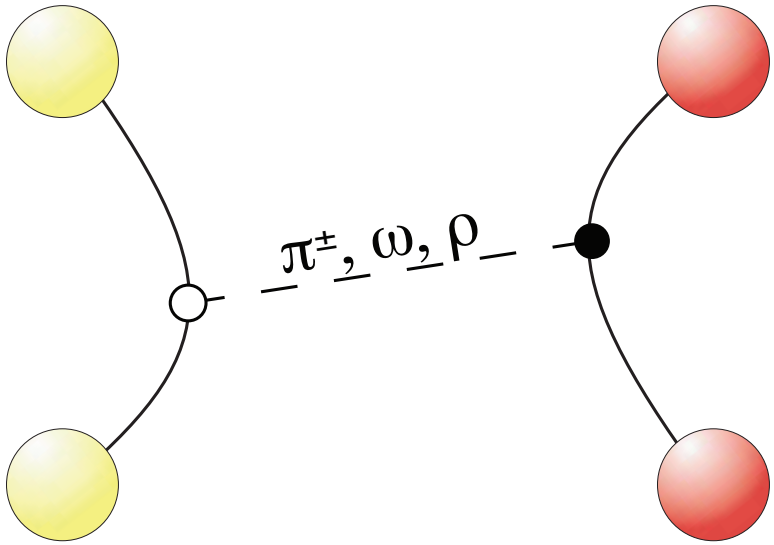
Investigating Hadronic Parity Violation Using the $\vec{\gamma}d \rightarrow np$ Reaction at the Proposed HIGS2 facility at TUNL



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Outline

- Hadronic Parity Violation
- Experiments in progress
- HIγS facility / Upgrade paths
- Proposed $\vec{\gamma}d \rightarrow np$ experiment using HIγS2

Hadronic Parity Violation

- Parity violation is built into the "Standard Model" and lives in weak interactions.
- Carriers of the weak force: W^-, W^+, Z^0
  - W^+ and W^- couple only to "left-handed" objects
  - Z^0 has unequal coupling to left and right-handed particles
- Particles interacting under the weak force:
  - leptons ℓ, ν_ℓ, $\ell = e, \mu, \tau$
  - quarks q, $q = u, d, s, c, t, b$
- Understanding PV in hadrons requires a description of QCD at low energies

NSAC Performance Measures (2008)

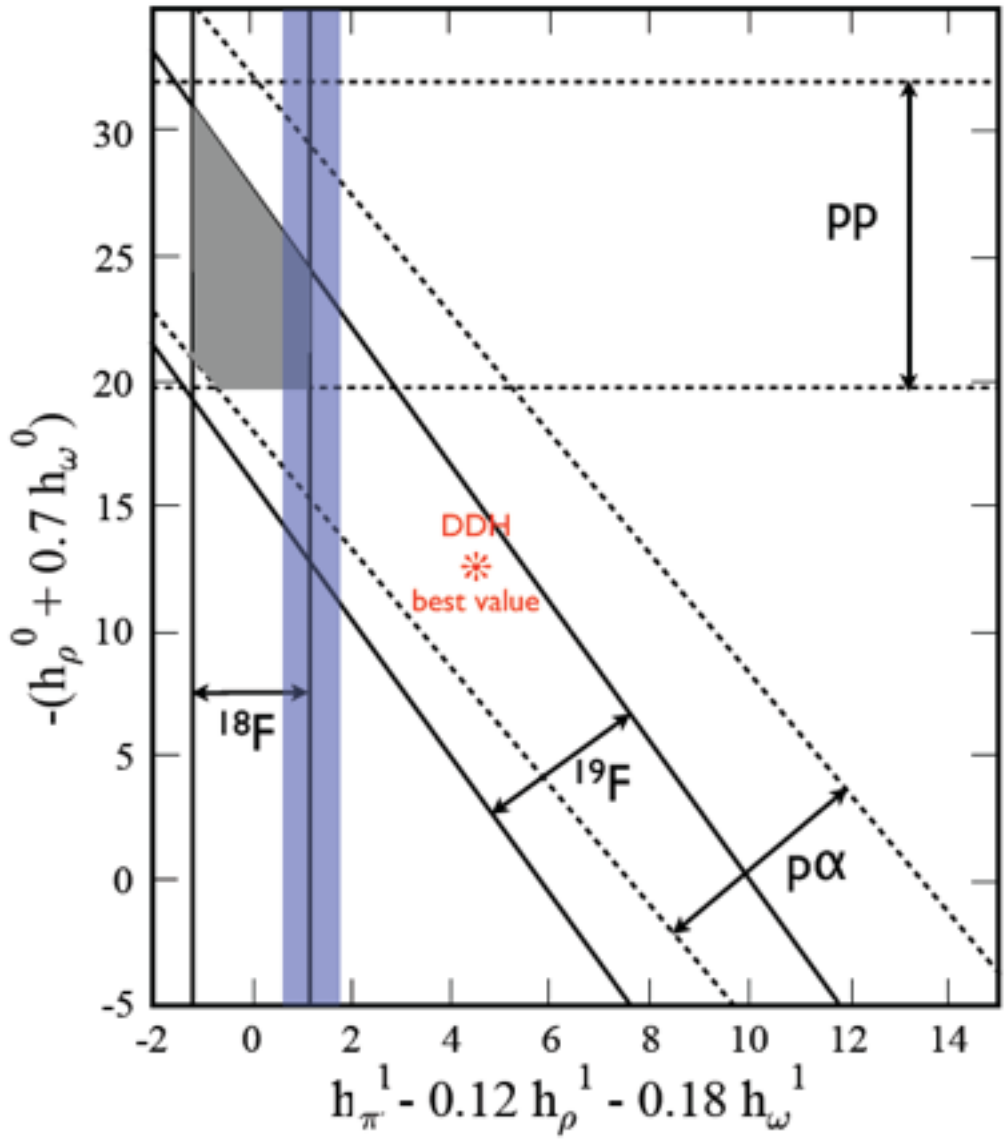
- **Performance Measures for Hadronic Physics:**
  "The broad goals of research in hadronic physics include linking the physics of nuclei to the fundamental theory of strong interactions, namely, Quantum Chromodynamics (QCD), …"

- **Performance Measure for Neutrinos, Neutrino Astrophysics and Fundamental Interactions:**
  "Perform independent measurements and key computations of parity violation in few-body systems to constrain the non-leptonic weak interaction."

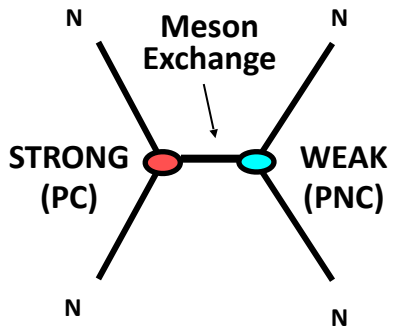
NSAC Implementation (2013)

- ``*Parity-violation measurements offer another way to probe the short-distance behavior of the nuclear force and its relation to QCD...An experiment [of* $\vec{\gamma}d \rightarrow np$ *] is being discussed at the High Intensity Gamma Source at …(TUNL)... if an upgrade to higher flux is carried out.*''

Hadronic Parity Violation



- Traditionally treated in the "DDH" framework
- Interactions characterized exchange of light mesons (π, ϱ, ω) with one strong interaction vertex and one weak interaction vertex
  - h_π^1, h_ϱ^0, h_ϱ^1, h_ϱ^2, h_ω^0, h_ω^1



Haxton/Holstein, arXiv:1303.4132

Hadronic Parity Violation

- Using an effective field theory (EFT) approach, there are only five parameters at leading order

Partial wave transition	ΔI	*n-n*	*n-p*	*p-p*	Exchanged Meson	Nucleon-Meson Weak Coupling
^{3}	1		✓		π	f_π
^3S	0		✓		ρ, ω°	h_ρ
^1S	0	✓	✓	✓	ρ, ω°	h_ρ
^{1}	1	✓		✓	ρ, ω°	h_ρ
^1S	2	✓	✓	✓	ρ	h

Schindler/Springer, arXiv:0907.5358

Hadronic Parity Violation Experiments

	$np \rightarrow d\gamma$ A	$nd \rightarrow t\gamma$ A	np (μrad/m)	n (μrad/m)	pp $\Delta\sigma/\sigma$ (ppm)	p (ppm)
h	-0.11	-0.92	-3.12	-0.97		-0.34
h		-0.50	-0.23	-0.32	0.08	0.14
h	-0.001	-0.10		0.11	0.08	0.05
h		0.053	-0.25		0.03	
h		-0.160	-0.23	-0.22	-0.07	0.06
h	0.003	0.002		0.22	0.07	0.06

