Correlation measurements in β decay

G. Ban, P. Delahaye, D. Durand, X. Fléchard, E. Liénard, O. Naviliat-Cuncic, G. Quéméner, D. Rodríguez, J. C. Thomas, Ph. Velten

LPC Caen, GANIL, Univ. de Granada

DESIR meeting, Leuven, 26-28 May 2010

Precision measurements performed at low energy

to search for physics beyond the Standard Model

Existence of exotic currents in weak interaction



to test the foundations of the Standard Model

Test of the unitarity of the CKM matrix

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

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

1) Exotic currents in weak interaction (S, T vs V, A)

Measurement of β -v angular correlation in *unpolarized* nuclei



Next step ?

New candidate

- Different methods
 → different systematic effects
- Combination of independent measurements
 - \rightarrow better constraint on C_T

Severijns, Beck and Naviliat RMP78 (2006)

- Coincidences $\beta \gamma \rightarrow$ Doppler shift depends on "a"
- Source confinement : gas cell or trap

Comparison ⁸He - ¹⁸Ne → *Egorov et al NPA621(1997)745*







Next step ?

New candidate

- Different methods
 → different systematic effects
- Combination of independent measurements
 - \rightarrow better constraint on C_T

Severijns, Beck and Naviliat RMP78 (2006)

- Coincidences $\beta \gamma \rightarrow$ Doppler shift depends on "a"
- Source confinement : gas cell or trap

Comparison ⁸He - ¹⁸Ne → *Egorov et al NPA621(1997)745*





5 10⁵ events needed to measure $a_{GT} @ 0.5\%$ with ⁸He





Spiral 2

 Date: 29/04/2010
 Ref. EDMS: I-020760

 Author: M. Lewitowicz
 Object: Summary of RIB requested for Day 1 SPIRAL2 Phase 2 experiments

 To: SPIRAL2 Direction, SPIRAL2 SAC, GANIL Direction, GANISOL Group

If tests are really performed @ LIRAT in the coming years, this experiment could be considered as a day-one experiment @ DESIR ...

Isotope	z	A Min	A A Energy Energ in Max Min Max [keV] [keV]		Energy Max [keV]	Intensity Min [pps]	Intensity Max [pps]
8He Ne19	2	8 19		10 10	30	1,00E+07	1.00F+07
Na21 29.30.31.32Na	11 11	21 29	32	10 40	60	1,00E+02 1,00E+03	1,00E+07
Mg23 Al25	12 13	23 25		10 10	60 60	1,00E+02 1.00E+02	1,00E+07 1,00E+07
Si27 P29	14	27		10	60 60	1,00E+02	1,00E+07 1,00E+07
S31 Cl33	16 17	31 33		10 10	60 60	1,00E+02 1,00E+02	1,00E+07 1,00E+07
Ar35 K37	18 19	35 37		10 10	30 60	1,00E+07 1,00E+02	1,00E+04
51,52,53,54K	19	51	54	40		1,00E+03	

2) Test of the unitarity of the CKM matrix

Coupling of quark weak eigenstates to mass eigenstates in SM



2) Test of the unitarity of the CKM matrix

Coupling of quark weak eigenstates to mass eigenstates in SM



V_{ud} from Ft values of T = $\frac{1}{2}$ mirror transitions

Alternative method to $0^+ \rightarrow 0^+$ study



Potential ?

• Analysis of available data (5 nuclei) already leads to $V_{ud} = 0.9719 (17)$ competitive with result of n decay Naviliat & Severijns PRL102(2009)



V_{ud} from Ft values of T = $\frac{1}{2}$ mirror transitions Alternative method to $0^+ \rightarrow 0^+$ study V_{ud}^2 $\frac{1}{(T_{1/2}/BR)(1+C\rho^2)}$ Talk of A. Bacquias ρ = GT/F precisely determined yesterday from a correlation measurement (a, A) Potential ? adapted from Severijns et al PRC78(2008) • Error budget 20 Q_{EC} 15 Parts in 10³ T_{1/2} Need of $T_{1/2}$ and BR 10 $\overset{\circ}{\bullet}_{\mathsf{R}} \overset{\circ}{\bullet}_{\mathsf{NS}}$ especially ρ precise measurements ! 5 ρ 0 ²¹Na ²³Mg ²⁵Al ²⁷Si 29**P** ³¹S ³³Cl ³⁵Ar ³⁷K ³⁹Ca Parent nucleus

Beams?

