The n3He experiment:
Hadronic parity violation in cold neutron capture on ^{3}He.

Spokespersons
D. Bowman (ORNL), C. Crawford (U. Kentucky), M. Gericke (U. Manitoba)

Project Manager
S. Penttila (ORNL)

S. Baessler (UVA), L. Barrón (UNAM),

J. Calarco (U. New Hampshire), V. Cianciolo (ORNL), C. Coppola (U. Tennessee),

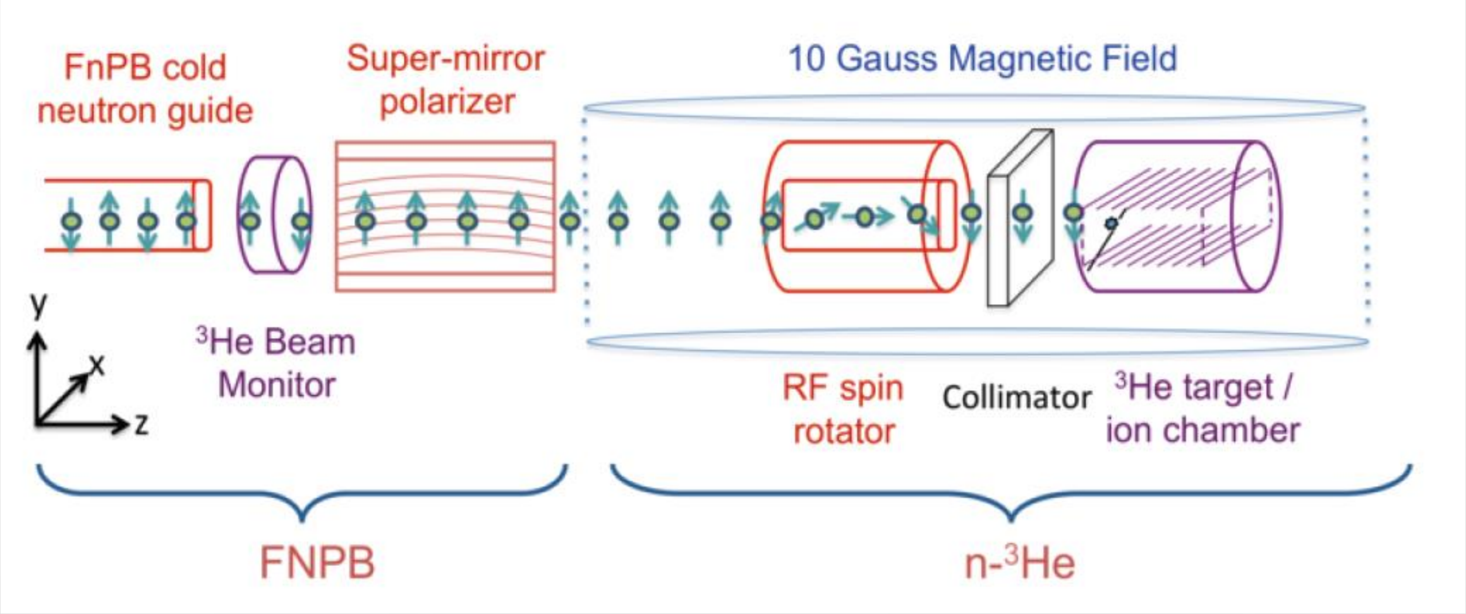
N. Fomin (U. Tennessee), I. Garishvili (U. Tennessee),

G. Greene (ORNL), J. Hamblen (U. Tennessee Chattanooga),

C. Hayes (U. Tennessee), K. Latiful (U Kentucky), M. McCrea (U. Manitoba),

A.R. Morales (UNAM), P. Mueller (ORNL), I. Novikov (Western Kentucky), C. Wickersham (U. Tennessee Chattanooga)

$$\vec{n} + {}^{3}He \rightarrow T + p + 764\ keV$$



$$A_{PV}^{exp} = f_{exp}\left(A_{PV}\cos\theta_{\vec{s}_n \cdot \vec{k}_p} + A_{PC}\cos\phi_{\vec{s}_n \times \vec{k}_n \cdot \vec{k}_p}\right)$$

Proposal Goal:

- Measure the up-down PV spin asymmetry to ~$2\text{x}10^{-8}$
- Measure the left right PC spin asymmetry to ~$5\text{x}10^{-8}$

- **Full four-body calculation of strong scattering wave functions**
- **Evaluation of the weak matrix elements in terms of the DDH potential:**

$$A_{PV} = a_\pi^1 h_\pi^1 + a_\rho^0 h_\rho^0 + a_\rho^1 h_\rho^1 + a_\rho^2 h_\rho^2 + a_\omega^0 h_\omega^0 + a_\omega^1 h_\omega^1$$

DDH Weak Coupling	(A^p_Z) $n^3He \rightarrow tp$
a_π^1	-0.189
a_ρ^0	-0.036
a_ρ^1	0.019
a_ρ^2	-0.0006
a_ω^0	-0.0334
a_ω^1	0.0413

$$A_{PV}(th.) \approx (-9.4 \rightarrow 2.5) \times 10^{-8}$$

M. Viviani, R. Schiavilla, Phys. Rev. C. 82 044001 (2010)
L. Girlanda et al. Phys. Rev. Lett. 105 232502 (2010)

- **Full four-body calculation of strong scattering wave functions**
- **Evaluation of the weak matrix elements in terms of the EFT potential:**

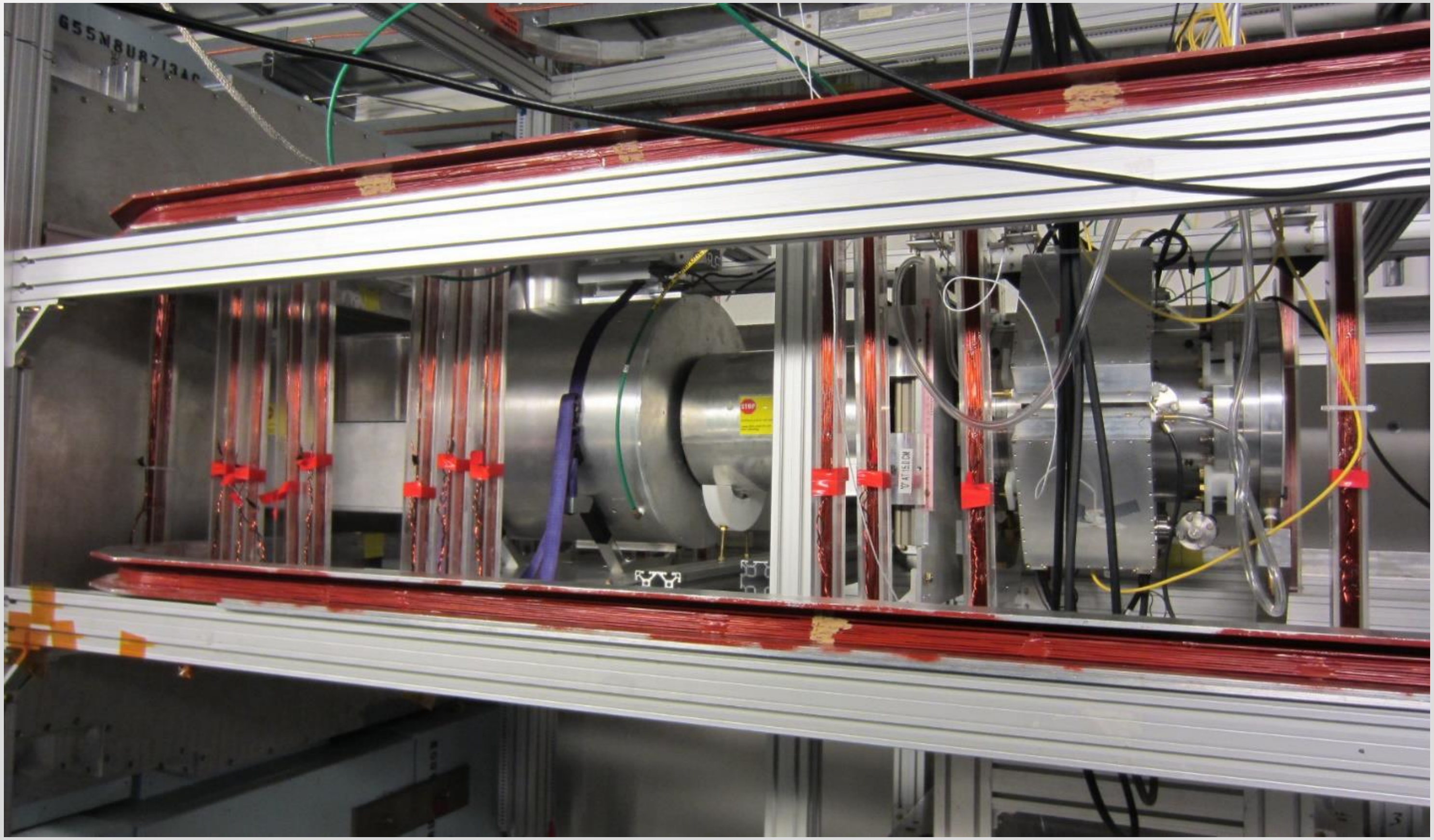
$$A_{PV} = a_0 h_\pi^1 + a_1 C_1 + a_2 C_2 + a_3 C_3 + a_4 C_4 + a_5 C_5$$

$$A_{PV}(th.) \approx 1.7 \times 10^{-8} \quad \Lambda = 500\ MeV$$

$$A_{PV}(th.) \approx 3.5 \times 10^{-8} \quad \Lambda = 600\ MeV$$

EFT coefficents	Λ = 500 MeV	Λ = 600 MeV
a_0	-0.1444	-0.1293
a_1	0.0061	0.0081
a_2	0.0226	0.0320
a_3	-0.0199	-0.0161
a_4	-0.0174	-0.0156
a_5	-0.0005	-0.0001

