The n-^{3}He Experiment at SNS

A measurement of the parity violating asymmetry in the neutron capture on ^{3}He at SNS.

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for the n-^{3}He Collaboration

Abstract: *Weak nucleon nucleon couplings are largely unknown because of it's non-perturbative nature which makes the calculations and experiments challenging. However, parity violation (PV) can be used to isolate the weak contributions from the strong part and thus studies of PV in hadronic systems offer a unique probe of nucleon structure. The n-^{3}He experiment at the Spallation Neutron Source at the ORNL measures the parity violating asymmetry of the recoil proton momentum $\vec{k}_p$ with respect to the neutron spin $\vec{\sigma}_n$ in the reaction $\vec{n}$ + ^{3}He $\longrightarrow$ p + T + 765keV. This asymmetry is sensitive to the isospin-conserving and isospin-changing (ΔI = 0,1) parts of the Hadronic Weak Interaction, and is expected to be extremely small (~ 10^{-7}). The experiment will determine this PV asymmetry with the statistical sensitivity of the order of 10^{-8}. Last year we completed the data taking and the data analysis is well advanced.*

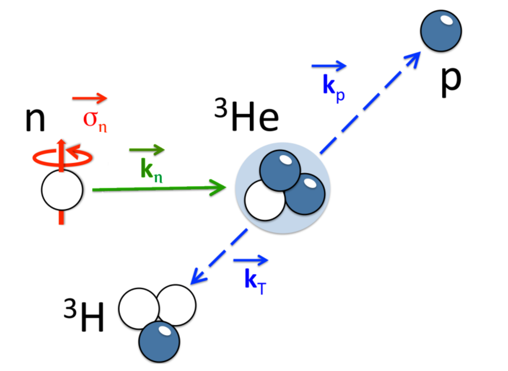
The n-^{3}He Experiment

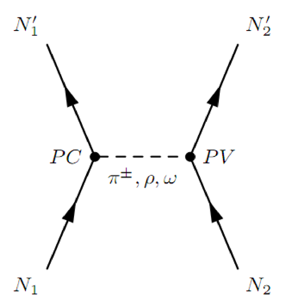
The n-^{3}He experiment at SNS is a high-precision measurement motivated to probe the hadronic weak interaction by measuring the parity violating asymmetry of the proton in the following reaction-

$$\vec{n} + {}^3He \rightarrow p + T + 765keV$$

$$\sigma = \sigma_0 (1 + \sigma_n . k_p A_{pv} + k_n x \sigma_n . k_p A_{pc})$$

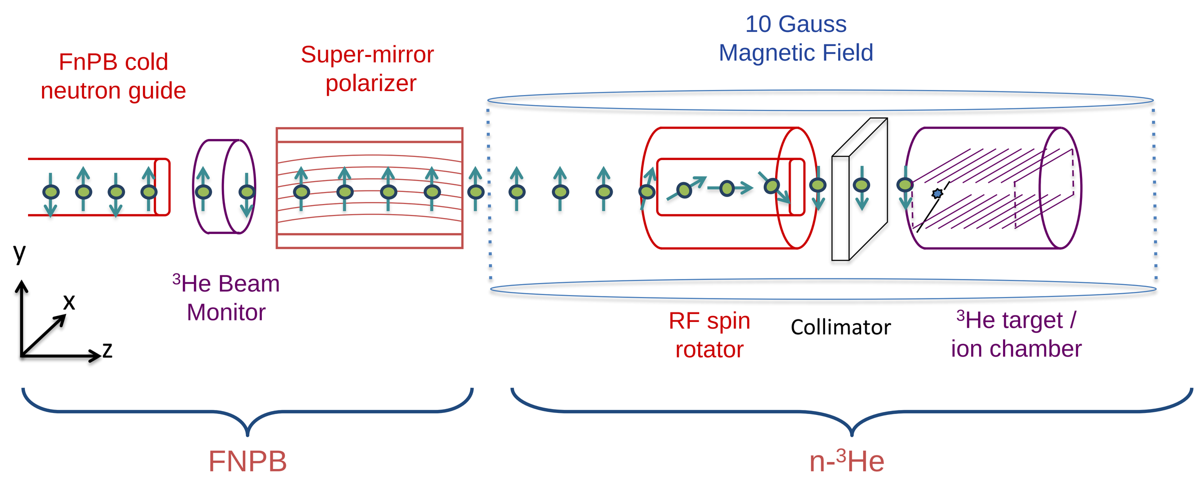
$$A_n^{n^3He} = -0.189 f_\pi - 0.036 h_\rho^0 - 0.033 h_\omega^0$$





