Parity Violation in Hadronic systems: the N-N Weak Interaction

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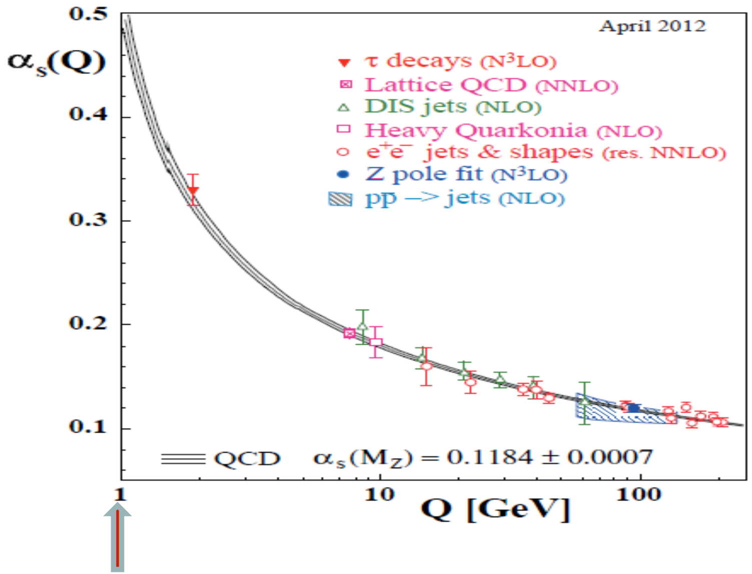
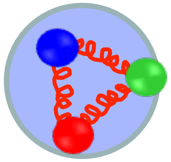
1. Theoretical background/present experimental status
2. Neutron experiment under analysis: n+p [NPDGamma]
3. Proposed neutron experiments:(a) n+3He, (b) n+4He
4. Experimental bounds on “long-range” neutron parity violation
5. Deuteron photodisintegration: future possibility
6. Recent Developments/Conclusions

What kind of a probe do we need to learn about strong QCD?

QCD coupling α_s

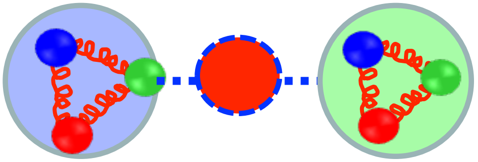


$$\Lambda_{QCD} \approx 1GeV$$



*** asymptotic freedom**
*** confinement**
*** chiral symmetry breaking**

$$E_B \approx MeV$$



NN interaction (meson exchange)

1. We want a “weak” probe which does not disturb the strong dynamics and leaves the system in its ground state

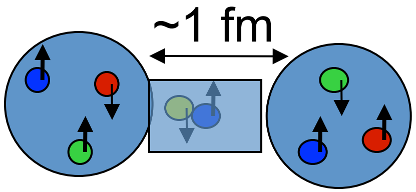
2. We want an “inside-out” probe which is understood at short distance scales

3. We want a “quark-quark” probe so that we are highly sensitive to QCD dynamics

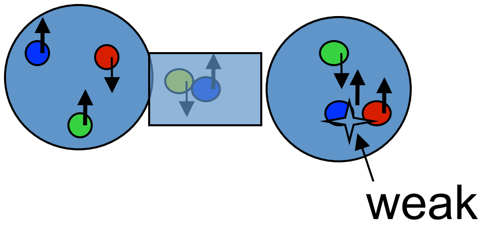
4. We want a “symmetry-violating” probe that we can see in the presence of strong dynamics

Can we understand quantitatively the evolution of strong dynamics from the q-q to the N-N level, through two nonperturbative scales?

The N-N Weak Interaction is what we want to study!



QCD (and strong NN): conserves parity



q-q weak interaction: violates parity

1. Is it "weak" enough not to disturb QCD effects? YES!

2. Is it an "inside-out" probe which is understood at short distance scales? YES! W and Z range [~1/100 fm] much smaller than nucleon

3. Is it a "quark-quark" probe? YES!

4. Is it a a "symmetry-violating" probe? YES! (QCD conserves parity, weak interaction violates parity)

So what's the problem?

Relative strength of weak / strong amplitudes in N-N system:

$$\frac{e^2}{M_W^2} / \frac{g^2}{m_\pi^2} \approx 10^{-7}$$

Too damn weak: experiments are very hard. But there is hope….

q-q Weak/NN Weak: Two Simple Facts

(1) At energies below the W± and Z° mass, the q-q weak interaction can be written in a current-current form, with contributions from charged currents and neutral currents.

$$M_{CC} = \frac{g^2}{2M_W^2} J^\dagger_{\mu,CC} J^\mu_{CC}; M_{NC} = \frac{g^2}{\cos^2\theta_W M_Z^2} J^\dagger_{\mu,NC} J^\mu_{NC}$$

$$J^\mu_{CC} = \bar{u}\frac{1}{2}\gamma^\mu(1-\gamma^5)\begin{pmatrix}\cos\theta & \sin\theta \\ -\sin\theta & \cos\theta\end{pmatrix}\begin{pmatrix} d \\ s\end{pmatrix}; J^\mu_{NC} = \sum_{q=u,d}\bar{q}\frac{1}{2}\gamma^\mu(c_V^q - c_A^q\gamma^5)q$$

(2) If we use energies low enough that **only *S*-waves are important for strong interaction,** parity violation is dominated by ***S- P interference***, we have 5 independent NN parity-violating transition amplitudes:

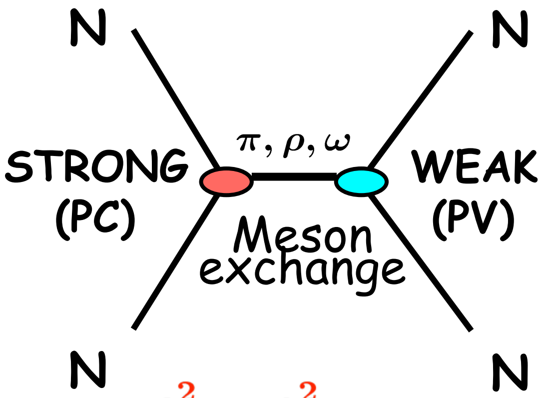
$^3S_1 \Leftrightarrow {}^1P_1$($\Delta I=0$, np); $^3S_1 \Leftrightarrow {}^3P_1$($\Delta I=1$, np); $^1S_0 \Leftrightarrow {}^3P_0$($\Delta I=0,1,2$; nn,pp,np)

possible isospin changes from q-q weak interactions	
	Δ I
charged current	0, 2 : (~V^2_{ud}) 1 : (~V^2_{us})
neutral current	0, 1, 2

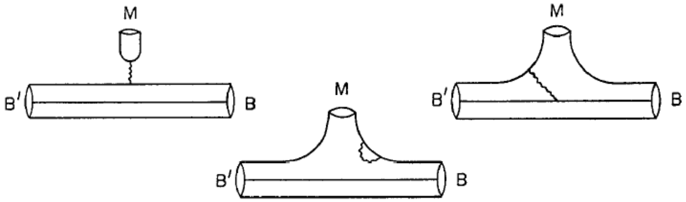
→ Neutral currents dominate Δ I=1, Δ I=2 only comes from one 4-quark operator

DDH Potential

PV meson exchange



$$\frac{e^2}{M_W^2} \Big/ \frac{g^2}{m_\pi^2} \approx 10^{-7}$$



Desplanques, Donoghue, Holstein, Annals of Physics 124, 449 (1980)

1. ***DDH model*** – uses valence quarks to calculate effective PV meson-nucleon coupling directly from SM via 6 weak meson coupling constants

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

P-odd observables can be written as linear combinations of these couplings

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

	np A_γ	nD A_γ	n^3He A_p	np ϕ	nα ϕ	pp A_z	pα A_z
f_π	-0.11	0.92	-0.18	-3.12	-0.97		-0.34
h_r^0		-0.50	-0.14	-0. 23	-0.32	0.08	0.14
h_r^1	-0.001	0.10	0.027		0.11	0.08	0.05
h_ρ^2		0.05	0.0012	-0.25		0.03	
h_ω^0		-0.16	-0.13	-0. 23	-0.22	-0.07	0.06
h_ω^1	-0.003	-0.002	0.05		0.22	0.07	0.06

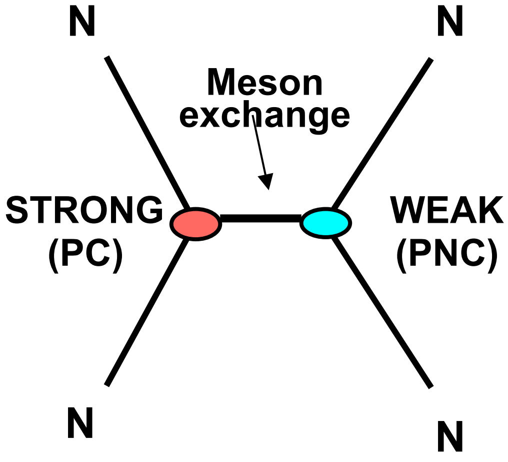
Adelberger, Haxton, A.R.N.P.S. **35,** 501 (1985)

Meson Exchange/NN Weak Effective Field Theories

Meson exchange model: exchange of light mesons (*π, ρ, ω*) with one strong interaction vertex and one weak interaction vertex (Desplanques, Donoghue, Holstein 1980)

Effective Field Theory approach: most general formulation for NN weak interaction consistent with QCD symmetries (Zhu et al 2005)

Pionless EFT (equivalent to 5 S-P transition amplitudes). Calculations in progress (Phillips, Schindler, Springer 2009, Springer,Schindler 2013)

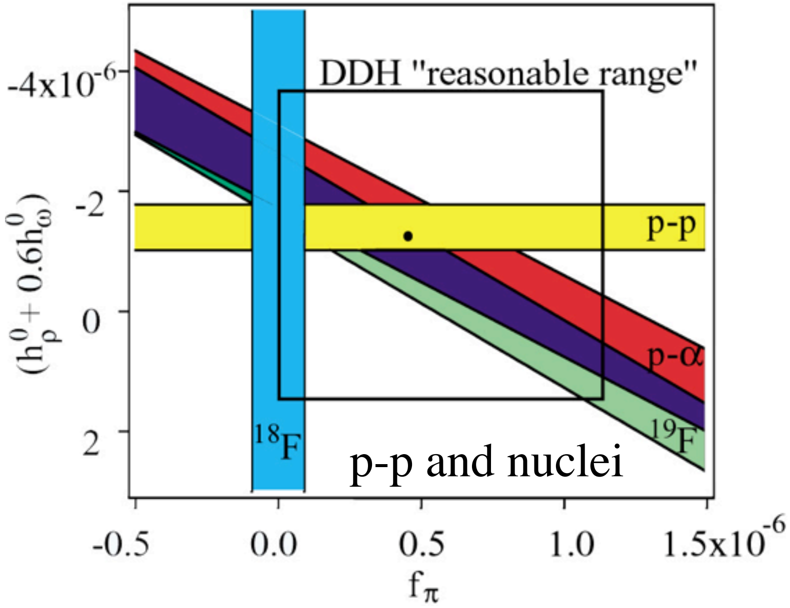


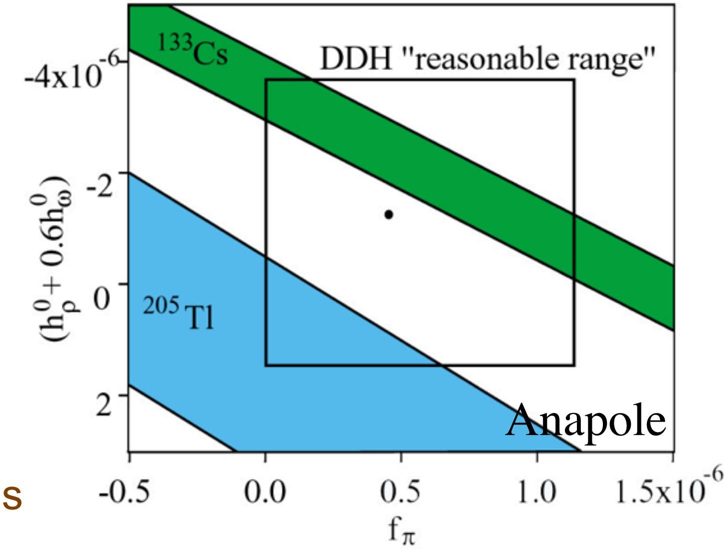
Partial wave transition	I ⇔ I'	ΔI	n-n	n-p	p-p	Hybrid EFT coupling	Pionless EFT coupling	Exchanged Meson
$^3S_1$ ⇔ $^3P_1$	0 ⇔ 1	1		✓		$m\rho_t$,C^π [~ f_π]	$C\,(^3S_1\text{-}\,^3P_1)$	$\pi^\pm$, ρ, ω°
$^3S_1$ ⇔ $^1P_1$	0 ⇔ 0	0		✓		$m\lambda_t$	$C(^3S_1\text{-}\,^1P_1)$	ρ, ω°
$^1S_0$ ⇔ $^3P_0$	1 ⇔ 1	0	✓	✓	✓	$m\lambda_s^{nn}$	$C\,(^1S_0\text{-}\,^3P_{0,}\Delta I=0)$	ρ, ω°
$^1S_0$ ⇔ $^3P_0$	1 ⇔ 1	1	✓		✓	$m\lambda_s^{np}$	$C\,(^1S_0\text{-}\,^3P_0,\ \Delta I=1)$	ρ, ω°
$^1S_0$ ⇔ $^3P_0$	1 ⇔ 1	2	✓	✓	✓	$m\lambda_s^{pp}$	$C(^1S_0\text{-}\,^3P_0,\ \Delta I=2)$	ρ

Existing NN weak interaction data

- p-p scat. 15, 45 MeV A_z^{pp}
- p-α scat. 46 MeV A_z^{pp}
- p-p scat. 220 MeV A_z^{pp}
- $n+p \rightarrow d+\gamma$ circ. pol. P_γ^d
- $n+p \rightarrow d+\gamma$ asym. A_γ^d
- n-α spin rot. $d\phi^{n\alpha}/dz$

- ^{18}F asym. $\Delta I = 1$
- ^{19}F, ^{41}K, ^{175}Lu, ^{181}Ta asym.
- ^{21}Ne (even-odd)
- ^{133}Cs, ^{205}Tl anapole moment

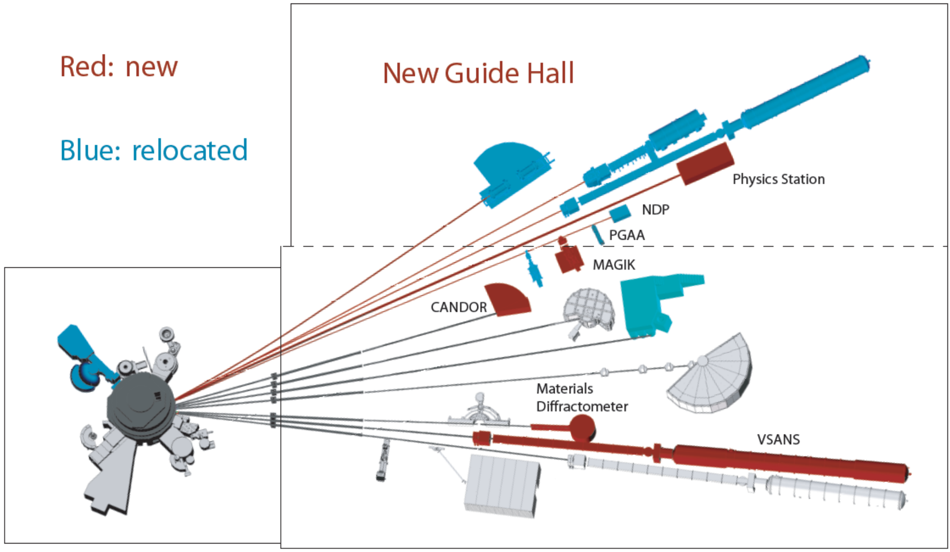


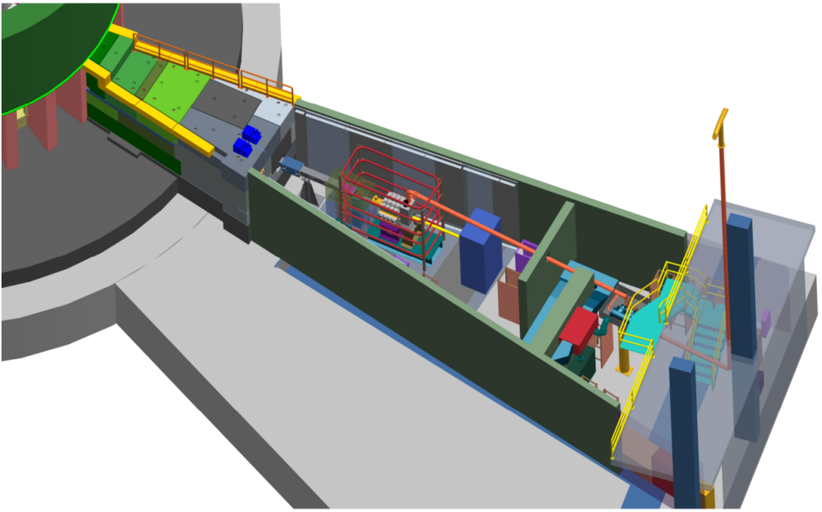


GOAL: determine all low energy NN weak amplitudes using NN and few nucleon data

STATUS: no hint of ΔI=1 weak pion exchange, ΔI=0 NN weak exists, no info on ΔI=2 NN weak

