1 T)
RF System	nr. 2 delta cavities; harmonic mode=4; f_{RF} =56 MHz; 70 kV peak voltage; 50 kW RF power (2 RF amplifiers)
Ion Source	Multi-cusp volume H^- source; I_{ext} =8mA; V_{ext}=40 kV; axial injection
Dimensions	Φ=4.5 m, h=2 m, W=190 tons

SPES-β: creation of an ISOL facility and acceleration of neutron-rich unstable nuclei

ISOL: Isotope Separation On Line from Cyclotron through Target to Experiment

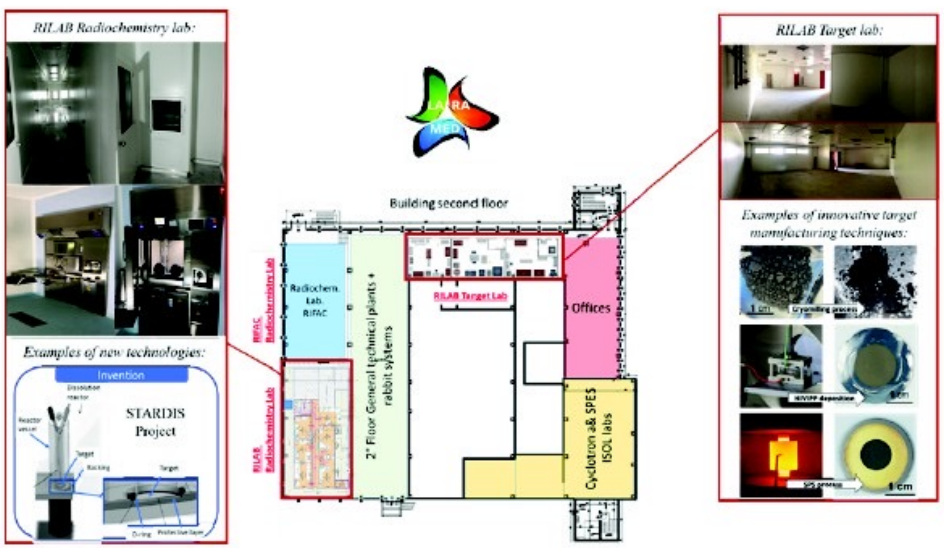


SPES-γ: Production of radionuclides for applications.



Two bunkers for irradiation:

- Measurement of nuclear cross-sections for proton beams <100nA
- Irradiation of high-intensity solid targets



