Nuclear mass exploration at the doorway to the region of superheavy elements

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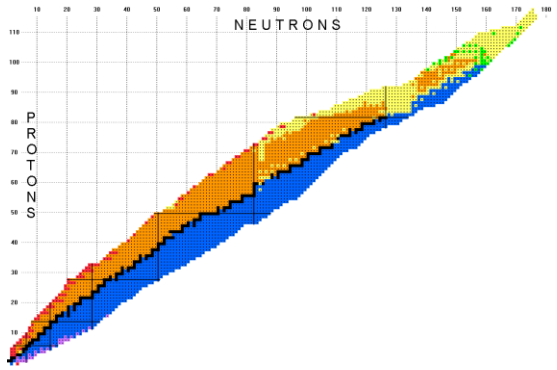
The 4th International Conference on the Chemistry and Physics of the Transactinide Elements
5 - 11 September 2011, Sochi, Russia

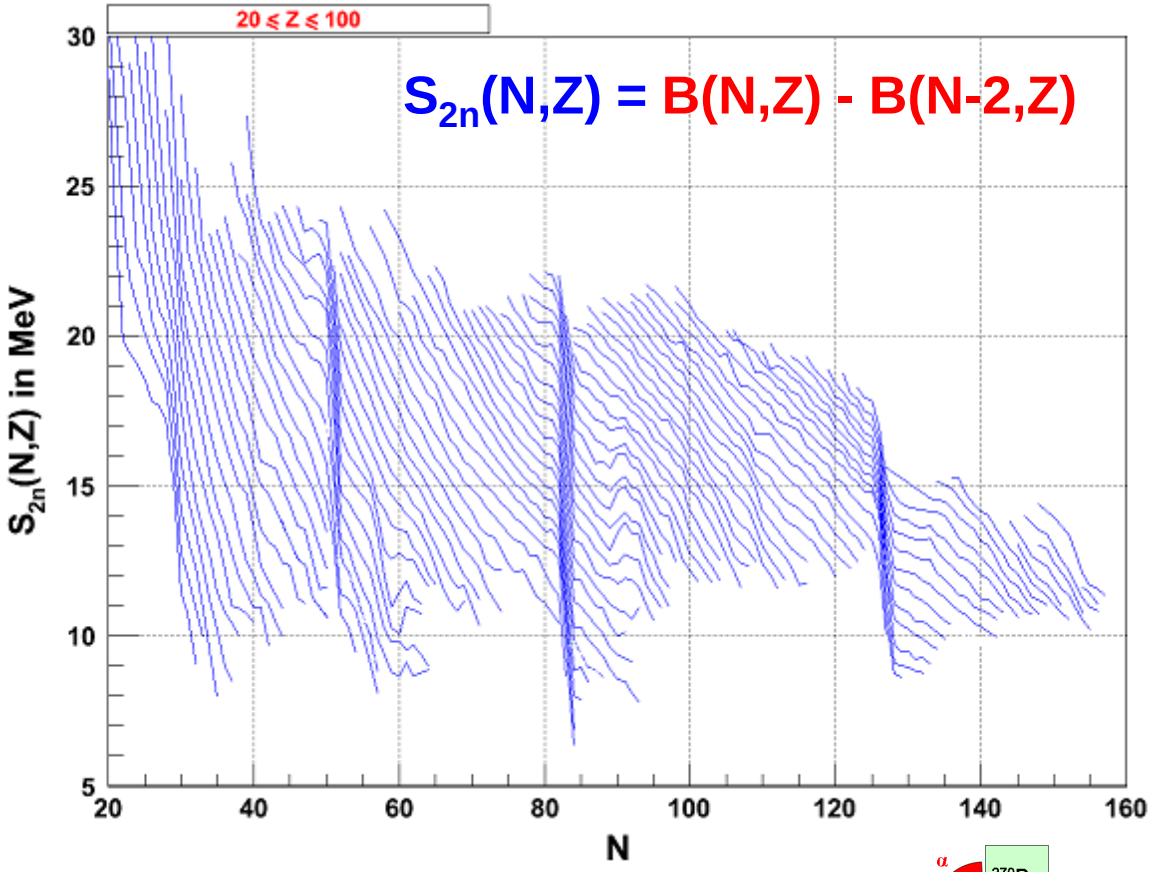
Direct mass measurements :

- What do we learn from them?
- Why do we need them at SHE?
- SHIPTRAP results

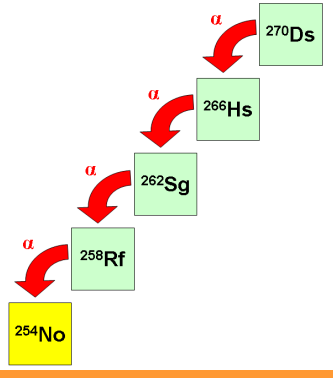
What do we learn from masses ?