• ¹⁹Ne, ³⁵Ar : already available @ LIRAT

 \rightarrow study started @ LPC :

• other beams :

Nucleus	T _{1/2}	BR (%)	(MoT)				
²¹ Na	22.49s	94.97	(ok)				
²³ Mg	11.32s	91.8	(ok)				
²⁵ AI	7.18s	99.16	(-)				
²⁷ Si	4.16s	99.77	(-)				
²⁹ P	4.14s	98.3	(-)				
³¹ S	2.57s	98.87	(-)				
³³ Cl	2.51s	98.58	(-)	Isotope	z	A Min	A Max
³⁷ K	1.23s	98.2	(ok)	8He Ne19	2 10	8 19	
³⁹ Ca	0.86s	100	(ok)	→ Na21 29,30,31,32Na → Mg23	11 11 12	21 29 23	32
⁴¹ Sc	0.6s	99.96	(-)	Al25 Si27 P29	13 14 15	25 27 29	
Date: 29/04/2010		Ref. EDMS	: 1-020760	S31 Cl33 Ar35	16 17 18	31 33 35	

- LPCTrap performances



Energy Energy Intensity Intensity

Min

[pps]

1,00E+03

60 1 00E+02 1 00E+07

60 1,00E+02 1,00E+07

60 1,00E+02 1,00E+07

30 1,00E+07

Мах

[pps]

Мах

[keV]

Min

[keV]

10

10

10

40

10

- feasibility study ...

Spiral2	1

					Al25	13	25		10	60	1,00E+02	1,00E+07
41		0.65	90 96	(-)	Si27	14	27		10	60	1,00E+02	1,00E+07
	00	0.05	00.00		P29	15	29		10	60	1,00E+02	1,00E+07
					S31	16	31		10	60	1,00E+02	1,00E+07
F			D (50)		CI33	17	33		10	60	1,00E+02	1,00E+07
	Date: 29/04/2010 Ref. EDMS: I-02		S: 1-020760	Ar35	18	35		10	30	1,00E+07		
	Author: M. Lewitov	vicz			K37	19	37		10	60	1,00E+02	1,00E+04
		(51,52,53,54K	19	51	54	40		1,00E+03	
Object: Summary of RIB requested for Day 1 SPIRAL2 Phase 2 experiments				> Ca39	20	39		10	60	1,00E+02	1,00E+07	
To: SPIRAL2 Direction, SPIRAL2 SAC, GANIL Direction, GANISOL Group					> Sc41	21	41		10	30	1,00E+07	
	L				78Co	27	78		30	60	5.00F-01	

Beams?

¹⁹Ne, ³⁵Ar : already available @ LIRAT

→ study started @ LPC :

• other beams :

Nucleus	T _{1/2}	BR (%)	(MoT)				
²¹ Na	22.49s	94.97	(ok)				
²³ Mg	11.32s	91.8	(ok)				
²⁵ AI	7.18s	99.16	(-)				
²⁷ Si	4.16s	99.77	(-)				
²⁹ P	4.14s	98.3	(-)				
³¹ S	2.57s	98.87	(-)				
³³ Cl	2.51s	98.58	(-)				
³⁷ K	1.23s	98.2	(ok)				
³⁹ Ca	0.86s	100	(ok)				
⁴¹ Sc	0.6s	99.96	(-)				
Date: 29/04/2010 Ref. EDMS: I-020760							

- LPCTrap performances - feasibility study ...

