

PENNING-TRAP MASS MEASUREMENTS OF NEUTRON-RICH COBALT ISOTOPES AT IGISOL

P. Ascher, D. Atanasov, B. Blank, L. Canete, D. D. Dao, Q. Délicnac, T. Eronen, M. Flayol, Z. Ge, M. Gerbaux, S. Grévy, M. Hukkanen, A. Husson, A. Jaries, A. Kankainen, I. D. Moore, M. Mougeot, F. Nowacki, M. Stryjczyk, A. de Roubin, J. Ruotsalainen, V. Virtanen

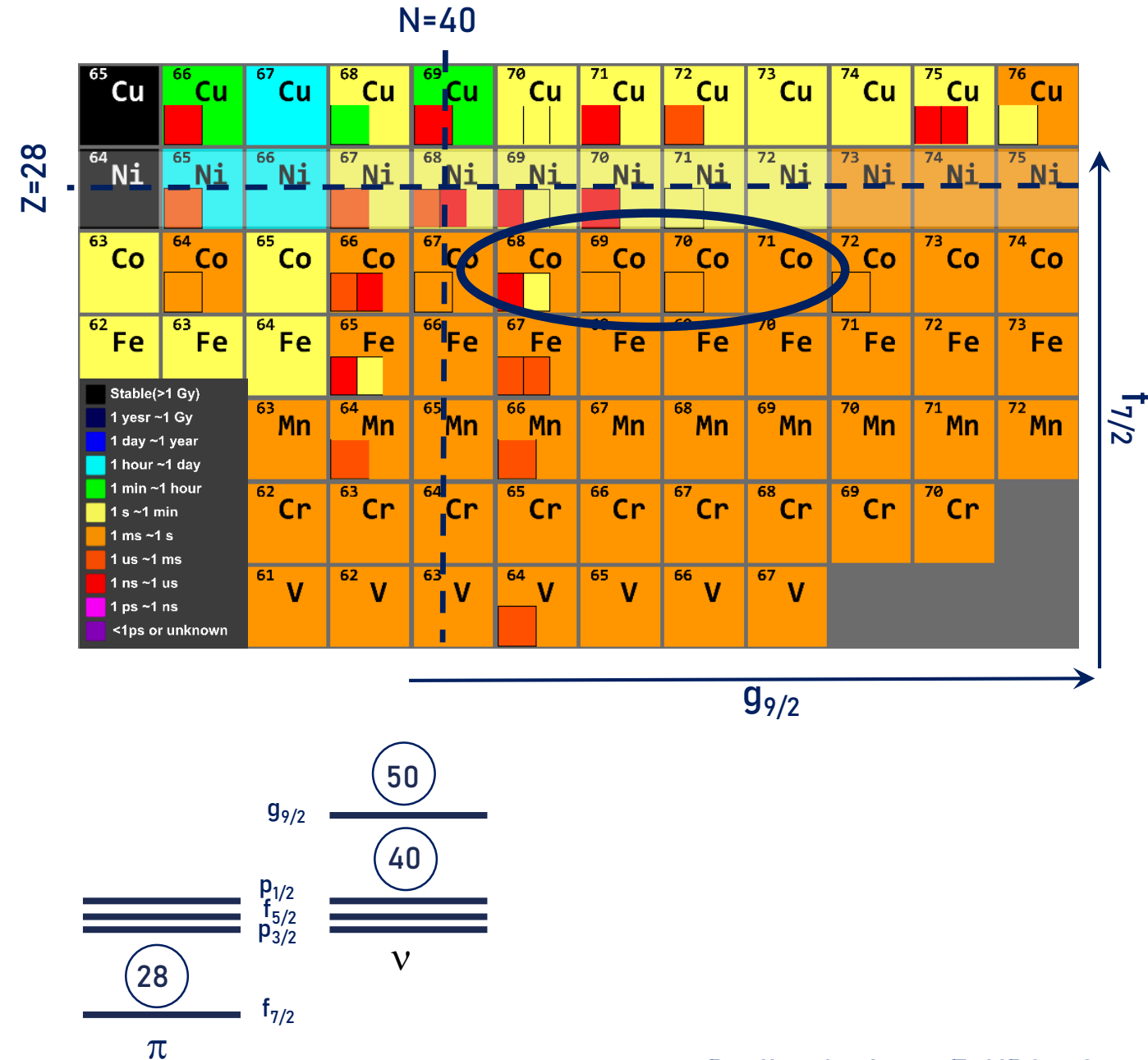


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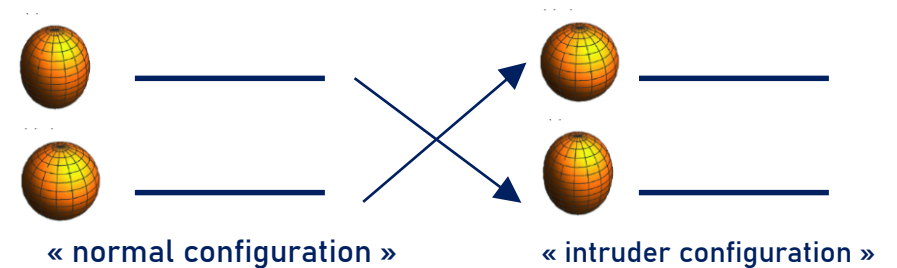


Pauline Ascher – EuNPC – September 22-26, 2025

N=40 REGION



- Collective behavior rapidly develops as protons are removed from f_{7/2} orbital (Sudden drop of E(2⁺) between ⁶⁸Ni and ⁶⁶Fe)
 - Adding neutrons on g_{9/2} weakens the Z=28 gap
 - Possibilities of ph excitations across both N=40 and Z=28
- Island of Inversion: region where intruder (deformed) configuration becomes the ground state



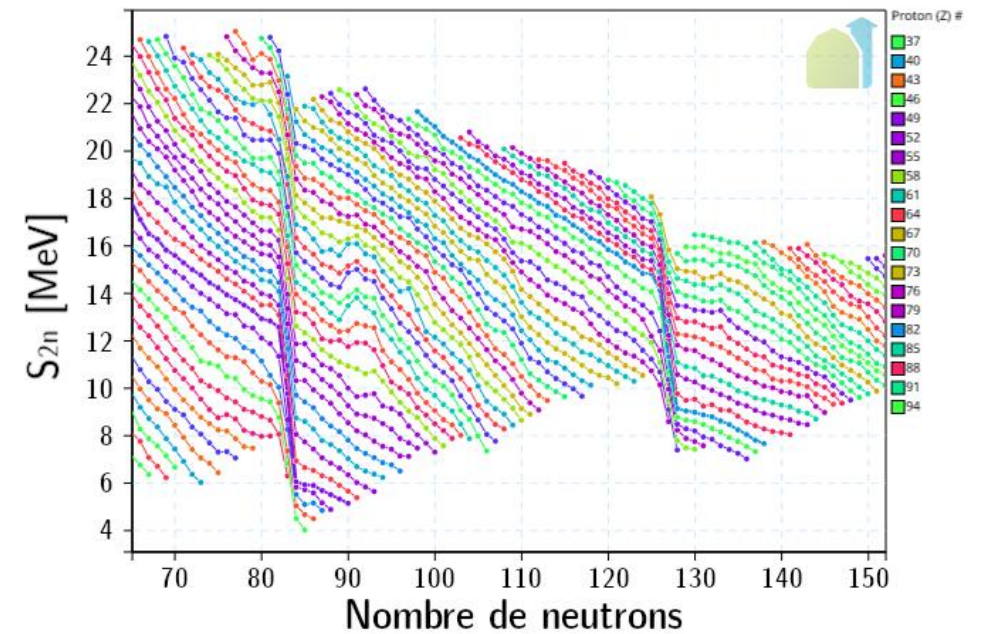
MASS SPECTROMETRY



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

Ground state masses but also excitation energy
of beta-decaying long-lived isomers (>50 ms)

