JORNADAS DEL CUIA EN ARGENTINA 10a. Edición

Pavia accelerator Project

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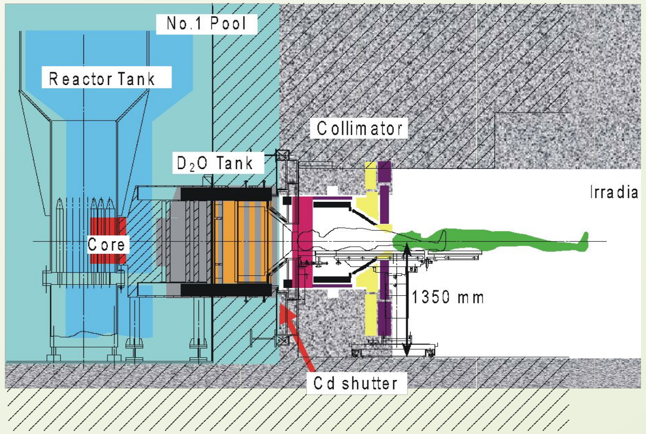
Infn section of pavia, italy

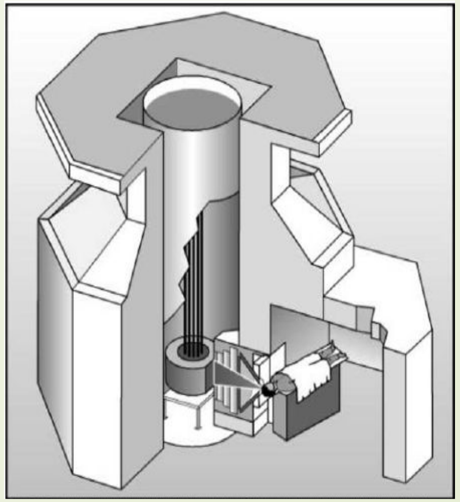
Neutron sources for BNCT

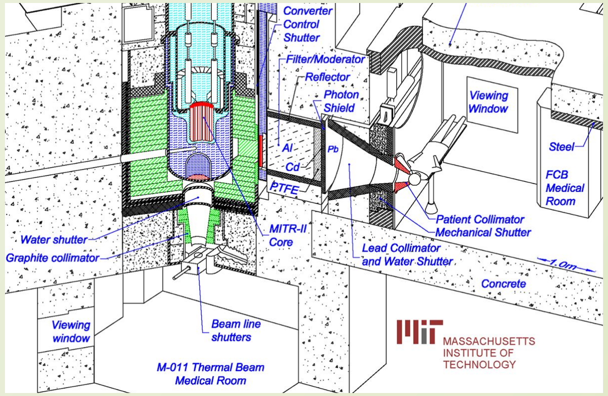
Nuclear Reactors

until now

Not the best environment for the patient
Usually far from the hospital
BNCT not the main activity of the reactor
Change reactor channel to create a BNCT beam

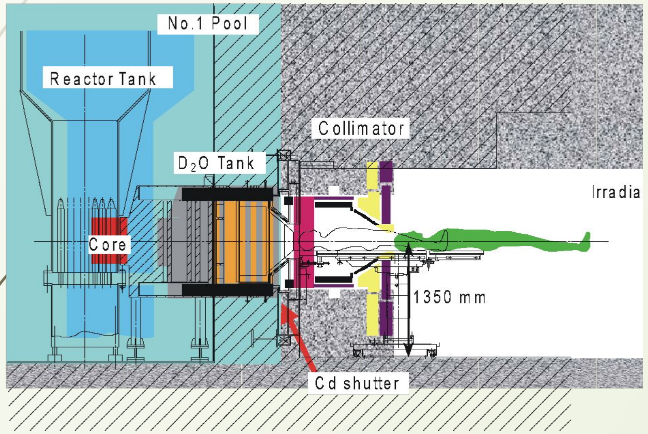


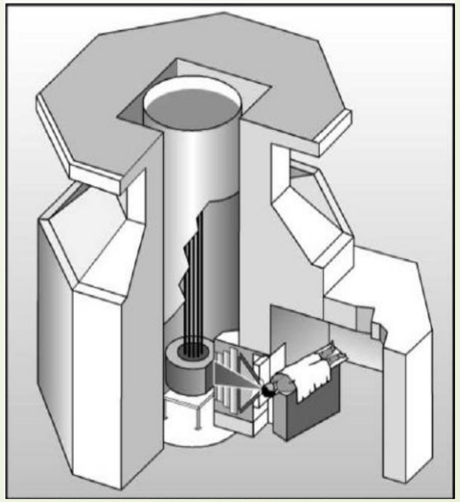


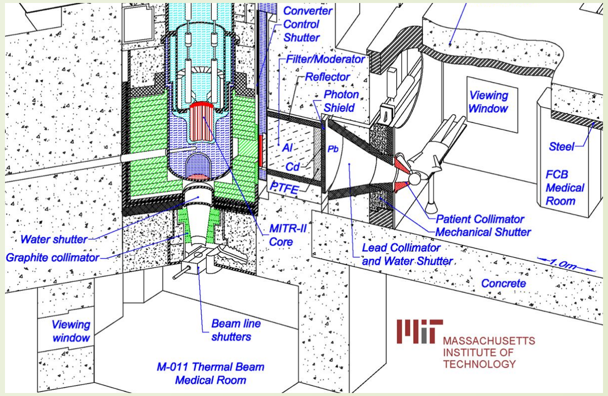


Neutron sources for BNCT

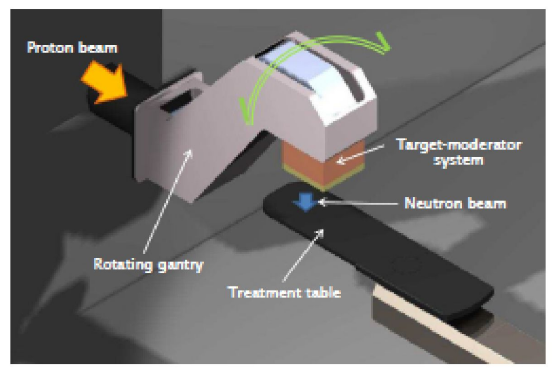
Nuclear Reactors







Finally proton accelerators



From reactor to ABNCT

MUNES

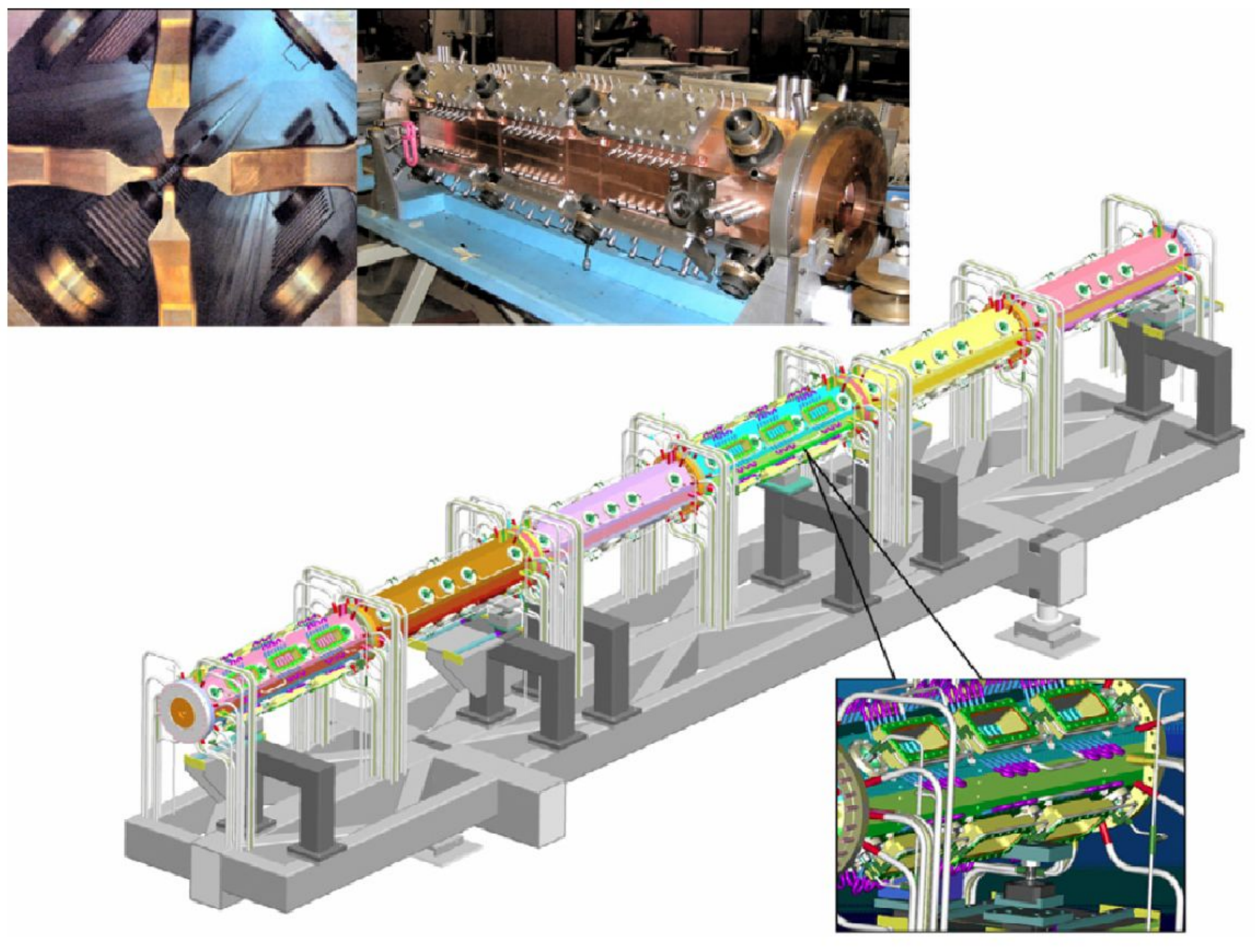
MUltidisciplinar NEutron Source

National Institute for Nuclear Phisycs (INFN)

