Neutron Mirror with Magnetic Repulsive Wall

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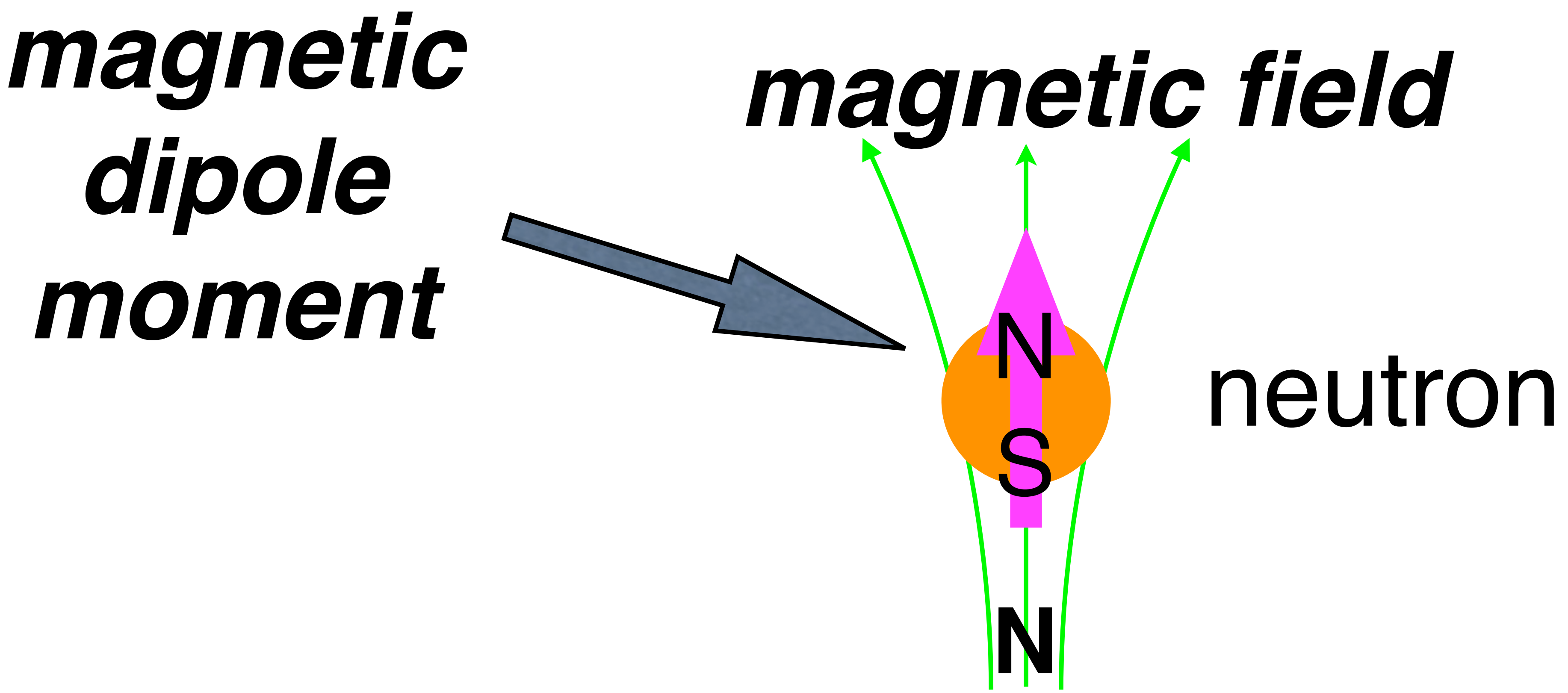
- Principle of Magnetic Potential Mirror
- Beam Guide with Magnetic Potential Mirrors
- Proof-of-Principle Experiment at JRR-3
- Prototype Mirrors Design and Experiment Plans
- Summary

Magnetic Potential on Neutrons



magnetic dipole moment

magnetic field

neutron

Due to the interaction between the magnetic moment of the neutron spin and the magnetic field, the magnetic field acts as a potential for the neutron.

Neutron spin potential in magnetic field :U

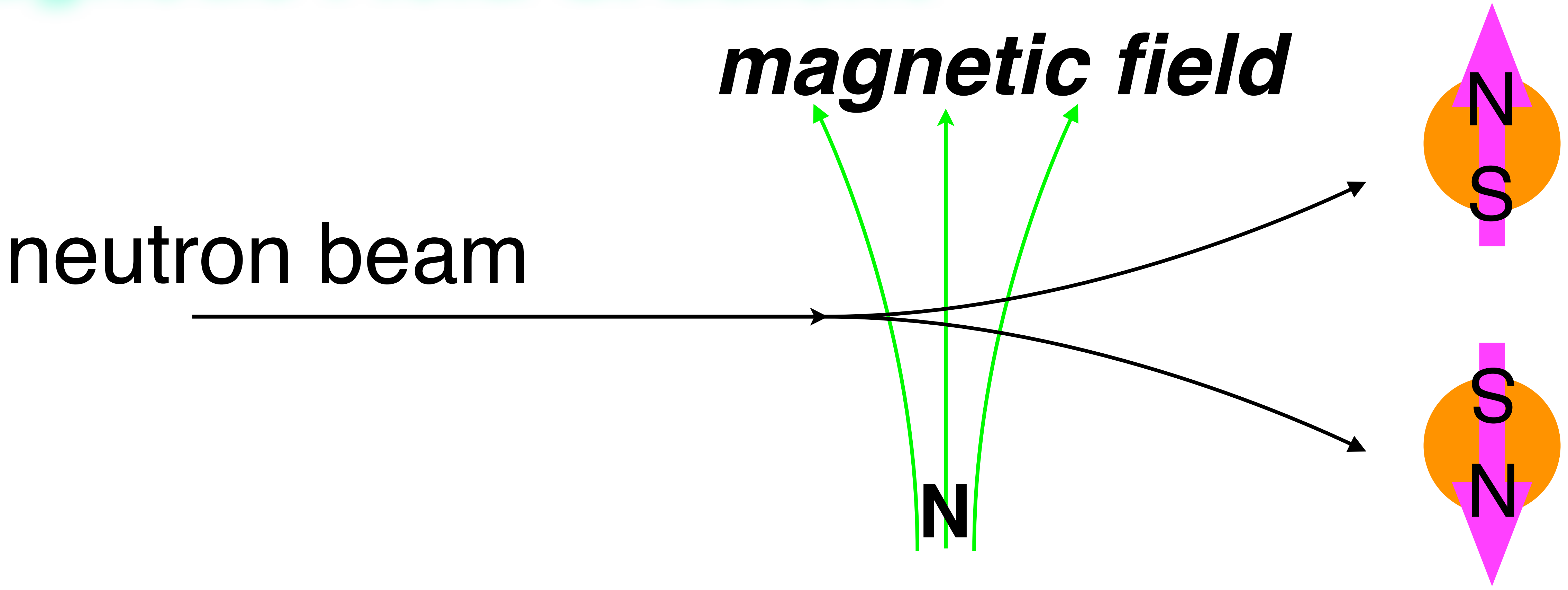
$$U = |\mu_{\mathrm{n}}|\boldsymbol{\sigma}\cdot\boldsymbol{B}$$

$\boldsymbol{\sigma}$; neutron spin

$\boldsymbol{B}$; Magnetic field

$\mu_{\mathrm{n}} = -9.6623707 \times 10^{-27}\ [\mathrm{JT}^{-1}]$

Deflection of Neutron Beam by Magnetic Field Gradient



When a neutron beam passes through a region where a magnetic field gradient exists, the beam orbit is deflected by a force in the direction of the gradient. The direction of deflection depends on the direction of the spin.