.ol 2010



2.51s	98.5	8	(-)		Isotope	z	A Min	A Max	Energy Min [keV]	Energy Max [keV]	Intensity Min [pps]	Intensity Max [pps]
1.23s	98.2	2	(ok)		8He	2	8		10	30	1,00E+07	4 005 07
			(- <i>)</i>		Ne19	10	19		10	60	$1,00E \pm 0.2$	1,000007
					-> Na21	11	21		10	60	1,00E+02	1,00E+07
0.865	100		(ok)		29,30,31,32Na	11	29	32	40		1,00E+03	
0.000	100				🔶 Mg23	12	23		10	60	1,00E+02	1,00E+07
					🔶 Al25	13	25		10	60	1,00E+02	1,00E+07
0.60	90 0	6 1	(_)		🔶 Si27	14	27		10	60	1,00E+02	1,00E+07
0.03	33.3	u	(-)		→ P29	15	29		10	60	1,00E+02	1,00E+07
					→ S31	16	31		10	60	1,00E+02	1,00E+07
					-> Cl33	17	33		10	60	1.00E+02	1.00E+07
		Ref. EDMS:	I-020760		Ar35	18	35		10	30	1.00E+07	_,
7					→ K37	19	37		10	60	1.00E+02	1 00F+04
۶ <u>۲</u>					51 52 53 54K	10	51	54	40	00	1,00E+02	1,002101
y of RIB requested	for Day 1 SPI	RAL2 Ph	ase 2 experiments		51,52,55,54K	20	20	54	+0	60	1,000+03	1 005 1 07
				Case	20	39		10	60	1,00E+02	1,00E+07	
To: SPIRAL2 Direction, SPIRAL2 SAC, GANIL Direction, GANISOL Group					→ Sc41	21	41		10	30	1,00E+07	
					78Co	27	78		30	60	5.00E-01	
2	2.51s 1.23s 0.86s 0.6s	2.51s 98.5 1.23s 98.2 0.86s 100 0.6s 99.9 v of RIB requested for Day 1 SPI n, SPIRAL2 SAC, GANIL Direction, GANISOL Groups	2.51s 98.58 1.23s 98.2 0.86s 100 0.6s 99.96 Ref. EDMS: z y of RIB requested for Day 1 SPIRAL2 Phrase	2.51s 98.58 (-) 1.23s 98.2 (ok) 0.86s 100 (ok) 0.6s 99.96 (-) Ref. EDMS: H020760	2.51s 98.58 (-) 1.23s 98.2 (ok) 0.86s 100 (ok) 0.6s 99.96 (-) Ref. EDMS: I-020760 z of RIB requested for Day 1 SPIRAL2 Phase 2 experiments n, SPIRAL2 SAC, GANIL Direction, GANISOL Group	2.51s 98.58 (-) Isotope 1.23s 98.2 (ok) 8He 0.86s 100 (ok) 93.21 0.86s 100 (ok) 92.3 0.6s 99.96 (-) 92.9 Ref. EDMS: H020760 531 51.52.53.54K x c133 Ar35 y of RIB requested for Day 1 SPIRAL2 Phase 2 experiments 6.41 n, SPIRAL2 SAC, GANIL Direction, GANISOL Group 5.41	2.51s 98.58 (-) Isotope z 1.23s 98.2 (0k) 8He 2 0.86s 100 (0k) Na21 11 0.6s 99.96 (-) Mg23 12 0.6s 99.96 (-) Si27 14 P29 15 Si27 14 0.6s 99.96 (-) P29 15 si27 14 Si27 14 P29 15 Si1 16 Cl33 17 Ar35 18 x Ka7 19 S1,52,53,54K 19 of RIB requested for Day 1 SPIRAL2 Phase 