Thermal Neutrons in HiSPANoS: Proposal for a moderating system

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Thermal Neutrons in HiSPANoS

- *Thermal Neutron Radiation*
  - *Applications and Motivation*
  - *HiSPANoS: current setup*
- *Design of the moderating system*
  - *Simulation validation*
  - *Optimization: Dimension and beam energy*
- *Thermal beam and field performance*

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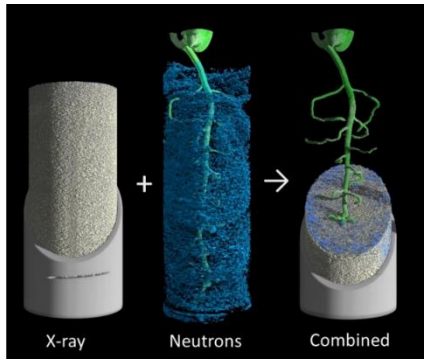
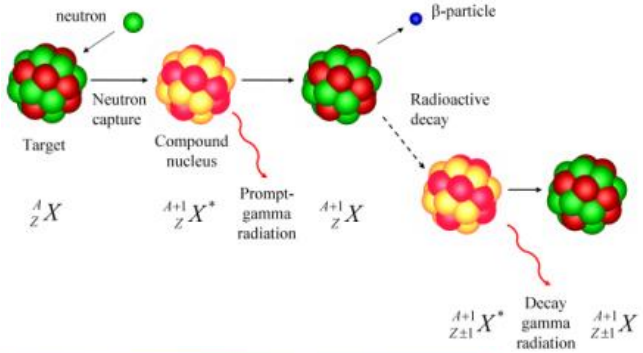
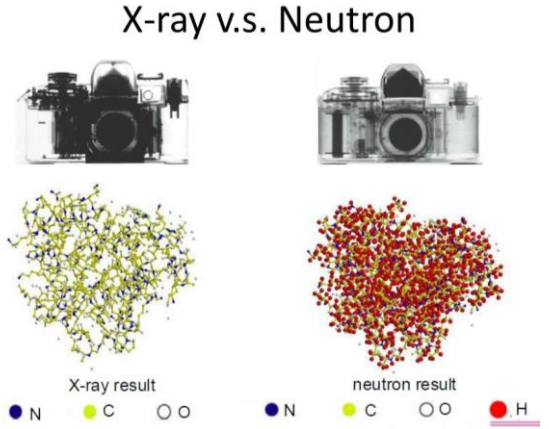
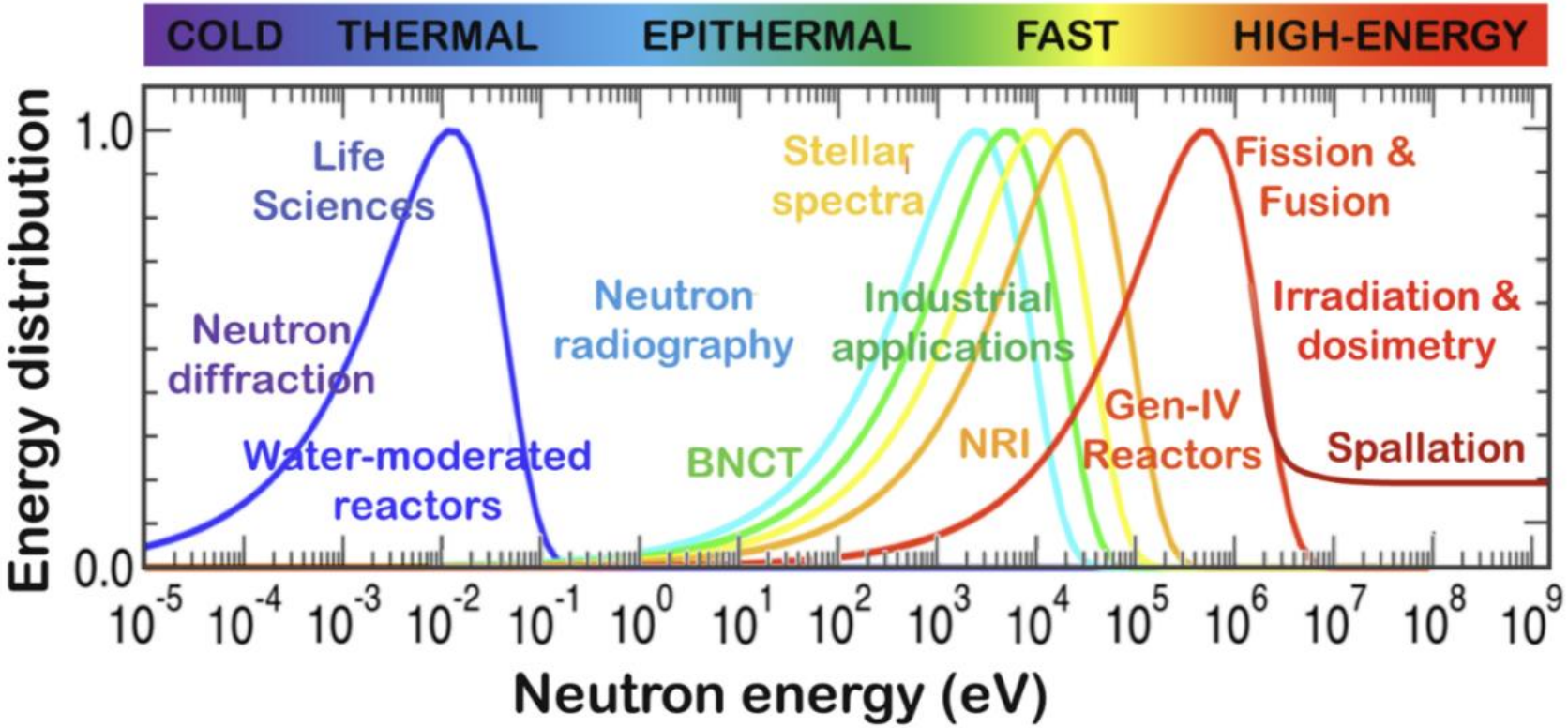
Neutron radiation: applications and motivation

