$\gamma\text{-ray}$ Branching Ratios in the B^+ Decay of ^{32}Cl

Revolutionary New Measurements



Mark Hernberg Advisor: Dr. Dan Melconian

Standard Model

A Predictive Model

•W and Z Bosons •Higgs Boson

A Unifying Model

Unified Weak and EM forces

•Grouped electroweak theory with quantum chromodynamics (strong)



An Incomplete Model?

CP Violation

- C Charge Conjugation
- P Parity
- Inelegant
- Gravity
- Dark Matter
- • •



Cabibbo-Kobayashi-Maskawa



• Gives the strength of flavour-changing weak decays.

V_{ud}	V_{us}	V_{ub}	$\left[\left d \right\rangle \right]$		$\left[\left d' \right\rangle \right]$
V_{cd}	V_{cs}	V_{cb}	$ s\rangle$	=	s' angle
V_{td}	V_{ts}	V_{tb}	$ b\rangle$		$ b'\rangle$

• Should be **unitary**



- Gives the strength of flavour-changing weak $V_{ij} = \begin{bmatrix} 0.97383 & 0.2272 & 0.00396 \\ 0.2271 & 0.97296 & 0.04221 \\ 0.00814 & 0.04161 & 0.999100 \end{bmatrix}$
- Should be **unitary**

|d'> = 0.974|d> + 0.227|s> + 0.004|b>

Unitarity implies $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$

Unitary Test

The CKM matrix has (for decades) failed the unitary test! Even renewed study has yielded values that are 2 standard deviations from unitary!

The newest experimental data and theoretical calculations now strongly support unitary:

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

CITATION:

J.C Hardy, I. Towner, Nucl. Phys. Rev. C77, 025501 (2008)

M.-W. Yao *et al*. J. Phys. G: Nucl. Part. Phys. C 1 (2006)

Measurement of V_{ud}

- o⁺ → o⁺ decays yield the most precise study
- Numerous correction terms (~1%)

 Isospin symmetry breaking correction





δ_{C} Calculations

- Measure δ_c in a case where it is large: ³²Ar
 - Recently measured





δ_{C} Calculations

- Measure δ_c in a case where it is large: ³²Ar
 - Recently measured
- δ_c is calculated with Ft values:
 - Q value (E released in decay)
 - Half life
 - Branching ratio



Motivation Summary

- Standard Model
 - Is it incomplete?
- CKM Matrix
 - Unitary Test
- V_{ud} Term
- $\delta_{\rm C}$ Correction Term
- Importance of Detector Calibration
 - 32Ar and 32CL energy overlap



More Experimental Setup

- ³²Cl beam was produced in the Cyclotron
- passed through MARS to purify
 - Momentum Achromat Recoil Separator
- A fast-tape transport system was then used to collect the ³²Cl, then quickly move it to a shielded counting position
- Measured gamma ray intensity in coincidence with beta particles



More Experimental Setup

- ³²Cl beam was produced in the Cyclotron
- passed through MARS to purify
 - Momentum Achromat Recoil
 Separator
- A fast-tape transport system was then used to collect the ³²Cl, then quickly move it to a shielded counting position
- Measured gamma ray intensity in coincidence with beta particles
- Best absolute efficiency calibrated HPGe detector in the world.



Spectrum Analysis



Spectrum Analysis



Spectrum Analysis



Peak Analysis

□ Peak Fitting

- Vary parameters to best match data
- Minimize χ² value

$$\sum_{i=1}^k \frac{(X_i - \mu_i)^2}{\sigma_i^2}$$

Used reduced χ²

□ Fitted non-existent peaks











□ Different cuts made on the data

- Timing
- Coincidence



□ Different cuts made on the data





Different cuts made on the data





Beta Yield Results

Beta yield of ³²Cl

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

Gamma Yield Results

E _γ (keV)	Detraz ³ (%)	This Work(%)*
1452		0.27 ±0.02
1548	3.6 ±0.6	3.04 ±0.06
2230.5	92 ±4	89.91 ±0.16
2463.8	4.0 ±0.4	4.10 ±0.06
2720		0.51 ±0.02
2885	1.0 ±0.4	0.96 ±0.02
3223		0.84 ±0.03
3317.5	2.5 ±0.4	2.37 ±0.06
3411		0.11 ±0.02
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
7194	0.41 ±0.10	.18 ±0.02



To Infinity and Beyond

- Further investigation of systematic errors is needed
 - How do different cuts affect the results?
 - Correct for detector efficiency

It's OK To Be Jealous

- Drastic improvement in precision of the branching ratios of ³²Cl.
- A dozen new gamma peaks were seen
- Results promise to improve the measurement of δ_{C} in $^{32}\mbox{Ar}$ decay
- Ultimately our high precision results will better test theoretical calculations used in superallowed decays.



- Dr. Dan Melconian
- Mr. Lawrence Wayne May Jr.
- Dr. Yenello





National Science Foundation



~3in



0.5mm Be 'window'

- **3 Main Events in Detector:**
- 1. Photoelectric Effect
- 2. Compton Scattering
- 3. Pair Production