Status and perspectives of an RFQ based neutron facility in Italy

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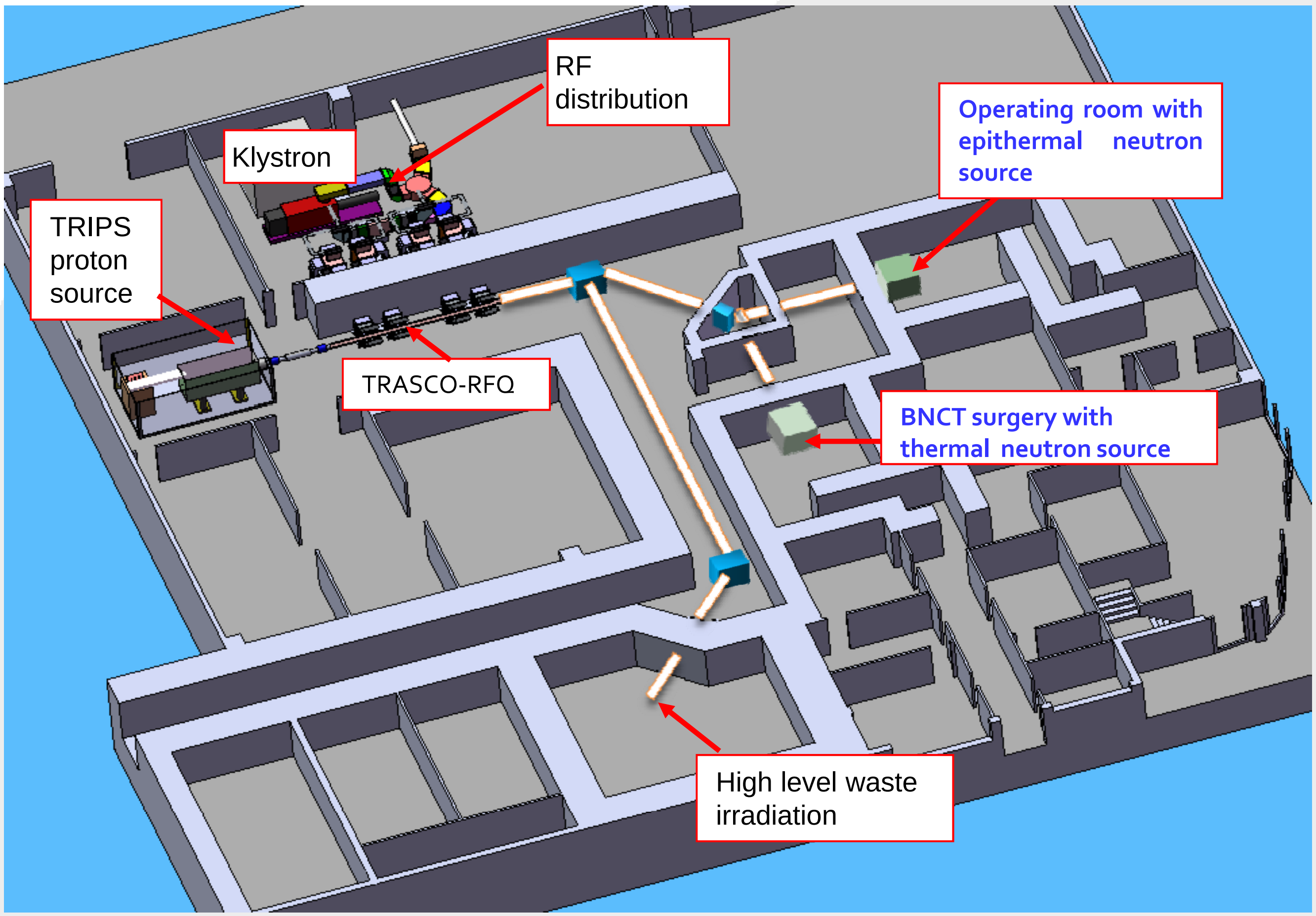
Outline

- Project overview
- BNCT application
- High intensity accelerator status
  - Proton source
  - Low energy beam transport
  - RFQ
- Beryllium target and neutron beam shaping assembly

Project overview

An accelerator-driven high intensity neutron source at INFN-LNL



TRASCO

SPES BNCT

IFMIF

Main parameters

Accelerator type: LINAC

Proton current: up to 50 mA

Proton energy: 5 MeV

Time structure: up to CW

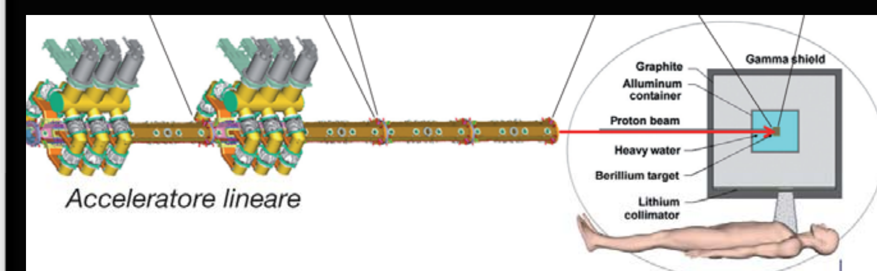
Beam power: up to 250 kW

Neutron converter: Be

Operative power density on Be target: 700 Watt/cm^2

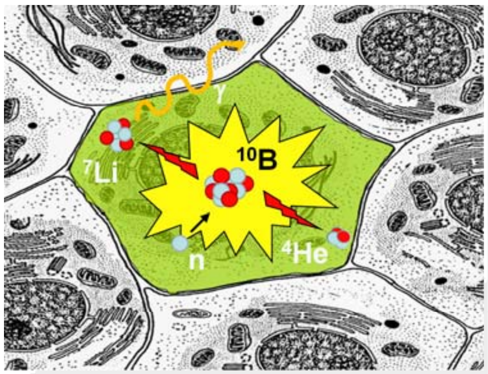
Neutron source intensity: 10^{14} s^{-1}

Main application: BNCT



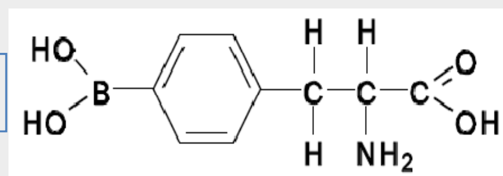
	Φ_{th} (E≤ 0.5 eV) (cm^{-2}s^{-1})	Φ_{th} / Φ_{total}	$K_{n\,(E>0.5\,eV)}$ / Φ_{th} (Gy·cm^2)	K_γ / Φ_{th} (Gy·cm^2)
LNL neutron source	4.3E+09	0.96	0.33E-13	0.92E-13
IAEA recommendations for BNCT	> 1.0E+09	> 0.90	≤ 2.0E-13	≤ 2.0E-13

Boron Neutron Capture Therapy (BNCT)

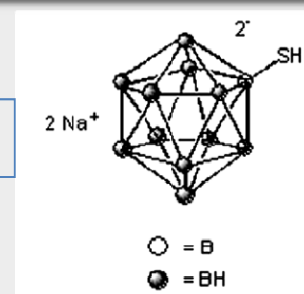


Boron Neutron Capture Therapy (BNCT) is an experimental binary radiotherapy which exploits the neutron capture reaction $^{10}B(n,\alpha)^{7}Li$ induced by thermal neutrons (<E> = 25 meV).
The α-particle and ^{7}Li recoiling nucleus are high LET and short range (< mean cell diameter ≈ 10 μm) particles able to deposit their energy entirely inside the ^{10}B loaded cell.

BPA



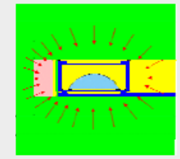
BSH



In this way the selectivity of BCNT depends on ^{10}B distribution and not on the irradiation field. This feature makes BNCT a valid option against the diffused tumors
Another crucial aspect for the good outcome of the treatment in the availability of ^{10}B carriers able to realize a selective delivery. The clinically approved molecules are BSH and BPA. Nowaday, the major challenge in BNCT research is the development of
more dedicated carrieris.

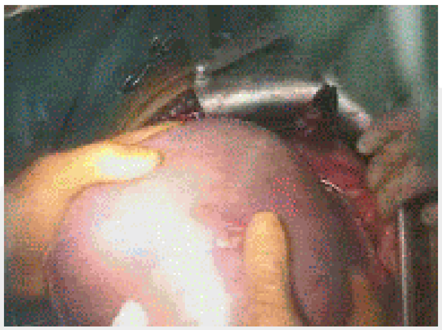
BNCT at Pavia: the TAOrMINA method

(Trattamento Avanzato d'Organi Mediante Irraggiamento Neutronico e Autotrapianto)



The therapeutic concept is based on the irradiation of the isolated, previously ^{10}BPA-infused organ in a neutron field where neutrons coming from all directions can irradiate the whole liver

After BPA infusion the liver is removed from the patient body



It is washed and put into 2 teflon bags

and then put into a teflon container

and irradiated into the reactor

Two terminal patients affected with colon adenocarcinoma liver metastases were treated in Pavia with the TAOrMINA method between 2001 and 2003.
In both cases, about 10 days after treatment the CT scanning evidenced the liver in normal condition while the adenocarcinoma metastases appeared in a necrotic state.

