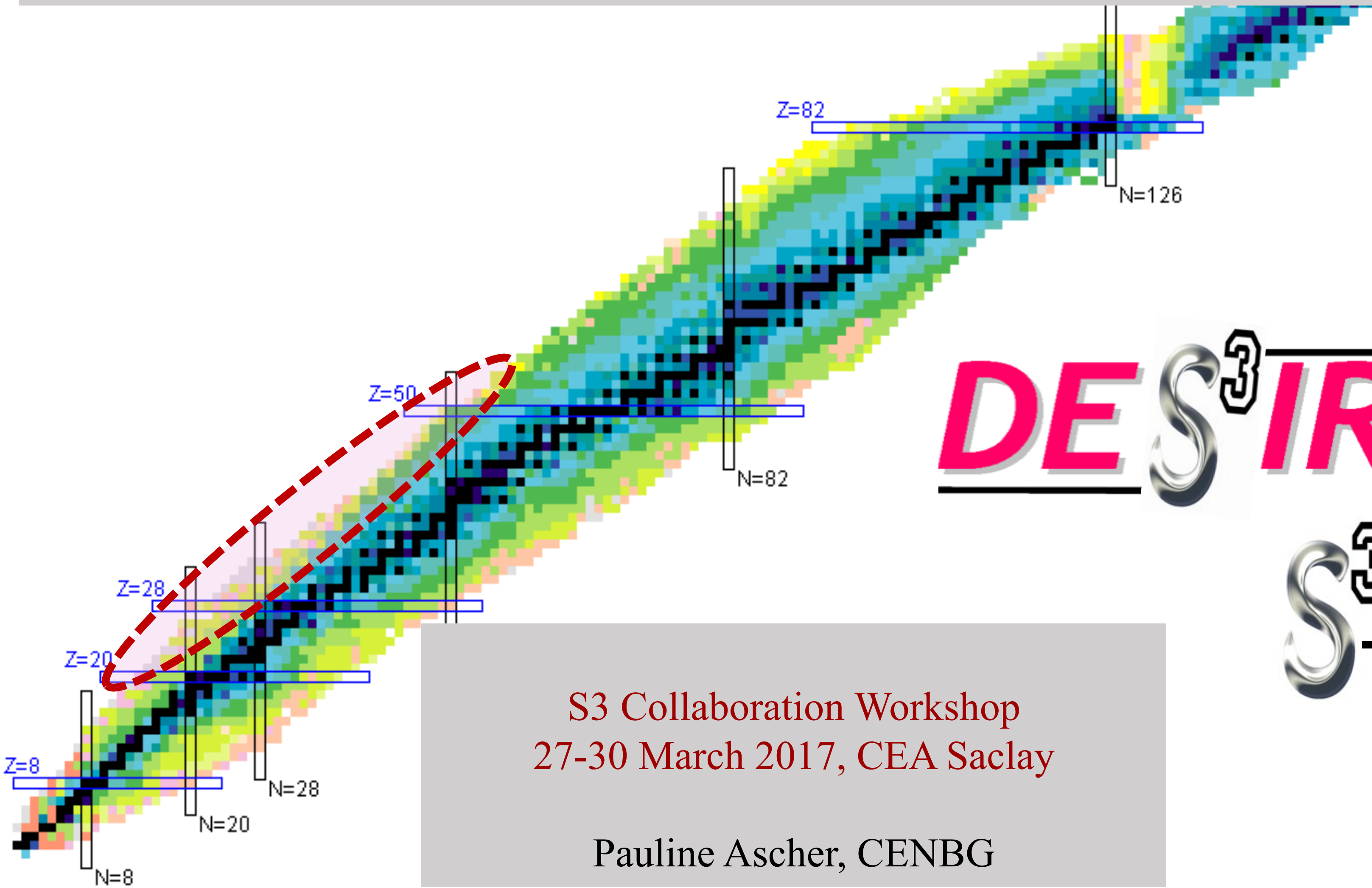
Mass measurements of neutron-deficient nuclei @ S3-LEB and @ S3-DESIR



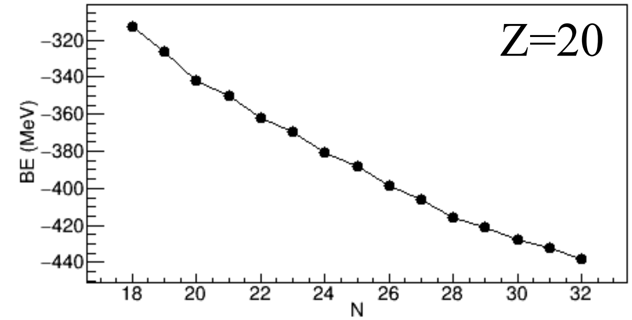
DES3IR

S3-LEB

S3 Collaboration Workshop
27-30 March 2017, CEA Saclay

Pauline Ascher, CENBG

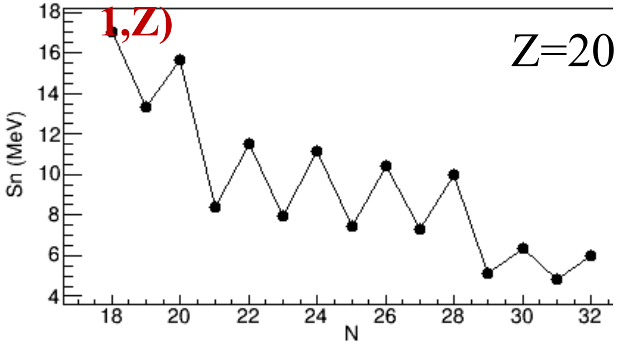
Mass spectrometry



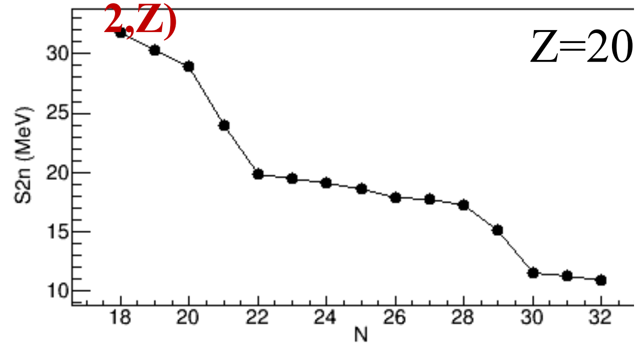
$$M(N,Z) = Z\,M_p + N\,M_n - BE(N,Z)$$

Use of « mass filters »

