Low Background Neutron Monitor

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Financed by brightnESS: WP4 detectors
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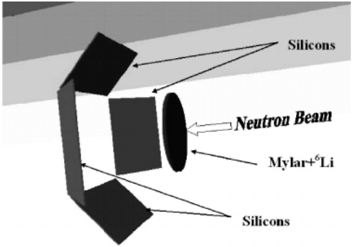
In-beam Neutron Monitors

- Gaseous detectors - most used
  MWPCs - fission chambers - GEMs
  2 vacuum windows are necessary
  ($\sim$ 1 mm aluminium each)
  Usually, detector thickness of the order of cm
- Others
  Scintillators, solid state detectors
  Usually, selfstanding Variable designs and materials
  Current posposal:
  Solid struture not breaking the vacuum
  Converter: B_4C or lithium compound
  Substrate not necessarly of metal

Neutron Monitors at ESS for Normalization

1. Radiation hard devices: life span of 10 years (> 10^{10} $n_{th,cold}/cm^2/s$)
2. Able to sustain high count rates
3. Low perturbation of the neutron beam
4. price ∼ 10 k€

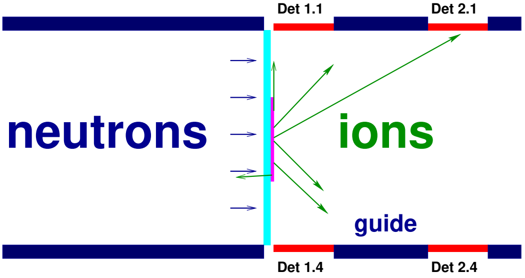


Development of a low interaction, low background monitor able to be coupled to a fast readout

The CERN experiment n_TOF uses since **20 years** monitors based on a thin layer of neutron converter in beam and ion detection on silicon detectors. Legnaro uses **MCP** as ion beam monitors.

Solid State Monitor for ESS

No vacuum windows	Thin materials in beam
Scattering reduction	Low mass approach: Only a solid substrate ($\sim$ μm) + the converter ($\sim$nm)
Multiple efficiencies	Relatively thick converter ($\sim$ μm)
Avoiding gaps in the guides	The ion detector can be embedded in the reflectors of the guides.

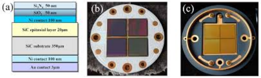


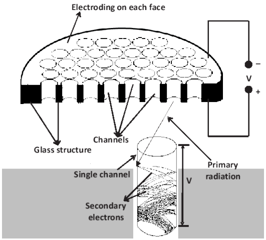
Design by MCNP simulations - BrightnESS

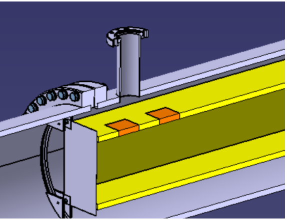
Substrate: Al foil (as thin as possible)
or **Kapton** (12.5 μm - 40 μm)
(reduction of the γ-ray production of a factor 100)

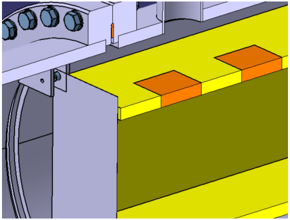
Converter: lithium compounds - $^{10}B_4C$

Detectors: **SiC** or rad hard Si
(low flux/efficiency solution)
(best accuracy)
Micro Channel Plates
(high flux/efficiency solution)









MCNP Simulations

Geometry

- MIRACLES neutron guide 12 x 12 cm^2
- Si detector 6 x 4 cm^2 x 300 μm
- Substrate: 300 μm Al or 40 μm Kapton
- Converter: variable thicknesses of ^{nat,6}Li, ^{nat,6}LiF, $^{nat,10}B_4C$
- Converter size: full area or fractions

Simulation approaches

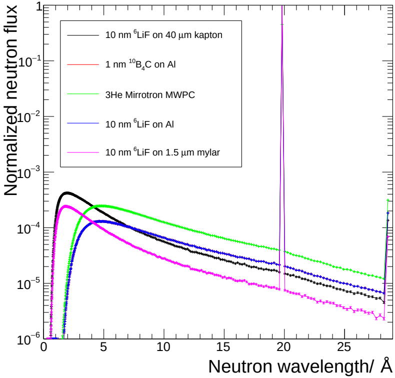
1. Thermal neutron source, MCNP simulating the capture and tracking all products ($^{10}B_4C$, ^{6}LiF)
2. Neutron tracking decoupled by the ion tracking
3. γ-ray background: monoenergetic 4.5 MeV source [Ni(n,γ)] 10 % of the neutron flux