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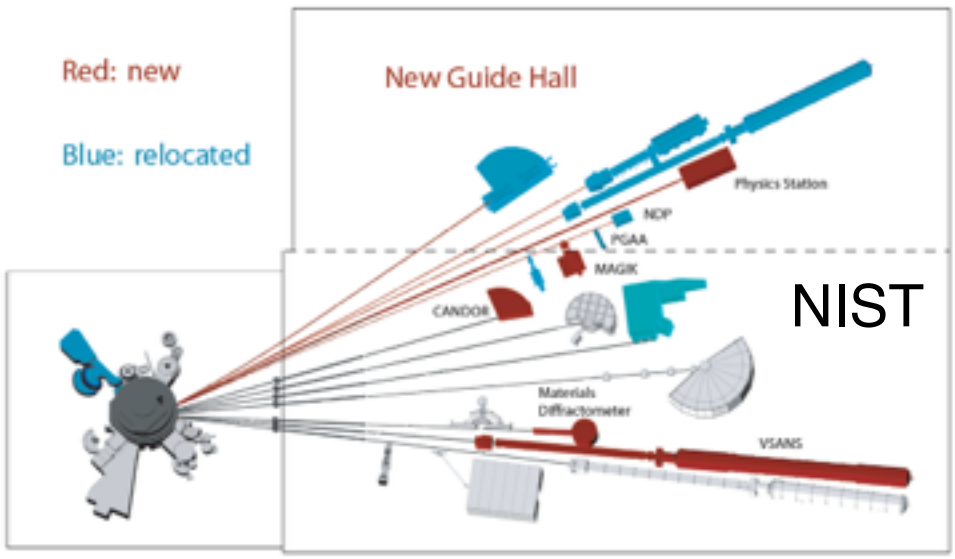
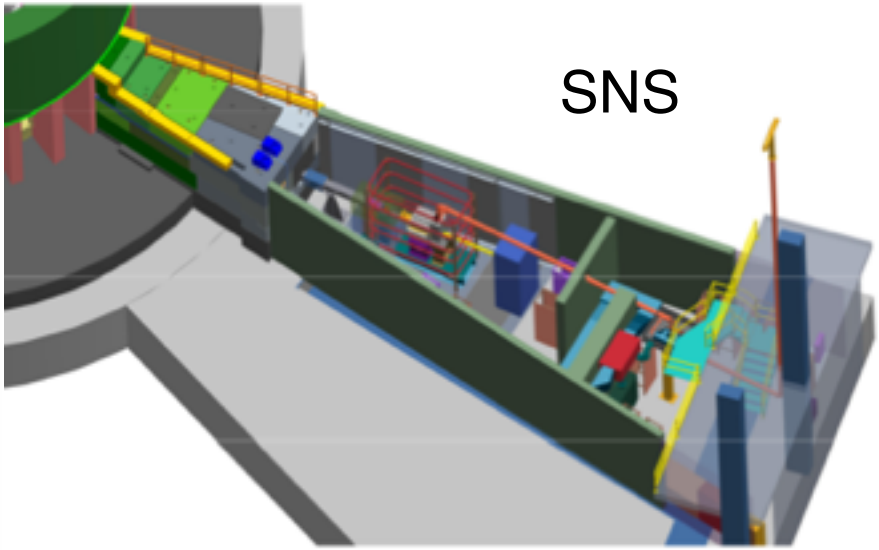
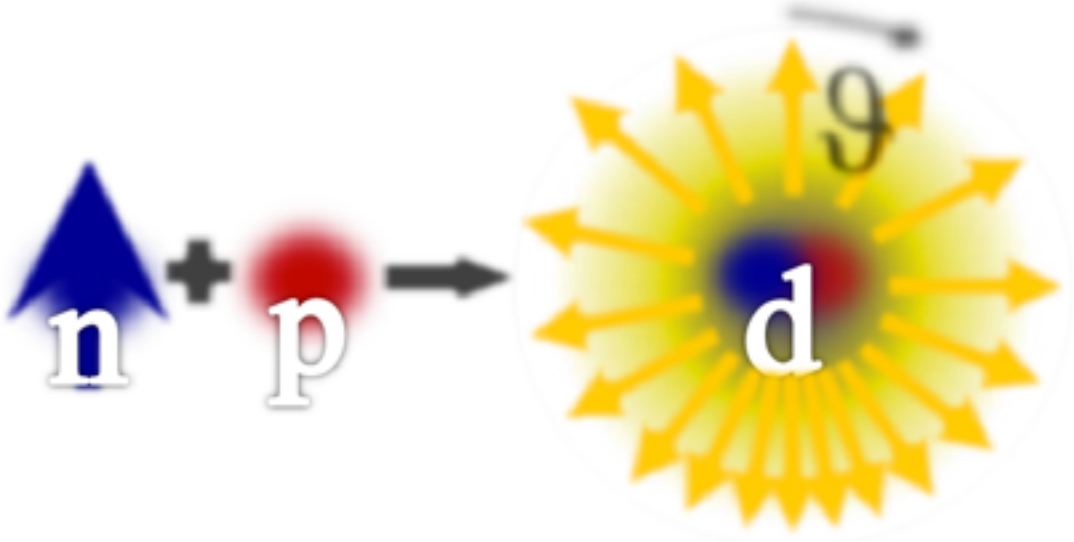
HPV Experiments





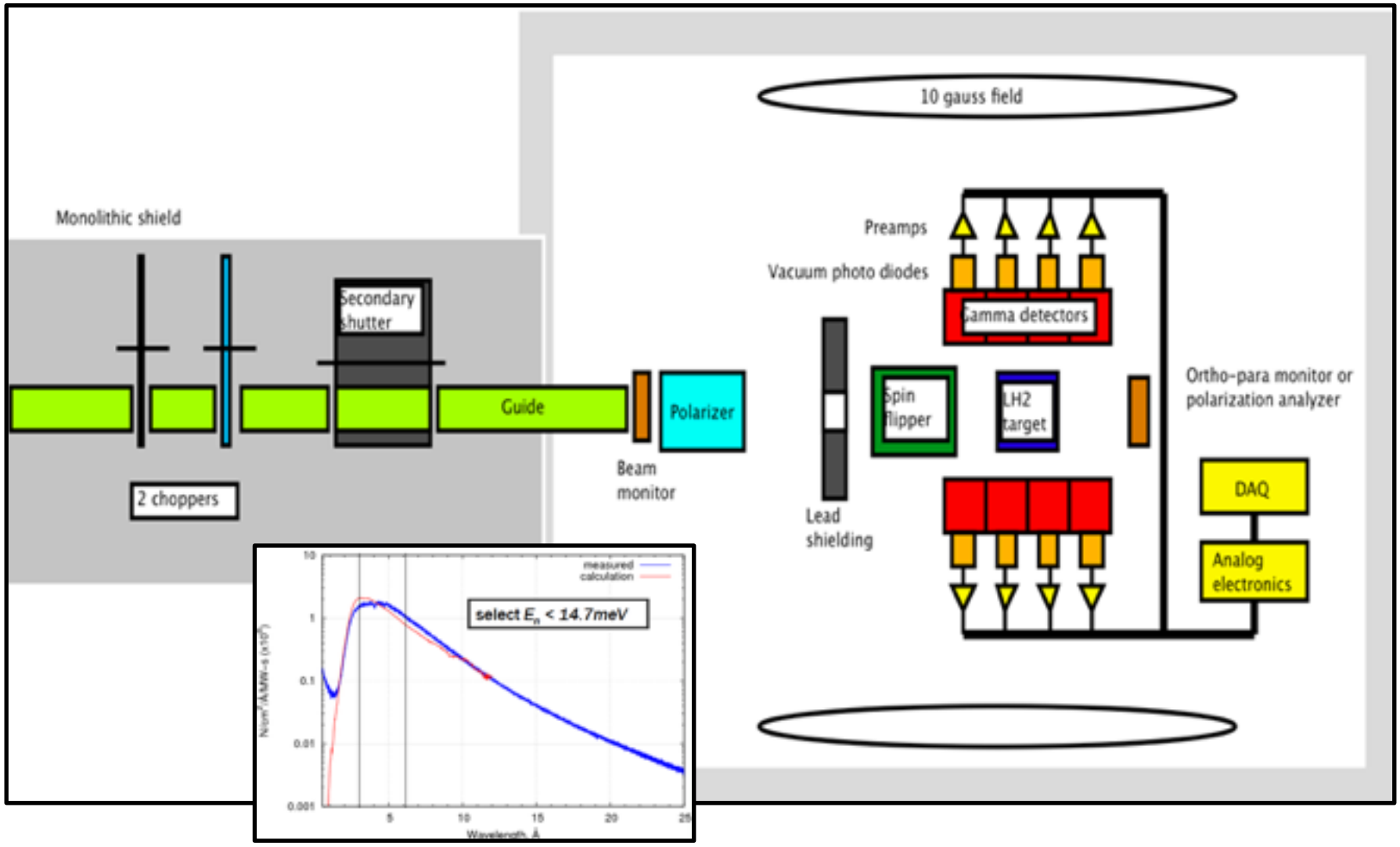
- ~ X10 increase in polarized slow neutron flux
- Experiments planned/in progress:
  - NPDGamma (SNS)
  - n-^{3}He (SNS)
  - n-^{4}He spin rotation (NIST)

The NPDGamma experiment at the SNS



- A_γ: directional asymmetry in the gammas emitted from cold polarized neutron capture on protons (goal $dA_\gamma = 10^{-8}$)
- $A_\gamma = -0.1 h_\pi$ isolates the long-range $\Delta I = 1$ amplitude

