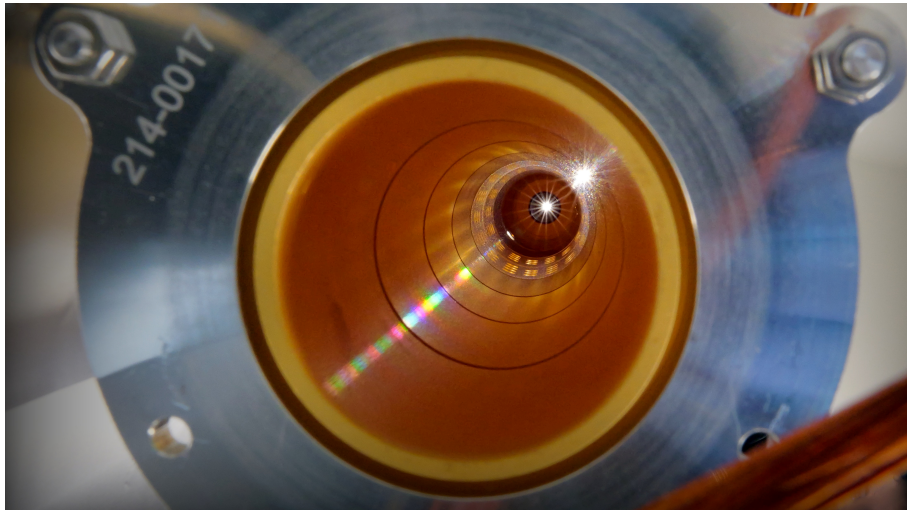
Technical progress at the double Penning trap PIPERADE

Emmanuel Rey-herme
On behalf of the **PIPERADE** collaboration

PIPERADE
PIEGES DE PENNING POUR LES RADIONUCLEIDES A DESIR



Outline

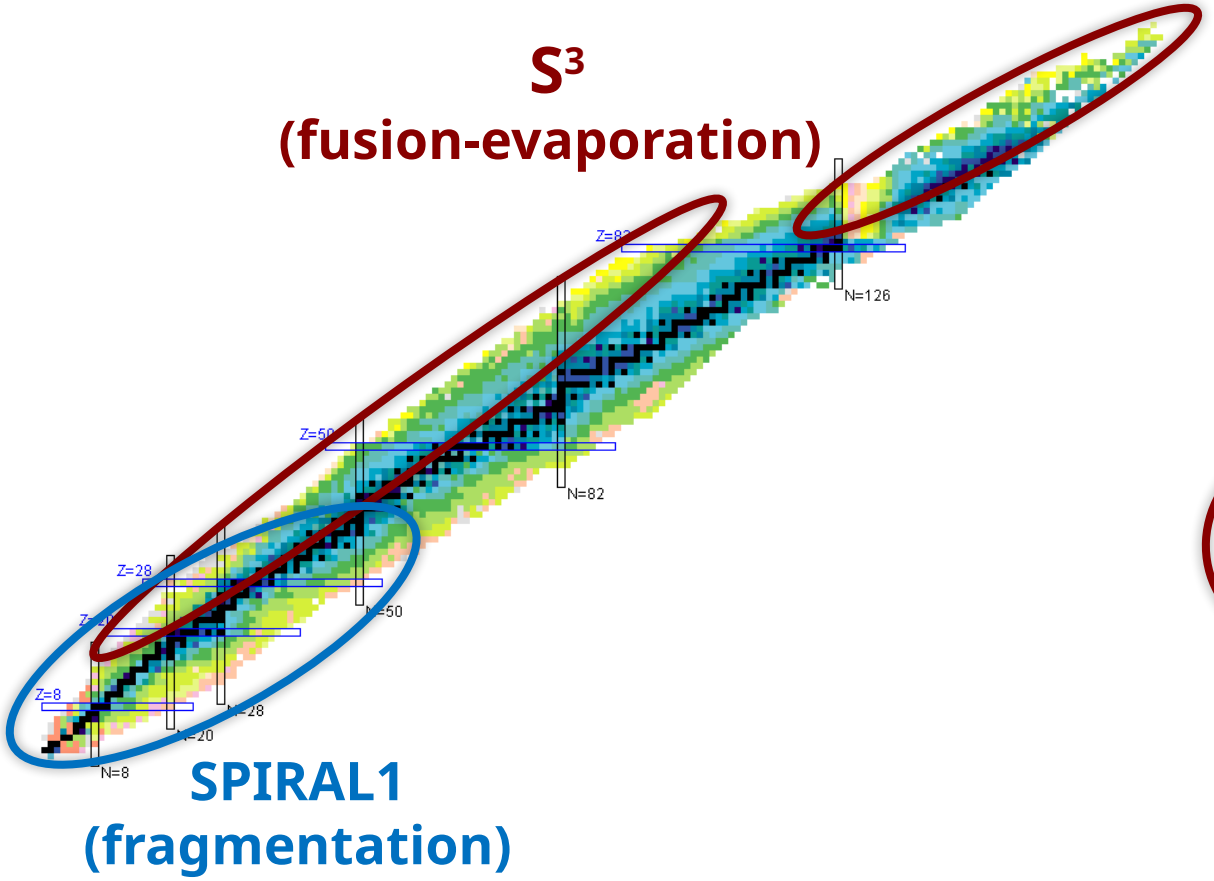
1. Context and motivation

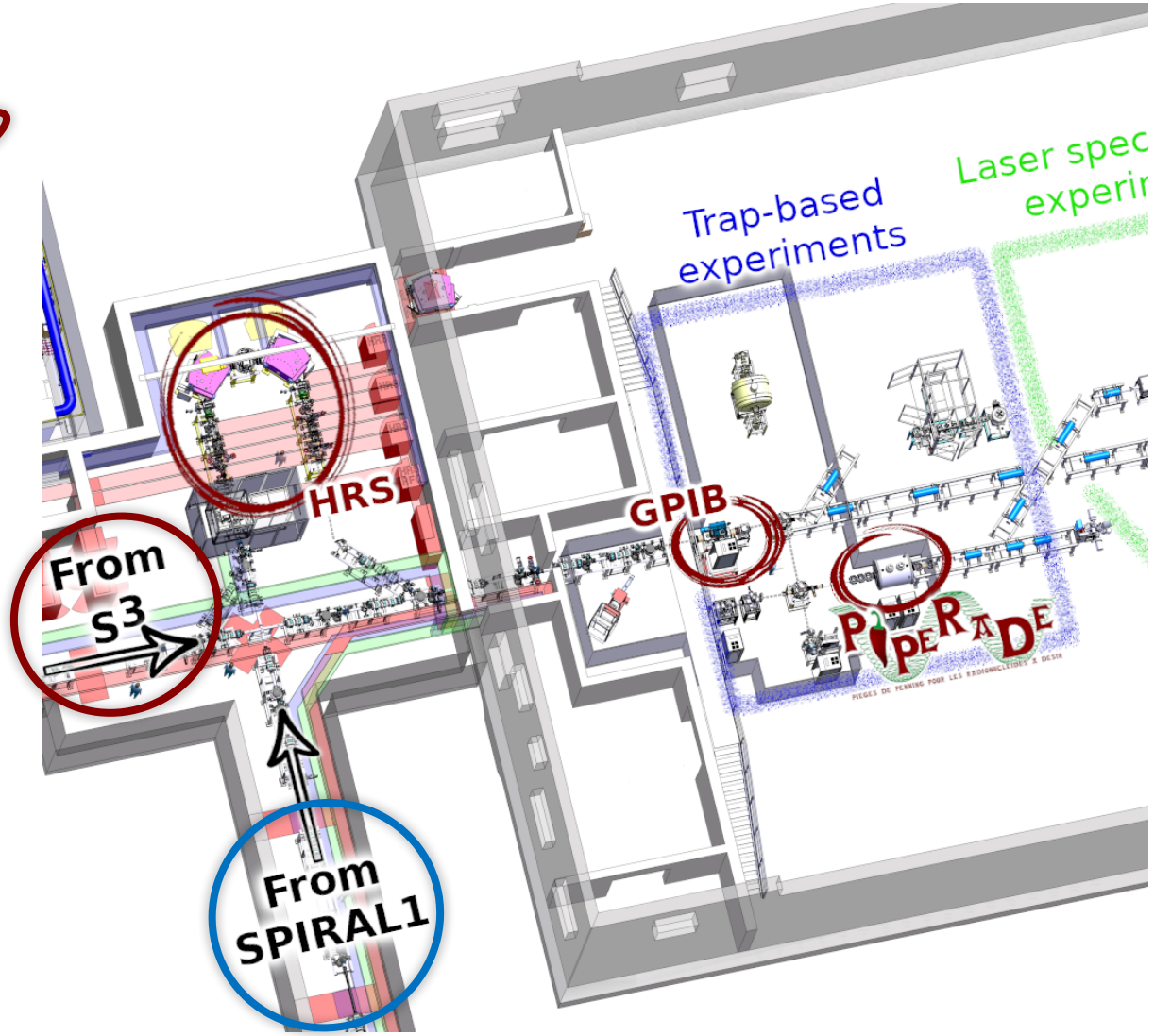
2. Status of PIPERADE

3. Conclusion

Context and motivation

PIPERADE at DESIR

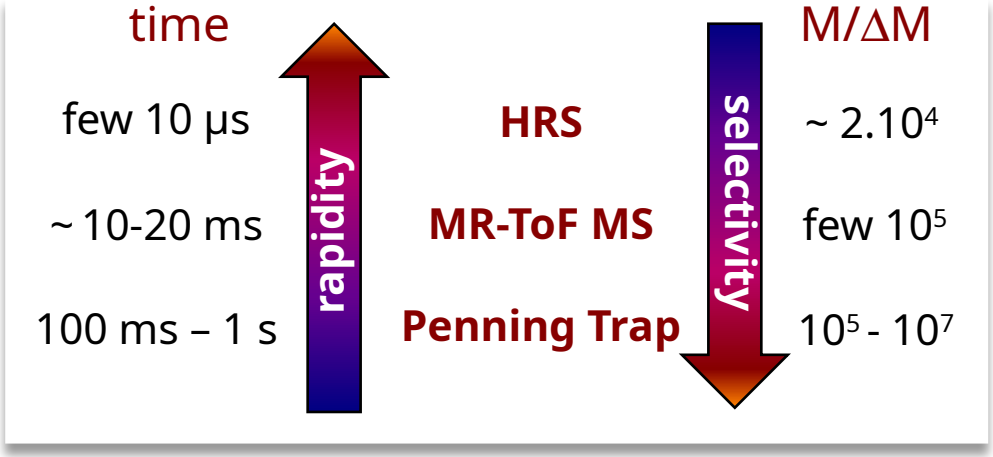




PIPERADE: 2 main objectives

Trap-assisted spectroscopy

- High resolution purification for decay/laser spectroscopy
  - Isobaric separation with buffer gas cooling
  - Phase cleaning for very high resolution purification (isomeric separation)



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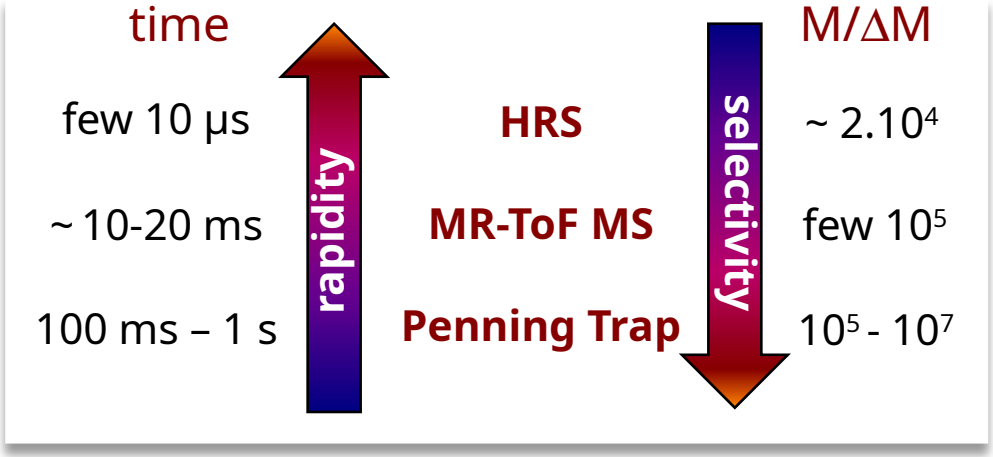

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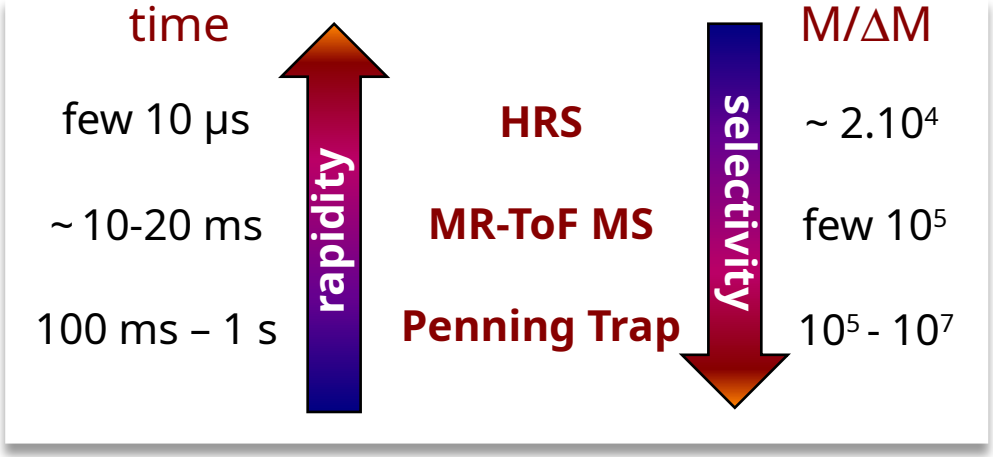

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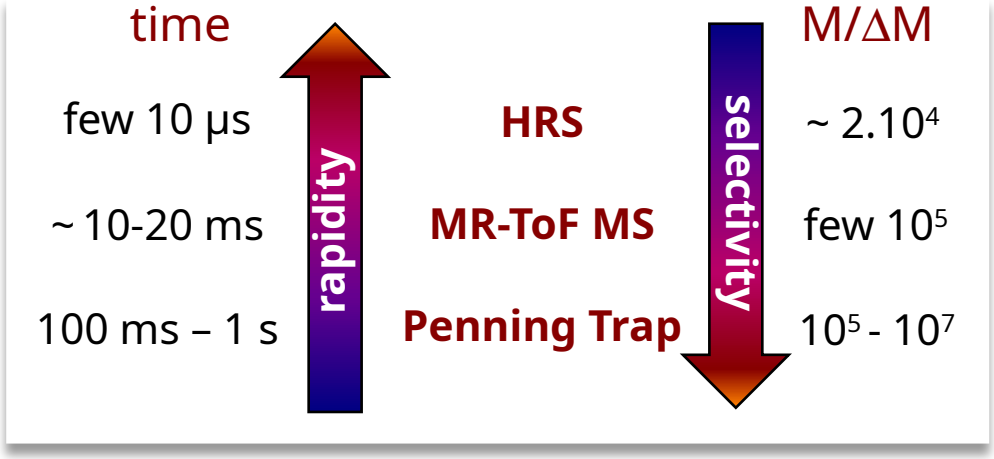
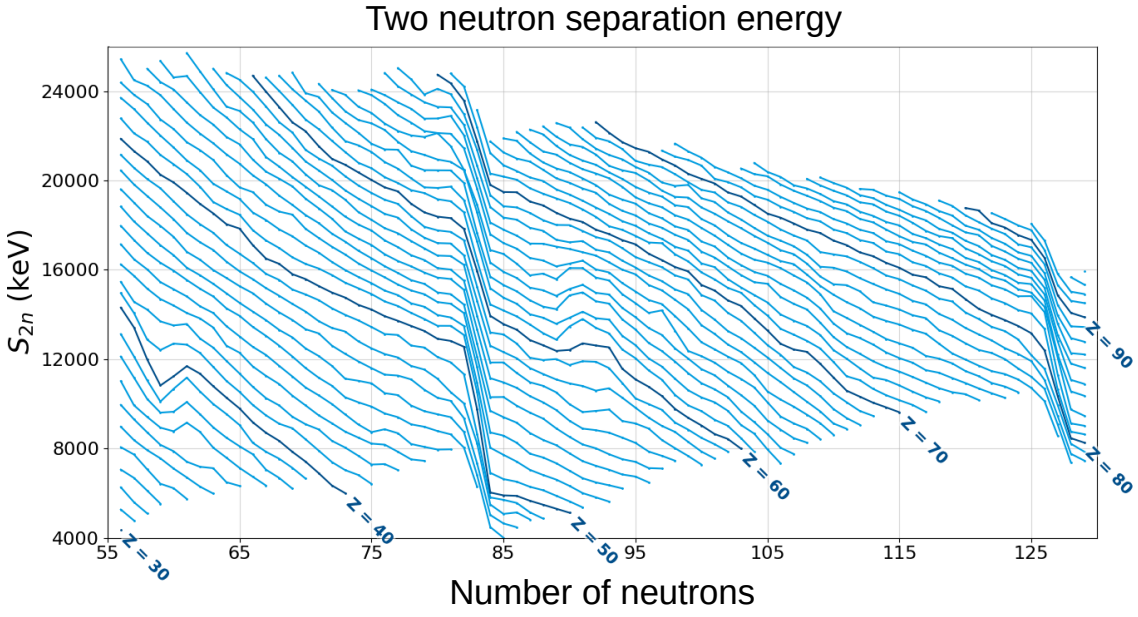


High-precision mass spectrometry

- Nuclear structure
  - Evolution of shell closures
  - Shape transitions and shape coexistence
  - Isospin symmetry (IMME, Wigner term, …)
  - Location of drip-lines and search for exotic rad.



