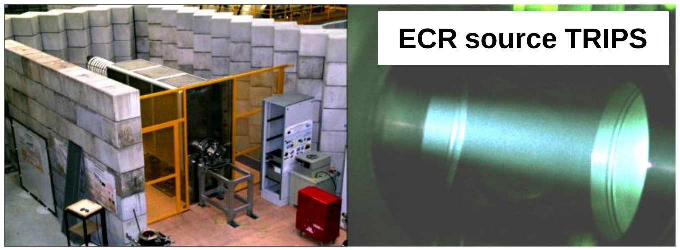
Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
INFN

PNRR - Anthem (AdvaNced Technologies for Human-centrEd Medicine)
STATUS of the spoke 4.9
An RF accelerator based BNCT facility in Caserta within INFN participation to Anthem PNRR initiative

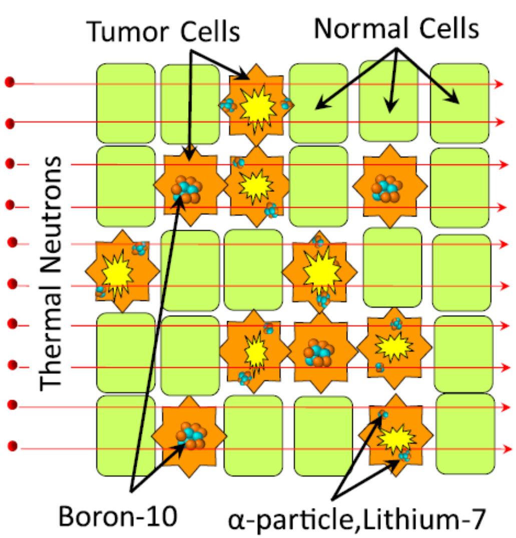
A.Pisent
INFN LNL, on behalf of INFN Anthem collaboration

TRASCO➔BNCT


Radio Frequency Quadrupole


ECR source TRIPS

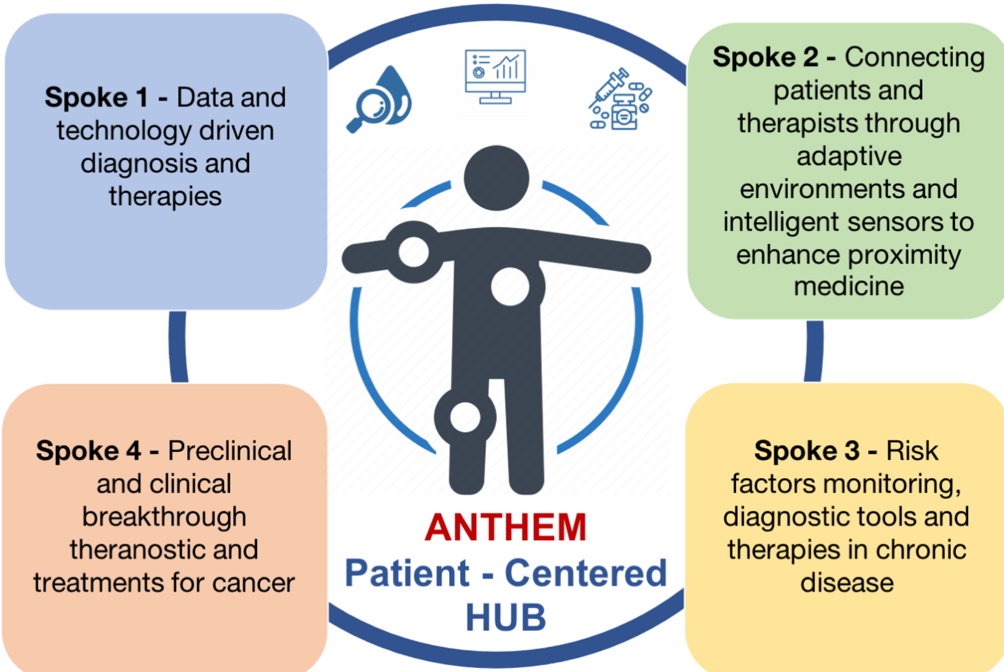
Principle of BNCT



- TRASCO RFQ and TRIPS ion source, built for Nuclear Wastes Transmutation Research (1998-2004). M. Napolitano, G. Fortuna, G. Ciavola.
- The idea of using the the 5 MeV 30 mA beam for BNCT (Boron Neutron Capture Therapy), G. Fortuna, P. Colautti and U. Amaldi since the beginning (and then part of SPES original program).
- Thanks to Giacomo and Valerio for the idea to include this program in the PNRR, together with the collegues of Vanvitelli, G. Paolisso and L. Gialanella, and to INFN management.

Anthem

AdvaNced Technologies for Human-centrEd Medicine
Project Code: PNC0000003
Total budget: 125.044.305,36 euros
Spoke 4 budget: 49.316.044,52 euros
INFN BNCT Pilot 4.9 7M€ + personale



ANTHEM will consider the following chronic diseases:

- **Cancers** Glioblastoma GBM, melanoma, lung and thyroid cancers);
- **Degenerative diseases** (i.e. neurodegenerative diseases),
- **Cardiovascular** and **pulmonary** diseases (i.e. fibrotic, atherosclerotic diseases),
- **Diabetes**

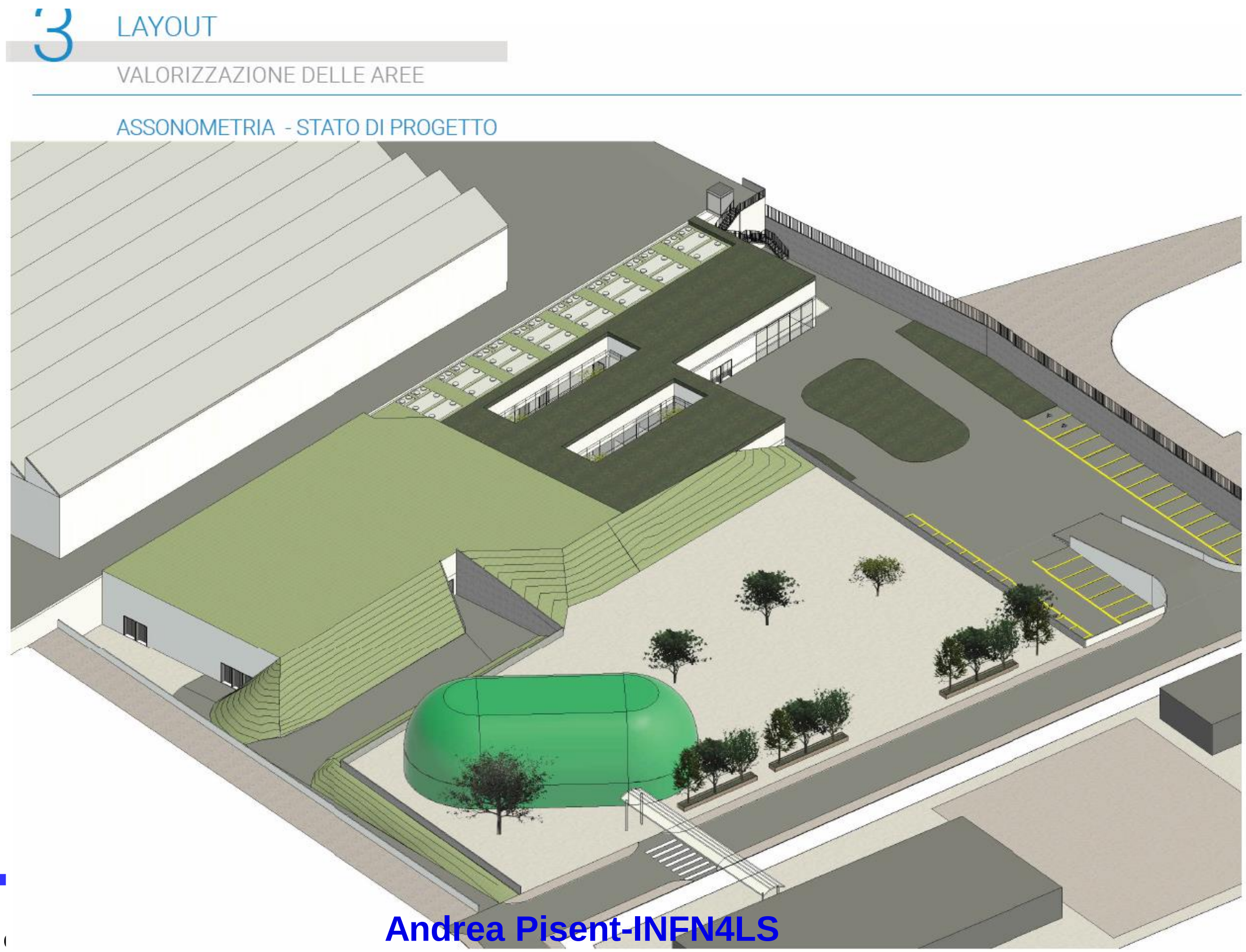
Coordinator Guido Cavaletti, MD, Professor of Human Anatomy Vice-Rector (Research,University of Milano-Bicocca)

Spoke 4 coordinator-Giovanni Li Volti Department of Biomedical and Biotechnological Sciences University of Catania

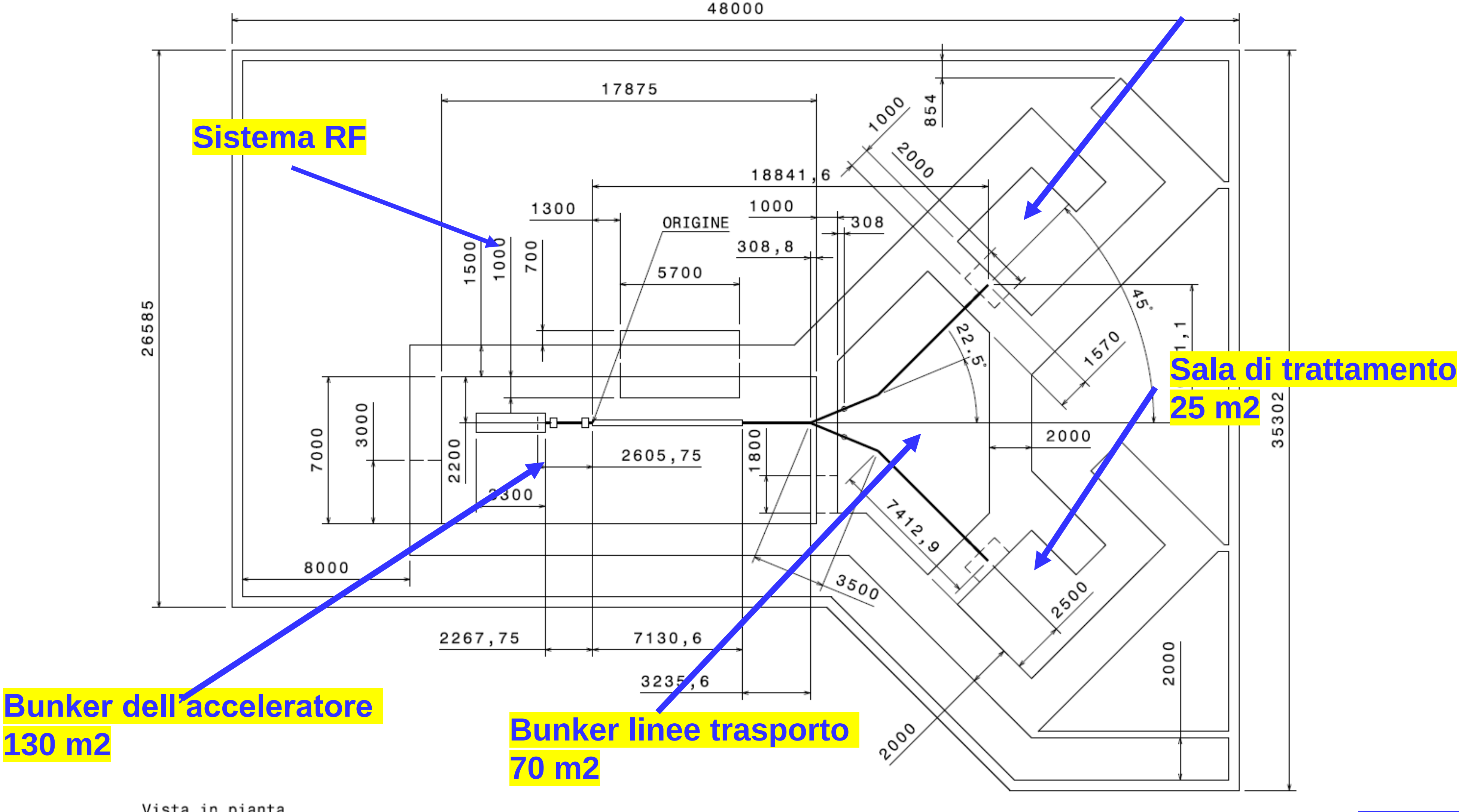
INFN participation coordinated by Valerio Vercesi

Local INFN coordinators
Pavia: V. Vercesi
LNL: A. Pisent
LNS: P. Cirrone
Catania: F. Romano
Napoli: L. Gialanella
Torino: P. Mereu

Anthem PNRR complementary initiative, construction of a BNCT facility (30 mA 5 MeV) at Caserta
Recent choice of the site, independent installation for BNCT studies and clinics close to Circe



Lay out of the building
(1400m^2 alta tecnologia)



Main deliverables: The time line,
4 Years from 1-1-2023

Anno	Descrizione	Deliverable	Mese Inizio	Mese fine	Anno I	Anno 2	Anno 3
1	-Produce the executive project of the installation -Conduct a call for tender for the procurement of three solid state amplifier for Radio-Frequency Quadrupole (RFQ) cavity -Construct the gas-detector for microdosimetric characterisation of clinical beams for BNCT	Deliverable: -Report on novel gas-detector construction -Report on recruitment and call for tenders advancement (all pilots)	1	12			
2	-Obtain proton beam nominal parameters at the end of the LEBT -Complete the radio-frequency power amplifier system for RFQ cavity and successfully test the high power couplers at nominal power -Accomplish tuning of the RFQ cavity -Conduct biological evaluation of BNCT, proteome and interactome characterization, immune response, study of organoids (all with neutron facilities already available)	Deliverable: -Report on beam transport optimization through LEBT -Report on RFQ coupler production and test -Report on RF system production and test -Report on cavity bead pulling and final optimization -Report on MPS, LLRF and LINAC control system	13	24			
3	-Complete bunker construction with related services -Successfully test the MPS, LLRF and LINAC control system -Get the high power Be target ready for proton test -Get the accelerator/neutron source ready for install+C4ation -Get the BSA characterised and ready for installation	Deliverable: -Report on control system off-site test -Report on Be target production	25	36			
4	-Install accelerator and ancillaries at Vanvitelli Caserta bunker -Produce the first neutron beam at low power -Characterise the final epithermal radiation field in air and phantom -Start procedure for CE marking of medical device	Deliverable: -Report on RFQ conditioning and accelerator beam commissioning -Report on accelerator and BSA installation -Report on final epithermal radiation field in air and phantom	37	48			

INFN participation: main activities

- **Pavia** design and construction of the BSA (beam shape assembly)
- **LNL**, accelerator, microdosimetry, production target, beam tests (source), RF tests and neutron production tests (electrostatic accelerator), controls
- **Torino**, mechanical development of the accelerator, transfer line and integration with the building. Documentation and QM.
- **Napoli** (sezione and Unicampania) accelerator development, integration with of the building, administrative coordination, tenders.
- **LNS** technical and administrative participation to main tenders

- A.Pisent, C. Baltador, L. Bellan, D. Bortolato, V. Conte, M. Comunian, E. Fagotti,, F. Grespan, J. Esposito , M. Montis, A. Palmieri, A. Selva , G. Sciacca INFNLNL
- P. Mereu, M. Nenni, C. Mingioni,E. Nicoletti INFN Torino
- V. Vercesi, I Postuma, S. Bortolussi,F.Setareh, R. Ramos INFN Pavia
- M. Masullo, A. Passarelli, L. Gialanella, NFN Napoli

- Personale «specifico» Anthem BNCT
  - C. Baltador, A.Pisent, V. Conte, L. Bellan, A. Selva,**+1 CTER(!?)** INFNLNL
  - E. Nicoletti, INFN Torino
  - V. Vercesi, I Postuma INFN Pavia
  - A. Passarelli NFN Napoli

The BNCT irradiation facility concept
epithermal neutrons for deep tumors (like glioblastoma)

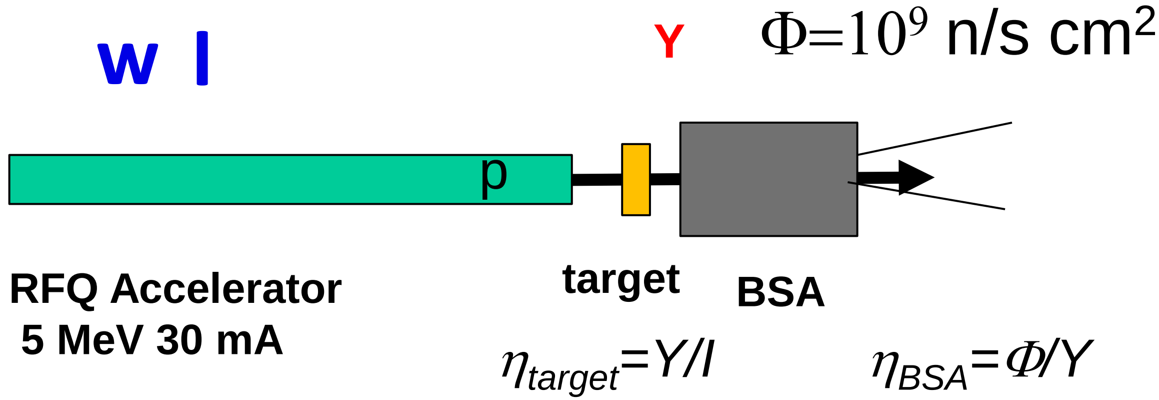


Table 1 Recommended neutron beam characteristics from IAEA TECDOC-1223

Beam characteristics	Recommended value
Neutron beam energy range (epithermal)	0.5 eV < E < 10 keV
Epithermal neutron flux, Φ_{epi}	$\geq 1 \times 10^{9}$ n/cm^{2}·s
Fast neutron contamination (fast neutron dose/Φ_{epi})	$\leq 2 \times 10^{-13}$ Gy·cm^{2}
γ-ray contamination (γ-ray dose/Φ_{epi})	$\leq 2 \times 10^{-13}$ Gy·cm^{2}
Thermal neutron ratio	≤ 0.05
Current to flux ratio	≥ 0.7

The choice of the thick target material and beam energy; $^{9}Be(p,n)^{9}B$, has respect to Li the advantage of better radioprotection (no ^{7}Be and T production) and better mechanical propr (1278 vs 180 deg C melting point). The Be oxide is chemically toxic.

