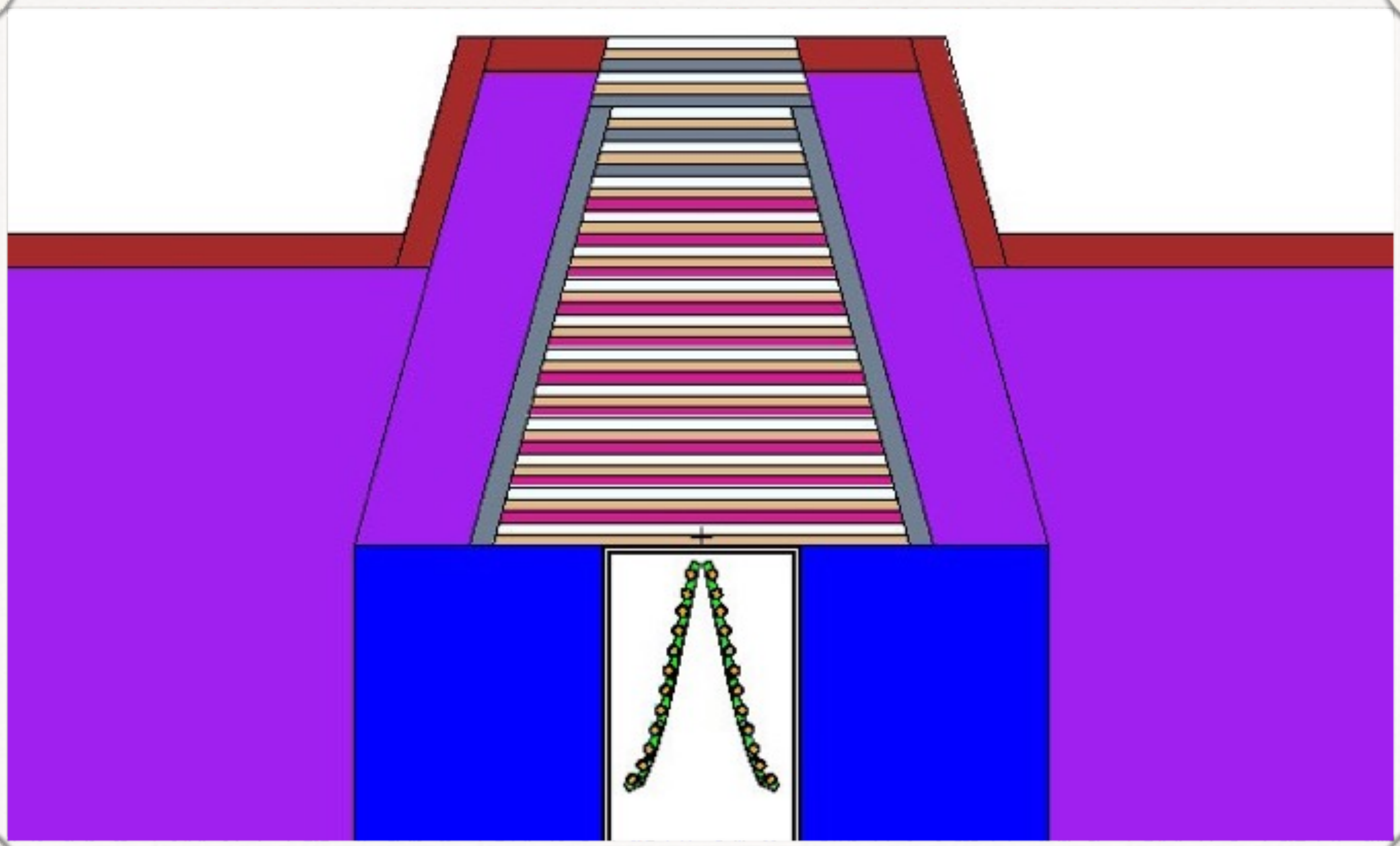


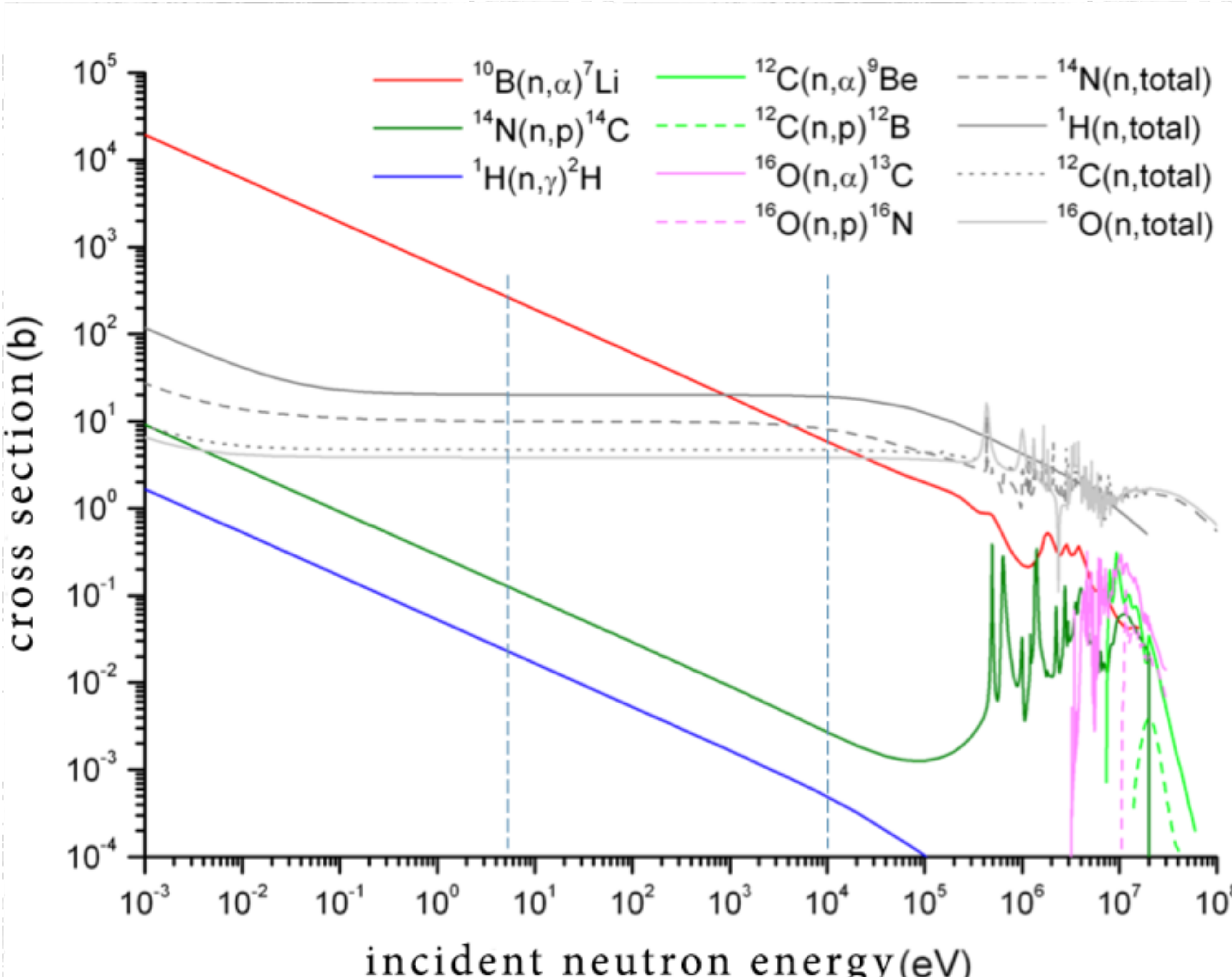
UCANS V - 13 May 2015 - Padova

BNCT neutron beam from accelerator

Ian Postuma
PhD student
university of Pavia
INFN sezione di Pavia & LNL
for the BNCT collaboration

What is BNCT ?

$$
{}^{10}\mathrm{B} + \mathrm{n} \Rightarrow \begin{cases} 1.78 \quad 1.01 & \text{(MeV)} \\ \alpha \;+\; {}^{7}\mathrm{Li} & (6\%) \\ 1.47 \quad 0.84 \quad 0.48 & \text{(MeV)} \\ \alpha \;+\; {}^{7}\mathrm{Li}^{*} + \gamma & (94\%) \end{cases}
$$



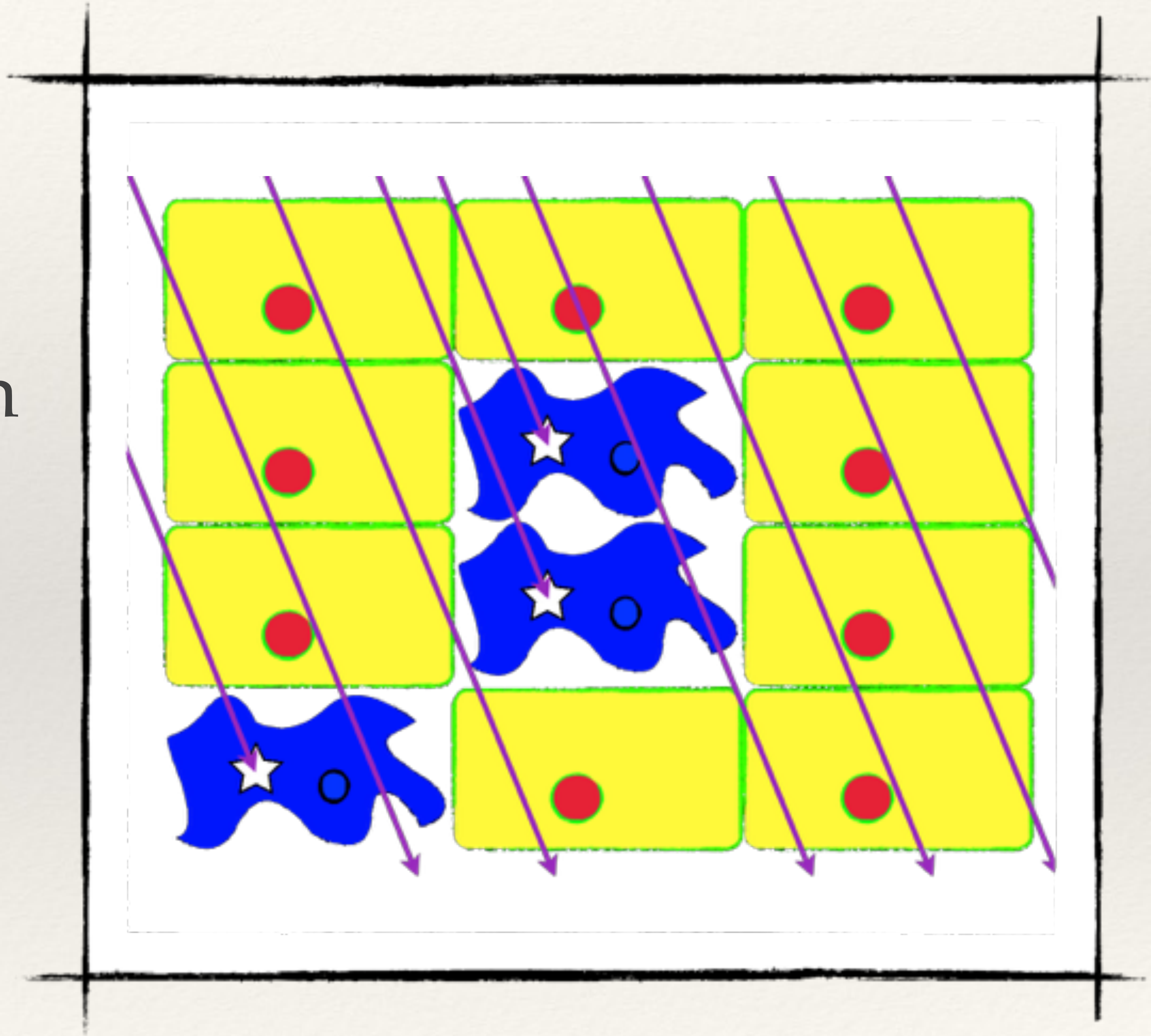
$^{10}B(n,\alpha)^{7}Li$
$^{14}N(n,p)^{14}C$
$^{1}H(n,\gamma)^{2}H$
$^{12}C(n,\alpha)^{9}Be$
$^{12}C(n,p)^{12}B$
$^{16}O(n,\alpha)^{13}C$
$^{16}O(n,p)^{16}N$
$^{14}N(n,total)$
$^{1}H(n,total)$
$^{12}C(n,total)$
$^{16}O(n,total)$
cross section (b)
incident neutron energy (eV)

