Isomer physics with stored ions

1. Techniques + results
2. Opportunities

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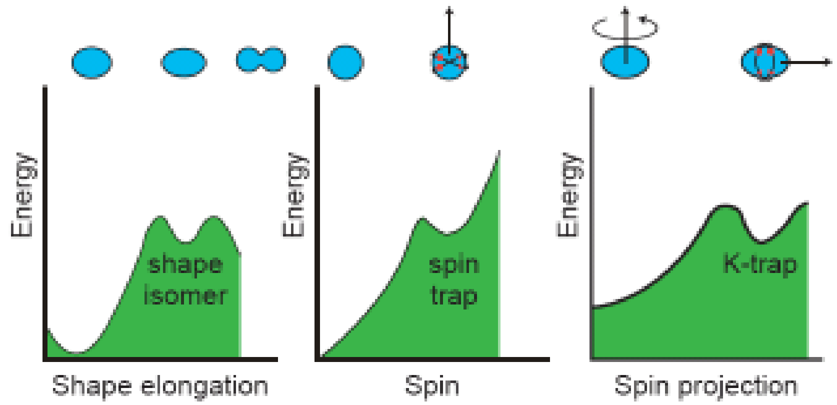
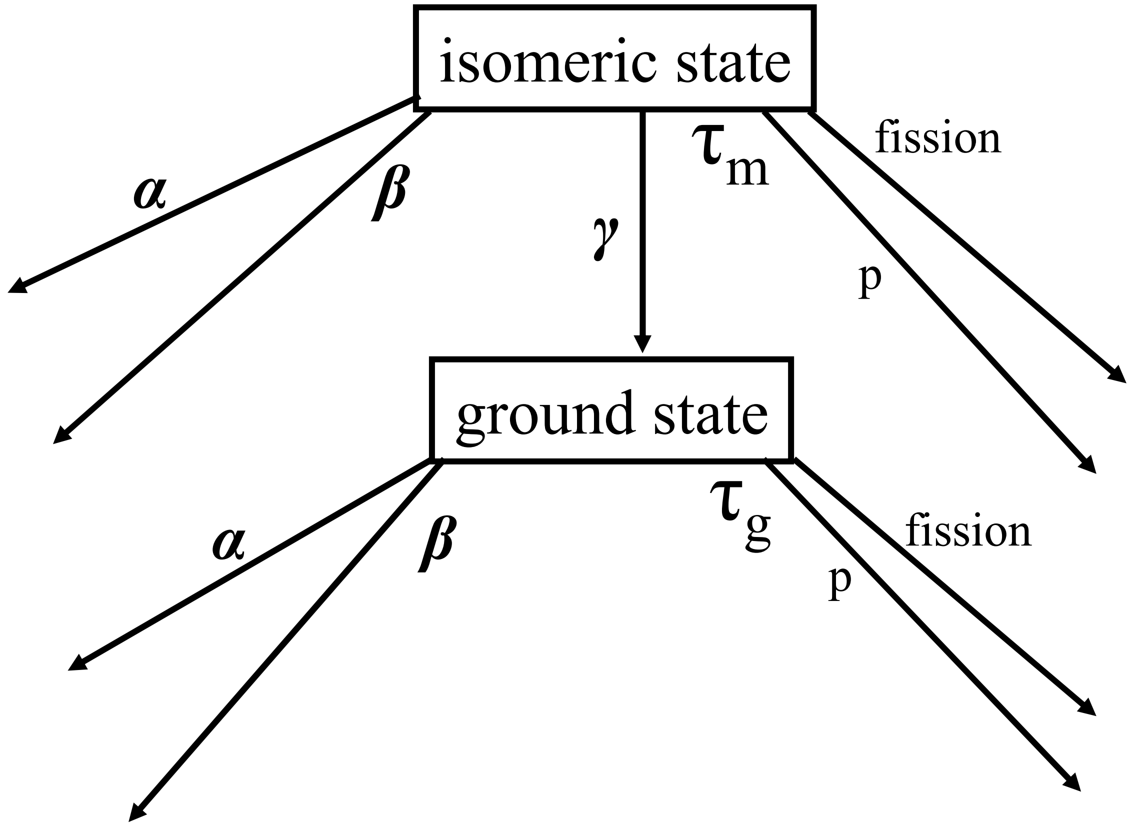




ion storage requires $T_{1/2} \gtrsim 10$ μs

ISOMERS:

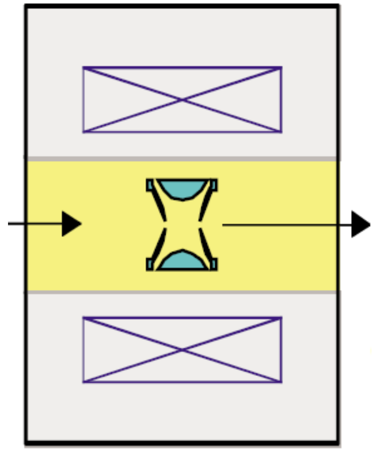
- **test the shell model** (spherical and deformed) – shell migrations far from stability
- **confer extra stability** – can live longer that their respective ground states
- **test models of nucleosynthesis** (*s*-process – photoactivation; *r*-process?)
- **test fundamental interactions** – e.g. electromagnetic parity mixing
- **confer specific experimental advantages** – transport to selected environments
- **enable identification of novel decay modes** – e.g. first example of proton radioactivity
- **give enhanced sensitivity to the atomic environment** – changed half-lives