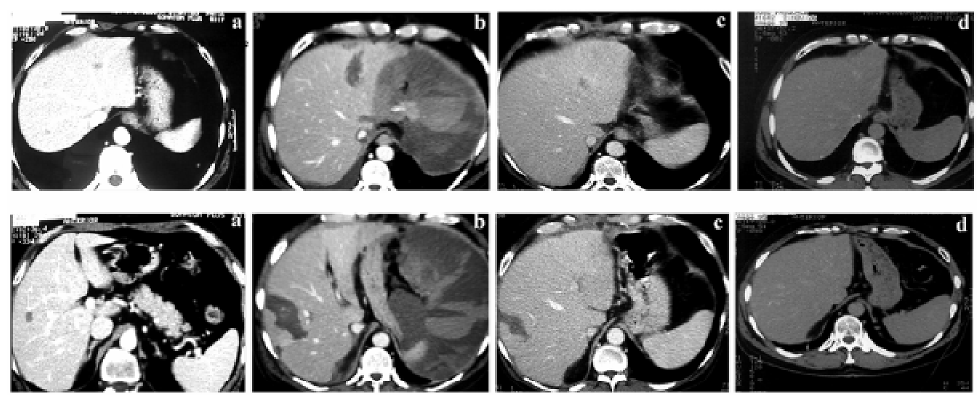
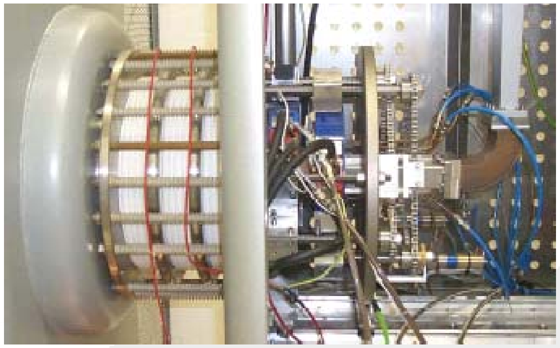


Figure 6. Sequence of CT images of the liver on a cranial (above) and a caudal (below) level in the first patient subjected to BNCT. Evolution at different times of the metastases towards necrosis with final substitution by normal hepatic tissue. (a): pre-operatively; (b): at 7 days, (c): at 6 months; (d): at 12 months after the procedure.

High Intensity Accelerator Status

Proton source

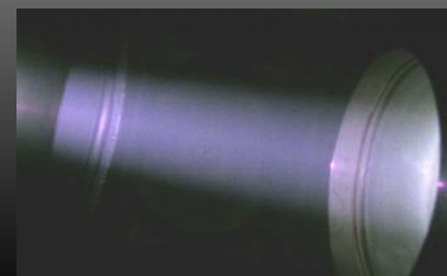


PS developed at LNS (2000)

PS optimized at LNL with magnetic shielding (2007)

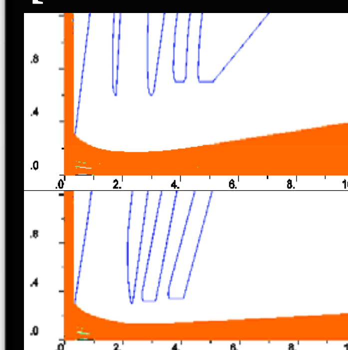
STATUS

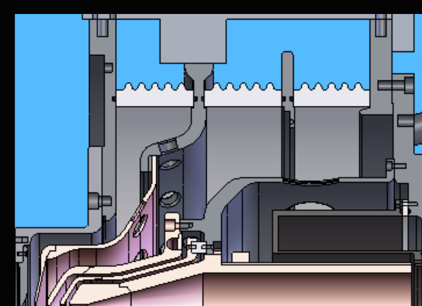
$I_p \approx 45$ mA
E = 80 KeV
$\varepsilon_{n,rms} < 0.1$ mm-mrad
$\varphi_b(z = 200 \text{ mm}) = 34$ mm
Beam time structure: CW

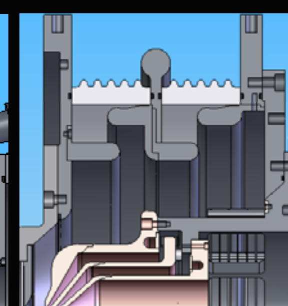


NEAR FUTURE

$\varphi_b(z = 200 \text{ mm}) = 10$ mm
[New extractor design] [LNL]

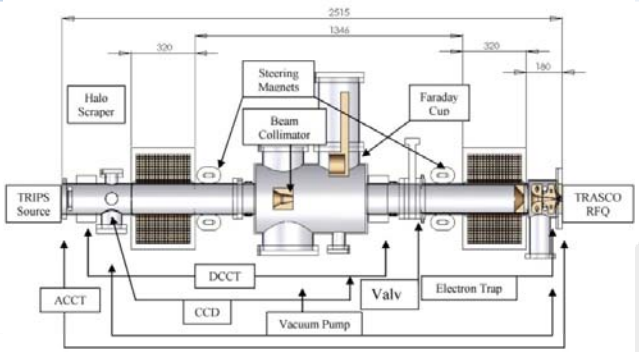






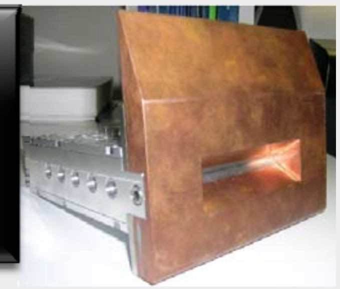
Beam time structure: CW & pulsed
[Magnetron pulser] [LNL & DEE/UPV]

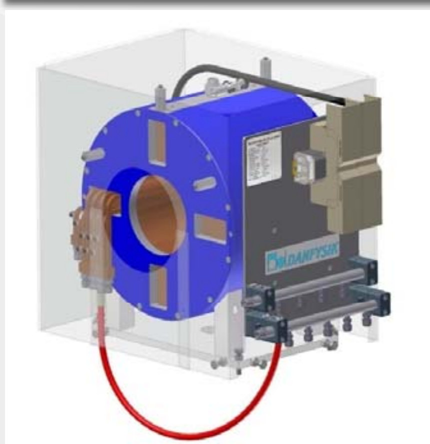
Low energy beam transport



LEBT developed at LNL

Fast Emittance Scanner (FES): high resolution q-q' rms emittance in less than 2 seconds

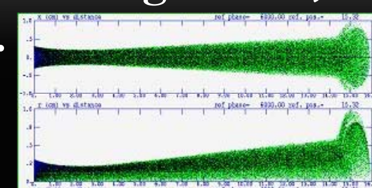




Solenoids developed at LNL

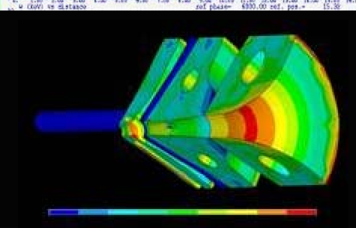
STATUS

LEBT ready for assembly with solenoids, pumping system, non interceptive profile and current diagnostics, interceptive profiler and termination FC.



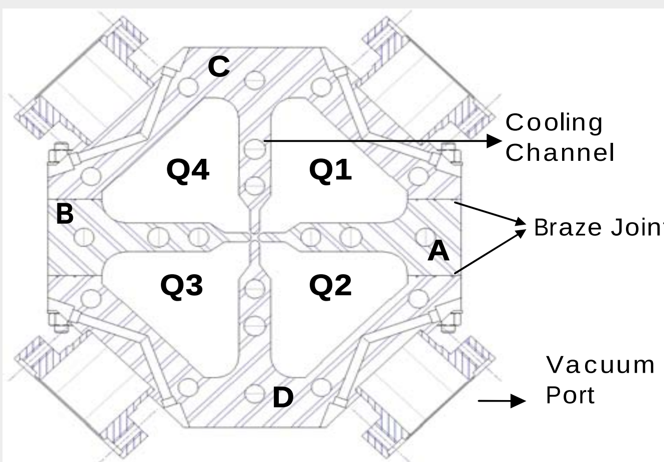
NEAR FUTURE

Neutralized transport optimization
FGA development
LEBT control system upgrade
e-trap construction

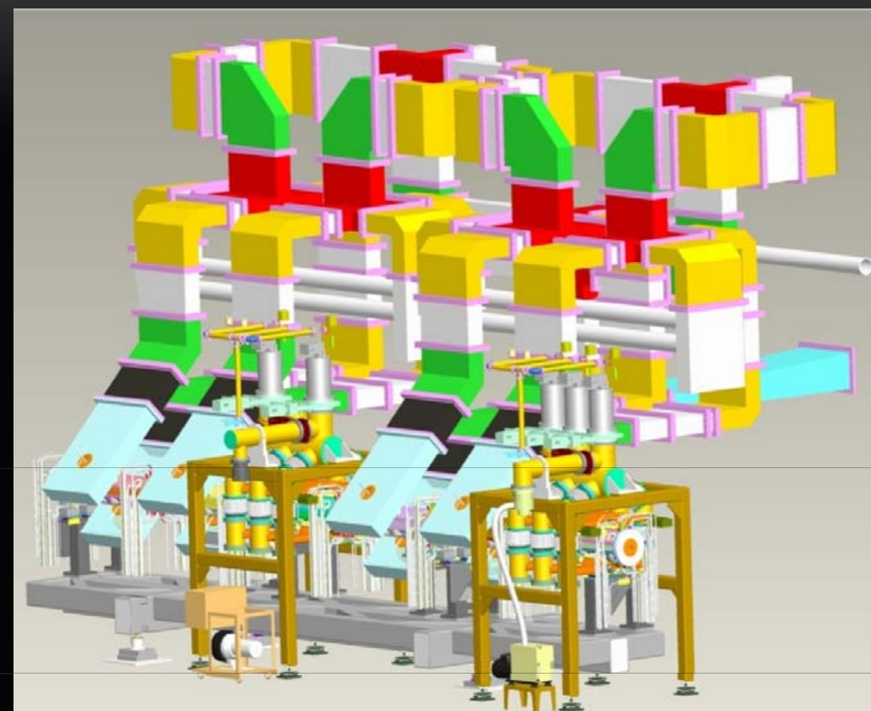


RFQ: parameters

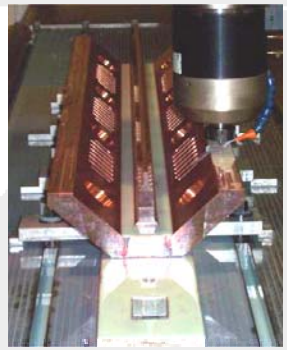
Parameter	Value	Unit
Energy In/Out	0.08/5.02	MeV
Frequency	352.2	MHz
Proton Current (CW)	50	mA
Emit. t. rms.n. in/out	0.20/0.21	mm-mrad
Emit. l. rms.	0.19	MeV-deg
RFQ length	7.13	m (8.4 λ)
Intervane Voltage	68	KV (1.8 Kilp.)
Transmission (Waterbag)	97.7	%
Q_0 (SuperFish)	10000	
Q_0 (measured)	8100	
Beam Loading	0.148	MW
RF Power dissipation	0.847	MW

