The masses of ^{32,33}Ar for fundamental tests + further recent results from ISOLTRAP

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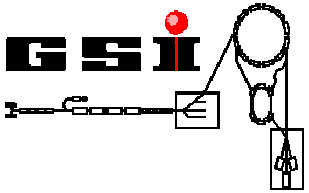
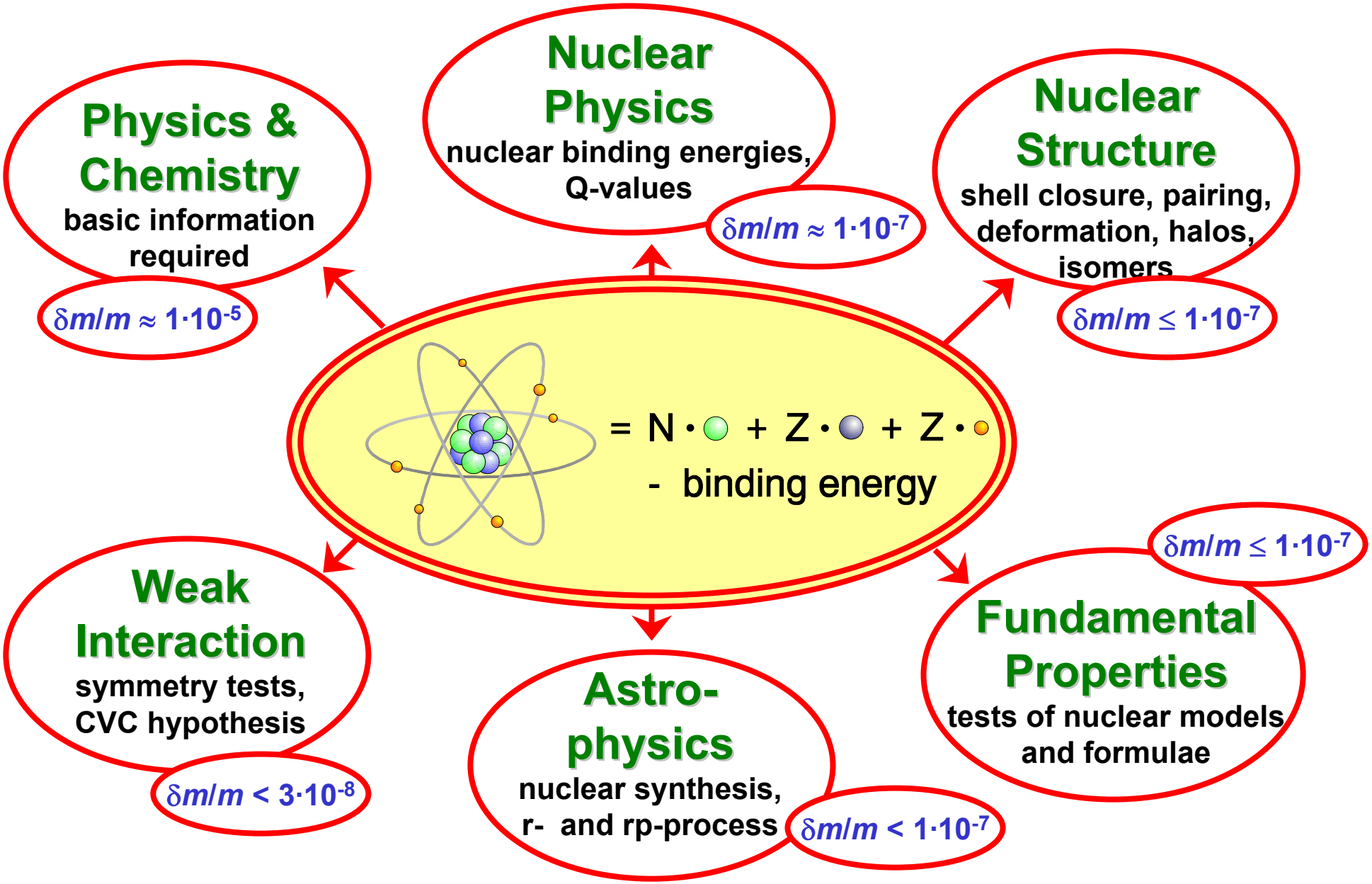
Outline

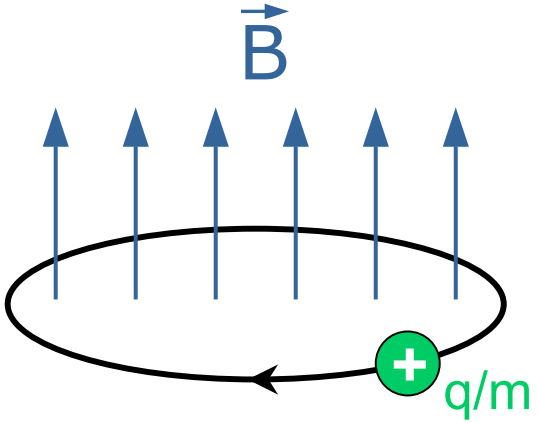
- Motivation for accurate mass measurements
- Principle of Penning traps
- Eperimental setup
- Recent highlights
- Summary and Outlook



Radionuclides - What accuracy is needed where?