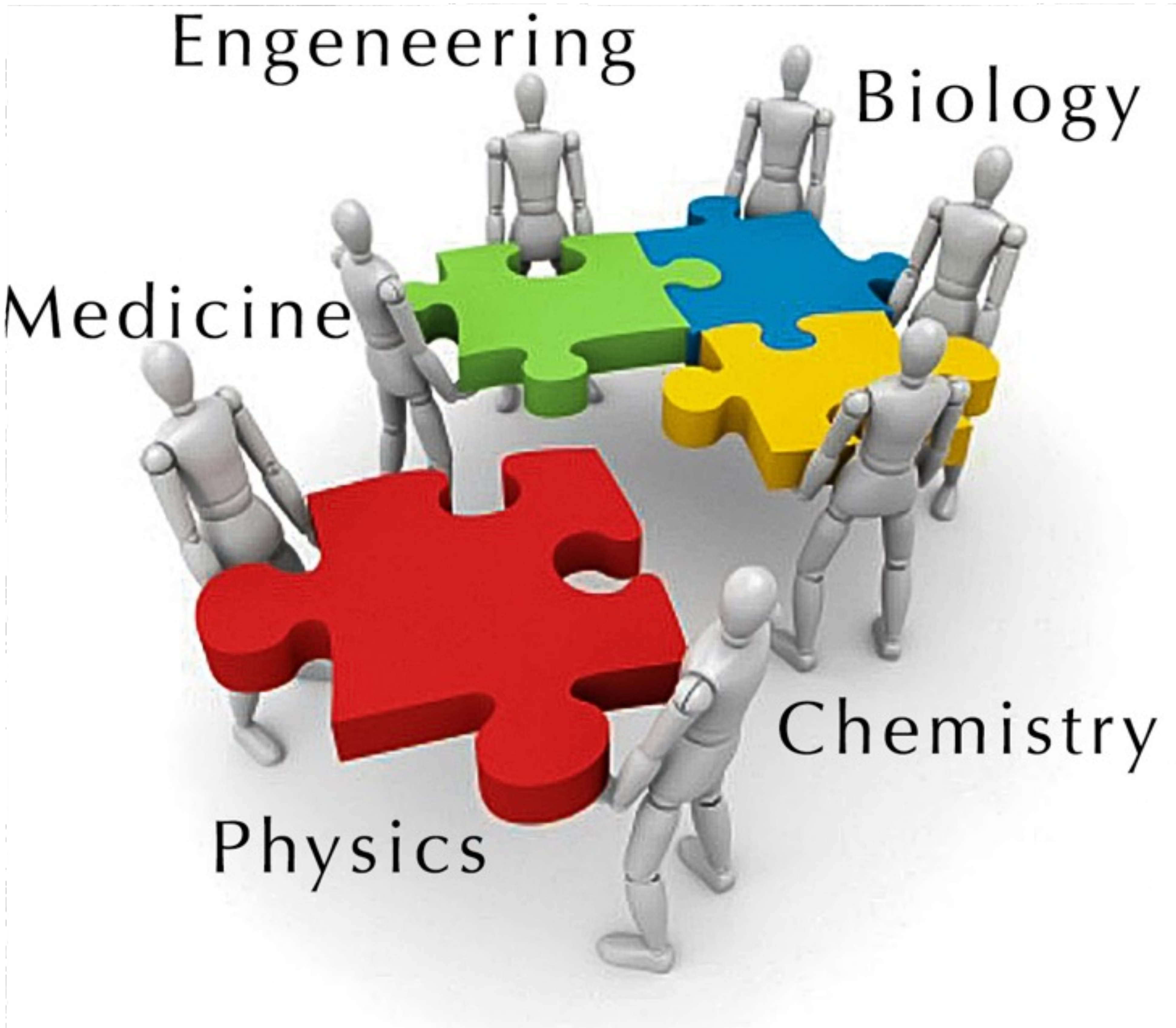
Boron Neutro Capture Therapy

Dose ∝ Boron concentration

$\mathbf{C_T > C_H}$

Tumor Control




Engeneering
Biology
Medicine
Chemistry
Physics

EFFECTIVENESS

^{10}B

concentration & distribution

EFFECTIVENESS

^{10}B

concentration & distribution

EFFECTIVENESS

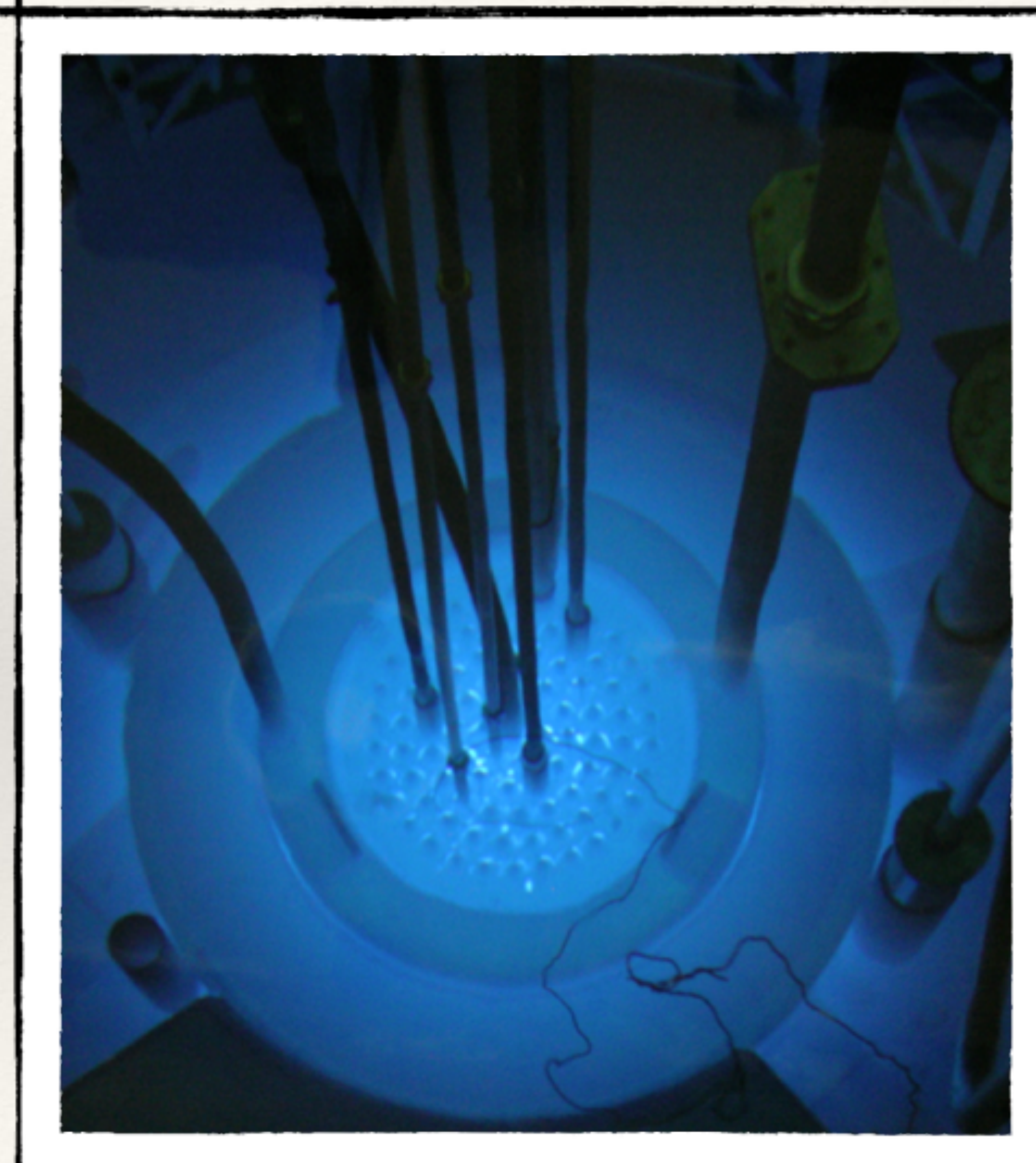
neutron

beam energy & quality

Nuclear Reactors

Thermal and Epithermal beams

10^9 $cm^{-2} \cdot s^{-1}$

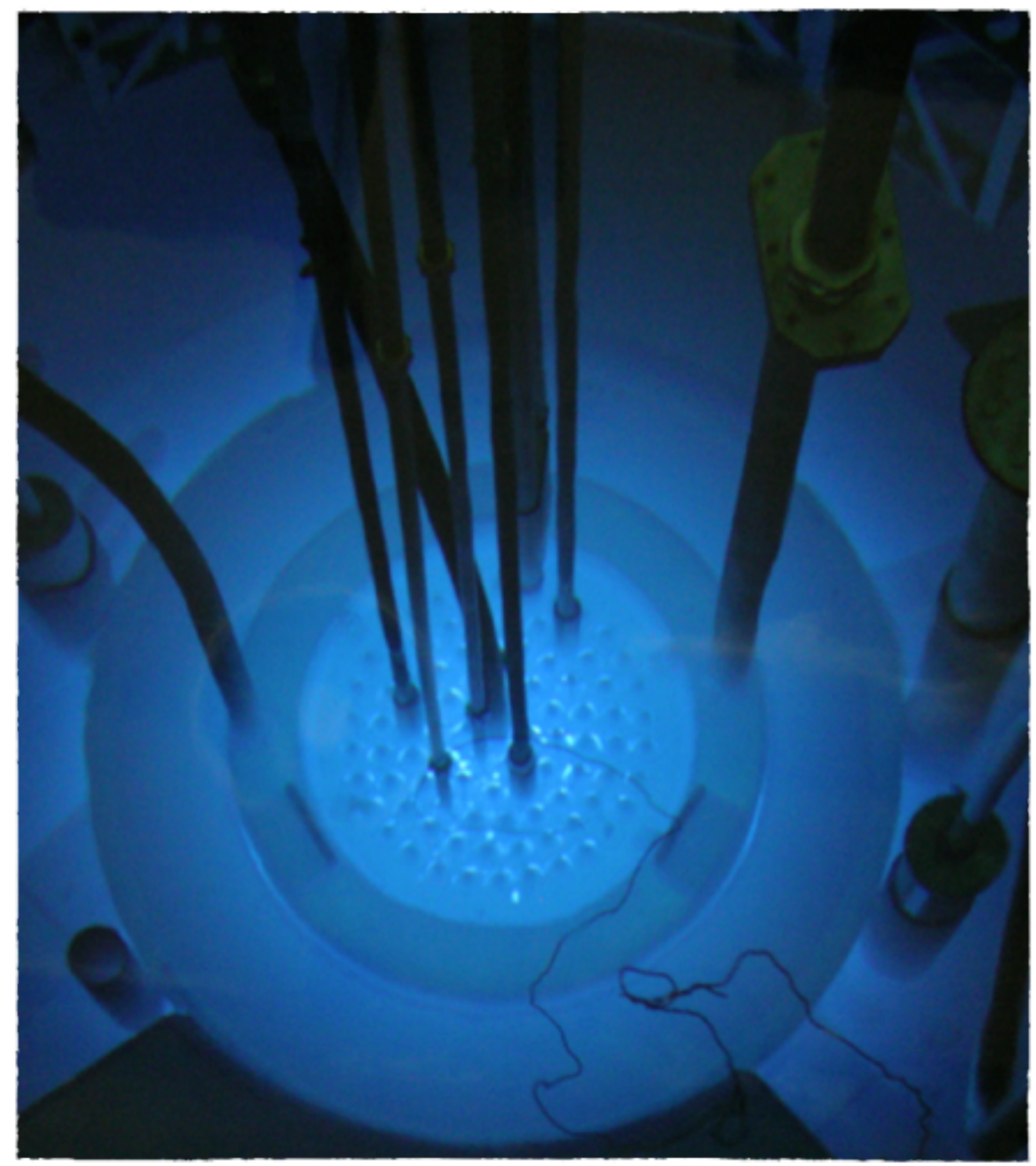


Nuclear Reactors

Thermal and Epithermal beams

10^9 cm^{-2} · s^{-1}

> 1000 patients (Argentina, Finland, Japan, Taiwan, Usa)



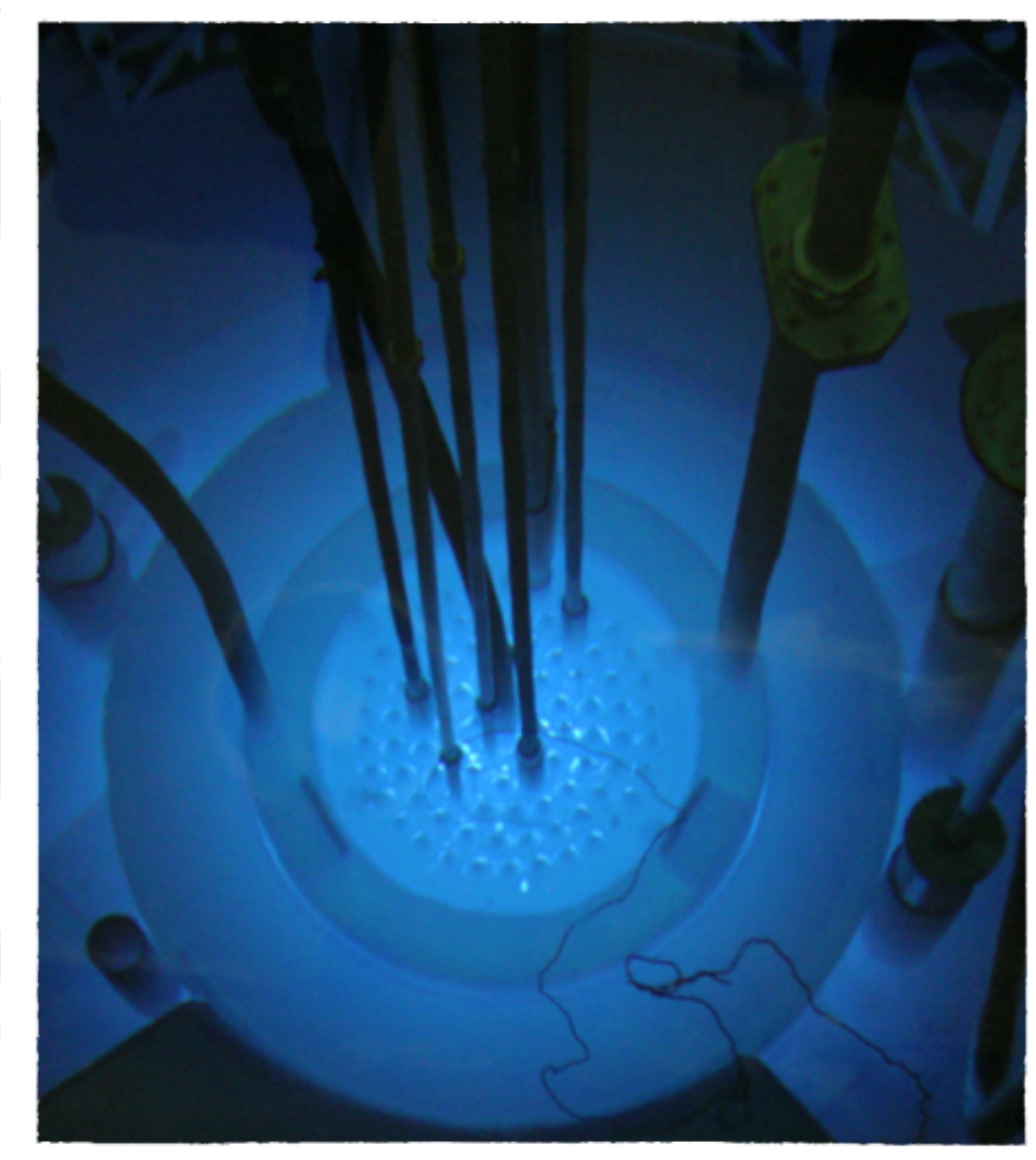
Nuclear Reactors

Thermal and Epithermal beams

10^9 cm^{-2} · s^{-1}

> 1000 patients (Argentina, Finland, Japan, Taiwan, Usa)

Nuclear Reactor
not well accepted

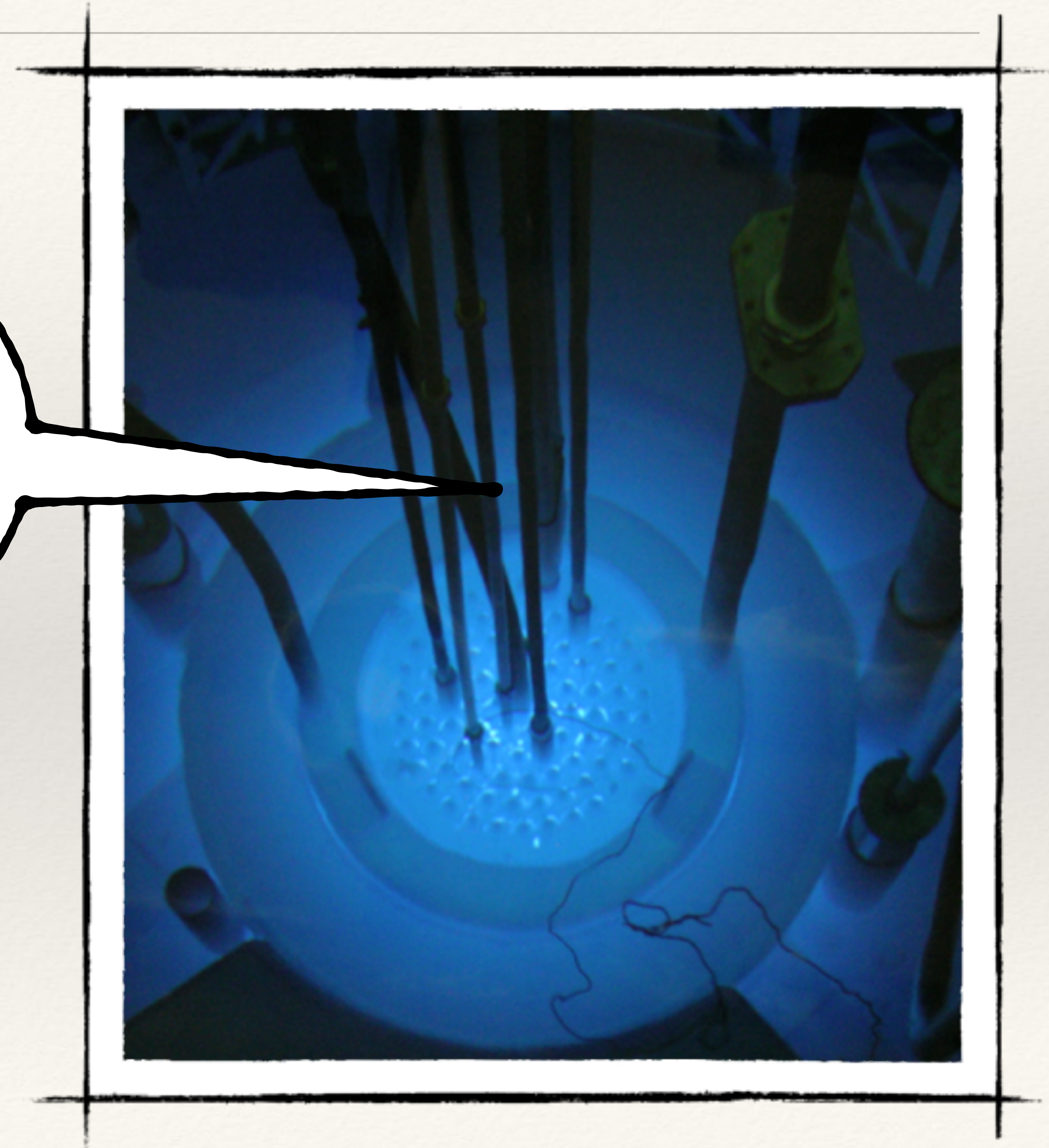


Nuclear Reactors

ITALIAN 2011 REFERENDUM
95%
OF POPULATION AGAINST
NUCLEAR ENERGY

Fi sa)

Nuclear Reactor
not well accepted



Nuclear Reactors

ITALIAN 2011 REFERENDUM
95%
OF POPULATION AGAINST
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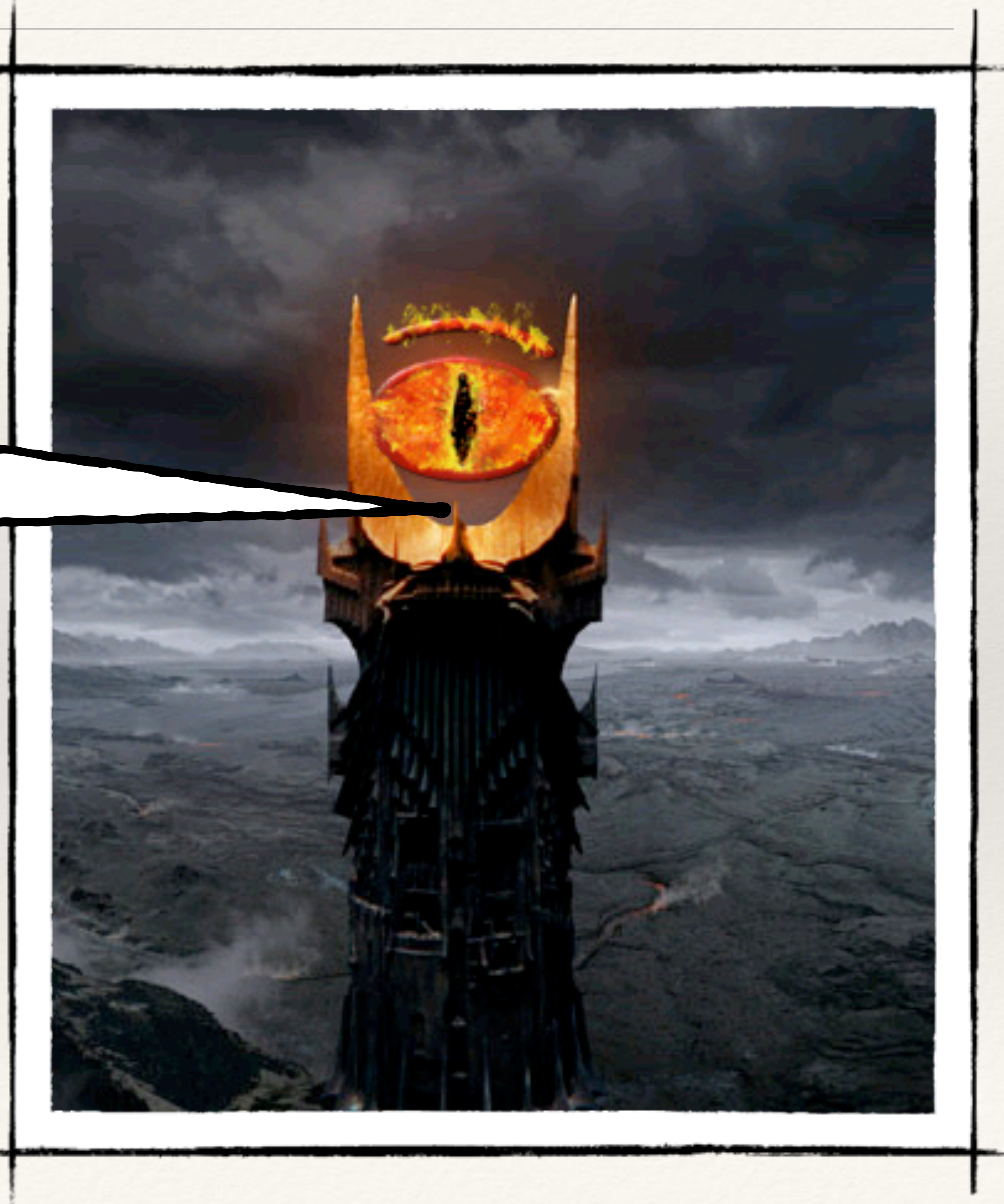
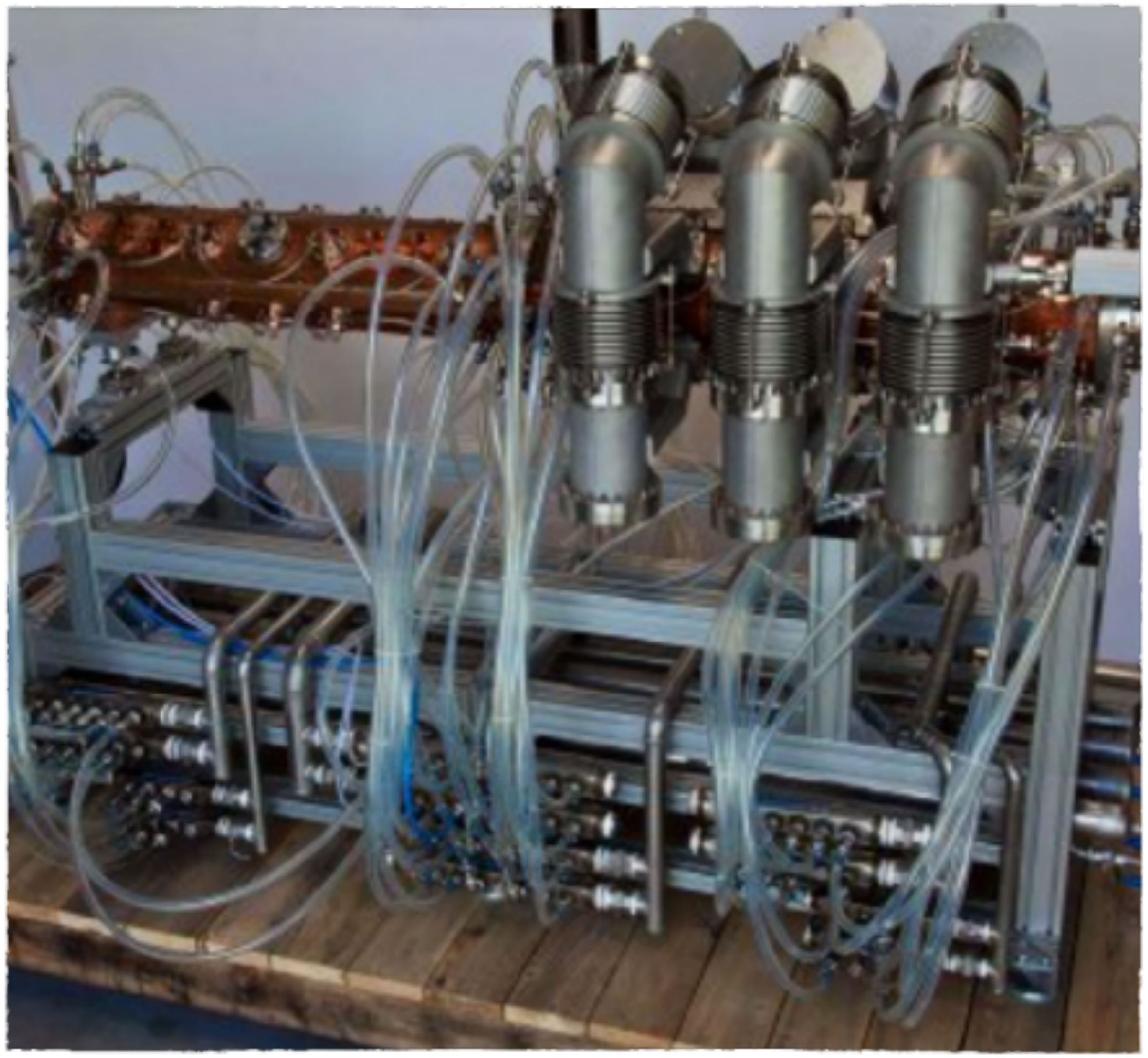
Nuclear Reactor
not well accepted



