Title: Development of a UCN guide and other handling devices at J-PARC with pulsed UCNs

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Metal tubes with nickel-phosphorus plating are used in many fundamental physics experiments using ultra-cold neutrons because of their easy fabrication, but their surfaces have a large average roughness of 25-150 nm. Our aluminum UCN guide tube for the TUCAN experiment [1] also have a mean square roughness of 6.4-17 nm. There has been no model to describe the diffuse scattering of UCN on such surfaces by using microscopic surface roughness information. We have developed a scattering model in which the scattering from random surface waviness with a size larger than the UCN wavelength is described by the microfacet Bidirectional Reflectance Distribution Function (mf-BRDF) model [3]. In our model, the scattering direction of UCNs is mainly determined by the classical specular reflection, and scattering from smaller structures in which the direction is determined by quantum mechanical calculations is simplified by the Lambert's cosine law. The parameter characterizing the magnitude of the surface waviness is only the standard deviation of the slopes of the local micro-surfaces and was estimated from the images obtained from atomic force microscopy measurements of a guide tube sample fragment. The probability of Lambertian diffusion per reflection is the only free parameter in this model and is determined by UCN transport experiments.

We have measured the UCN transport efficiency of this guide tube using pulsed UCNs produced by a Doppler-shifter type UCN source at BL05 in the J-PARC/MLF [3], as shown in Figure 1. In this experiment, pulsed UCNs collimated to a divergence angle smaller than ±6° were injected into the tilted guide tube, and the attenuation and deformation of the time-of-flight spectra of transmitted UCNs caused by diffuse reflections were measured. The guide tube was mounted by an angled flange at an inclination angle of either 0°, 10°, 15°, or 30°, by which the total number of reflections of the transmitted UCN beam was controlled. Comparison of these results with particle transport simulations using our reflection model showed that the mf-BRDF model explains the experimental results better than Lambertian diffusion alone for both attenuated UCN transmittance (shown in Figure 2) and deformed TOF pulse shape as the inclination angle increases.

In this presentation we will primarily present this development of the UCN guide tube. We have also developed several other UCN handling devices at BL05, which will also be presented.

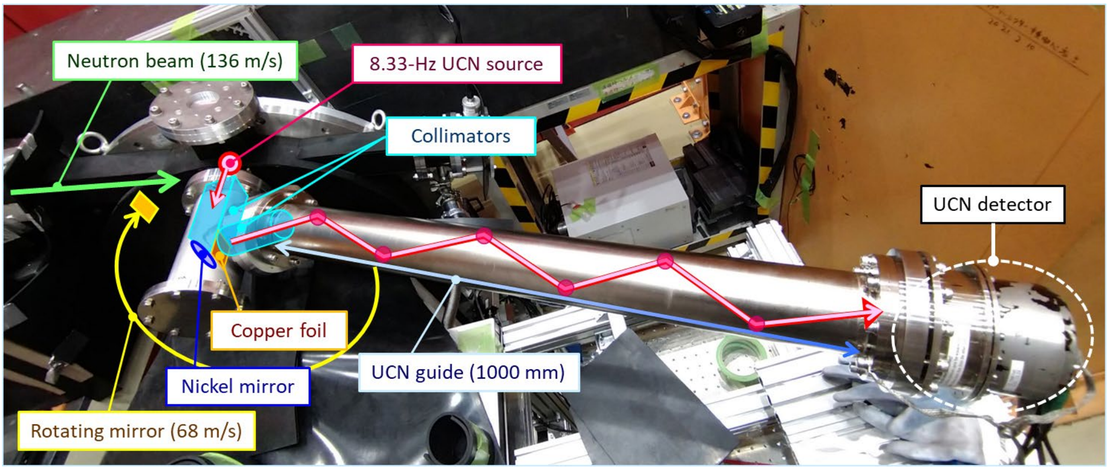

Figure 1: Photograph of the experimental setup of the UCN transmittance measurement at J-PARC. In the photo, an UCN guide is installed with the 30-degree configuration. Key components are schematically drawn. The mean flight path of UCNs is estimated to be 1.6 m.

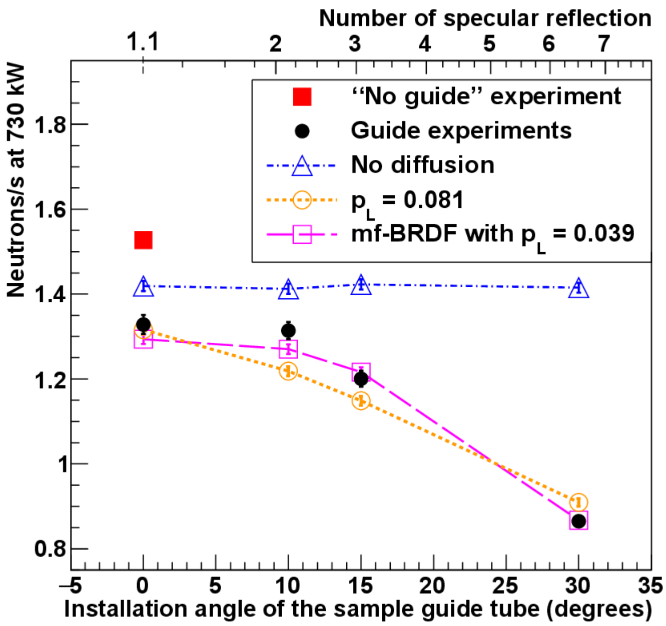

Figure 2: Measured rate of transmitted neutrons with no guide (a red square) and with sample guide installed at different angles (black dots), compared to simulations with no diffuse reflection (blue triangles), pure Lambert scattering with probability p_L = 0.081 (orange circles), and mf-BRDF scattering combined with Lambert scattering with probability p_L = 0.039 (pink squares).

[1] H. Akatsuka *et al.*, Nucl. Instr. Meth. Phys. Res. A **1049**, 168106 (2023).
[2] S. Imajo *et al.*, e-print arXiv:2303.15461 [physics.ins-det] (2023).
[3] S. Imajo *et al.*, Prog. Theor. Exp. Phys. **2016**, 013C02 (2016).