High-precision mass measurements for reliable nuclear-astrophysics calculations

Alexander Herlert

CERN, PH-IS

High-precision mass measurements for reliable nuclear-astrophysics calculations

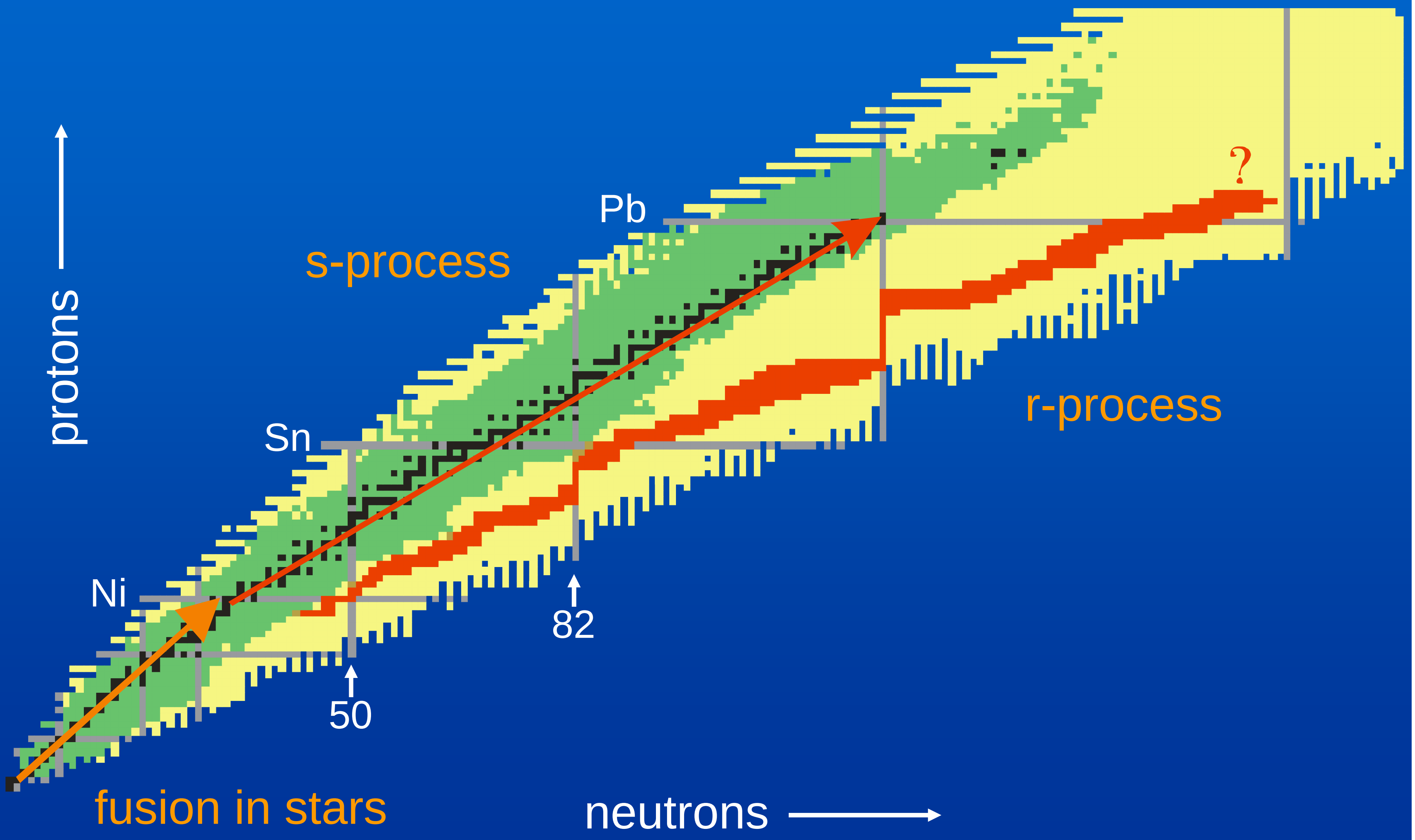
Atomic masses of radionuclides

The ISOLTRAP experiment

Principle of mass measurement

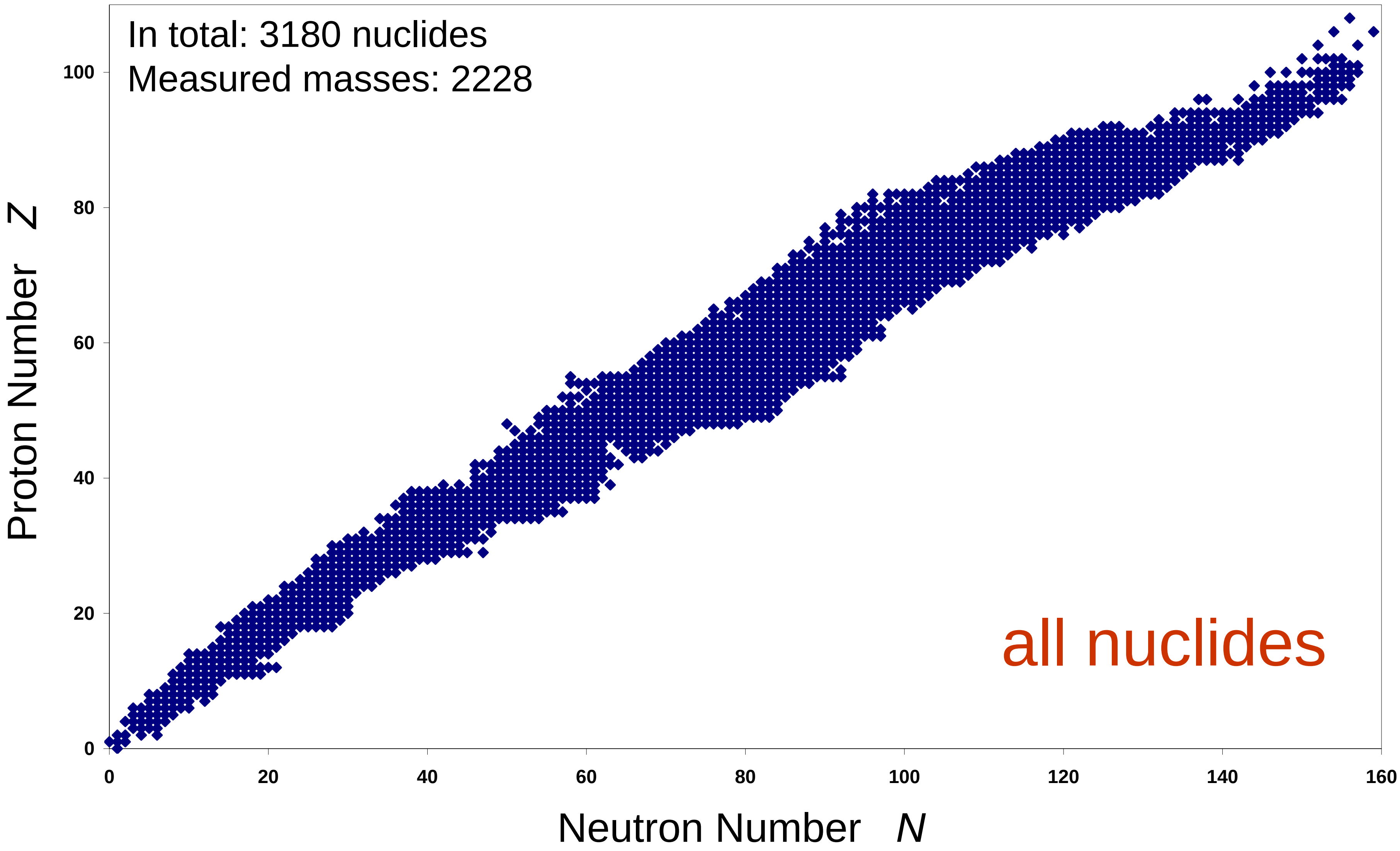
Recent experimental results

Nucleosynthesis and r-process



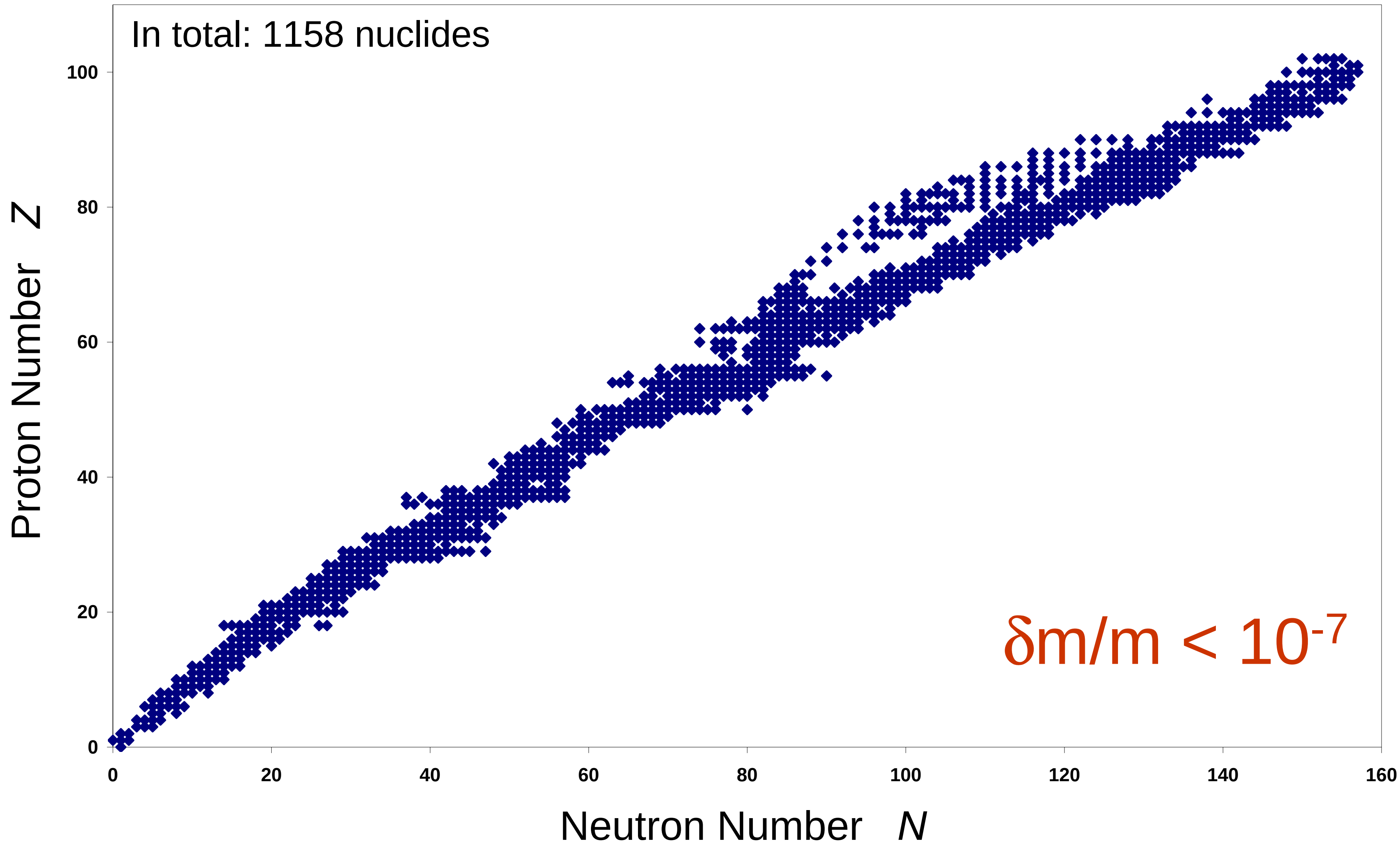
courtesy: K. Blaum, H. Schatz

Atomic Mass Evaluation 2003



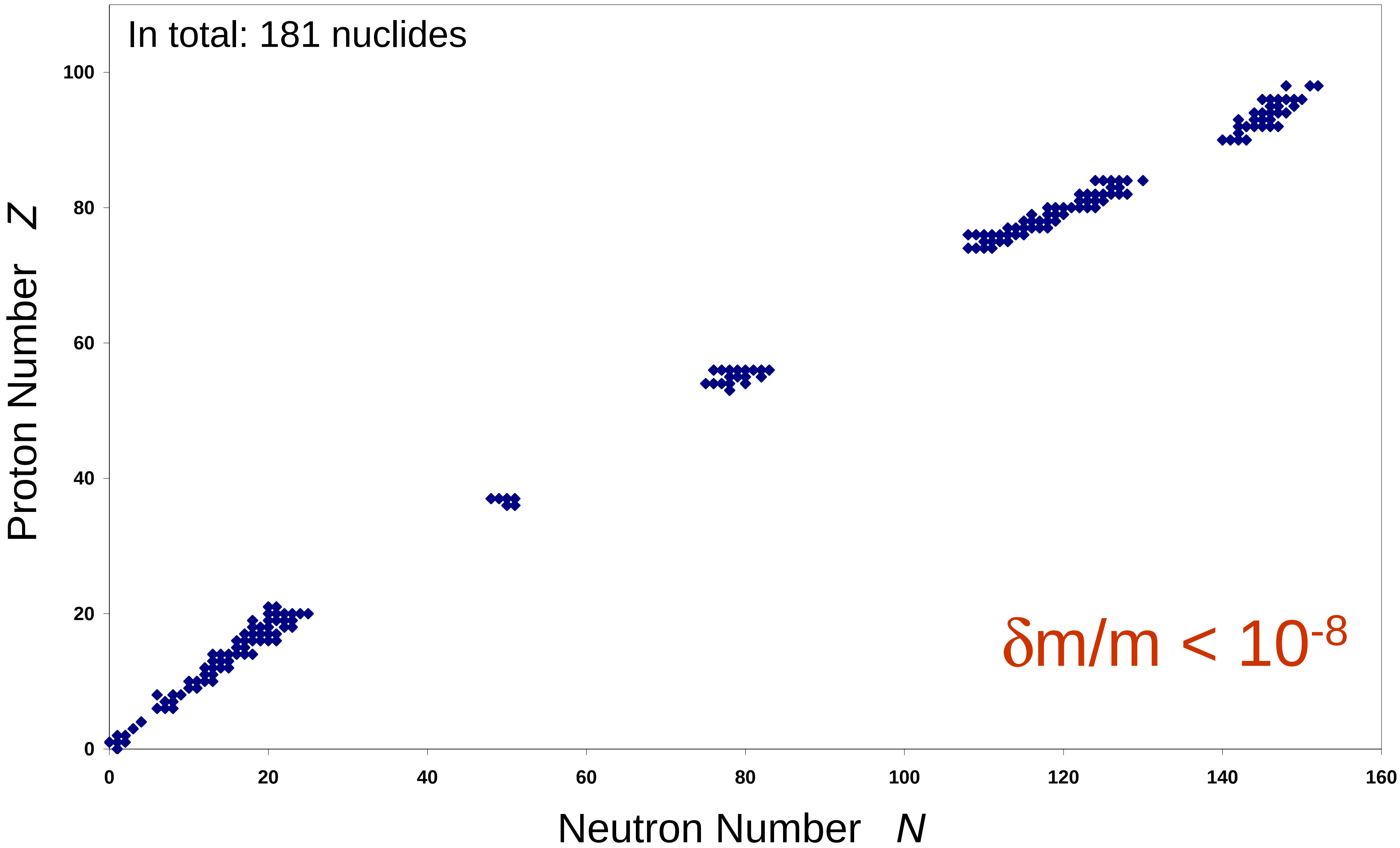
G. Audi, A.H. Wapstra, C. Thibault, Nucl. Phys. A 729