M. Viviani, et al. Phys. Rev. C 89, 064004 (2014)

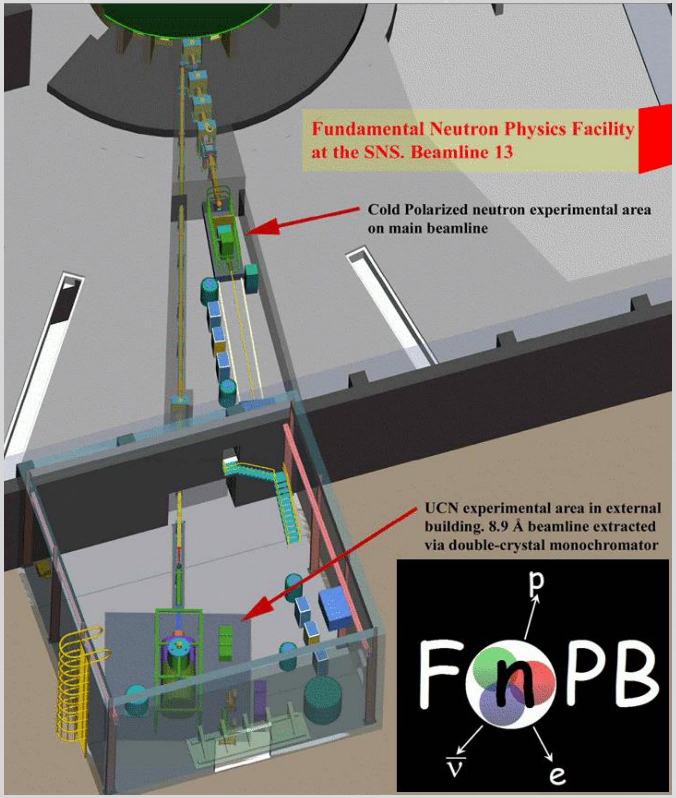


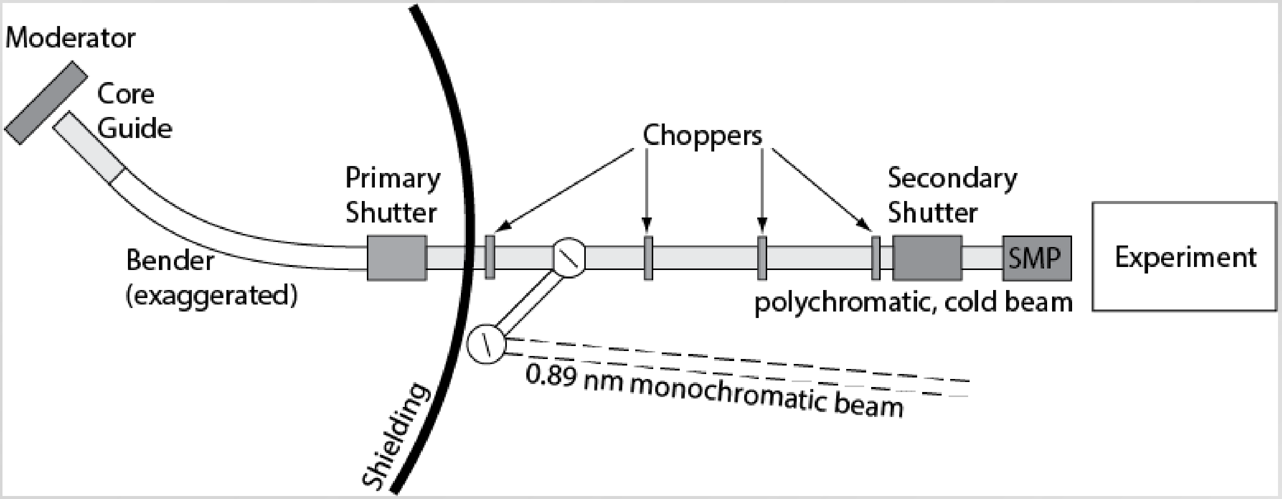
Proposal Goal:

- Measure the up-down PV spin asymmetry to ~2×10^{-8}
- Measure the left right PC spin asymmetry to ~5×10^{-8}

The Fundamental Neutron Physics Beam (FnPB)

- LH2 moderator
- 17 m long guide ~ 20 m to experiment
- one polyenergetic cold beam line
- one monoenergetic (0.89 nm) beam line
- ~ 40 m to nEDM UCN source
- 4 frame overlap choppers
- 60 Hz pulse repetition





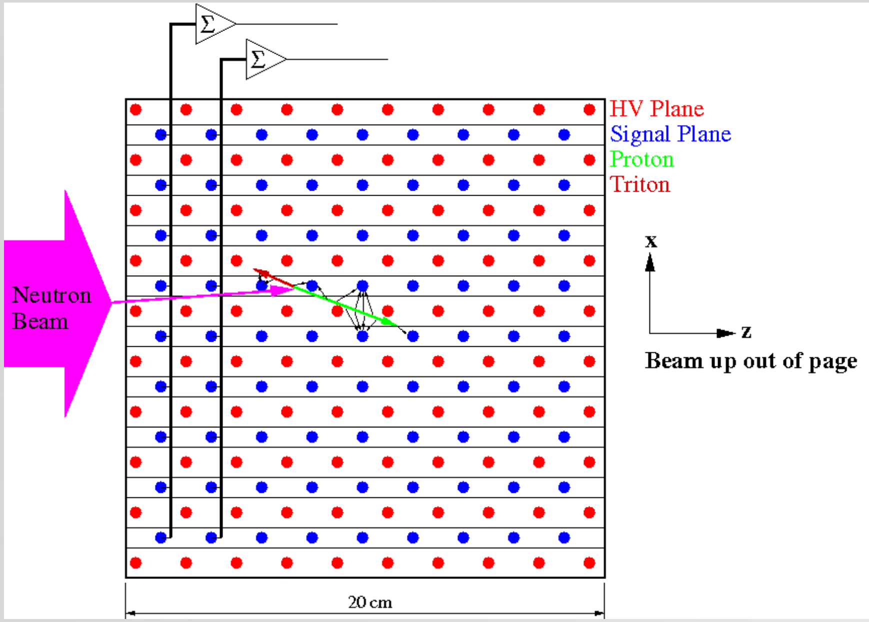
n^3He Principle of Measurement

Measure the asymmetry in the number of forward going protons in a ^3He wire chamber as a function of neutron spin:

$\vec{\sigma}_n \cdot \vec{k}_T$ Directional PV asymmetry in the number of tritons

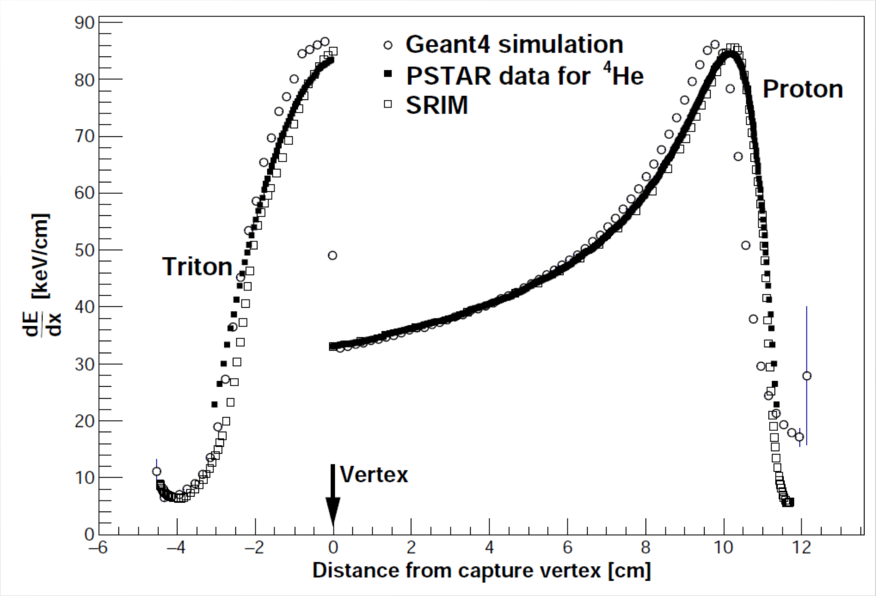
$\vec{\sigma}_n \cdot \vec{k}_p$ Directional PV asymmetry in the number of protons (much larger track length)

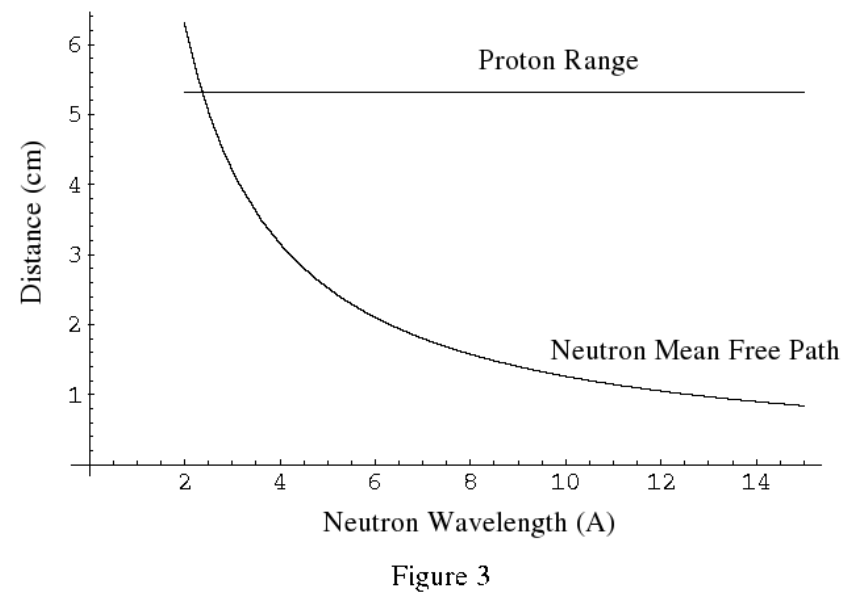
- wire chamber is both target and detector
- wires run vertical or horizontal
- no crossed wire: keep the field simple to avoid electron multiplication (non-linearities)



