Overview of the parity violating measurement of $n+{}^{3}\mathrm{He}\rightarrow p+t$

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- The Hadronic Weak Interaction and the DDH model

- n-3He Experimental Overview

- Analysis and Simulation

Weak interaction in hadronic systems.

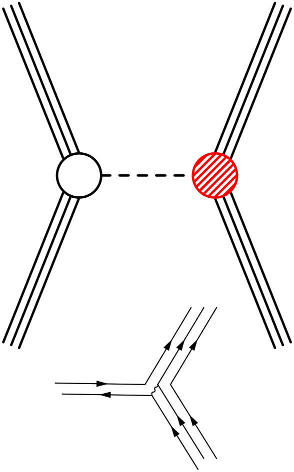
"Pure hadronic" weak reactions are the least understood weak interaction. In nuclear reactions, weak signals are dominated by strong interactions:

$$\frac{e^2}{M_W^2}\frac{m_\pi^2}{g^2} \approx 10^{-7}$$

Parity is not conserved in weak interactions. However, it is in EM and QCD, which gives us a signal with which to observe weak physics!

Complementary probe of nuclear structure. HWI is sensitive to quark-quark correlations.

Experimental verification: once the couplings are determined from experiment, they can be used to test nucler wavefunctions, and compare with lattice QCD results.



Right: The DDH diagram with one PC and one PC vertex.
Bottom Right: One possible vertex with a weak boson propagator.

Desplanques, Donoghue, Holstein (1980) and status of experimental tests

The "DDH" model characterizes the NN potential in terms of six spin and isospin couplings[1], $h_m^{\Delta I}$:

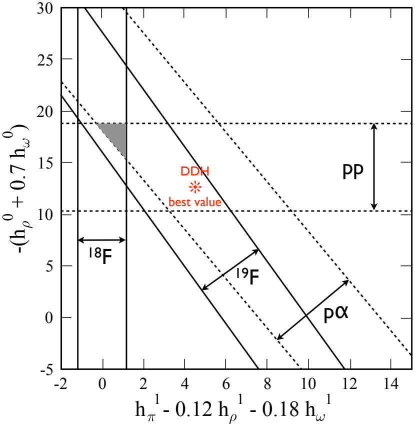
$$V_{PV}^{DDH} \propto h_\pi^1 V_\pi^1 + h_\rho^0 V_\rho^0 + h_\rho^1 V_\rho^1 + h_\pi^2 V_\pi^2 + h_\omega^2 V_\omega^2 + h_\omega^1 V_\omega^1$$

For few-body HWI reactions, the sensitivity of each reaction's asymmetry to each of the coupling constants is calculated using nuclear wavefunctions with the DDH operators:

Asymmetry coefficients for selected experiments

Experiment	h_π^1	h_ρ^0	h_ρ^1	h_ρ^2	h_ω^0	h_ω^1
$n + {}^3He \rightarrow p + t$	-0.189	-0.036	–	–	-0.033	–
$n + p \rightarrow d + \gamma$	-0.107	–	-0.001	–	–	0.003
$n + d \rightarrow n + n + p$	0.92	-0.50	0.027	0.0012	-0.13	0.05
$p + p \rightarrow p + p$	–	0.079	0.079	0.032	-0.073	0.073
$p + \alpha \rightarrow p + \alpha$	-0.340	0.140	0.047	–	0.059	0.059
$n + p \rightarrow n + p$	-3.12	-0.23	–	-0.25	-0.23	–
$n + \alpha \rightarrow n + \alpha$	-0.97	-0.32	0.11	–	-0.22	0.22

Observed isoscalar vs. isovector coefficients [2]



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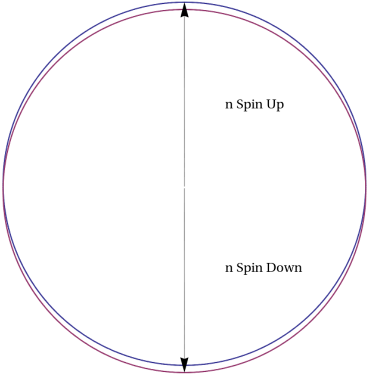
[1] B.Desplanques, J.F.Donoghue,and B.R.Holstein, Ann.Phys.124,449(1980).

