676548

Shielding Optimisation Against Intrinsic Scattered Neutron Background in Multi-Grid Detector

E. Dian,
K. Kanaki, X. X. Cai, R. Hall-Wilton, A. Khaplanov, P. Zagyvai

dian.eszter@energia.mta.hu
HAS Centre for Energy Research
European Spallation Source ESS ERIC

11 September 2018, IKON15, Lund

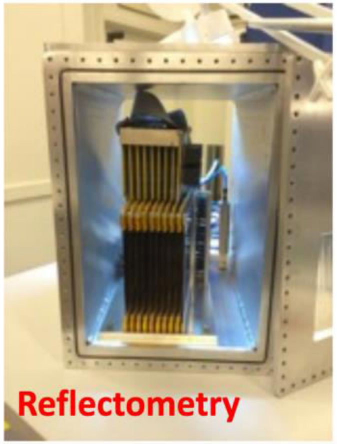
The ESS detector challenge

- Various detectors for various instruments at ESS
- All with **different designs**, all have to be **optimised** for respective instrument requirements

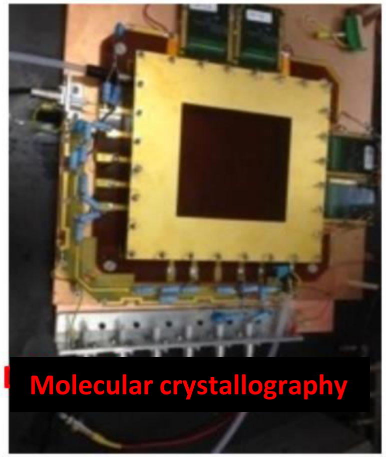
↓

Serious efforts made on
detector simulations
@ ESS DG

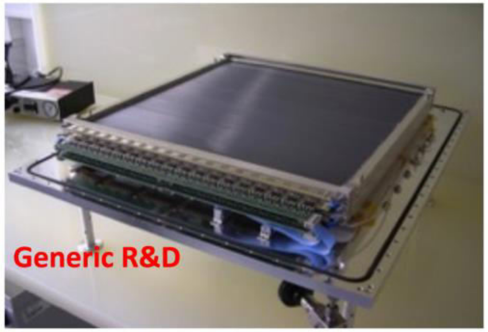
MultiBlade (ESS/Wigner/LU/LiU)



Gd-GEM (ESS/CERN/LiU)



B-MWPC/ Macrostructures (ESS/FRM2)



MultiGrid (ILL/ESS/LiU)

BandGEM (Milan/CNR/INFN/CERN/ESS)

Scattered neutron background – simulation tools

- **Great progress in neutron scattering simulation**
  - **Improved modeling** for neutron scattering on crystalline material (NXSG4, NCrystal)
  - **Effective particle interchange** (MCPL)
    - Easy to combine MC codes
  - ESS Coding Framework, where all tools are combined

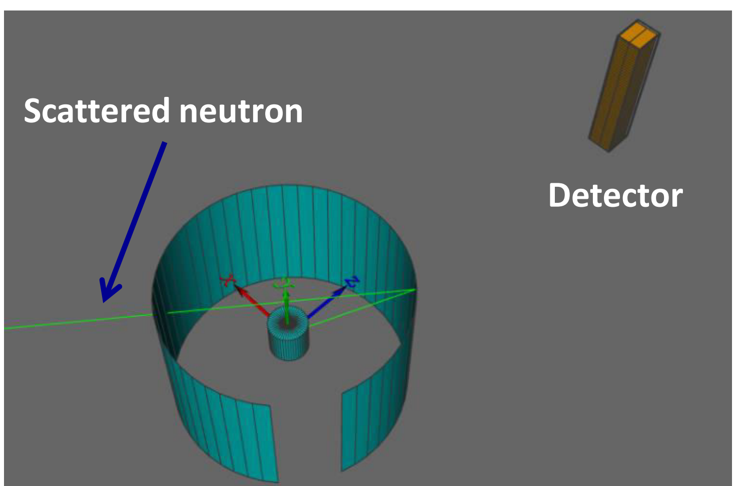
    ↓
  - **Full-scale instrument** simulation can be done with a single application

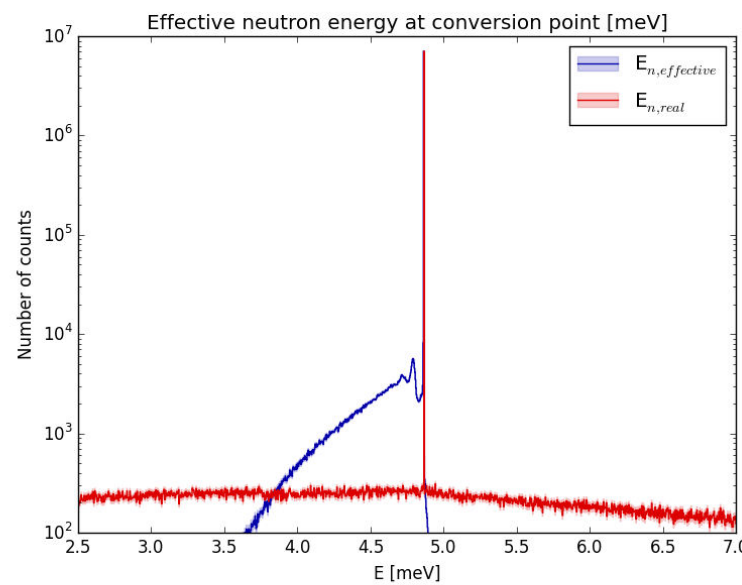
See T. Kittelmann's talk Tuesday 13:30

A powerful neutron simulation toolkit developed

↓

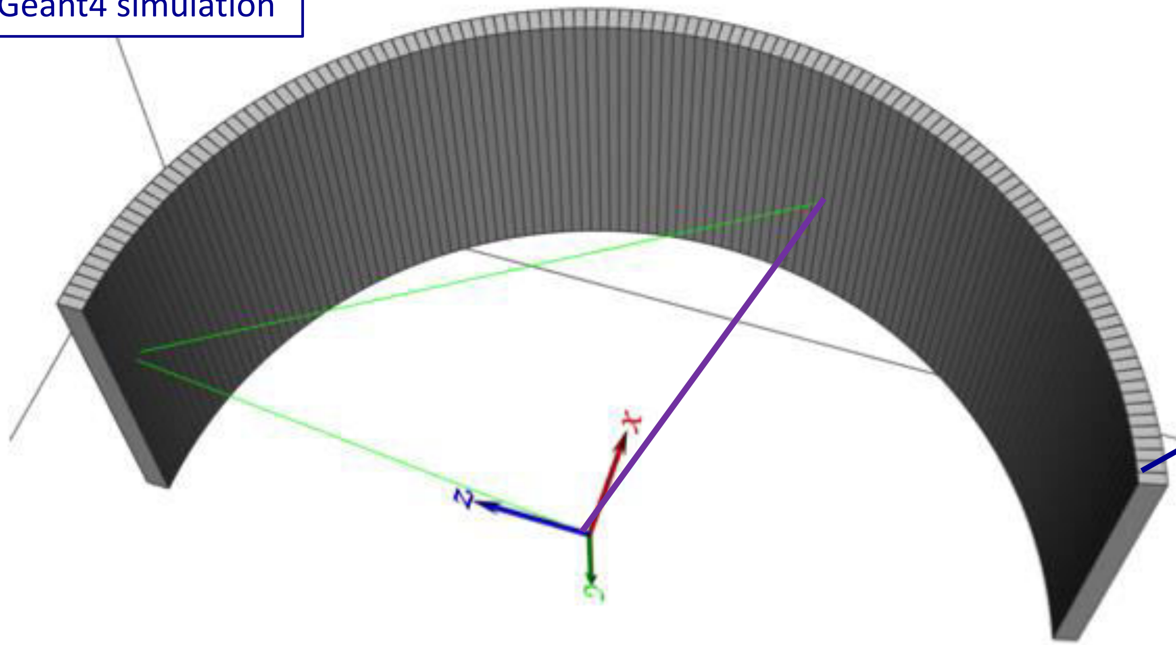
Realistic simulation



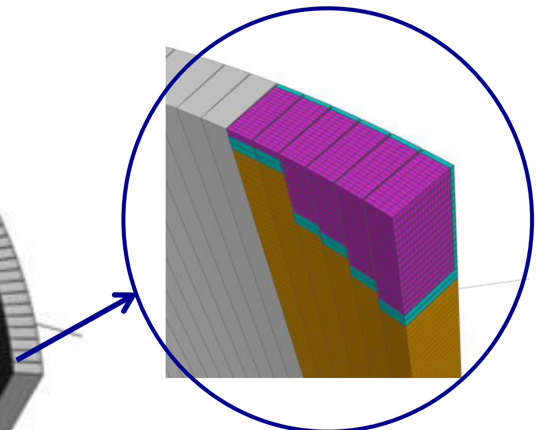


Multi-Grid - Large area detector for chopper spectroscopy

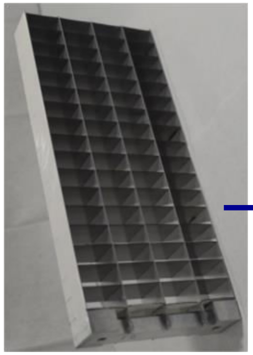
Geant4 simulation

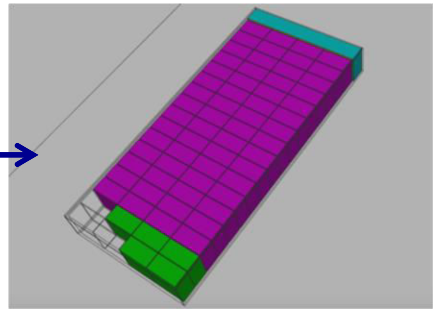


See A. Khaplanov's talk Tuesday 14:30



- Large area Multi-Grid detector
- Solid B_4C converter
- Ar/CO_2 counting gas
- Chopper spectroscopy:
  - Low background is essential





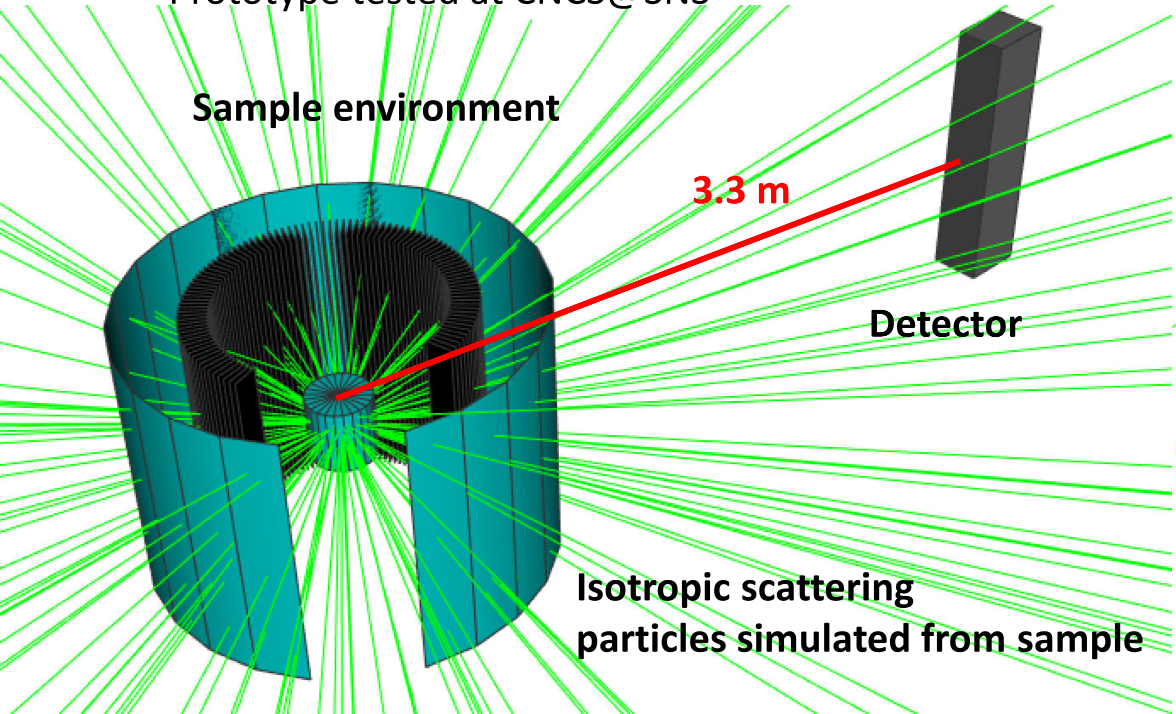
A. Khaplanov et al.
http://dx.doi.org/10.1016/j.nima.2012.12.021

Scattered neutron background study on CNCS prototype and C-SPEC design

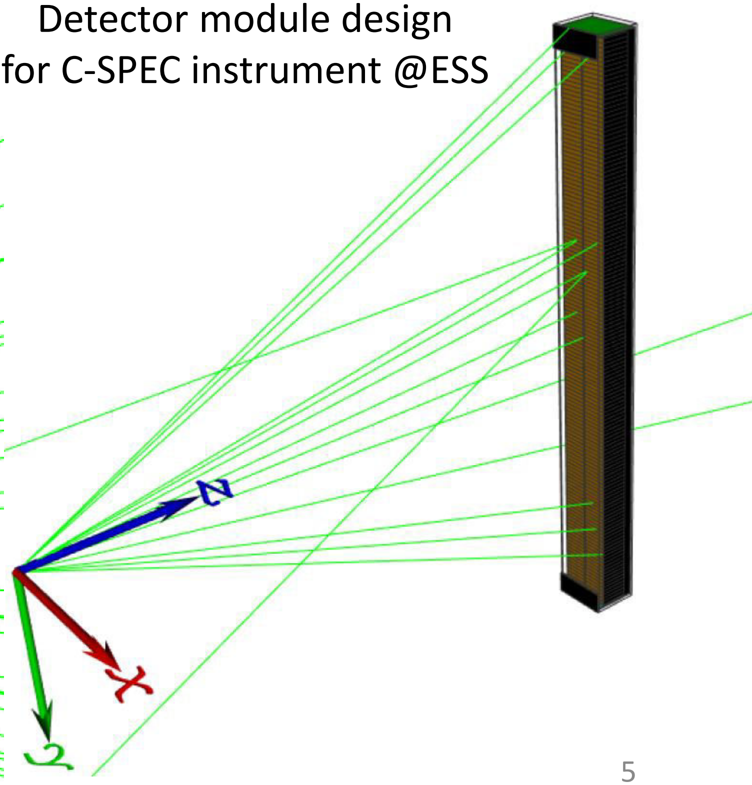
See A. Khaplanov's talk
Tuesday 14:30

- Geant4 simulation study performed on 2-column CNCS and C-SPEC detector modules
  - Scattering on vessel window
  - Shielding study

CNCS simulation geometry
Prototype tested at CNCS@SNS



Detector module design
for C-SPEC instrument @ESS



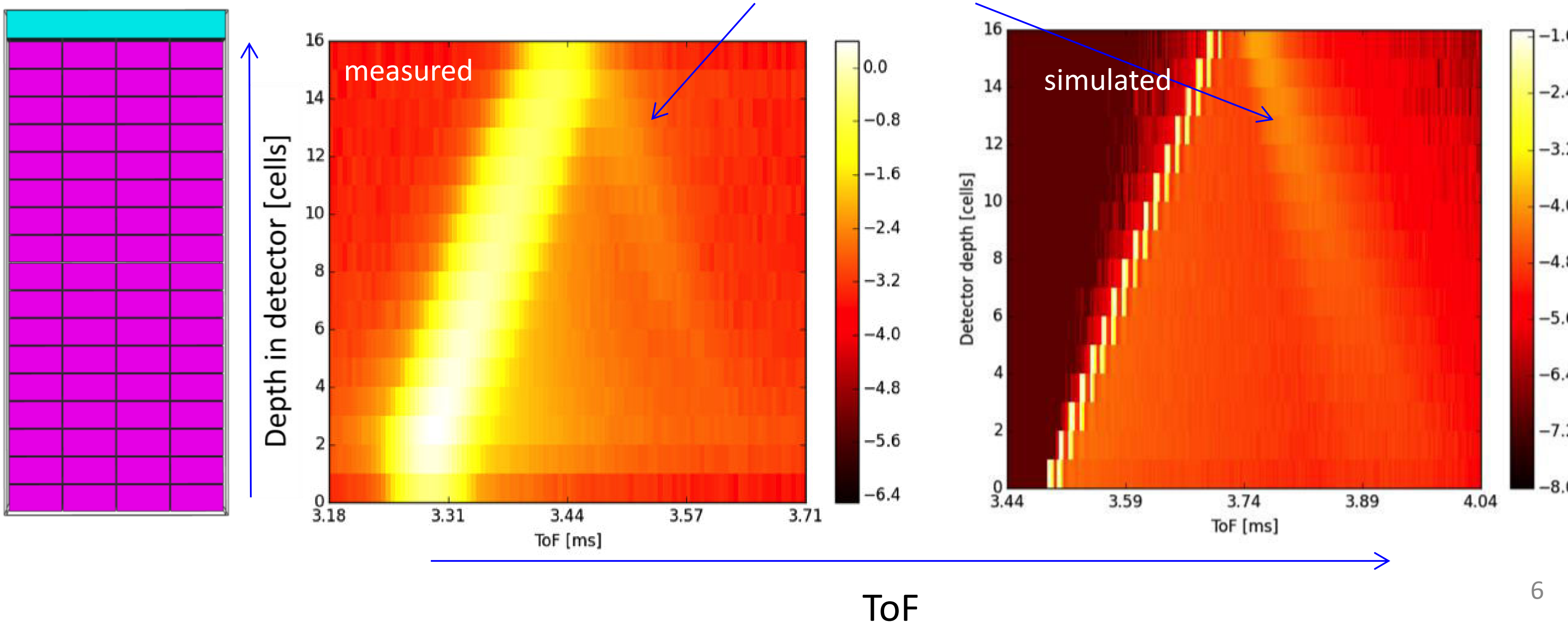
Validated Multi-Grid detector model – IN6

- Geant4 model was validated:
  - IN6 measurement: ToF comparison
  - CNCS measurement: ToF, energy transfer, etc

E. Dian et al.
https://doi.org/10.1016/j.nima.2018.04.055

Validation

Backscatter from the unshielded rear wall of the detector at 4.6 Å



Validated Multi-Grid detector model

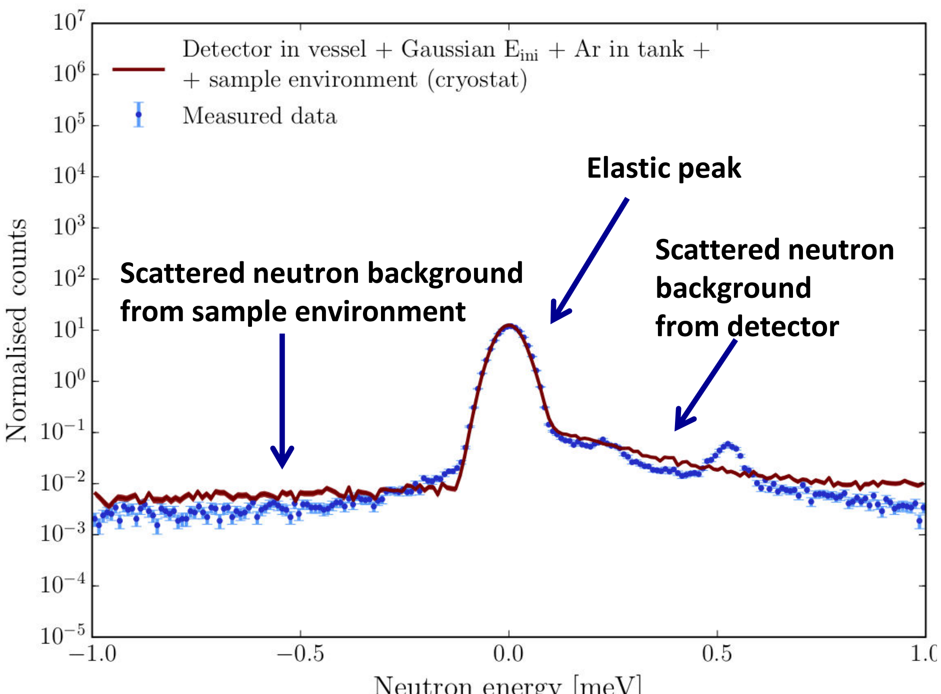
- Geant4 model was validated:
  - IN6 measurement: ToF comparison
  - CNCS measurement: ToF, energy transfer, etc

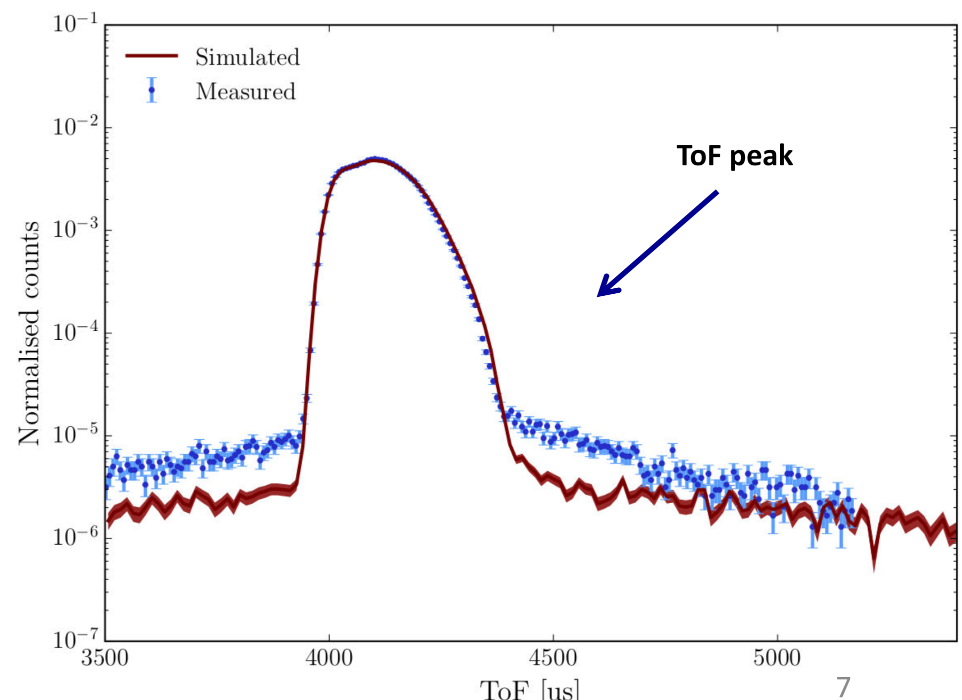
E. Dian et al.
https://doi.org/10.1016/j.nima.2018.04.055

