Status of RFQ and RF

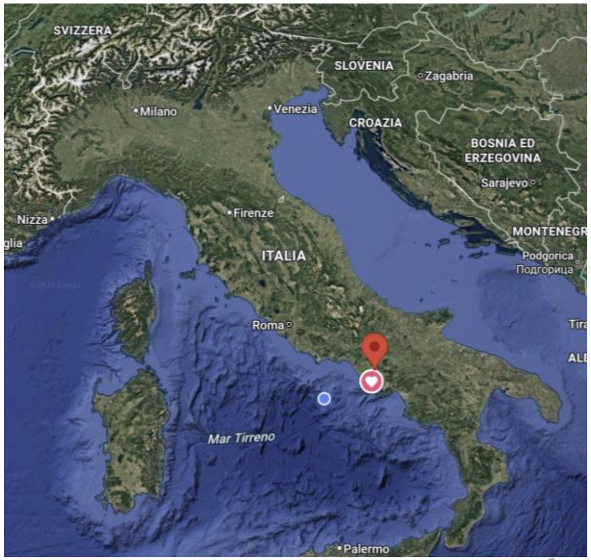
ANTHEM

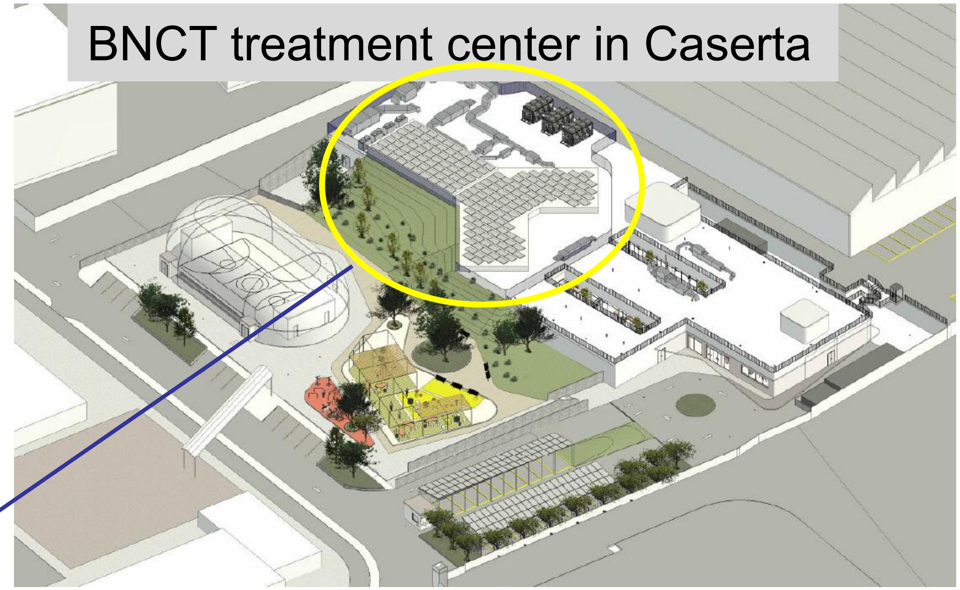
Outline

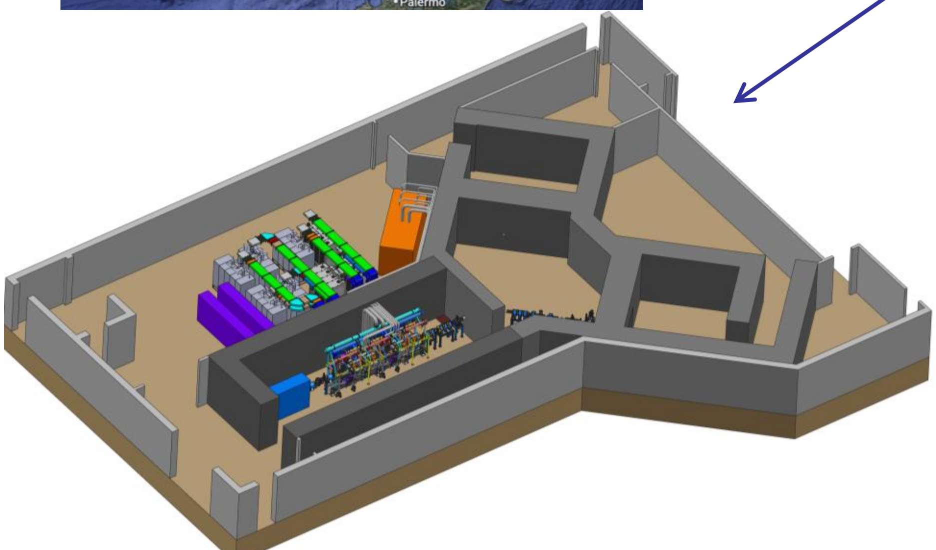
- Overview of the project
- RF system architecture
- RFQ: tuning, integration, couplers
- Ion source and LEBT
- Conclusions

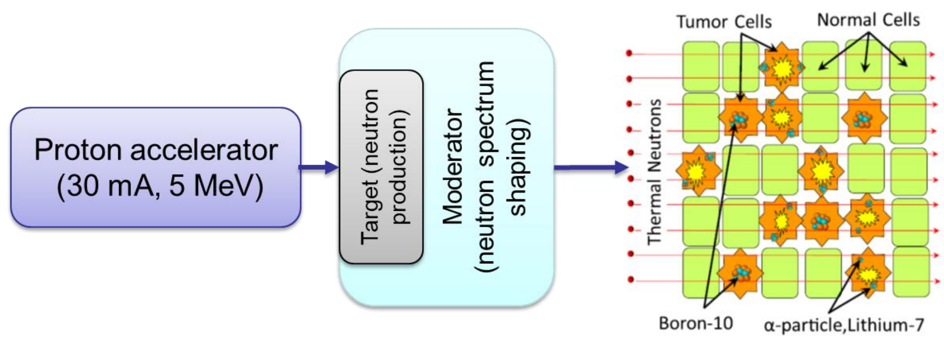
- **INFN – Laboratori Nazionali di Legnaro – acceleratore e target**
  - F. Grespan, C. Baltador, L . Bellan, A. Bianchi, D. Bortolato, M. Comunian, V. Conte, J. Esposito, E. Fagotti, L. Ferrari, M. Montis, Y. Ong, A. Selva, A. Palmieri, A. Baldo, P. Bottin, A. Colombo, P. Francescon, A. Pisent
- **INFN – Sezione di Napoli - acceleratore**
  - M.R. Masullo, A. Passarelli, L. Gialanella, L. Bagnale, D. Pistone, G. Porzio
- **INFN – Sezione di Torino – acceleratore e integrazione**
  - Paolo Mereu, Carlo Mingioni, Marco Nenni, Edoardo Nicoletti
- **INFN – Sezione di Pavia - BSA**
  - S. Bortolussi, I. Postuma, S. Fatemi, R. Ramos, B. Marcaccio, A. Kourkoumeli, A. Lanza, V. Vercesi – Principal Investigator INFN retired cum laude

ANTEHM BNCT project overview









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ANTHEM BNCT project overview

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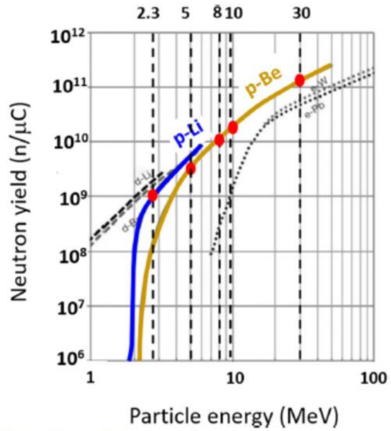
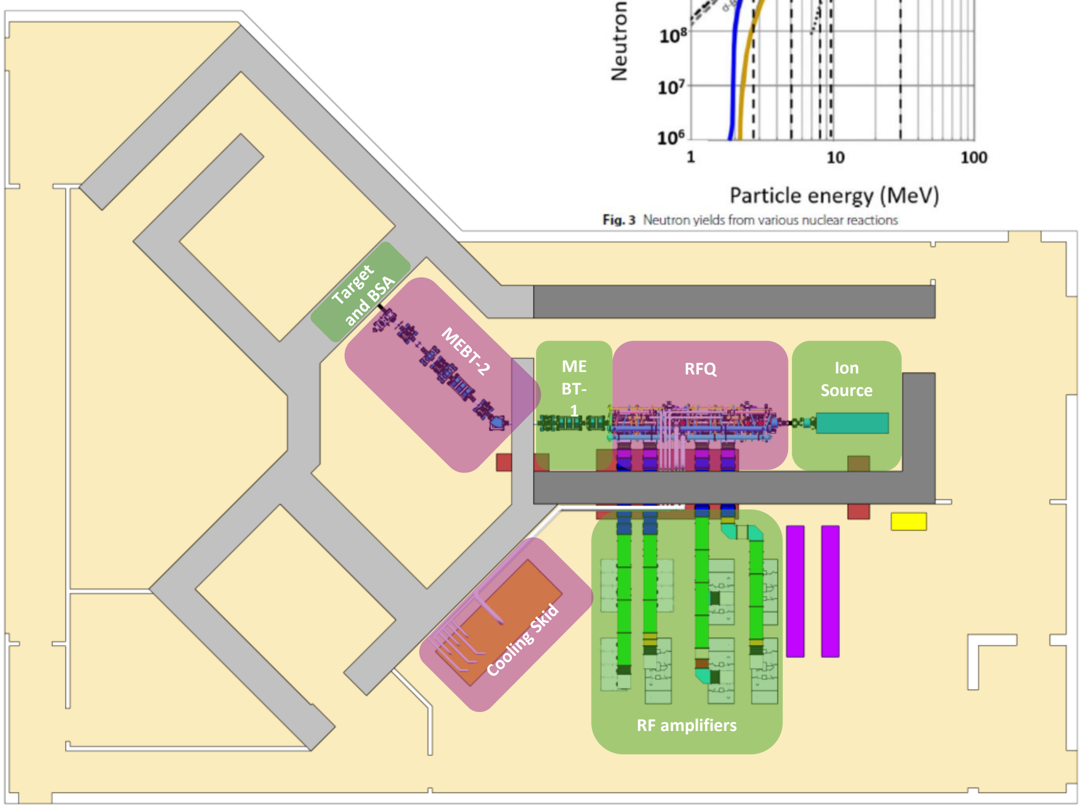