Nuclear/Particle/Astrophysics with Slow Neutrons: New Beams in US

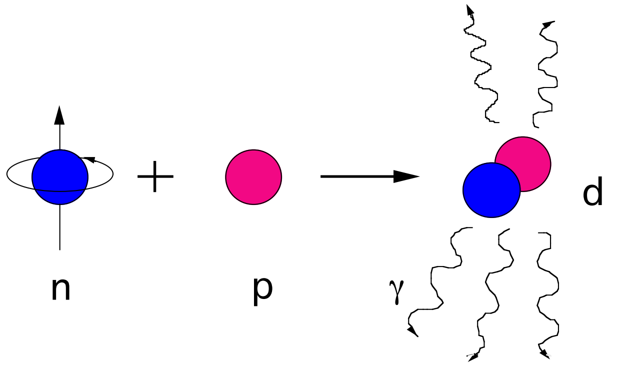




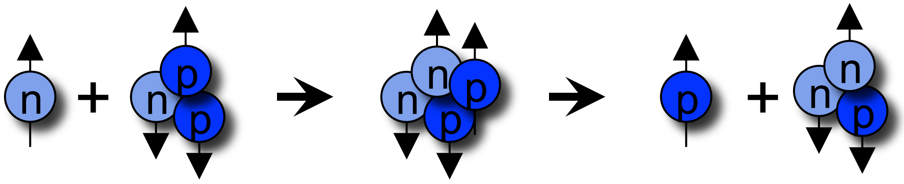
NIST Center for Neutron Research
Gaithersburg MD
Most intense reactor-based US slow neutron source, new beam
#2 intensity in the world in 2014

Spallation Neutron Source
Oak Ridge National Lab (TN)
Most intense pulsed spallation neutron source in the world.
Now in operation

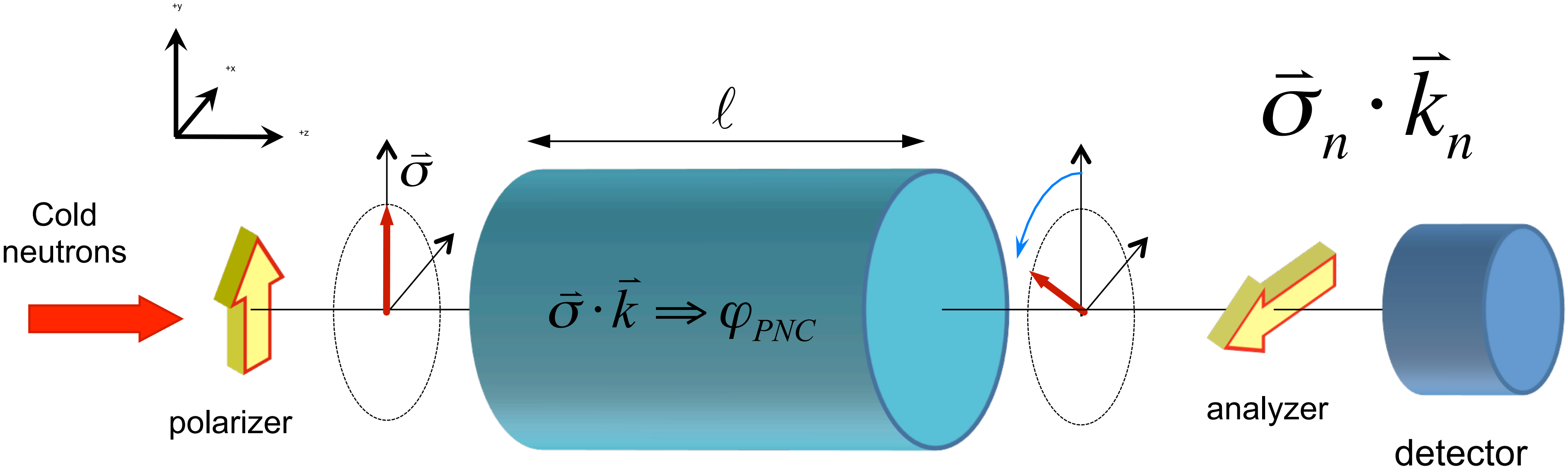
Neutron P-odd Observables: n-p, n-3He, and n-4He



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



$$\vec{\sigma}_n \cdot \vec{k}_p$$



$$\vec{\sigma}_n \cdot \vec{k}_n$$

The NPDGamma collaboration

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[20]TRIUMF, Canada
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NSERC (CANADA)
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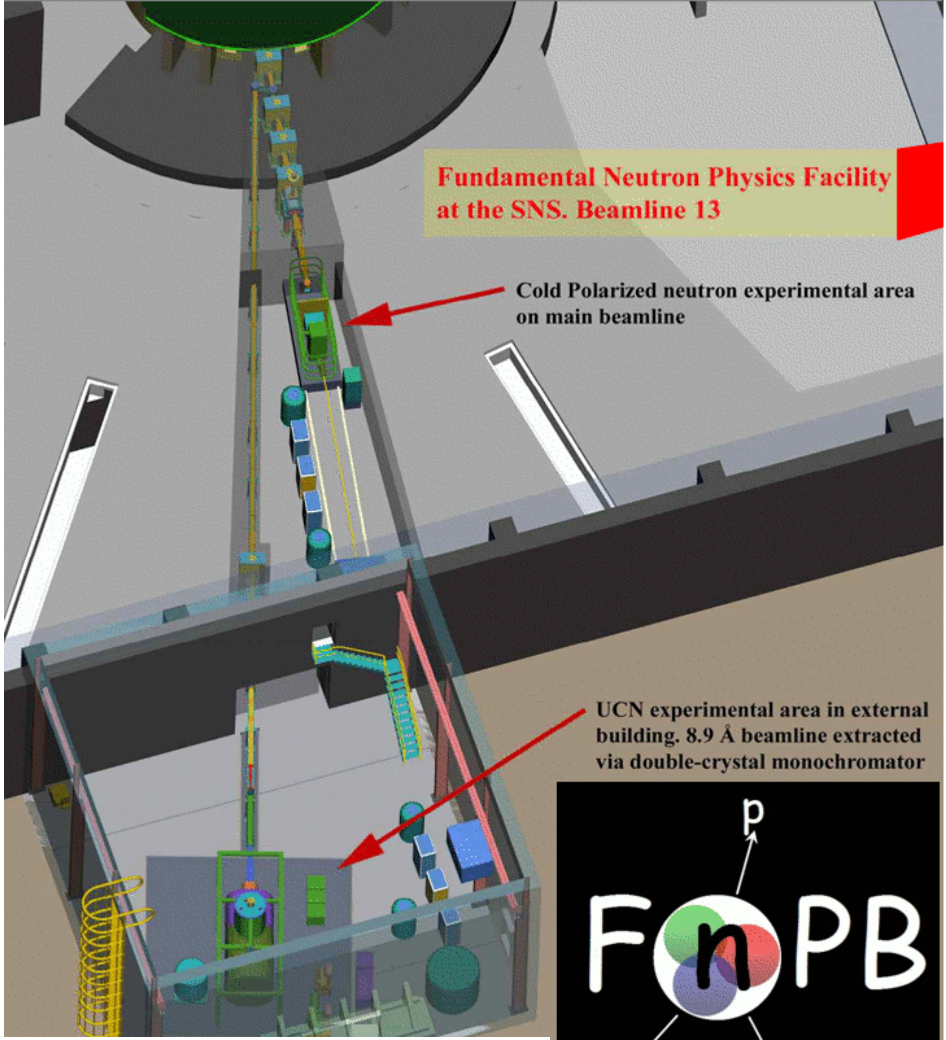
BARC (INDIA)

Spallation Neutron Source (SNS)

The Fundamental Neutron Physics Beam (FnPB) at SNS

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

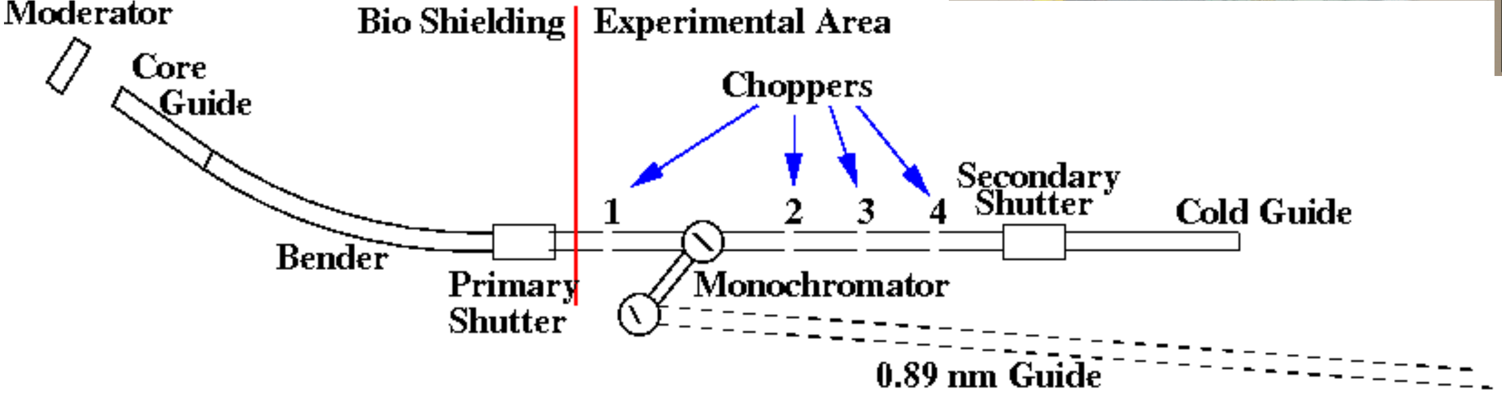


Fundamental Neutron Physics Facility at the SNS. Beamline 13

Cold Polarized neutron experimental area on main beamline

UCN experimental area in external building. 8.9 Å beamline extracted via double-crystal monochromator

FnPB



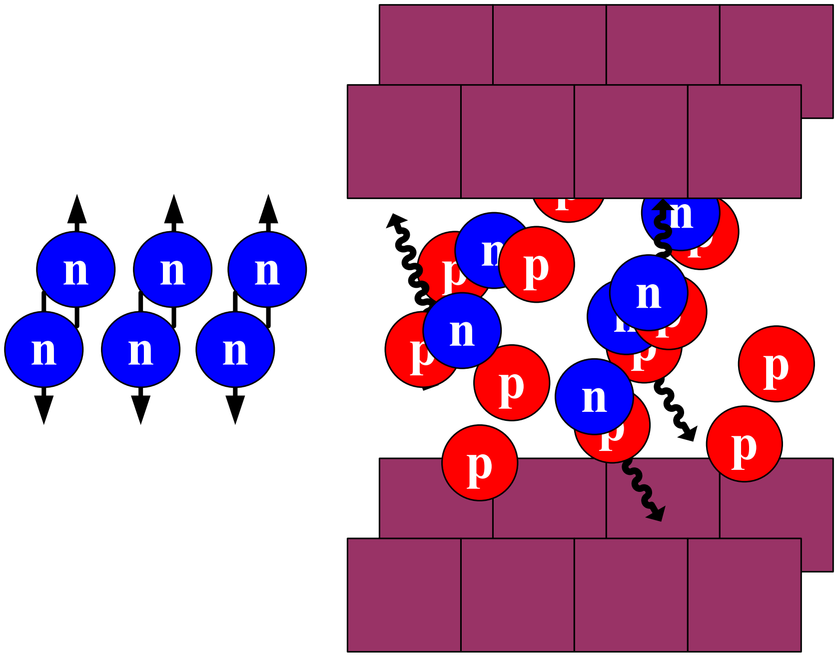
NPDγ: A Gamma-ray Asymmetry Measurement

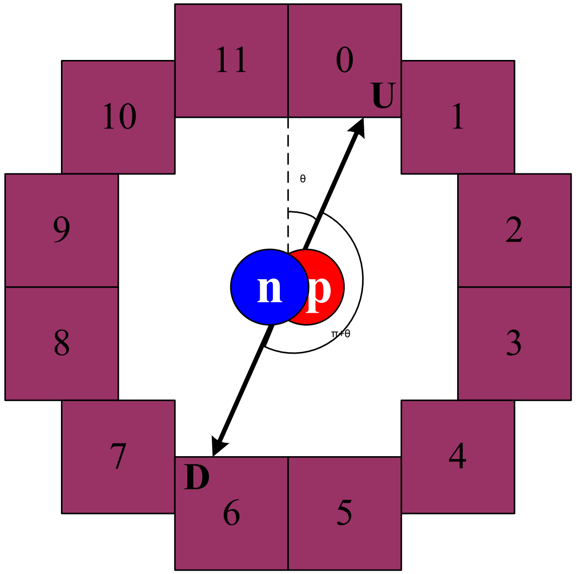
$$A_\gamma(t) P_n \cos\theta = \frac{U_\uparrow - D_\uparrow - (U_\downarrow - D_\downarrow)}{U_\uparrow + D_\uparrow + U_\downarrow + D_\downarrow}$$

$$A_\gamma = -0.107 f_\pi^1 - 0.001 h_\rho^1 - 0.004 h_\omega^1$$

$$\boxed{A_\gamma^{\vec{n}p} \approx \tilde{C}^{3S1->3P1}}$$ Pionless EFT

$$\boxed{A_\gamma^{\vec{n}p} \approx -0.27\tilde{C}_6^\pi - 0.09 m_\mathrm{N} \rho_\mathrm{t}}$$ Hybrid EFT