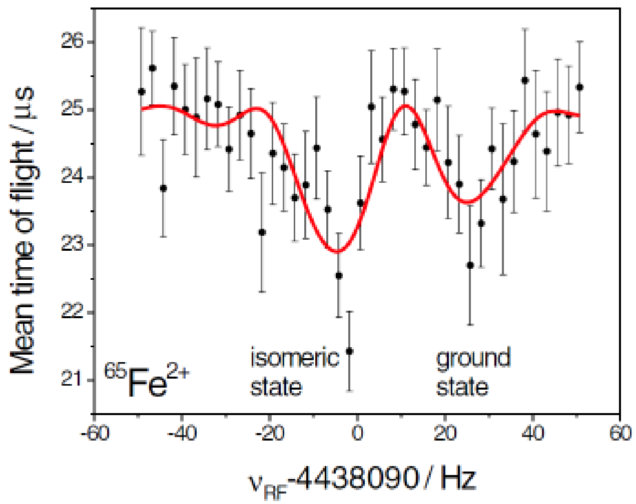
Isomer discoveries with stored ions

Penning trap

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

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

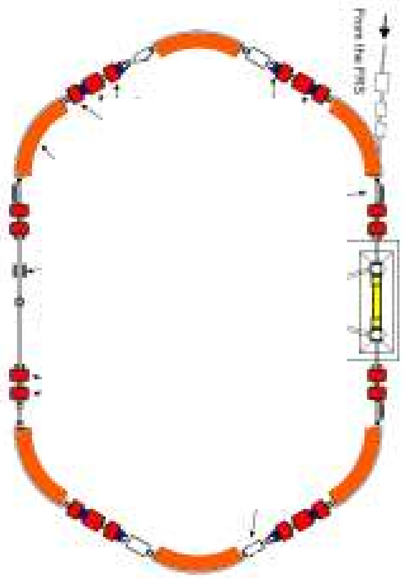


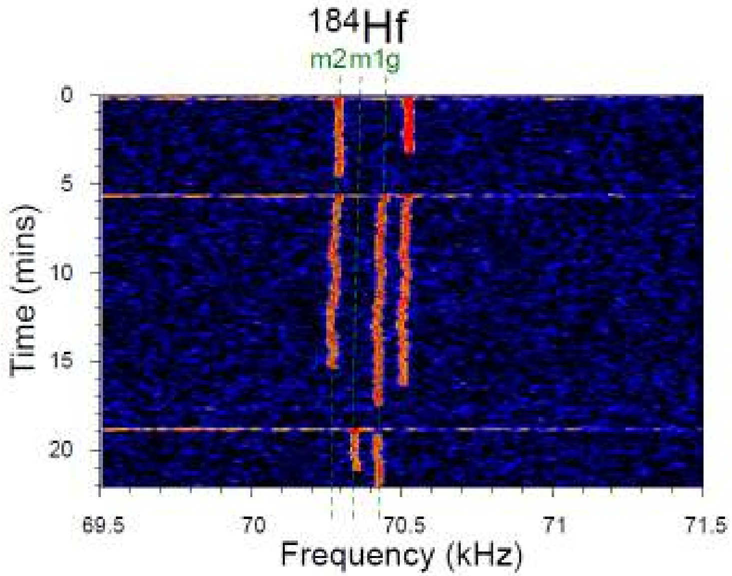


Storage ring

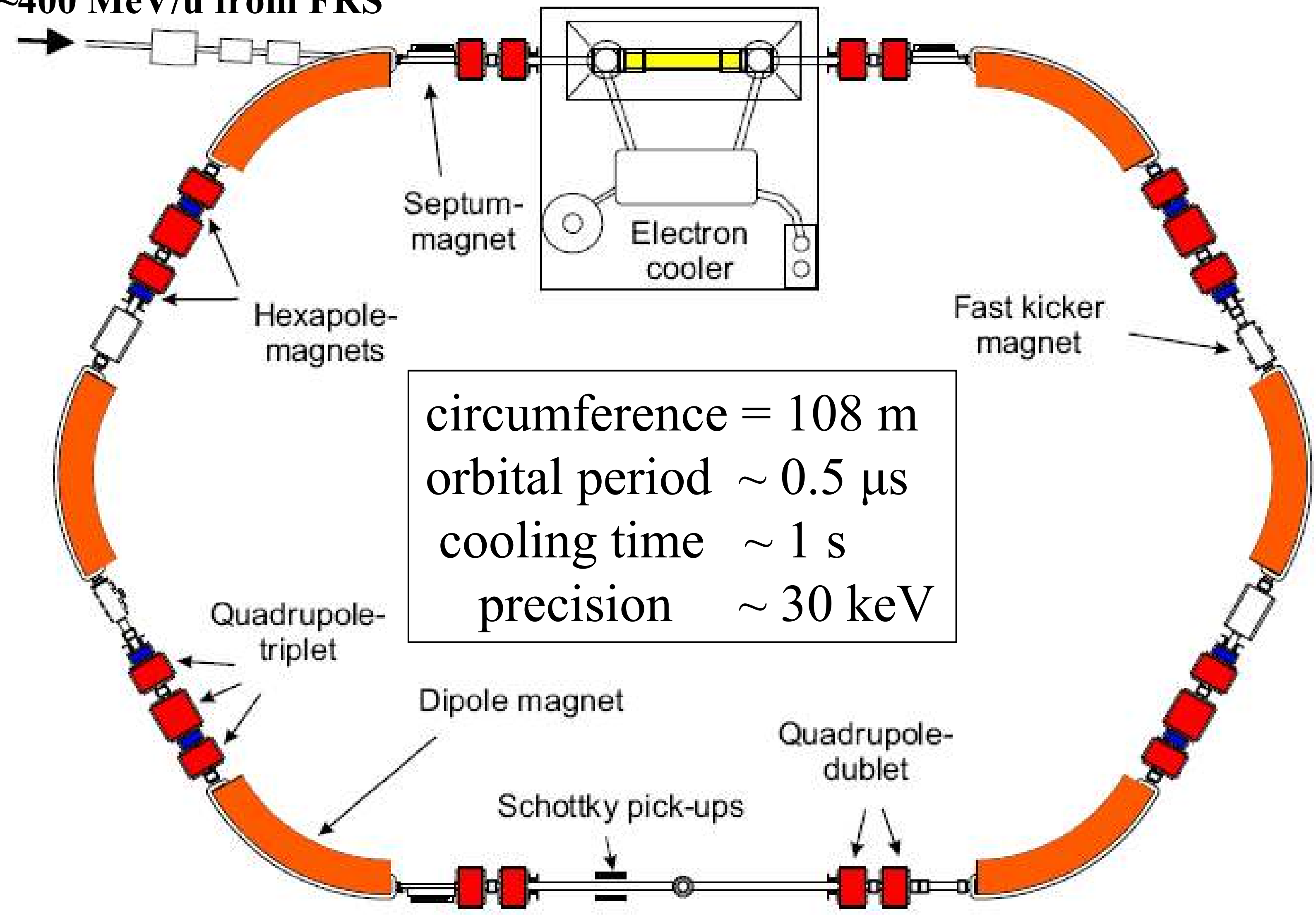
$^{184m2}Hf$ and ^{184g}Hf

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



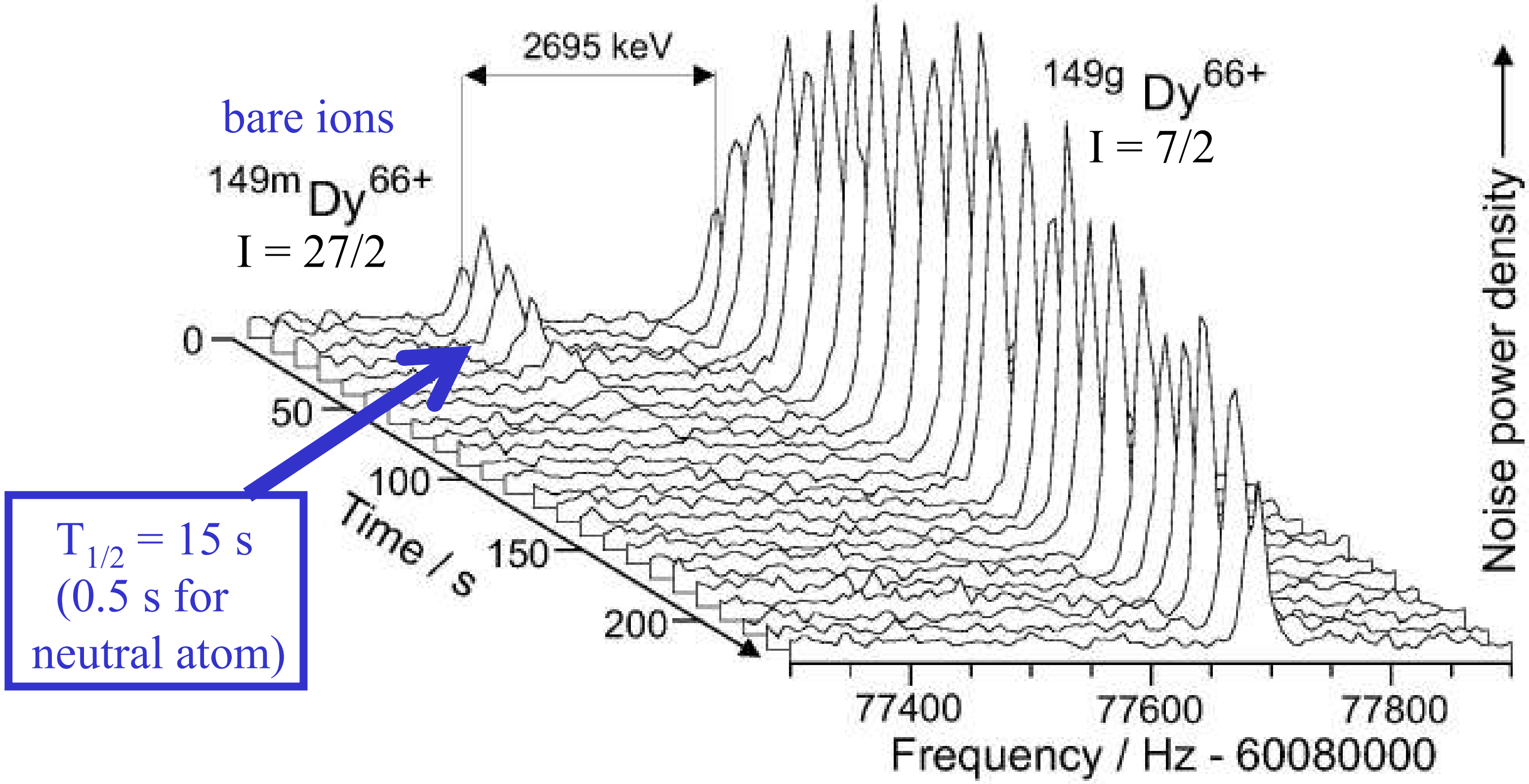


Experimental Storage Ring



circumference = 108 m
orbital period ~ 0.5 μs
cooling time ~ 1 s