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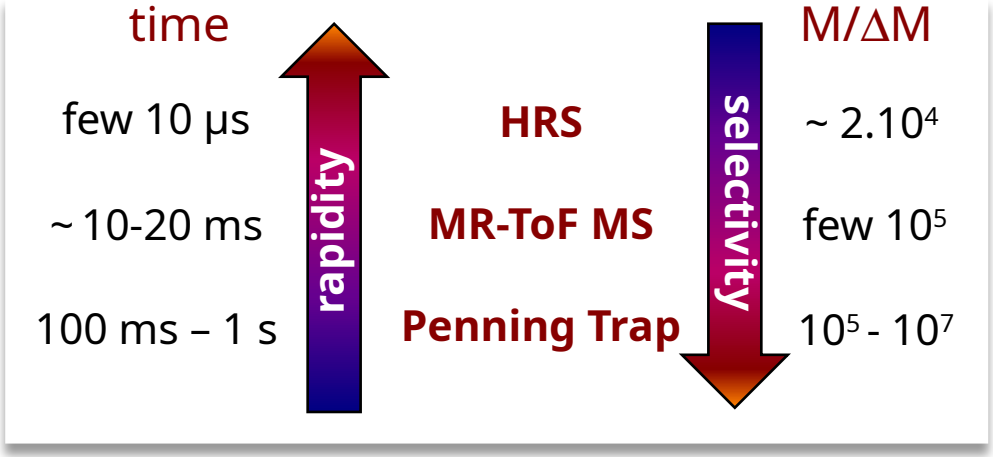

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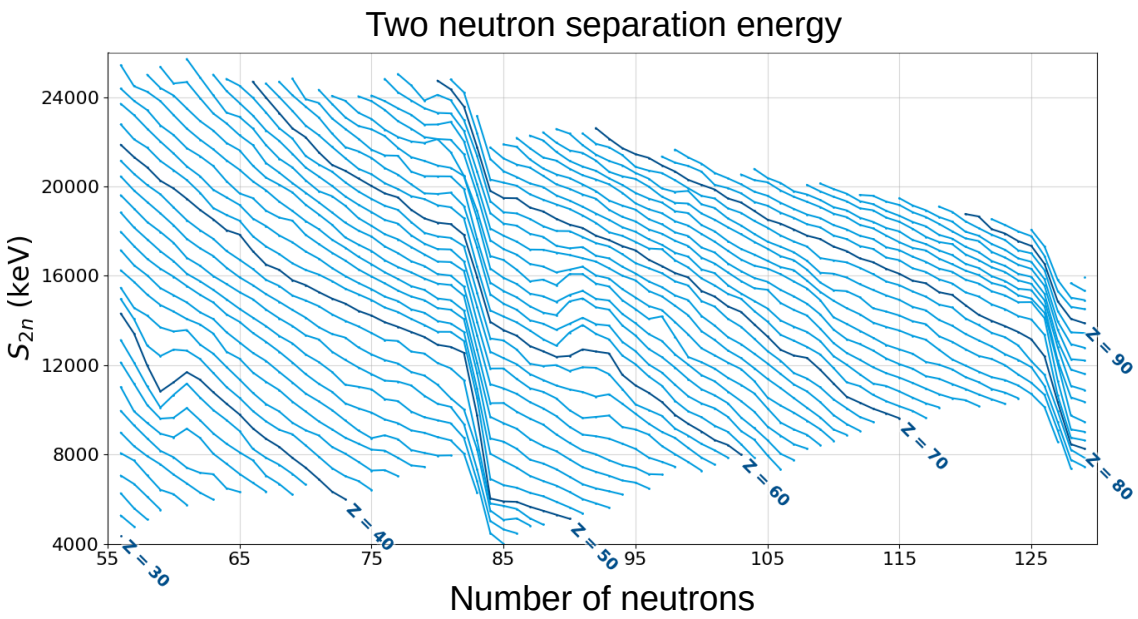

PIPERADE: 2 main objectives

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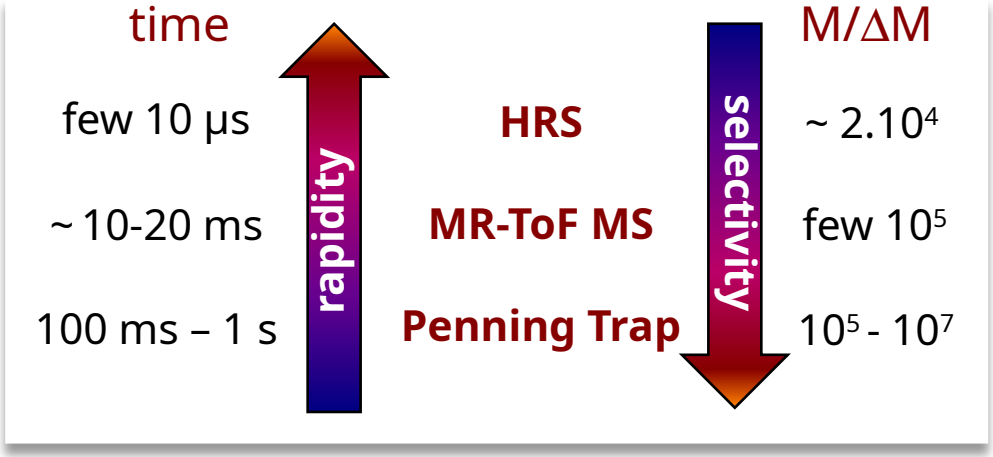

High-precision mass spectrometry

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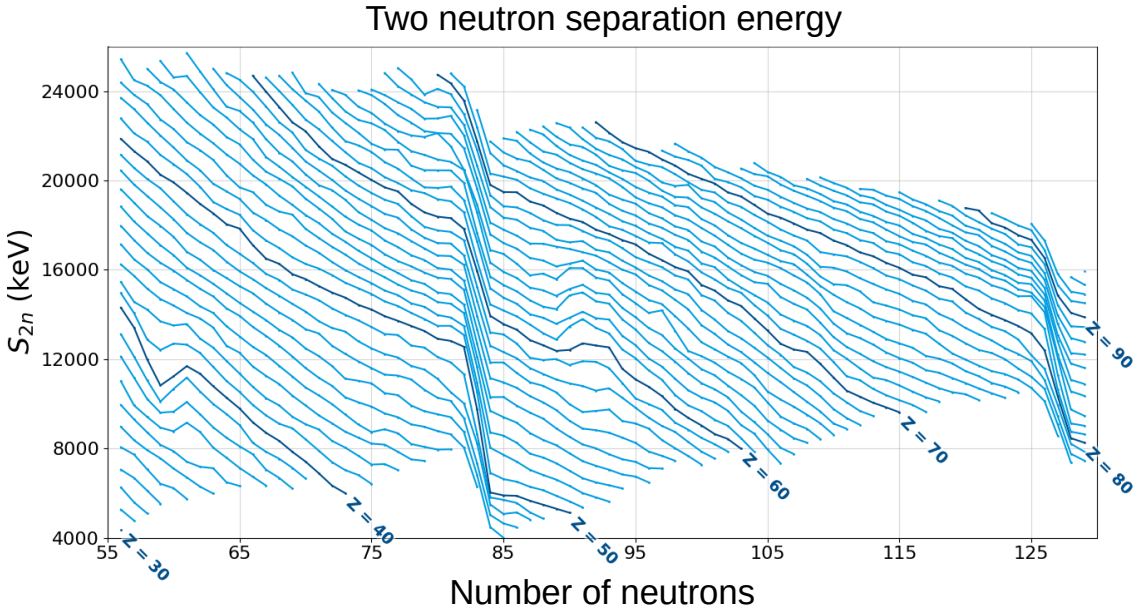
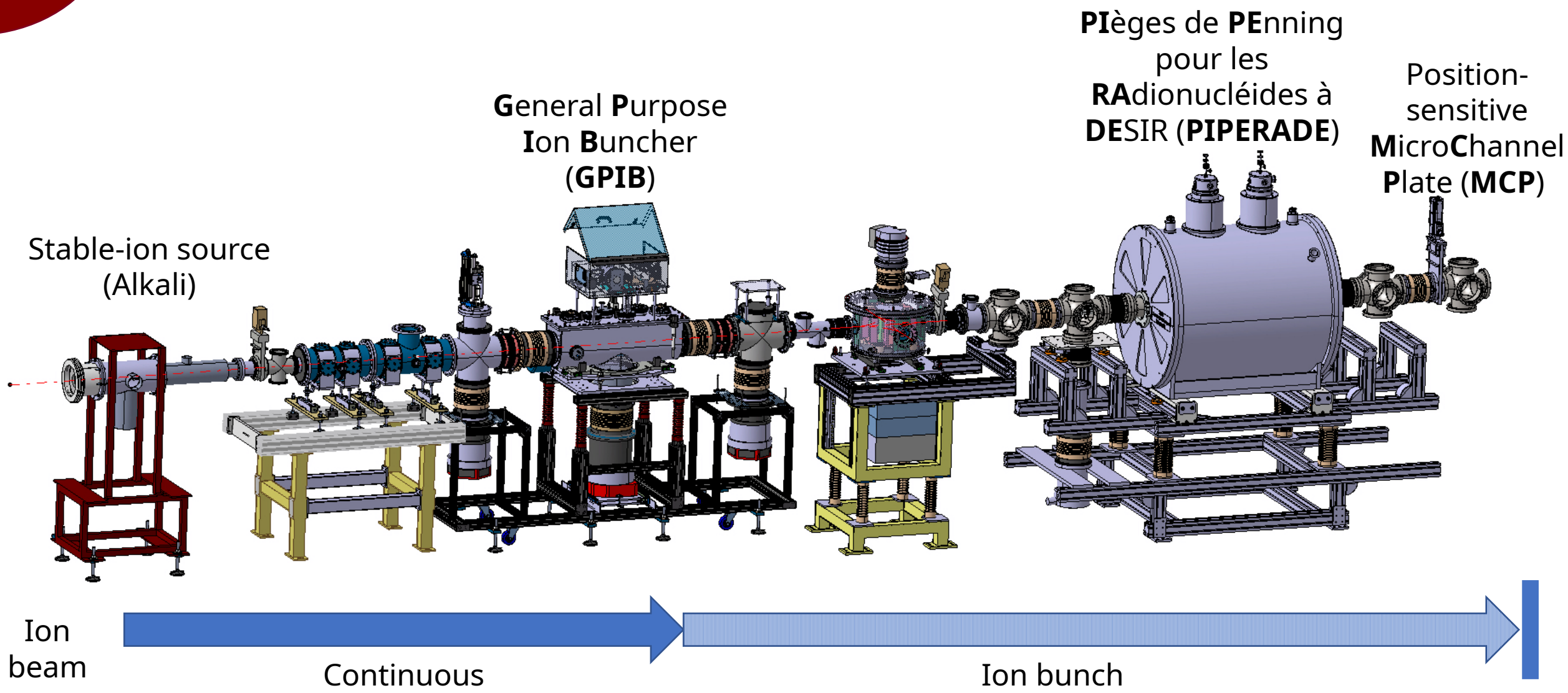
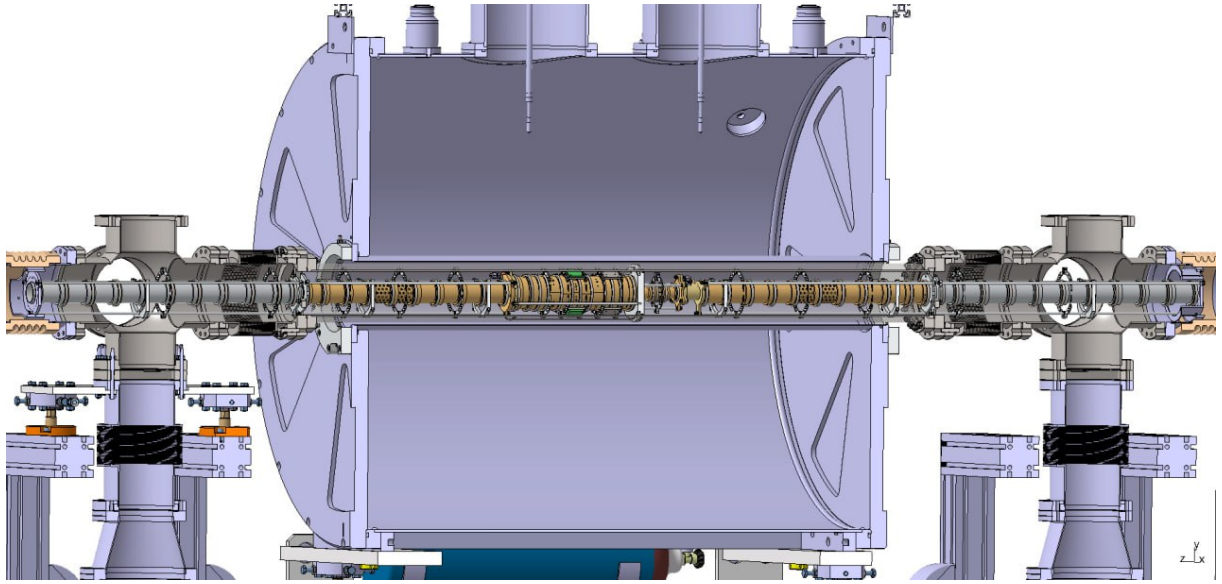
- Nuclear astrophysics modelling inputs
- Q-Values for ft values determination (V_{ud} CKM matrix)

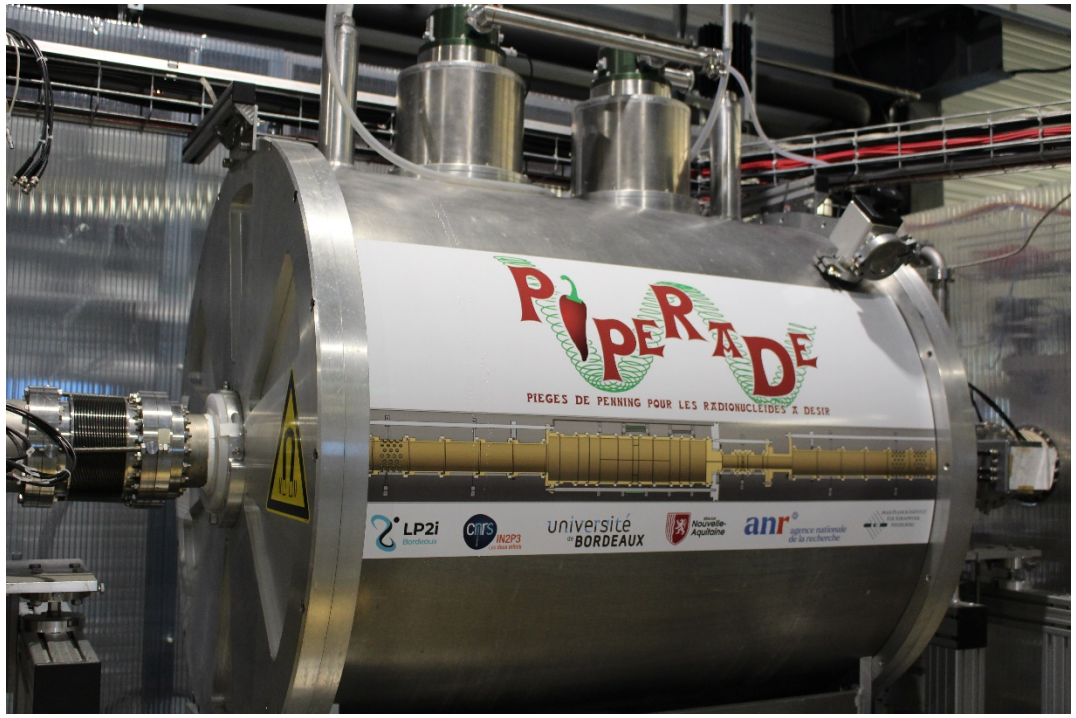


PIPERADE at LP2iB

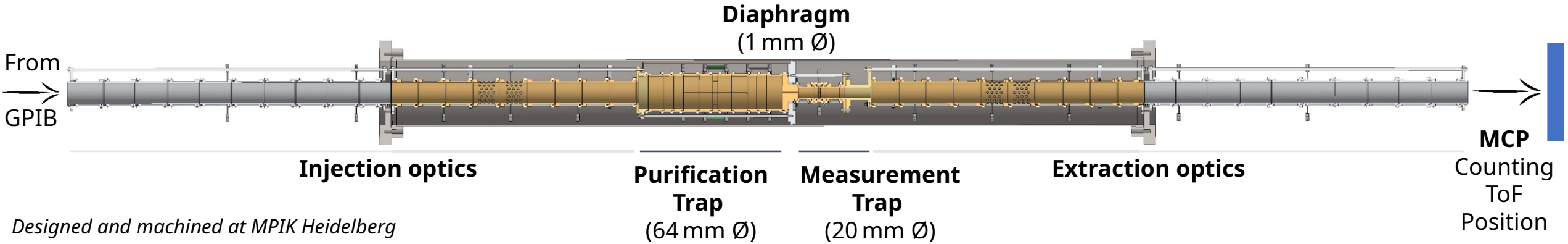


PIPERADE





P. Ascher *et al.*, *PIPERADE: A double Penning trap for mass separation and mass spectrometry at DESIR/SPIRAL2*, Nucl. Instrum. Methods Phys. Res. A 1019 (2021) 165857



Designed and machined at MPIK Heidelberg

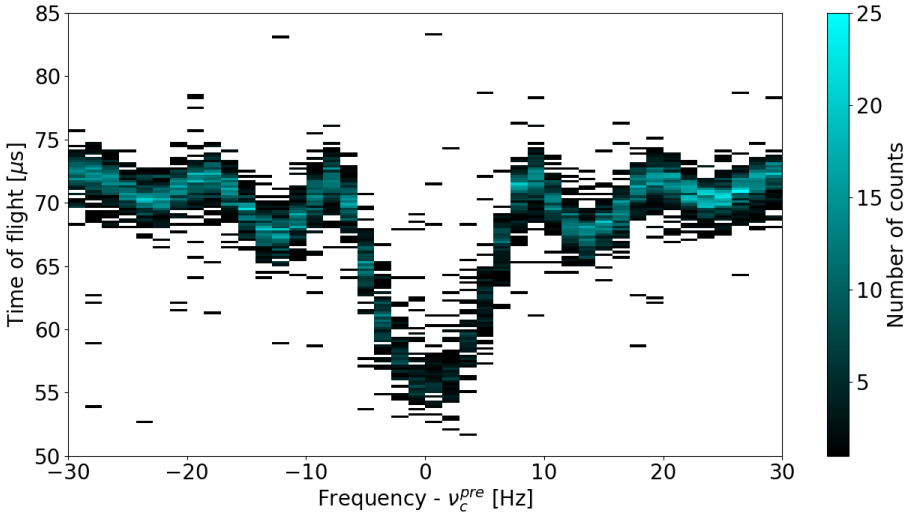
Mass measurement techniques

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

M. Flayol, PhD Thesis (2024)

Mass measurement techniques

ToF-ICR



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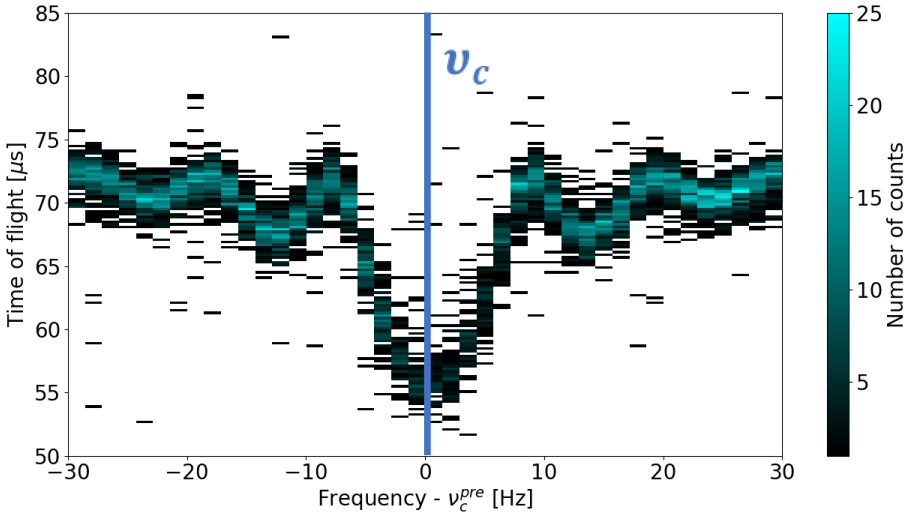