Atomic Mass Evaluation 2003



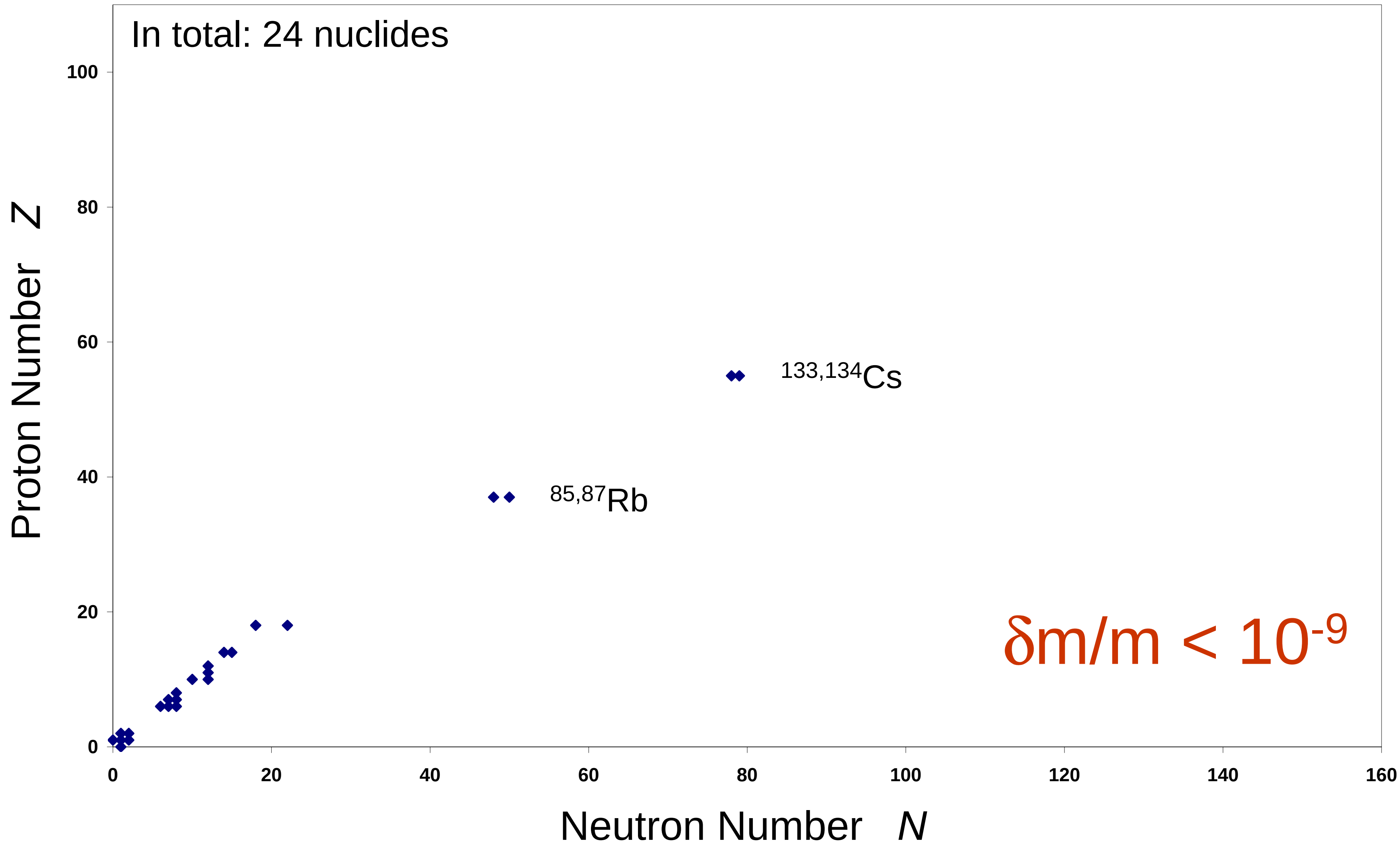
G. Audi, A.H. Wapstra, C. Thibault, Nucl. Phys. A 729

Atomic Mass Evaluation 2003



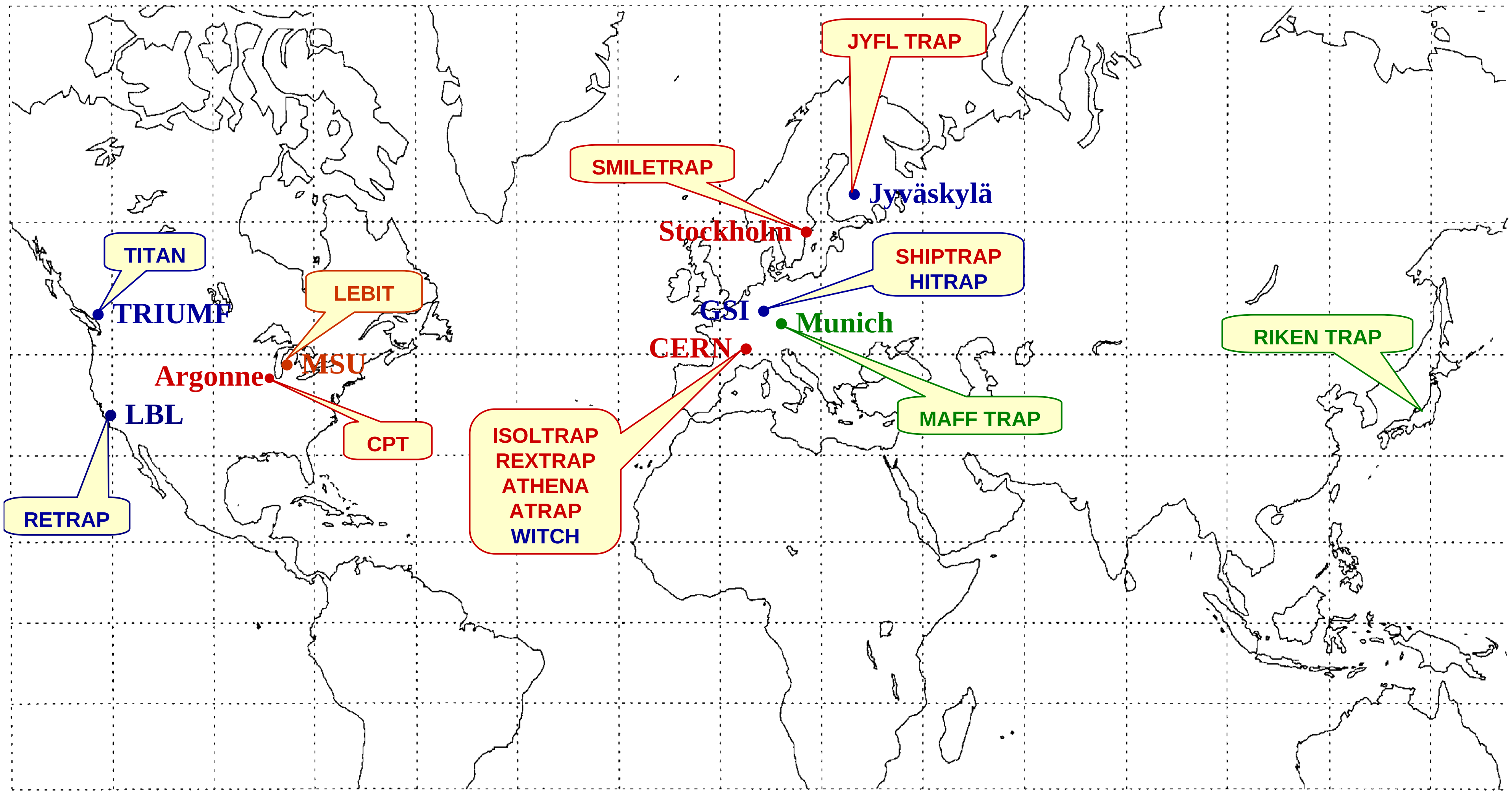
G. Audi, A.H. Wapstra, C. Thibault, Nucl. Phys. A 729

Atomic Mass Evaluation 2003



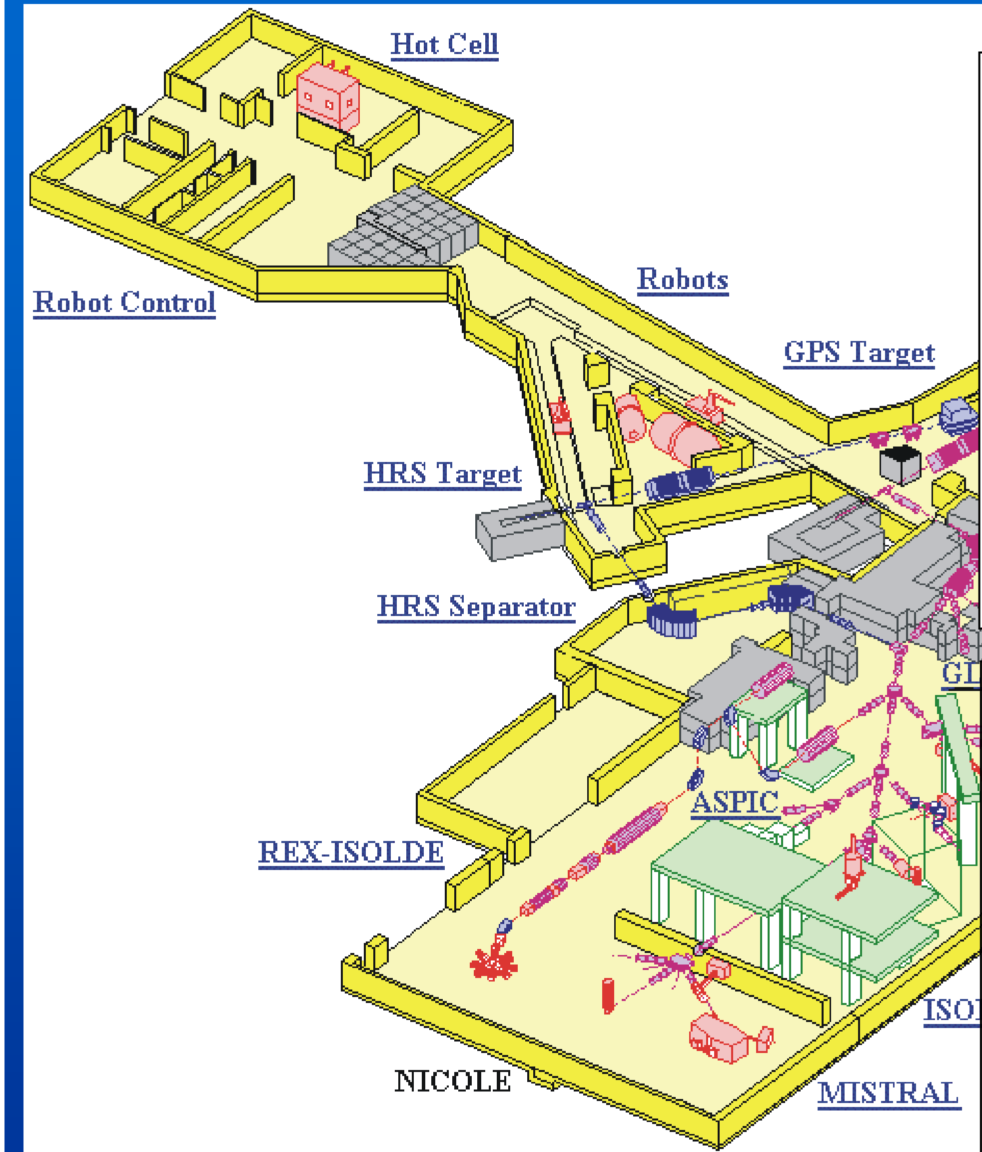
G. Audi, A.H. Wapstra, C. Thibault, Nucl. Phys. A 729

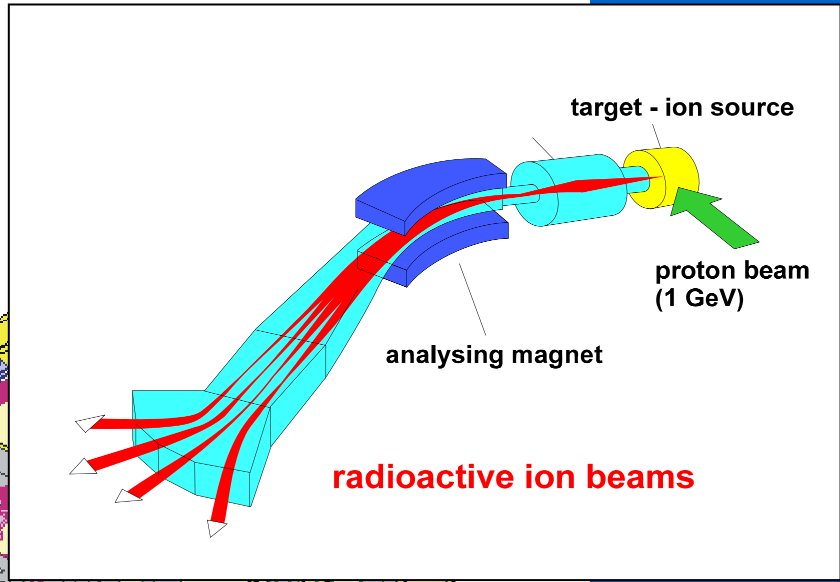
Penning traps at accelerators

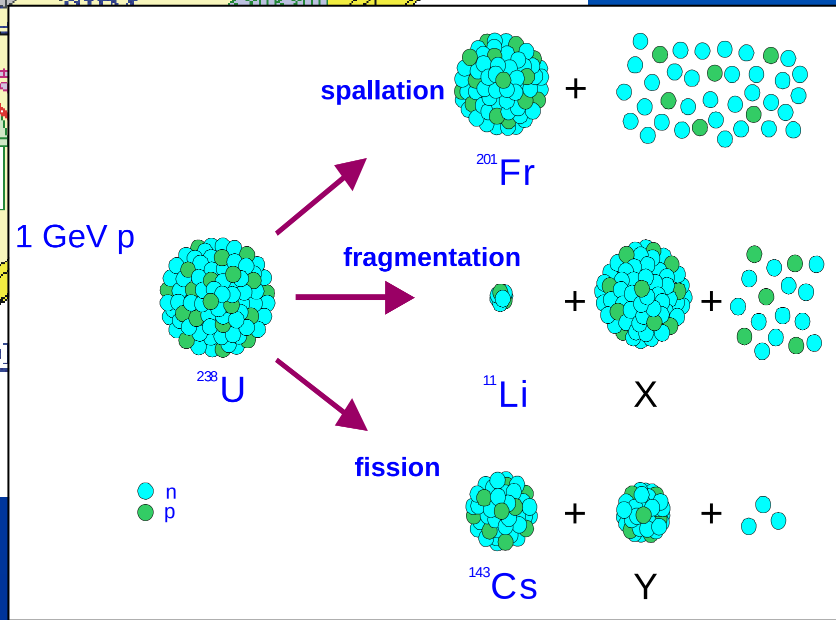


• operating facilities • facilities under construction or test • planned facilities