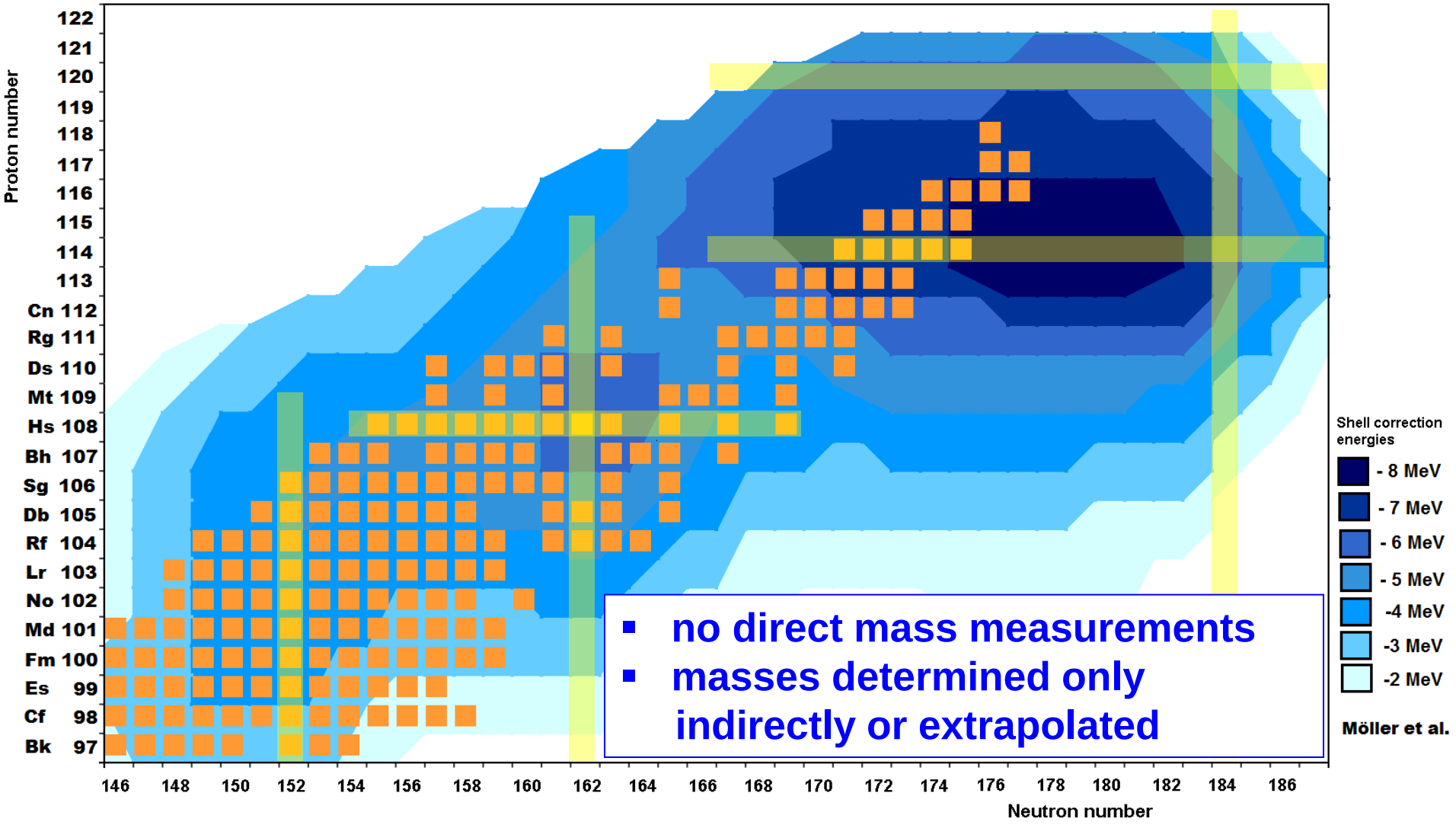
$M(N,Z) = Z\,M_p + N\,M_n - B(N,Z)$



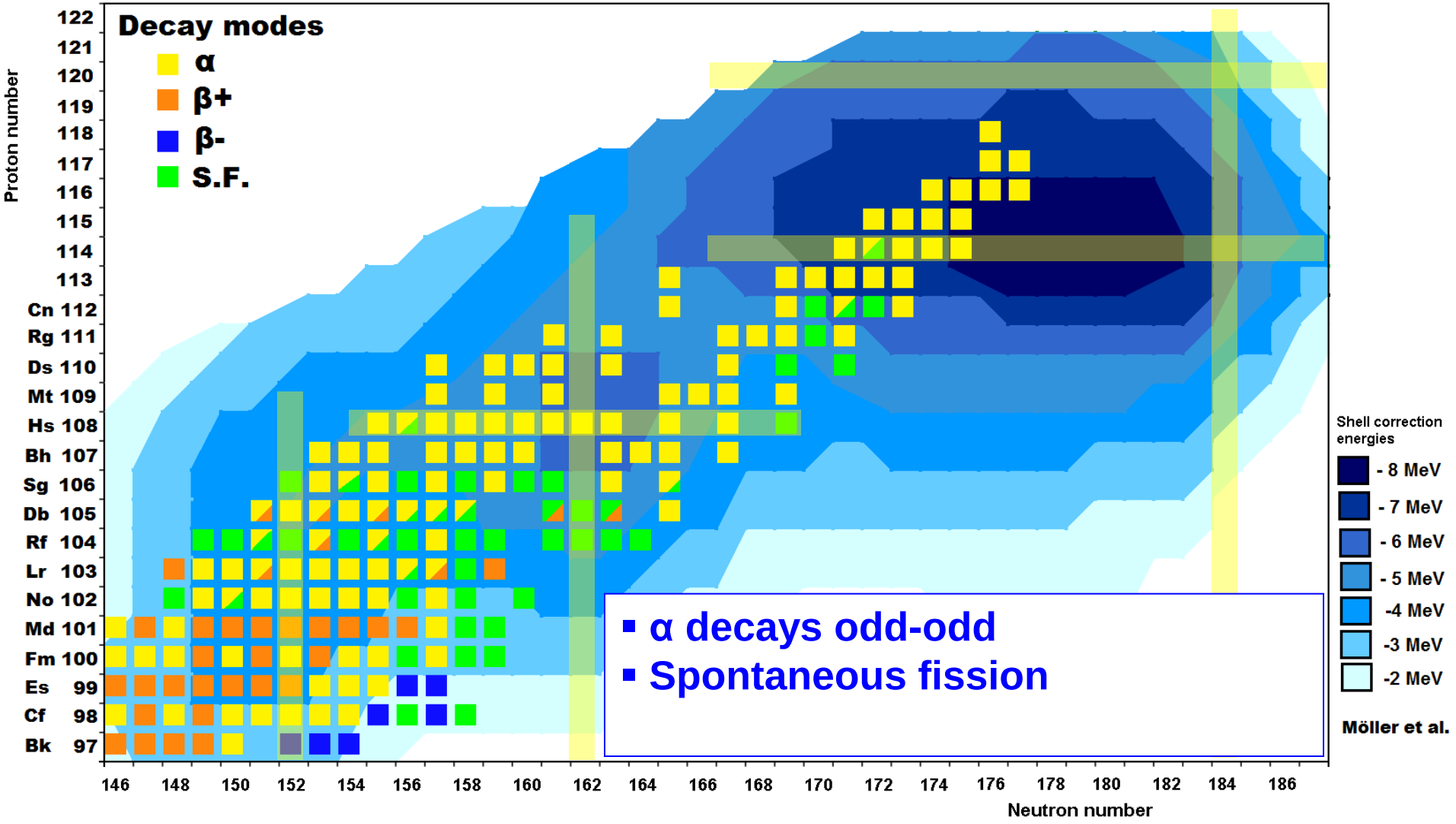
- **Absolute nuclear binding energy**
- **shell structure evolution**
- **benchmark nuclear models**
- **anchor points to fix decay chains**



Mass measurements above uranium

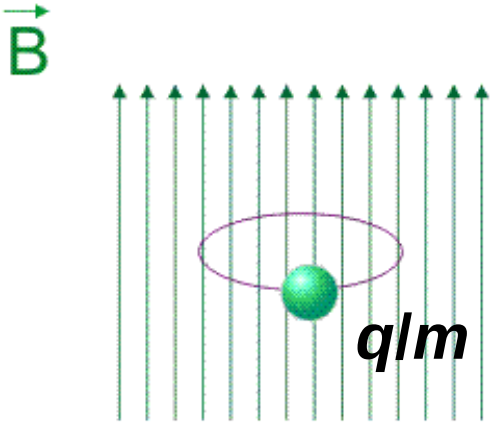


Mass measurements above uranium

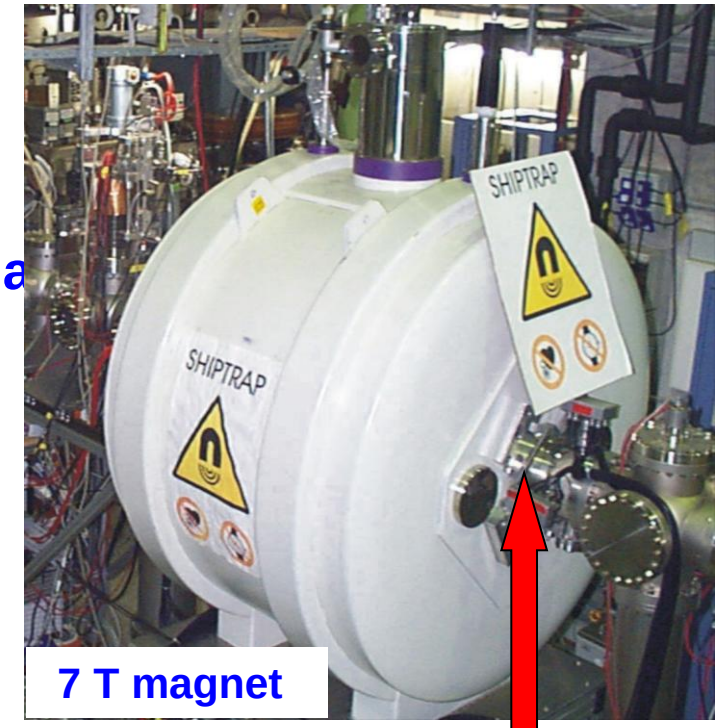


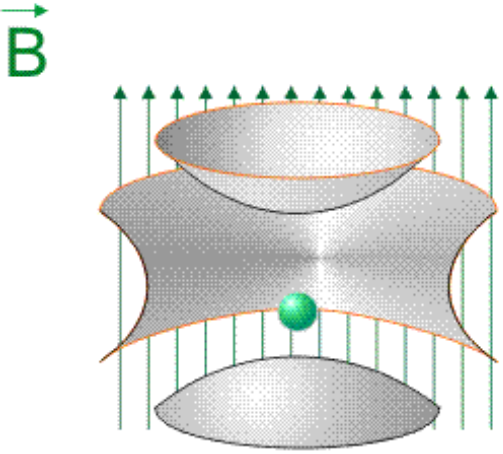
How to measure the mass ?

Penning trap



strong homogeneous ma





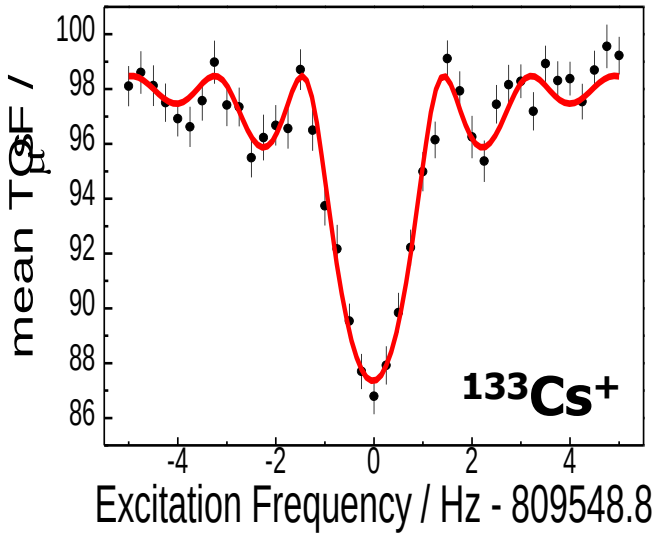
\+ weak electrostatic field

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

How to measure the mass ?

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

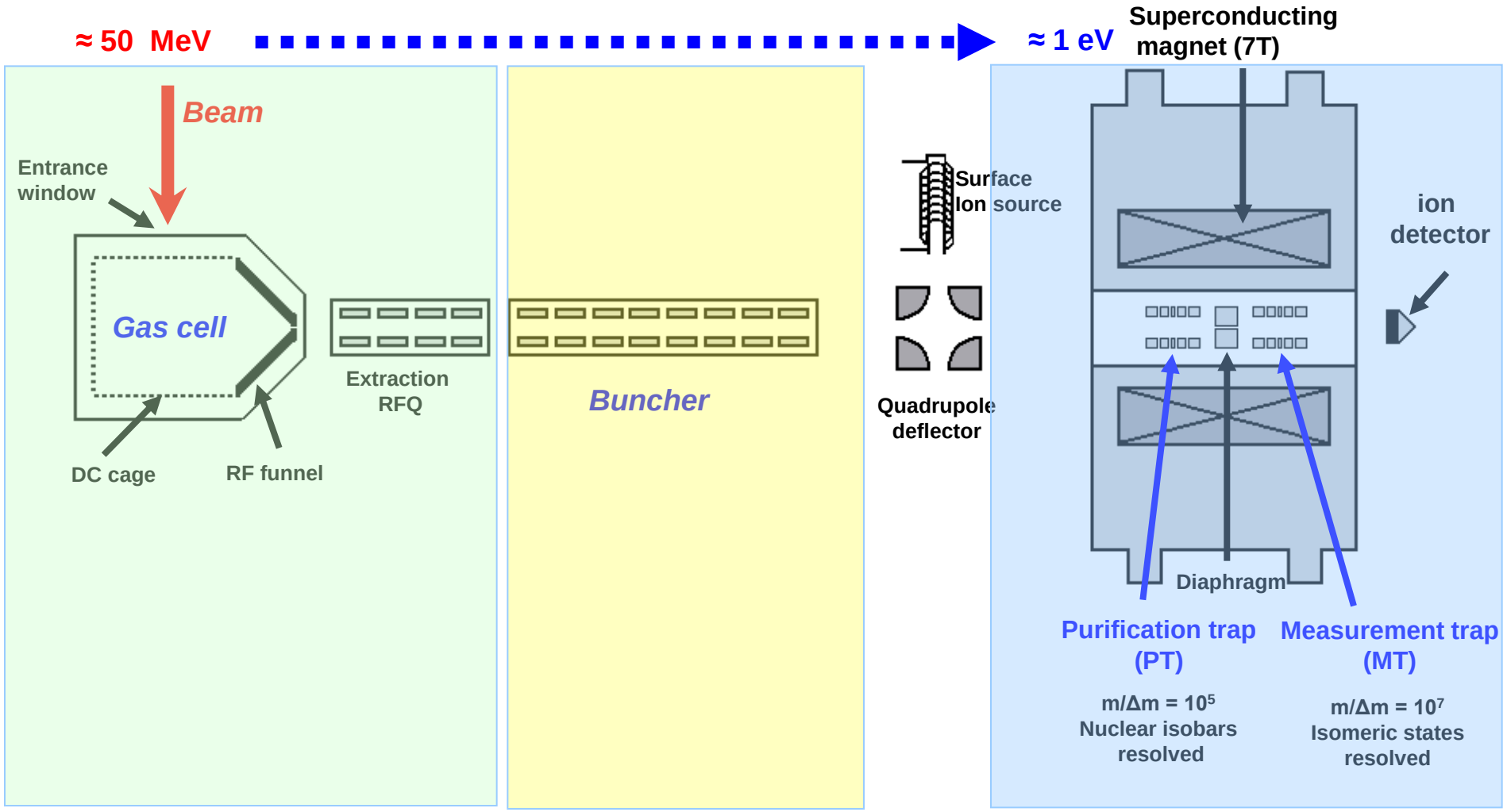
(B = 7 T, A = 133, $f_c \approx$ 800 kHz)



