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Neutron Transmission through Sapphire Crystals: Experiments and Simulations



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Introduction

Sapphire crystals are excellent filters of fast neutrons, while at the same time exhibit moderate to very little absorption at smaller energies. We have performed an extensive series of **measurements** in order to quantify the above effect. Alongside our experiments, we have performed a series of **simulations**, in order to reproduce the transmission of cold neutrons through sapphire crystals. Those simulations were part of the effort of validating and improving the newly developed interface between the Monte-Carlo neutron transport code MCNP and the Monte Carlo ray-tracing code McStas.

Experiments

Our experiments were performed at the **BOA** testing beamline at **PSI** (Figs. 1-3). In total, 12 crystals were used, all with same dimensions of 26mm×26mm×10mm, and with the 10mm edge parallel to the beam direction. The crystals were obtained by three different commercial providers (four crystals from each provider). We have measured the dependence of both fast (>0.1eV) and cold (~1-10Å) neutron transmission to the crystals' thickness, and also we have tested for potential performance differences, due to e.g. inherent impurities (quality check), among the three types of sapphire crystals from our three suppliers.

--Figs. 4-6 show our results for fast neutron transmission through sapphire crystals of varying thickness: after 120mm-thick crystal, the integral intensity is reduced by a factor of ~6 (i.e. ~17% of fast neutrons go through; Fig 5), while the peak intensity is reduced by factor ~13 (or ~7% transmission; Fig. 6)

--Fig. 7 show our results for cold neutron transmission through sapphire crystals of various thicknesses for wavelengths between 0.7-10Å: the minimum transmission for a 120mm sapphire crystal is around ~30%. This goes up to ~50% when considering wavelengths between 1.5-6Å.