The NPDGamma experiment at the SNS



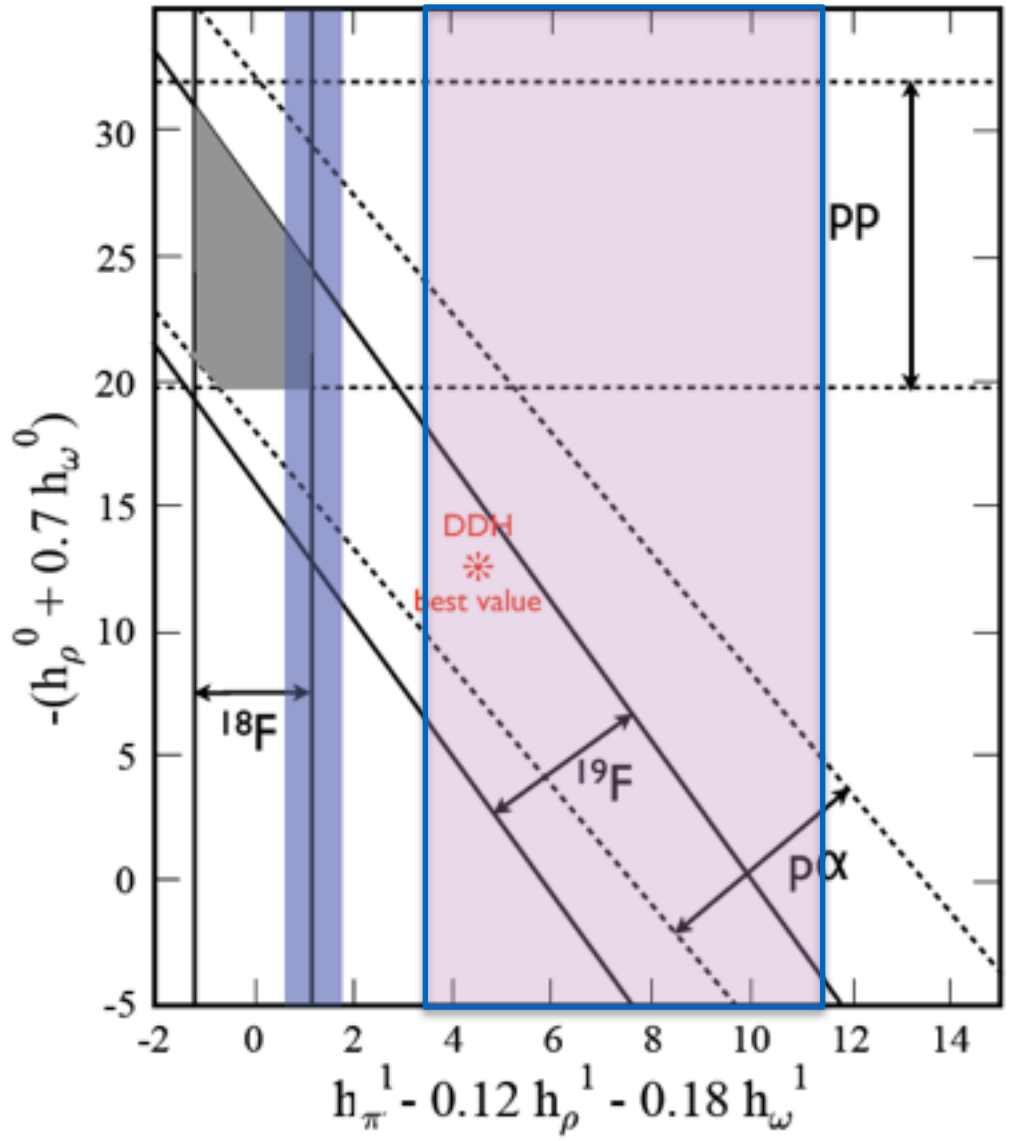
The NPDGamma experiment at the SNS

- Presently finishing up on the beam line at the SNS
- Preliminary interim result presented at the Fall DNP meeting:

$$A_{UD} = (-7.1 \pm 4.4)\ x10^{-8} \qquad A_{LR} = (-0.91 \pm 4.3)x10^{-8}$$

- On track for a final asymmetry error of $dA = 1 \times 10^{-8}$, a final number has not been released.

Hadronic Parity Violation



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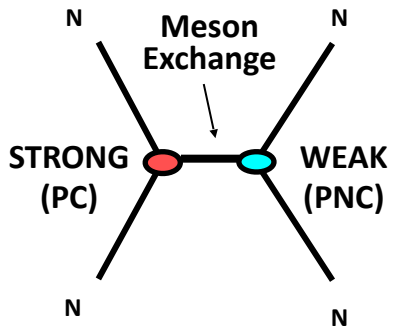

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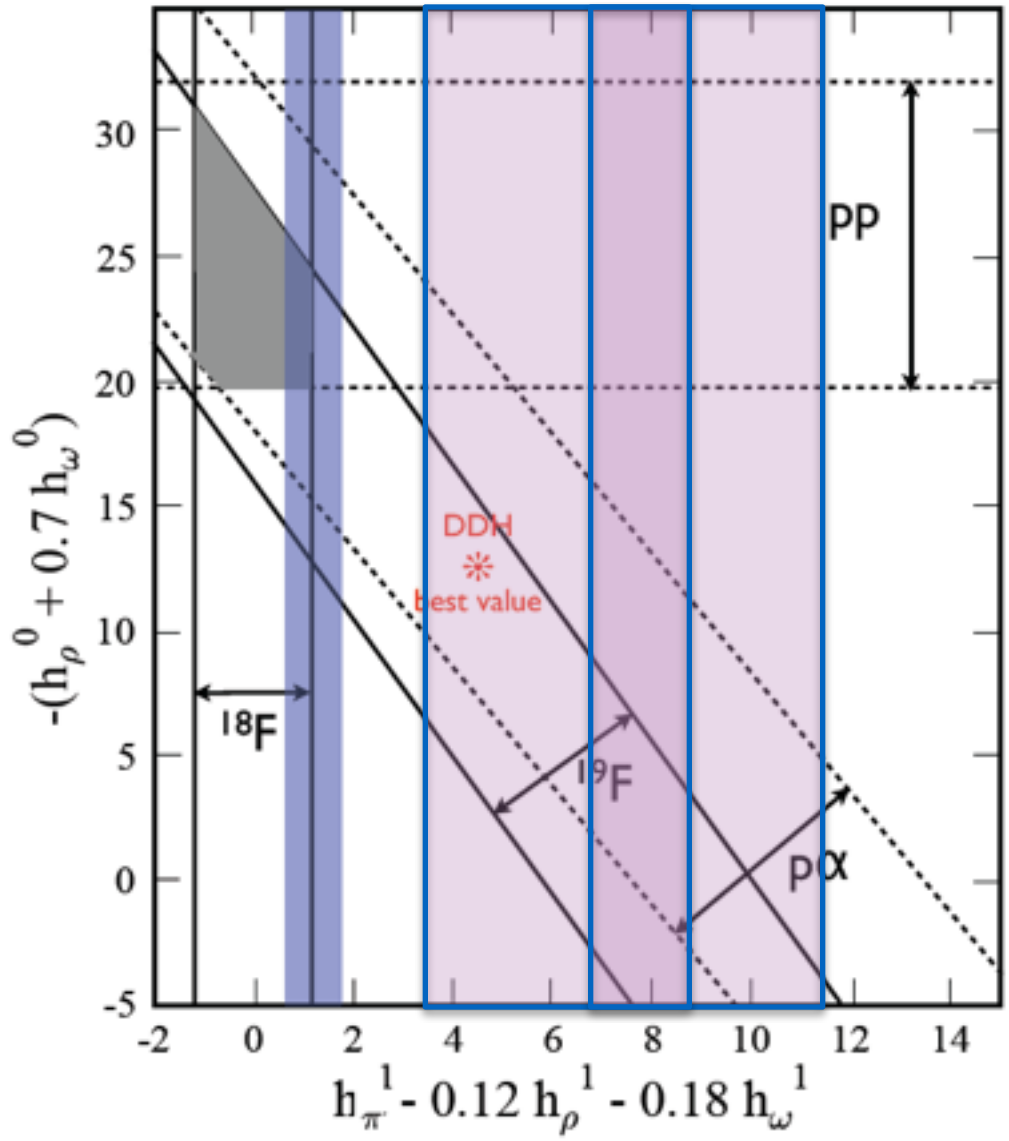

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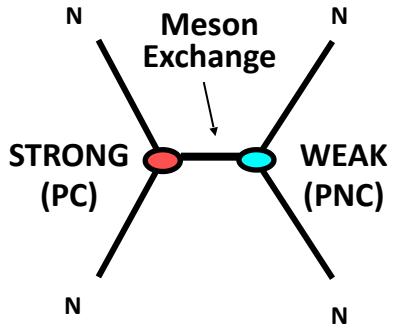

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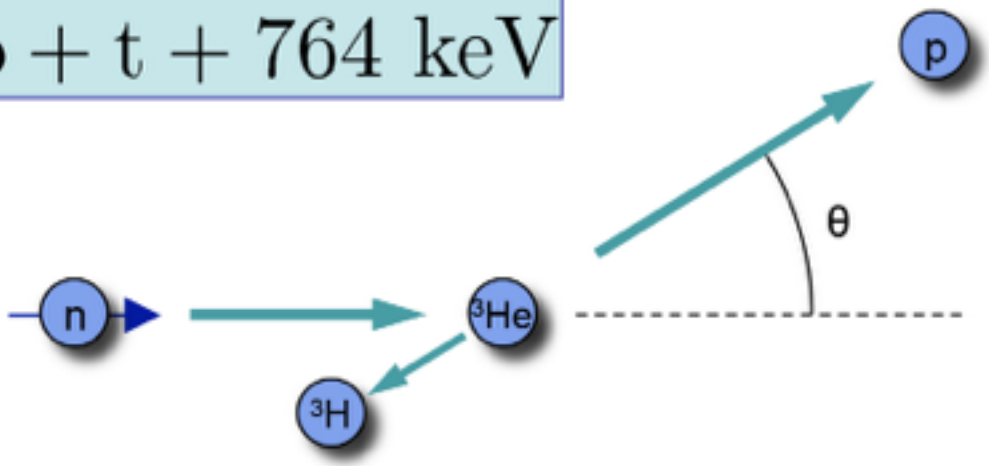
n-^{3}He PV Asymmetry at SNS

