Measurement of thermal neutron detection efficiency of NMX detector using enriched Gd samples

Letter of Intent to be submitted to the n-TOF collaboration at CERN

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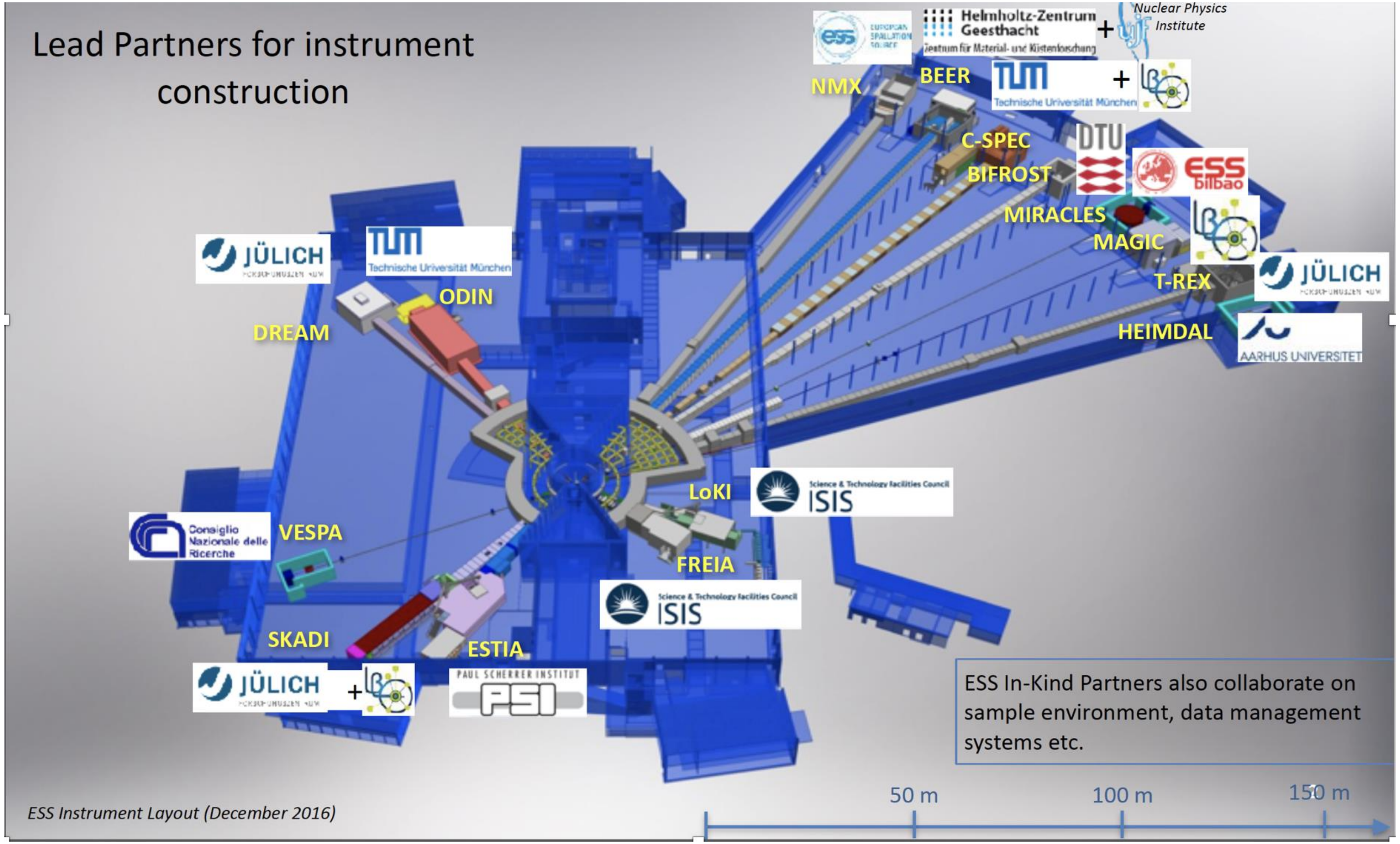
NMX instrument

