Proposal to the ISOLDE and Neutron Time-of-Flight Committee
77th Meeting - 12/11/24

Mass measurements of neutron-rich Ag and In isotopes for r-process nucleosynthesis studies

INTC P-716

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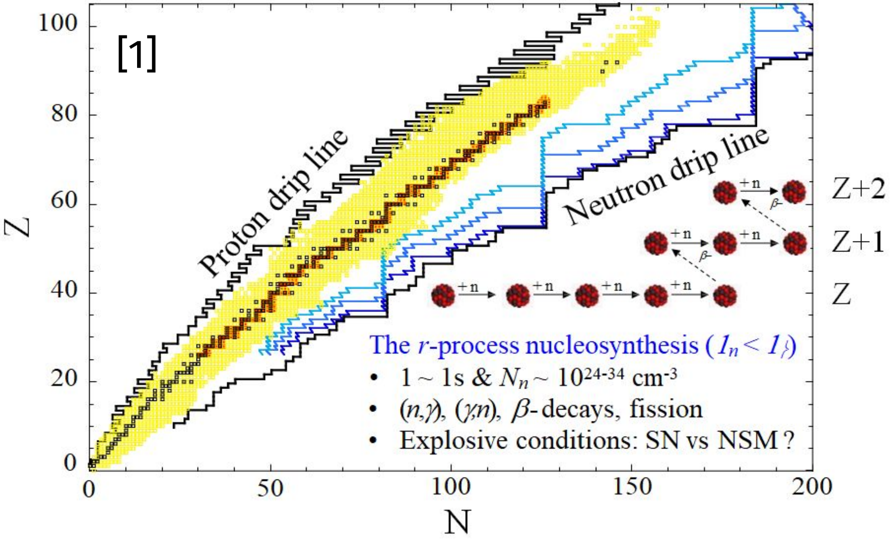
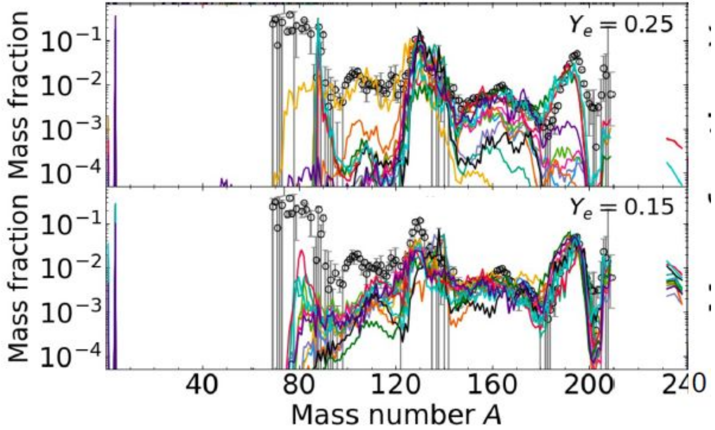
r - process



15 different “acceptable” sets of nuclear **inputs** (masses, β-decay, n-capture, fission) [2]

Different color line = Different r-process model:



Uncertainties remaining :

- observed r-process nuclei in NSM, major site?
- process conditions and path
- competition between β-decay and fission

neutron photo-disintegration rate:

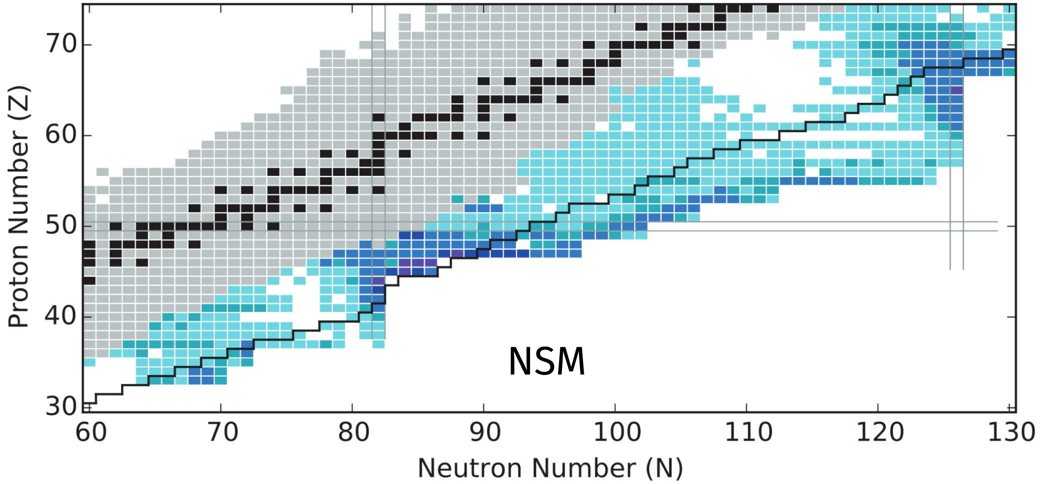
$$\lambda_{(\gamma,n)} = \frac{2}{n_n}\frac{G'(T)}{G(T)}\left(\frac{\mu k_B T}{2\pi\hbar^2}\right)^{3/2}\lambda'_{(n,\gamma)}e^{-S_n/k_B T}$$ [3]