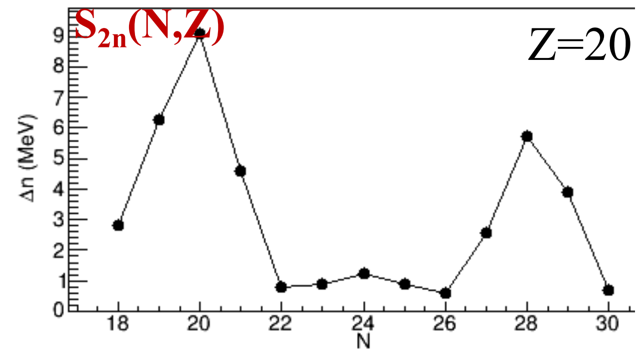
$S_n(N,Z) = BE(N,Z) - BE(N-1,Z)$

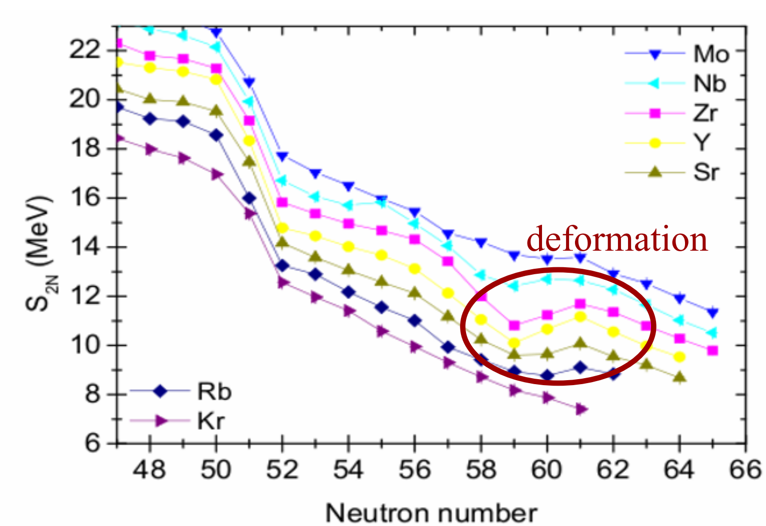


$S_{2n}(N,Z) = BE(N,Z) - BE(N-2,Z)$



$\Delta_{2n}(N,Z) = S_{2n}(N+2,Z) - S_{2n}(N,Z)$

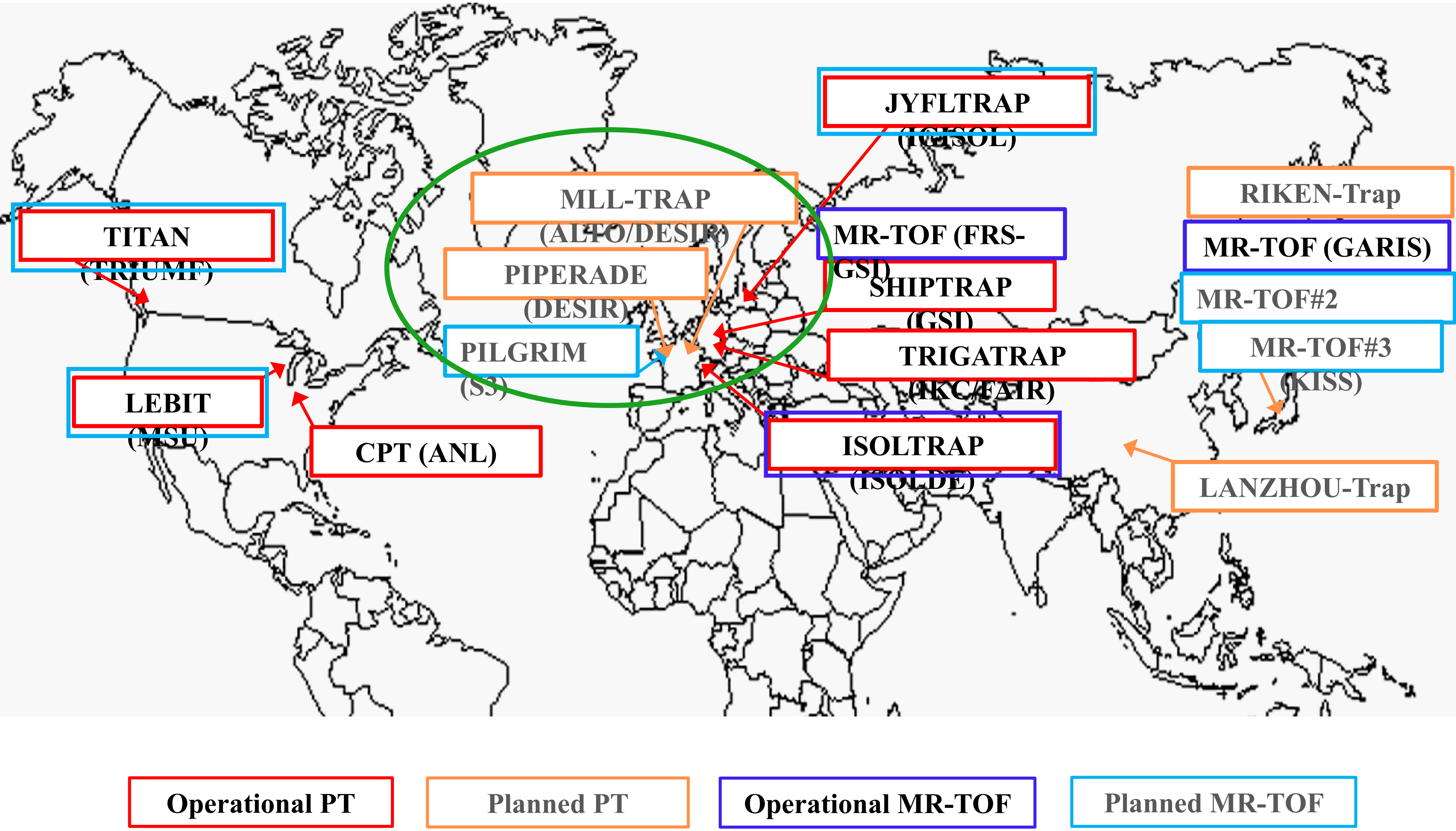




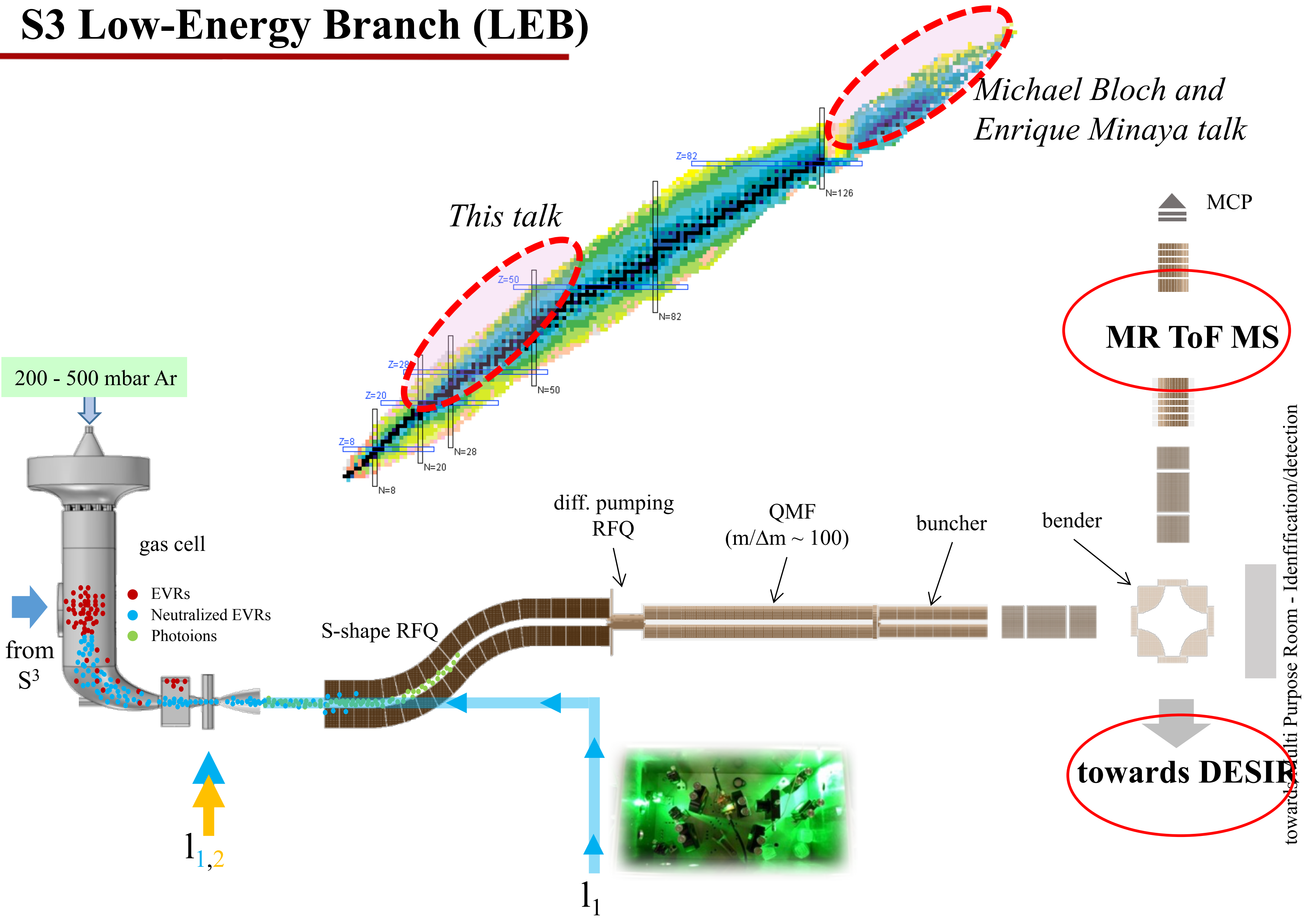
- ✓ First hint on nuclear structure effects but has to be combined with other observables (charge radii, beta decay studies, Coulomb excitation, …)
- ✓ Constrain models: nuclear models (shell model, mean-field models, …), local mass models as well as nuclear astrophysics models (nucleosynthesis processes)