Legnaro National Laboratory (LNL)
and
Section of Pavia

The RadioFrequency Quadrupole RFQ

Protons are accelerated by a radiofrequency quadrupole



Layout of the 7.13 m long accelerating structure on the support system,

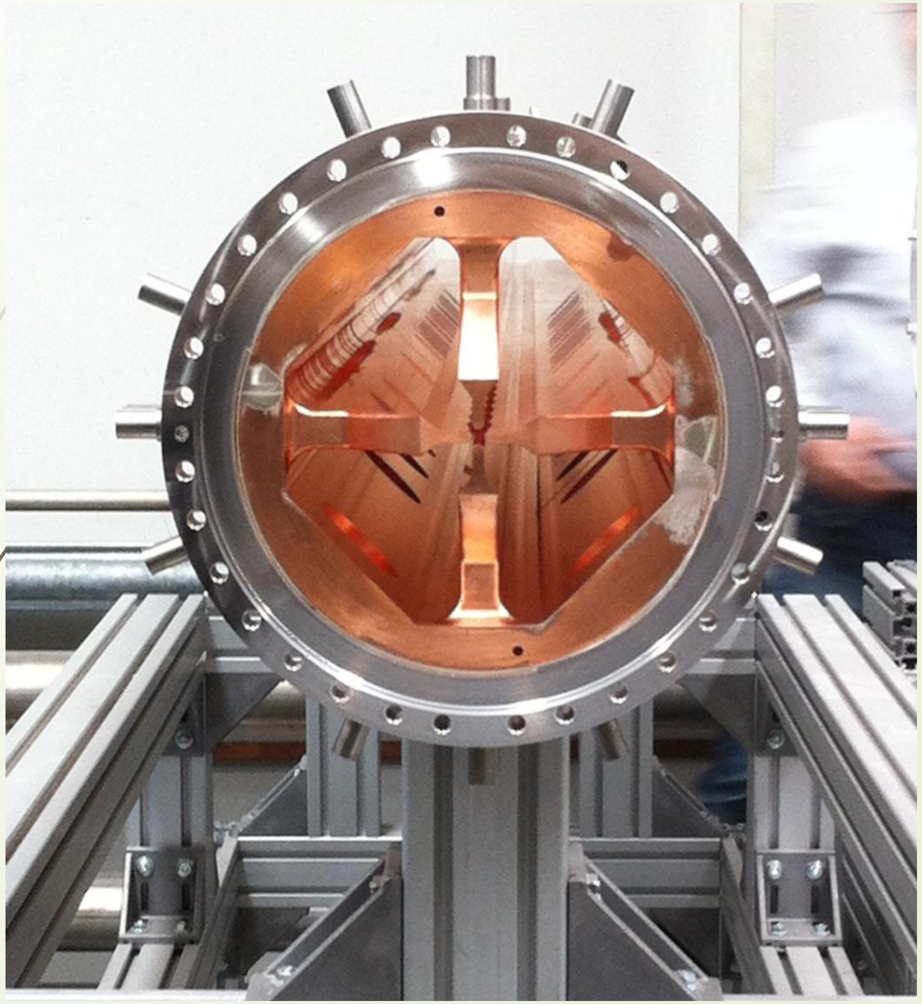
the main cooling pipes connections,

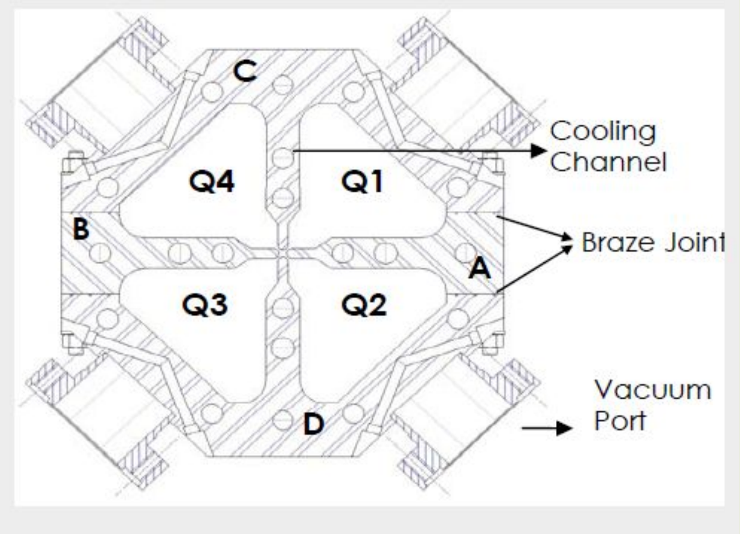
quadrupole cross section

and view of the first module constructed

The RadioFrequency Quadrupole RFQ

Protons are accelerated by a radiofrequency quadrupole

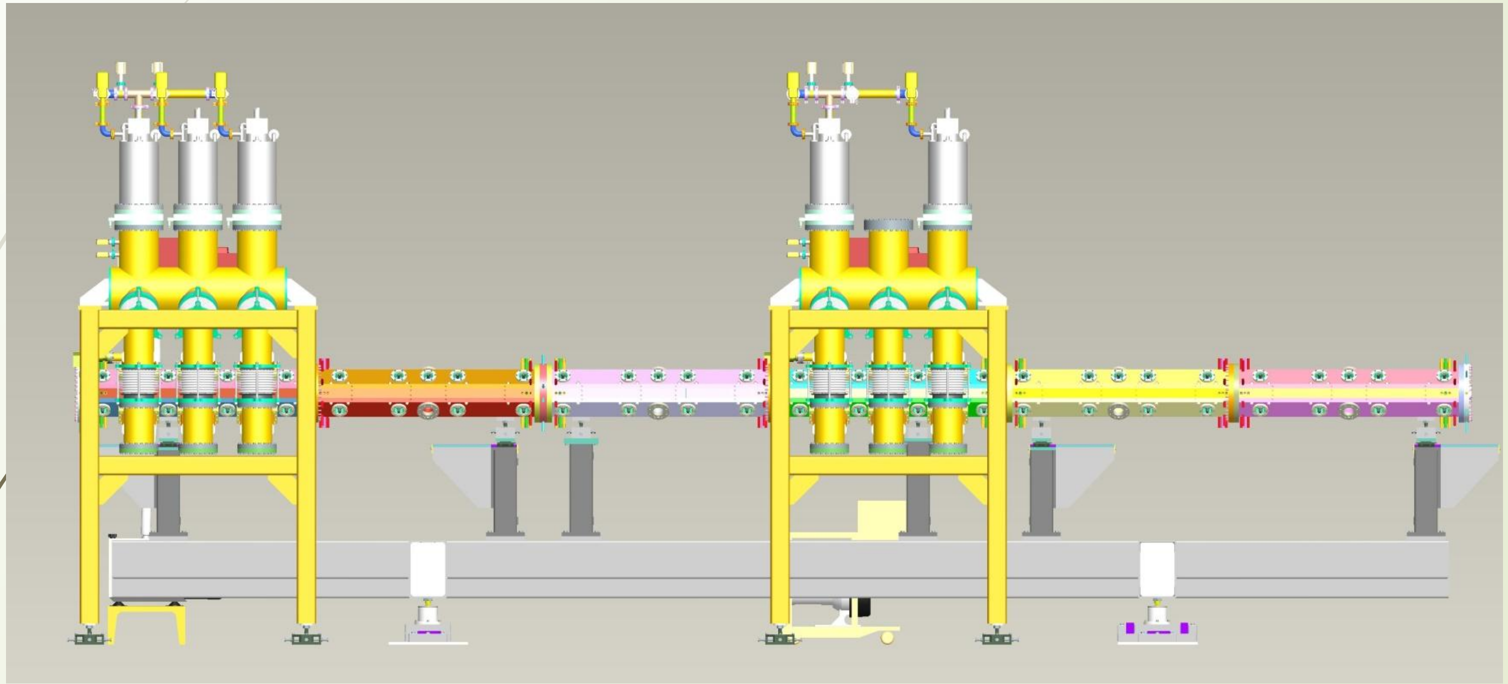




Accelerator type: RFQ
Proton energy: 5 MeV
Proton current: up to 50 mA
Beam power: 150 kW
Time structure: up to CW
Neutron converter: Be
Operative power density
on Be target: 700 Watt/cm^2
Neutron source intensity: 10^{14} s^{-1}

From the reactor to the ABNCT

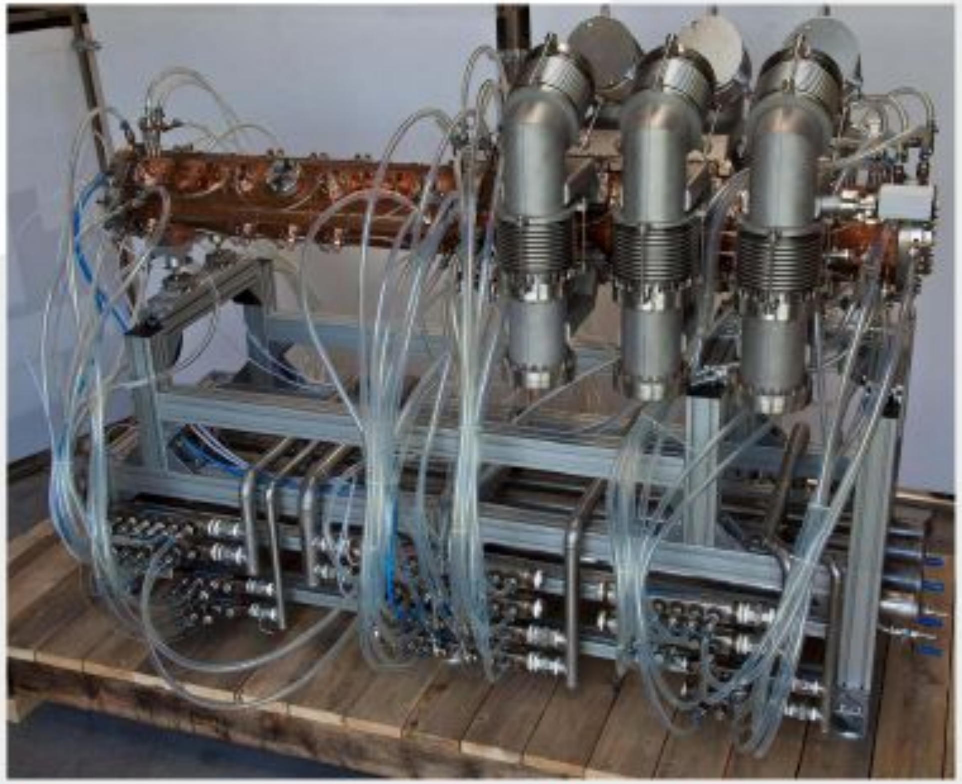
The accelerator is made of 3 segments



- 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)

From the reactor to the ABNCT

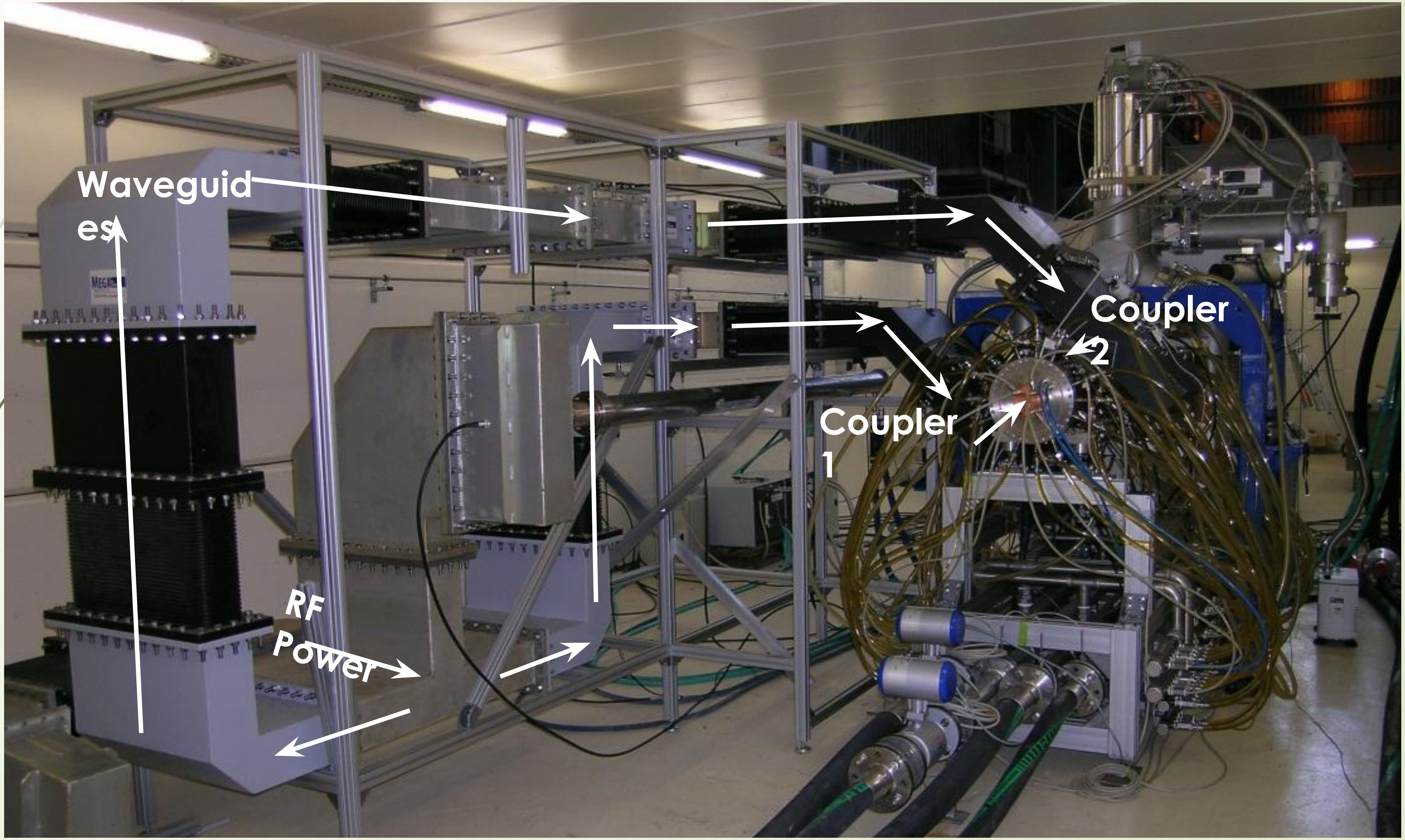
The accelerator is made of 3 segments



- 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)