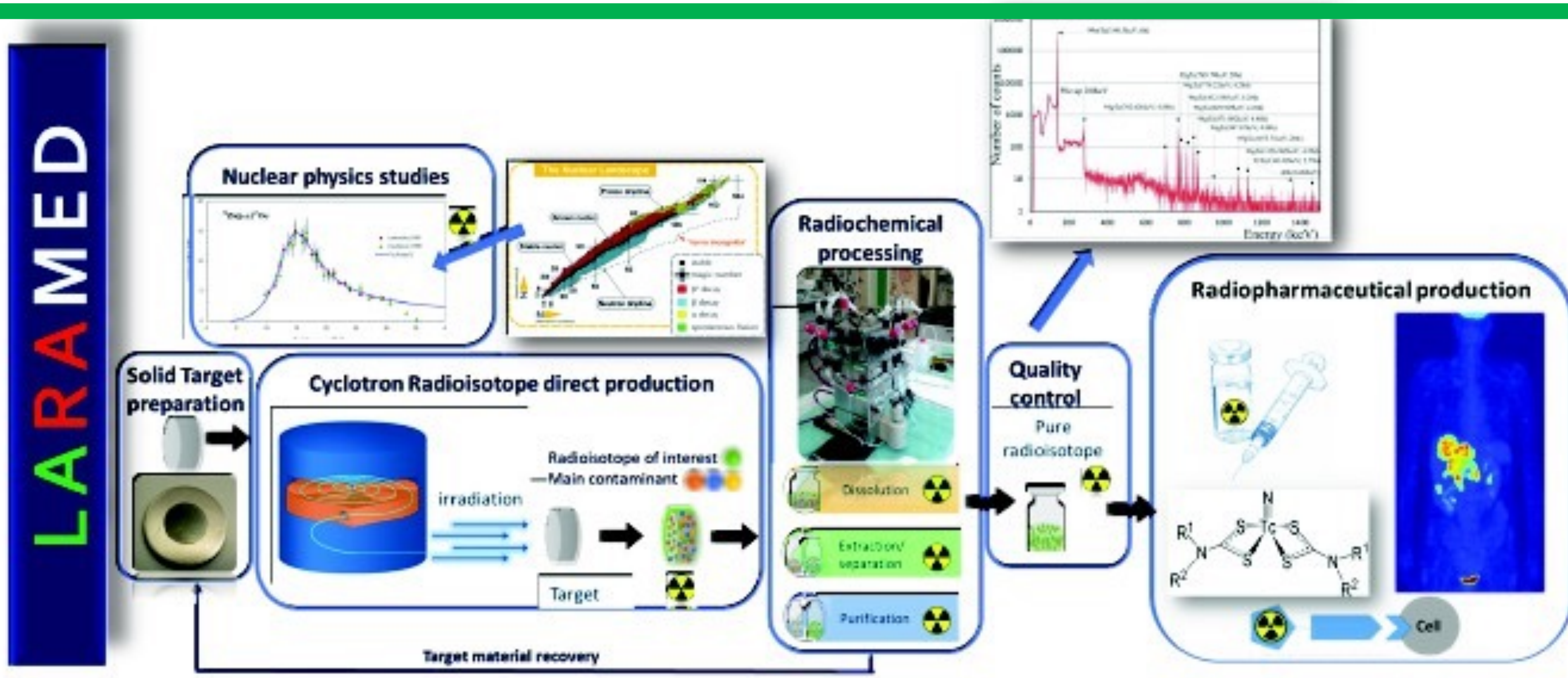
Two laboratories on the second floor:

- Target preparation
- Radiochemistry, R&D for production, separation/purification

SPES-γ: Production of radionuclides for applications

Target technology, fundamental nuclear physics, radiochemistry, radio-pharmacy, technological development, nuclear modelling, computational dosimetry

