Direct observation of neutron spin rotation in Bragg scattering due to the spin-orbit interaction in silicon

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SCHWINGER SCATTERING

J. Schwinger, Phys. Rev. 73, 407 (1948) ***"On the polarization of fast neutrons"***

– torque on a moving neutron's magnetic dipole moment (MDM) due to interaction with the atomic electric field

C.G. Shull, Phys. Rev. 10, 297 (1963) ***"Neutron spin-orbit interaction with slow neutrons"***

C. G. Shull and R. Nathans, Phys. Rev. 19, 384 (1967).

"Search for a neutron electric dipole moment by a scattering experiment"

V.V. Fedorov, J. Phys. Soc. Japan Conf. Proc. 22, 011007 (2018).

"Modern Status of Searches for nEDM, using neutron optics and diffraction in noncentrosymmetric crystals"

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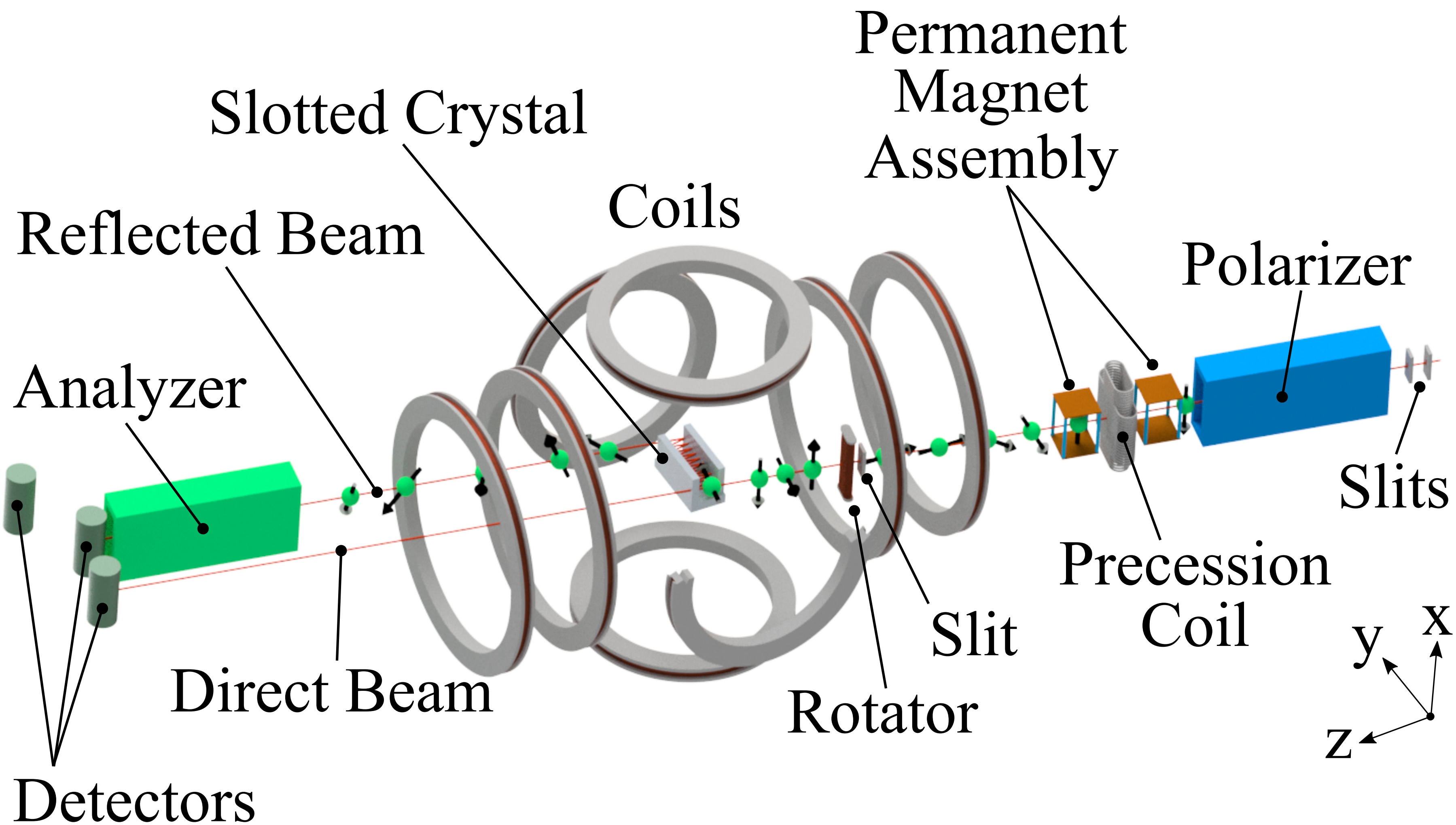
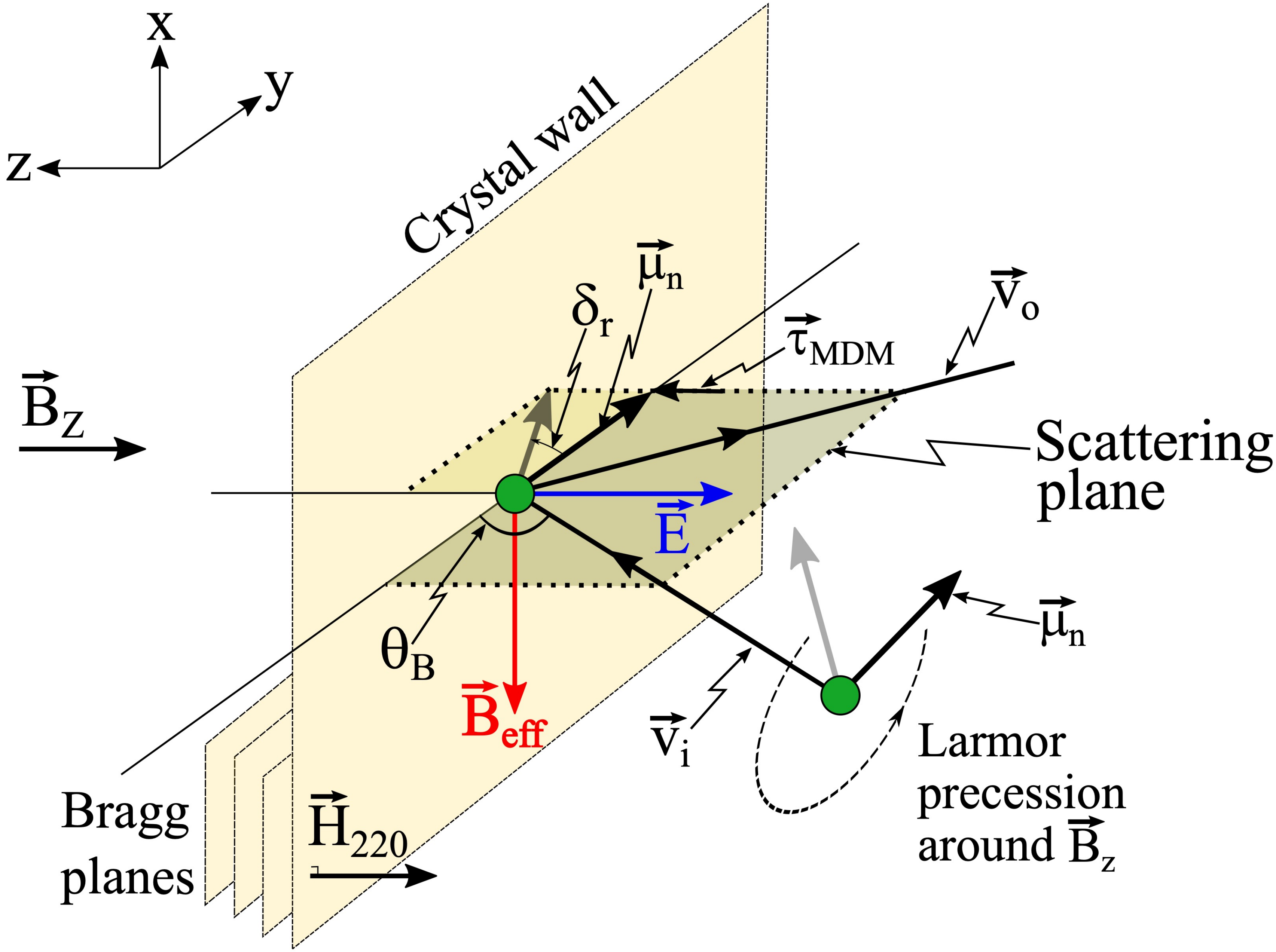
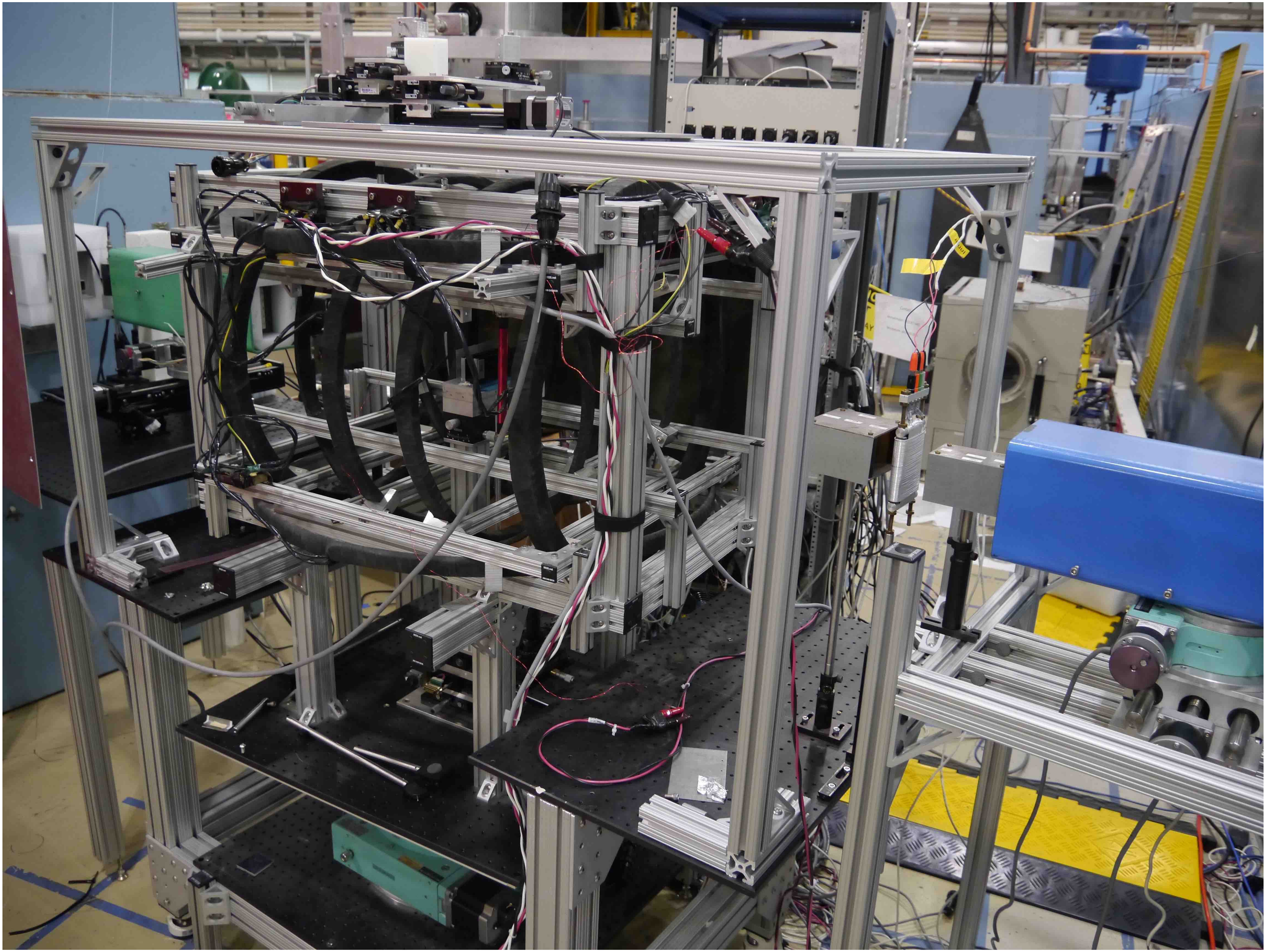
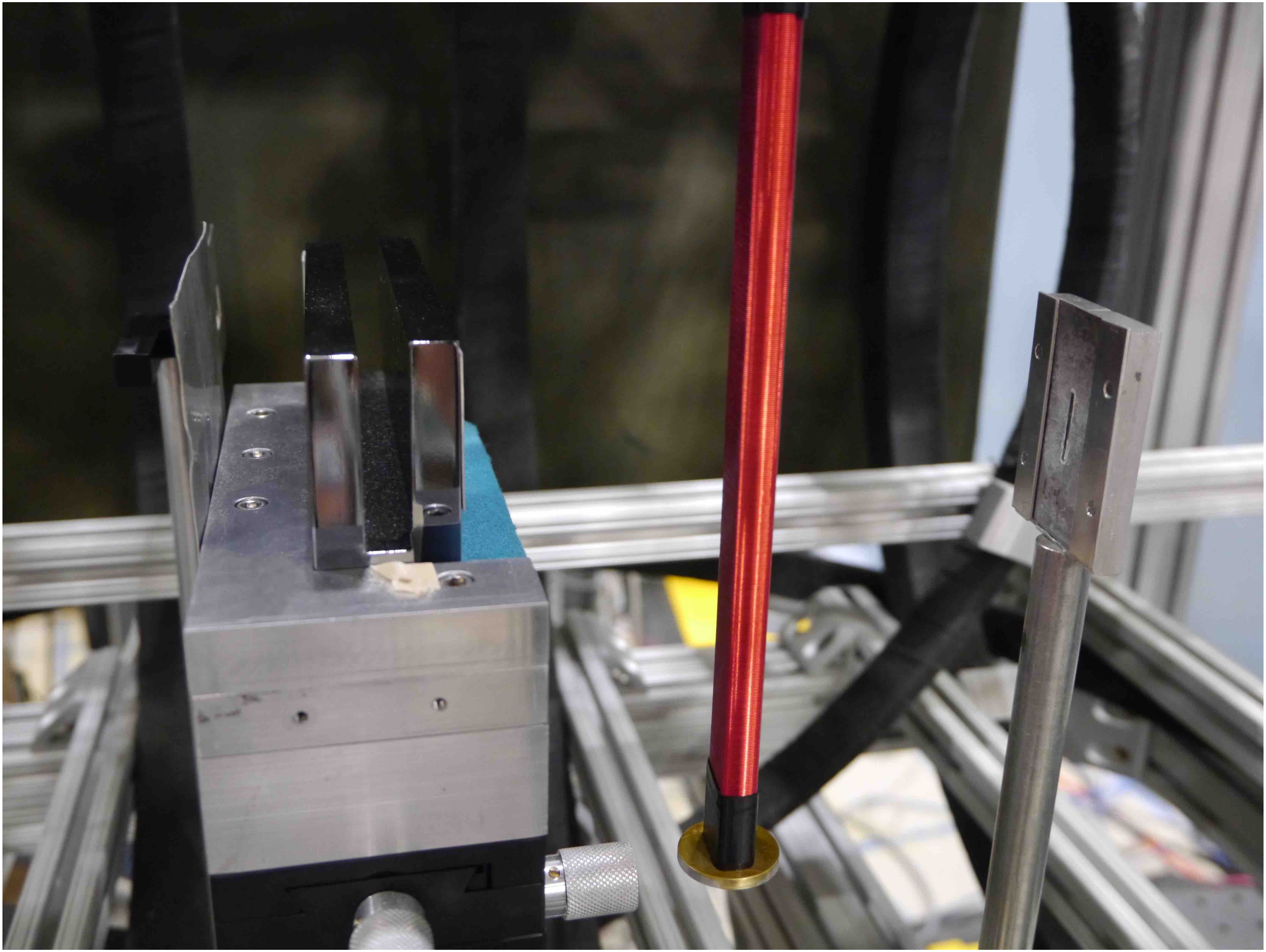