The RadioFrequency Quadrupole RFQ

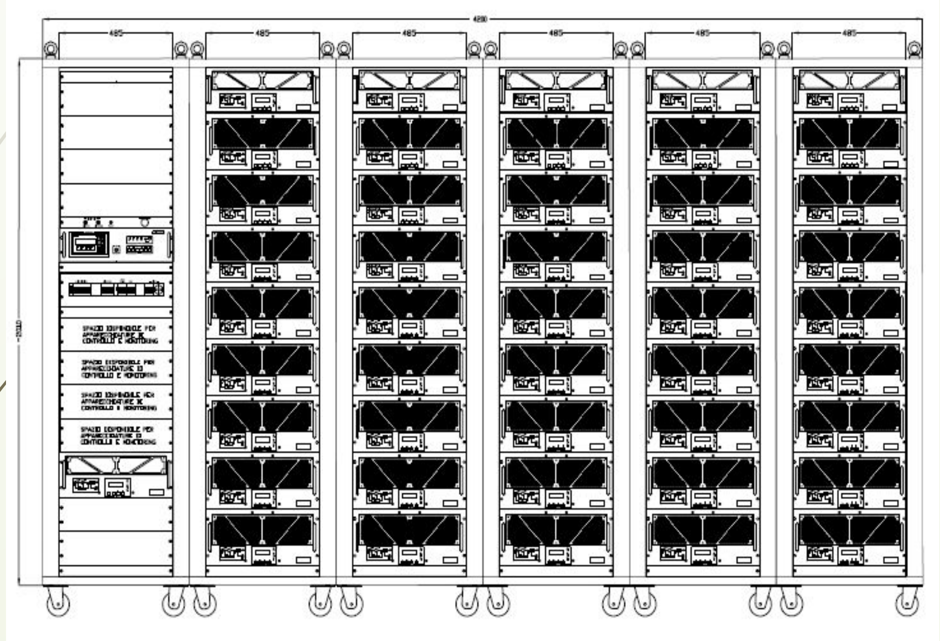
Two waveguides transport the radio frequency into the cavity through two couplers

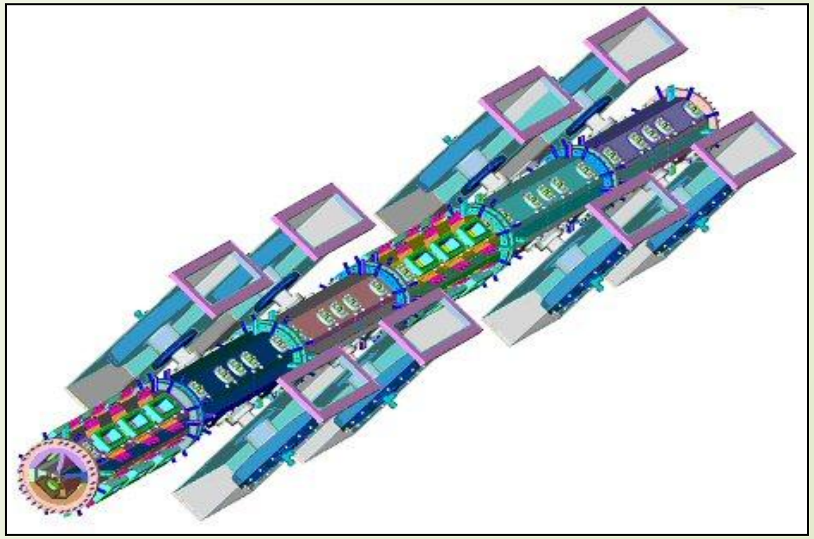


The power supplies

No klystron but 8 independent solid state 125 kW amplifiers

4.2 m





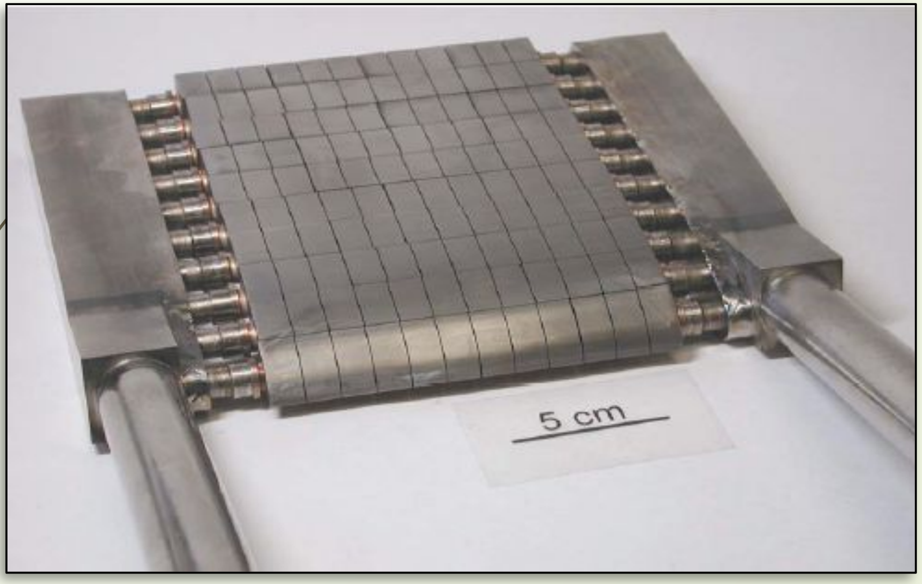
Advantages with respect to a klystron:

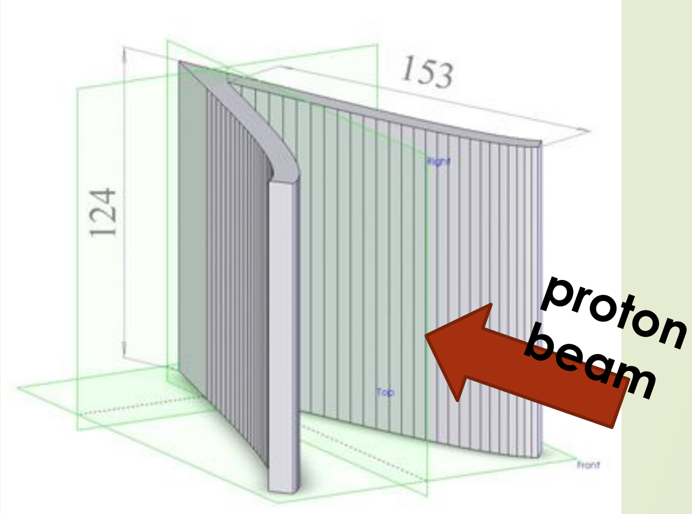
- Lower operating costs (cost and duration of components)
- Availability e reliability (no stop operation in case of components failure)
- Absence of high voltages (important for the operation in an hospital)

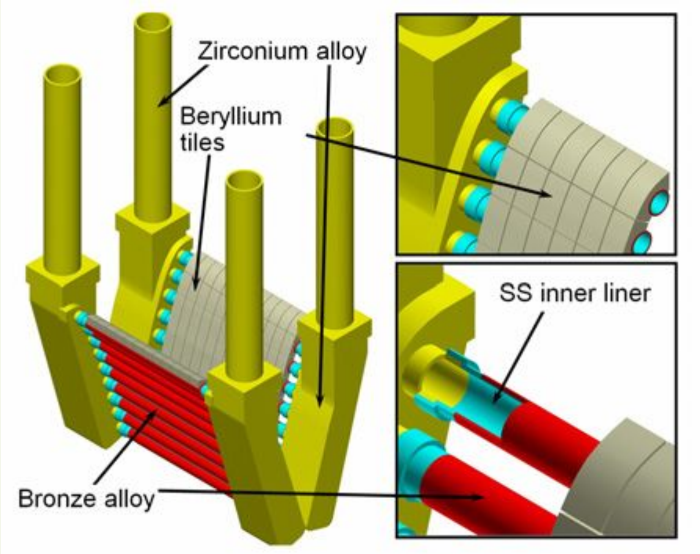
Berillium target

Be has high melting point 1278 °C and high heat conductivity, but gas permeability is extremely low (9 order lower than average materials). H bubbles can be trapped in bulk beryllium and cause fractures.

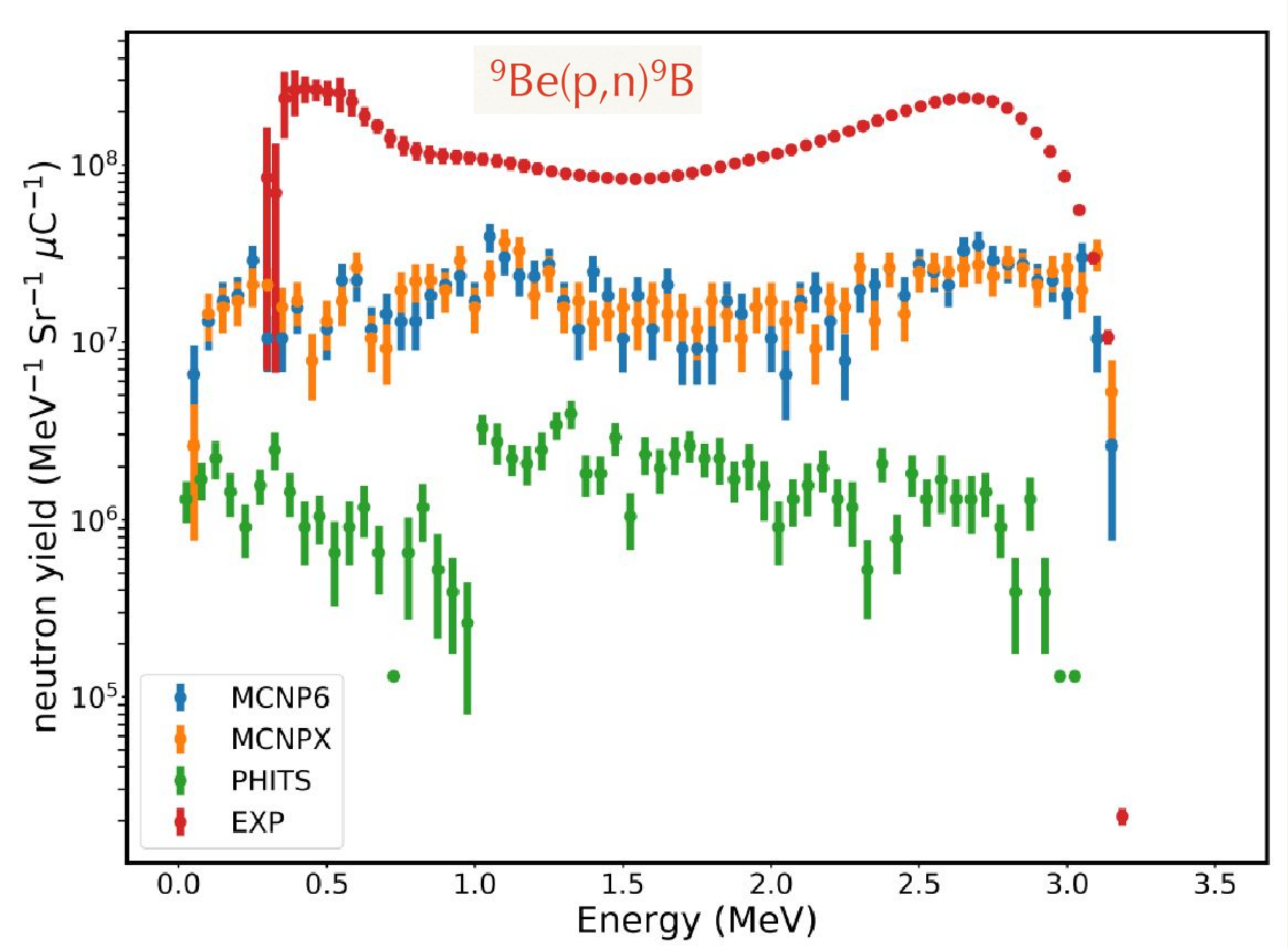
^{9}Be(p,n)







