Correlation measurements in β decay

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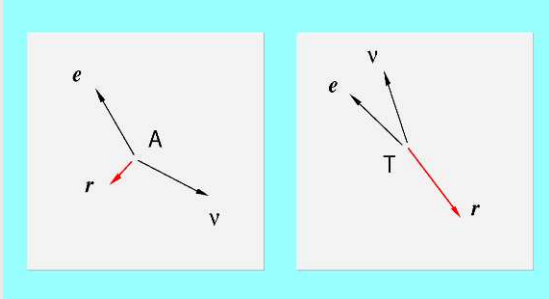
LPC Caen, GANIL, Univ. de Granada

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

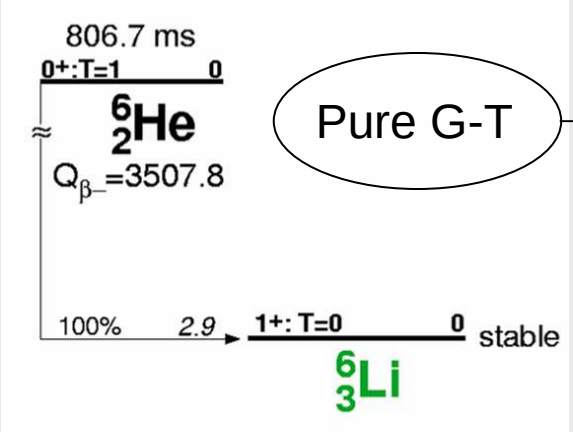
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

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

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

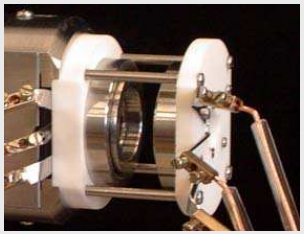
Measurement of β-ν angular correlation in *unpolarized* nuclei

$$W(E,\theta) = W(E)\,[1 + a\,\frac{v_e}{c}\cos(\theta) + b\,\frac{m}{E}\,]$$

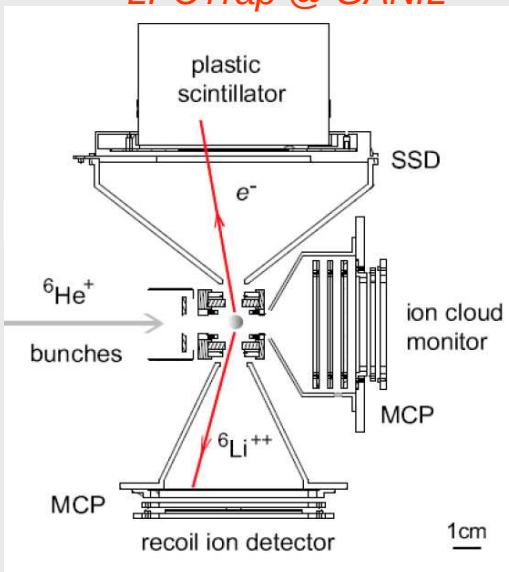


Pure G-T

- a (C_A, C_T)
- β - recoil coincidences



LPCTrap @ GANIL

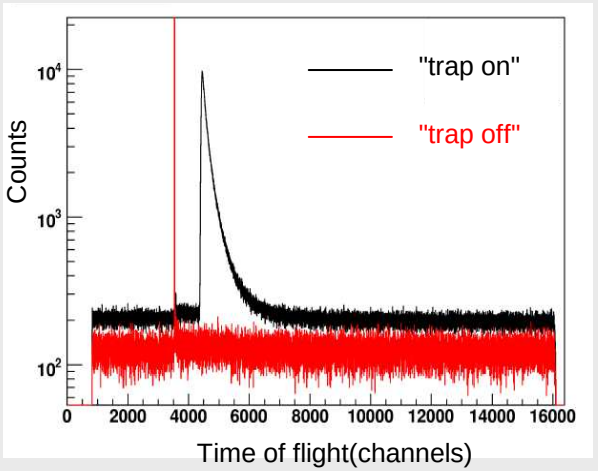


Fléchard et al PRL101(2008)

