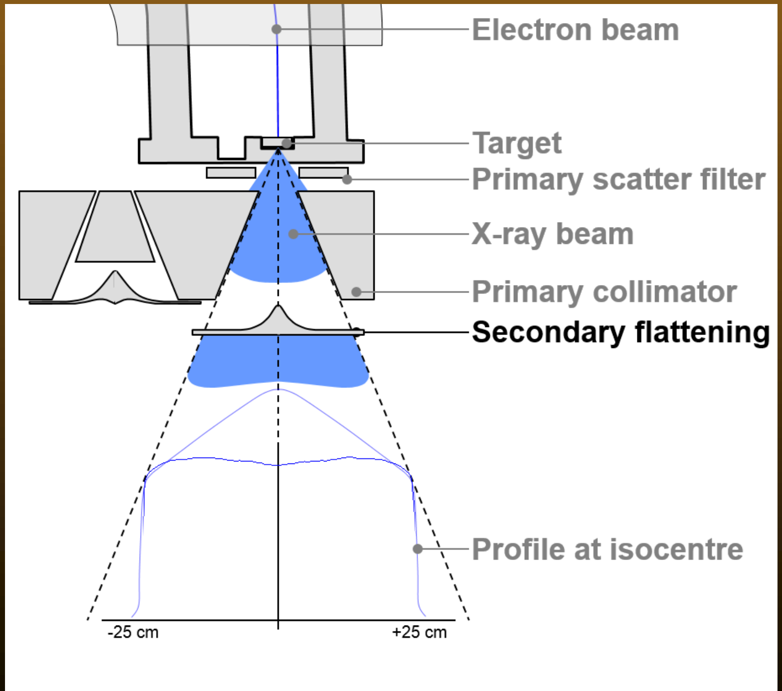
DEVELOPMENT OF GAMMA INSENSITIVE SILICON CARBIDE DIAGNOSTICS TO QUALIFY INTENSE THERMAL AND EPITHERMAL NEUTRON FIELDS

On behalf of the e_Libans collaboration:
Oriol Sans Planell – IPRD19 Siena, 16th Oct 2019
oriol.sansplanell@to.infn.it

ELEKTA PRECISE 18MeV

Peak current	35 mA
Frequency	200 Hz
Pulse duration	2.4 μs
Duty cycle	4.8 10^{-4}
#e- per second on target	1.05 10^{14}



Linac Set-up

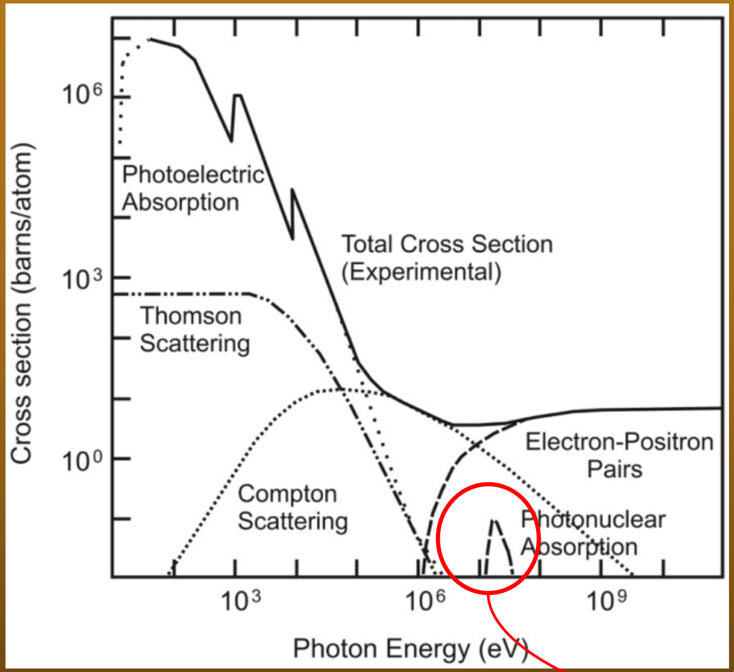
γ source: 15 MV, 18 MV, 18 MV w/o flattening filter

Electron source: 18 MeV , 18 MeV w/o scatter foil

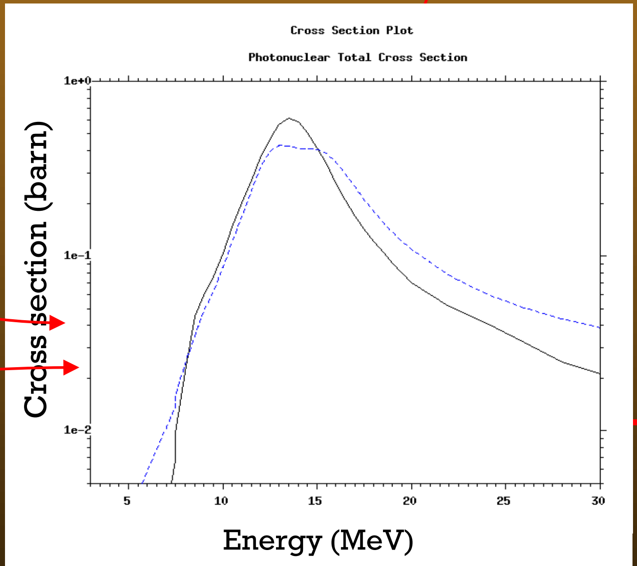
O. Sans Planell – UniTo

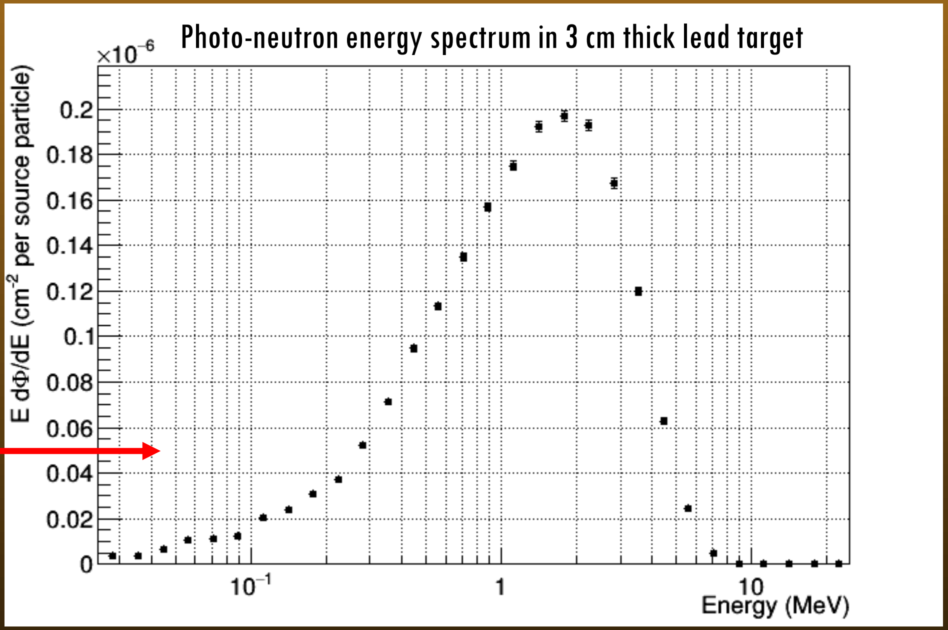
PHOTON – NEUTRON PRODUCTION

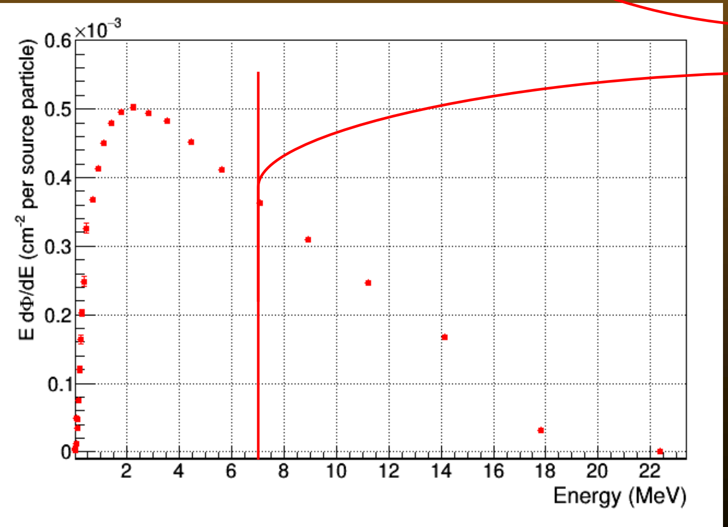
O. Sans Planell – UniTo



$$\int_0^{\infty} \sigma_{abs}(E_y)\, dE = \frac{\pi e^2 h}{MC} \cdot \frac{NZ}{A}$$