- Relative uncertainty ≈ 10^{-8}
- Accessible half-lifes > 100 ms
- Typical Resolving power ≈ 10^6

$$R = f_c \cdot T_{exc} \qquad (T_{exc} = 2\ s)$$

SHIPTRAP

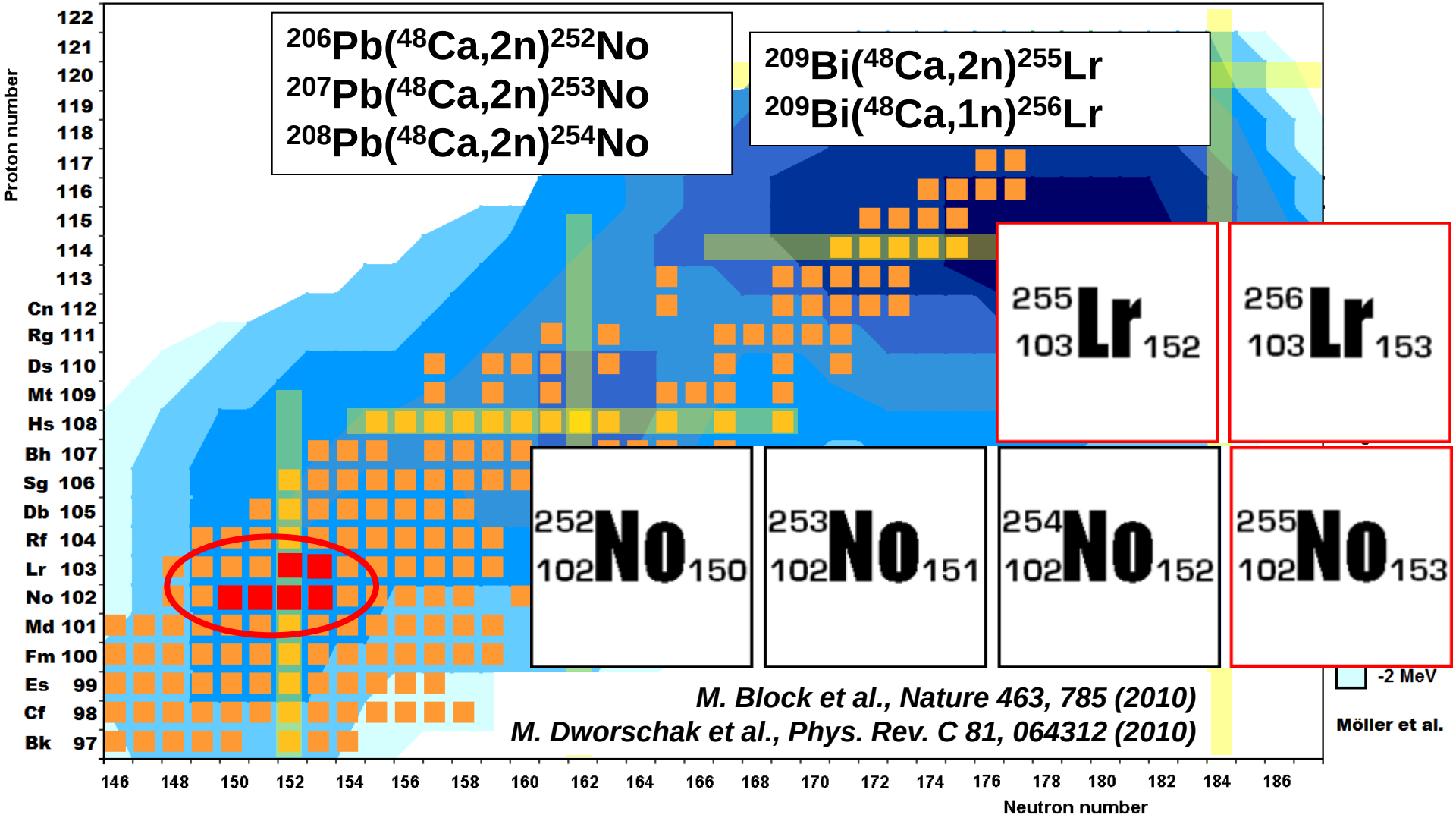


Stopping, extraction

Cooling + Accumulation

Purification, Storage, Identification

Direct mass measurements



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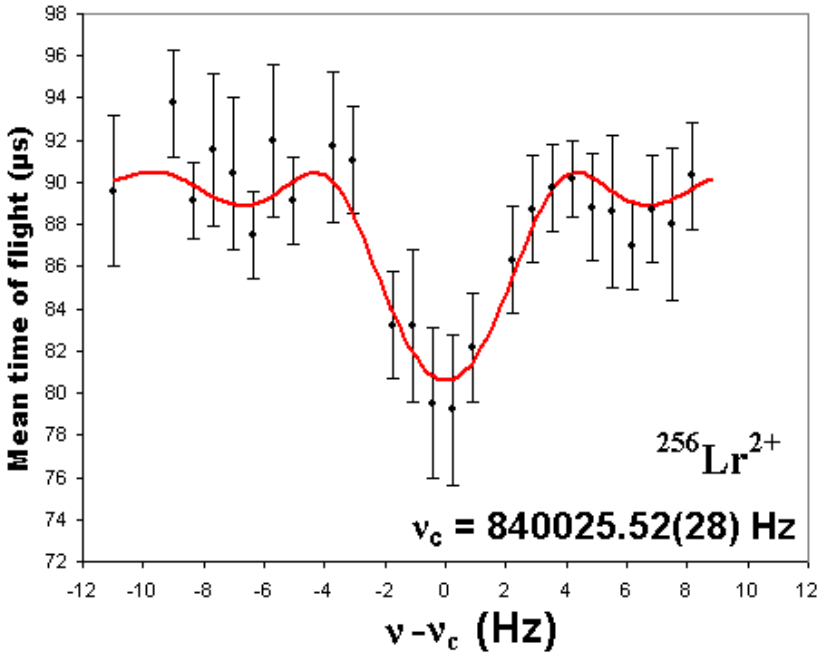
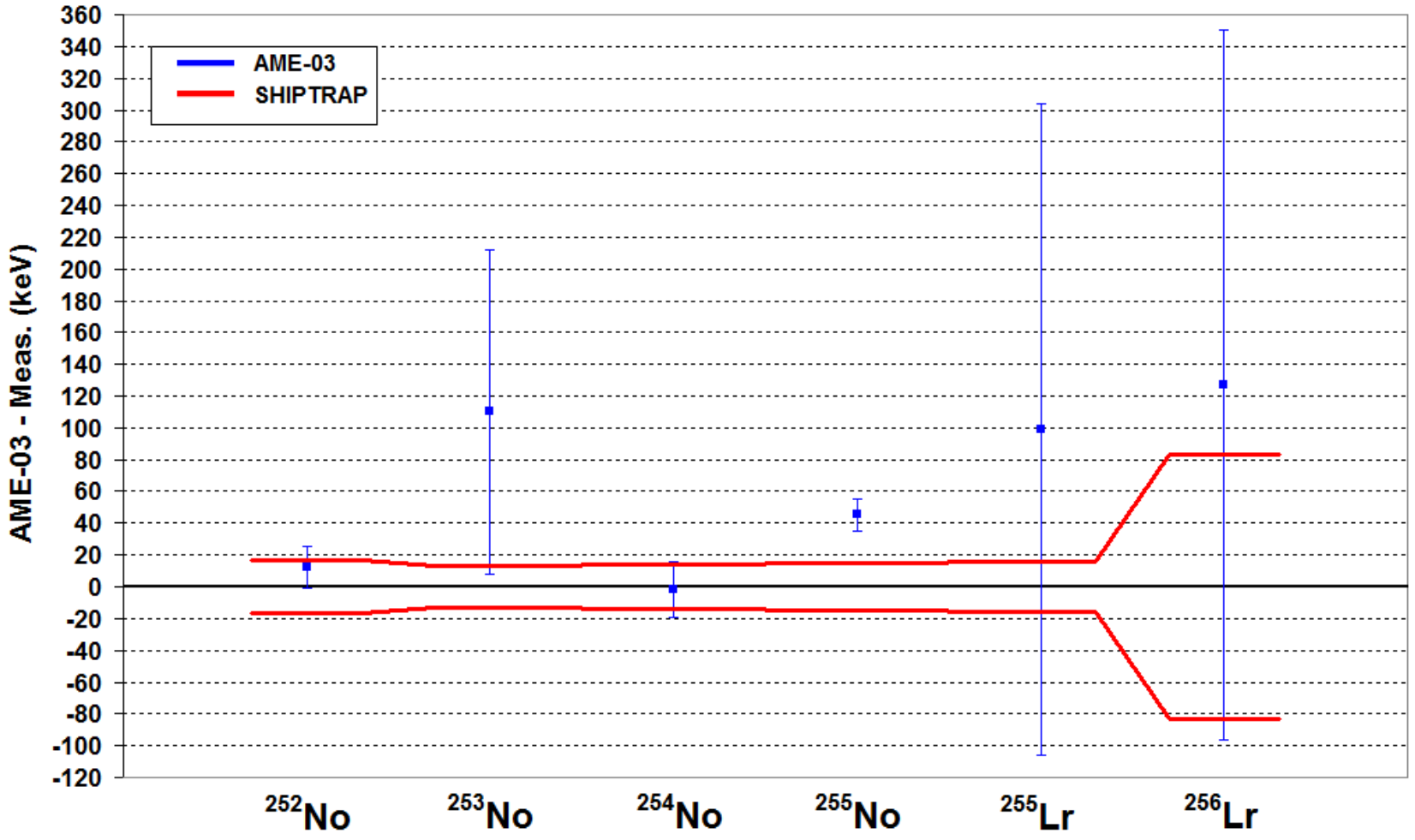