Paul Trap : clean source / low energy recoil detection

October 2008 : 2 10^6 coincidences

→ $(\sigma_a/a)_{stat}$ ~ 0.5%

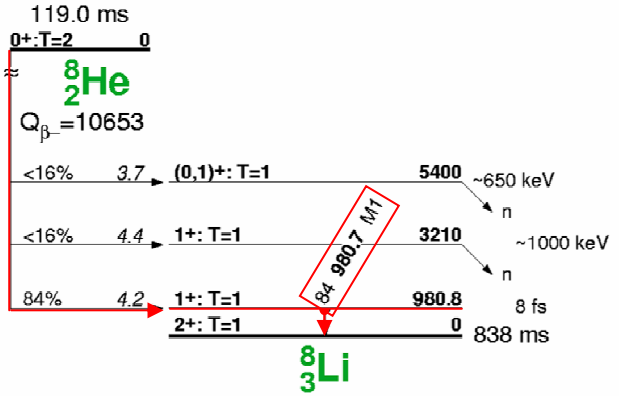


Next step ?

New candidate

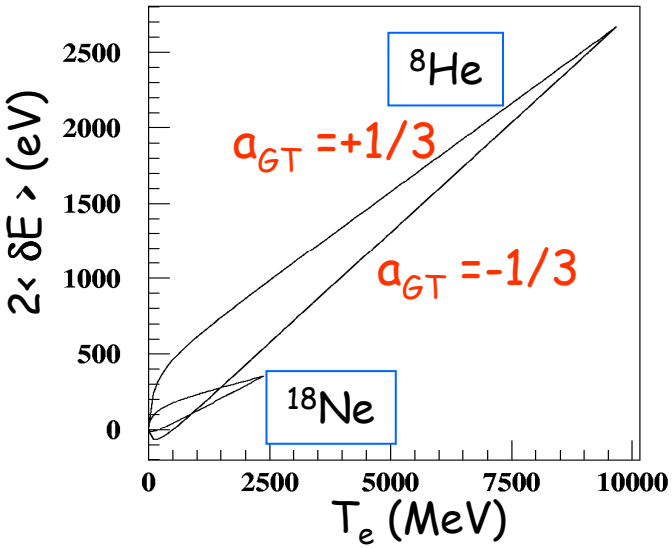
- Different methods
  → different systematic effects
- Combination of independent measurements
  → better constraint on C_T

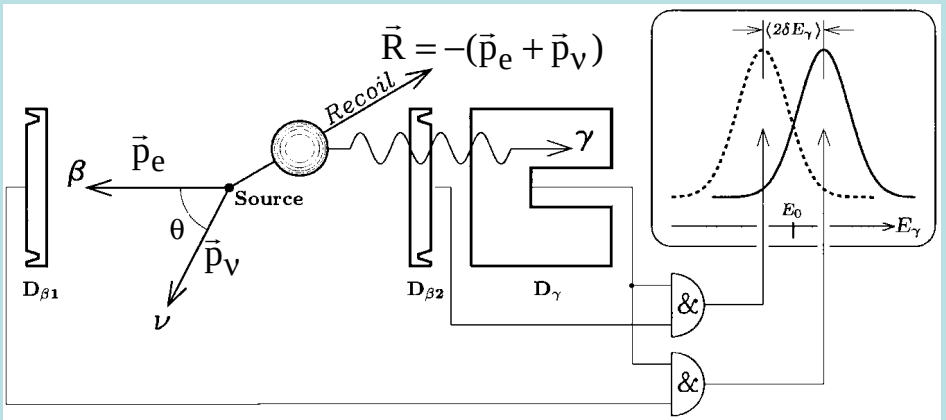
Severijns, Beck and Naviliat RMP78 (2006)



- Coincidences β - γ → Doppler shift depends on "a"
- Source confinement : gas cell or trap

Comparison ^{8}He - ^{18}Ne ⟶ *Egorov et al NPA621(1997)745*





Vorobel et al EPJA16(2003) (^{14}O)

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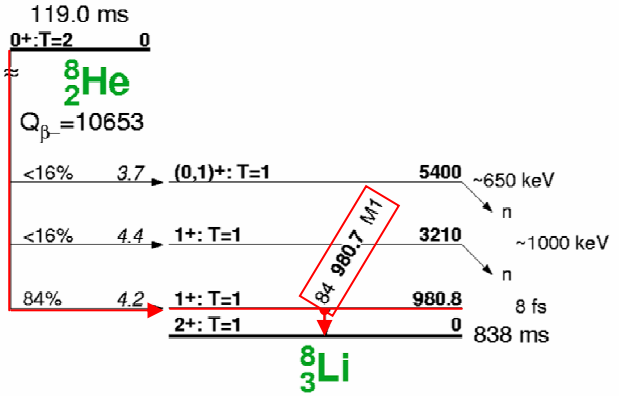