$$S_{2n}(Z, N) = BE(Z, N) - BE(Z, N - 2)$$



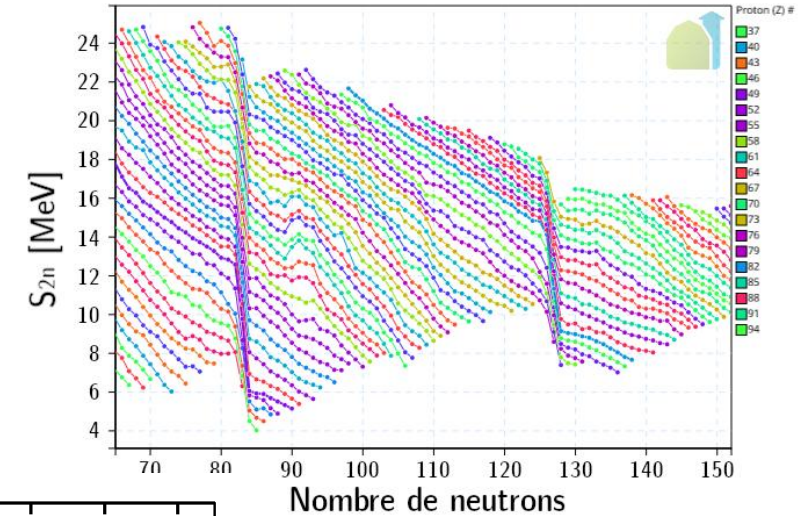
MASS SPECTROMETRY



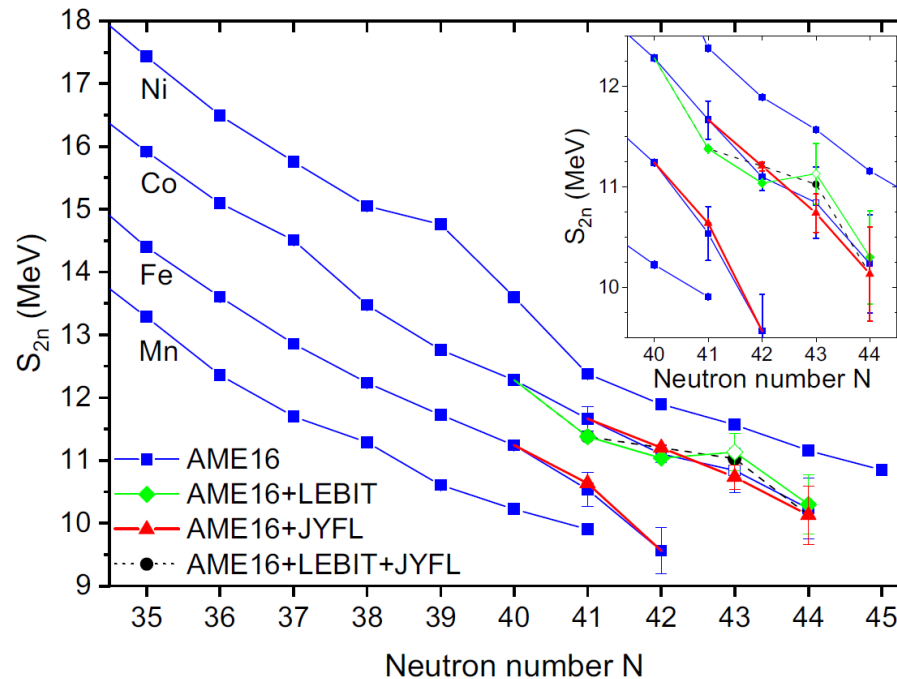
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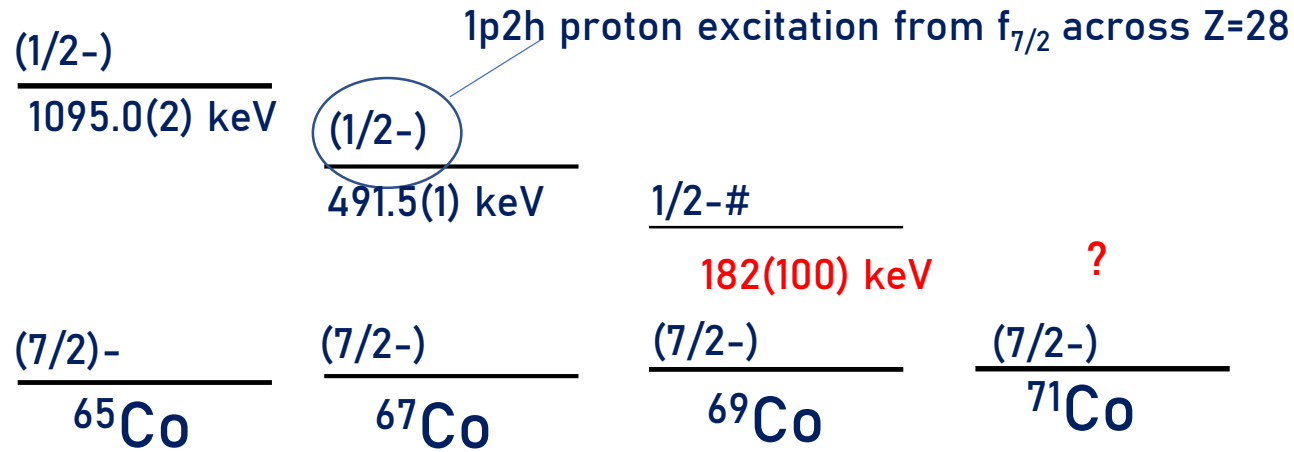
- Previous PT measurements
 - 2018 LEBIT $\rightarrow {}^{68,69}\text{Co}$
Izzo et al., PRC 97 014309 (2018)
 - 2020 JYFL $\rightarrow {}^{69,69m}, {}^{70}\text{Co}$
Canete et al., PRC 101 041304 (2020)
- Lead to different trends
- Isomer in ${}^{68,70}\text{Co}$ measured ?



L. Canete et al, PRC 101, 041304(R) (2020)

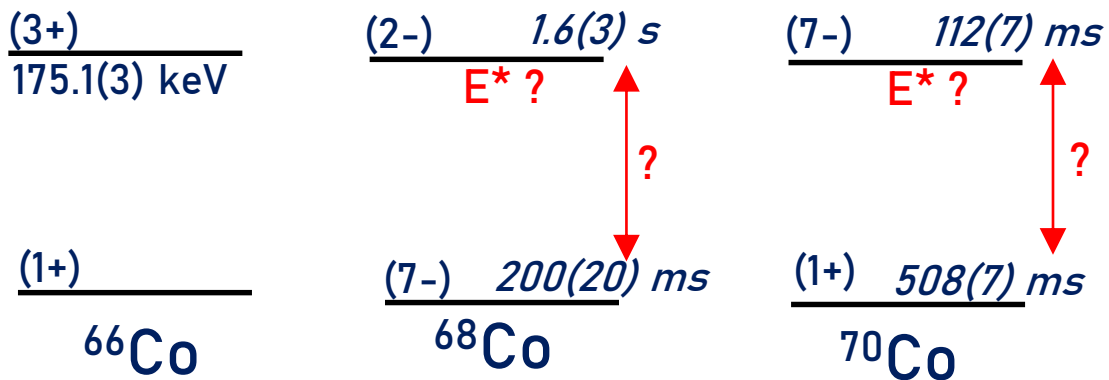
STATE OF THE ART

Odd – even Co: position of the $\frac{1}{2}-$?

