The SPES neutron sources

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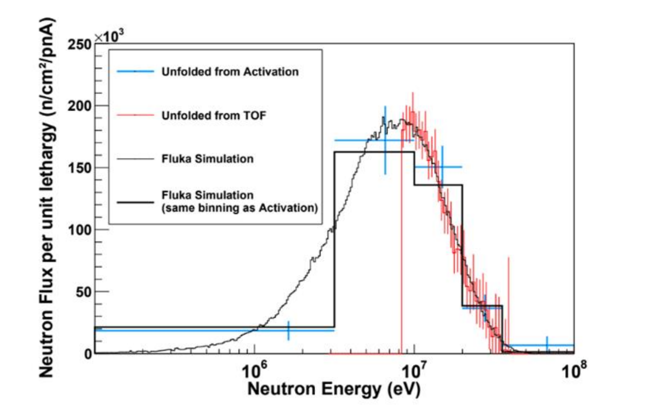
Fast neutrons at LNL

1) CN

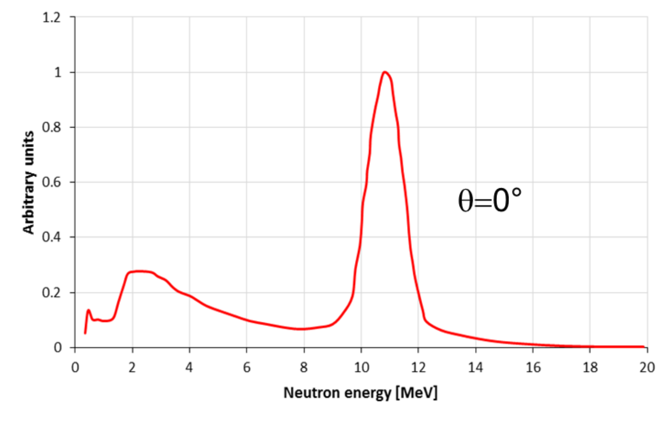
---> Talk of L. Bellan "*Neutron sources from the CN accelerator*"

- Belina
- Munes



2) TANDEM/PIAVE-ALPI

- 14N on Lithium (submitted article https://arxiv.org/abs/2311.06143)
- QMN 11B and 15N on hydrogen gas (planned)



30 μA of ^{11}B on a 3 cm gaseous hydrogen cell @ 3 atm
Neutron flux at @ 10 cm is $4 \cdot 10^4$ n cm^{-2} s^{-1}

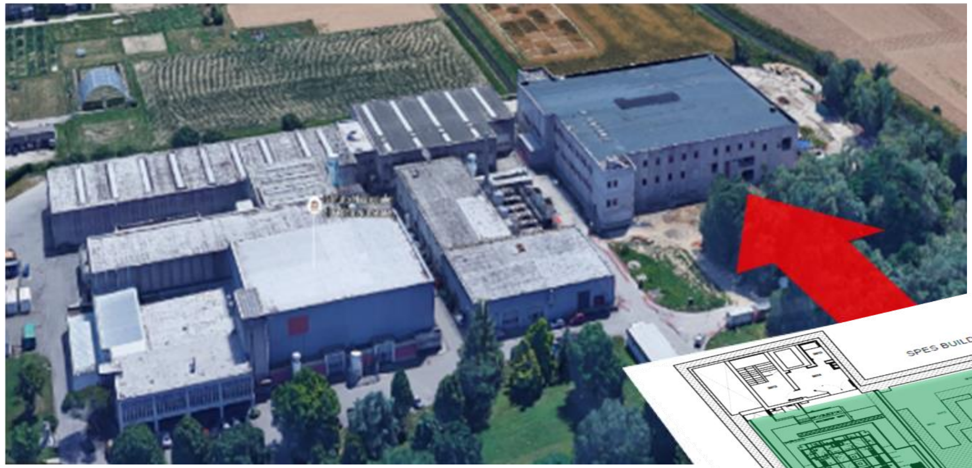
3) SPES NEPIR (this talk)

- phase-0 (partially funded)
- phase-1
  - ❑ Quasi Monoenergetic Neutrons (QMN)
  - ❑ Atmospheric Neutron Emulator (ANEM)