Validation

$E_{trf} = E_{initial} - E_{final}$

ToF





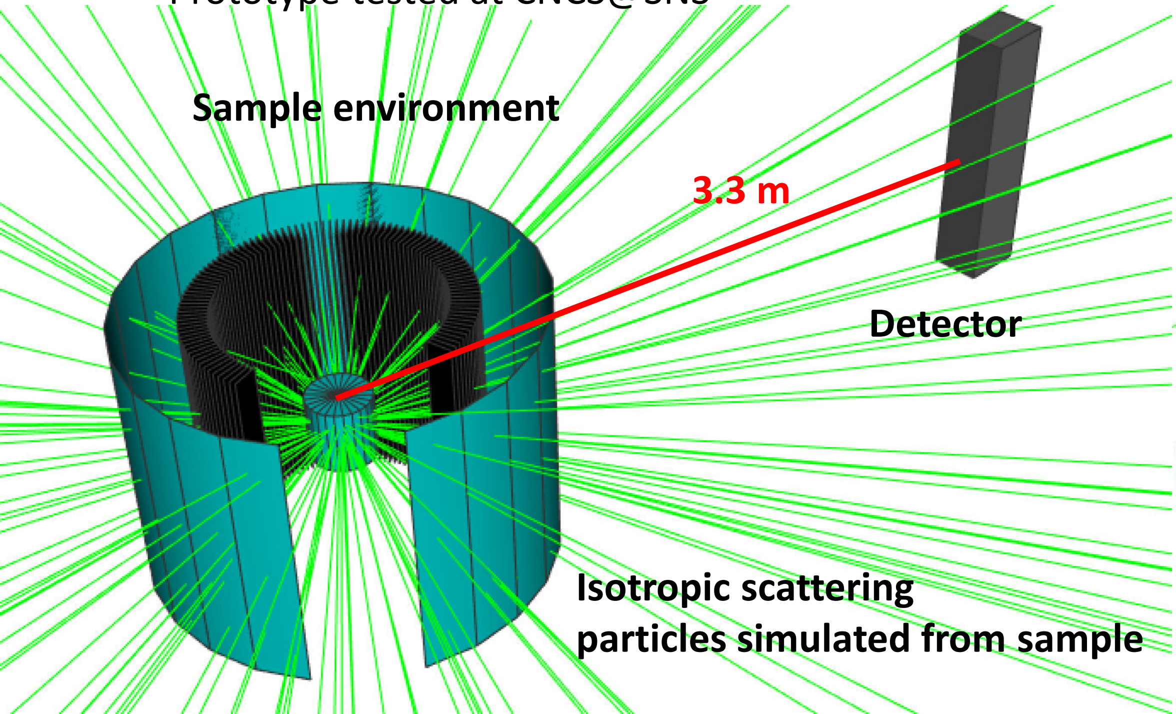
4.6 Å incident neutrons on vanadium sample

Scattered neutron background study on CNCS prototype and C-SPEC design

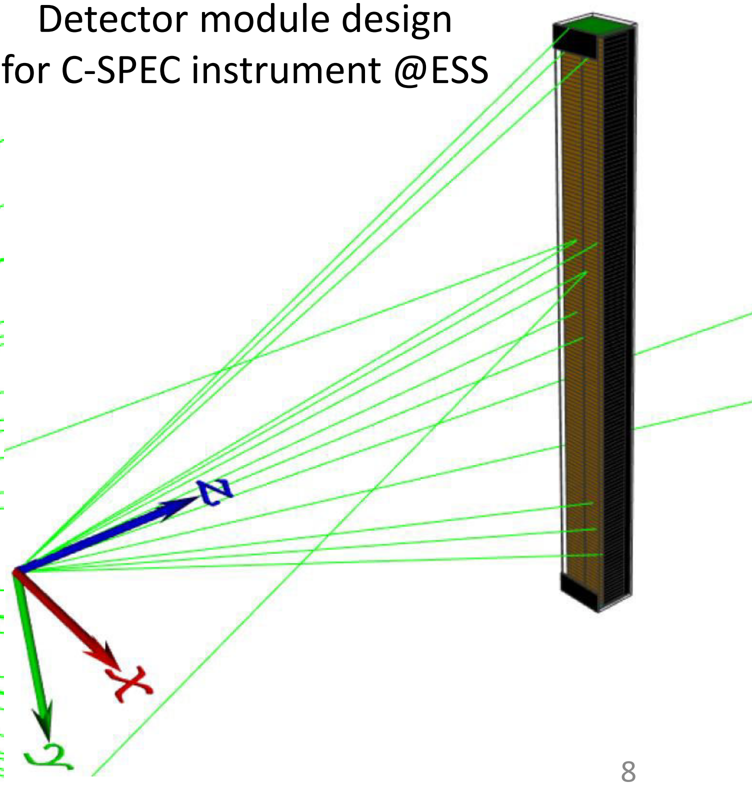
See A. Khaplanov's talk Tuesday 14:30

- Geant4 simulation study performed on 2-column CNCS and C-SPEC detector modules
  - Scattering on vessel window
  - Shielding study

CNCS simulation geometry
Prototype tested at CNCS@SNS

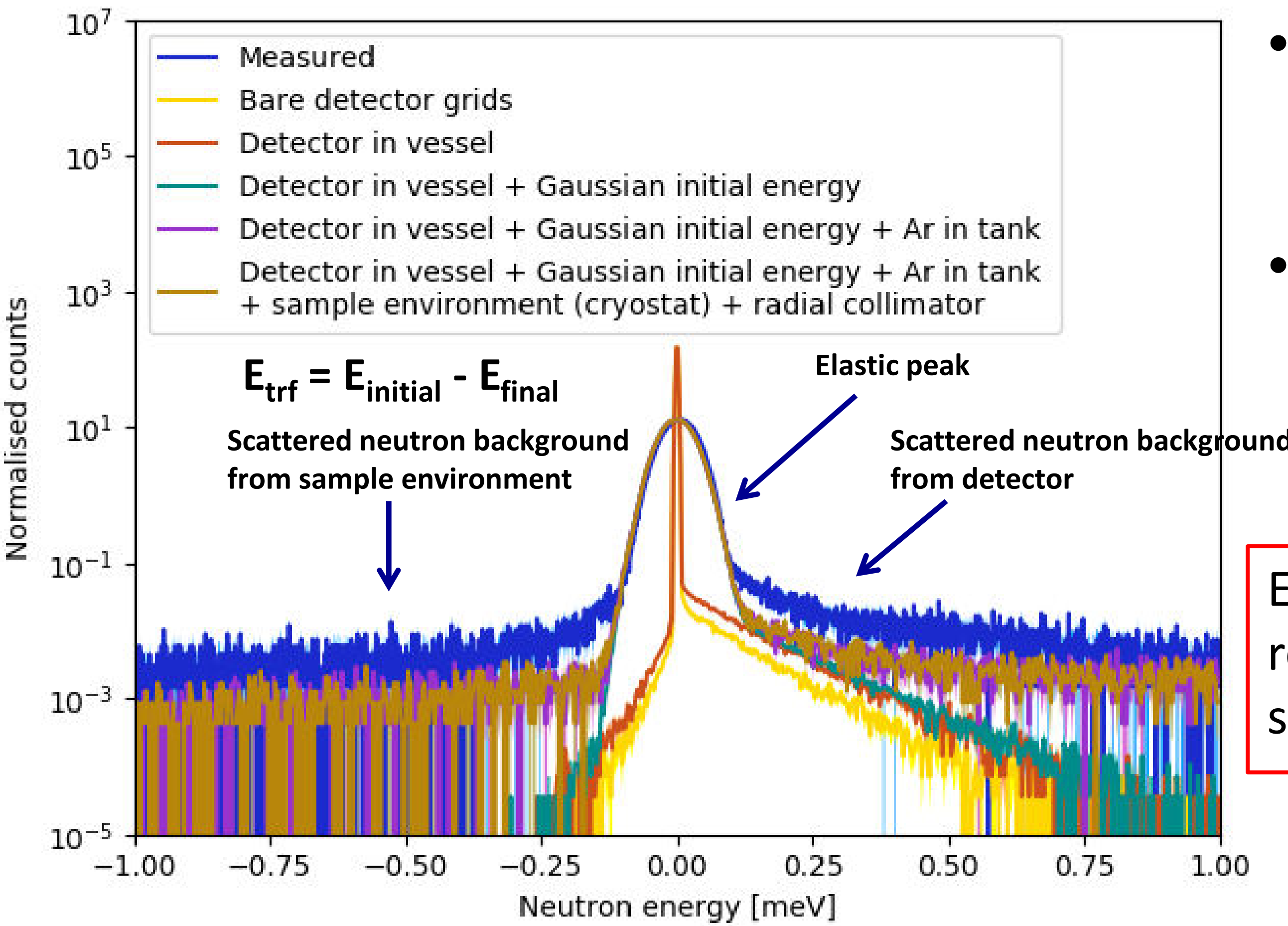


Detector module design
for C-SPEC instrument @ESS



Multi-Grid detector test at CNCS, SNS

Derived energy transfer at 4.7 Å
from simulation, with mono-energetic beam



Validation

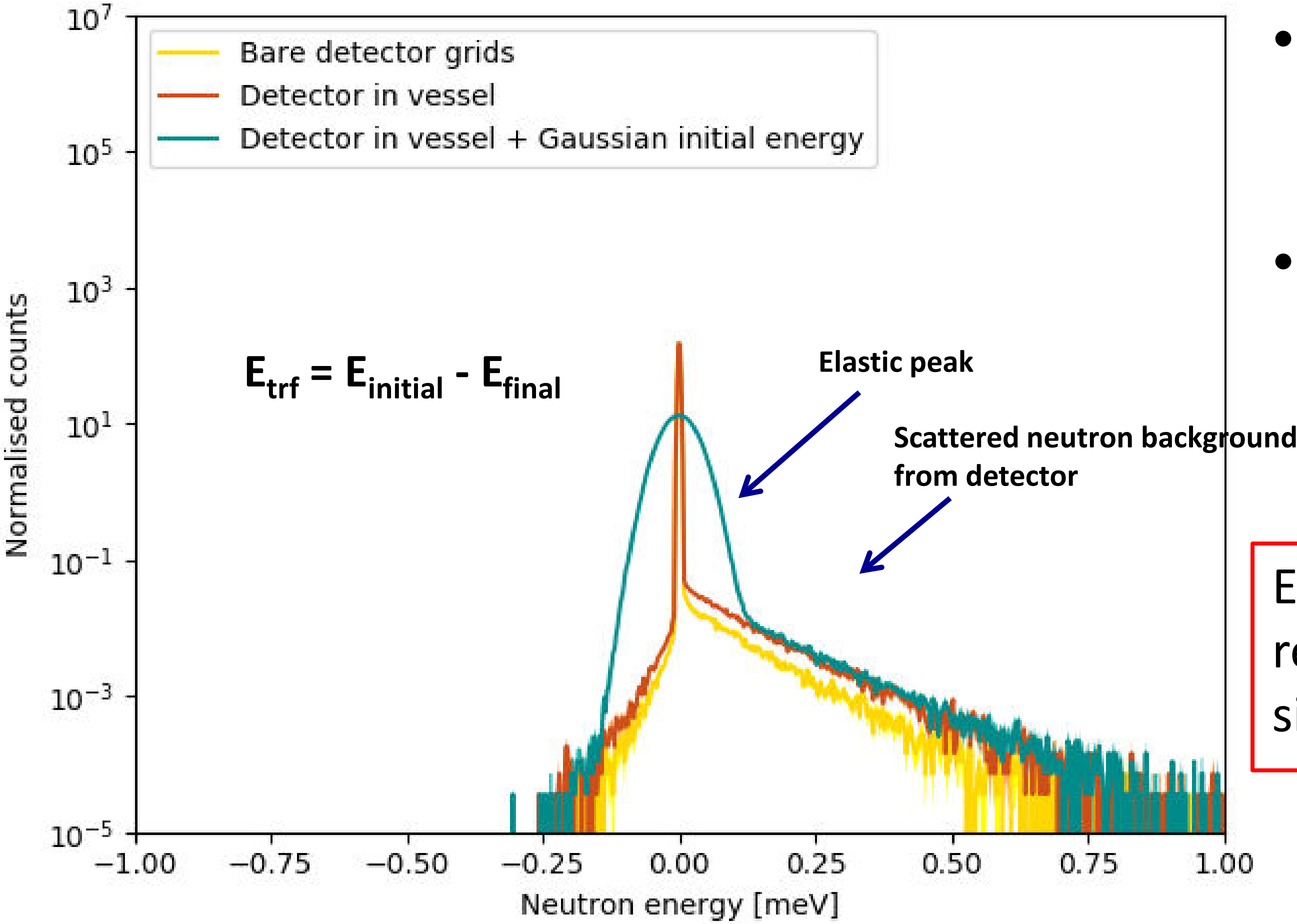
- Distinguish different sources of background
- Detailed analysis and quantification of background effects

Energy transfer reproduced with simulation at 4.7 Å ✓

Multi-Grid detector test at CNCS, SNS

EUROPEAN SPALLATION SOURCE

Derived energy transfer at 4.7 Å
from simulation, with mono-energetic beam



Validation

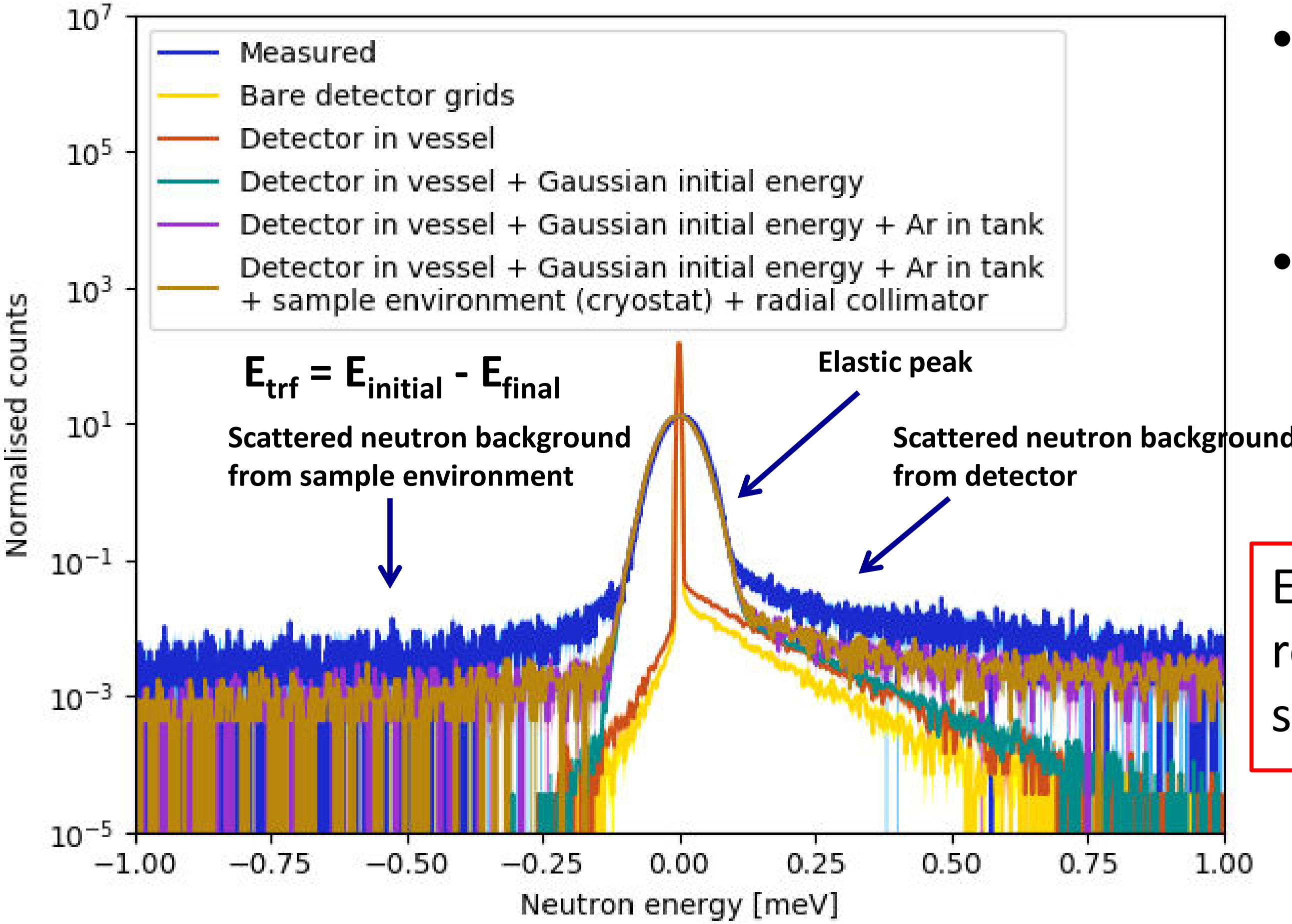
- Distinguish different sources of background
- Detailed analysis and quantification of background effects

Energy transfer reproduced with simulation at 4.7 Å

Multi-Grid detector test at CNCS, SNS

EUROPEAN SPALLATION SOURCE

Derived energy transfer at 4.7 Å
from simulation, with mono-energetic beam



Validation

- Distinguish different sources of background
- Detailed analysis and quantification of background effects

Energy transfer reproduced with simulation at 4.7 Å ✓

mta EK

EUROPEAN SPALLATION SOURCE

Nuclear Inst. and Methods in Physics Research, A 902 (2018) 173–183

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

ELSEVIER

Scattered neutron background in thermal neutron detectors

E. Dian [a,b,c,*], K. Kanaki [b], G. Ehlers [d], R.J. Hall-Wilton [b,e], A. Khaplanov [b], T. Kittelmann [b], P. Zagyvai [a,c]

[a] *Hungarian Academy of Sciences, Centre for Energy Research, 1525 Budapest 114., P.O. Box 49., Hungary*
[b] *European Spallation Source ESS ERIC, P.O Box 176, SE-221 00 Lund, Sweden*
[c] *Budapest University of Technology and Economics, Institute of Nuclear Techniques, 1111 Budapest, Műegyetem rakpart 9., Hungary*
[d] *Oak Ridge National Lab, Neutron Technologies Division, Oak Ridge, TN 37831-6475, USA*
[e] *Mid-Sweden University, SE-851 70 Sundsvall, Sweden*

E. Dian et al.
10.1016/j.nima.2018.04.055

ARTICLE INFO

Keywords:
ESS
Neutron detector
Neutron scattering
Monte Carlo simulation
Geant4
Validation

ABSTRACT

Inelastic neutron scattering instruments require very low background; therefore the proper shielding for suppressing the scattered neutron background, both from elastic and inelastic scattering is essential. The detailed understanding of the background scattering sources is required for effective suppression. The Multi-Grid thermal neutron detector is an Ar/CO_2 gas filled detector with a $^{10}B_4C$ neutron converter coated on aluminium substrates. It is a large-area detector design that will equip inelastic neutron spectrometers at the European Spallation Source (ESS). To this end a parameterised Geant4 model is built for the Multi-Grid detector. This is the first time thermal neutron scattering background sources have been modelled in a detailed simulation of detector response. The model is validated via comparison with measured data of prototypes installed on the IN6 instrument at ILL and on the CNCS instrument at SNS. The effect of scattering originating in detector components is smaller than effects originating elsewhere.

1. Introduction

Inelastic neutron scattering is a very powerful technique for exploring atomic and molecular motion, as well as magnetic and crystal field excitations [1]. Time-of-Flight (ToF) spectrometers allow a broad phase space to be measured in a single setting; this is typically achieved with a large area detector array [2]. In typical state-of-the-art neutron instruments [2–8], this detector array can be 10–50 m^2. One of the main performance criteria of these spectrometers is typically defined by the Signal-to-Background Ratio (SBR), therefore understanding and enhancing the latter is important for the instrument optimisation. In particular, scattered neutrons have a significant contribution to the SBR. The estimation of the SBR is done currently on a series of prescriptions based on observations of historical instrument installation.

As a consequence of the recent restructuring of the ^{3}He market [9], a need for cost effective ^{3}He-replacing detector solutions is raised [10], especially for inelastic neutron scattering instruments, where large area detectors with high SBR are required. A potent new solution for this type of instruments is the Multi-Grid detector [11,12], which will be used for the three Time-of-Flight chopper spectrometers at ESS [13–16]. The Multi-Grid design was invented at the Institut Laue-Langevin (ILL) [17,18], and the detector now is jointly developed by the ILL and the ESS within the CRISP [19] and BrightnESS [20] projects.

The Multi-Grid detector is an Ar/CO_2-filled proportional chamber with a solid boron-carbide ($^{10}B_4C$) neutron converter, enriched in ^{10}B [21–23]. The basic unit of the Multi-Grid detector is the grid, an aluminium frame; thin aluminium lamellas, coated on their both sides with boron-carbide, the so called blades are placed in this frame, parallel with each other and the entrance window of the grid, dividing the grid into cells. In the detector the grids are structured into columns, and this way the cells one above the other form tubes, and the signals are readout both from the frames and the anode wires that go through the whole length of the column in the centre of the cells. The planned detector modules and the prototypes are built of these columns. A series of small size prototypes and large scale demonstrators are already built and tested at different sources and instruments [24,25], and the development of the detector has already entered the up-scaling phase. As Multi-Grid is a large area detector, full scale design is limited by cost considerations. However, detailed Monte Carlo modelling can help tackle the limitations and provide guidelines for the up-scaling design, which is particularly important for detectors that have to provide excellent SBR $\sim \mathcal{O}(10^5)$.

