Searching for new physics in the Nucleus

Presentation to
REU Students
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Weak interactions in nuclei: a probe to search for new physics

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While the LHC searches at the energy frontier.

Precision experiments in nuclear beta decays can be more sensitive in some specific areas.

Students David Zumwalt and Andy Palmer look at the device they built to produce 6He at UW.
Are weak decays carried only by W’s?

Or is there something new?

6He collaboration: searches for Tensor currents.

P. Muller, Z.-T. Lu
Argonne National Lab

O. Naviliat-Cuncic
NSCL, Michigan State University

X. Fléchard, E. Liénard
LPC-Caen, Caen, France

University of Washington
Helicities in the Standard Model

\[ \mathcal{H} = \frac{\vec{p} \cdot \vec{J}}{\|\vec{p}\| J_{\text{max}}} \]

Example: photons have \( \mathcal{H} = \pm 1 \).

The electro-weak interactions are mediated by VECTOR (Spin=1) particles (Photon, Z0, Ws)

A consequence is that the interactions don’t flip helicities.

Or equivalently (notice anti nu):

All the particles that couple to the Weak interactions are left handed;

Particles → Left handed
Anti particles → Right handed
Helicities in the Standard Model

If the nuclear spins don’t flip then the leptons have total $J_z=0$

$J^e_z \quad \rightarrow \quad \rho^e$

$J^\nu_z \quad \rightarrow \quad \rho^\nu$

Consequence: e-antineutrino correlation

$\frac{d\Gamma}{d\Omega_{e\nu}} = 1 + \frac{\vec{p}^e}{E_e} \cdot \frac{\vec{p}^\nu}{E_\nu}$

If the nuclear spins flip then the leptons have total $J_z=1$

$J^e_z \quad \rightarrow \quad \rho^e$

$J^\nu_z \quad \rightarrow \quad \rho^\nu$

Consequence: e-antineutrino correlation

$\frac{d\Gamma}{d\Omega_{e\nu}} = 1 - \frac{\vec{p}^e}{E_e} \cdot \frac{\vec{p}^\nu}{E_\nu}$
Helicities in with Scalar or Tensor Currents

If the nuclear spins don’t flip then the leptons have total $J_z=0$

\[
\begin{align*}
J_z^e & \quad \leftrightarrow \quad p^e \\
J_z^\nu & \quad \rightarrow \quad p^\nu
\end{align*}
\]

Consequence: e-antinu correlation

\[
\frac{d\Gamma}{d\Omega_{ev}} = 1 - \frac{\vec{p}^e}{E_e} \cdot \frac{\vec{p}^\nu}{E_\nu}
\]

If the nuclear spins flip then the leptons have total $J_z=1$

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Consequence: e-antinu correlation

\[
\frac{d\Gamma}{d\Omega_{ev}} = 1 + \frac{\vec{p}^e}{E_e} \cdot \frac{\vec{p}^\nu}{E_\nu}
\]
Searching for tensor currents in $^6\text{He}$

Instead of detecting the neutrino, determine momentum of electron and $^6\text{Li}$

Problem: slow $^6\text{Li}$, will loose momentum in ANY supporting layer.

Solution: hold $^6\text{He}$ with light!
Interaction for GT transitions

\[ H = \overline{\Psi}_f \gamma^\mu \gamma_5 \Psi_i \quad 2C_A \overline{e^L} \gamma_\mu \gamma_5 \nu_e^L + \]
\[ \overline{\Psi} \gamma^\mu \gamma^\nu \Psi_i \quad \left( C_T - C_T' \right) \overline{e^L} \gamma_\mu \gamma_\nu \nu_e^R + \left( C_T + C_T' \right) \overline{e^R} \gamma_\mu \gamma_\nu \nu_e^L \]

Decay rate:

\[ dw = dw_0 \left[ 1 + a \frac{p_e}{E_e} \cdot \frac{p_\nu}{E_\nu} + b \frac{\Gamma m_e}{E_e} \right] \]

\[ b \approx \frac{\text{Re} \left[ 2C_A \left( C_T + C_T' \right) \right]}{2 \left| C_A \right|^2 + \left| C_T \right|^2 + \left| C_T' \right|^2} \]

\[ a \approx -\frac{1}{3} \frac{2 \left| C_A \right|^2 - \left| C_T \right|^2 + \left| C_T' \right|^2}{2 \left| C_A \right|^2 + \left| C_T \right|^2 + \left| C_T' \right|^2} \]
Magneto-Optical Trap

- Six orthogonal, counter-propagating beams of opposite circular polarization are red-detuned as in the Doppler cooling configuration.
- Anti-Helmholtz coils introduce a quadrupole field with zero magnetic field at the center and linearly increasing field in the directions of the lasers.
Production of $^6$He at Seattle via $^7$Li(d,$^3$He)$^6$He

Now have a reliable source of $^6$He yielding $10^9$ atoms/s in a clean room!

A High-Intensity Source of 6He Atoms for Fundamental Research
A. Knecht et al.
NIM A. 660, 43 (2011)
Extracting $g_A$ from the lifetime of $^6$He

- Two previous experiments disagreed by 9 ms. Resolved the discrepancy.
- Our results in combination with ab-initio calculations shows that quenching is at most about 2%.
Trapping of $^6\text{He}$

- RF discharge in xenon/krypton to excite into metastable state
- Cycling on 1083 nm transition to transversely cool, slow down and trap magneto-optically
- Trapped atoms transferred to detection chamber with dipole trap
- Based on experience from $^6\text{He}$, $^8\text{He}$ charge radius measurements by ANL collaborators:  
  L.-B. Wang et al., PRL 93, 142501 (2004)  
$^6$He Little $a$, detection

- Electron and $^6$Li recoil nucleus detected in coincidence

- $\Delta E$-E scintillator system for electron detection (energy, start of time-of-flight)

- Micro-channel plate detector for detection of recoil nucleus (position, time-of-flight)
We have already trapped about 500 atoms of $^6\text{He}$ at CENPA. But need a more stable source for e-n correlation experiment.
Recent work on low-energy nuclear physics

$^{22}\text{Na}(p,\gamma)$ and expected gamma signatures from Novae.

Nuclear Astrophysics

Our measurements revealed that $^{22}\text{Na}(p,\gamma)$ rate is about 3 times higher than previously thought! Partially explains why it has not yet been observed with gamma - telescopes!

-in collaboration with TRIUMF

Measurement of largest isospin breaking correction and determination of $V_{ud}$

Fundamental symmetries

Our measurements allowed for a stringent test of calculations that are important in determining $V_{ud}$, the quark weak mixing angle.

A. Sallaska et al.
PRL 105, 152501 (2010)
PRC 83, 034611 (2011)

D. Melconian et al.
PRL 107, 182301 (2011)
Recent work on low-energy nuclear physics

Searches for Time-Reversal Symmetry breaking.

Determination of the axial coupling Constant with Ultra-cold neutrons.

Fundamental symmetries

Most sensitive search for breaking of $T$ in nuclear beta decays

- in collaboration with NIST, Berkeley, Michigan...

P. Mumm et al. (emiT collaboration)
PRL 107, 102301 (2011)

Fundamental symmetries

Our measurements allowed for a stringent test of calculations that are important in determining $V_{ud}$, the quark weak mixing angle.

J. Liu et al. (UCNA Collaboration)
The End