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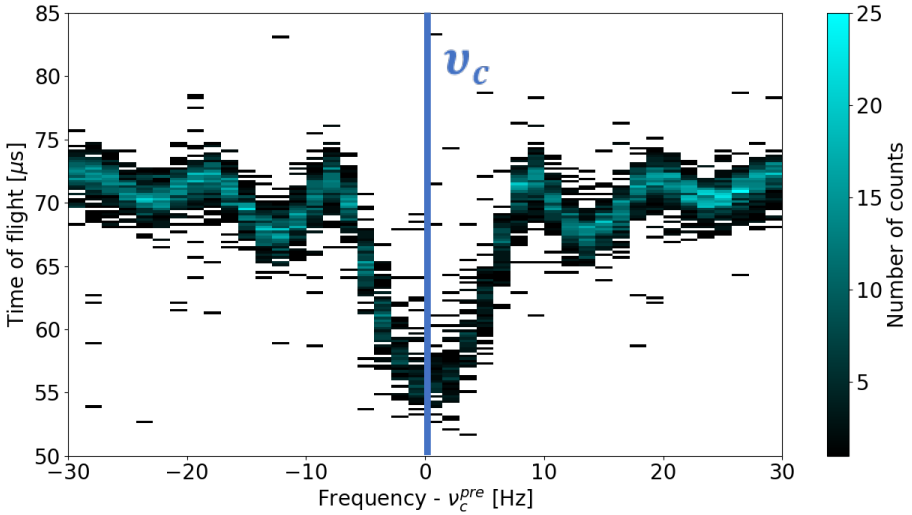

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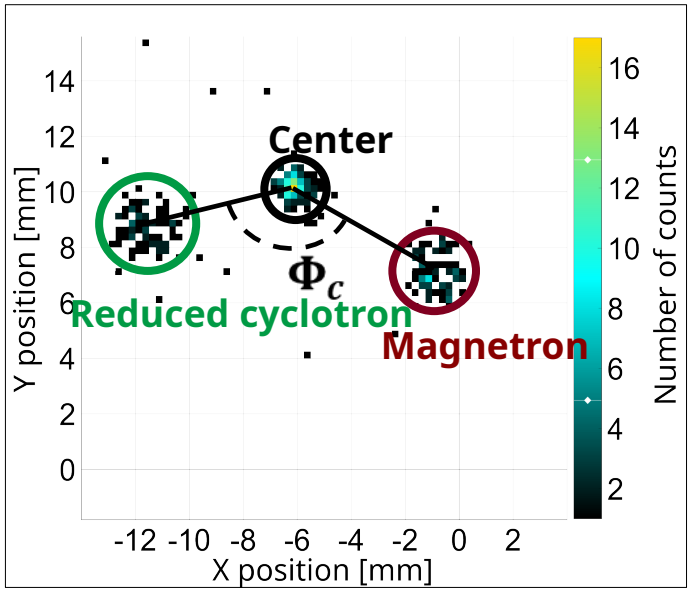

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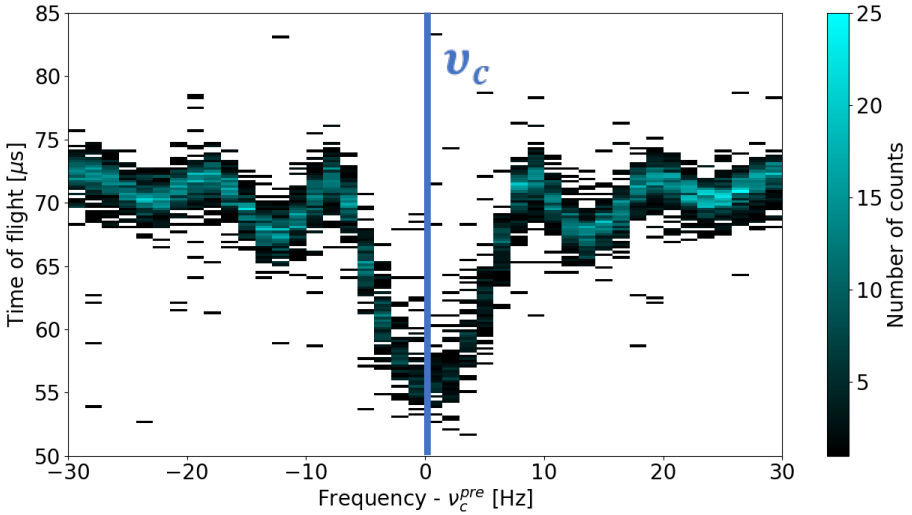
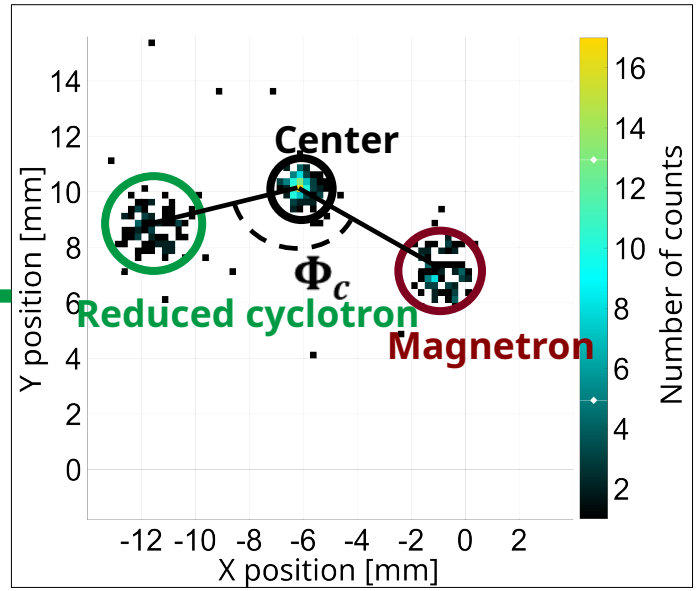


$$\phi_c = 2\nu_c \pi t_{acc} - 2\pi n$$

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

PI-ICR



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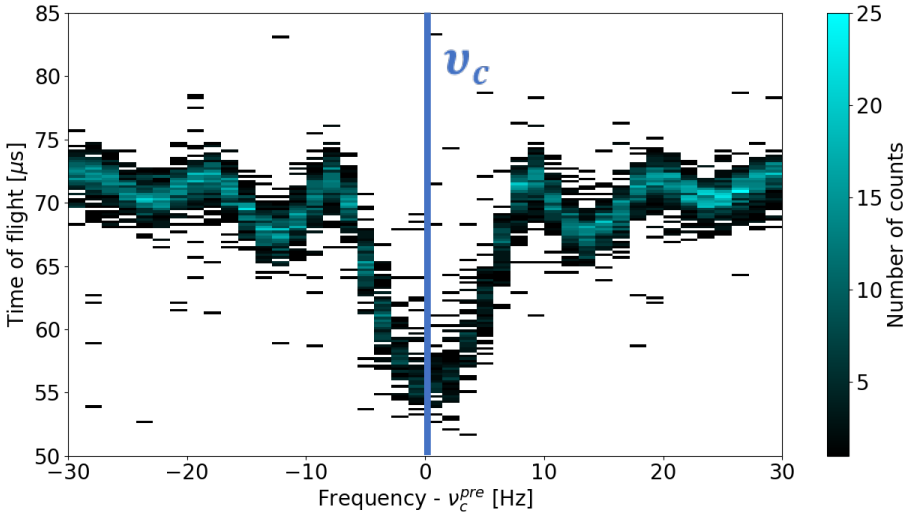

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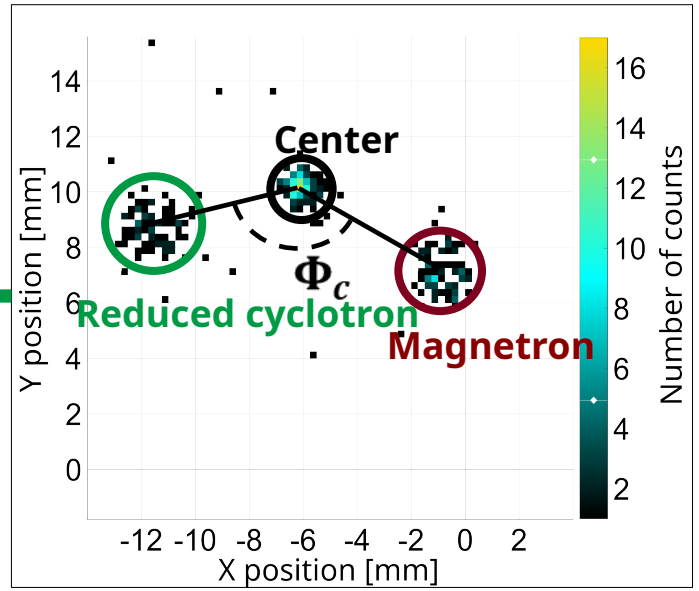

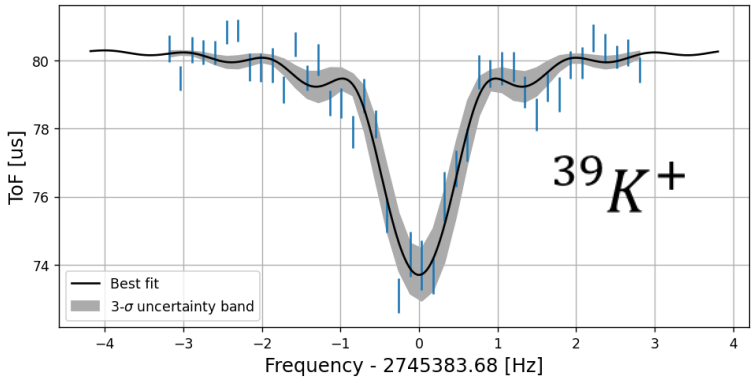

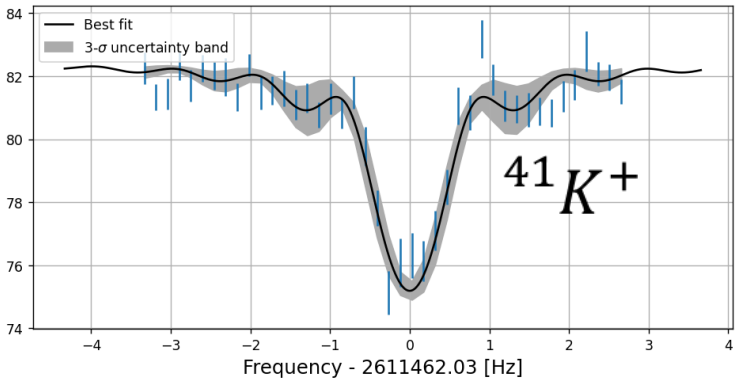

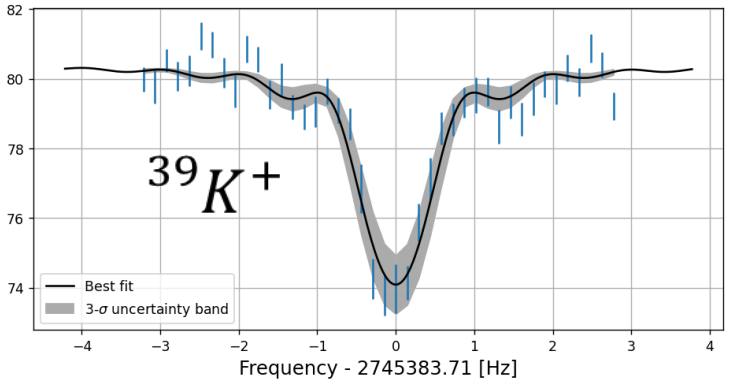

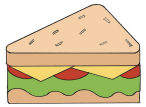

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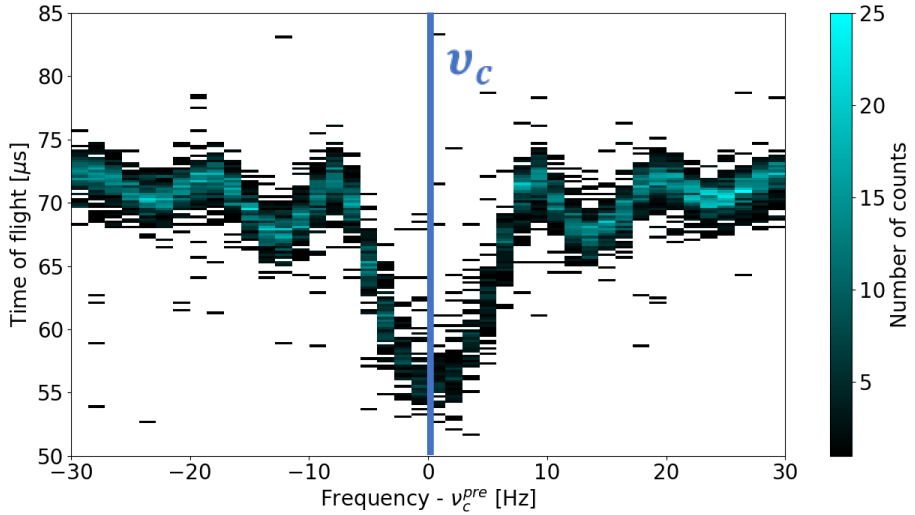

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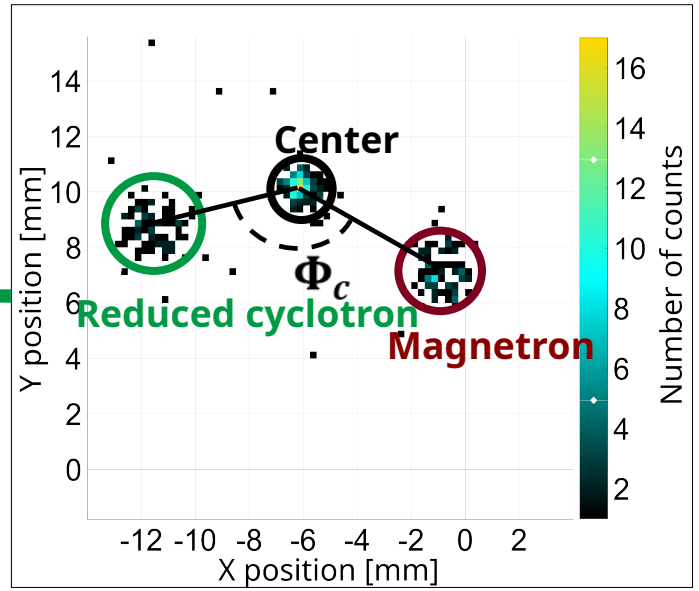
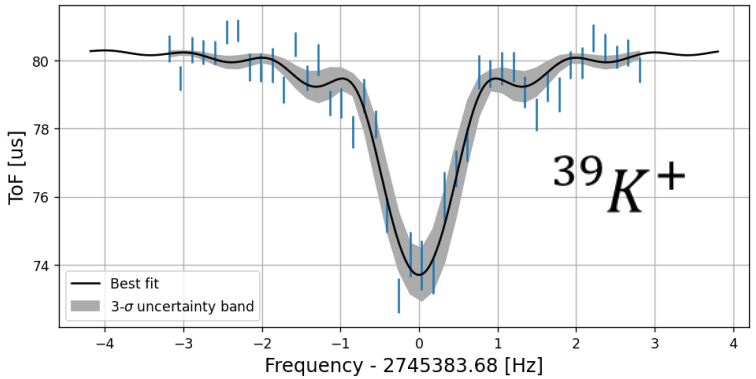
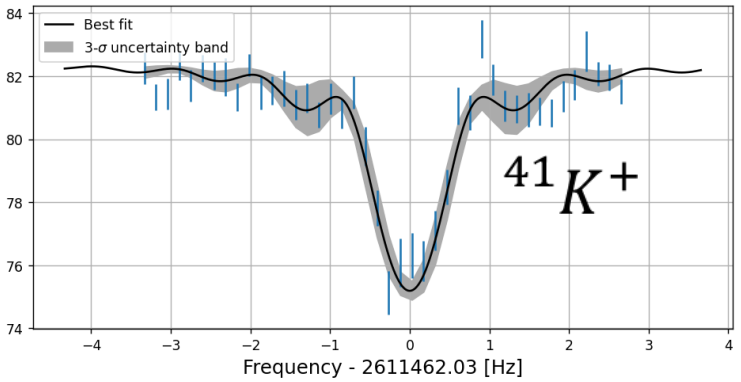


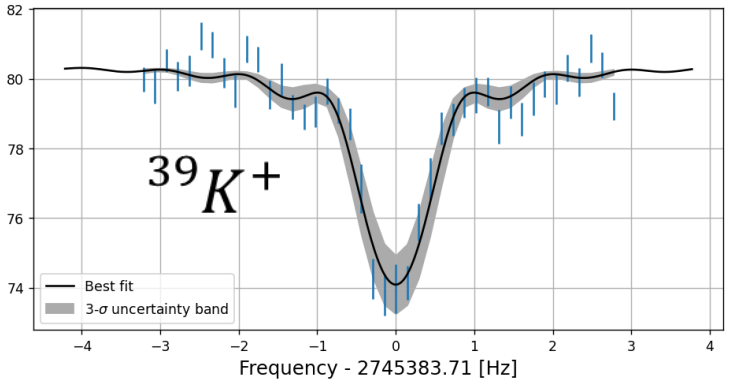
$$\phi_c = 2\nu_c \pi t_{acc} - 2\pi n$$

