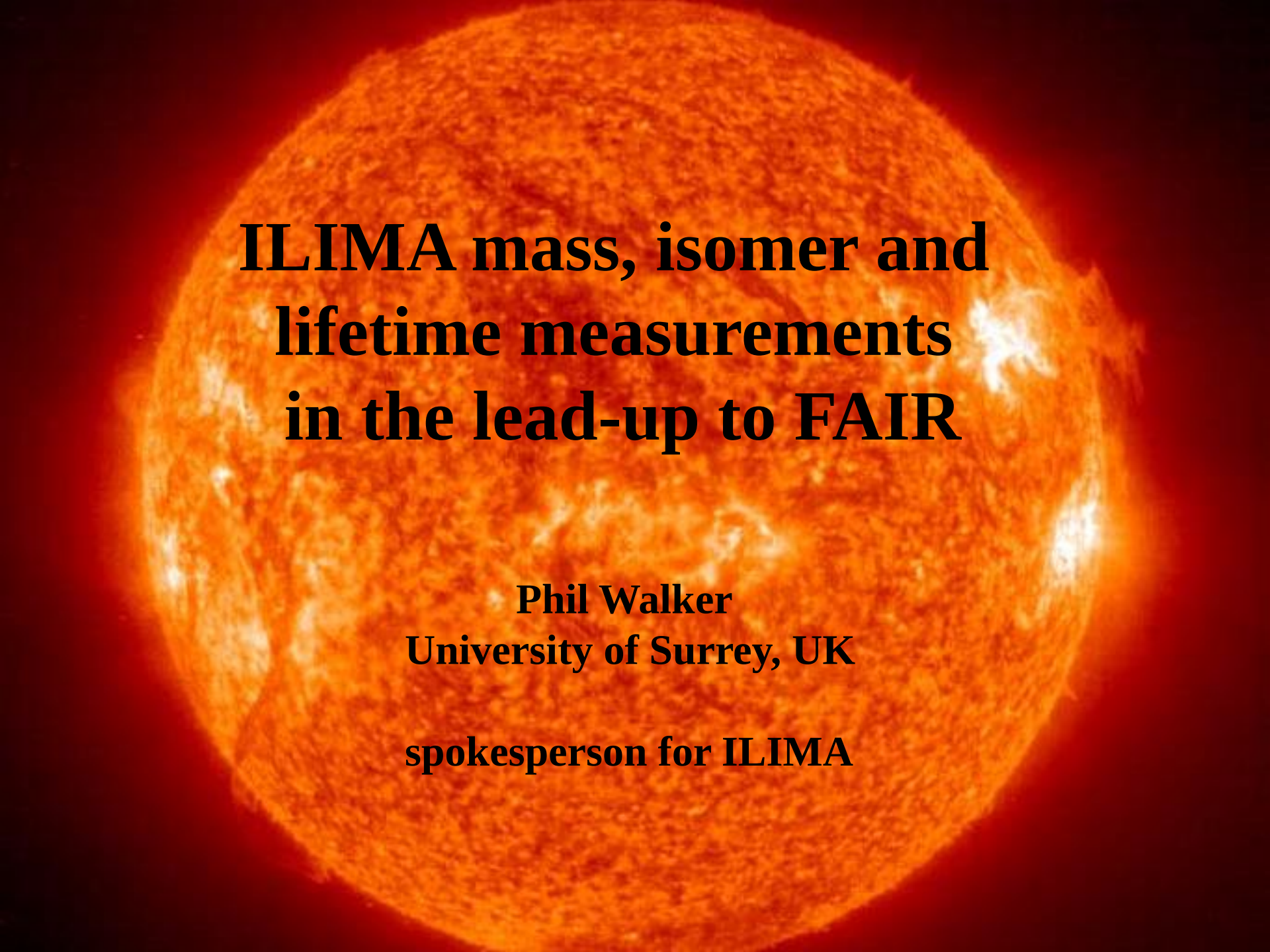
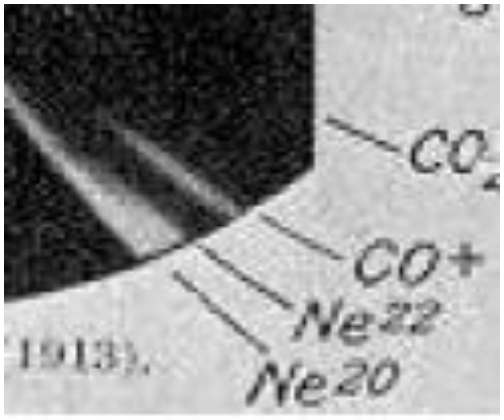


ILIMA mass, isomer and lifetime measurements in the lead-up to FAIR

Phil Walker
University of Surrey, UK

spokesperson for ILIMA

100 years of mass spectrometry



Discovery of neon isotopes:
J. J. Thomson, “Rays of positive electricity”
Proc. Roy. Soc. A89 (1913) 1

J.J. Thomson

First: separation of **isotopes** (different A)
Later: separation of **isobars** (same A = N + Z, different N and Z)
Now: separation of **isomers** (same N and Z, different configuration)

100 years of mass spectrometry

International Journal of Mass Spectrometry 349–350 (2013) 247

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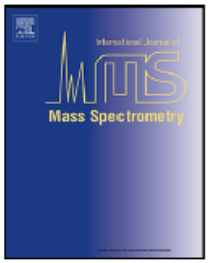
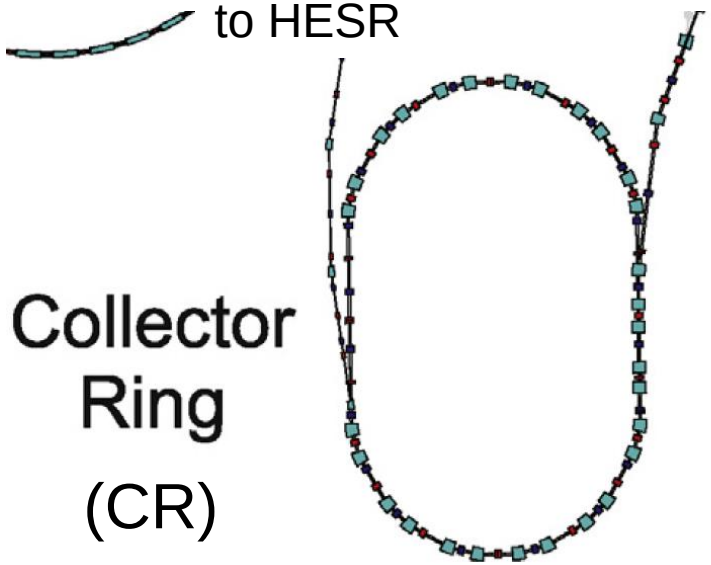
journal homepage: www.elsevier.com/locate/ijms



The ILIMA project at FAIR

P.M. Walker
Yu.A. Litvinov
H. Geissel

ILIMA



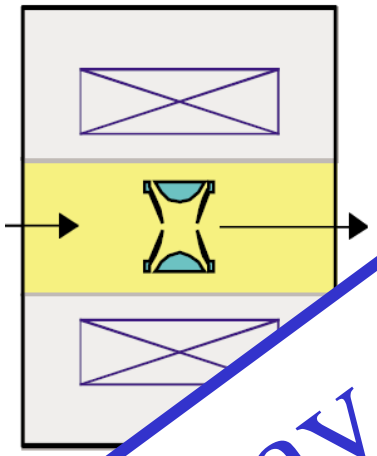
Isochronous and Schottky mass and lifetime spectrometry

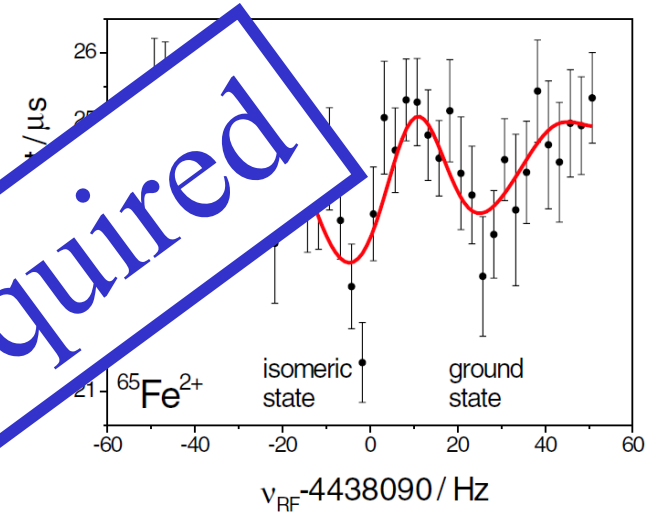
Isomer discoveries with stored ions

Penning trap

^{65m}Fe and ^{65g}Fe

M. Block et al., Phys. Rev. Lett. 100 (2008) 132501 at NSCL





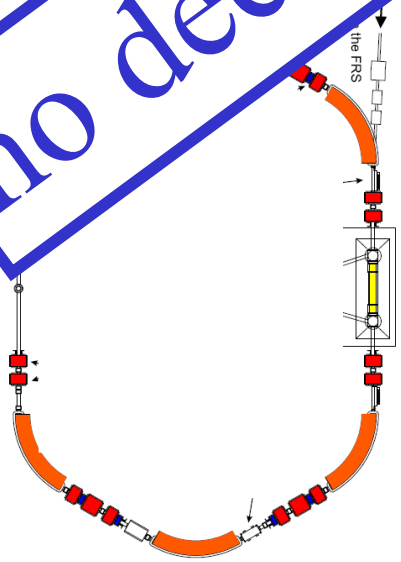
no decay required

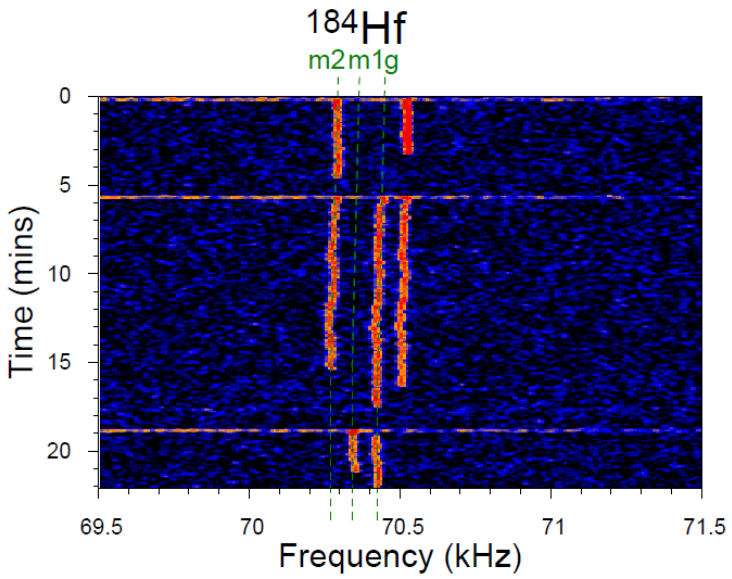
Storage ring (ESR)