Permanent
Magnet
Assembly
Slotted Crystal
Coils
Reflected Beam
Polarizer
Analyzer
Slits
Precession
Coil
Slit
Direct Beam
Rotator
Detectors
y
x
z


x
y
z
Crystal wall
$\vec{B}_Z$
δ_r
$\vec{\mu}_n$
$\vec{\tau}_{MDM}$
$\vec{v}_o$
Scattering plane
$\vec{E}$
θ_B
$\vec{B}_{eff}$
$\vec{\mu}_n$
$\vec{v}_i$
Larmor precession around $\vec{B}_z$
Bragg planes
$\vec{H}_{220}$





EXPECTED POLARIZATION ROTATION ANGLE

***Schwinger scattering length* = $b_{so} = (2\pi\mu_n/hc)\, Ze\, (1 - f_{220}) \cot(\theta_B)$**

***Rotation angle per bounce* = $\delta = 2\,|\, b_{so} \,/\, b_c \,|$ = 3.27×10^{-4} rad**

Total rotation for 136 bounces = 0.0473 rad

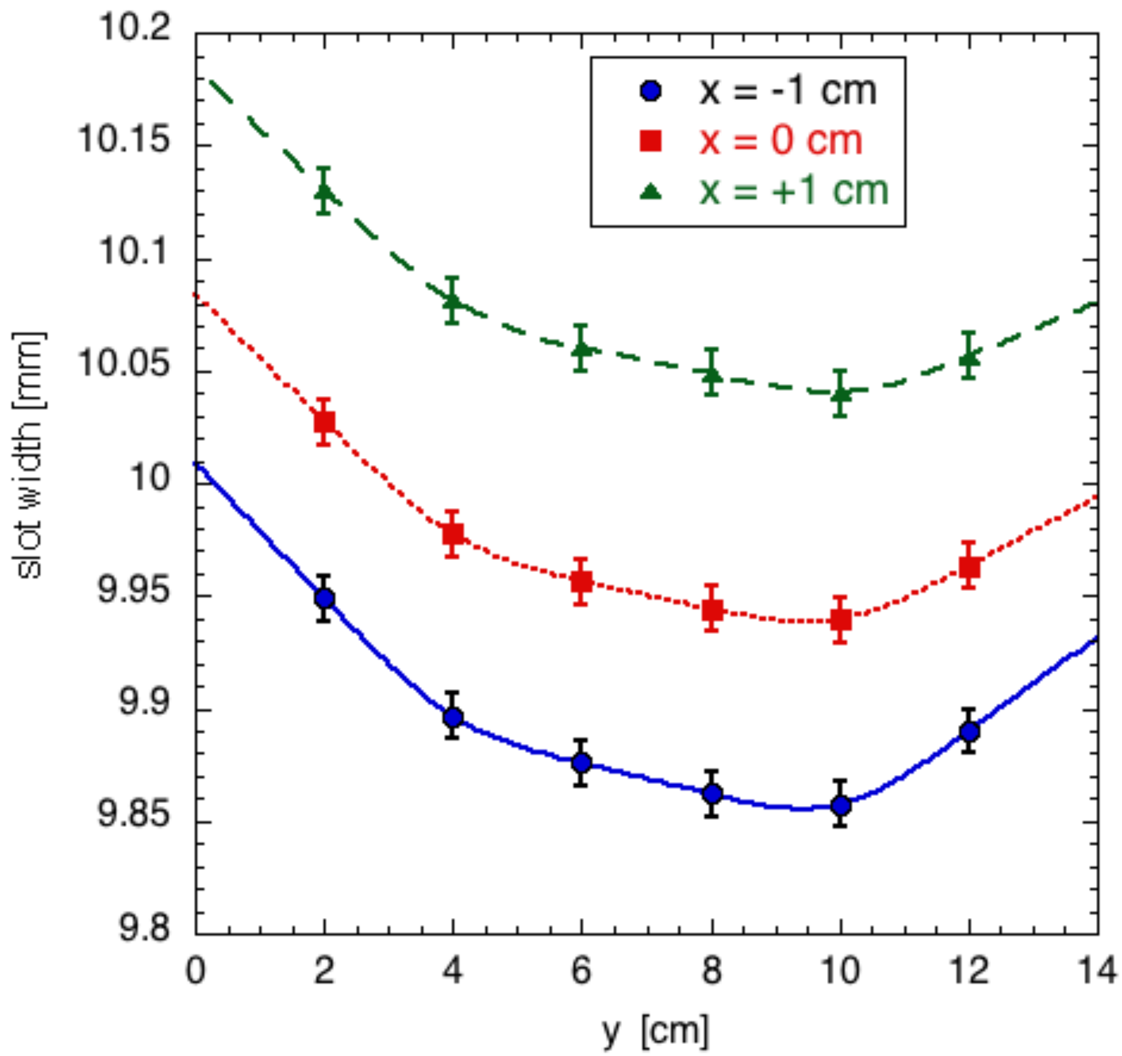
μ_n = ***neutron magnetic dipole moment***