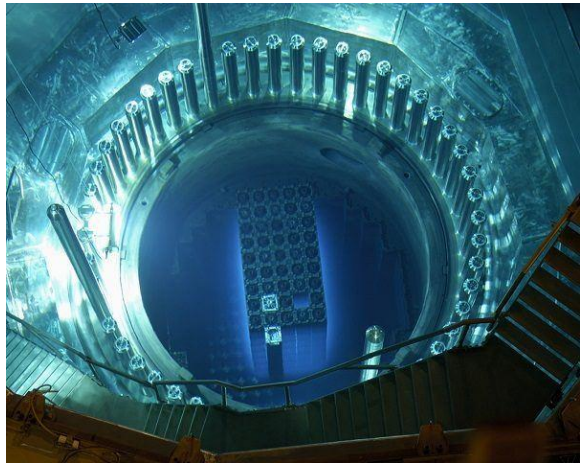
A versatile and useful tool









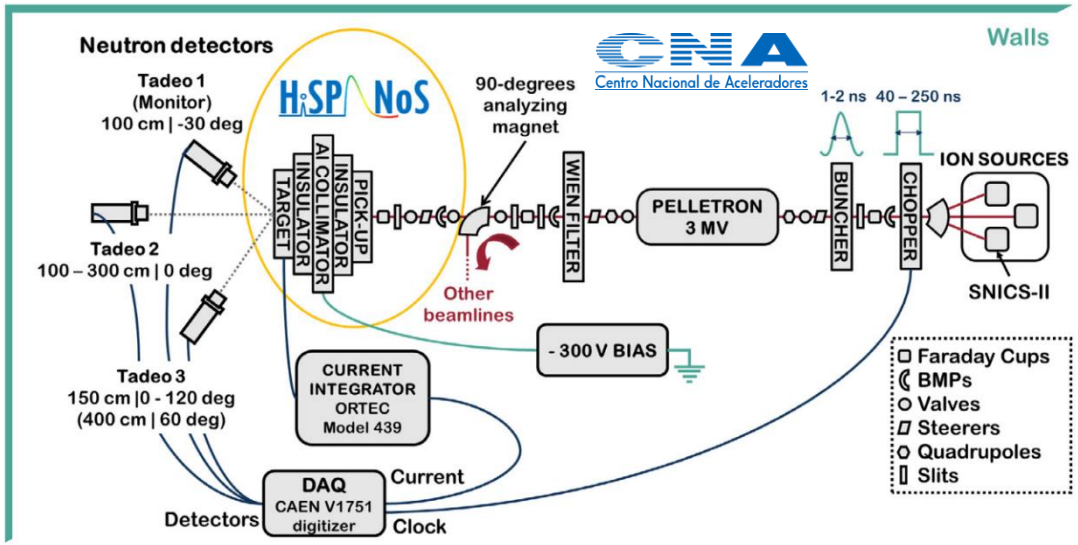


HiSPANoS: an accelerator driven neutron source

HiSPANoS: *Only accelerator-driven neutron source in Spain.*

Linear Tandem Pelletron 3MV

Continuous and pulsed



p, d beams up to 6MeV

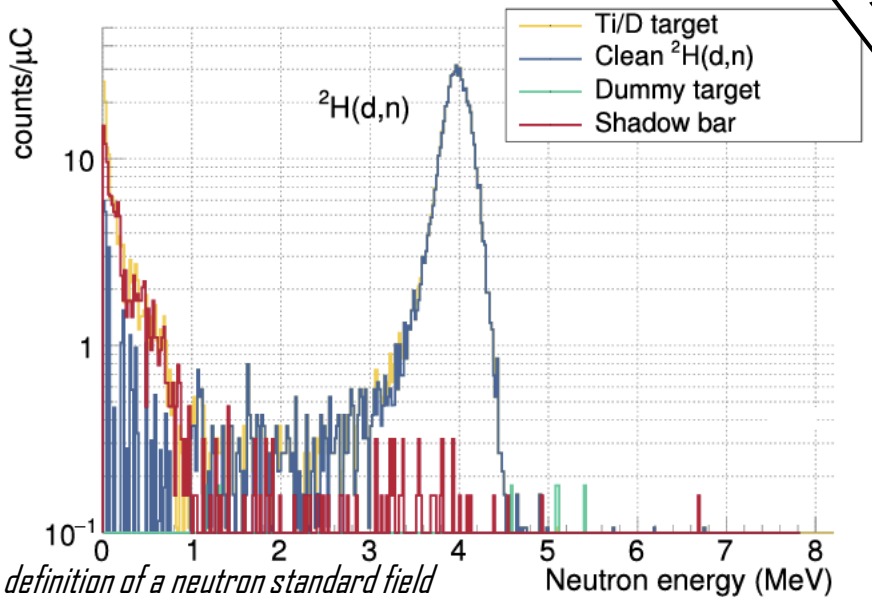
- *Epithermal neutrons:*

  E_p=1912keV->^{7}Li(p,n)->E_n~1-100 keV

- *Fast neutrons:*

  X(p/d, n)->E_n~0-20 MeV

Currently



[1] M. Macías, B. Fernández, J. Praena, The first neutron time-of-flight line in Spain: Commissioning and new data for the definition of a neutron standard field

HiSPANoS: an accelerator driven neutron source

p, d beams up to 6MeV

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- *Fast neutrons:*

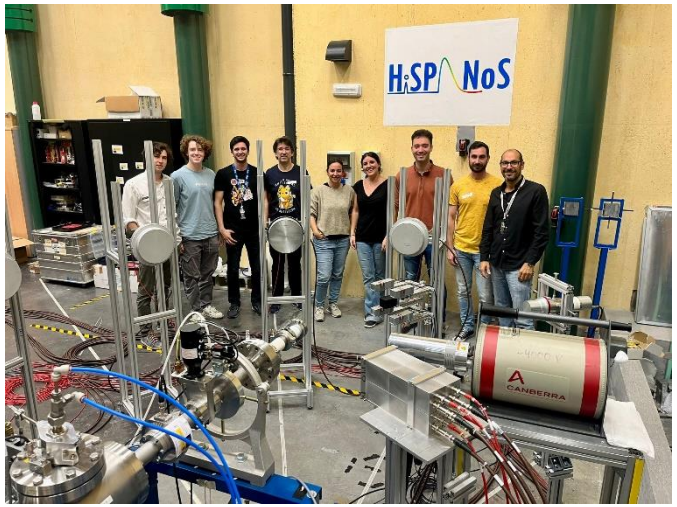
  X(p/d, n)->E_n~0-20 MeV

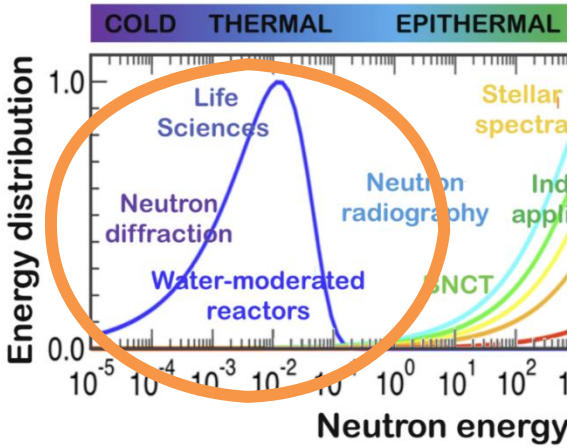
- **Thermal neutrons: E_n~25 meV**

Currently

Near Future

Beam currents up to 10s of μA





Thermal Neutrons in HiSPANoS

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  - Applications and Motivation
  - HiSPANoS: current setup
- **Design of the moderating system**
  - Simulation validation
  - Optimization: Dimension and beam energy
- Thermal beam and field performance

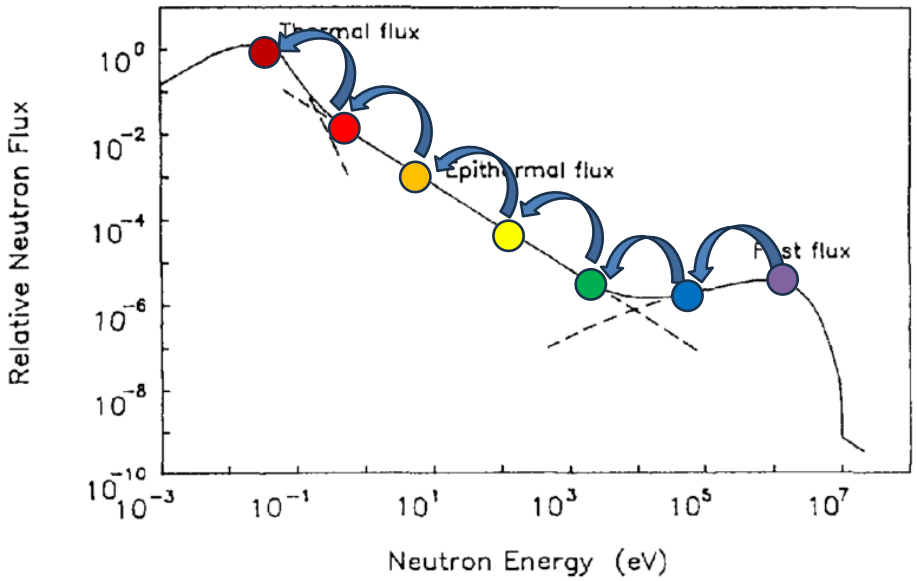
Design of the moderating system: What is moderation?