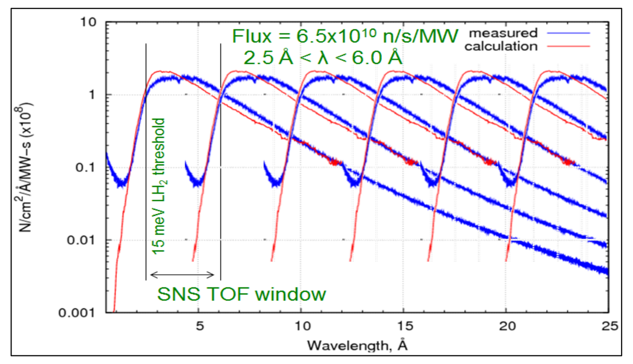
This asymmetry is expected to be extremely small (of the order 10^{-7}). Our goal is to measure the asymmetry A_{pv} in this reaction to a precision of 2 x 10^{-8} . We also measure parity conserving asymmetry to confirm the sensitivity of our instruments.

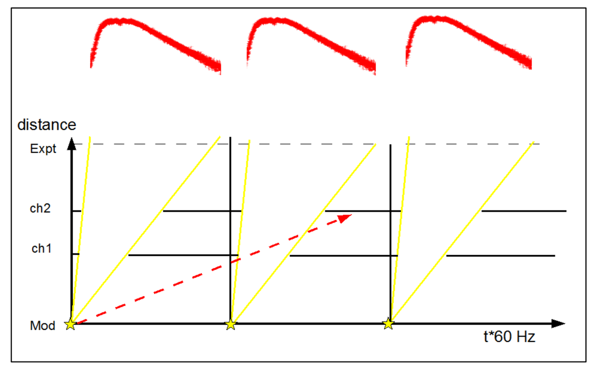
Experimental Setup



- Has two modes of operation.
- The orientation of the target (as shown) where the wires inside the target are horizontally aligned is called the up-down mode or parity violating (PV) mode.
- The other mode is left-right or parity conserving (PC) mode where the wires inside the target are vertically aligned.