INFN LNL
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Legnaro

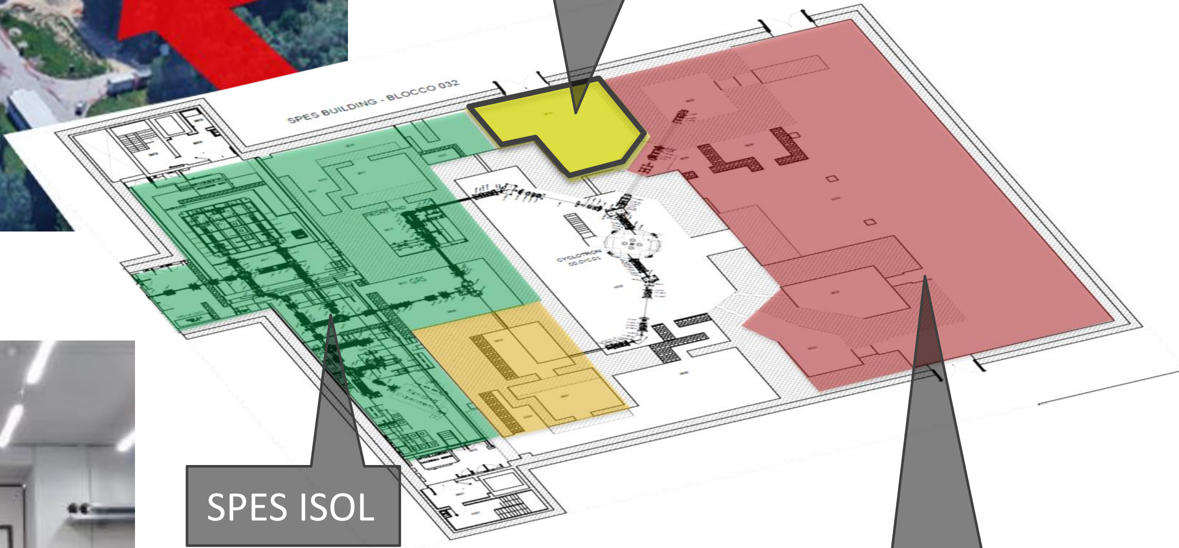
Status of NEPIR facility

Completed SPES infrastructure



Existing (empty) NEPIR experimental hall, 140 m^2

NEPIR



SPES ISOL

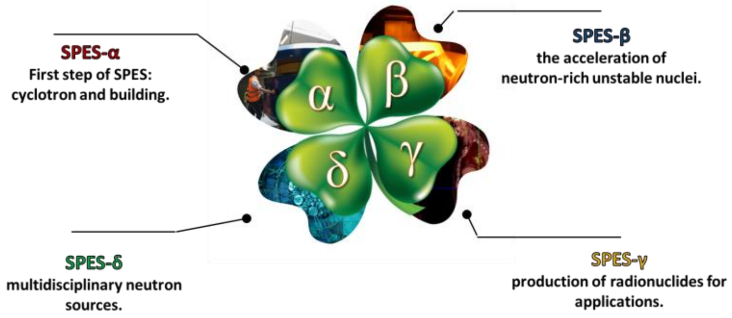
Radioisotope R&D and production

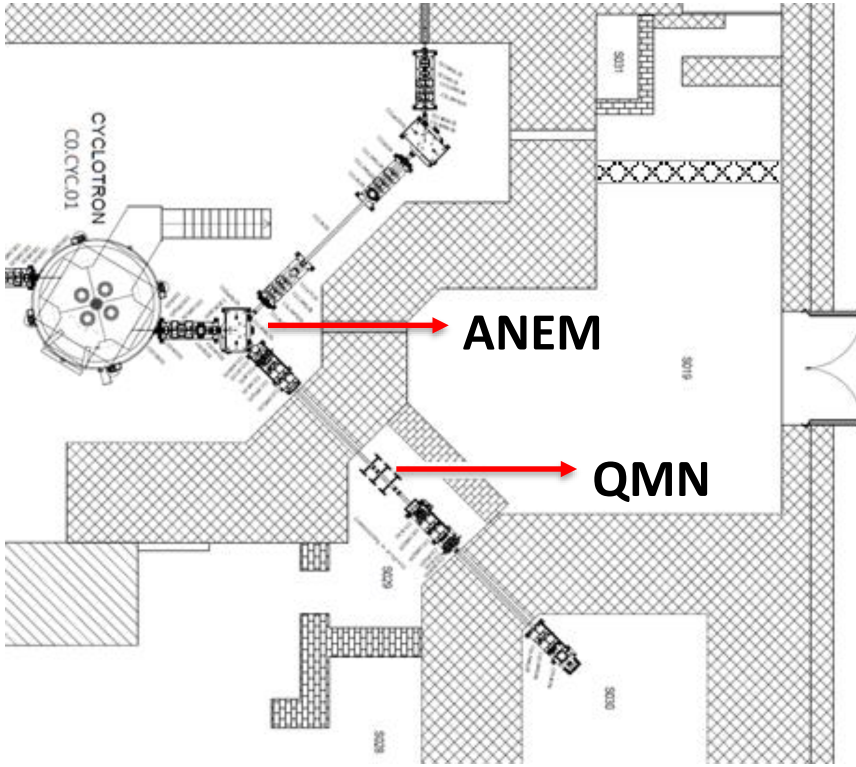
Fast neutrons at LNL

- NEPIR facility is planned within the **delta phase** of **SPES**. It is conceived as:
    1. **Quasi Mono-energetic Neutrons (QMN)** $35 < E_n < 70$ MeV (possibly lower)
    2. **Atmospheric Neutron Emulator (ANEM)** $1 < E_n < 70$ MeV
    3. **Proton** $35 < E_p < 70$ MeV (possibly down to 20 MeV)
- Physics motivations:
    - Study of **radiation damage effects in electronic devices and systems** induced by flight-altitude and sea-level *atmospheric neutrons*
    - Nuclear physics cross-sections for different applications: fission next generator reactors, ADS, fusion reactors, etc..
    - Neutron yield spectra measurements : X(p,n+x)
    - Shielding performance evaluation for space missions
    - Biological samples irradiation, radiation damage in hibernated lives
    - Detector characterization and calibration
    - Dosimeter calibration

Neutron tomography

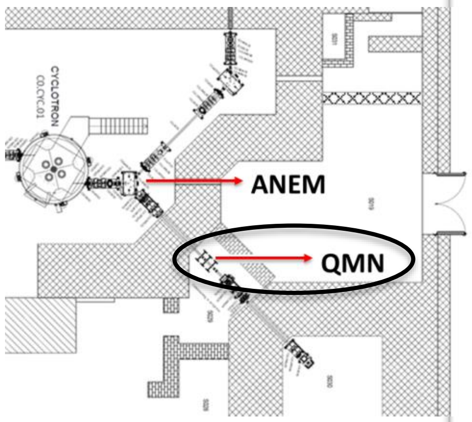
….

