Mass Measurements and Nuclear Structure

G. Bollen
National Superconducting Cyclotron Laboratory NSCL
Michigan State University

Overview and Motivation

Mass Measurements at ISOLDE …

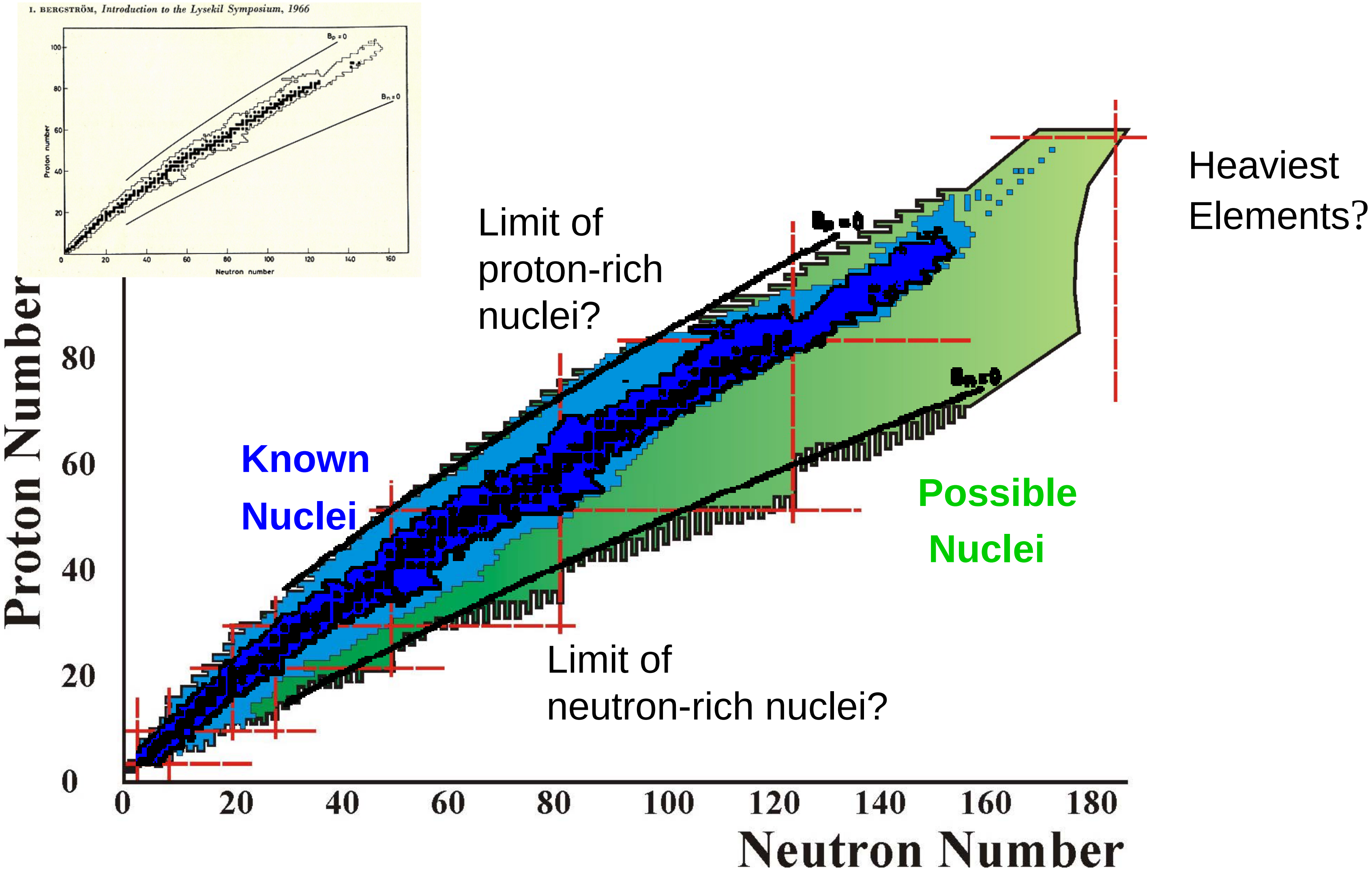
… and elsewhere

Conclusions

MICHIGAN STATE UNIVERSITY

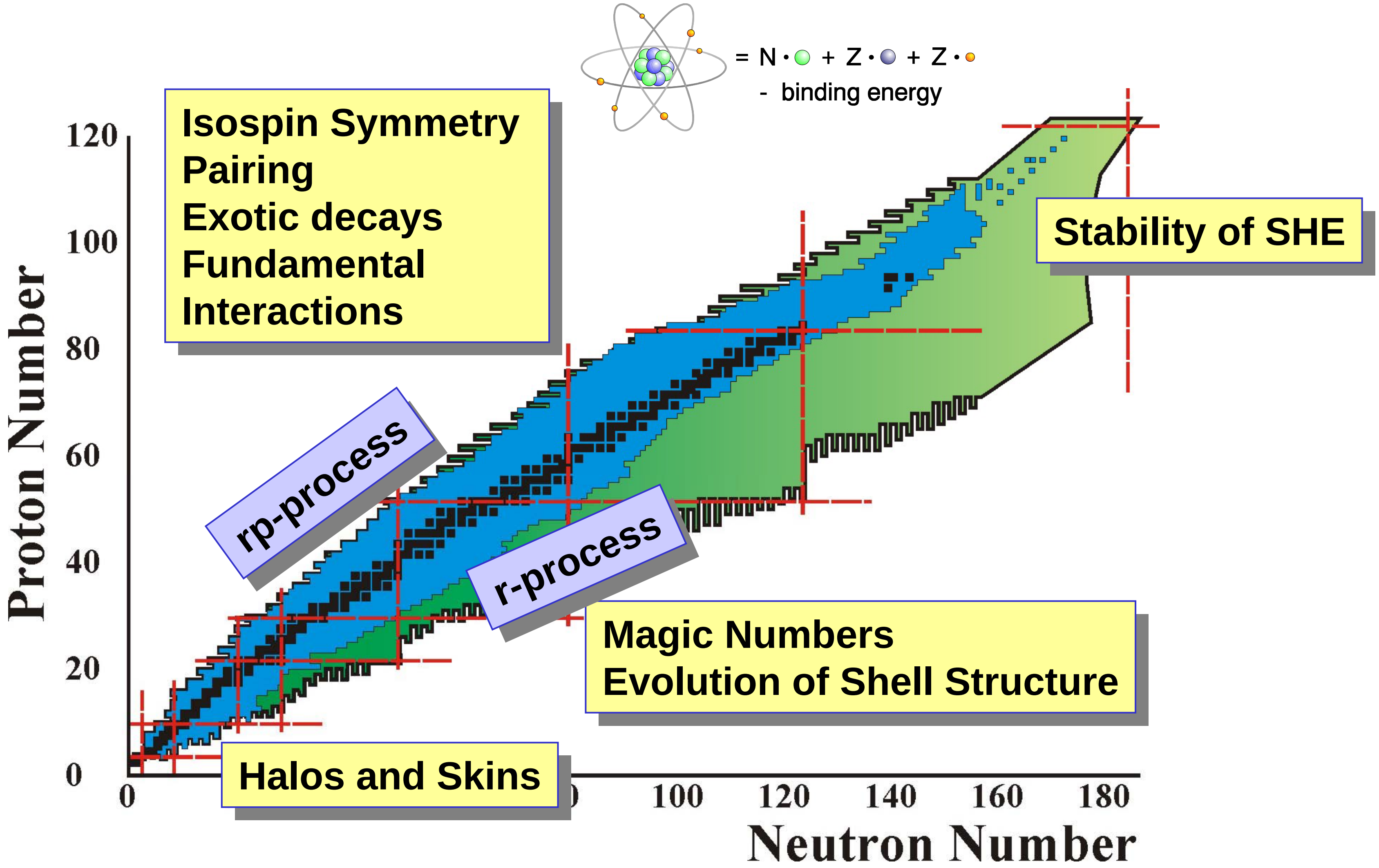
NSCL

Rare Isotope Physics
- an expedition by far not completed!



Binding energies determine limits of existence

How do mass measurements contribute?



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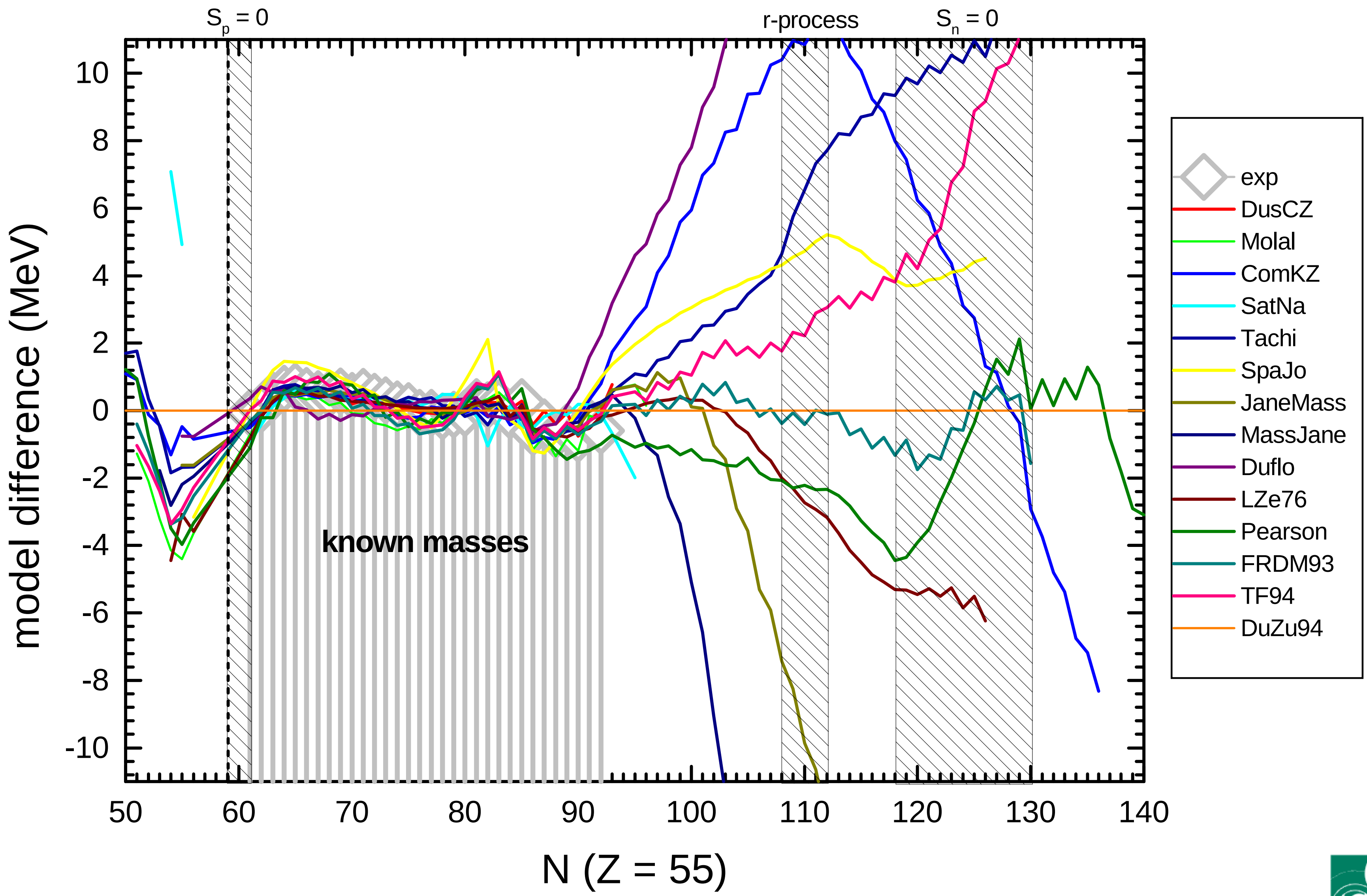
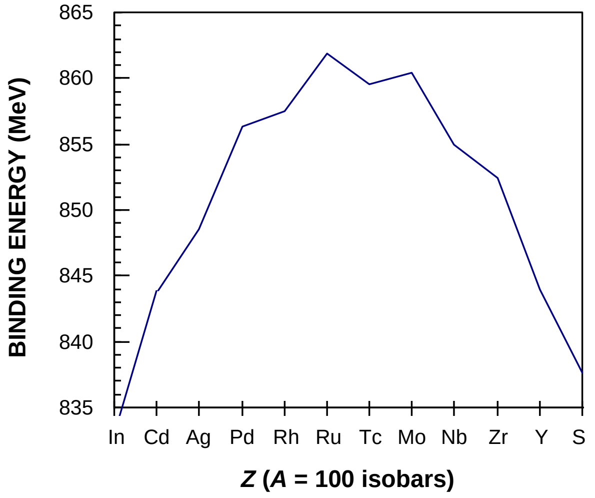
Constraints for nuclear models

