Low Background Neutron Monitor Project

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Istituto Nazionale di Fisica Nucleare

Laboratori Nazionali di Legnaro

Project steps

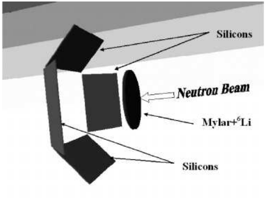
1. First **simulations** financed by **Brightness** 01/01/2018 - 31/09/2018
   - MIRACLES beam line geometry
   - Efficiency determination
   - Background evaluation
2. Developing the **ESS Bilbao source laboratory** since
   - 1 Ci Am/Be source
   - Alpha source for damage evaluation*
   - 5 mCi ^{137}Cs source
   - Calibration sources*
3. **Attract proposal** submitted together with ESS
4. ESS Bilbao **internal project** since 01/01/2019
5. A defined ESS-ESS Bilbao cooperation is encouraged
6. Other collaborations are welcome!

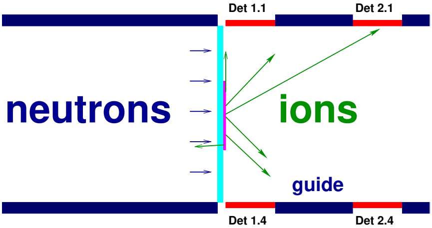
Neutron monitoring for ESS

- Variety of monitors for different necessities:
  1. TOF measurements (determination and calibration of flight path, chopper diagnostics)
  2. Spectral normalisation (possibily detection with **two efficiencies**)
  3. Transmission measurements (2d spatial detection)
- Variety of environments:
  - Monolith and bunker: Very high radiation ($\sim 10^{13}$ $n_{fast}/cm^2/s$ in the bunker)
  - Straight beam lines: Fast neutrons
  - Choppers: Vibrations
  - Beam lines and sample areas
- ESS monitors in general:
  1. **Radiation hard devices** ($> 10^{10}$ $n_{th,cold}/cm^2/s$) able to have a life span of 10 years
  2. Able to sustain **high count rates** and possibly variable efficiency
  3. **Low attenuation** of the neutron beam
  4. price $\sim$ 10 - 30 k€

Low Background, Time Resolution, Counting accuracy

Adaptation of the monitors installed at n_TOF
20 years of operation, ns TOF resolution, $< 2\ \mu$s dead time





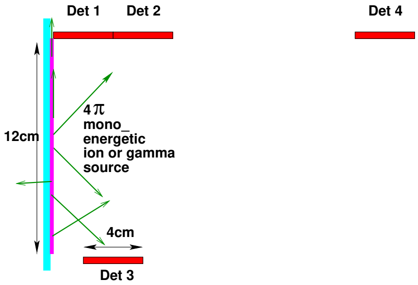
1. Low interaction:
   - 1 window of $\sim \mu$m thickness or **no additional window** if one is already present
   - (n, ions) converter $\sim$ 100 nm - few μm according to efficiency
   - ion detector embedded in the guides
2. Ion spectroscopy accuracy
3. Double efficency by using two ion detectors (different size or different position) or exchanging the deposit

Geometry

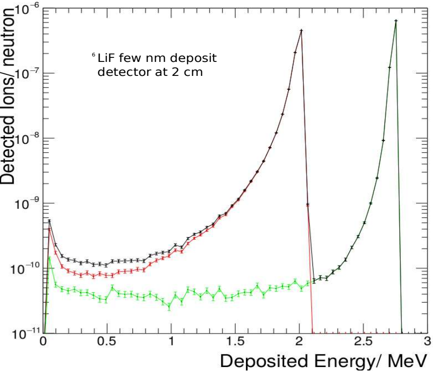
- MIRACLES neutron guide 12 x 12 cm^2
- Si detector 6 x 4 cm^2 x 300 μm
- Substrate: 300 μm Al or 40 μm Kapton
- Converter: variable thicknesses of $^{nat,6}Li$, $^{nat,6}LiF$, $^{nat,10}B_4C$
- Converter size: full area or fractions

Simulation approaches

1. Thermal neutron source, MCNP simulating the capture and tracking the ions
2. Neutron tracking decoupled by the ion tracking