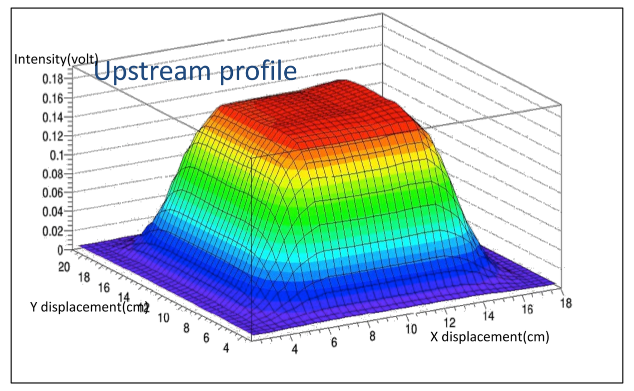
Neutron Beam Profile

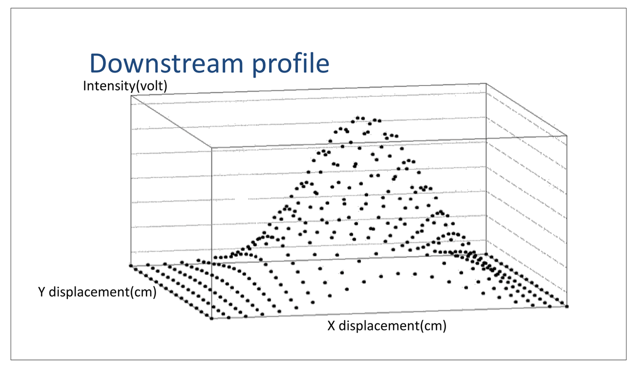




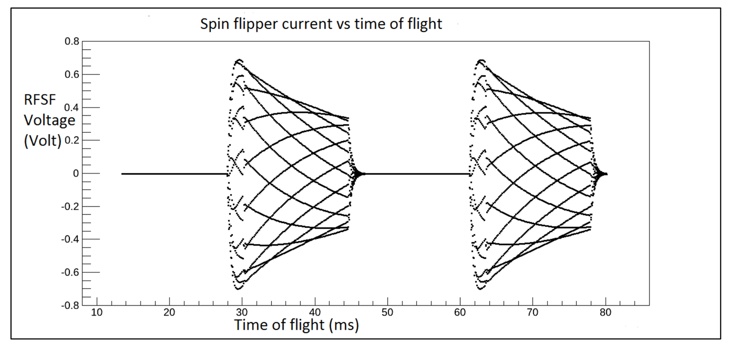
- We have 60 Hz pulsed neutron beam from the accelerator.
- Two choppers are used to chop out mixing between pulses and remove wraparound.

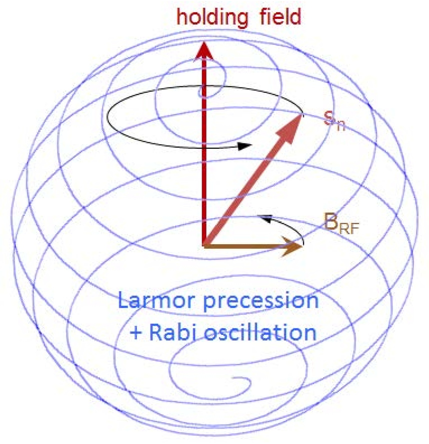
The two plots in the bottom show the beam profile just before the target and beam profile far behind the target.



