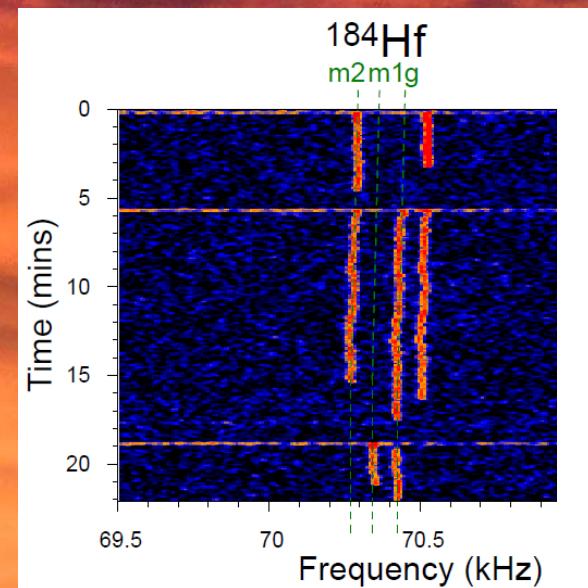


Stored Exotic Nuclei

Phil Walker
University of Surrey, UK

Stored Exotic Nuclei

- Single-ion observations
- Mass measurements
- Half-lives
- Electron conversion
- Isotope and isomer discoveries
- Future facilities