BSA study

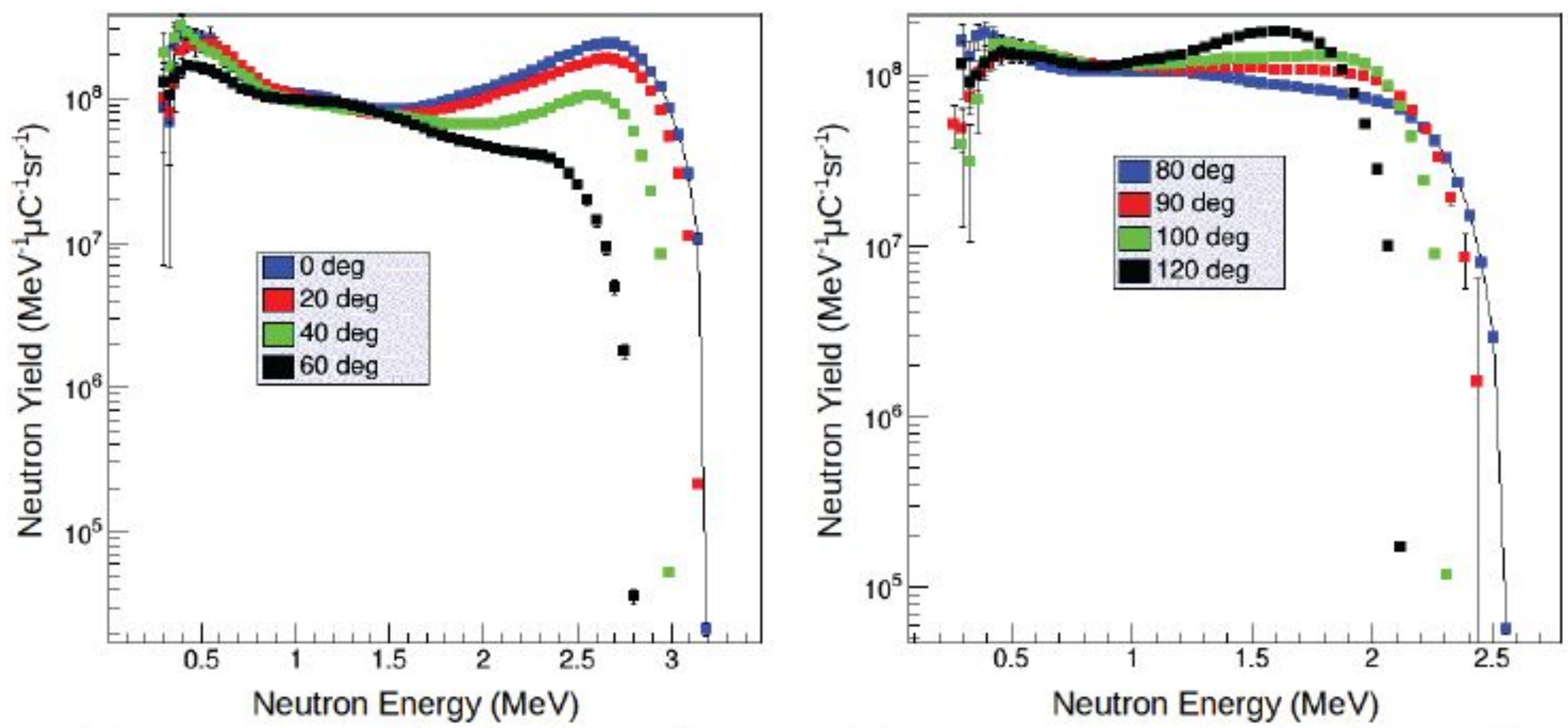


^{9}Be(p,n)^{9}B
neutron yield (MeV^{-1} Sr^{-1} μC^{-1})
10^8
10^7
10^6
10^5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Energy (MeV)
MCNP6
MCNPX
PHITS
EXP

BSA study

$^{9}Be(p,n)^{9}B$

on a point-like Be target



(a) Emission angles: 0°, 20°, 40° and 60°. (b) Emission angles: 80°, 90°, 100° and 120°.

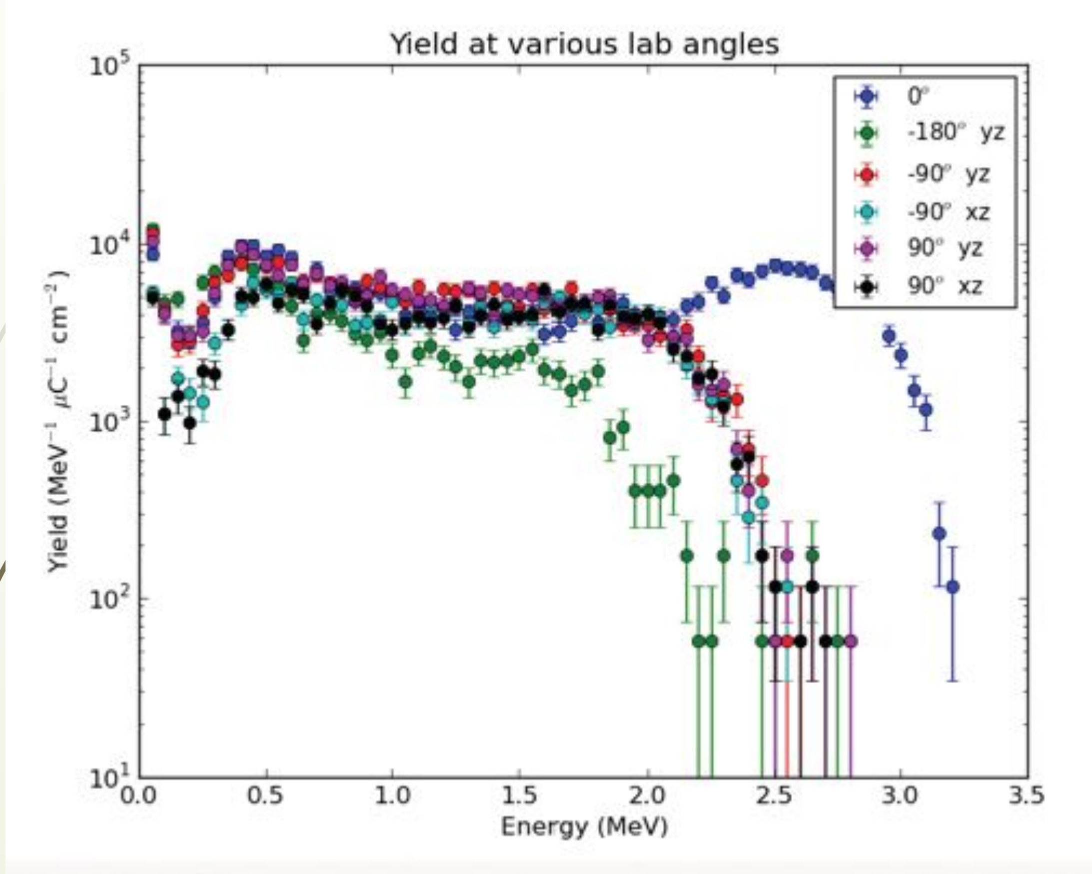
Figure 2.2: Distribution of neutron yield measured at different emission angles [14].

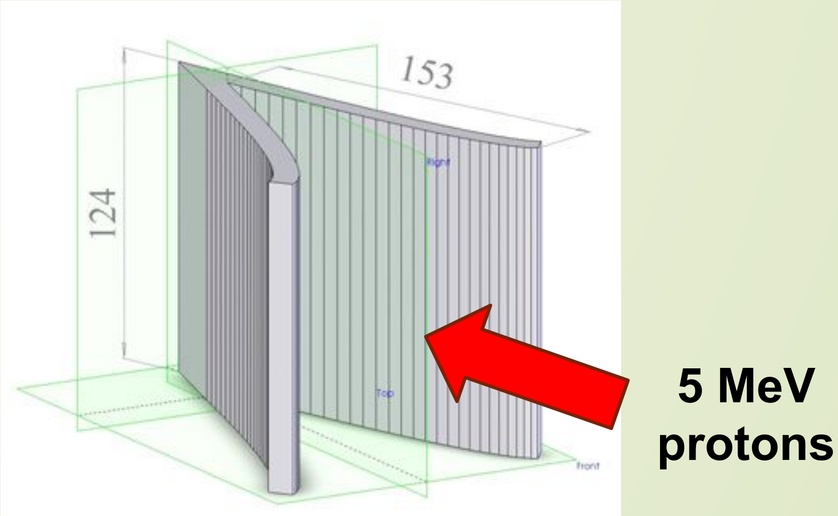
Agosteo et al. Characterization of the energy distribution of neutrons generated by 5 MeV protons on a Be target

Applied Radiation and Isotopes, (2011).