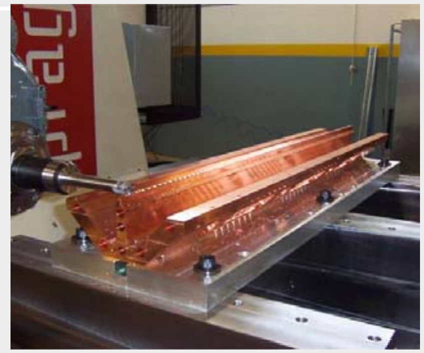


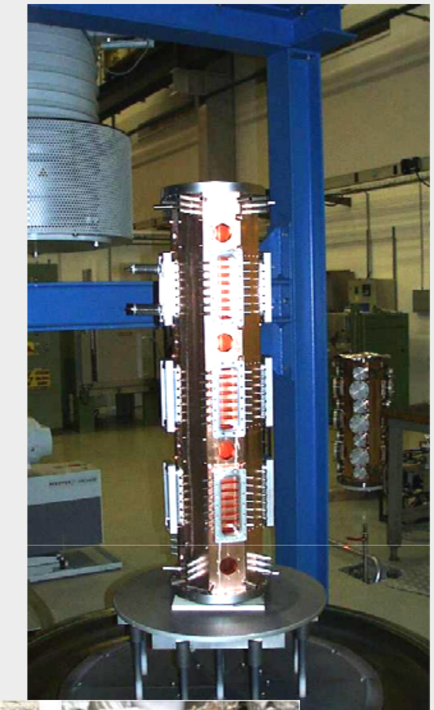
- 3 electromagnetic segments 2.4 meters long
- 2 resonant coupling cells + dipole stabilizers
- each segment consists of two 1.2 meters long modules (basic construction units)

