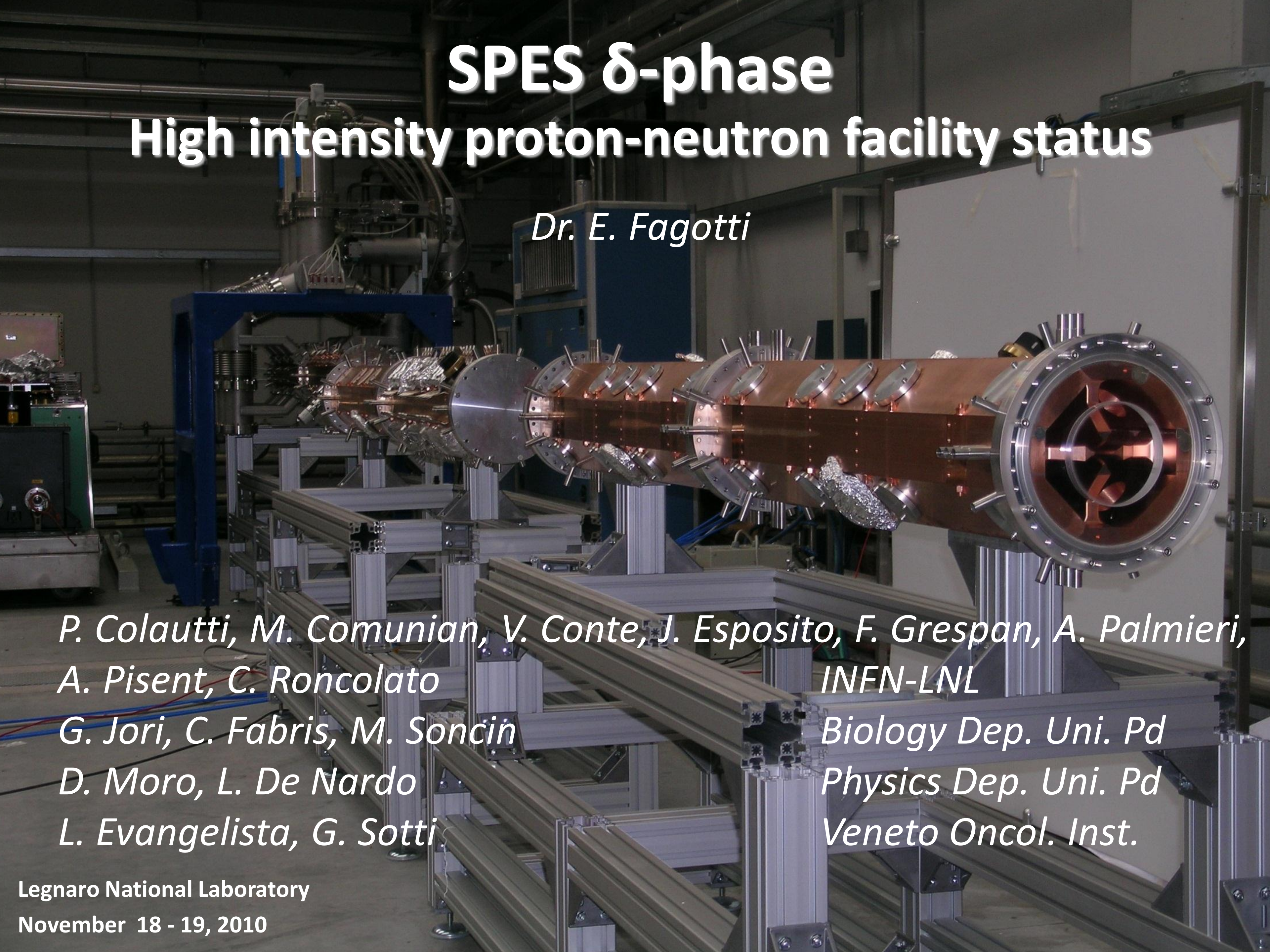

SPES δ-phase
High intensity proton-neutron facility status

Dr. E. Fagotti

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G. Jori, C. Fabris, M. Soncin — *Biology Dep. Uni. Pd*

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Legnaro National Laboratory

November 18 - 19, 2010

Summary

- δ-project overview: High current RFQ & neutrons for accelerator driven Neutron Capture Therapy (BNCT)

- High Intensity Accelerator Status
  - Proton Source (PS)
  - Low Energy Beam Transport and Diagnostics (LEBT&BD)
  - Main accelerator (RFQ)
  - Beryllium Target and Beam Shaping Assembly (BT&BSA)

- Accelerator Based Neutron Source Applications

δ-project overview
High current RFQ & neutrons for accelerator driven Neutron Capture Therapy (BNCT)

δ-project overview

An accelerator-based intense thermal neutron source, aimed at the **skin melanoma tumor treatment** through a combined **Boron Neutron Capture** plus **Photodynamic (BNCT+PDT)** therapy approach is under construction at LNL in the framework of SPES project.