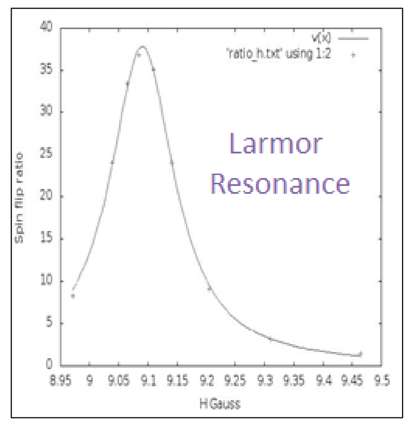


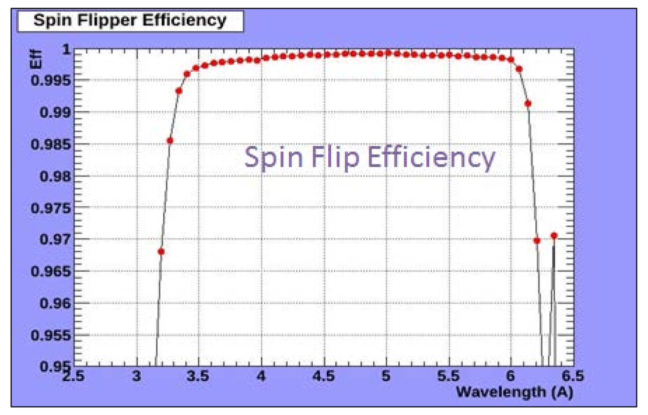
Radio Frequency Spin Flipper



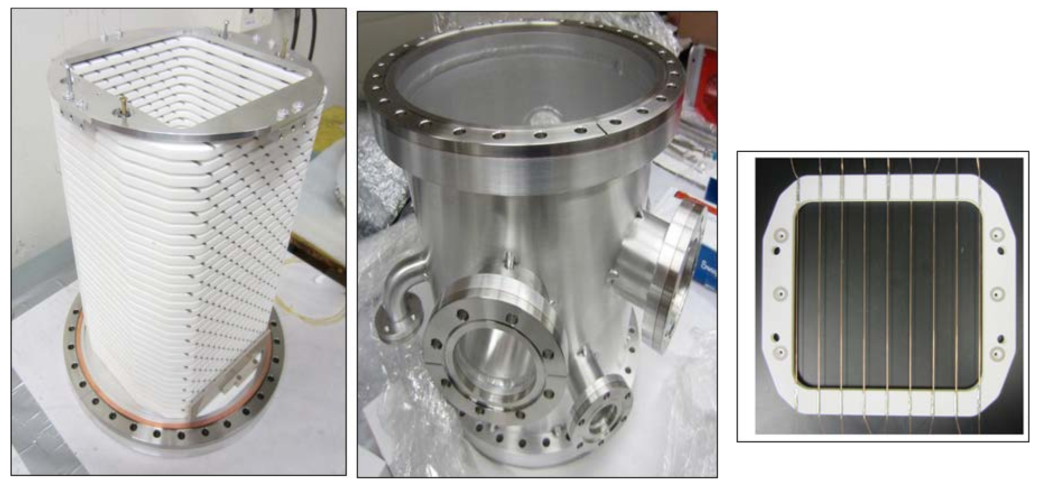


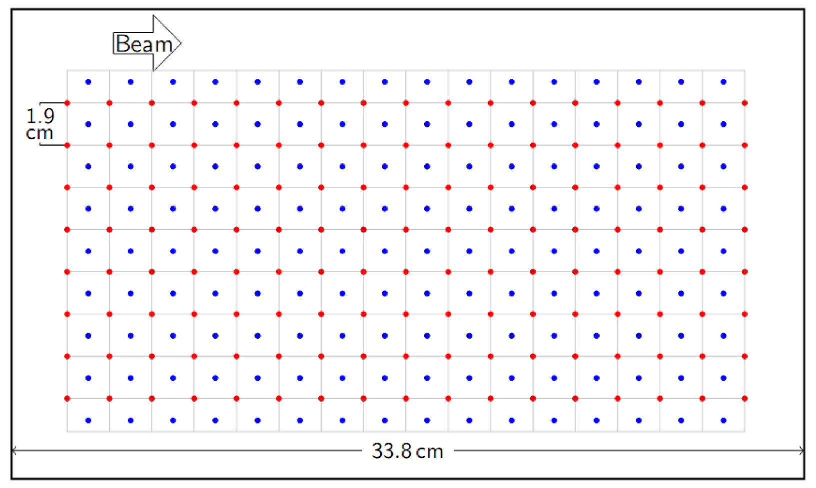
- Spin flipper with transverse windings allows for both longitudinal and transverse spin rotation.
- It's basically a cosine theta coil.
- The spin flip happens through Larmor precession plus Rabi oscillation.
- The neutrons enter the experiment with a transverse polarization.
- ^{3}He transmission polarimetry is performed once every month to make sure the persistent performance of the spin flipper.