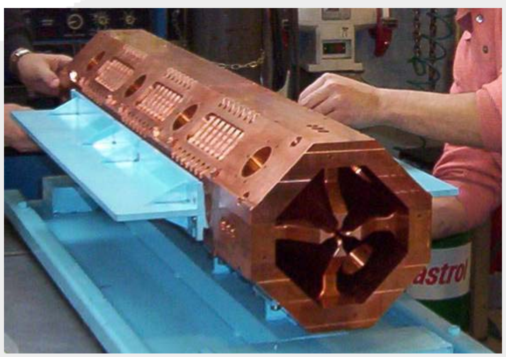


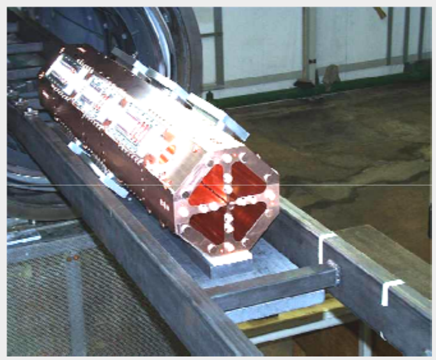
RFQ: fabrication history…

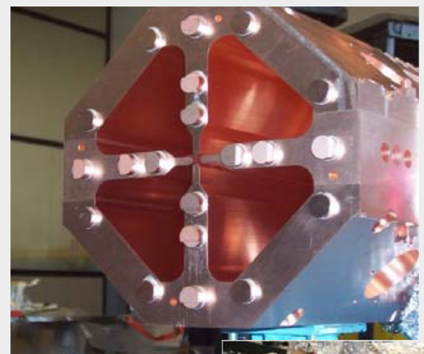


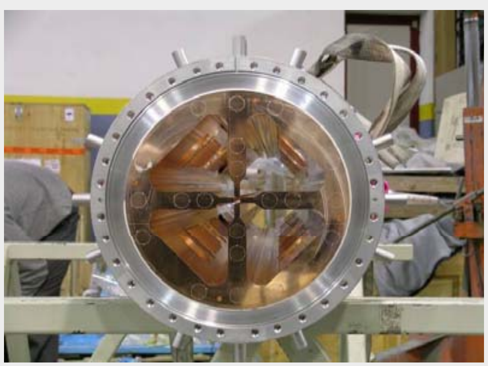


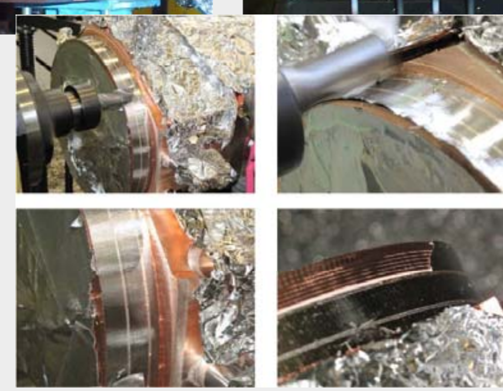






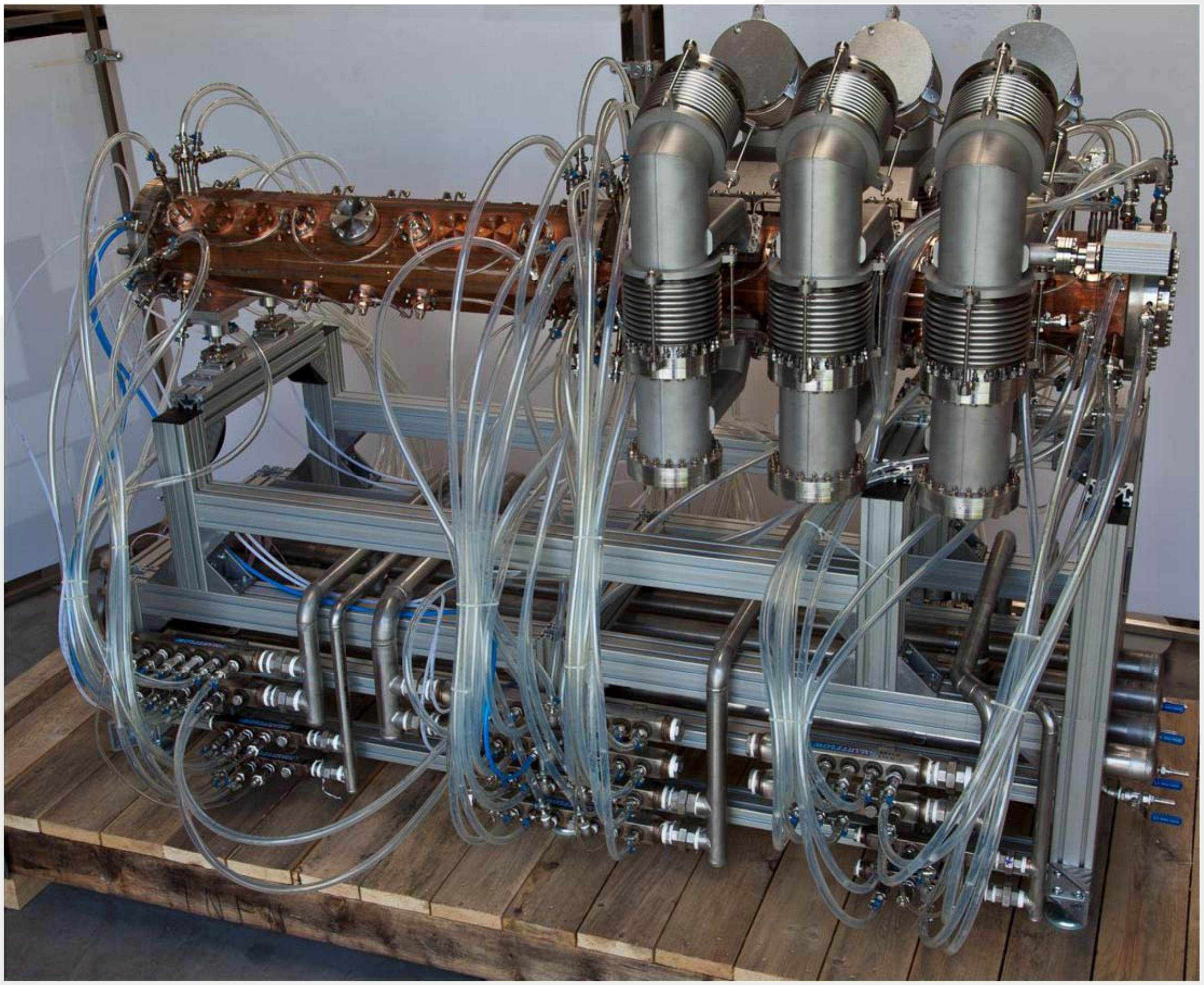


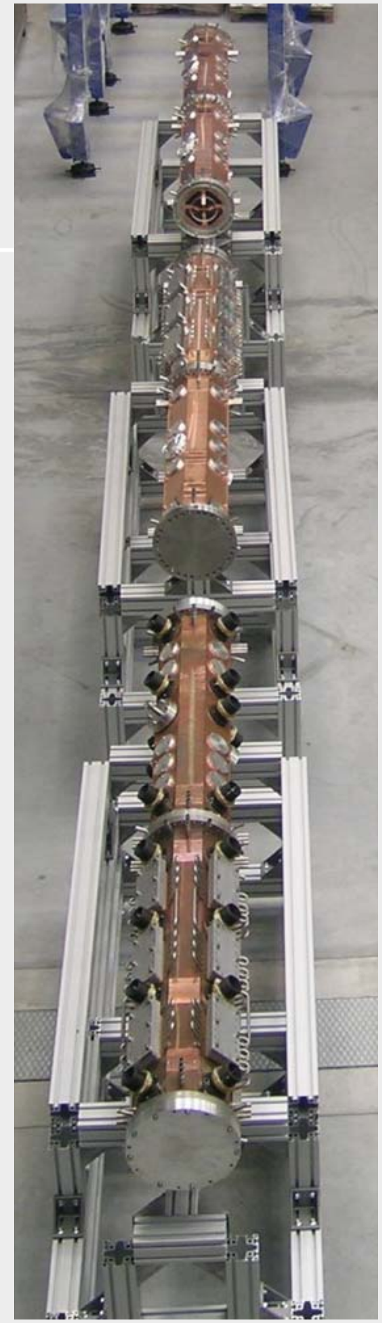




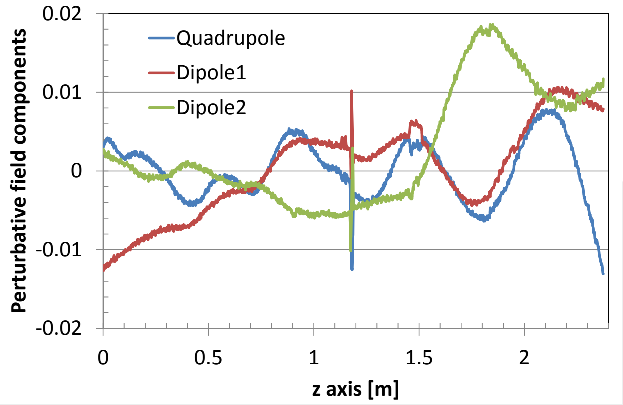
… and some troubles

RFQ: fabrication complete



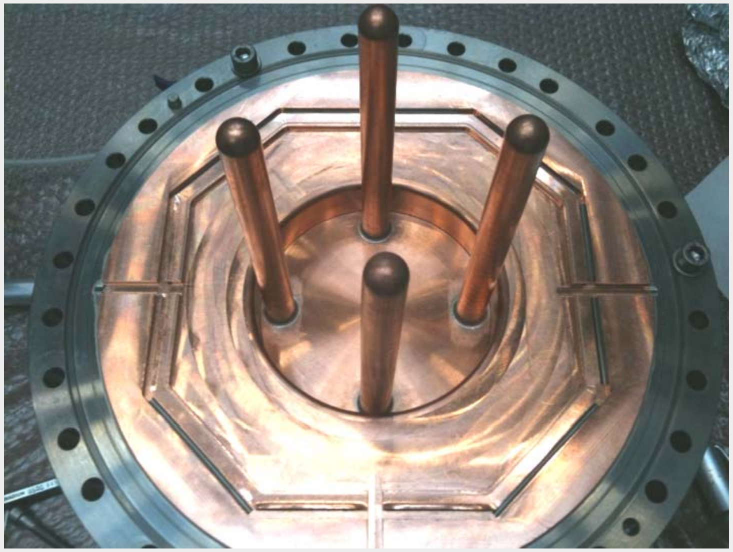


RFQ: tuning



2010. Low power RF measurements.

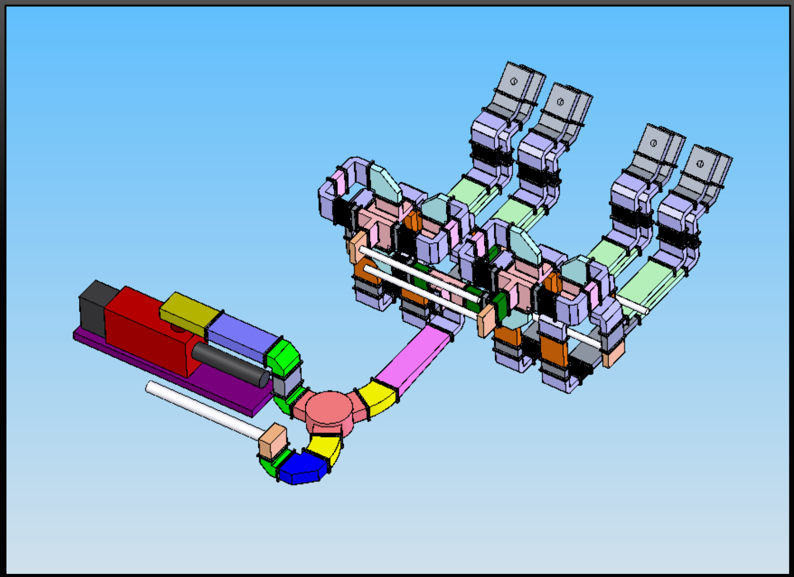
- Field and frequency tuning with aluminum couplers
- Copper Tuners and Copper End Plates with RF contacts
- Q_0=8100 (SF 9900)
- Final High Power Coupler design (3D HFSS simulations) and Coupler Production

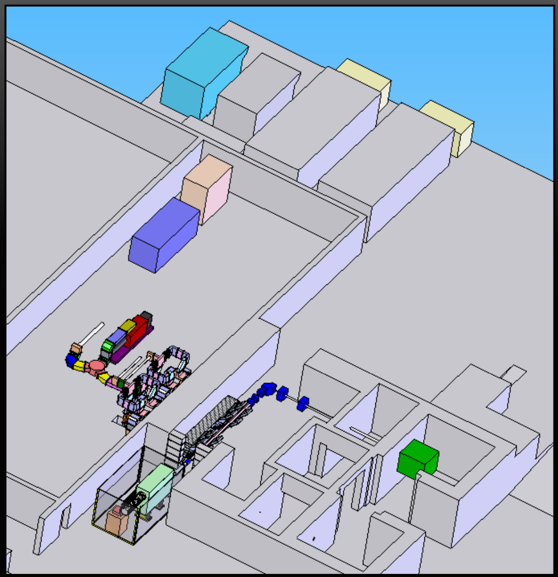


RFQ: ancillaries

2010/2011. All Ancillaries for High Power Test ready and tested

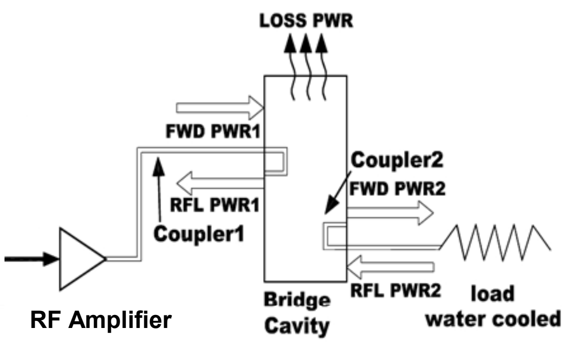
- High technology part (RFQ cavity, RF distribution, local cooling/tuning system, local control system) was developed

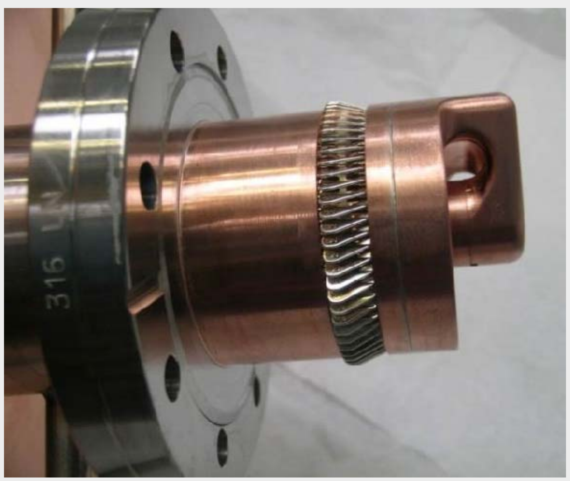




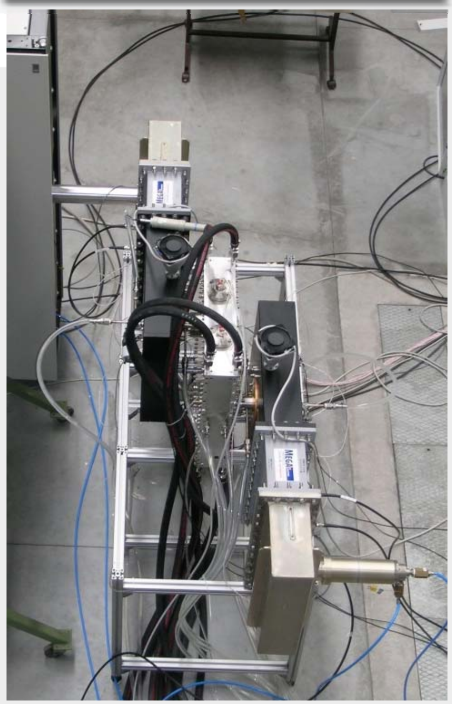
- Conventional installation (Klystron and conventional power supplies, secondary cooling system, building) is required.
- According to an agreement between INFN and CEA, couplers and RFQ are under high power test at Saclay.

