Hadronic Parity Violation and Neutron Capture Reactions

Michael Gericke

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physics & astronomy university of manitoba

Outline

PV and the hadronic weak interaction

Meson Exchange Picture

EFT and Hadronic PV

The Experimental Program

Shi-Lin Zhu, et al. , Nuclear Physics A 748 (2005) 435–498
M.J. Ramsey Musolf and S. Page, Annu. Rev. Nucl. Part. Sci. 2006. 56:1–52
C.-P. Liu, Nuclear Physics Phys. Rev. C 75, 065501 (2007)

Parity violating processes between nucleons are used as a tool to study the hadronic weak interaction (HWI) as well as how it is modified by the strong interactions from the simple Standard Model prediction.

Two (common) ways to study HWI:

1. *Flavor changing $\Delta S=1$ hyperon and meson decay*
   - *Decay amplitudes, asymmetries, ...*
2. *Flavor conserving $\Delta S=0$ PV interactions at low energy*
   - *Mostly asymmetries, analyzing power, rotation angles*

Flavor changing decay of mesons and hyperons:

- *Much theoretical progress from EFT, χPT, heavy quark EFT*

- *Structure of operators from effective Lagrangians incorporate the symmetries of QCD*

Not so, in hyperon decay:

- *Unresolved $\Delta I = \frac{1}{2}$ rule puzzle*

- *Anomalously large PV asymmetries in hyperon radiative decays*

- *Etc.*

Do the unexpected observations in the ΔS=1 sector come from a dynamical strange quark or some other process ?

→ **Look at the ΔS=0 sector**

Standard Model:

$$\mathcal{L}_W^{INT} = -\frac{g}{2\sqrt{2}}\left(J_C^{\mu\dagger}W_\mu + J_c^\mu W_\mu^\dagger\right) - \frac{g}{4\cos\theta_w}J_N^\mu Z_\mu$$

Charged currents:

$$\begin{aligned} J_C^\mu \; = \; & \overline{\psi}_d\gamma^\mu(1-\gamma_5)\psi_u\cos\theta_c + \overline{\psi}_s\gamma^\mu(1-\gamma_5)\psi_u\sin\theta_c \\ & -\overline{\psi}_d\gamma^\mu(1-\gamma_5)\psi_c\sin\theta_c + \overline{\psi}_s\gamma^\mu(1-\gamma_5)\psi_c\cos\theta_c \end{aligned}$$

Neutral currents:

$$\begin{aligned} J_N^\mu \; = \; & \overline{\psi}_u\gamma^\mu(1-\frac{8}{3}\sin^2\theta_w-\gamma_5)\psi_u + \overline{\psi}_c\gamma^\mu(1-\frac{8}{3}\sin^2\theta_w-\gamma_5)\psi_c \\ & -\overline{\psi}_d\gamma^\mu(1-\frac{4}{3}\sin^2\theta_w-\gamma_5)\psi_d - \overline{\psi}_s\gamma^\mu(1-\frac{4}{3}\sin^2\theta_w-\gamma_5)\psi_s \end{aligned}$$

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$\Delta S = \pm 1$

Neutral currents:

$$\begin{aligned} J_N^\mu \;=\; & \overline{\psi}_u\gamma^\mu(1-\frac{8}{3}\sin^2\theta_w-\gamma_5)\psi_u + \overline{\psi}_c\gamma^\mu(1-\frac{8}{3}\sin^2\theta_w-\gamma_5)\psi_c \\ & -\overline{\psi}_d\gamma^\mu(1-\frac{4}{3}\sin^2\theta_w-\gamma_5)\psi_d - \overline{\psi}_s\gamma^\mu(1-\frac{4}{3}\sin^2\theta_w-\gamma_5)\psi_s \end{aligned}$$

$\Delta S = 0$

Hadronic weak interaction!

Goals of $\Delta S=0$ HWI studies:

1. Answer how the symmetries of QCD characterize the HWI in strongly interacting systems

   The HWI is just a residual effect of the q-q weak interaction for which the range is set by the mass of the Z,W bosons which is much smaller than the size of nucleons, as determined by QCD dynamics

   → HWI probes short range qq correlations at low energy

2. Shed light on the puzzles in the $\Delta S=1$ sector of the HWI

Applications of $\Delta S=0$ HWI studies:

1. Atomic Parity Violation (anapole moment)
2. Parity Violation in Nuclei
3. Parity Violating Electron Scattering

ΔS=0 HWI studies:

The ΔS=0 HWI can only be isolated experimentally via PV observables, to isolate the weak interaction from the much larger EM and strong interactions.

$$\frac{g_W^2}{\alpha M_W^2} \approx 10^{-4}$$

Weak e-N scale

$$\frac{g_W^2}{M_W^2} \cdot \frac{M_\pi^2}{g_{\pi NN}^2} \approx 10^{-7}$$

Weak N-N scale

Very challenging !

$\Delta S=0$ HWI studies:

So people started to look for nuclear many-body (large A) systems for which there exists some fortuitous enhancement of the size of the observable:

→ *coming from nearly degenerate opposite parity state mixing and interference with the much larger parity allowed transition in nuclear excited states.*

e.g. TRIPLE collaboration:
parity violation in compound nuclei from neutron-nucleus resonant scattering with longitudinal cross section asymmetries of order 10^{-3}–10^{-1} (up to 10^{6} enhancement)

G.E. Mitchell *et al.* Phys. Rep. 354, 157 (2001)

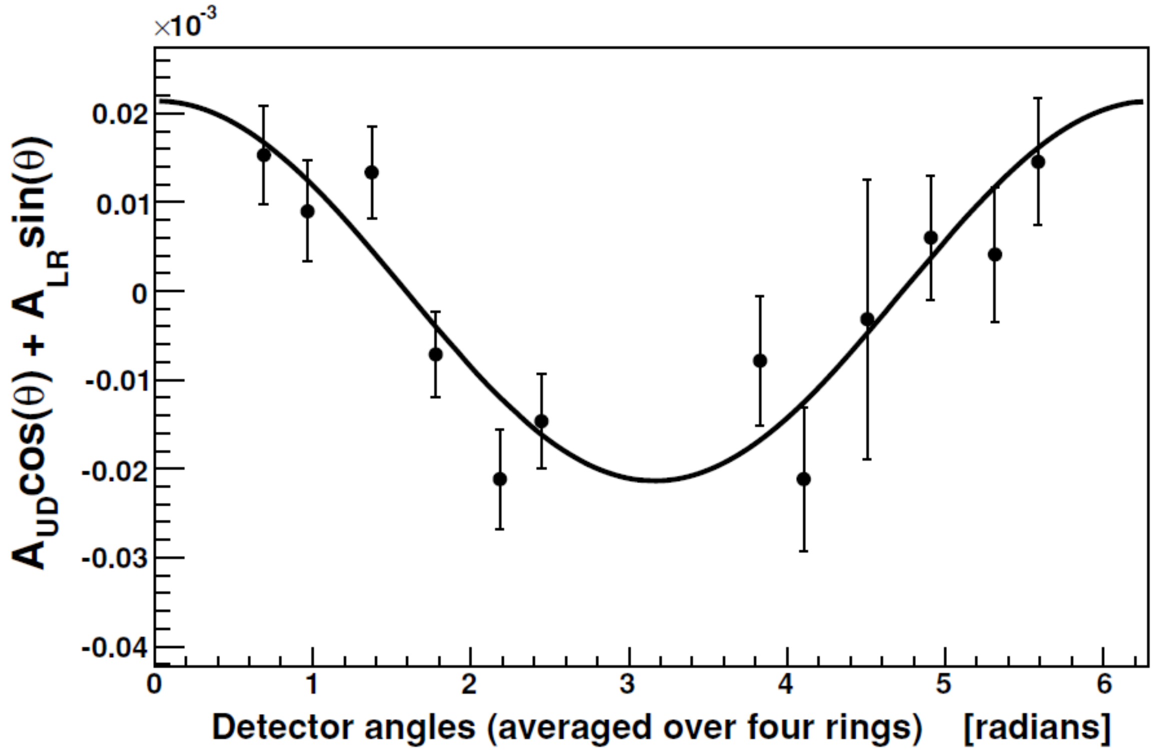
You can get the weak spreading width (weak mixing amplitude) from statistical analysis of this data:

$$\Gamma_W = 1.8^{+0.4}_{-0.3} \times 10^{-7}\ eV \qquad \left(\frac{\langle \psi_f | W | \psi_i \rangle}{\Delta E} \approx \sqrt{\frac{\Gamma_W}{2\pi D}} \right)$$

Can also have large(r) asymmetries from neutron radiative capture (here Cl):

M.T. Gericke *et al.* Phys. Rev. C 74, 065503 (2006)

$$A_\gamma = (-19 \pm 2) \times 10^{-6} \text{ and } A_{LR} = (-1 \pm 2) \times 10^{-6}$$



n-capture on Chlorine (CCl_4)

ΔS=0 HWI studies:

However, many-body systems are hard to deal with when it comes to interpretation of the results in a non-statistical fashion.

There is no transparent connection to the SM.

→ So back to few body systems

- No nuclear structure physics
- Low nucleon momentum ($\leq$ ~40 MeV) allows for EFT momentum expansion
- But no enhancement of asymmetries

→ Need better experiments

DDH Model – Benchmark

B. Desplanques, J.F. Donoghue, B.R. Holstein, Annals of Physics 124:449-495 (1980)

Arrive at 7 weak meson-nucleon couplings:

h_π^1 , $h_\rho^{0,1,2}$, $h_\omega^{0,2}$, $h_\rho^{1'}$ ← calculated later by Holstein $\simeq 1.8\, g_\pi$

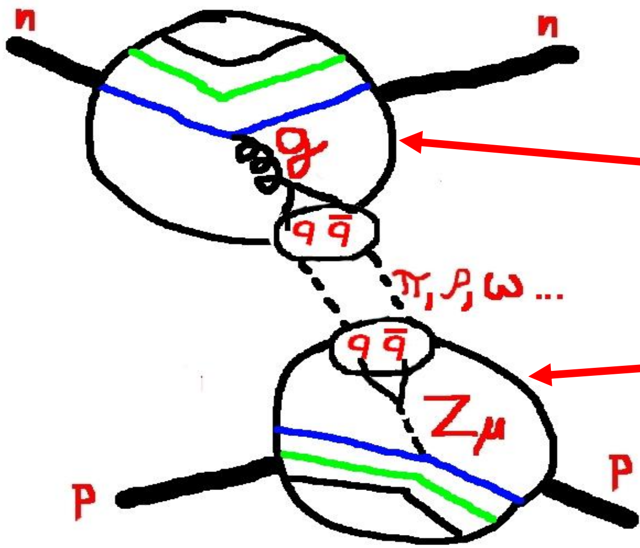
PV coupling	DDH range	DDH best value	DZ	FCDH
h_π^1	$0 \to 30$	$+12$	$+3$	$+7$
h_ρ^0	$30 \to -81$	-30	-22	-10
h_ρ^1	$-1 \to 0$	-0.5	$+1$	-1
h_ρ^2	$-20 \to -29$	-25	-18	-18
h_ω^0	$15 \to -27$	-5	-10	-13
h_ω^1	$-5 \to -2$	-3	-6	-6

All values are quoted in units of $g_\pi = 3.8 \times 10^{-8}$.

DZ: Dubovik VM, Zenkin SV. *Ann. Phys.* 172:100 (1986)

FCDH: Feldman GB, Crawford GA, Dubach J, Holstein BR. *Phys. Rev. C 43:863 (1991)*

The Nucleon-Nucleon Weak Interaction
Meson Exchange "Traditional" Picture



$$H_{PC} = ig_{\pi NN} \int d^3x \overline{\psi}_i(x)\gamma^5\psi_j(x)\left(\vec{\tau}\cdot\vec{\phi}(x)\right)$$

$$H_{PNC} = \frac{h_\pi^1}{\sqrt{2}} \int d^3x' \overline{\psi}_i(x')\psi_j(x')\left(\vec{\tau}\times\vec{\phi}(x')\right)$$

Solutions to the Lippmann-Schwinger equation - Essentially the first order term in a Born series:

$$\langle f|V_{PNC}|i\rangle = \langle N_f N_f|H_{PC}\frac{1}{E_0 - H_0 + i\varepsilon}H_{PNC}|N_i N_i\rangle \longrightarrow \frac{ig_{\pi NN}h_\pi^1}{\sqrt{32}M}\left[\vec{\tau}_1\times\vec{\tau}_2\right]_z\left[\vec{\sigma}_1+\vec{\sigma}_2\right]\cdot\left[\vec{p},\frac{e^{-mr}}{4\pi r}\right]$$

Weak π-Nucleon Coupling (ρ,ω not shown)

Meson exchange picture cont.

$$\left\langle N_f N_f \left| H_{PC} \frac{1}{E_0 - H_0 + i\varepsilon} H_{PNC} \right| N_i N_i \right\rangle$$

$$= \sum_I \int \frac{d^3k}{(2\pi)^3} \left\langle N_f \left| S \right| N_i \,, \pi_I(k) \right\rangle \frac{1}{\omega_k} \left\langle N_f \,, \pi_I(k) \left| S \right| N_i \right\rangle$$

Meson exchange picture cont.

$$\langle N_f N_f | H_{PC} \frac{1}{E_0 - H_0 + i\varepsilon} H_{PNC} | N_i N_i \rangle$$

$$= \sum_{I} \int \frac{d^3k}{(2\pi)^3} \langle N_f | S | N_i , \pi_I(k) \rangle \frac{1}{\omega_k} \langle N_f , \pi_I(k) | S | N_i \rangle$$

Relationship to quark degrees of freedom:

$$S = \frac{i}{2} \int dt_1 \int dt_2 \int dt_3 \{ H_W^I(t_1) H_W^I(t_2) H_S^I(t_3) \}$$

$$H_W^I = \int d^3x \left[\frac{g}{2\sqrt{2}} \left(J_C^{\mu^*} W_\mu + J_C^\mu W_\mu^* \right) + \frac{g}{4\cos\theta_W} J_N^\mu Z_\mu \right]$$

$$H_S^I = -\int d^3x \int d^3y \int dt_y \left[J_S f(x,y) \delta(t_x - t_y) \right]$$

Meson exchange picture cont.

$$\langle N_f N_f | H_{PC} \frac{1}{E_0 - H_0 + i\varepsilon} H_{PNC} | N_i N_i \rangle$$

$$= \sum_{\mathcal{I}} \int \frac{d^3k}{(2\pi)^3} \langle N_f | S | N_i , \pi_{\mathcal{I}}(k) \rangle \frac{1}{\omega_k} \langle N_f , \pi_{\mathcal{I}}(k) | S | N_i \rangle$$

Relationship to quark degrees of freedom:

$$S = \frac{i}{2} \int dt_1 \int dt_2 \int dt_3 \left\{ H_W^{\mathcal{I}}(t_1) H_W^{\mathcal{I}}(t_2) H_S^{\mathcal{I}}(t_3) \right\}$$

$$H_W^{\mathcal{I}} = \int d^3x \left[\frac{g}{2\sqrt{2}} \left(J_C^{\mu *} W_\mu + J_C^{\mu} W_\mu^* \right) + \frac{g}{4\cos\theta_W} J_N^{\mu} Z_\mu \right]$$

$$H_S^{\mathcal{I}} = -\int d^3x \int d^3y \int dt_y \left[J_S f(x,y) \delta\left(t_x - t_y\right) \right]$$

DDH use SU(6), quark model, and measured hyperon decay amplitudes instead !