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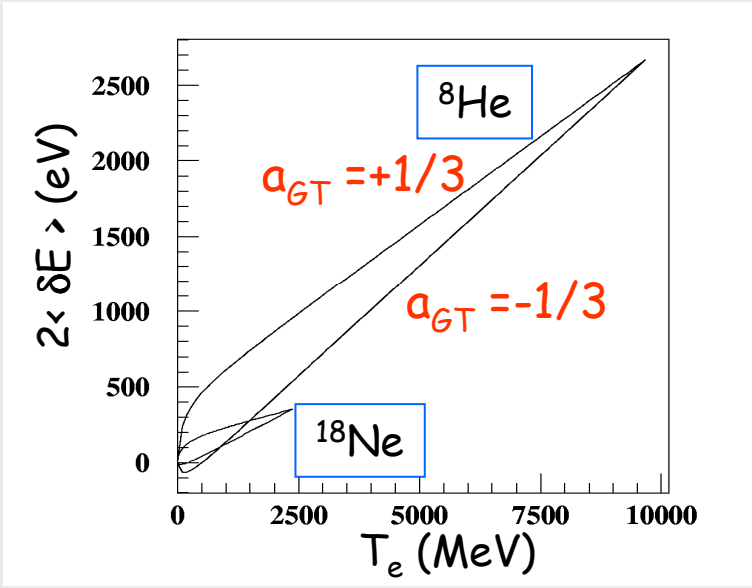

Gain of 3.5 in sensitivity

5 10^5 events needed to measure a_{GT} @ 0.5% with ^{8}He

5 10^5 events needed to measure a_{GT} @ 0.5% with ^{8}He = *2 10^6 events needed to measure a_{GT} @ 0.5% with ^{6}He* / 4

→ I(^{8}He) = I(^{6}He)/4 ~ 5 10^7 pps (1 week)

Beam ?

^{8}He : available @ SPIRAL with I ~ 1.5 10^6 pps

→ enough to start tests

→ LoI presented at the last GANIL PAC (March 2010)

→ final experiment could be performed @ DESIR if I(^{8}He) > 10^7 pps

Spiral2

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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	
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Al25	13	25		10	60	1,00E+02	1,00E+07
Si27	14	27		10	60	1,00E+02	1,00E+07
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K37	19	37		10	60	1,00E+02	1,00E+04
51,52,53,54K	19	51	54	40		1,00E+03	

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

2) Test of the unitarity of the CKM matrix

Coupling of quark *weak* eigenstates to *mass* eigenstates in SM

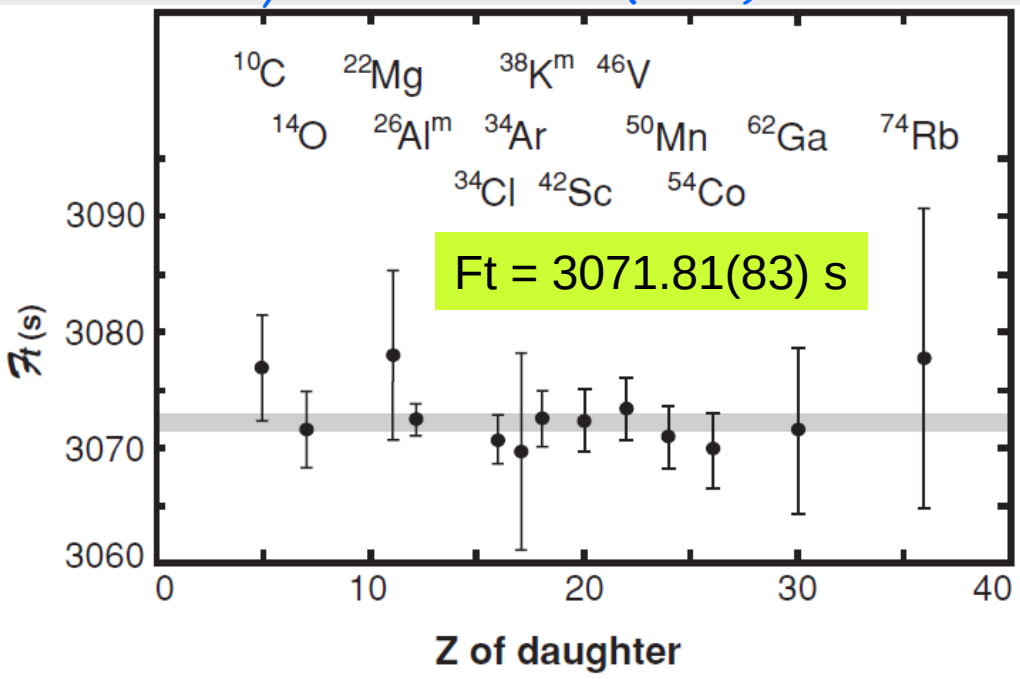
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

