Proposal to the ISOLDE and Neutron Time-of-Flight Committee
72nd Meeting - 08/02/23

INTC-P-650

Exploring the evolution of the N = 126 magic number with the masses of neutron-rich gold isotopes

Vladimir Manea,
Université Paris-Saclay, CNRS/IN2P3, IJCLab, Orsay, France

K. Blaum, D. Lange, Yu. A. Litvinov, D. Lunney, M. Mougeot,
S. Naimi, L. Nies (contact person), Ch. Schweiger, L. Schweikhard, F. Wienholtz

A. Andreyev for the IDS Collaboration

Laboratoire de Physique des 2 infinis Irène Joliot-Curie

ISOLTRAP ISOLDE CERN

Summary

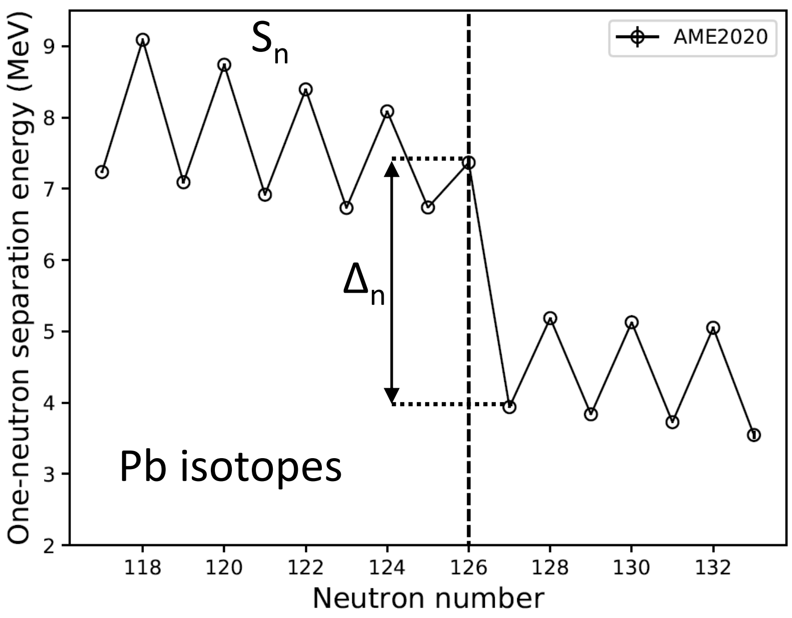
- Measure with ISOLTRAP the masses of neutron-rich gold isotopes around N = 126 ($^{204\text{-}206}Au$)

- Determine neutron separation energies (S_n, S_{2n}) and the (one-/two-)neutron empirical shell gap (Δ_n/Δ_{2n})

- Constrain nuclear models:
  - Monopole interaction
  - Open shell correlations (quadrupole)

- Improve the description of the mass surface around N = 126, with impact on modeling the r-process

Study shell evolution via mass measurements



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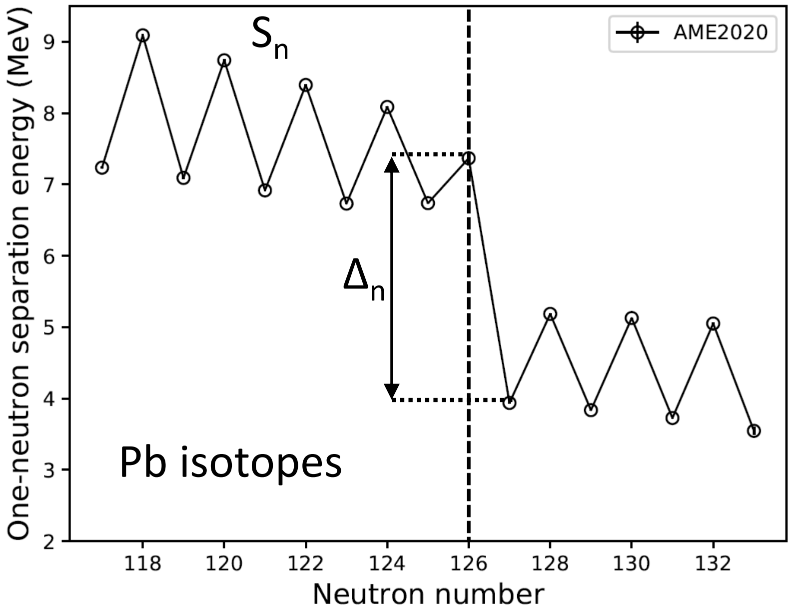
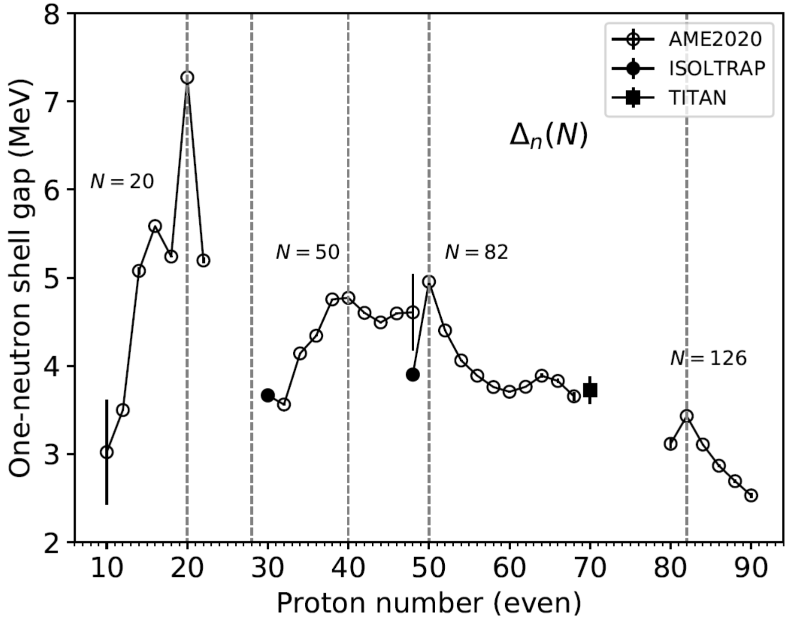
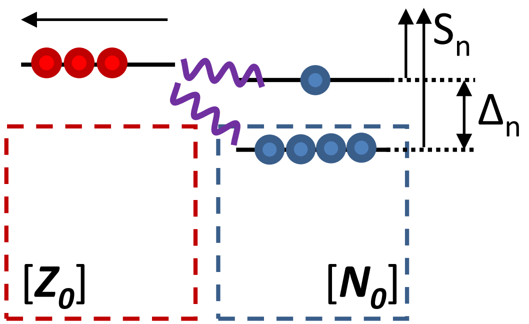


