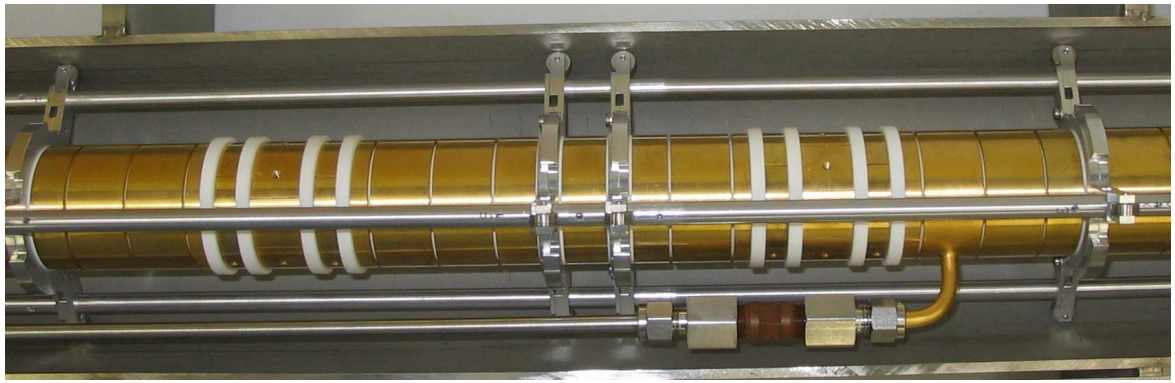


MLLTRAP : un spectromètre de masse à base de pièges de Penning

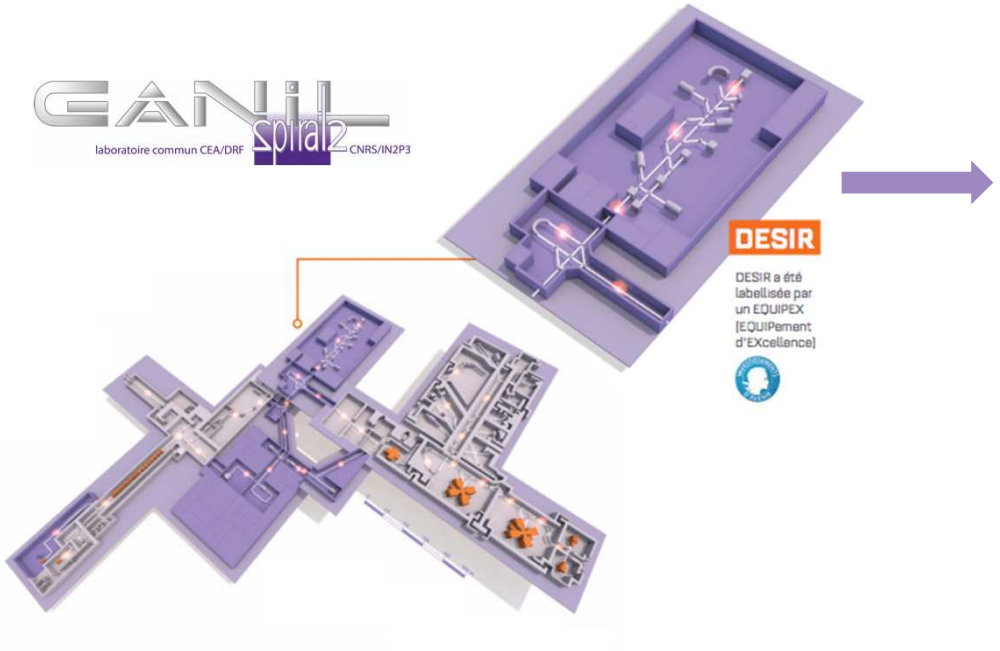
Enrique Minaya Ramirez

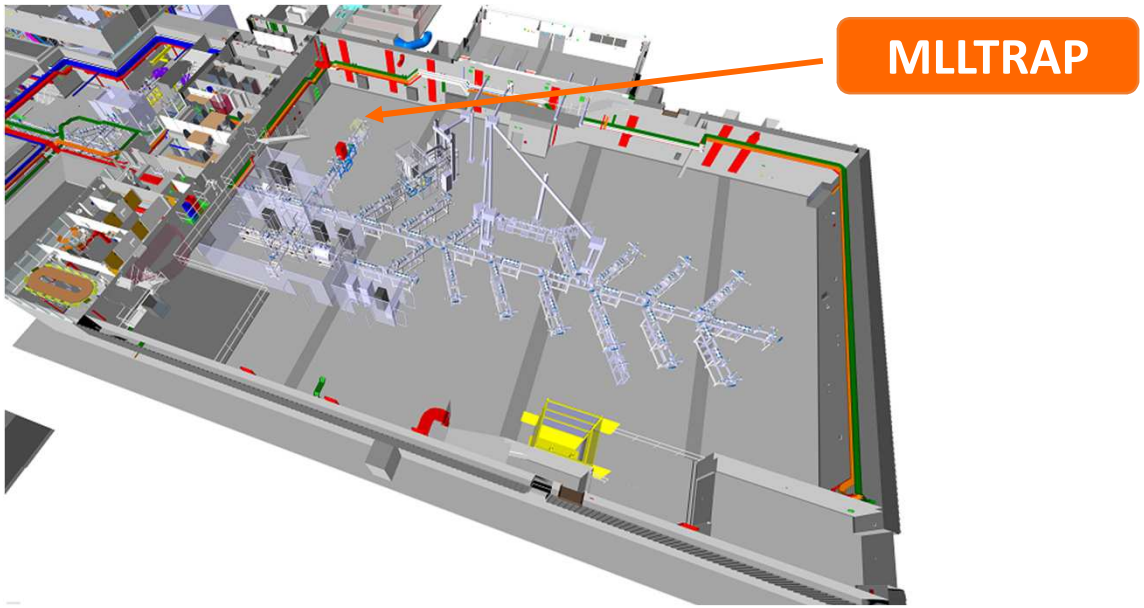
IJCLAB

MLLTRAP project in France

MLLTRAP → Spiral2 DESIR