Neutron source gain factor expected at
Ep= 5 MeV → Yn ~2.9·10^{12} s^{-1}mA^{-1}
Range in Be approx. 230 um
Average neutron spectrum at target 1.2 MeV

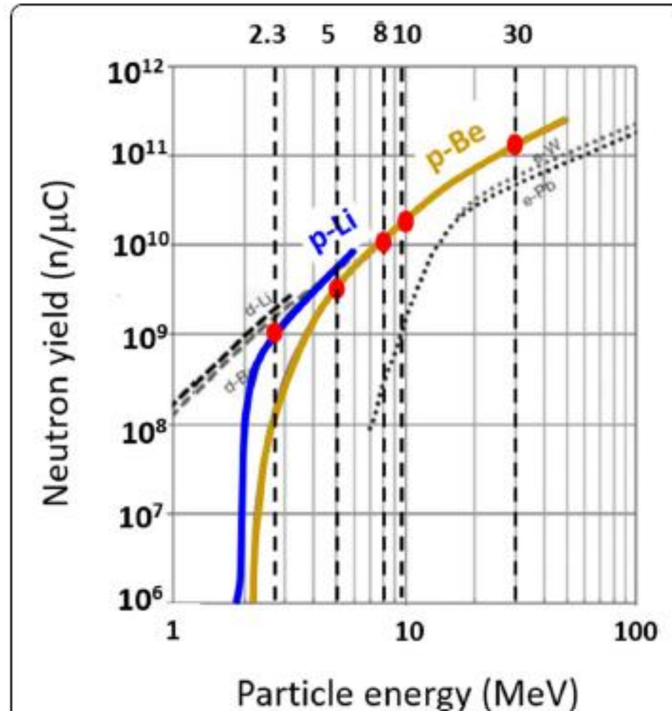


Fig. 3 Neutron yields from various nuclear reactions

BNCT facility landscape (2019)

Status of Accelerator-Based BNCT Projects Worldwide

Yoshiaki Kiyanagi[1, a)], Yoshinori Sakurai[2, b)], Hiroaki Kumada[3, c)] and Hiroki Tanaka[2, d)]

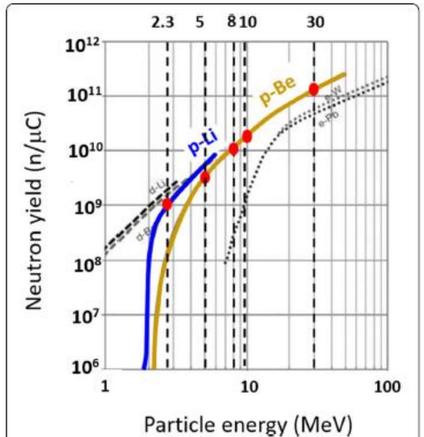


Fig. 3 Neutron yields from various nuclear reactions

Facility name	Accelerator	Target	Incident particle, Produced neutron energy (MeV)	Designed current (mA)	Present current status (mA)	Present status
Kyoto University	Cyclotron	Be	P: 30, N: < 28	1	1	Clinical trial
Southern Tohoku Hospital	Cyclotron	Be	P: 30, N: < 28	1	1	Clinical trial
Tsukuba University	Linac	Be	P: 8, N: <6	5	<2	Physical meas.
National Cancer Center	Linac	Solid Li	P: 2.5, N: < 1	20	12	Physical meas.
Kansai BNCT Medical Center	Cyclotron	Be	P: 30, N: < 28	1	—	Commissioning
Edogawa Hospital BNCT Center	Linac	Solid Li	P: 2.5, N: < 1	20	—	Constructing
Nagoya University	Electrostatic	Solid Li	P: 2.8, N: < 1	15	—	Commissioning
Budker Institute (Russia)	Electrostatic	Solid Li	P:2.0, N: < 1	10	3	Developing
Helsinki University Central Hospital (Finland)	Electrostatic	Solid Li	P:2.6, N: < 1	30	20	Constructing
SARAF (Israel)	Linac	Liq-Li	P<4, N: < 1	20 (?)	1-2	Developing
CNEA (Argentina)	Electrostatic	Be, ^{13}C	P, d: 1.4, N: < 6	30	<1	Constructing
Legnaro INFN (Italia)	Linac	Be	P<4, N: < 2	30	—	Developing
A-BNCT(Korea)	Linac	Be	P:10, N:<8	8	—	Construction
Xiamen BNCT Center	Electrostatic	Solid Li	p:2.5, N:<1	10	—	Developing

TESTS AGAINST BLISTERING (LNL electrostatic accelerator CN 2020-22)

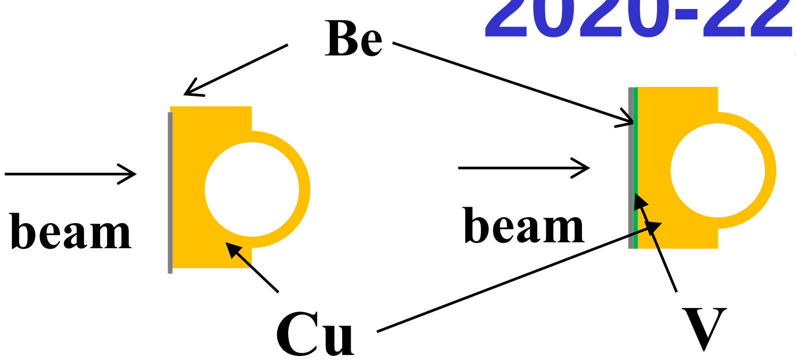


Fig. 1. MUNES test source installed on the +15° beam line at the CN accelerator.

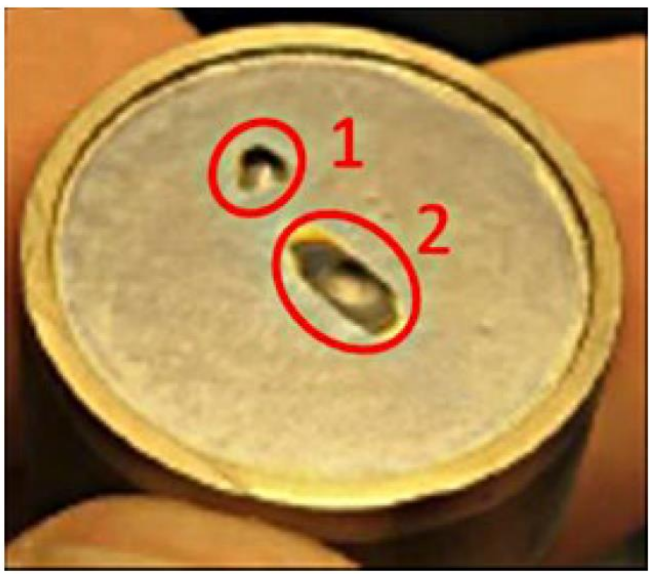


Fig. 2. Beryllium-copper target after irradiation. Beam spot (1) corresponds to perpendicular impact, beam spot (2) to an inclination of 68°. In both cases surface blistering is visible.

Fig. 3. Beryllium-vanadium target after irradiation. Beam spot (3) and (4) correspond to the run with surface power density of 600 and 400 W/cm^2, respectively. In both cases, no macroscopic blistering is visible.

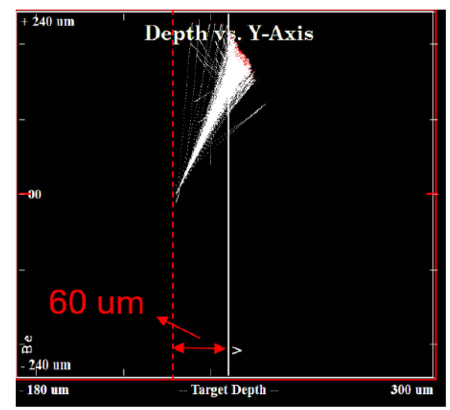


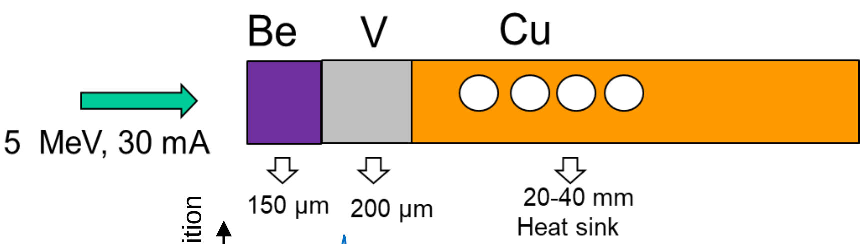
Fig. 1: proton range into BeV target. Angle of incidence is 67.8°. The Be layer is shown.

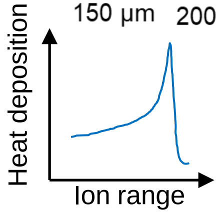
CONCLUSIONS

The irradiation runs performed with the MUNES test source installed at the CN accelerator showed the suitability

Main neutron converter specifications to overcome hydrogen blistering formation in Be

The proposed Be/V/Cu configuration





The Bragg peak position MUST lie within the V layer (~ 80µm)

Bae et al. AAPPS Bulletin, (2022) 32:34, https://doi.org/10.1007/s43673-022-00063-2

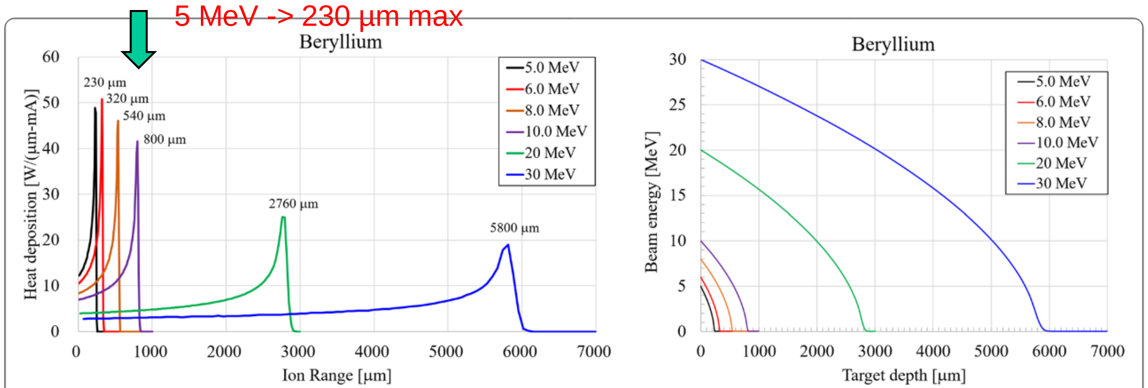
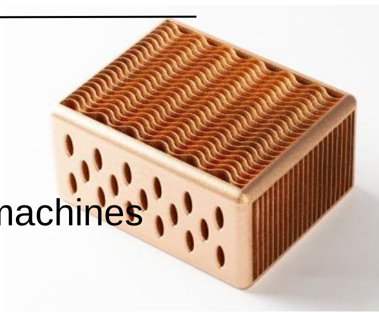


Fig. 6 (Left) Heat deposition profile of beryllium target for various incident proton beam energies. The numbers on the peak position of each profile give the Bragg peak position. (Right) The remaining beam energy along the target depth

Heat-sink Manufacturing options under assessment

- Produced by **additive manufacturing (Cu-OFE)**
  - New heat exchanger configurations unavailable with traditional techniques
  - Microchannels (different geometries) to improve water cooling
  - Cu-OFE powder technology now very well know with leding-edge 3D printing machines
  - many advantages in pushing the limits of high thermal power performances (goal: **heat transfer coefficient HTC approaching h ~ 10^5 W/m^2 K)**
- Produced by more conventional configuration → **wire discharge and brazing (Cu OFE)**



Beryllium (150-180 µm) and Vanadium (200 µm) layers thickness joined to Cu-OFE by HIP (Hot Isostatic Pressing) technology by expert companies working in the field.

New 1 kW/cm² neutron converter design concept

n-target main specifications

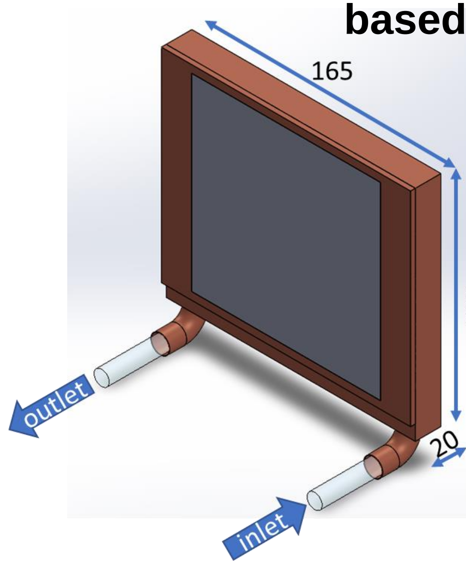
- **150 kW** beam power (5 MeV, cw 30 mA)
- **Be** layer thickness t_{Be} = 0.15 mm
- **V** layer thickness t_{eV} = 0.2 mm
- **Cu-OFE** backing structure

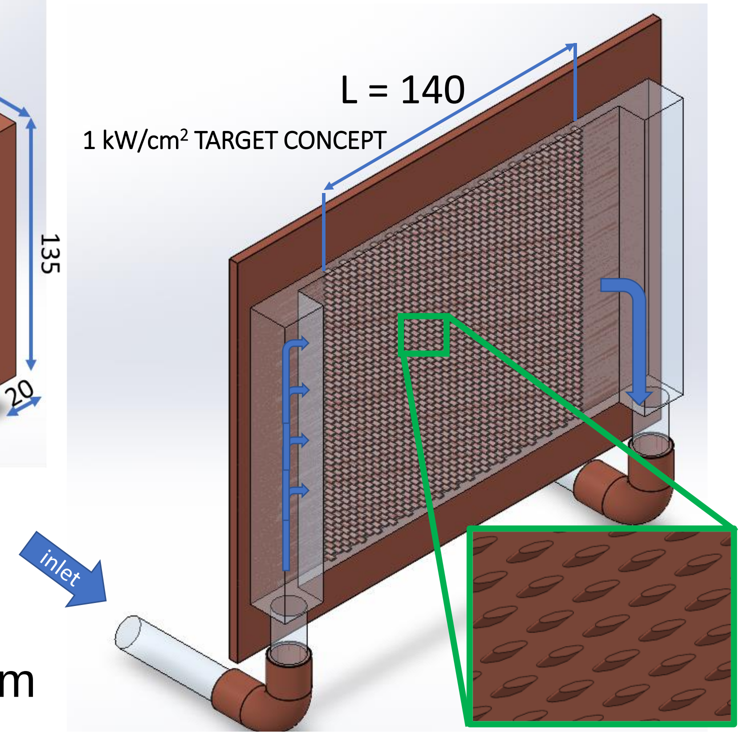
Be material chosen

HP-HR Be PF-60 ($\sigma_y \approx$ 395 MPa at T_{amb} [1])

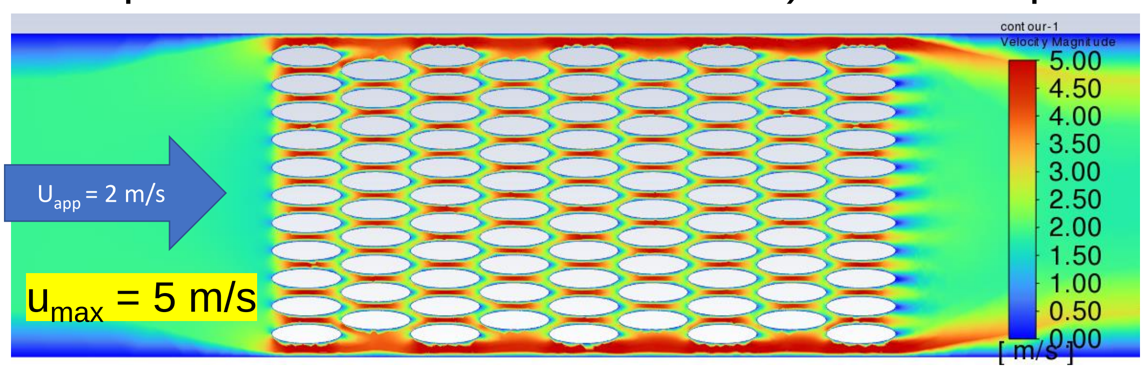
[1] Krivko, V.P., et al. , 1991. The Effect of Annealing on the Mechanical Properties and the Structure of Beryllium Foil, Met. Sci. Heat Treat., Vol 33 (No. 1–2), p 12–14

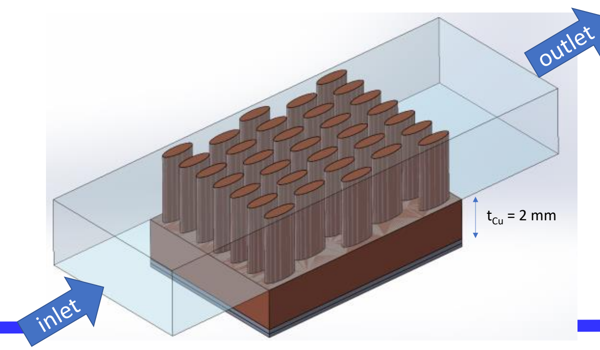
First n-target concept under study based upon Pin-fins heat sink geometry



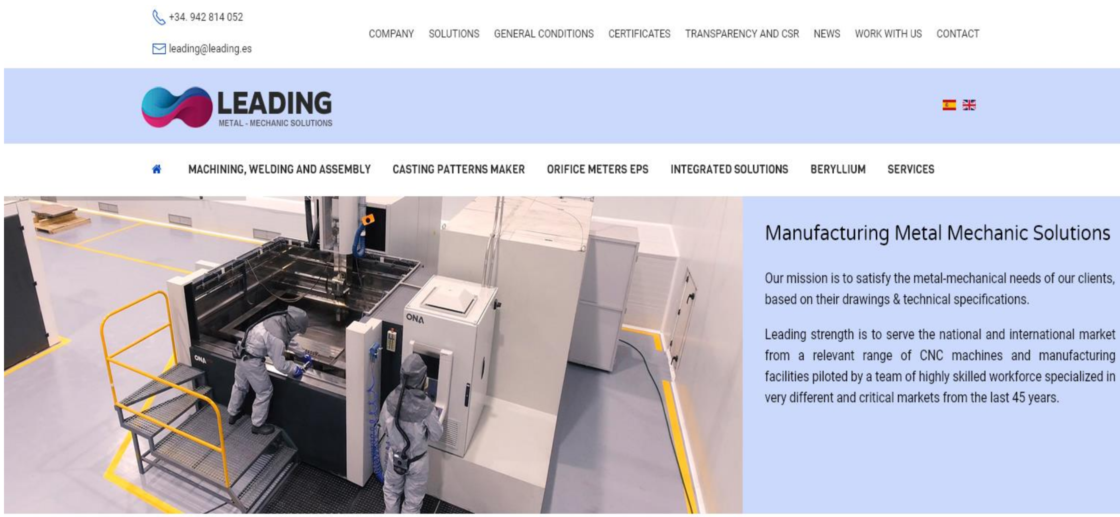


- **First design Goal:** **achieve HTC = 10^5 W/m²K**
- Squared target size 200 cm²
  (beam spot area not less than 150 cm²) normal to p-beam

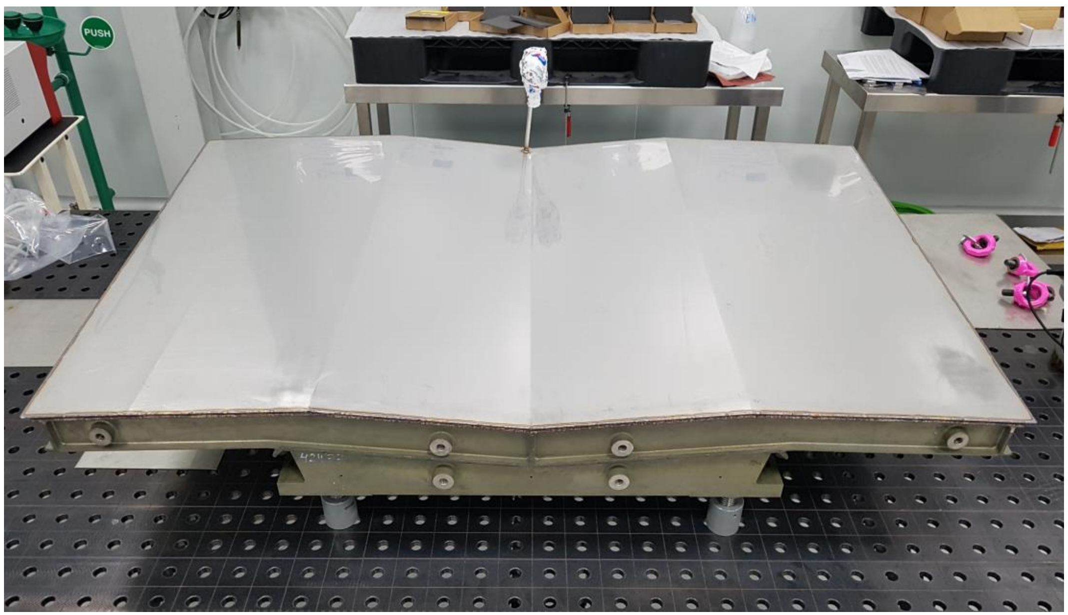


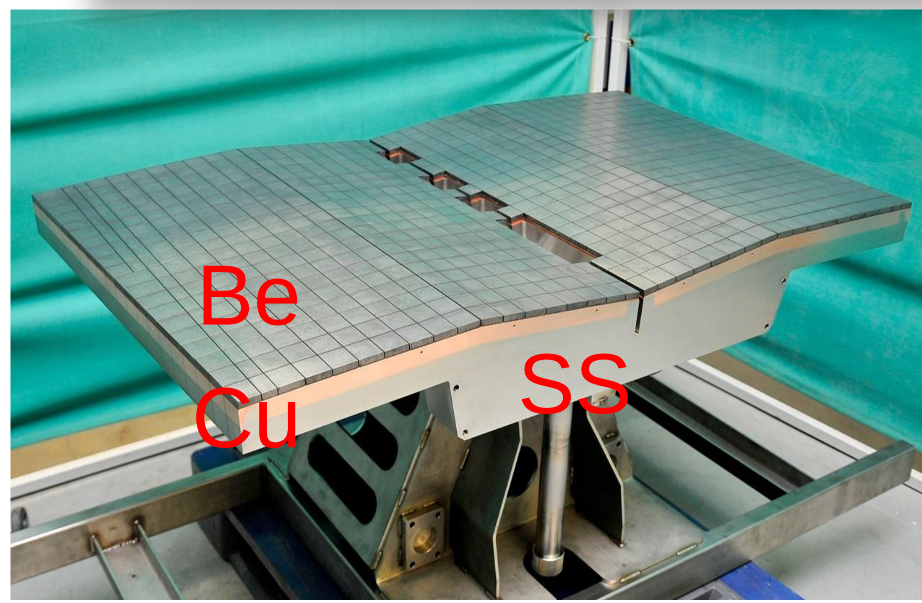


Discussions with LEADING company (Spain)



- Long Experience in manufacturing components of First Wall Panels (FWP) of ITER reactor and different mockups
- Manufacturing process: machining, cleaning, canister, HIPping and final machining and cleaning.