DDH Model – Benchmark

In general, a measured PV NN observable can be expanded in terms of these:

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

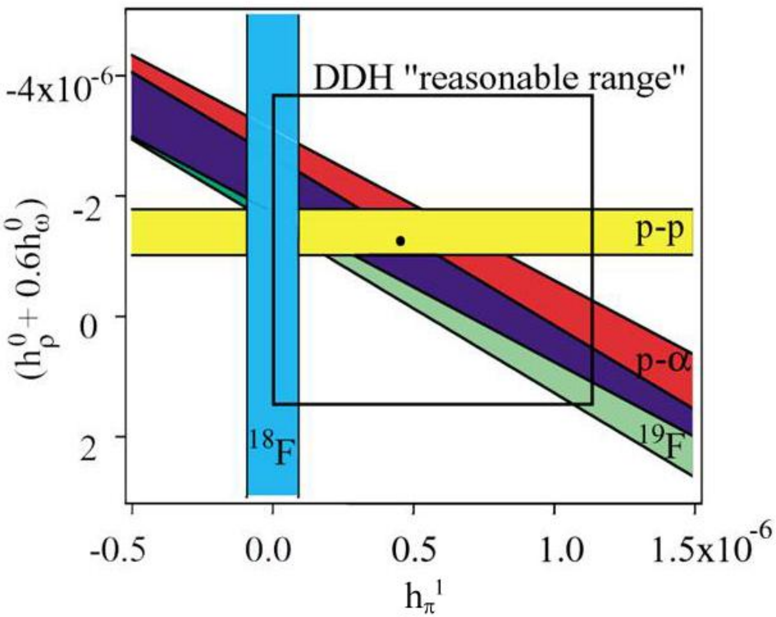
E. G. Adelberger and W. C. Haxton, Ann. Rev. Nucl. Part. Sci. 35, 501 (1985).

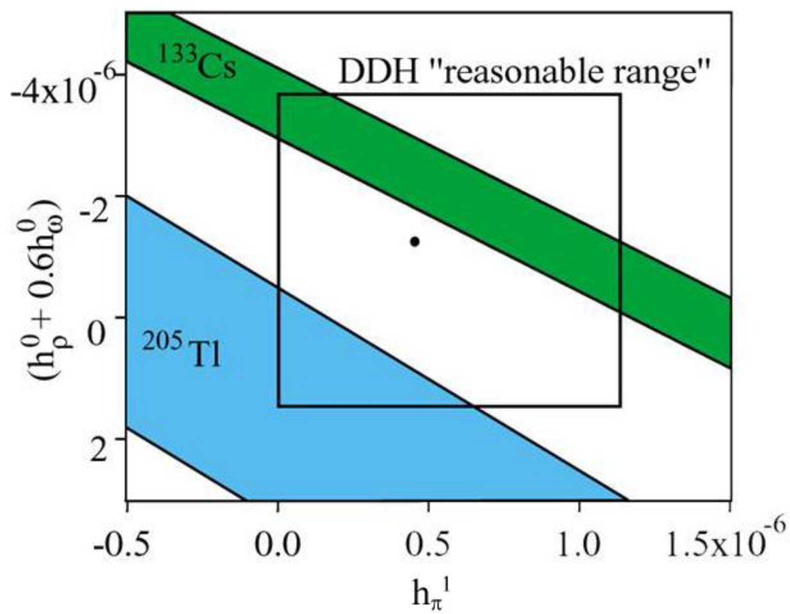
DDH Weak Coupling	(A_γ) $np \to d\gamma$	(A_γ) $nd \to t\gamma$	(ϕ_{PV}) n-p (μrad/m)	(ϕ_{PV}) n-α (μrad/m)	$\left(\frac{\Delta\sigma}{\sigma}\right)$ p-p	$\left(\frac{\Delta\sigma}{\sigma}\right)$ p-α	(A^p_Z) $n^3He \to tp$
a_π^1	-0.107	-0.92	-3.12	-0.97	0	-0.340	-0.189
a_ρ^0	0	-0.50	-0.23	-0.32	0.079	0.140	-0.036
a_ρ^1	-0.001	0.103	0	0.11	0.079	0.047	0.019
a_ρ^2	0	0.053	-0.25	0	0.032	0	0.0006
a_ω^0	0	-0.160	-0.23	-0.22	-0.073	0.059	-0.033
a_ω^1	0.003	0.002	0	0.22	0.073	0.059	0.041

Viviani *et al.*
PRC 044001

Experimental results generally agree with the DDH ranges, but:

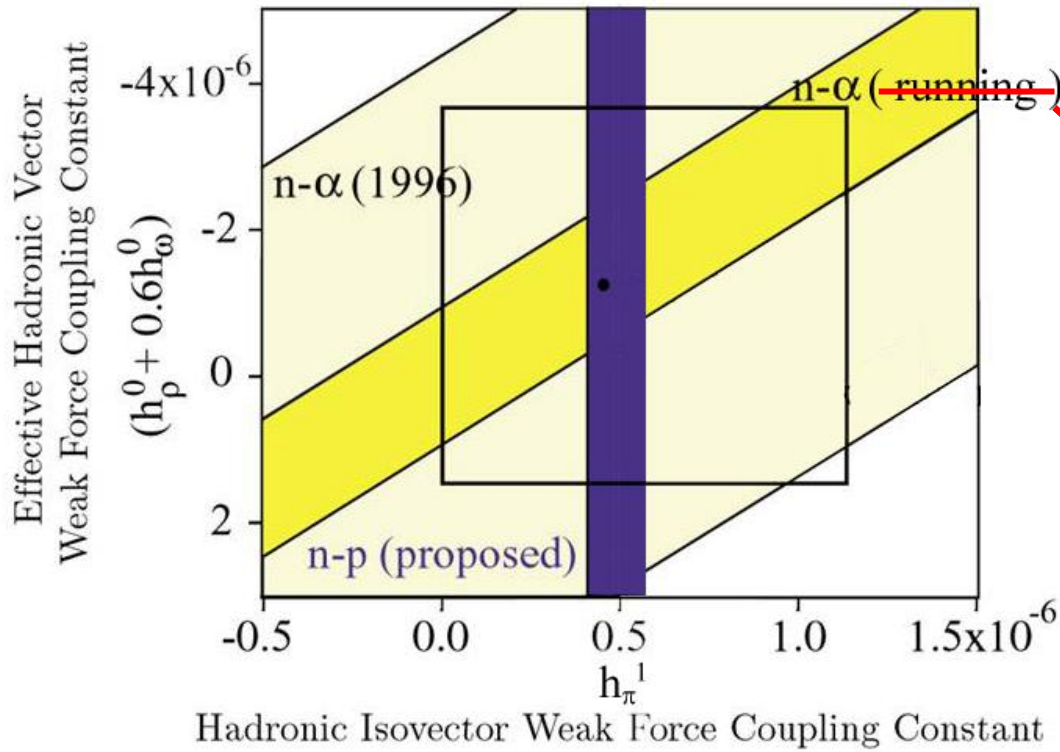
- *Uncertainties are large*
- *Some experimental results produce conflicting values for coupling constants (e.g. Values for h_π^1 from ^{18}F and ^{133}Cs differ by several σ)*





p-p scat. 15, 45 MeV A_z^{pp}
p-p scat. 221 MeV A_z^{pp}
p-α scat. 46 MeV A_z^{pp}

^{133}Cs, ^{205}Tl anapole moments



Completed

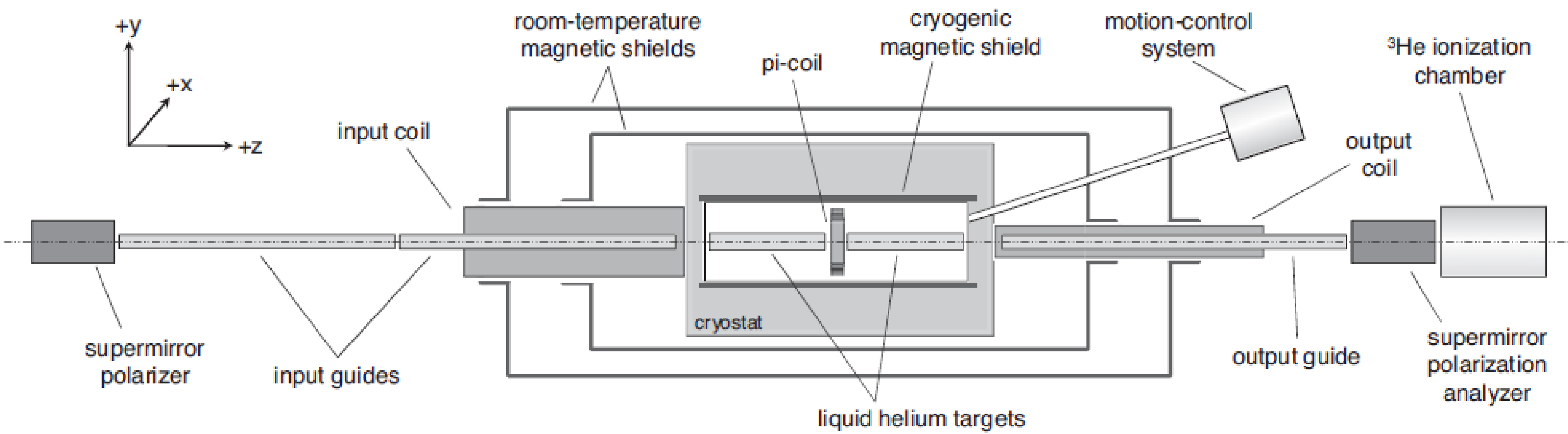
$n+p \rightarrow d+\gamma$ $\qquad$ A_γ^d

n-α spin rot. $d\phi^{n\alpha}/dz = [+1.7 \pm 9.1(\text{stat.}) \pm 1.4(\text{sys.})] \times 10^{-7}$ rad/m

W. M. Snow *et al.* Phys. Rev. C 83, 022501(R) (2011)

n^4He Spin Rotation

NIST Experiment:



- *Vertically polarized neutrons*
- *Enter liquid helium target with four chambers*
- *Neutrons rotate in helium in a spin dependent way*
- *Neutrons are rotated in the x-y plane after acquiring the PV rotation*
- *Neutrons are analyzed in another supermirror polarizer*
- *Transmitted neutrons are detected in the ion chamber*

$$\frac{N_+ - N_-}{N_+ + N_-} = \langle P A \sin\phi \rangle$$

EFT Calculations (Upshot)

The $\Delta S=0$ HWI can be parameterized in terms of 5 (8 with pions) low energy phenomenological constants.

At very low momenta ($\leq$ ~50 MeV) the constants essentially reduce to the 5 Danilov parameters:

→ $\lambda_s^0, \lambda_s^1, \lambda_s^2, \lambda_t, \rho_t$

originally determined from NN scattering theory (Born approximation) write down simplest S-P amplitudes with PV and CP cons. amplitudes in addition to singlet and triplet strong …

At higher momentum include explicit pions.

EFT Calculations

Write down 12 possible general P violating and CP conserving current-current terms with all isospin changes up to ΔI=2:

$$O_1 = \frac{g_1}{\Lambda_\chi^2}\overline{\psi}_N 1\gamma_\mu\psi_N\overline{\psi}_N 1\gamma^\mu\gamma_5\psi_N \qquad O_2 = \frac{g_2}{\Lambda_\chi^2}\overline{\psi}_N 1\gamma_\mu\psi_N\overline{\psi}_N \tau_3\gamma^\mu\gamma_5\psi_N$$

$$\tilde{O}_1 = \frac{\tilde{g}_1}{\Lambda_\chi^3}\overline{\psi}_N 1 i\sigma_{\mu\nu}q^\nu\gamma_\mu\psi_N\overline{\psi}_N \tau_3\gamma^\mu\gamma_5\psi_N \quad \bullet\bullet\bullet$$

etc…

The NN contact potentials are expressed in terms of 12 parameters, but no mesons:

$$C_{1-5} = \frac{\Lambda_\chi}{2m_N}g_{1-5} \quad , \quad \tilde{C}_{1-5} = \tilde{g}_{1-5} + \frac{\Lambda_\chi}{2m_N}g_{1-5}$$

$$C_6 = \tilde{g}_6 - \frac{\Lambda_\chi}{2m_N}g_6$$

Shi-Lin Zhu, et al. , Nuclear Physics A 748 (2005) 435–498

Appropriate linear combinations of these reproduce the 5 Danilov coupling constants to be determined by experiment:

$$\lambda_t \propto (C_1 - 3C_3) - (\tilde{C}_1 - 3\tilde{C}_3)$$

$$\lambda_s^0 \propto (C_1 + C_3) + (\tilde{C}_1 + \tilde{C}_3) \qquad {}^3S_1 \to {}^1P_1 \quad I = 0$$

$$\lambda_s^1 \propto (C_2 + C_4) + (\tilde{C}_2 + \tilde{C}_4) \qquad {}^1S_0 \to {}^3P_0 \quad I = 1$$

$$\lambda_s^2 \propto -\sqrt{\frac{8}{3}}(C_5 + \tilde{C}_5)$$

$$\rho_t \propto \frac{1}{2}(C_2 - C_4) + C_6 \qquad {}^3S_1 \to {}^3P_1 \quad I = 1 \to 0$$

$$\lambda_s^{pp} = \lambda_s^0 + \lambda_s^1 + \frac{1}{\sqrt{6}}\lambda_s^2$$

$$\lambda_s^{np} = \lambda_s^0 - \frac{2}{\sqrt{6}}\lambda_s^2$$

$$\lambda_s^{nn} = \lambda_s^0 - \lambda_s^1 + \frac{1}{\sqrt{6}}\lambda_s^2$$

Shi-Lin Zhu, et al. , Nuclear Physics A 748 (2005) 435–498

Experimental Program

We need at least 5 (8) few body experiments to completely determine the EFT parameters.