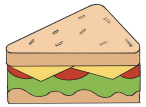
$$\nu_c = \frac{qB}{2\pi m}$$

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









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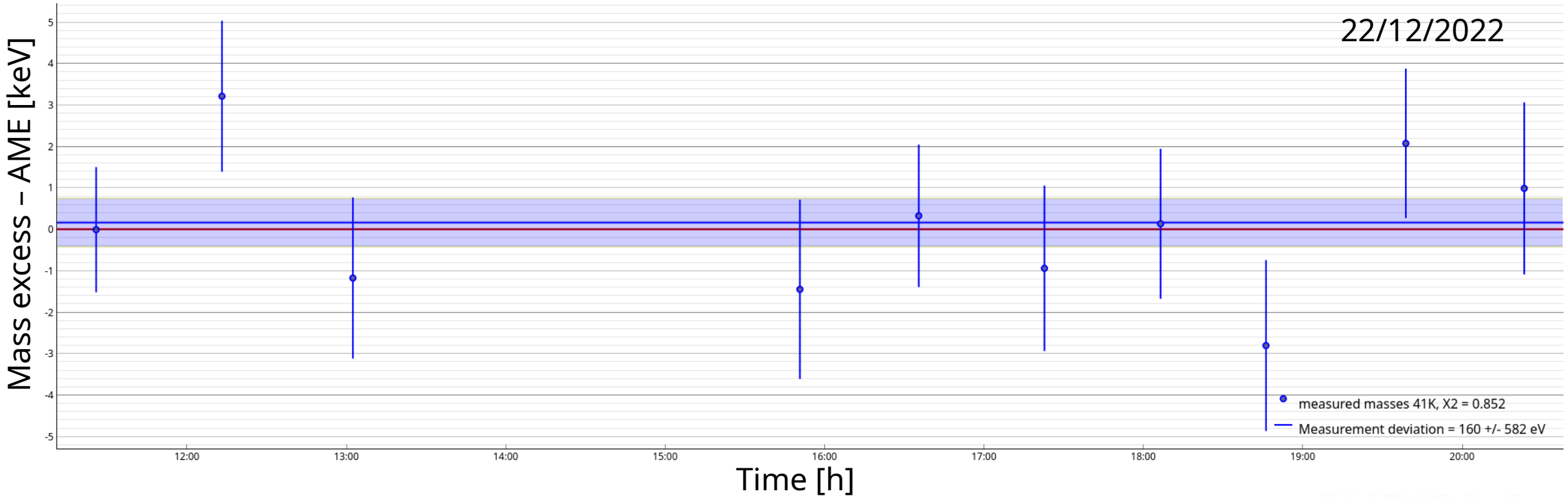
Status
of PIPERADE

Current ToF-ICR measurement

ToF-ICR measurements of ^{41}K with ^{39}K as reference with 100 ms of conversion time

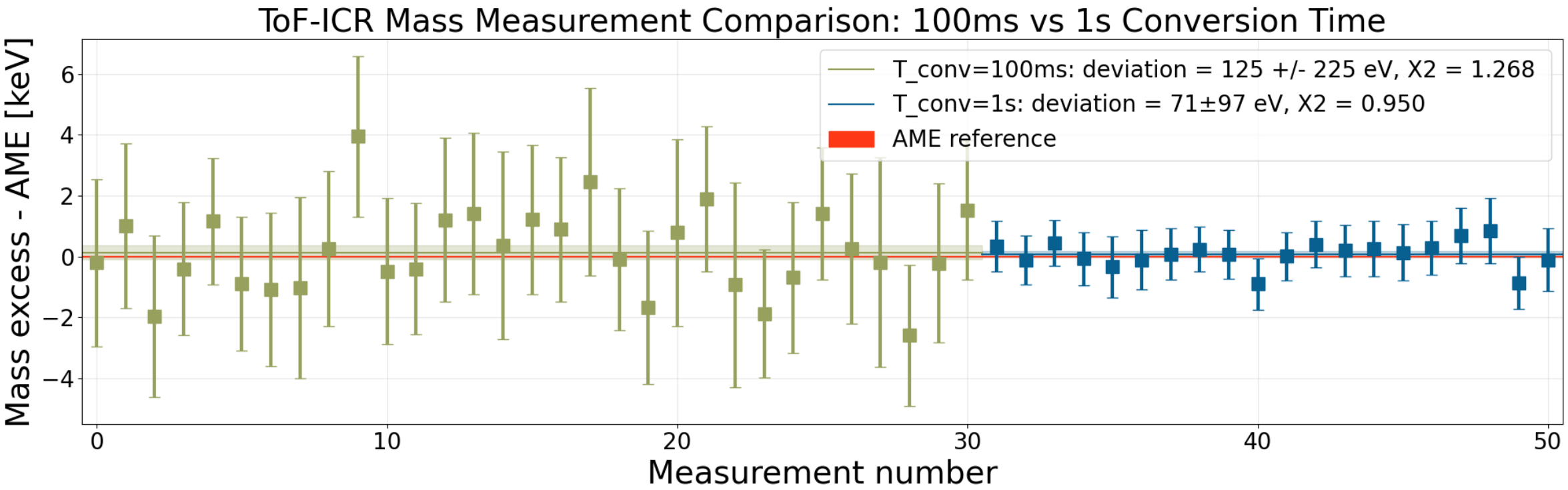


Good agreement with the tabulated value

Precision: $\frac{\delta m}{m} \sim 1.5 \cdot 10^{-8}$

Accuracy: $\frac{\delta m}{m} \sim 4 \cdot 10^{-9}$

Current ToF-ICR measurement



Good agreement with the tabulated value

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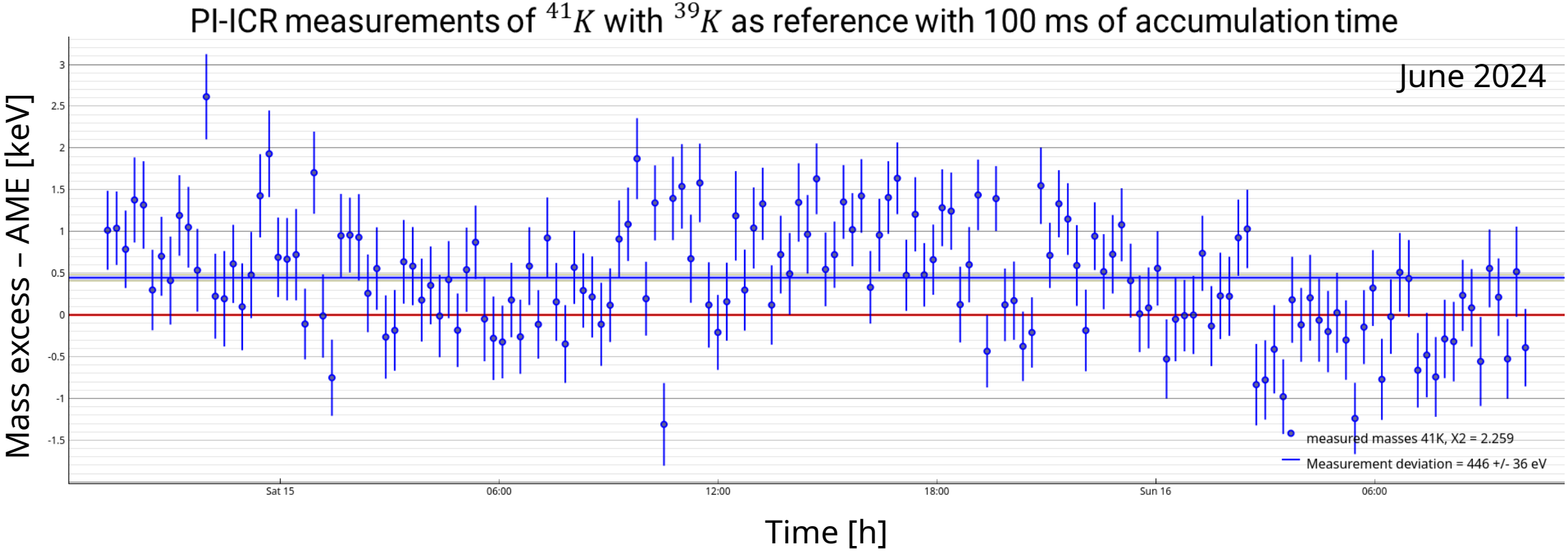
PI-ICR measurement



~~Good agreement with the tabulated value~~

Precision: $\frac{\delta m}{m} \sim 1 \cdot 10^{-9}$

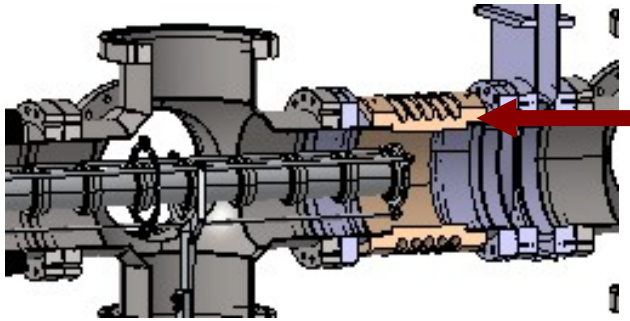
Accuracy: $\frac{\delta m}{m} \sim 1.2 \cdot 10^{-8}$

Improvements

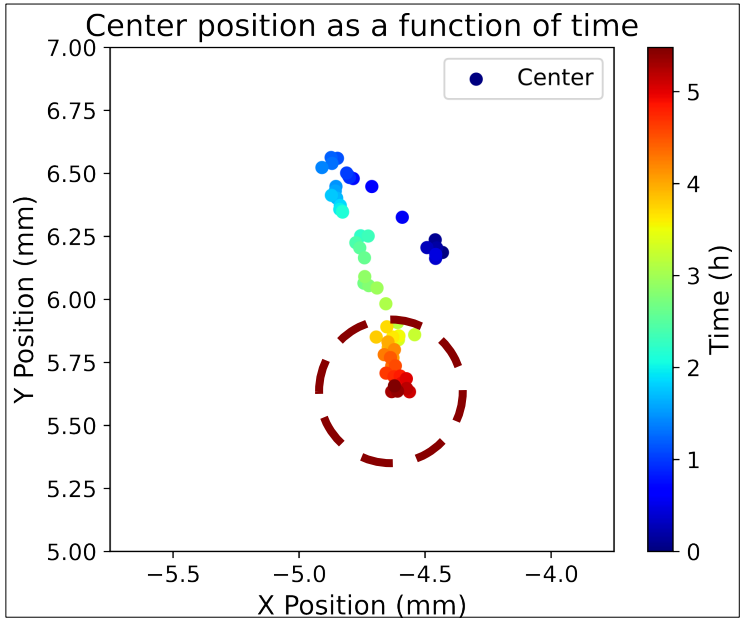
- Trap center movement

Improvements

- Trap center movement



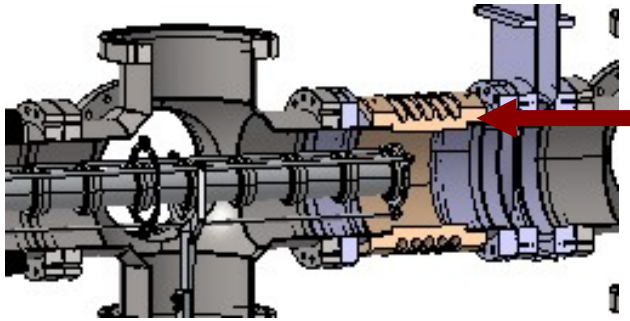
Ions are not « shielded » from insulator



Bunch FWHM

Improvements

- Trap center movement



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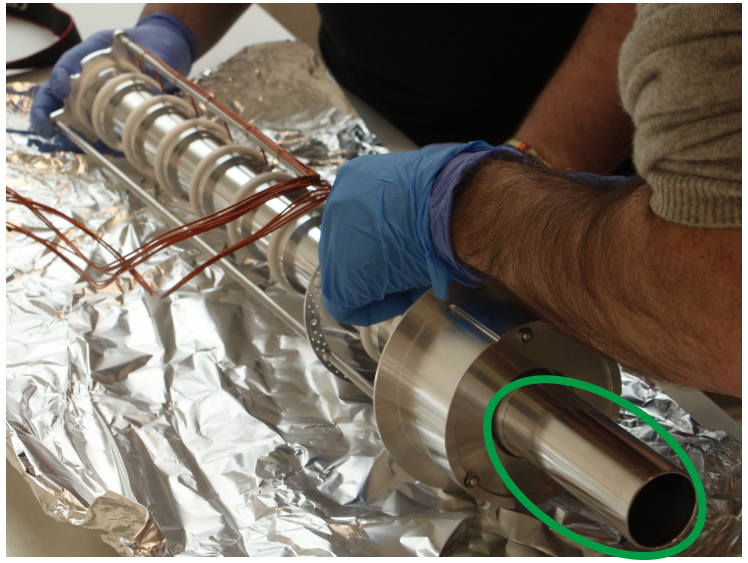
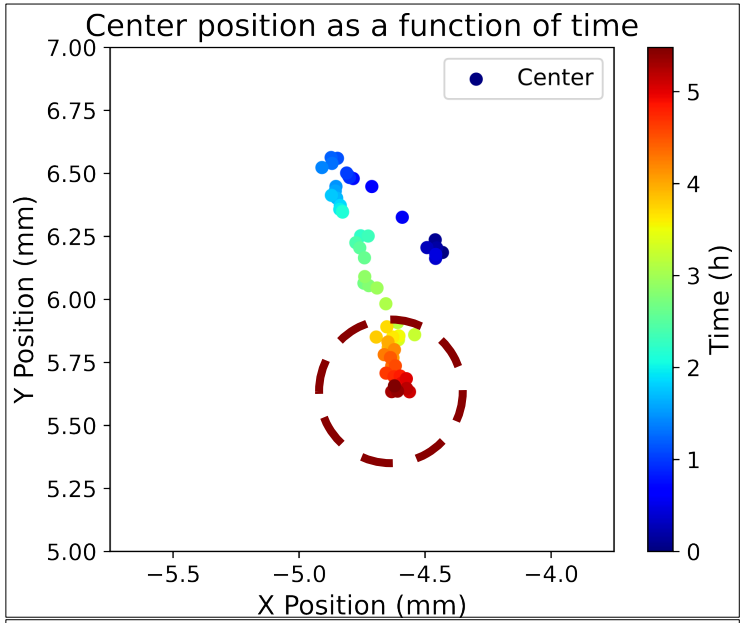
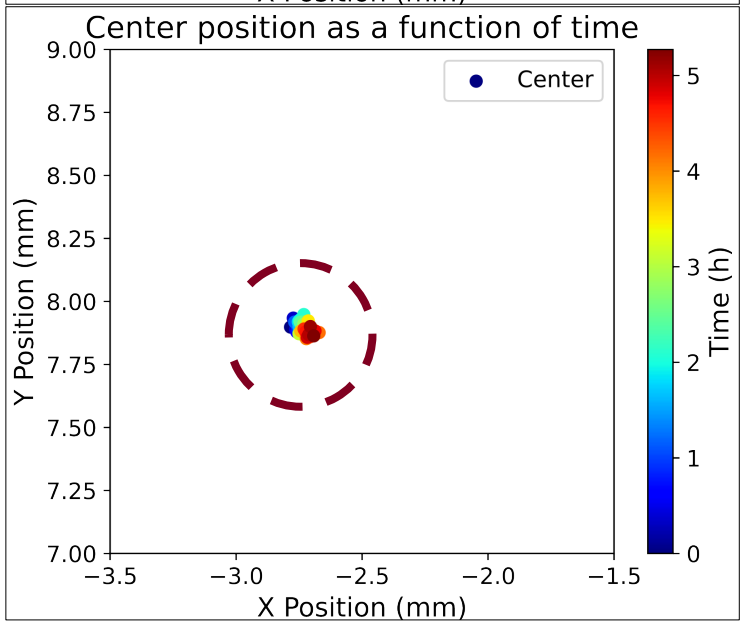