Final agreement achieved to test the HIP process technology on small samples

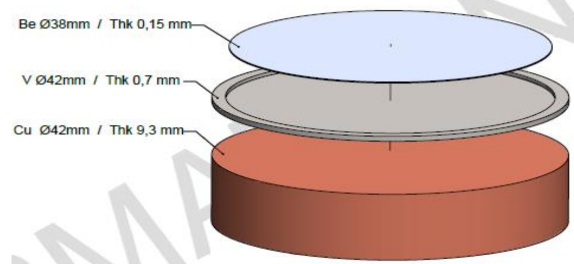
No past experience joining Be+V+Cu mockups. The manufacturing process has to be tested

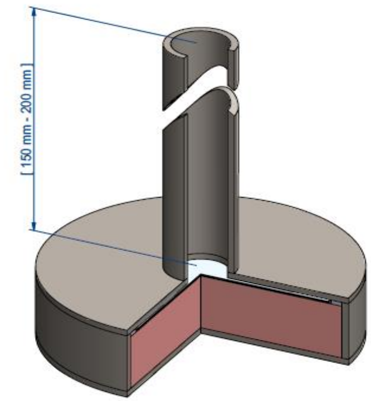
- **Phase 1: 2 Be Targets (Ø20mmx10mm, 0.12 mm Be)** using 2 different HIP cycles according to data found in literature.
- **Phase 2**: **1 Be Target (Ø42mmx10mm, 0.15 mm Be)** using 1 HIP cycle considering the best parameters (pressure, temperature and duration) and results obtained Phase 1.

- The activities included are as follows:

- Order of raw material: Be, V and Cu
- Machining ATDs of V (99%) and Cu (99%). Dimensional control analysis
- Manufacturing of the canister for the HIP process
- Cleaning of all surfaces (degreasing and elimination of any oxides)
- Assembly of the parts into the canister
- Closing the canister by TIG welding and leak testing
- Evacuation and sealing
- HIP process (according to the appropriate parameters)
- Final machining and opening the canister
- Dimensional control analysis of the final component
- NDT: Ultrasonic testing
- Final cleaning and packaging. Be shipping certificate included (cleaning-swab analysis)
- Transport to INFN Italy

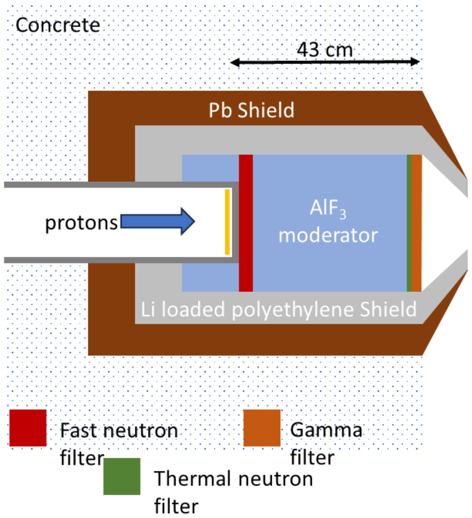
Delivery time: 10-12 weeks (since PO received)

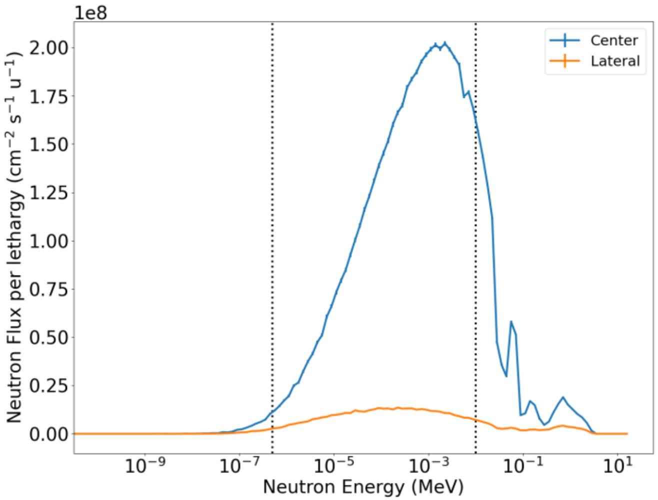




The BSA

(beam shaping assembly, n-spectrum traslator)





Work in progress (Pavia group)

- *Production and beam test of AlF_3 blocks*
- *BSA design with the planar target geometry*

The neutron spectra were accumulated through an MCNP6 simulation. The tallies are centered at the beam port on a plane perpendicular to the neutron beam axis. With the tally surface being:

Central: a circle of 6cm radius

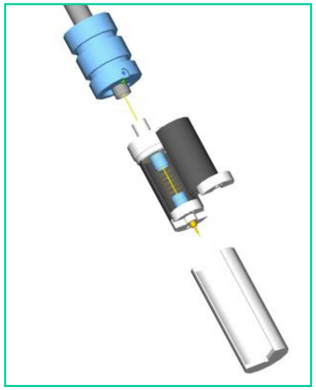
Lateral: a ring with minimum radius of 6cm and maximum radius of 12 cm

IAEA FOM (2023 update)

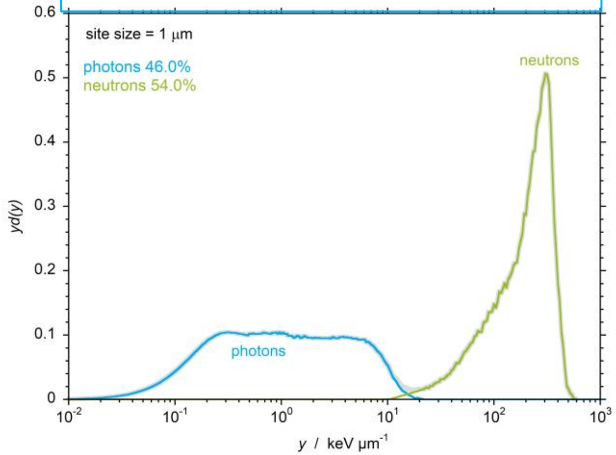
BSA	**Flux** (10^9 cm^{-2} s^{-1})	**thermal n cont.**	**fast n cont.** (10^{-13} Gy cm^2)	**photon cont.** (10^{-13} Gy cm^2)	**J/phi**
IAEA rec.	> 0.5	$< 5 \cdot 10^{-2}$	< 7	< 2	> 0.7
Actual beam	1.18	$0.86 \cdot 10^{-2}$	8.81	3.58	0.73

Micro dosimetry: characterization of BNC

Detector with interchangeable cathode

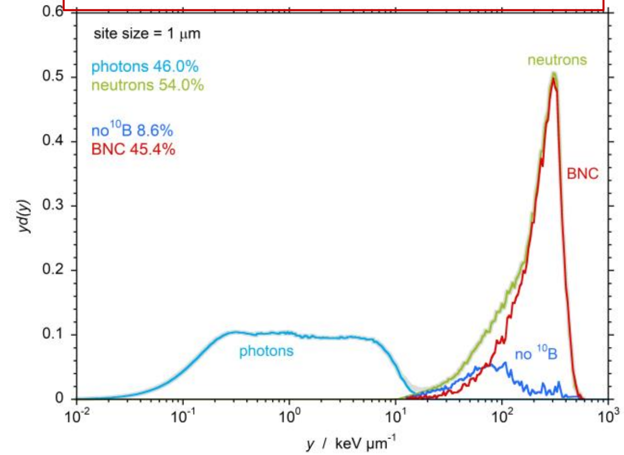


Discrimination of gamma/neutron doses

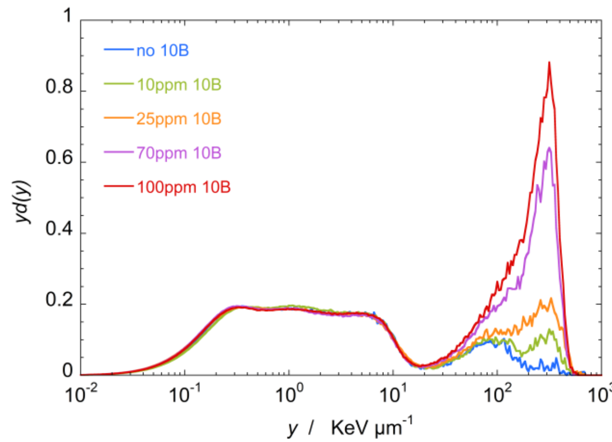


+ BNC dose

Discrimination of BNC/no-BNC doses



Pairwise measurements, with and without 10B, allow to determine the gamma & neutron doses



Different Boron concentrations to mimic the real scenario in human tissue

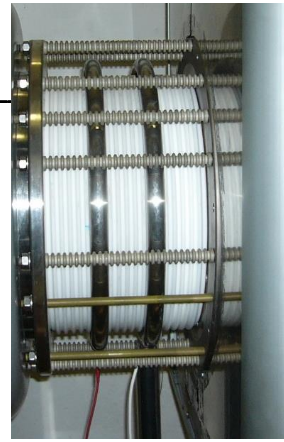
Accelerator development

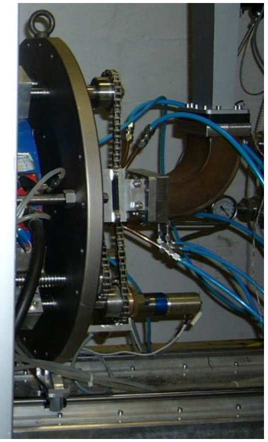
- Injector revamping=>beam characterization at LNL
- RFQ couplers => production and high power tests at LNL
- RFQ ➔ assembly and low power test LNL
- RF system procurement and test at LNL on RF load of the 8 solid state amplifiers
- Design and procurement of beam lines
- Computer control system
- Integration of the linac (preparation to medical use)

TRIPS source, built by LNS, developed at LNL since 2006

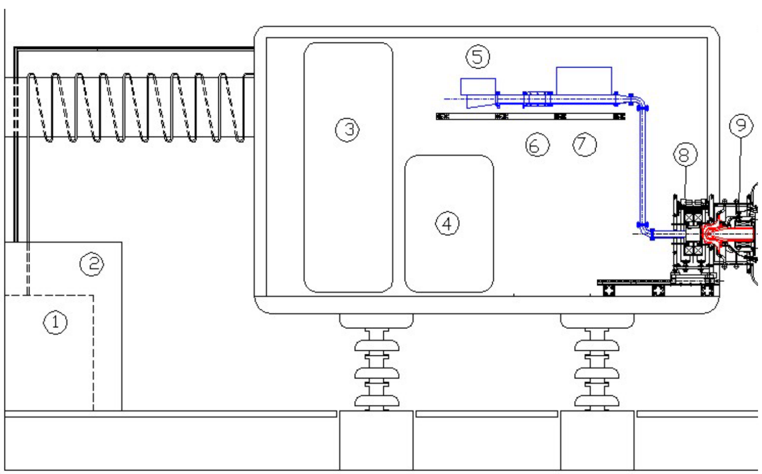
Ion source general setup:

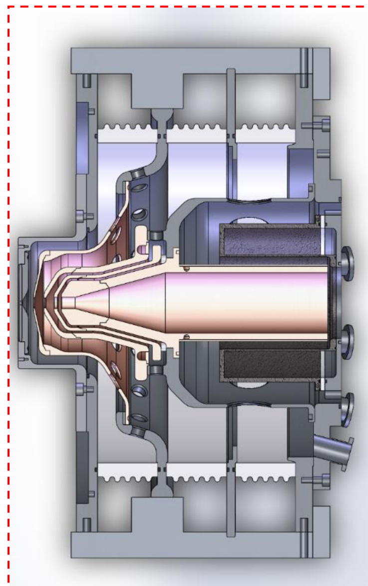
1. Water tank
2. Insulating transformer
3. Auxilliaries rack
4. HV Control rack
5. Magnetron
6. Circulator
7. ATU
8. Source
9. Extraction column





TRIPS nominal info	
type	MDIS
beam	H^+
Current p	**40 mA**
energy	80 keV
Rms emittance	0.2 π mm mrad
5 electrodes extraction column	



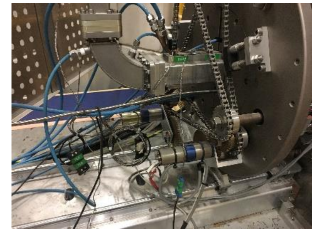


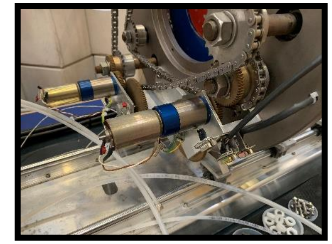
Further upgrade to 55 mA H+ Could be beneficial for power saving.

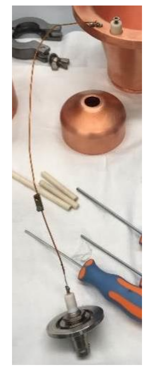
Indeed according to IBNCT data the average current necessary for half an hour treatment is around 10-15 mA and already allowes reducing the duty cycle to 50 %

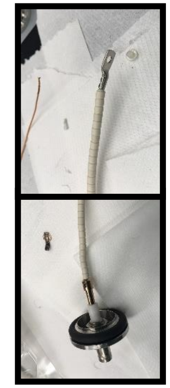
TRIPS Refurbishing process:

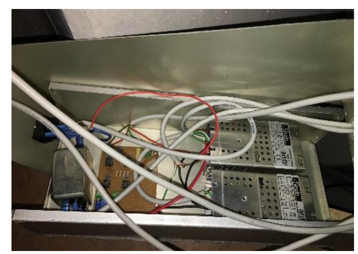
- HV platform and faraday cage restoration
- New transformer (with status check via control sys.)
- New and re-arranged connections under false floor
- Complete source dismantling for repairs and cleaning ops.
- Laser tracker alignment
- PPS updated (self-managed and not eludible) approved by LNL security responsible
- General replacement and improvement of source components, electronics, connections, cooling and others auxiliaries

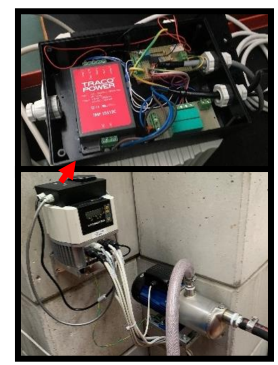






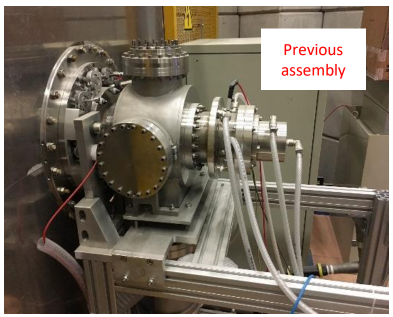






Source diagnostics (before LEBT installation):

old	*New (already available)*
• Collimator + Beam stop	• DDCT (inside source) • CCD • RGA • Wire scanner (BPM) • Collimator + Beam stop • Thermocouples *

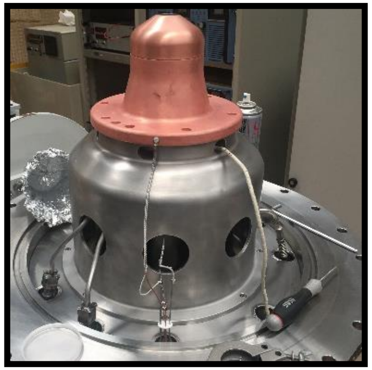


*all the thermocouples on the source side were also replaced

New cooling system:

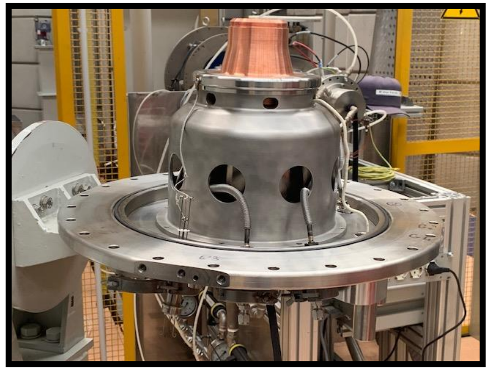
Old

- Rigid pipes
- Oring sealing hold by screws on exit side
- Oring sealing hold by screws on both ground electrodes

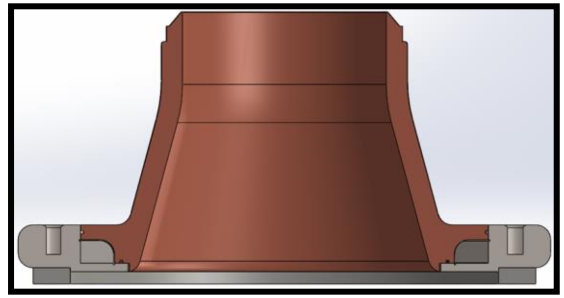


New

- Flexible pipes
- Matallic gasket Swagelock sealing on exit side
- Soldered pipes on both ground electrodes



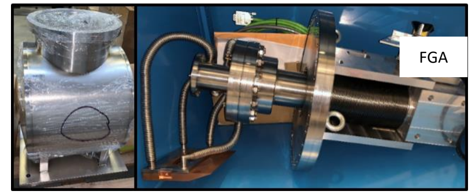
Cross section of new ground 1

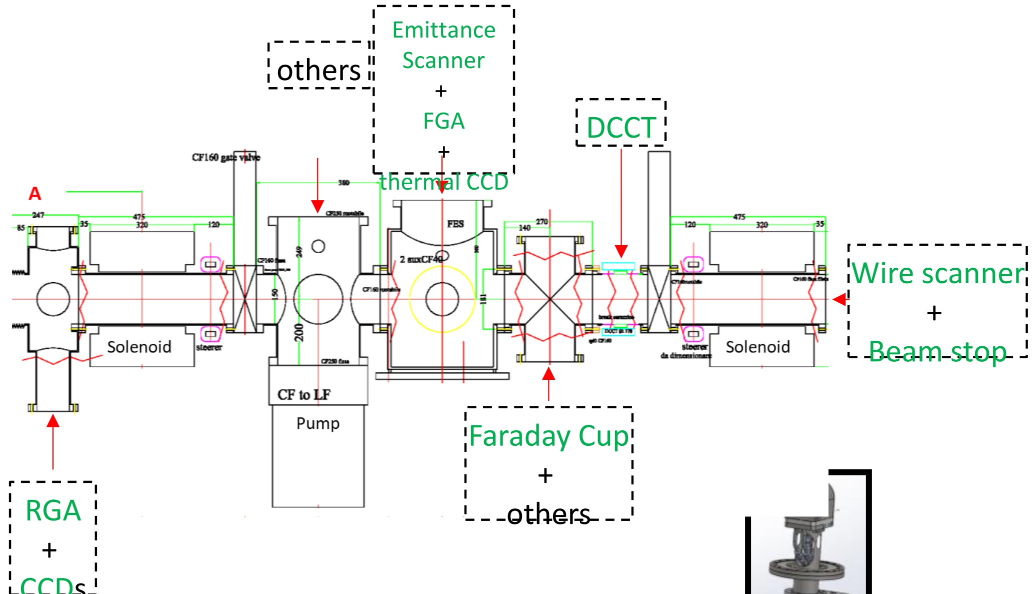


Steel ring is brazed to the copper electrode. The space in between them is the cooling channel

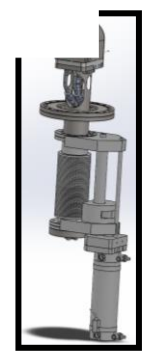
Reinstalled, controls to be tested. The LEBT will be installed and tested in 2024

