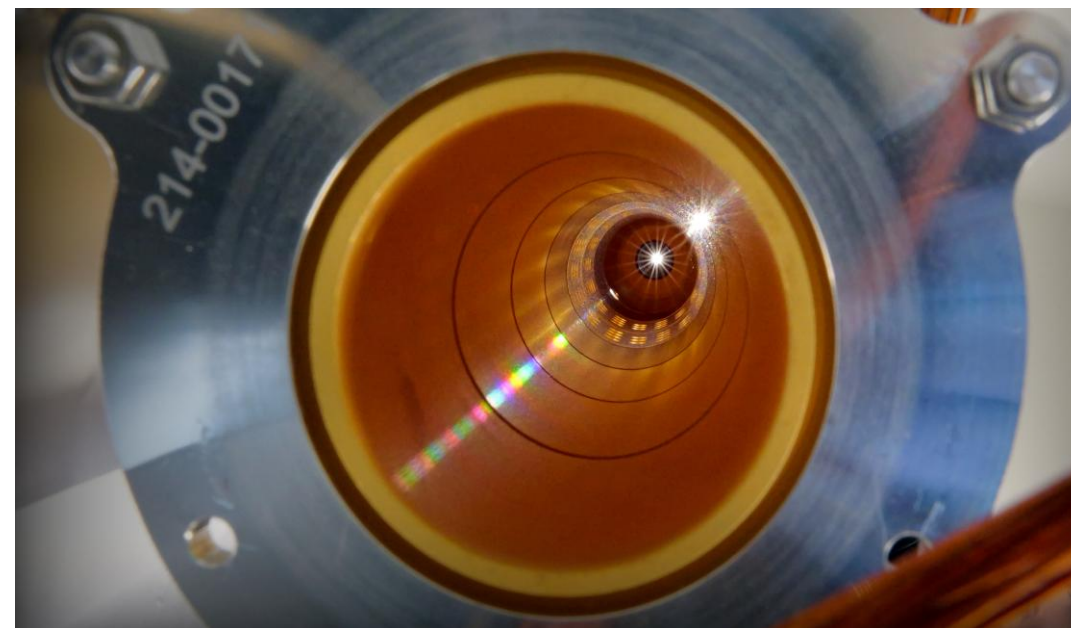


PRECISION MASS SPECTROMETRY @DESIR

- ☐ Mass spectrometry: introduction
- ☐ Status of the double Penning trap PIPERADE
- ☐ Physics cases @DESIR



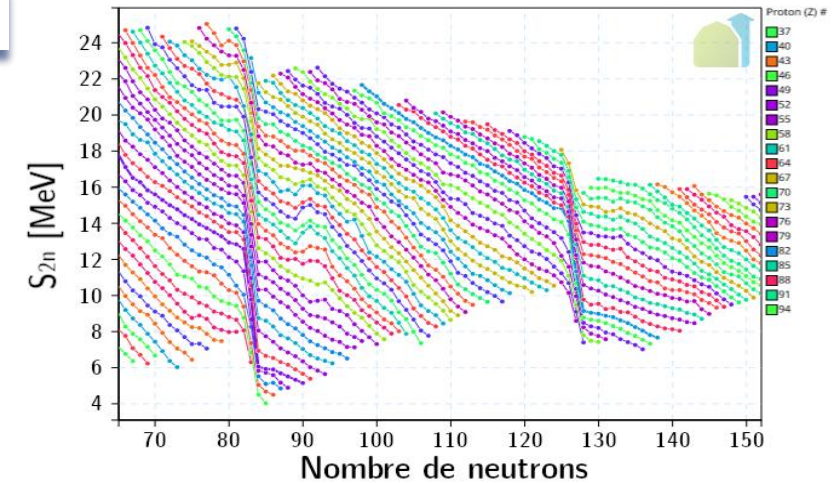
Pauline Ascher – LP2iB
Colloque GANIL, Bussang, 21-25 September 2026

WHY ?

MASS SPECTROMETRY: why and how ?

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

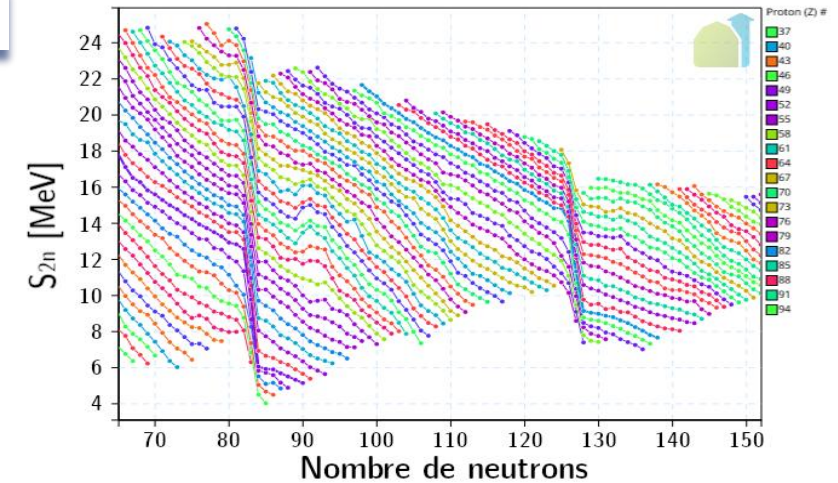
- ❑ Nuclear structure
 - ✓ Test nuclear models
 - ✓ Changes in structure evolution (shells, deformation, pairing, ...)
 - ✓ Isomeric states (shape coexistence, ...)
- ❑ Inputs for nuclear astrophysics (rp process, X-ray bursts)
- ❑ ft-values for weak interaction studies



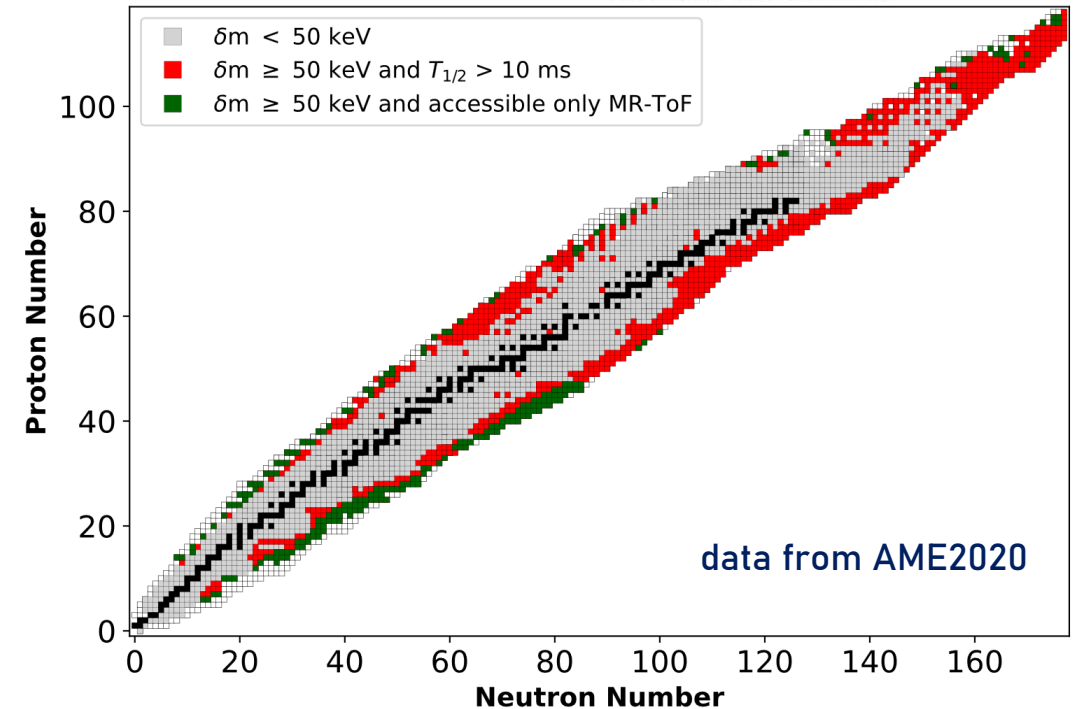
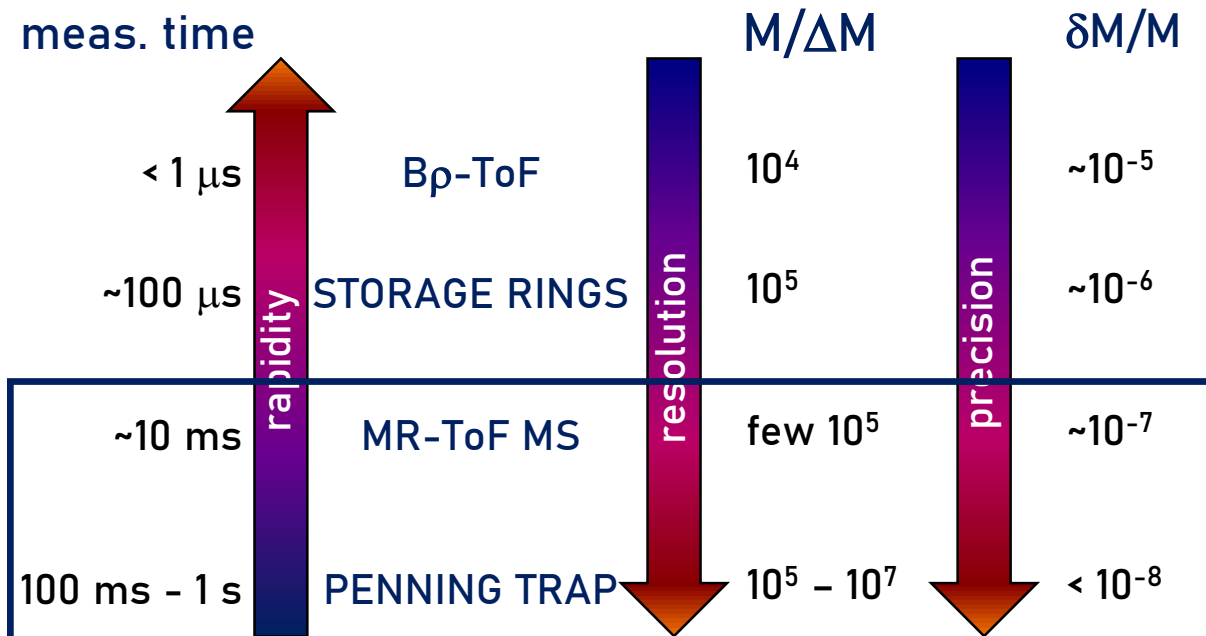
WHY ?