* Corresponding author at: Hungarian Academy of Sciences, Centre for Energy Research, 1525 Budapest 114., P.O. Box 49., Hungary.
E-mail address: dian.eszter@energia.mta.hu (E. Dian).

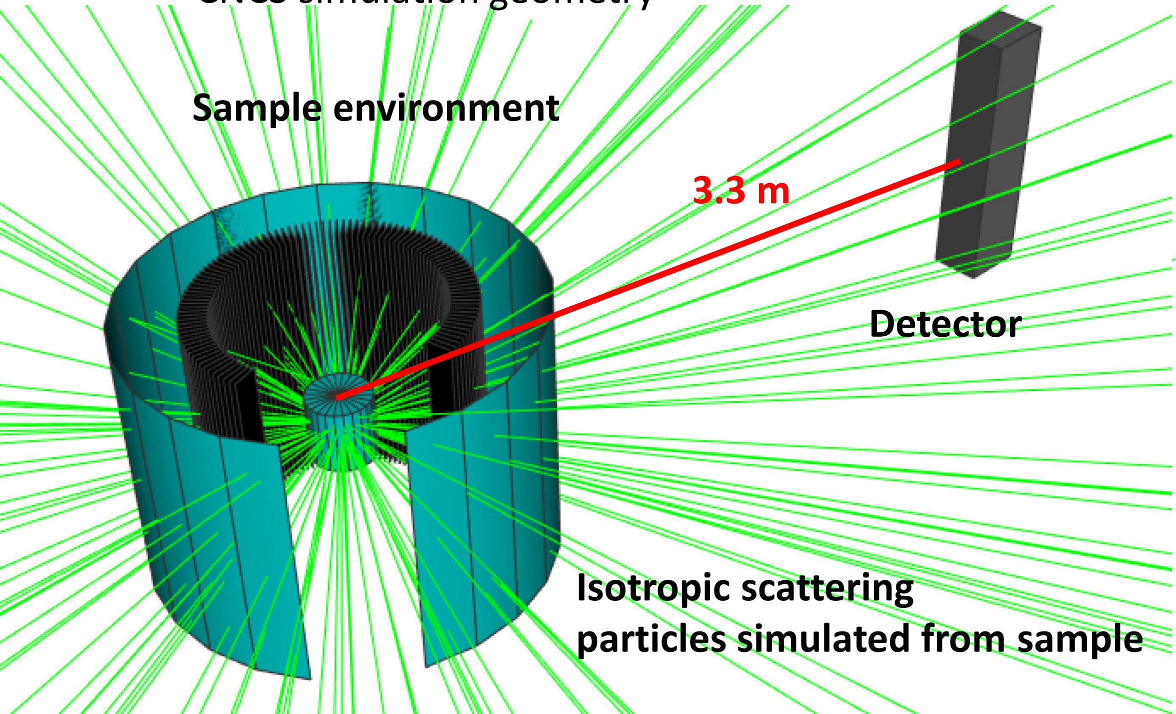
https://doi.org/10.1016/j.nima.2018.04.055
Received 18 January 2018; Received in revised form 13 April 2018; Accepted 25 April 2018
Available online 3 May 2018

Scattered neutron background study on CNCS prototype and C-SPEC design

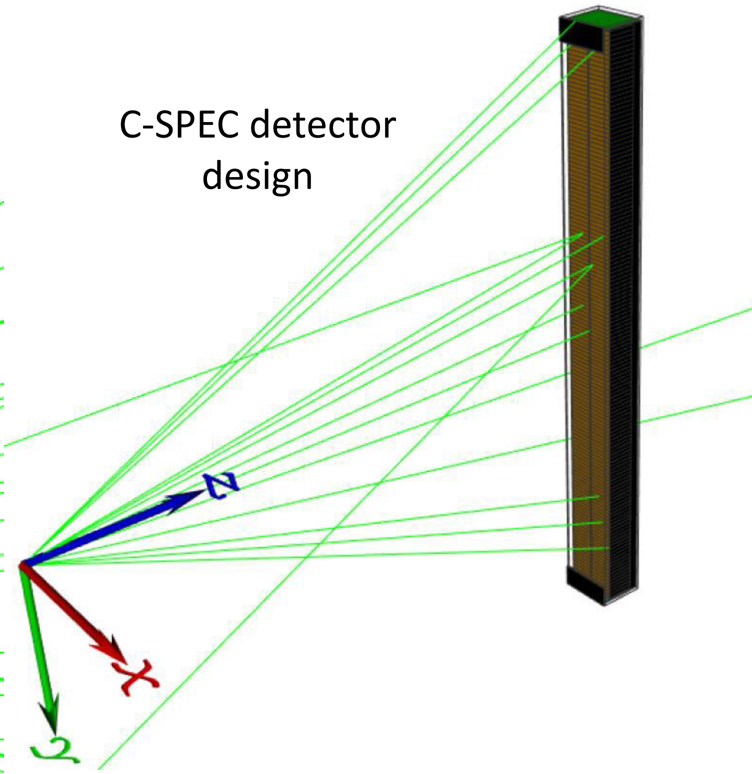
- Geant4 simulation study performed on 2-column CNCS and C-SPEC detector modules
  - Scattering on vessel window
  - Shielding study

See A. Khaplanov's talk Tuesday 14:30

CNCS simulation geometry

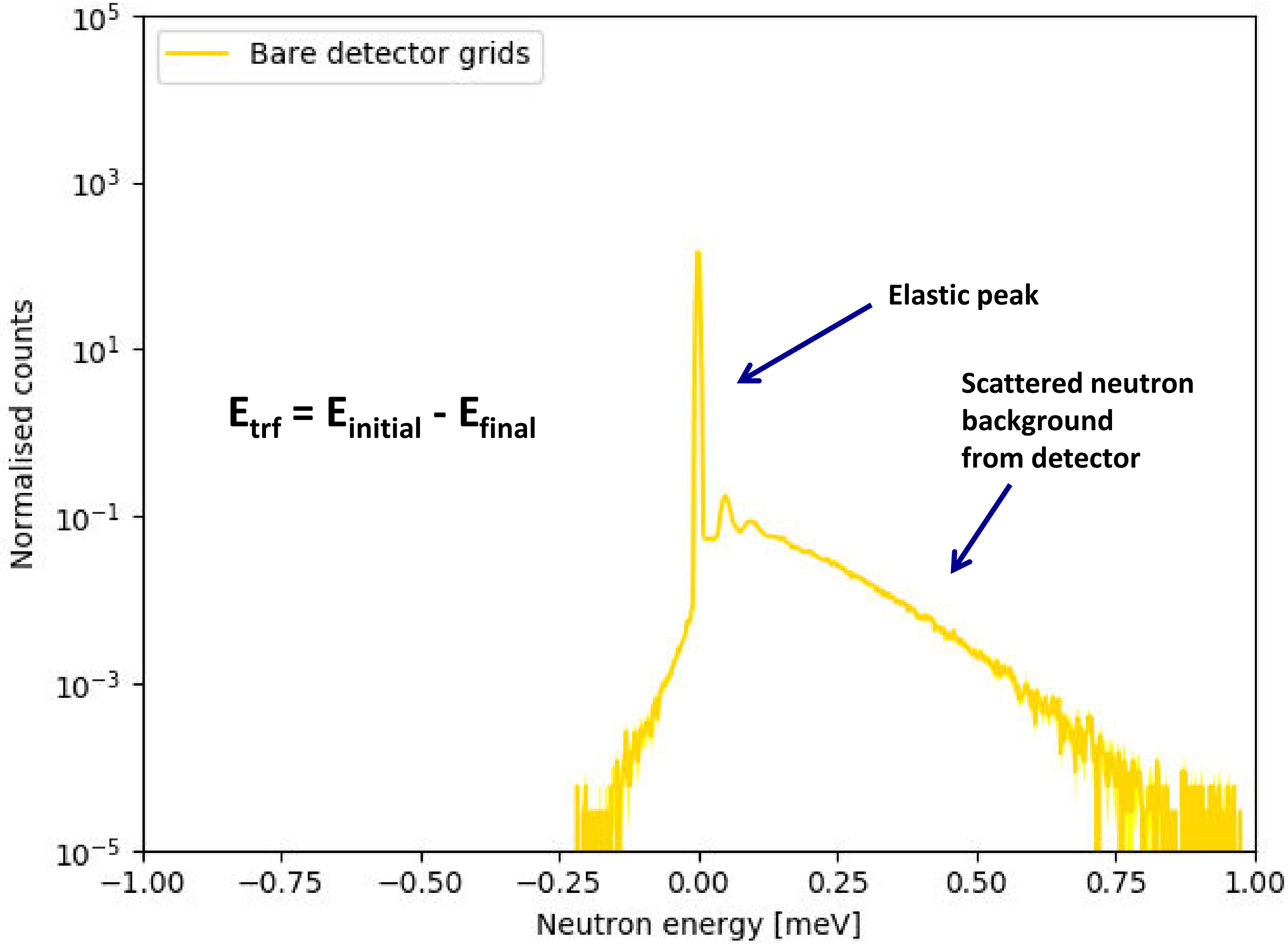


C-SPEC detector design

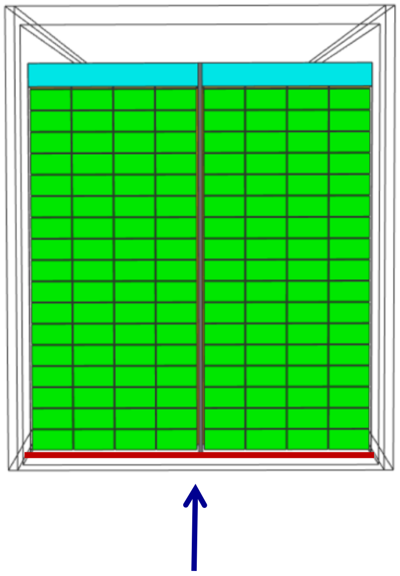


Scattering on Multi-Grid detector vessel & window at CNCS

Derived energy transfer at 4.6 Å
from simulation, with mono-energetic beam



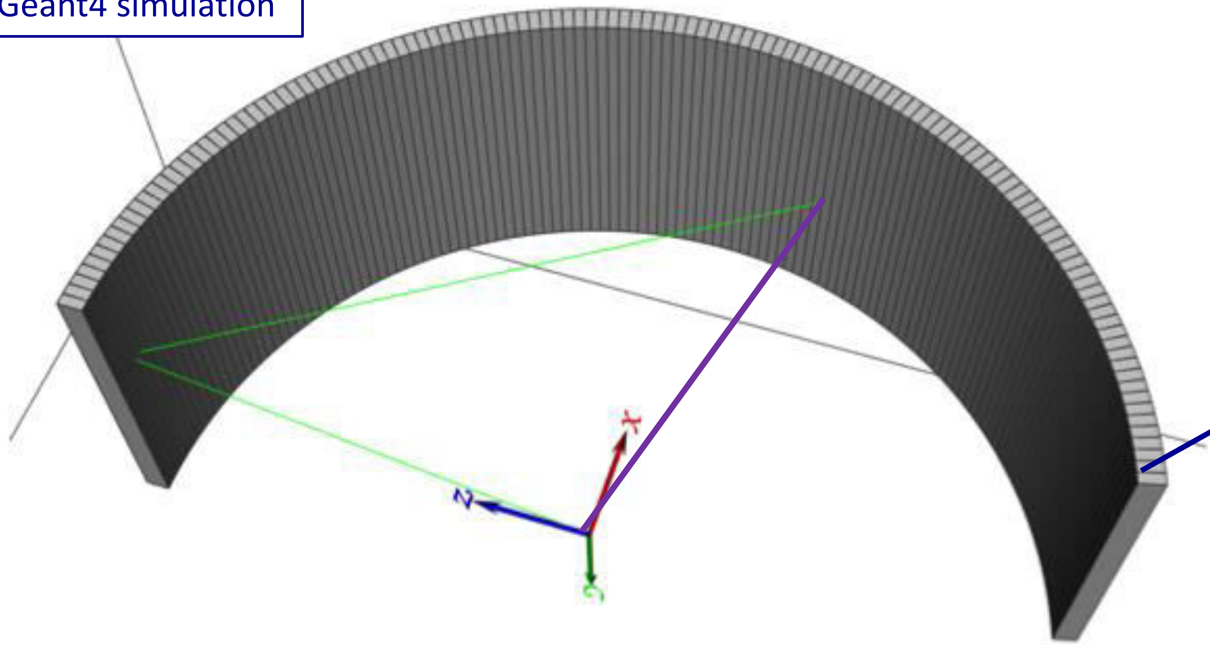
- Bare detector
  - 0.5 mm window



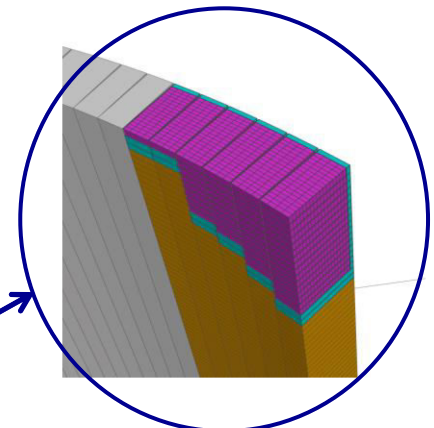
3 - 9 Å incident neutrons

Multi-Grid - Large area detector for chopper spectroscopy

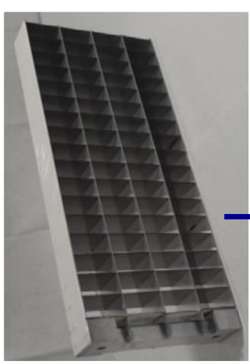
Geant4 simulation

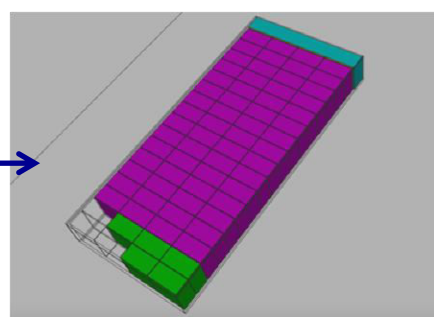


See A. Khaplanov's talk Tuesday 14:30



- Large area Multi-Grid detector
- Solid B_4C converter
- Ar/CO_2 counting gas
- Chopper spectroscopy:
  - Low background is essential

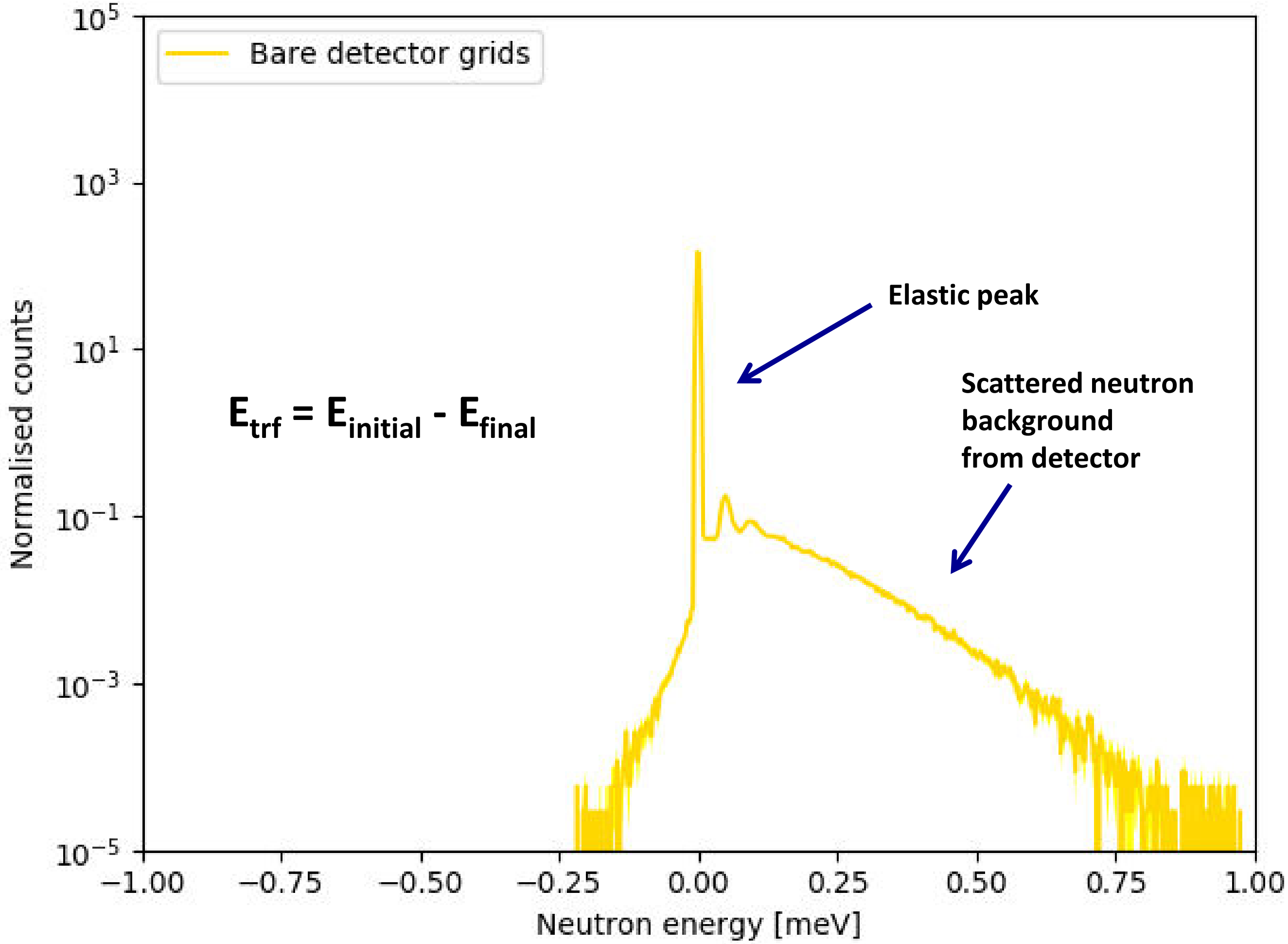




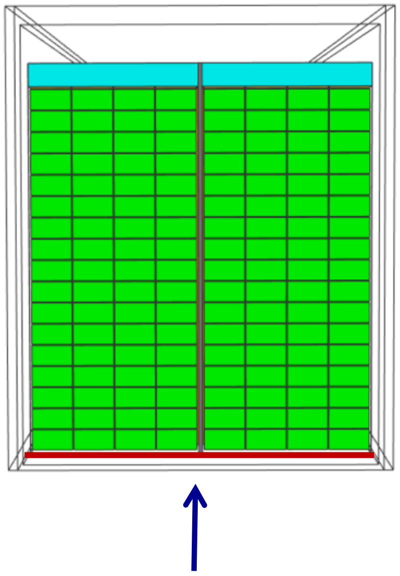
A. Khaplanov et al.
http://dx.doi.org/10.1016/j.nima.2012.12.021