^{184m2}Hf and ^{184g}Hf

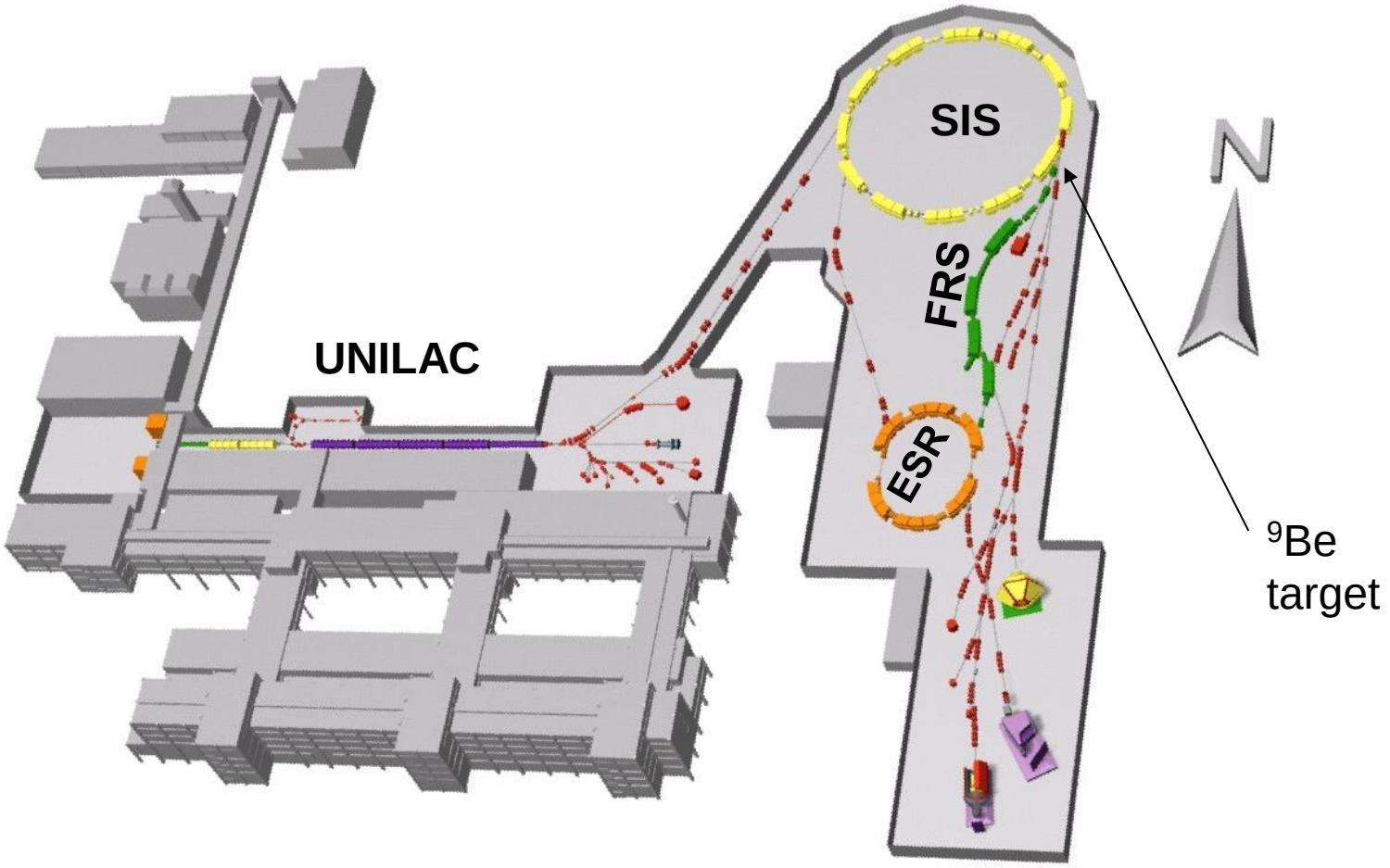
M.W. Reed et al., Phys. Rev. Lett. 105 (2010) 172501 at GSI