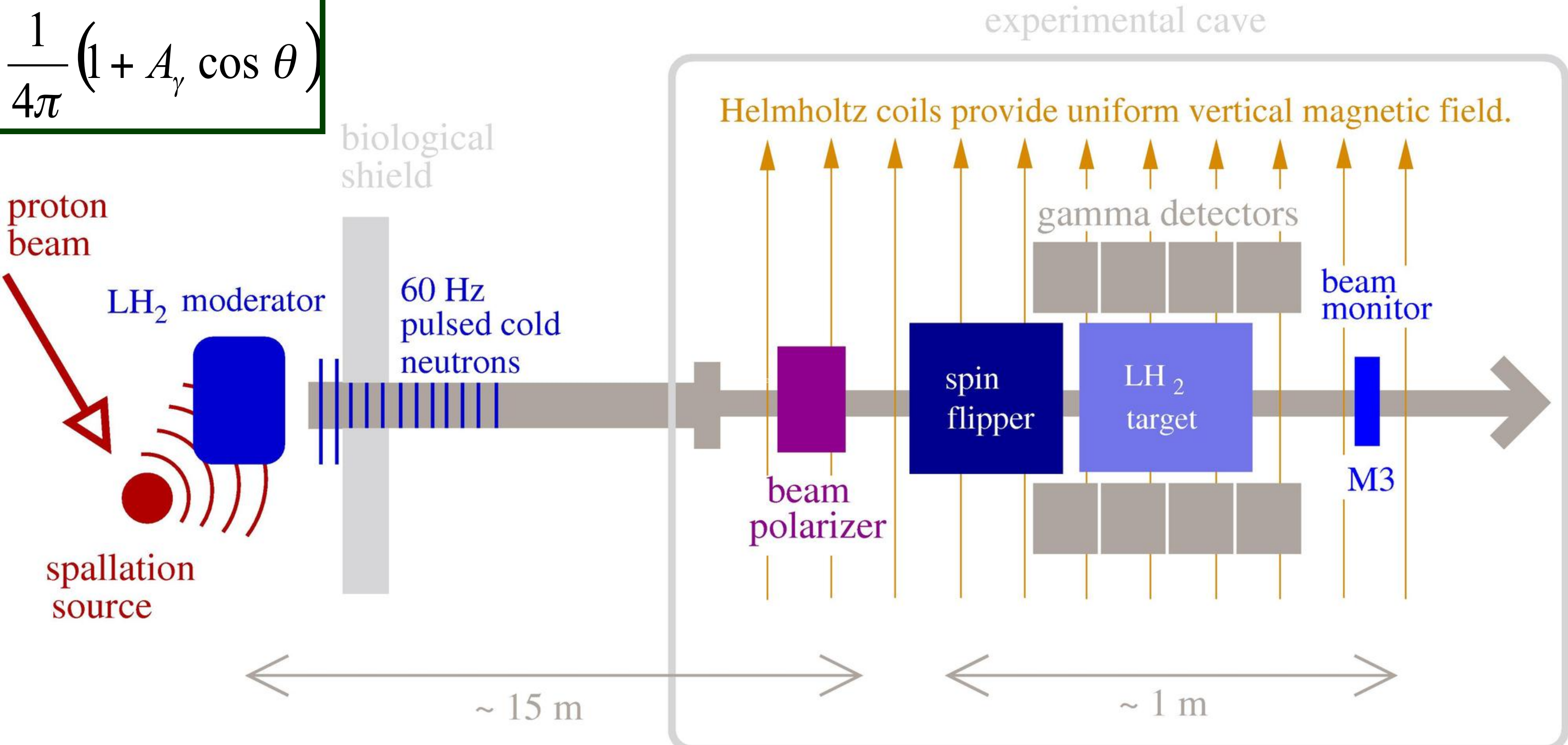




- Reverse the polarization pulse-by-pulse according to the sequence ↑↓↓↑↓↑↑↓ to cancel linear and quadratic time-dependent gain drifts
- Analyze opposite detector pairs to extract asymmetry as a function of θ
- **Goals for gamma asymmetry: ~ 1×10^{-8} statistical error, ~ 10^{-9} systematic error.**

PV Gamma Asymmetry Apparatus Concept

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



experimental cave

Helmholtz coils provide uniform vertical magnetic field.

biological shield

proton beam

LH_2 moderator

60 Hz pulsed cold neutrons

spallation source

gamma detectors

beam monitor

beam polarizer

spin flipper

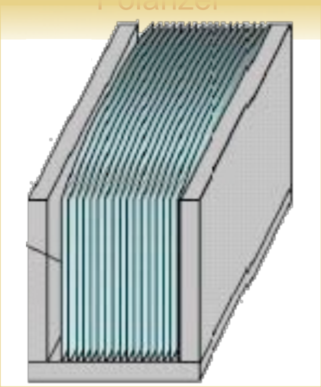
LH_2 target

M3

~ 15 m

~ 1 m

Supermirror Polarizer



Beam Monitors

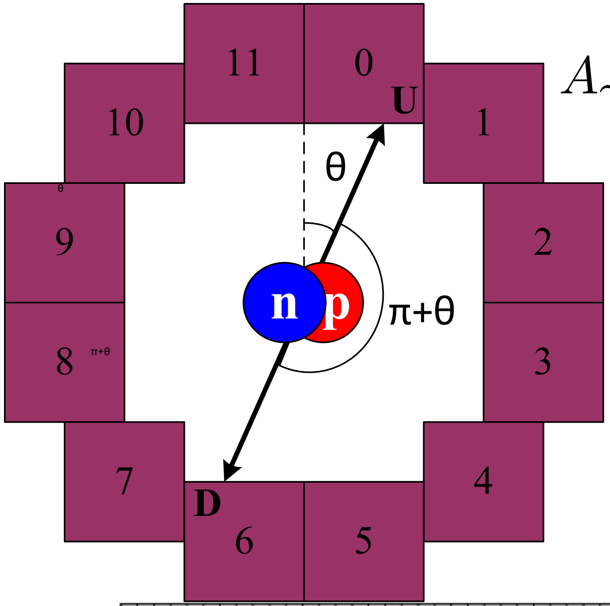
RF Spin Rotator

LH_2 Target

Gamma Detectors

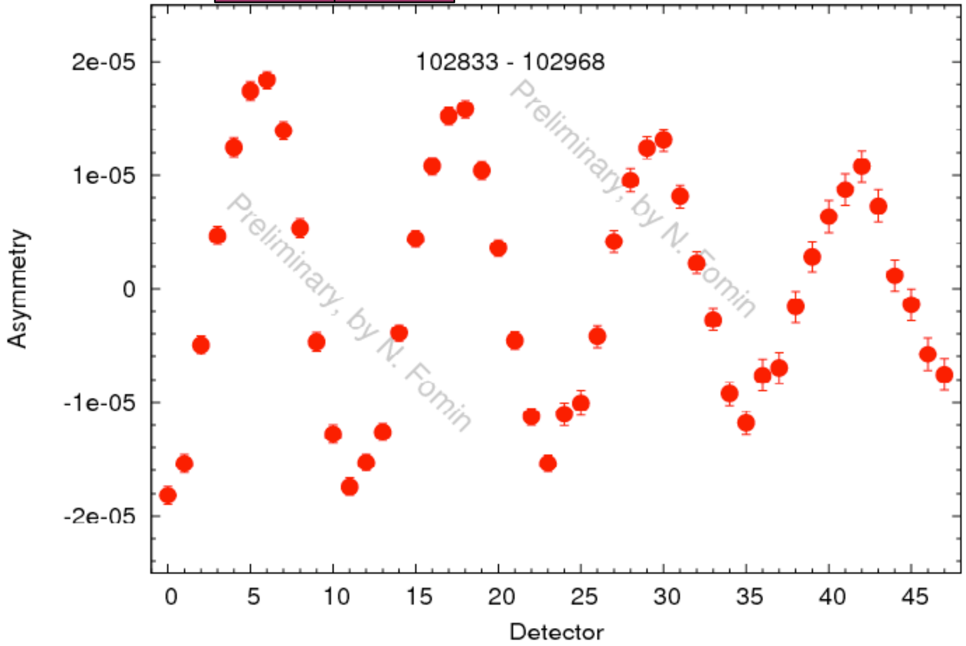
NPDGamma Apparatus at SNS

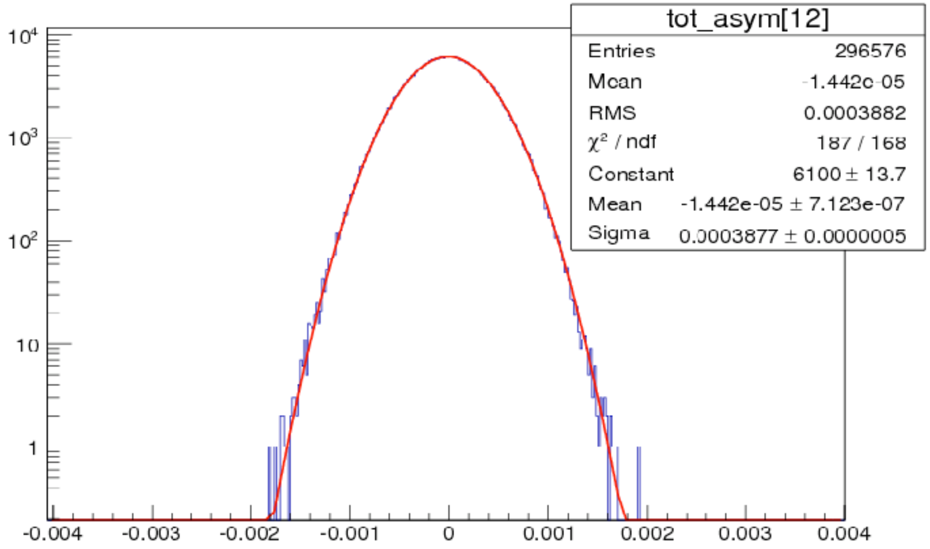
PV asymmetry in 35Cl



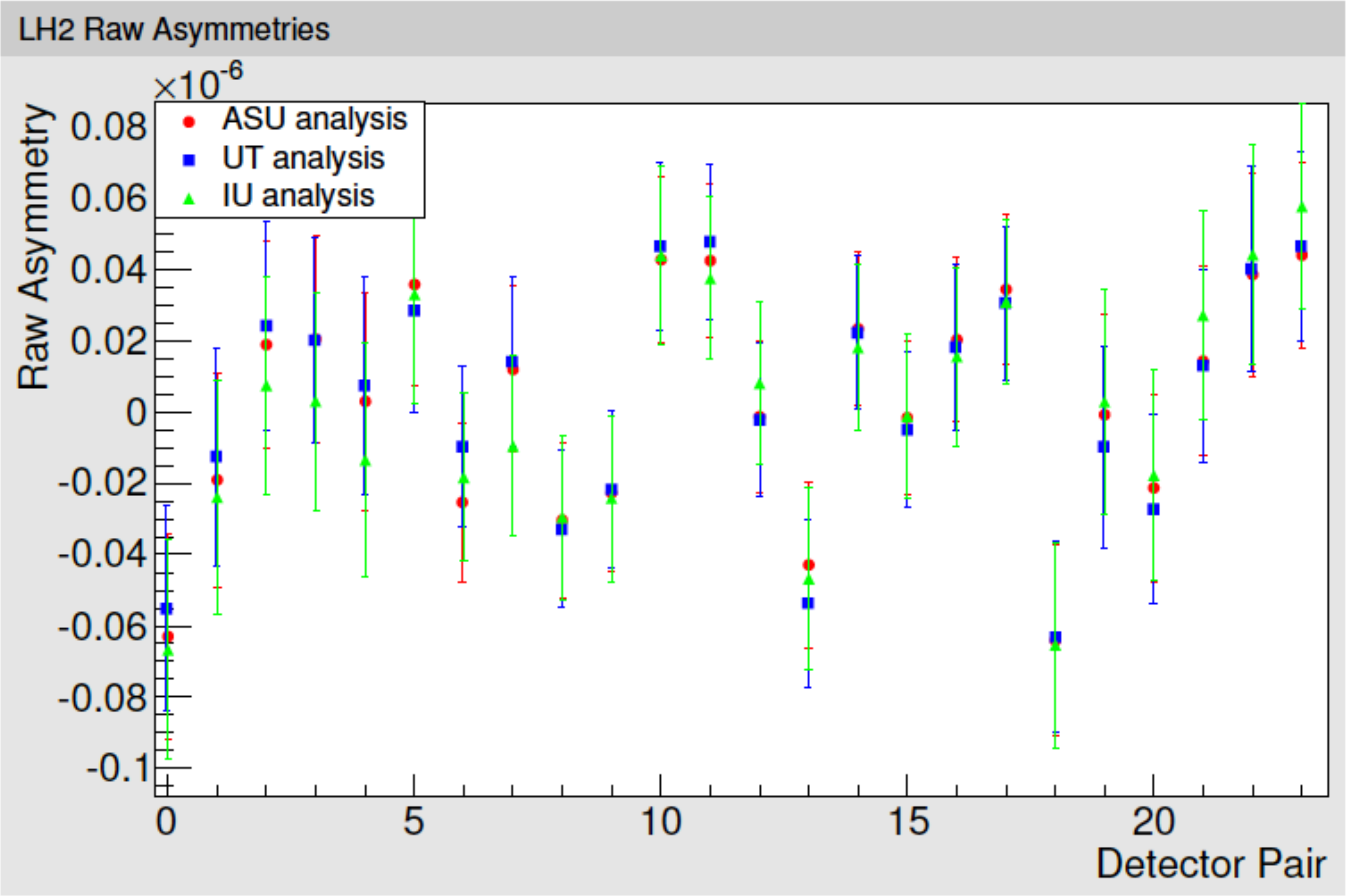
$$A_\gamma P_N cos(\theta) = \frac{[N(\theta) - N(\theta+\pi)]_\uparrow - [N(\theta) - N(\theta+\pi)]_\downarrow}{[N(\theta) - N(\theta+\pi)]_\uparrow + [N(\theta) - N(\theta+\pi)]_\downarrow}$$

Measurement	Asymmetry (x10^{-6})
LANL	-29.1 ± 6.7
Leningrad	-27.8 ± 4.9
ILL	-21.2 ± 1.72
SNS (Current result)	-25.9 ± 0.6

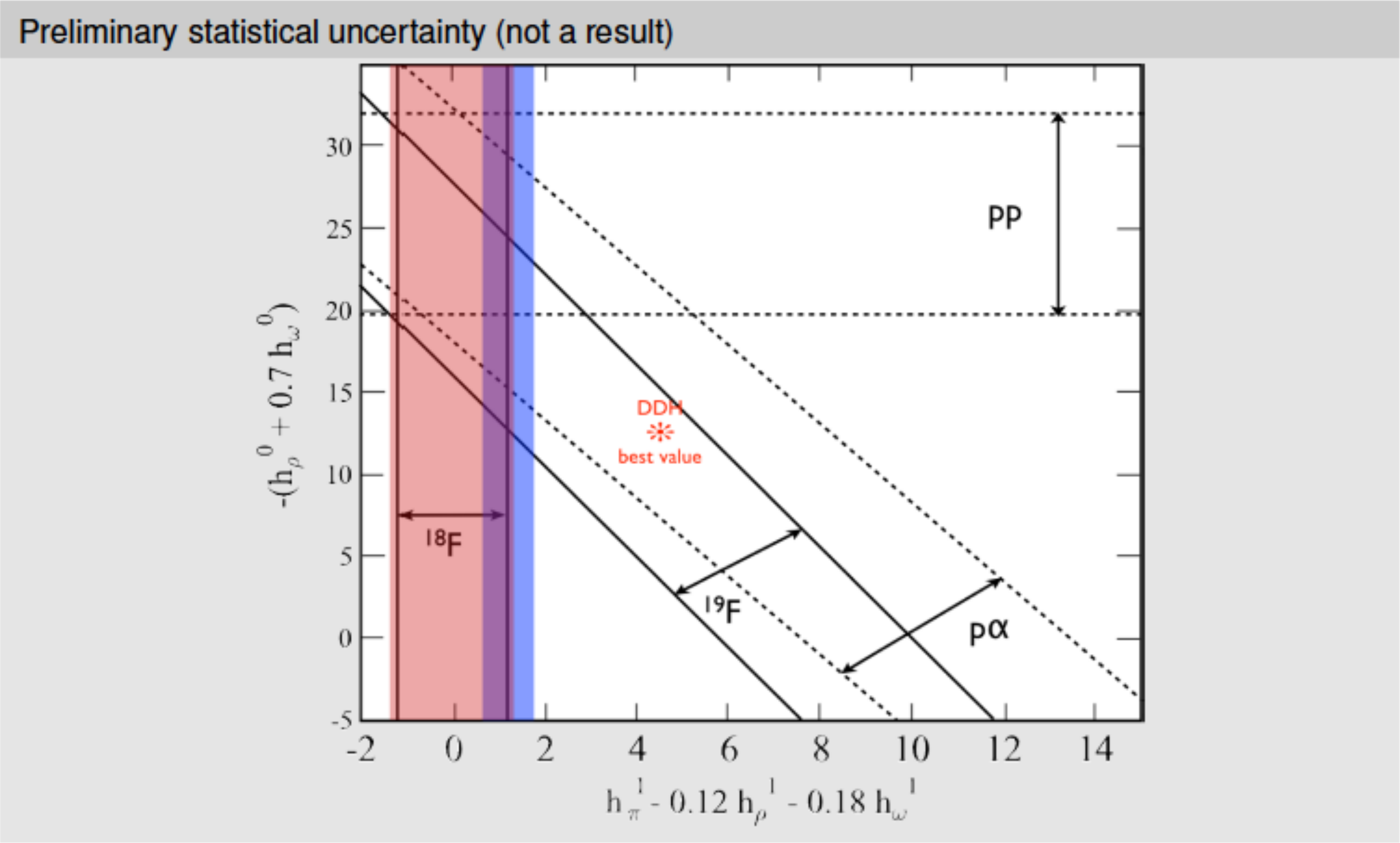




Hydrogen: Analyses of Different Runs

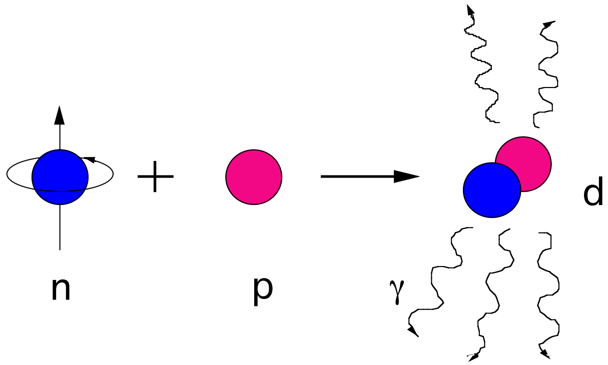


Constraint on Weak Pion Coupling

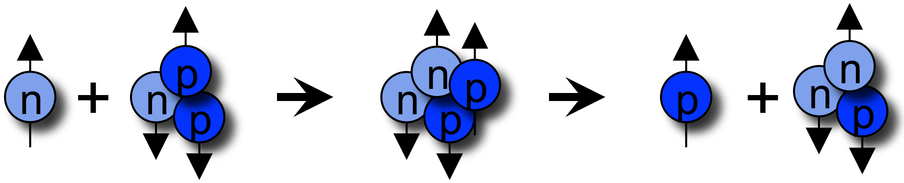


Official collaboration statement: “asymmetry is small, the stat. error is ~13 ppb, negligible sys error