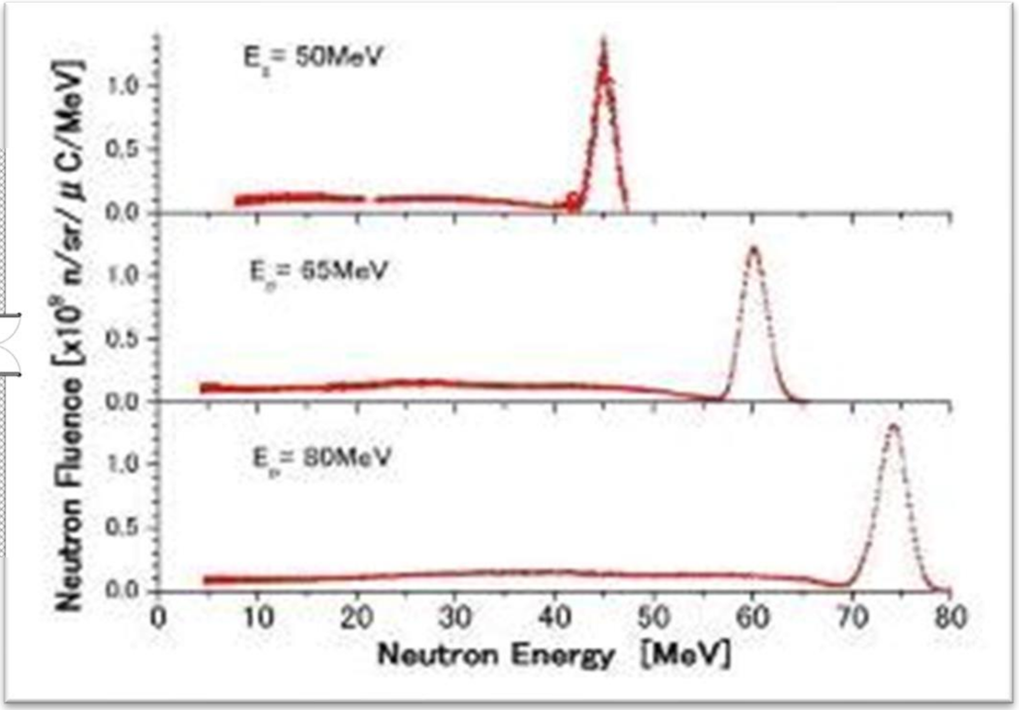




QMN beams @ SPES

- Suitable for excitation function measurements on electronics and nuclear data
- Best option for detector and dosimeter response studies as well as calibrations
- Available from **35 to 70 MeV in NEPIR 1**

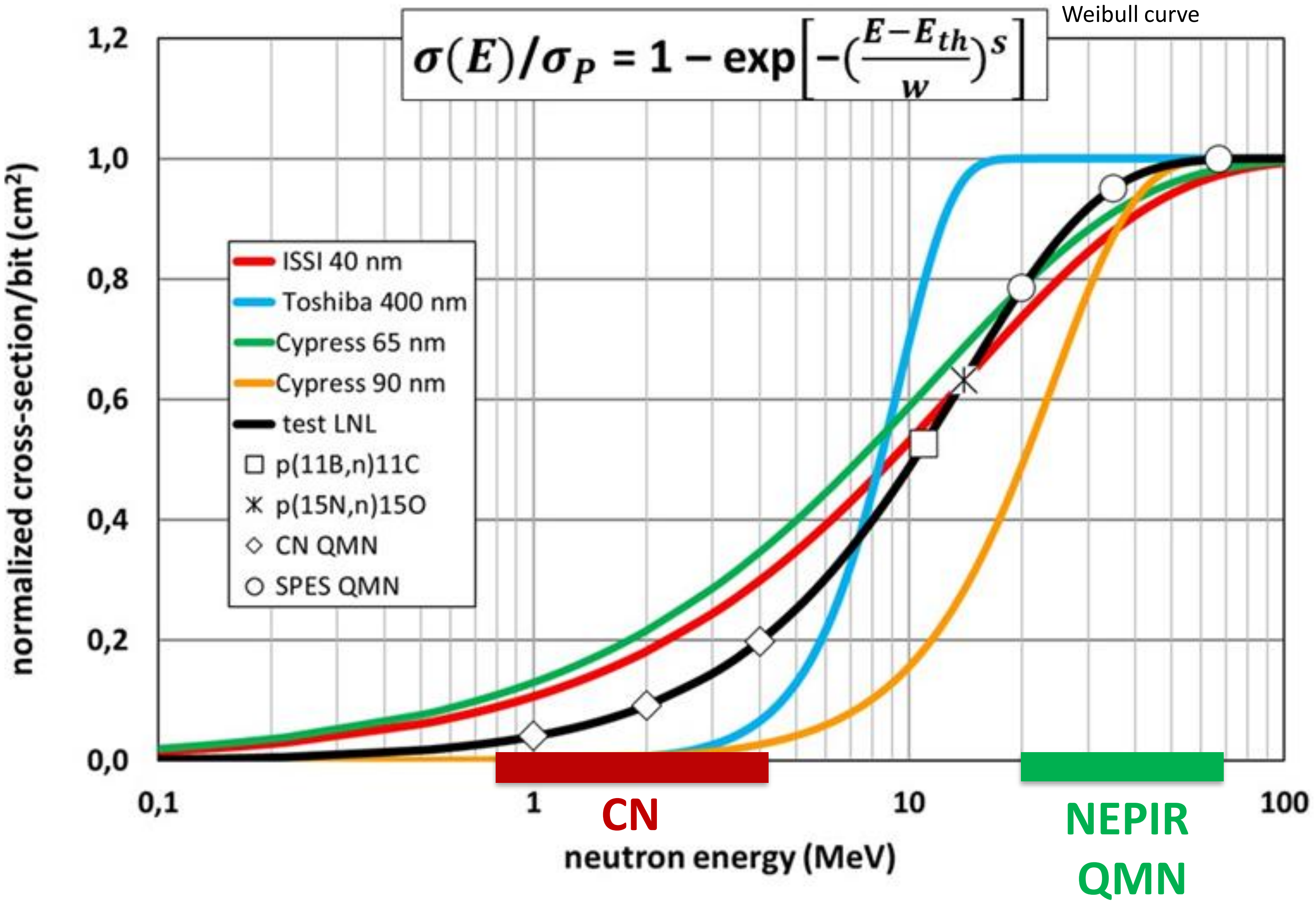




QMN sources (Lithium) beams around the world.

LAB	Energy of the protons (MeV)	Distance (m) of target to the test point	Mono-energetic neutron (peak) flux at the test point
TIARA (Japan)	40-90	12.9	~3.5-5 $\cdot 10^3$ n cm-2 s-1 for max 1-3 μA
CYRIC (Japan)	14-80	1.2	10^6 n cm-2 s-1 or 3 μA
RCNP (Japan)	100-400	10	10^4 n cm-2 s-1 for 1 μA
ANITA (Sweden)	25-200	3.73	~ $3 \cdot 10^5$ n cm-2 s-1 for max 5-10 μA
NFS (France) *UNDER CONSTR.*	1-40	5	~ $8 \cdot 10^7$ n cm-2 s-1 for 50 μA, 40 MeV
iTHEMBA (South Africa)	25-200	8	1-1.5 $\cdot 10^4$ n cm-2 s-1 for typical 3 μA
QMN (LNL) *PROPOSED*	**35-70 (possibly lower using degrader)**	**3 (reduce?)**	**~ $2.6 \cdot 10^5$ n cm-2 s-1 for 10 μA, 70 MeV**

QMN beams @ SPES



Of cross-section, it is important to know:

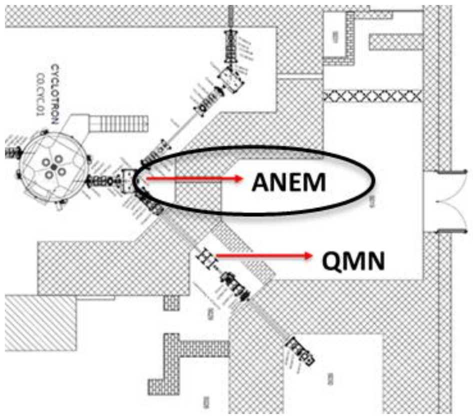
- **Saturation value (NEPIR)**
- **Threshold (CN)**

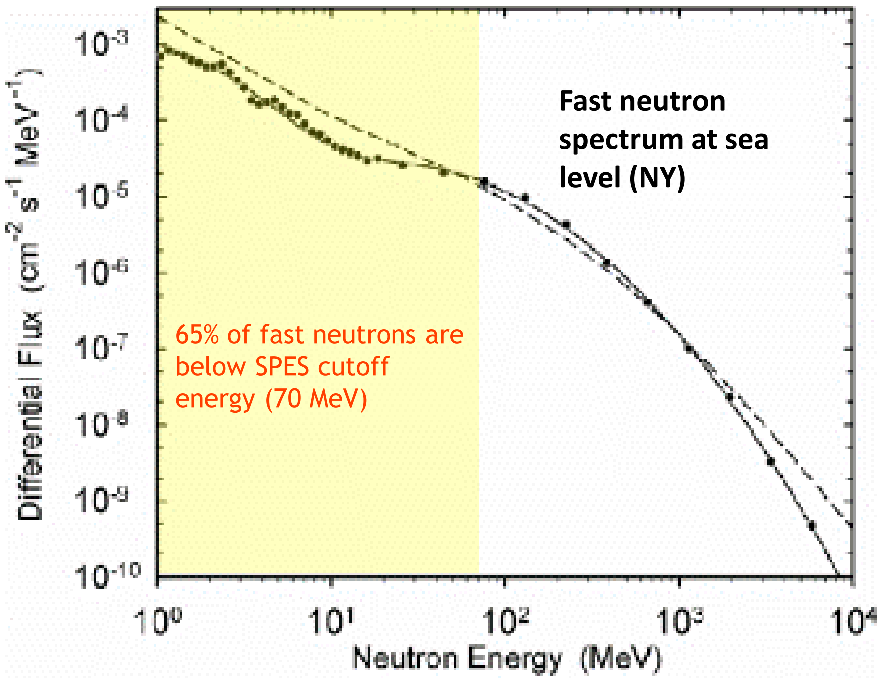
- Knee is useful to constrain fit

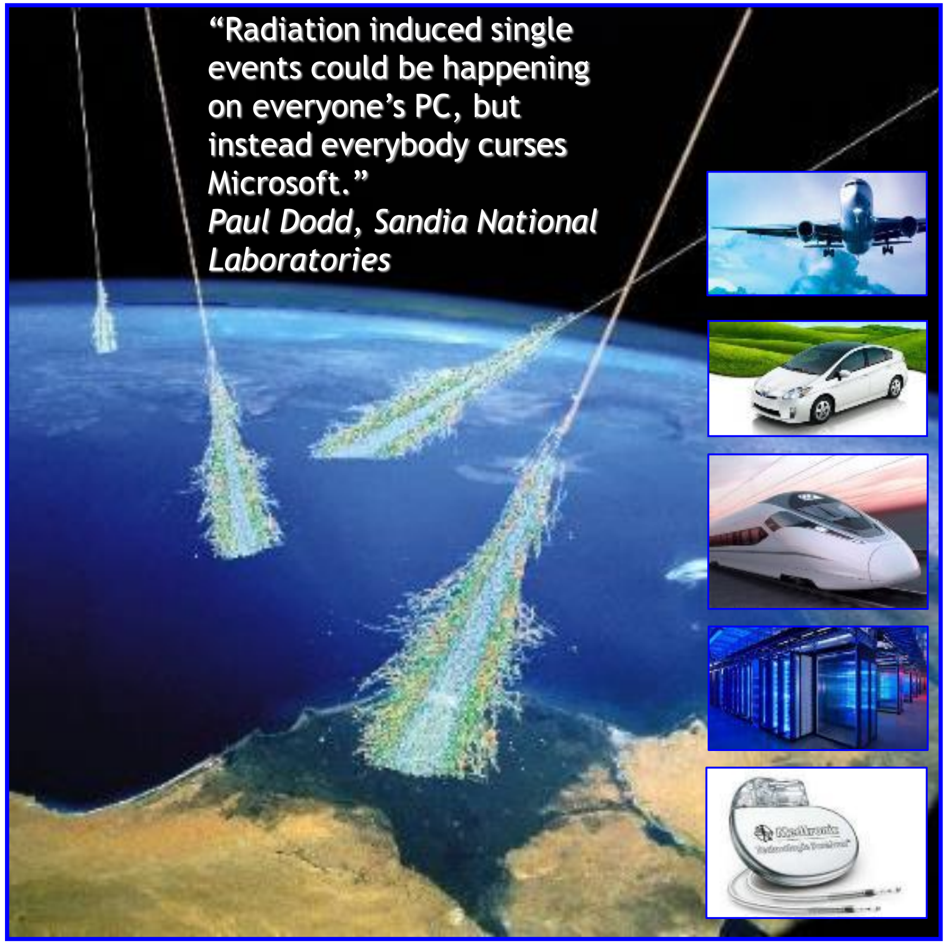
Atmoshperic neutrons

Neutrons in cosmic-ray air-showers are a widening problem for industry:

- Aviation (historical)
- Automotive
- Trains
- Information technology and Infrastructure
- Medical (life support, e.g. pace makers,…)