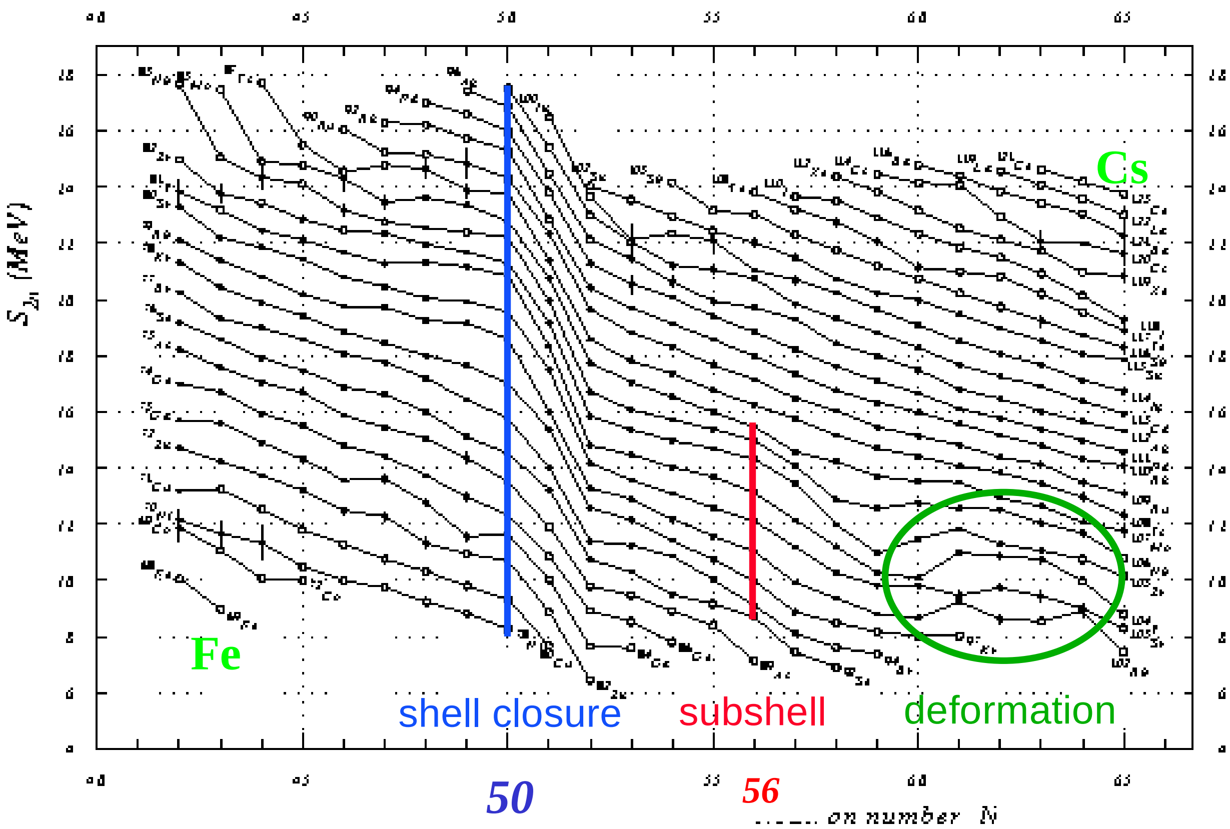


Nuclear Structure and Masses



total binding energies

two-neutron separation energies



Systematic study of masses – first indicator of new nuclear structure effects

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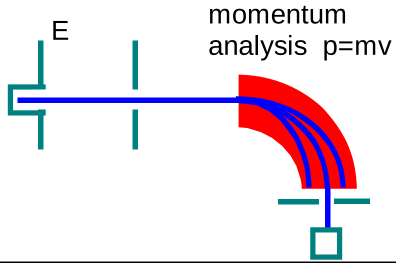
Tools for mass measurements on rare isotopes

Conventional mass spectrometry

CERN-PS + ISOLDE
Chalk-River
St. Petersburg

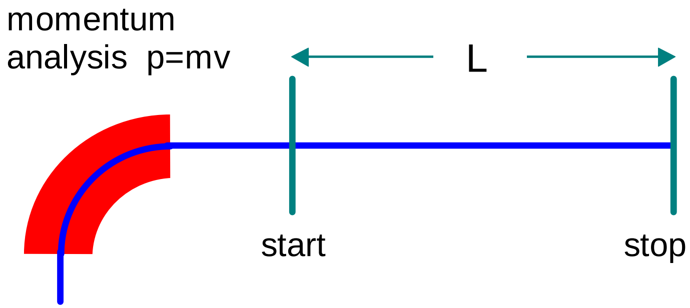


Out of Stock

Time-of-flight spectrometry

single turn: SPEG, TOFI

multi turn: cyclotrons CSS2, SARA,
storage ring ESR

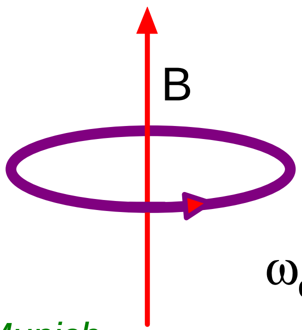


Frequency measurements

storage ring ESR/GSI, future NESR, RIBF rings

RF transmission spectrometer MISTRAL/ISOLDE

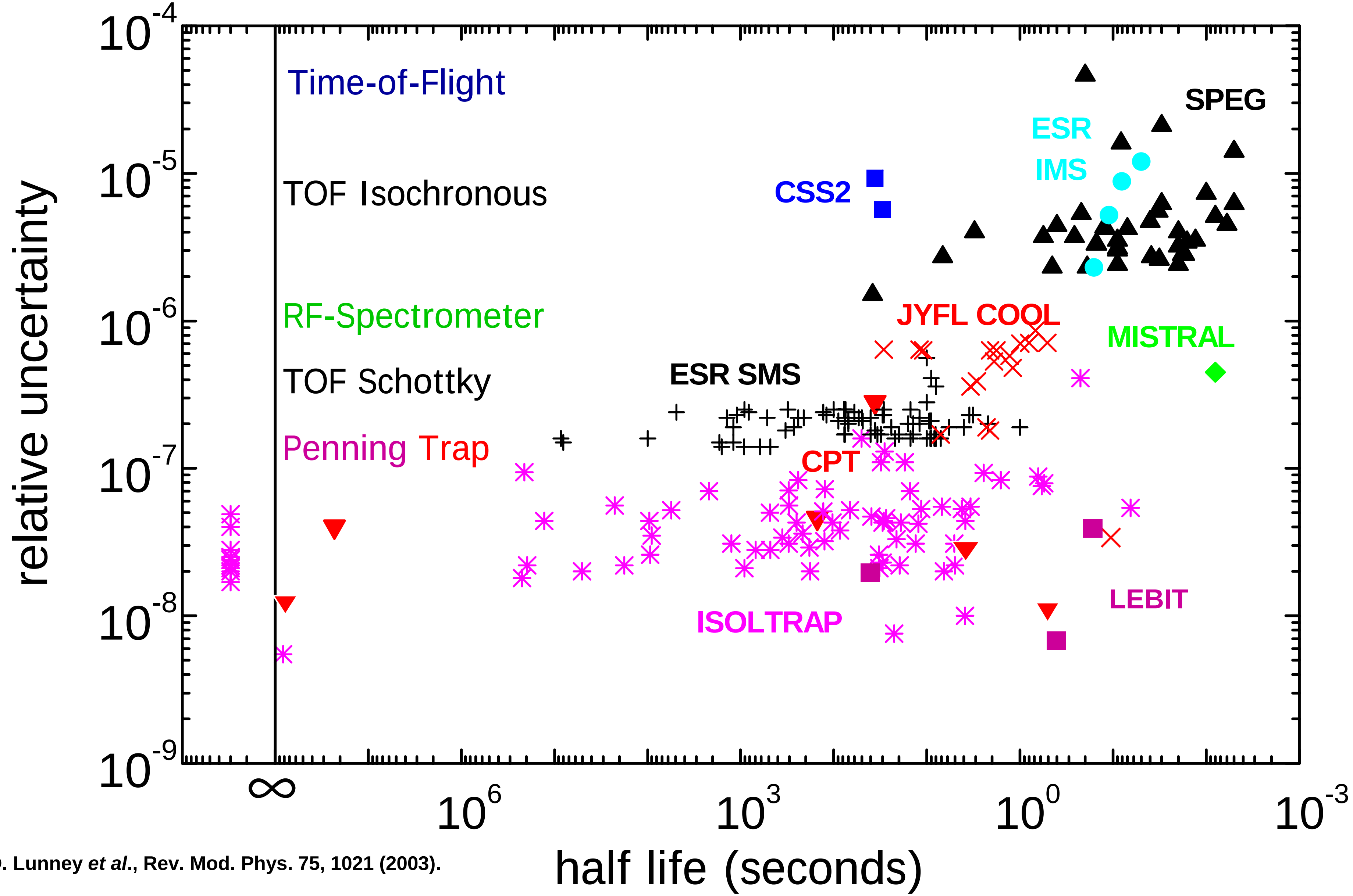
Penning traps ISOLTRAP/ISOLDE, LEBIT/NSCL,
JYFLTRAP/JYFL, CPT/ANL
SHIPTRAP/GSI, *TITAN/TRIUMF, MAFFTRAP/Munich*



$\omega_c = q/m\ B$

+ Q-values from reactions and decays

Comparison of Methods



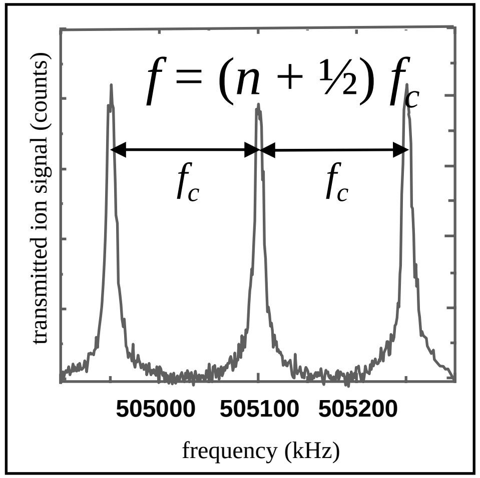
D. Lunney *et al*., Rev. Mod. Phys. 75, 1021 (2003).

