Final Results for the n3He Parity Violating Asymmetry Measurement

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for the n3He Collaboration

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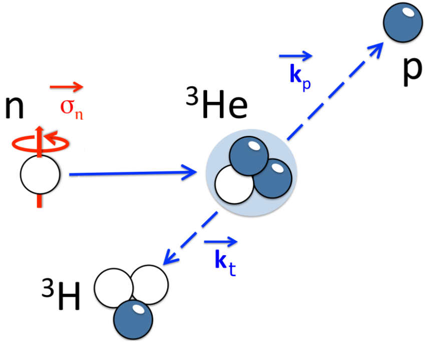
n3He Introduction

The n3He experimental goal was to make a high precision measurement of the parity violating directional asymmetry in the proton emission direction from the reaction

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



Theoretical Calculations

- DDH Reasonable Range

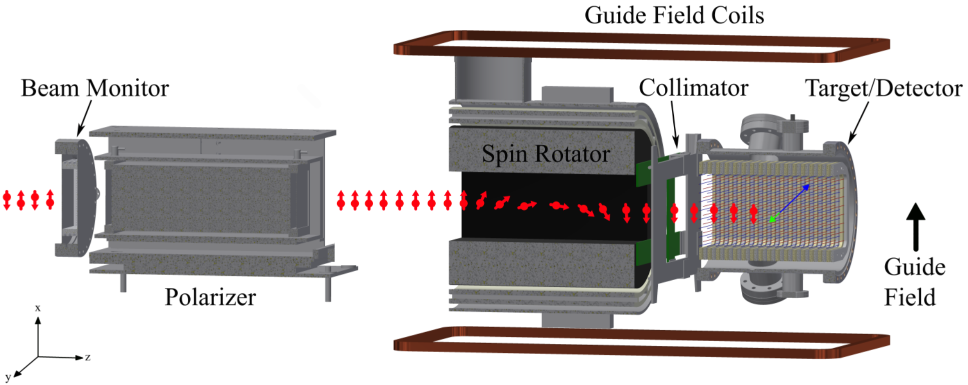
$$A_{PV}(th) = -0.185h_{\pi}^{1} + 0.050h_{\omega}^{1} + 0.023h_{\rho}^{1} - 0.023h_{\omega}^{0} - 0.038h_{\rho}^{0} - 0.001h^{2}\rho \quad (1)$$
$$A_{PV}(th) = \left(-0.6^{+8.3}_{-10.7}\right) \times 10^{-8} \quad (2)$$

  - M Viviani, R Schiavilla, Phys. Rev. C. 82 044001 (2010)
  - L. Girlanda et al. Phys. Rev. Letters 105 232502 (2010)
- EFT Calculations of the Asymmetry with a cutoff of $\lambda = 550$
  - Evaluation of the weak matrix elements in terms of χ^{PT} EFT:

$$A_{PV}(th) = \left(2.1^{+13.3}_{-10.6}\right) \times 10^{-8} \quad (3)$$

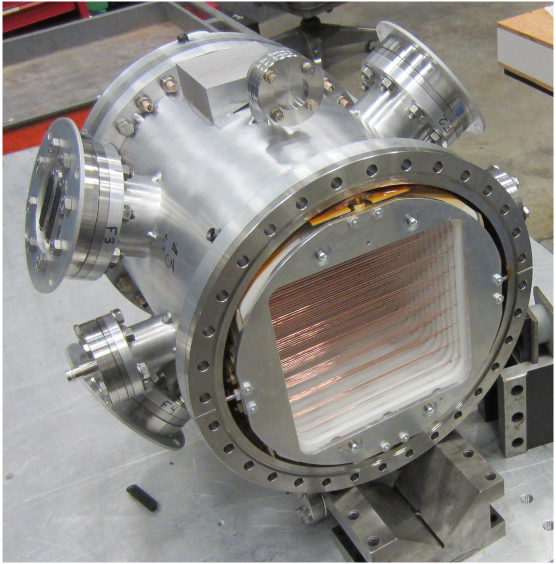
  - M. Viviani, et al Phys. Rev. C 89, 064004 (2014)
- Our goal was to measure the asymmetry to 2×10^{-8}.