Ion Chamber / Detector

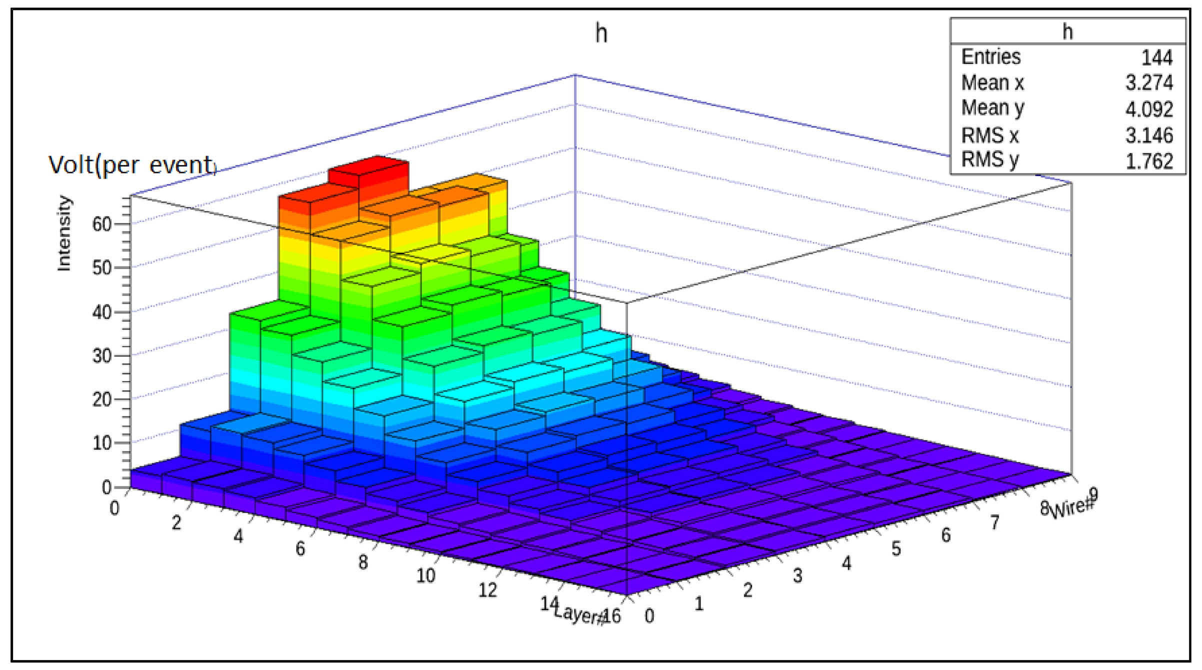




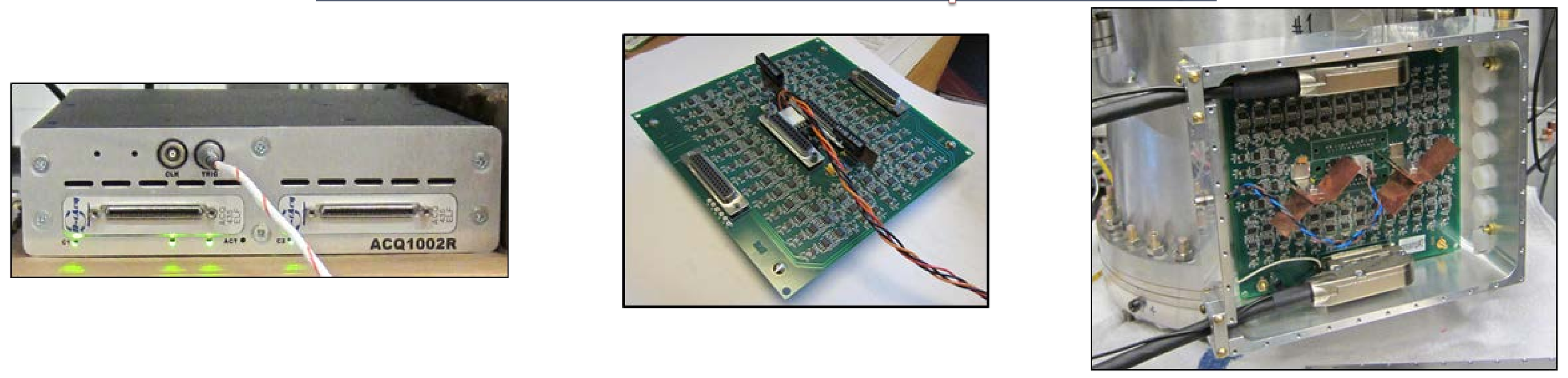
- HV 17 HV Frames with 8 wires each
- Signal 16 signal Frames with 9 wires each

- The ion chamber acts both as target and detector.
- The detector works in current mode.
- The ion chamber is filled with ^{3}He at 0.5 atm.
- Inside the chamber we have 17 high voltage frames with 8 wires per frame.
- It also has 16 signal frames with 9 wires each.

The bottom plots shows the intensity distribution among all the 144 signal wires for one neutron pulse.

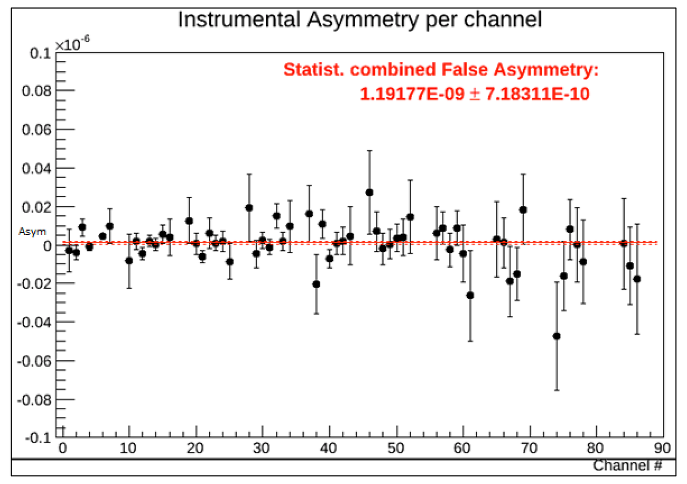


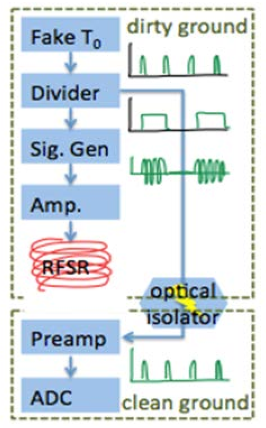
Readout Electronics : Preamp and DAQ



The current from each signal wire is converted to voltage using the current to voltage amplifier which was designed at Oak Ridge. The voltages are then digitized using the 24 bit delta-sigma ADC from d-tacq. These are ADCs with high channel density and simultaneous input. It can run as fast as 128 KHz. Each ADC has 48 channels. We have five of them, four having detector signals and one having beam monitor and RFSF signal.