Emit. scanner



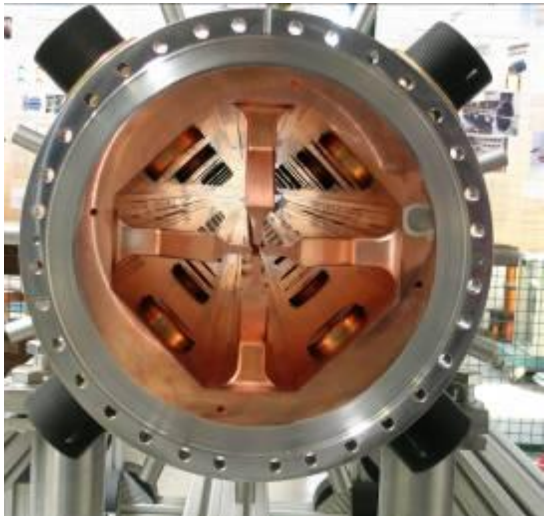


FC



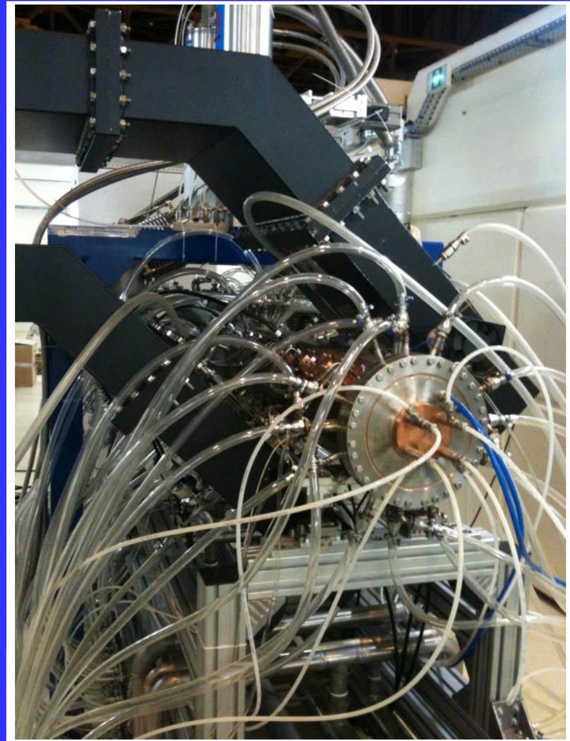
TRASCO RFQ (developed al LNL for ADS studies)

	Name	Lab	ion	energy	vane voltage	beam current	power	RF Cu power	Freq.	length		Emax	Power density ave	max
				MeV/u	kV	mA	kW	kW	MHz	m	lambda	kilpat	W/cm^2	W/cm^2
	IFMIF EVEDA	**LNL**	**d**	**2.5**	**79-132**	**130**	**650**	**585**	**175**	**9.8**	**5.7**	**1.8**	**3.5**	**60**
CW	LEDA	LANL	p	6.7	67-117	100	670	1450	350	8	9.3	1.8	11.4	65
	FMIT	LANL	d	2	185	100	193	407	80	4	1.0	1	0.4	
high p	IPHI	CEA	p	3	87-123	100	300	750	352	6	7.0	1.7	15	120
	TRASCO	**LNL**	**p**	**5**	**68**	**30**	**150**	**847**	**352**	**7.3**	**8.6**	**1.8**	**6.6**	**90**



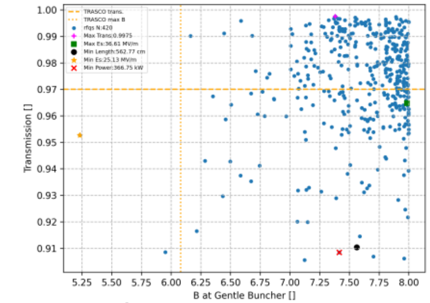
TRASCO@LegnaroINFN

TRASCO RF tests @Saclay.CEA



Tested up to 2 Ekp, 80 kW/m 100% duty cycle in 2013

Is a more performant RFQ possible?



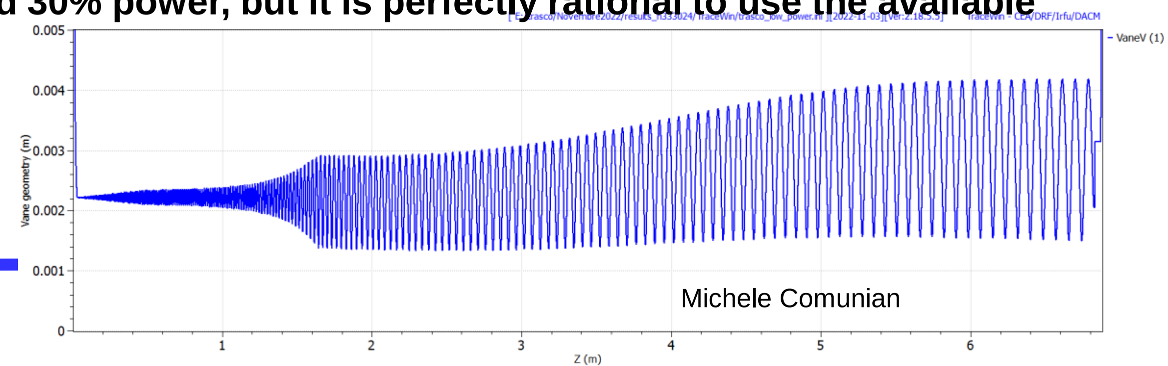
"Best cases" with variable voltage as IFMIF on Accelerator and $\rho/R0$ const=0.75
3d machining with a modern temperature-controlled milling machine

Better than TRASCO in any aspect

20 cm shorter **1.7 kp** **+10% Ez** **30% less power**

RunNum	L[cm]	V[kV]	Esmax[MV/m]	trans	emitz[degMeV]	Vacc[kV]	Pd[kW]	amin[cm]
n333024	688.036	51.237	31.2406	0.9778	0.20253	64.934	424.887	0.133
x030202	687.98	51.756	30.6531	0.9791	0.23093	68.468	439.0103	0.1377
r141340	685.108	50.741	30.366	0.97825	0.20439	70.308	439.0678	0.1368
q133241	665.644	50.169	30.614	0.98035	0.22027	70.616	440.6494	0.1349
g304014	653.896	53.595	30.9884	0.9765	0.19705	71.945	452.1616	0.1407
q034330	692.889	53.284	31.8303	0.98205	0.19226	67.761	455.402	0.1382
d243330	686.548	50.893	30.0674	0.9789	0.18026	71.982	455.952	0.1381
q322422	686.363	52.906	31.3268	0.9792	0.22934	68.083	457.3036	0.139
z414422	683.256	50.511	30.7436	0.98705	0.19255	72.886	459.1788	0.1347
s024022	675.783	51.448	31.1951	0.98795	0.19347	74.147	470.0226	0.1353
Trasco	**713**	**68**	**32.75 (1.77kp)**	**0.97**	**0.18**	**68**	**~617**	**0.205**

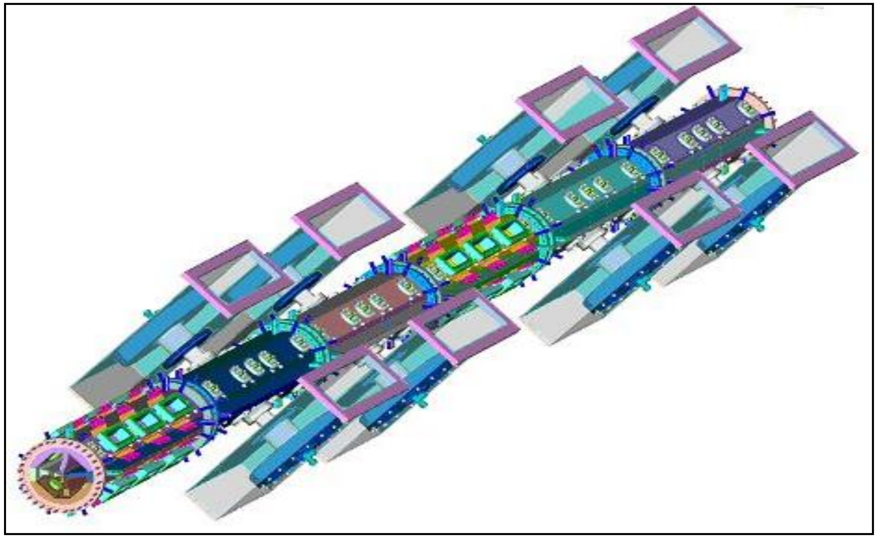
with new design tools we could have spared 30% power, but it is perfectly rational to use the available structure



Michele Comunian

Eight independent 125 kW amplifiers (one per RF coupler) 5 available and tested to full power on RF load

Each amplifier needs 5 racks (including power supply)



The 3 missing RF systems will be ordered in 2023

Advantages respect to a klystron

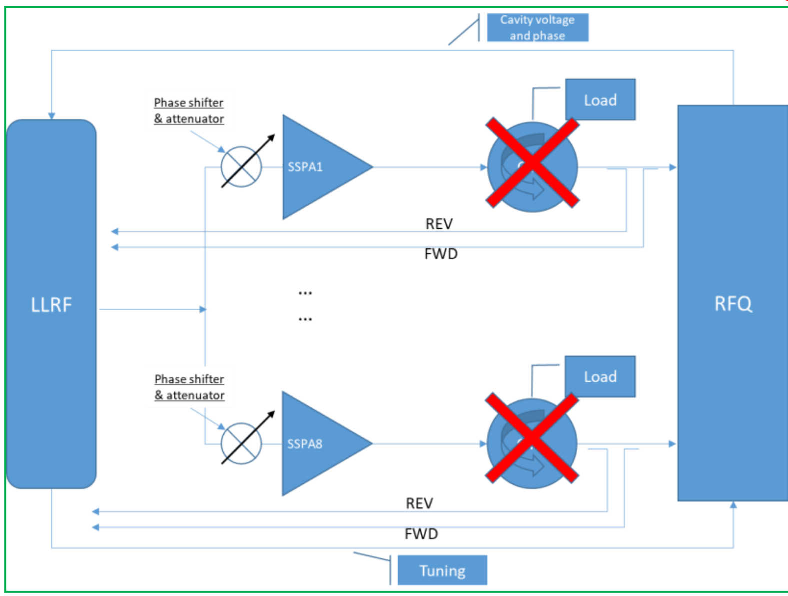
- *Lower operating costs (cost and duration of components)*
- *Availability e reliability (no stop operation in case of components failure)*
- *Absence of high voltages very important for the operation in a hospital*

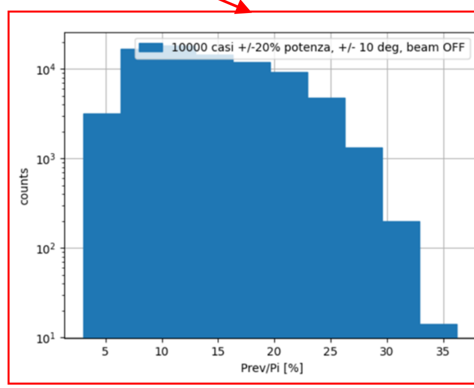
Tender for 8 RF power amplifiers (3 new + 5 to be updated)

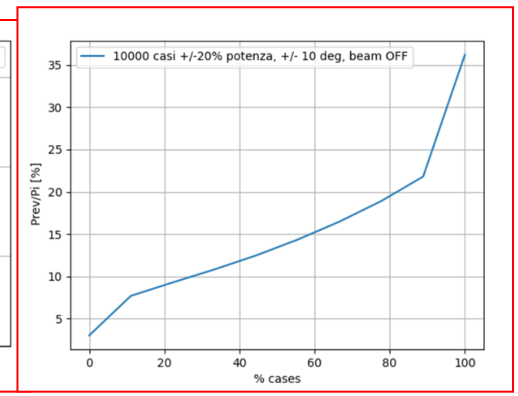
Peculiarita' del nostro sistema:

1. 8 amplificatori connessi alla stessa cavita'
2. Mancanza di circolatori.
3. Singola LLRF splittata su 8 catene

Numero di amplificatori accesi	Potenza riflessa verso gli amplificatori accesi	Potenza verso gli amplificati spenti
1	70.3%	2.1%
2	50.4%	8.4%
3	31.9%	18.9%
4	17.7%	33.6%
5	7.6%	52.5%
6	1.7%	75.6%
7	0.0%	103%
8	2.5%	-



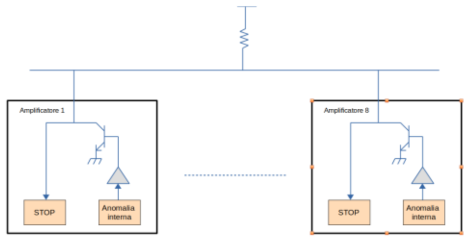




Francesco Grespan Damiano Bortolato

Tender for 8 RF power amplifiers (3 new + 5 to be updated)

Peculiarita' del nostro sistema:
1. 8 amplificatori connessi alla stessa cavita'
2. Mancanza di circolatori.
3. Singola LLRF splittata su 8 catene



Richiesto un sistema di protezione veloce che possa lavorare assieme agli altri amplificatori connessi alla stessa cavità. Il requisito fondamentale è che appena uno degli amplificatori va in protezione per un qualsiasi intervento interno, deve segnalare agli altri amplificatori la condizione di errore ed interrompere l'erogazione di potenza per tutti.

ANTHEM

AdvaNced Technologies for Human-centrEd Medicine

ALLEGATO 1

CAPITOLATO TECNICO

per la fornitura di RF Systems per il progetto

"ANTHEM-AdvaNced Technologies for Human-centrEd Medicine"

PNC-PNRR Piano nazionale per gli investimenti complementari finalizzato ad integrare con risorse nazionali gli interventi del Piano nazionale di ripresa e resilienza, di cui al decreto-legge n. 59 del 2021, convertito, con modificazioni, dalla legge 1° luglio 2021, n. 101; D.D. N.931 del 06/06/2022; Iniziativa A: Iniziative di ricerca per tecnologie e percorsi innovativi in ambito sanitario e assistenziale (Ministero Università e Ricerca).

Atto G.E. n. XXXXX del gg/mm/aaaa
CUP B53C22006730001

Indice

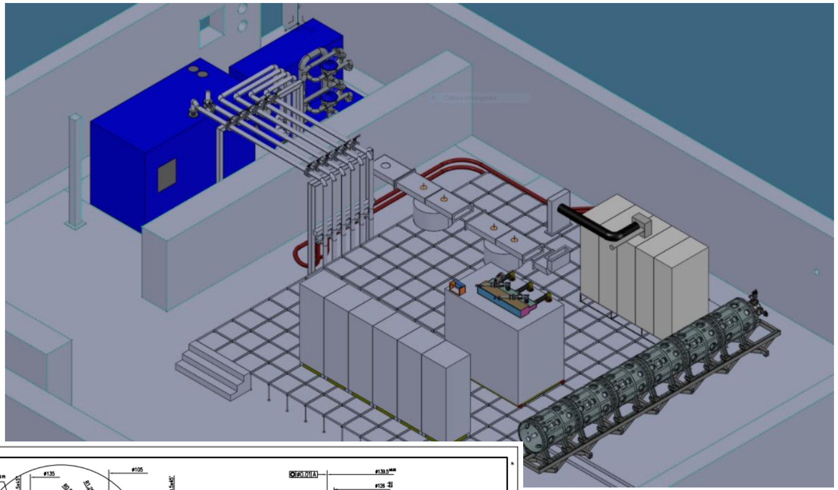
Istituto Nazionale di Fisica Nucleare
codice fiscale 84001850589

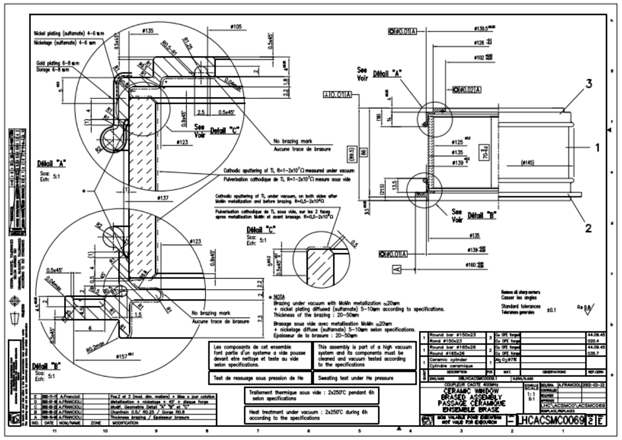
1

Documentazione di gara pronta a fine Aprile, in attesa di aggiornamento codice appalti.
Call for tender milestone: M9
Delivery milestone: M24

Francesco Grespan Damiano Bortolato

Attivita' RFQ a LNL: power coupler conditioning

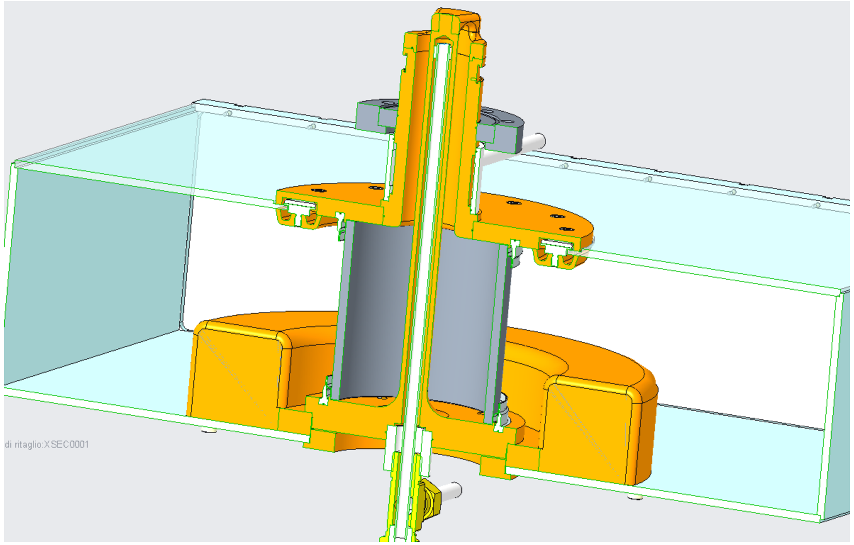




1. **Preparation of High Power Test area at LNL (main accelerator hall)**
2. **Coupler tendering**
   1. **Prototyping of one complete RF coupler (including cylindrical RF window) (*)**
   2. **Purchase of 8 RF windows + couplers**
   3. **coupling cavity**
3. High Power Test of the prototype coupler (**)
4. Construction of the remaining couplers
5. High Power Conditioning of the remaing Couplers at LNL
6. Installation of the High Power Couplers on the RFQ Cavity on Site (***)
7. Leak Test of the RFQ (***)
8. Waveguide installation from amplifiers to couplers
9. High Power Tests (Milestone M24)

- In principle the tenders for couplers and RF windows can be separate
- ** A coupler used for the tests at Saclay coupld be used as a «receiver»
- ***See Point 18 of the previous list

Francesco Grespan



RF couplers, cylindrical windows

- Two already produced and tested to full power (CEA-Saclay 140 kW cw) and used for RFQ test.
- We need to produce and test in LNL (with INFN solid state amplifiers) 8 new couplers. Milestone in 2025.

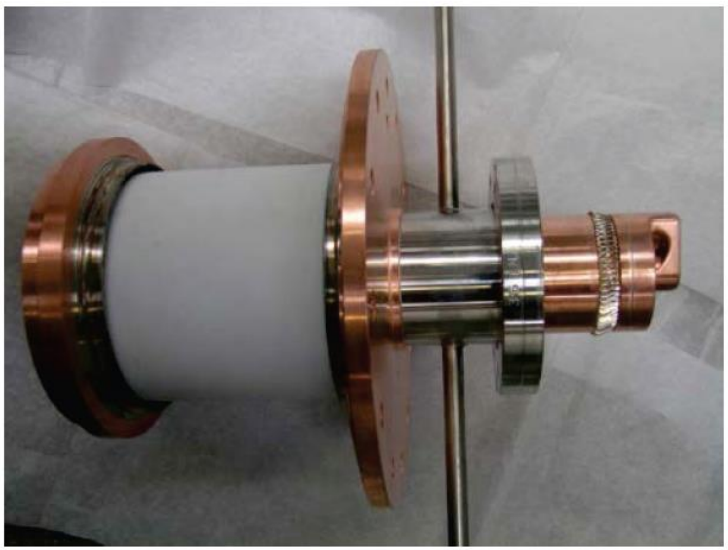


Figure 1: RF coupler system with loop, coaxial transmission line and coaxial alumina window.

