22nd Gentner Day, CERN, October 26th 2022

Nuclear Structure Studies With ISOLTRAP

Lukas Nies[1,2] *for the ISOLTRAP Collaboration*

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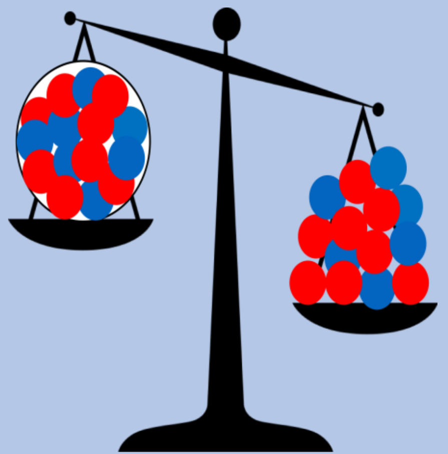
Atomic physics methods probe nuclear properties

Nuclear Binding Energy



$$M_{atom}(Z,N) = M_{nuc}(Z,N) + Zm_e - B_e(Z)$$

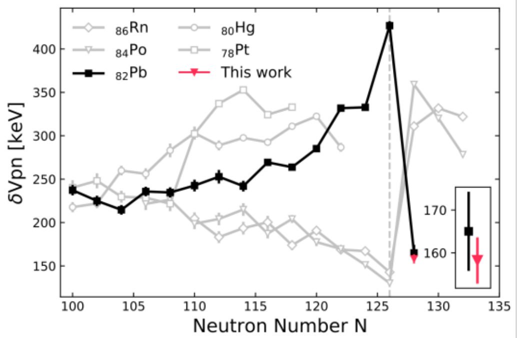
$$M_{nuc}(Z,N) = Zm_p + Nm_n + \frac{E(Z,N)}{c^2}$$

Nuclear Theory

"Mass filters"

Shell model, *ab initio*, etc.

Many-body interactions

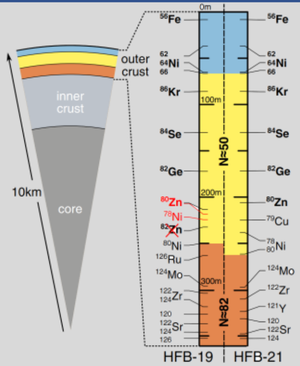


Nuclear Astrophysics

Nucleosynthesis

Light curves

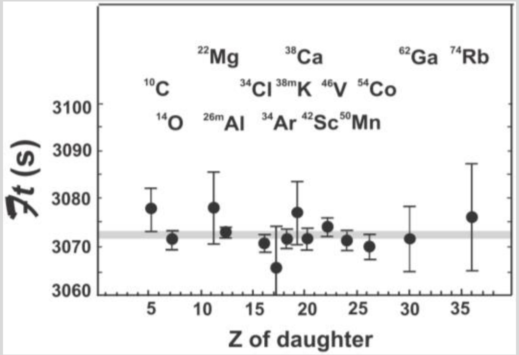
Neutron star compositions



Weak Interaction Physics

Unitarity of CKM Matrix

ν_e mass searches



Atomic physics methods probe nuclear properties

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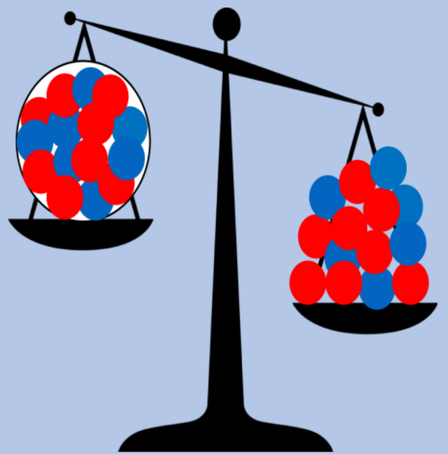

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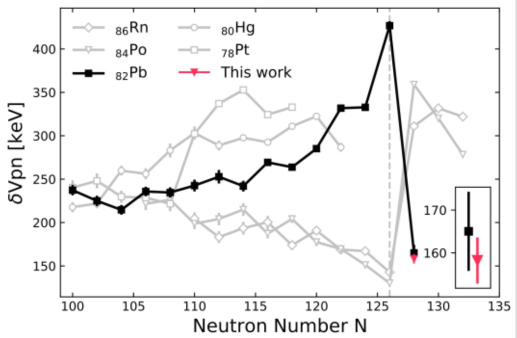
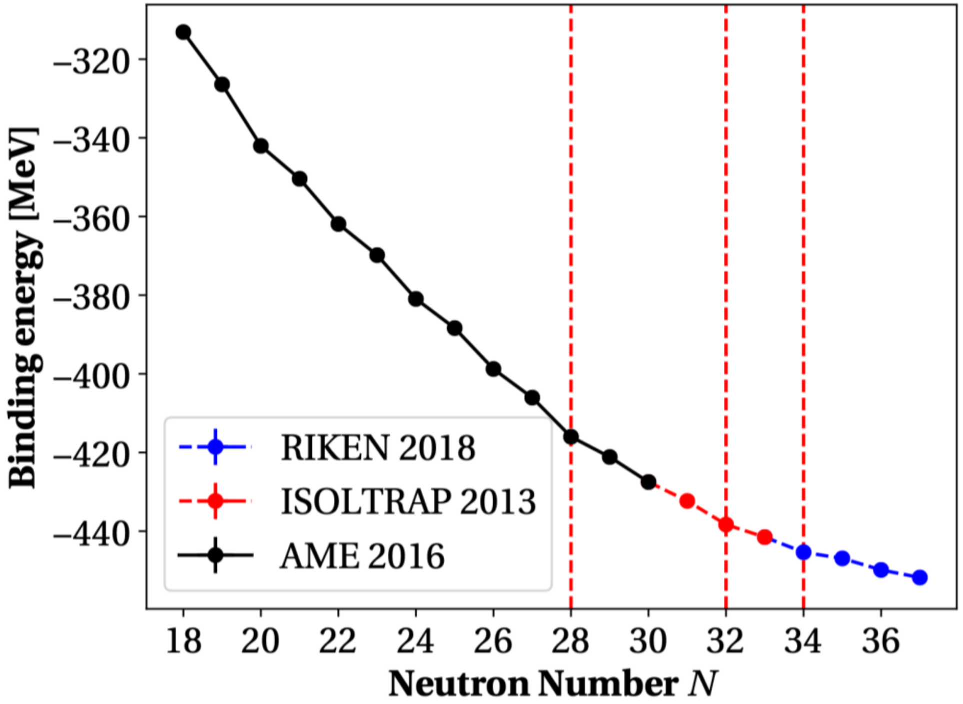
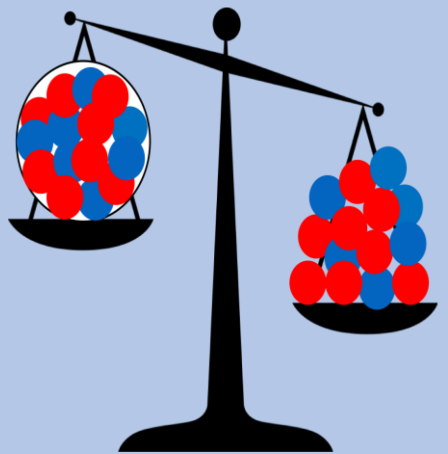




Atomic physics methods probe nuclear properties

Nuclear Binding Energy



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Nuclear Theory

"Mass filters"