Principles of Penning traps

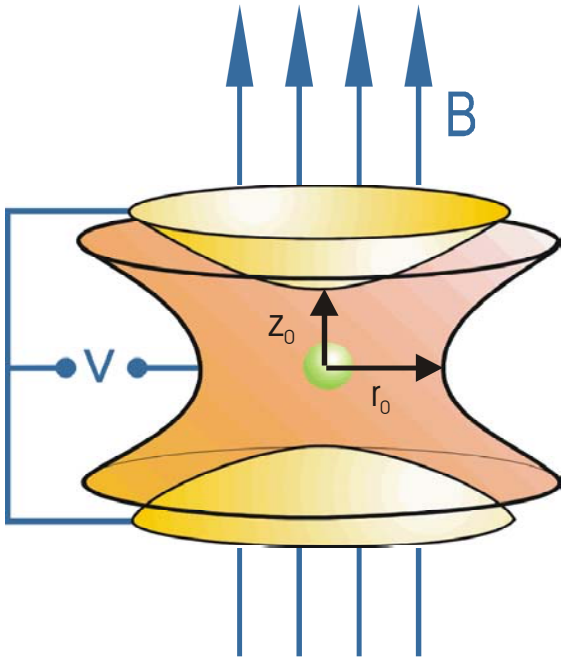


Cyclotron frequency: $\nu_c = \frac{1}{2\pi} \cdot \frac{q}{m} \cdot B$

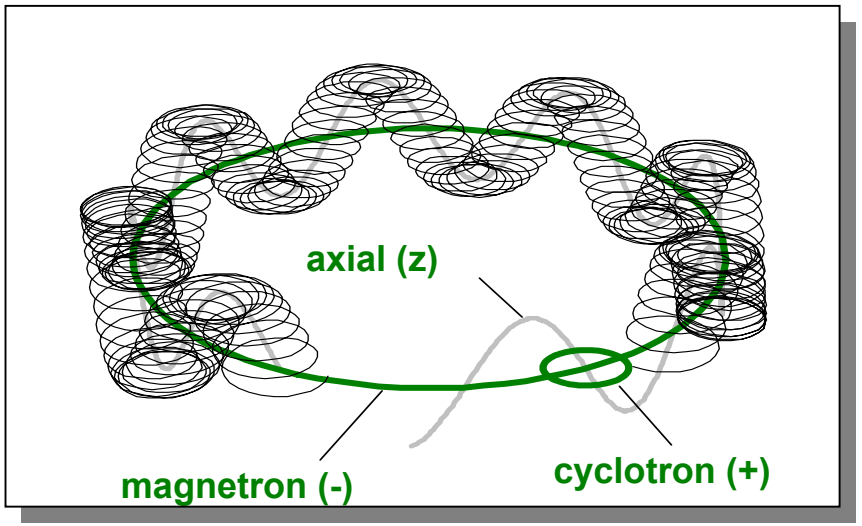
Superposition

- strong homogeneous magnetic field
- weak electrostatic quadrupole field

PENNING trap



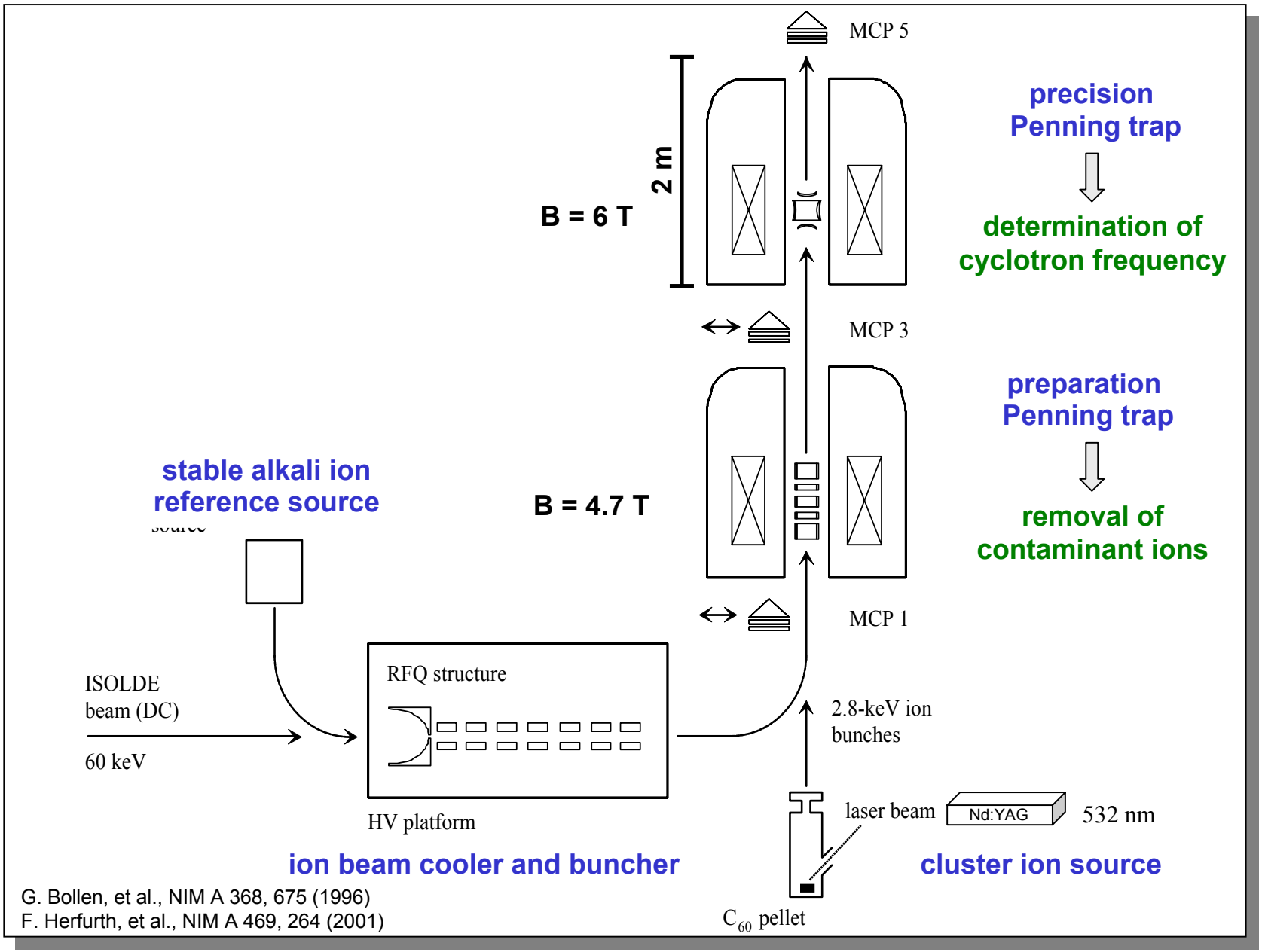
Frans Michel Penning



A=100, q=1, B=6T

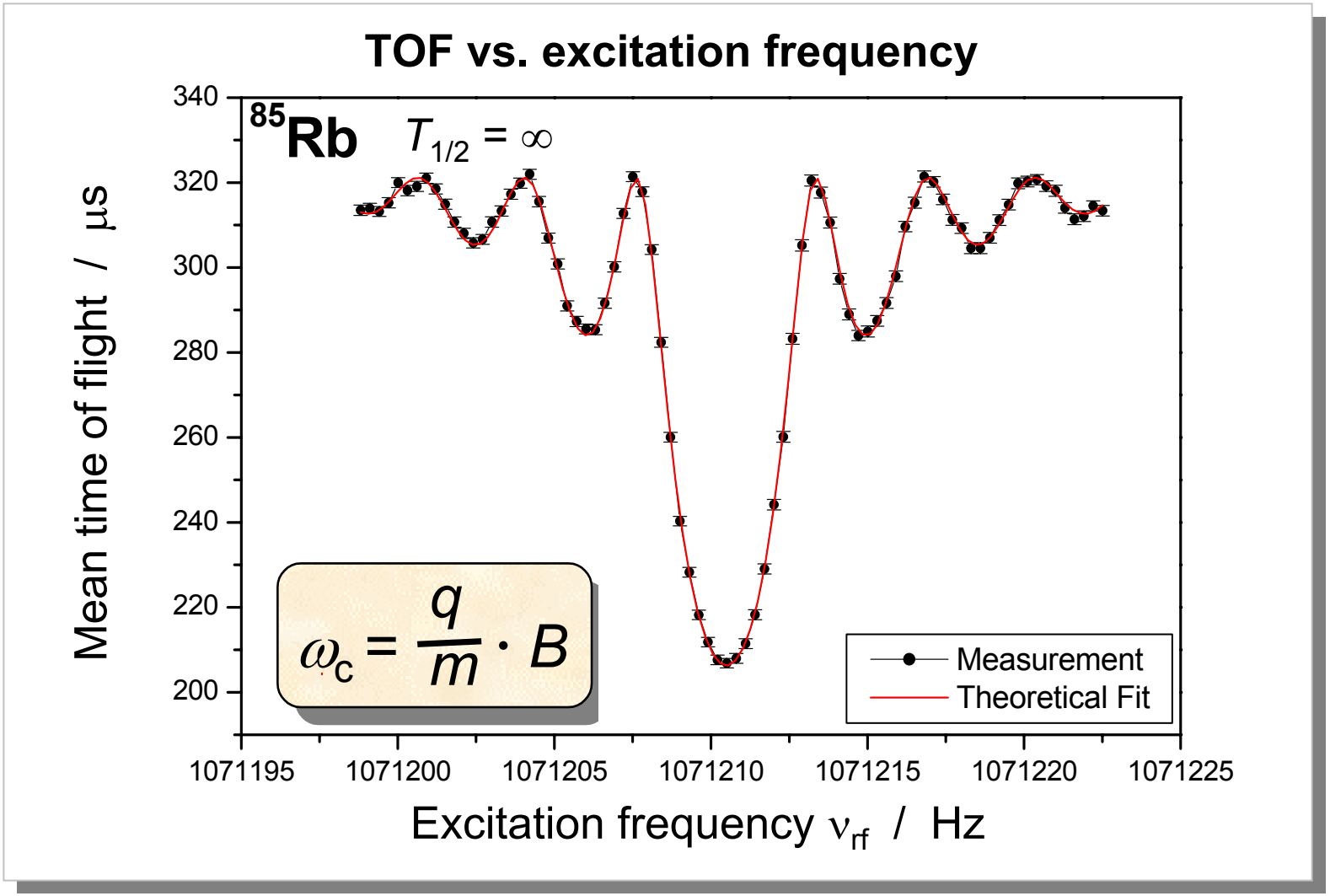
- $\nu_+ \approx 1$ MHz
- $\nu_- \approx 1$ kHz
- $\nu_z \approx 44$ kHz

