Parity Violation From Few Nucleon Systems

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physics & astronomy
university of manitoba

Outline

PV and the hadronic weak interaction

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)

Meson Exchange Picture

EFT and Hadronic PV

The experimental program

I am not a theorist!

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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→ **Look at the ΔS=0 sector**

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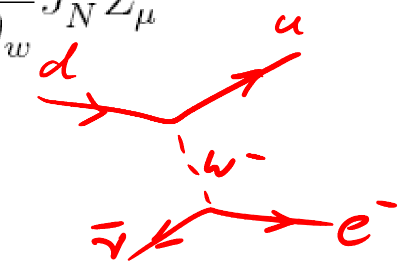

Charged currents:

beta decay ⇒

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

$\Delta S = \pm 1$

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$$-\overline{\psi}_d\gamma^\mu(1-\frac{4}{3}\sin^2\theta_w-\gamma_5)\psi_d - \overline{\psi}_s\gamma^\mu(1-\frac{4}{3}\sin^2\theta_w-\gamma_5)\psi_s$$

} $\Delta S = 0$ 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

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

Q^p_{Weak} measures the electron beam helicity correlated asymmetry in the number of elastically scattered electrons from protons in a liquid hydrogen target at very forward angles, to extract the weak charge of the proton.

$$A_{LR}(\vec{e},p) \quad = \quad \frac{d\sigma_L - d\sigma_R}{d\sigma_L + d\sigma_R} = k(A_{Q^p_W} + A_{H,V} + A_{H,A})$$

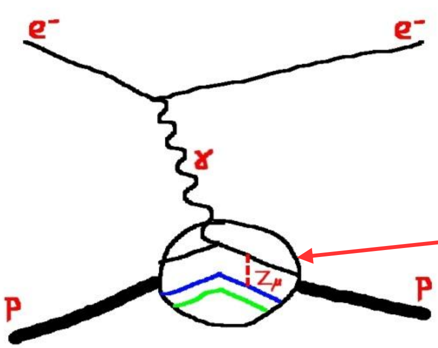
$$A_{Q^p_W} \quad = \quad Q^2 Q^p_W$$

Quantity of interest = -0.288 ppm

$$A_{H,V} \quad = \quad Q^n_W \frac{\epsilon G_E^{p,\gamma} G_E^{n,\gamma} + \tau G_M^{p,\gamma} G_M^{n,\gamma}}{\epsilon \left(G_E^{p,\gamma}\right)^2 + \tau \left(G_M^{p,\gamma}\right)^2} + Q^s_W \frac{\epsilon G_E^{p,\gamma} G_E^s + \tau G_M^{p,\gamma} G_M^s}{\epsilon \left(G_E^{p,\gamma}\right)^2 + \tau \left(G_M^{p,\gamma}\right)^2}$$

$$A_{H,A} \quad = \quad Q^e_W \frac{\epsilon' G_A^{p,Z} G_M^{p,\gamma}}{\epsilon \left(G_E^{p,\gamma}\right)^2 + \tau \left(G_M^{p,\gamma}\right)^2}$$

Must know this from world data:



$G_A^{p,Z}$

Axial form factor due to q-q weak interaction related to NN experimental results

Hadronic structure: Must know hadronic wave function or measured form-factors

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 ! → NIMP experiments

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Very challenging ! → NIMP experiments

↑

Nearly Impossible

$\Delta S=0$ 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)

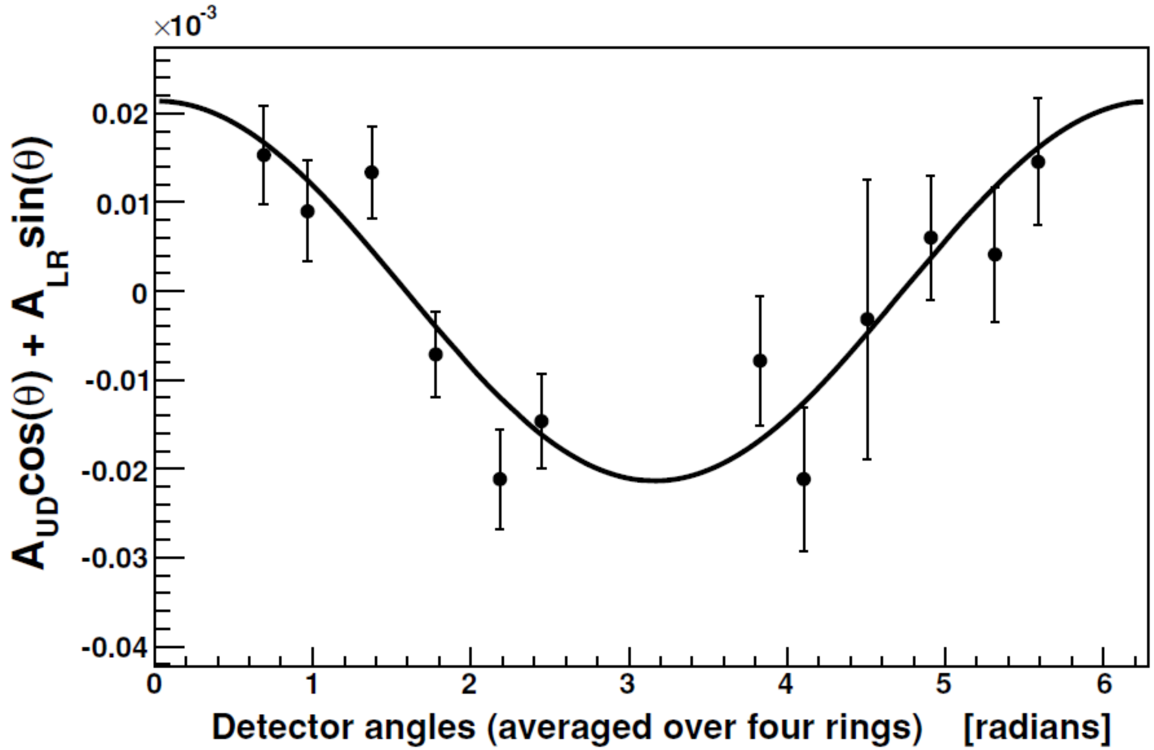
But you can get the weak spreading width (weak mixing amplitude) from statistical analysis of this data:

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

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.

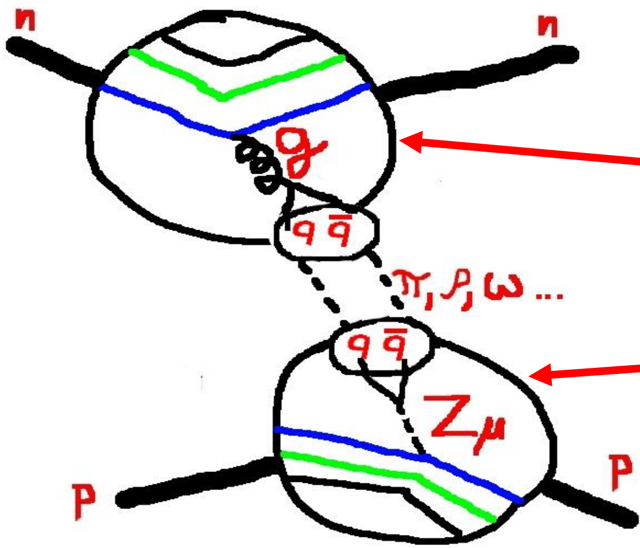
There is no transparent connection to SM.

→ 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

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



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

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

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

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

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.

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Relationship to quark degrees of freedom:

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

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

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

Meson exchange picture cont.

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

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

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

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

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)*

DDH Model – Benchmark

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

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

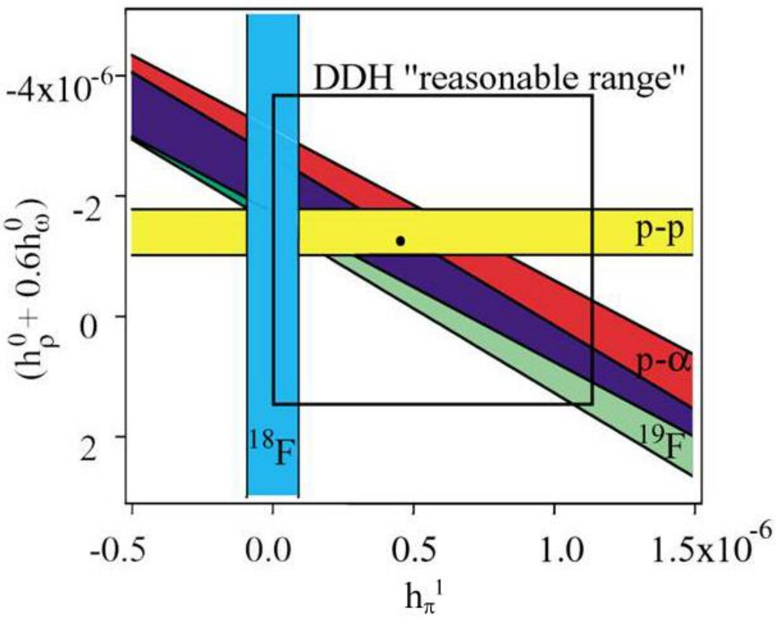
E. G. Adelberger and W. C. Haxton, Ann. Rev. Nucl. Part. Sci. 35, 501 (1985).

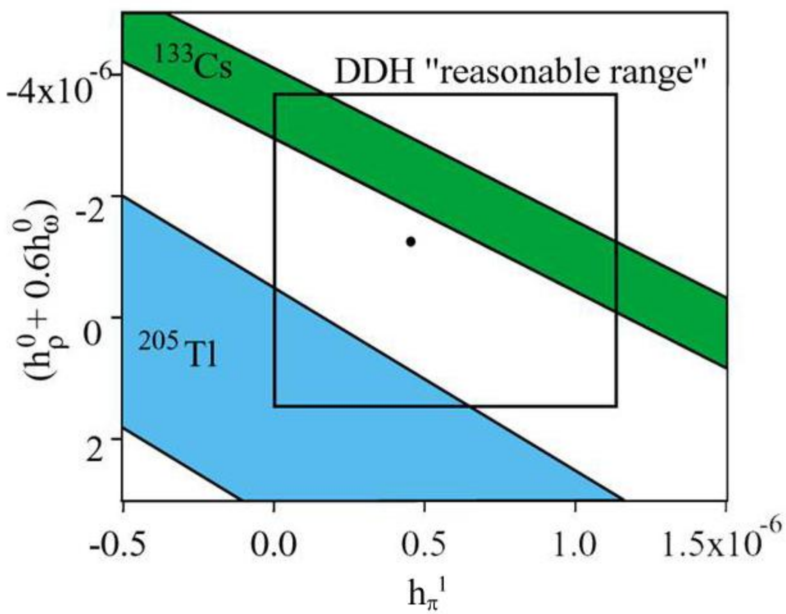
DDH Weak Coupling	(A_γ) $np \to d\gamma$	(A_γ) $nd \to t\gamma$	(ϕ_{PV}) n-p (μrad/m)	(ϕ_{PV}) n-α (μrad/m)	$\left(\frac{\Delta\sigma}{\sigma}\right)$ p-p	$\left(\frac{\Delta\sigma}{\sigma}\right)$ p-α	(A^p_Z) $n^3He \to tp$
a_π^1	-0.107	-0.92	-3.12	-0.97	0	-0.340	-0.182
a_ρ^0	0	-0.50	-0.23	-0.32	0.079	0.140	-0.145
a_ρ^1	-0.001	0.103	0	0.11	0.079	0.047	0.0267
a_ρ^2	0	0.053	-0.25	0	0.032	0	0.0012
a_ω^0	0	-0.160	-0.23	-0.22	-0.073	0.059	-0.1269
a_ω^1	0.003	0.002	0	0.22	0.073	0.059	0.0495

Viviani *et al.* preliminary

Experimental results generally agree with the DDH ranges, but:

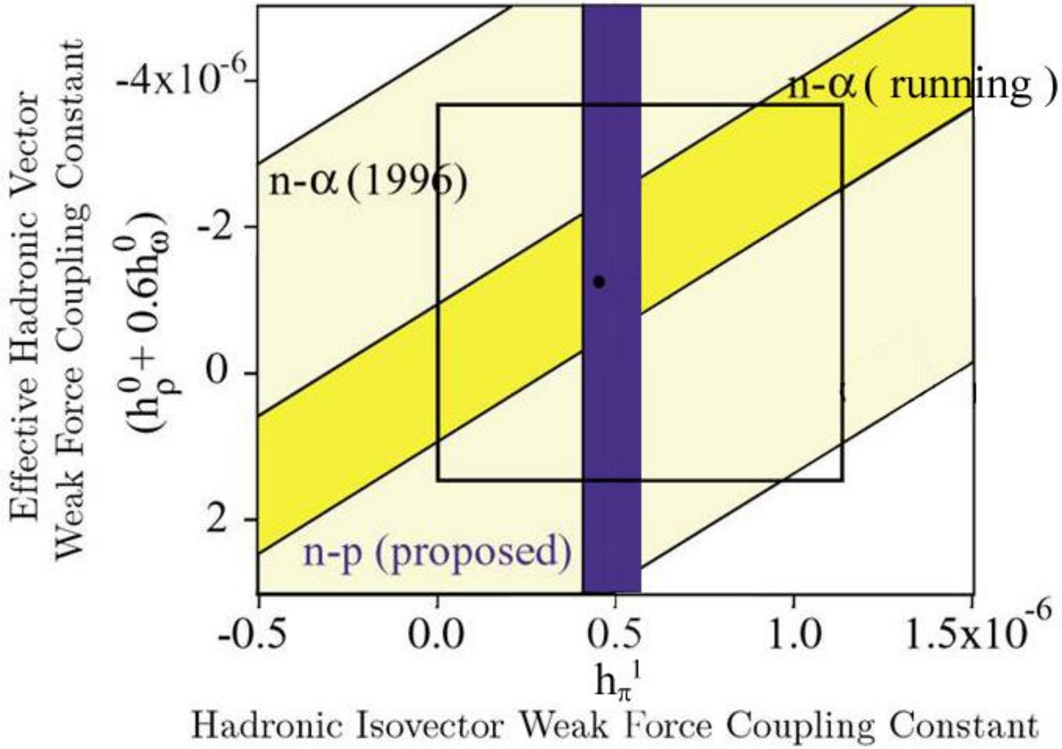
- ***Uncertainties are large***
- ***Some experimental results produce conflicting values for coupling constants (e.g. Values for h_π^1 from ^{18}F and ^{133}Cs differ by several σ)***





