The NPDGamma Experiment

A measurement of the parity violating directional γ-asymmetry in polarized cold neutron capture on hydrogen.

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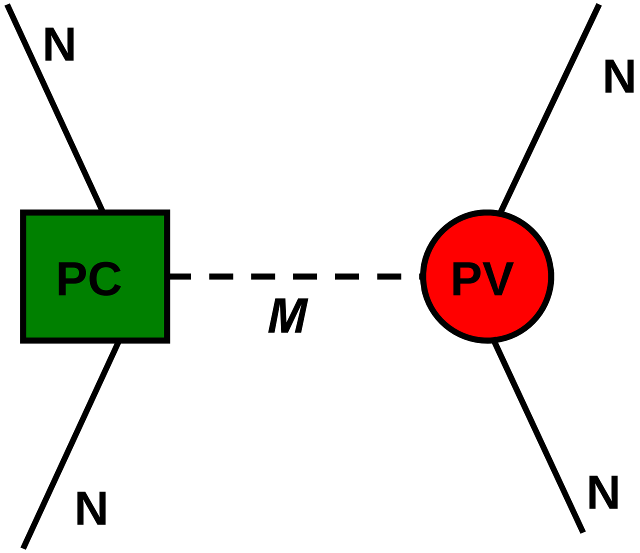
Outline

- Introduction and Motivation
- Experiment
- Analysis and Preliminary Results from first run
- Next run at SNS

Introduction



- Weak interaction at low momentum transfer between nucleons is accessible through measurements of small parity-odd amplitudes
- Natural scale ~x10^{-7}, set by relative size of meson vs boson exchange amplitudes
- Weak NN couplings are largely unknown: non-perturbative regime makes calculations and experiments challenging

Why do we care?

- Weak interaction is manifested in long range nuclear interactions
- Inconsistent results from previous measurements (ex: f_π)
- weak NN couplings => allows for a quantitative interpretation of PV phenomena at nuclear and atomic scales
- probe of QCD – nuclear properties at short range

Introduction - continued

- ***DDH model*** – uses valence quarks to calculate effective PV meson-nucleon coupling directly from SM via 7 weak meson coupling constants

$$f_\pi^1, h_\rho^0, h_\rho^1, h_\rho^{1'}, h_\rho^2, h_\omega^0, h_\omega^1$$

- Observables can be written as their combinations

$$A = a_\pi^1 f_\pi^1 + a_\rho^0 h_\rho^0 + a_\rho^1 h_\rho^1 + a_\rho^2 h_\rho^2 + a_\omega^0 h_\omega^0 + a_\omega^1 h_\omega^1$$

DDH Weak Coupling	$n+p\to d+\gamma$ A_γ (ppm)	$n+d\to t+\gamma$ A_γ (ppm)	n-p ϕ_{PV} (μrad/m)	n $-^4$He ϕ_{PV} (μrad/m)	p $-$ p $\frac{\Delta\sigma}{\sigma}$ (ppm)	p $-^4$He $\frac{\Delta\sigma}{\sigma}$ (ppm)
f_π	-0.107	-0.92	-3.12	-0.97		-0.340
h_ρ^0		-0.50	-0.23	-0.32	0.079	0.140
h_ρ^1	-0.001	0.103		0.11	0.079	0.047
h_ρ^2		0.053	-0.25		0.032	
h_ω^0		-0.160	-0.23	-0.22	-0.073	0.059
h_ω^1	0.003	0.002		0.22	0.073	0.059

Introduction - continued

EFT

– developed by Holstein, Ramsey-Musolf, van Kolck, Zhu and Maekawa

– model-independent

- NN potentials are expressed in terms of 12 parameters, whose linear combinations give us 5 low energy coupling constants
  - connect to 5 parity-odd S-P NN amplitudes

$\lambda_t, \lambda_s^{I=0,1,2}, \rho_t$ Corresponding to

$$^1S_0 \rightarrow {}^3P_0 \quad (\Delta I = 0,1,2)$$

$$^3S_1 \rightarrow {}^1P_1 \quad (\Delta I = 0)$$

$$^3S_1 \rightarrow {}^3P_1 \quad (\Delta I = 1)$$

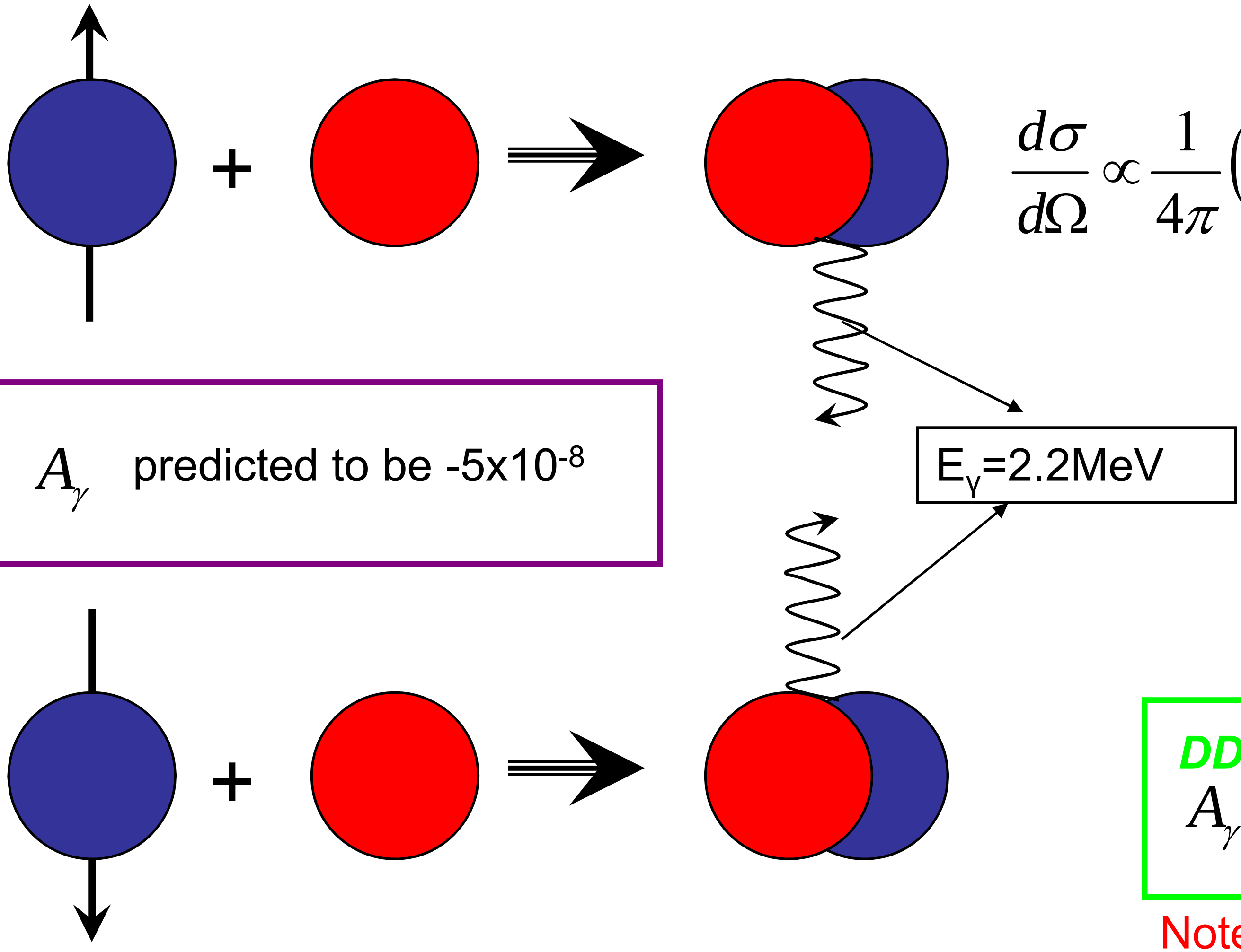
- Additionally, a long-range pion-nucleon coupling constant ($\sim f_\pi$)

$$A_\gamma^{\vec{n}p} \approx -0.27\tilde{C}_6^\pi - 0.09 m_N \rho_t$$

– In a proton-neutron system, nucleons are loosely coupled, and f_π is believed to be the dominant coupling (same as in DDH model)