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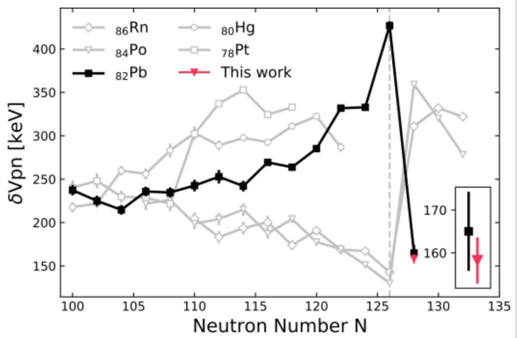
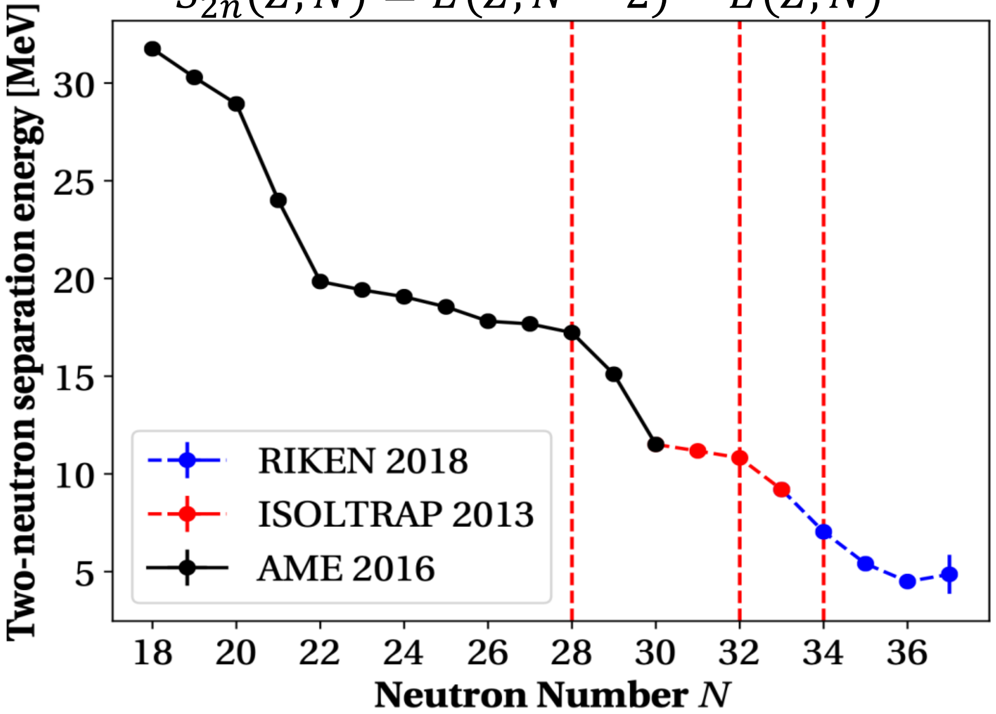
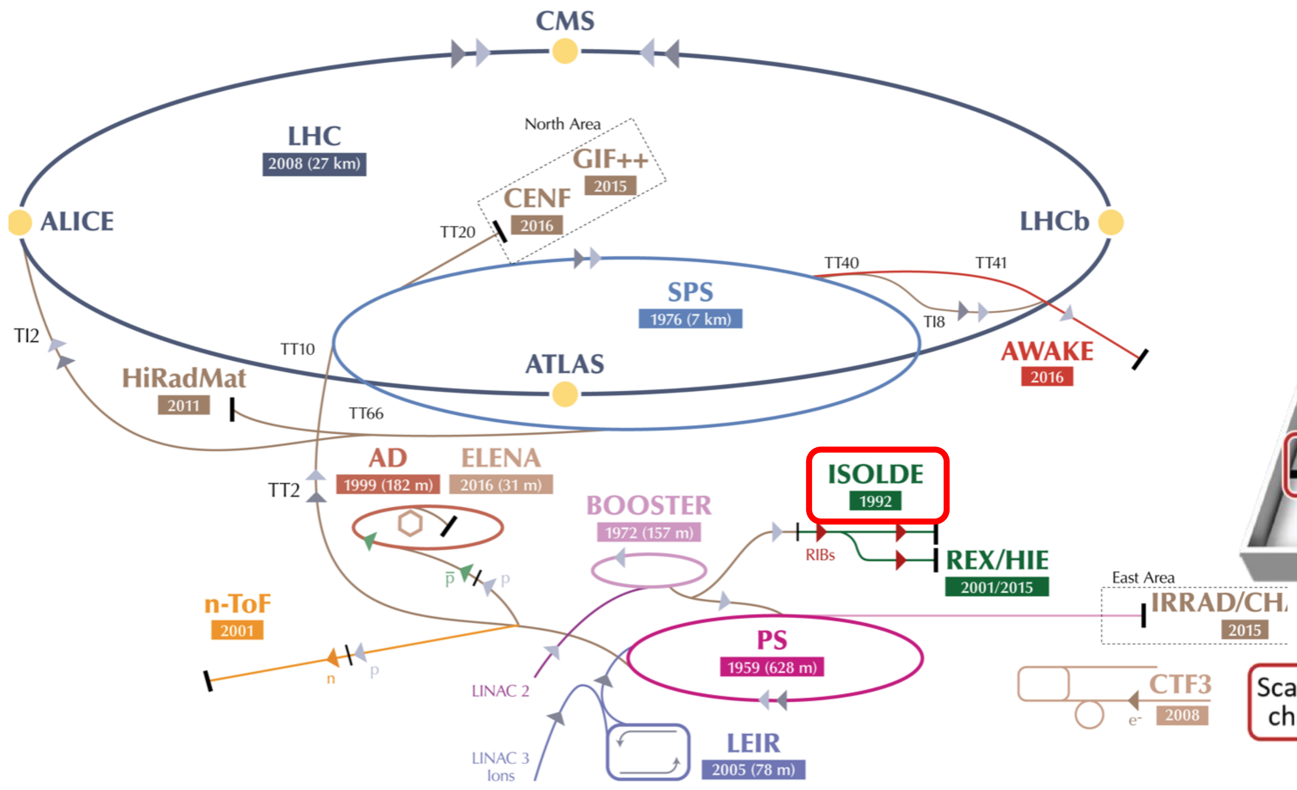
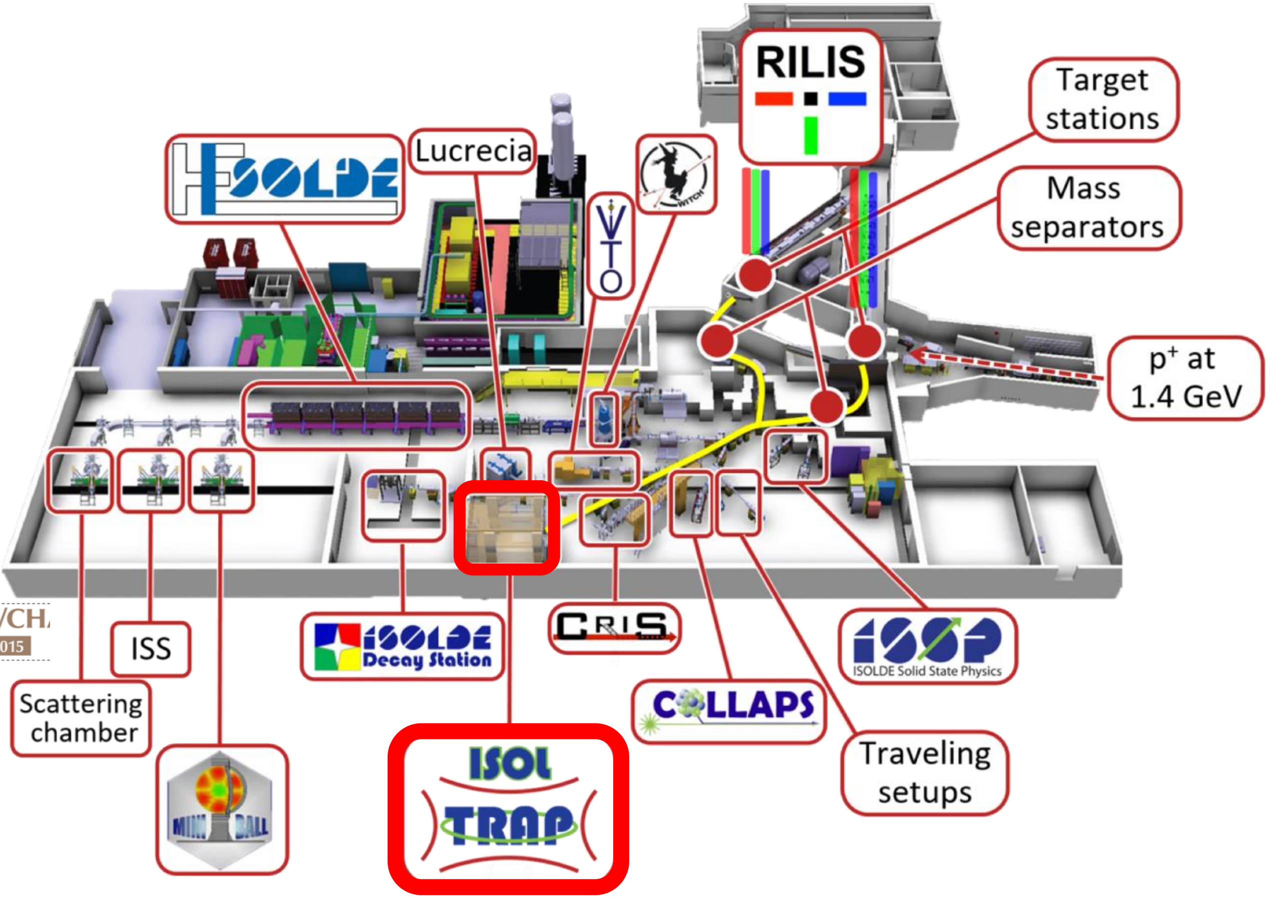