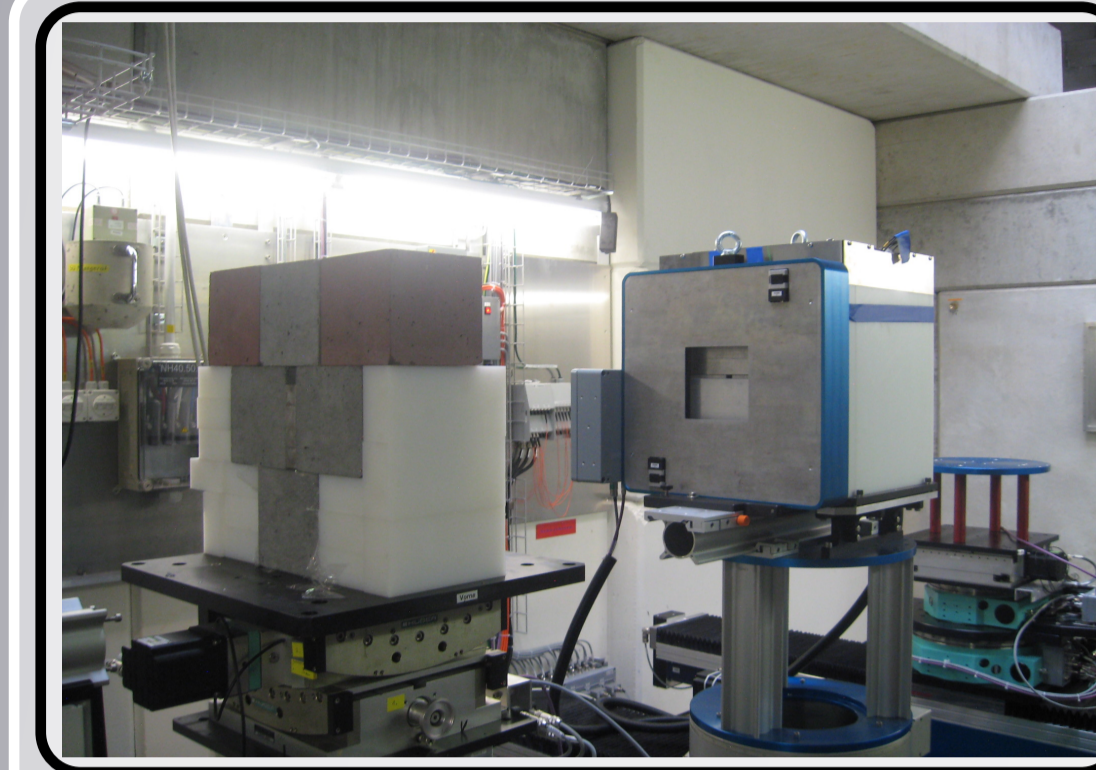


Figure 1: Experimental set up: crystals in place with shielding and ³He detector

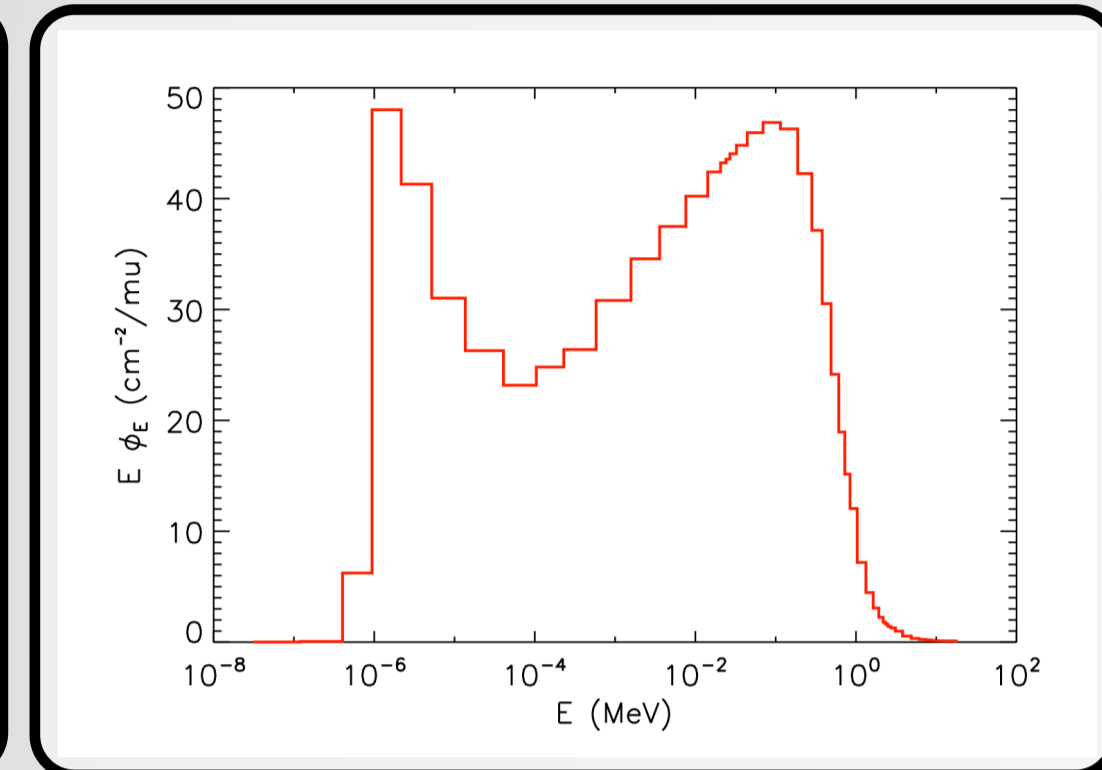


Figure 2: Energy distribution of fast neutron fluence at BOA

Figure 3: Cross sections of ¹¹³Cd (BOA's experimental shutter) and ³He (neutron detector). For the fast neutron measurements, our experimental set-up was securely shielding against neutrons lower than ~0.1 eV, while allowing for energies 0.1<E<10⁴eV