Considerations:

- Detection energy spread due to electronics ignored
- Si dead layer not considered

MCNP Simulations of a $\varepsilon = 10^{-5}$ Monitor. 2 π source

Interaction of 20 Å neutrons with 40 μm kapton or 300 μm Al + deposits



^{6}Li/^{nat}Li
^{6}LiF/^{nat}LiF
$^{10}B_4C$ /$^{nat}B_4C$
^{6}Li/^{6}LiF
^{6}LiF

	not interacting	perturbed
40 μm kapton	88.3 %	5.58 %
0.3 mm Al	93 %	1.53 %
1.5 μm mylar	93.5 %	3 %

Thicknesses

	2 π	straight beam
$^{10}B_4C$	1 nm	$\sim$
$^{nat}B_4C$	5 nm	
^{6}LiF	4 nm	x
^{nat}LiF	100 nm	
^{6}Li	6 nm	$3 \div 8$
^{nat}Li	160 nm	

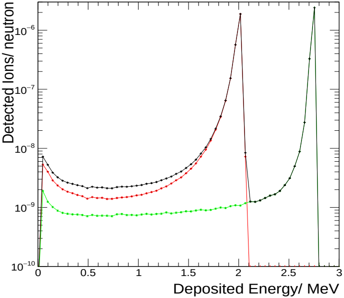
γ-ray background

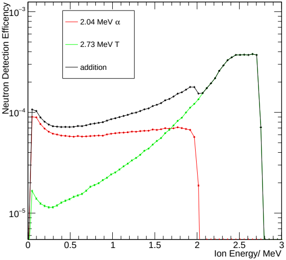
$$\frac{0.3\text{ mm Al} + B_4C}{40\ \mu\text{m kapton} + \text{Li}}\ \gamma\text{-yield} \sim 100$$

Accuracy of the Monitor: semiconductor detectors

- Evaluation of the % of the ions above the threshold
  Depends on
  - Ion struggling: detector position, thickness of the layer, size of the deposit
  - Separation between ion species is an advantange

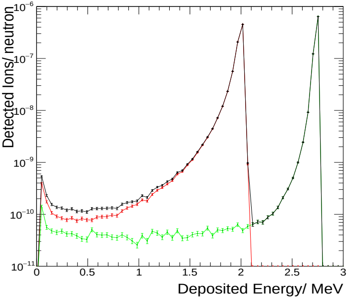
➡ Metallic lithium converter!!





(left) 5 μm ^{6}LiF detector in contact 4 nm ^{6}LiF
(right up) detector in contact

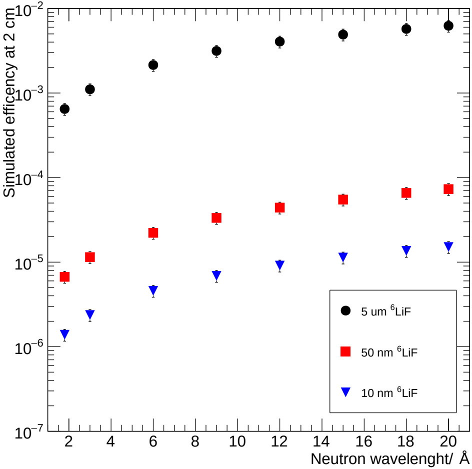
(right) detector 4 cm away



Examples of suitable thicknesses:

- **^{6}LiF 5 μm**
  $\varepsilon = 10^{-3}$ near, 10^{-6} at 30 cm
- **$^{10}B_4C$ 1 μm**
  $\varepsilon = 10^{-3}$ near, 10^{-5} at 30 cm