$$S_{2n}(Z,N) = E(Z,N-2) - E(Z,N)$$

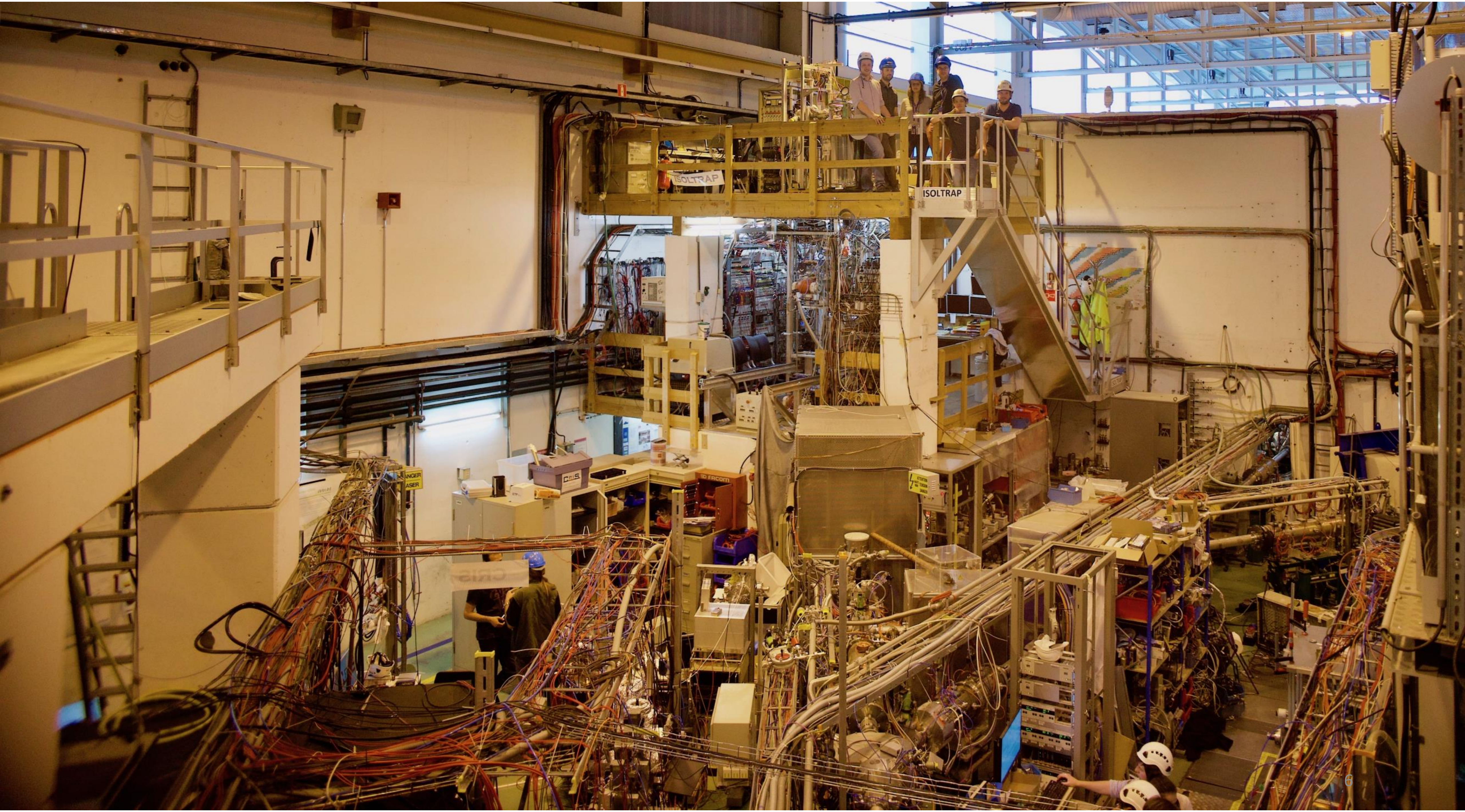


ISOLDE at CERN

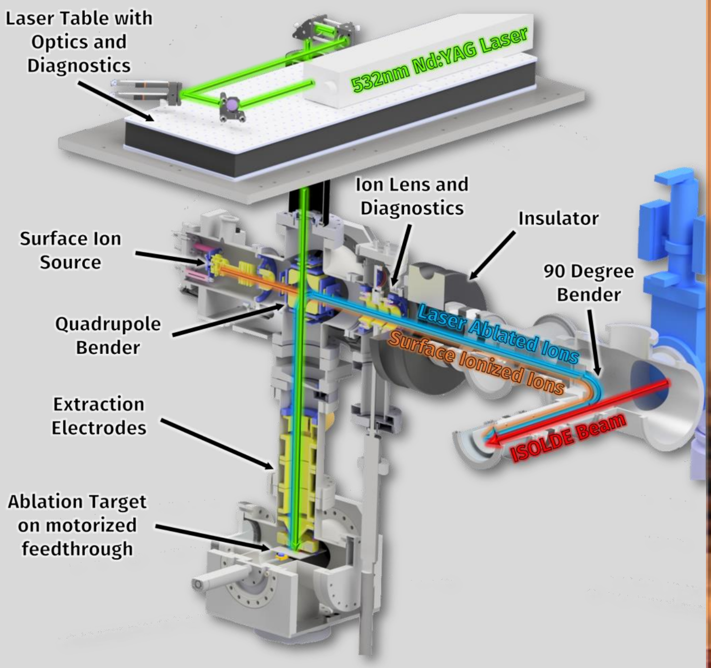


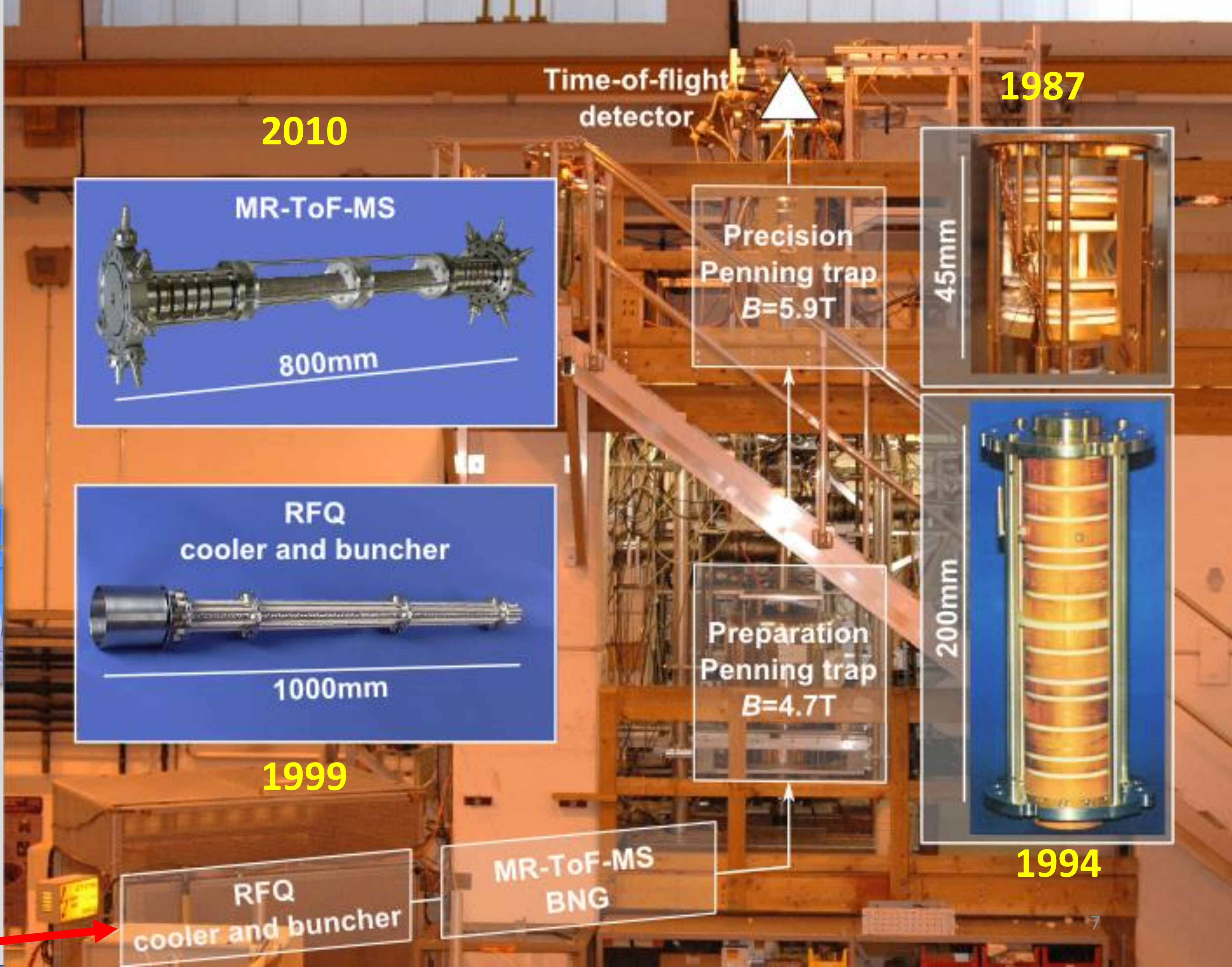


Lukas Nies
ISOLTRAP Collaboration

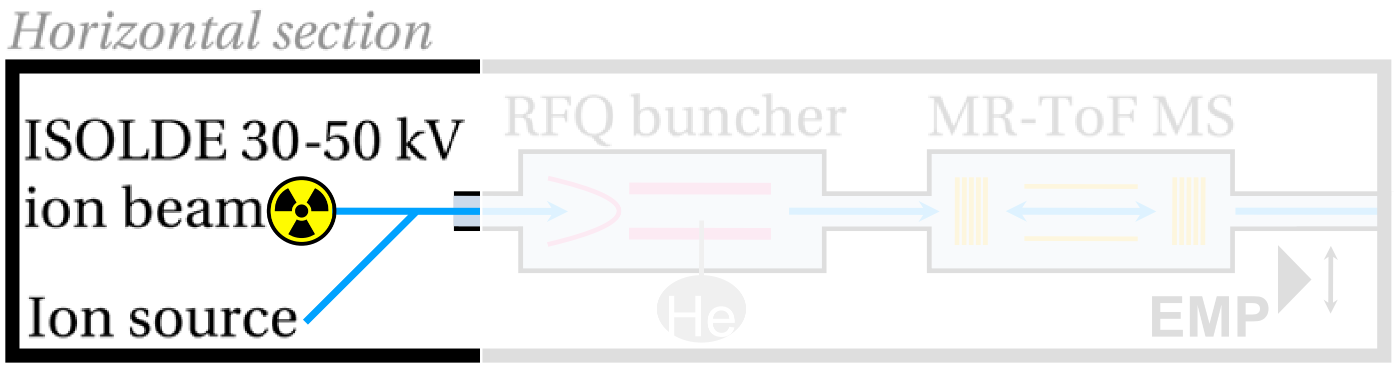

ISOLTRAP
ISOLTRAP

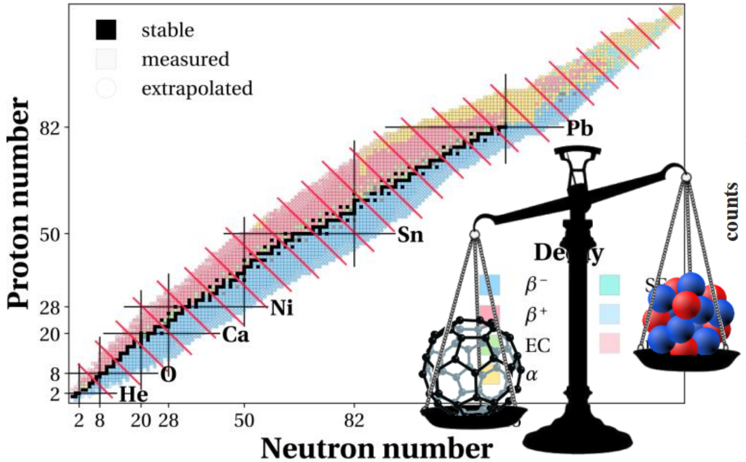
Laser-Ablation Ion Source + Alkali Ion Source
2020