Fig. 3 Neutron yields from various nuclear reactions

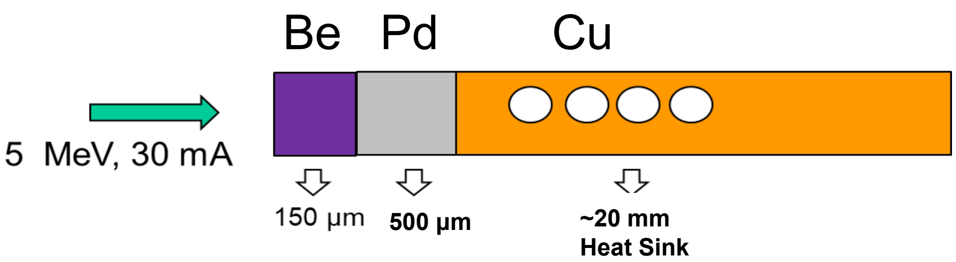


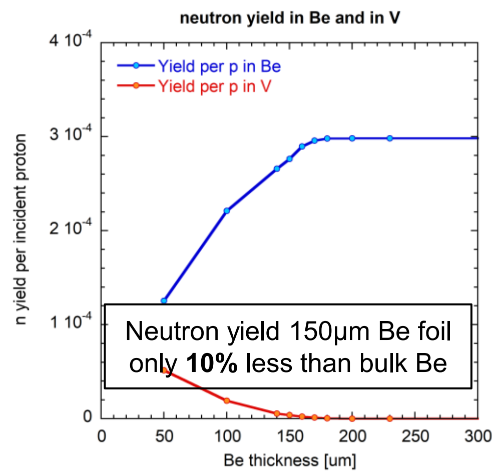
Parameter	Value	Notes
Ion source	MDIS	H+, 80 kV
Accelerator type	RFQ	352.2 MHz, 7.13 m
Output energy	5 MeV	
Beam current	30 mA	accelerated
Duty cycle	100 %	Lower DC possible
p-n Converter	Beryllium	150 kW, 1kW/cm^2
Neutron yield	~10^{14} s^{-1}	ave. energy 1.2MeV (4π)
Neutron flux	~10^9 s^{-1}cm^{-2}	Epithermal @ BNCT port
RF power	1.0 MW	$(P_{Cu}+P_{Beam}) \cdot 1.3$
Installed Power	~3.5 MVA	
Total length	25 m	ISRC extraction to target

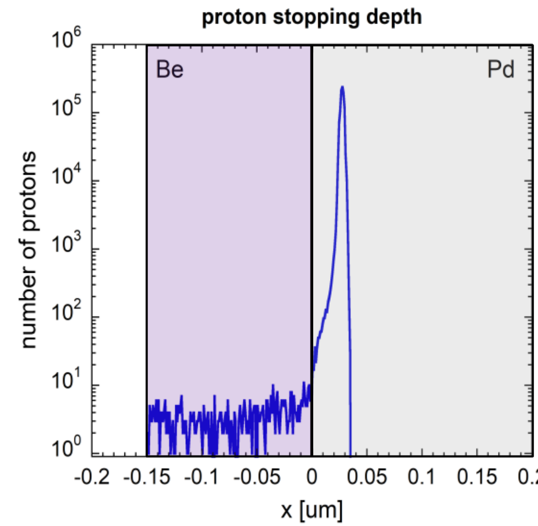
Beryllium preferred to Lithium

- better mechanical and thermal properties (Melting point [Be]=1278°C, Melting point [Li]= 180°C, Therm.Cond.[Be]=201 W/mK, Therm.Cond.[Li]=85 W/mK).
- With H+ irradiation, lithium produces tritium and beryllium-7, a radioactive isotope with a half-life of 53 days
- Comparable n-production at 5 MeV

Target general requirements





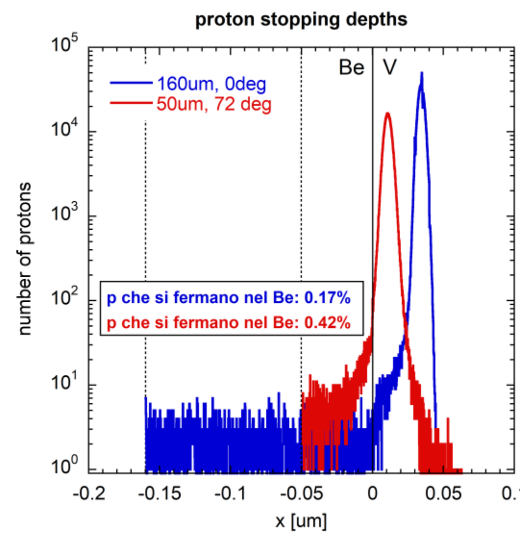


Composite n-target separated functions:

- Be layer → maximizes neutron production (150 um)
- Pd layer → blistering tolerant material, proton beam stop here (Bragg peak in Be at 230 um)
- Cu bulk for power dissipation
- bonded using a hot isostatic pressing (HIP) method, to have high level of mechanical, electrical and thermal continuity without additional alloys or welding

Heat-sink system performance design parameters:

- operation mode: 150 kW power (CW)
- power areal density: ≥ 1 kW/cm²
- water temperature < 100°C and the Be surface tempera-ture < 300°C
- heat transfer coefficient HTC to be maximized ($h = \frac{P_{dens}}{\Delta T} > 5 \cdot 10^4 \ W/m^2K$)
- The beam collide perpendicularly on the target. An angular target (preferable for power density dilution) increase the risk of blistering and require too high precision on the layer thickness



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Target Thermal design

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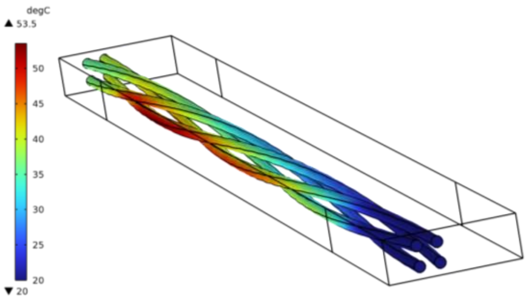


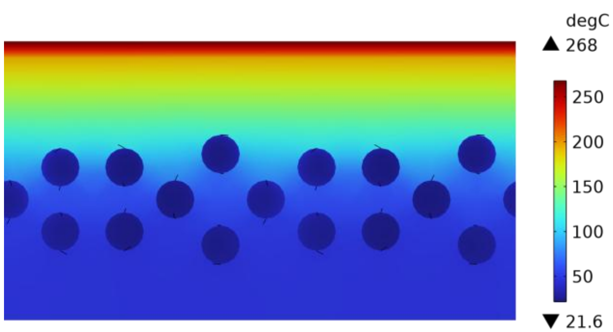
Beam pwr dens:	1	[kW/cm^2]
Cooling channel diam:	1.5	[mm]
Be foil	150	[µm]
Pd foil	500	[µm]

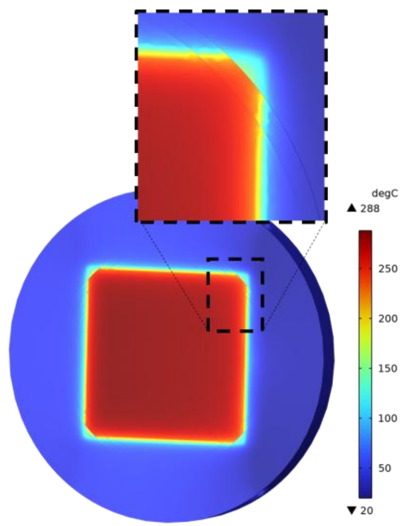
Helix channels design:

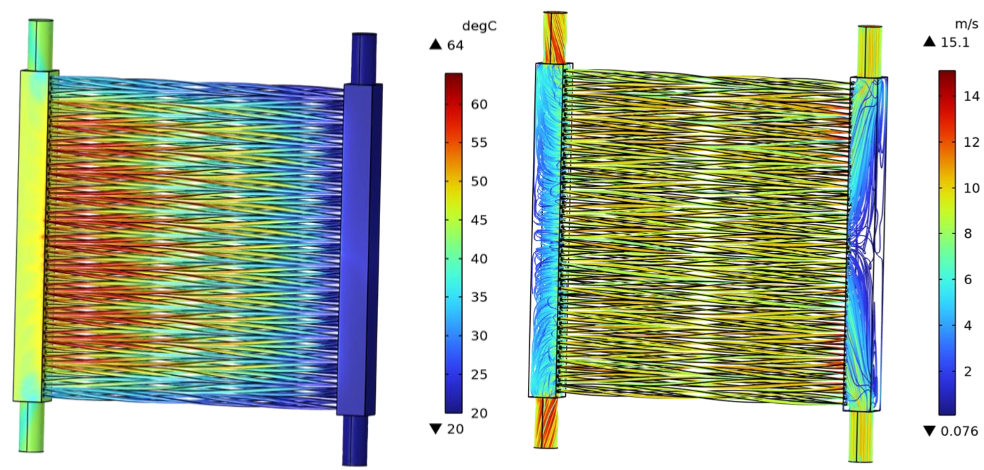
Pro: 4 cooling channels in the same row

Cons: feasible via 3D printing only

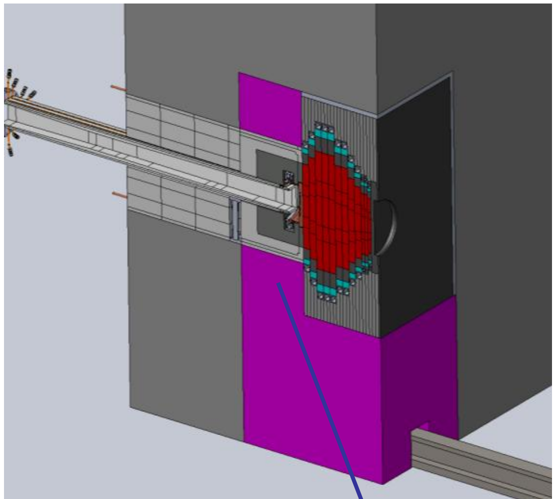
flow [l/min]	velocity [m/s]	pressure drop [bar]	Be surface temp [°C]	Cu surface temp [°C]	Hc [W/(m²·K)]	Max water Temp [°C]
80	7,3	2,1	300	212	51975	73
100	9,1	3,2	288	201	55325	64
120	11,0	4,6	278	192	58093	58
150	13,7	7,1	268	183	61500	52