Production of radioactive nuclides at ISOLDE

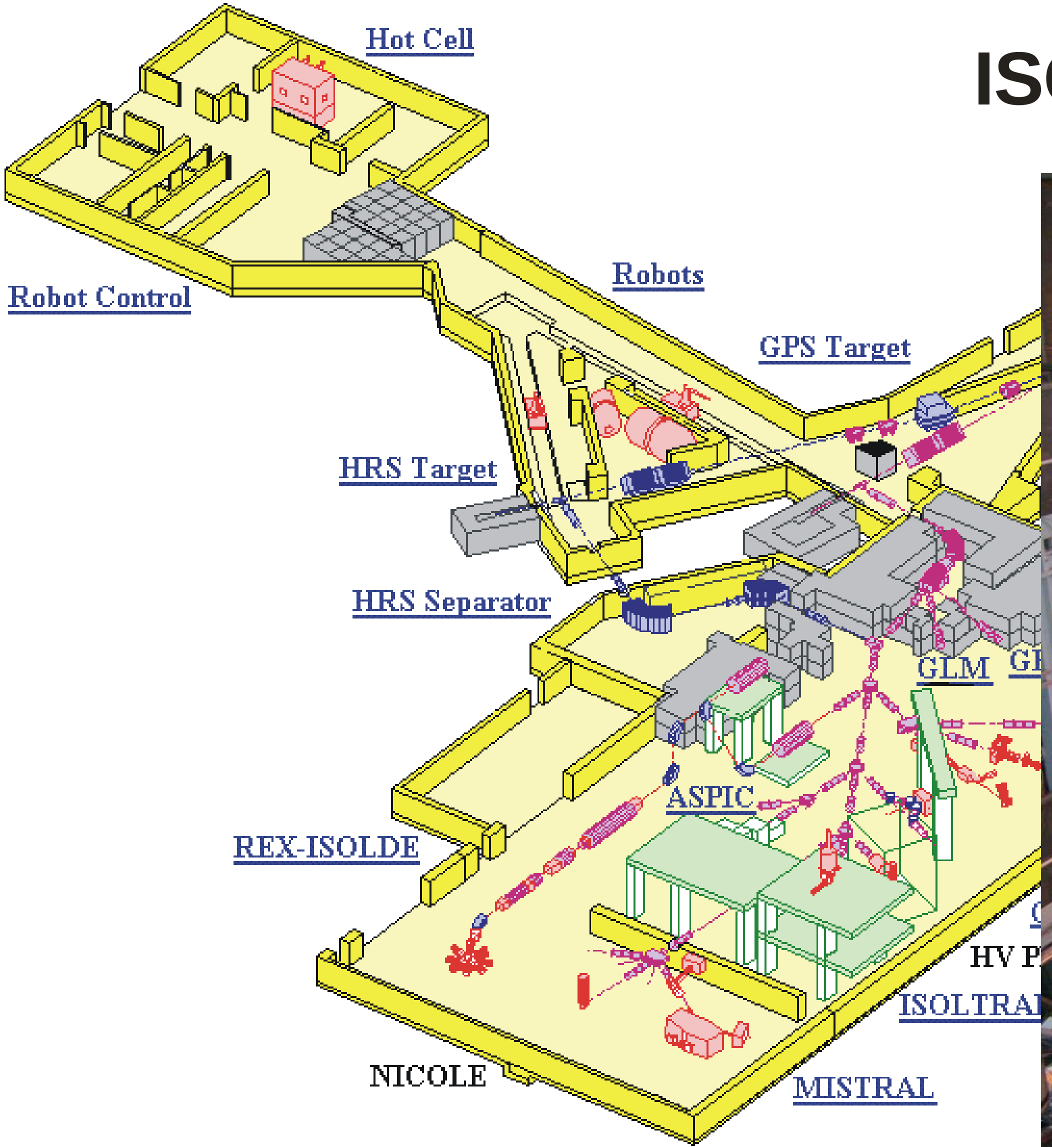


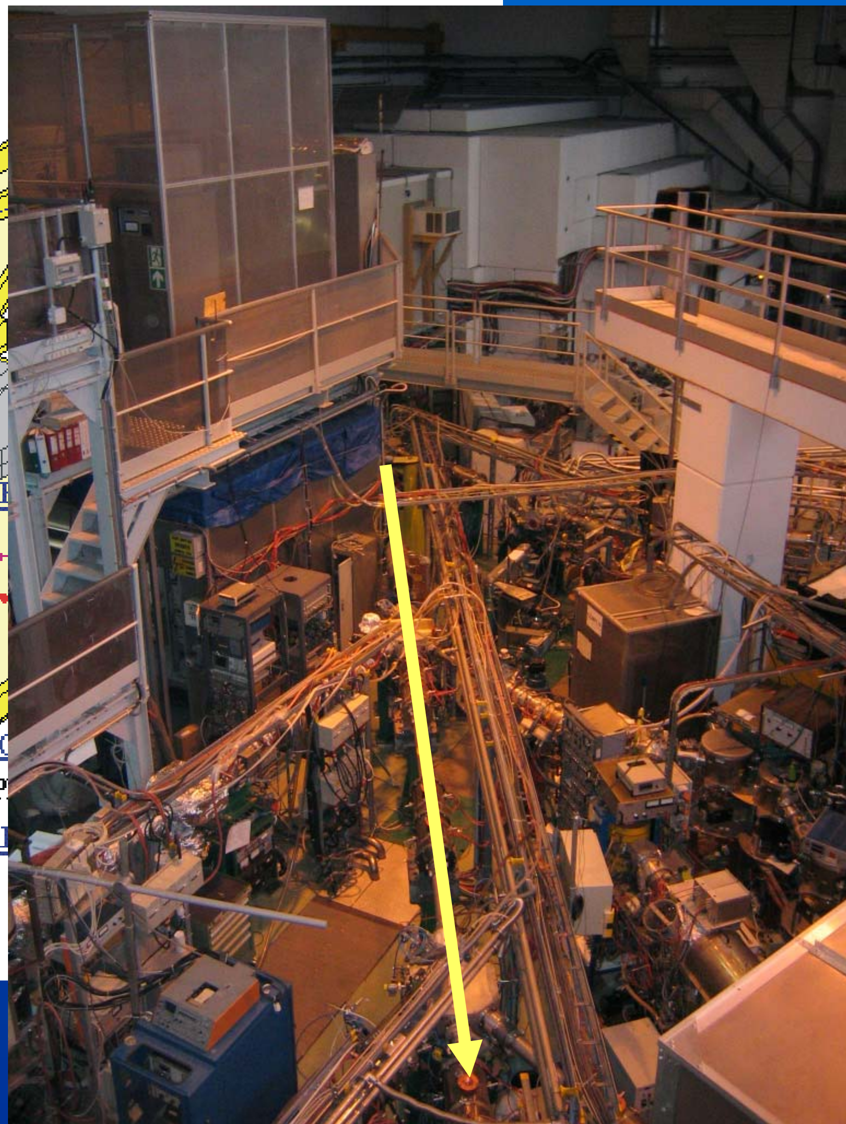




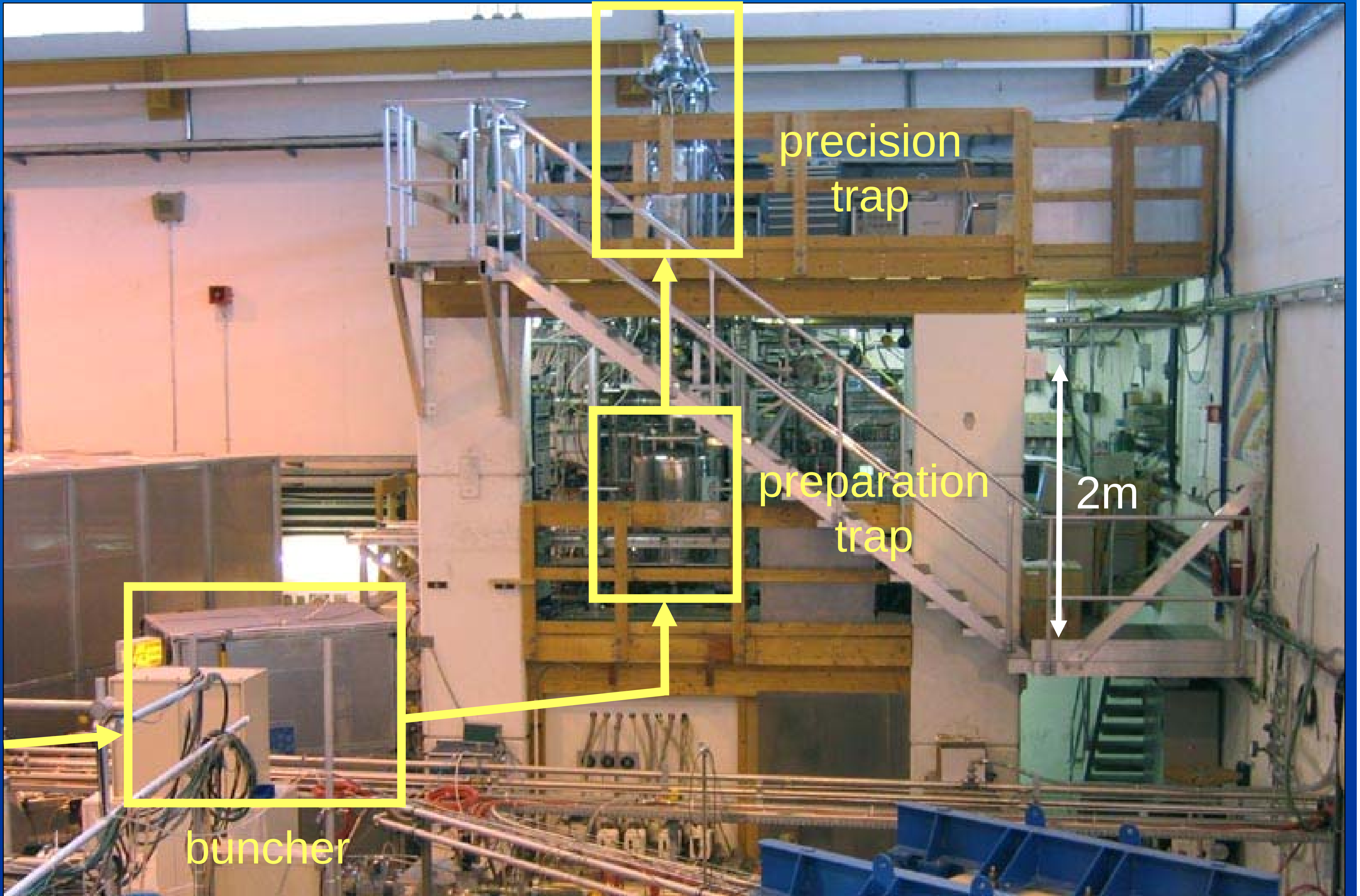
Production of radioactive nuclides at ISOLDE

ISOLDE/CERN

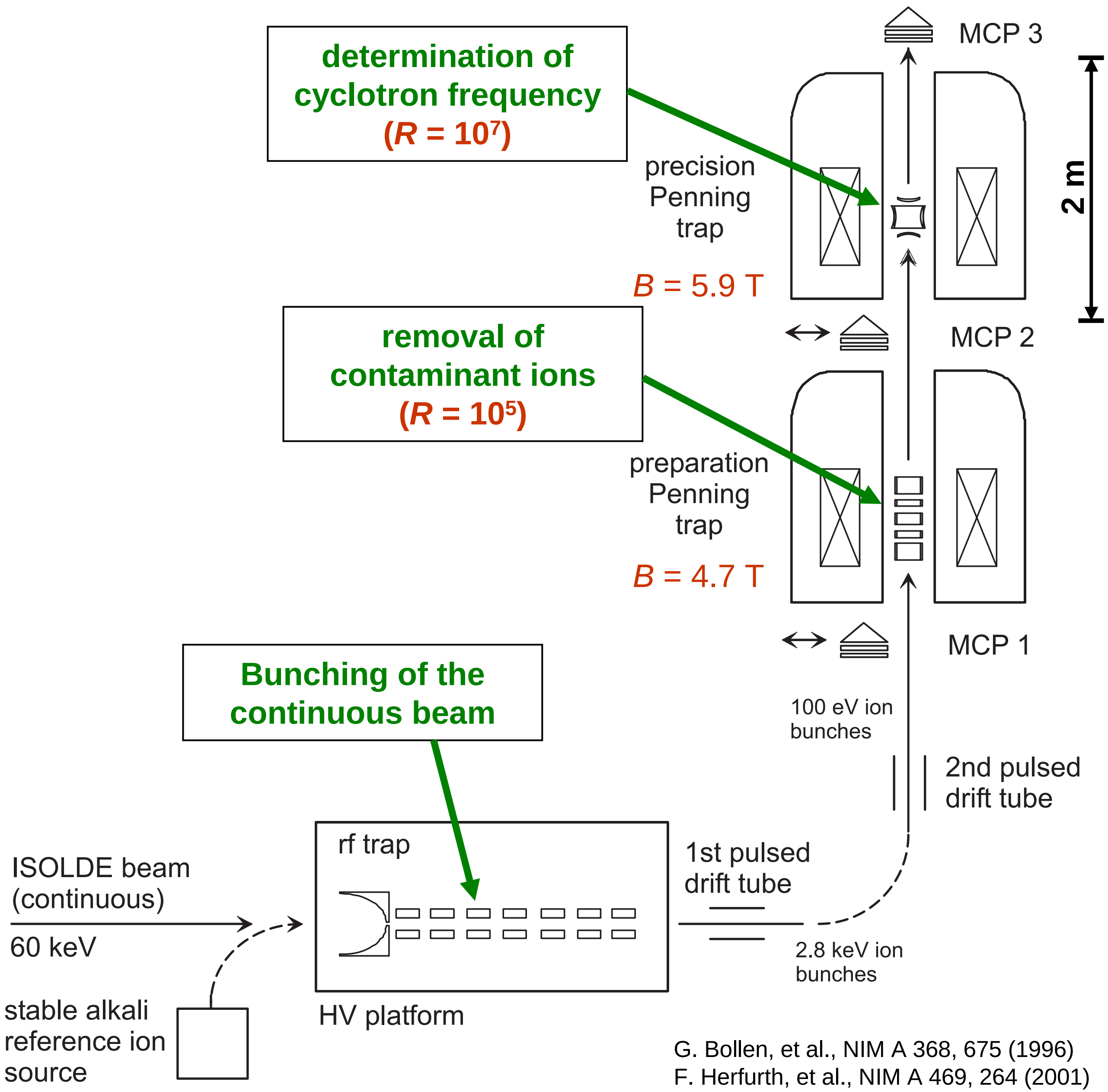




ISOLTRAP: Experimental setup

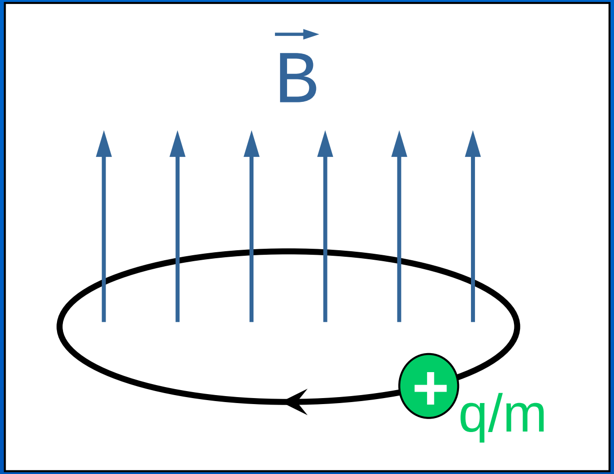


ISOLTRAP: Experimental setup



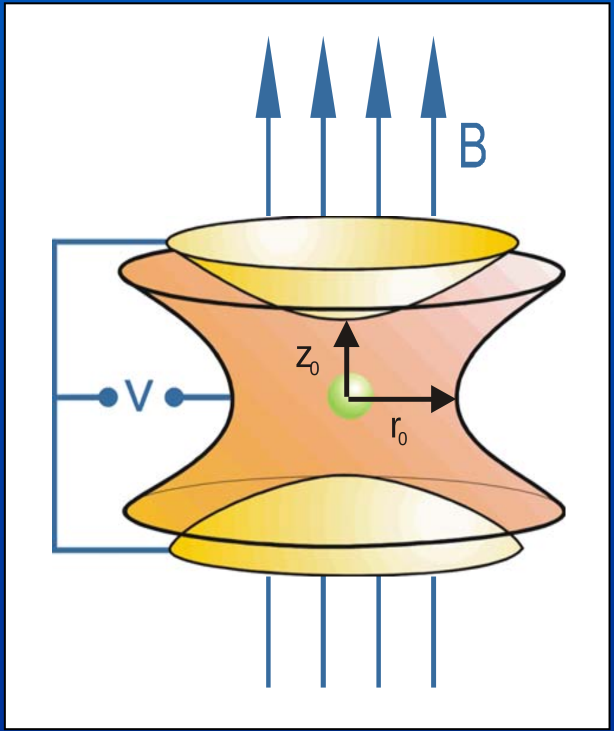
G. Bollen, et al., NIM A 368, 675 (1996)
F. Herfurth, et al., NIM A 469, 264 (2001)