Framework : "adaptation of experimental devices for their use with DESIR"



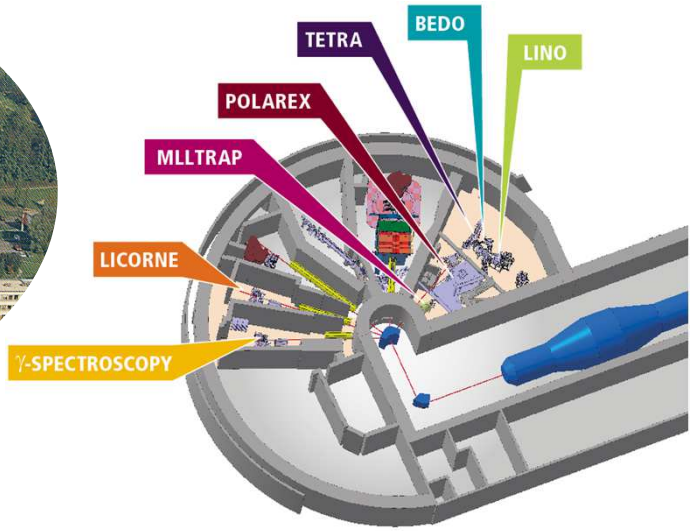


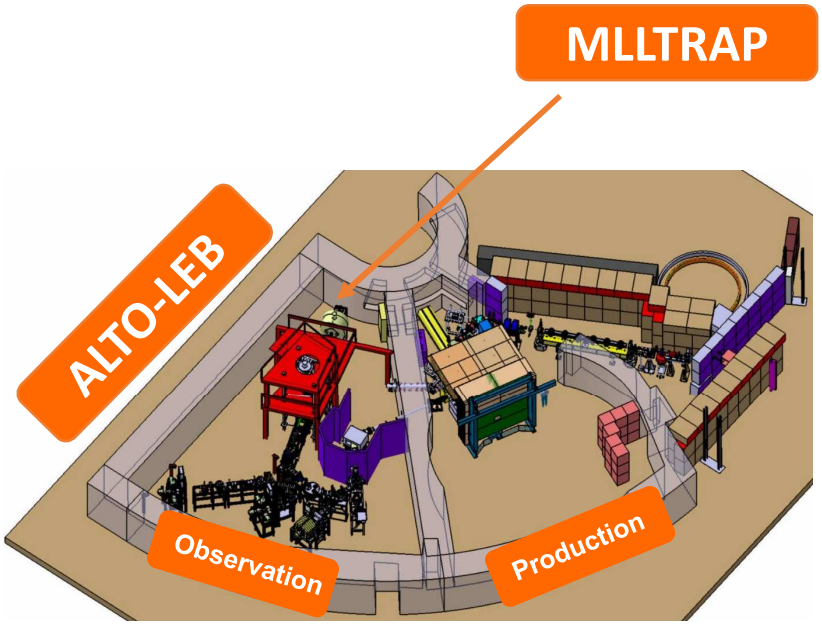
MLLTRAP project in France

MLLTRAP → Spiral2 DESIR

Framework : "adaptation of experimental devices for their use with DESIR"

