Pulsed Cold Neutron Beam Polarimetry for the

NPDGamma Experiment

UNIVERSITY OF MANITOBA

U of Manitoba
Subatomic Physics Club
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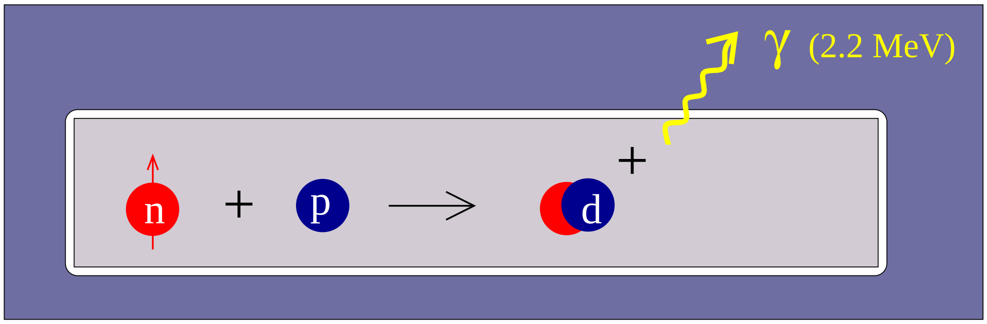
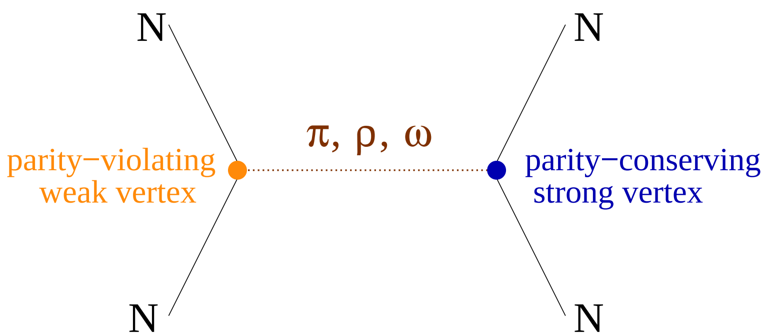


The meson exchange model of the
weak interaction between nucleons:



A full quantitative description of this model has not been completed.

NPDGamma: Measure the **parity-violating asymmetry** A_γ in order to determine the **pion-nucleon weak coupling constant** f_π:

$$A_\gamma \approx -0.11 f_\pi \text{ [1]}.$$

The NPDGamma apparatus is tested and delivers the accuracy required to measure the cleanly interpretable but small ($A_\gamma \approx -5 \times 10^{-8}$ expected) effect from a two-body system.

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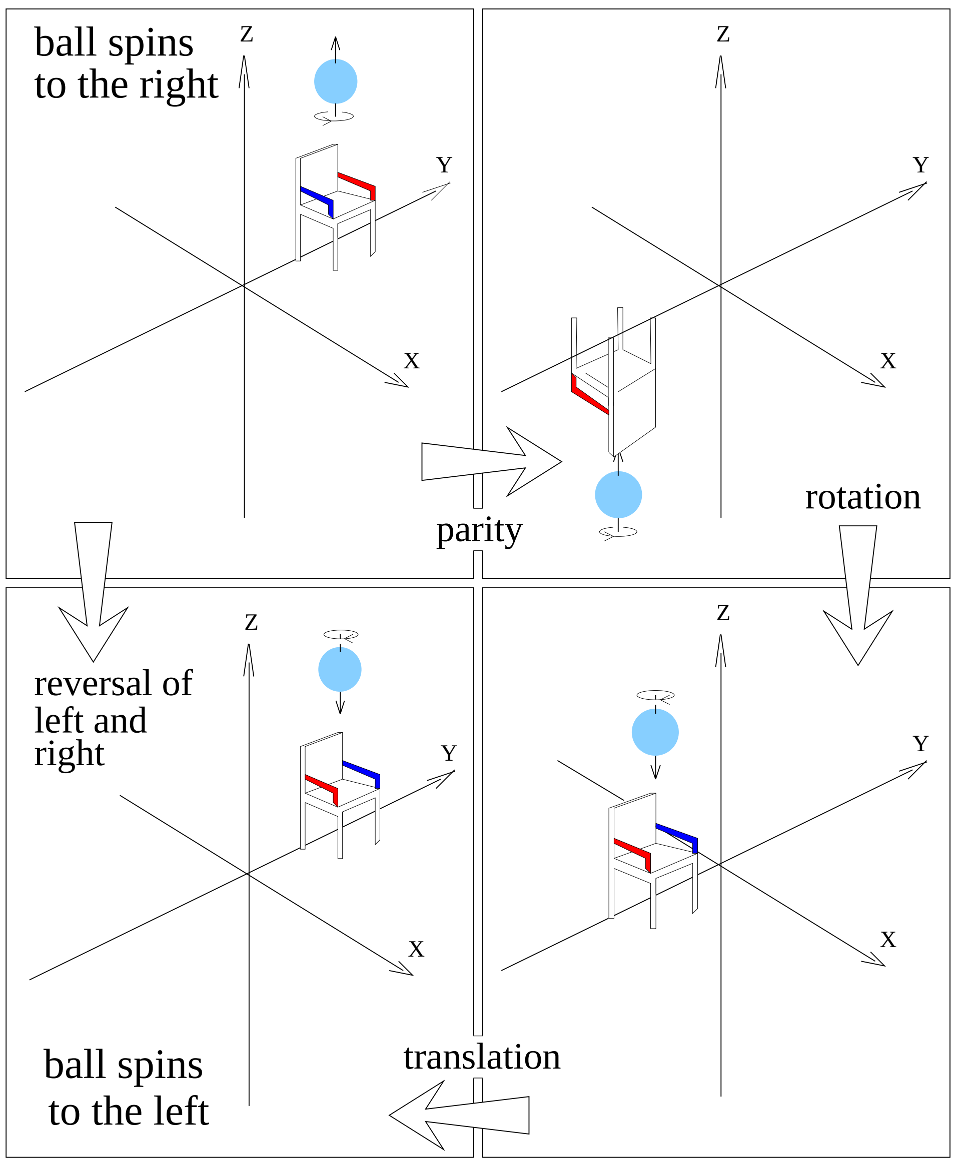
[1] R. Schiavilla, J. Carlson and M. Paris, Physical Review C 67, 032501 (2003).

The parity transformation (P):

$$x \to -x \quad ; \quad y \to -y \quad ; \quad z \to -z$$

For experimental purposes, a parity reversal is equivalent to a reversal of left and right, which includes a reversal of angular momentum.