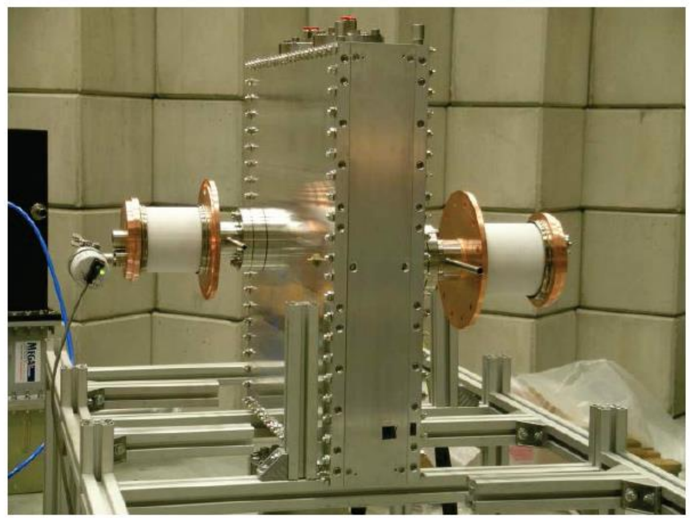
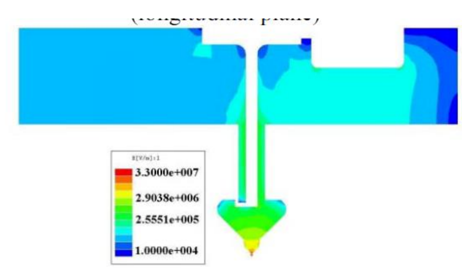
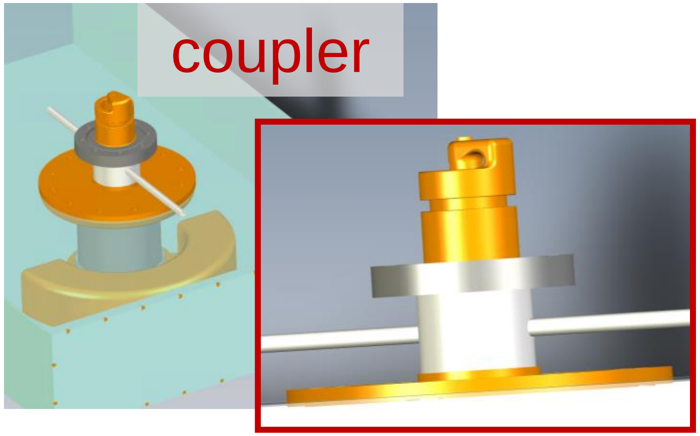


Figure 2: View of the two couplers connected with the bridge cavity. It is possible to notice the cooling channels and the RF windows.

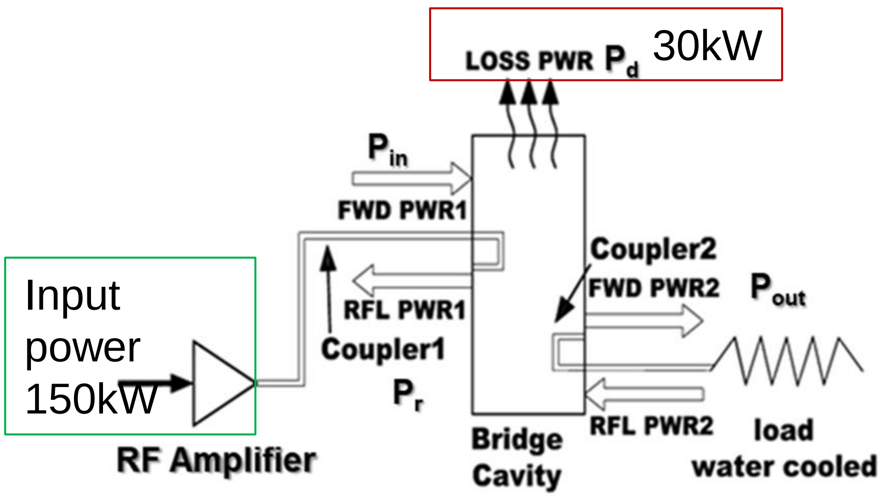


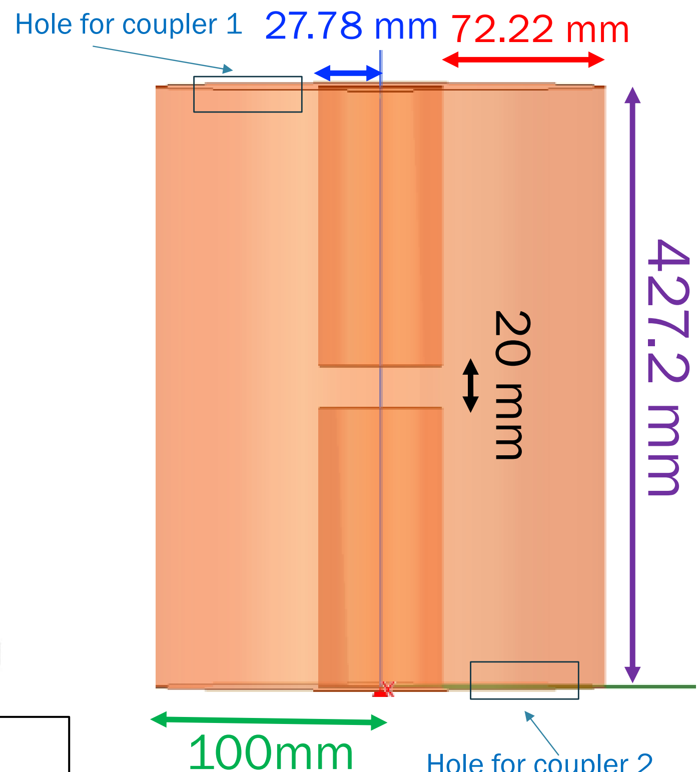
8 Electric field magnitude in the RFQ and coupler (transverse plane)

Bridge cavity (collaboration among INFN LNL - Na - To)



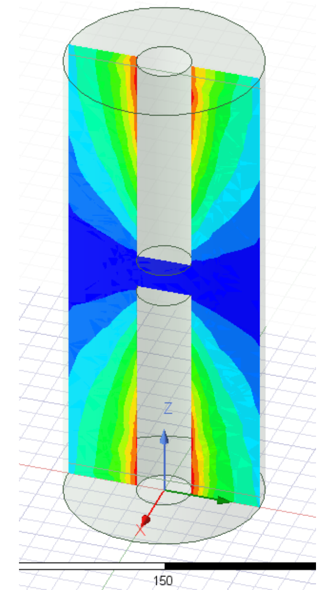
Electromagnetic design and study of mechanical tolerances (interfacing with INFN-To mechanical designers) for the bridge cavity construction for **coupler conditioning test at nominal power (150kW)**, minimizing reflected and dissipated power





Antonio Palmieri Andrea Passarelli

magnetic field distribution
f = 352.2 MHz



80% transmission from coupler 1 to coupler 2

Dissipated power

	P diss [kW]
Cylinder int 1	9.25
Cylinder int 2	9.25
Plate 1	3.16
Plate 2	3.16
Cylinder ext	5.25
TOTAL	30

for dimensioning of the cooling system

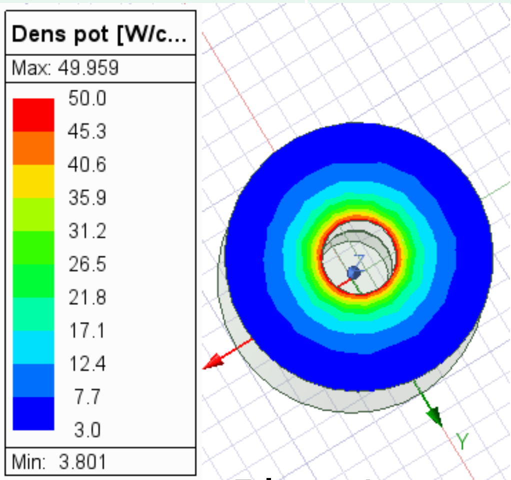
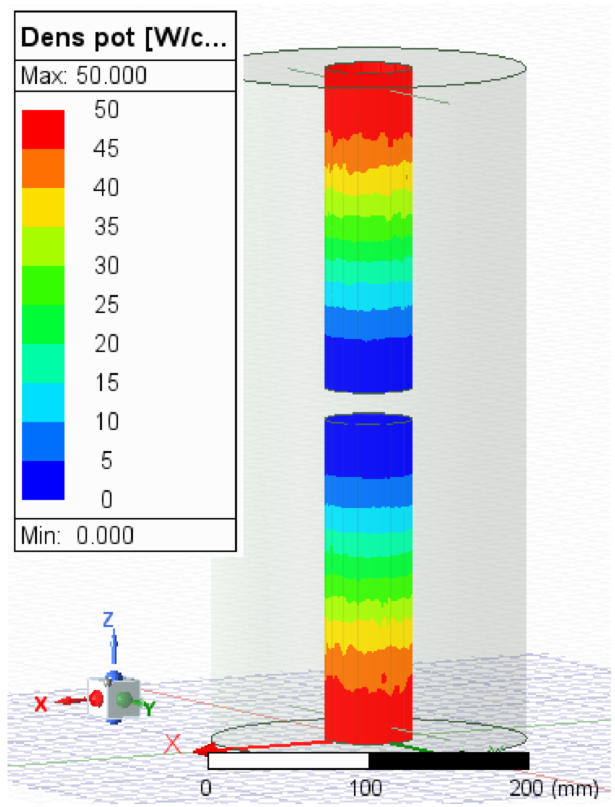
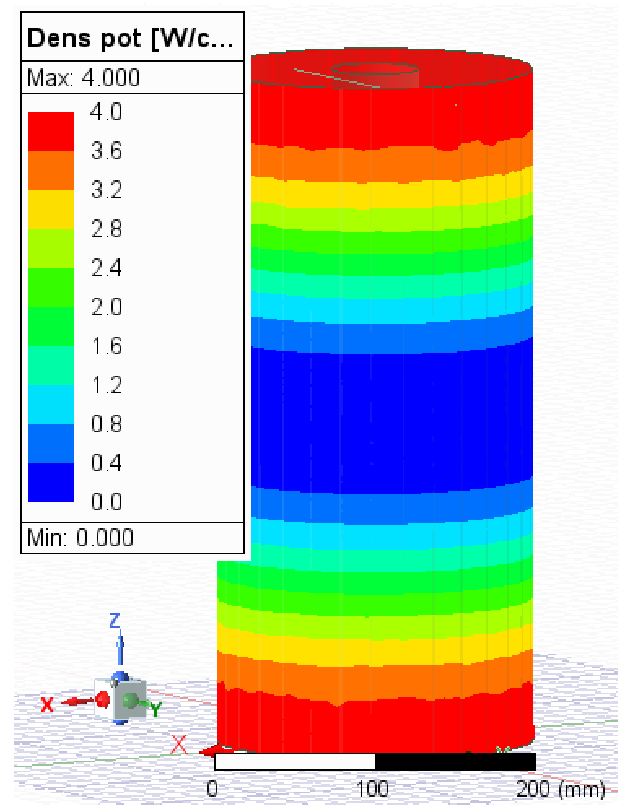


Plate 1

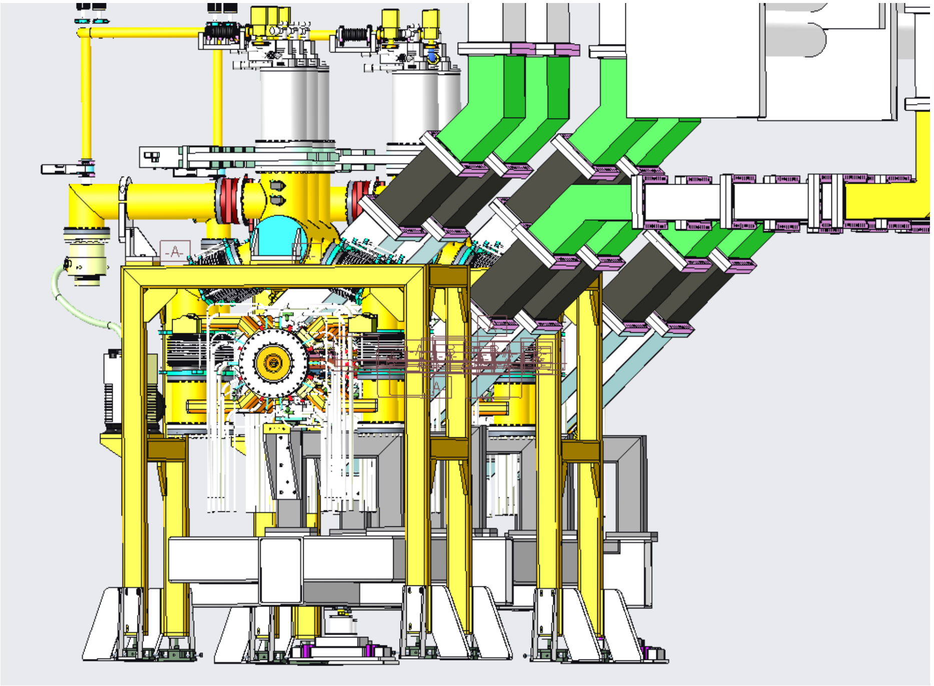


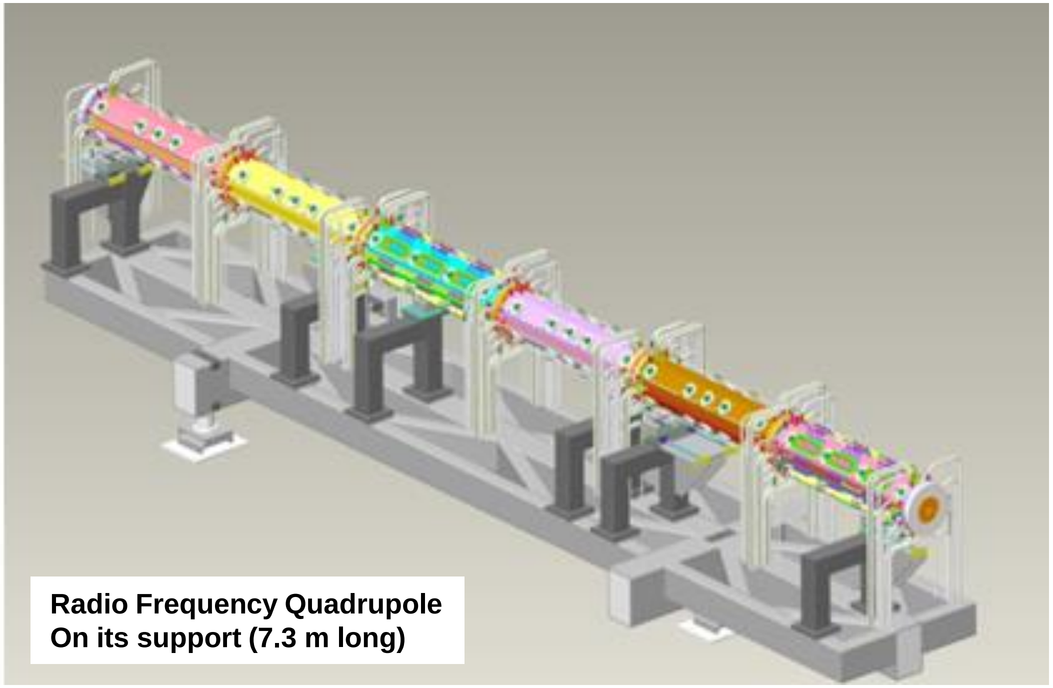
Cylinder int 1 and 2



Cylinder ext

TRASCO mechanical integration

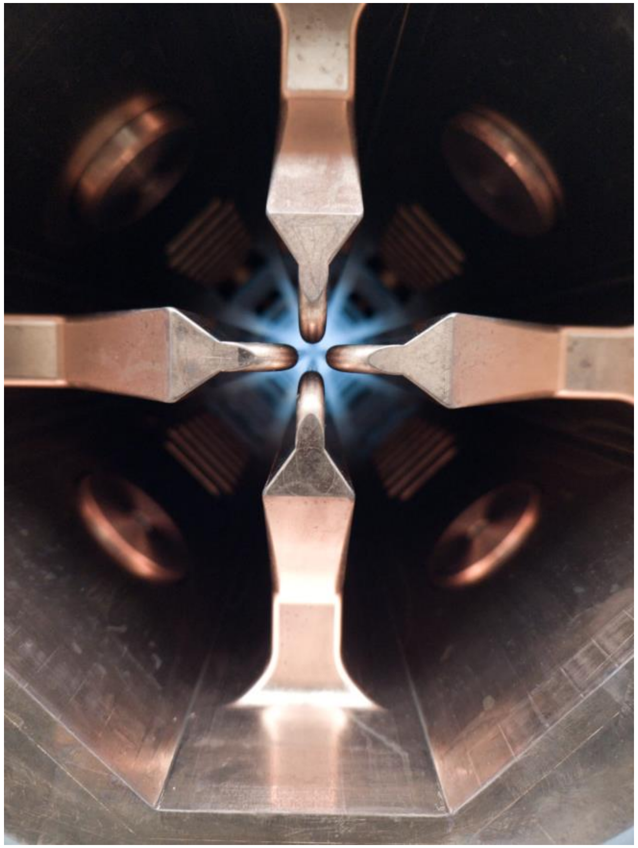




- Many components are available (RFQ modules, vacuum system, tuners and end cells…) the support and the couplers have to be built
- The integration will be updated by Torino group (on the bases of IFMIF and ESS experience)
- The idea is to have a single solid support to assemble and tune the RFQ at LNL and then transport it to Caserta

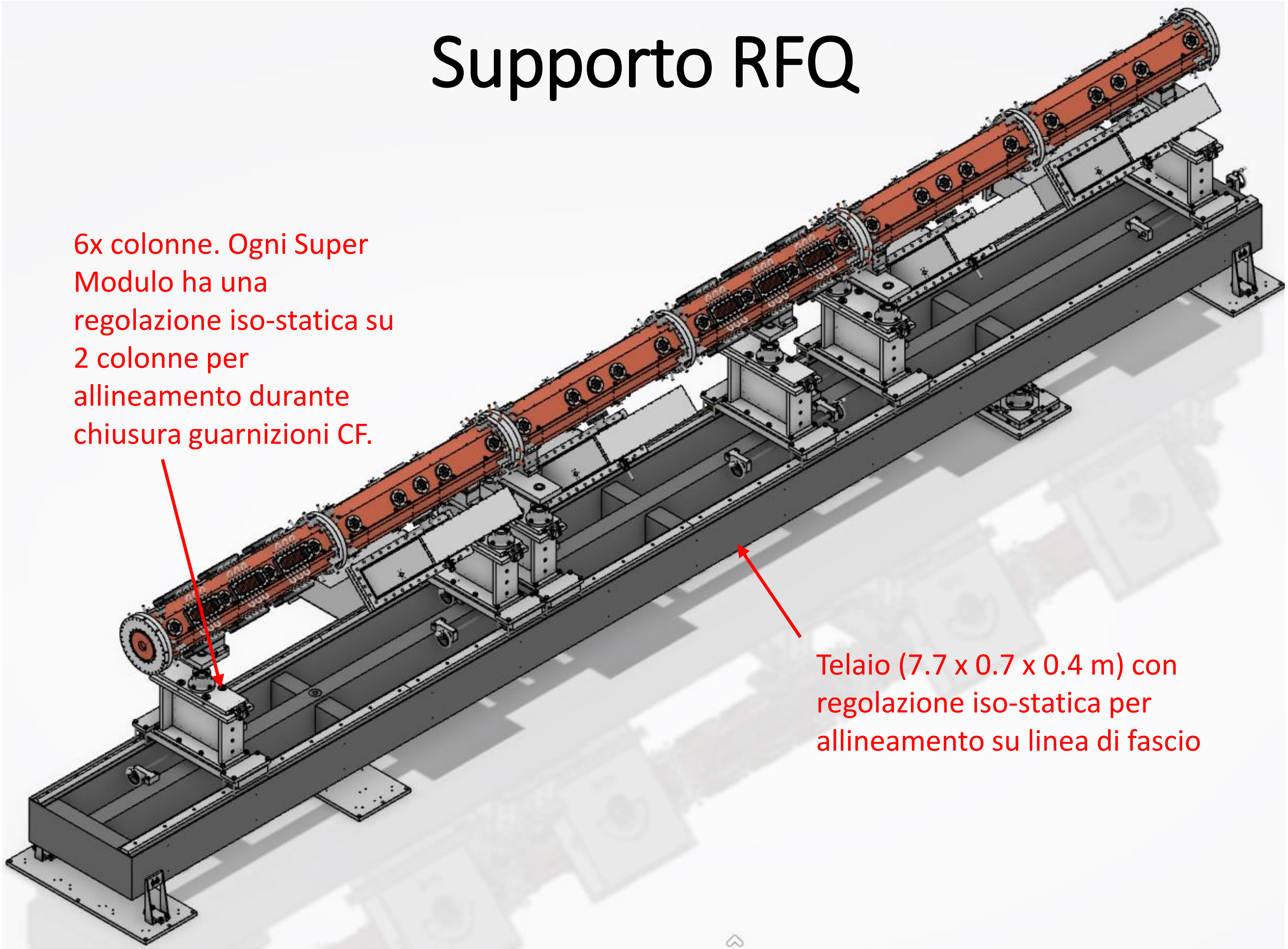
Attivita' RFQ a LNL: cavity assembly and tuning