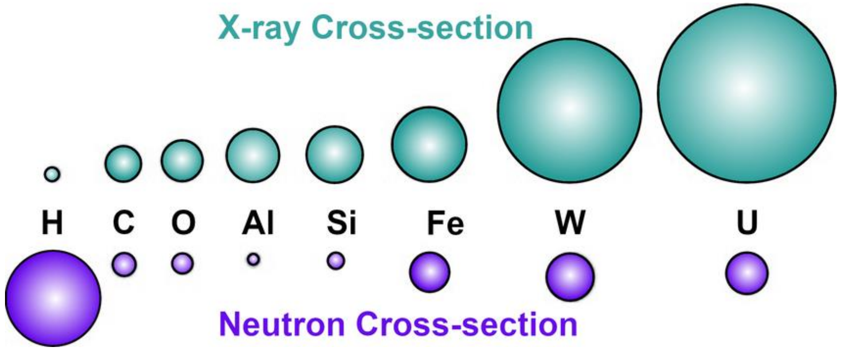


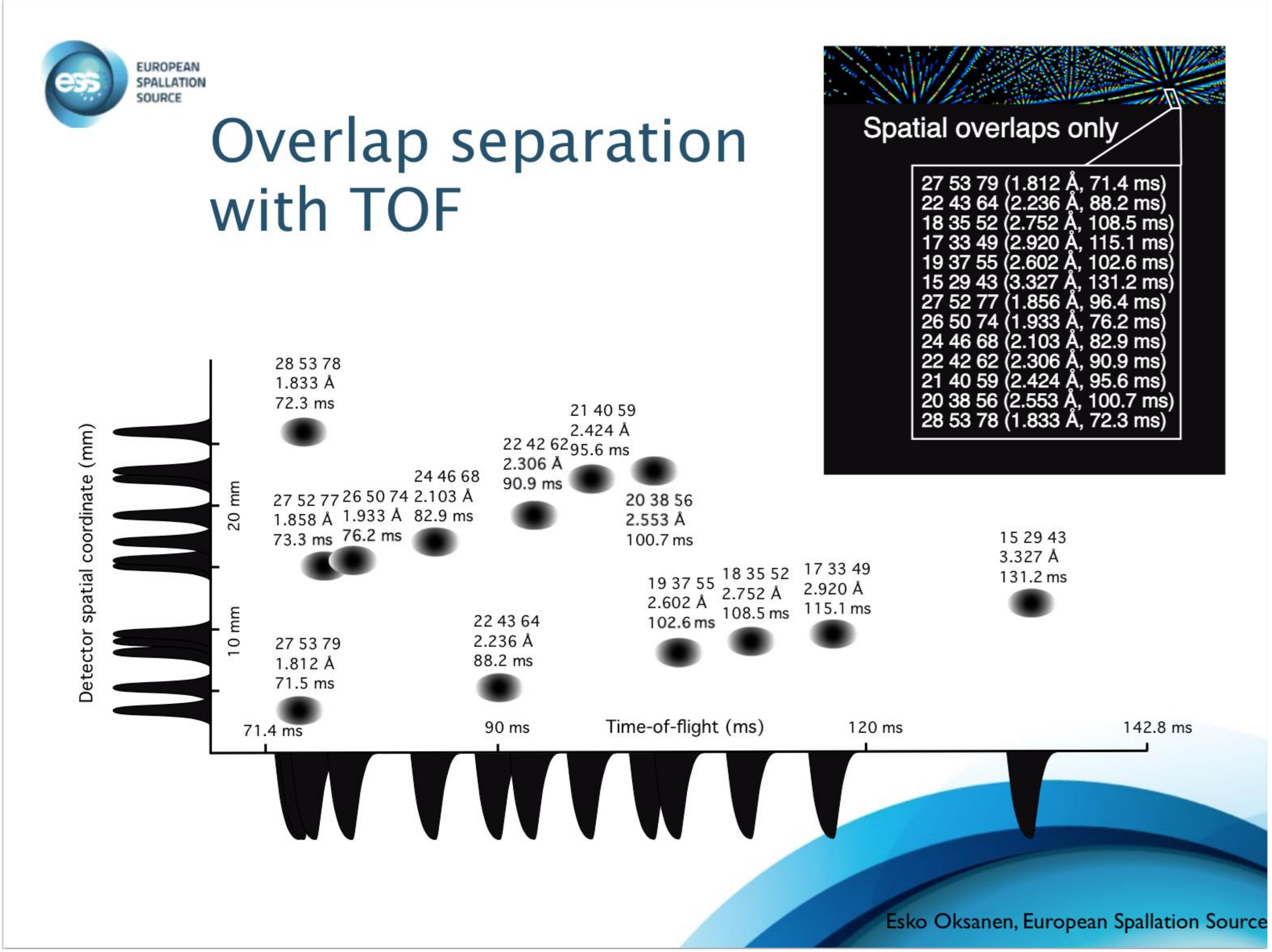
K. H. Andersen et al., The instrument suite of the European Spallation Source, NIM A (957) 2020, https://doi.org/10.1016/j.nima.2020.163402

NMX instrument at ESS

Neutron Macromolecular Crystallography (NMX)

- Physics case for NMX is the study of large protein crystals with thermal and cold neutrons
- Neutrons are useful probes because they can identify position of H atoms
- A detector with good spatial (~400 um) and time-resolution (ns) is needed to resolve the spatial and temporal overlap of diffraction spots