Principle of mass determination

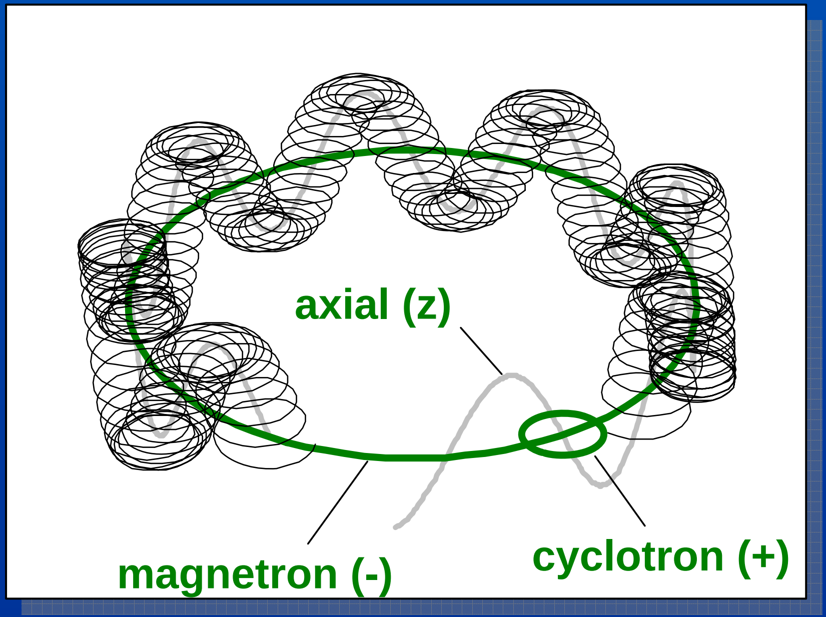


measurement of cyclotron frequency

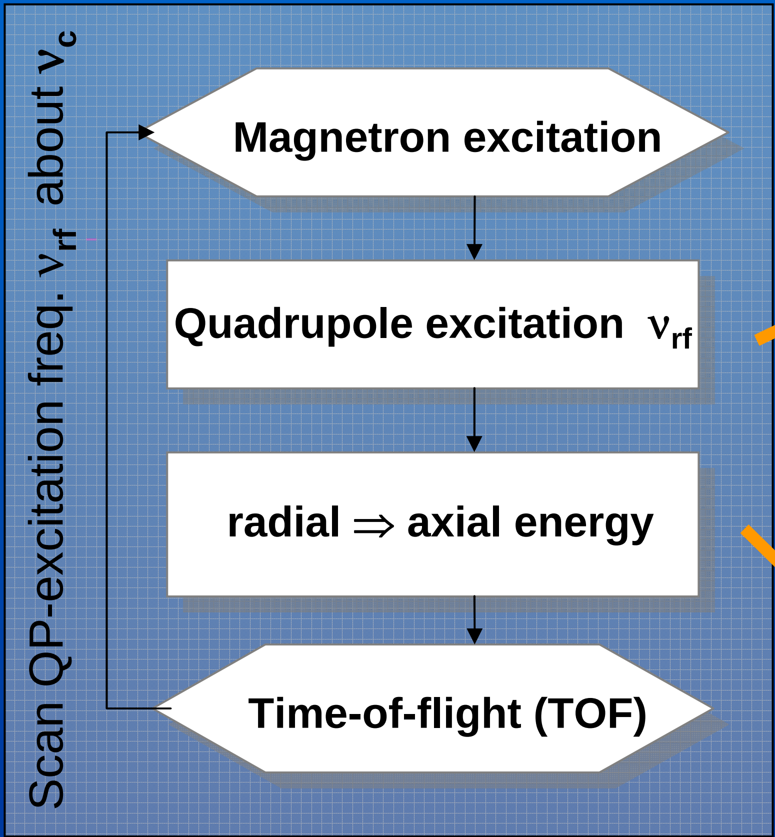
$$\nu_c = \frac{1}{2\pi}\frac{q}{m}B$$



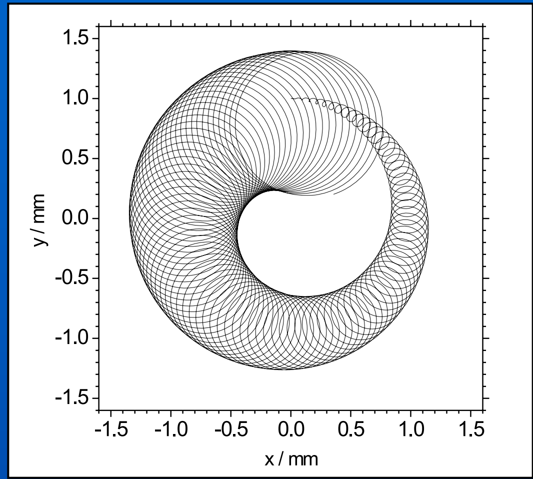
motional modes of ion stored
in a Penning trap

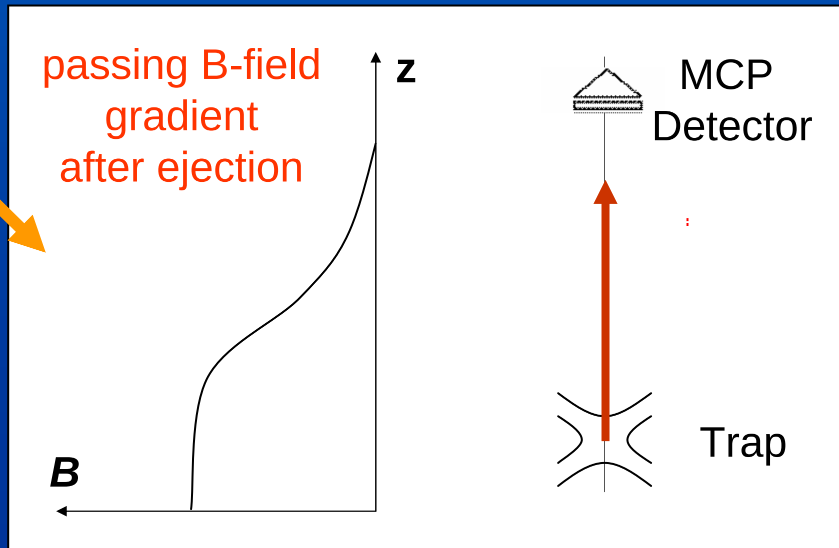


Principle of mass determination



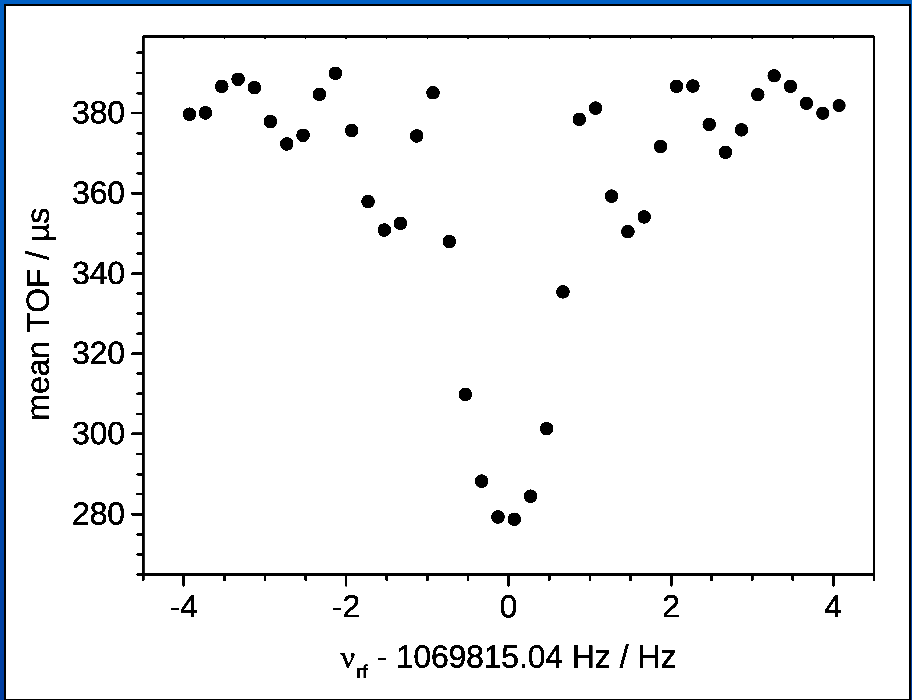
Conversion of magnetron into cyclotron motion



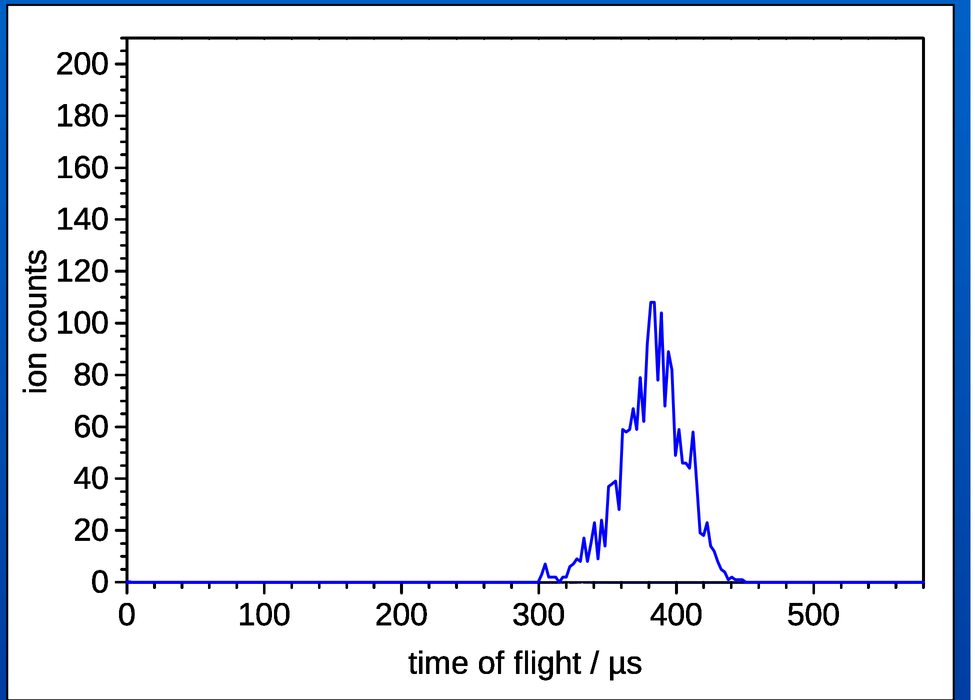


Principle of mass determination

mean TOF



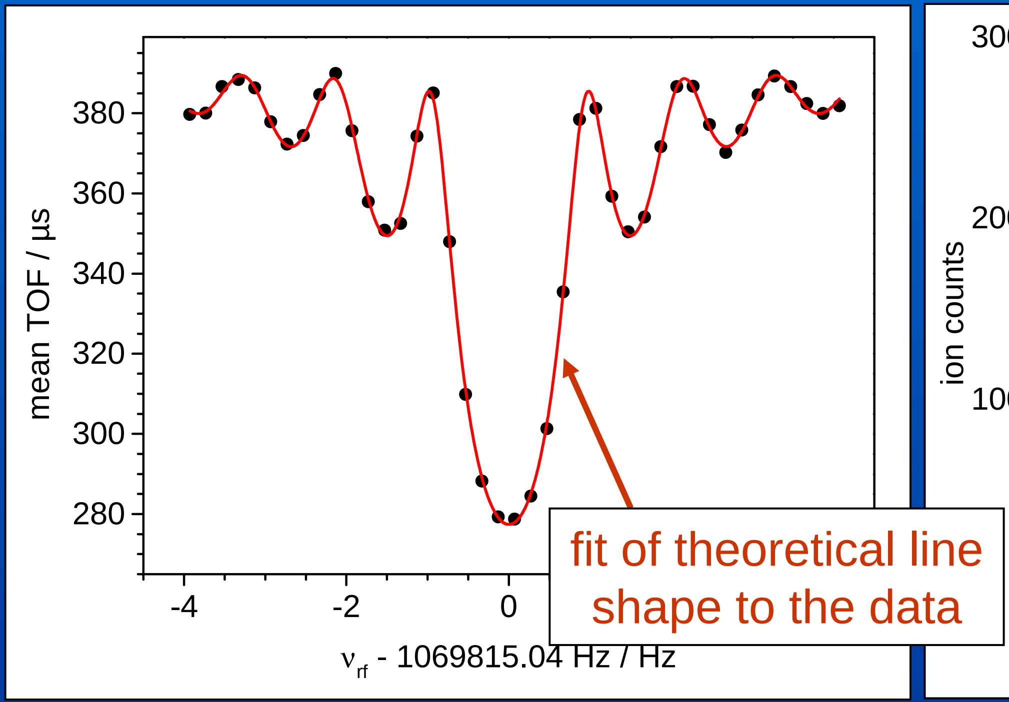
TOF spectrum



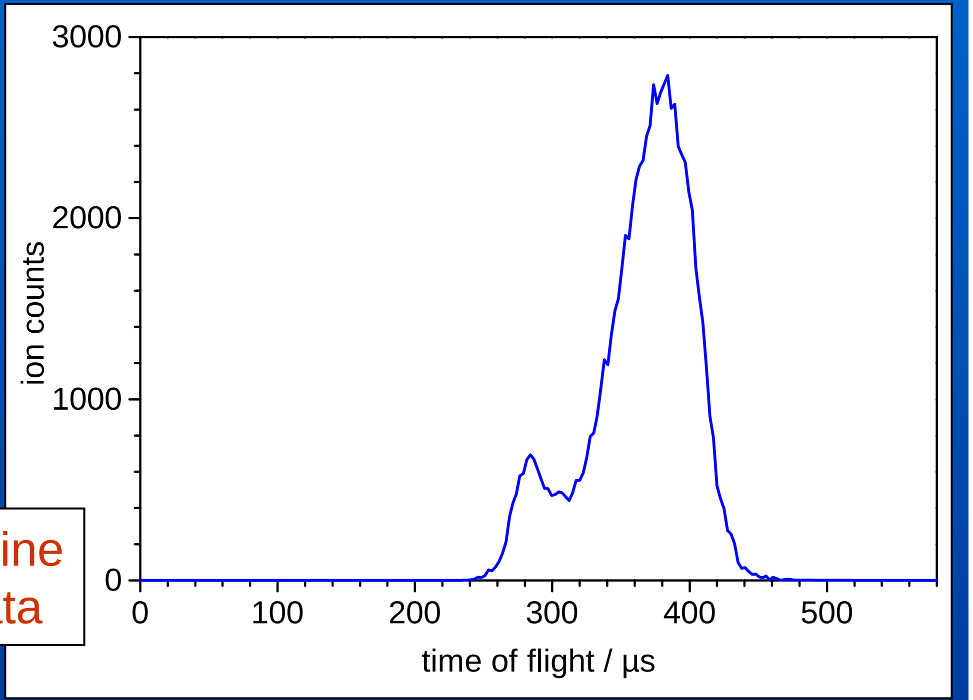
Example: ^{85}Rb (900ms excitation duration)

Principle of mass determination

mean TOF



TOF spectrum



Example: ^{85}Rb (900ms excitation duration)

