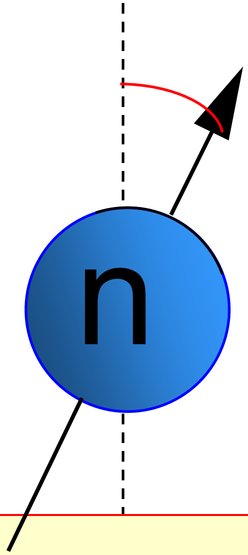

Measuring Parity Violating Neutron Spin Rotation

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Collaboration

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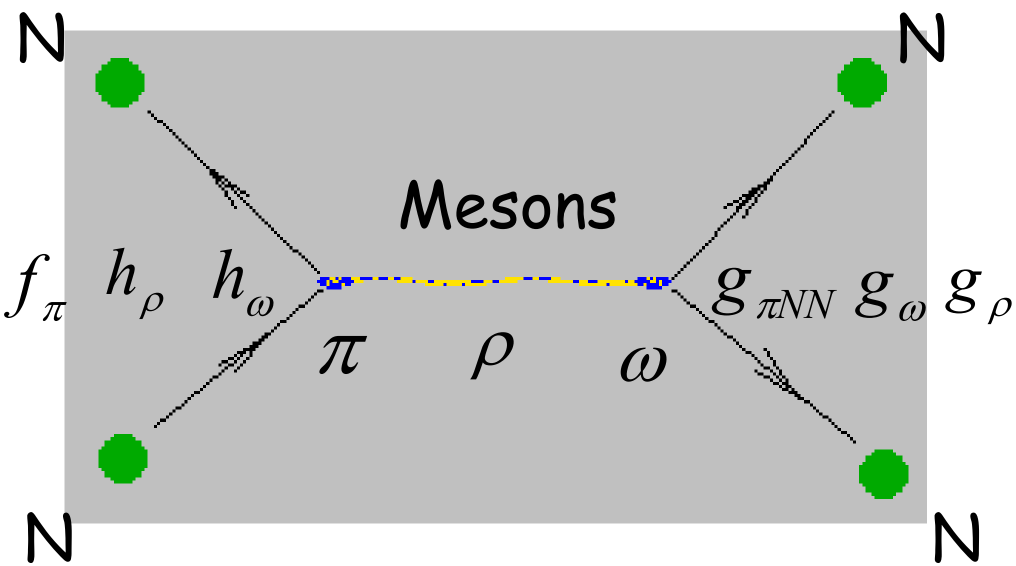
Motivations

Compared to strong interaction, the magnitude of weak interaction is very small. $\sim 10^{-7}$

Direct exchange of short ranged weak vector bosons (W, Z) suppressed by repulsive strong interaction.



In Nucleon-Nucleon (NN) interactions, the weak interaction couplings are not well understood. DDH model (Desplanques et al, 1980)

*Holstein. *Weak Interactions in Nuclei*

Theoretical description

Historically the PV nuclear interaction has been described by the DDH quark model

=> 6 weak meson exchange coupling constants: $f_\pi, h_\rho^0, h_\rho^1, h_\rho^2, h_\omega^0, h_\omega^1$

n-**4**He spin rotation in terms of weak couplings

$$-0.97\left[f_\pi + 0.33h_\rho^0 - 0.11h_\rho^1 + 0.23(h_\omega^0 - h_\omega^1)\right]rad/m$$

*New “Hybrid” Effective Field Theory description is valid for $E_{Lab} < 40MeV$

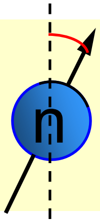
⇒5 dimensionless Danilov parameters (related to the S-P scattering amplitudes: $^1S_0$-$^3P_0$, $^3S_1$-$^1P_1$, $^3S_1$-$^3P_1$ transitions)

⇒and a long-range one-pion exchange parameter (proportional to the PV pion-nucleon coupling constant h^1_π)

*Liu, C.P., 2006, Parity Violating Observables of Two-Nucleon Systems in Effective Field Theory, arXiv: nucl-th/0609078 v1 28 Sep 2006

Low Energy, Few Body Interaction measurements are useful

⇒ Neutron Spin Rotation project



PV Neutron Spin Rotation

Forward scattering amplitude for low-energy neutrons:

$$f(0) = A + B(\vec{\sigma}_n \cdot \vec{S}_N) + C(\vec{\sigma}_n \cdot \vec{k}_n) + D(\vec{S}_N \cdot \vec{k}_n) + E(\vec{\sigma}_n \cdot (\vec{k}_n \times \vec{S}_N))$$

For ^{4}He: $\vec{S}_N = 0$ $\Longrightarrow$ $f(0) = A + C(\vec{\sigma}_n \cdot \vec{k}_n) = f_{PC} + f_{PNC}(\vec{\sigma}_n \cdot \vec{k}_n)$

Index of Refraction of a medium: $\mathrm{n} = 1 + \left(\frac{2\pi}{k^2}\right)\rho f(0)$

Neutron's phase as it passes through the medium:

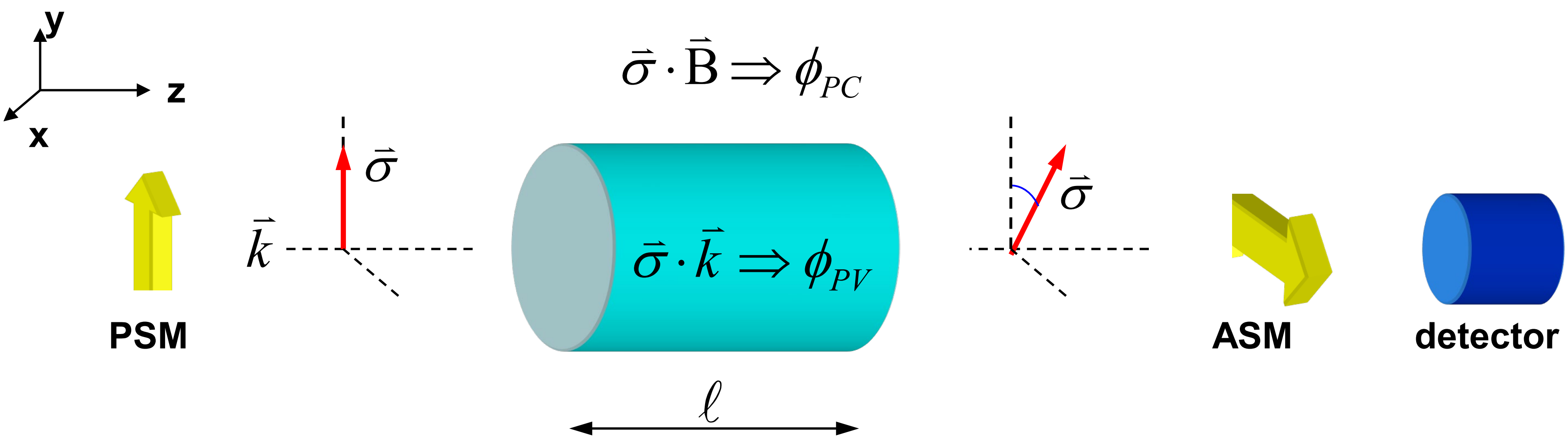
$$\phi = \left(1 + \frac{2\pi\rho}{k^2} f(0)\right) k_n z \quad \Longrightarrow \quad \phi_{PC} = \left(1 + \frac{2\pi\rho}{k^2} f_{PC}\right) k_n z$$

$$\phi_{PNC} = 2\pi\, \rho\, z\, f_{PNC}$$

For a neutron polarized in the +y direction: $\left|\uparrow\right\rangle_y = \frac{1}{\sqrt{2}}\left(\left|\uparrow\right\rangle_z + \left|\downarrow\right\rangle_z\right)$

$$\Longrightarrow \quad \frac{1}{\sqrt{2}}\left(e^{i\phi_{PC}} e^{i\phi_{PNC}}\right)\left|\uparrow\right\rangle_z + \frac{1}{\sqrt{2}}\left(e^{i\phi_{PC}} e^{-i\phi_{PNC}}\right)\left|\downarrow\right\rangle_z$$