Accelerator neutron sources

Thermal and Epithermal beams

10^9 cm^{-2} · s^{-1}



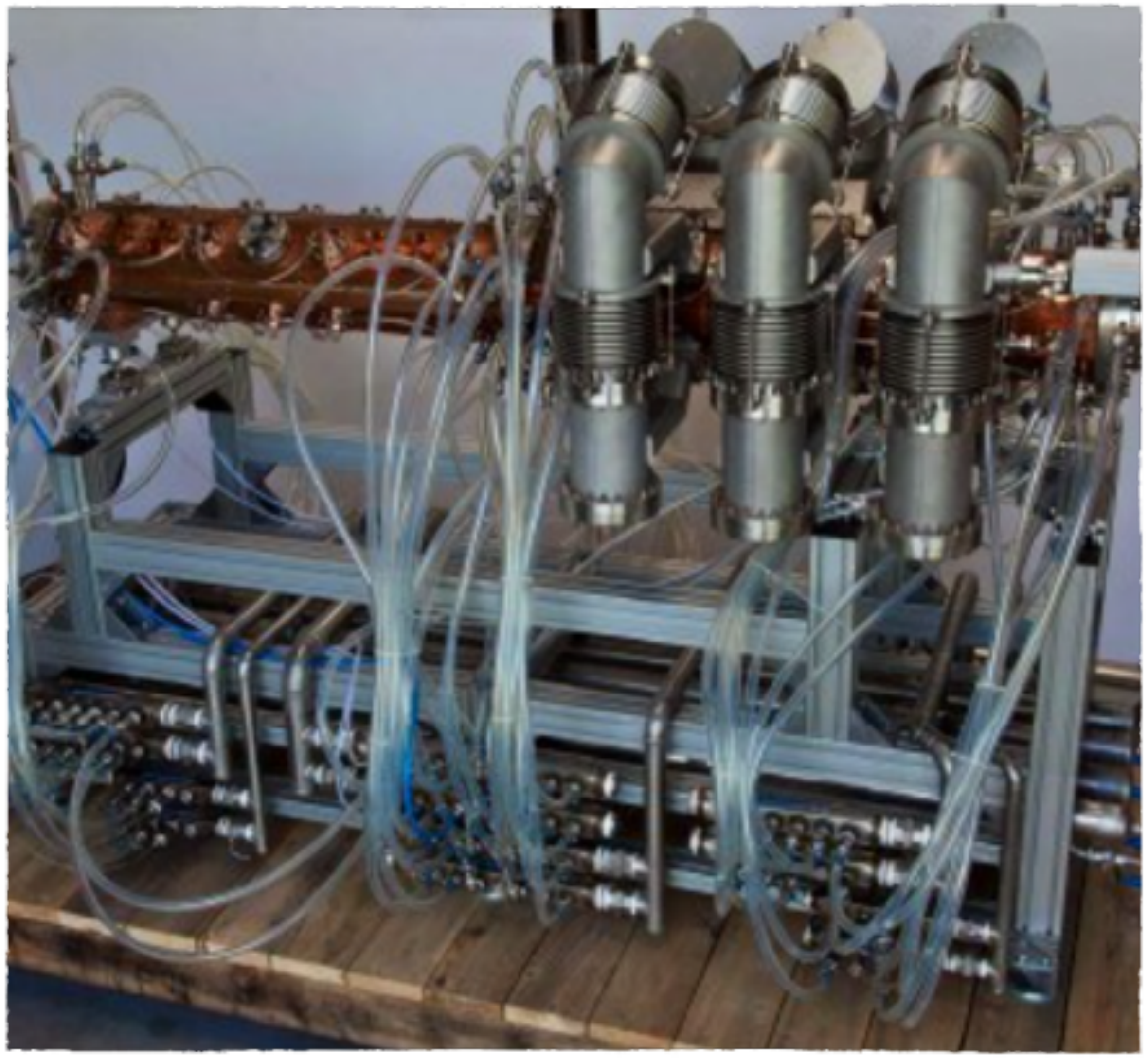
Accelerator neutron sources

Thermal and Epithermal beams

10^9 cm^{-2} · s^{-1}

High **current** proton/deuteron beam **> 1 mA**

possible reactions : $^{7}Li(p,n)^{7}Be$, $^{9}Be(p,n)^{9}B$, $^{9}Be(d,n)^{10}B$ …



