Simulation of ion chamber signals in the $n+{}^3\mathrm{He}\rightarrow p+t$ experiment

Christopher Coppola

University of Tennessee

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Brief Experimental Outline

Weak interaction in hadronic systems.

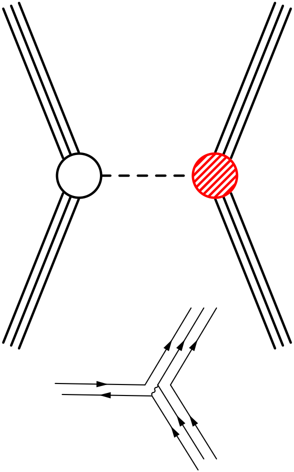
"Pure hadronic" weak reactions are the least understood weak interaction.
In nuclear reactions, weak signals are dominated by strong interactions:

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

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!

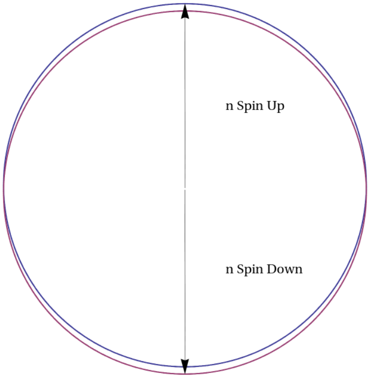
Complementary probe of nuclear structure. HWI is sensitive to quark-quark correlations.

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.

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



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

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

$$\mathrm{A}_{observed} \approx 1 + A_{PV}\cos\theta$$

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

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

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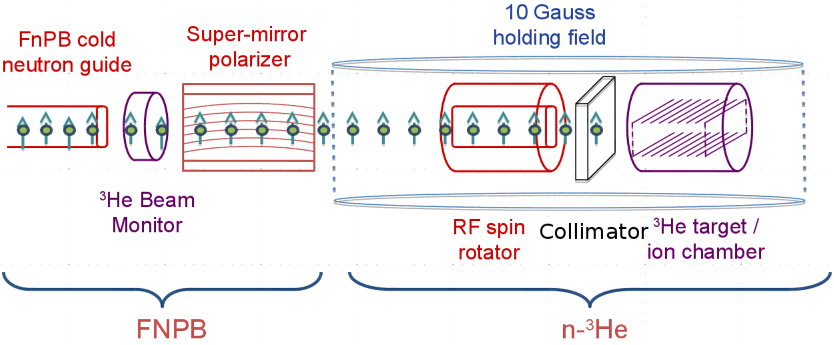
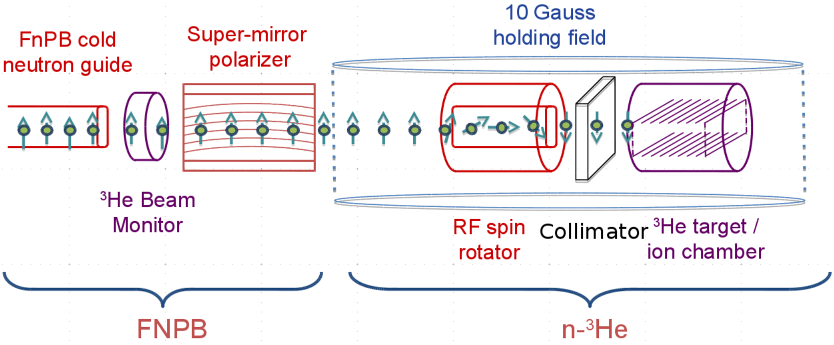
[1] Viviani et al, PRC 82 (2010), 044001

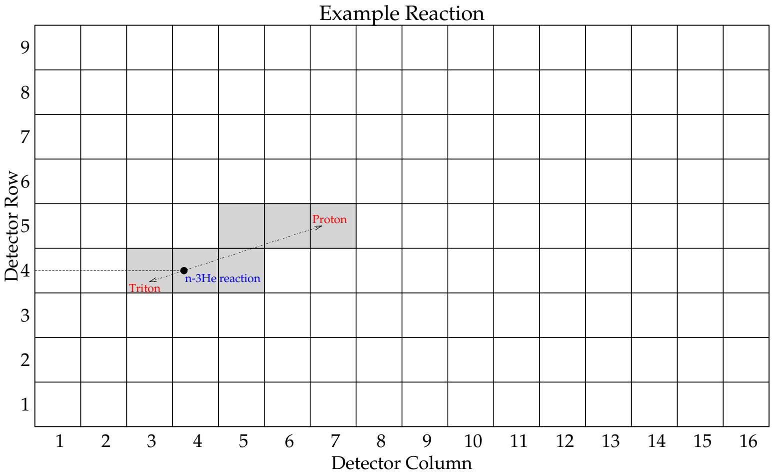
Instrument Diagram – Spin Up



Instrument Diagram – Spin Down



Wire Chamber Model



The proton carries 573 keV away from the reaction, and the triton carries 191 keV. These products will ionize the ^{3}He and travel a total of 12 cm in the gas.

