Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Legnaro

Alpha DTL beta

LNL-GruppoV- 12/03/2024

Abstract

Alpha-DTL is a **high perfomance linac for radioisotope** production.

The approach of using alpha particles beams may allow to yield radionuclides hard to be obtained with more traditional nuclear reactors or by proton accelerators, by exploiting new reaction routes. This approach may lead to better radionuclide impurity profiles, simplifying the radiochemical separation and purification process.

From the accelerator point of view, the use of cyclotron for α particles has an intensity limitation (mainly related to the extraction system): the IBA cyclotron at Arronax is for example limited to 35 microA .

The key idea of the alpha-DTL is to use **a high duty cycle linac (ECRIS, RFQ, DTL),** able to accelerate an **average current of 0.5 mA** alpha beam from few to 40 MeV, to cover the cross sections of many interesting reactions for radionuclides. **The energy at the exit of the DTL will be regulated** by a particular use of the stabilization system (Post couplers) of the DTL cavity.

The goal of the present experiment “alpha-DTL_beta” is to address the **R&D activities recognized as critical** during the evaluation of the “alpha-DTL” call and solve the feasibility of the accelerator for a future design report of the complete facility.

A full description of the scientific case can be found in the alpha-DTL call documentation, listed in the references and available to the referees, while in the next pages we will recall just for convenience the main accelerator aspects, then we will describe the project organization and the risk analysis.

This experiment will benefit from experiences and well-developed tools of the previous high intensity linac projects realized by the participants (ESS, TRASCO, IFMIF EVEDA).

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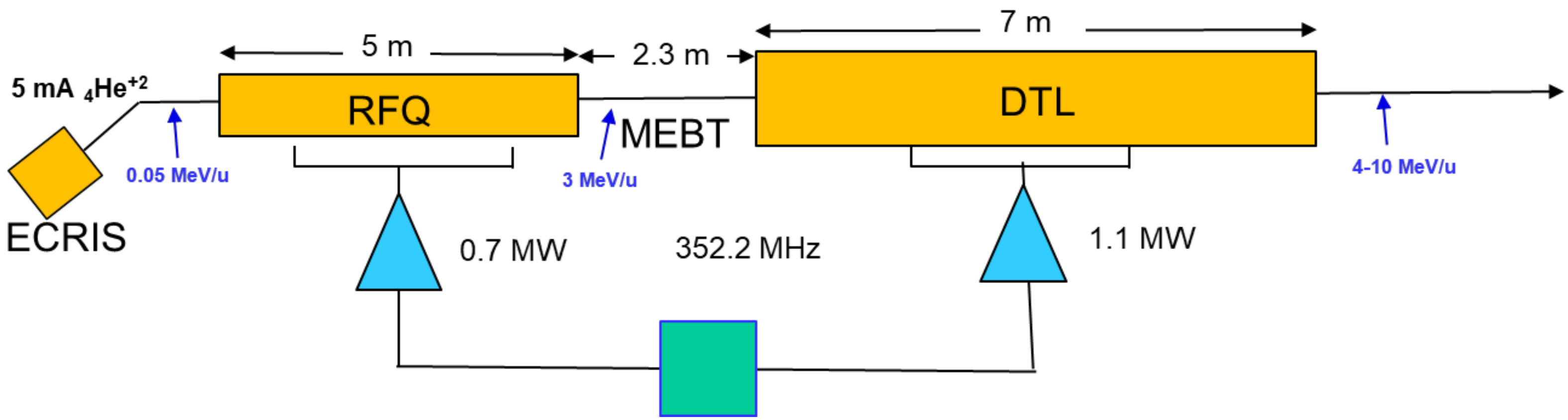
Linac general scheme

The key idea of the alpha-DTL is to use a high duty cycle linac (ECRIS, RFQ, DTL), able to accelerate an average current of 0.5 mA alpha beam from few to 40 MeV, to cover the cross sections of many interesting reactions for radionuclides. **The energy at the exit of the DTL will be regulated by a particular use of the stabilization system (Post couplers) of the DTL cavity**. An average of 0.5 mA of fully stripped He can be delivered to the target.

The starting points:

- ECRIS studies →AISHA source of LNS.
- RFQ→ TRASCO RFQ
- DTL→ ESS.
- RF system→ two klystrons-single modulator architecture is the same of ESS normal conducting section. To be used at ½ peak power and twice duty cycle.