Scattering on Multi-Grid detector vessel & window at CNCS

Derived energy transfer at 4.6 Å
from simulation, with mono-energetic beam



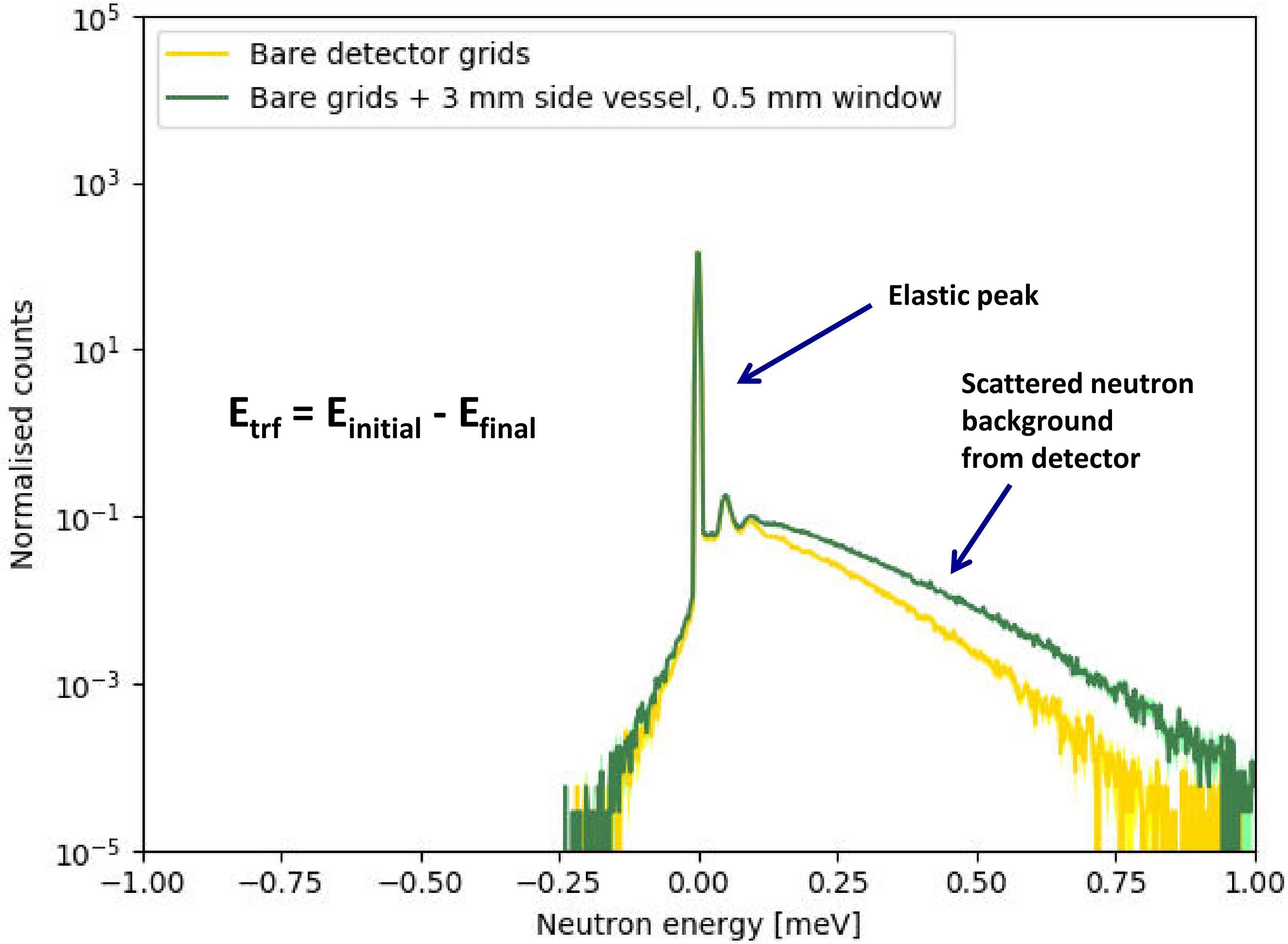
- Bare detector
  - 0.5 mm window



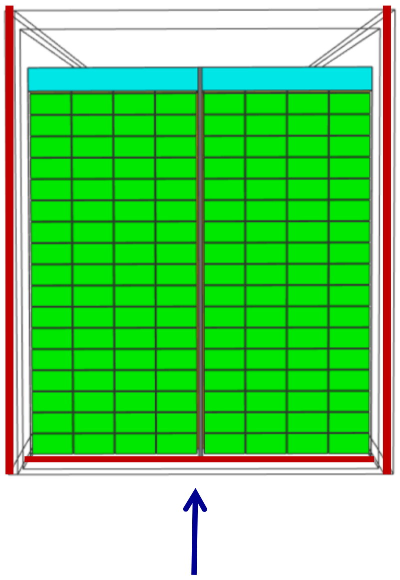
3 - 9 Å incident neutrons

Scattering on Multi-Grid detector vessel & window at CNCS

Derived energy transfer at 4.6 Å
from simulation, with mono-energetic beam

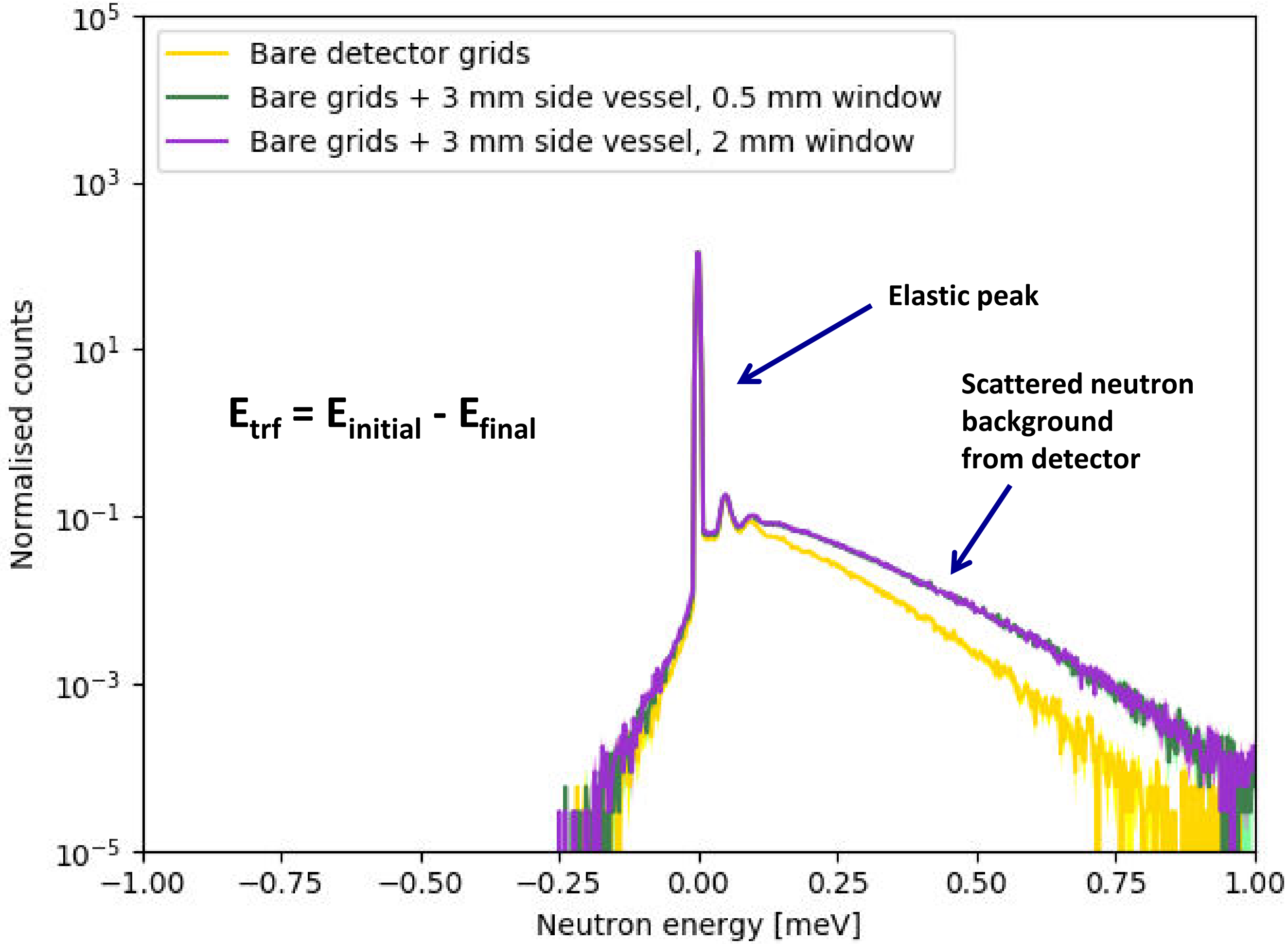


- Detector in vessel
  - 0.5 mm window
  - 3 mm vessel side walls

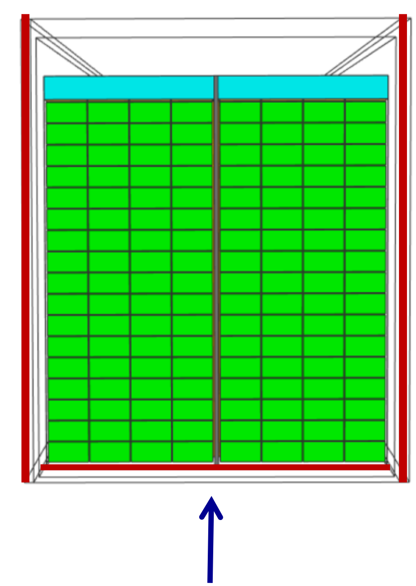


Scattering on Multi-Grid detector vessel & window at CNCS

Derived energy transfer at 4.6 Å
from simulation, with mono-energetic beam



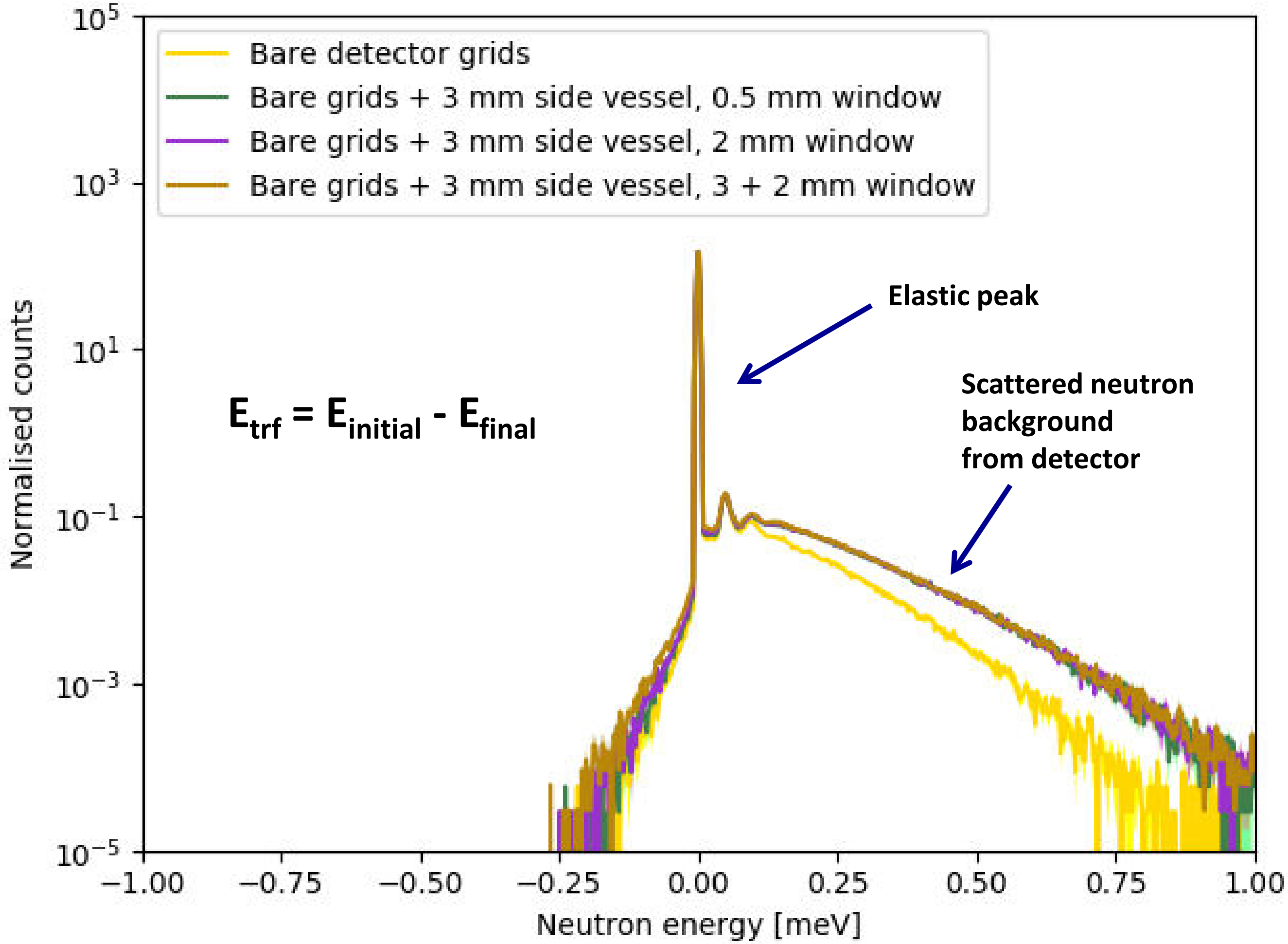
- Detector in vessel
  - 3 mm side walls
  - 2 mm window



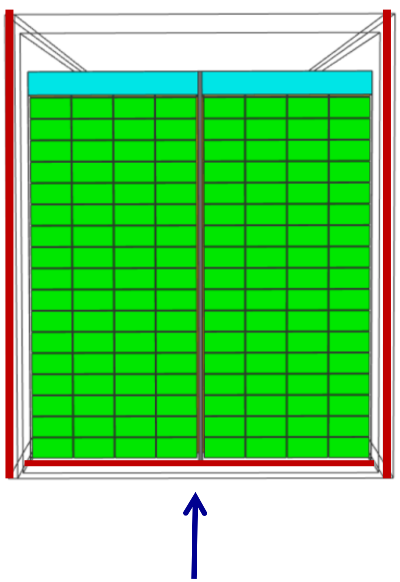
3 - 9 Å incident neutrons

Scattering on Multi-Grid detector vessel & window at CNCS

Derived energy transfer at 4.6 Å
from simulation, with mono-energetic beam



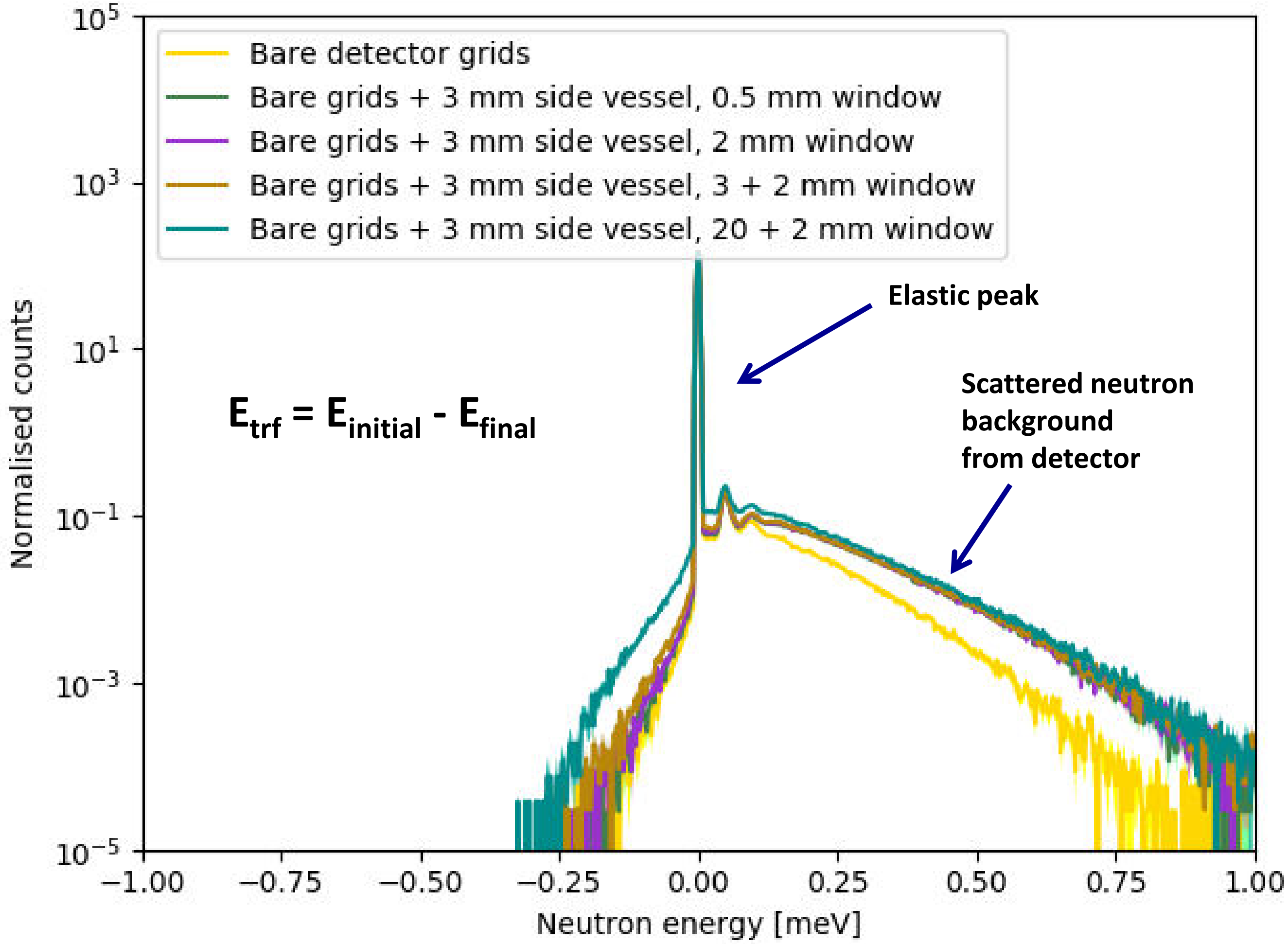
- Detector in vessel
  - 3 mm side walls
  - 3 + 2 mm window



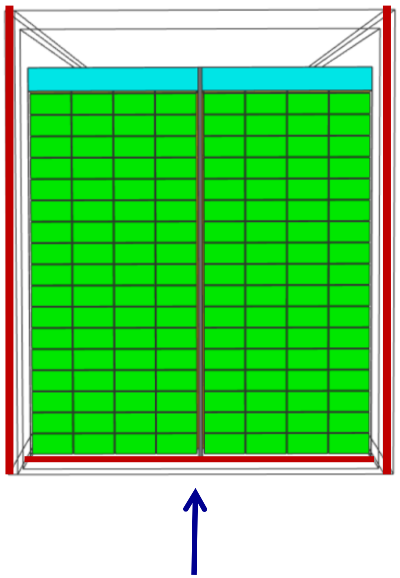
3 - 9 Å incident neutrons

Scattering on Multi-Grid detector vessel & window at CNCS

Derived energy transfer at 4.6 Å
from simulation, with mono-energetic beam



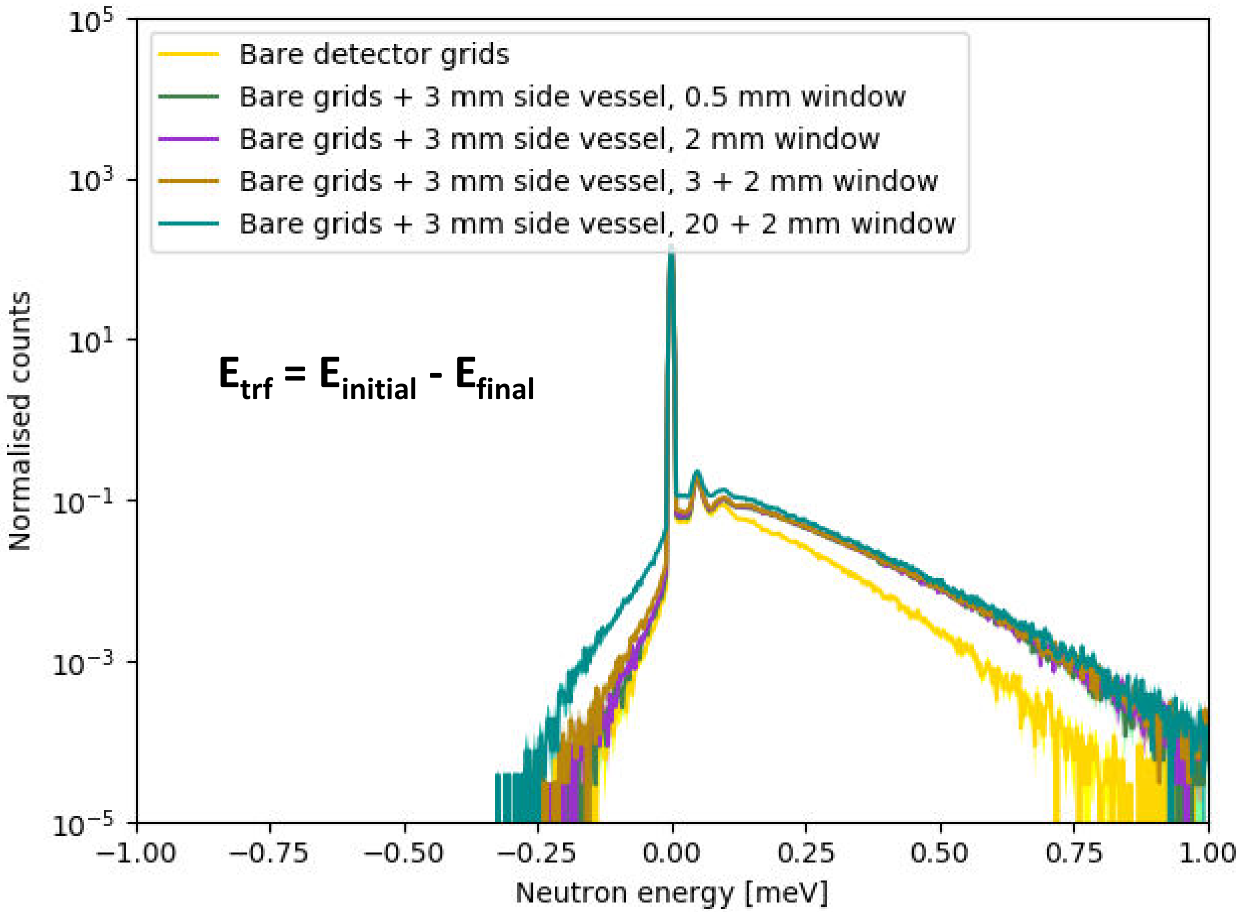
- Detector in vessel
  - 3 mm side walls
  - 20+2 mm window



3 - 9 Å incident neutrons

Scattering on Multi-Grid detector vessel & window at CNCS

Derived energy transfer at 4.6 Å
from simulation, with mono-energetic beam



- No significant change in background for reasonable window thicknesses (3 - 9 Å)
- Significant scattering effect of unshielded vessel side