Deflecting Force on Neutron Beam :F

$$\boldsymbol{F} = \mp k \cdot \nabla |\boldsymbol{B}|$$

k ; constant

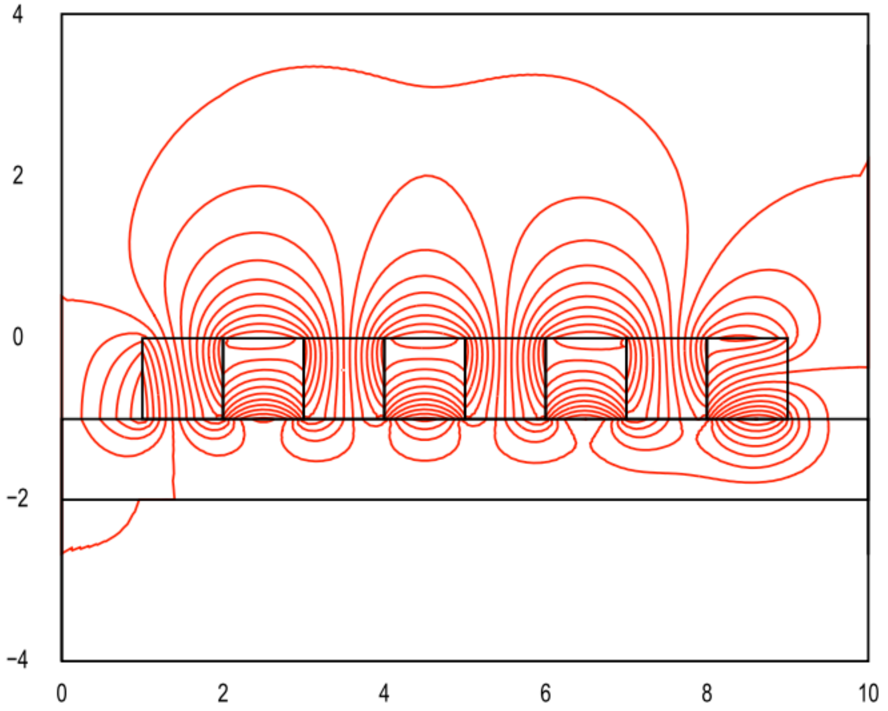
$\boldsymbol{B}$; Magnetic field

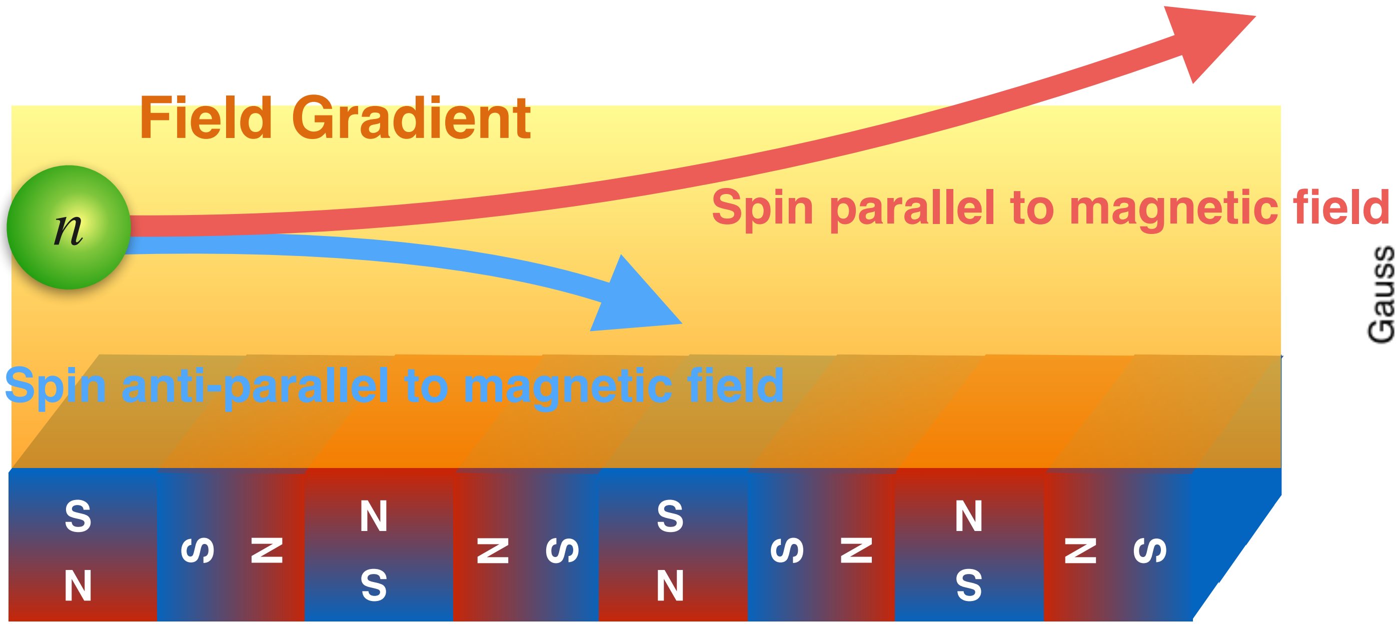
(sign depends on neutron spin direction)

Neutron Mirror with Magnetic Field Gradient

Generating a uniform magnetic field gradient spreading in the plane can be regarded as the existence of a potential wall for neutrons with parallel spins.
==> The planar potential wall acts as a mirror!!

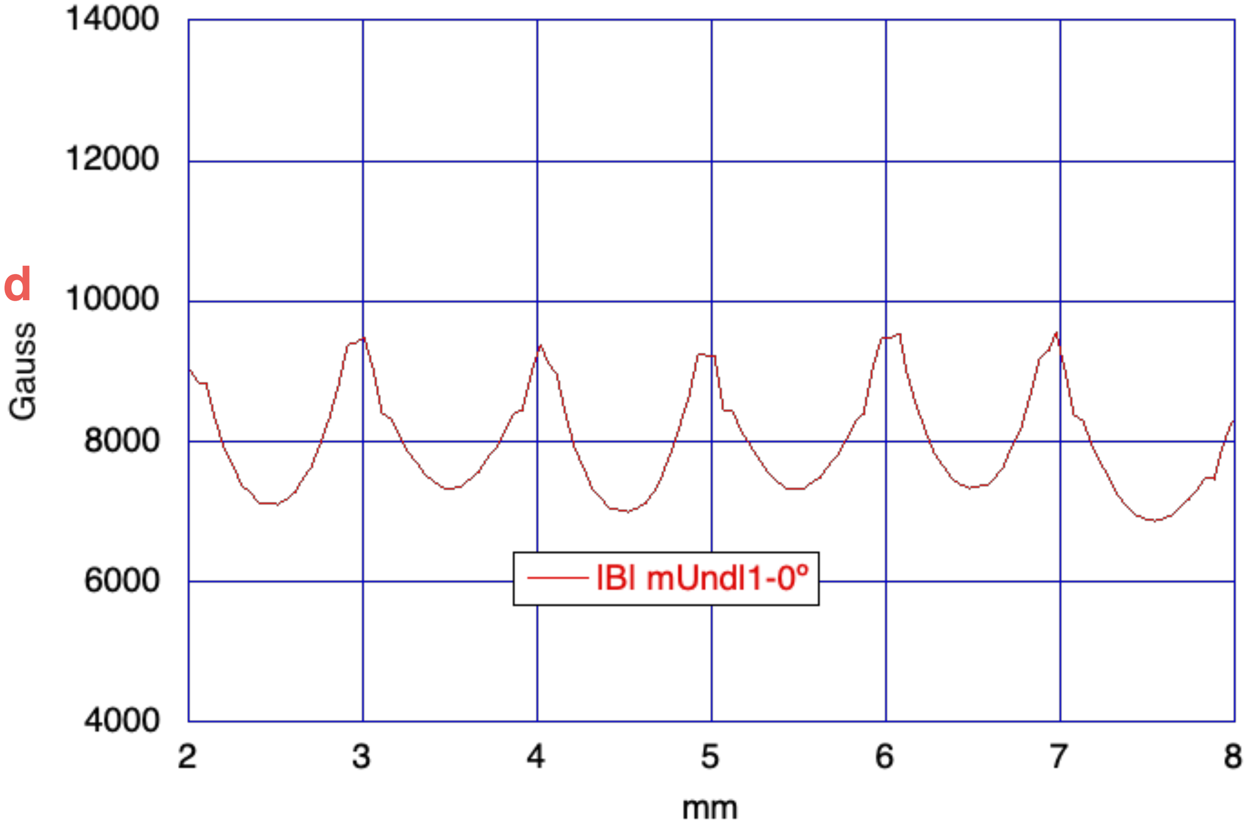
Configuring permanent magnets in Halbach array, potential wall with magnetic field gradient can be constructed.




