Experimental report

07/09/2022

Proposal: **DIR-245** **Council:** 4/2021

Title: Observation of quantized states ofUCNs in the gravitational field bynuclear emulsion detectors

Research area: Methods and instrumentation

This proposal is a new proposal

Main proposer: **Tobias JENKE**

Experimental team: Jakob MICKO
Rene SEDMIK
Janik TRAUNER

Local contacts: Tobias JENKE
Stephanie ROCCIA

Samples:

Instrument	Requested days	Allocated days	From	To
PF2 TES	14	0		
PF2 EDM	0	5	15/09/2021	22/09/2021

Abstract:

The aim of this experiment is to demonstrate the capability of nuclear emulsion detectors to analyze the height distribution of UCNs in quantized states in the gravitational field with submicron resolution and accuracy. This study paves the way for new-generation experiments to explore the weak equivalence principle in the quantum range. In this experiment, improved detectors and holders from a previous TEST-experiment performed in 2019 will be used.

ILL Experimental Report

Observation of quantized states of UCNs in the gravitational field by nuclear emulsion detectors

prepared by René Sedmik

Scope

The purpose of the proposed measurements was to demonstrate the capability of nuclear emulsion detectors to measure gravitational UCN quantum states at high precision.

Setup

We used the same basic setup for measurements for 3-14-422 and for DIR-245 that resembled the one used for quantum bouncing ball measurements in 2009 [1]. As shown in Figure 1, the EDM neutron guide wa attached

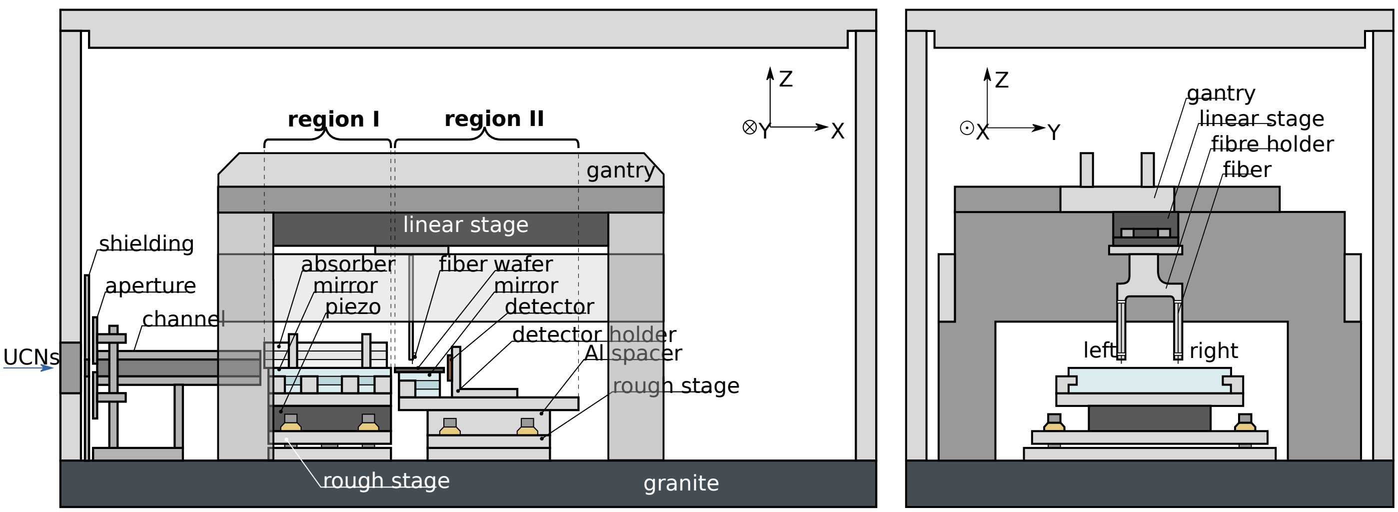

Figure 1: Experimental setup used for all measurements during DIR-245. Left: side view; Right: cut view at the position of the detector. Graphics courtesy of Janik Trauner.