- ❑ Nuclear structure
 - ✓ Test nuclear models
 - ✓ Changes in structure evolution (shells, deformation, pairing, ...)
 - ✓ Isomeric states (shape coexistence, ...)
- ❑ Inputs for nuclear astrophysics (rp process, X-ray bursts)
- ❑ ft-values for weak interaction studies

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



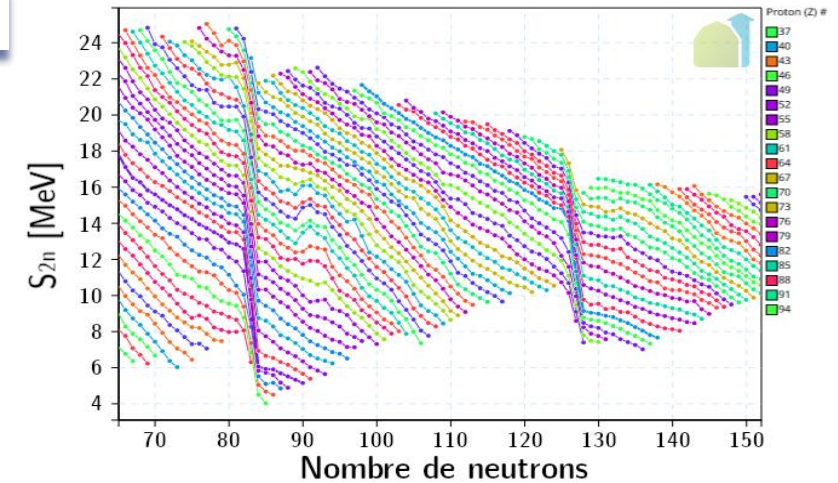
HOW ?



WHY ?

- ☐ Nuclear structure
 - ✓ Test nuclear models
 - ✓ Changes in structure evolution (shells, deformation, pairing, ...)
 - ✓ Isomeric states (shape coexistence, ...)
- ☐ Inputs for nuclear astrophysics (rp process, X-ray bursts)
- ☐ ft-values for weak interaction studies

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



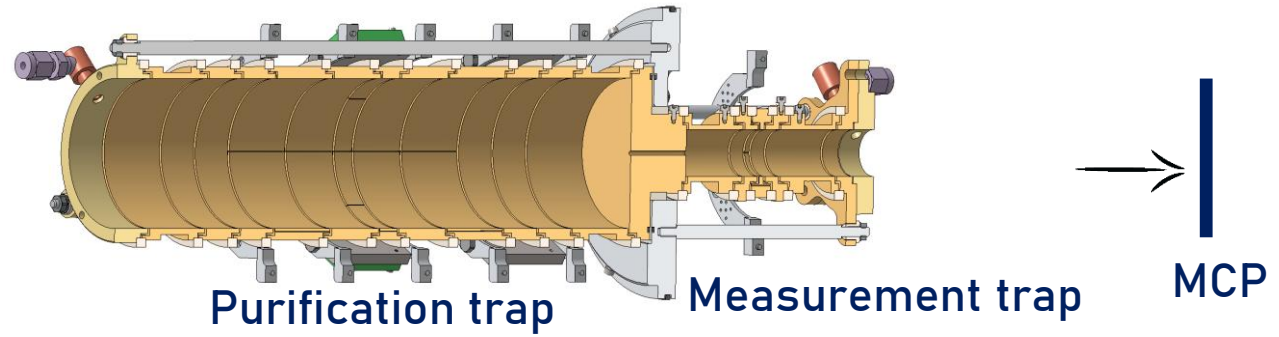
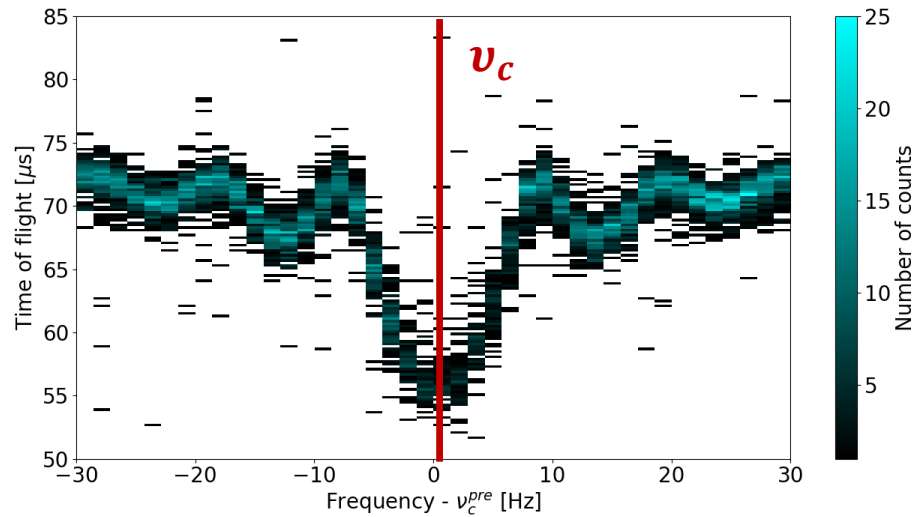
HOW ?

meas. time			$M/\Delta M$	$\delta M/M$
$< 1 \mu s$	Bp-ToF		10^4	$\sim 10^{-5}$
$\sim 100 \mu s$	STORAGE RINGS		10^5	$\sim 10^{-6}$
$\sim 10 ms$	MR-ToF MS		few 10^5	$\sim 10^{-7}$
100 ms - 1 s	PENNING TRAP		$10^5 - 10^7$	$< 10^{-8}$

@DESIR

- ☐ TRAMWAY (~ 2029-2030) (L. Canete)
- ☐ PIPERADE (2027)
- ☐ MLLTRAP(>2030) (E. Minaya)

ToF-ICR



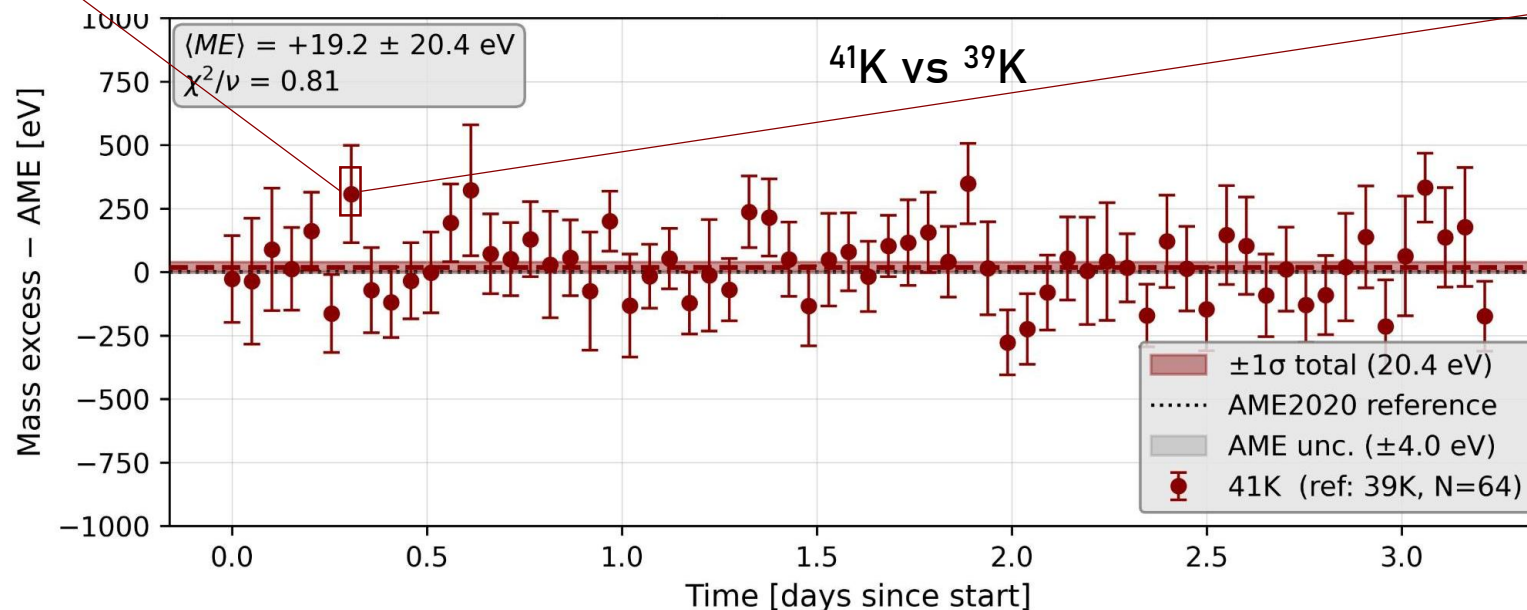
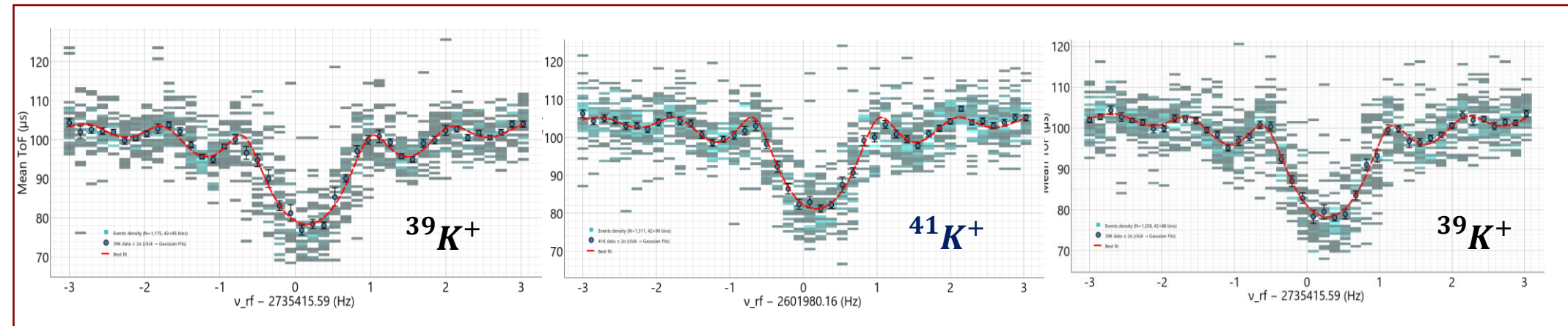
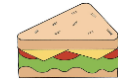
$$\nu_c = \frac{qB}{2\pi m}$$

$$m_{41K} = \frac{\nu_c(^{39}\text{K}^+)}{\nu_c(^{41}\text{K}^+)} (m_{39K} - m_e) + m_e$$

Studies and fine optimisations performed:

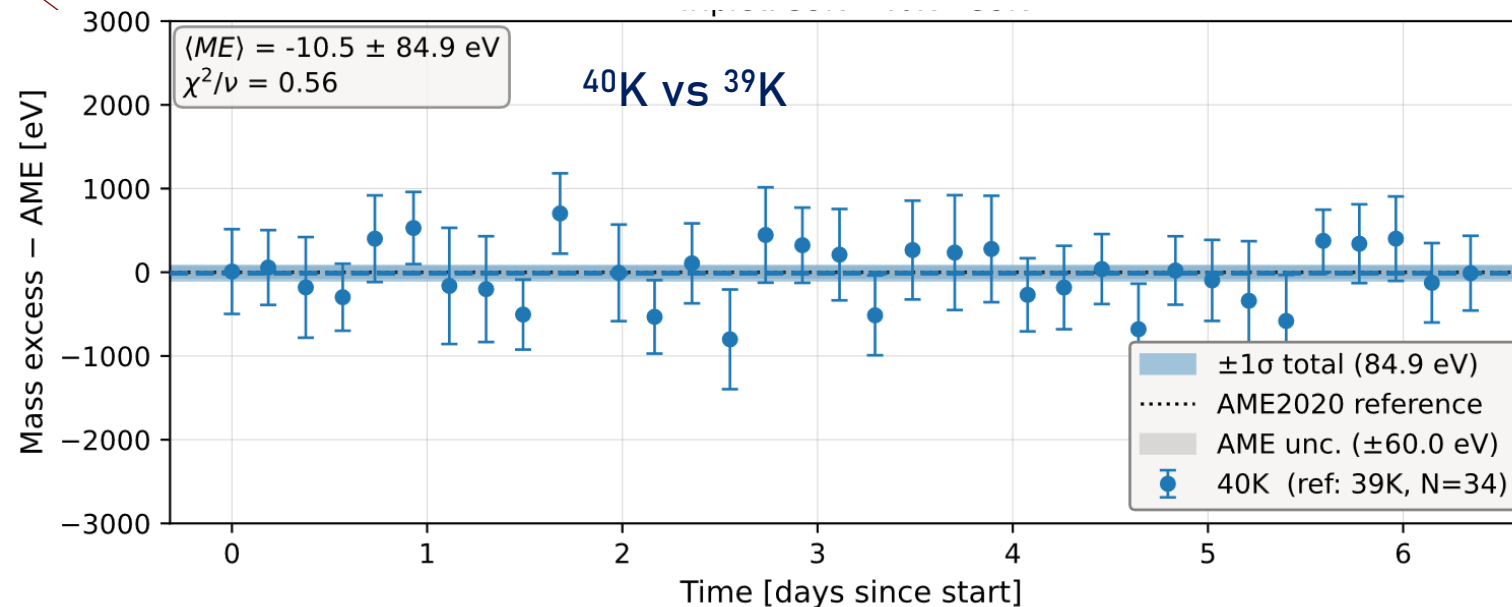
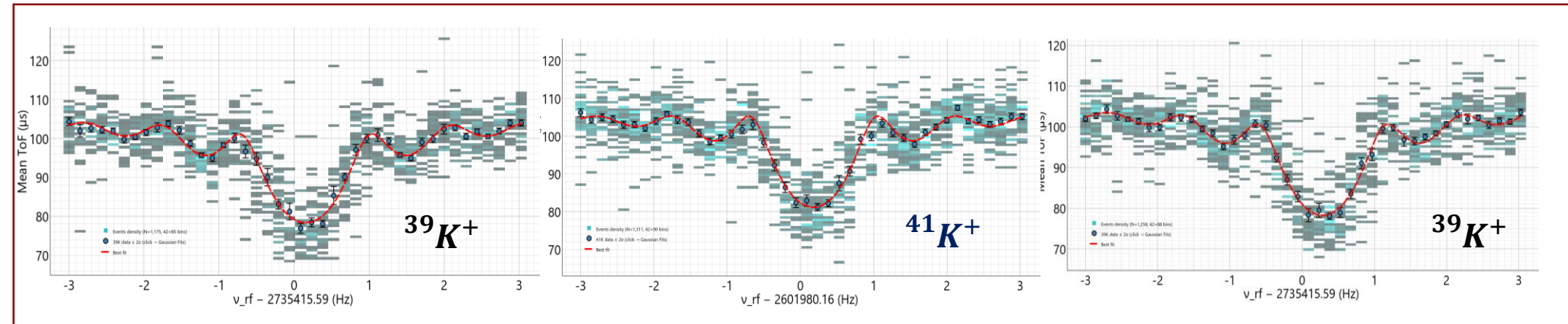
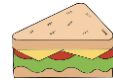
- Minimization of ion motions
- Compensation of the B-field drift
- Optimisation of E-field anharmonicities
- Temperature/pressure dependences
-

MASS MEASUREMENTS AT PIPERADE: ToF-ICR



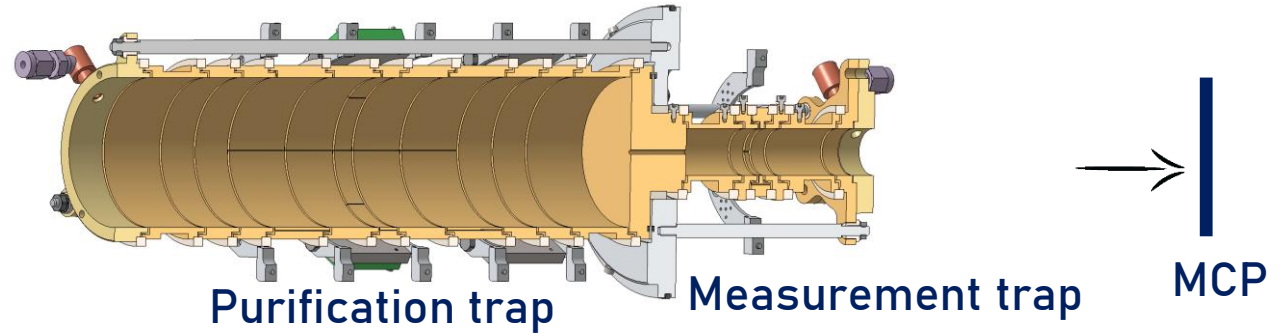
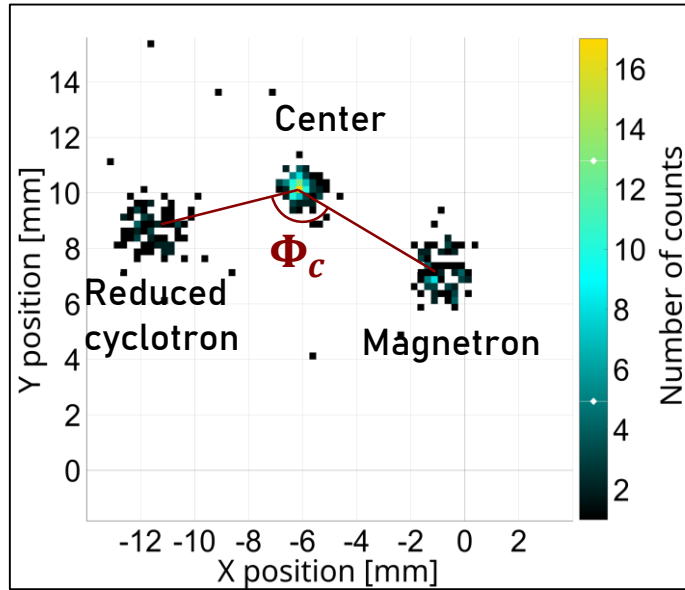
- Individual statistical uncertainty of $\sim 5 \cdot 10^{-9}$!
- If temperature fluctuations are small:
 → Excellent stability (long-term measurement)
 → stat. uncertainty down to $5 \cdot 10^{-10}$
- ^{40}K measurements achieved

MASS MEASUREMENTS AT PIPERADE: ToF-ICR



- ❑ Individual statistical uncertainty of $\sim 5 \cdot 10^{-9}$!
- ❑ If temperature fluctuations are small:
→ Excellent stability (long-term measurement)
→ stat. uncertainty down to $5 \cdot 10^{-10}$
- ❑ ^{40}K measurements achieved

MASS MEASUREMENTS AT PIPERADE: PI-ICR

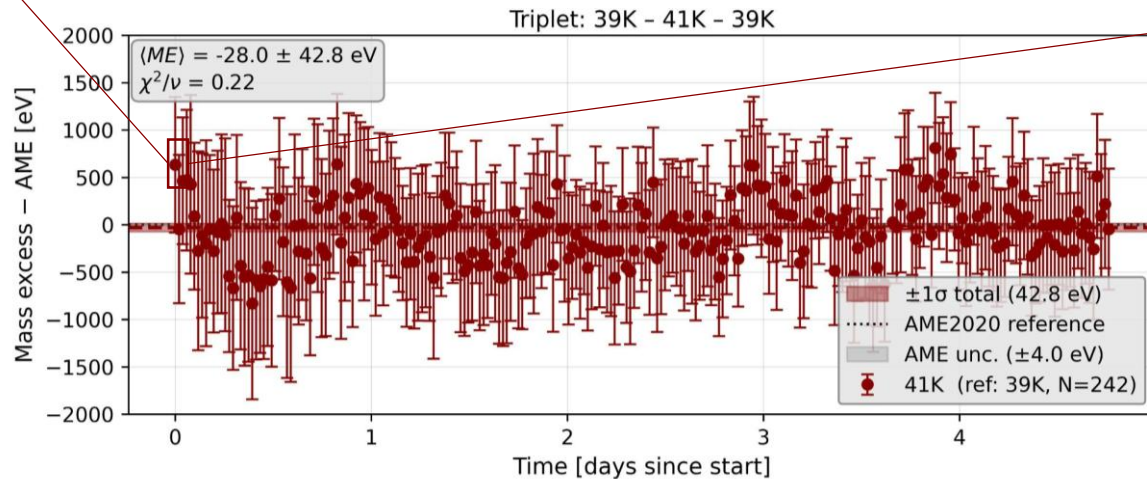
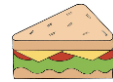
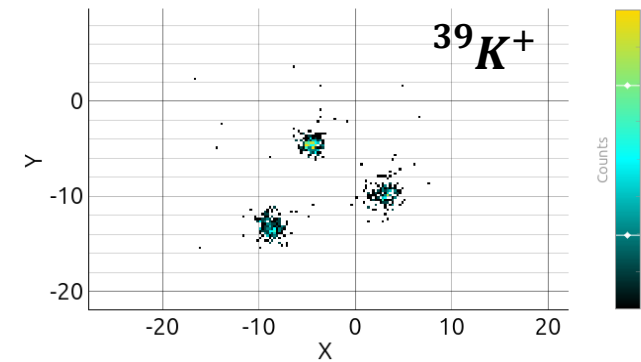
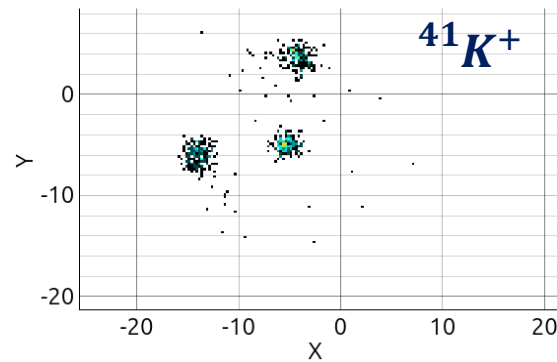
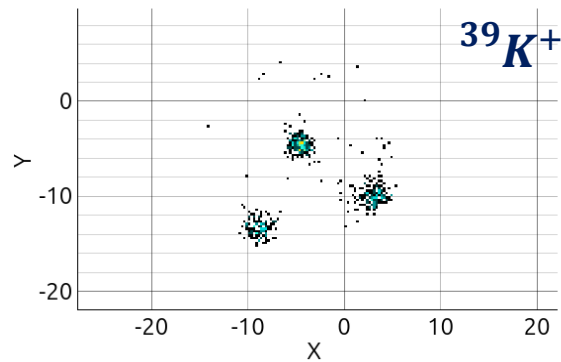