Neutrons are neutral particles: **Only nuclear forces**

- -Very penetrating
- -Very hard to slow down

Scattering with the medium

Neutrons transfer energy to other nuclei via elastic or inelastic interactions



Limit:

Thermal equilibrium

Neutron capture

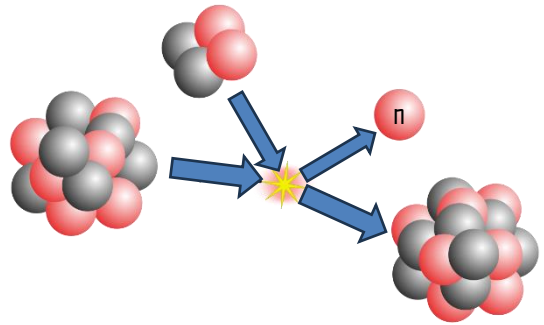
Our biggest enemy!!

Design of the moderating system: Simulation Validation

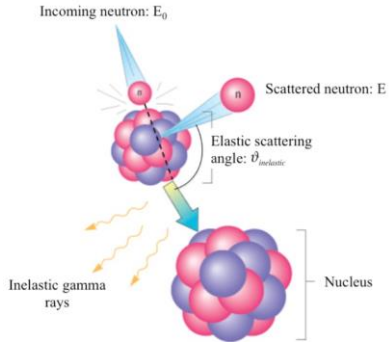
Geant4 Neutron Simulation

- Neutron production **X(*,n)**
  G4TENDL1.4 library
- Neutron transport/moderation **X(n,n)**
  JEFF-3.3 library

Neutron Production [$\sigma_{*,n}$]



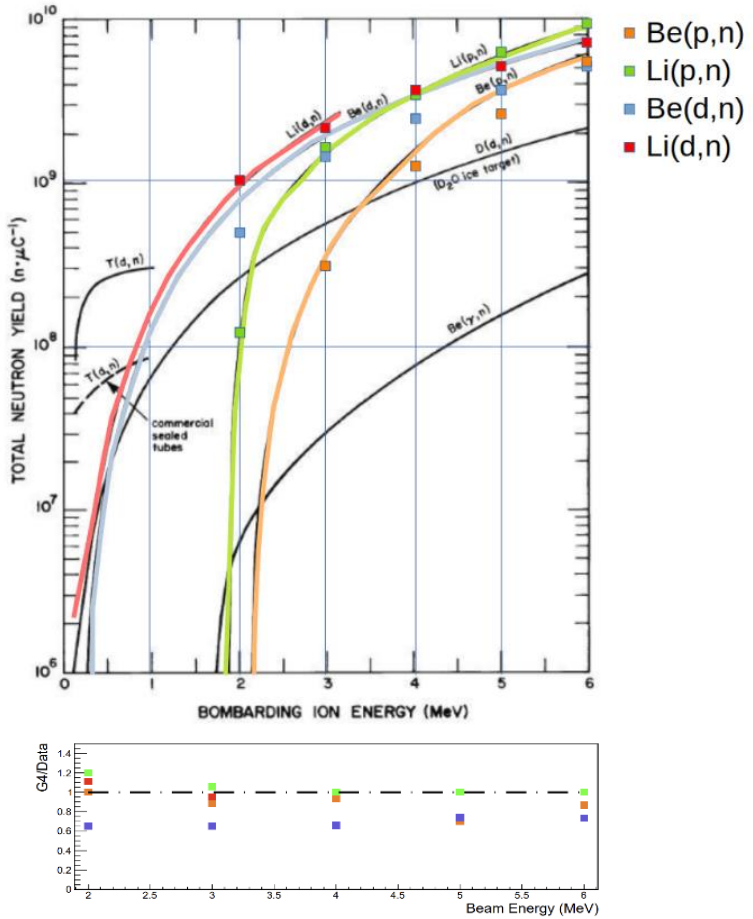
Neutron scattering [$\sigma_{n,n}$]



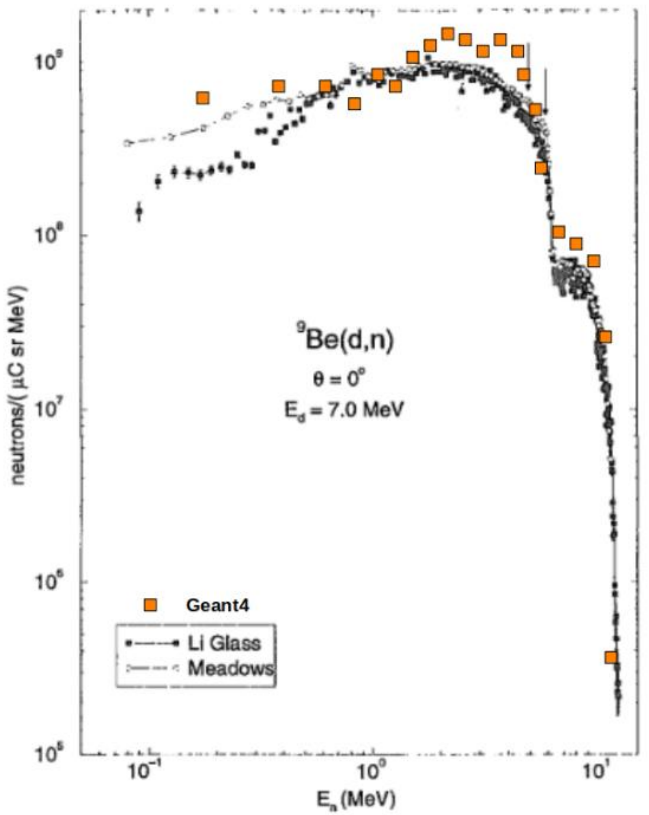
Design of the moderating system: Simulation Validation

Geant4 (G4TENDL1.4) vs Experiments

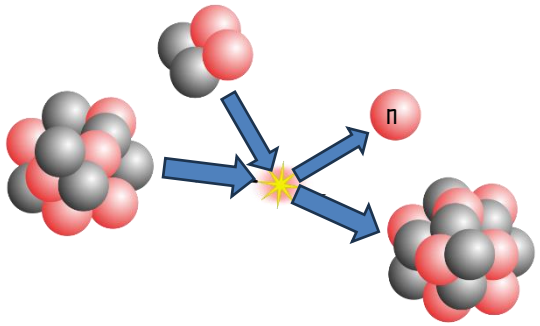
Thick Target Yield



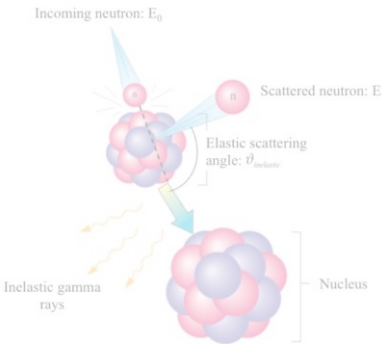
Neutron energy spectrum (Be(d,n) 7 MeV)



Neutron Production [$\sigma_{x,n}$]

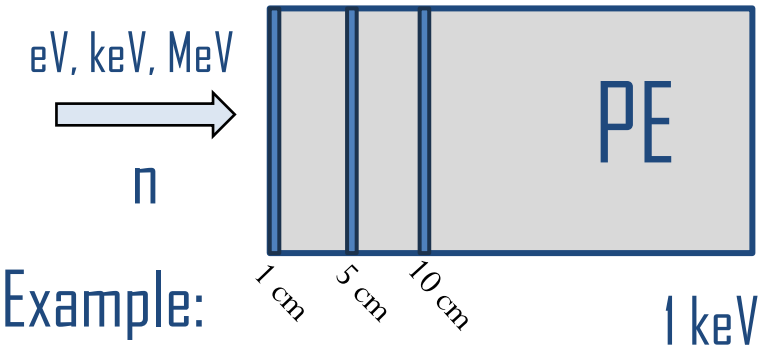


Neutron scattering [$\sigma_{n,n}$]