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}

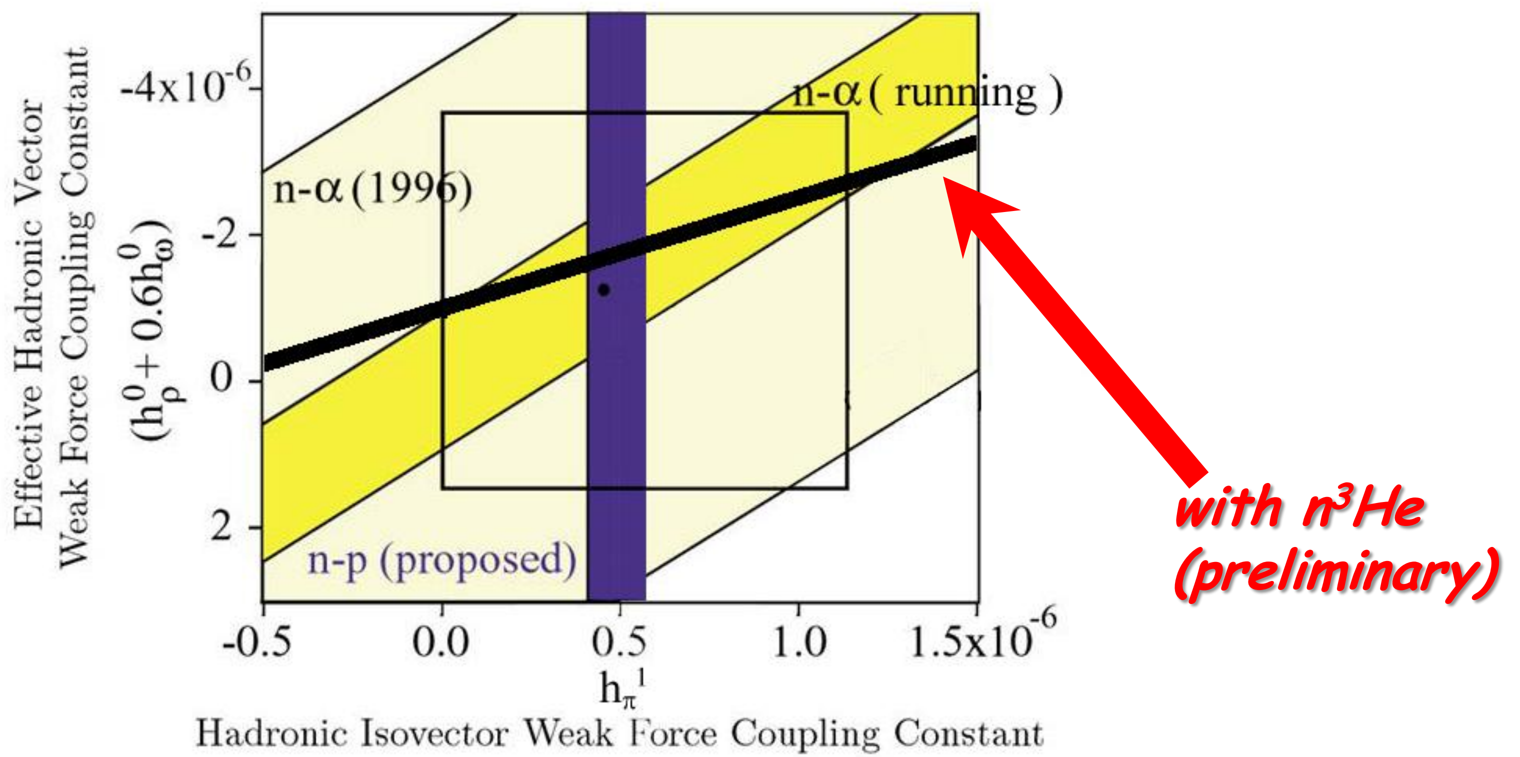
^{133}Cs, ^{205}Tl anapole moments



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

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

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



$n+p \rightarrow d+\gamma$ A_γ^d
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EFT Calculations (Upshot)

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

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

→ $\lambda_s^{0,1,2}$, λ_t, ρ_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: $h^1_{\pi NN}$, $k^{1a}_{\pi NN}$, $\tilde{C}_{\pi}$, $\tilde{C}_{2\pi}$

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 produce the 5 Danilov coupling constants to be determined by experiment:

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

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

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

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

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

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

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

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

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

Experimental Program

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

Some have already been done:

Longitudinal Asymmetries in p-p 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*

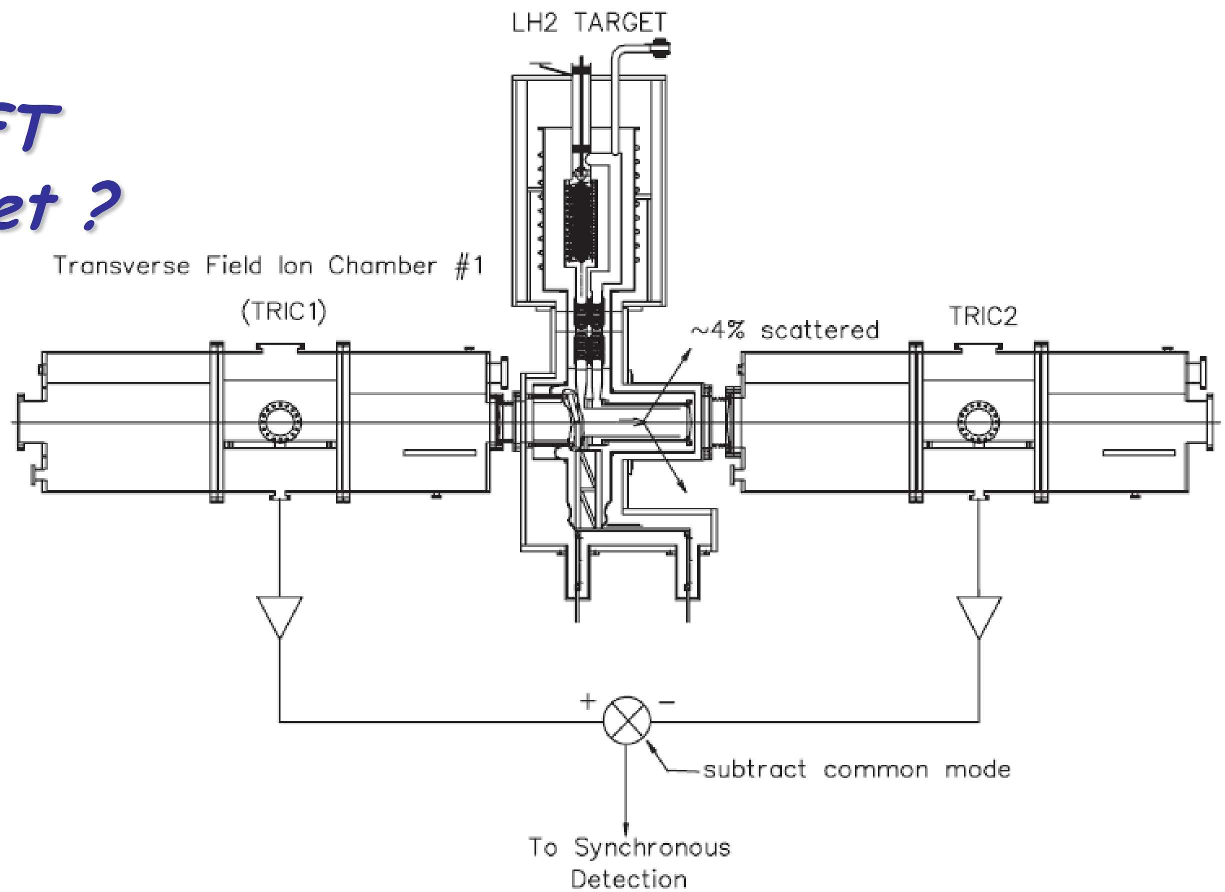
Experimental Program

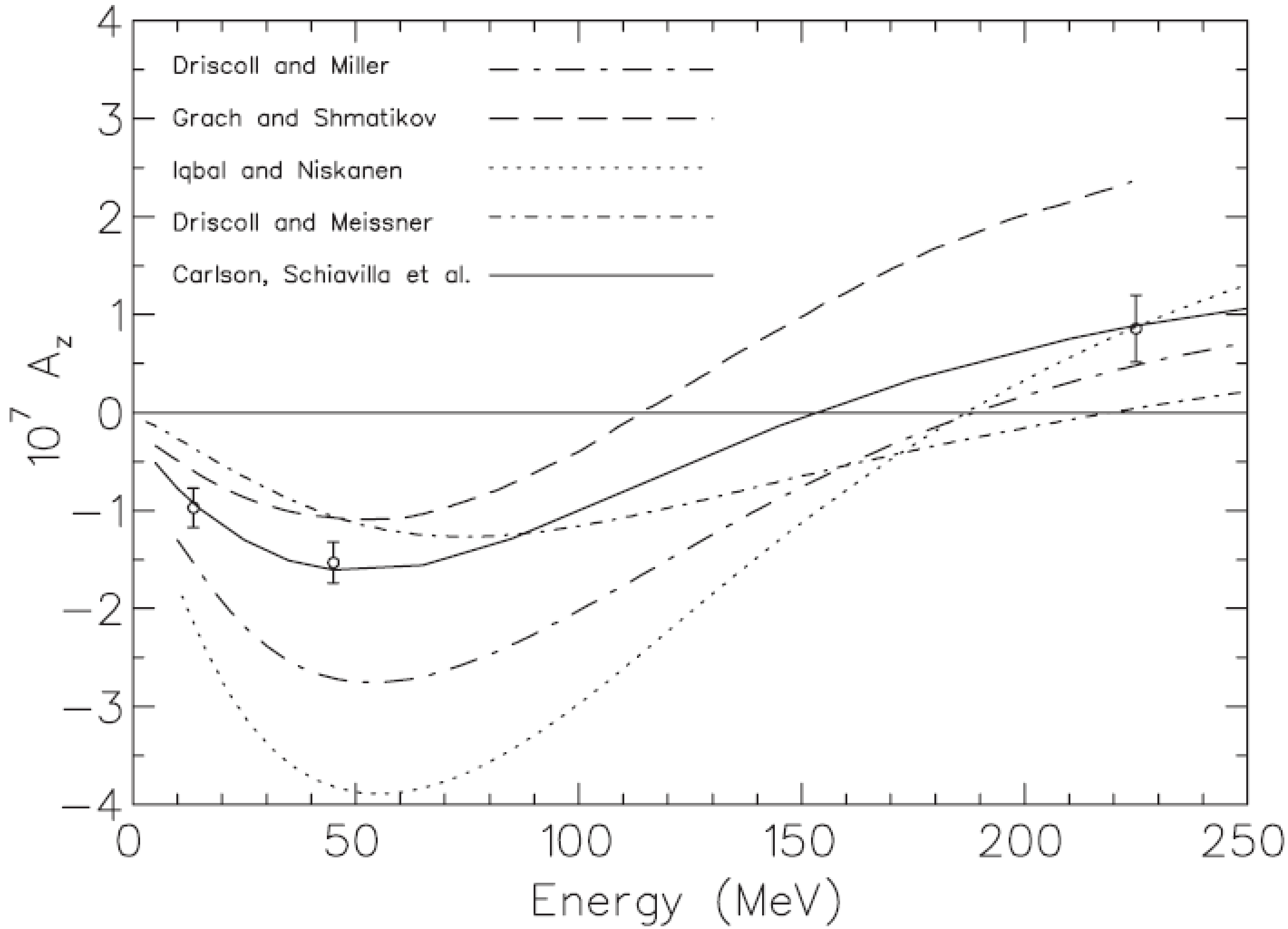
The TRIUMF 220 MeV pp experiment

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

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

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





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

Experimental Program

Longitudinal Asymmetry in p-α scattering:

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

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

New experiments:

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

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

Experimental Program

New experiments (or repeats):

- Neutron capture:
  - Circ. Polarization:

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

  - Gamma Asymmetry in np radiative capture:

    $$A_\gamma = -0.107\,\rho_t\, m_N$$ LANSCE compl. SNS 2010

  - Gamma Asymmetry in nd radiative capture:

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

Hadronic Parity Violation with Cold Neutrons

Two experiments (at the SNS):

NPDGamma:

Transversely polarized cold neutrons on hydrogen – looks for a directional asymmetry in the number of γ-rays, after decay: $n + p \rightarrow d + \gamma$