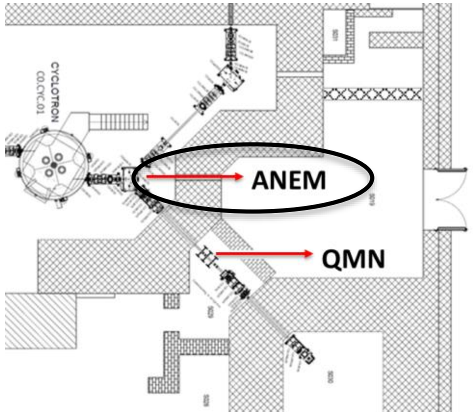




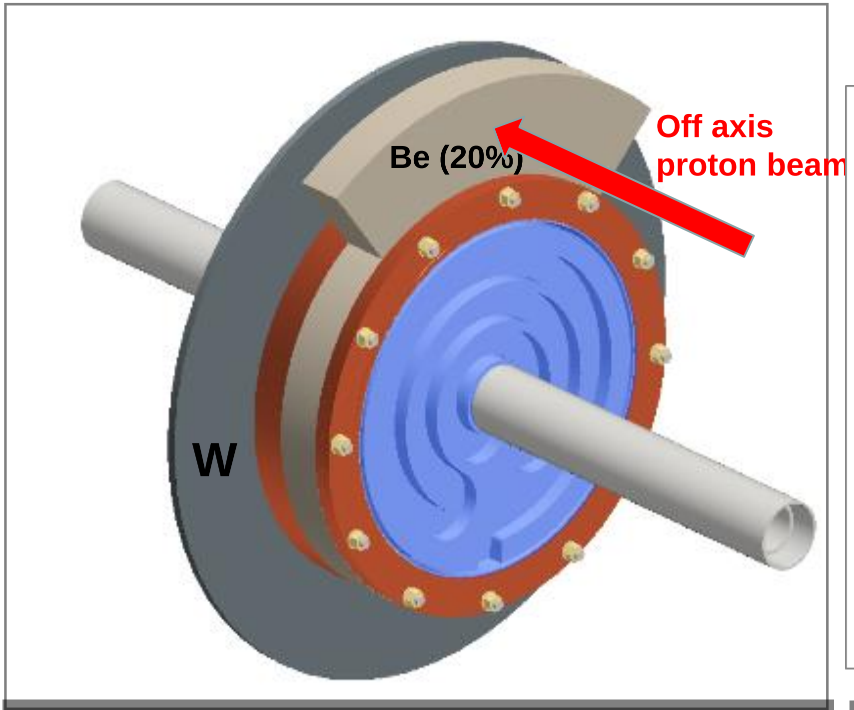
The fast (E > 1 MeV) neutron flux at sea level is 21 n cm^{-2} hr^{-1}

Atmospheric Neutron Emulator (ANEM) target

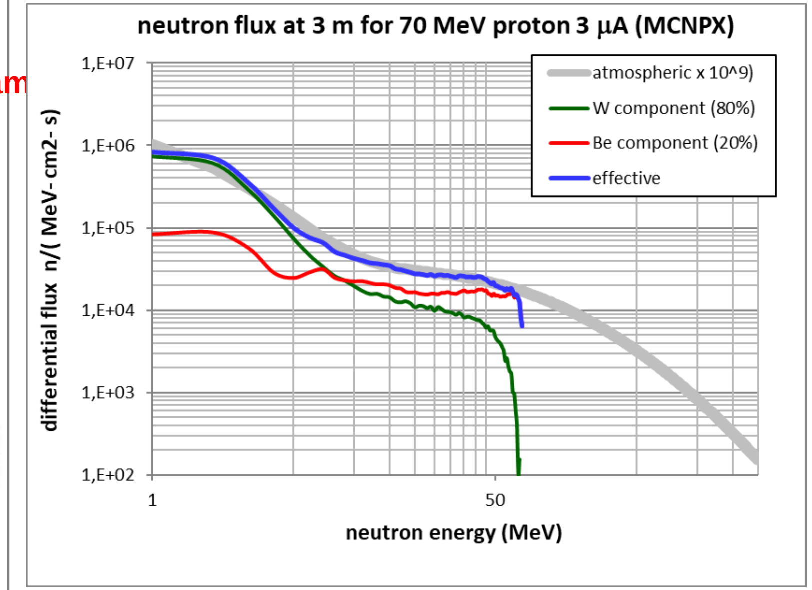
- A **novel** target made of thick Be and W
- W disk and a Be circular sector rotate
- Common water-cooled hub and alternatively intercept an off axis 70 MeV proton beam
- The effective atmospheric-like neutron spectrum in the 1-65 MeV range is composed without the use of moderators



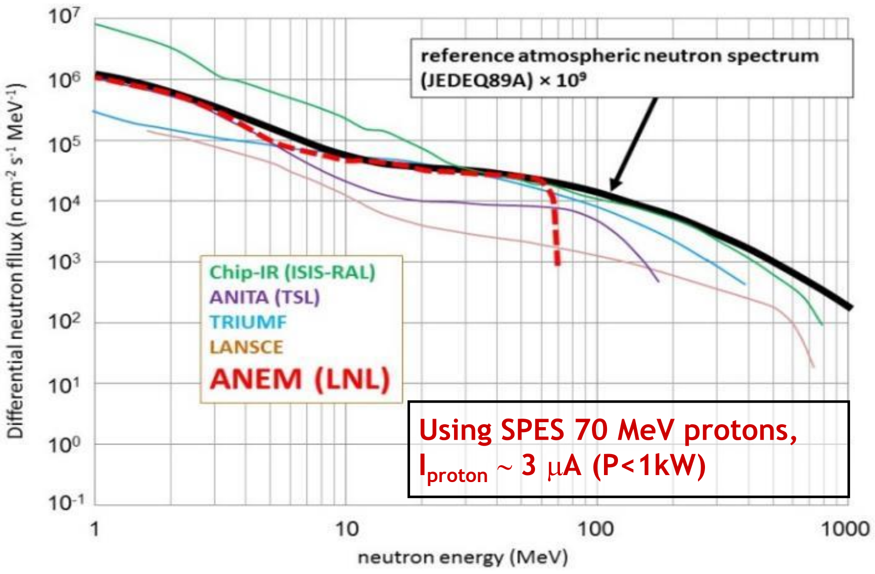
- Combination of 20% Be spectrum and 80% W spectrum yields the best fit of the atmospheric spectrum
- **Flux of neutrons in the 1-65 MeV range is 3.7×10^6 cm^{-2} s^{-1}** (at 3 m for a 3 μA proton current), corresponding to an ***acceleration factor of 10^9***