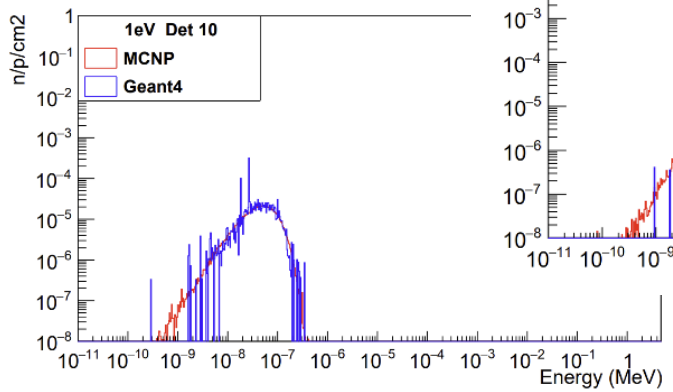
Design of the moderating system: Simulation Validation

Geant4 (JEFF-3.3) vs MCNP (E. Mendoza, CIEMAT)

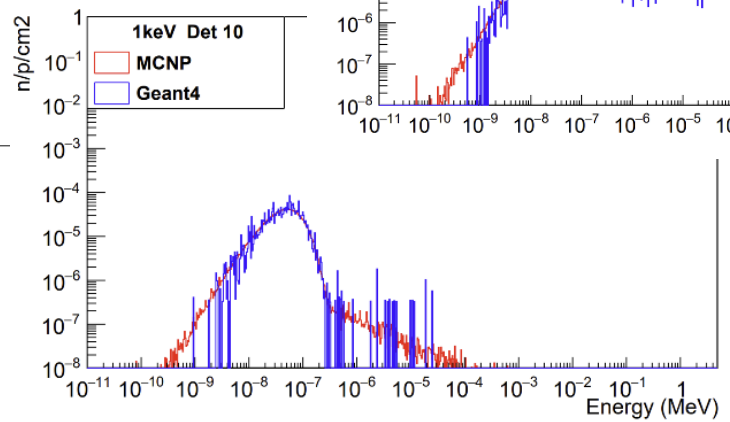


Example:
10cm

1 eV



1 keV



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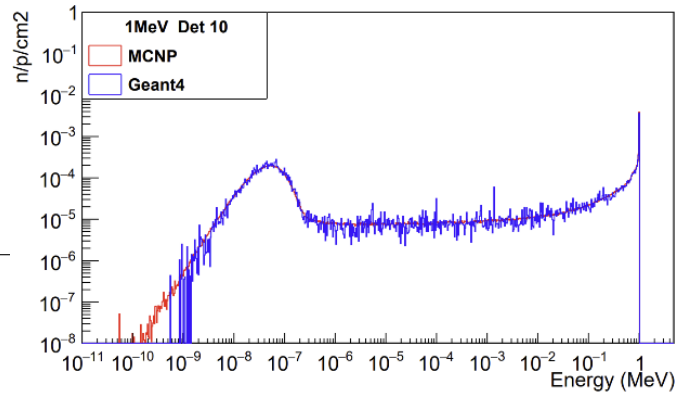
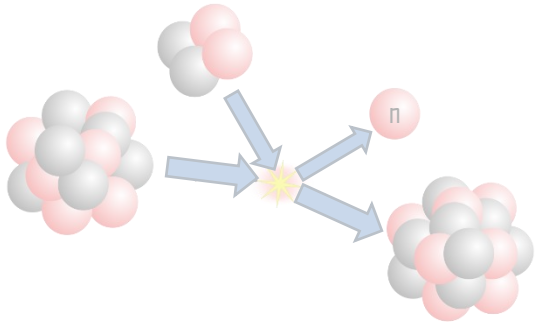


Neutron Production [$\sigma_{*,n}$]



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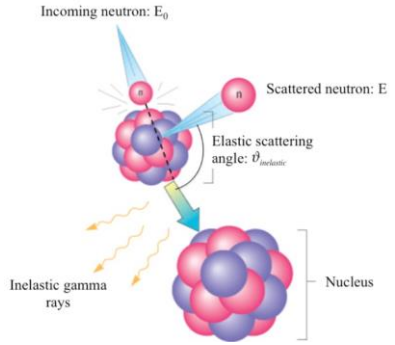
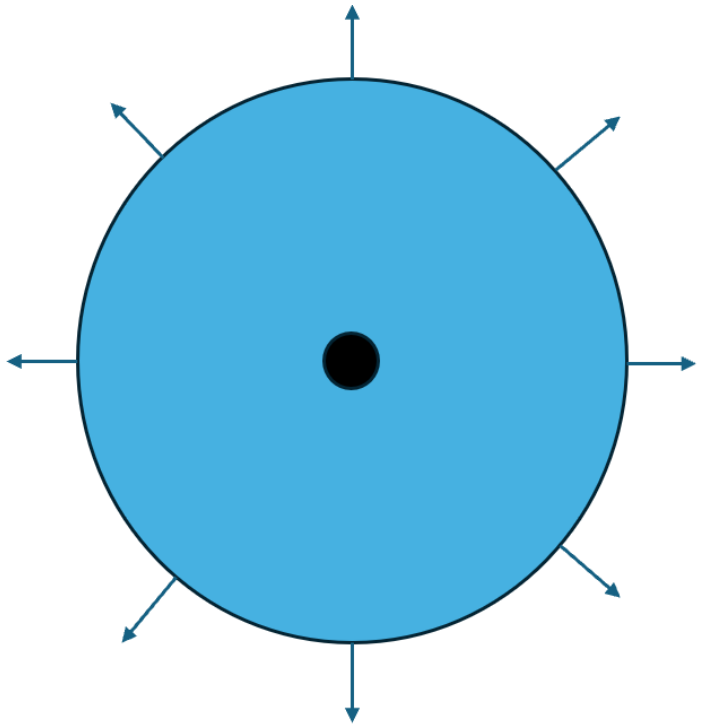


Design of the moderating system: Optimization

Moderating material: How well does each material slow down neutrons?

- **Graphite (C)**
- **Heavy Water (D_2O)**
- **Polyethylene $(CH_2)_n$**



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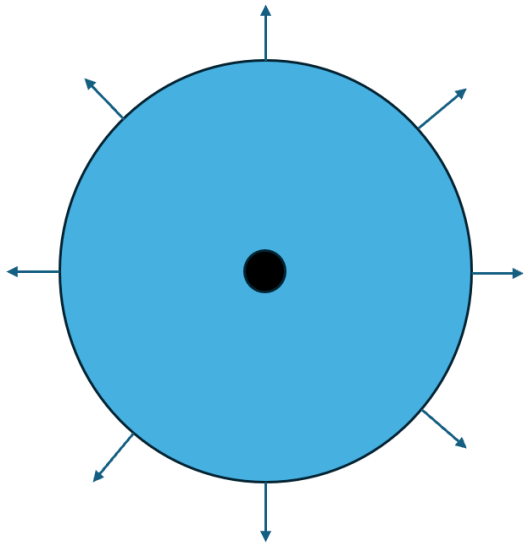
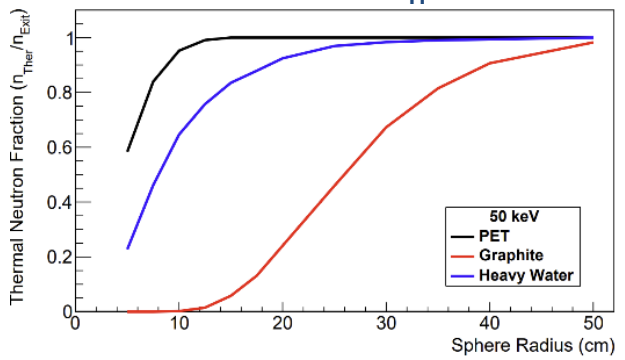
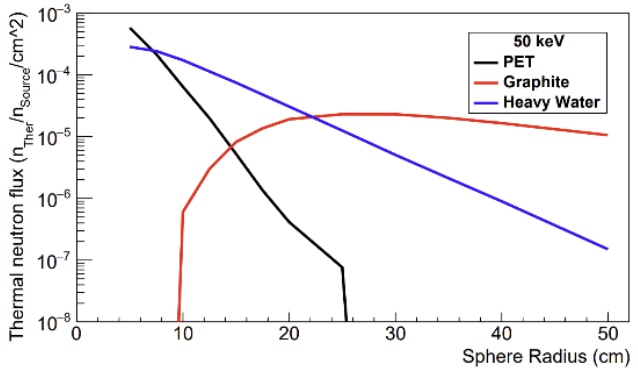