Lowest production cross section :
$^{256}Lr^{2+}$ (60 nb)
4 days for one resonance (50 ions)

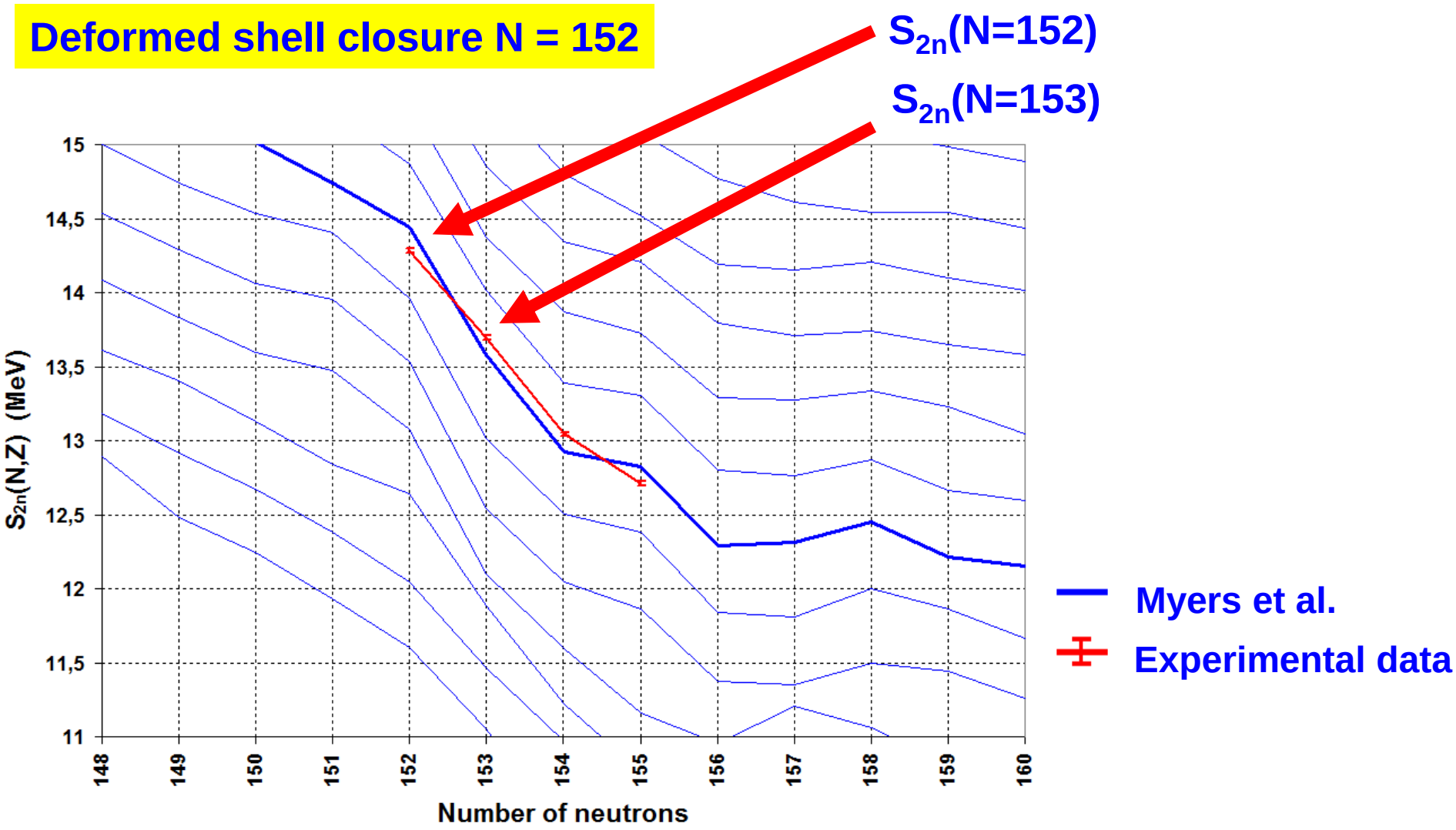
Element	$T_{1/2}$ (g.s.)	σ (nb)
^{252}No	2.44(4) s	400
^{253}No	1.62(15) min	1800
^{254}No	51(10) s	2000
^{255}No	3.1(2) min	140
^{255}Lr	30(4) s	300
^{256}Lr	28(3) s	60

