Demonstration of a multilayer-type neutron interferometer with pulsed source and nuclear scattering length measurement

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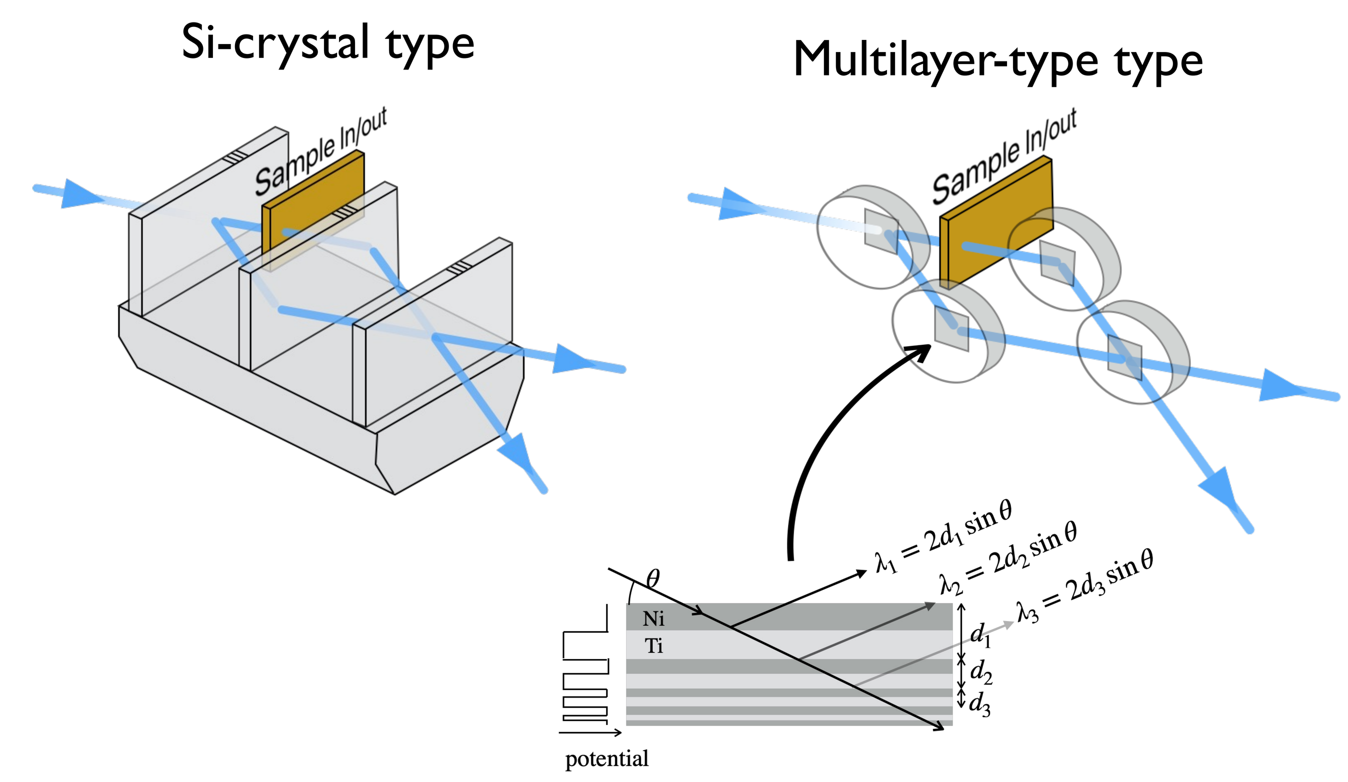
Neutron Interferometer

A neutron interferometer is a device that splits the wavefunction of a single neutron into two paths, superimposes them, and detects the potential difference between the two paths as a phase difference. Neutron interferometers were practically used in the 1970s, and have contributed greatly to the development of quantum mechanics, such as the verification of spinors or the phase shift of matter waves due to gravity. The sensitivity of the neutron interferometer is described as