single-ion sensitivity

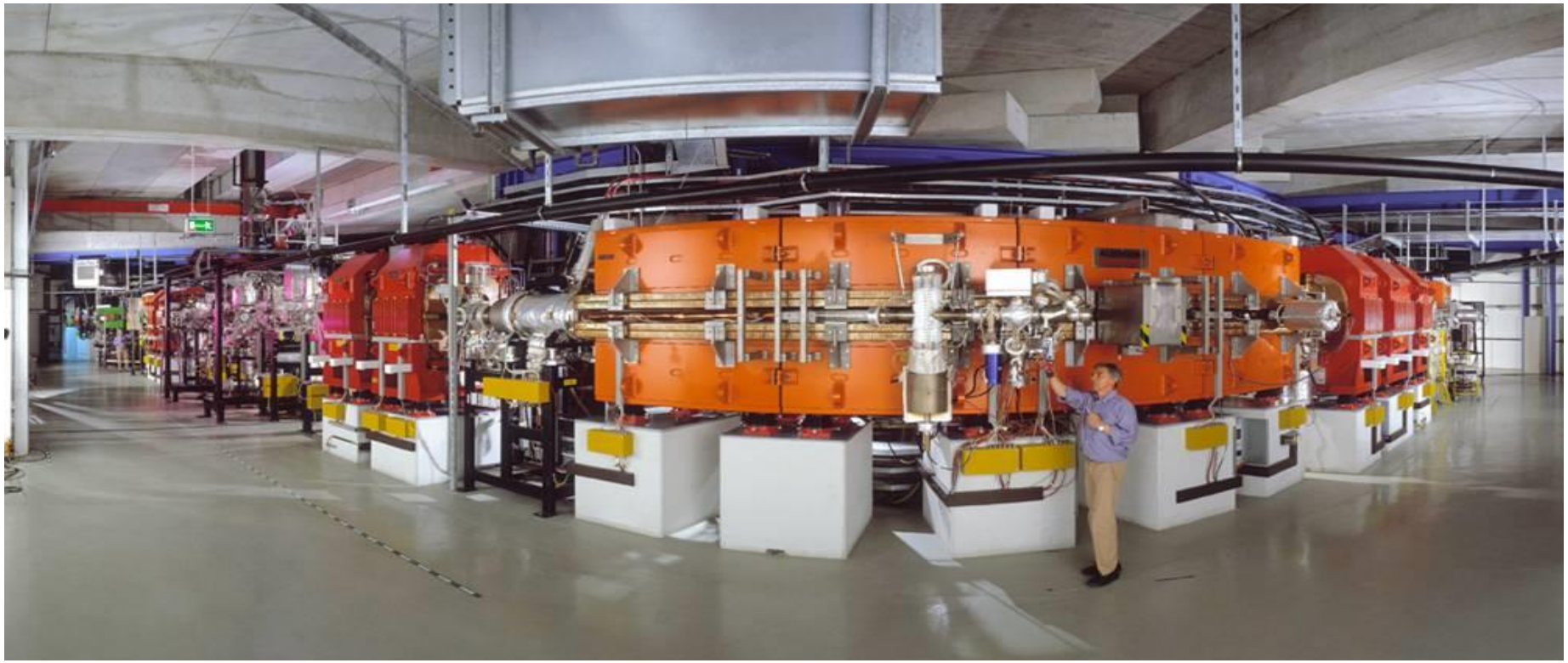




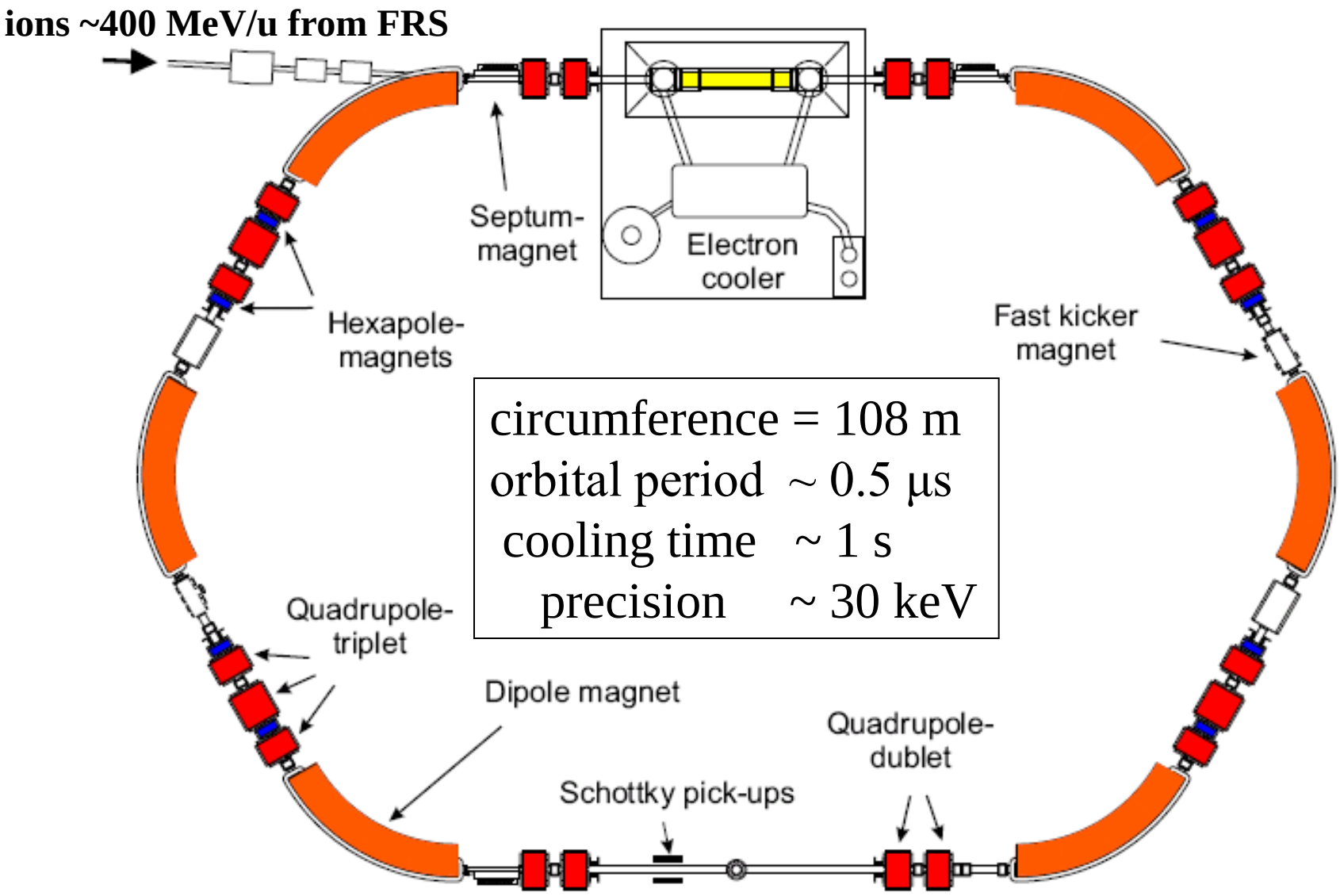
GSI accelerator complex



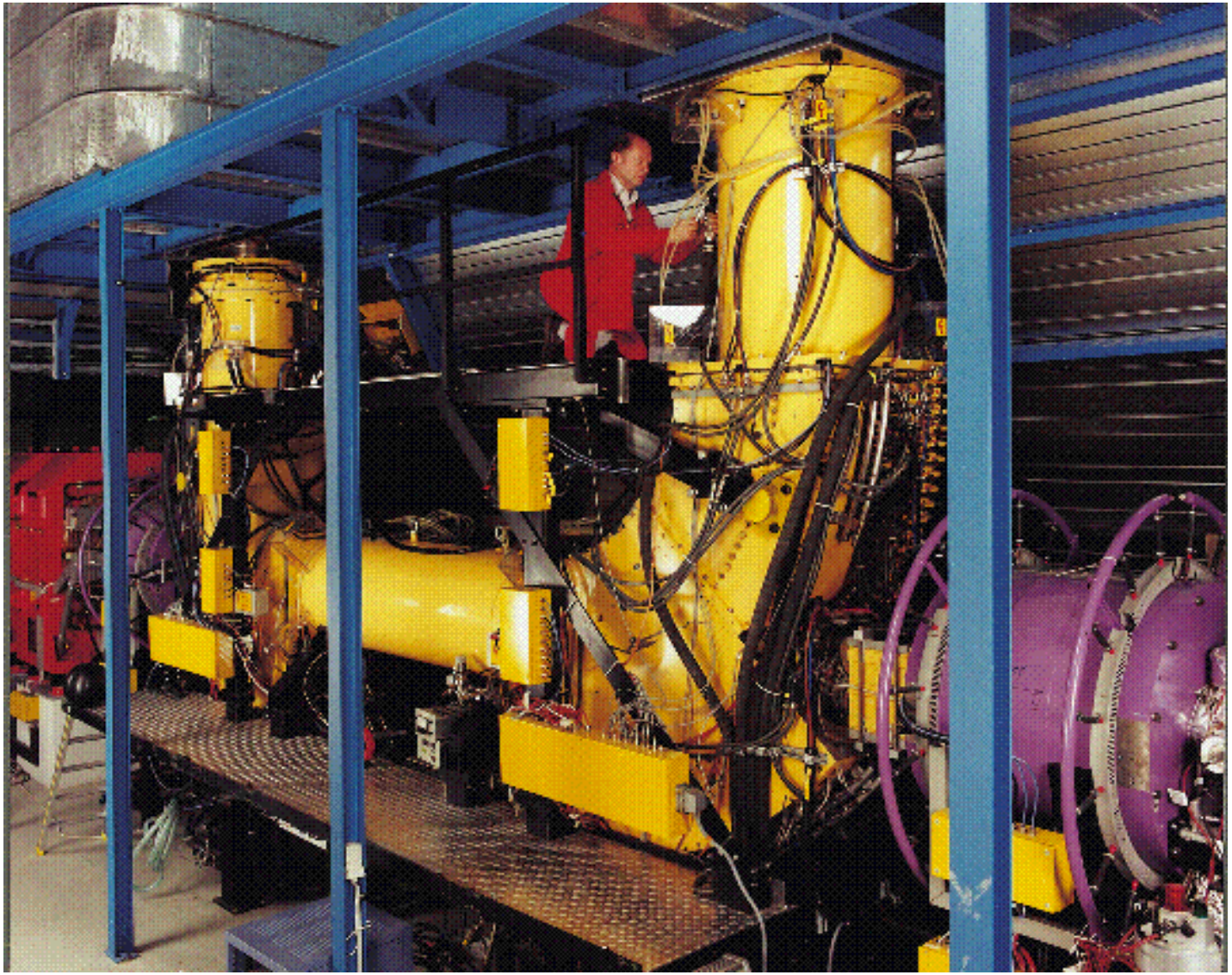
Experimental Storage Ring (ESR)



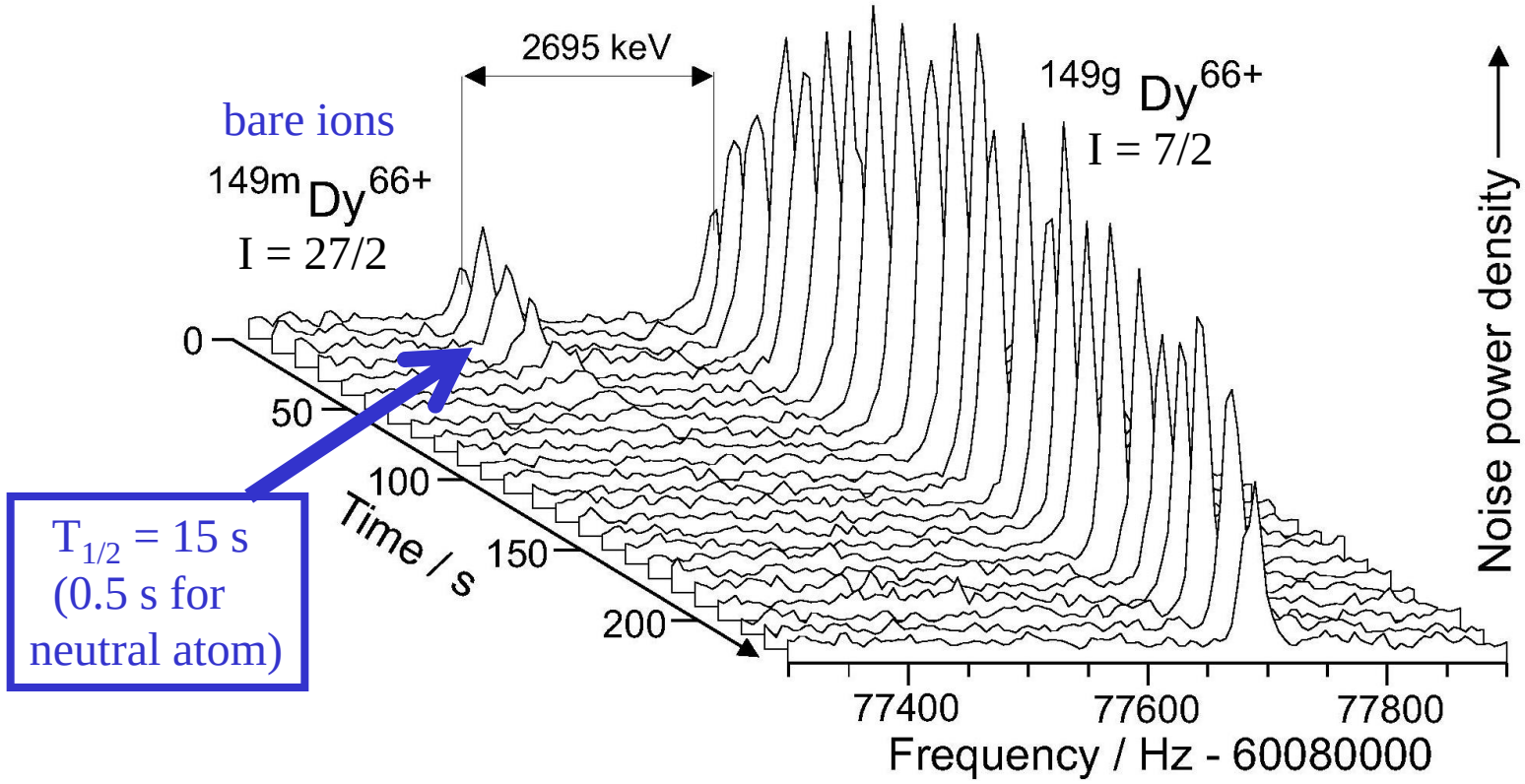
Experimental Storage Ring (ESR)



electron cooling



$^{149m+g}$Dy: isomers, lifetimes and masses
=> ILIMA collaboration at GSI-FAIR



Schottky mass spectrometry

Litvinov et al., Phys. Lett. B573 (2003) 80

[isomers up to I = 55/2 seen in fragmentation
Podolyak et al., Phys. Lett. B632 (2006) 203;
Denis Bacelar et al., Phys. Lett. B723 (2013) 302]

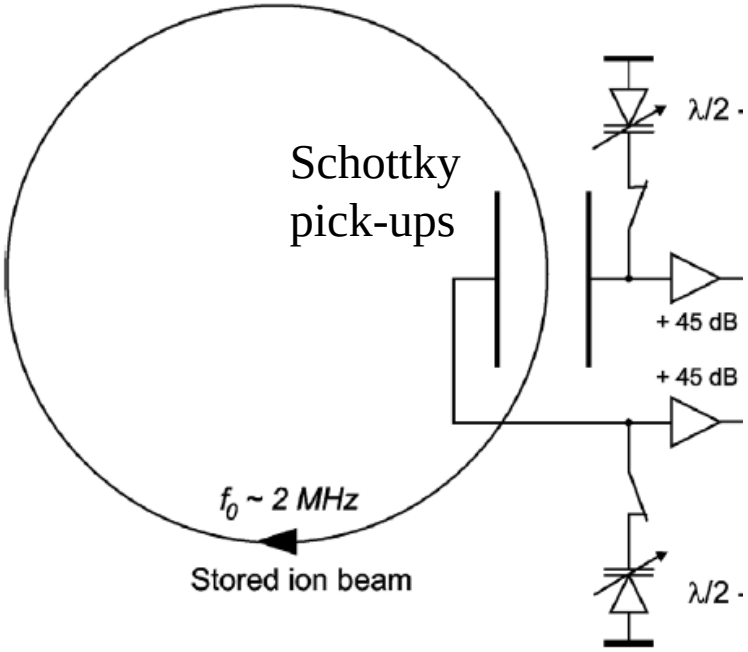
SMS and IMS
mass measurements

both methods have single-ion sensitivity

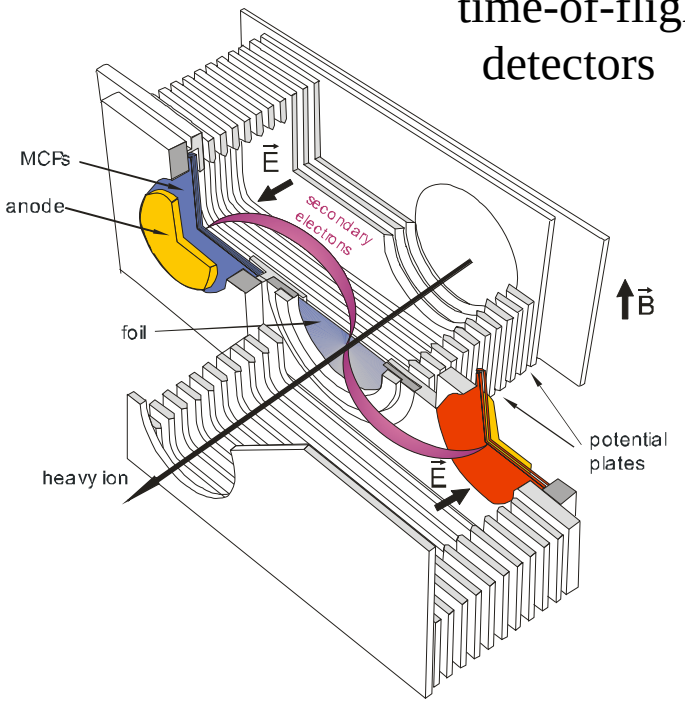
resolving power ~ 10^6 *accuracy ~ 30 μu, i.e. ~ 30 keV*