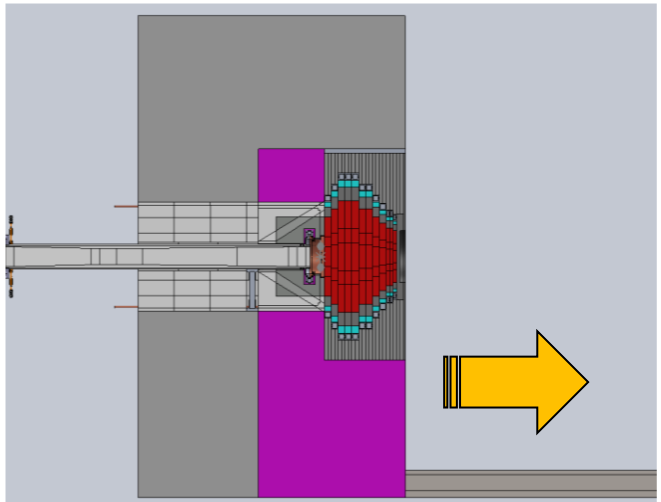


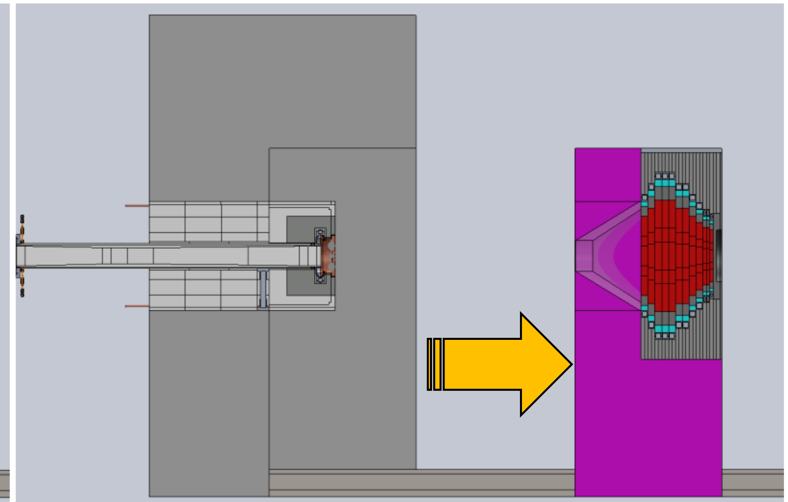


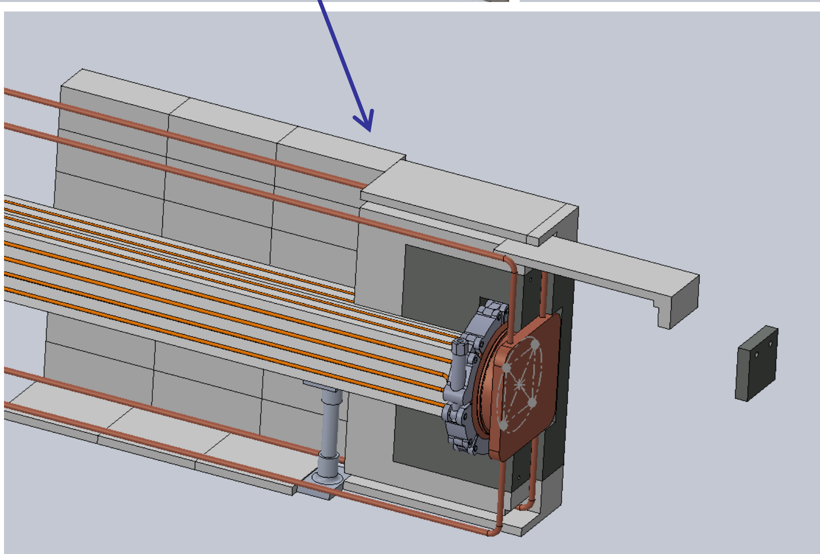


Target-BSA integration

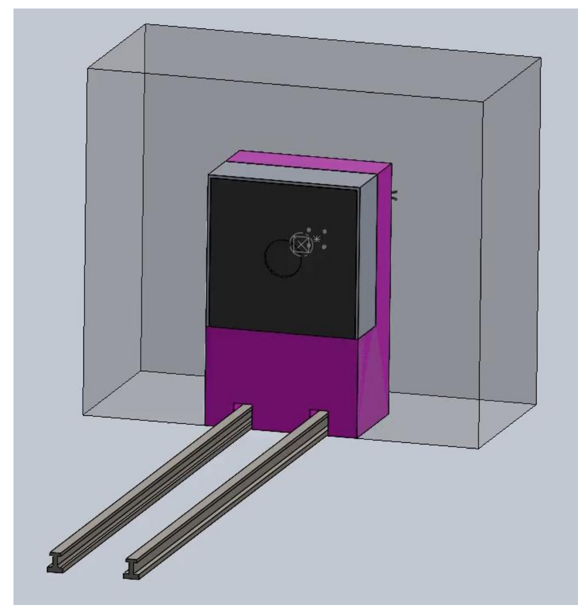








Baltador



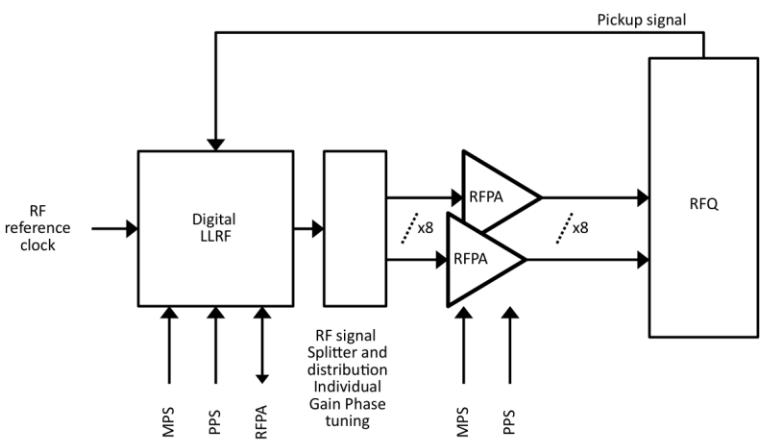
RF system

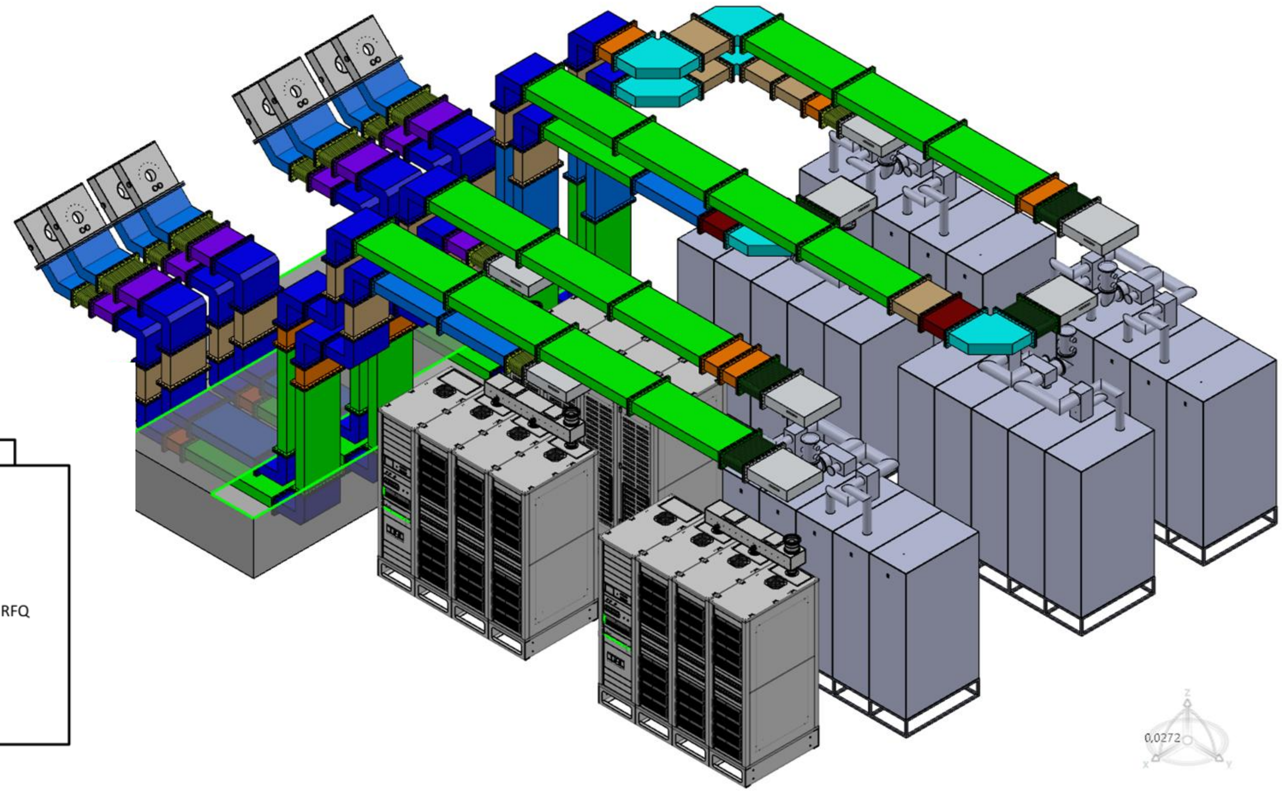
5 “old” SS amplifiers to be updated.