Principle of mass determination

ISOLTRAP

cyclotron frequency
of "unknown" nuclide

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

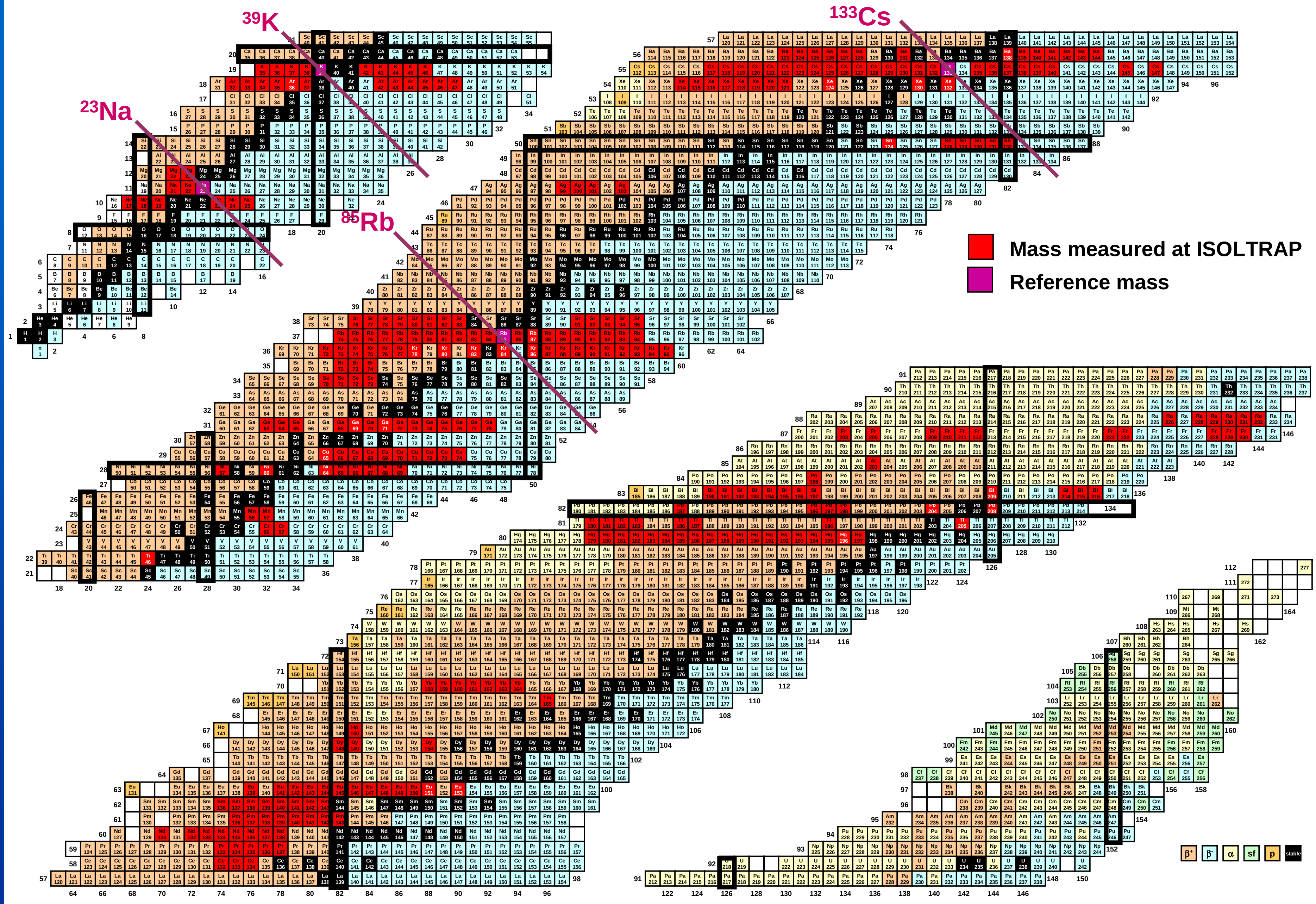
cyclotron frequency
of well-known nuclide

$$\nu_{c,ref} = \frac{1}{2\pi}\frac{q}{m_{ref}}B$$

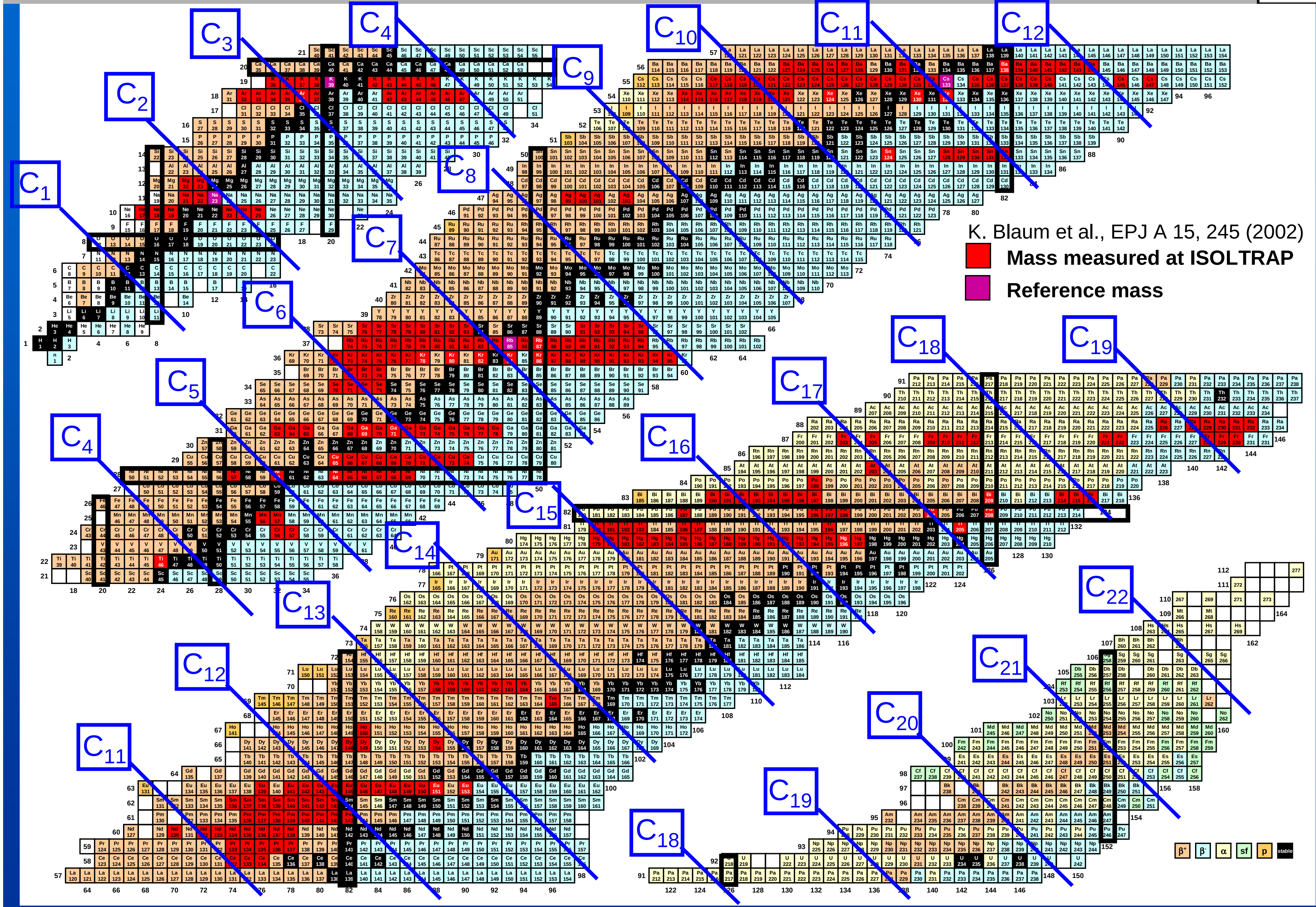
$$\frac{\nu_{c,ref}}{\nu_c} = \frac{m}{m_{ref}}$$