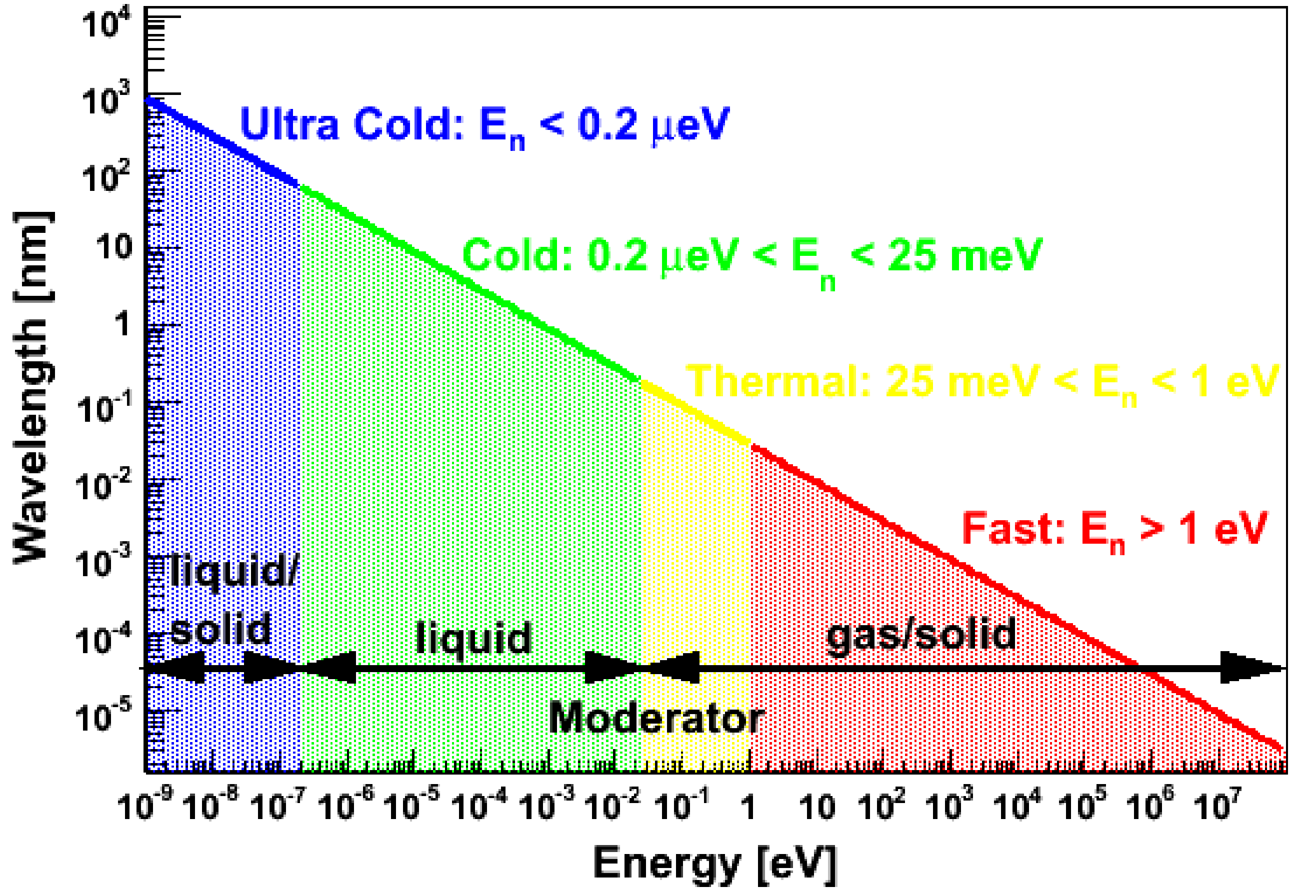
n3He:

Longitudinally polarized cold neutrons on helium 3 – looks for a directional asymmetry in the number of protons after breakup: $n + {}^3He \rightarrow t + p$

Spallation Neutron Source (SNS)

The Neutron Energy Scale

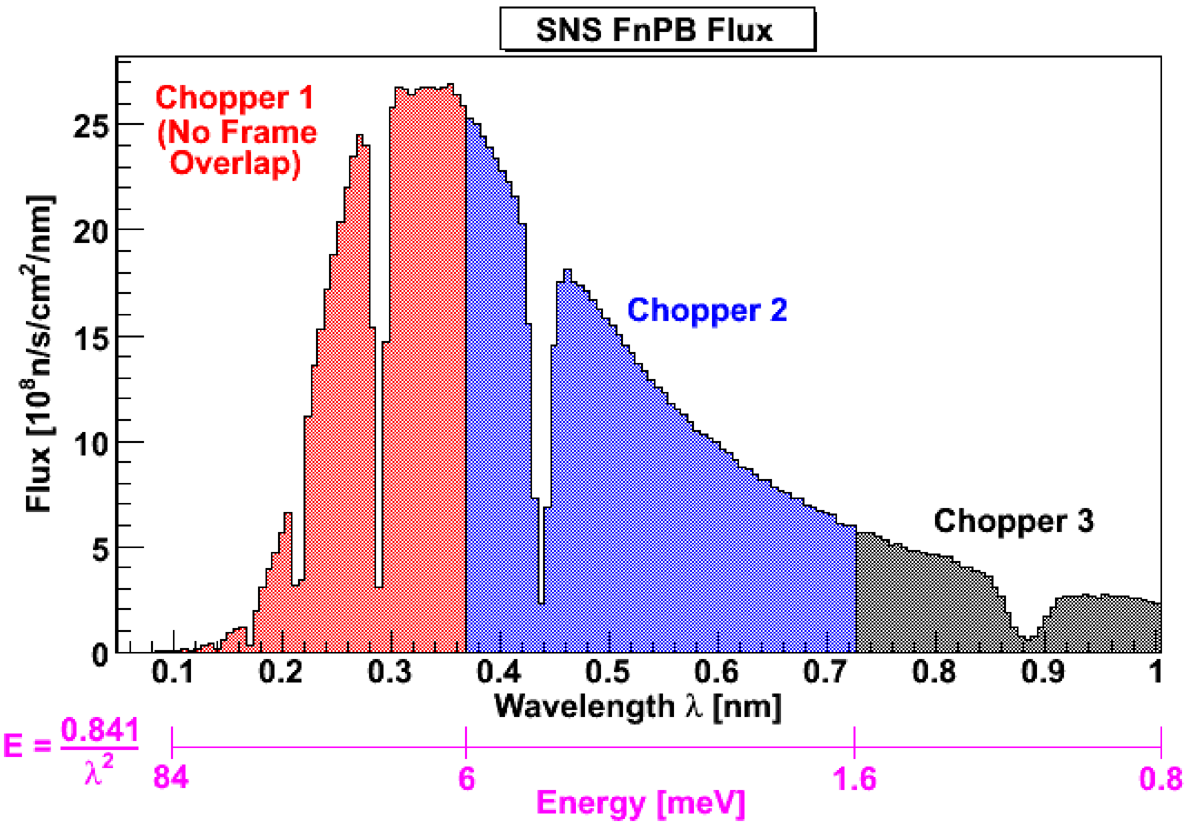
$$\lambda \approx \frac{29}{\sqrt{E_k}} fm$$



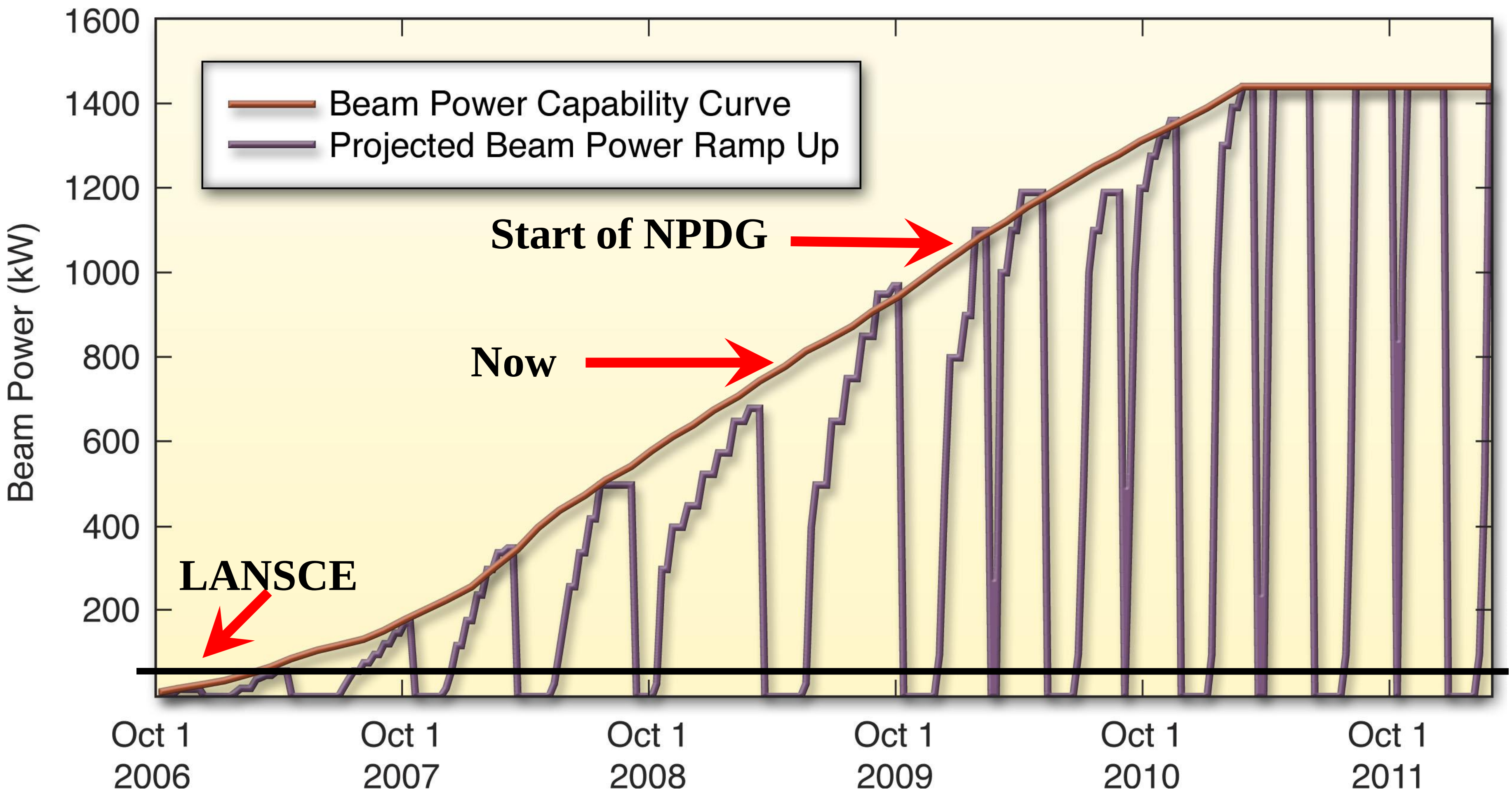
$$E_k = \frac{\hbar^2 k^2}{2M_n} = k_B T \quad , \quad k = 43.4\sqrt{E_k[MeV]}\ \ MeV/c$$

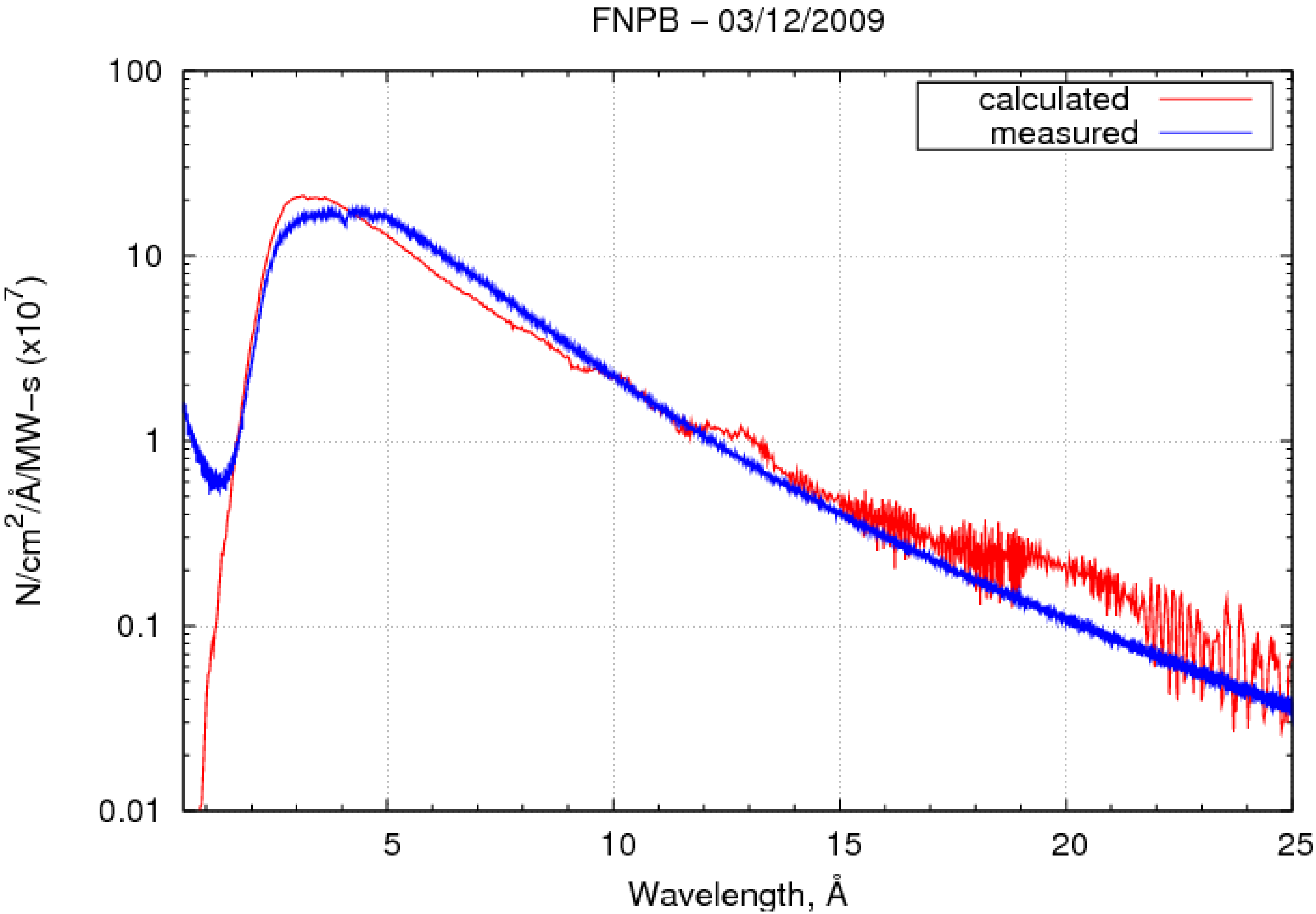
SNS Beam Properties

- 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
- 4 choppers required for various experimental conditions
  - eliminate overlap with slower neutrons from previous pulses
  - accommodate extraction of 0.89 nm beam
  - avoid potential background problems from leakage of fast neutrons
  - neutrons above 4.0 nm are not necessarily caught by this chopper arrangement (these come ~180 ms after pulse onset (> 10 frames later) intensity down by 4 orders of magnitude