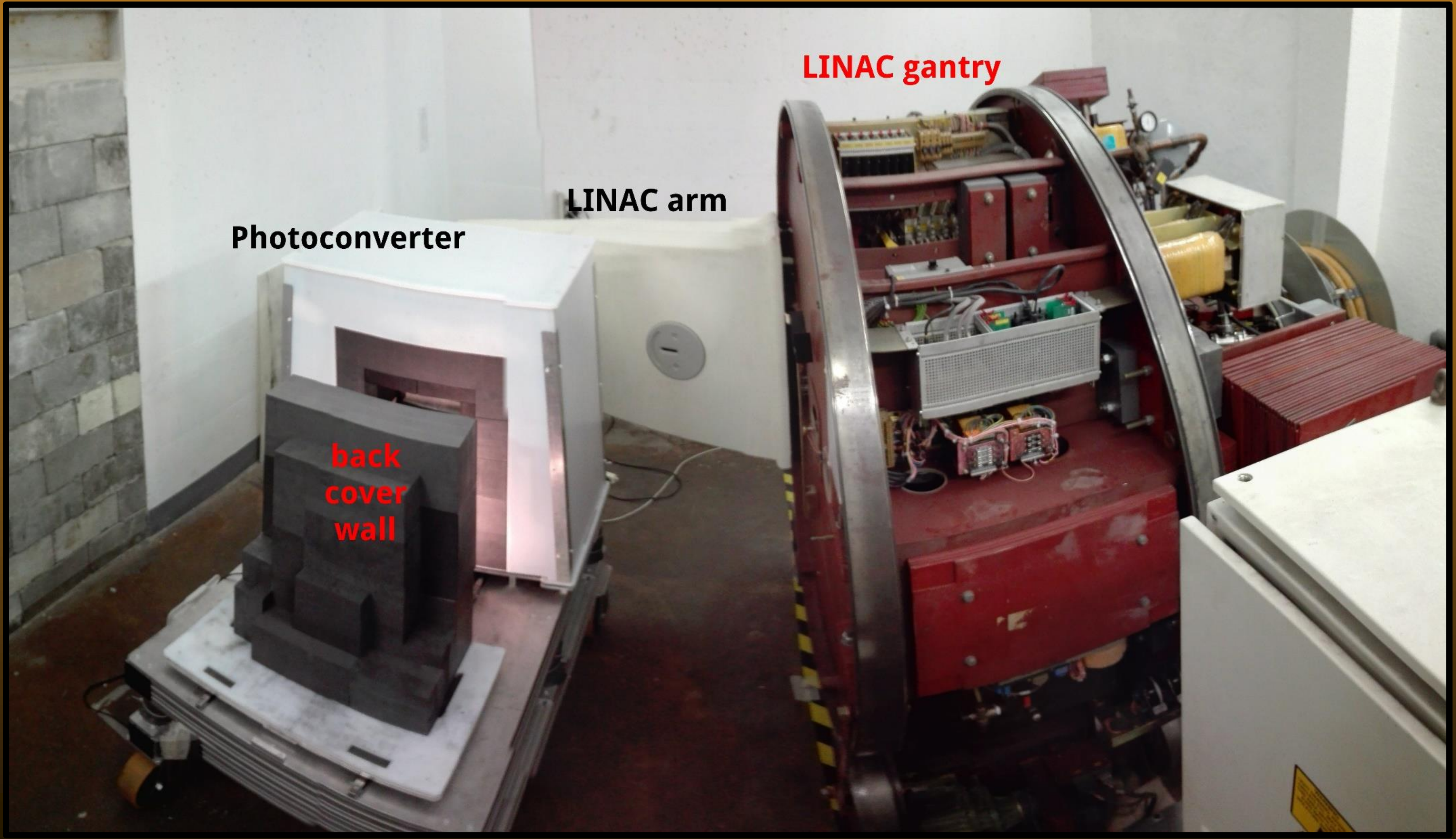


E_{thr} = 7MeV

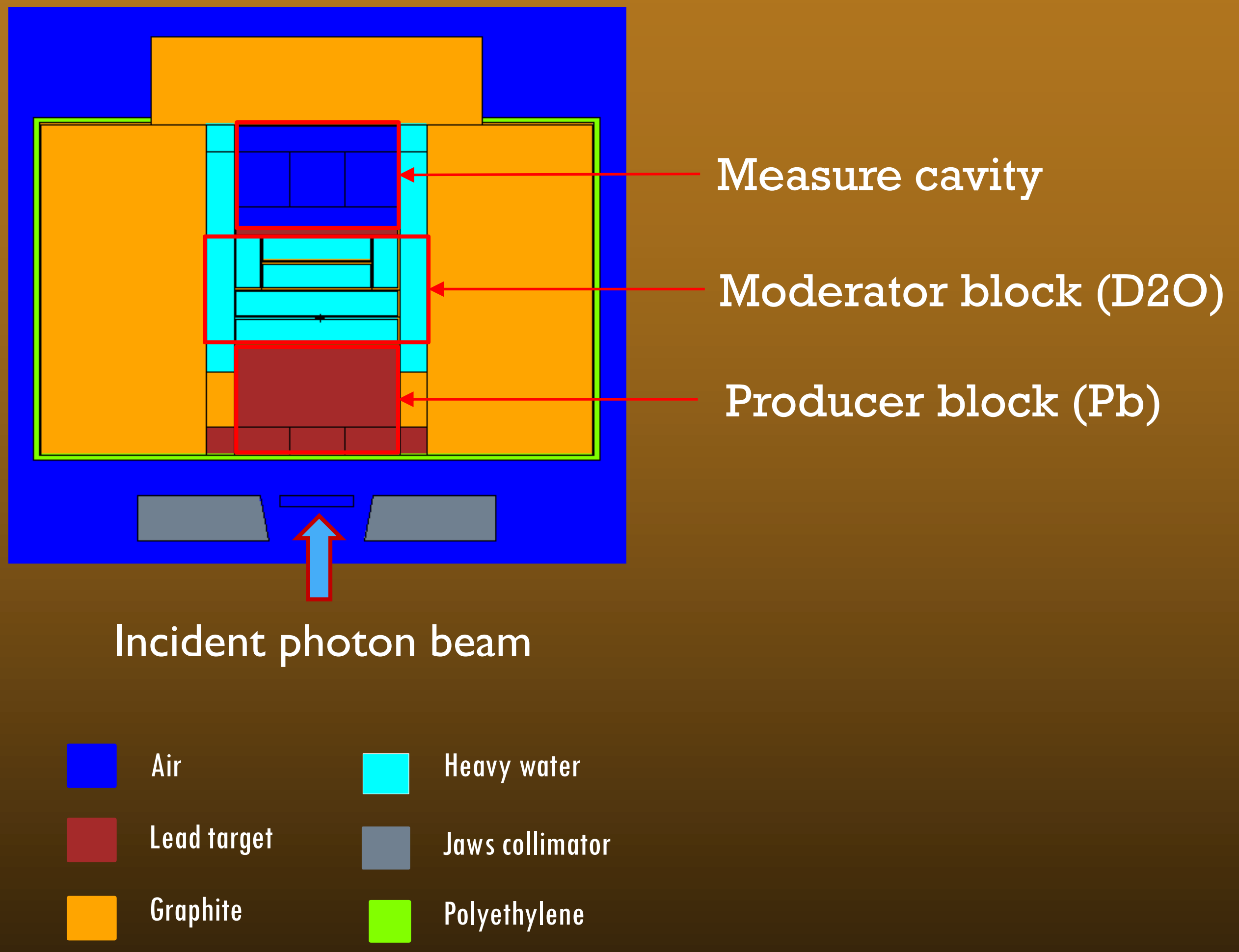
Typical neutron evaporation spectrum

THE NEUTRON FACILITY IN TORINO

O. Sans Planell – UniTo



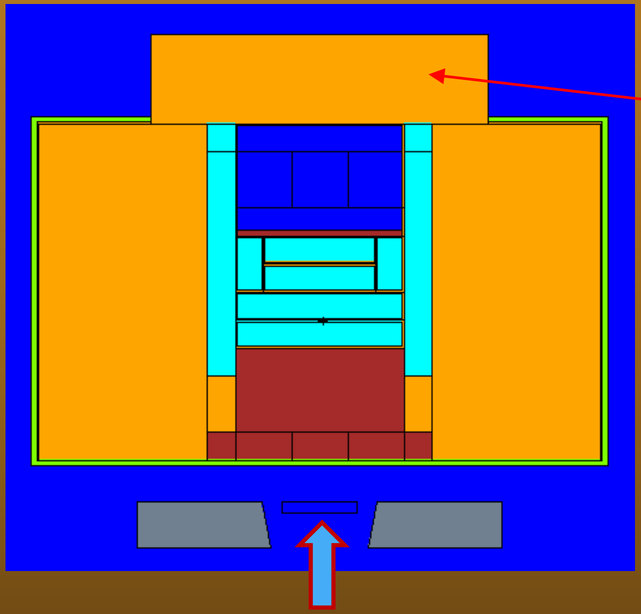
THERMAL NEUTRON PHOTOCONVERTER



O. Sans Planell – UniTo

THERMAL NEUTRON PHOTOCONVERTER

O. Sans Planell – UniTo

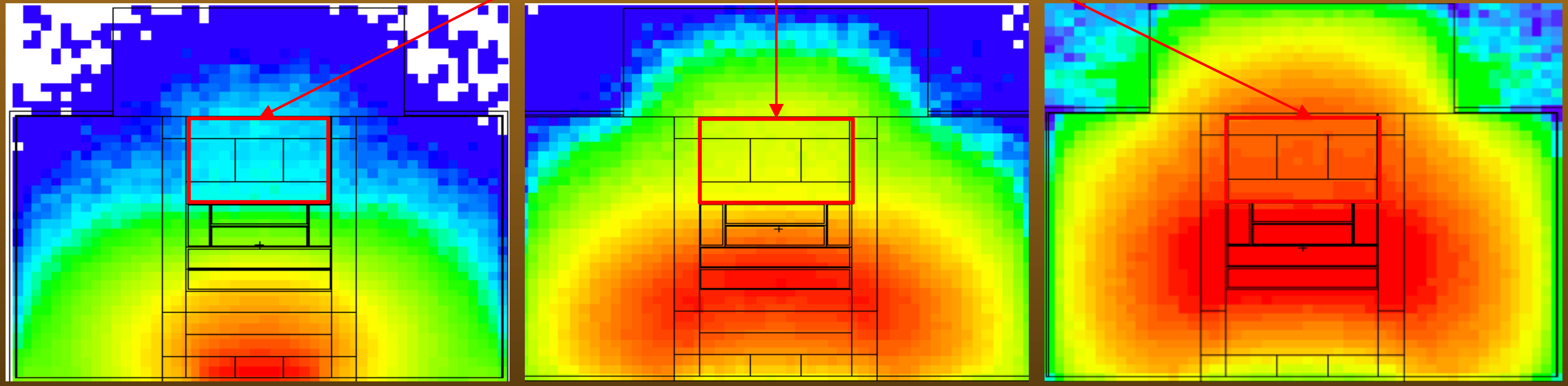


Incident photon beam

- Air
- Lead target
- Graphite
- Heavy water
- Jaws collimator
- Polyethylene

Open or closed cavity for different experiments

Measure cavity

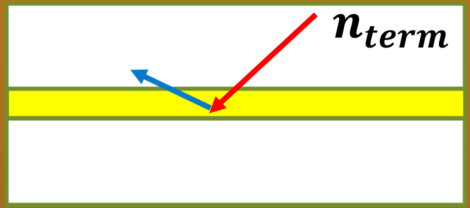


Fast neutron fluence | Epithermal neutron fluence | Thermal neutron fluence

- maximize thermal fluence rate in the cavity Φ_{th} [$cm^{-2}s^{-1}$]
- optimize energy spectrum shape
- optimize spatial field uniformity