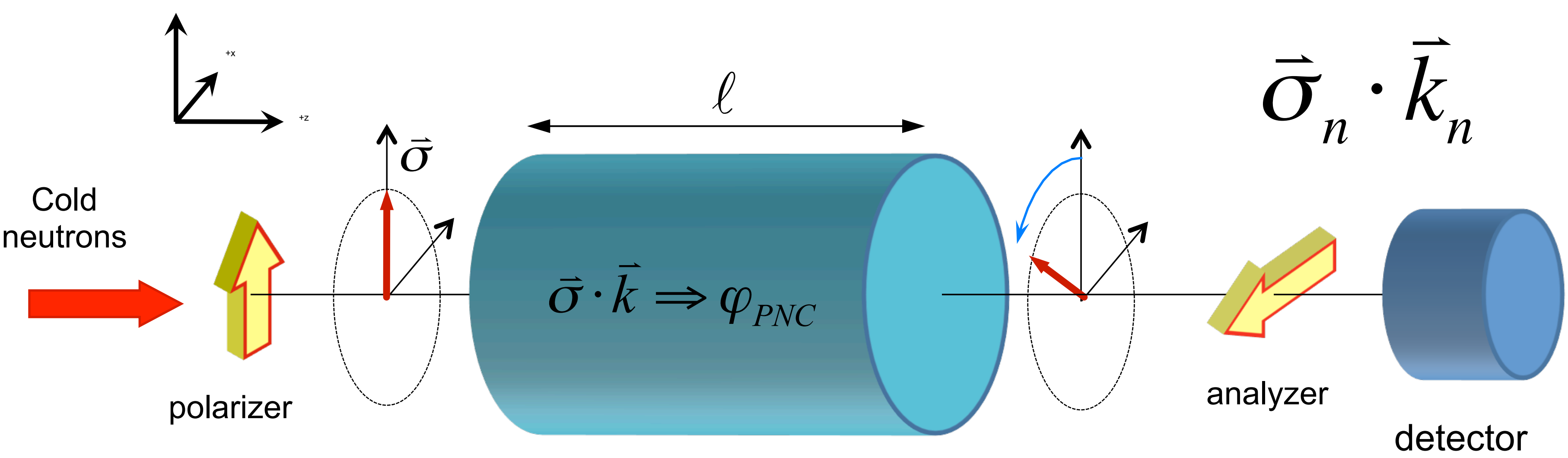
P-odd Observables: n-p, n-3He, and n-4He



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

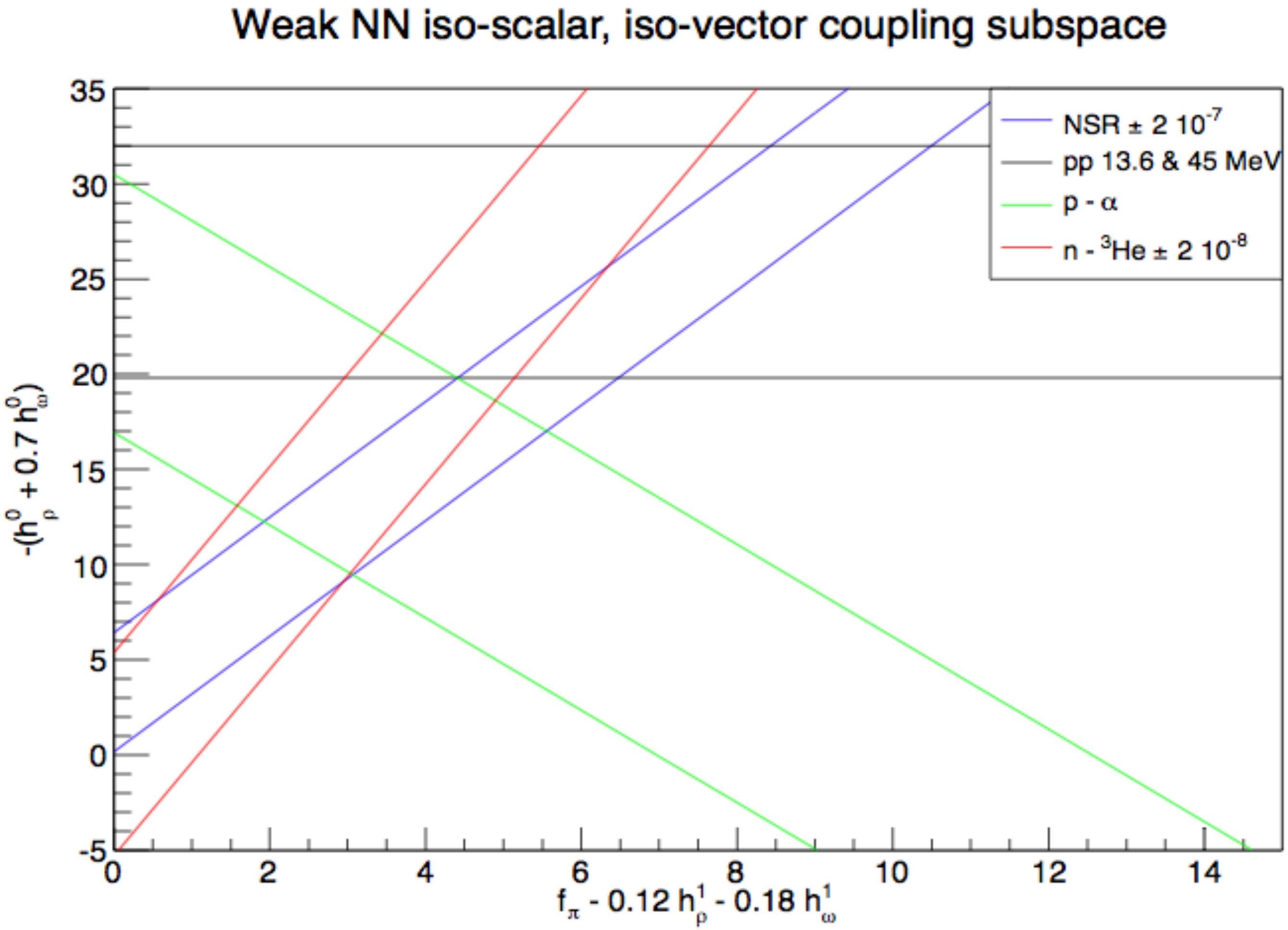


$$\vec{\sigma}_n \cdot \vec{k}_p$$



$$\vec{\sigma}_n \cdot \vec{k}_n$$

Constraints from n-3He and n-4He experiments



Will be orthogonal to existing constraints from proton experiments (p-alpha)

Can be used to determine other NN weak couplings

The n3He Collaboration

- Spokespersons

D. Bowman, M. Gericke, C. Crawford

- Local Project Manager

S. Penttila

- Project Engineer

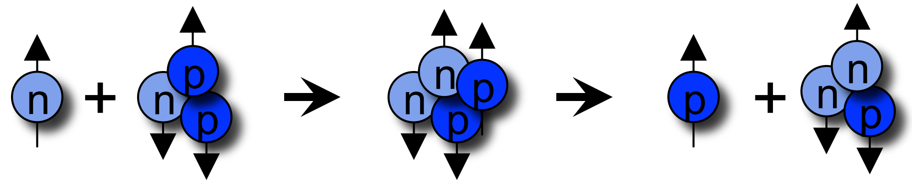
Jack Thomison

- Work Subpackage Leaders

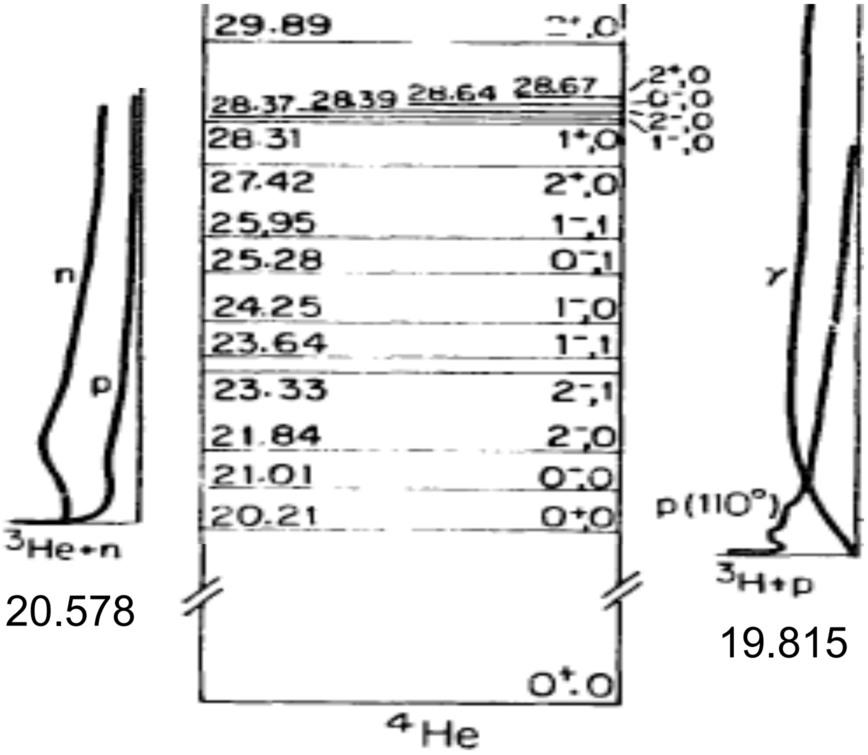
G. Greene	Neutronics
L. Barrón	Solenoid
C. Crawford	Spin rotator
M. Gericke	Target / detector
D. Bowman	Preamplifiers
C. Crawford	Data acquisition
N. Fomin	Online analysis
J. Hamblen	Integration
D. Bowman	Commissioning

Institution	Researcher	Category	2014 Effort
Duke University, Triangle Universities Nuclear Laboratory			
	Pil-Neo Seo	Research Staff	10
Istituto Nazionale di Fisica Nucleare, Sezione di Pisa			
	Michele Viviani	Research Staff	15
Oak Ridge National Laboratory			
	Seppo Penttilä	Research Staff	70
	David Bowman	Research Staff	70
	Paul Mueller	Research Staff	50
	Jack Thomison	Engineer	50
	Vince Cianciolo	Research Staff	10
University of Kentucky			
	Chris Crawford	Faculty	50
	Kabir Latiful	Grad Student	100
Western Kentucky University			
	Ivan Novikov	Faculty	70
University of Manitoba			
	Michael Gericke	Faculty	50
	Mark McCrea	Grad Student	70
	Carlos Olguin	Grad Student	100
Universidad Nacional Autónoma de México			
	Libertad Baron	Faculty	50
	Andrés Ramírez Morales	Grad Student	100
University of New Hampshire			
	John Calarco	Faculty	50
University of South Carolina			
	Vladimir Gudkov	Faculty	5
	Matthias Schindler	Faculty	5
Univeristy of Tennessee			
`	Geoff Greene	Faculty	30
	Nadia Fomin	Faculty	30
	Irakli Garishvili	Postdoc	50
	Chris Hayes	Grad Student	100
	Chris Coppola	Grad Stduent	100
Univeristy of Tennessee at Chattanooga			
`	Josh Hamblen	Faculty	75
	Caleb Wickersham	Undergraduate	100
University of Virginia			
	S. Baessler	Faculty	10

n-^{3}He PV asymmetry at SNS

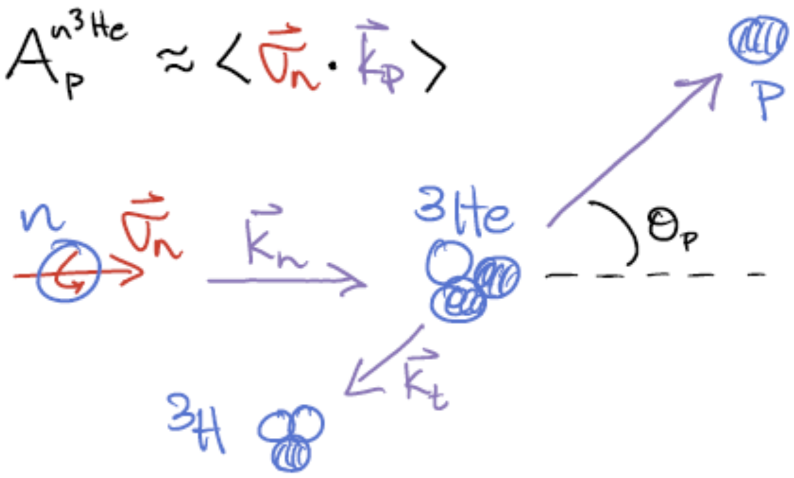


$$\vec{n} + {}^3\mathrm{He} \rightarrow \mathrm{p} + \mathrm{t} + 764\ \mathrm{keV}$$



Tilley, Weller, Hale, Nucl. Phys. A541, 1 (1992)