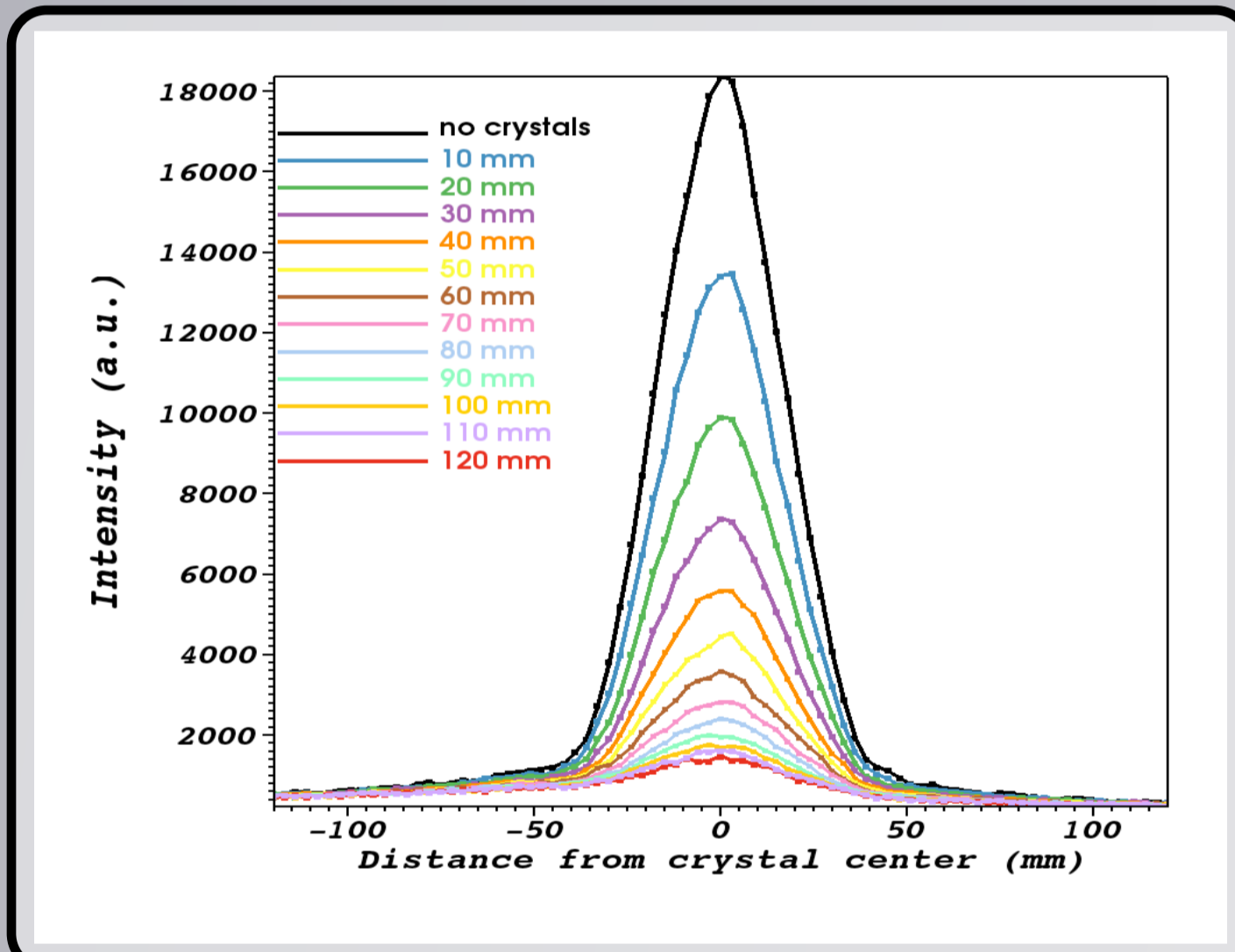
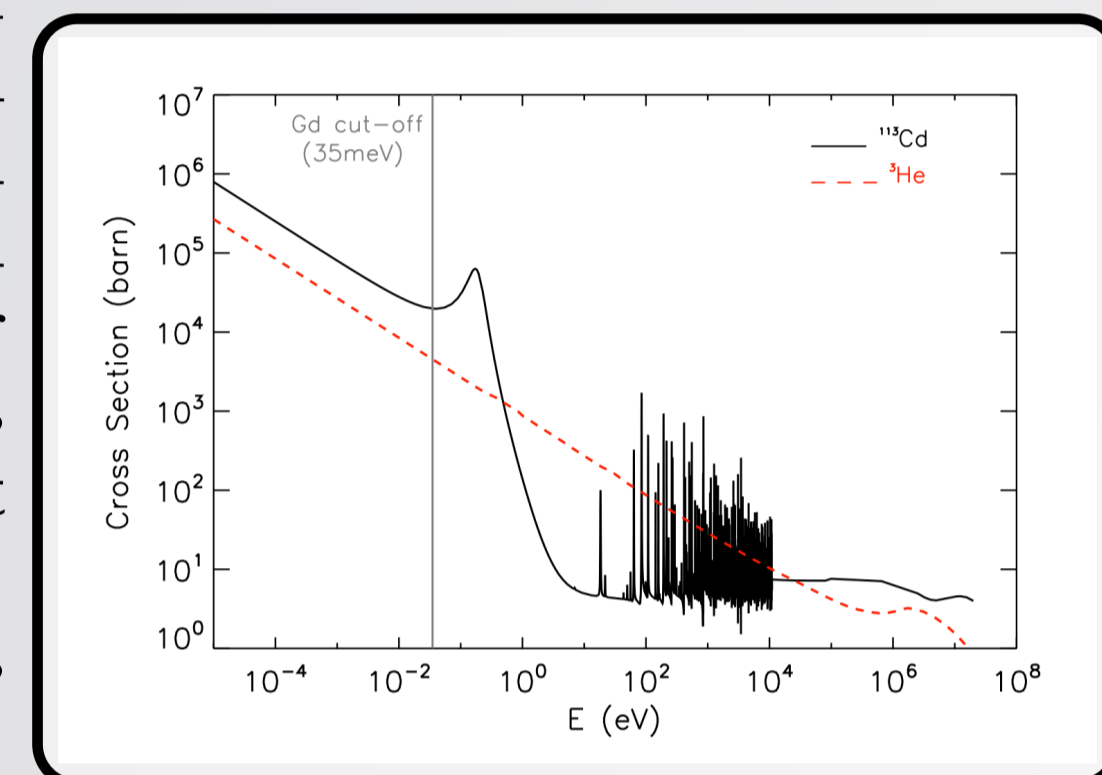