The triple-trap mass spectrometer ISOLTRAP



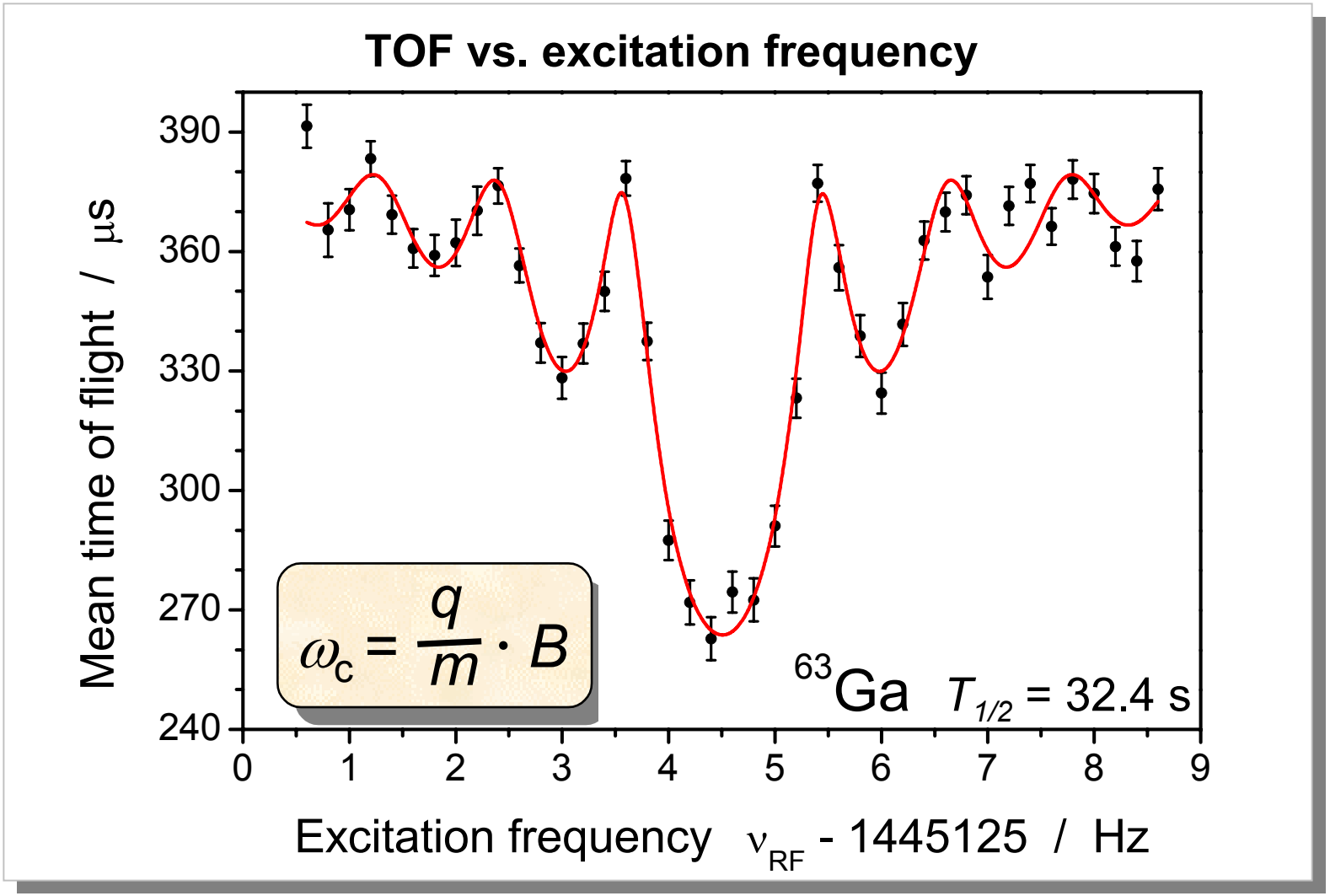
G. Bollen, et al., NIM A 368, 675 (1996)
F. Herfurth, et al., NIM A 469, 264 (2001)