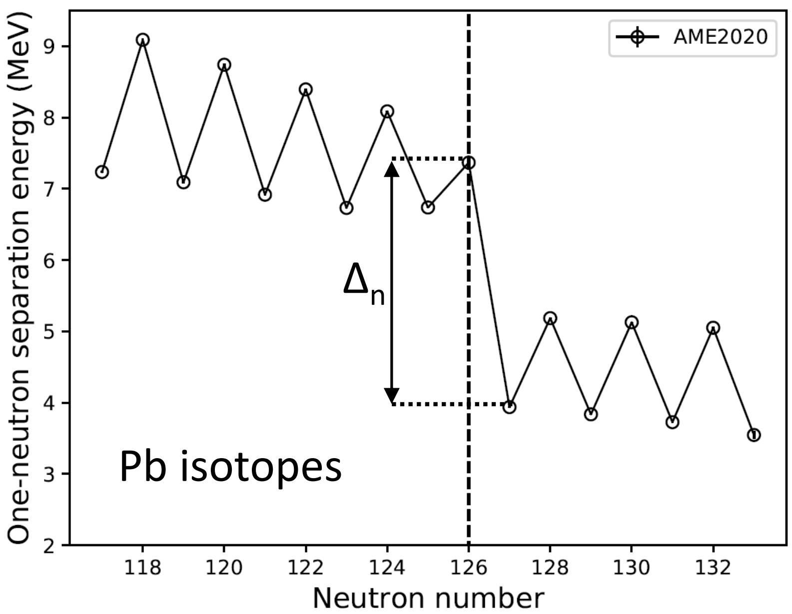


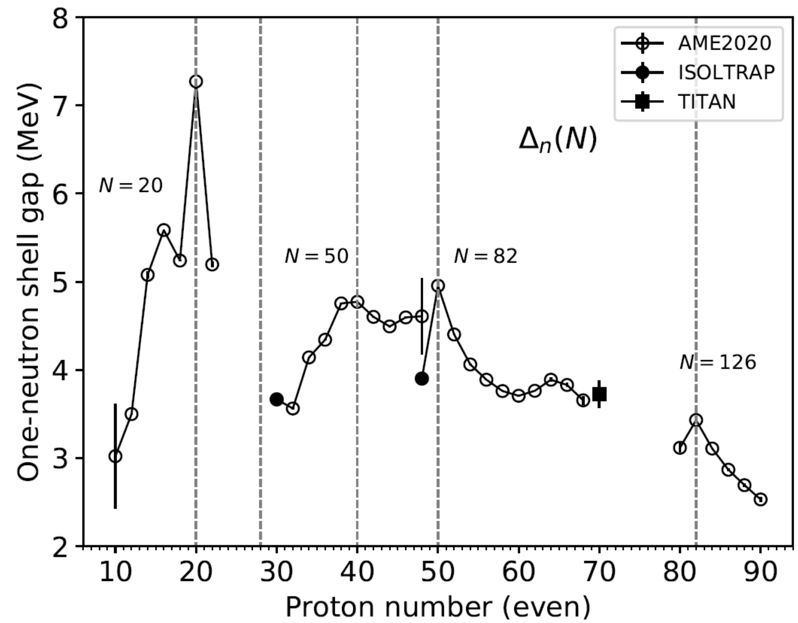
- ❑ Empirical neutron shell-gap evolution driven by the monopole proton-neutron interaction



What is the evolution of the higher neutron shell gaps?

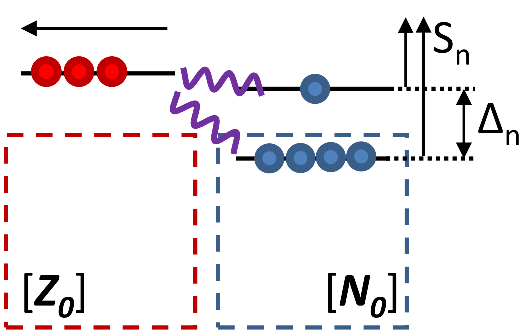
Study shell evolution via mass measurements

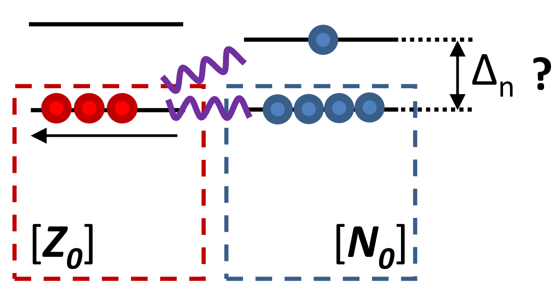




- ❑ Empirical neutron shell-gap evolution driven by the monopole proton-neutron interaction

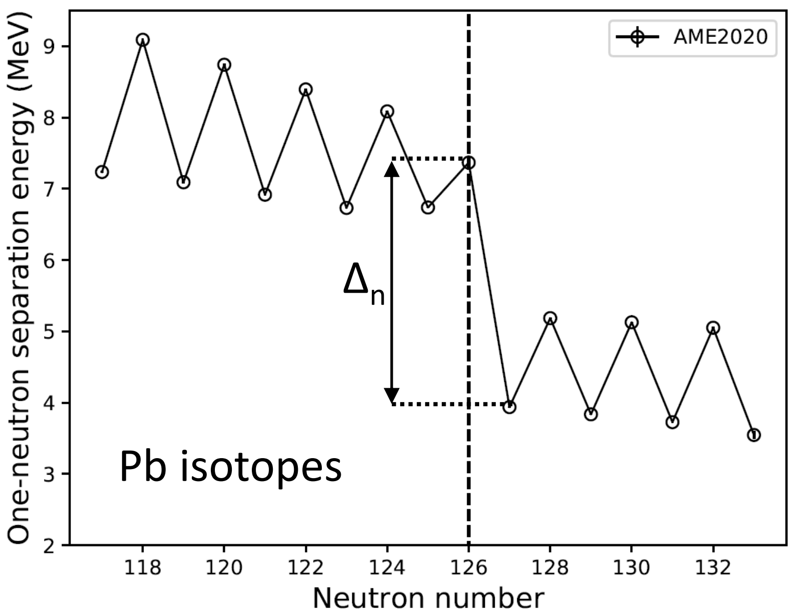
- ❑ $V_M \sim A^{-2/3}$ but …
- ❑ crossing proton shell closures can dramatically change the trend

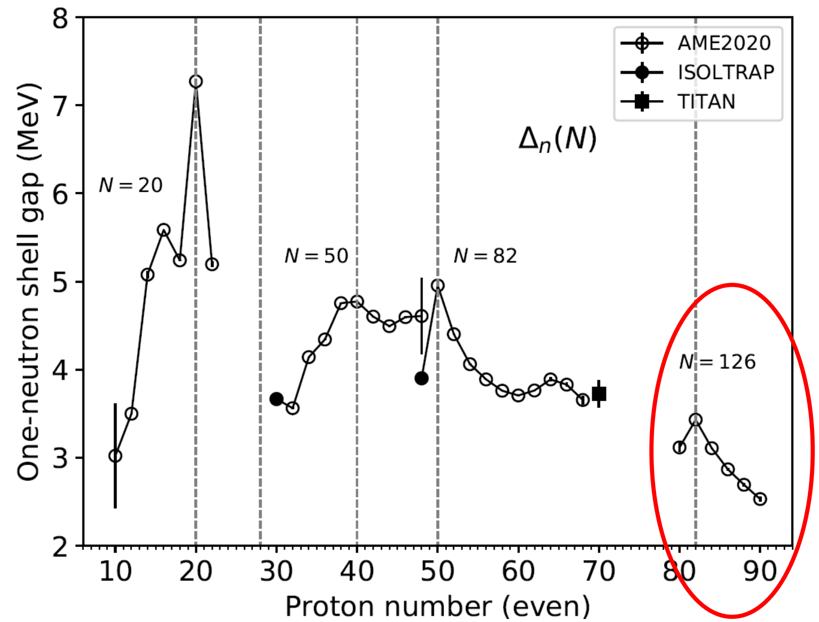




e.g. Z = 14 (N = 20)
Z = 50 (N = 82)

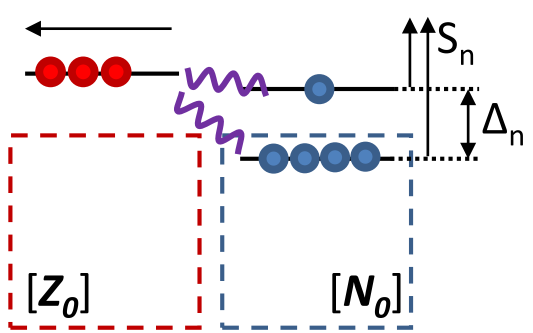
Study shell evolution via mass measurements