Figure 4: Horizontal measurements (scan) of fast neutron transmission through the sapphire crystal and its surrounding shielding (seen in Fig. 1), as a measurement of the shielding efficiency around the sapphire target. Various lines correspond to different crystal thickness between 10-120mm (the black line is our measurement without crystals).

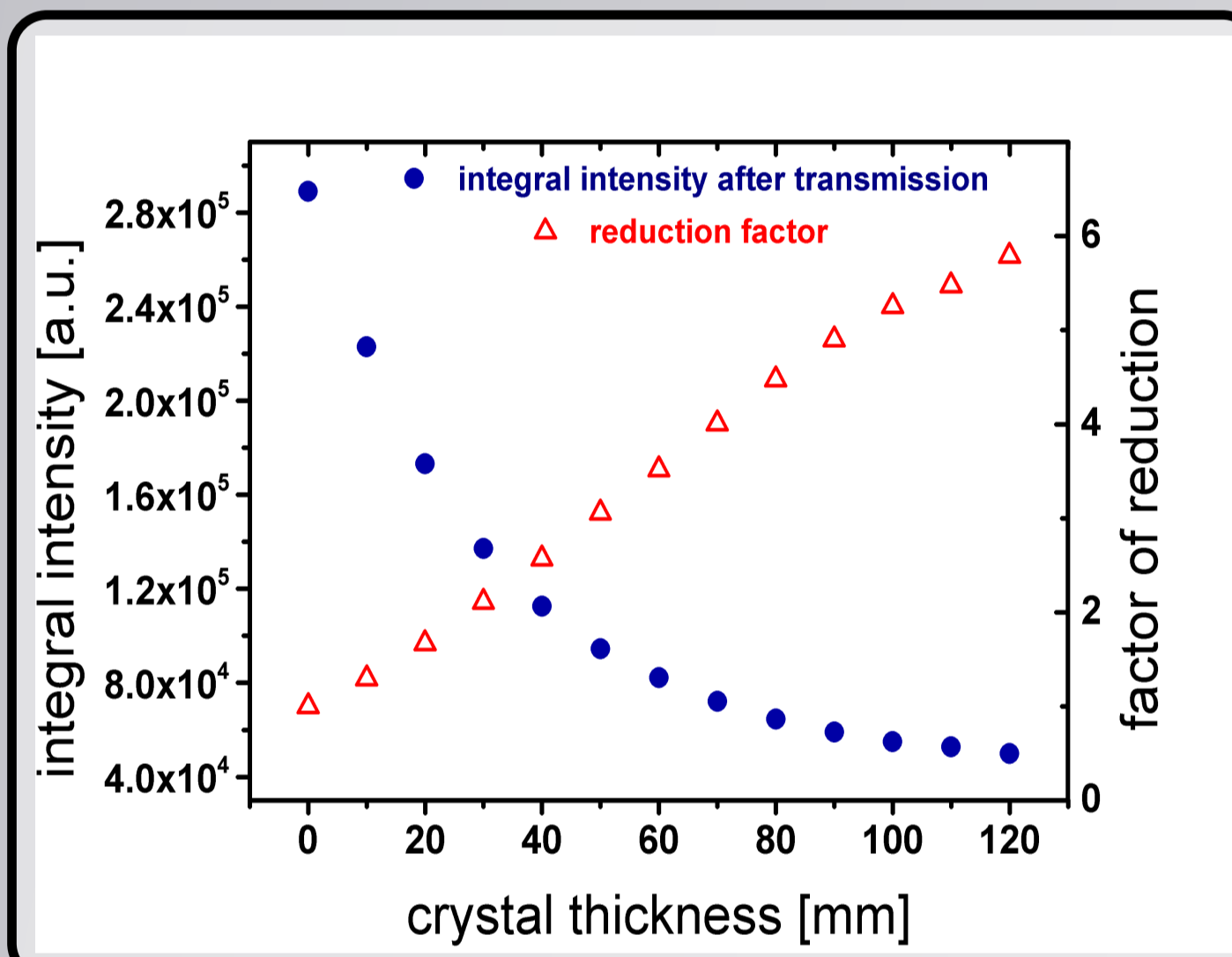


Figure 5: Integral intensity (and its reduction factor) of fast neutrons transmitted through sapphires, as a function of the crystals' thickness. The integral intensity of the transmitted fast neutrons dropped to ~17% after a 120mm-thick crystal (reduction factor of ~6).