Time-of-flight cyclotron resonance curve



Determine atom mass from frequency ratio with a well-known reference mass

Time-of-flight cyclotron resonance curve



Determine atom mass from frequency ratio with a well-known reference mass

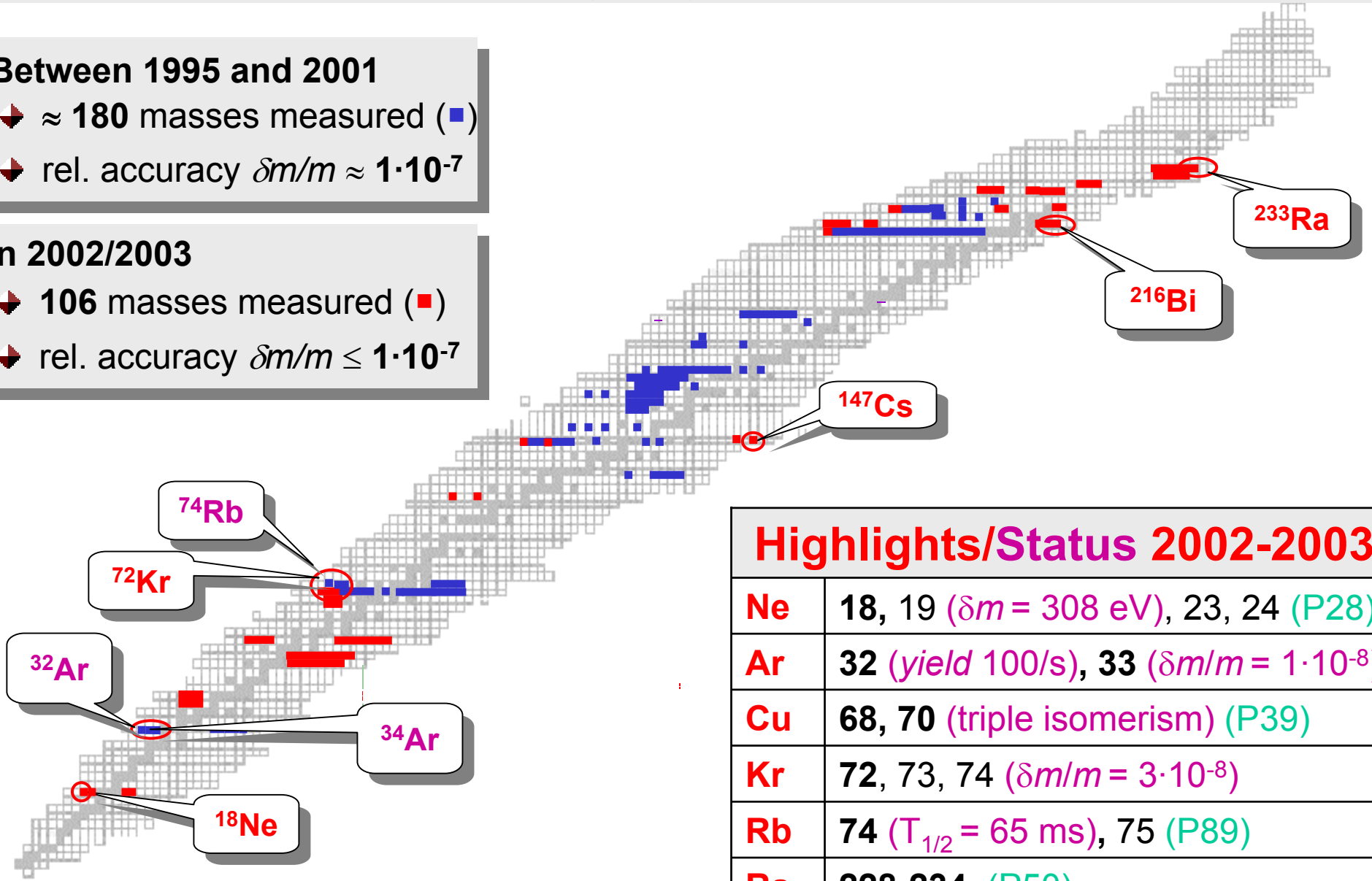
ISOLTRAP highlights and status

Between 1995 and 2001

- ≈ **180** masses measured (■)
- rel. accuracy $\delta m/m \approx$ **1·10^{-7}**

In 2002/2003

- **106** masses measured (■)
- rel. accuracy $\delta m/m \leq$ **1·10^{-7}**



Highlights/Status 2002-2003	
Ne	**18,** 19 (δm = 308 eV), 23, 24 (P28)
Ar	**32** (*yield* 100/s), **33** ($\delta m/m = 1 \cdot 10^{-8}$)
Cu	**68, 70** (triple isomerism) (P39)
Kr	**72**, 73, 74 ($\delta m/m = 3 \cdot 10^{-8}$)
Rb	**74** ($T_{1/2}$ = 65 ms), 75 (P89)
Ra	**228-234** (P50)

F. Herfurth, JP B 36, 931 (2003); K. Blaum et al., NIM B 204, 478 (2003).

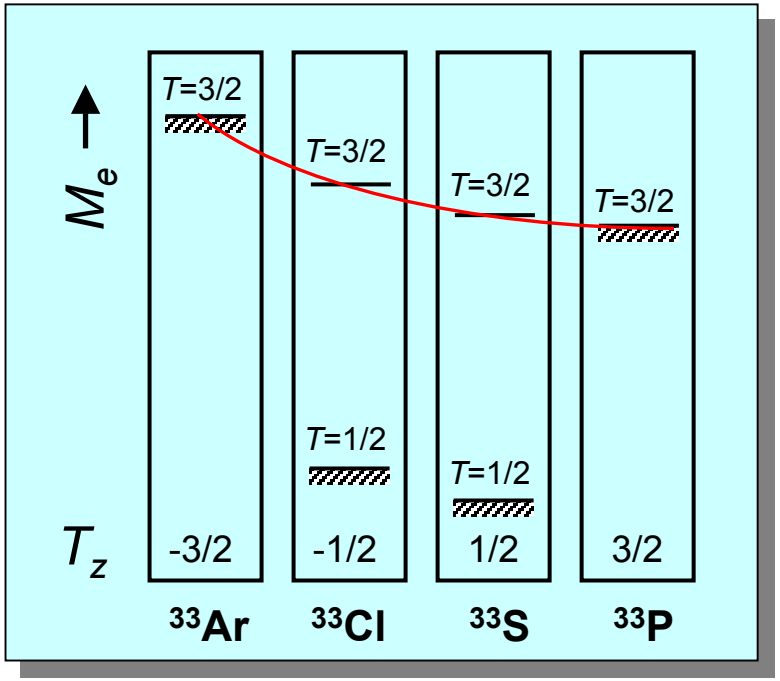
IMME test: T = 3/2 quartet @ A = 33

Isobaric Multiplet Mass Equation

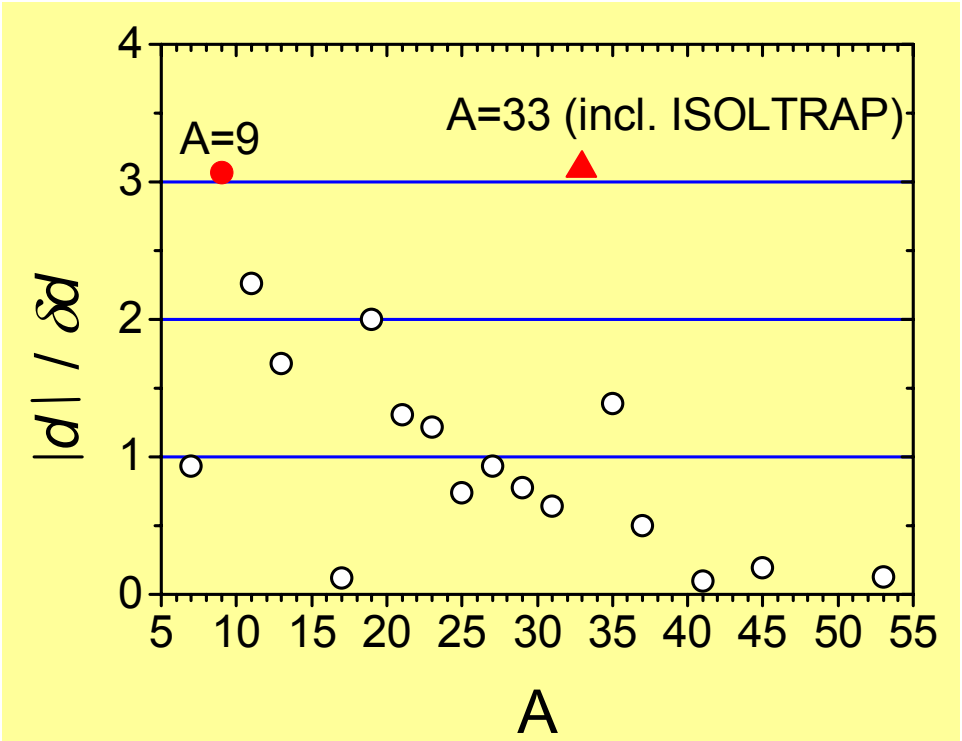
$$M = a + bT_z + cT_z^2 + dT_z^3$$

Commonly used quadratic form

?