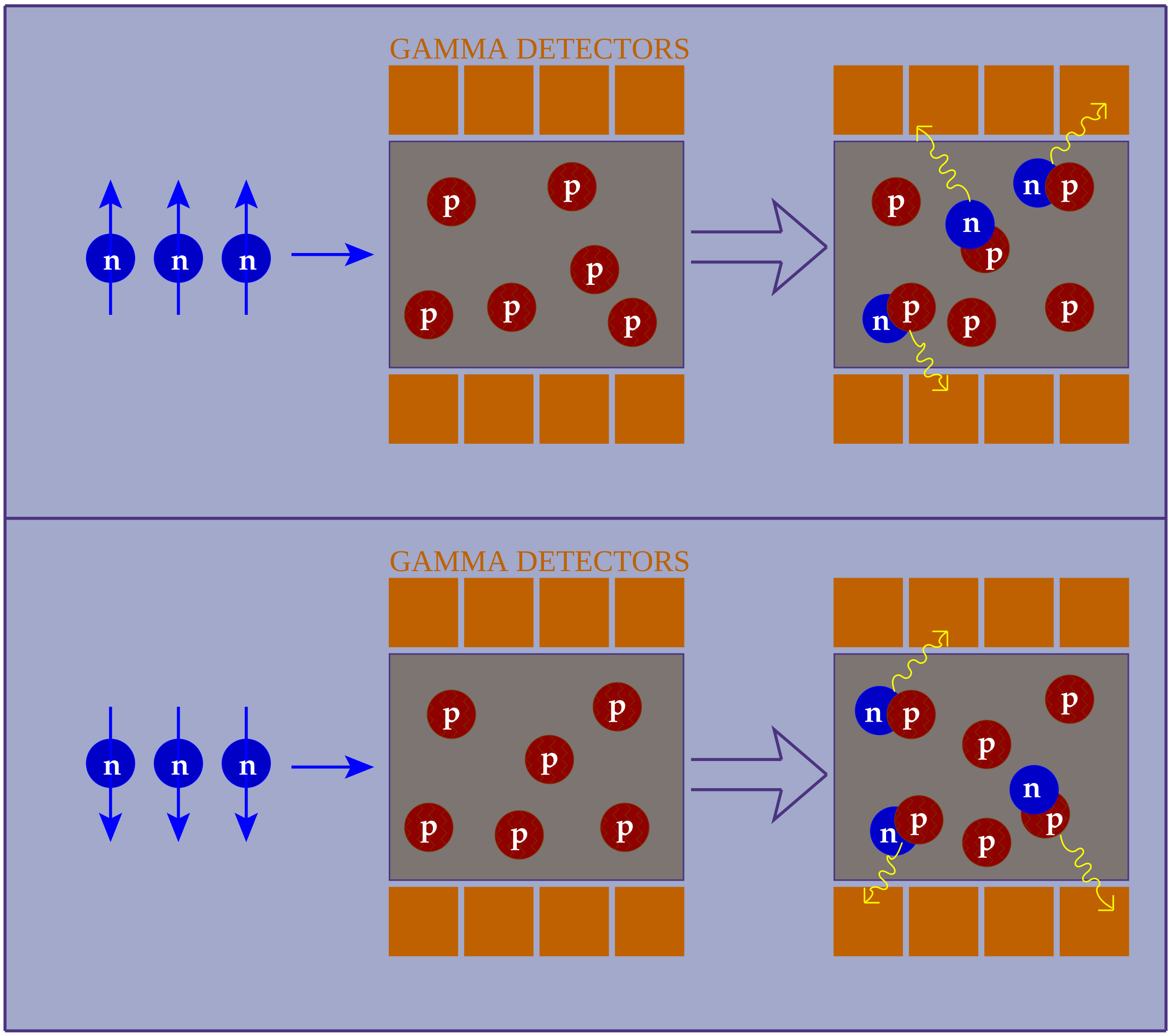


The weak interaction is the only interaction known to violate parity.

To isolate the weak force use a polarized beam.