Field Gradient

Spin parallel to magnetic field

Spin anti-parallel to magnetic field



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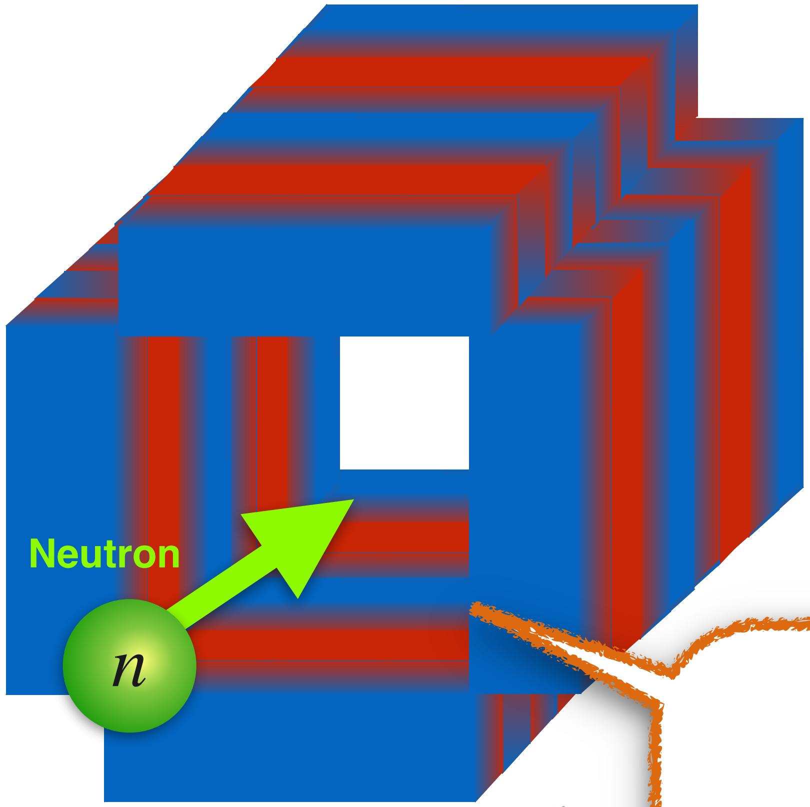
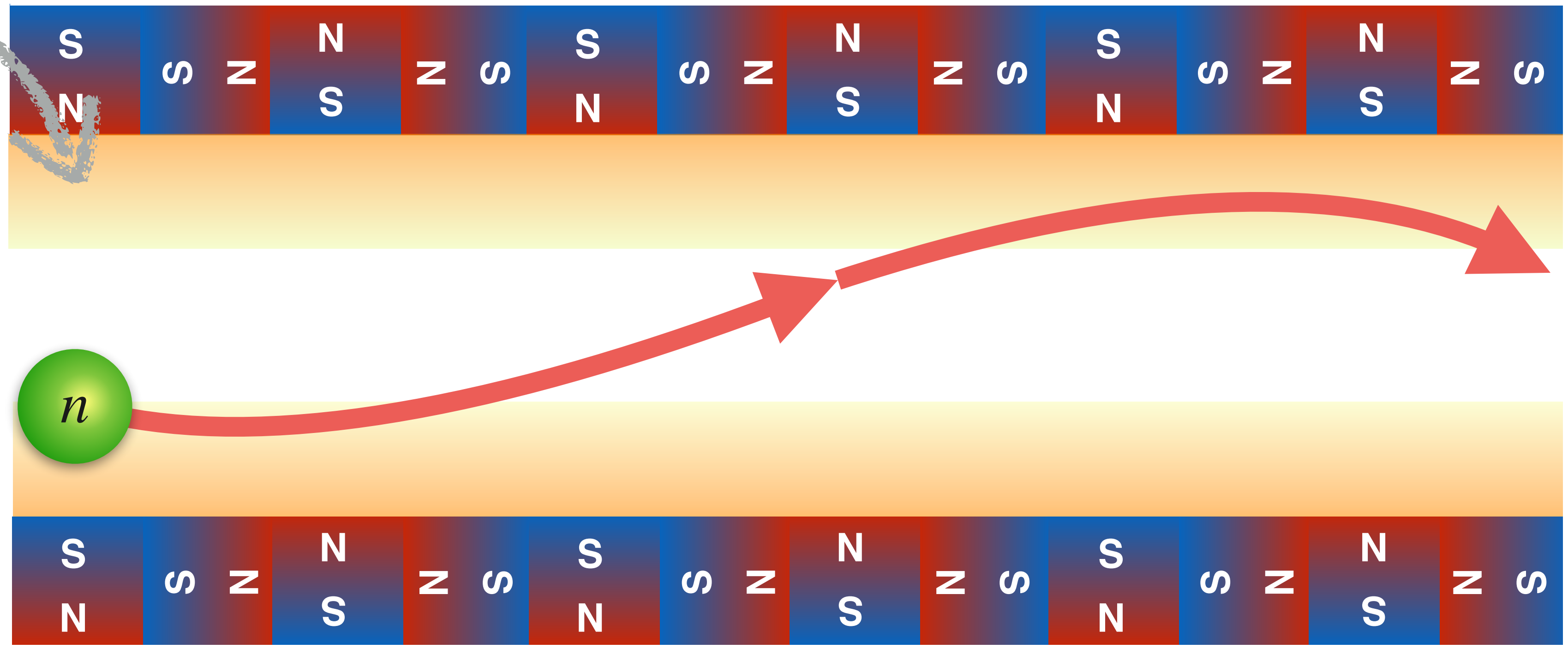
"Magnetic Repulsive Neutron Guide”



A beam guide for slow neutrons can be formed by arranging magnetic gradient mirrors in a duct-like configuration.



The reflective surface of the magnetic potential mirror is “fuzzy”.