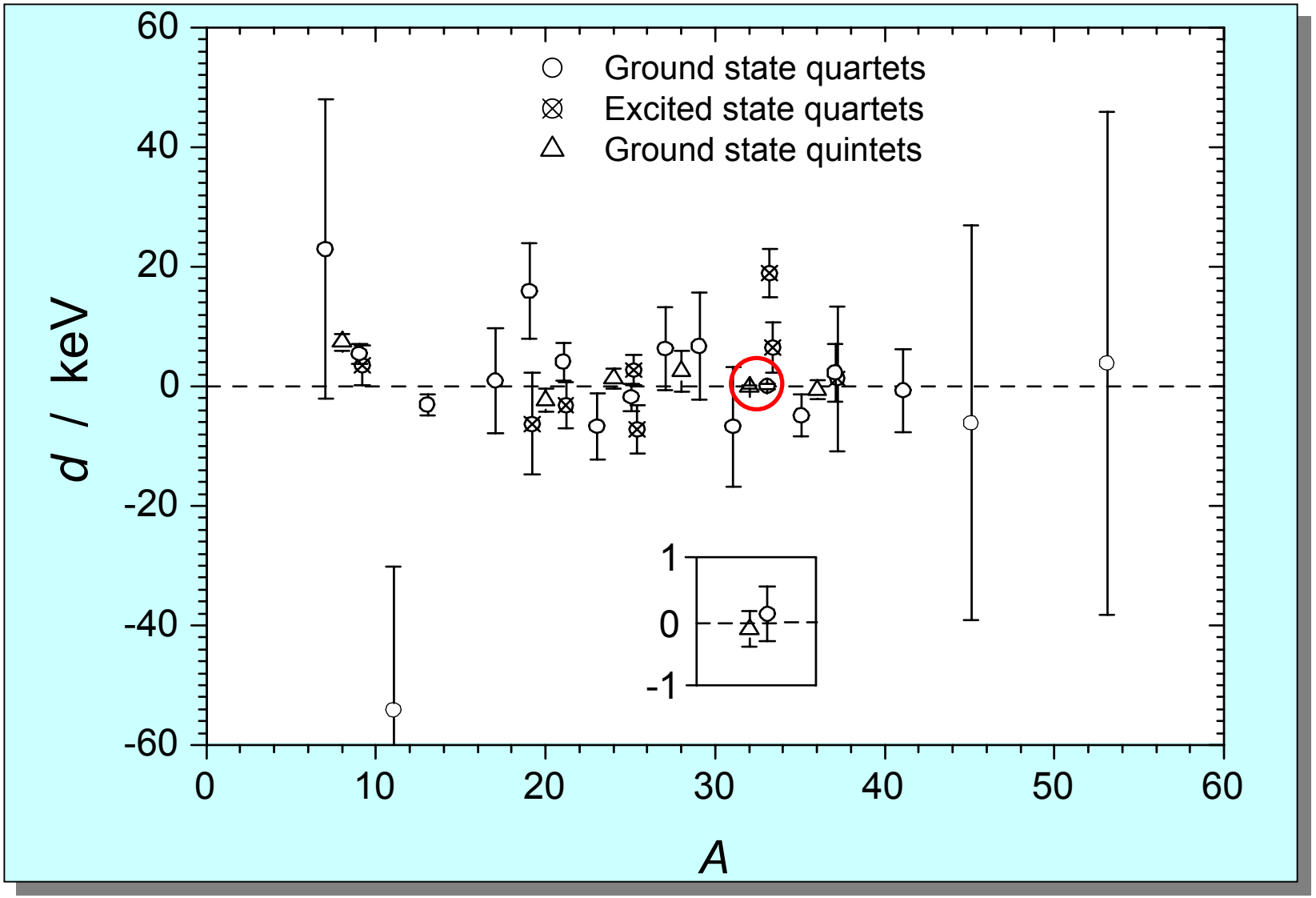
d coefficients for all 18 complete ground state quartets



2001: Breakdown of IMME
F. Herfurth et al.
PRL 87 (2001) 142501

2002: Revalidation of IMME
T=3/2 state in ^{33}Cl wrong
M.C. Pyle et al.
PRL 88 (2002) 122501

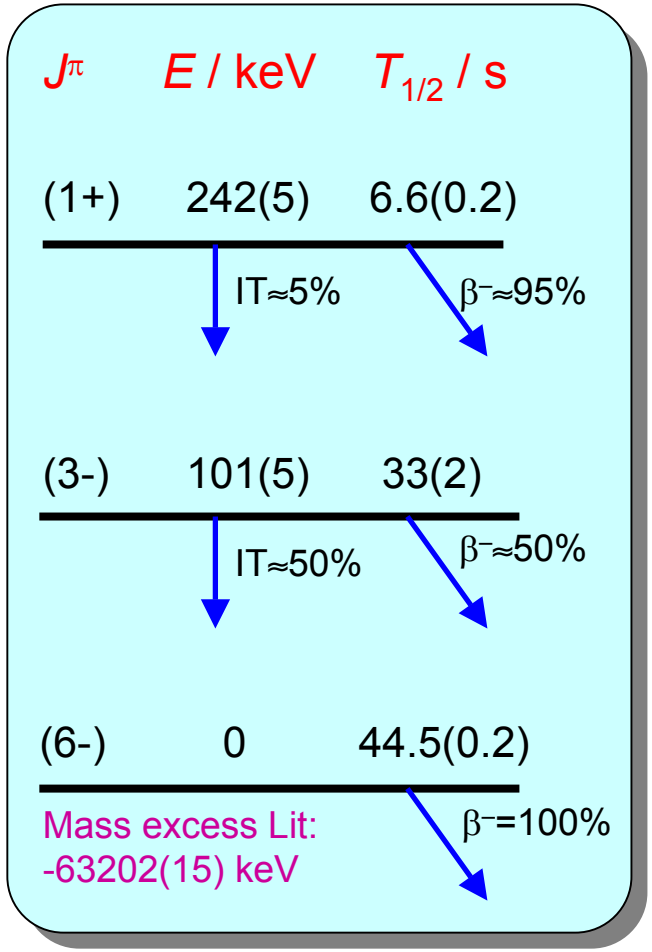
Recently: Most stringent test of IMME (with ^{32,33}Ar)



☺ $m(^{32}\mathrm{Ar})_{\mathrm{exp}}$ will allow for a better constraint on scalar contributions to WI (the beta-neutrino correlation coefficient *a* does no longer rely on IMME).

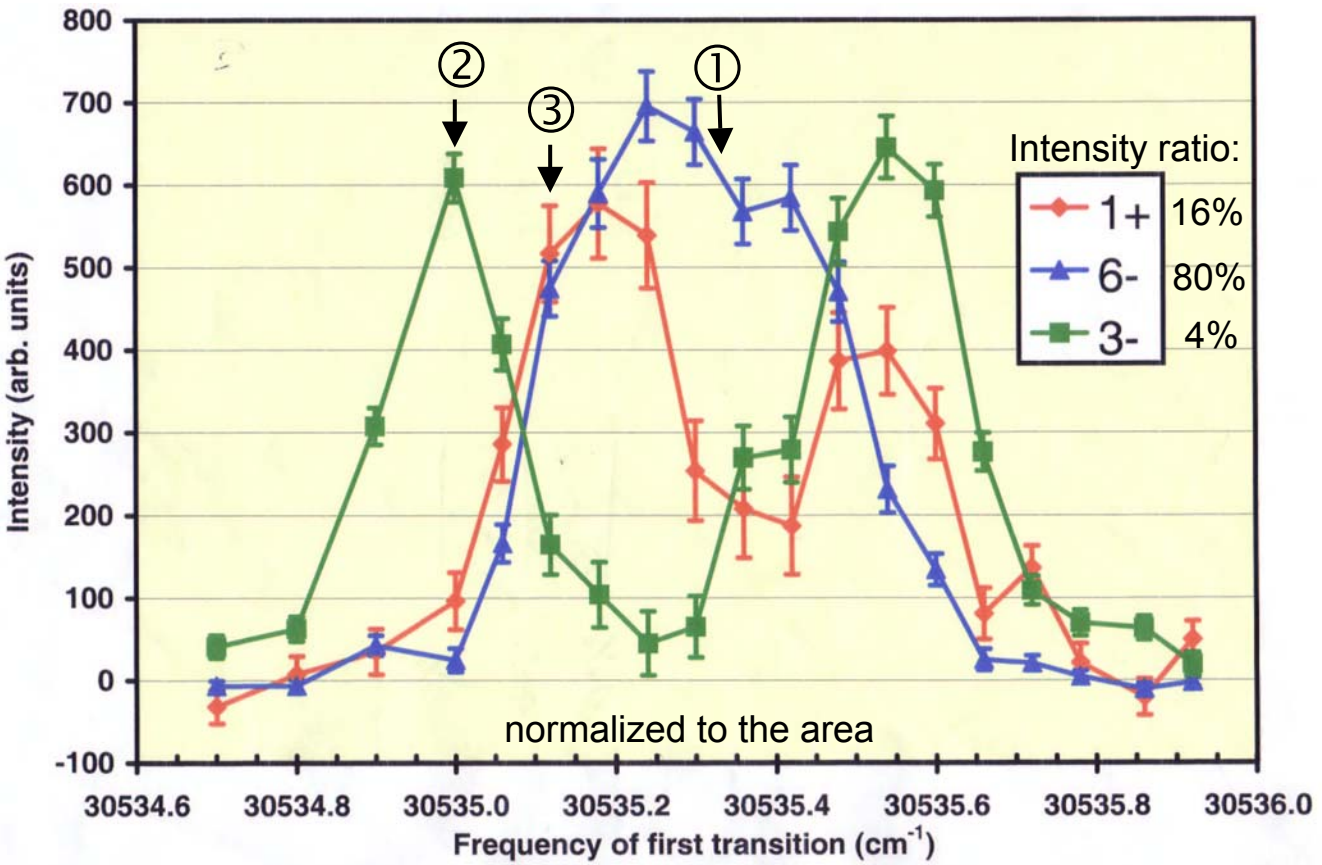
Solving the identification puzzle in ^{70}Cu