Extension electrode was added





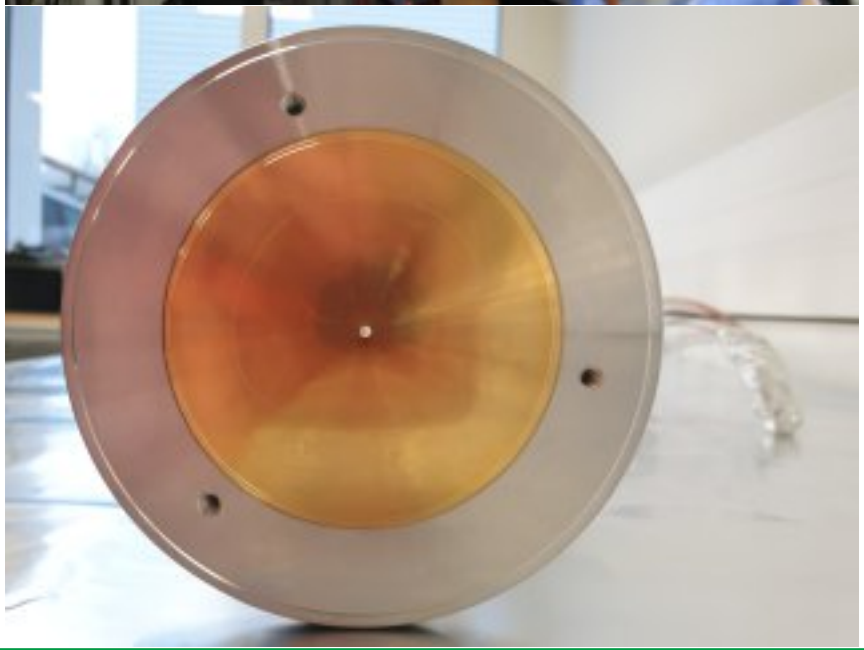
Bunch FWHM

Improvements

- Trap center movement

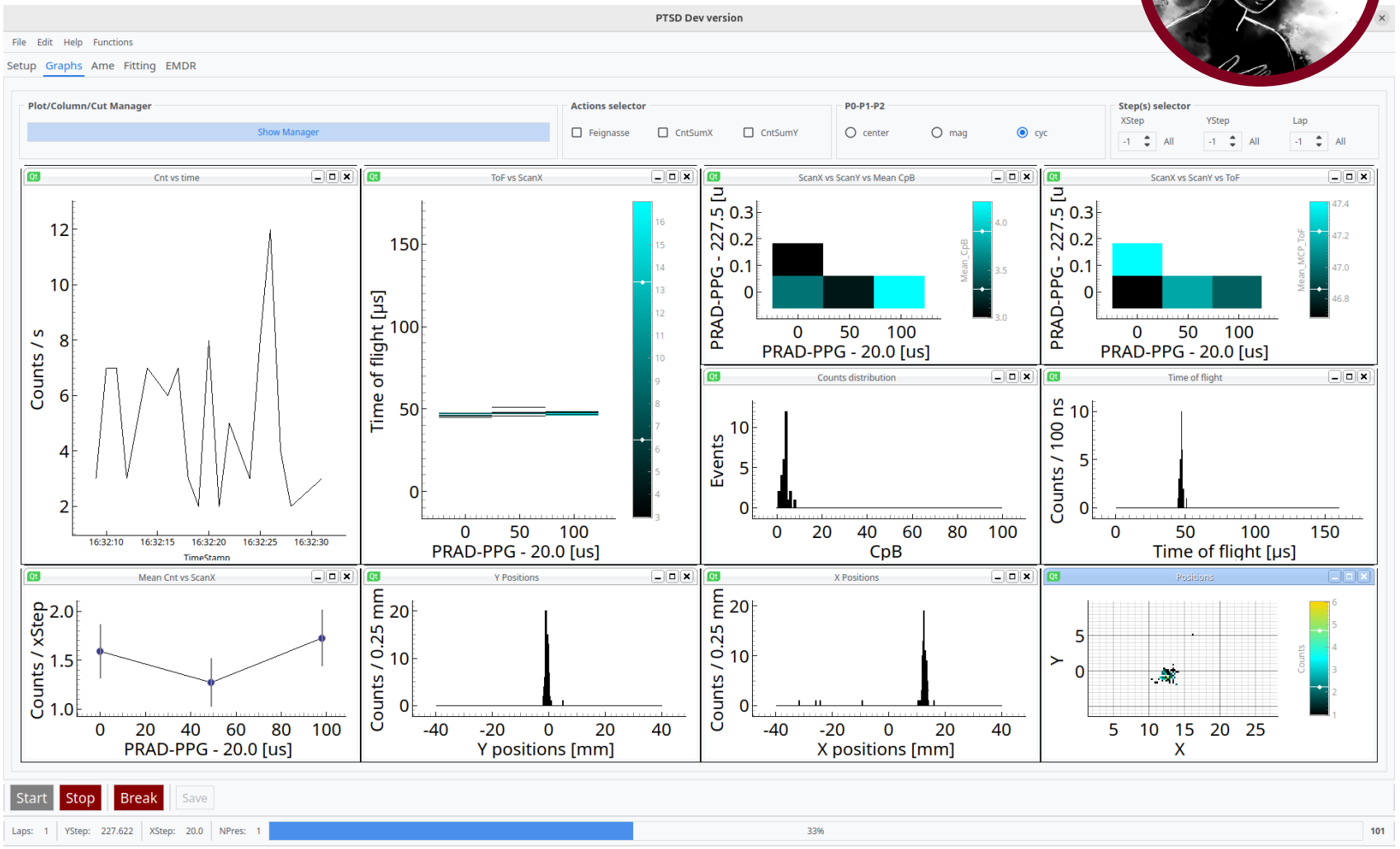
- Diaphragm change

Less gas transfer from PT to MT !



Improvements

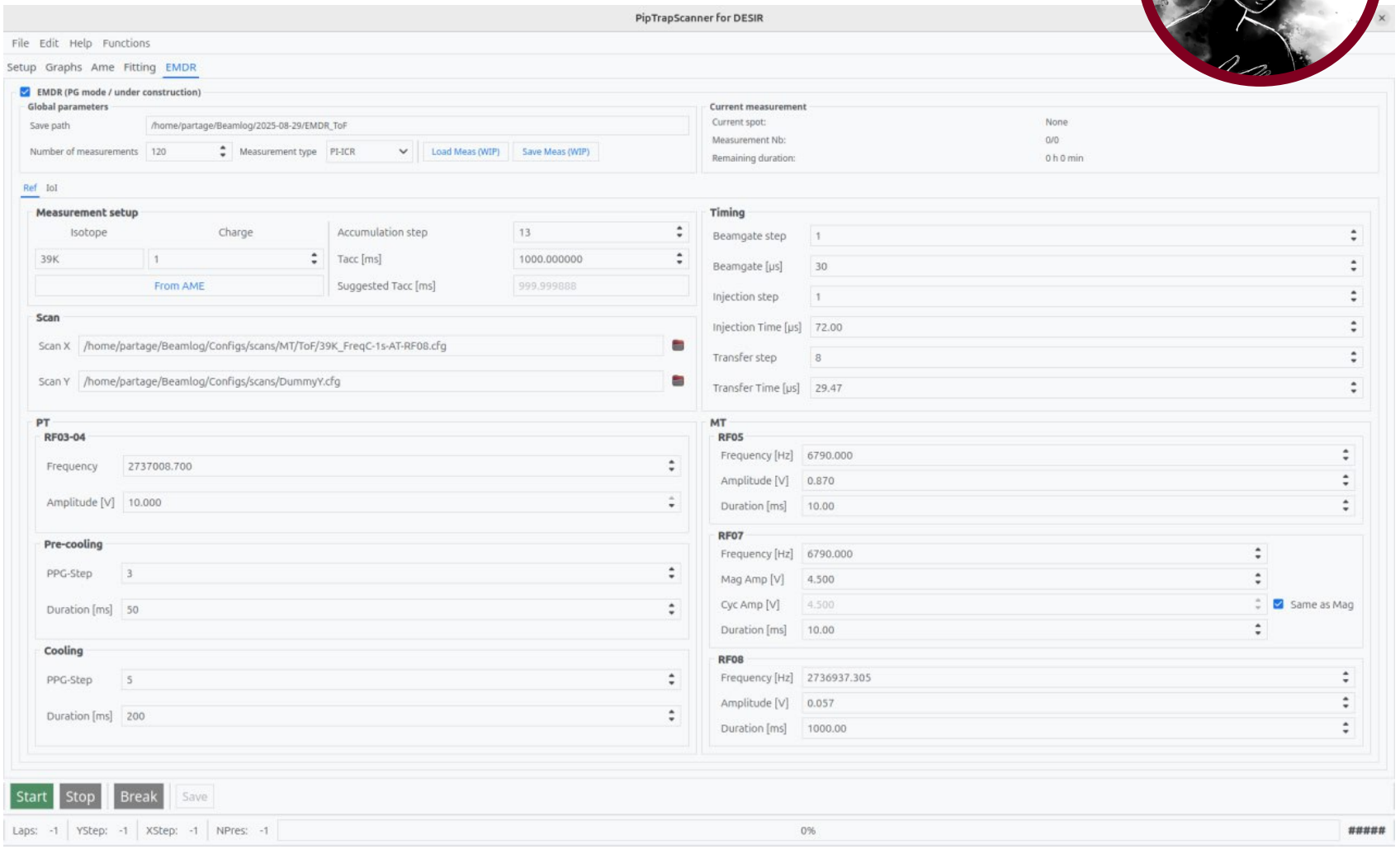
- Trap center movement
- Diaphragm change
- Software developments



Python **T**rap **S**canner for **D**esir (**PTSD**)

Improvements

- Trap center movement
- Diaphragm change
- Software developments



Python **T**rap **S**canner for **D**esir (**PTSD**)

Improvements

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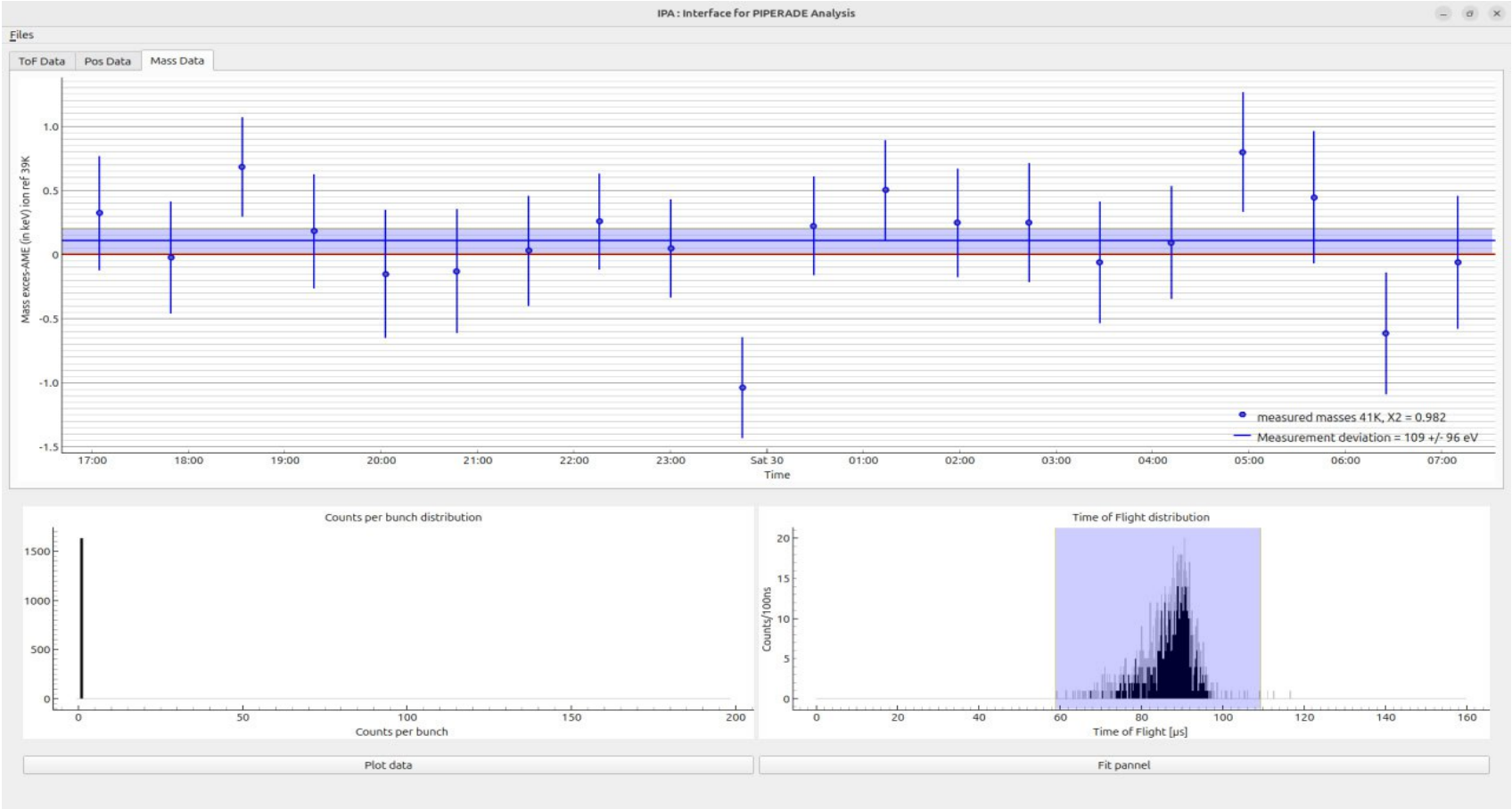
- Diaphragm change
- Software developments
- Analysis improvements



Interface for **P**IPERADE **A**nalysis (**IPA**)

Improvements

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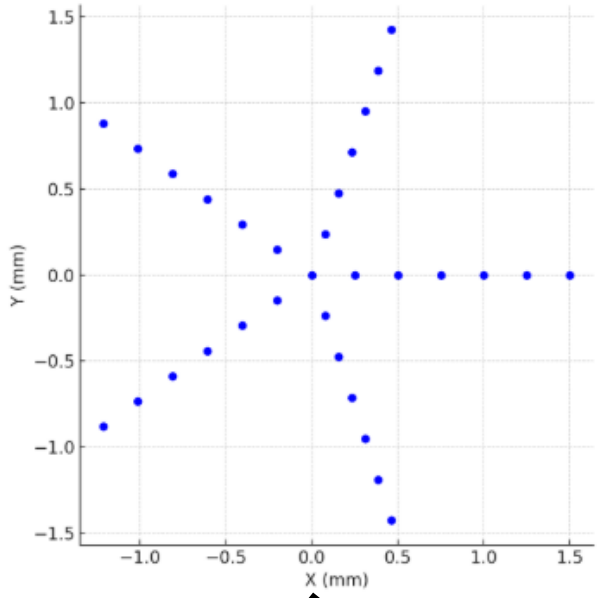
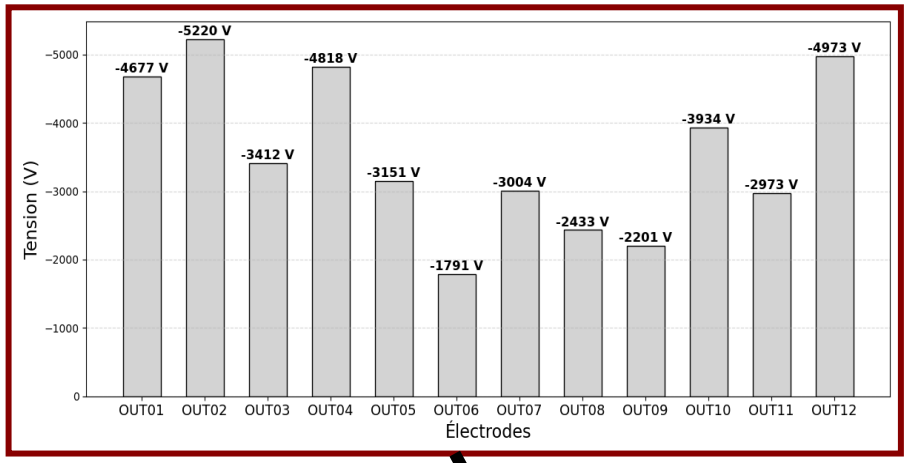
- Diaphragm change
- Software developments
- Analysis improvements
- Simulations improvements

Extraction optimization : simulation

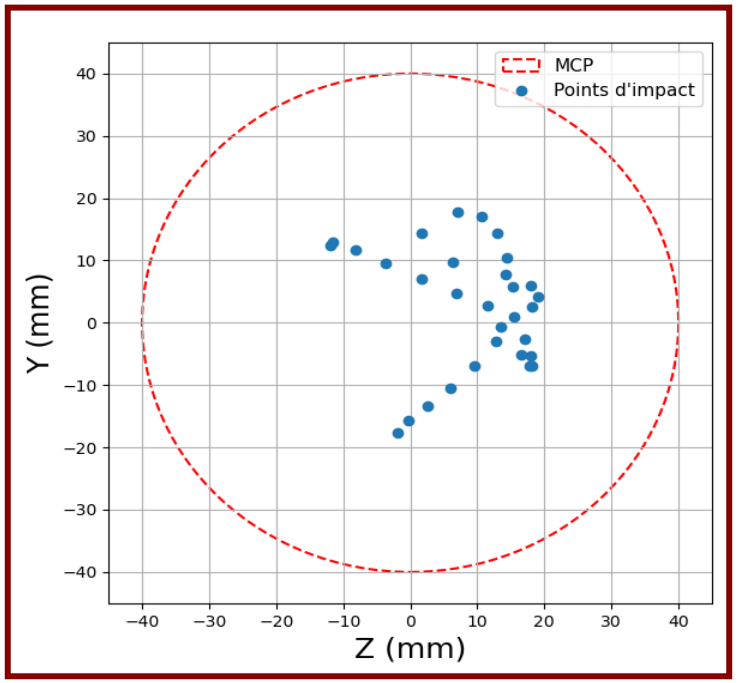
Ideal template

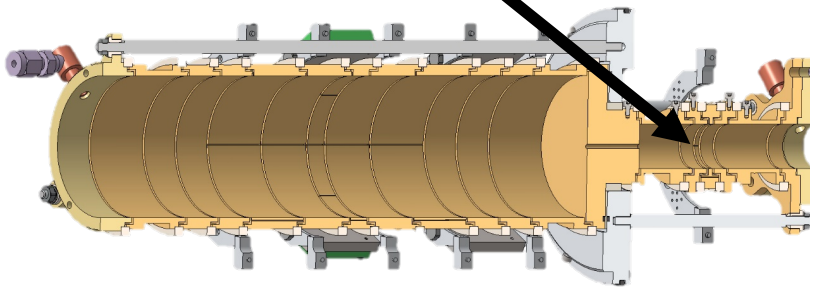


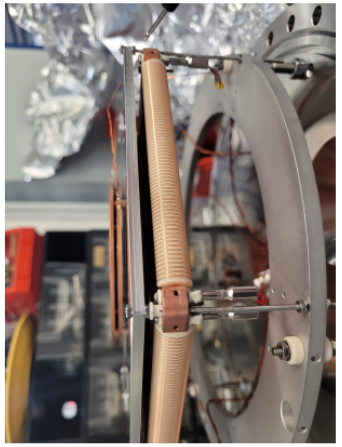
Random extraction



Position on the detector



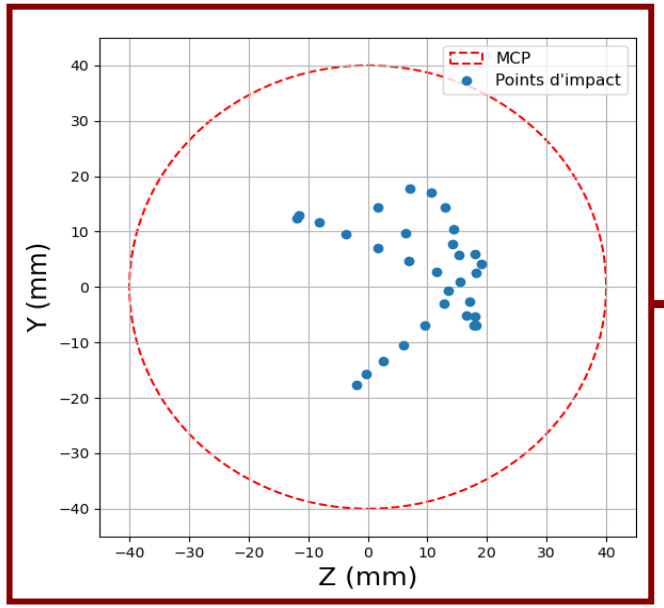




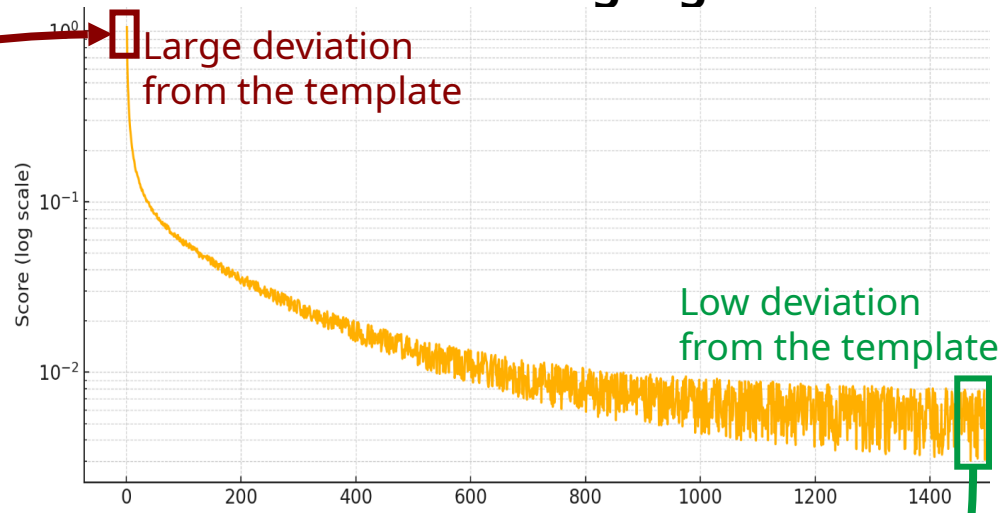
K. Ronxin, Intership (2025)