1. **<u>Preparation of the 3rd experimental hall at LNL</u>**
2. **<u>Visual Inspection of the cavity modules</u>**
3. **<u>Ancillary removal (vacuum manifolds, water cooling hoses, tuners, end plates etc.)</u>**
4. Verification and/or production of dummy and coupling elements and 8 Aluminum dummy couplers
5. Production of bead pulling apparatus(*)
6. **<u>Design and tender for final RF ancillaries (couplers(**), end plates, coupling plates, tuners)</u>**
7. **<u>Decoupling of the modules connected together</u>**
8. **<u>Cleaning of each modules, including cooling channels (procedure to be discussed)</u>**
9. **<u>Implementation of references for fiducials and alignment</u>**
10. **<u>Support design and construction (single beam support as for SPES RFQ as a basic idea) (***)</u>**
11. Module to module coupling, vertically via pin references (3 "resonant segments" as output)
12. Resonant segment installation on the support
13. Resonant segment alignment with insertion of the dummy coupling cells and end cells
14. Cavity tuning with dummy elements (Milestone M24)



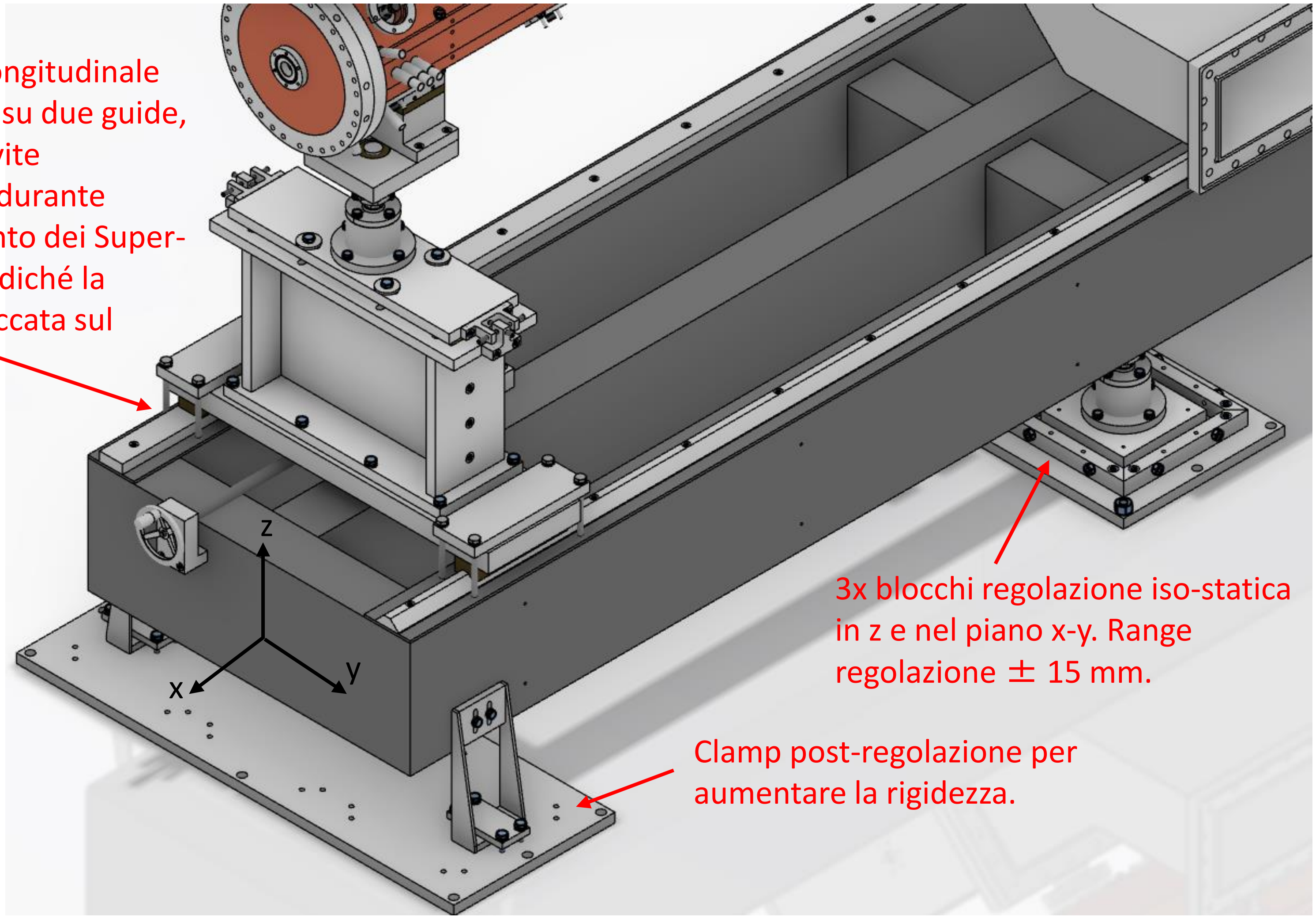
Francesco Grespan

Supporto RFQ



Paolo Mereu, Marco Nenni

Supporto RFQ-telaio



Movimento longitudinale delle colonne su due guide, regolato con vite trapezoidale, durante l'accoppiamento dei Super-Moduli. Dopodiché la colonna è bloccata sul telaio.

3x blocchi regolazione iso-statica in z e nel piano x-y. Range regolazione ± 15 mm.

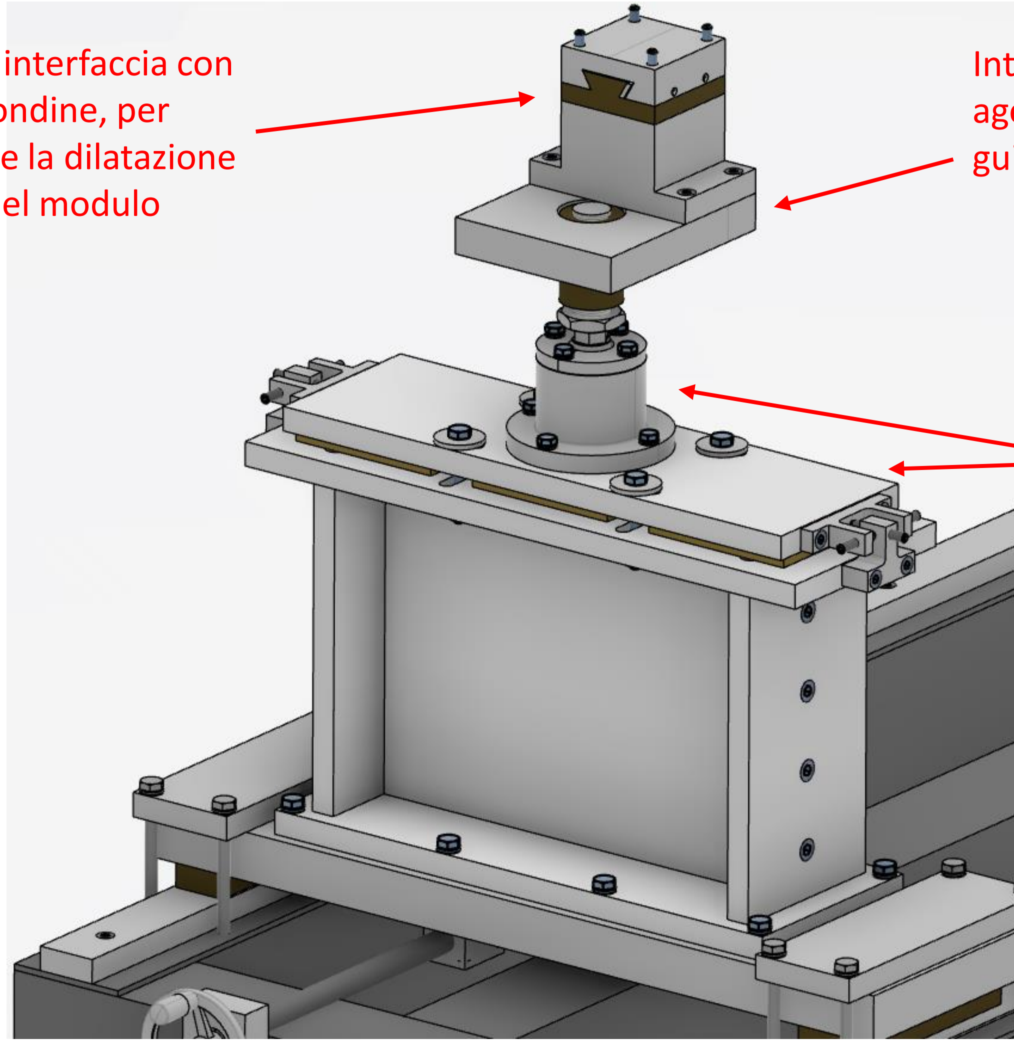
Clamp post-regolazione per aumentare la rigidezza.

Paolo Mereu, Marco Nenni

Supporto RFQ-colonne

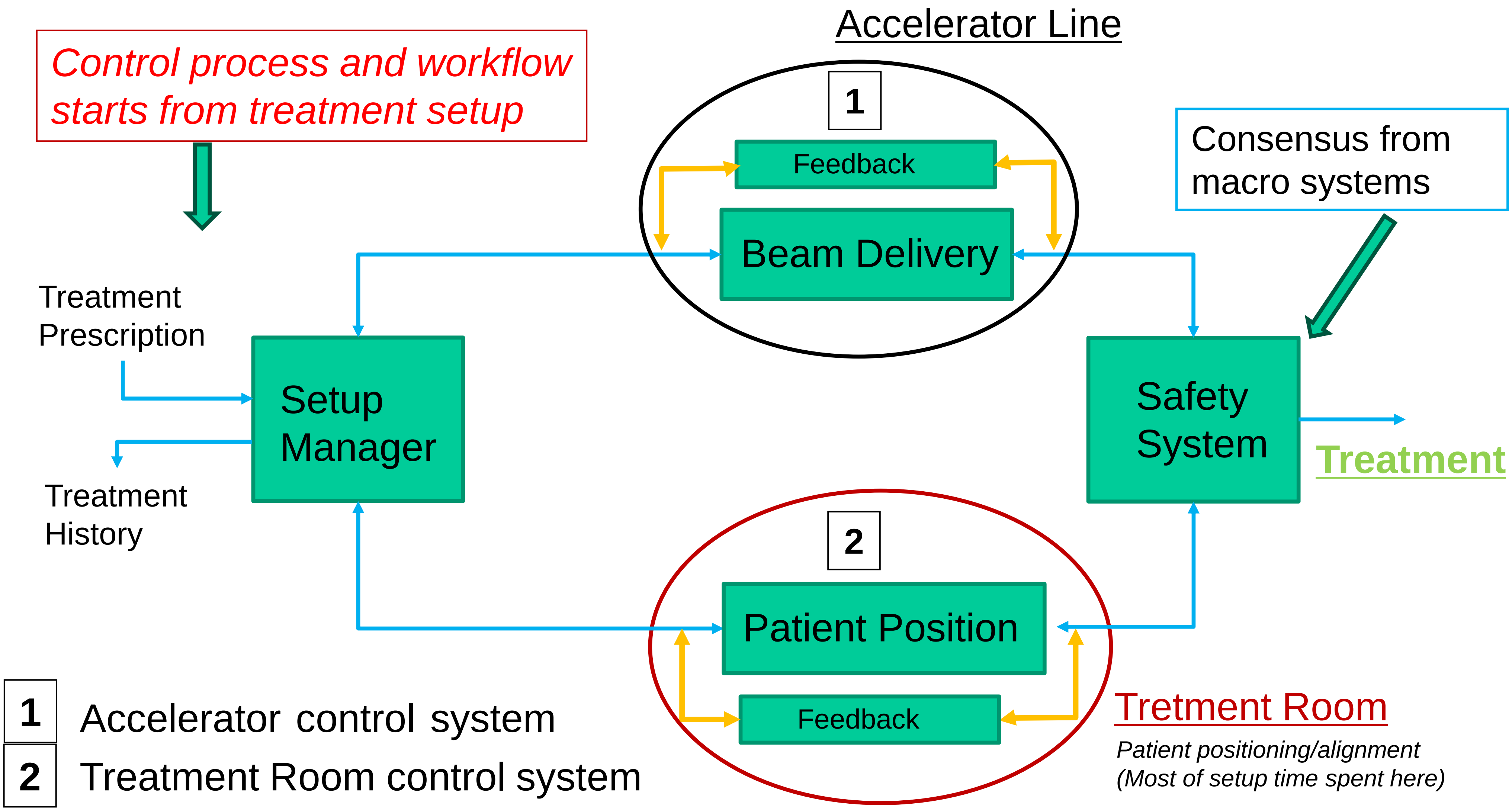
Blocco di interfaccia con coda di rondine, per consentire la dilatazione termica del modulo

Interfaccia RFQ eccentrica, per agevolare l'integrazione delle guide d'onda

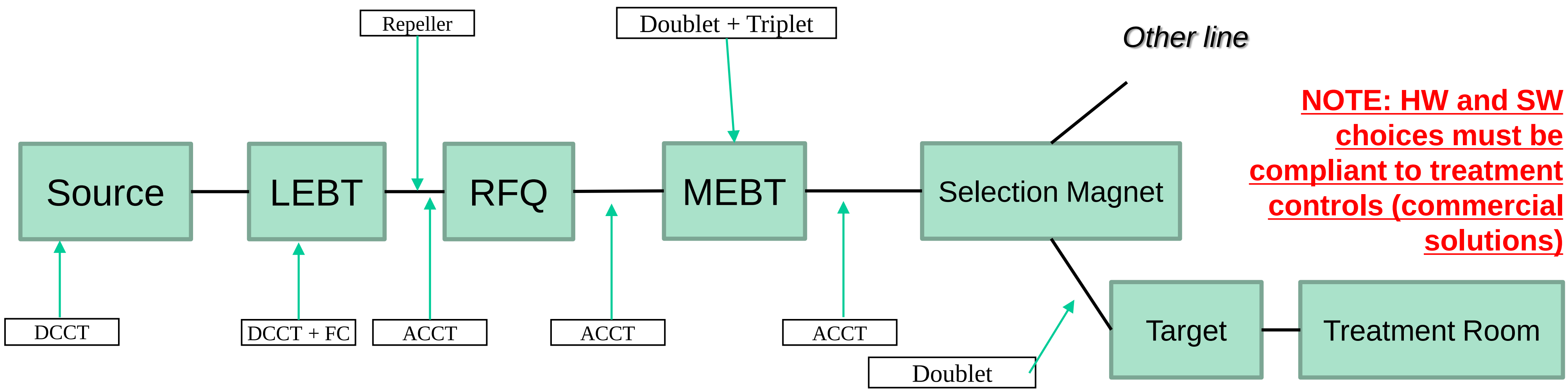


3x blocchi regolazione iso-statica (uno nell'immagine, due nella colonna all'altra estremità del Super-Modulo) in z e nel piano x-y. Range regolazione ± 10 mm.

Radiation Therapy Process - Control Diagram



Anthem Accelerator Controls



NOTE: HW and SW choices must be compliant to treatment controls (commercial solutions)

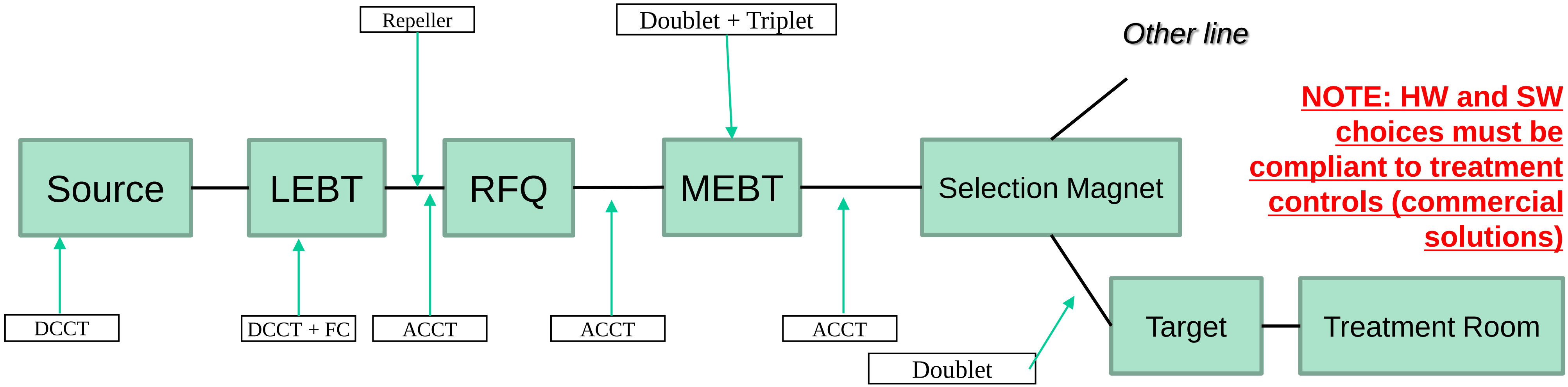
Accelerator Control System:

- **Ion Source**: HV platform and ground PLCs updated to Siemens family – software upgrade required; MPS update; FUG PS communication upgrade and direct interface to high-level control (EPICS); no beam profile used; DCCT to be integrated in high-level control (EPICS); cooling system upgraded required
- **LEBT**: lens PS based on CaenELS HW (already used in ALPI) - SW already available, minor modifications; FC requires integration to MPS system, PS upgrade for Repeller with CaenELS HW; DCCT and ACCT to be integrated in high-level control (EPICS)

Power Supplies - estimation

Elem	Num.	PS/elem	Total	Available
Lens	7	2	14	0
Steerers	2	2	4	4
FC/beamstop	1	1	1	0 (1 Glassman)
Solenoids	2	1	2	0 (2 Lambda)
Repeller	1	1	1	0

Anthem Accelerator Controls



NOTE: HW and SW choices must be compliant to treatment controls (commercial solutions)

Accelerator Control System:

- **RFQ**: logic and algorithms inherited by IFMIF controls (high-level logic); vacuum upgrade with actual SPES HW and SW – devices (pumps, etc.) must be checked before integration, logic update and configuration required; cooling skid based on ESS DTL controls, minor integration logic required (migration from ESS to Anthem SW standards); RF acquisition system upgrade (HW and firmware)
- **MEBT:** lens PS based on CaenELS HW (already used in ALPI), SW already available, minor modifications
- **Selection Magnet:** device control must be interfaced to high-level control (EPICS)
- **Target and MPS:** preliminary design stage, investigations in similar sites are required

Preliminary Timeline

- **2023**
  - **Creation of contact network of BNCT's control system experts (VCs, visits, seminars, proton school course)**
  - **Detailed design of Munes CS status and requirements to upgrade to Anthem**
  - **Preliminary conceptual design of Anthem Control System until end of 2023**
  - **Purchase IT items (WS, networking, NAS, etc..)**
  - **Man Power Recruitments**
- **2024**
  - **Started development of the Accelerator Control System**
  - **Started purchasing of necessary items to Accelerator Control System**
  - **(*TBD*) Purchase of Patient Room control System with integration capability**
- **2025**
  - **Completion of Machine Control System and commissioning with power-tests @LNL** **[MS09 – M30]**
  - **(*TBD*) Completion of treatment apparatus**
- **2026**
  - **Integration of Treatment apparatus with Accelerator control System @Vanvitelli** **[MS13 – M42]**

2 IL PROGETTO

INQUADRAMENTO DELL'AREA DI PROGETTO

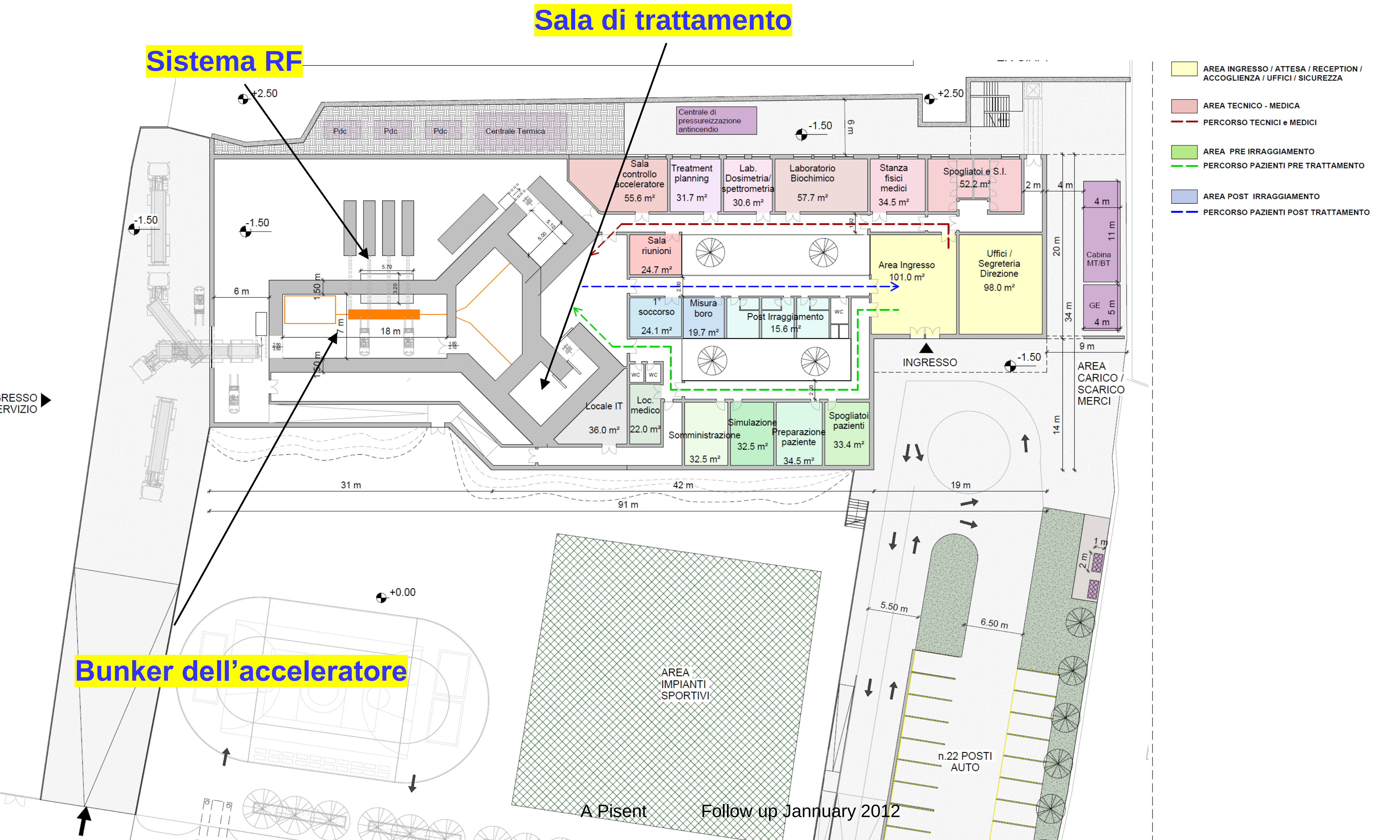
BNCT - NUOVO CENTRO DI PROTONTERAPIA DI CASERTA

Il Progetto riguarda la costruzione di un nuovo edificio per l'alloggiamento dell'acceleratore di particelle per la produzione di fasci di neutroni e delle attrezzature ad esso collegate posto a ridosso del fabbricato ex Ciapi di San Nicola La Strada di Caserta per la radioterapia **BNCT – Boron Neutron Capture Therapy a Caserta** (il «BNCT"), un centro innovativo per la sperimentazione e la cura dei malati tumorali.