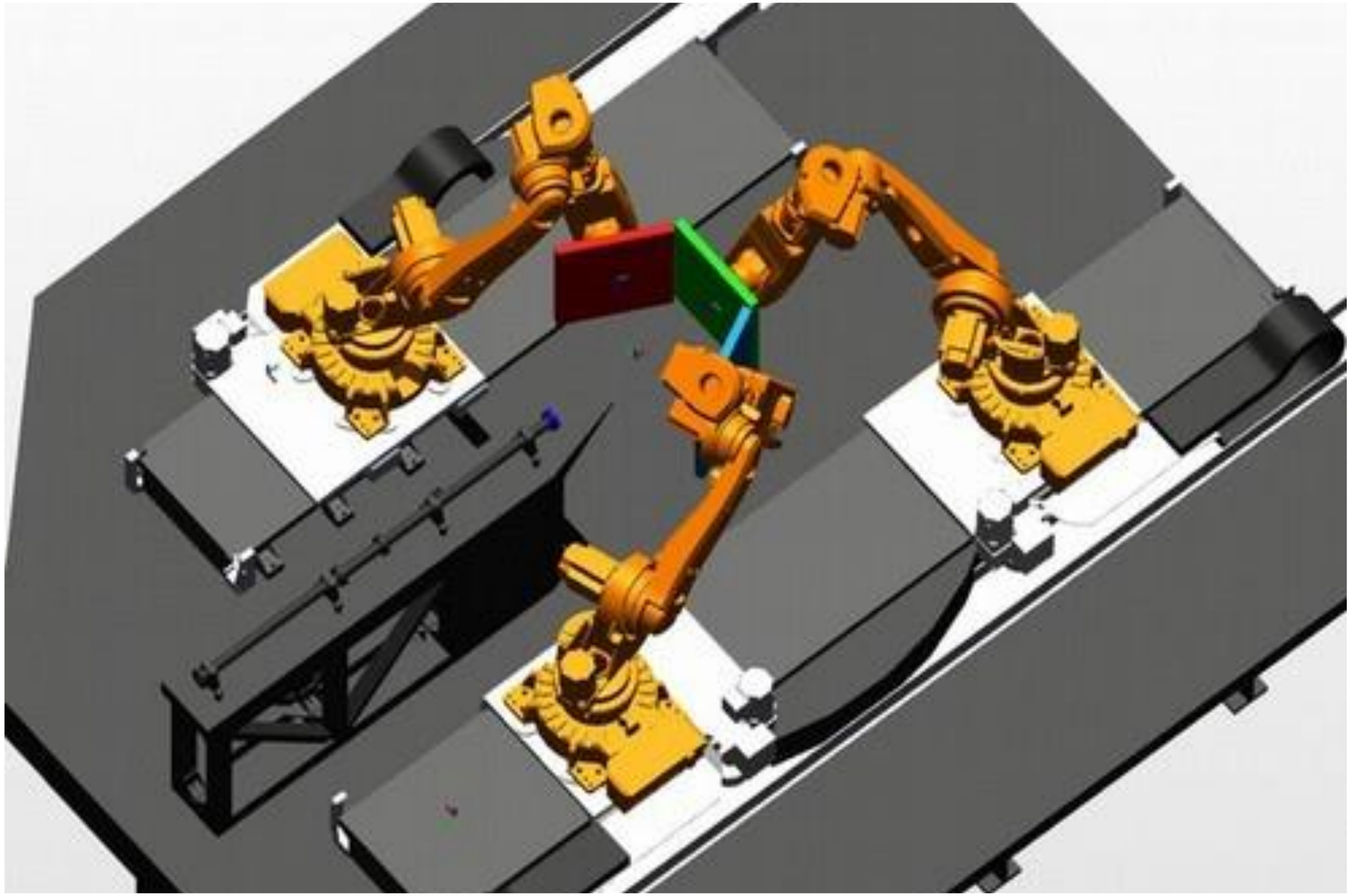


M. Marko, G. Nagy, G. Aprigliano, E. Oksanen, Methods in Enzymology (634) 2020,
Chapter Seven - Neutron macromolecular crystallography at the European spallation source, https://doi.org/10.1016/bs.mie.2020.01.005

NMX instrument at ESS

Detector configuration

- Three detector panels mounted on robotic arms
- Can be positioned in various position around the sample
- Detector technology based on Micro Pattern Gaseous Detectors (MPGD)
- NMX uses a Triple GEM (Gas Electron Multiplier) detector with at the moment natural Gadolinium converter
- Converter upgrade to enriched Gd is studied