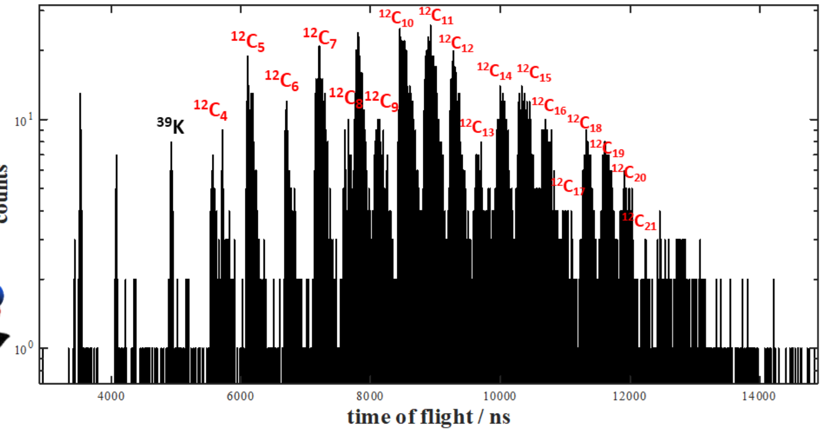


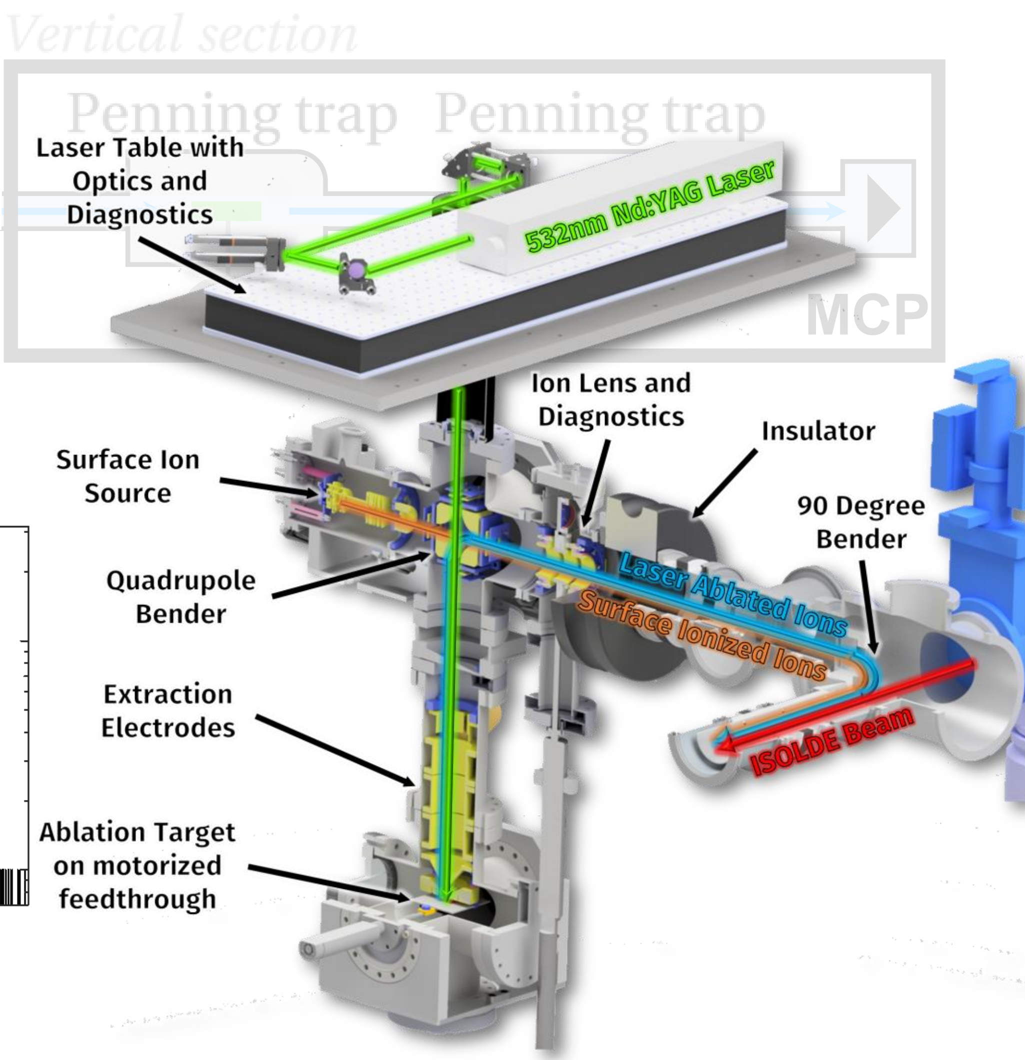


Laser-Ablation Ion Source



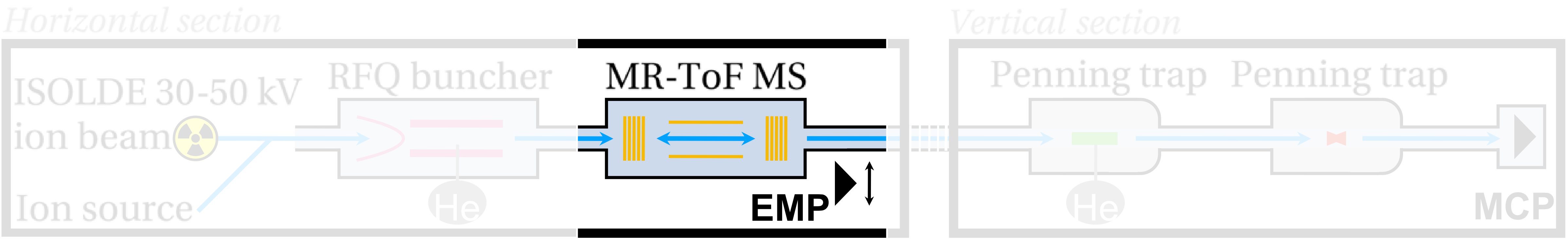


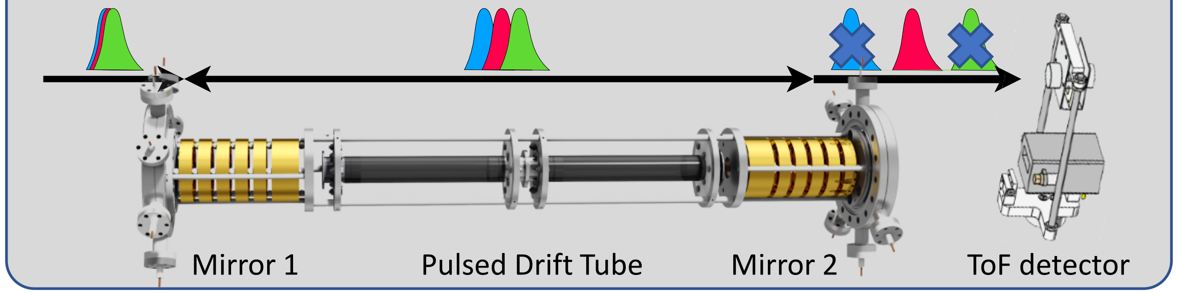


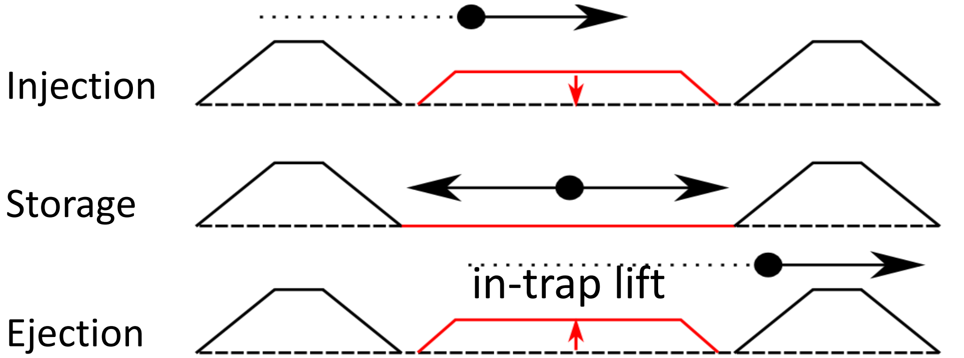


L. Nies, in preparation

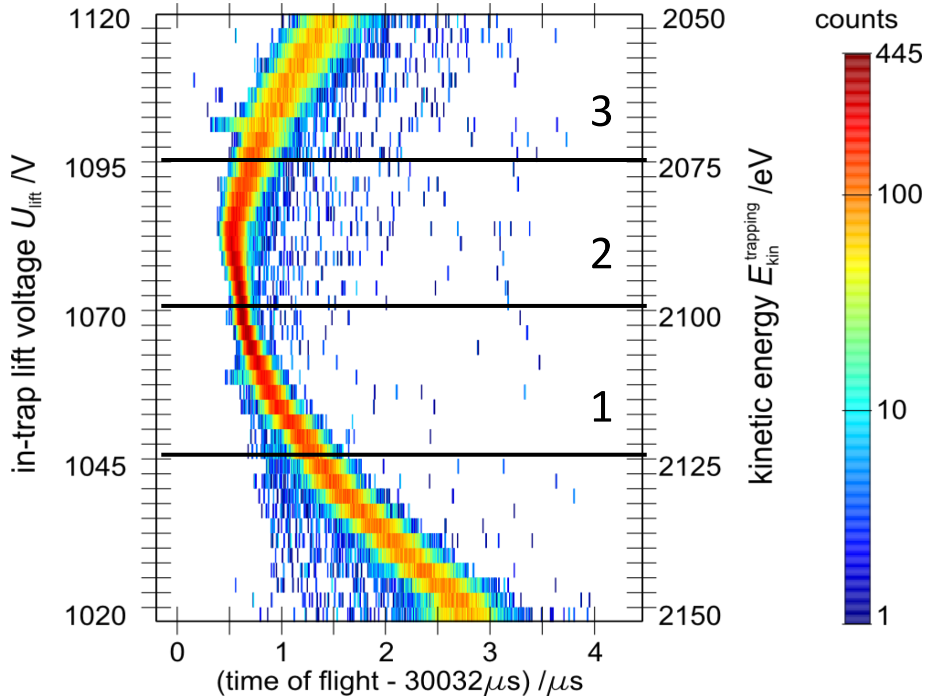