n3He Schematic Diagram



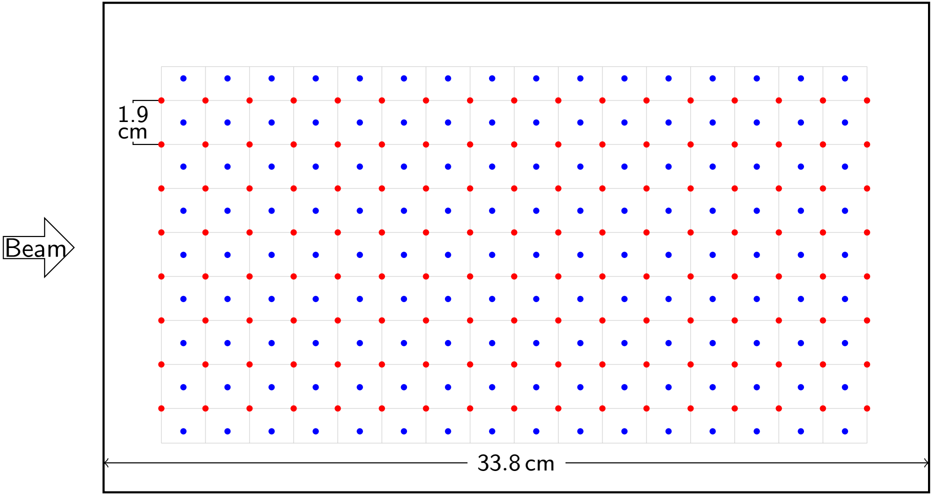
- Ran at the Spallation Neutron Source of the Oak Ridge National Laboratory (ORNL)
- 60 Hertz pulsed spallation source
- n3He took data during 2015 on the Fundamental Neutron Physics Beamline
- 20 K liquid hydrogen moderator to produce cold neutrons

Combined Target and Detector Chamber



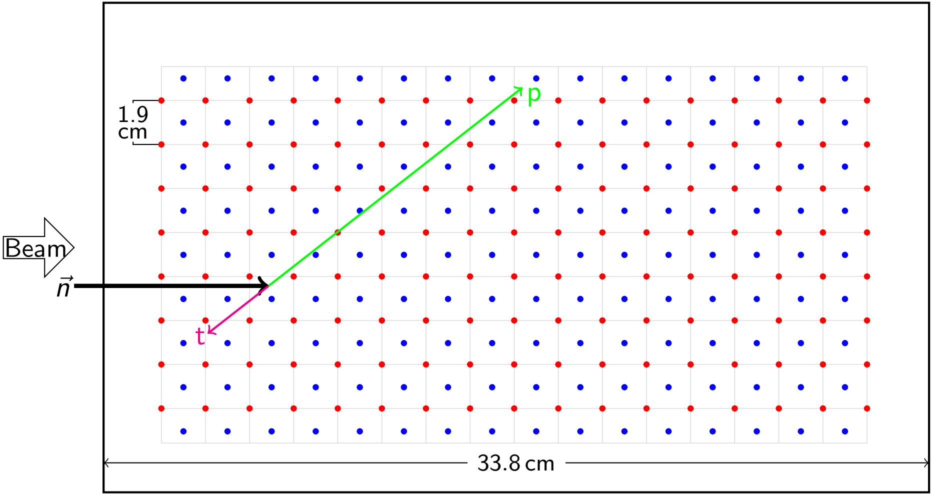
- Multi-wire proportional chamber
- Combined Target and Detector
- 0.43 atm pure He-3 fill gas
- operated near unity gain
- 9 wires per signal plane
- 16 signal planes
- 144 total signal wires