PV Neutron Spin Rotation



$$\varphi_{PNC} = \phi_{\uparrow} - \phi_{\downarrow} = 2\,\phi_{PNC} = 4\,\pi\,\rho\, l f_{PNC}$$

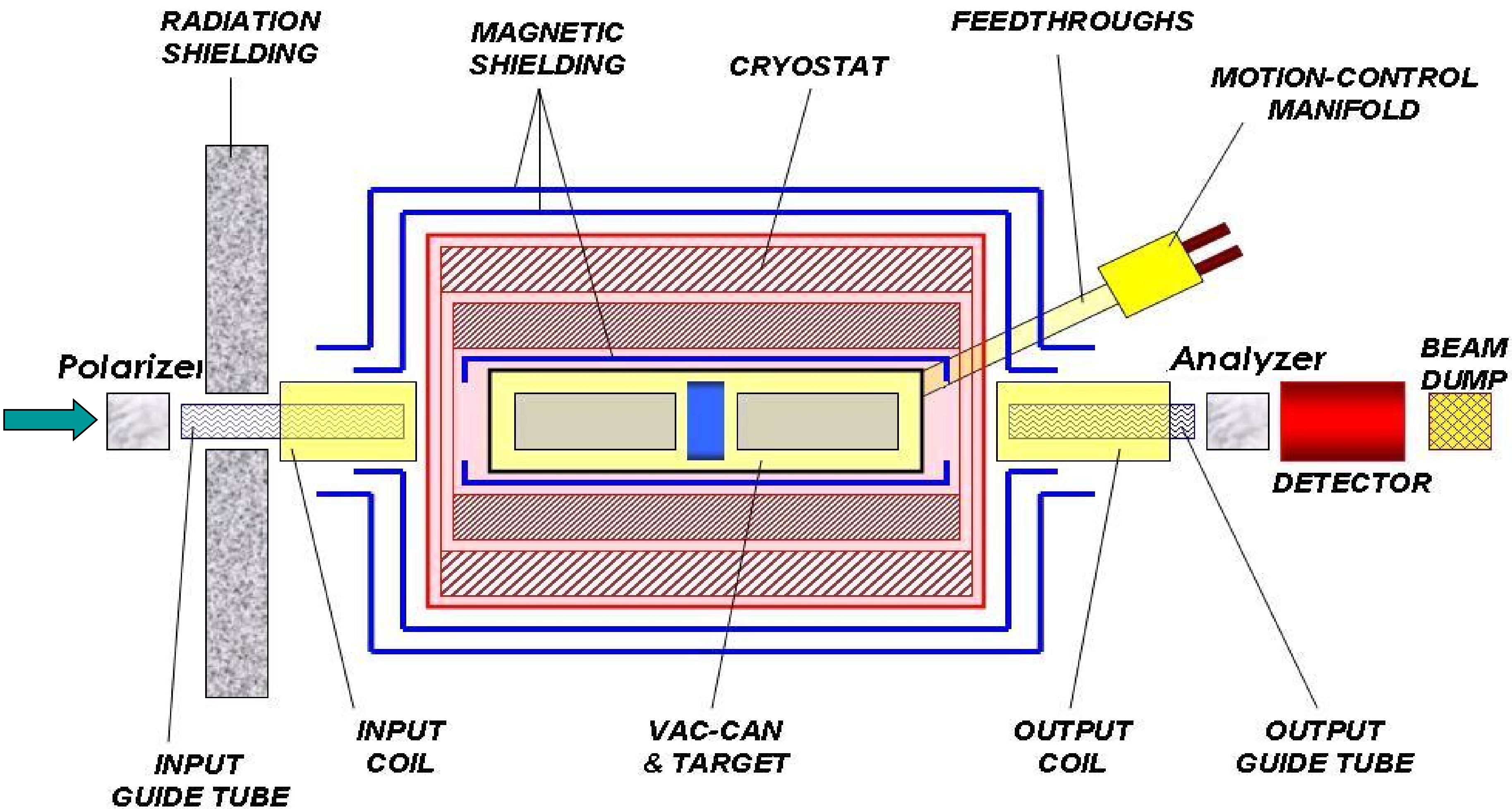
- PV rotation angle / unit length ($d\phi_{PV}/dx$) approaches a finite limit for zero neutron energy:

  $d\phi_{PV}/dx \sim 10^{-6}$ rad/m based on dimensional analysis

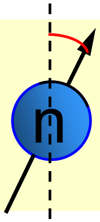
  <u>$3\mathrm{x}10^{-7}$ rad/m goal in n+^{4}He</u>

- $d\phi_{PC}/dx$ (due to B field) can be much larger than $d\phi_{PV}/dx$, and is v_n dependent

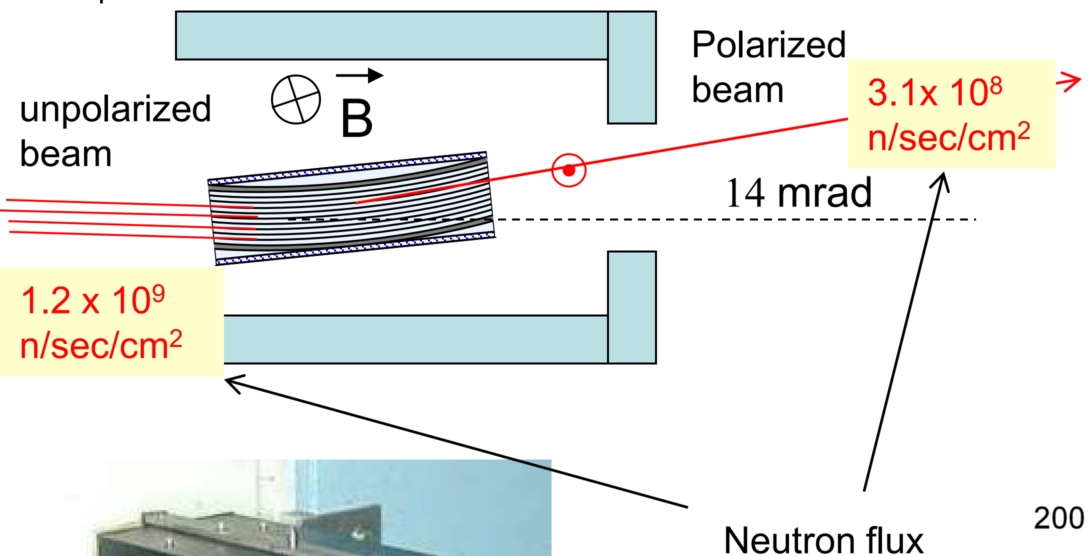
Cross section of Spin Rotation Apparatus