Reduction of installation/ manufacturing accuracy

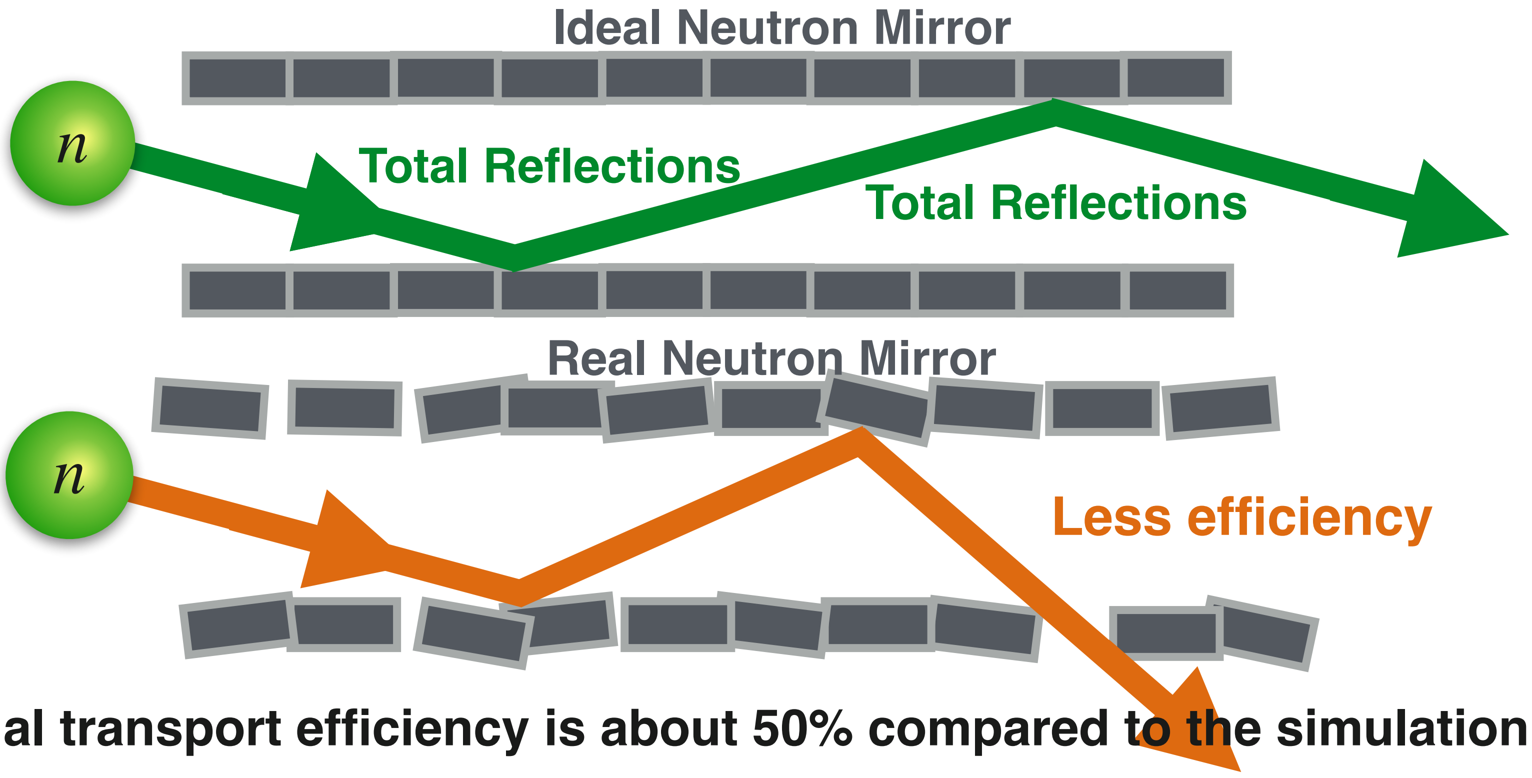
Merit of “Fazzy” Neutron Guides

Current Device

Neutrons are transported by total reflection on the inner surface of the hollow tube.

But

Low actual transport efficiency due to accumulation of alignment errors.
Expensive due to installation and processing accuracy requirements.

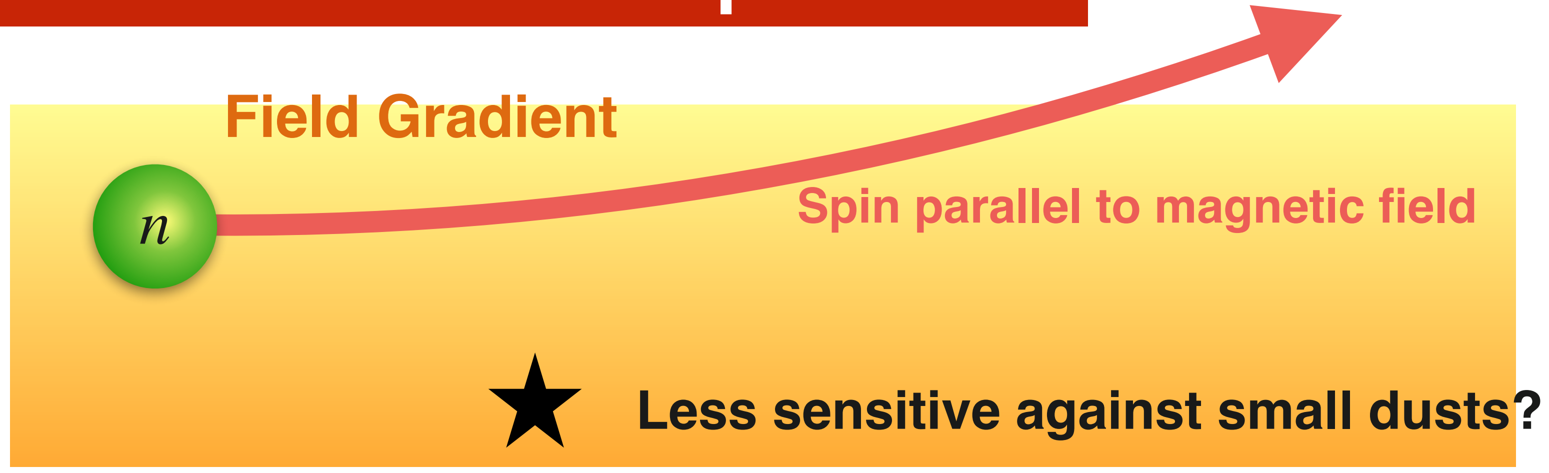


For example, in J-PARC MLF BL05, the actual transport efficiency is about 50% compared to the simulation.

Possible solution to the current problems

Magnetic Potential Mirror

Deflects neutron orbits by magnetic field gradient and transports them without contacting the material.



★ Less sensitive against small dusts?

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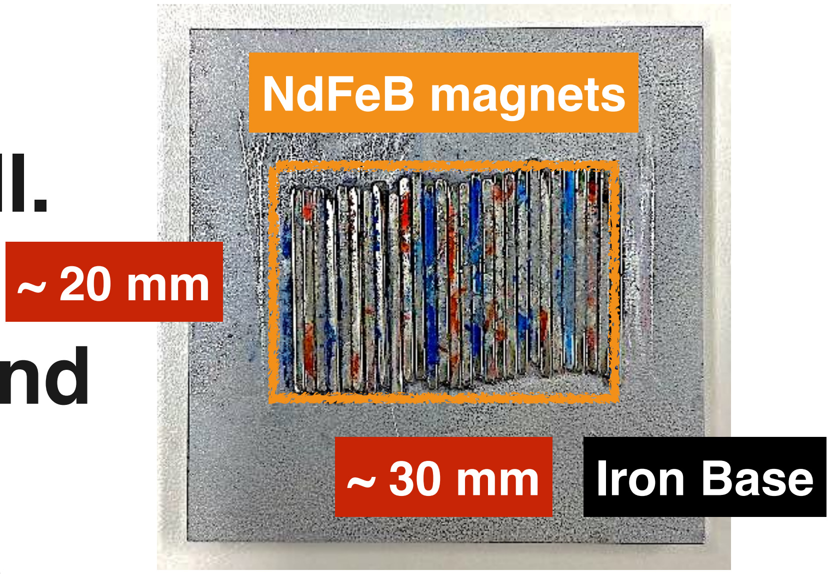
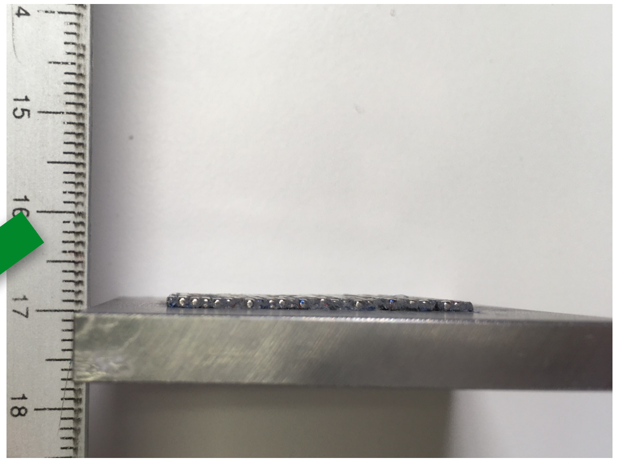
Proof of Principle Experiment 1: Sample

Small sample mirror was constructed with neodymium magnets to build a potential wall.

