The LENOS project at Laboratori Nazionali di Legnaro of INFN: a thermal to 70 MeV neutron beam facility

Lenos
Legnaro Neutron Source

INFN

SPES
exotic beams for science

P. Mastinu

Istituto Nazionale di Fisica Nucleare

- Laboratori Nazionali di Legnaro-

LNL (Legnaro Nuclear Labs)

The Legnaro Nuclear Laboratories, located in the town of Legnaro (Italy), at 10 km from Padova.

Aereal view of the Legnaro Laboratories

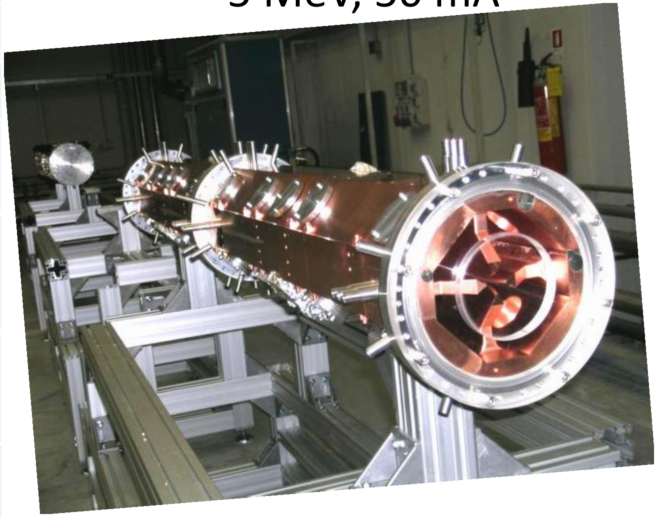
Accelerators for neutrons

7 MV Van Der Graaf (CN)

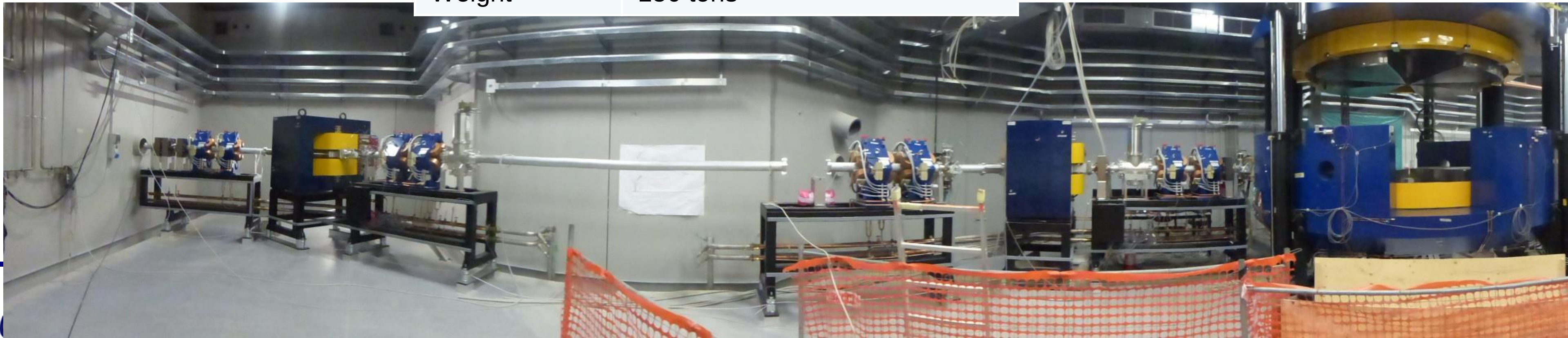
Main Parameters	
Accelerator Type	Cyclotron AVF 4 sectors
Particle	**Protons (H^- accelerated)**
Energy	**Variable within 30-70 MeV**
Max Current Accelerated	**750 µA** (52 kW max beam power)
Available Beams	**2 beams at the same energy** (upgrade to different energies)
Max Magnetic Field	1.6 Tesla
RF frequency	56 MHz, 4th harmonic mode
Ion Source	Multicusp H^- I=15 mA, Axial Injection
Dimensions	Φ=4.5 m, h=1.5 m
Weight	150 tons

RFQ(Radio Frequency Quadrupole),

5 MeV, 50 mA



Cyclotron, 35-70 MeV two exits. I_{max} =750 uA



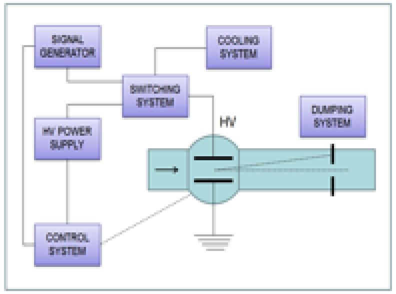
LeNoS facility: CN 7 MV Van der Graff

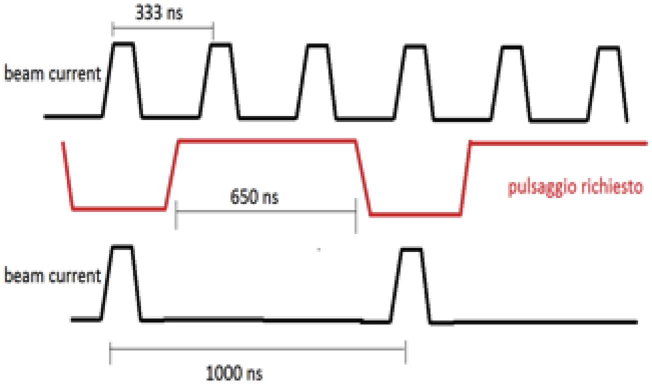
Legnaro Neutron Source

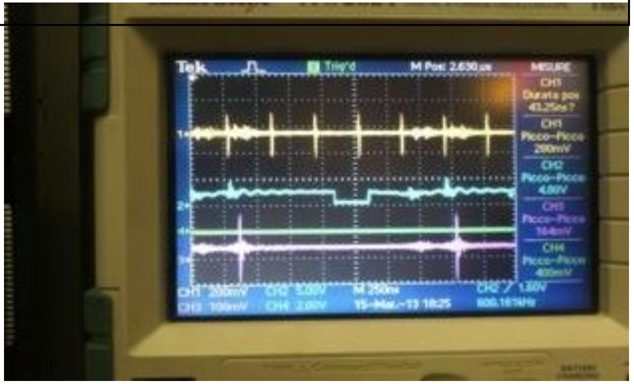
Pulsed beam:

- 3 MHz rf pulsing system on the high voltage terminal.
- 1 ns pulse width.
- Only 3 MHz operating: no adequate for neutron TOF measurement in the energy range of interest.

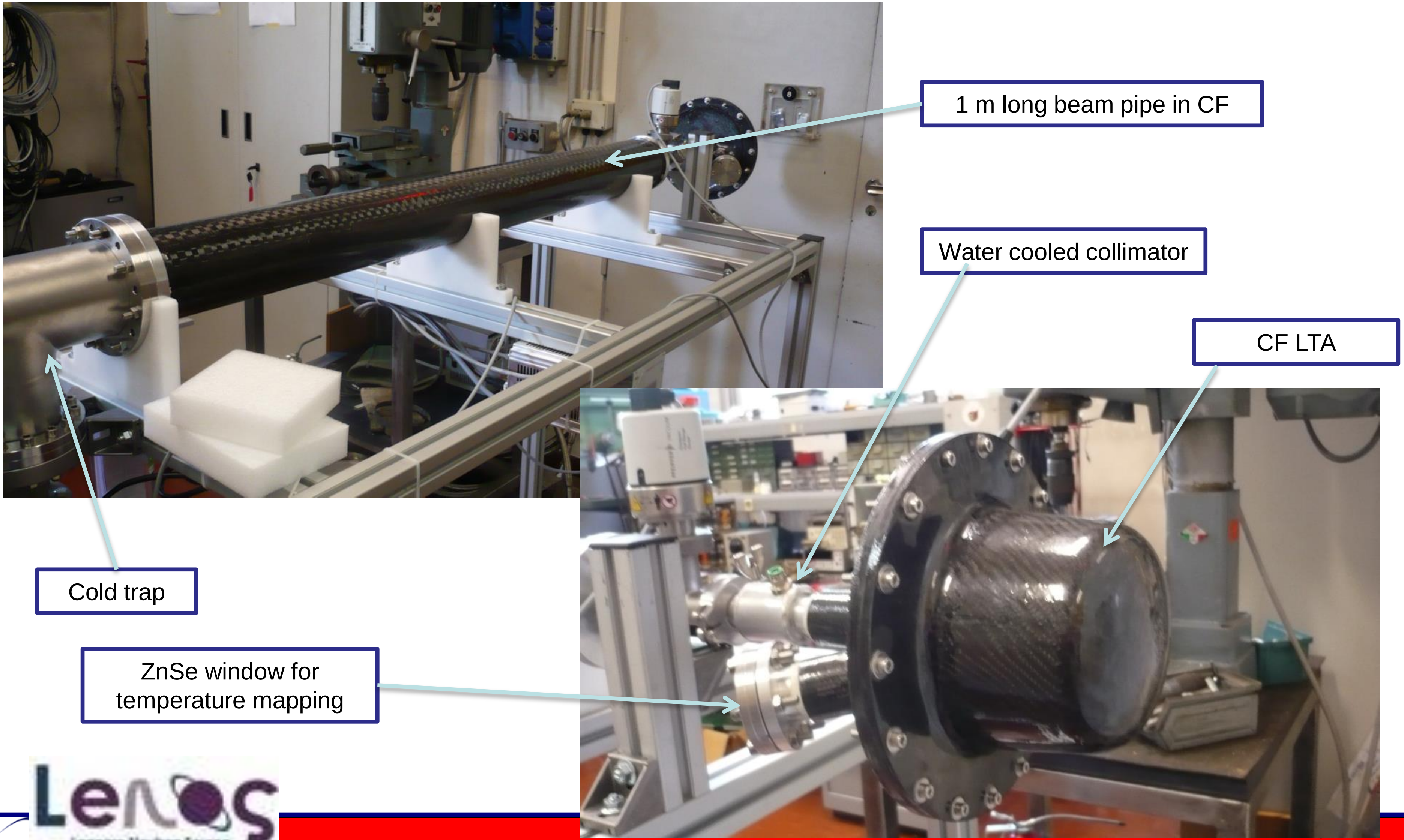
We have developed, installed and tested a switching system able to provide 1 ns pulse at 1 MHz, 625 kHz…. (*) low Rep rate available now for TOF measurements