Some have already been done:

Longitudinal Asymmetries in PV proton scattering:

$$A_L^{pp}(13.6\ MeV) = -(0.93 \pm 0.20 \pm 0.05) \times 10^{-7} = \boxed{-0.48 \lambda_s^{pp} m_N}$$

Bonn: **P.D. Evershiem *et al.* Phys. Lett. 256 (1991) 11**

$$A_L^{pp}(45\ MeV) = -(1.5 \pm 0.22) \times 10^{-7} = \boxed{-0.82 \lambda_s^{pp} m_N}$$

PSI: **S. Kistryn *et al.* Phys. Lett. 58 (1987) 1616**
R. Balzer *et al.* *Phys. Rev. C. 30 (1984) 1409*

$$A_L^{p\alpha}(46\ MeV) = -(3.3 \pm 0.9) \times 10^{-7} = \boxed{\left[-0.48\left(\lambda_s^{pp} + \frac{1}{2}\lambda_s^{np}\right) - 0.107\left(\rho_t + \frac{1}{2}\lambda_t\right)\right] m_N}$$

Bonn: **J. Lang *et al.* Phys. Rev. Lett. 54 (1985) 170**

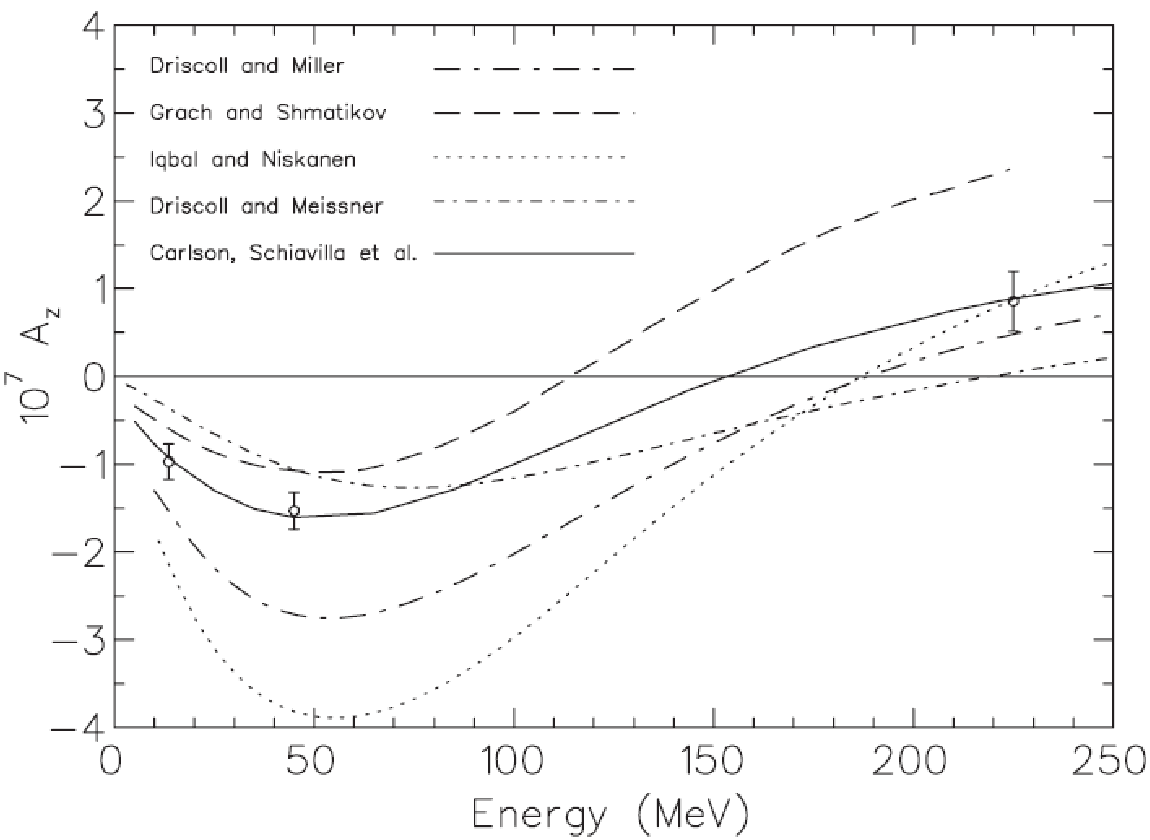
Experimental Program

The TRIUMF 220 MeV pp experiment

$$A_L^{pp}(221\ MeV) = -(0.84 \pm 0.29 \pm 0.17) \times 10^{-7} \propto h_\omega^0 + h_\omega^1 \equiv h_\omega^{PP}$$

TRIUMF: A.R. Berdoz *et al.* Phys. Rev. C 68 034004 (2003)

Of order Q^3 in EFT
- no calculation yet ?



Experimental Program

New experiments (or repeats):

- Neutron capture:
  - Circ. Polarization:

$$P_\gamma = \boxed{\left(0.63\lambda_t - 0.16\lambda_s^{np}\right)m_N}$$

Very challenging!

  - Gamma Asymmetry in np radiative capture:

$$A_\gamma = \boxed{-0.107\,\rho_t m_N}$$

LANSCE compl. SNS 2010

  - Gamma Asymmetry in nd radiative capture:

$$A_\gamma = \boxed{\left(1.42\rho_t + 0.59\lambda_s^{nn} + 1.18\lambda_t + 0.51\lambda_s^{np}\right)m_N}$$

Hard, SNS planned

  - Proton Asymmetry in n^3He capture

$$A_Z^p = (?)m_N$$

Relatively easy, SNS approved ~2011

Experimental Program

New experiments (or repeats):

- Neutron spin rotation:
  - In helium:

$$\frac{d\phi^{n\alpha}}{dz} = \left[1.2\left(\lambda_s^{nn} + \frac{1}{2}\lambda_s^{np}\right) - 2.68\left(\rho_t - \frac{1}{2}\lambda_t\right)\right] m_N \left[\frac{rad}{m}\right]$$

W.M. Snow *et al*, Completed (NIST)

  - In hydrogen LH2

$$\frac{d\phi^{np}}{dz} = \left[0.45\lambda_s^{nn} + 1.28\lambda_s^{np} + 0.45\lambda_s^{pp} + 1.26\rho_t - 0.63\lambda_t\right] m_N \left[\frac{rad}{m}\right]$$

SNS planned

Experimental Program

New experiments:

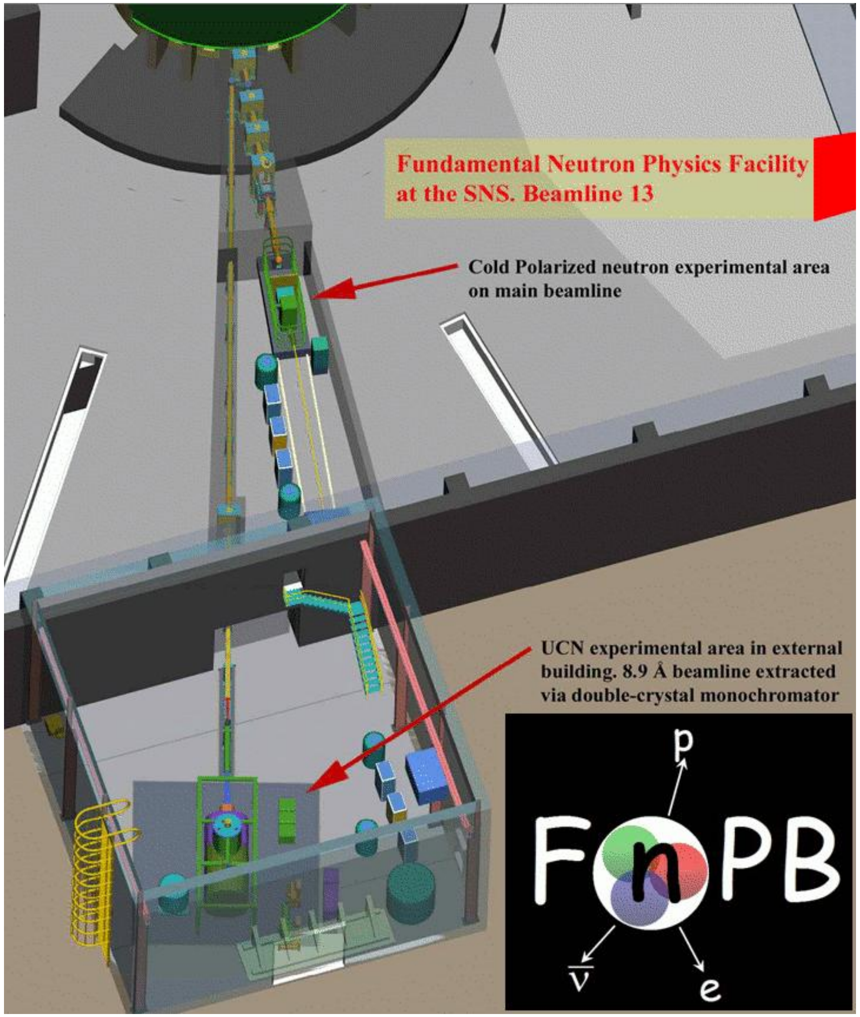
- **Longitudinal asymmetry in proton scattering:**
  - **p-d :**

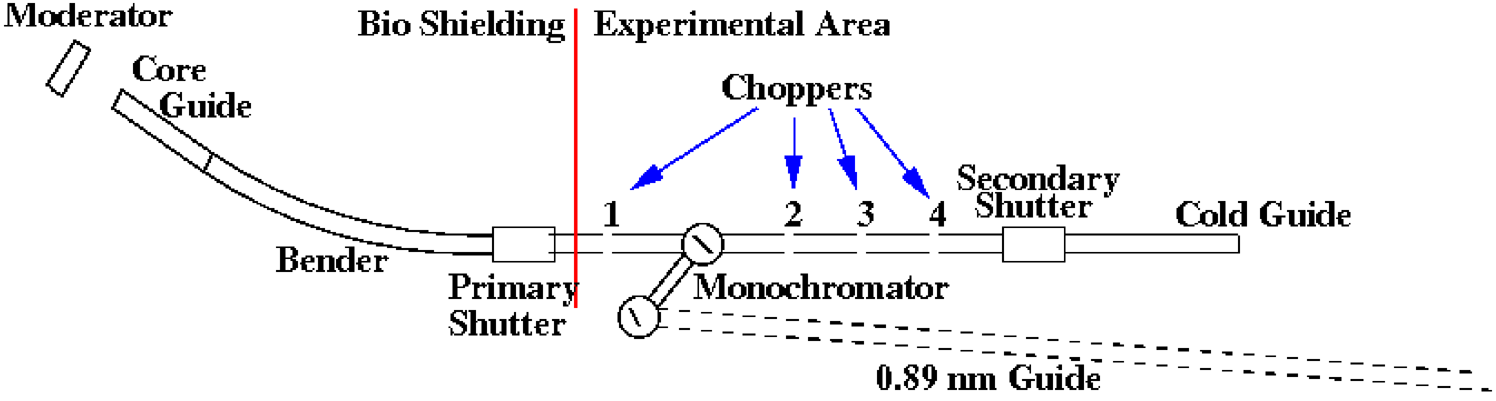
$$A_L^{pd}(15\ MeV) = \boxed{\left(-0.21\rho_t - 0.07\lambda_s^{pp} - 0.13\lambda_t + 0.04\lambda_s^{np}\right)m_N}$$

Spallation Neutron Source (SNS)

The Fundamental Neutron Physics Beam (FnPB)