Mass market worldwide (short-lived nuclei)

7 operational Penning traps + 3 operational MR-TOF



S3 Low-Energy Branch (LEB)



R. Ferrer et al., Nuclear Instruments and Methods in Physics Research B 317 (2013) 570–58

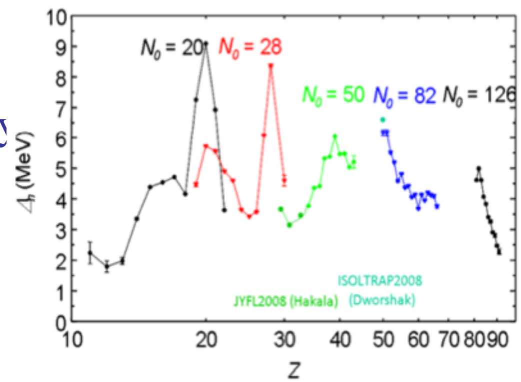
Mass measurements @S3: motivations

❑ N=Z nuclei up to ^{100}Sn

Neutrons and protons occupy the same orbitals
Isospin symmetry breaking (Coulomb, strong force, …)
Extra binding energy
Understanding of the "Wigner effect"
T=0 np pairing ? SU(4) spin-isospin symmetry

P. Van Isacker, PRL 1995
Goriely & Pearson, PRL 2009

D. Lunney et al., LOI DESIR

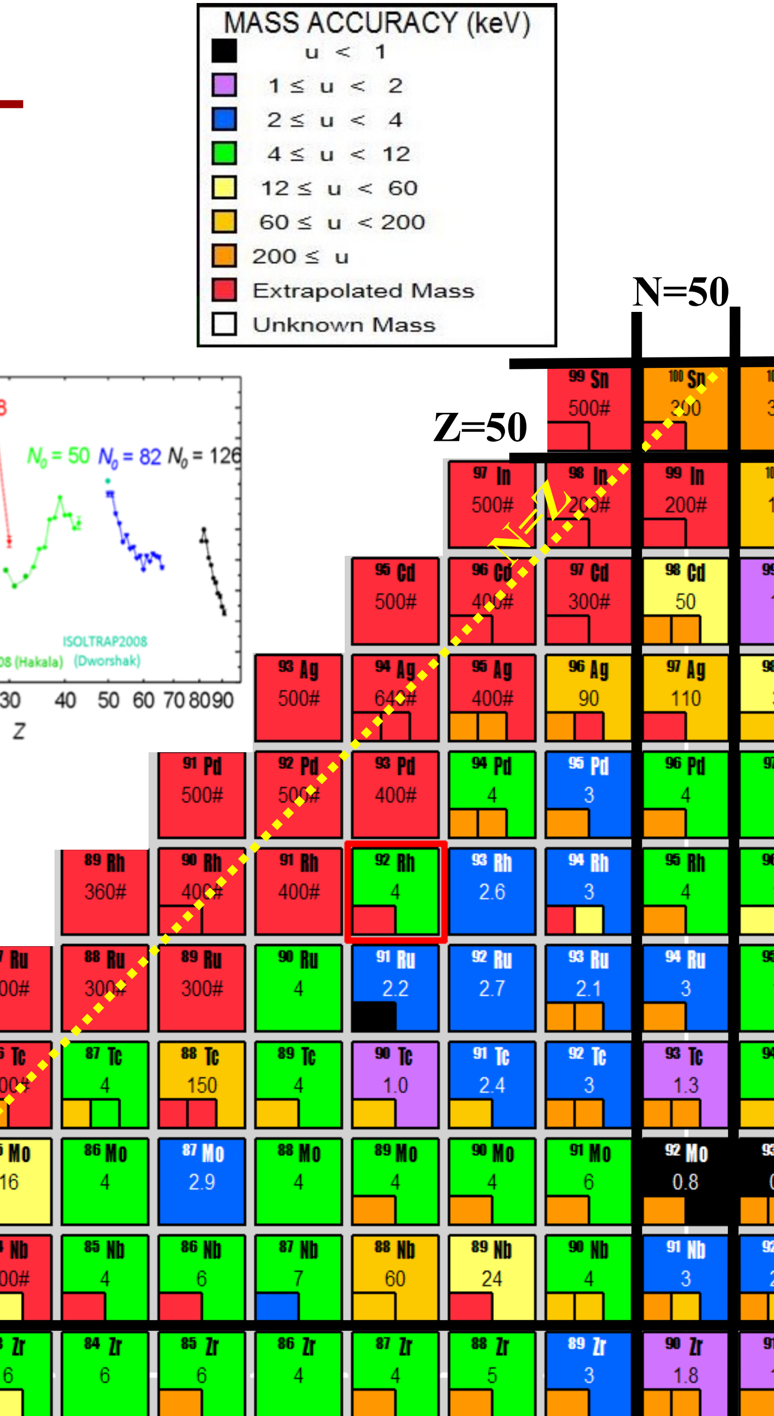


❑ Nuclear structure studies

- ➢ Evolution of shell effects
- ➢ High-spin isomerism
- ➢ Shape transition, coexistence
- ➢ Isospin effects
- ➢ IMME breakdown (isospin mixing, charge-dependent effects, …)