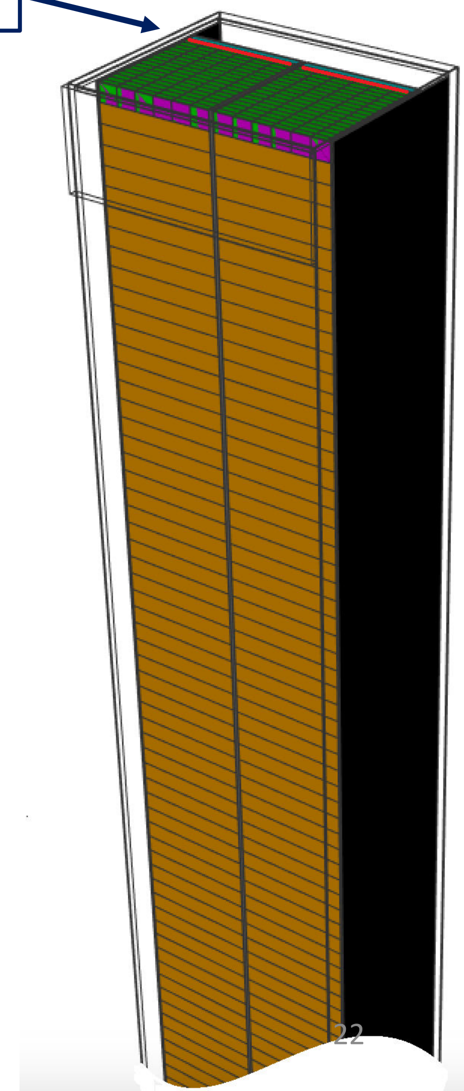
↓

- Shielding study for scattered neutron background

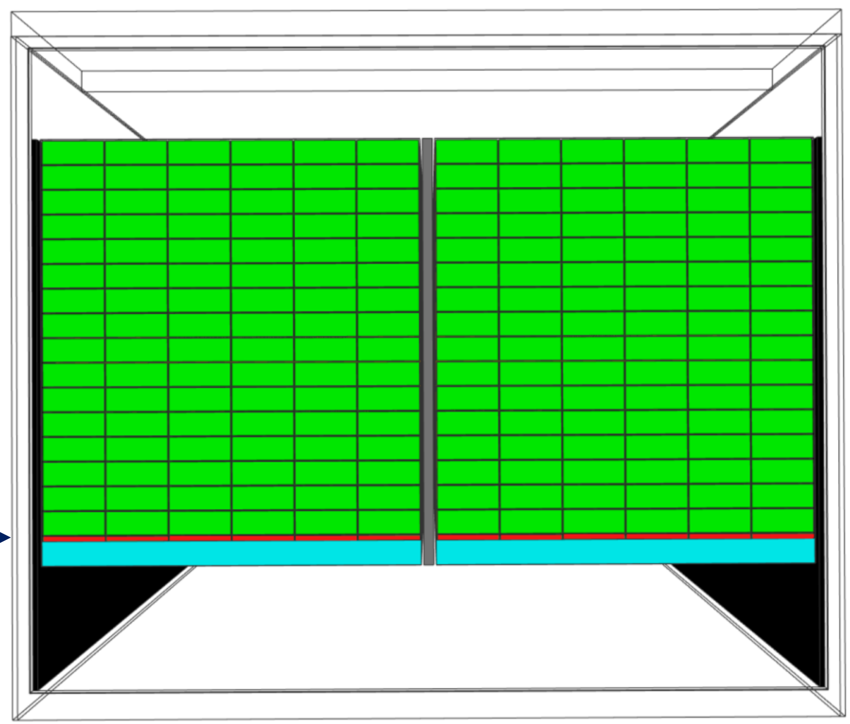
Shielding locations on C-SPEC module

- Common shielding materials tested at different locations:
  - B_4C, Cd, LiF, Gd_2O_3 +PE
  - Ideal black shielding
- 0.4 – 10 Å

Grid end shielding

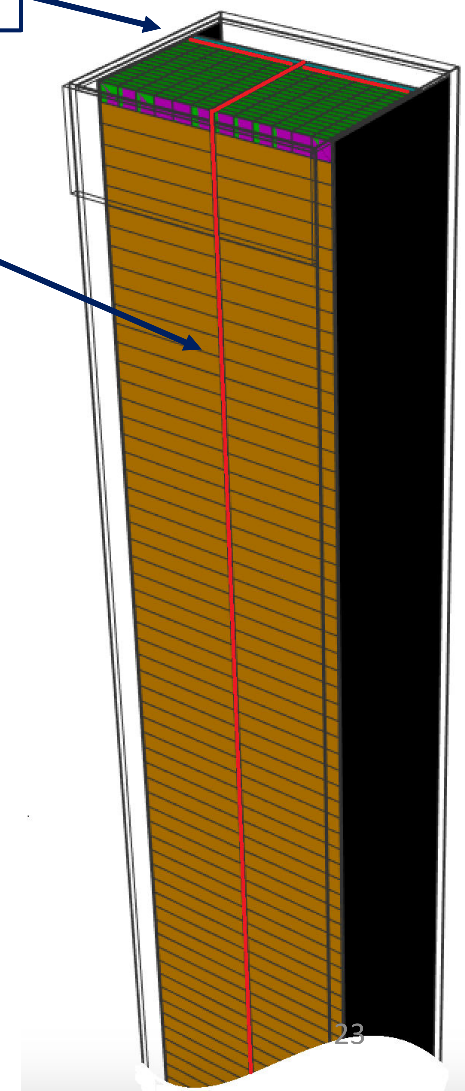


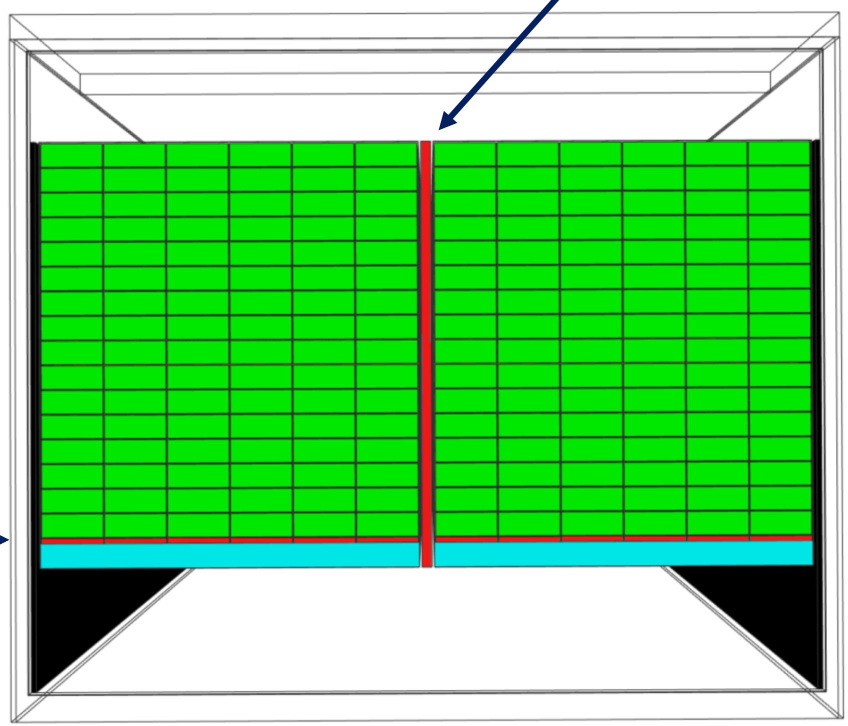
Gird end shielding



Shielding locations on C-SPEC module

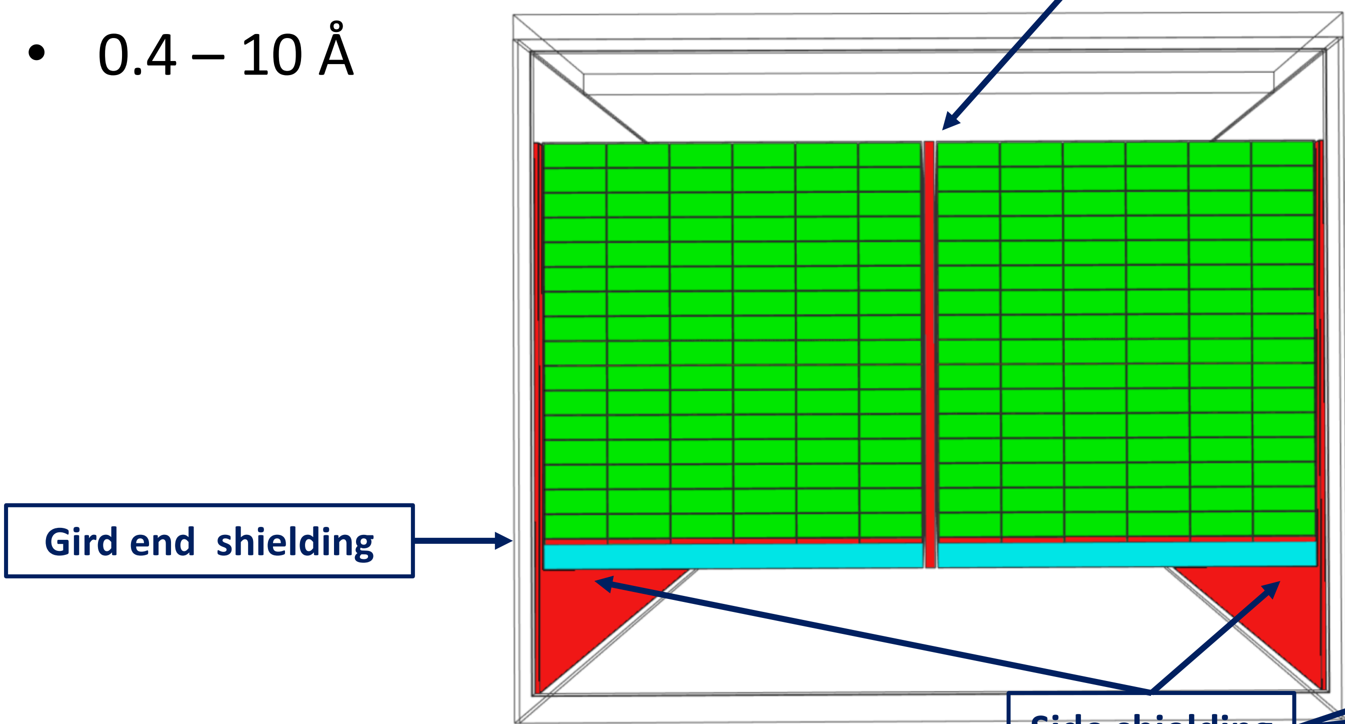
- Common shielding materials tested at different locations:
  - B_4C, Cd, LiF, Gd_2O_3 +PE
  - Ideal black shielding
- 0.4 – 10 Å

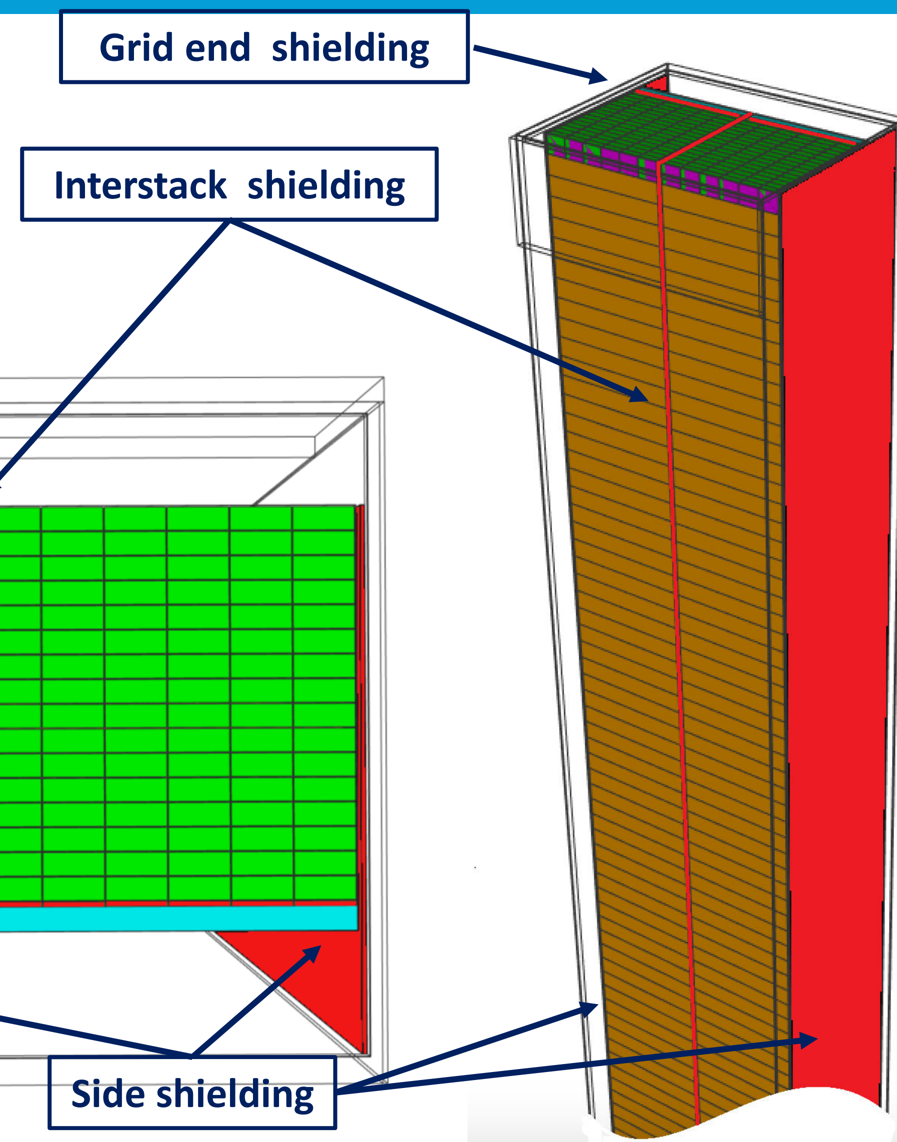




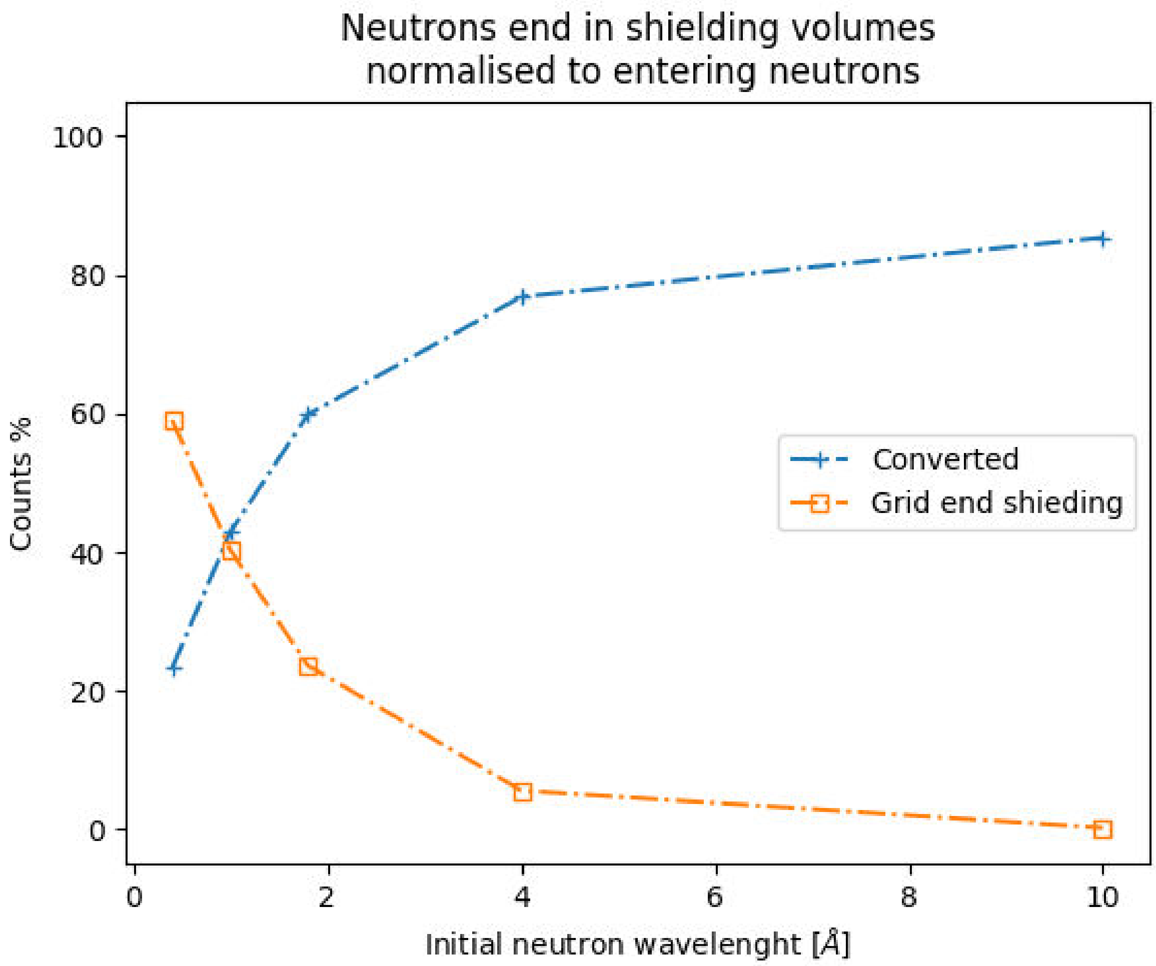
Shielding locations on C-SPEC module

- Common shielding materials tested at different locations:
  - B_4C, Cd, LiF, Gd_2O_3 +PE
  - Ideal black shielding
- 0.4 – 10 Å

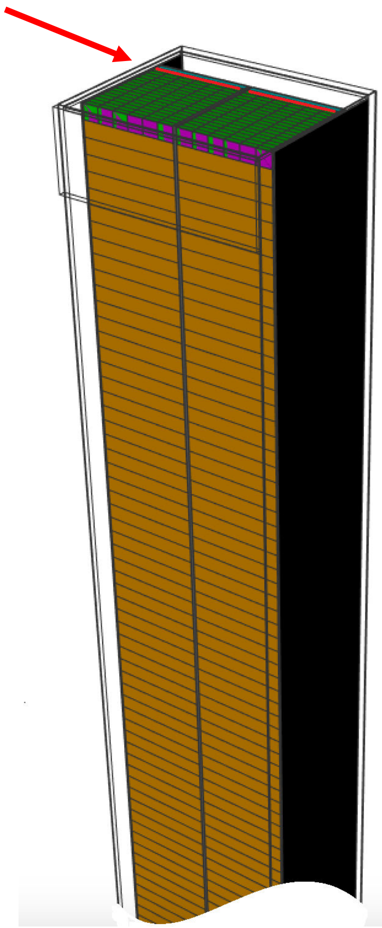




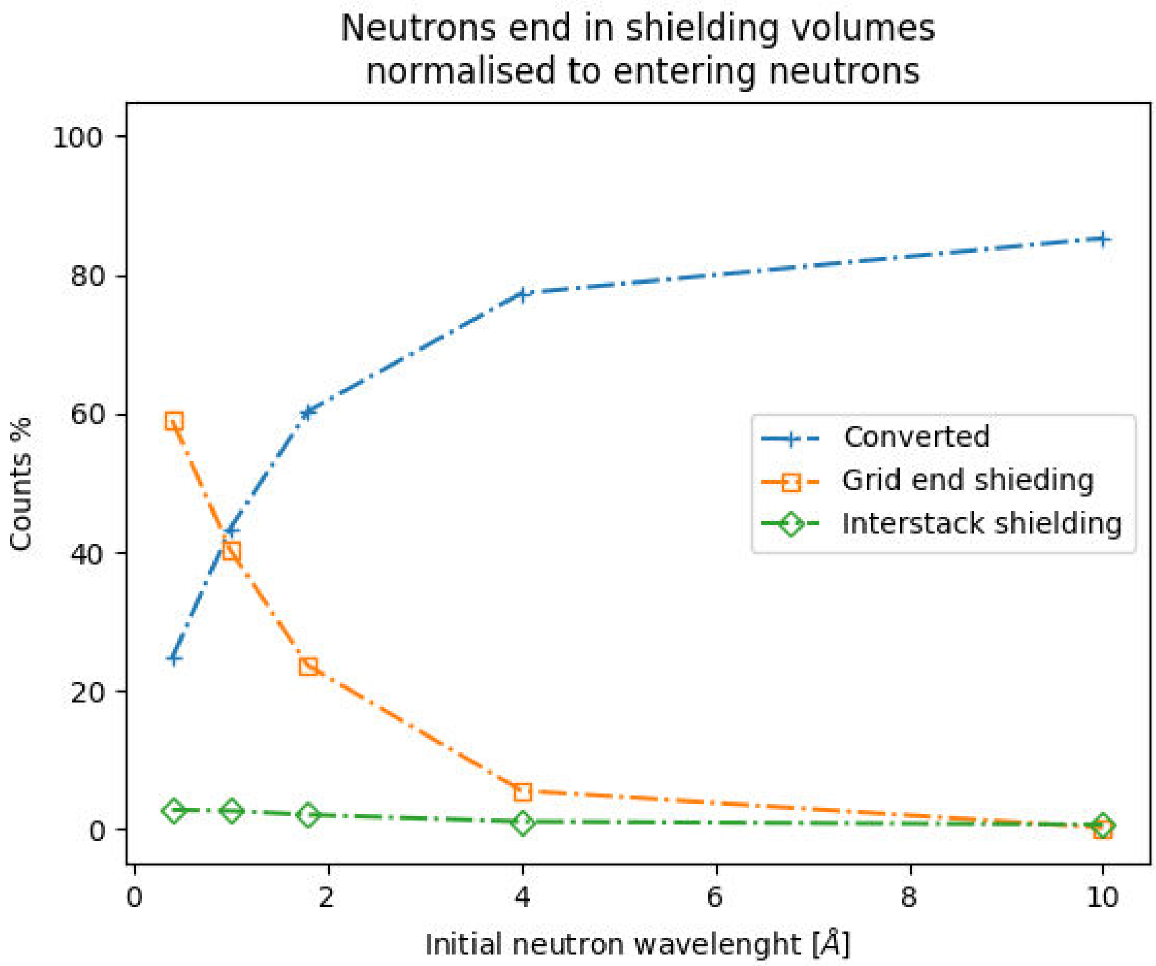
Neutron absorption at different shielding locations – black materials