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



PV observables:

$\sigma_n \cdot k_n$ ~ k_n very small for low-energy neutrons

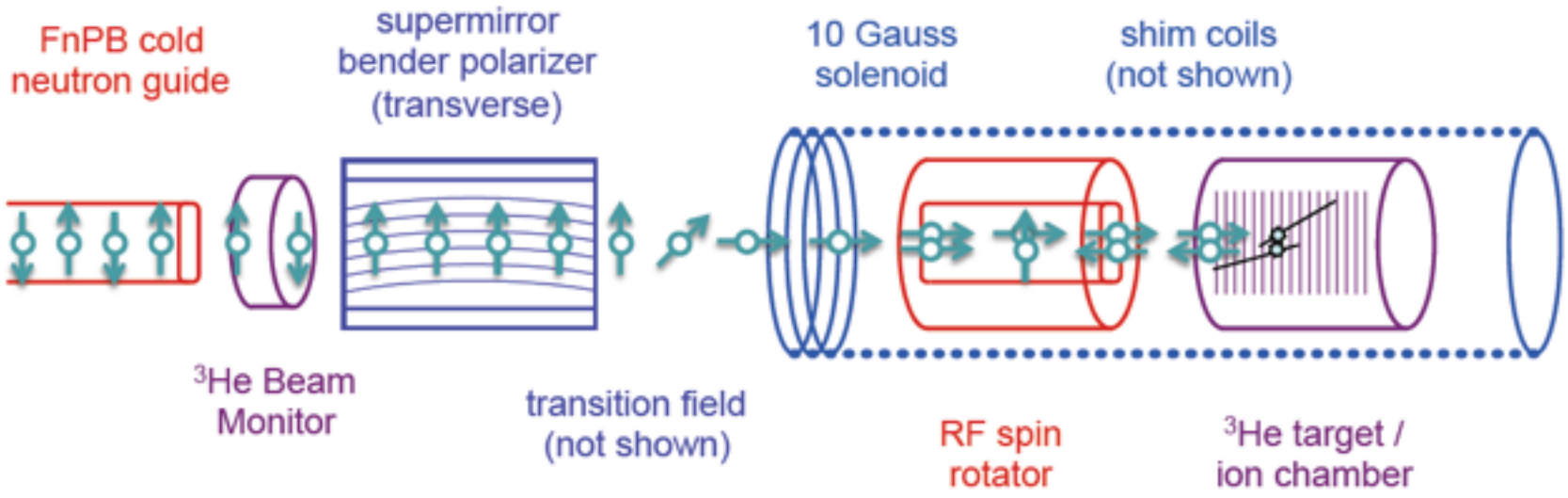
$\sigma_n \cdot k_p$ / $\sigma_n \cdot k_t$ - the same asymmetry
- must discriminate between back-to-back proton-triton

$$N = N_0 \frac{d\Omega}{4\pi}\left(1 \pm P_n A_p \cos\theta\right)$$

- sensitive to I=0 and I=1 couplings
- PV A ~ 1.1 x 10^{-7} (Viviani)
- PC A ~ 1.7 x 10^{-6} (Hale)

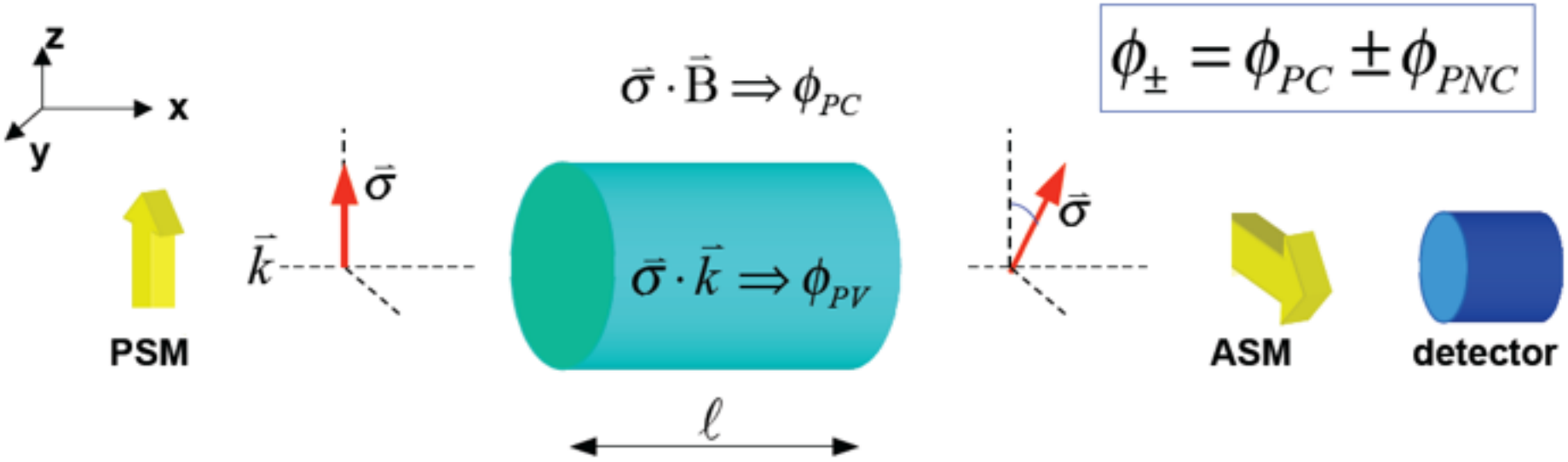
GOAL: $\delta A = 1.3 \times 10^{-8}$

n-^{3}He PV Asymmetry at SNS



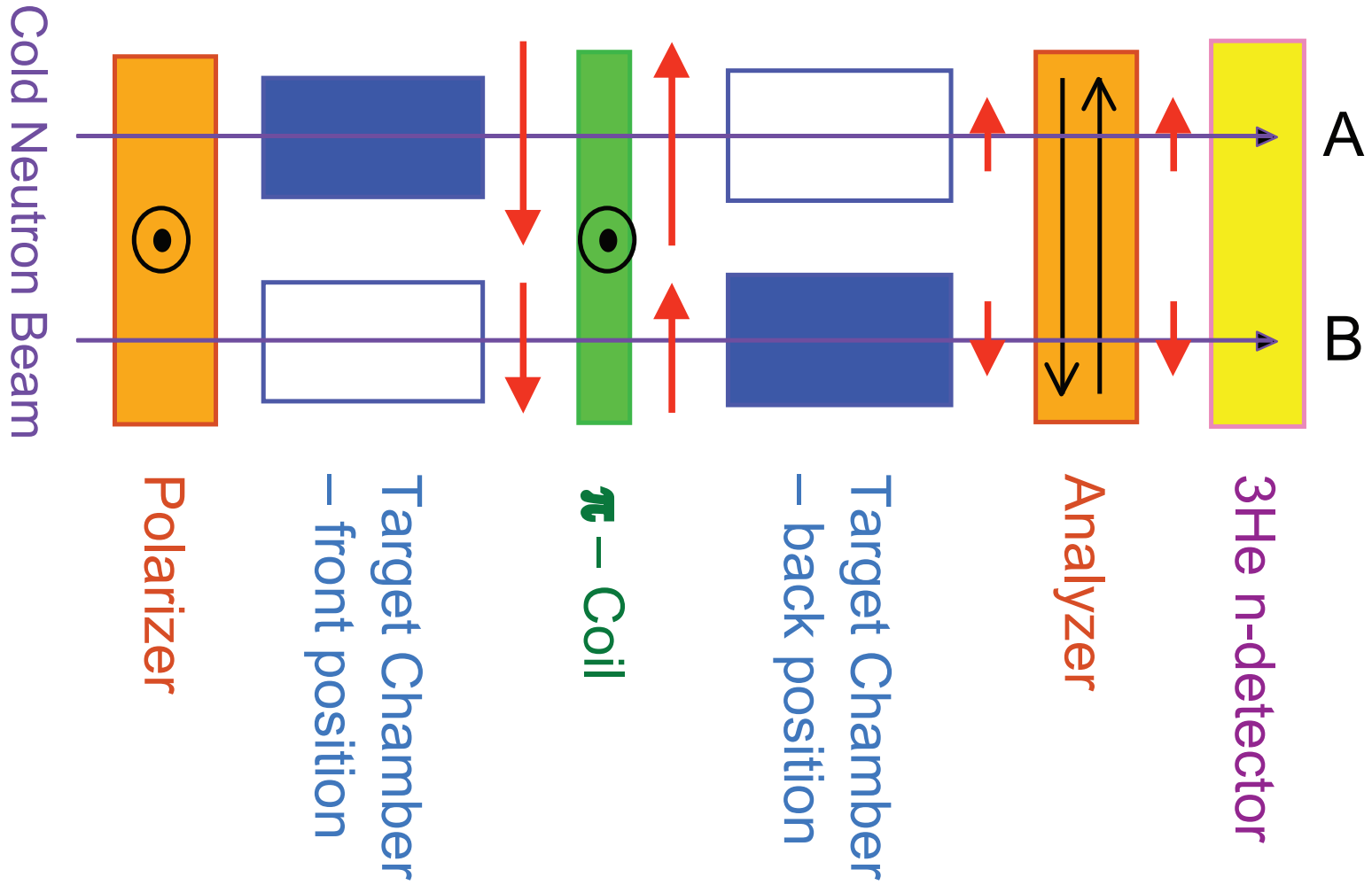
- Will be ready to commission and run after NPDGamma

Neutron Spin Rotation in ^{4}He at NIST



- Analogous to optical rotation in an "handed" medium.