Rotating target concept

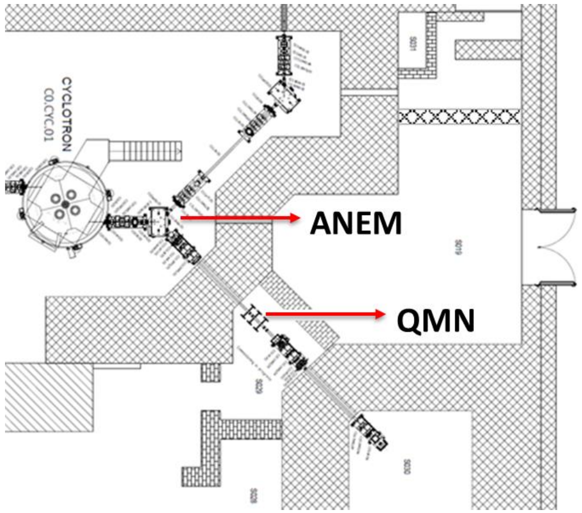


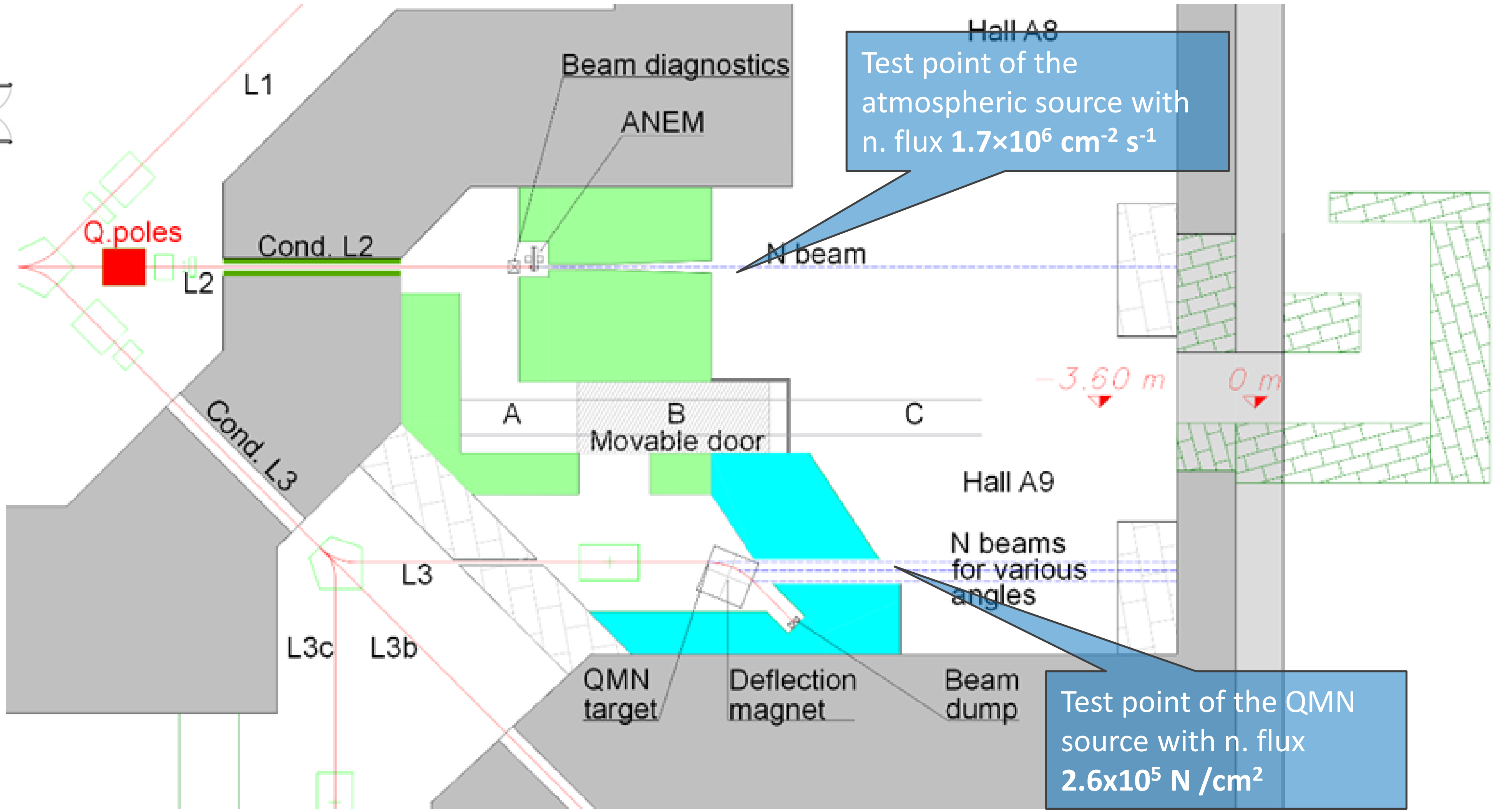
Combined energy spectrum and Be and W components



ANEM target is designed to tolerate a maximum current I_{beam} = 30 μA (2.1 kW).

Current NEPIR phase 1 layout





Test point of the atmospheric source with n. flux **1.7×10^{6} cm^{-2} s^{-1}**

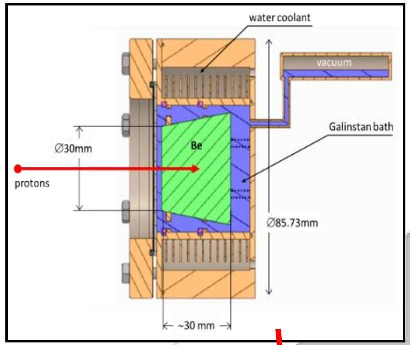
Test point of the QMN source with n. flux **$2.6\text{x}10^{5}$ N /cm^{2}**

