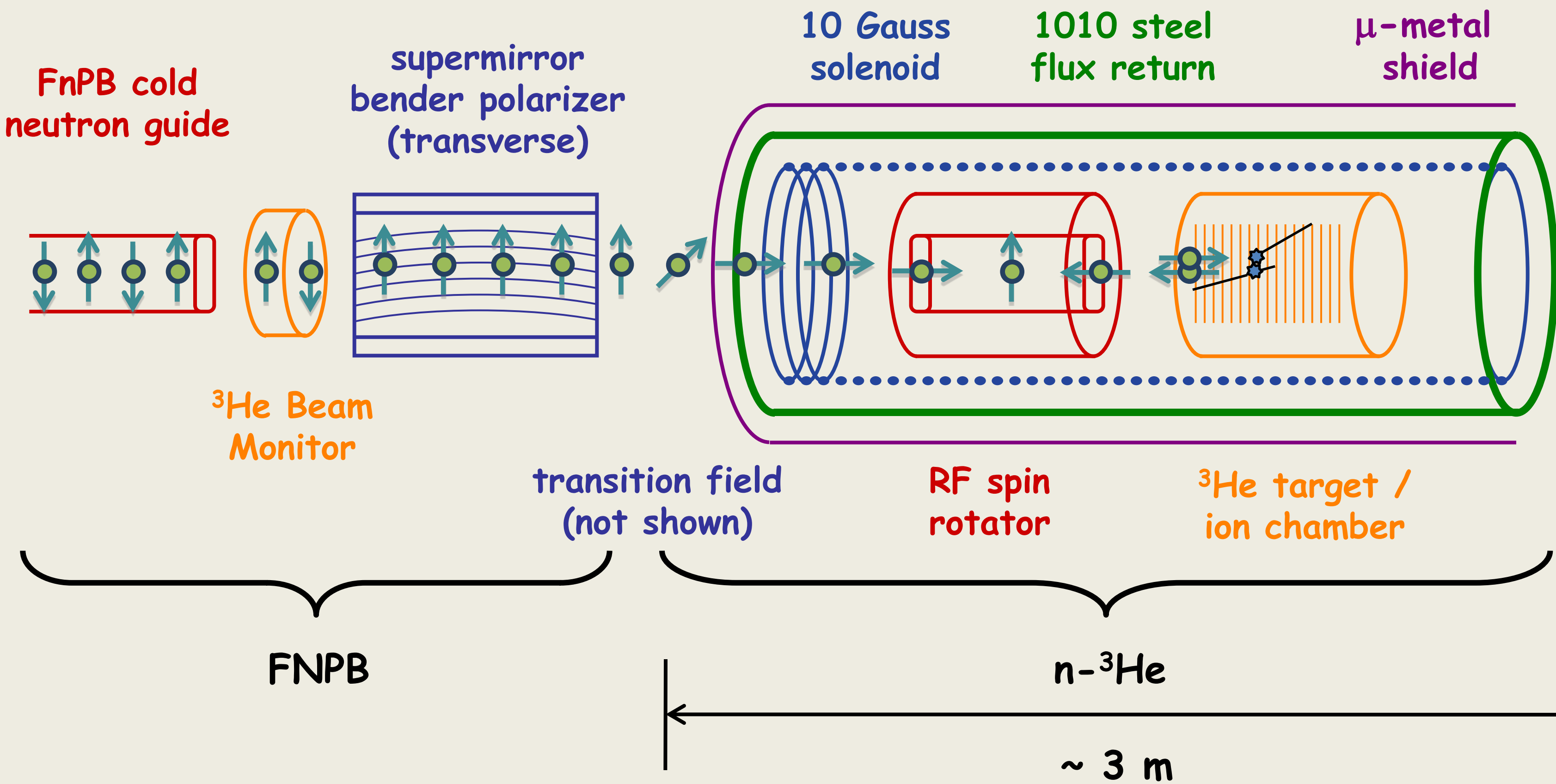
n3He Experimental Setup



- longitudinal holding field – suppressed PC asymmetry
- RF spin flipper – negligible spin-dependent neutron velocity
- ^{3}He ion chamber – both target and detector