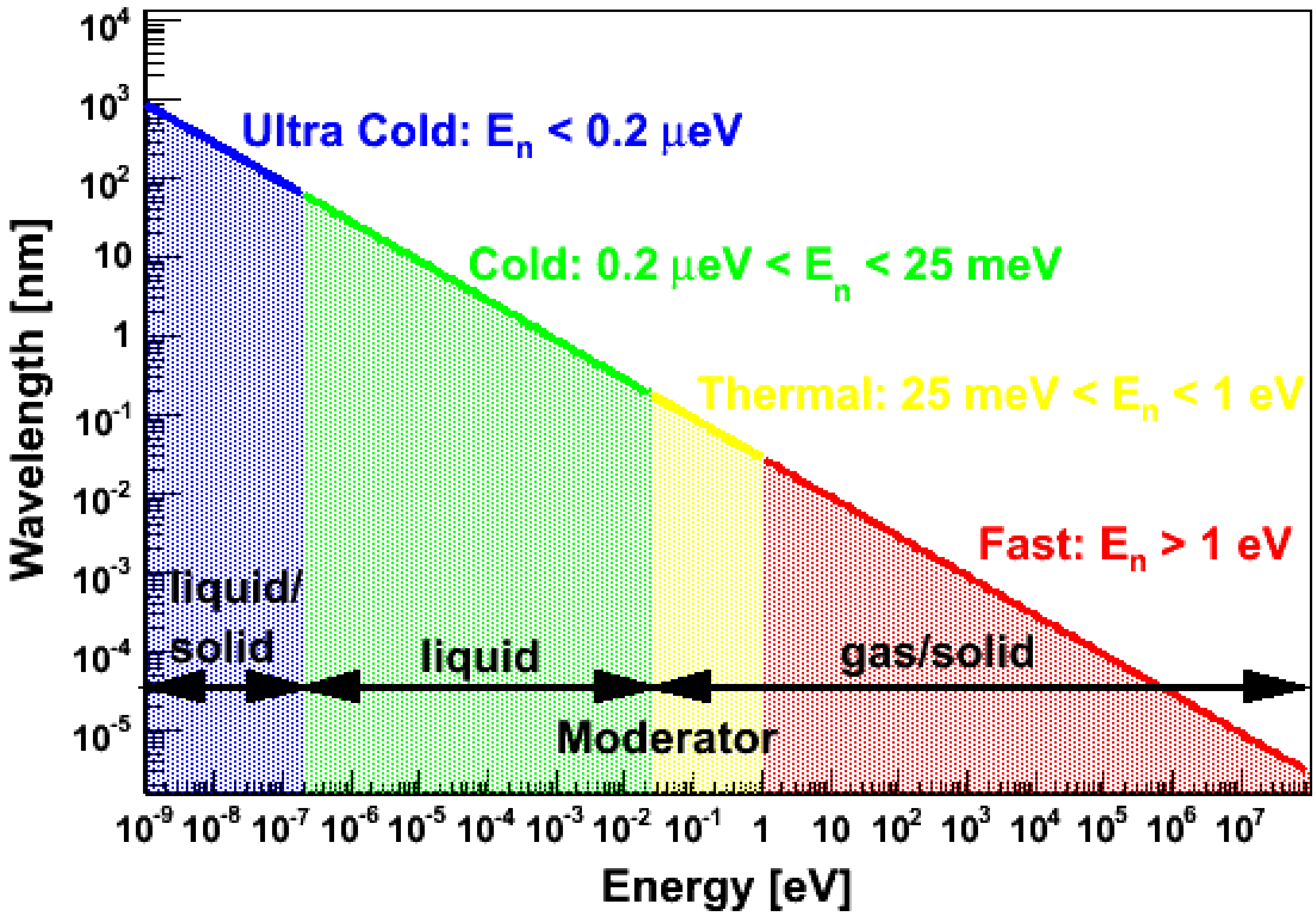
- LH2 moderator
- 15 m long guide ~ 18 m to experiment
- one polyenergetic cold beam line
- one monoenergetic (0.89 nm) beam line
- ~ 40 m to nEDM UCN source
- 4 frame overlap choppers
- 60 Hz pulse repetition





The Neutron Energy Scale

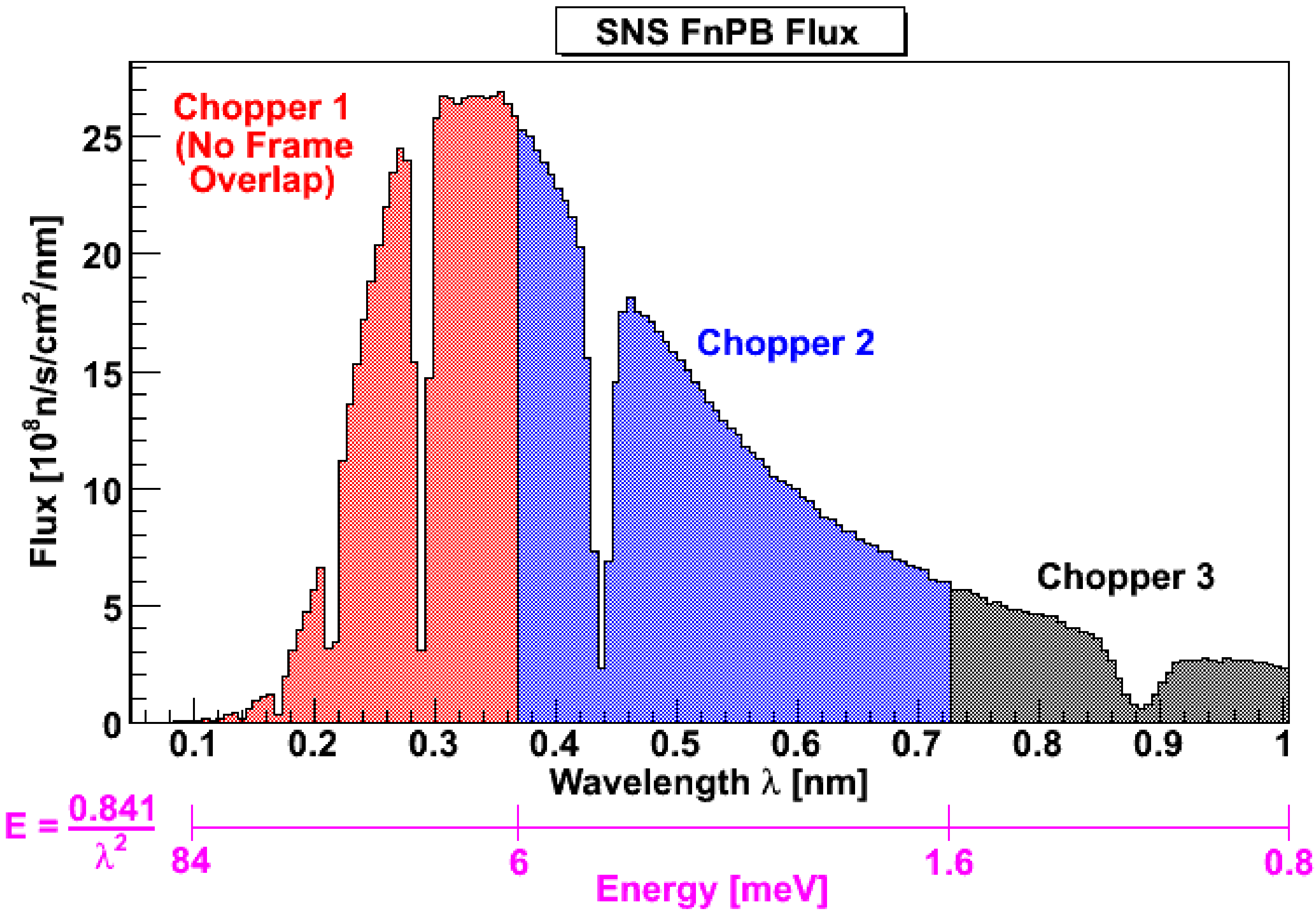
$$\lambda \approx \frac{29}{\sqrt{E_k}}\ fm$$

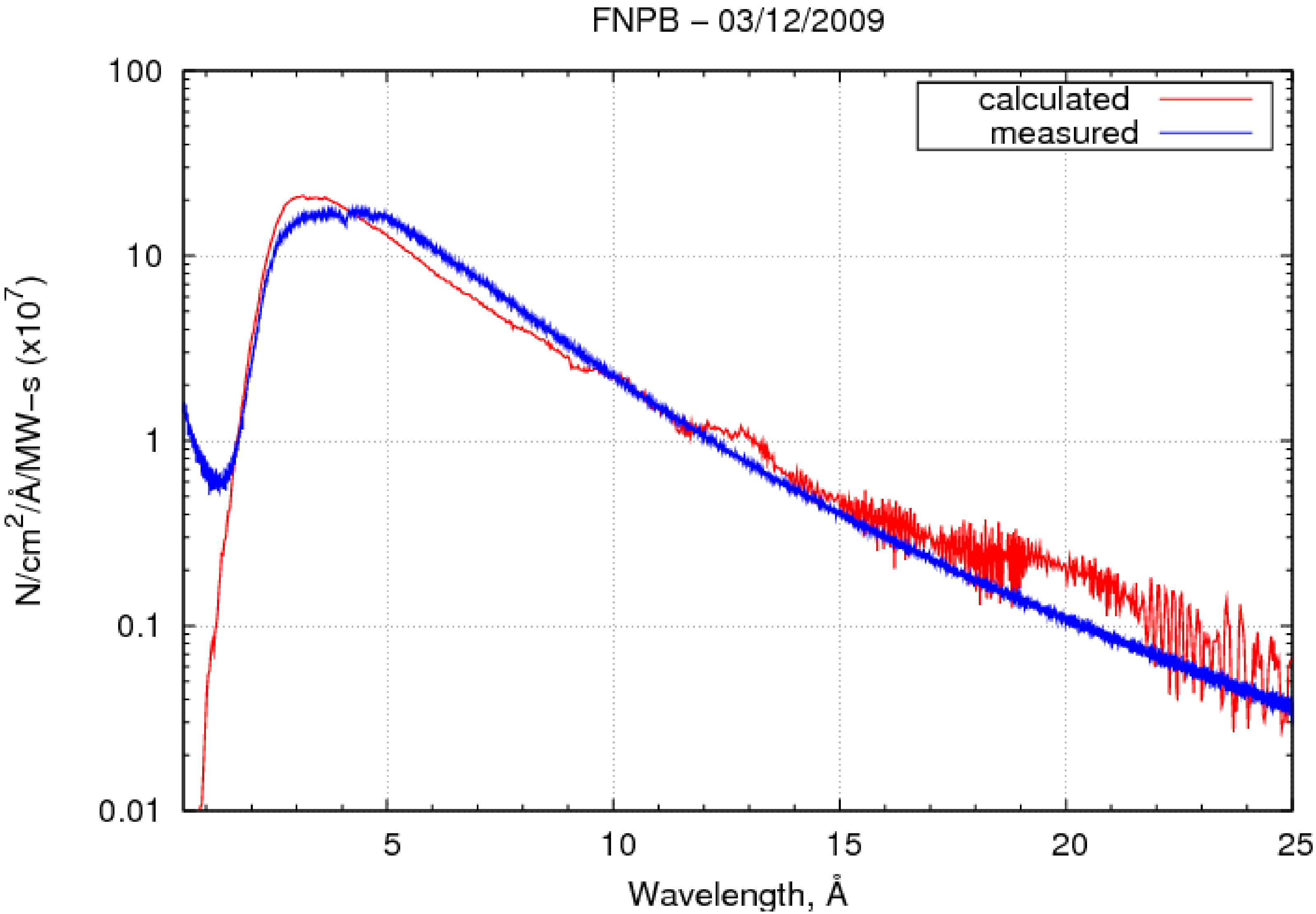


$$E_k = \frac{\hbar^2 k^2}{2M_n} = k_B T \quad , \quad k = 43.4\sqrt{E_k\left[MeV\right]}\ \ MeV/c$$

SNS Beam Properties

- total ~ 1.1×10^{11} neutrons/second
- 4.1×10^{10} n/s , 5.4×10^{10} n/s, 1.1×10^{10} n/s
  for three example regions with no frame overlap



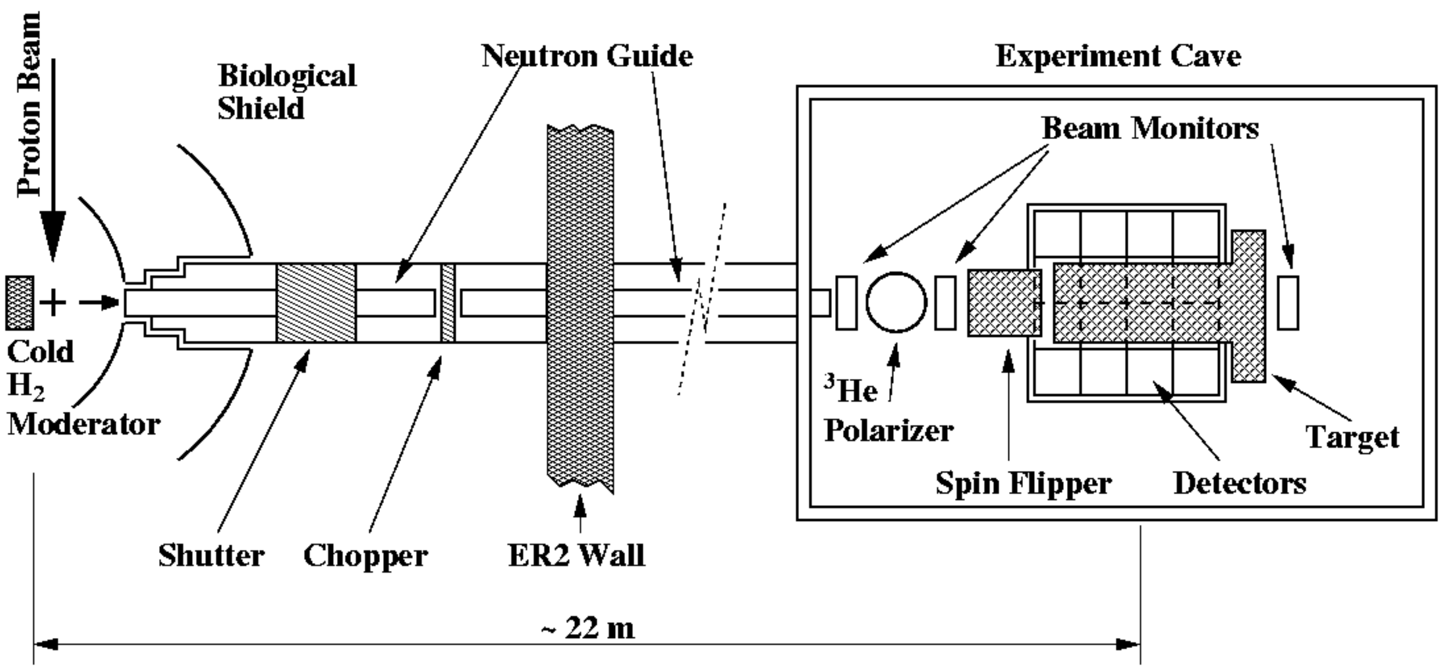


FNPB – 03/12/2009
calculated
measured
100
10
1
0.1
0.01
N/cm²/Å/MW-s (x10⁷)
5
10
15
20
25
Wavelength, Å