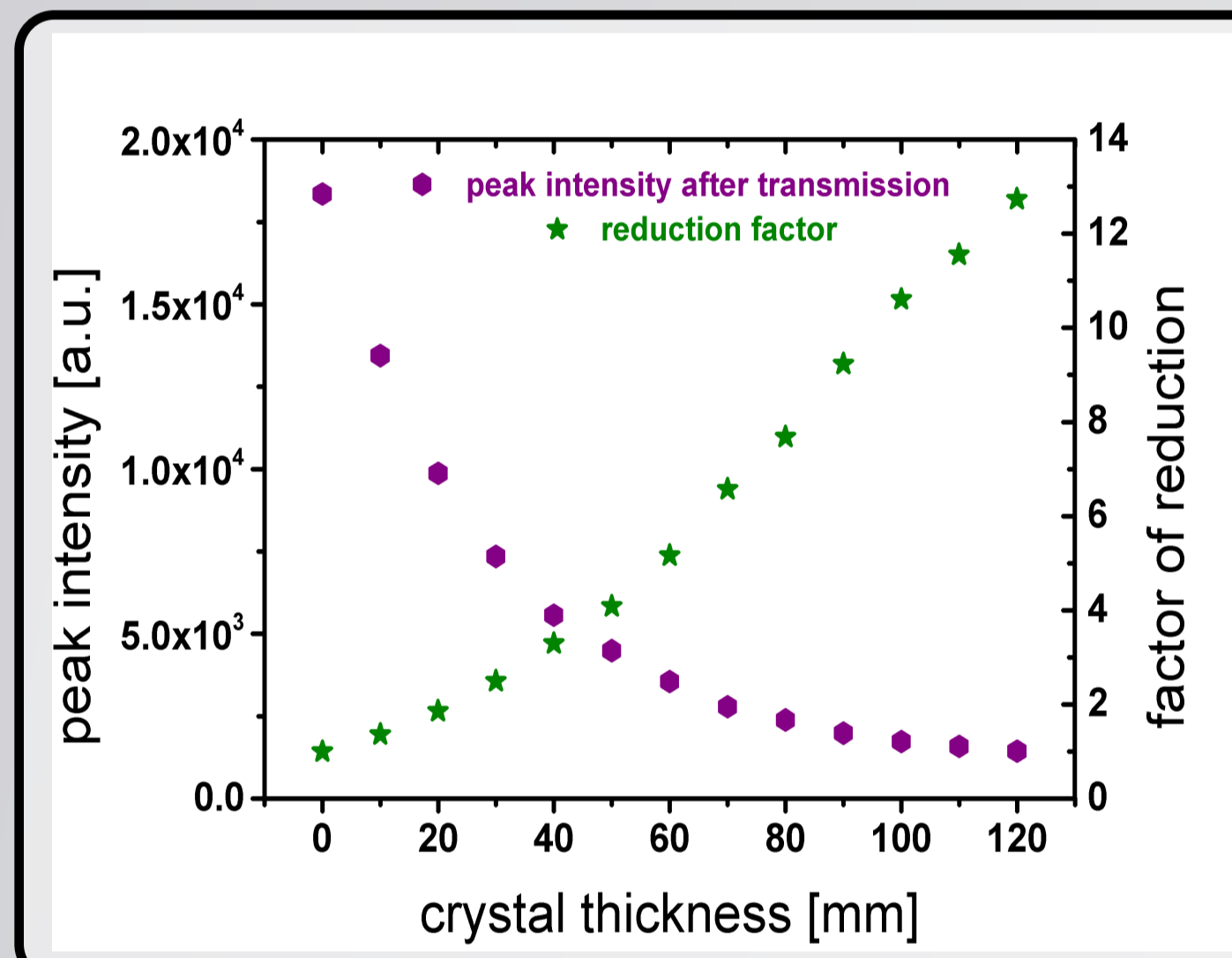


Figure 6: Peak intensity (and its reduction factor) of fast neutrons transmitted through sapphires, as a function of the crystals' thickness. The peak intensity of the transmitted fast neutrons dropped to ~7.5% after a 120mm-thick crystal (reduction factor of ~13).