2016 - 2026 : Commissioning and upgrade of MLLTRAP + mass measurement campaign @ ALTO





MLLTRAP project in France

MLLTRAP → Spiral2 DESIR

Framework : "adaptation of experimental devices for their use with DESIR"

2016 - 2026 : Commissioning and upgrade of MLLTRAP + mass measurement campaign @ ALTO

2016 P2IO Physique des 2 Infinis et des Origines — Investissements d'avenir

"Charting Terra Incognita of Exotic Nuclei"

2017 Région îledeFrance — SESAME

"Reaching Terra Incognita of Exotic Nuclei"

People involved at IJCLab from

Scientific poles : Accelerator and Nuclear Physics :
E. Minaya Ramirez, A. Leite, L. Perrot, S. Franchoo, A.Lopez-Martens, V. Manea, D. Lunney

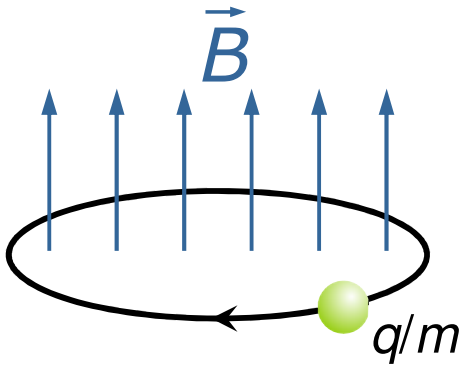
Engineering pole : Mechanical engineering :
H. Ramarijaona Ny Aina, B. Geoffroy

Platform : ALTO :
A. Said, S. Semsoum, E. Borg, A. Bouafia, F. Debray, F. Fahy, S. Jourdain, F. Lemaitre

Postdocs : P. Chauveau (2017-2019)
PhD students : E. Morin (2019 – 2022) / S. Morard (2022 – 2025)

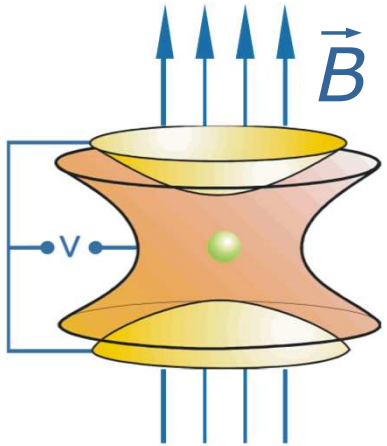
MLLTRAP : double Penning trap mass spectrometer

Strong homogeneous magnetic field (B)

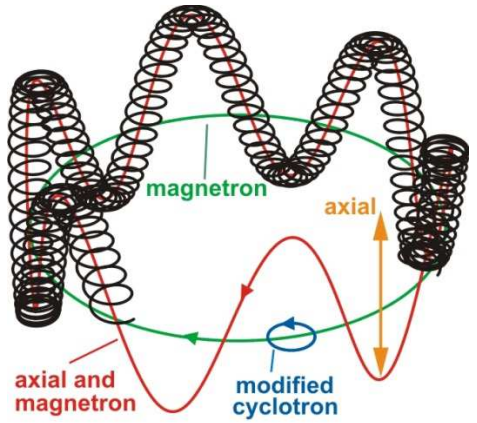


+

weak electrostatic field (V)