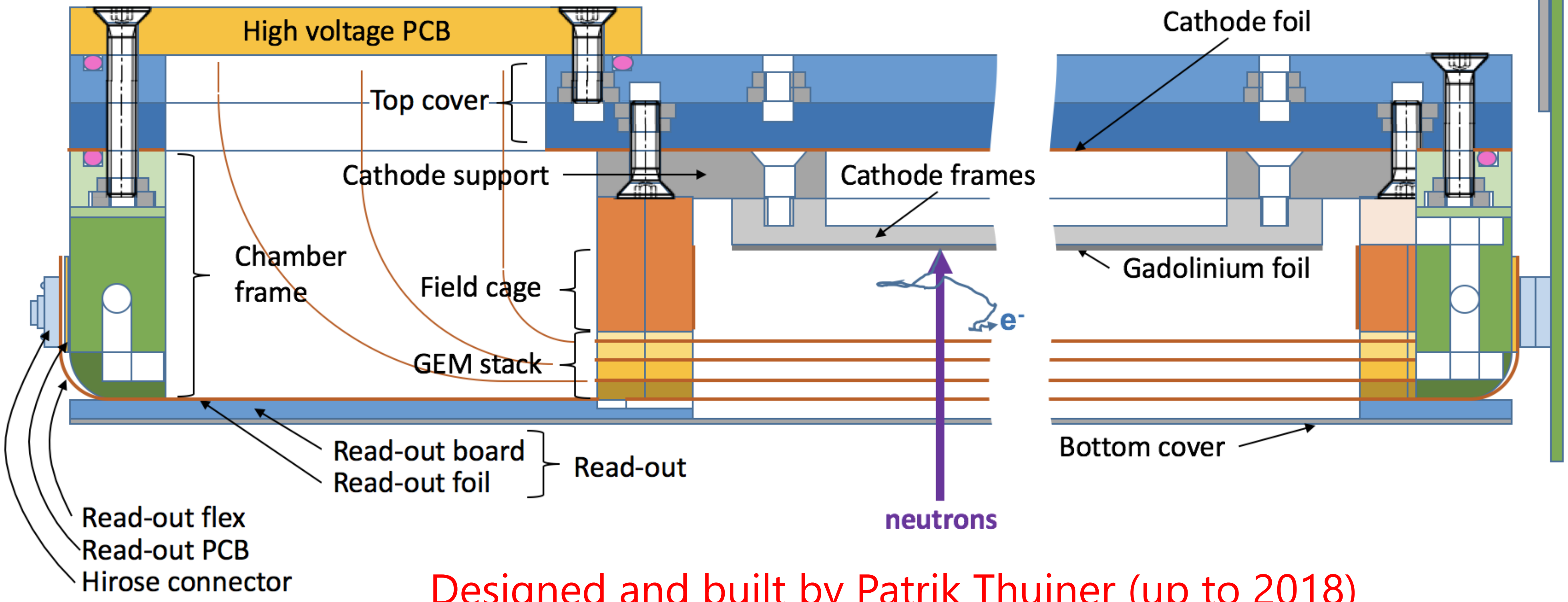
D. Pfeiffer, P. Thuiner, BrightnESS deliverable 2015, Work Package 4: Innovation of Key Neutronic Technologies: Detectors and Moderators, https://doi.org/10.17199/BRIGHTNESS.D4.3

NMX detector

Schematic drawing of detector in backwards configuration

D. Pfeiffer et al., First measurements with new high-resolution gadolinium-GEM neutron detectors, JINST (11) 05 2016, https://doi.org/10.1088/1748-0221/11/05/P05011

D. Pfeiffer et al., Demonstration of Gd-GEM detector design for neutron macromolecular crystallography applications, JINST (18) 04 2022, https://doi.org/10.1088/1748-0221/18/04/P04023



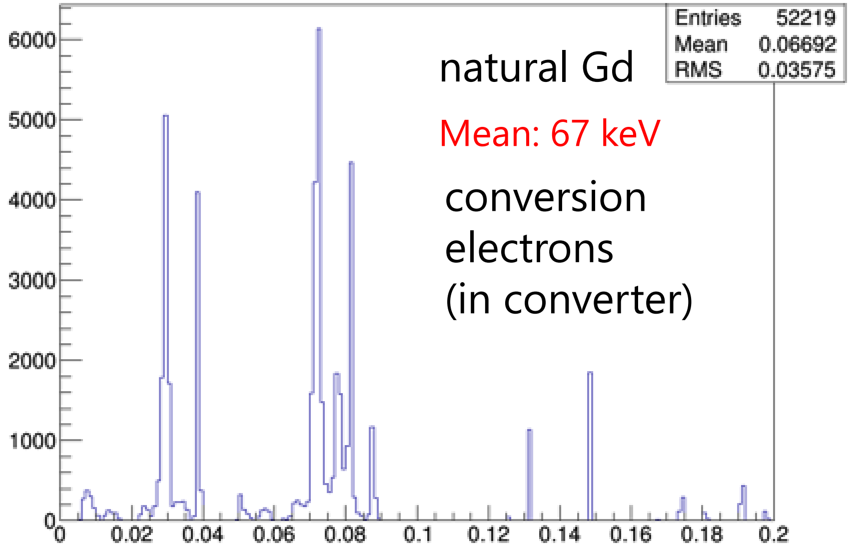
Designed and built by Patrik Thuiner (up to 2018) and Jerome Samarati (since 2019)