- reduce fast neutron contamination (Φ_{fast}/Φ_{total}) (D_{fast}/D_{tot})
- minimize gamma contamination (Φ_{γ}/Φ_{th}) (D_{γ}/D_{th})

DEVELOPMENT OF NOVEL COMPACT NEUTRON DIAGNOSTICS

THERMAL NEUTRON RATE DETECTOR (TNRD)



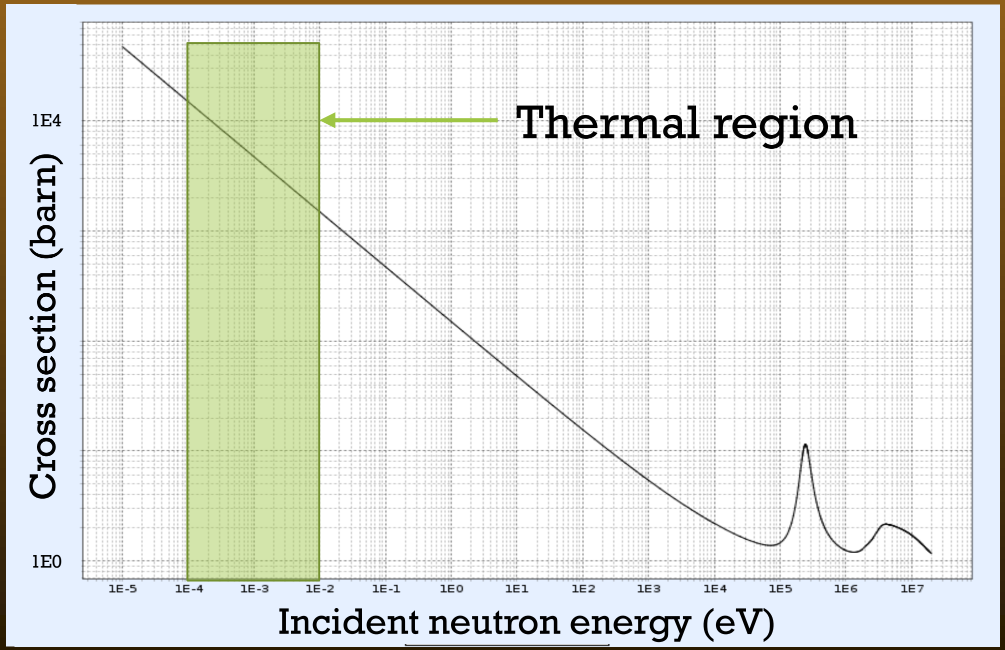
Si Diode 1 = Signal + Background

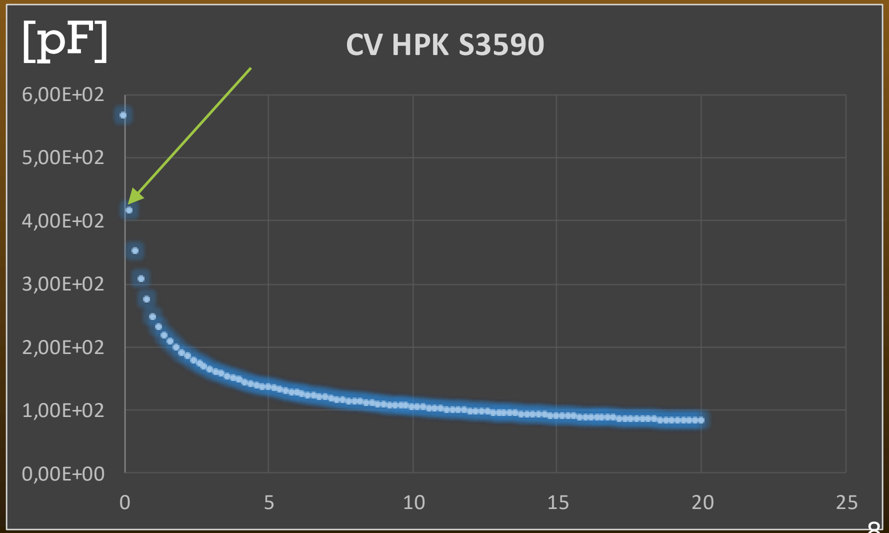
^{6}LiF Active layer

Si Diode 2 = Background

$$^{6}_{3}Li + n \rightarrow \ ^{3}_{1}H(2.73\ MeV) + \alpha(2.05 MeV)$$

- Differential readout
- Minimal gamma sensitivity
- Unbiased (20μm depletion depth by the pn contact potential)
- <u>It can work in a pulsed field (Linac RF)</u>
- Linear response on a wide fluence range





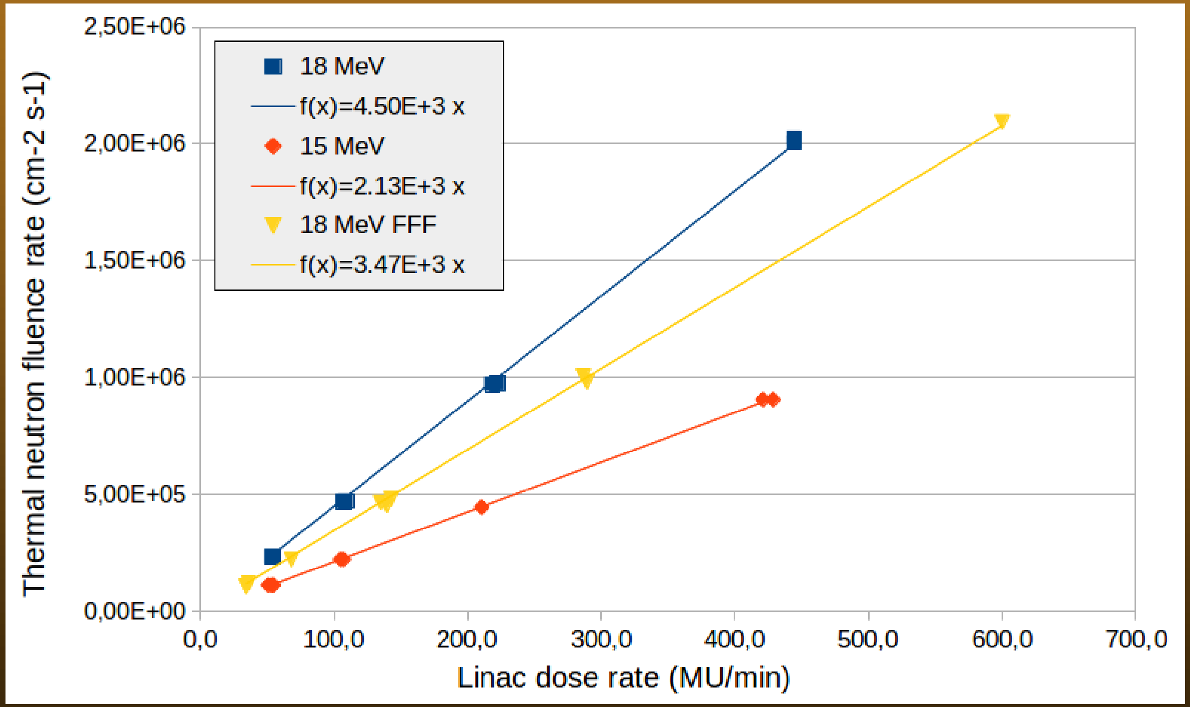
Bias Voltage

[1] Bedogni et al.,Radiat. Prot. Dosim. (2014) 161 241-244

THERMAL NEUTRON RATE DETECTOR (TNRD)