RFQ: RF coupler high power test



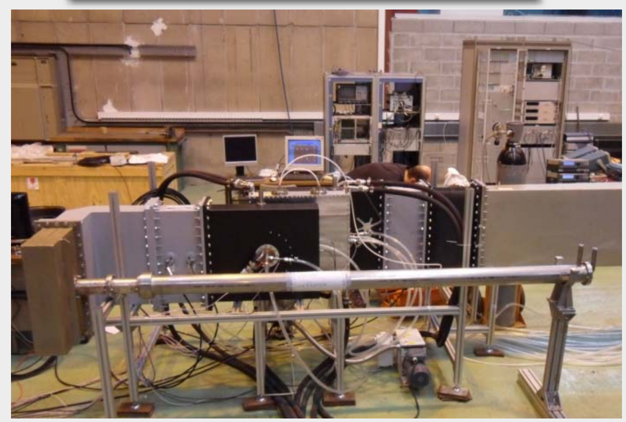


March 2011
10 kW couplers test



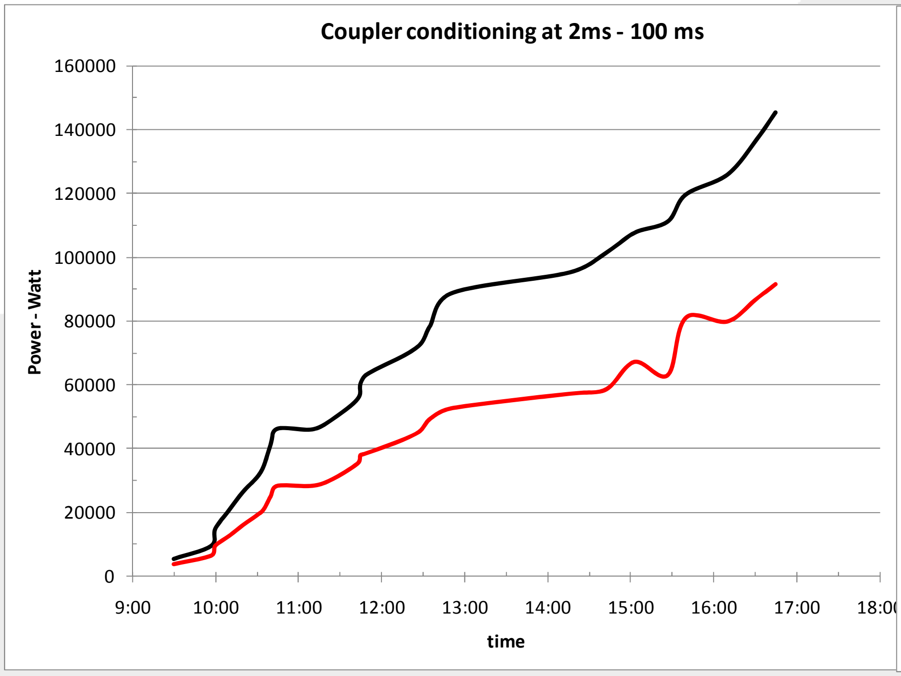
LNL

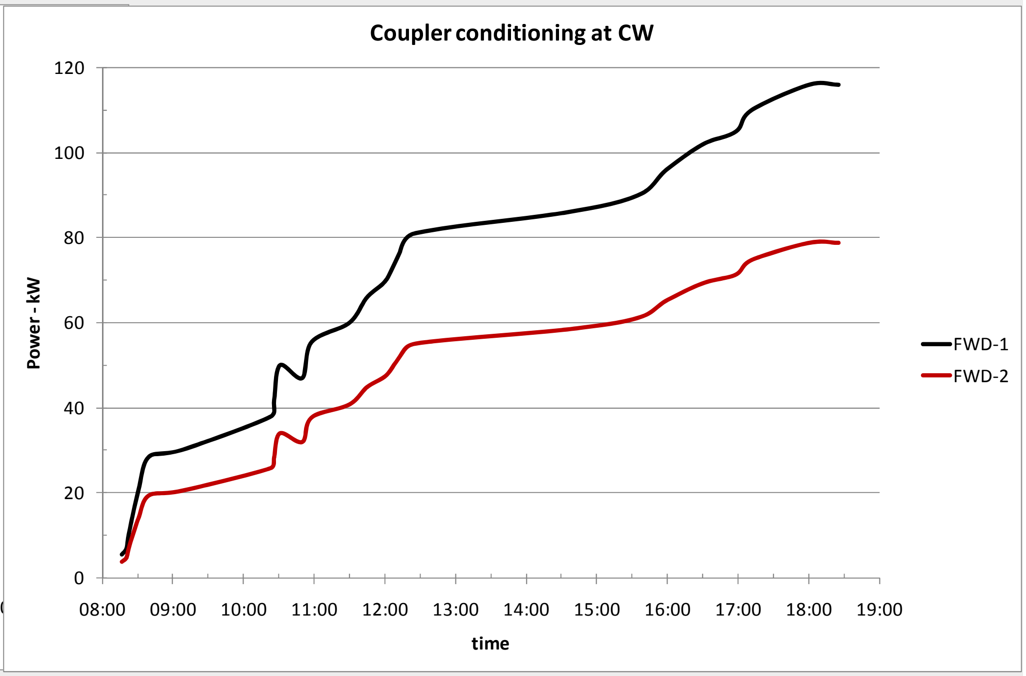
June 2011
150 kW couplers test



CEA Saclay

Coupler high power test results (1st July update)

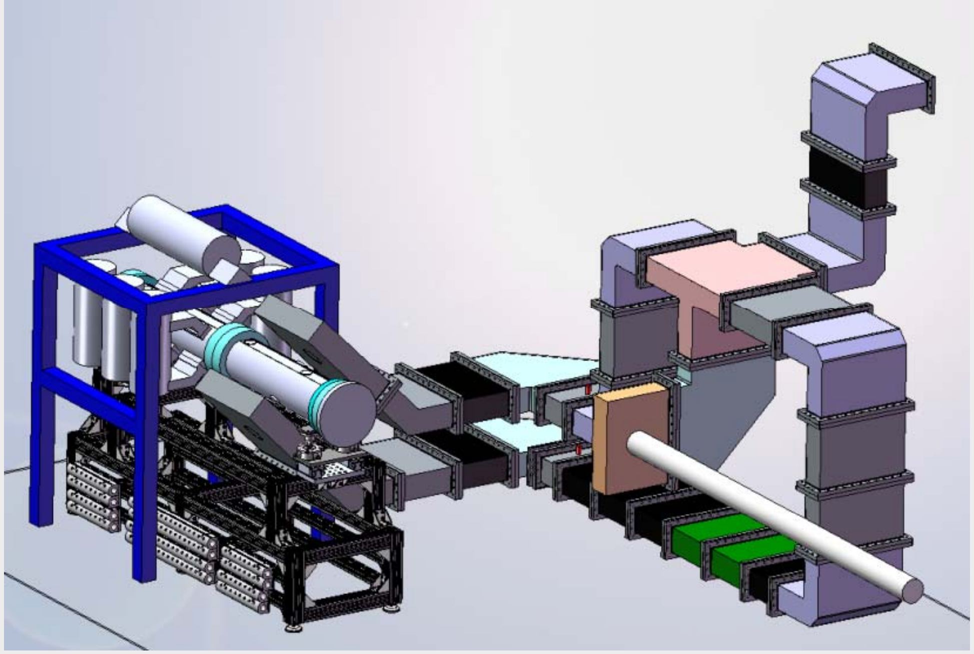




RFQ: high power test

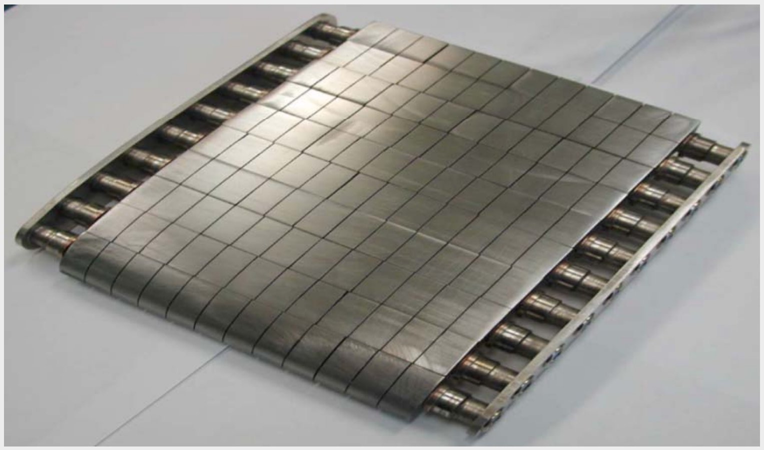
RFQ high power test stand is under construction.
First test foreseen after summer.