From the reactor to the ABNCT

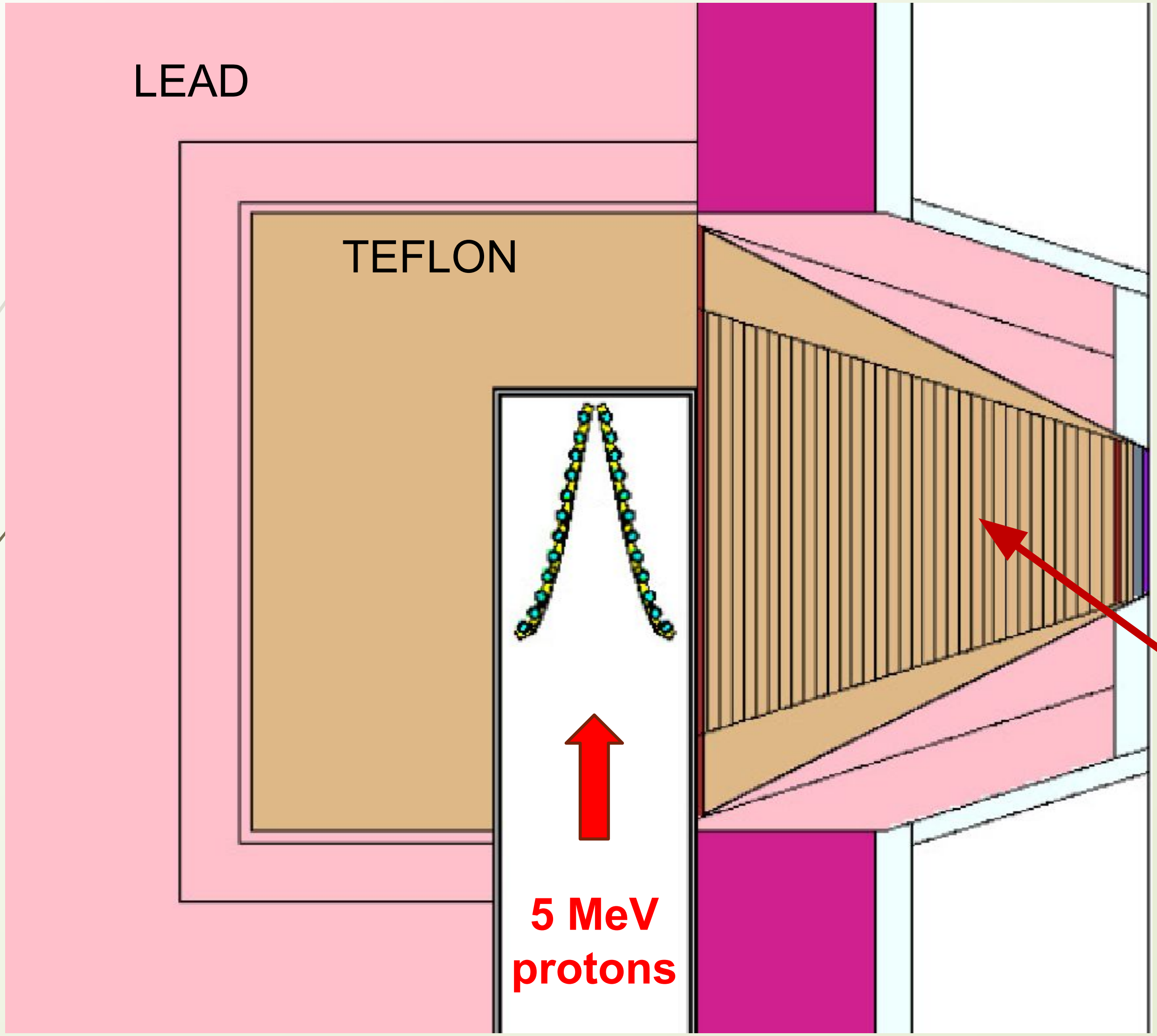
$^9Be(p,n)^9B$

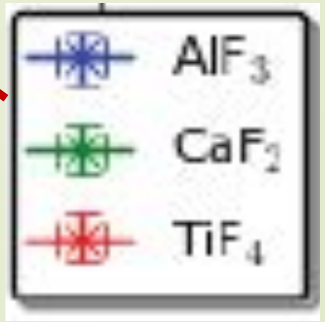




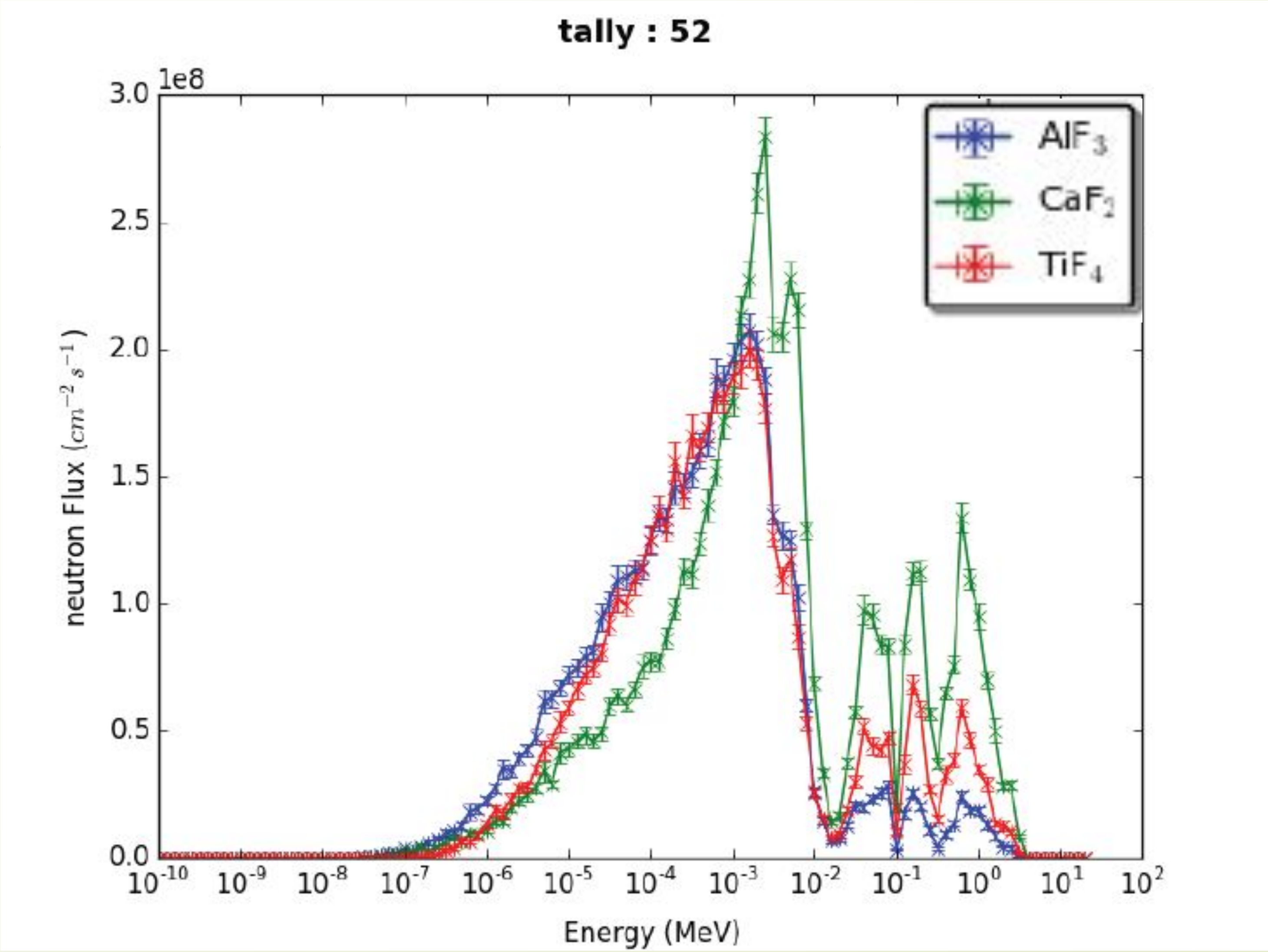
5 MeV protons

From the reactor to the ABNCT

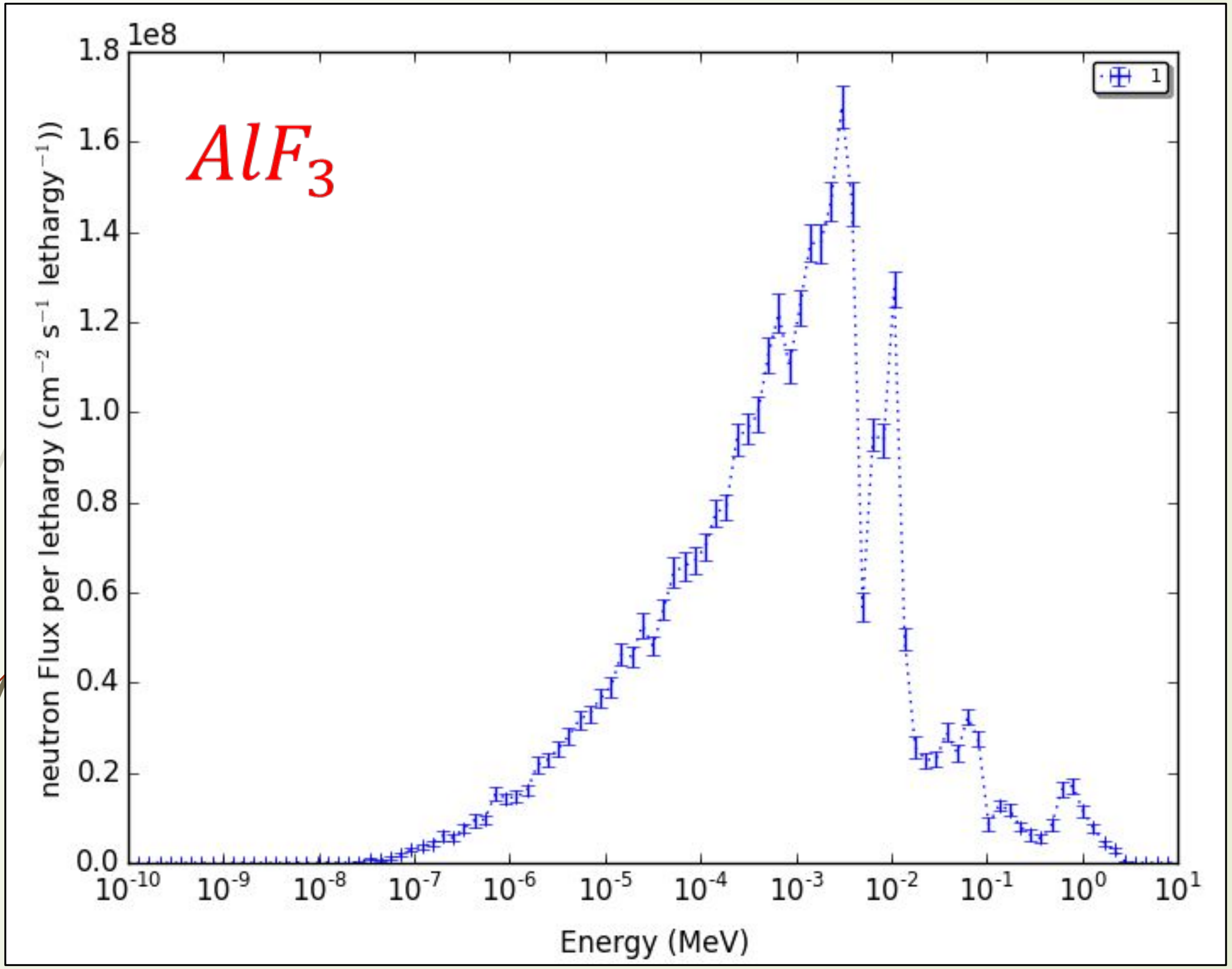




From the reactor to the ABNCT



Tailoring of a neutron beam around 1 keV



p+

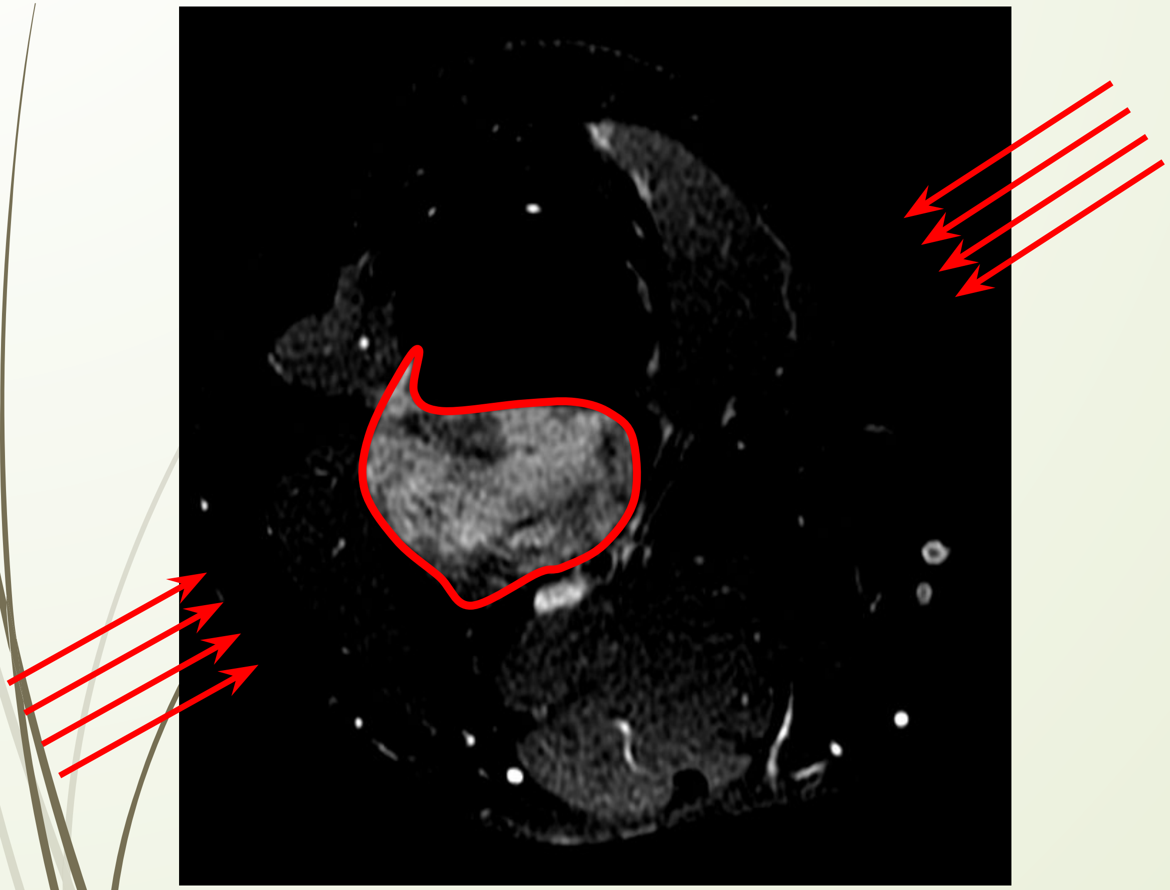
FIGURES OF MERIT

Flux $2.8 \cdot 10^{9}$ $cm^{-2}\ s^{-1}$
Fast cont $8.9 \cdot 10^{-13}$ Gy cm^2
Gamma cont $3.7 \cdot 10^{-13}$ Gy cm^2