Multi-Reflection Time-of-Flight Device



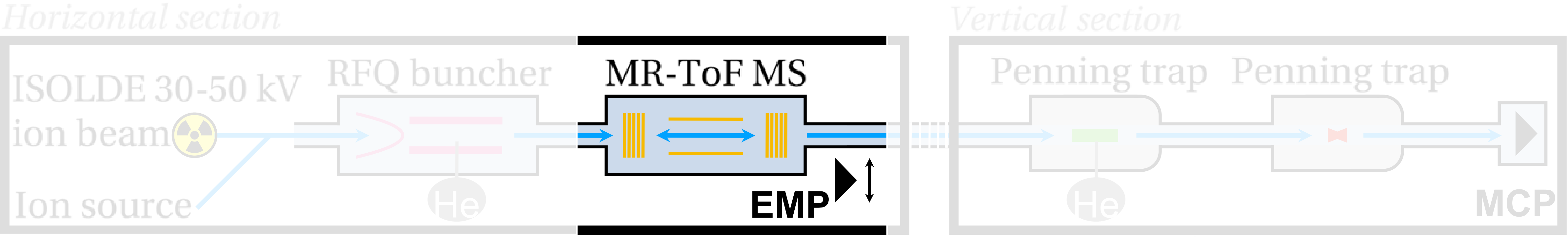


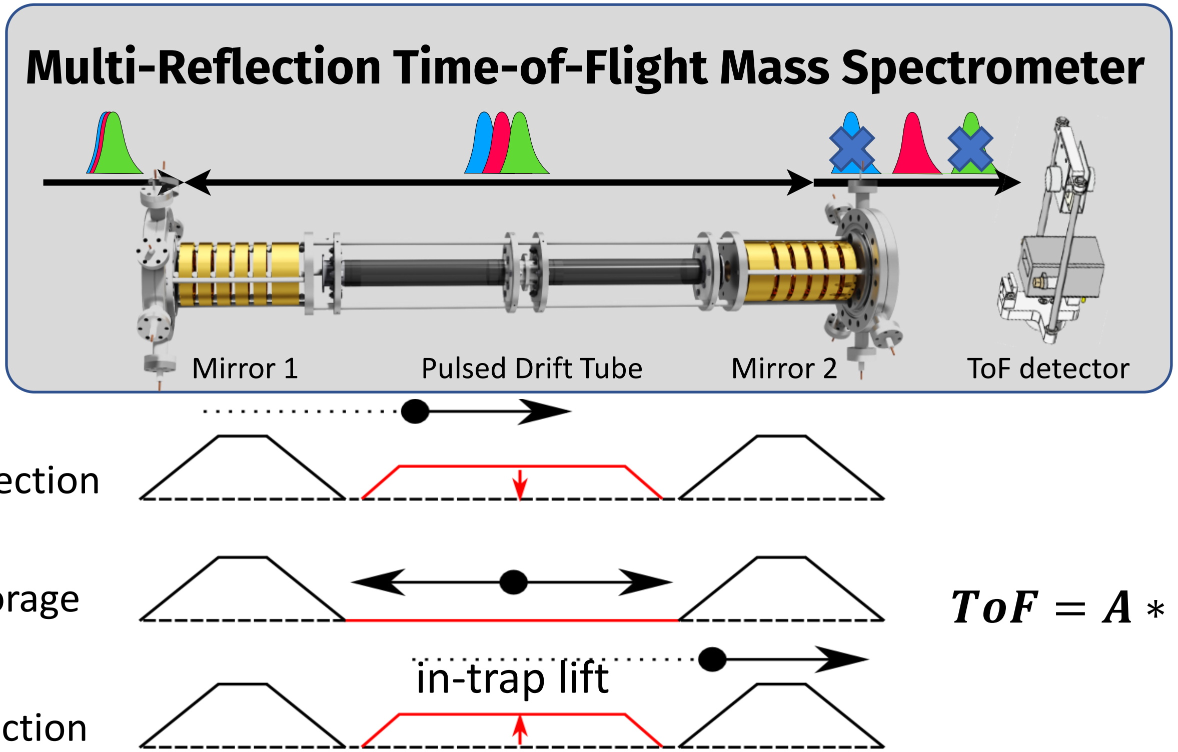


$$ToF = A * \sqrt{\frac{m_{ion}}{q}} + B$$



Multi-Reflection Time-of-Flight Device





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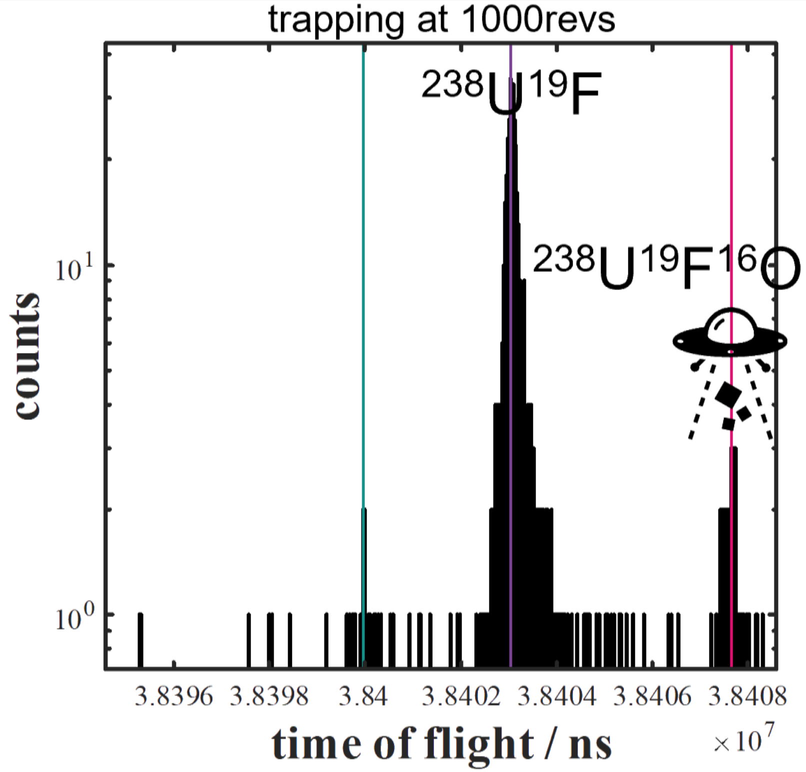