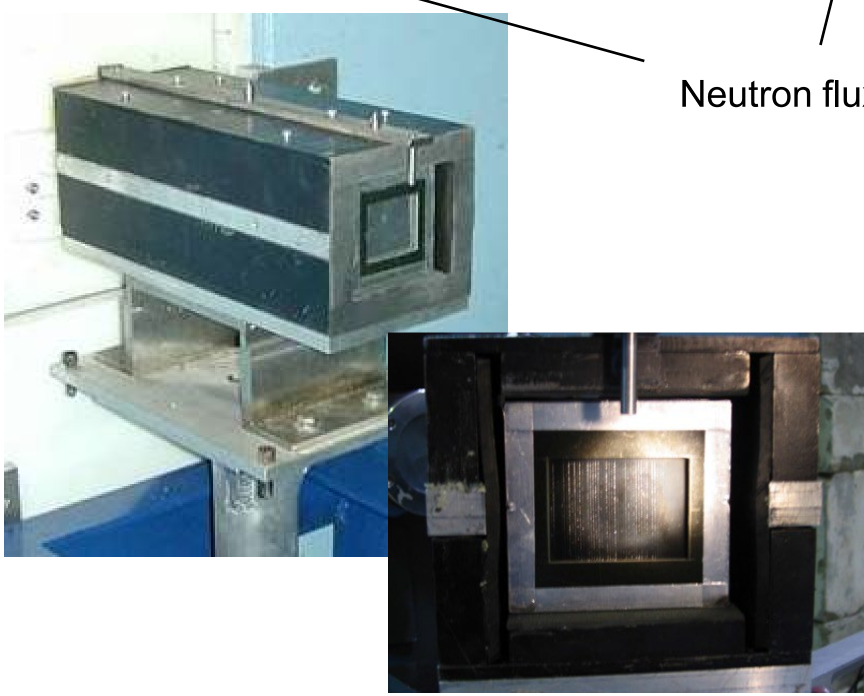
Side View

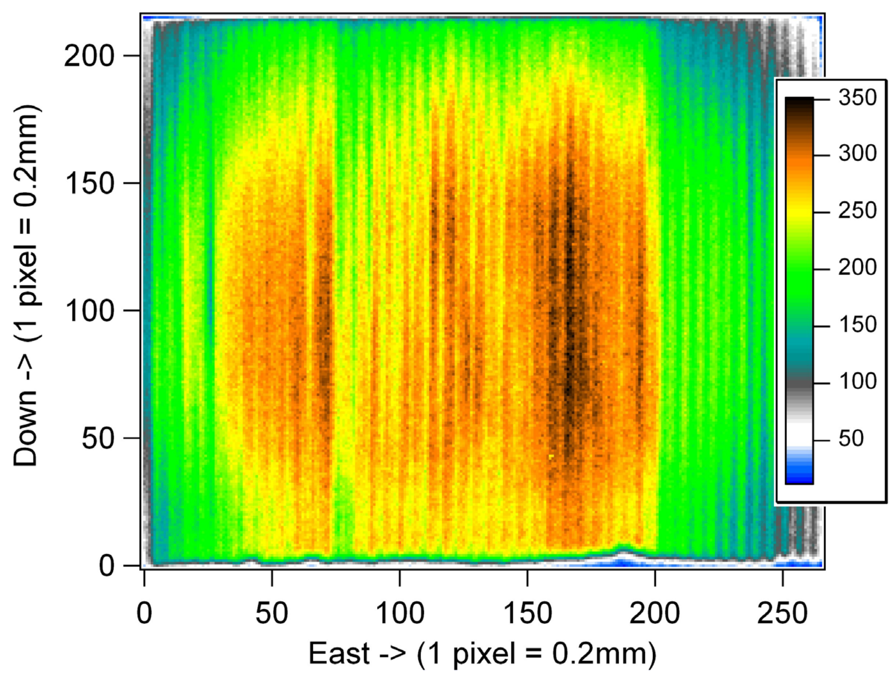


Polarizing Super Mirror

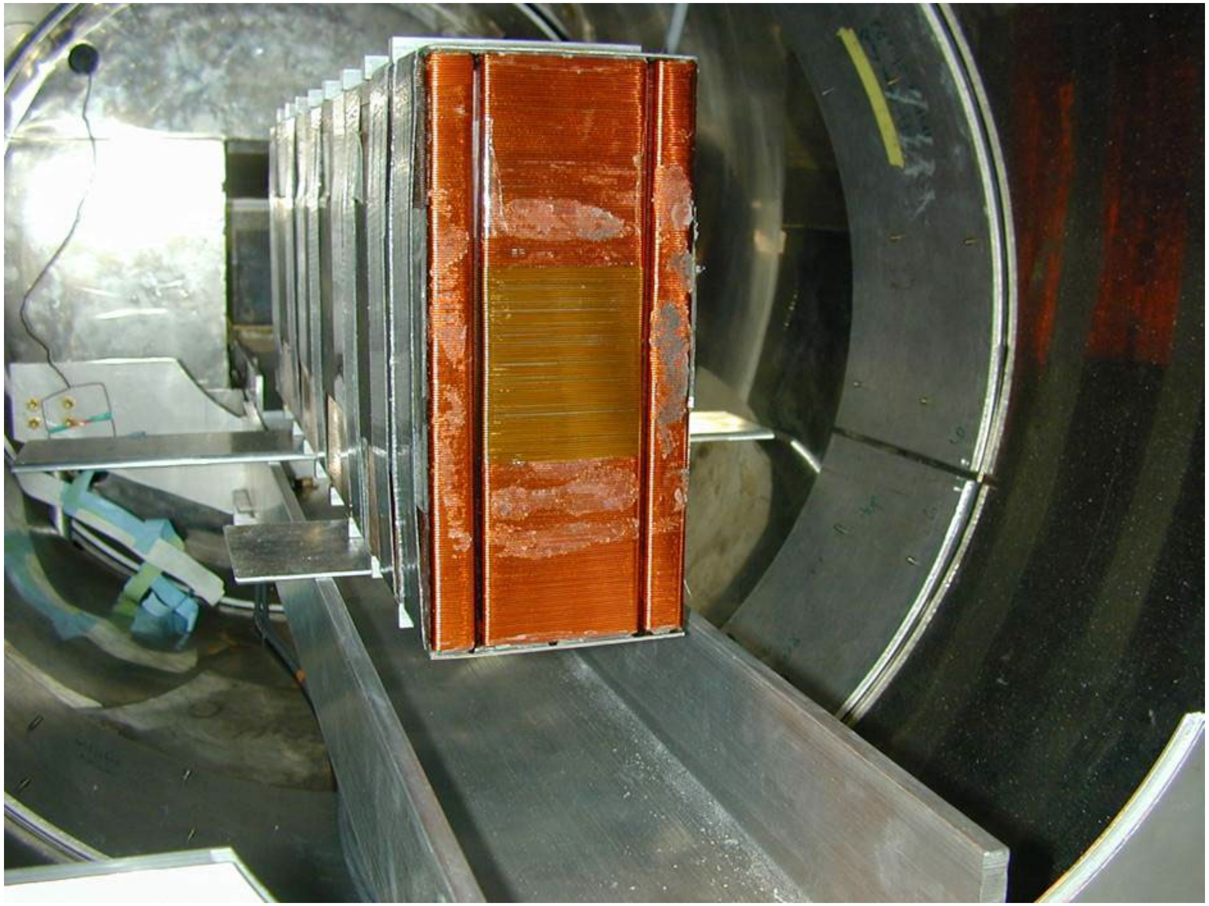


- spin-dependent scattering from magnetized mirrors
- Alternating layers of magnetic surface (cobalt) and absorptive layer (titanium and gadolinium); 1mm separation; Placed in 300 G permanent box.
- Typical polarization: 98%; transmission: 25%