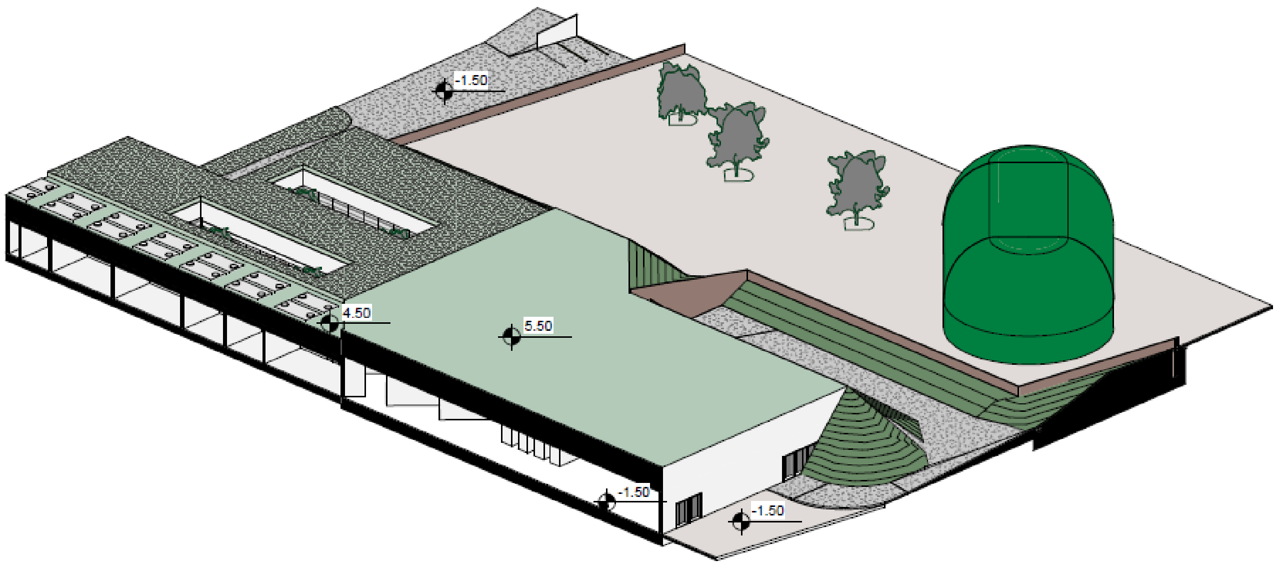
Il Centro, in fase di sviluppo, consentirà alla Regione Campania un riconoscimento quale Centro di Eccellenza e di Ricerca internazionale per la Radioterapia delle malattie oncologiche. Sarebbe il primo macchinario del genere in tutto il Centro Sud Italia, il secondo in tutta Italia.

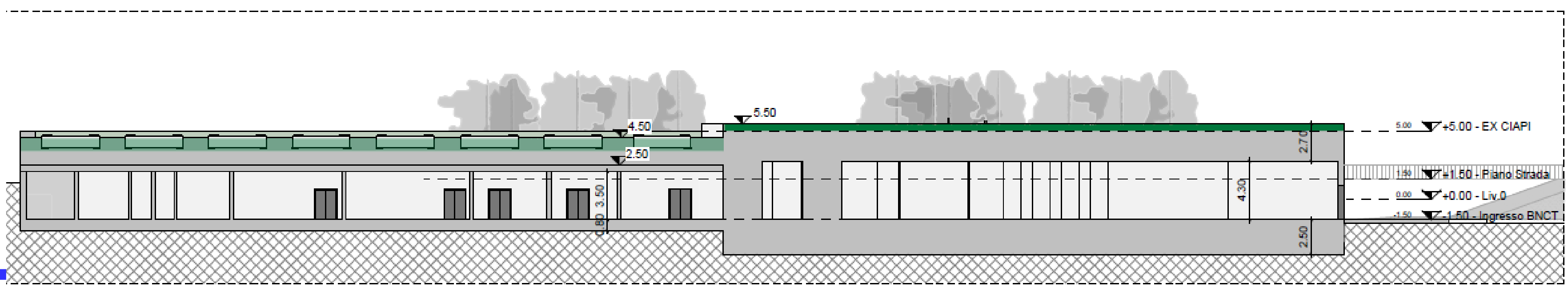
Trattandosi di una tecnica basata su radiazioni nucleari generate da macchinari pesanti e di non semplice sostituzione, le caratteristiche del nuovo fabbricato dovranno essere compatibili con la tipologia della attività terapica, tenendo in speciale considerazione gli aspetti ambientali, strutturali e funzionali.

Lay out of the building (under definition)



SEZIONE

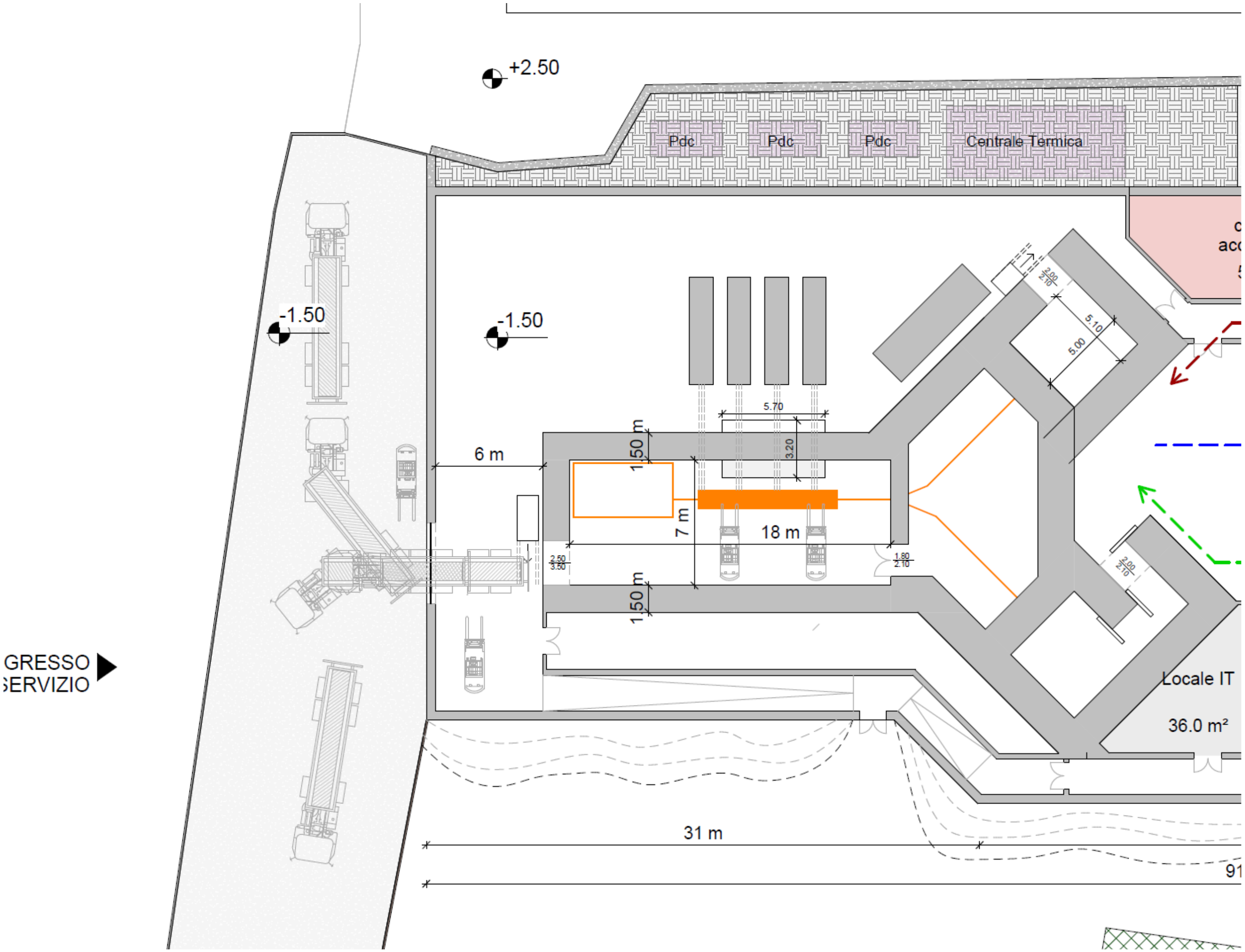

-1.50
4.50
5.50
-1.50
-1.50


5.50
4.50
2.50
+5.00 - EX CIAPI
+1.50 - Piano Strada
+0.00 - Liv.0
-1.50 - Ingresso BNCT

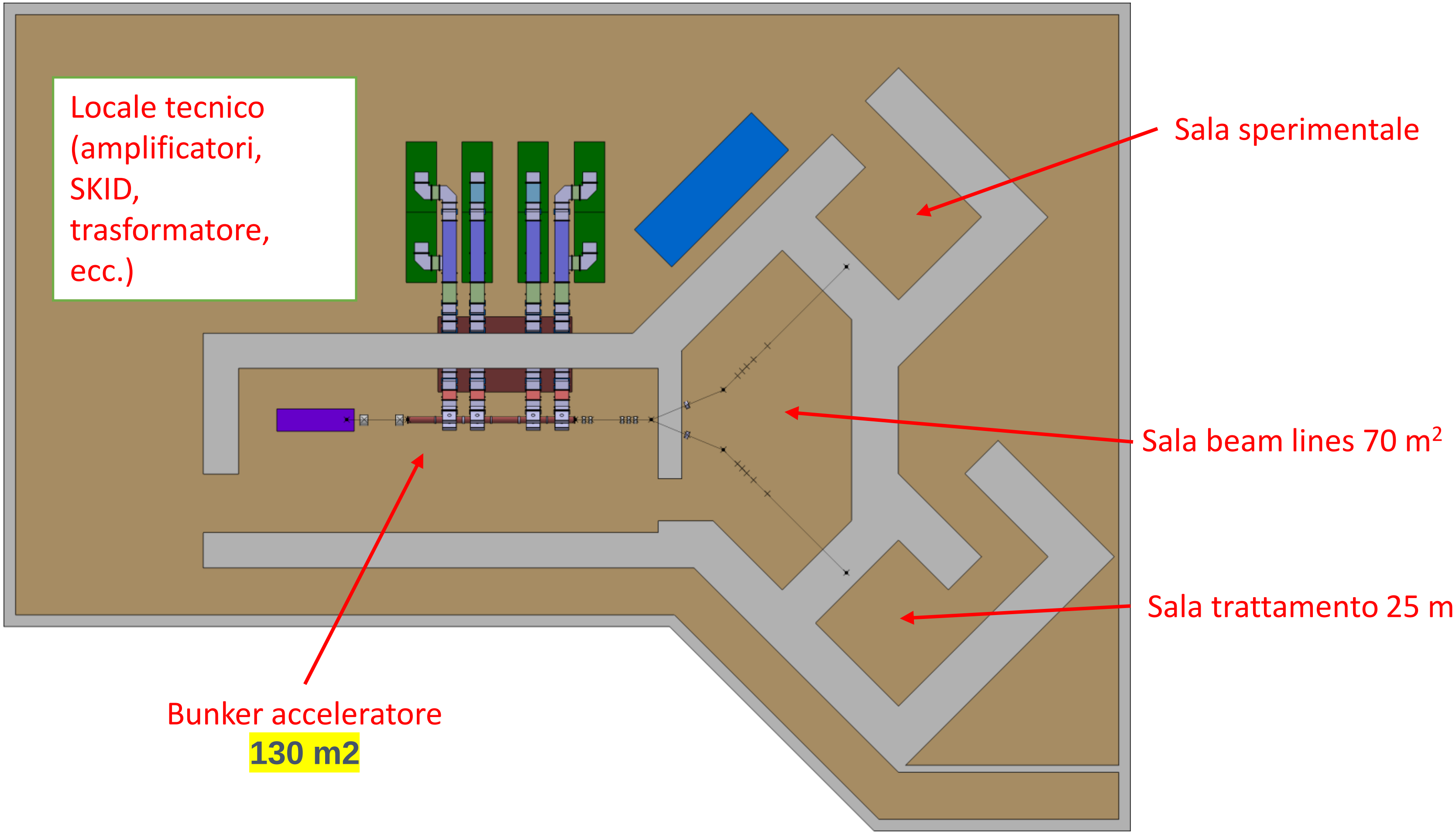
3 IL PROGETTO

VALORIZZAZIONE DELLE AREE

Accesso del camion con l'RFQ



Layout edificio
integrazione meccanica di INFN To



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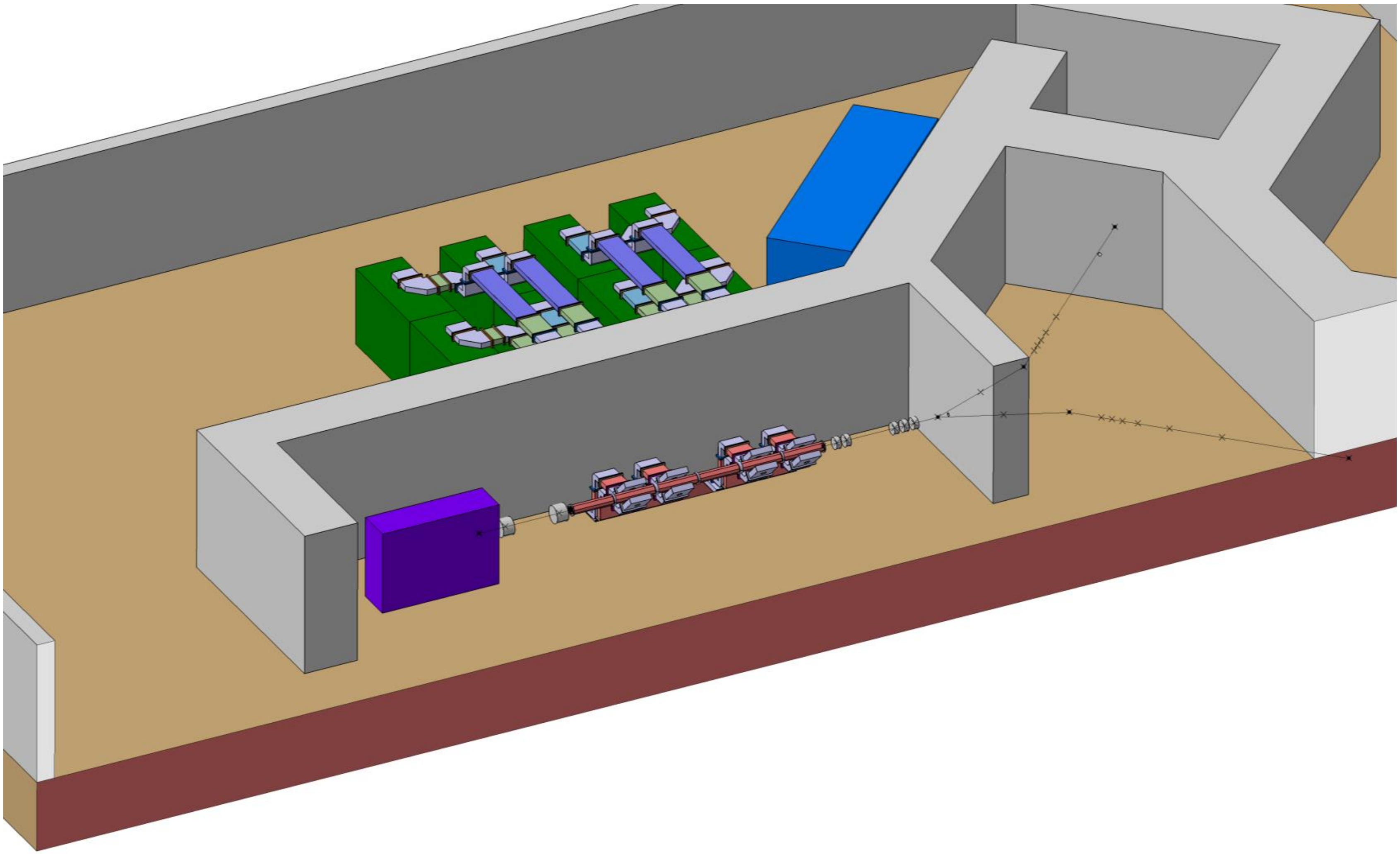
Layout edificio