Reaction of interest: $\vec{n} + p \Rightarrow d + \gamma$

isolates the ΔI=1 part of the weak interaction



$$\frac{d\sigma}{d\Omega} \propto \frac{1}{4\pi}\left(1 + A_\gamma \cos\theta\right)$$

$\vec{s}_n \cdot \vec{k}_\gamma$

A_γ predicted to be -5x10^{-8}

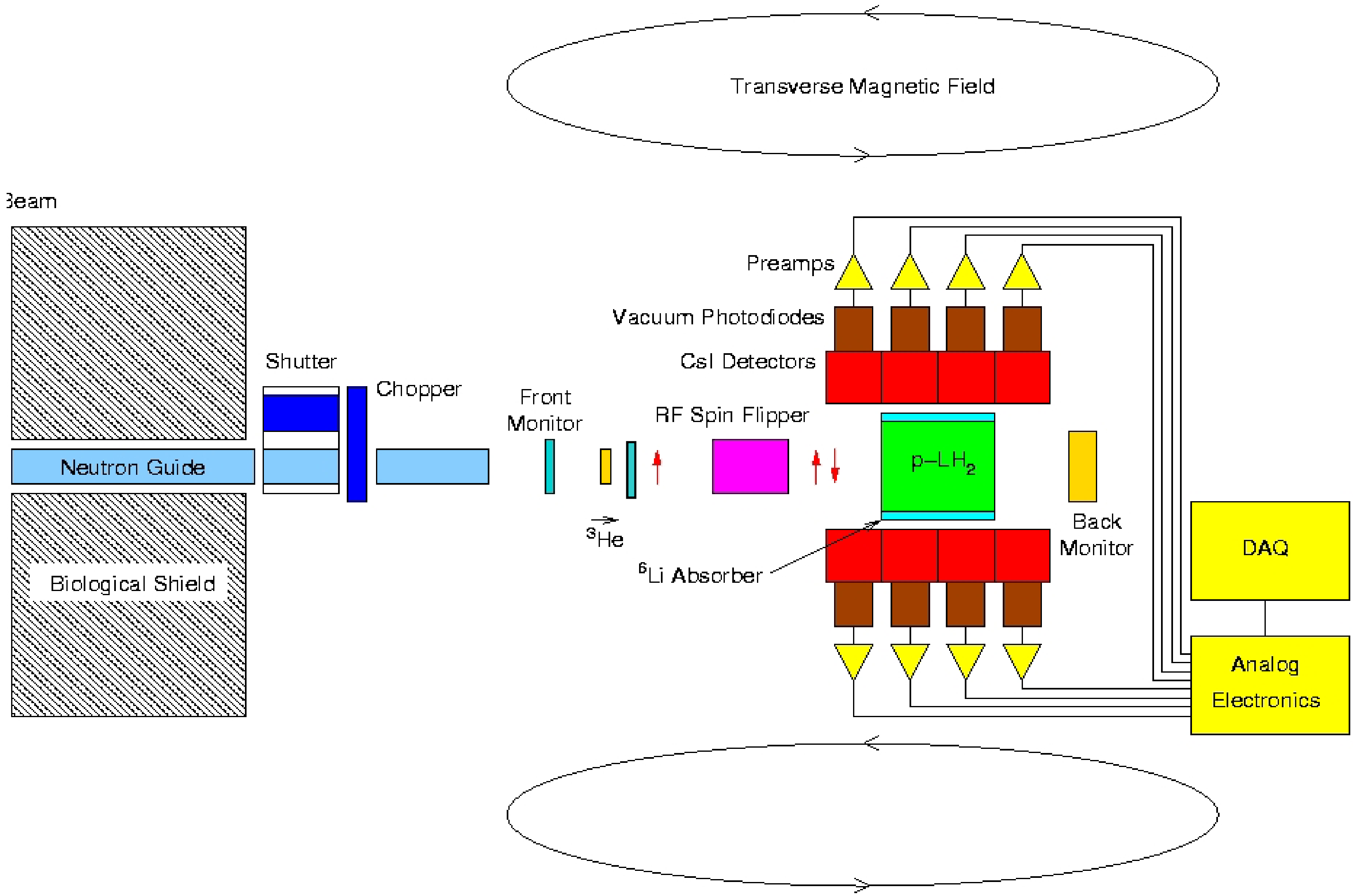
DDH

$$A_\gamma \approx -0.11 f_\pi^1$$

Note That EFT
Gives about same value

We measure A_γ, the PV asymmetry in the distribution of emitted gammas.

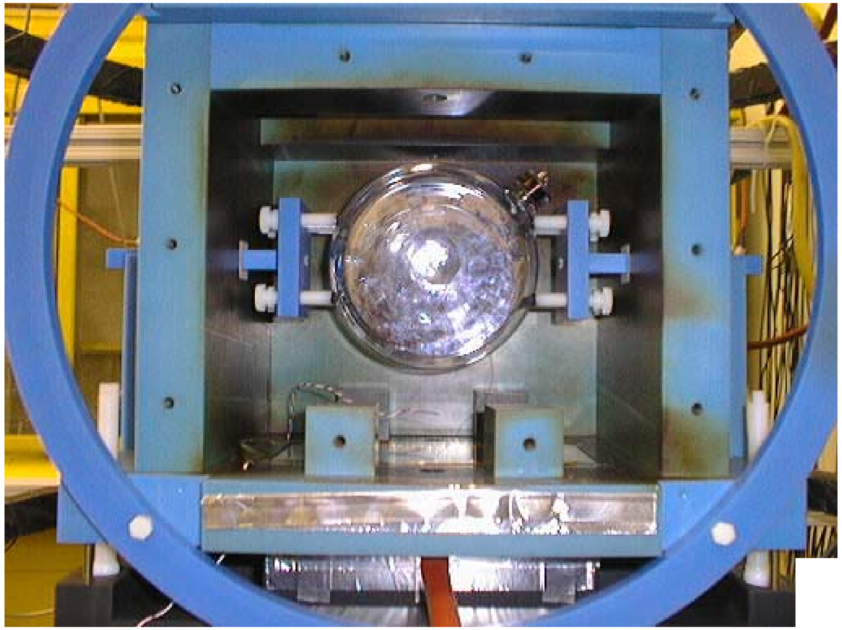
Experimental Setup



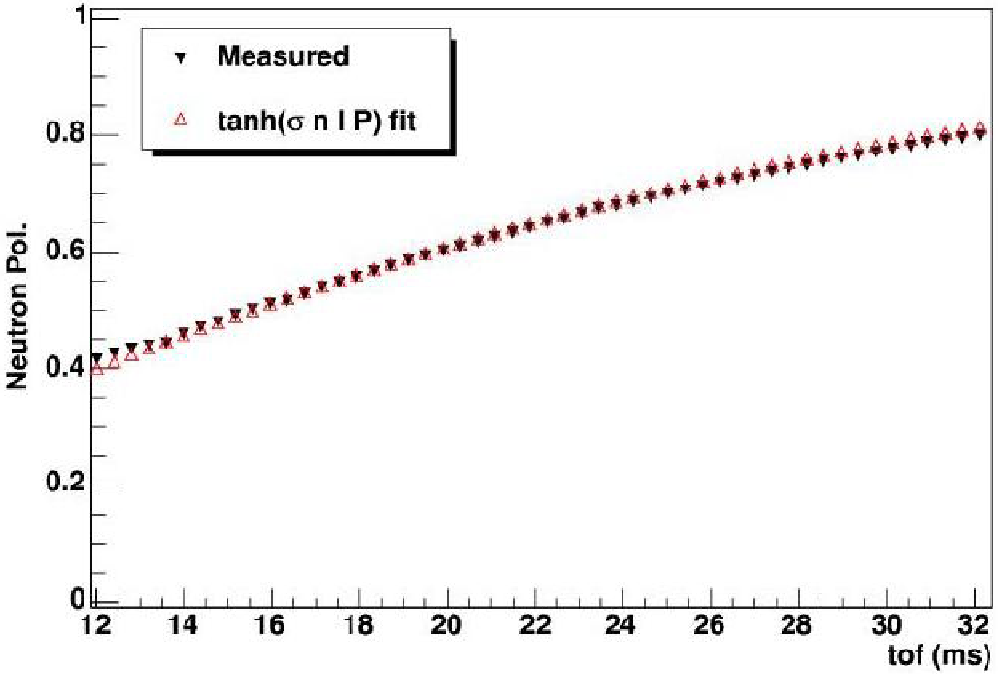
NDPGamma on FP12

10G magnetic guide field coils to preserve neutron polarization

^{3}He Spin Filter (Run 1 only)