n3He Target Chamber Schematic



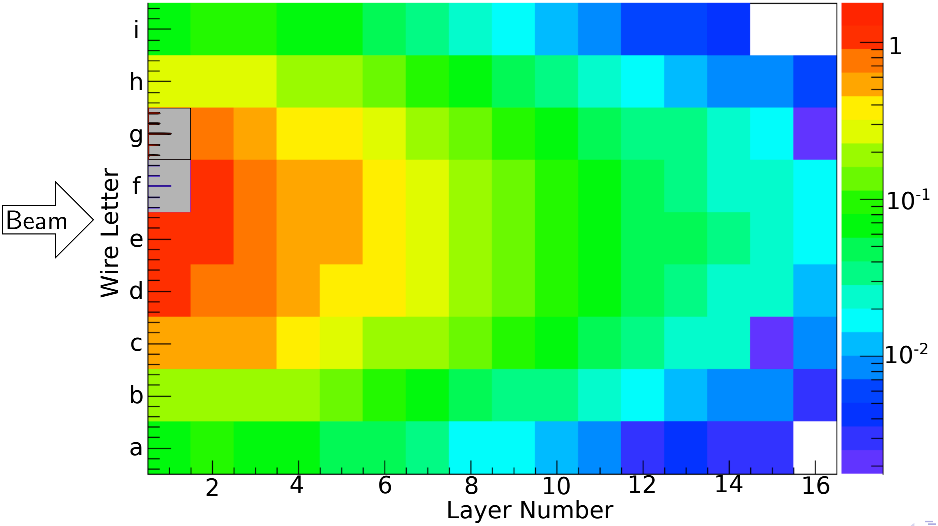
- HV   17 HV Frames with 8 wires each
- Signal   16 signal Frames with 9 wires each

Signal Formation in the Target Chamber

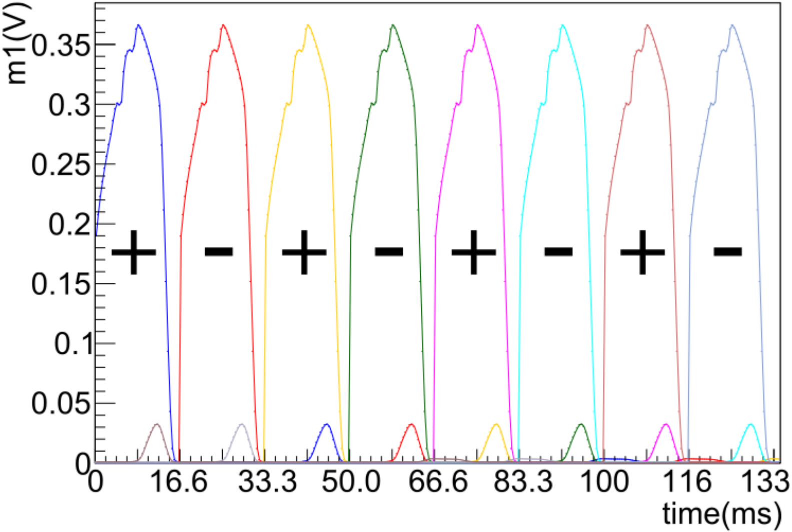


- HV — 17 HV Frames with 8 wires each
- Signal — 16 signal Frames with 9 wires each

Measured Charge Distribution in the Chamber



60 Hz Neutron Pulse Spin Sequence



- + indicates is a neutron pulse with the spin flipper off and the neutron polarization orientated parallel to gravity
- – indicates a pulse with the spin flipper on the neutron polarization anti-parallel
- Each line color indicates neutrons from one pulse.

Physics Asymmetry Calculations

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_c \left(1 + A_{PV}\cos\theta_{\vec{s}_n\cdot\vec{k}_p} + A_{PC}\cos\theta_{\vec{s}_n\times\vec{k}_n\cdot\vec{k}_p}\right) \tag{4}$$

$$Y^{+/-} = Y_0\left(1 \pm \epsilon P\left(A_{PV}G_{UD} + A_{PC}G_{LR}\right)\right) \tag{5}$$