IAEA GUIDELINE VALUSE

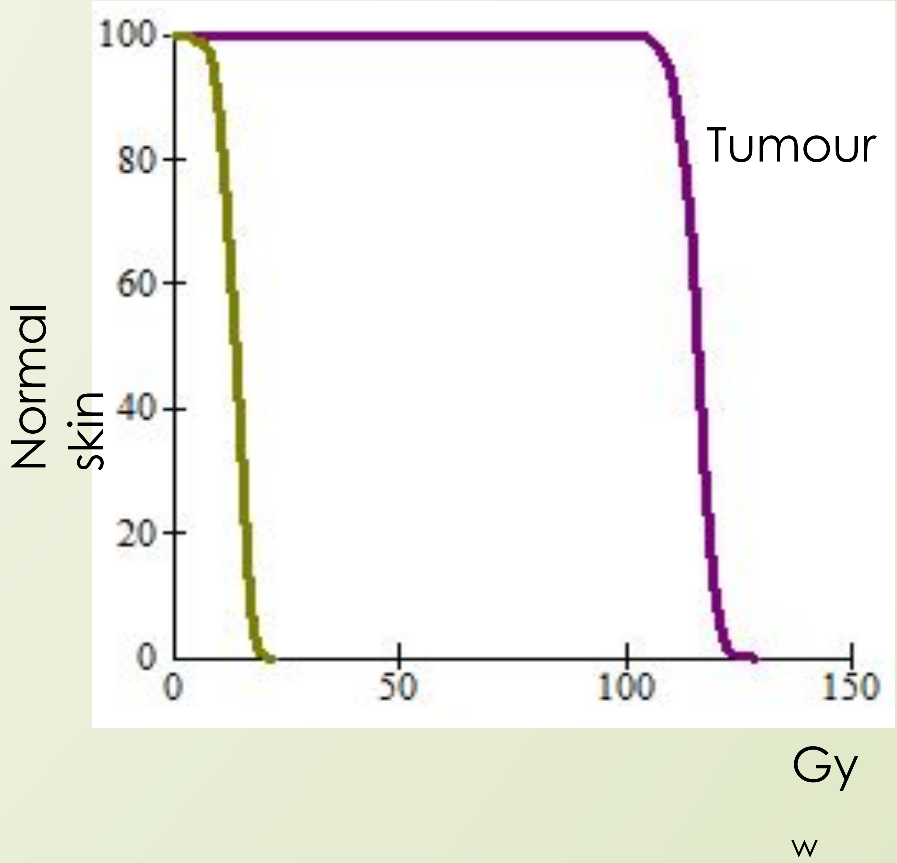
Flux $> 10^{9}$ $cm^{-2}\ s^{-1}$
Fast cont $< 2.5 \cdot 10^{-13}$ Gy cm^2
Gamma cont $< 2.0 \cdot 10^{-13}$ Gy cm^2

Validation of the beam with a TPS



Limb
Osteosarcoma

The prescription of 22 GyEq to skin,
leads to a tumour dose of 99.3 – 129 Gy_Eq
with a good uniformity in all the tumour volume

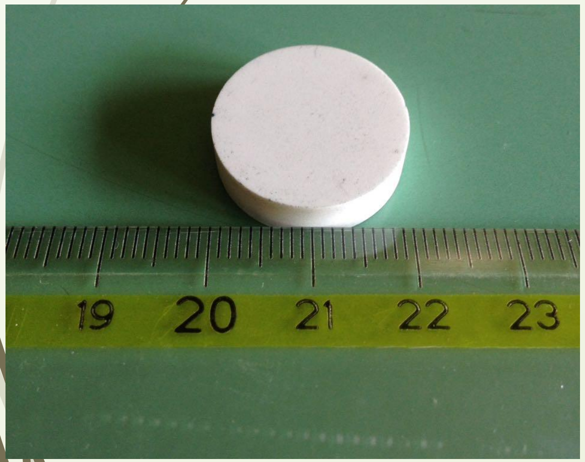


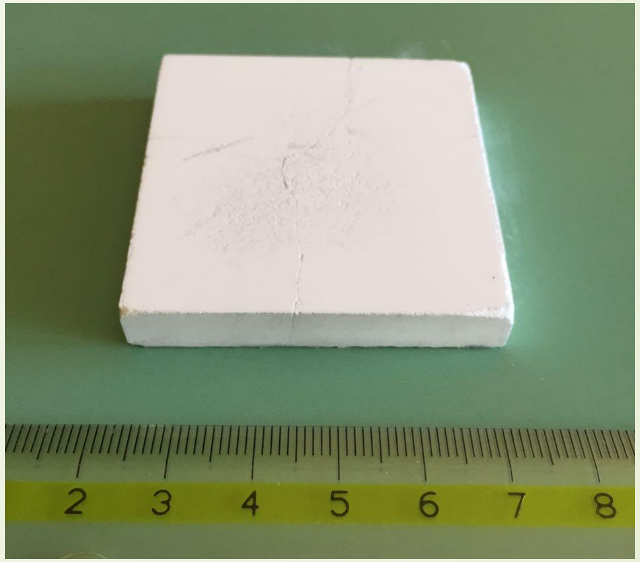
Design and construction of a prototype of syntherization machine @INFN workshop in collabration with Chemistry Department of Pavia

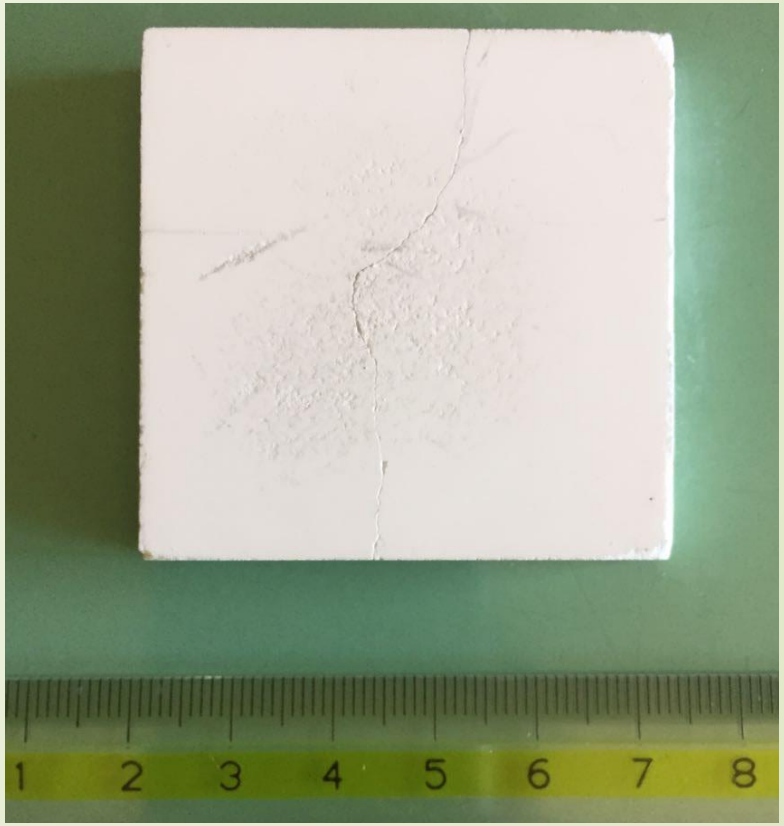
Powder

Pressure + temperature

Solid AlF_3







density 99%

50x50x10 mm density 82%

Characterization of AlF_3

Neutron activation

Nuclide	Half-Life	Present in samples			
Al-28	2.414 min	raw	pure		Al std
As-76	1.0778 d	raw			
Au-198	2.69517 d				Al std
Cl-38	37.24 min		pure	Na std	
Co-60	5.2714 y	raw			
Ga-72	14.10 h	raw			
Mg-27	9.458 min	raw	pure		Al std
Mn-56	2.5785 h				Al std
Na-24	14.9590 h	raw	pure	Na std	Al std
Sb-124	60.20 d		pure		

Table 2.3: Nuclides found in samples irradiated with rabbit

Nuclide	Half-Life	Present in samples	
As-76	1.0778 d	raw	
Br-82	35.30 h	raw	pure
Co-60	5.2714 y	raw	pure
Cr-51	27.7025 d		pure
Fe-59	44.503 d	raw	
Ga-72	14.10 h	raw	pure
La-140	1.6781 d		pure
Na-24	14.9590 h	raw	pure
Sb-122	2.7238 d	raw	pure
Sb-124	60.20 d	raw	pure
Sc-46	83.79 d	raw	pure
Se-75	119.779 d		pure
Zn-65	244.26 d	raw	