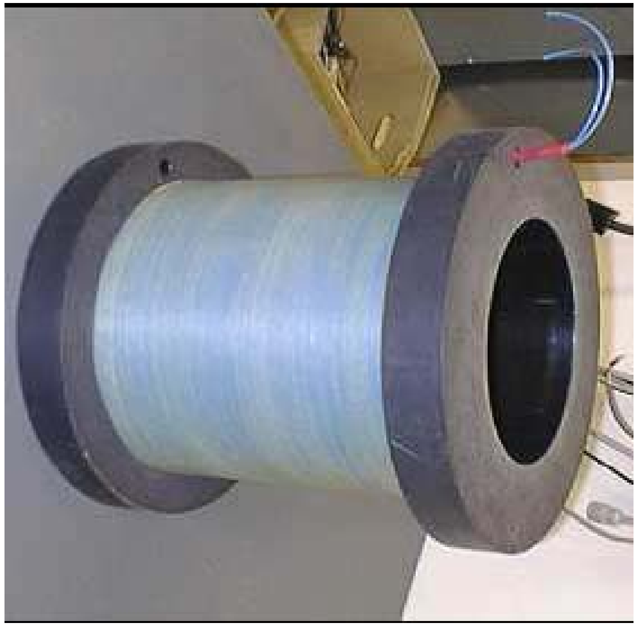
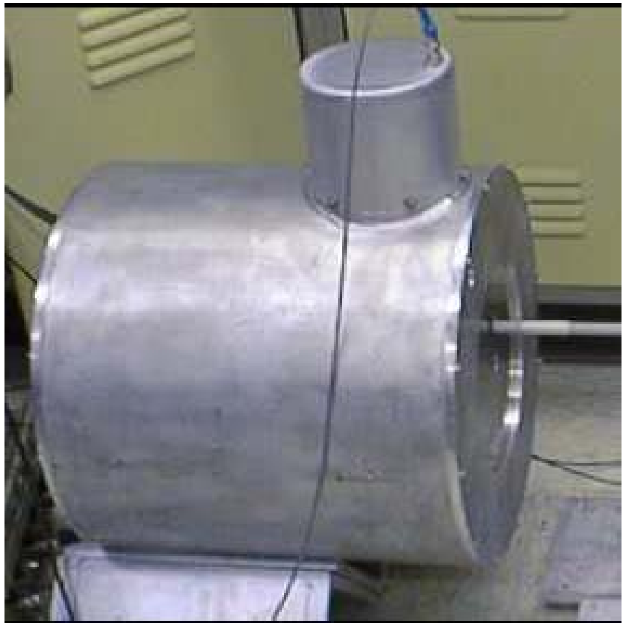
- 3He gas is polarized via spin exchange with laser-polarized Rb
- $\sigma_{singlet}/\sigma_{triplet}$~$10^4$ – neutrons with spins || to ^{3}He pass through (filter)
- ^{3}He Polarization ~ 55%
- Relaxation time ~500hrs



TOF ∝ 1/λ

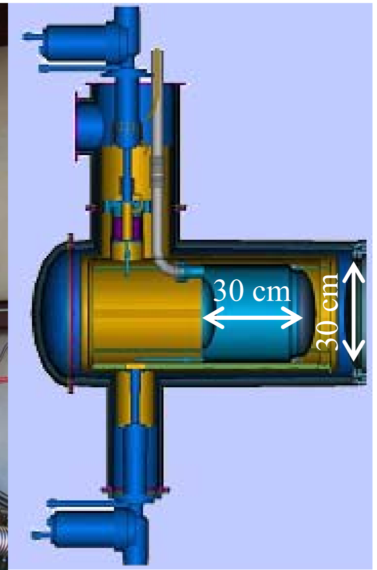
At the pulse source, a simple relationship exists between energy and arrival time of the neutrons

Resonant RF Spin Flipper

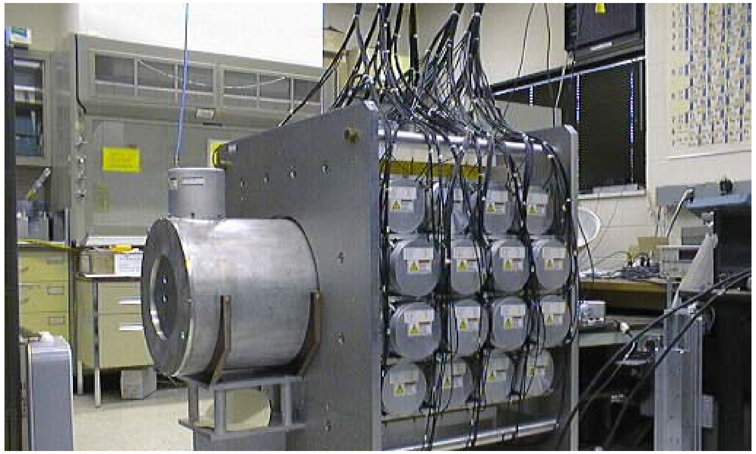
- A resonant RF magnetic field ($B_1 \cos wt$) is applied for a time t to precess the neutron spin by π.
- $B_1(t) \propto 1/TOF$, for reversing neutron spin in wide energy range (~0.5-50 meV).
- Rapid spin reversal minimizes systematic effects ↑↓↓↑↓↑↑↓

LH_2 target and CsI detector array

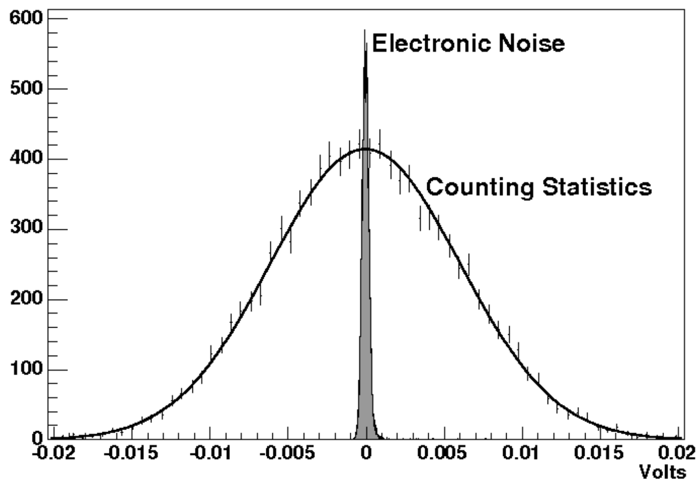


16L vessel of liquid parahydrogen

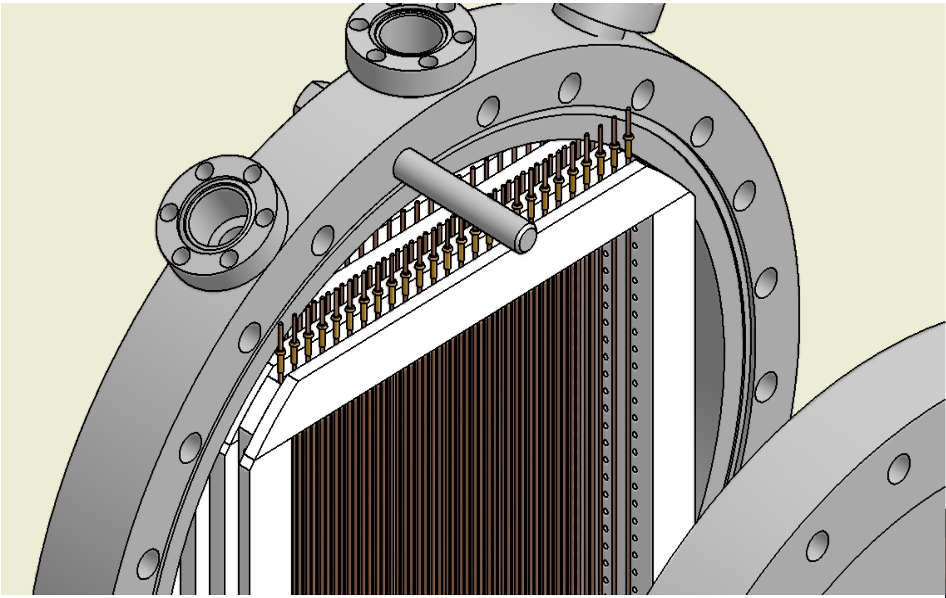
Ortho-hydrogen scatters the neutrons and leads to beam depolarization