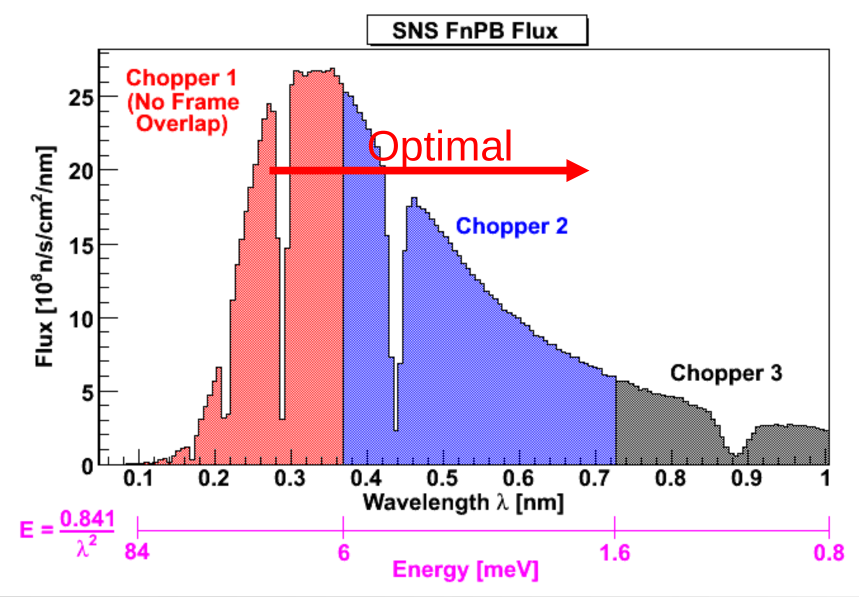
$$\vec{n} + {}^3\mathrm{He} \rightarrow \mathrm{p} + \mathrm{t} + 764\ \mathrm{keV}$$

n^3He Principle of Measurement



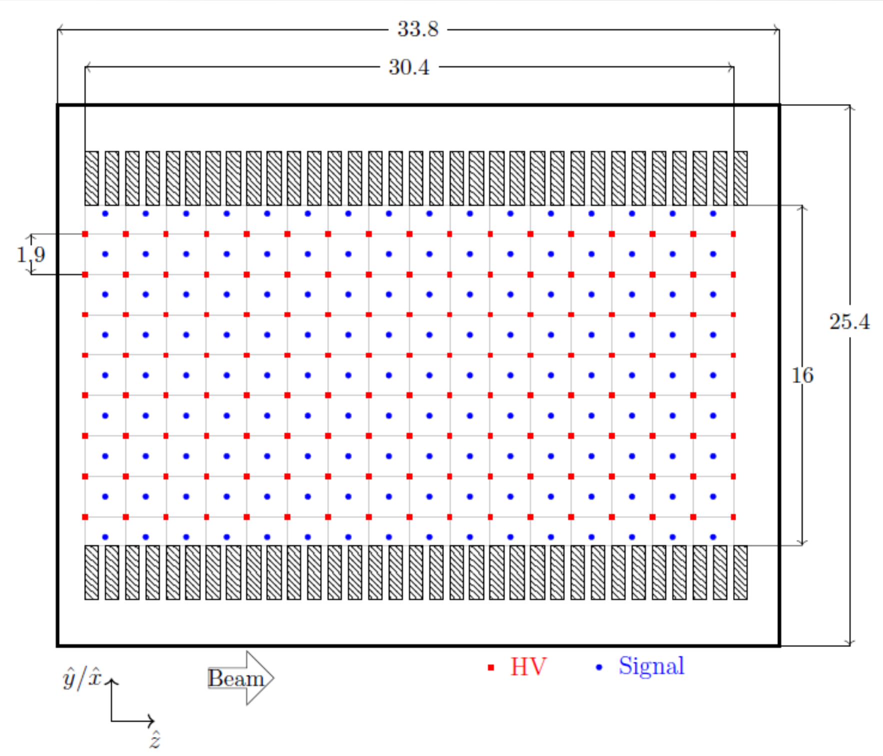


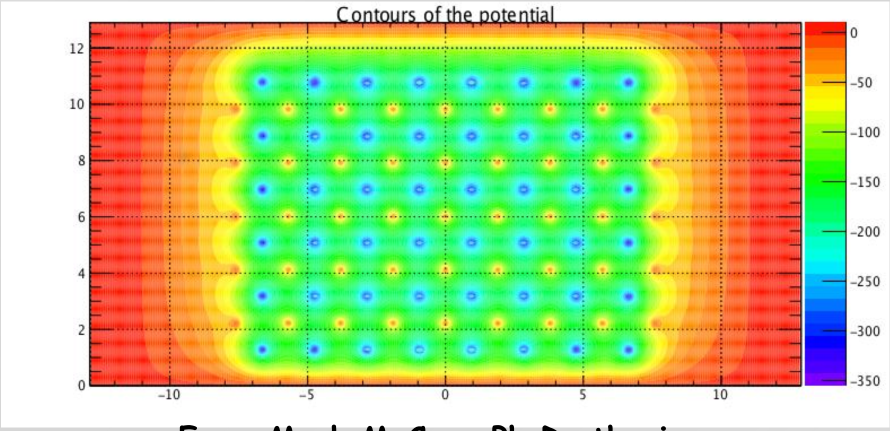
- Chamber filled with Helium 3
- Want to let protons range out
- Proton range r_p~10 cm
- Neutron mfp should be < r_p / 2
- Optimize wavelength range
- Maximize neutron beam intensity



n^3He Principle of Measurement

Split the ^3He target volume into 144 equally spaced cells using wires:





From Mark McCrea Ph.D. thesis.

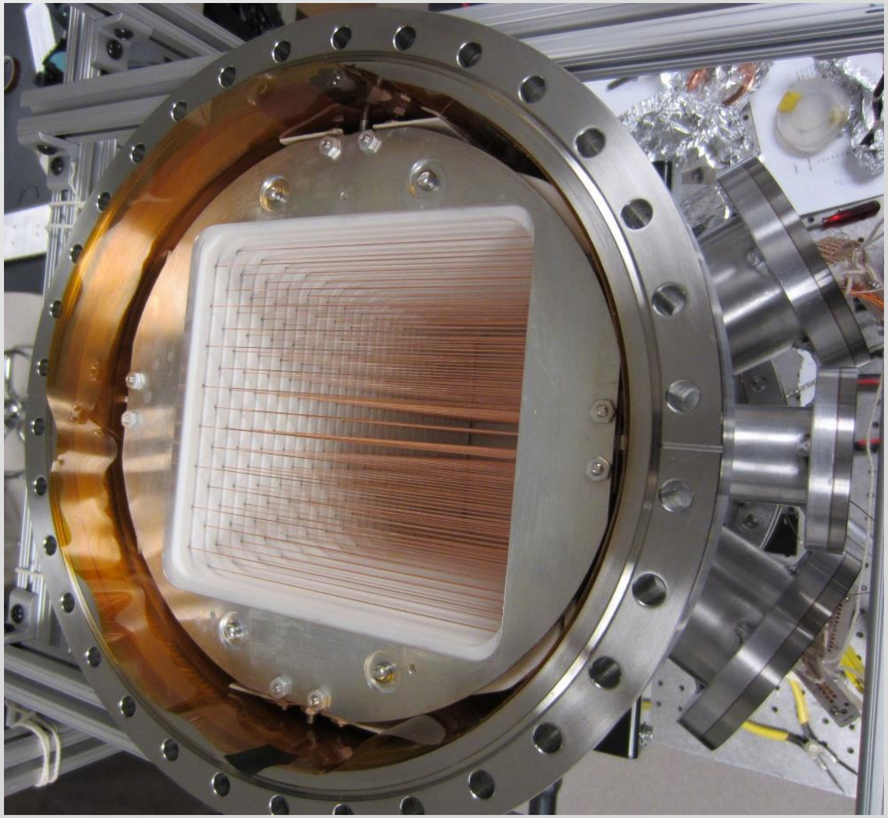
$$A_{raw} = \left(\frac{y^{\uparrow} - y^{\downarrow}}{y^{\uparrow} + y^{\downarrow}} \right)$$

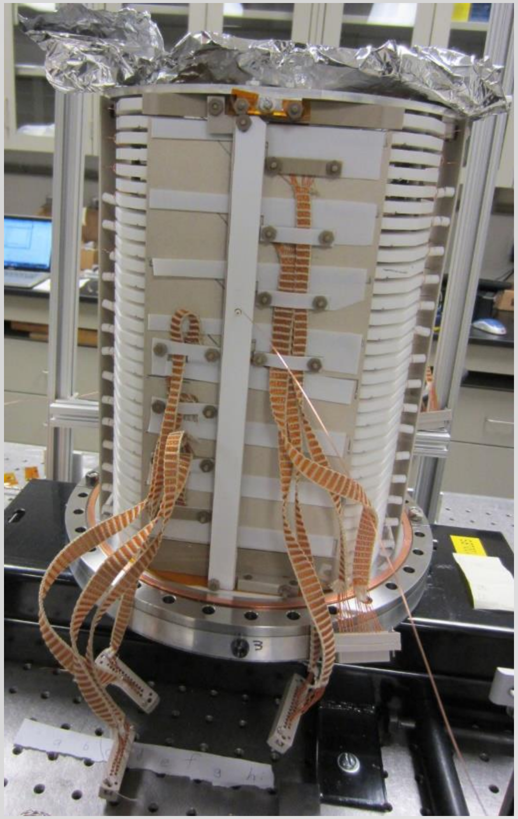
The asymmetry is determined either from the yield of a single wire for two different spin states, or

from the yield of two opposite (conjugate) wire pairs in the same spin state.

n³He Principle of Measurement

Target-Detector Chamber:

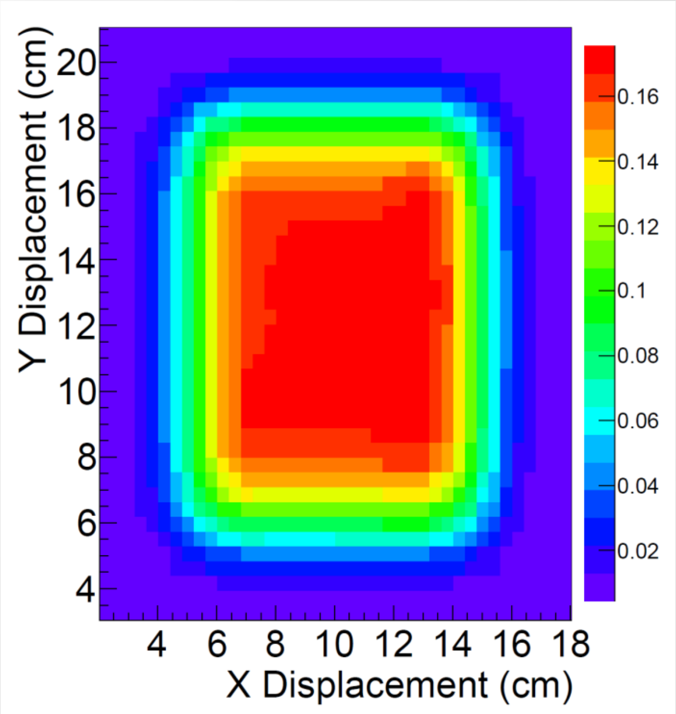


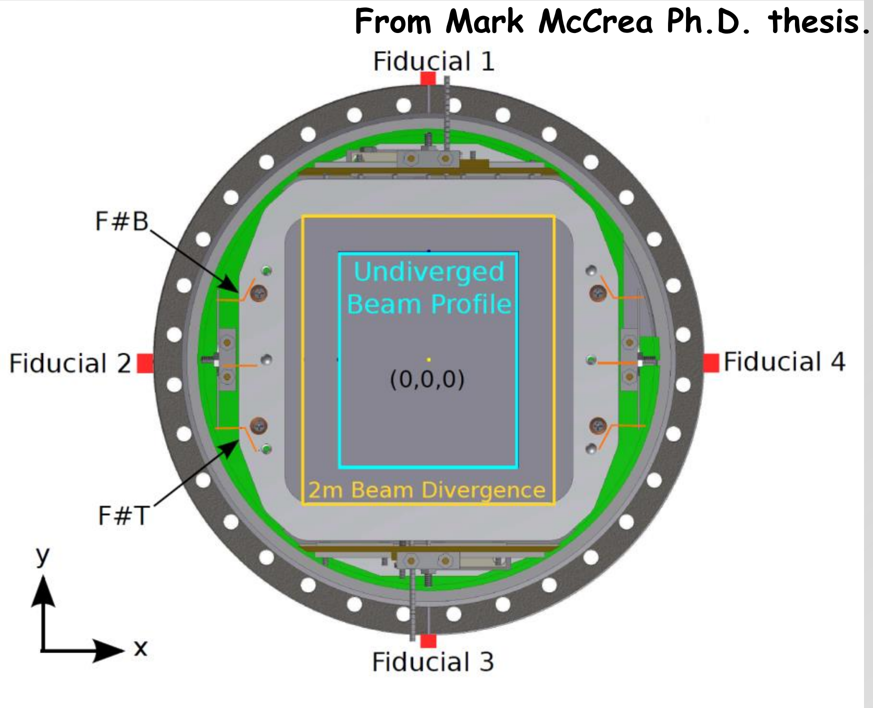


From Mark McCrea Ph.D. thesis.

n^3He Principle of Measurement

Beam Profile:

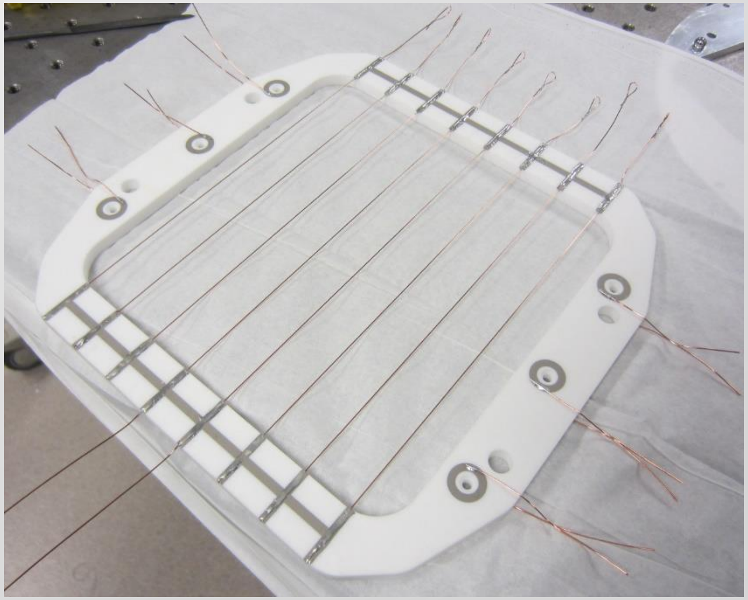


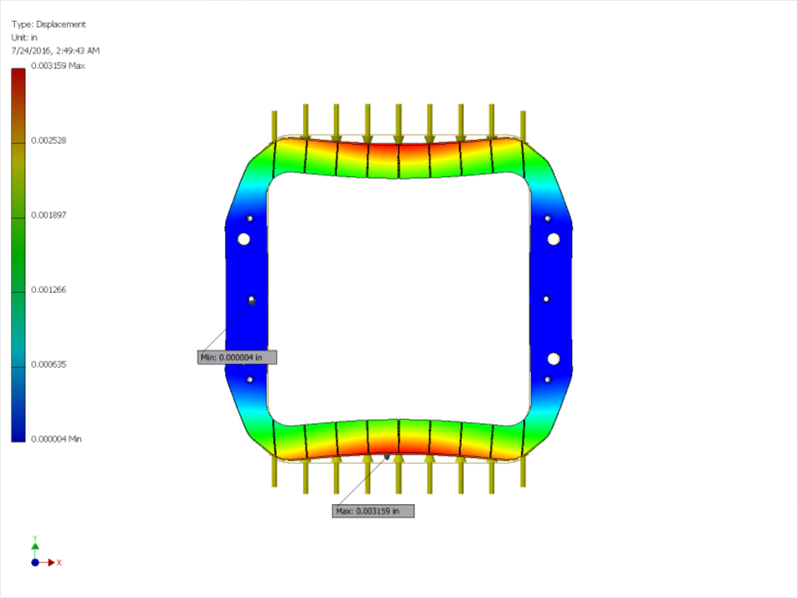


The size of the wire frame was designed to cover the beam profile including beam divergence.

n^3He Principle of Measurement

Target-Detector Chamber:

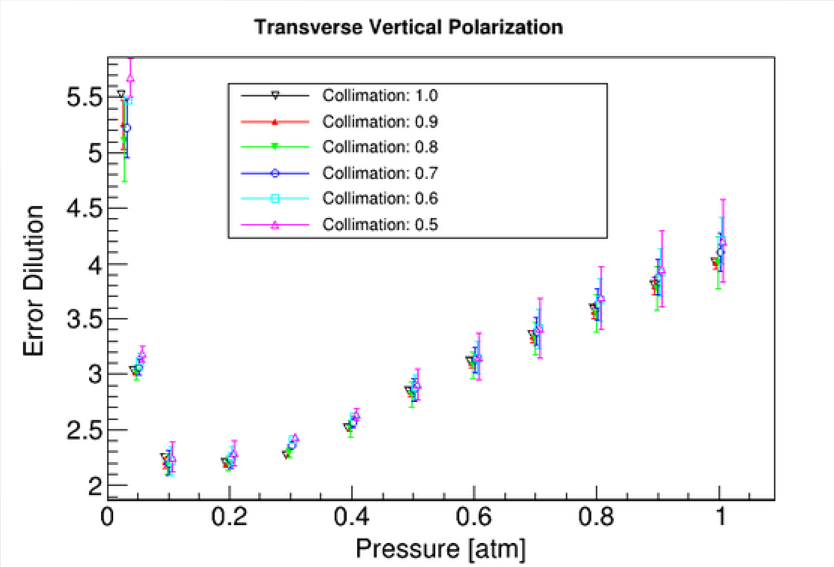


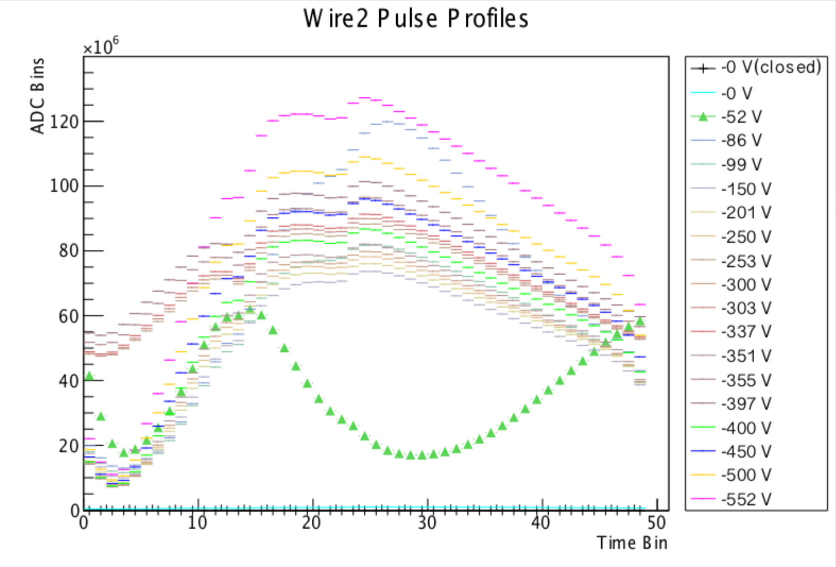


From Mark McCrea Ph.D. thesis.