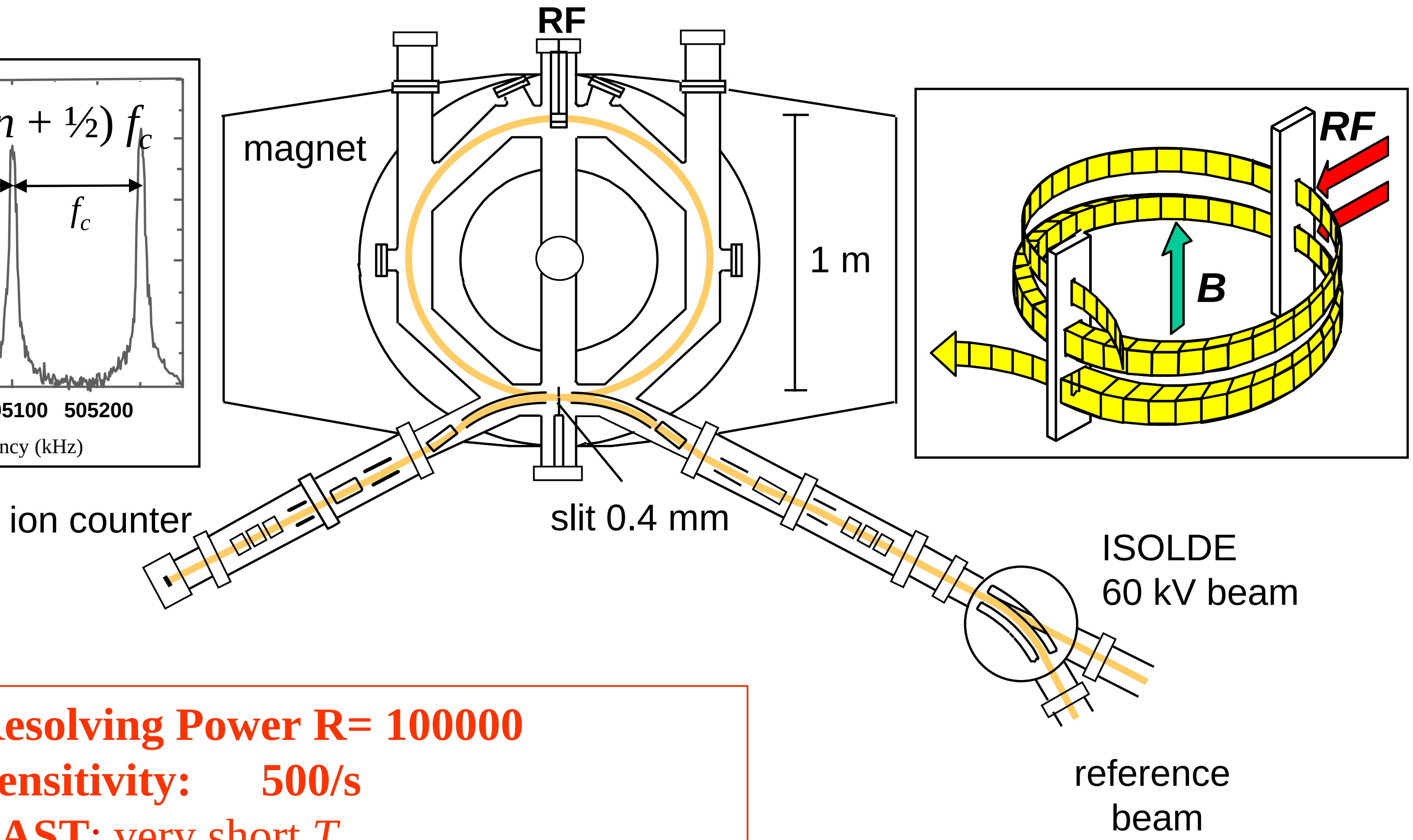
Mass measurements far from stability at CERN

- **CERN pioneered direct mass measurements far from stability**
  - Na isotopes (SPS) → discovery of island of inversion
  - ^{11}Li (SPS) → first loosely bound exotic nucleus discovered
  - Rb isotopes (ISOLDE) → first subshell closure observed in long isotopic chains

- **ISOLDE pioneered new techniques for short-lived isotopes**
  - Penning trap mass spectrometry + many related techniques (ISOLTRAP)
  - RF mass spectrometry (MISTRAL)

***MISTRAL**: **M**ass measurements at **IS**OLDE with a **T**ransmission **RA**diofrequency spectrometer on-**L**ine*

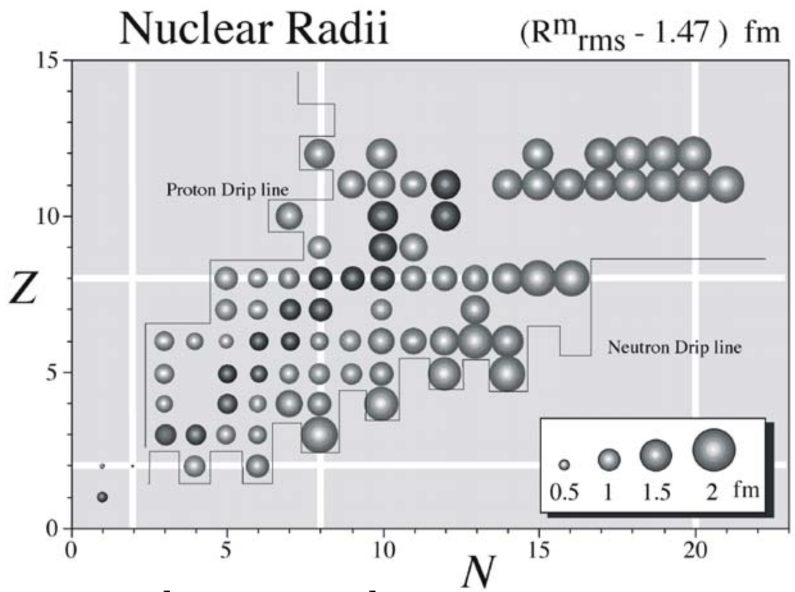




Resolving Power R= 100000
Sensitivity: 500/s
FAST: very short $T_{1/2}$

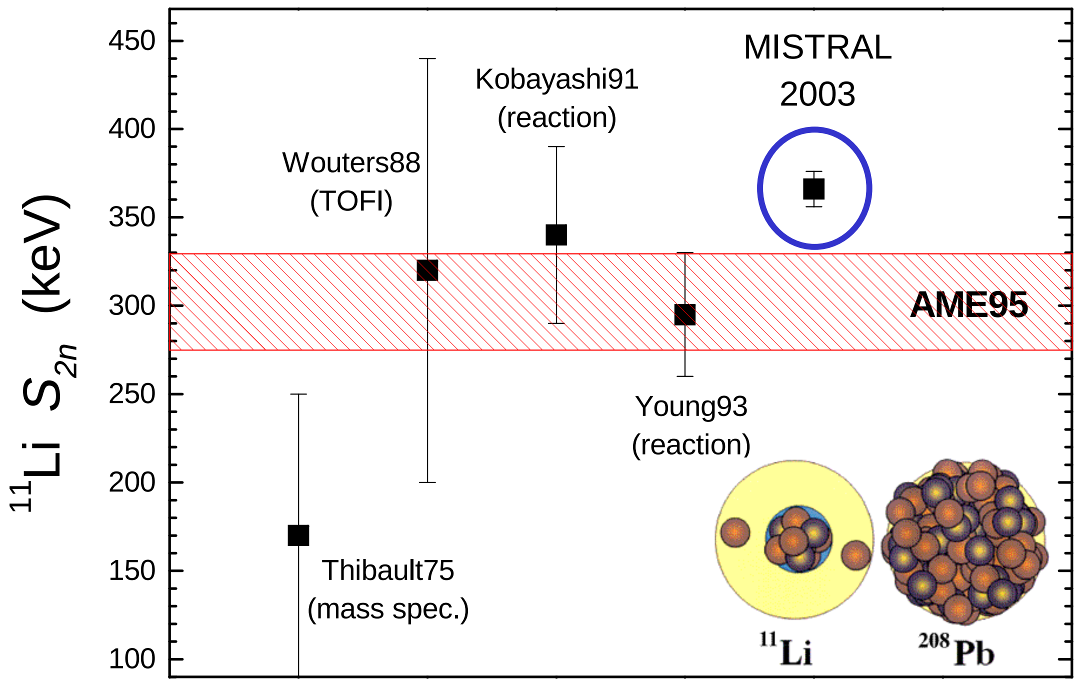
D. Lunney/Orsay

Mass measurements of halo nuclei - ^{11}Li



Graphics: I. Tanihata

C. Bachelet, Ph.D. thesis (2004),
EPJ A direct
DOI: 10.1140/epjad/i2005-06-005-5



MISTRAL:
S_{2n}=376(5) keV

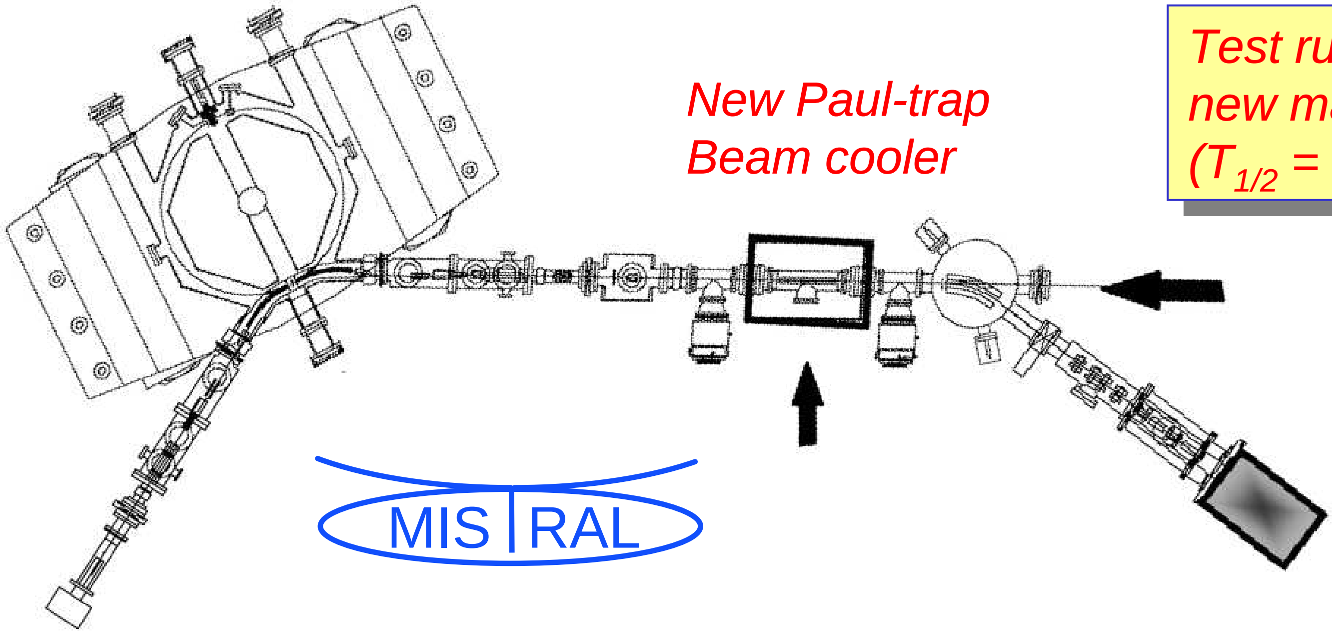
20% higher than currently used to adjust models...