Neutron Spin Rotation in ^{4}He at NIST



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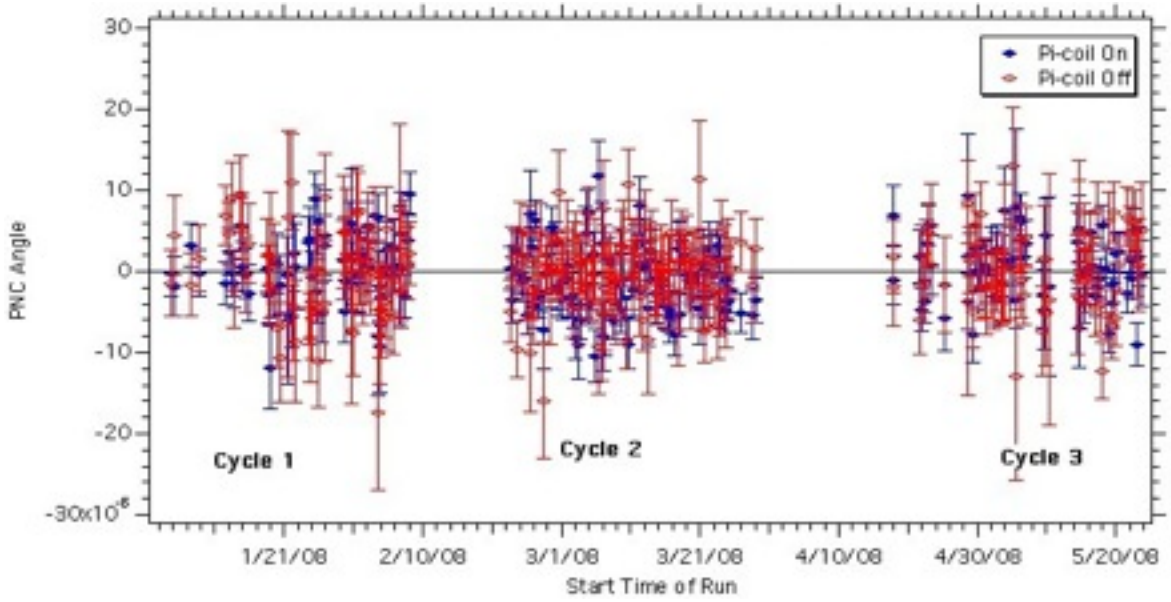
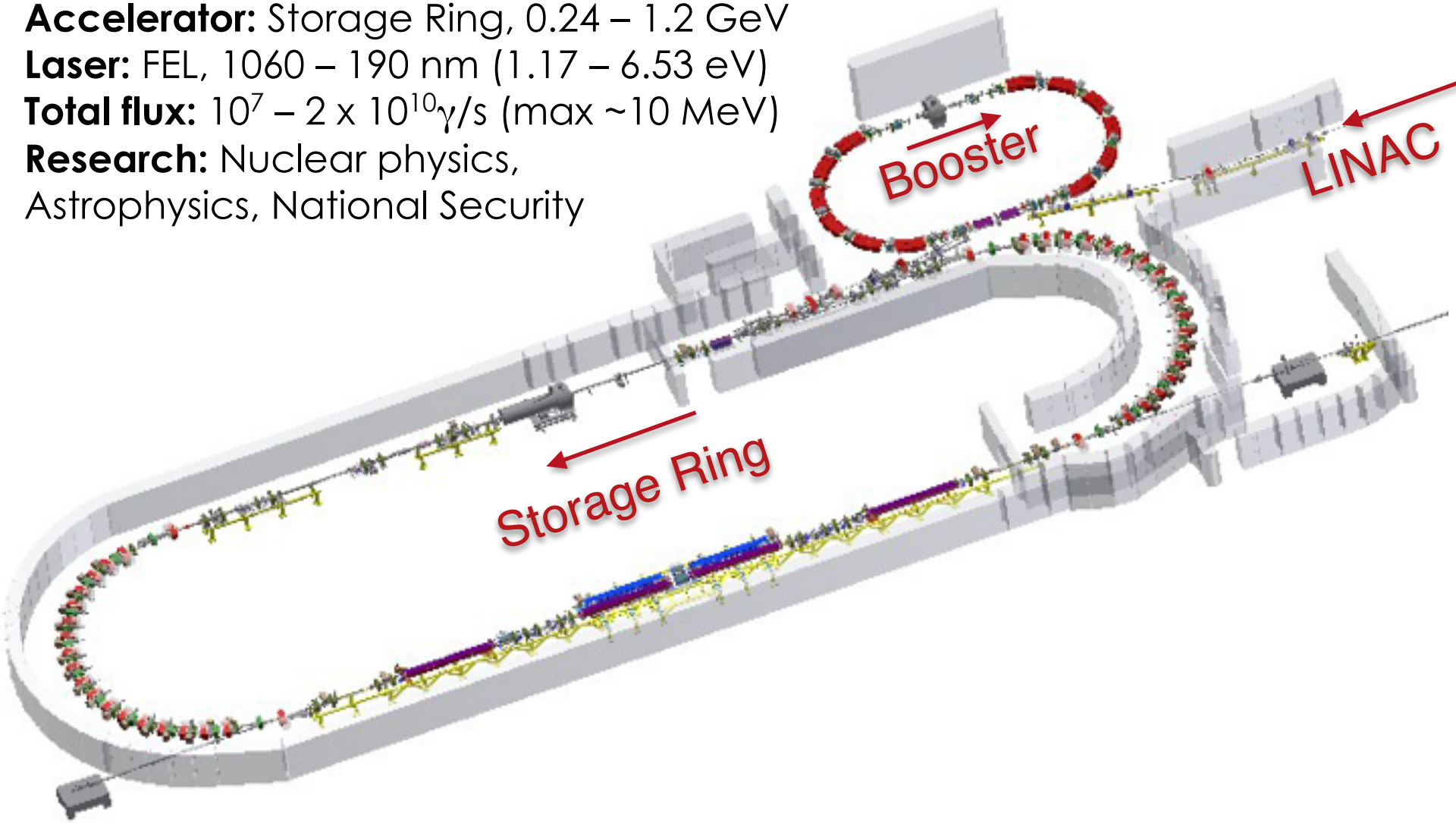


- φ_{PNC}= [+1.7 ± 9.1 (stat) ± 1.4 (sys)] x 10^{-7} rad/m
- 1 x 10^{-7} rad/m goal on the new NIST NG-C beam

C. D. Bass *et al.*, Nucl. Instrum. Meth. A612, 69-82 (2009).
A. M. Micherdzinska *et al.*, Nucl. Instrum. Meth. A631, 80 (2011).
W. M. Snow *et al.*, Phys. Rev. C83, 022501(R) (2011).

HIγS Facility / Upgrade Paths

Accelerator: Storage Ring, 0.24 – 1.2 GeV
Laser: FEL, 1060 – 190 nm (1.17 – 6.53 eV)
Total flux: 10^7 – 2 x 10^{10}γ/s (max ~10 MeV)
Research: Nuclear physics, Astrophysics, National Security



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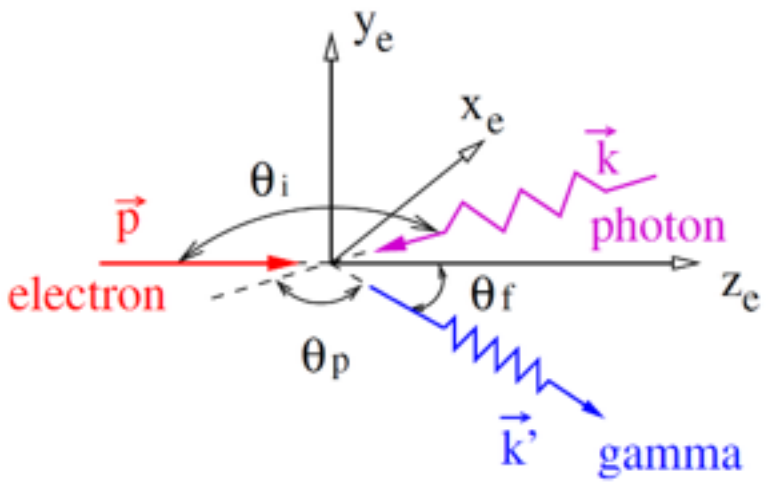
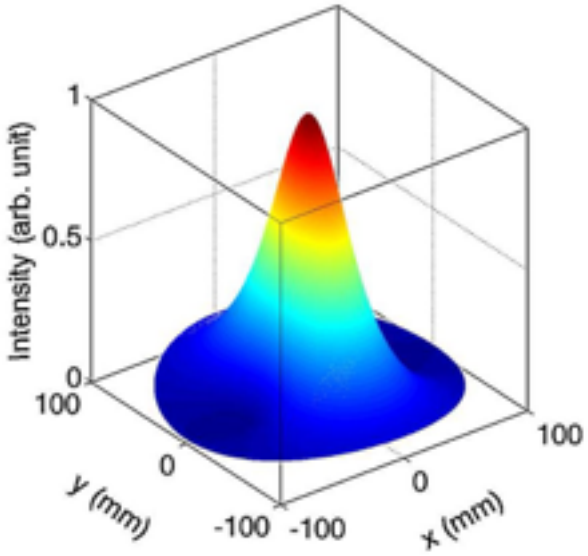
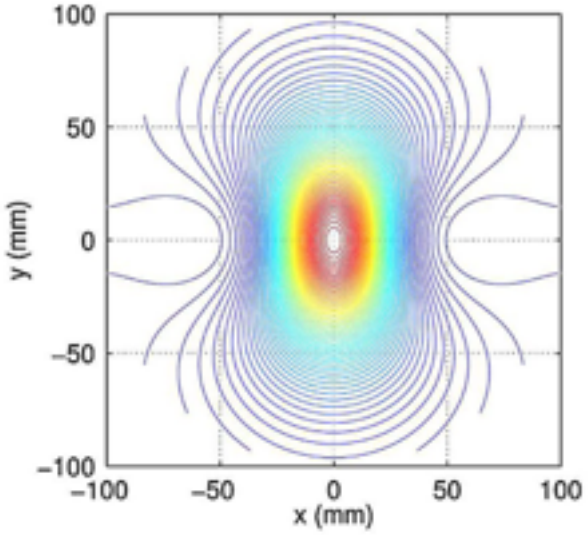