- 3π acceptance
- Current-mode experiment
- γ-rate ~100MHz (single detector)
- Low noise solid-state amplifiers

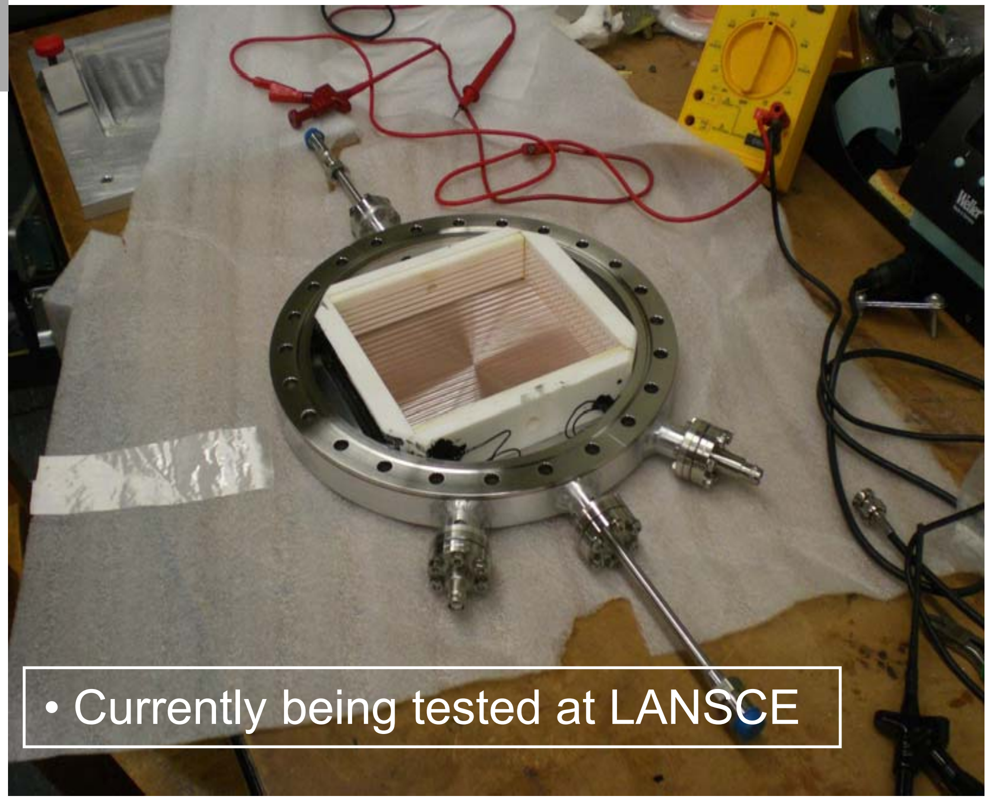


New Wire Chamber Beam Monitors



- Neutron Flux
- Neutron Polarization (in conjunction with ^{3}He analyzer – once)
- Monitor ortho/para ratio in the target

- Larger beam cross section
- Use wires rather than plates
  - Reduce absorption and scattering of beam
  - Reduce micro-phonic noise pickup



- Currently being tested at LANSCE

Data Summary from 2006 run

Number of good runs (8.5min long)	~5000
Neutron Polarization (ave)	53±2.5%
Spin Flip Efficiency	98.8±0.5%
Para fraction in LH_2 target	99.98±0.2%
Al background	~25% (ave)
Depolarization	2%
Stern-Gerlach steering Asym	10^{-10}
γ-ray circ.pol. Asym	10^{-10}

Analysis Procedure

$$Y_{\det} = \frac{V_d}{4\pi}[1 + A_\gamma g_d(\theta,\phi) P_n(E_n)\varepsilon_{sf}(E_n)\varepsilon_\uparrow(E_n)] \cdot h(z, E_n)\, f_d(\vec{x},\theta,\phi)$$

Neutron Polarization

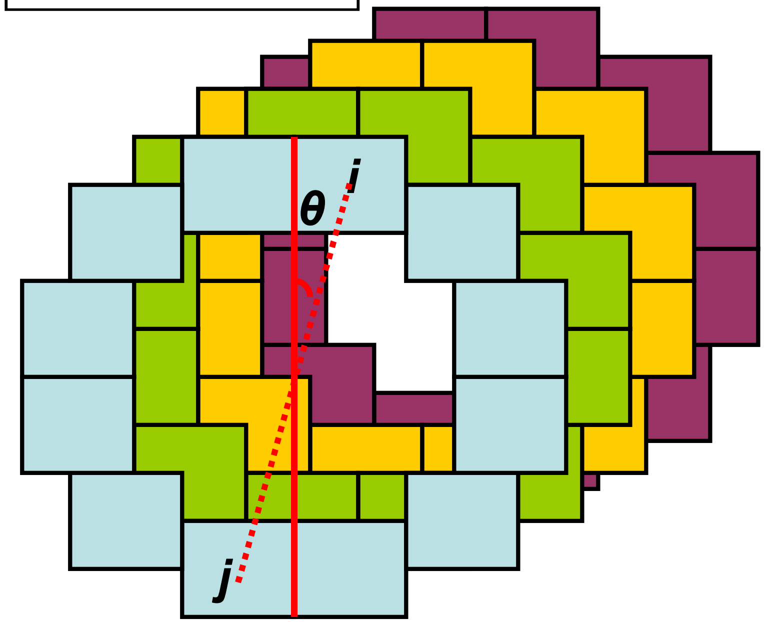
Neutron depolarization

γ energy deposition

Detector geometry

SF efficiency

Capture Locus



Raw asymmetry is formed between each pair of detectors {*i,j*} for each spin sequence, for each time bin via

$$A_{raw} = \frac{1}{2}\left(\frac{Y_i^\uparrow - Y_j^\uparrow}{Y_i^\uparrow + Y_j^\uparrow} + \frac{Y_j^\downarrow - Y_i^\downarrow}{Y_j^\downarrow + Y_i^\downarrow}\right)$$

Raw asymmetry for a detector pair ***{ij}***, time bin ***t***, is related to physics asymmetry via:

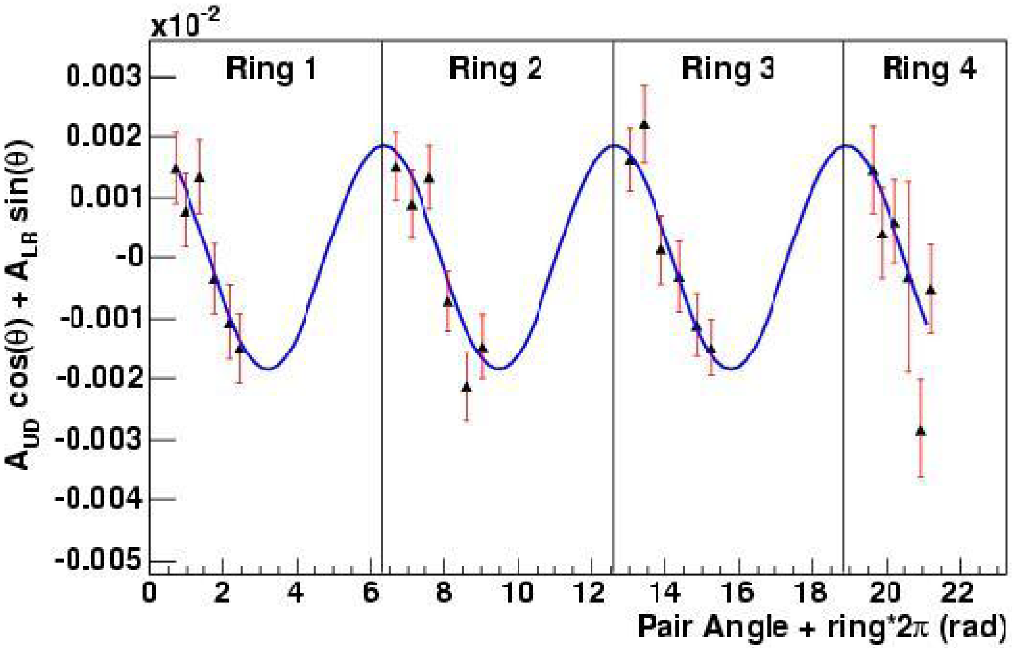
$$A_{UD}(t)\langle G_{UD}(t)\rangle + A_{LR}(t)\langle G_{LR}(t)\rangle = \frac{A_{raw}(t) - A_{gain}A_{beam}(t) - A_{noise}}{P_n(t)\varepsilon_{sf}(t)\varepsilon_\uparrow(t)}$$