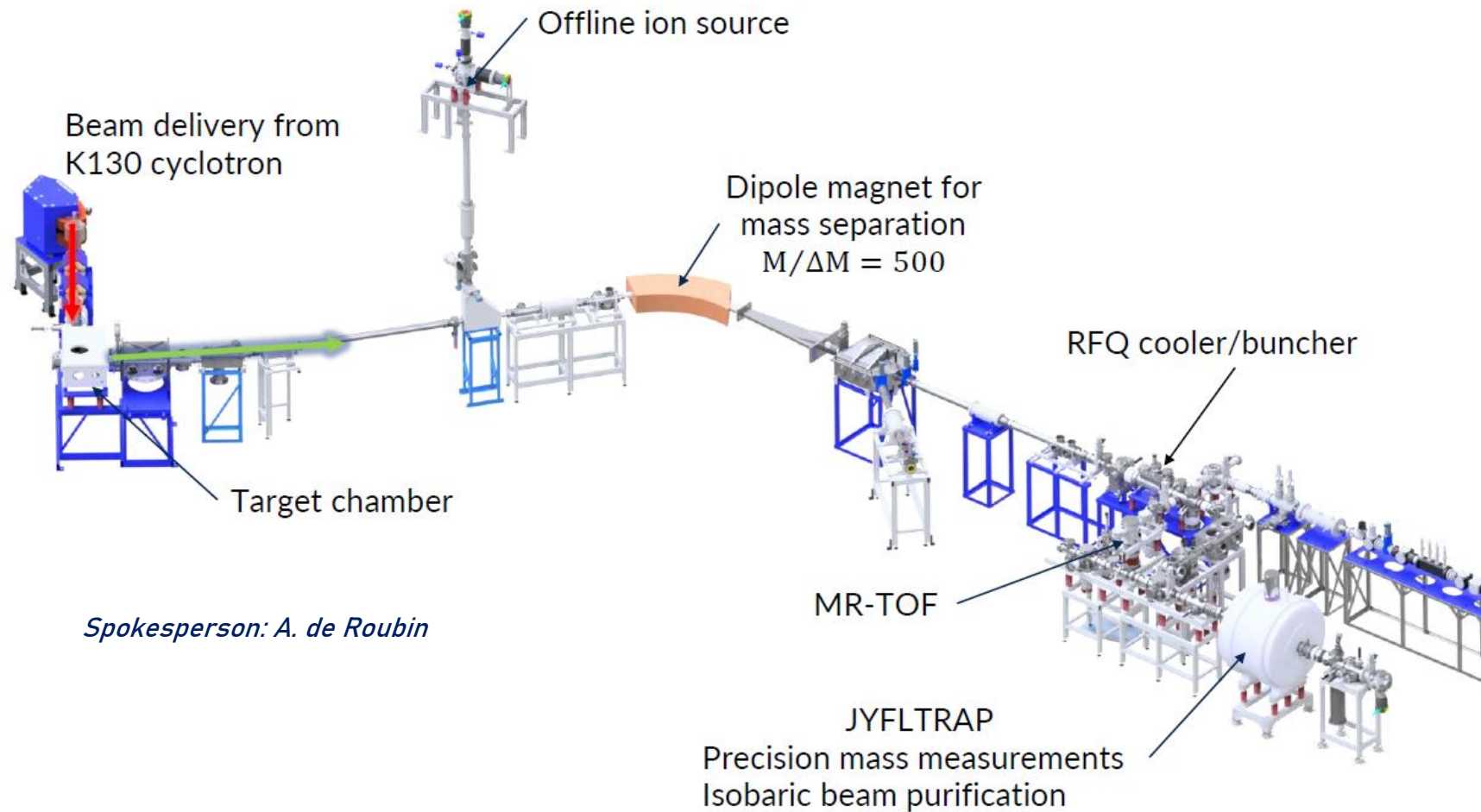


- Excitation energy in ^{69}Co not precise
- Intruder state in ^{71}Co ? and mass precision 500 keV
- Ordering of states in ^{68}Co and ^{70}Co unknown
- Excitation energy of isomers unknown for ^{68}Co and ^{70}Co
- Gs masses of $^{68,70}\text{Co}$ known ?