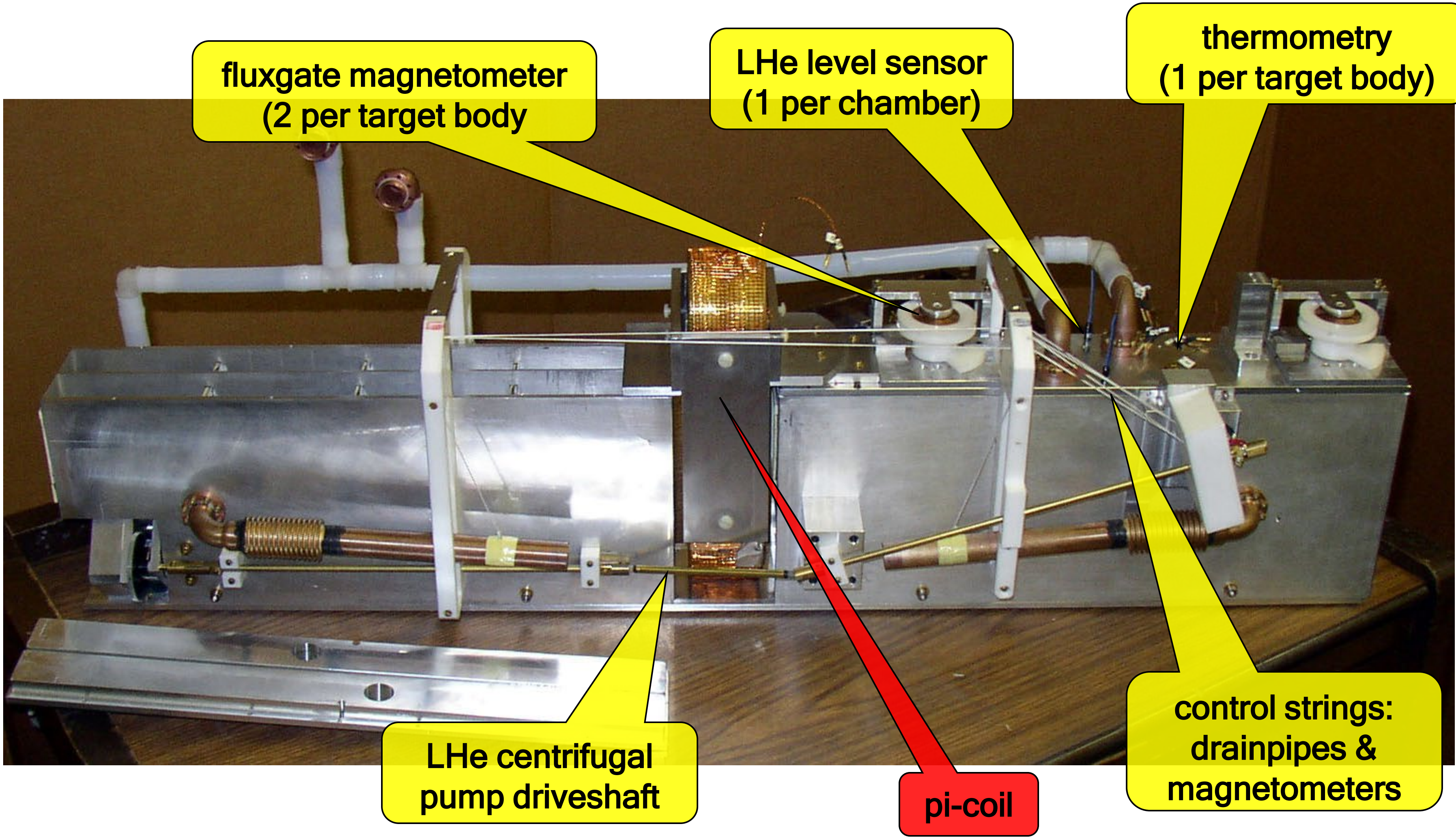


Input Coil

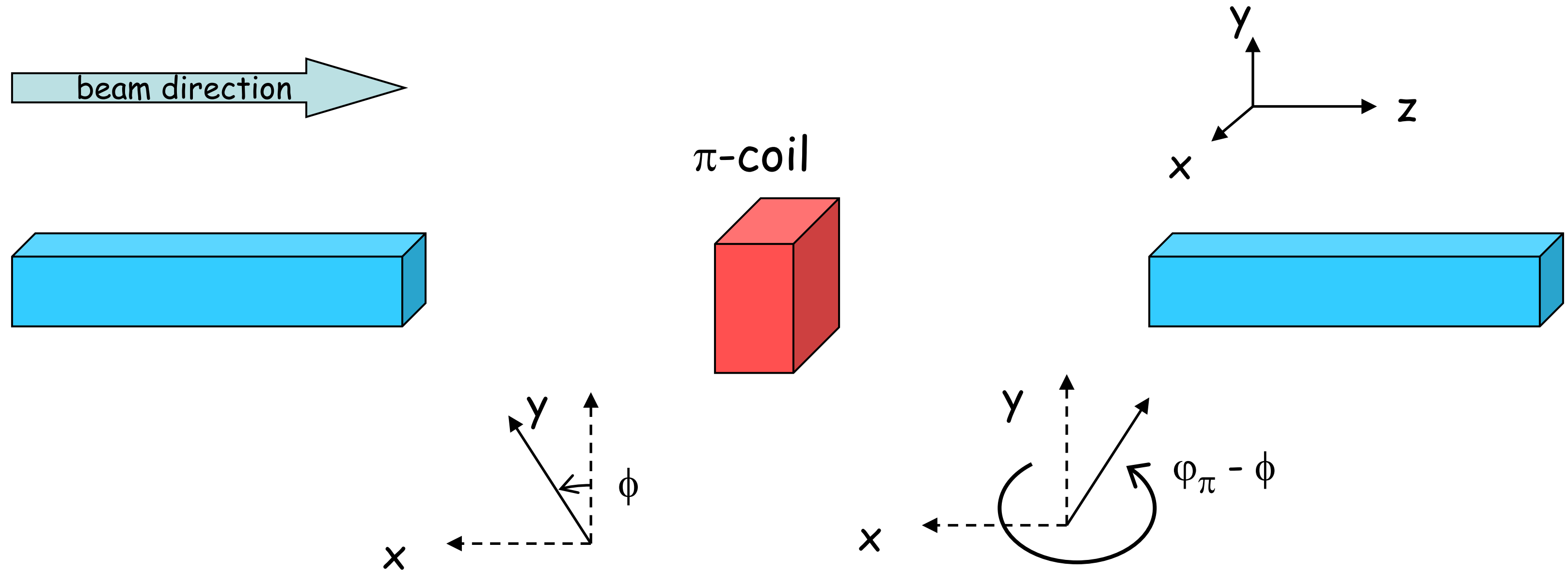


Beam Guide

Target Design



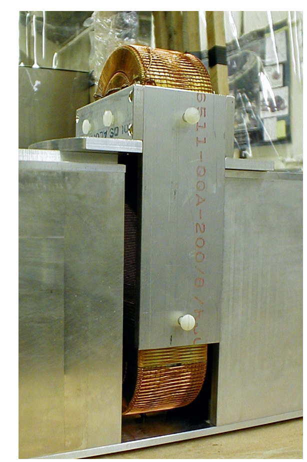
π-Coil



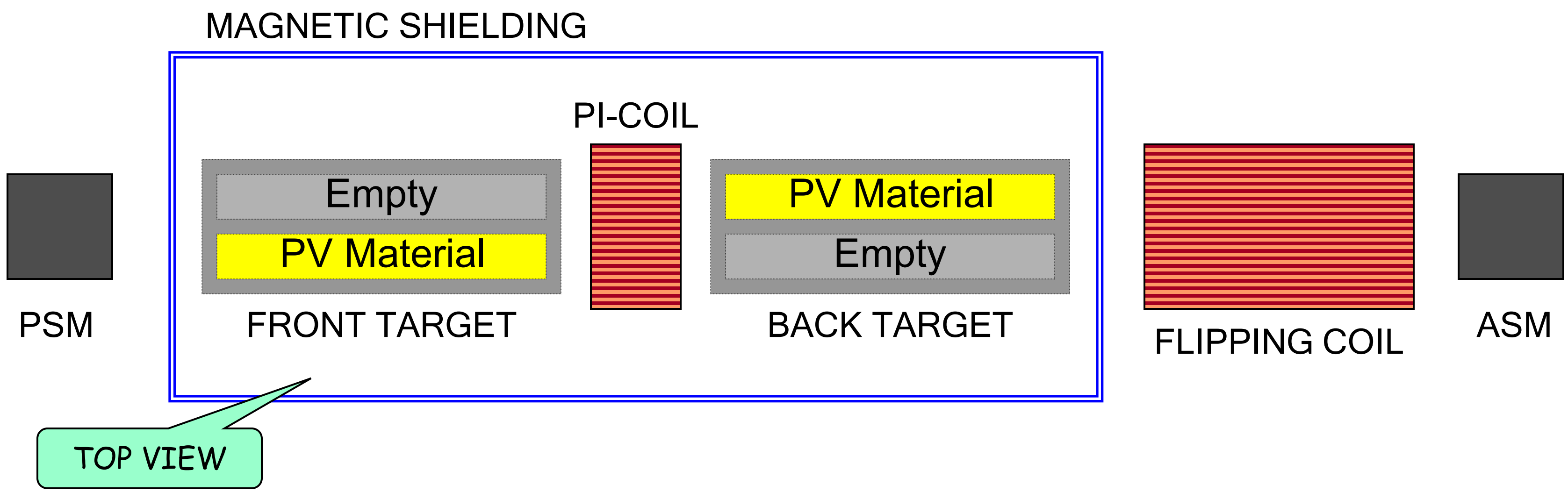
- a rectangular coil that produces a vertical magnetic field in the path of the beam

- wound to prevent field leakage beyond the coil

