Beta decay of $^{32}$Ar for fundamental tests

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Outline

• 1999 measurement of positron-neutrino correlation in $^{32}$Ar($e^+ \ nu_e$): ISOL facility (CERN-ISOLDE)

• 2008 measurement the $ft$ value for superallowed $^{32}$Ar($e^+ \ nu_e$) decay to test isospin symmetry breaking corrections: fragmentation facility (MSU-NSCL)

• Where does ATLAS fit in to this? A bridge from stability to $^{32}$Ar!
Detecting scalar currents in weak decays

The $e^-\nu$ correlation depends strongly on the nature of the carrier (we take a $0^+ \rightarrow 0^+$ transition).

- Spins have to couple to zero
- $e^+$
- $\nu$

**Standard Model**

**Vector Currents**

**New Physics?**

**Scalar Currents**

\[
dW/d\Omega = 1 + \frac{p_{e}p_{\nu}}{E_e E_{\nu}}
\]

\[
dW/d\Omega = 1 - \frac{p_{e}p_{\nu}}{E_e E_{\nu}}
\]
A trick to avoid detecting the neutrino

Instead of detecting the neutrino
We detect the proton that contains the info about the $^{32}\text{Cl}$ recoil (Doppler)

Monte-Carlo calculation of proton energy

$$\frac{dn}{dE} \text{ (arbitrary units)}$$
Problem: Summing with positrons distorts the shape of the proton peak

\[ \Delta E_p (\text{keV}) \]

These events belong here
Experimental set-up

Super-conducting solenoid
\[ B = 3.5 \text{ Tesla} \]

PIN diode
At \(-11\) C

32Ar beam from Isolde

Collimator

Peltier with feedback

LN2 cavity and bell

LN2 intake

Beam collimator
Simultaneous fit of $^{32}\text{Ar}$ and $^{33}\text{Ar}$ data

1999 result: $\tilde{\alpha} = 0.9980(52)_{\text{stat}}(39)_{\text{syst}}$

[Adelberger et al., PRL 83 (1999) 1299]
But, since then…

- Precision measurement of $^{32}\text{S}(p,p)^{32}\text{S}$ 3374.7-keV resonance energy [Pyle et al. PRL 88, 122501 (2002)]
- Precision measurement of $^{32}\text{Ar}$ mass [Blaum et al., PRL 91, 260801 (2003)]
- Precision determination of the mass of the lowest $T=2$ level in $^{32}\text{Cl}$ via precision measurement of $^{31}\text{S}$ mass [CPT collaboration, to be submitted]
- All of these change ∆a substantially!
$T=2$ nuclei present an alternative way to check Isospin breaking corrections

Bhattacharya et al., PRC 77, 065503 (2008)
\( V_{ud} \) from superallowed \( 0^+ \Rightarrow 0^+ \) beta decay

- Determining \( ft \) value requires precision measurements of \( Q \) value, \( t_{1/2} \), and superallowed branching
- Extracting corrected \( F_t \) from \( ft \) requires radiative and isospin-symmetry-breaking corrections
- Measurements on \( T=1 \) decays are so precise that correction terms now dominate uncertainty in the average \( F_t \), which determines \( V_{ud} \)
- Need to test theoretical corrections by experiment: eg. test \( \delta_C \) for \( T=2 \) \(^{32}\)Ar
proton and gamma-ray emission from T=2 state
Experiment to determine branch of $^{32}$Ar super-allowed transition (MSU)

Beta-delayed proton spectrum

$^{32}$Ar ion identification

Beta-delayed proton spectrum

all decays

superallowed

p1 decays
Summary of super-allowed $^{32}$Ar branches:

$$\frac{N_p}{N_{Ar}} = \frac{N_{p0}}{N_{Ar}} (1 + \frac{N_{p1}}{N_{p0}} + \frac{N_{p2}}{N_{p0}}) = 20.9(1)\%$$

$$\frac{N_{\gamma}}{N_{Ar}} = \frac{\sum_{i} N_{\gamma}(i)}{N_{Ar} \sum_{i} \epsilon_{\gamma}(i) \epsilon_{\beta}} = 2.03(10)\%$$

Systematic uncertainties:

<table>
<thead>
<tr>
<th>Component</th>
<th>$b(%)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>implt. $^{32}$Ar’s</td>
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</tr>
<tr>
<td>p0 branch</td>
<td>0.5</td>
</tr>
<tr>
<td>p1 branch</td>
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<tr>
<td>p2 branch</td>
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<td>gamma branch</td>
<td>0.4</td>
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<tr>
<td>other</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Isospin-breaking correction:

Measurement: $\delta_c^{\text{exp}} = 2.1(8)\%$

Theory: $\delta_c^{\text{th}} = 2.0(4)\%$
But, results are dependent on…

- **Absolute gamma-ray branchings from \( ^{32}\text{Cl}(\beta\gamma)^{32}\text{S} \):** measured separately [Melconian *et al.*, to be submitted]

- **Results of the lepton-correlation experiment described previously** [Adelberger *et al.* PRL 83 (1999) 1299], which are in turn strongly dependent on quantities that are still being measured!
An idea to determine lepton correlations and particle branches with high precision to be used with FRIB.

In the short term we can improve determination of $a$ in 32Ar by a factor of 5!

In the longer range this device can be used in FRIB to produce useful standards for calibration of particle branches and as a spectroscopic tool.
Where does ATLAS fit in to this?

- In this mass region and below ATLAS has unique capabilities (e.g., CPT & Gammasphere) to obtain precision data on nuclides 1 or 2 nucleons from stability on the proton-rich side.
- Would be very useful if this information were more complete before other precision decay studies on $T=2$ nuclides commence.
- Request that ATLAS PAC take into consideration proposed measurements of unstable nuclides near stability that utilize ATLAS’s unique capabilities simply to “fill in” detailed information about these nuclides and facilitate future precision experiments at FRIB.
Thank you!