f_{220} = ***form factor for the charge distribution of atomic electrons***

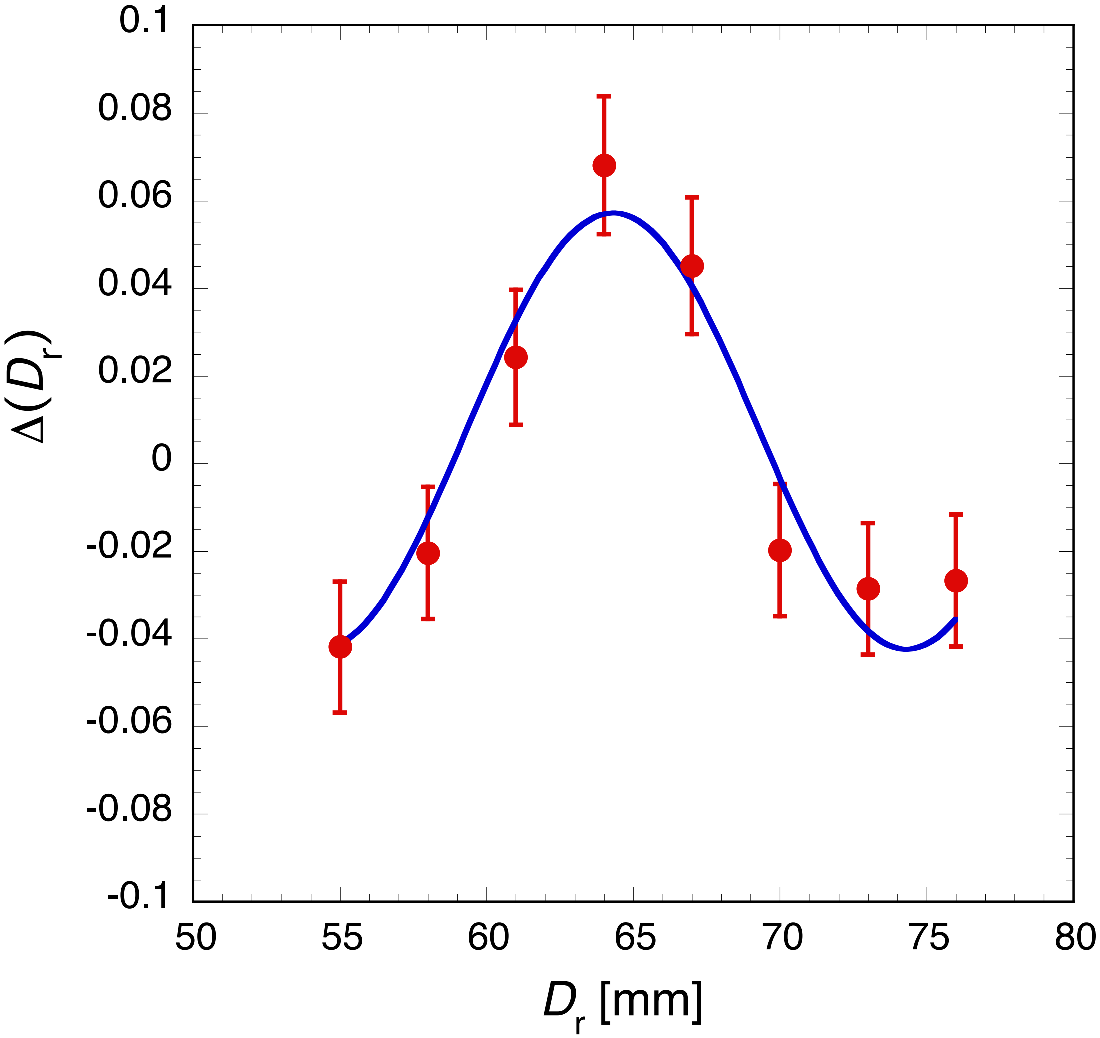
θ_B = ***Bragg angle***

b_c = ***coherent scattering length***

The best laid plans of mice and men: SLOT IS NON-UNIFORM

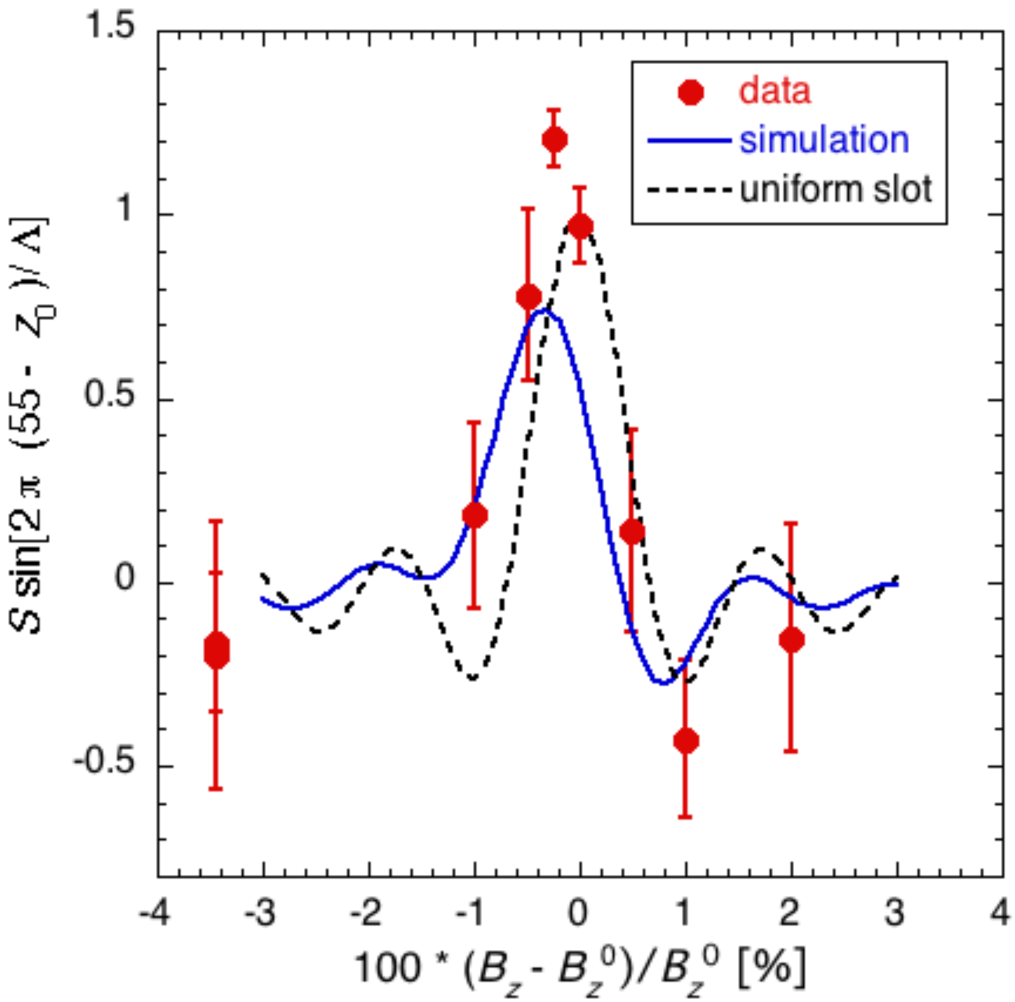