precision ~ 30 keV

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



Schottky mass spectrometry

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

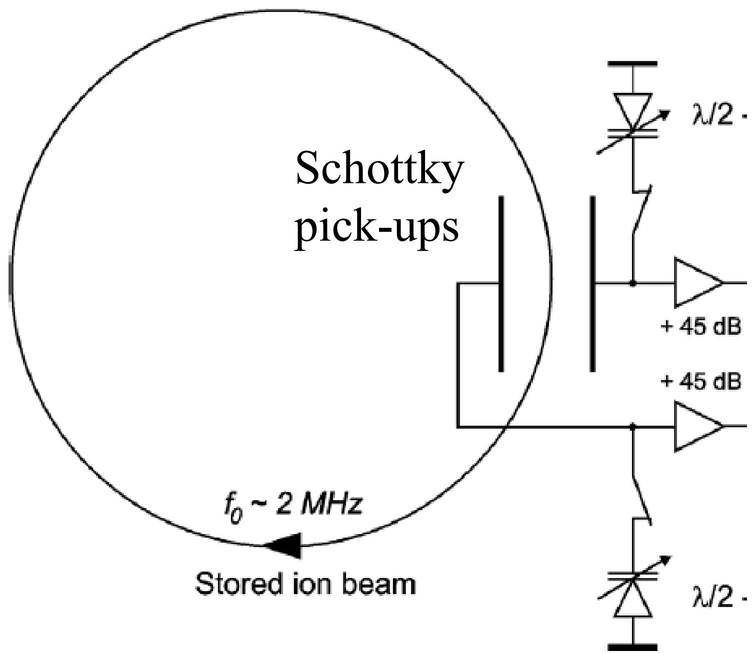
[isomers up to I = 43/2 seen in fragmentation
Podolyak et al., Phys. Lett. B632 (2006) 203]

SMS and IMS
mass measurements

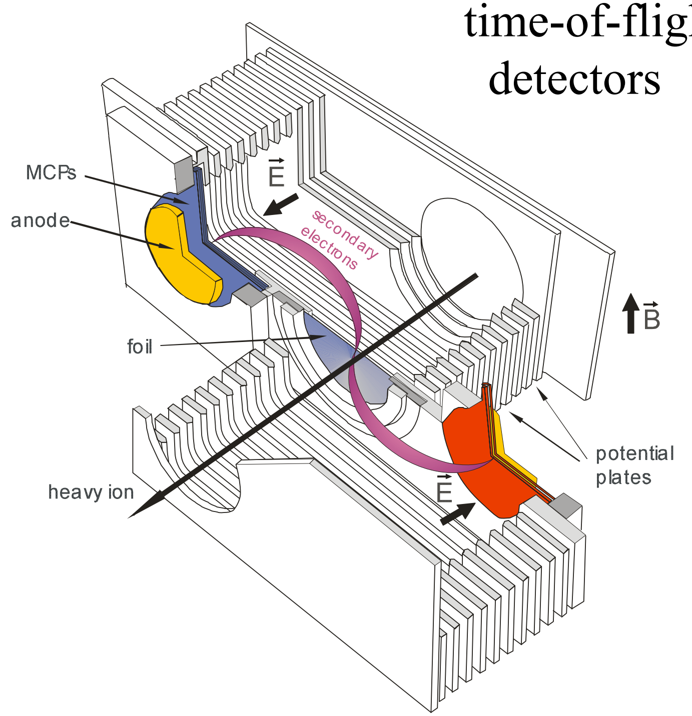
both methods have single-ion sensitivity

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

Schottky Mass Spectrometry (with cooling): $T_{1/2} > 1$ s	Isochronous Mass Spectrometry: $T_{1/2} > 10\ \mu s$