n^3He Principle of Measurement

Target-Detector Chamber:

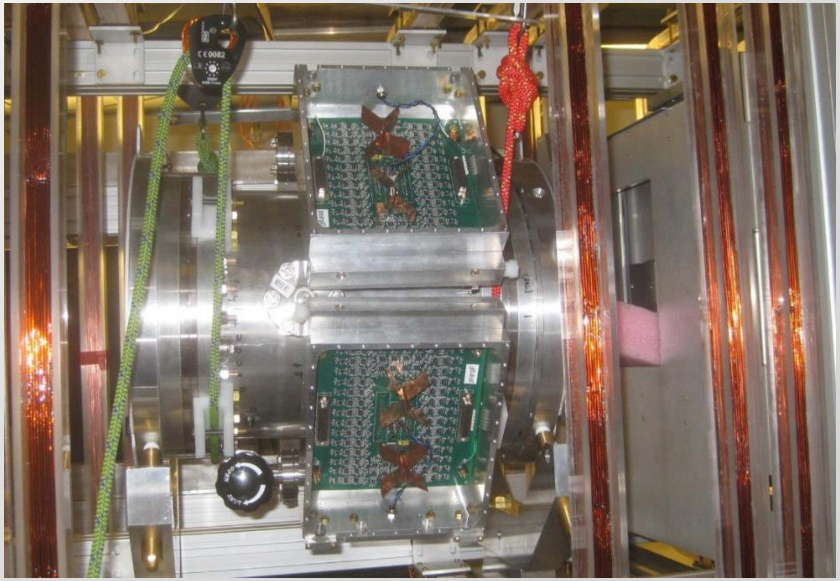


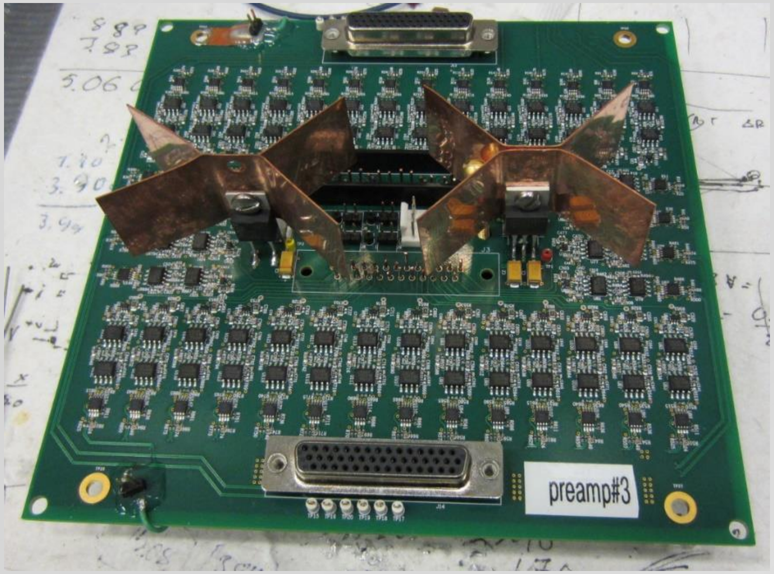


From Mark McCrea Ph.D. thesis.

n^3He Principle of Measurement

Target-Detector Chamber:





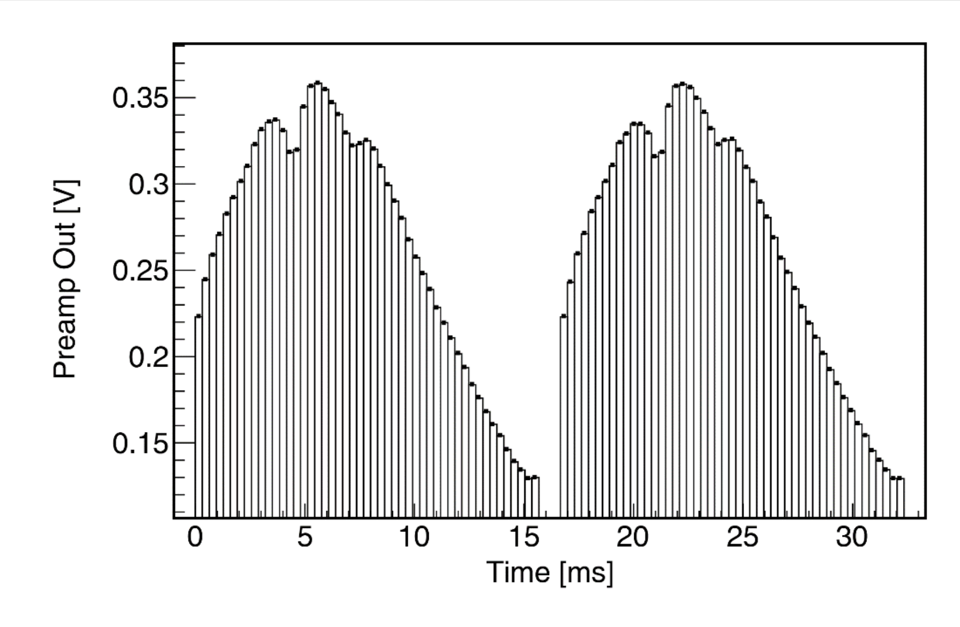
From Mark McCrea Ph.D. thesis.

Using trans-impedance amplifiers to convert signal wire current to voltage signal.

n^3He Principle of Measurement

Wire signal:

Two consecutive pulses:



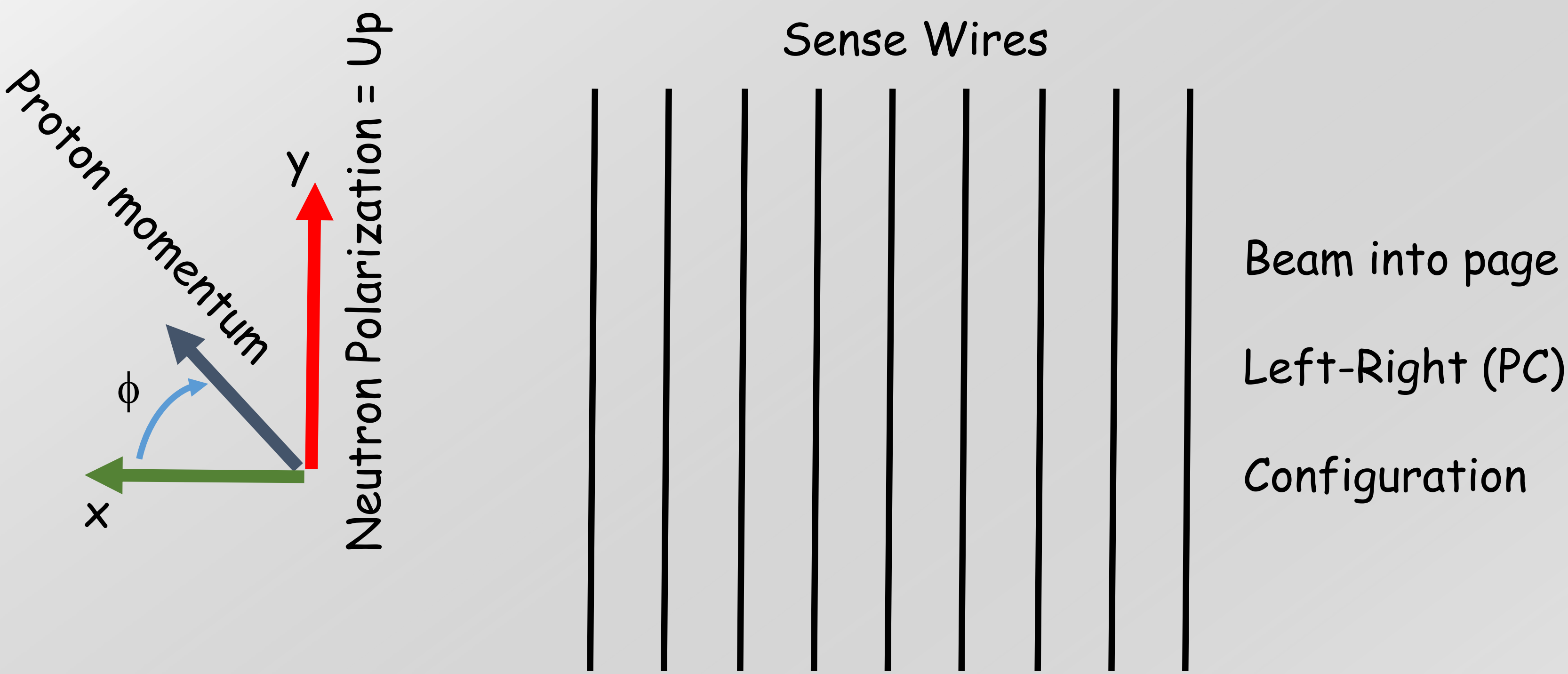
Each neutron pulse window signal yield is divided into 49 TOF bins of 0.34 ms width.

We usually integrate over the a TOF range within each pulse to get the wire yield.