$$\phi_c = 2\nu_c \pi t_{acc} - 2\pi n$$

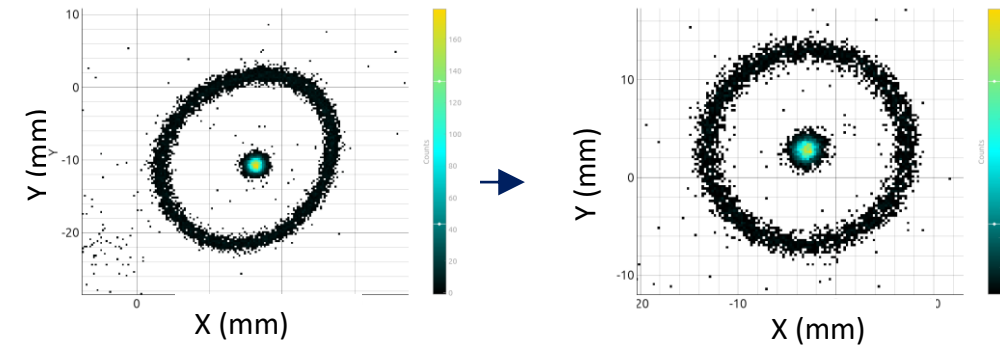
$$\nu_c = \frac{qB}{2\pi m}$$

$$m_{41K} = \frac{\nu_c(^{39}K^+)}{\nu_c(^{41}K^+)} (m_{39K} - m_e) + m_e$$

MASS MEASUREMENTS AT PIPERADE: PI-ICR



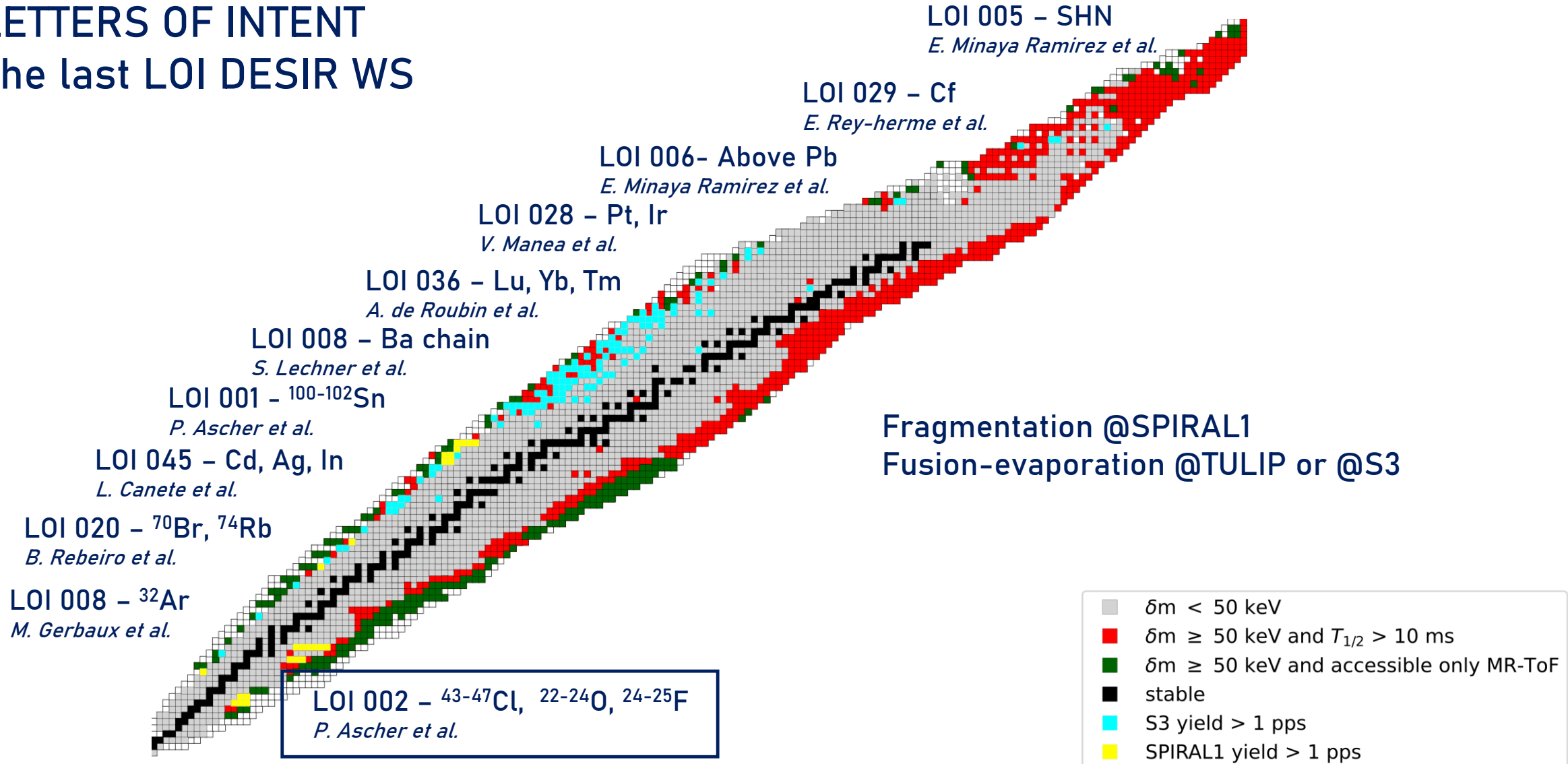
- ❑ PI-ICR fully operational and optimized
- ❑ Ongoing systematic studies:
 - ✓ Image distortion
 - ✓ Temperature effects



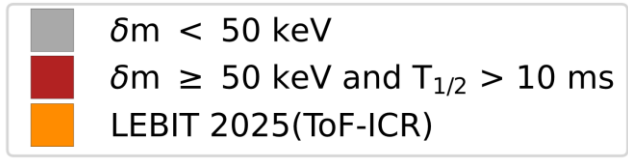
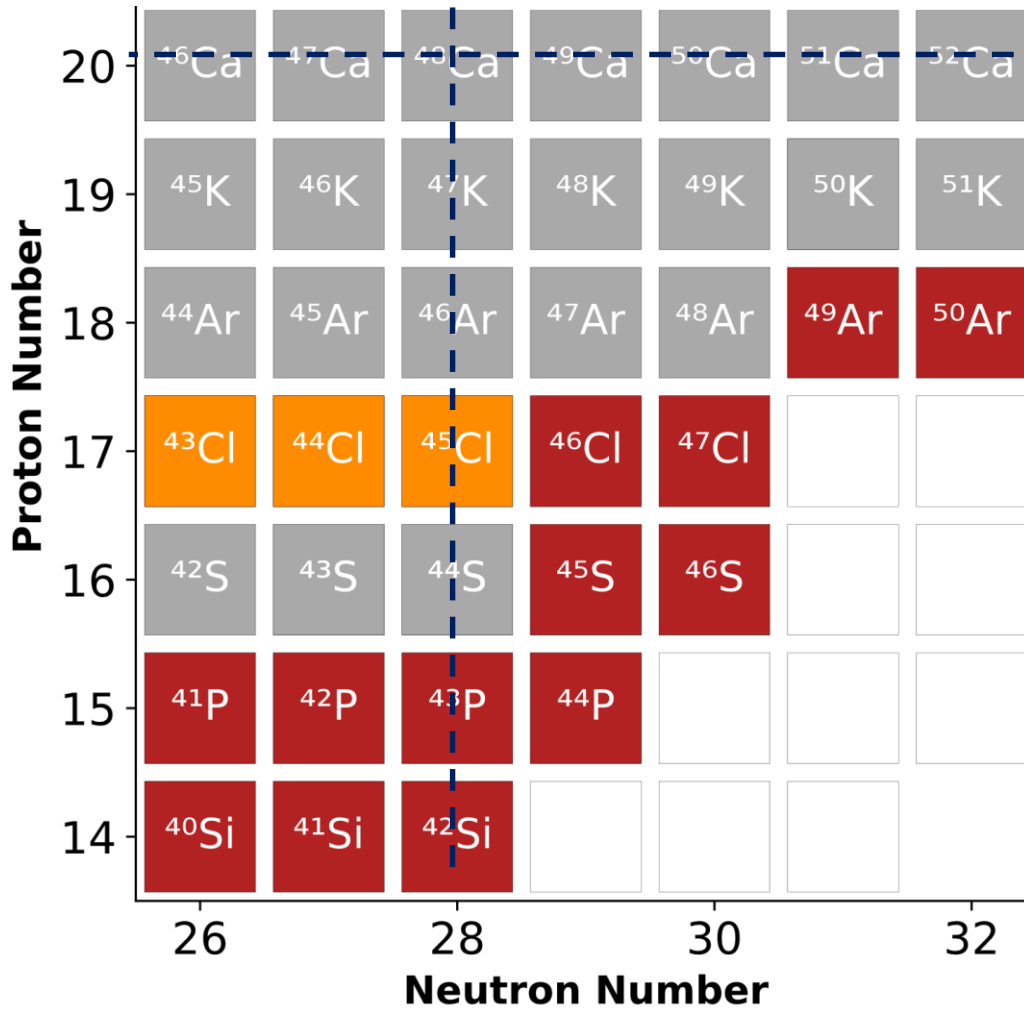
READY TO TRANSFER THE SETUP TO GANIL
(→ MID-2027) - **anr** PEPPER

Next step: temperature stabilisation for E and B fields

11 LETTERS OF INTENT at the last LOI DESIR WS



EROSION OF THE N=28 GAP



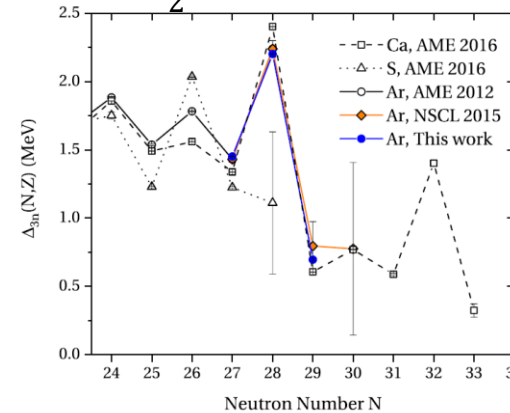
data from AME2020

N=29 and N=30 isotones → only K and Ar are well known

47-50K @TITAN A. Lapierre et al., PRC 85, 024317 (2012)

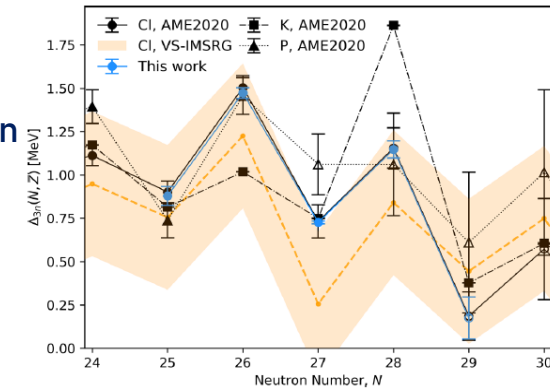
46-48Ar @ISOLTRAP Mougéot et al., PRC 102, 014301 (2020)

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



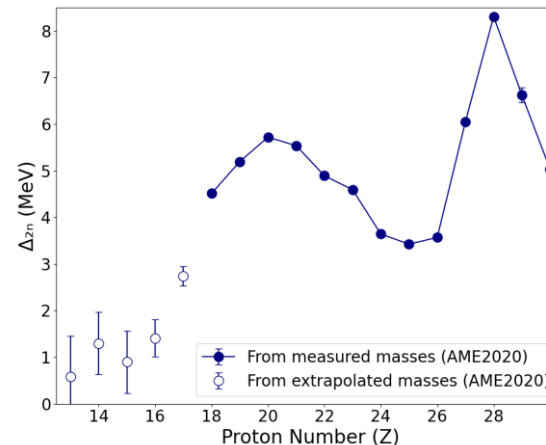
Shell gap from Δ_{3n}
Ca: 4.8 MeV
Ar: 4.4 MeV
S: 2.8(10) MeV