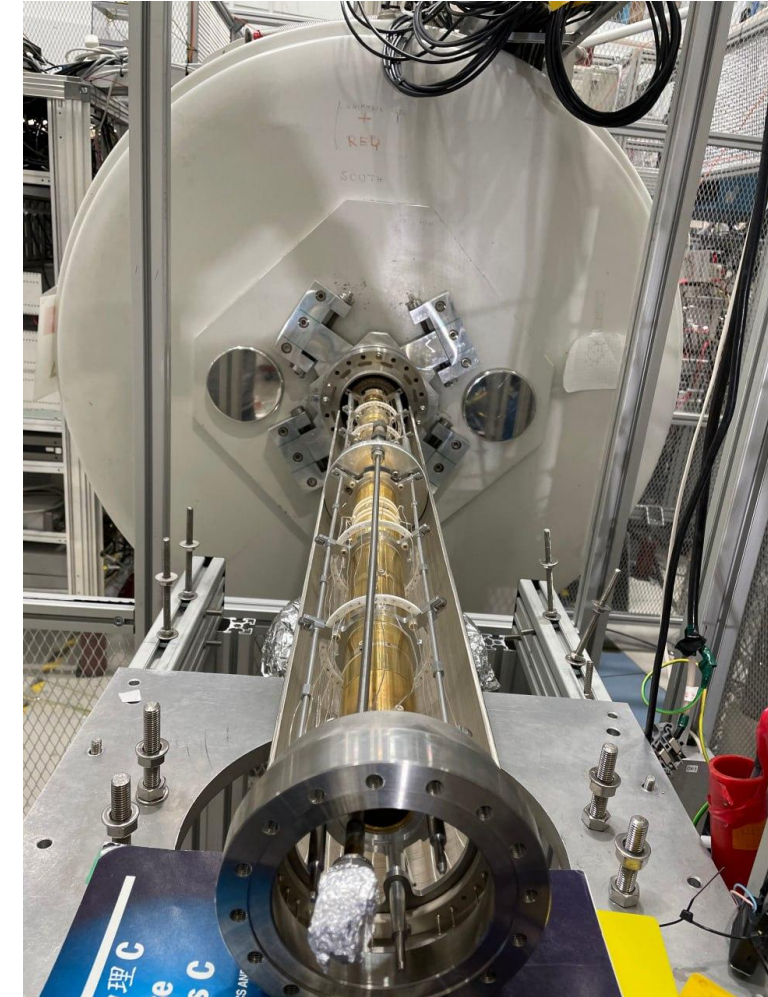
Odd – odd Co



IGISOL facility – JYFL Accelerator Laboratory



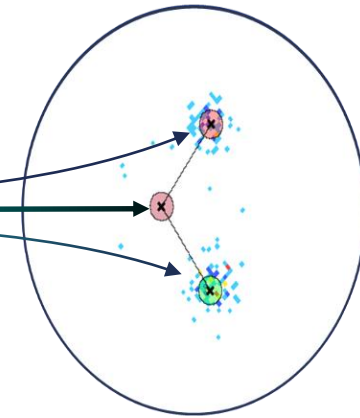
JYFLTRAP



JYFLTRAP DOUBLE PENNING TRAP

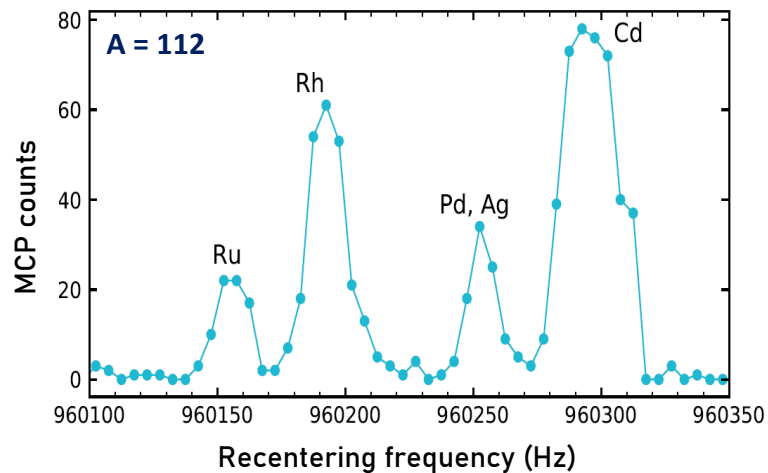
PURIFICATION TRAP

MEASUREMENT TRAP



Position-sensitive
MCP

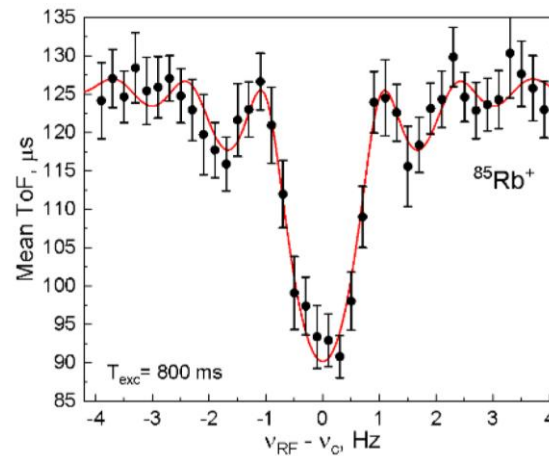
Mass-selective buffer-gas cooling



M. Hukkanen et al., PhD Thesis 2023

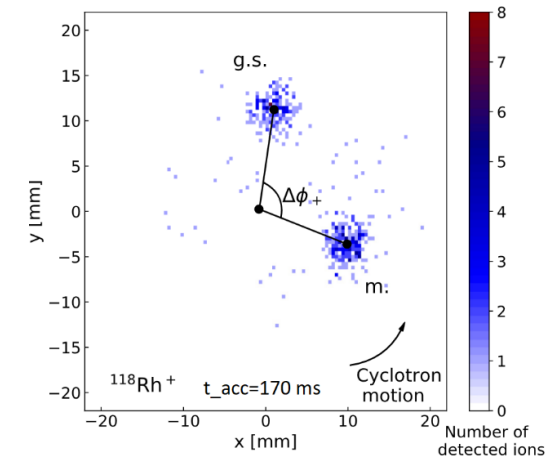
ToF-ICR

(Time-of-Flight Ion-Cyclotron-Resonance)



PI-ICR

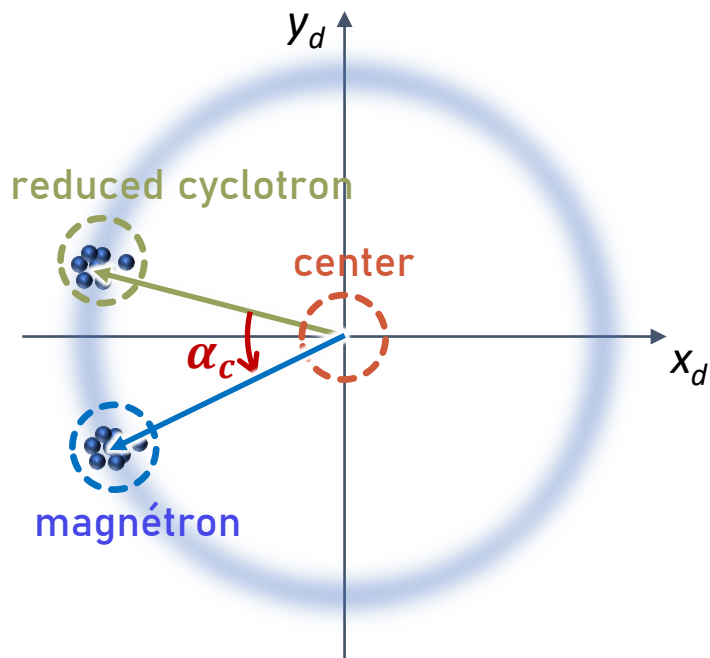
(Phase-Imaging Ion-Cyclotron-Resonance)



M. Hukkanen et al., PRC 107, 014306

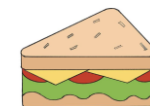
$$v_c = \frac{qB}{2\pi m}$$

PI-ICR MASS MEASUREMENT



$$v_c = \frac{\alpha_c + 2\pi n}{2\pi t_{acc}} = \frac{qB}{2\pi m} \leftarrow \frac{\delta B}{B\delta t} = 2,01(25) \cdot 10^{-12} \text{min}^{-1}$$

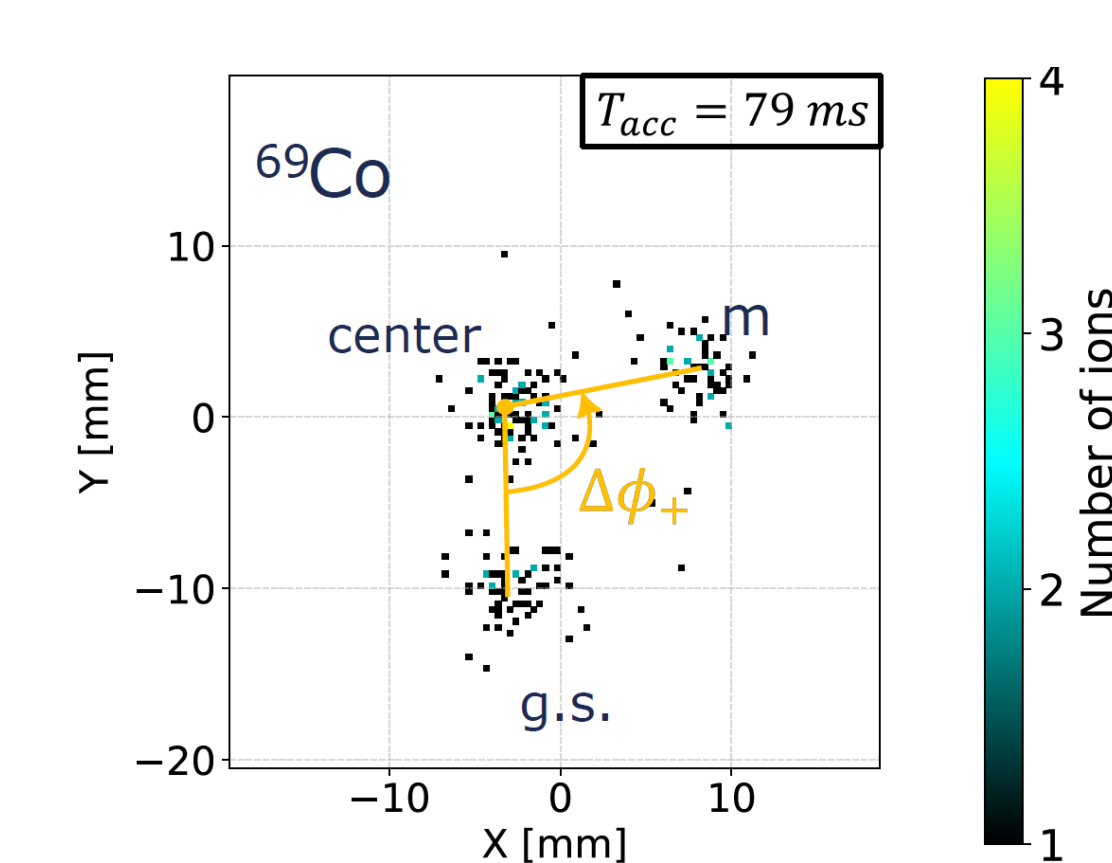
$$m_{ioi} = \frac{v_c(ref)}{v_c(ioi)} (m_{ref} - m_e) + m_e$$



$$\delta\nu_c = \frac{\delta\alpha_c}{2\pi t_{acc}} = \frac{\Delta r}{\pi r t_{acc} \sqrt{N}}$$