from the left to a box-shaped Al vacuum chamber. Velocity selection of the neutrons was performed by defining a small range of flight parabolae via an aperture made of borated Al, and the entrance slit of a state selector. The latter consists of a flat polished BK7 glass mirror on the bottom, and an inverted rough mirror from the same material on top. Such stacks are routinely used in qBounce to select the lowest gravitational quantum states [1–4], and are called `absorbers'. After the absorber, we first placed a counter detector to determine the basic rate and operation of the absorber. Subsequently, the counter detector was replaced by a position-sensitive nuclear emulsion detector [5] to determine the state distribution resulting from the combination of velocity selector and absorber. In later stages, the position-sensitve detector was shifted further away from the reactor and a flat glass mirror of 50 mm length was inserted. Eventually, a vertical step of 30 μm between regions 1 and 2 was introduced. The vertical alignment between the regions was controlled using an absolute-distance fiber-based interferometer. Both measurement configurations are shown schematically and on photos in Figure 2. Note that the detector was enclosed in a box made from borated rubber mats and aluminum to reduce the background.
In addition to the shown measurements, we also conducted exposures in configuration 1 with just a flat mirror (without absorber), and in configuration 2 without the step (not shown) for testing purposes and calibration.

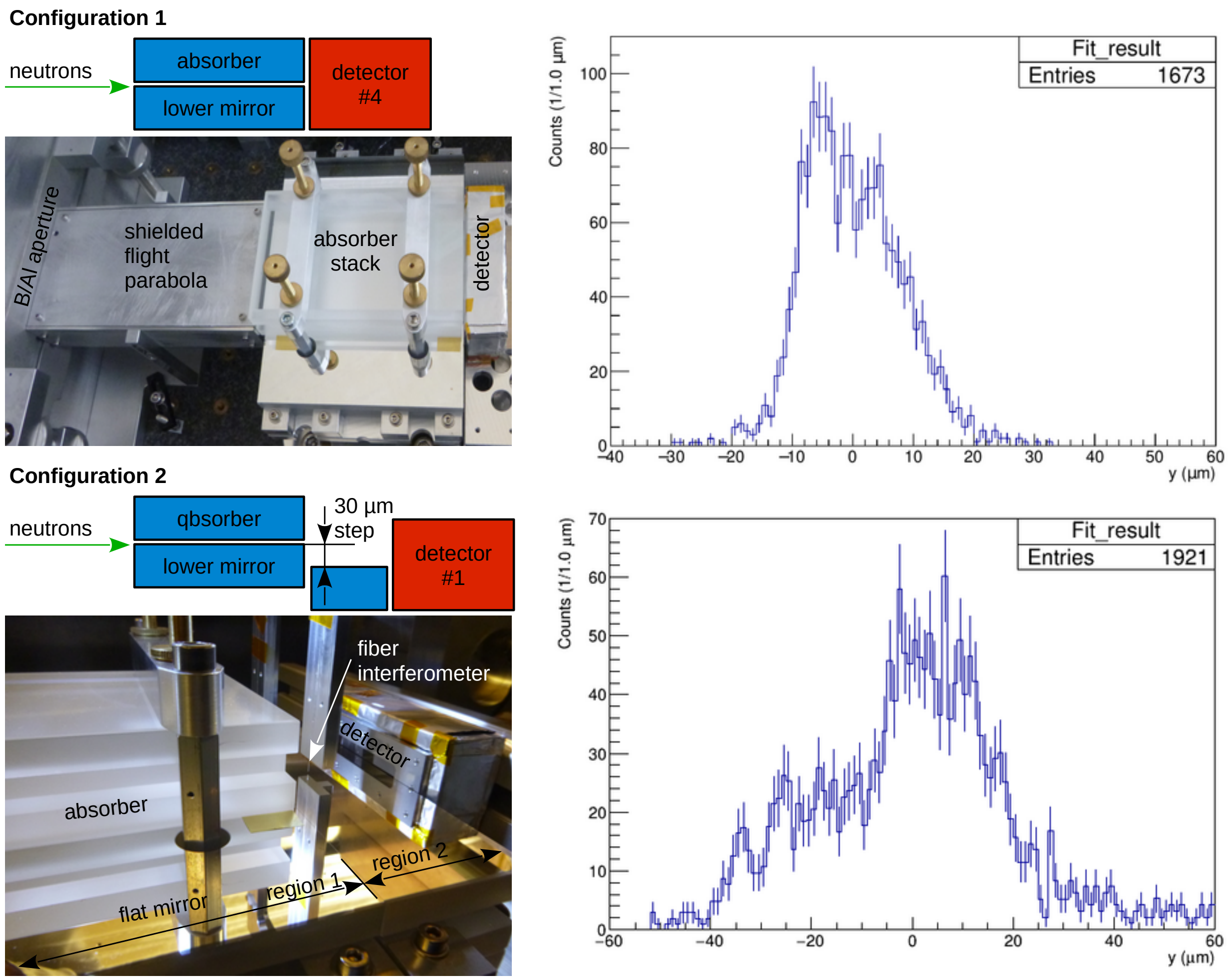