$^{64,67}Cu$ ^{47}Sc ^{52}Mn $^{149,152,155,161}Tb$

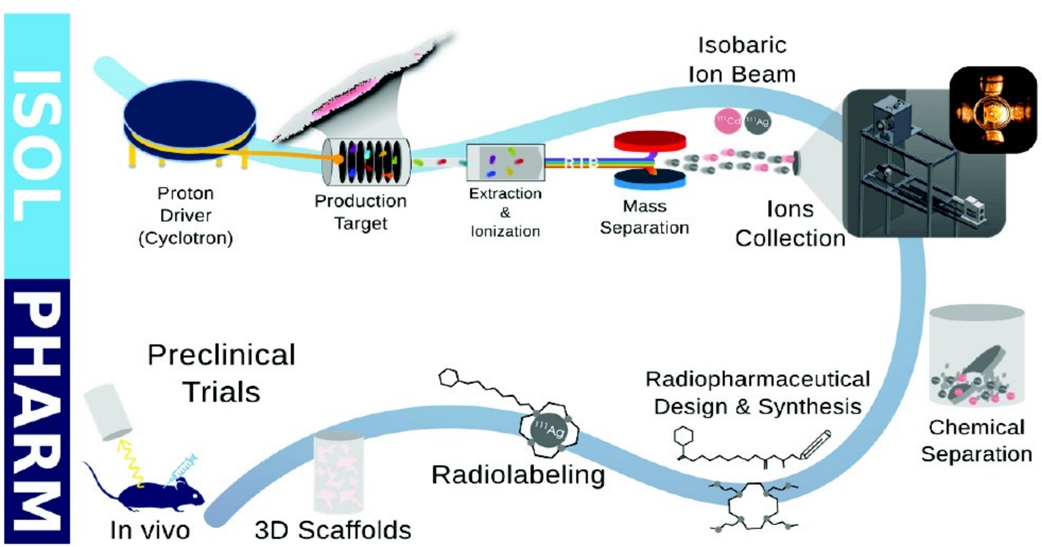


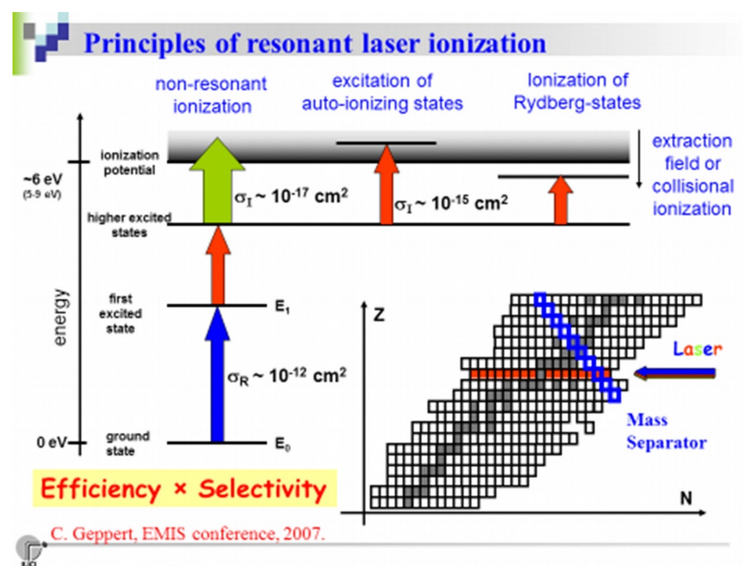
SPES-γ: Production of radionuclides for applications

International INFN patent

Excellent level of radioisotopic purity achievable. Inexpensive targets capable of populating various regions of the nuclide chart (10^{13} fissions/s @ 40 MeV, 200 μA proton beam, 60 isotopes with suitable half-lives and decay properties).

^{18}Mg, ^{43}K, ^{51}Cr, ^{111}Ag





MC simulations challenges and requirements

- **Complexity and resource demands:**

the simulations we aim to execute are inherently complex, highly time-consuming, and require significant CPU resources.

- **Diverse Monte Carlo codes:**

our simulations leverage a variety of MC/deterministic codes, including TALYS, EMPIRE, MCNP, PHITS, FLUKA, and Geant4.

- **Single-Threaded limitation:**

FLUKA and TALYS are designed to operate as single-threaded processes. This design prevents them from fully utilizing modern hardware capabilities, such as multi-core CPUs and GPUs, which significantly reduces simulation efficiency. These codes do not support parallelism.

- **An advanced computing architecture is needed for:**

A unified and user-friendly interface to define, build, configure, debug, monitor, and run simulations.

Efficient and scalable deployment and computation in a distributed environment, with fault tolerance to avoid outages and interruptions.

Distributing single-threaded tasks across multiple cores and nodes.

Real-time simulation diagnostics, including events produced, performance metrics, and estimated completion time

Evolution from past experience

Platform characteristics:

1) developed as a Kubernetes service and deployed on CloudVeneto's Container-as-a-Service (CaaS) production cluster

2) MC applications need to be containerized

3) initially designed to parallelize FLUKA and Geant4 simulations, extensible to support other required codes for SPES_MED

4) successful in various radiological aspects and In-Target production analysis for SPES and ISOLPHARM

5) significant reduction of execution time for highly computing-intensive and time-consuming MC simulations

Nuclear simulation for direct production

The importance of cross-section knowledge in radionuclide production

F Barbaro, L Canton, L De Nardo, Y Lashko, L Zangrando

Good modelling is crucial in the study and optimization of the production routes
When nuclear data are missing, it is possible to predict cross sections and quantify the theoretical model variability.
When nuclear data are available, we have developed a genetic algorithm approach to reproduce the cross section optimizing the model parameters.