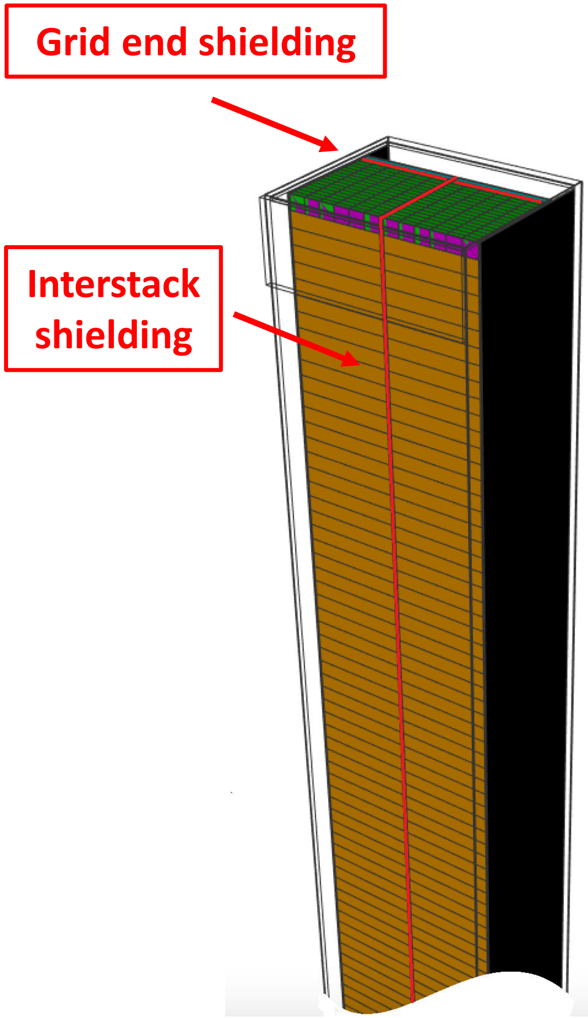


Grid end shielding

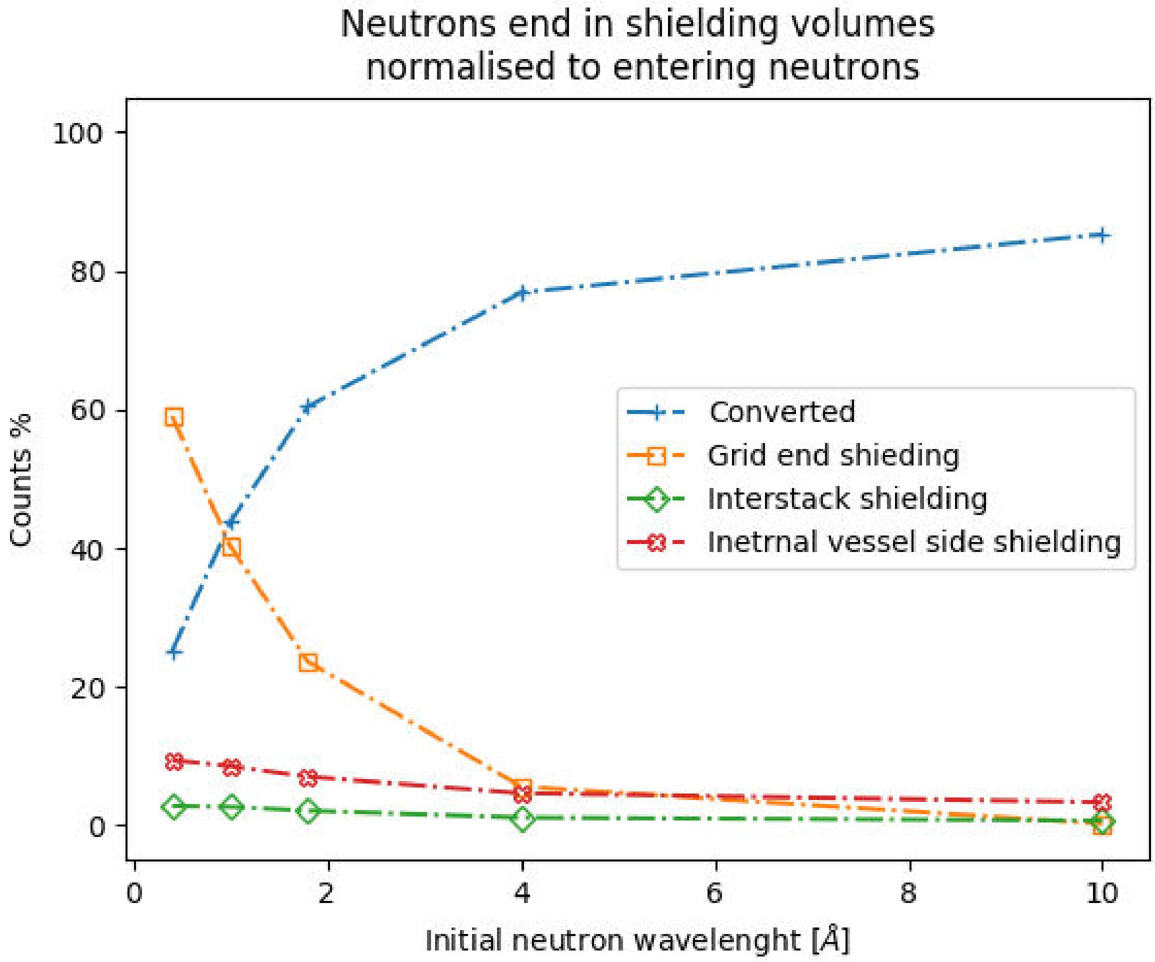


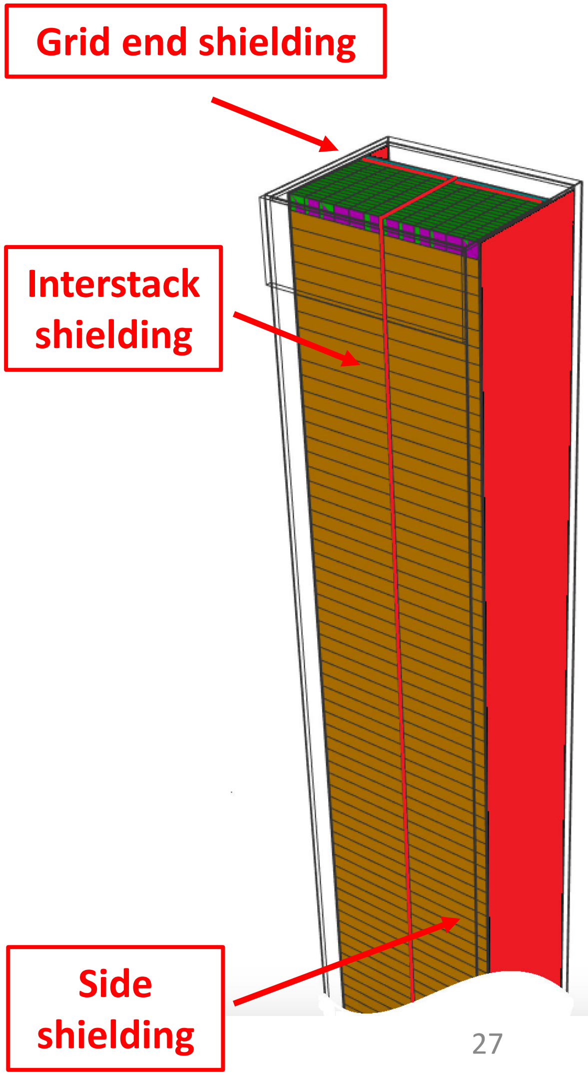
Neutron absorption at different shielding locations – black materials



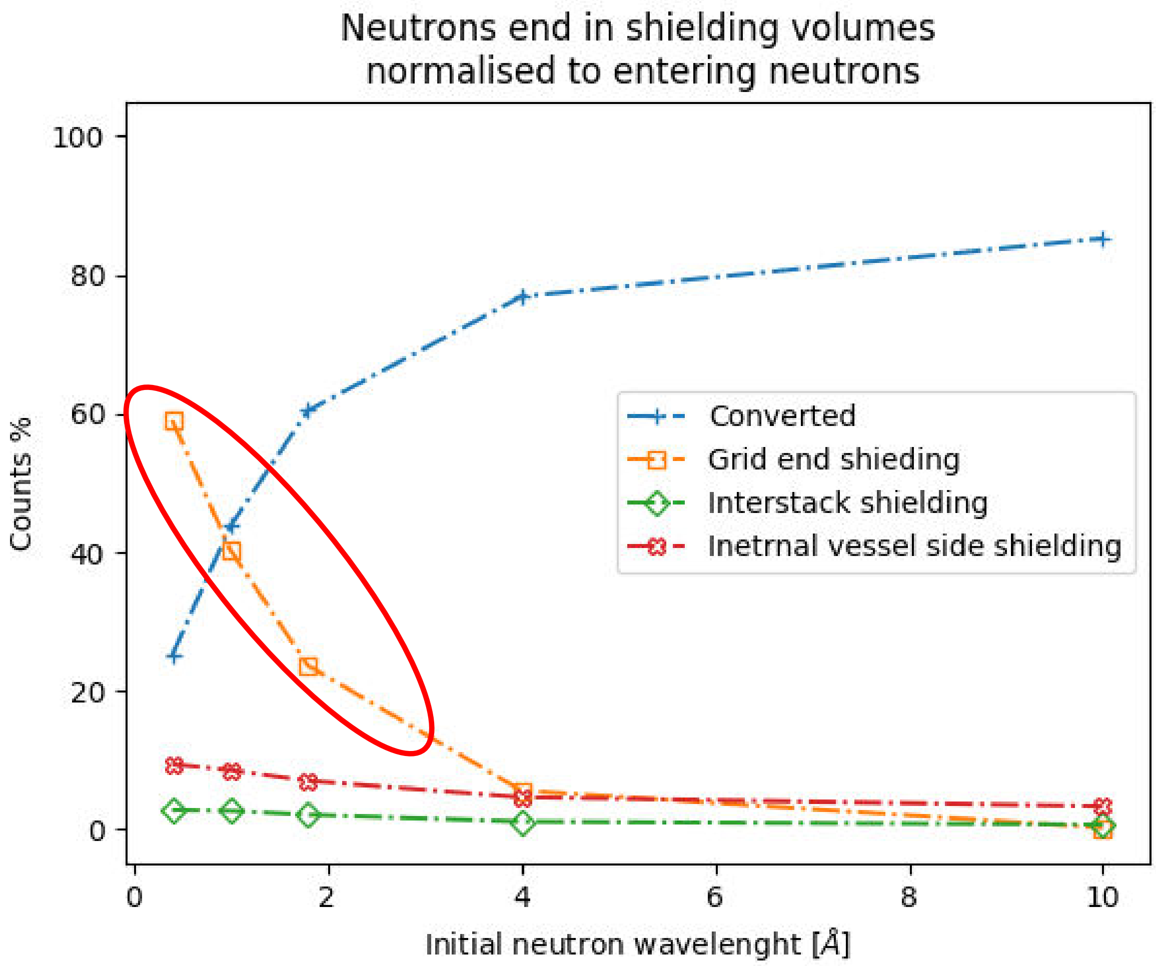


Neutron absorption at different shielding locations – black materials





Neutron absorption at different shielding locations – black materials



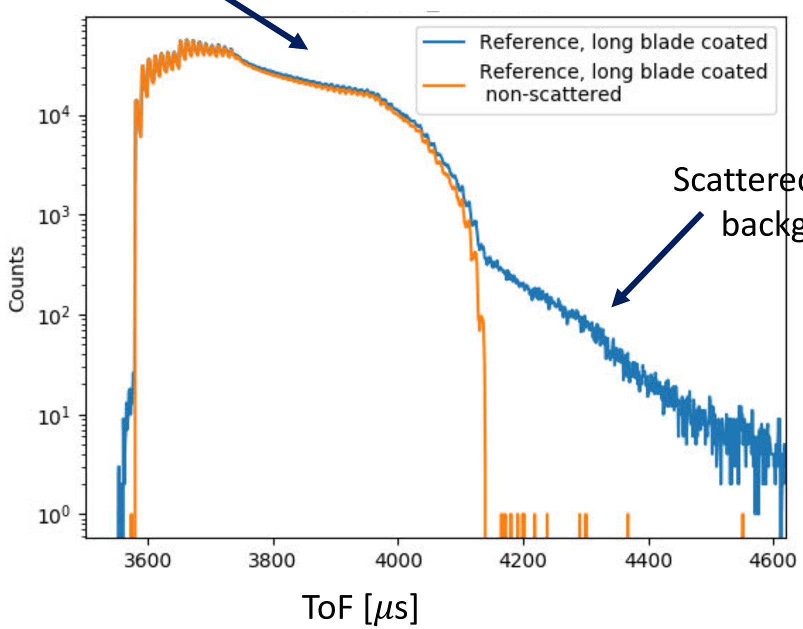
- Grid end shielding has highest absorption
  - Significant below 4 Å
- 5-10 % of neutrons absorbed in the vessel side
  - Even in presence of black grid end shielding

Signal-to-Background Ratio

- Signal-to-Background Ratio:

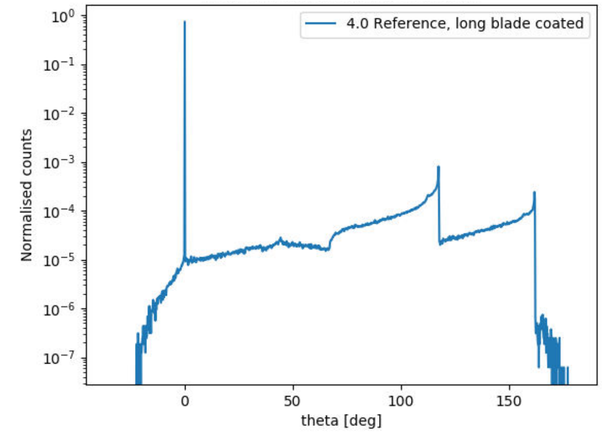
$$SBR = \frac{non - scattered\ neutrons}{scattered\ neutrons}$$

Non-scattered neutrons (Signal)

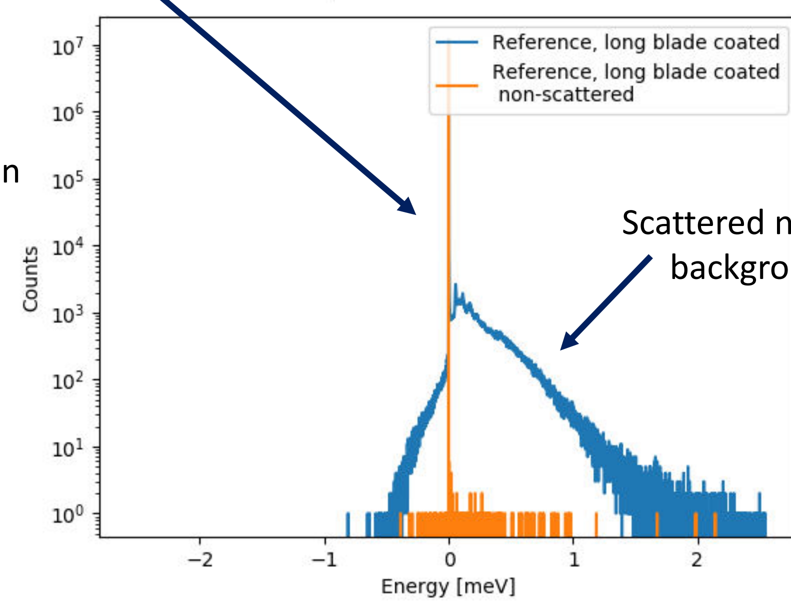


Scattered neutron background

Δθ

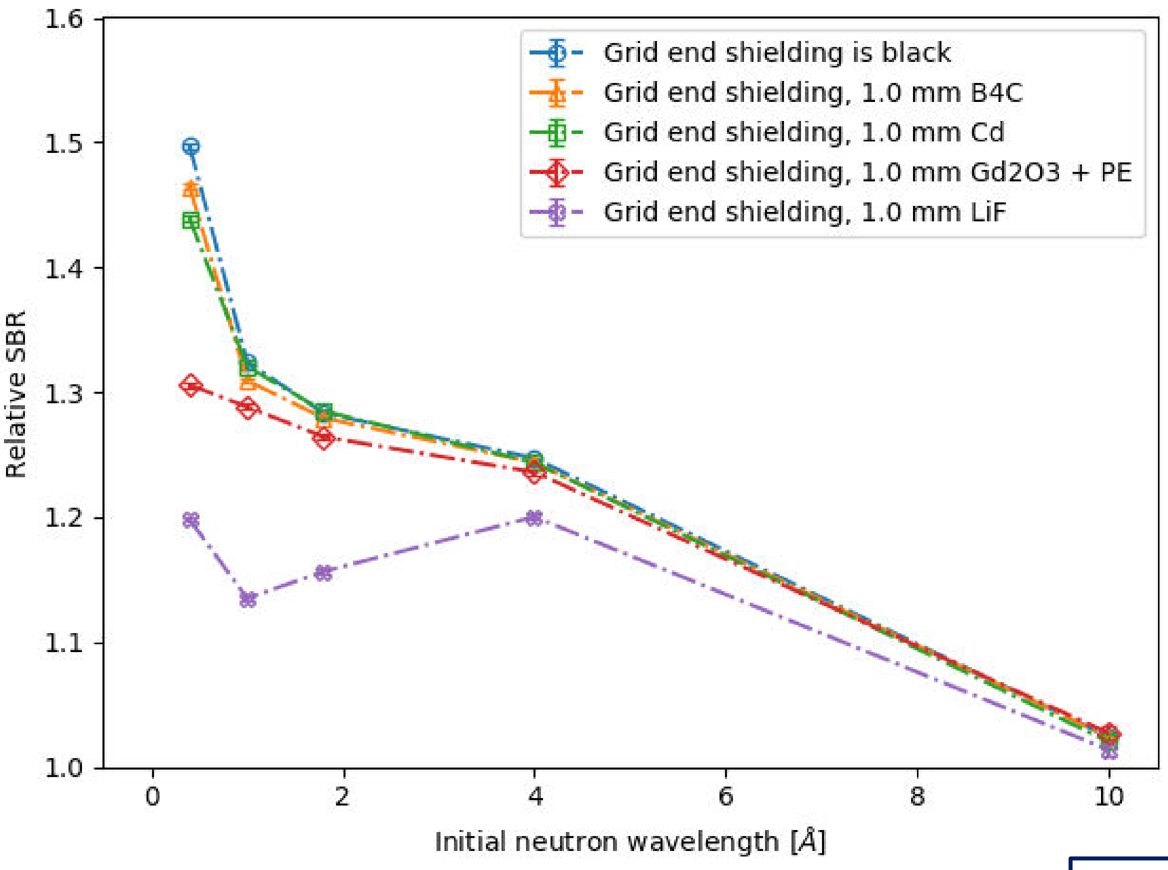


Non-scattered neutrons (Signal)



Scattered neutron background

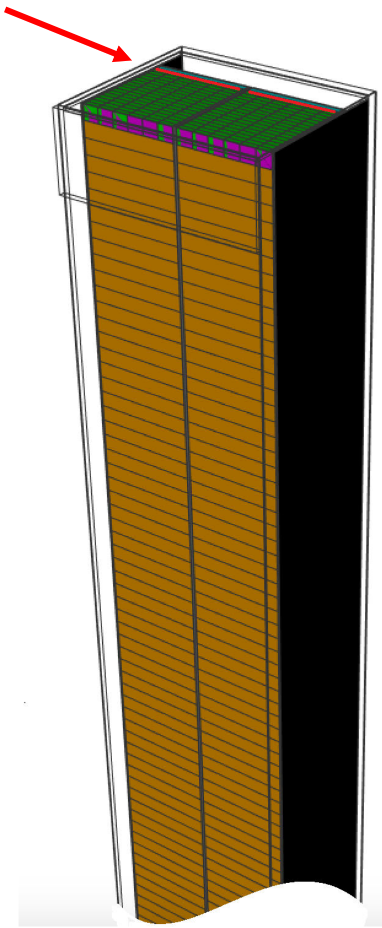
Signal-to-Noise Ratio with different **grid end shielding** materials