SNS Ramp-Up Plan



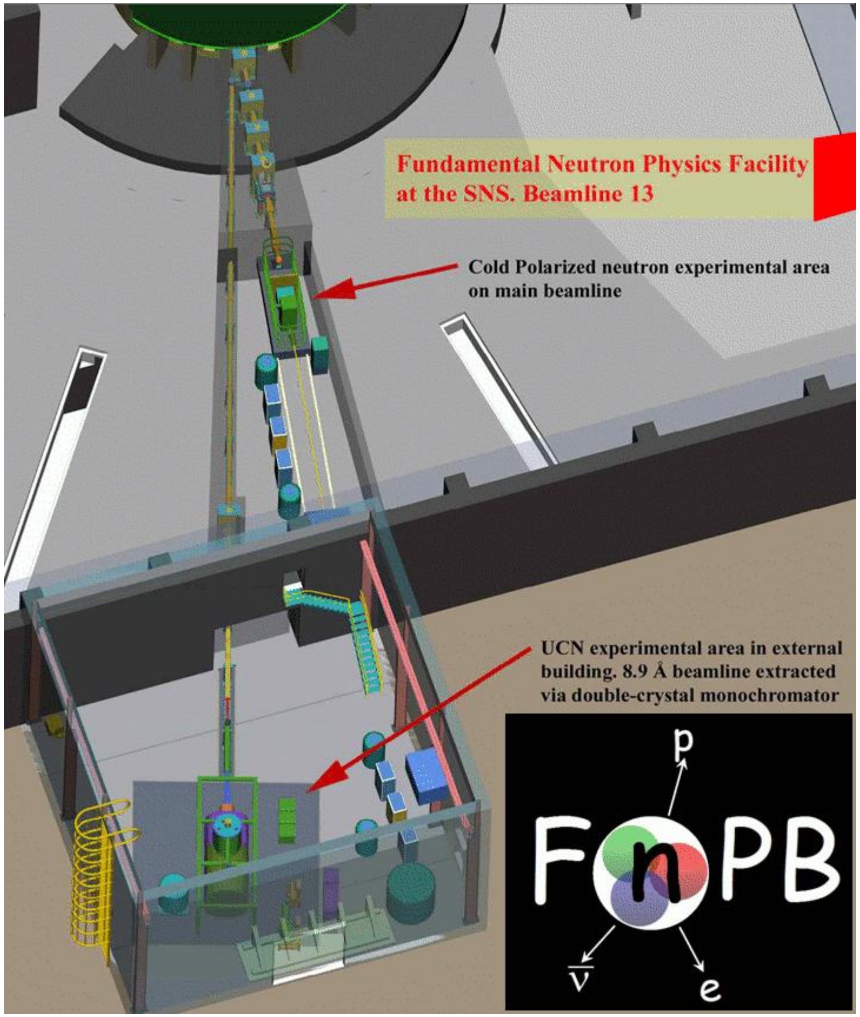


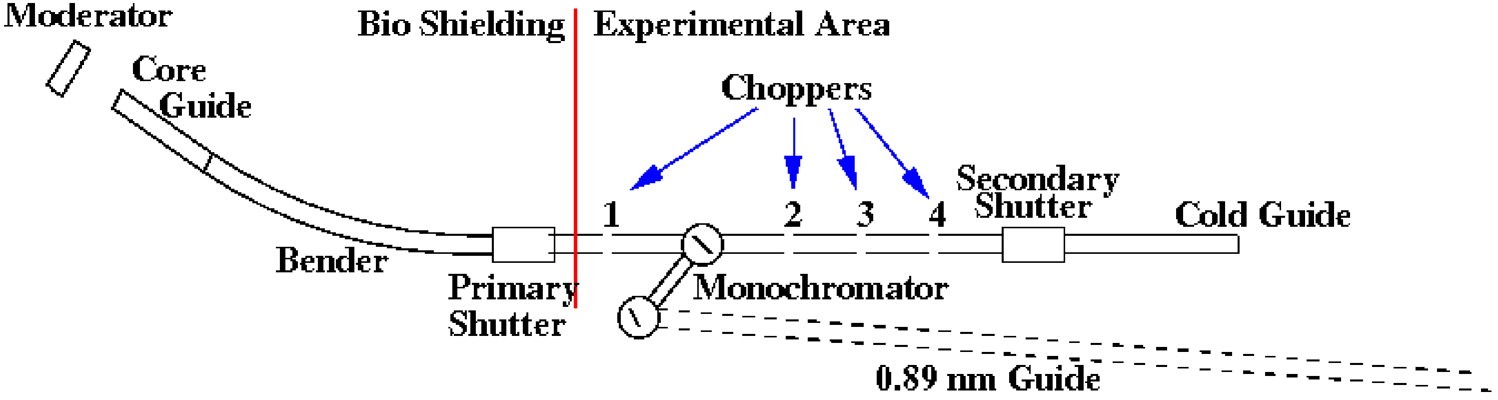
FNPB – 03/12/2009
calculated
measured
N/cm^2/Å/MW–s (x10^7)
Wavelength, Å
100
10
1
0.1
0.01
5
10
15
20
25


Egal wo Du bist, es gibt immer ein...
Arschloch
Reciba estos chistes para adultos, gratis, email a
tavojaja0alta@elista.net
Tavojaja
abr2003
Dr. Tavo

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

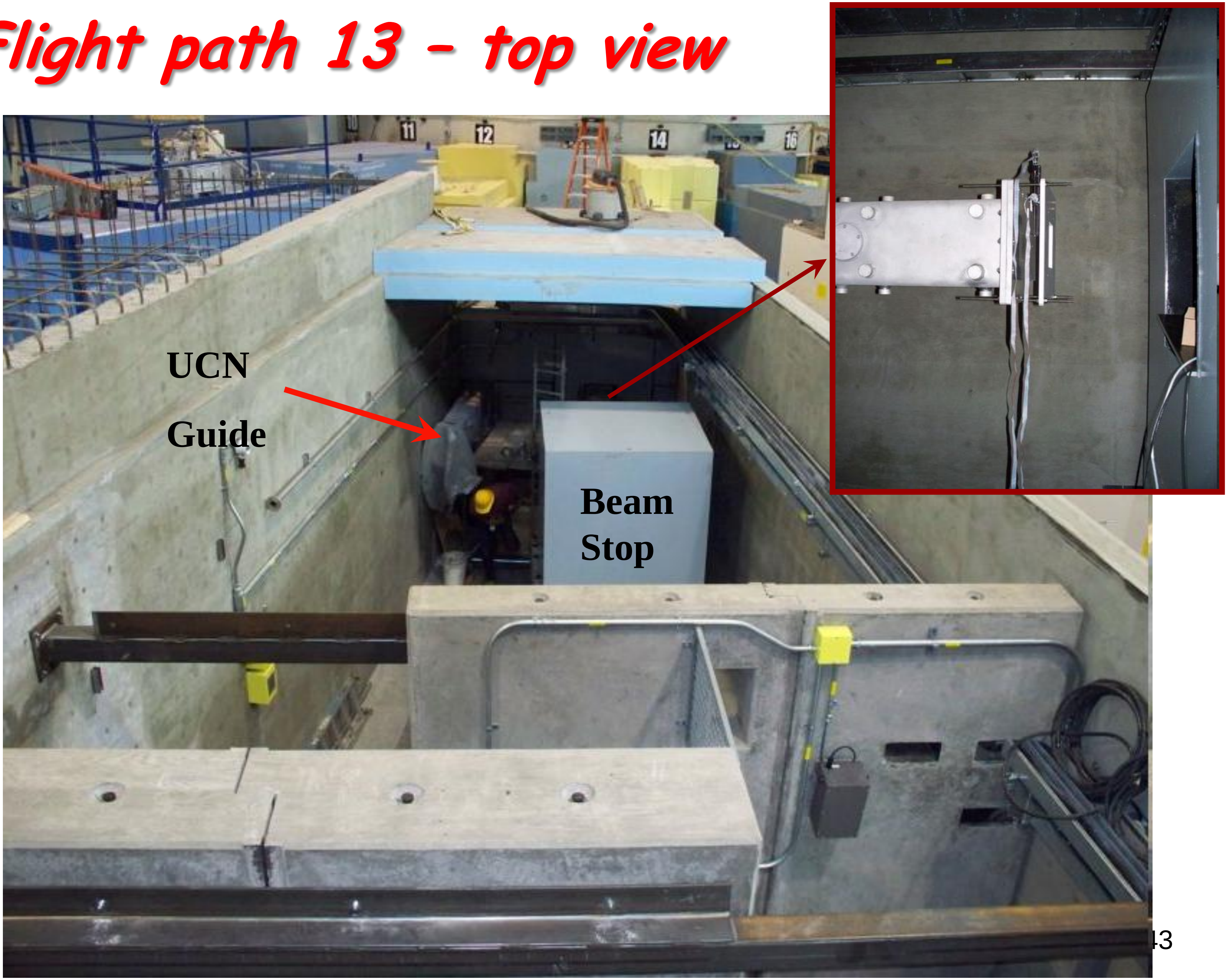





DeSHAZO

Cold Beamline - Realized

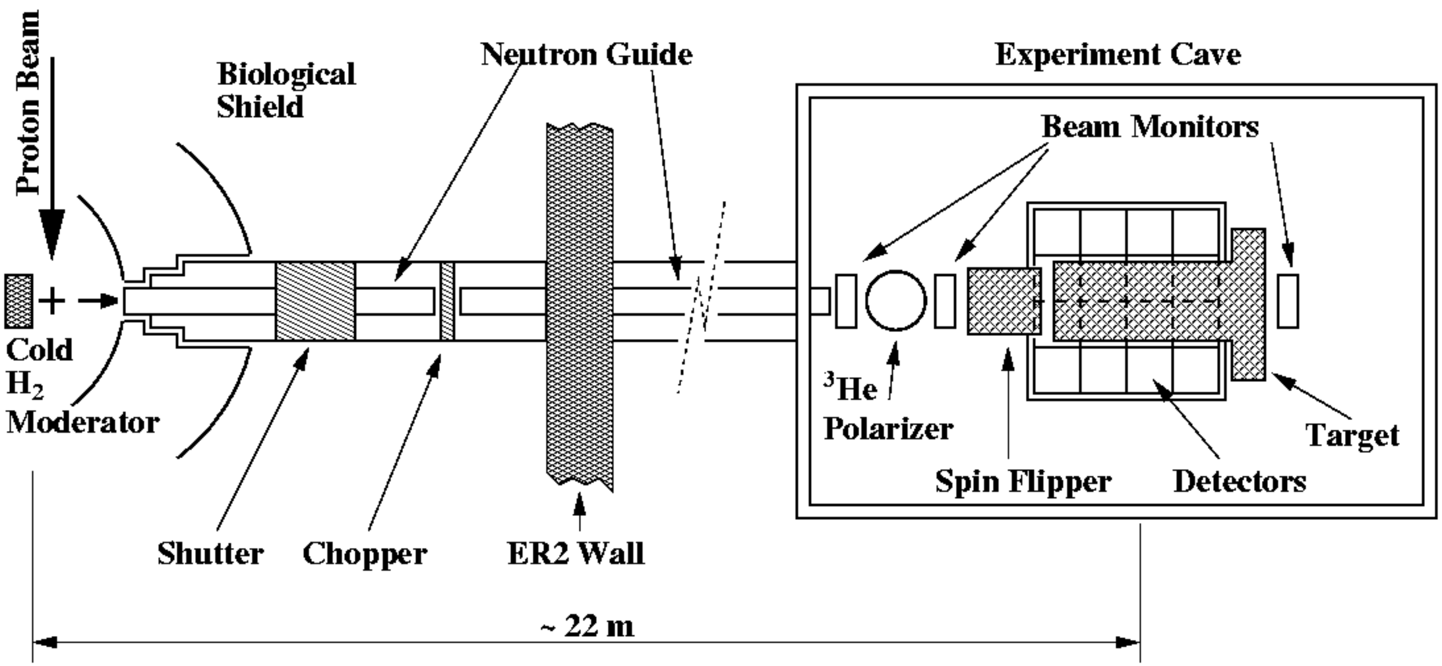
Flight path 13 – top view



The NPDGamma Collaboration

Los Alamos National Laboratory,
University of Manitoba,
University of Michigan,
University of Tennessee,
TJNAF,
University of Dayton,
Institute for Nuclear Research, Dubna,
NIST,
University of Kentucky

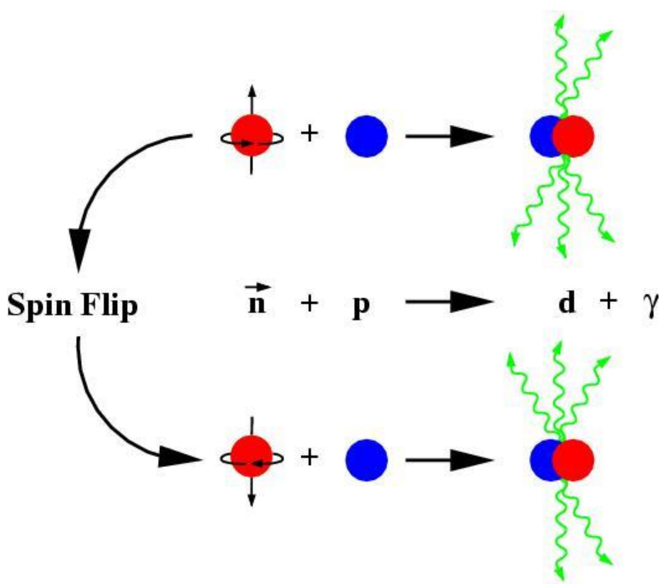
Indiana University,
TRIUMF,
University of New Hampshire,
Oak Ridge National Laboratory,
University of California-Berkeley,
Hamilton College,
KEK National Laboratory, Japan
University of Virginia,
UNAM

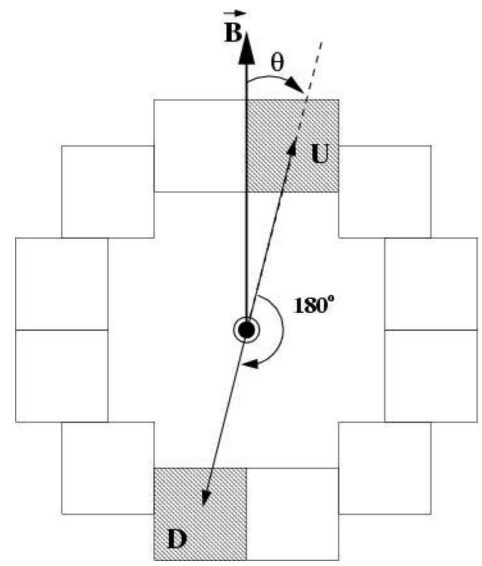


The NPDGamma Observable / Theory

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

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





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

The observed cross-section is the result of an electro-magnetic transition between initial and final two nucleon states.