Nuclear reaction mechanisms:
statistical evaporation
pre-equilibrium
direct collision

Model parameters:
level densities
excitons, FKK parameters
optical potentials

INFN PADOVA

Step-by-step production-route study

CROSS SECTION

Production rate

$$R = \frac{I_0}{z_{proj}\,|e|}\frac{N_A}{A}\int_{E_{out}}^{E_{in}} \sigma(E)\left(\frac{dE}{\rho_t\, dx}\right)^{-1} dE$$ stopping power

Bateman equations

$$\frac{dN_i}{dt} = R_i - \lambda_i N_i + \sum_{j<i} f_{ij}\lambda_j N_j$$ number of produced radionuclides

activities

$$A_i(t) = \lambda_i N_i(t)$$

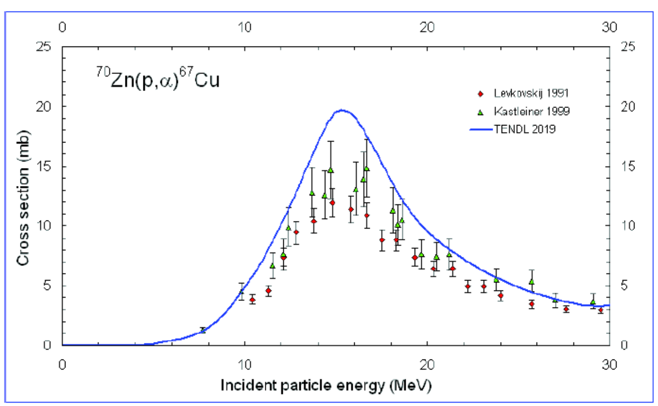
purities

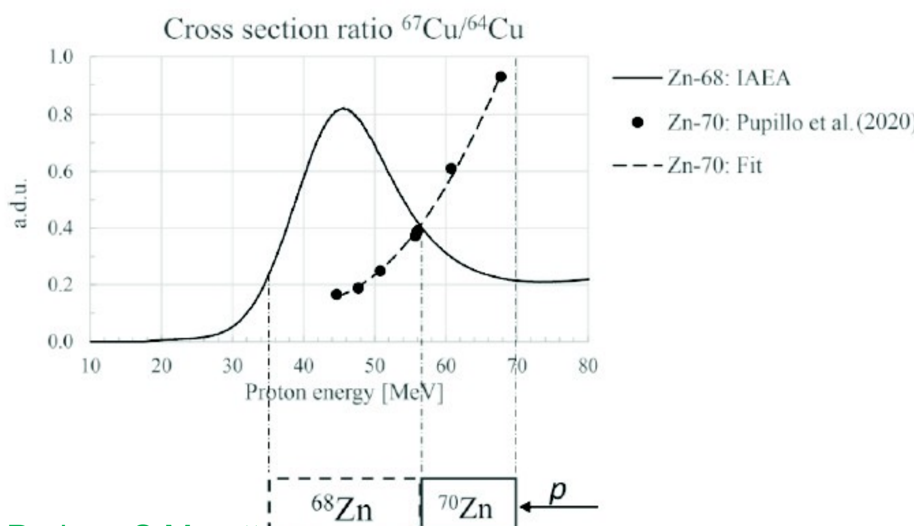
$$RNP(t) = \frac{A^{*}_{x}(t)}{\sum_i A^{i}_{x}(t)}$$ radionuclidic purity

+ dosimetric assessment

^{67}Cu, β⁻ (E_m = 141 keV) and γ (93 keV, 185 keV) emitter, for Targeted Radionuclide Therapy (TRT), Single-Photon Emission Computed Tomography (SPECT) imaging

	Half-Life	Main γ-ray Energy, Intensity (keV) (%)	Mean β⁺ Energy, Intensity (keV) (%)	Mean β⁻ Energy, Intensity (keV) (%)	Auger and IC Electrons
^{67}Cu	61.83 h	184.577 (48.7)	-	141 (100)	Yes
^{64}Cu	12.701 h	1345.77 (0.475)	278 (17.6)	191 (38.5)	Yes
^{61}Cu	3.336 h	282.956 (12.7) 656.008 (10.4)	500 (61)	-	Yes
^{60}Cu	23.7 m	826.4 (21.7) 1332.5 (88.0) 1791.6 (45.4)	970 (93)	-	Yes





^{47}Sc, β^- (E_m = 162 keV) and γ (159 keV) emitter, for therapeutic treatment, SPECT imaging, possibility to be paired with ^{44g}Sc and ^{43}Sc, β^+ emitters for PET imaging

Table 3. Main decay characteristics of ^{47}Sc, ^{44g}Sc, and ^{43}Sc radionuclides.