3 new amplifiers.

RF System peculiarities:

1. 8 amplifiers are directly connected to the same cavity.
2. No circulator to protect the RF amplifiers form Rev Power.
3. LLRF will be one for all the RFPA chains, the signal being split to each of the chain.





Nenni, Bortolato, Grespan

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Area 2 pilot test stand @LNL

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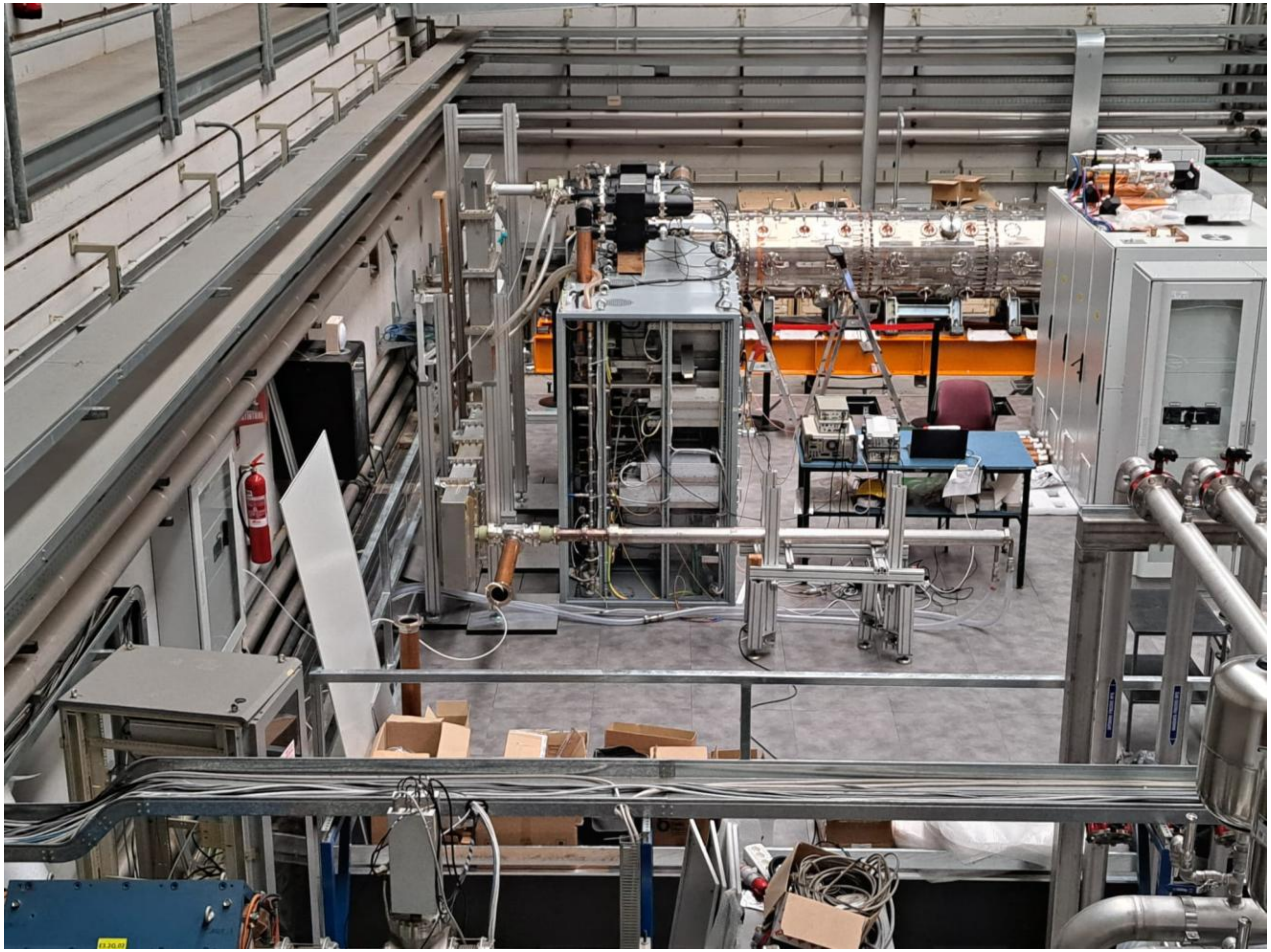
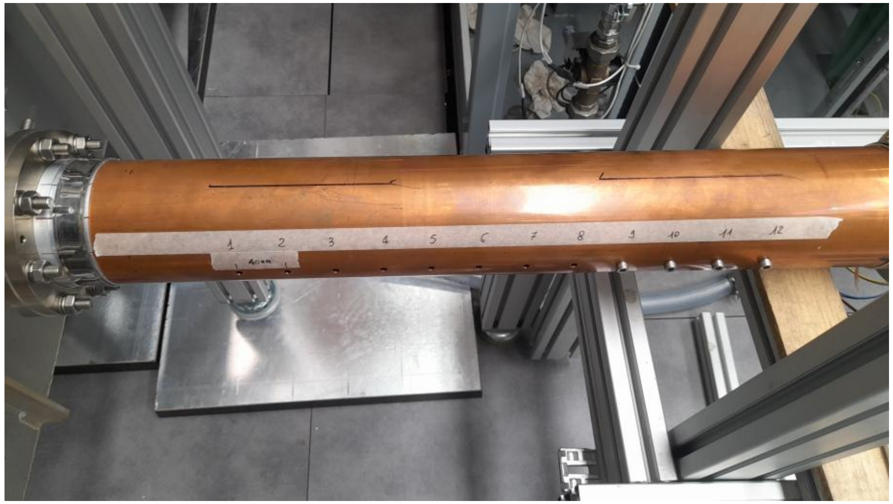
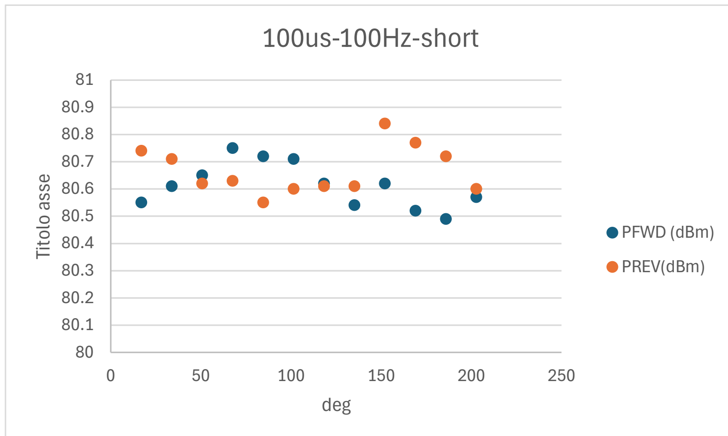


RF system

To address the possible sources of failure:

1. **pulsed operation** → amplifiers tested at 125 kW - 100us – 100 Hz on a short circuit covering λ/2 at all phases.
2. **RF operation without beam** → amplifiers tested at 125kW-CW with 10% reverse power for 48 hours (margin factor: 10).
3. **stability requirements** of the 8 amplifiers→ statistical study with input phases and amplitudes random uniform distribution [±10° phase, ±10 % amplitude]. 90% of the cases below Prev<3%.
4. **cross talk of the power trough the RFQ** → fast protection system: if of the amplifiers goes into protection, it must send out a fast signal (20 us) to interrupt the power supply to all of them.





Bortolato, Grespan

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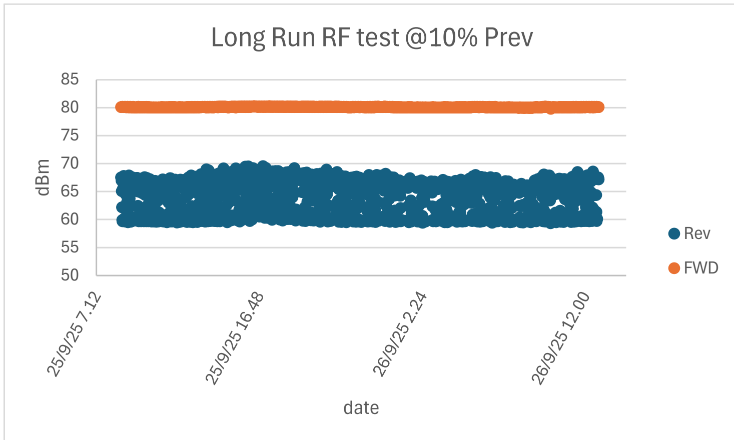