Reference accelerator design

Table summarize the main parameters of the reference linac. The frequency is 352 MHz. The RFQ will end at 3 MeV/u, the DTL at 10 MeV/u. The total lengh of the linac will be around 15 m. It is important to highlight here that a criticality is **the demonstration of the starting beam parameters: the intensity goal of 5 mA within 0.2 mm.mrad normalized r.m.s. emittance is possible but challenging**.

Parameter	Symbol, unit	RFQ Value	DTL Value
Frequency	f [MHz]	352.21	352.21
Peak Current	**I_p [mA]**	**5**	**5**
Ion		$^4He^{2+}$	$^4He^{2+}$
Duty Cycle	**D.C. [%]**	**10**	**10**
Input / Output Energy	E_{in}/E_{out} [MeV/u]	0.05/3.0	3.0/10.125
Resonator length	L [m], λ	4.99, 5.874	6.8, 8.0
Maximum surface field	K_p	1.85	1.6
Transmission WB, Gaussian	[%]	92.5, 88.9	100, 100
Transverse Emittance in/out	$\varepsilon_{in,n,x,rms}/\varepsilon_{out,n,x,rms}$ [mm mrad]	0.2/0.17	0.24 /0.24
Longitudinal Emittance	$\varepsilon_{l,rms}$ [deg MeV/u]	0.129	0.15
Min and Max Voltage	V_{GB}, V_{acc} [kV]	68, 102.5	-
Average Acc. Field	E_0[MV/m]	-	2.6
Quadrupoles Gradient	G_{max}, G_{min} [T/m]	-	57.6, 41
Quadrupoles Length	PMQ length [mm]	-	50
Average Aperture	$R_{0,GB}$ $R_{0,ACC}$ [mm]	2.55, 4.13	-
Quadrupoles Bore	Rbore [mm]	-	10
dissipated Power and beam loading (peak)	**Pd, Pb [kW]**	**672, 29.5**	**1020, 70**

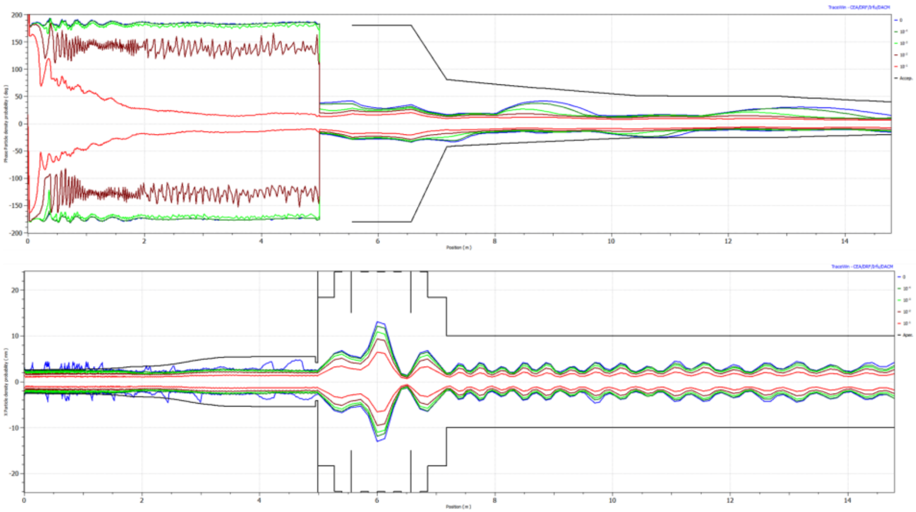


Fig. 5: Start to End simulation from the begin of RFQ to the end of DTL.

DTL energy regulation

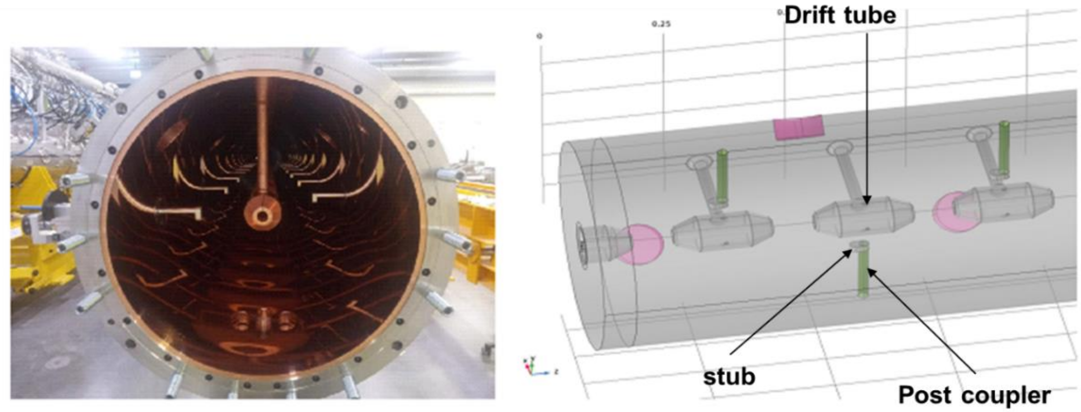
Alpha-DTL is equipped with a **set of post couplers terminated by stubs**, to stabilize and flatten the accelerating field E0.