time-of-flight detectors

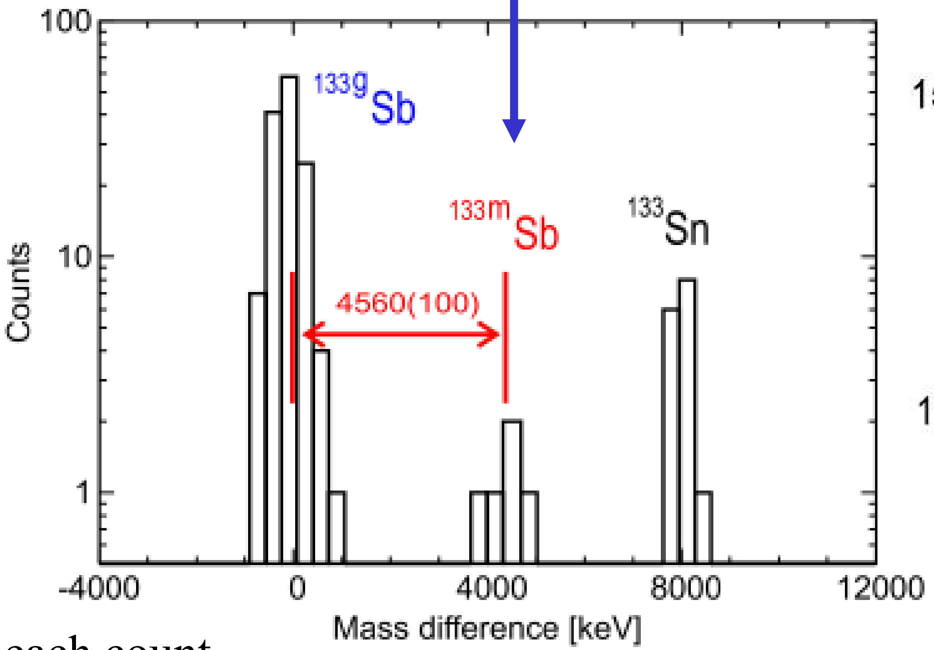


Shell-model isomer in n-rich ^{133}Sb

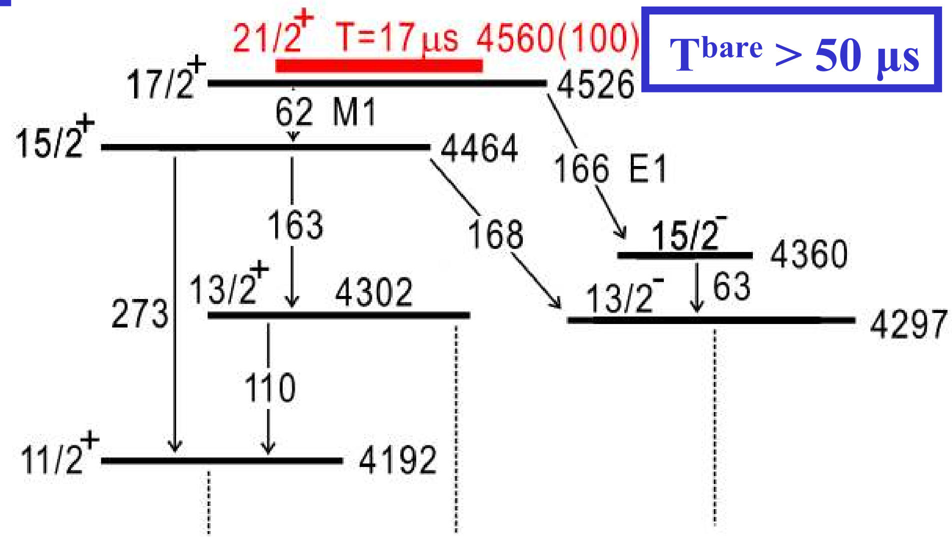
- first direct observation of this isomer
- shortest-lived stored ion