Direct mass measurements

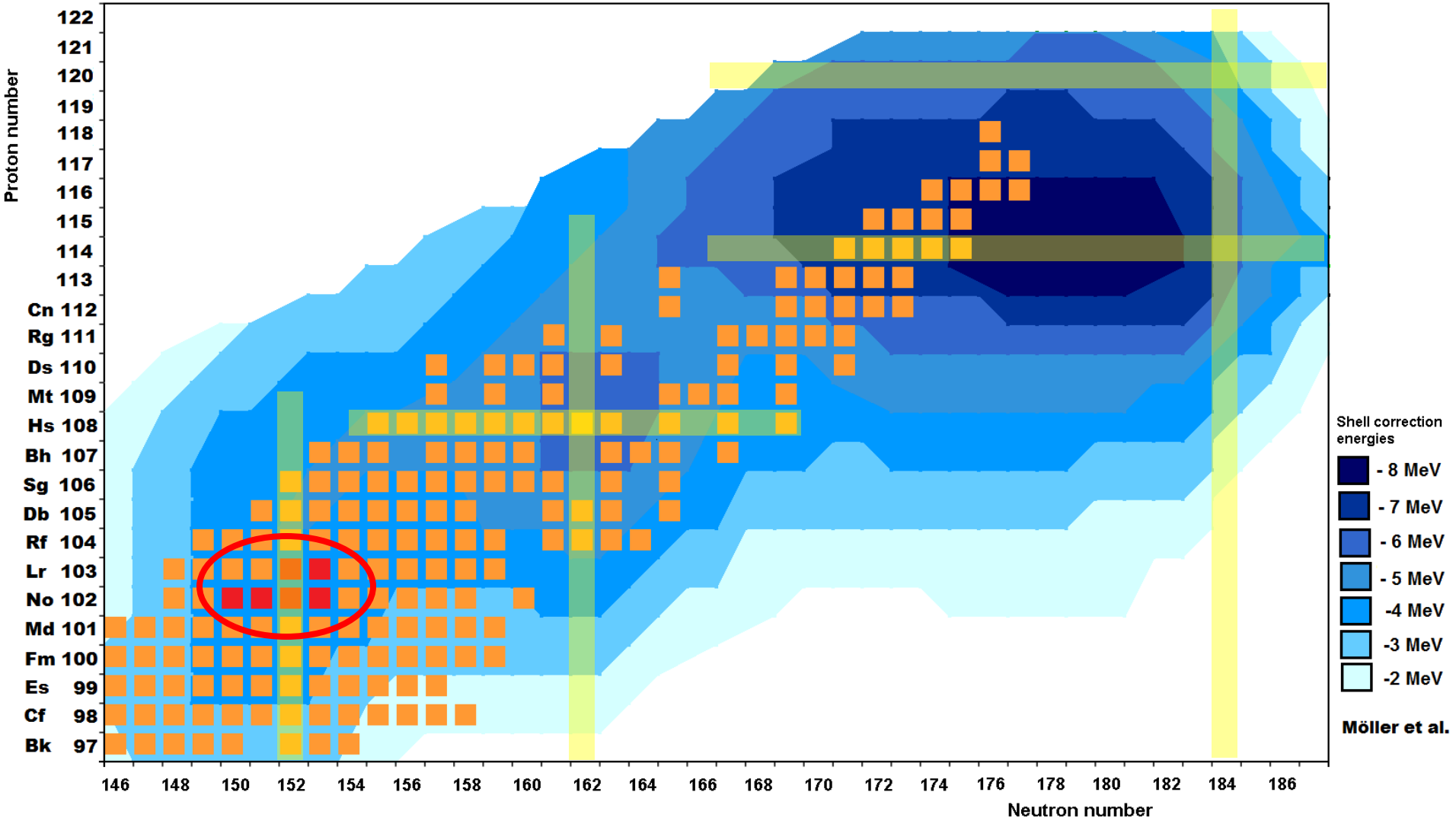


Direct mass measurements

Deformed shell closure N = 152



Direct mass measurements



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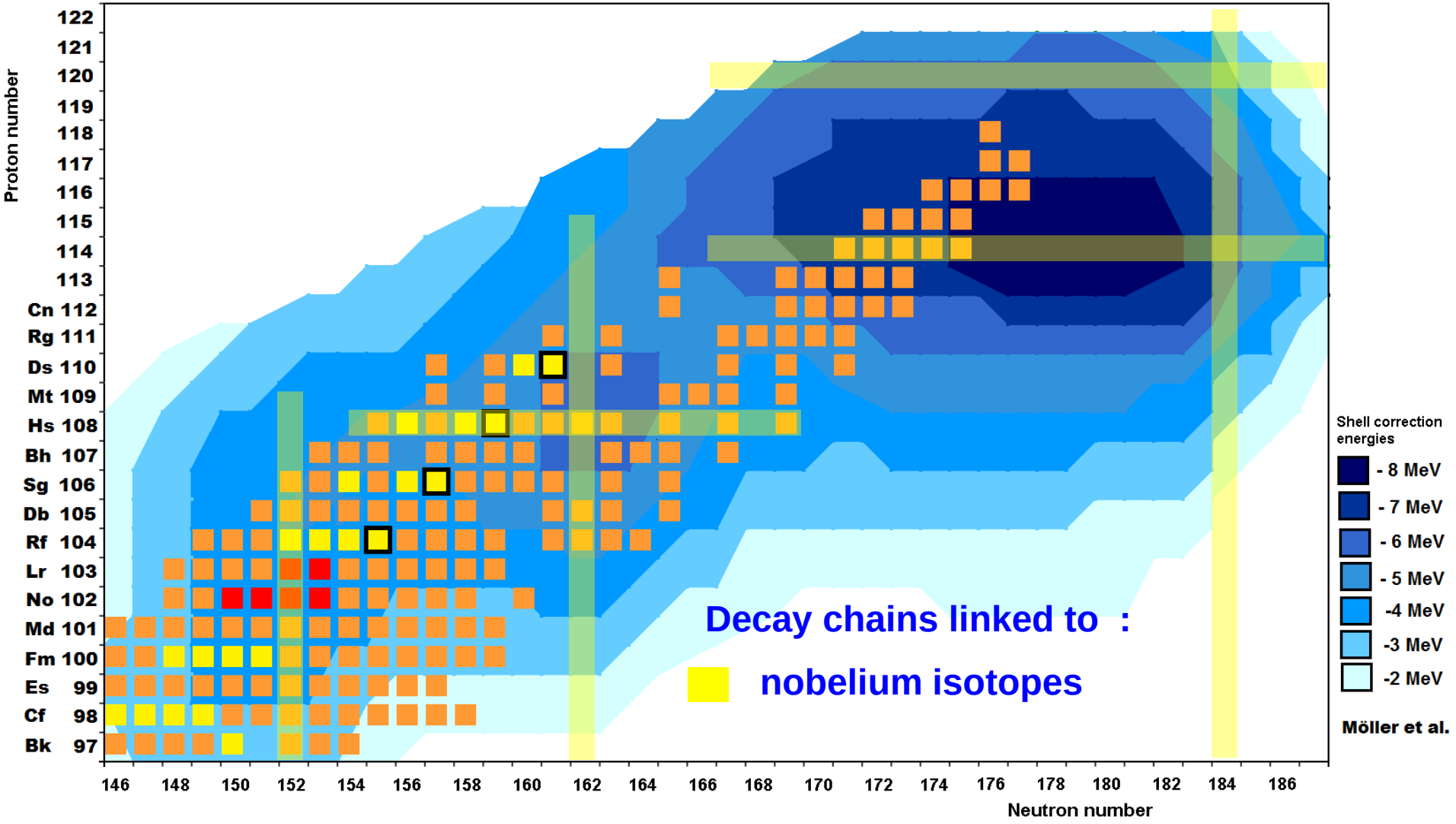

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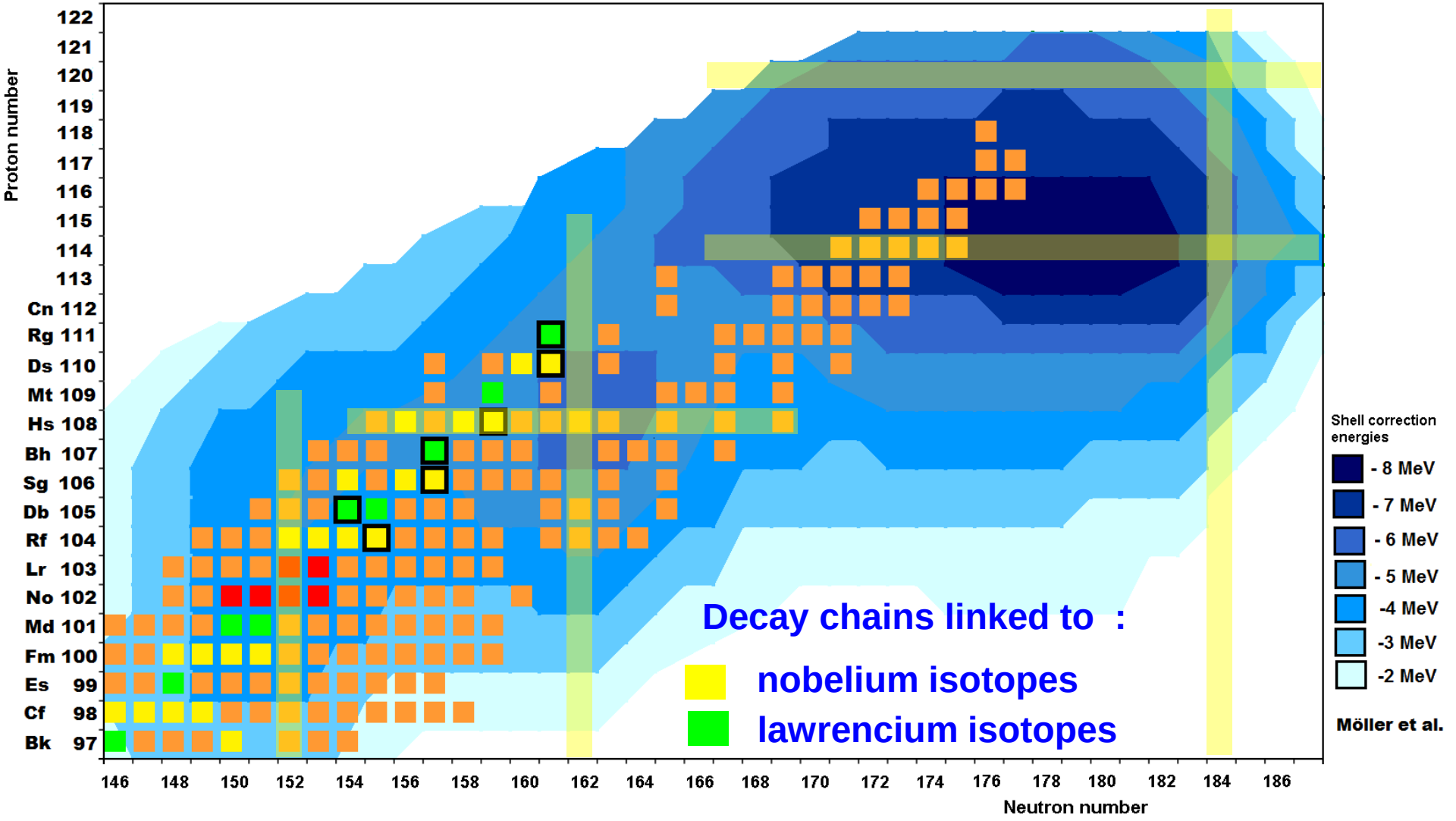