determination of mass ratio

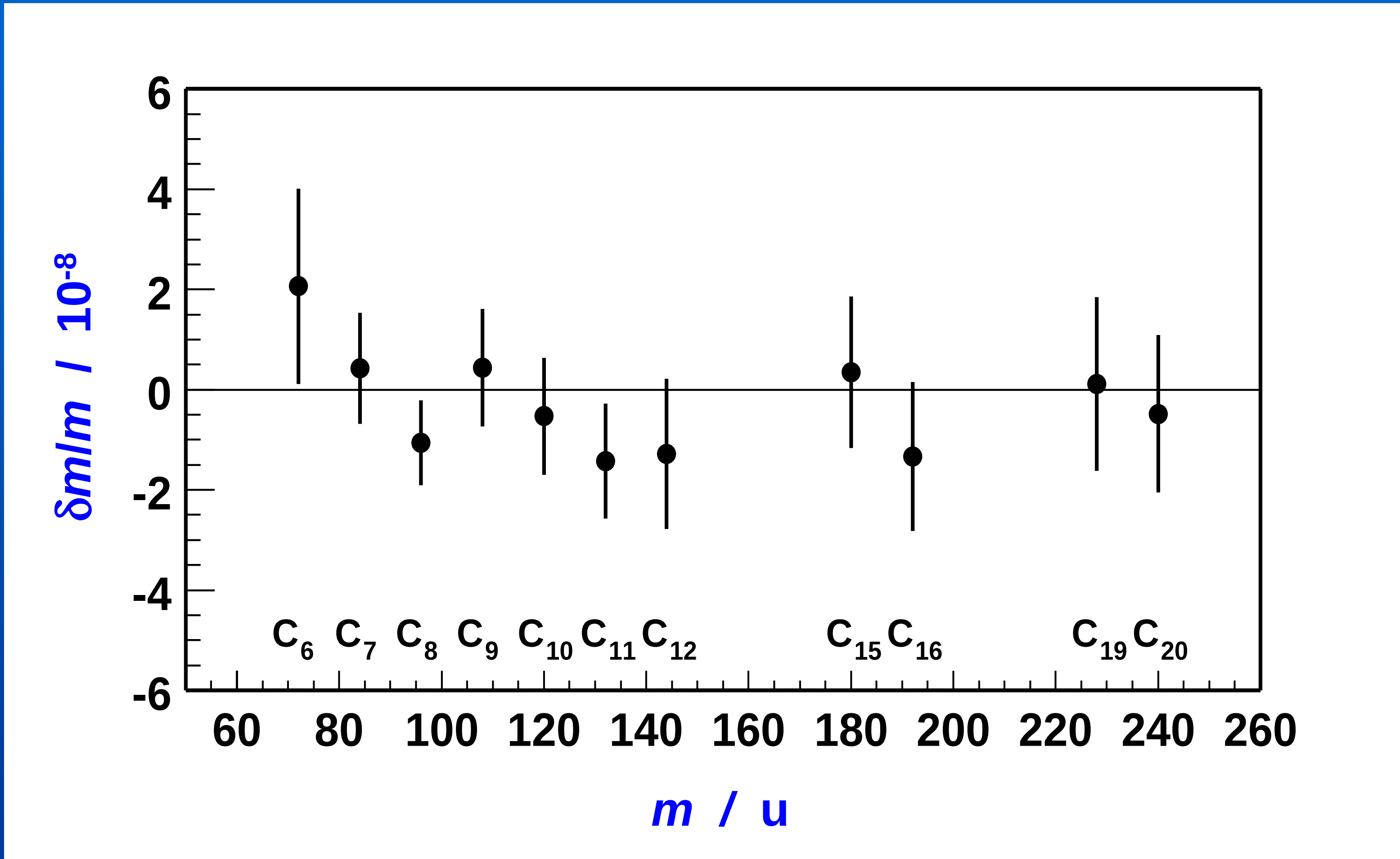
Stable alkali ions as mass references



Carbon clusters as mass references



Combined carbon cluster cross-reference measurements

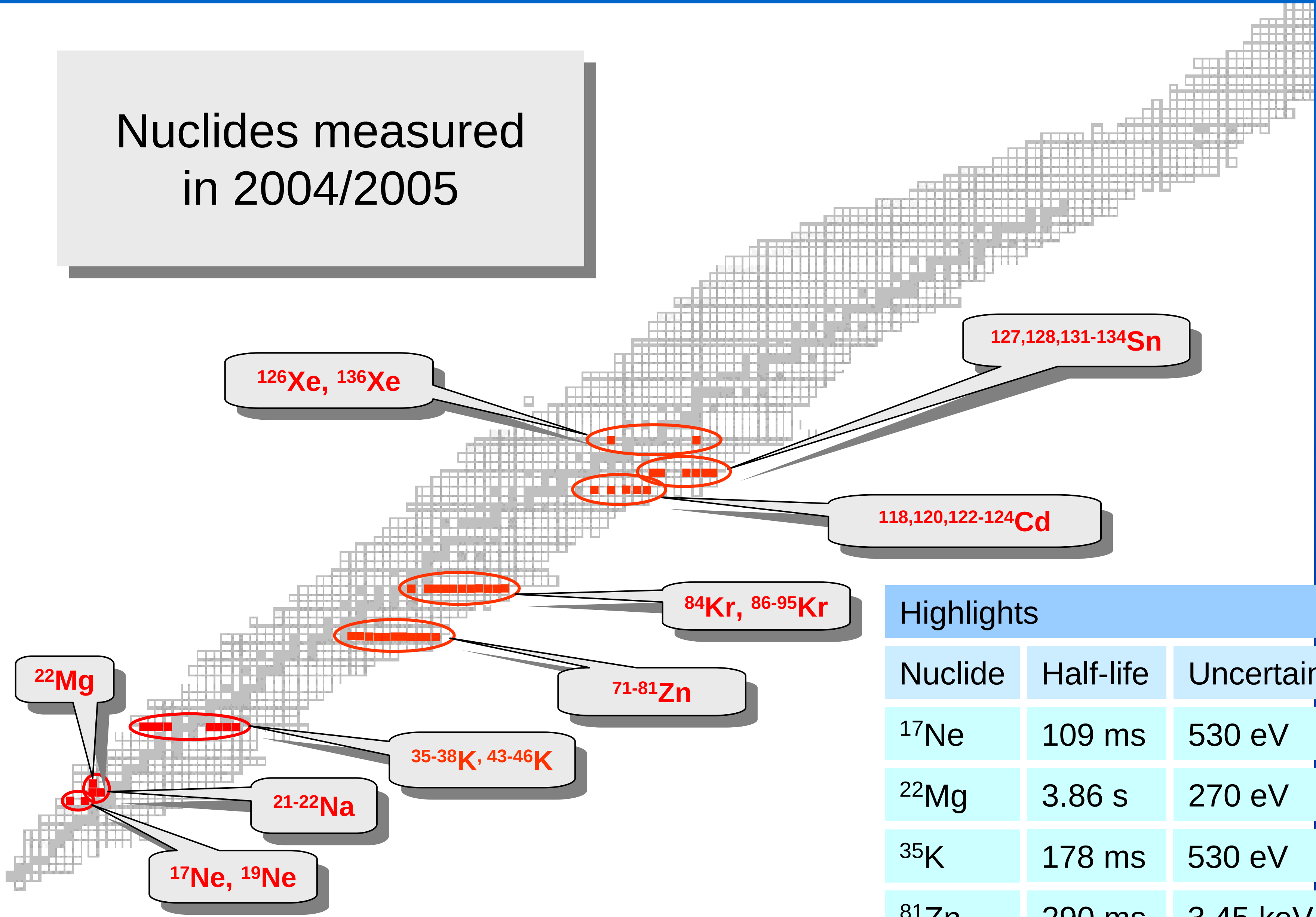


Relative mass accuracy limit: $(\delta m/m)_{lim} = 8\cdot10^{-9}$

A. Kellerbauer *et al.*, EPJ D 22, 53 (2003)

ISOLTRAP mass measurements in 2004-2005

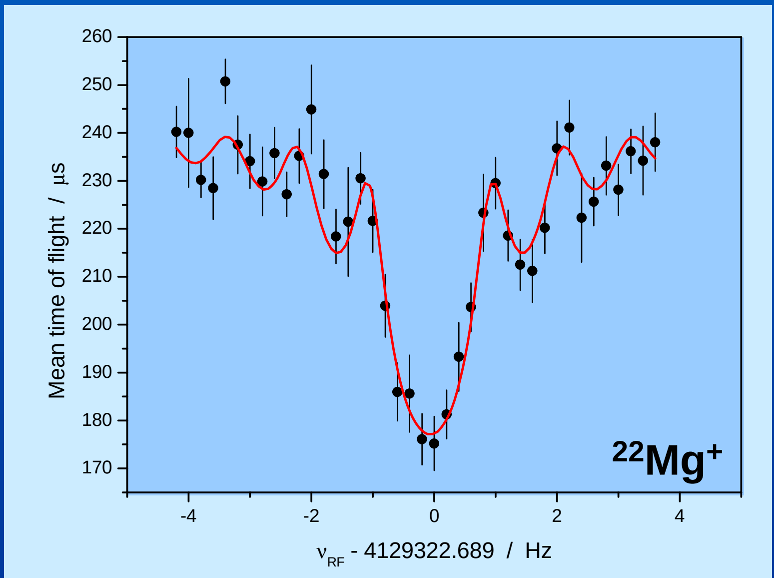
Nuclides measured
in 2004/2005

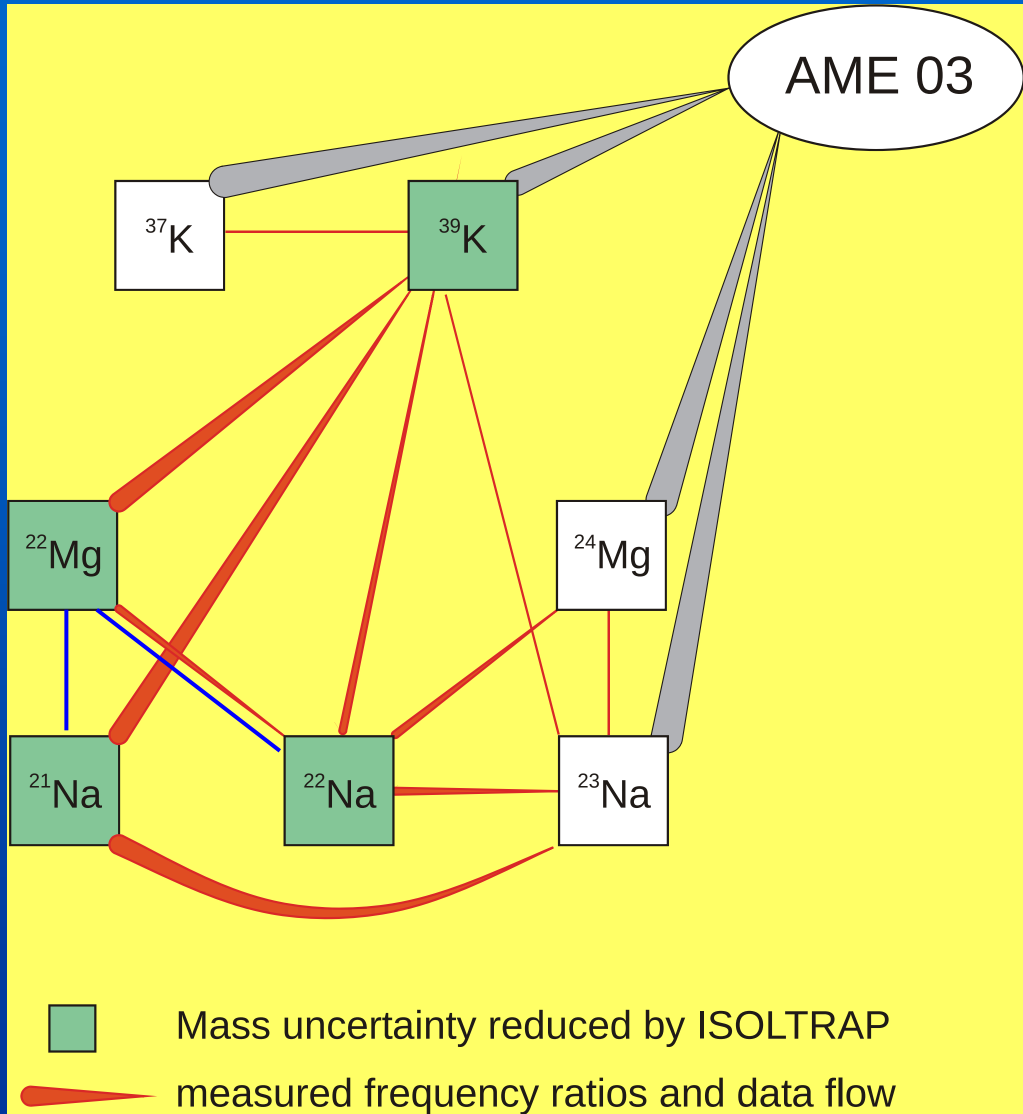


Highlights		
Nuclide	Half-life	Uncertainty
^{17}Ne	109 ms	530 eV
^{22}Mg	3.86 s	270 eV
^{35}K	178 ms	530 eV
^{81}Zn	290 ms	3.45 keV

The mass of ^{22}Mg

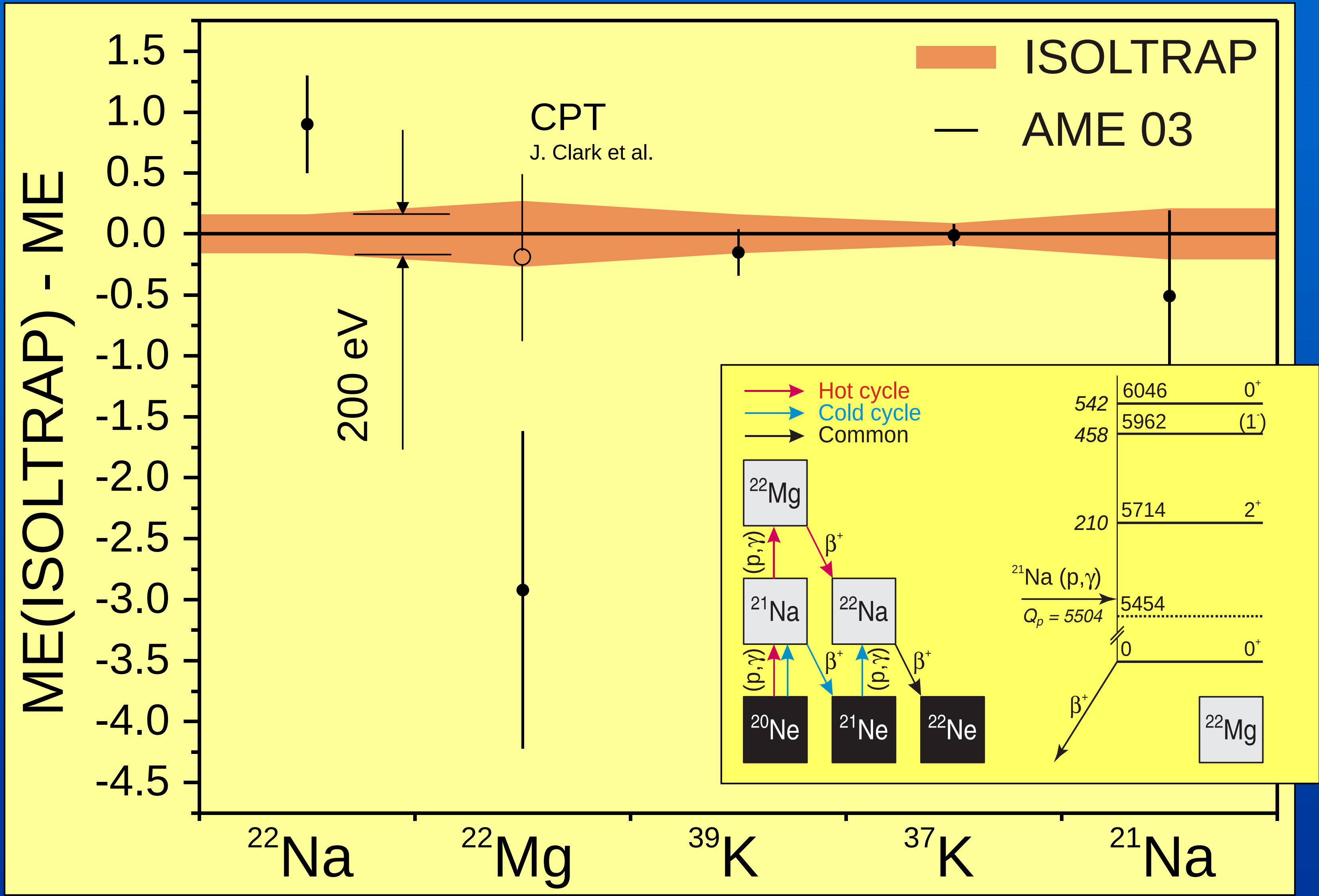
- 10 frequency ratios measured
- 16 relations included in χ^2 adjustment





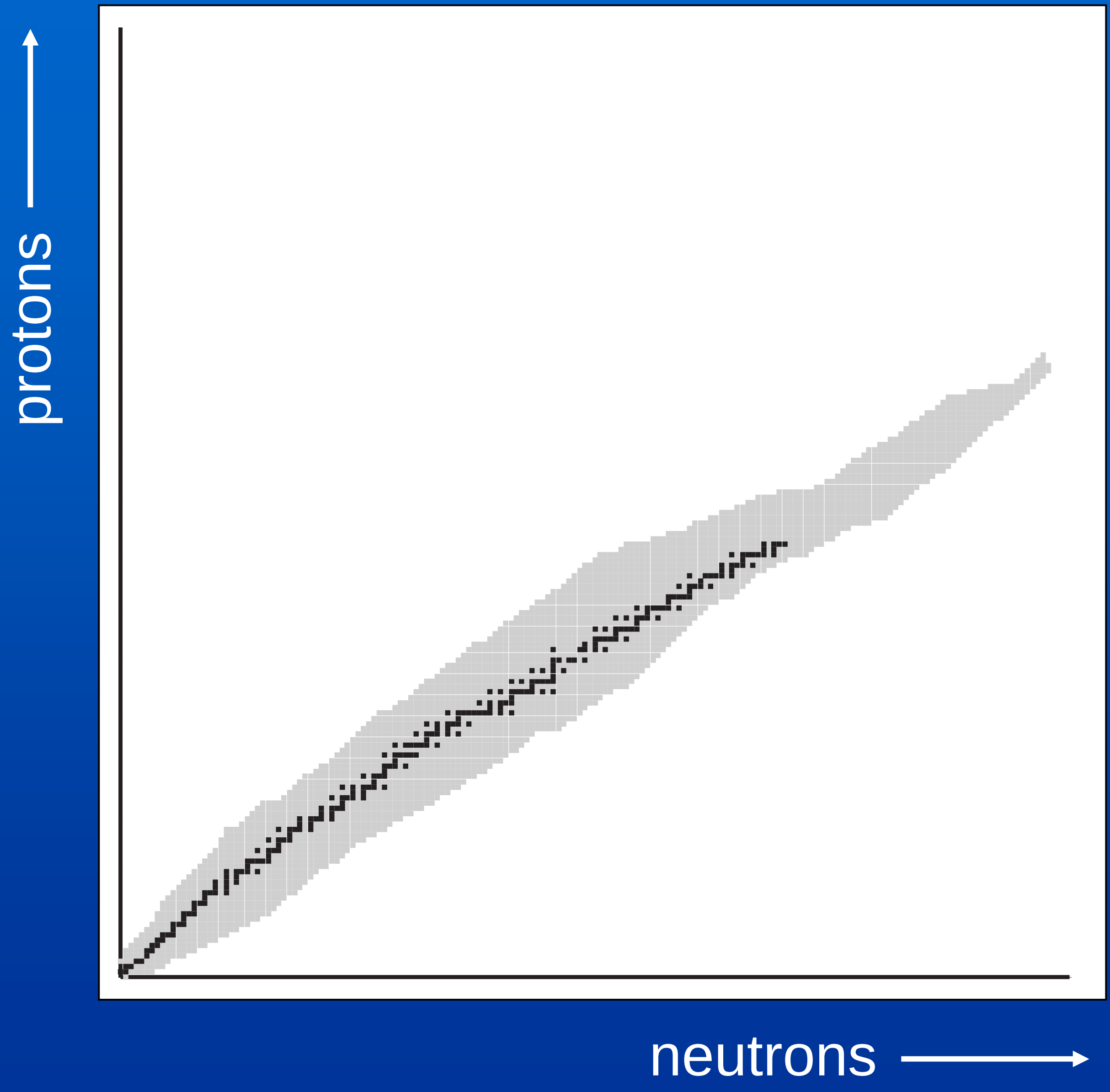
M. Mukherjee *et al.*, Phys. Rev. Lett. 93, 150801 (2004).