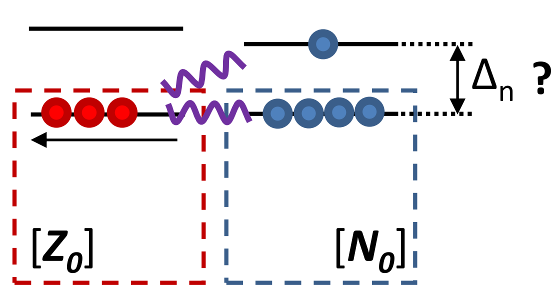




- ❑ Empirical neutron shell-gap evolution driven by the monopole proton-neutron interaction

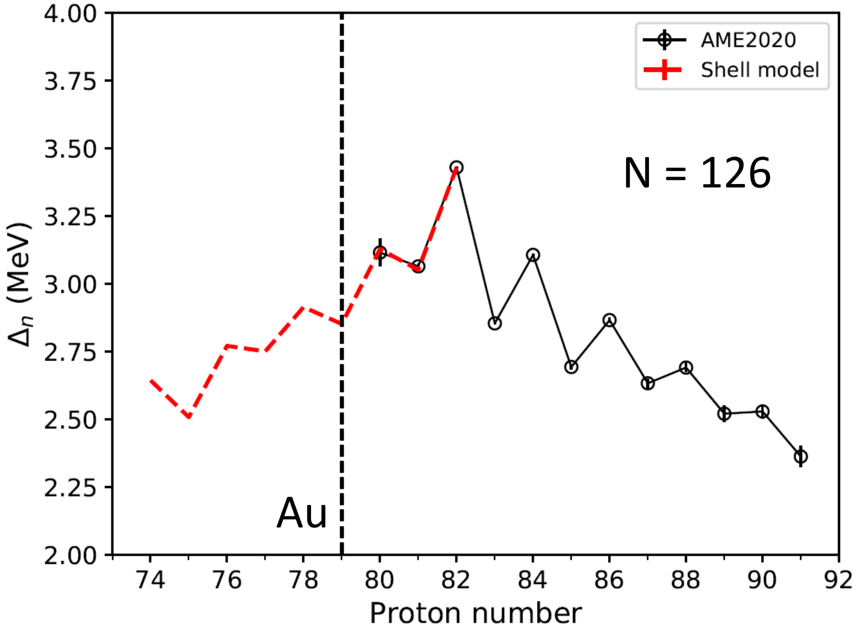
What is the evolution of N = 126?





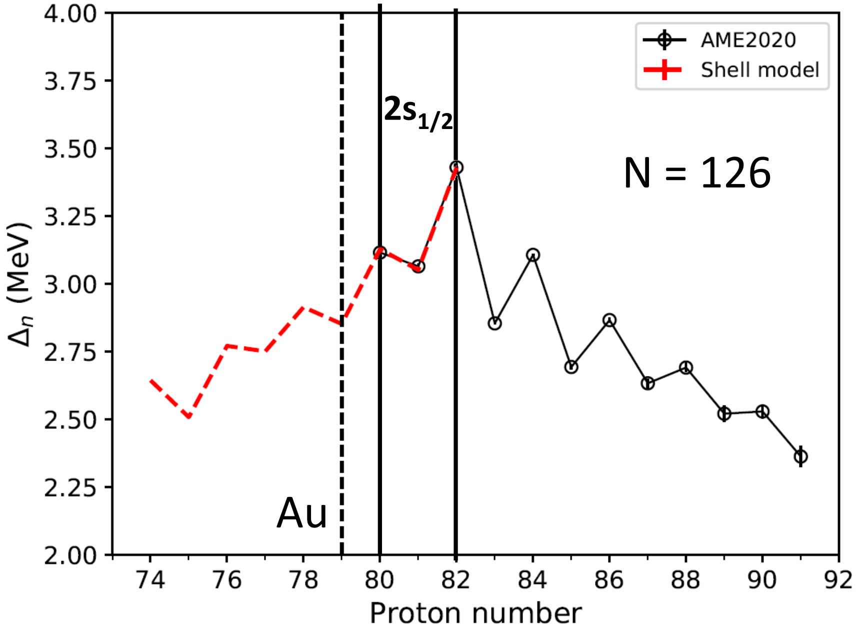
e.g. Z = 14 (N = 20)
Z = 50 (N = 82)

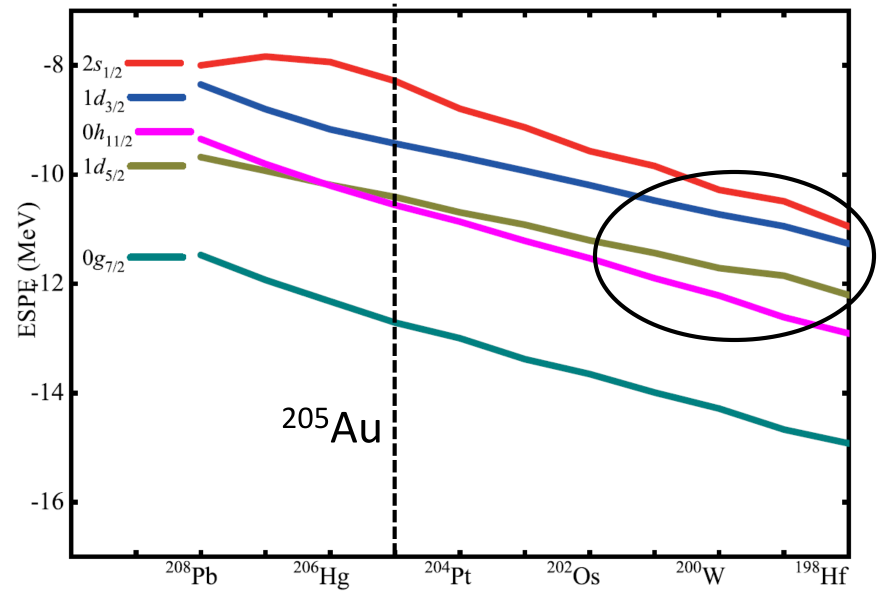
Evolution of the *N* = 126 shell



- *N* = 126 shell gap predicted to decrease towards Z = 70

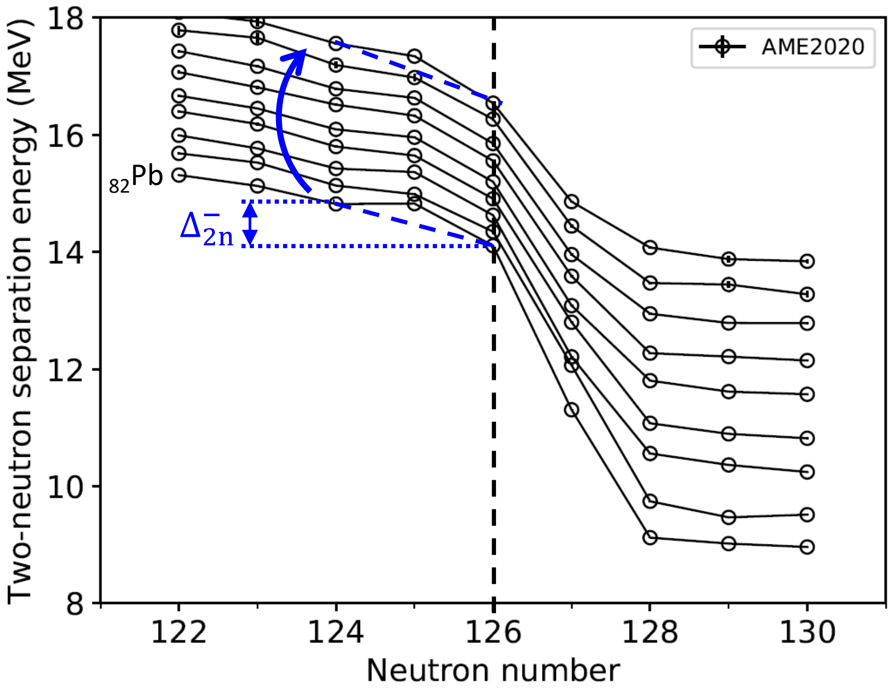
Evolution of the N = 126 shell





- ❑ N = 126 shell gap predicted to decrease towards Z = 70
- ❑ Difficult extrapolation towards Z = 70:
  - ➢ new proton orbitals below Z = 80 (different slopes)
  - ➢ configuration mixing due to high density of proton orbitals (non-linear trend)