LEBIT 43-45Cl



H. Errington, PRC 112, 044313 (2025)

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



SPIRAL1 fragmentation

(measured)
2E4 pps

43Cl

3.1 s

44Cl

562 ms

45Cl

413 ms

30 pps 0.02 pps

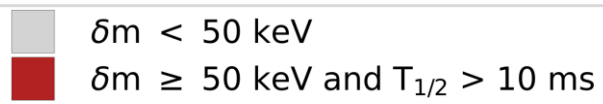
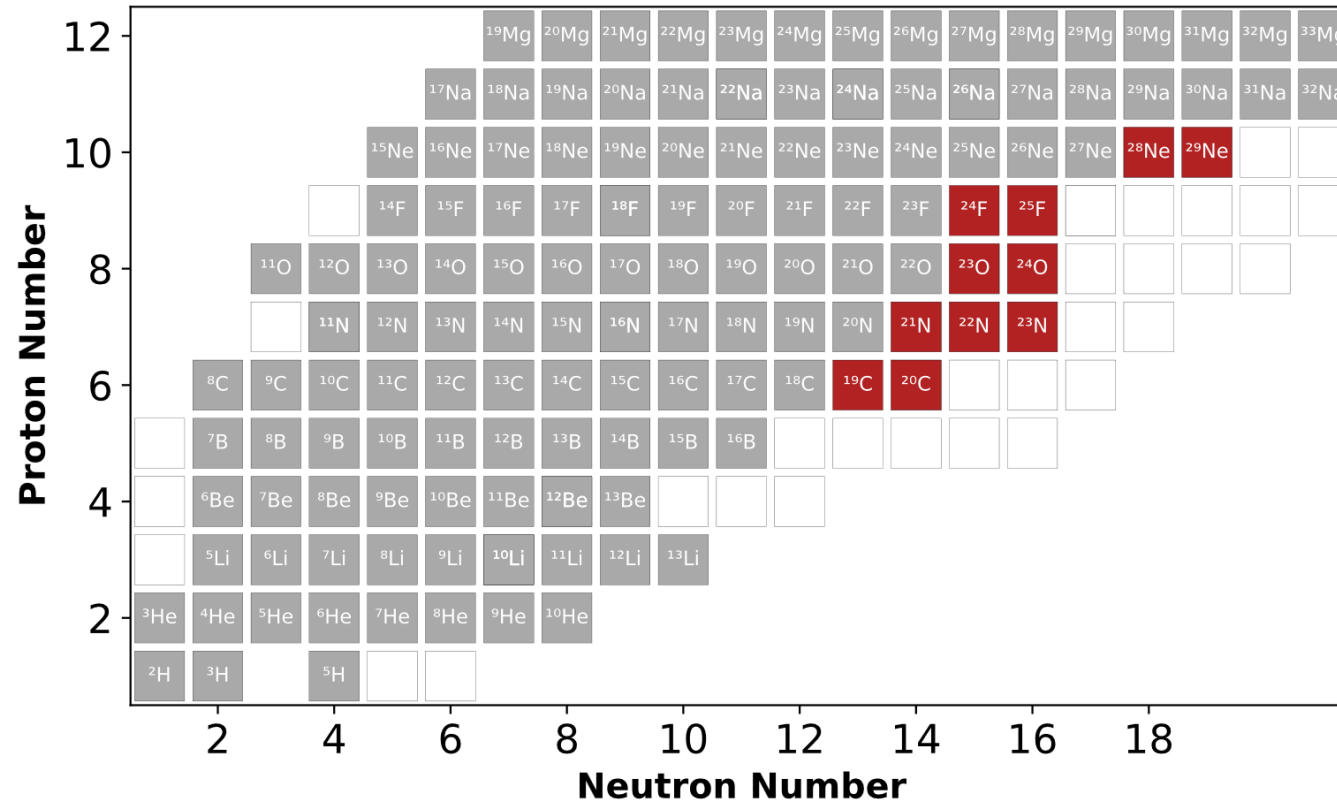
46Cl

232 ms

47Cl

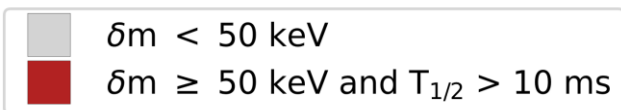
101 ms

FLUORINE AND OXYGEN



data from AME2020

- ☐ Region unexplored by precision mass spectrometry
 - $^{24,25}\text{F}$ and $^{22-24}\text{O}$: $\delta m > 100 \text{ keV}$
- ☐ Vpn interaction strength determined from the masses: cases of ^{26}F and ^{22}N
 - masses must be wrong in the region
 - A. Lepailleur et al., PRL 110, 082502 (2013)*
- ☐ Evolution of N=14 and N=16 shell closures
- ☐ S_n of more n-rich nuclei are known (E_n measurements)
 - Only ^{24}O mass is needed for the gap
 - ^{24}O and ^{25}F masses will constrain the masses of more n-rich nuclei !

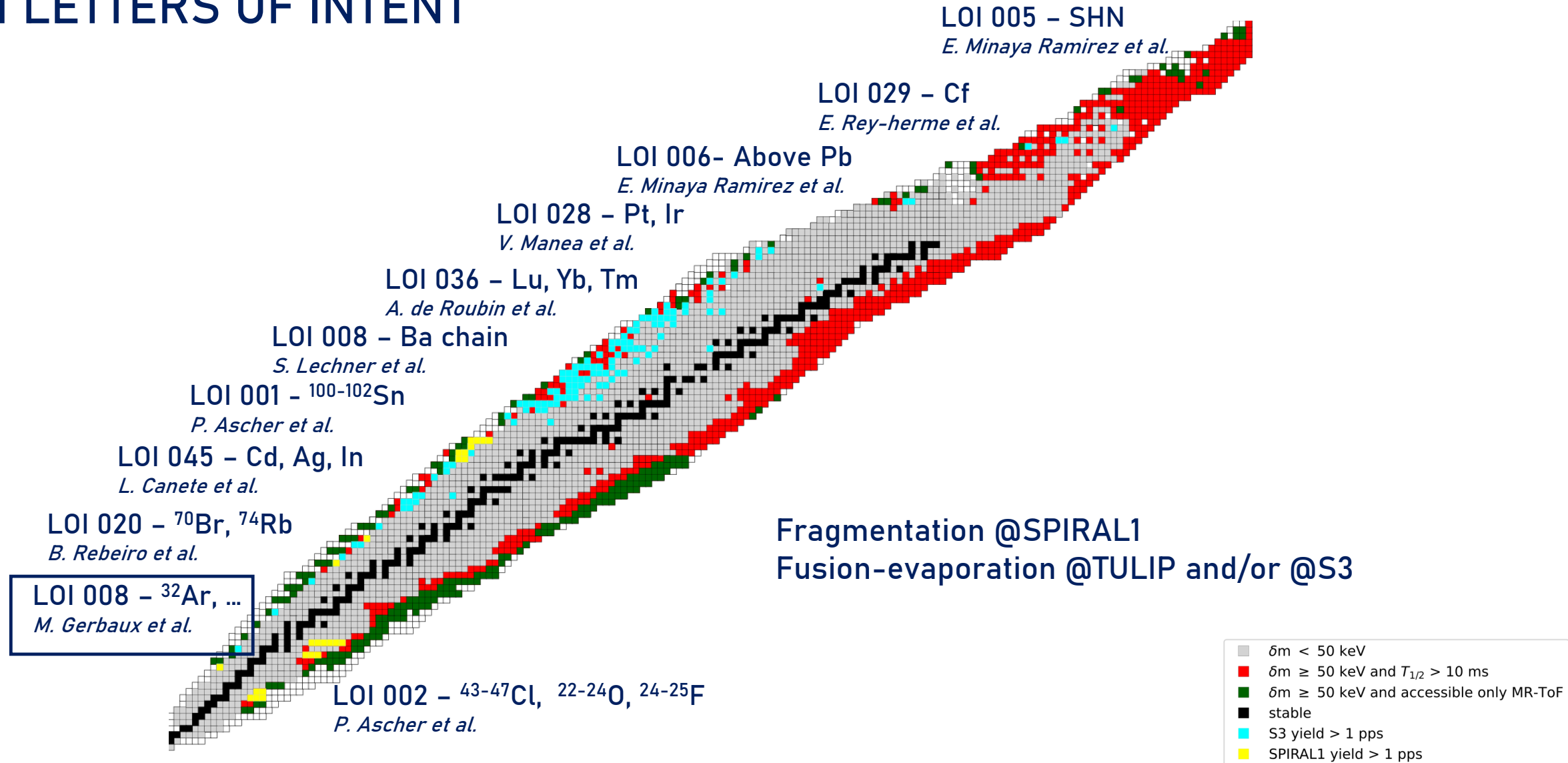


data from AME2020

- ❑ Region unexplored by precision mass spectrometry
 - $^{24,25}\text{F}$ and $^{22-24}\text{O}$: $\delta m > 100 \text{ keV}$
- ❑ Vpn interaction strength determined from the masses: cases of ^{26}F and ^{22}N
 - masses must be wrong in the region
A. Lepailleur et al., PRL 110, 082502 (2013)
- ❑ Evolution of N=14 and N=16 shell closures
- ❑ S_n of more n-rich nuclei are known (E_n measurements)
 - Only ^{24}O mass is needed for the gap
 - ^{24}O and ^{25}F masses will constrain the masses of more n-rich nuclei !

→ $^{23-25}\text{F}$ and $^{22-24}\text{O}$ are all feasible for day-one experiments

11 LETTERS OF INTENT

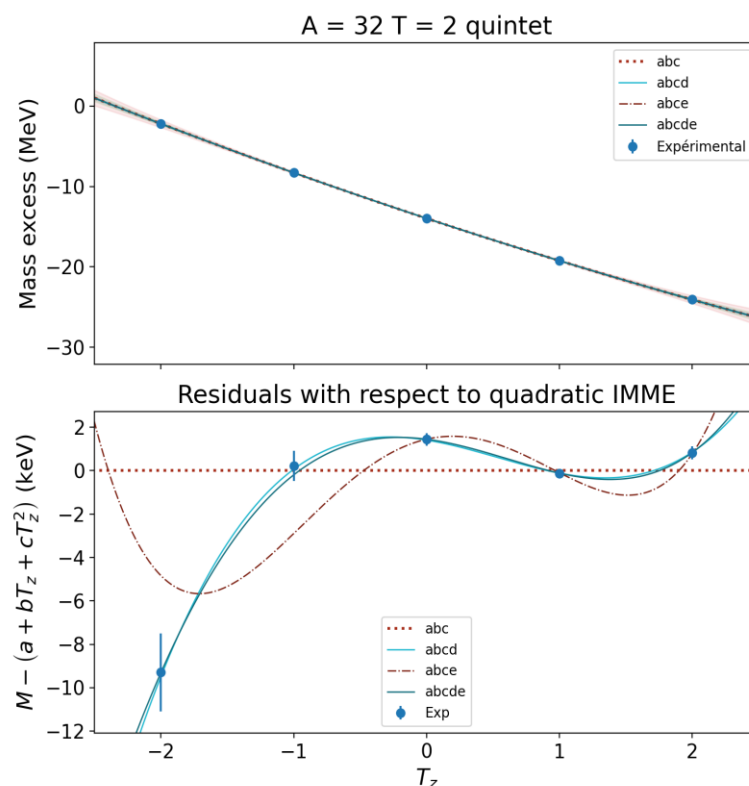
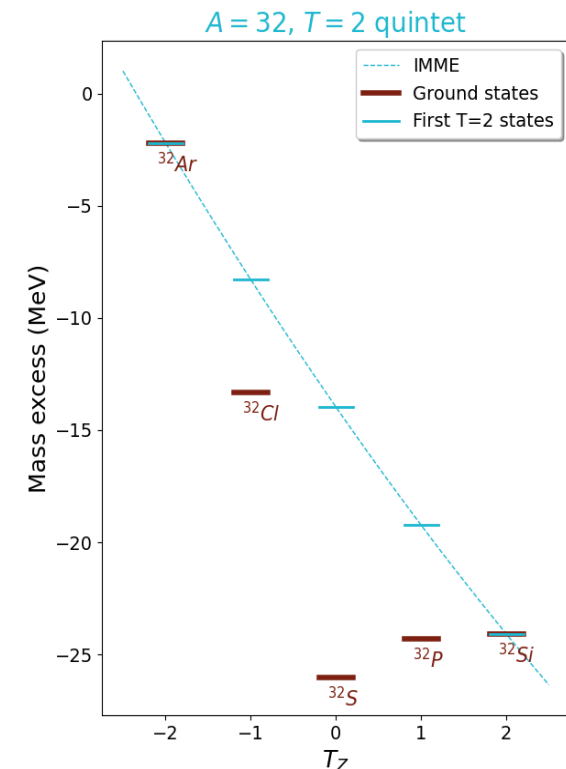


$$M(A, J^+, T, T_z) = a + b T_z + c T_z^2$$

Successfully used for many topics :