Phil Walker
University of Surrey, UK

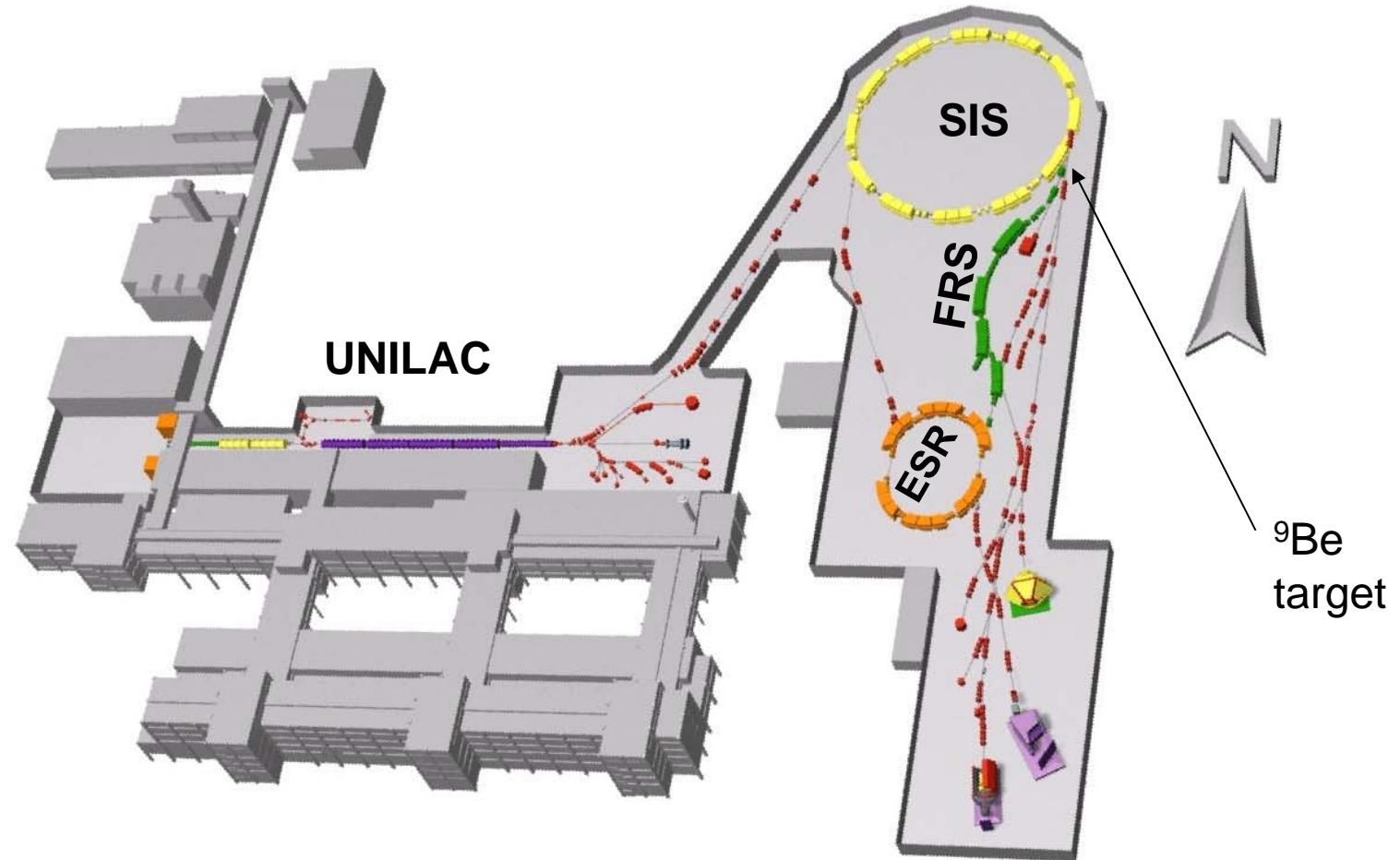


ESR at GSI

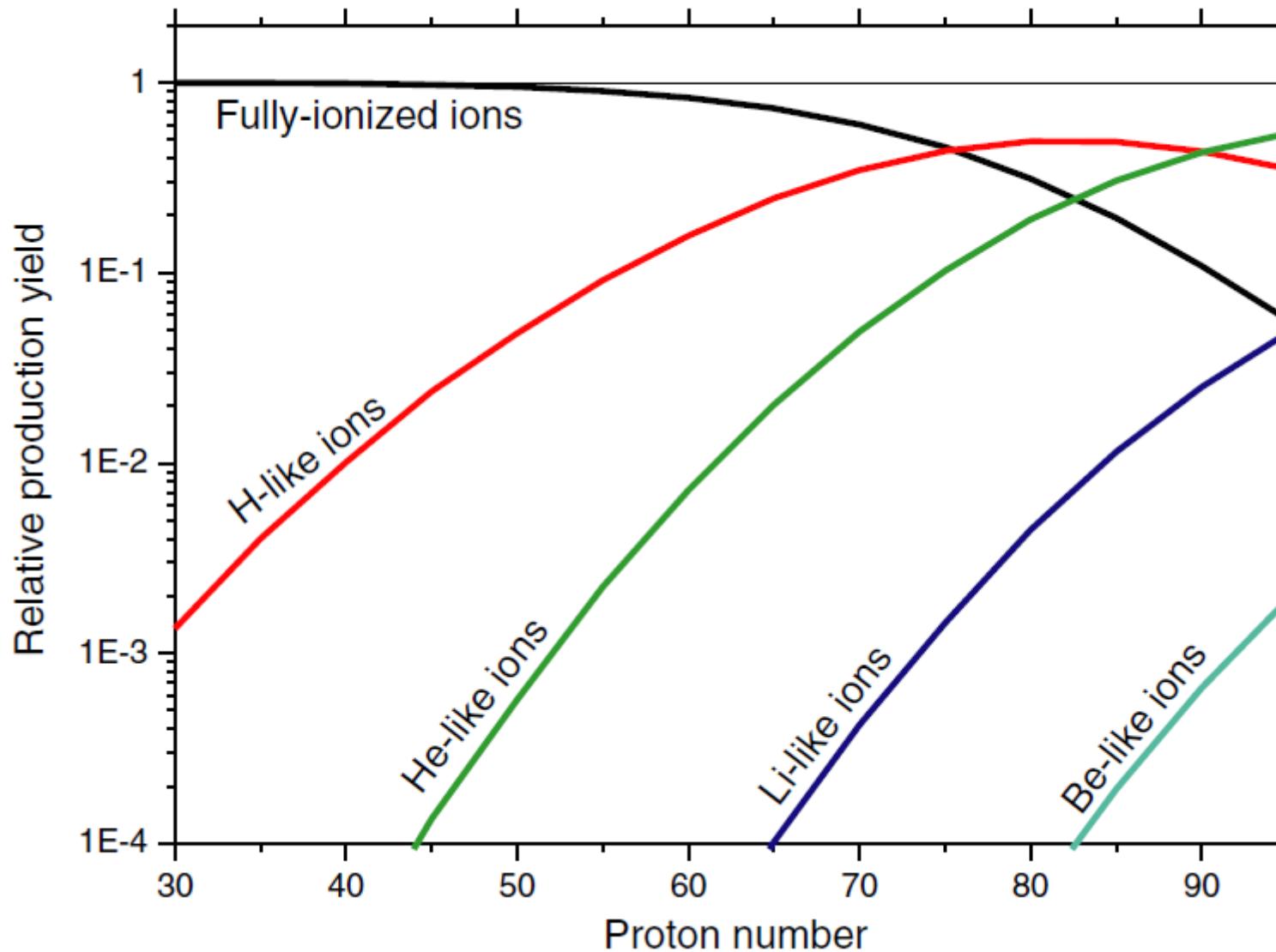


CSR实验环

GSI accelerator complex

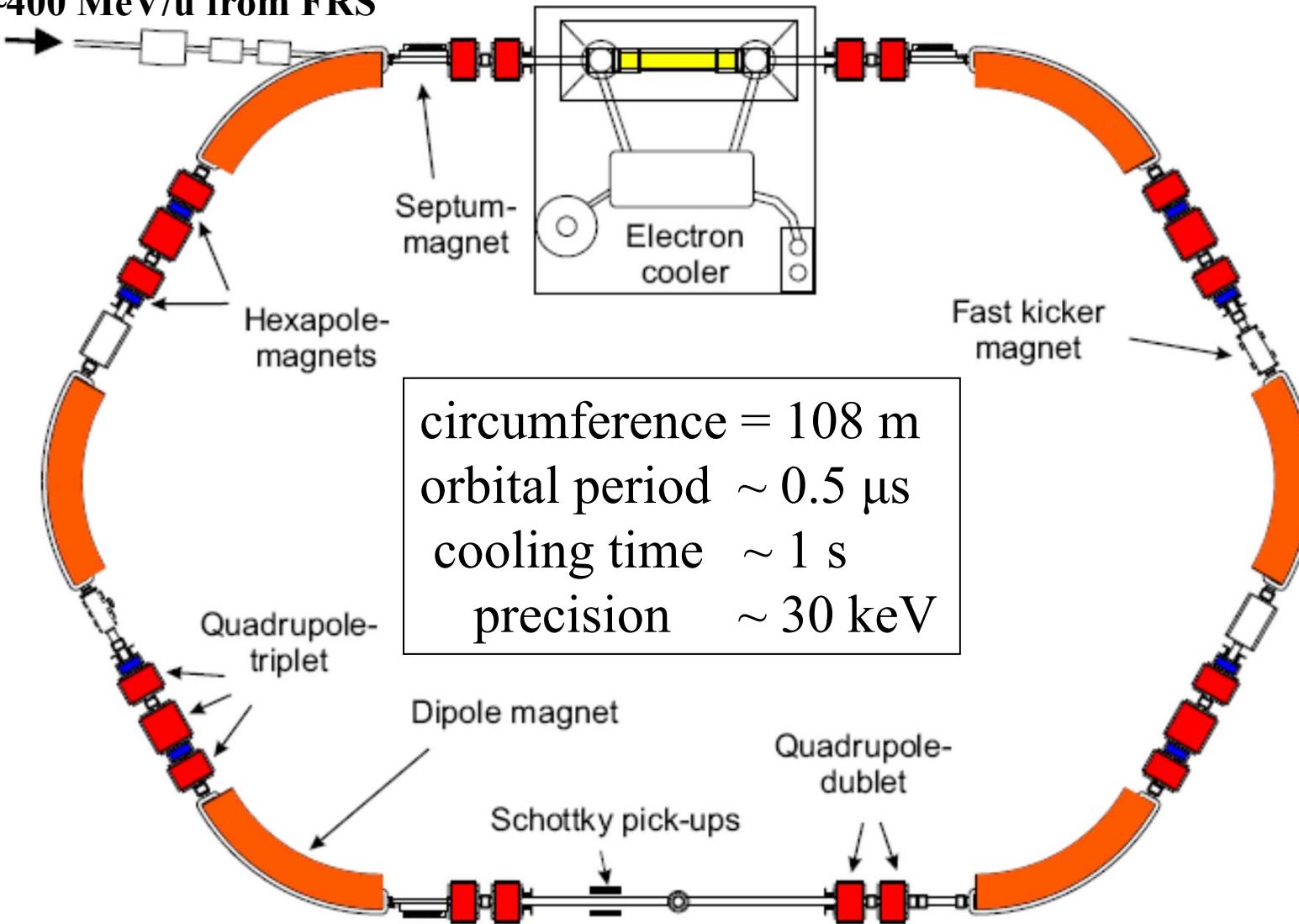


GLOBAL code charge-state calculations for 400 A.MeV ions through Be foil



Experimental Storage Ring

ions ~400 MeV/u from FRS



SMS and IMS

mass measurements

both methods have single-ion sensitivity

resolving power $\sim 10^6$ accuracy $\sim 30 \mu u$, i.e. $\sim 30 \text{ keV}$

Schottky Mass Spectrometry
(with cooling): $T_{1/2} > 1 \text{ s}$

Isochronous Mass
Spectrometry: $T_{1/2} > 10 \mu \text{s}$

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

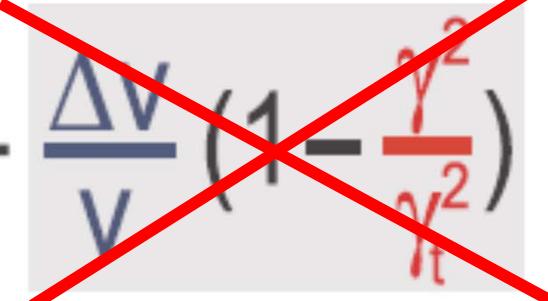
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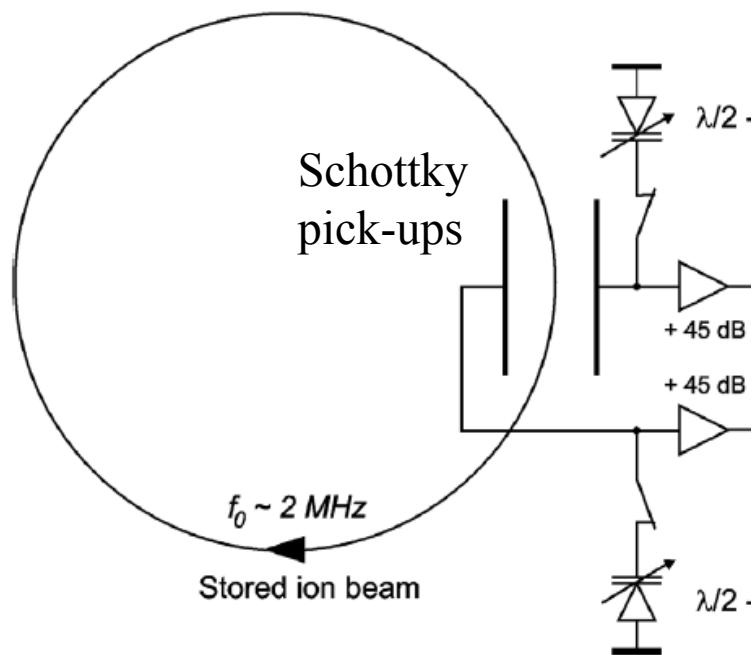
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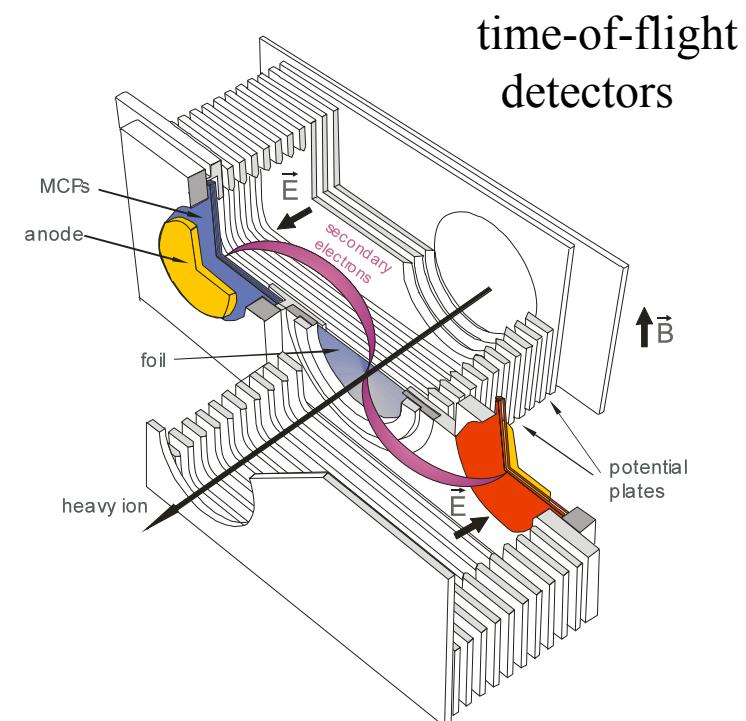
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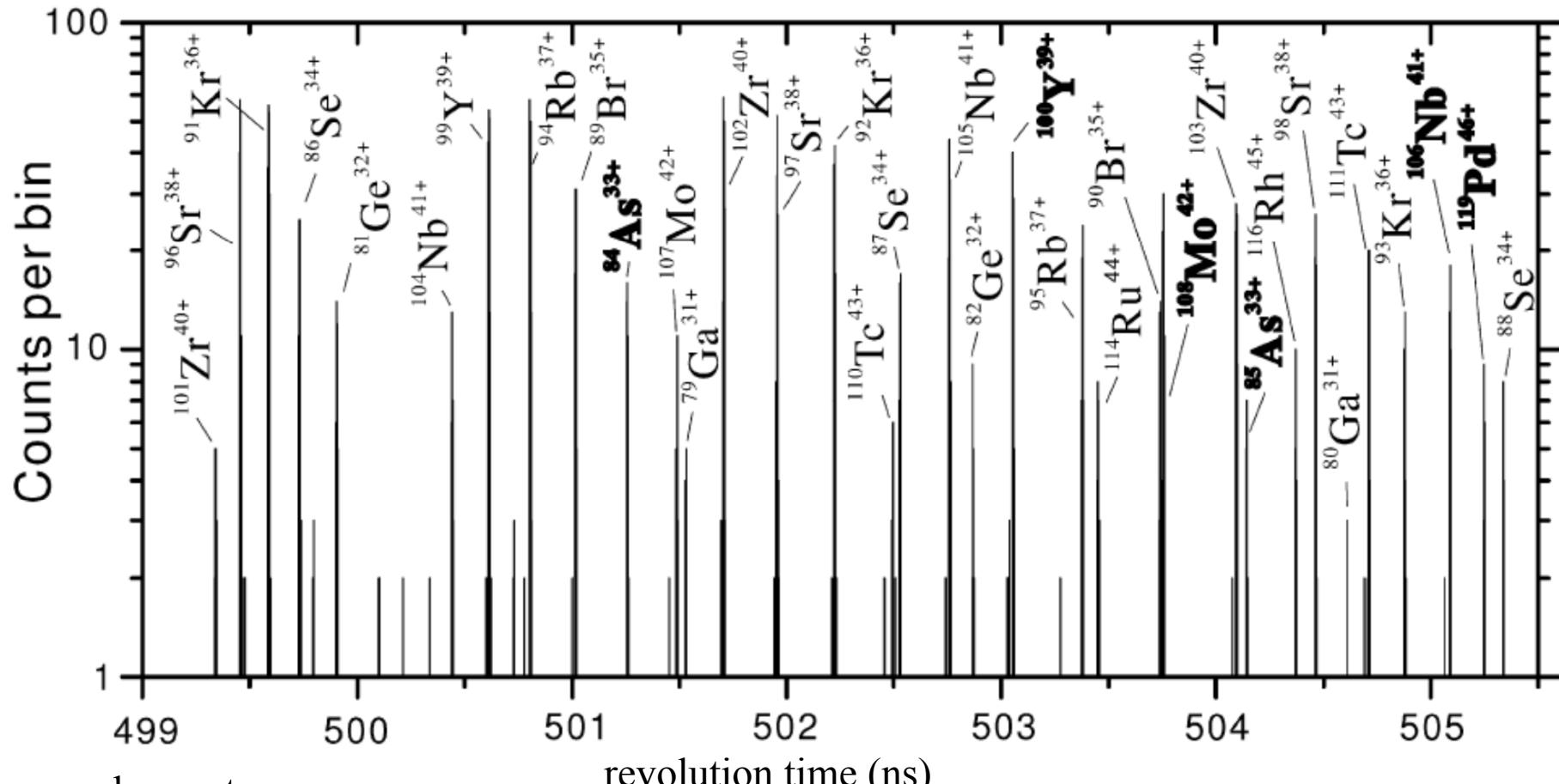


Isochronous Mass
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Isochronous Mass Spectrometry