Accelerator neutron sources

Thermal and Epithermal beams

10^9 $cm^{-2} \cdot s^{-1}$

High **current** proton/deuteron beam **> 1 mA**

possible reactions : $^7Li(p,n)^7Be$, $^9Be(p,n)^9B$, $^9Be(d,n)^{10}B$ …

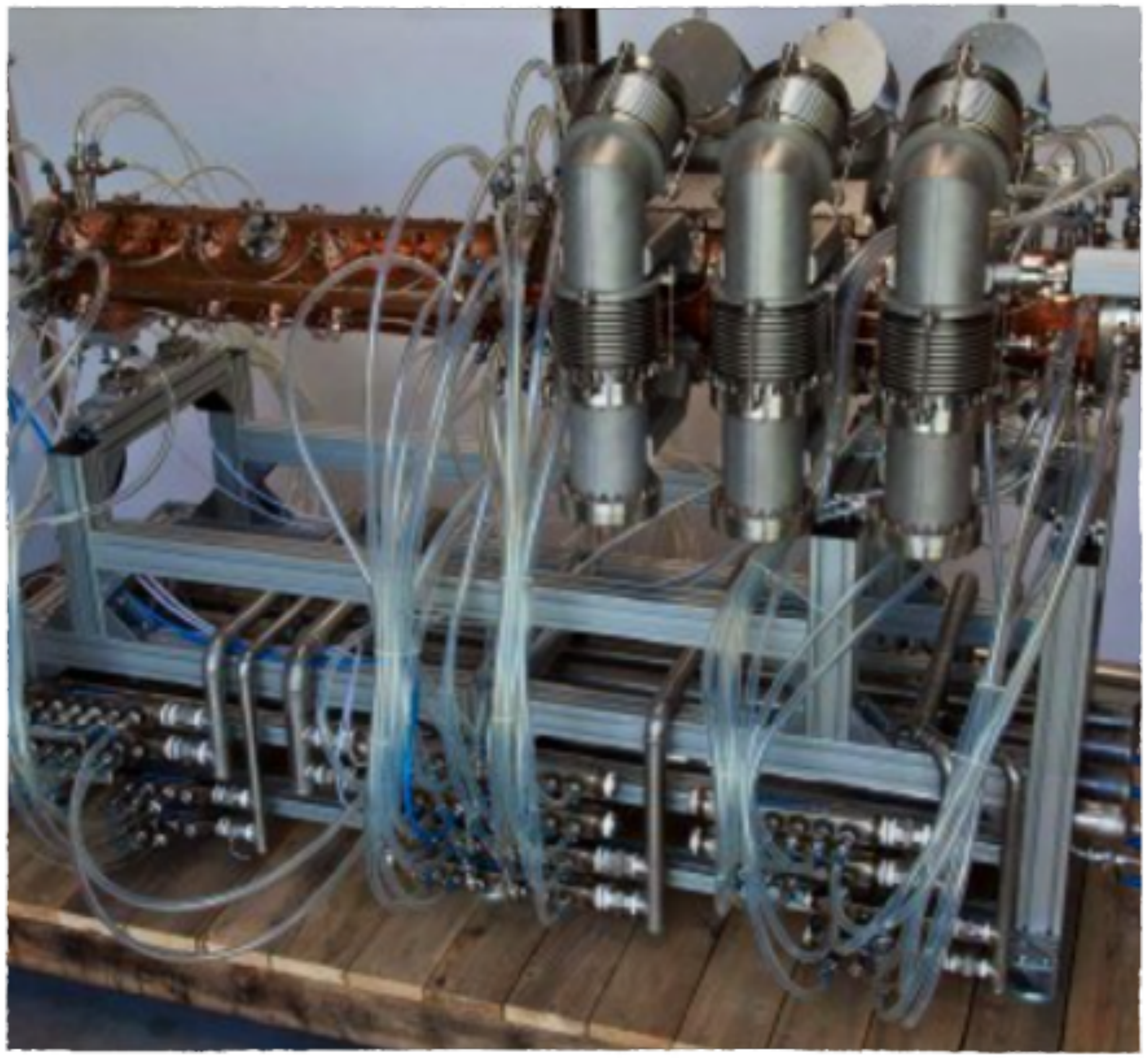
COMPACT

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

MUNES project

5MeV proton beam - RFQ linac

30 mA current



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

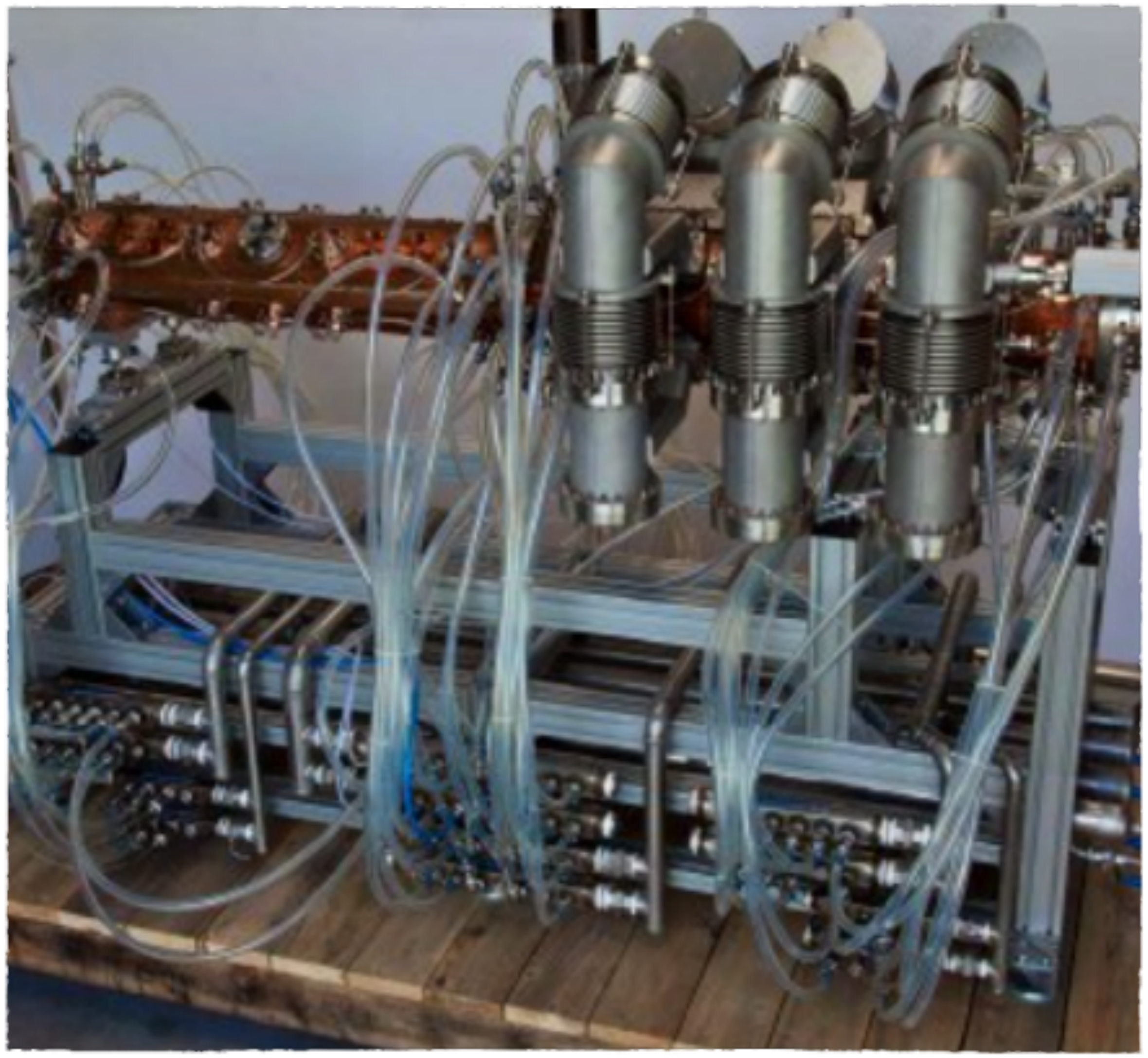
<u>**MUNES project**</u>

5MeV proton beam - RFQ linac

30 **mA** current

^{9}**Be** target

≈ **10^{14} neutrons · s^{-1}**

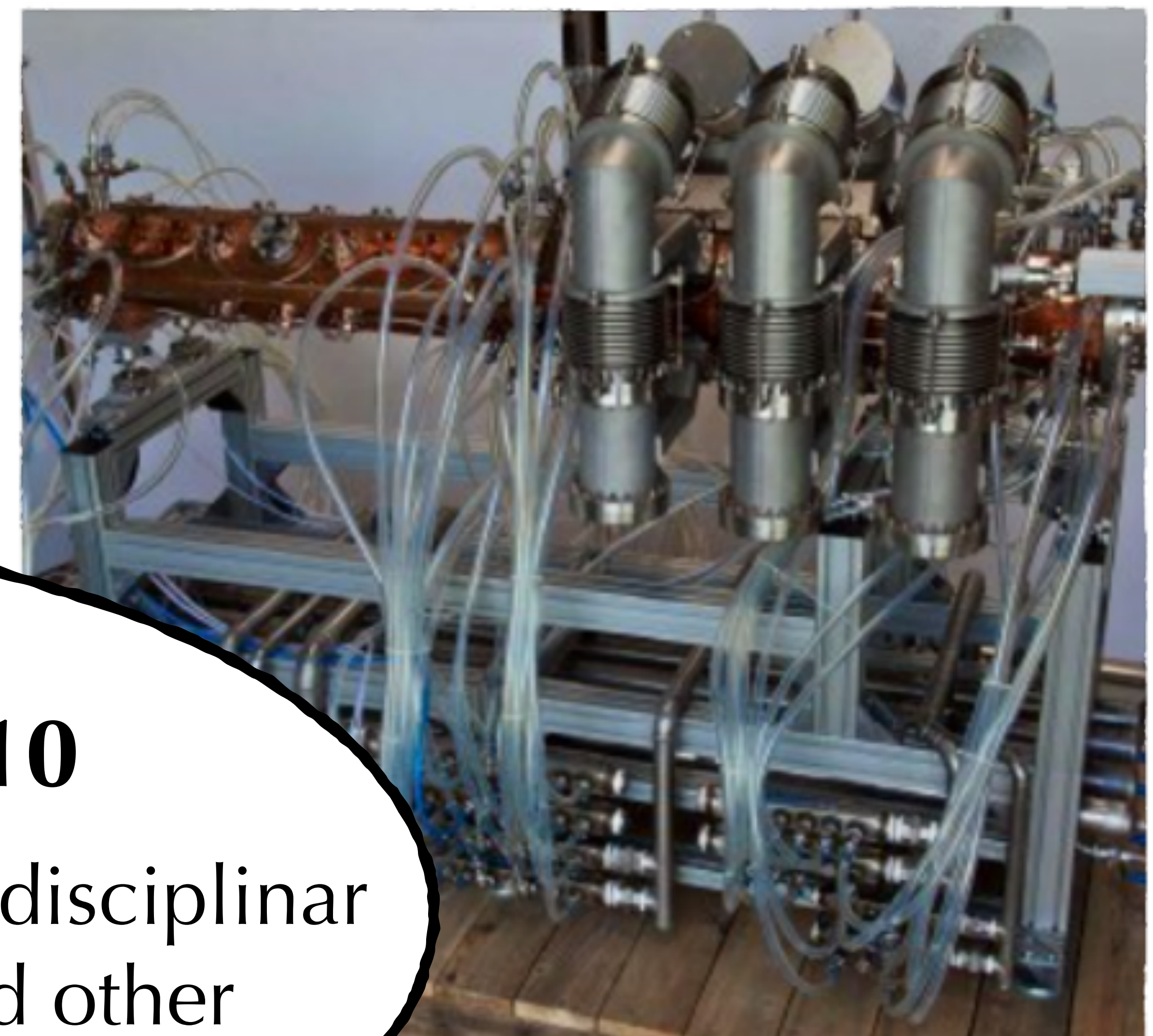


$^{9}Be(p,n)^{9}B$

MUNES project

5MeV proton beam - RFQ linac

30 mA

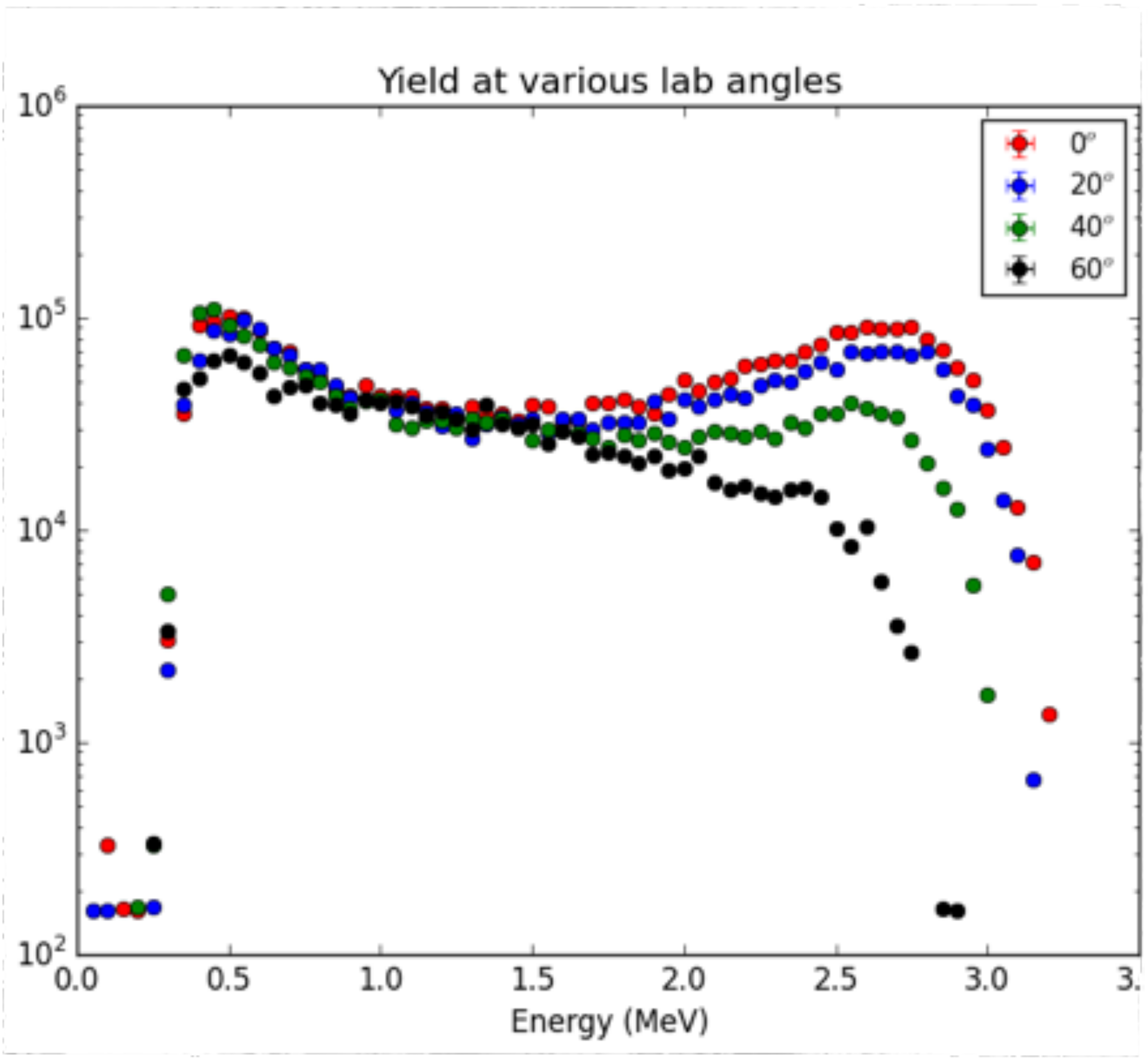


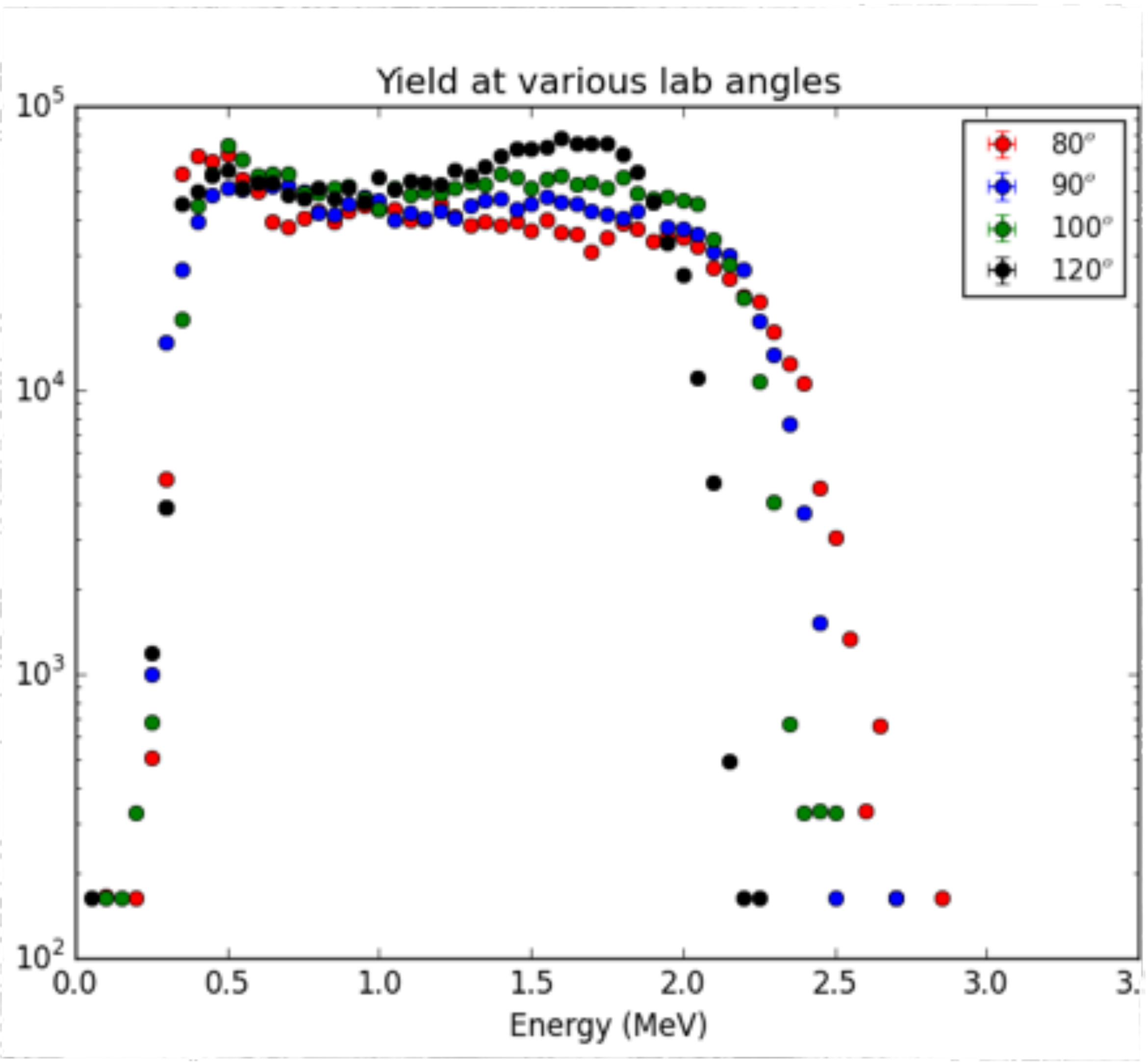
Andrea Pisent

friday 15 may at 11:10

MUNES project: an intense Multidisciplinar Neutron Source for BNCT and other applications based on a high intensity RFQ accelerator

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





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

Beam Shaping Assembly

BNCT

thermal neutrons (meV) for shallow tumors

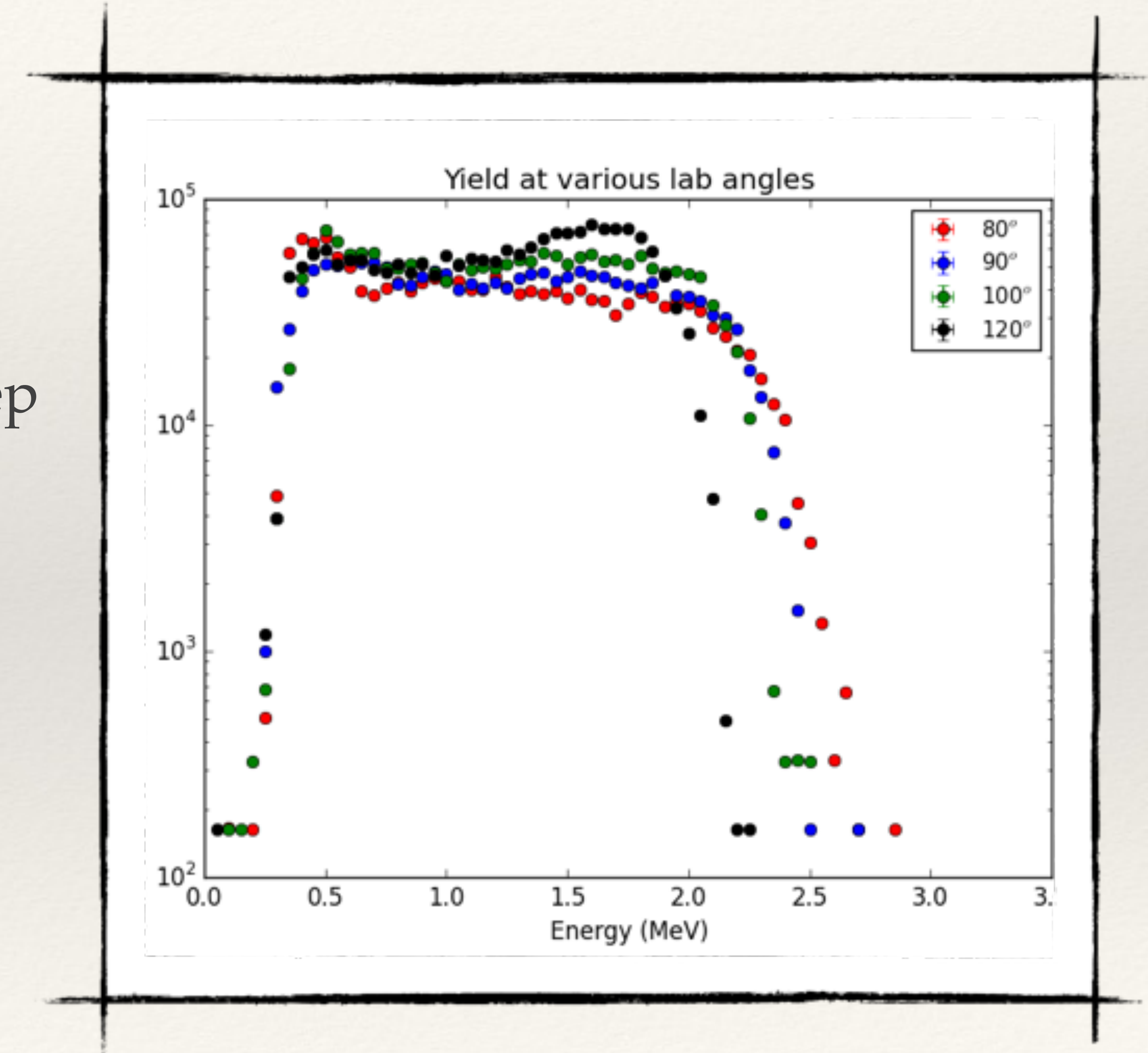
epithermal neutrons (keV) for deep tumors