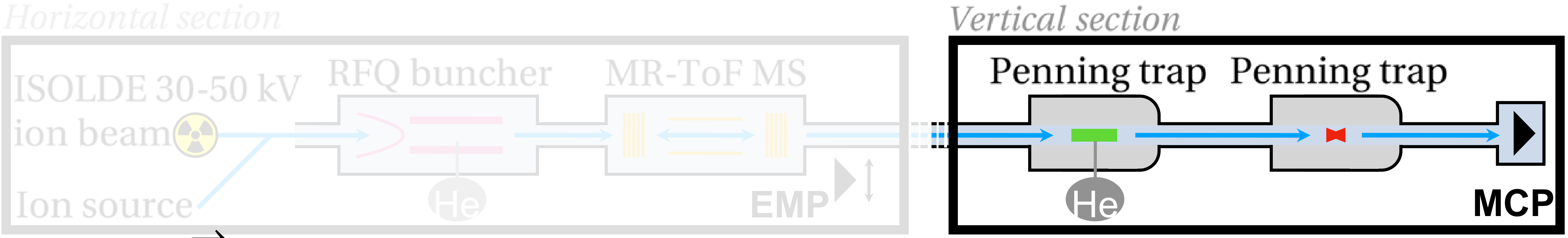
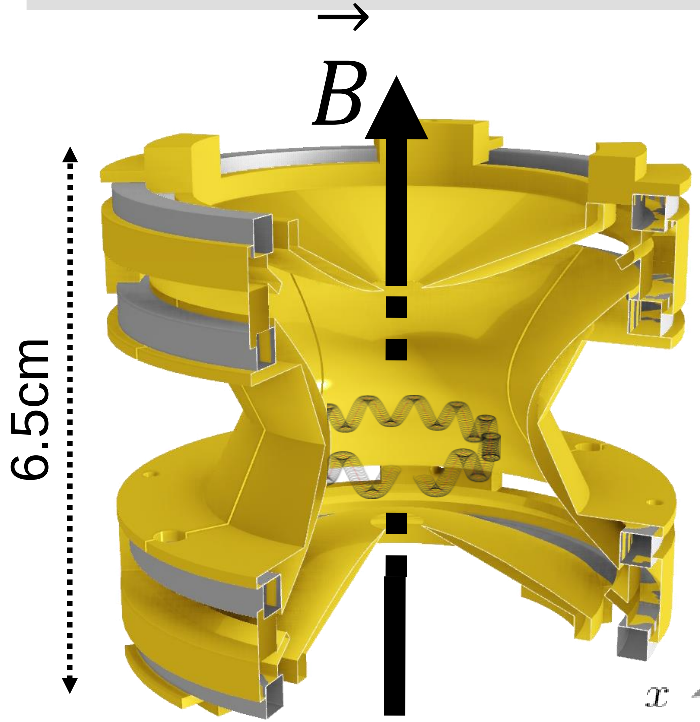
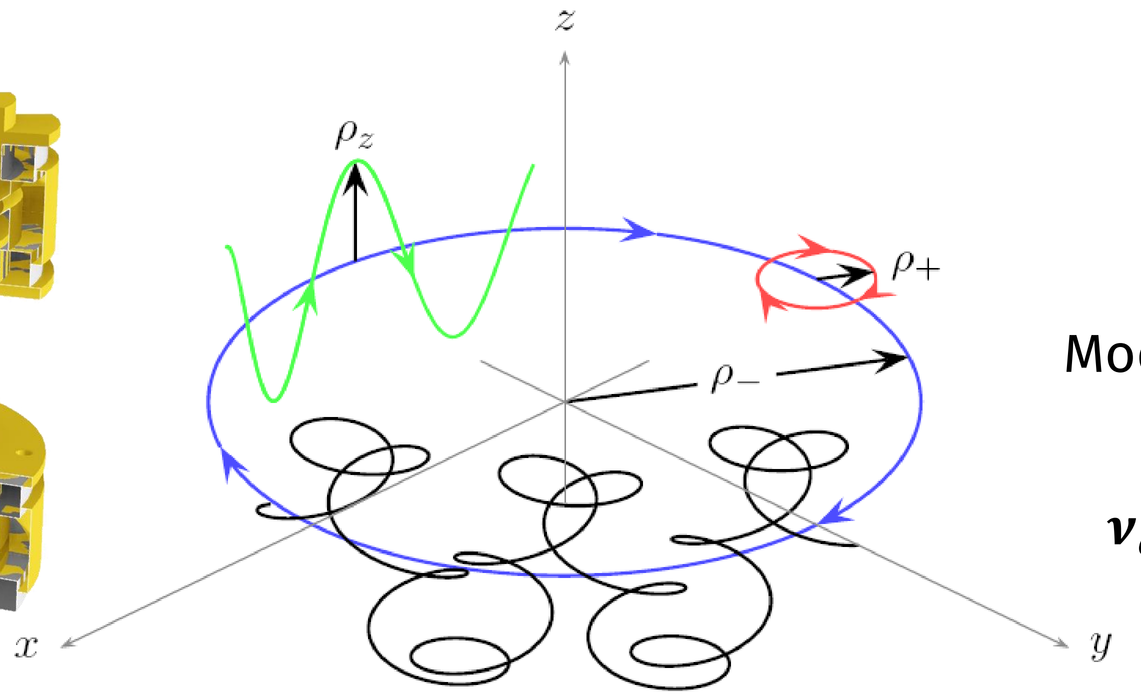


Tandem Penning Trap







Magnetron motion

$\nu_- \ll \nu_c$

Modified cyclotron motion

$\nu_+ \approx \nu_c$

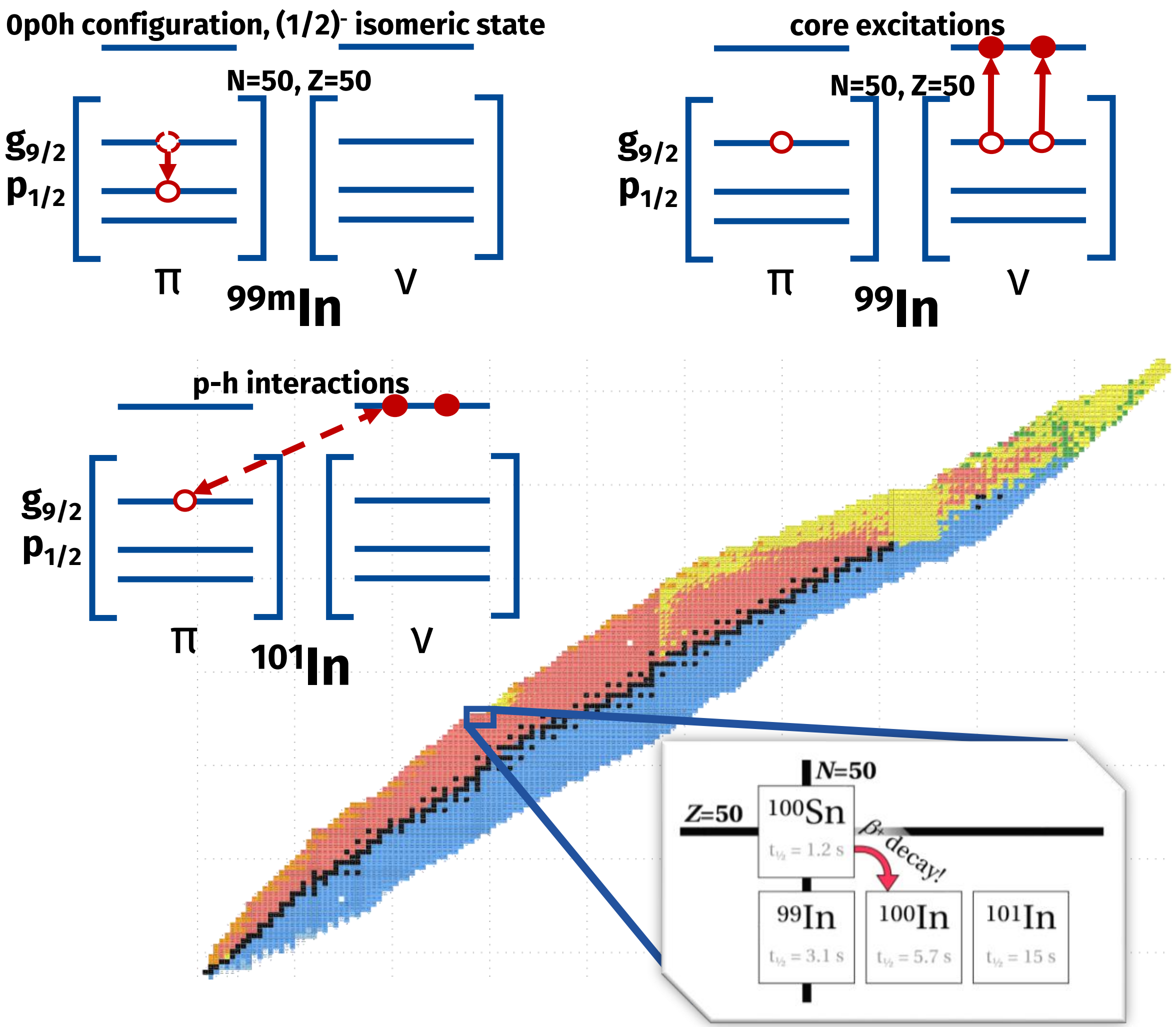
$$\nu_c = \nu_+ + \nu_- = \frac{qB}{2\pi m_{ion}}$$