The NPDGamma reaction

$$\vec{n} + \text{p} \rightarrow \text{d} + \gamma \ \ (2.2 \text{ MeV})$$

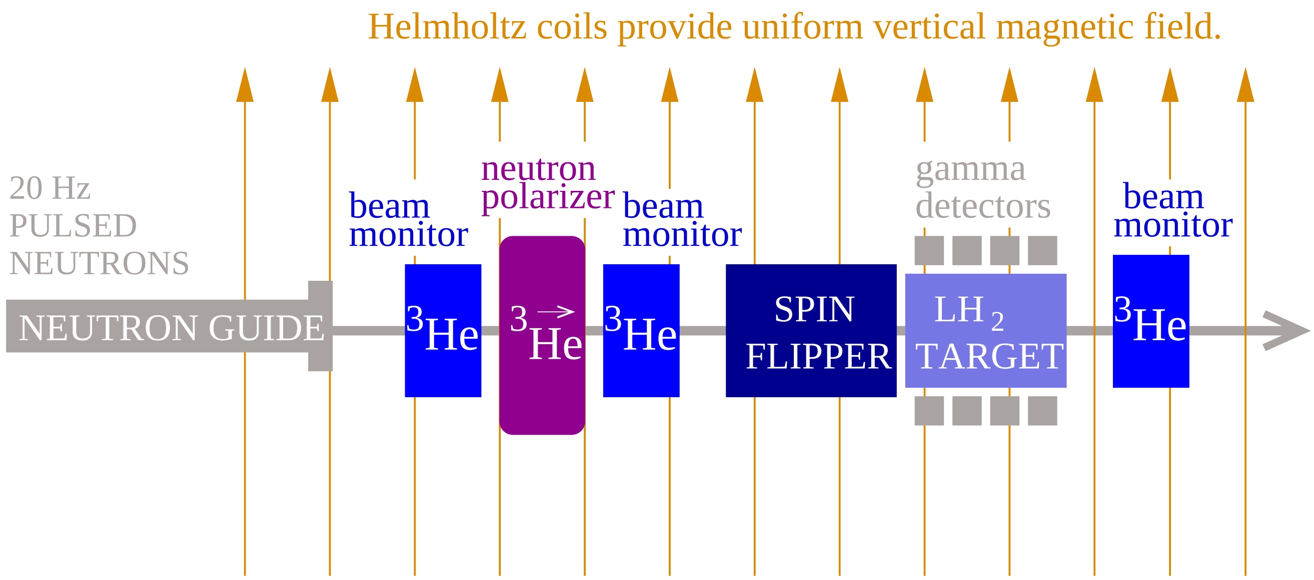


$$A_\gamma = \frac{1}{P_n}\frac{N_{up}-N_{down}}{N_{up}+N_{down}}$$

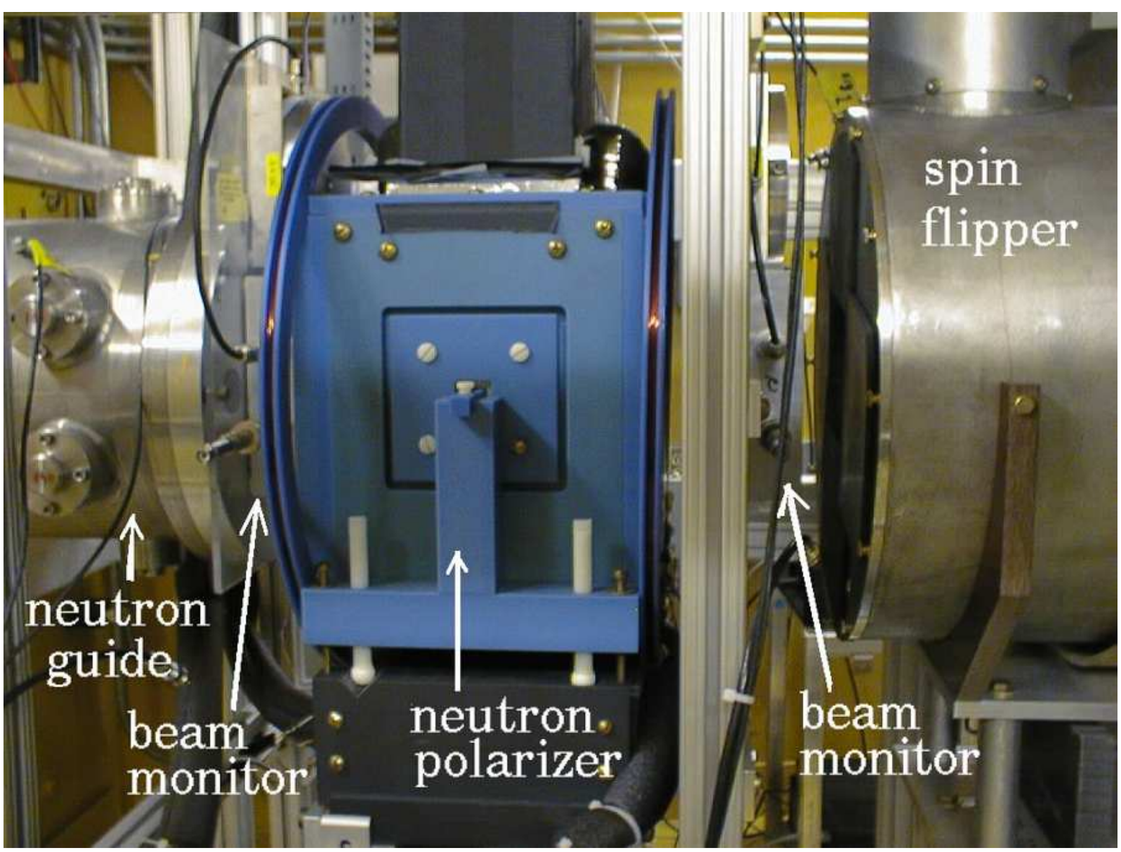
$$P_n = \text{neutron polarization} = \frac{n_{up}-n_{down}}{n_{up}+n_{down}}$$

N = number of gammas
n = number of neutrons

The NPDGamma Apparatus

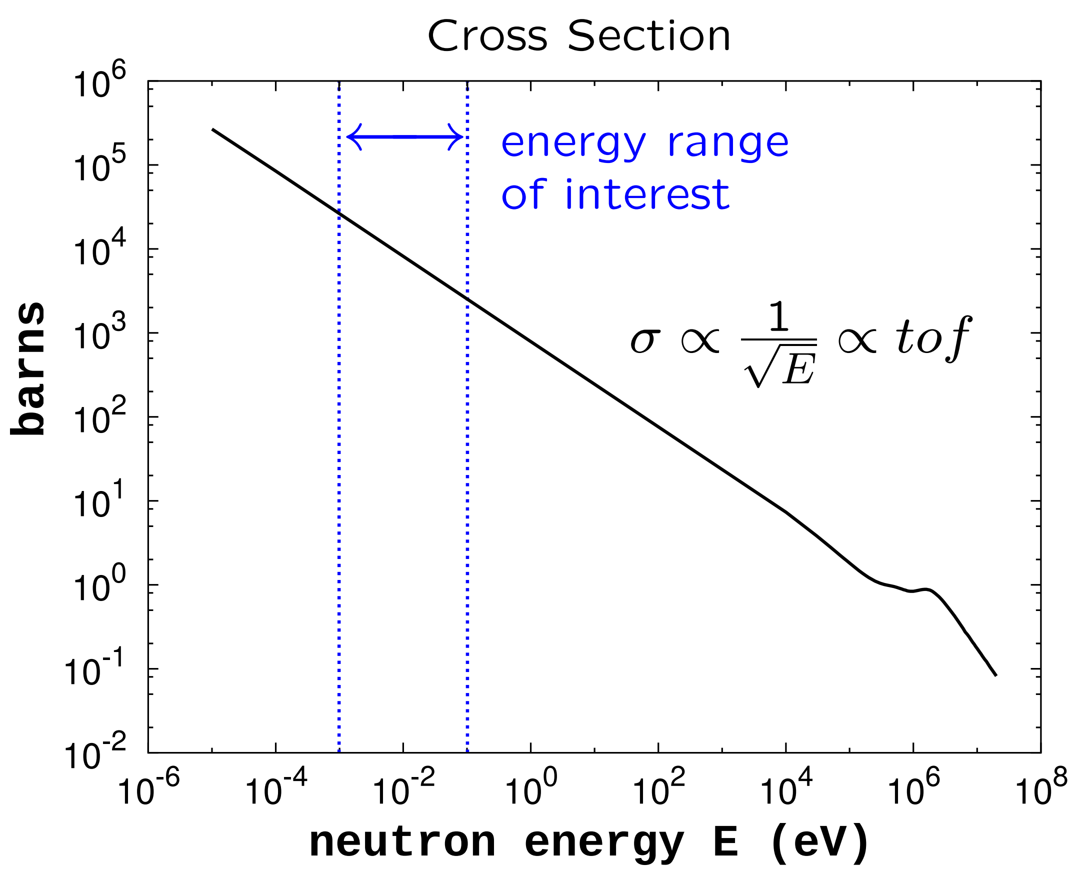


- LH_2 moderator slows neutrons (peak at 9 meV = 3 Å)
- Frame overlap chopper prevents pulse overlap
- Pulsed source provides correspondence between neutron energy and time of flight.



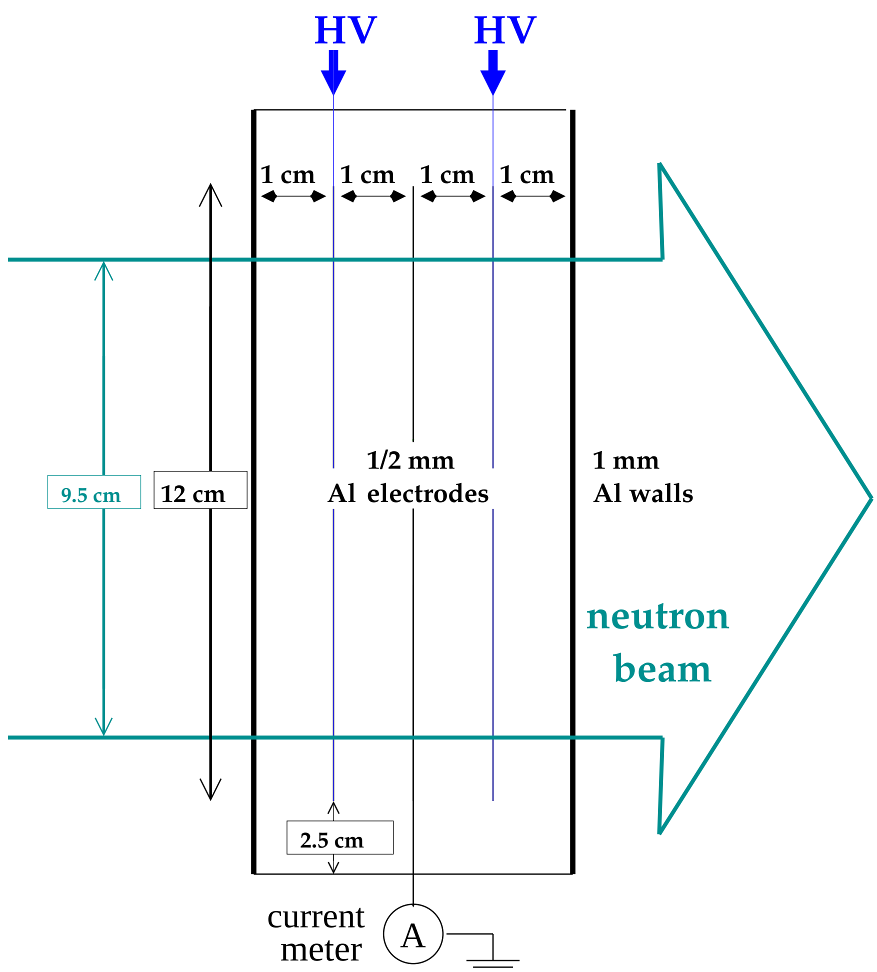
^{3}He **has a strong affinity for neutrons.**