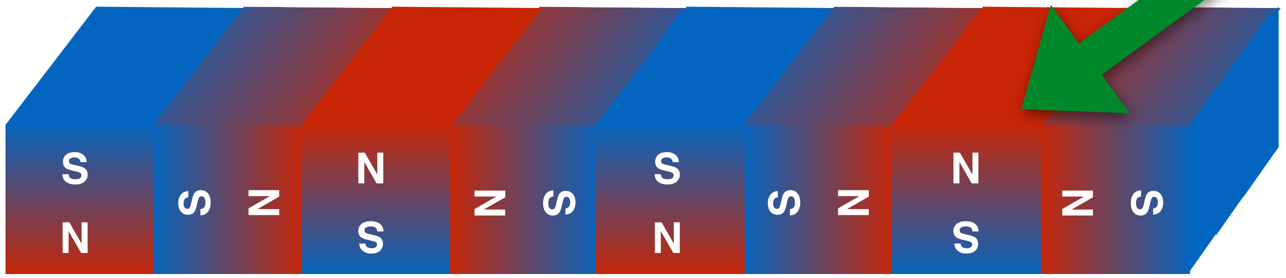
- **Effective mirror surface is 20 mm height and 30 mm width.**
- **The neodymium magnets were glued onto an iron base plate.**
- **Magnetic field flux density on the magnet pole is nearly 1 T.**





Built magnetic wall:
28 prisms
(1 mm × 1 mm × 20 mm)

Halbach Magnet Configuration

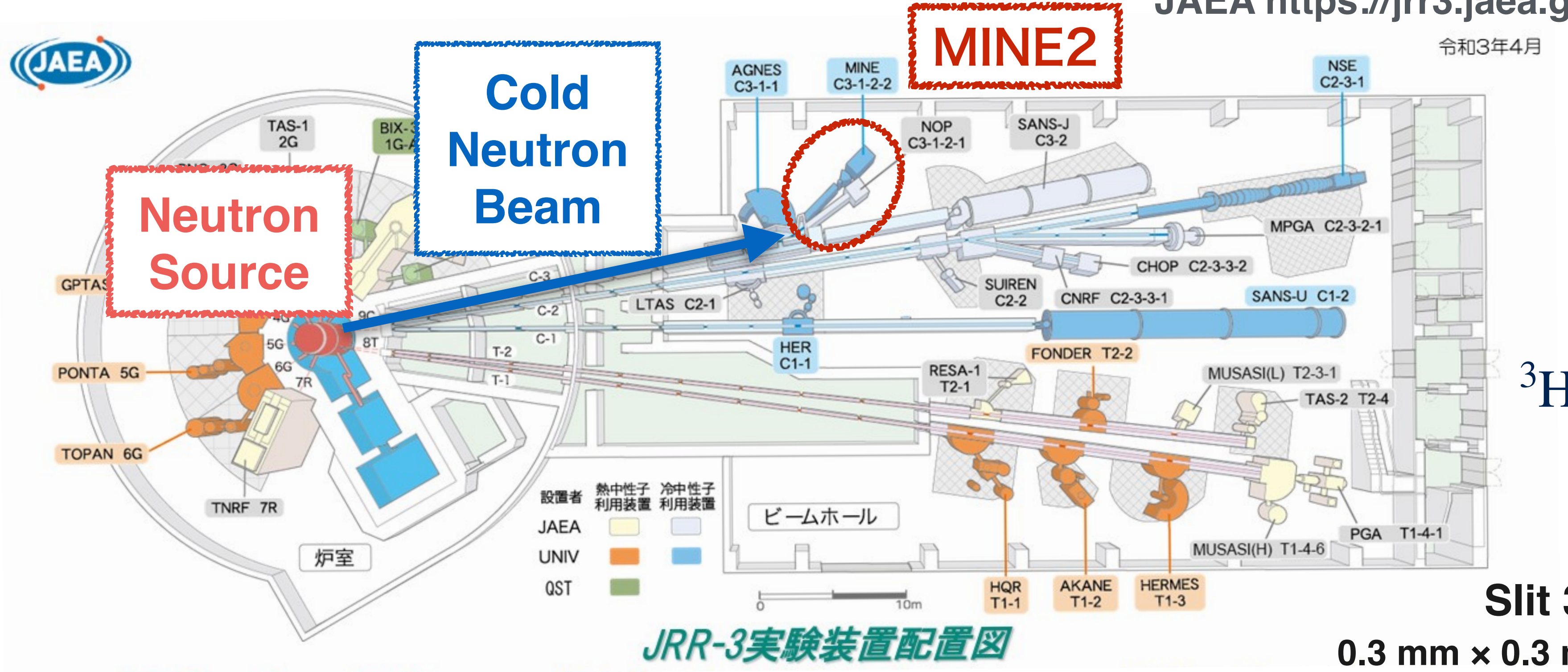


Proof of Principle Experiment 2: Setup

Experiment was performed at JAEA JRR-3 MINE2.

