NOPTREX: A Neutron Optics Time-Reversal Violation Experiment

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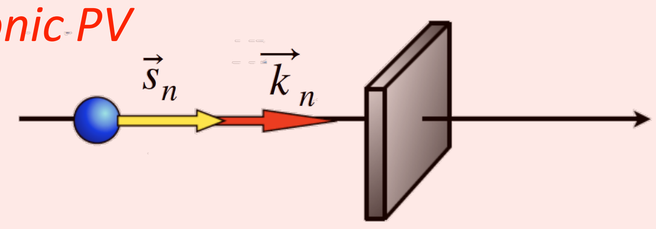
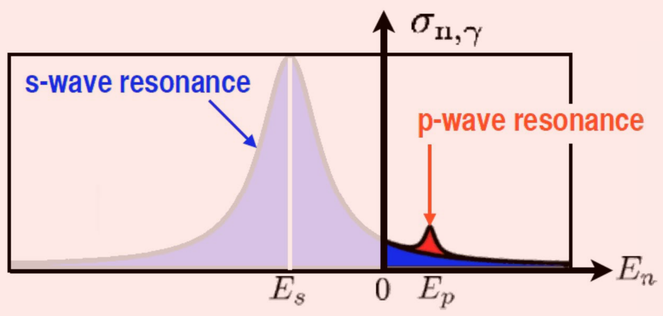
Abstract: *The forward neutron-nucleus scattering amplitude has a T-odd, P-odd component proportional to $\sigma_n \cdot I \times k_n$. Thus, the double spin-dependent neutron absorption cross section is a suitable observable in which to search for a new source of CP-violation needed to explain the baryon asymmetry of the universe. Unlike other complementary observables such as the electric dipole moment of fundamental particles, this effect can be amplified by up to a factor of 106 by the interference of closely-lying mixed parity states in heavy nuclei such as ^{139}La, ^{131}Xe, ^{81}Br, and ^{117}Sn. The goal of the NOPTREX collaboration is to prepare a search for time-reversal invariance violation(TRIV) in neutron scattering by performing precision measurements of hadronic parity violation (HPV) and of κ(J), which relates the sensitivity of TRIV to that of HPV. I will present an overview of the international effort coordinated across four neutron sources, towards building the NOPTREX experiment.*

$$f = \underbrace{A'}_{\text{Spin Independent P-even T-even}} + \underbrace{B'}_{\text{Spin Dependent P-even T-even}} \boldsymbol{\sigma}\cdot\boldsymbol{I} + \underbrace{C'}_{\text{P-violation P-odd T-even}} \boldsymbol{\sigma}\cdot\hat{\boldsymbol{k}} + \underbrace{D'}_{\text{T-violation P-odd T-odd}} \boldsymbol{\sigma}\cdot(\hat{\boldsymbol{I}}\times\hat{\boldsymbol{k}})$$

Hadronic PV

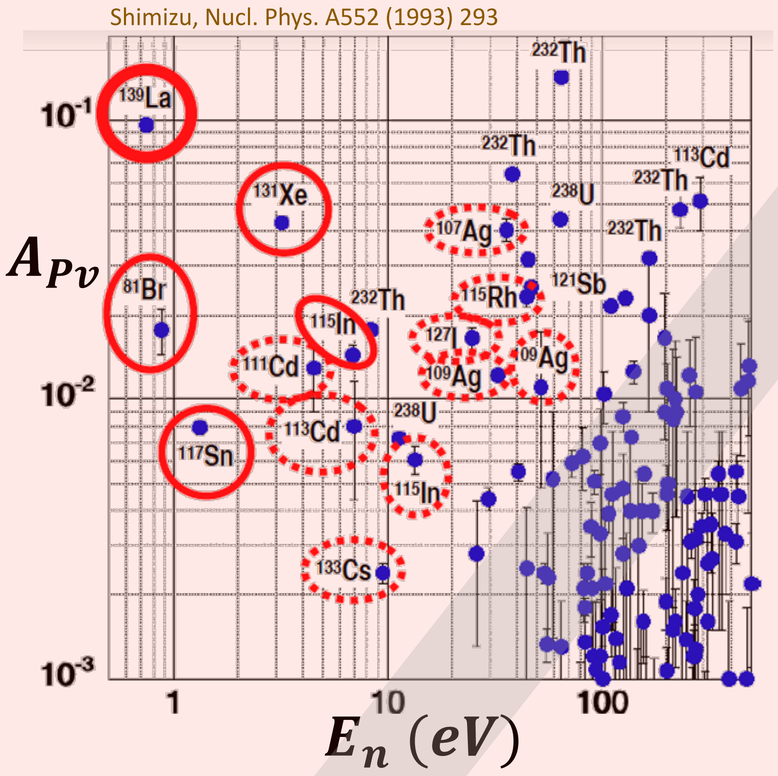


The mixing of closely spaced S and P states of equal J in heavy nuclei leads to enhancements of up to 10^6 above the NN couplings due to the small ΔE denominator in 1st order perturbation.