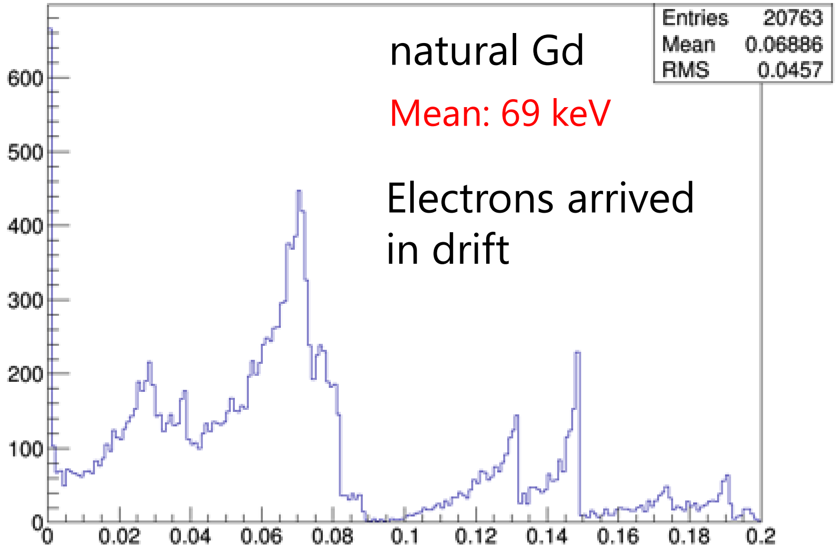
NMX detector

Gd as neutron converter

- High cross section for thermal and cold neutrons (cross sections have been reliably measured e.g. by n-TOF)
- High probability of production of charged particle (some publications of conversion electron spectra available)
- High probability of escape of charged particle into drift space of detector (int forward mode thickness has to be optimized to increase escape probability)
- High detection probability of charged particle (with a GEM detector, we are basically 100% efficient above our readout threshold)