The possible amplitudes include both parity even M1 and parity odd E1 transitions from L=1 states as a result of the weak perturbation.

$$\frac{d\sigma}{d\Omega} \propto \left| \langle \psi_f | E1 | \psi_i \rangle + \langle \psi_f | M1 | \psi_i \rangle \right|^2$$

$$H = H_s + V_{PNC} \qquad a = \frac{\langle \psi_1 | V_{PNC} | \psi_0 \rangle}{\Delta E} \qquad |\psi_{i,f}\rangle = |\psi_0\rangle + a|\psi_1\rangle$$

A measurement of the asymmetry at the 20 % level (10 ppb) will be the most precise measurement of the weak-pion nucleon coupling

$$\frac{i g_{\pi NN} h_\pi^1}{\sqrt{32} M} [\vec{\tau}_1 \times \vec{\tau}_2]_z [\vec{\sigma}_1 + \vec{\sigma}_2] \cdot \left[\vec{p}, \frac{e^{-mr}}{4\pi r} \right] \qquad \frac{g_{\pi NN} h_\pi^1}{\sqrt{32}} \approx 1.1 \times 10^{-6}$$

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

NPDGamma EFT Relevance

Systematic study of the NN weak interaction described in terms of a model independent theory appropriate at the low energy scale.

NN weak interaction effects enter into nucleon structure (needed for standard model tests) and atomic parity violation measurements.

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

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

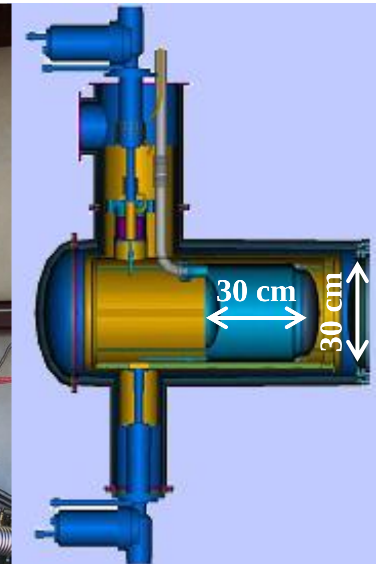
$$^1S_0(I=0,1,2) \leftrightarrow {}^3P_0(I=0,1,2)$$

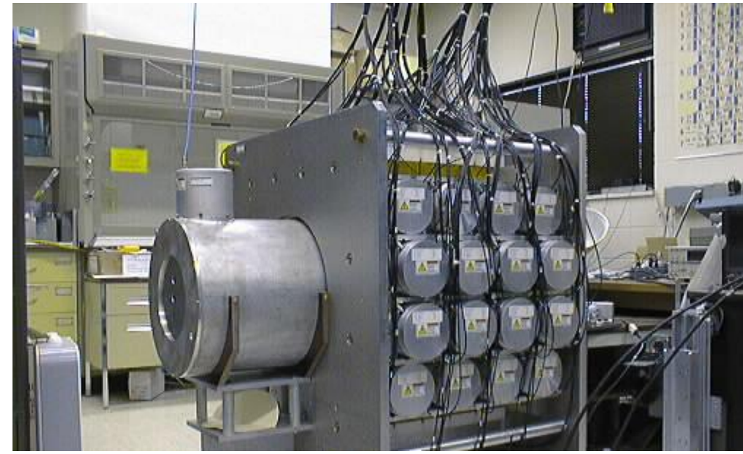
$$^3S_1(I=0) \leftrightarrow {}^3P_1(I=1)$$

NPDGamma asymmetry relation to EFT constant: $A_\gamma^{\vec{n},p}(th.) = -0.107\, m_N \rho_t = -5\times 10^{-8}$

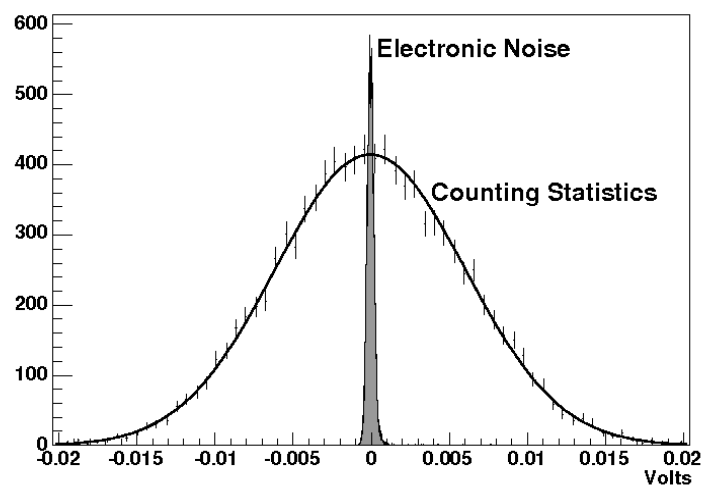
C.-P. Liu, Nuclear Physics Phys. Rev. C 75, 065501 (2007)

LH_2 target and CsI detector array



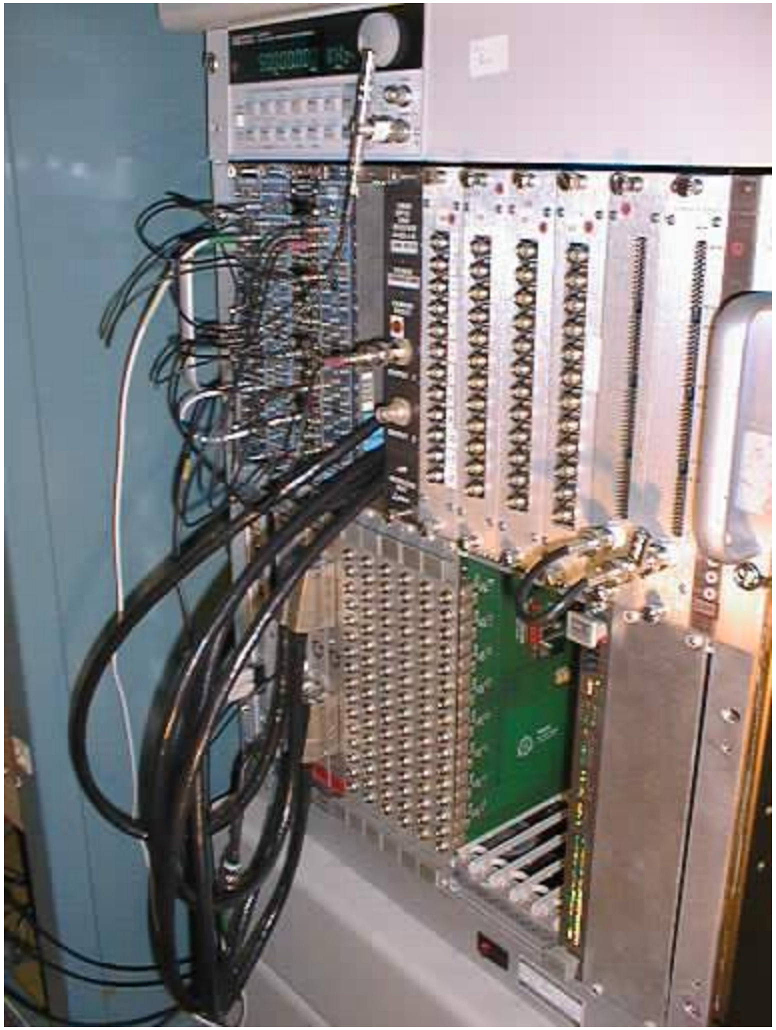


- 3π acceptance
- Current-mode experiment
- γ-rate ~100MHz (single detector)



20L vessel of liquid parahydrogen

Ortho-hydrogen scatters the neutrons and leads to beam depolarization



NPDGamma has successfully taken 48 days of continuous production data in 2006 – now on par with the best previous measurement – in preparation for one more year of production data at the SNS.

Data Summary from 2006 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}

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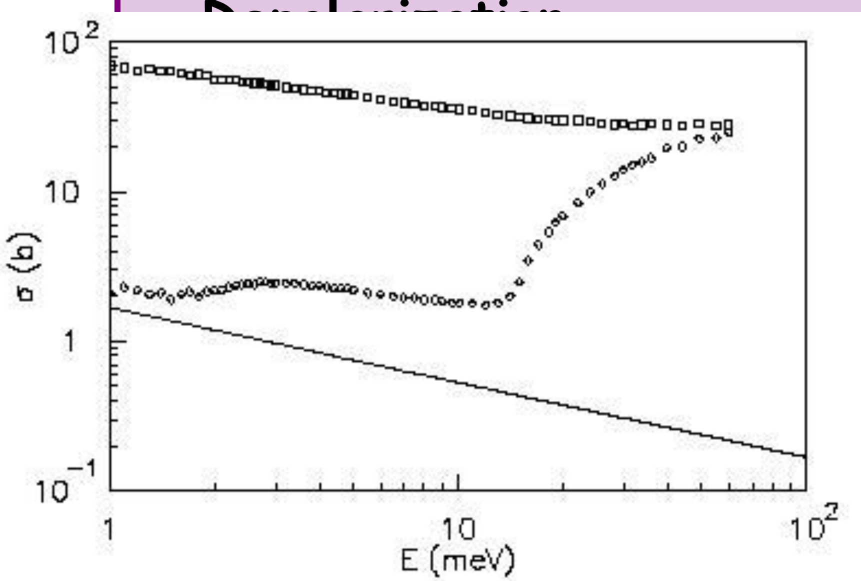
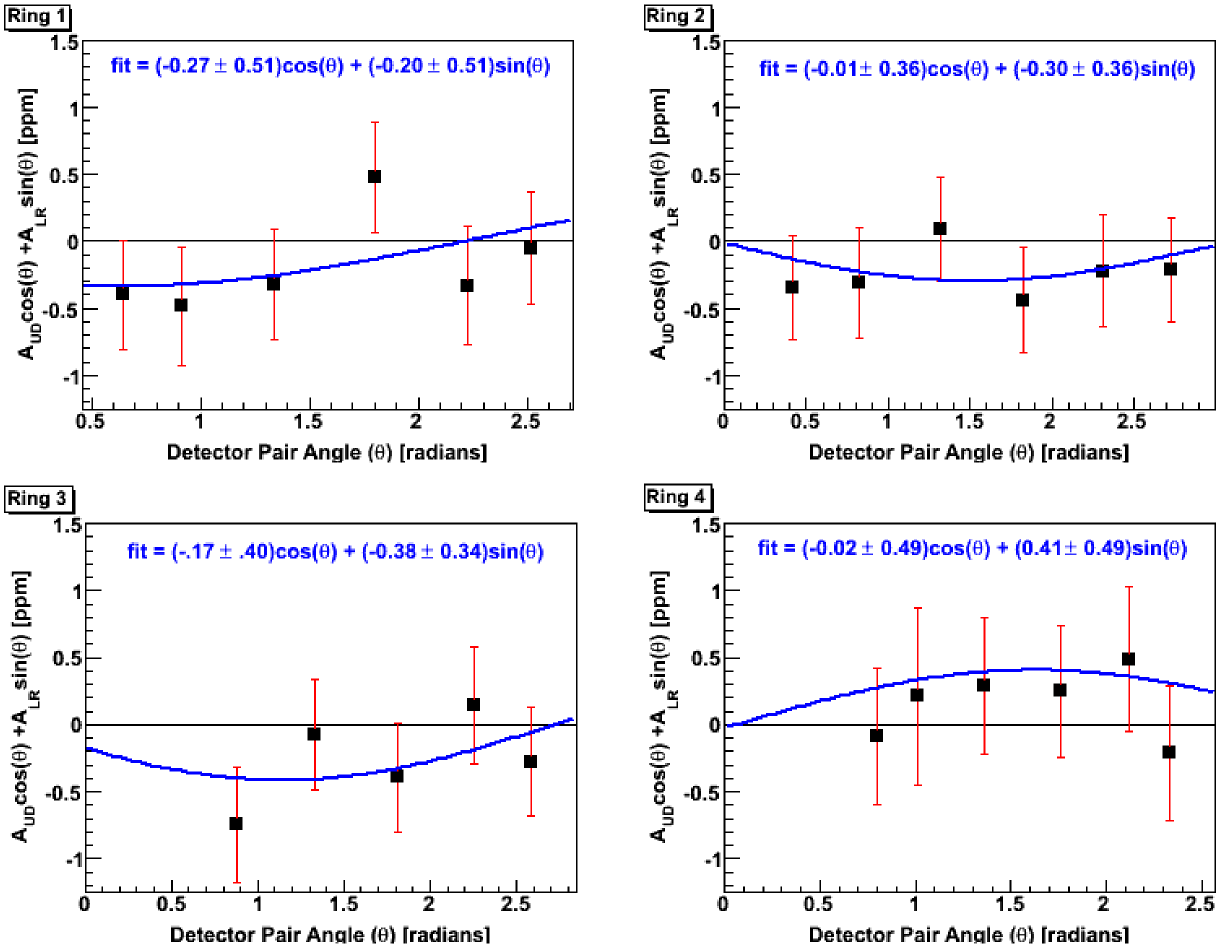
[illegible] sym	10^{-10}
[illegible]	10^{-10}