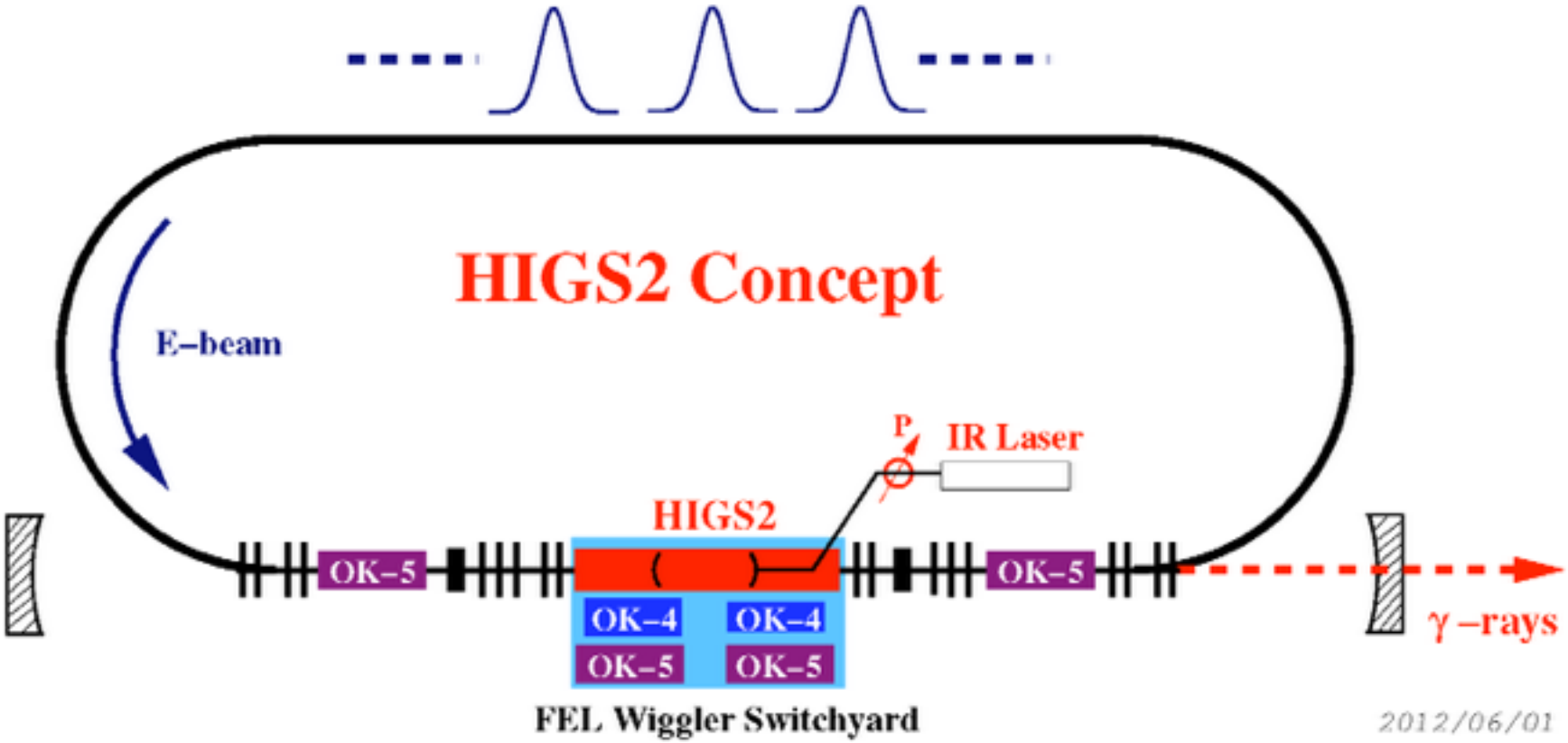


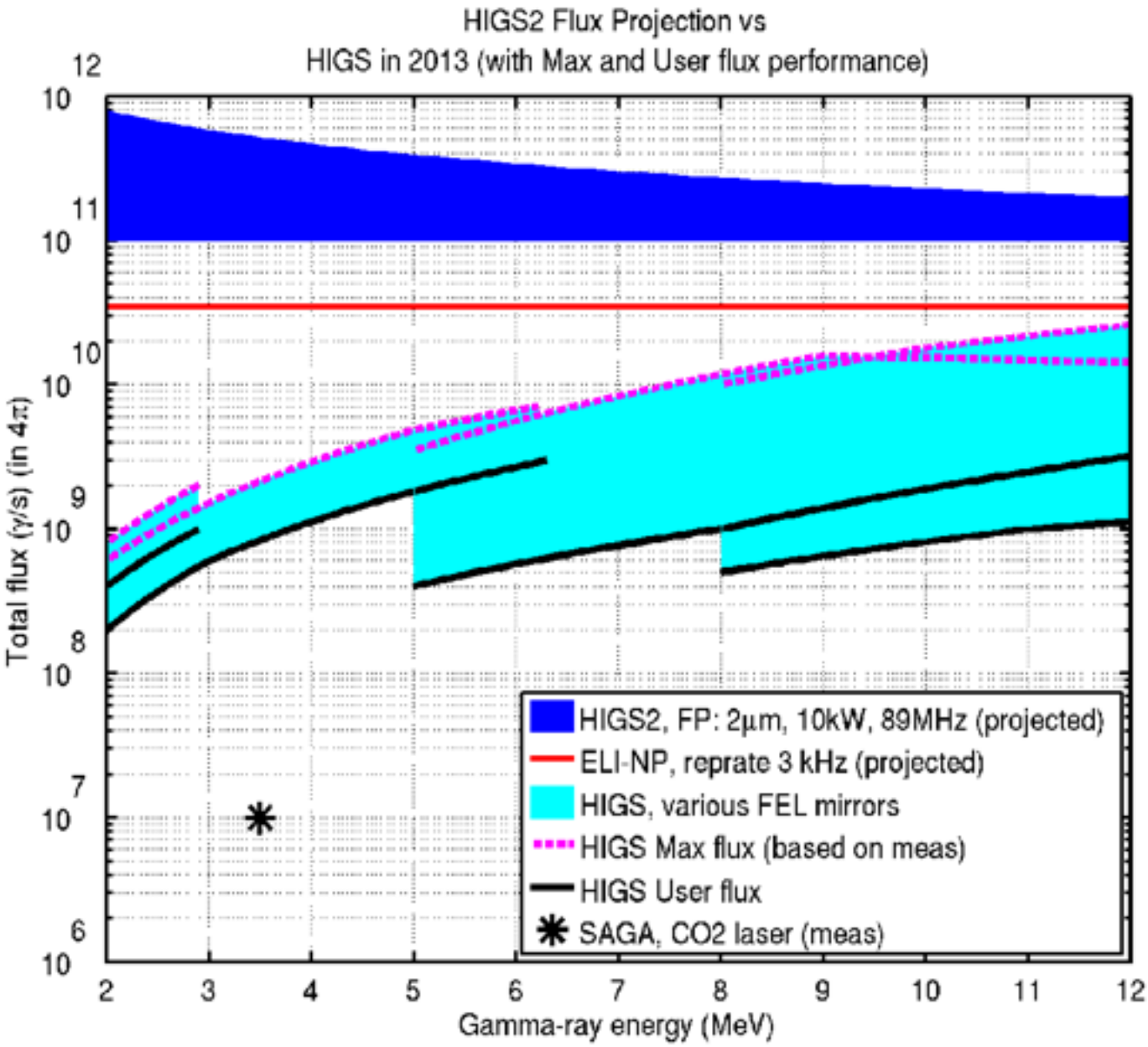
$$E_\gamma \equiv \hbar\omega' = \frac{\hbar\omega(1-\beta\cos\theta_i)}{1-\beta\cos\theta_f+\frac{\hbar\omega}{\mathcal{E}_e}(1-\cos\theta_{ph})}$$