Simulation with Geant4 10.0

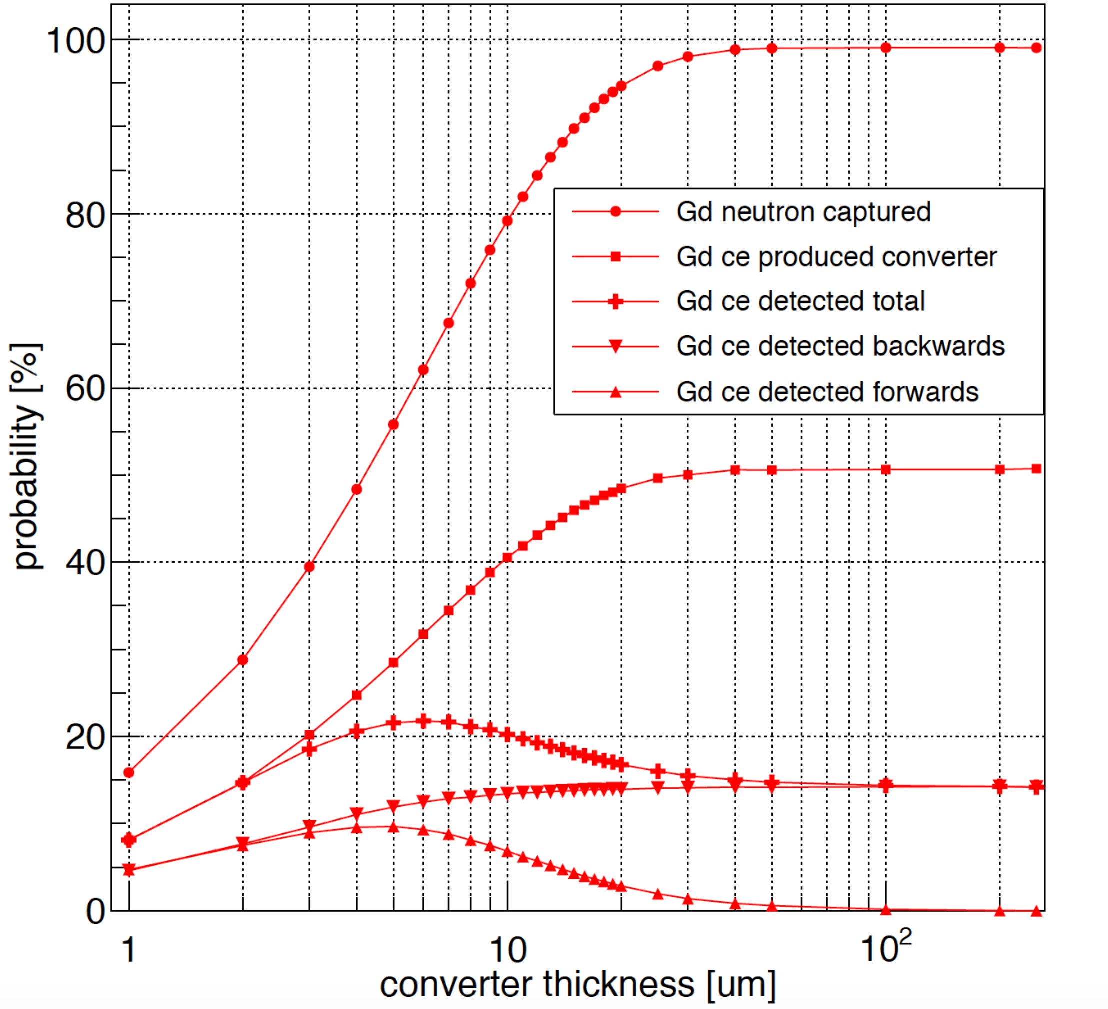


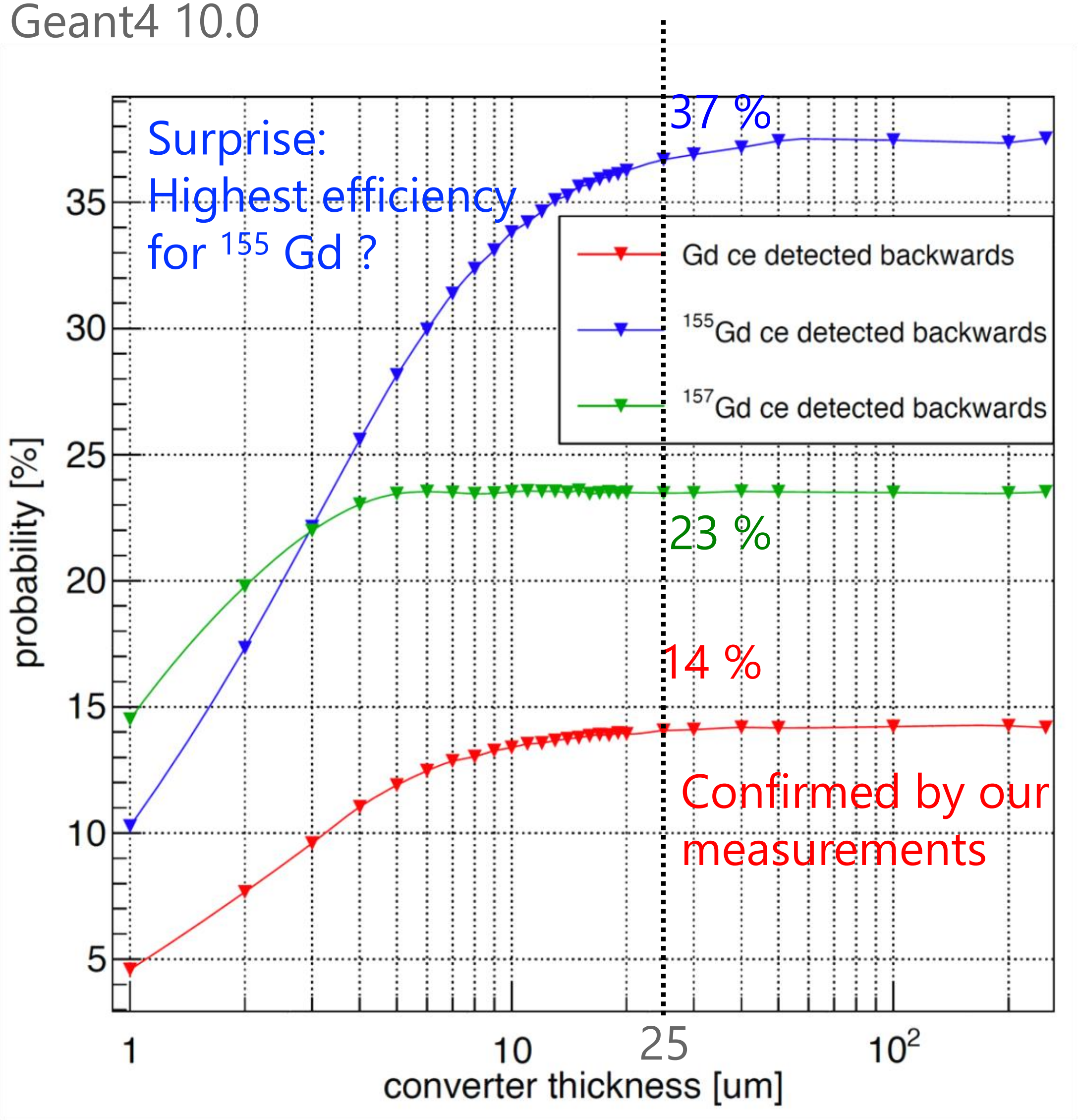


Geant4 simulations

Detection efficiency for thermal neutrons 1.8 A (25 meV)

Simulation with Geant4 10.0





Geant4 simulations

Problems with photo-evaporation model

- Neutron capture cross section correct
- Photo-evaporation model produces different amounts of conversion electrons from version to version (persists in Geant4 version 11)
- ^{155}Gd systematically produces too many conversion electrons, ^{157}Gd not enough compared to the literature (appendix)
- Expectation from literature: around 35% efficiency for ^{157}Gd with thermal neutrons
- In Geant4 cases with several ce per neutron, measured efficiency might be overstated if such an event is reconstructed as several conversion electron tracks (i.e. one neutron is counted as several neutrons)

Geant4 10.1	155 Gd	157 Gd	Ge
captured	100000	100000	100000
events CE produced	85131	43408	50778
total ce	127115	51933	65388
ce per neutron	1.27115	0.51933	0.65388
avg ce	1.493169351	1.19639237	1.28772303
ekin ce	38.72 keV --> 1.1805 MeV	29.264 keV --> 1.1358 MeV	11.523 keV --> 1.1792 MeV

Geant4 10.2	155 Gd	157 Gd	Ge
captured	100000	100000	100000
events CE produced	0	0	0
total ce			
ce per neutron	0	0	0
avg ce			
ekin ce			

Geant4 10.2.p02	155 Gd	157 Gd	Ge
captured	100000	100000	100000
events CE produced	69070	72184	71738
total ce	69070	72184	71741
ce per neutron	0.6907	0.72184	0.71741
avg ce	1	1	1.000041819
ekin ce	38.719 keV --> 88.608 keV	29.264 keV --> 79.148 keV	4.292 keV --> 79.81 keV