O. Sans Planell – UniTo

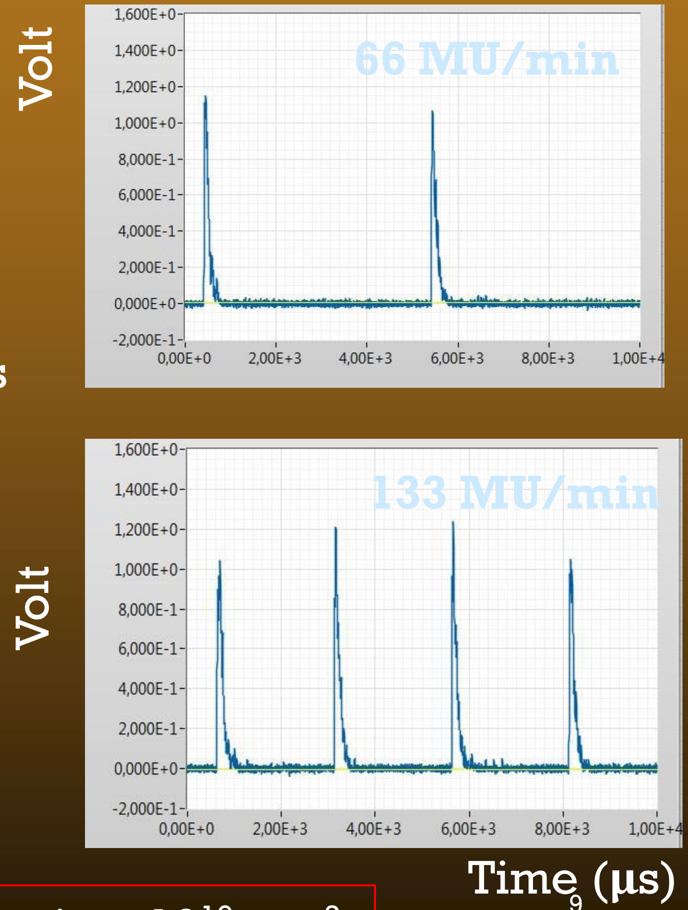
Linear dependence of the neutron fluence rate on the linac dose rate (MU/min) and on the linac energy



e-Linac pulses

↓

neutron pulses in the cavity



Active thermal neutron fluence meter

Radiation resistance circa 10^{10} cm^{-2}

BONNER SPHERE SPECTROMETER WITH TNRD

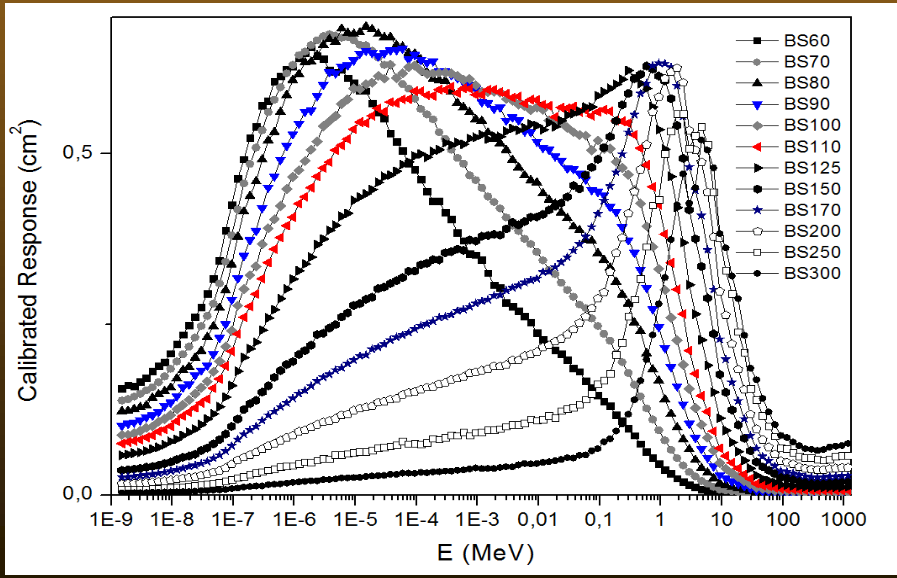
O. Sans Planell – UniTo

BSS to measure the neutron energy spectrum:

- Capable of reading up to 11 orders of magnitude of energy
- Calibrated at NPL + ENEA FNG
- Insensitive to LINAC RF
- Sequential exposition of the spheres in the cavity
- Unfolding of the detector readings

$$M_i = \sum_{j=0}^{n} R_{ij}\Phi_j$$

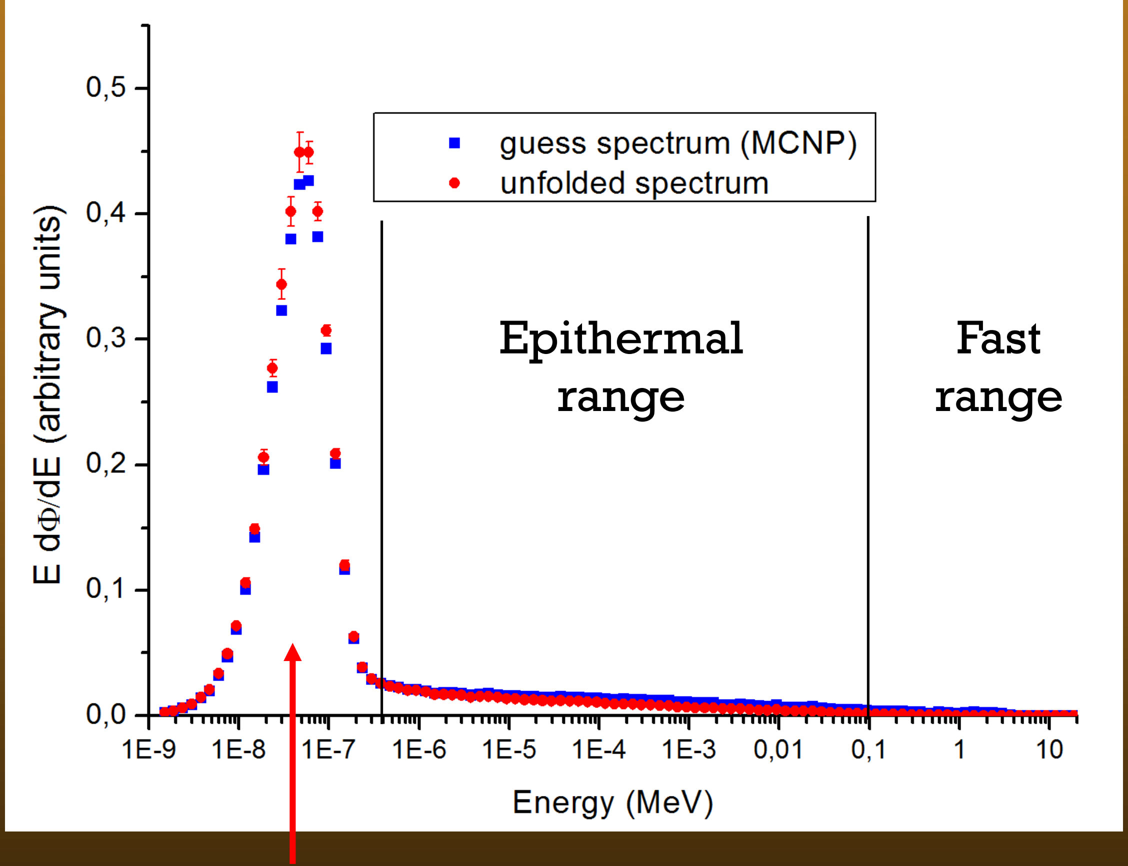
Bonner Spheres System (BSS)



Response curves for Bonner Spheres + TNRD system

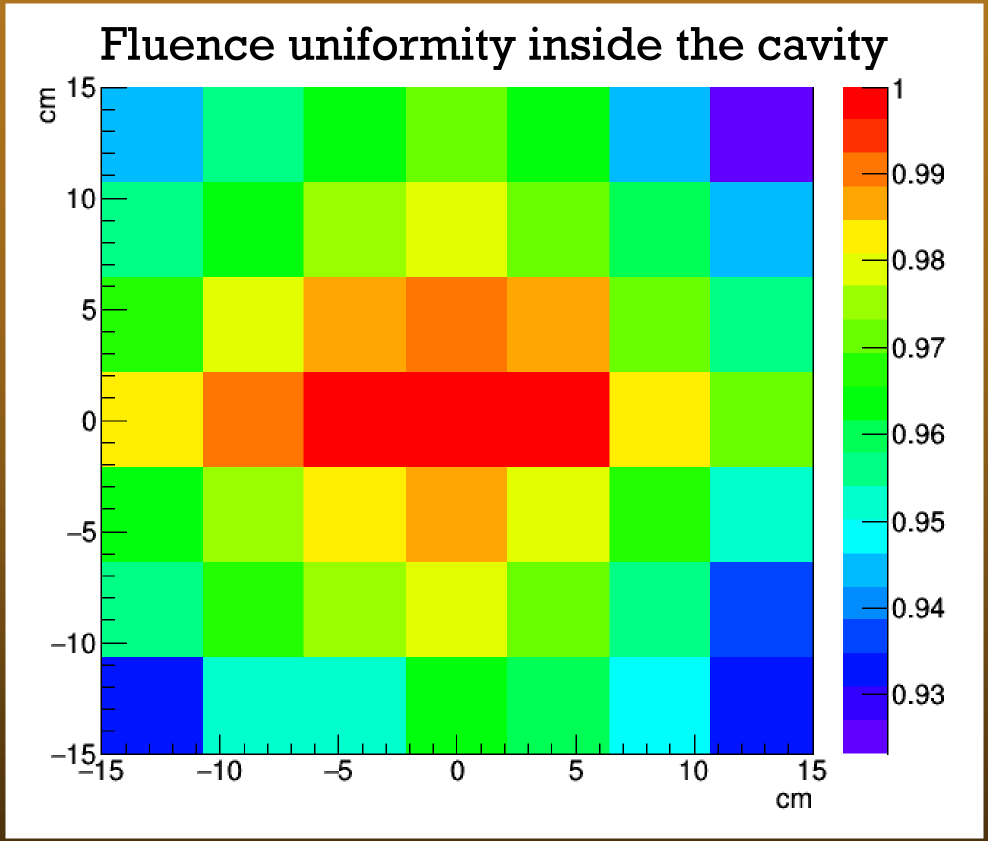
THERMAL CAVITY SPECTRUM

O. Sans Planell – UniTo



True thermal neutron fluence rate:

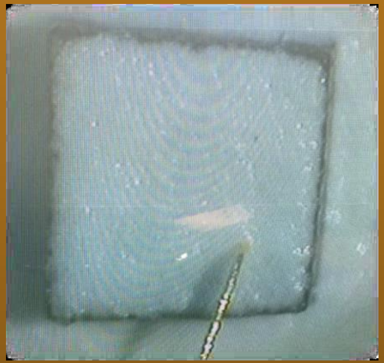
$$\Phi_{th} = (2.07 \pm 0.07)10^6\ cm^{-2}\ s^{-1}$$



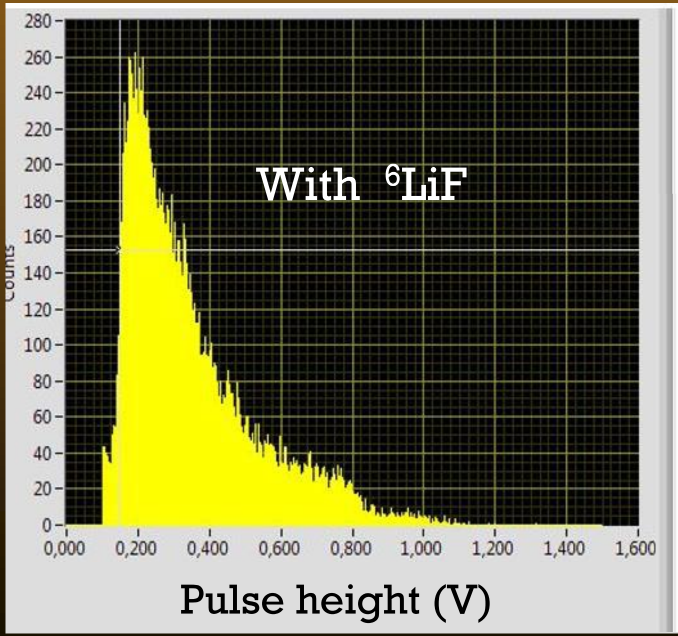
	TNRD	MCNP6
Maximum deviation	7%	8%
Standard deviation	2%	2%

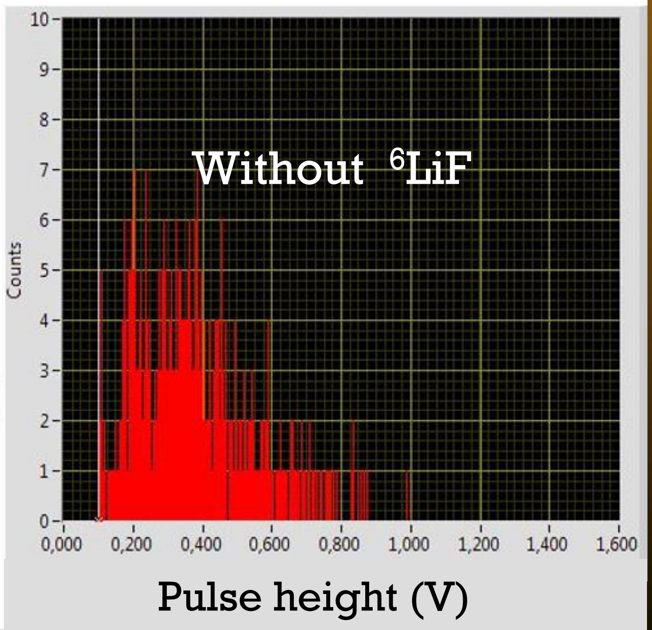
SILICON CARBIDE DETECTORS

- SG01XL by SGLux gmbh
- 7.6mm^2 active area
- More radiation resistant than TNRD



Silicon Carbide Matrix
10x10cm^2





O. Sans Planell – UniTo

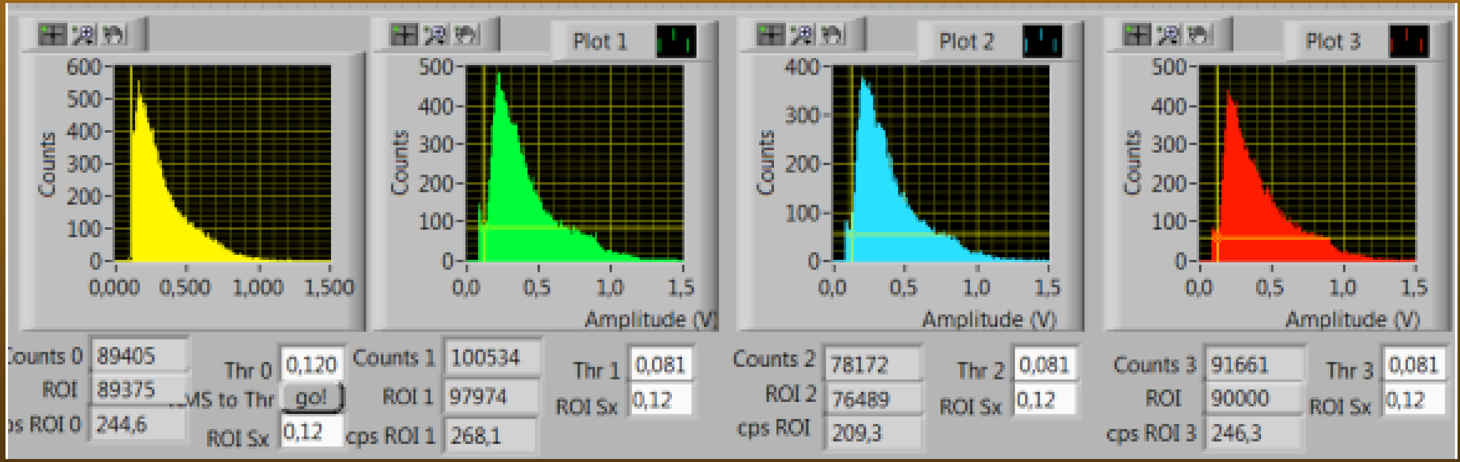
SILICON CARBIDE MATRIX

- 10 x 10 cm field of view
- Capability to work unbiased
- Radiation resistant up to 10^{13} cm^{-2}
- Can be read both in impulse or in current mode
- Minimal photon sensitivity
- Linear response