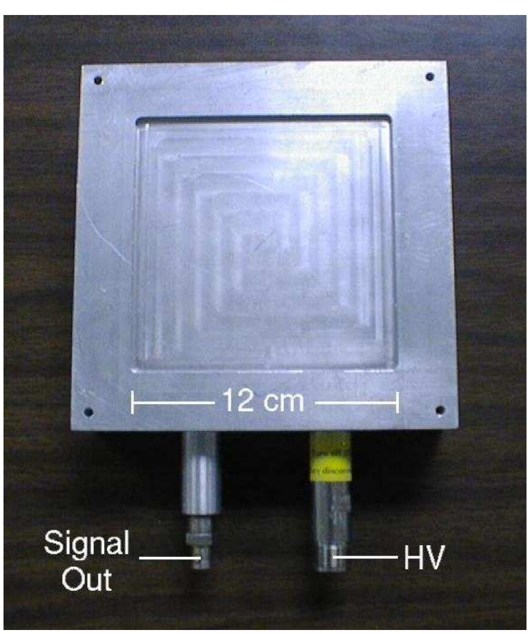
$$n + {}^3He \rightarrow p + {}^3H + 764 \text{ keV of KE}$$



The NPDGamma Beam Monitors

Primary function: To provide a signal proportional to the rate of neutrons passing through.





Gas mixture:

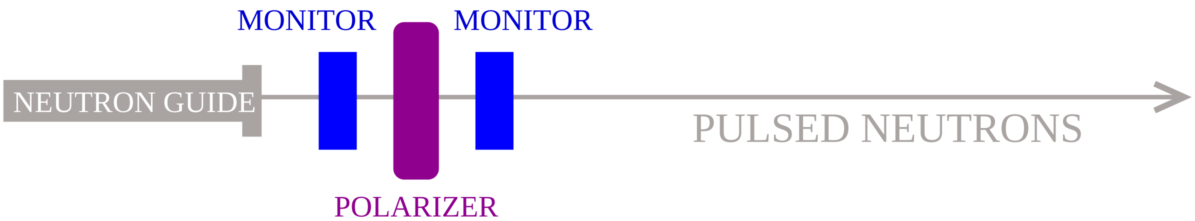
- $\frac{1}{2}$ Atm (^{3}He + ^{4}He)
- $\frac{1}{2}$ Atm N_2

Amount of ^{3}He depends on monitor's purpose

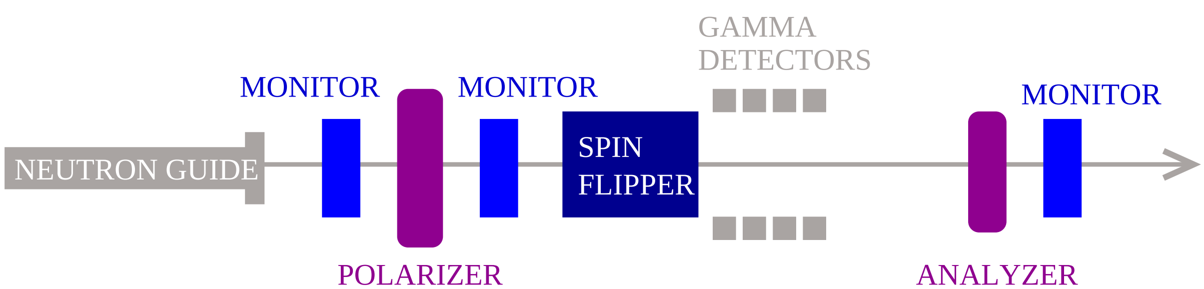
Uses of the NPDGamma Beam Monitors

Until present:

- Monitor **neutron flux.**
- Measurement of **beam polarization:**

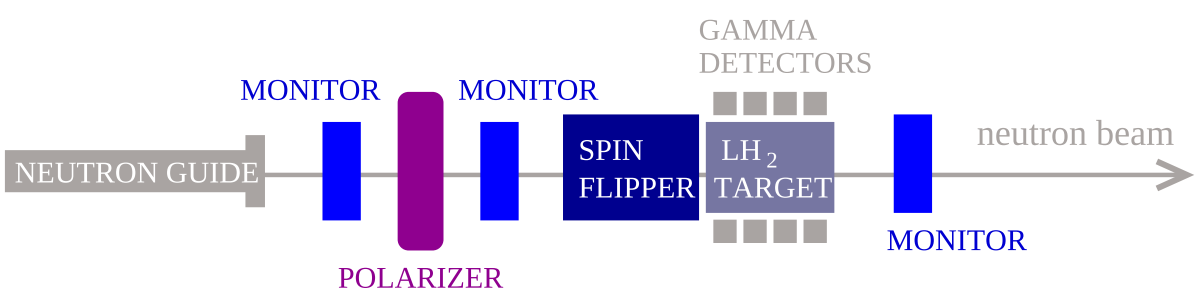


- Commissioning of the **RF spin flipper:**

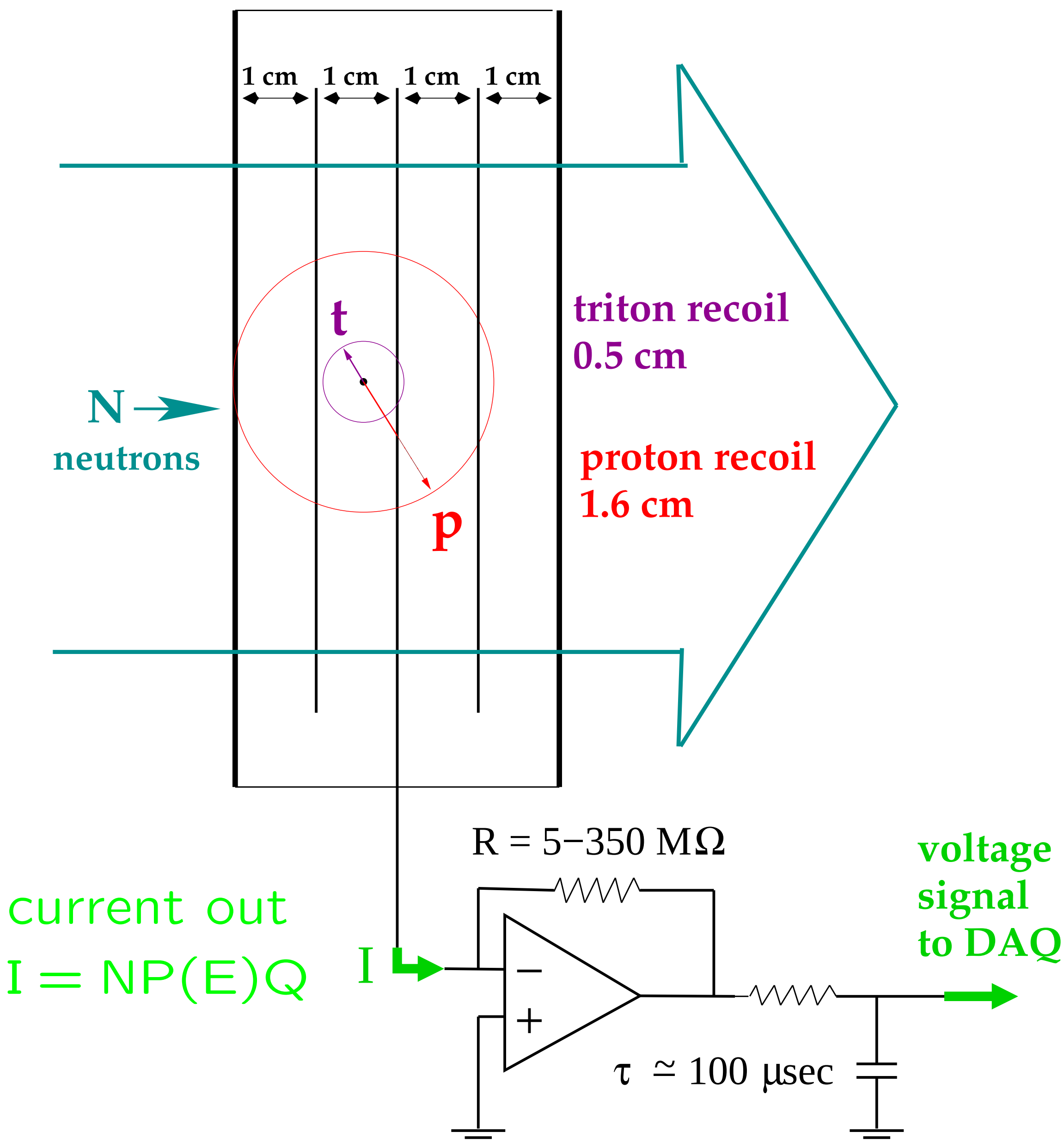


In the future:

- Measurement of the **ortho-para ratio** of the **LH_2 target:**



Beam Intensity Measurement



P(E): known neutron capture probability

increases with neutron tof

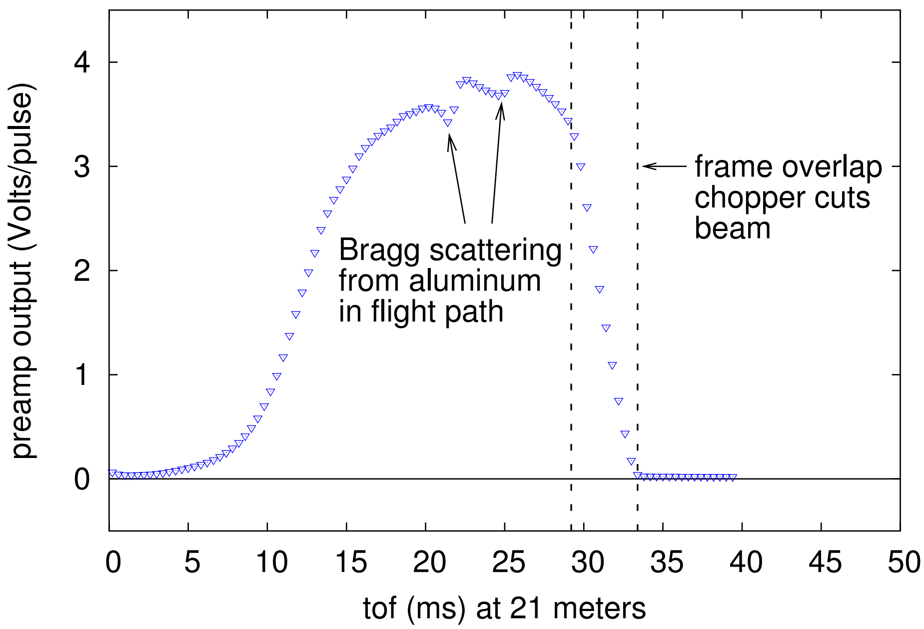
Q: charge liberated in the gas per neutron

$\approx 10^4$ e

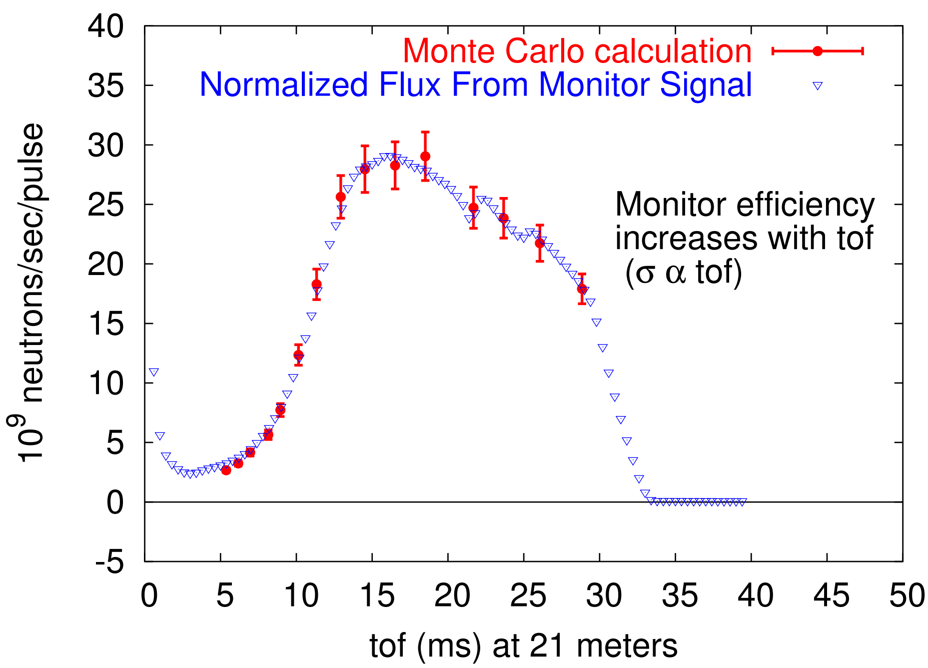
independent of neutron tof

Beam Intensity Measurement

voltage signal from upstream monitor preamp



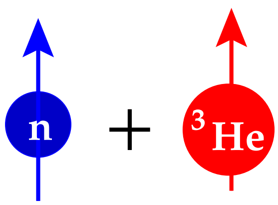
flux calculation normalized to monte carlo



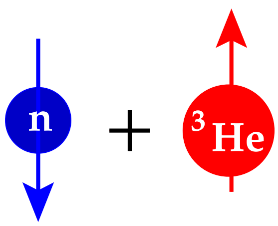
$\mathrm{I} = \mathrm{NP(E)Q}$ Calibration of the monitors is a determination of Q.