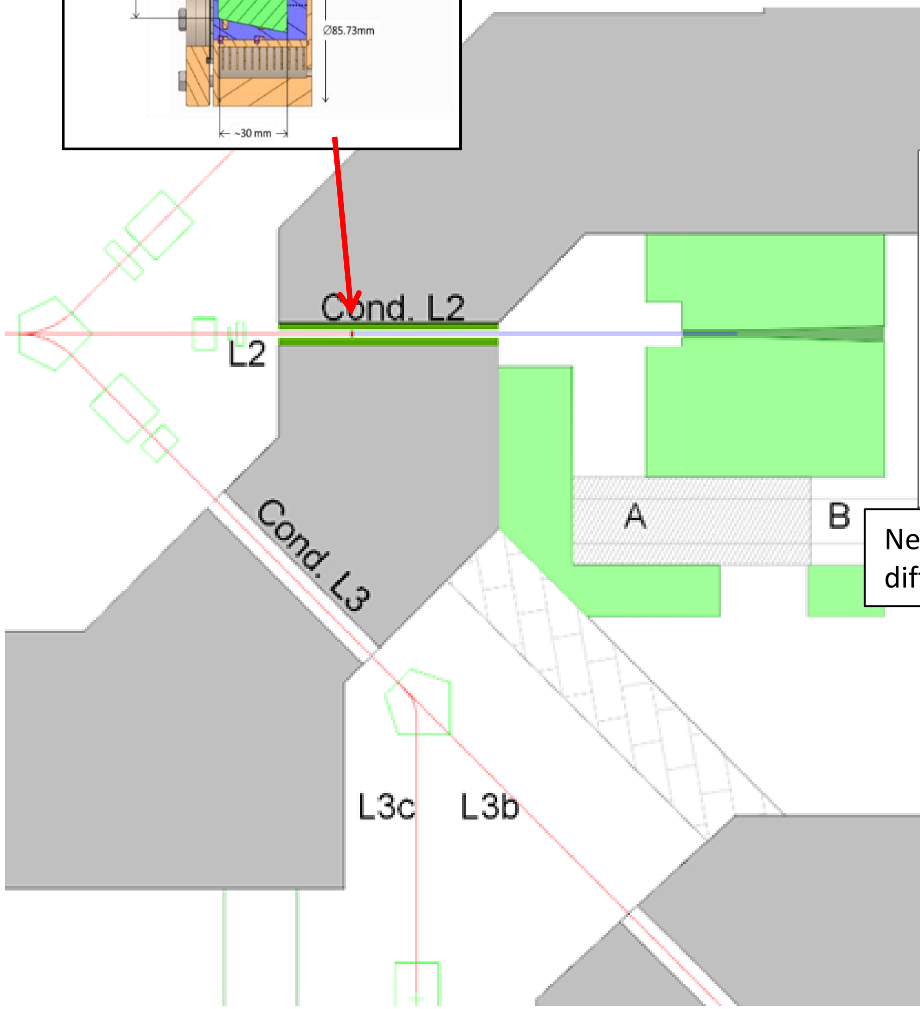
NEPIR phase 0: CoolGal

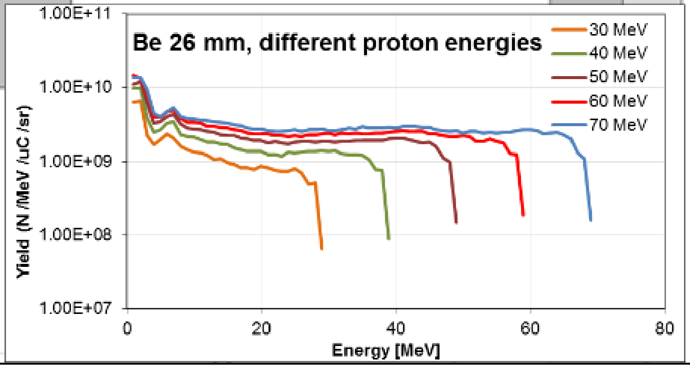
The maximum **proton current:** 1 μA (P = 70 W)

Maximum flux at 3 meters: **3×10^6 N /cm^2 /s** with 1 μA of 70 MeV protons

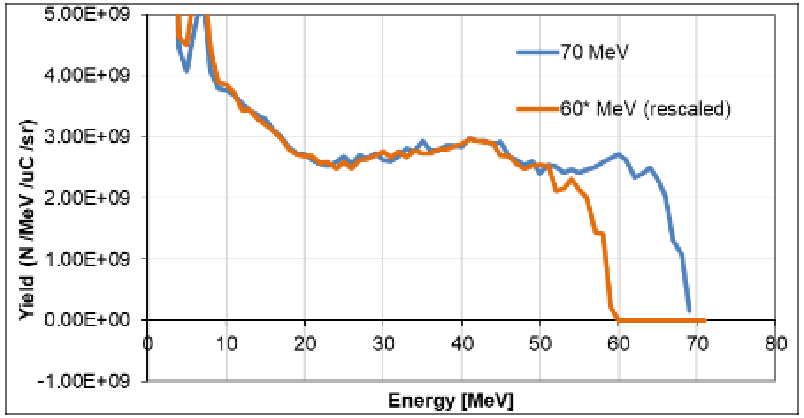
Acceleration factor ≈ 10^9



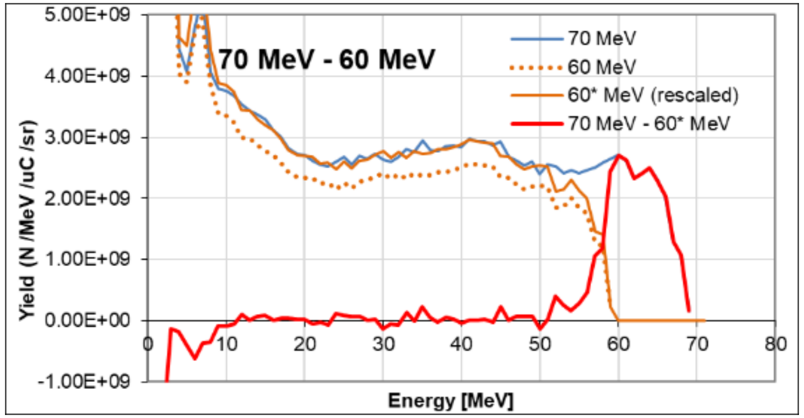




Neutron spectra (simulated with MCNP) at test point for different energies of the impinging proton beam.