The NPDGamma Collaboration

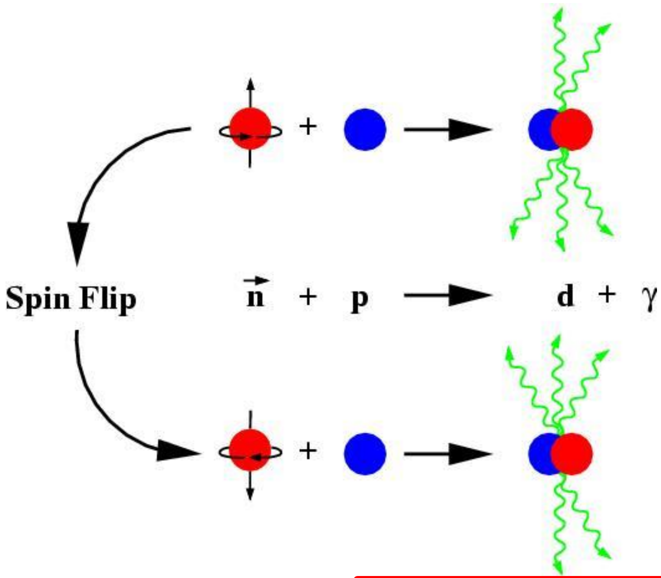
Oak Ridge National Laboratory,
University of Kentucky
UNAM,
University of Manitoba,
University of Michigan,
TJNAF,

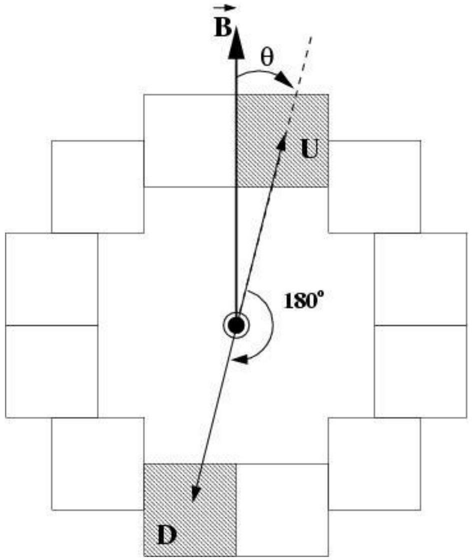
Indiana University,
University of Virginia,
University of Tennessee,
TRIUMF,
Los Alamos National Laboratory
Institute for Nuclear Research, Dubna,



The NPDGamma Observable / Theory

The main NPDGamma observable is the up-down asymmetry in the angular distribution of gamma rays with respect to the neutron spin direction:





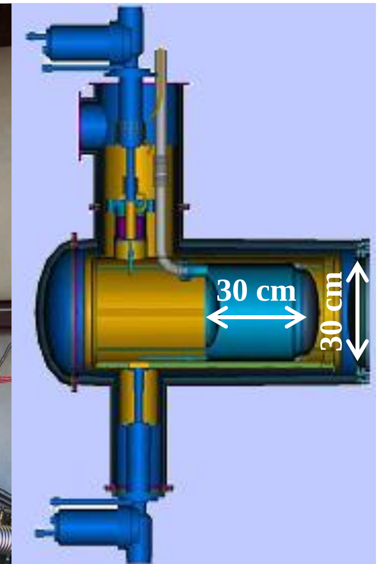
$$\frac{d\sigma}{d\Omega} \propto \frac{1}{4\pi}\left(1 + A_{\gamma} \cos\theta\right)$$

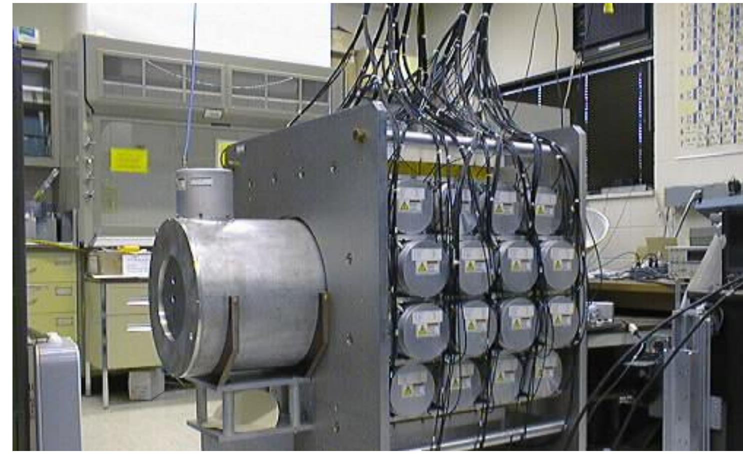
$$A_{raw} = \left(P_n F_n D_n G\right) A_{\gamma} \cos\theta = \frac{1}{2}\left(\frac{\sigma_U^{\uparrow} - \sigma_D^{\uparrow}}{\sigma_U^{\uparrow} + \sigma_D^{\uparrow}} + \frac{\sigma_U^{\downarrow} - \sigma_D^{\downarrow}}{\sigma_U^{\downarrow} + \sigma_D^{\downarrow}}\right)$$

DDH: $A_{\gamma} = -0.107\, h_{\pi}^{\Delta I=1} \approx -0.107 \times 12 \times g_{\pi} = -5 \times 10^{-8}$

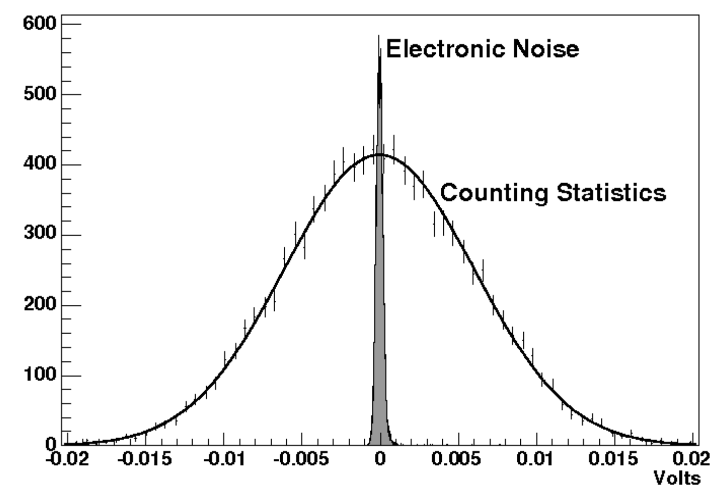
EFT: $A_{\gamma} = -0.107\, m_N \rho_t = -5 \times 10^{-8}$

LH_2 target and CsI detector array



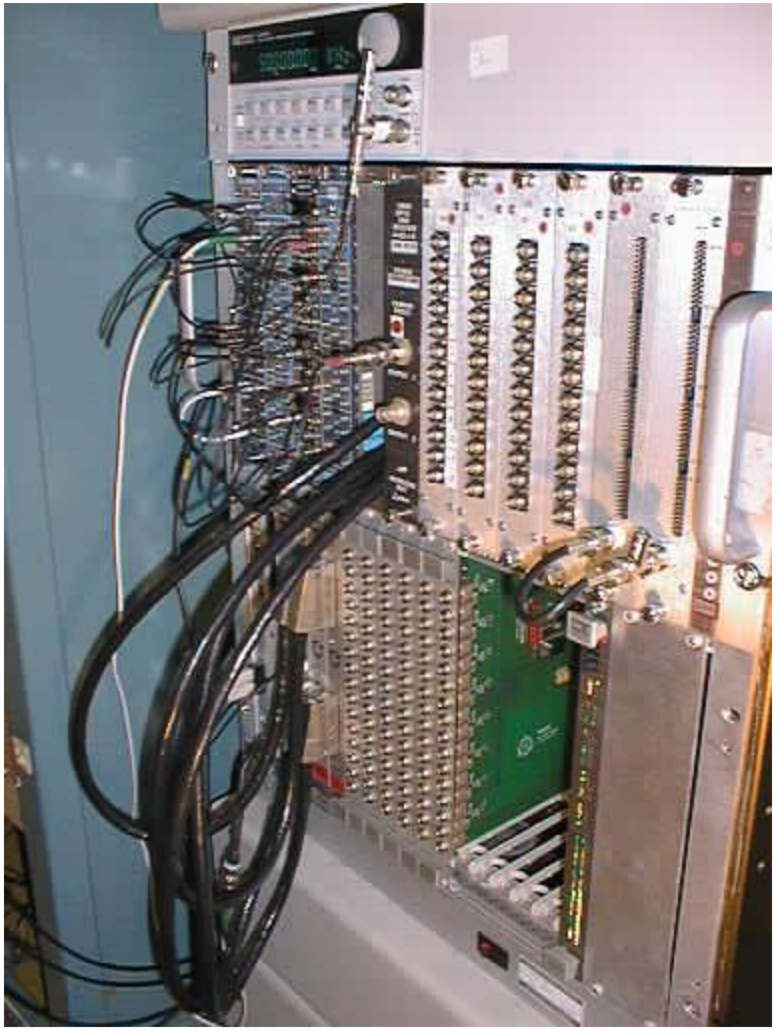


- 3π acceptance
- Current-mode experiment
- γ-rate ~100MHz (single detector)



20L vessel of liquid parahydrogen

Ortho-hydrogen scatters the neutrons and leads to beam depolarization



LANL Setup

(essentially same as SNS)

NPDGamma successfully took about 48 days of continuous production data in 2006.

Data Summary from 2006 LANL run

Number of good runs (8.5min long)	~5000
Neutron Polarization	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}

Data Summary from 2006 LANL run

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sym	10^{-10}
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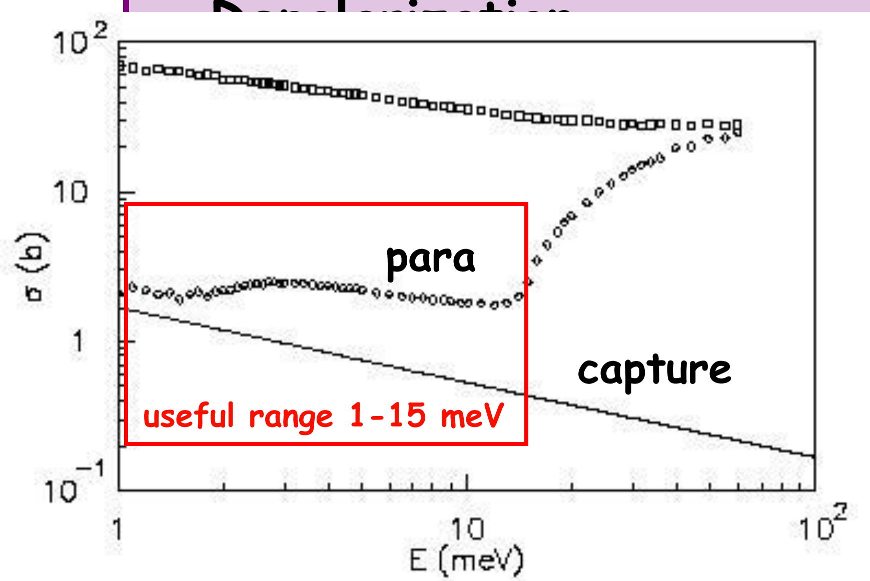
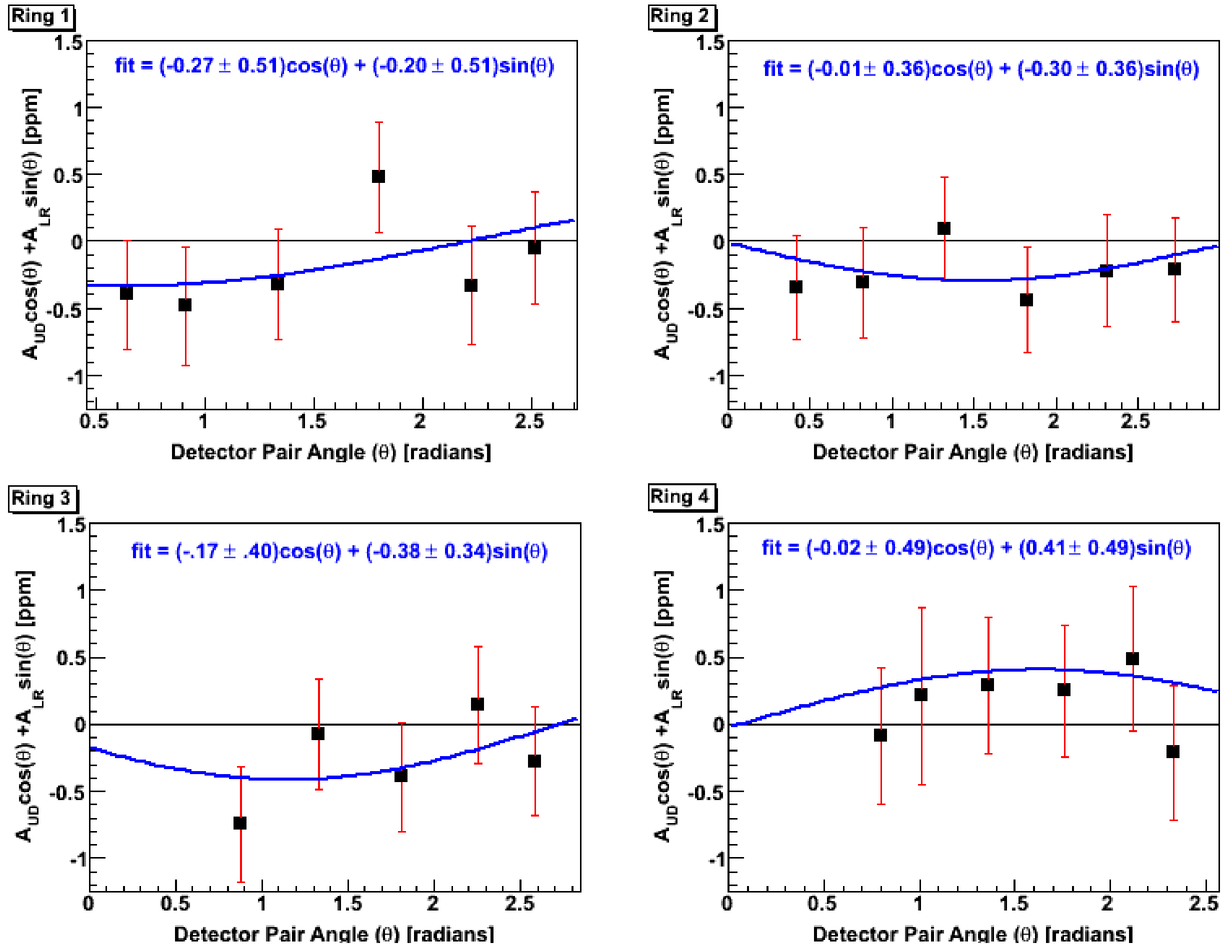


2006 LANL Hydrogen Results:



Total statistical error:

$$A_{\gamma,UD} = (-1.1 \pm 2.1) \times 10^{-7} \qquad A_{\gamma,LR} = (-1.9 \pm 2.0) \times 10^{-7}$$

Total systematic error: a (very) conservative 10% mostly due to pol.