Beam Polarizer Diagnostics

The probability of interaction for a neutron with ^{3}He is highly spin-dependent:



σ_p ~ **3 barns**

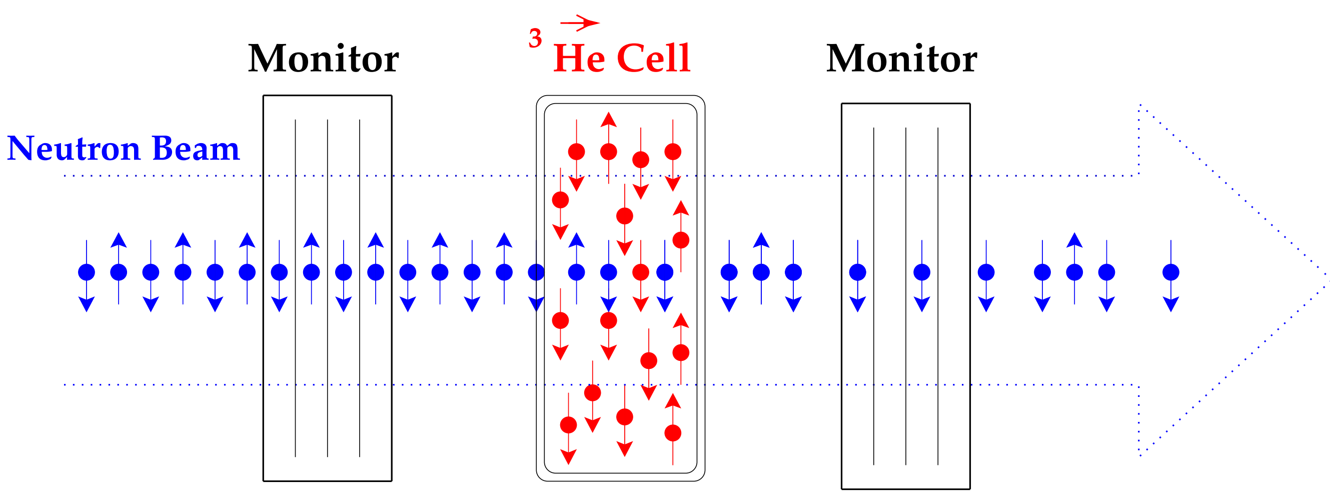


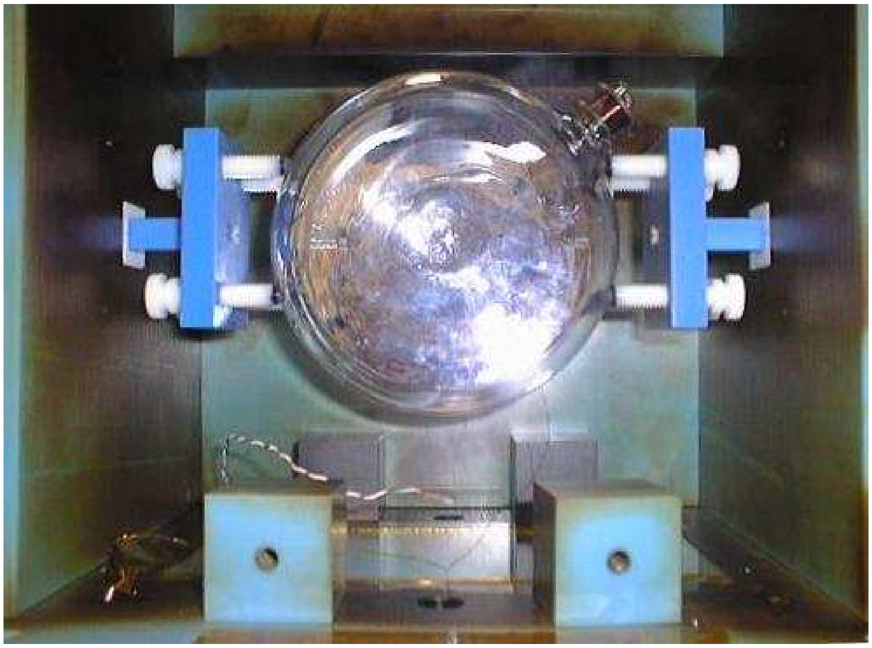
σ_a **~ 17,000 barns @ 10 meV**

$\sigma_a \;\alpha\; 1/v$ (v = neutron speed)

A cell of polarized ^{3}He filters out neutrons of one spin state.

Beam monitors are used to measure that effect.





Relative transmission through the cell polarized and unpolarized is an **absolute measure** of **neutron polarization** P_n:

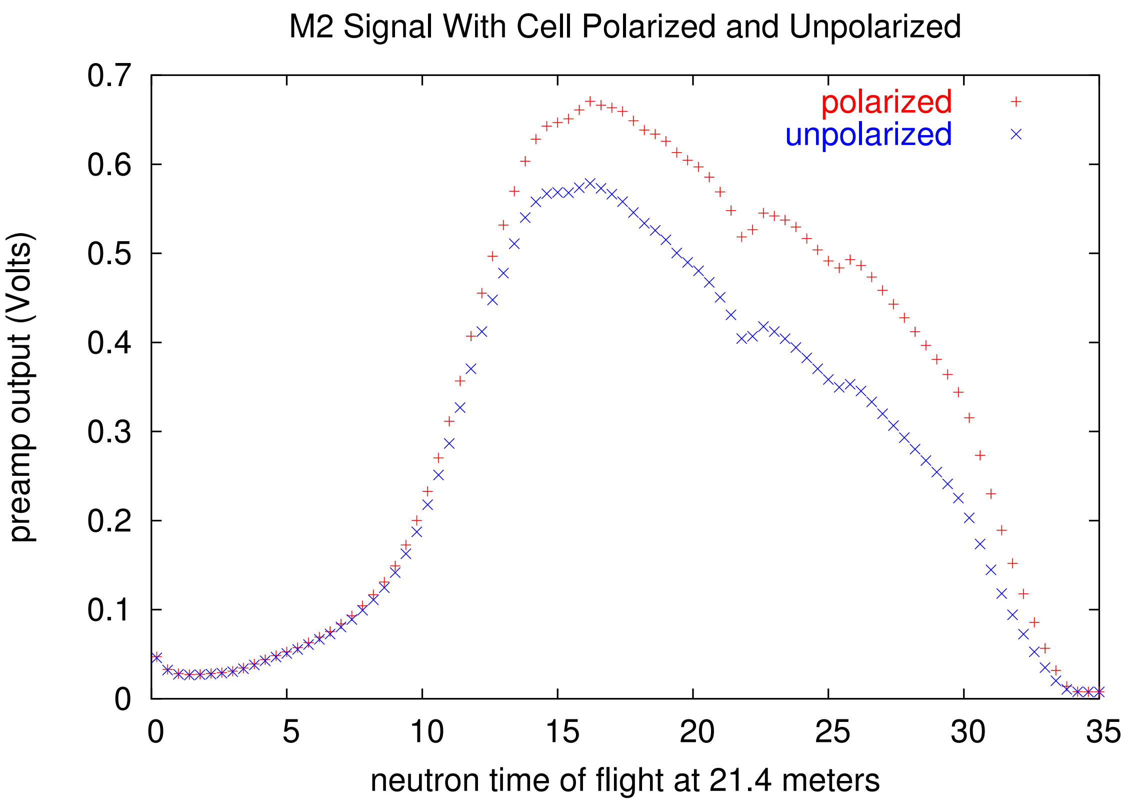
$$P_n = \sqrt{1 - \left(\frac{T_0}{T}\right)^2}$$