Schottky Mass Spectrometry (with cooling): $T_{½} > 1$ s

Isochronous Mass Spectrometry: $T_{½} > 10$ μs



time-of-flight detectors



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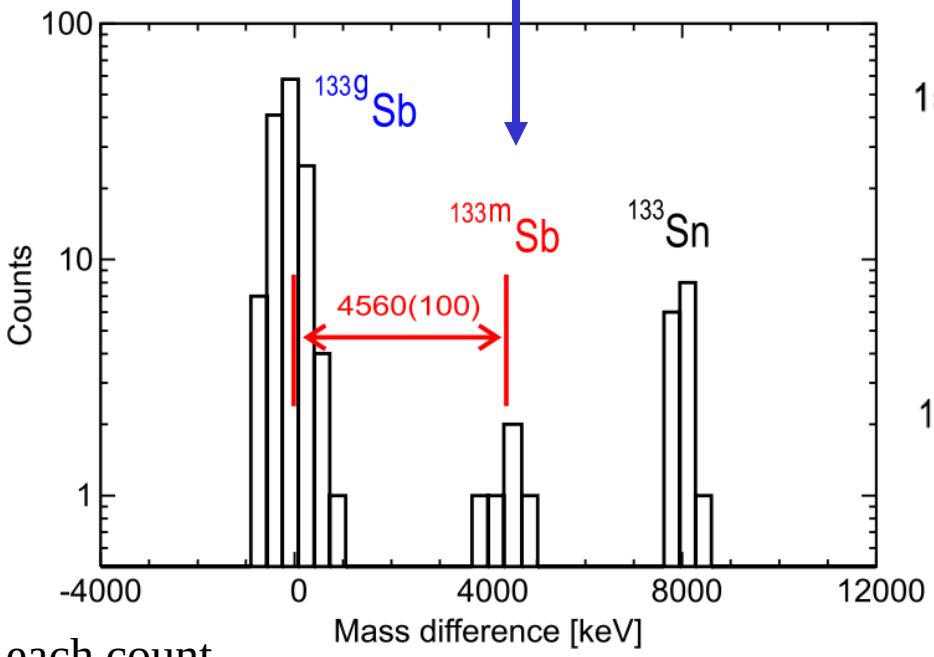
Schottky Mass Spectrometry (with cooling): $T_{½} > 1$ s

Isochronous Mass Spectrometry: $T_{½} > 10$ μs

$$\frac{\Delta f}{f} = -\frac{1}{\gamma_t^2}\frac{\Delta(m/q)}{m/q} + \frac{\Delta v}{v}\left(1 - \frac{\gamma^2}{\gamma_t^2}\right)$$

Shell-model isomer in n-rich ^{133}Sb

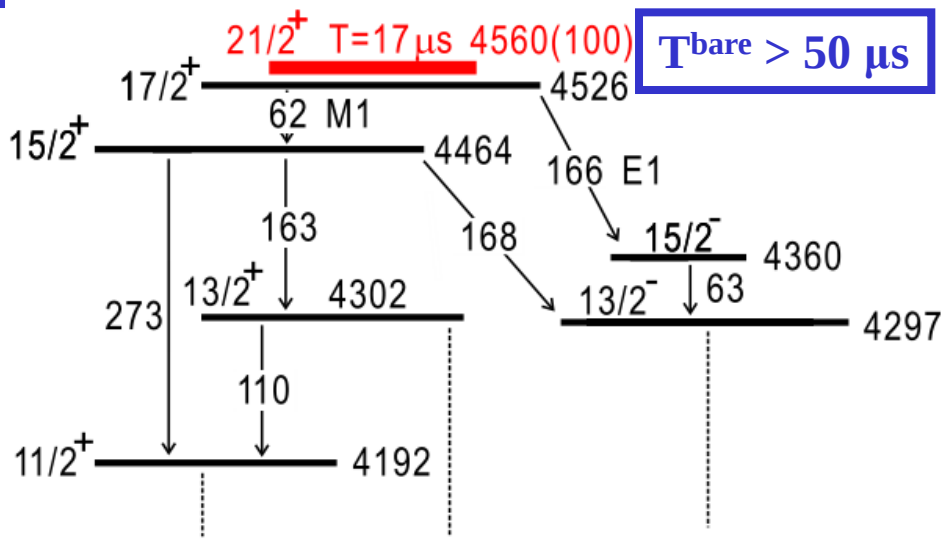
- first direct observation of this isomer
- shortest-lived stored ion



each count represents a single ion

^{238}U fission

isochronous mass spectrometry



$T^{bare} > 50$ µs

consistent with shell-model calculations: *Urban et al., Phys. Rev. C62 (2000) 027301*