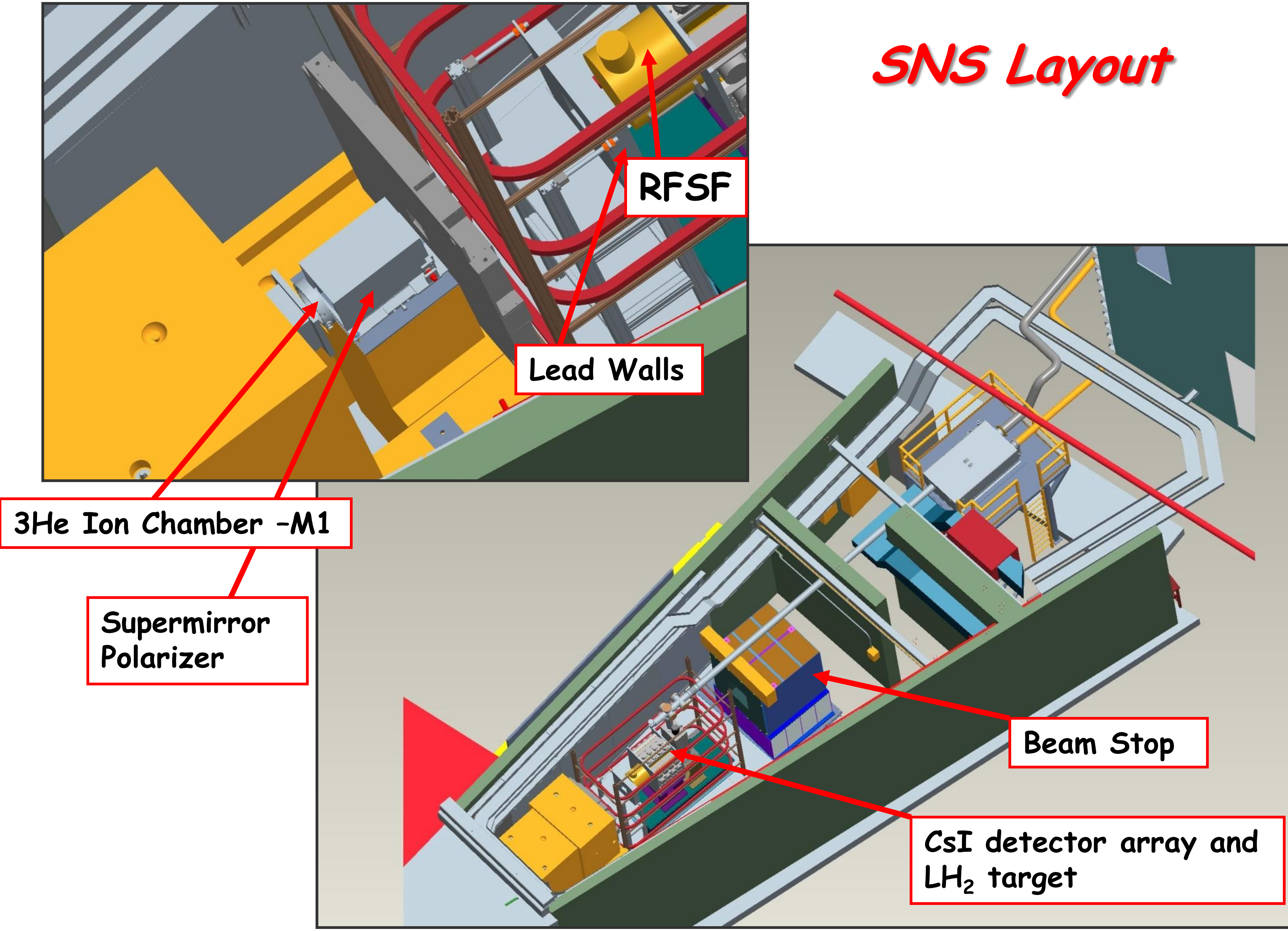
What's new for the SNS run

- New and improved safety and engineering rules !!!
- Supermirror Polarizer replaces the ^3He Polarizer (x4.1)
- Higher moderator brightness (x12) => more neutrons
- New LH2 target – thinner windows, smaller background

Predicted size -5×10^{-8} - NPDGamma can make a 20% measurement in

- Installation began in … (before time)
- Commissioning started in December 2010
- Production hydrogen data expected to begin December 2012

SNS Layout


RFSF
Lead Walls
3He Ion Chamber –M1
Supermirror Polarizer
Beam Stop
CsI detector array and LH_2 target

What has been measured to date:

- Beam flux at the experiment:

Expected: 2×10^{10} n/s (based on facility flux)
Measured: 5×10^{9} n/s

→ $5\times10^{9} / 2\times10^{10} = 25\%$ (consistent with polarizer transmission

- Beam Polarization:

~ 0.96

- Aluminum Asymmetry:

$\sim\pm\, 0.4 \times 10^{-7}$

- Counting Statistics and Runtime Estimate:

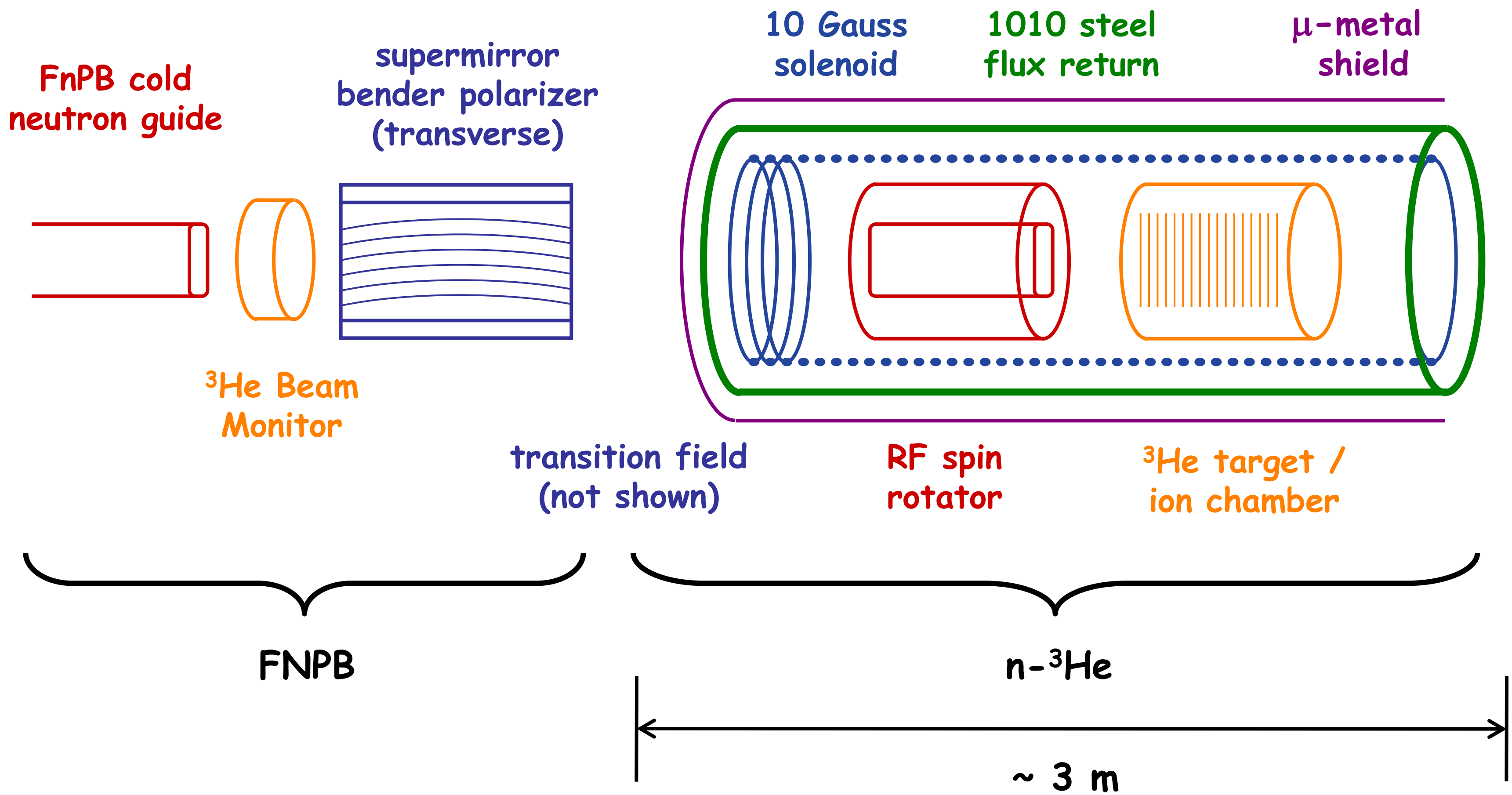
$\delta A_\gamma = 10^{-8}$ → $N = 10^{16}$ → 160 days

The Parity Violating Longitudinal Asymmetry in Polarized Cold Neutron Capture on Helium 3

n^3He

J.D. Bowman, S.I. Penttilä	Oak Ridge National Laboratory
R. Carlini	Jefferson National Laboratory
M. Gericke, S.A. Page	University of Manitoba
C. Crawford	University of Kentucky
V. Gudkov	University of South Carolina
J. Martin	University of Winnipeg
C. Gillis	Indiana University
C .Gould	NC State University
P-N. Seyo	Duke
P. Alacorn, T. Balascuta	Arizona State University
S. Baessler	University of Virginia
M. Viviani	INFN, Sezione di Pisa
Anna Hayes, Gerry Hale, and Andi Klein	Los Alamos National Laboratory

Experimental Setup



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

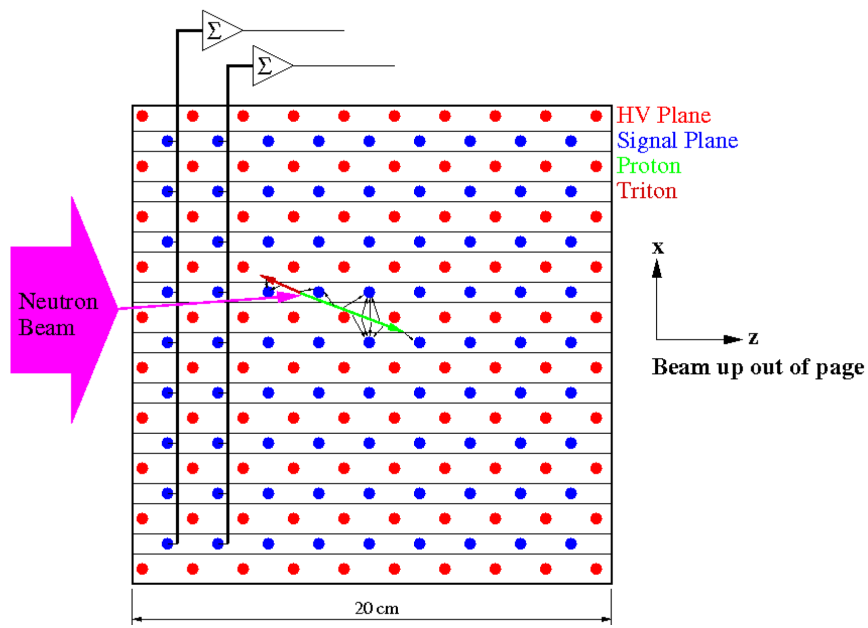
n^3He Principle of Measurement

Measure the asymmetry in the number of forward going protons in a ^{3}He 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)*



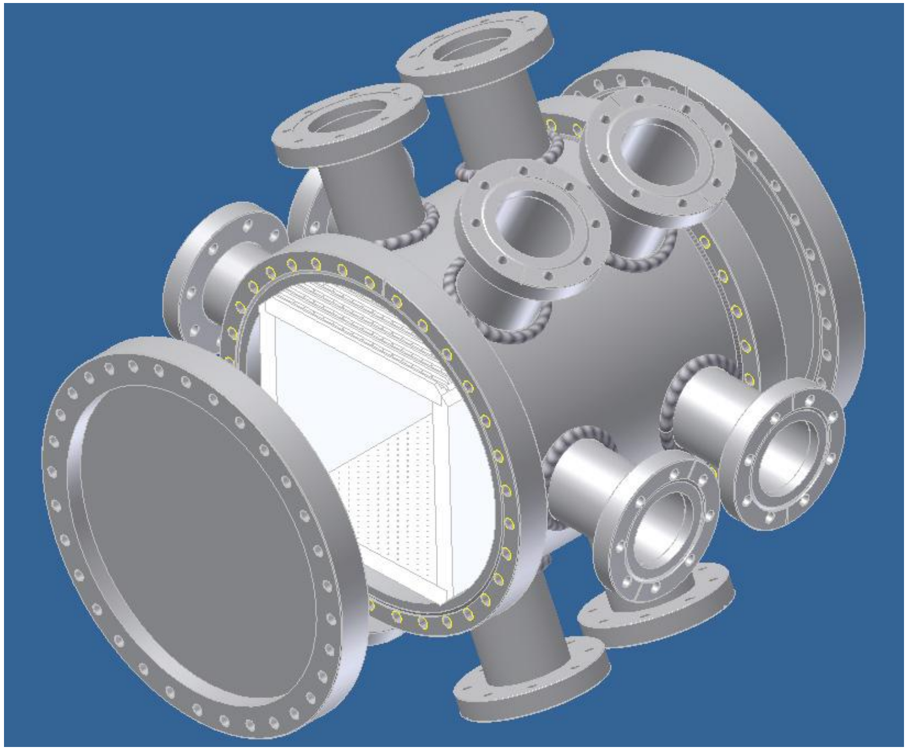
$$A_p^{\vec{n},^3He}(th.) \approx -2 \times 10^{-8}$$

$$A_p^{\vec{n},^3He}(th.) \approx +1.4 \times 10^{-7}$$

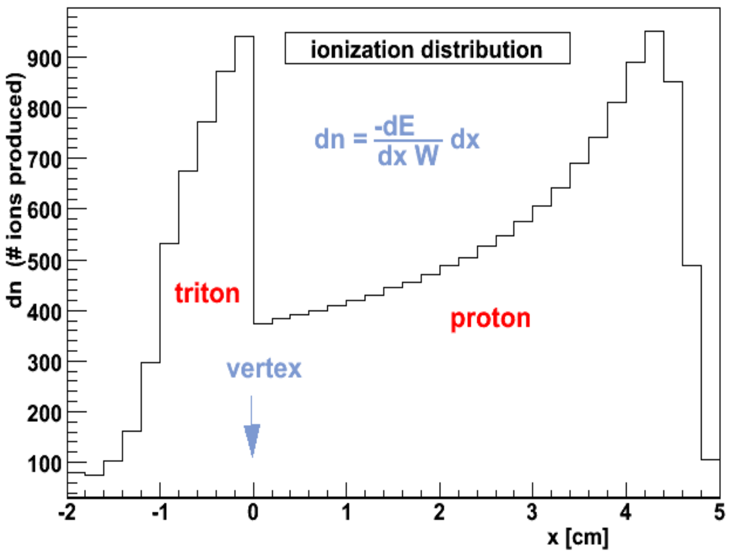
$$\vec{n} + {}^3\mathrm{He} \rightarrow {}^3\mathrm{H} + p$$