The **BNCT facility** will exploit the intense proton beam provided by the RFQ, formerly thought as driver of the SPES accelerator, to obtain an intense neutron yield.

The **INFN-BNCT project** will therefore represent a fundamental test bench for an operative accelerator-based BNCT facility. The actual BNCT centers are indeed all based on nuclear research reactors.

A collaborative R&D effort in different research areas

Last news

A memorandum of understanding between INFN and CEA was signed last month for accelerator high power tests at Saclay

A memorandum of understanding between INFN and DEE/UPV was signed last month for collaboration on accelerator

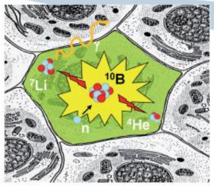
INFN-MED officially presented BNCT at the 1^{st} National Health Research Conference (8/9 November 2010) organized with the scientific management of the Ministry of Health

BNCT: UNA TERAPIA CELLULARE

Istituto Nazionale di Fisica Nucleare

La Boron Neutron Capture Therapy (BNCT) è una ***tecnica sperimentale per il trattamento del cancro*** *in cui le cellule cancerose vengono eliminate per mezzo di una reazione nucleare.* ***La reazione indotta dai neutroni si concentra sul tessuto malato grazie all'immissione in esso di un farmaco contenente atomi di Boro.*** *I nuclei di Boro si spaccano, rilasciando frammenti che eliminano le cellule malate con grande efficacia.*

Meccanismo d'azione



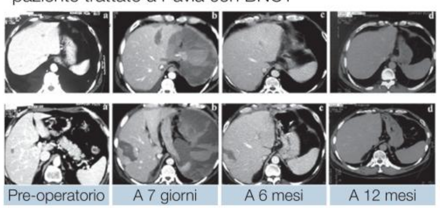
BNCT si basa sull'elevata selettività di interazione del ^{10}B con neutroni termici, a bassa energia, per dare ^{11}B; tale specie è instabile e la sua fissione produce due particelle molto veloci: ^{7}Li ed ^{4}He (o particella a). Queste provocano la morte delle cellule intorno all'atomo di ^{11}B

Il progetto italiano INFN

La BNCT è stata fatta in Italia su un progetto INFN e funziona!

Caso clinico:

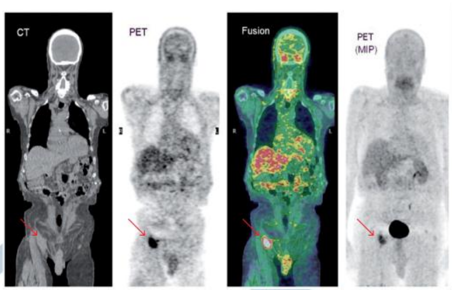
sequenze di immagini tomografiche del fegato a livello craniale (sopra) e caudale (sotto) nel primo paziente trattato a Pavia con BNCT



Pre-operatorio | A 7 giorni | A 6 mesi | A 12 mesi

Come agisce a livello linfonodale

Distribuzione in vivo con PET/CT del ^{18}F- FBPA e suo accumulo a livello linfonodale.



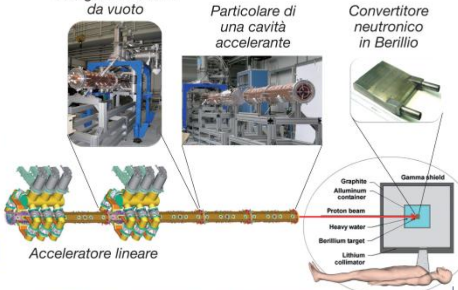
L'acceleratore di Protoni

L'INFN in collaborazione con l'Istituto Oncologico Veneto (IOV– IRCCS), l'Università di Padova e l'Università di Pavia opera da tempo nel campo della BNCT, e sta costruendo un acceleratore di protoni per produrre una sorgente neutronica per BNCT.

	Φ_{th} (E≤ 0.5 eV) (cm^{-2}s^{-1})	Φ_{th}/Φ_{total}	$K_{n\,(E>0.5\,eV)}/\Phi_{th}$ (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

Caratteristiche della sorgente neutronica INFN

La sorgente sarà INTENSA, SICURA, FLESSIBILE.