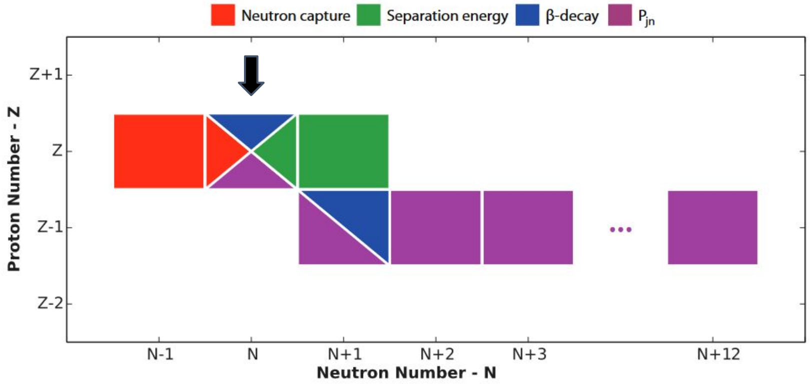
[1] S. Goriely, 3rd PhyNuBE meeting (2024) : **Fission and Nuclear Astrophysics**
[2] I. Kullmann *et al.*, 10.1093/mnras/stad1458 (2023)
[3] J. Clark *et al.*, 10.1140/epja/s10050-023-01037-0 (2023)

Nuclear Masses

Nuclear masses to calculate important properties :

- neutron capture rates
- separation energy
- β-decay rates
- β-delayed emission probabilities





Nuclei **around** the **magic numbers** have **largest impact** on **r-process** abundances according to sensitivity studies

study of isomers -> impact on reaction rates

Actinide Production

2017: observation of Sr and lanthanides in NSM kilonova but :