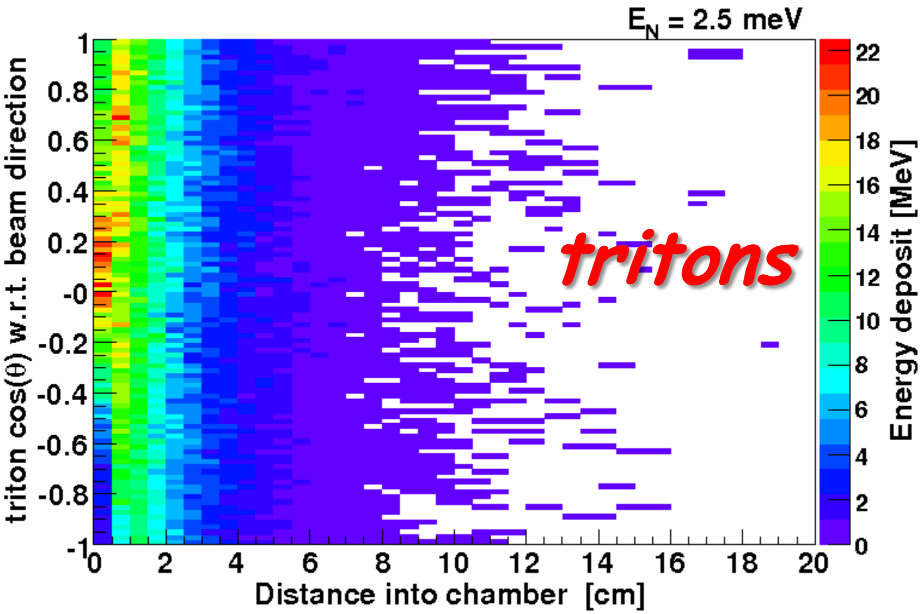
- *MC simulations of sensitivity to proton asymmetry*
  - *including wire correlations*
  - $$\delta A_{ph} = \frac{1}{\sqrt{N}P_N}\sqrt{\sigma_D^2 + \sigma_{coll}^2}$$

$$\sigma_d \simeq 6$$



- *tests at LANSCE FP12*
  - *fission chamber flux calibration*
  - *prototype drift chamber R&D*
  - *new beam monitors for SNS*





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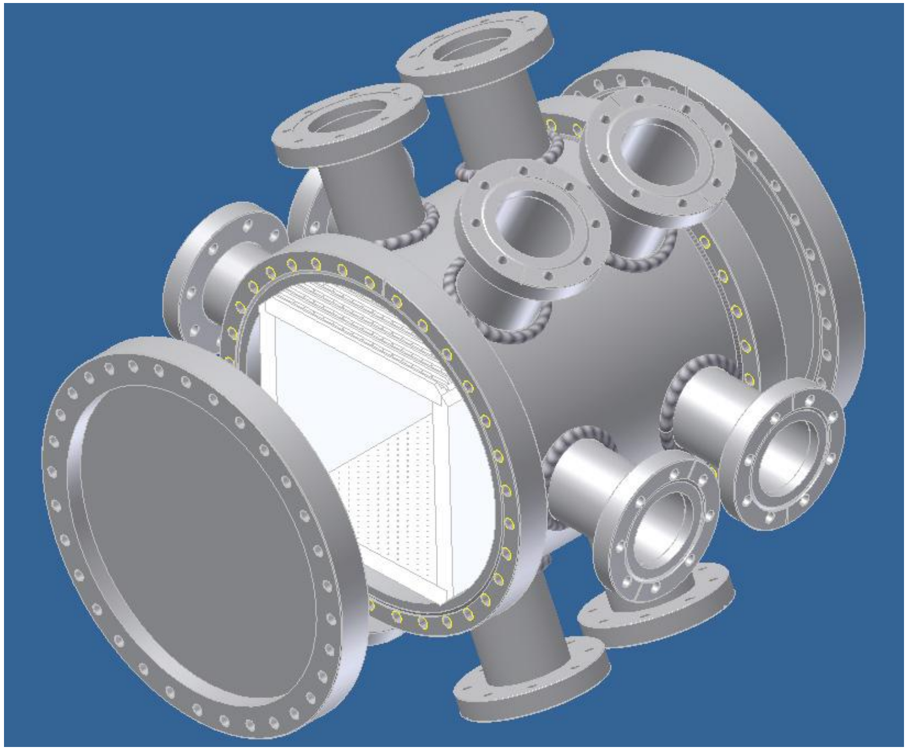
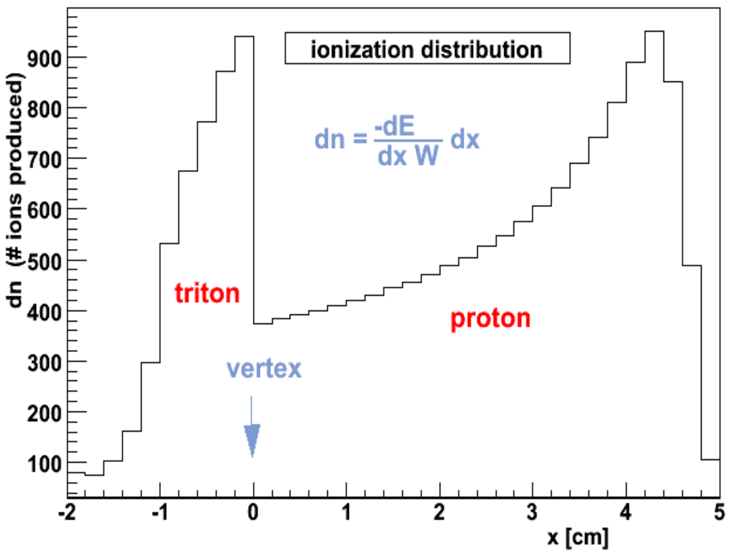
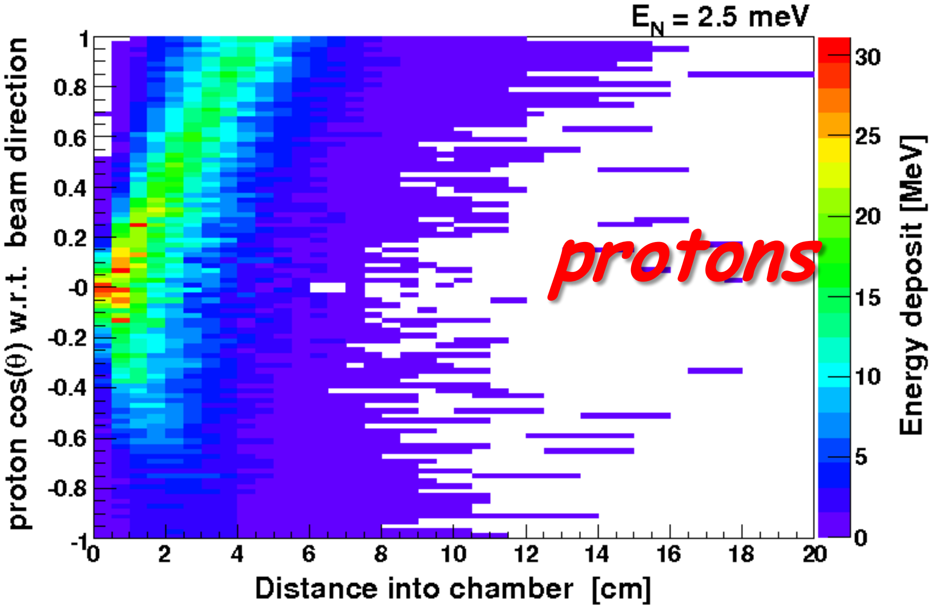
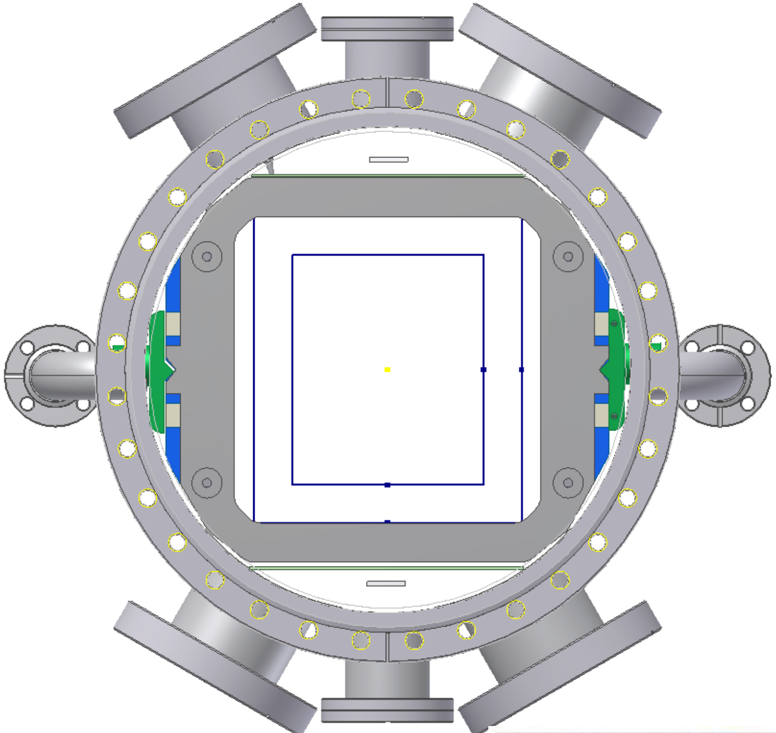








Chamber design finished in 2010

Delivered to U. of Manitoba Fall of 2010.

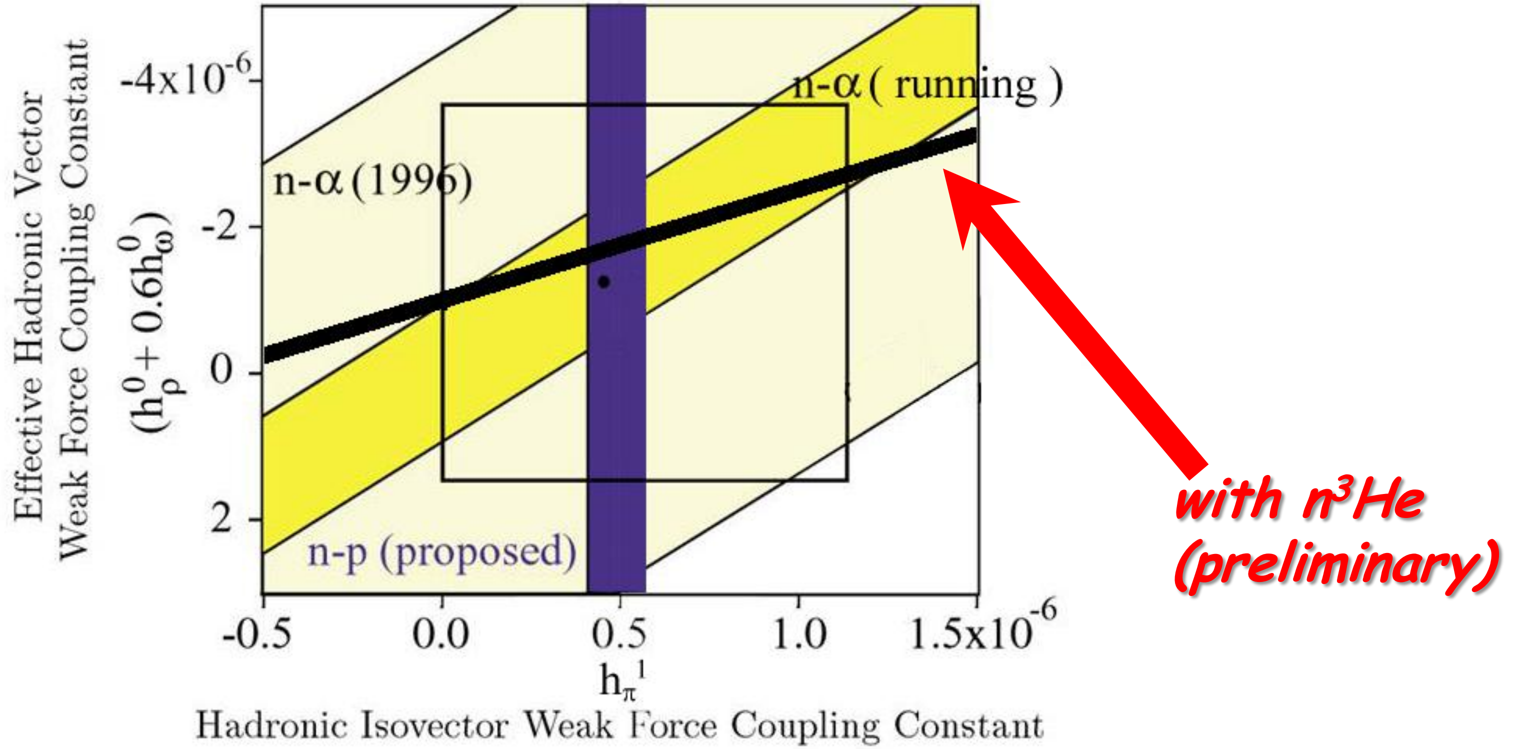
The chamber has:
- 4 data ports for up to 200 readout channels.
- 2 HV ports
- 2 gas inlets/outlets
- 12 inch conflat aluminum windows (0.9 mm thick).