Modest perturbations to the symmetry of the Post-Coupler/Drift-Tube geometry can introduce few per cent cell-to-cell changes in the fields across the post coupler.

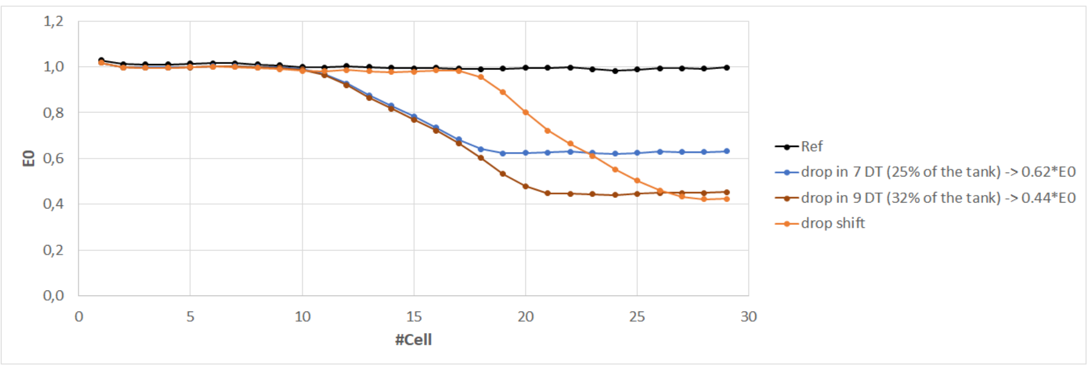
Several such perturbations on adjacent post couplers can introduce a sizable reduction in the fields over the region of a few cells.

Such steps in the fields can be used to drop the beam out of synchronism with the accelerating fields and provide a variable-energy capability for the single-tank, post-coupled DTL.

The max output energy will correspond to fully flat field over all the DTL gaps. The creation of the field step in different points of the DTL will provide different output energies.



DTL cavity inner view and 3d simulation model. Post couplers with stubs are visible