Thermal Fraction (E_n <0.5 eV)

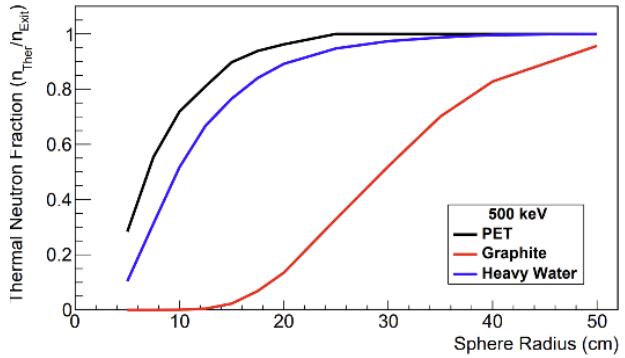
Thermal Neutron Flux

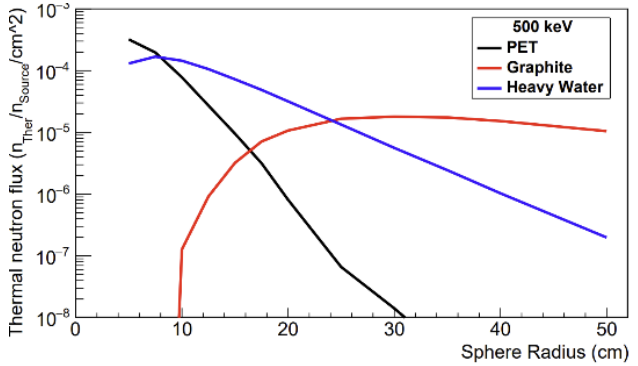
50 keV



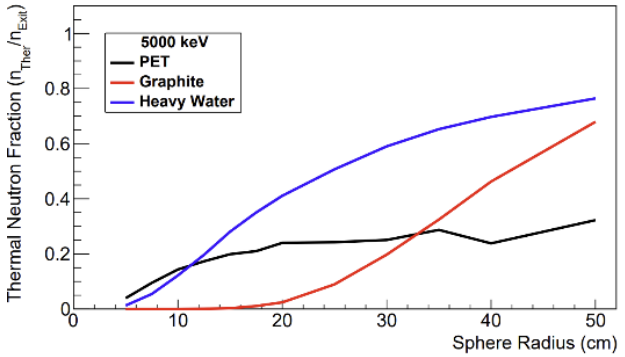


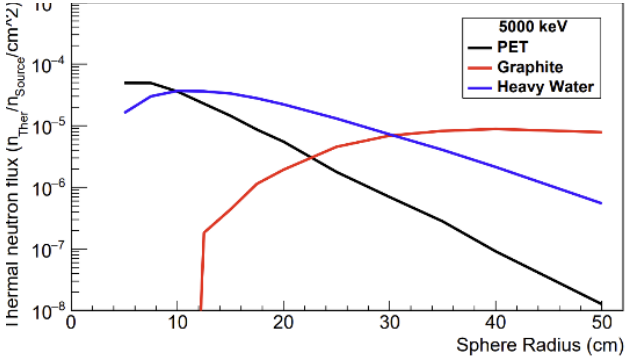
500 keV





5 MeV





Design of the moderating system: Optimization

Moderating material:

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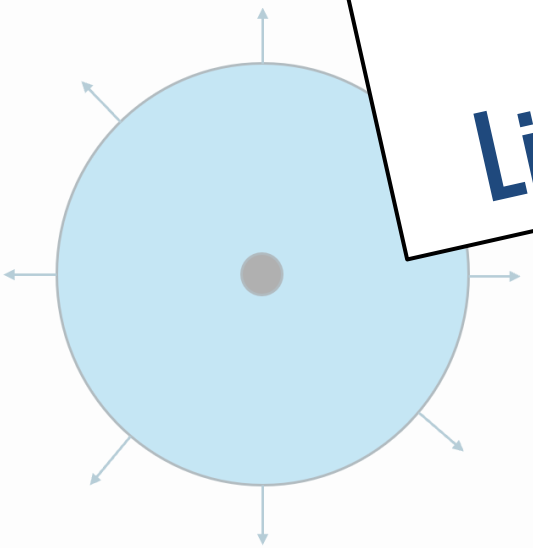
- Polyethylene (CH_2)



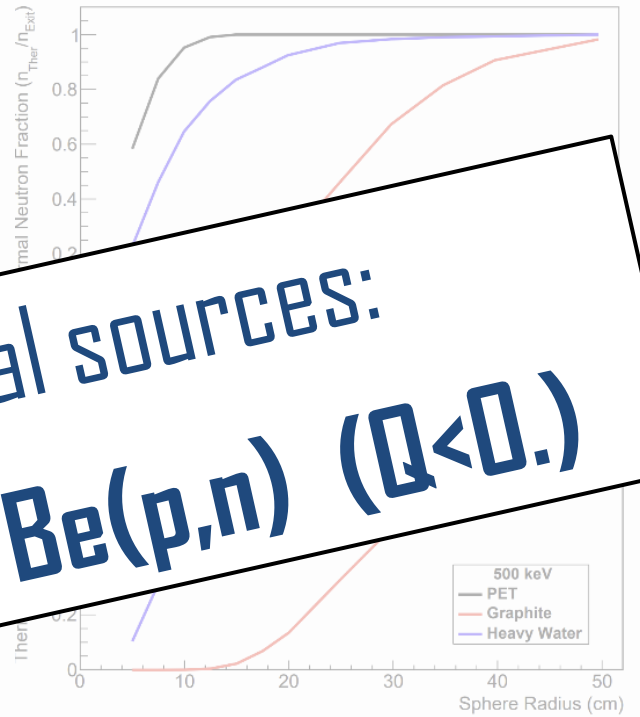
Potential sources:

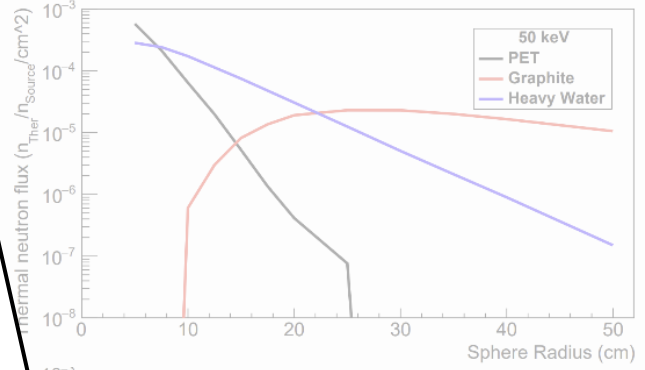
Li(p,n) and Be(p,n) (Q<0.)

