Momentum Spectroscopy of Neutron Beta Decay Products with NoMoS

Waleed Khalid for the NoMoS Collaboration
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Thanks for contributions from R. Jiglau, G. Konrad, D. Moser, & M. Valentan
Neutron Decay in the Standard Model

\[
\tau_n \propto \frac{1}{|V_{ud}|^2 (1 + 3|\lambda|^2)} \quad ; \quad \tau_n = 879.4(0.6)\text{s}
\]

\[
T_{p,max} = 751\text{ eV} \quad ; \quad T_{e,max} = 781.6\text{ keV}
\]

\[\lambda = \frac{g_A}{g_V}\]

quark mixing
Neutron Decay in the Standard Model

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Electron-Neutrino Correlation Coefficient

\[ a = \frac{1 - |\lambda|^2}{1 + 3|\lambda|^2} = -0.1059(28) \]

Fierz Interference Term

\[ b = 2 \frac{\text{Re}(g_s + 3\lambda g_T)}{1 + 3|\lambda|^2} = 0.067(90) \]
Measurement Principles

\[ \vec{v}_D \propto \frac{1}{q} \frac{\vec{R} \times \vec{B}}{R^2 B^2} \]

\[ D(p, \theta) = \int_{T} \nu_D \, dt \]

\[ = \frac{p}{qB} \cdot \frac{1}{2} \left( \cos \theta + \frac{1}{\cos \theta} \right) \cdot \alpha \]

X. Wang et al., NIM A 701, 254 (2013)
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Systematic Effects


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- **Beam definition**
  - Neutron beam: shape of profile, residual polarization
  - B Field: homogeneities
  - Aperture: edge effect & backscattering

- **RxB drift**
  - B Field: absolute height, homogeneity, radial gradient
  - Opening angle \( \alpha \)

- **Drift distance measurement**
  - Detector alignment & Edge effects
  - Backscattering & Detector Efficiency

- **Background**: Residual gas, neutron-induced radiation

- **Proton measurements**
  - Electrostatic potentials: E×B, filter, offset, trapping
  - Doppler effect: neutron velocity
Proton Detector Considerations

- $T_{p,max} = 751 \text{ eV}$
  - Post Acceleration ($\approx -15 \text{ kV}$)
- Large Detection Area (10x7 cm$^2$)
- Low Backscattering
- High spatial resolution (<1 mm)
- Linear Gain
- High Efficiency
- High S/N ratio
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Proton Detector Efficiency

![Graph showing the detection efficiency of proton detectors under different conditions.]{:width=576}

- **Post-Accelerated Proton Energy**
  - 2keV
  - 10keV
  - 5keV
  - 15keV

- **Detection Threshold in no. of Electron/Hole Pairs Generated**

  - **pLGAD**
  - **DEPFET (uncooled)**
  - **DEPFET (-50° C)**
  - **SSD**

*Preliminary Results*
Summary and Outlook

• Precision measurements of neutron decay
  • Independent value for $V_{ud}$ needed to shed light on top row CKM unitarity
  • Search for Physics beyond the Standard Model
• NoMoS Magnet system
  • Final optimizations in progress
• Systematic effects
  • Most systematic effects incorporated into fit function
  • Further investigations incl. MC simulations under way (using Geant)
• Detection System
  • Comparison of different detection techniques for secondary detectors in progress
  • Electrode design being developed (TASK Poster ID: 386)
  • Pursuit of pLGADs as the proton drift detector looks promising
Influence of Electron-Neutrino Coefficient on Spectra

![Graph showing the influence of electron-neutrino coefficient on spectra. The graph plots momentum (p) in keV/c against yield (a.u.). Two curves are shown: one for a = 0 and another for a = -0.103.](image)
Residual Spectra

The graph shows the residual spectra for different detector positions. The upper graph represents the yield (a.u.) with two curves: red (p+) and blue (e−), while the lower graph shows the residual intensity multiplied by 10^-5 (a.u.) for p+ with Δa/a = 2.8×10^-3 and e− with Δb = 1.2×10^-3.
Systematic Effects
Surface Effects (Charge Collection Efficiency)

- For Protons CCE is an important effect to consider
- CCE is not uniform due to
  - Surface defects
  - Recombination of holes and electrons

\[ f_{cce}(z) = 1 - \gamma e^{-\frac{z}{\tau}} \]

\( \gamma \in [0.6, 0.9] \) & \( \tau = [50, 100] \text{nm} \)

Post-Acceleration Electrode

Different Geometries

Cylinder

Field Degrader

$$D_{E\times B} \propto \frac{E_n}{\sqrt{T - eU}}$$

*Work in Progress*
Best sensor: DEPFET

- Depleted P-channel Field Effect Transistor
- Fully depleted pixel sensor, pixels of any size possible
- Stores signal charge, can be read repeatedly
  - Very low noise
  - Best suited to our needs
- But long lead time (2 years), very expensive (5 sensors, 300 k€) and it requires additional cooling
  → not feasible at the moment
Current focus: pLGAD

- Combination of two existing concepts:
  - Low Gain Avalanche Diode for internal signal amplification
  - Pixel readout structure for 2D information and low noise rate

- Compared to a cooled DEPFET sensor, this sensor type
  - Has higher noise and thus lower efficiency
  - Has a much simpler readout
  - It is a lot cheaper
  - Would be a new, custom development (2 years)