→ ***unitarity condition:***

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

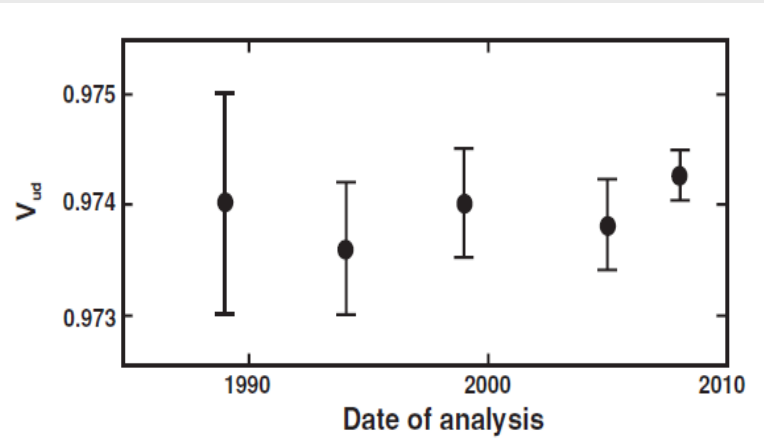
Ft values of $0^+ \rightarrow 0^+$ transitions → $T_{1/2}$, BR, Q_{EC} measurements

Hardy & Towner PRC79(2009)



→ $V_{ud} = 0.97425\ (22)$

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.99995 \pm 0.00061$$



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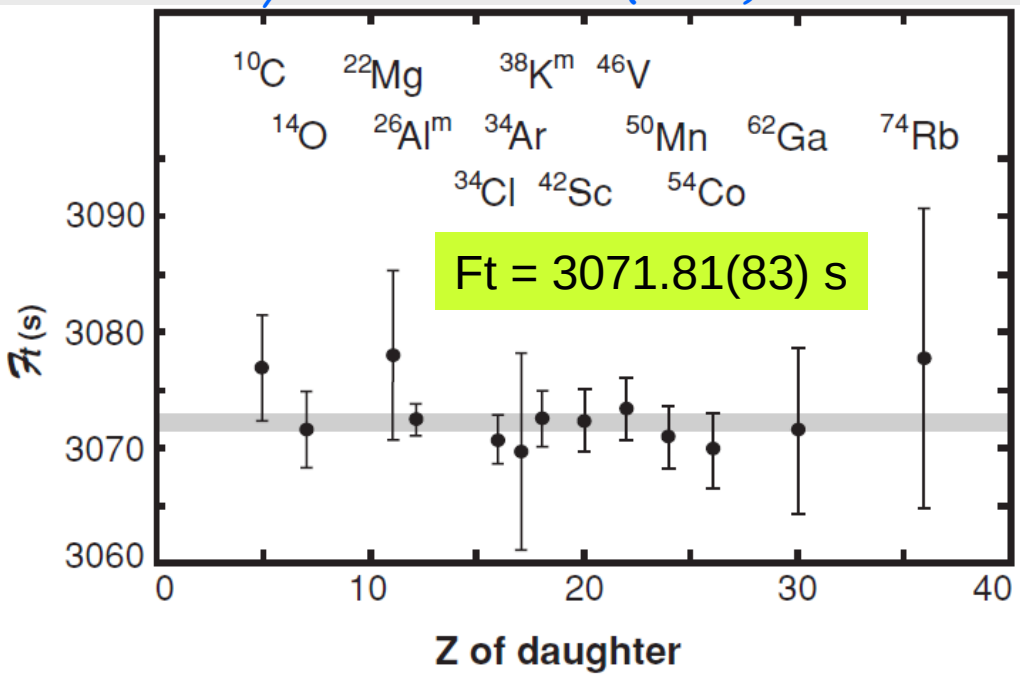