M. Mc Cormick et al., LOI DESIR

D. Lunney et al., LOI DESIR



Mass measurements @S3: motivations

❑ Masses of rp-process

Sequence of (p,γ) reactions and β+ decays

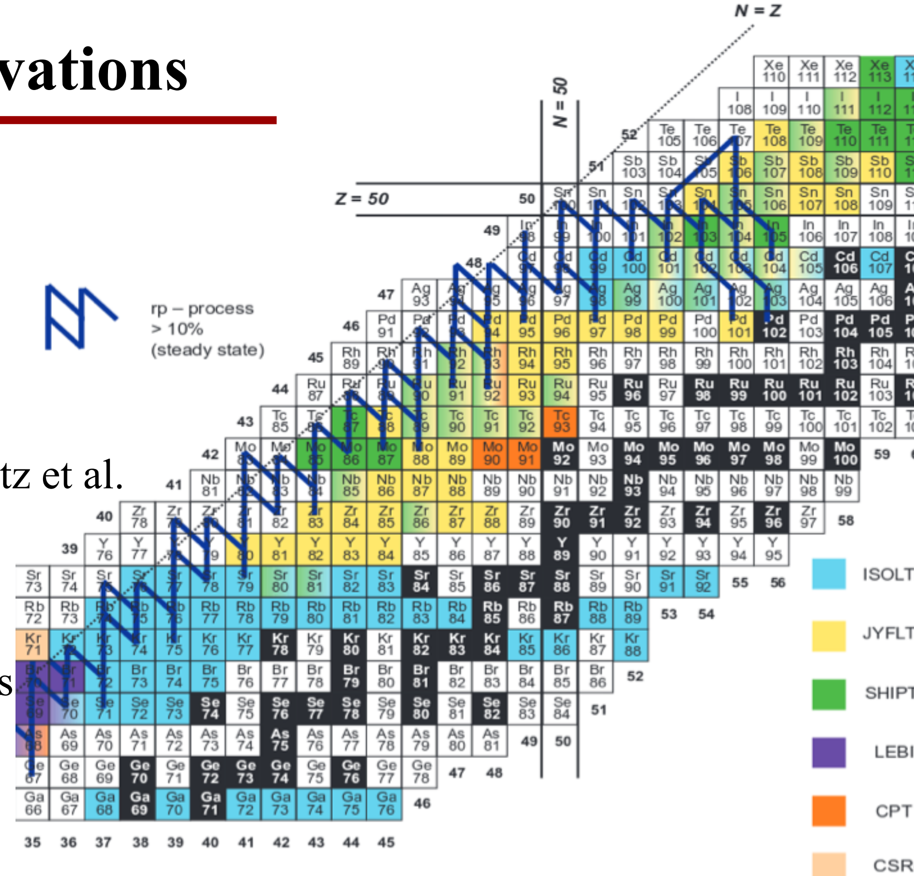
Exponential dep. of rates on S_p

$$\lambda_{(\gamma,p)} = \frac{2G_f}{G_i}\left(\frac{\mu kT}{2\pi\hbar^2}\right)^{3/2} \exp\left(-\frac{Q_{(p,\gamma)}}{kT}\right) < \sigma v >_{(p,\gamma)}$$

→ need 10 keV mass precision
(i.e. $\delta m/m = 10^{-7}$)

D. Lunney et al., LOI DESIR

H. Schatz et al.



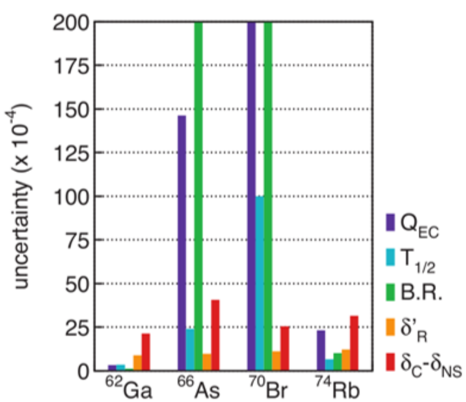
K. Blaum, J. Dilling and W. Nörtershäuser, Phys. Scr. T 152 (

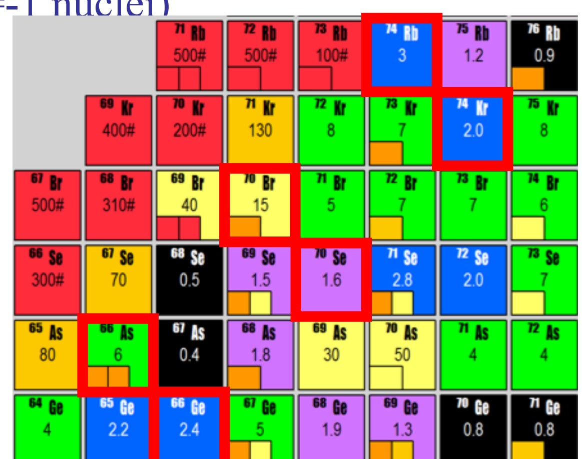
Complementary measurements of SPIRAL1 beams below Z=40

❑ Weak interaction

CVC hypothesis and unitarity of CKM matrix
Tests of theoretical corrections
0+ -> 0+ transitions (Tz=0 and Tz=-1 nuclei)