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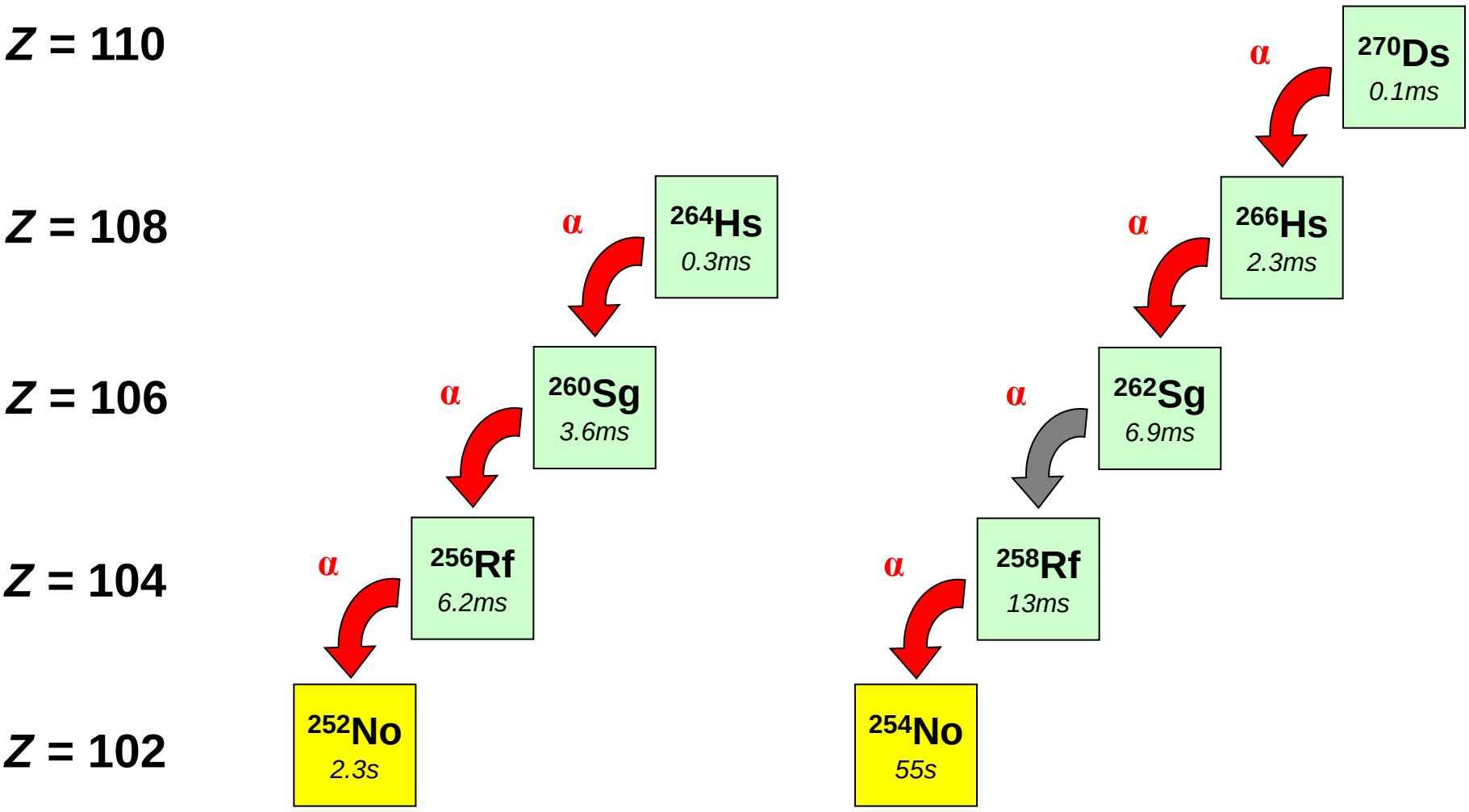
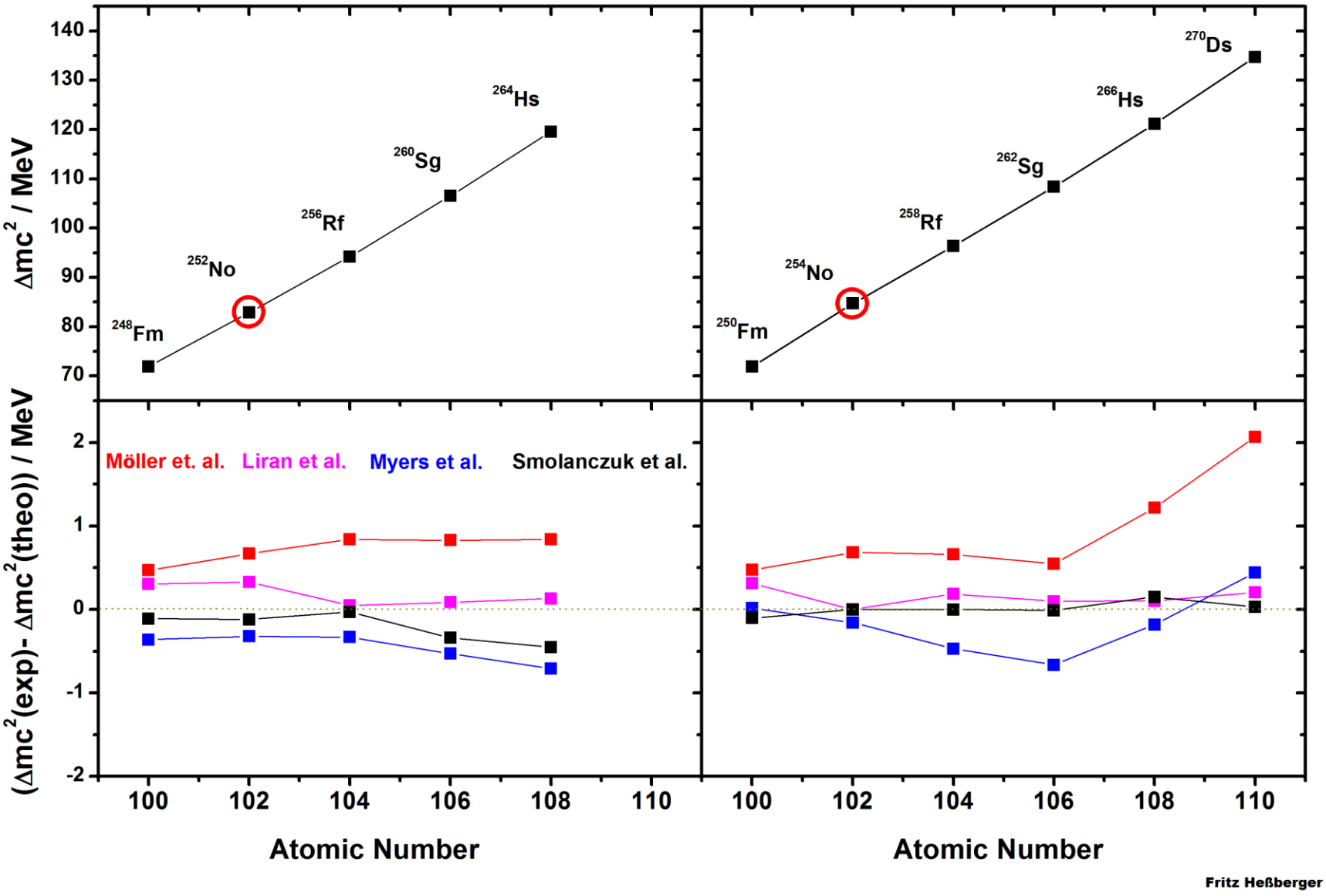


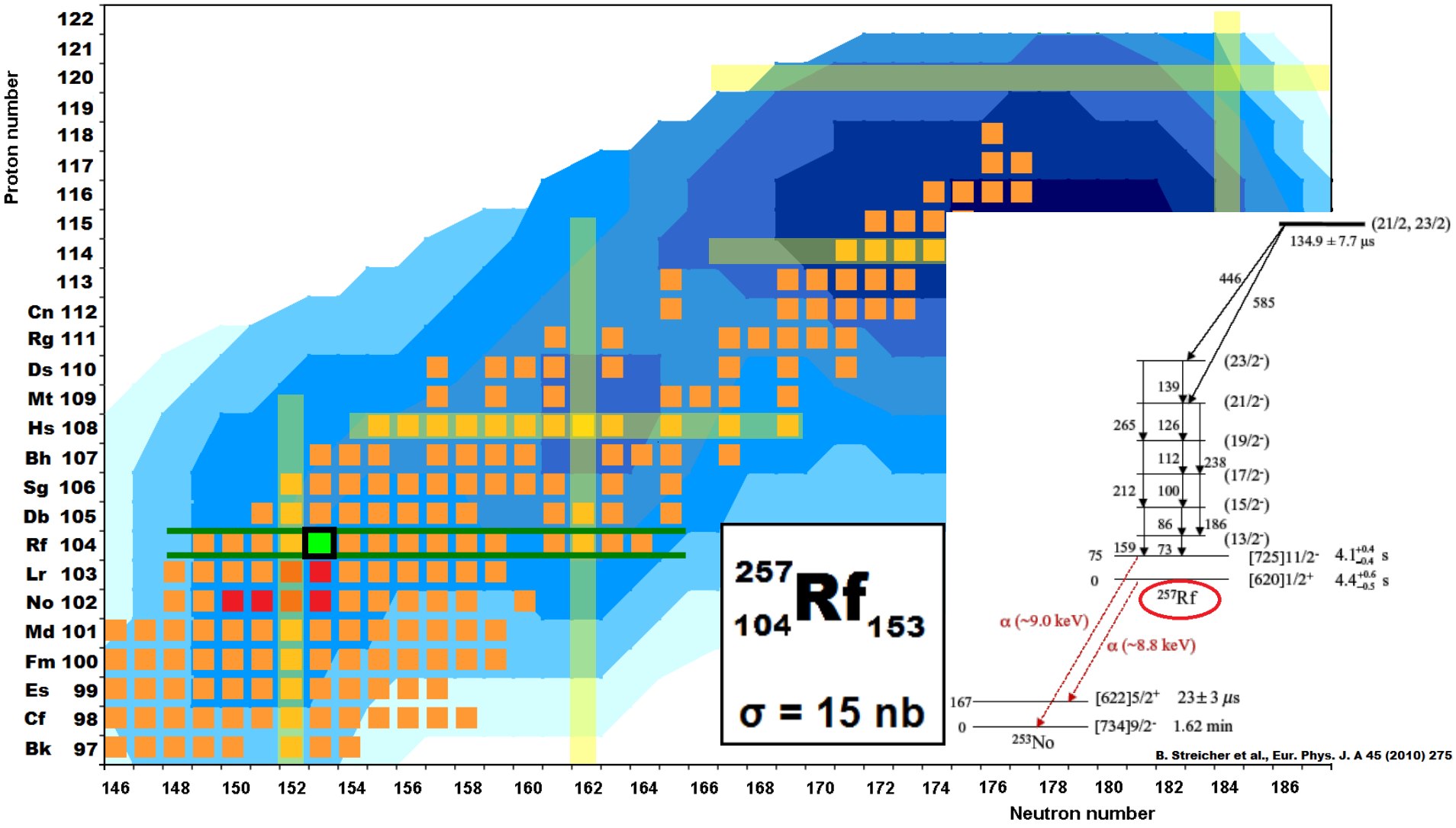
^{270}Ds and Its Decay Products – Decay Properties and Experimental Masses