Lithium Target Assembly



1 m long beam pipe in CF

Water cooled collimator

CF LTA

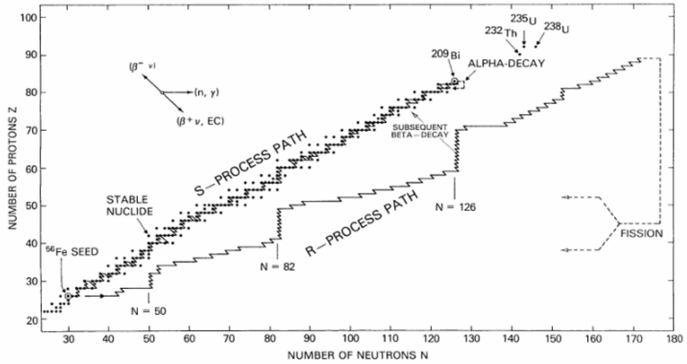
Cold trap

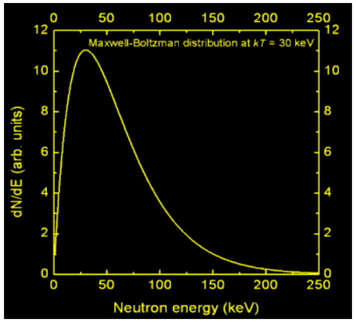
ZnSe window for temperature mapping

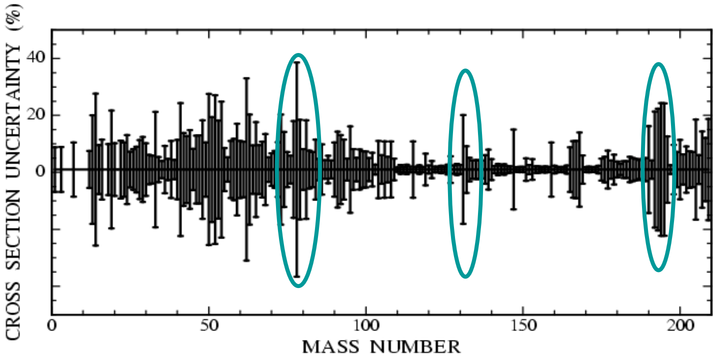
(my main) Motivations: Astrophysics

Nucleosynthesis of elements beyond Fe (B=8.8 MeV/A) are produced in stars by successive (n,ɣ) and β- decays.

The stellar velocity neutron spectrum is a Maxwell-Boltzmann distribution. Depending on the stellar site and the evolutionary stage of the star the most important kT are 8, 30 or 90keV, being 30 keV the standard temperature of reference.





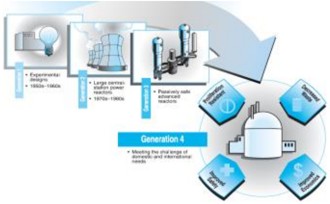


$$\frac{dN_A(t)}{dt} = N_{A-1}(t)\cdot n_n(t)\langle\sigma\cdot v\rangle_{A-1} - N_A(t)\cdot n_n(t)\langle\sigma\cdot v\rangle_A - \lambda_\beta(t)N_A(t)$$

$$MACS \equiv \langle\sigma\rangle = \frac{\langle\sigma\cdot v\rangle_A}{v_T}$$

→ **MACS (Maxwellian Averaged Cross Section)**

Motivations: Validation of Evaluated Nuclear Data



Large request of data from the most important agencies (IAEA, NEA).

Some actinides for AFC and Gen-IV:

Pu-239 fission in 1 keV – 1 MeV

Pu-241 fission in 1 keV – 1 MeV

U-238 capture in 2 – 200 keV

Am-243 capture in fast and thermal energy range

Am-241fission in fast energy range

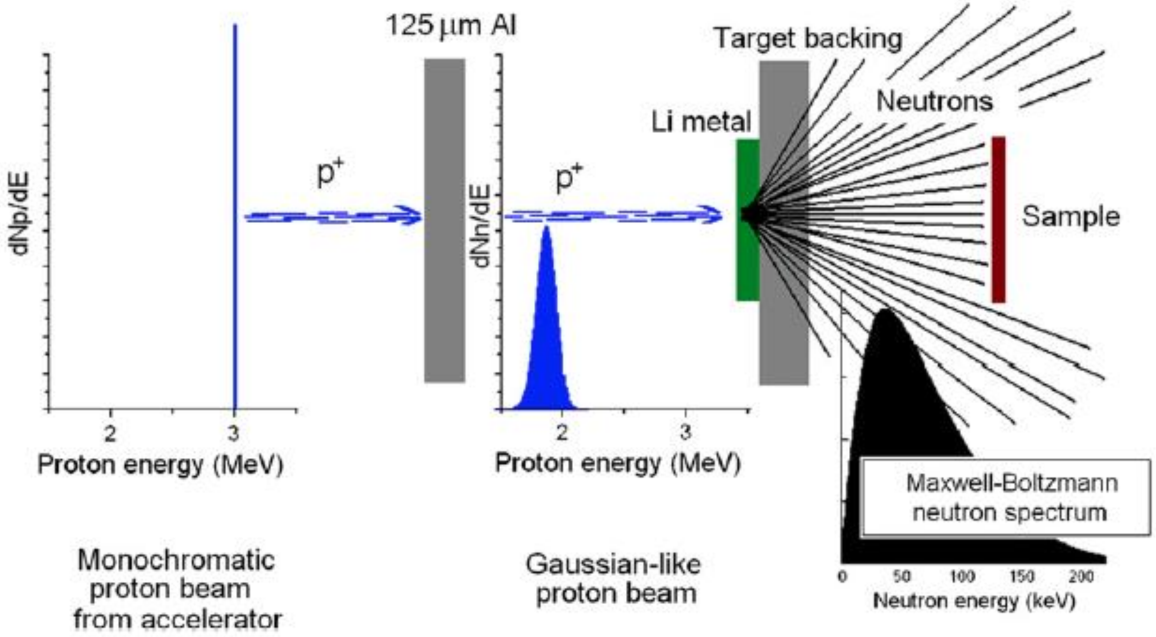
P. Oblozinsky, NNDC

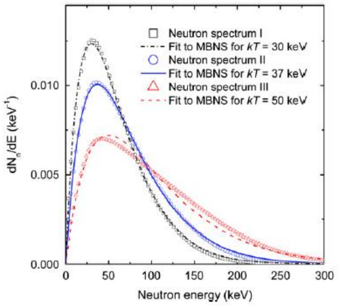
Often large discrepancies between data bases (ENDF, JENDL, JEFF, BRONDL) for many already measured isotopes.

No measurements for some important isotopes (mainly radioactive).

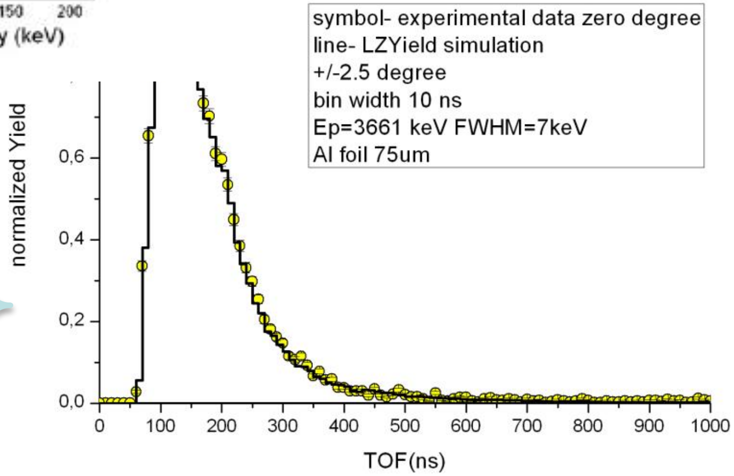
Integral measurements are accurate. The epithermal integral measurement can be performed using a well-characterized neutron spectrum (for example, Maxwell-Boltzmann like).