L'acceleratore nudo: le tre cavità acceleranti

Un acceleratore lineare ad alta potenza genera un **fascio ad alta intensità di protoni.** Il fascio viene trasportato su un **bersaglio di Berillio** che **converte i protoni in neutroni.** Questi vengono opportunamente rallentati da un moderatore e convogliati verso la porta d'irraggiamento.

infografica centimetri.it

L'acceleratore di Protoni

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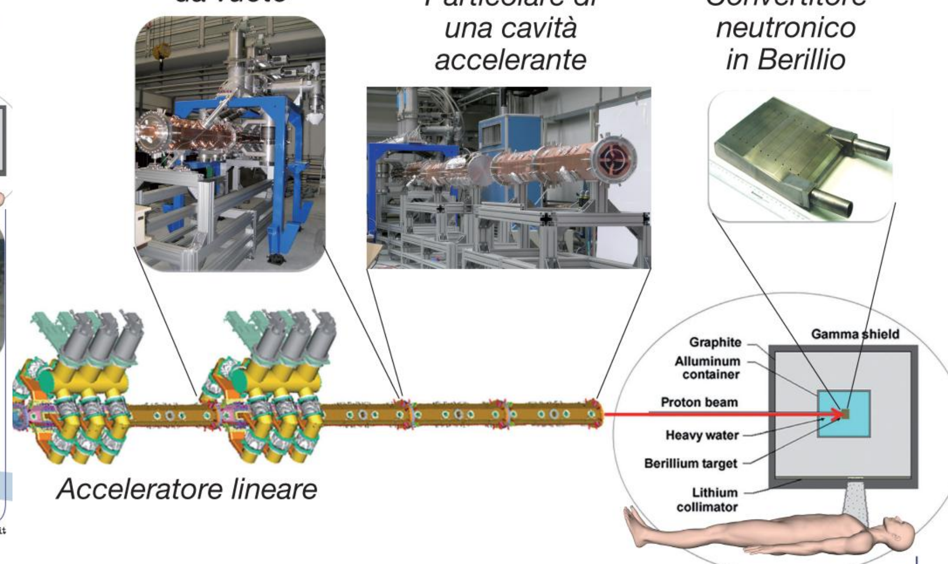
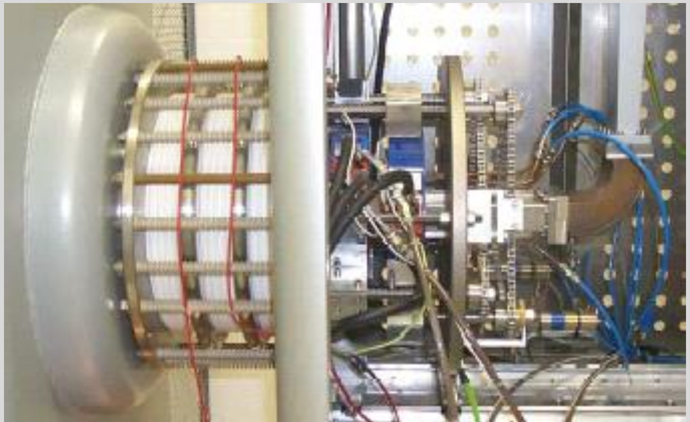
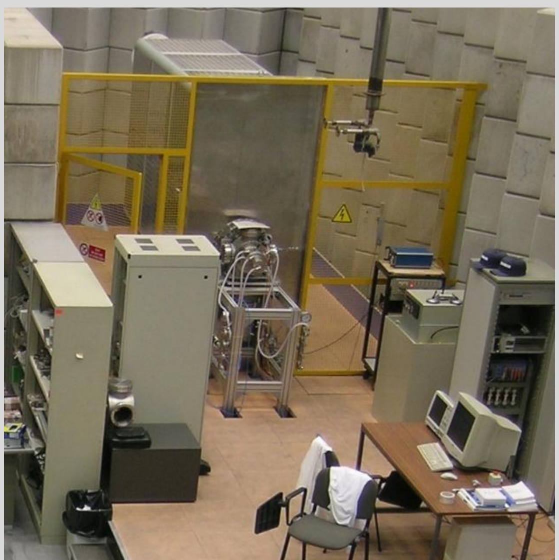


High Intensity Accelerator Status

Proton Source (PS)



PS developed at LNS (2000)



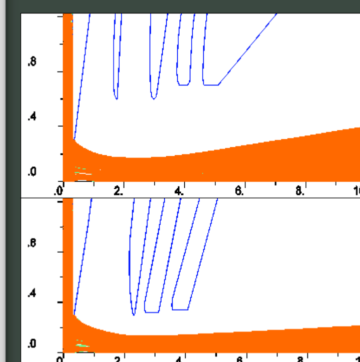
PS optimized at LNL with magnetic shielding (2007)

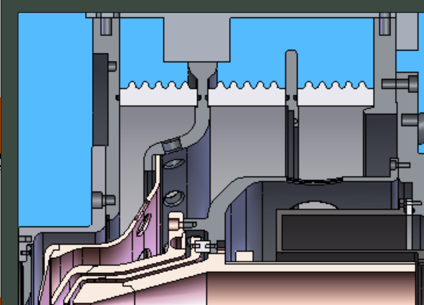
STATUS

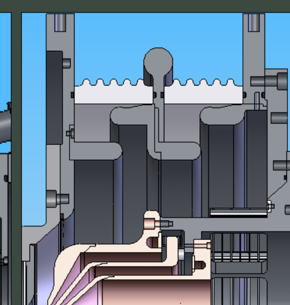
$I_p \approx 45$ mA
E = 80 KeV
$\varepsilon_{n,rms} < 0.1$ mm-mrad
$\phi_b(z = 200\ \text{mm}) = 34$ mm
Beam time structure: CW