Milestones:
- 1° Segment RFQ test→300 kW
- Check of the water cooling/tuning system



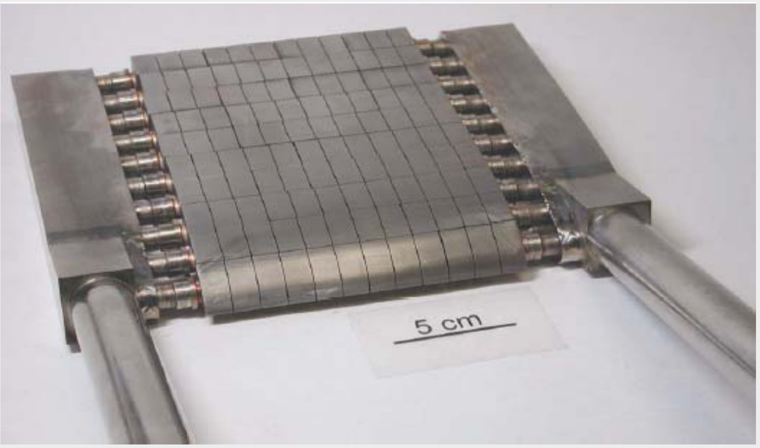
The Be proton-neutron converter

1. Be-tile brazed cooling pipes with Zr adapters



3. collector plates welding & EDM manufacturing process

2. Zr cooling system manifold & collector plates

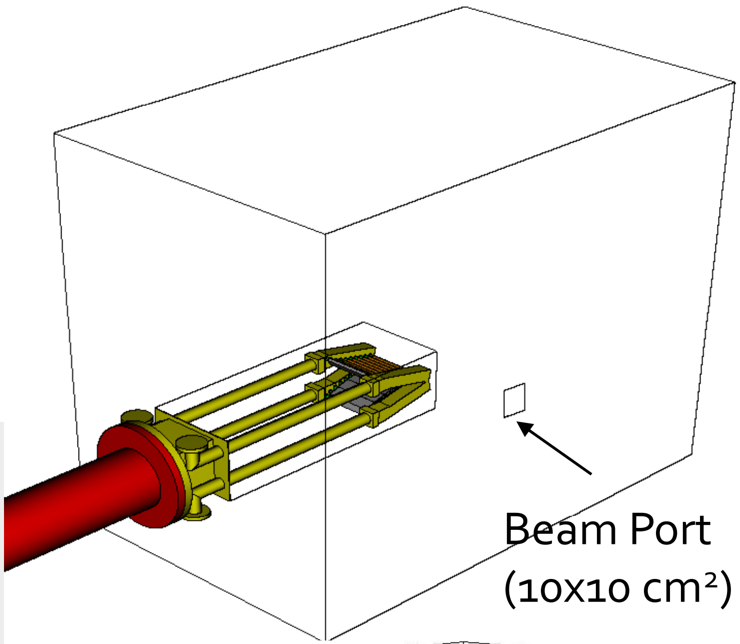


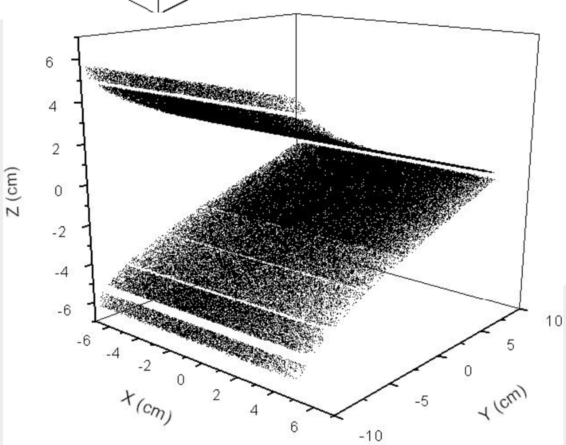
4. Half target: final assembling ready for e-beam test

The Be target test result summary

Test type	Test performed	Main test results	Test passed
Thermal-mechanical	Number of cycles: 2350 ~ 10 times higher than requested (200)	• No any visible damage • No cracks observed at metallographic analyses • Reliability better than expected	YES
Radiation damage: neutron	Proper neutron fluence levels (10^{18}-10^{20} cm^{-2})	• Material hardening level half than expected • Mechanical properties not compromised even at higher dose levels (~0.1 dpa) • He bubbles generation observed at higher dose levels only (~0.08 dpa) • Lifetime estimation: 3100 hrs (doubled) with respect to design parameters (1600 hrs) =1yr	YES
Radiation damage: proton	Preparation of experimental set-up	In progress	

The Beam Shaping Assembly modeling





In-air beam port quality design requirements

$\phi_{n\ th}$ ($\leq$ 0.5 eV) $\geq 10^{9}$ [$cm^{-2}\ s^{-1}$]

$\phi_{n\ th}\ /\ \phi_{n\ total} \geq 0.90$

$\dot{D}_{n\ epi+fast}\ /\ \phi_{n\ th} \leq 2\cdot 10^{-13}$[Gy cm²]

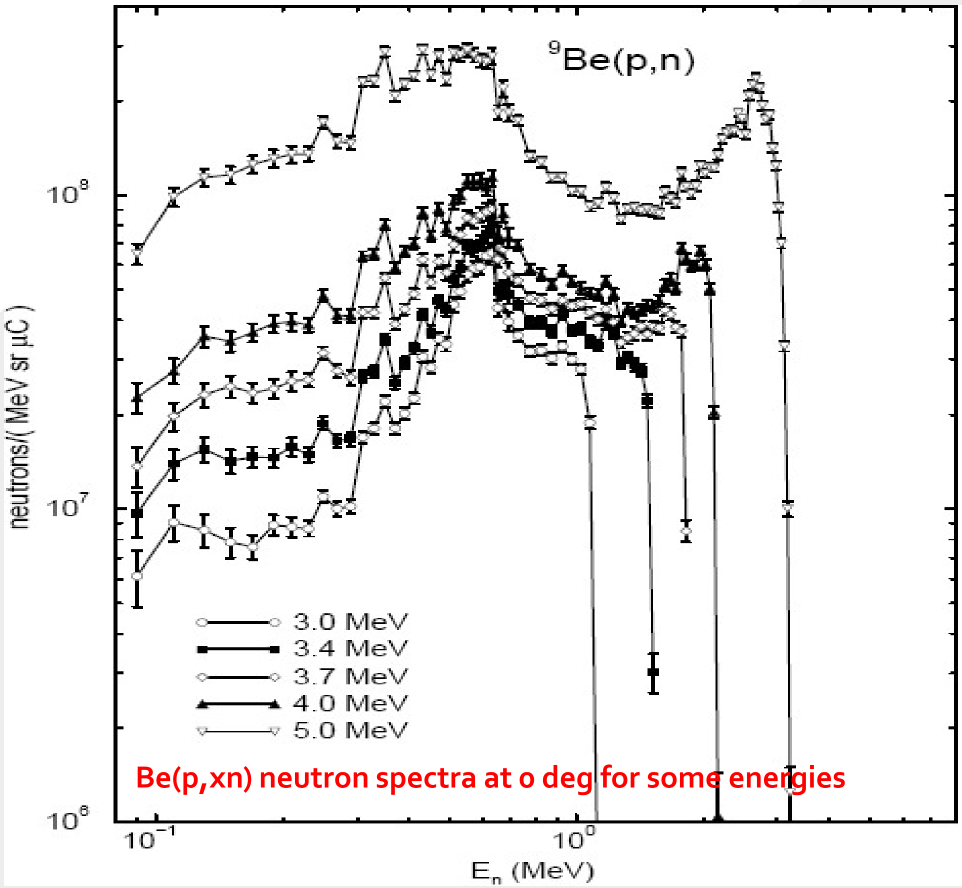
$\dot{D}_{\gamma}\ /\ \phi_{n\ th} \leq 2\cdot 10^{-13}$[Gy cm²]

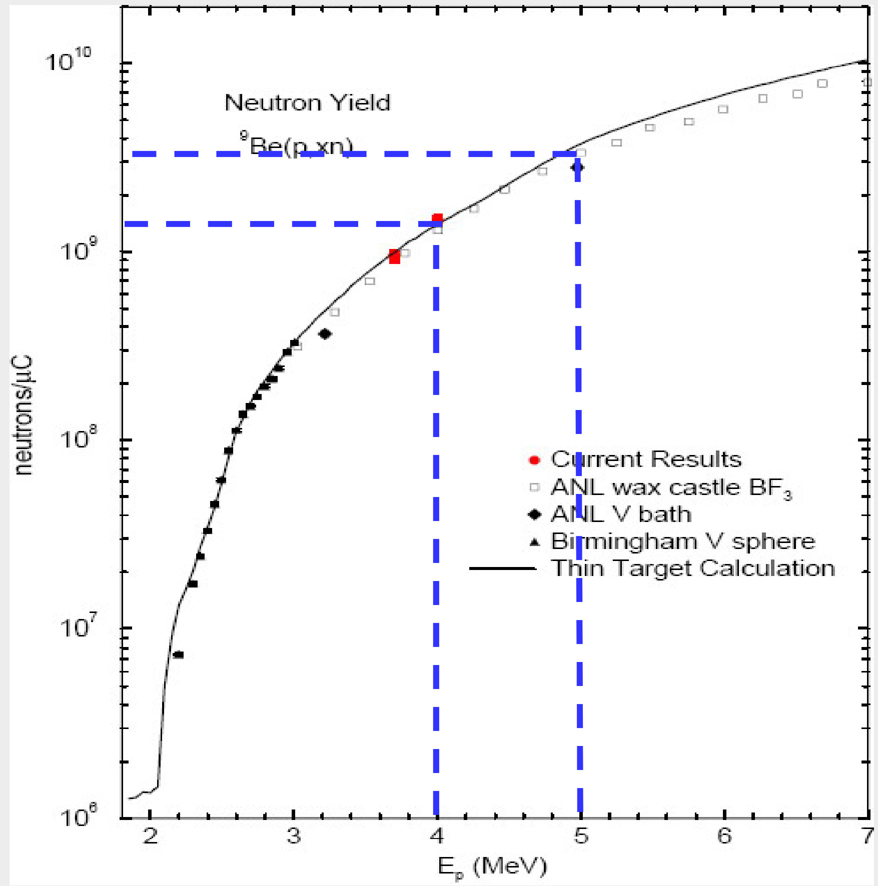
Current Status of BNCT. *IAEA-TECDOC-1223, IAEA. May 2001*