Extraction optimization : simulation

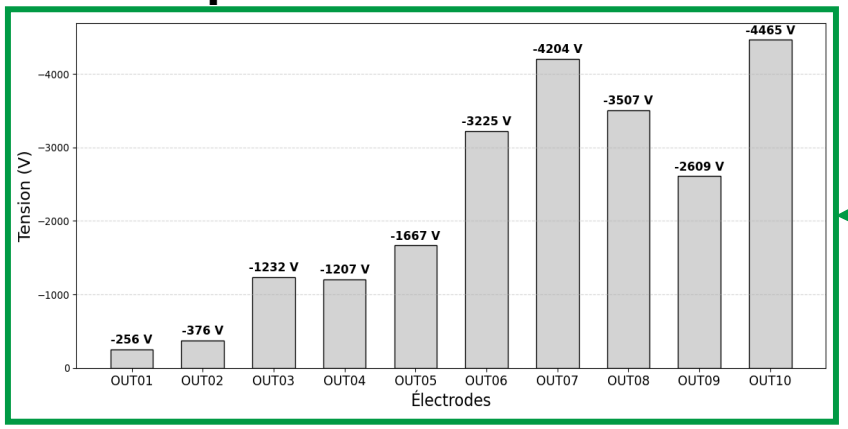
Position on the detector



Simulated annealing algorithm



Optimized extraction



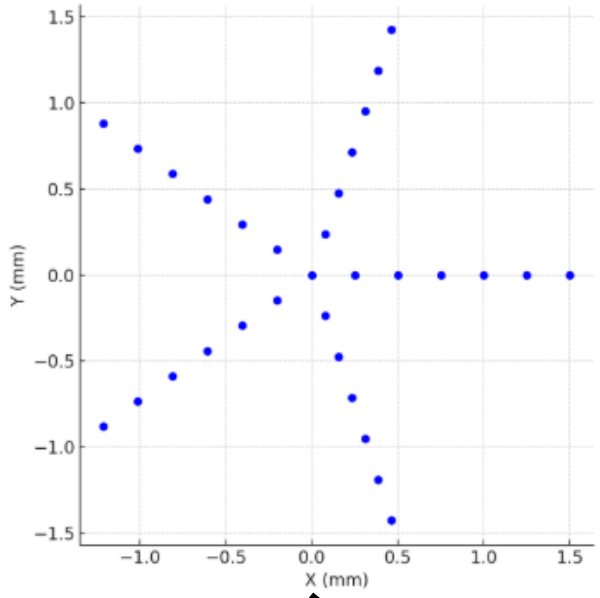
<u>Evaluates this star based on two criteria:</u>

- Straightness of the arms
- Deviation from ideal template

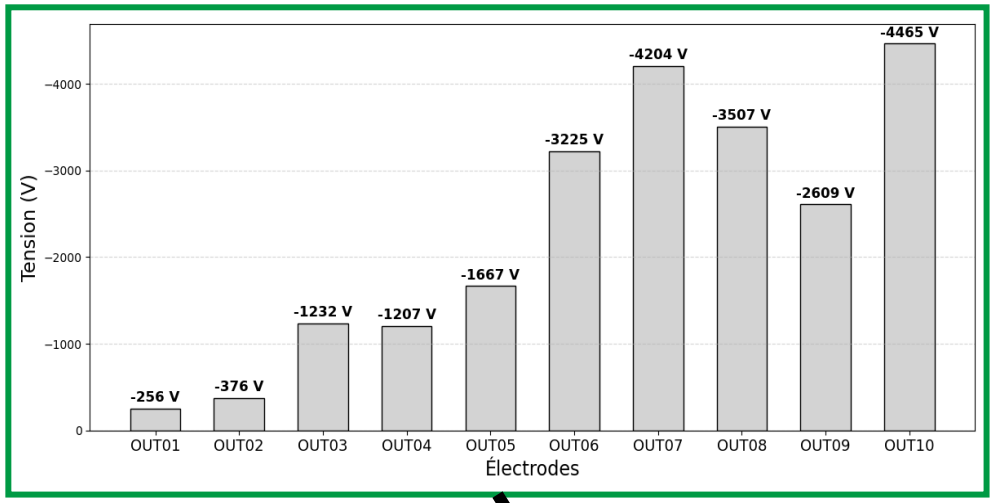
K. Ronxin, Intership (2025)

Extraction optimization : simulation

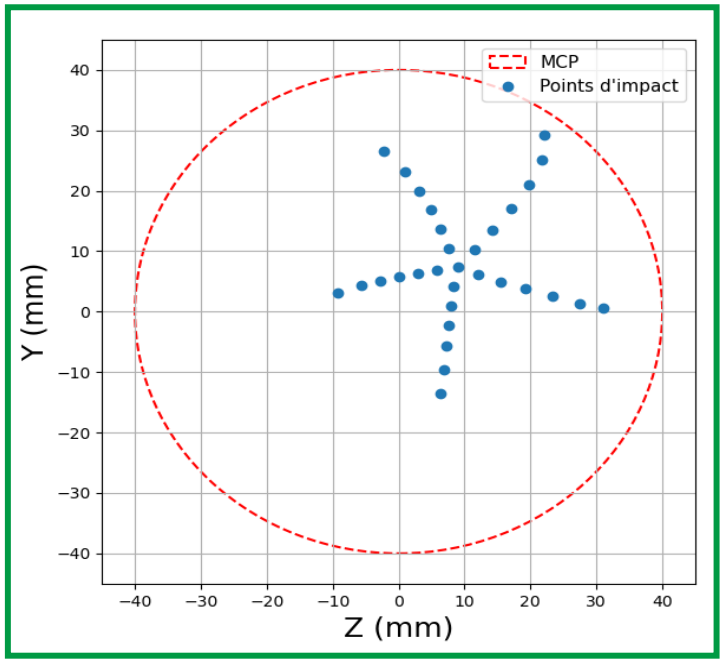
Ideal template

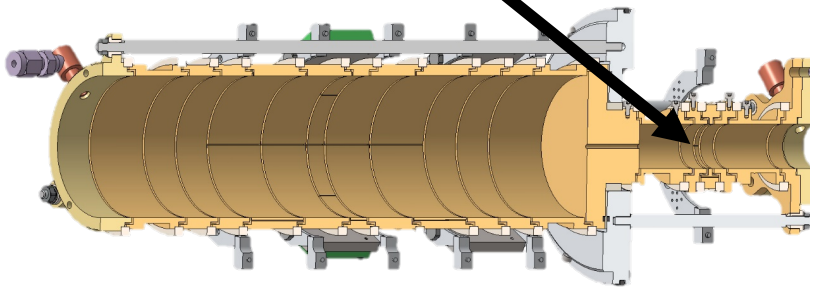


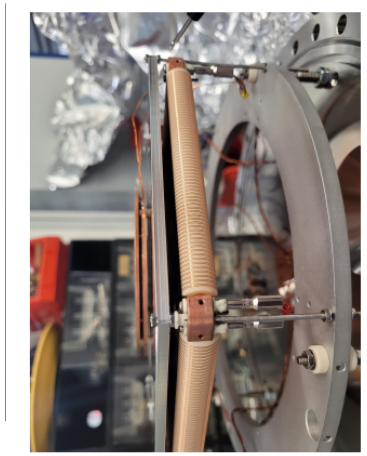
Optimized extraction



Position on the detector



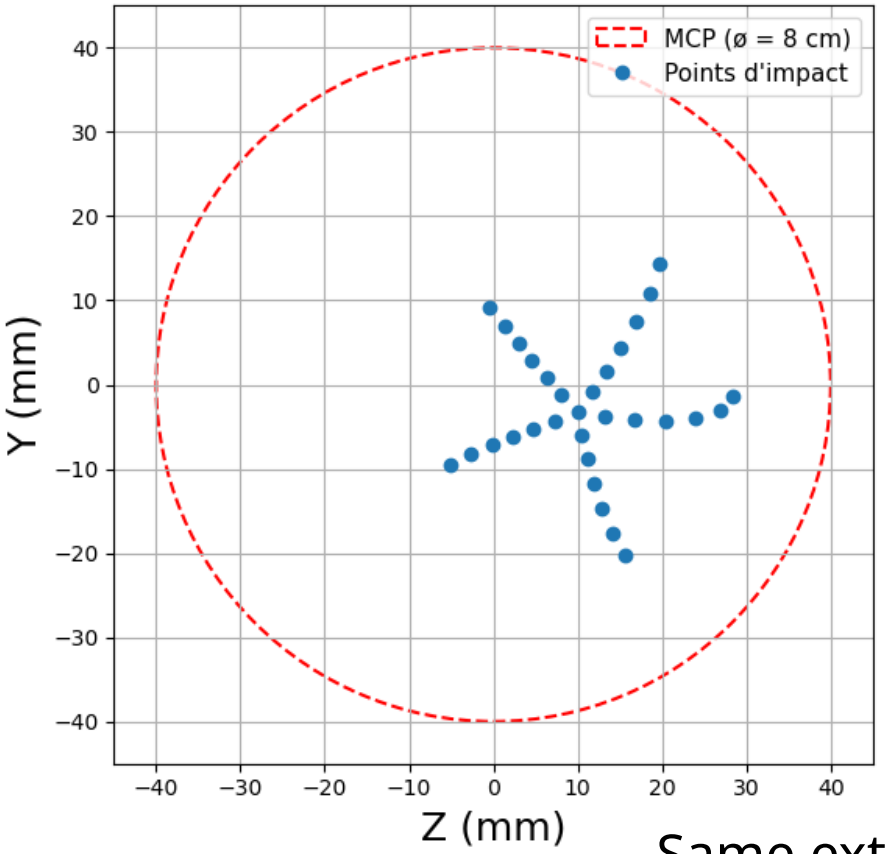




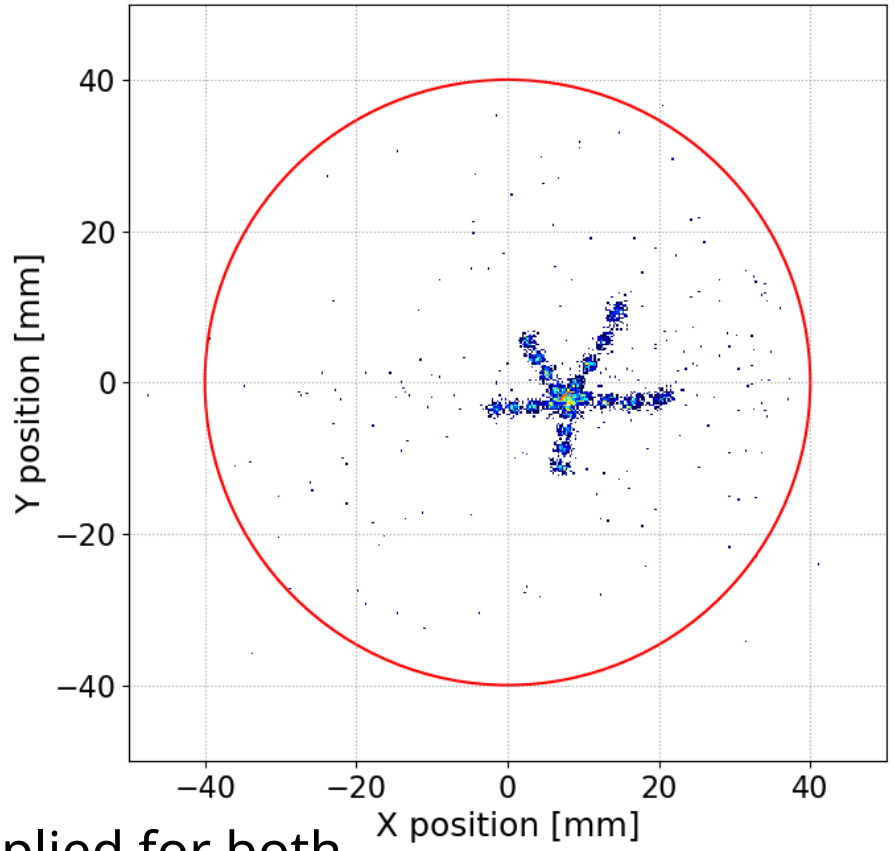
K. Ronxin, Intership (2025)