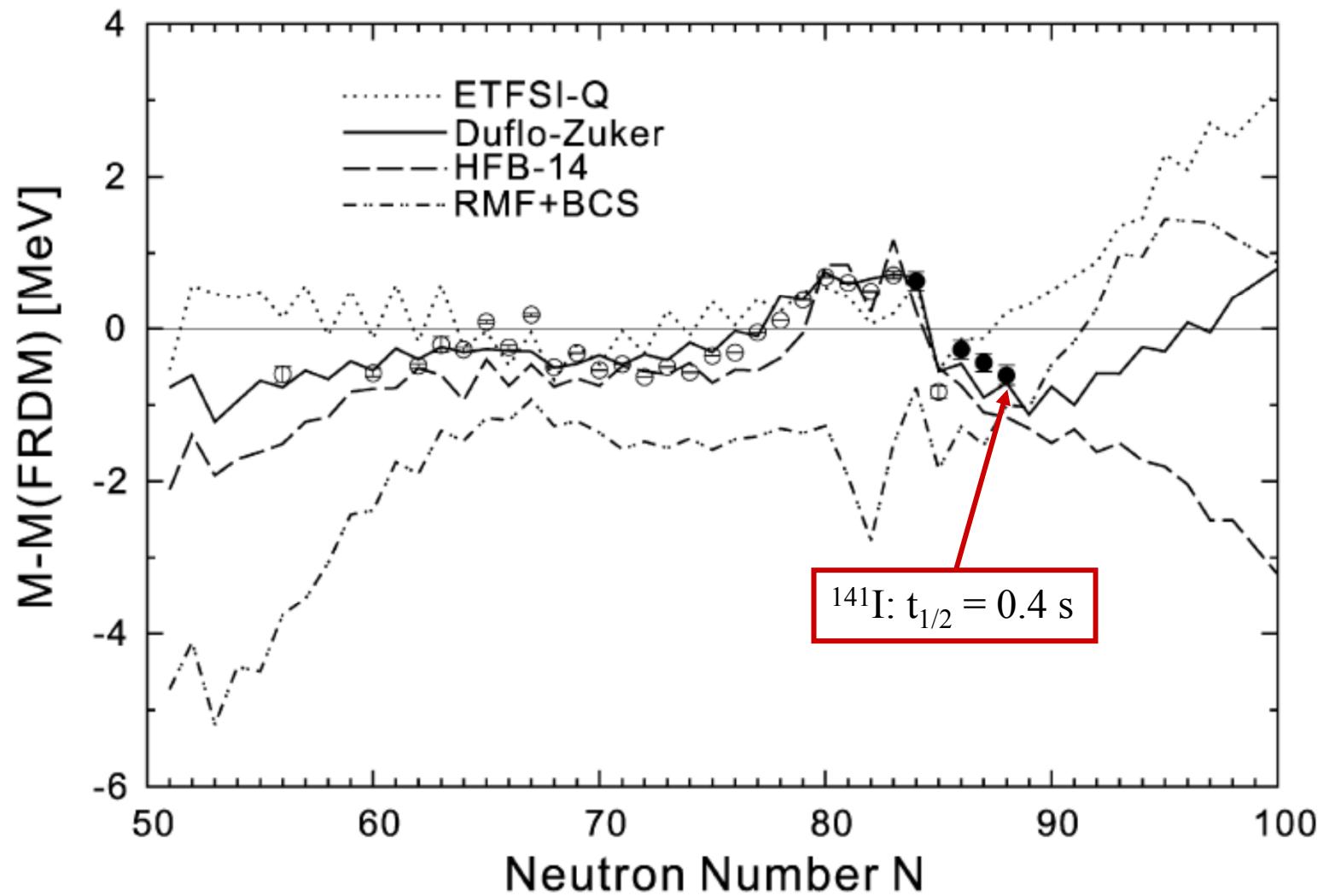
^{238}U primary beam at 411 MeV/u

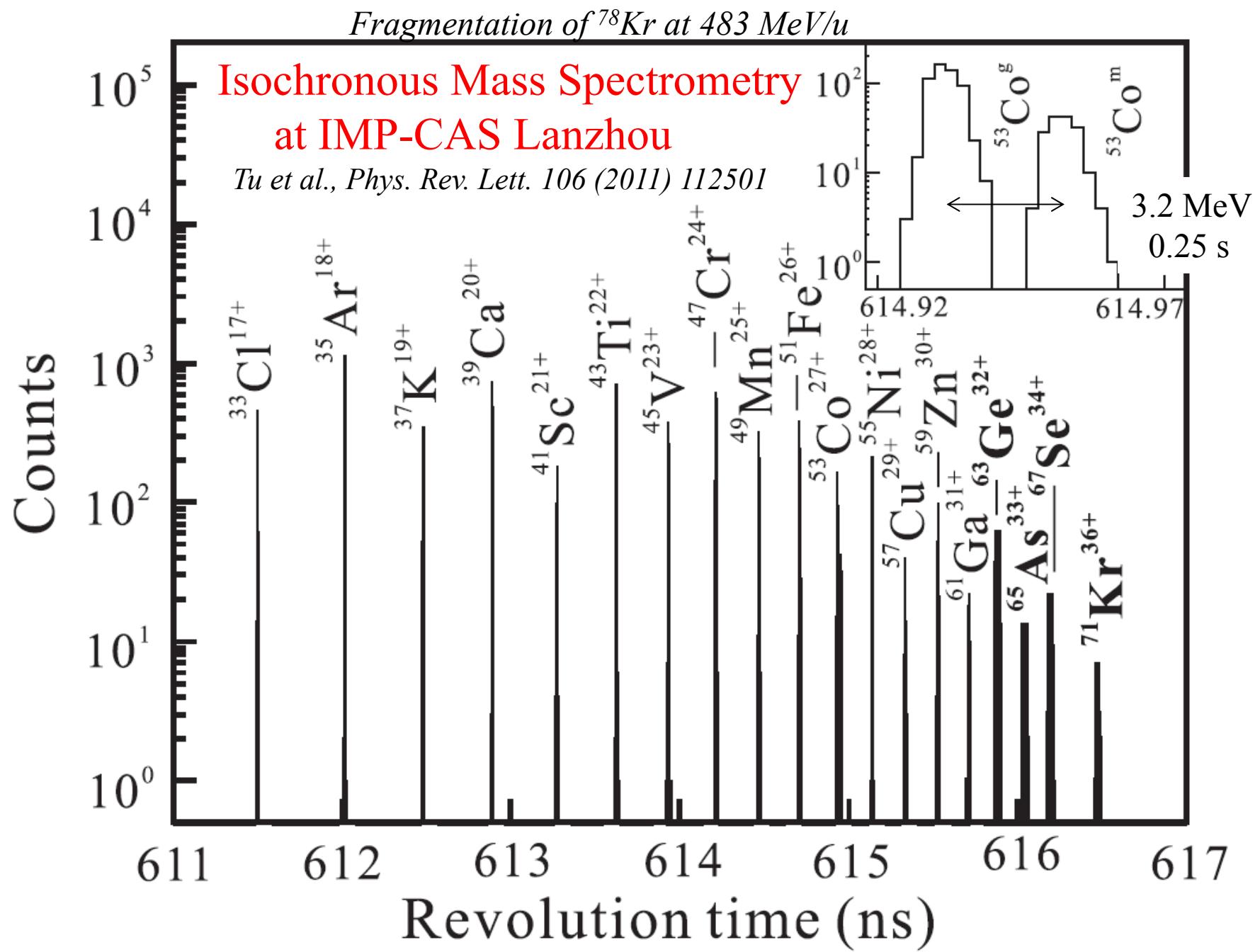


each count
represents
a single ion

Sun et al., Nucl. Phys. A812 (2008) 1

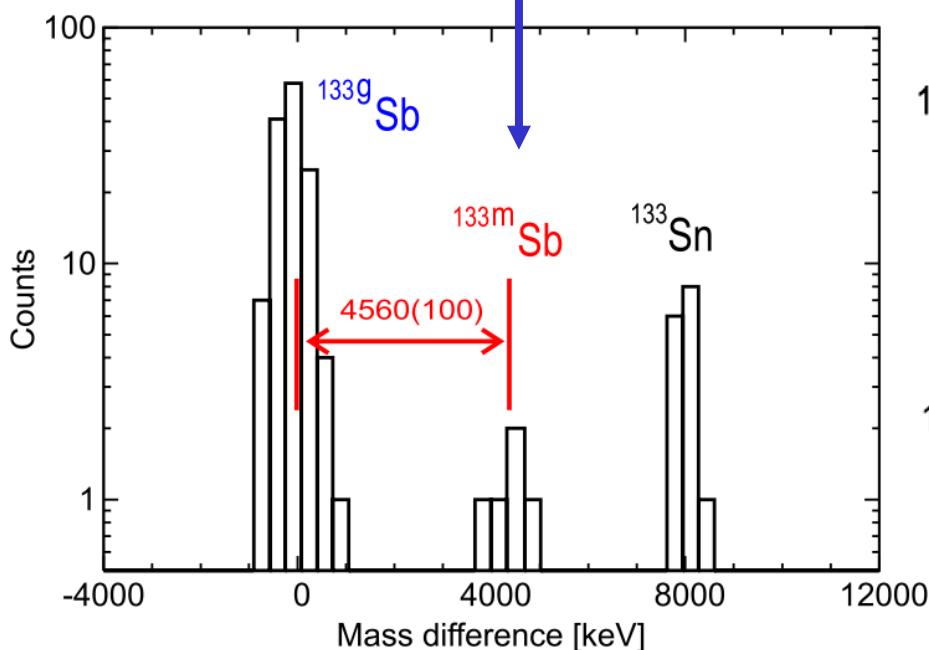
iodine isotope masses



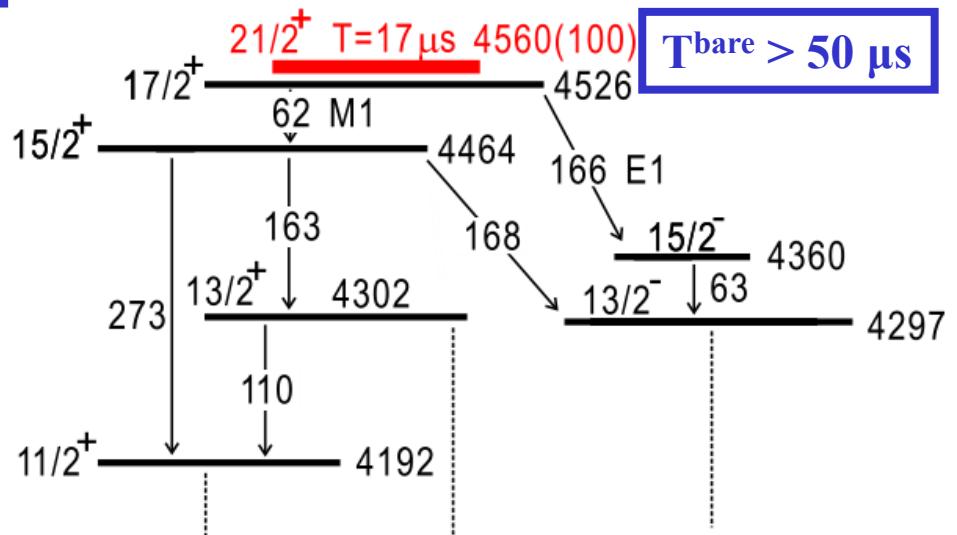


Shell-model isomer in n-rich ^{133}Sb

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

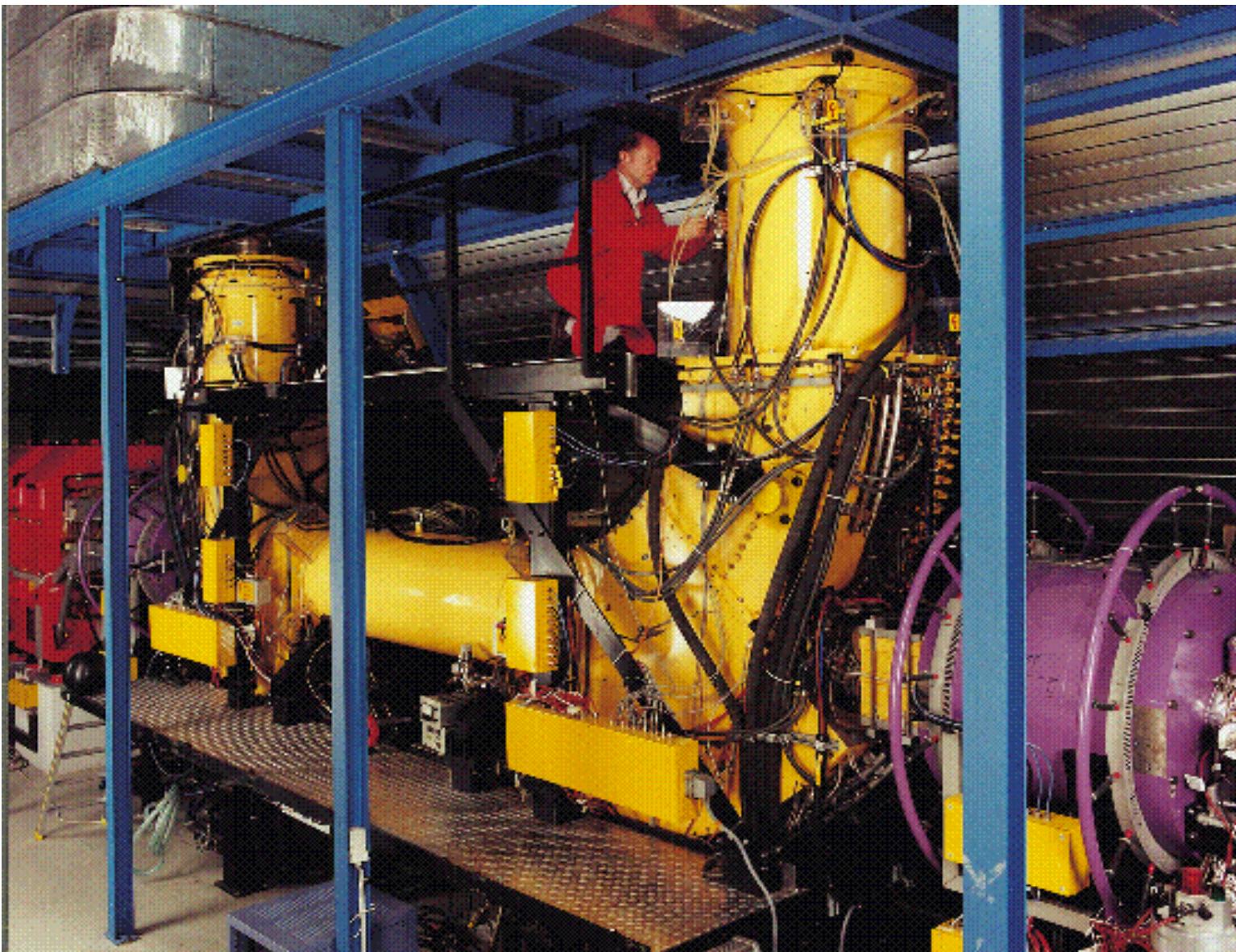


^{238}U fission
isochronous mass spectrometry



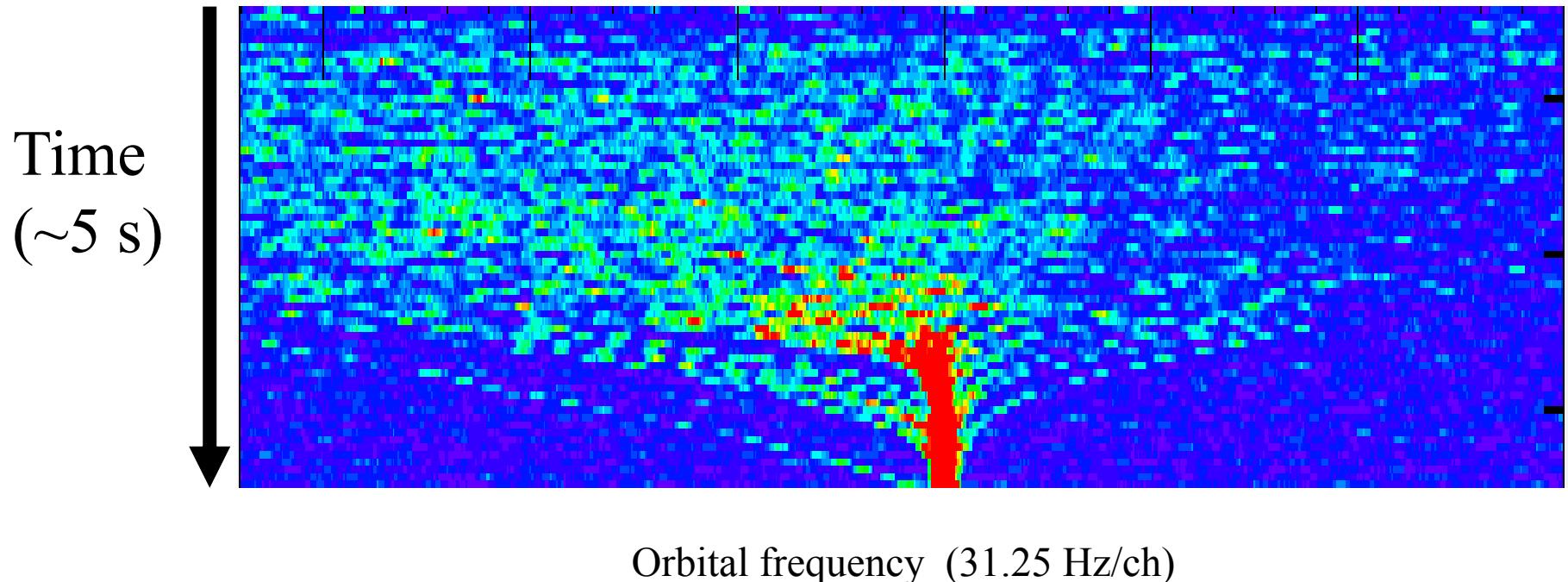
consistent with shell-model
calculations: *Urban et al.,*
Phys. Rev. C62 (2000) 027301

electron cooling (~ 200 mA, ~ 200 kV)



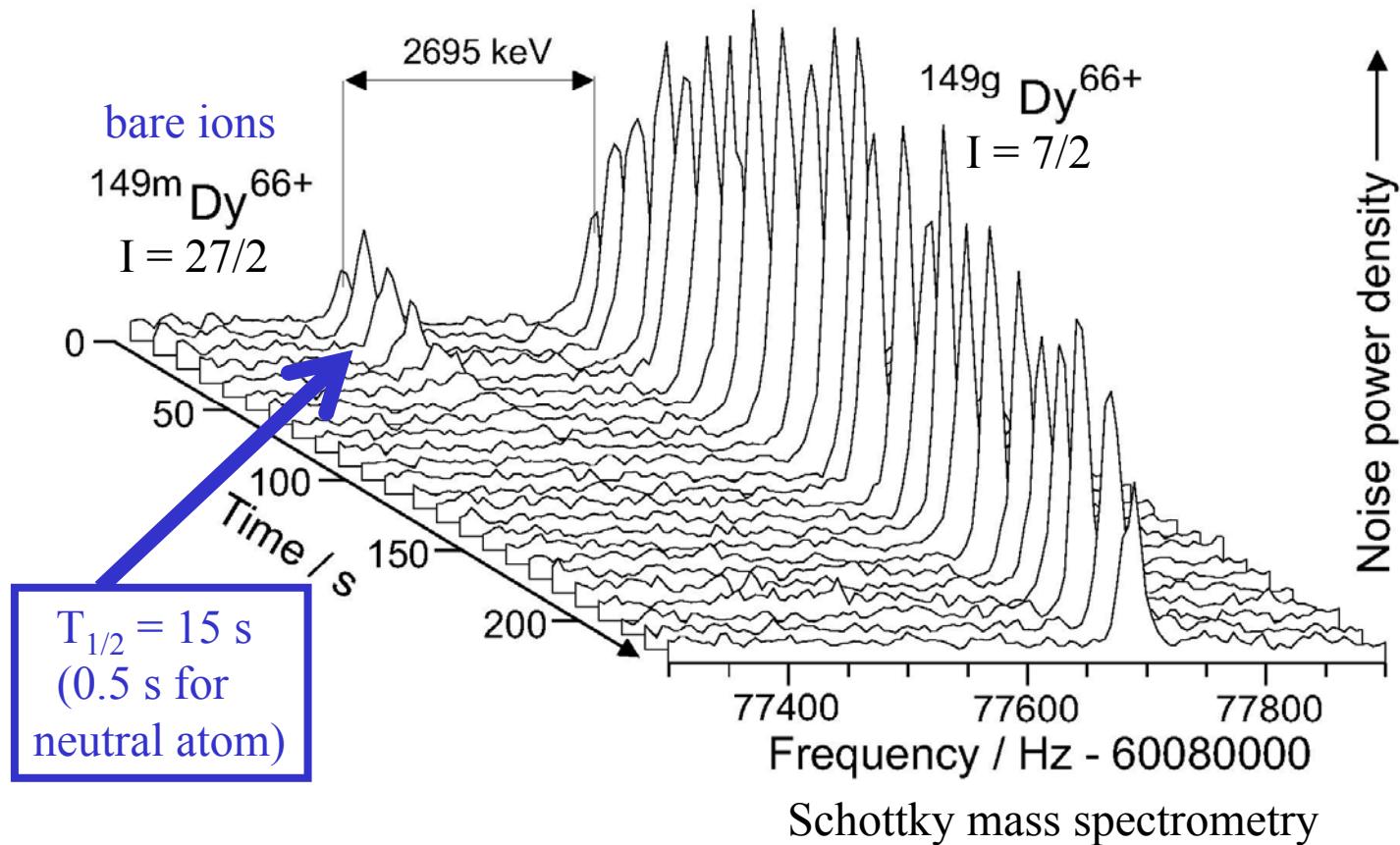
Schottky Mass Spectrometry

Cooling of ^{142}Pm ions (resonant Schottky pick-up)



Nolden et al., NIM A659 (2011) 69, and Yu. Litvinov, private communication

149m+gDy in the ESR



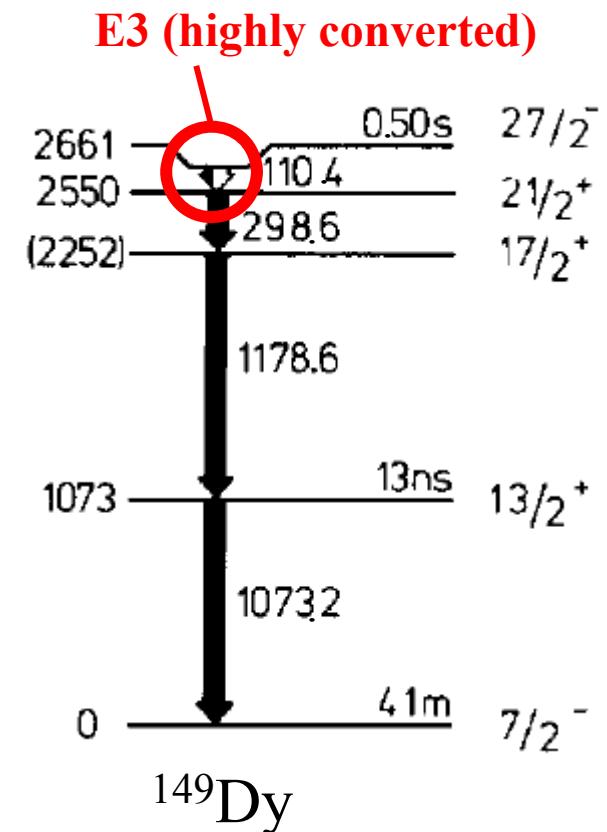
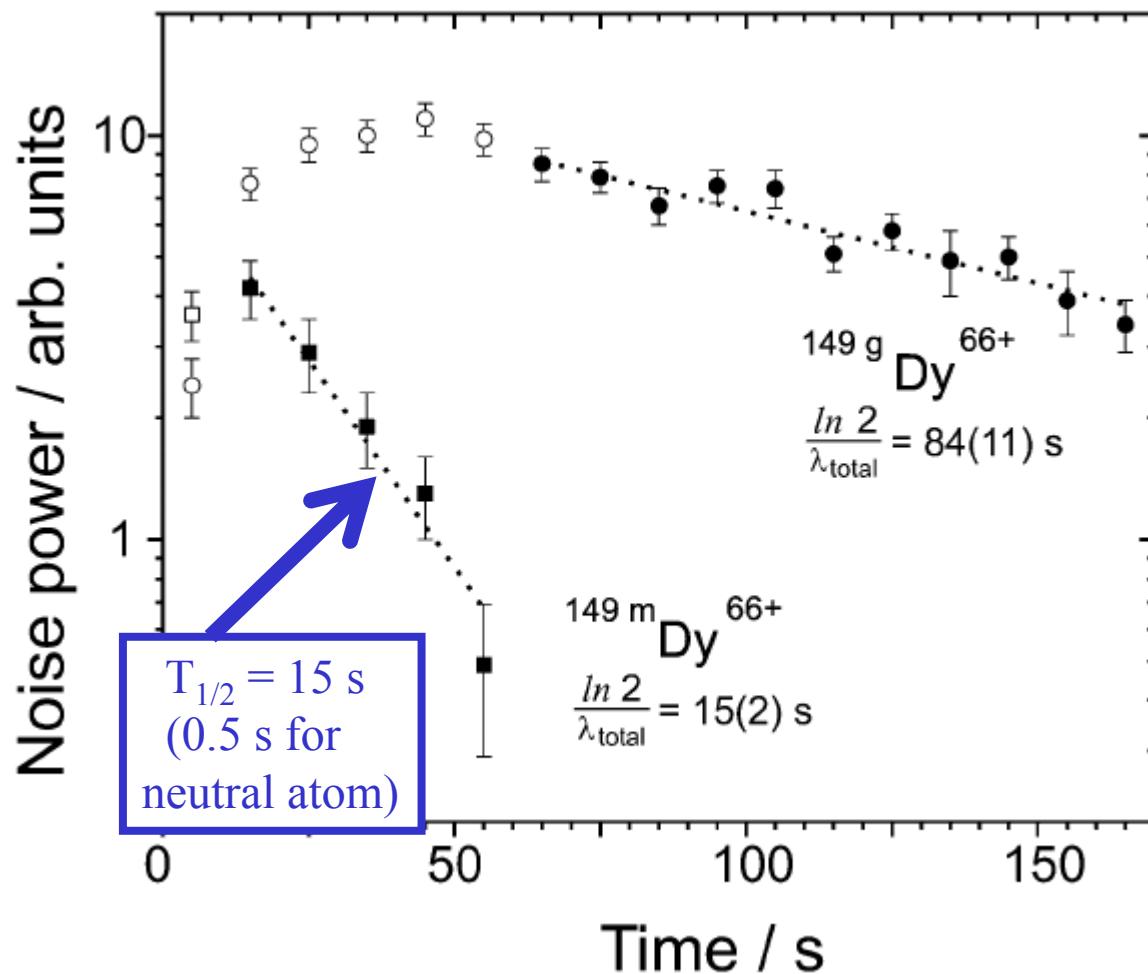
Schottky mass spectrometry

High spin: see talk by Zsolt Podolyak (Tuesday)

[isomers up to $I = 55/2$ seen in fragmentation:
Denis Bacelar et al., Phys. Lett. B723 (2013) 302]