Figure 2: Experimental configurations used during DIR-245, and preliminary histograms showing the probability distributions obtained from the detectors in the respective configuration.

Results

Step measurement and feedback

Due to late availability of the translation stage, its controller, and a number of software problems with the interferometer, the control software for the step feedback could only be written during the beamtime. After completion, the control circuit achieved a long time step error of 169±99 nm (over a period of 83 h, see Figure 3),

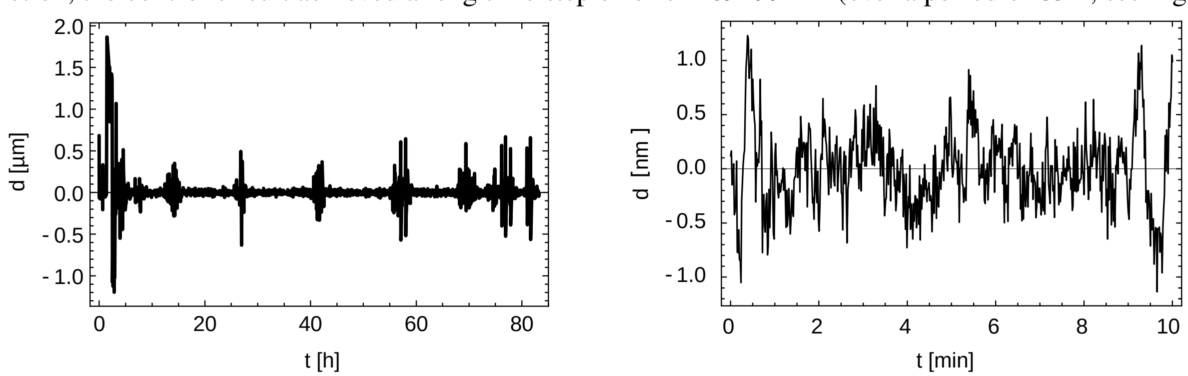

Figure 3: Interferometric measurements. Left: Continuous measurements with active PID feedback. At around 9:00 in the morning and in the evening each day during the week, strong vibrations occurred on Niveau D, which are visible as disturbances. Right: Interferometer stability in a temperature-controlled vibration isolated environment (post beamtime). Graphs courtesy of Janik Trauner

while the intrinsic measurement uncertainty of the interferometers was measured to be 0.37 nm. The reason for this discrepancy were ambient vibrations on Niveau D. Nonetheless, the performance is significantly better than the long-time average of ~500 nm achieved with capacitive sensors and manual tactile measurements in qBounce. For measurements in configuration 2, the rms deviation of the step from 30 μm was only 52±43 nm (37 h). Here, we benefited from less vibrations on the weekend. These results show that the 300 kg granite table used in the measurements was insufficient to eliminate vibrations and that a dedicated isolation system is required to maintain good alignment between the mirrors in future measurements.