2 experiments C339 20 Sc41 21 n, SPIRAL 2 SAC, GANIL Direction, GANISOL Group Sc41 21 7800 70	2.51s 98.58 (-) Isotope z A 1.23s 98.2 (0k) 8He 2 8 0.86s 100 (0k) Na21 11 21 0.86s 100 (0k) Mg23 12 23 0.6s 99.96 (-) Mg23 12 23 Al25 13 25 5i27 14 27 Si27 14 27 929 15 29 Si27 14 27 929 15 29 Si31 16 31 16 31 Cl33 17 33 Ar35 18 35 K37 19 37 51,52,53,54K 19 51 Ca39 20 39 39 39 36 39 n, SPIRAL 2 SAC, GANIL Direction, GANISOL Group Sc41 21 41 78Co 27 78	2.51s 98.58 (-) Isotope Z A A Min Max 1.23s 98.2 (0k) 8He 2 8 Ne19 10 19 0.86s 100 (0k) Mg23 11 21 23 23 0.6s 99.96 (-) Mg23 12 23 24 25 13 25 32 0.6s 99.96 (-) P29 15 29 531 16 31 c Ref. EDMS: 1-020760 K37 19 37 51,52,53,54K 19 51 54 of RIB requested for Day 1 SPIRAL2 Phase 2 experiments Ca39 20 39 54 54 of RIB requested for Day 1 SPIRAL2 Phase 2 experiments Ca39 20 39 54 54	2.51s 98.58 (-) Isotope z A Max Energy Min [keV] 1.23s 98.2 (0k) 8He 2 8 10 0.86s 100 (0k) Na21 11 21 10 0.86s 100 (0k) Mg23 12 23 10 0.6s 99.96 (-) 5i27 14 27 10 Si27 14 27 10 10 10 10 Kef. EDMS: 1020760 K37 19 37 10 10 10 v of RIB requested for Day 1 SPIRAL2 Phase 2 experiments Ca39 20 39 10 10 Sc41 21 41 10 10 10 10 10 10 Sc41 21 41 10 10 10 10 10 10 Sc41 21 41 10 10 10 10 10 10 Sc41 21 41 10 10 10 10 10 10	2.51s 98.58 (-) Isotope z A A Energy Min Energy Max [keV] 1.23s 98.2 (ok) 8He 2 8 10 30 0.86s 100 (ok) Na21 11 21 10 60 0.86s 100 (ok) Mg23 12 23 10 60 0.6s 99.96 (-) 5i27 14 27 10 60 0.6s 99.96 (-) 5i27 14 27 10 60 V of RIB requested for Day 1 SPIRAL2 Phase 2 experiments K37 19 37 10 60 Ar35 18 35 10 30 Ar35 19 37 10 60 Ar35 18 35 10 30 Ar35 19 37 10 60 Ar35 18 35 10 30 Ar35 18 35 10 30 Ar35 5c41 21 41 10 30	2.51s 98.58 (-) Isotope z A Energy Min Energy Max Energy Max Intensity Min (keV) 1.23s 98.2 (0k) 8He 2 8 10 30 1,00E+07 0.86s 100 (0k) Na21 11 21 10 60 1,00E+02 0.86s 100 (0k) Mg23 12 23 10 60 1,00E+02 0.6s 99.96 (-) P29 13 25 10 60 1,00E+02 Si27 14 27 31 10 60 1,00E+02 Si27 14 27 10 60 1,00E+02 Si27 14 27 10 60 1,00E+02 Si27 14 27 10 60 1,00E+02 Cl33 17 33 10 60 1,00E+02 Si1,52,53,54K 19 37 10 60 1,00E+02 St1,52,53,54K 19 54 40 1,00E+02 St1,52,53,54K