NEAR FUTURE

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

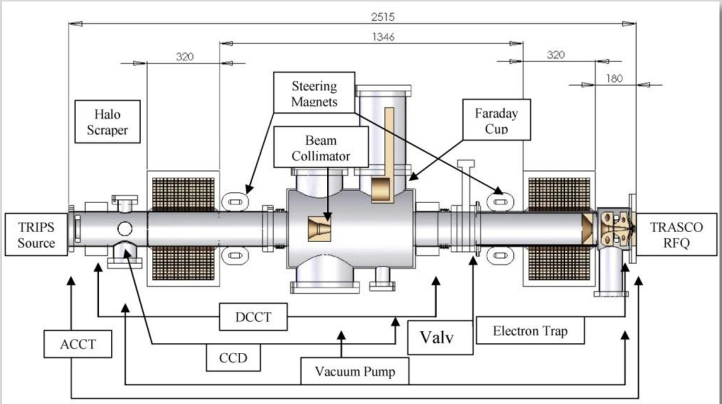




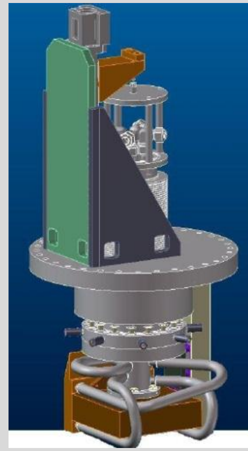


Beam time structure: CW & pulsed
[Magnetron pulser] [LNL & DEE/UPV]

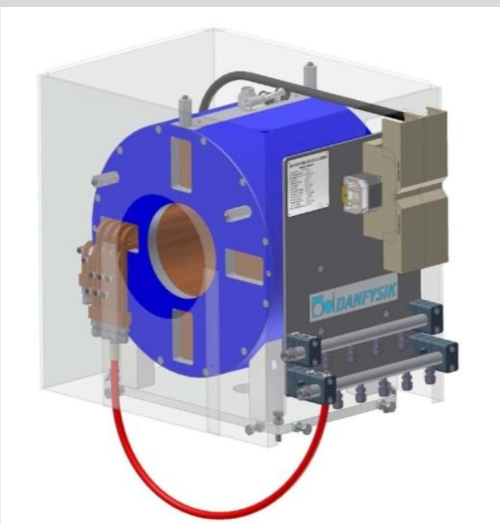
LEBT&BD



LEBT developed at LNL (2002)



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



Solenoid developed at LNL (2008)

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

[FES electronics development] [LNL & DEE/UPV]

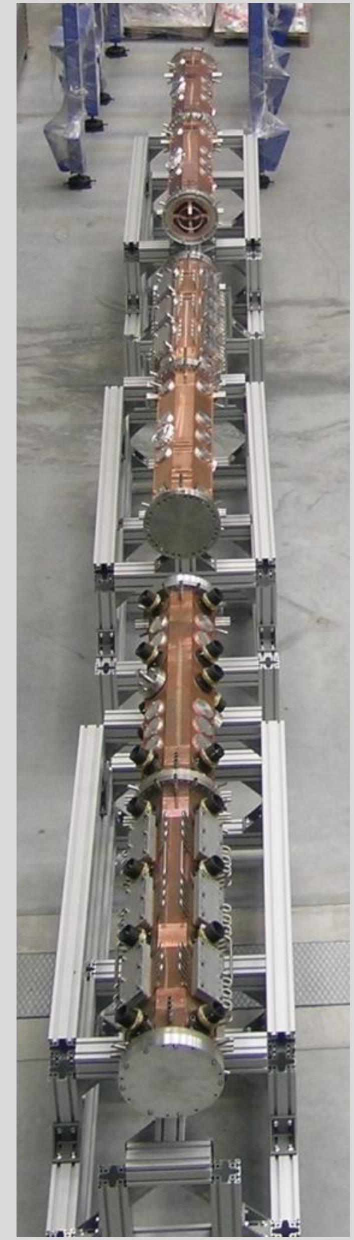
[FGA development] [LNL (TRASCO-3) & DEE/UPV]

[LEBT control system] [LNL (TRASCO-3) & DEE/UPV]