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

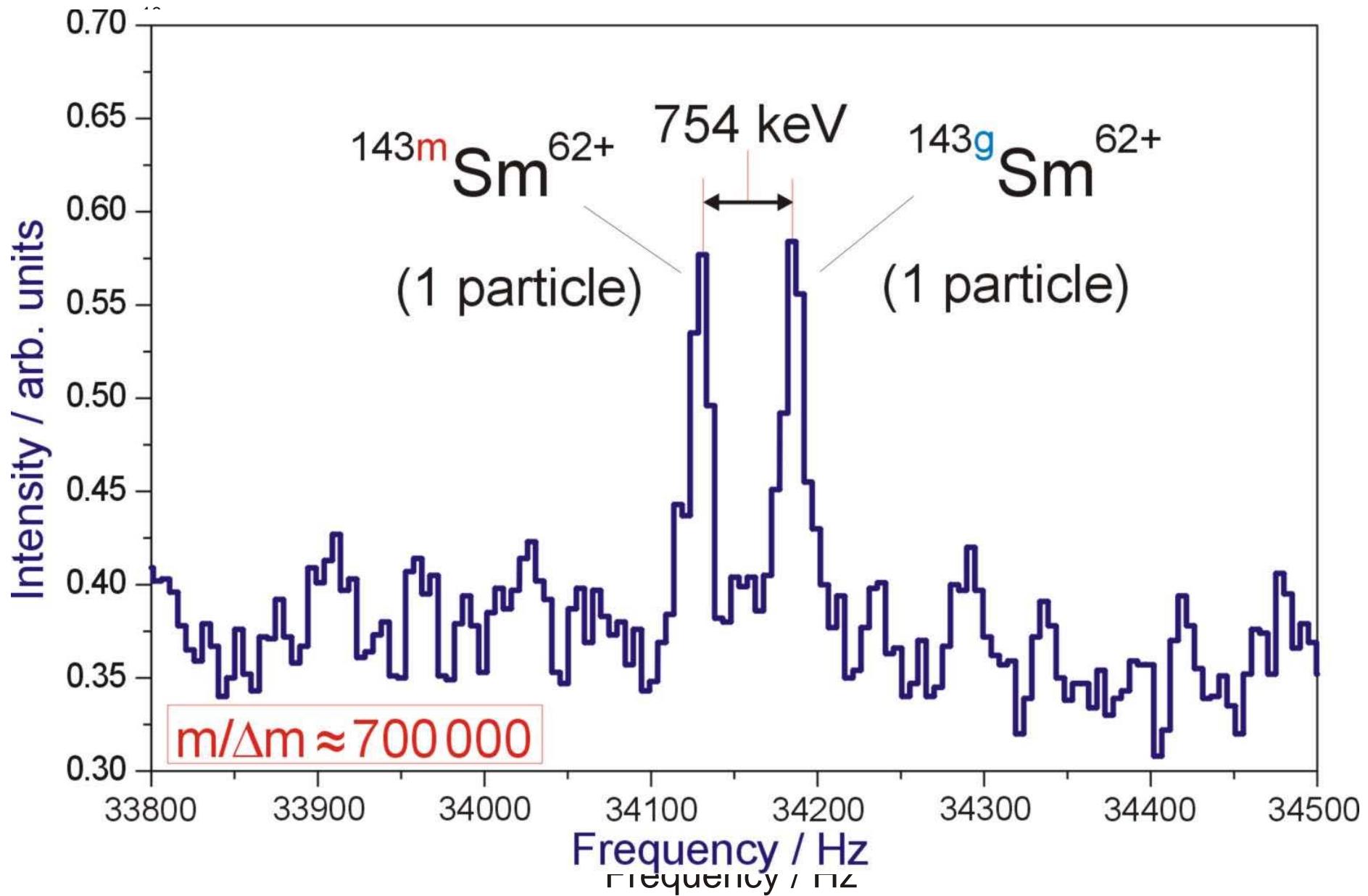
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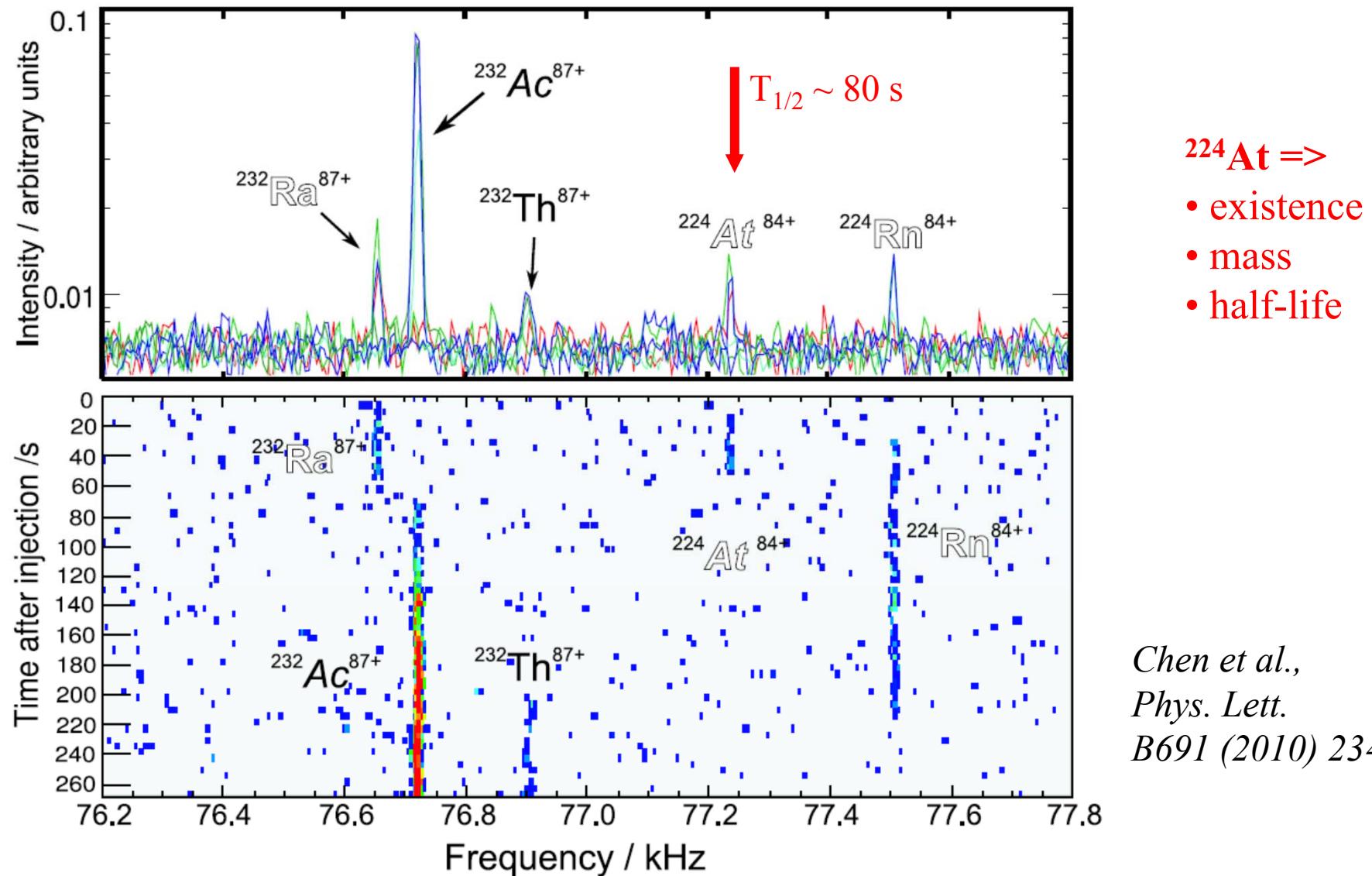
Litvinov et al., Phys. Lett. B573 (2003) 80

Stefanini et al., Phys. Lett. B62 (1976) 405

Broad-band Schottky frequency spectra

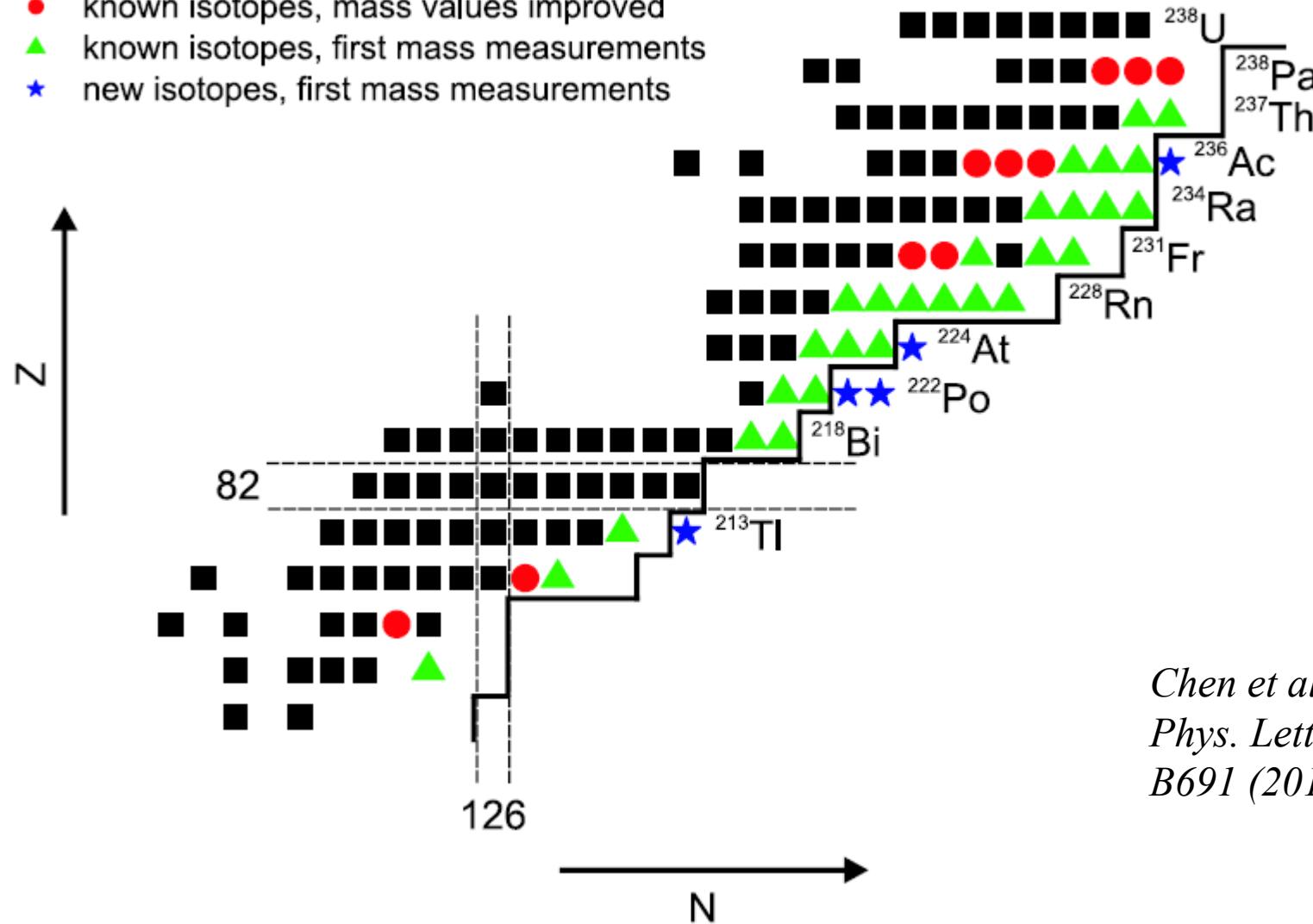


New isotopes of heavy elements



New isotopes of heavy elements

- isotopes with well-known masses
- known isotopes, mass values improved
- ▲ known isotopes, first mass measurements
- ★ new isotopes, first mass measurements



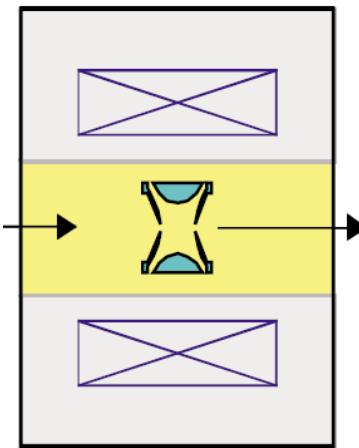
Chen et al.,
Phys. Lett.
B691 (2010) 234

Isomer discoveries with stored ions

Penning trap

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

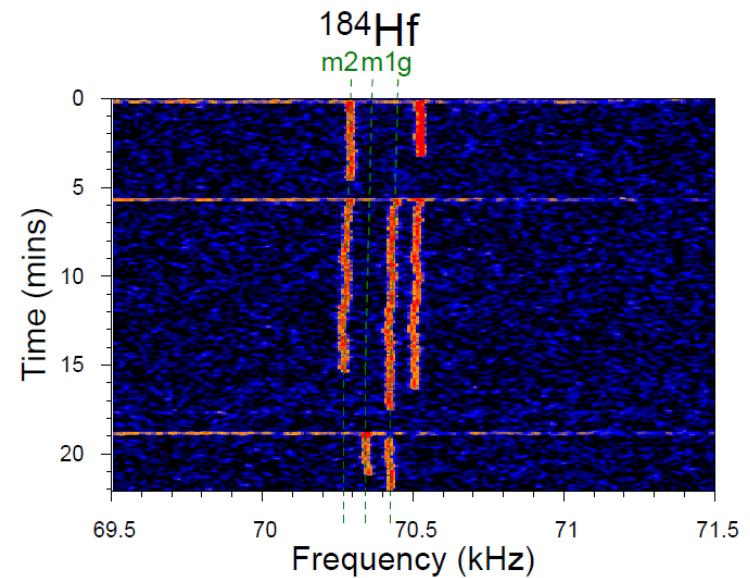
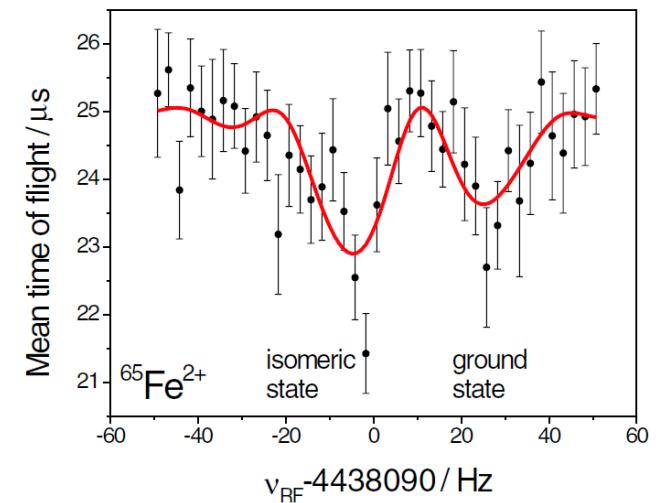
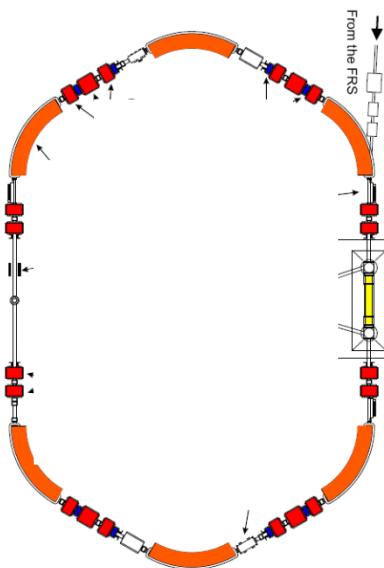
M. Block et al., Phys. Rev. Lett.
100 (2008) 132501 at NSCL



Storage ring

$^{184m^2}\text{Hf}$ and ^{184g}Hf

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

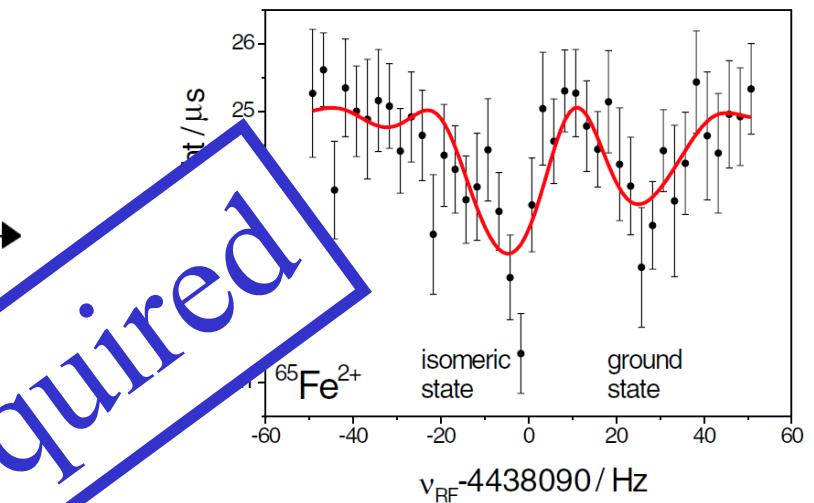
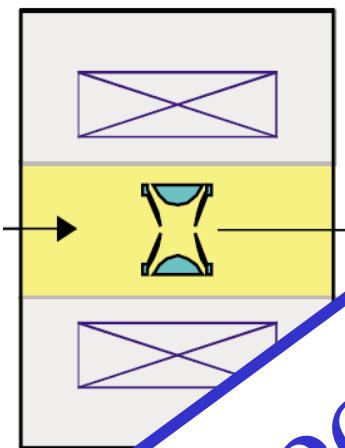