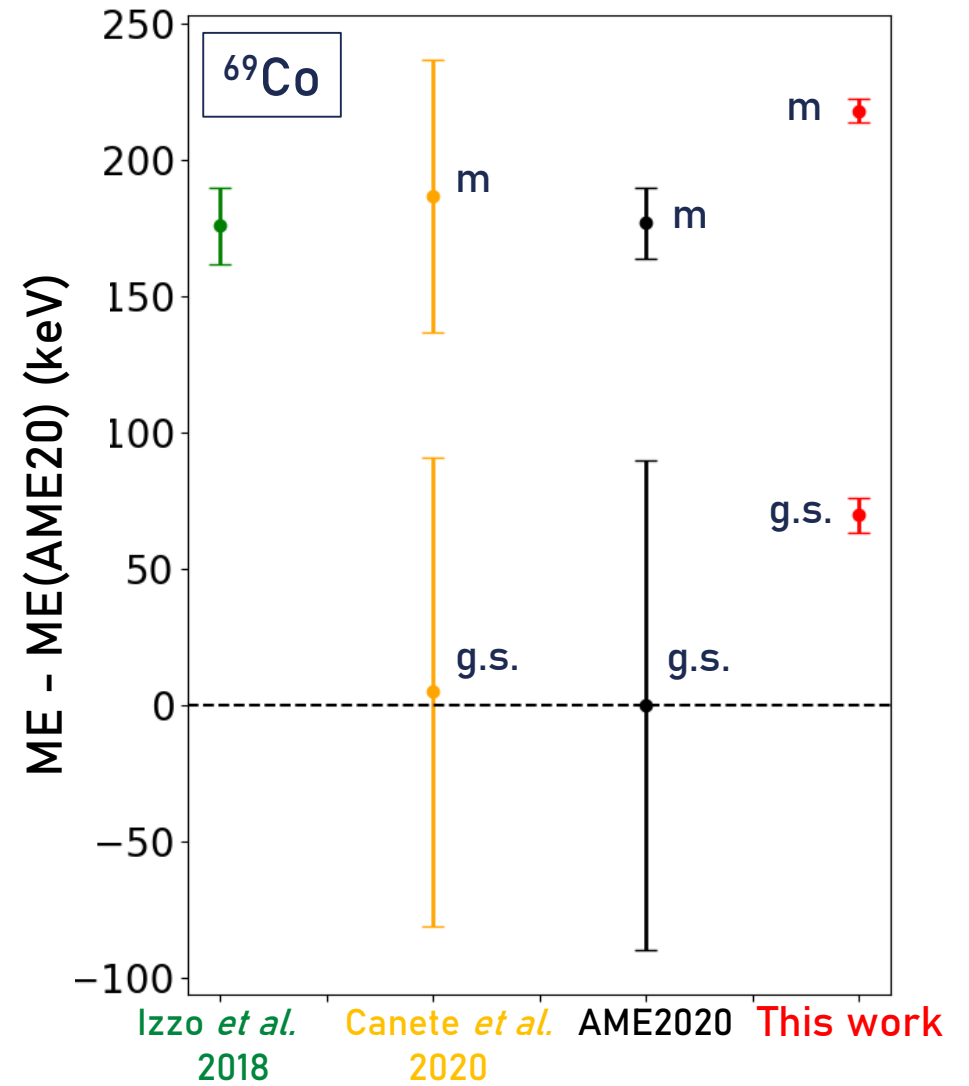
Precision for the Co cases $\rightarrow \frac{\delta m}{m} \sim \text{few } 10^{-8}$

^{69}Co MASS EXCESS

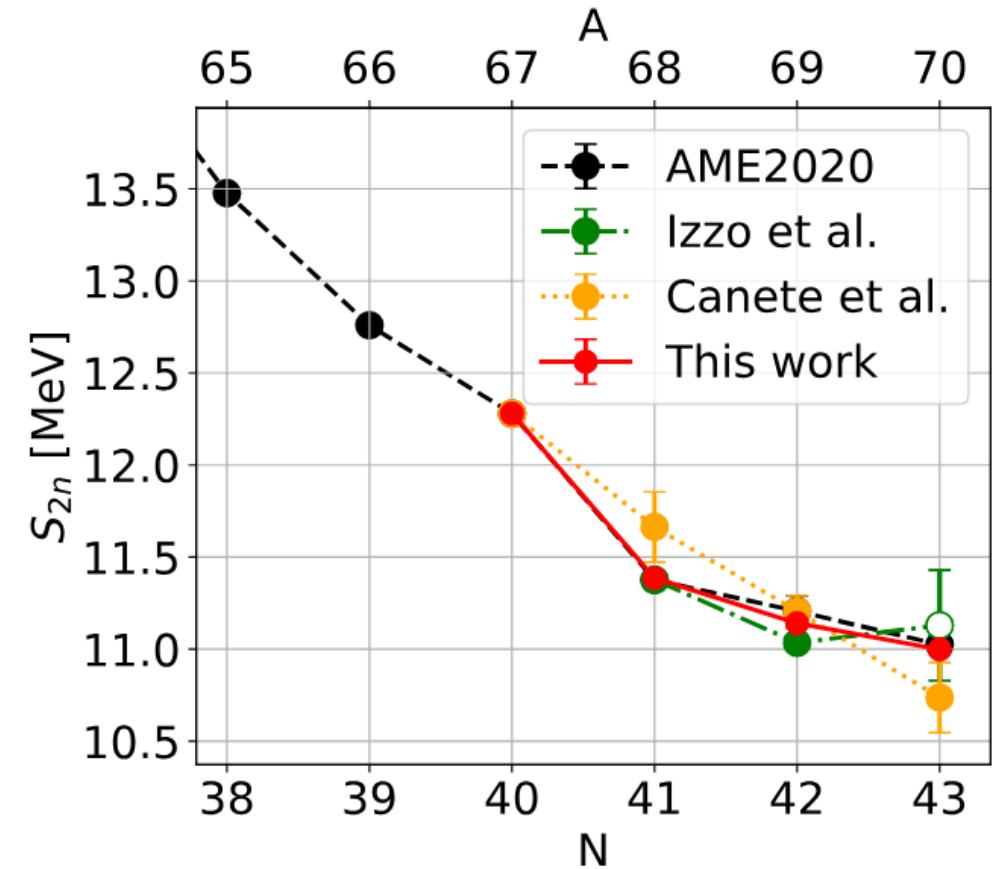
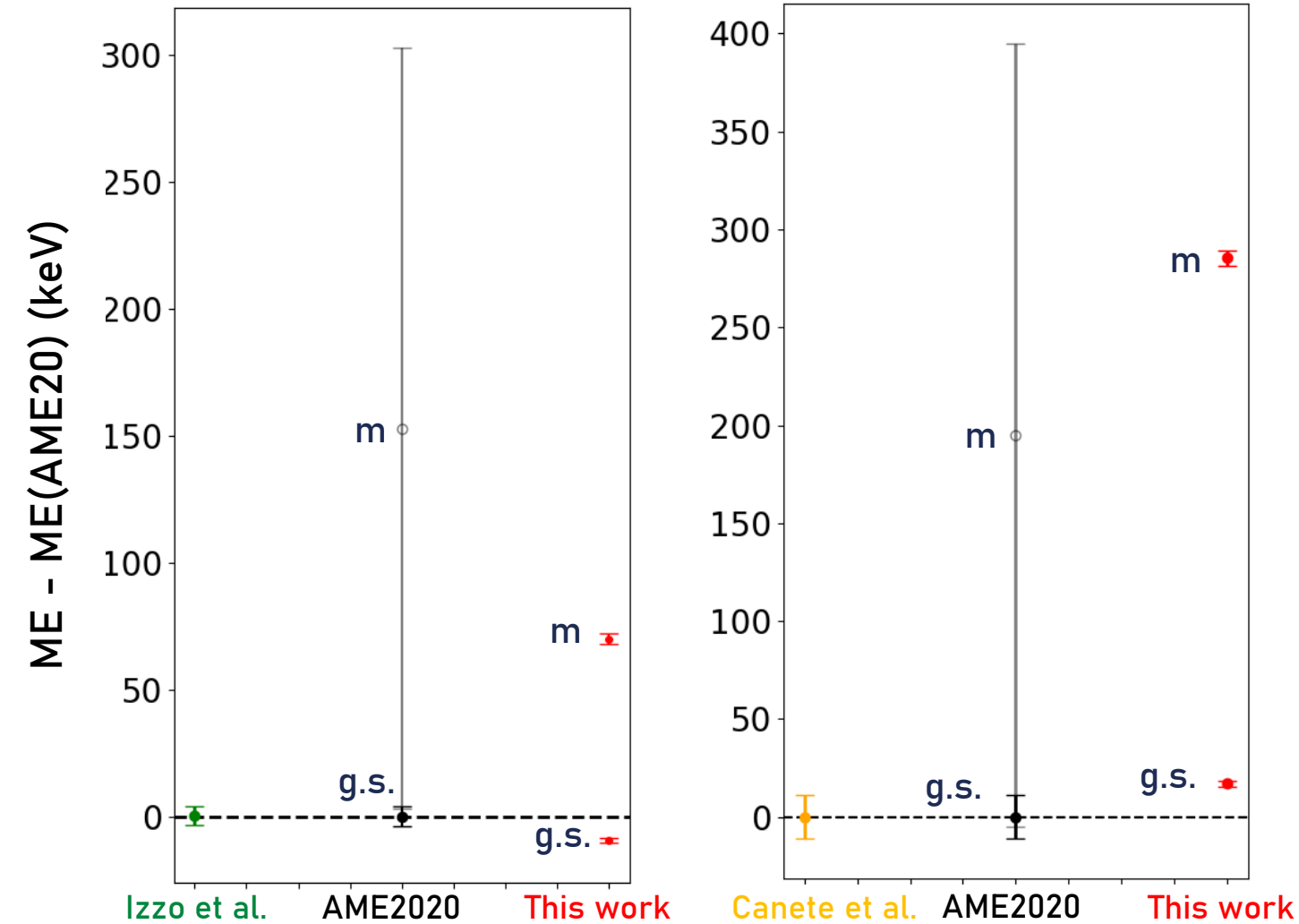