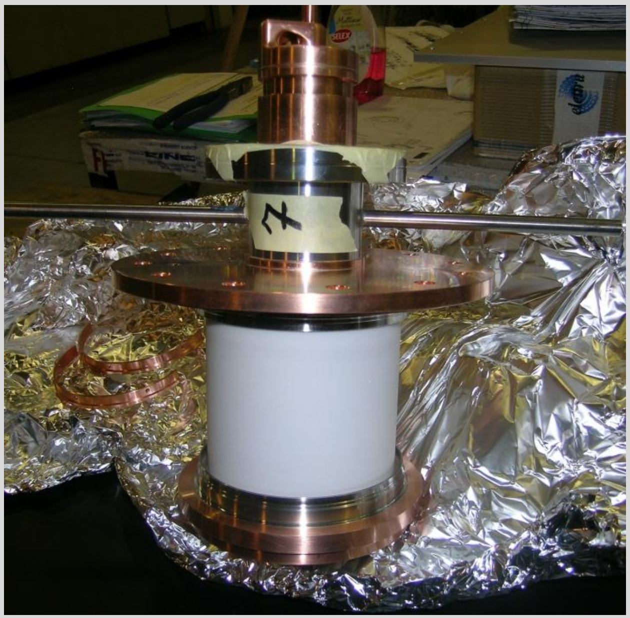
[e-trap] [LNL (TRASCO-3)]

RFQ - 1

- Entire RFQ structure completed and installed at LNL since November 2009



- High Power Couplers construction completed



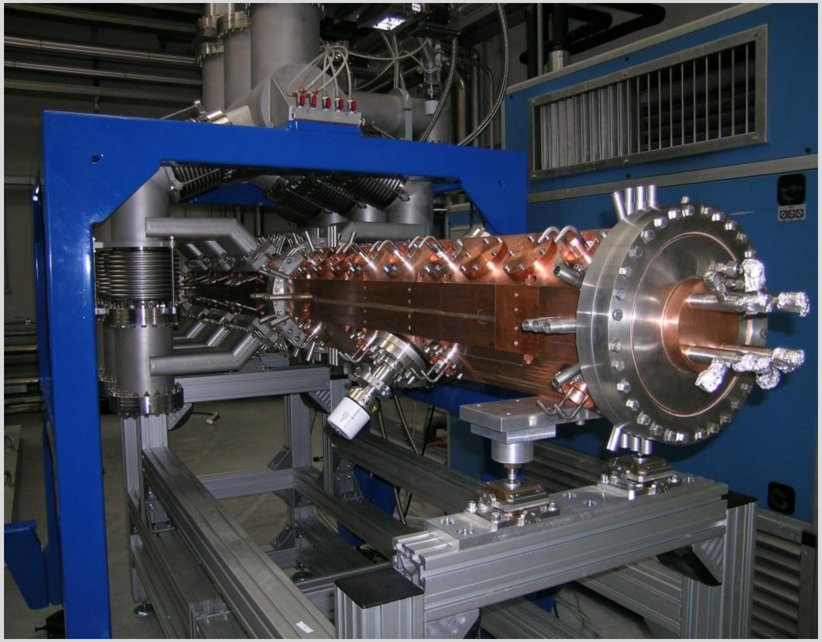
- RFQ cooling and tuning system, developed for IFMIF RFQ high power test, is ready for operation

- RFQ low power tests successfully completed

RFQ - 2

- Q_0 (measured) = 8500 → P_{max}(50 mA-5 MeV)=1115 kW [one klystron]

- Vacuum system tested on cavity with excellent performances (1X10^{-8} mbar)