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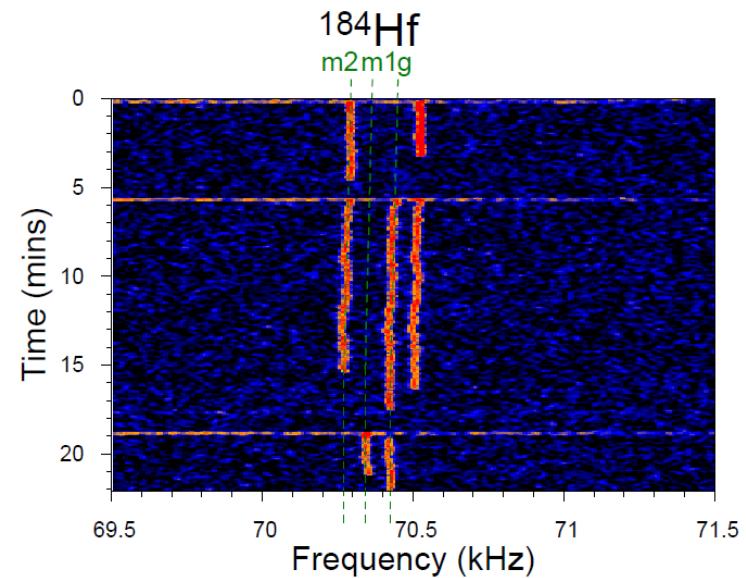
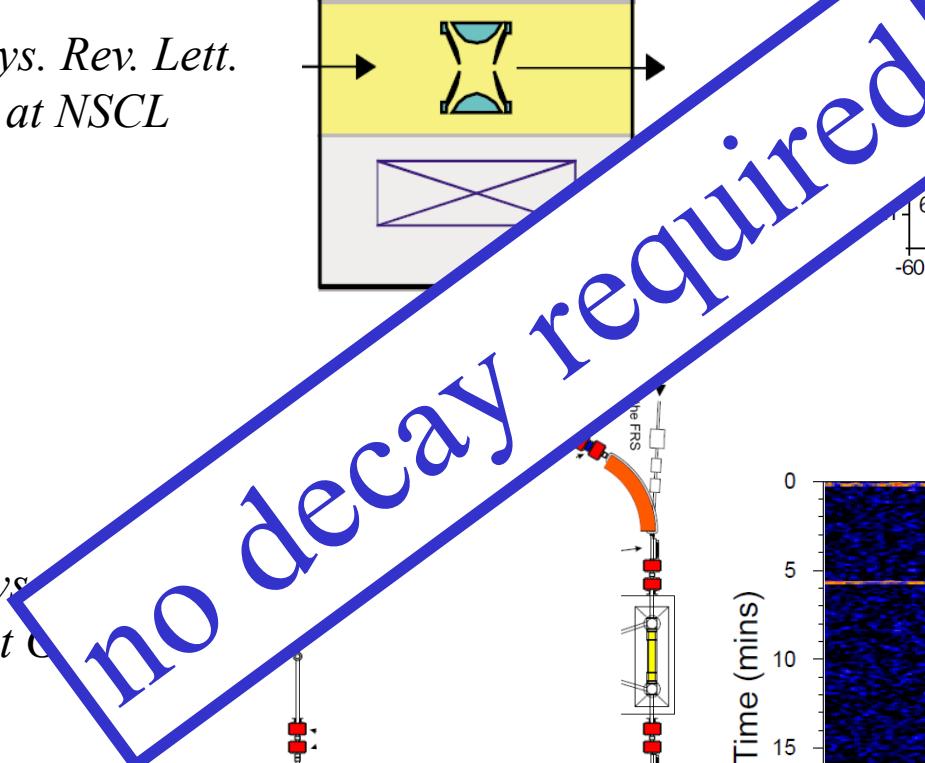
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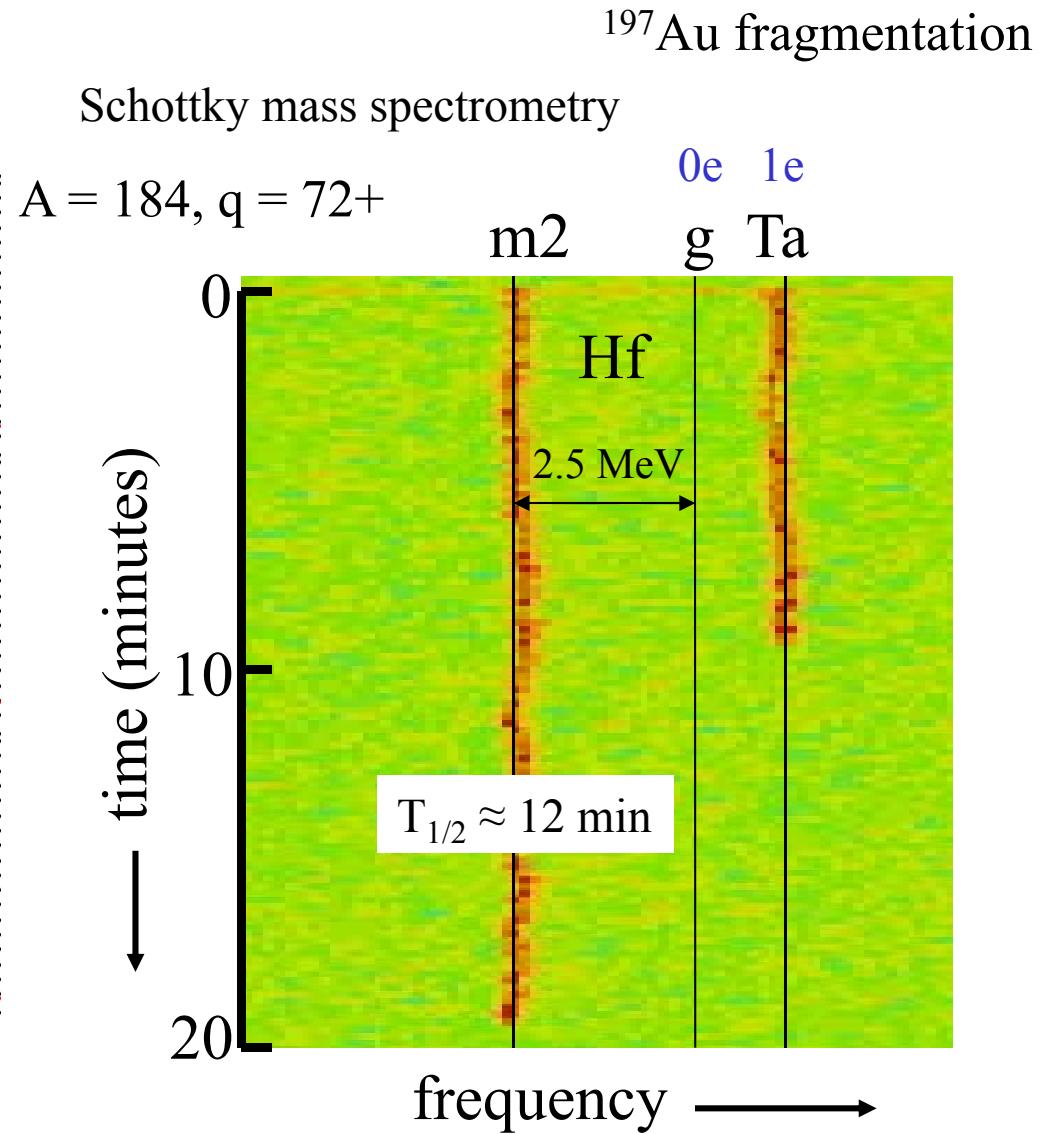
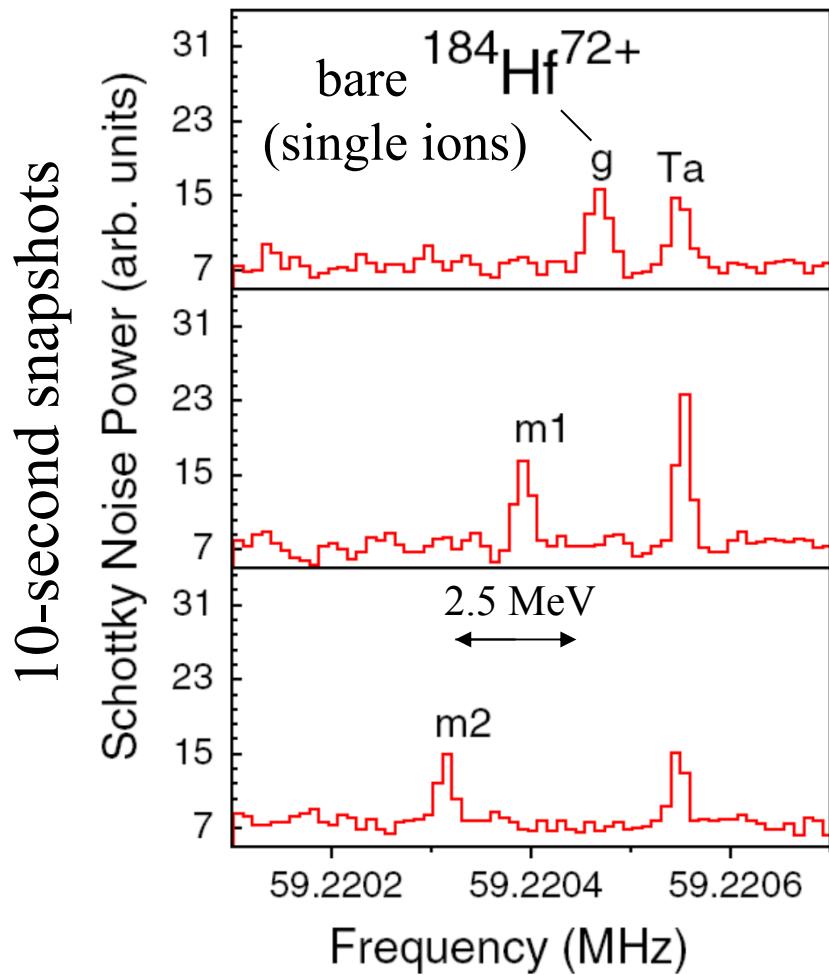
M.W. Reed et al., Phys.
105 (2010) 172501 at CERN



no decay required

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

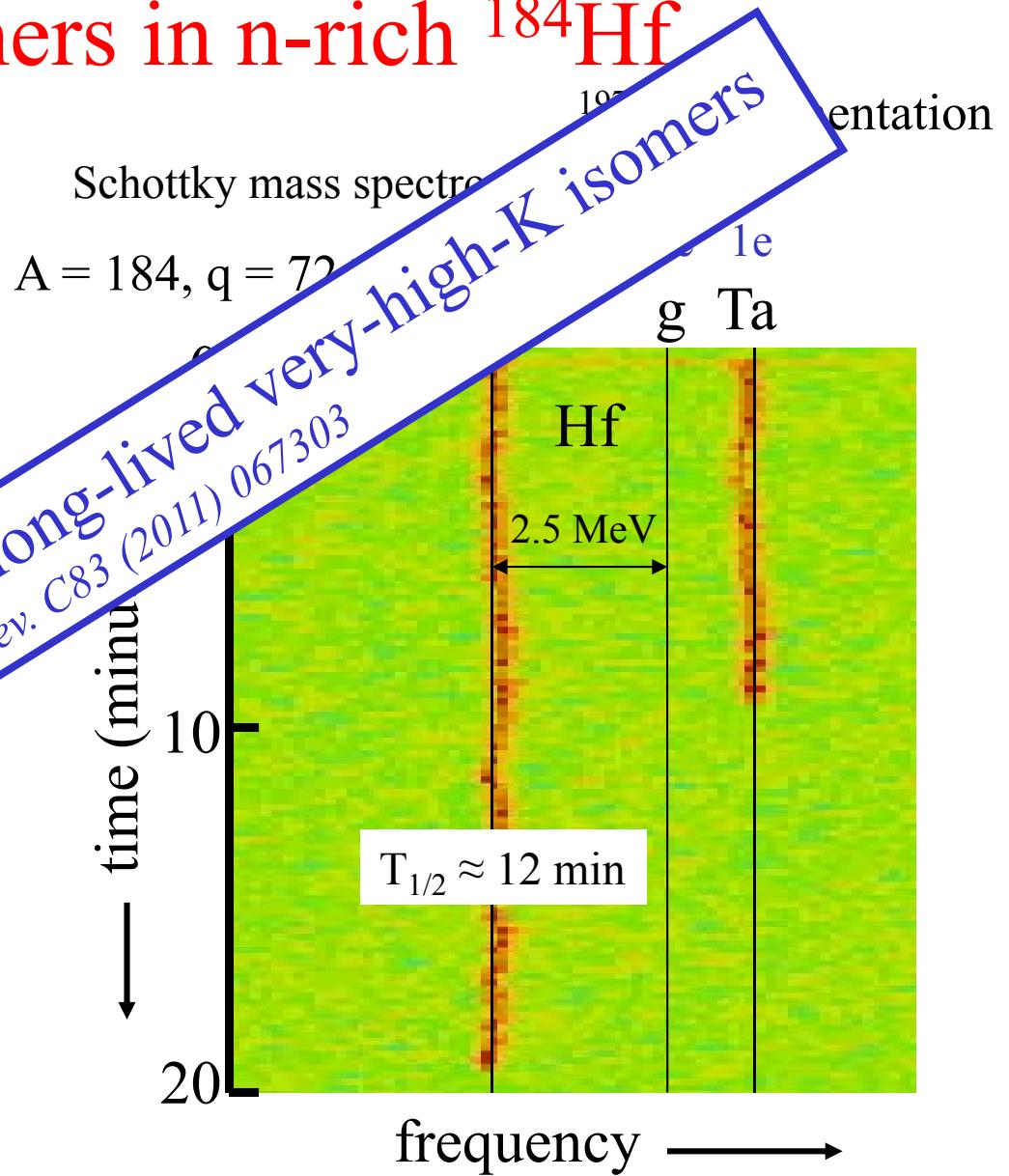
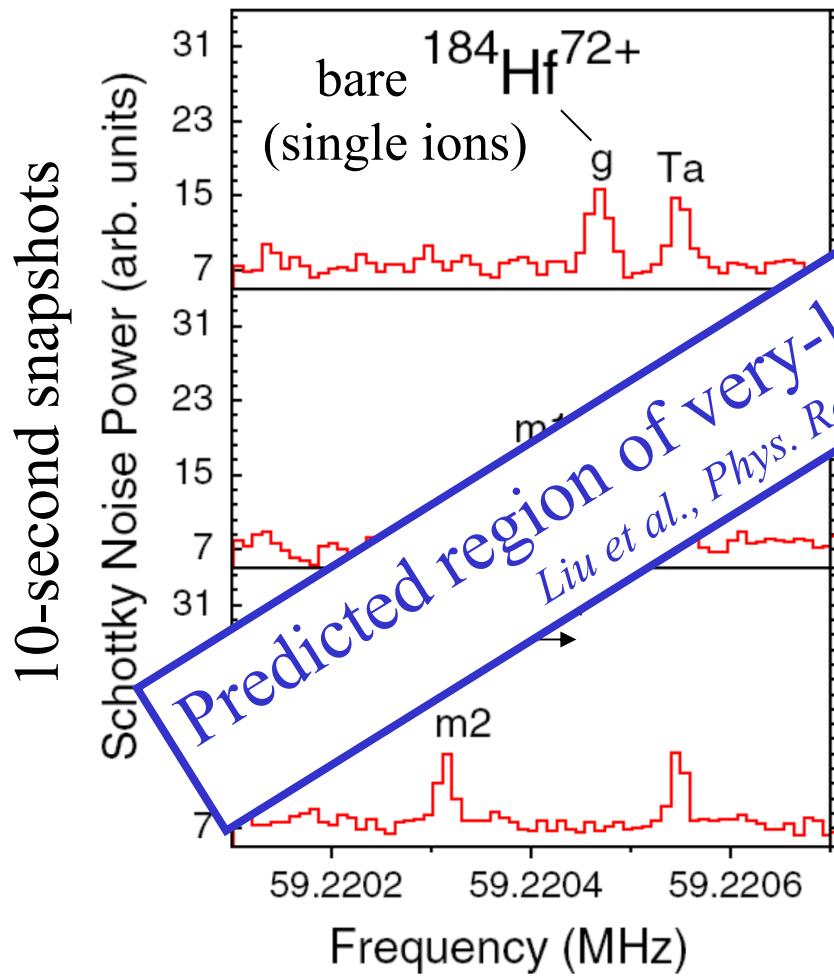
- first observation of m2 isomer
- long-lived β -decaying isomer