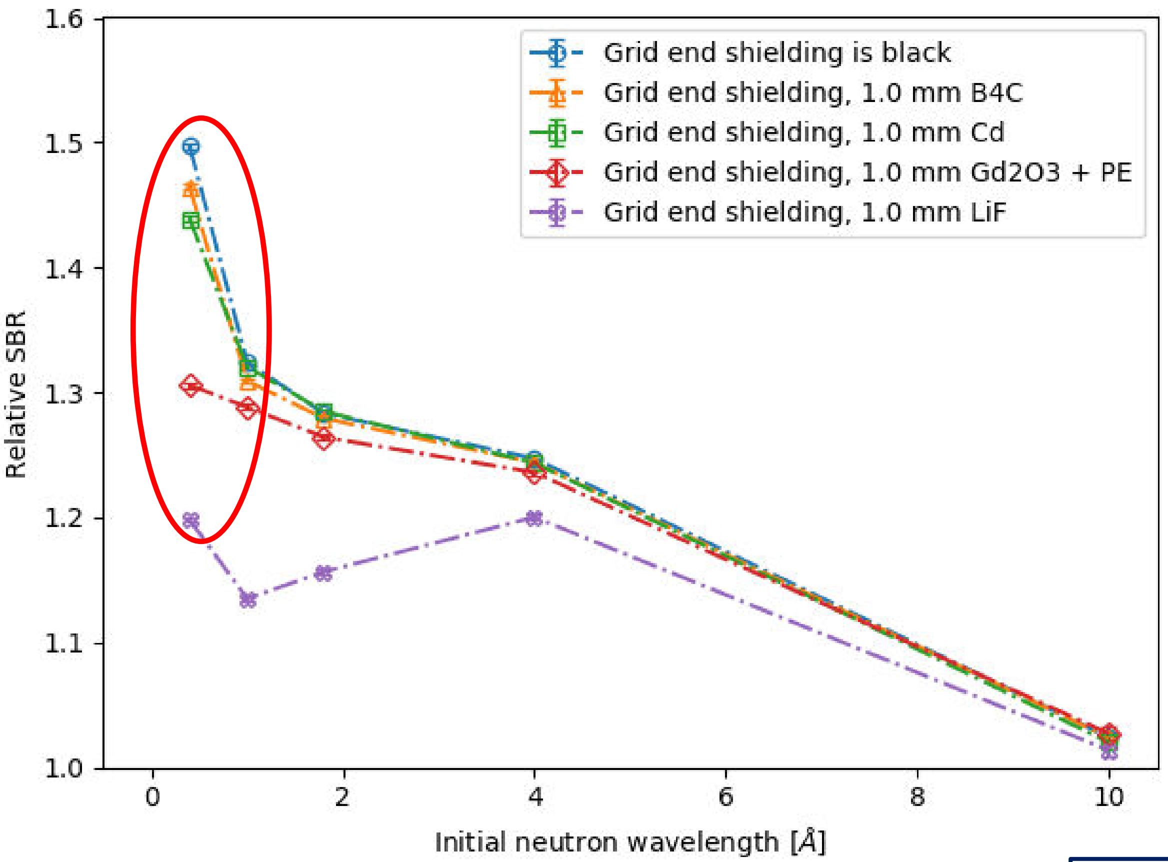
Relative Signal-to-Noise Ratio

Compared to unshielded detector

Grid end shielding



Signal-to-Noise Ratio with different **grid end shielding** materials

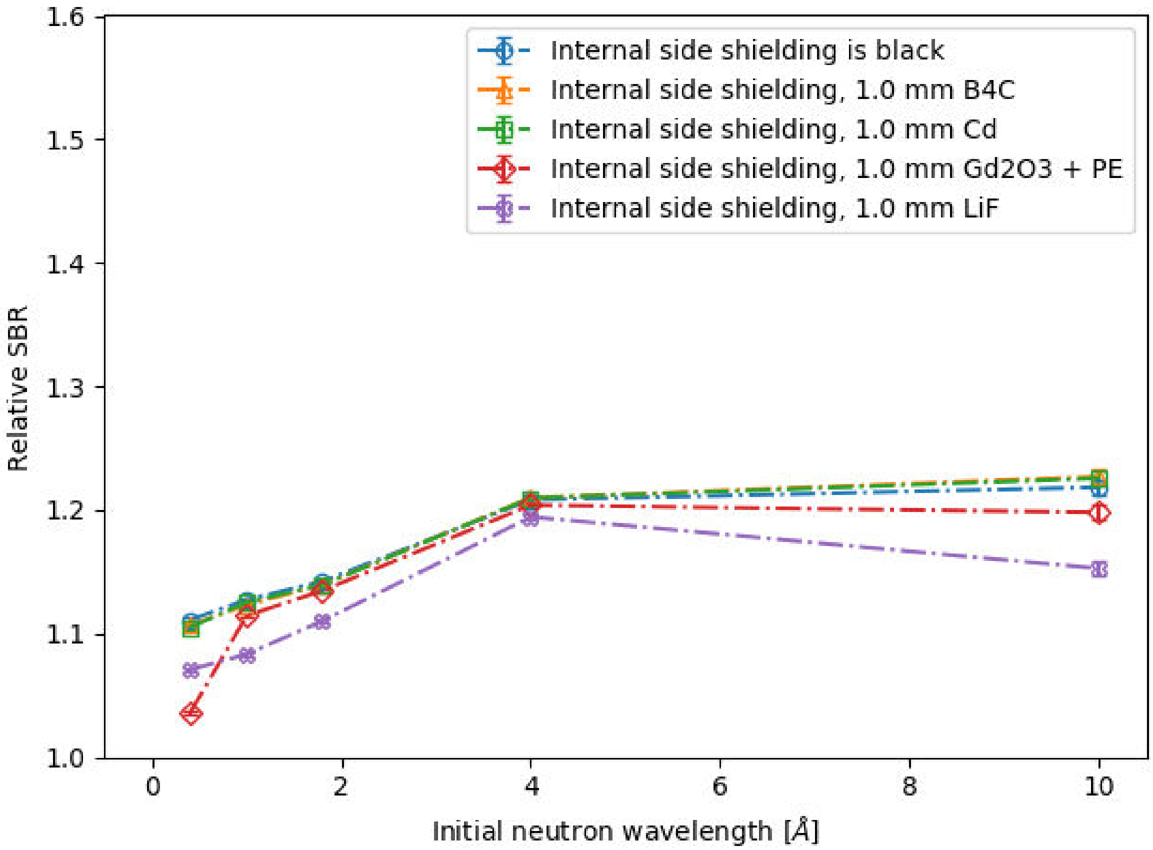


- 1.5 x SBR can be reached for low wavelengths
- 1 mm B_4C or Cd is great approximation of total absorber
- Gd_2O_3 is also good except low wavelengths
  - Impact of filler mixture

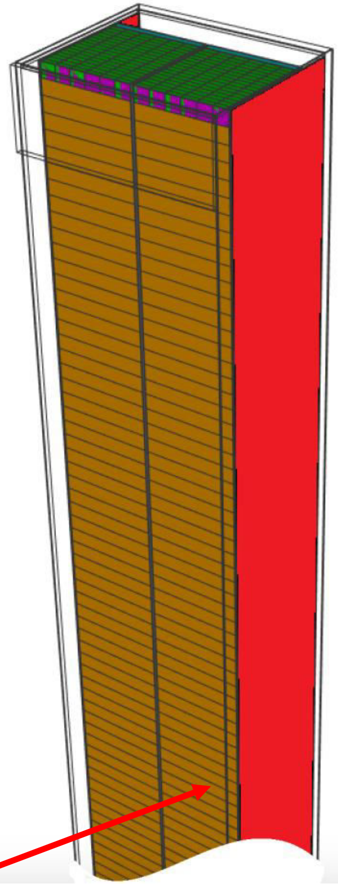
Relative Signal-to-Noise Ratio

Compared to unshielded detector

Signal-to-Noise Ratio with different **vessel side shielding** materials

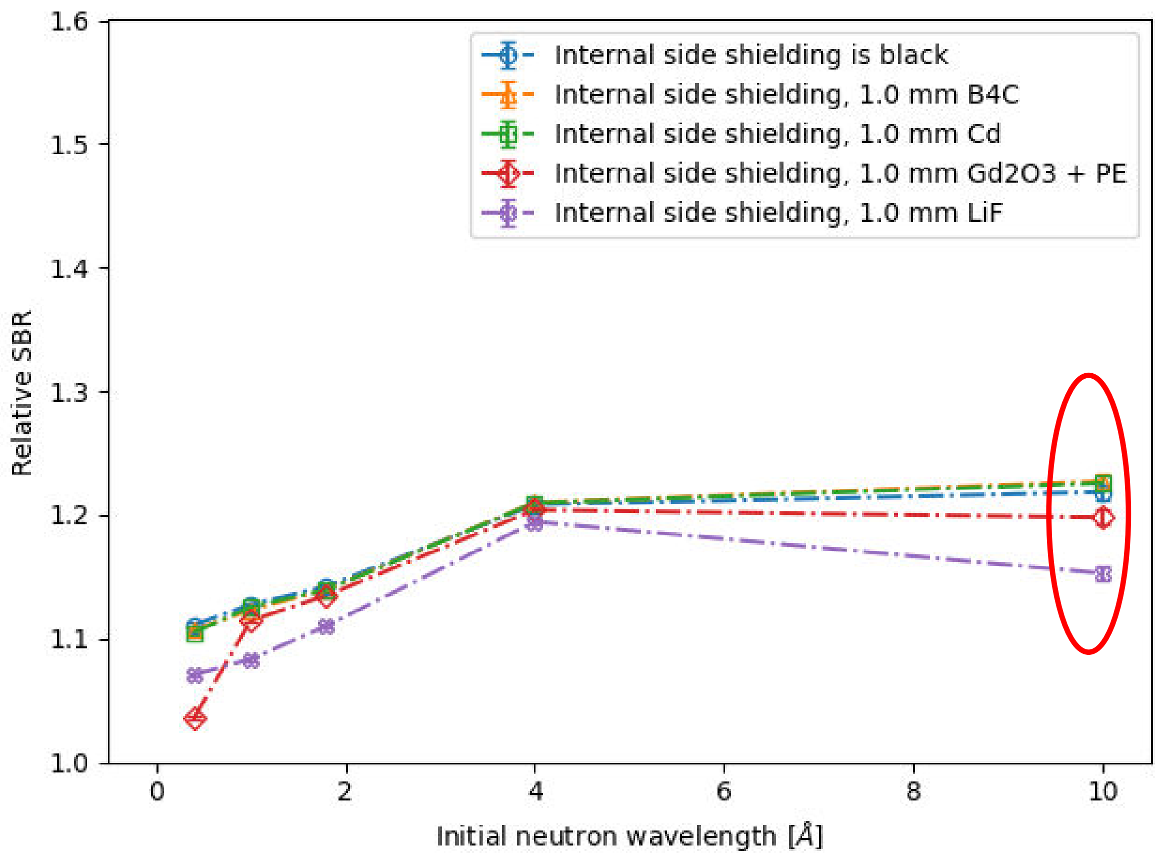


Relative Signal-to-Noise Ratio



Side shielding

Signal-to-Noise Ratio with different **vessel side shielding** materials

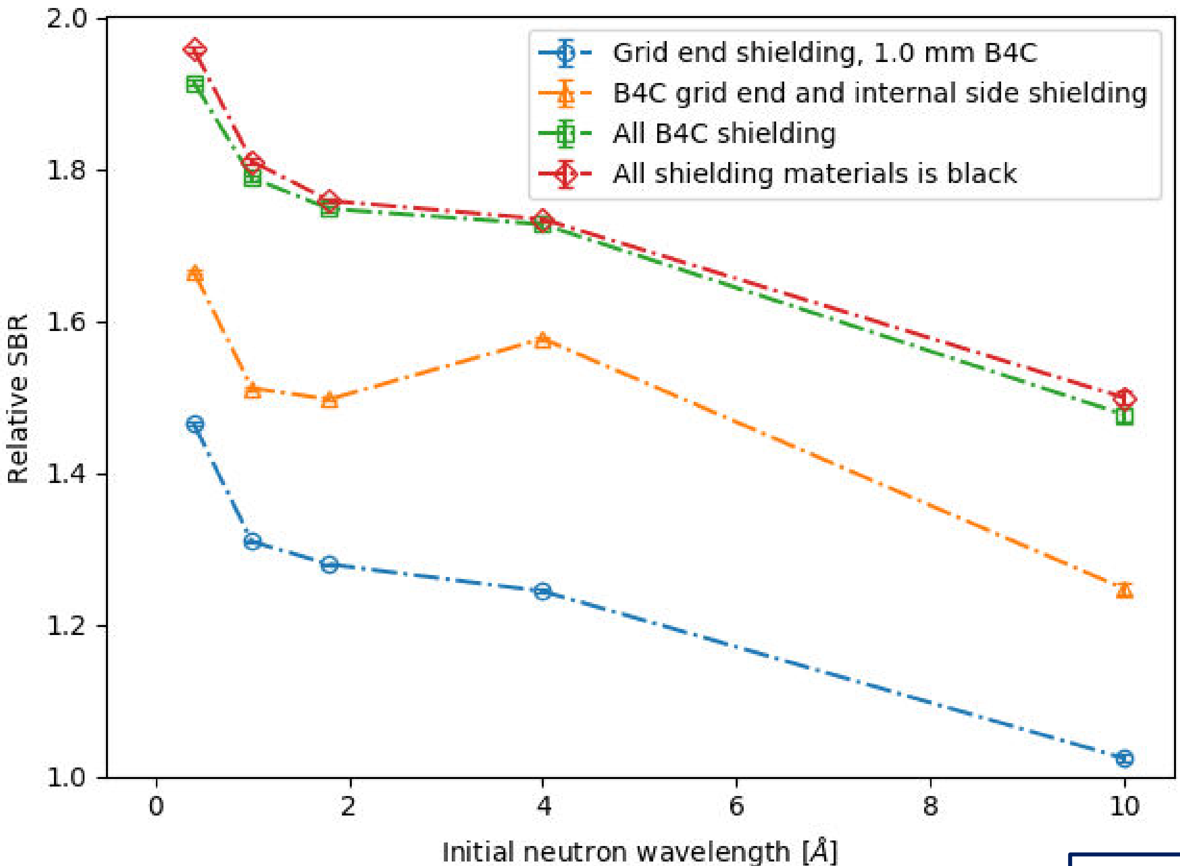


- 10 -20 % > increase of SBR can be reached with shielding on the internal side of vessel at high wavelengths
- 1 mm B_4C or Cd is great approximation of total absorber

Relative Signal-to-Noise Ratio

Compared to unshielded detector

Signal-to-Noise Ratio with combined shielding



Relative Signal-to-Noise Ratio

- 50-91% > increase of SBR for 0.4-10 Å wavelengths
- 1 mm B_4C or Cd is great approximation of total absorber

Compared to unshielded detector

Summary

- Great progress in neutron scattering simulation
- A validated model used for design optimisation
- Distinguish different sources of scattered neutron background

- 50-91% > SBR increase with optimal combined shielding
- 1 mm B_4C or Cd quasi-equivalent for black shielding
- With carefully chosen filler mixture, Gd_2O_3 is also good for shielding
- Scattering on reasonable window thickness is negligible in 3 – 9 Å
- Considerable effect of internal vessel side shielding

- Shielding can be optimised in comparison with ideal, total absorber through realistic design and quantities

Instruments with better signal-to-background ratio by design

EUROPEAN SPALLATION SOURCE

Prepared for submission to JINST

Suppression of intrinsic neutron background in the Multi-Grid detector

E. Dian,[a,b,c,1] K. Kanaki,[b] A. Khaplanov,[b] T. Kittelmann,[b] P. Zagyvai,[a,c] R. Hall-Wilton[b,d]

[a] *Hungarian Academy of Sciences, Centre for Energy Research, 29-33 Konkoly Thege Miklós street 1121 Budapest, Hungary*
[b] *European Spallation Source ESS ERIC, P.O Box 176, SE-221 00 Lund, Sweden*
[c] *Budapest University of Technology and Economics, Institute of Nuclear Techniques, 1111 Budapest, Műegyetem rakpart 9., Hungary*
[d] *Mid-Sweden University, SE-851 70 Sundsvall, Sweden*

E-mail: dian.eszter@energia.mta.hu

Abstract: One of the key requirements for all neutron scattering instruments is the high enough Signal-to-Background ratio (SBR), and while the increased signal is already provided, as the ESS aspires to be the brightest neutron source of the world, further increase of SBR can be reached with background reduction. The Multi-Grid detector, a large-area thermal neutron detector with solid boron-carbide converter, is a novel solution for chopper spectrometers. This detector design will be installed for the 3 prospective chopper spectrometers at the European Spallation Source (ESS). As the Multi-Grid detector is a large area detector with a complex structure, the intrinsic detector background, and its suppression via advanced shielding design should be considered. The intrinsic scattered neutron background and its effect on the SBR is determined via detailed Monte Carlo simulation for the Multi-Grid detector module, designed for the C-SPEC instrument at the ESS. The impact of scattering on the detector vessel and the entry window is determined, revealing the importance of optimised inner detector shielding. The background-reducing capacity of common shielding geometries, like side shielding and end shielding is determined by using ideal total absorber as shielding material, and common shielding materials, like B_4C and Cd are tested.

On the basis of the comparison of the effectiveness of the different shielding topologies and materials, recommendations are given for a combined shielding of the Multi-Grid detector module, optimised for increased SBR.

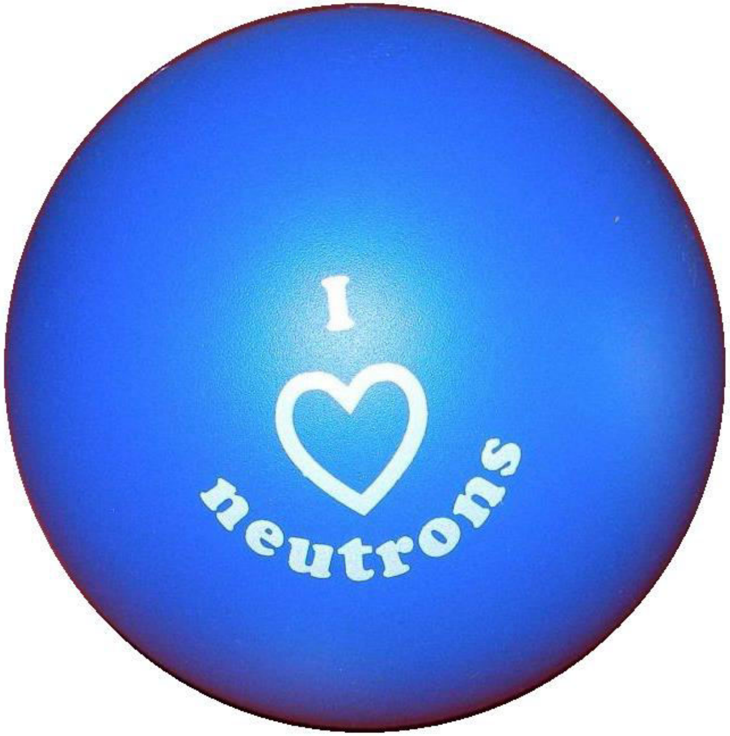
Keywords: Multi-Grid, Shielding, Monte Carlo, Geant4, neutron scattering, optimisation

ArXiv ePrint: arxiv to fill

[1] Corresponding author.

Upcoming submission

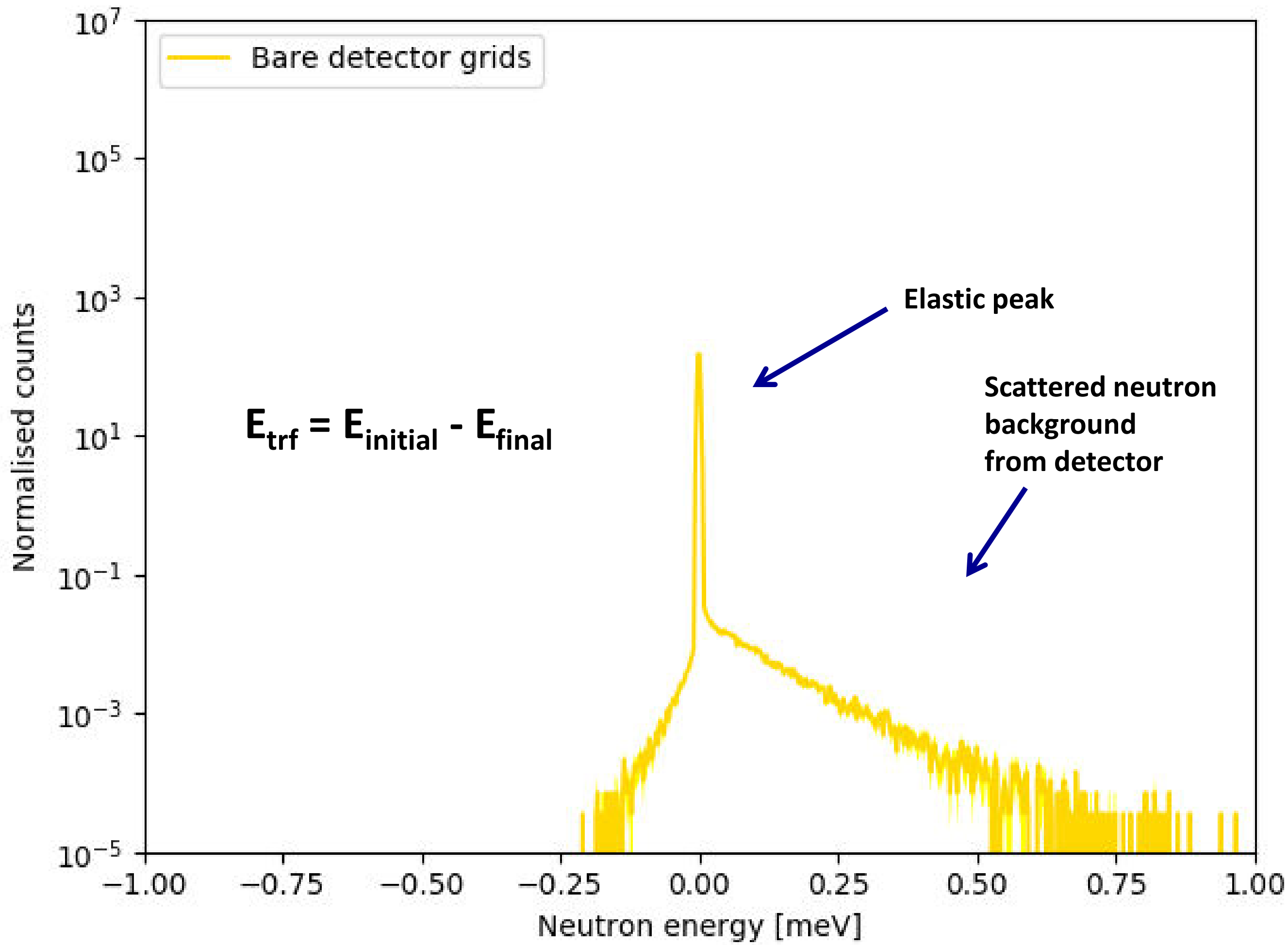
676548



Thank you for your attention!