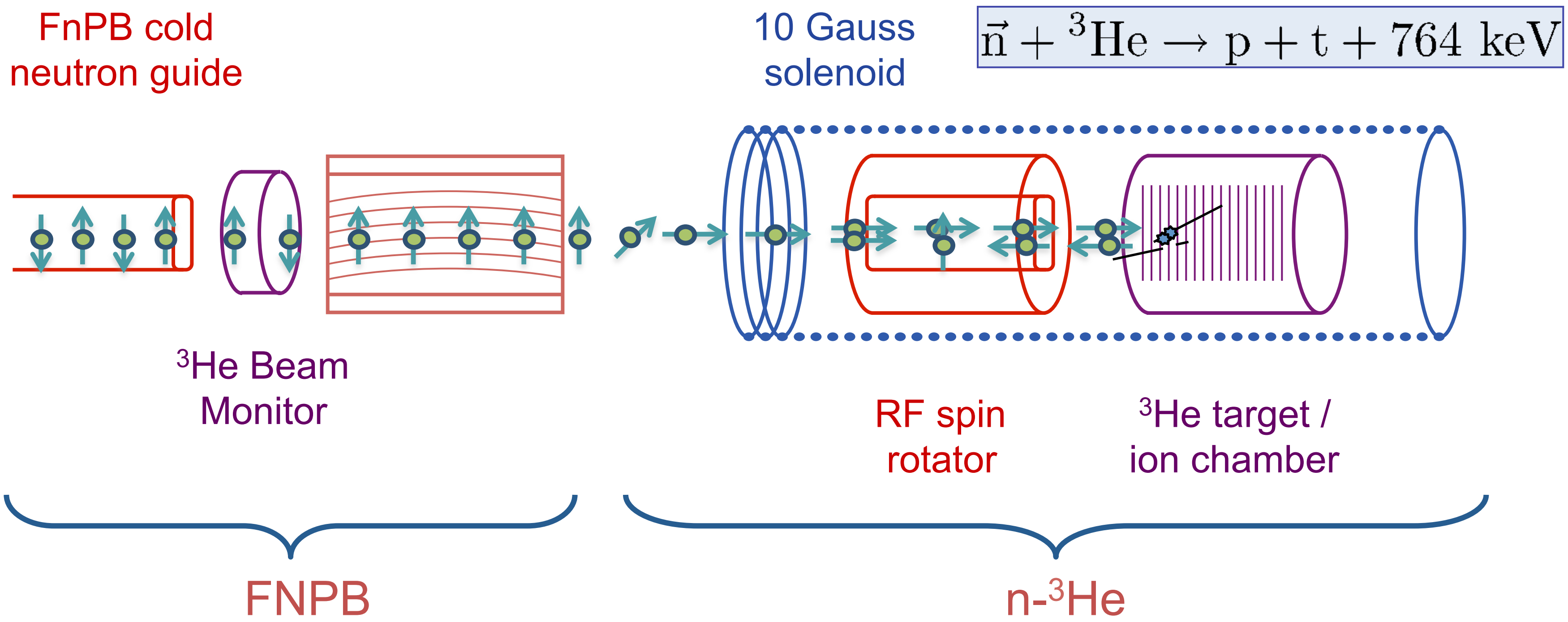
PV observables:



$A_p^{n^3He} \approx \langle \vec{\sigma}_n \cdot \vec{k}_p \rangle$

- Sensitive to isoscalar couplings (ΔI=0) of the hadronic weak interaction
- Complementary to NPDGamma (ΔI=1)
- “large” asymmetry predicted from DDH best values: A = 1.15 x 10^{-7} (Viviani, et al., PRC 82, 044001 (2010),)
- GOAL: measure asymmetry to ~2 x 10^{-8}

Experimental Setup



FnPB cold neutron guide

10 Gauss solenoid

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

^{3}He Beam Monitor

RF spin rotator

^{3}He target / ion chamber

FNPB

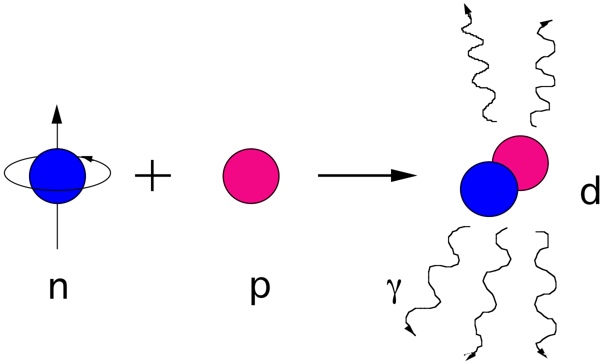
n-^{3}He

- Measure PV spin asymmetry to 2x10^{-8}
- Longitudinal holding field – suppressing PC nuclear asymmetry:

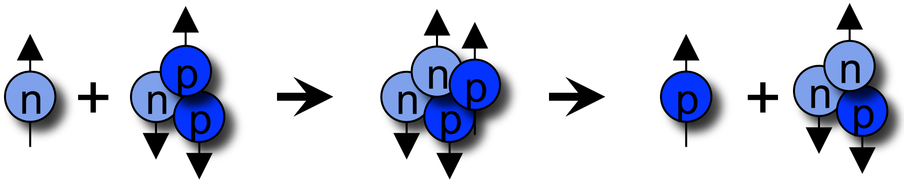
  (1.7x10^{-6} $\propto s_n \bullet k_n \times k_p$ (Hale) suppressed by two small angles
- RF spin flipper – negligible spin-dependence of neutron velocity
- ^{3}He ion chamber – both target and detector

STATUS: on the beamline at NIST

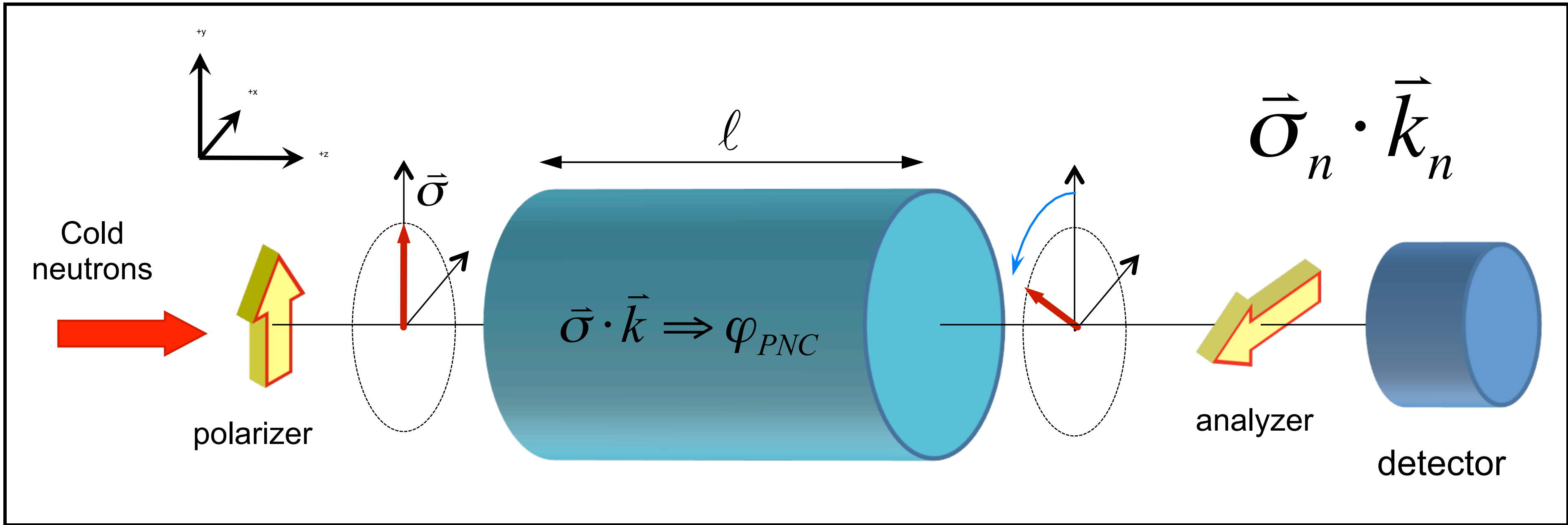
P-odd Observables: n-p, n-3He, and n-4He



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



$$\vec{\sigma}_n \cdot \vec{k}_p$$



$$\vec{\sigma}_n \cdot \vec{k}_n$$

NSR Collaboration

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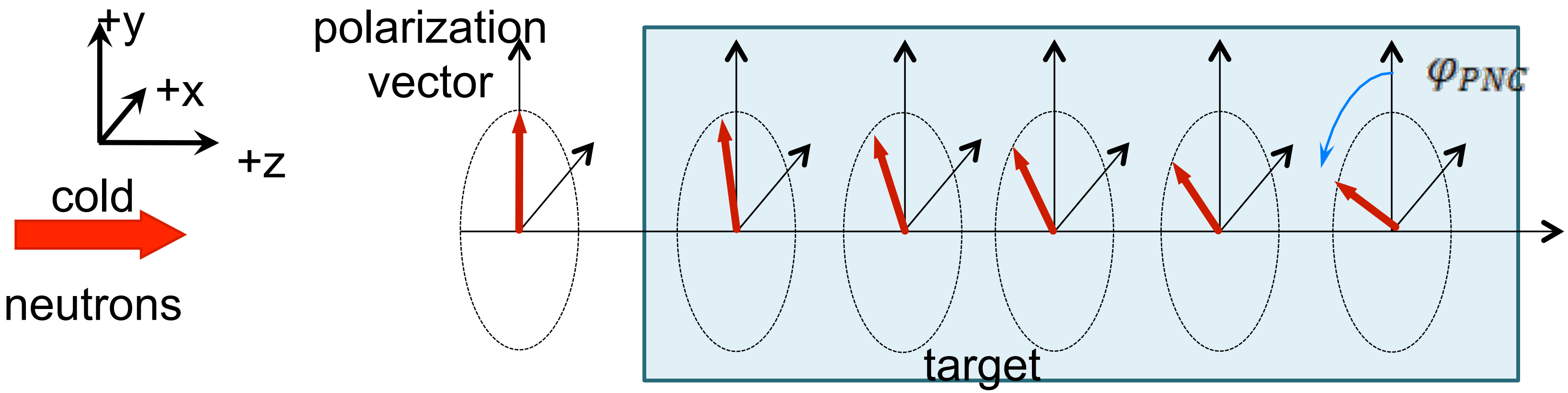
S. van Sciver

A Parity-Violating Observable: Neutron Spin Rotation



$$f(0) = f_{PC} + f_{PNC}(\vec{\sigma}\cdot\vec{k})$$

neutron index of refraction in target dependent on incident neutron helicity

transversely-polarized neutrons corkscrew due to the NN weak interaction

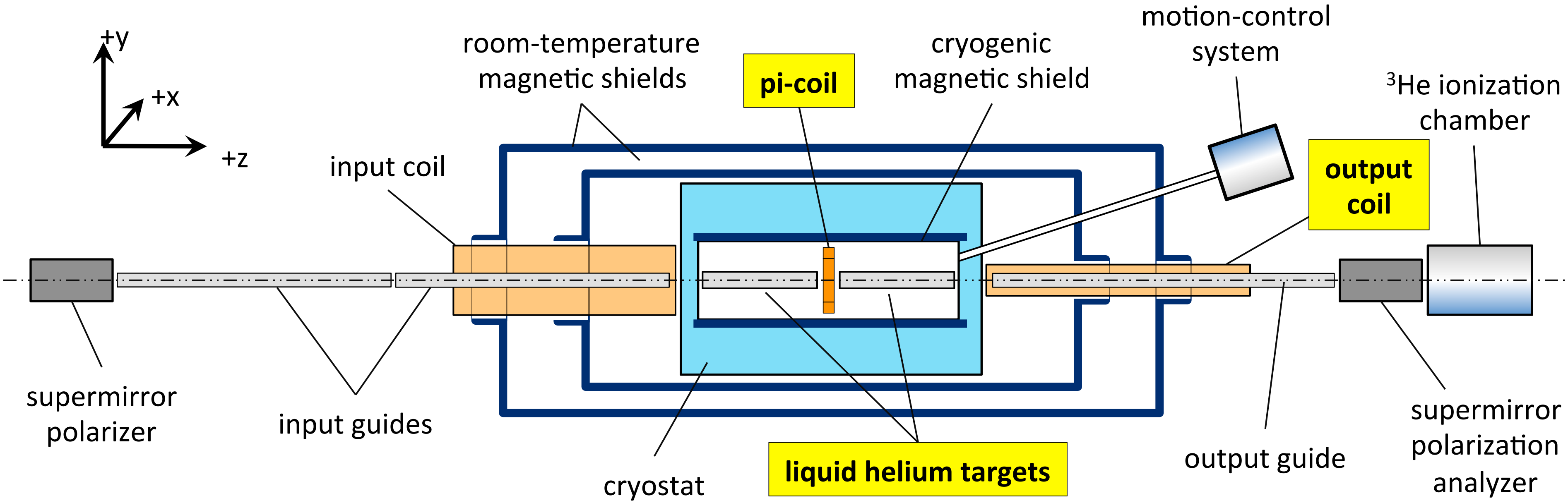
$$|+y\rangle = \frac{1}{\sqrt{2}}(|+z\rangle + |-z\rangle) \Rightarrow \frac{1}{\sqrt{2}}\left(e^{-i(\phi_{PC}+\phi_{PNC})}|+z\rangle + e^{-i(\phi_{PC}-\phi_{PNC})}|-z\rangle\right)$$

PNC spin rotation angle is independent of incident neutron energy

$$\varphi_{PNC} = \phi_{+} - \phi_{-} = 2\phi_{PNC} = 4\pi l\rho f_{PNC}$$

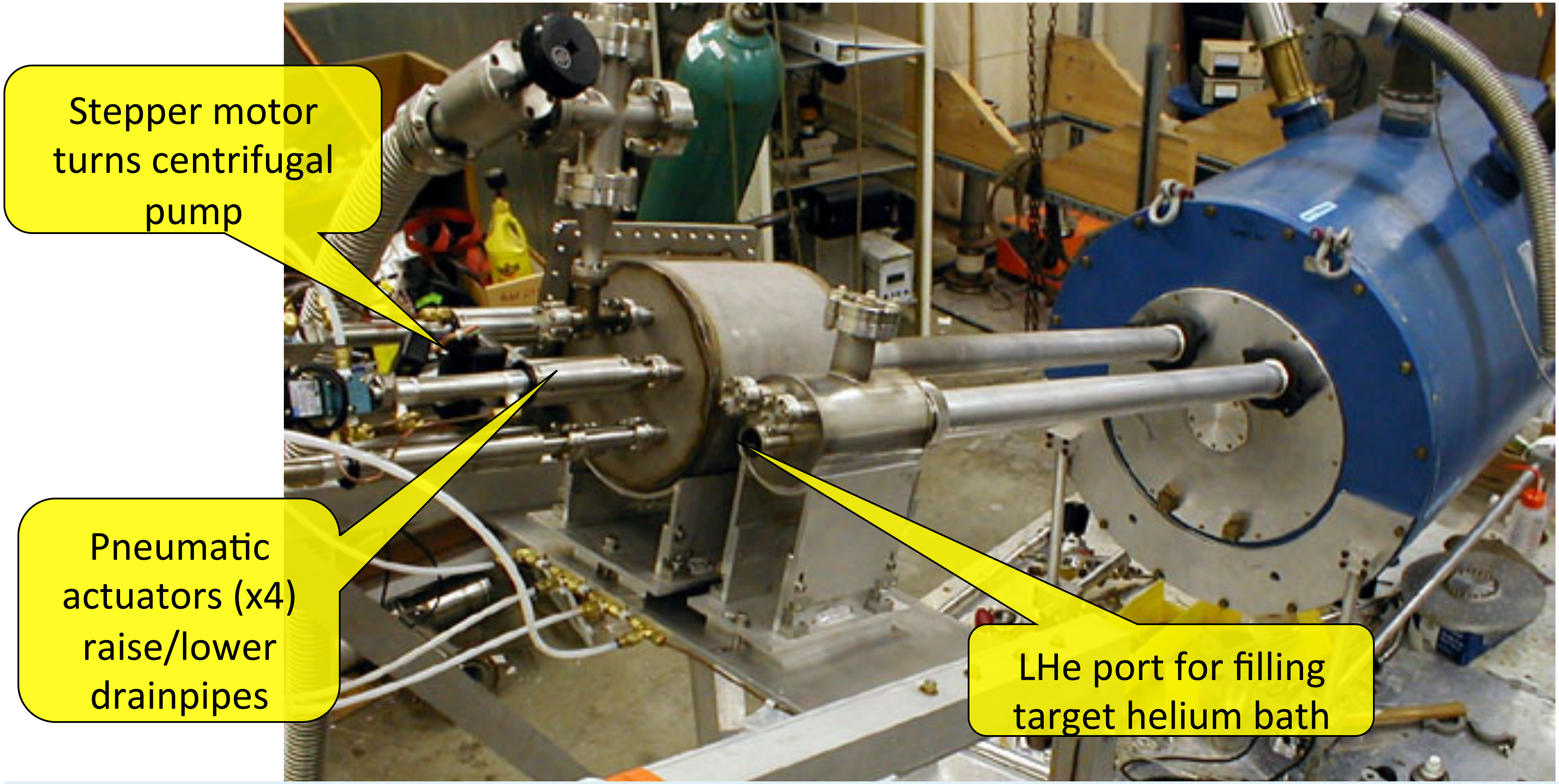
Parity Violation in Neutron Spin Rotation

Apparatus measures the horizontal component of neutron spin generated in the liquid target starting from a vertically-polarized beam



$$|\uparrow>=\frac{1}{\sqrt{2}}(|+>+|->)\rightarrow\frac{1}{\sqrt{2}}(e^{i\phi_+}|+>+e^{i\phi_-}|->)$$