Central wavelength 0.88 nm (~ 1.1 meV), width 2.8 %

JRR3 Beamline MINE2



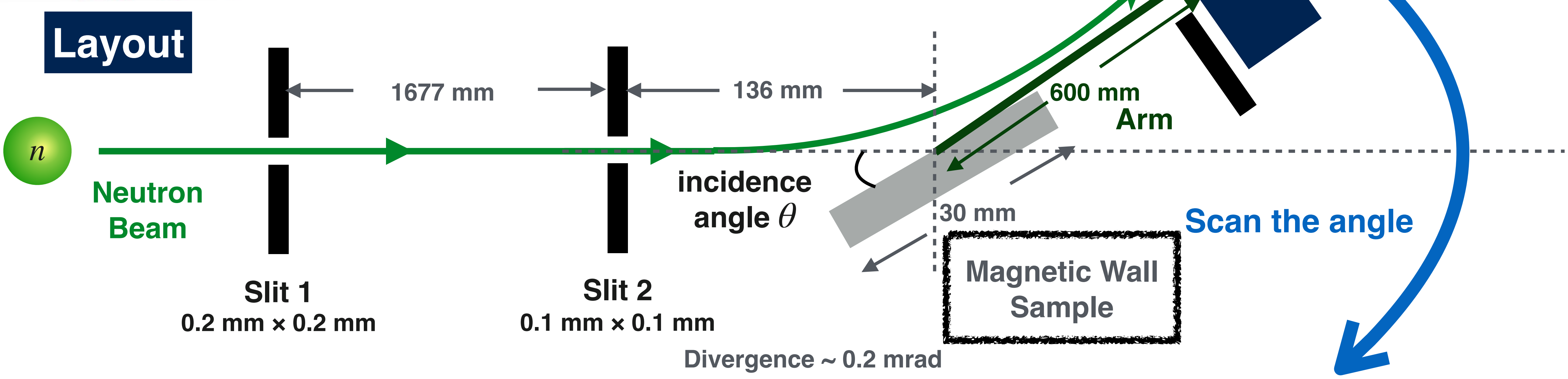
MINE2

Cold Neutron Beam

Neutron Source

JAEA https://jrr3.jaea.go.jp

JRR-3実験装置配置図



Layout

Neutron Beam

Slit 1
0.2 mm × 0.2 mm

Slit 2
0.1 mm × 0.1 mm

incidence angle θ

Divergence ~ 0.2 mrad

Magnetic Wall Sample

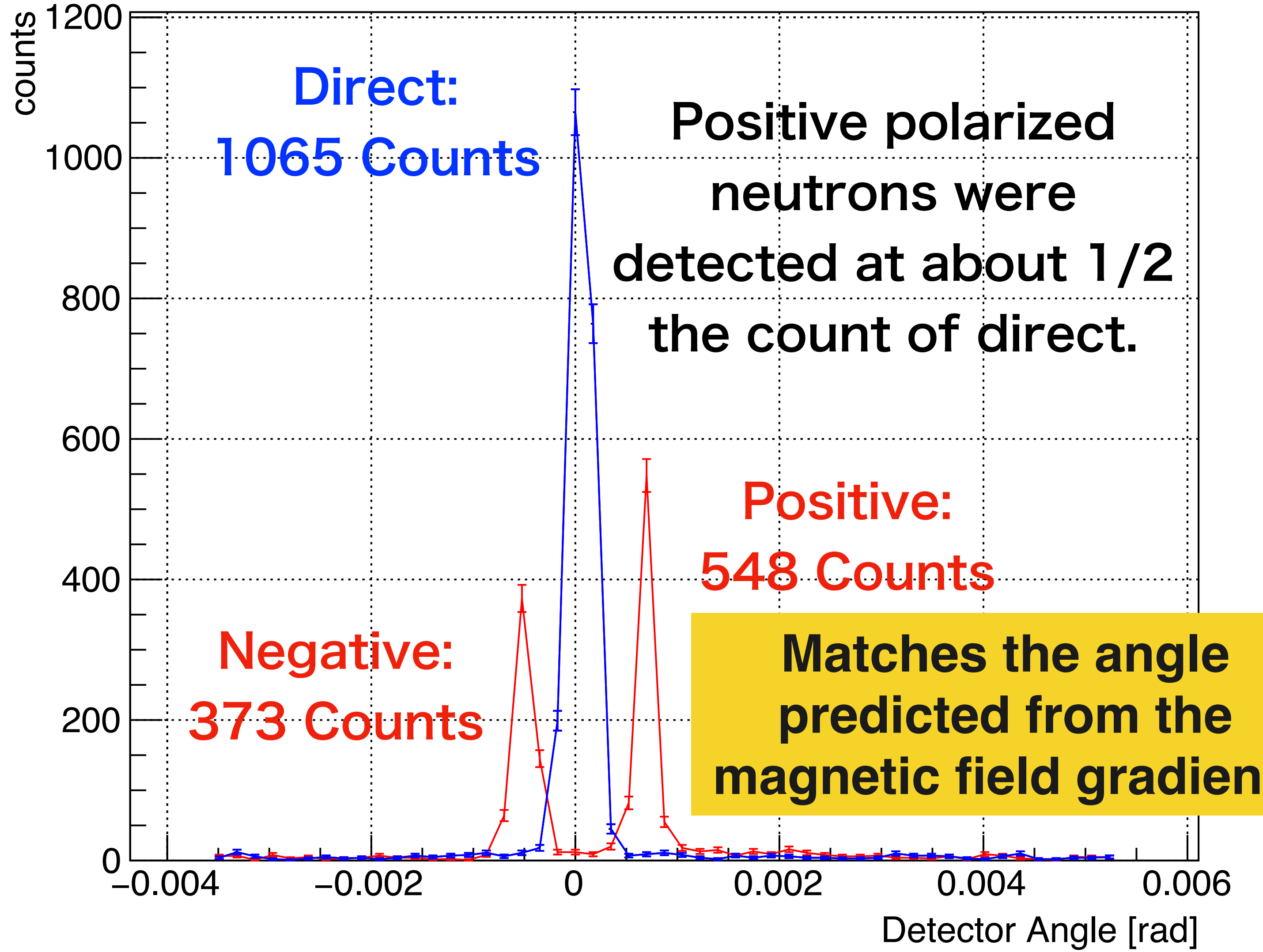
Slit 3
0.3 mm × 0.3 mm

^{3}He **Detector**

Scan the angle

Proof of Principle Experiment 3: Result

Incident angle θ~1.7 mrad, (measurement time 75 s).



Direct: 1065 Counts

Negative: 373 Counts

Positive: 548 Counts

Positive polarized neutrons were detected at about 1/2 the count of direct.

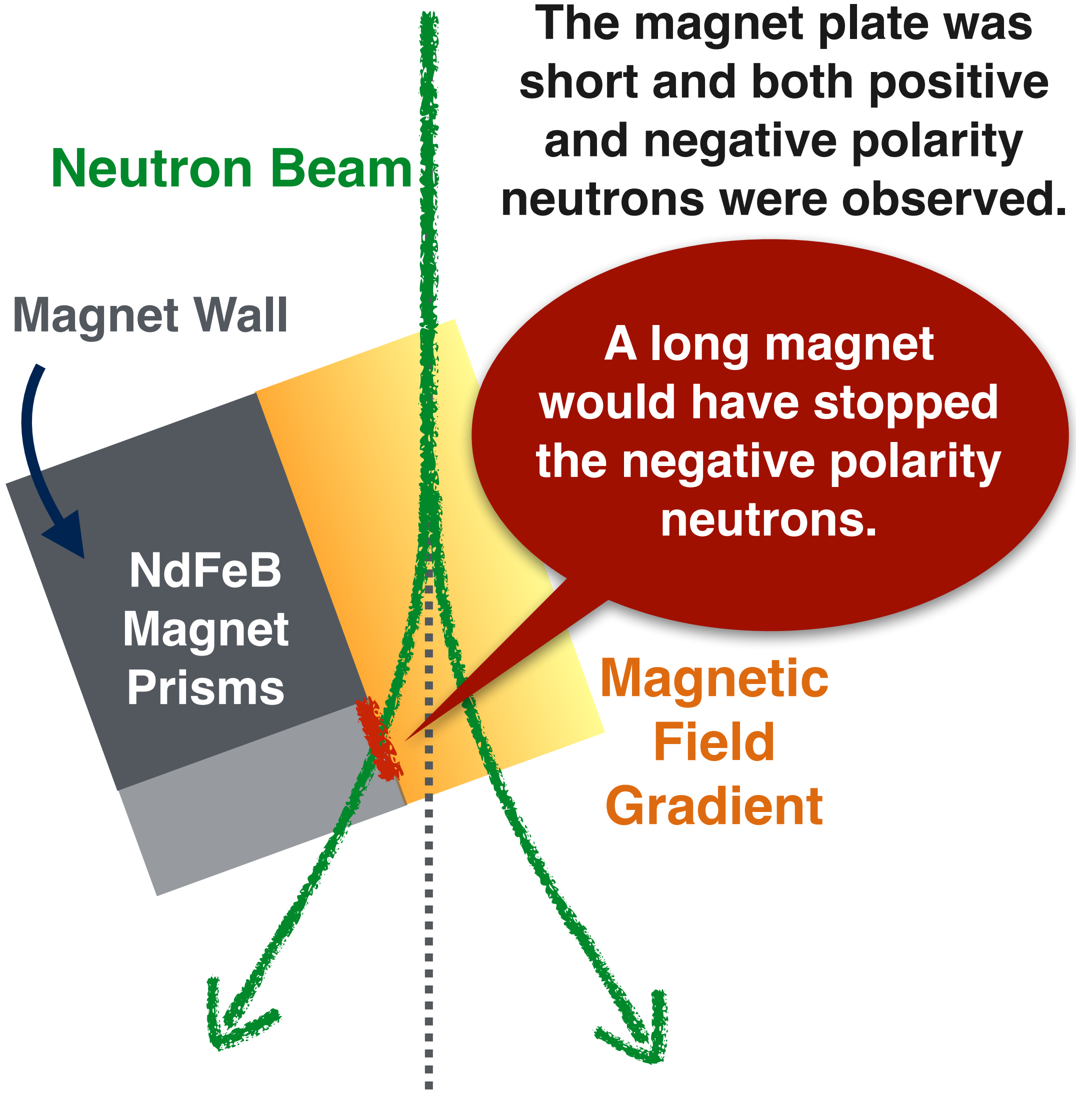
Matches the angle predicted from the magnetic field gradient!

Negative-polarity neutrons are thought to be detected in small numbers, as some of them hit magnets or substrates and could not be detected

→ Neutrons could be separated into two paths (spin parallel and anti-parallel)

Neutron deflection using a magnetic field gradient plate was confirmed

The magnet plate was short and both positive and negative polarity neutrons were observed.