[2] W. C. Haxton and B. R. Holstein, Prog.Part.Nucl.Phys. 71, 185 (2013)

Spin-correlated asymmetry in $n+{}^3\text{He}\rightarrow p+t$



The experimentally measured asymmetry arises from the observables $\sigma_n \cdot k_p$ and $k_n \times (\sigma_n \cdot k_p)$:

$$\alpha_{observed} \propto 1 \pm A_{PV}\sigma_n \cdot k_p \pm A_{PC}k \times \sigma_n \cdot k_p$$

$$\alpha_{observed} \approx 1 + A_{PV}\cos\theta$$

The calculation by Viviani (2010) of the $n+{}^3\text{He} \rightarrow p+t$ reaction gives the following coefficients of the coupling constants:

$$\alpha_p^{n^3He} = -0.1892h_\pi^1 - 0.0364h_\rho^0 - 0.0334h_\omega^0$$ [3]

If the polarization of the neutrons is precisely controlled, the parity of the reaction can be observed. Since weak interactions do not conserve parity, any weak coupling will produce an asymmetric distribution in the reaction products. So we can use the measurement of the asymmetry as a test of the strength of these weak couplings.

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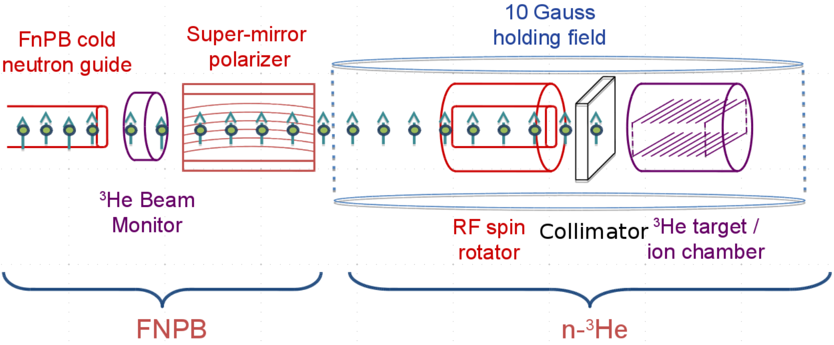
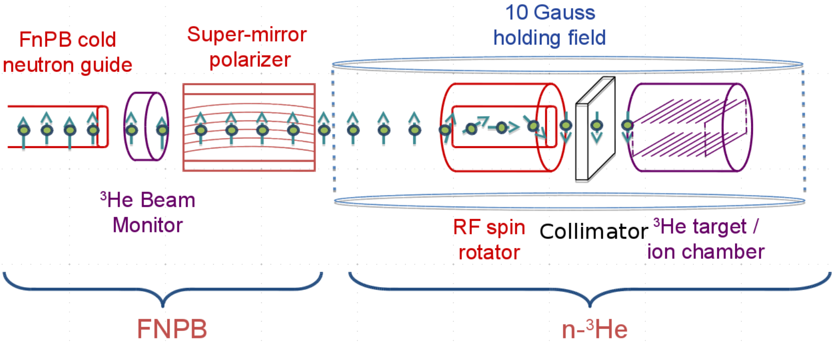
[3] Viviani et al, PRC 82 (2010), 044001

Instrument Diagram – Spin Up



Instrument Diagram – Spin Down



FnPB cold neutron guide

Super-mirror polarizer

10 Gauss holding field

^{3}He Beam Monitor

RF spin rotator

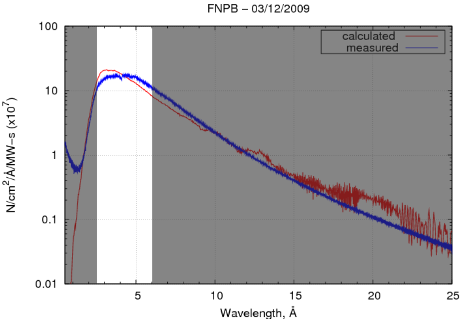
Collimator

^{3}He target / ion chamber

FNPB

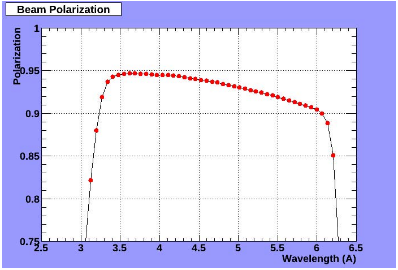
n-^{3}He

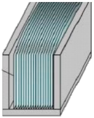
Neutron Spectrum and Spin State



The wavelength distribution of neutrons traveling down the guide of BL-13 at SNS after a pair of choppers blocks neutrons outside of the peak intensity range. The resulting spectrum has energies from approximately 2.5Å to 6Å.