^{238}U fission

isochronous mass spectrometry



each count represents a single ion



T^{bare} > 50 μs

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

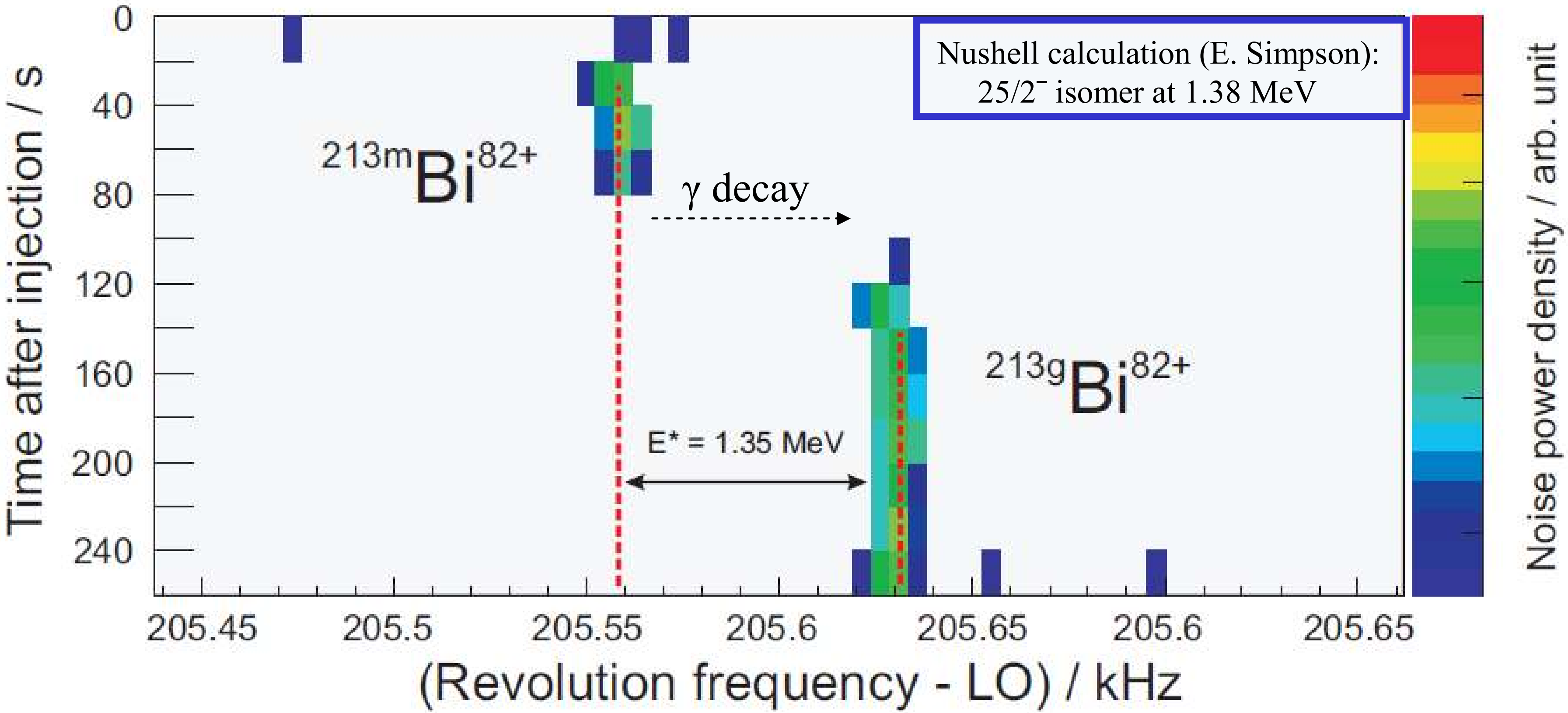
Sun et al., Phys. Lett. B688 (2010) 294

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

^{238}U fragmentation

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

Schottky mass spectrometry



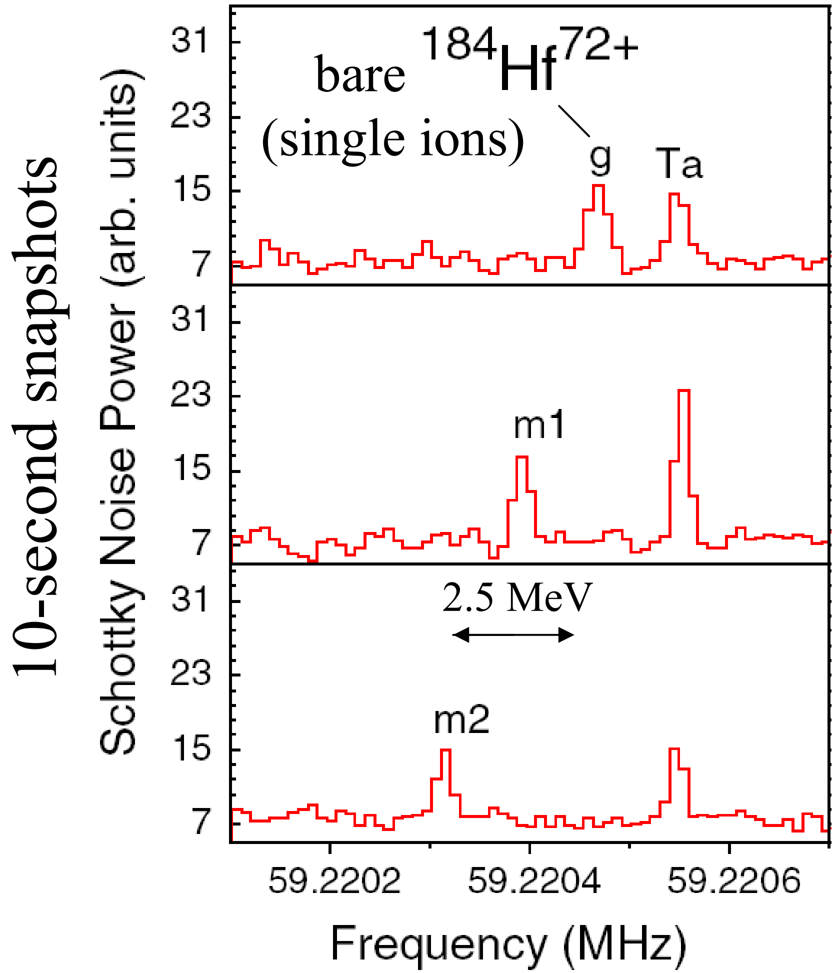
Chen et al., Nucl. Phys. A in press

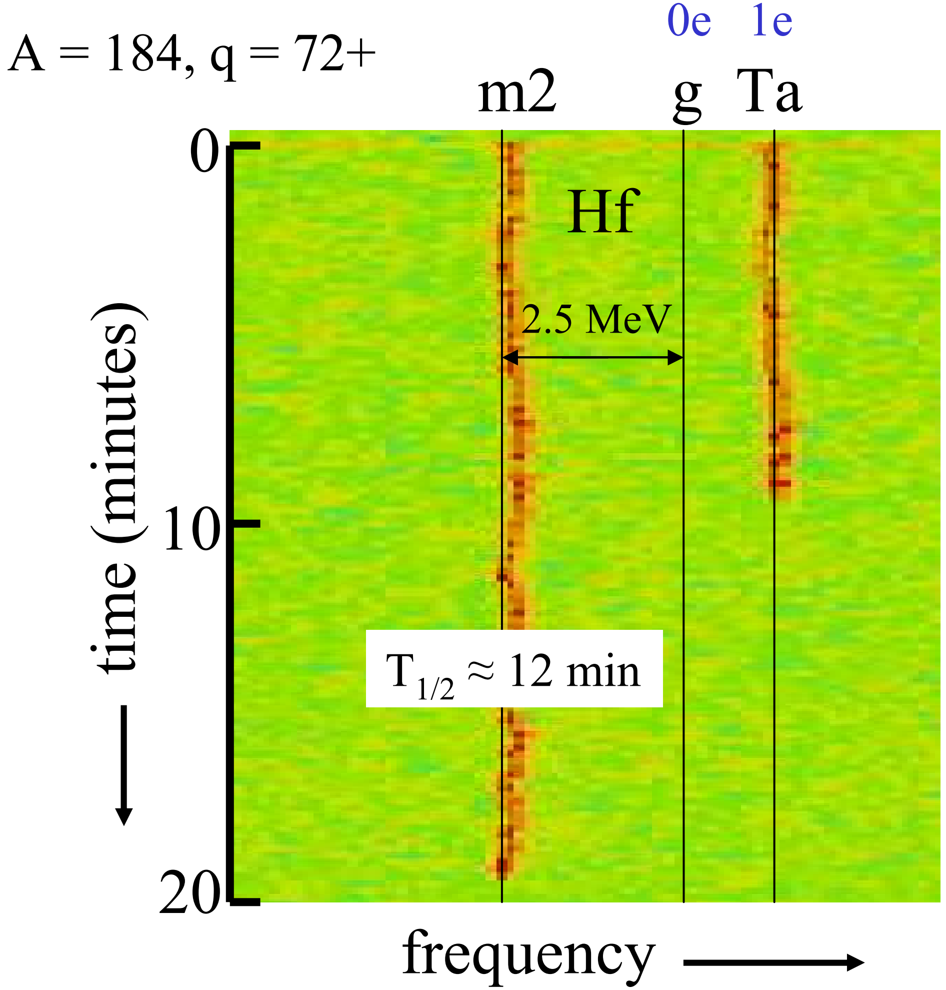