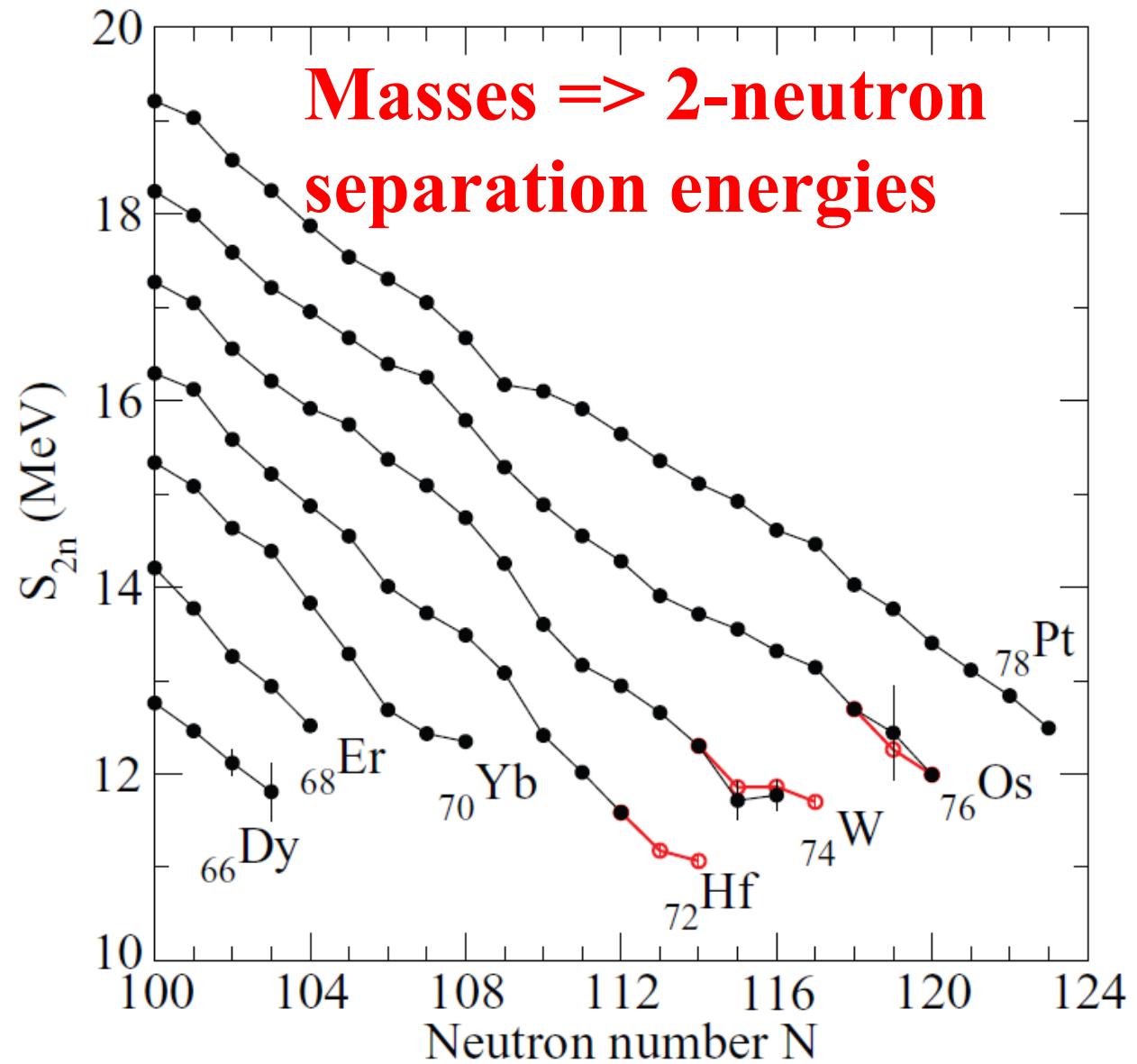
Reed et al., Phys. Rev. Lett. 105 (2010) 172501; Phys. Rev. C86 (2012) 054321

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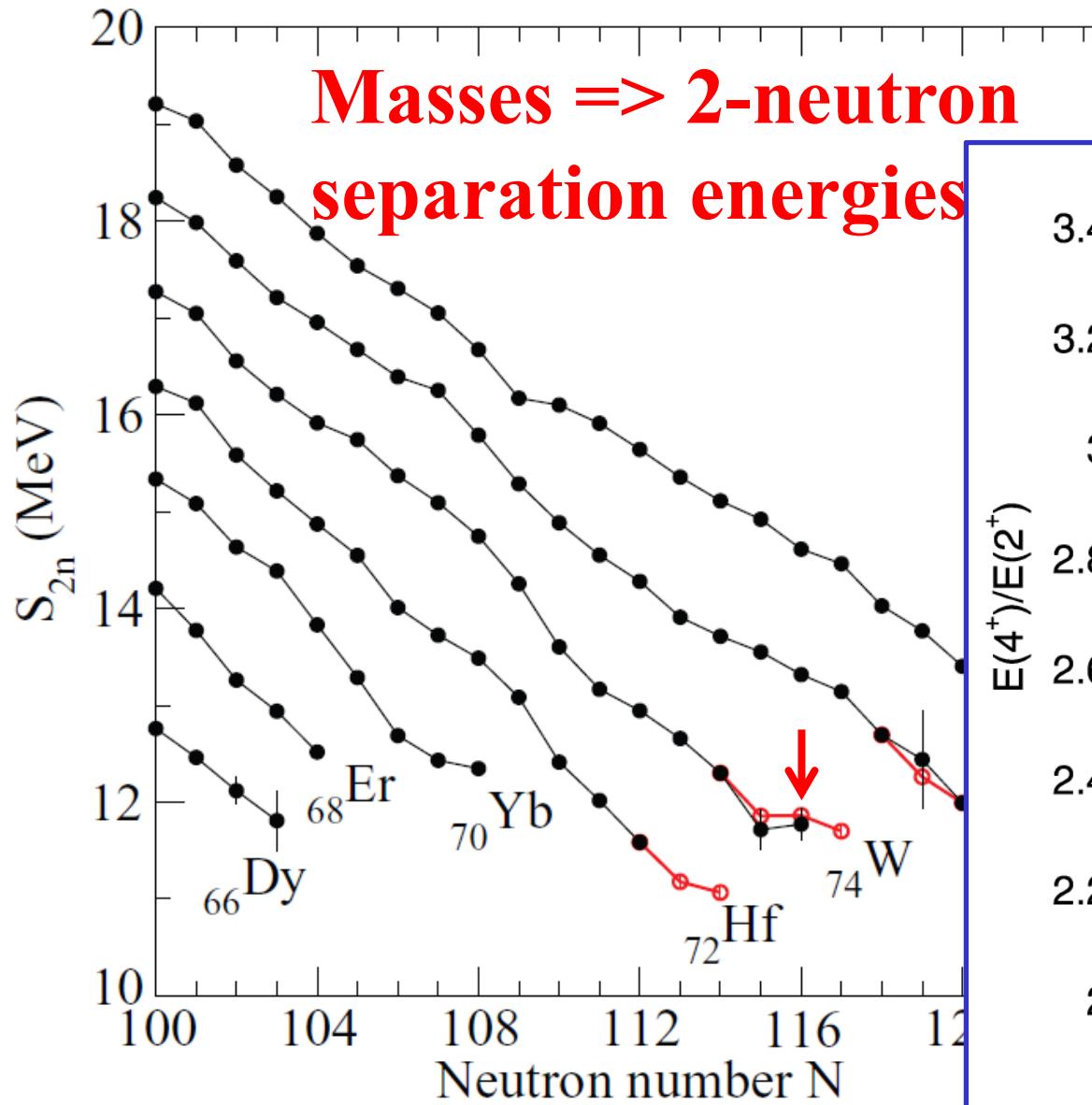
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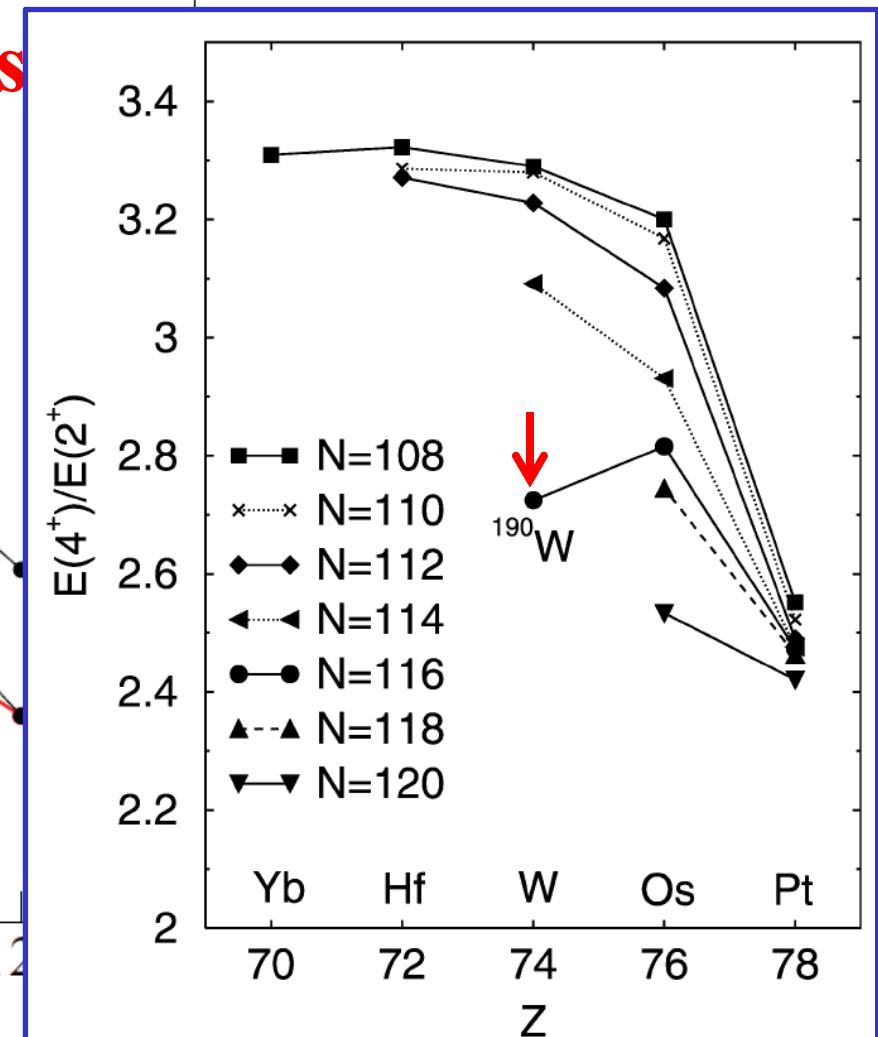
Reed et al., Phys. Rev. Lett. 105 (2010) 172501; Phys. Rev. C86 (2012) 054321



Shubina et al., Phys. Rev. C88 (2013) 024310

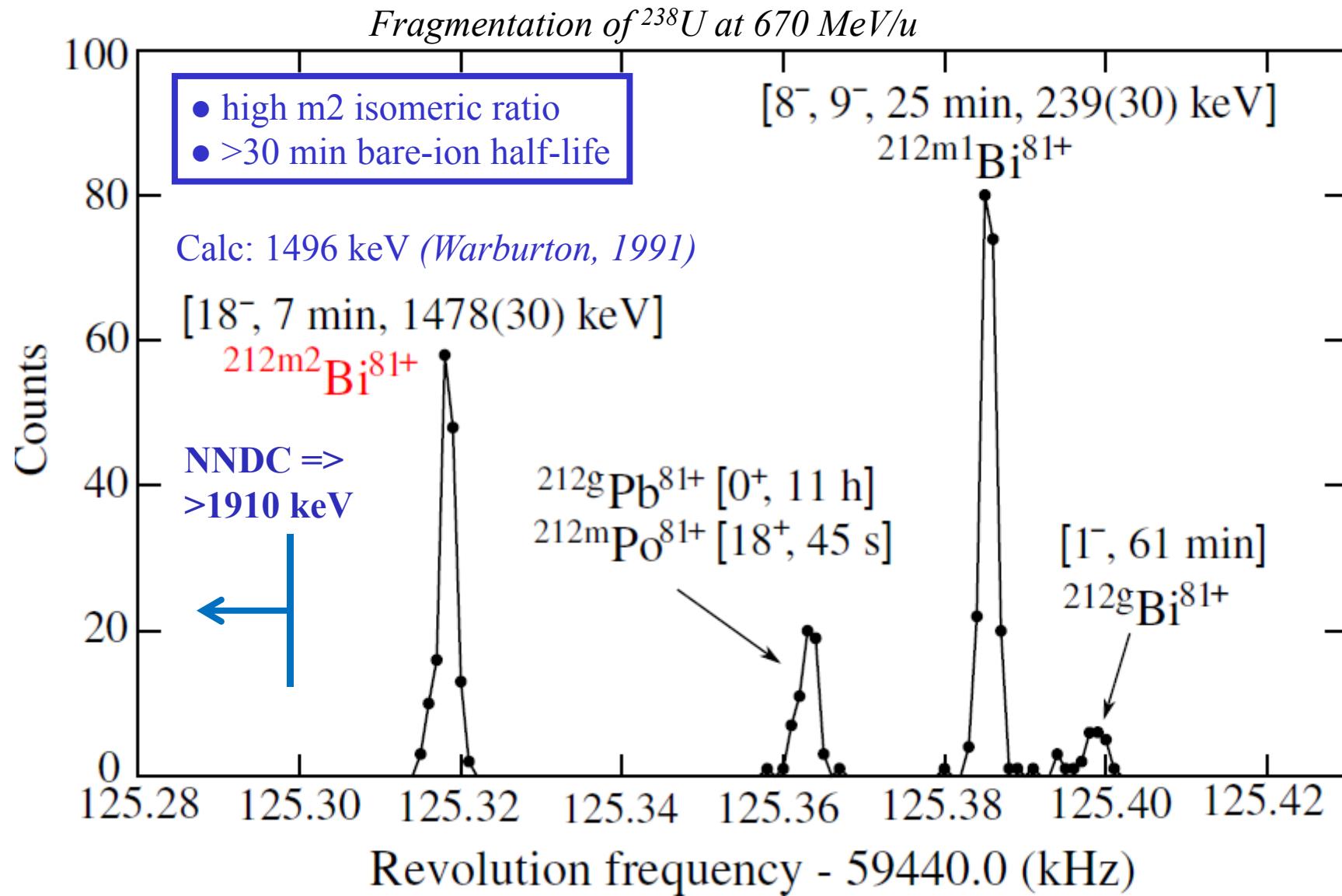


Shubina et al., Phys. Rev. C88 (2013) 024310



Podolyak et al., Phys. Lett. B491 (2000) 225

Shell-model isomers in ^{212}Bi



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

Exotic nuclei in storage rings

Current:

ESR at GSI, Germany

CSRe at Lanzhou, China

Commissioning:

Rare-RI ring at RIBF, Japan

Construction:

CRYRING at GSI, Germany (very low energies)

Advanced stage of planning:

Ring Branch at FAIR, Germany

TSR at ISOLDE, CERN (Coulomb barrier energies)

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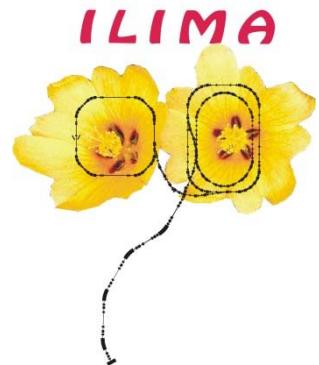
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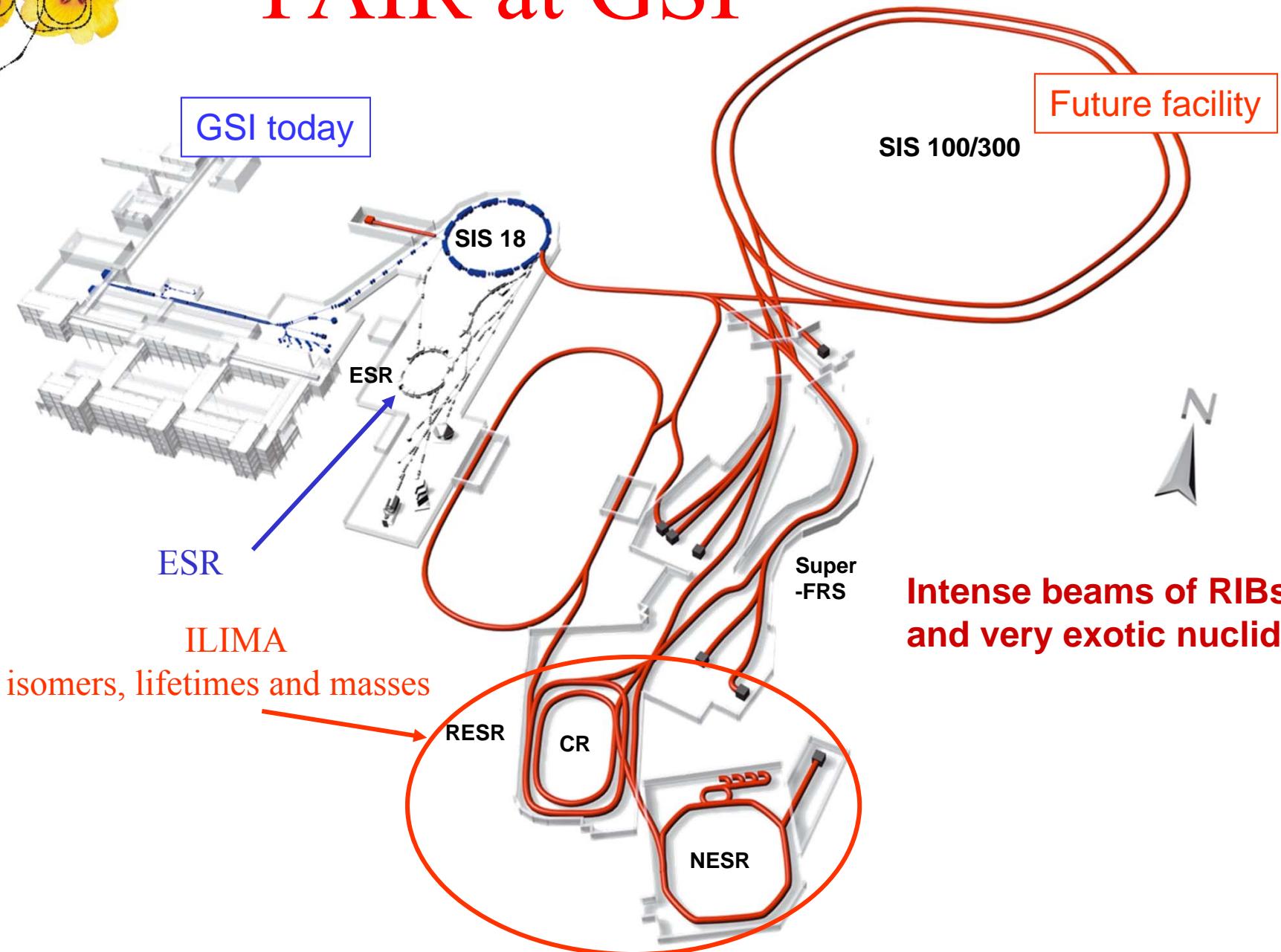
Advanced stage of planning:

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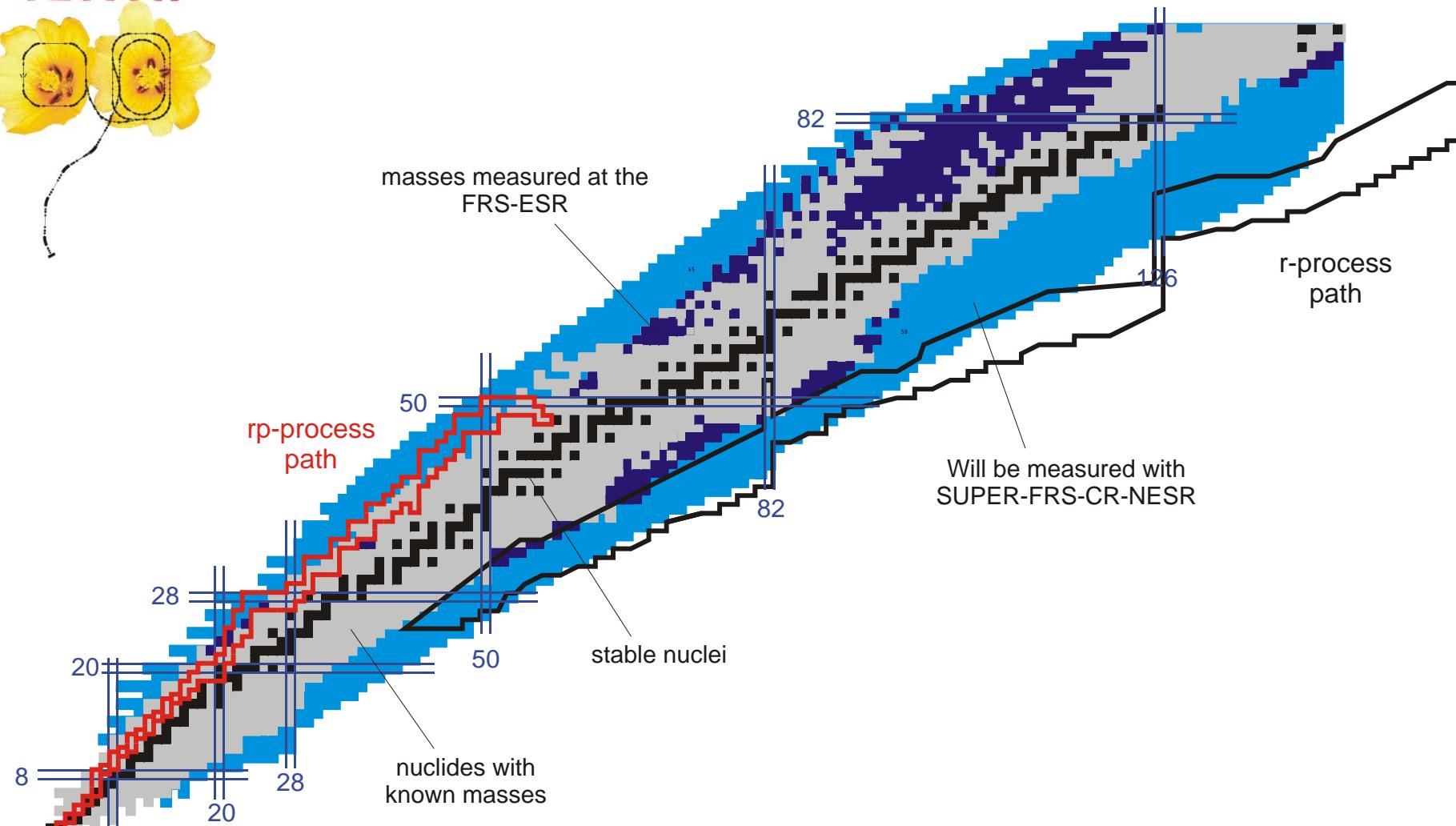
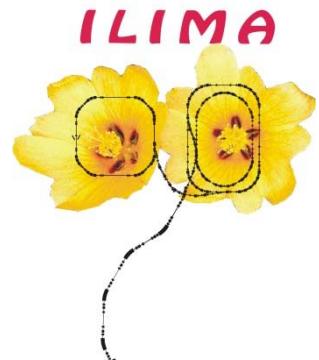
TSR at ISOLDE, CERN (Coulomb barrier energies)



FAIR at GSI



Intense beams of RIBs
and very exotic nuclides



potential for new masses with ILIMA

Summary – exotic nuclei in storage rings

- Single-ion sensitivity – IMS and SMS
- Masses
- Half-lives
- Unavailable electron conversion
- β decay – see Yuri Litvinov's talk (Tuesday)
- Isotope and isomer discoveries
- New facilities

many thanks to members
of the ILIMA collaboration

“To pursue it
with forks and hope”

*Lewis Carroll
The Hunting of the Snark (1876)*



“To pursue it with forks and hope.”

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. Sobczewski, 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

München, Germany: T. Faestermann, P. Ring, D. Vretenar

Frankfurt, Germany: Th. Bürvenich

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

Thessaloniki, Greece: G.A. Lalazissis

Warsaw, Poland: Z. Janas, M. Pfützner, Z. Patyk

Stockholm, Sweden: S. Tashenov

Surrey, UK: Z. Podolyak, P.M. Walker

Edinburgh, UK: P.J. Woods, Z. Liu

Manchester, UK: D.M. Cullen

Catania, Italy: A. Musumarra

Madrid, Spain: R. Rodriguez-Guzman

Belgrade, Serbia: D. Toprek

UTK, USA: M. Matoš; *TAMU, USA:* L. Chen

MSU, USA: M. Hausmann, H. Schatz

Los Alamos, USA: D. Madland, P. Moeller, D. Vieira

TRIUMF, Canada: I. Dillmann

Lanzhou, China: X. Ma, R. Mao, Z. Sun, X. Tu, M. Wang, G. Xiao, H. Xu, X. Yan, Y. Zhang, X. Zhou, Y. Yuan