Bortolato, Grespan

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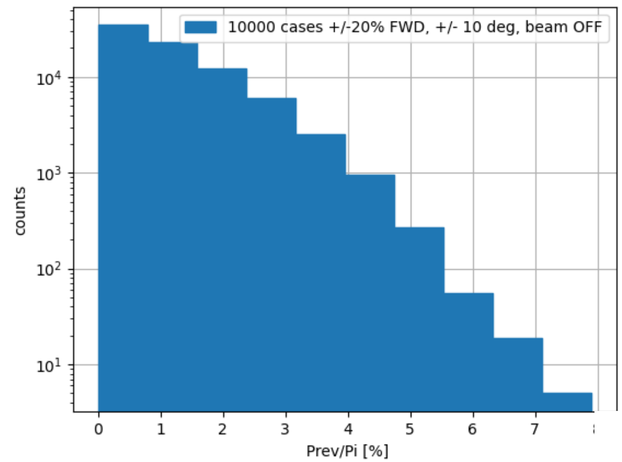
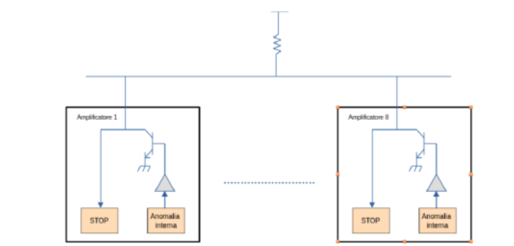
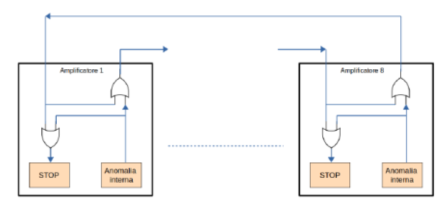
N°Ampli ON	Prev to each amplifier ON	Prev to each amplifier OFF
1	70.3%	2.1%
2	50.4%	8.4%
3	31.9%	18.9%
4	17.7%	33.6%
5	7.6%	52.5%
6	1.7%	75.6%
7	0.0%	103%
8	2.5%	-





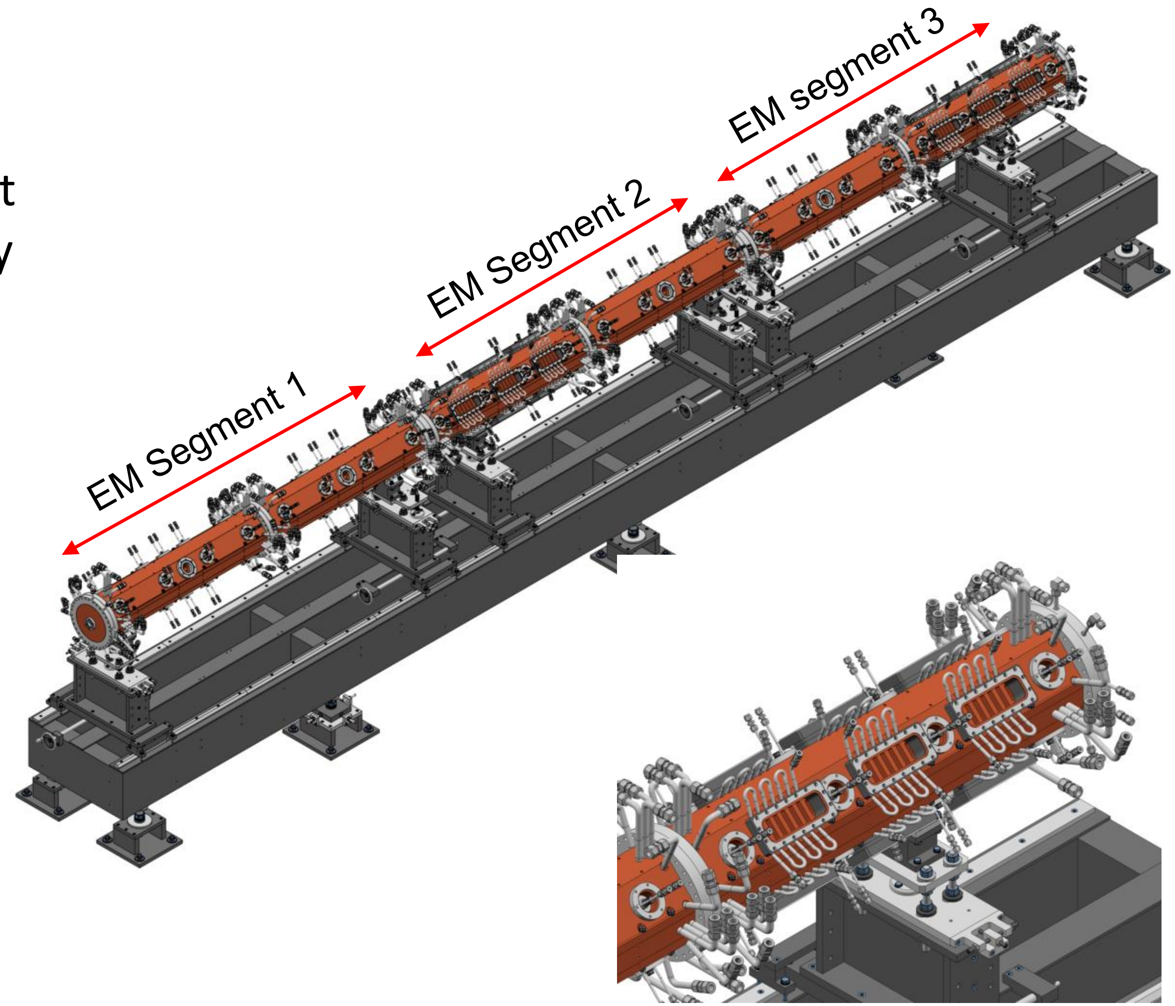
Un'altra possibile soluzione è una struttura ad anello:



Bortolato

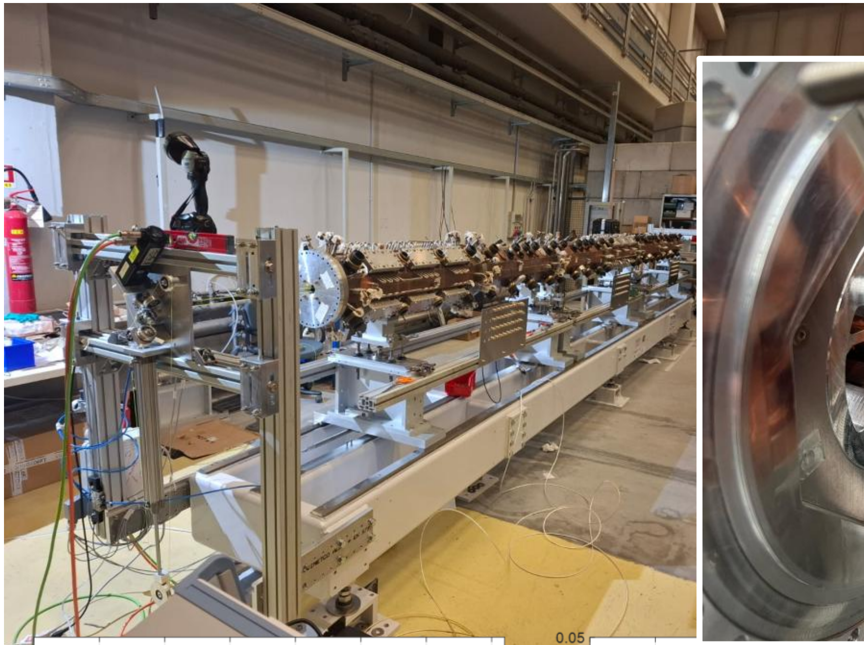
RFQ (ex TRASCO)

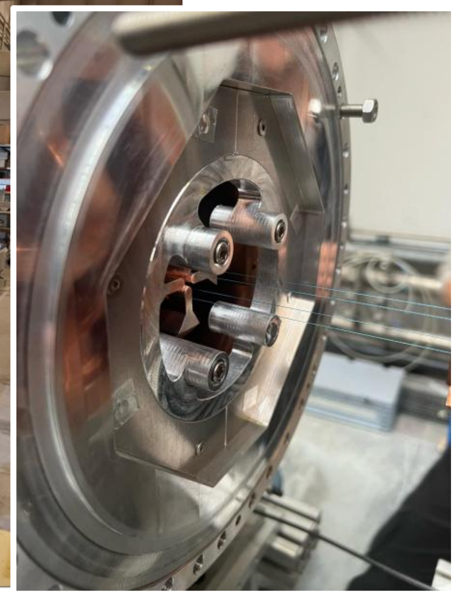
- 6 brazed **mechanical modules**
- 2 modules are one **EM segment (3)**, coupled with the neighbors → resonant coupling for tunability and field stability in operation
- EM boundary conditions are given by 2 Endcells + 2 Coupling Cells
- Dipole stabilizers are needed but only on the End Plates
- Local frequency adjustment by slug 96 tuners