Geant4 10.3	155 Gd	157 Gd	Ge
captured	100000	100000	100000
events CE produced	83266	59181	63607
total ce	110383	63920	72522
ce per neutron	1.10383	0.6392	0.72522
avg ce	1.325667139	1.080076376	1.14015753
ekin ce	38.72 keV --> 2.9598 MeV	29.264 keV --> 2.2656 Me	1.5615 keV --> 3.0312 MeV

N-TOF LOI

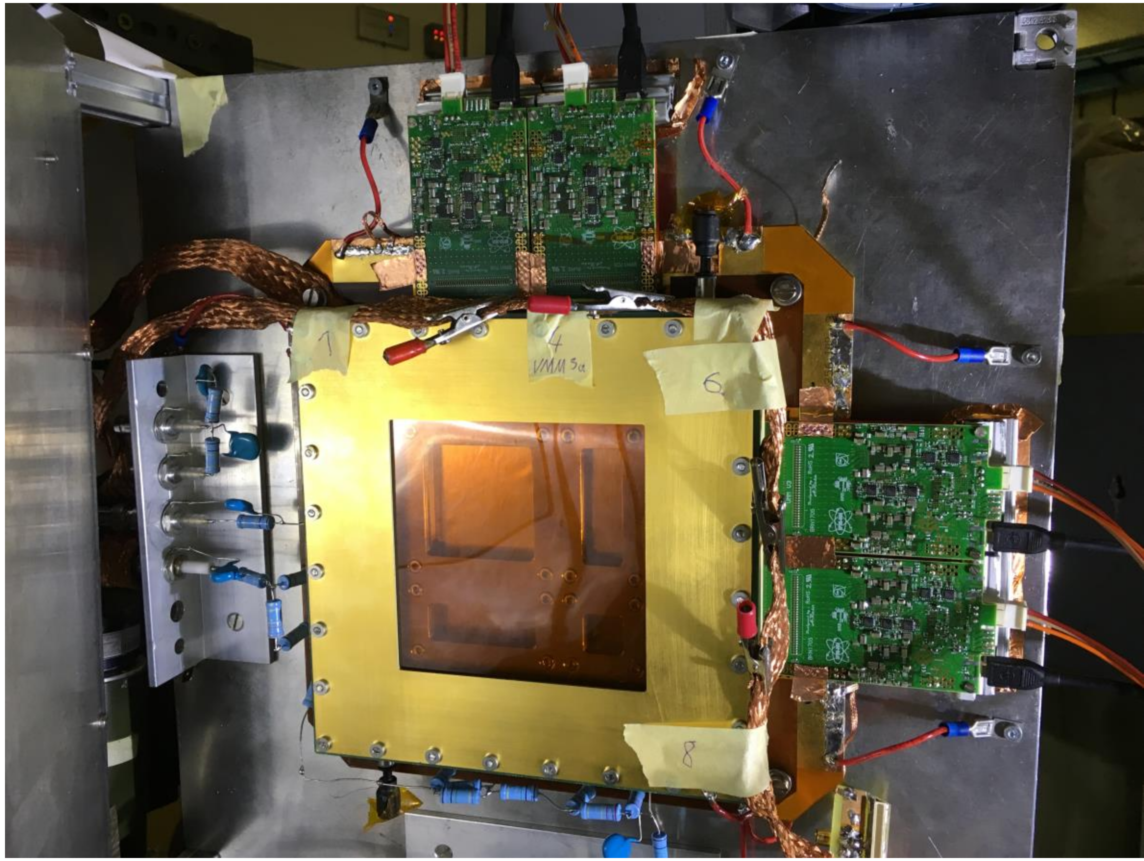
Measurement of ^{155}Gd and ^{157}Gd

- To answer the question of how much NMX would profit from an upgrade to isototopically enriched Gd, we would like to measure the detection effiency of the NMX detctor at n-TOF
- We kindly ask the collaboration to lend us the thick samples of ^{155}Gd (40um) and ^{157}Gd (80um) that have been used by n-TOF to measure the cross-sections
- Samples are circular with 20 mm diameter
- Plan is to tape these samples with copper tape to the natural Gd cathode in a small 10 cm x 10 cm prototype detector
- Tests with natural Gd have shown that taping makes a good electrical connection (cathode will be on 4600 V)
- Removal of circular samples should not damage samples, damage more likely to occur on our cathode

N-TOF LOI

Measurement of ^{155}Gd and ^{157}Gd

- We would like to take beam on the vertical beamline at n-TOF
- We would like to ask for about one day of beam time (number of protons to be calculated)
- We would need at least one day before the beam time to install the detector
- The detector has a footprint of about 40 cm x 40 cm
- We plan an n-TOF visit to measure distances etc to construct a vertical detector support that allows horizontal movements of the detector to focus the beam on different parts of the 10 cm x 10 cm cathode