Lukas Nies
ISOLTRAP Collaboration

Masses of neutron-deficient indium

Shell evolution around ^{100}Sn

- Nuclear shell model predicts shell closures (magic numbers)
- Model calculations perform well for closed shells + few nucleons in valence space
- Vicinity of doubly magic *N* = *Z* = 50 **^{100}Sn** ideal case for shell model studies
- Neutron deficient In isotopes as **^{100}Sn** core with single p-hole and n or n-holes
- Direct mass-measurements probe:
  -> **single-particle states in ^{100}Sn**
  -> **core-excitation** dependent energy shifts
  -> **particle-hole interactions**



Lukas Nies
ISOLTRAP Collaboration

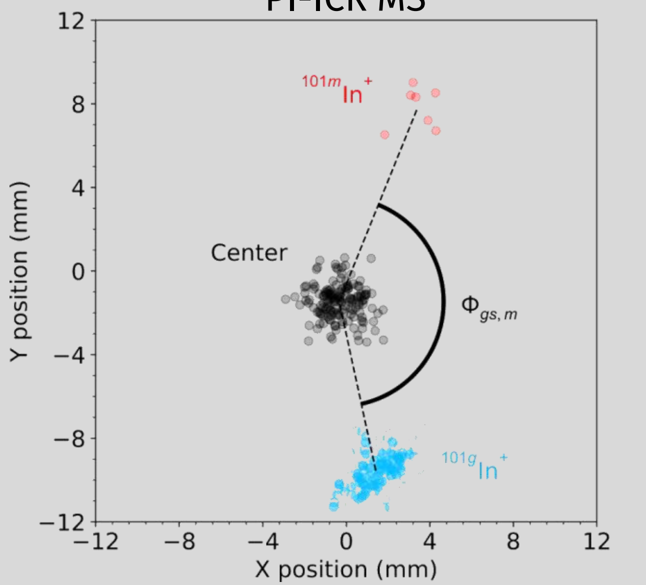
Masses of neutron-deficient indium

Published in M. Mougeot *et al.*, Nature Physics 17, 1099–1103 (2021) and L. Nies, in preparation

^{101m,gs}In

- Resolving power >10^6 in t_{acc} = 65ms
- Uncertainty < 10 keV
- Agrees with and **improves on previous measurements [3-4]**

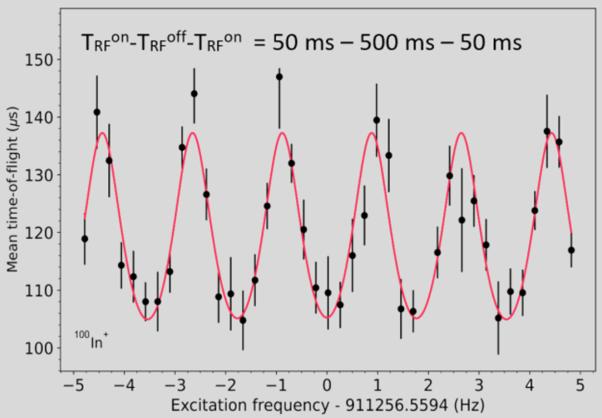
PI-ICR MS



^{100}In

- ~ keV precision (90 times more precise)
- PI-ICR study —> No long lived isomers
- Reduction of ^{100}Sn g.s. mass unc. from **300kev to 240keV**
- Suggests **validity of Q-value from [1] over [2]**

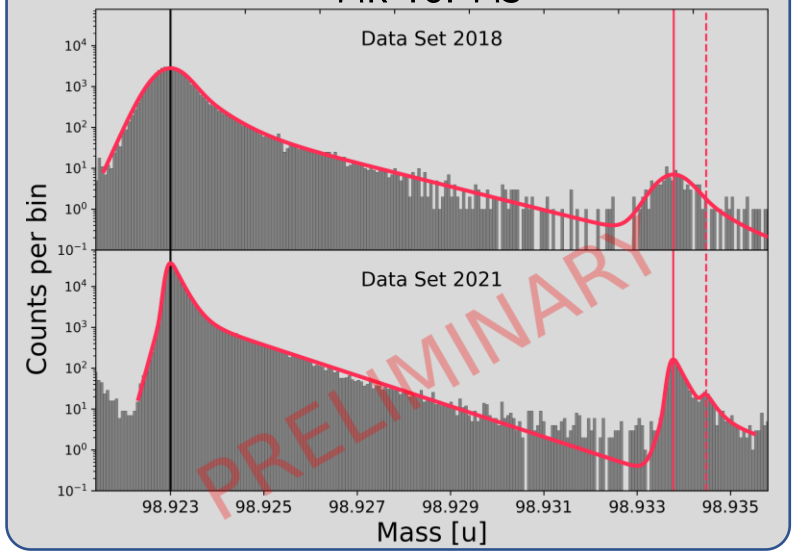
ToF-ICR MS



^{99gs,m}In

- Well separated from contamination, $5x10^5$ mass res. power
- Element ID through laser on/off effect and ToF
- **First mass measurement of g.s. and isomer**