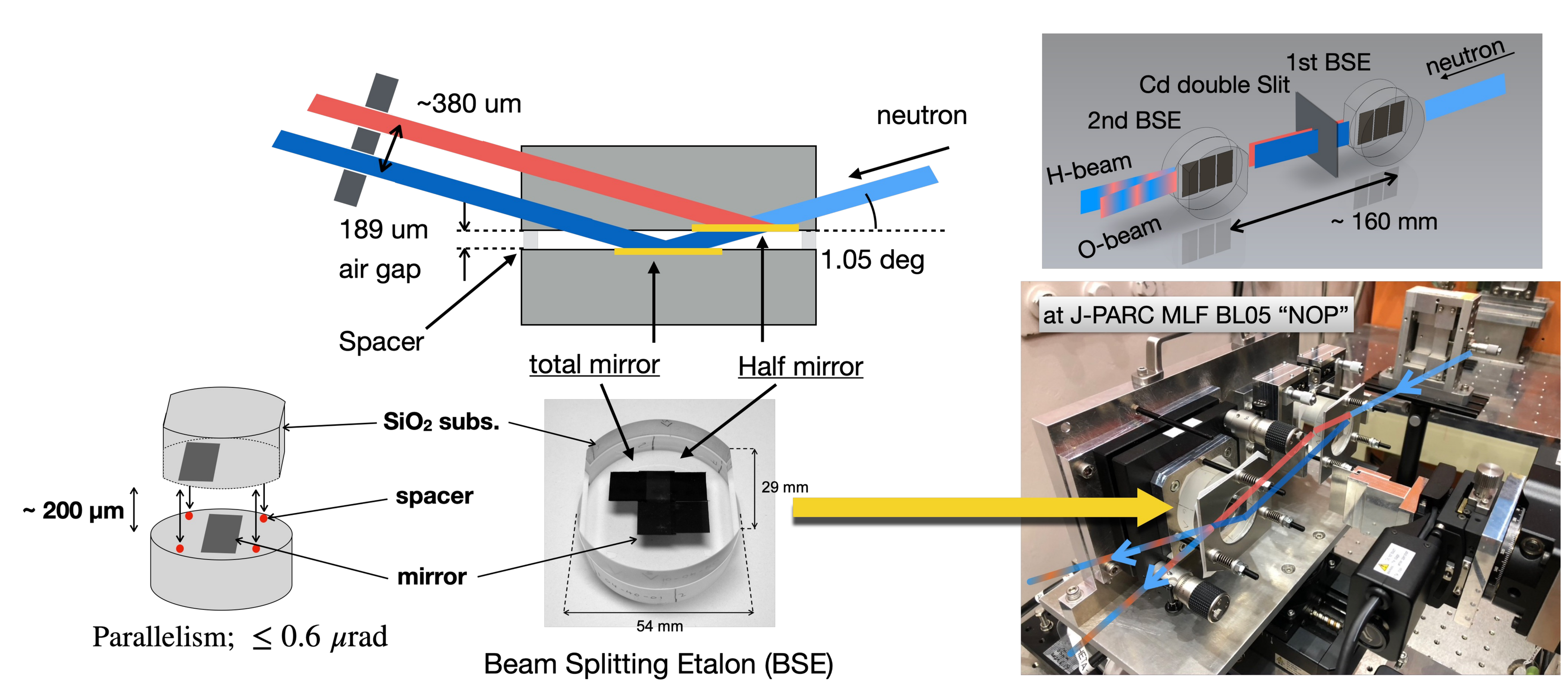
$$\Delta\phi = \frac{2\pi m_n \lambda_n L}{h^2}\Delta E$$