FRACTIONAL CHANGE IN THE REFLECTED BEAM COUNT RATE* vs. DISTANCE FROM ROTATOR COIL TO SLOTTED CRYSTAL

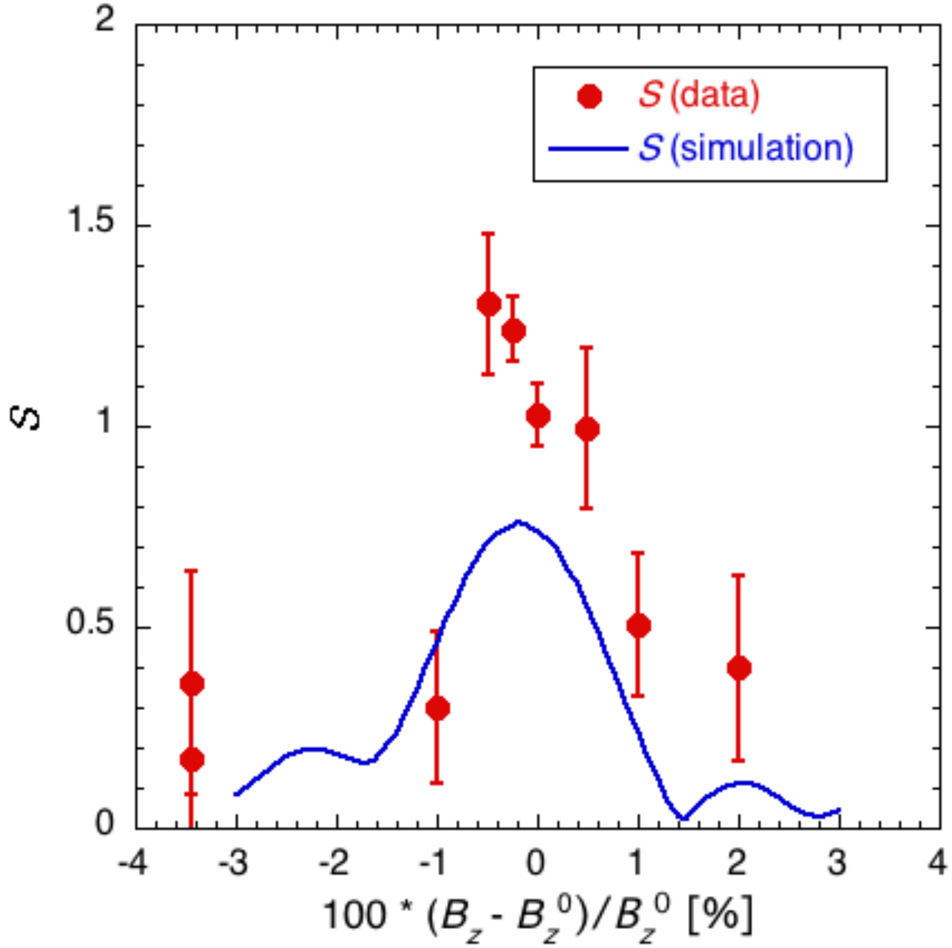


* Normalized to main beam rate and corrected for background

AMPLITUDE EVALUATED at D_r = 55 mm vs. MAGNETIC FIELD

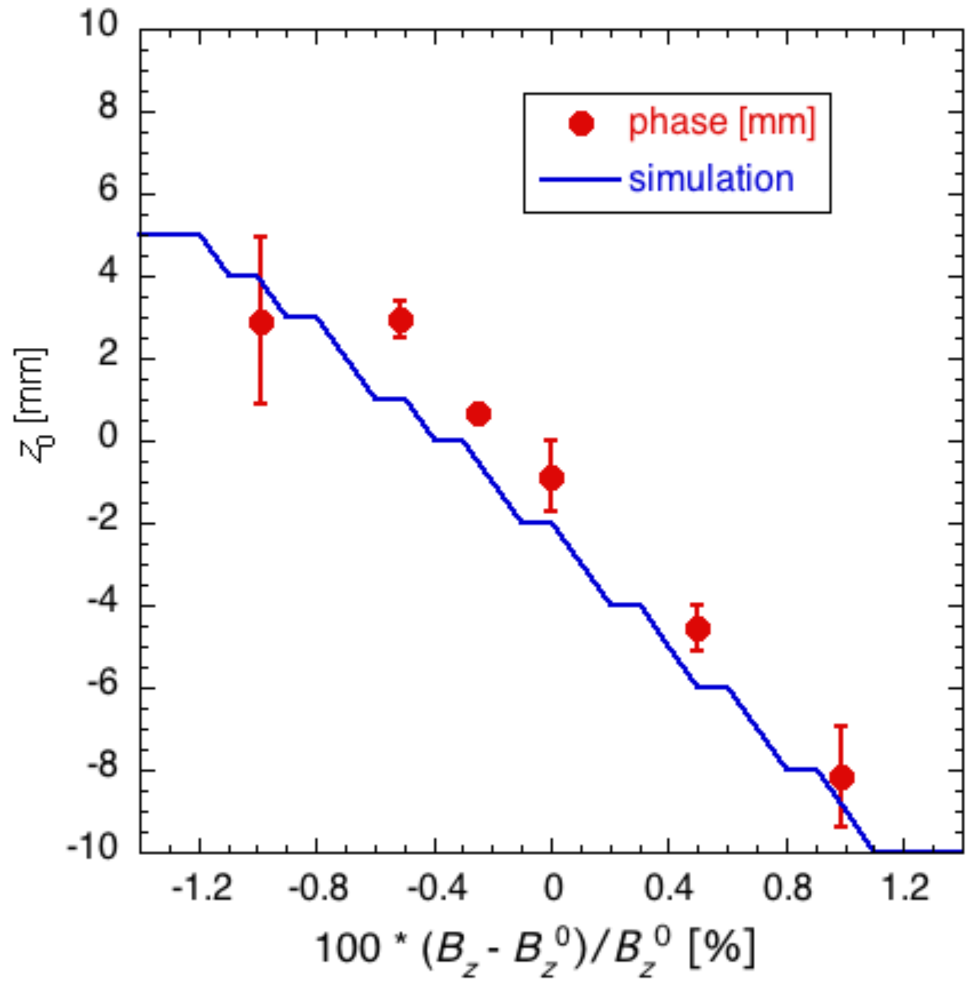


AMPLITUDE of OSCILLATION* vs. MAGNETIC FIELD