Solving the mass discrepancy of ^{22}Mg

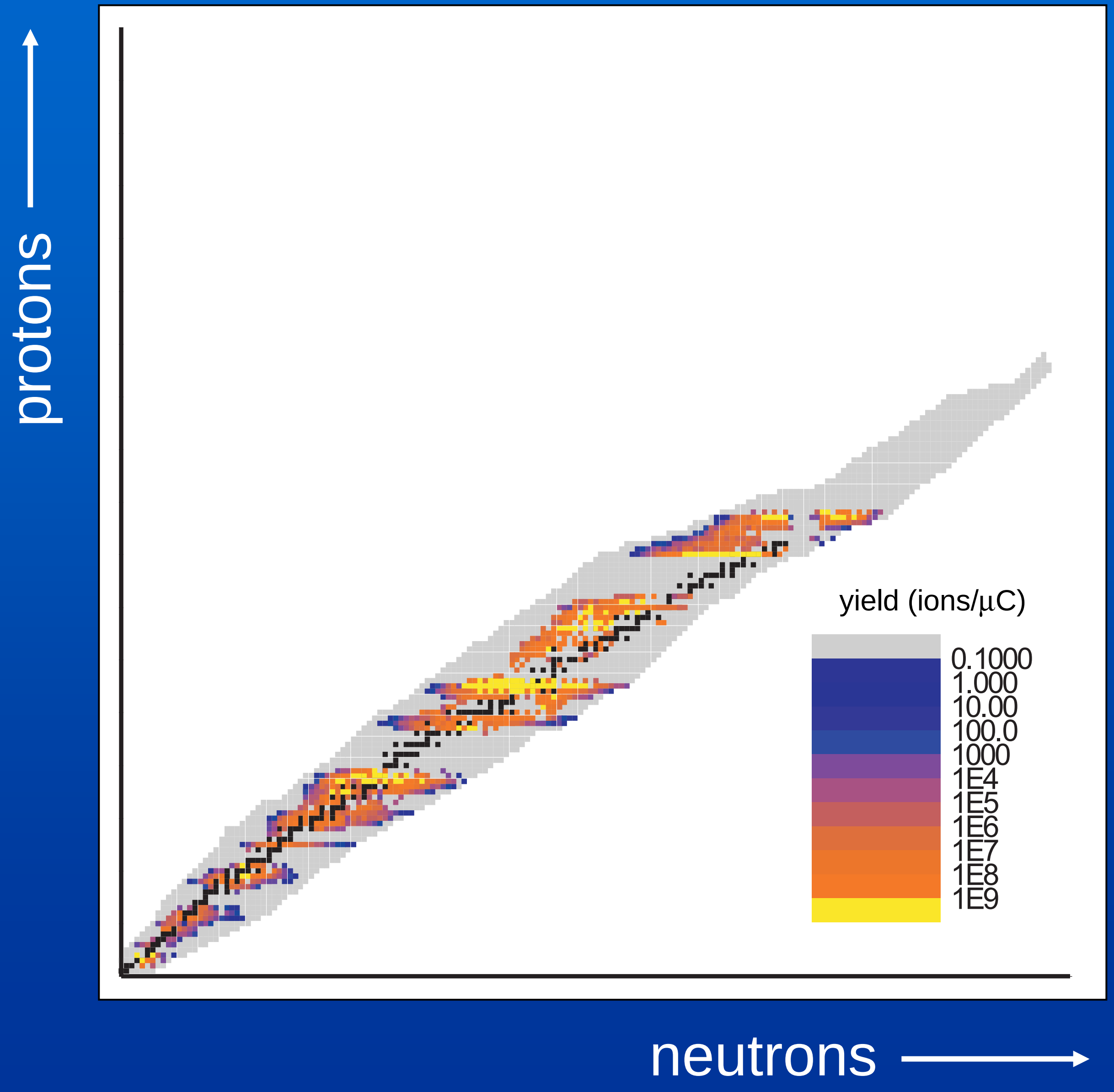


M. Mukherjee *et al.*, Phys. Rev. Lett. 93, 150801 (2004).

Ion yields at ISOLDE



Ion yields at ISOLDE



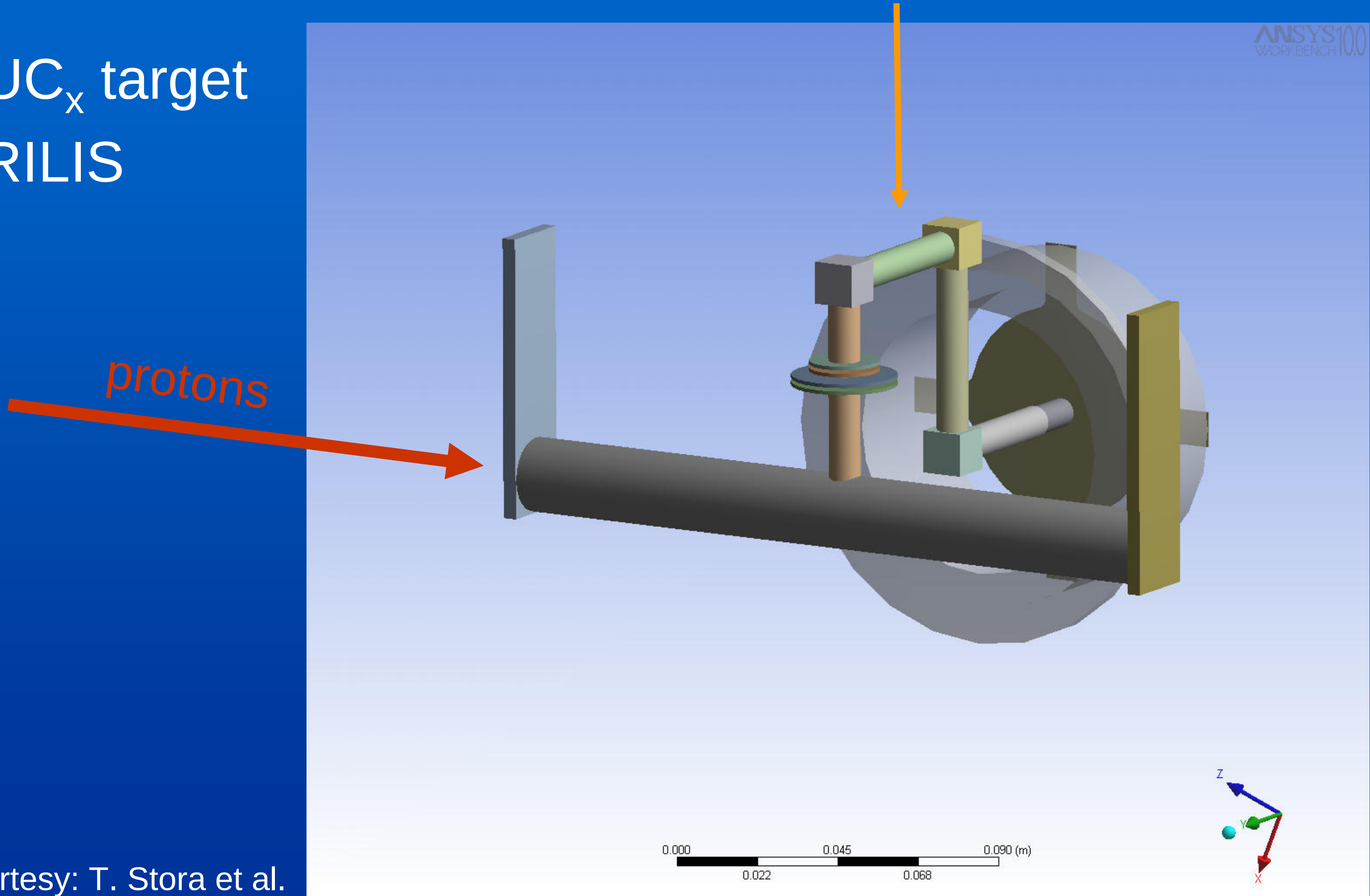
SC and PSB yields

courtesy: M. Turrion

ISOLDE target for Zn run

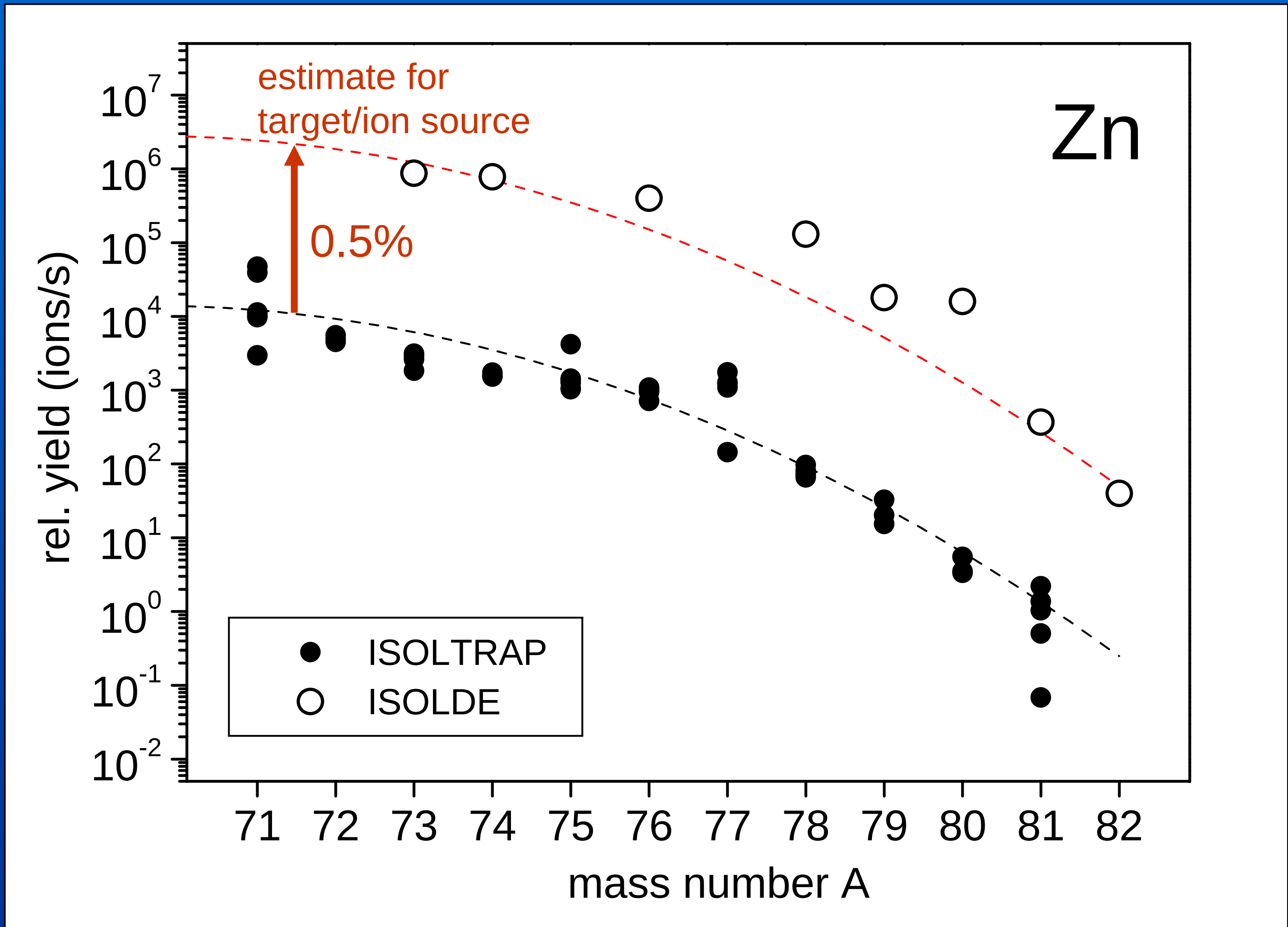
UC$_x$ target

RILIS

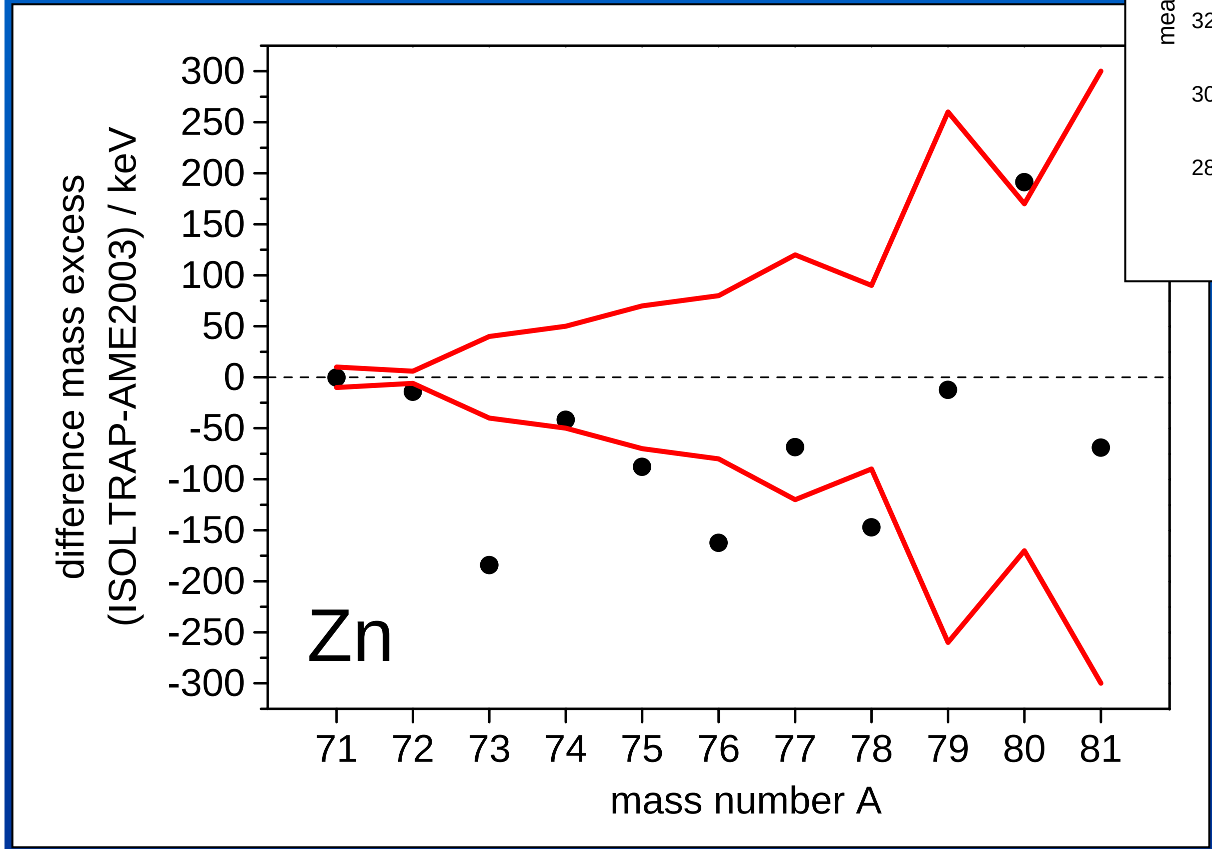


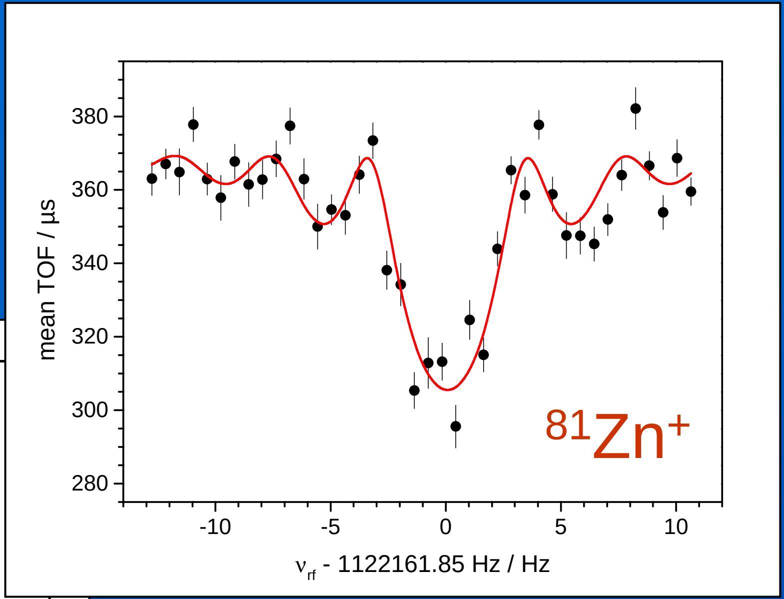
courtesy: T. Stora et al.