A long magnet would have stopped the negative polarity neutrons.

Negative polarity neutrons.

Positive polarity neutrons.

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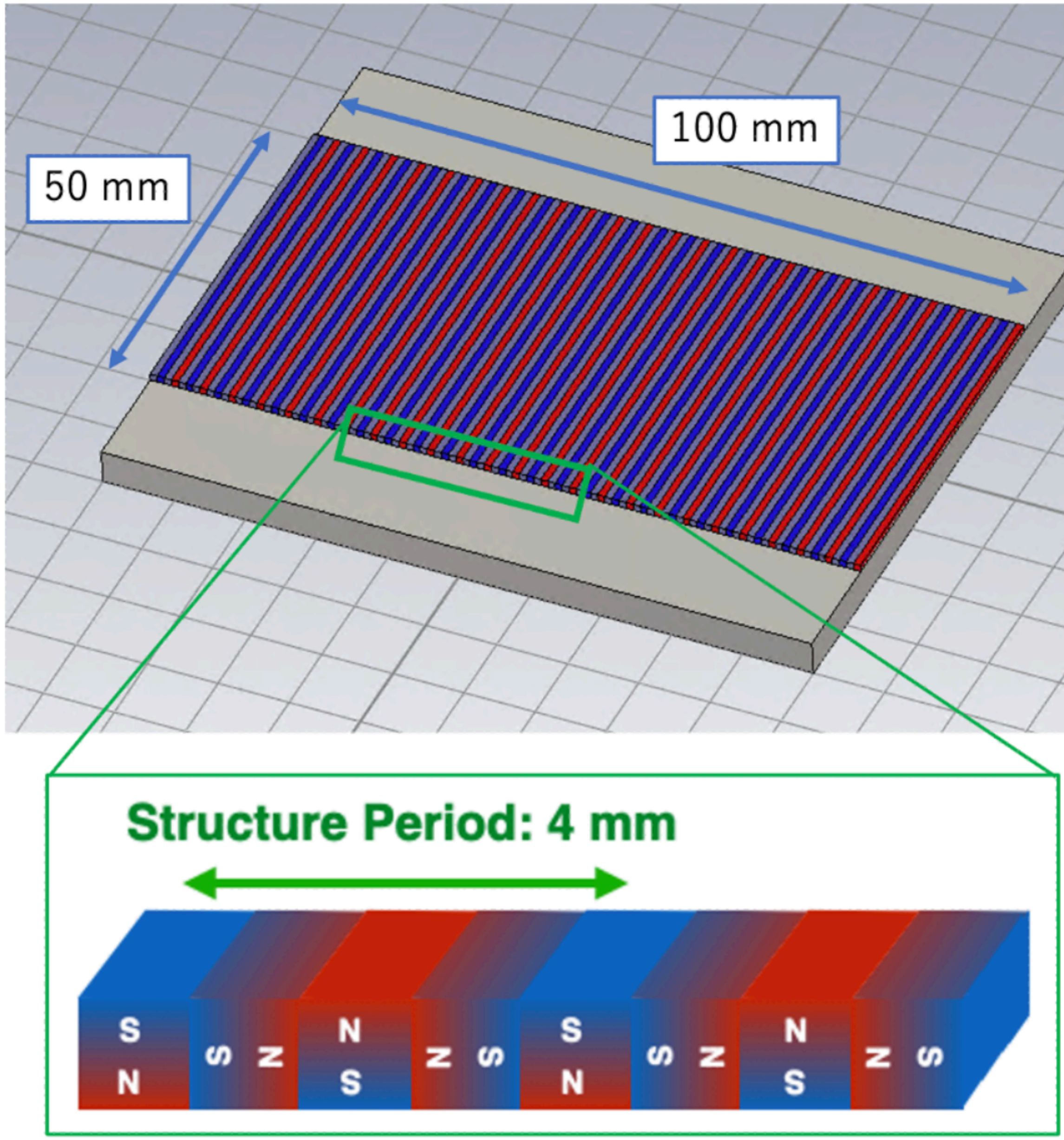
Prototype Mirror Development

A couple of larger prototype mirrors are being fabricated to evaluate mirror characteristics in more detail.



Specifications of mirror:

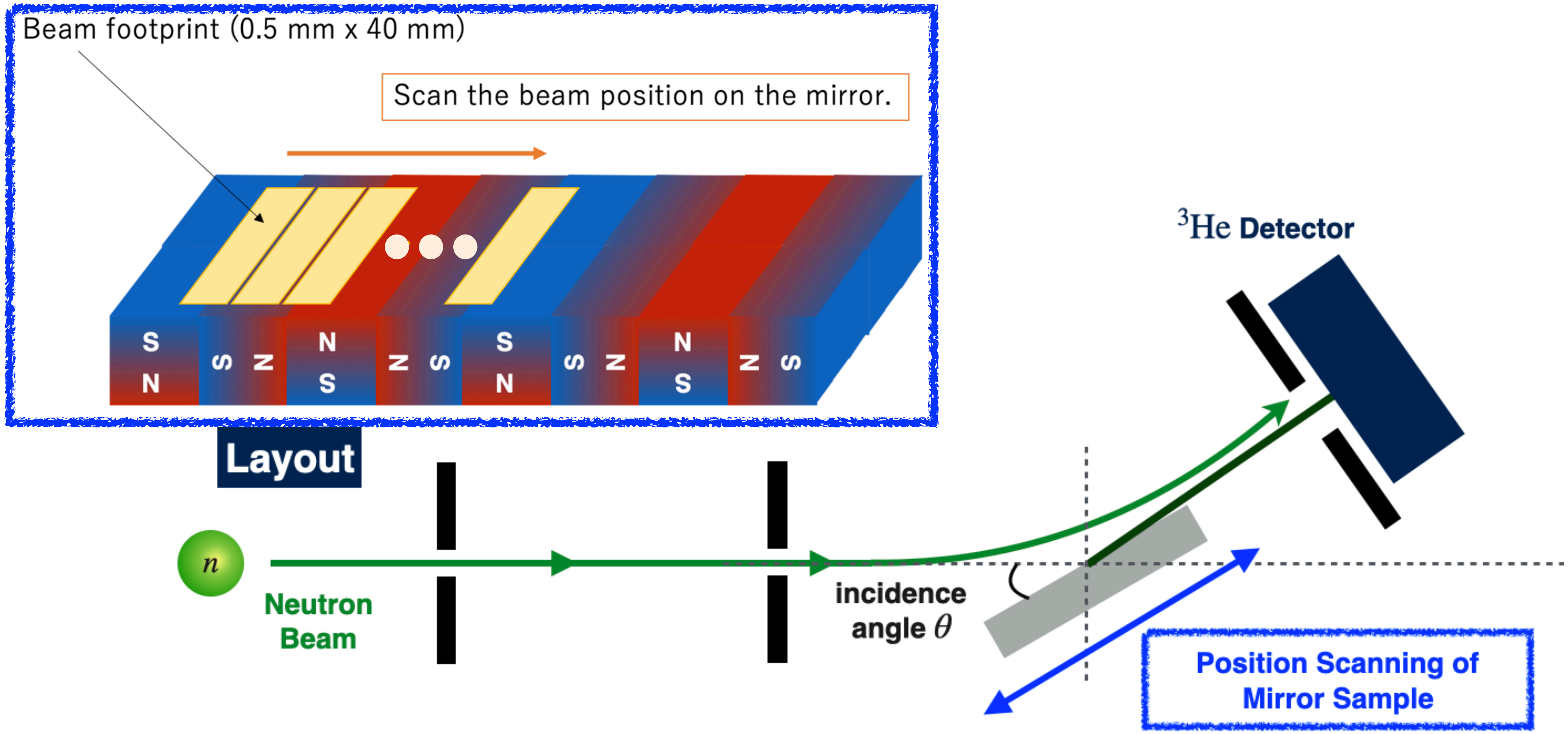
- **Height: 50 mm**
- **Width: 100 mm**
- **Magnets: H48 $Nd_2Fe_{14}B$**
- **Base Plate: SS430**

Assembling is currently in progress by a local company and is expected to be completed by the end of this August.