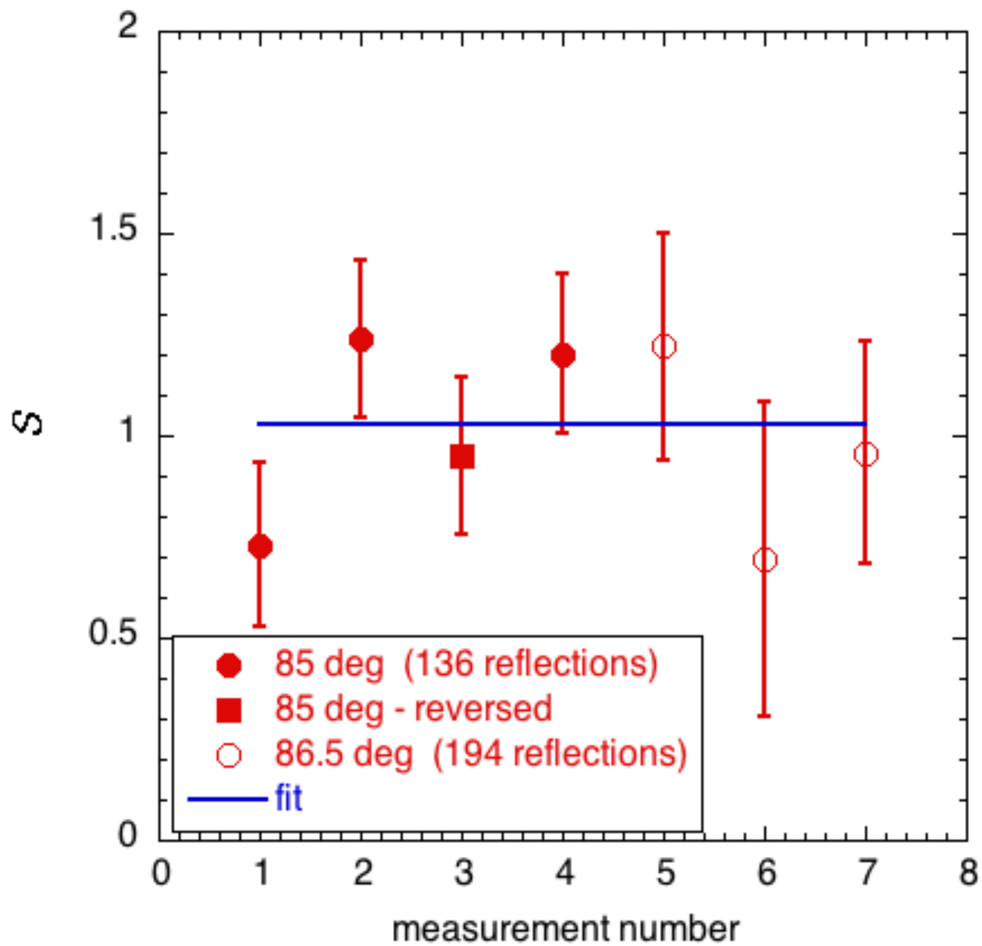


* Normalized to that expected for a perfect crystal

PHASE of OSCILLATION vs MAGNETIC FIELD

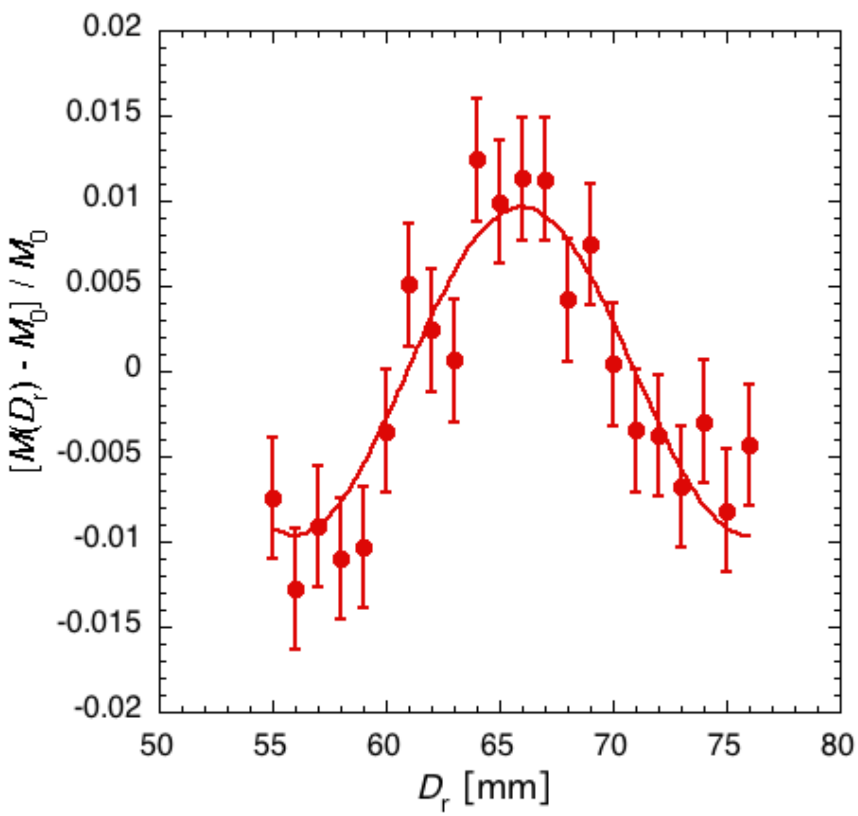


AMPLITUDE of OSCILLATION at 17.672 G*



* Field calibrated by NMR with polarized 3He, uncertainty 0.01%, variation over slot 0.03%