→ $V_{ud} = 0.97425\ (22)$

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.99995 \pm 0.00061$$

- Essentially limited by theoretical corrections
- New and independent source of data is welcome

  → Mirror transitions …

V_{ud} from Ft values of T = ½ mirror transitions

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

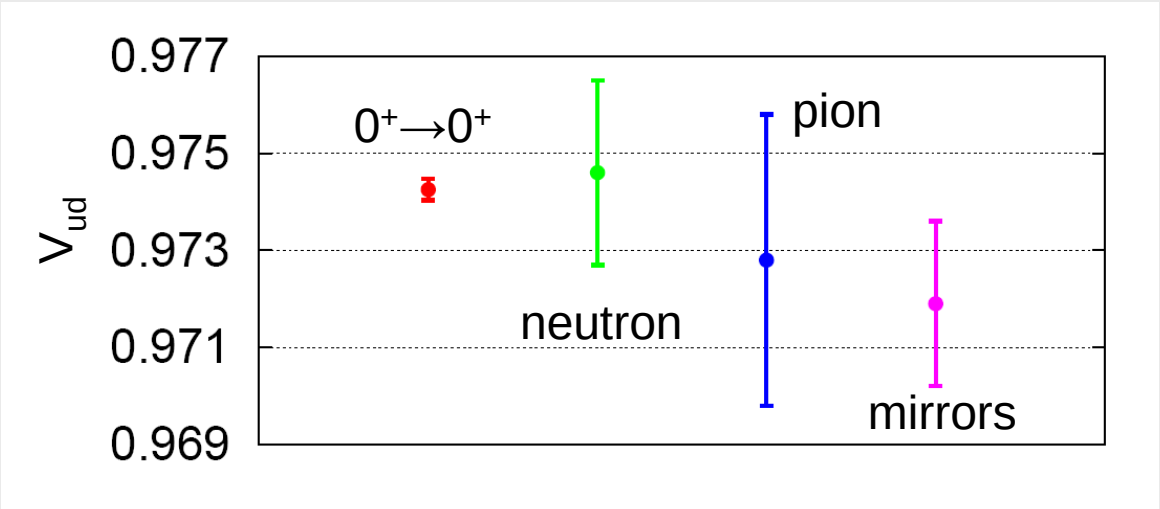
$$V_{ud}^2 = \frac{K}{(T_{1/2}/BR)(1+C\rho^2)}$$

Talk of A. Bacquias yesterday

ρ= GT/F precisely determined from a correlation measurement (a, A)

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)*



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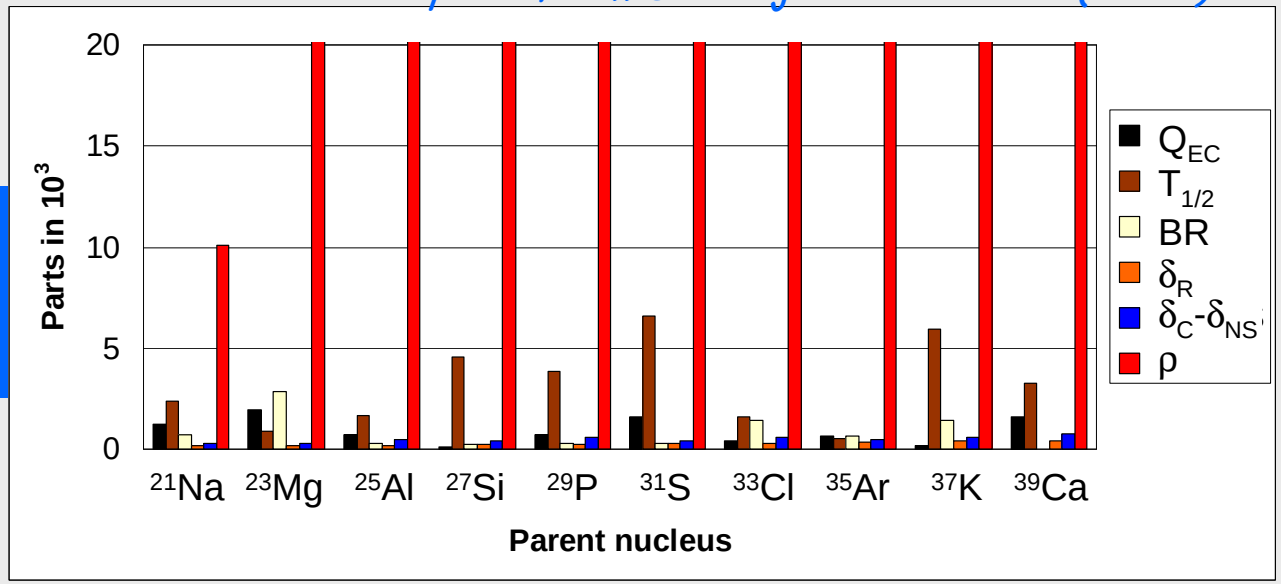
Potential ?