	Half-life	Main γ-ray energy, intensity (keV) (%)	Mean β^+ energy, intensity (keV) (%)	Mean β^- energy, intensity (keV) (%)	Auger and IC electrons
^{47}Sc	3.3492 d	159.381 (68.3)	-	162.0 (100)	Yes
^{44g}Sc	4.0420 h	1157.022 (99.8867)	630.2 (94.278)	-	Yes
^{43}Sc	3.891 h	372.9 (22.5)	476 (88.1)	-	Yes

isotopes of Tb

^{149}Tb, β^+ and α emitter, α radiotherapy and PET studies

^{152}Tb, β^+ emitter, PET Imaging

^{155}Tb, γ emitter, SPECT imaging

^{161}Tb, β^- e γ emitter

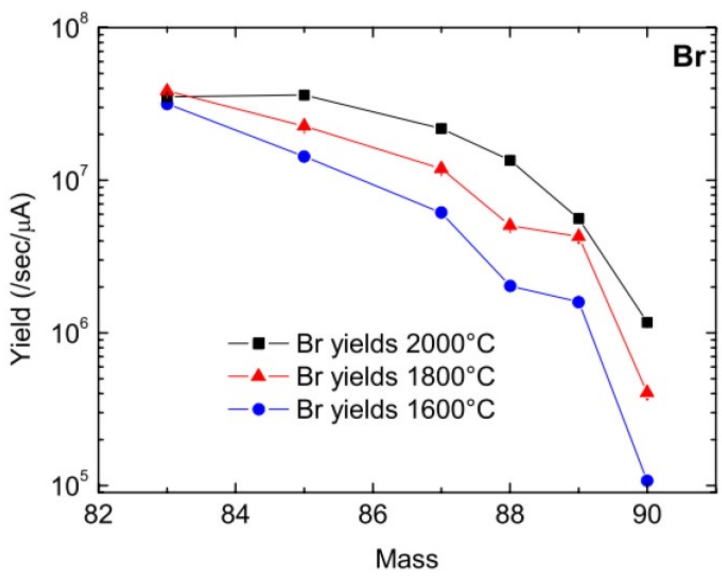
Table 4. Main decay characteristics of Tb isotopes suitable for medical applications (^{149}Tb, ^{152}Tb, ^{155}Tb, ^{161}Tb).

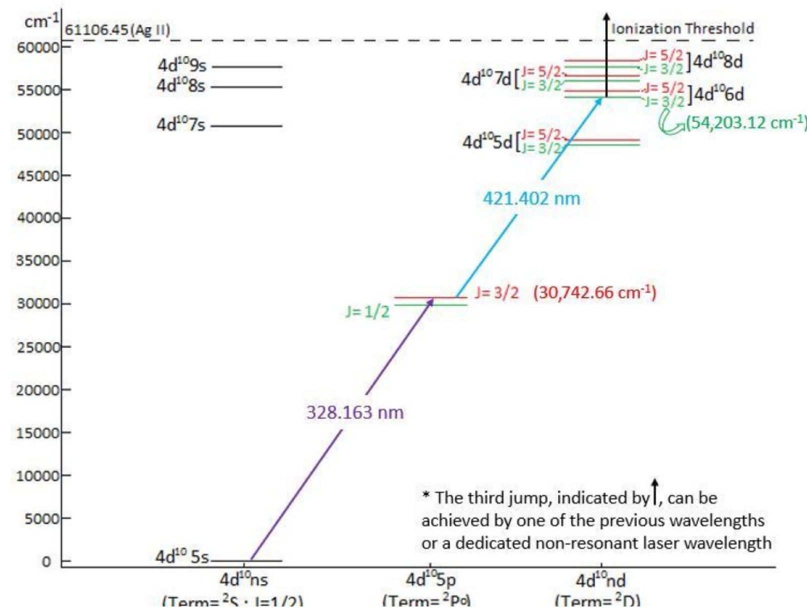
	Half-life	Main γ-ray energy, intensity (keV) (%)	Mean β^+ energy, intensity (keV) (%)	Mean β^- energy, intensity (keV) (%)	α energy, intensity (keV) (%)	Auger and IC electrons
^{149}Tb	4.1 h	352.24 (29.8), etc	720 (7.11)	-	3967 (16.7)	Yes
^{152}Tb	17.5 h	344.2785 (63.5), etc	1140 (20.3)	-	-	Yes
^{155}Tb	5.32 d	86.55 (32.0), etc	-	-	-	Yes
^{161}Tb	6.89 d	74.56669 (10.2)	-	154 (101)	-	Yes