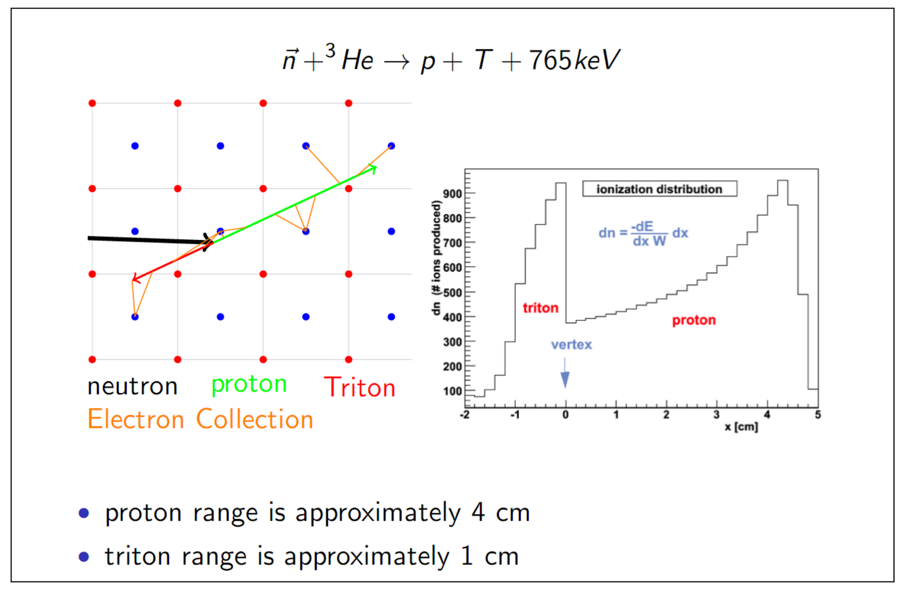
While our desired goal of precision puts stringent constraint on instrumental asymmetry, a combined performance of the DAQs with the pre-amps shows that with five hours of data we achieve instrumental asymmetry of the order of 10^{-10}.
The lower right sketch shows a test setup to check the instrumental asymmetry even in the worst possible case.
The lower left plot shows the outcome from this instrumental asymmetry test.





Asymmetry Estimation and Statistics

The diagram on the right with track shows the physics going on inside the chamber. When neutron hits the helium in the chamber it produces triton and proton having opposite tracks to conserve the momentum. While travelling through the chamber proton and triton induce charges around the signal wires which is then read by the readout electronics. The plot on the right shows the ionization distribution of proton and triton as they travel through the chamber.



- proton range is approximately 4 cm
- triton range is approximately 1 cm

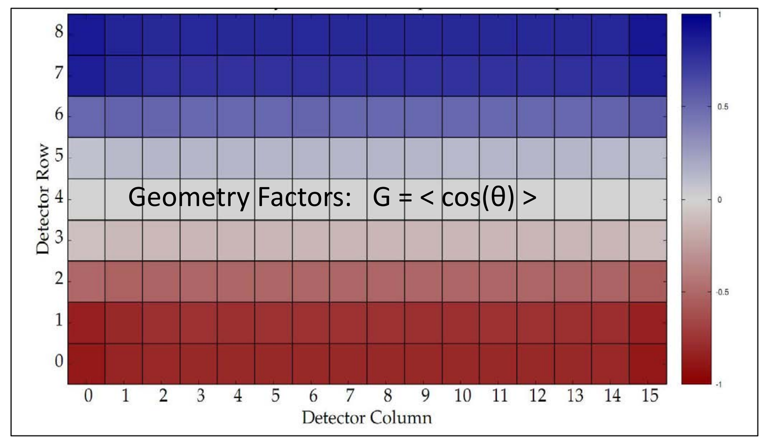
We can related the yield from the signal wire to our desired physics asymmetry as follows :