Be(p,xn) neutron yielding and spectra at E = 5 MeV

The only one experimental measurements available so far ……TOF technique, MIT (2000)

Howard, et.al., *Measurement of the thick-target 9Be(p,n) Neutron Energy Spectra,* ***Nuc. Sci. Eng., 138, 145-160, (2001)***



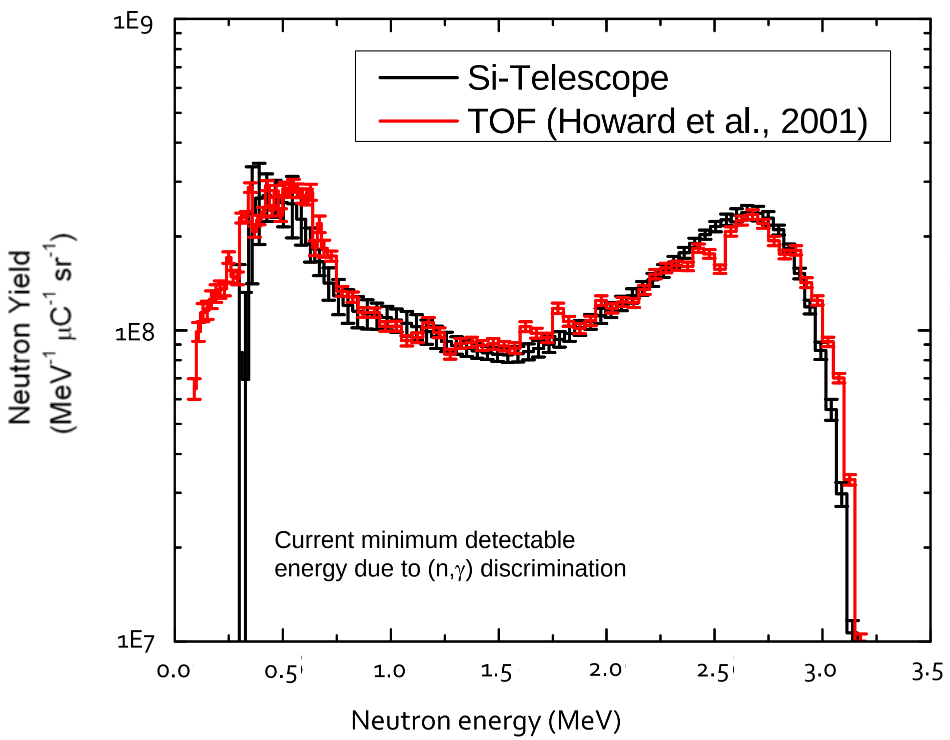


Total neutron yield measured at Ep= 4 MeV: **Yn $1.05 \cdot 10^{12}$ $s^{-1}mA^{-1}$**

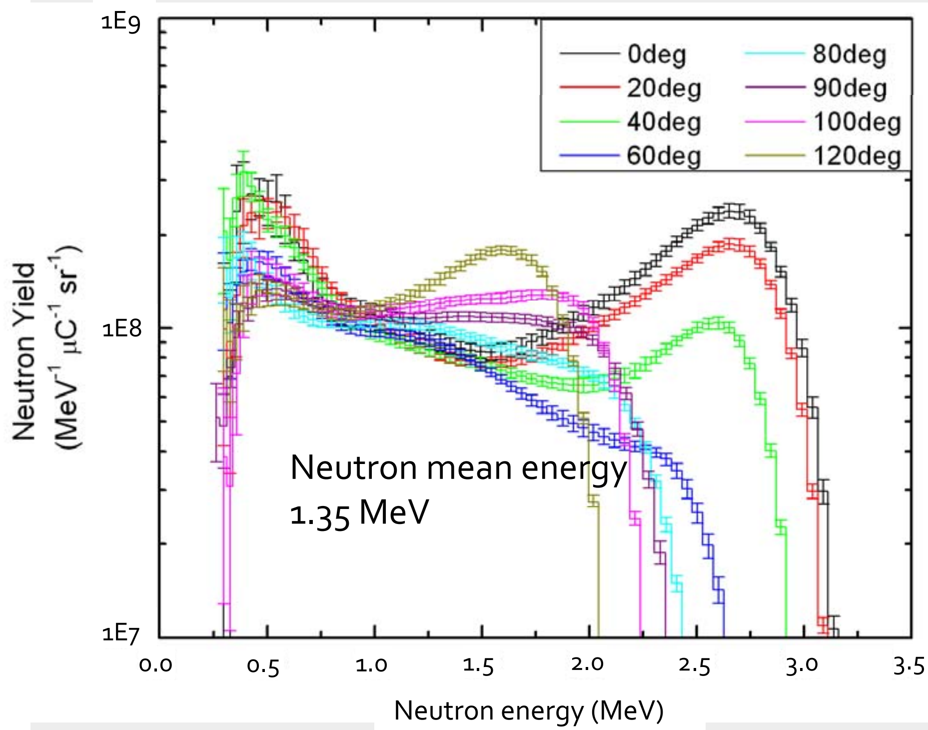
Neutron source gain factor expected at Ep= 5 MeV ≅ 2.8 **→Yn ~$2.9 \cdot 10^{12}$ $s^{-1}mA^{-1}$**

Ep=5 MeV Be(p,xn) thick target neutron spectra measurements at the 6 MeV Van de Graff accelerator at LNL new p-recoil detector (Milan Polytechnic)

Be(p,xn) neutron spectra comparison with at 0 deg



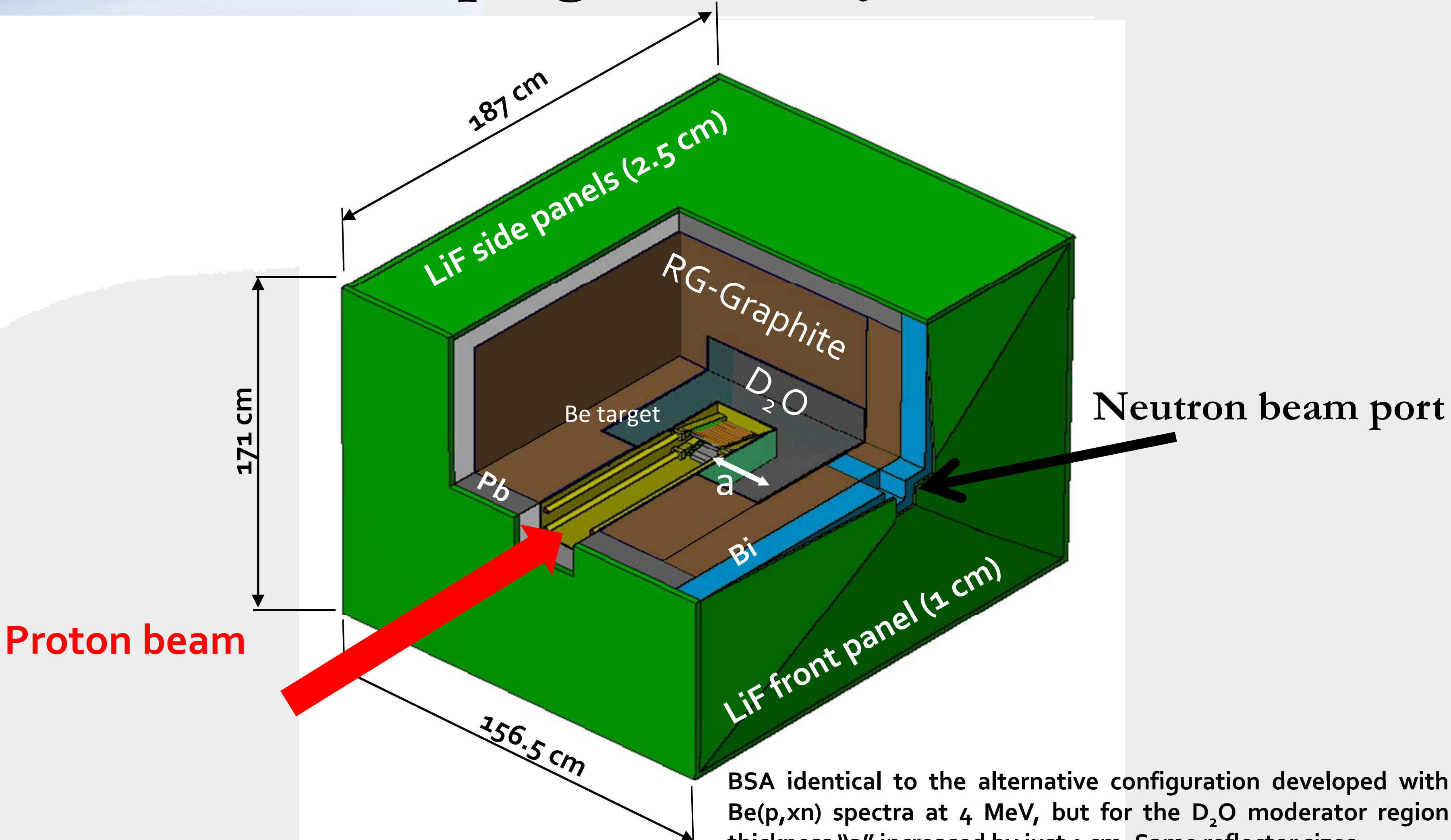
Be(p,xn) all measured neutron spectra



POLIMI - Silicon Telescope
Be(p,xn) Ep= 5 MeV total neutron Yield measured $Y_{n\,(4\pi)} = 3.05 \cdot 10^{12}\ s^{-1} mA^{-1}$