2006 Hydrogen Results:

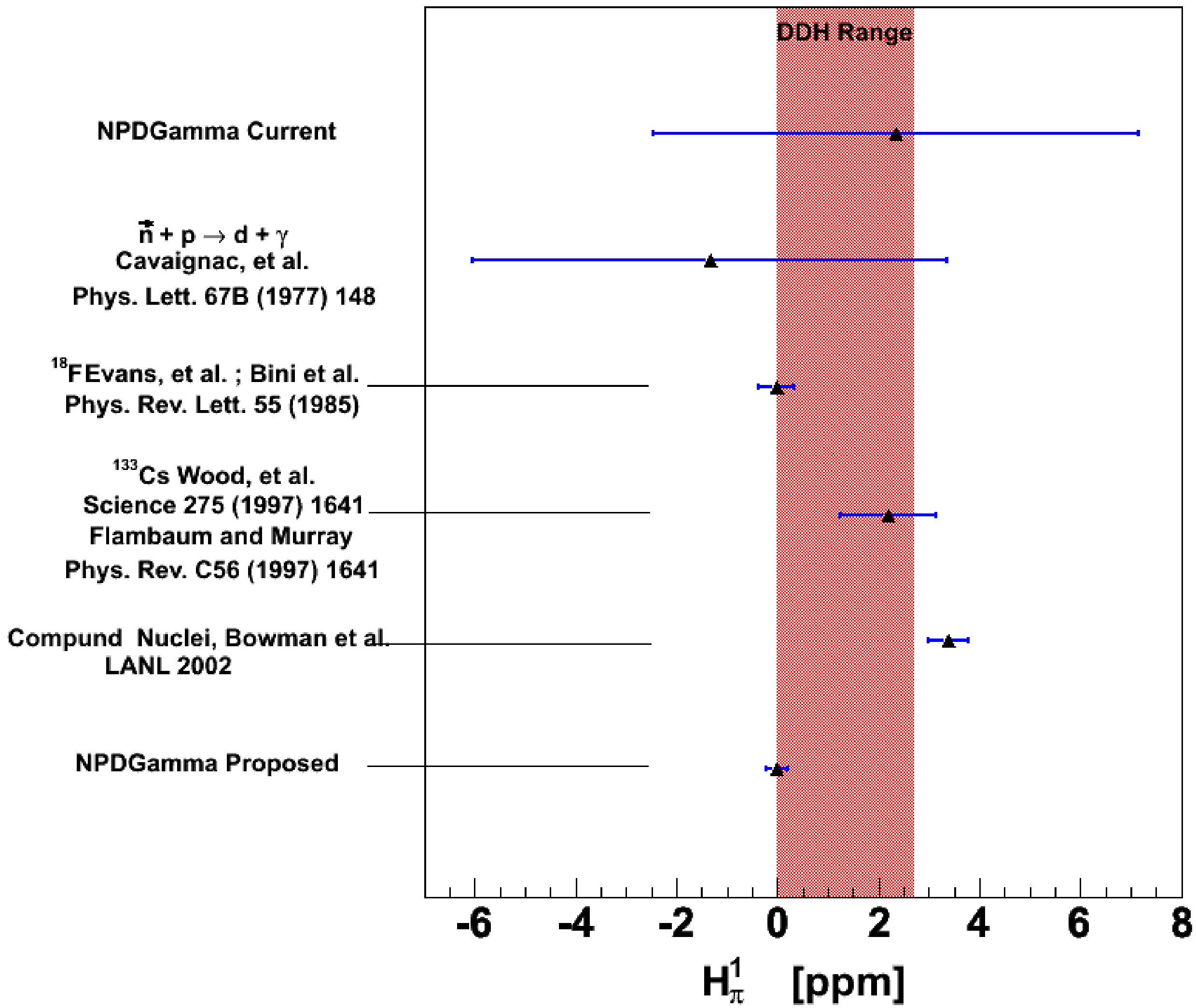


Total statistical error:

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

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

Preliminary Hydrogen Results:



What's new for the SNS run

- Supermirror Polarizer replaces the ^3He Polarizer (x4.1)
- Higher moderator brightness (x12) => more cold/slow neutrons
- New LH2 target – thinner windows, smaller background contribution

Predicted size -5×10^{-8} - NPDGamma will make a 20% measurement, most precise so far

- Installation begins in July 2009
- Production Hydrogen Data: Summer 2010

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

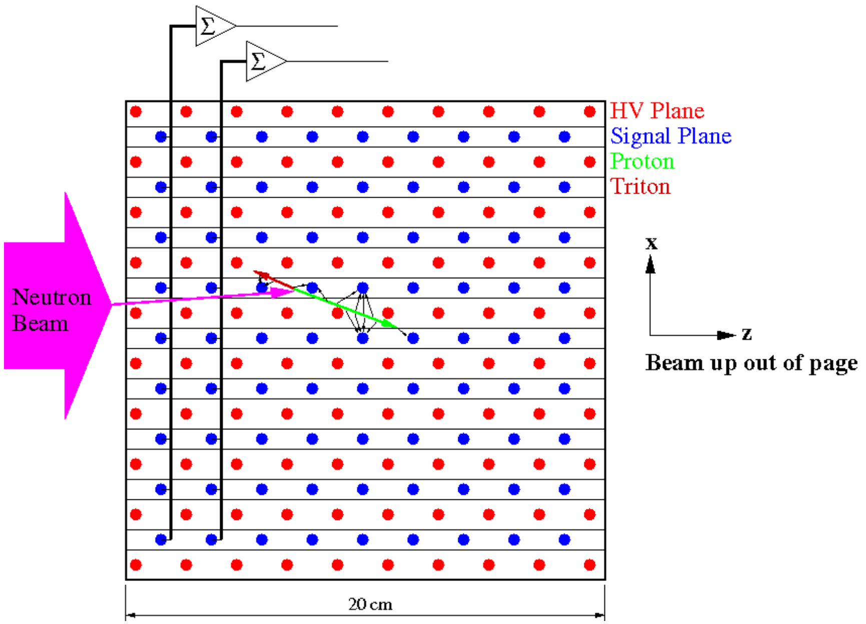
n^3He Principle of Measurement

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)*



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

Estimated Size Of The Asymmetry

Asymmetry from mixing in the intermediate bound states (RMS width estimate)

$\vec{n} + {}^3\mathrm{He} \rightarrow {}^3\mathrm{H} + p$ has a $(0^+, I = 0)$ resonance at $20.21\mathrm{MeV}$

Parity mixing can occur with the $(0^-, I = 0)$ resonance at $21.01\mathrm{MeV}$

$$\frac{d\sigma}{d\Omega} \propto |\langle\psi_{f0}|H_s|\psi_{i0}\rangle|^2 \left[1 + \alpha_{PV} \frac{|\langle\psi_{f1}|H_s|\psi_{i0}\rangle + \langle\psi_{f0}|H_s|\psi_{i1}\rangle|}{|\langle\psi_{f0}|H_s|\psi_{i0}\rangle|}\right]$$

$$|\psi_i\rangle = |\psi_{i0}\rangle + \alpha_{PV}|\psi_{i1}\rangle$$

$$|\psi_f\rangle = |\psi_{f0}\rangle + \alpha_{PV}|\psi_{f1}\rangle$$

$$\alpha_{PV} = \frac{\langle f|V_{PNC}|i\rangle}{\Delta E} \approx \frac{M_{rms}}{\Delta E} \approx O(10^{-6})$$

$$\Gamma_W = \frac{2\pi M_{rms}^2}{D} = (1.8^{+0.4}_{-0.3}) \times 10^{-7} eV.$$

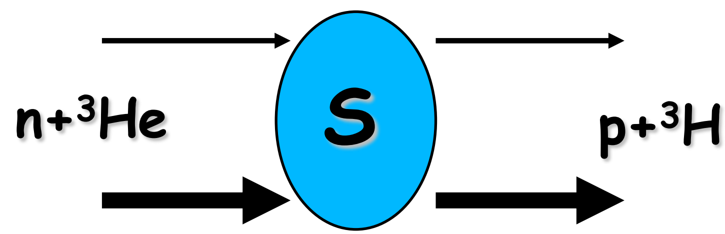
G.E. Mitchell *et al.* Phys. Rep. 354, 157 (2001)

Calculations by the Pisa Group

Use a cluster calculation:

Set A

$$\mathbf{x}_{1A} = \sqrt{\frac{3}{2}}\left(\mathbf{r}_m - \frac{\mathbf{r}_i + \mathbf{r}_j + \mathbf{r}_k}{3}\right),$$
$$\mathbf{x}_{2A} = \sqrt{\frac{4}{3}}\left(\mathbf{r}_k - \frac{\mathbf{r}_i + \mathbf{r}_j}{2}\right),$$
$$\mathbf{x}_{3A} = \mathbf{r}_j - \mathbf{r}_i,$$



J. Phys. G: Nucl. Part. Phys. **35** (2008) 063101

Obtain scattering wave functions from expansions in hyperspherical harmonic basis

$$S^{\gamma,\gamma'}_{\alpha,\alpha'} = -2\mathrm{i}\langle\overline{\Psi}^{(-)}_{\alpha,\gamma}|H - E|\overline{\Psi}_{\alpha',\gamma'}\rangle$$
$$= -2\mathrm{i}\langle\overline{\Psi}^{(-)}_{\alpha,\gamma}|V_{\mathrm{PV}}|\overline{\Psi}_{\alpha',\gamma'}\rangle\ .$$

Work out the allowed angular momentum transition (up to J = 2) and use the Kohn variational principle to obtain S matrix elements

$$A_z \propto S^+ - S^- \approx \sum_{J_1,L_1,S_1,L_1',S_1'} \sum_{J_2,L_2,S_2,L_2',S_2'} {C^{npJ_1}_{L_1,S_1,L_1',S_1'}}^{*} C^{npJ_1}_{L_2,S_2,L_2',S_2'} \left[1-(-)^{L_1+L_2+L_1'+L_2'}\right] S^+$$

n^3He Relevance

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

Correspond to:

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

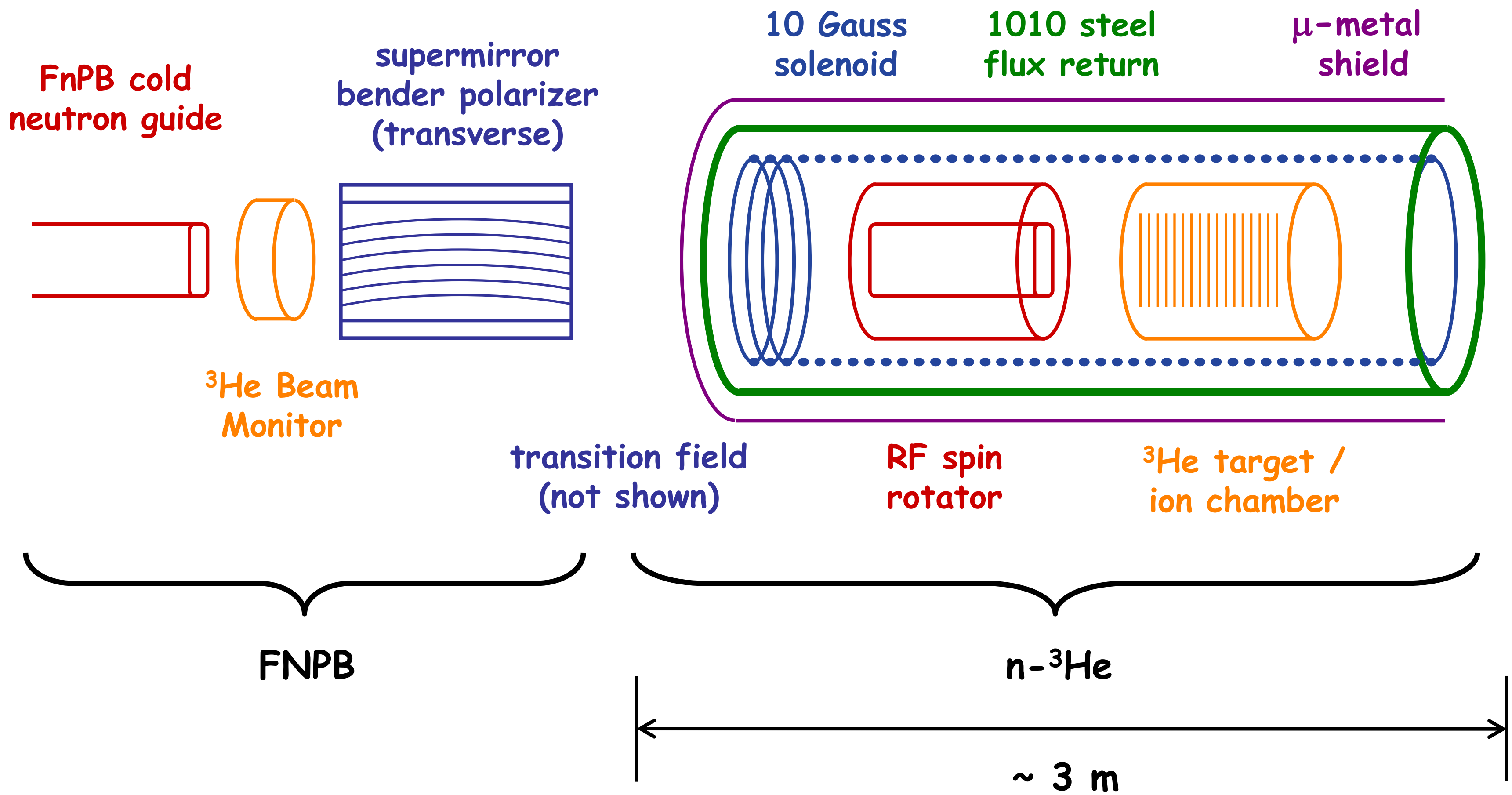
$$^3S_1(I=0) \leftrightarrow {}^3P_1(I=1)$$

n3He asymmetry relation to EFT constant:

$$A_p^{\vec{n},{}^3He}(th.) = \kappa\lambda_S^{I=0} + \ldots \approx 3\times10^{-7}$$