Liquid Helium Cryostat and Motion Control



Stepper motor turns centrifugal pump

Pneumatic actuators (x4) raise/lower drainpipes

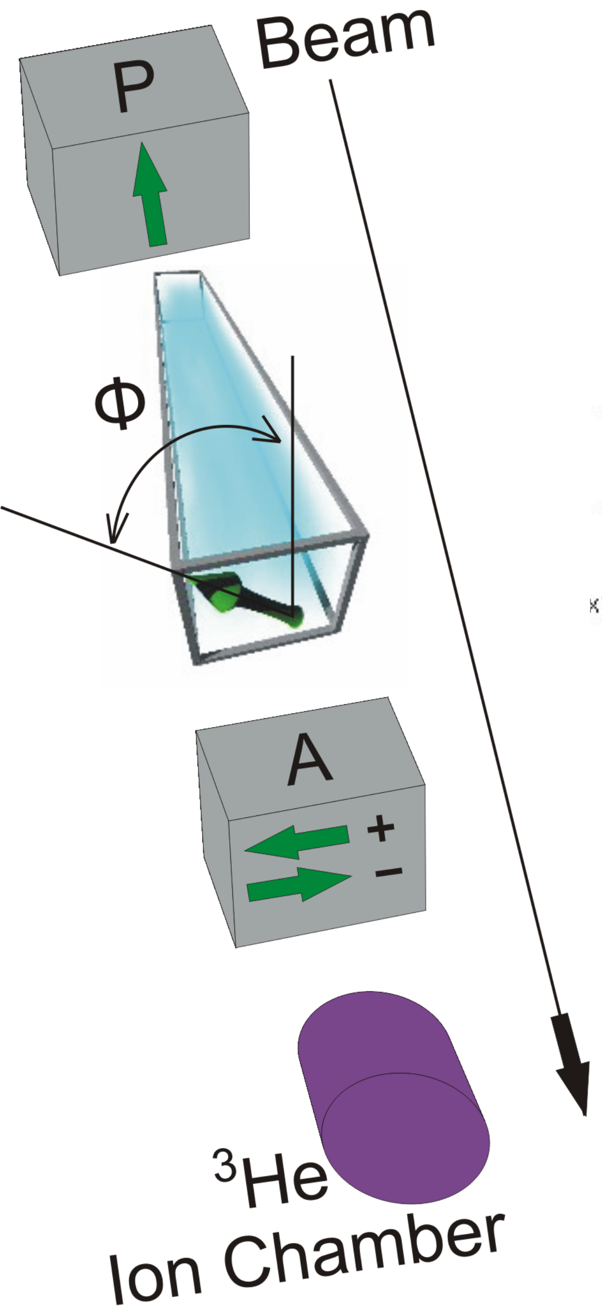
LHe port for filling target helium bath

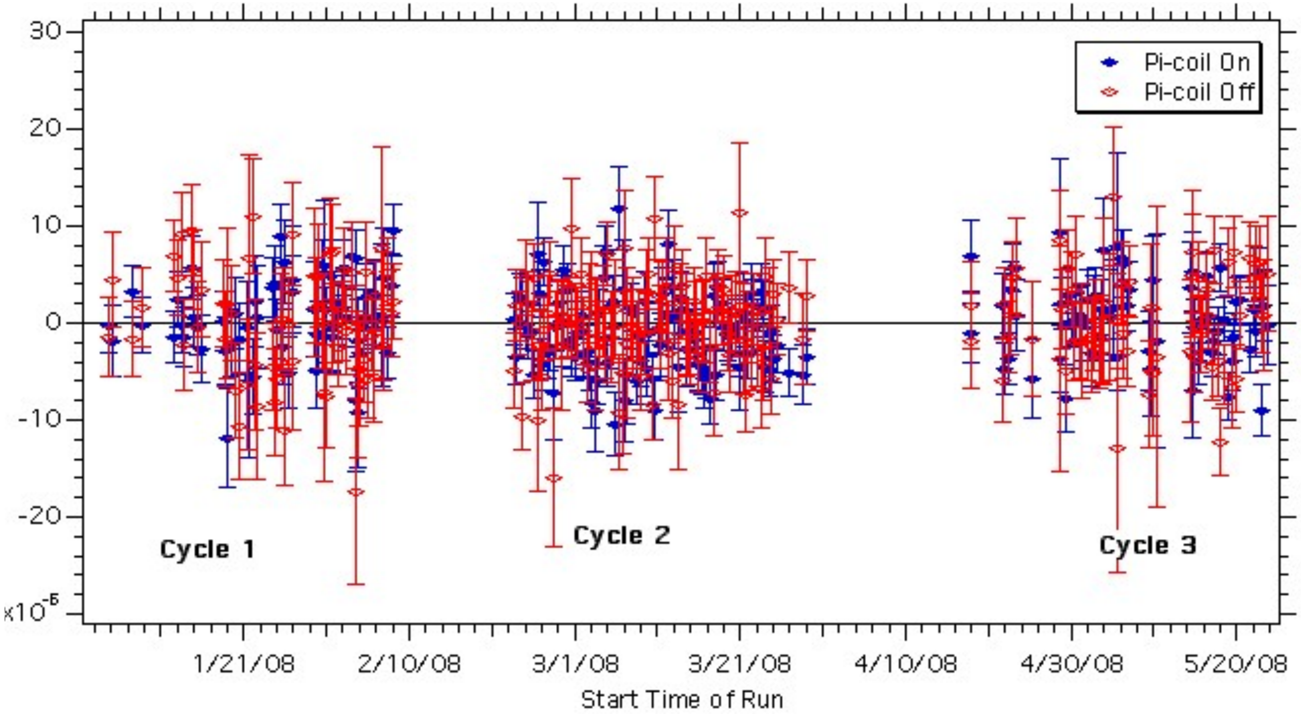
- Nonmagnetic movement of liquid helium.

- Cryogenic target of 4K helium, volume~10 liters

C. D. Bass et al, Nucl. Inst. Meth. A612, 69-82 (2009).

Neutron Spin Rotation in n+4He





Transversely polarized neutrons corkscrew due to weak interaction

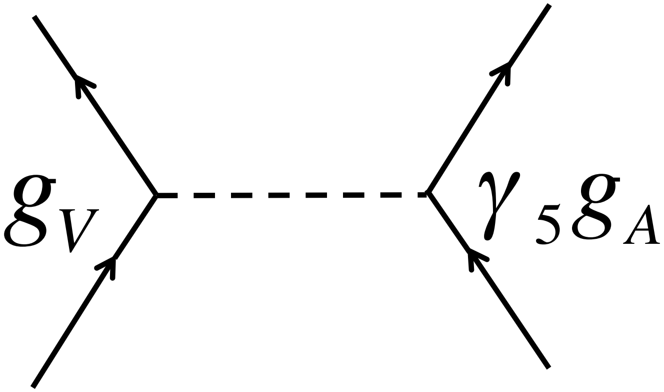
ϕ_{PNC}= [+1.7 ± 9.1 (stat) ±1.4 (sys)] x 10^{-7} rad/m

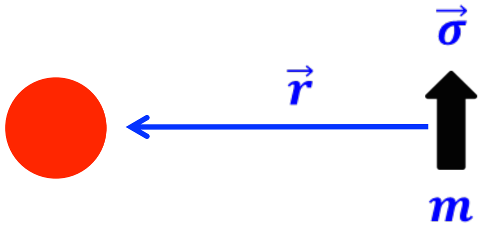
W. M. Snow et al., Phys. Rev. C83, 022501(R) (2011).

PLAN: experiment to be repeated at NIST, ~1 x 10^{-7} rad/m goal

Exotic Physics: Example of a nonstandard P-odd interaction from spin 1 boson exchange:

[Dobrescu/Mocioiu 06, general construction of interaction between nonrelativistic fermions]

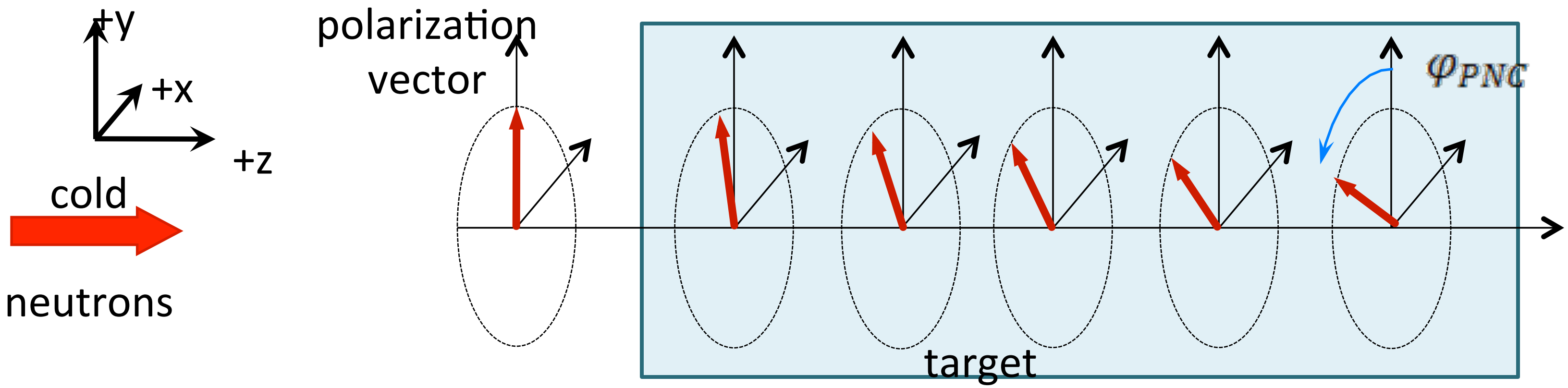




$$V(\vec{\sigma},\vec{r},\vec{v}) = \frac{\hbar}{8\pi mc^2} g_A g_V \vec{\sigma} \bullet \vec{v} \frac{1}{r} e^{-\frac{r}{\lambda}}$$

- Induces an interaction between polarized and unpolarized matter
- Violates P symmetry
- Not very well constrained over "mesoscopic" ranges(millimeters to microns)
- Best investigated using a beam of polarized particles

Neutron Spin Rotation:
A Parity-Odd Observable in Neutron Optics



$$f(0) = f_{strong} + f_{P-odd}(\vec{\sigma}\cdot\vec{p})$$

$$f_{P-odd} = g_A g_V \lambda^2$$

Forward scattering amplitude of neutron in matter sensitive to all neutron-matter interactions

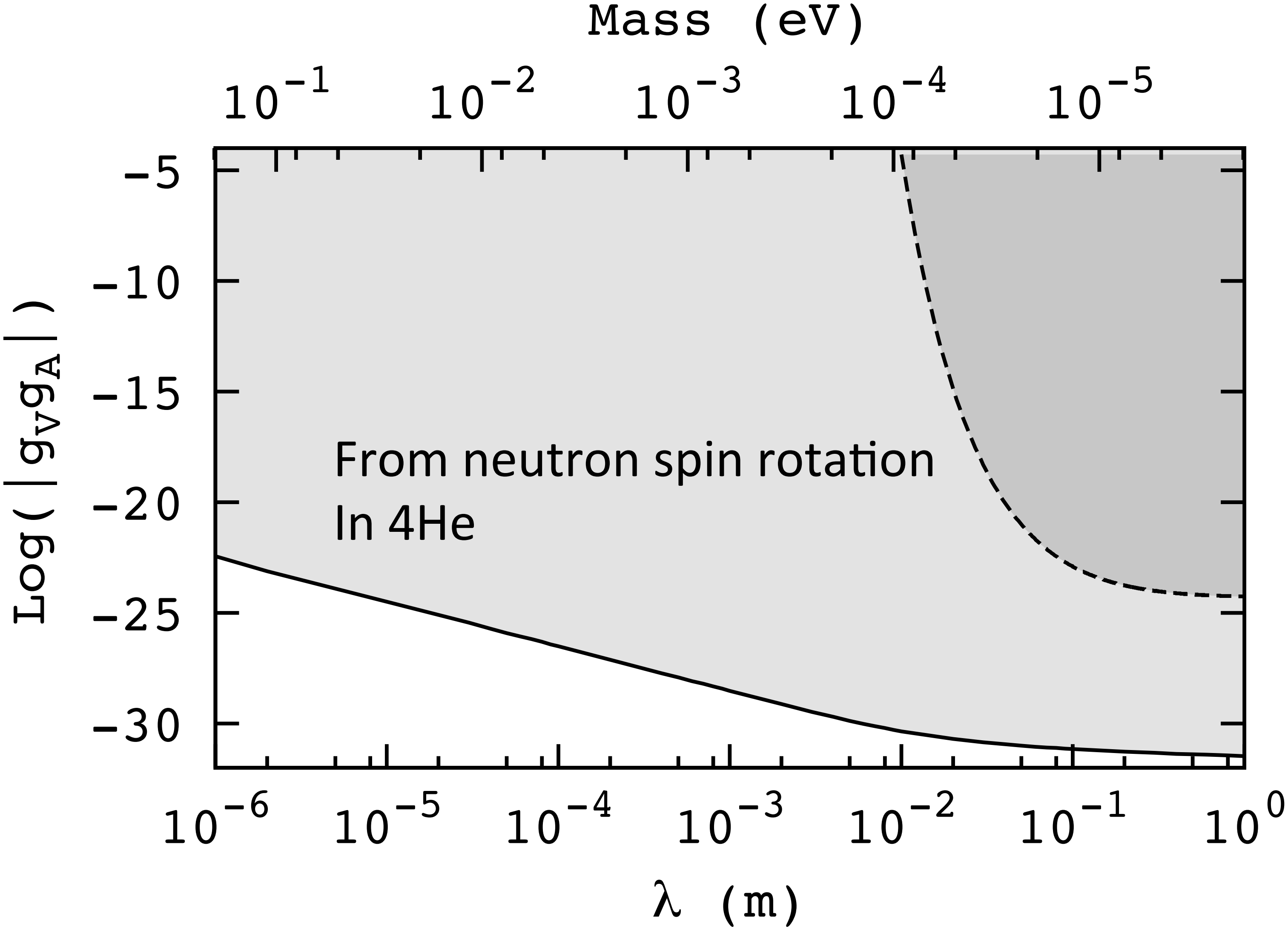
$$\phi_{\pm} = \phi_{strong} \pm \phi_{P-odd}$$

Parity violation gives helicity-dependent phase shift and therefore rotation of plane of polarization vector

$$\frac{d\phi_{P-odd}}{dL} = 4 g_A g_V \rho \lambda^2$$

An upper bound on $f_{P\text{-odd}}$ places a constraint on possible new P-odd interactions between nucleons over a broad set of distance scales