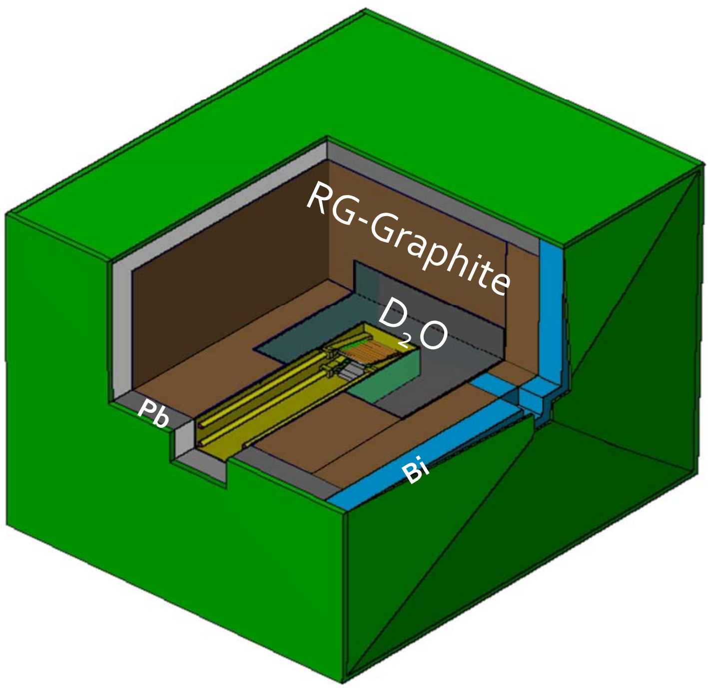
Neutron source level expected with TRASCO RFQ + Be target → Sn ~$1.05 \cdot 10^{14}\ s^{-1}$

The Beam Shaping Assembly solution



BSA identical to the alternative configuration developed with Be(p,xn) spectra at 4 MeV, but for the D_2O moderator region thickness "a" increased by just 1 cm. Same reflector sizes

MCNPX calculation results



Neutron Fluence-to-kerma conversion factors from ICRU-63

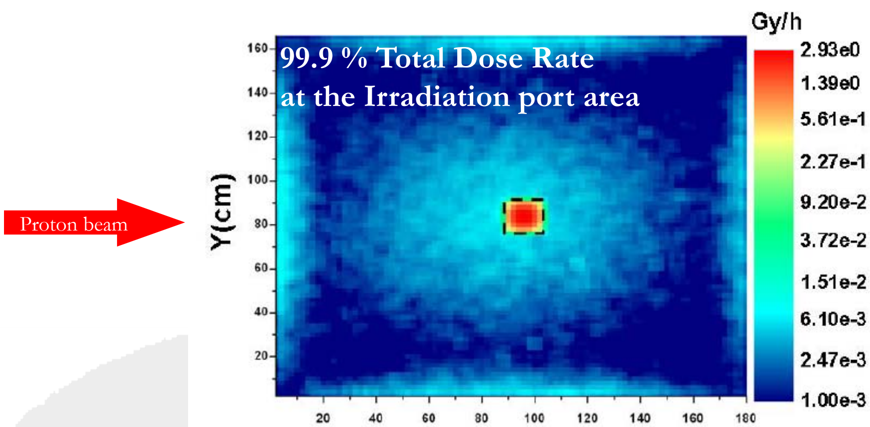
Gamma Fluence-to-kerma conversion factors from ICRU-46

Total measured neutron yield ~$3.05 \cdot 10^{12}\ s^{-1} \cdot mA^{-1}$

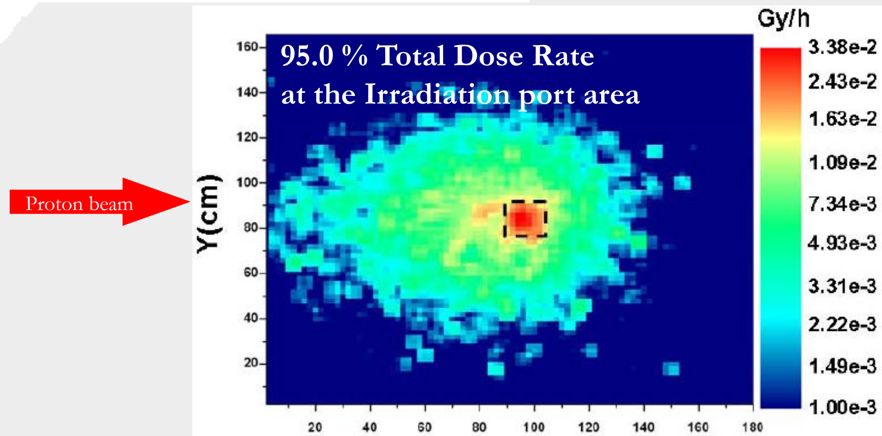
Agosteo et al., 2010. Proc. of ICNCT-14, Argentina (2010)

	Φ_{th} (E≤ 0.5 eV) ($cm^{-2}s^{-1}$)	Φ_{th} / Φ_{total}	K_{nth} ($Gy \cdot h^{-1}$)	$K_{n\ epi\text{-}fast}$ ($Gy \cdot h^{-1}$)	K_{γ} ($Gy \cdot h^{-1}$)	$K_{\gamma} / K_{n\ tot}$	$K_{n\ (E>0.5\ eV)} / \Phi_{th}$ ($Gy \cdot cm^2$)	K_{γ} / Φ_{th} ($Gy \cdot cm^2$)
IAEA TECDOC-1223 ref. parameters	**> 1.0E+09**	**> 0.90**					**≤ 2.0E-13**	**≤ 2.0E-13**
MCNPX results	**4.30E+09**	**0.96**	2.53	0.51	1.42	0.46	**0.33E-13**	**0.92E-13**

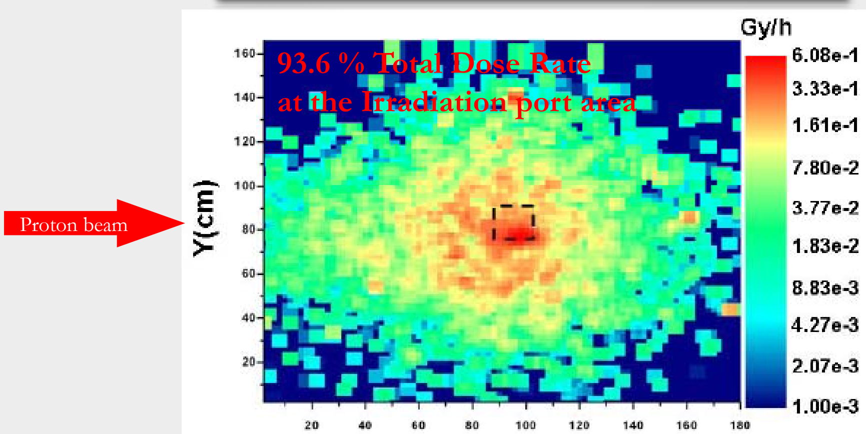
Neutron & gamma dose beam port wall mapping



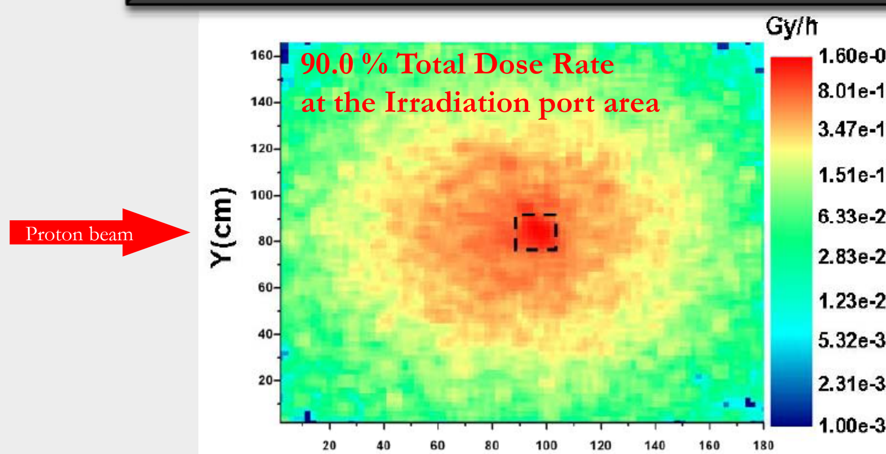
Thermal neutrons (E≤ 0.5 eV)



Epithermal neutrons (0.5 eV≤E≤10 keV)



Fast neutrons (E>10 keV)



Prompt gammas

Conclusion

- Proton source upgrade & LEBT completion is possible in the framework of TRASCO-3 project
- High power coupler test was successful at nominal power. We plan to reach 130% of nominal power (end of this month)
- RFQ passed all low power tests
- Two important points remain:
  - RFQ high power test (September - December 2011)
  - Converter proton irradiation test (next year)

In the mean time…

- A consortium between INFN, Pavia University and SOGIN was born two months ago to provide the project with necessary funds for completion