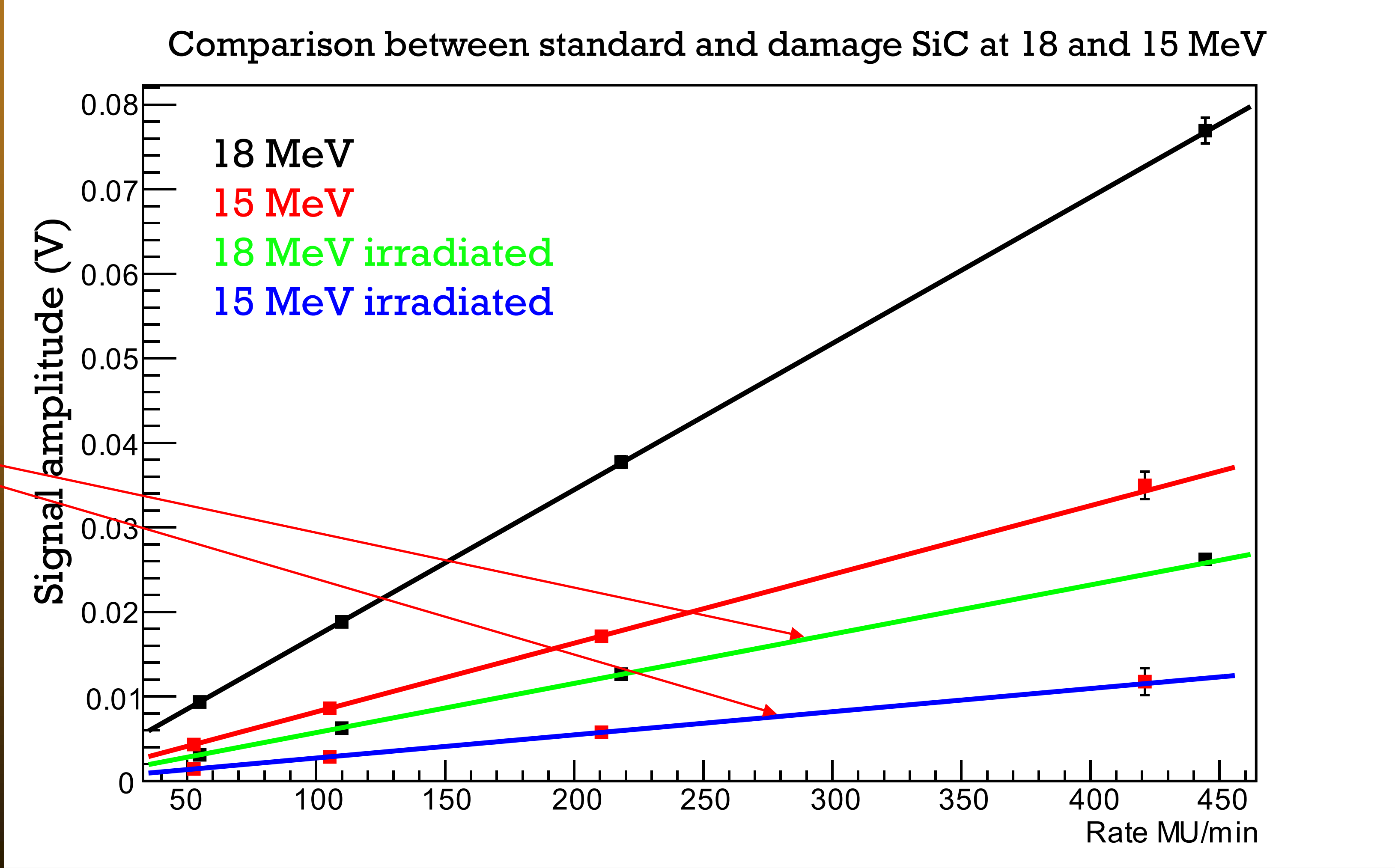
O. Sans Planell – UniTo

SILICON CARBIDE MATRIX

O. Sans Planell – UniTo



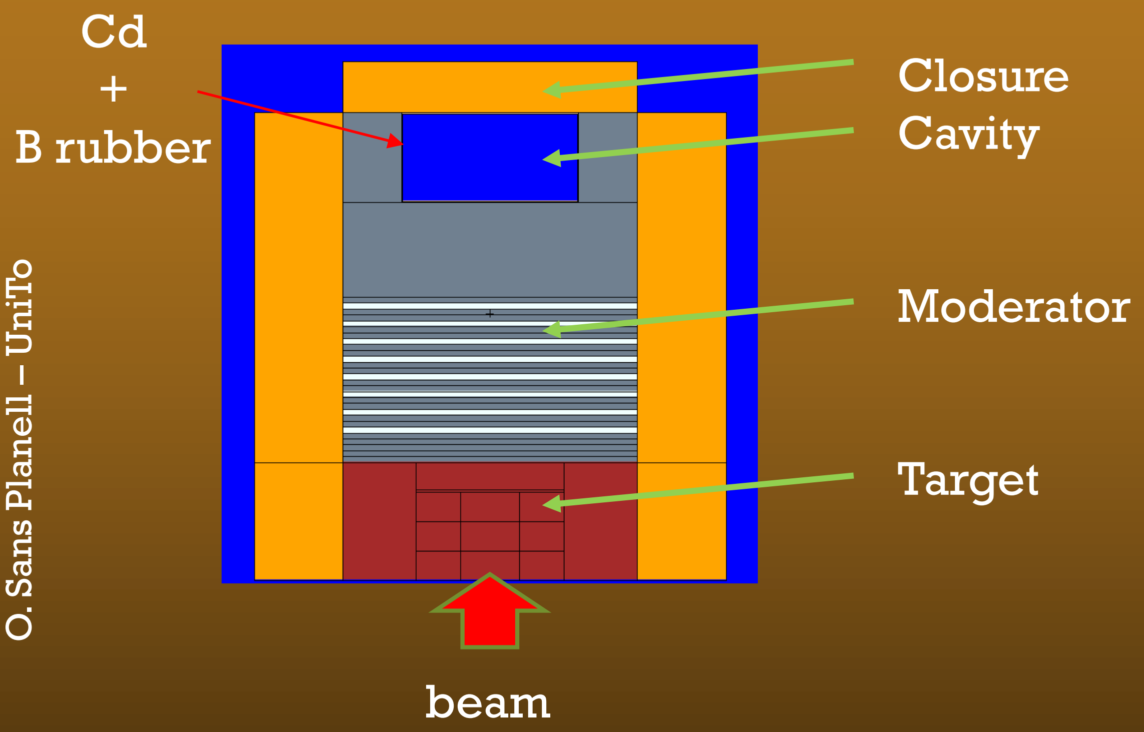
SILICON CARBIDE DETECTORS

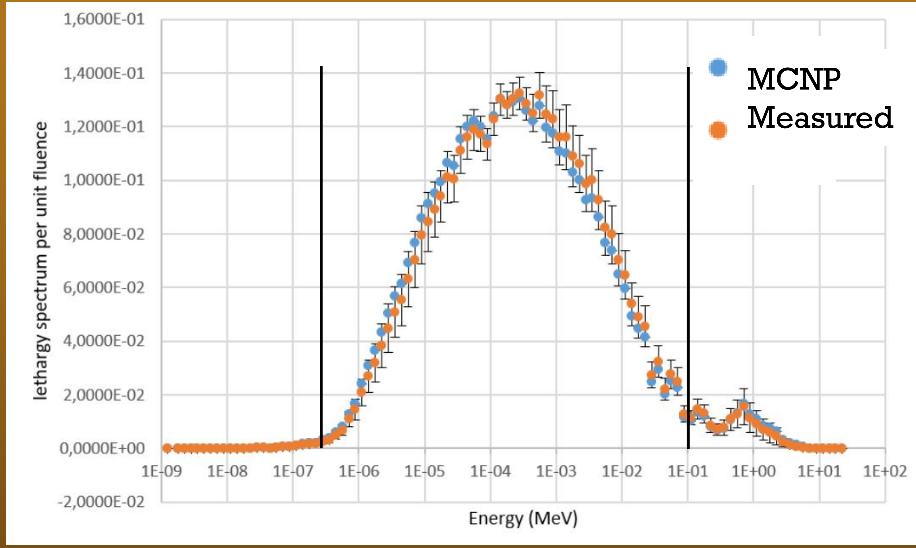


O. Sans Planell – UniTo

EPITHERMAL NEUTRON PHOTOCONVERTER

0.4eV < E < 0.1MeV





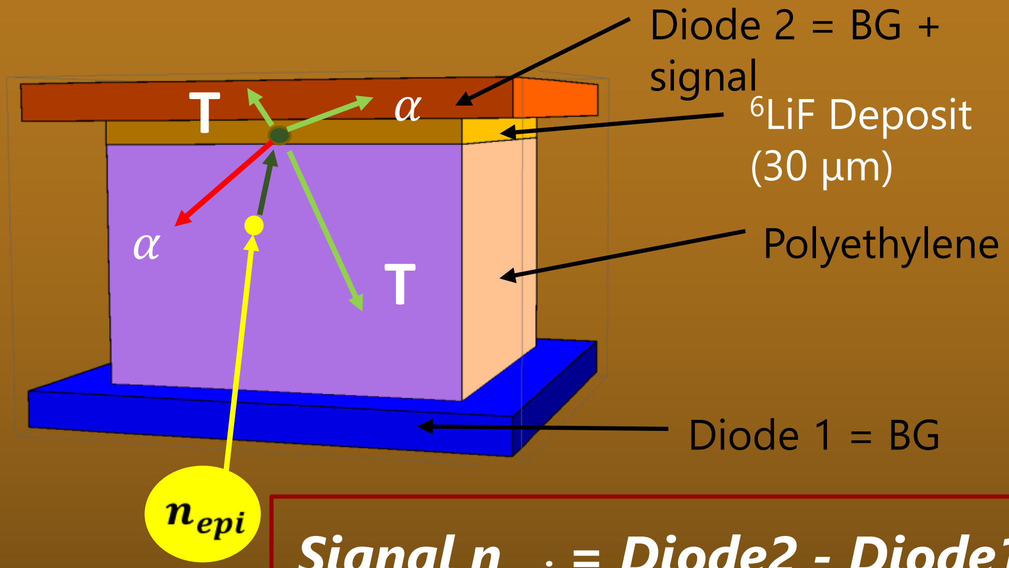
Aluminium and Teflon complement their cross section resonances in the epithermal region

	Measures + FRUIT	MCNP6
Thermal	0.25 %	0.38 %
Epithermal	88.9 %	88.5 %
Fast	10.8 %	11.1 %