Table 2.6: Nuclides found in samples irradiated in CT

Activation dose

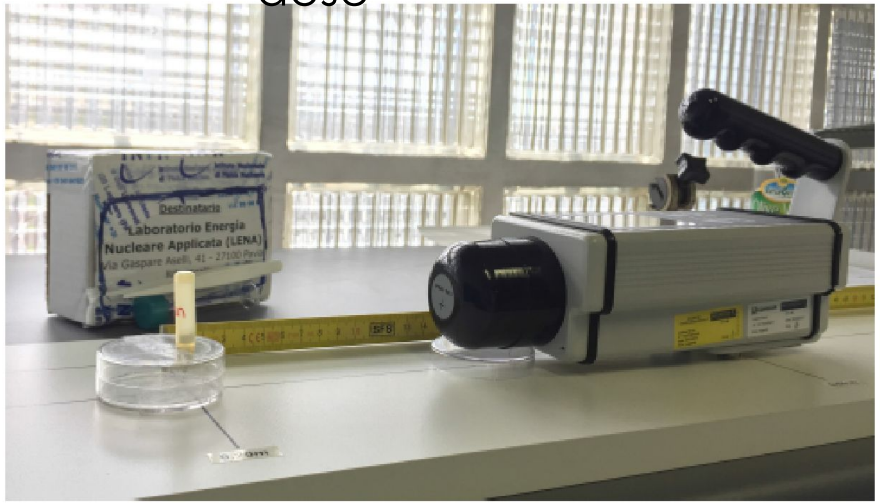
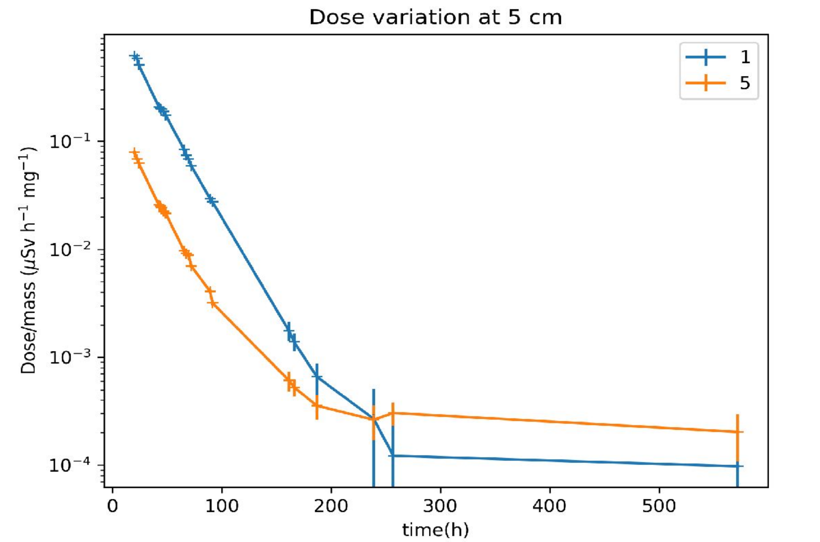
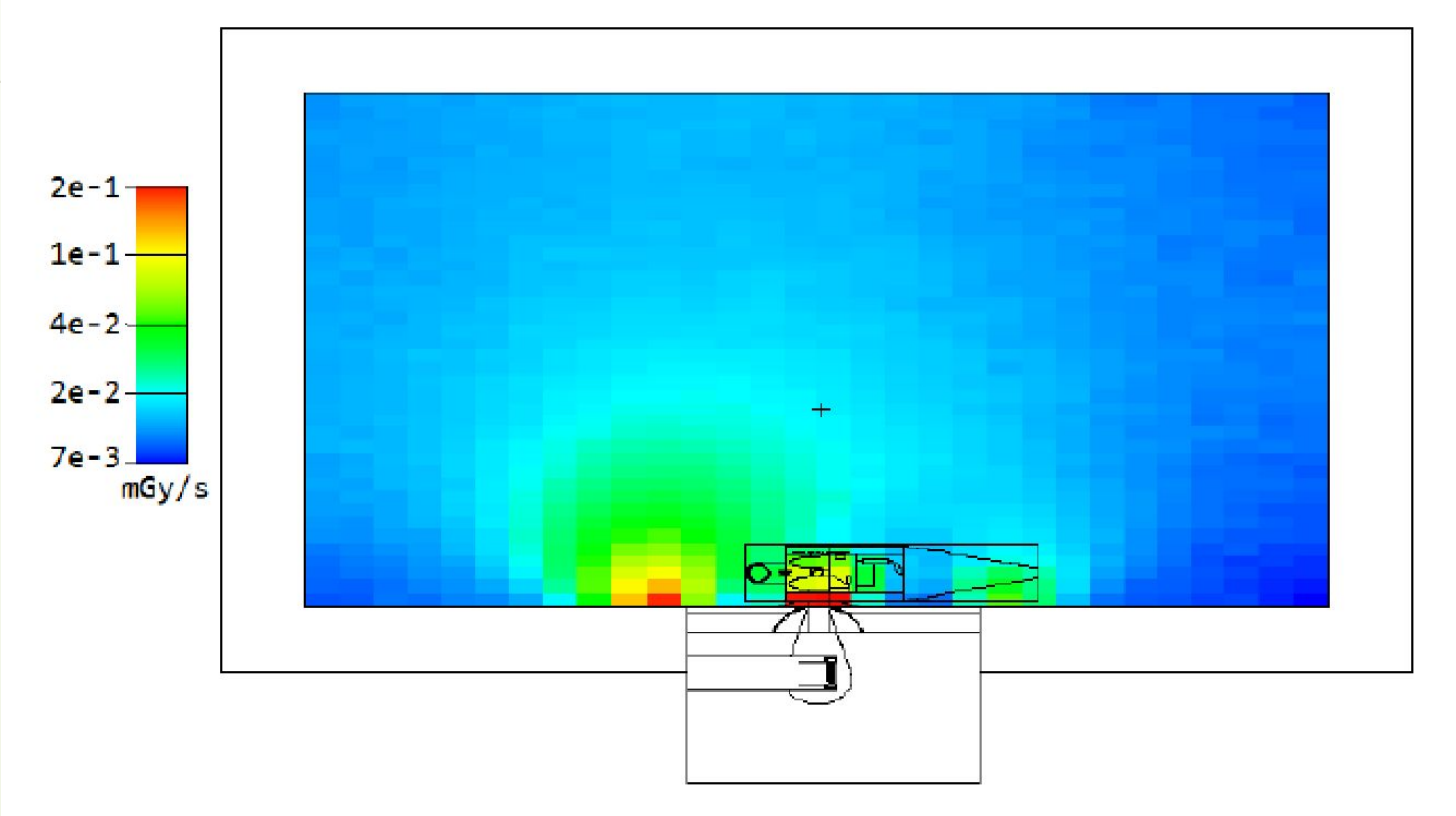


Figure 2.6: Experimental set-up for dose measurements effectuated



BNCT treatment room



Absorbed dose MESH in the room air with walls of ordinary concrete due to thermal neutrons

Dose to patient

	Dose in 2h [mGy]	
	ordinary concrete	concrete+boron
brain	773±7	573±5
bladder	415±11	329±7
stomach	419±7	363±5
kidneys	526±7	450±6
intestine	624±7	548±5
lungs	501±4	490±3
liver	122±11	115±7

Table 4.3: Doses absorbed by the principal organs in 2h of irradiation

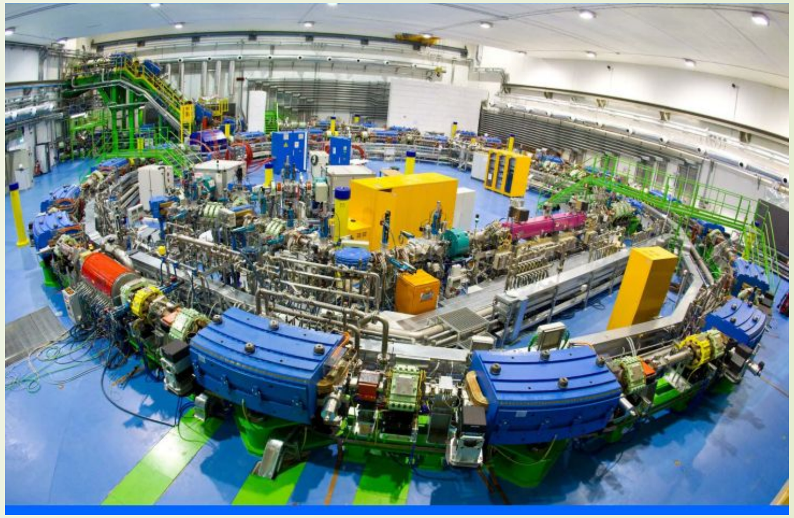
Patient activation

Nuclide	Half-life [s]	R [s^{-1} g^{-1}]	a [Bq/g]
Cl-38	37.24 min	34.98 ± 0.07	23.53 ± 0.04
K-42	12.360 h	30.80 ± 0.06	1.680 ± 0.003
Fe-59	44.503 d	0.4180 ± 0.0011	0.0002712 ± 0.000007

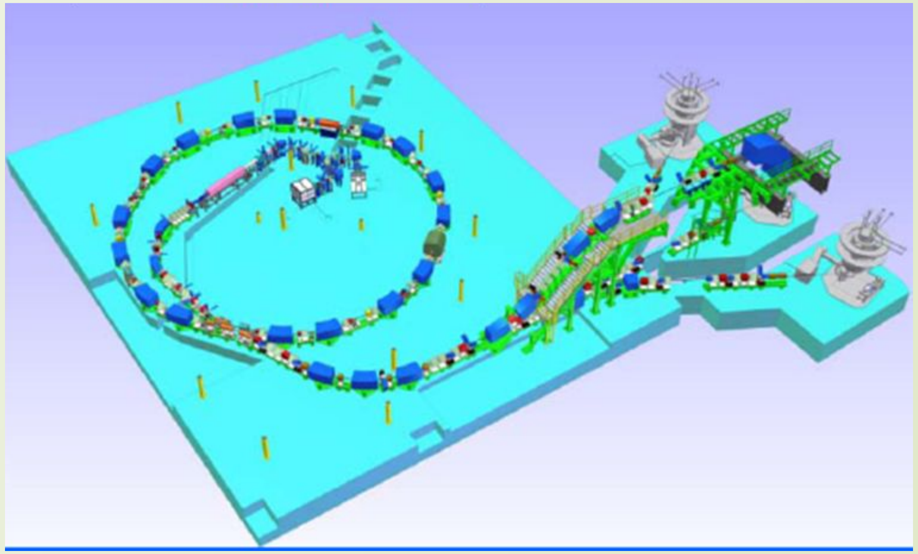
Table 5.3: Simulated reaction rates and specific activity after 2h of irradiation for soft tissue elements, with the walls of ordinary concrete

Where we can install the BNCT accelerator?

National Hadron Therapy Center in Pavia (CNAO)



Particles	p, He, C, O
Accelerator Type	Synchrotron
Ion Sources	2 ECRIS (Supernanogan, Pantechnik)
Injector	7 MeV/u linac injector
Particle Energy (MeV/u)	p: 60 - 250 MeV C: 120 - 400 MeV/u
Beam Intensity, particles per spill (pps)	p: 10^{10}
	C: 4 10^{8}
Repetition Rate	0.4 Hz for 1s spill
Spill Length (msec)	250 - 10,000
Beam Range (mm)	p: 30 - 370 C: 35 - 275
Beam Spot Size (mm FWHM)	4 - 10
Treatment Rooms	2 H; 1 H+V
Beam Delivery Technique	raster scan



The INFN BNCT accelerator

www.cnao.it

Clinical Activity

Radioresistent tumors

- Salivary gland tumors
- Mucosal melanoma
- Recurrent pleomorphic adenoma
- ReRT head and neck tumors
- High risk prostate cancer