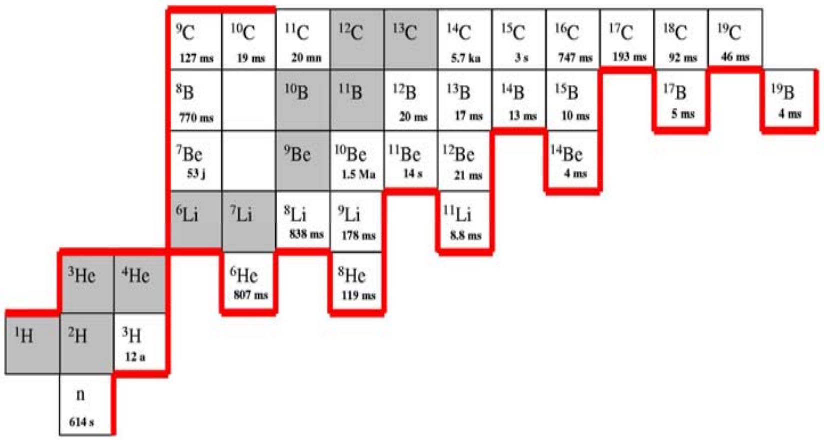
NSCL

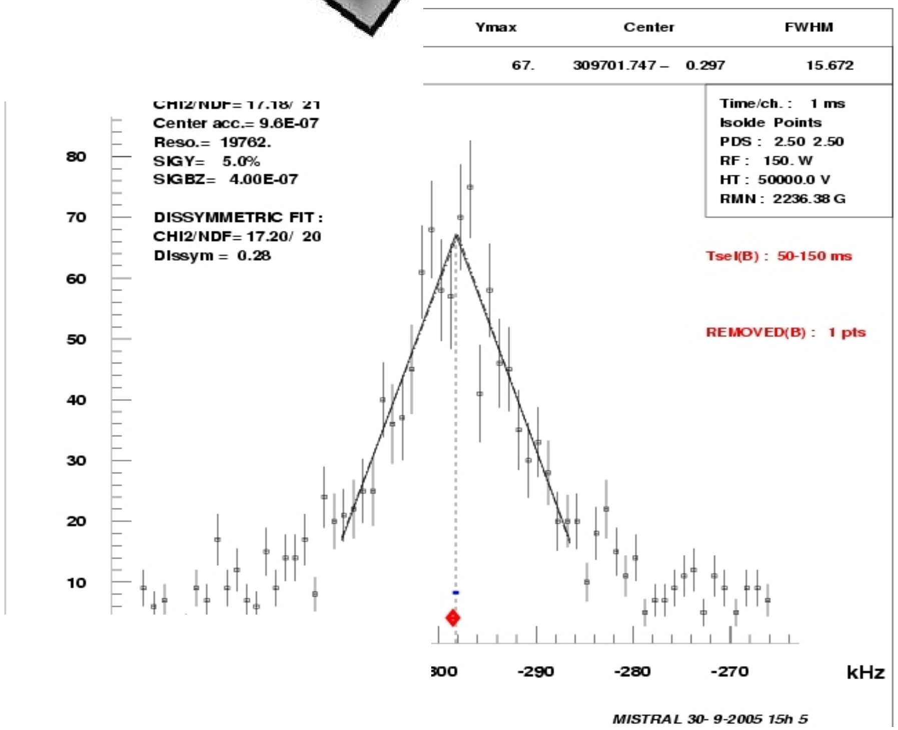
^{11}Be, ^{12}Be, towards ^{14}Be

Test run (Sept. 2005) :
new mass for ^{12}Be
($T_{1/2}$ = 21 ms)

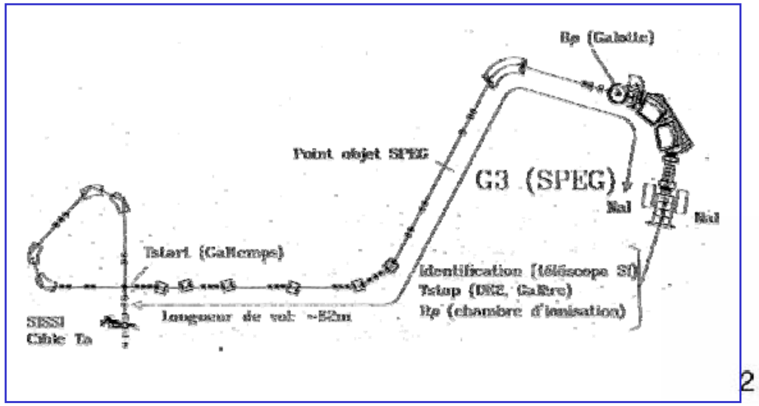
New Paul-trap
Beam cooler







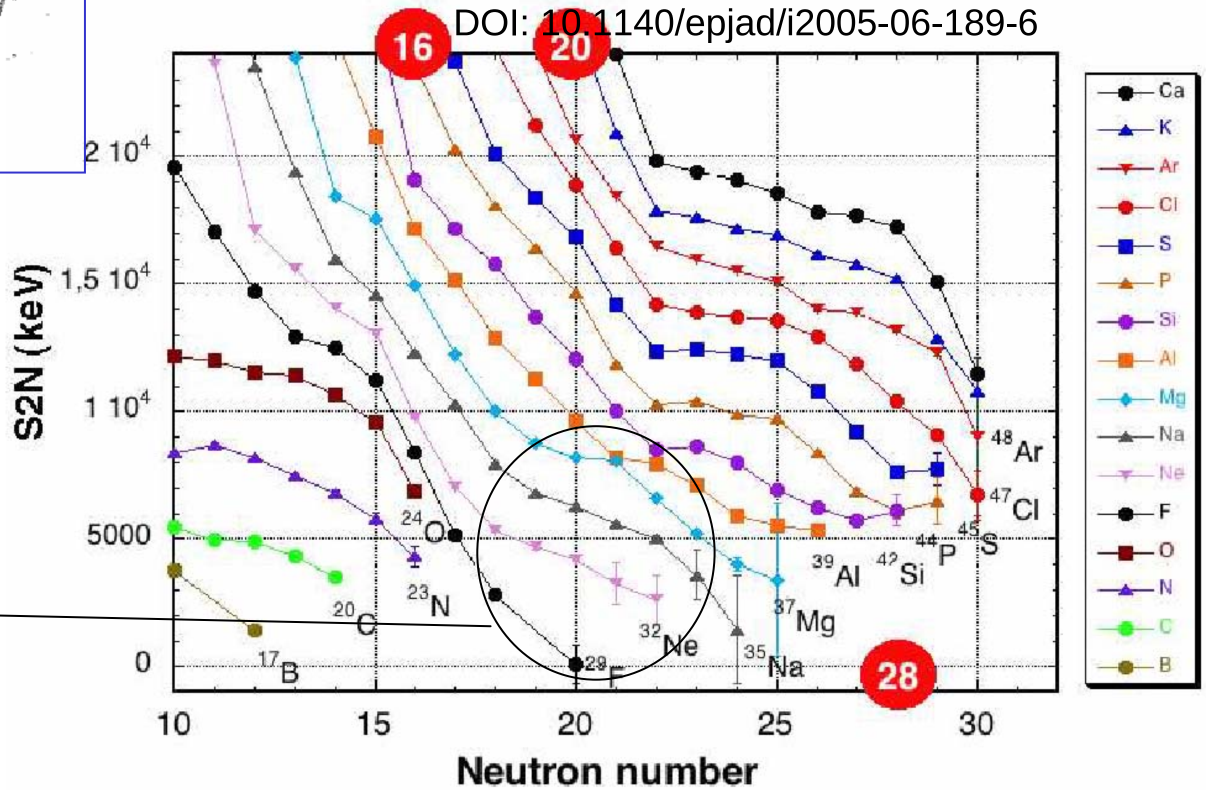
How magic are magic numbers?



SPEG/GANIL

H. Savajols et al., Eur. Phys. J. A direct (2005)

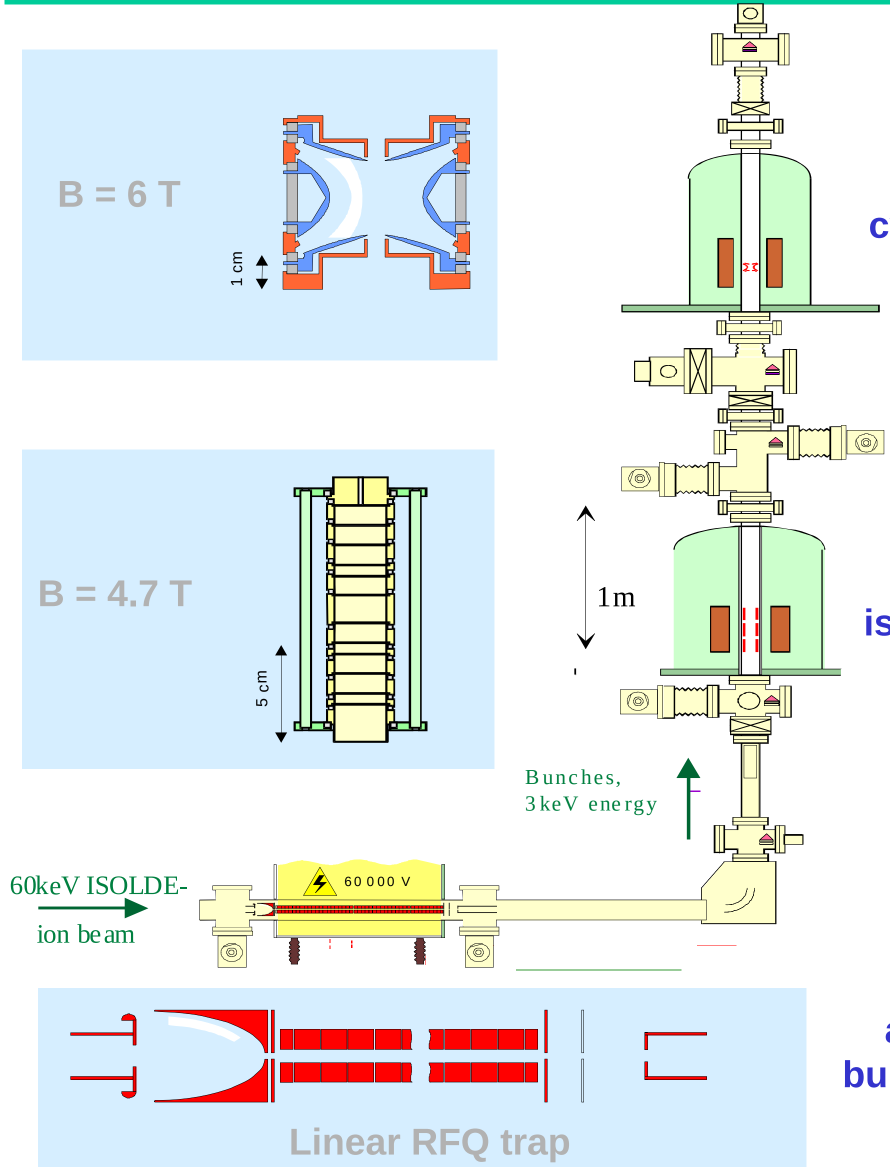
DOI: 10.1140/epjad/i2005-06-189-6



Island of Inversion

MISTRAL: n-rich Na and Mg isotopes with high precision

ISOLTRAP – triple trap spectrometer



determination of cyclotron frequency

$$R = \frac{m}{\Delta m} = 5 \cdot 10^6$$

cooling
isobar separation

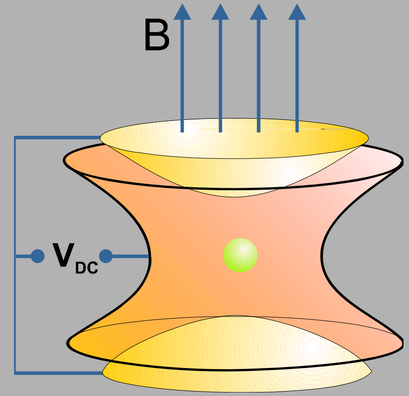
$$R = \frac{m}{\Delta m} = 1 \cdot 10^5$$

accumulation & bunching of ISOLDE 60 keV beam

G. Bollen et al., NIM A 368 (1996) 675
H. Raimbault-Hartmann, NIM B 126 (1997) 378
F. Herfurth et al., NIM A 469 (2001) 254