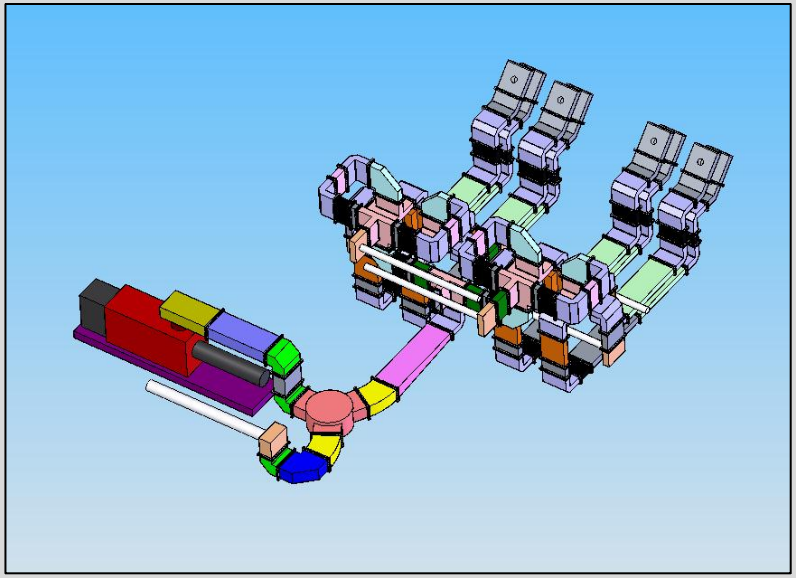


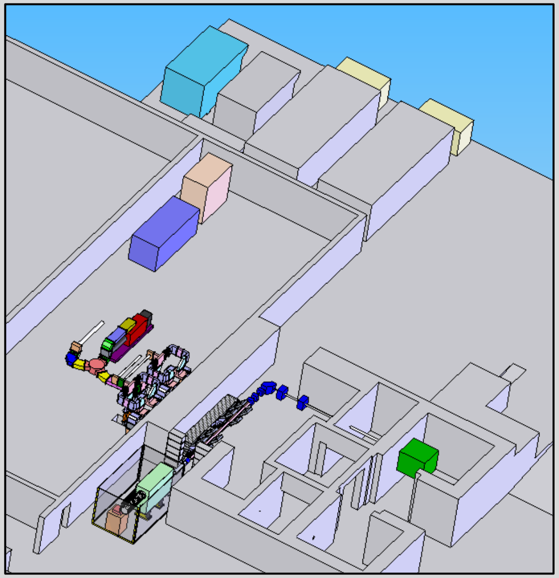
- RFQ high power test is the last critical milestone

- The RFQ high power test has become also a milestone for nuclear fusion studies (IFMIF). This is the reason for the MoU between INFN and CEA Saclay

RFQ - 3

- All high tecnology part (RFQ cavity, RF distribution, RF amplifier, local cooling-tuning system, local control system) was developed





- Conventional installation (Klystron and conventional power supplies, secondary cooling system, building) is required.
- A collaboration with BNL RF team is started to write down the main specifications for the klystron power supply.
- Considering that CEA has the complete conventional installation realized for IPHI project RFQ, agreement with CEA gives INFN the possibility to test the accelerating structure.

High Power Test - 1

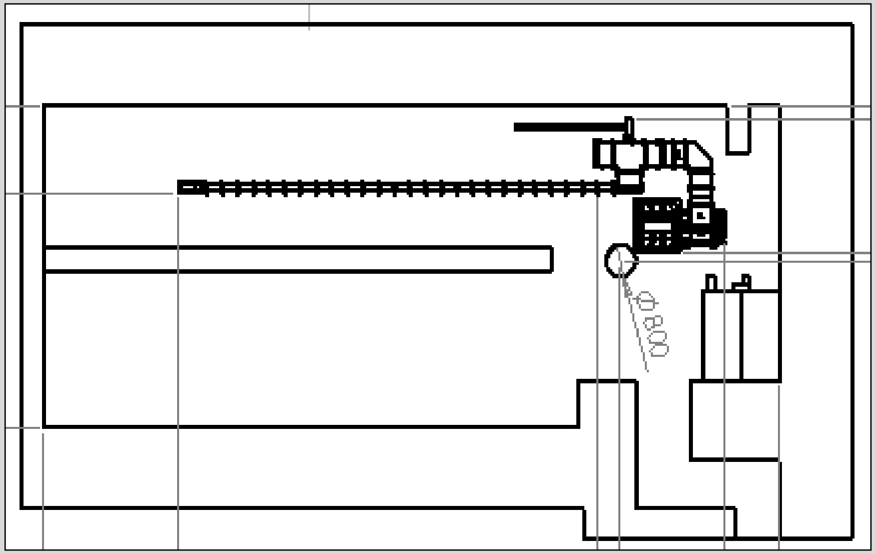
- First part of sub-systems will be transferred to Saclay before the end of this month. RFQ will be moved before Christmas holidays
- Start of high power tests is foreseen in the second week of January 2011

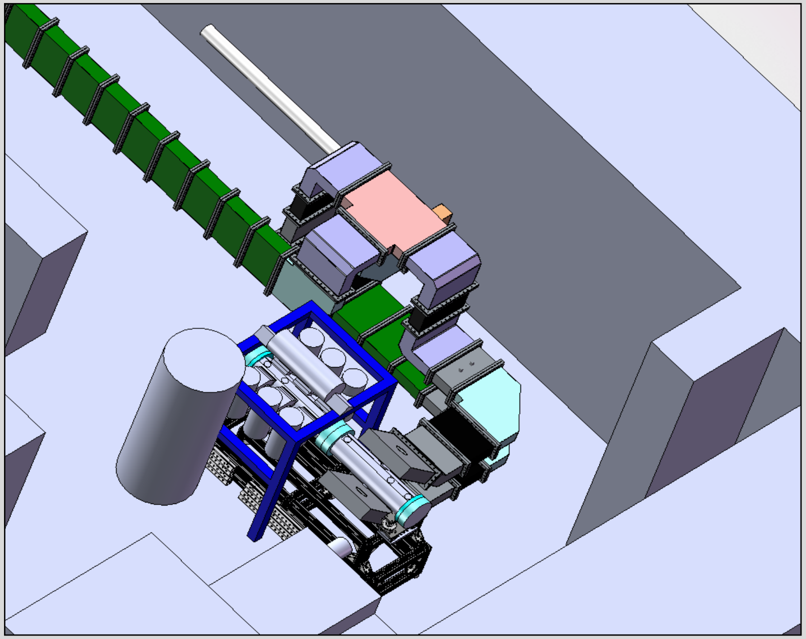
High Power Test Stand in Saclay

High Power Test - 2

Installation of high power test:

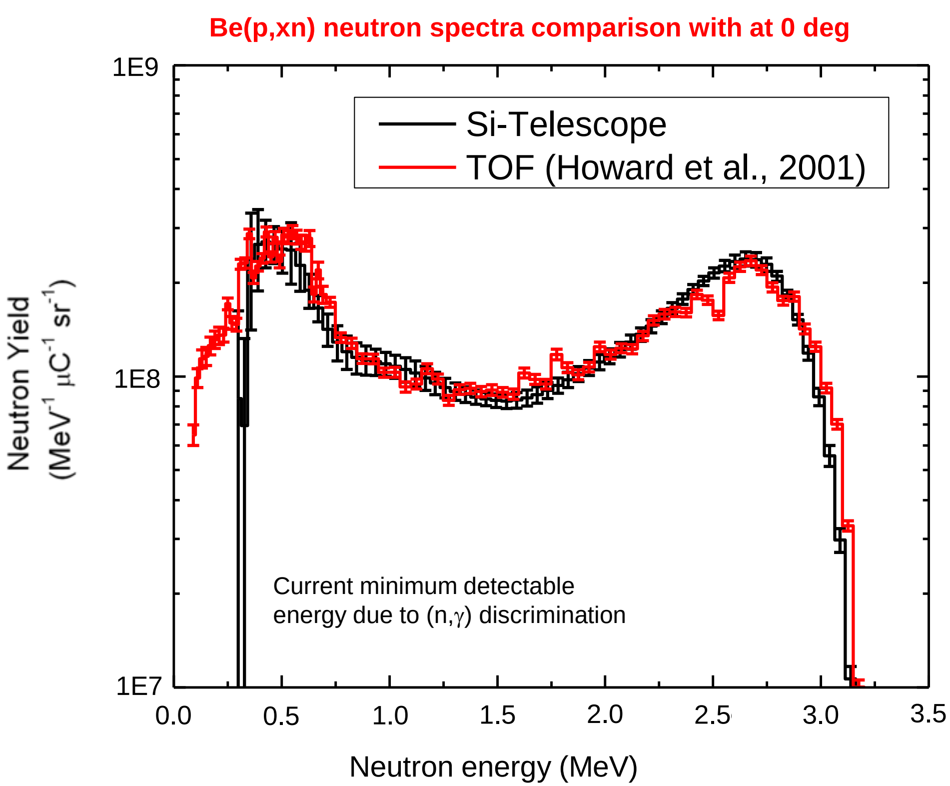
- RFQ cavity with its own mechanical support, water distribution system, vacuum system
- RF system (WGs, magic T, directional couplers, water load)
- Cooling skid
- Diagnostics (vacuum gauges, arc detectors, temperature monitors, water flow meter, power pick-ups)
- Local control system (PLC S7 based control system with WinCC interface)

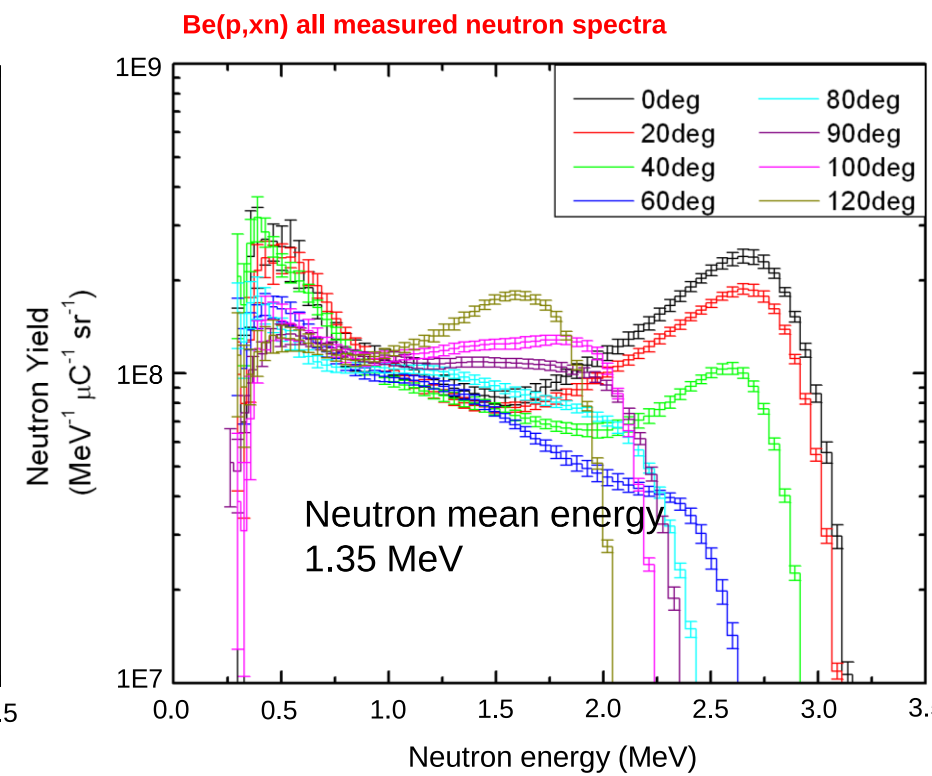




BT&BSA - 1

E_p = 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)