Configuration mixing near the N = 126 shell

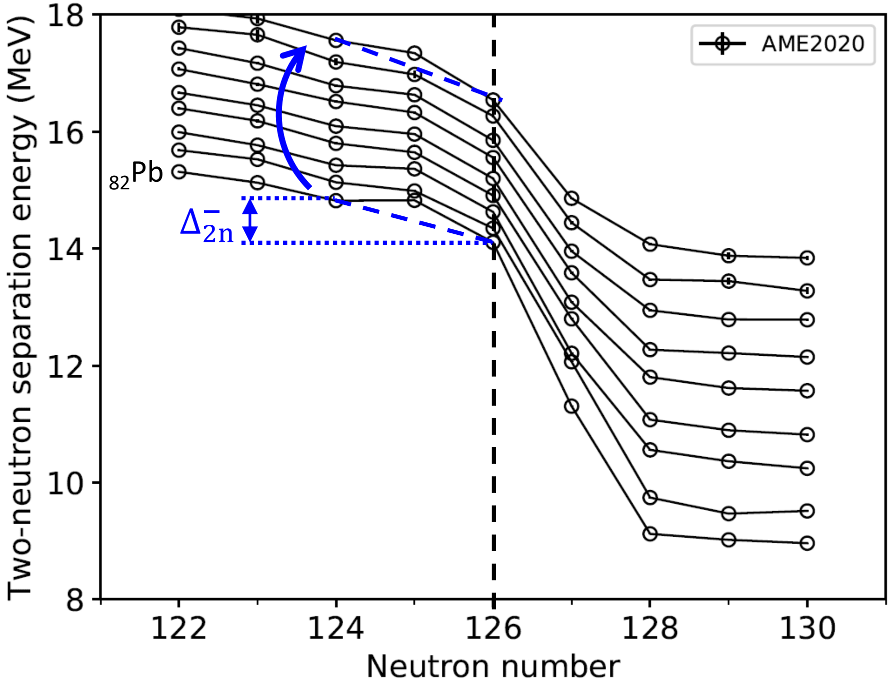


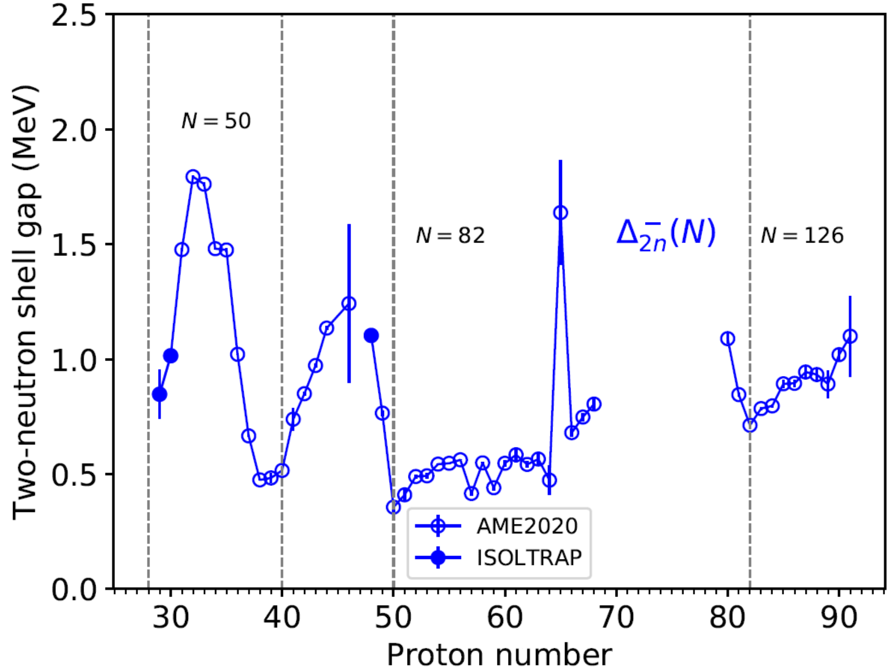
- Configuration mixing visible in S_{2n}:
  - Δ^{-}_{2n}: effect of the quadrupole correlations

R. N. Wolf, et al., PRL 110 (2013)
A. Welker, et al., PRL 119 (2017), V. Manea, J. Karthein et al., PRL 124 (2020)
C. Izzo et al., PRC 103 (2021) S. Beck et al., PRL 127 (2021)

Configuration mixing near the *N* = 126 shell

V. Manea, M. Mougeot, D. Lunney EPJA, in press (2023)





- ❑ Configuration mixing visible in S_{2n}:
  - ➢ Δ_{2n}^{-}: effect of the quadrupole correlations