Radioresistent tumors & Critical location

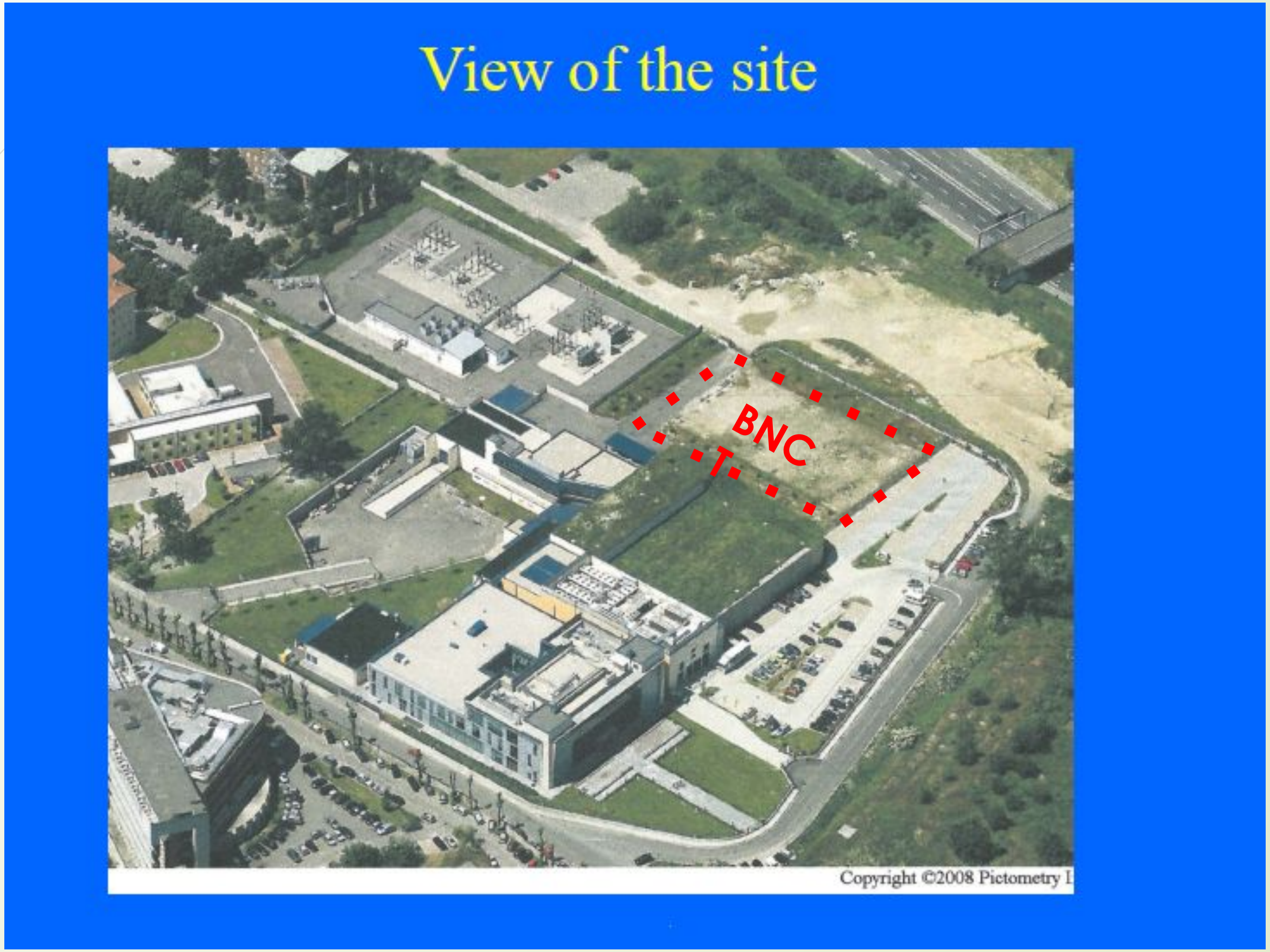
- Skull base and Spine chordoma and chondrosarcoma
- Spine and H&N bone and soft tissue sarcoma

Critical location

- Intracranial Meningioma
- Orbital tumor
- Boost for locally advanced head and neck cancer

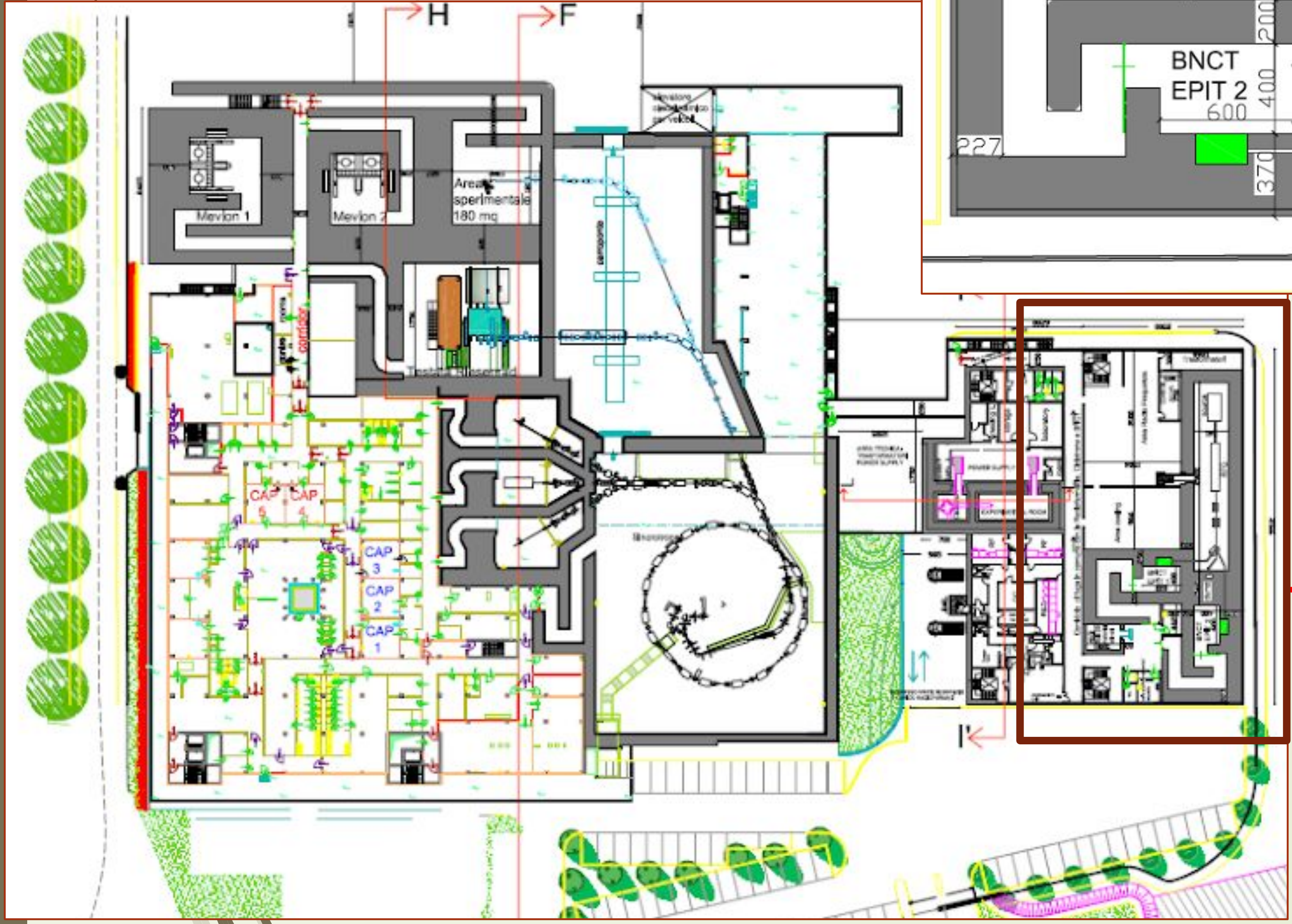
The INFN BNCT accelerator

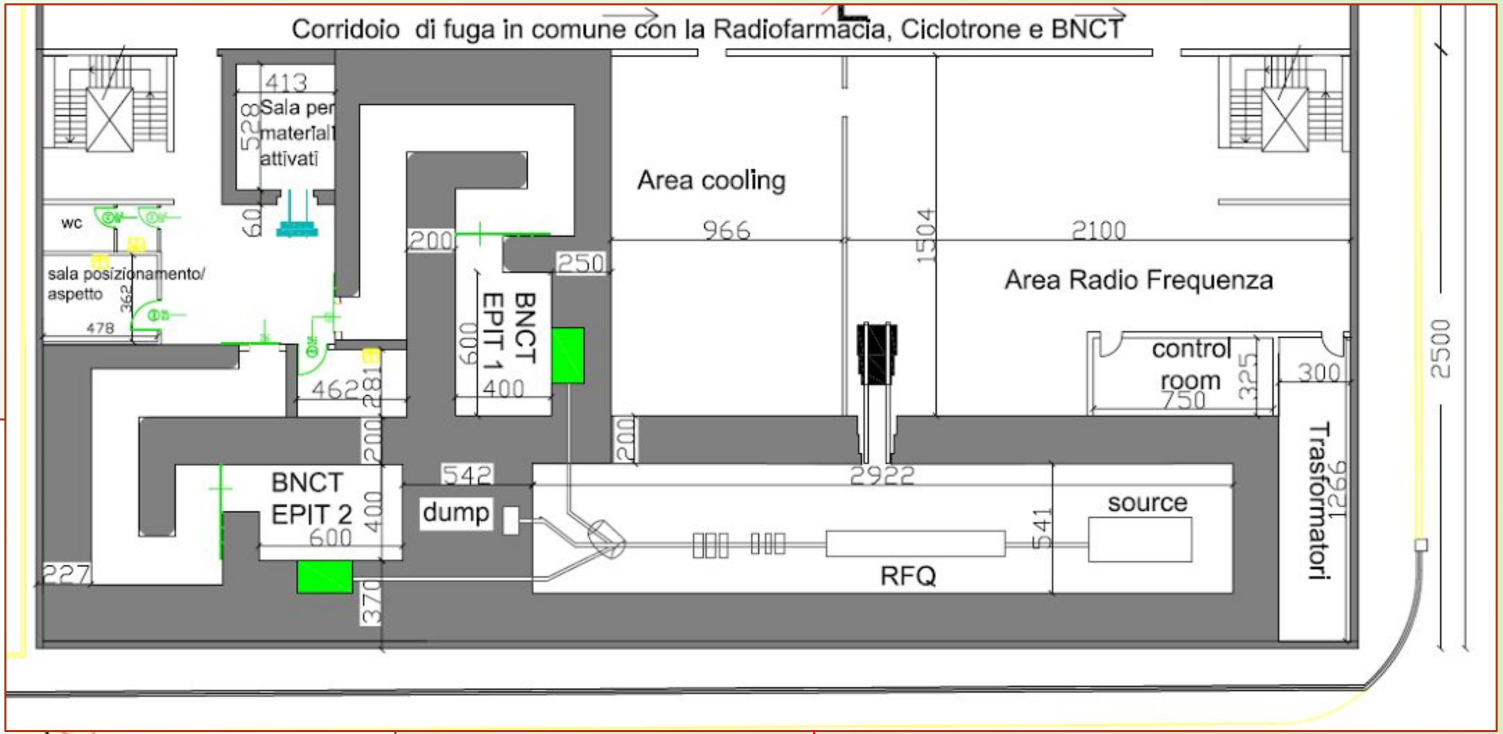
The INFN BNCT accelerator



INFN

UNIVERSITÀ DI PAVIA





fondazione CNAO

Centro Nazionale di Adroterapia Oncologica per il trattamento dei tumori

Italian collaboration

- *University of PAVIA*
  - Department of Physics
  - Department of Clinical-Surgical, Diagnostic and Pediatric Sciences
  - Department of Chemistry, University of Pavia
  - Department of Molecular Medicine, University of Pavia
  - IRCCS S. Matteo Foundation, Pavia
  - *CNAO, Pavia*
  - *INFN, Pavia*
  - *INFN - LNL, Legnaro*
- *University of TORINO*
- *University of NOVARA*
- *University of Palermo*
- *IMEM-CNR Parma*
- *Due2lab s.r.l. Parma*
- *INAF-OAS, Bologna*

International collaborations

- *CNEA, Argentina: very active researchers exchange for computational dosimetry, treatment planning, beam design, B concentration measurement methods inter-comparison, BNCT efficacy and toxicity on animal models,*
- *INL, Idaho, USA: neutron spectrometry in irradiation facilities*
- *HUCH, Helsinki University Central Hospital and FIR 1, Finland*
- *QEH,University Hospital, Birmingham*
- *Okayama University (Y. Ichikawa)*
- *Nagoya University (Tsuchida)*
- *China* Funded project in the frame of the Executive Programme of Scientific and Technological Cooperation between Italy and China for the years 2016-2018. Italian Ministry of Foreign Affairs and International Cooperation (MAECI). Project: NEU_BEAT (Neutron Beams for Cancer Treatment). Collaboration on:

-New materials for neutron beams design
-Treatment Planning calculations
-Computational dosimetry
-Integration of BNCT and heavy ion therapy

Silva Bortolussi
Nicoletta Protti
Ian Postuma
Setareh Fatemi
Chiara Magni
Francesca Ballarini
Mario Carante
Cinzia Ferrari
Laura Cansolino
Saverio Altieri

Thank you

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http://www.bnct.it

Thank you