n^3He Principle of Measurement

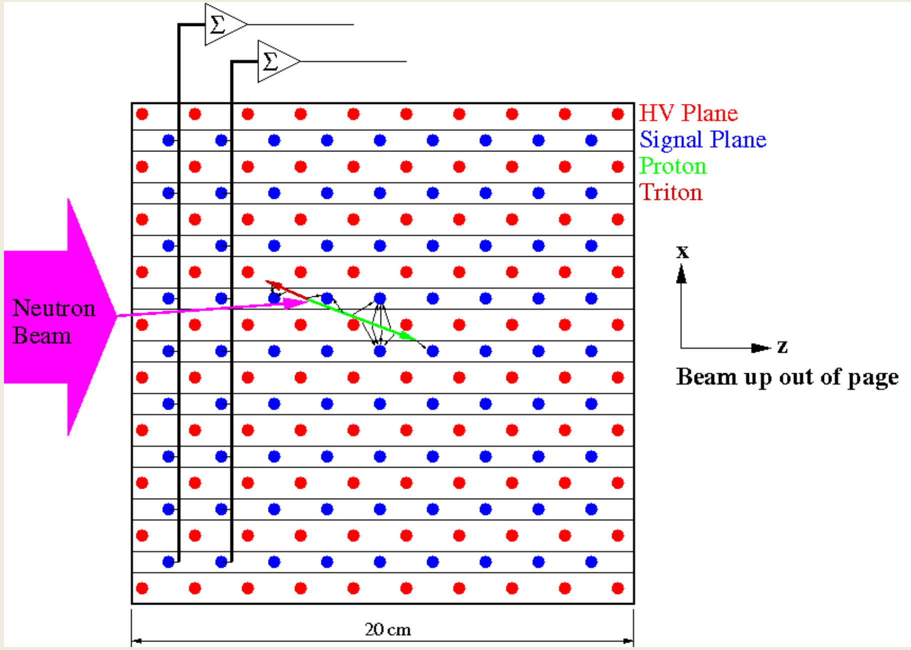
Measure the asymmetry in the number of forward going protons in a ^3He wire chamber as a function of neutron spin:

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

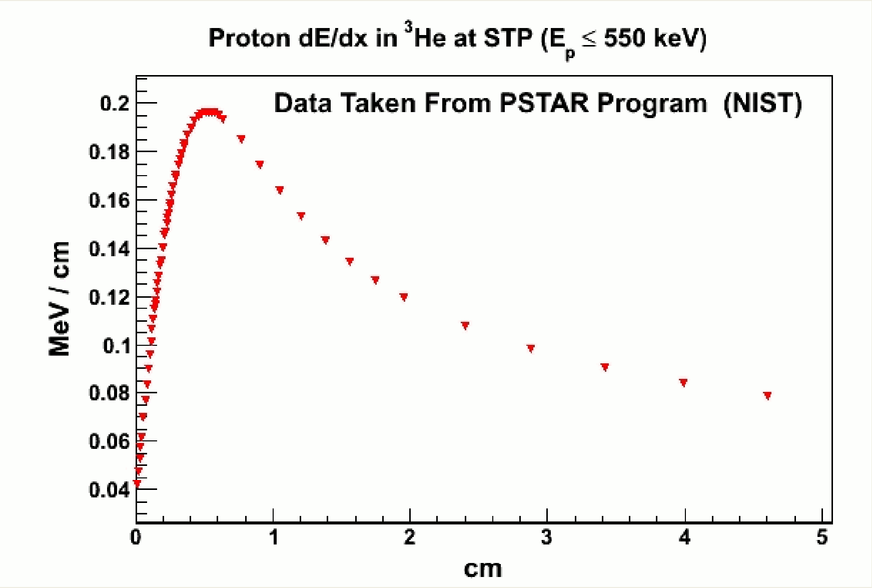
$\vec{\sigma}_n \cdot \vec{k}_T$ Directional PV asymmetry in the number of tritons