$E^* = 148.3(76) \text{ keV}$

Precision on E^* improved by a factor >10



^{68}Co AND ^{70}Co MASS EXCESSES



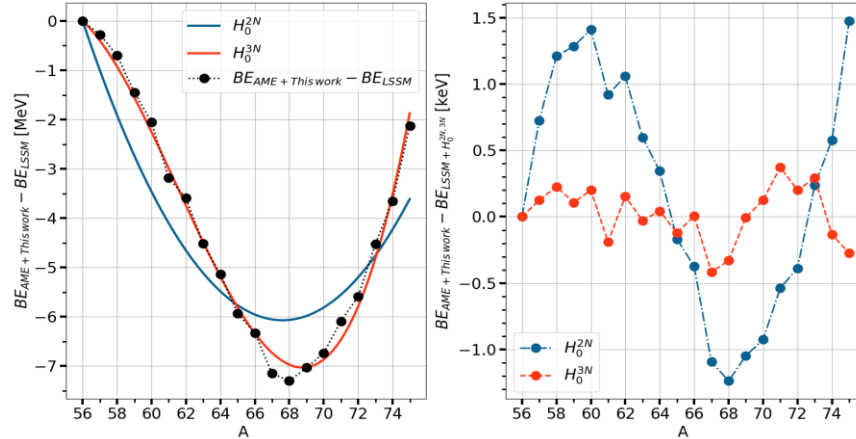
→ CLARIFIED SCENARIO !

LNPS Interaction, PRC 82 054301 (2010)

Phenomenological correction on master term of Duflo/Zucker mass formula Duflo, Zucker, PRC 52, R23 (1995)

→ Using only a 2-body term H_0^{2N} or a 3-body term H_0^{3N}

$$H_0^{2N,3N} = n\epsilon_0 + \frac{n(n-1)}{2}W_0 + \frac{n(n-1)(n-2)}{6}W_d$$



→ Final rms of 170 keV with 3-body term

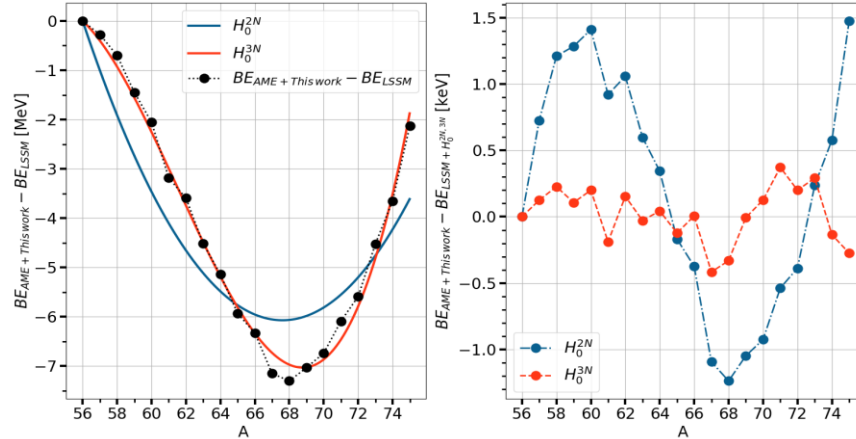
→ Final rms of 513 keV with only 2-body term

LNPS Interaction, PRC 82 054301 (2010)

Phenomenological correction on master term of Duflo/Zucker mass formula Duflo, Zucker, PRC 52, R23 (1995)