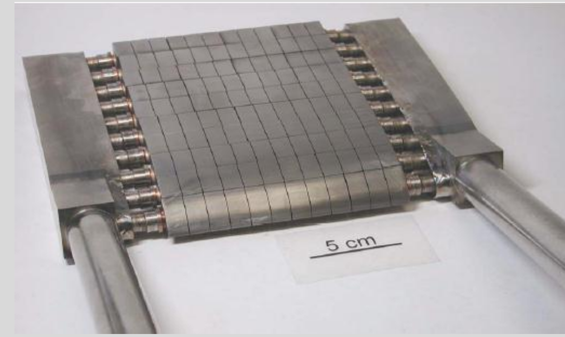


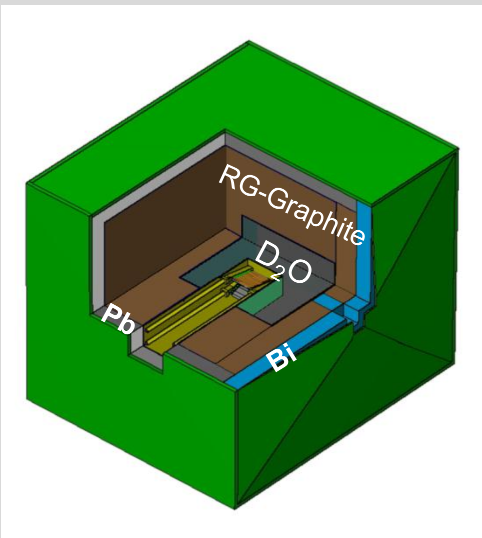
POLIMI - Silicon Telescope
Be(p,xn) Ep= 5 MeV total neutron Yield measured $Y_{n\ (4\pi)}$ **= $3.5 \cdot 10^{12}\ s^{-1} mA^{-1}$**

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

BT&BSA - 2

High Power Be target prototype already constructed. The thermal mechanical as well as the neutron radiation damage tests, already passed. The remaining radiation damage test program with proton is in progress.





Beam Shaping Assembly modeling: the RG-Graphite final configuration chosen meets the required beam port reference parameters at 5 MeV proton beam. An intense thermal neutron flux in excess of $4 \cdot 10^9$ cm^{-2}s^{-1} will be provided, with an overall good collimation.

	Φ_{th} (E≤ 0.5 eV) (cm^{-2}s^{-1})	Φ_{th} / Φ_{total}	K_{nth} (Gy·h^{-1})	$K_{n\ epi\text{-}fast}$ (Gy·h^{-1})	K_{γ} (Gy·h^{-1})	$K_{\gamma} / K_{n\ tot}$	$K_{n\ (E>0.5\ eV)} / \Phi_{th}$ (Gy·cm^2)	K_{γ} / Φ_{th} (Gy·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**

Accelerator Based Neutron Source Applications

- δ-phase project provides an effective new mean for constructing neutron source for multi-purpose applications on a variety of scales.
- Such source offer unique tools for basic and applied research in physics, chemistry, biology, material science, medicine, energy production, nuclear physics, etc.
- Implementation of a rough beam pulsing system is just foreseen in the agreement with UPV. Variable pulse width from tens of *μs* up to several *ms* can be implemented.
- Uniqueness of δ-phase project respect to other small and medium scale ADNS around the world is the possibility to increase duty factor up to CW operation.

SPES δ-phase at LNL

Phase I: 5MeV, 40mA, 100%DF, 1.4×10^{14} n/s

Phase II (pulsed mode): 5MeV, 50mA, 6%DF, 1×10^{13} n/s

LENS at IUCF

Phase I: 7MeV, 7mA, 0.3%DF, 2×10^{11} n/s

Phase II: 7MeV, 20mA, 2%DF, 4×10^{12} n/s

Phase III: 13MeV, 20mA, 1.25%DF, 1×10^{13} n/s

Conclusion

- Proton source and RFQ accelerating stucture are complete
- LEBT completion is possible in the framework of TRASCO-3
- Be target tests with protons are foreseen next year in the framework of INFN-MED/BNCT
- RFQ high power test will start at the beginning of next year in collaboration with CEA within IFMIF EVEDA project.
- First studies on pulsing system will start very soon in collaboration with UPV.
- Collaboration with BNL RF group related to klystron power supply is growing.
- National Health Research Conference and International Congress on Neutron Capture Therapy showed that a great interest is growing around the project from the medical community.