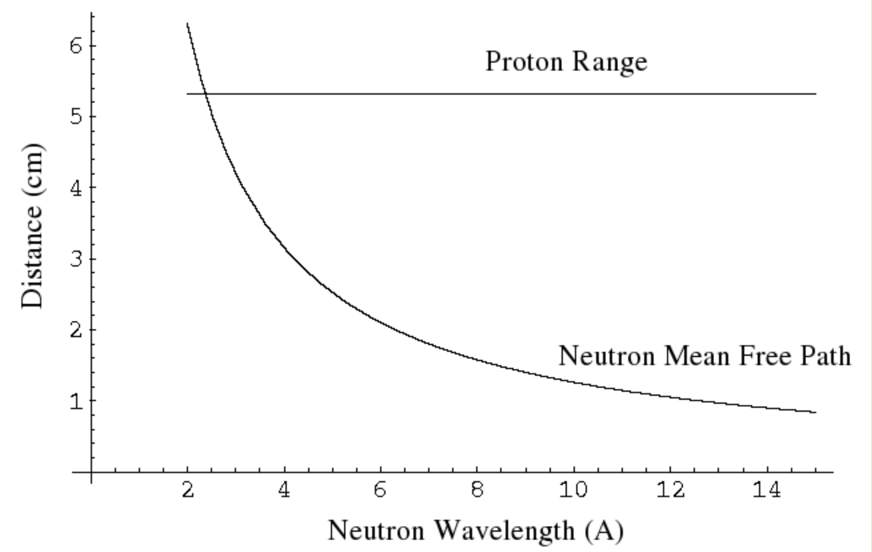
$\vec{\sigma}_n \cdot \vec{k}_p$ Directional PV asymmetry in the number of protons (much larger track length)

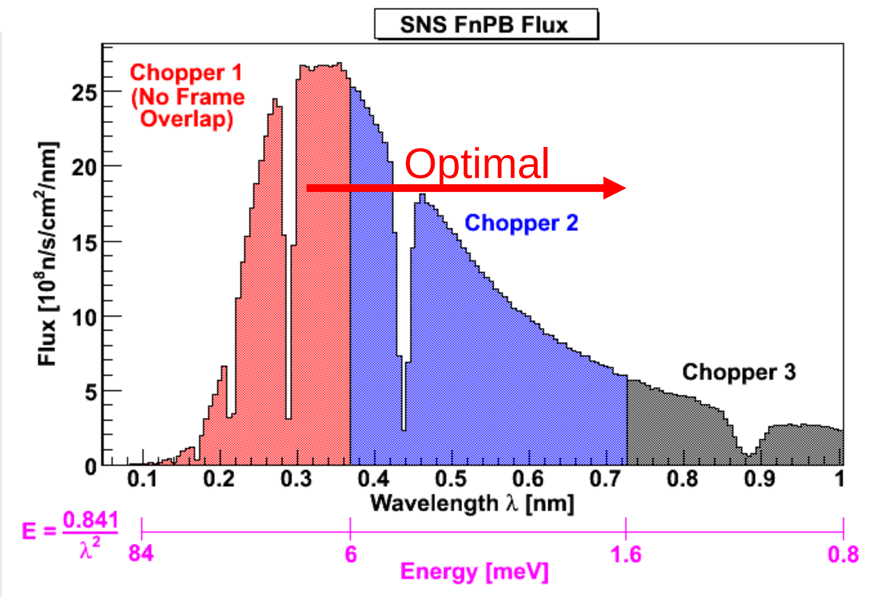
- *wire chamber is both target and detector*
- *wires run vertical or horizontal*



Design Criteria For the Chamber







- Chamber mostly filled with Helium 3
- Want to let protons range out
- Proton range r_p~5.5 cm
- Neutron mfp should be < r_p / 2
- Optimal wavelength range > 4.7 A
- Will have 6.5 x 10^{10} n/s

n^3He Asymmetry

The asymmetry is a result of partial wave mixing due to a weak interaction perturbation:

$$A_{PV} = \alpha_{PV} \frac{\left| \langle \psi_{f1} | H_S | \psi_{i0} \rangle + \langle \psi_{f0} | H_S | \psi_{i1} \rangle \right|}{\left| \langle \psi_{f0} | H_S | \psi_{i0} \rangle \right|} = \alpha_{PV} \frac{\left| \langle f \| Q_{PV} \| i \rangle \right|}{\left| \langle f \| Q_{PC} \| i \rangle \right|} \cos\theta_{\sigma,k}$$

$$\left| \psi_{i,f} \right\rangle = \left| \psi_{i,f,\ell=0} \right\rangle + \alpha_{PV} \left| \psi_{i,f,\ell=1} \right\rangle$$

The important part here is the **angular** correlation between initial neutron spin and final particle momentum.