Configuration mixing near the N = 126 shell

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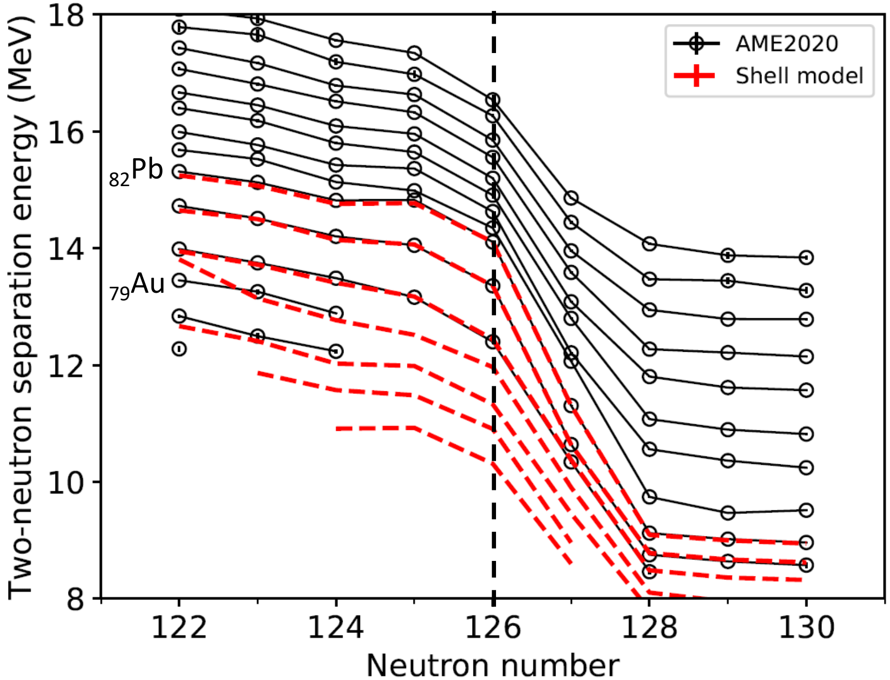
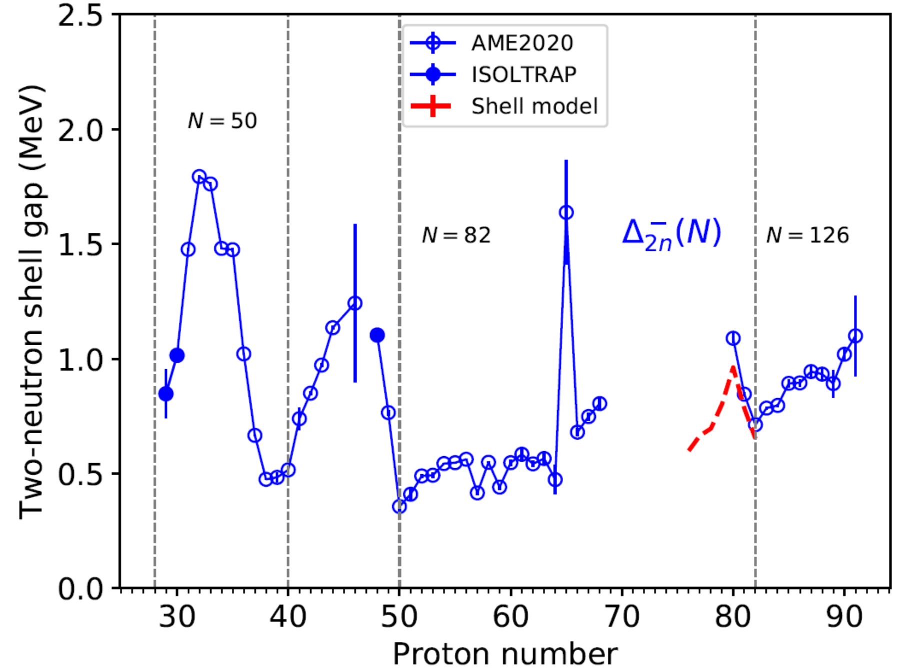
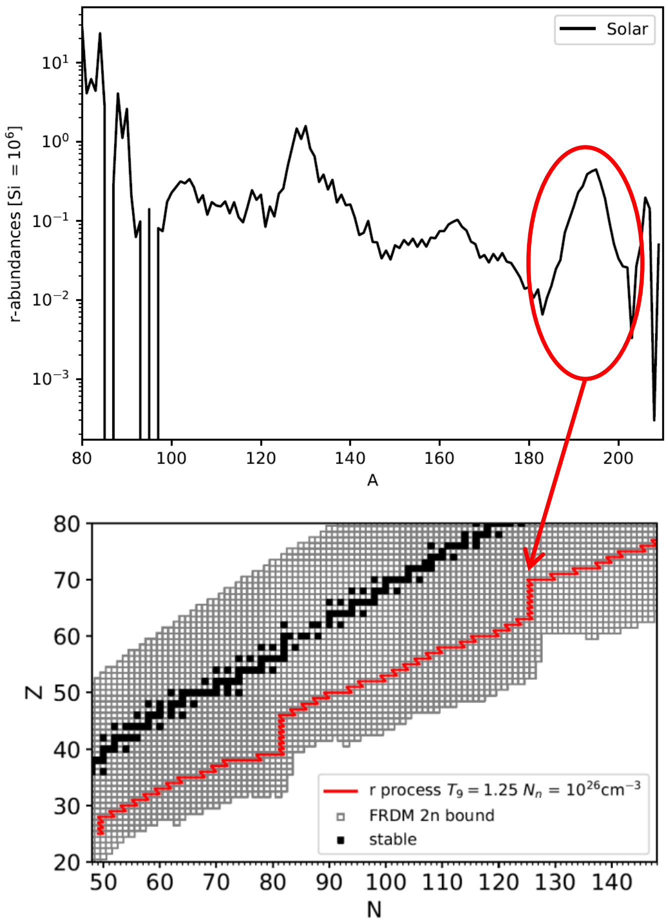




- ❑ Configuration mixing visible in S_{2n}:
  - ➢ Δ^{-}_{2n}: effect of the quadrupole correlations

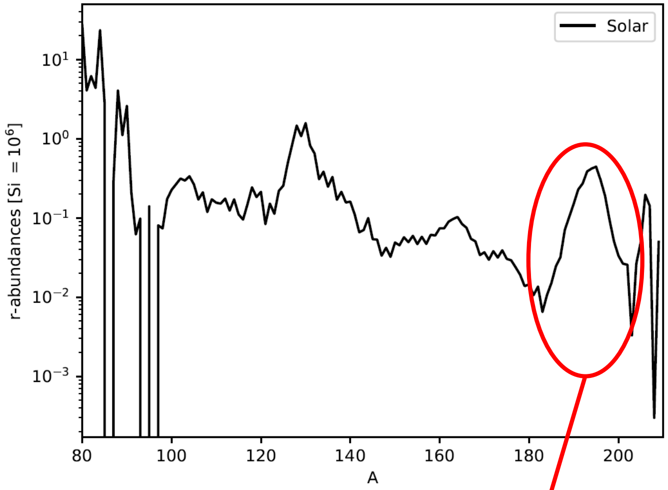
- ❑ Measurements in the Au chain would allow to confirm or correct predicted trend of Δ^{-}_{2n}

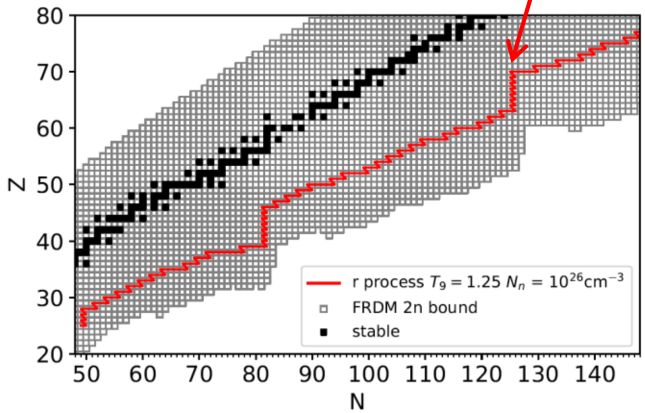
Connection to the r-process of nucleosynthesis



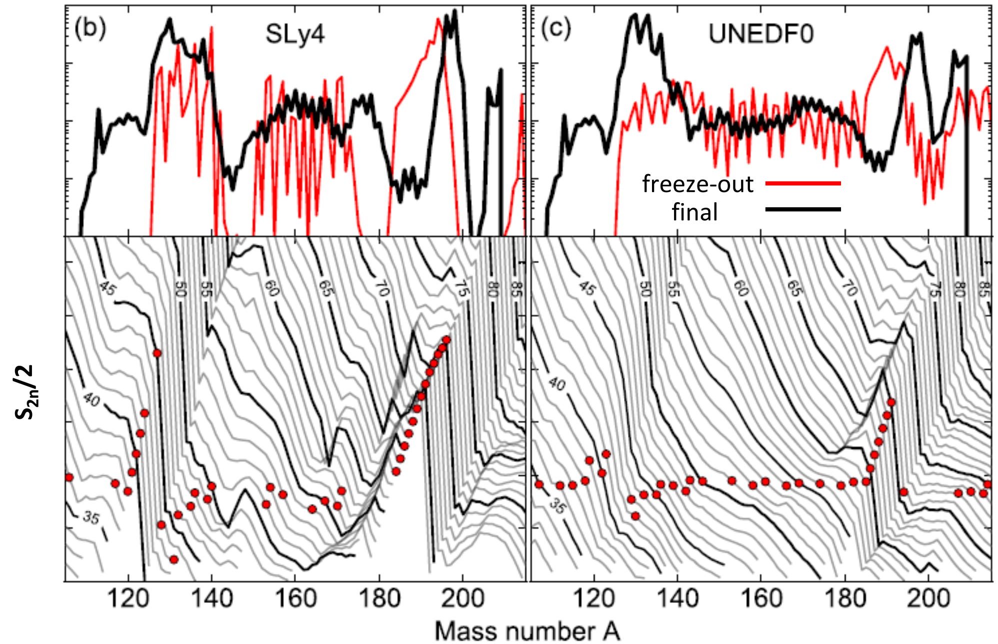
❑ $A \approx 195$ r-process abundance peak: effect of the $N = 126$ shell closure