- designed so that the spin of a typical cold neutron will precess a total of π radians over the path of the coil

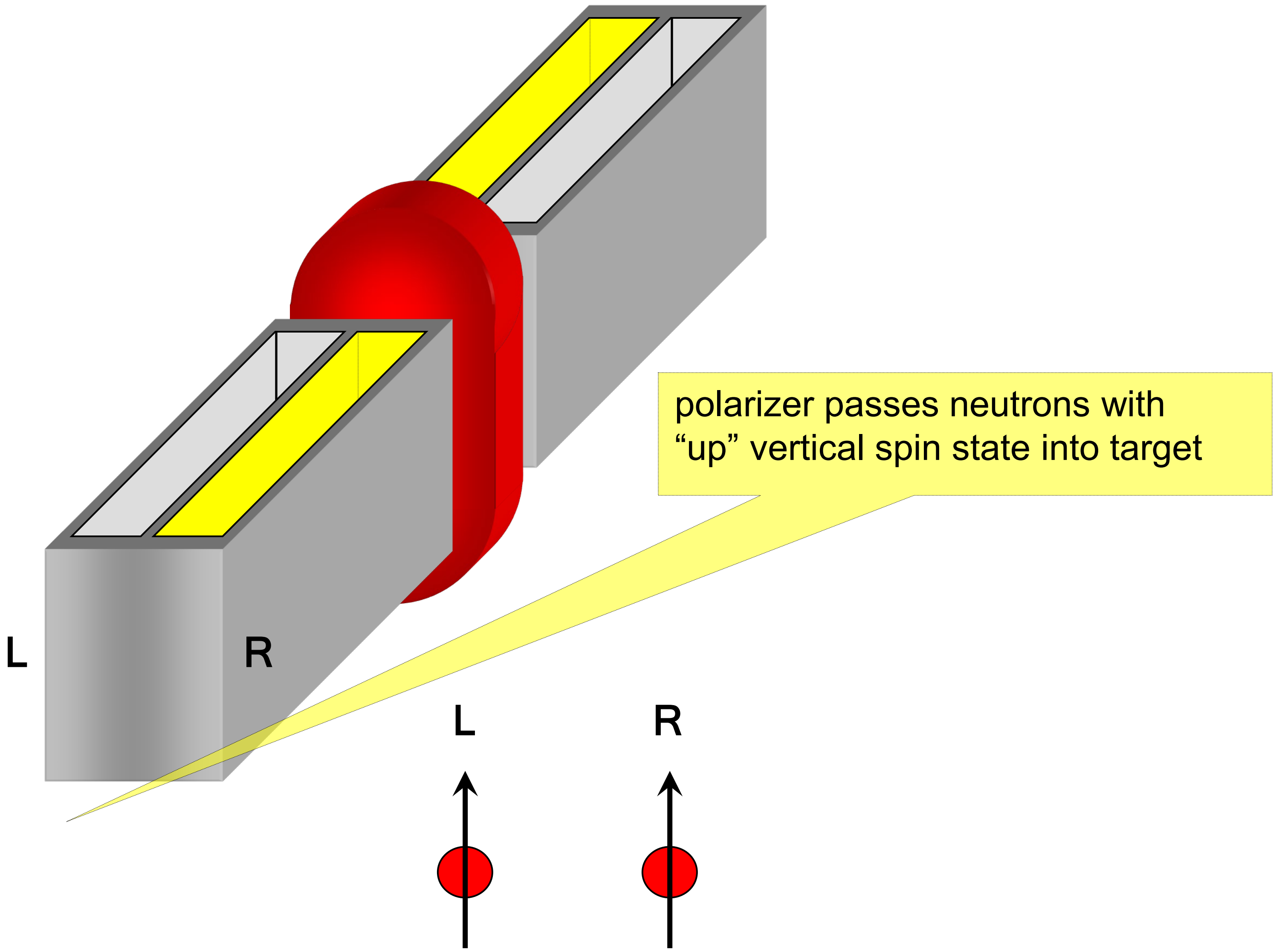


Polarimeter Design



- Moving LHe target about pi-coil isolates ϕ_{PV} from ϕ_{PC} signal that can be measured as an asymmetry in beam intensity between target states