State distributions

The impact coordinates were extracted from the track detector using an automatized alignment and detection system [5]. After obtaining the track coordinates from this system, the data were binned vertically to obtain the histograms shown in Figure 2. While the analysis of the measurements in configuration 2 (right side of Figure 4) is still going on, we compare here preliminary results from DIR-245 to previous results from 2019 [5]. Previously, we were forced to include a blurring parameter in the theory to fit the data. The blurring was caused

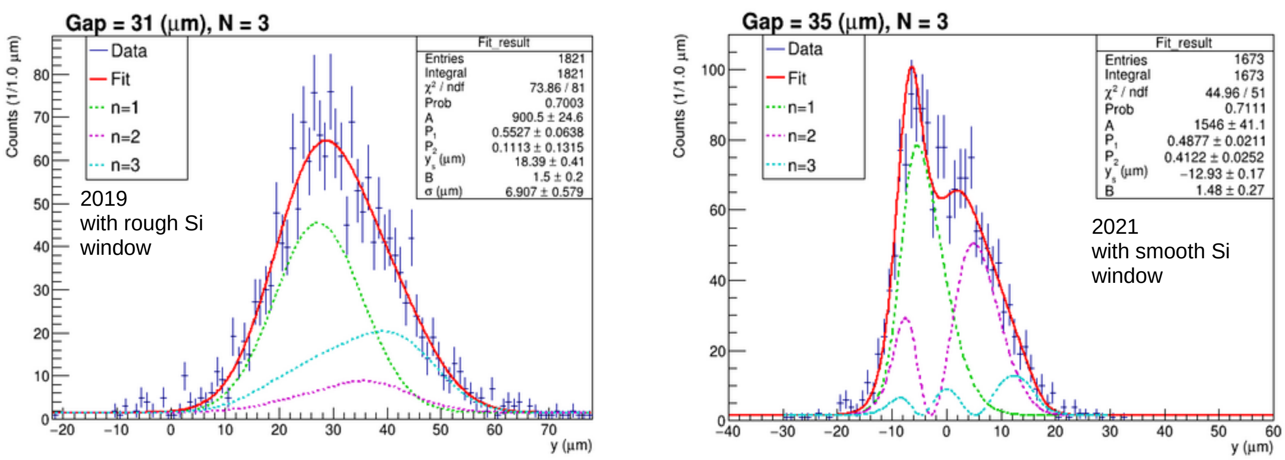

Figure 4: Comparison of the resolution 2019 [5] (left) where a rough entrance window led to blurring, and the new (preliminary) results from DIR-245 (right) where the blurring was avoided by using a smooth Si entrance window.

by roughness on the upstream window of the emulsion detector. Prior to DIR-245, we produced new detectors with polished substrates of roughness 0.5 nm. Clearly, this step has significantly improved our spatial resolution. From a least squares fit to the data, the state distribution 48±2% $|1\rangle$, 41±3% $|2\rangle$, and 10±3% $|3\rangle$, was obtained, where the $|n\rangle$ symbolize the n^{th} vertical gravitational UCN quantum state.

Summary

We performed several exposures of nuclear emulsion detectors in different configurations during DIR-245. Using a partially automatized evaluation procedure, we were able to extract the probability distributions of UCNs that arrive in low gravitational quantum states. We significantly improved the spatial resolution with respect to previous measurements. Our experimental data clearly show that nuclear emulsion detectors are suitable to perform measurements of UCN probability distributions with high spatial accuracy.

References

[1] T. Jenke *et al.*, Nucl. Instrum. Methods Phys. Res. **611**, 318 (2009), doi: 10.1016/j.nima.2009.07.073.

[2] T. Jenke *et al.*, Nat. Phys. **7**, 468 (2011), doi:10.1038/nphys1970.

[3] G. Cronenberg *et al.*, Nat. Phys. **14**, 1022 (2018), doi:10.1038/s41567-018-0205-x.

[4] R. I. P. Sedmik *et al.*, EPJ Web Conf. **219**, 05004 (2019), doi:10.1051/epjconf/201921905004.

[5] N. Muto *et al.*, J. Inst. **17**, P07014 (2022), doi:10.1088/1748-0221/17/07/P07014.