SPIN TRANSPORT OSCILLATION SYSTEMATIC



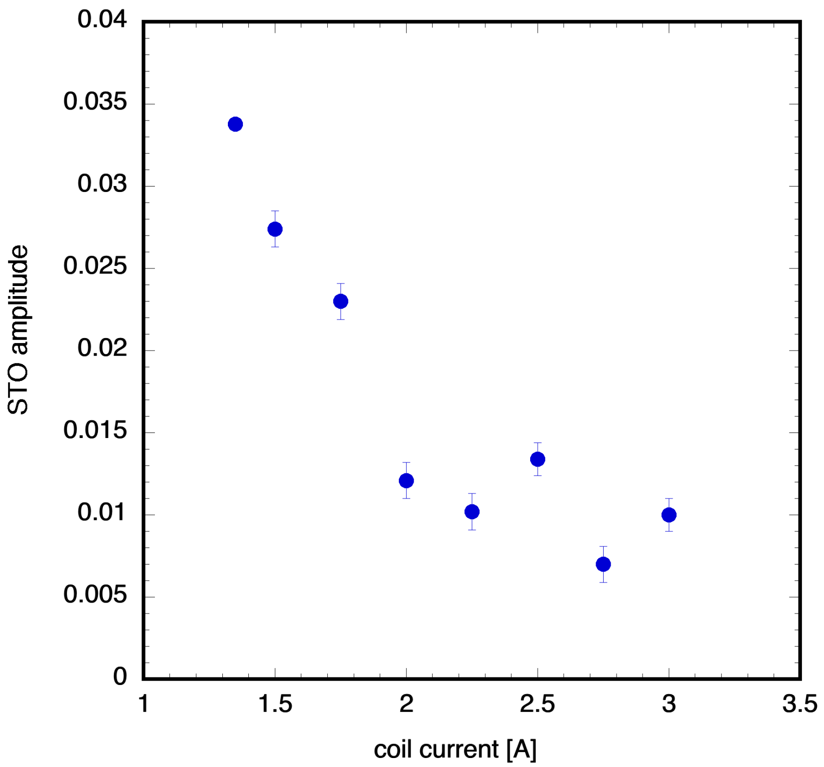
Oscillation amplitude = 0.0088

Assuming polarization is at an angle θ,
θ = arcsin (0.0088) = 0.50 deg

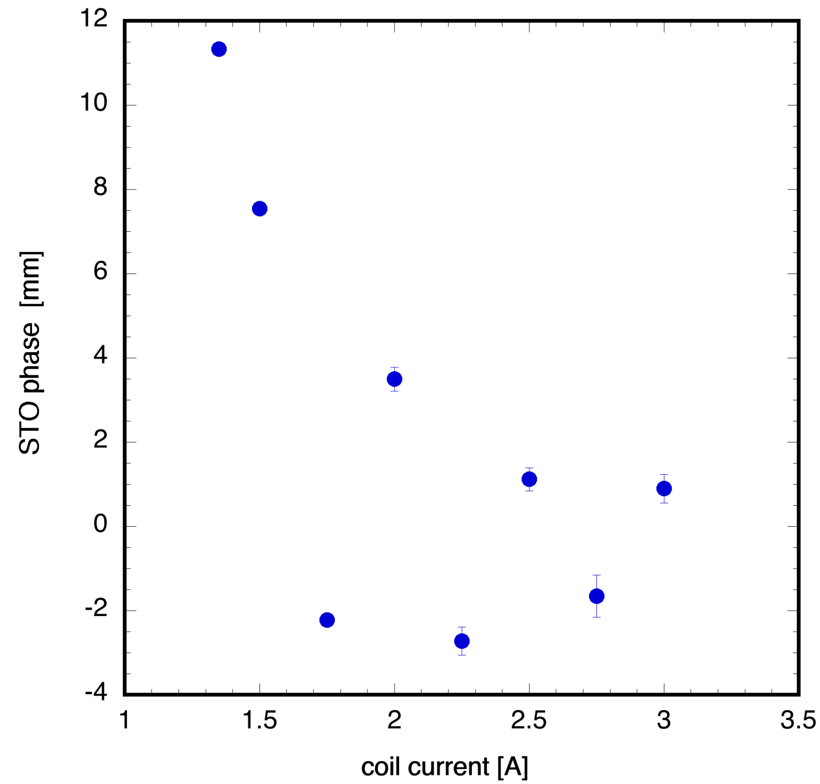
Spin transport efficiency = cos θ = 0.99996

If preserved in reflected beam,
this imperfect spin transport
would yield an oscillation with 24% of
expected amplitude for an ideal crystal