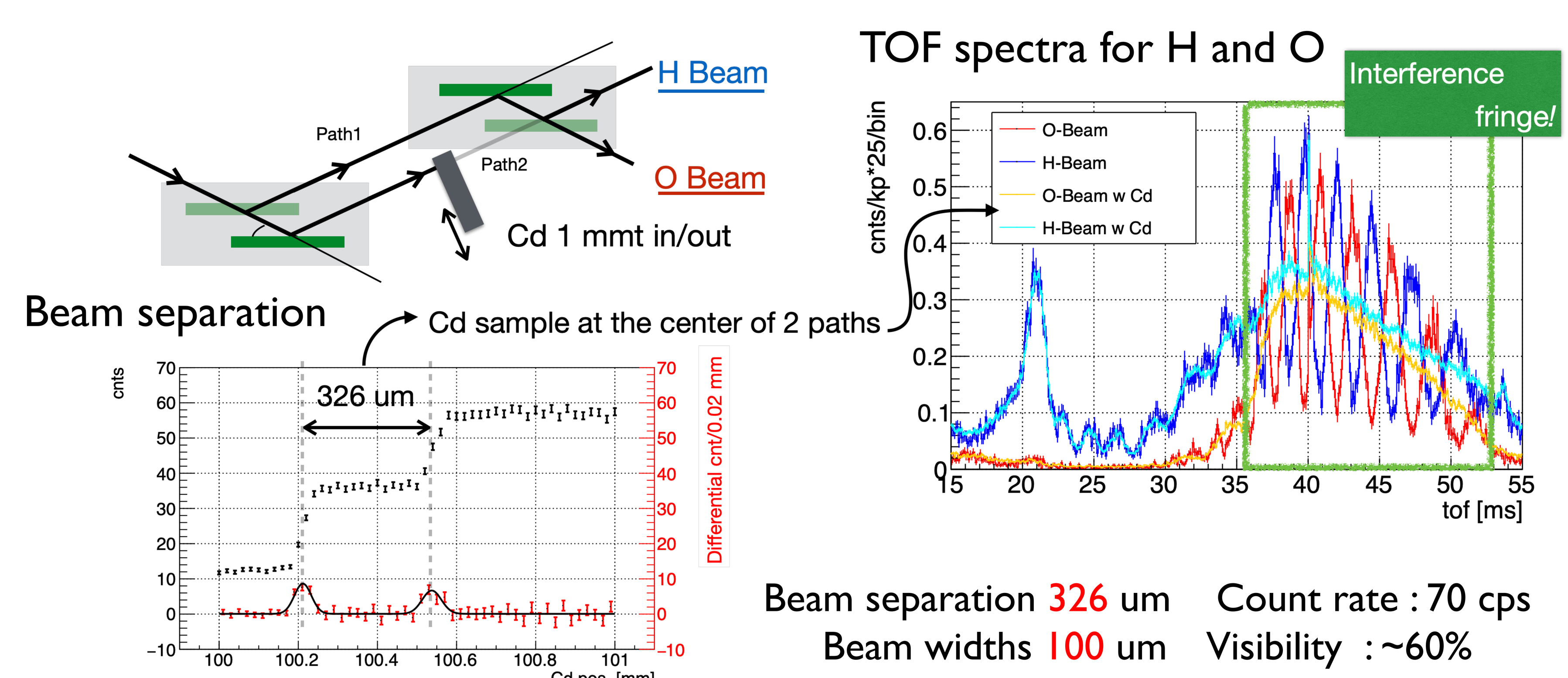
The ordinal neutron interferometers have been cut out of a perfect crystal of Si ingots, which could only use mono-energetic neutrons and were limited in size. In order to overcome the limits, we developed a multilayer-type neutron interferometer, which uses neutron supermirrors.



Multilayer-type neutron interferometer

The multilayer-type neutron interferometer consists of two beam splitting etalons (BSE) with total reflection and half mirrors across 189-um gaps. A neutron wavefunction is splitted by the first BSE and superposed on the second one. A demonstration experiment was conducted at NOP/BL05 beamline using the pulsed neutron of J-PARC.