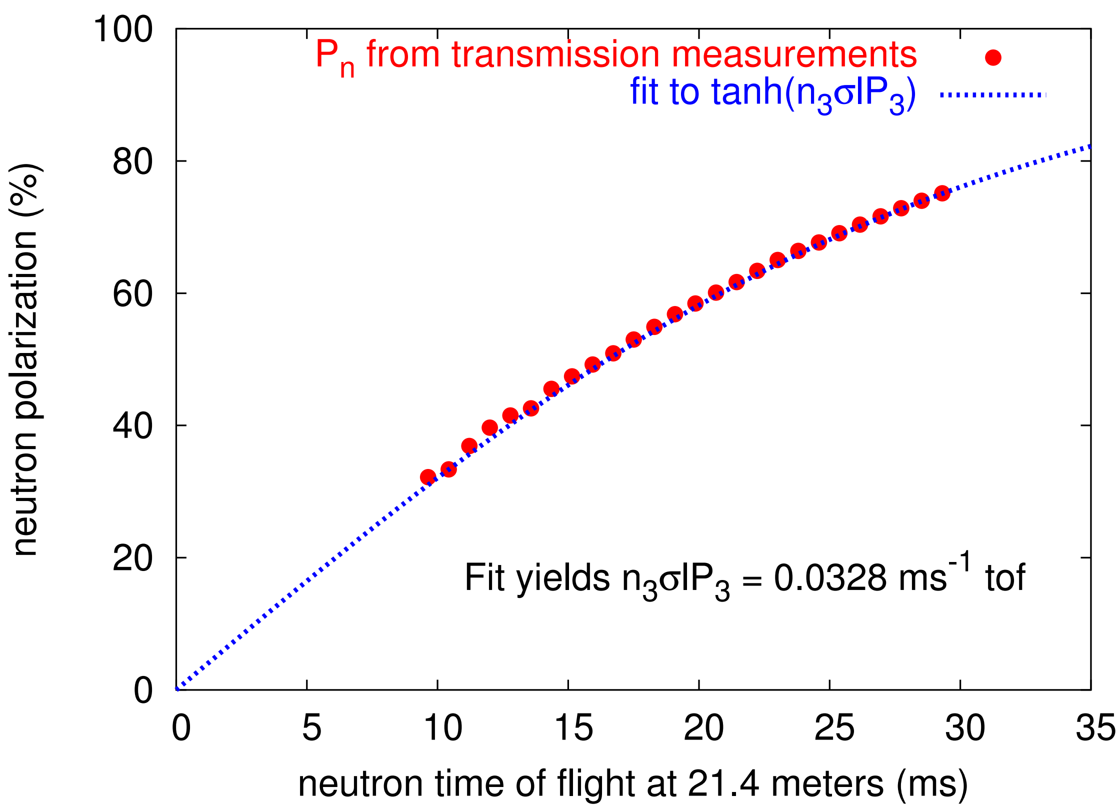
T_0 = transmission of unpolarized cell
T = transmission of polarized cell

Knowing P_n and the amount of ^3He in the cell, it's possible to calculate the ^3He polarization:

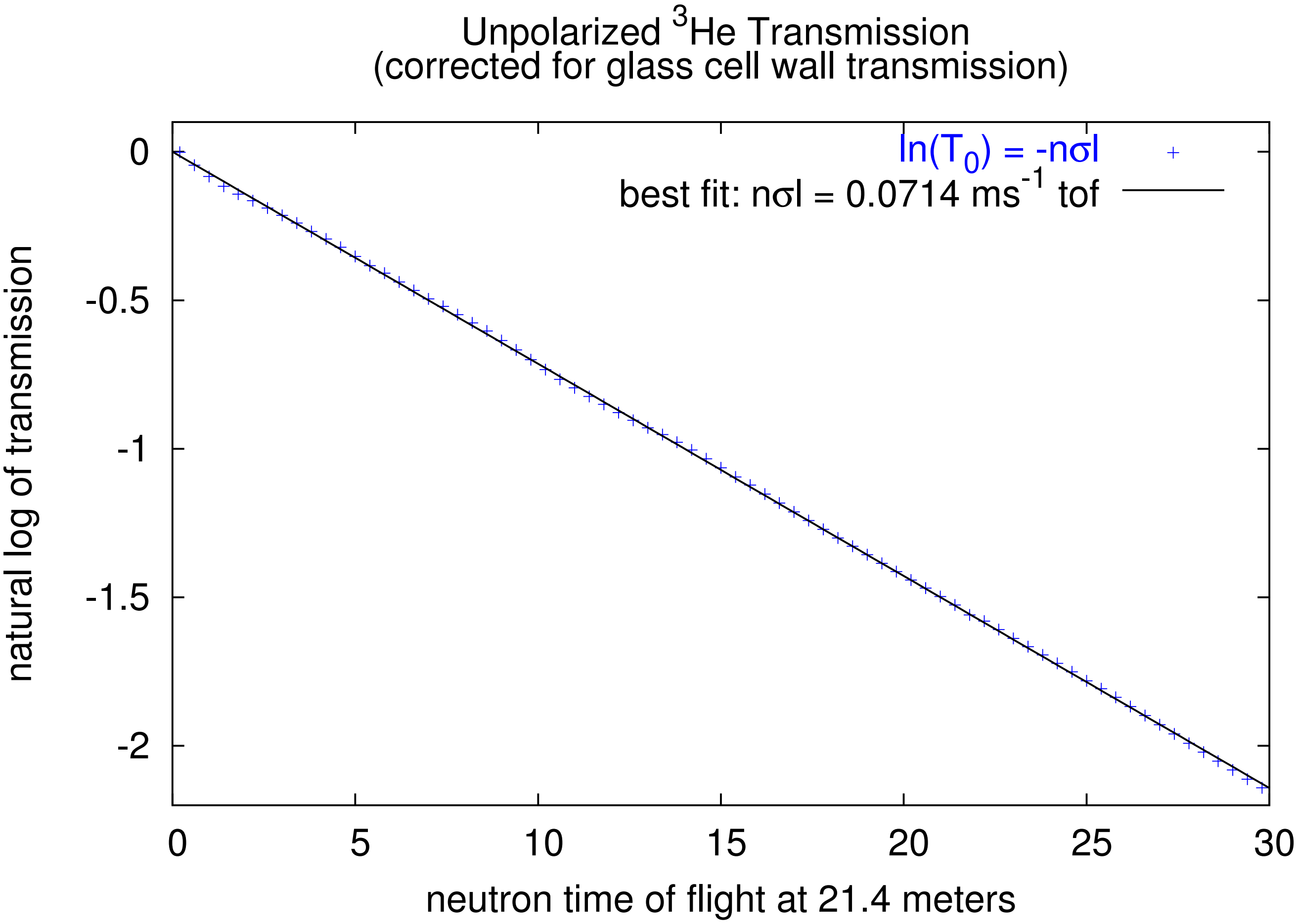
$$P_n = tanh(n_3 \sigma l P_3)$$

P_3 = ^3He polarization
n_3 = ^3He number density
l = width of cell


M2 Signal With Cell Polarized and Unpolarized
polarized
unpolarized
preamp output (Volts)
neutron time of flight at 21.4 meters