Extraction optimization : result

Result of the simulation optimisation



Experimental magnetron star

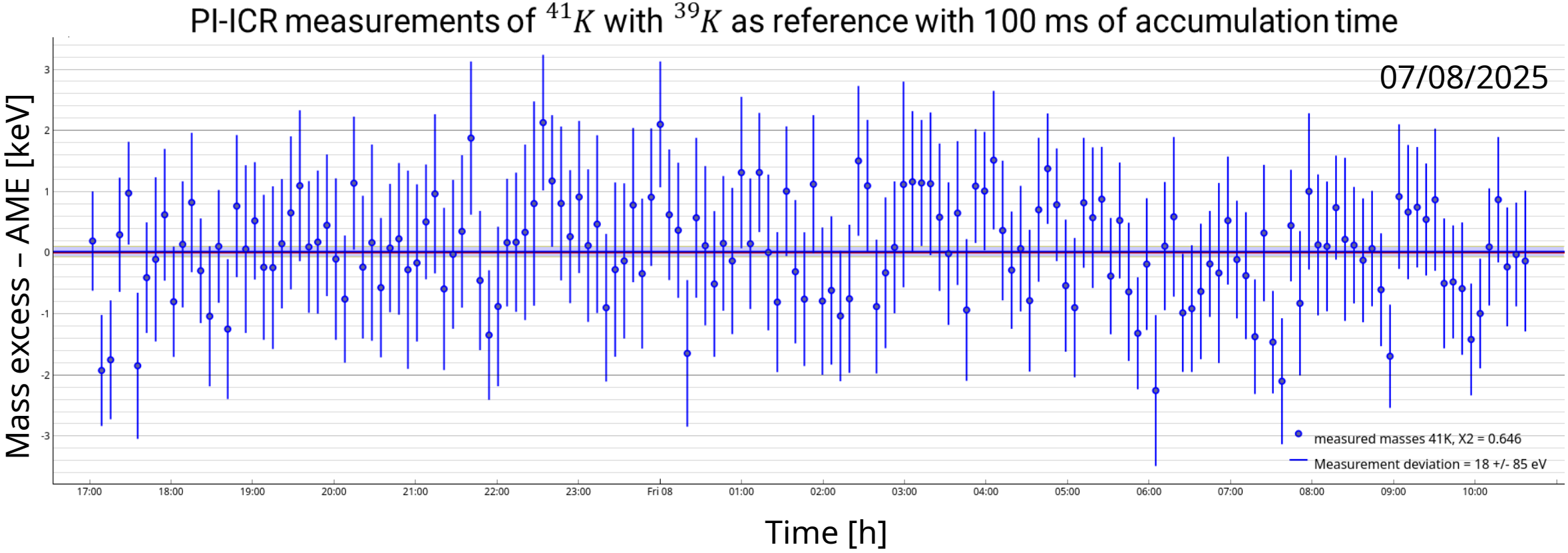


Same extraction applied for both

Different initial radii

K. Ronxin, Intership (2025)

Current PI-ICR measurement

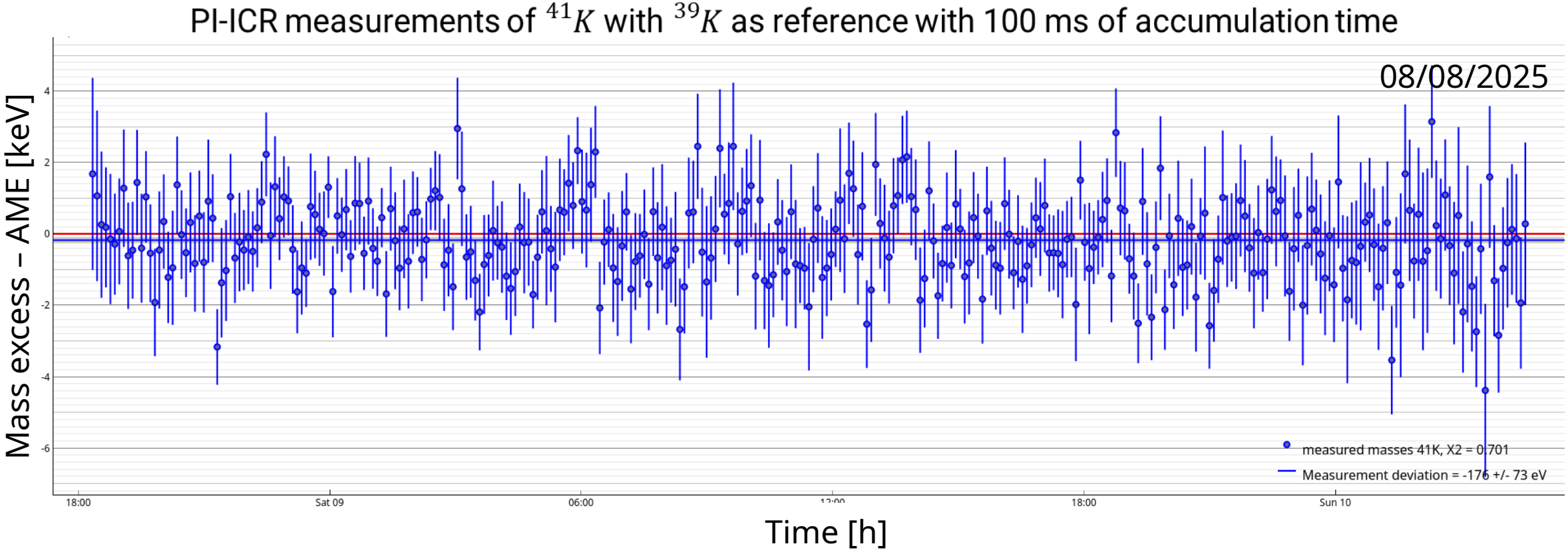


Good agreement with the tabulated value

Precision: $\frac{\delta m}{m} \sim 2 \cdot 10^{-9}$

Accuracy: $\frac{\delta m}{m} \sim 5 \cdot 10^{-10}$

Current PI-ICR measurement



Good agreement with the tabulated value

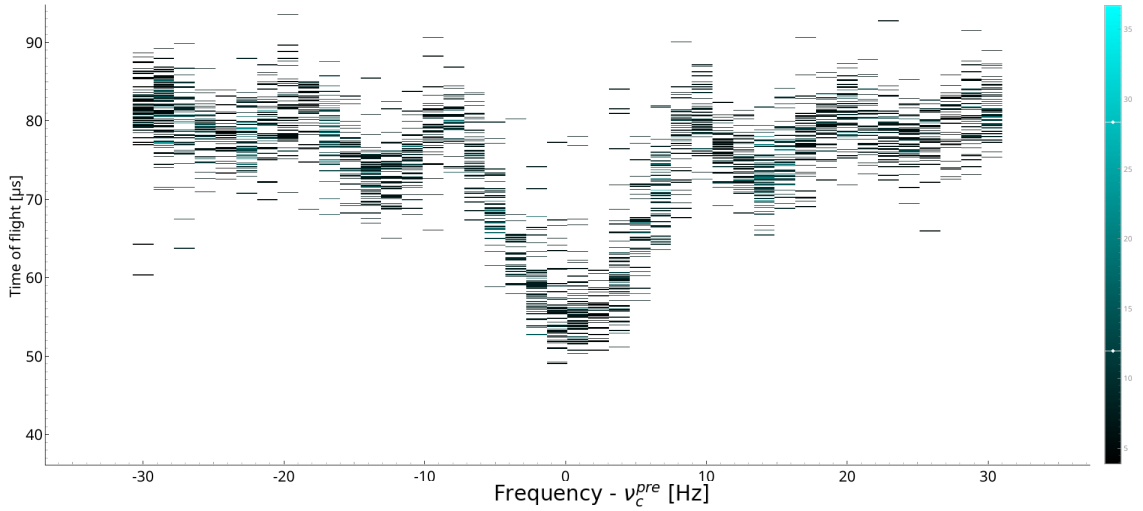
Precision: $\frac{\delta m}{m} \sim 2 \cdot 10^{-9}$

Accuracy: $\frac{\delta m}{m} \sim 5 \cdot 10^{-9}$

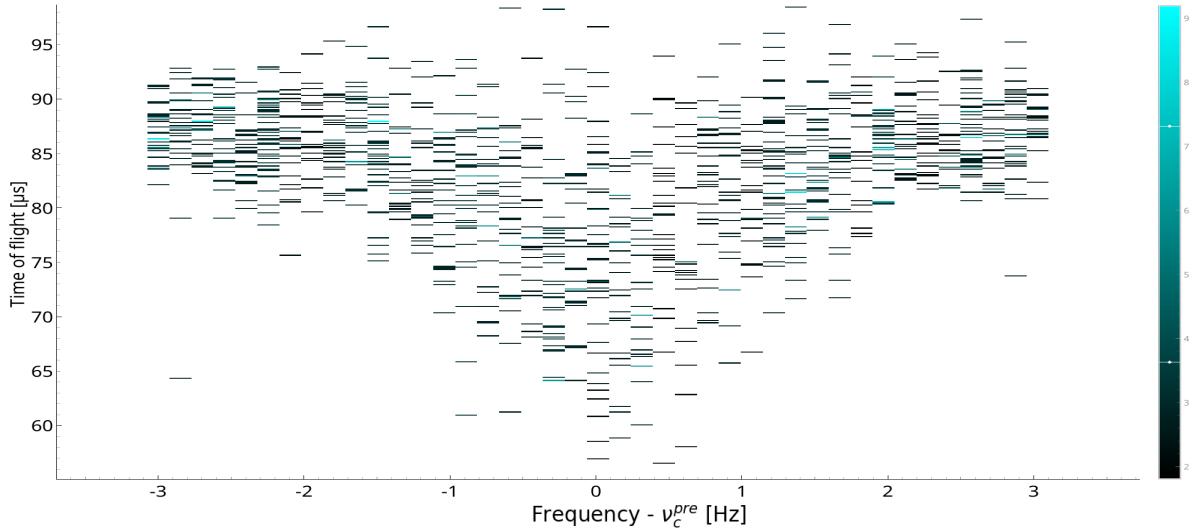
→ Still some systematic effects that are not understood

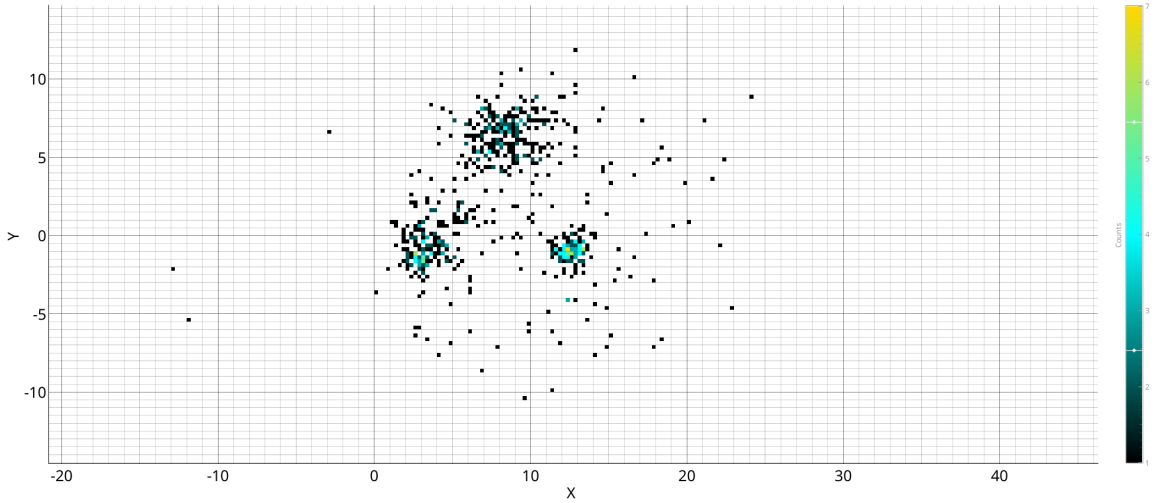
Current issue with mass measurement

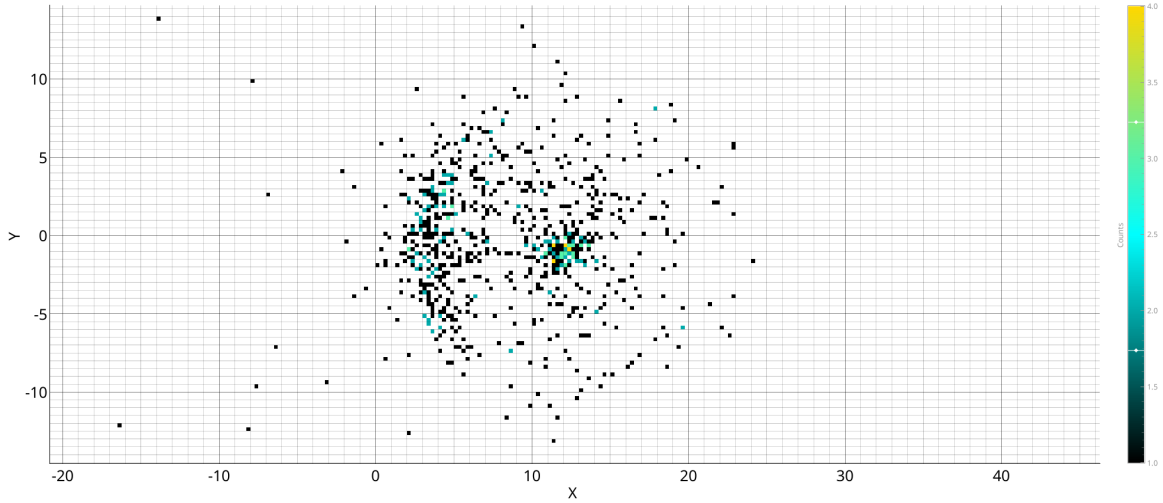
100 ms



1 s







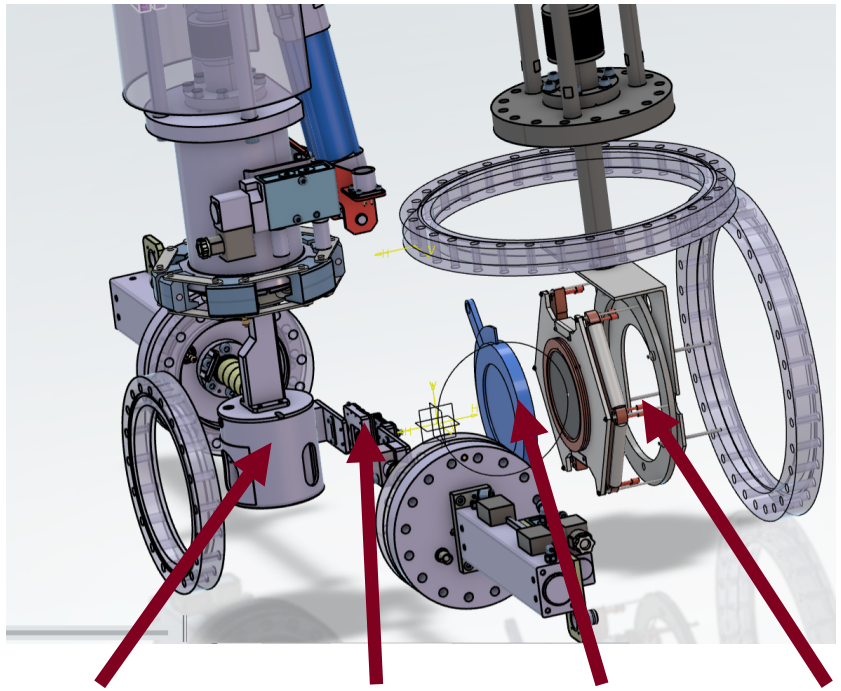
Conclusion and perspectives

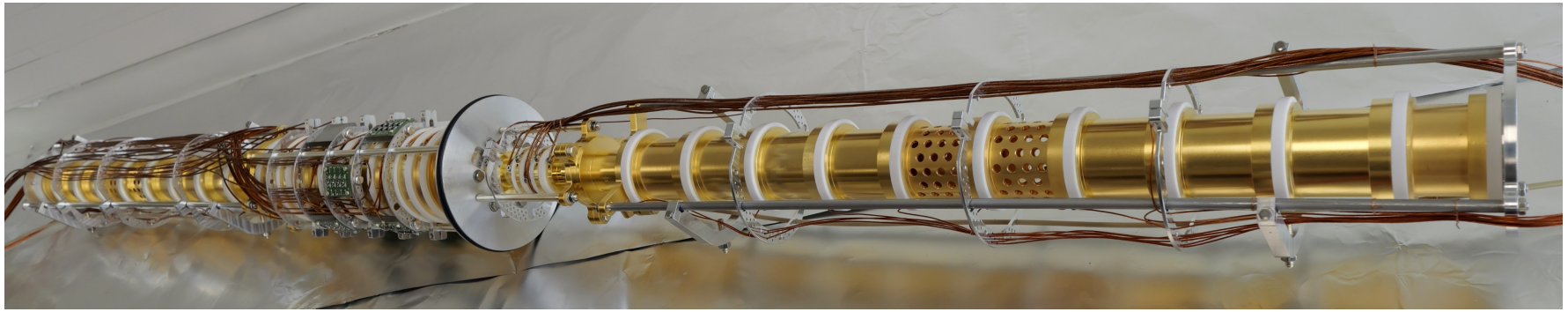
Conclusion:

- PIPERADE characterisation is progressing well
  - ➔ ToF-ICR measurements routinely performed
  - ➔ PI-ICR development is progressing
- Systematics under investigation for ToF-ICR and PI-ICR
  - ➔ E-field anharmonicities
  - ➔ B-field fluctuations
  - ➔ Pressure and temperature effects
- Software development on-going

Perspectives:

- Reach longer trapping time
- New MCP chamber under development
  - ➔ Demonstration of high-resolution purification for large number of ions
- Moving to GANIL (2026-2027)
  - ➔ Pressure and temperature stabilisation
  - ➔ Access to exotic beams





Thanks for your attention!

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

PIPERADE
PIEGES DE PENNING POUR LES RADIONUCLEIDES A DESIR

Backup

Ion motions in a Penning trap

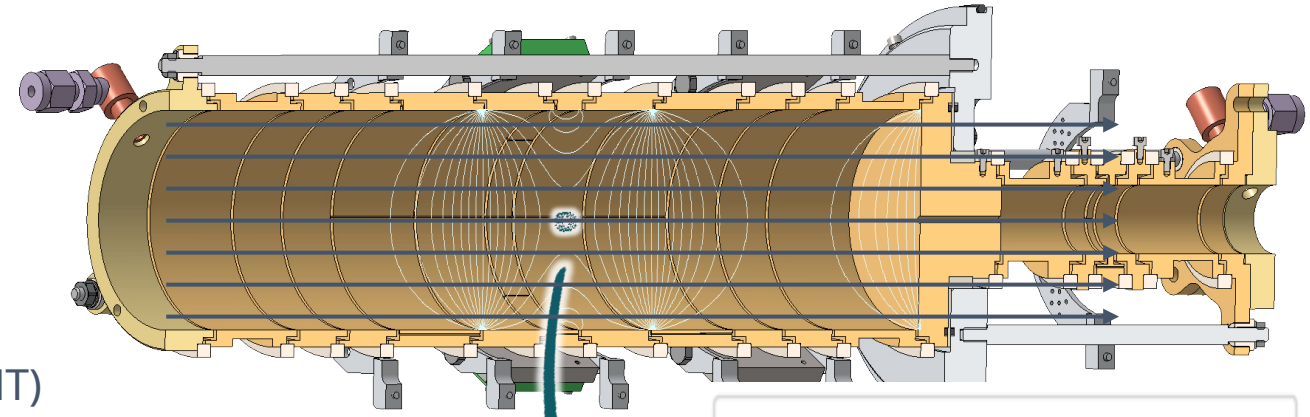
- 7 T homogenous magnetic field: radial confinement (2 homogeneous regions < 1 ppm over 1 cm³)
- Quadrupolar electrostatic field: axial confinement ($\Delta V \approx 80\,V$)
  - ν_- : Magnetron motion (~ 700 Hz for PT, ~ 7 kHz for MT)
  - ν_z : Axial motion (~100 kHz)
  - ν_+ : Reduced cyclotron motion (~ MHz)

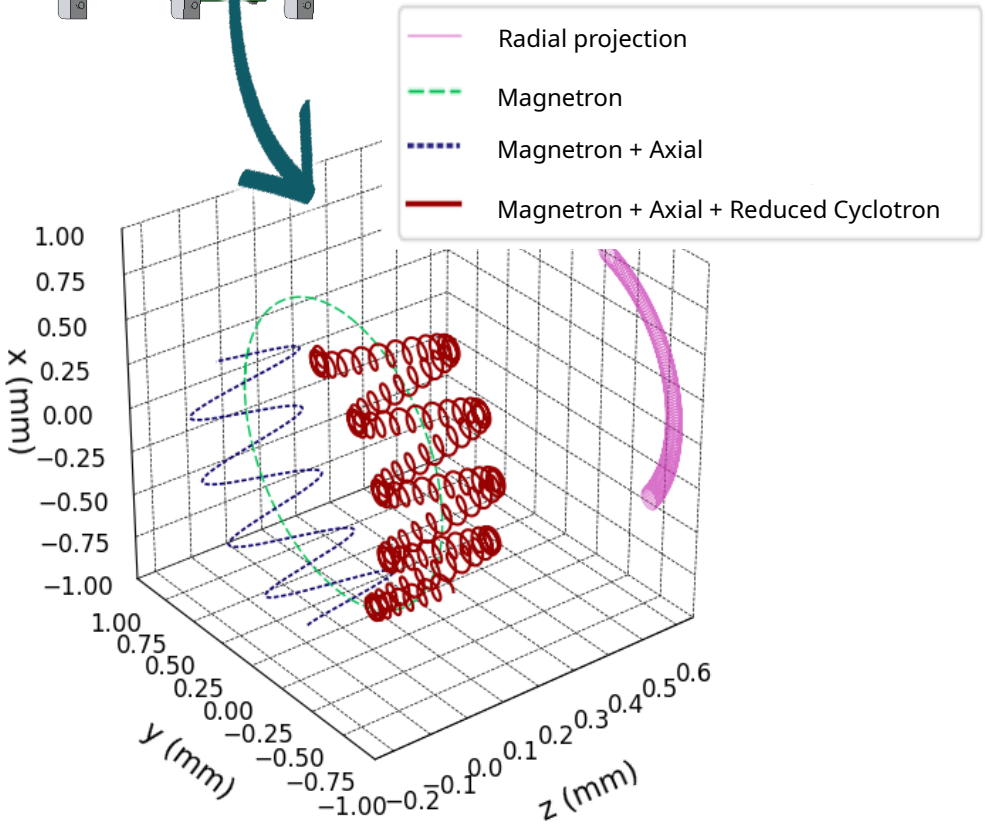
Damped by gas

$$\frac{qB}{2\pi m} = \nu_c \approx \nu_+ + \nu_-$$

Motions amplitude can be manipulated with buffer gas and RF-excitation
- ✓ Dipolar to increase/decrease a motion
- ✓ Quadrupolar to convert one motion into another one

