

Daniel Burdette University of Notre Dame

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The 13th International Conference on Stopping and Manipulation of Ions and related topics (SMI-2019)



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The Standard Model of Elementary Particles



- Provides a description of matter in the universe
- There are still a couple shortcomings:
 - matter vs. antimatter asymmetry
 - dark matter/energy
 - why 3 generations?
 - neutrino hierarchy
- Want to find some sort of experimental evidence that there is something beyond this







 The CKM matrix describes mixing between quark's strong eigenstates through weak interactions

$$\begin{pmatrix} |d_w\rangle \\ |s_w\rangle \\ |b_w\rangle \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} |d_s\rangle \\ |s_s\rangle \\ |b_s\rangle \end{pmatrix}$$



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 The standard model requires the CKM matrix to be unitary, with most precise test given by top row

$$\sum_{i} |V_{ui}|^2 = |V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$$

- Imperfections could lead to new physics:
 - Another quark generation
 - Extra Z boson
 - Supersymmetry

...or be from bad experimental data..



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 V_{ud} can be obtained via nuclear beta decay



Obtaining the V_{ud} element

- For a reliable CKM matrix unitarity test, V_{ud} need to be precise and accurate.
- Accuracy tested by a determination of V_{ud} using multiple systems.



I.S. Towner and J.C. Hardy, Rep. Prog. Phys. 73, 046301 (2010)

- Neutron decay
 - > No nuclear corrections
 - Lifetime issues
 - Need Fermi-GT mixing ratio

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- Pion decay
 - No nuclear corrections
 - Very low branching ratio
- Pure Fermi transitions
 - Most precise determination
 - Need nuclear corrections
- Nuclear Mirrors
 - Need nuclear corrections
 - Need Fermi-GT mixing ratio





Study strength of transition with corrected $\mathcal{F}t$ value,

$$\mathcal{F}t^{0^{+} \to 0^{+}} = ft(1 + \delta_{R}^{\prime})\left(1 + \delta_{NS}^{V} - \delta_{C}^{V}\right) = \frac{K}{2G_{V}^{2}(1 + \Delta_{R}^{V})}$$

Need both experimental measurements and theoretical calculations:

- Experimental
 - Q value (*f*)
 - half-life $(t_{1/2})$
 - branching ratio (BR)

$$t = t_{1/2} \left(\frac{1 + P_{EC}}{BR} \right)$$

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- Theoretical
 - Nucleus dependent radiative terms (δ_R' and δ_{NS}^V)
 - Isospin symmetry breaking correction term (δ_C^V)









J.C. Hardy and I.S. Towner, PRC **91**,025501 (2015).



Z of daughter





V_{ud} from mirror transitions

- Other avenue to extract V_{ud} , test CVC, and test δ_c .
- Only 5 nuclei
- 1.04One more parameter needed: • 1.02Half-life \checkmark qn **Branching ratios** 0.98 $\frac{1}{2}$ 0.96 **Q**-values ^{sn} 0.94 Fermi-to-Gamow 0.92 $\overset{+}{\sim}$ 0.92 $\overset{-}{\sim}$ 0.988 $\overset{-}{\sim}$ Teller mixing ratio p ρ determined by measuring either: 0.86 β asymmetry parameter A_{β} 0.84^{-1} 202530 35 40 15 Mass Number Av asymmetry parameter B_v
- β -v angular correlation $a_{\beta v}$



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Nuclear Science Laboratory









TwinSol facility



F.D. Becchetti et al., NIM A 505, 377 (2003)









Expended list of delivered RIB due to growing research activities

														36Sc	37Sc	38Sc	395c	40Sc	41Sc	42Sc	43Sc	44Sc	45Sc	46S
												34Ca	35Ca	36Ca	37Ca	38Ca	39Ca	40Ca	41Ca	42Ca	43Ca	44Ca	45C	
recent years									32K				33K	34K	35K	36K	37K	38K	39K	40K	41K	42K	43K	448
									30Ar	31Ar	32Ar	33Ar	34Ar	35Ar	36Ar	37Ar	38Ar	39Ar	40Ar	41Ar	42Ar	43A		
									28Cl	29Cl	30 C 1	31 C l	32 C 1	33 C l	34Cl	35 C l	36Cl	37 C l	38Cl	39C)	40Cl	41Cl	420	
							26S	27S	285	295	30S	315	325	335	34S	35S	36S	375	385	395	40S	415		
24P						25P	26P	27P	28P	29P	30P	31 P	32P	33P	34P	35P	36P	37P	38P	39P	401			
22Si 23Si						24Si	25Si	26Si	27Si	28Si	29Si	30Si	31Si	32Si	33Si	34Si	35Si	36Si	37Si	38Si	395			
21AI 22AI						23Al	24Al	25A1	26Al	27Al	28Al	29Al	30A1											
19Mg 20Mg 21Mg						22Mg	23Mg	24Mg	25Mg	26Mg	27Mg	28Mg	29Mg											
18Na 19Na 20Na						21Na	22Na	23Na	24Na	25Na	26Na	27Na	28Na											
16Ne 17Ne 18Ne 19Ne						20Ne	21Ne	22Ne	23Ne	24Ne	25Ne	26Ne	27Ne											
14F 15F 16F 17F 18F							19F	20F	21F	22F	23F	24F	25F	26F										
			120	130	140	150	160	170	180	190	200	210	220	230	240	250								
		10N	11N	12N	13N	14N	15N	16N	17N	18N	19N	20N	21N	22N	23N	24N								
	8C	90	10C	11C	12C	13C	14C	15C	16C	17C	18C	19C	20C	21C	22C	23C								







Recent Work with the β -Counting Station



Superallowed Transisiton Beta-Neutrino Decay Ion Coincidence Trap





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Superallowed Transisiton Beta-Neutrino Decay Ion Coincidence Trap





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Decay Ion Coincidence Trap





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Decay Ion Coincidence Trap











NSF



Paul Trap Simulations















- Although the most precise determination for V_{ud} comes from superallowed pure Fermi decays, mixed mirrors provide another test for accuracy
- With the half-life program winding down and production of mirror nuclei developed, the compilation of St. Benedict can begin
- Fast beams from *TwinSol* will be decelerated, thermalized and formed into bunches for injection into the Paul trap using a combination of a gas catcher, RF funnel, SPIG, and cooler-buncher
- Simulations of the Paul Trap are underway to determine the ideal electrode geometry to perform the angular correlation measurement







Acknowledgements

Maxime Brodeur Jason Clark James Kelly Jeffrey Klimes Andreas Pardo **Biying Liu**

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Thank you!