Ion motion



ν_+ : reduced cyclotron

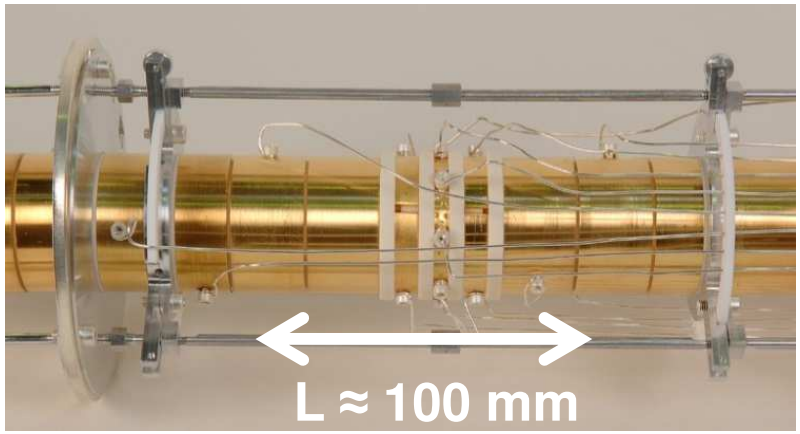
ν_- : Magnetron

ν_Z : Axial

Cyclotron frequency

$$\nu_c = \sqrt{\nu_+^2 + \nu_z^2 + \nu_-^2}$$

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

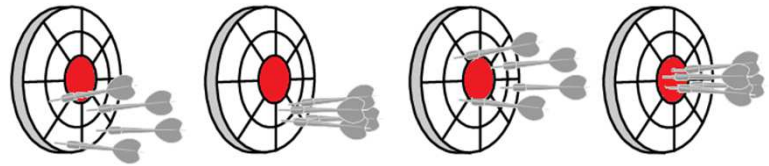


Penning trap mass spectrometers at radioactive ion beam facilities

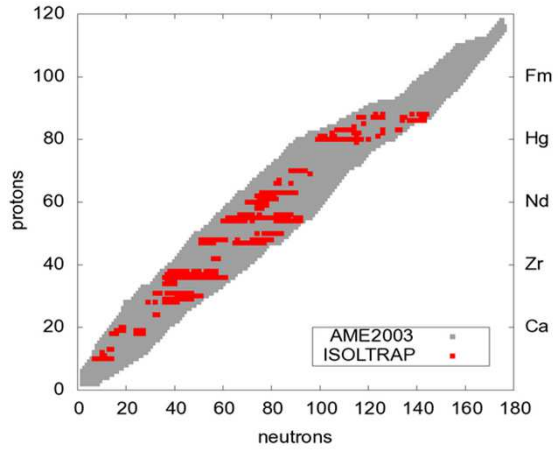
Name	Year	Location	Facility	Reaction(s)
ISOLTRAP	1987–present	ISOLDE, CERN	ISOL	Spallation, fission
CPT	1998–2009	ATLAS, ANL	In-flight	Transfer, fusion–evaporation
CPT	2009–present	CARIBU, ANL	ISOL	^{252}Cf fission
SHIPTRAP	2004–present	SHIP, GSI	In-flight	Fusion–evaporation
JYFLTRAP	2004–present	JYFL, Jyväskylä	IGISOL	Various
LEBIT	2005–present	NSCL, MSU	In-flight	Fragmentation
TITAN	2007–present	ISAC, TRIUMF	ISOL	Spallation, fission
TRIGATRAP	2017–present	TRIGA, Mainz	Reactor	Fission

→The year of operation starts with the first mass measurement of a radioactive ion

J. Dilling et al., Annu. Rev. Nucl. Part. Sci. 68 (2018) 45



- Relative uncertainty ≈ 10^{-8}
- Accessible half-lives > 10 ms
- Typical Resolving power ≈ 10^{7}



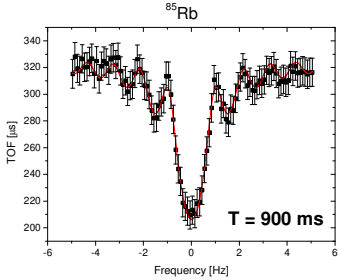
MLLTRAP @ ALTO

MLL Maier-Leibnitz-Laboratorium für Kern-, Teilchen- & Beschleunigerphysik

LMU

Peter G. Thirolf , Christine Weber et al.