M. Viviani, R. Schiavilla, calculation in progress

Experimental Setup

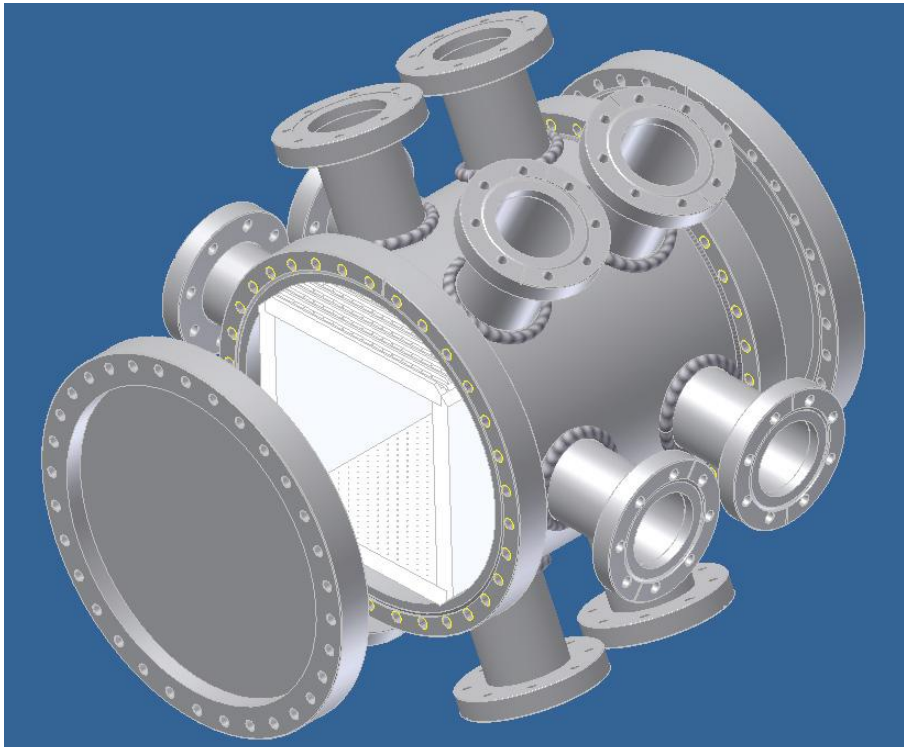


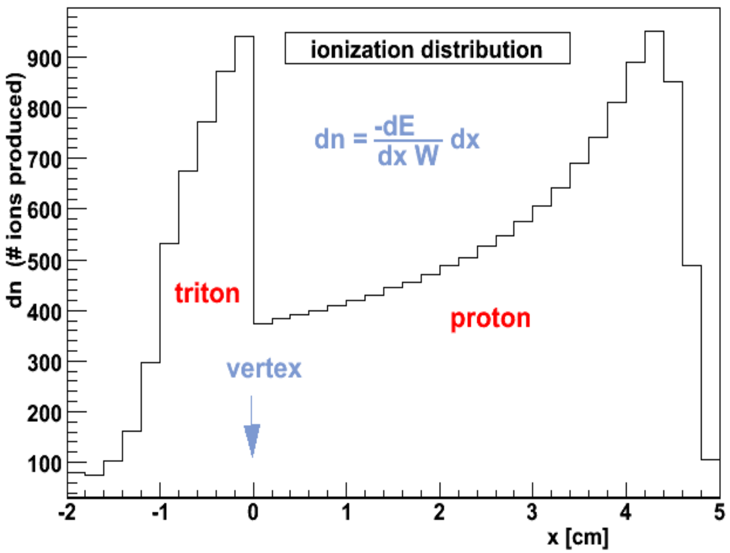
- *longitudinal holding field – suppressed PC asymmetry*
- *RF spin flipper – negligible spin-dependent neutron velocity*
- *^{3}He ion chamber – both target and detector*

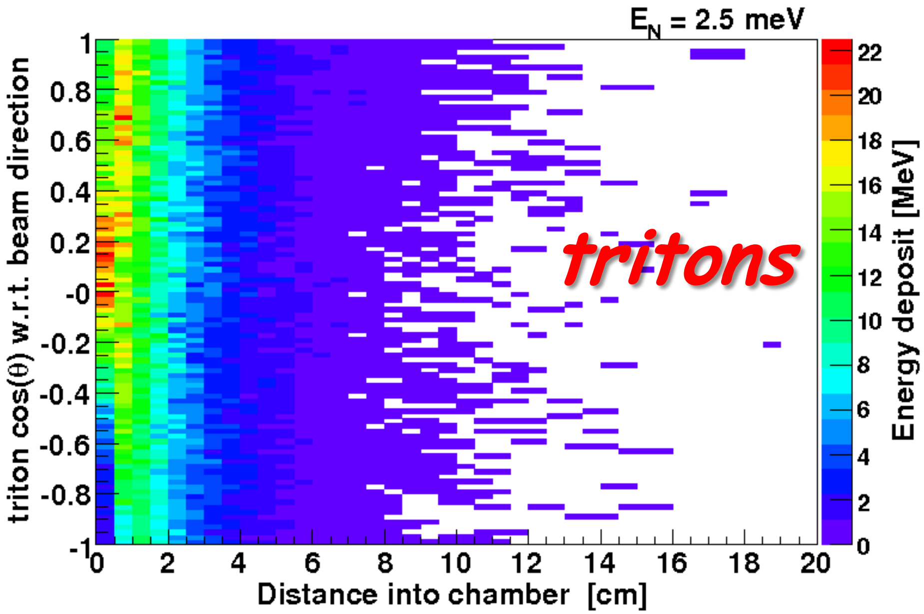
- ***MC simulations of sensitivity to proton asymmetry***
  - ***including wire correlations***
  - $$\delta A_{ph} = \frac{1}{\sqrt{N} P_N} \sqrt{\sigma_D^2 + \sigma_{coll}^2}$$

$$\sigma_d \simeq 6$$

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







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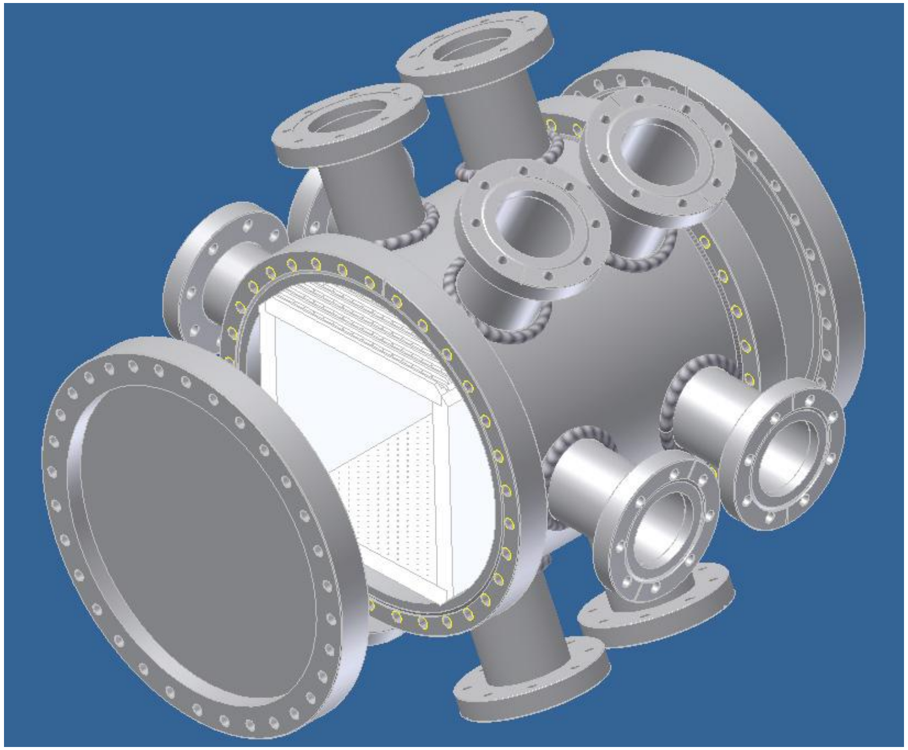
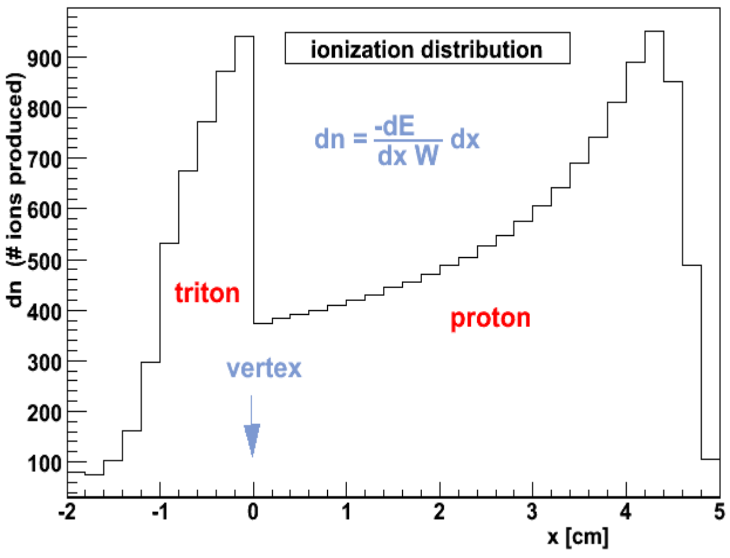
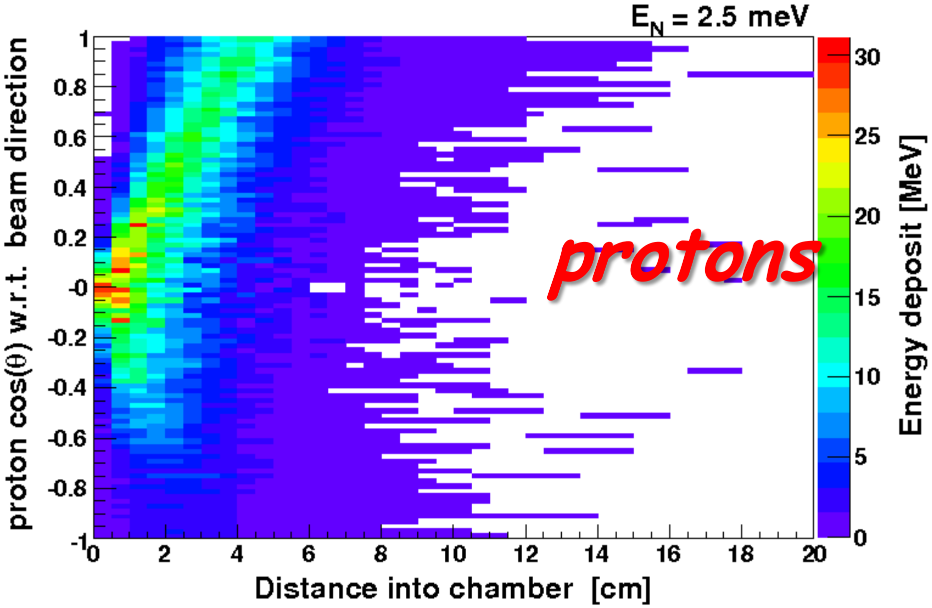
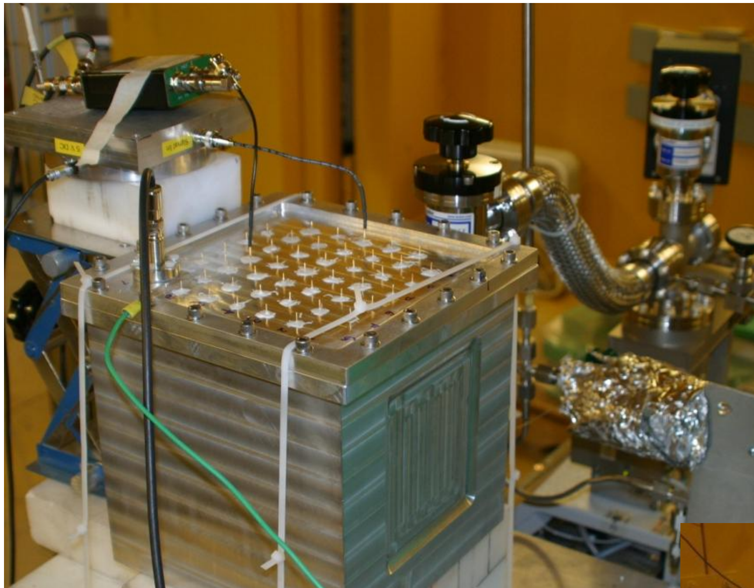
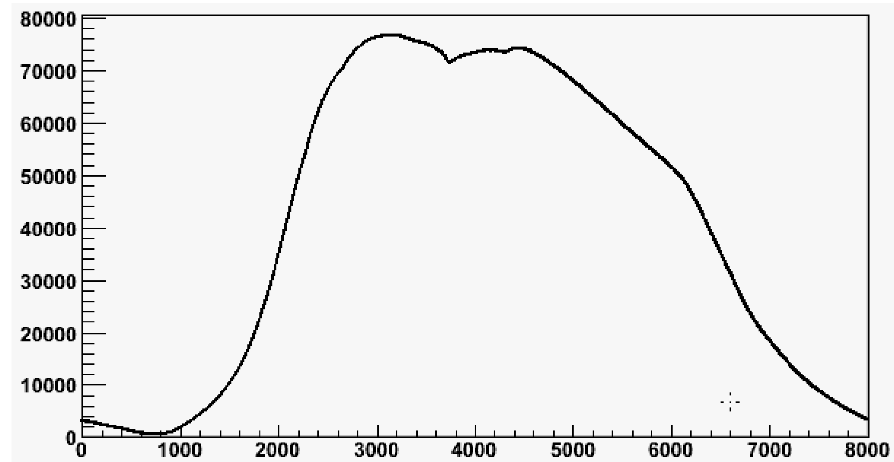