↳ no actinides observed yet

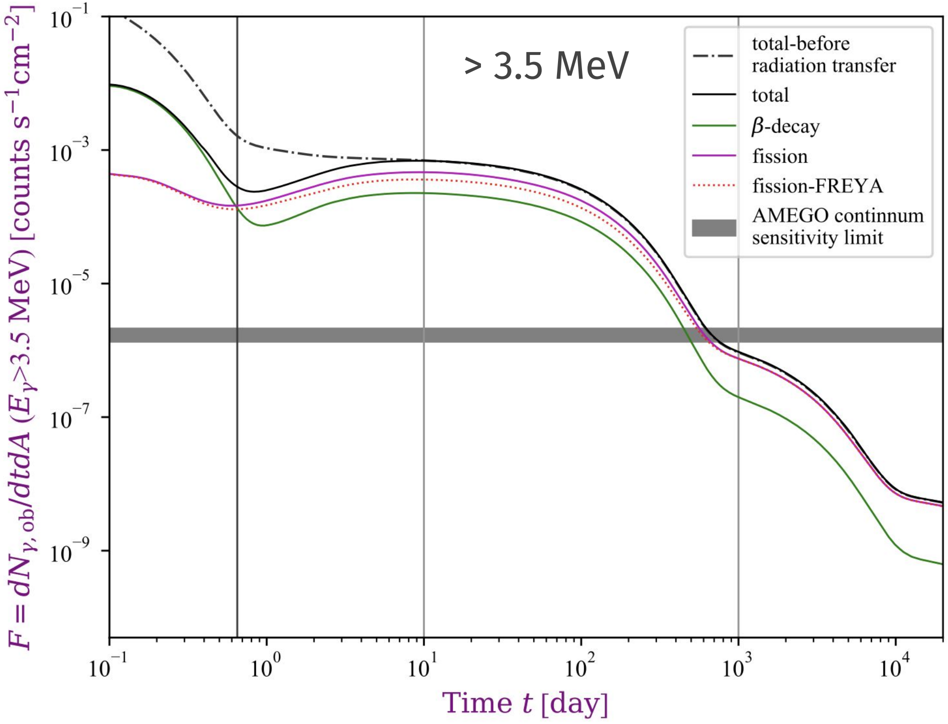
↳ close NSM not common

Prediction of **NSM light spectrum** 3.5-10 MeV:

- ***β*-decay** γ-rays dominant **earlier**
- **fission** γ-rays dominant **later**

γ-rays > 3.5 MeV ⇒ low flux :

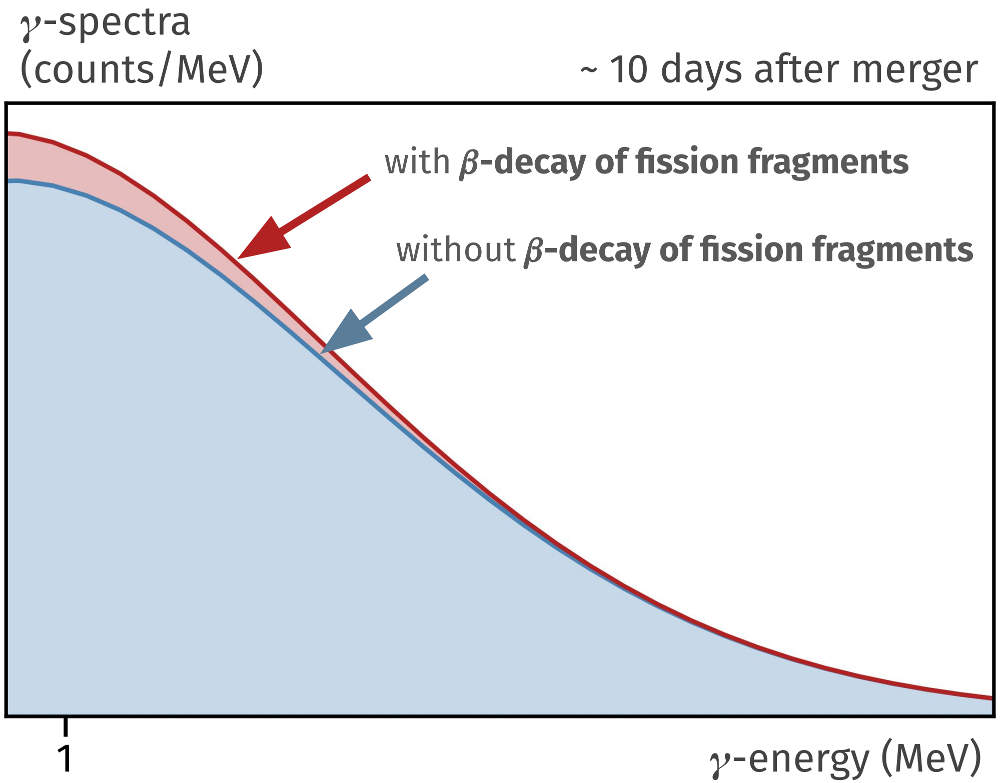
↳ NSM observed only in close neighborhood