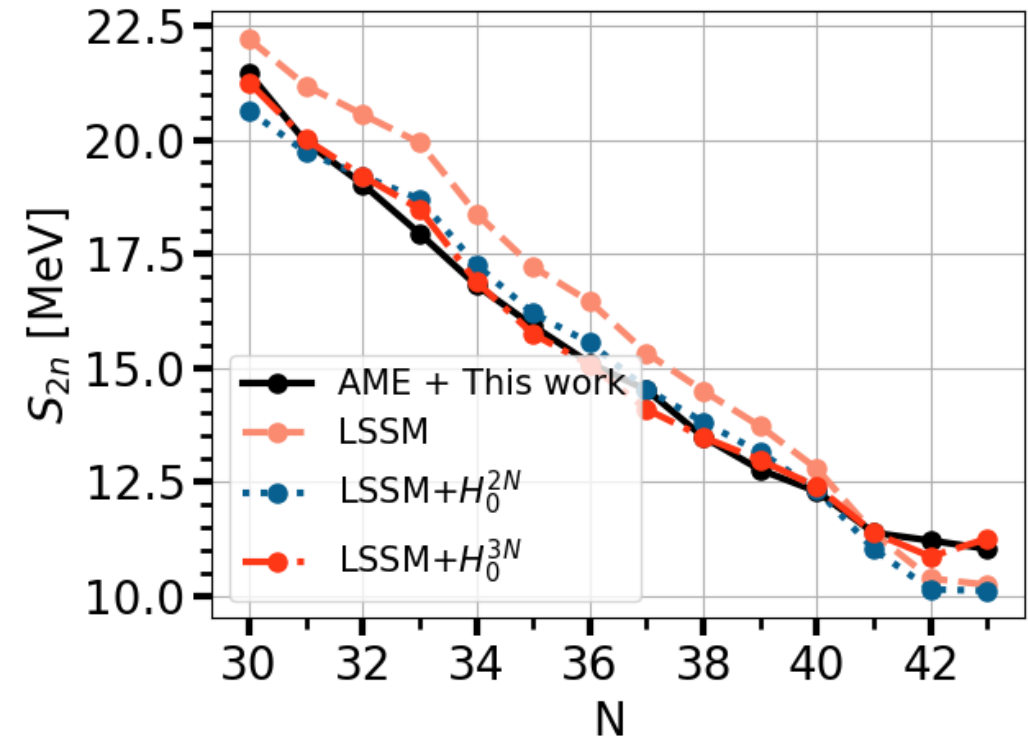
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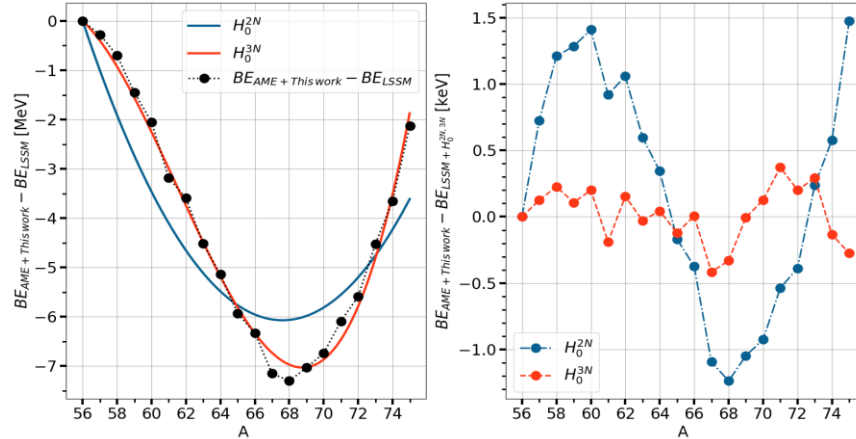


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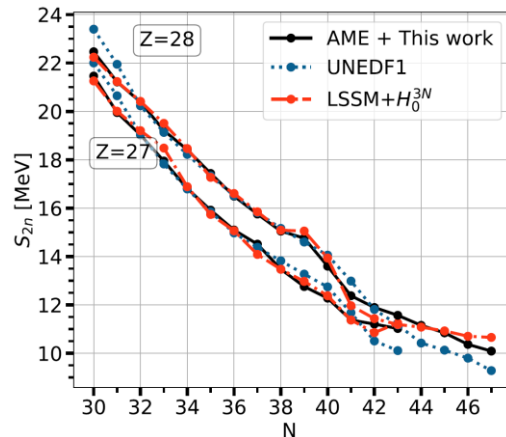
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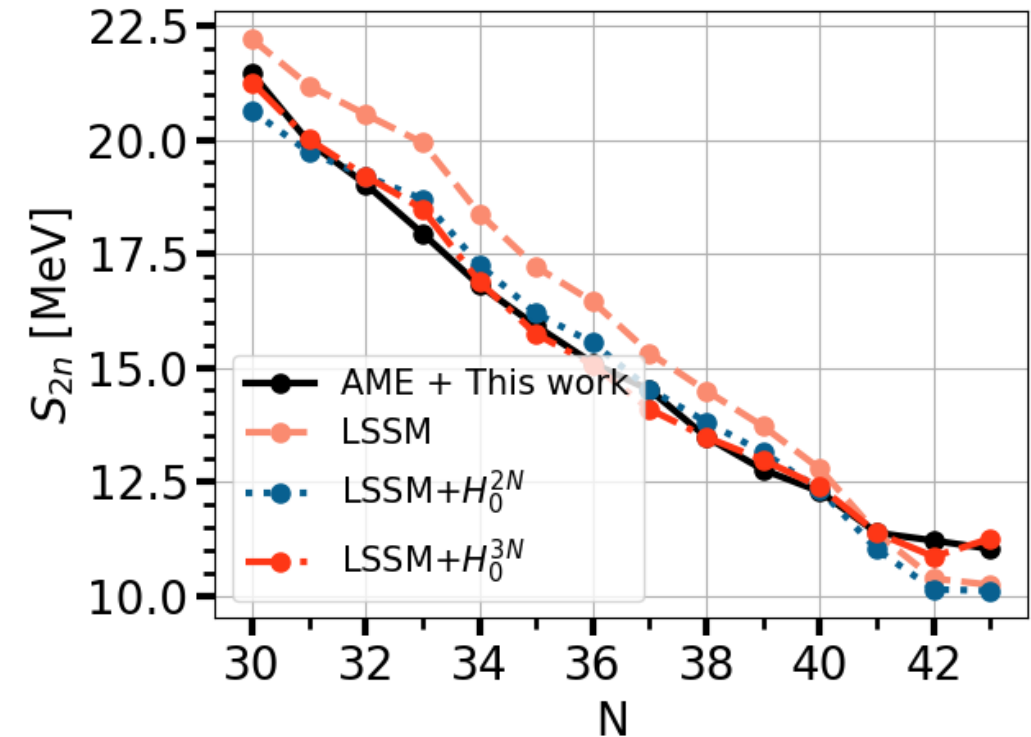


Nickel isotopes

→ Final rms of 207 keV with 3-body term

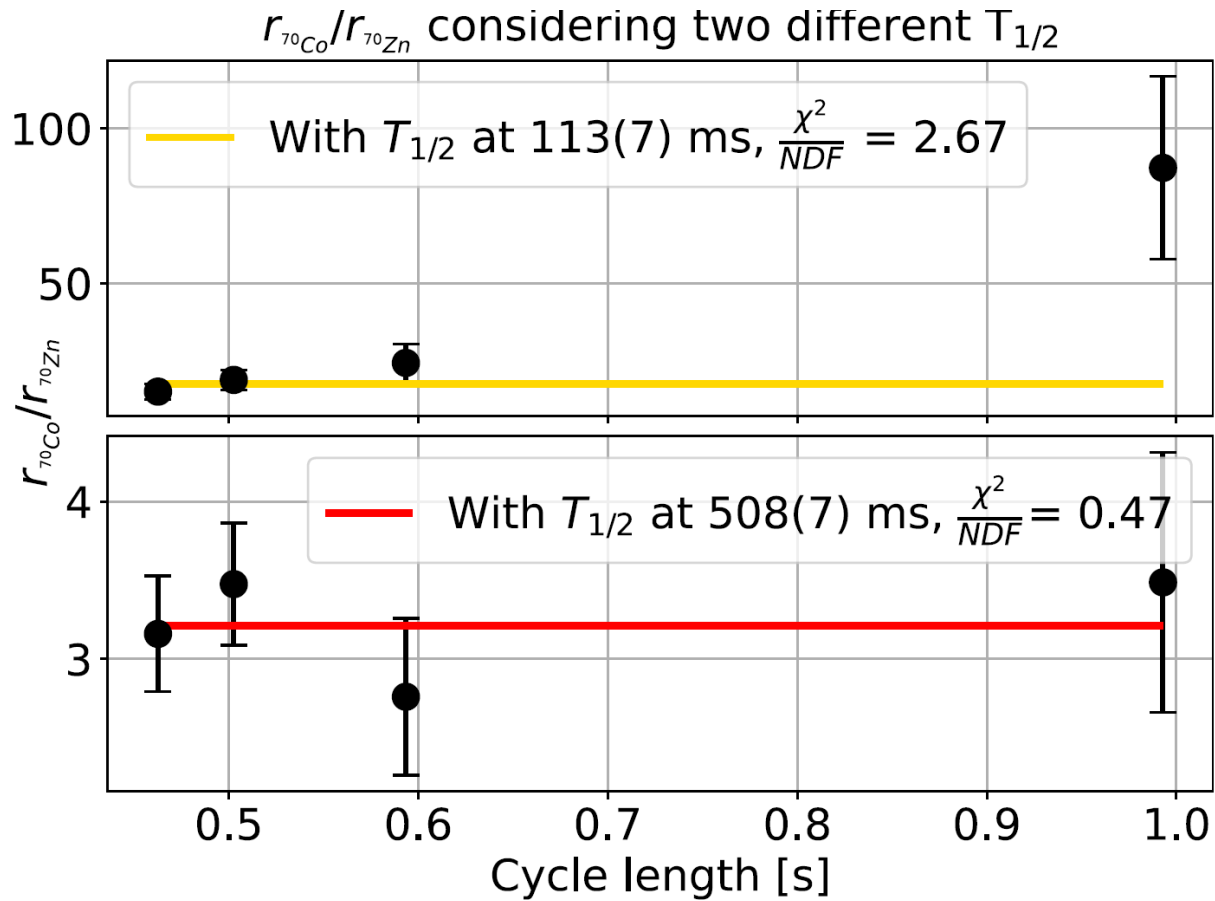
→ Final rms of 893keV with only 2-body term