C. Weber et al., LOI DESIR

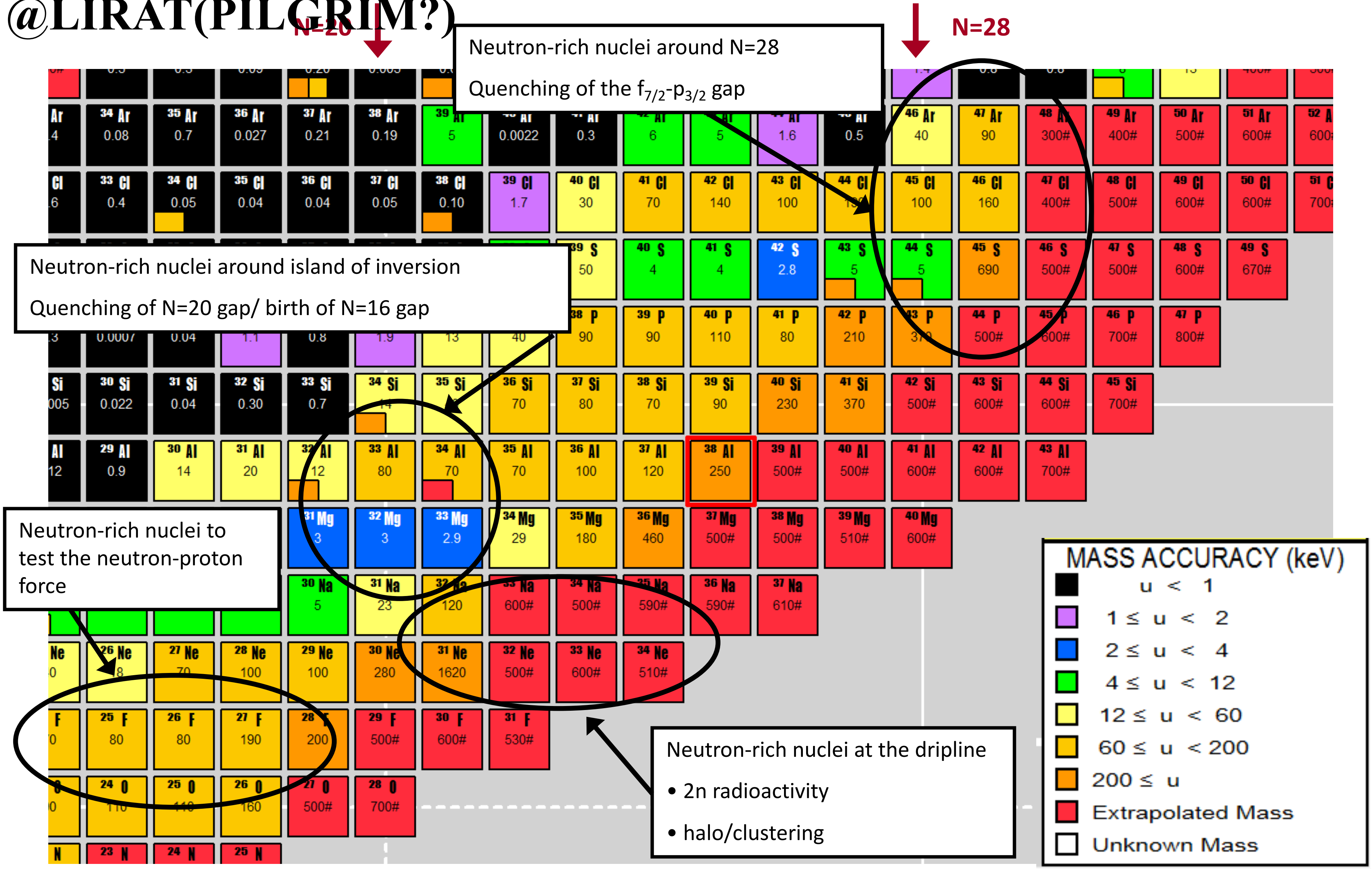




Short half-lives → fast gas cell

→ **experiments at DESIR**

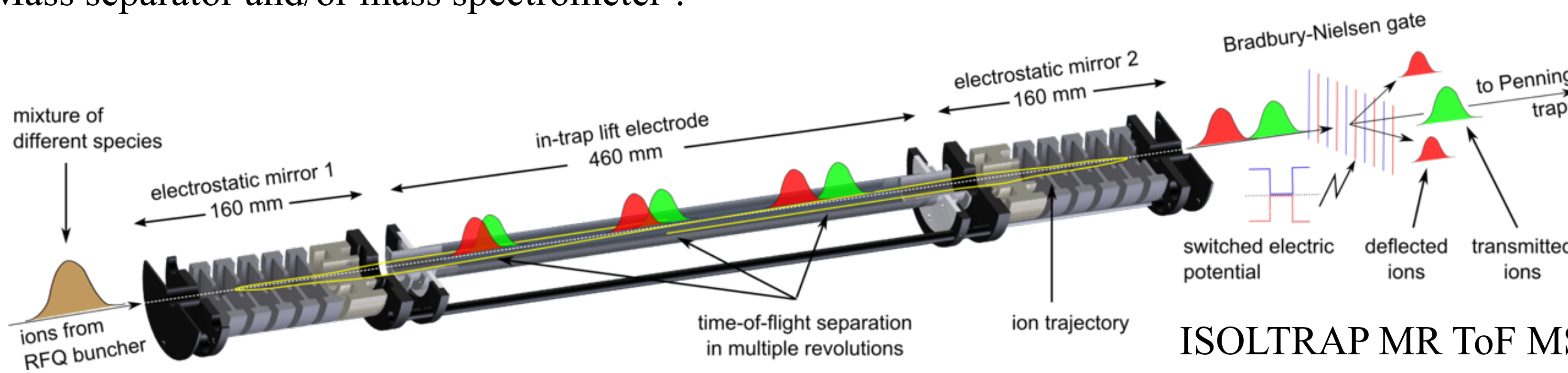
Mass measurements with SPIRAL1 beams @DESIR and @LIRAT(PILGRIM?)



P. Ascher et al., LOI DESIR

MR-TOF technique

Mass separator and/or mass spectrometer !



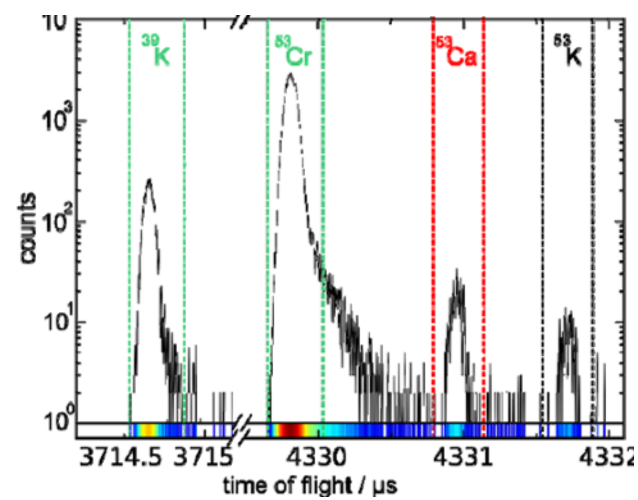
ISOLTRAP MR ToF MS
R. Wolf et al., IJMS

- Typical trapping time: 10-30 ms
- Resolving power: up to few 10^5
- Mass measurement: $\delta m/m \sim 10^{-6}$-10^{-7}
- Intensities down to fractions of pps (single ion sensitivity)

$$\sqrt{m} = C_{tof} \times (\sqrt{m_{ref,1}} - \sqrt{m_{ref,2}}) + \frac{1}{2} \times (\sqrt{m_{ref,1}} + \sqrt{m_{ref,2}})$$

$$C_{tof} = \frac{t}{t_{ref,1} - t_{ref,2}} - \frac{t_{ref,1} + t_{ref,2}}{2(t_{ref,1} - t_{ref,2})}$$

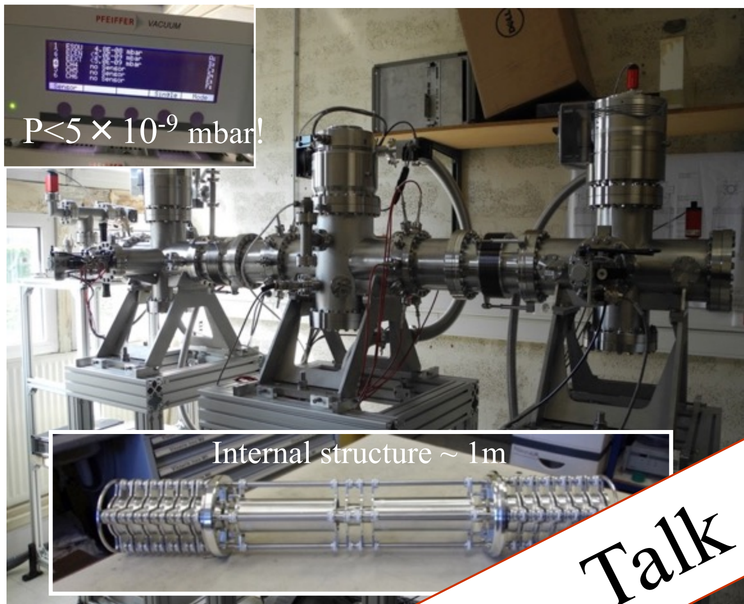
Such performances require
- Cooled and bunched beams, with Δt <100ns
- High vacuum ($<10^{-8}$ mbar)
- High precision and stability of voltage supplies

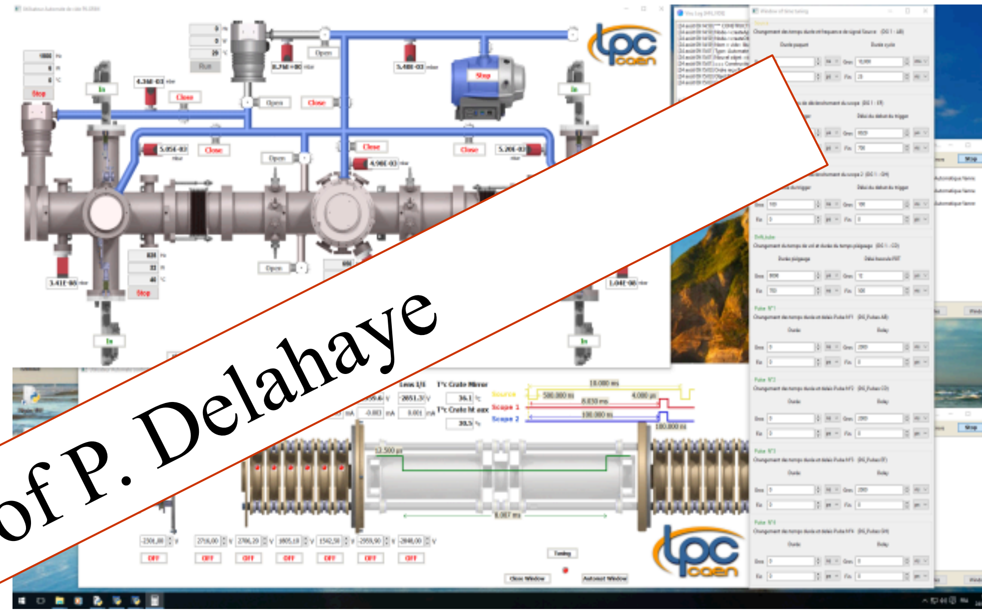


F. Wienholtz et al., Nature ***498*** *(2013) 346-349*

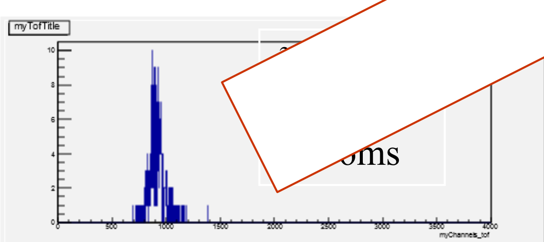
PILGRIM

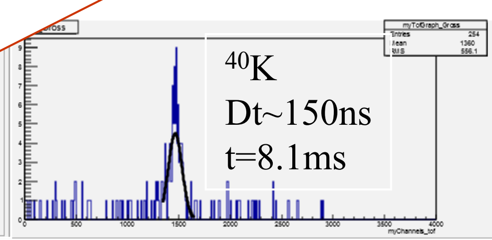
- Tests with stable beams **at LPC Caen** since July 2016
- Tests with radioactive beams **at LIRAT (?)**: 2018
- Measurements at **S3-LEB**: 2019+