Beams?

• ¹⁹Ne, ³⁵Ar : already available @ LIRAT

→ study started @ LPC :

• other beams :

	Nucleus ²¹ Na		T _{1/2}	BR (%)	(MoT)	
			22.49s	94.97	(ok)	
	23	Mg	11.32s	91.8	(ok)	
	2	⁵ AI	7.18s	99.16	(-)	
	2 [.]	⁷ Si	4.16s	99.77	(-)	
	2	٩P	4.14s	98.3	(-)	
	3	¹ S	2.57s	98.87	(-)	
	3:	³ Cl 2.51s		98.58	(-)	:
	3	⁷ K	1.23s	98.2	(ok)	8He Ne19
	³⁹ Ca		0.86s	100	(ok)	 → Na21 29,30 → Mg23
	41	Sc	0.6s	99.96	(-)	→ Al25 → Si27 → P29
Spiral?	- And	Date: 29/04/2010	 → S31 → Cl33 Ar35			
		Author: M. Lewitor	 → K37 51,52			

To: SPIRAL2 Direction, SPIRAL2 SAC, GANIL Direction, GANISOL Group

LPCTrap performances feasibility study ...

Lol 2010



	Isotope	z	A Min	A Max	Energy Min [keV]	Energy Max [keV]	Intensity Min [pps]	Intensity Max [pps]
	8He	2	8		10	30	1,00E+07	
	Ne19	10	19		10	60	1,00E+02	1,00E+07
	 ▶ Na21	11	21		10	60	1,00E+02	1,00E+07
	29,30,31,32Na	11	29	32	40		1,00E+03	
	 ▶ Mg23	12	23		10	60	1,00E+02	1,00E+07
	 ► AI25	13	25		10	60	1,00E+02	1,00E+07
	 ➡ Si27	14	27		10	60	1,00E+02	1,00E+07
	 ▶ P29	15	29		10	60	1,00E+02	1,00E+07
	► S31	16	31		10	60	1,00E+02	1,00E+07
	 ► CI33	17	33		10	60	1,00E+02	1,00E+07
	Ar35	18	35		10	30	1,00E+07	
	 ► K37	19	37		10	60	1,00E+02	1,00E+04
	51,52,53,54K	19	51	54	40		1,00E+03	
ents	 ► Ca39	20	39		10	60	1,00E+02	1,00E+07
	 ▶ Sc41	21	41		10	30	1,00E+07	-
	78Co	27	78		30	60	5.00F-01	

Future LPCTrap option : MOT

Already used with great success in America : 38m K (Triumf), 21 Na (LBNL) and precision of 0.1% in $\sigma(a)/a$ is envisaged (*Behr et al, JPG36(2009)*)

- Advantages :
- smaller cloud size, easy imaging
- continuous loading
- selectivity (isobar suppression)
- high detection efficiency with extraction fields
- nuclei polarization (A $_\beta$,...)

- Disadvantages :
- lower trapping efficiency
- setup complexity
- selectivity \rightarrow ¹⁹Ne, ²¹Na, ²³Mg, ³⁷K, ³⁹Ca "only"...



MOT @ LPC for atomic studies



Blieck et al, RSI79(2008)

57 fs 1/2+ 0 ³⁹Ca : excellent candidate 859.6 ms 3/2+ ³⁹20 Q_{FC}=6530.6 Estimated performances with $I_{Ca} \sim 10^7$ pps 2522.5 0.0023% 7.1 stable 3/2+ <u>0</u>_~100% 3.6 LPCTrap MOT VS ³⁹/₁₉K MOT LPCTrap (adapted from ⁶He (literature) experiment) ε (set-up) ~ 5 10⁻⁴ ~ 0.001 Hoekstra et al, PRA71(2005) 200ms 200ms τ_{cycle} Trapped nuclei 2000 1000 Vetter et al, PRC77(2008) 0.05 ε(detection) 0.003 Coinc. yield 5/s 40/s \rightarrow 2 10⁶/5days \rightarrow 1.5 10⁷/5days $(\sigma_a/a)_{stat}$ 0.3% 0.5%

Feasibility study started @ LPC firstly with ¹⁹Ne available @ LIRAT (X. Fléchard)



Precision measurements performed at low energy

• to search for exotic currents in weak interaction



- β - γ coincidences
- tests feasible @ LIRAT with $I = 1.5 \ 10^6 \text{ pps}$
- final experiment @ DESIR if I ~ 5 107 pps



• to test the unitarity of the CKM matrix

- ¹⁹Ne, ³⁵Ar - available @ LIRAT with I > 10⁷ pps
 - feasibility studies started @ LPC with LPCTrap and MOT (¹⁹Ne)



- ²¹Na ... ³⁹Ca ²⁷Si, ³⁷K & ³⁹Ca : very good decay properties
 - present in the beams list of SP2/ ϕ 2
 - requirements : $I > 10^7 \text{ pps}$ & no radioactive isobar (LPCTrap)