Setup for low power accelerators: the beam line at CN (7 MV Van Der Graaf accelerator @ INFN-LNL)





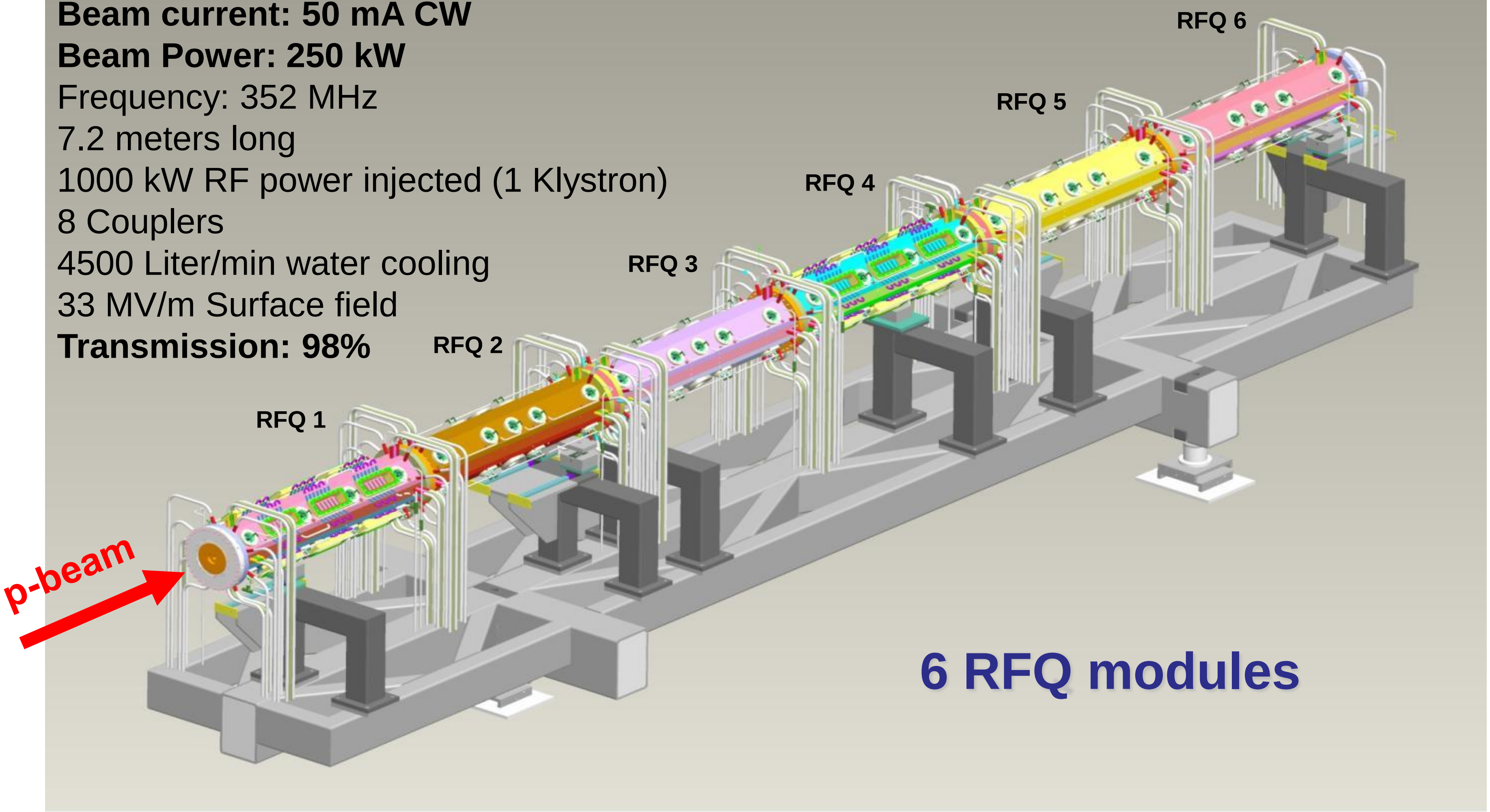
Tunable stellar temperature (25-60 keV)



- Proton energy shaper: Al or Pb foil (70-125 um)
- Li metal target
- Low mass water cooled target
- Tunable proton energy
- Tunable viewing angle

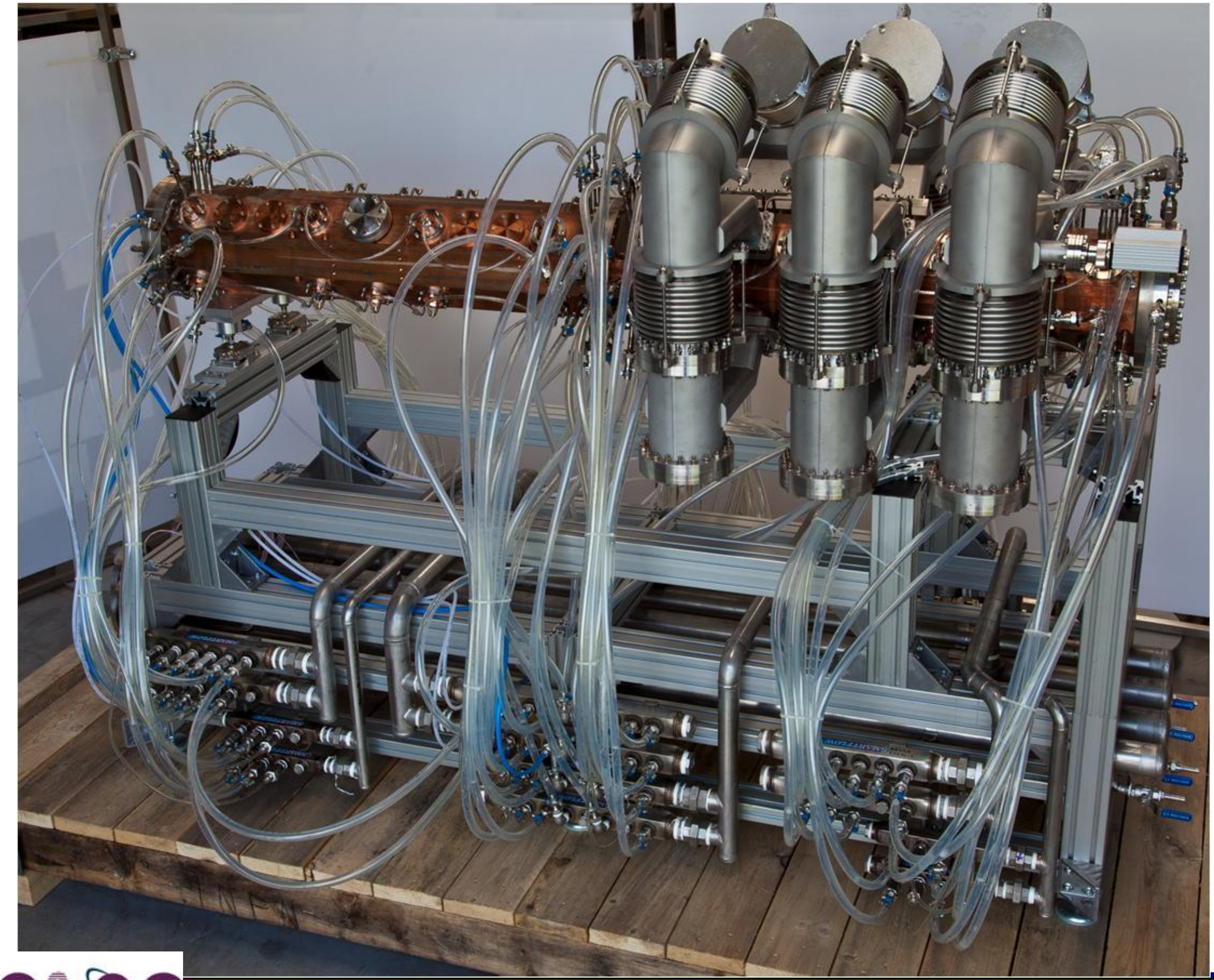
TRASCO (TRAsmutazione SCOrie) project
RFQ (Radio Frequency Quadrupole)

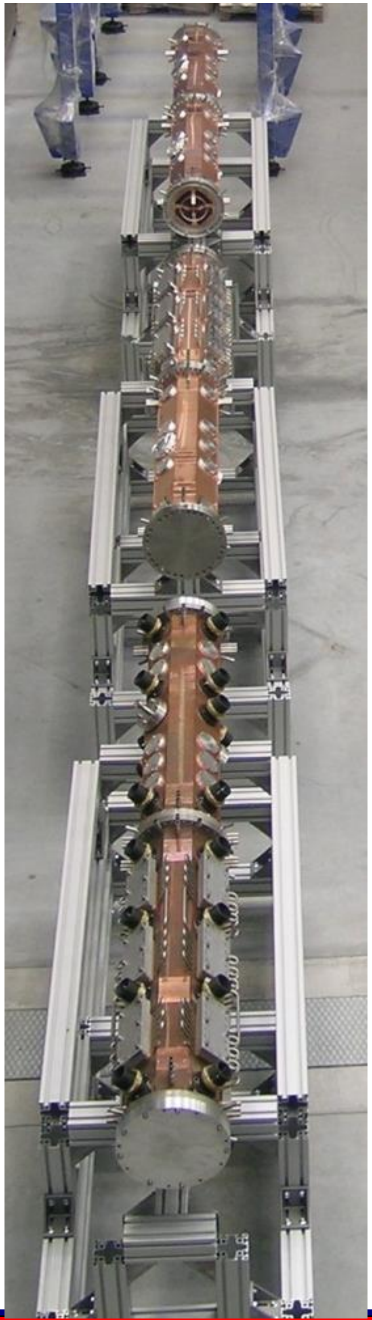
Energy range: 0.08 - 5 MeV
Beam current: 50 mA CW
Beam Power: 250 kW
Frequency: 352 MHz
7.2 meters long
1000 kW RF power injected (1 Klystron)
8 Couplers
4500 Liter/min water cooling
33 MV/m Surface field
Transmission: 98%