Talk of P. Delahaye





- $R=\Delta t/(2t)$~65,000 in 5 days (!)
- No trapping losses up to t~32ms
- Optimizations going on

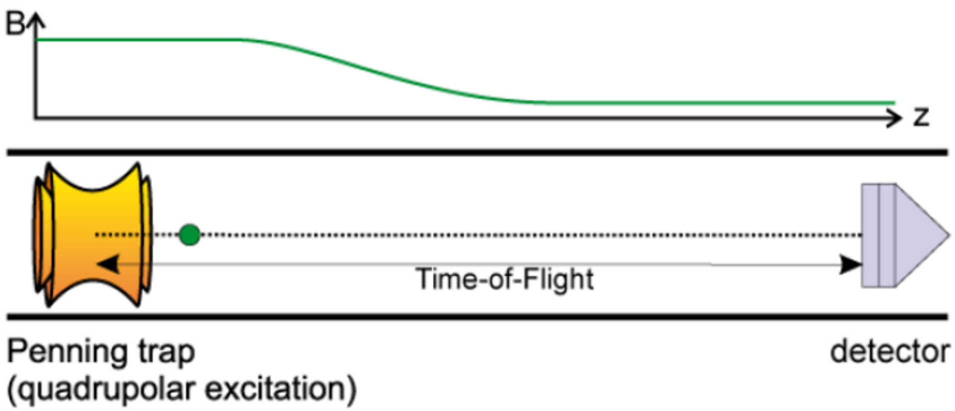
Goals: R>100,000 and $\delta m/m \sim 10^{-6}$

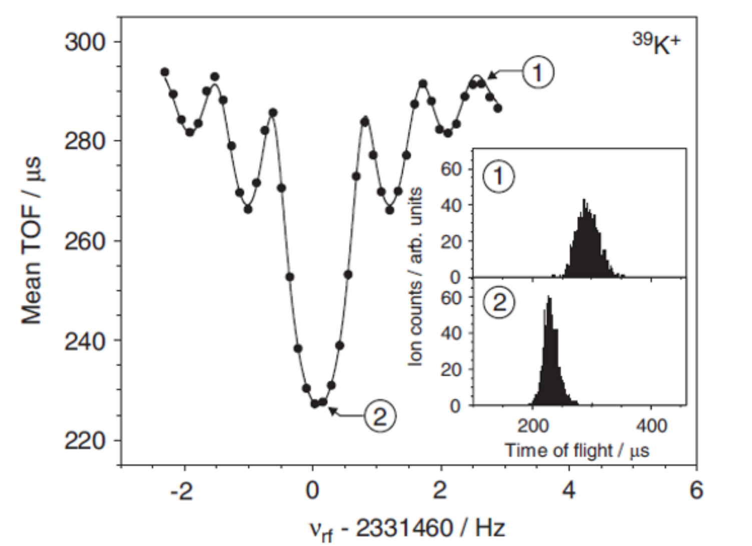
Design, simulation et tests (GANIL)
P. Chauveau, P. Delahaye, Y Liu, A. Shornikov

Collaboration avec uni – Greifswald
R. Wolf, M. Rosenbusch et L. Schweikhard

Design and construction, electronics and slow control (LPC Caen)
Y. Merrer, J. Lory, P. Desrues, J. F. com, C. Vandamme, J. Brégeault et F. Boumard

Penning trap technique



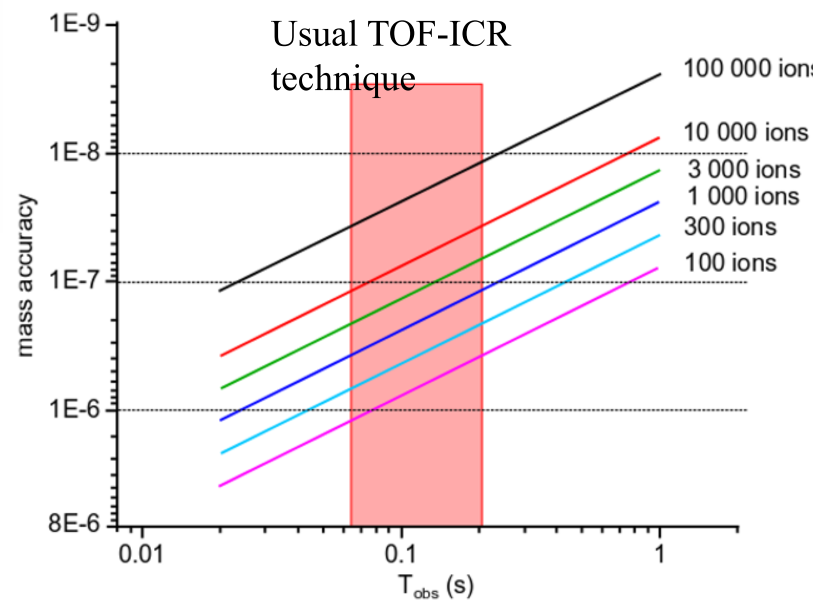


$$\nu_c = qB/2\pi m$$

$$\nu_{c,ref} = \frac{qB}{2\pi(m_{ref} - m_e)} \Rightarrow \boxed{B = 2\pi\nu_{c,ref}\frac{(m_{ref} - m_e)}{q}}$$

$$\boxed{m_x = r_{ref,x}(m_{ref} - m_e) + m_e} \text{ with } r_{ref,x} = \frac{\nu_{c,ref}}{\nu_{c,x}}$$

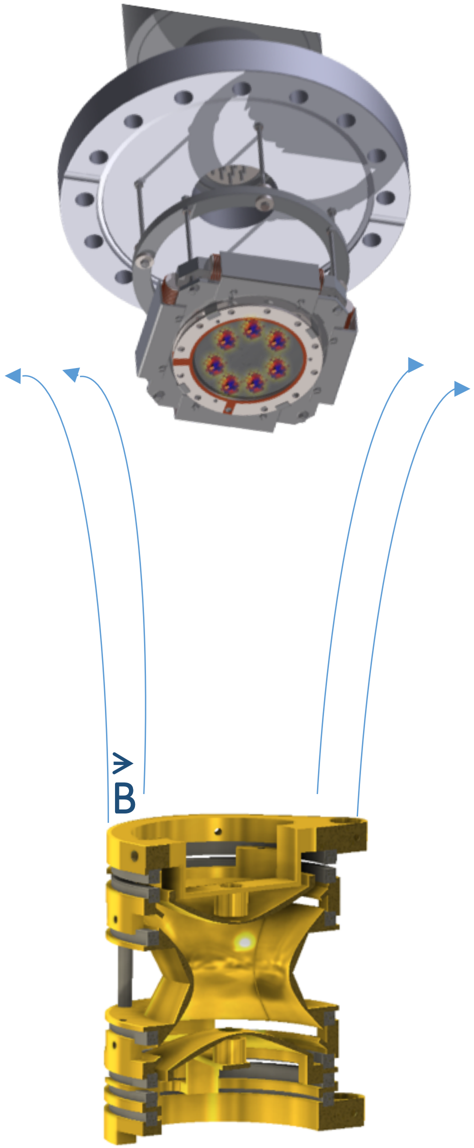
- precision: ~10^{-7}-10^{-8}
- minimum yield: ~1-10 pps
- isomeric separation ($\Delta M/M > 10^{6}$)