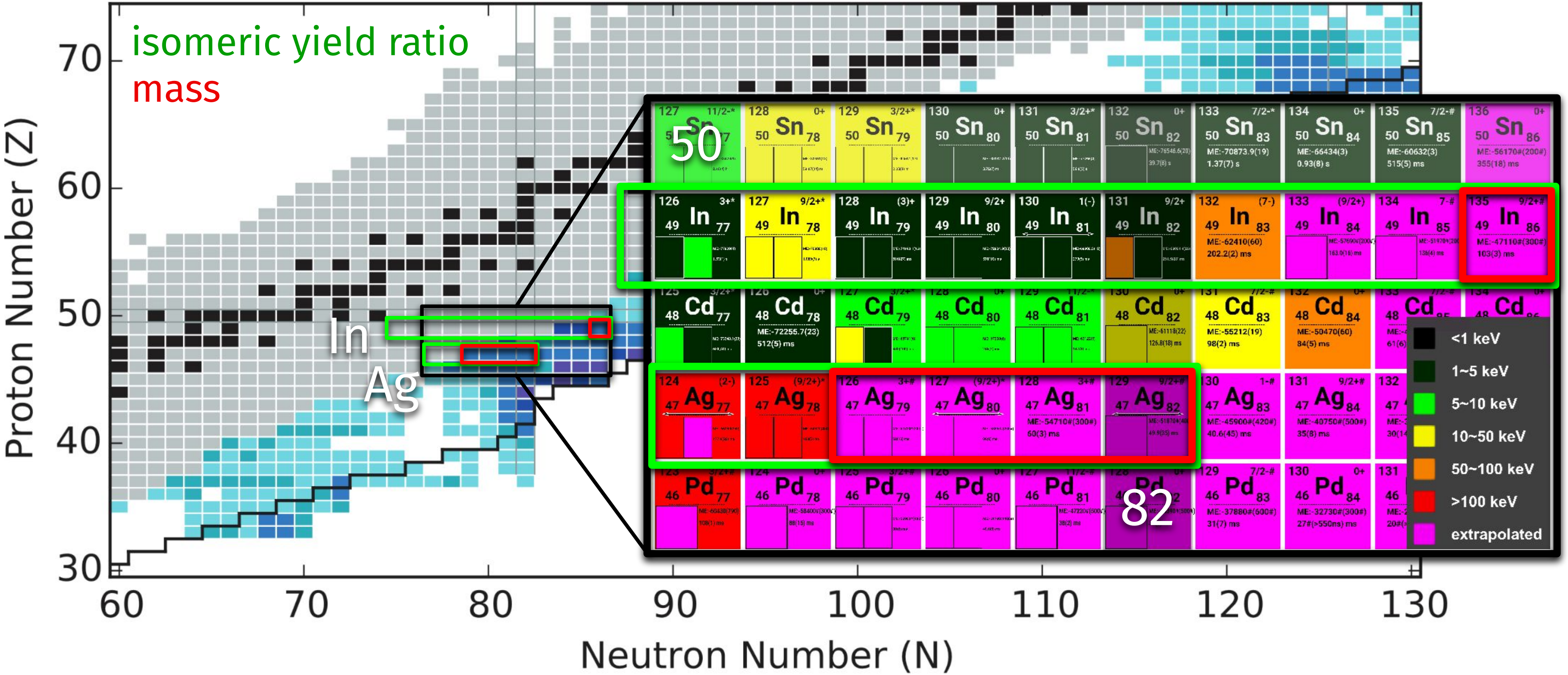
Isomeric yield ratios

***β*-decay** of **fission fragments** emit
***γ*-rays** ~ 1 MeV:
↳ light curve **intensity enhanced**
↳ **higher flux** at 1 MeV
↳ further distance **NSM** observations

⇒ **Isomeric Yield Ratios** to:
↳ quantify the **kilonova light curve intensity**
↳ identify Actinides in **multi-messenger astronomy** observations
↳ better knowledge of isomeric state **production at ISOLDE**