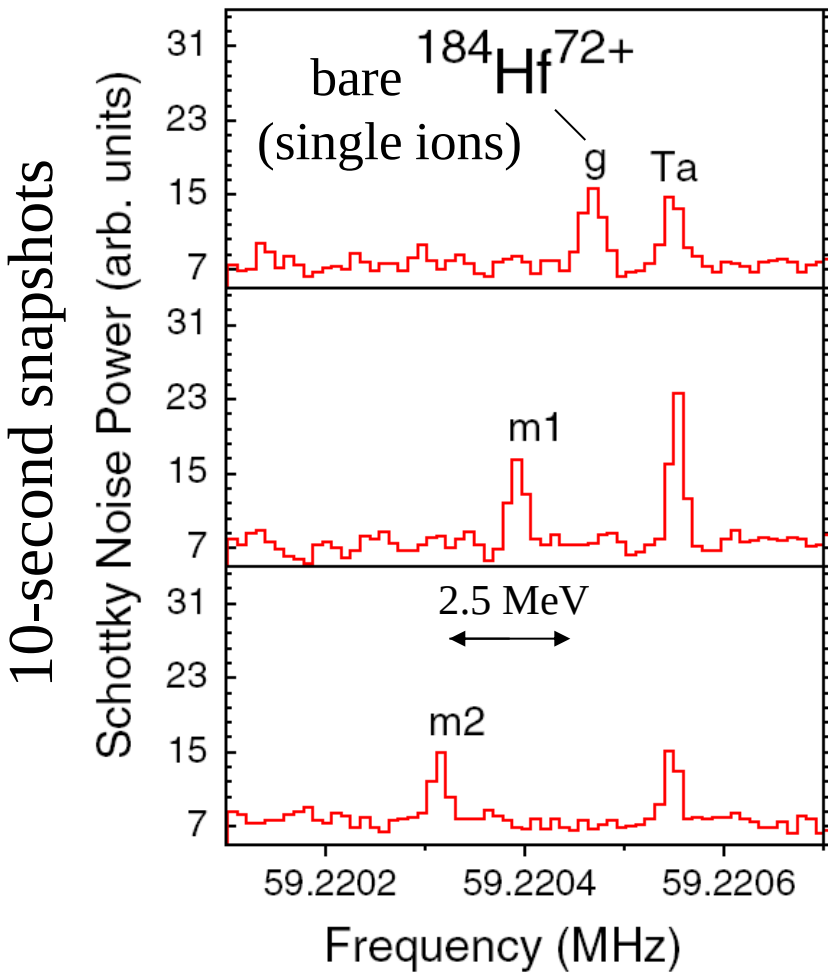
Sun et al., Phys. Lett. B688 (2010) 294

High-K isomers in n-rich ^{184}Hf

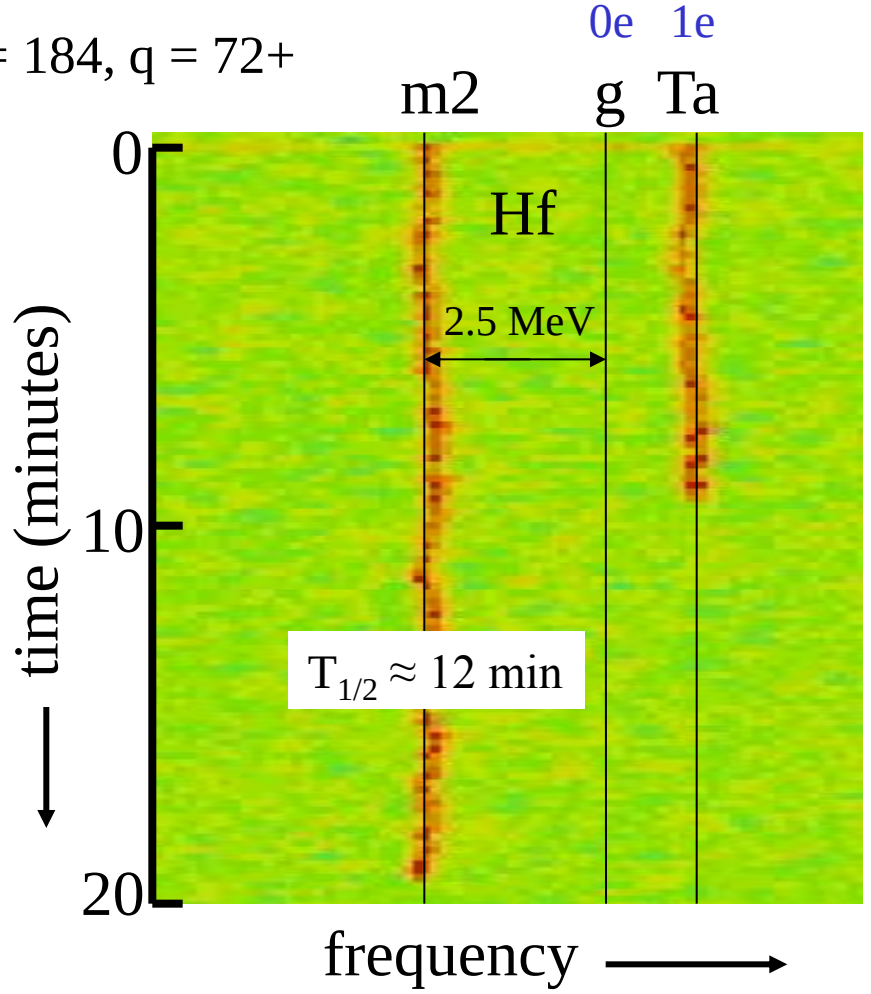
^{197}Au fragmentation

- first observation of *m2* isomer
- long-lived β-decaying isomer

Schottky mass spectrometry



A = 184, q = 72+



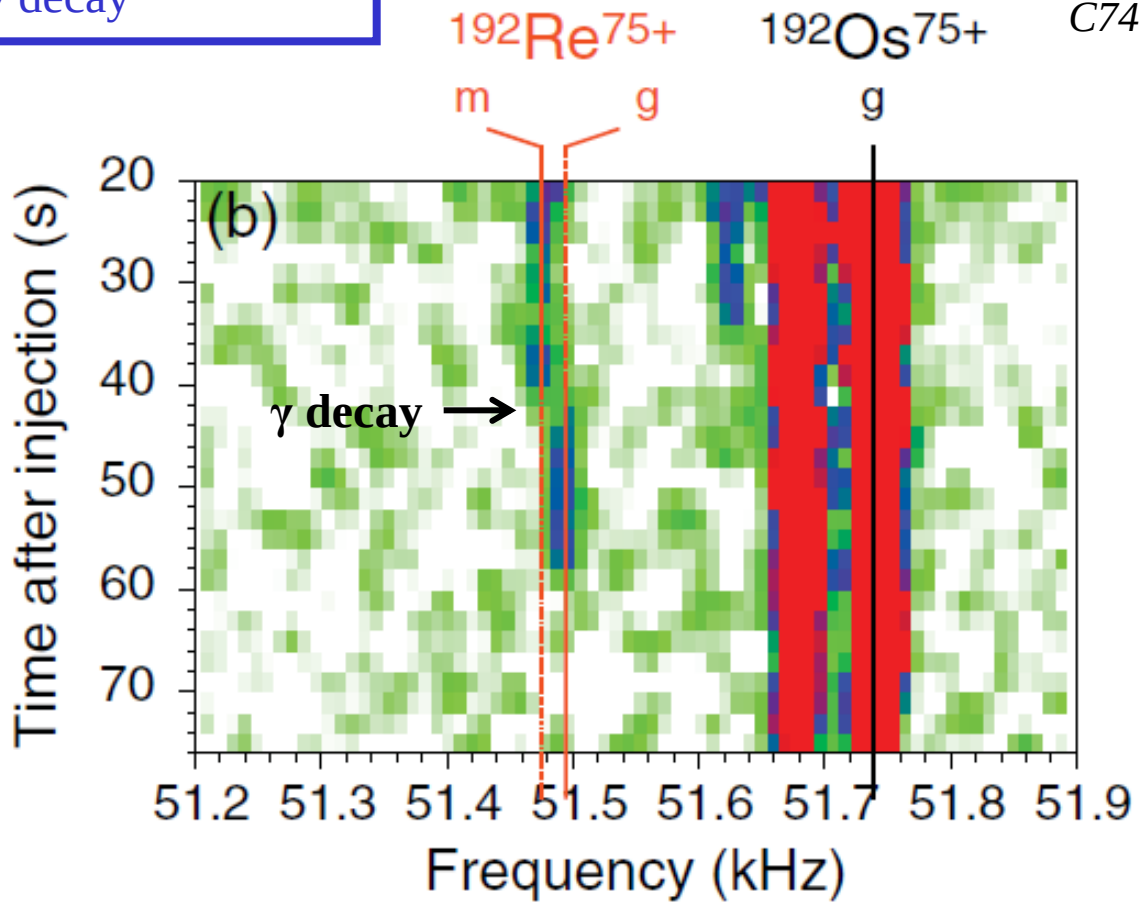
Reed et al., Phys. Rev. Lett. 105 (2010) 172501

Shape(?) isomer in n-rich ^{192}Re

- first observation of this isomer
- 7 ions with γ decay

region of prolate-oblate shape coexistence

Walker and Xu, Phys. Rev. C74 (2006) 067303



Reed et al., Phys. Rev. C86 (2012) 054321

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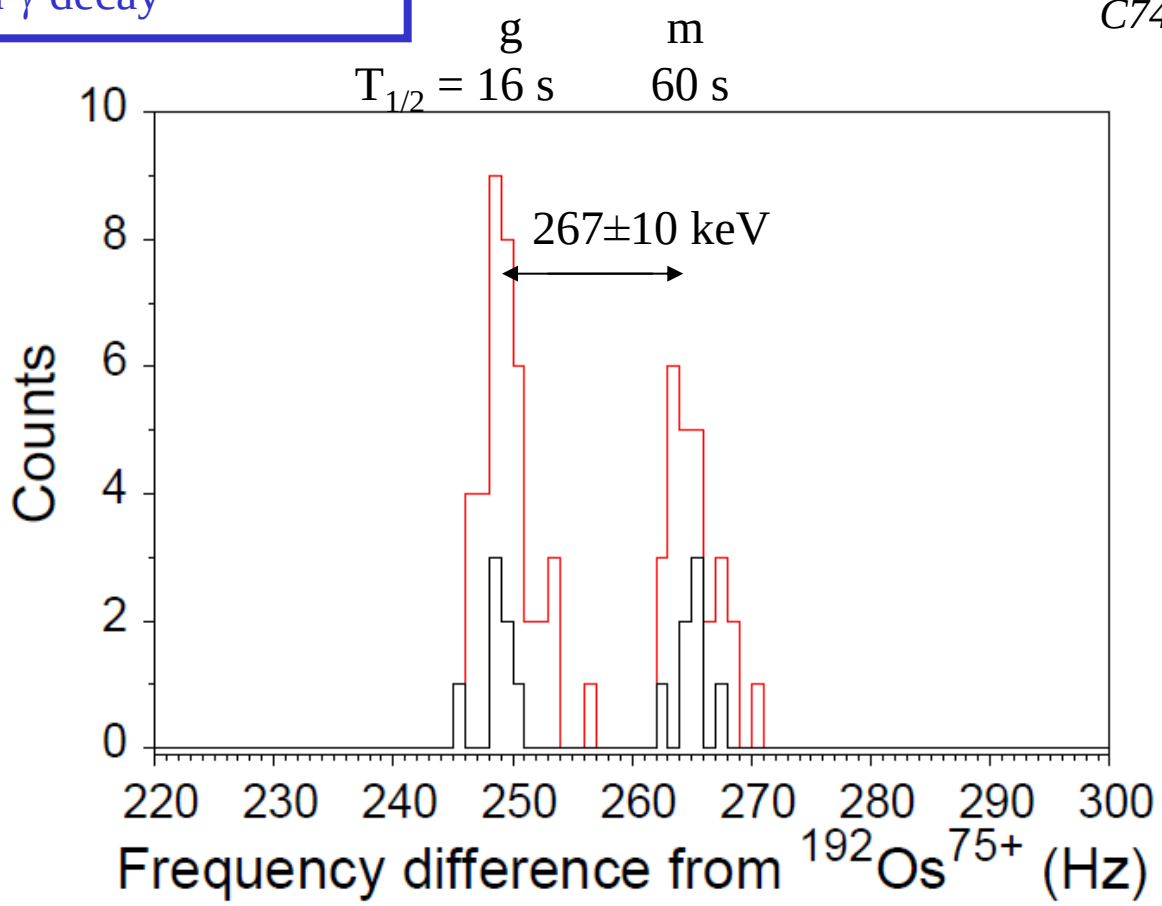


each count represents a single ion

all single ions

ions before and after γ decay

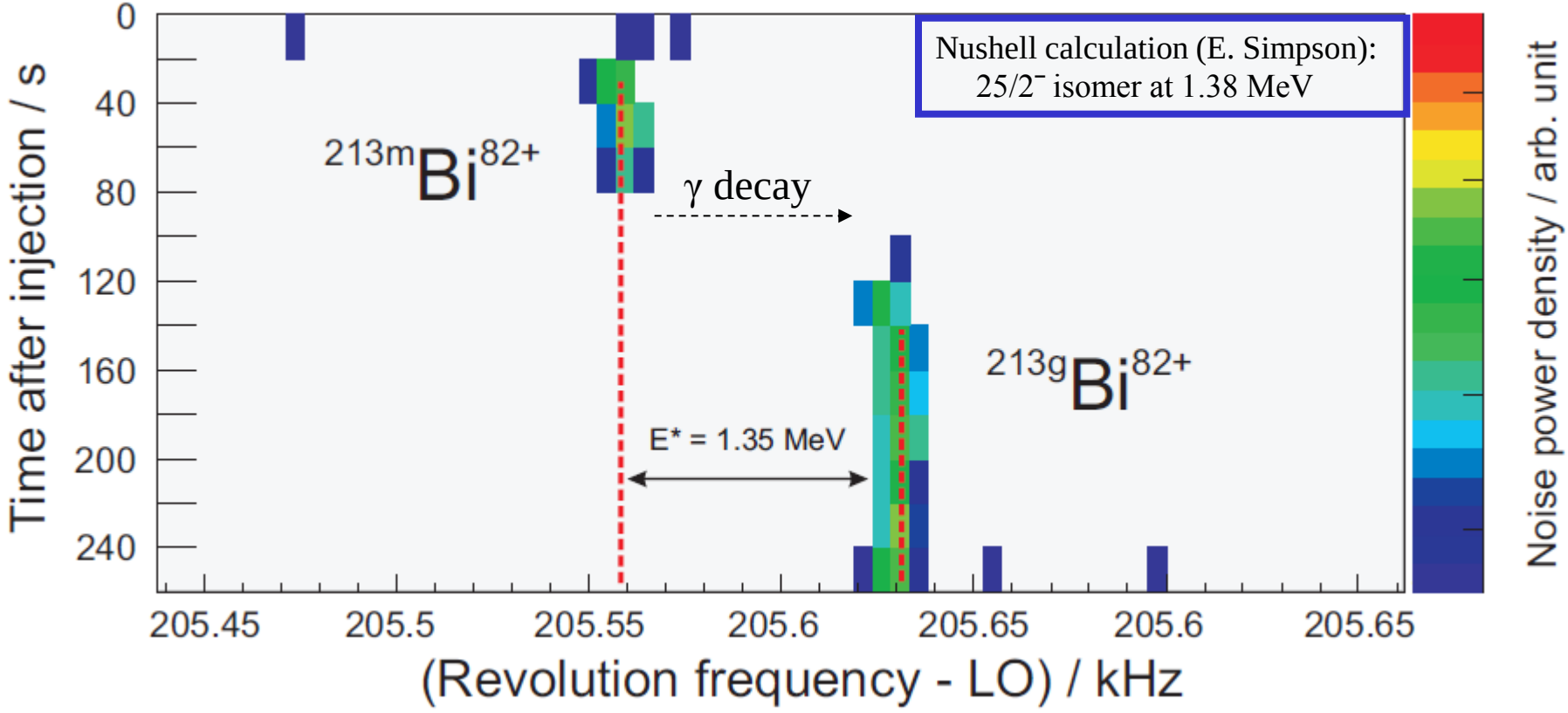
Reed et al., Phys. Rev. C86 (2012) 054321; and J. Phys. Conf. Series 381 (2012) 012058