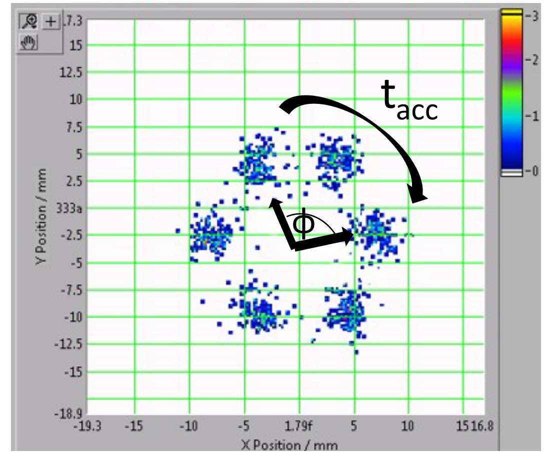
K. Blaum, J. Dilling and W. Nörtershäuser, Phys. Scr. T 152 (201

Phase Imaging – ICR (PI-ICR)

Projection of the ion cloud on a position-sensitive detector



DAQ



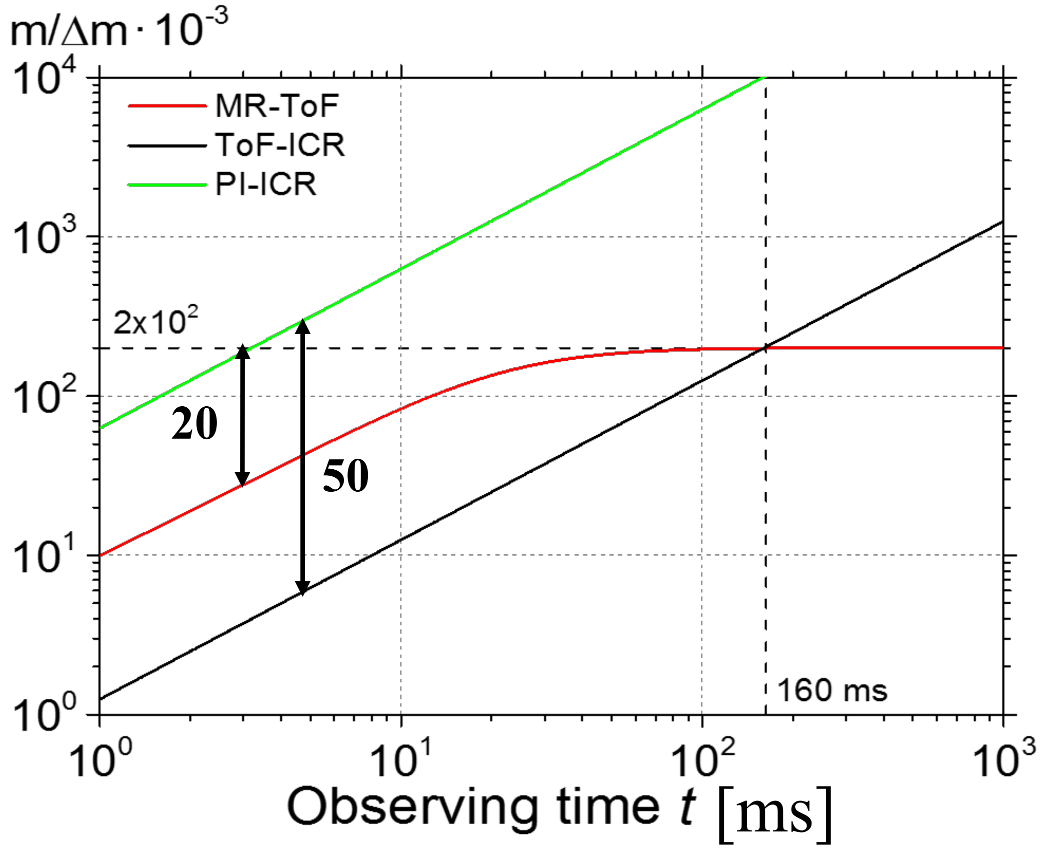
Courtesy: A.Welker

$$\left.\begin{aligned} \nu_+ &= \frac{\phi_+ + 2\pi n_+}{2\pi t_+} \\ \nu_- &= \frac{\phi_- + 2\pi n_-}{2\pi t_-} \end{aligned}\right\} \nu_+ + \nu_- = \nu_c = \frac{qB}{2\pi m}$$