Work in progress



^{68}Co AND ^{70}Co STATE ASSIGNMENT

PI-ICR allows individual state counting !



(7-) 113(7) ms
 $E^* = 268.4(50) \text{ keV}$

(1+) 508(7) ms
 ^{70}Co

→ long-lived low-spin state corresponds to the ground state

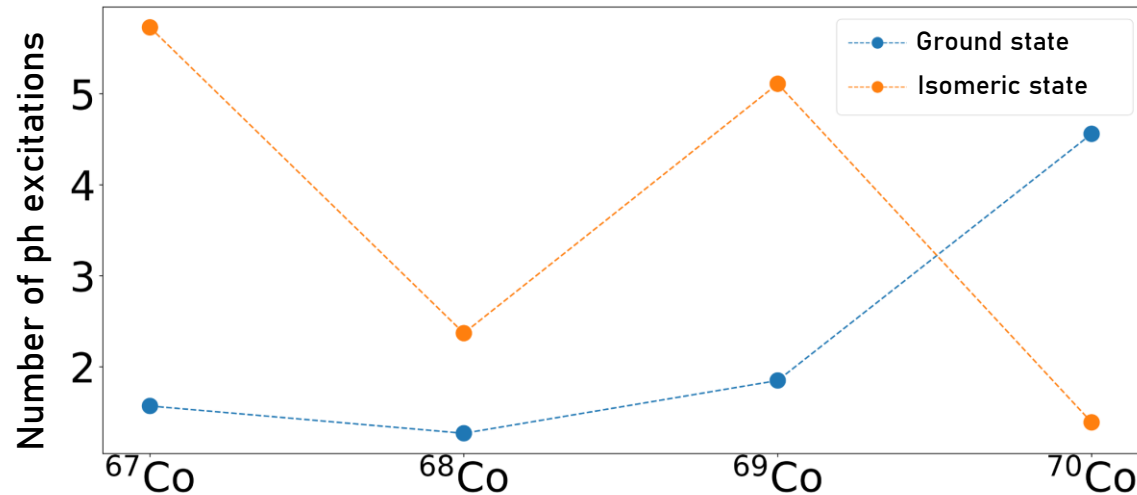
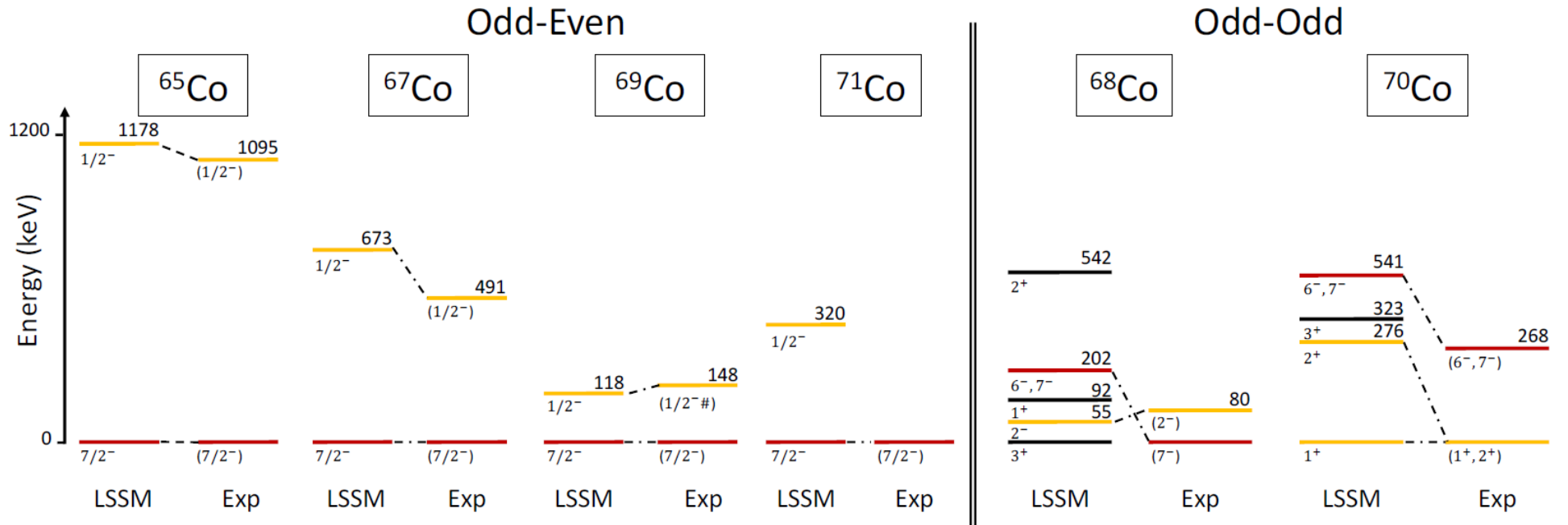
(2-) 1.6(3) s
 $E^* = 79.5(2) \text{ keV}$

(7-) 200(20) ms
 ^{68}Co

→ short-lived high-spin state corresponds to the ground state

COMPARISON WITH LSSM CALCULATIONS

F. Nowacki, D. D. Dao
LNPS interaction



- Overall good agreement between experiment and theory
- Inversion of intruder and « normal » configuration from $N=43$ and $1/2^-$ state is predicted to increase again for ^{71}Co
- Northern border of IOI: transitional regime between Ni and Fe

CONCLUSIONS

- Mass measurements of both ground states and isomeric states in $^{68, 69, 70}\text{Co}$
- Mass surface clarified and excellent agreement with LSSM calculations
- Assignment of states thanks to PI-ICR counting
- Level energies in agreement with LSSM calculations
- Co chain in the transitional chain between spherical Ni and deformed Fe: in the IOI at N=43
→ need more measurements beyond N=43 and below Co to map the IOI

THANK YOU FOR YOUR ATTENTION !

I284 EXPERIMENT

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THEORETICAL CALCULATIONS

D. D. Dao and F. Nowacki

Data analysis performed by Mathieu Flayol (MIT)
(PhD Thesis Univ. Bordeaux 2024)



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