STO AMPLITUDE vs COIL CURRENT



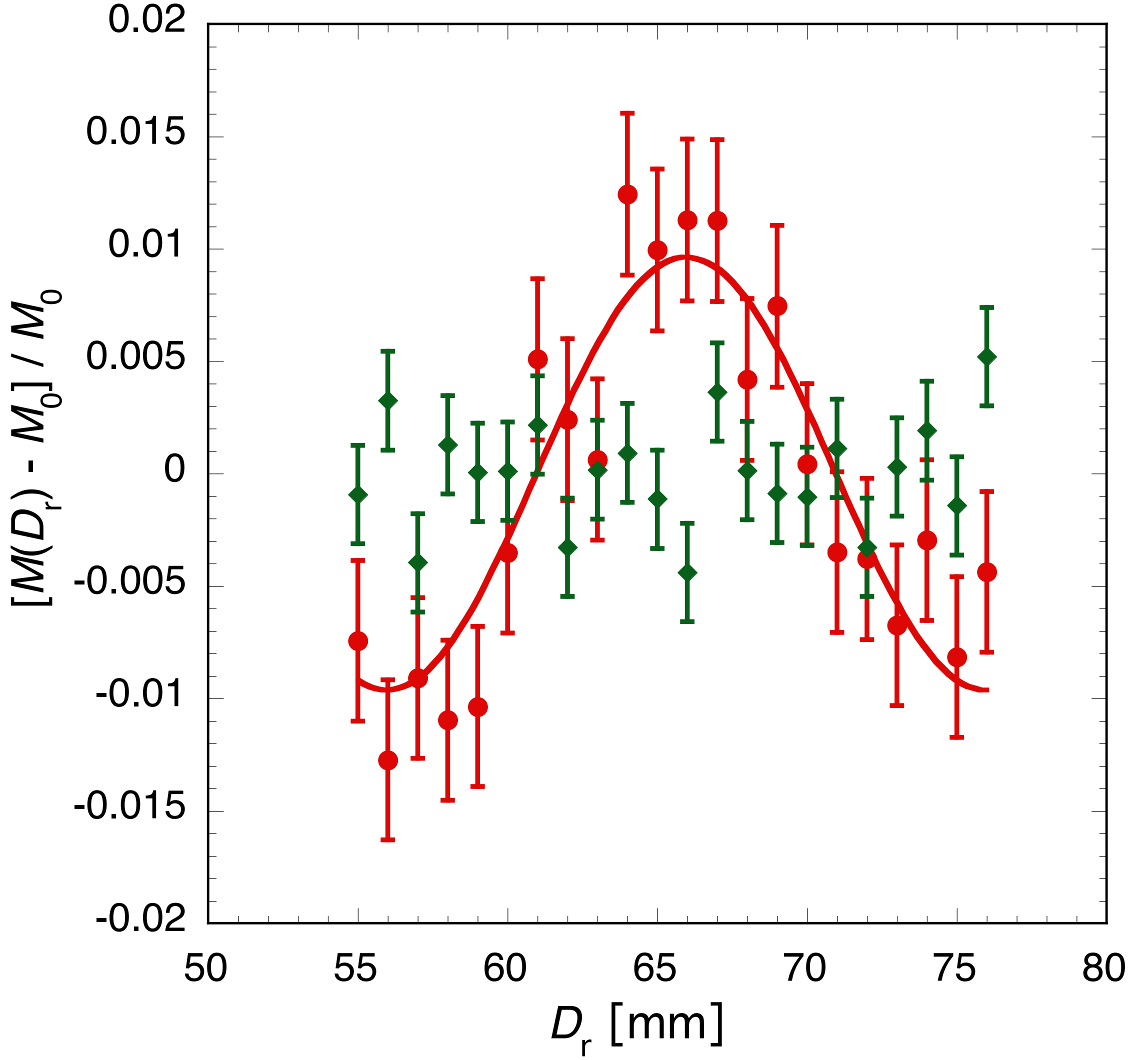
STO PHASE vs. COIL CURRENT



ELIMINATED THE SPIN TRANSPORT ISSUE WITH POLARIZED ^{3}He SPIN FILTERS

*** but with 2 (initial) – 6 (final) times lower count rate**

(even with 80% initial ^{3}He polarization and 300 - 400 h relaxation times)



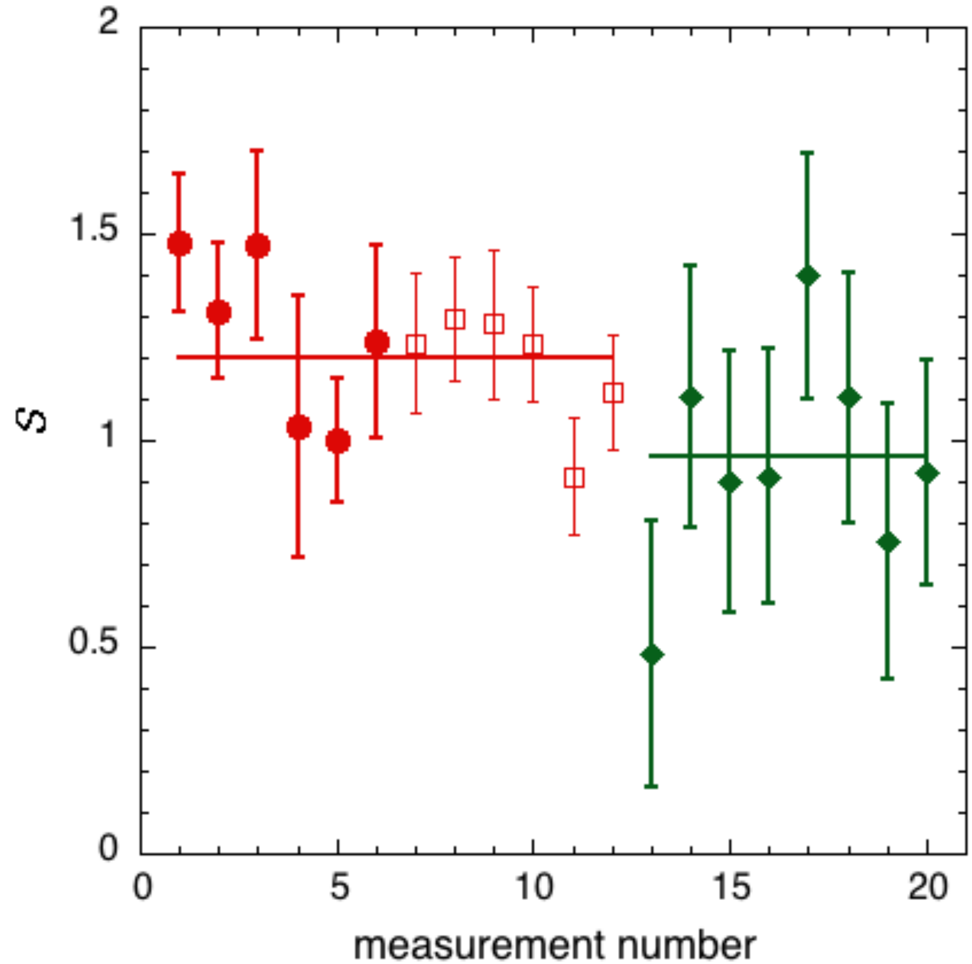
AMPLITUDE OF OSCILLATION AT -0.25% BELOW 17.672 G

Red – supermirrors

solid – permanent magnet

open – longitudinal coil

Green – polarized ^{3}He spin filters



SUMMARY of RESULTS

Supermirrors: S = 1.32 +/- 0.05 (stat) +/- 0.18 (sys)

Spin filters: S = 1.06 +/- 0.12 (stat)

Calculated: S = 0.75 (our crystal)

Finkelstein: S = 0.75 * 1.178 = 0.883 +/- 0.016
(*K.D. Finkelstein, Ph.D thesis, MIT, 1987. "Neutron spin-Pendellosung resonance"*)

Method of multiple spin rotations demonstrated
- but result for observed rotation larger than expected

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