- Gain in precision of a factor ~ 5 (compared to TOF-ICR)
- High sensitivity

S. Eliseev et al., PRL 110, 082501 (2013)

Resolving power



$v_c = 1$ MHz,
$R_0 = 1$ mm,
$\Delta r_0 = 50\ \mu$m,

$$\frac{\nu_+}{\Delta\nu_+} = \frac{\pi\nu_+ t R_+}{\Delta R_+}$$

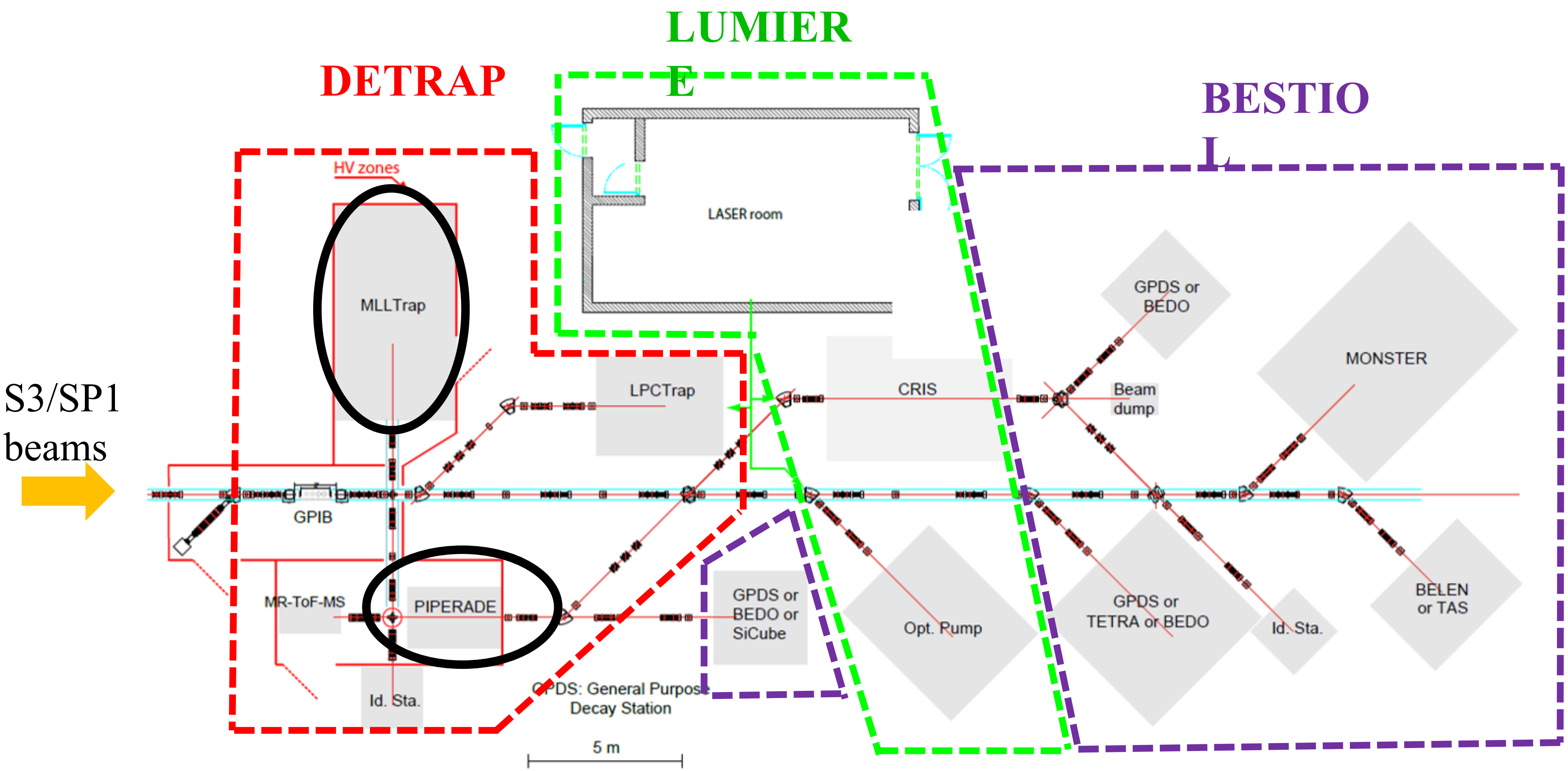
PI-ICR

- Simultaneous mass measurements of gs/isomer states
- Can also be used for delivering pure-isomeric beams (trap-assisted spectroscopy)

Courtesy: A.Welker

*R. Wolf et al. IJMS **349-350** (2013) 123-133*
*S. Eliseev et al. Appl. Phys. B, **13** (2013)*

DESIR Experimental equipment



Penning traps at DESIR: MLLTRAP and PIPERADE

- MLLTRAP is being installed at ALTO
- Dedicated to mass measurements and in-trap spectroscopy

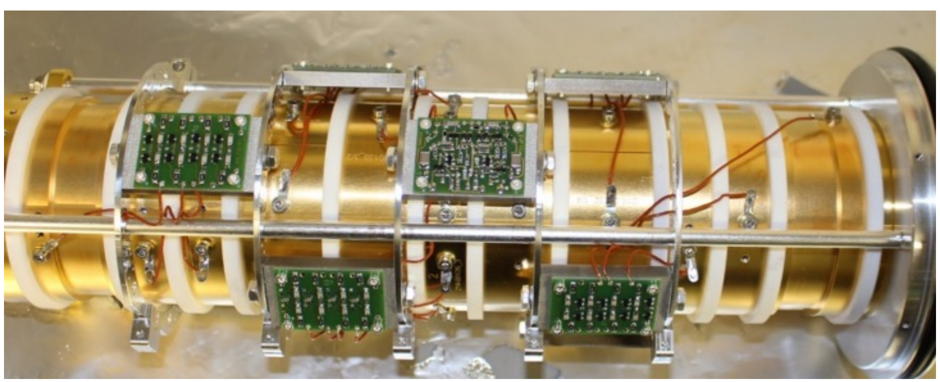
See talks of Enrique Minaya Ramirez and Araceli Lopez-Martens

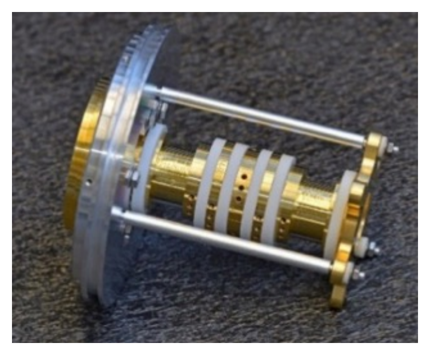
- PIPERADE is being developed at CENBG
- Dedicated to purification purposes but can also be used for mass measurements

Status

- Traps delivery from MPIK HD: Feb 2017
- Magnet delivery from Cryogenic: May 201
- First stable beam tests: Autumn 2017

Possibility to be installed at SPES before DESI



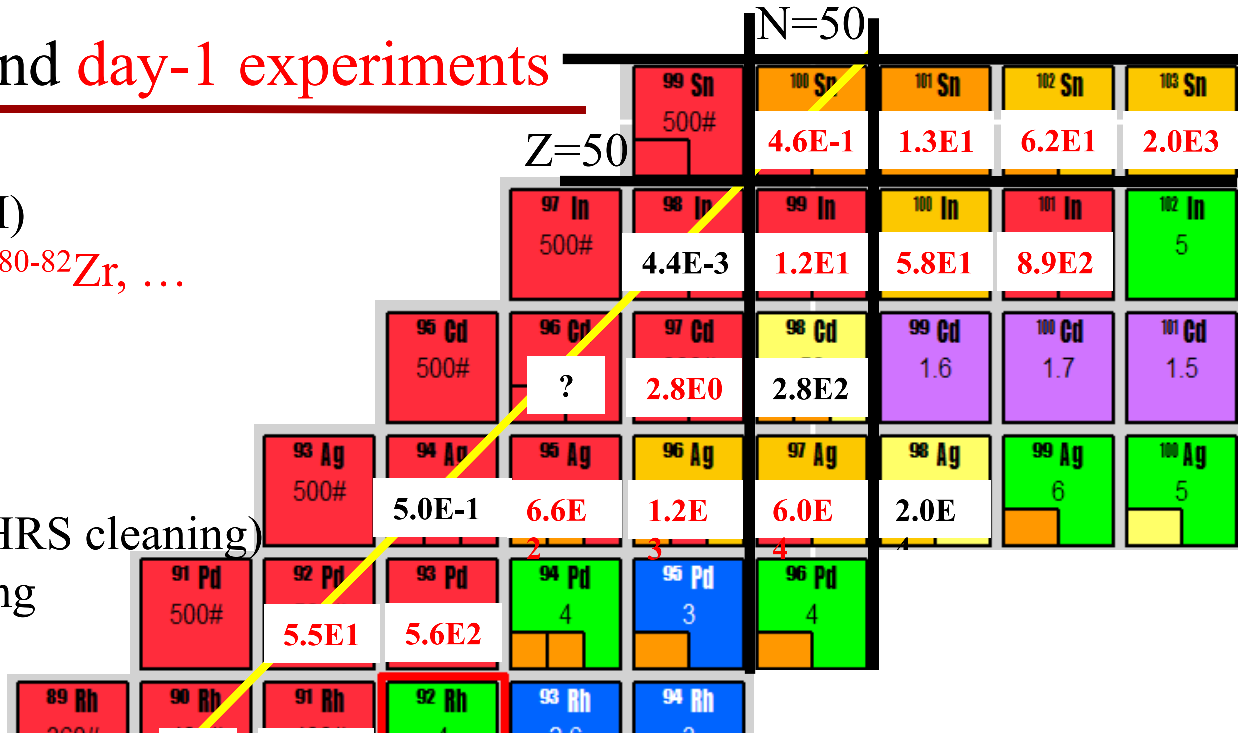


PIPERADE
PIEGES DE PENNING POUR LES RADIOISOTOPES A DESIR

First trap (purification)

Second trap (accumulation/selection/measurement)

Estimated yields at *N~Z* and day-1 experiments



possible day-1 cases (PILGRIM)
$^{100-103}$Sn, $^{99-101}$In, ^{97}Cd, $^{95-97}$Ag, $^{80-82}$Zr, …
($T_{1/2}$ > 700 ms, yields > 0.1pps)

then…
Higher precision → DESIR
Shorter $T_{1/2}$ → fast gas cell (+ HRS cleaning)
Isomers → PenningTrap cleaning

Thank you for your attention !