$$Y_\pm = Y_0(1 \pm P A_p \langle\cos\theta\rangle)$$

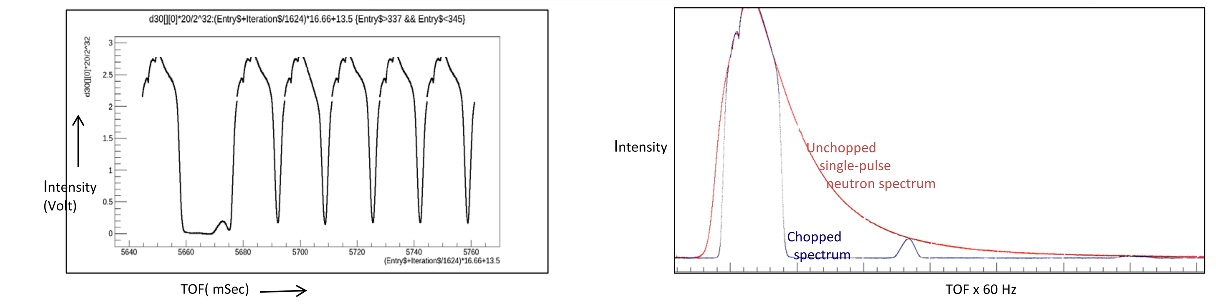
$$A_p = \frac{1}{P\langle\cos\theta\rangle} \frac{Y_+ - Y_-}{Y_+ + Y_-}$$

$$\delta A = \frac{\sigma_d}{P\sqrt{N}} \quad 2.9 < \sigma_d < 6$$

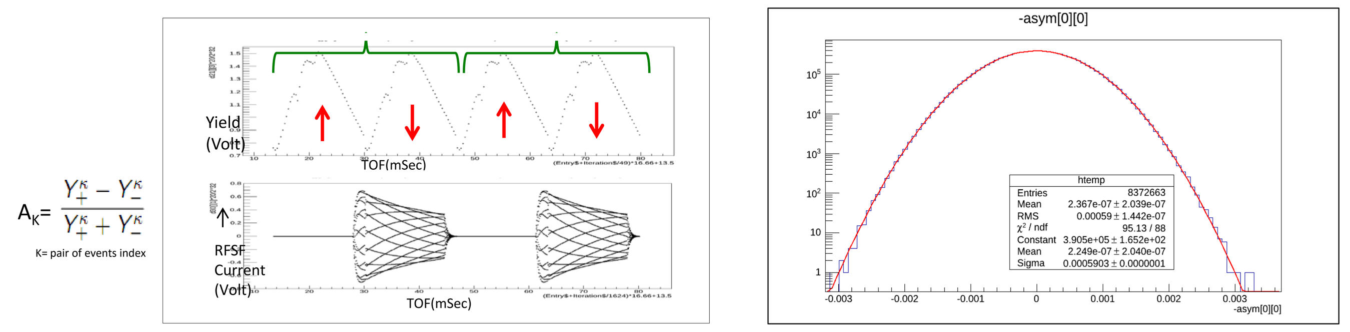
The average value of cosine theta in the expression is called geometry factor which arises because of the fact that our detector has a finite volume and as a result signal sensitivity is not uniformly distributed over all the signal wires.
We get the geometry factors through Monte Carlo simulations.