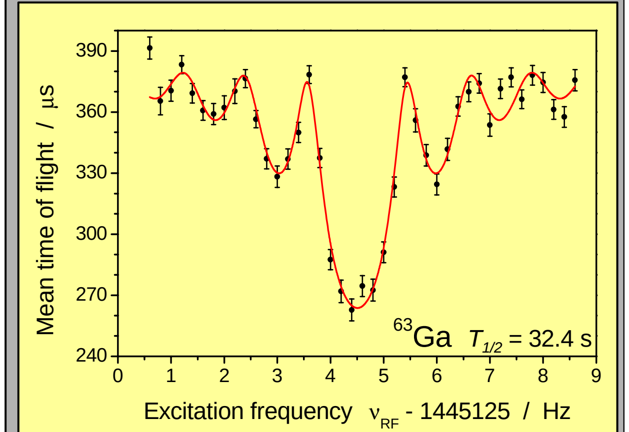
A. Herlert, K. Blaum

PRINCIPLE



Mass measurement via determination of cyclotron frequency

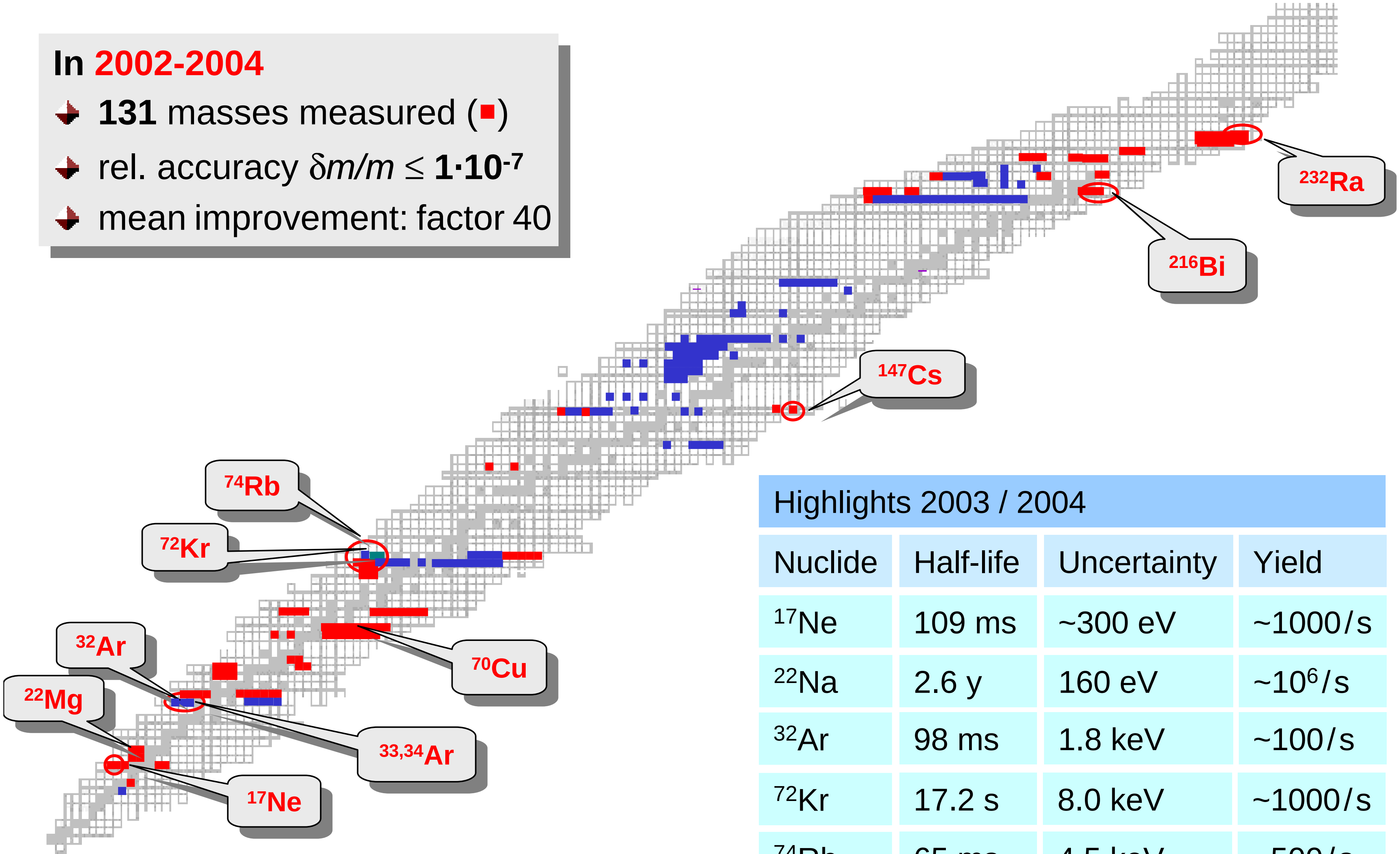
$$\omega_c = (q/m) \cdot B$$



ISOLTRAP harvest

In 2002-2004

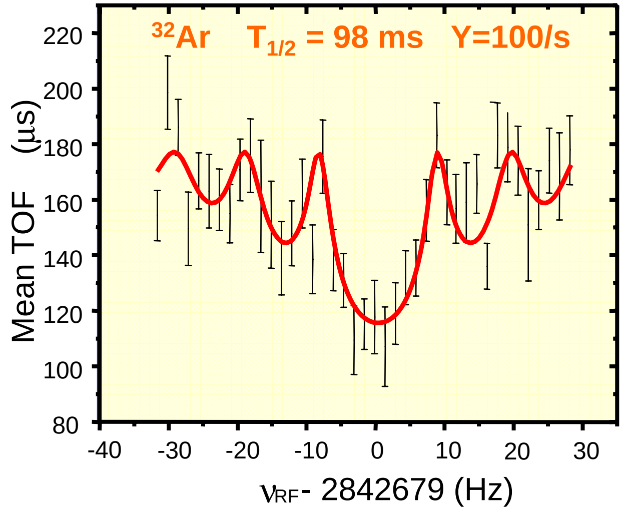
- **131** masses measured (■)
- rel. accuracy $\delta m/m \leq \mathbf{1 \cdot 10^{-7}}$
- mean improvement: factor 40

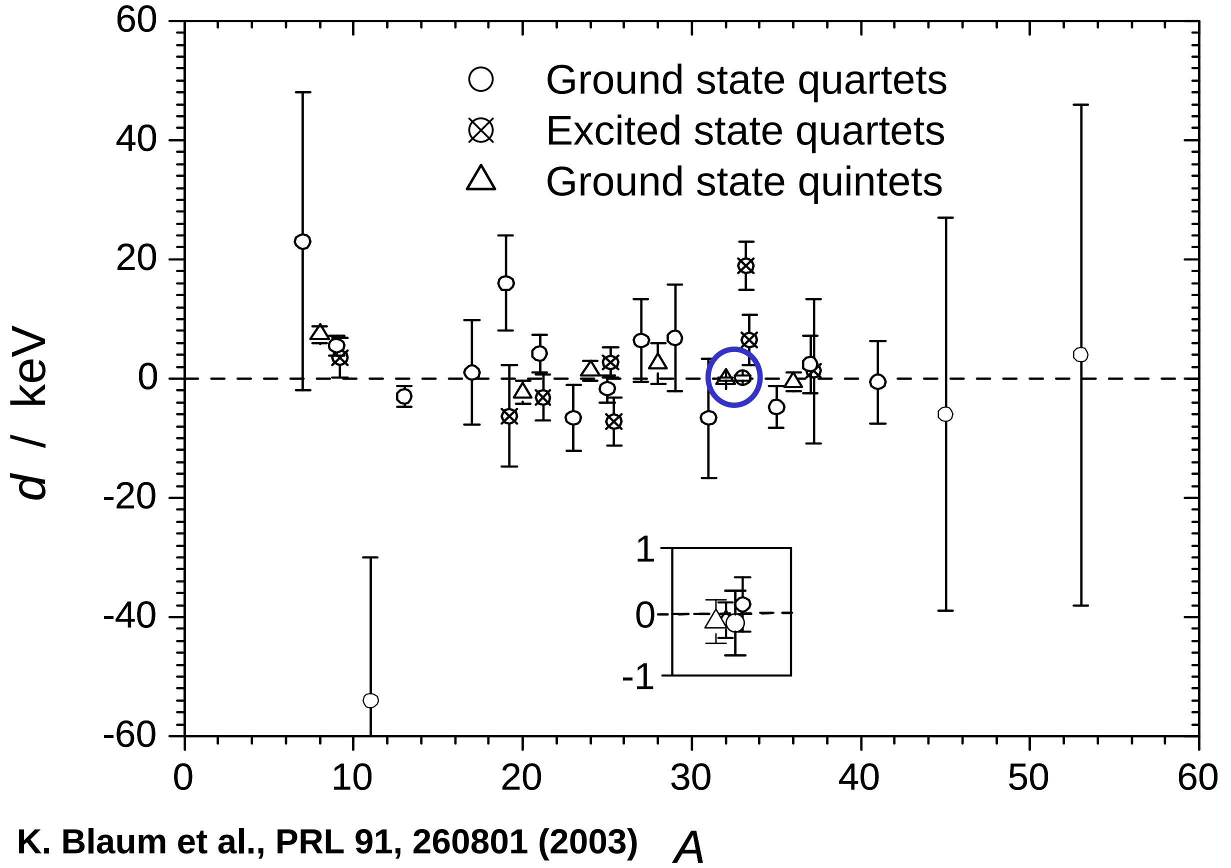


Highlights 2003 / 2004			
Nuclide	Half-life	Uncertainty	Yield
^{17}Ne	109 ms	~300 eV	~1000/s
^{22}Na	2.6 y	160 eV	~10^{6}/s
^{32}Ar	98 ms	1.8 keV	~100/s
^{72}Kr	17.2 s	8.0 keV	~1000/s
^{74}Rb	65 ms	4.5 keV	~500/s

^{32,33}Ar - most stringent test of IMME
$M = a + bT_z + cT_z^2$ $(+ dT_z^3)$?