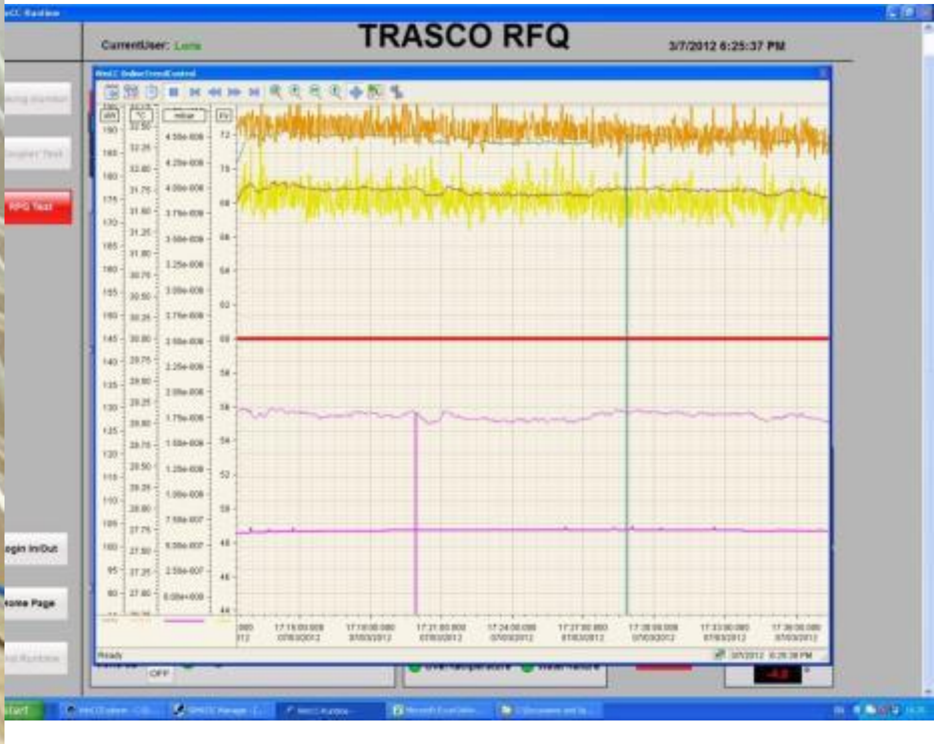
6 RFQ modules

RFQ: construction phase completed



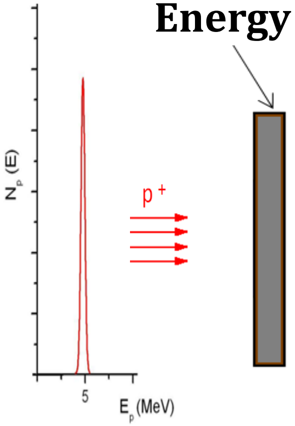


RFQ of TRASCO stable condition cw nominal field 80kW/m, 1.8 Ekp

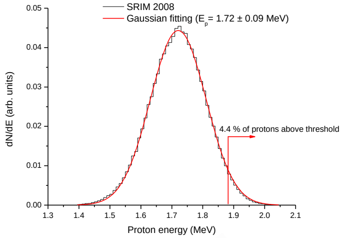


Sketch of RFQ Layout

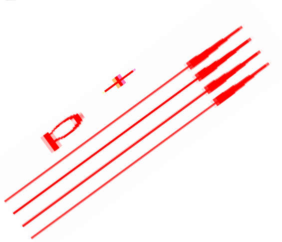
Energy Shaper



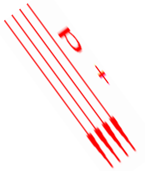
RFQ Proton
5 MeV, 50mA
250 kW



Protons
Ep>1.88 MeV

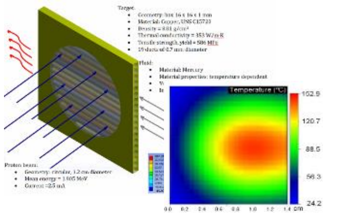


Magnet

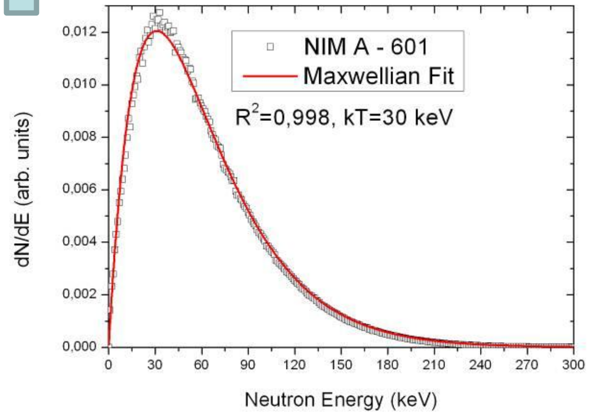


Protons Ep<1.88 MeV
Other line or beam dump

Li target
4 kW



NEUTRONS



Neutron Flux = 5 10^{10} n/(s cm²)

Sample

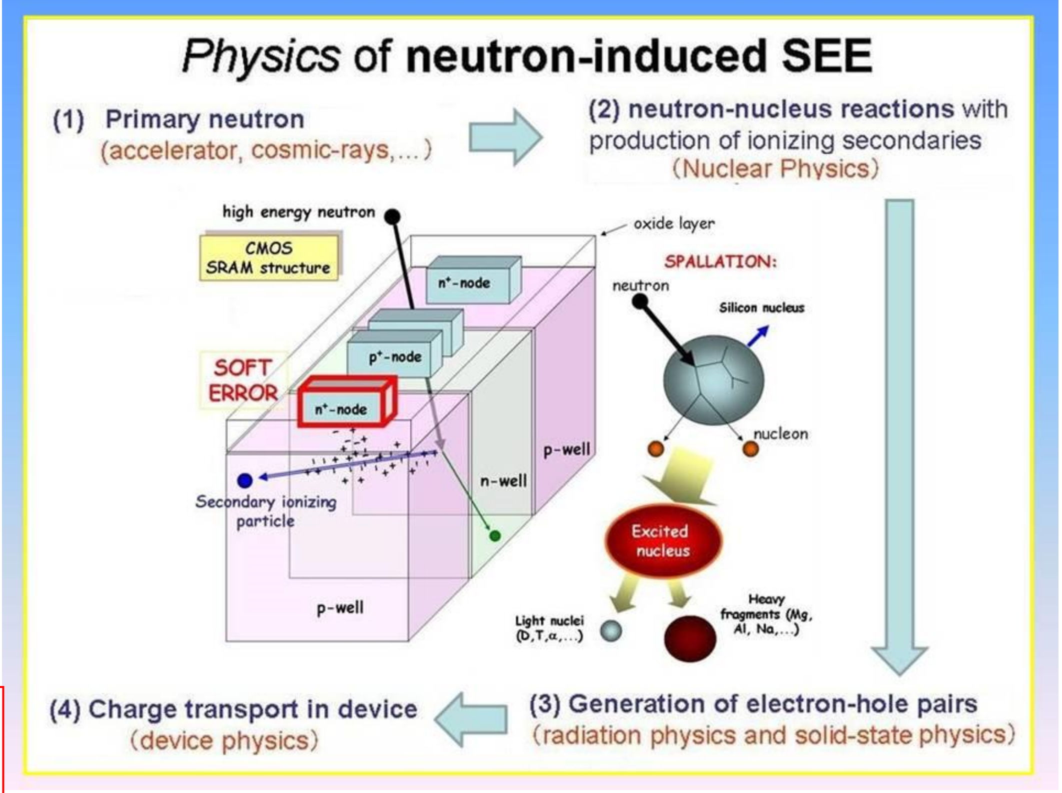
Possibility
SPES RIB

High energy neutrons with 35-70 MeV Cyclotron

electronics

If neutron is fast enough …

a Single Event Effect (SEE) may occur (depends on where it strikes)



Physics of neutron-induced SEE

(1) **Primary neutron** (accelerator, cosmic-rays,…)

(2) **neutron-nucleus reactions** with production of ionizing secondaries (Nuclear Physics)

(3) **Generation of electron-hole pairs** (radiation physics and solid-state physics)

(4) **Charge transport in device** (device physics)

neutron-induced SEE cross-sections *vs* energy

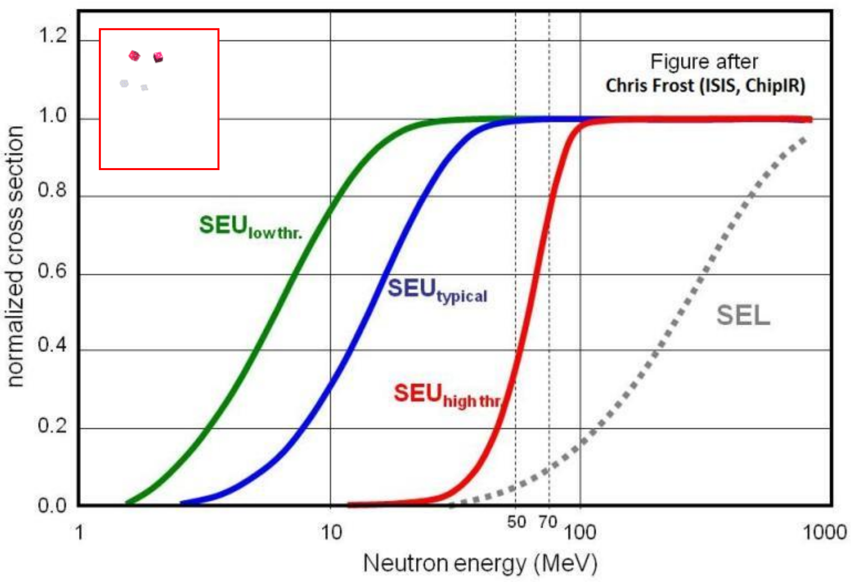


Figure after Chris Frost (ISIS, ChipIR)

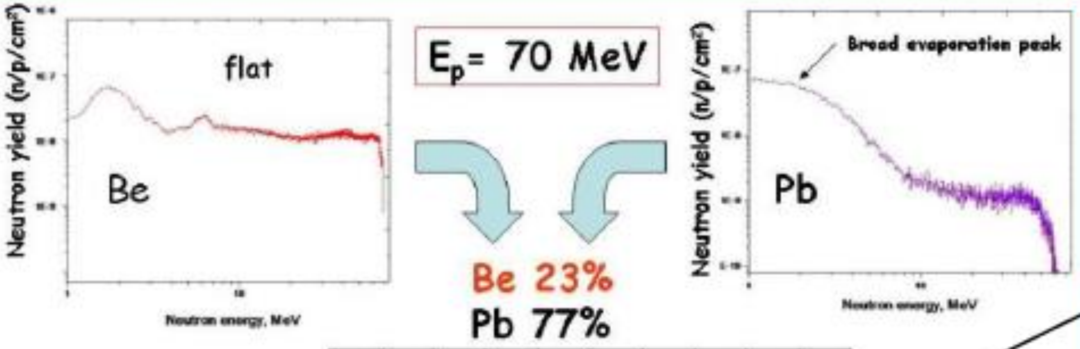
Reference cross-section for

“Soft Errors” such as **SEUpset**:

$\sigma_{SEU} = 10^{-14}$ **cm²/bit**,

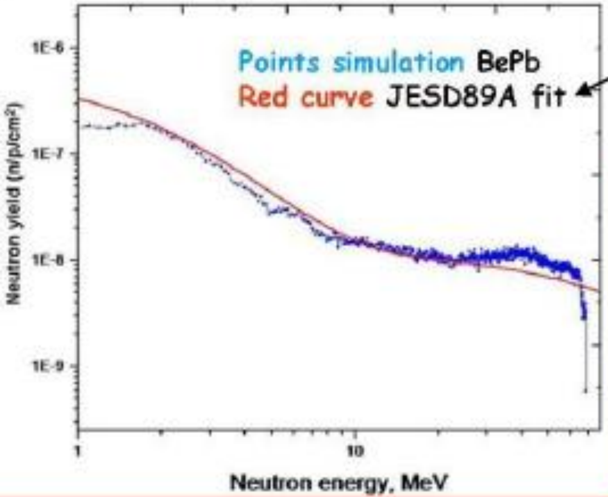
N_{bits} per device = 4 10^{6} (minimum)

Fast neutron energy spectrum of ANEM (BePb variant)



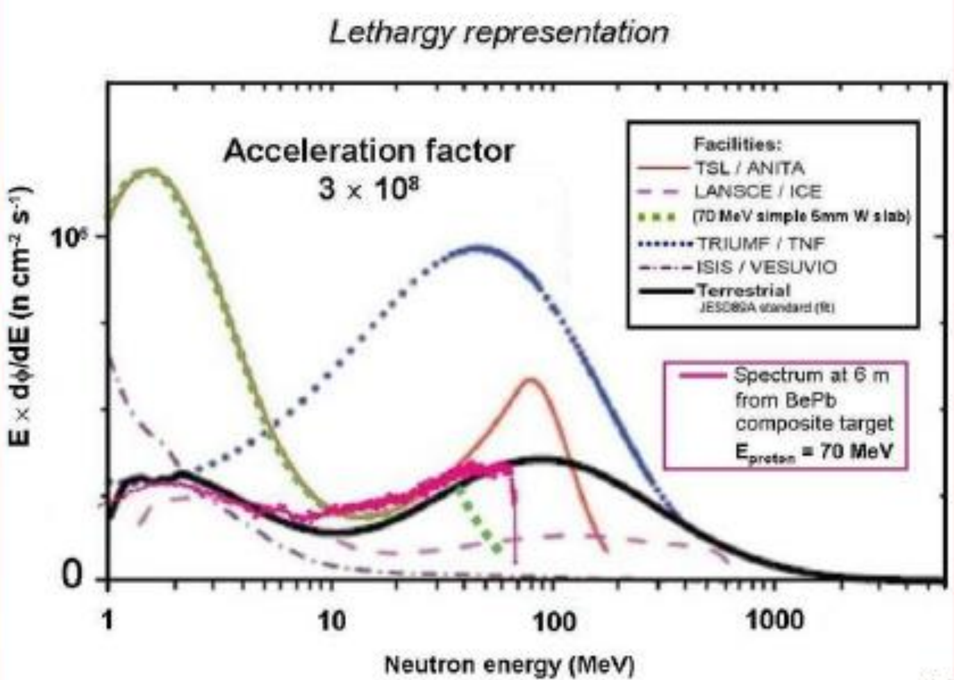
E_p = 70 MeV

Be 23%
Pb 77%



Atmospheric neutrons at sea level at New York
integrated flux E > 1 MeV
ϕ_n (E > 1 MeV) = 21 cm^{-2} hr^{-1}

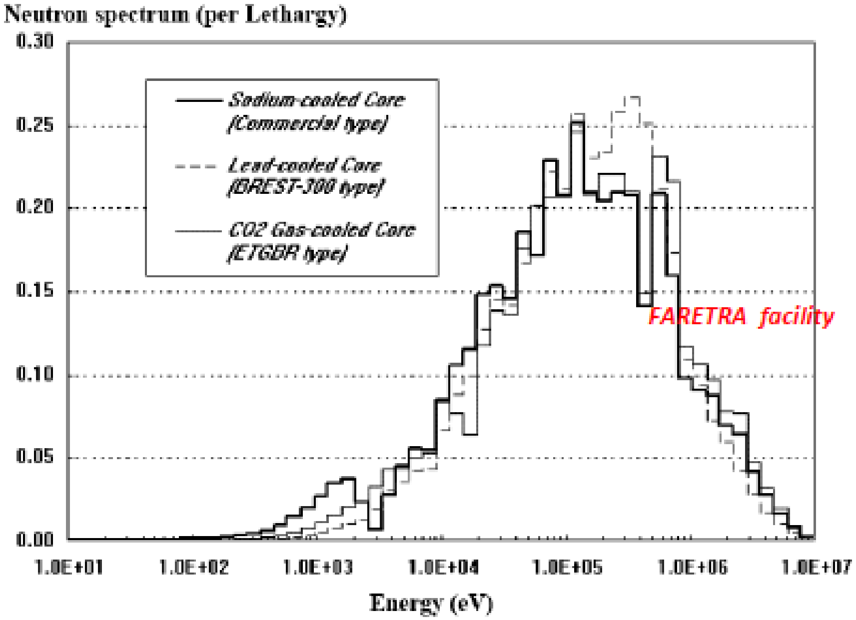
Neutron FLUX at 6 m from the target: 20-30×10^9 n cm^{-2} s^{-1}
(current: 50-100 μA)
An "acceleration factors" of few 10^9 can be achieved with few tens of μA.

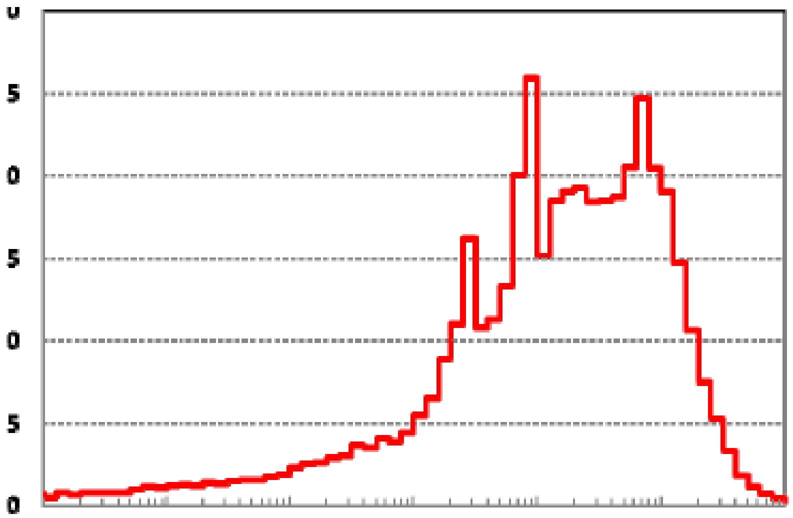


FARETRA

Neutron spectrum inside irradiation chamber MCNPX calculation results (Preliminary)

Accelerator-driven Systems (ADS) and Fast Reactors (FR) in Advanced Nuclear Fuel Cycles: A comparative study
NEA-OEDC, 2002





Moderation Efficiency (10 eV -10 MeV) : ~ $5 \cdot 10^{-4}$

Integral neutron flux: Φ_n = ~ $1.0 \cdot 10^{11}$ $cm^{-2}s^{-1}$

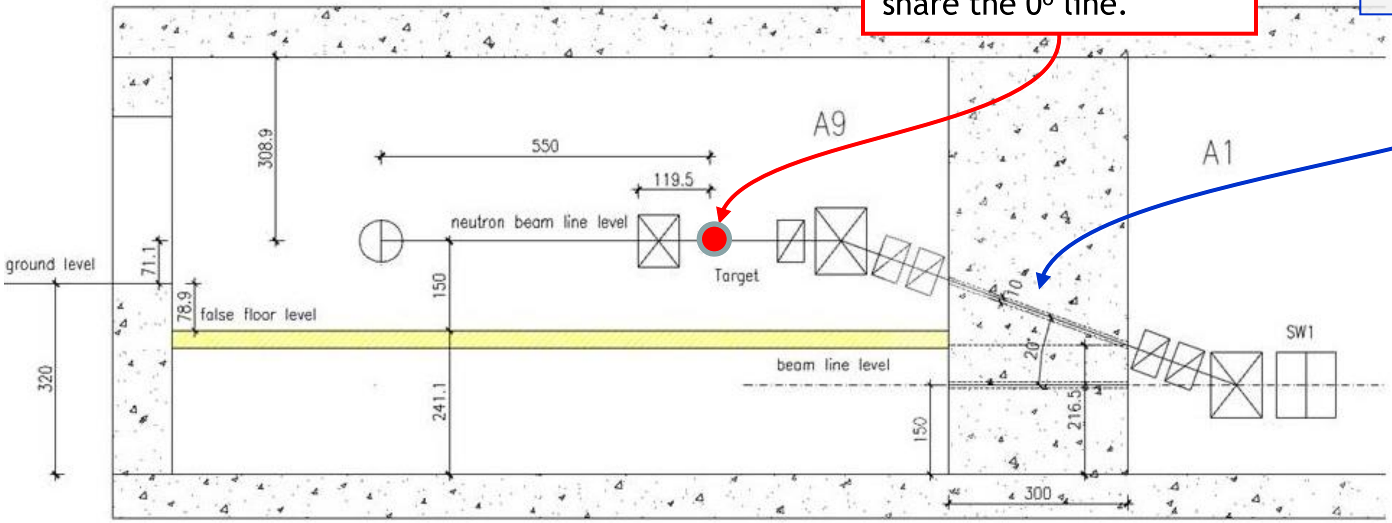
experimental hall

SPES hall A9, side view of the Fast Neutron Line (QMN+ANEM)

The ANEM target system will exchange position with the QMN multi-target system and will share the 0° line.