Beam separation 326 um Count rate : 70 cps
Beam widths 100 um Visibility : ~60%

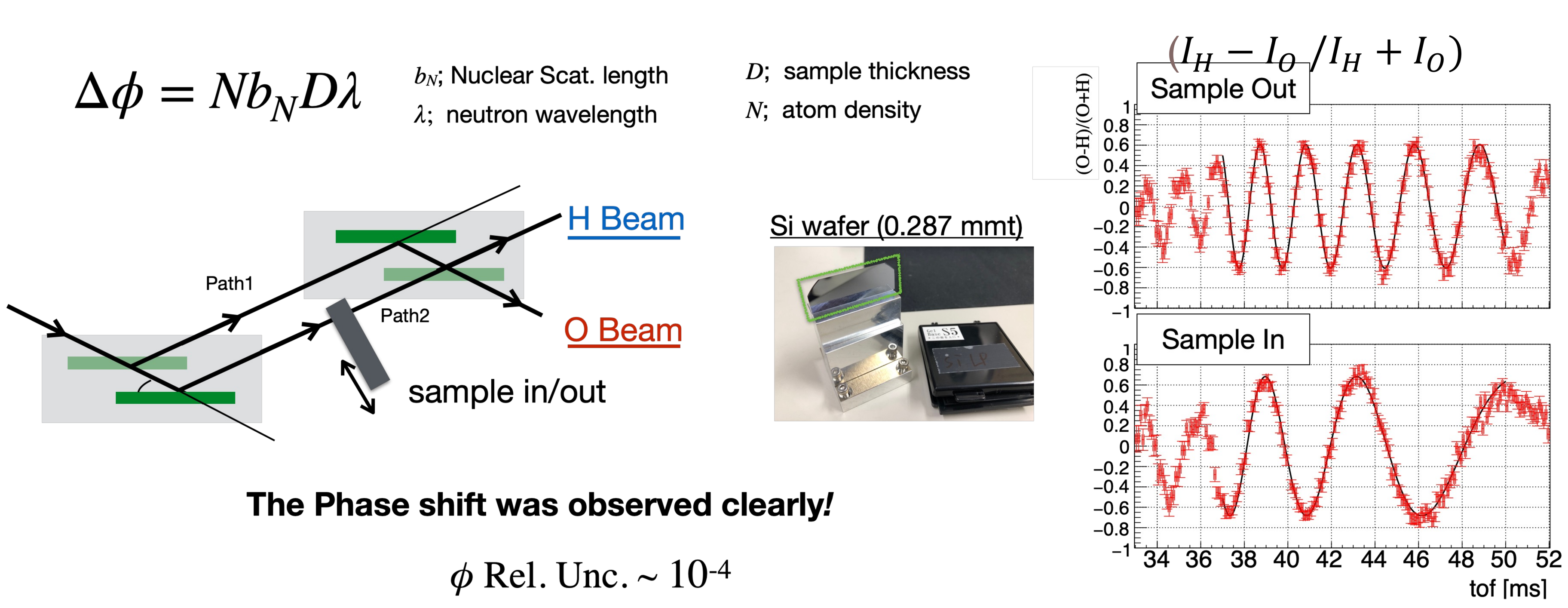
Clear interference signals were observed with completely separated beams. In case of the pulsed neutron beam, the phase shift is promotional to the TOF; NO phase shifter required. It can mitigate systematic effects due to vibration or thermal fluctuations.

Measurement of neutron scattering lengths

A sample can be installed in a one path between the etalons to measure its potential. We have measured Si, Al, Ti, V, and V-Ni of 95:5wt%, knows as "mull alloy" for scattering length measurement. The phase shift due to the sample installation gives the scattering length of the sample. The sample thickness is 0.3 – 1.0 mm. The measurement time is about 30 min.