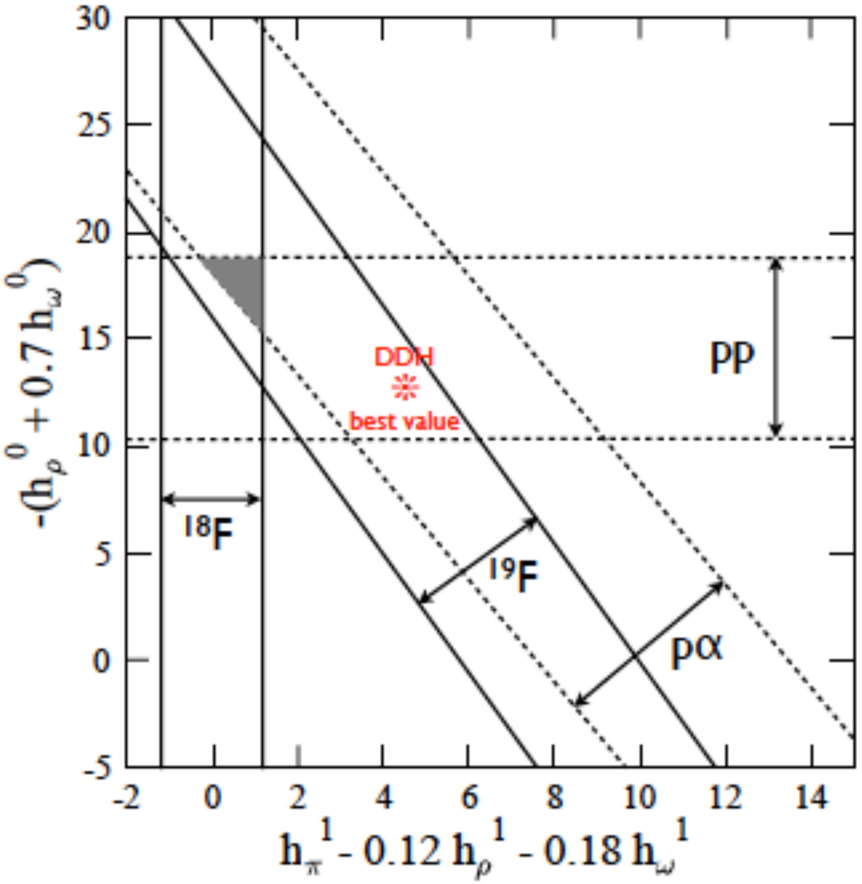
Constraints on exotic V-A interactions



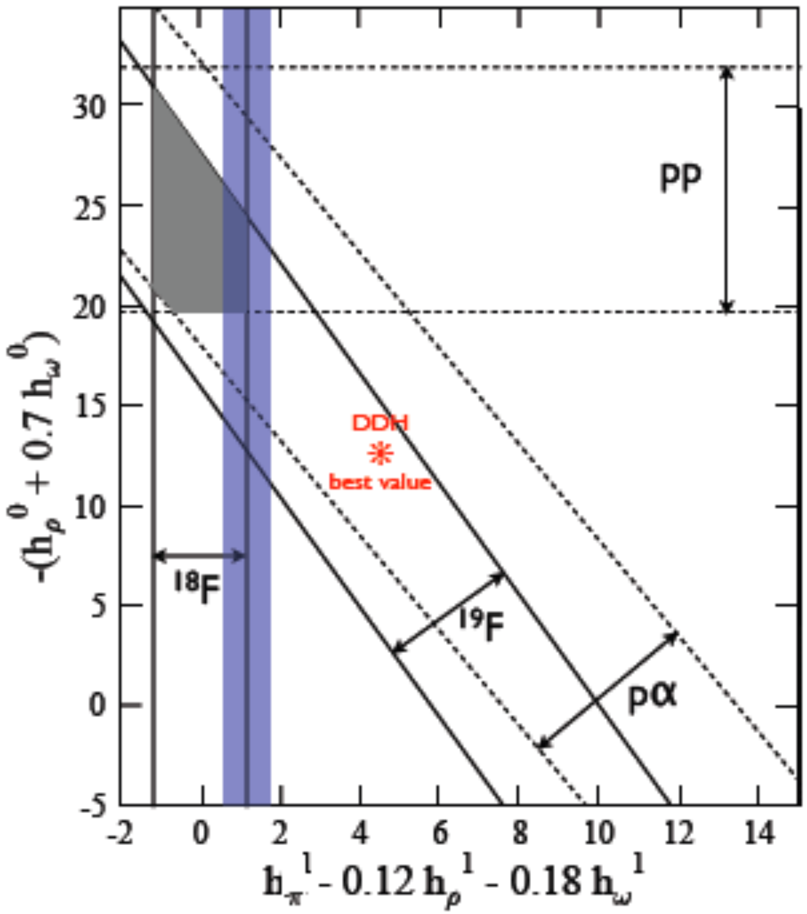
H. Yan, and W. M. Snow, PRL 110, 082003 (2013).
Also: much stronger constraints now above ~1 cm from Eot_Wash+
other data [E. G. Adelberger and T. A. Wagner, PRD 88, 031101 (2013)]

Haxton and Holstein 2013: reanalysis of pp parity violation

Corrected pp analysis for treatment of strong NN couplings
Result: isoscalar linear combination goes up by ~50%

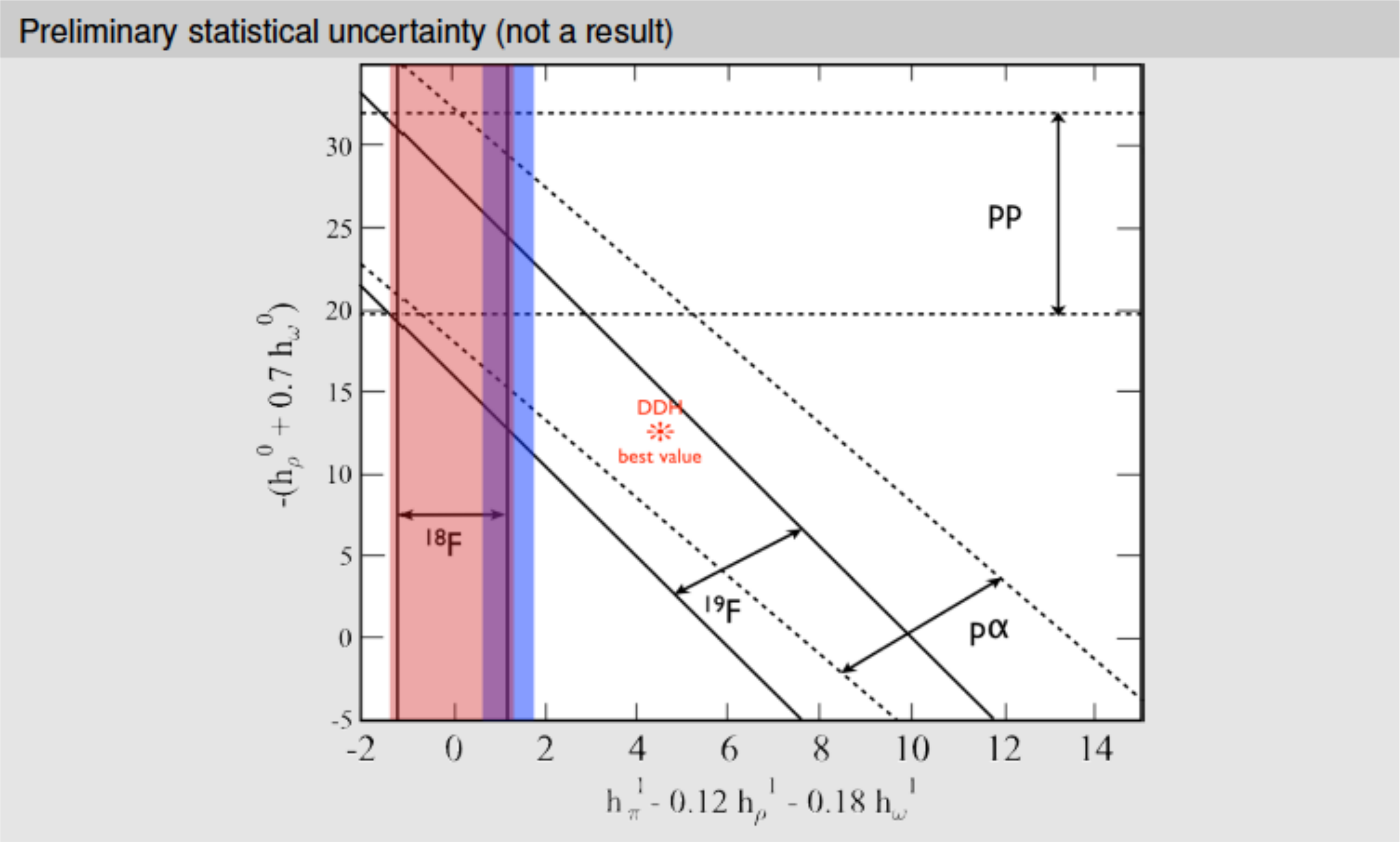


Haxton/Wieman ~2001



Haxton/Holstein 2013

Information on Weak Couplings



Preliminary statistical uncertainty (not a result)

All data says weak pion exchange is ~ factor of 10 smaller than ΔI=0 NN weak amplitudes.

NN Weak Amplitudes in $1/N_c$ Expansion of QCD

Large N expansion of QCD: works well for many low E observables (including strong NN couplings): what about weak NN couplings?

$$h^0_\rho \sim \sqrt{N_c}\,,\ \ h^2_\rho \sim \sqrt{N_c}\,,$$
$$\frac{h^{1'}_\rho}{\sin^2\theta_W} \lesssim \sqrt{N_c}\,,\ \ \frac{h^1_\omega}{\sin^2\theta_W} \sim \sqrt{N_c}\,,$$
$$\frac{h^1_\rho}{\sin^2\theta_W} \lesssim \frac{1}{\sqrt{N_c}}\,,\ \ \frac{h^1_\pi}{\sin^2\theta_W} \lesssim \frac{1}{\sqrt{N_c}}\,,\ \ h^0_\omega \sim \frac{1}{\sqrt{N_c}}\,, \quad (8)$$

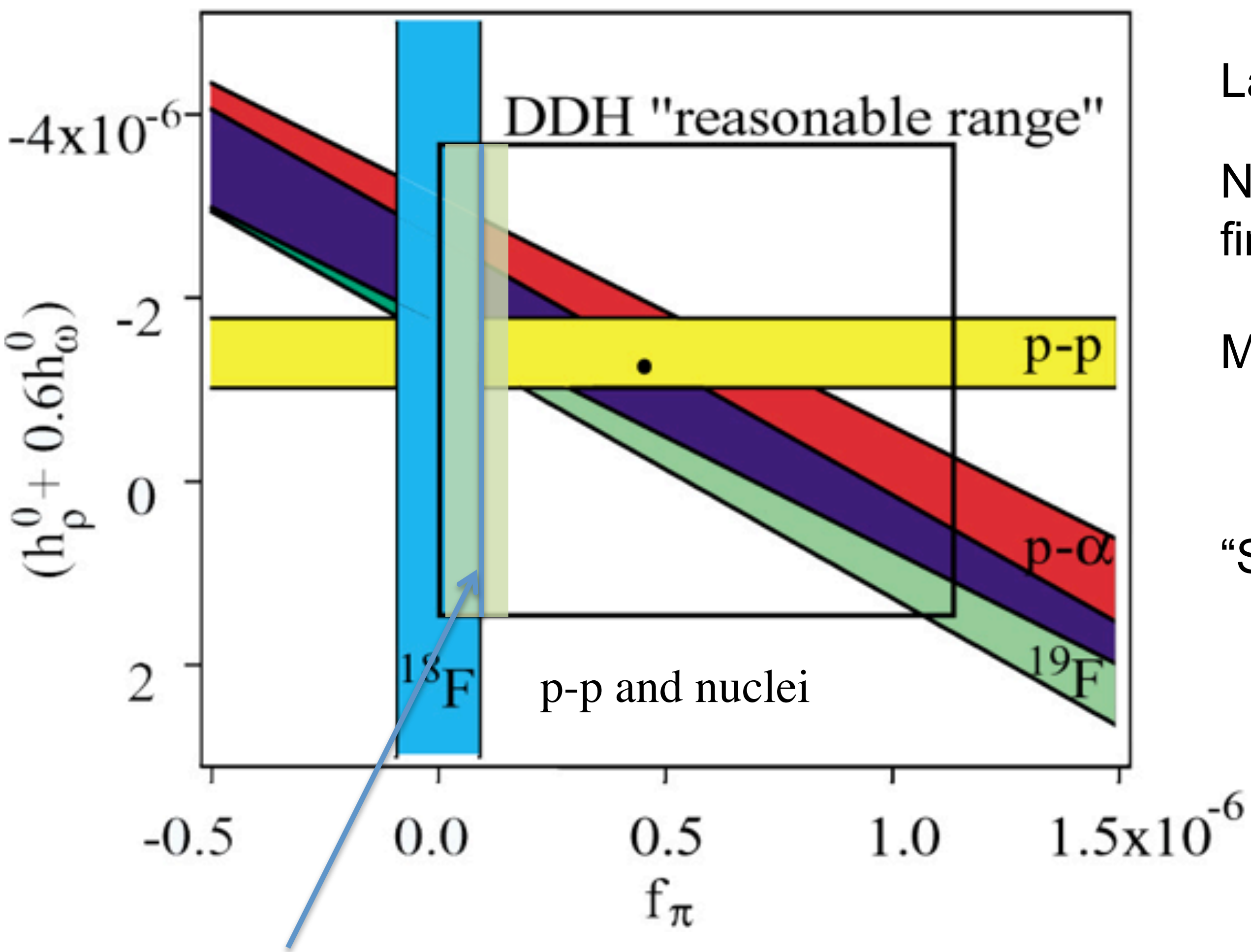
Large N expansion of QCD Implies that weak pion coupling expected to be smaller than isoscalar rho coupling by ~

$$\sin^2\theta_W / N_c \sim 1/10$$

Looks like it agrees with experimental data! Explains why weak pion coupling has not yet been seen in experiment. First explanation of this long-suspected result from a model with direct connection to QCD

Phillips, Samart, Schat, arXiv:1410.1157, submitted to PRL (2014)

NN weak theory: progress from the lattice!



Lattice gauge theory:
gearing up to calculate
NN weak amplitudes from
first principles.

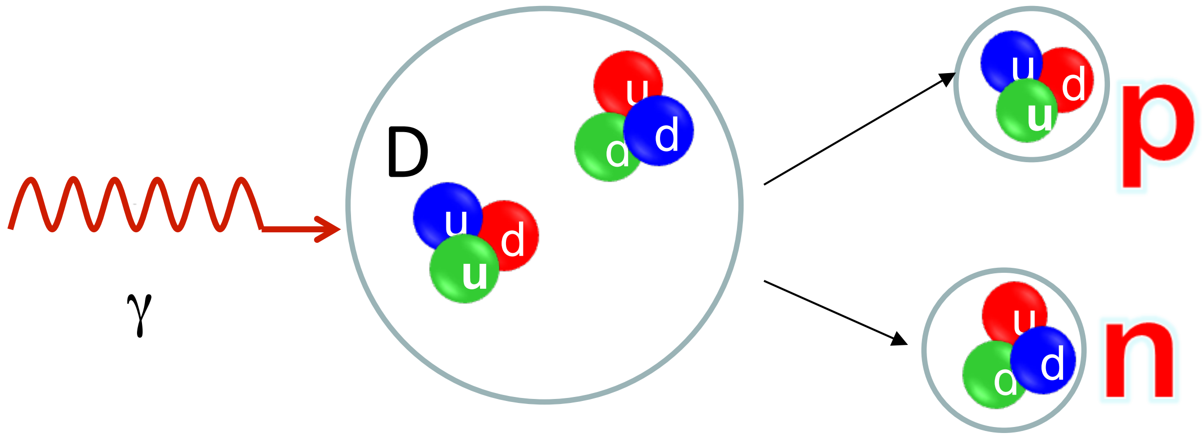
Major bechmark goal for
high-performance
computing development

"Spin physics meets
computational physics"

Wasem, Phys. Rev. C **85** (2012) 022501 *1st Lattice QCD result for NN weak! (heavy pion mass)*

CalLat collaboration goals (using exoscale computing): calculate from the Standard Model using the lattice:
(1) ΔI=1 weak pion exchange, (2) ΔI=2 NN weak amplitude

Parity Violation in deuteron photodisintegration



Parity violation leads to helicity dependence of photodisintegration cross section

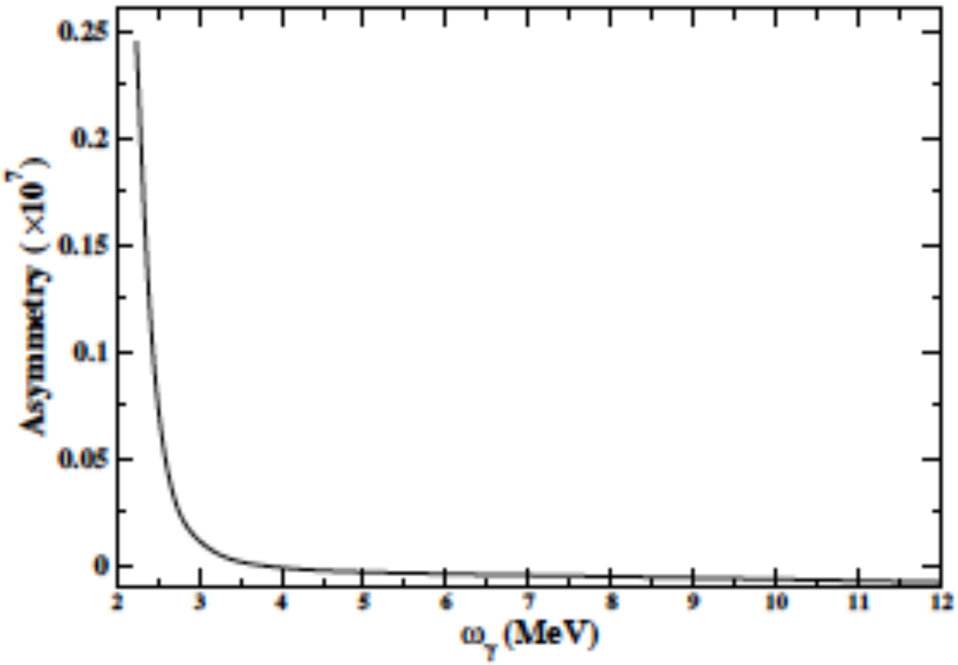
The neutron can escape the target and its intensity can be detected in current mode