High-K isomers in n-rich ^{184}Hf

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

^{197}Au fragmentation

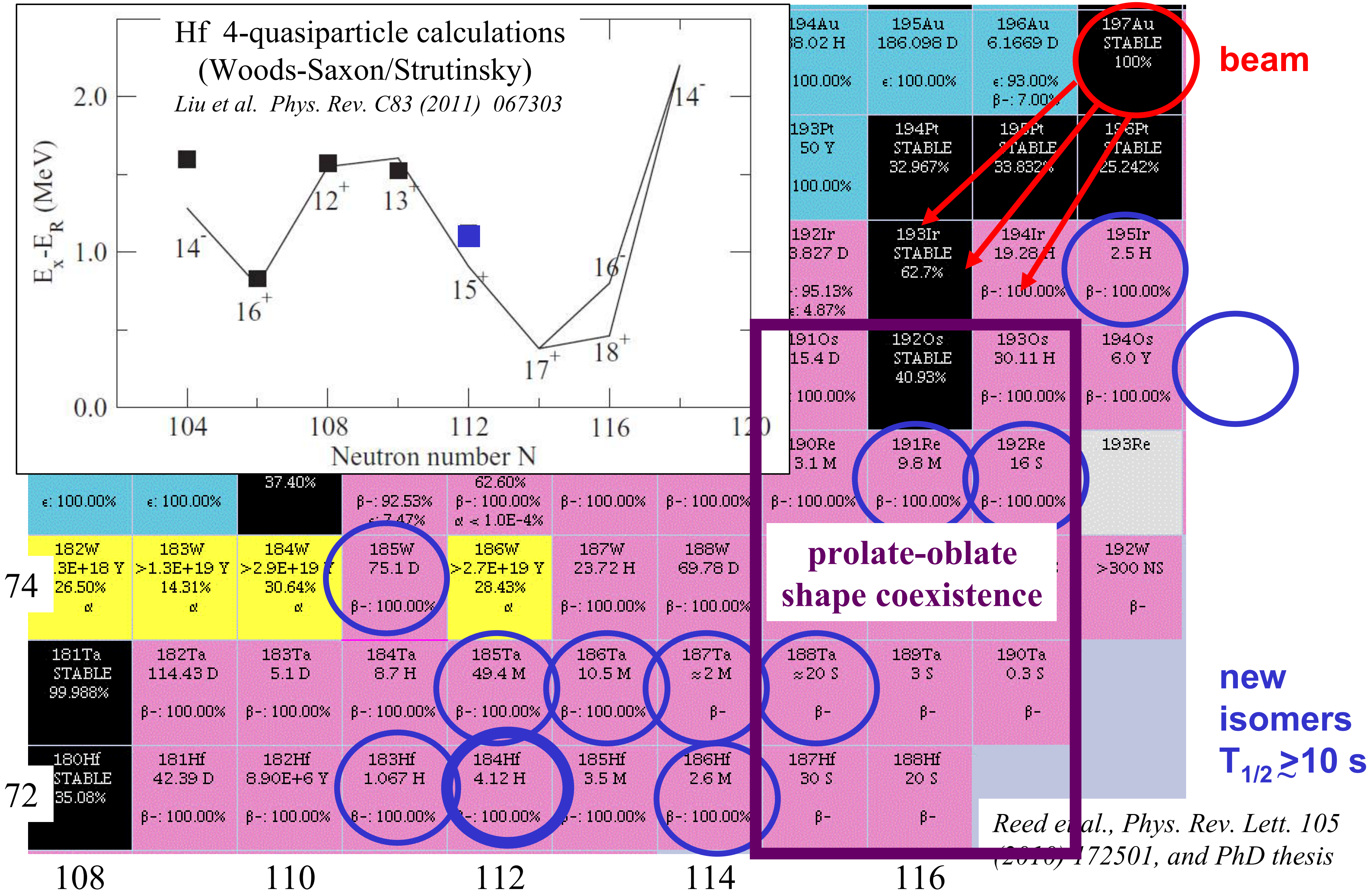
Schottky mass spectrometry





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

^{197}Au fragmentation

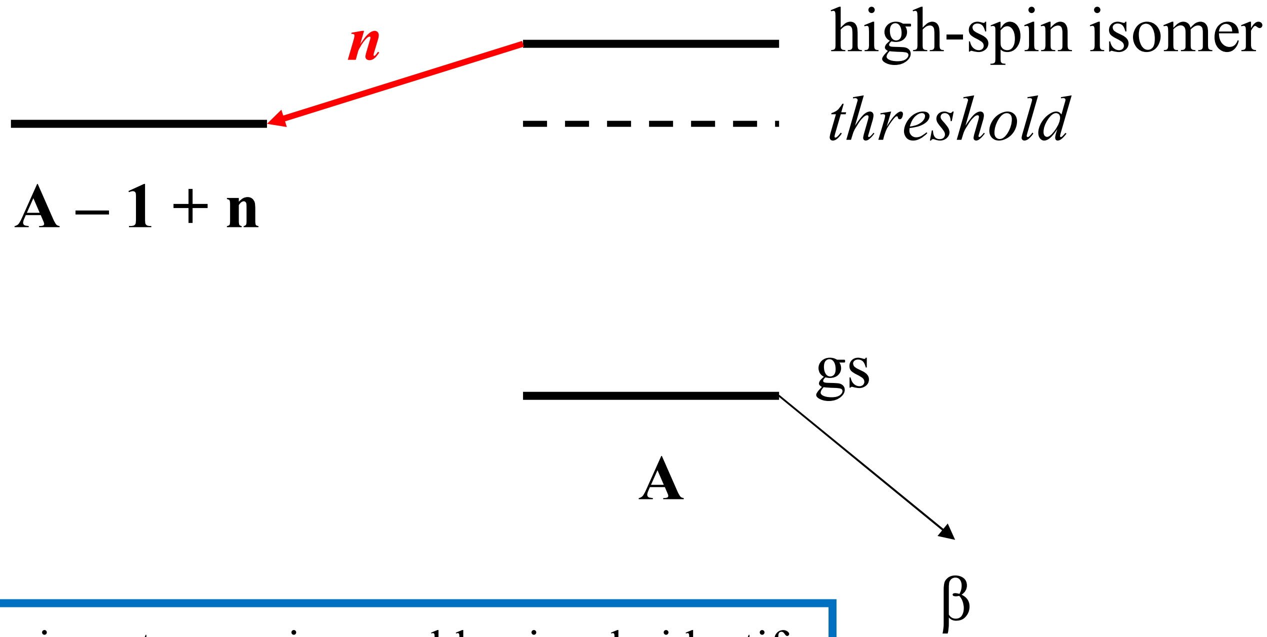


Reed et al., Phys. Rev. Lett. 105 (2010) 172501, and PhD thesis opportunities

neutron radioactivity

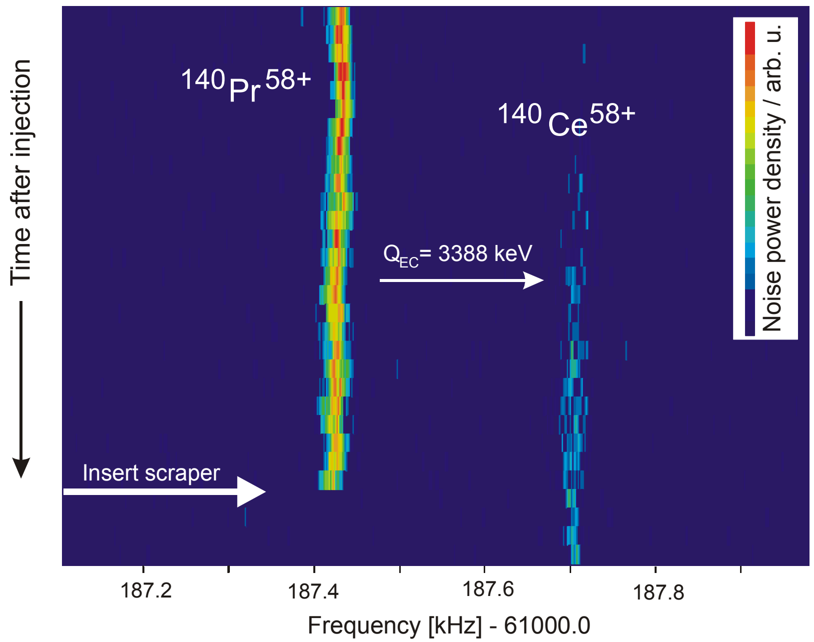
mono-energetic neutrons ~1 MeV

unique to isomers?