WP2 (Leaders: A.Arzenton, P.Delogu)

Based on the results attained before, SPES_MED intends to investigate further the dependence of isotope yields on experimental set-up and target characteristics with a novel detection system and the first exotic beams run by SPES. The information obtained in this investigation will be useful for the rest of the CSN3 SPES users that will use the same targets to generate the RIBs.

$$Y = \sigma \Phi N \, \varepsilon_d \, \varepsilon_e \, \varepsilon_i \, \varepsilon_t$$

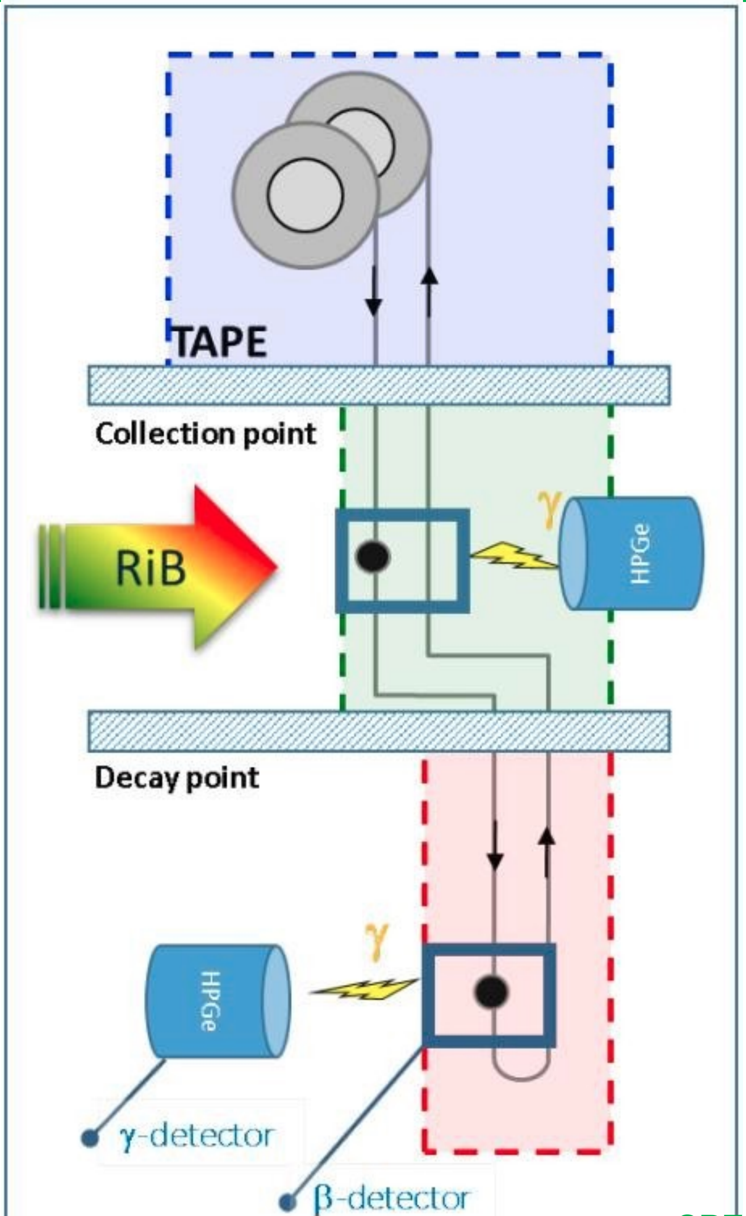




Half-lives, decay modes and ISOL production properties of the main radionuclides of medical interest attainable within the SPES_MED experiment.