- Error budget

Need of $T_{1/2}$ and especially ρ precise measurements !

adapted from Severijns et al PRC78(2008)



Beams ?

- ^{19}Ne, ^{35}Ar : already available @ LIRAT

  → study started @ LPC :

  - LPCTrap performances
  - feasibility study …

  LoI 2010

- other beams :

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^{21}Na	22.49s	94.97	(ok)
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^{25}Al	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	(-)

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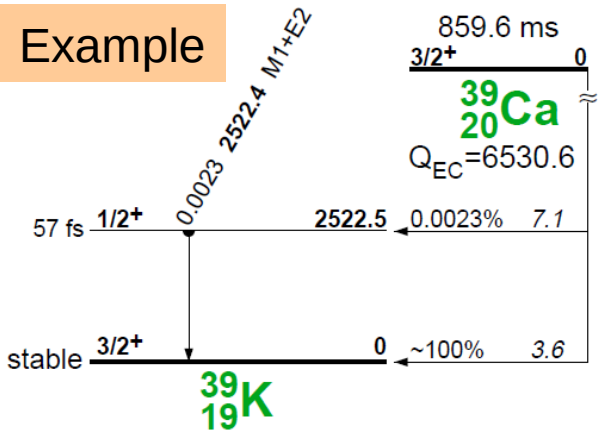

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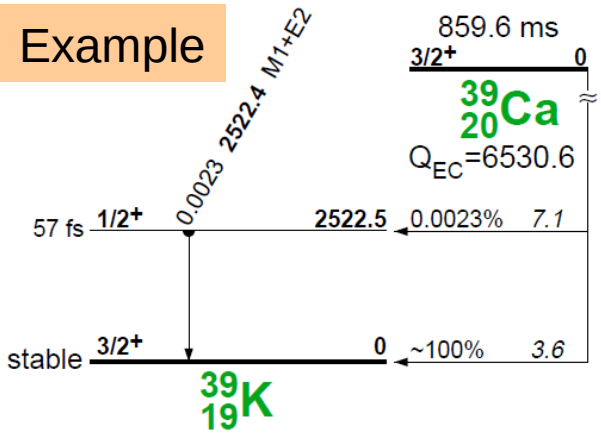

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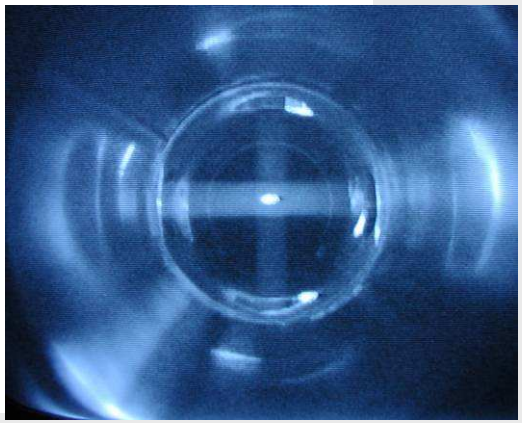
Future LPCTrap option : MOT