- Predict specific unmeasured masses
- Evaluate accuracy of large-scale nuclear-mass model predictions
- ...

$$M(T, T_z) = a + b T_z + c T_z^2 + d T_z^3 + e T_z^4$$



Can be due to...

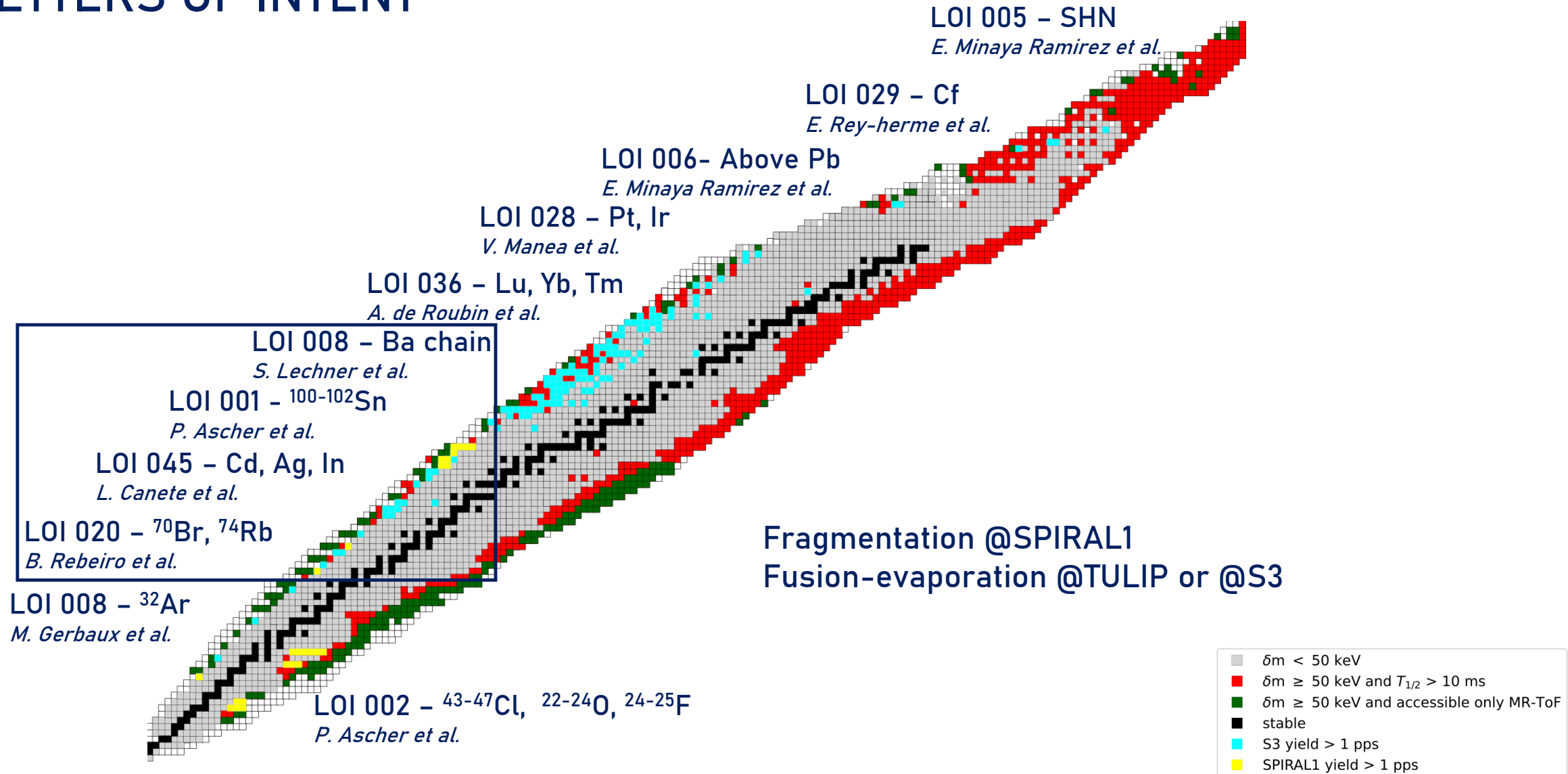
- Incorrectly measured or evaluated masses
- Higher order Coulomb/nuclear interaction (3-body)
- Isospin-mixing

→ ³²Ar: an « easy » case on paper, but unsuccessful in other RIBs because of contamination

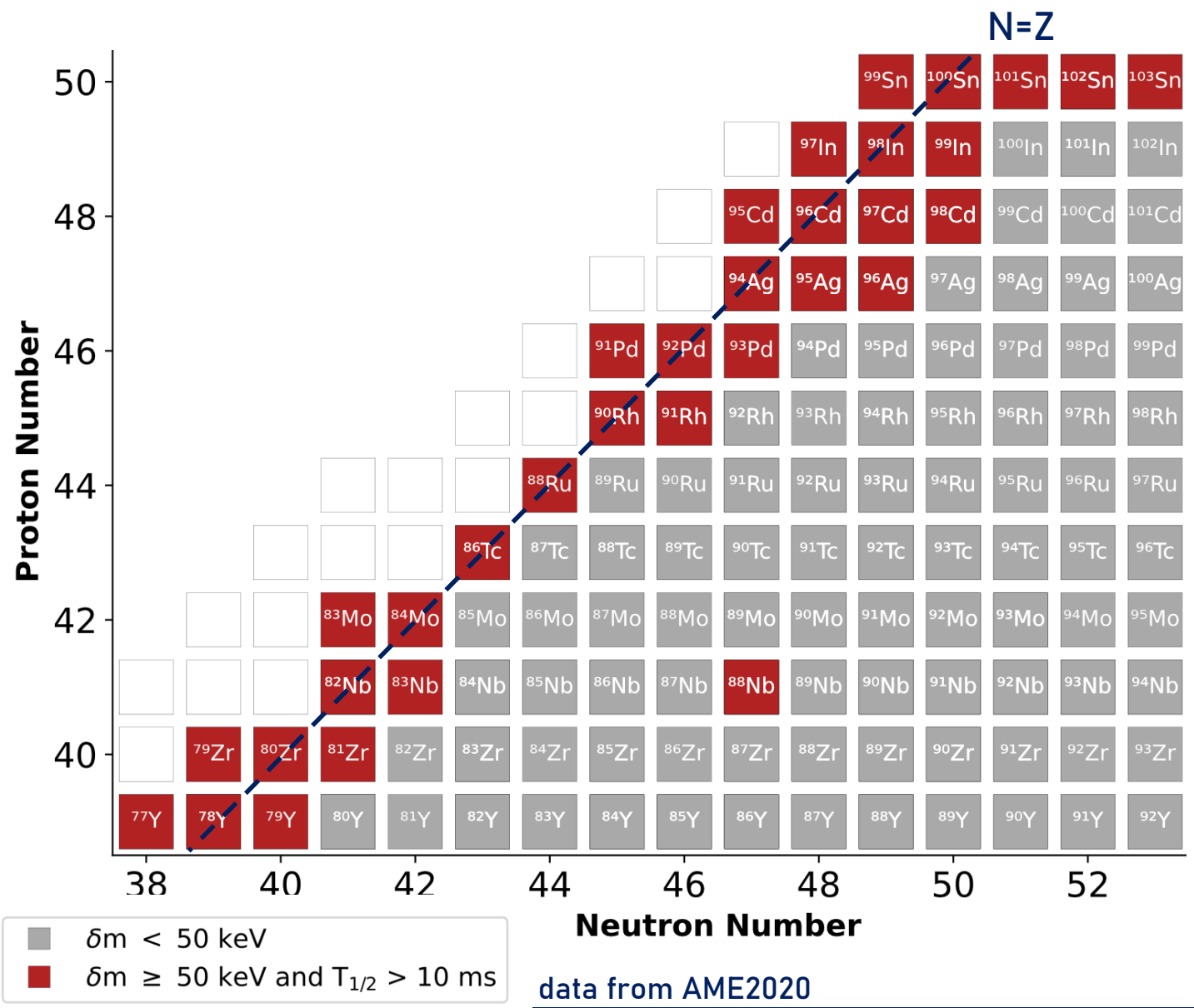
→ Purity at DESIR wil enable this measurement

→ Many other cases identified with
 → SPIRAL1 (²⁰Mg, ²⁰Na, ²⁰O, ²⁴Ne, ⁴⁰Sc, ⁵⁴Mn, ...)
 → S3 beams (²⁴Si, ⁴⁰Ti, ⁵⁴Ni, ...) but fast gas cell needed

