New measurements of γ-ray branching ratios in the β^+ decay of ^{32}Cl.

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MOTIVATION

The Standard Model has long been a foundation of particle physics theory. In the decades since its inception, it has predicted new particles, unified the electromagnetic and weak forces, won the Nobel Prize, and withstood the test of many rigorous experiments.

Although the Standard Model is a triumph of modern science, it is believed to be incomplete; for example, it does not include dark matter or gravity and it can't explain why there is more matter than anti-matter in the universe.

The Cabibbo-Kobayashi-Maskawa (CKM) matrix describes the probability of a transition from one quark to another: in others words, it gives the strength of flavor-changing weak decays. Because the CKM matrix should be unitary, its experimental verification becomes a powerful test of the Standard Model.

$$\begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} \begin{bmatrix} |d\rangle \\ |s\rangle \\ |b\rangle \end{bmatrix} = \begin{bmatrix} |d'\rangle \\ |s'\rangle \\ |b'\rangle \end{bmatrix}$$

The CKM matrix is shown above on the left with the mass eigenstates of the quarks in the middle and the weak force eigenstates on the right.

- Within the last year new experimental data and theoretical calculations have yielded values that now strongly support a unitary CKM matrix:

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1.0000 \pm 0.0011.$$ [1]

- This ± 0.1% uncertainty sets stringent limits on new physics.
- The largest factor of the unitary test is the up-down quark-mixing matrix element V_{ud}, and its most accurate value comes from experimental tests of superallowed 0+ → 0+ beta decays.
- The value of V_{ud} is modified by a number of calculated terms, among them the isospin – symmetry breaking correction, δc. This term may be measured in some cases which could help validate the theoretical calculations and reduce uncertainties in the extraction of V_{ud}.

BACKGROUND

A recent experiment measuring the δ_c in ^{32}Ar found the following value:

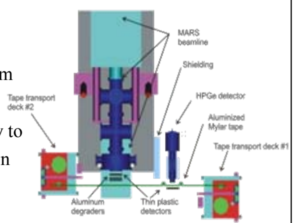
$$\delta_c^{exp} = (2.1 \pm 0.8)\ \%^2$$

This result is in agreement with the theoretical prediction, δ_C = (2.0 ±0.4)%; however, reducing the uncertainty will make it a more rigorous test of theory. One of the sources of uncertainty in δ_C was the γ branching ratios from the decay measured by a set of 5 high-purity Germanium (HPGe) detectors. ^{32}Cl is a decay product of ^{32}Ar and has γ-rays which cover the same energy range; it could therefore be used as an *in situ* calibration source for the δ_C experiment. However, Detraz *et al.*[3] last measured the ^{32}Cl γ and β branching ratios over 35 years ago, and the uncertainties in their results contributed to the final uncertainty in δ_C.

By measuring the γ-ray branching ratios in the β^+ decay of ^{32}Cl (a decay product of ^{32}Ar which covers the same energy range), the detector efficiencies can be better determined, allowing for a more precise determination of δ_C.

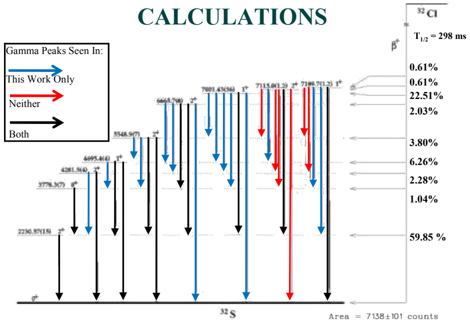
EXPERIMENTAL SETUP

- A beam of ^{32}Ar was produced at the Texas A&M Cyclotron and purified in the MARS recoil spectrometer
- A fast-tape transport system collected the ^{32}Ar and was used to transfer the activity to a shielded counting position in $T_{transfer} \approx 0.2$ seconds



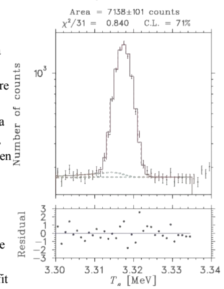
- The intensity of the gamma rays was measured in coincidence with beta particles. This HPGe was used because its absolute efficiency has been calibrated better than any other in the world.