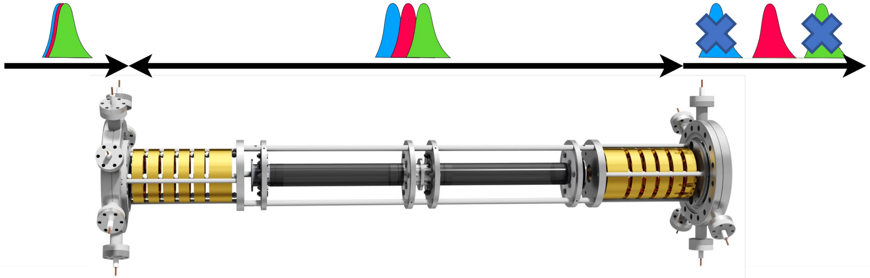
Nuclei of interest

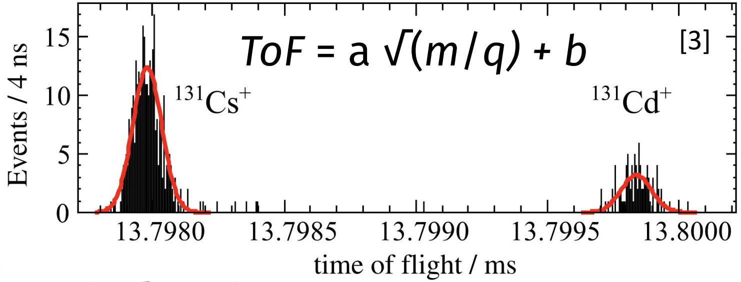


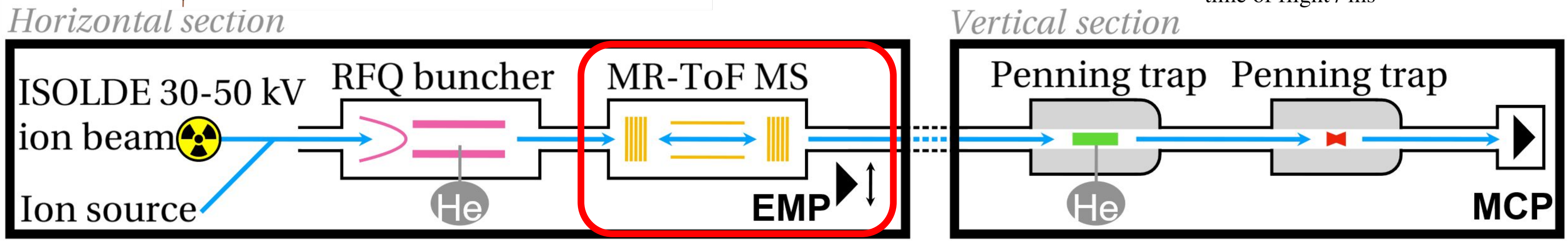
Experimental Techniques

MR-ToF MS [1]:
versatile and fast

- **Mass separation** mode: mass selective ejection out of MR-ToF MS [2]
  ⇒ **removal of isobaric contaminants**
- mass spectrometry mode
  ⇒ up to $R = 5{\times}10^5$





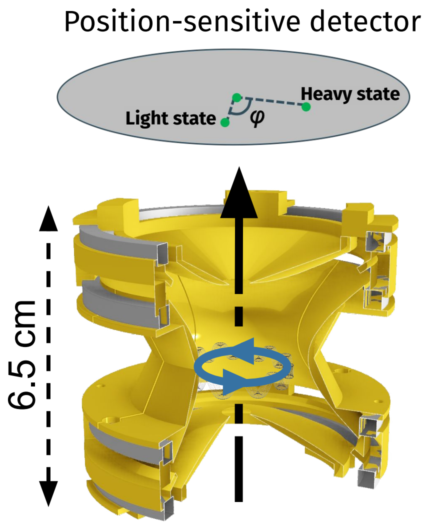


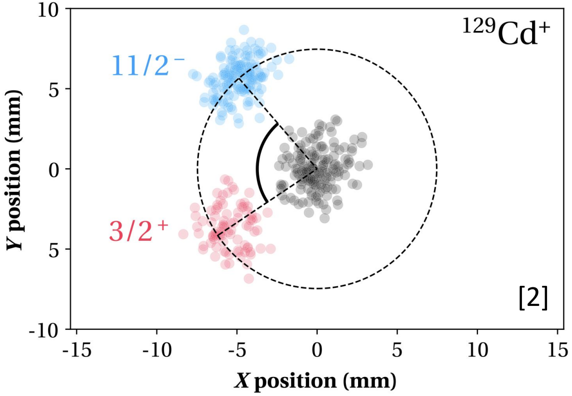
[1] R. N. Wolf *et al.*, 10.1016/j.ijms.2013.03.0201 (2013)
[2] F. Wienholtz *et al.*, 10.1016/J.IJMS.2017.07.016 (2017)
[3] D. Atanasov *et al.*, 10.1103/PhysRevLett.115.2325012 (2015)