The proton and triton tracks both contribute to the signal:

$$I = I_p + I_T = f_p I_p^0 \left(1 + A_p \cos\theta_p \right) + f_T I_T^0 \left(1 + A_T \cos\theta_T \right)$$

With energy deposition: $f_p \equiv f\left(\theta_p, z_p, E_n\right)$ and $f_T \equiv f\left(\theta_T, z_T, E_n\right)$

n^{3}He Asymmetry

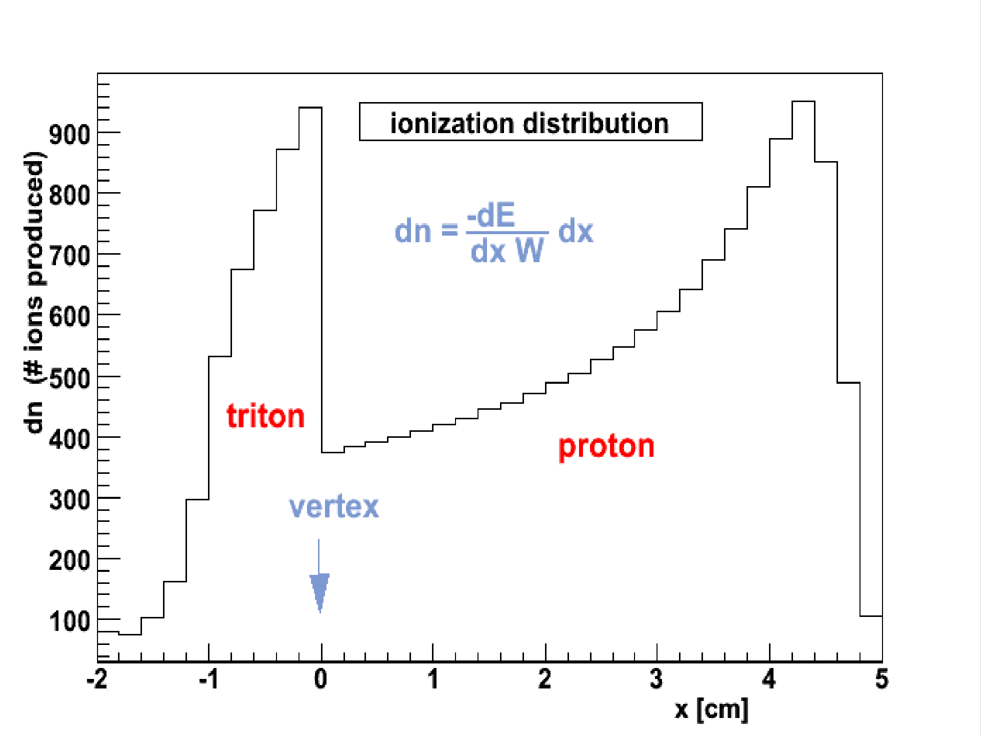
The triton deposits about a third of the energy of the proton:

$$I_p \approx 3 I_T$$

$$A_p \approx 3 A_T$$

Proton and triton are emitted Back-to-back:

$$\cos\theta_p = -\cos\theta_T \equiv \cos\theta$$

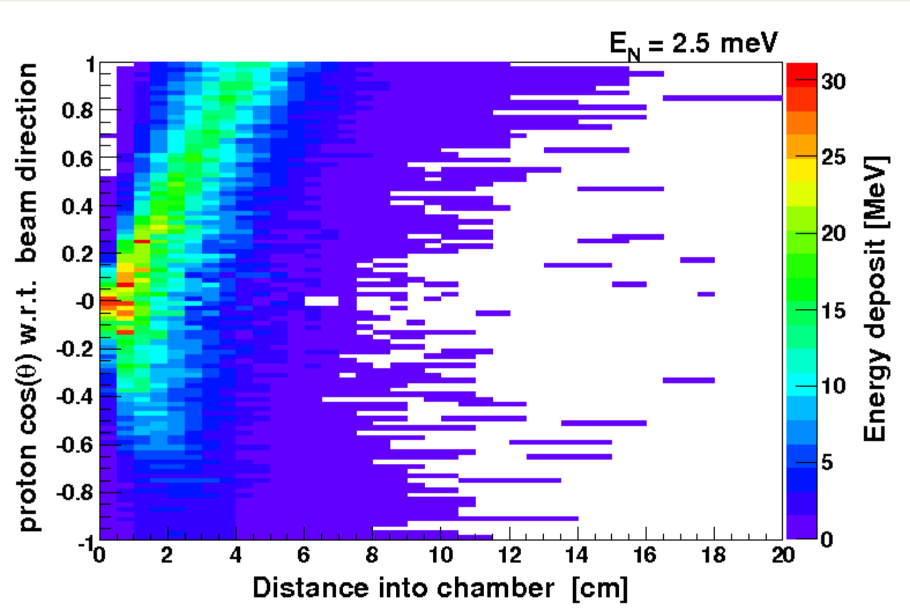


So the experimental asymmetry is:

$$A_{\exp}^{i,j} = \frac{I_R^{i,j} - I_L^{i,j}}{I_R^{i,j} + I_L^{i,j}} = \frac{A_{PV}^{i,j} \int \left(f_p^{i,j} - f_T^{i,j}/3 \right) \cos\theta \, d\theta}{\int \left(f_p^{i,j} + f_T^{i,j}/3 \right) d\theta}$$

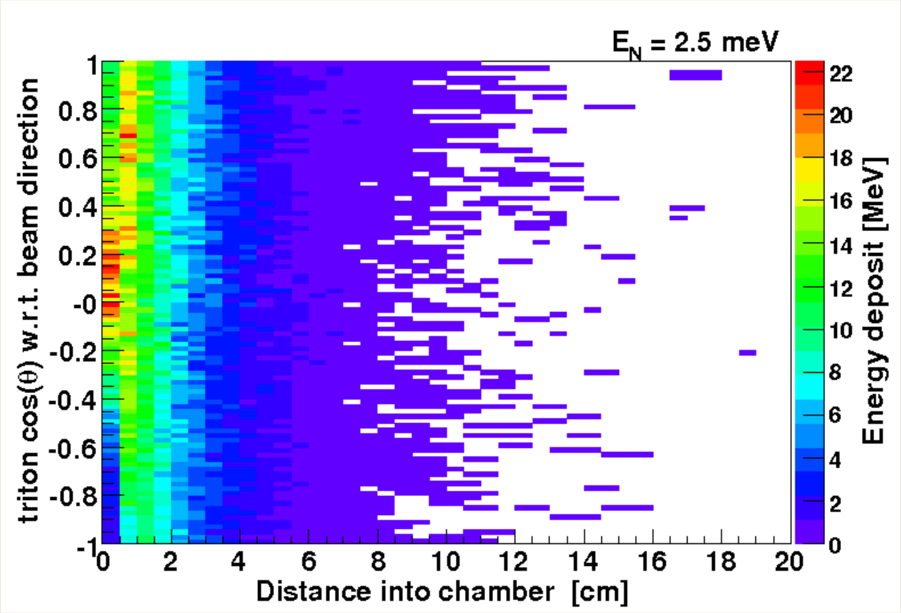
- **Determine energy depostion using MC simulations**

protons



$$f_p \equiv f(\theta_p, z_p, E_n)$$

tritons



$$f_T \equiv f(\theta_T, z_T, E_n)$$

Statistical Error and Dilution

Define:

$$\xi^{i,j}\left(z^i, E_n^j\right) \equiv \frac{\int \left(f_p^{i,j} - f_T^{i,j}/3\right)\cos\theta d\theta}{\int \left(f_p^{i,j} + f_T^{i,j}/3\right) d\theta}$$