PV asymmetry collected ~ 30000 good runs with 25000 pulses each.

n^3He Principle of Measurement

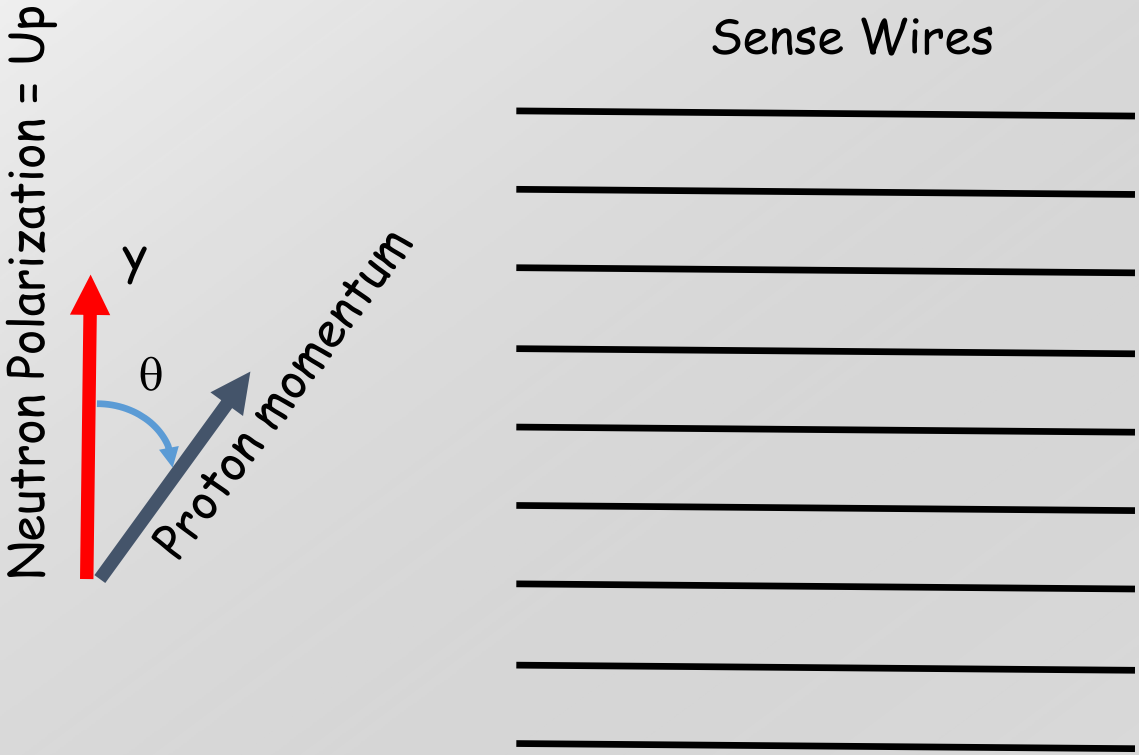
Measurement principle of the chamber:



$$A_{PV}^{exp} = f_{exp}\left(A_{PV}\cos\theta_{\vec{s}_n\cdot\vec{k}_p} + A_{PC}\cos\phi_{\vec{s}_n\times\vec{k}_n\cdot\vec{k}_p}\right)$$

n^3He Principle of Measurement

Measurement principle of the chamber:



Beam into page

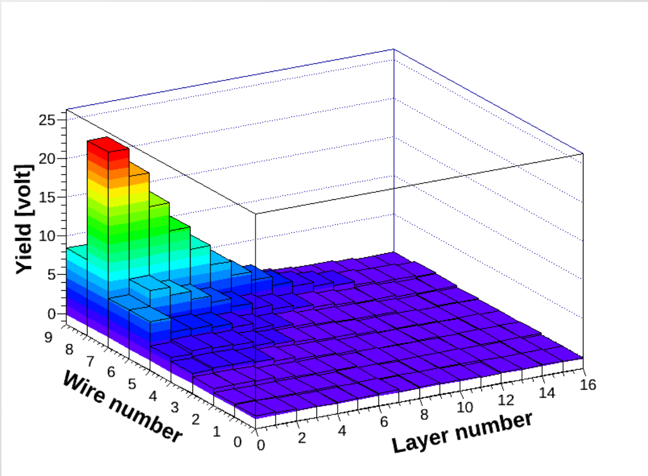
Up-Down (PV)

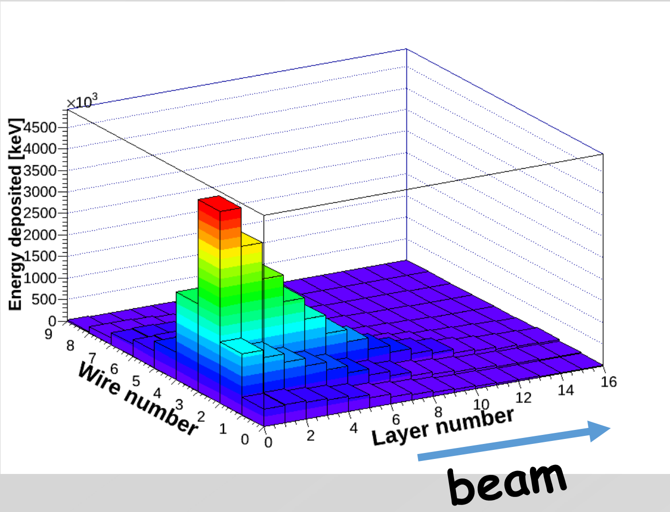
Configuration

$$A_{PV}^{exp} = f_{exp}\left(A_{PV}\cos\theta_{\vec{s}_n\cdot\vec{k}_p} + A_{PC}\cos\phi_{\vec{s}_n\times\vec{k}_n\cdot\vec{k}_p}\right)$$

n^3He Principle of Measurement

Finite geometry correction factors:

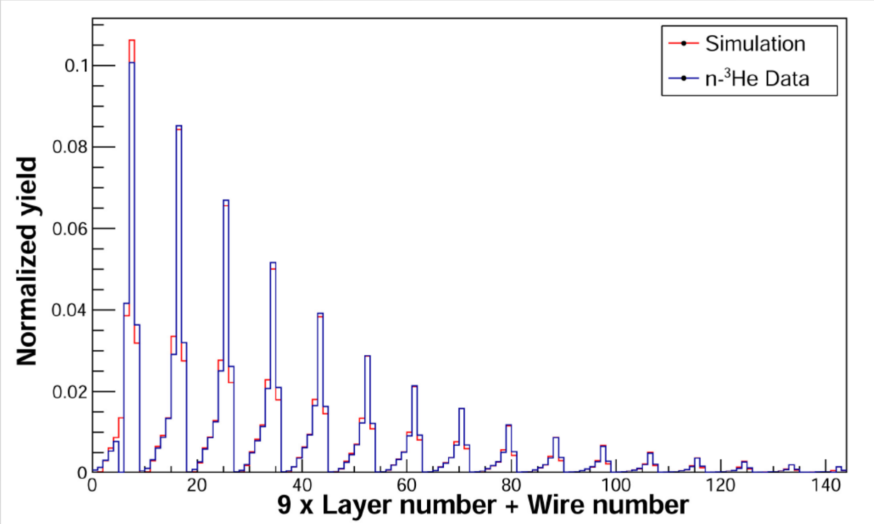




Comparisons between data and Simulation were used to verify the geometry effect of the chamber and the beam.

$$\cos\theta_{\vec{s}_n \cdot \vec{k}_p} \rightarrow G_{UD}$$

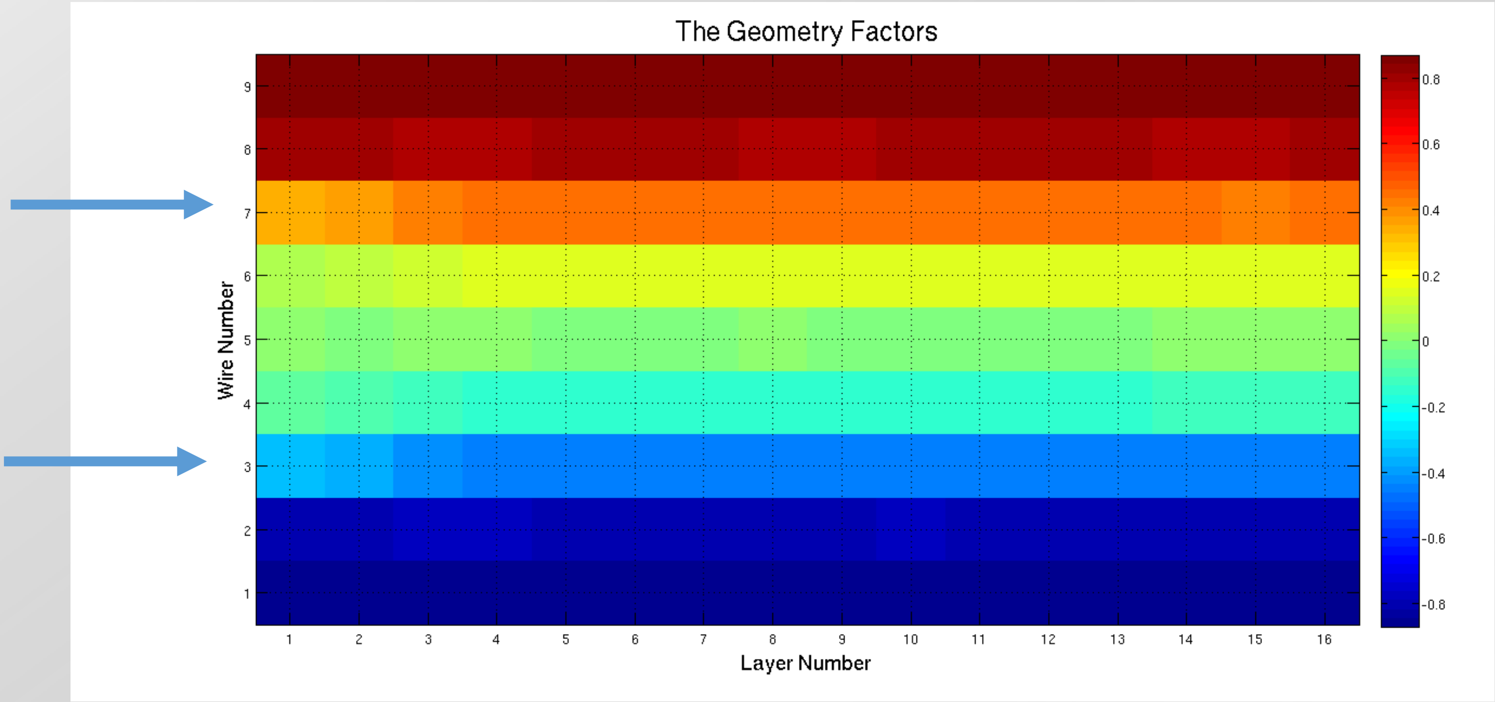
$$\cos\phi_{\vec{s}_n \times \vec{k}_n \cdot \vec{k}_p} \rightarrow G_{LR}$$



n^3He Principle of Measurement

Finite geometry correction factors:

Conjugate wire pair rows



$$A_{PV}^{exp} = f_{exp}\left(A_{PV}G_{UD} + A_{PC}G_{LR}\right)$$

n^3He Analysis

Detector wire yield:

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

$$\Rightarrow \quad y^{\pm} = Y_0\left(1 \pm \varepsilon P A_{PV} G_{UD} \pm \varepsilon P A_{PC} G_{LR}\right) \text{ per wire}$$

Raw asymmetry: $A_{raw} = \left(\frac{y^+ - y^-}{y^+ + y^-}\right)$ **(theoretically:** $\varepsilon P A_{PC/PV} = \left(\frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}\right)$ **)**

Things that one has to take care off:

- **Pedestals and possible electronic false asymmetries**
- **Beam fluctuations and associated false asymmetries**
- **Correlations between wires**

n^3He Analysis

Incorporating the pedestal and neutron beam intensity asymmetries in the analysis:

- **So the yield for wire (i)**

$$Y_i^{\pm} = Y_i^{o\pm}(1 \pm \varepsilon P g_i A_{PV}) + p_i^{\pm}$$

Leads to an asymmetry (from beam normalized yields)

$$A_{i,raw} = \varepsilon P g_i A_{PV} + \frac{1}{2}\left(\frac{p_i^+}{Y_i^{o+}} - \frac{p_i^-}{Y_i^{o-}}\right)$$

Define

$$A_{i,ped} = \frac{p_i^+ - p_i^-}{Y_i^{o+} + Y_i^{o-}}$$

pulse-pair beam off asymmetry

$$A_{Beam} = \frac{Y_i^{o+} - Y_i^{o-}}{Y_i^{o+} + Y_i^{o-}} = \frac{I^+ - I^-}{I^+ + I^-}$$

neutron beam intensity asymmetry

n^3He Analysis

Incorporating the pedestal and neutron beam intensity asymmetries in the analysis :

Leads to:

$$A_{i,raw} = Pg_iA_{PV} + \frac{p_i^+}{2Y_i^{o+}}\left(1 - \frac{1 + A_{Beam}}{1 - A_{Beam}}\right) + \frac{A_{i,ped}}{1 - A_{Beam}}$$

The measured asymmetries are small (or zero), so we can expand to first order in the asymmetries to get

$$A_{i,raw} = Pg_iA_{PV} - \frac{p_i^+}{Y_i^{o+}}A_{Beam} + A_{i,ped} + A_{i,ped}A_{Beam} + \mathcal{O}\left(A^2\right) + \ldots$$

If we can ignore everything of order A^2 then we can just average the pulse pair asymmetries, so that for all pulses, the wire asymmetry would be

$$\left\langle A_{i,raw}\right\rangle \approx \langle P\rangle g_iA_{PV} - \left\langle\frac{p_i^+}{Y_i^{o+}}\right\rangle\langle A_{Beam}\rangle + \left\langle A_{i,ped}\right\rangle$$

n^3He Analysis

Incorporating the pedestal and neutron beam intensity asymmetries in the analysis :

- From Latiful Kabir's (U. Kentucky) thesis: $A_{Beam} \sim \mathcal{O}(10^{-7})$ (beam monitor data over all runs)
- From data $\frac{p_i^+}{Y_i^{o+}} \sim \mathcal{O}(10^{-3})$
- From this analysis $A_{ped} = (0.26 \pm 1.97) \times 10^{-9}$
- So that over all runs we get a contribution from these factors of order

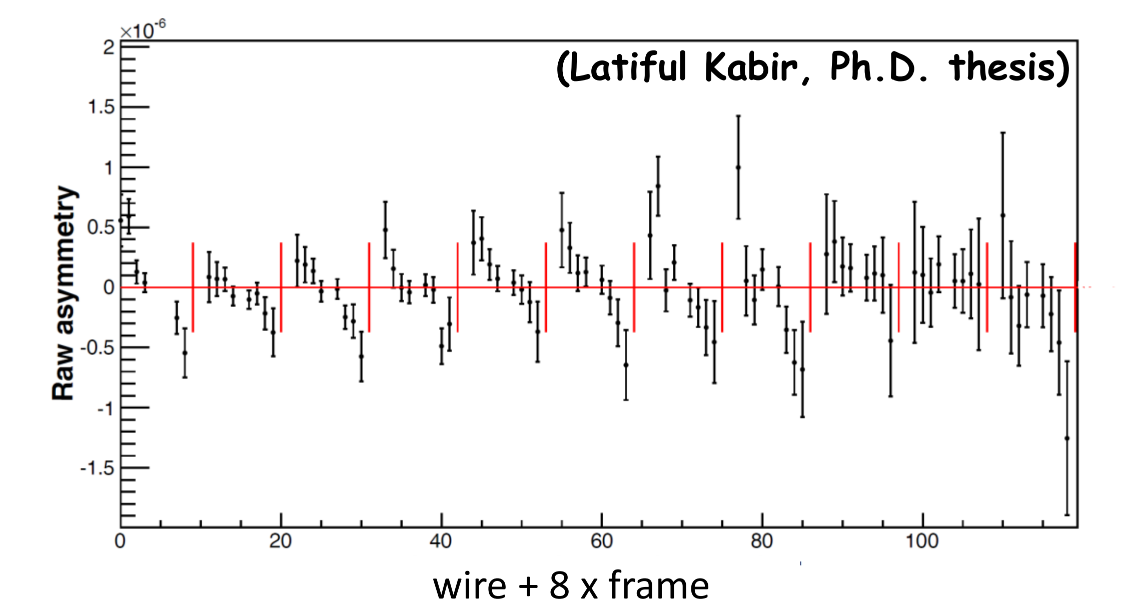
$$A_{i,raw} = P g_i A_{PV} \pm \mathcal{O}(10^{-9})$$

Future experiments that want to push the error boundary will have to pay extreme attention to beam fluctuations and electronic noise/asymmetries.

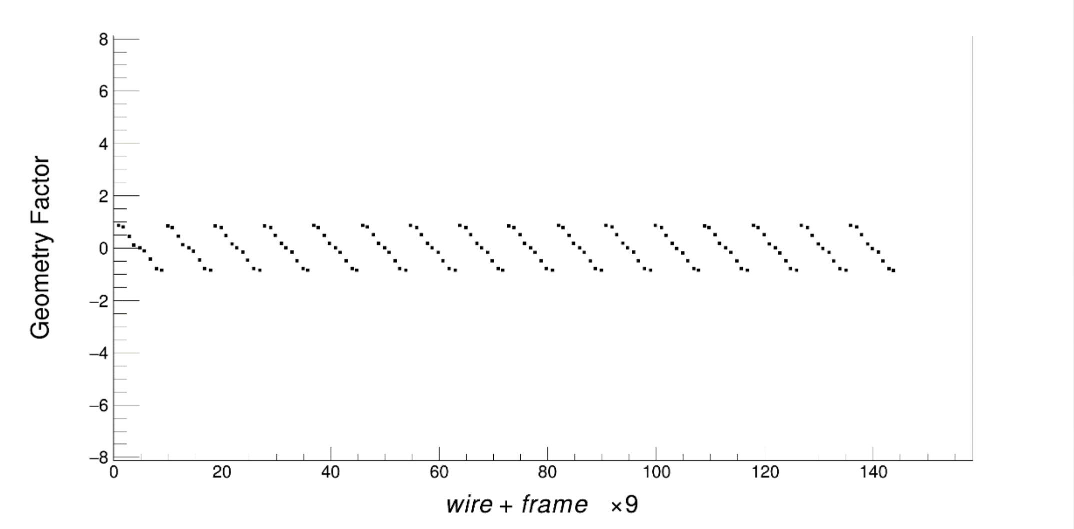
This isn't unique to n3He (all e,p,n, analyzing power measurements, etc…)

n³He Preliminary Results

Uncorrected
PC (LR) asymmetry:



Compare with simulated form factor structure:

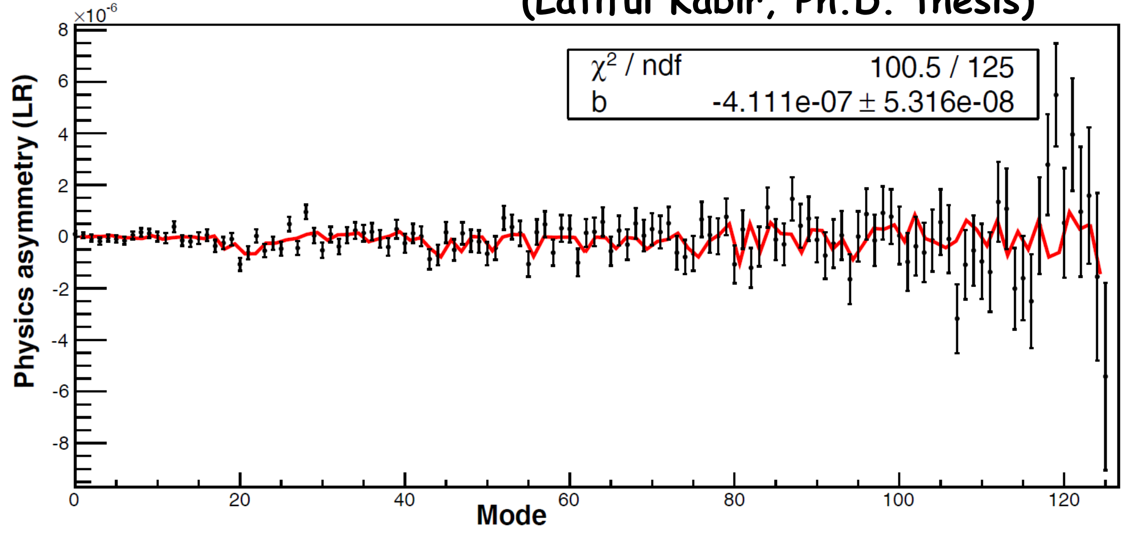


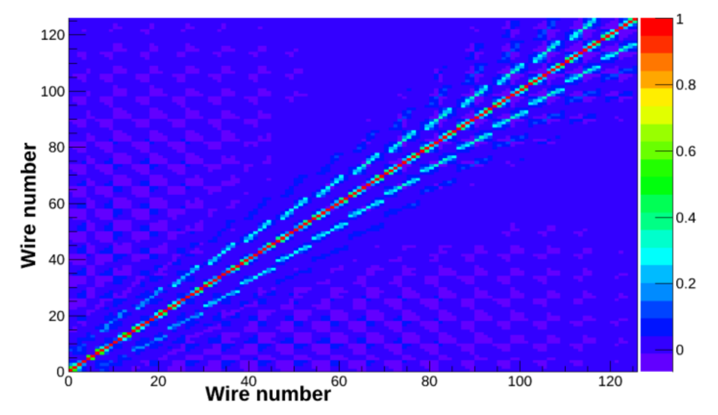
n^3He Preliminary Results

Corrected PC (LR) asymmetry:

$$A_{LR} = \left(-41 \pm 5\right) \times 10^{-8}$$

(Latiful Kabir, Ph.D. thesis)

