Residual Gas Effect on aCORN

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Outline

1. aCORN Experiment Overview
2. Residual Gas Effect Overview
3. Residual Gas Simulation Results
4. Measurement of the Residual Gas Composition
5. How do we arrive at a final value for the size of this systematic effect?
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Neutron Decay
What is aCORN?

Little a CORrelation
in Neutron Decay
Neutron Decay Parameters

Phenomenological ($\frac{1}{2}^+ \rightarrow \frac{1}{2}^+$) beta decay formula
(Jackson, Treiman, Wyld, 1957)

$$dW \propto \frac{1}{\tau} F(E_e) \left[ 1 - \frac{\vec{p}_e \cdot \vec{p}_\nu}{E_e E_\nu} + A \frac{\vec{p}_e \cdot \vec{p}_\nu}{E_e E_\nu} + B \frac{\vec{p}_e \cdot \vec{p}_\nu}{E_\nu} + D \frac{\vec{p}_e \times \vec{p}_\nu}{E_e E_\nu} + b \frac{m_e}{E_e} \right]$$

In the standard model we have

- $a \approx \frac{1 - \lambda^2}{1 + 3 \lambda^2}$
- $A \approx -2 \frac{\lambda^2 + \text{Re}(\lambda)}{1 + 3 \lambda^2}$
- $\tau \approx \frac{1}{g^2 \nu (1 + \lambda^2)}$
- $b = 0$
- $B \approx 2 \frac{\lambda^2 - \text{Re}(\lambda)}{1 + 3 \lambda^2}$
- $D \approx 2 \frac{\text{Im}(\lambda)}{1 + 3 \lambda^2}$

Where $\lambda \equiv \frac{G_F}{g_\nu}$

**Standard Model Predictions**

- $F_1 \equiv 1 + A - B - a = 0$
- $F_2 \equiv a B - A - A_2 = 0$

**Present Limits**

- $F_1 = (3 \pm 6) \times 10^{-3}$
- $F_2 = (3 \pm 5) \times 10^{-3}$

(dominated by “a”)

$a = -0.1030 \pm 0.0040$
aCORN Schematic

Proton Momentum Space Diagram

Group I (Fast)  Group II (Slow)
The Wishbone

• Group I = Fast, Small TOF
• Group II = Slow, Large TOF

\[ a = \frac{1}{\nu_\beta} K(E_\beta) \left[ \frac{N_{Fast} - N_{Slow}}{N_{Fast} + N_{Slow}} \right] \]
The aCORN Apparatus

Proton Collimator Location

Solenoid

Decay Volume Location
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Residual Gas Effect

• The gas remaining in the vacuum apparatus during data collection will have an effect on the asymmetry we are measuring.

• We are attempting to measure the size of this residual gas effect by increasing the pressure in the apparatus and recording the effect this has on the asymmetry. Is the effect linear?

• We are also modelling the effect in order to guarantee that the physics of the effect is well enough understood to trust the experimental data.

High Pressure = 100 times running pressure
Effect = -.1 (deviation in asymmetry)

Running Pressure
Effect = -.1/100 = -.001
Residual Gas Effect Continued

185 cm

Proton Detector
Residual Gas
Neutron Decay!
Residual Gas Experiment

= High pressure
  \( (2.5 \times 10^{-5} \text{ torr}) \)

= Normal pressure
  \( (4 \times 10^{-7} \text{ torr}) \)
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Geant 4 Simulation

= Running pressure (4x10^{-7} torr)

= High pressure (2.5x10^{-5} torr)
Residual Gas Simulation: Things to Consider

• Neutralization and Scattering
• Residual gas composition: Initially assumed to be $\text{H}_2$
• Pressure and Temperature in proton collimator: $4 \times 10^{-7} \text{ torr, 200K}$
Cross Sections: Proton in H₂ Gas

Cross Section Derivatives

• Recall:
  \[
  \text{Asymmetry} = \frac{N_{\text{Fast}} - N_{\text{Slow}}}{N_{\text{Fast}} + N_{\text{Slow}}}
  \]

• Thus:
  • Intuitively, a positive derivative would result in a negative change in asymmetry.
  • And a negative derivative would result in a positive change in asymmetry.
Neutralization

Method:

• Alteration of existing Runge-Kutta Monte Carlo to incorporate the effect of neutralization. Proton Energy and distance traveled per step are used to calculate proton weight.

\[ \text{Weight}_i = \text{Weight}_{i-1} \times e^{-\sigma \Delta x_i \pi} \]

- Neutron Decay
- Step 1
- Step 2
- Step 3
- Step 4
- Proton Detector
Scattering

• Energy considerations lead us to believe that the $\text{H}_2$ molecules are in their vibrational ground state.

• The large relative energy of the proton makes many vibrational states accessible for excitation.

Method:

• Alteration of existing Runge-Kutta Monte Carlo to incorporate the effect of scattering. When scattered the proton recoil velocity direction is randomized within a cone.
Monte Carlo Results

• The change in asymmetry (delta asymmetry) caused by the residual gas found in the MC is both the right sign and comparable in size to the preliminary experimental results.
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Residual Gas Analyzer (RGA) Results

Running Pressure (1.04 x 10^{-6} torr)

Highest Gas Load: \(\text{H}_2\) and \(\text{H}_2\text{O}\)

High Pressure (5.89 x 10^{-5} torr)

Highest Gas Load: \(\text{N}_2\) and \(\text{O}_2\)
Residual Gas Analyzer (RGA) Results

Running Pressure:
Highest Gas Load: \( \text{H}_2 \) and \( \text{H}_2\text{O} \)

High Pressure:
Highest Gas Load: \( \text{N}_2 \) and \( \text{O}_2 \)
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How to measure this Effect?

• Our proposed method for measuring the size of the effect will probably not suffice.

• We may need to just scale the pressure by a factor of 4 as opposed to a factor of 40 in order to maintain the same gas composition. But measuring the effect this way will take longer and be more difficult because the pressure effect will be smaller.

• Cross sections for low energy protons in H₂O must be found and put into the Monte-Carlo simulation.
Conclusion

• The residual gas systematic effect is relevant to several major neutron decay experiments (aCORN, Beam Lifetime, Nab) and thus a thorough investigation is necessary, especially when programs like Geant 4 are failing to aptly model the problem.

Thank you!
What are the energies of these protons?

- I recorded the energy of the proton for each step in the Monte Carlo for a given proton group (Fast or Slow) and Beta energy.
Residual Gas Analyzer (RGA) Results

Running Pressure (1.04 x 10^{-6} torr)

High Pressure (5.89 x 10^{-5} torr)

Highest Gas Load: \(\text{H}_2\) and \(\text{H}_2\text{O}\)

Highest Gas Load: \(\text{N}_2\) and \(\text{O}_2\)
RGA Results Continued

• Our proposed method for measuring the size of the effect will not work as we had thought.

• The regular running pressure, temp, RG composition. And the high pressure temp and RG composition?

• The purpose of the MC and the purpose of the experiment. And how the experimental value is used to actually get a value for the size of the systematic uncertainty.

\[
a = \frac{1}{v_\beta} K(E_\beta) \left[ \frac{N_{Fast} - N_{Slow}}{N_{Fast} + N_{Slow}} \right]
\]

\[
a(E_\beta) = \frac{1}{v_\beta} K(E_\beta) \left[ \frac{N_I - N_{II}}{N_I + N_{II}} \right]
\]