- Head-on Collision:
  $E_\gamma^{max} \approx (\gamma(1+\beta))^2\,\hbar\omega \approx 4\,\gamma^2\,\hbar\omega$

HIγS Facility / Upgrade Paths

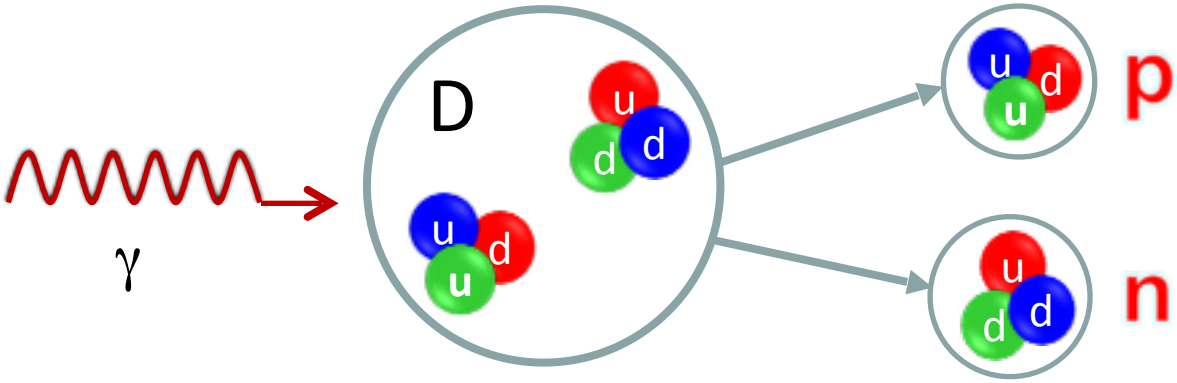



HIGS2 Flux Projection vs
HIGS in 2013 (with Max and User flux performance)
Total flux (γ/s) (in 4π)
Gamma-ray energy (MeV)
HIGS2, FP: 2μm, 10kW, 89MHz (projected)
ELI-NP, reprate 3 kHz (projected)
HIGS, various FEL mirrors
HIGS Max flux (based on meas)
HIGS User flux
SAGA, CO2 laser (meas)

Parity Violation Experiments at HIγS2?

- **Attractive features for parity violation experiments**
- ~10^{11} to 10^{12} polarized γ/sec (X 100 increase in polarized gamma flux relative to HIγS.)
- Circularly polarized gammas (> ~90 %), fast (~100 Hz) gamma helicity reversal possible
- Controlled beam phase space: ~1 % energy resolution on gamma energy (2–12 MeV)

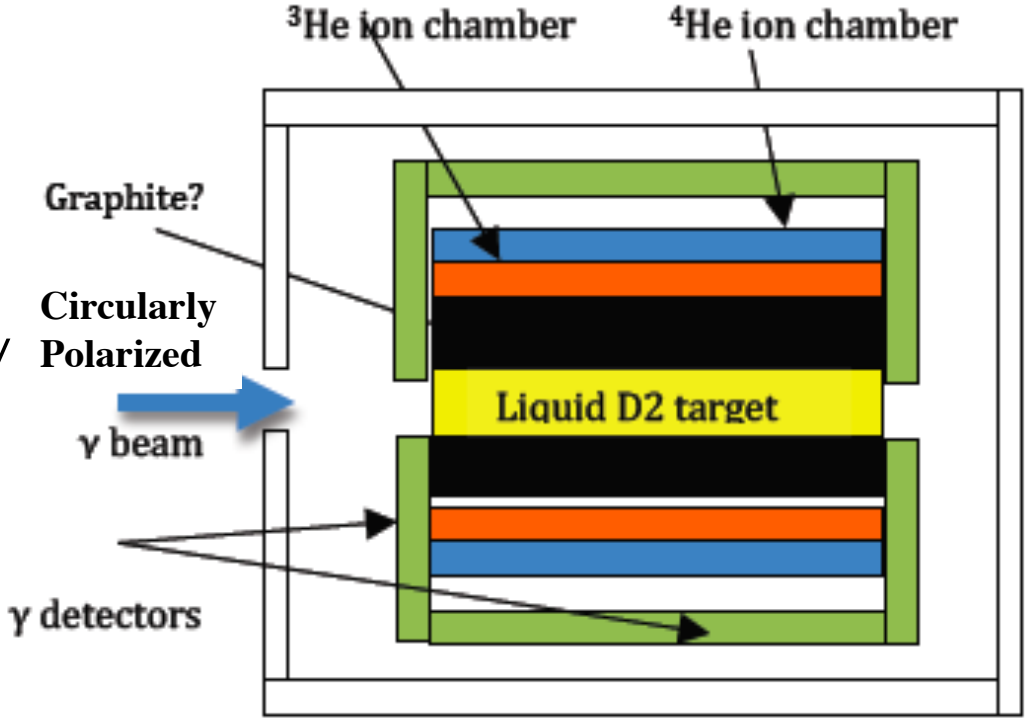
PV in Deuteron Photodisintegration



- Parity violation leads to a helicity dependence of photodisintegration cross section
- Provides a clean access to the $\Delta I = 2$ piece of weak NN interaction
- Signal is helicity dependence of neutron intensity (detected in current mode) from the target
- Also detect scattered and transmitted gammas for normalization/ systematics effect suppression
- Need to detect > ~10^{16} n's to be sensitive to a 10^{-8} asymmetry.

Experimental Concept

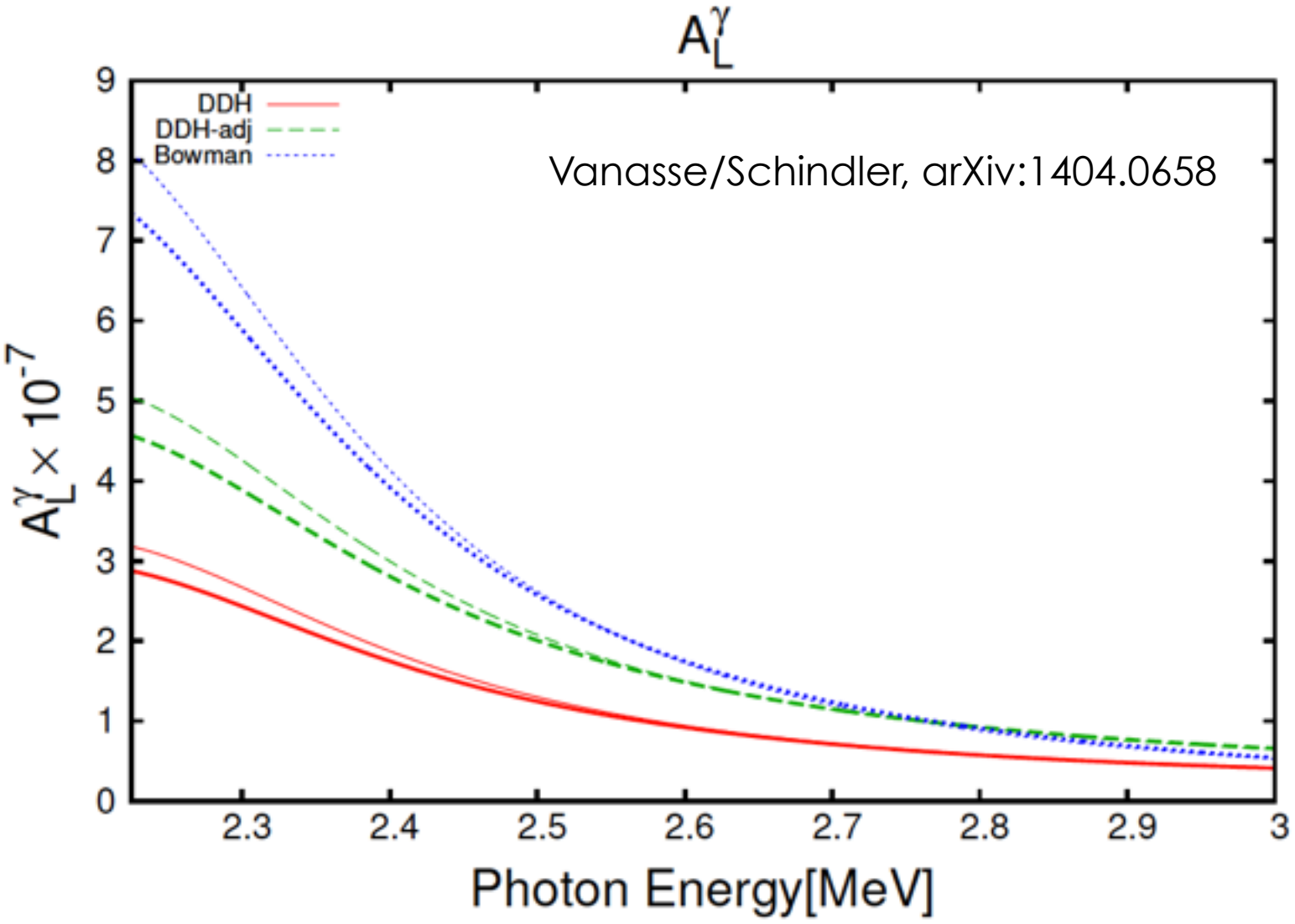
- The neutron can be moderated in the liquid deuterium target, escape with low energy (~10 meV), and be detected efficiently in current mode in a ^{3}He/^{4}He ion chamber