Ground and isomeric states of ^{70}Cu



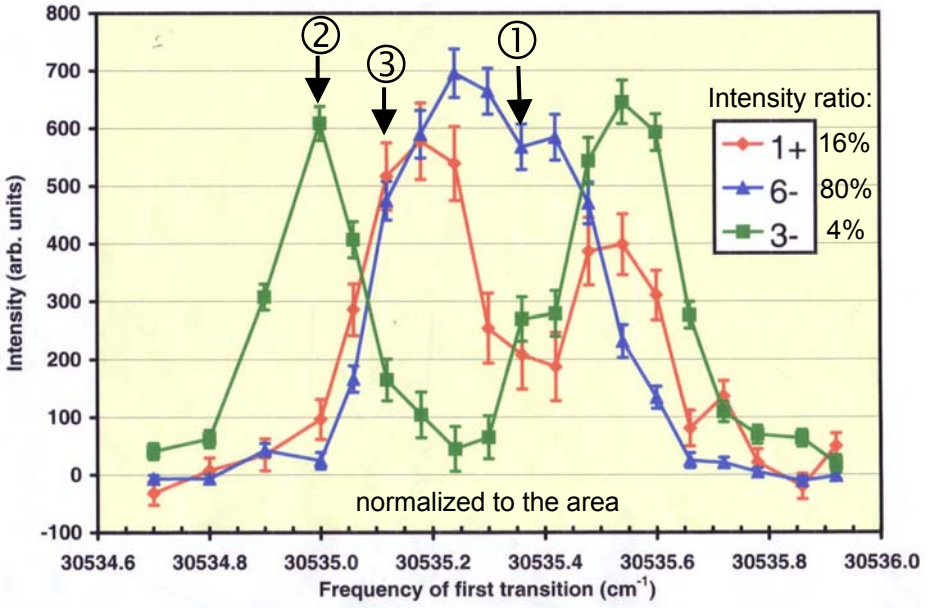
J. Van Roosbroeck, to be published (2003).

Hyperfine structure of ^{70}Cu isomers (using laser ionization)



(spectrum provided by U. Köster)

Identification of triple isomerism in ^{70}Cu



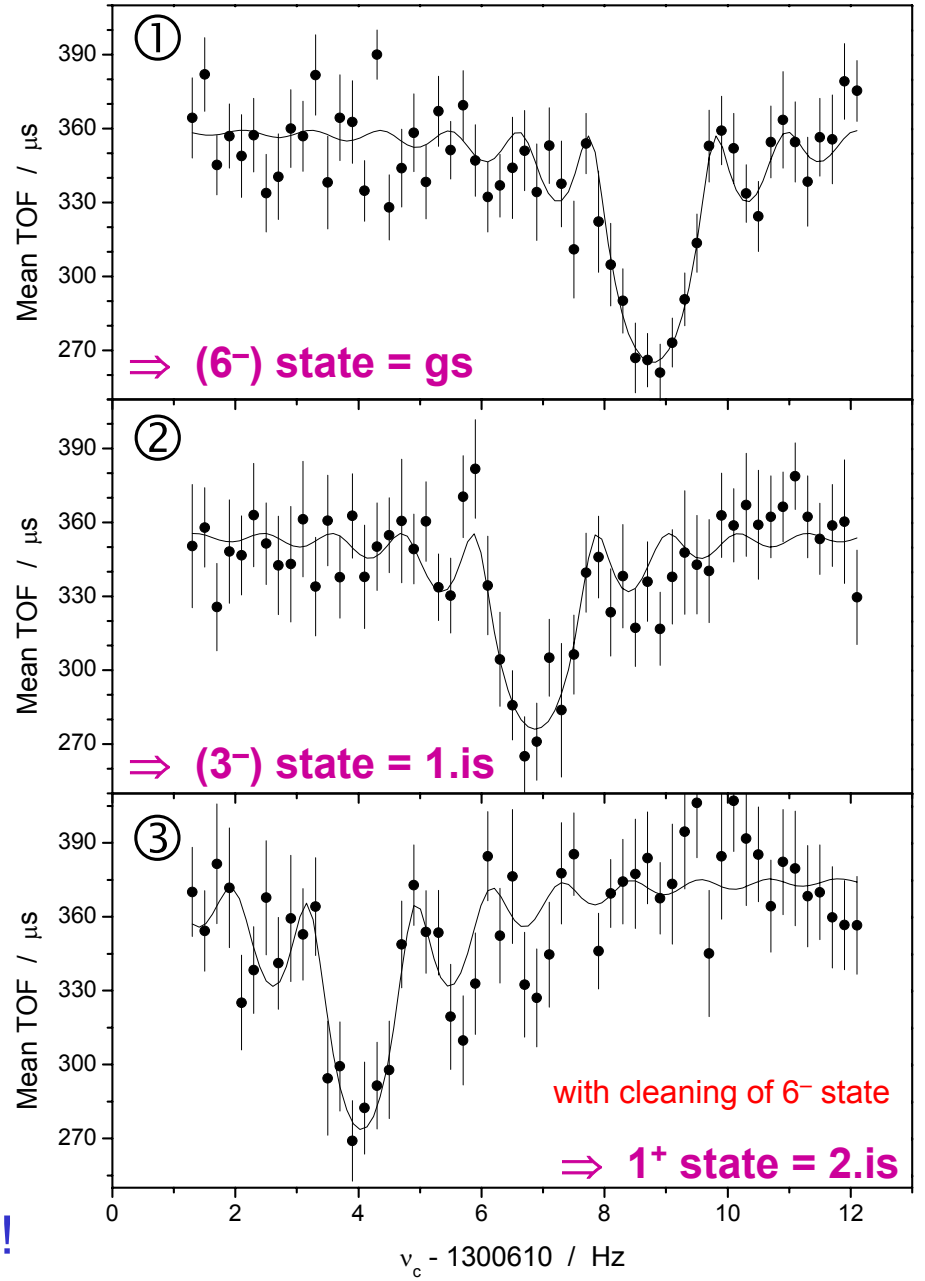
$$\omega_c = \frac{q}{m} \cdot B$$

Unambiguous spin to state assignment!

ME of ground state is 240 keV higher than literature value!

$R \approx 1 \cdot 10^{-7}$

Preparation of an isomerically pure beam!