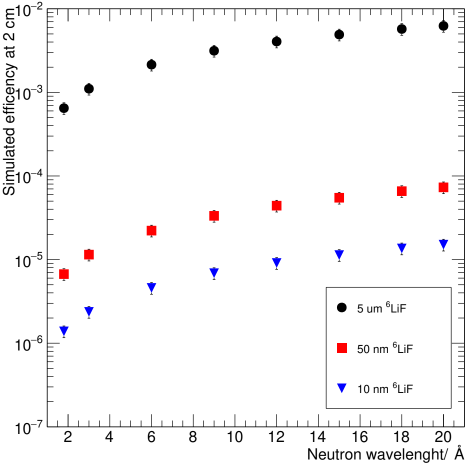
Efficiencies: $\varepsilon = 10^{-3}$ and 10^{-5}, 10^{-6}



Examples of thicknesses yielding double efficiency:

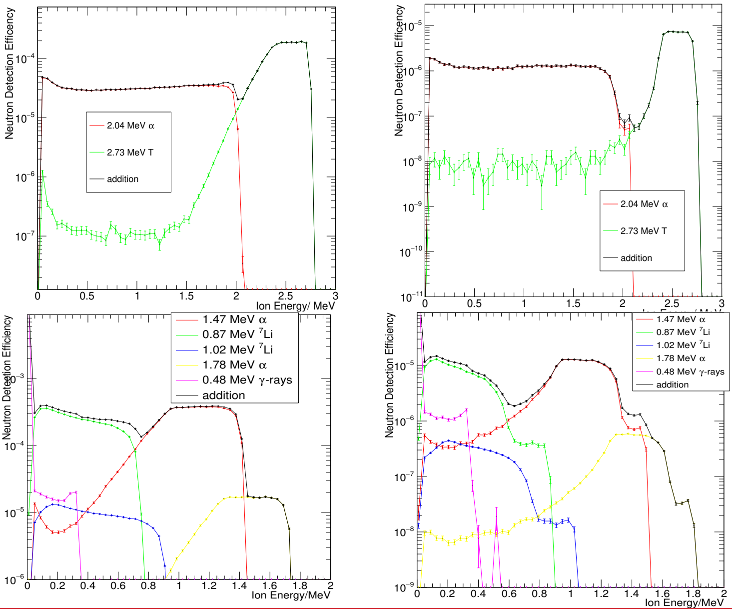
- ^{6}**LiF 5 μm**
  $\varepsilon = 10^{-3}$ near, 10^{-5} at 30 cm
- ^{10}**B$_4$C 1 μm**
  $\varepsilon = 10^{-3}$ near, 10^{-5} at 30 cm

Neutron Wavelength dependence



Detector at 2 cm

Ion spectra for two efficiencies detector

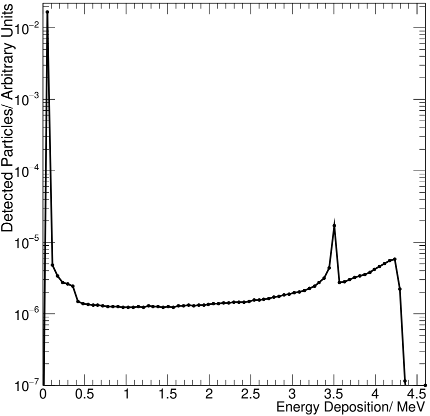


5 μm ^{6}LiF at 4 cm and at 30 cm 10^{-2}mbar

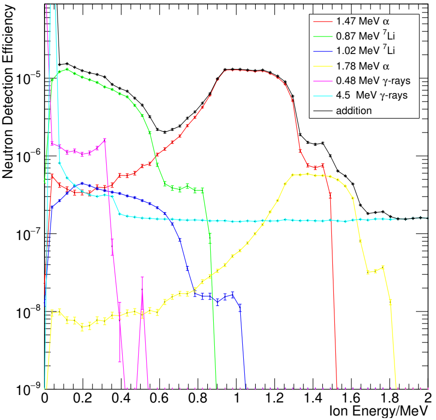
1 μm ^{10}B4C at 4 cm and at 30 cm 10^{-2}mbar

Detection of the γ-ray Background in Silicon

Neutron capture in the guides generated 4.5 MeV γ-ray generated considering the full beam impinging in the guides capturing with a 10% occurance.