Neutron spectra with 70 MeV and 60 MeV (60 MeV protons rescaled by a factor 1.15)

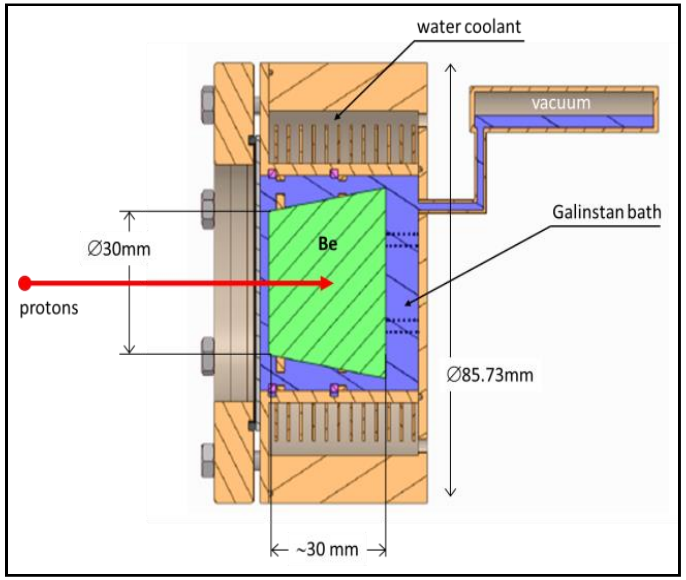


Spectra differences return a quasi-rectangular energy distribution, with controllable width, down to few MeV.

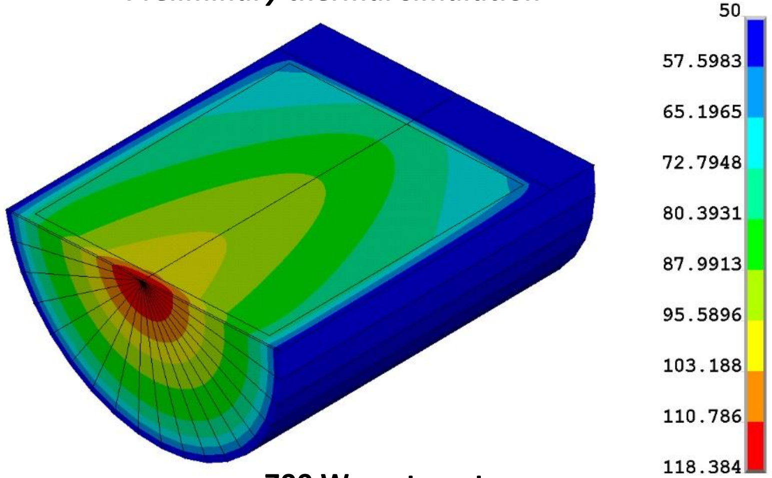
CoolGal deliverable

- Freeze facility layout
- Study and design the target for 70 MeV, 1 μA of proton beam
- Preliminary design of shielding (to validate by RP)
- Target dose evaluation
- Target maintenance and timeschedule
- Production of the target
- Test the target under proton beam to verify:
  - Target integrity
  - Neutron beam spectrum

End of project: **September 2025**

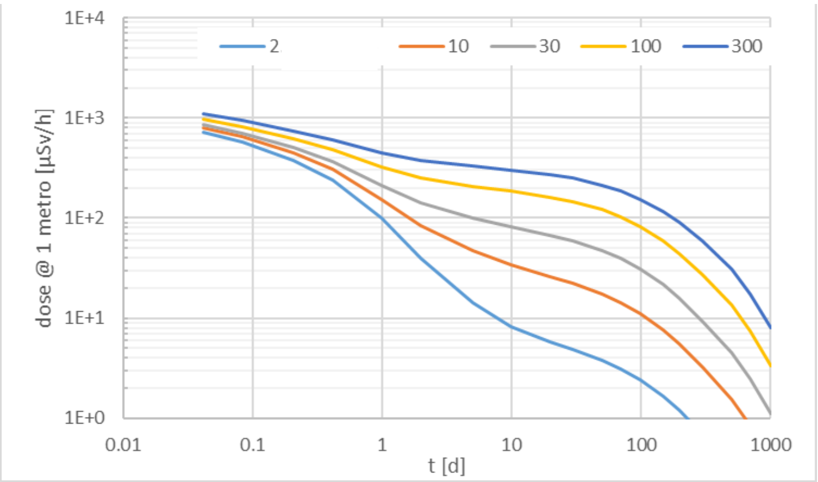


Preliminary thermal simulation

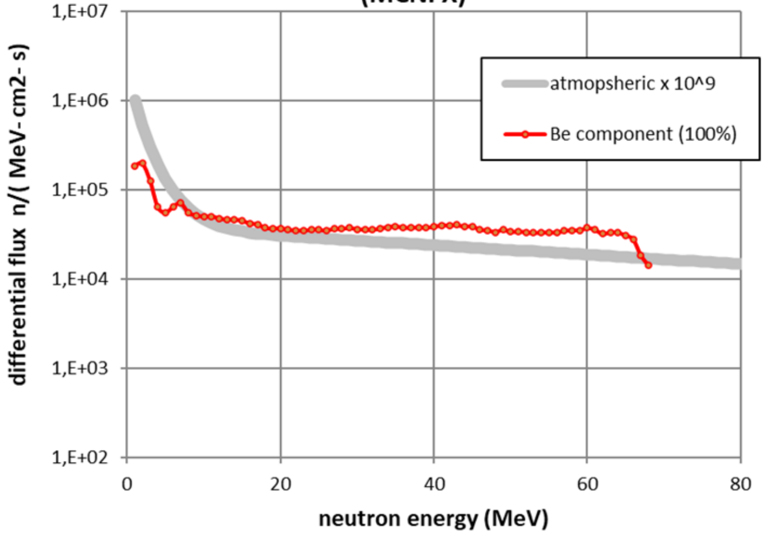


700 W on target

Irradiation time [days]



neutron flux at 2.6 m for 70 MeV proton 1 μA (MCNPX)



Conclusions

- Time scale of NEPIR is set by the SPES accelerator.
- For LNL and the INFN, the SPES facility has highest priority. NEPIR is part of the delta phase, which is low priority.
- A design of a Phase-0 version of the facility, with a white spectrum target (CoolGAL) is being developed. Completion will require about 2 year. Shielding, systems and few beam optic elements are not funded.
- The conceptual design of the NEPIR facility (shielding, optics) in its final configuration and different neutron production target systems are defined. The QMN is to be designed. The shielding has to be radio-protection validated, and the ANEM prototype tested. The present funds are not sufficient.
- In final configuration, NEPIR will be a high level neutron facility in Europe and the first in Italy. Phase 0 is still very interesting for academia and small companies and represents a step toward NEPIR