CALCULATIONS



Peak Fitting & Analysis

- Data was fit using a line-shape consisting of a Gaussian peak, low energy tail, and background. A variety of peak parameters were varied to obtain the best possible χ^2 value.
  - All the peaks (save 2230 and 4770) had a reduced χ^2 (χ^2 per d.o.f.) of less than 1.6, with most centering on 1.0 (example given to the right)
  - Small gain variations can contribute to a non-Gaussian line shape when peaks are summed; fitting each run separately counteracts this effect. Doing this for the 2230 and 4770 peaks improved the χ^2 dramatically without changing the total fit area.
  - If a potential γ-ray did not show a peak above background in our spectrum, we still fit the area to be able to set limits on the possible yield.



- The data underwent various cuts to remove impurities and ensure a high signal-to-noise ratio.
  - Cut on time after $T_{transfer}$: to remove impurities with longer and shorter half-lives than ^{32}Cl
  - B-γ timing cut: to reduce random γ events that were not collected in coincidence with β events

RESULTS

Our preliminary results agree for the most part with Detraz's work while maintaining a much higher degree of precision, though some strong inconsistencies remain.

Beta yield of ^{32}Cl

^{32}S daughter level (keV)	Detraz[3] (%)	This Work (%)*
2230.5	60 ±4	61.05 ±0.17
3778.7	2.6 ±0.8	1.00 ±0.07
4281.5	3.1 ±0.4	2.18 ±0.07
4694.2	6.8 ±0.8	6.12 ±0.08
5548	4.1 ±0.5	3.67 ±0.07
6664.0	1.8 ±0.5	2.02 ±0.07
7000.5	20.5 ±2.0	21.74 ±0.13
7112	0.5 ±0.2	0.59 ±0.04
7194	0.9 ±0.1	0.63 ±0.04

* Statistical uncertainty only

Gamma yield from the decay of ^{32}Cl

E_γ(keV)	Detraz[3] (%)	This Work(%)*
853		0.02 ±0.01
917		0.03 ±0.01
1267		0.03 ±0.01
1452		0.27 ±0.02
1548	3.6 ±0.6	3.04 ±0.06
1771		0.12 ± 0.02
1970		0.15 ± 0.04
2051.2		0.44 ±0.06
2230.5	92 ±4	89.91 ±0.16
2419.6		0.045 ±0.018
2463.8	4.0 ±0.4	4.10 ±0.06
2720		0.51 ±0.02
2833.5		.02 ±0.01
2885	1.0 ±0.4	0.96 ±0.02
3223		0.84 ±0.03
3317.5	2.5 ±0.4	2.37 ±0.06
3336		0.03 ±0.01
3411		0.11 ±0.02
3778		0.04 ±0.03
4281.5	2.6 ±0.1	2.38 ±0.05
4433	0.8 ±0.2	0.78 ±0.04
4694	2.8 ±0.6	2.36 ±0.04
4770.0	20.5 ±2.0	19.94 ±0.12
4881	0.45 ±0.20	0.49 ±0.03
4959.4		0.32 ±0.02
5549.5	1.6 ±0.3	1.41 ±0.04
6665		0.04 ±0.02
7001		0.06 ±0.02
7194	0.41 ±0.10	.18 ±0.02

* Statistical uncertainty only

- The data collected in this work is about an order of magnitude more precise in most of the peaks, and almost 2 orders in the 4881 keV peak.
- Though most of the γ-yield percentages are in agreement, discrepancies are seen in the 4281 and 7194 keV peaks.
- 17 new gamma peaks are seen, this is due to a combination of factors: a quality beam produced in the A&M Cyclotron, MARS purifying of the beam, and the precise HPGe detector.

CONCLUSIONS

Though these results are preliminary, their statistical precision far surpasses the previous measurements of the branching ratios of ^{32}Cl. In addition, numerous new gamma peaks were seen. Systematic uncertainties, from the different timing cuts for example, still remain to be investigated. Even with systematic uncertainties yet to be included, the results promise to drastically increase the precision in ^{32}Cl branching ratios. This will help improve the measurement of δ_C in ^{32}Ar decay and ultimately better test theoretical calculations used to extract V_{ud}.

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