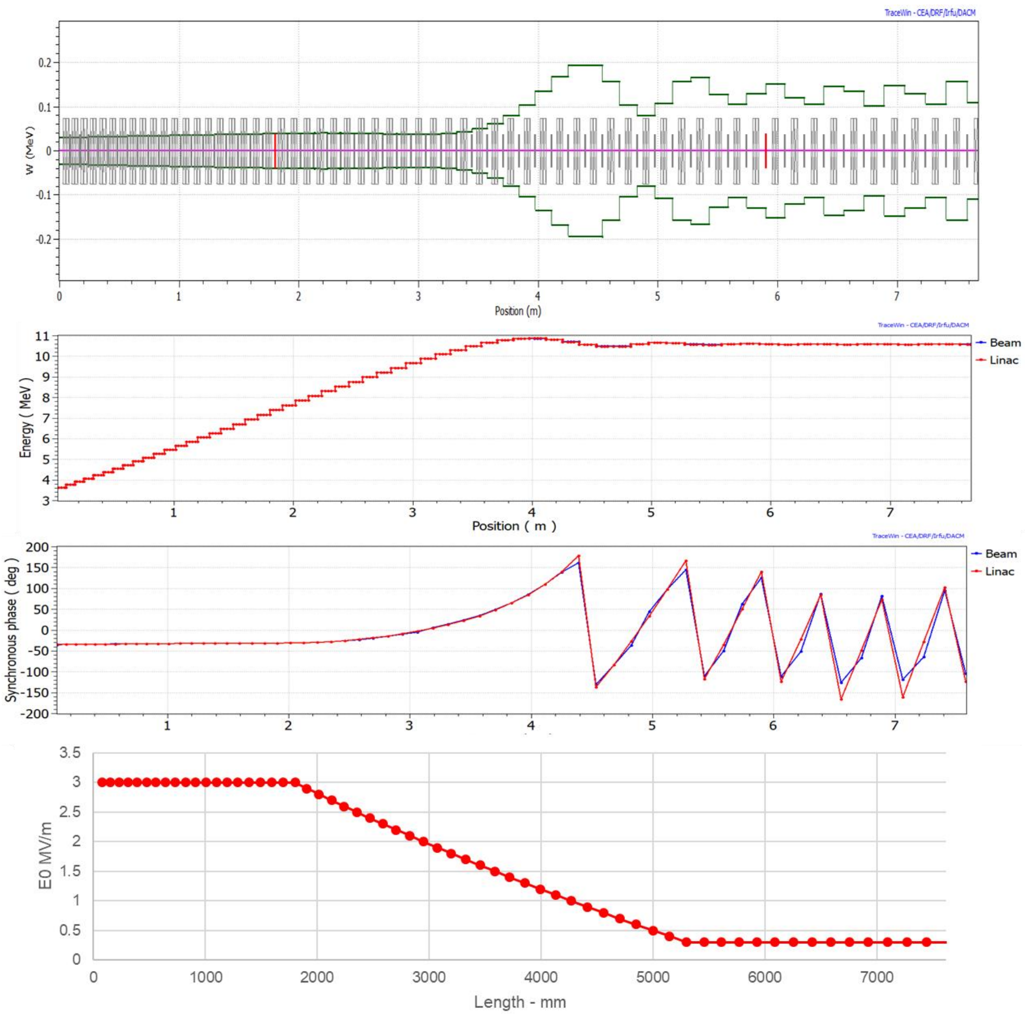
Field steps experimentally obtained by post coupler rotation in ESS-DTL3

Roughly $k(n)*E0(n)=k(n+1)*E0(n+1)$

BD energy regulation: loose of synchronism

Particles in the ramped gaps start to loose synchronism, up to not being accelerated anymore.
The focusing given by the PMQs guarantees full transmission of the beam to the end of the DTL.

Increasing the number of Post Coupler per meter as well as the dimension of the stub, it will improve the capability of obtaining a sharper edge on the field. This condition will preserve the beam quality and the energy spread.



Maybe in the future of LNL?

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A Andrea Pisent

Cc Enrico Fagotti, francesco grespan

Rispondi | Rispondi a tutti | Inoltra | Archivia | Indesiderata | Elimina | Altro

16/02/2024, 16:4

Re: brainstorming of today

Very useful number to keep in mind..
Grazie

Faical

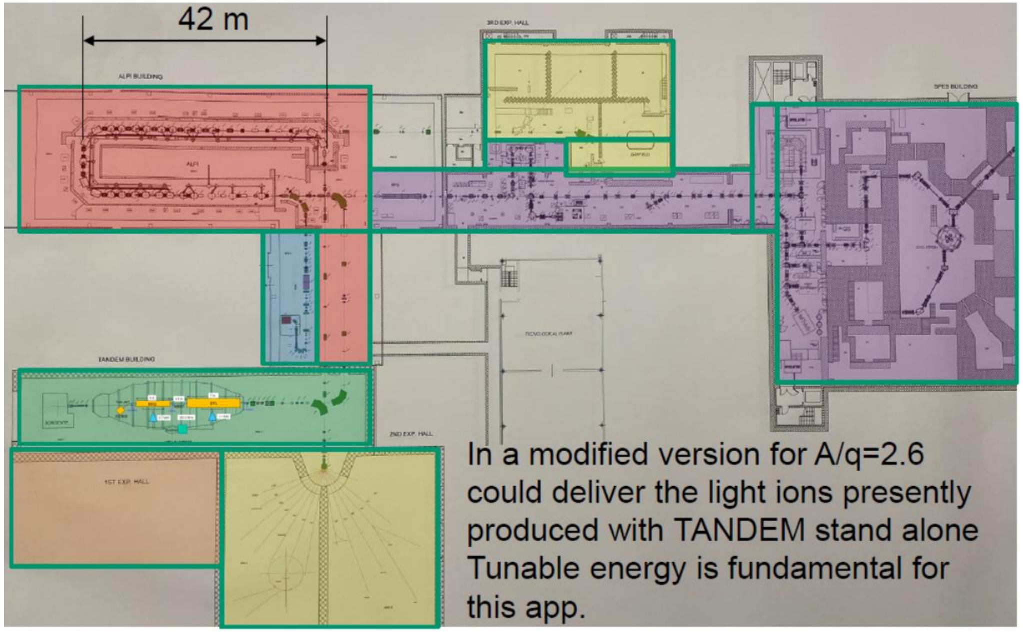
From: Andrea Pisent <andrea.pisent@lnl.infn.it>
Sent: Thursday, February 15, 2024 8:15 PM
To: Faical Azaiez <faical.azaiez@lnl.infn.it>
Cc: Enrico Fagotti <Enrico.Fagotti@lnl.infn.it>; francesco grespan <Francesco.Grespan@lnl.infn.it>
Subject: brainstorming of today