ISOLTRAP





K. Blaum et al., PRL 91, 260801 (2003)

^{33}**Ar** δm = 0.44 keV

^{32}**Ar** δm = 1.8 keV

A = 33, T = 3/2 quartet:

d = -0.13(45) keV

A = 32, T = 2 quintet:

d = -0.11(30) keV

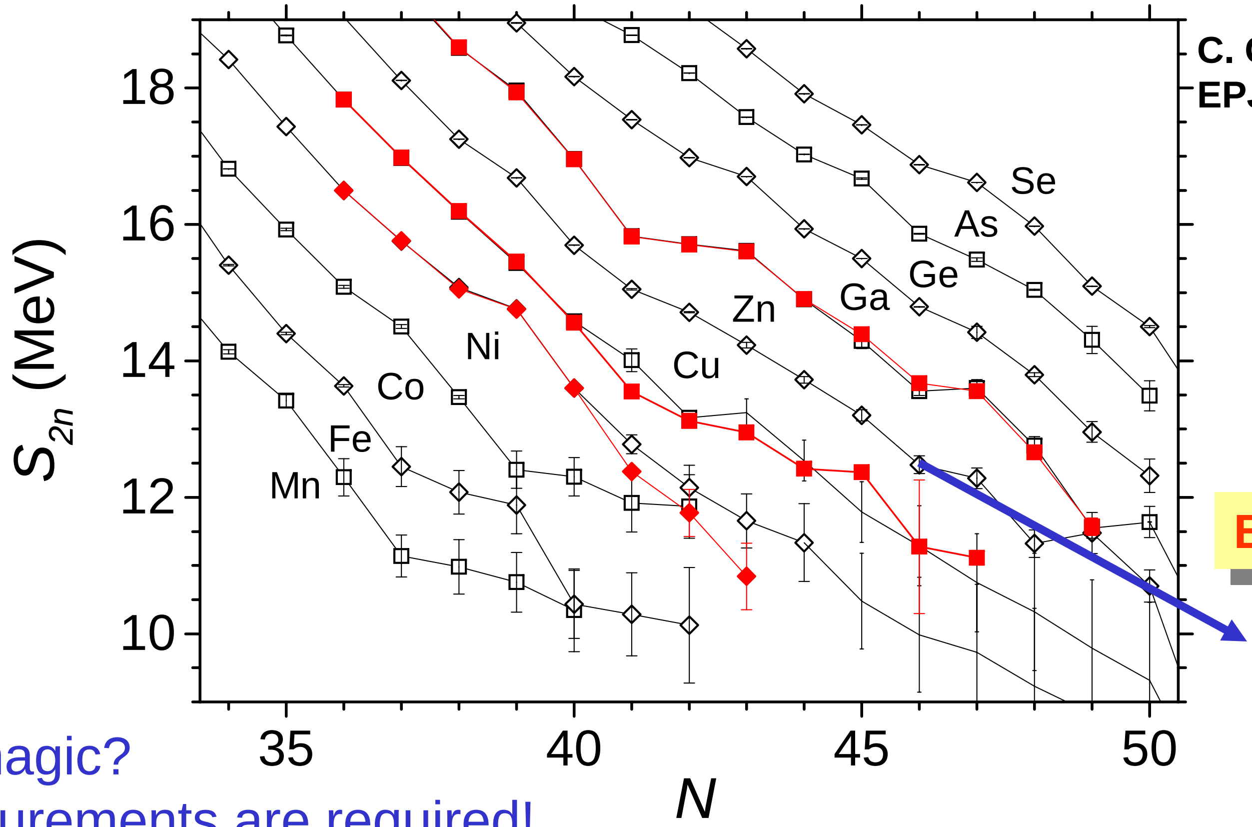
Limits for Scalar Currents from β-delayed p-decay of ^{32}Ar can now be put on purely experimental ground

***a* = 1.0050 ± 0.0052(stat) ± (syst)**

Towards exotic doubly magic nuclei - ^{78}Ni

ISOLTRAP

Evolution of nuclear binding towards doubly-magic ^{78}Ni is not known
nuclear structure – r-process



C. Guenaut PhD 2005
EPJA direct 2005

BRAND NEW

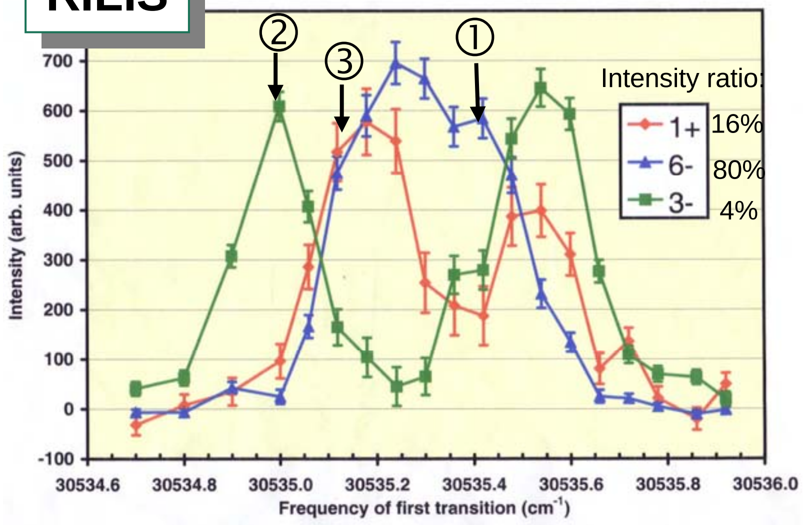
^{81}Zn

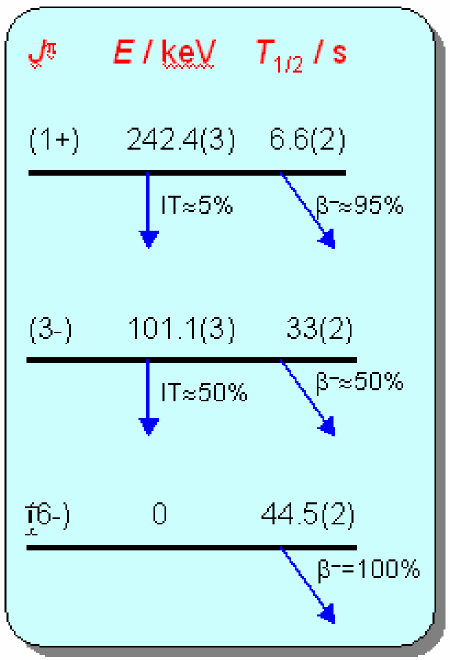
Is N = 40 magic?
More measurements are required!

+ n-rich tin isotopes up to ^{135}Sn

Identification of triple isomerism in ^{70}Cu

RILIS



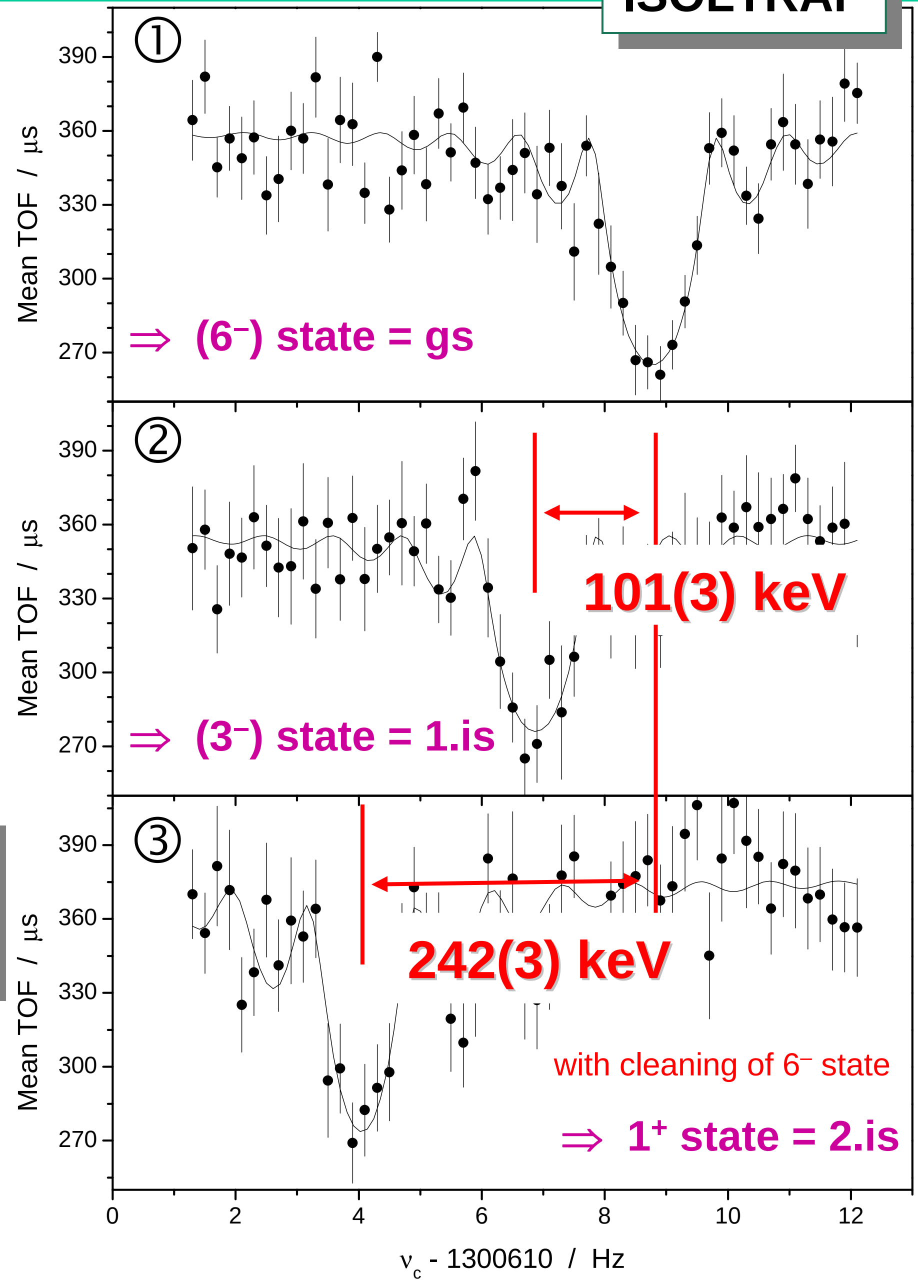


$\omega_c = q/m \cdot B$

Unambiguous state assignment!

J. Van Roosbroeck et al., PRL 92, 112501 (2004)

ISOLTRAP



Mass measurement programs outside ISOLDE

TRAPS	LEBIT	NSCL at MSU	Fragmentation, In-flight fission	Short-lived, non-ISOL elements
	SHIPTRAP	GSI	Fusion-Evaporation	Superheavies p-rich
	CPT	ANL	Fusion-Evaporation Fission	p-rich and n-rich (selected regions)
	JYFLTRAP	JYFL	IGISOL, Spallation, Fission	Non-ISOL elements
Storage Ring	ESR	GSI	Fragmentation In-flight fission	Schottky (large surveys $T_{1/2}$>10s) TOF: short-lived
Spectrometer TOF	SPEG	GANIL	Fragmentation	Short-lived, very exotic
Cyclotron TOF	CSS2	GANIL	Fragmentation	Short-lived

+ reactions (unbound states, beyond the dripline) and decays

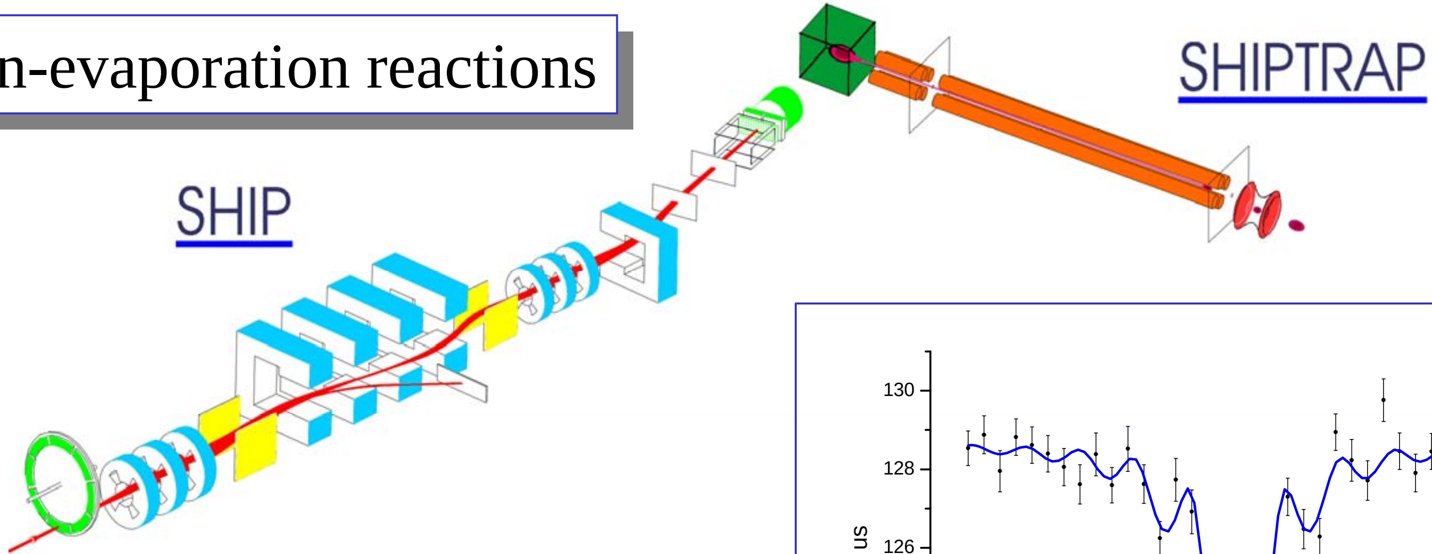
New projects: TITAN at ISAC (highly-charged ions), MAFFTRAP (n-rich)