11 LETTERS OF INTENT



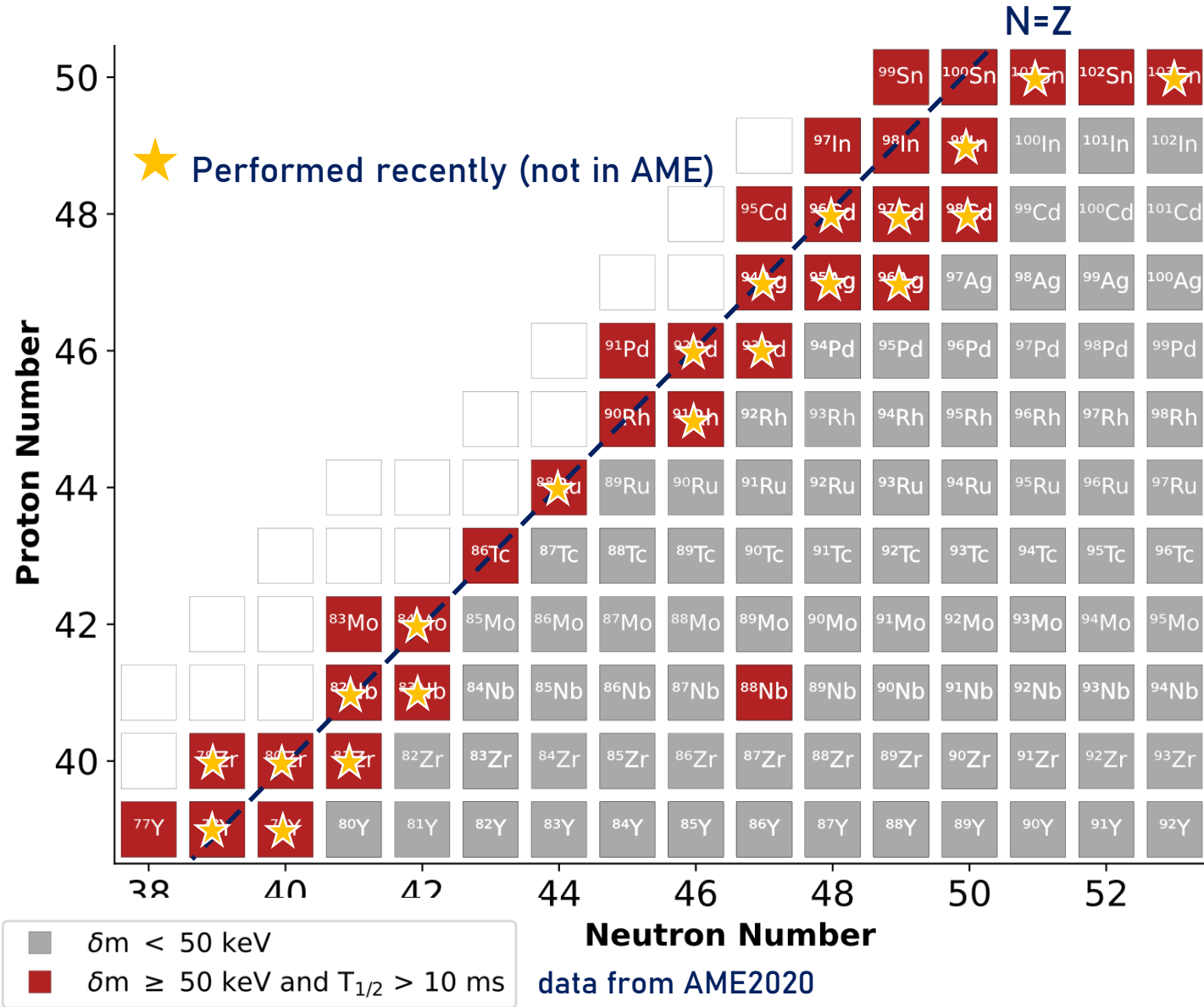
N=Z region



- pn pairing, Wigner energy
- shell evolution, pn interaction
- mapping proton-dripline
- many isomers
- rp-process (path, X-ray bursts properties)
- ft values for weak interaction studies
→ LOI 020 ^{74}Rb , ^{70}Br

data from AME2020

N=Z region



- ☐ pn pairing, Wigner energy
- ☐ shell evolution, pn interaction
- ☐ mapping proton-dripline
- ☐ many isomers

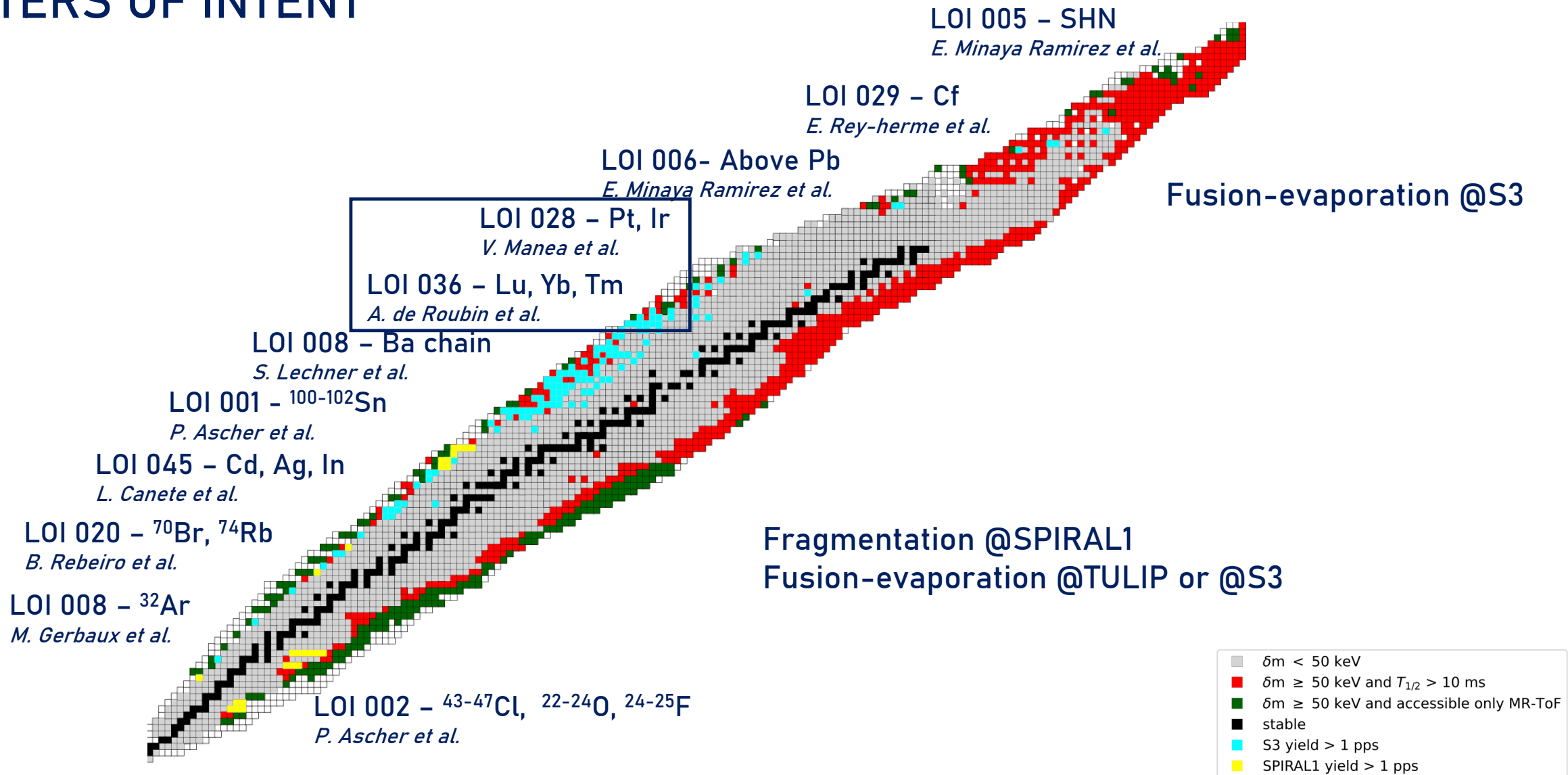
- ☐ rp-process (path, X-ray bursts properties)
- ☐ *ft* values for weak interaction studies
→ LOI 020 ^{74}Rb , ^{70}Br

- ☐ Region highly competitive (MSU, RIKEN, GSI, CSRe, ISOLDE, IGISOL) BUT many remaining cases feasible at DESIR

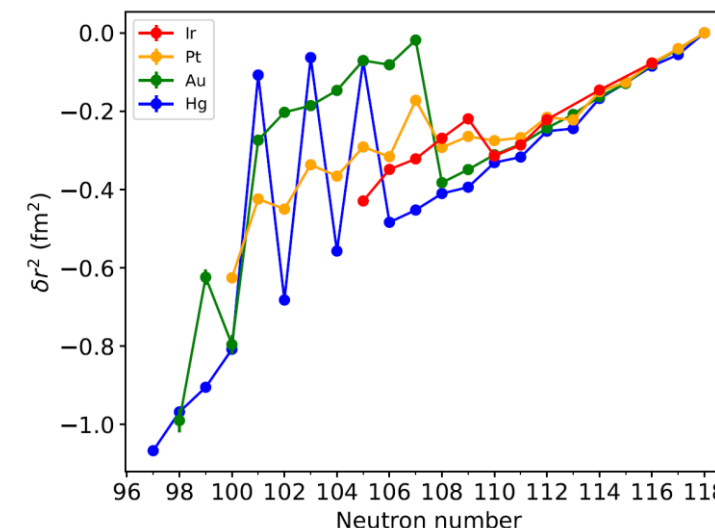
- ☐ 3 LOIs
 - ✓ $^{98,99}\text{In}$, ^{96}Cd ^{94}Ag (LOI 045)
 - ✓ $^{99,100,102}\text{Sn}$ (LOI 001)
 - ✓ Barium chain (LOI 008)→ Accessible with TULIP and/or S3

- ☐ More cases below with S3 beams (refractory)

11 LETTERS OF INTENT

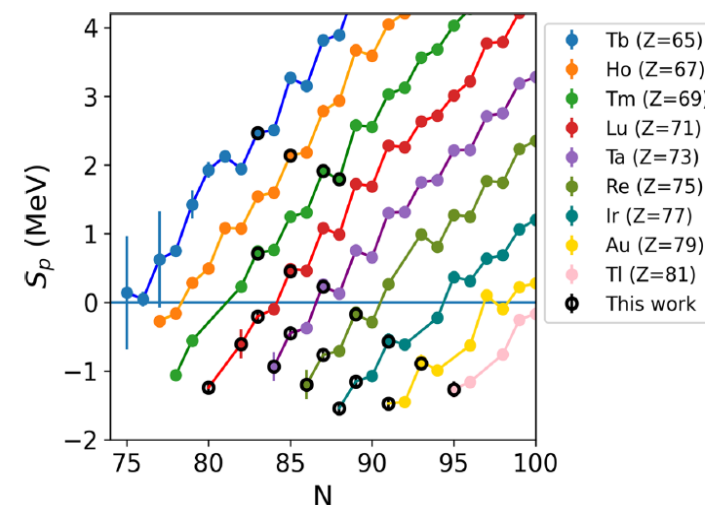


- ❑ Charge radii and masses to
 - ✓ probe deformation and shape coexistence
 - ✓ characterize and study proton radioactivity
 - ✓ locate the proton drip-line
 - ✓ N=82 neutron shell gap for heaviest isotopes
- ❑ Refractory elements are poorly known → niche at S3
- ❑ Some chains rich in isomerism (Ir, Tm, Yb)
 - PI-ICR mass measurements at DESIR
 - S3-LEB/DESIR as a single experimental set-up with PI-ICR – assisted laser spectroscopy
 - Ultimate sensitivity and proper assignement for laser spectroscopy
- ❑ Proposed cases: $^{174-181}\text{Pt}$, $^{168-181}\text{Ir}$, $^{151-170}\text{Lu}$, $^{148-169}\text{Yb}$, $^{146-166}\text{Tm}$
 - ❑ Most of them are feasible
 - ❑ Some developments needed on the laser scheme