Experimental Techniques

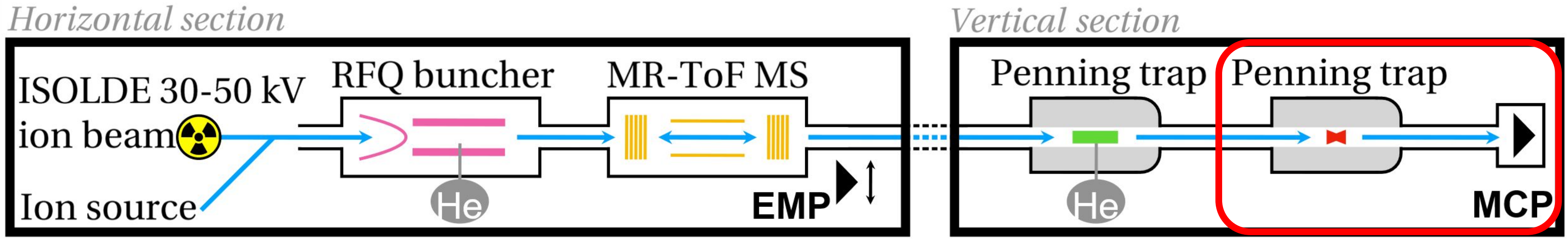
PI-ICR [1]: high precision even with low yields

- Mass resolving power ***R* > 10^6** in 100 ms at A = 129
- Longer storage times improve resolving power
- **Isomeric separation** capability demonstrated





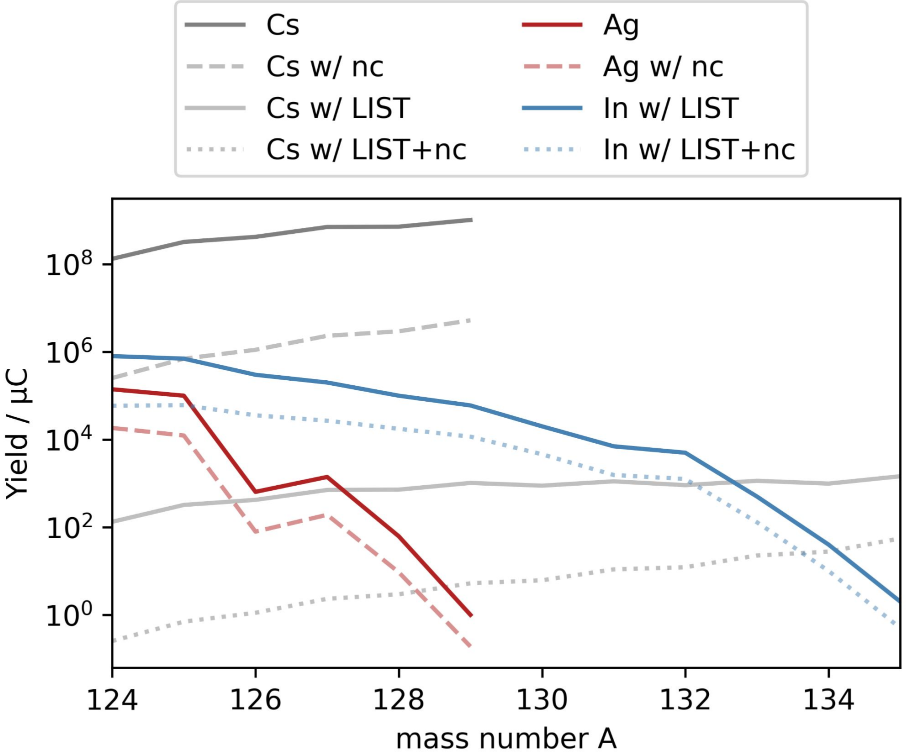
$\omega_c = qB/m$



Yields and contamination

Yields:
- multiple shifts of data taking required for most exotic isotopes of Ag and In

Contamination: **Cs** and **Ba**
- **neutron converter** to improve IOI-to-contaminant ratio (also reduces IOI yield by order of magnitude)
- **LIST** for **In** to further reduce contaminants by ≈10^6
  - both narrow and broadband (like in recent Hg measurement)
- **MR-ToF MS** allows separation of remaining contaminants in tens of milliseconds



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Shift Summary

Indium shifts (UCx + nc & RILIS LIST)