Basic Arithmetic Asymmetry

$$Y^{\kappa} = \langle E^{\kappa}(1 + \mathrm{A}\cos\theta)\rangle$$

$$\frac{Y_{+}^{\kappa} - Y_{-}^{\kappa}}{Y_{+}^{\kappa} + Y_{-}^{\kappa}} = \mathrm{A}_{\kappa}\frac{\langle E^{\kappa}\cos\theta\rangle}{\langle E^{\kappa}\rangle} \Rightarrow \boxed{G_{\kappa} = \frac{\langle E^{\kappa}\cos\theta\rangle}{\langle E^{\kappa}\rangle}}$$

$$\mathrm{A}_{\kappa} = \frac{1}{G_{\kappa}}\frac{Y_{\kappa}^{+} - Y_{\kappa}^{-}}{Y_{\kappa}^{+} + Y_{\kappa}^{-}}$$

We will call the mean sensitivity the geometry factor.

Selected Methods from Simulation

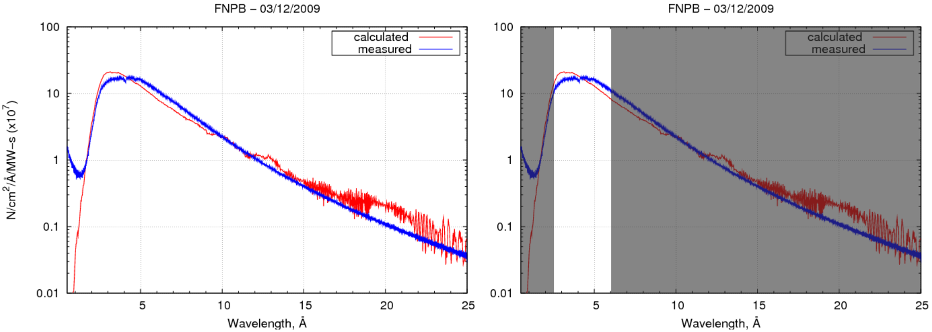
Simulation Objectives

Some desired simulation objectives:

-Calculated geometry factors
-Optimized pressure
-Optimized collimation
-Estimated running time / uncertainty
-Model gains and correlations

In order to construct a successful simulation, one must find the best compromise between complex physics and fast calculations. It also should be scalable and able to take advantage of parallel resources. A custom code will allow the best approximations to be made where available for a given system.

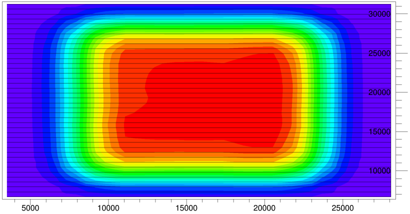
Neutron Wavelength



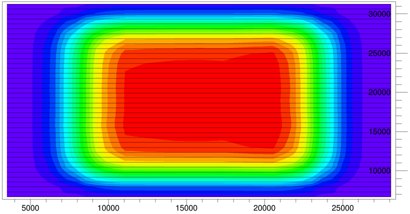
Left: the wavelength distribution of neutrons traveling down the guide of BL-13 at SNS.

Right: the distribution after a pair of choppers blocks neutrons outside of the peak intensity range. The resulting spectrum has energies from approximately 2.5Å to 6Å.

Physical Beam Profile



X-Y Intensity Scan

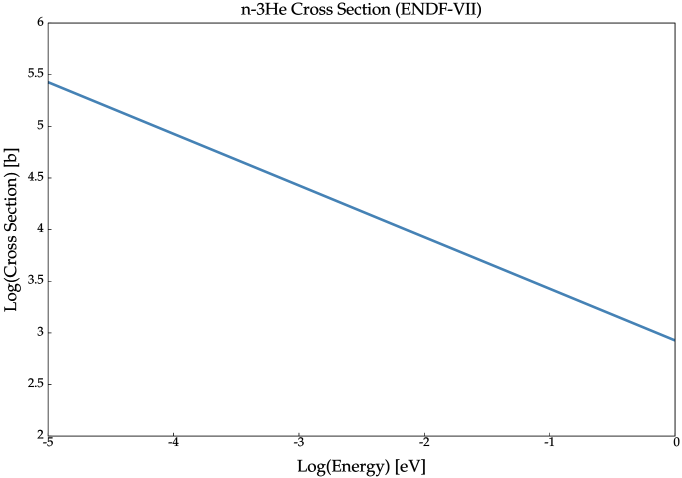


First-order product

The beam was scanned on a grid to determine the centroid and shape. Shown on the left is the upstream scan, right after the neutrons exit the guide aperture.

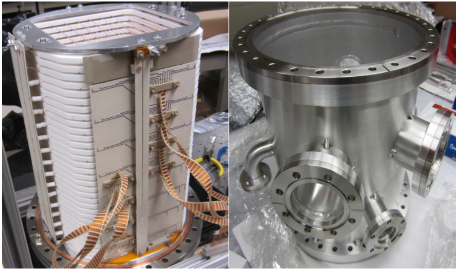
On the right is a model for the beam shape which is calculated using two one-dimensional generators instead of a two-dimensional one, approximating the shape well, ($\chi^2 = 0.01$), and making the computation considerably faster.