Shell-model isomer in n-rich ^{213}Bi

^{238}U fragmentation

- first observation of this isomer
- single ion with γ decay

Schottky mass spectrometry



Chen et al., Nucl. Phys. A882 (2012) 71

The case of ^{212m2}Bi

≥16

^{212m2}Bi

7 min

>1910 keV

log *ft* > 5.1

β

18$^+$

^{212m}Po

45 s

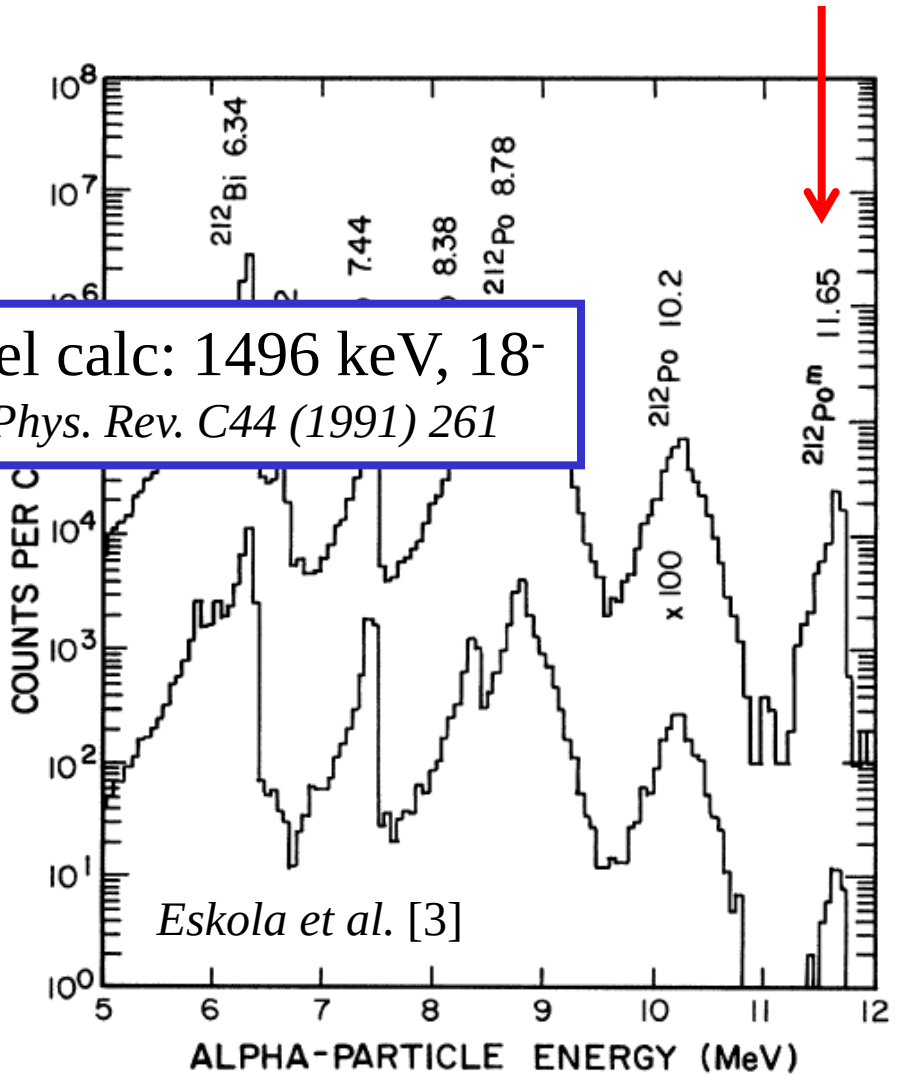
α

0$^+$

^{208}Pb

Shell model calc: 1496 keV, 18$^-$

Warburton, Phys. Rev. C44 (1991) 261



detection:

- ^{40}Ar on ^{238}U [1]
- ^{208}Pb on ^{nat}U [2]
- ^{18}O on ^{208}Pb [3]
- ^{238}U on ^{9}Be [new data]

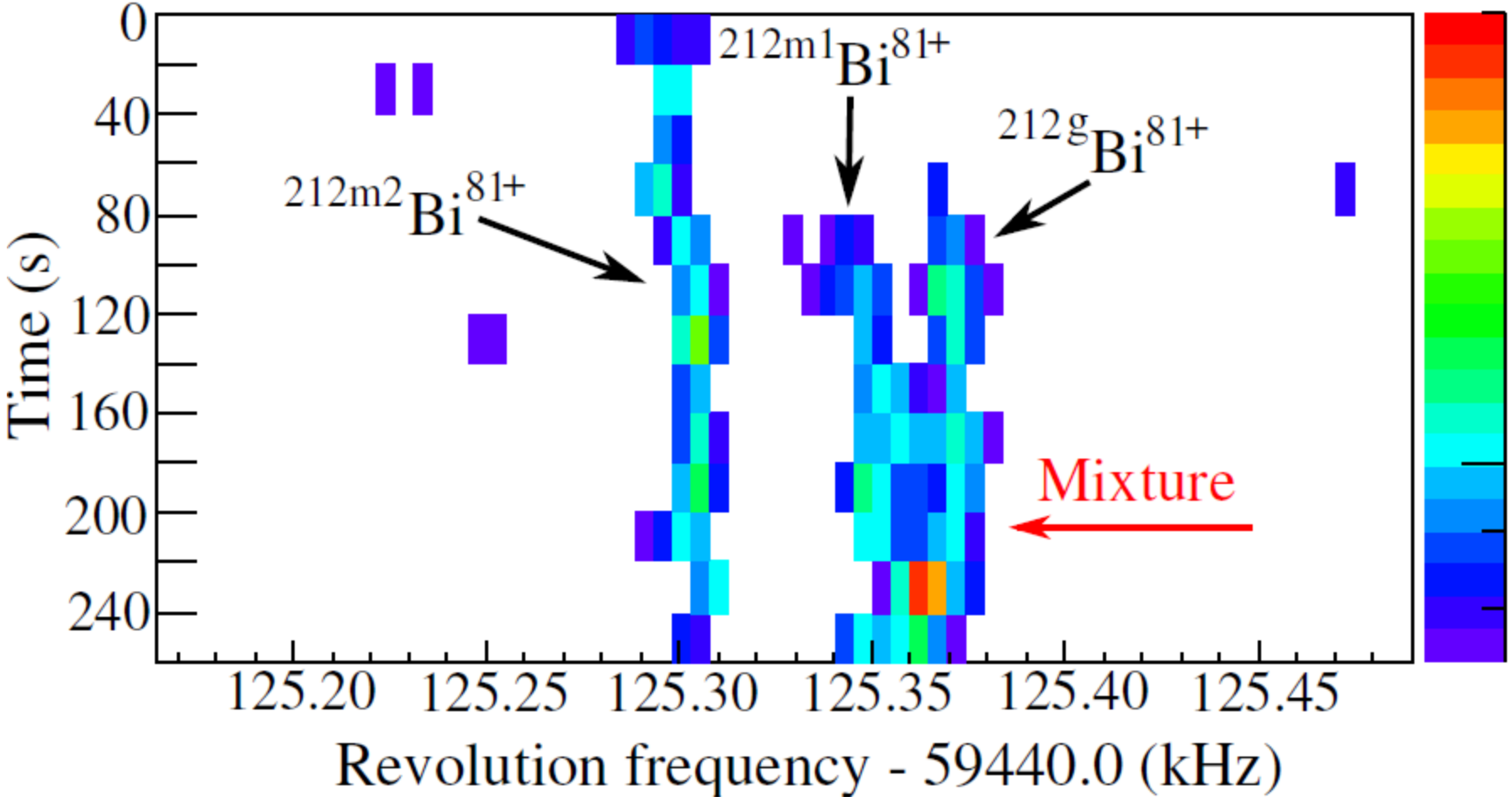
[1] *Baisden et al. Phys. Rev. Lett. 41 (1978) 738*