Beam characteristics

low fast neutron and gamma contamination

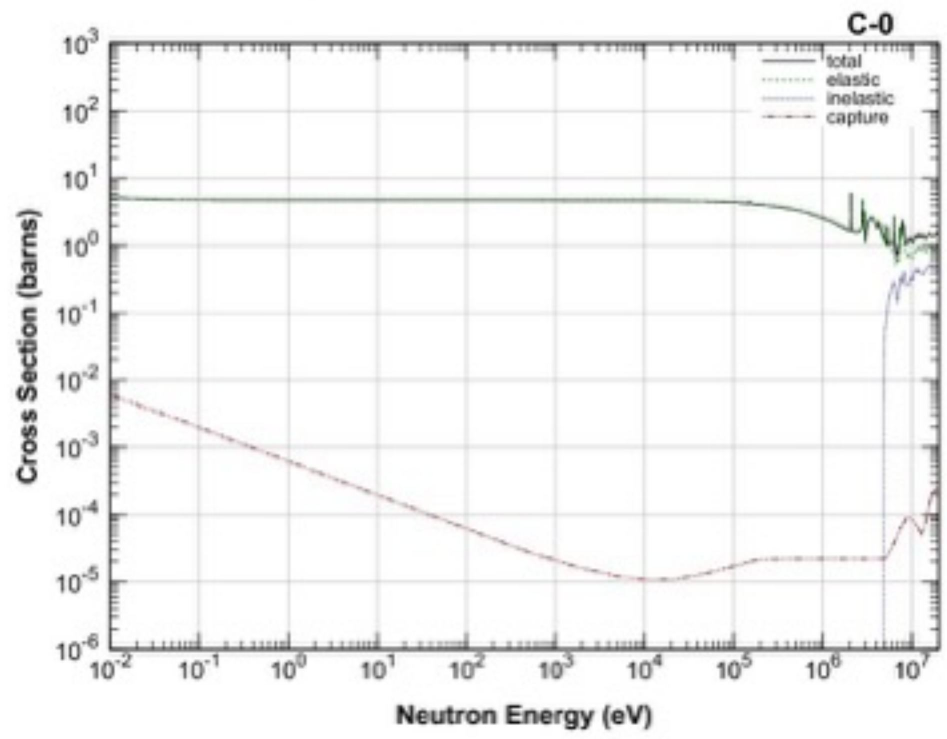
well collimated

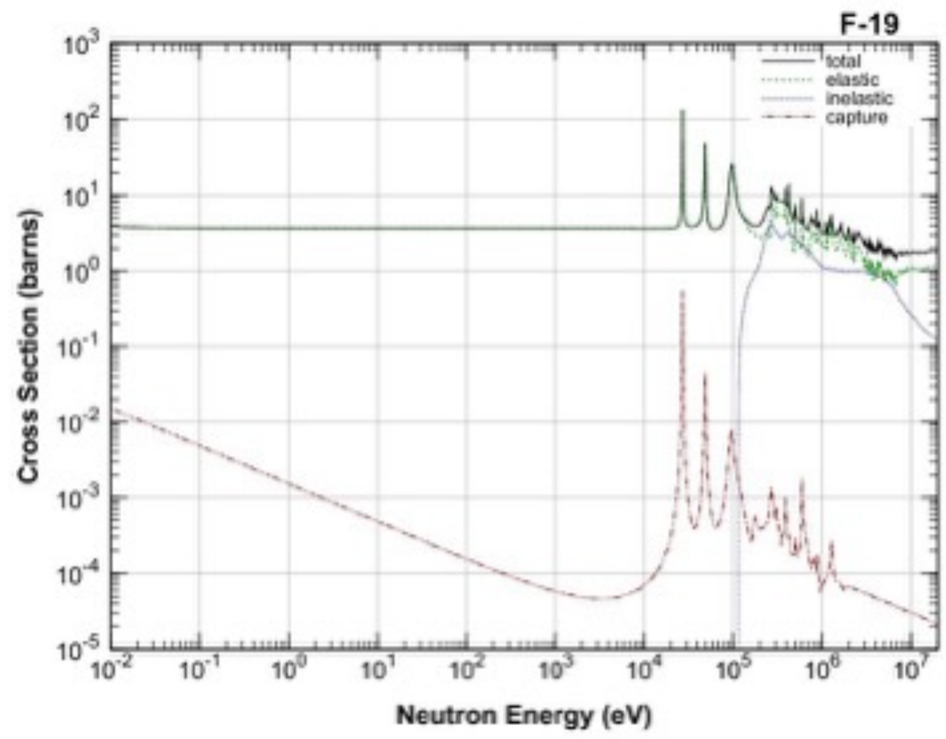
flux > 10^9 $cm^{-2} \cdot s^{-1}$



Beam Shaping Assembly

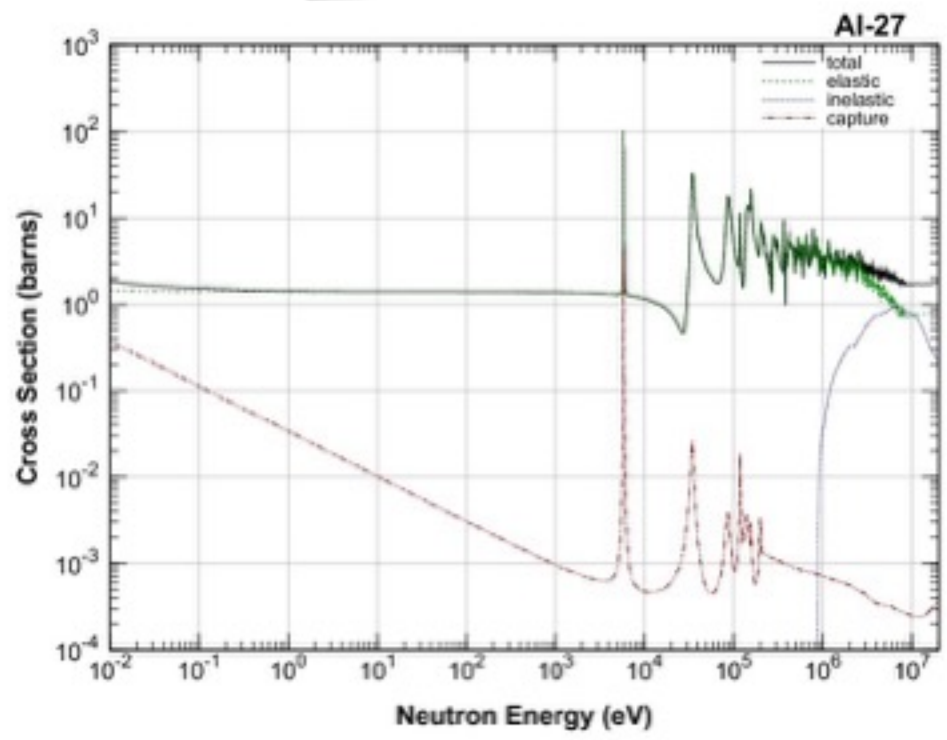
neutron moderator

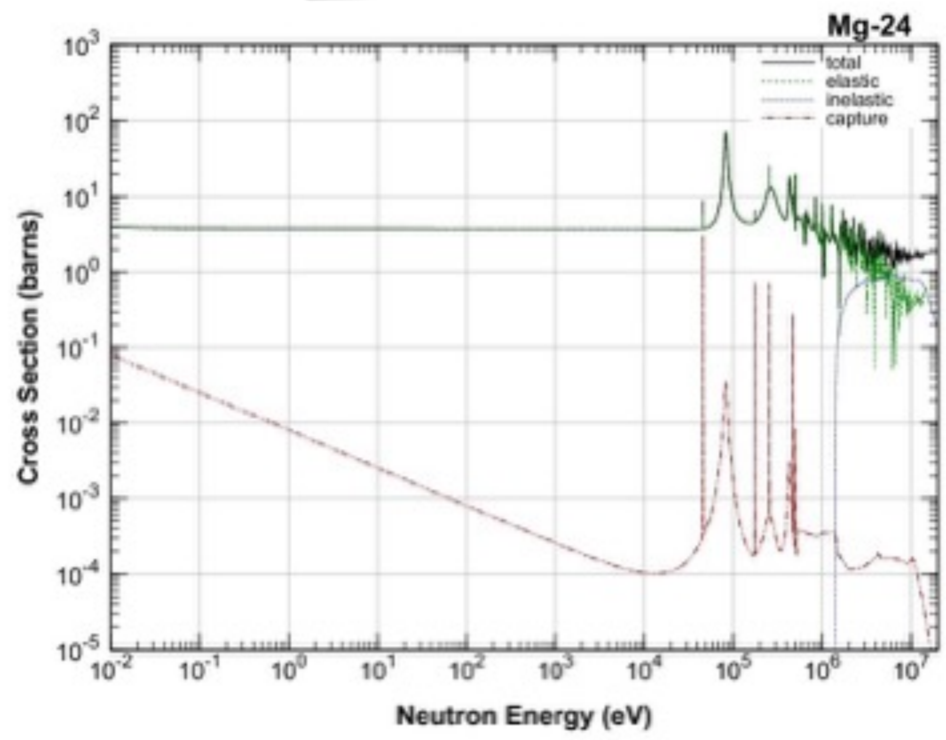




Beam Shaping Assembly

neutron moderator



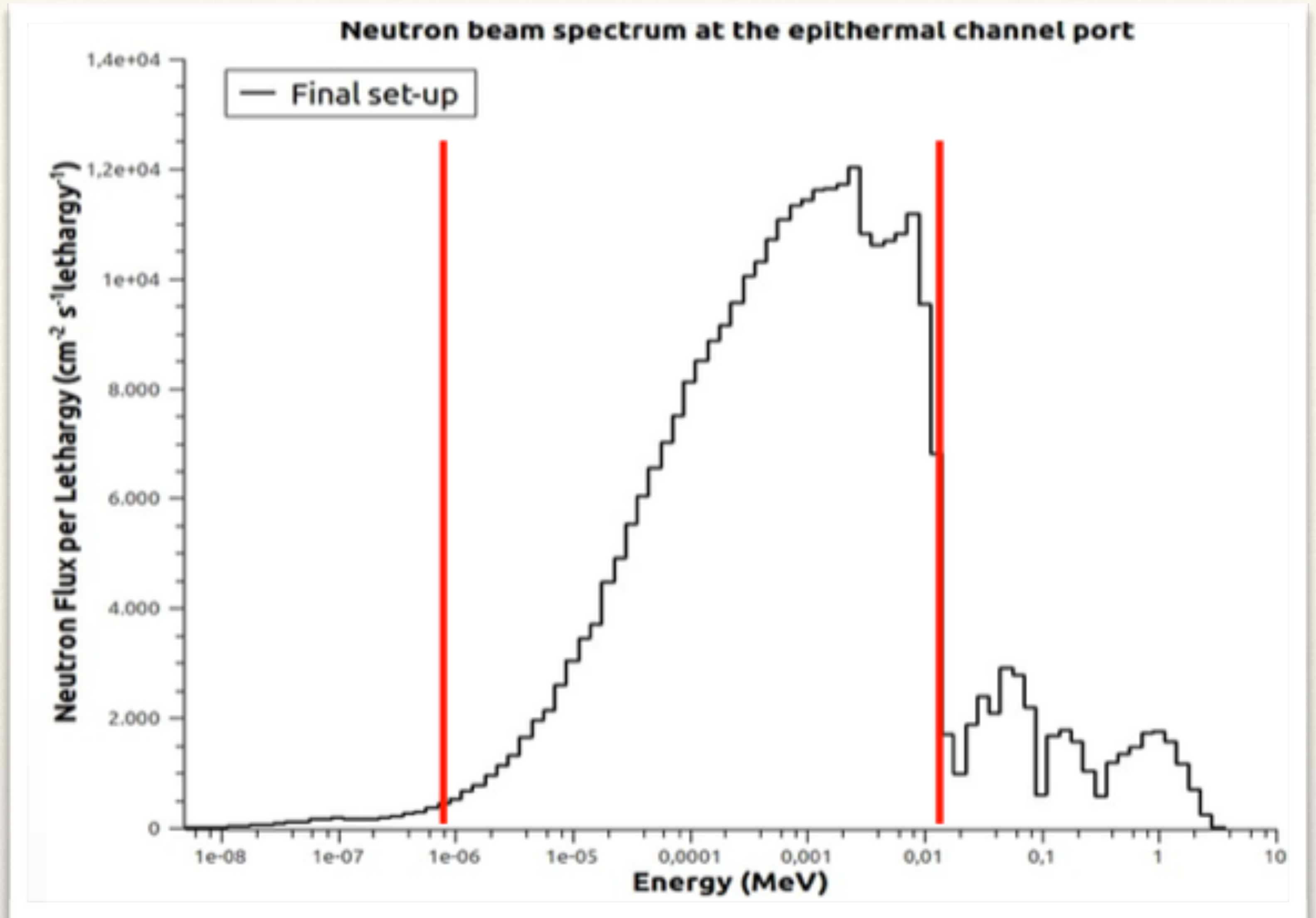


BSA design for the CN proton accelerator

where Agosteo et al. measured the $^{9}Be(p,n)^{9}B$ neutron distribution

simple flat target

CN-accelerator accelerator [INFN LNL]



MSc Thesis Jacopo Valsecchi

CN proton acc. Legnaro

5MeV - 3μA

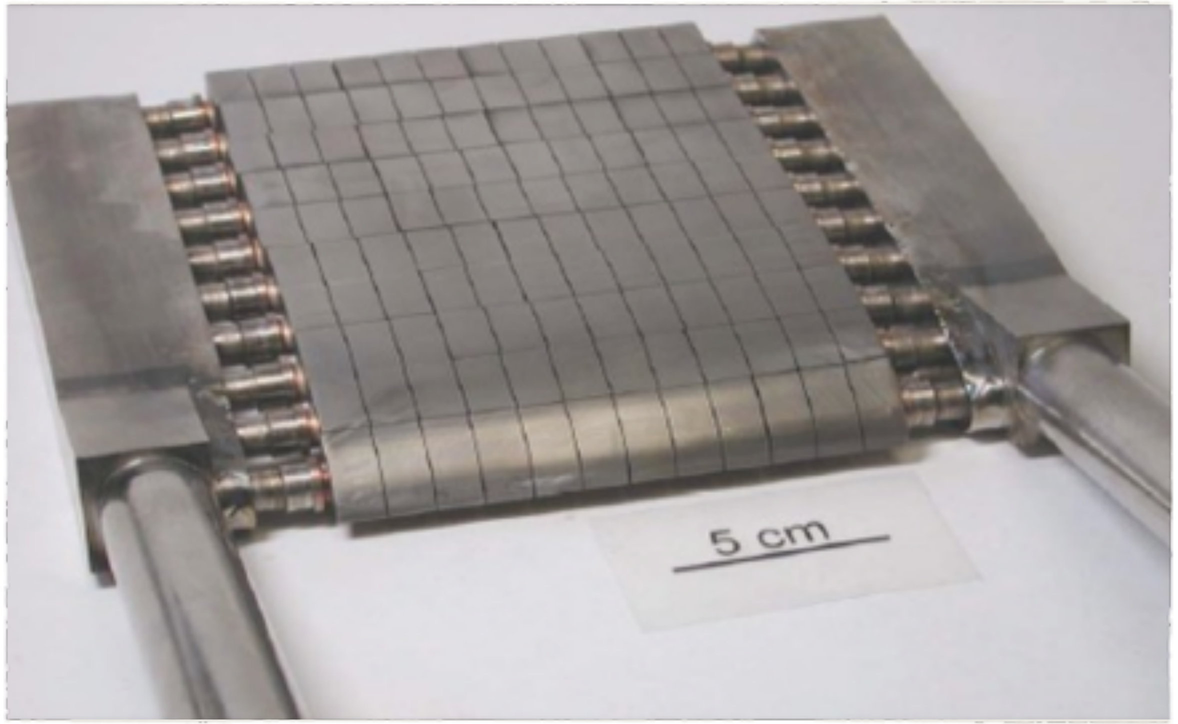
point source

BSA :
200mm Teflon, **10mm Mg** alloy, **5mm Teflon**, **10 mm Mg** alloy, **5x**(10 mm Al / 5 mm Teflon /15 mm Mg alloy), **5 mm Teflon**, **2x**(5 mm Mg alloy / 5 mm Al), **2x**(5 mm Mg alloy / 5 mm Ti) and **5 mm Mg** alloy

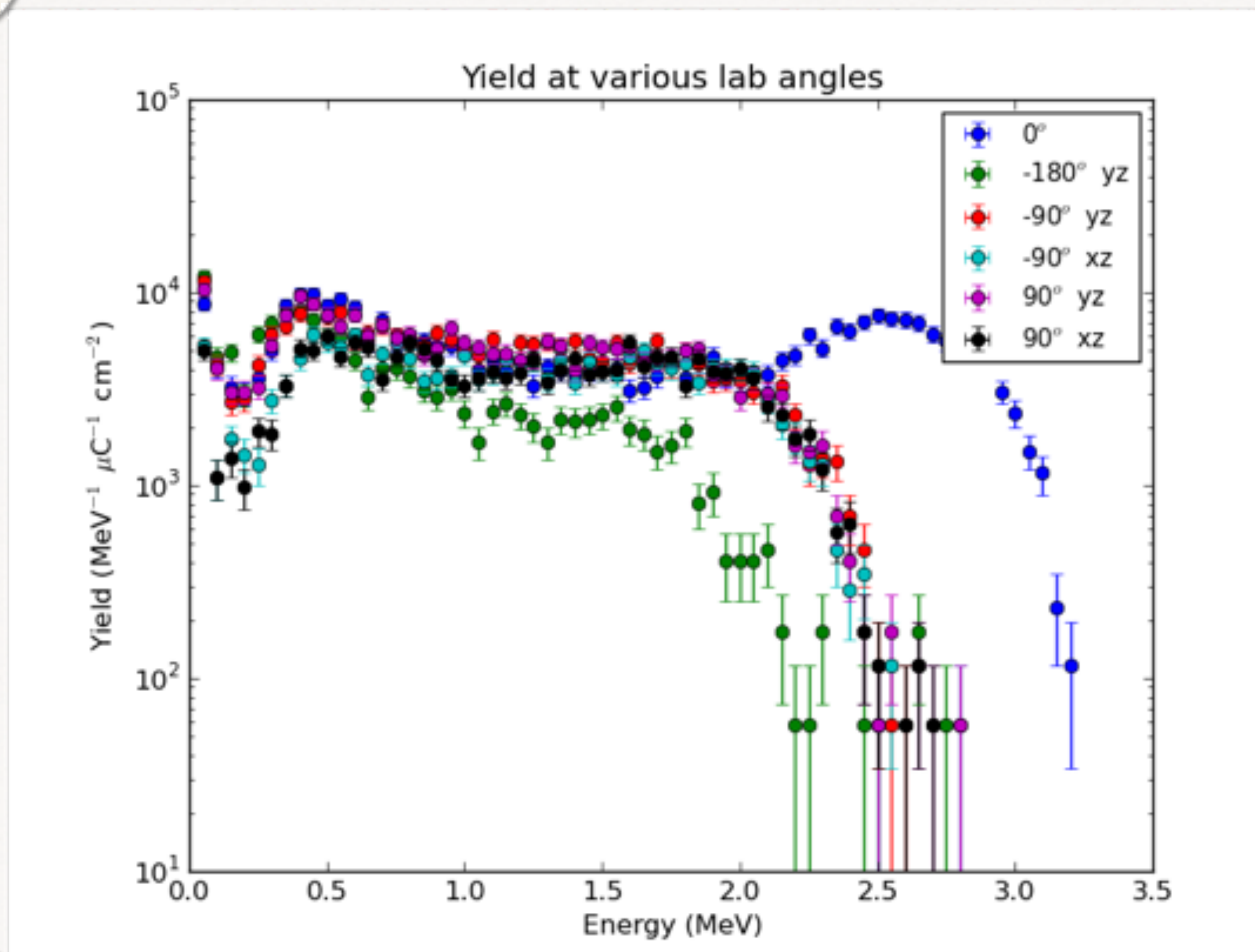
BSA with an Extended neutron source

MUNES Be Target

beam spot 300cm^2



[Esposito et al. Be target development for the accelerator-based SPES-BNCT facility at INFN Legnaro]



Neutron energy spectrum

Thick Be Target

MCNP6 simulations

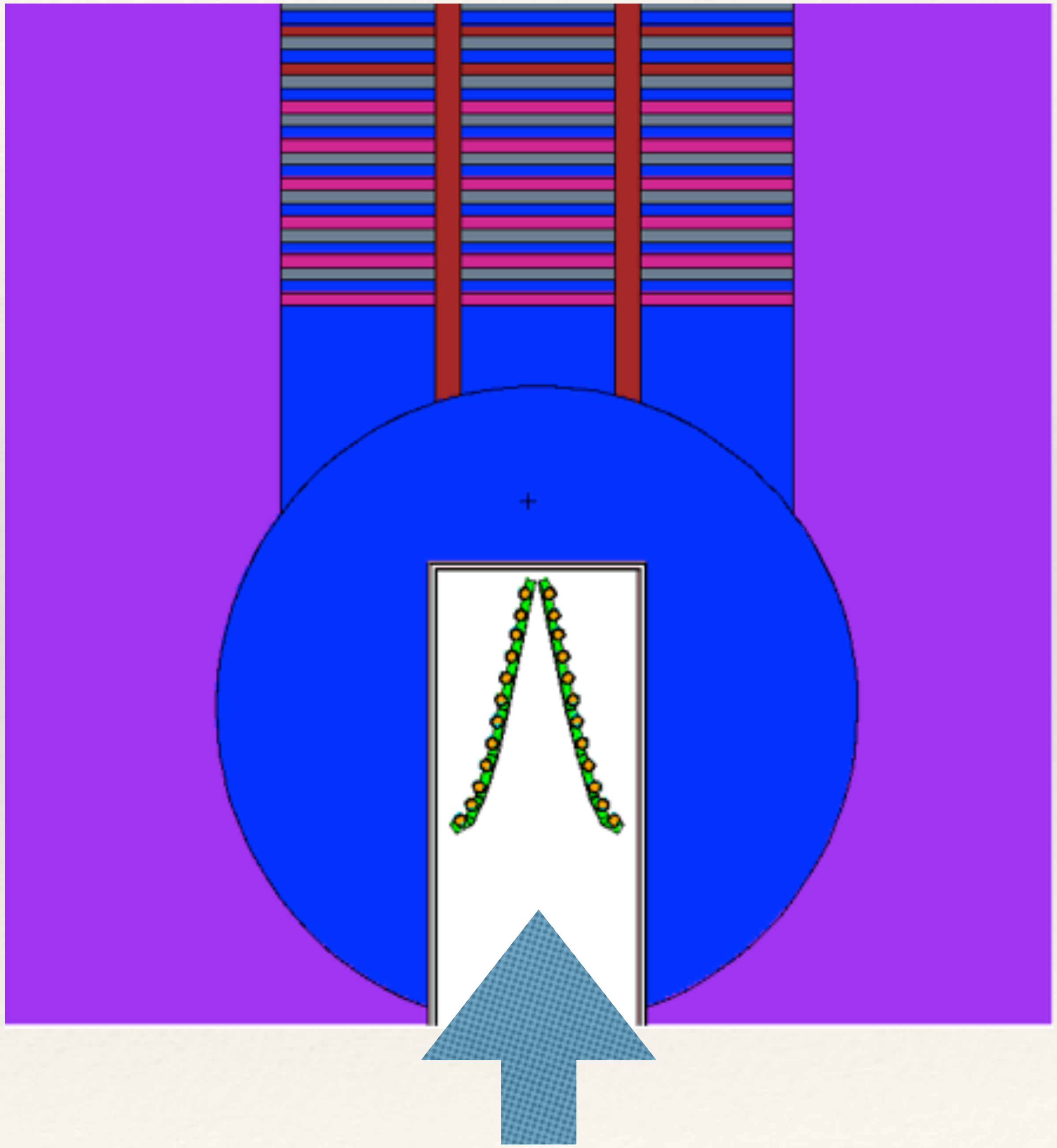
1cm^2 Tally at 20cm from the target center

Starting Configuration

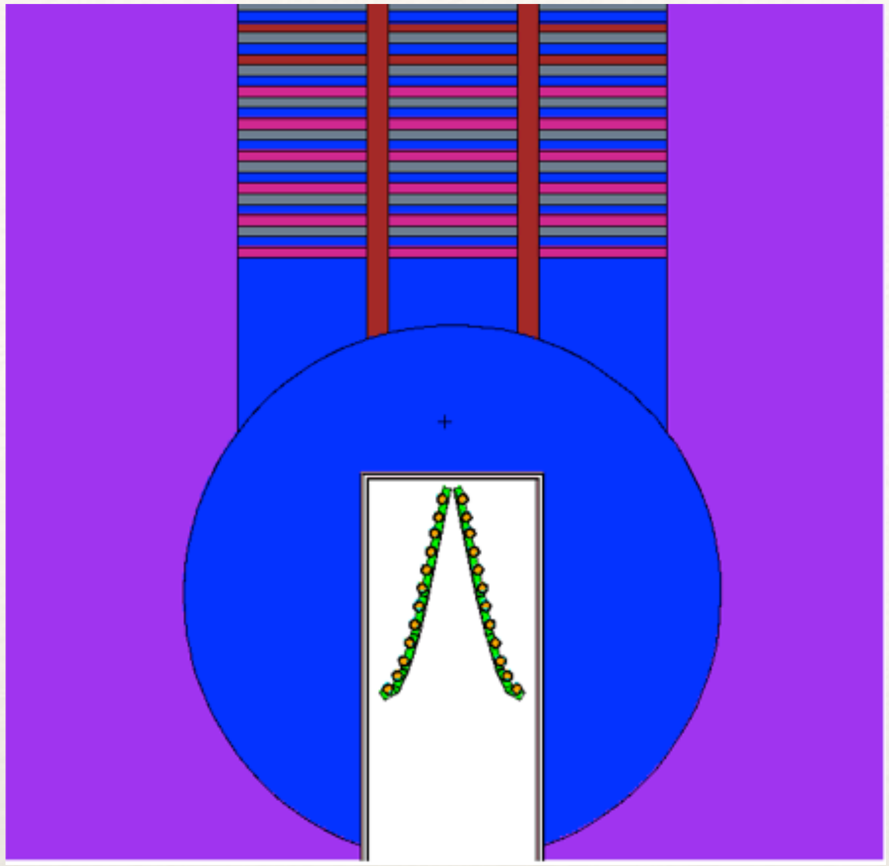
200 mm Teflon

6 x (10mm Al, 10mm Teflon, 10mm MgAl)