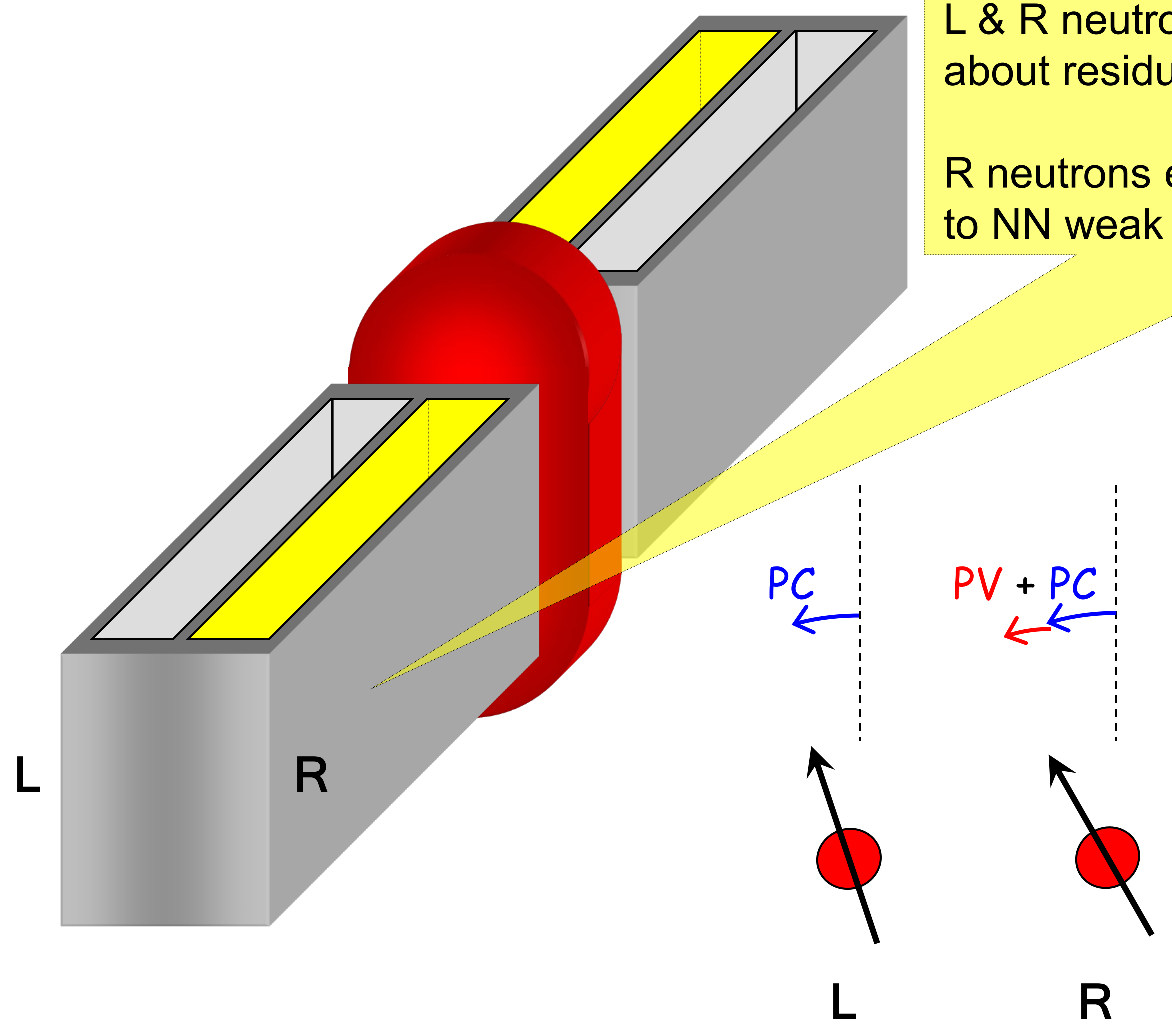
Flight of the Neutron



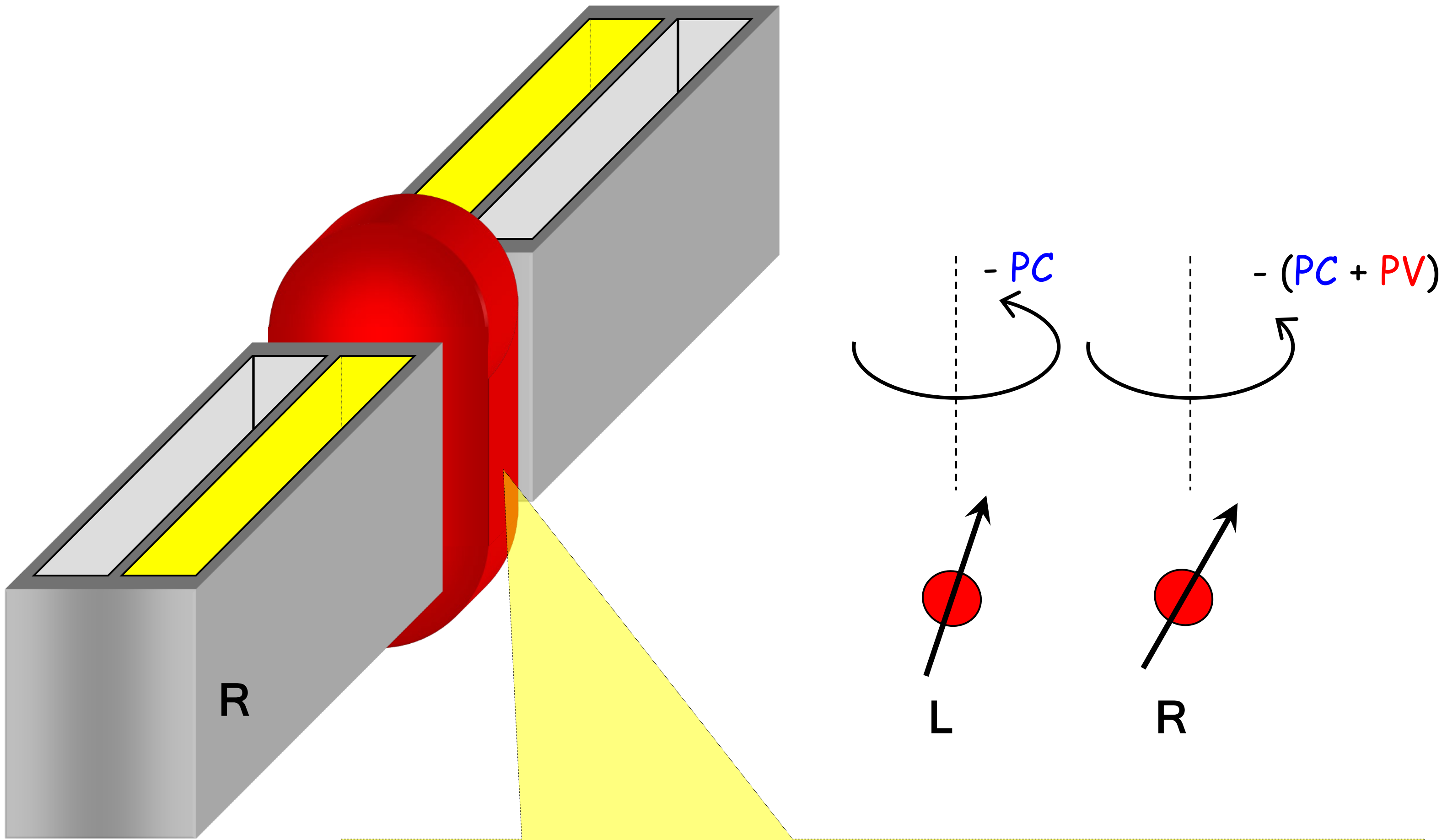
Flight of the Neutron

L & R neutrons experience Larmor precession about residual B-fields

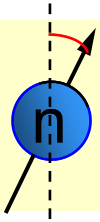
R neutrons experience additional rotation due to NN weak interaction