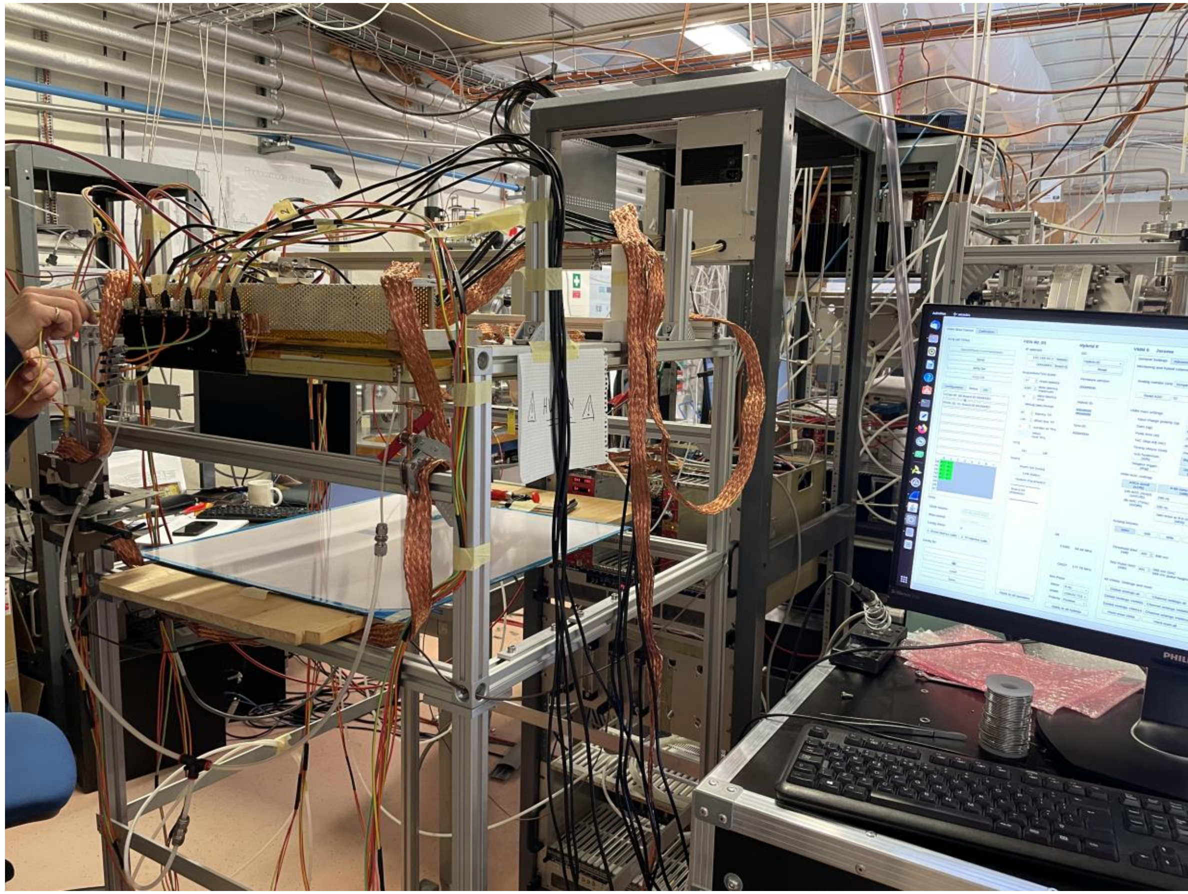


Small prototype detector with 10 cm x 10 cm active area and 40 cm x 40 cm footprint

N-TOF LOI

Planned measurements at n-TOF

- Focus beam on natural Gd cathode
- Focus beam on enriched samples
- Focus beam on intersection of natural and enriched Gd (might be difficult due to beam size)
- Use time-of-flight technique and n-TOF reference detector to directly measure thermal and epi-thermal neutron efficiency
- Indirectly measure efficiency benefit of enriched Gd by comparing natural with enriched regions of our cathode
- Question: Prompt gamma peak, can it cause problems to electronics?



Vertical support of our full-size 60 cm x 60 cm detector
A similar support could be constructed for the n-TOF measurements

Literature

Gd neutron converters: Calculation and measurements

- D.A. Abdushukurov, Mathematical Modeling of the Efficiency Gadolinium Based Neutron Converters, Applied Mathematics Vol. 4 No. 8A (2013) 27-33.
- A. Bäcklin et al., Isotopic Conversion in Gadolinium-Exposure Neutron Imaging, Nuclear Physics A380 (1982) 189-260.
- G. Bruckner et al., Position sensitive detection of thermal neutrons with solid state detectors (Gd Si planar detectors), Nuclear Instruments and Methods in Physics Research A 424 (1999) 183-189.
- R.C. Greenwood et al., Collective and two-quasiparticle states in 158Gd observed through study of radiative neutron capture in 157Gd, Nuclear Physics A304 (1978) 327-428.
- C.K. Hargrove et al., Use of Gd in gas counters as neutron detectors in SNO, Nuclear Instruments and Methods in Physics Research A 357 (1995) 157-169.
- A.A. Harms and G. McCormack, Isotopic conversion in Gadolinium-exposure neutron imaging,Nuclear Instruments and Methods in Physics Research 118 (1974) 583-587.

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