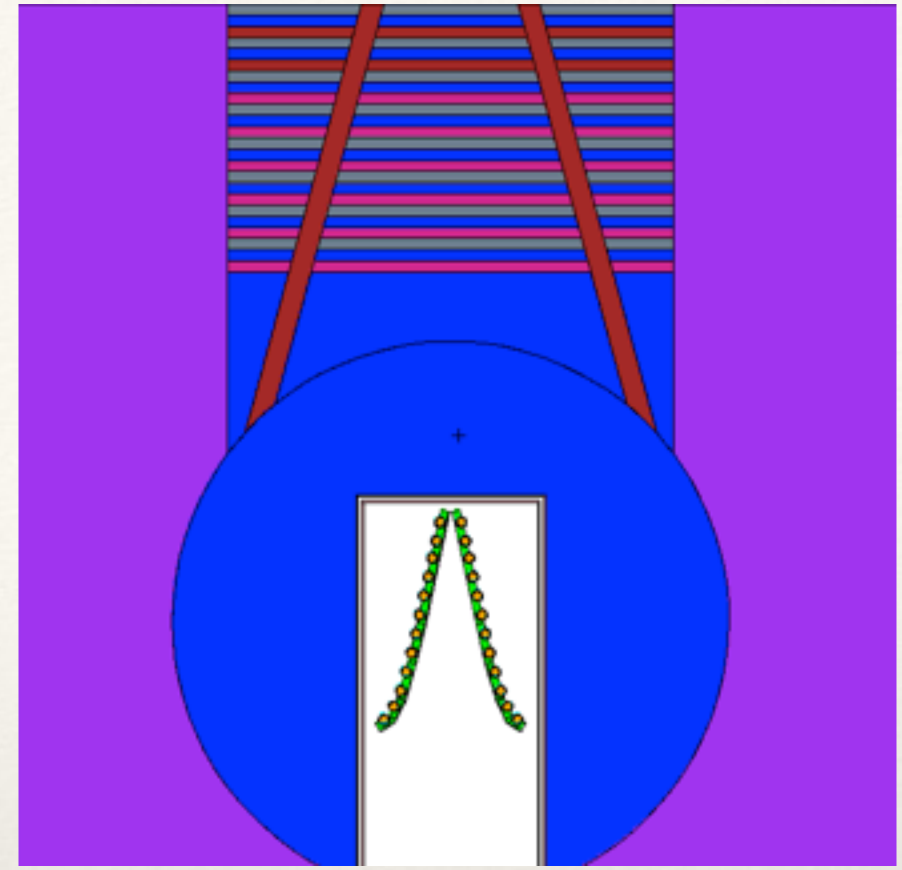
2 x (10mm Ti, 10mm Teflon, 10mm MgAl)



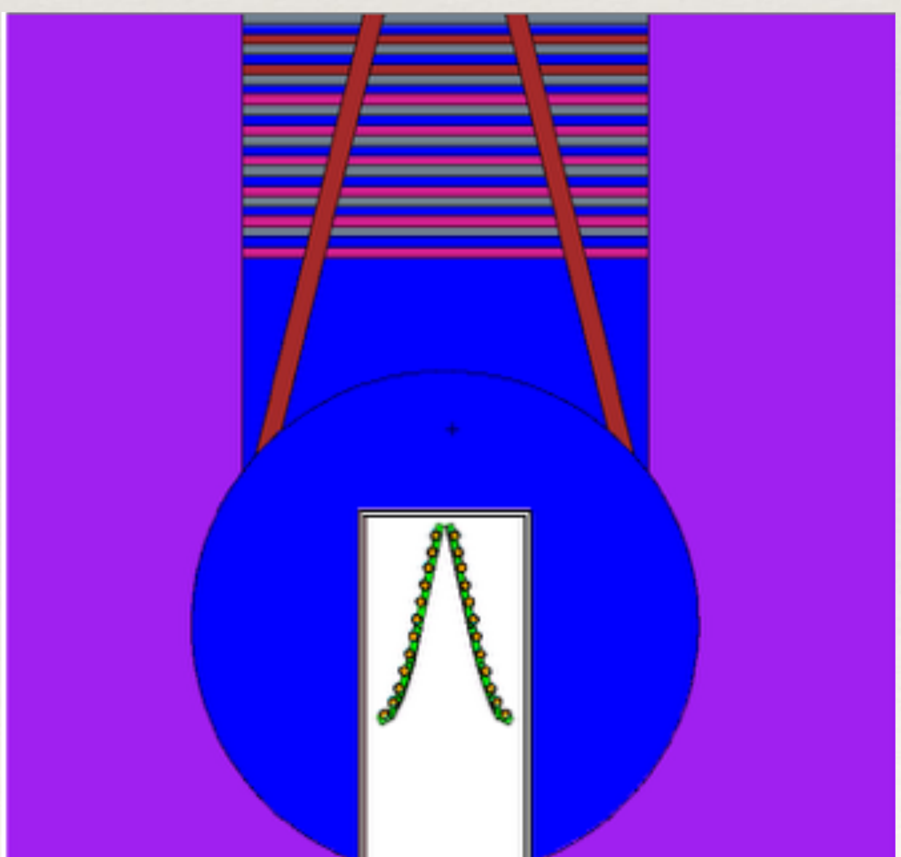
1)



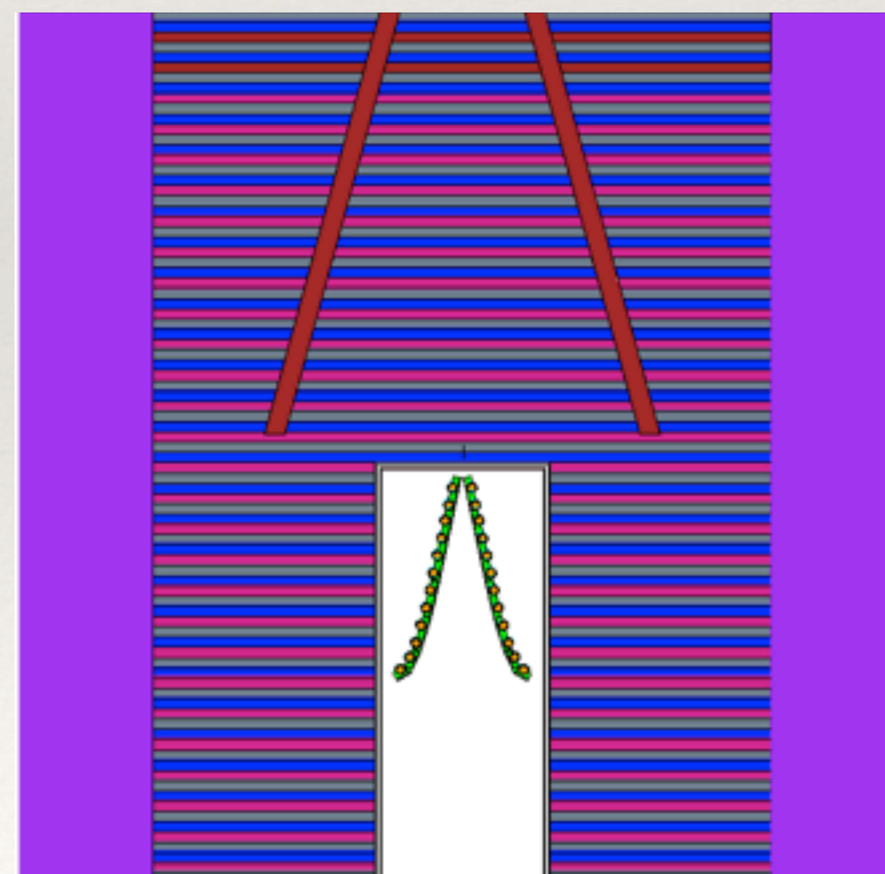
2)



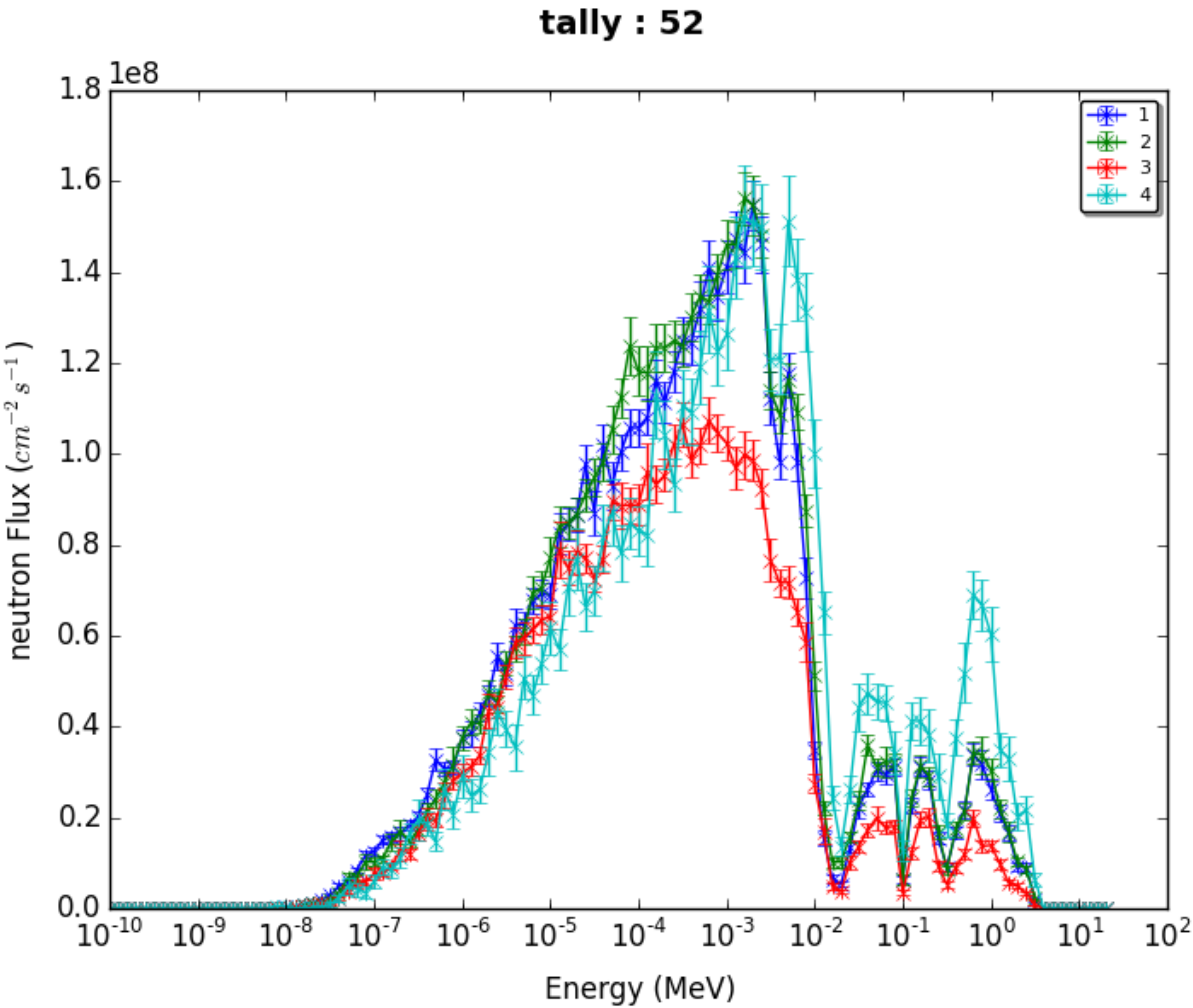
3)



4)



	ϕ_{epi}	D_{fast}/ϕ_{epi}	D_{γ}/ϕ_{epi}	J/ϕ_{epi}
1	4.0E+09	1.5E-12	2.8E-12	0.675
2	4.2E+09	1.5E-12	2.3E-12	0.667
3	3.2E+09	9.9E-13	2.5E-12	0.656
4	3.7E+09	3.2E-12	2.8E-13	0.757



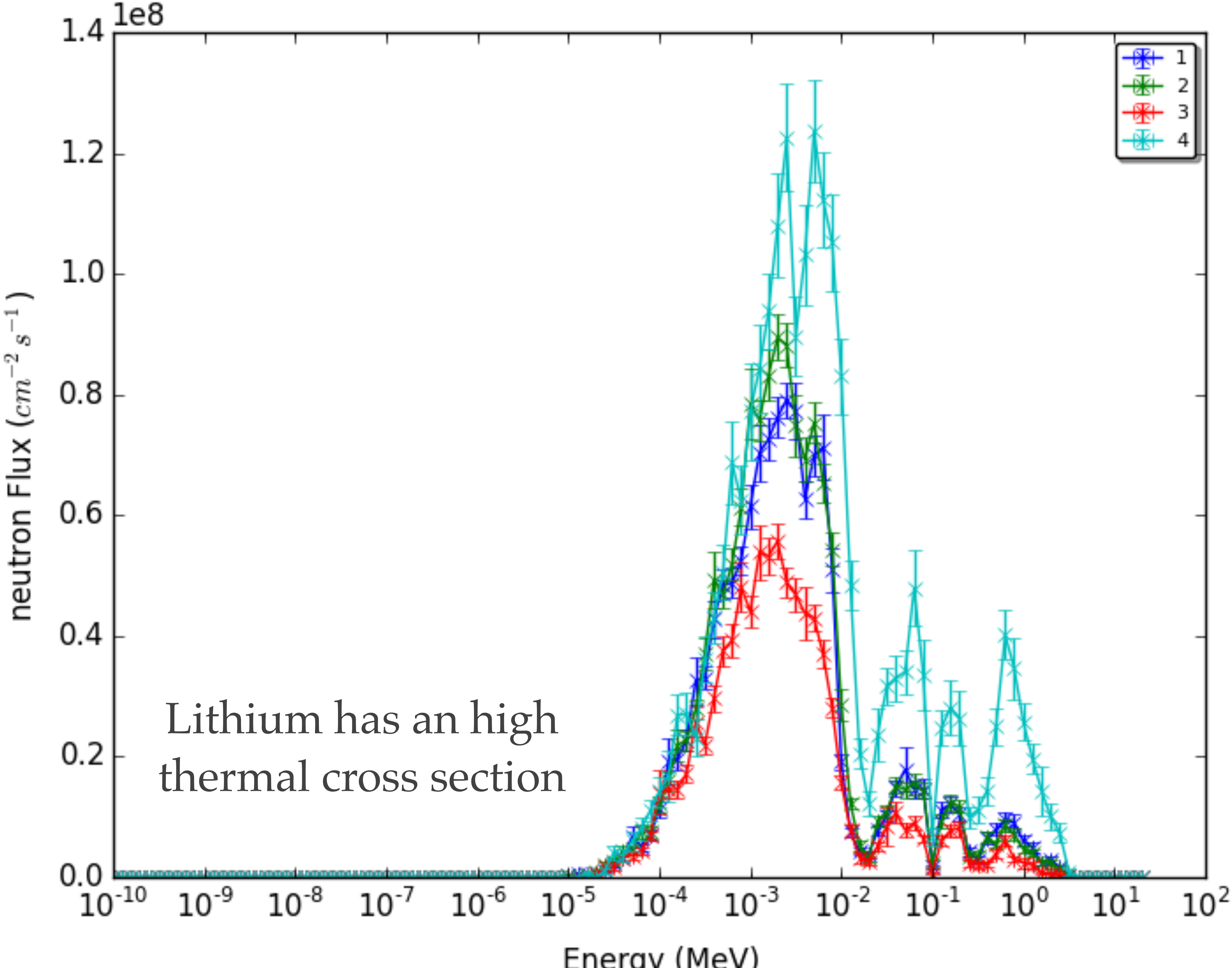
tally : 52
1e8
neutron Flux ($cm^{-2}s^{-1}$)
Energy (MeV)
1
2
3
4

Material Change

FLi substitutes Teflon

keeping the same 4 configurations

	ϕ_{epi}	D_{fast} / ϕ_{epi}	D_{γ} / ϕ_{epi}	J / ϕ_{epi}
1	1.1E+09	1.8E-12	3.2E-13	0.664
2	1.2E+09	1.5E-12	3.3E-13	0.650
3	7.6E+08	1.3E-12	3.5E-13	0.658
4	1.5E+09	4.1E-12	8.7E-14	0.800



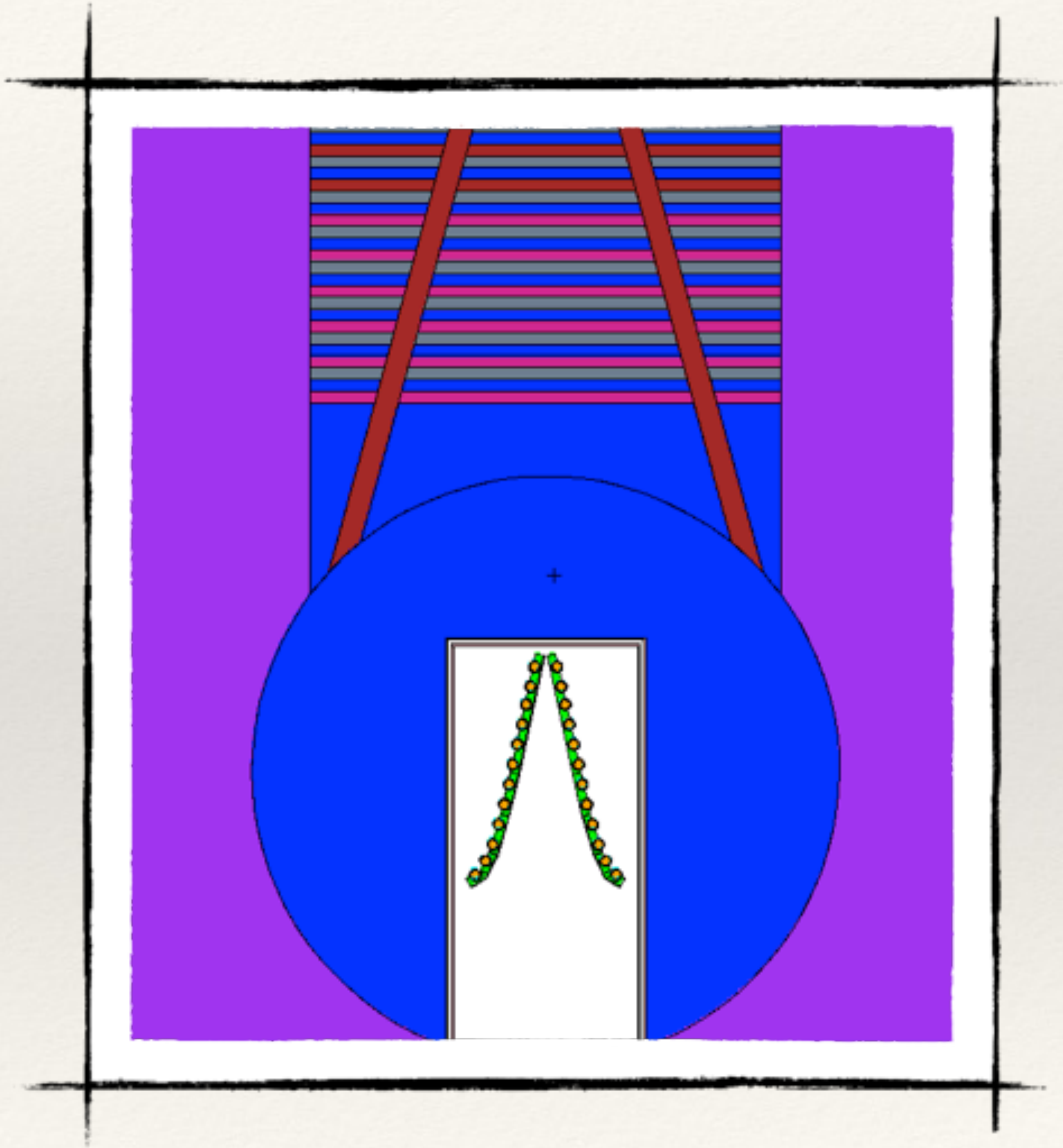
1e8
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
neutron Flux ($cm^{-2} s^{-1}$)
10^{-10} 10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2}
Energy (MeV)
1
2
3
4
Lithium has an high
thermal cross section