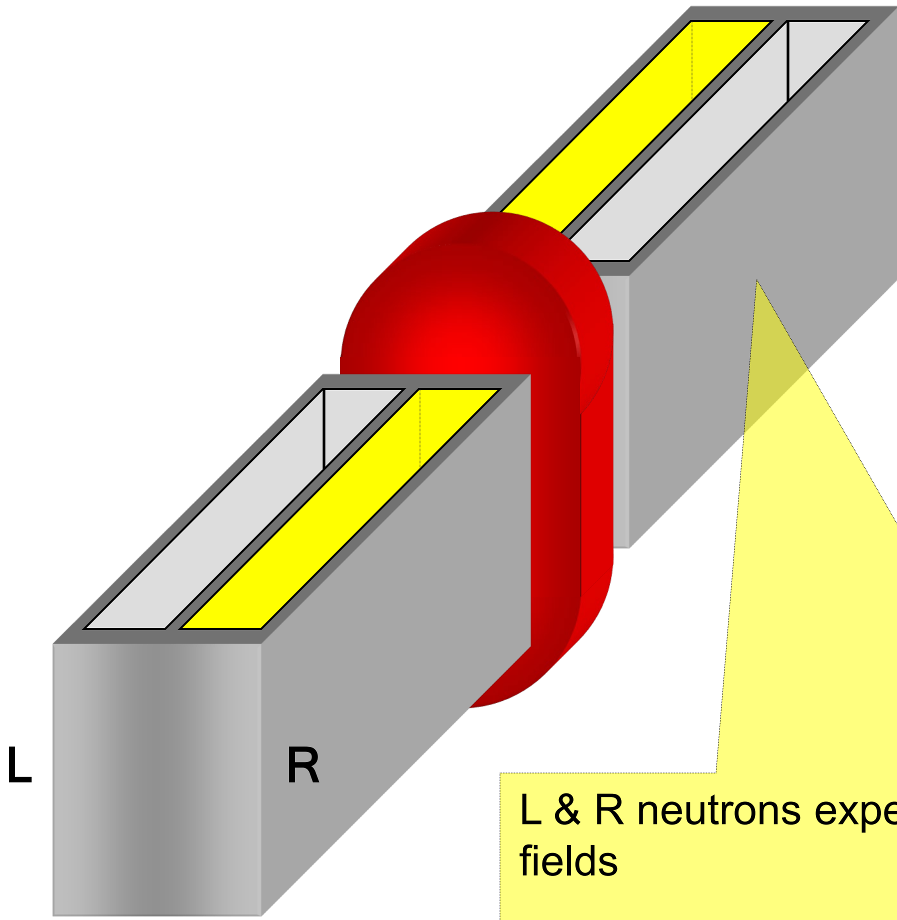
Flight of the Neutron

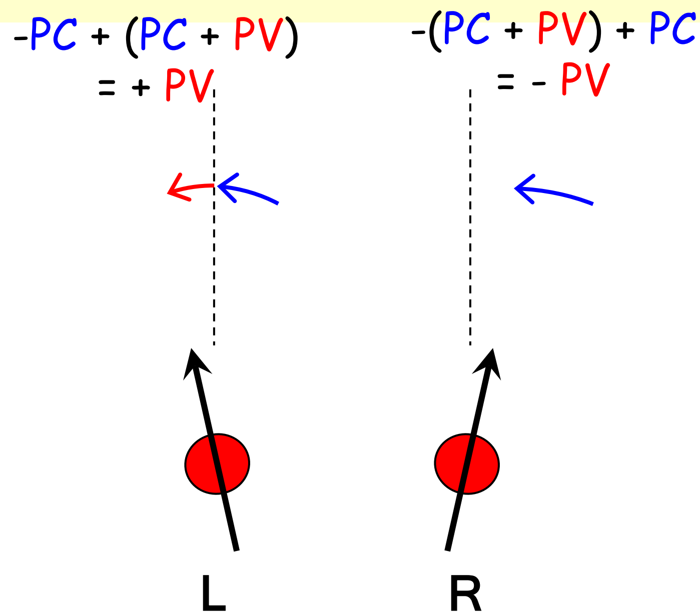


Pi-Coil precesses neutron spin 180° about vertical axis



Flight of the Neutron

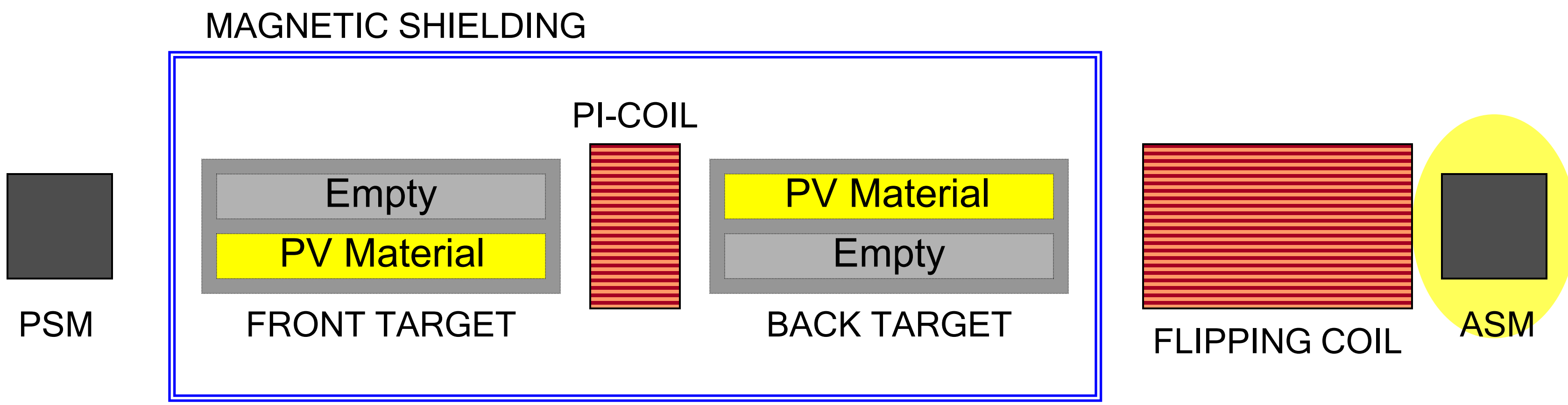




L & R neutrons experience Larmor precession about residual B-fields

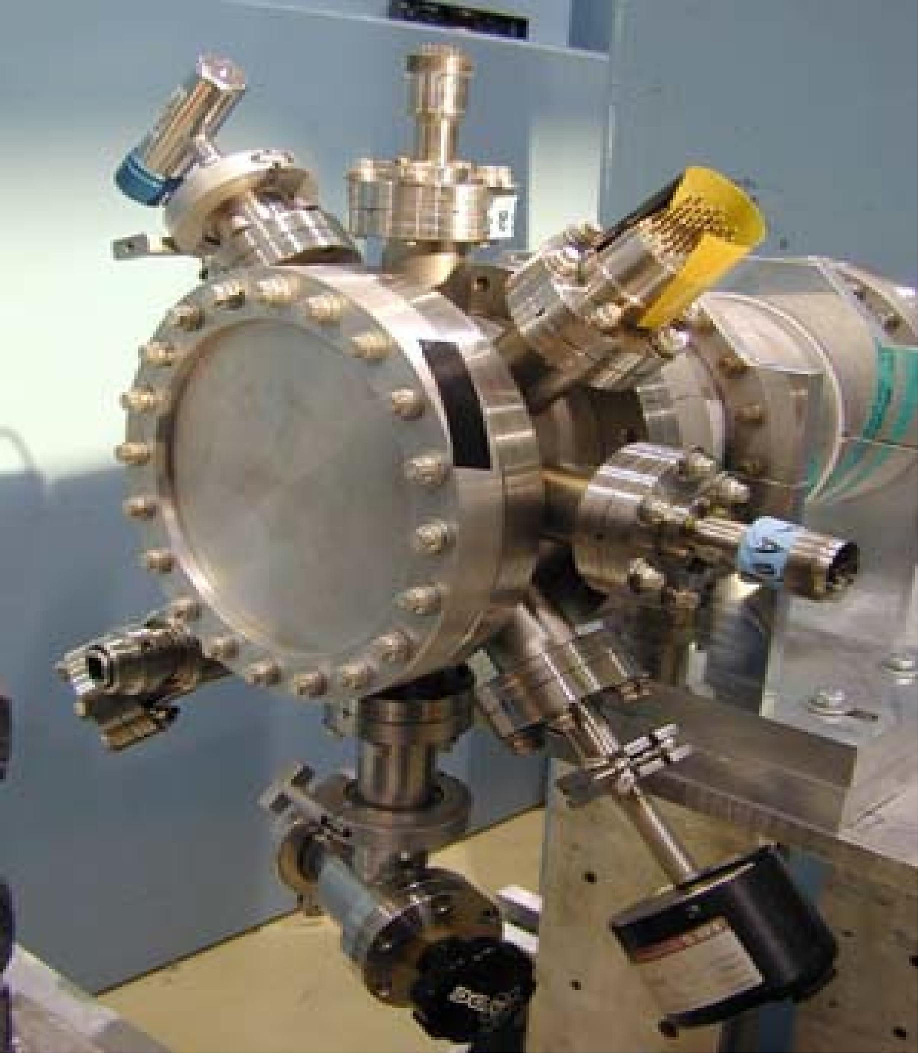
L neutrons experience additional rotation due to NN weak interaction with LHe

Flight of the Neutron

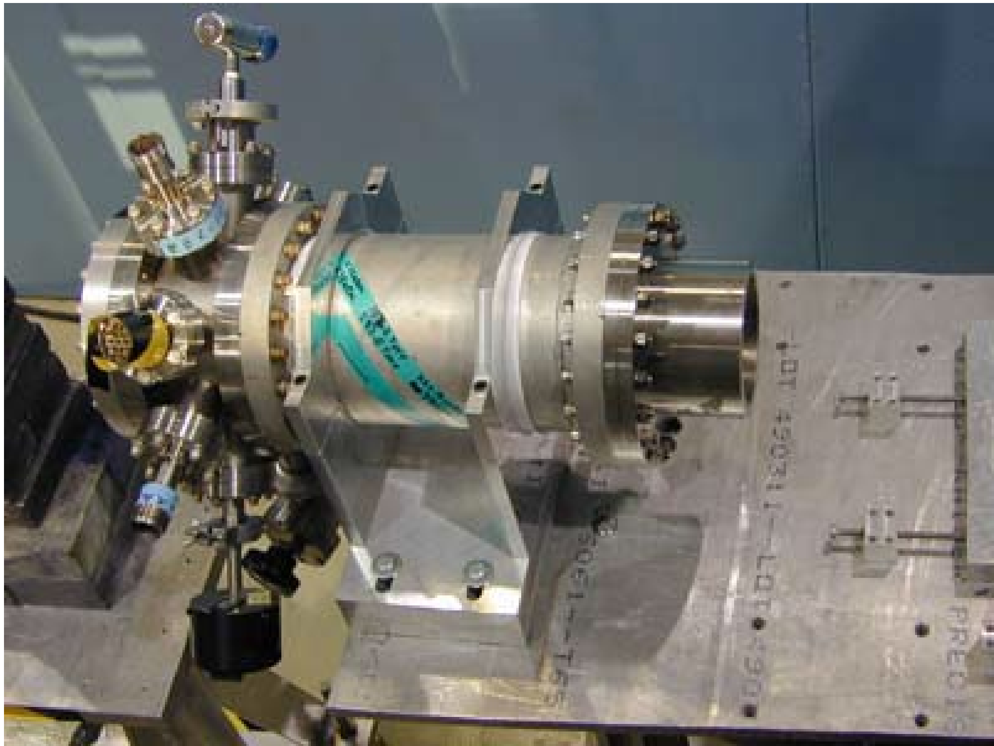


- Neutron spins are either parallel or antiparallel to the ASM
- Parallel spins pass through ASM and enter ^{3}He Ion Chamber detector
- Asymmetry of count rate for flipping coil states & target states yields spin rotation

$$\sin\varphi = \frac{N_+ - N_-}{N_+ + N_-}$$



Looking from downstream End.



Top view.

Segmented Ion Chamber Detector

- High flux n beam, current mode detector
- Not sensitive to gammas
- High efficiency, low noise
- Separate PV rotation (**v** independent) from NPV rotation (**v** dependent)

$$n + {}^{3}He \rightarrow p + {}^{3}H + Q$$

$$(Q = 763.75 \text{ keV})$$

$$\left.\begin{array}{l} 1 \text{ neutron} \rightarrow 2.5\times10^{4} \text{ ion pairs} \\ e = 1.6\times10^{-19} C \end{array}\right\} \rightarrow 3.84\times10^{-15} C/\text{n};$$

So for a current of $x(A)$:

$$\frac{x\ (C/s)}{3.84\times10^{-15}\ (C/\text{n})} = 2.6\times10^{14}\cdot x\ (\text{n}/s)$$

Layout (4 segmentations)

Graph by: Chris S. Blessinger