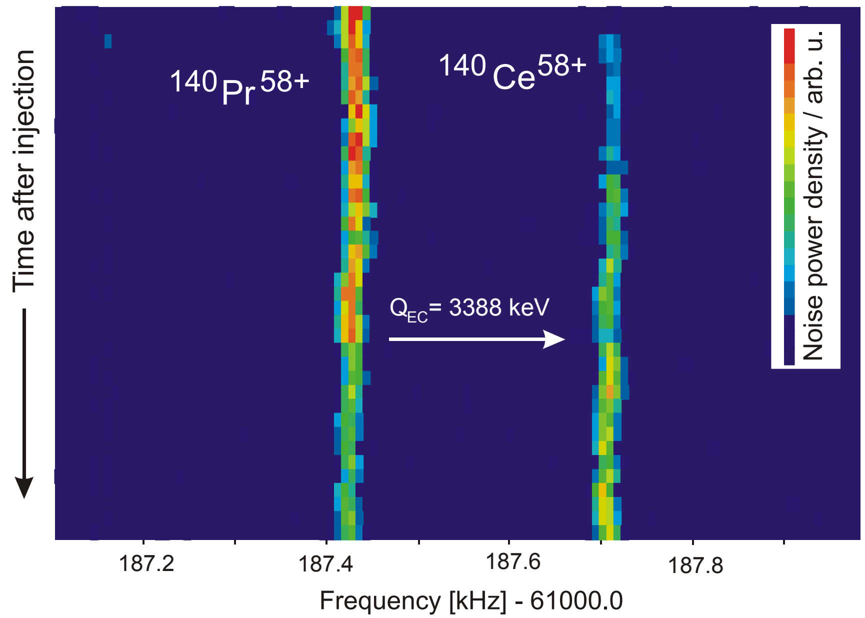


orbit change of a ***single ion*** in a storage ring could uniquely identify the neutron decay mode without detecting the neutron