The neutrons are polarized through the with a multi-layer supermirror in a large magnetic field. The mean polarization efficiency is 0.94.





$$n(\lambda) = \sqrt{1 - \frac{\lambda^2 Nb}{2\pi} \pm \frac{\lambda^2 \mu B 2m}{(2\pi\hbar)^2}}$$

After the neutron beam is chopped and polarized, the 10G magnetic field surrounding all of the components preserves the spin state of the neutrons as they travel through the components.

Spin Rotator

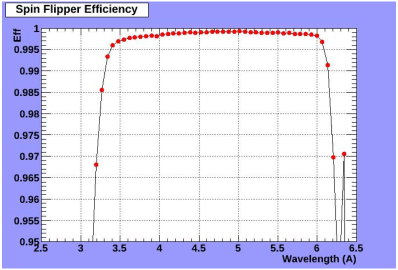
Neutrons in the ∼10G holding field will experience a precession about the field axis, due to torque on their magnetic dipole moment:

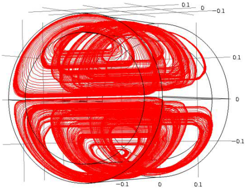
$$\tau = \vec{\mu} \times \vec{B}; \quad \omega = \frac{2\mu B}{\hbar}$$

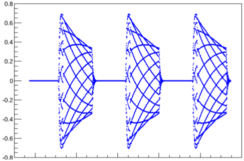
For our configuration, the precession frequency is 26.655 ± .005 kHz.

Apply spatially uniform magnetic field, oscillating at ω_r, to rotate spin orientations of all neutrons in the beam at the maximum rate. Tune to achieve exactly rotation of π, flipping the spins into the down state.

The coil was designed to have a zero magnetic field outside of the volume, which prevents perturbations to the neutrons as they enter and exit the spin flipper.

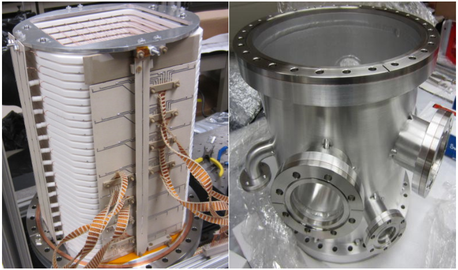


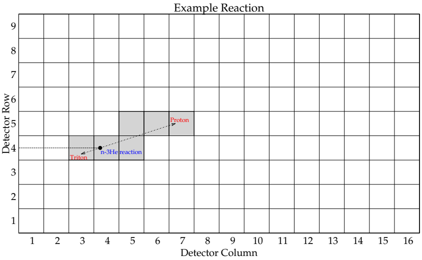


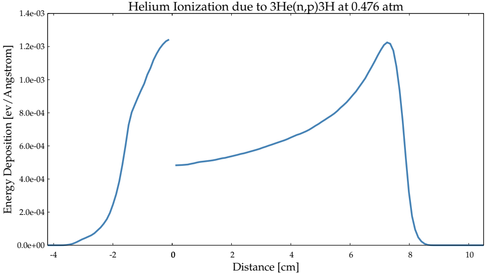


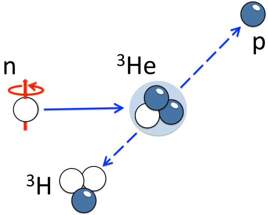
Pulsed source means $v \propto \frac{1}{t}$

Ion Energy Deposition









High voltage wires in between the signal wires create a strong electric field that drives gas ions to the signal wires. The mean current is measured at 3kHz. The proton carries 573 keV away from the reaction, and the triton carries 191 keV. These products will travel a total of 13 cm in the gas before losing all energy. The long proton distance is what allows the experiment to distinguish the spin states.