$$P = \text{polarization}$$

$$\epsilon = \text{charge collection efficiency}$$

$$G = \text{geometry factor}$$

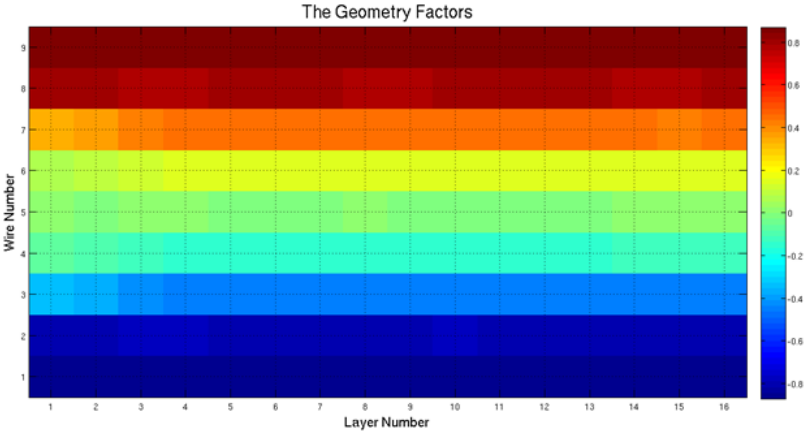
The single wire physics asymmetry is calculated for pairs of consecutive neutron pulses with the spin sequence $+-$:

$$A_{exp} = \frac{Y^+ - Y^-}{Y^+ + Y^-} \tag{6}$$

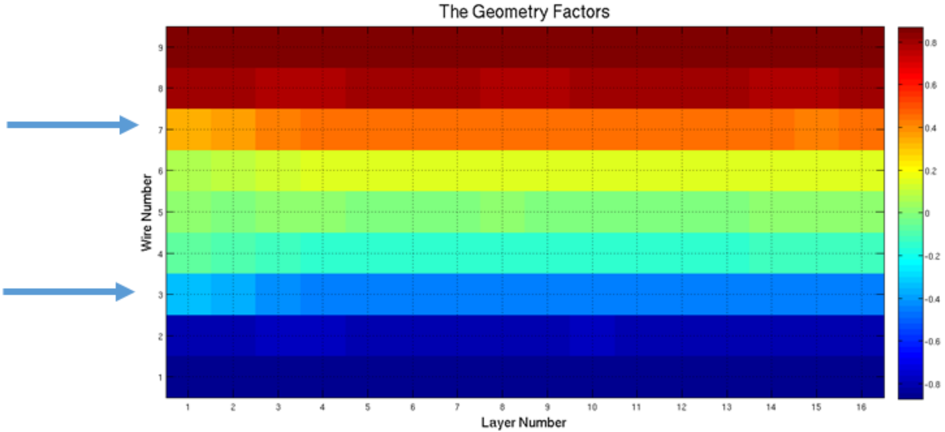
Corrections are required for the electronic pedestal $Y_i^{+/-} \rightarrow Y^{+/-} + p_i^{+/-}$ and beam stability.

Geometric Factors

$$G_i = \frac{\langle E_i \cos\theta \rangle}{\langle E_i \rangle} \tag{4}$$



$$G_i = \frac{\langle E_i \cos\theta \rangle}{\langle E_i \rangle} \tag{4}$$



Conjugate Pair Physics Asymmetry Calculation

By choosing pairs of wires that are opposite sides of the center of the target chamber such that $G_u = -G_d$, a wire pair asymmetry can be calculated that is less sensitive to the beam fluctuations than the single wire asymmetry.

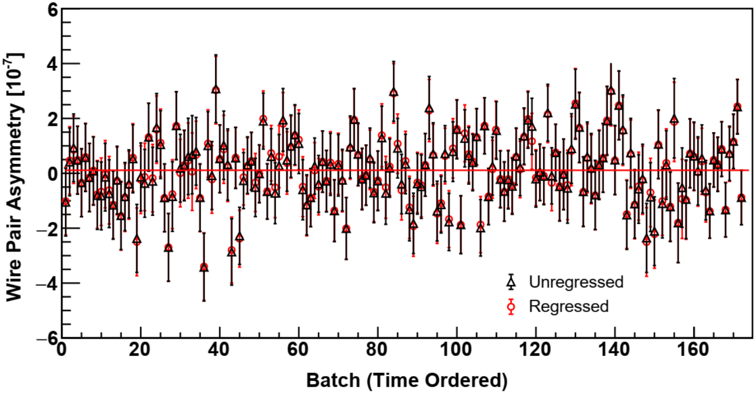
$$A_{exp} = \frac{Y_u^+ - Y_u^-}{Y_u^+ + Y_u^-} - \frac{Y_d^+ - Y_d^-}{Y_d^+ + Y_d^-} \tag{8}$$

$$\approx 2PG_uA_{PV} + \frac{p_u^+ - p_u^-}{Y_{0,u}^+ + Y_{0,u}^+} - \frac{p_d^+ - p_d^-}{Y_{0,d}^- + Y_{0,d}^-} + CA_{beam} \tag{9}$$

$$A_{beam} = \frac{Y_u^+ - Y_u^-}{Y_u^+ + Y_u^-} + \frac{Y_d^+ - Y_d^-}{Y_d^+ + Y_d^-} \tag{10}$$

and we can measure the pedestal and beam asymmetries for a given wire and then use linear regression to determine C.