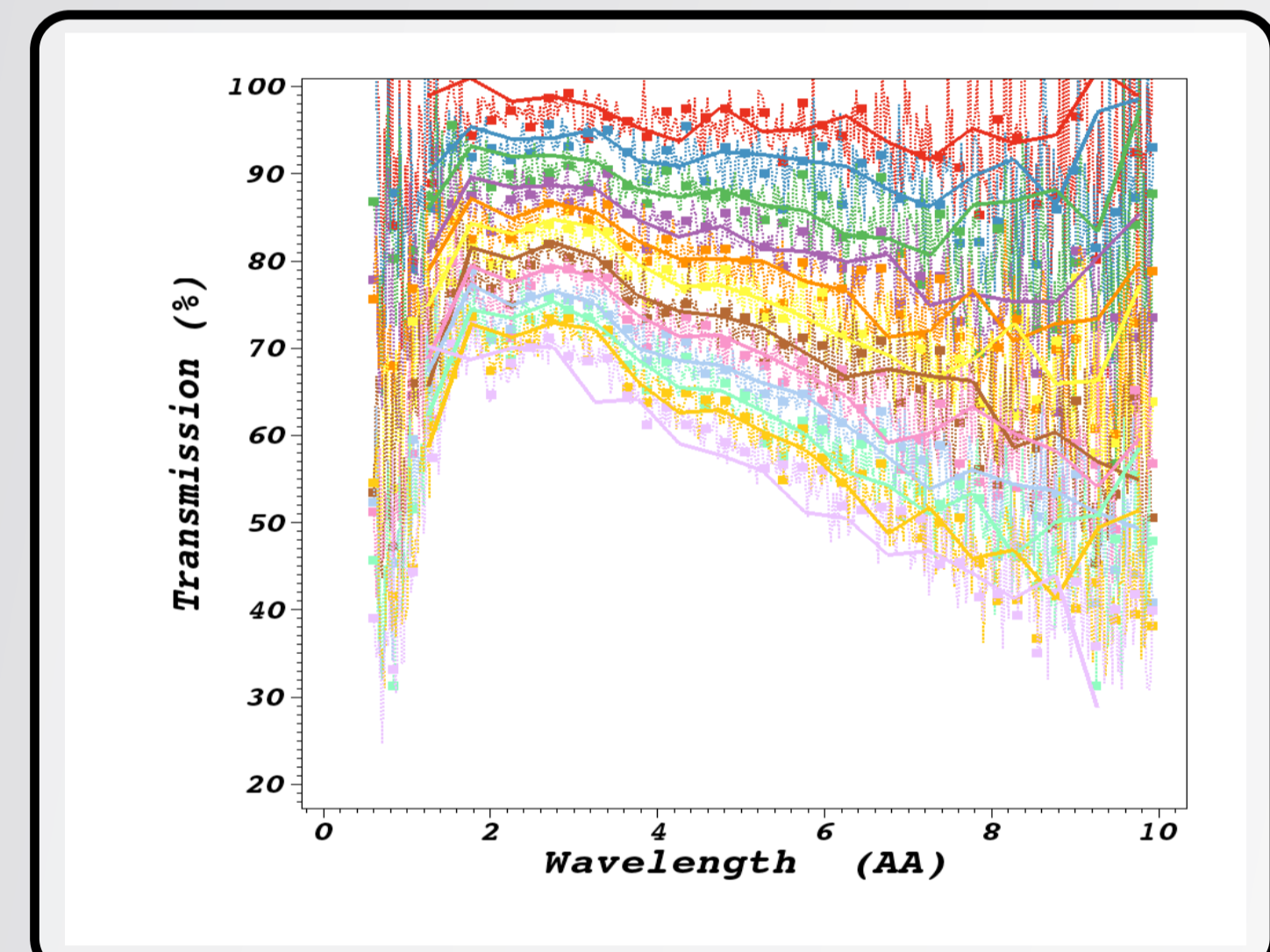


Figure 7: Cold neutron transmission as a function of wavelength. Different lines correspond to different crystal thickness between 10mm (upper red) and 120mm (lower purple). We notice that neutrons between 2-6Å have a minimum transmission of ~50% when going through a 120mm-thick sapphire crystal.

Simulations

We used the codes MCNP and McStas to simulate the transmission of cold neutrons through sapphire crystals. For the MCNP simulations we have used newly acquired sapphire cross section libraries^[1]. McStas on the other hand, uses a semi-analytical formula^[2] to calculate neutron absorption by sapphire crystals (the relevant component file is *Sapphire_Filter.comp* within the regular McStas distribution).

We performed a series of simulations, reproducing our experimental set up, in order to: a) test the performance of a **newly developed interface** between the two codes[‡], b) compare experimental results to the sapphire cross sections for MCNP and the semi-analytical formula used by McStas.