Asymmetries and Geometry Factors

$$Y_{\pm}^{\kappa} = \langle E^{\kappa}(1 \pm \alpha \cos\theta)\rangle$$

$$\frac{Y_{+}^{\kappa} - Y_{-}^{\kappa}}{Y_{+}^{\kappa} + Y_{-}^{\kappa}} = \alpha_{\kappa} \frac{\langle E^{\kappa} \cos\theta\rangle}{\langle E^{\kappa}\rangle} \quad \left\{ = \alpha_{\kappa} G_{\kappa} \right\}$$

We will call the mean sensitivity of each element the geometry factor.

$$\Rightarrow \boxed{\alpha_{\kappa} = \frac{1}{G_{\kappa}} \frac{Y_{\kappa}^{+} - Y_{\kappa}^{-}}{Y_{\kappa}^{+} + Y_{\kappa}^{-}}}$$

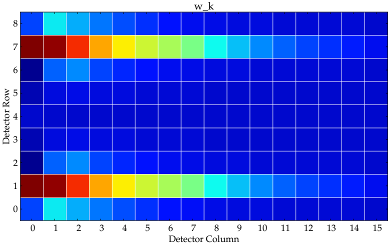
See the talk immediately following this one for more details about our calculation method and results.

There are 7056 (144x49) signal elements. Choose a normalized weighting set to combine all of the channel asymmetries.

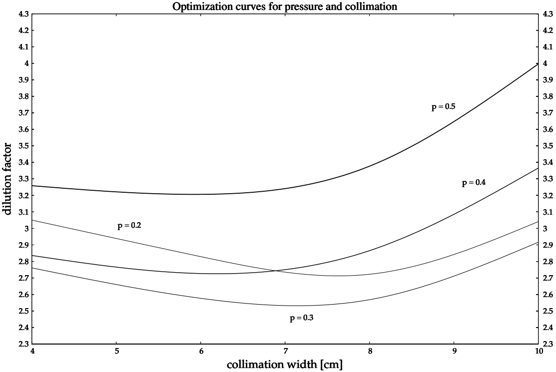
$$\alpha = \sum\nolimits_{\kappa} w_{\kappa}\alpha_{\kappa} = \vec{w} \cdot \vec{\alpha}; \qquad \sum\nolimits_{\kappa} w_{\kappa} = 1$$

Sensitivities and Optimizations

From the geometry factors and simulated yields, the sensitivity of each element can be calculated.



The uncertainty in alpha can also be calculated from simulation. This can then be used as an optimization metric. For example, apply to pressure and collimation parameters:



$$\frac{\partial \sigma_\alpha^2}{\partial w_k} = \lambda_k \frac{\partial\left(\sum_i w_i - 1\right)}{\partial w_k}$$

$$\Rightarrow \mathit{minimized}\ \frac{1}{\sigma_\alpha^2} = \sum_i \sum_j [\sigma^{-1}]_{ij}$$

$$\boxed{\frac{1}{\sigma_\alpha^2} = \sum_i \sum_j [\sigma_{\alpha_\kappa \alpha_\beta}]_{ij}^{-1}}$$

Current Status

Approximately 4500 hours of data has been taken. From MC simulation of detector signals, current statistics, and measured polarization efficiency, the uncertainty in our measurement of the physics assymetry is:

$$\sigma_\alpha = \frac{\sigma_d}{P\sqrt{N}} < 2 \cdot 10^{-8}$$

We expect that this experiment will measure the value of the physics asymmetry with a precision of $2 \cdot 10^{-8}$. Data taking finished in December 2015. Analysis and asymmetry calculations are in progress...

Systematic uncertainties.

Invariant	Parity	Size	Comments
$\vec{\sigma}_n \cdot \vec{k}_p$	Odd	3×10^{-7}	Nuclear capture asymmetry
$\vec{\sigma}_n \cdot (\vec{k}_n \times \vec{k}_p)$	Even	2×10^{-10}	Nuclear capture asymmetry
	Even	6×10^{-12}	Mott-Schwinger scattering
$\vec{\sigma}_n \cdot \vec{B}$	Even	1×10^{-10}	Stern-Gerlach steering
	Even	2×10^{-11}	Boltzmann polarization of ^{3}He
	Even	4×10^{-13}	Neutron induced polarization of ^{3}He
$\vec{\sigma}_n \cdot \vec{k}_p$	Odd	1×10^{-11}	Neutron beta decay

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