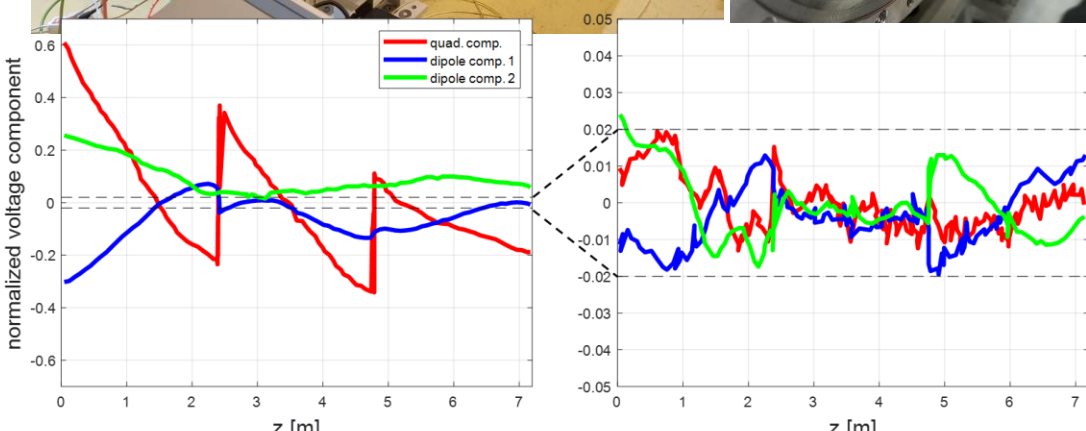


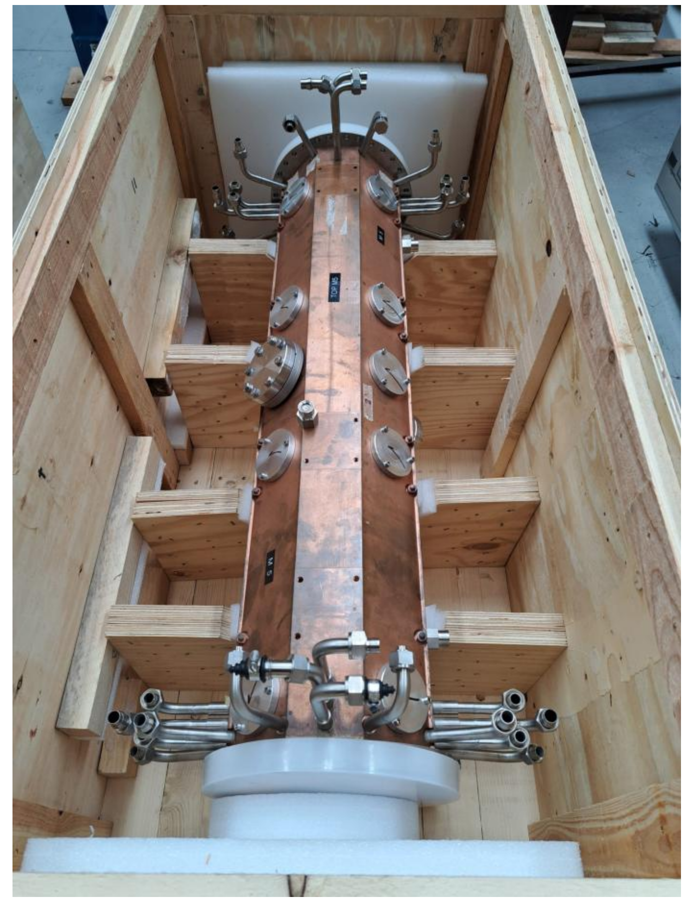
RFQ tuning

Resonantly coupler RFQ (the 3rd of the world ?) tuned!









Palmieri, Grespan, Ferrari

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RFQ cleaning 6 modules completed

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RELAZIONE TECNICA PULIZIA CAVITA' RFQ ANTHEM MODULI RFQ5 – RFQ6 - pag. 1/5

OPERAZIONI ESEGUITE

1) Cavità estratte dalla cassa e fotografate. Vasca 1 controllo soluzione Citrajet pH 2,6. Vasca 2 riempita con acqua ultrapura 18MΩ nuova per ogni modulo.

2) Sgrassaggio moduli con panni bianchi da clean room e alcool

3) Immersione cavità in vasca 1 per 10 min + flusso azoto nel bagno

4) Estrazione della cavità dal bagno e posizionamento sul tavolo

5) Rotazione della cavità di 180° + spostamento cinghia

6) Immersione cavità in vasca 1 per 10 min + flusso azoto nel bagno

7) Estrazione della cavità dal bagno e posizionamento sul tavolo

8) Rimozione ossido esterno cavità passando a mano un panno tipo scotch bright (grigio) bagnato con soluzione citrajet (serve una rotazione del pezzo)

9) Immersione cavità in bagno di Citrajet 10 min + flusso azoto

10) Estrazione della cavità dal bagno in sospensione sulle cinghie

11) Risciacquo a mano con getto d'acqua ultrapura 18MΩ

12) Immersione cavità vasca 2 di risciacquo 20 min + flusso azoto

13) Estrazione della cavità dal bagno

14) Asciugatura accurata con azoto puro e panni clean room

15) Documentazione fotografica dello stato del pezzo dopo la pulizia

16) Pulizia flange di chiusura e o-ring con alcool e panni clean room

17) Montaggio flange di chiusura

18) Protezione della cavità con film plastico protettivo (senza sigillatura)

19) Inserimento della cavità in cassa e chiusura coperchio con viti

Foto Allegate

14/11/2025

ZANON Research & Innovation Srl

Page 1

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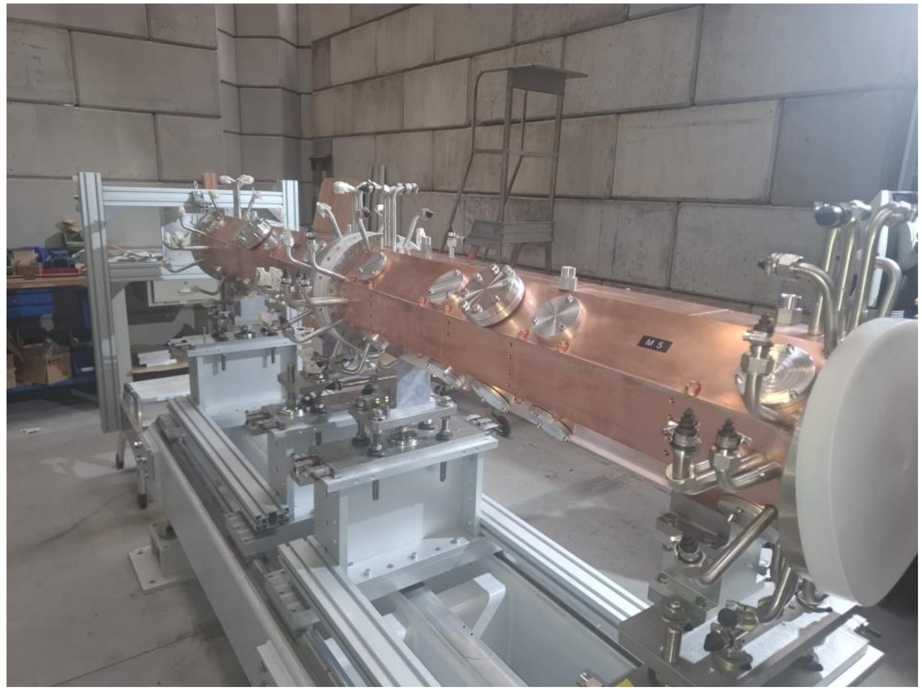
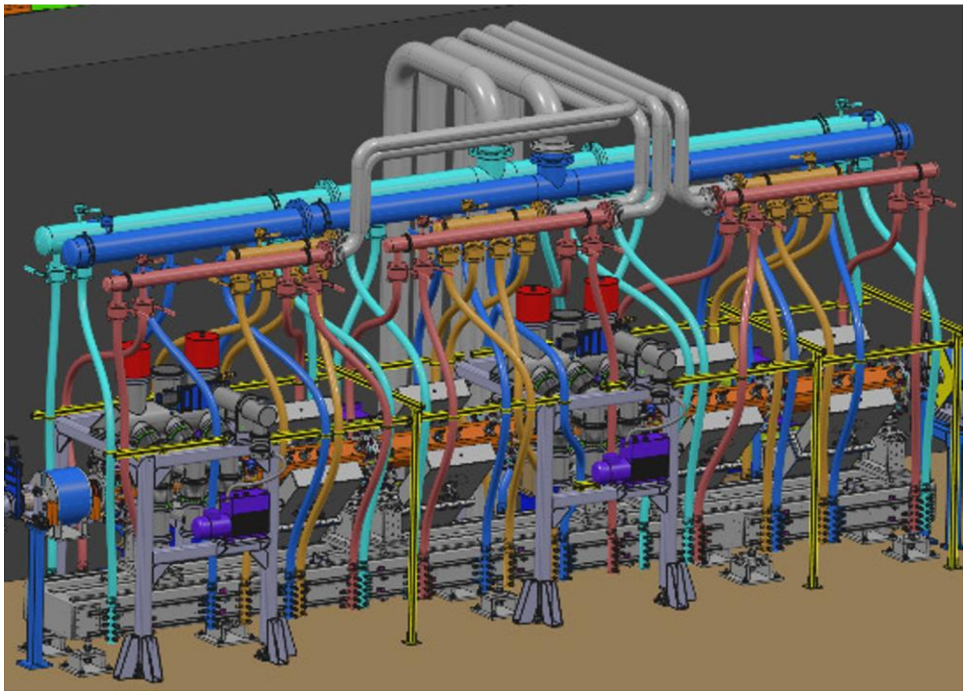
Grespan, Roncolato, Minarello