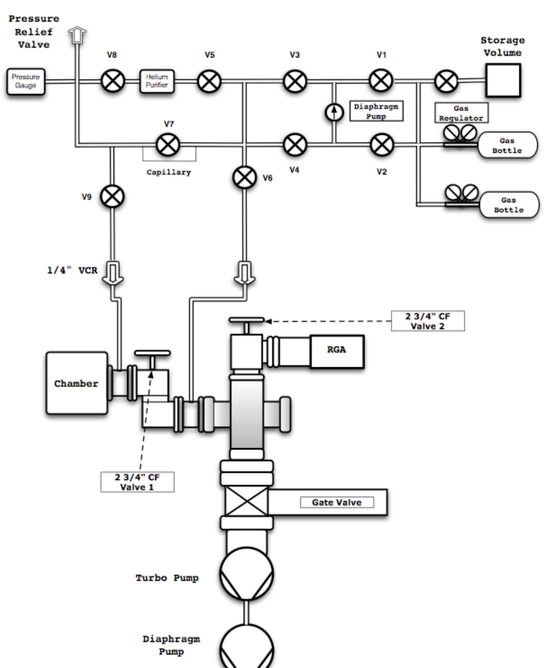


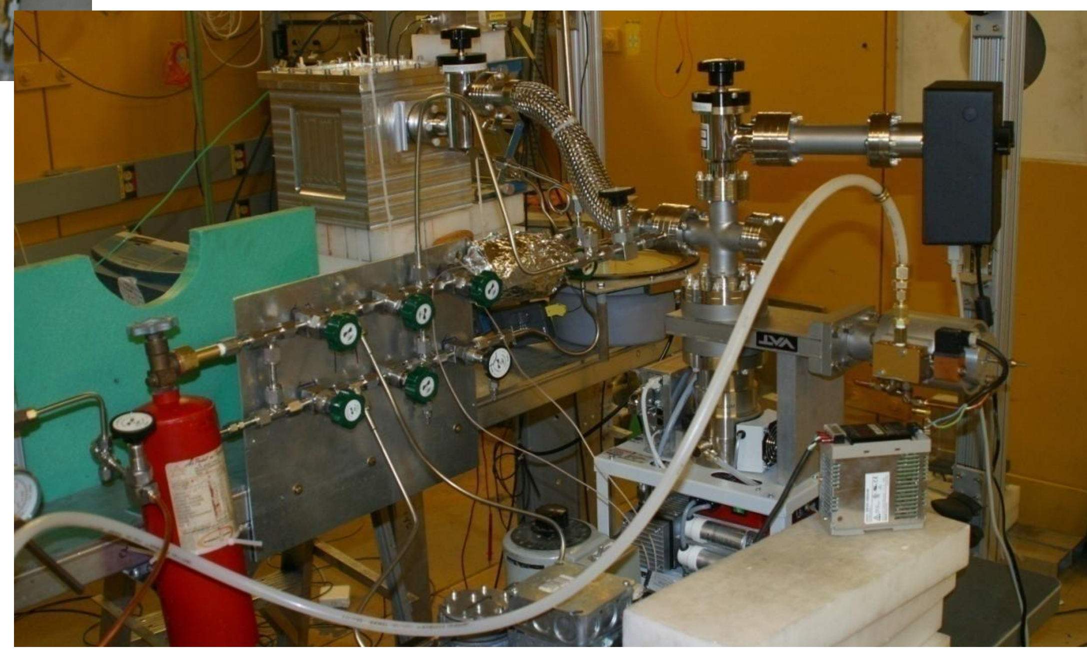


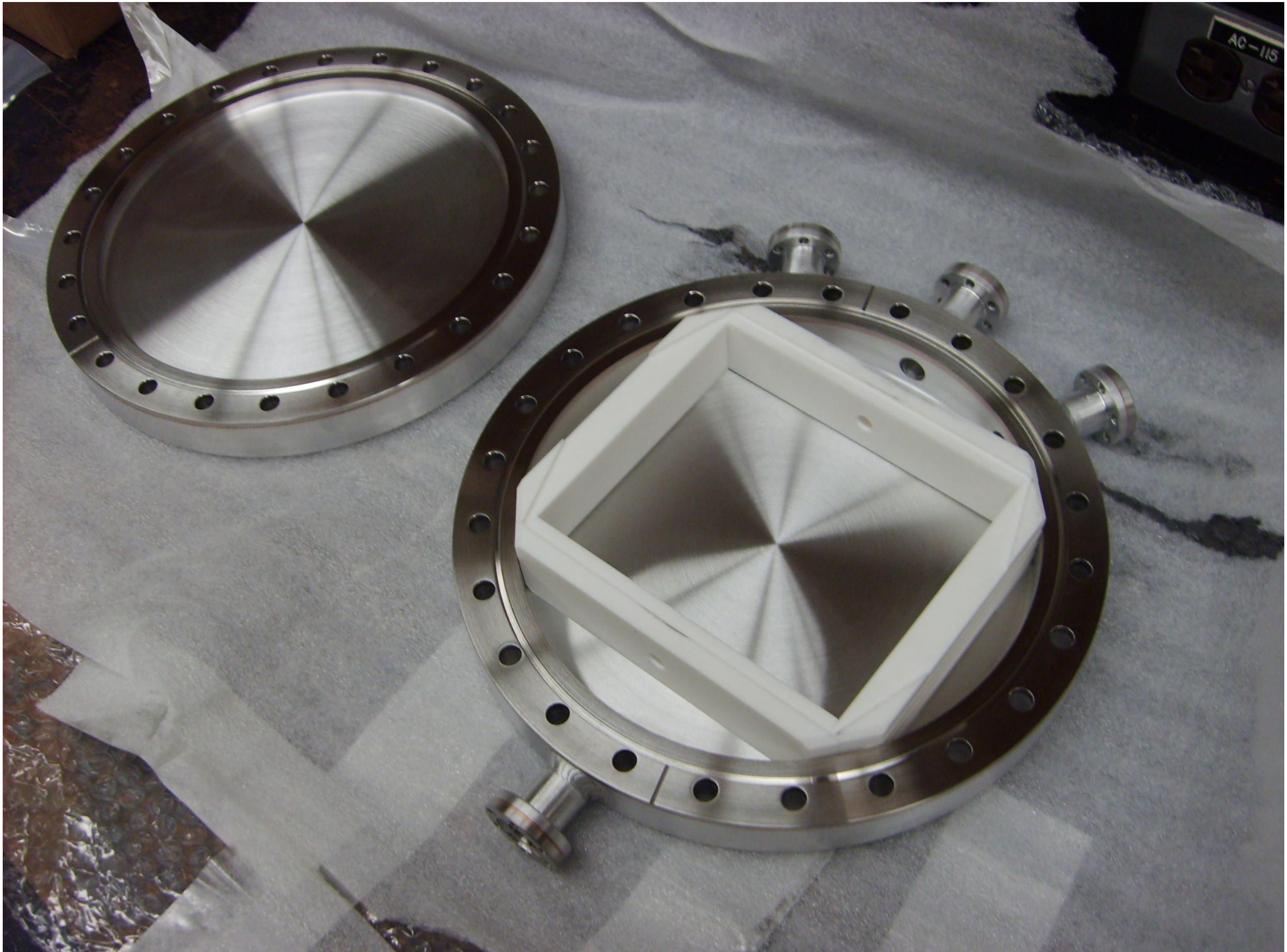
LANSCE n³He Chamber Tests

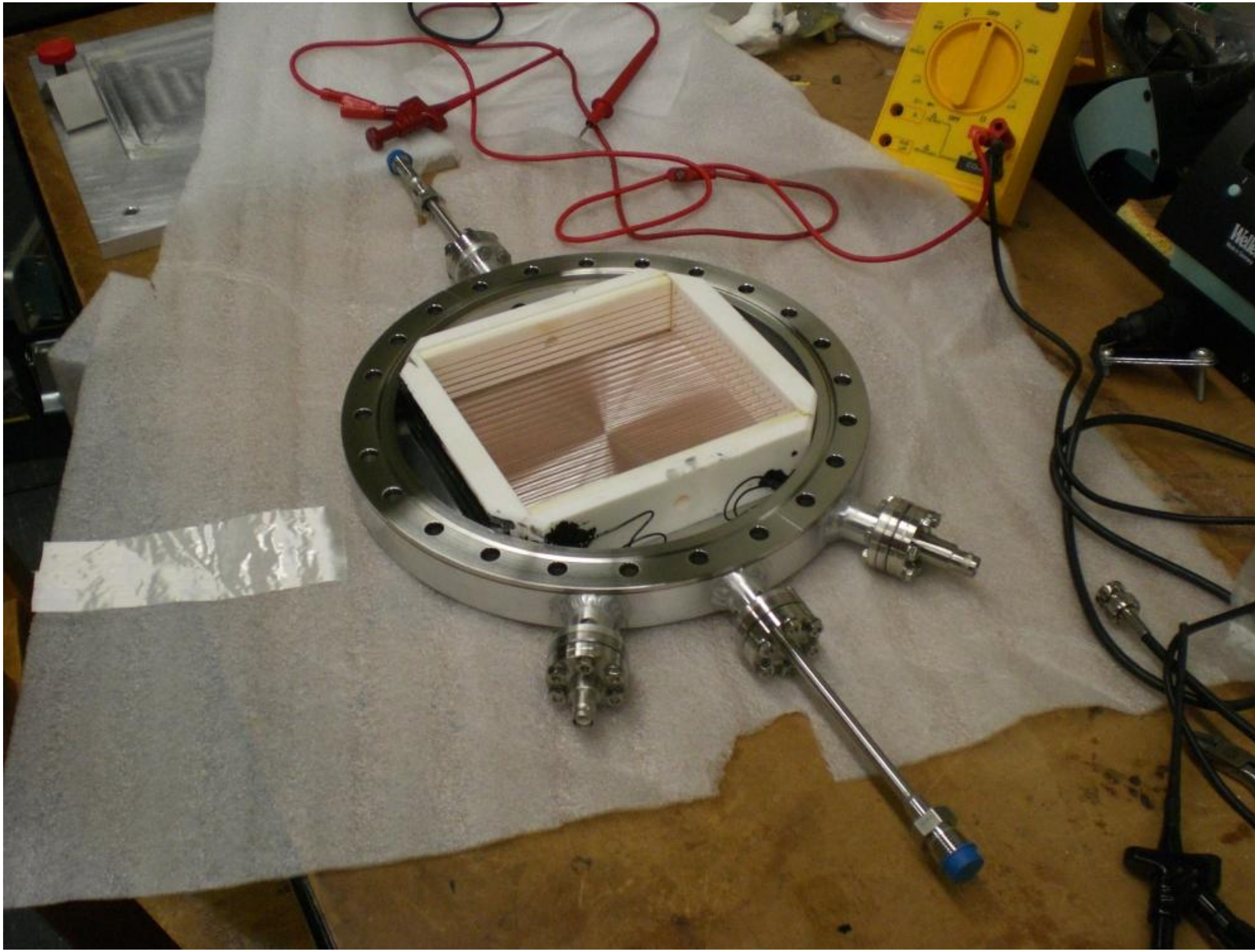






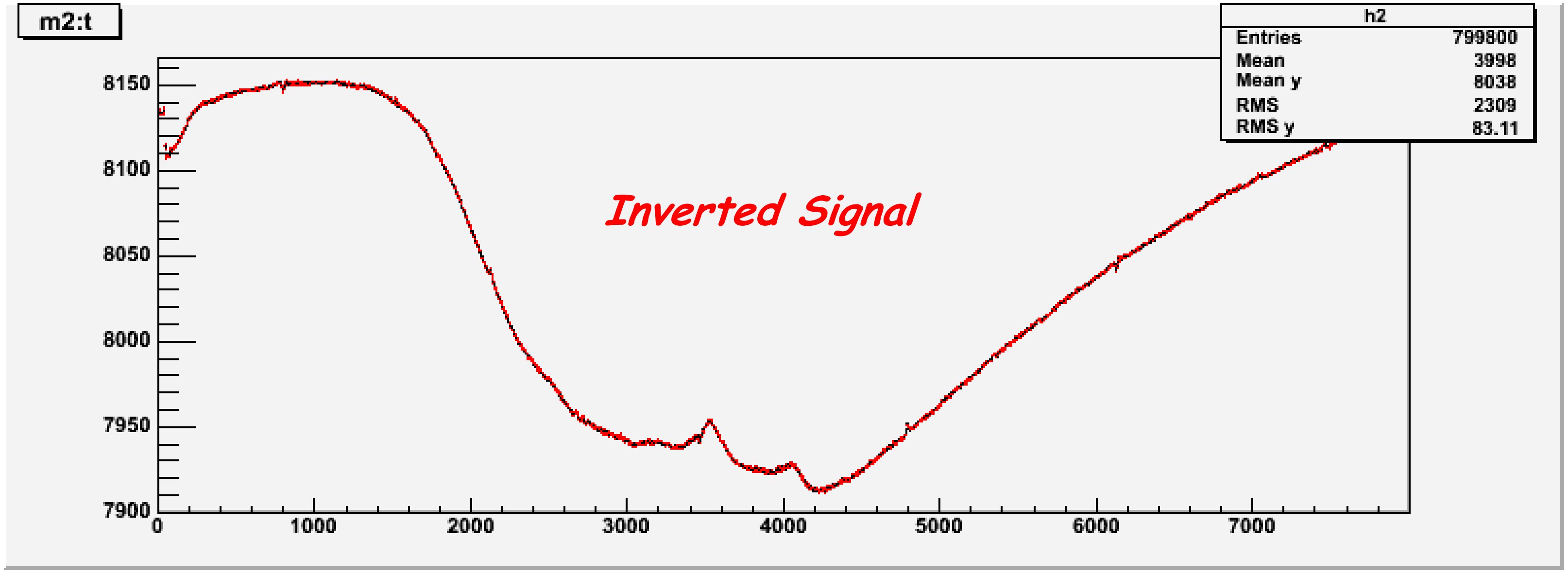



AC-115


Weller

Right: LANL FP12 beam line with new beam monitor installed

Below: New beam monitor signal at 100 μA proton beam current.



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*
  - *2009-2010 Design and development*
  - *Late 2011 Installation*
  - *2012 Run*

Ciao