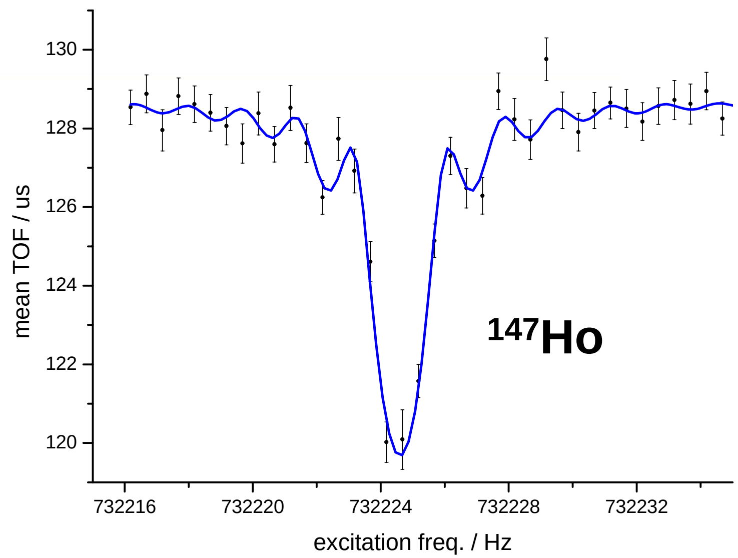
SHIPTRAP – Towards SHE

precision measurements with
heavy ions produced at SHIP/GSI

M. Block/GSI

Fusion-evaporation reactions



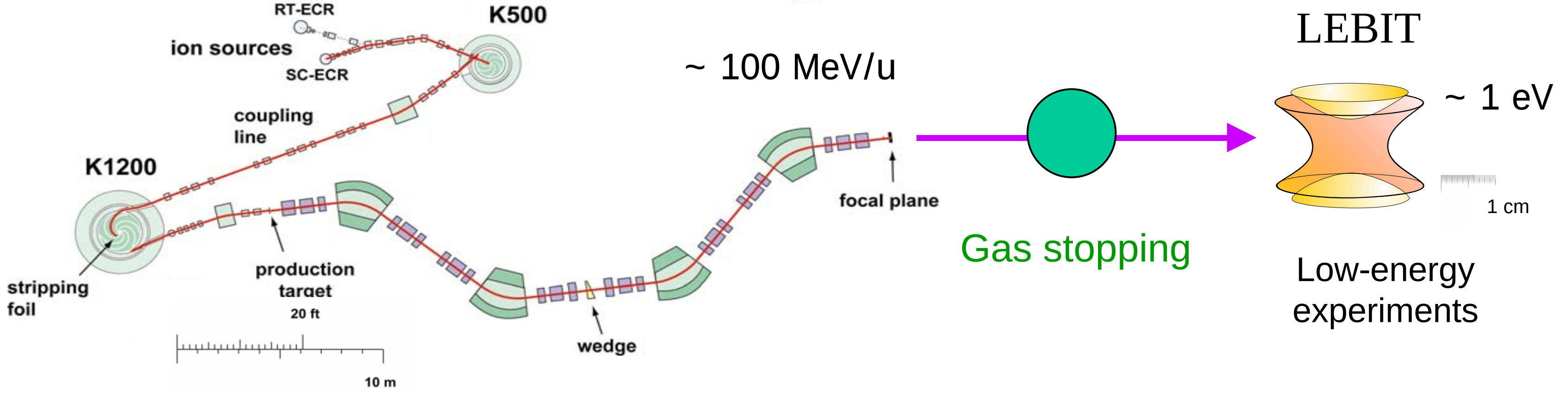


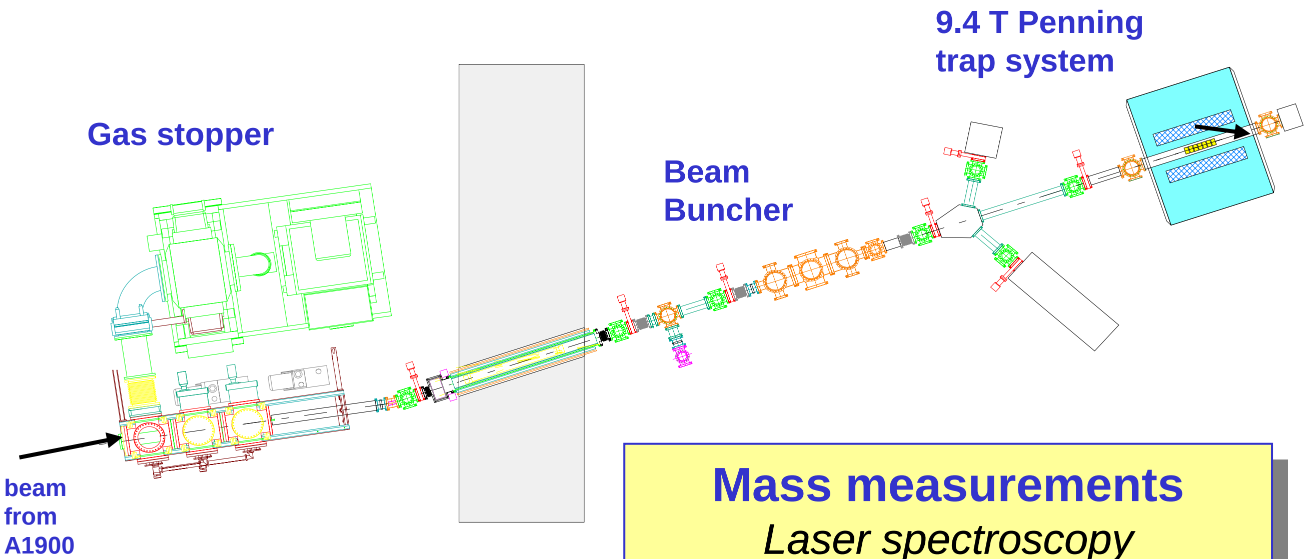
BRAND NEW

^{146}Ho(#), ^{147}Ho, ^{147}Er(#), ^{148}Er(#), ^{147}Tb, ^{147,148}Dy, ^{148}Tm(#)

Low Energy Beam and Ion Trap Facility at NSCL/MSU

Precision experiments at low-energies with rare isotopes from **fast-beam fragmentation**





Mass measurements

Laser spectroscopy

Post Acceleration

Precision Mass Measurement of Fast Beam Fragments

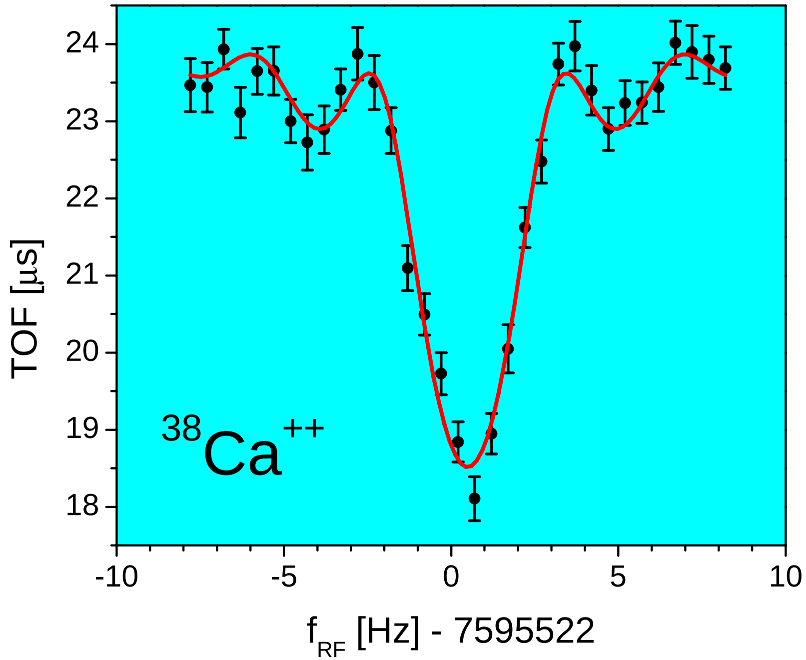
Secondary Beam ^{38}Ca (92 MeV/u)

Statistical uncertainty $\delta m \approx 80$ eV

Expected final uncertainty $\delta m < 300$ eV

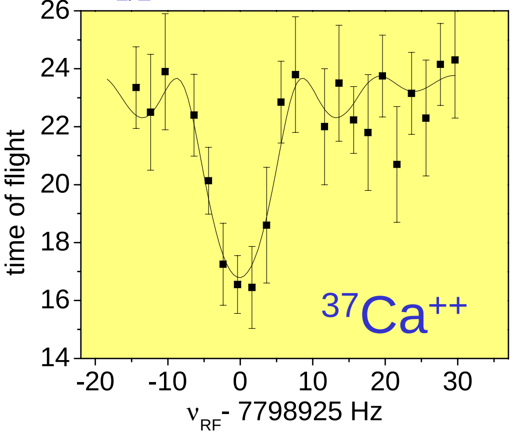
- **First successful nuclear physics experiment with a thermalized beam from fast beam fragmentation.**
- **^{38}Ca is a $0^+ \rightarrow 0^+$ beta emitter: new candidate for CVC tests.**

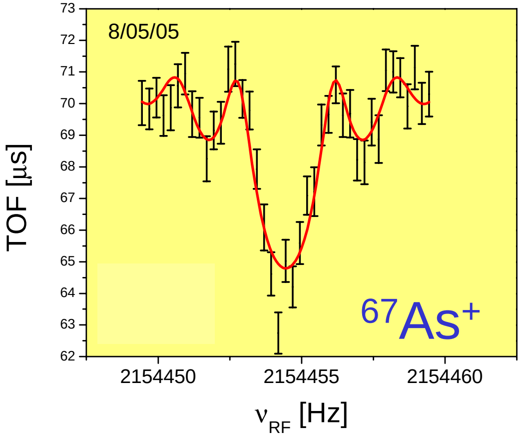
$m(^{38}Ca^{++})/m(H_30^+)$



&

$T_{1/2}$ = 181 ms





… and more to come

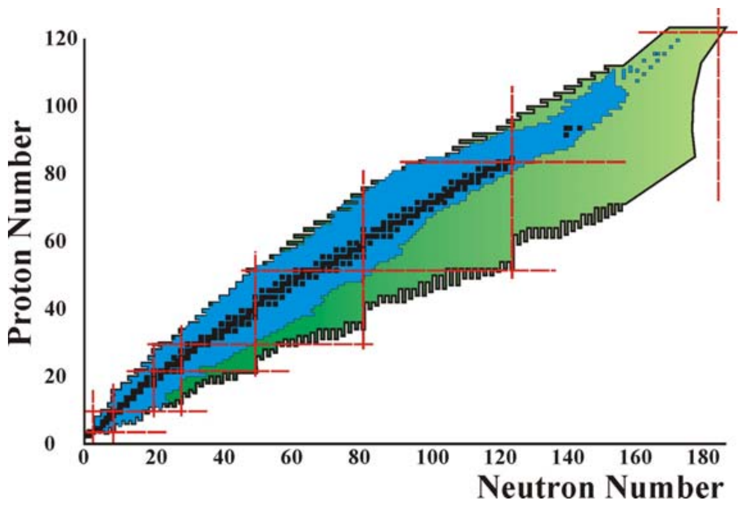
Conclusions

Mass measurements are key to a better understanding of nuclear structure and important to other fields of research with radioactive isotopes