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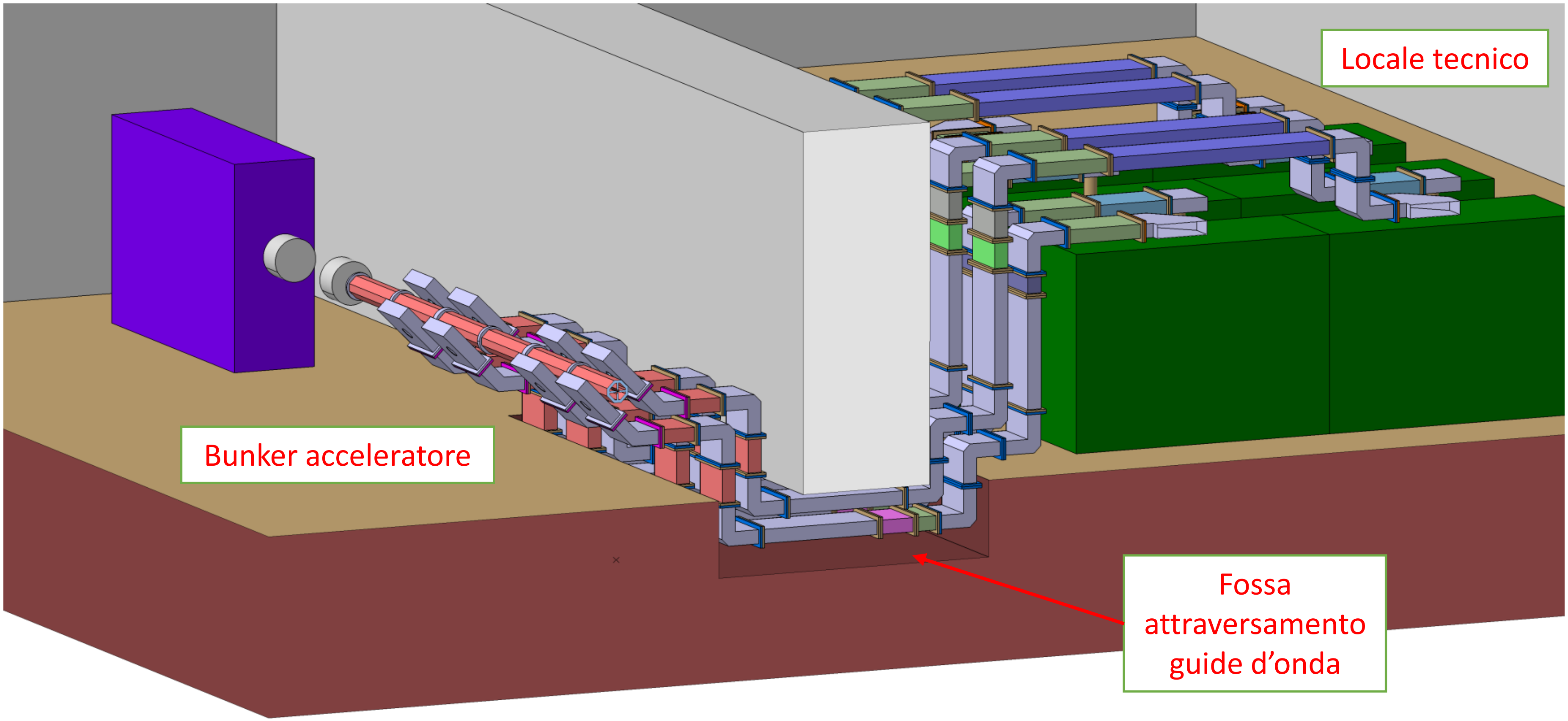
Attraversamento guide d'onda



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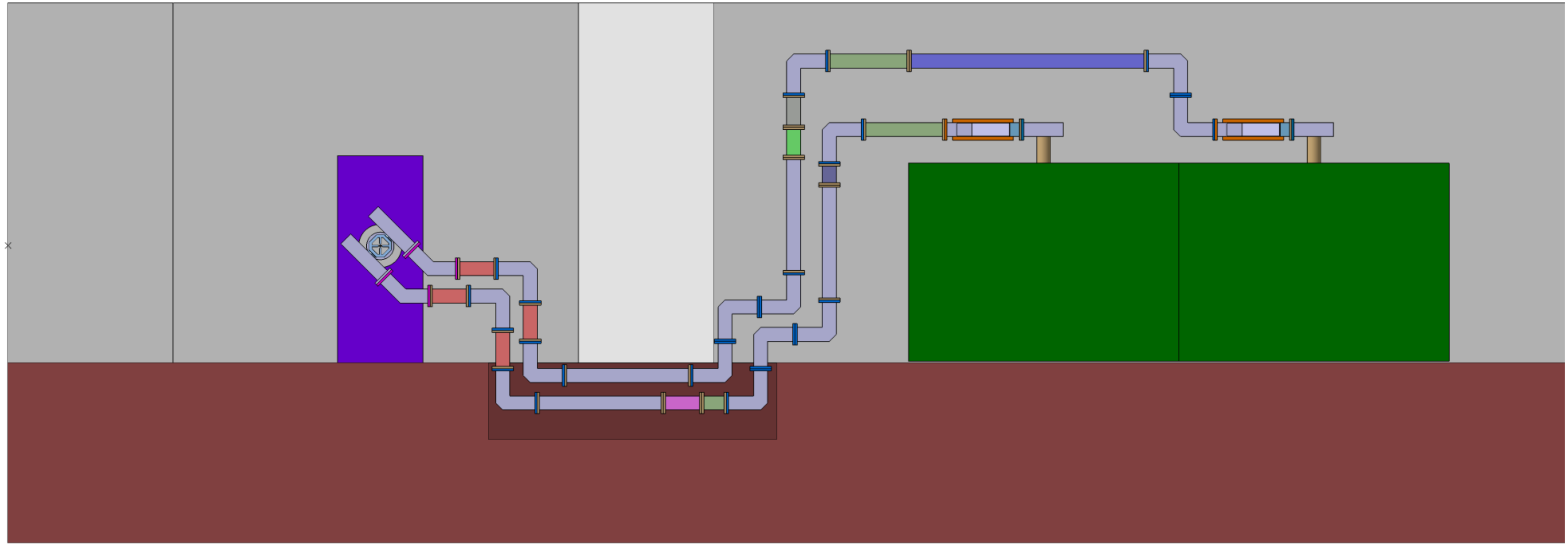
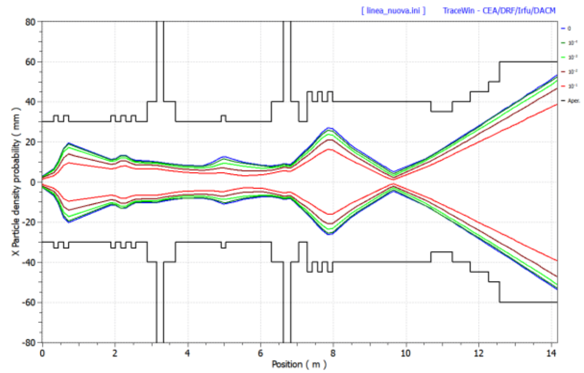
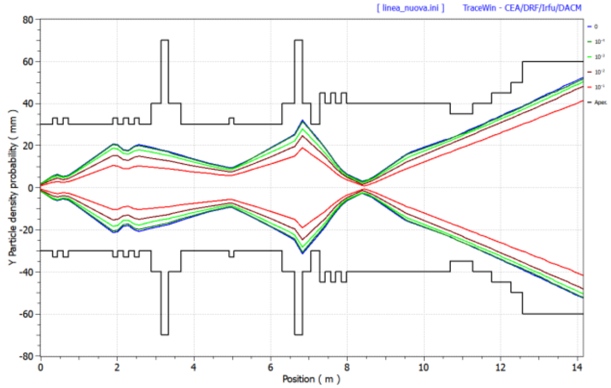
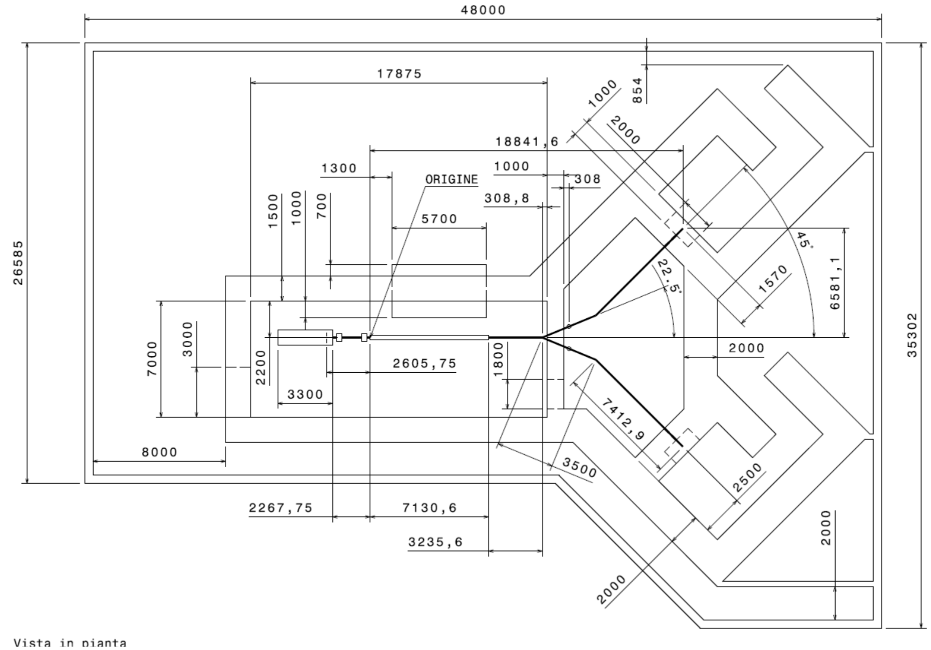


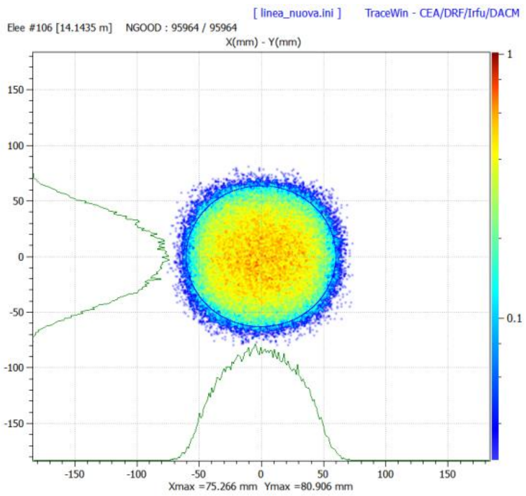
Paolo Mereu, Marco Nenni

transport Line layout

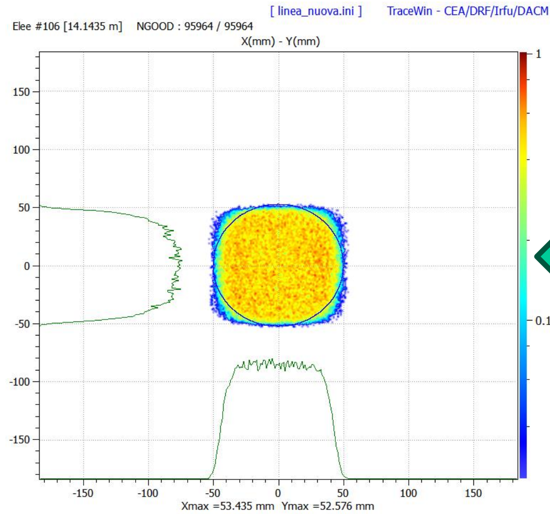


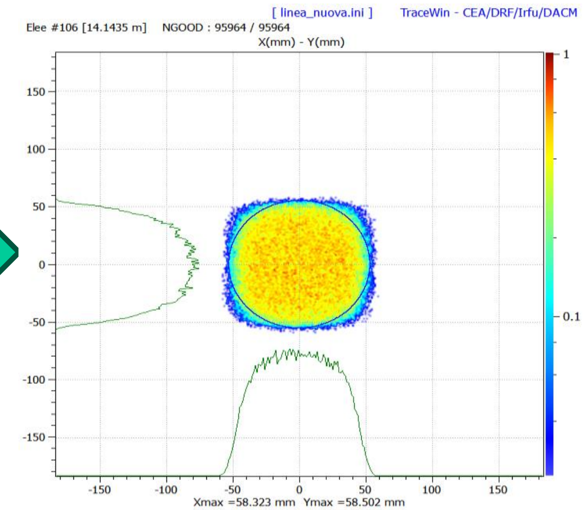






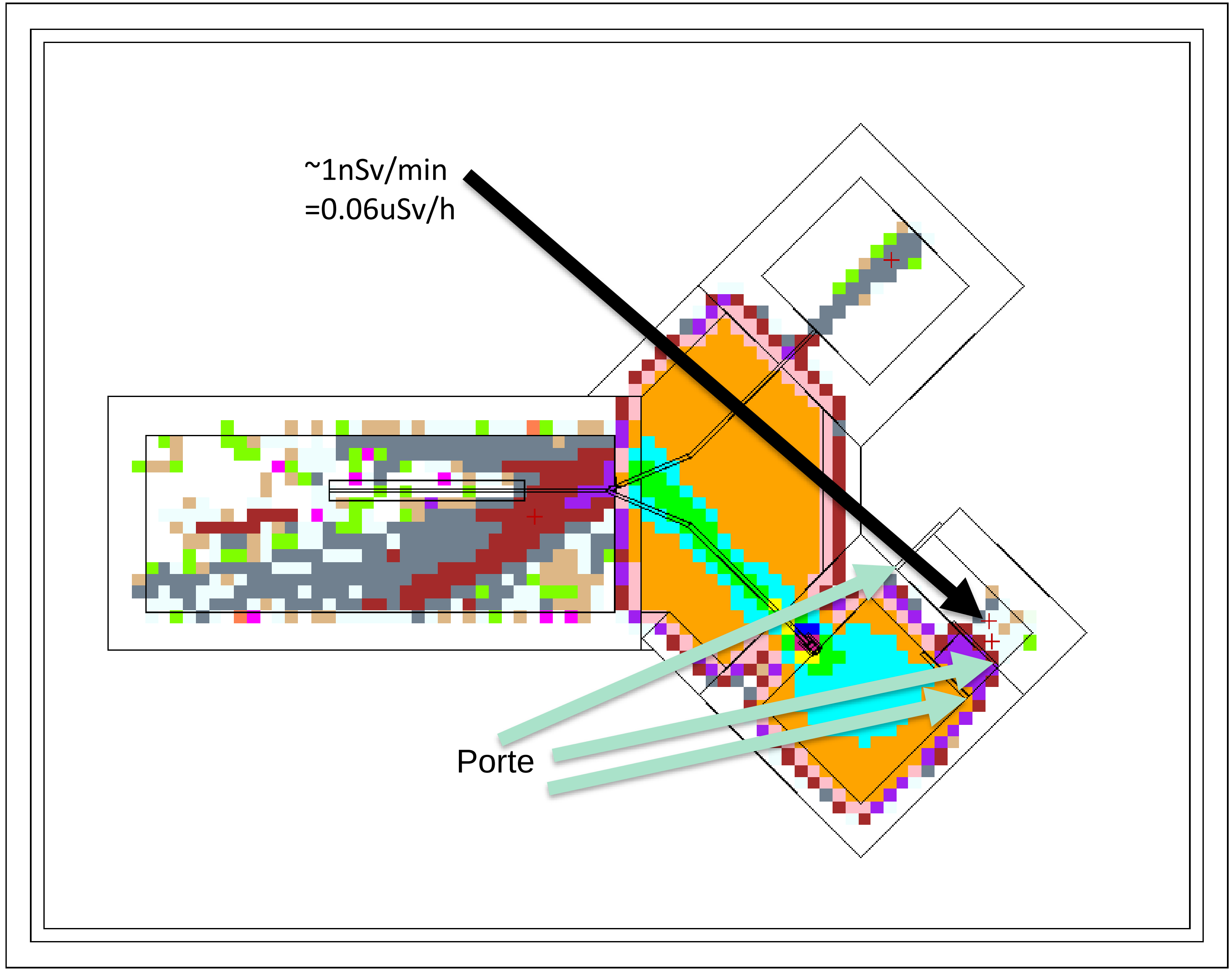
Octupoles action



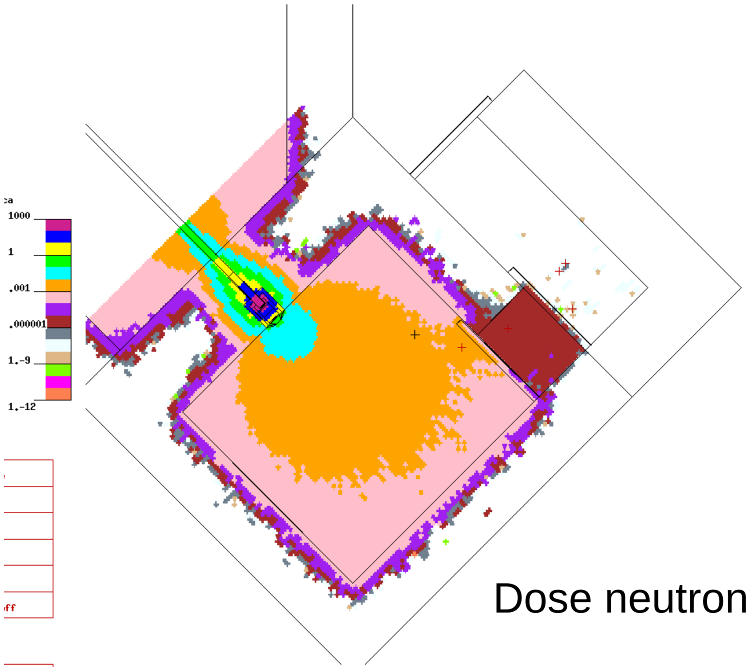


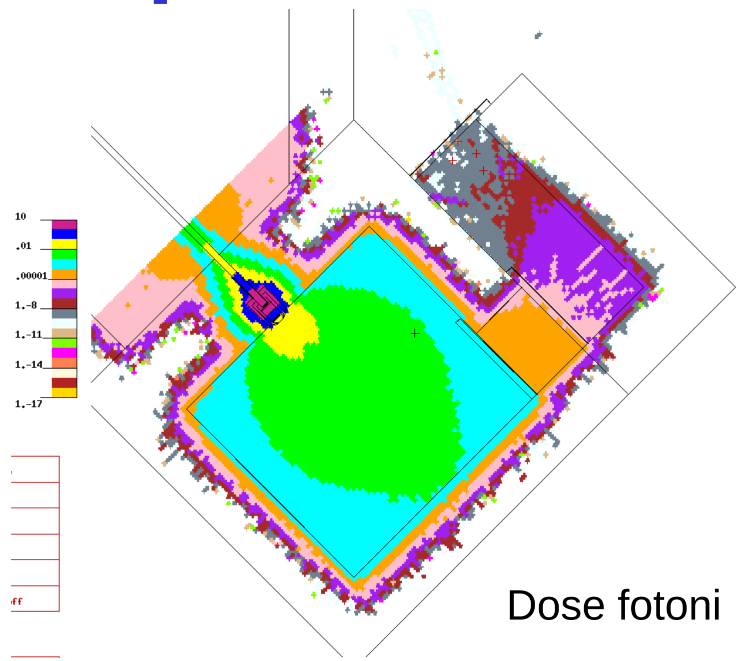
Distribuzione di dose nella facility

Rate di Dose **Neutroni** in Sv/min
Flux converted to Dose (kerma A 150 *) then to Equivalent Dose (Wr **)



Risultati con 3 porte





Pareti della stanza ridotte a 1.5 m sembrano essere sufficienti, bisogna aumentare il numero di particelle di sorgente per affermare questo con maggiore confidenza.

3 Porte sono sufficienti ad abbattere i neutroni. Bisogna valutare se aggiungere del boro nel primo strato di polietilene per abbattere i fotoni generati sulla seconda porta. (Ongoing)

Valutare architettonicamente se e' possibile avere la porta mobile nella sala sperimentale !

Direct contacts with Tsukuba University iBNCT

Beryllium target assembly and treatment bed at iBNCT

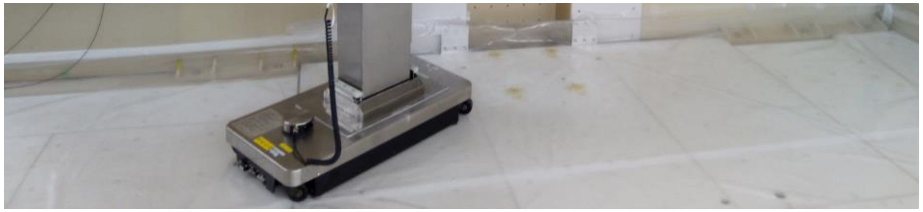
Direct contacts with Tsukuba University iBNCT

Francesco Grespan
INFN-LNL
ESS Lund
+46 72 179 24 52
+39 393 32 49 110

From: Hiroaki KUMADA <kumada@pmrc.tsukuba.ac.jp>
Sent: martedì 4 luglio 2023 11:55
To: 'francesco grespan' <Francesco.Grespan@lnl.infn.it>; 'Hasegawa Kazuo' <hasegawa.kazuo@qst.go.jp>
Cc: 'fang' <fang@post.kek.jp>
Subject: RE: request of meeting about BNCT

Dear Dr. Grespan-san,

Thank you for your interesting mail.
I know your concept for the accelerator neutron source for BNCT of 5 MeV x 30 mA = 150 kW.
This specification is very challenging and interesting.
My impression when I heard the specifications was that if you success to generate neutrons stably with these specifications,
it would be the most ideal accelerator neutron source for BNCT.



Beryllium target assembly and treatment bed at iBNCT

Conclusions

- Pilot 4.9 of Anthem project foresees the realization in Caserta of a BNCT facility for epithermal neutrons.
- The project (4 years foreseen)
  - Use of existing main components still at technology frontier.
  - the participation of LNL, LNS, Pavia, Torino and Napoli INFN sections.
  - Procurement of many components with Napoli and LNS.
  - The experimental test at LNL of many component
  - INFN follow up of the design and realization of the installation at Caserta site
- Thanks for your attention