	Half-life	Main γ-ray energy, intensity (keV) (%)	Mean β^- energy, intensity (keV) (%)	In-target production @ 40 MeV, 200 µA (nuclides/s)	Expected release efficiency	First ionisation potential (eV)
^{28}Mg	20.915 h	30.6383 (89), etc	156.0 (94.8)	5.0e7 (SiC)	very good	7.61
^{43}K	22.3 h	372.760 (86.2), etc	304.85 (90.9)	3.4e9 (TiC)	very good	4.32
^{51}Cr	27.704 d	320.0824 (9.91)	-	3.5e8 (TiC)	sufficient	6.74
^{111}Ag	7.45 d	342.13 (6.7), etc	360.4 (92)	6.1e8 (UCx) *	good	7.54

WP2



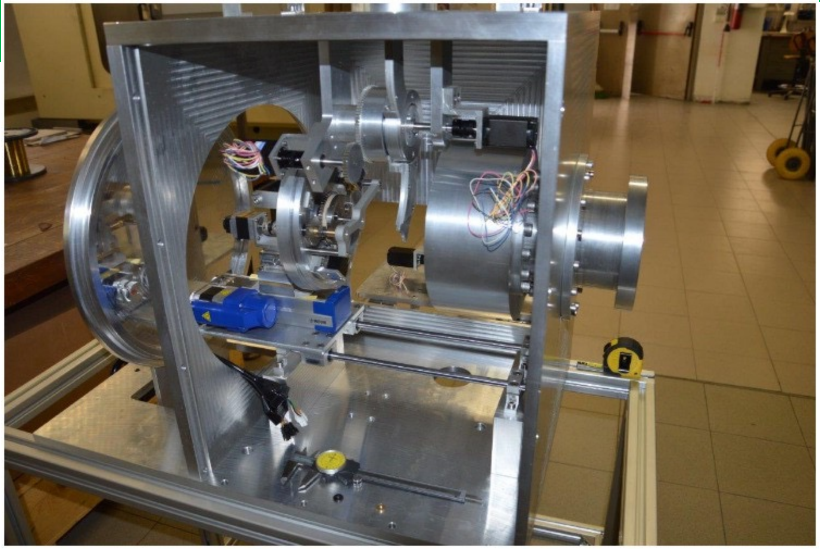
The SPES Tape Station (STS) comprises two germanium detectors model Reverse Electrode Coaxial (REGe) GR3021

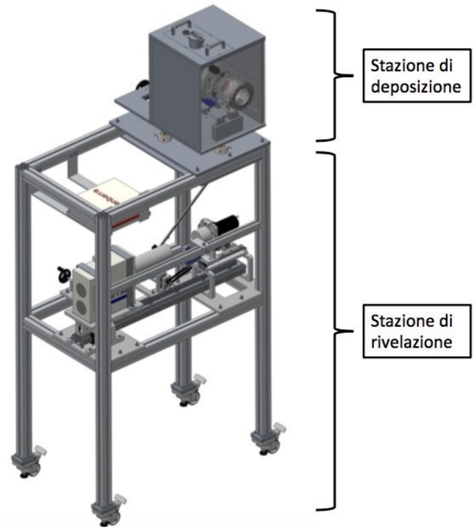
These are characterised by relative efficiency larger than 30%, FWHM of 2.1 keV at 1.3 MeV energy, peak to Compton ratio equal to 42 (IEEE Std 325-1996).