$$A_{UD} = A_{UD,PHYS} + A_{UD,BG}$$

Analysis Procedure - continued

Calibration Target: ^{35}Cl

-target with a large and well-known γ-asymmetry $(26\pm7)\times10^{-6}$

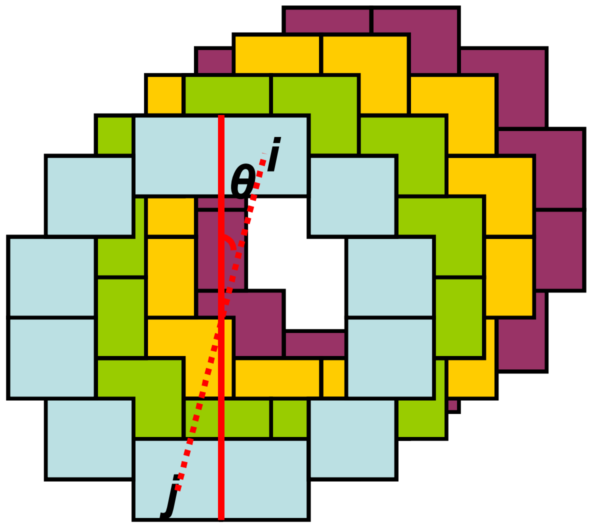


•Time bins (40μs) are averaged over with neutrons polarization and other energy-dependent quantities as weights.

•Asymmetry for a detector pair is then given by

$$A_{raw} = A_{UD} \cos\theta + A_{LR} \sin\theta$$

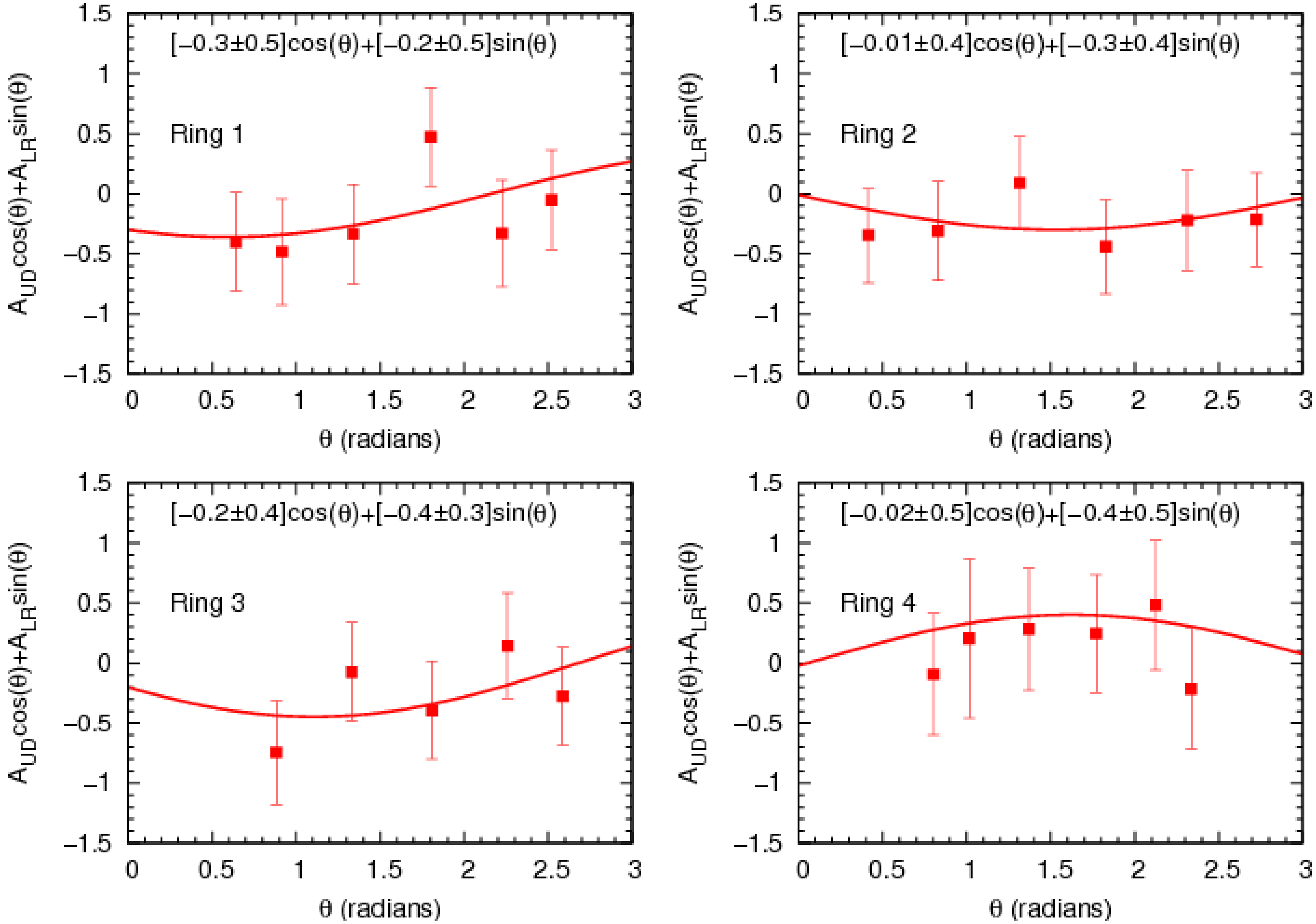
•$\mathbf{A_{UD}}$ is extracted from a fit of $\mathbf{A_{raw}}$ to $\boldsymbol{\theta}$, the angle of detector pair



Preliminary Hydrogen Result

$A_{\gamma,UD}=(-1.9\pm2.0\pm0.2)\times10^{-7}$

$A_{\gamma,LR}=(-1.1\pm2.1\pm0.2)\times10^{-7}$



Continuing NPDGamma at the SNS in Oak Ridge, TN

	LANSCE	***SNS***
Sensitivity	$2x10^{-7}$	$1x10^{-8}$
Polarizer	^{3}He polarizer (average 55% NP)	SuperMirror Polarizer (98% NP)
FOM (NP^2)	$8.9x10^{7}$/s	X200 improvement
Target	16L, LH_2	New and improved, thinner windows

Improved Understanding of systematic effects

PV asymmetries

- Stern-Gerlach force 2×10^{-11}
- Circularly polarized γs 9×10^{-13}
- In-flight β decay 1×10^{-11}
- Capture on ^{6}Li 2×10^{-11}
- Al γ's 1.3×10^{-8}
- Al β decay 1×10^{-10}