γ-ray pulse height spectrum



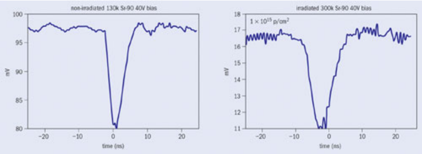
γ-ray background for a detector seeing 1 μm of ^{10}B4C at 30 cm distance

Design Based on Simulation Results

- If a window has to be: plastic (best mechanical properties, no bragg peaks, less γ-rays)
- **Natural lithium or lithium compound** converter ($\sim$ 500 nm thickness for ε 10^{-5})
- Efficiency range: 10^{-3} - 10^{-6} (detector dependant!!)
- Ion detector to be selected among:
  - Radiation hard silicon detectors
    1. Ion selection
    2. max 2 μs dead time at n_TOF
    3. well extablished technology
    4. radiation resistance has to be verified
  - SiC
    - Better radiation resistance
    - Small detectors
  - MCP
    - Ultra fast signal
    - No particle identification

Radiation Damage in Silicon

- Lattice damage
- Increase of noise and resistivity
- Dopant alteration



Cinzia da Via, *CERN courier*, 2003

ORTEC and MIRION 300-500 μm detectors for alpha spectroscopy

Threshold doses (particles/cm^2)

n_{fast}	p	α
10^{12}	10^{10}	10^{9}

300μm MSX03 MICRON SEMICONDUCTOR LIMITED

Survival doses (particles/cm^2)

1 MeV n_{eq}	p	α
10^{14}	10^{15}	*10^{11}*

CERN/BNL et al. studies describe how to obtain the last values.
Relevant to us: pixelation, use of thin detectors and cooling.

Experimental tests

1. Radiation damage

   if $\varepsilon = 10^{-5}$, 10^{11} ions in 30 years

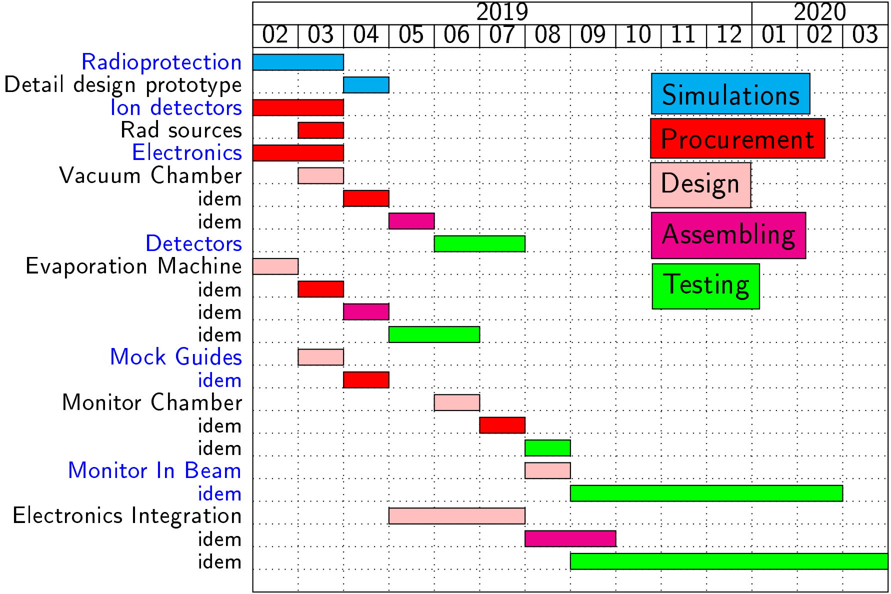
   10^{11} α particles can be delivered by an alpha source in a reasonable time

2. Energy resolution with α-sources
3. Background tests:
   - γ-ray sensitivity with sources
   - Effects of the neutron guide background during the in-beam tests of the prototype

Research Strategy

- Simulations in parallel with the prototype design
- Comparing all kind of detectors with alpha sources
- α resistance of the chosen silicon
- if lithium deposits cannot be delivered on-time: tests with B_4C deposits
- Tests of coulping the detectors and deposits at a neutron source source
- Prototype tested in a neutron beam line

Project schedule



Conclusions and further developments

1. A conceptual design of a neutron beam monitor has been performed according to ESS specifications
2. Ready to start procurements waiting for our licence for having sources
3. Ready to set the experimental tests
4. Even if radiation hard Si detectors are promising we will test other options
5. Define how to operate a MCP in low vacuum
6. Evaluate the γ-ray background detection in MCP
7. Prototyping

Contributors

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Thank you for your attention!