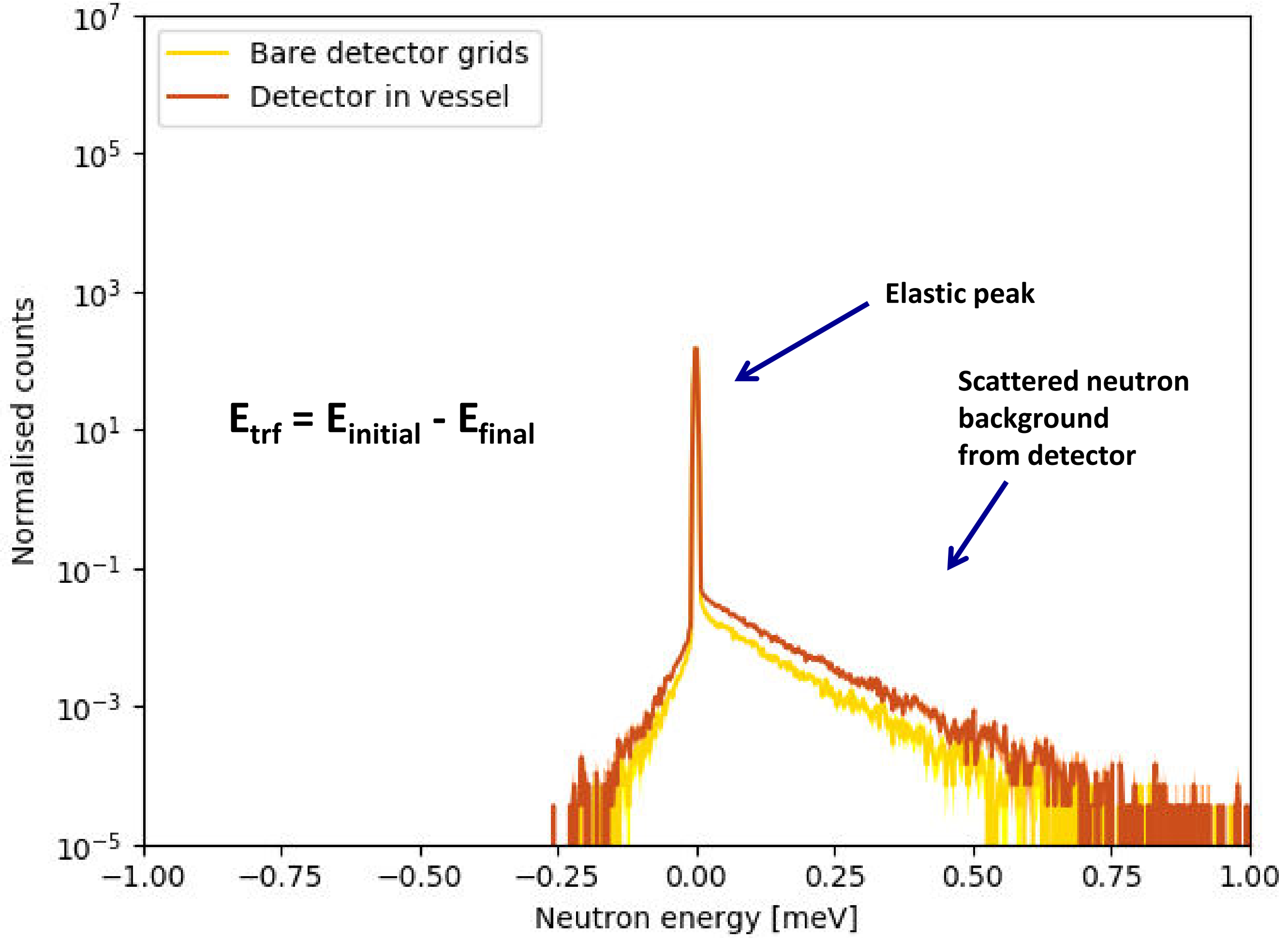
Multi-Grid detector test at CNCS, SNS

Derived energy transfer at 3.678 meV from simulation



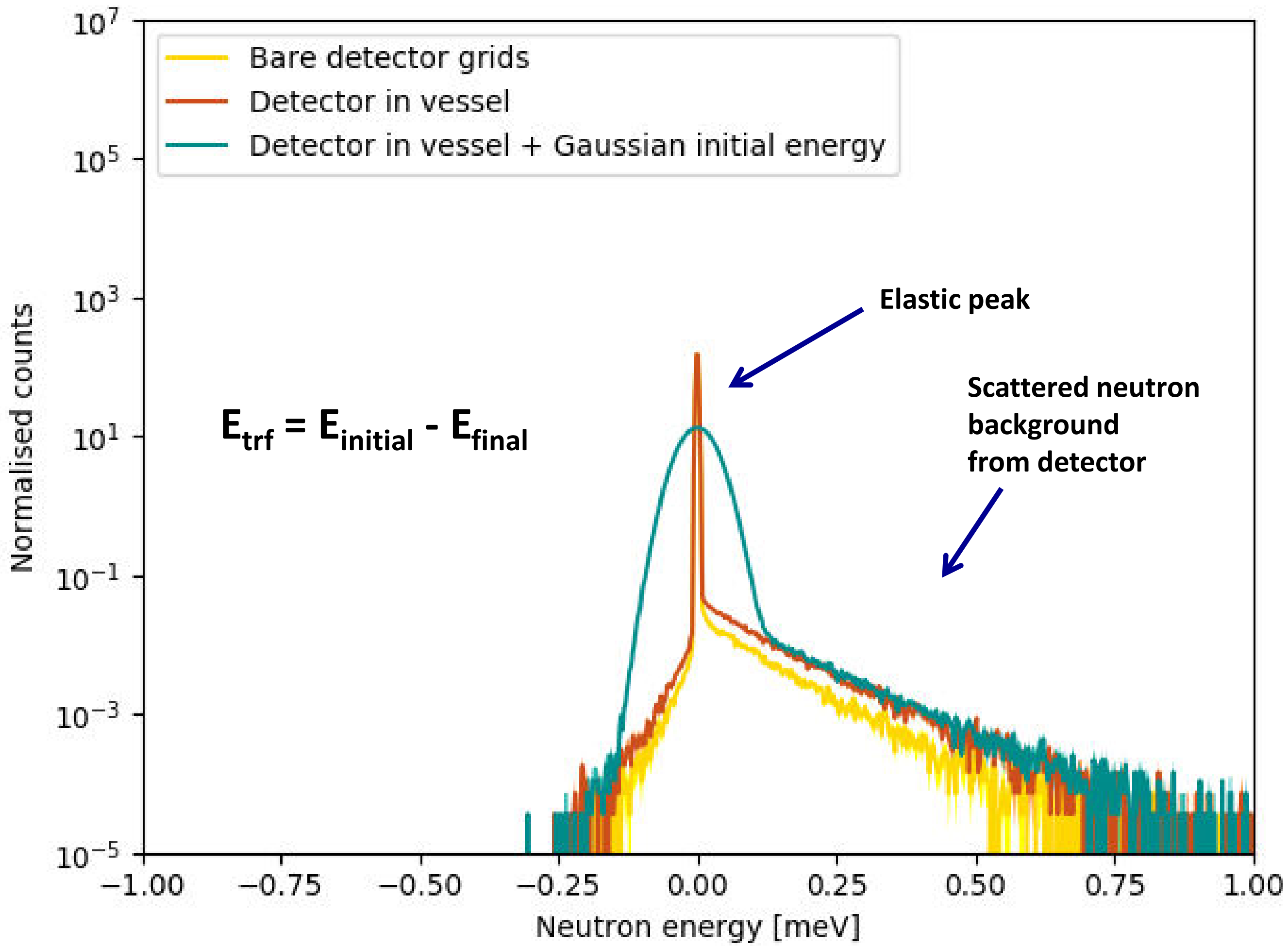
Multi-Grid detector test at CNCS, SNS

Derived energy transfer at 3.678 meV from simulation



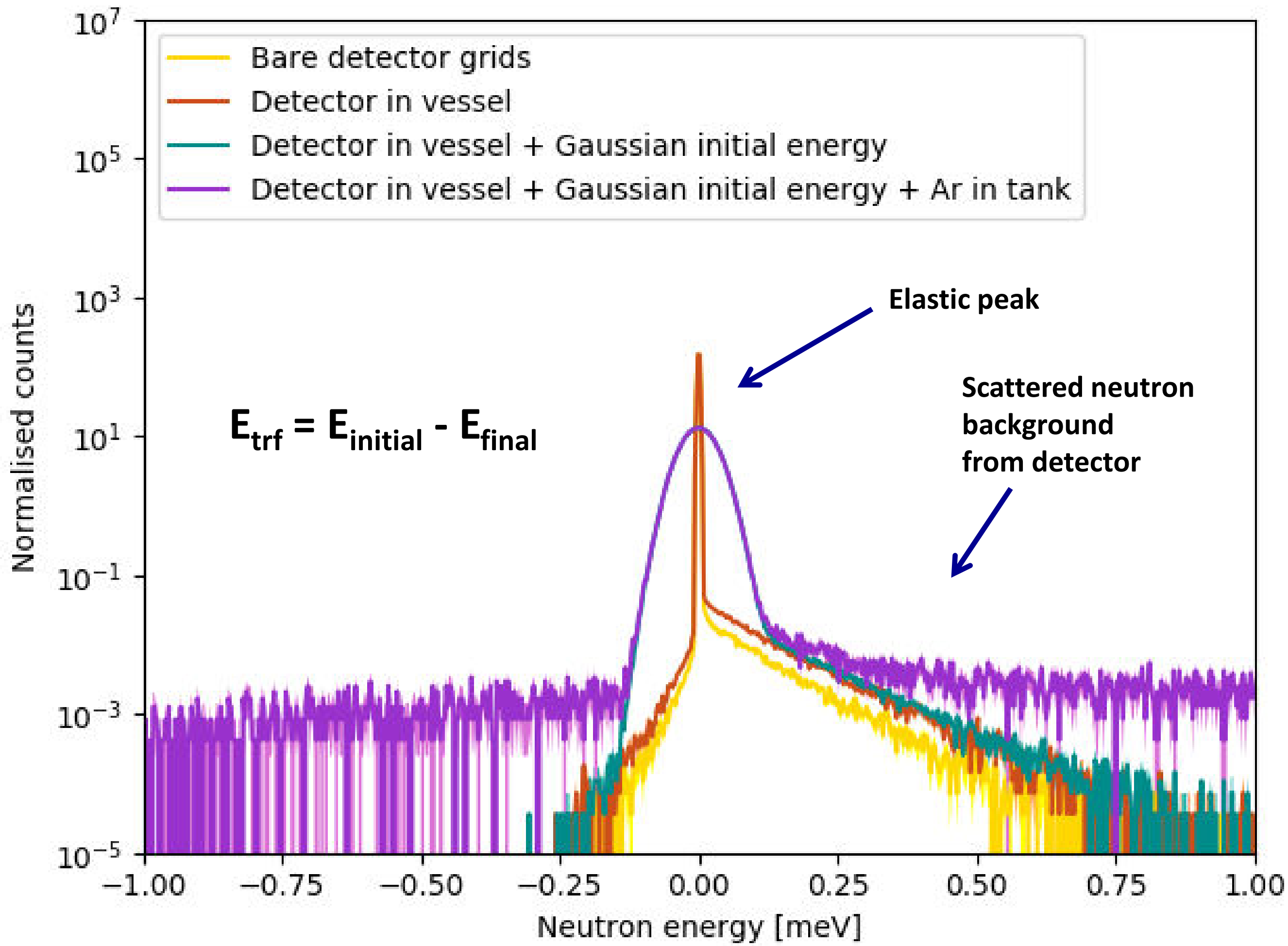
Multi-Grid detector test at CNCS, SNS

Derived energy transfer at 3.678 meV from simulation



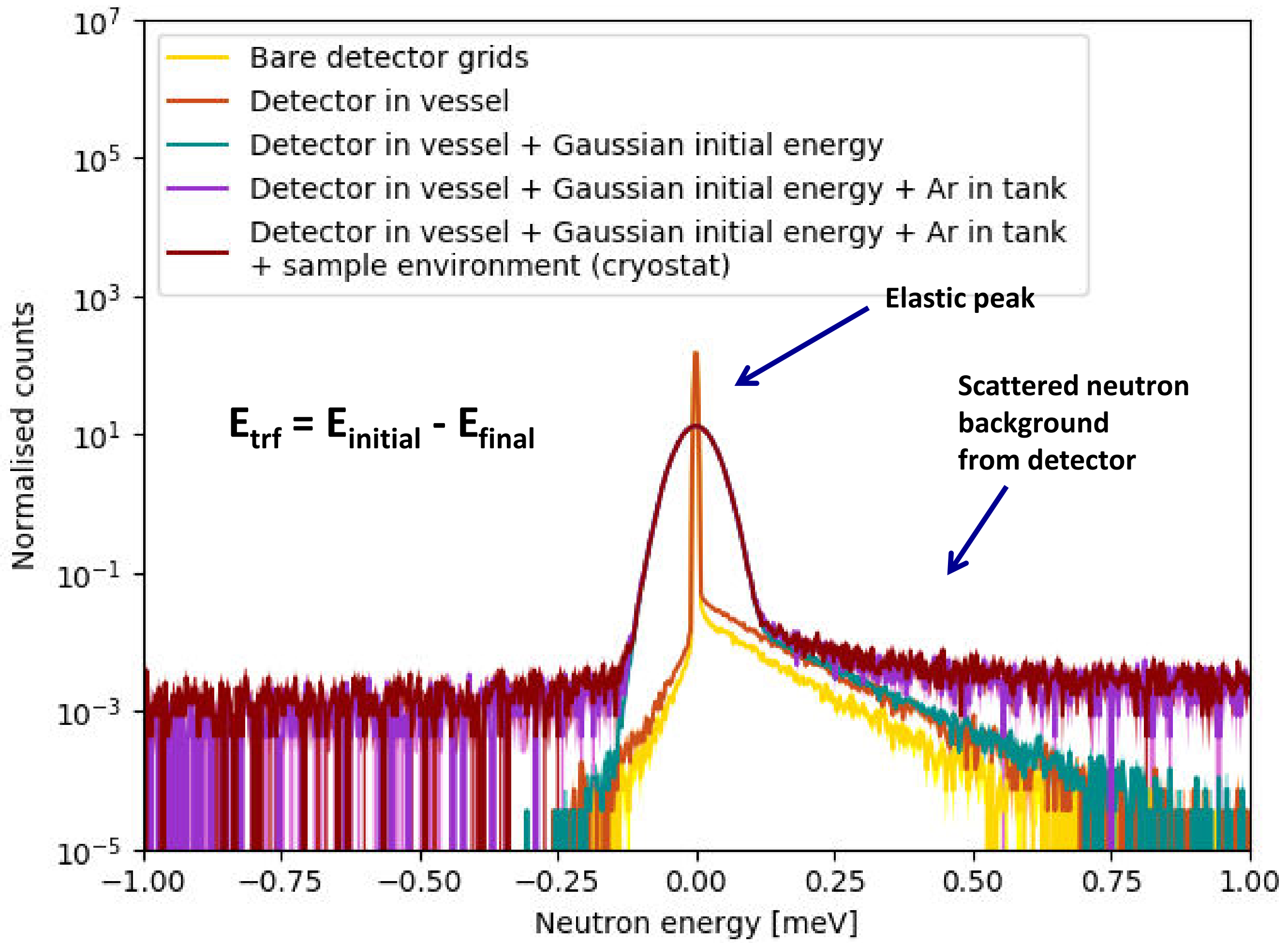
Multi-Grid detector test at CNCS, SNS

Derived energy transfer at 3.678 meV from simulation



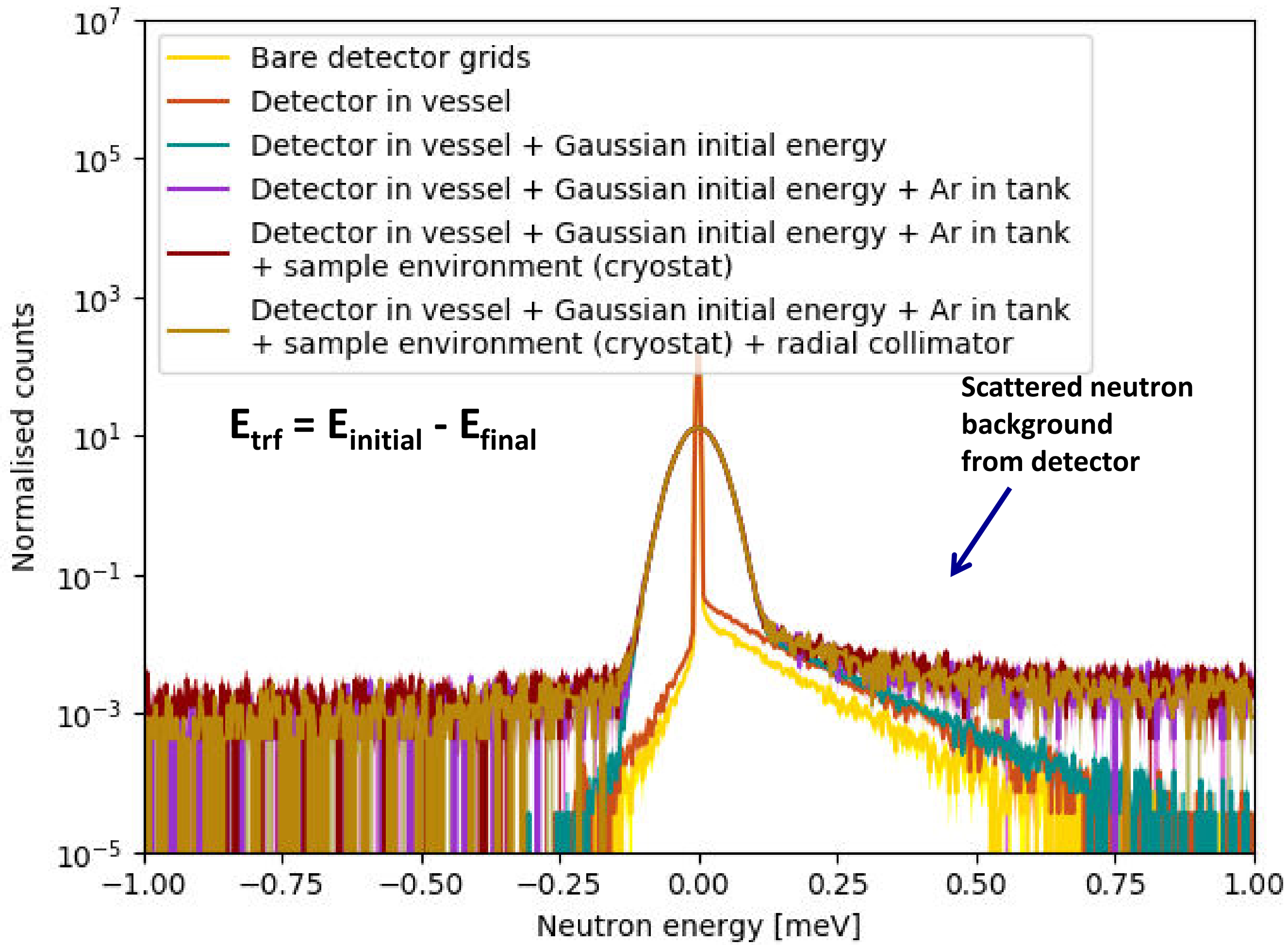
Multi-Grid detector test at CNCS, SNS

Derived energy transfer at 3.678 meV from simulation



Multi-Grid detector test at CNCS, SNS

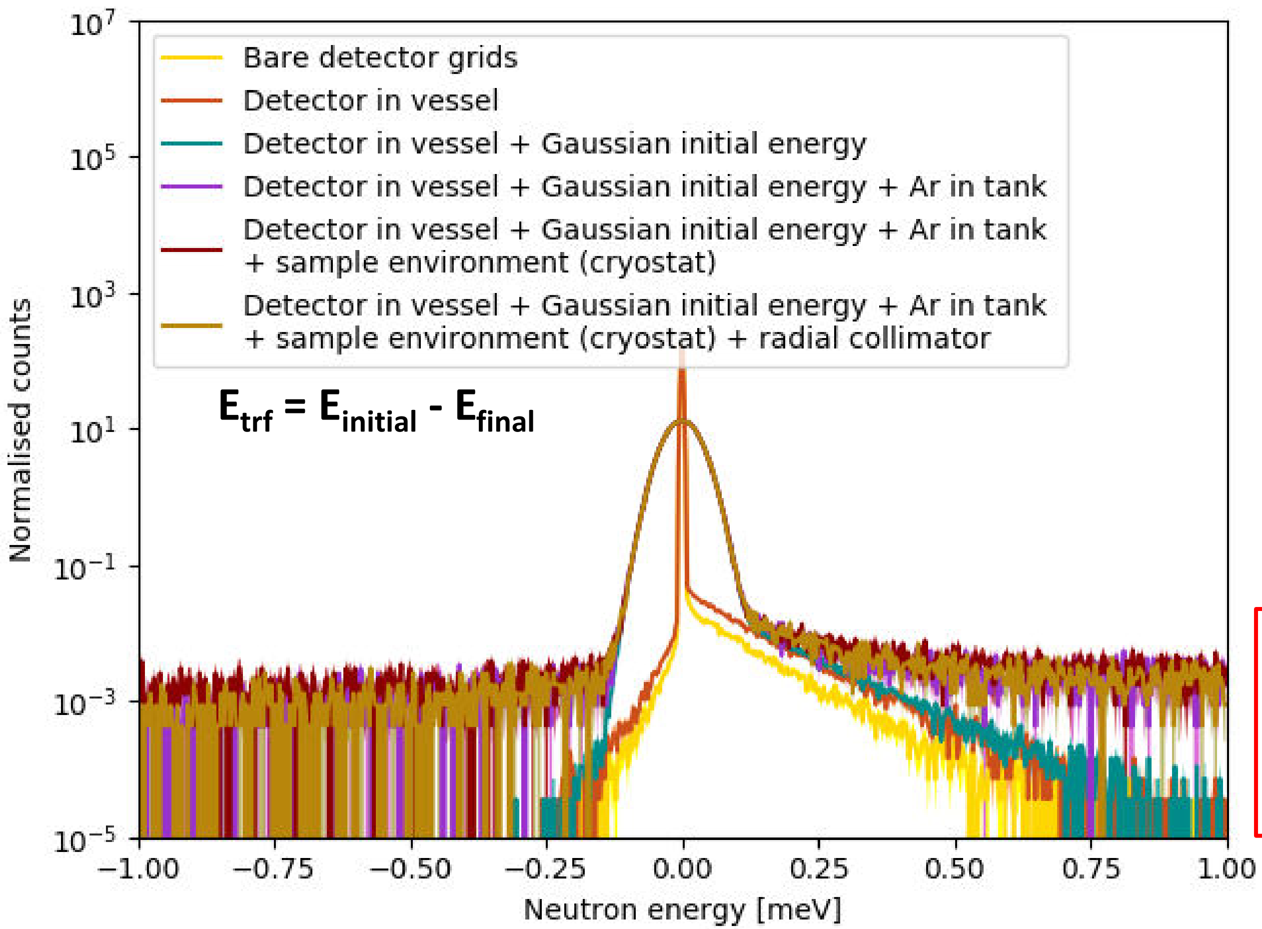
Derived energy transfer at 3.678 meV from simulation



Multi-Grid detector test at CNCS, SNS

EUROPEAN SPALLATION SOURCE

Derived energy transfer at 3.678 meV from simulation



Validation

- Distinguish different sources of background
- Detailed analysis and quantification of background effects

Energy transfer reproduced with simulation at 3.678 meV