Then the error on the asymmetry is

$$\delta A_{PV} = \frac{1}{\sqrt{N P_n}} \sqrt{\sigma_D^2 + \sigma_{coll}^2}$$

with

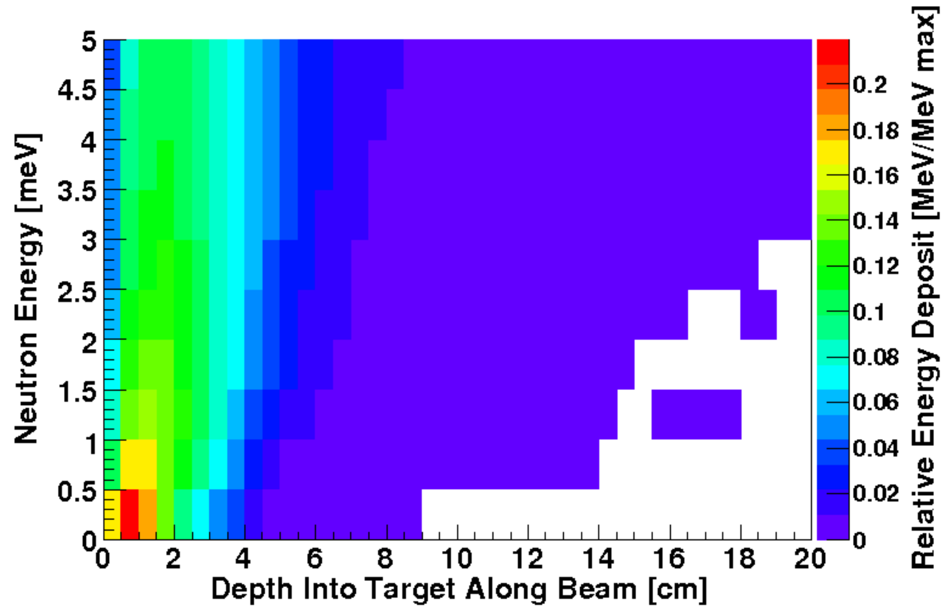
$$\sigma_D = \frac{\sqrt{N}}{\sqrt{\sum_{i,j} \left(N_{i,j} / \left(\xi^{i,j}\right)^2 \right)}}$$

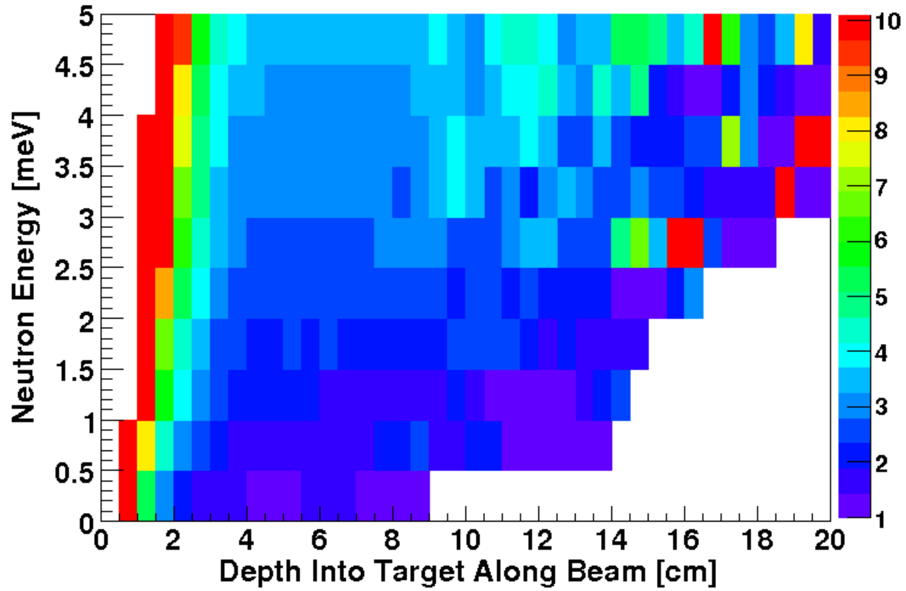
Determine efficiency and wavelength from simulations:

Neutron Wavelength Window Optimization			
Chopping Phase (at 17 m)	σ_d	δA^{-2} ($\times 10^6$)	Comments
244	???	1.259	
234	6.60	1.29	
244	6.55	1.31	
254	6.51	1.33	
284	6.33	1.35	
300	6.24	1.356	$\lambda \simeq 0.3 \rightarrow 0.69$ nm
320	6.10	1.35	
360	5.8	1.311	
500	5.0	1.019	

Effect of Wire Plane Spacing on Correlations			
Wire Planes	Width [mm]	σ_d (no correlation)	σ_d (with correlation)
10	20	5.27	6.24
20	10	4.19	5.97
40	5	3.37	5.90