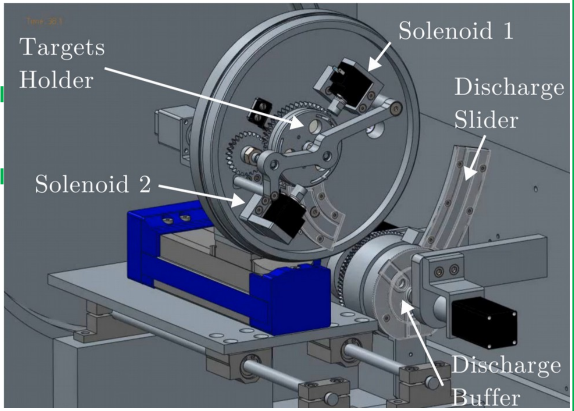
Another β detector is placed close to the decay point (as CERN-ISOLDE tape station, the β detector can be made of 23×23×3 mm3 plastic scintillators)

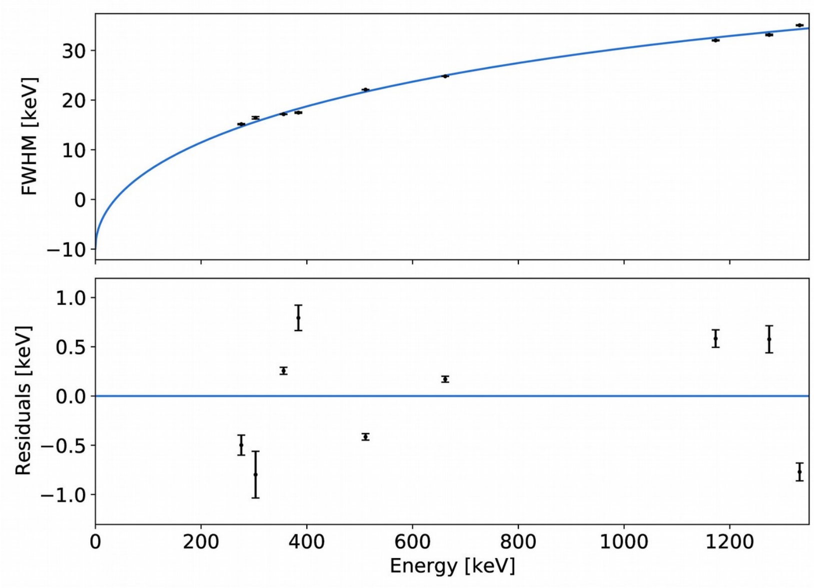
the germanium mounted in IRIS (Figure 4b) is a Broad Energy (BEGe) BE2020. The relative efficiency is typically larger than 9%, while the FWHM is 0.34 keV at 5.9 keV and 1.80 keV at 1.3 MeV.
it is mounted on a rack that allows placing the endcap of the detector with a distance between 100 and 1000 mm

WP2









LBC crystal: It has a fast anode signal (about 100 ns) and dead time effects are negligible below 50 kHz. It presents a cylindrical shape, with 1.5
inches diameter and 1.5 inches height,
On the same rack, it can be moved between 100 to 1000 mm

WP3: Modelling and MonteCarlo Simulations

Main goal: simulate high-purity radionuclide production for medical applications through nuclear reactions and examine different models for the nuclear reaction mechanisms analysis.

● **Cross sections studies:** cross sections will be computed using codes such as TALYS or EMPIRE, and different models will be considered for the analysis, with the main objective of optimising the irradiation parameters. The simulations' outcomes will then be compared with experimental results.
A collaboration with experimentalists and medical physicists will guide measurements and
dosimetric assessments, particularly focusing on the impact of contaminants.
● **In-target production analysis:** different Monte Carlo codes (MCNP, PHITS, FLUKA, and Geant4) will be employed to precisely simulate the nuclear interactions. To simulate the radioisotope formation and decay at different times during the irradiation period and in the following cooling phase, the aforementioned codes have to interface with nuclide evolution programs.