RFQ metrology and re-assembly



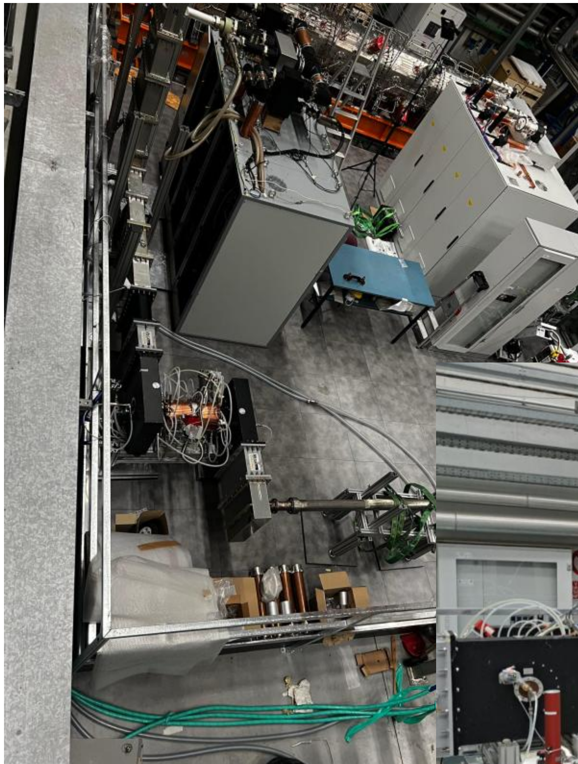
L. Ferrari, M. Nenni, C. Mingioni

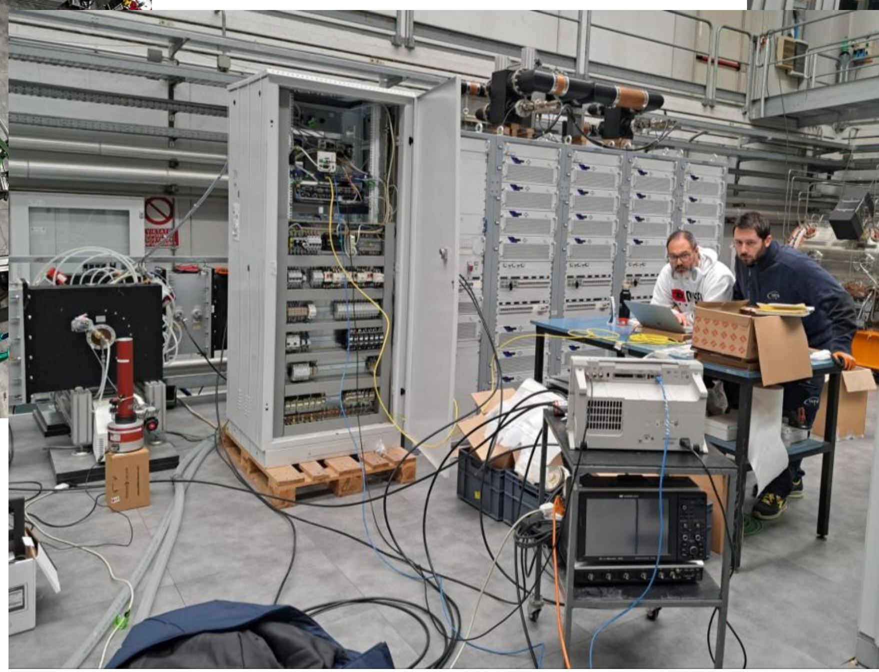
RFQ integration

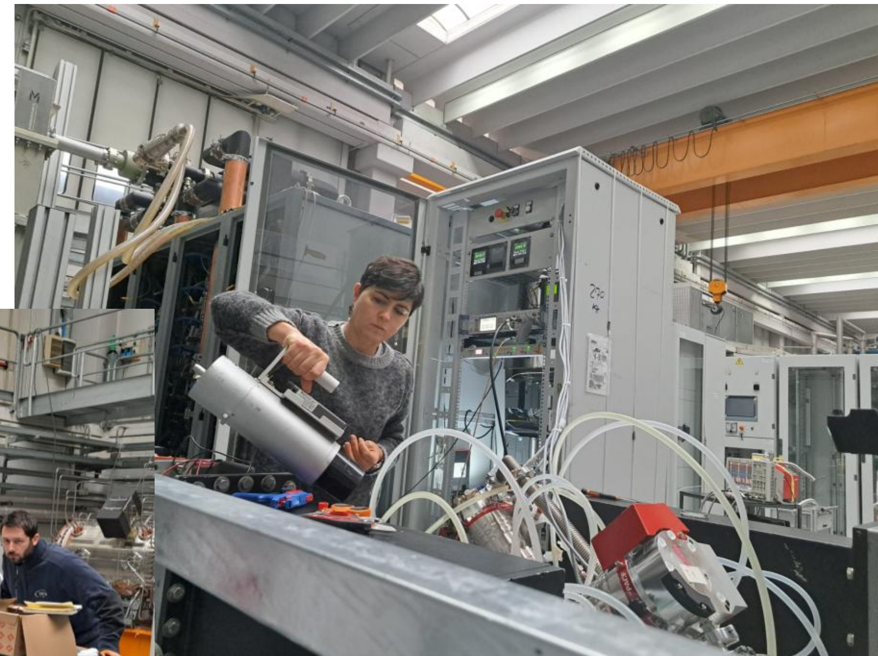


- Cooling and vacuum system full integration
- 4 NEG pumps, 8 gauges (couplers), 2 TMP, 2 primary
- RFQ will be vacuum and cooling tested at LNL.
- Final support studied for
  - Assembly and disassembly of the RFQ
  - Tuning of the RFQ
  - shipment of fully assembled and tested cavity
  - Fine alignment in situ