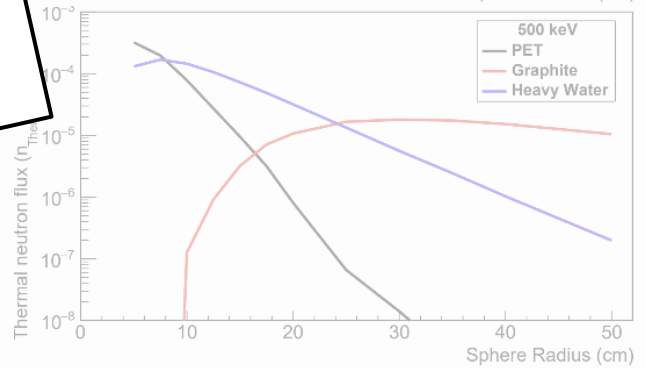
Thermal Fraction (E_n <0.5 eV)

Neutron Flux

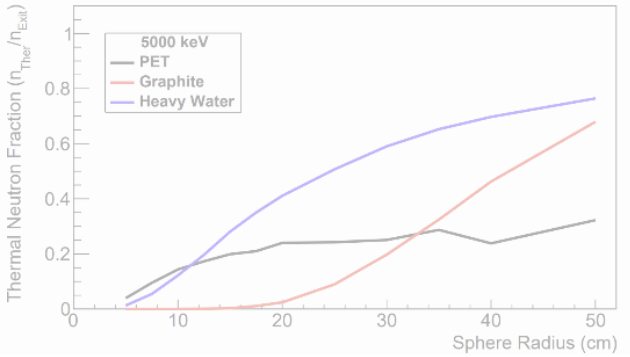
50 keV

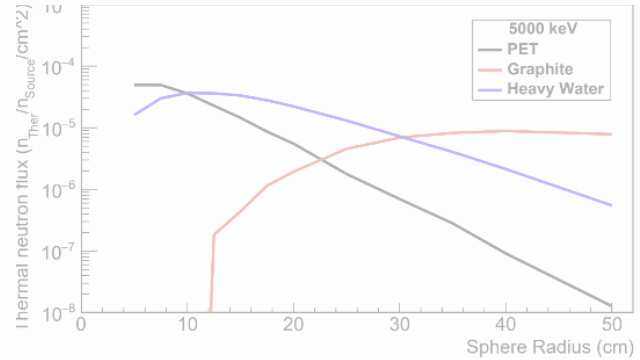






5 MeV





Design of the moderating system: Optimization

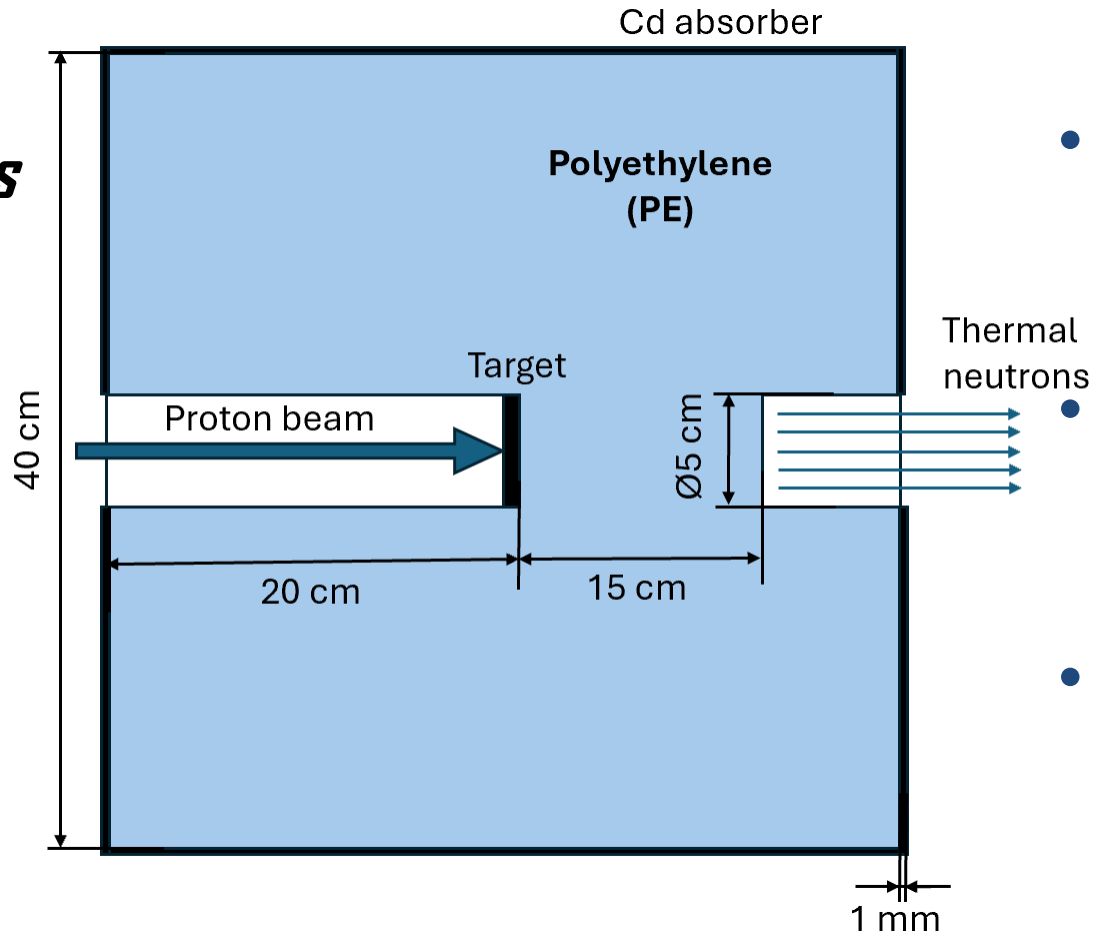
Proposed geometry: Thermal BEAM

Different Geometries

Reflectors

Source placing

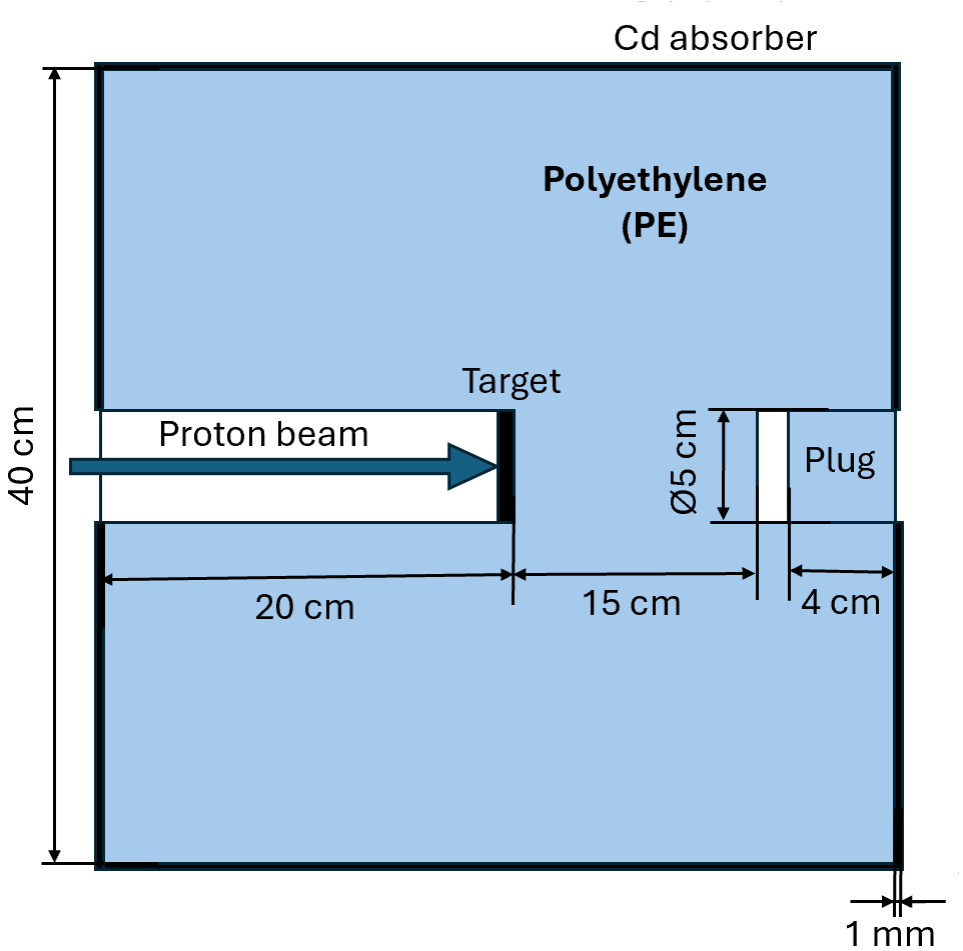
Collimators



- **Cubic design:**
  Easy to implement.
- **Collimator:**
  Cylindrical opening for beam focus.
- **Line opening:**
  Needed for centering the neutron source.
- **Cadmium lining:**
  Reduce emissions in undesired directions.