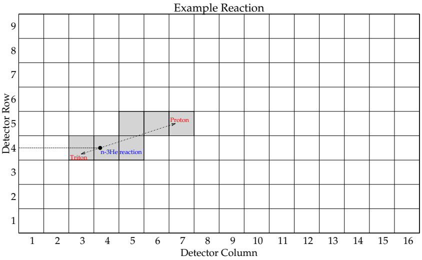
Time-dependent Cross Section

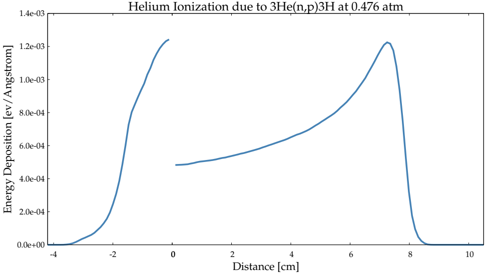


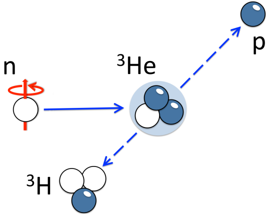
Cross section generated from function, rather than by lookup, by taking advantage of $\frac{1}{v}$ behavior. Linear parameter found by fitting ENDF data to linear function: C = 2.92709

Ion Energy Deposition



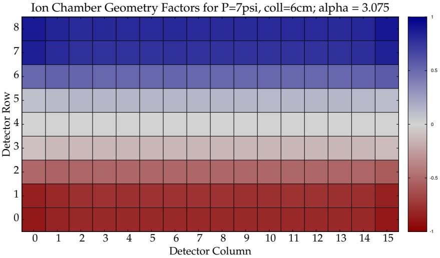


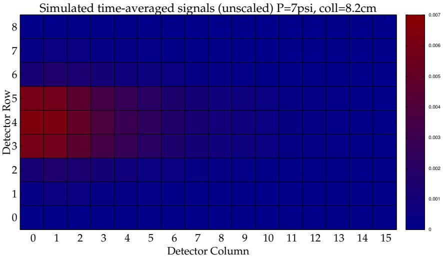




High voltage wires in between the signal wires create a strong electric field that drives gas ions to the signal wires. The mean current is measured at 3kHz. The proton carries 573 keV away from the reaction, and the triton carries 191 keV. These products will travel a total of 13 cm in the gas before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

Geometry Factors and Yields



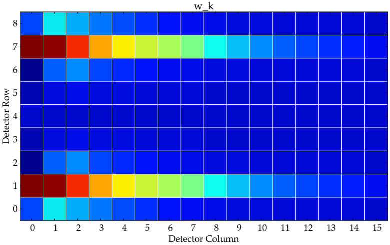


Left: plot of the sign and size of the geometry factors in the chamber.
Right: an unscaled simultation of the time-summed signals observed in each element.

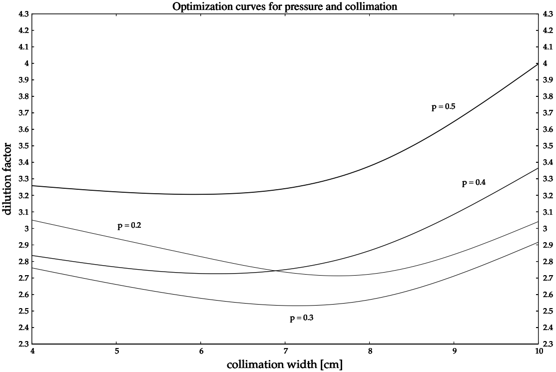
$$\mathrm{A}_{\kappa} = \frac{1}{G_{\kappa}} \frac{Y_{\kappa}^{+} - Y_{\kappa}^{-}}{Y_{\kappa}^{+} + Y_{\kappa}^{-}}$$

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:



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

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

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

Current Status

Continued analysis and asymmetry calculations are ongoing on the approximately 4500 hours of data. From MC simulation of detector signals, current statistics, and measured polarization efficiency, we expect that the uncertainty in our measurement of the physics assymetry will be:

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

n3He Collaboration

Duke University, Triangle Universities Nuclear Laboratory

- Pil-Neo Seo

Istituto Nazionale di Fisica Nucleare, Sezione di Pisa

- Michele Viviani

Oak Ridge National Laboratory

- Seppo Penttila
- David Bowman
- Vince Cianciolo
- Jack Thomison

University of Kentucky

- Chris Crawford
- Latiful Kabir
- Aaron Sprow

Western Kentucky University

- Ivan Novikov

University of Manitoba

- Michael Gericke
- Mark McCrea
- Carlos Olguin

Universidad Nacional Autónoma de México

- Libertad Baron
- Jose Favela

University of New Hampshire

- John Calarco

University of South Carolina

- Vladimir Gudkov
- Matthias Schindler
- Young-Ho Song

University of Tennessee

- Nadia Fomin
- Geoff Greene
- S. Kucuker
- Irakli Garishvili
- C. Hayes
- Christopher Coppola
- Eric Plemons

University of Tennessee at Chattanooga

- Josh Hamblen
- Caleb Wickersham

University of Virginia

- S. Baessler