Other materials 1 configuration

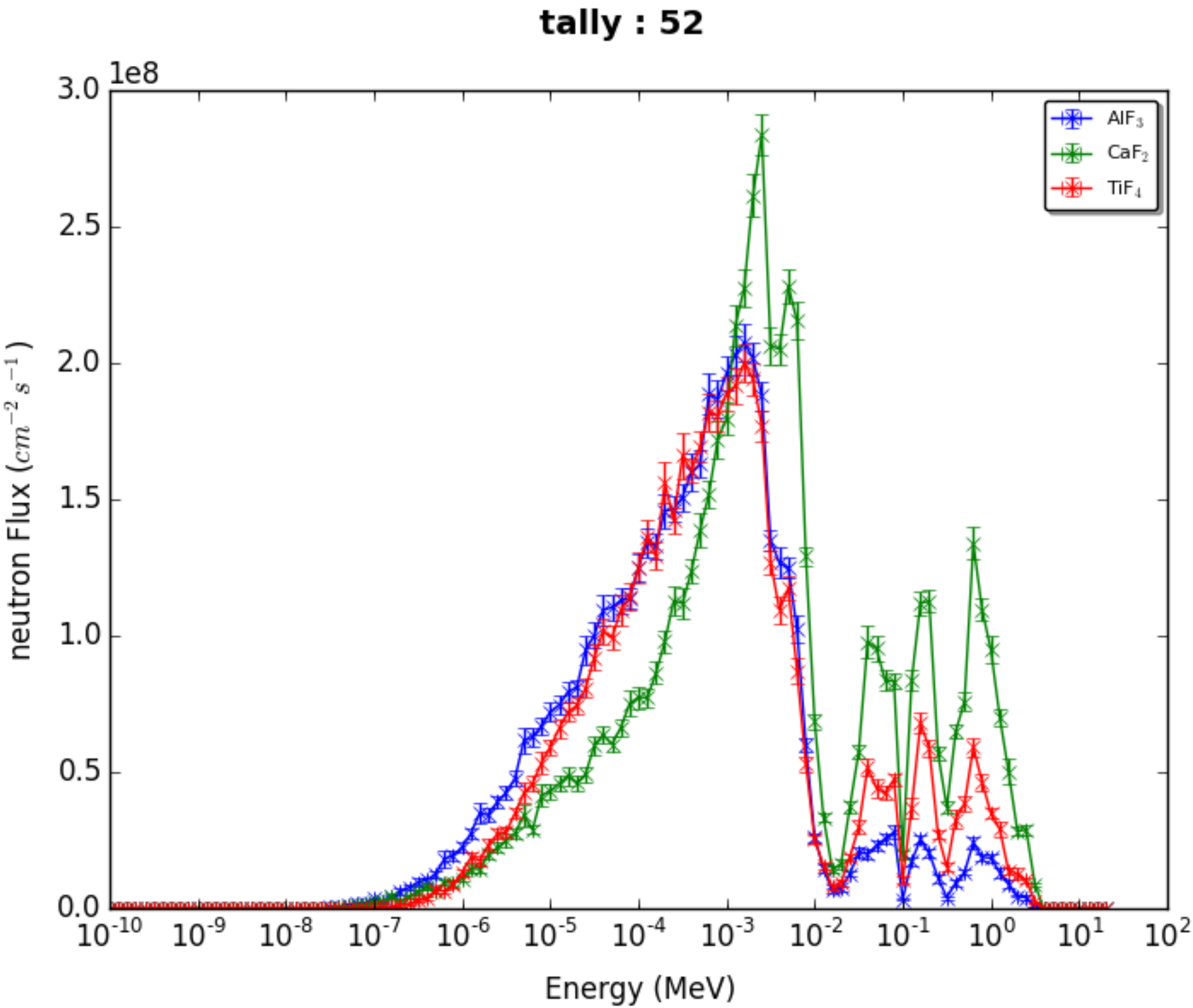
AlF_3

CaF_2

TiF_4



	ϕ_{epi}	D_{fast} / ϕ_{epi}	D_{γ} / ϕ_{epi}	J / ϕ_{epi}
AlF_3	4.5E+09	9.3E-13	1.6E-12	0.644
CaF_2	4.2E+09	4.8E-12	1.2E-12	0.810
TiF_4	4.2E+09	2.1E-12	1.3E-12	0.690



tally : 52
1e8
3.0
2.5
2.0
1.5
1.0
0.5
0.0
neutron Flux ($cm^{-2}s^{-1}$)
10^{-10}
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
Energy (MeV)
AlF_3
CaF_2
TiF_4

Cone implementation

Target

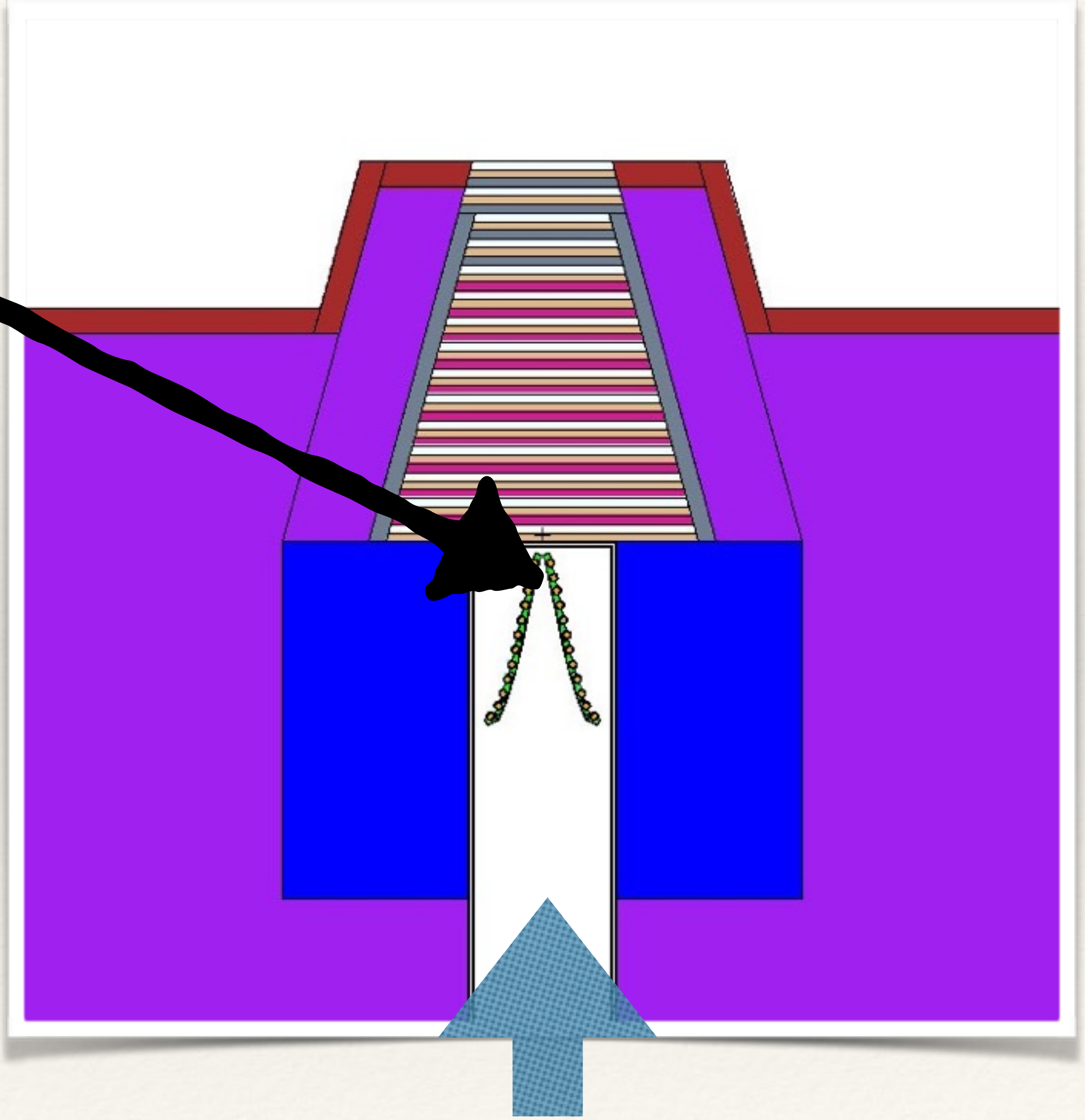
Pb shield

Li loaded polyethylene

Teflon reflector

BSA

Titanium aluminide
Ti6Al4V Grade5 (Ti 94% Al 6%)
Magnesium alloy
Aluminium
AlF_3



5 MeV protons

Cone implementation

Target

Pb shield

Li loaded polyethylene

Teflon reflector

BSA

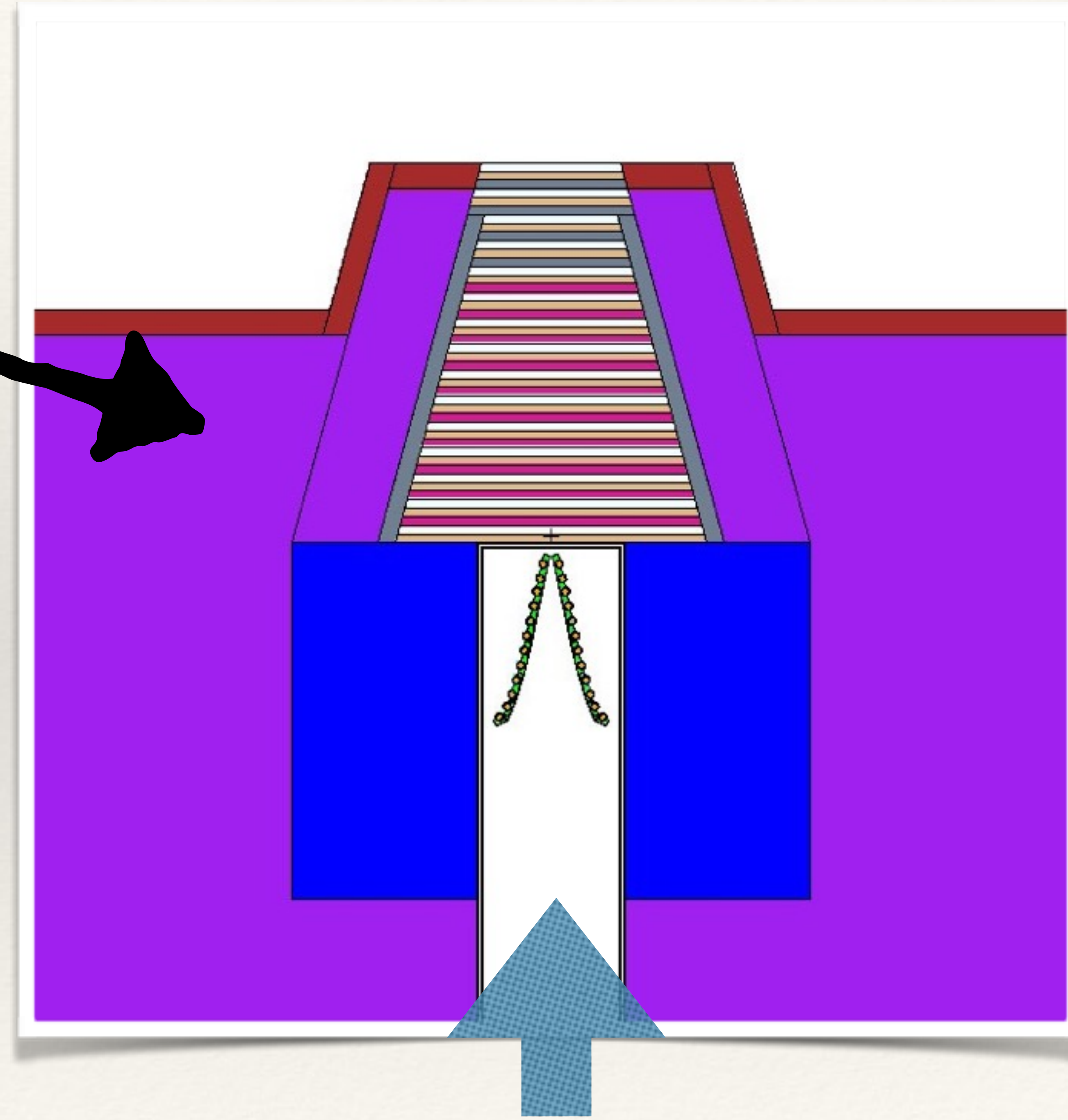
Titanium aluminide

Ti6Al4V Grade5 (Ti 94% Al 6%)

Magnesium alloy

Aluminium

AlF_3



5 MeV protons

Cone implementation

Target

Pb shield

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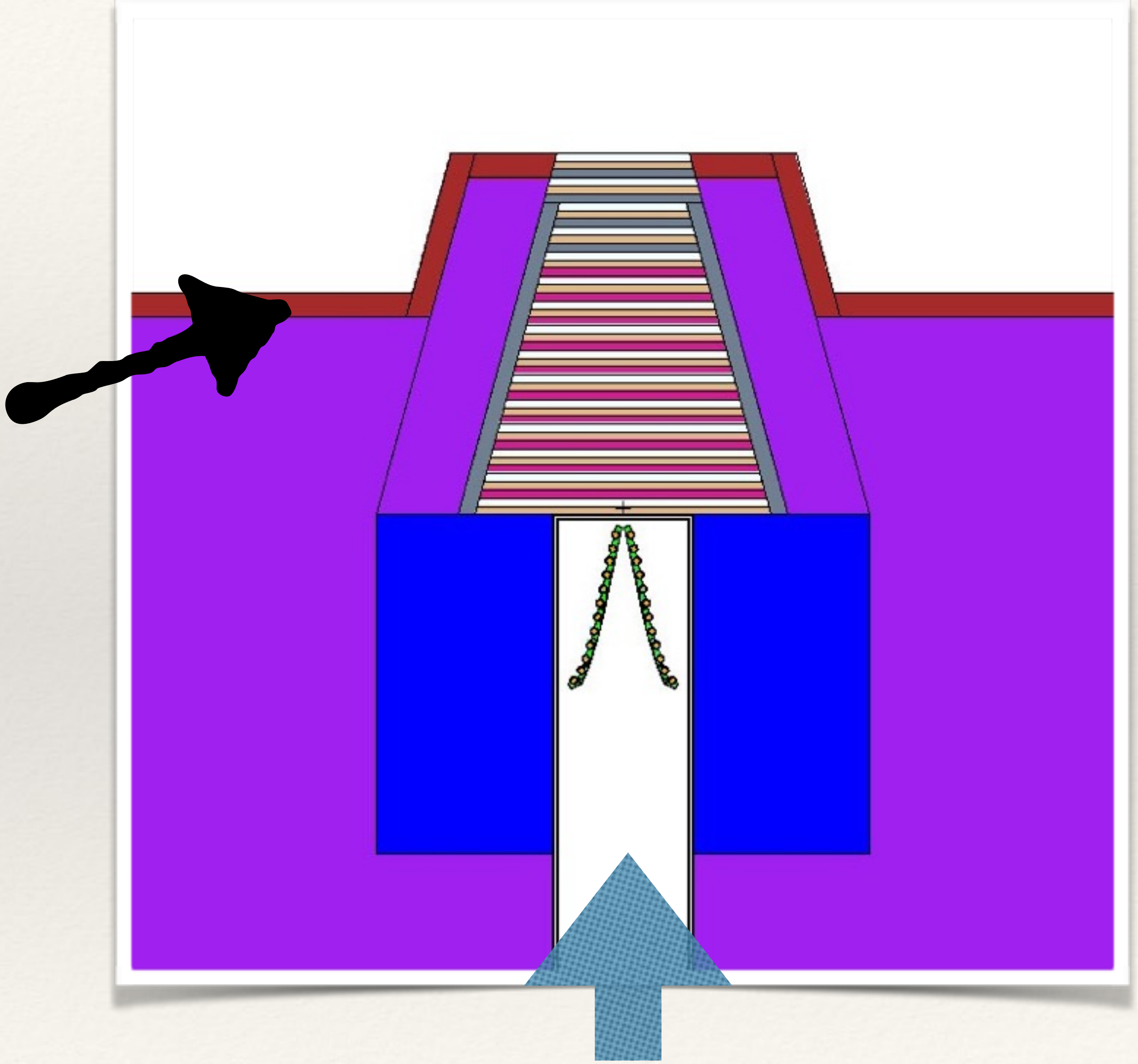
Teflon reflector

BSA

Titanium aluminide
Ti6Al4V Grade5 (Ti 94% Al 6%)
Magnesium alloy
Aluminium
AlF_3



5 MeV protons

Cone implementation

Target

Pb shield

Li loaded polyethylene

Teflon reflector

<u>BSA</u>

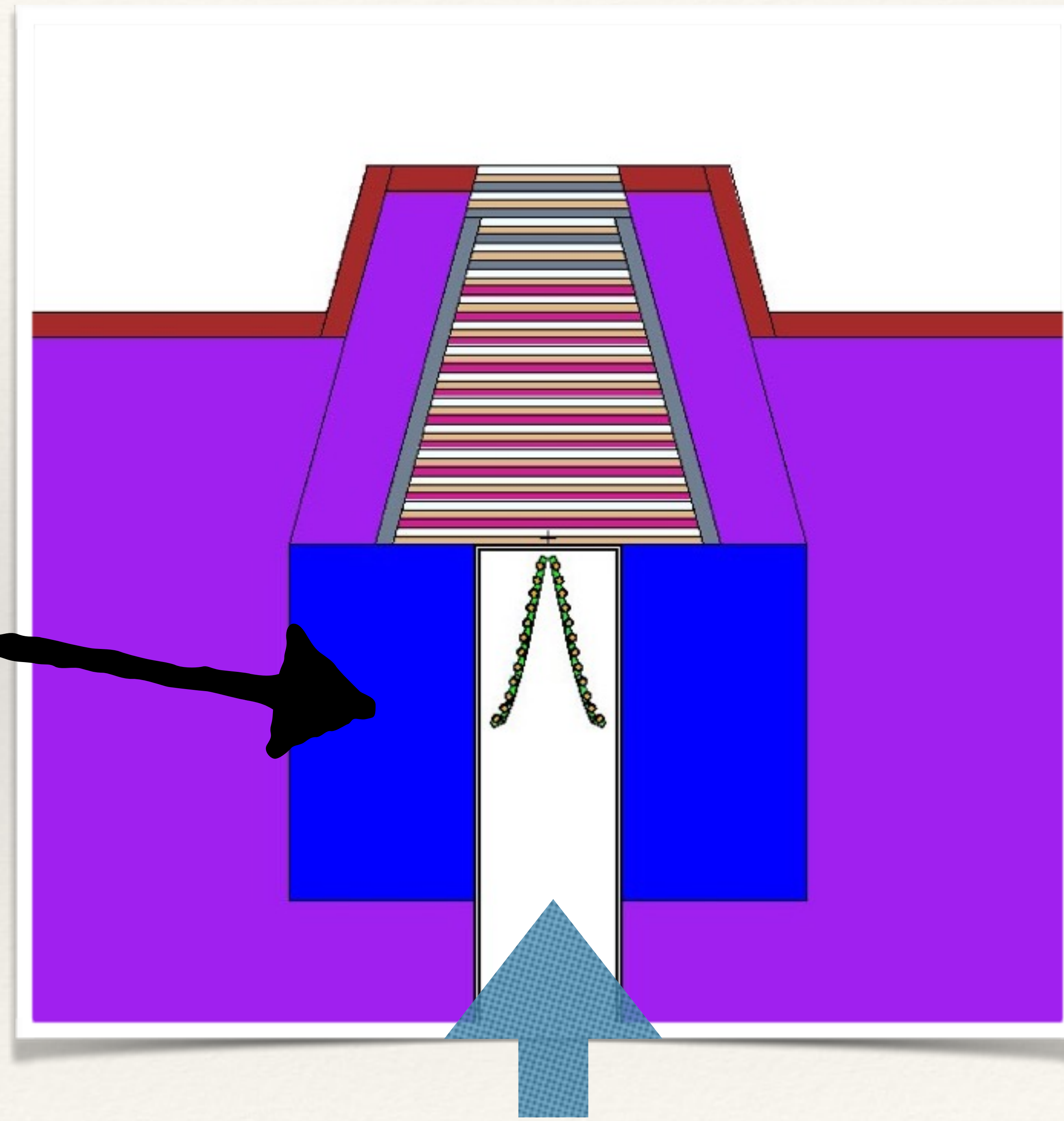
Titanium aluminide

Ti6Al4V Grade5 (Ti 94% Al 6%)