Nuclide	$T_{1/2}$	Yield / μC	cts / h	Shifts
$^{124,125}In^{(m)}$	2-12 s	$\approx 1\times10^6$	$\approx 1\times10^7$	1
$^{126\text{-}131}In^{(m\text{-}q)}$	0.1-4 s	$\geq 7\times10^3$	$\geq 3\times10^4$	3
^{132}In	202 ms	$\approx 5\times10^3$	$\approx 2\times10^4$	2
^{133}In $^{133}In^m$	163 ms 167 ms	≈500	≈2100	2
^{134}In	136 ms	≈40	≈180	3
^{135}In	103 ms	≈2	≈2	4
Total with radioactive beam				15 + 2 = **17**

Silver shifts (UCx + nc & RILIS)

Nuclide	$T_{1/2}$	Yield / μC	cts / h	Shifts
$^{124,125}Ag^{(m)}$	50#-178 ms	$\approx 1\times10^5$	$\geq 1\times10^5$	2
^{126}Ag $^{126}Ag^m$	52 ms 108 ms	$\approx 1\times10^3$	≈70	2
^{127}Ag $^{127}Ag^m$ $^{127}Ag^n$	89 ms 20# ms 86 ms	$\approx 1\times10^3$	≈600	2
^{128}Ag	60 ms	≈60	≈10	3
^{129}Ag $^{129}Ag^m$	50 ms 10# ms	≈1	≈5	4
Total with radioactive beam				13 + 2 = **15**

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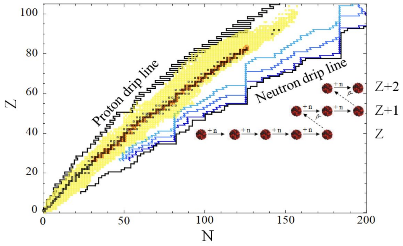
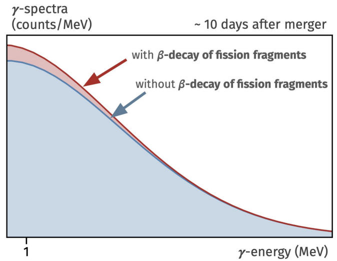
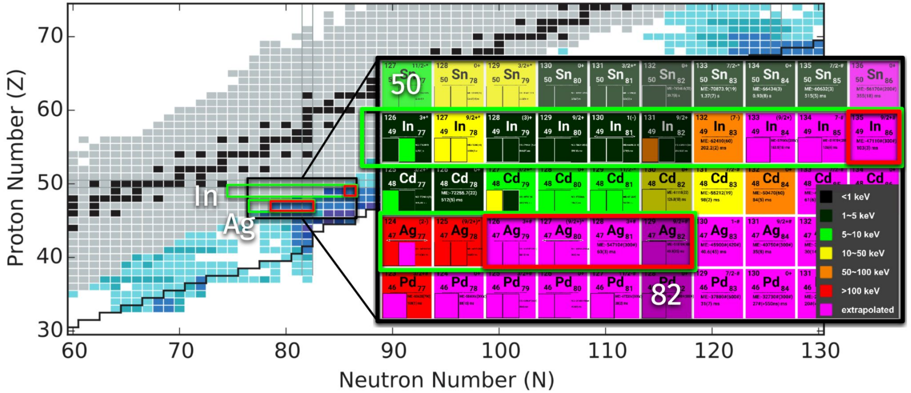
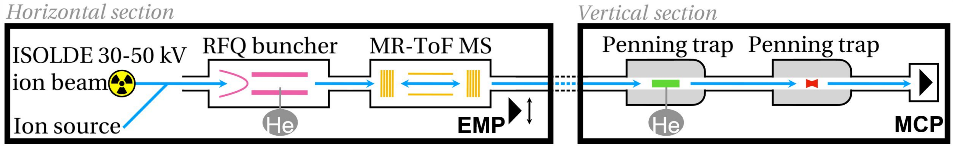
Summary

- **masses for** second abundance peak of **r-process** to pin down its **path** through the nuclear landscape
- **isomeric yield ratios** of neutron-rich nuclei as an alternative for **identifying actinides in NSMs**
- isotope separation in MR-ToF MS
- simultaneous mass and yield-ratio measurement with Penning trap (PI-ICR)









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