MR-ToF MS

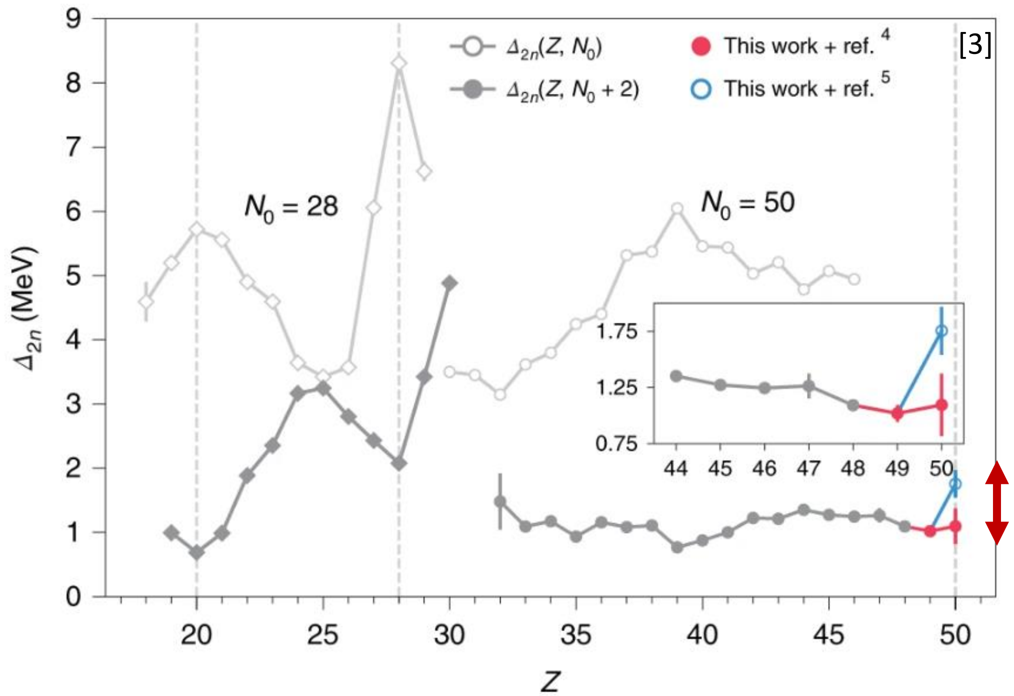


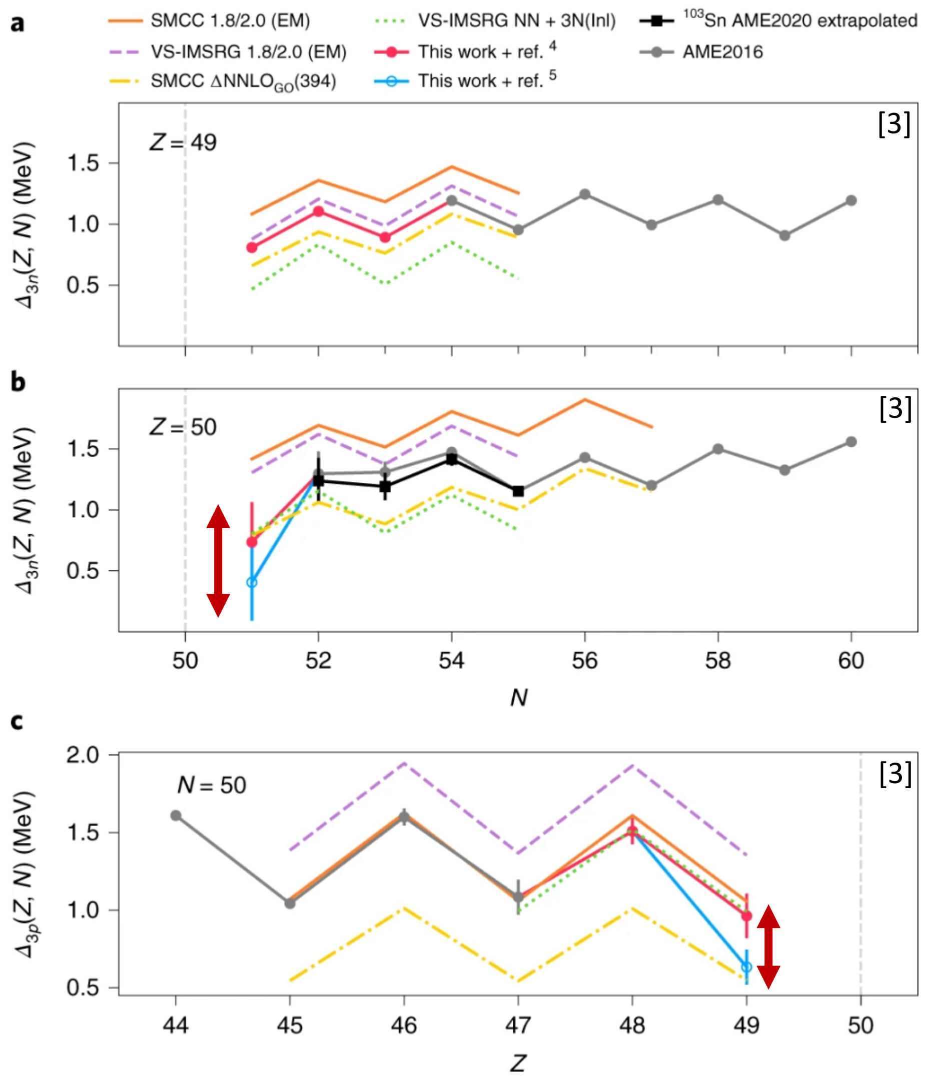
[1] Hinke et al., Nature **486,** 341-345 (2012)
[2] Lubos et al, PRL **122**, 222502 (2019)
[3] C. Hornung *et al.*, Phys. lett. B 802, 135200 (2020)
[4] X. Xu *et al.*, Phys. Rev. C 100(5), 051303(R) (2019)

Back to binding energies: Q-value questions…

- Mass of ^{100}**Sn** improved by 60 keV based on Q-value to ^{100}In [1-2]
- in-accurate **mass** for ^{103}Sn derived from Q-values **rejected** from AME2020
- extrapolated masses yield more consistent behavior
- direct mass-measurement to confirm expected behavior of mass filters

$$\Delta_{3n}(Z,N) = 0.5\times(-1)^N\,[B(Z,N-1) - 2B(Z,N) + B(Z,N+1)]$$



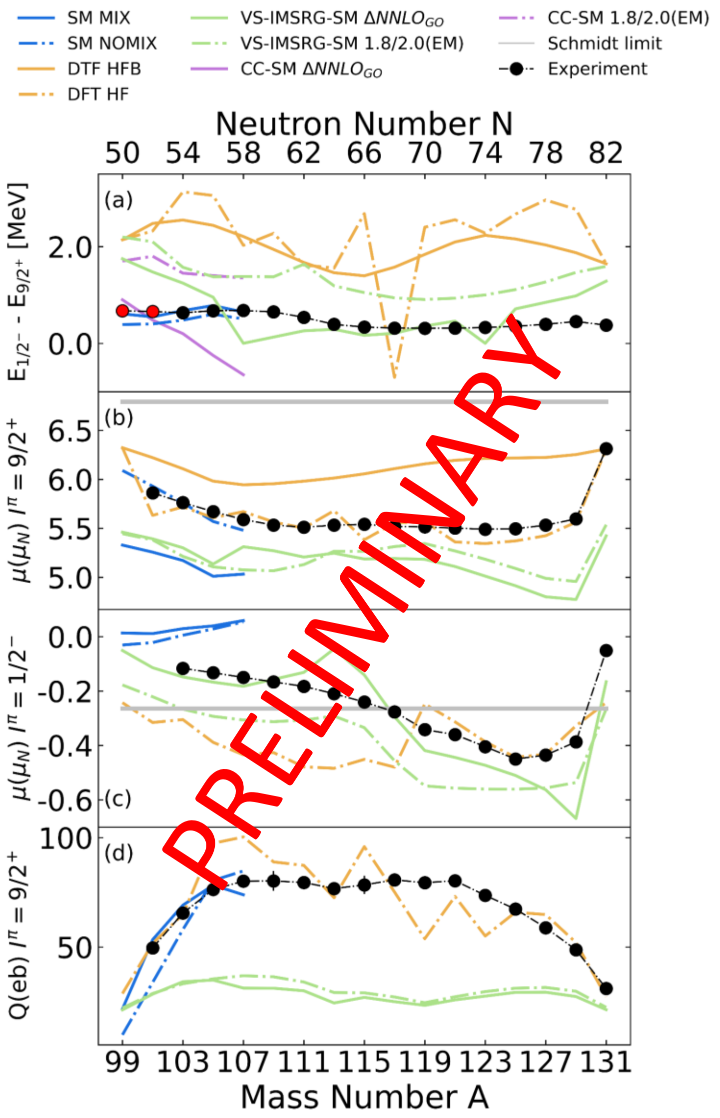


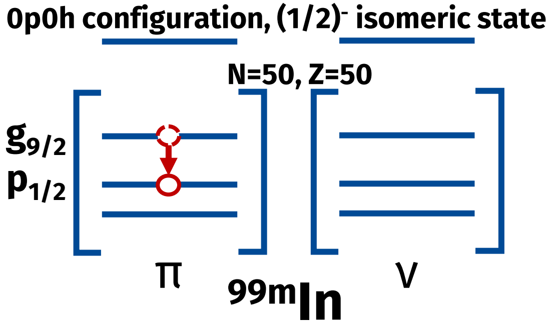
[1] Hinke et al., Nature **486,** 341-345 (2012)
[2] Lubos et al, PRL **122**, 222502 (2019)
[3] M. Mougeot et al., Nature Physics 17, 1099–1103 (2021)

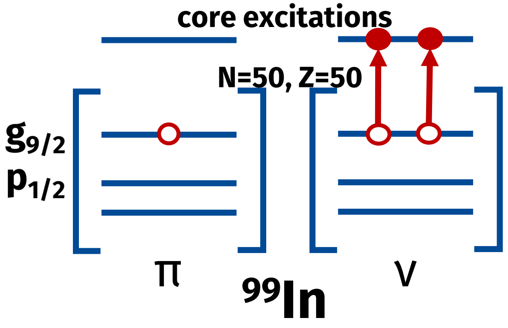
Lukas Nies
ISOLTRAP
Collaboration

What about the moments?

- **Magnetic dipole** moment very well reproduced by DFT with time-odd fields [1]
- LS-SM nomix unexpectedly more accurate, probably due to effective charge tuning
- Only VS-IMSRG somewhat successful in describing **½- dipole moment**, more moments data to be published soon by CRIS/ISOLDE
- **Quadrupole moments** reproduced rather well by LSSM and DTF w/ t-odd fields







Modern nuclear theory challenged in "simple" single-particle hole state model for ^{99}In

D. Atanasov, K. Blaum,
J. Karthein, Yu. Litvinov,
D. Lunney, V. Manea,
M. Mougeot, L. Nies,
Ch. Schweiger,
L. Schweikhard,
F. Wienholtz, *et al.*

Federal Ministry of Education and Research

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