Magnesium alloy

Aluminium

AlF_3



5 MeV protons

Cone implementation

Target

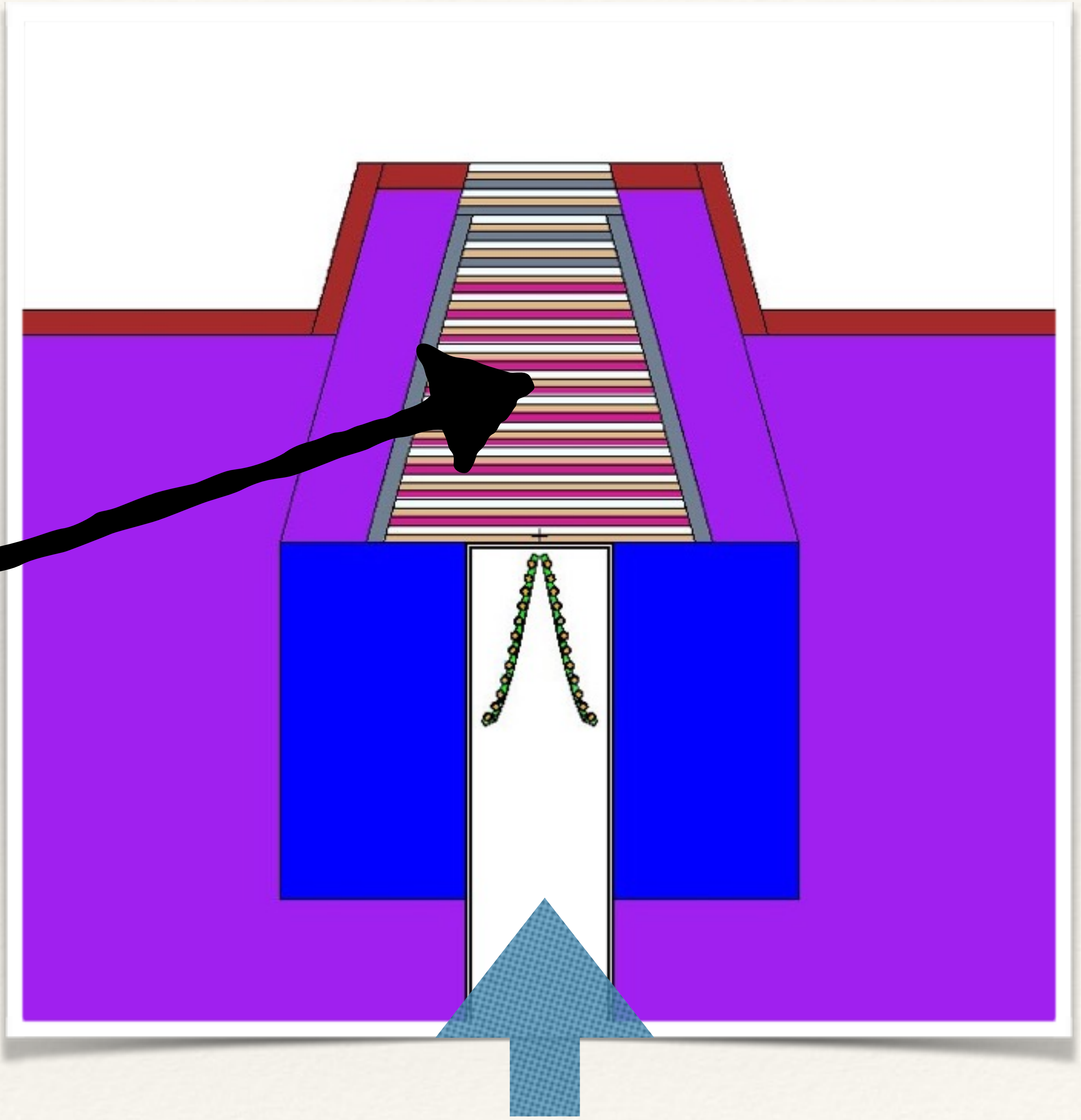
Pb shield

Li loaded polyethylene

Teflon reflector

BSA

Titanium aluminide
Ti6Al4V Grade5 (Ti 94% Al 6%)
Magnesium alloy
Aluminium
AlF_3



5 MeV protons

2nd Cone implementation

Target

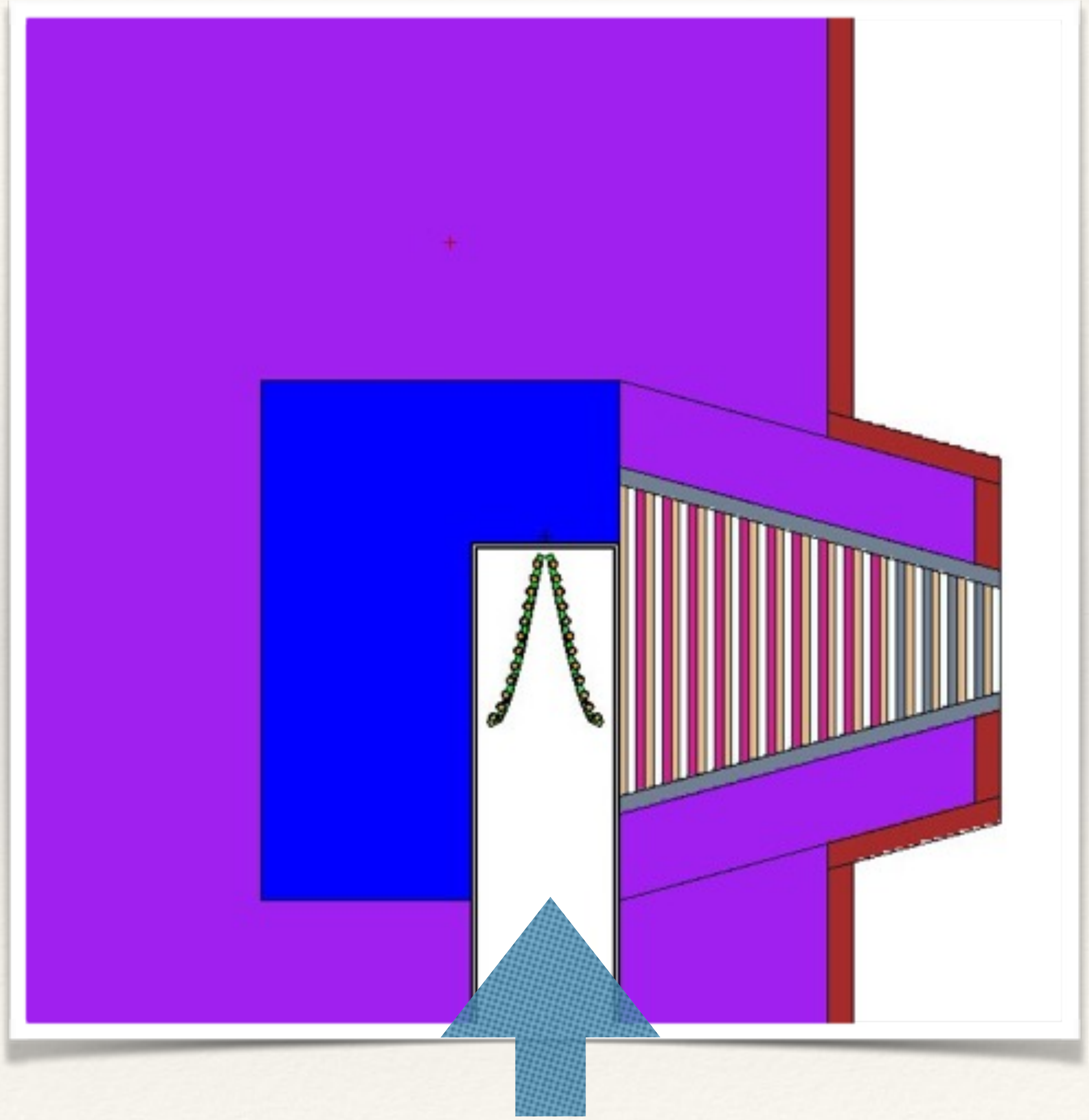
Pb shield

Li loaded polyethylene

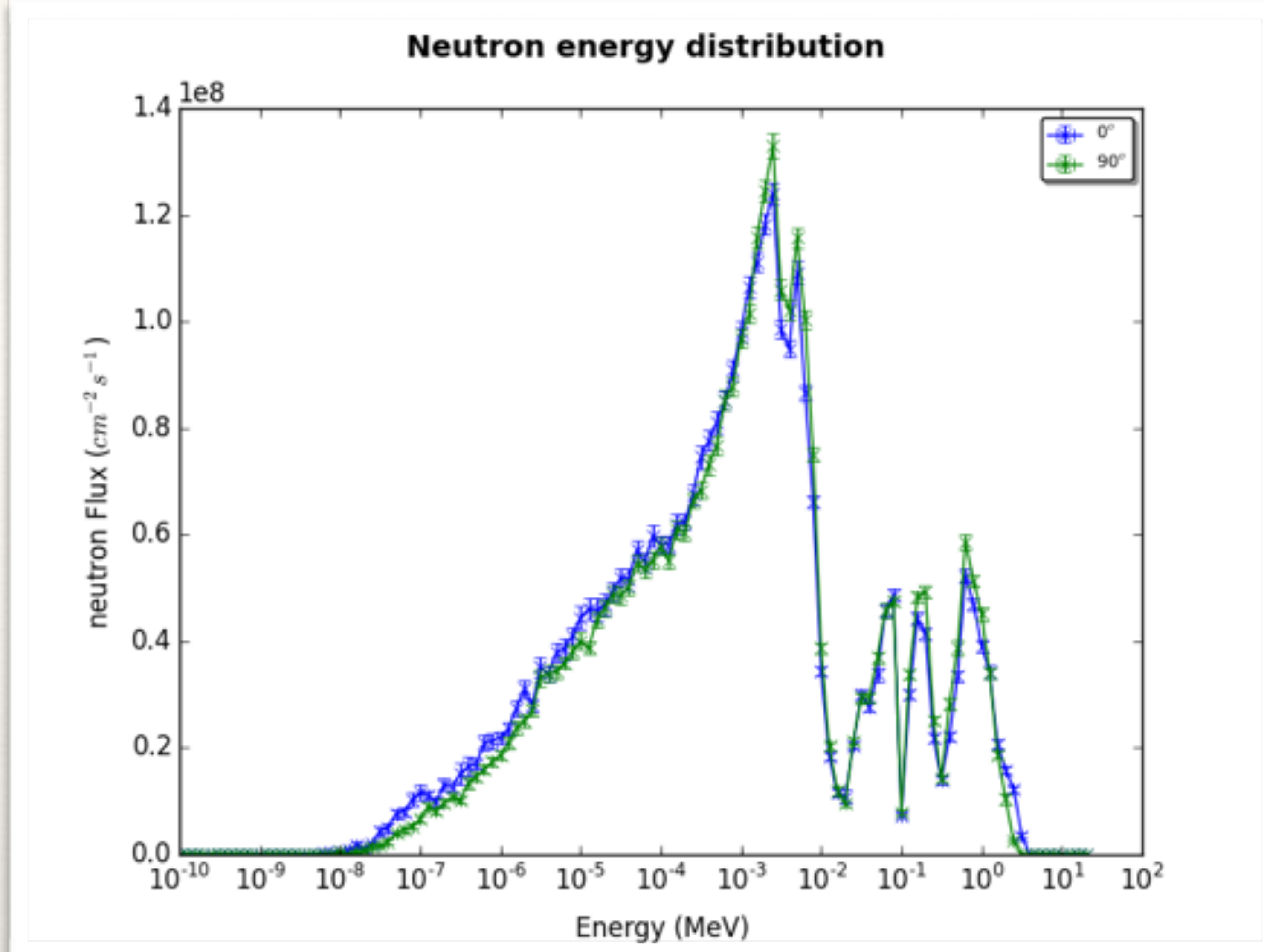
Teflon reflector

<u>BSA</u>

Titanium aluminide
Ti6Al4V Grade5 (Ti 94% Al 6%)
Magnesium alloy
Aluminium
AlF_3



5 MeV protons



Neutron energy distribution of the 2 configurations

0º and 90º comparison

BSA:
11 x (AlF3 10mm, Mg alloy 10mm, Al 10mm) 4 x (Ti 10mm, AlF3 10mm, Mg alloy 10mm)

	ϕ_{epi} ($cm^{-2}s^{-1}$)	D_{fast} / ϕ_{epi}	D_{γ} / ϕ_{epi}	J / ϕ_{epi}
0^o	2.6E+09	1.1E-12	1.9E-12	0.808
90^o	2.6E+09	1.0E-12	2.1E-12	0.805

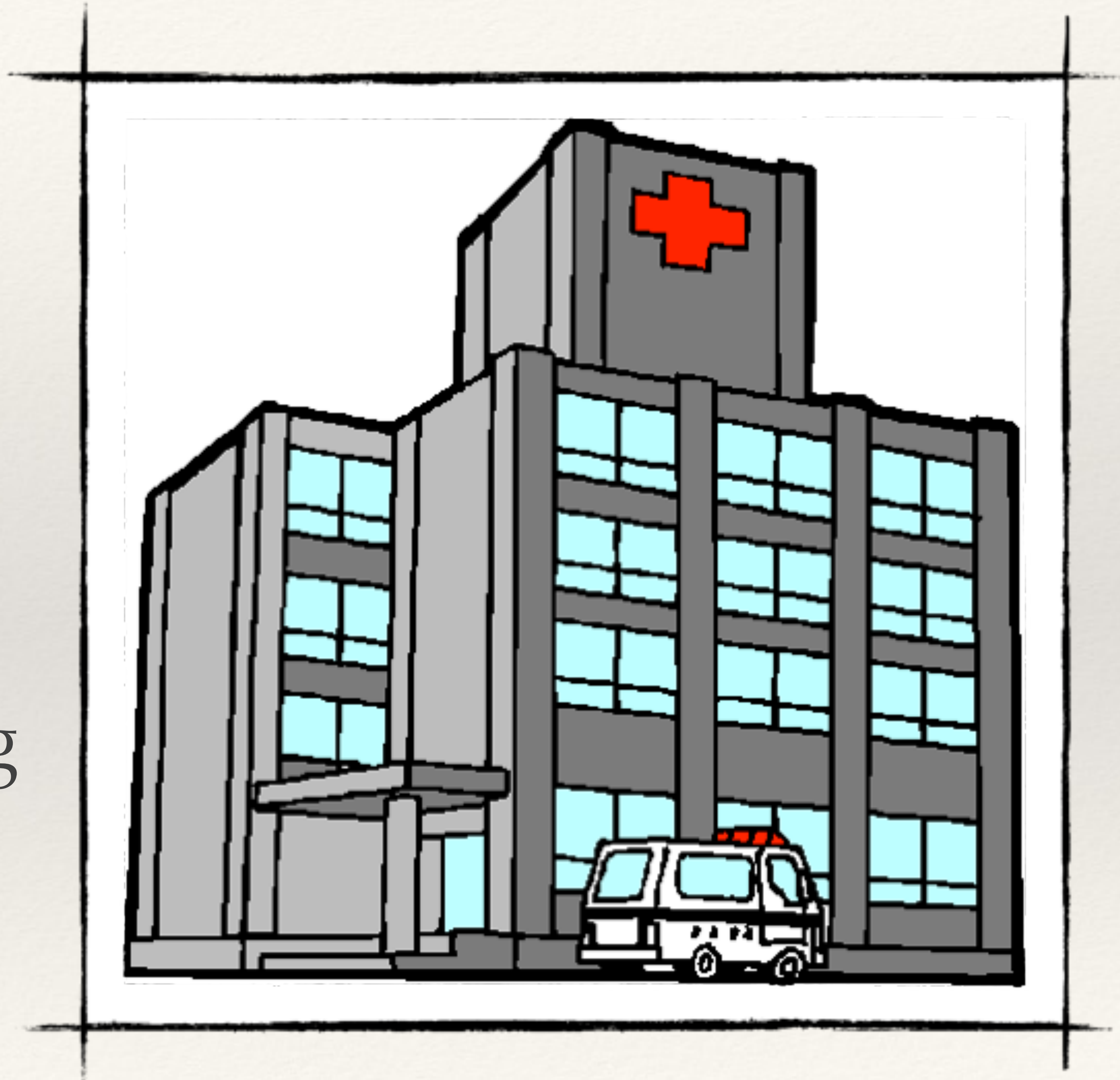
	ϕ_{epi} ($cm^{-2}s^{-1}$)	D_{fast}/ϕ_{epi}	D_{γ}/ϕ_{epi}	J/ϕ_{epi}
0°	2.6E+09	1.1E-12	1.9E-12	0.808
90°	2.6E+09	1.0E-12	2.1E-12	0.805

Neutron source	ϕ_{epi} ($10^{-9} cm^{-2} s^{-1}$)	$\frac{\dot{D}_{fast}}{\phi_{epi}}$ ($10^{-13} Gy\ cm^{-2} s^{-1}$)	$\frac{\dot{D}_{\gamma}}{\phi_{epi}}$ ($10^{-13} Gy\ cm^{-2} s^{-1}$)
FCB [37] (5 MW)	4.3	1.4	3.6
JRR-4 (3.5 MW) [38]	2.2	3.1	1.5
THOR (1.2 MW) [16,39]	1.1	3.4	1.3
Fir (0.25 MW) [40,41]	1.1	2.1	0.5
KURR (5 MW) [42]	0.46	6.2	2.8
HFR (45 MW) [43]	0.33	12.1	3.8
Li ABNS 30 mA [22]	0.95	5.2	4.9

BSA final selection

Compare beam configurations with real case scenarios

Select the most performing BSA set-up



Herrera M.S. et al. Evaluation of performance of an accelerator-based BNCT facility for the treatment of different tumor targets

Conclusions

Future of BNCT lies in compact neutron sources

MUNES RFQ-linac accelerator can be used for BNCT

what's next ?

Final **BSA selected** by comparing results with real clinical cases

Thank you for the attention