- The transmitted and scattered γ's can be measured using current-mode γ detectors located behind the ^{3}He/^{4}He ion chamber

- Cylindrical symmetry of detector array to help suppress possible systematic errors

Theoretical Sensitivity



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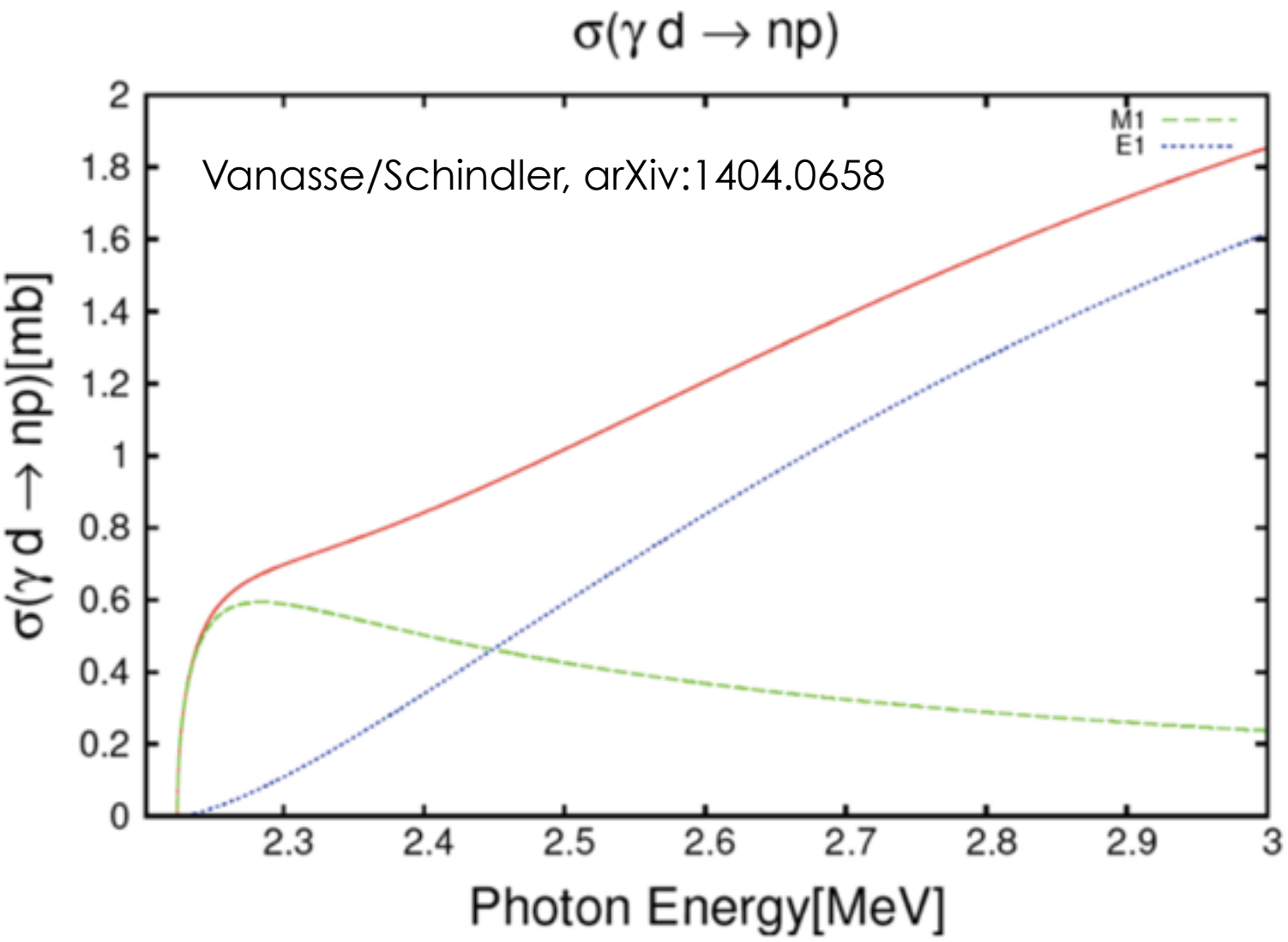

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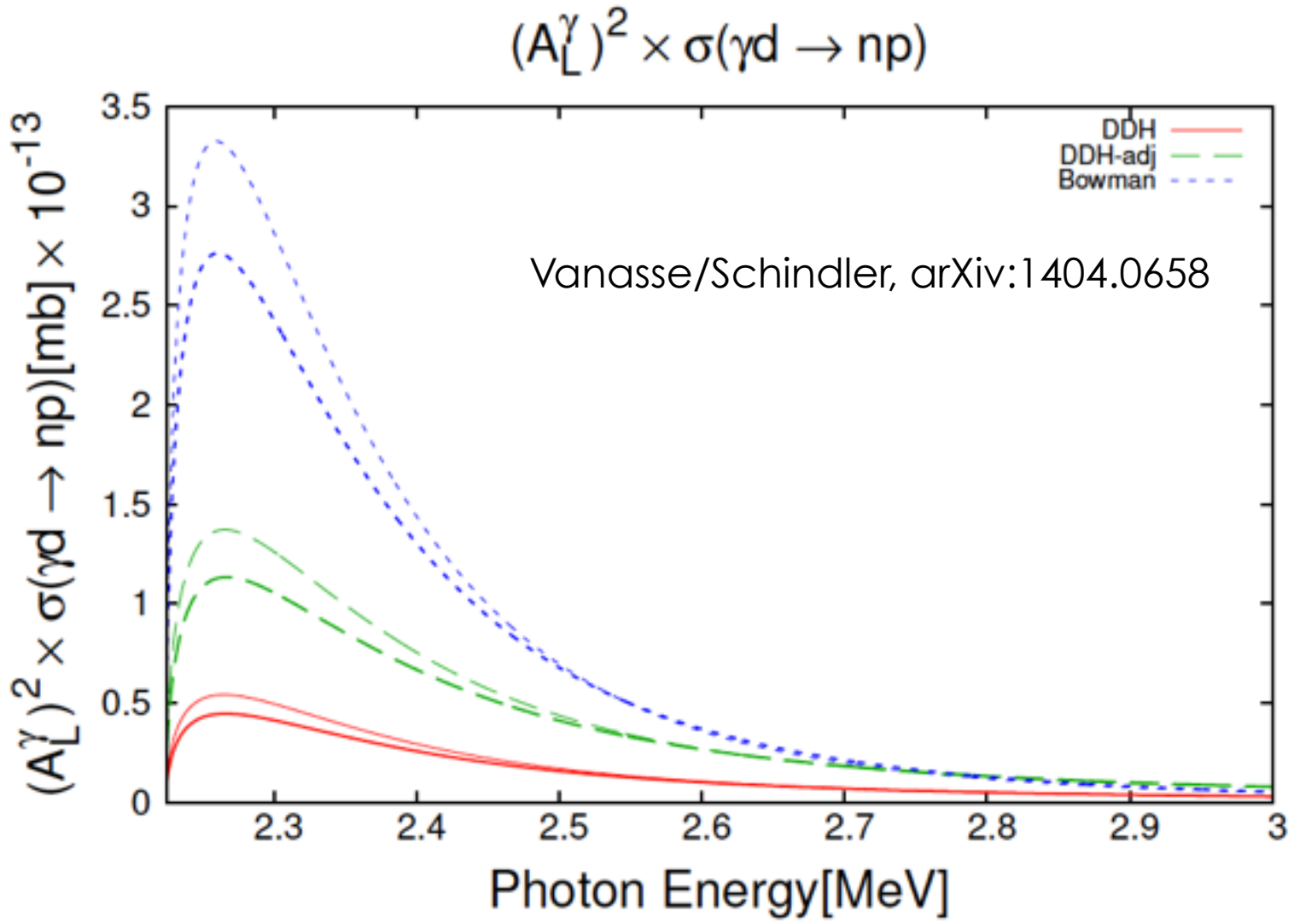

Other P-odd experiments at HIγS2?

- Few(ish)- body systems potentially accessible at HIγS2:
  $\gamma + {}^3He \rightarrow p + d$ $\gamma + {}^3He \rightarrow p + p + n$ $\gamma + {}^{12}C \rightarrow \gamma + {}^{12}C$
  - Can the theory be done?
    (success in model calculation of PV in $n + {}^3He \rightarrow {}^3H + p$)
  - How to measure? (gamma transmission+scintillation in the ^3He?)

- Intermediate-mass nuclei with parity doublets:
  - Much work at U Washington NPL in the 80's–90's already done: effects are amplified due to small splitting of energy levels

- Parity violation in heavy nuclei:
  - Huge amplifications of P-odd effects seen in ev-keV neutron experiments on *p*-wave resonances: opportunities to further test the statistical theory of discrete symmetry breaking in complex systems?

Conclusions/Questions

- Projected HIγS2 beam properties may suffice to perform parity violation measurements, but such experiments will place stringent demands on HIγS2 performance
- Few precise NN weak interaction measurements in few-body systems exist. Any opportunity to measure something new is worth careful scrutiny.
- PV in deuteron photodisintegration:
  a process with clean access to $\Delta I = 2$ piece of weak NN interaction.
- Experience with slow neutron and γ current mode detector technology exists.

Conclusions/Questions

- What are the dominant systematic errors?
- What are the beam requirements and can they realistically be achieved?
- What is the list of "known unknowns" that need to be investigated?