Dear all

just as complementary information of tbe brain stroming of today, our reference number for thermal neutron flux in BNCT is 10^9 neutron/s (on an aperture of approximately 20 cm^2). We use 30 mA 5 MeV protons on a be target, but 10 or 20 MeV is more efficient and now we have the DTL that we think we can realize with variable final energy. As a provocative transparence last year we produced a possible replacement of target for light ions.....the RF linac is much smaller than target of course, with a lot of space for additional schielding.

Have a nice evening Andrea

field
ex



Experimental Halls

ALPI

TANDEM=>DTL

SPES

PIAVE

W_{max} (10 MeV/u)

^{13}C 120 MeV
^{7}Li 70 MeV
H 10 MeV
^{18}O 180 MeV
^{10}B 100 MeV
^{15}N 150 MeV

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WP1 Post Coupler R&D

People: Marco Nenni (INFN-To), Luigi Ferrari (INFN-LNL), Andrea Pisent (INFN-LNL)

Program

- Design and develop the **motor system and the remote control to rotate the post couplers in vacuum** and in high RF power conditions. In particular Post coupler shall be water cooled.
- Production of the motorized post coupler.
- Test the post coupler movement in a vacuum chamber.

Budget

The cost includes the material, bellows, motor and actuator, the production and test. It is based on the budget of similar equipment for the ESS-DTL project (movable tuners).

Activity: Design of the rotable post coupler.

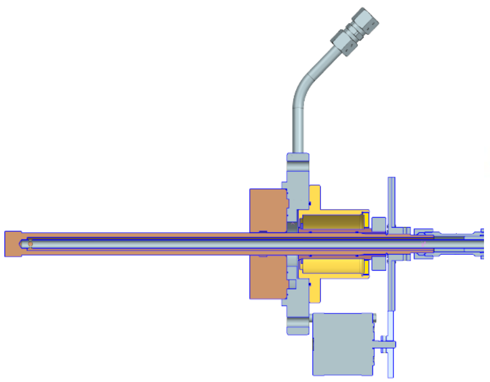
After evaluating different options we decided to use the ferrofluidic technology.

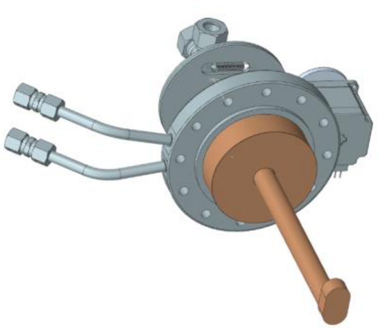
One design has been developed with FERROTEC which will provide the complete assembly, including motor.

A second design has been designed by the INFN team, based on another product procured by kurt-lesker, with mechanical part in production at INFN-LNL.

Orders have been placed in 2023. You can see the attached pictures and models.

WP1	**Movable Post coupler prototyping**		
MS# or DLV#	Description	Months from T0	
MS2.1.a	Mech. Design of motorized post coupler	6	100
MS2.1.b	Production of 1 motorized post coupler and vacuum chamber	18	30
MS2.1.c	Test in vacuum of 1 motorized post coupler	24	0
DLV2.1	Report of test in vacuum of a motorized PC	24	0





WP2 RF system R&D

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People: Francesco Grespan (INFN-LNL),

Program

The activities of this task want to demonstrate the **applicability of the ESS high power RF System to the alpha-LINAC** requirements in terms of Output power, repetition rate, pulse length, electrical efficiency. This task will involve for 2 years 2 RF technologist.

Budget

For the travels and the meetings with ESS staff, it will be harmonized in the activities to be done in Lund for ESS-DTL installation and commissioning.