$$\sigma_d \simeq 6$$





Statistical Error and Dilution

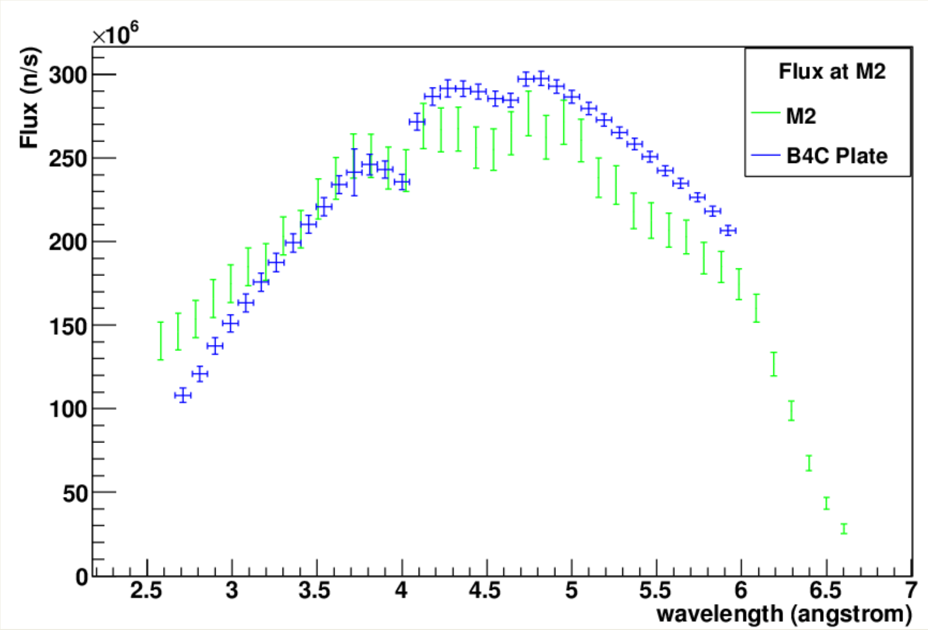
Statistical error based on neutron counting statistics and dilution factor.

Based on measured flux, we can get

1.5×10^{10} n/s

per pulse on target.

We need two pulses to calculate the asymmetry.



So for a 5000 hr (208 days) run, the measurement error is

$$\delta A_{PV} = \frac{6}{0.96\sqrt{7.5 \times 10^{16}}} = 1.7 \times 10^{-8}$$

Theoretical n^3He Asymmetry

- Full four-body calculation of strong scattering wave functions
- Using AV18 potential
- Evaluation of the weak couplings based on available nuclear and few body

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

$$A_p^{\vec{n},{}^3He}(th.) \approx 1.15 \times 10^{-7}$$

So with this size we would achieve a 20% measurement in 116 days of running

$$\frac{\delta A_{PV}}{A_{PV}} = \frac{1.7 \times 10^{-8}}{1.15 \times 10^{-7}} = 0.15$$

Weak Couplings	From data	(A^p_z) $n^3He \rightarrow tp$ (AV18)
a_π^1	h_π^1=-0.46	-0.189
a_ρ^0	h_ρ^0=-43	-0.036
a_ρ^1	h_ρ^1= 0	0.019
a_ρ^2	h_ρ^2= 37	-0.0006
a_ω^0	h_ω^0= 14	-0.0334
a_ω^1	h_ω^1= 0	0.0413

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

Systematic Effects

The biggest advantage in this measurement is the low background and few systematic effects.

Only need to consider correlations that involve terms linear in neutron spin:

Invariant	Parity	Size	Comments
$\vec{\sigma}_n \cdot \vec{k}_p$	Odd	1×10^{-7}	RMS value
$\vec{\sigma}_n \cdot (\vec{k}_n \times \vec{k}_p)$	Even	$2 \times 10^{-6} \times 10^{-2} \times 10^{-2}$	size times alignment factors
$\vec{\sigma}_n \cdot \vec{k}_p(\vec{k}_n \cdot \vec{k}_p)^m$	Odd	$k_n r = 3.7 \times 10^{-5}$	gets smaller by 10^{-5} for each additional power (m)
$\vec{\sigma}_n \cdot (\vec{k}_n \times \vec{k}_p)(\vec{k}_n \cdot \vec{k}_p)^m$	Even	$k_n r = 3.7 \times 10^{-5}$	gets smaller by 10^{-5} for each additional power (m)
$\vec{\sigma}_n \cdot \vec{B}$	Even		Stern-Gerlach steering: analysis in progress
$\vec{\sigma}_{^3He} \cdot \vec{k}_p$ or $\vec{\sigma}_{^3He} \cdot \vec{k}_n$	Even		Polarization of ^3He: small effect, can be countered with magnetic holding field reversal
$\vec{\sigma}_n \cdot (\vec{E} \times \vec{v_n})$	Even	1×10^{-4}	Mott-Schwinger Scattering for transverse polarization only