2009 → Off-line commissioning



f_c=1266324.354 Hz

V.S. Kolhinen, et al., NIMA A 600 (2009) 391

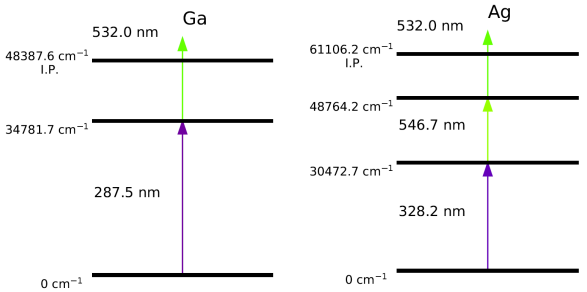
The truck left MLL the **14th of July 2016**

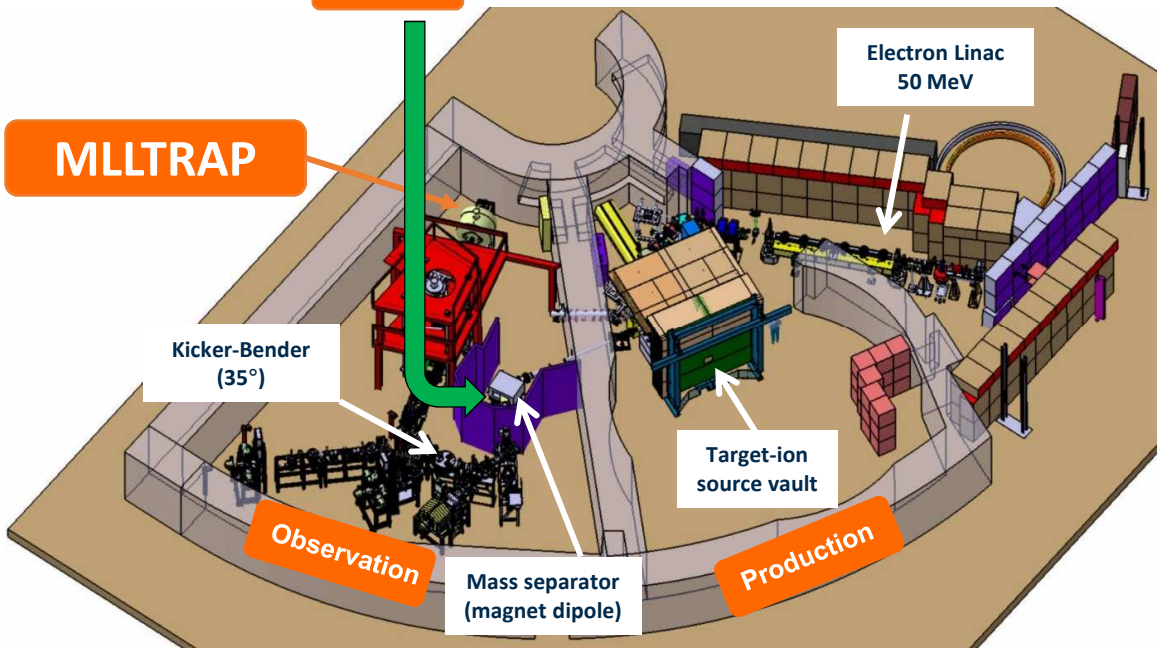
New area rehabilitated

7 T superconducting magnet with 2 homogenous regions