--Fig. 8 shows the comparison between our experimental measurements and MCNP simulations. We observe a good agreement between the two, particularly in the range 2-6Å and for crystals of thickness ≥ 30mm.

-- Fig. 9 shows the comparison between our MCNP and McStas simulations. The agreement is good for crystal thickness < 30mm (up to ~4% difference) and it improves for bigger thickness.

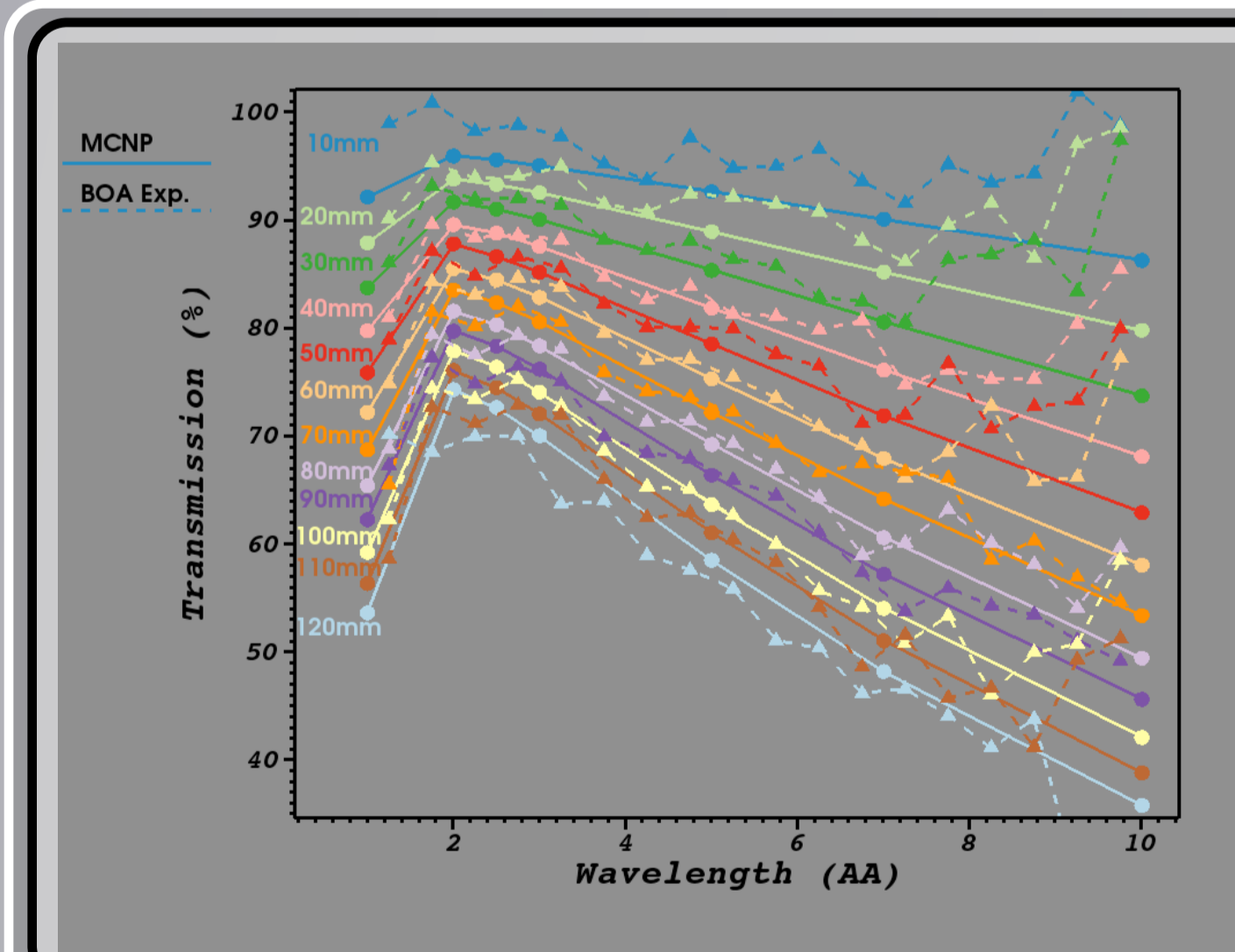


Figure 8: Comparison of experiments (BOA Exp., solid lines) and MCNP simulations (dashed lines) of cold neutron transmission through sapphires. Different colors correspond to different crystal thickness, between 10mm and 120mm. Experimental values and MCNP calculations best agree for crystal thickness >30mm. For smaller wavelengths 2-7Å and crystal thicknesses, the difference increases to ~4%.