Chamber made completely from aluminum except for the knife edges.

Status/Schedule

- *n-^{3}He experiment approved by the FnPB PRAC, 2008-01-07*
  - *first measurement of PV in the n-^{3}He reaction*
  - *large asymmetry ~10^{-7}*
  - *proposed measurement accuracy* $\delta A = 1.0 \times 10^{-8}$
- *recent progress in experimental design*
  - *full 4-body calculation of PV observable*
  - *R&D projects on target/detector design at LANL*
  - *new spin flipper design permitting compact / less expensive layout*
  - *preliminary holding field design*
- *leverage existing hardware / technology*
  - *major components based on similar NPDGamma instrumentation*
  - *can reuse NPDGamma electronics / power supplies*
- *FnPB infrastructure*
  - *no safety hazards, no LH_2 target, new power or cooling requirements*
  - *minimal modification of FnPB cave – stand for n-^{3}He solenoid*
  - *technician support for readiness review preparation, setup of experiment*
- *Tentative Schedule*
  - *2010-2012 Design and development*
  - *Late 2012 Installation*
  - *2013 Run*

Thanks!

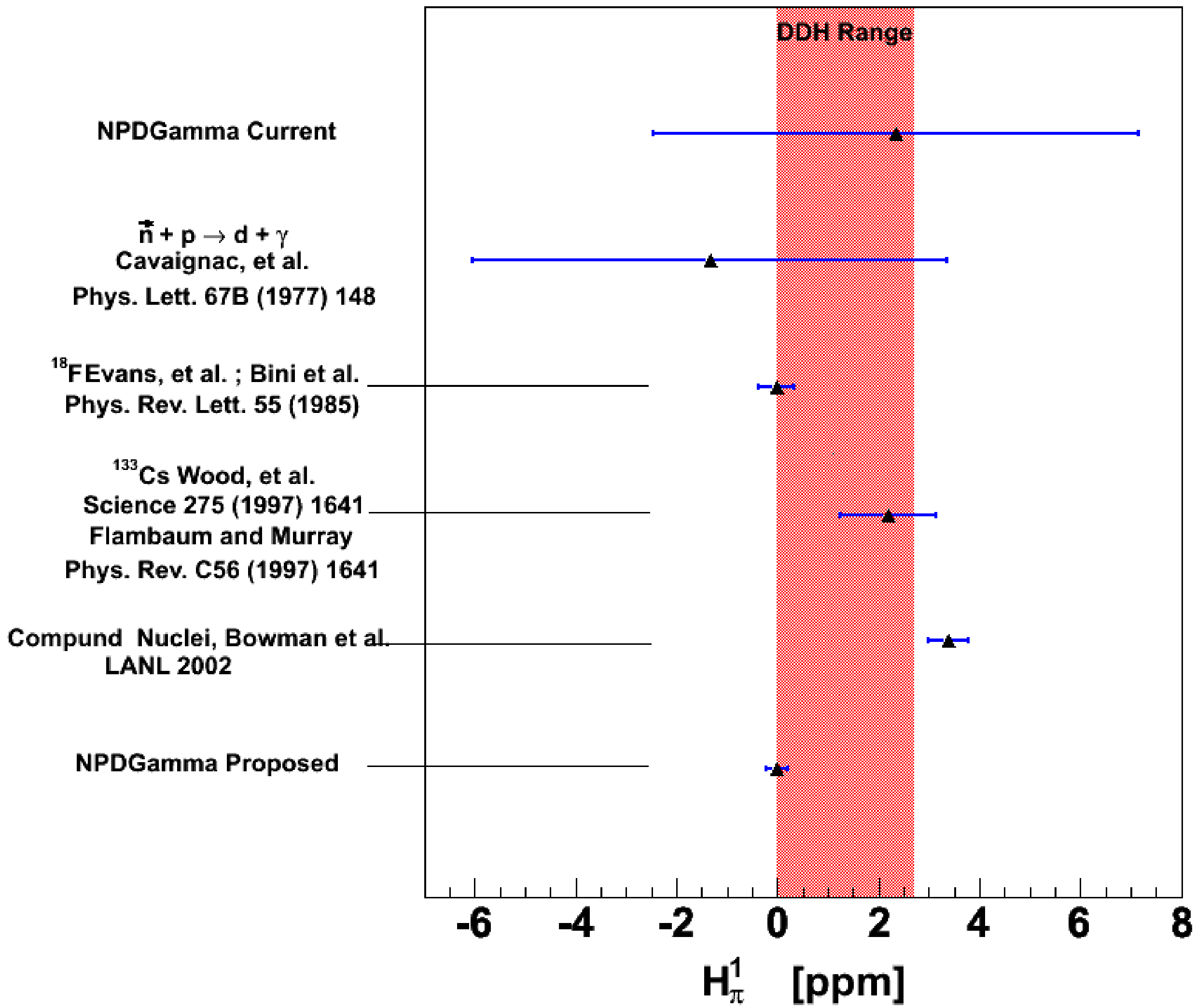


$n+p \rightarrow d+\gamma$ A_γ^d

$n-\alpha$ spin rot. $d\phi^{n\alpha}/dz$

Unfortunately , the connection between the PV observables and the SM is essentially unknown.

2006 Hydrogen Results:



n^3He Relevance

5 EFT parameters : $(\lambda_t, \lambda_s^{I=0,1,2}, \rho_t)$

Correspond to:

$$^3S_1(I = 0) \leftrightarrow {}^1P_1(I = 0)$$
$$^1S_0(I = 0,1,2) \leftrightarrow {}^3P_0(I = 0,1,2)$$

$$^3S_1(I = 0) \leftrightarrow {}^3P_1(I = 1)$$

n3He asymmetry relation to EFT constant:

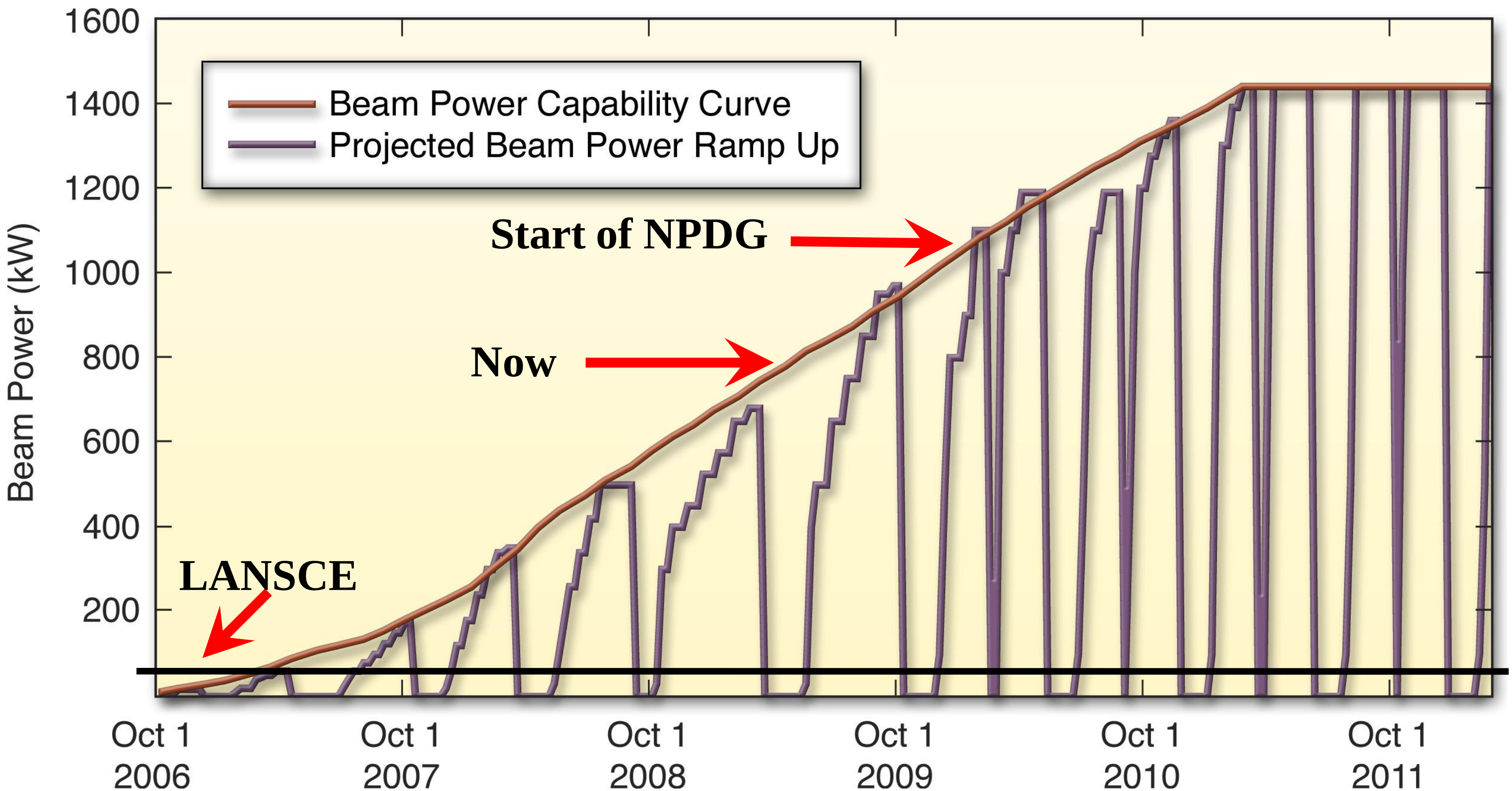
$$A_p^{\vec{n},{}^3He}(th.) = \kappa \lambda_s^{I=0} + \ldots \approx 3\times 10^{-7}$$

M. Viviani, R. Schiavilla, calculation in progress

DDH:

$$A_p^{\vec{n},{}^3He}(th.) = -0.182 h_\pi^1 - 0.145 h_\rho^0 - 0.127 h_\omega^0 + 0.06 h_\omega^1$$

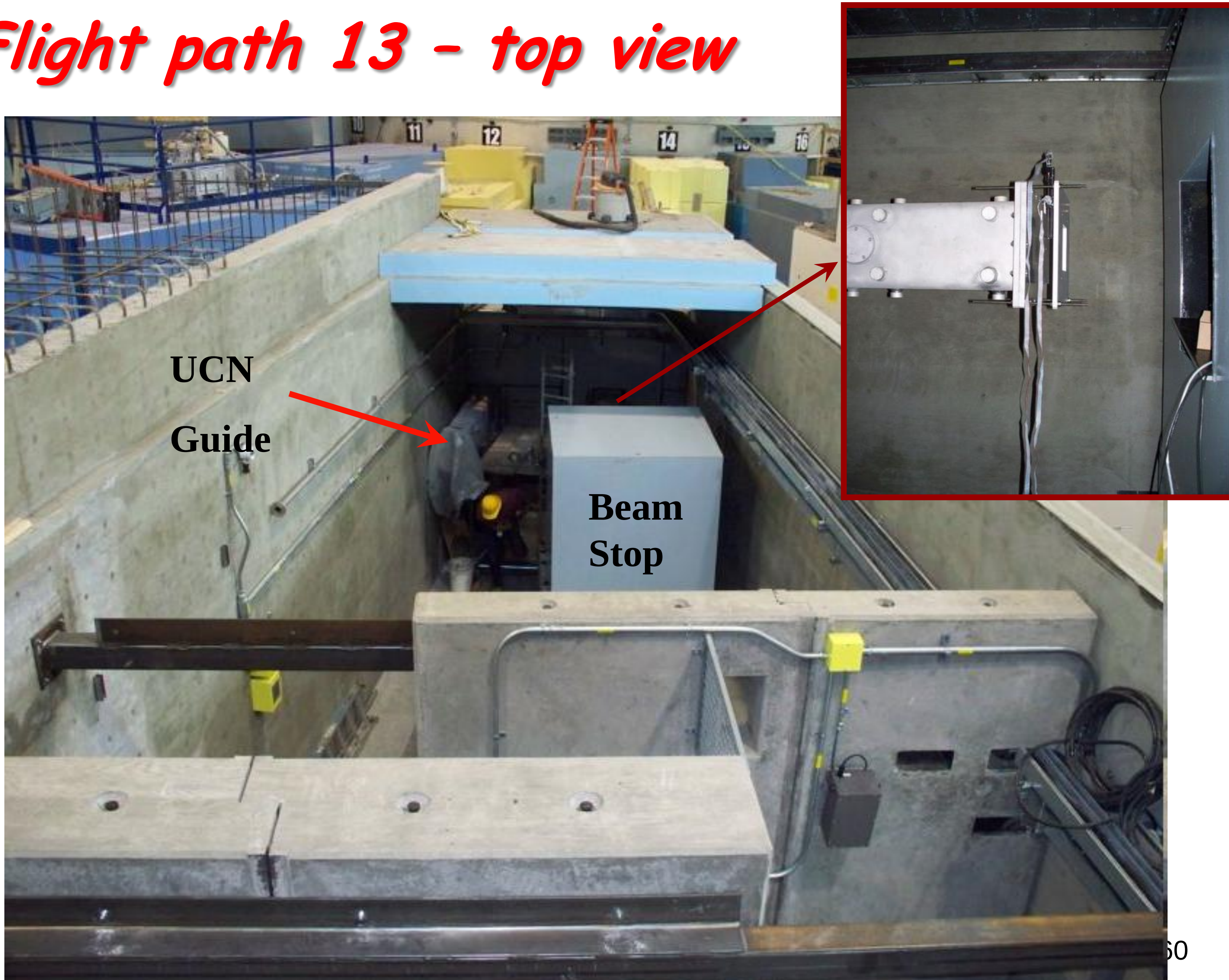
SNS Ramp-Up Plan




DeSHAZO

Cold Beamline - Realized

Flight path 13 – top view




Egal wo Du bist, es gibt immer ein...
Arschloch
Tavojaja


Egal wo Du bist, es gibt immer ein...
Arschloch
Thank You!
Tavojaja