ISOLDE has a very strong mass measurement program

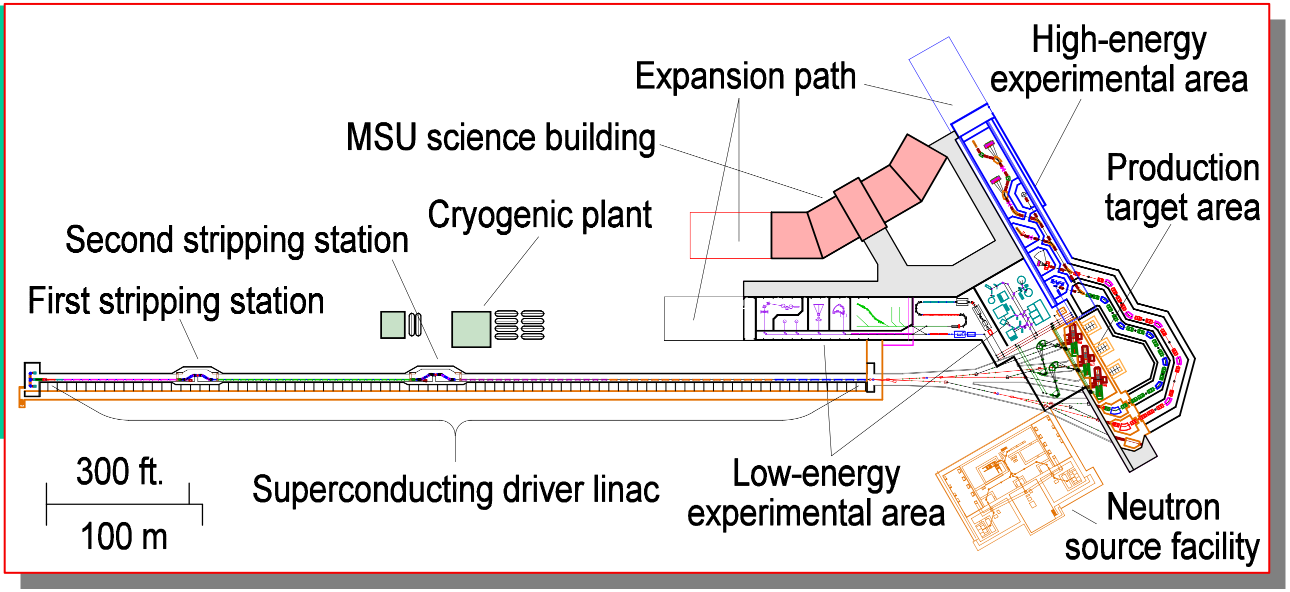
- **Experiments related to key topics: halos, evolution of shell structure, nuclear astrophysics, fundamental interaction tests**
- **Two excellent experimental devices with significant development potential**

Complementary programs exist worldwide– different techniques (PTMS, TOF, ESR) – different production methods

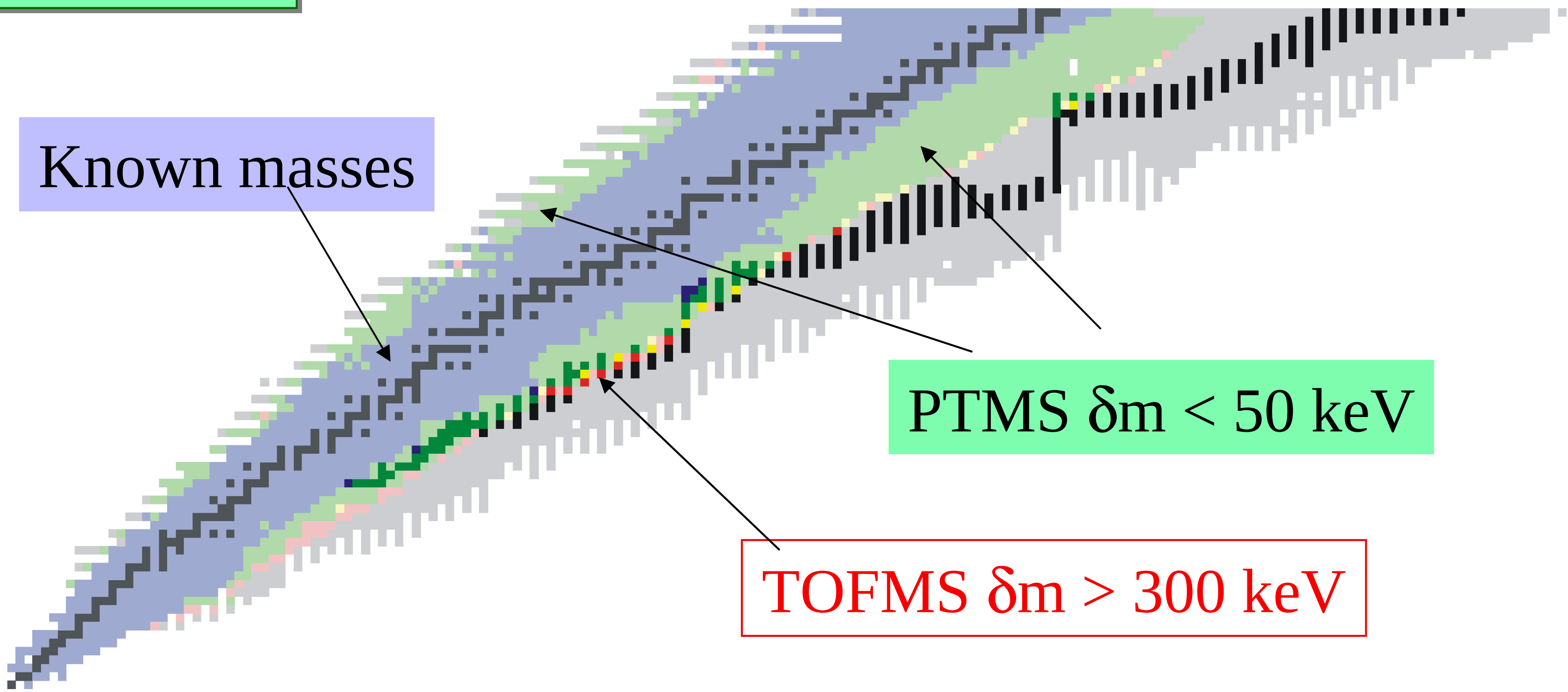


… still a lot to be done!

Mass Measurements at RIA



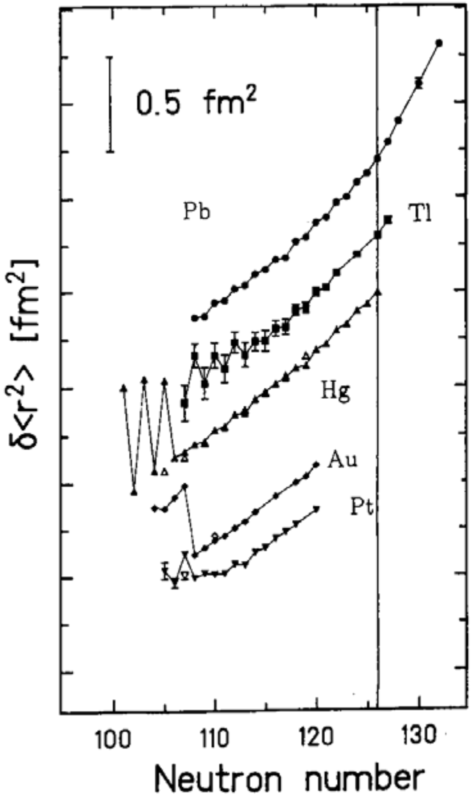
RIA-TRAP with 21 Tesla

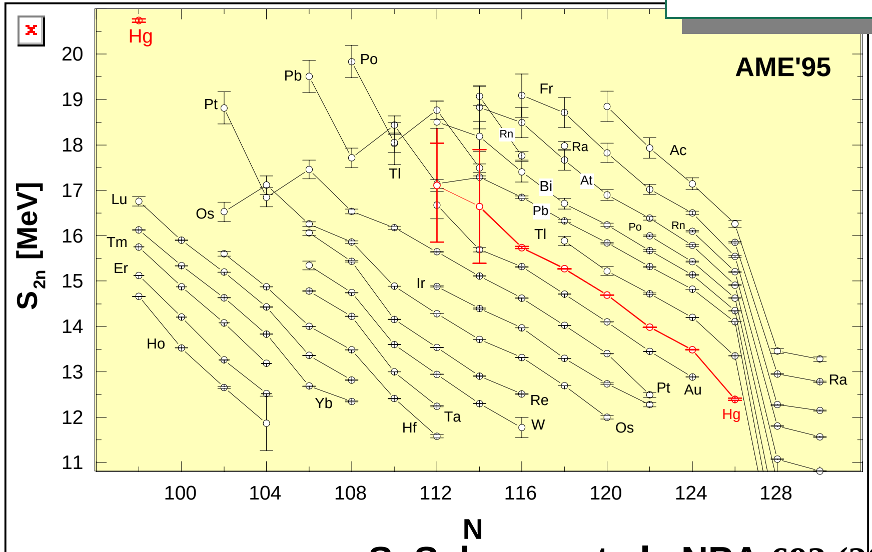


Masses close to Z=82

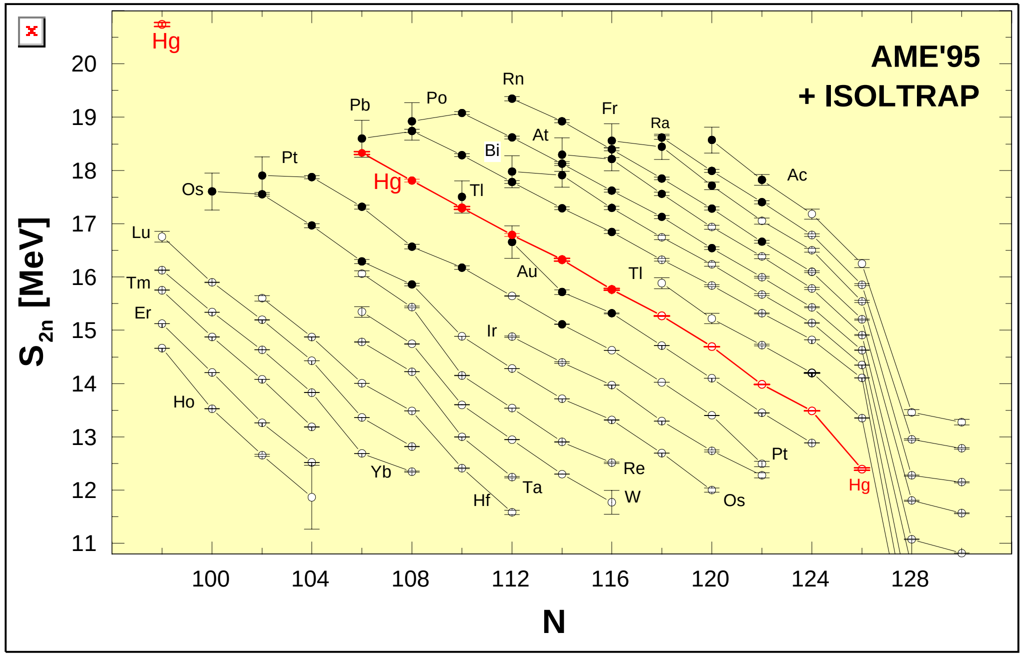
ISOLTRAP

Region of shape-coexistence with interesting nuclear structure effects





S. Schwarz et al., NPA 693 (2001) 533



Discussion within IBM & microscopic-macrosopic model
R. Fossion et al., NPA 697 (2002) 703