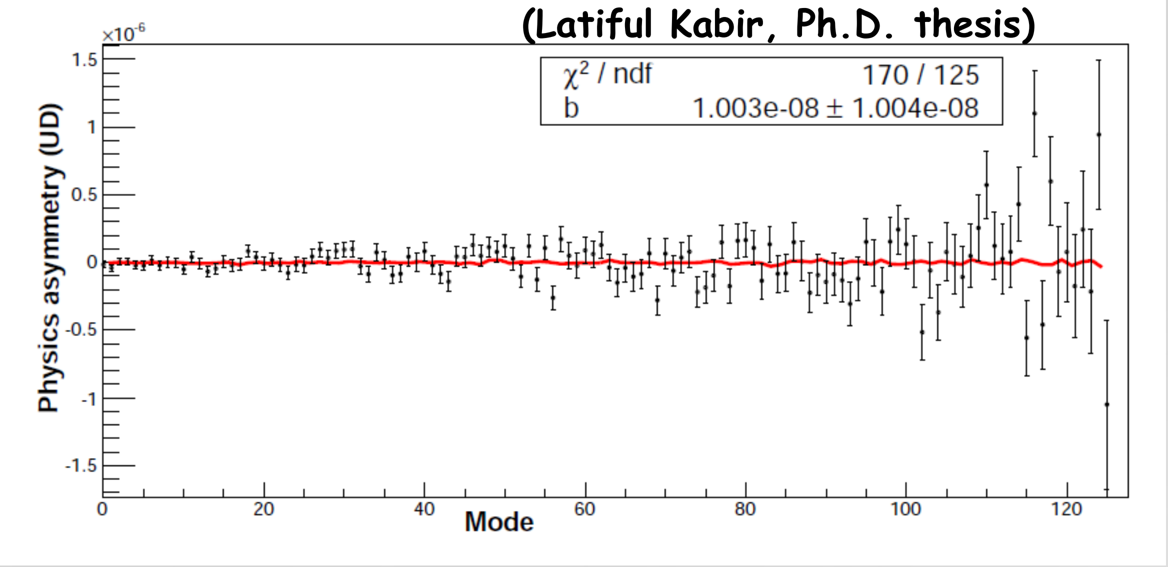


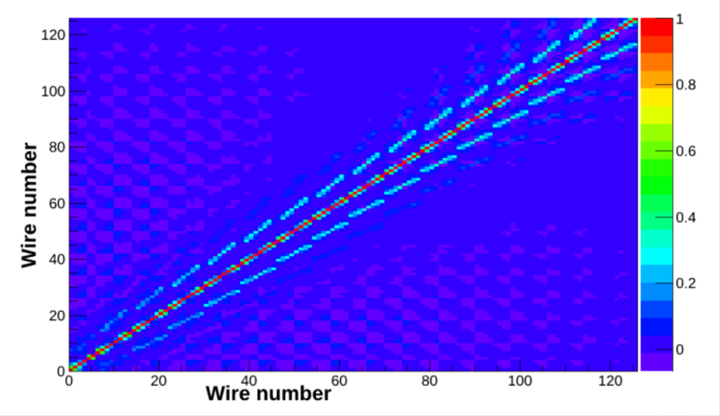


n^3He Preliminary Results

Corrected PV (UD) asymmetry:

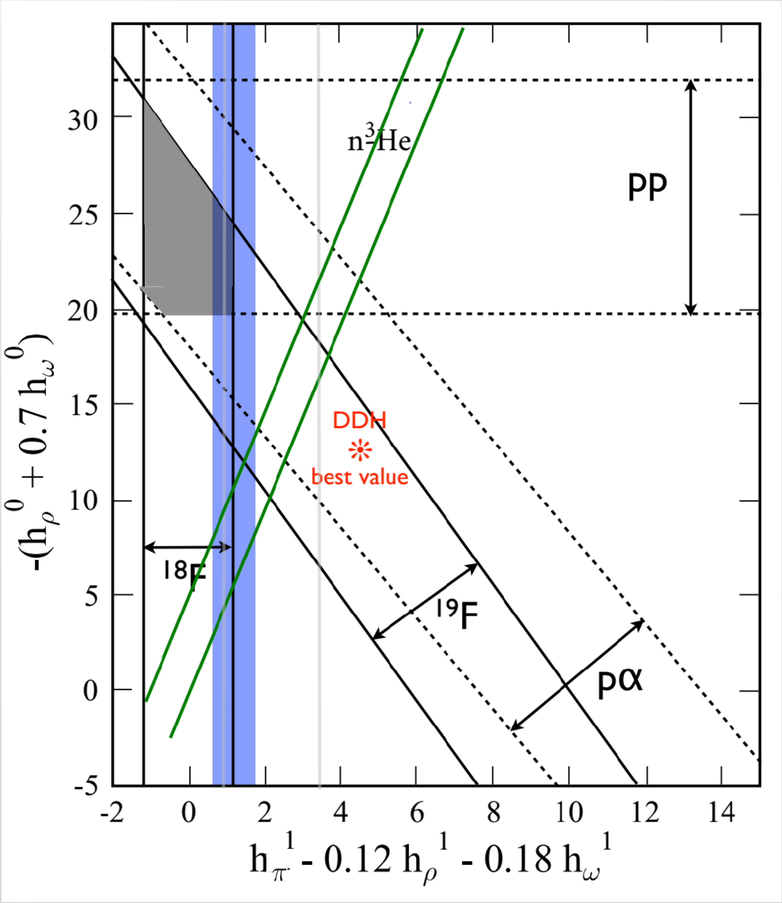
$$A_{UD} = \left(1 \pm 1\right) \times 10^{-8}$$

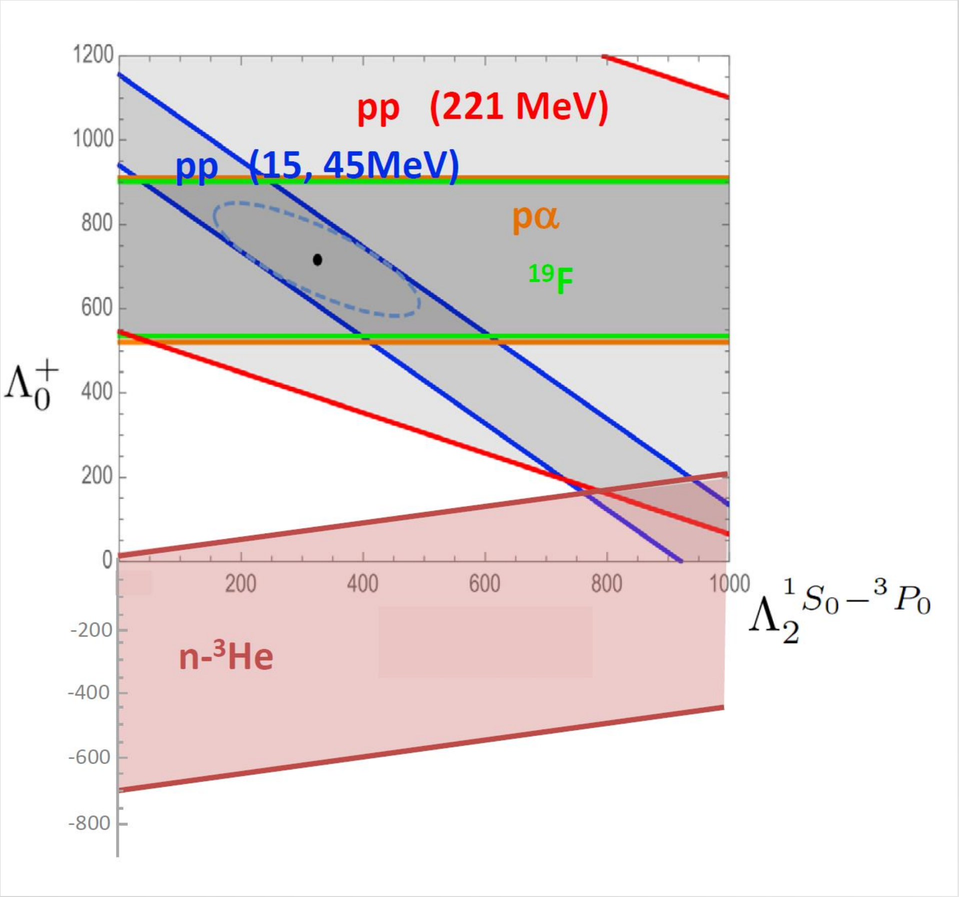




n³He Preliminary Results

Constraints from this experiment:





(Latiful Kabir, Ph.D. thesis)

Summary

• Development and Construction	2010 - 2014
• Installation	Fall 2014
• Commissioning	Fall 2014 – January 2015
• Production Data Taking	February – December 2015
• Analysis	To be completed this spring

Thank you