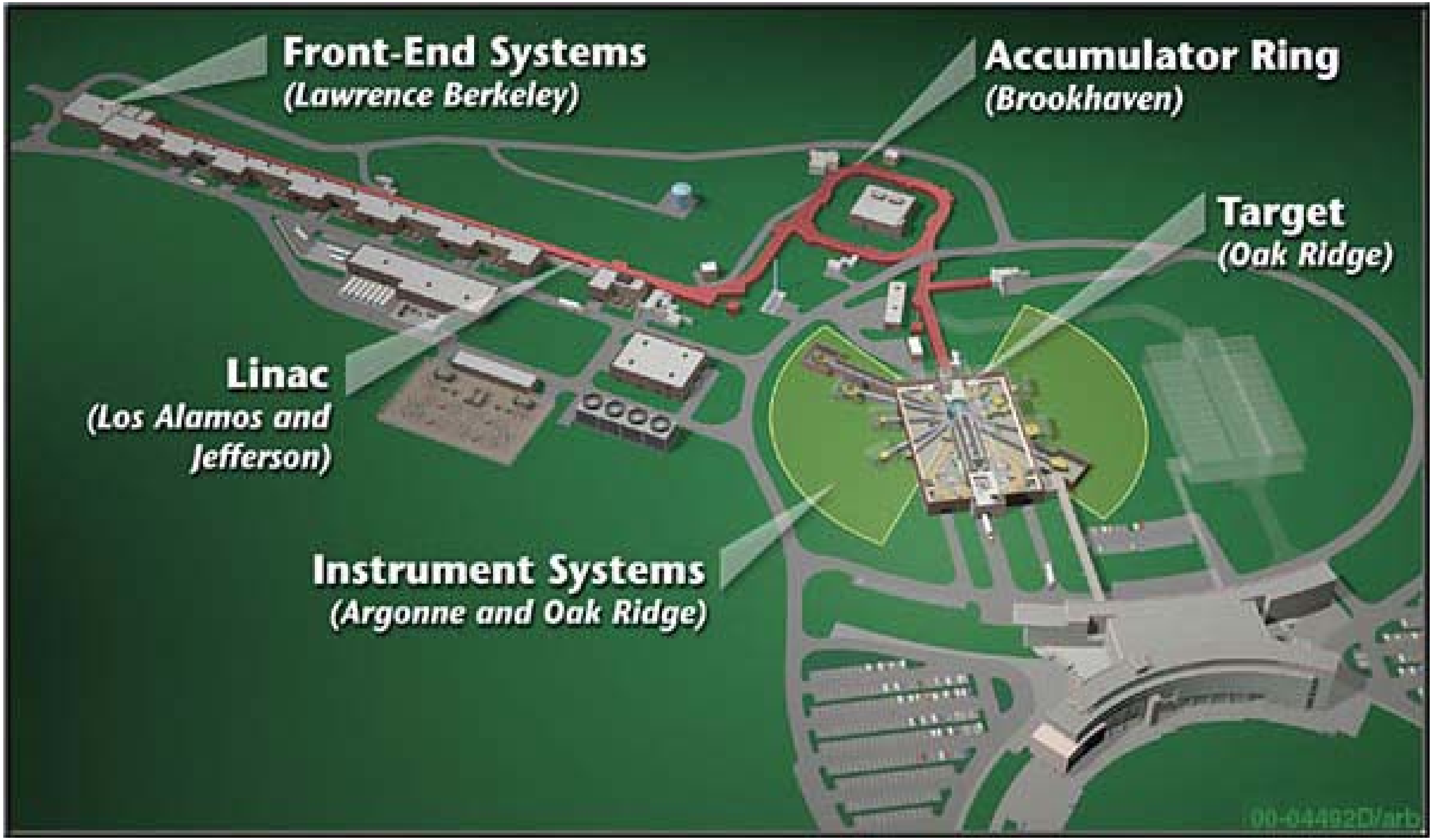
Last two must be measured

PC LR asymmetries

- Mott-Schwinger in LH_2 (must be modeled)
- Parity-allowed $\vec{n}+p \longrightarrow d+\gamma$ 2×10^{-8}
- Parity-allowed LR asymmetry in capture on Al=0

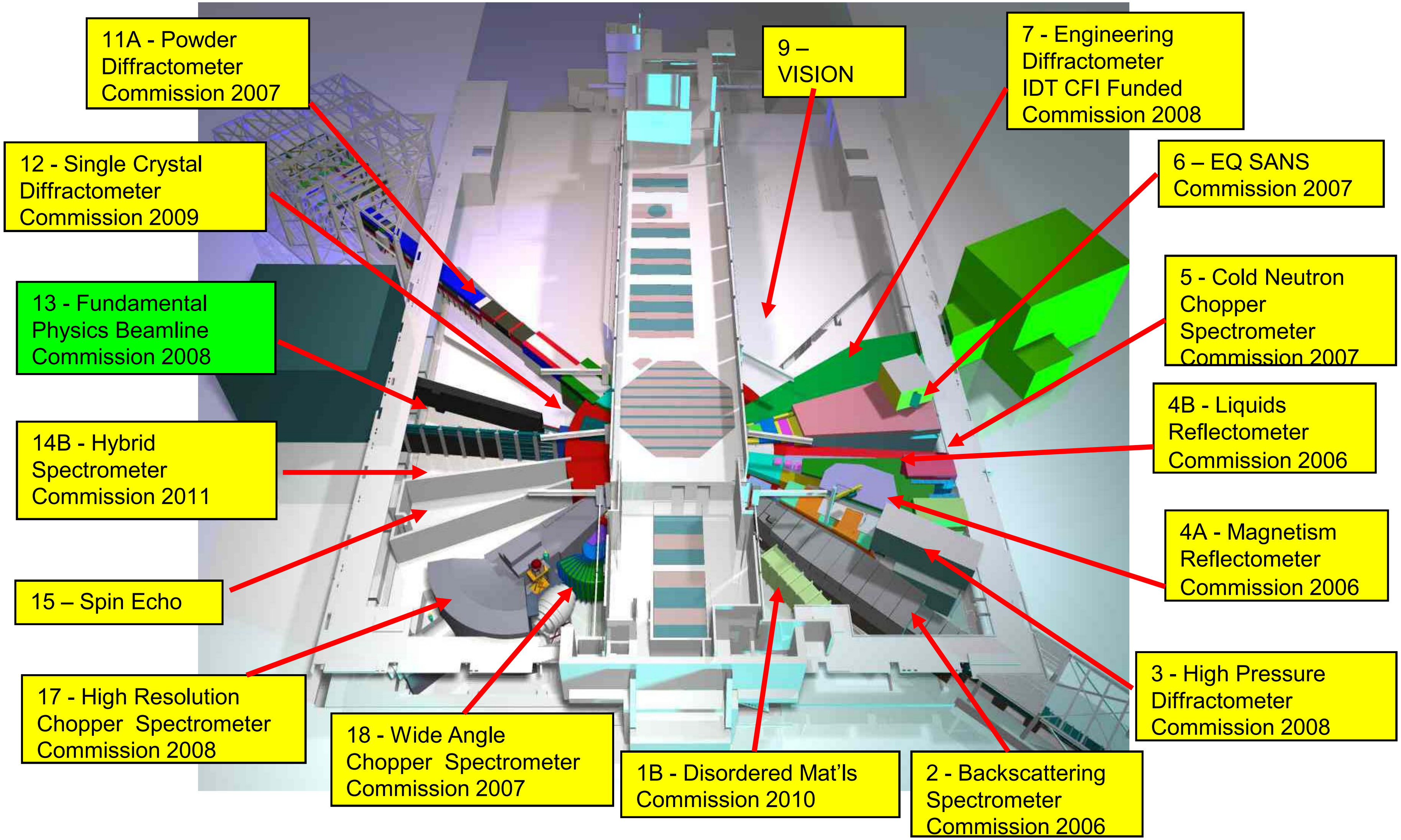
- These asymmetries can mix into the U-D channel if the detector and guide field are not aligned