Dieter Ackermann

Direct mass measurements



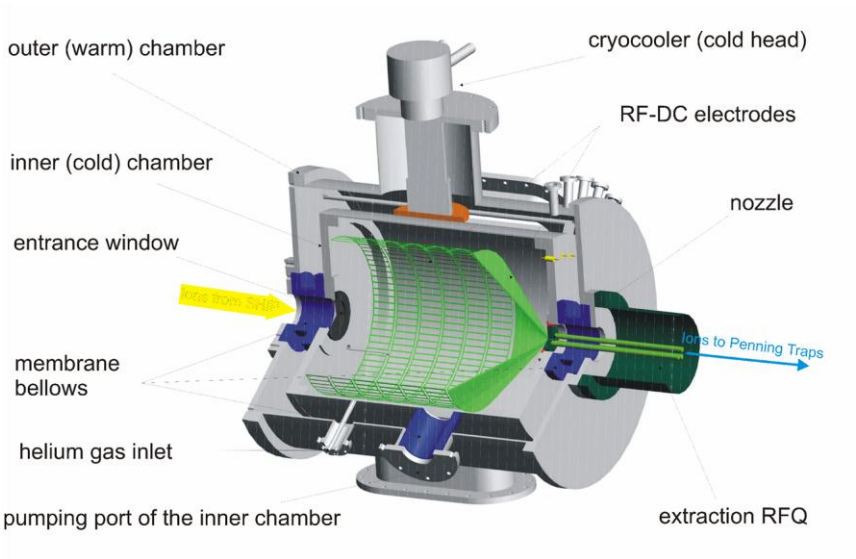
Nearby the superheavy region

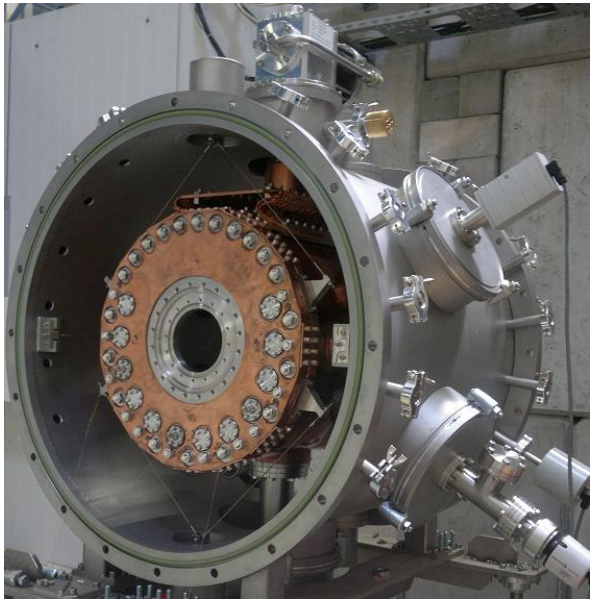


Nearby the superheavy region

→ increase sensitivity and efficiency

- non-destructive detection with single-ion sensitivity (FT-ICR)
- cryogenic gas cell





- **Larger stopping volume**
- **Coaxial injection of reaction products**
- **Higher cleanliness of buffer-gas**
- **Larger gas density at a smaller absolute pressure**

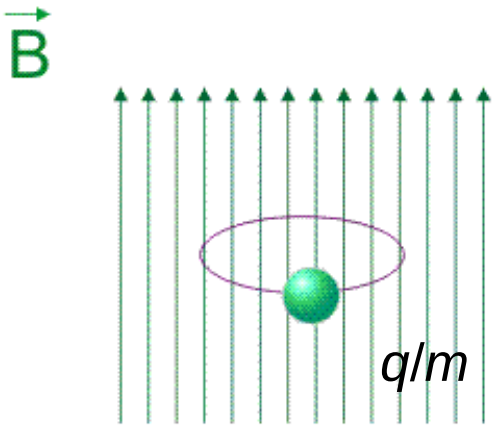
Summary

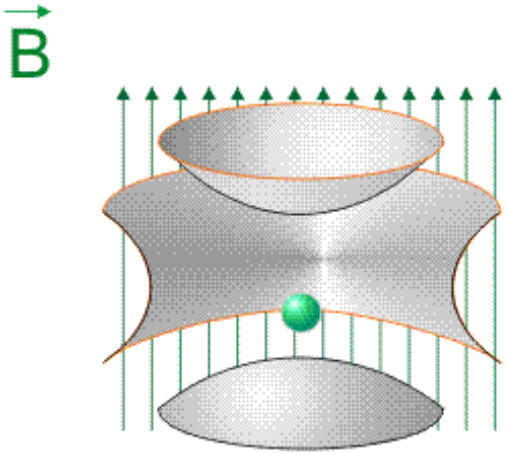
- Direct high-precision mass measurements of nobelium (*Z*=102) and lawrencium (*Z*=103) isotopes
- ^{254}No connected to ^{270}Ds (*Z*= 110) via α-decay chains
- Future developments will pave the way to access the transactinides

Thank you for your attention

Traps

Penning trap (static)





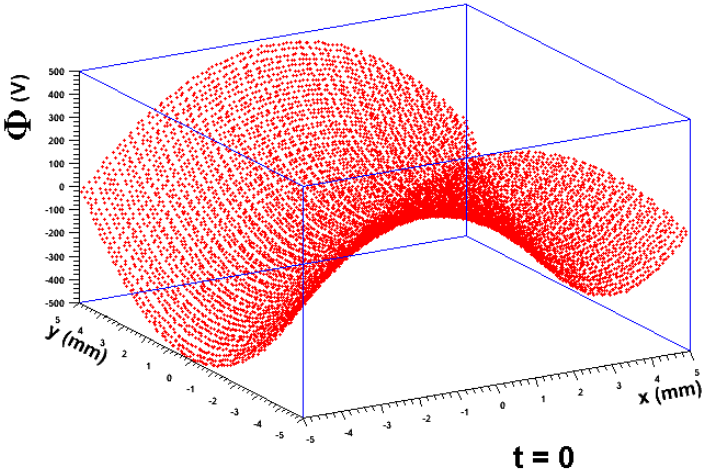
Cyclotron frequency

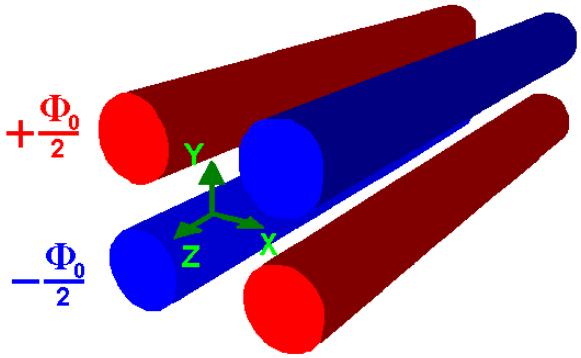
$$f_c = \frac{1}{2\pi} \cdot \frac{q}{m} \cdot B$$

B = 7 T, A = 133, $f_c \approx$ 800 kHz

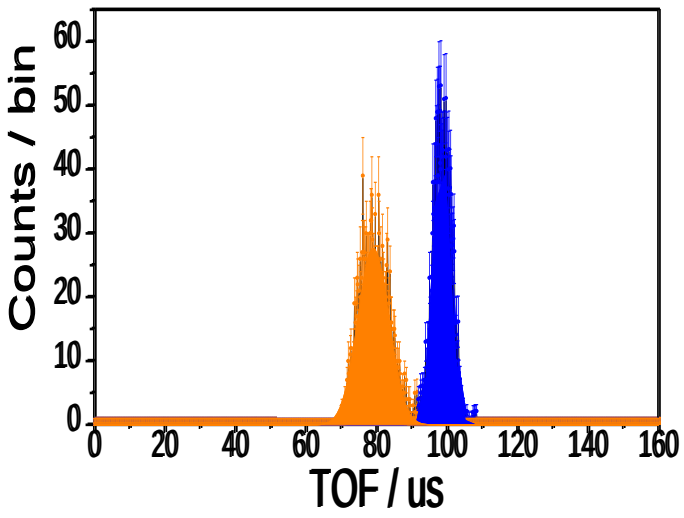
Paul trap (dynamic)