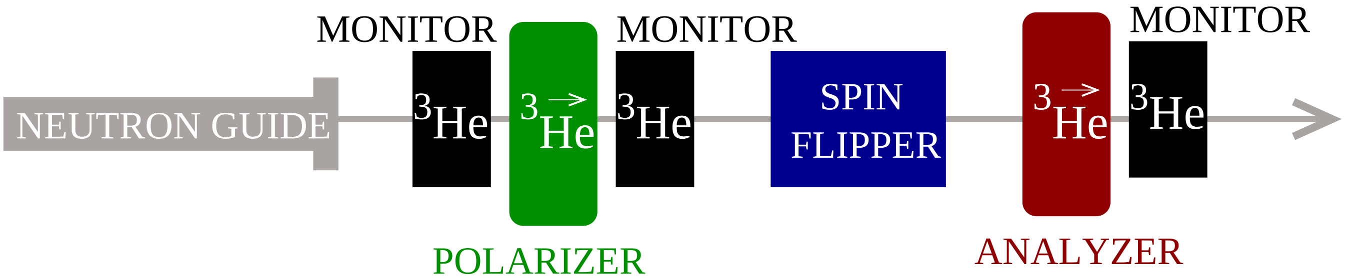

P_n from transmission measurements
fit to tanh(n_3σlP_3)
Fit yields n_3σlP_3 = 0.0328 ms^-1 tof
neutron polarization (%)
neutron time of flight at 21.4 meters (ms)

$$T_0 = e^{-n\sigma l}$$
$$ln(T_0) = -n\sigma l \propto tof$$

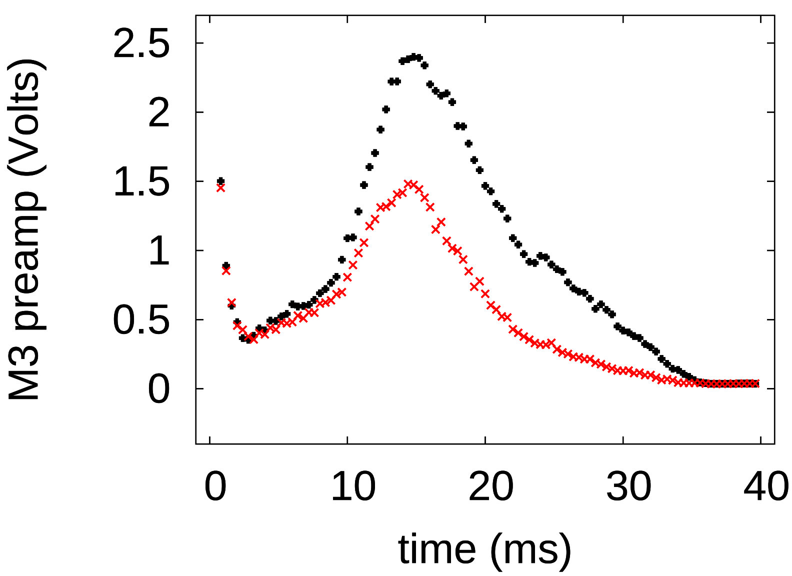


$$P_3 = \frac{n_3 \sigma l P_3}{n_3 \sigma l} = \frac{0.0328\ ms^{-1}\ tof}{0.0714\ ms^{-1}\ tof} = 0.46$$

Spin Flipper Commissioning



Spin-dependent transmission of the analyzer cell can be seen in the third monitor:



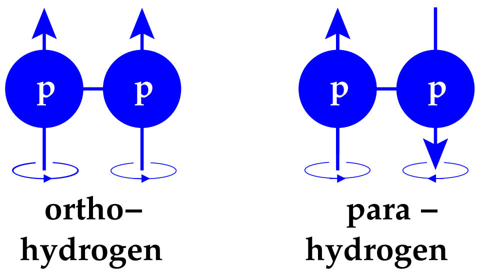
Spin flipper performs an imperfect flip:

$$P_n \to -RP_n \quad ; \quad R < 1$$

The ratio between spin flipper on and spin flipper off signals is dependent on polarizer and analyzer properties and R.

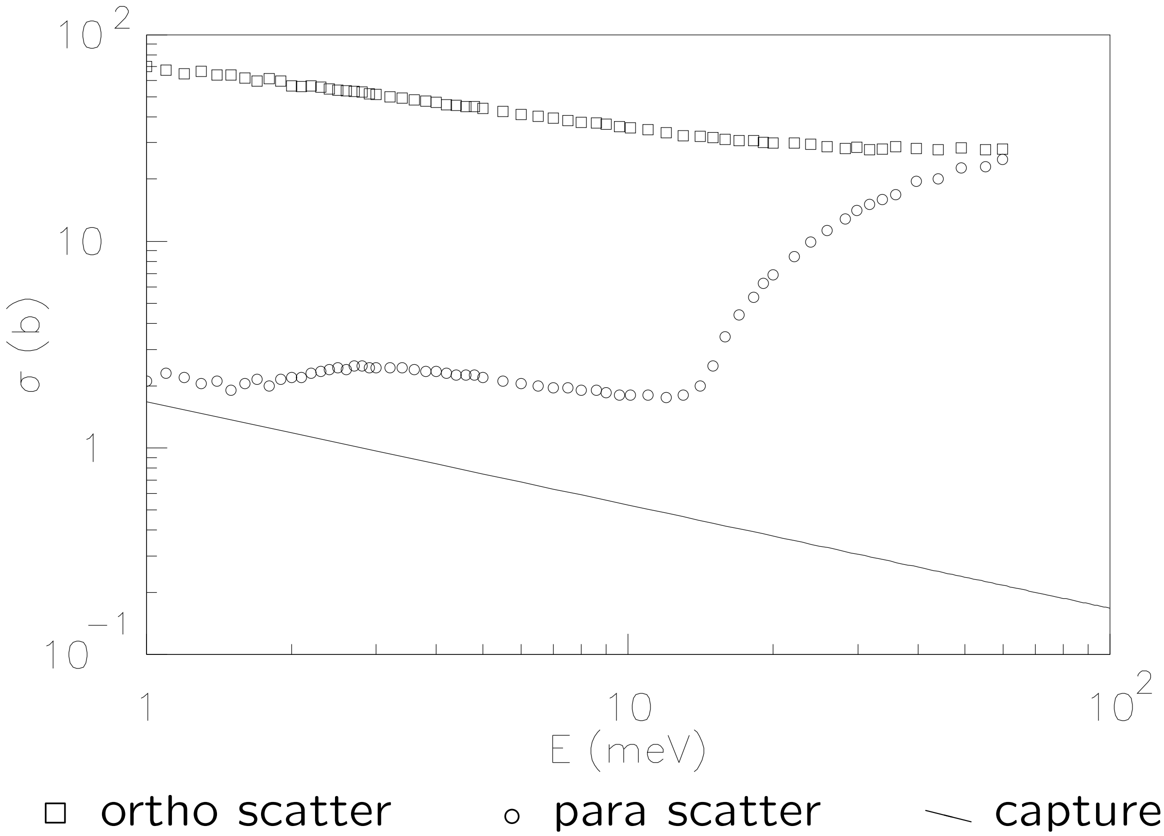
Liquid H_2 target diagnostics

Two nuclear spin states of the H_2 molecule:



$\Delta E = 15$ meV

Cross-section as a function of neutron KE[1]



- ortho-H_2 has a high spin-incoherent cross-section for neutron scattering.
- para-H_2 below 15 meV does not.

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[1] W.D. Seiffert, Technical Report No. EUR 4455d, Euratom (unpublished).

Concluding Remarks

- Neutron polarization for the NPDGamma experiment is provided by a polarized ^{3}He spin filter.

- Pulse-by-pulse spin flips are performed by an RF neutron spin rotator.

- ^{3}He ion chambers provide the ability to perform neutron flux and neutron transmission measurements.

- Knowledge of neutron polarization and spin flip efficiency is provided by performing neutron transmission measurements of polarized ^{3}He.

- The polarization of the ^{3}He in the polarizer and analyzer cells can similarly be determined.

- Beam monitors will also be used to monitor the ortho-para ratio of our liquid hydrogen target during the $\vec{n} + \mathrm{p} \rightarrow \mathrm{d} + \gamma$ asymmetry measurement.