Spallation Neutron Source at ORNL

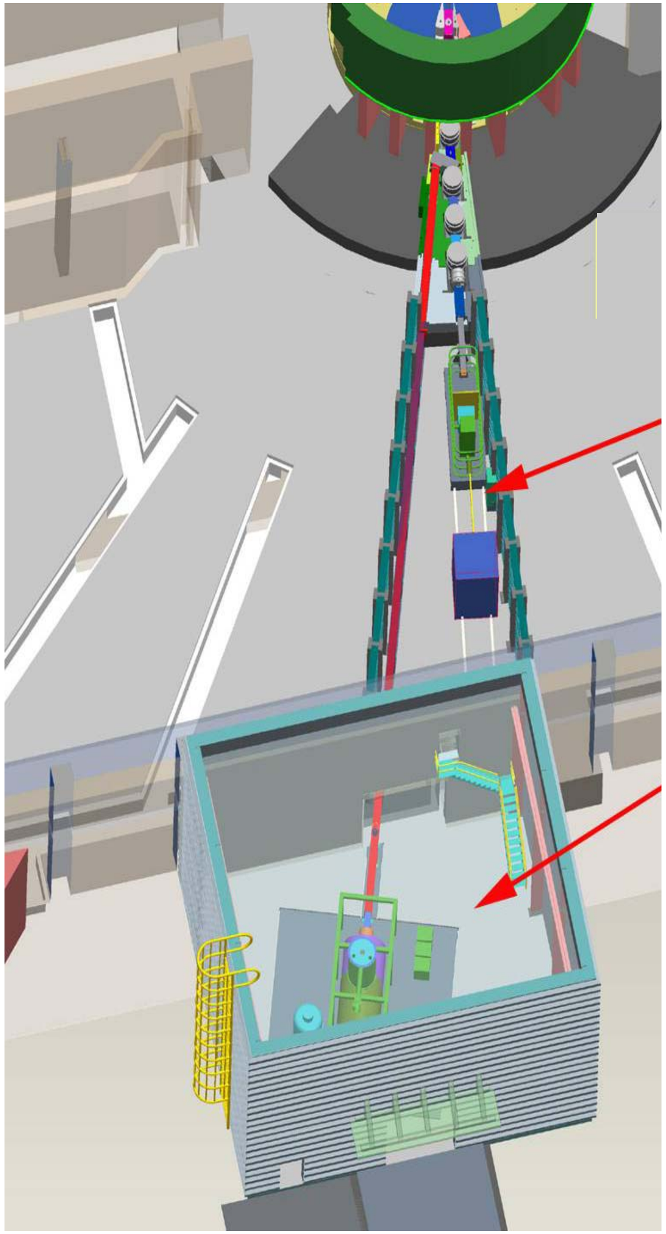


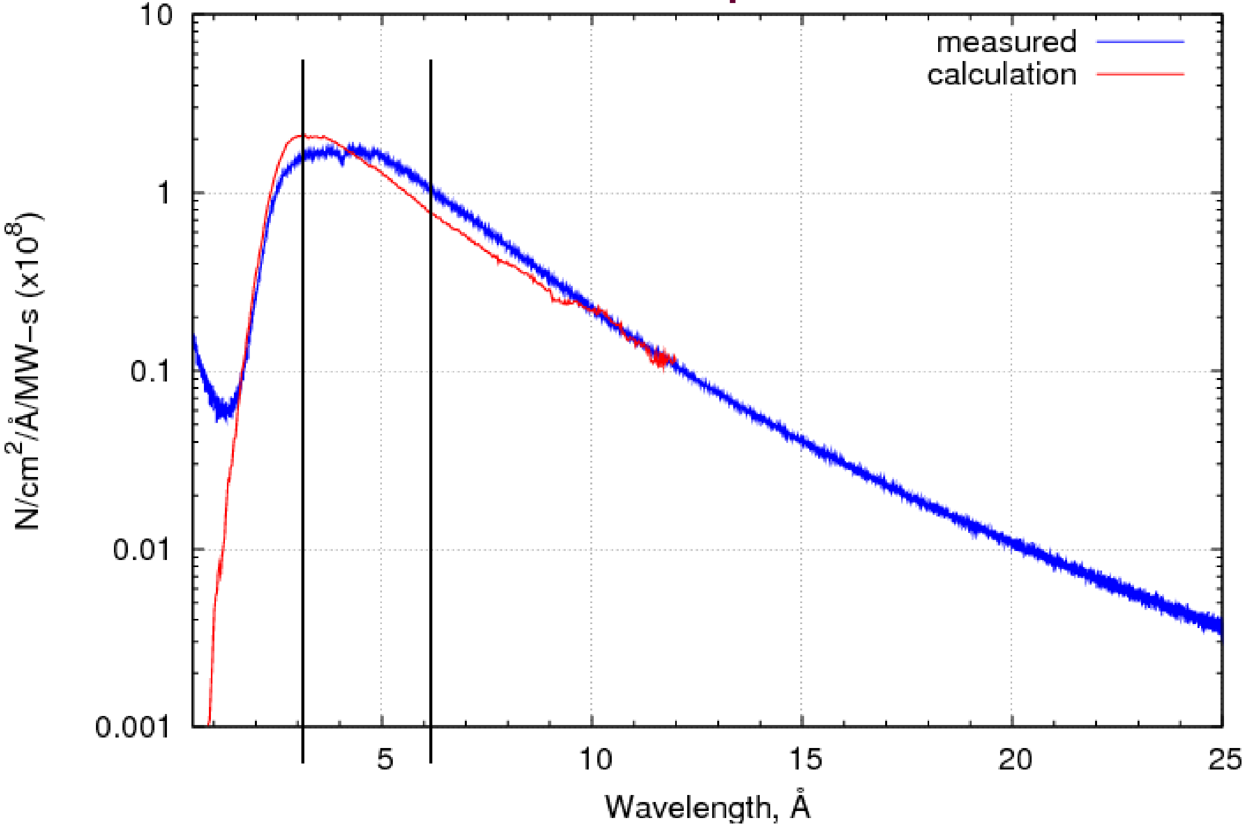
- 1.4 GeV protons, 60Hz
- LHg Spallation target -> neutrons
- H_2 moderator
- 17m SM guide, curved