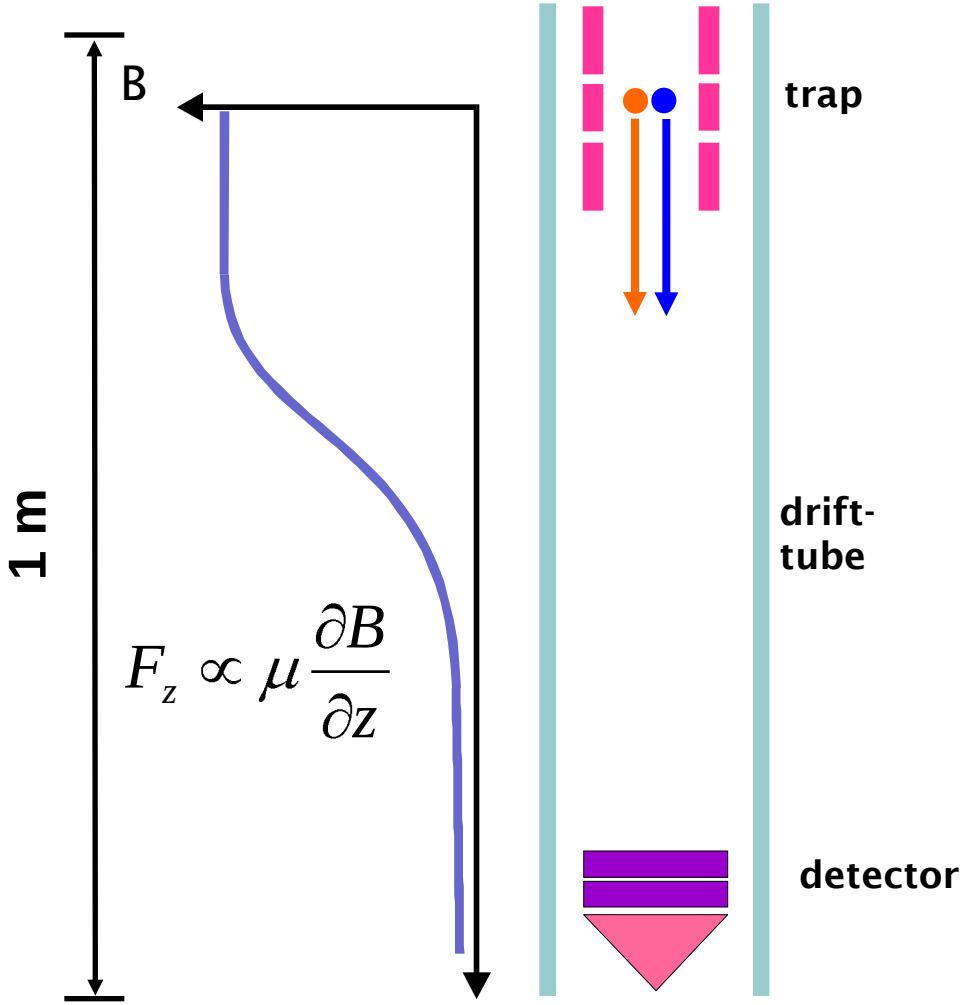
$$\phi_0(t) = V_{DC} - V_{RF} \cos \Omega t$$





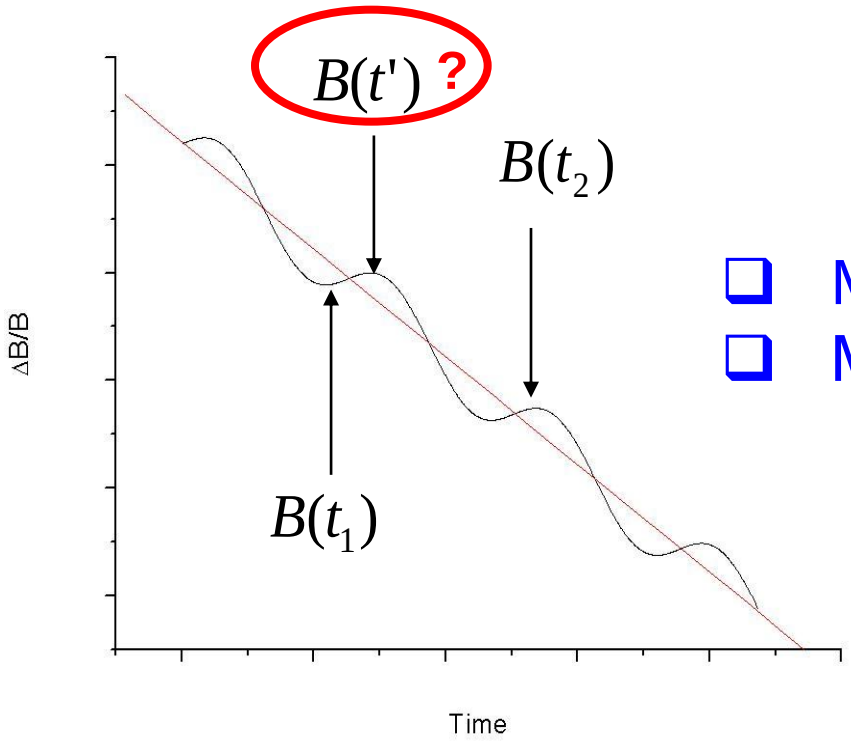
Time-of-flight resonance technique





M. König et al., Int. J. Mass Spec. Ion Process. 142 (1995) 95

How to measure the mass ?



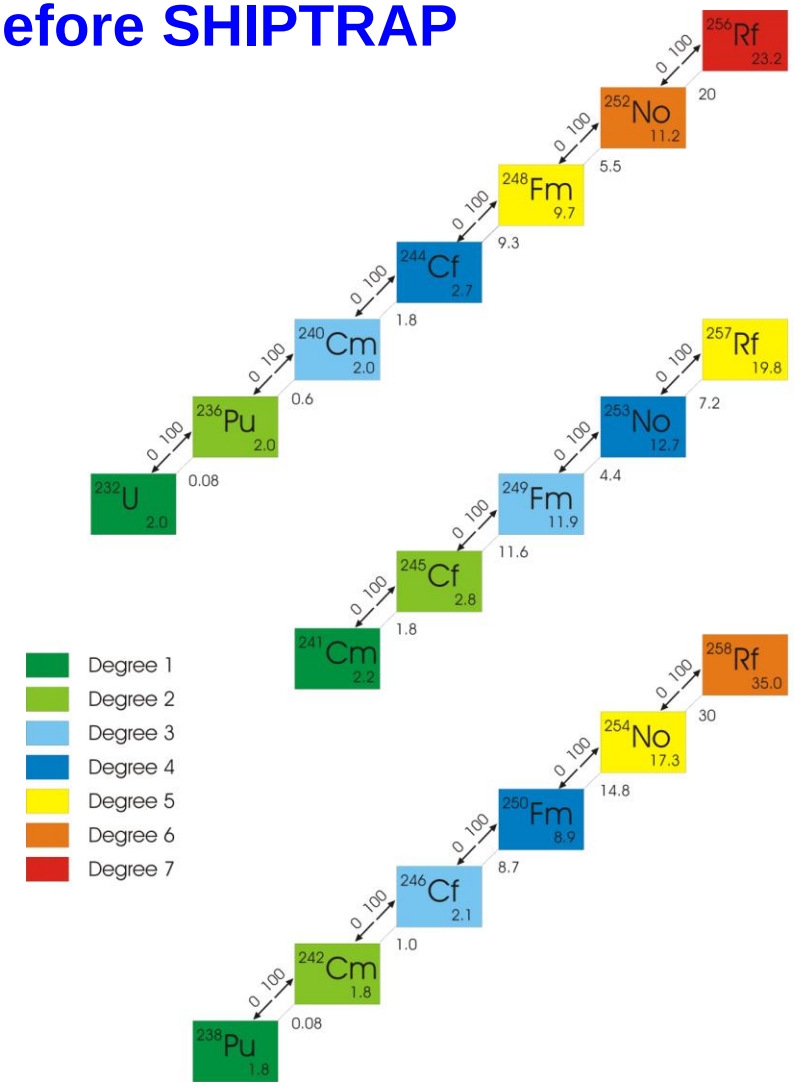
- Magnetic field calibrated at t_1 and t_2
- Measurement at t'

Average linear decay ≈ 1.10^{-8} /h

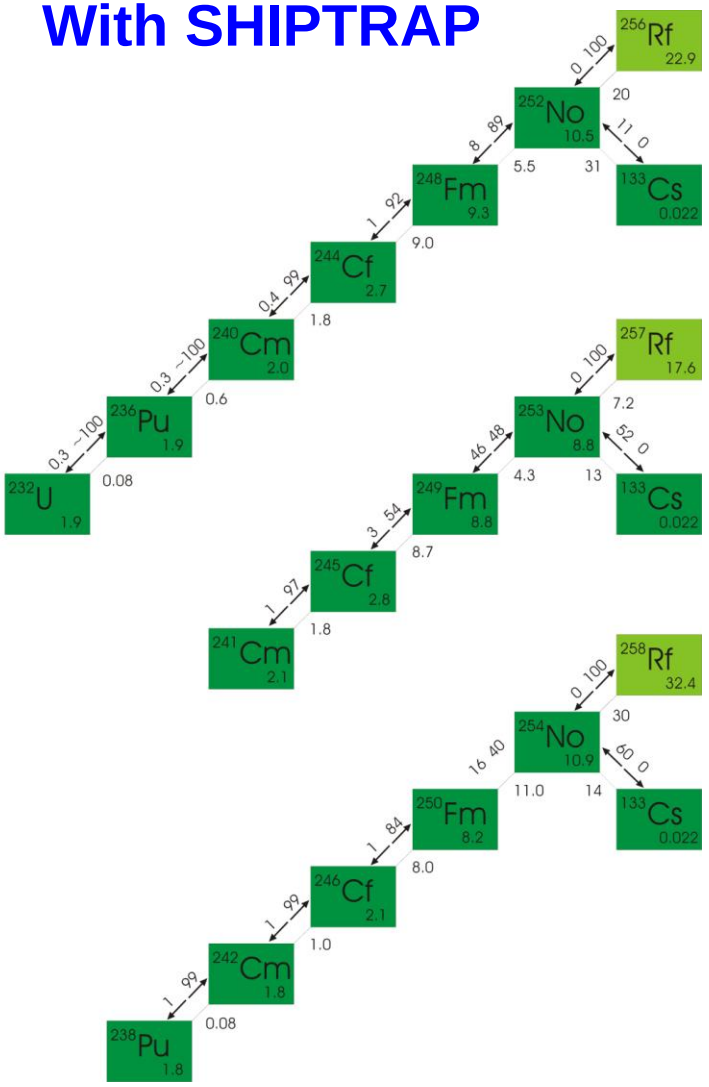
magnetic field fluctuations during time → stabilization of pressure and temperature in magnet

Mass impact

Before SHIPTRAP



With SHIPTRAP



M. Dworschak et al., Phys. Rev. C 81, 064312 (2010)