Design of the moderating system: Optimization

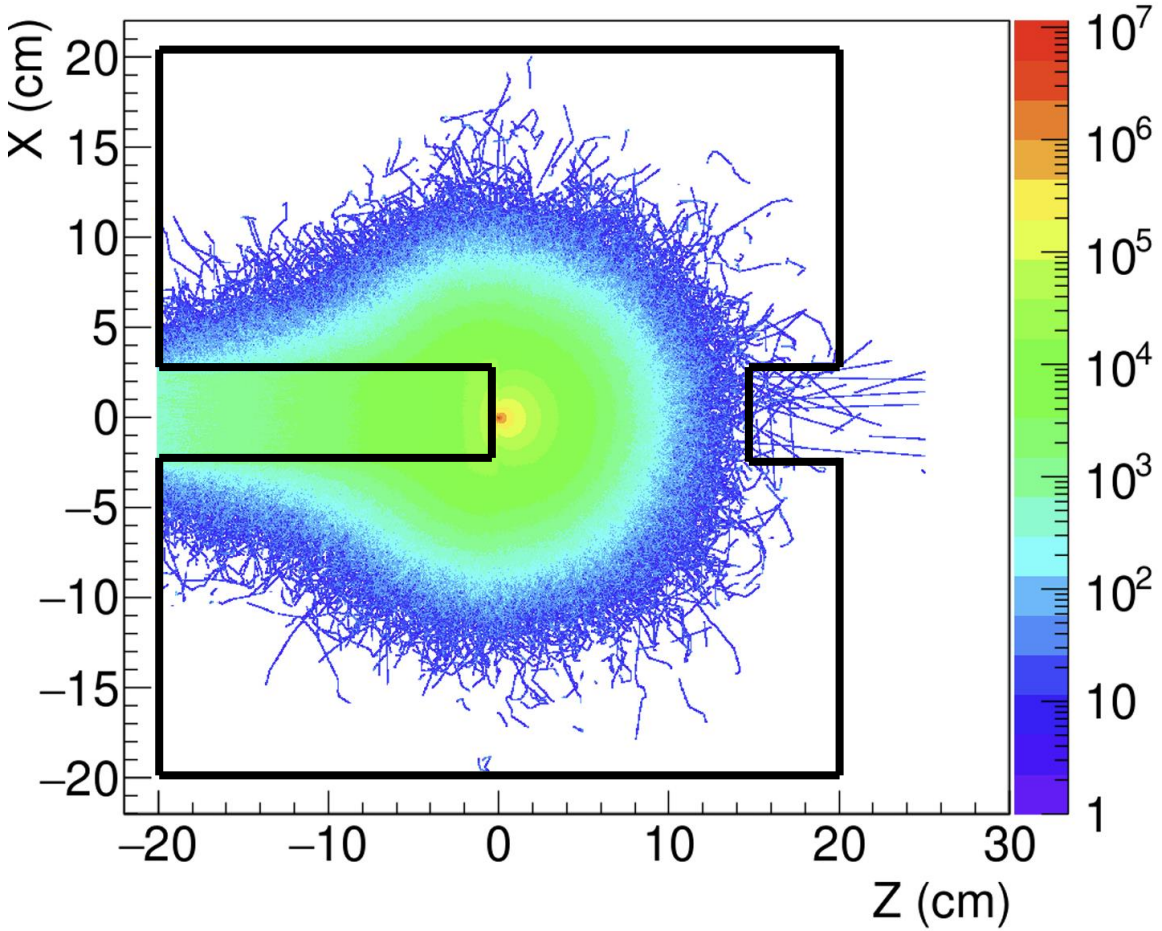
Proposed geometry: Thermal FIELD



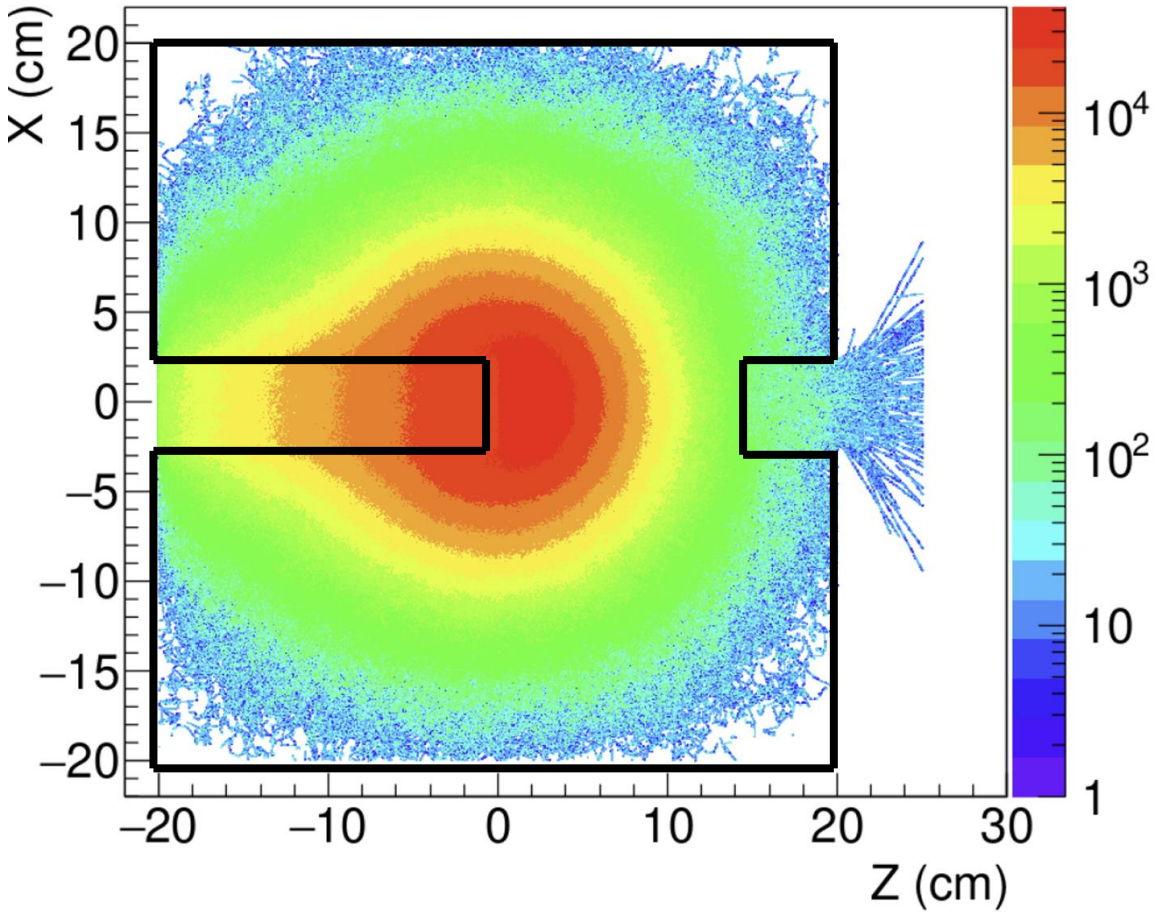
- Higher neutron flux
- Higher thermal fraction
- Smaller irradiation chamber

Design of the moderating system: Optimization

Fast neutrons



Thermal neutrons



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- ***Thermal beam and field performance***

Thermal beam and field characterization

Neutron BEAM characteristics:

At ~90% thermal:

- $^{7}Li(p,n)^{7}Be$ ($T_{1/2}$=52 d): **~10^4 n/cm^2/μC**

Fixed geometry:
Thermal fraction & Flux
regulated by **Proton Beam Energy**

	E_{beam} (keV)	Thermal fraction	Neutron Flux 0 cm (n/cm^2/μC)	Neutron Flux 10 cm (n/cm^2/μC)
Li(p,n)	2000	0.994±0.001	(1.87±0.03)·10^3	(1.63±0.05)·10^2
Li(p,n)	2350	0.917±0.004	(1.44±0.02)·10^4	(1.24±0.03)·10^3
Li(p,n)	3000	0.608±0.004	(5.14±0.06)·10^5	(4.35±0.09)·10^3

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At ~90% thermal:

- $^{7}Li(p,n)^{7}Be$ ($T_{1/2}$=52 d): **~10^4 n/cm^2/μC**
- $^{9}Be(p,n)^{9}B$ ($T_{1/2}$~0): : **~10^2 n/cm^2/μC**

Fixed geometry:
Thermal fraction & Flux
regulated by **Proton Beam Energy**

	E_{beam} (keV)	Thermal fraction	Neutron Flux 0 cm (n/cm^2/μC)	Neutron Flux 10 cm (n/cm^2/μC)
Li(p,n)	2000	0.994±0.001	(1.87±0.03)·10^3	(1.63±0.05)·10^2
Li(p,n)	2350	0.917±0.004	(1.44±0.02)·10^4	(1.24±0.03)·10^3
Li(p,n)	3000	0.608±0.004	(5.14±0.06)·10^5	(4.35±0.09)·10^3
Be(p,n)	2250	0.932 ± 0.0047	(6.4±0.1)·10^1	(5.7±0.2)·10^0
Be(p,n)	2500	0.869 ± 0.005	(5.7±0.1)·10^2	(4.9±0.1)·10^1
Be(p,n)	4000	0.362 ± 0.003	(2.27±0.03)·10^4	(1.95±0.04)·10^3

Thermal beam and field characterization

Neutron FIELD characteristics:

At ~90% thermal:

- $^{7}Li(p,n)^{7}Be$ ($T_{1/2}$=52 d): **~5·10^{5} n/cm^{2}/μC**
- $^{9}Be(p,n)^{9}B$ ($T_{1/2}$~0): : **~10^{5} n/cm^{2}/μC**

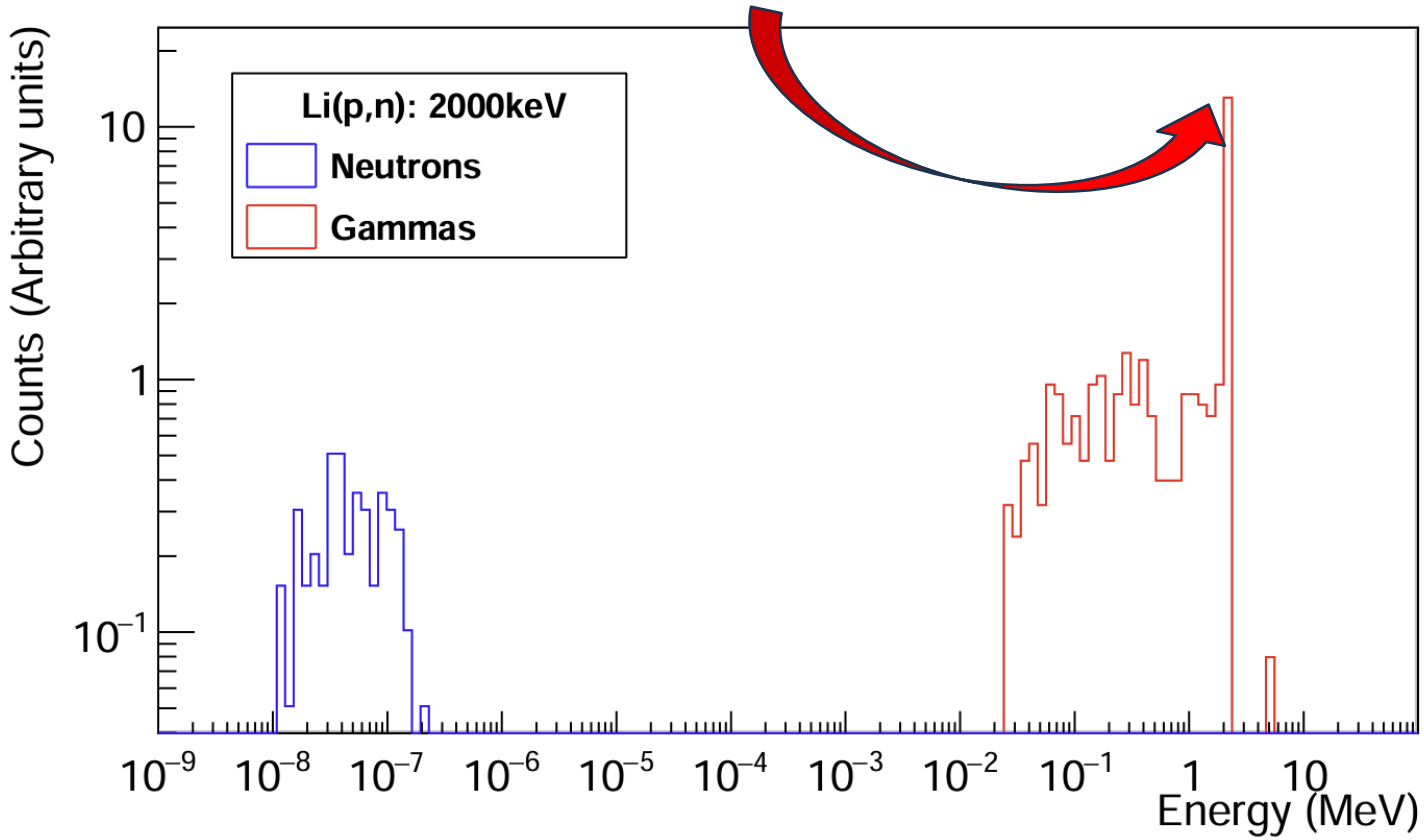
Fixed geometry:
Thermal fraction & Flux
regulated by **Proton Beam Energy**

	E_{beam} (keV)	Thermal fraction	Φ (n/cm^2/μC)
Li(p,n)	2000	0.997±0.001	(2.52±0.07)·10^4
Li(p,n)	2350	0.971±0.004	(1.54±0.04)·10^5
Li(p,n)	3000	0.909±0.008	(6.14±0.03)·10^5
Be(p,n)	2250	0.983 ± 0.004	(7.02±0.02)·10^2
Be(p,n)	2500	0.968 ± 0.005	(6.44±0.02)·10^3
Be(p,n)	4000	0.852 ± 0.007	(2.92±0.01)·10^5

Thermal beam and field characterization

γ-ray component:

$^{1}H + n \rightarrow {}^{2}H + \gamma$ (2.2 MeV) Neutron capture in the PE

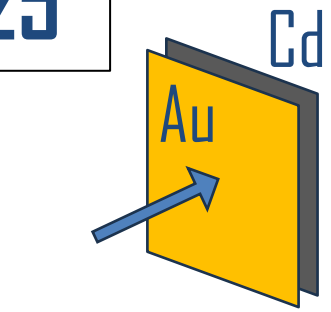


~20x more γ-rays than neutrons

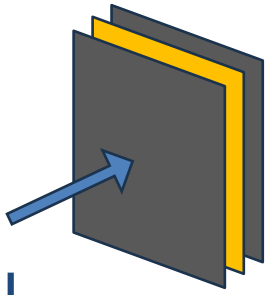
Thermal beam and field characterization

Comissioning and future steps: **Winter 2025**

- Build and install the moderator
- Caracterization of total neutron flux:
  - **Au** activation
- Non thermal neutron component:
  - **Au** activation shielded with **Cd**
- Characterize Gamma radiation emmited



$^{197}Au(n,\gamma)^{198}Au$ (3d)



Cd captures all termal neutrons

The most intense thermal neutron source in Spain will be open to the community

Thank you for your attention!!

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

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