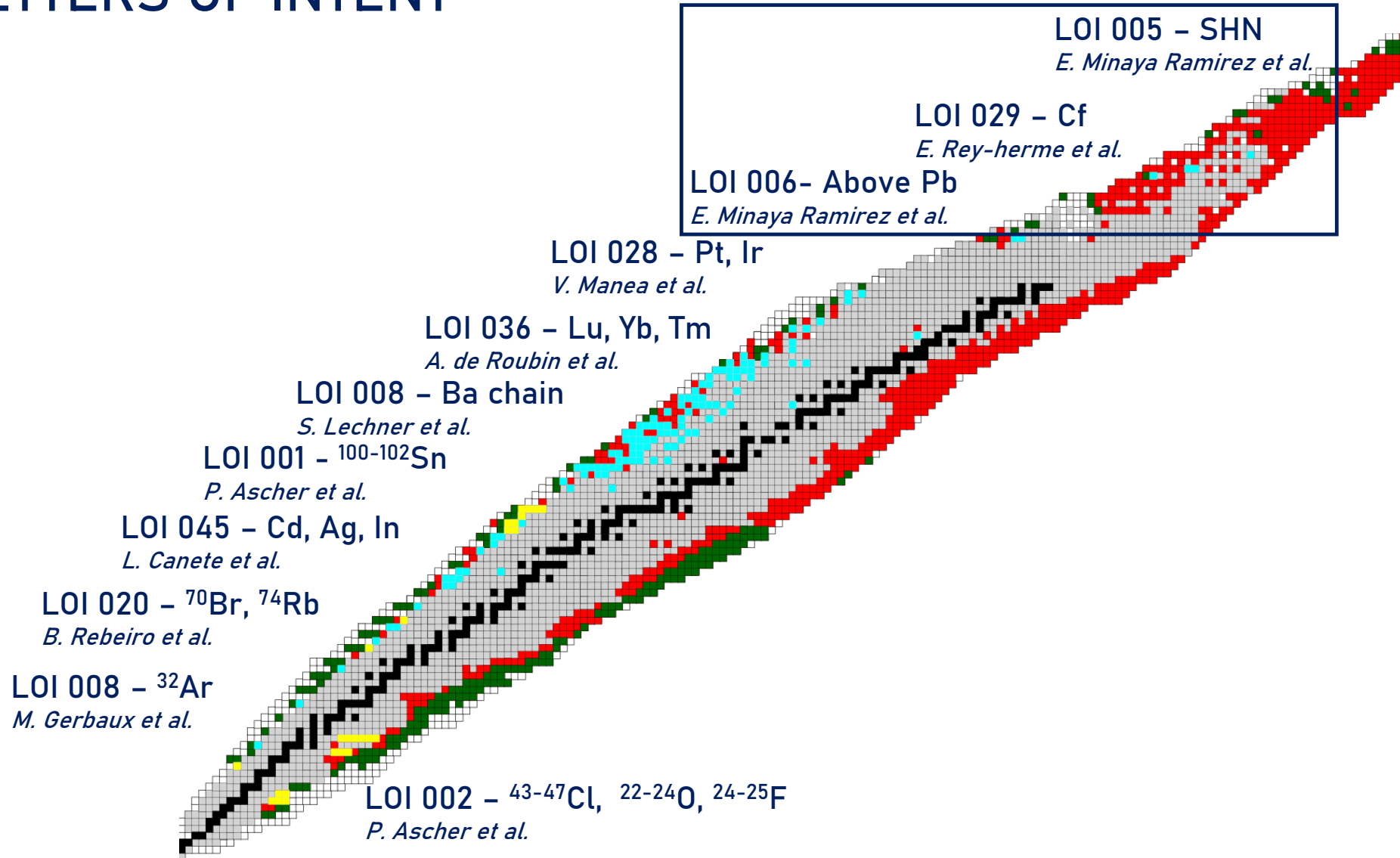


F. Le Blanc et al., Phys. Rev. C 60, 054310 (1999)
D. Verney et al., Hyperfine Interactions 127, 79–82 (2000)

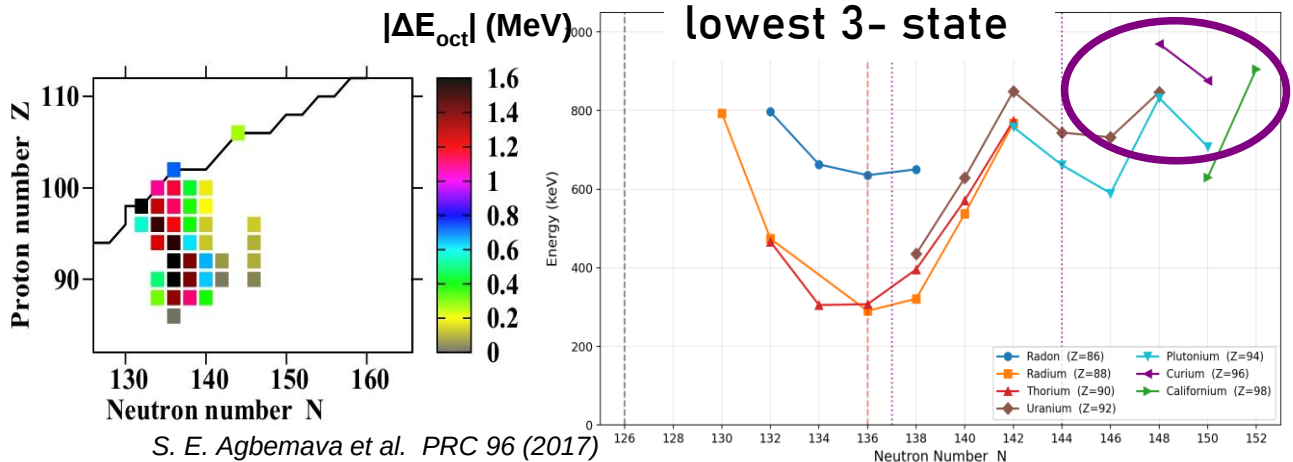
E. M. Lykiardopoulou, Phys. Rev. C 107, 024311 (2023)



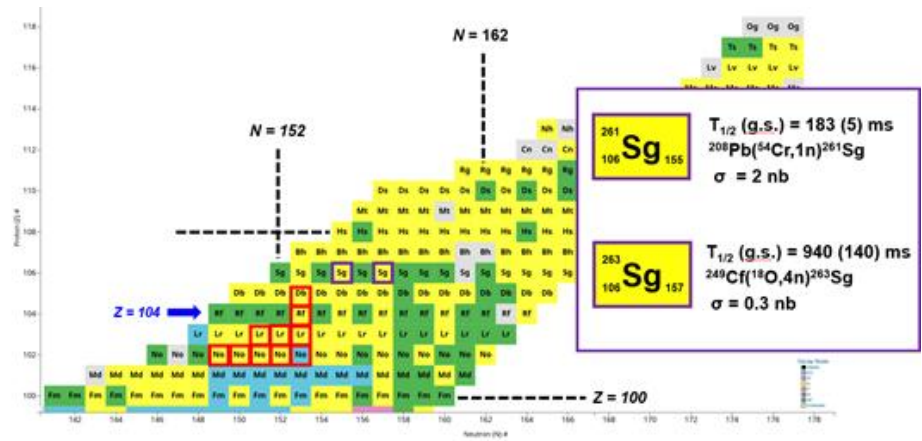
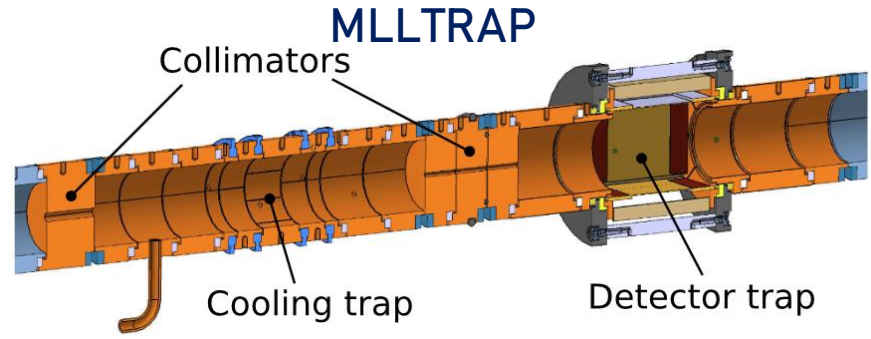
11 LETTERS OF INTENT



- ❑ Mass measurements provide anchor points to fix decay chains, in particular in the VHN and SHN regions
- ❑ Probe octupole deformation limit at high Z (²³⁷⁻²⁴⁴Cf and ²³³⁻²⁴⁰Cm)
→ masses, charge radii and low-energy spectroscopy



- ❑ For lighter isotopes, such as n-deficient Po: mass measurements combined with in-trap decay spectroscopy
→ lifetimes of first excited nuclear states populated by a decay (see E. Minaya’s talk)



- ❑ Super-heavy: ²⁶¹⁻²⁶³Sg are the first candidates for SHN mass measurements at DESIR ($\sigma = 2$ and 0.3 nb)
→ Beam/target development needed

A FEW CONCLUDING REMARKS

- ❑ PIPERADE is fully operational and will move next year
- ❑ Exciting program for MS at DESIR (first experiments planned for 2029)
 - Collaborations/Discussions are welcome
 - Campaigns on a physics case with masses, charge radii, nuclear moments, spins and decay spectroscopy
- ❑ DESIR needs SPIRAL1 and S3 !

THANK YOU FOR YOUR ATTENTION !

LP2iB DESIR TEAM

P. Alfaut, P. Ascher, D. Atanasov, B. Blank, L. Daudin,
 M. Flayol, M. Gerbaux, S. Grévy,
 G. Guignard, M. Hukkanen, A. Husson, B. Lachacinski,
 S. Lechner, E. Rey-herme, M. Roche, K. Ronxin,
 C. Roumegou, A. de Roubin

+ LOI people: L. Canete, M. Gerbaux, S. Lechner,
 V. Manea, E. Minaya, B. Rebeiro, E. Rey-herme,
 A. de Roubin

+ C. Berteloite and J.-C. Thomas

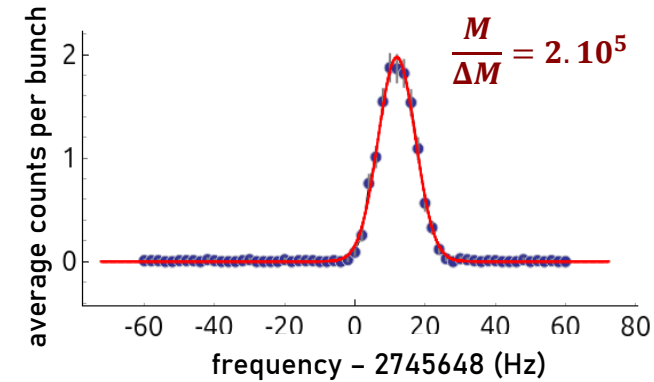


PIPERADE: Purification



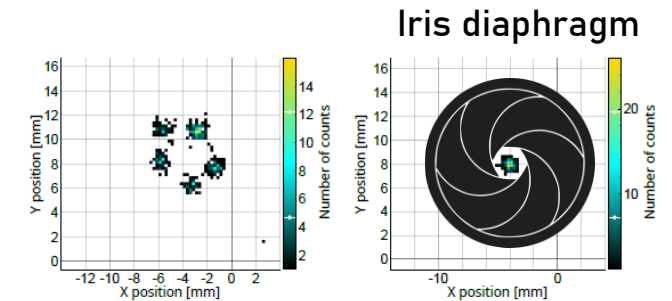
Designed and machined at MPIK Heidelberg
Offline commissioning at LP2iB

- Buffer gas cooling in the first trap



- Phase cleaning in the second trap

$M/\Delta M$ of 10^7 in ~ 500 ms
($\rightarrow 10^6$ in 50 ms) for $A \sim 100$



P. Ascher et al., NIMA 1019, 165857 (2021)