The TRIPLE collaboration measured PV in many large-A nuclei, measuring asymmetries up to 10% (in ^{139}La). The circled nuclei can be polarized and have large sensitivity, making them candidates for hadronic TRIV searches.

G.E. Mitchell et al. Phys. Rep. 354 (2001) 157
Shimizu, Nucl. Phys. A552 (1993) 293



R&D is being carried out at LANL and J-PARC to remeasure these PV asymmetries, and to search for new candidate nuclei in the range 140<A<180, where the S1/S0 ~ 1, similar to known nuclei with large PV enhancements.

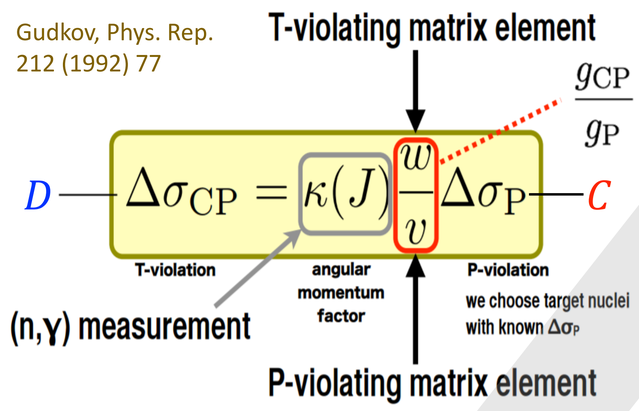
New instrumentation being constructed to carry out these measurements includes:

1) SEOP ^{3}He spin filter at Indiana University,
2) NaI scintillator array at Eastern Kentucky U.
3) DC neutron spin flipper U.K. and U.N.A.M.

NOPTREX

Hadronic PV and TRIV share similar nuclear enhancements:

Gudkov, Phys. Rep. 212 (1992) 77



The ratio of sensitivities, κ, for ^{139}La, was measured at J-PARC by the angular distribution in (n,γ) capture on the same 0.739 eV resonance.

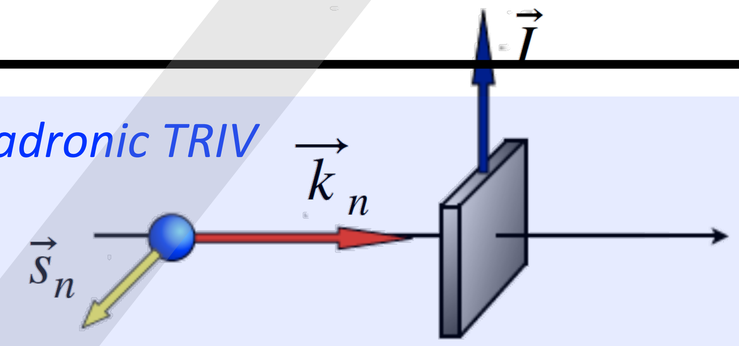
Okudaira et al., Phys. Rev. C 97 (2018) 03462

An experiment to remeasure $\Delta\sigma_{PV}$ in ^{139}La was carried out at the LANSCE FP12 beamline using two cooled La targets (one as a polarizer and the other as an analyzer) separated by a neutron spin flipper. This setup tests our sensitivity to small asymmetries and does not require knowledge of the neutron polarization.