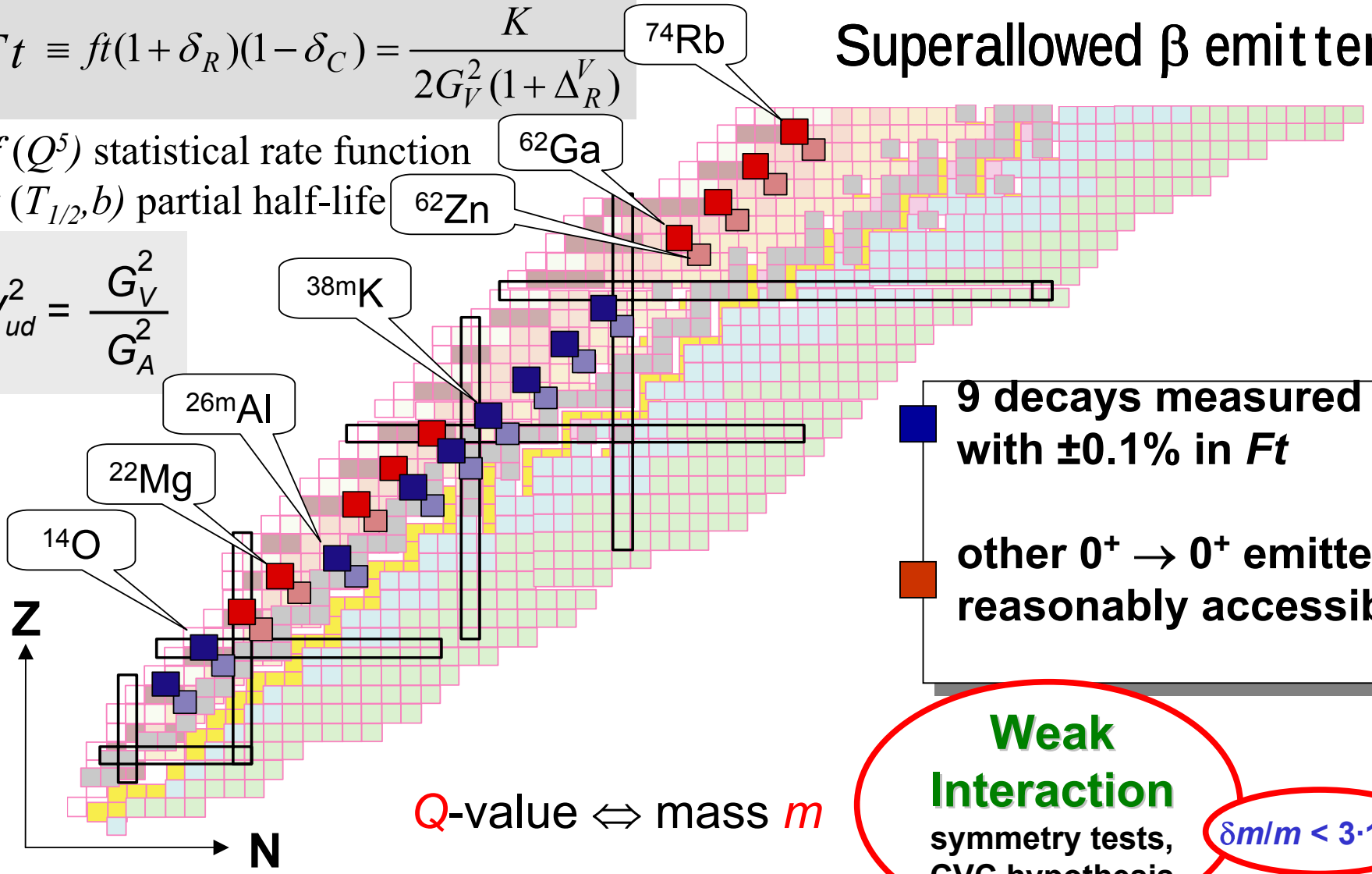
Test of the CVC hypothesis and CKM unitarity

$$Ft \equiv ft(1+\delta_R)(1-\delta_C) = \frac{K}{2G_V^2(1+\Delta_R^V)}$$

$f(Q^5)$ statistical rate function

$t(T_{1/2},b)$ partial half-life

$$V_{ud}^2 = \frac{G_V^2}{G_A^2}$$



Superallowed β emitters

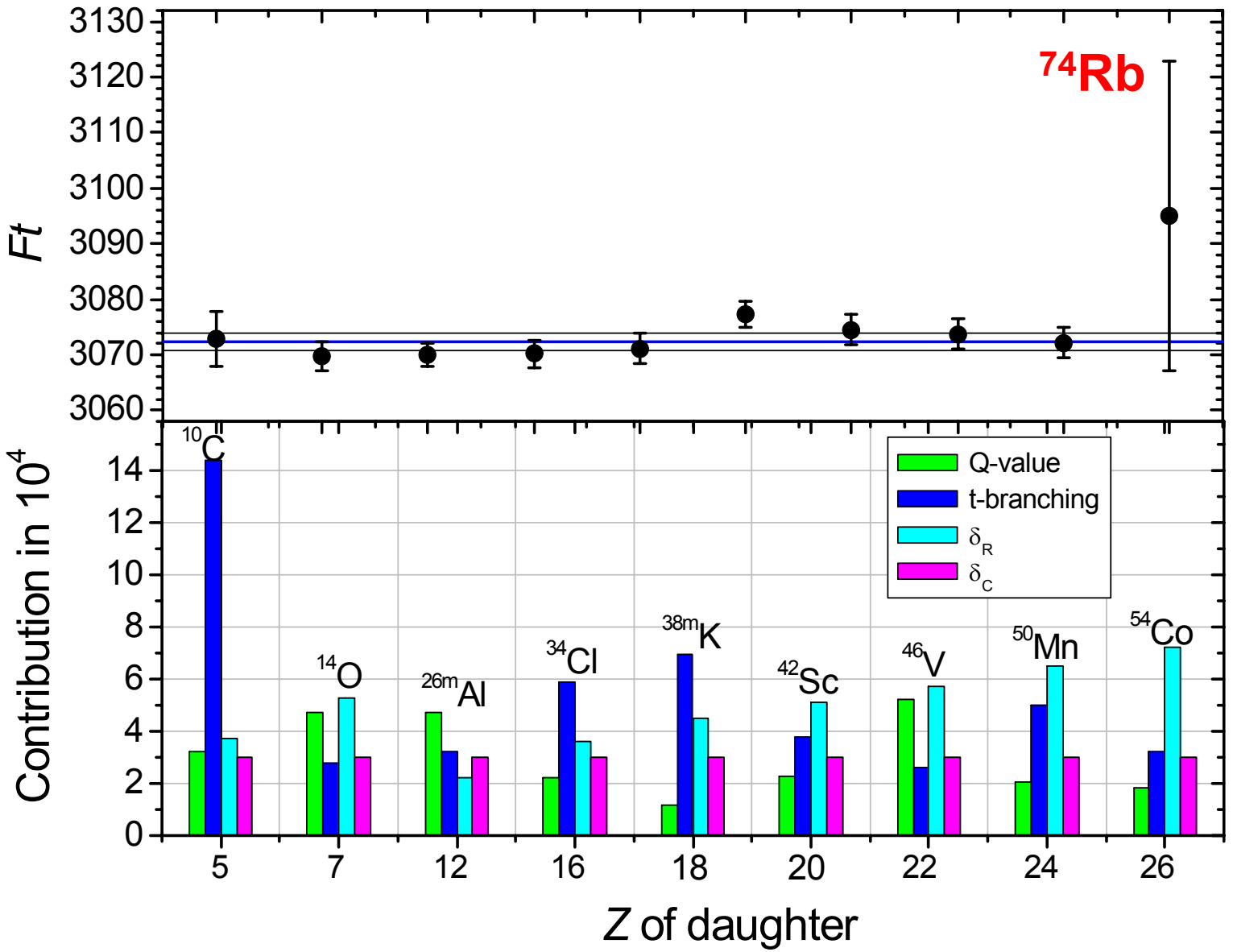
- 9 decays measured with ±0.1% in *Ft*
- other $0^+ \rightarrow 0^+$ emitters reasonably accessible