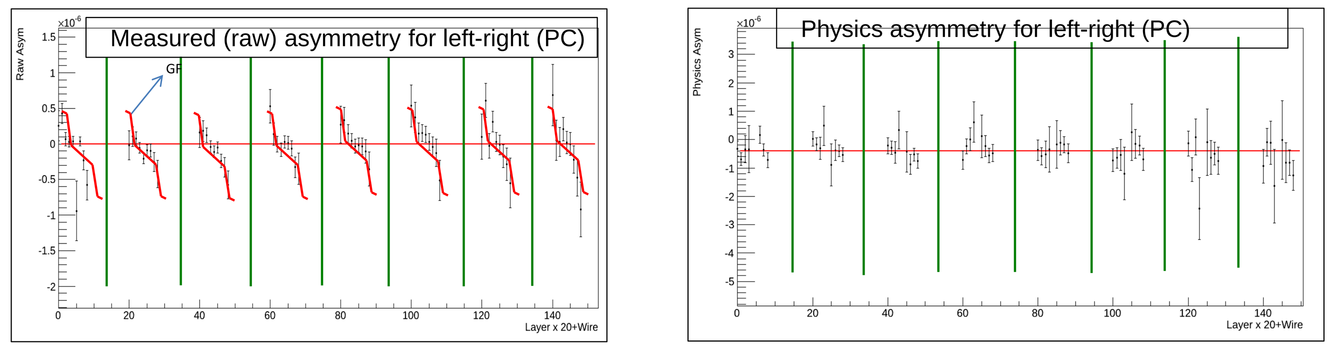
Asymmetry Extraction from Data



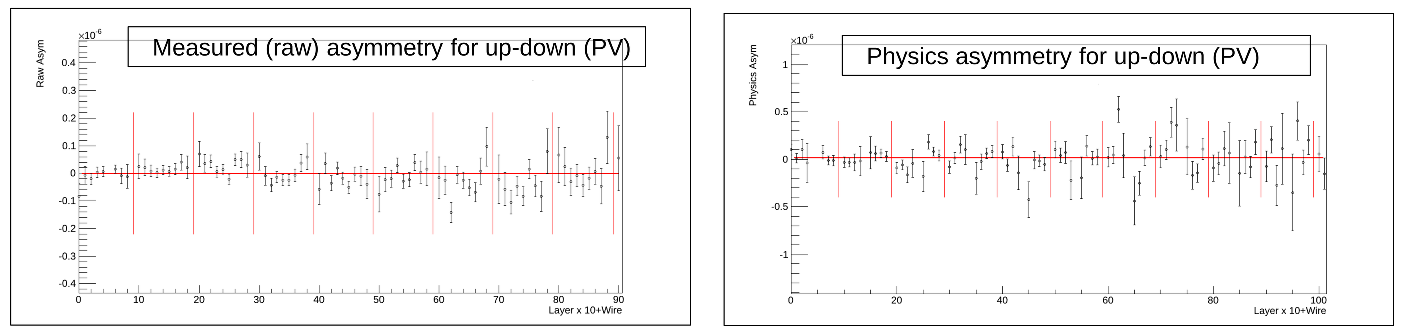
We construct the asymmetry for pair of events for each wire. But there are things that we need to be careful about in the analysis, for example -- dropped pulses, wraparound neutrons from dropped pulses, beam fluctuations and others. We exclude pulses around any dropped pulse. We also normalized each detector yield by sum of all the detector signals for that event to get rid of beam fluctuation. The lower right histogram is the distribution of the raw asymmetry for one of the signal wires.



Preliminary Result



The upper left is the measured (raw) asymmetry for left-right (PC) case for the front wires. The red lines indicate the trend of the geometry factor. So we see that the trend matches data as we expect. If we normalize the measured asymmetry by the geometry factor then we get the physics asymmetry as shown in the upper and lower left plots. Once we apply the geometry factor the asymmetries become almost flat. The lower two plots are measured and physics asymmetry for up-down (PV) case.



Correlations and Systematics

The final step is to calculate the overall physics asymmetry and its uncertainty out of all the signal wires. Now for each proton and triton pair produced from one event inside the chamber, they can contribute for energy deposition to more than one cell, meaning the wires are correlated. So we need to correct for that. The formalism we follow is : we diagonalize our covariance matrix as --

$$S^TCS = D$$

Where , C is the variance matrix and D is diagonal matrix. D is related to the weight as $W = D^{-1}$.
Now we transform both our data and fit to this orthogonal basis , so that in this new basis they are uncorrelated. But the fit $\bar{A} = Xb$ is no more flat as a consequence.

$$\bar{A}^{tot} = (X^TWX)^{-1}X^TW\bar{A}$$
$$(\Delta\bar{A}^{tot})^2 = (X^TWX)^{-1}$$
$$\chi^2 = (\bar{A} - \bar{A}^{tot})^T W (\bar{A} - \bar{A}^{tot})$$

So we modify the above relations with A $\longrightarrow$ S^TA & X $\longrightarrow$ S^TX to get overall physics asymmetry and it's error with correlations taken care of.
The table on the right lists all the systematics for the experiment.

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
$\vec{\sigma}_n \cdot \vec{k}_n$	Odd	1×10^{-11}	Neutron beta decay