Niigata, Japan: T. Ohtsubo

ILIMA Collaboration

100 scientists

29 institutes

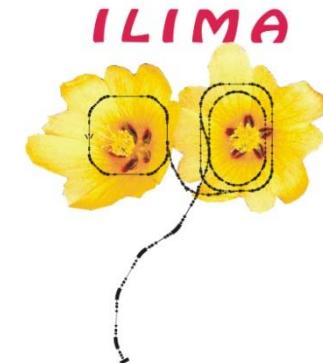
16 countries

Beihang, Beijing, China: B. Sun

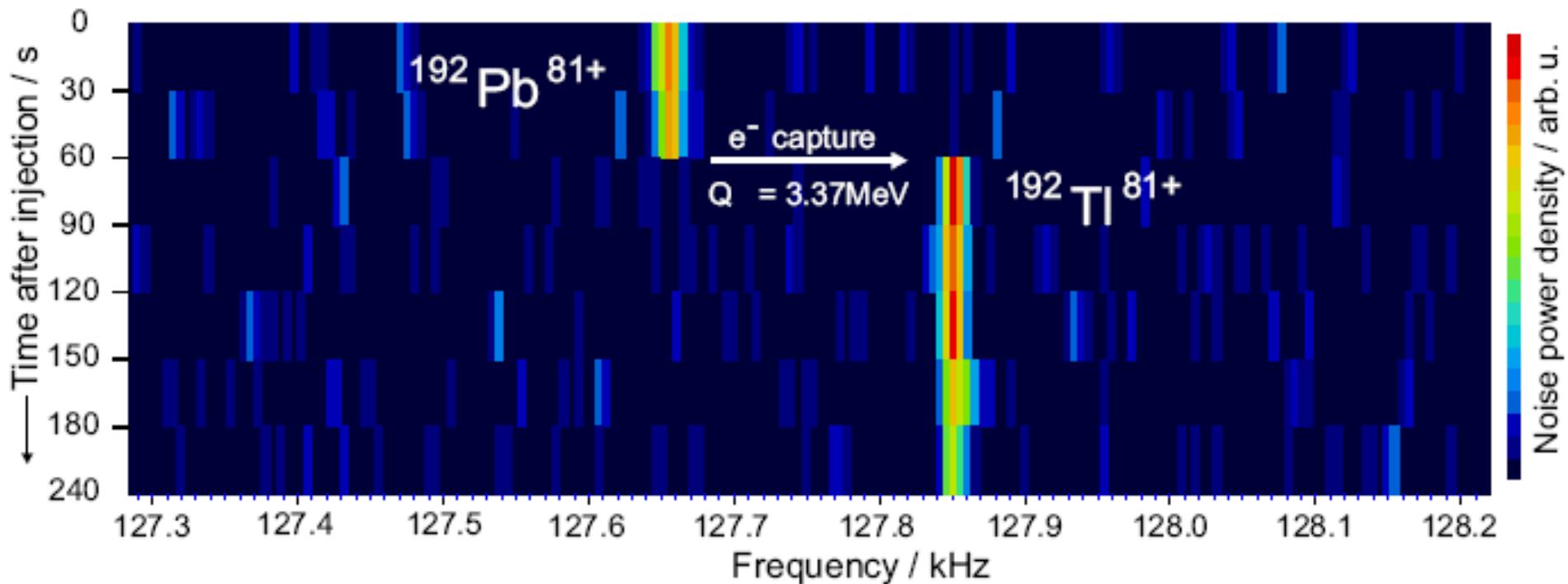
Saitama, Japan: T. Suzuki, T. Yamaguchi

Tsukuba, Japan: A. Ozawa

ANU Canberra, Australia: M.W. Reed

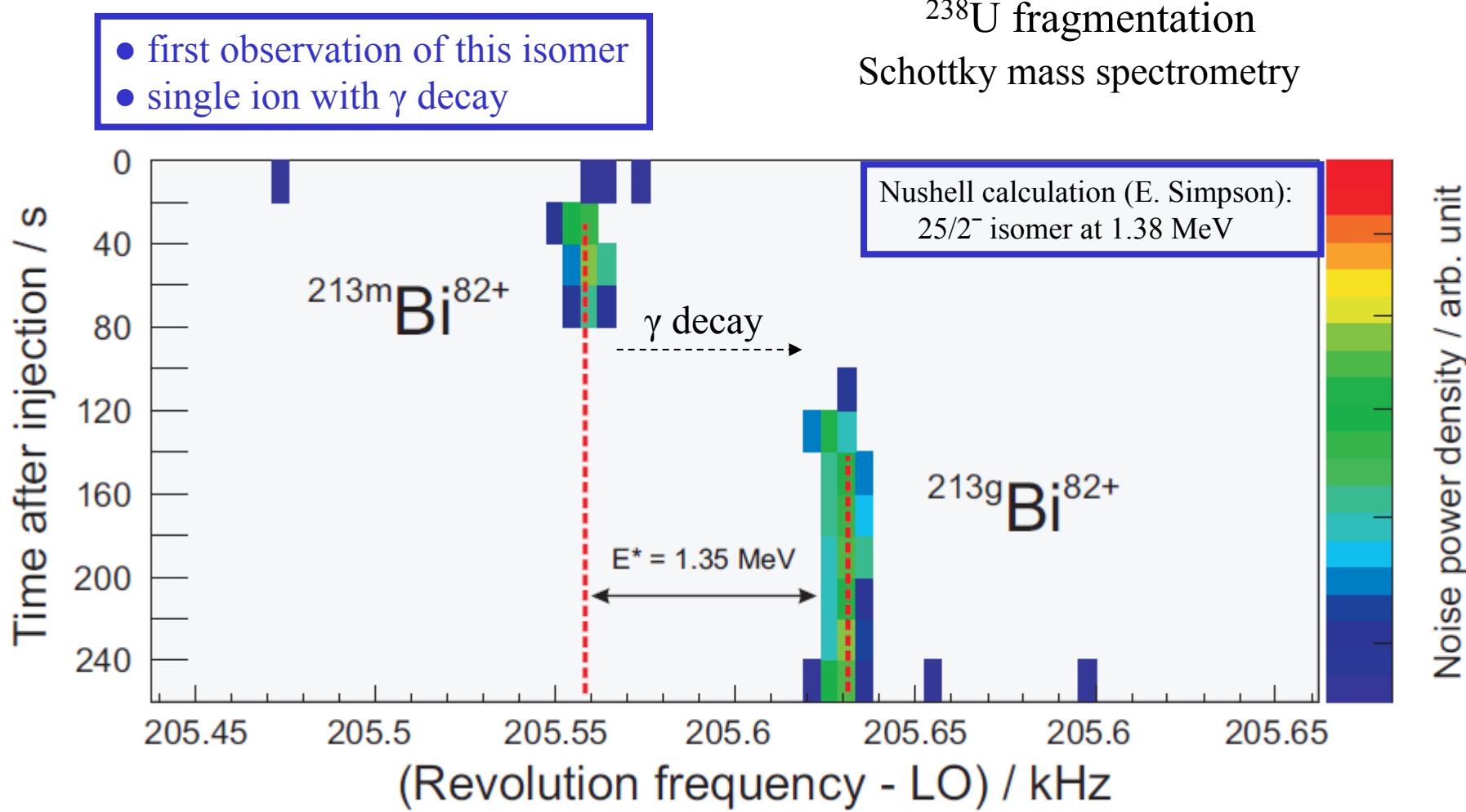


single-ion in-ring EC decay



Litvinov et al., Nucl. Phys. A756 (2005) 3

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



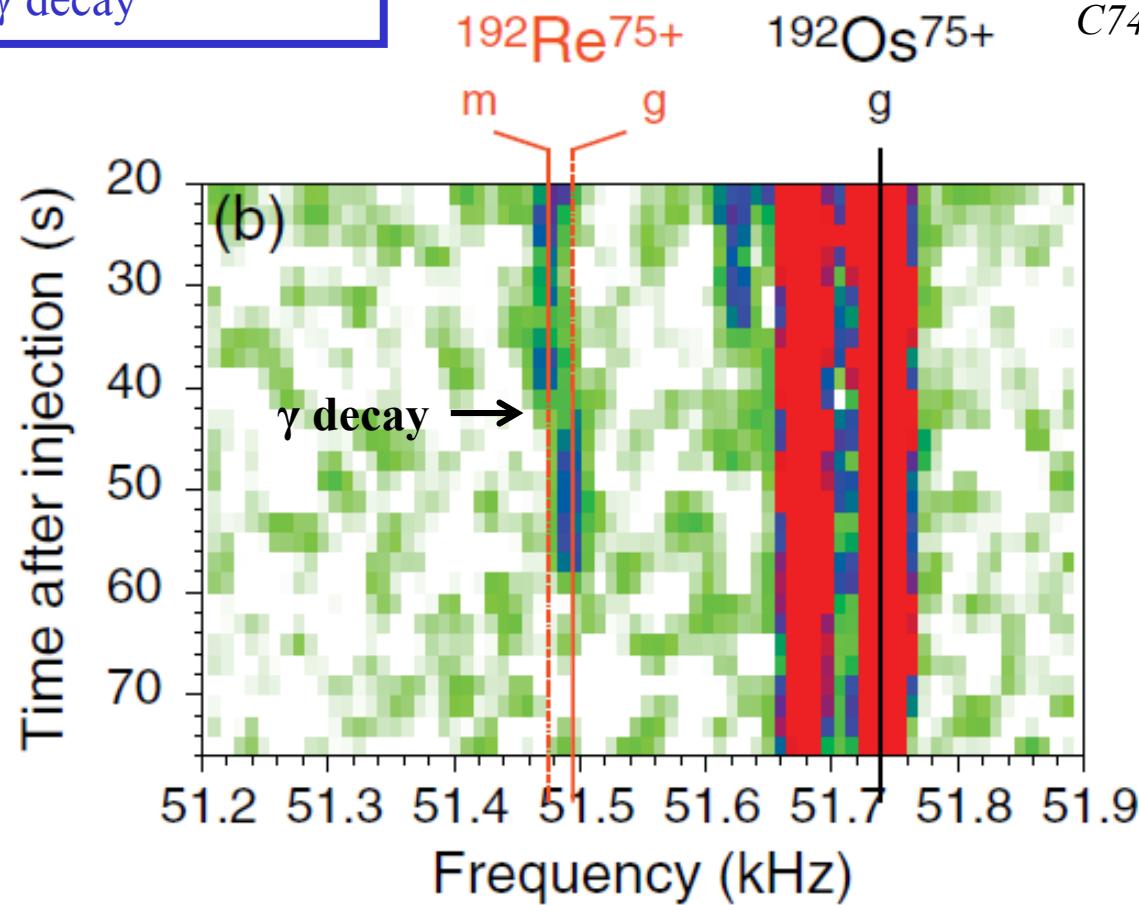
Chen et al., Nucl. Phys. A882 (2012) 71

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

region of prolate-oblate shape coexistence

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

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



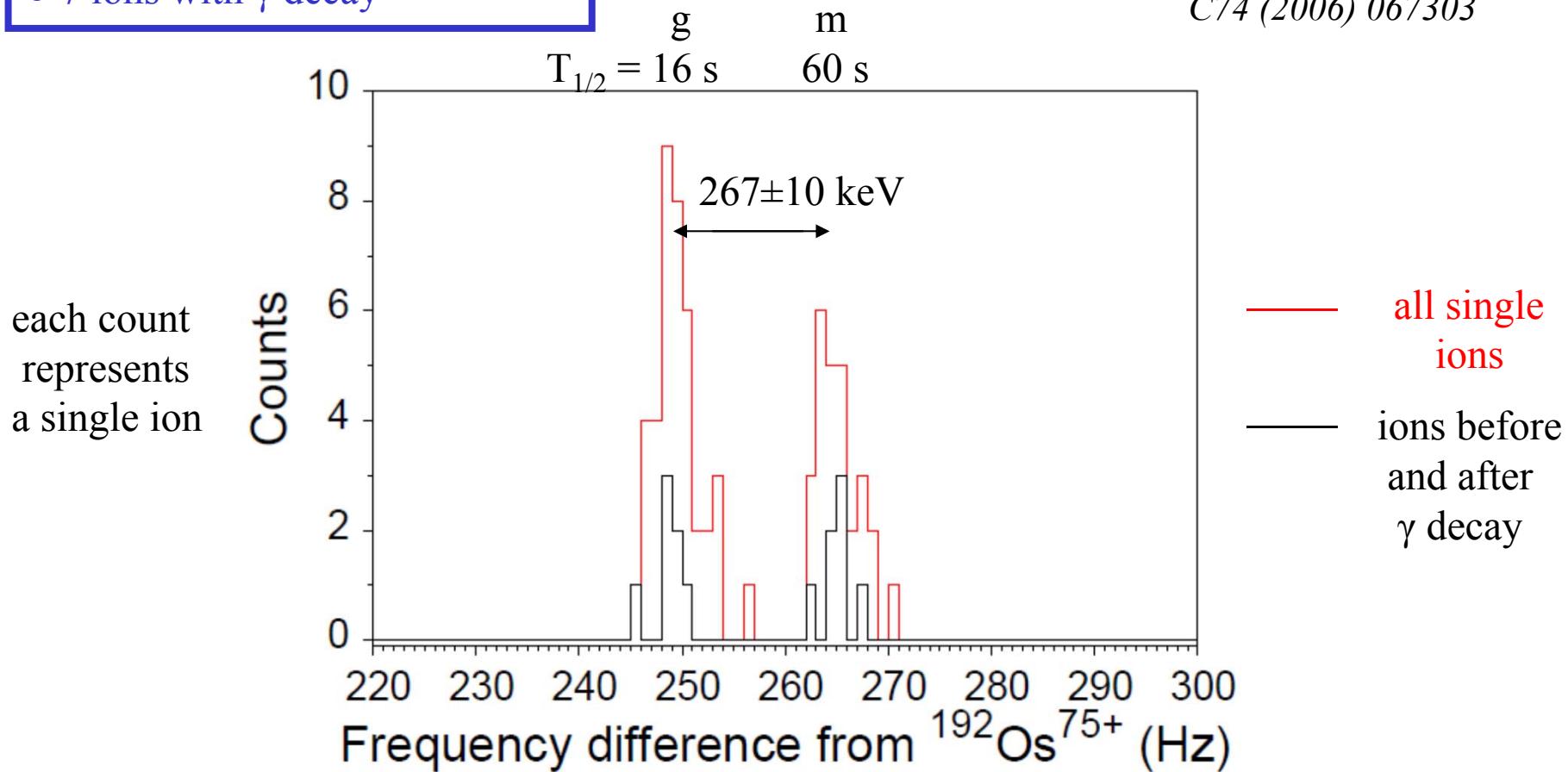
Reed et al., Phys. Rev. C86 (2012) 054321

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

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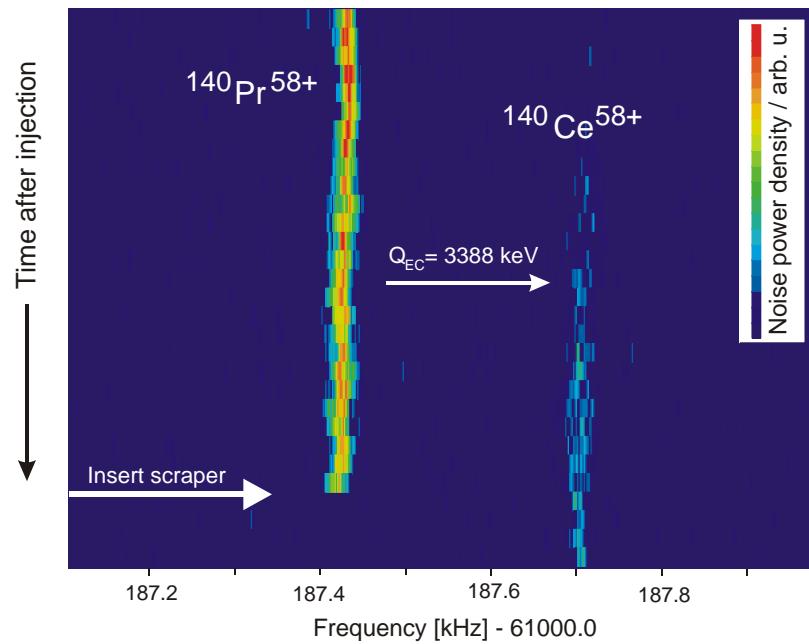
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Walker and Xu, Phys. Rev. C74 (2006) 067303

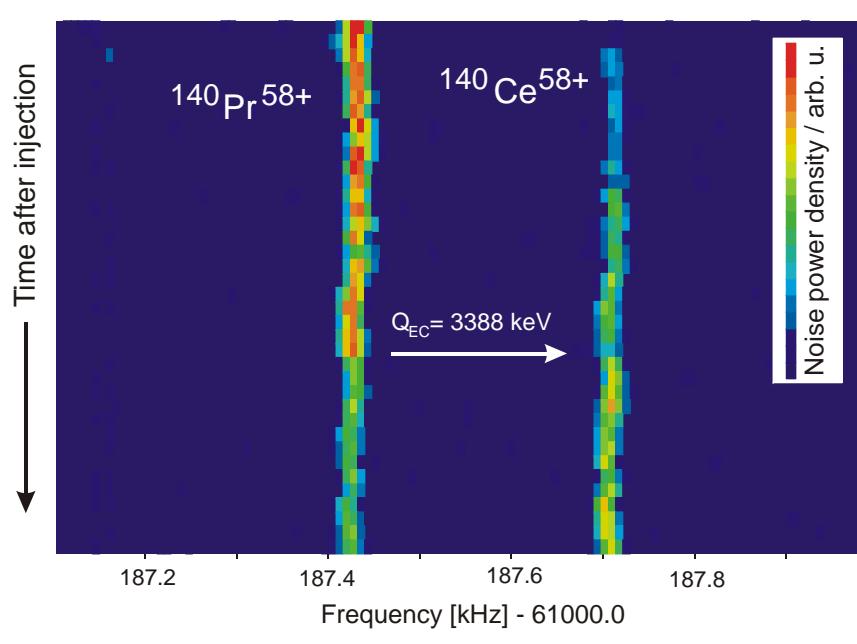


Reed et al., Phys. Rev. C86 (2012) 054321; and J. Phys. Conf. Series 381 (2012) 012058

potential for isomer beam purification



Injection length 170 s

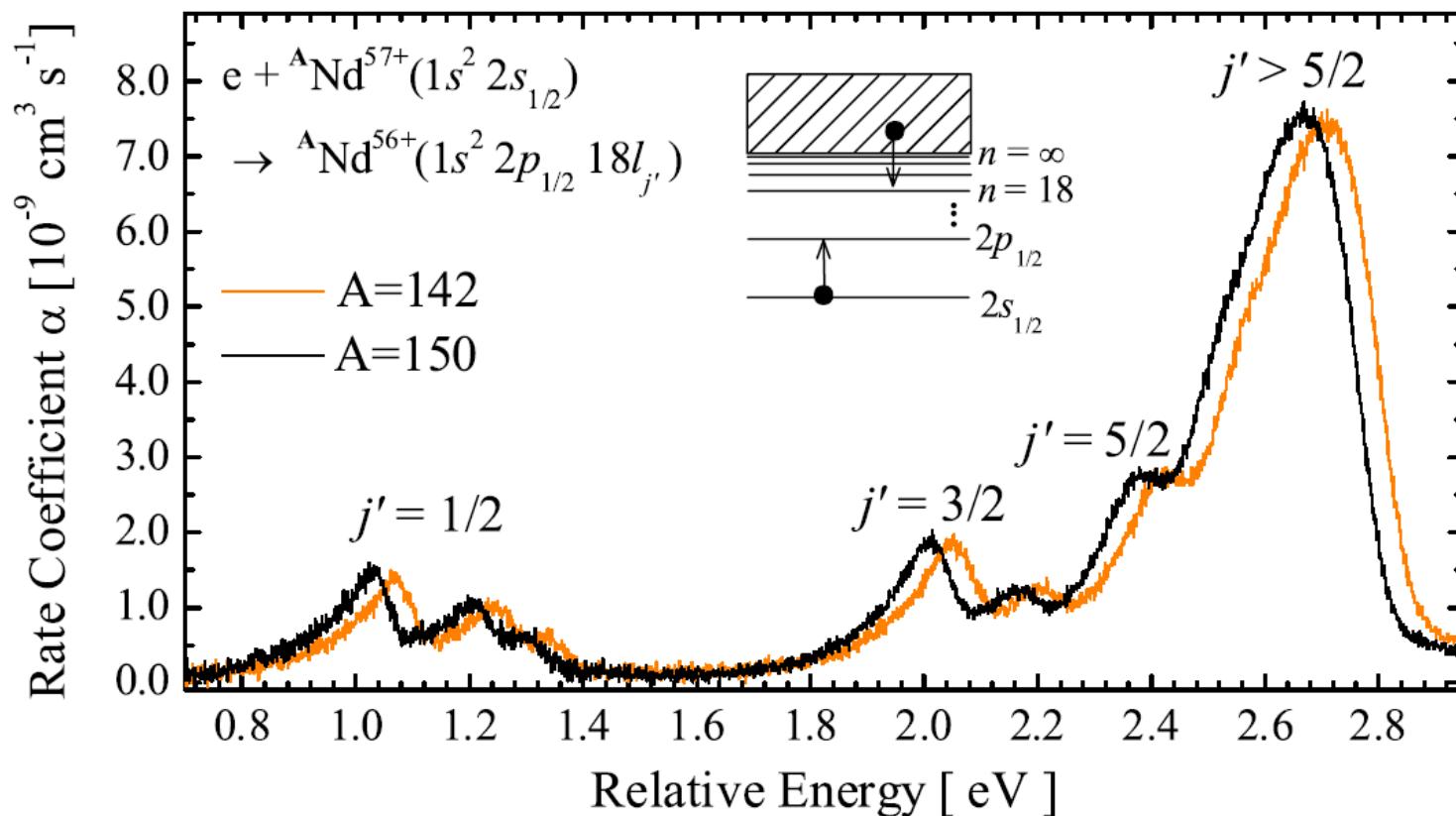


Injection length 520 s

Bosch *et al.*, Int. J. Mass Spec. 251 (2006) 212

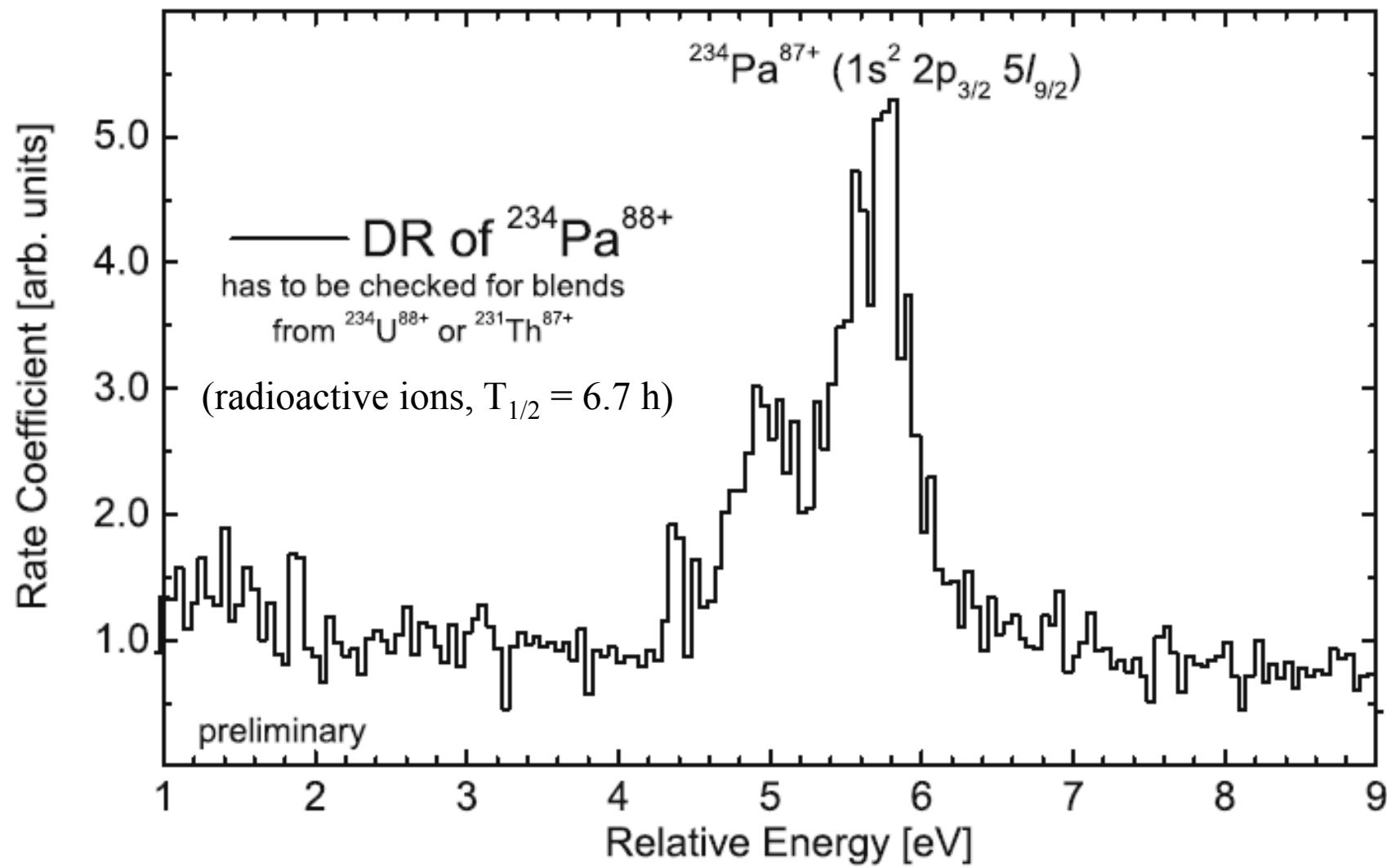
dielectronic recombination of lithium-like ions

a way to obtain moments, spins and radii, and to purify isomeric beams, using hyperfine shifts and splittings

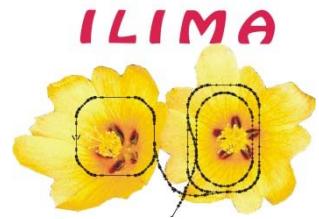


Brandau et al., Phys. Rev. Lett. 100 (2008) 073201; Hyp. Int. 196 (2010) 195

dielectronic recombination of lithium-like ions



Brandau et al., Phys. Rev. Lett. 100 (2008) 073201; Hyp. Int. 196 (2010) 195



Possibility to prepare <100 keV bare ions