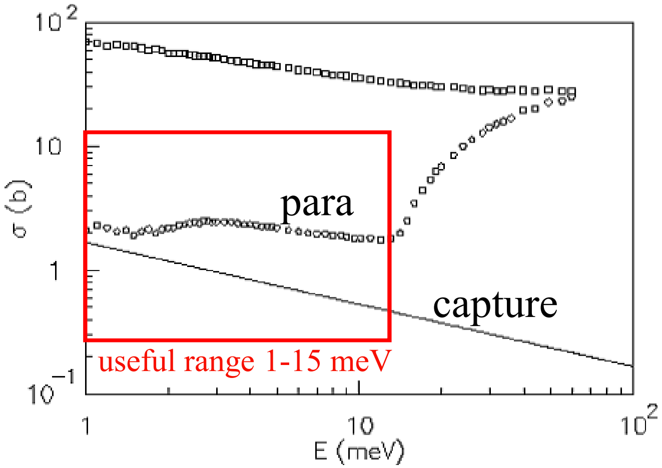
Spallation Neutron Source at ORNL



FNPB – cold beamline commissioned on Sep 12th, 2008

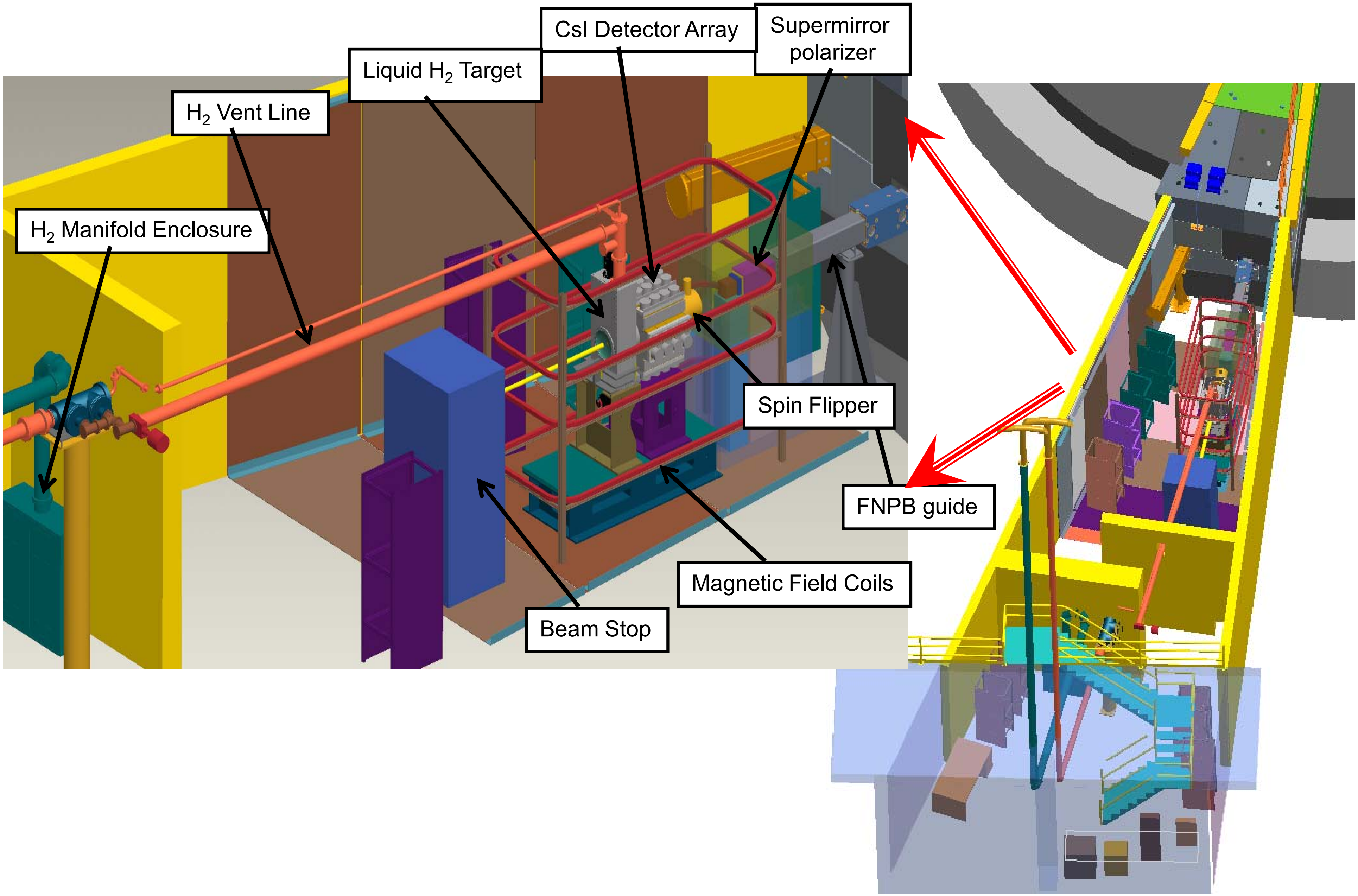






Getting cave ready for NPDGamma

Conceptual design of Experiment



Summary

- SuperMirror Polarizer replaces the ^3He Polarizer (x4.1)
- Higher moderator brightness (x12) => more cold neutrons
- New LH_2 target – thinner windows, smaller background contribution

Predicted size $-5x10^{-8}$ (DDH) - NPDGamma will make a 20% measurement ($1x10^{-8}$)

- Installation is currently under way
- Production Hydrogen Data – early 2010

The NPDGamma collaboration

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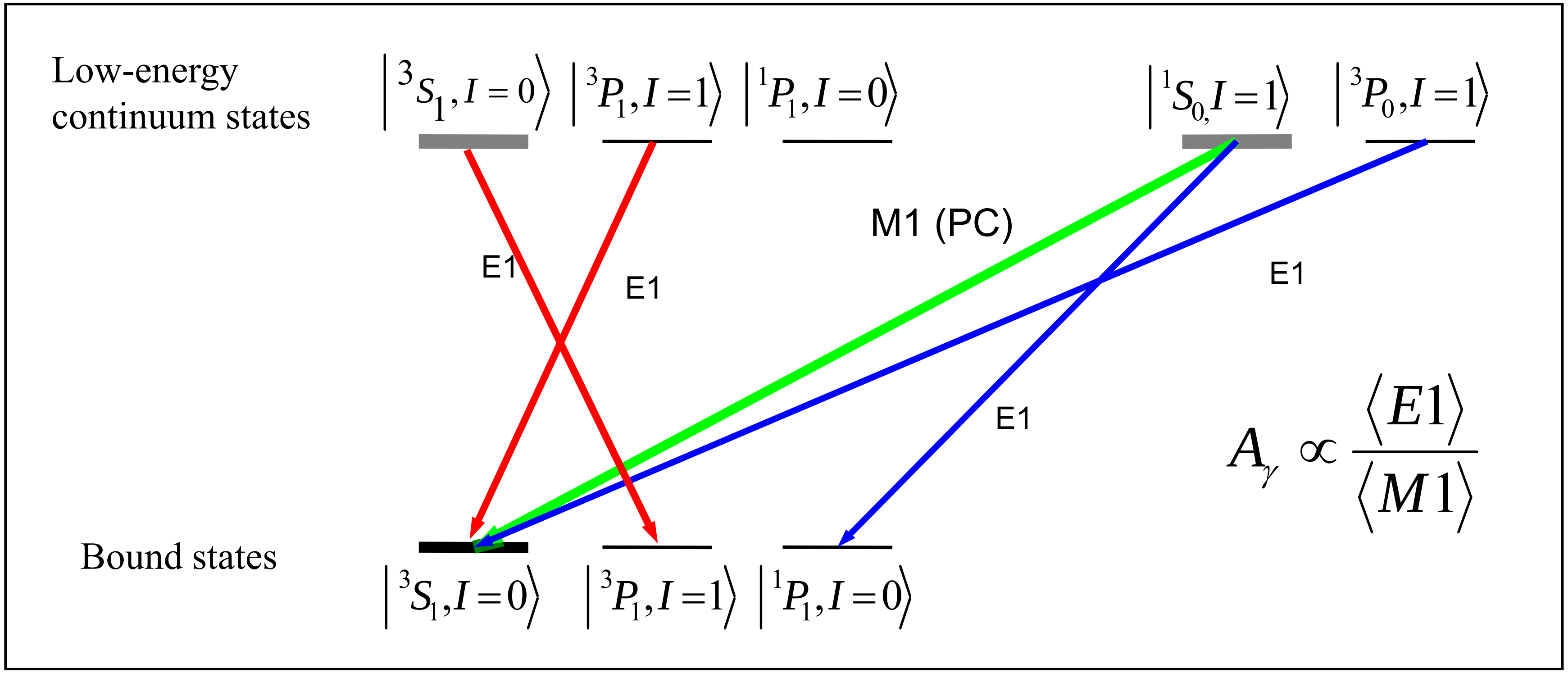
Systematic Effects

Interaction	Vector correlation	U D/ L R	P V/ PC	Time of flight dependence	Size of asymmetry
n+p→d+γ (NPDGamma)	$\mathbf{s_n} \cdot \mathbf{k_\gamma}$	ud	pv	no	$5 \times 10^{-8(*)}$
n+p→**n**+p (scattering shift)	$\mathbf{k'_n} \cdot \mathbf{s_n} \times \mathbf{k_n}$	lr	pc	1/t	$1 \times 10^{-9(*)}$
n+p→d+γ (#)	$\mathbf{k'_\gamma} \cdot \mathbf{s_n} \times \mathbf{k_n}$	lr	pc	$1/t^2$	$1 \times 10^{-10(*)}$
n+p→d+γ (magnetized iron)	$\mathbf{s_n} \cdot \mathbf{k_\gamma}$	ud	pc	no	$1 \times 10^{-10(*)}$
n→p+e+n_e **(beta decay)**	$\mathbf{s_n} \cdot \mathbf{k_e}$	ud	pv	no	$3 \times 10^{-11(*)}$
n+d→t+γ (D_2 contamination)	$\mathbf{s_n} \cdot \mathbf{k_\gamma}$	ud	pv	no	$1 \times 10^{-10(*)}$
n+p→**n**+p (Mott-Schwinger)	$\mathbf{k'_n} \cdot \mathbf{s_n} \times \mathbf{k_n}$	lr	pc	$1/t^{2.8}$	$5 \times 10^{-10\,(**)}$
n+^{6}Li→α+t (Li-shield)	$\mathbf{s_n} \cdot \mathbf{k'_n}$	ud	pv	no	$2 \times 10^{-11(*)}$
$(\mu_n \cdot \nabla)\mathbf{B}$ (Stern-Gerlach)	$(s_n \cdot \nabla)\mathbf{B}$	ud	pc	t^1	$1 \times 10^{-10(**)}$
n+A→**(A**+1)+e+n_e	$\mathbf{s_n} \cdot \mathbf{k_e}$	ud	pv	varies	$<10^{-10(*)}$
n+A→**(A**+1)+γ	$\mathbf{s_n} \cdot \mathbf{k_\gamma}$	ud	pv	no	$<10^{-9(**)}$
n+^{27}Al→^{28}**Al+γ**	$\mathbf{s_n} \cdot \mathbf{k_\gamma}$	ud	pv	no	$< 2 \times 10^{-7(**)}$

(#) see Ref. [30]
sn is the neutron spin and **k** is momentum of particle.
(*) size calculated
(**) size measured

What gives rise to parity violation in $\vec{n} + p \Rightarrow d + \gamma$?



$\vec{n} + p \rightarrow d + \gamma$ is primarily sensitive to the $\Delta I = 1$ component of the weak interaction

$$^1S_0 \rightarrow {}^3P_0 \quad (\Delta I = 0,1,2)$$

$$^3S_1 \rightarrow {}^1P_1 \quad (\Delta I = 0)$$

$$^3S_1 \rightarrow {}^3P_1 \quad (\Delta I = 1)$$ ← π exchange