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



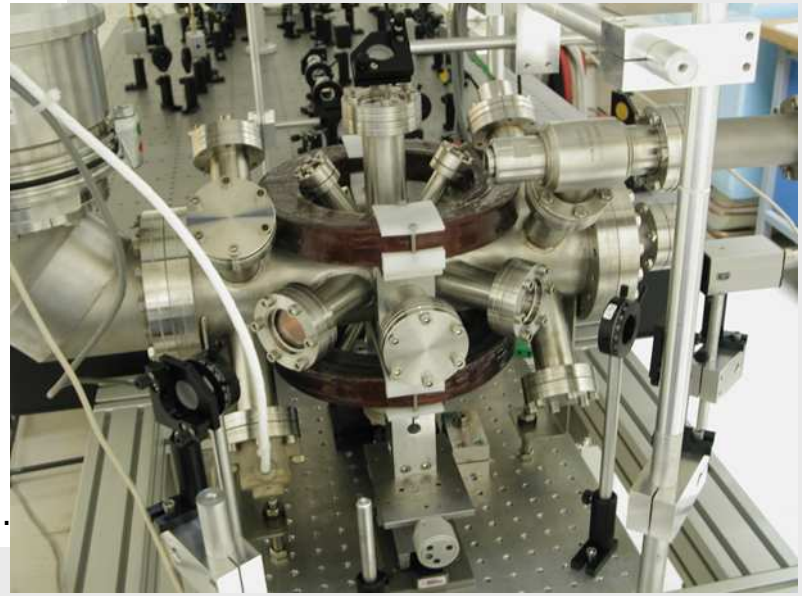
MOT @ LPC for atomic studies

- Advantages :

- no RF effect on recoil ions (Mass ↑ → T_{recoil} ↓)
- smaller cloud size, easy imaging
- continuous loading
- selectivity (isobar suppression)
- high detection efficiency with extraction fields
- nuclei polarization (A_β ,…)

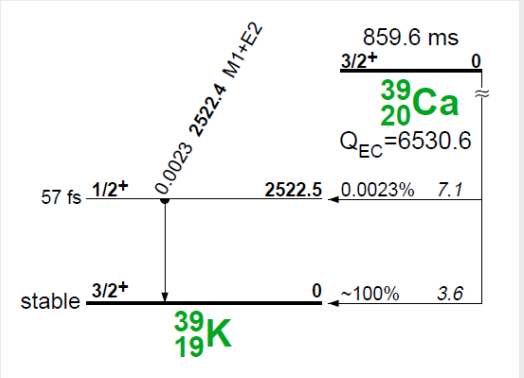
- Disadvantages :

- lower trapping efficiency
- setup complexity
- selectivity → ^{19}Ne, ^{21}Na, ^{23}Mg, ^{37}K, ^{39}Ca "only"...



Blieck et al, RSI79(2008)

^{39}Ca : excellent candidate



Estimated performances with $I_{Ca} \sim 10^7$ pps

LPCTrap vs MOT

	LPCTrap (adapted from ^{6}He experiment)	MOT (literature)
ε (set-up)	~ 0.001	~ 5 10^{-4}
τ_{cycle}	200ms	200ms
Trapped nuclei	2000	1000
ε(detection)	0.003	0.05
Coinc. yield	5/s	40/s
	→ 2 10^6/5days	→ 1.5 10^7/5days
$(\sigma_a/a)_{stat}$	0.5%	0.3%

Hoekstra et al, PRA71(2005)

Vetter et al, PRC77(2008)

⇨ *Feasibility study started @ LPC firstly with ^{19}Ne available @ LIRAT (X. Fléchard)*

Summary

Precision measurements performed at low energy

• *to search for exotic currents in weak interaction*

^{8}He

- β-γ coincidences
- tests feasible @ LIRAT with I = 1.5 10^{6} pps
- final experiment @ DESIR if I ~ 5 10^{7} pps

LoI March 2010

• *to test the unitarity of the CKM matrix*

^{19}Ne, ^{35}Ar

- available @ LIRAT with I > 10^{7} pps
- feasibility studies started @ LPC with LPCTrap and MOT (^{19}Ne)

LoI March 2010

^{21}Na … ^{39}Ca

- ^{27}Si, ^{37}K & ^{39}Ca : very good decay properties
- present in the beams list of SP2/φ2
- requirements : I > 10^{7} pps & no radioactive isobar (LPCTrap)