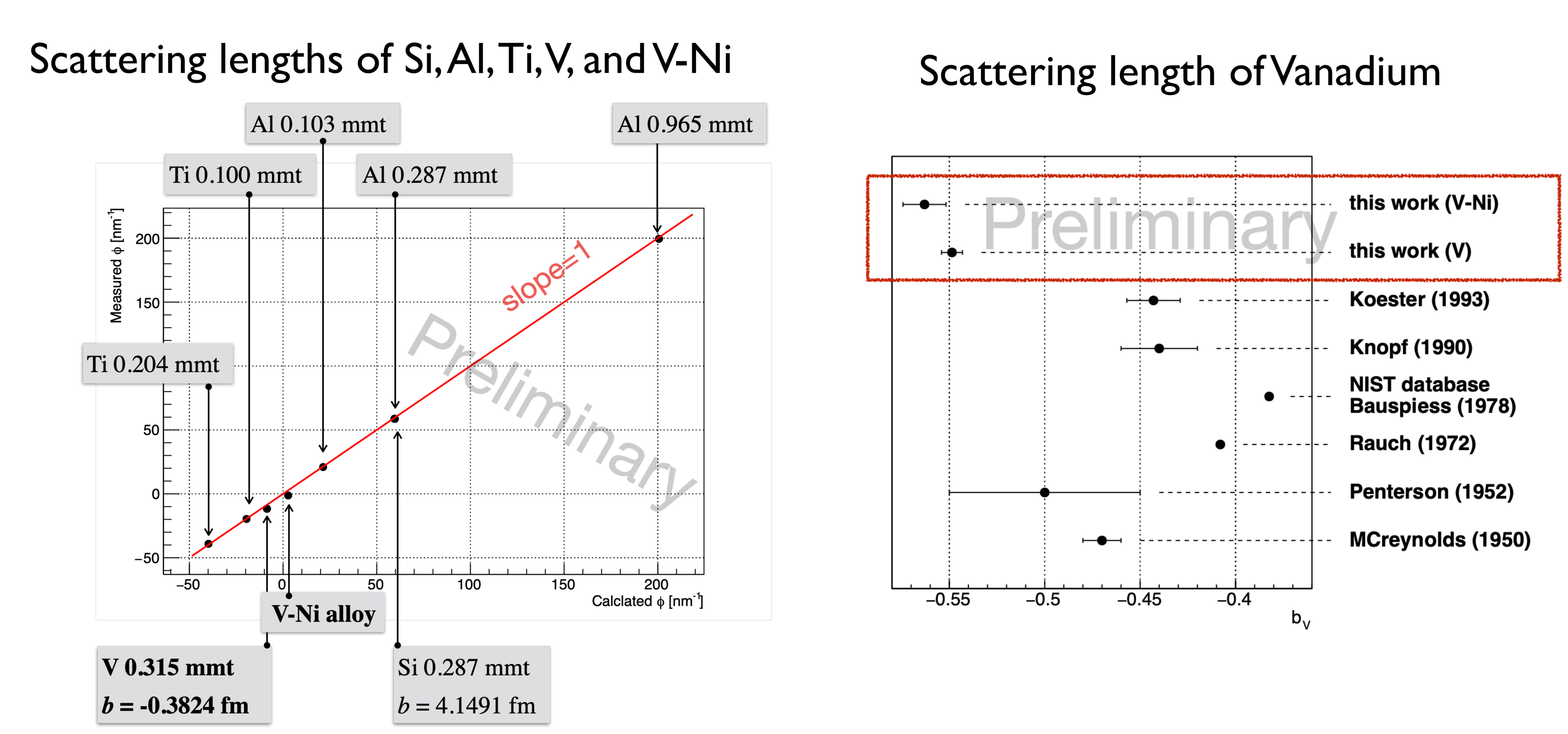
$$\Delta\phi = N b_N D \lambda$$

b_N; Nuclear Scat. length
λ; neutron wavelength
D; sample thickness
N; atom density



The Phase shift was observed clearly!