[2] *Lemmertz et al. Z. Phys. A298 (1980) 311*

[3] *Eskola et al., Phys. Rev. C29 (1984) 2160*

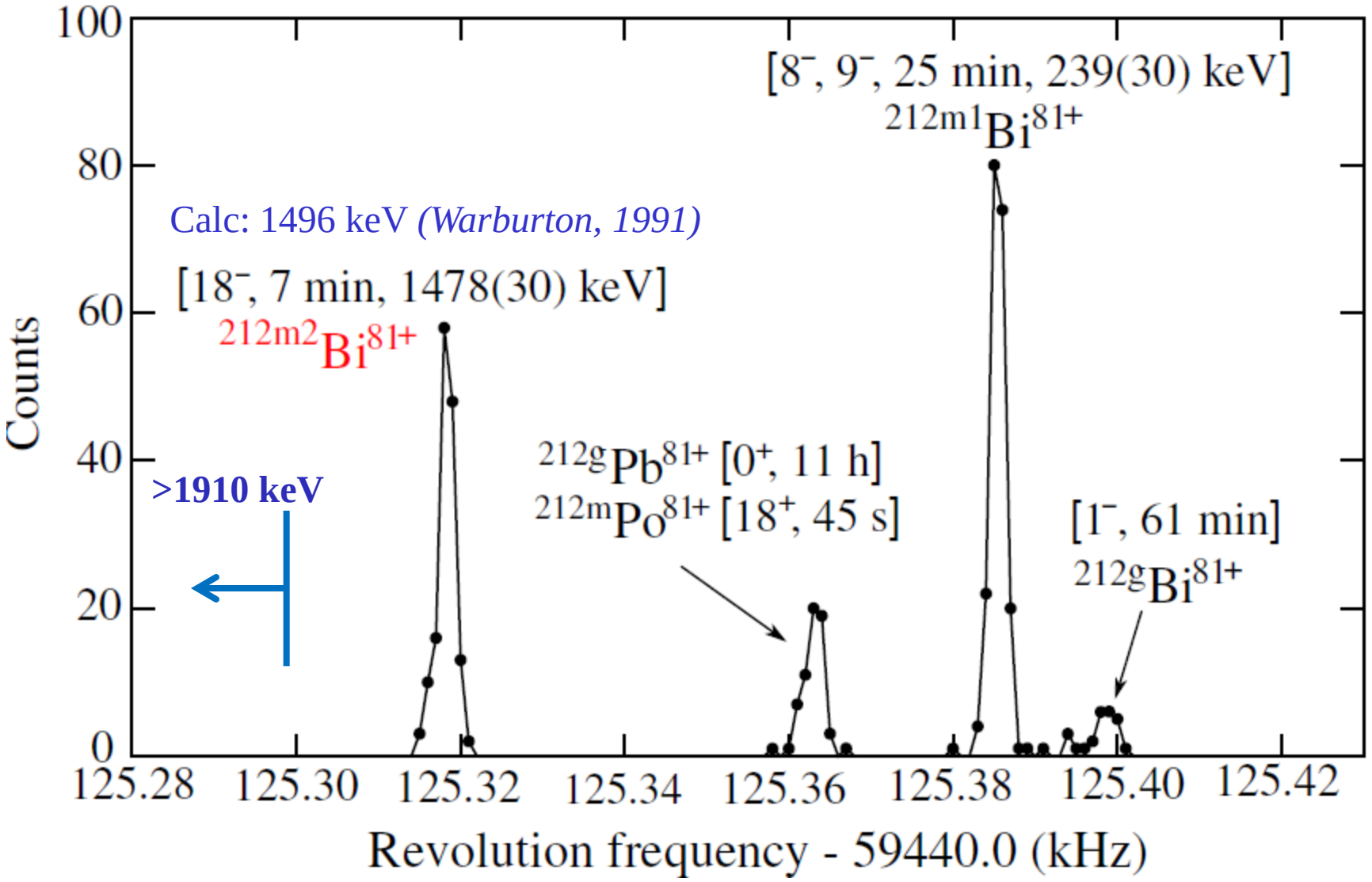
Shell-model isomers in ^{212}Bi

Schottky mass spectrometry ^{238}U fragmentation



Chen et al., Phys. Rev. Lett. 110 (2013) 122502

Shell-model isomers in ^{212}Bi



Chen et al., Phys. Rev. Lett. 110 (2013) 122502

Half-life of ^{212m2}Bi

Previous half-life (neutral atoms): 7.0(3) min

Now (highly charged ions):

cumulated observation time: 182 min
number of "lost" ions (decays): 3

$\Rightarrow$ Mean survival time = 182/3 = 60 min (lab frame)
$\Rightarrow$ Survival half-life = 30 min (local frame of reference)

$\Rightarrow$ Nuclear half-life > 30 min

$\Rightarrow$ Highly converted internal decay (>75%)

Chen et al., Phys. Rev. Lett. 110 (2013) 122502

^{212}Bi: 3 inter-related problems

1. Excitation energy => partial $t_{1/2}(\beta)$ >30min
   resolves log *ft* problem

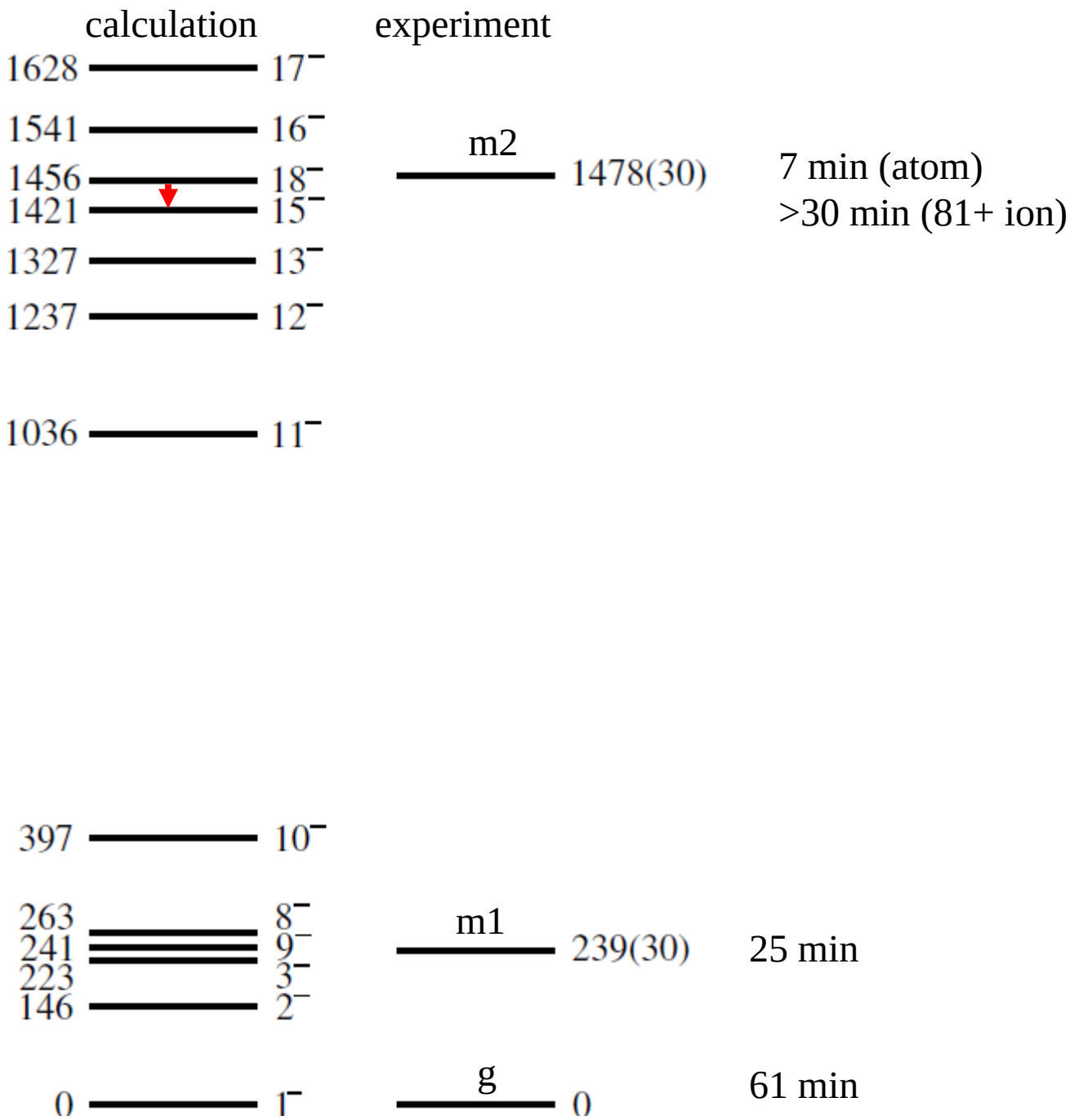
2. Half-life => highly converted internal decay

3. Isomeric ratio => internal decay was “missing”

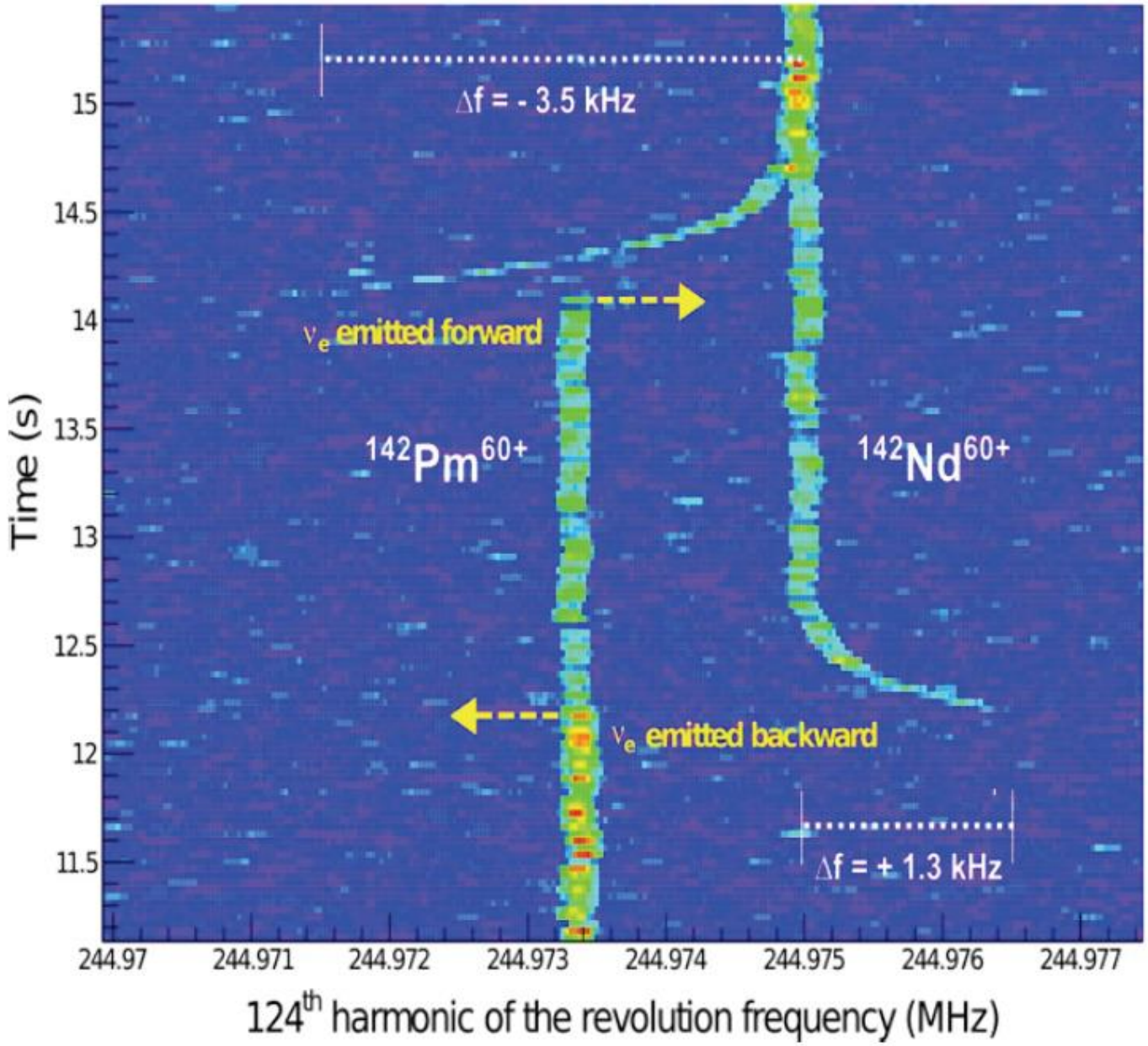
Chen et al., Phys. Rev. Lett. 110 (2013) 122502