Signal is helicity dependence of neutron current from target

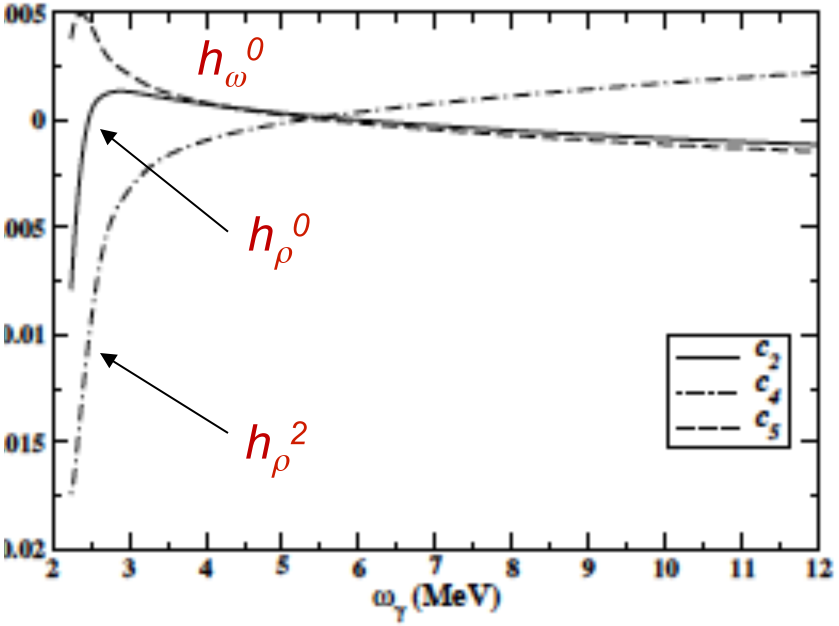
Detect also scattered and transmitted gammas for normalization/systematics effect suppression

Need to observe >~10^{16} γs to be sensitive to a 1E-8 asymmetry.

PV D Photodisintegration in DDH and EFT



PV asymmetry in DDH model



Relative contributions of h_ρ^0, h_ω^0, *and* h_ρ^2 with gamma energy

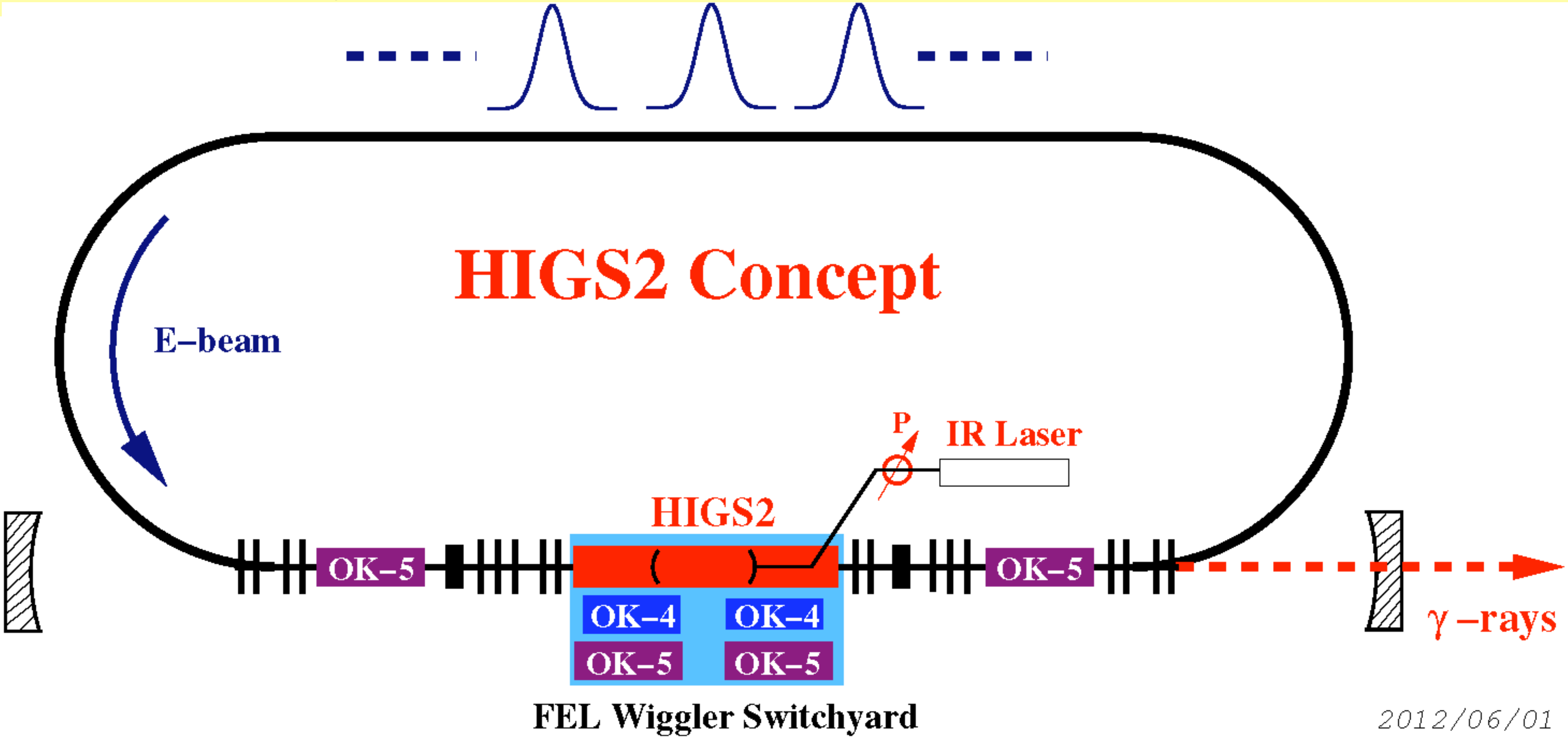
A_γ *(threshold)=* $-8.44\, h_\rho^0 + 3.63\, h_\omega^0 - 17.6\, h_\rho^2$

The only known P-odd NN observable
which is sensitive to ΔI=2 NN parity violation

ΔI=2 NN parity violation calculable
in lattice gauge theory (CalLat collaboration)

Liu/Hyun/Desplanques, arXiv:0403009

Parity Violation Experiments at HiGS2?



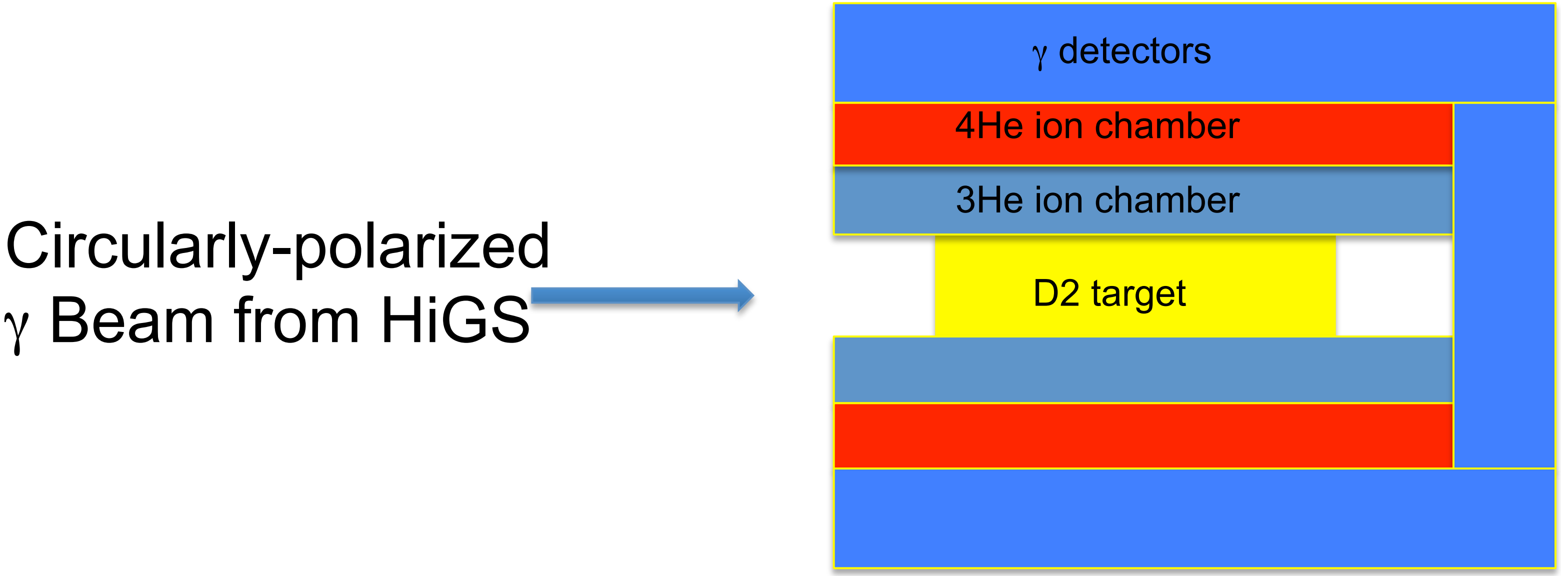
~10^{11} to 10^{12} polarized γ/sec (X100 increase in polarized gamma flux relative to HiGS1.)

Circularly polarized gammas (>~90%), fast (~100 Hz) gamma helicity reversal possible

Controlled beam phase space: ~1% energy resolution on gamma energy (2-12 MeV)

These are attractive features in principle for parity violation experiments

Concept of P-odd Deuteron Photodisintegration Expt.



The neutron can be moderated in the liquid deuterium target, escape with low energy (~10 meV), and be detected efficiently in current mode in a 3He/4He ion chamber

The transmitted and scattered γs can be measured using current-mode γ detectors located behind the 3He/4He ion chamber

Cylindrical symmetry of detector array to help suppress possible systematic errors

NN parity violation: theory summary

$\Delta I=1$ weak pion amplitude: FACTOR of 10 SMALLER than $\Delta I=0$ NN weak from both $1/N_c$ argument and preliminary pioneering lattice calculation.

$\Delta I=1$ weak pion amplitude and $\Delta I=2$ NN weak amplitude: can be calculated over the next few years using lattice gauge theory and high performance computing!

Combination of $1/N_c$ analysis, chiral effective theory, and lattice can PREDICT results for upcoming experiments in

n-3He parity violation
n-4He parity violation
γ-D P-odd photodisintegration

Success would represent a major milestone for our computational ability in nonperturbative strong interaction physics

NN parity violation: experiment summary

NPDGamma: on track to get ~13 ppb error on P-odd asymmetry.
Asymmetry will be small ->small ΔI=1 weak pion amplitude

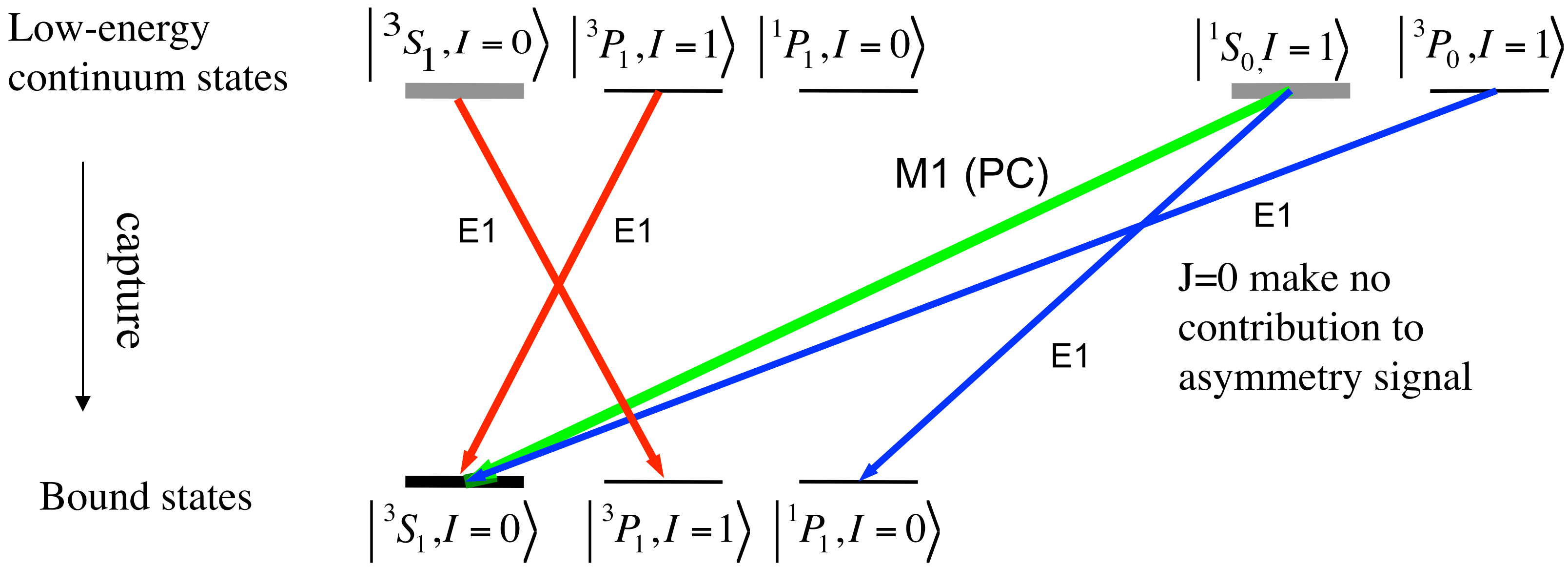
n-3He P-odd asymmetry and n-4He P-odd spin rotation:
~orthogonal to already-measured p-4He in isoscalar/isovector coupling space

Status:

n-3He parity violation experiment at SNS: installation now
n-4He parity violation experiment at NIST: planned for NIST NG-C

γ-D P-odd photodisintegration: sensitive to ΔI=2 piece of NN weak which is easiest for lattice gauge theory to calculate

Simple Level Diagram of *n-p* System



Low-energy continuum states

$\left|{}^3S_1, I=0\right\rangle$ $\left|{}^3P_1, I=1\right\rangle$ $\left|{}^1P_1, I=0\right\rangle$ $\left|{}^1S_0, I=1\right\rangle$ $\left|{}^3P_0, I=1\right\rangle$

capture

E1

E1

M1 (PC)

E1

E1

J=0 make no contribution to asymmetry signal

Bound states

$\left|{}^3S_1, I=0\right\rangle$ $\left|{}^3P_1, I=1\right\rangle$ $\left|{}^1P_1, I=0\right\rangle$

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

- Weak interaction mixes in *P* waves to the singlet and triplet *S*-waves in initial and final states.
- Parity conserving transition is $M1$.
- Parity violation arises from mixing in *P* states and interference of the $E1$ transitions.
- A_γ is coming from ${}^3S_1$ - ${}^3P_1$ mixing and interference of $E1$-$M1$ transitions in $\Delta I = 1$ channel.

Mixing amplitudes:

$\left\langle {}^3S_1 \middle| V_W \middle| {}^3P_1 \right\rangle ; \Delta I = 1$

$\left\langle {}^3S_1 \middle| V_W \middle| {}^1P_1 \right\rangle ; \Delta I = 0$

$\left\langle {}^1S_0 \middle| V_W \middle| {}^3P_0 \right\rangle ; \Delta I = 2$