Three main purification/measurement techniques :
- **Buffer gas cooling**
- **ToF-ICR** (Time-of-Flight Ion-Cyclotron-Resonance)
- **PI-ICR** (Phase-Imaging Ion-Cyclotron-Resonance)





Beam purification with PIPERADE

Resolving power at DESIR:

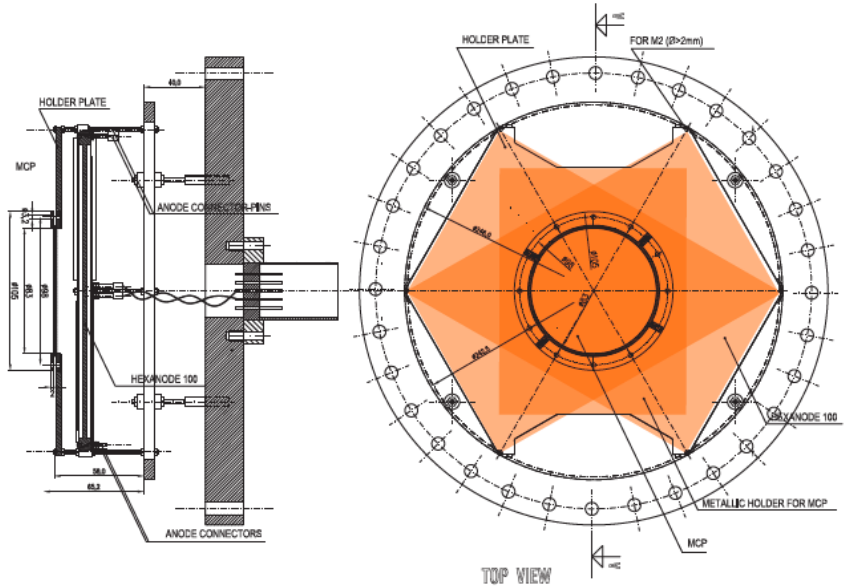
HRS — $\frac{M_0}{\Delta M} \sim 20\,000$ → Clean most of isobars

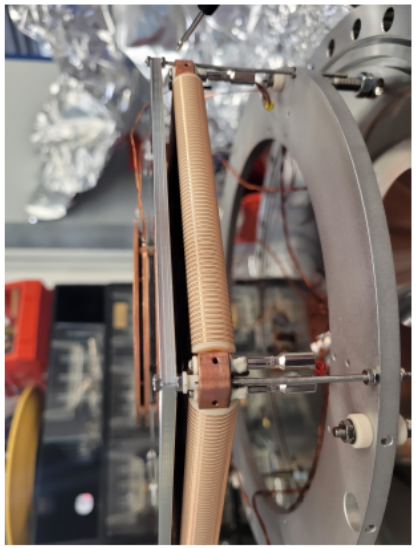
MR-ToF — $\frac{M_0}{\Delta M} \sim 10^5$ → Clean almost all isobars

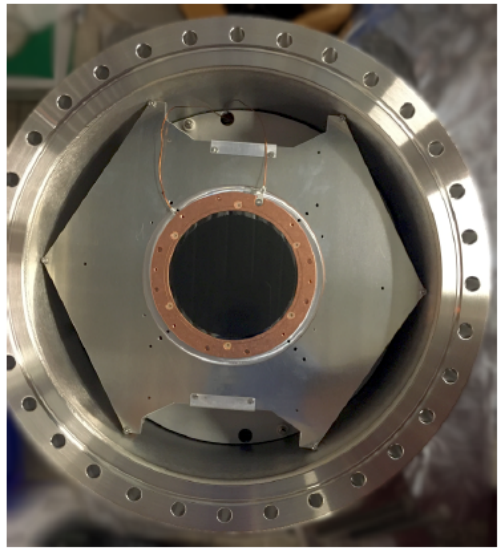
Piperade 1st trap — $\frac{M_0}{\Delta M} \sim 10^5$ → Clean almost all isobars

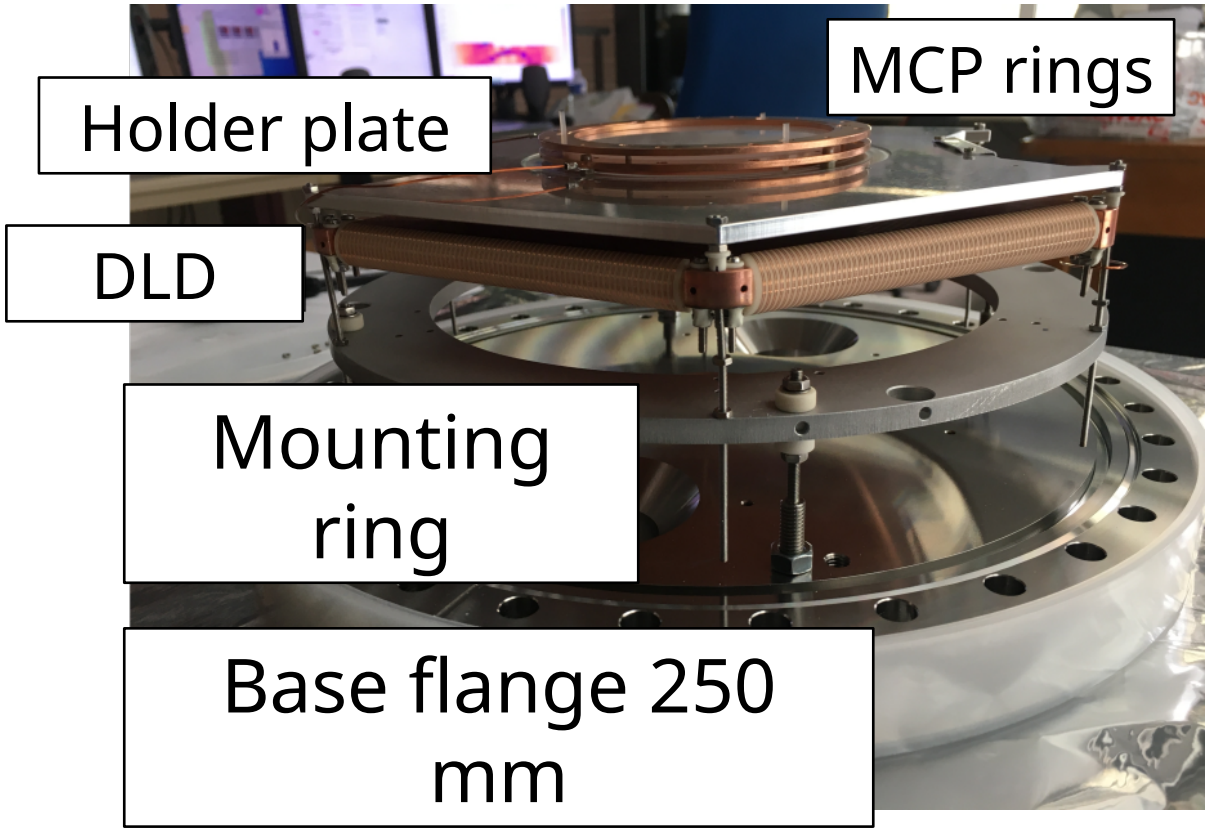
PIPERADE goal : purify 10^4-10^5 ions per bunch

Piperade 2nd trap — $\frac{M_0}{\Delta M} \sim 10^6 - 10^7 (expected)$ → Clean isomeric state separated by a few 10 keV





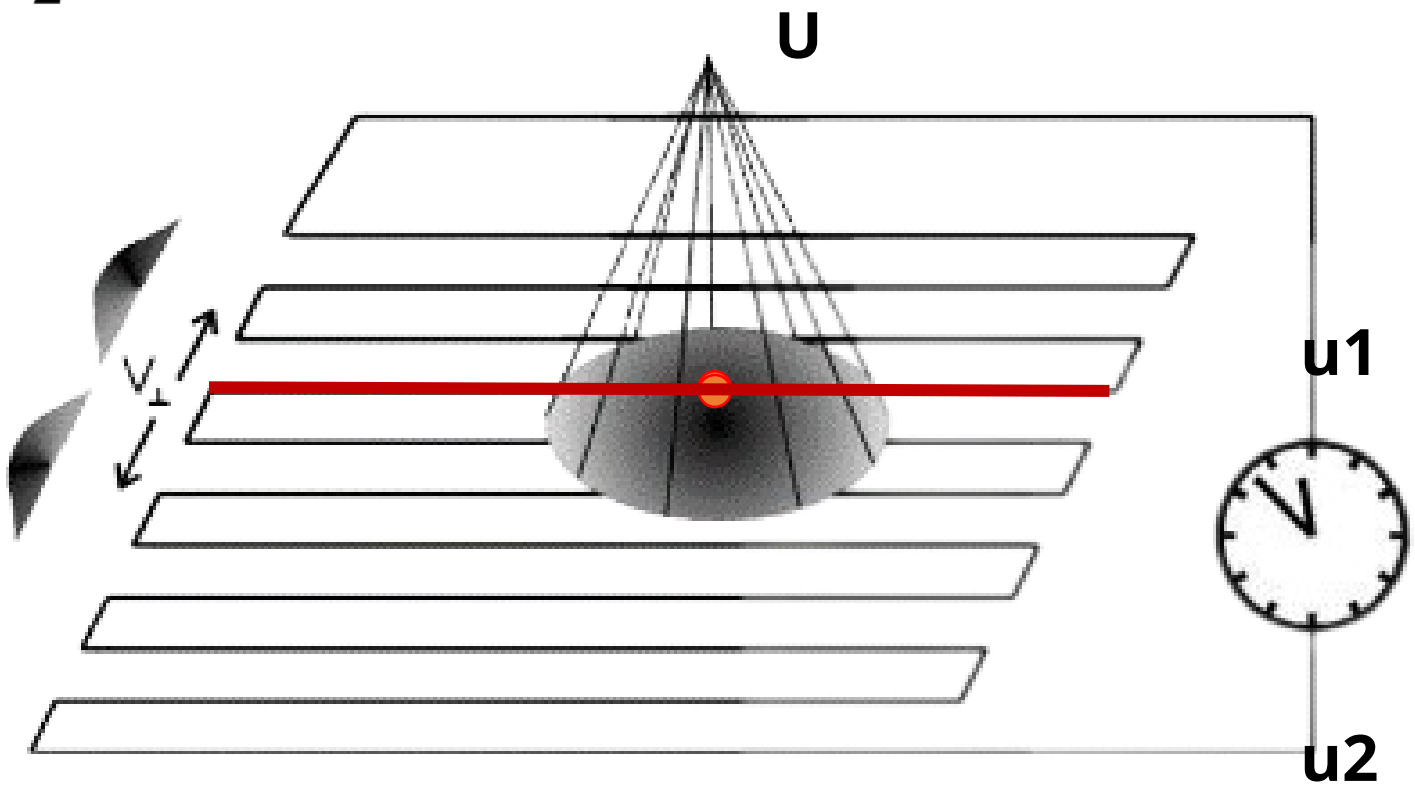




MCP active diameter	80 mm
Position resolution	<100 μm
Temporal resolution	<0.2 ns
Maximum rate	1 MHz
Multi-hit dead time	10 to 20 ns
Dark count rate	0.132 count/s

Voltage settings	
MCP front	−2400 V
MCP back	0 V
Delay-line anode Holder	0 V
Reference wires	250 V
Collecting (signal) wires	300 V

$$T_{sum} = u_1 + u_2 = c$$

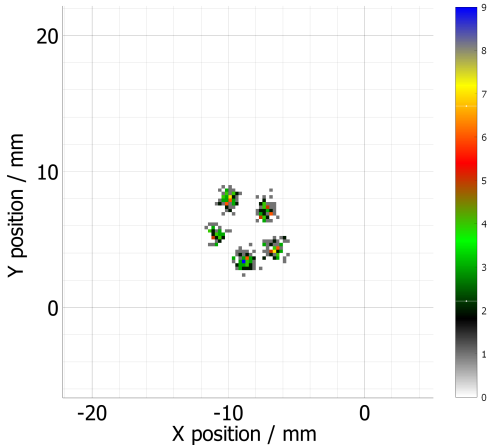


Multiple Hit Readout of a Microchannel Plate Detector With a Three-Layer Delay-Line Anode

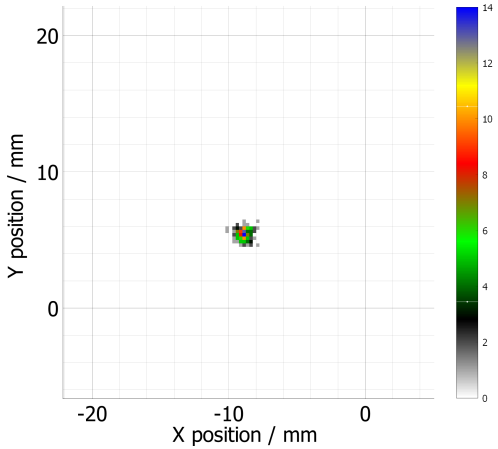
Isometric view

PI-ICR at PIPERADE

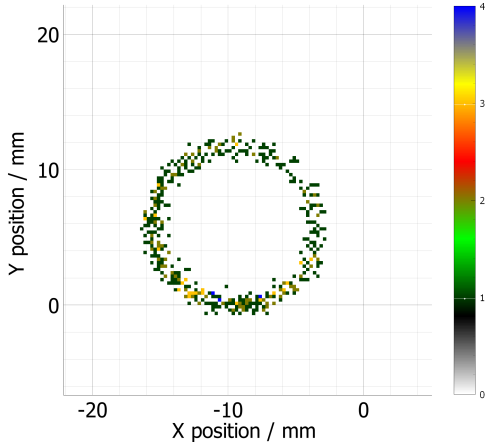
Initial conditions



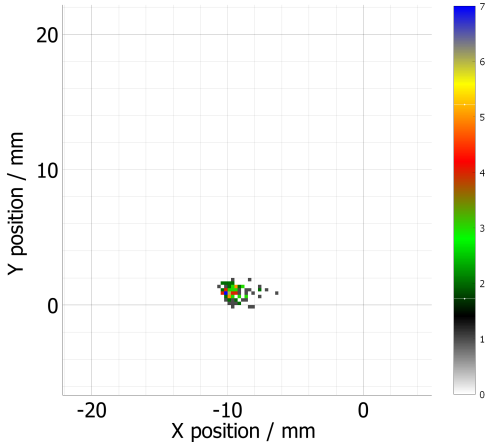
Magnetron damping

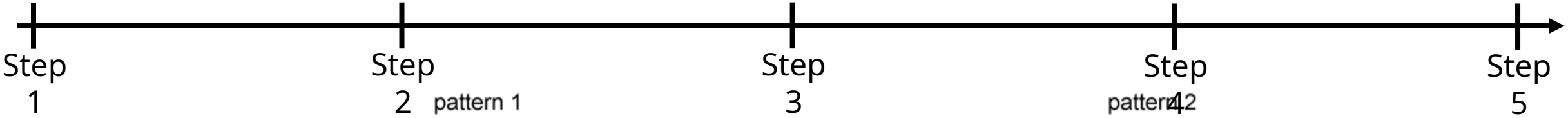


ν_+ excitation

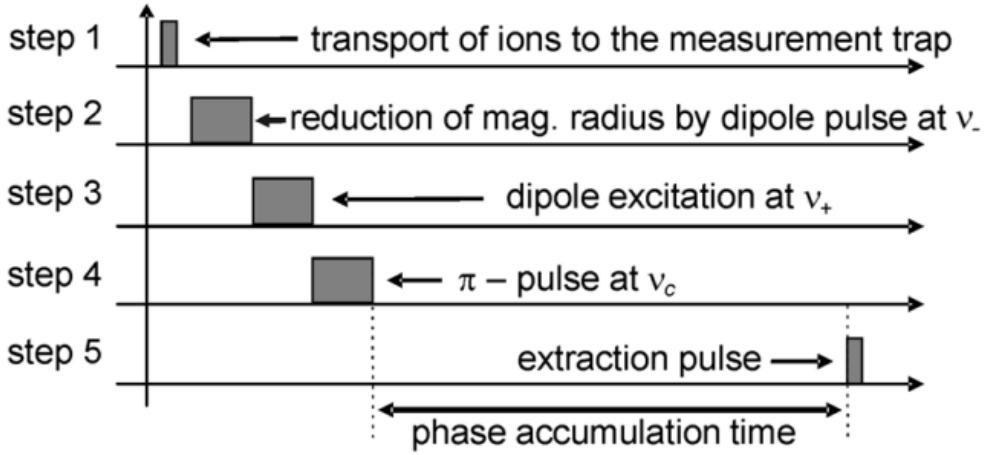


Conversion magnetron

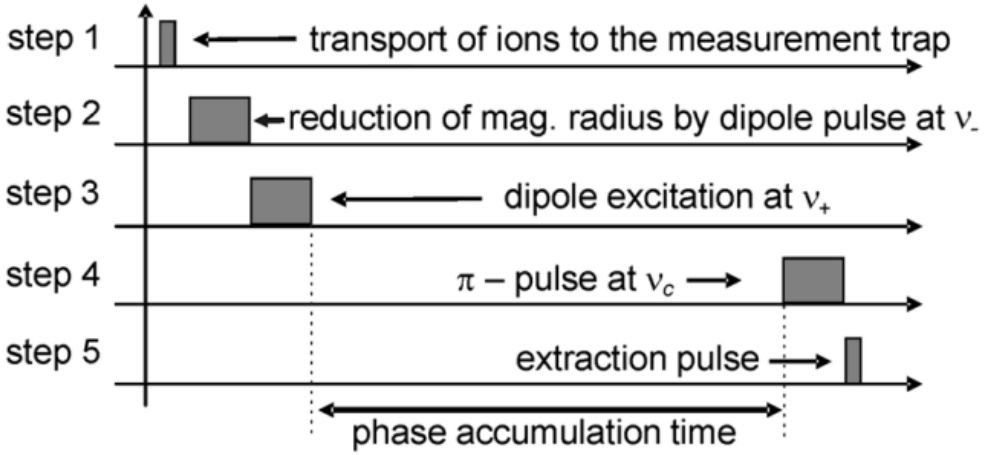




pattern 1



pattern 2



*Eliseev, S et al. Appl. Phys. B **114** (2014) 107–128*

Magnetic field fluctuations