Chicane to:

- avoid neutrons towards cyclotron
- have test point at same distance from floor and ceiling (minimize albedo)
- use degradator for lower energy neutrons



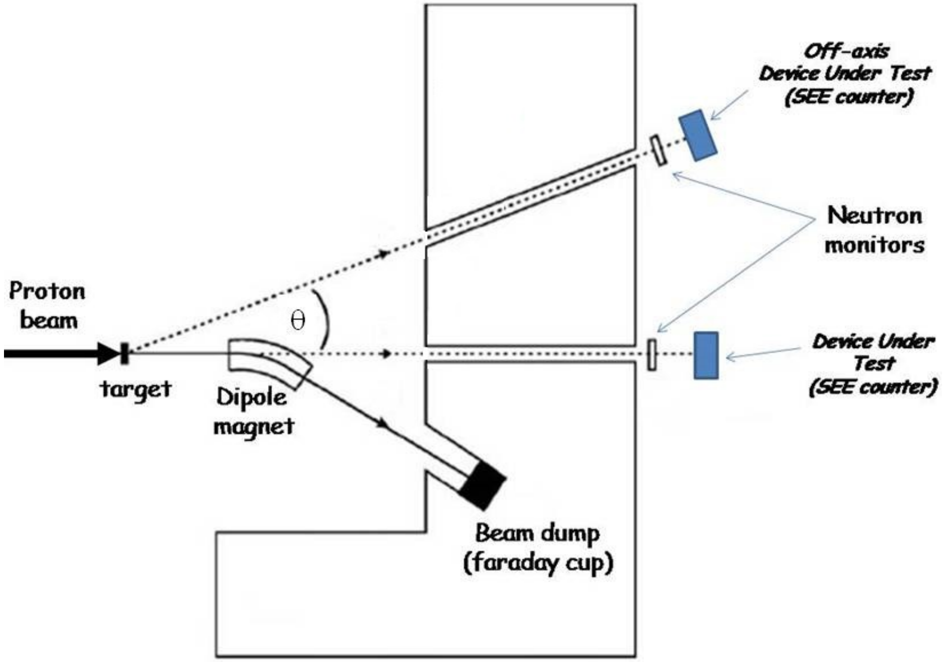
At the test point, the neutron beam is 1.50 m from the false floor (3.91 m from the bottom cement floor). The optics: two dipole magnets, two quadrupole doublets, a single quadrupole, and a bending magnet for the spent proton beam. The supplementary shielding is not shown.

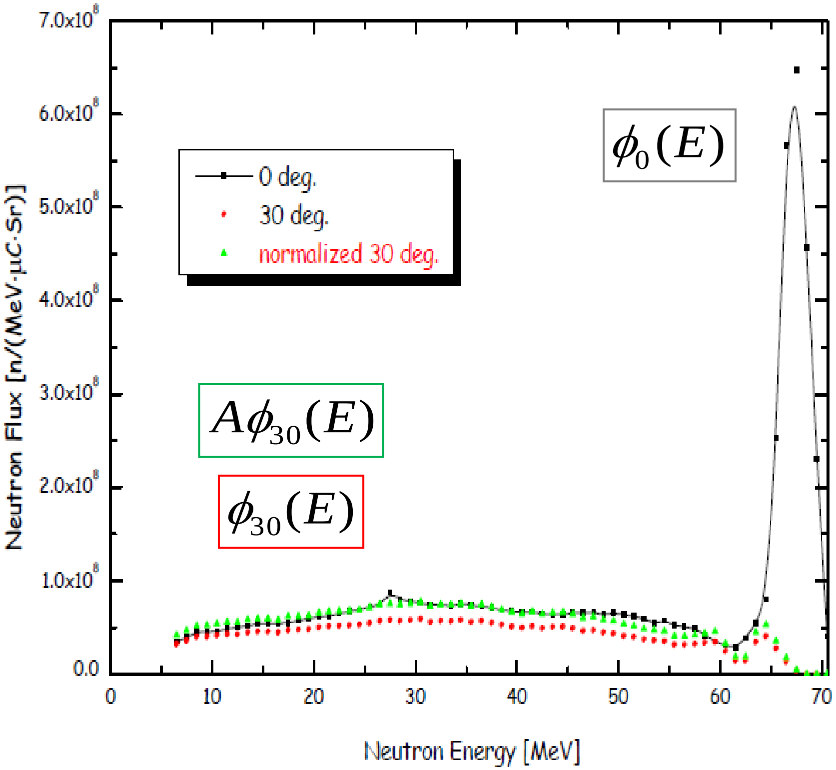
QMN

Multi-purpose Quasi Mono-energetic Neutrons (QMN) in the 20-70 MeV energy range, produced in few mm thick Li or Be targets.

The neutron fluence of forward going mono-energetic neutrons can be corrected by subtracting the neutrons measured at angles typically in the 15^{o}-30^{o} range (*“wrong-energy tail correction technique”);*

iThemba-like
multi-angle collimator



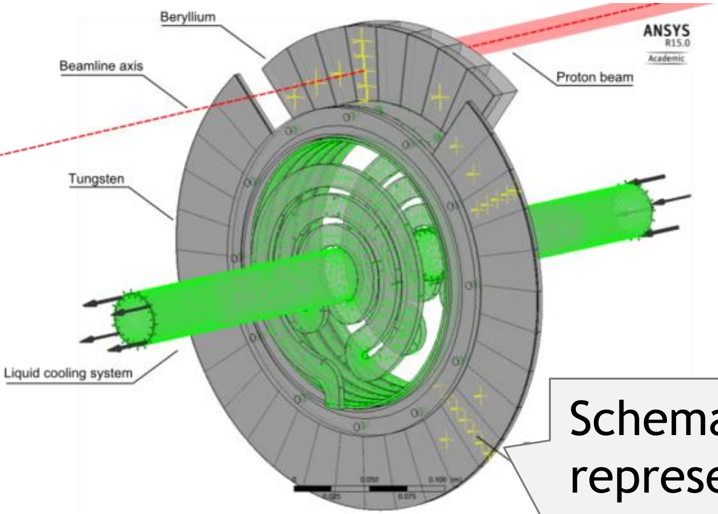


Neutron targets

Different applications needs different spectra and thus different targets:

- Micro-channel based target (Li target, high specific power target)
- Beryllium target (thermal BNCT)
- Rotating multi-layer target (ANEM)
- Thin target (QMN)- to be developed

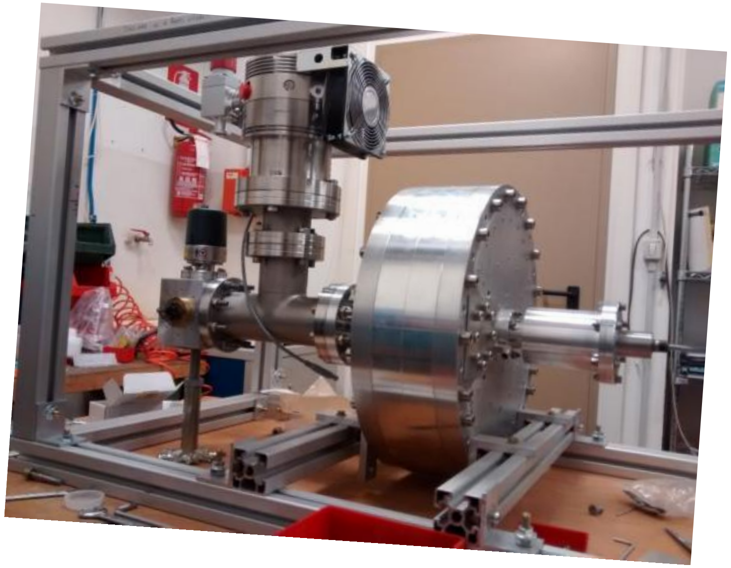
ANEM target

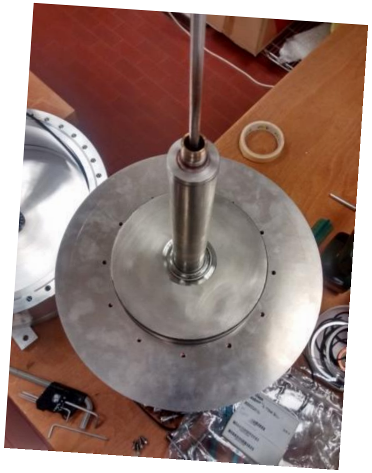


Thermal performance modeling

Schematic representation of the two sectors alternatively intercepting the proton beam

Prototype already realized

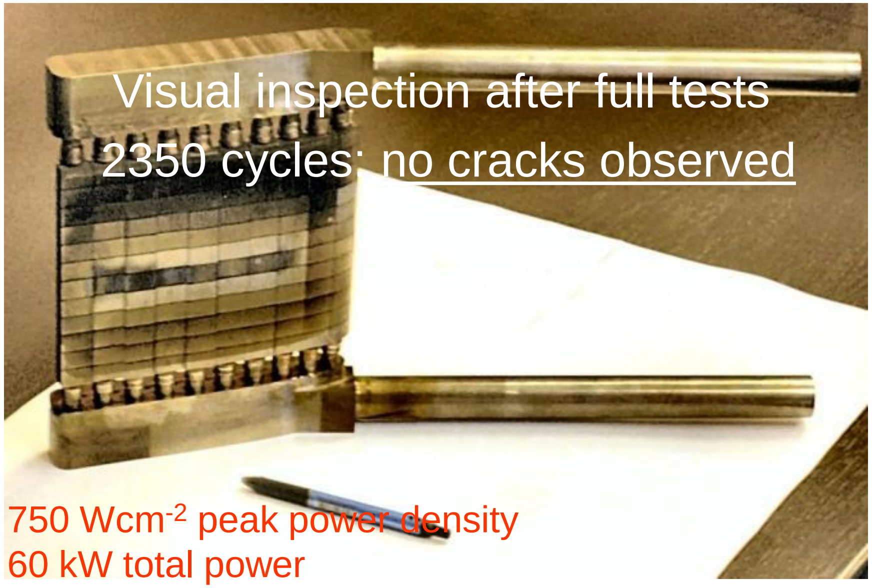




Ready to tested (thermal tests only)
We will use a 10 kV electron beam,
- Maximum current 1 A
- - Independent magnetic focusing coil (by Danfysik): minimum beam spot 1 cm^2 (Gaussian);