Wire Pair Asymmetries - Batches



Asymmetries calculated by Michael Gericke.

- Asymmetries were calculated in batches of consecutive runs using wire pair asymmetries.
- Asymmetries were calculated over 600 pulse sequences coordinated with pulses intentionally dropped by the facility.
- A correction of less than 0.04×10^{-8} for beam fluctuations was made using regression analysis with the beam monitor data.

n3He Systematic Effects / background

TABLE I. Systematic Corrections and Errors.

Additive Sources	Comment	Correction [ppb]	Uncertainty [ppb]
Frame Twist (0 to 20 mrad)	compare simulation and data [13]	2.5	0.2
Electronic false asymmetry A_{ped}	measured [13]	0.0	2.0
Chamber field alignment	compare simulation and data [13]	0.0	1.2
Geometry factors	compare simulation and data [13]	0.0	0.5
Mott-Schwinger scattering	published calculation [25]	-0.24	0
Residual ^{3}He Polarization	calculation [13]	< 0.001	0
Background (β, γ)	simulation and calculation	$<< 0.1$	0
In-flight β-decay	calculation [10]	$<< 0.1$	0
Stern-Gerlach steering	measurement and calculation (≤ 2 mG/cm)	$<< 0.1$	0
Total		2.26	2.39

Multiplicative Sources	comment	Correction [$frac.$]	Uncertainty [$frac.$]
Polarization	measurement [15, 20]	0.936	0.002
Spin-flip efficiency	measurement [15, 20]	0.998	0.001

Source: M.T. Gericke et al. (n3He Collaboration) Phys. Rev. Lett. 125, 131803 – Published 23 September 2020

Measured Asymmetries

$$A_{PV} = (1.58 \pm 0.97(stat) \pm 0.24(sys)) \times 10^{-8}$$
$$A_{PC} = (-43.7 \pm 5.9(stat) \pm 0.43(sys)) \times 10^{-8}$$

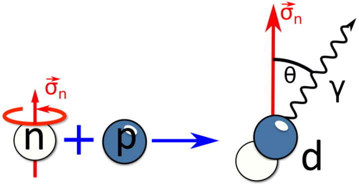
- The systematic uncertainty in the experimental result is small compared to the statistical uncertainty.
- The goal accuracy of the experiment has been reached.
- Note: the PC asymmetry is energy depdendent
- First Precision Measurement of the Parity Violating Asymmetry in Cold Neutron Capture on ^{3}He, M.T. Gericke et al. (n3He Collaboration) Phys. Rev. Lett. 125, 131803 – Published 23 September 2020

[0]This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics under Award Number DE-SC0014622.

NPDGamma Experiment

The NPDGamma experimental goal was to make a high precision measurement of the parity violating directional asymmetry in the γ-ray emission direction relative to the incoming neutron polarization from the reaction

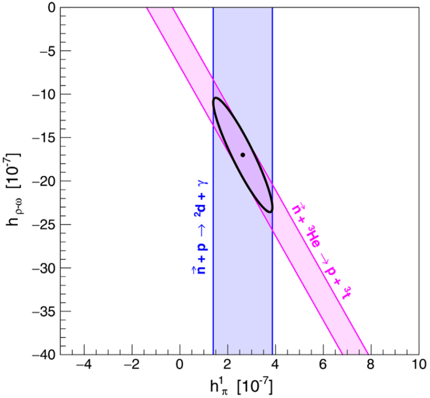
$$\vec{n} + p \rightarrow d + \gamma$$



- $A_{\gamma}^{np} = -0.114 h_{\pi}^{1} - 0.001 h_{\rho}^{1} + 0.002 h_{\omega}^{1}$
- $A_{\gamma}^{np} = (-3.0 \pm 1.4(stat.) \pm 0.2(sys.)) \times 10^{-8}$
- $h_{\pi}^{1} = (2.6 \pm 1.2(stat) \pm 0.2(sys)) \times 10^{-7}$
- First Observation of P-odd γ Asymmetry in Polarized Neutron Capture on Hydrogen, D. Blyth et al. Phys. Rev. Lett. 121, 242002 – Published Dec. 2018