Q-value ⇔ mass *m*

Weak Interaction
symmetry tests,
CVC hypothesis

$\delta m/m < 3 \cdot 10^{-8}$

Superallowed β emitters - Ft status at present



CVC - test

$$\frac{\chi^2}{\nu} = 1.1$$

i.e. CVC true at the $3 \cdot 10^{-4}$ level

very recent measurement:

$\delta m(^{74}\mathrm{Rb}) < 4$ keV
($\delta FT \sim 20$ s)

Problem of the non-unitarity of the CKM

Present status:

V_{ud} (nuclear β-decay) = 0.9740(5)
V_{us} (kaon-decay) = 0.2196(12)
V_{ub} (B meson decay) = 0.0036(5)

(non-)unitarity of CKM-matrix

$$V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 0.9968 \pm 0.0014$$

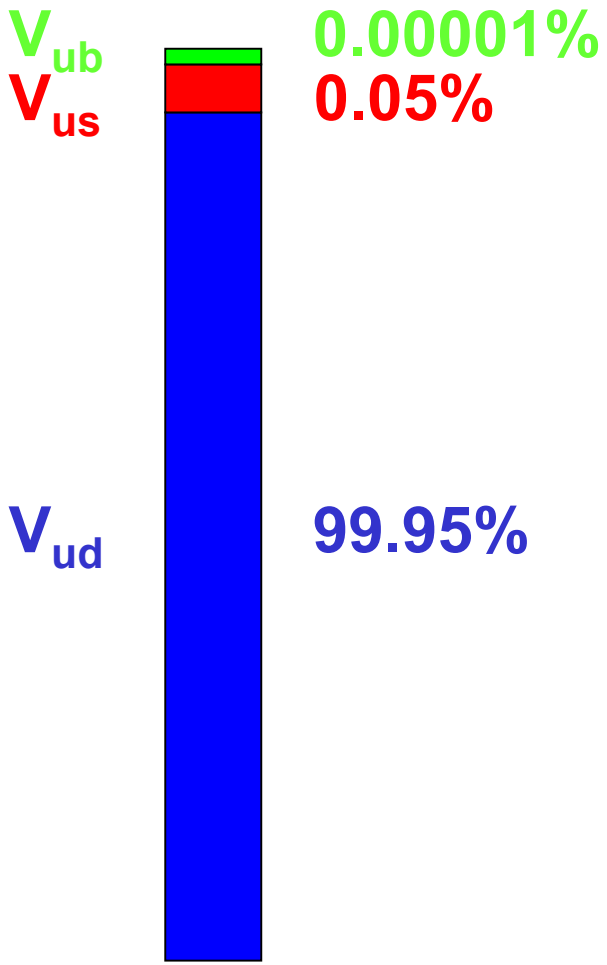
i.e. CKM not unitary at the 98% confidence level

Result confirmed by neutron β-decay:

V_{ud} (neutron β-decay) = 0.9717(13)

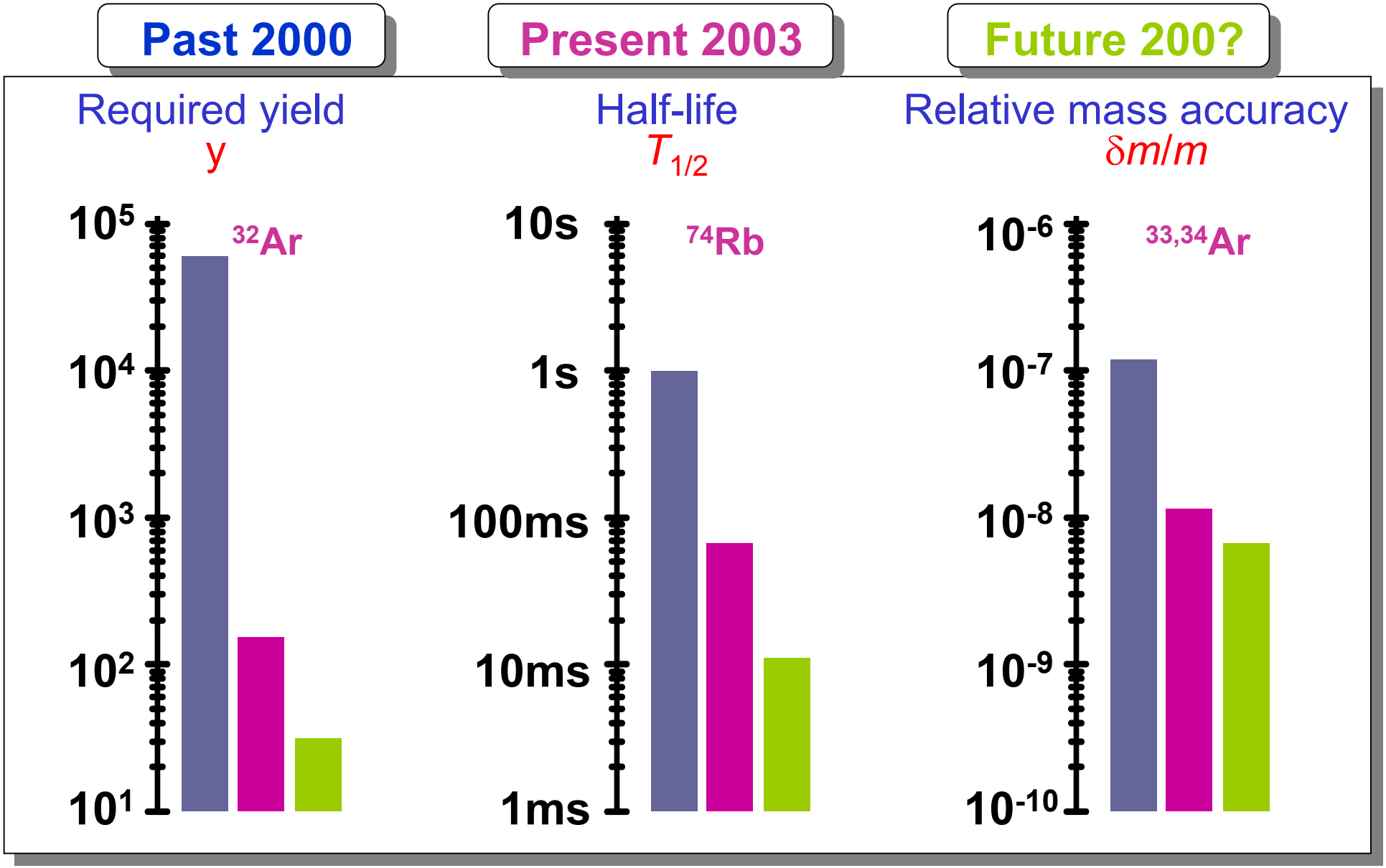
$$V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 0.9924 \pm 0.0015$$

Contribution to the unitarity:



V_{us} (K-decay) ≈ 0.2265

Summary and outlook: Performance



Not to forget …

Thanks to my co-workers:

A. Audi, G. Bollen, D. Beck, P. Delahaye, C. Guénaut, F. Herfurth, A. Kellerbauer, H.-J. Kluge, D. Lunney, D. Rodríguez, S. Schwarz, L. Schweikhard, G. Sikler, C. Weber, C. Yazidjian ..., and the ISOLTRAP and ISOLDE collaboration

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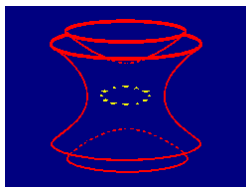

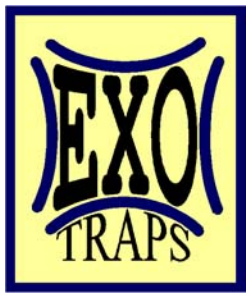

Thanks a lot for your attention.