Altair electron gun

Thermal BNCT target: The thermal-mechanical full power tests results (see P. Colautti's talk):



Visual inspection after full tests

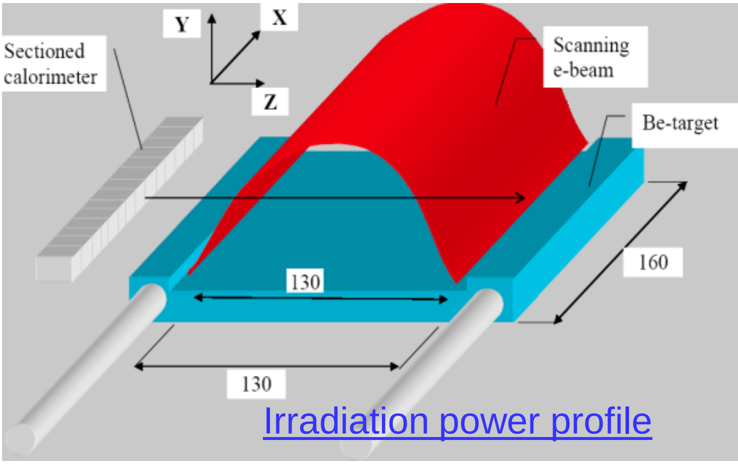
2350 cycles: no cracks observed

$750\ \mathrm{Wcm^{-2}}$ peak power density

60 kW total power

Probe calorimeter

Target on support



Irradiation power profile

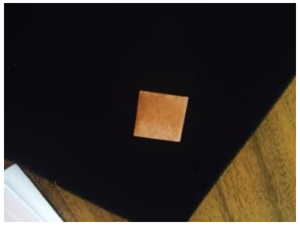
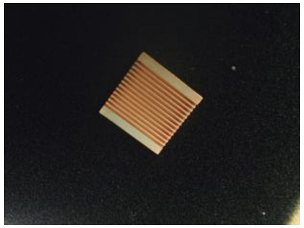
- **Testing condition (half-target): Tsefey facility**

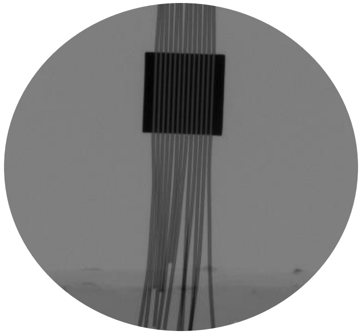
E-beam	E=20 keV, I=3.0 A; P=60 kW
Beam power distribution	close to parabolic shape;
Peak power density in loading area	$0.75\ \mathrm{kW/cm^2}$
Number of cycles	1350 +1000, 15 s-on and 15 s-off;
Target position	horizontal;
Cooling system mechanical fixing	as in the converter design;
Cooling parameters	P_{inlet} =0.3 - 0.5 MPa,
	w=3.0 l/s, T_{inlet}=20 °C
Diagnostics	surface temperature (IR camera)

The μ-channels target

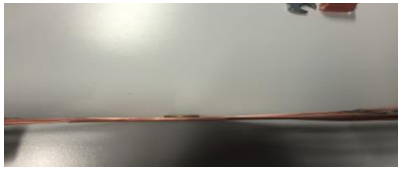
Micro-channels are produced trough micro-tubes

- Grooves are produced in the target backing (one or both faces)



- Micro-tubes are inserted in the grooves
- Interference is produced in order to have a full thermal contact




tubes:

- 0.66 mm internal diameter
- 0.88 mm external diameter

Copper substrate 1.2 mm thickness, 2x2 cm

Wall thickness tube distance 0.5 mm

Number of tubes: 13

INFN international patent APPLICATION n. PCT/IB2014/067156

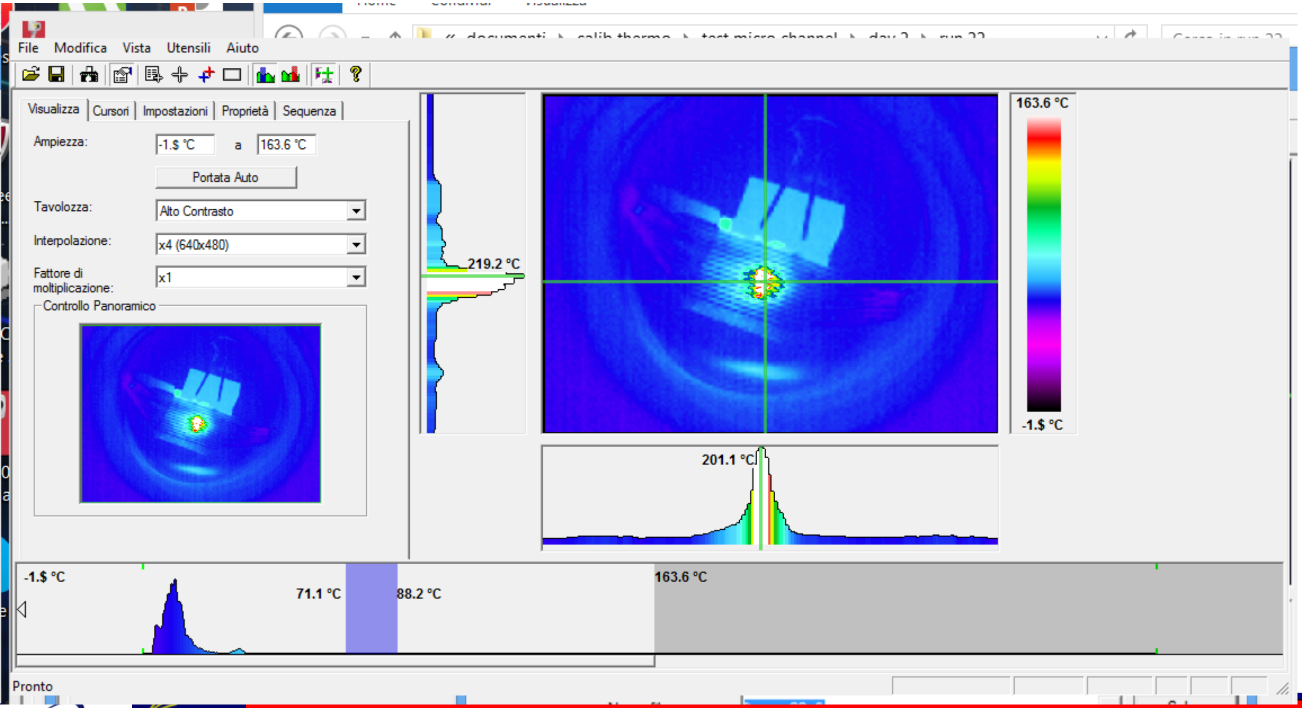
Target : beam tests at Birminghamm University

In July 2014 the target has been tested at Birmingham University.

2.8 MeV proton beam, with different current and beam spot has been used

- Delivered beam power has been measured by measuring the mass flow and difference of temperature at inlet and outlet

Surface temperature has been measured by thermo camera (IRISYS model 4000)



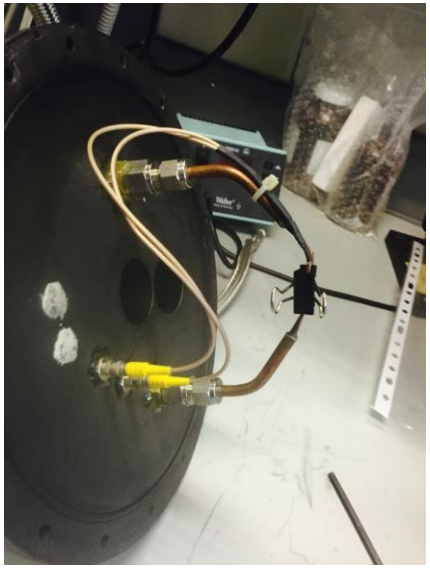
Ampiezza: -1.$ °C a 163.6 °C

Tavolozza: Alto Contrasto

Interpolazione: x4 (640x480)

Fattore di moltiplicazione: x1

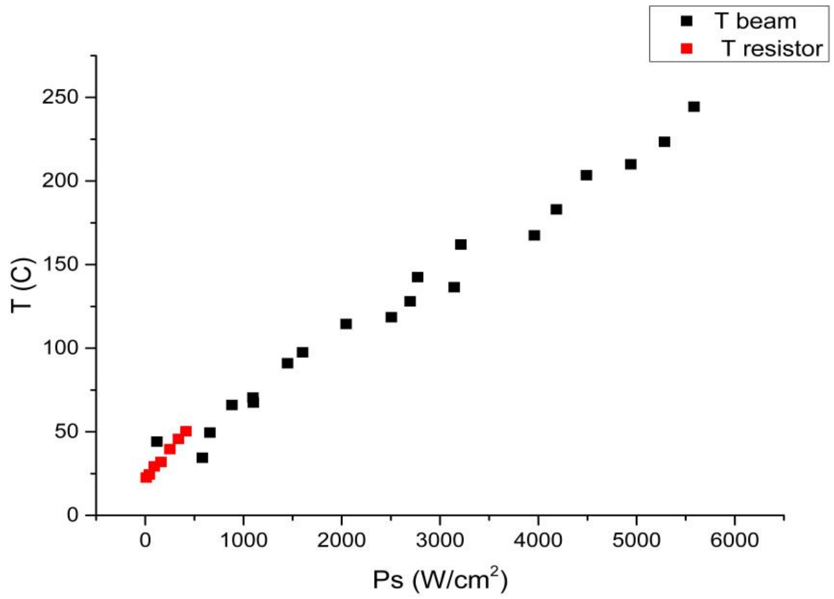
Thermocouple has been used for cross check