Conclusions

- As both NPDGamma and n3He have calculations in the DDH model with small model uncertainties so they can be used to constrain the model parameters.
- Assuming the DDH values for the $\Delta I = 1$ and 2 couplings, we can estimate the size of the $\Delta I = 0$ terms:



$$h_{\rho-\omega} \equiv h^0_\rho + 0.605 h^0_\omega - 0.605 h^1_\rho - 1.316 h^1 \omega + 0.026 h^2 \rho = (-17.0 \pm 6.56) \times 10^{-7} \quad (11)$$

Conclusions

- n3He and NPDGamma set the constraint:

$$h_\rho^0 + 0.605 h_\omega^0 = (-17.0 \pm 6.56) \times 10^{-7}$$

- From the analysis in Haxton and Holstein Prog. Part. Nucl. Phys. 71, 185 (2013):

$$h_\rho^0 + 0.7 h_\omega^0 = -25.9^{+6.1}_{-6.0} \times 10^{-7} \qquad (12)$$

  using an independent data set of p-p and p-α scattering, with 18F data.
- The agreement between these two analysis supports a prediction from pionless EFT that the $\Delta I = 0$ couplings may be large.

n3He Collaboration

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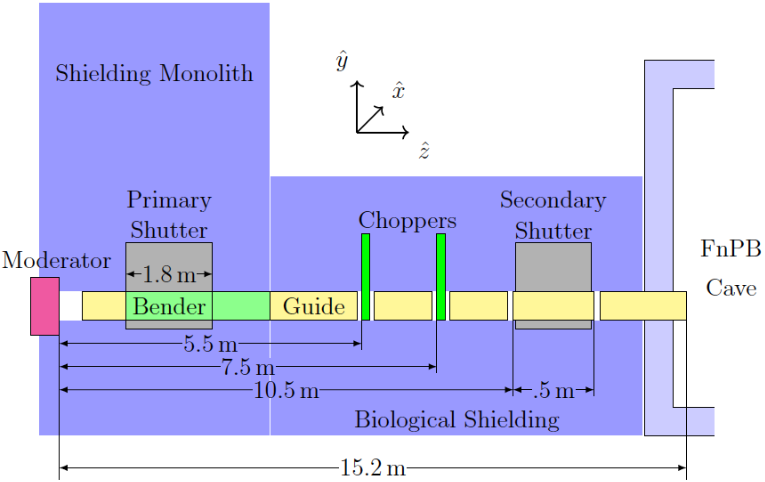
- Caleb Wickersham

University of Virginia
- S. Baessler

* students who received masters or Ph.D. degrees on the n3He Experiment

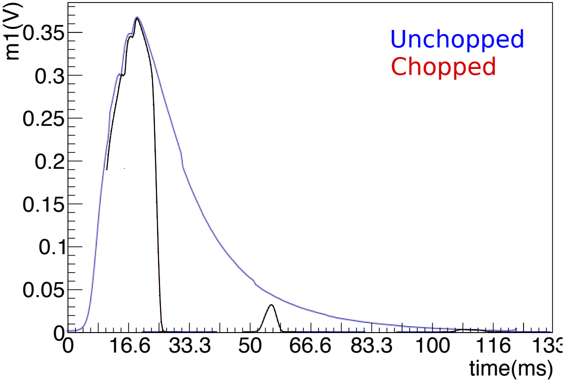
Additional Slides

FnPB Schematic

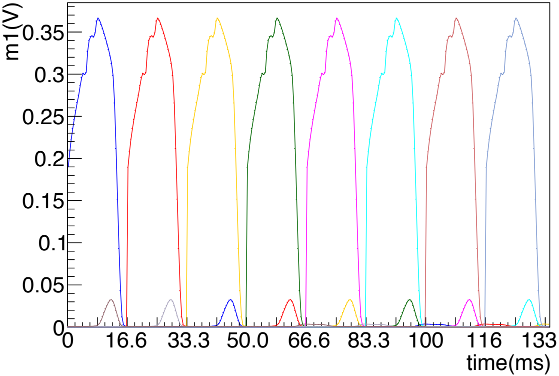


- n3He ran at the SNS FnPB at the Oak Ridge National Laboratory in Tennessee
- 60 Hertz pulsed spallation source
- 20K liquid hydrogen moderator for cold neutron beam lines