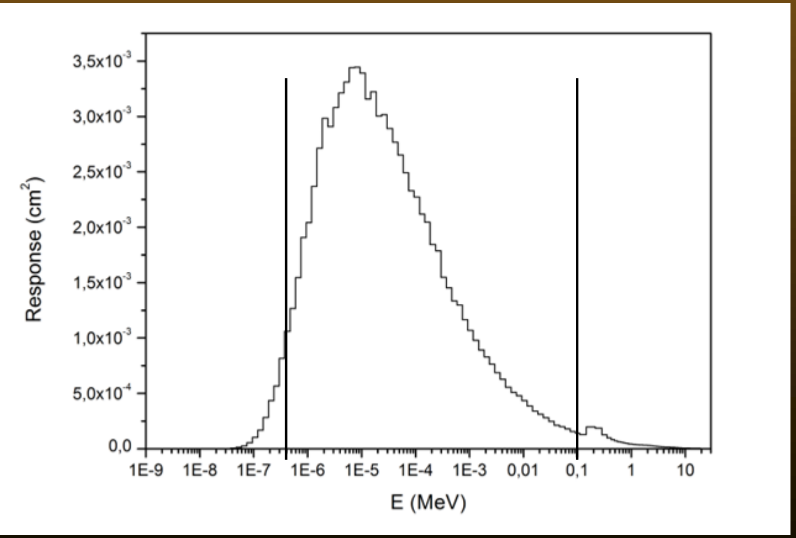
$$\phi_{epi,true} = (8.98 \pm 0.03) \cdot 10^4 \ \text{cm}^{-2}\text{s}^{-1}$$

O. Sans Planell – UniTo

DEVELOPMENT OF EPITHERMAL NEUTRON DETECTOR



Signal n_{epi} = Diode2 - Diode1



Neutron active detector

- Moderation based
- 1 diode with ^{6}LiF, 1 diode w.o.
- 1 cm^3 di polyethylene
- overall size is 4.5 x 3 x 2 cm^3
- Calibrated in the Turin facility

O. Sans Planell – UniTo

CONCLUSIONS

- The **NEW e_LiBANS facility** in Torino provides easy accessible, intense and homogeneous neutron fields, tunable in intensity by varying the beam current and energy
- Typical values in the *cavity's central position, 18 MeV, 400 MU/min*:

$$\Phi_{th} = (2.07 \pm 0.07)10^6\ cm^{-2}\ s^{-1}$$
$$\Phi_{Epi} = (8.98 \pm 0.3)10^4\ cm^{-2}\ s^{-1}$$

- **Thermal and epithermal neutron detectors were developed**: main process is a well controlled ^6LiF deposit developed in Frascati on Si/ SiC devices (satisfactory n/g, sensitivity scales with area, able to work in pulsed fields, good linear response)
    - **Bonner Sphere Energy Spectrometers with TNRD** can span thermal up to 20 MeV neutron energy in pulsed or continuous field.
    - **4 x 4 matrix of SiC's** as active thermal neutron field uniformity monitor with scalable architecture
        - More radiation resistant than TNRD with a neutron to photon sensitivity of 10^{-4}.
        - After 5×10^{13} n cm^{-2} the linear response in energy and rate is kept (factor 3 of efficiency loss).
        - Radiation resistance studies ongoing.
    - **Novel EPI3** Active compact epithermal fluence-meter.