Connection to the r-process of nucleosynthesis





neutron-star merger scenario

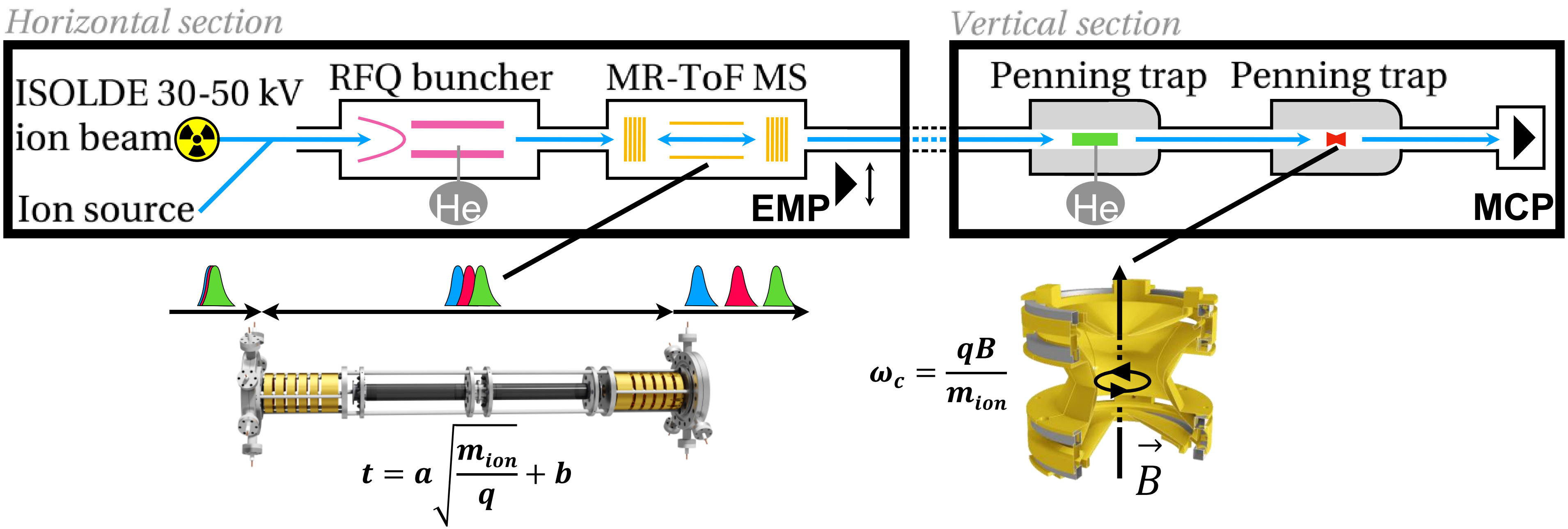


- ❑ $A \approx 195$ r-process abundance peak: effect of the $N = 126$ shell closure

- ❑ S_n have a strong impact on the (γ,n) rates

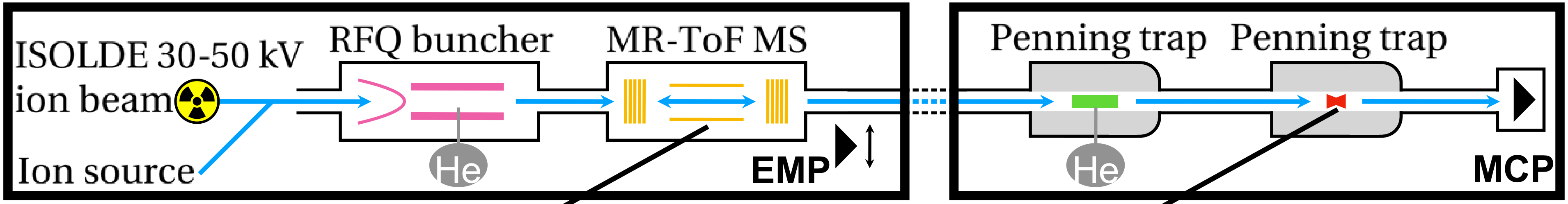
- ❑ The evolution of the N = 126 empirical shell gap: position and height of the $A \approx 195$ peak

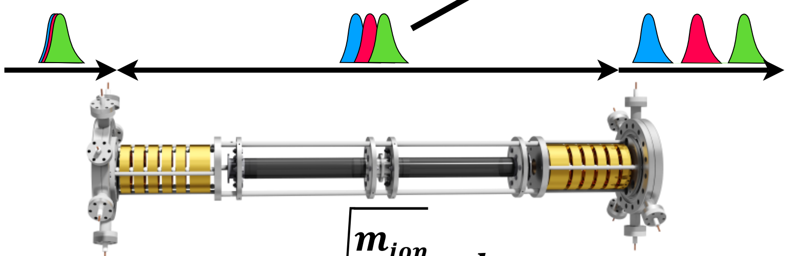
Mass measurements with ISOLTRAP



Mass measurements with ISOLTRAP

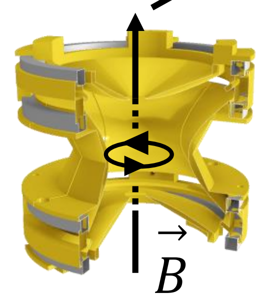
Horizontal section *Vertical section*

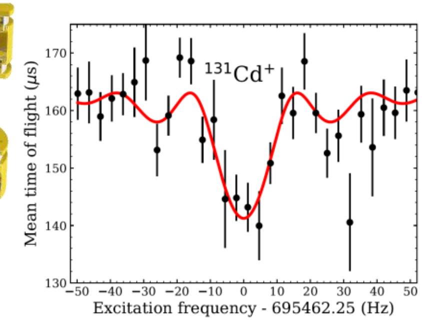


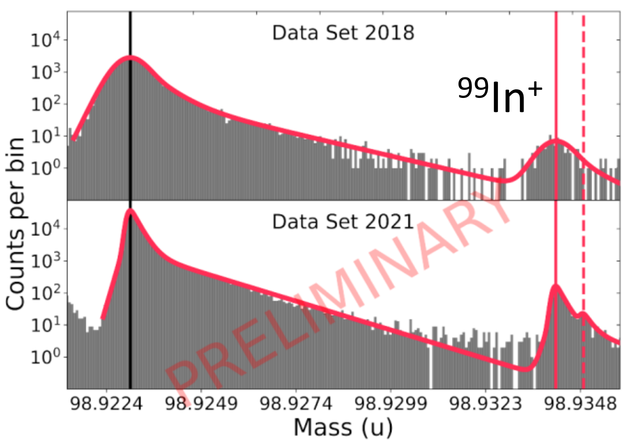


$$t = a\sqrt{\frac{m_{ion}}{q}} + b$$

$$\omega_c = \frac{qB}{m_{ion}}$$

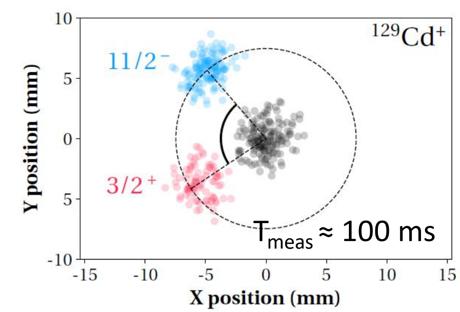






Important upgrades in the last years:

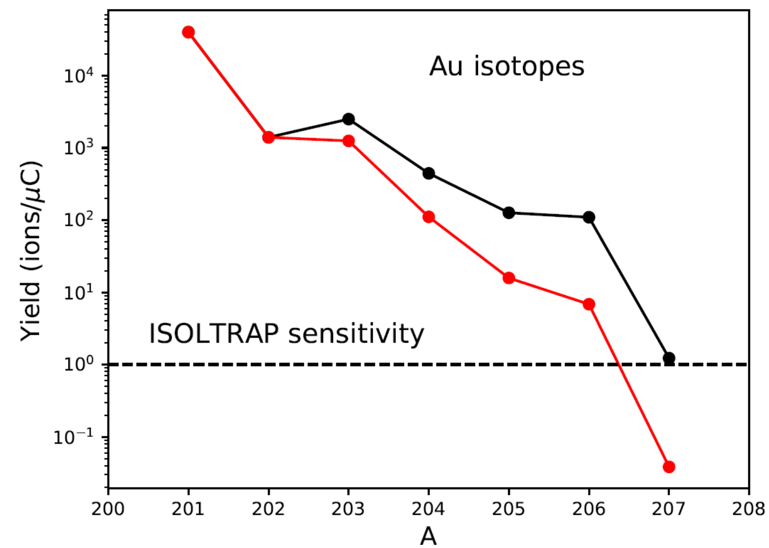
- ❑ <u>Resolving power of MR-TOF MS</u> improved to ≈ 400 000.
- ❑ PI-ICR method significantly increases the <u>sensitivity of the Penning traps</u> in the presence of contamination.



L. Nies et al., submitted.

Beam request

- ISOLDE database yields for ^{201m202}Au
- Release information from in-source laser spectroscopy campaign
- Extrapolation based using in-target yield drop between ^{201}Au-^{202}Au (or 2x the value)
- Francium contamination:
  - lower line temperature
  - beam gate delay (faster release of francium)
  - optimal resolving power of MR-TOF MS (Au is lighter than Fr, no effect of tail)
- Possible use of IDS for studying beam composition

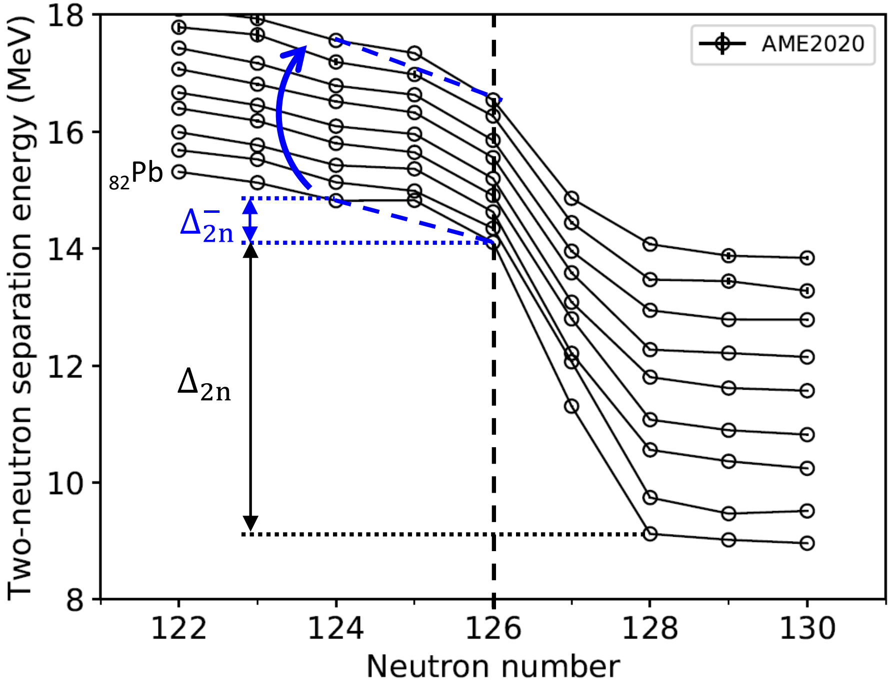


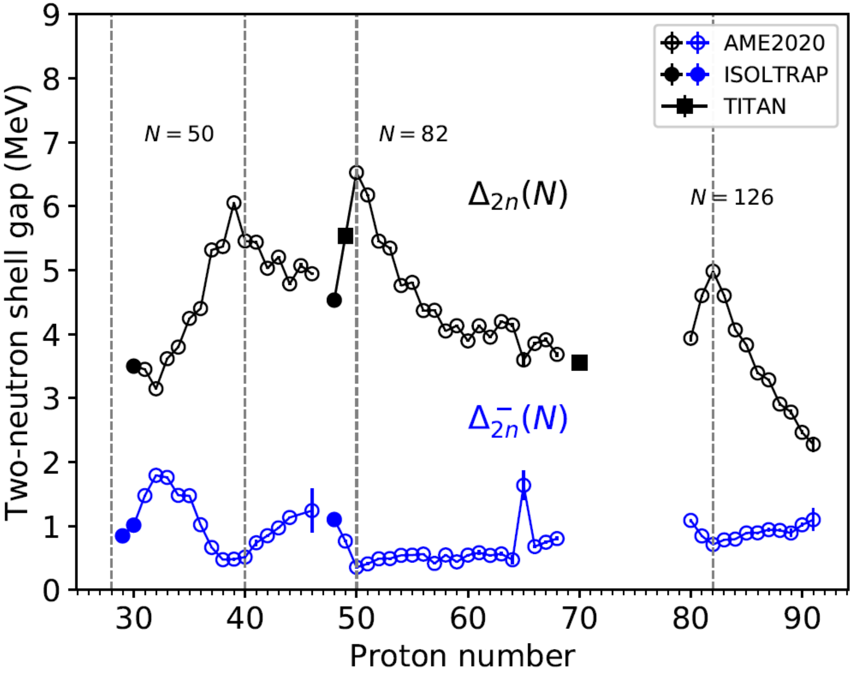
Isotope	Half-life	Yield [ions/μC]	Target/ ion source	Method	Shifts
$^{201-203}$Au	> 20 s	> 10^3	UC_x/RILIS	MR-TOF MS/PT/IDS	2
^{204}Au	38.3 s	110-440		MR-TOF MS	3
^{205}Au	32.0 s 6.0 s	15-125			4
^{206}Au	47.0 s	5-110			6
				Beam optimization, purification	2
				Total shifts	**17**