Spallation Neutron Source Neutron Pulses



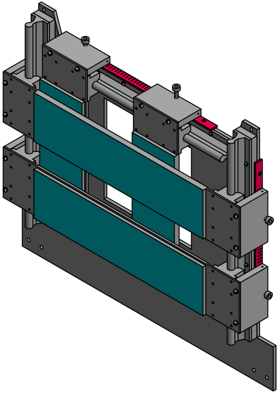
1 Hz Pulse

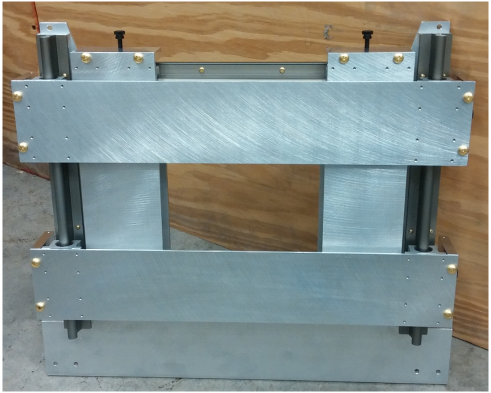


60 Hz Pulses

- located at the Oak Rdge National Laboratory (ORNL) in Tennessee
- 60 hertz pulsed spallation source
- n3He will located at the FnPB
- 20k liquid hydrogen moderator for cold neutron beam lines

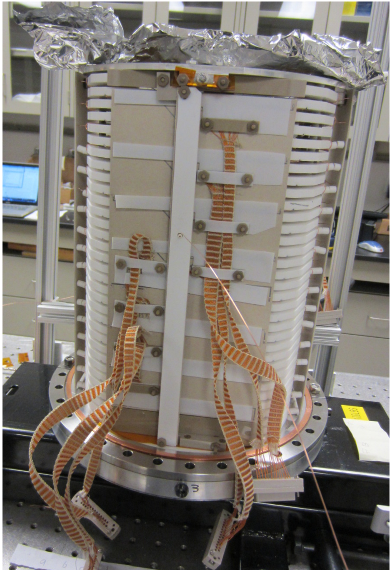
Collimator CAD Drawing





The jaws had a layer of Li loaded plastic over cadmium sheets to fully stop the neutrons.

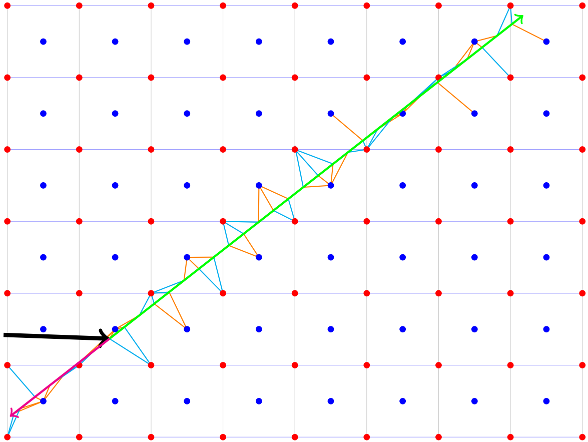
Target Chamber Assembled Frame Stack



- 17 HV frames
- 16 signal frames
- 9 signal wires per frame
- 144 signals to read out
- 0.02" diameter wires

Signal Formation in the Target Chamber

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



neutron
proton
Triton
Electron Collection
Ion Collection

Objects are to scale.

Run Statitics

- Parity Violating Runs
  - Runs: 31854
  - Number of Good Pulses: 690937760
  - Number of Cut Pulses: 78335992
- Parity Conserving Runs
  - Runs: 1110
  - Number of Good Pulses: 22529520
  - Number of Cut Pulses: 4468923
- 2500 neutron pulses per run
- 60 neutron pulses per second
- Approximately 10^{10} neutrons/second