potential for isomer beam purification



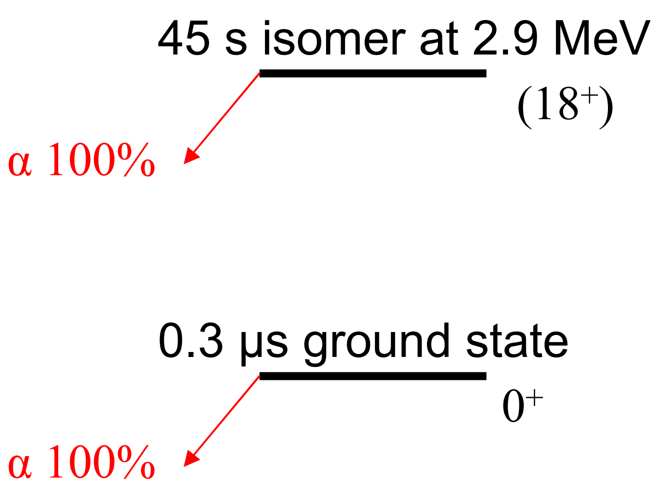
Injection length 170 s



Injection length 520 s

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

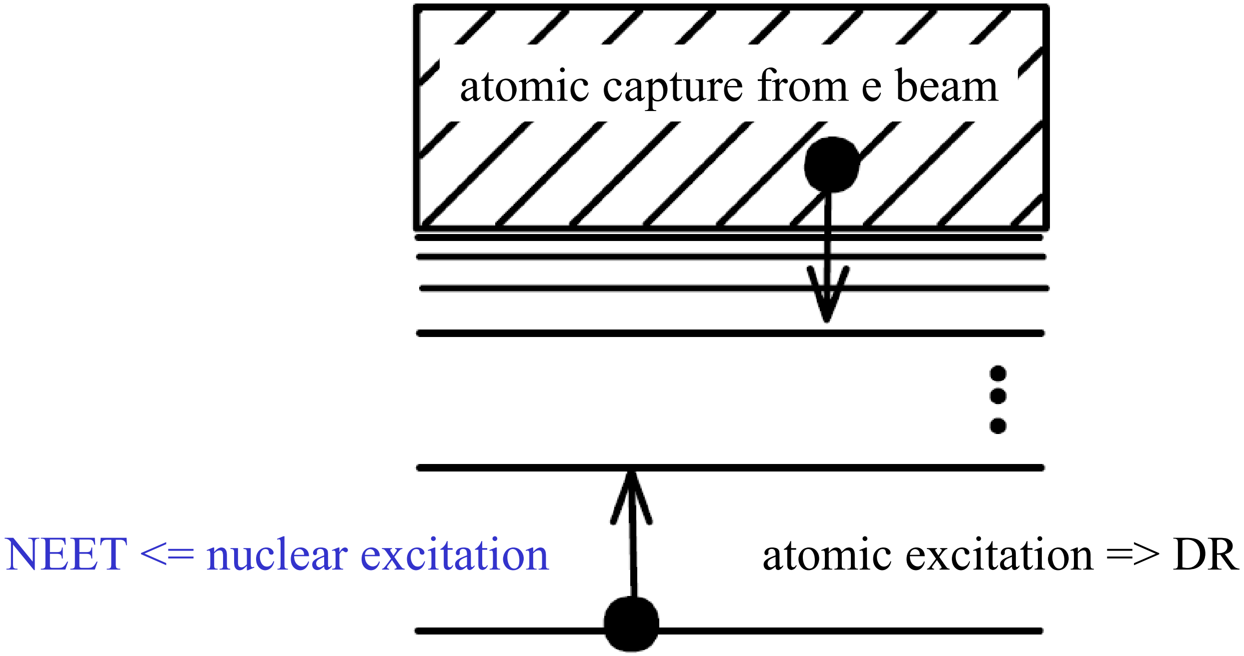
$^{212m}_{84}Po$: pure high-spin isomer



resonant capture of atomic electrons by highly charged isomeric ions

- NEET (nuclear excitation by electron capture) is as-yet unobserved

- DR (dielectronic recombination) can yield moments, spins and radii

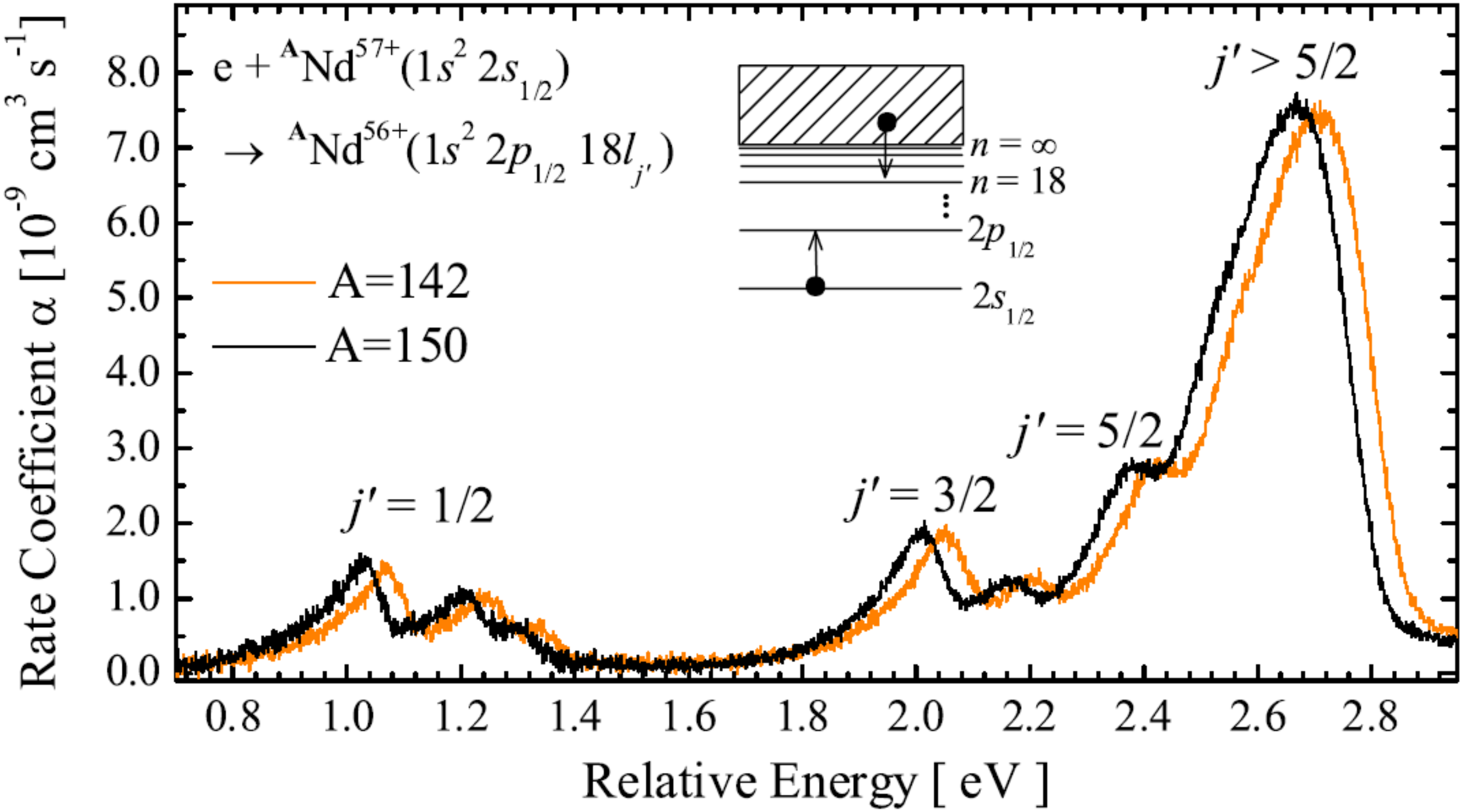


Palffy et al., Phys. Rev. Lett. 99 (2007) 172502
Arigapudi and Palffy, Phys. Rev. A85 (2012) 012710

Brandau et al., Phys. Rev. Lett. 100 (2008) 073201
Hyp. Int. 196 (2010) 115

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

other isomer opportunities:

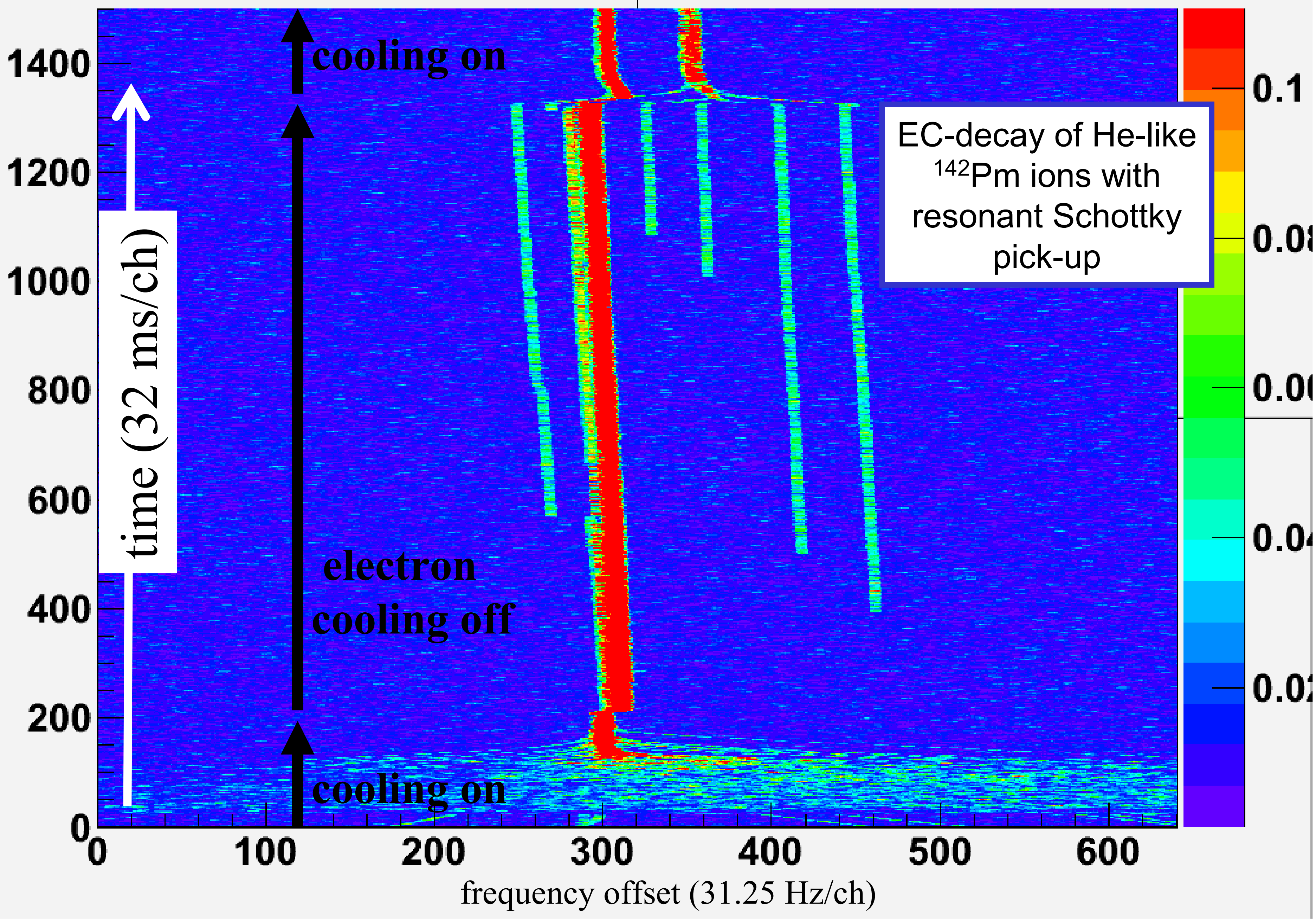
- **nuclear reactions** with (purified) isomeric beams
- **laser interactions** with (purified) isomeric beams
- **resonant Schottky pick-up** with *ms* time response
- **storage ring for ISOL beams** – TSR at ISOLDE

Ring experiments
Thomas Stöhlker
11.15 today

TSR at ISOLDE
Klaus Blaum
11.05 tomorrow

Ring experiments
Nasser Kalantar
11.30 Friday

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



many thanks to members of the ILIMA collaboration