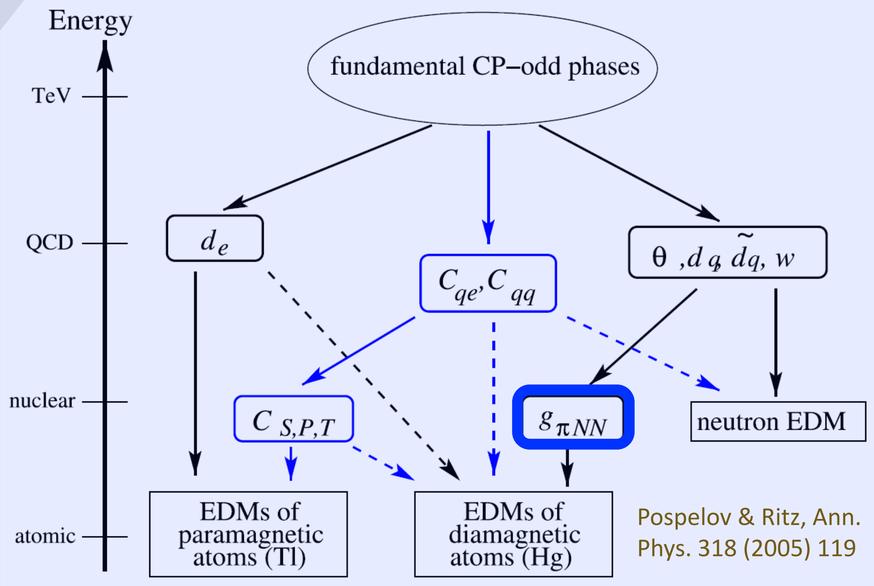
Schaper et al., NIM A969 (2020) 163961

The raw asymmetry shows a peak at 0.739 eV. Analysis is underway.

Hadronic TRIV

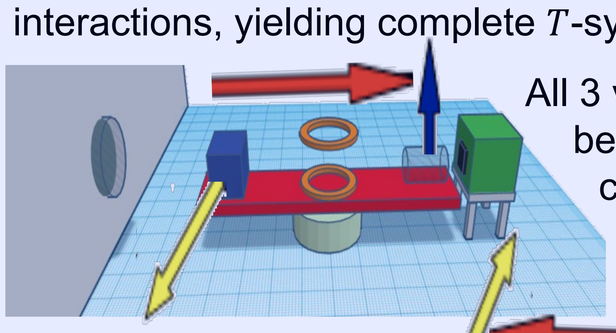


Hadronic TRIV is directly sensitive to the $\not{P},\not{T}$ coupling constant $g_{\pi NN}$, and thus it could be a complementary source of $\not{C}\not{P}$ to static EDMs.



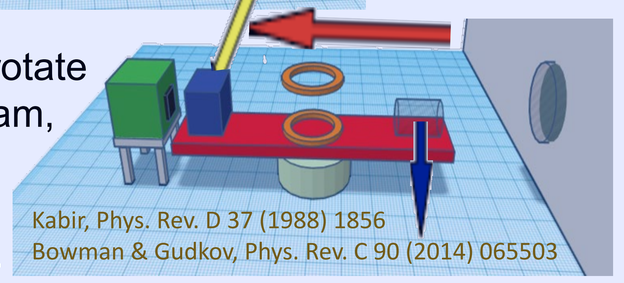
Pospelov & Ritz, Ann. Phys. 318 (2005) 119

The total absorption cross section σ, equivalent to the forward elastic scattering amplitude f by the optical theorem, is insensitive to final state interactions, yielding complete T-symmetry.



All 3 vectors must be reversed to control alignment error.

Rather than rotate the entire beam, the polarizer and analyzer are reversed.

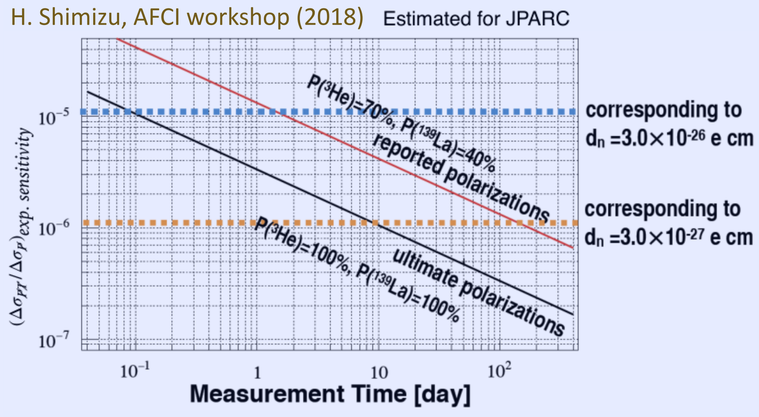


Kabir, Phys. Rev. D 37 (1988) 1856
Bowman & Gudkov, Phys. Rev. C 90 (2014) 065503

Misalignment errors can be minimized by fixing the beam collimators and rotating the polarized targets and spin flipper on a common turret.

Experimental Sensitivity

H. Shimizu, AFCI workshop (2018) Estimated for JPARC



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