Yields at ISOLTRAP

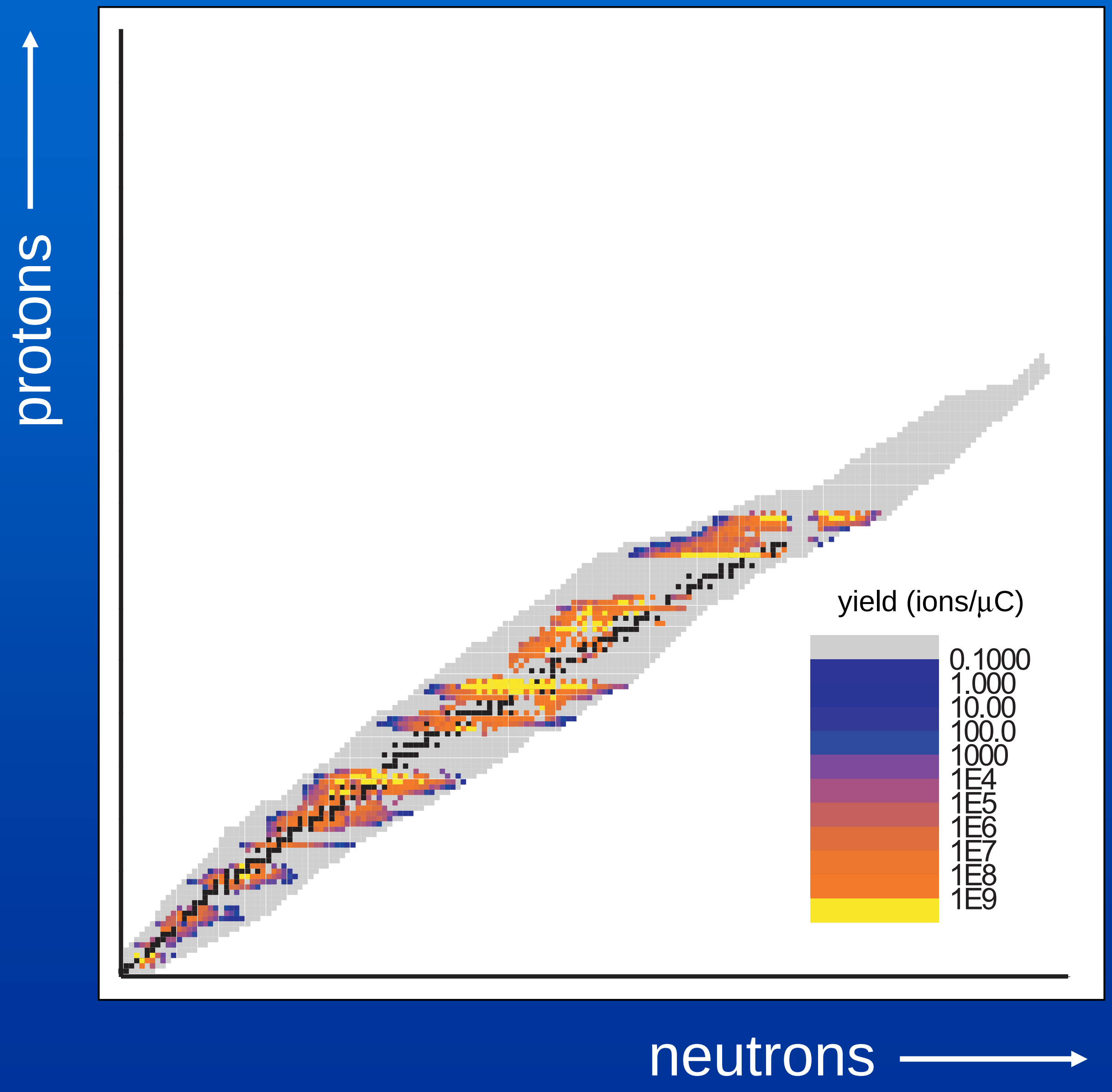


Preliminary result for mass excess Zn





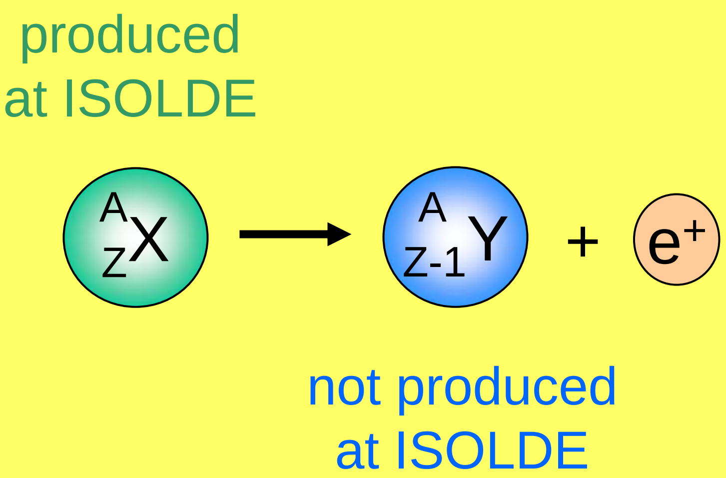
Ion yields at ISOLDE



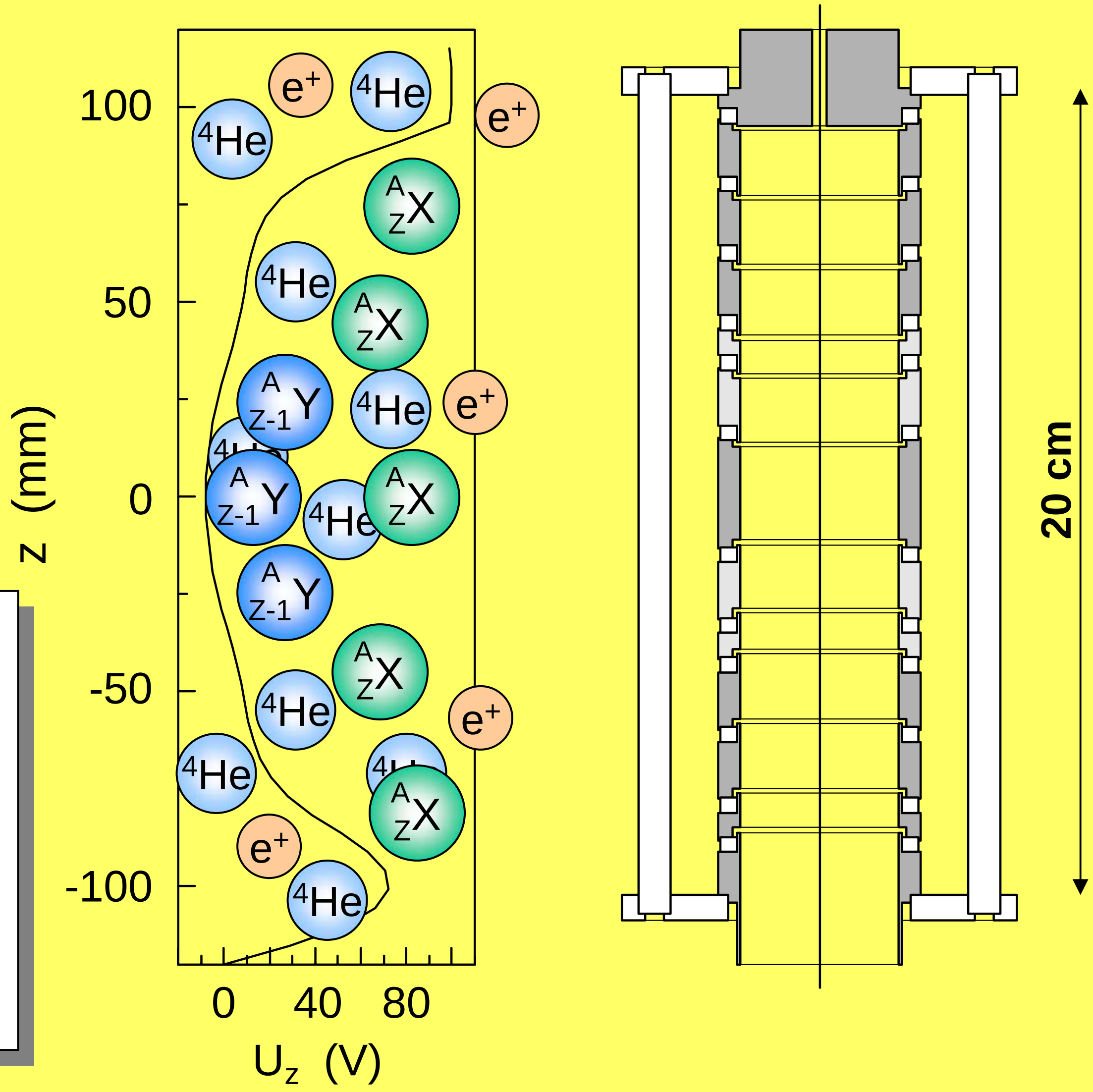
SC and PSB yields

courtesy: M. Turrion

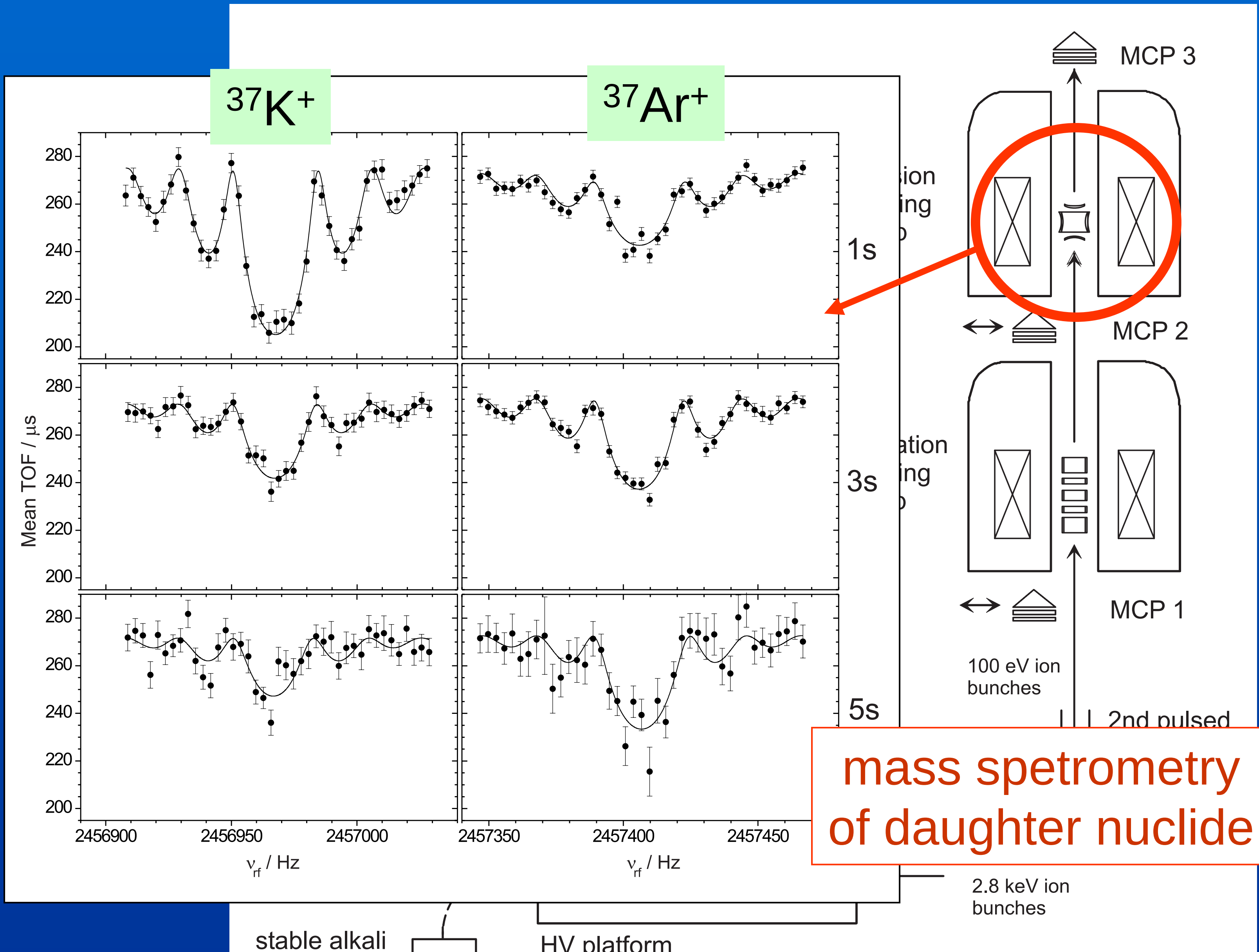
Decay in the buffer-gas-filled preparation trap



- **Make more radioactive species available**
- **Nearly simultaneous ω_c measurement of mother and daughter nuclei**
- **Test candidate: $^{37}K \rightarrow {}^{37}Ar$**



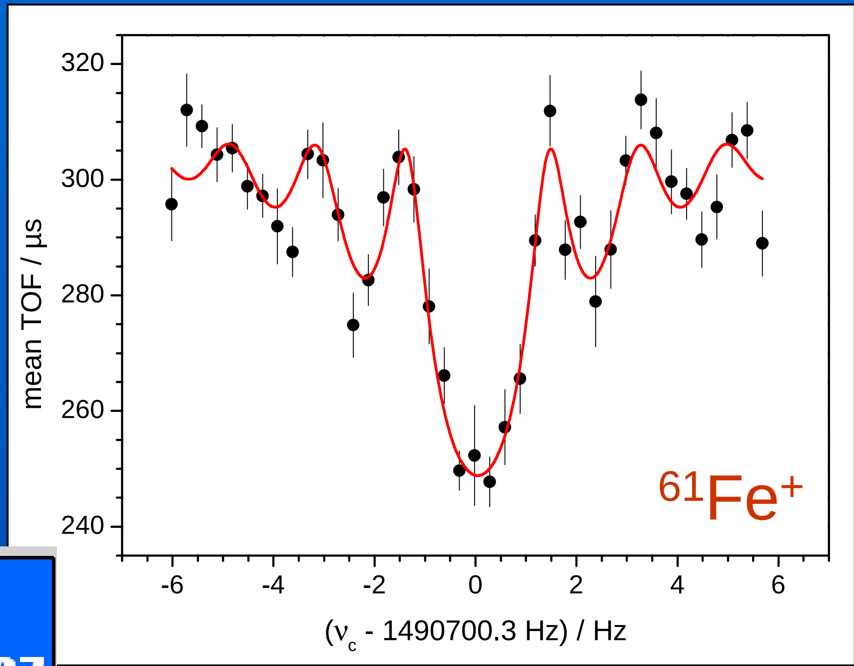
In-trap decay results

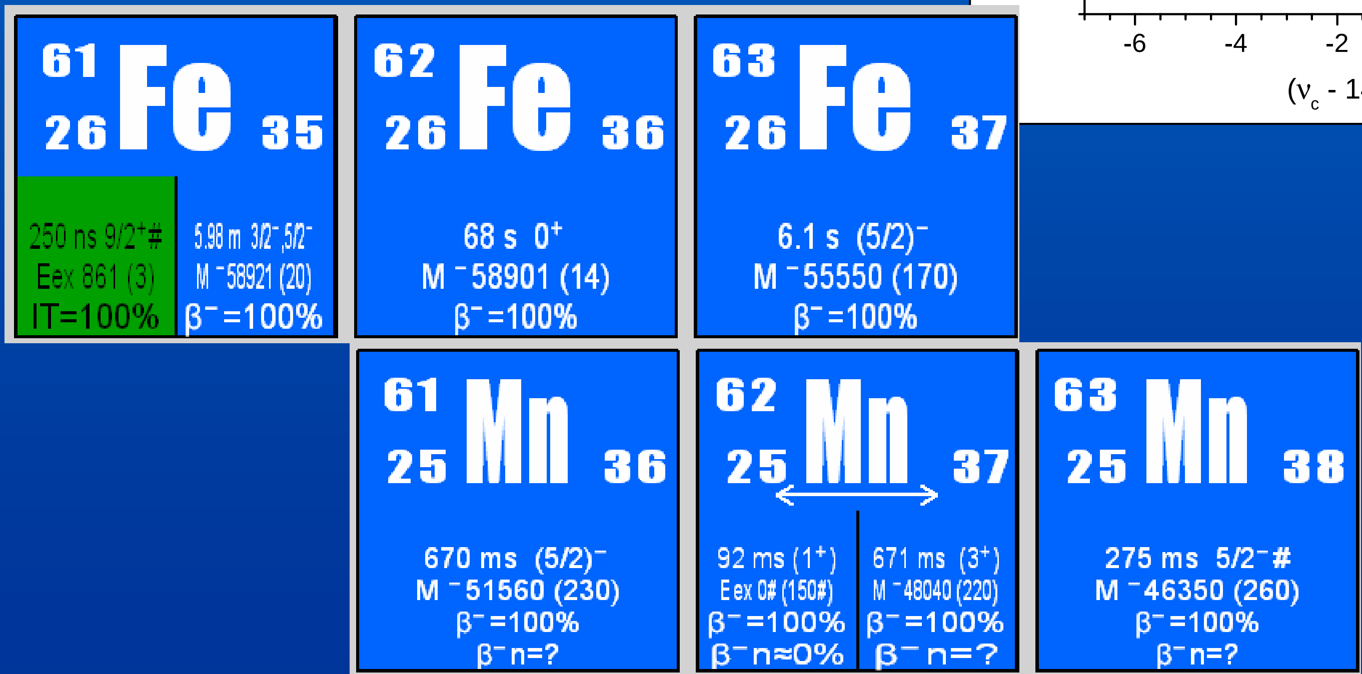


mass spetrometry of daughter nuclide

Elements/isotopes which are in principle not produced are accessible!

First application of in-trap decay mass spectrometry





Summary

- mass determination with a time-of-flight cyclotron resonance detection technique

  limited by:

  nuclide production rate above 100 s^{-1}
  half-life (so far) over 65ms
  systematic uncertainty limit:

$$(\delta m/m)_{lim} = 8 \cdot 10^{-9}$$

- so far mass measurements on more than 300 radionuclides at ISOLTRAP for tests of nuclear structure, mass models, a contributions to a CKM unitarity test, ...

- new techniques and development:
  in-trap decay method, new ion sources and detector,
  magnetic field stabilization, new excitation schemes, ...

Not to forget …

Thanks to my co-workers:

G. Audi, S. Baruah, D. Beck, K. Blaum, G. Bollen, M. Breitenfeldt, P. Delahaye, M. Dworschak, S. George, C. Guénaut, U. Hager, F. Herfurth, A. Kellerbauer, H.-J. Kluge, D. Lunney, M. Marie-Jeanne, M. Mukherjee, S. Schwarz, R. Savreux, L. Schweikhard, C. Weber, C. Yazidjian, ...,
and the ISOLTRAP and ISOLDE collaboration

Thanks for the funding and support:

BMBF, GSI, CERN, ISOLDE,
EU networks EUROTRAPS, EXOTRAPS, and NIPNET

Thanks a lot for your attention!