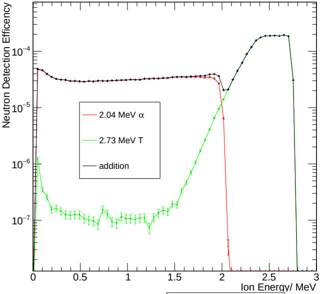
Neutron wavelength dependence



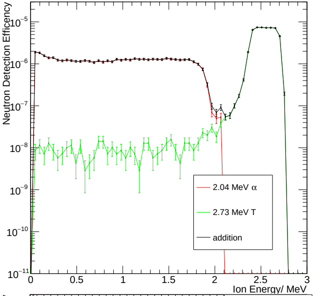
Thickesses for a detector at 2 cm

Ion Spectra for Two Efficiency Monitor

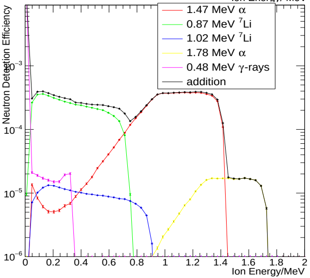
Detector at 4 cm

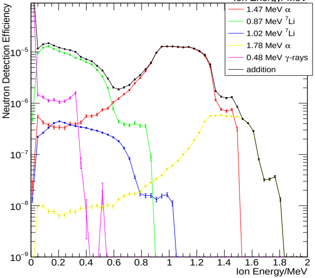


Detector at 30 cm



5 μm ^{6}LiF
10^{-2}mbar

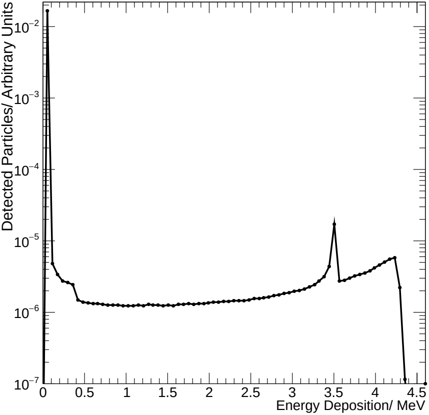




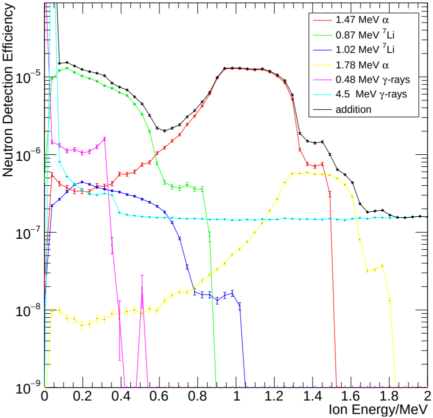
1 μm ^{10}B4C
10^{-2}mbar

Detection of the γ-ray background in silicon

Neutron capture in the guides generated 4.5 MeV γ-ray with an occurance equal to 10 % of the neutron flux



γ-ray pulse height spectrum



Simulation of the γ-ray background for a detector seeing 1 μm of ^{10}B4C at 30 cm distance

Conclusions and Futher Developments

Conclusions

- The effect of the usage of plastic as substrate has been investigated
- Thicknesses generating different efficiencies determined for many converters
- Position of the detectors determined
- Effect of the γ-ray background on a silicon detector estimated
- Best converter if semiconductors are used: metallic lithium

Futher Developments

1. Define how to operate a MCP in low vacuum
2. Evaluate the γ-ray background detection in MCP
3. Design with SiC
4. Experimental tests
5. Prototyping

Contributors

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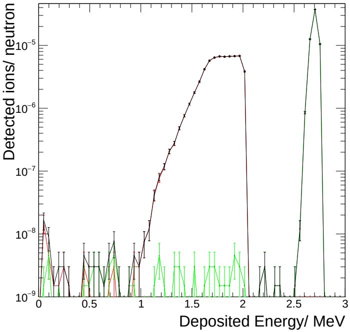
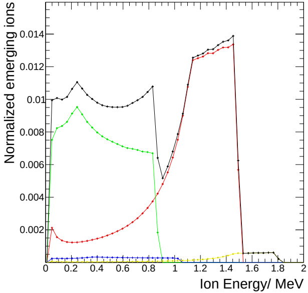
Thank you for your attention!

- n_TOF efficiency reproduced at 1 eV (them: 6 10^{-4} %, us: 5 10^{-4} %)
- Emerging ions/neutron for common B_4C layers

	thickness	Ions/n	Ions/ion
$^{10}B_4C$	1 μm	5.2 %	39 %
$^{10}B_4C$	0.5 μm	3.4 %	45 %
$^{nat}B_4C$	0.5 μm	0.8 %	45 %





Above: Ions detected in the SiMoN replica

Left: Ions emerging from 1 μm $^{10}B_4C$ & 0.5 μm $^{10}B_4C$