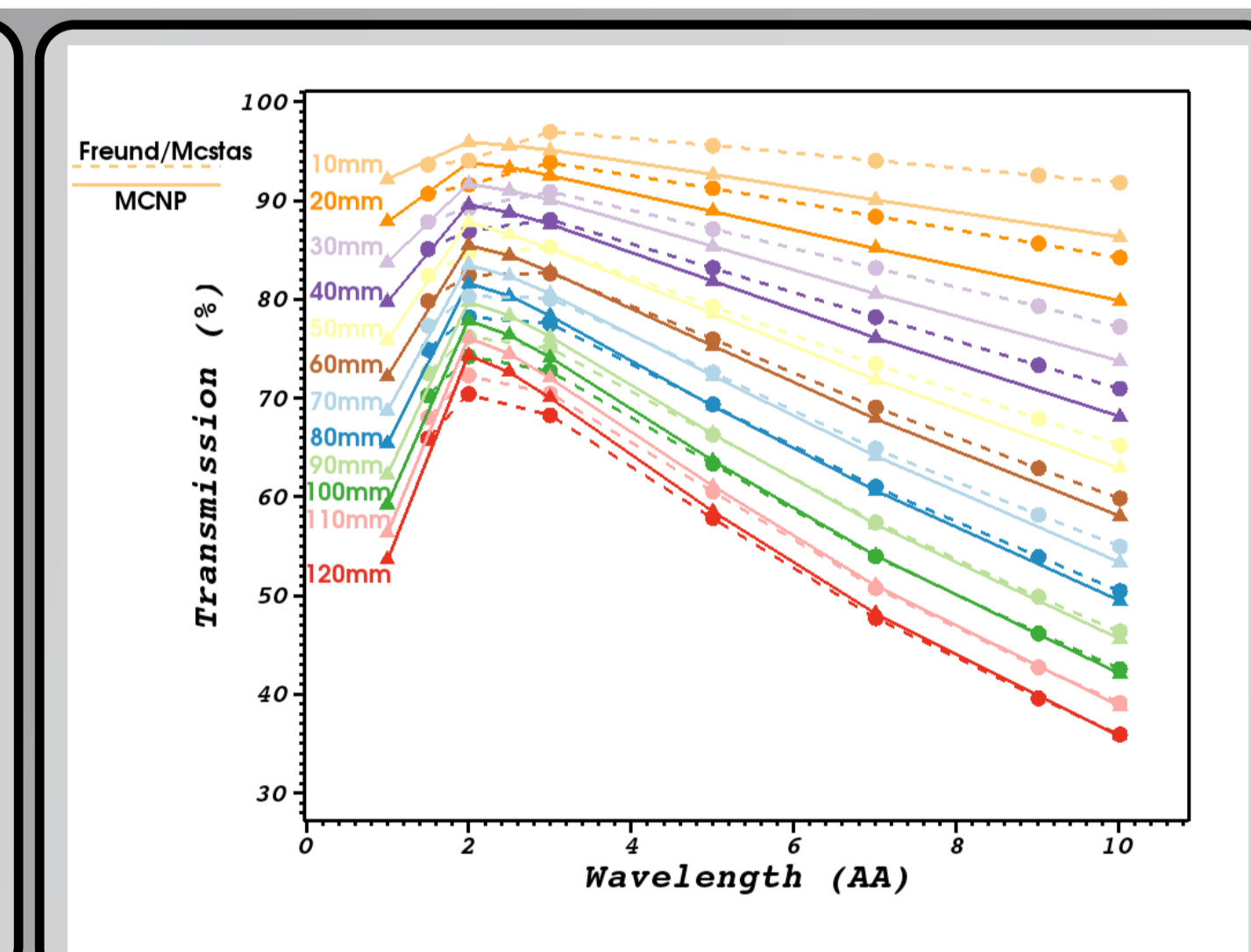


Figure 9: Comparison of McStas (dashed lines) and MCNP simulations (solid lines) of cold neutron transmission through sapphires. Different colors correspond to different crystal thickness, between 10mm and 120mm. The agreement is very good for MCNP calculations best agree for crystal thicknesses, the difference increases to ~4%.

‡Simulations

Although not shown here, we have used a newly developed MCNP +McStas interface to reproduce our cold neutron/sapphire experiments presented above, in our effort to test the performance of the "coupling" interface. The relatively simple geometry of the experimental set up, made it a good benchmark for the coupled code. We were able to reproduce successfully our experimental results and provide thus a validity test of the coupling interface. **Check poster by Uwe Filges for further details on the topic.**

References

- [1] Cantargi F et al. (2013); (to be published)
[2] Freund (1983) Nucl. Instrum. Methods, A278, 379-401