T. Stora, Nucl. Instr. Meth. B 317, 402 (2013)
A. E. Barzakh, et al., Nucl. Instr. Meth. B 513, 26 (2022)

Backup: Δ_{2n} and Δ^{-}_{2n}

V. Manea, M. Mougeot, D. Lunney EPJA, in press (2023)





- ❑ Configuration mixing visible in S_{2n} and Δ_{2n}
  - ➢ Δ_{2n}: impure filter for the shell gap
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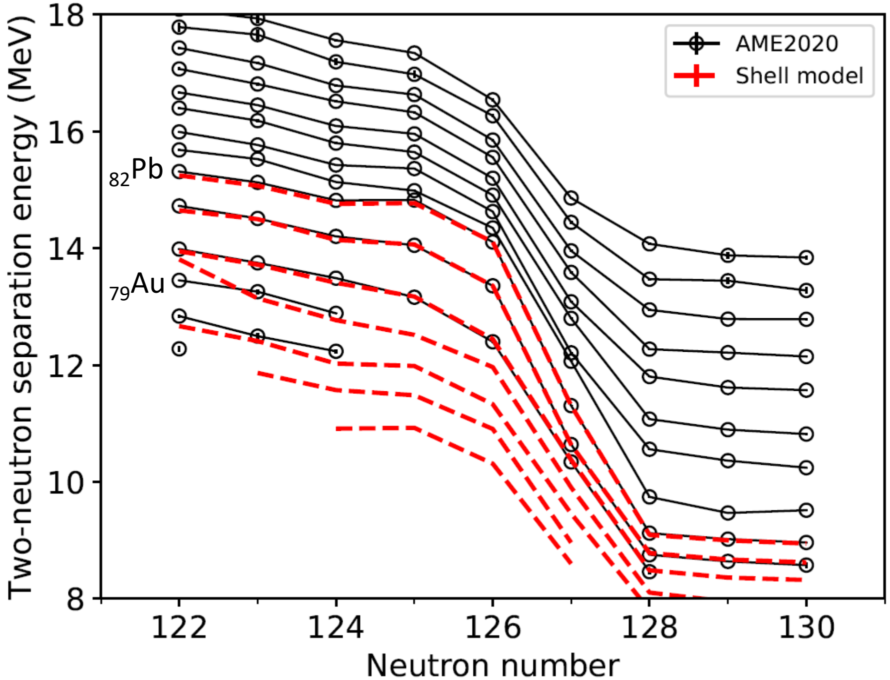
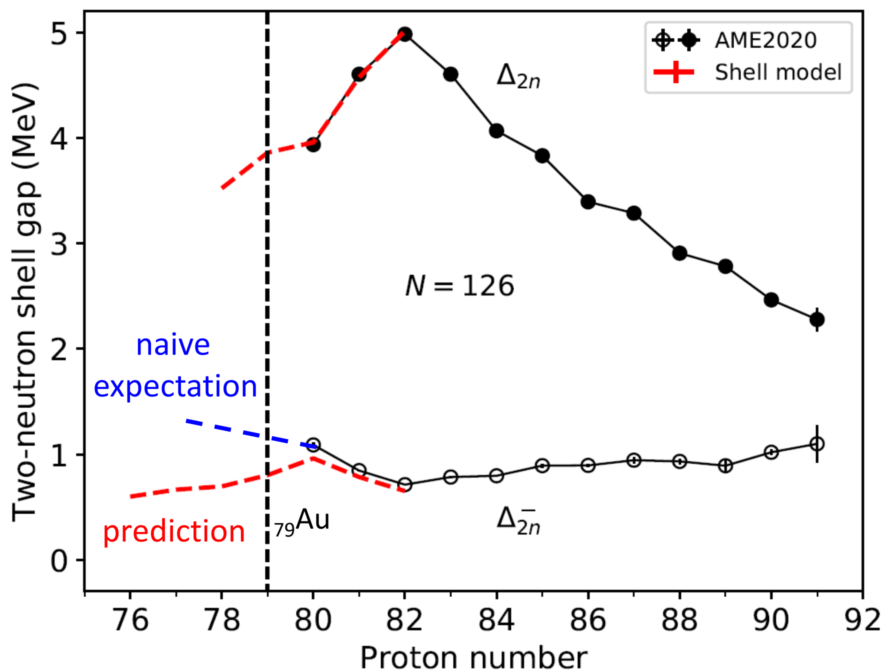
Backup: Δ_{2n} and Δ^{-}_{2n}





- ❑ Configuration mixing visible in S_{2n} and Δ_{2n}
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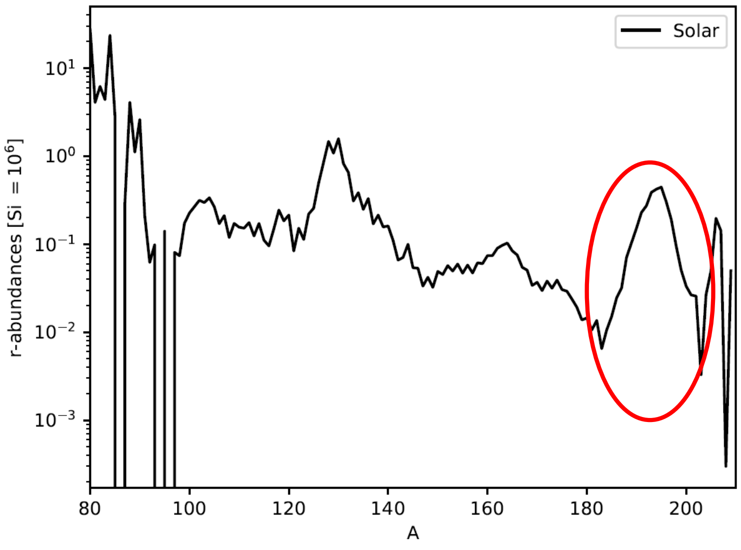
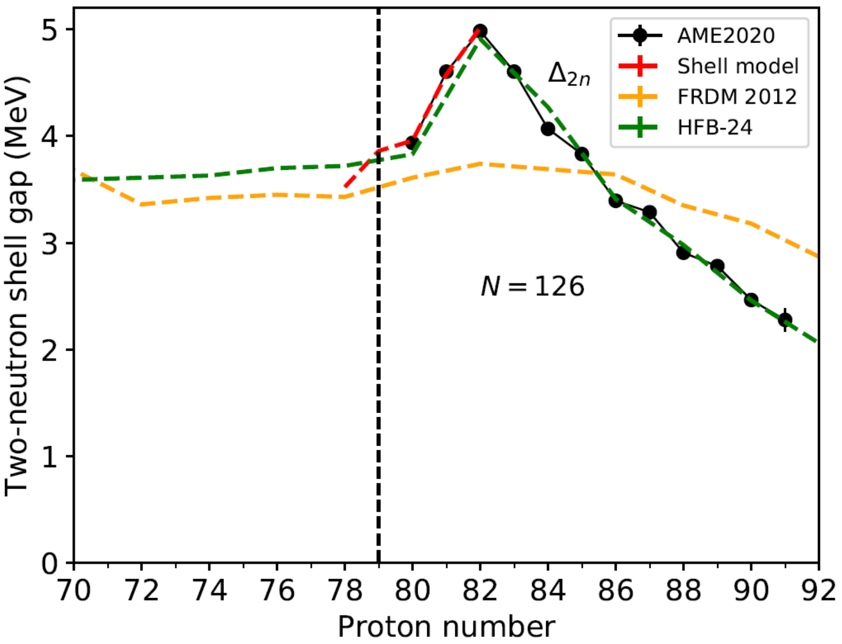
  - ➢ Δ^{-}_{2n}: effect of the quadrupole correlations

- ❑ Measurements in the Au chain would allow to confirm or correct predicted trend of Δ^{-}_{2n}

Backup: r-process and Δ_{2n}





- $A \approx 195$ r-process abundance peak is linked to the effect of the $N = 126$ shell closure on the r-process path.
- S_n have a strong impact on the (γ,n) rates.
- Q_β enter the calculation of beta-decay $T_{1/2}$

- The strength of the N = 126 empirical shell gap affects the position and height of the $A \approx 195$ peak
- Most mass models tend to overestimate or predict a large gap