^{212}Bi

45-keV M3
highly converted
(α = 61,000)

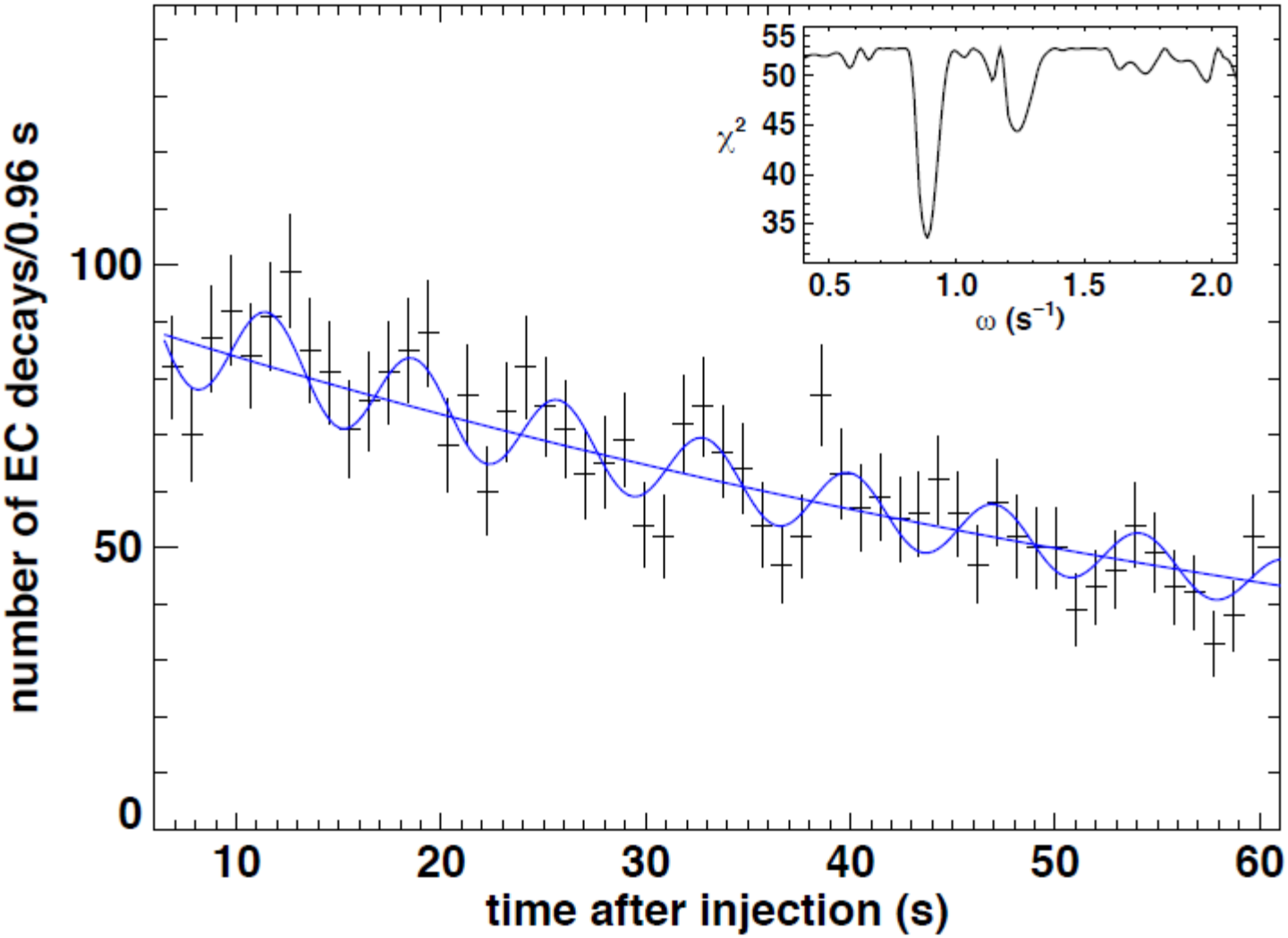


Chen et al., Phys. Rev. Lett. 110 (2013) 122502



Kienle et al.
Phys. Lett. B
in press

Traces of two cooled $^{142}Pm^{60+}$ parent ions,



Number of EC decays per 0.96 s of H-like $^{142}Pm^{60+}$ ions

Kienle et al.
Phys. Lett. B
in press

see also
Litvinov et al.,
Phys. Lett. B
664 (2008) 162

summary

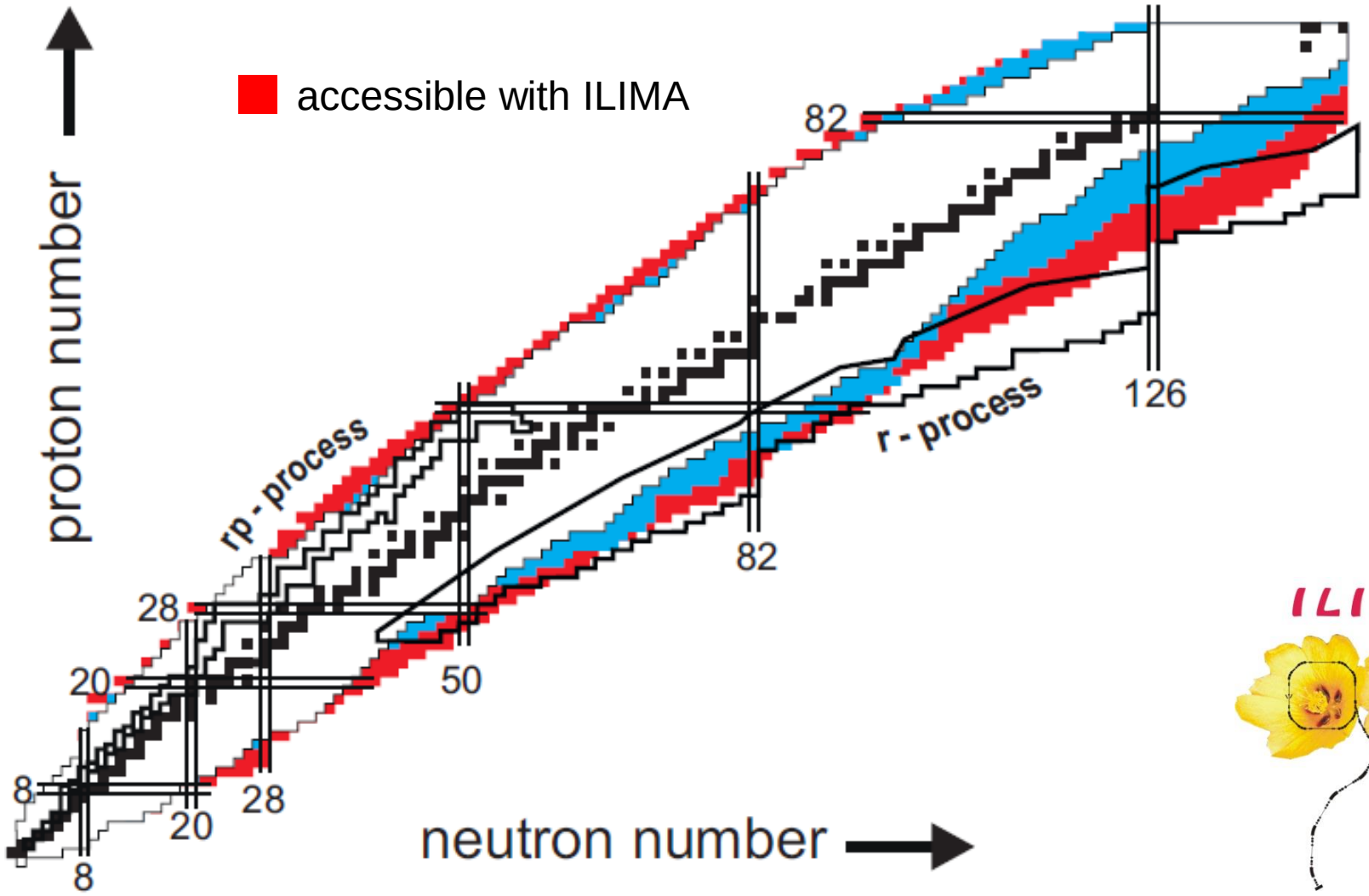
ions in the GSI storage ring

- revolution frequency => mass => excitation energy
- half-life
- isomeric ratio

understanding ^{212m2}Bi

decay oscillations persist

looking forward to ILIMA



Walker, Litvinov and Geissel, Int. J. Mass Spec. 349-350 (2013) 247

GSI, Germany: E. Badura, F. Bosch, C. Brandau, C. Dimopoulou, A. Dolinski, P.Egelhof, A. Evdokimov, B. Franczak, B. Franzke, H. Geissel, F. Herfurth, J. Hoffmann, H.-J. Kluge, R.K. Knöbel, C. Kozhuharov, N. Kurz, S.A. Litvinov, Yu.A. Litvinov, M. Marta, G. Münzenberg, F. Montes, F. Nickel, F. Nolden, C. Nociforo, W. Quint, S. Sanjari, C. Scheidenberger, D. Shubina, H. Simon, A. Sobiczewski, M. Steck, Th. Stöhlker, S. Typel, G.K. Vorobjev, H. Weick, N. Winckler, M. Winkler
Gießen, Germany: D. Boutin, T. Dickel, B. Fabian, A. Fettouhi, M. Petrick, W.R. Plaß, D. Zhenyu
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Heidelberg, Germany: K. Blaum, B. Cakirli, A. Palffy
Mainz, Germany: K.-L. Kratz, B. Pfeiffer
St.Petersburg, Russia: I. Burzov,Yu.N. Novikov, D.M. Seliverstov, Yu. Gusev
Orsay, France: G. Audi, D. Lunney
Bruxelles, Belgium: S. Goriely, P-H. Heenen, K. Takahashi
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Los Alamos, USA: D. Madland, P. Moeller, D. Vieira
TRIUMF, Canada: I. Dillmann
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Beihang, Beijing, China: B.Sun
Saitama, Japan: T. Suzuki, T. Yamaguchi
Tsukuba, Japan: A. Ozawa
ANU Canberra, Australia: M.W. Reed

ILIMA Collaboration

100 scientists
29 institutes
16 countries