Experimental results

Range of 2.8 MeV protons on copper is 30.73 um

The used target was not optimized. Much better performances obtainable



3,0 kW/cm^2 dissipated with a peak temperature of 150 ^{o}C

P_V about 1 Mw/cm^3

Mass flow: 2.94 l/min

T^{in}_{water}=13.0 ^{o}C

250<P<1360 W

0.064<beam spot area<0.2 cm^2

Summary

- **We have an ambitious project : having a neutron facility from thermal to 70 MeV neutron energies.**
- Characteristics: high brilliance, large versatility, easy access.
- We already have:
  - A Cyclotron 35-70 MeV 750 uA in the commissioning phase
  - An RFQ 5 MeV 50 mA (already produced and tested)
  - Targets for different applications
- We don’t have yet:
  - All Buildings
  - Infrastructures
  - Partners

Everybody which like to Join the project is welcome.
Synergies needed

Possible application of IFMIF accelerator

- Pulsed beam (about 2 ns or more):
  - D-TOF line
  - N_TOF line:
    - Cross section measurements for fusion and new generation fission reactors, nuclear medicine (radio isotope) etc… large needs (see IAEA and NEA reports)
    - Lead slowing down spectrometer ?
- CW beam:
  - Integral measurements for neutron dosimetry (IRDFF2 database), validation of codes, etc...
  - ~~Studying the appropriate reactions, an atmospheric neutron spectra up to 40 MeV~~
  - ~~Target tests~~
  - RIB

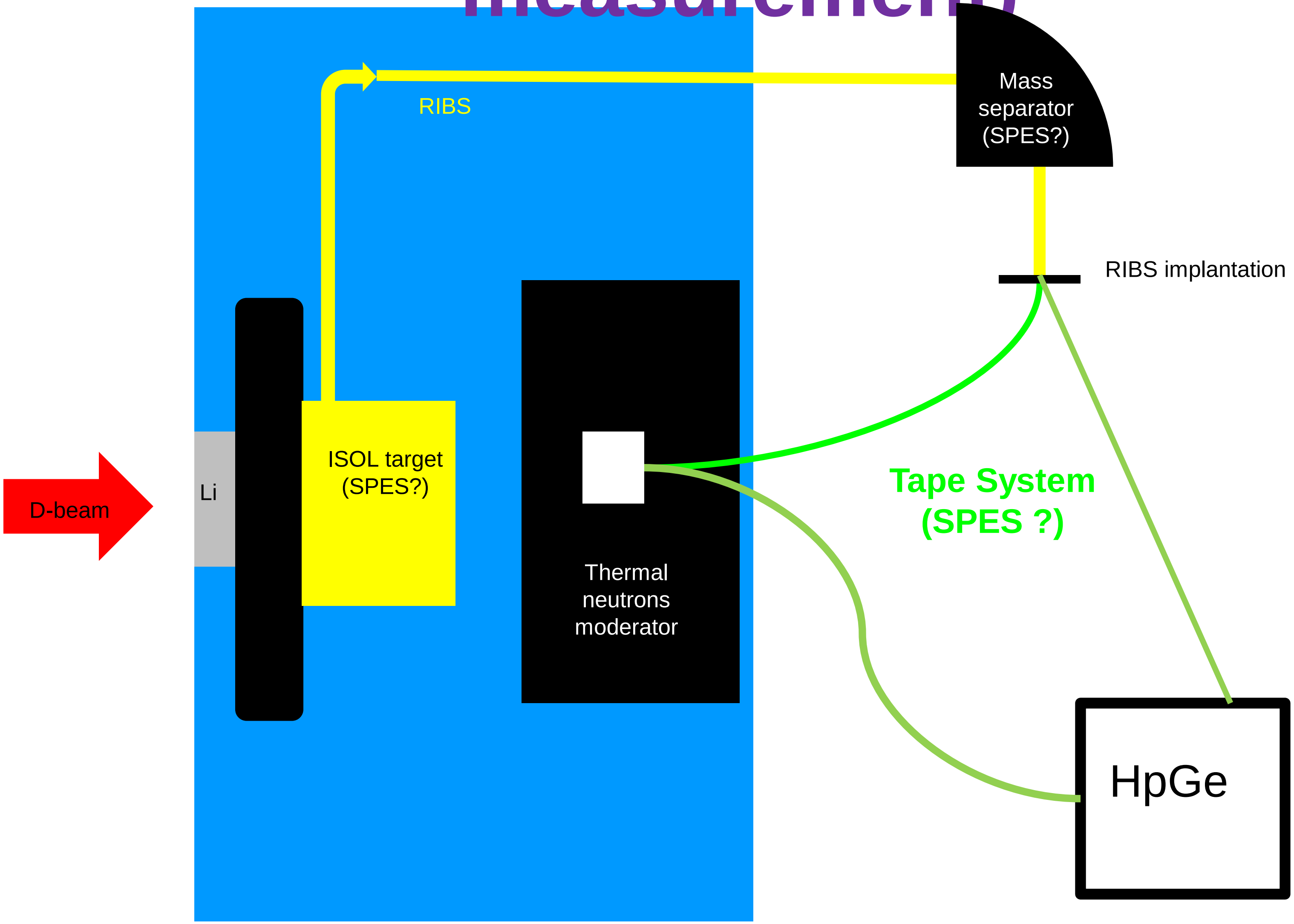
Possible synergies

- Targets, R&D
- Pulsing system
- Radio-isotopes production for medicine
- Extraction, separation and targets for RIBS
- Tape systems (life time measurements)

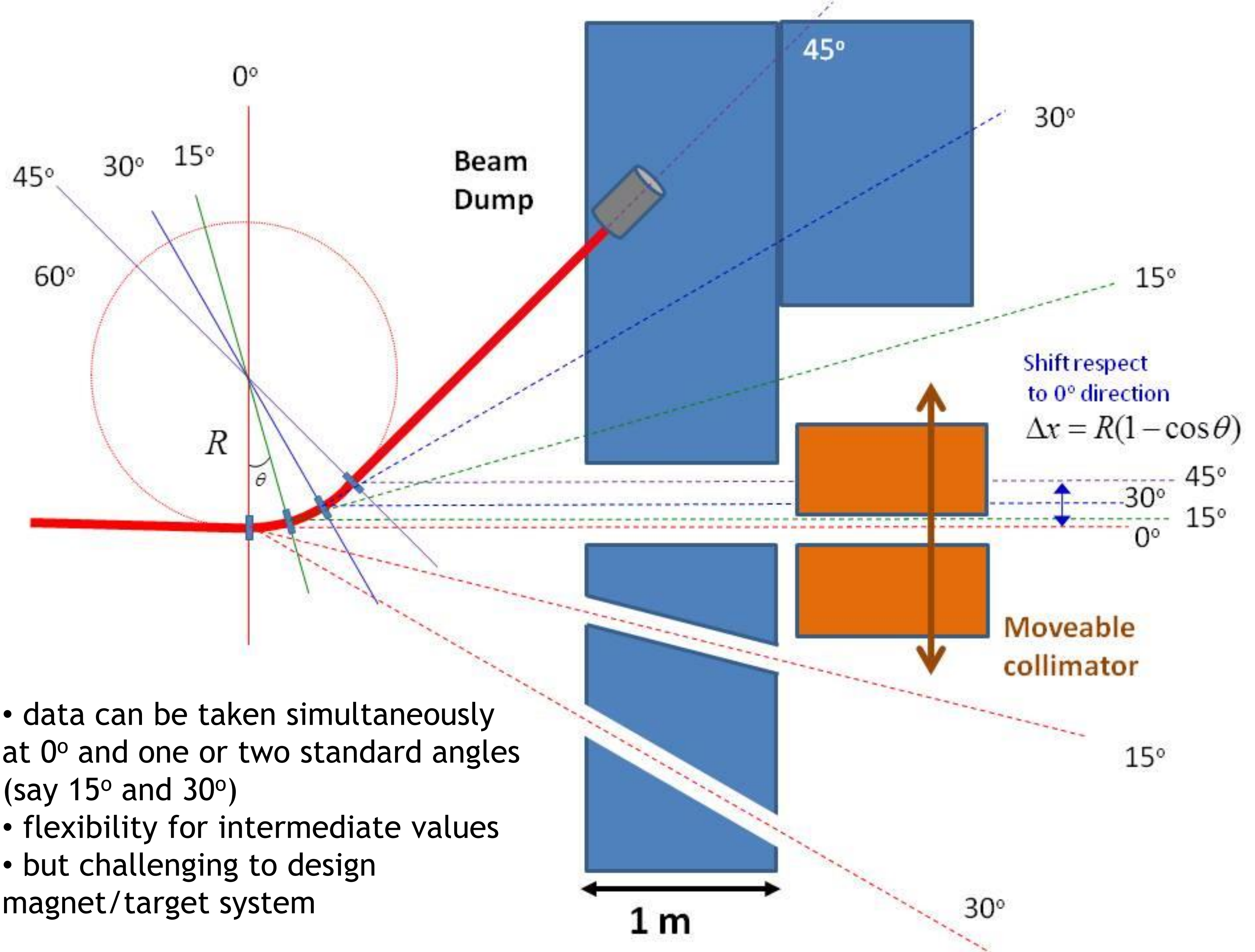
Thank You for your attention

Backup slides follow

R-Process (β decay life time measurement)



RIKEN-like collimator



- data can be taken simultaneously at 0° and one or two standard angles (say 15° and 30°)
- flexibility for intermediate values
- but challenging to design magnet/target system