Experiments with Prototype Mirror 1

Using larger prototype mirror (size of 100 mm x 50 mm), we are planning to measure the mirror characteristics at BL05 (NOP) or BL16 (SOFIA) at MLF in J-PARC from late 2023 to 2024.

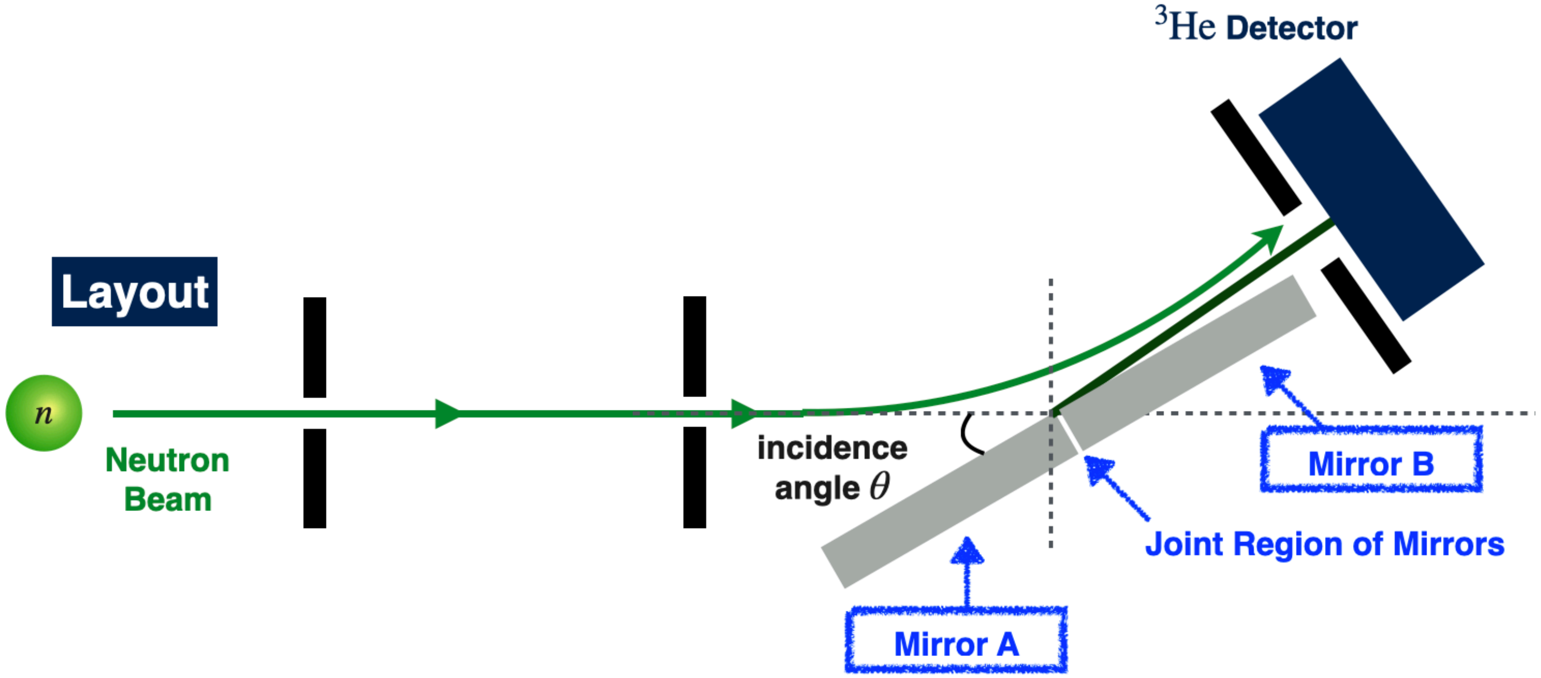
Mirror characteristics to be measured:
- m-value evaluation of mirror
- position dependence of reflectivity



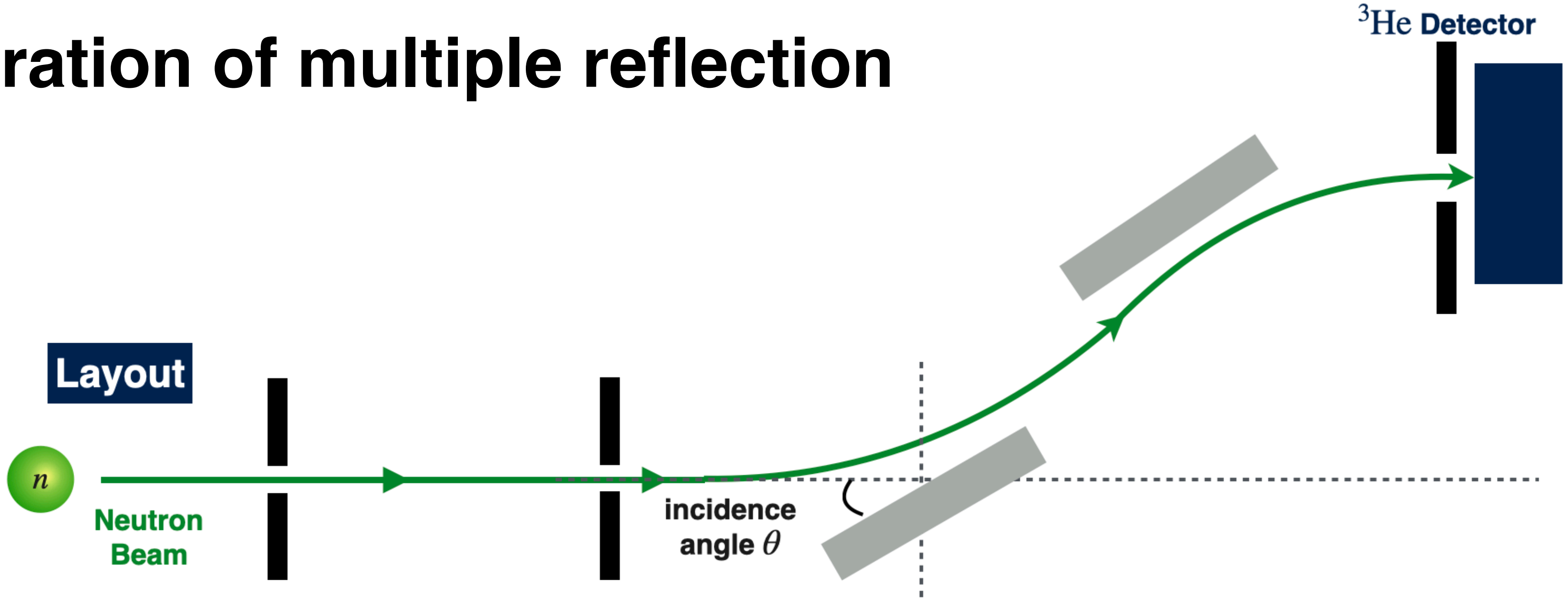
Experiments with Prototype Mirror 2

Mirror characteristics to be measured (continued):

- reflection characteristics in mirror-joint region



- demonstration of multiple reflection



Summary and Future Plan

- A Magnetic Potential Mirror is proposed as efficient and cost-effective neutron mirrors.
- Since the reflective surface of the magnetic potential mirrors is “fuzzy”, transport efficiency is less sensitive to alignment errors and fabrication precision compared with conventional mirror.
- Maybe less sensitive against dusts on mirror.
- A proof-of-principle experiment was performed at JRR-3.
- Prototype mirrors are under fabrication, which will be used in a performance test at J-PARC MLF.
- As a future plan, we plan to fabricate a 1-meter guide tube in 2025 and conduct a slow neutron transport experiment.