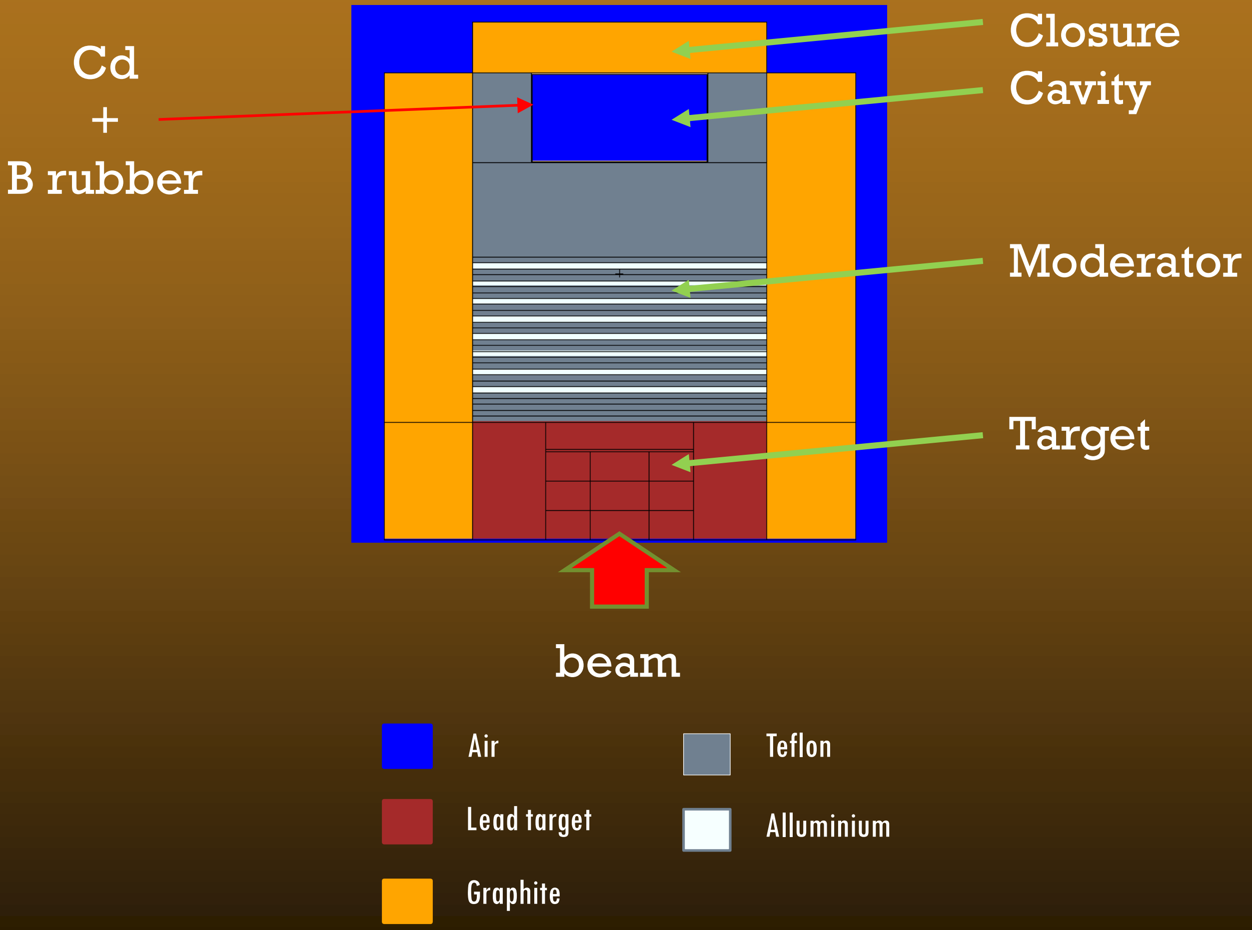
O. Sans Planell – UniTo

Thanks to all e_LiBANS group

EPITHERMAL NEUTRON SOURCE

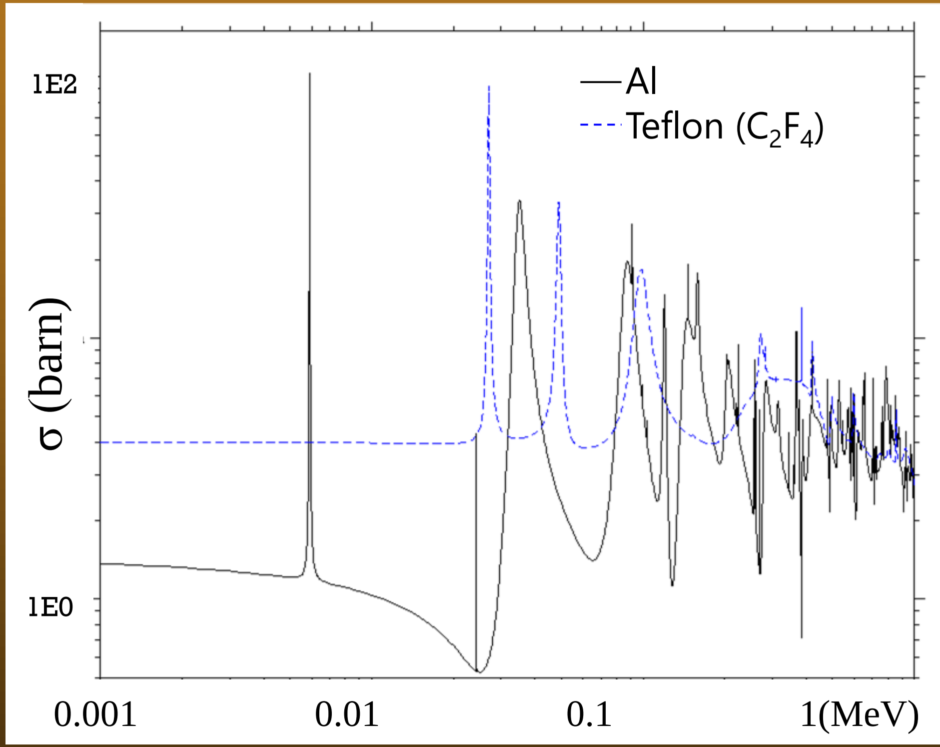
EPITHERMAL NEUTRON PHOTOCONVERTER

O. Sans Planell – UniTo



EPITHERMAL NEUTRON PHOTOCONVERTER

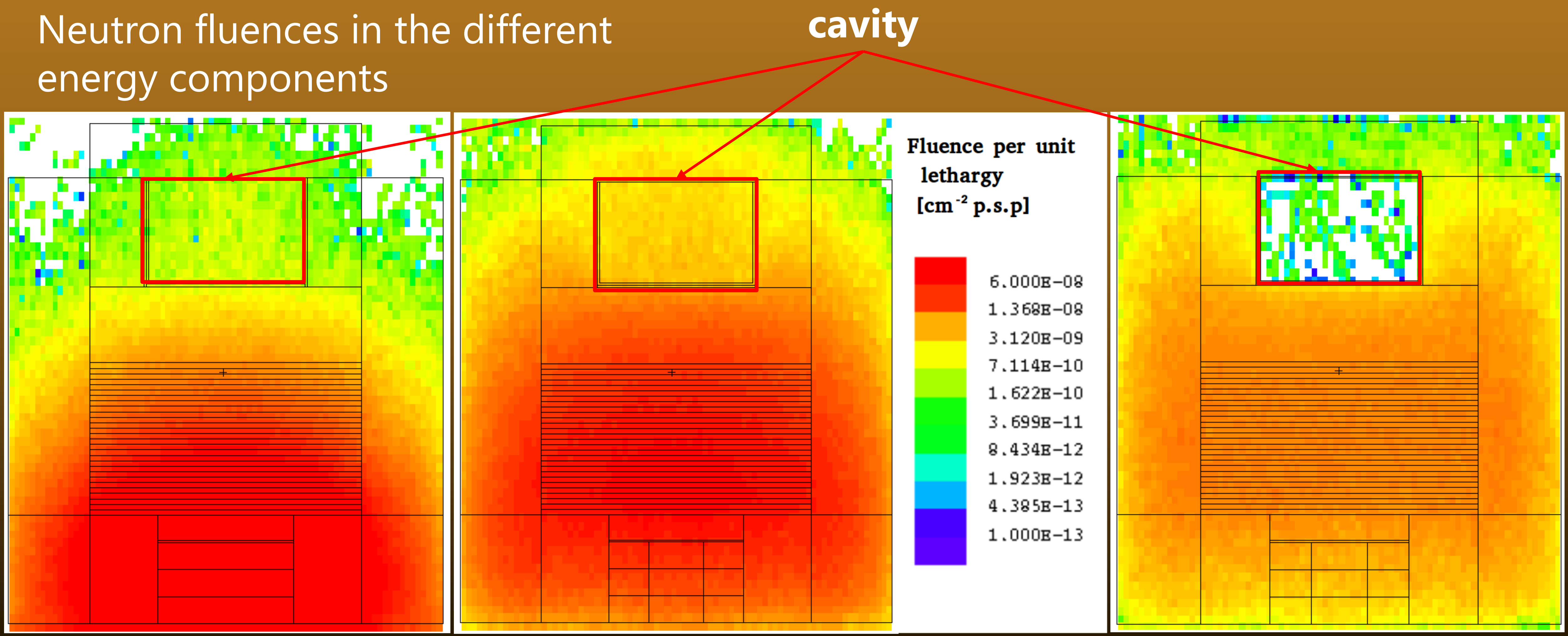
O. Sans Planell – UniTo



Aluminium and Teflon complement their resonances in the epithermal region

EPITHERMAL CONVERTER MCNP SIMULATIONS

Neutron fluences in the different energy components

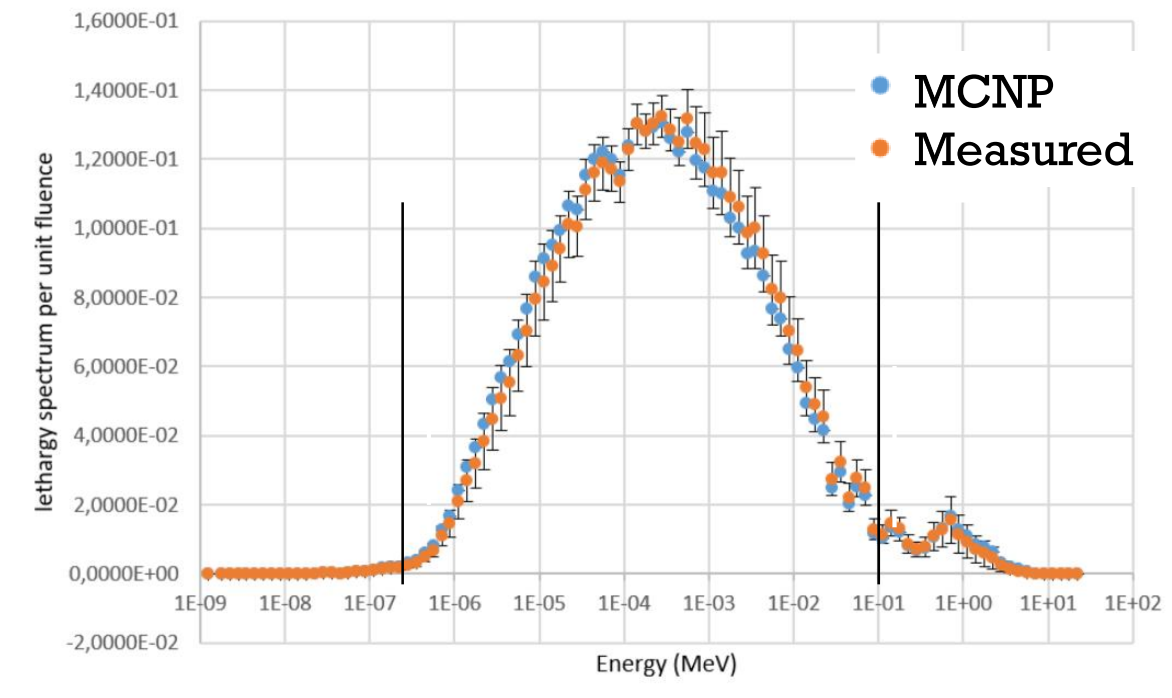


Fast *Epithermal* *Thermal*

EPITHERMAL CAVITY BSS MEASUREMENTS

O. Sans Planell – UniTo

CAVITY double BR
0.7 thick Cd layer on front surface
4 mm Borated rubber 25% B doped
3mm Borated rubber $^{10}B+^{11}B= 7.9\%$



	Measures + FRUIT	MCNP6
Thermal	0.40 %	0.38 %
Epithermal	88.2 %	88.5 %
Fast	11.4 %	11.1 %

γ /**n**= 0.85

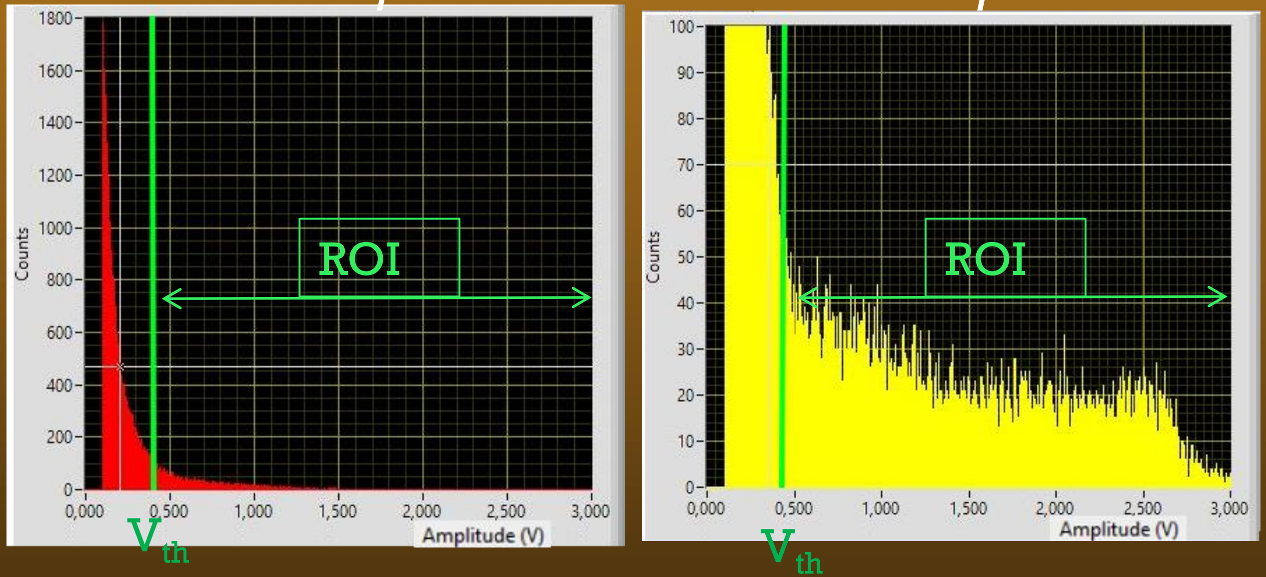
$$\dot{\phi}_{epi,true} = (8.98 \pm 0.03) \cdot 10^4 \text{ cm}^{-2}\text{s}^{-1}$$

EPITHERMAL DETECTOR

O. Sans Planell – UniTo

- **First use of an epithermal active device**
- Pulse mode configuration
- Differential readout
- Linearity with dose rate (MU/min)

w.o 6Li deposit *w. 6Li deposit*



Dose Rate [MU/min]	Diode 1 [entries]	Diode 2 [entries]	Difference/MU [MU^{-1}]
200	17206	6260	50.21
55	15947	6560	46.94
109	15887	6471	47.08
200	15666	5659	50.04
440	15592	6252	46.7

The device shows a linear response when varying the dose rate given by the source.