RFQ high power couplers



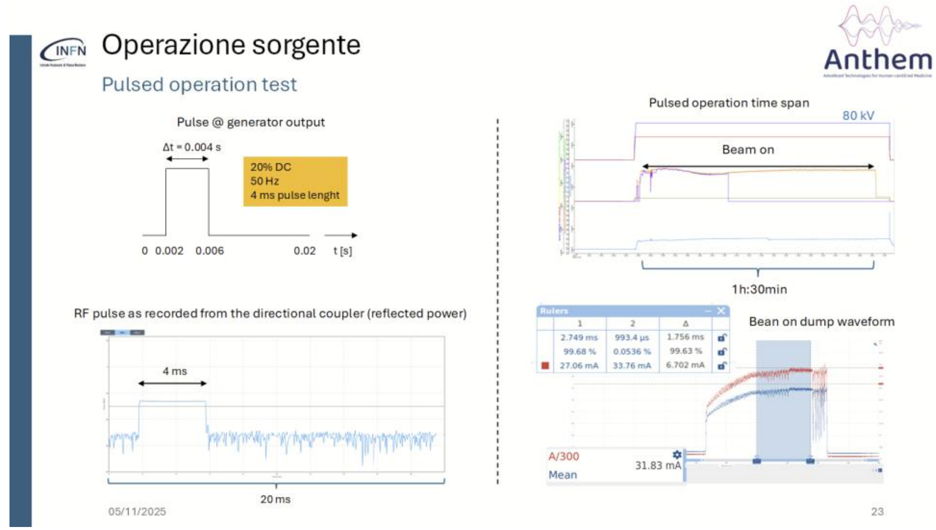


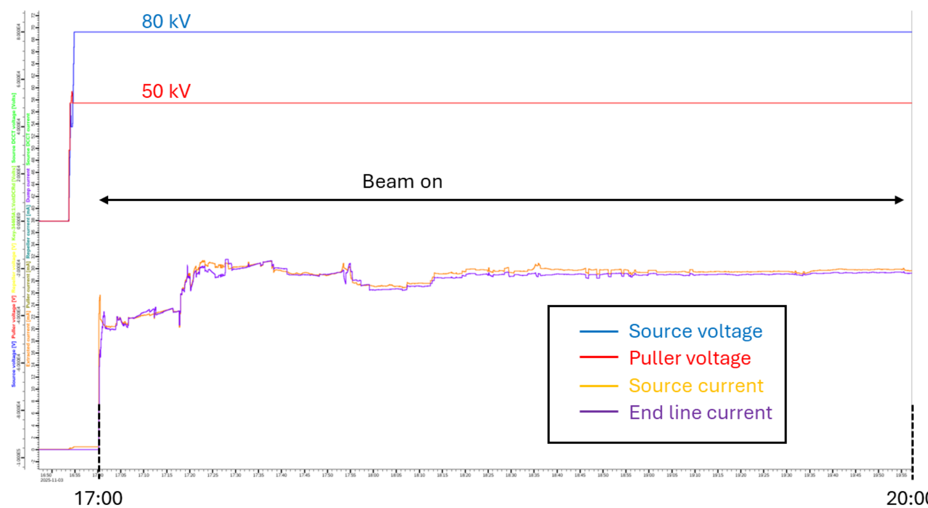


Montis, Baltador

Ion Source: long test DC and pulsed

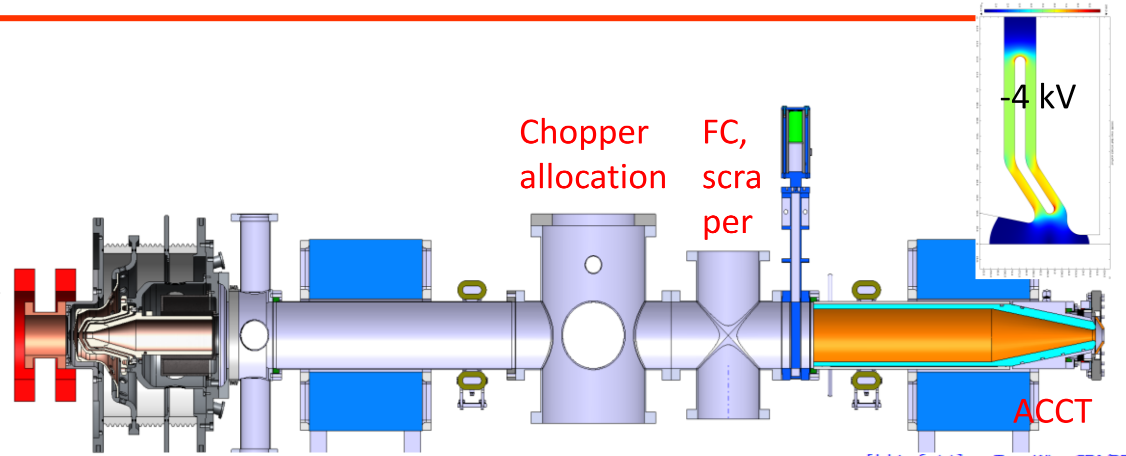
Baltador

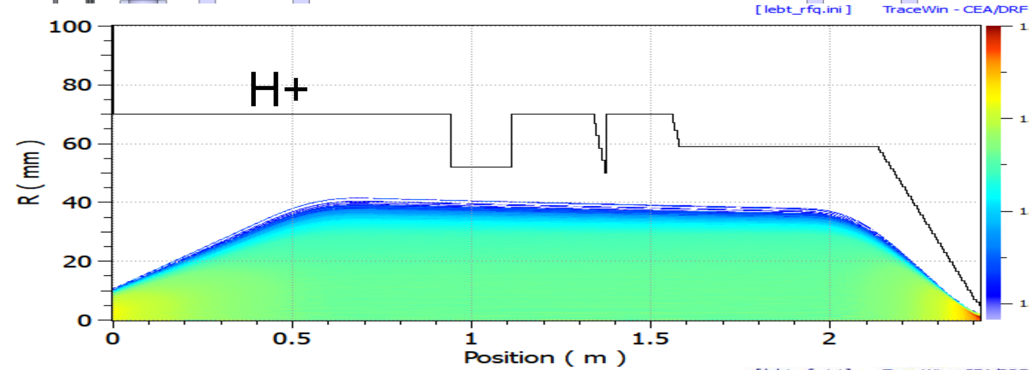


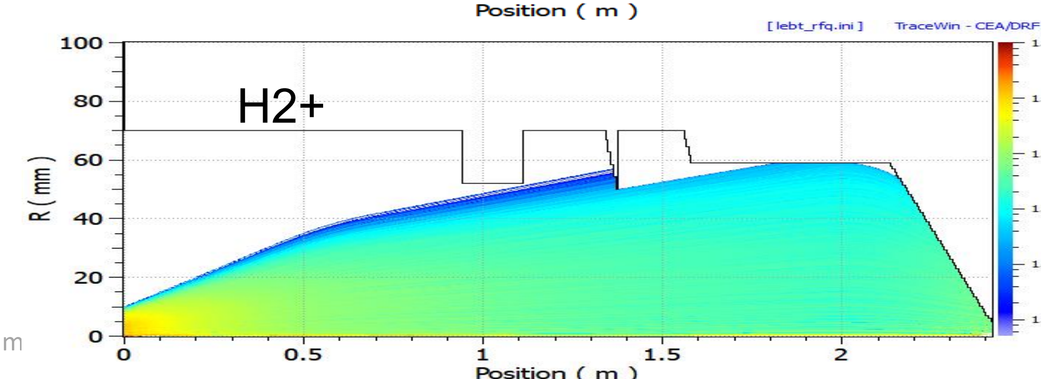


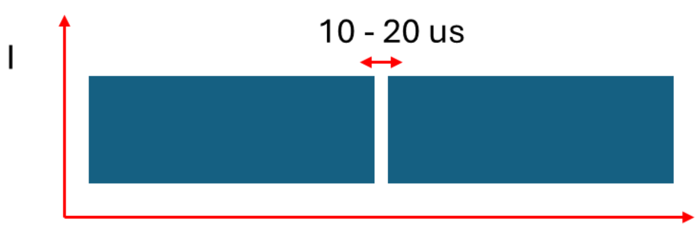
LEBT

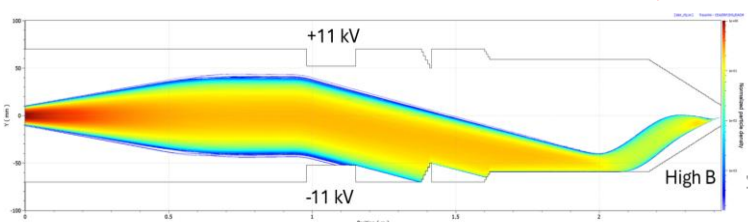
- 40 mA TOTAL beam extracted at 80 kV, DC.
- Multispecies plasma, with space charge effects and space charge compensations phenomena from secondary plasma
- High B RFQ
- In order to correctly design the line, a multiphysics model needs to be implemented. (IFMIF, ESS)
- Geometric acceptance tuned on RFQ input matching beam (6 sigma cut) and input RFQ flange
- RFQ cone repeller: ensure mirror effect on escaping electron from LEBT. Essential for s.c.c. close to RFQ input.
- Chopper for 20 us CWbeam interruption (ACCTs), physical design for 1ms ON/OFF











Target in case of pulsed operation (Be/Pd/Cu stress-strain)

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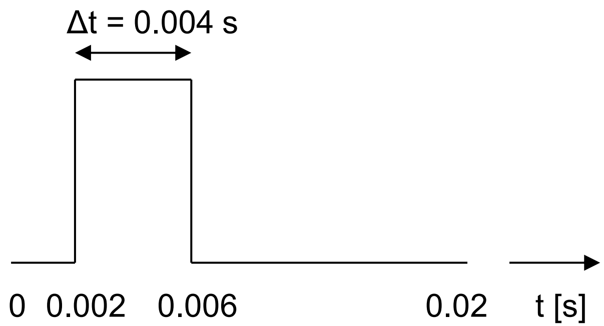
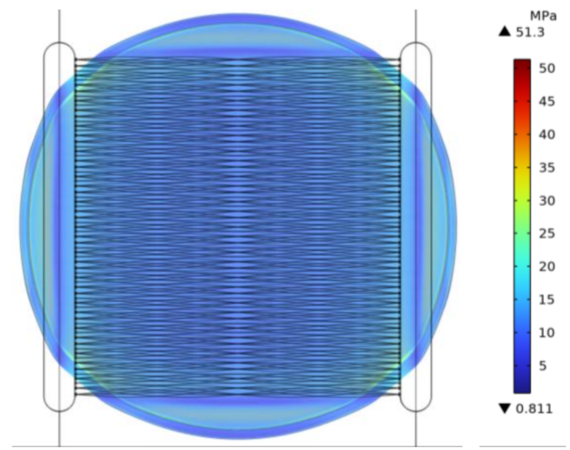
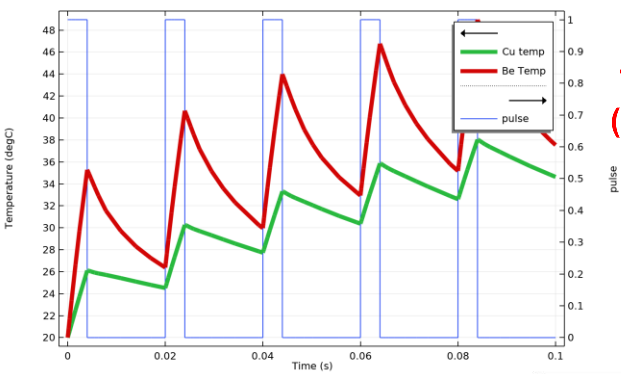
20% DC
50 Hz
4 ms pulse lenght
150 kW peak
30 kW average power
30 mA



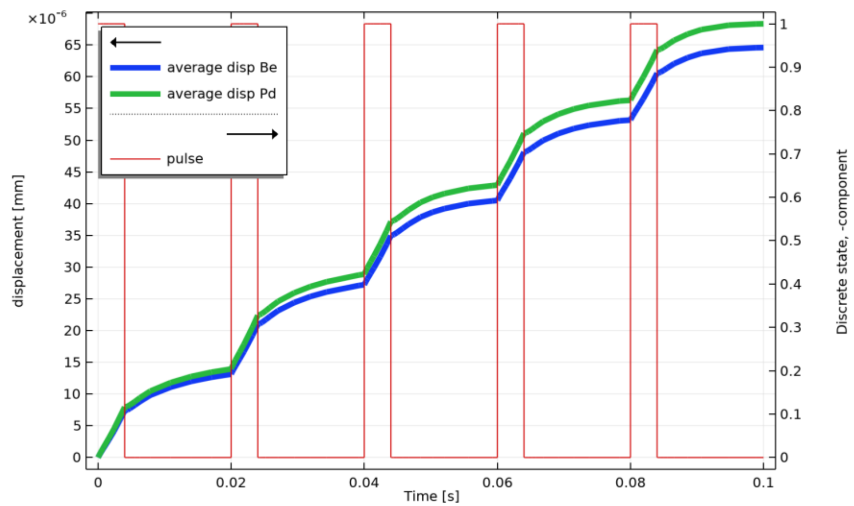


Von Mises @ 0.1 s

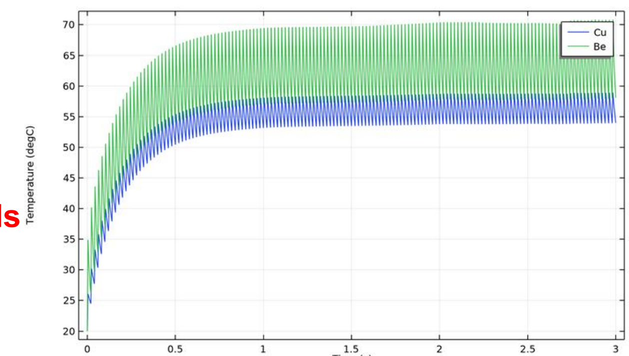


Temperatures evolution (first 0.1 s) - average values

Average Radial displacement



when pulsed at 50Hz, the HS achieve thermal equilibrium after 2 - 3 seconds with a mean temp. 65°C



Baltador, Bellan

Summary

- Il programma ANTHEM è iniziato nel 2022
- L'edificio sarà pronto nei prossimi 2 anni.
- L'ISRC e la RFQ stanno completando i test di pre-installazione.
- I componenti RFQ sono quasi tutti consegnati (end plates, couling cells, couplers, tuners, cooling)
- Skid e guide RF vicine al contratto
- Gli amplificatori RF sono in fase di test a Caserta.
- Coupler test, citofonare Maurizio
- I componenti MEBT saranno consegnati entro la fine del 2026 (magneti, vuoto, linee di fascio diagnostiche).
- Il sistema di Target per neutroni richiede diverse contromisure per affrontare la dissipazione di potenza e il processo HIP, e sta completando il protocollo di prototipazione.


Ormai la strada è in discesa…

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Legnaro

Conclusions

Anthem
AdvaNced Technologies for Human-centEred Medicine