The **technical design of the modulator will be outsourced**, since there is not internal expertise in the group.

Activity RF system design.

In collaboration with ESS RF team the table of specifications for the modulator have been decided, based on the rescaling of the parameters of ESS modulators and klystrons. The attached files include a table with the specs. To be submitted to a specialised company for the preliminary design in 2024.

We would like to keep as much as possible the solution of ESS, in particulare we are looking for a single voltage modulator, serving 2 klystrons with different output power.

If we want to keep the present ESS klystron, the optimization of the voltage is roughly derived from the following calculations:

- PRF=1.5 MW
- PDC=1.5MW/(50% efficiency)=3MW
- K=1.3e-6 perveance of the klystron electron gun
- Klystron current I=kV^3/2 (it is the klystron gun which determine the current request to the modulator)
- PDC=IV=kV^5/2
- **V=(P/k)^2/5=89kV**

WP2	RF system development		
MS# or DLV#	**Description**	**Months from T0**	**%**
MS2.2.a	Set up development program with ESS-RF group	6	100
MS2.2.b	Technical specifications of a modulator and RF system compliant with alpha-Linac requirements	15	100
DLV2.2	**Preliminary Design of Modulator and RF system for apha-DTL**	24	0

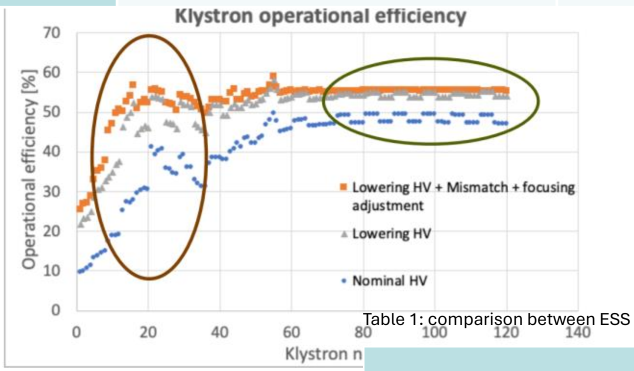

Table 1: comparison between ESS and alpha RF power needs.

	Alpha	ESS
PRFQ, peak (1.2margin) kW	850	2900
PDTL, peak (1.2 margin) kW	1320	2900
Pmodulator, Pulse (50% eff. RF/DC) MW	5	11
Rep.Rate Hz	50	14
Pulse ms	2	3.2
DC%	10	4.5

Riassunto anagrafica e bilancio

Person	Activity	Structure	WP	2023	2024	totale	p-month
Francesco Grespan (National Responsible)	RF system development	LNL	2	0.2	0.2	0.4	4.8
Andrea Pisent	movable post coupler design	LNL	1	0.1	0.1	0.2	2.4
Alessio Galata	Ion source	LNL	3	0.1	0.1	0.2	2.4
Luca Bellan	Ion source	LNL	3	0.1	0.1	0.2	2.4
Luigi Ferrari	movable post coupler design	LNL	1	0.2	0.2	0.4	4.8
Antonio Palmieri	RF system development	LNL	2	0.1	0.1	0.2	2.4
Ornella Leonardi	Ion source	LNS	3	0.1	0.1	0.2	2.4
Luigi Celona	Ion source	LNS	3	0.1	0.1	0.2	2.4
Marco Nenni	movable post coupler design	To	1	0.2	0.2	0.4	4.8
				1.2	1.2	totale	24

2023	LNL	TO	LNS
WP1	0.3	0.2	0
WP2	0.3	0	0
WP3	0.2	0	0.2
Tot	1.2		

Sigla Loc.	Capitolo	Note Alla Richiesta	Rich. 2023	Assegn. 2023	Rich. 2024
LNL	MISS	Experiment at AISHA LNS	10.0	5.0	5
		Totale MISS	10.0	5.0	5.0
	CON	Motorized post coupler mech. design	5.0	5.0	0
		Test motorized PC in vacuum chamber	0	0	10.0
		Experiment at AISHA LNS	5.0	5.0	5.0
		Totale CON	10.0	10.0	15.0
	APP	Motorized post coupler production	25.0	25.0	10
		Totale APP	25.0	25.0	10.0
	SPSERV	Modulator design	0	0	10
		Totale SPSERV			10
Totale LNL			45.0	40.0	40.0
Totale Generale ALPHA_DTL_BETA			45.0	40.0	40.0