ϕ Rel. Unc. ~ 10^{-4}

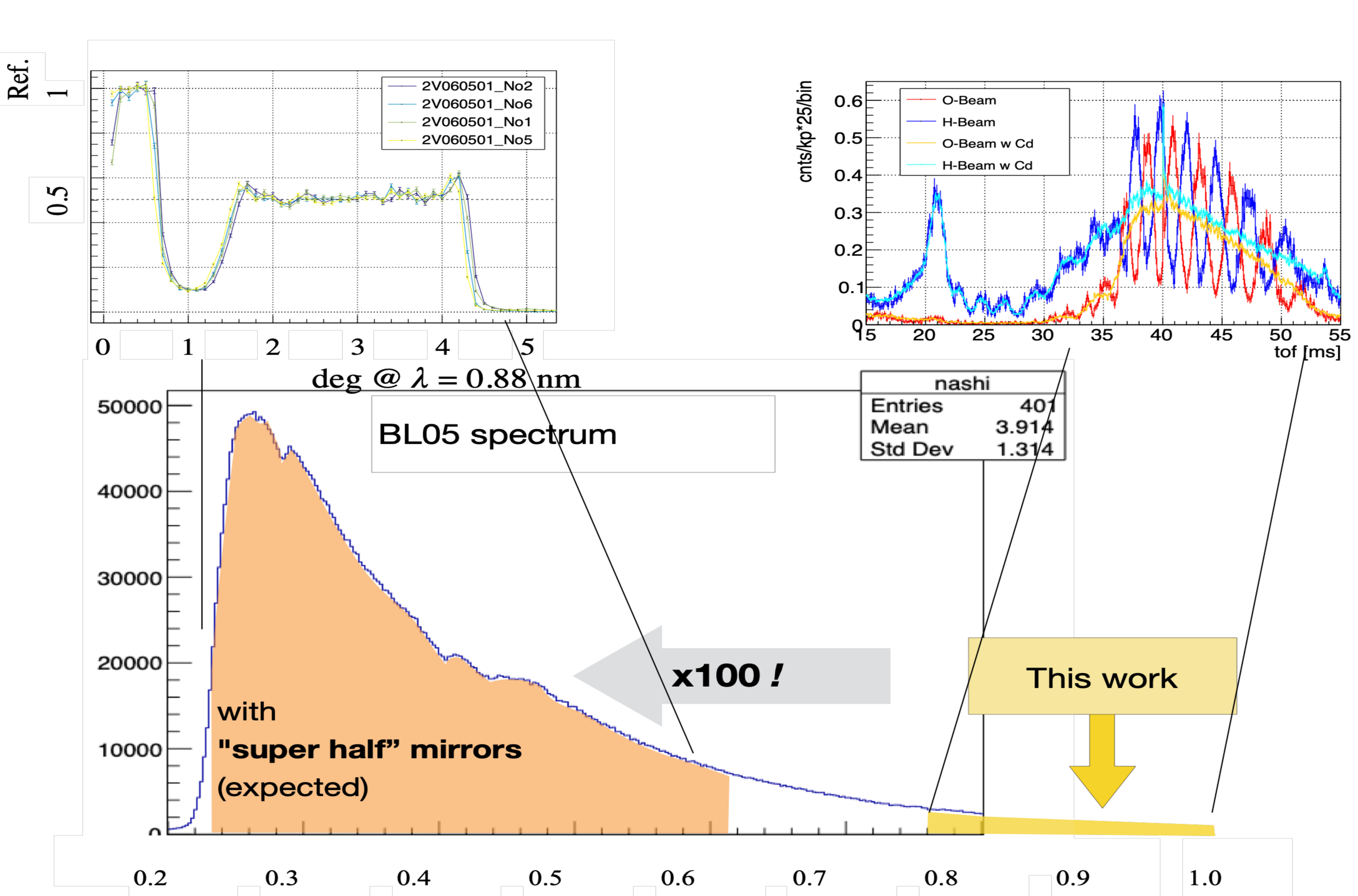


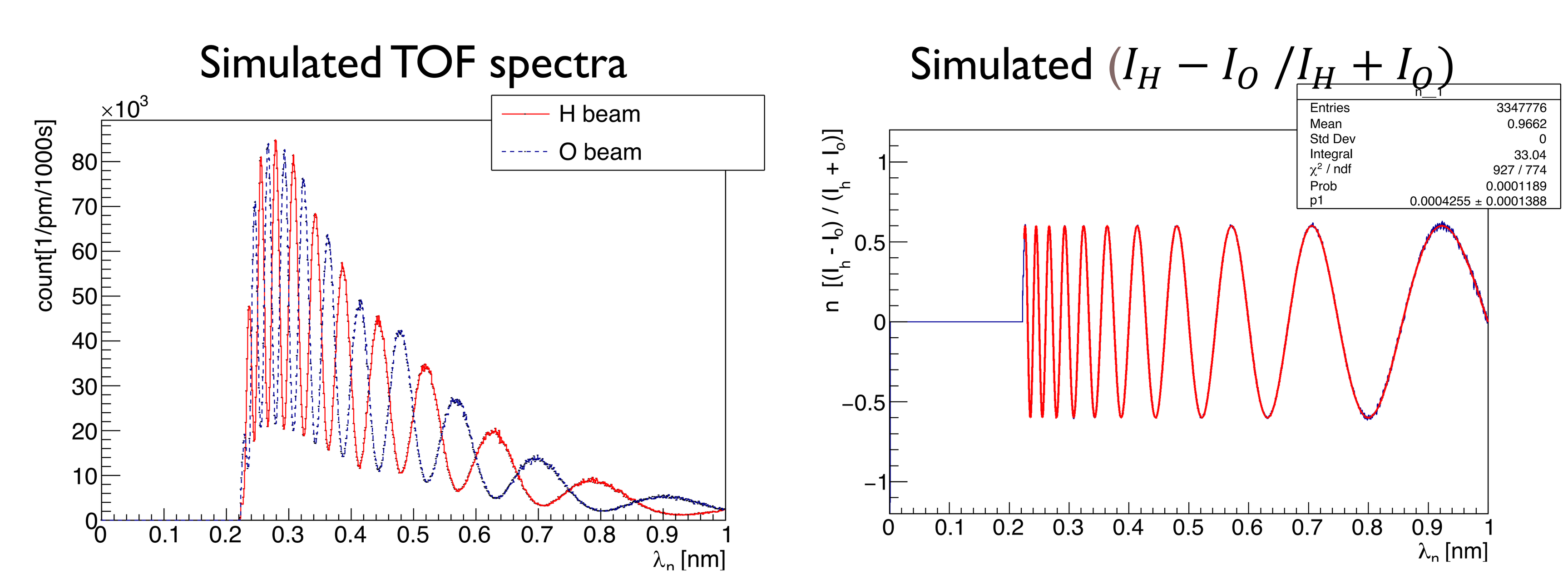
The obtained scattering lengths were consistent with literature values [1] except V, whose scattering length was about 40% larger than that. Note that the contaminations in our V or V-Ni samples are ~0.5%, which can not explain the difference.

[1] V. F. Sears, "Neutron scattering lengths and cross sections", Neutron news 3.3 (1992), 26-37.

Future development

The present interferometer is optimized for the experiment for reactors; the acceptance of the wavelength was only 20%. We have developed "super-half-mirror" for the interferometer. A new interferometer with the mirror is now prepared.





The expected contrate is 15 kcps at BL05 / J-PARC.
The sensitivity will achieve at

$\Delta E = 3.6\times10^{-16}$ eV in 1,000 s with mirror distance of 10 cm

$\Delta E = 1.0\times10^{-17}$ eV in 10,000 s with mirror distance of 30 cm

Our planning research items :

- Precise measurements of scattering lengths
- Short range gravitational force at $\lambda_5 = 5\ \mu m$
- Chameleon field search
- Chern-Simons modified gravity theory
- Aharonov-Chaser / Scaler Aharonov-Borm effect
- Etc...

New sciences with atto eV !!
Any new Ideas are Welcome !!