→Energized in November 2017 @ ALTO-LEB

MLLTRAP @ ALTO-LEB

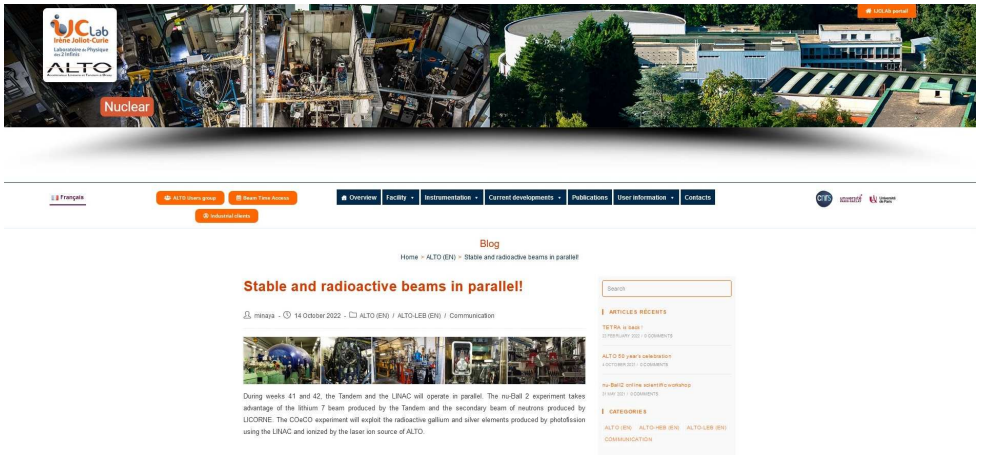
RIALTO





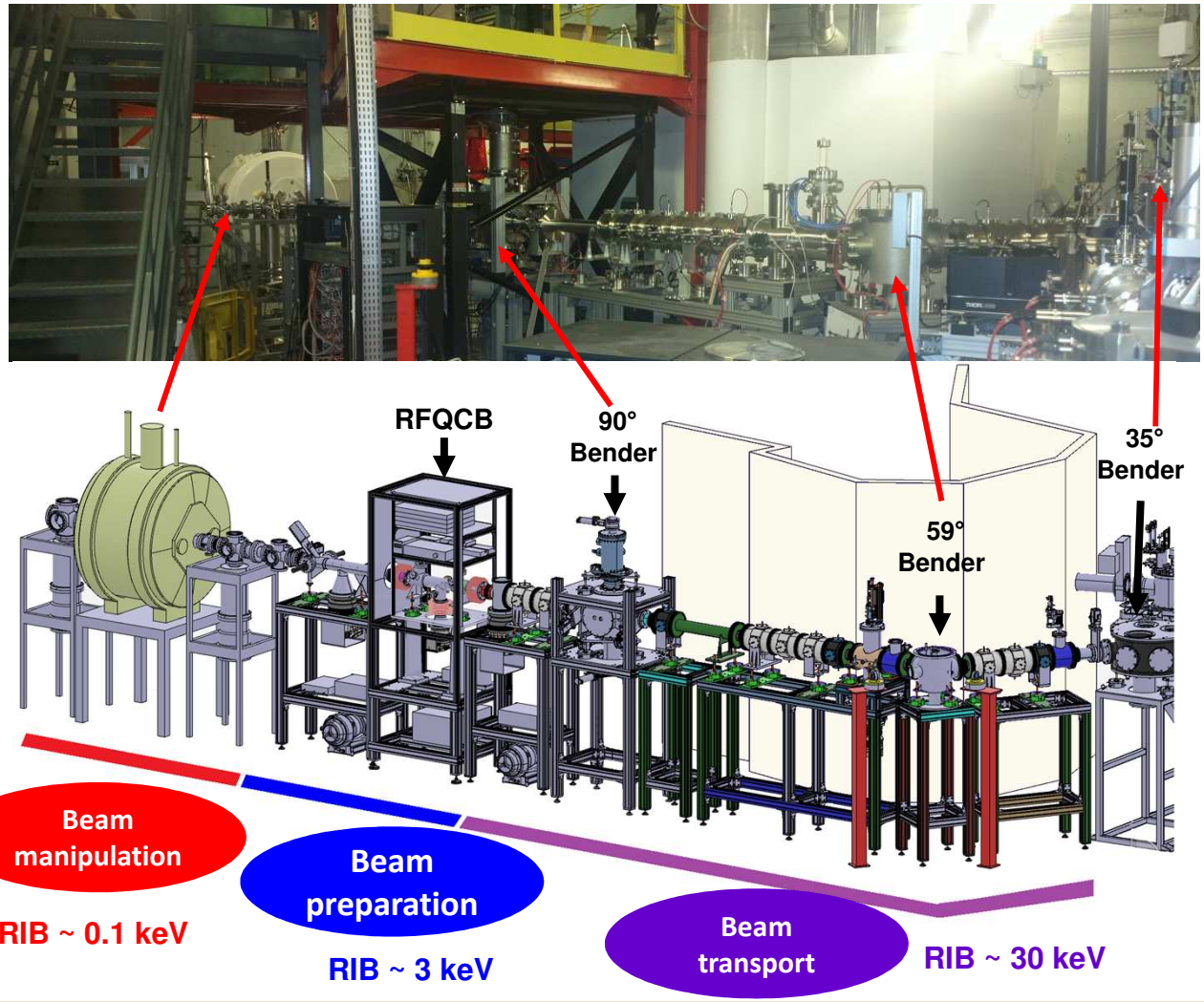
First operational RIB facility based on photo-fission → populating the GDR of ^{238}U(~10^{11} f/s)

- **50 MeV** & **10 µA** e^- beam
- UCx target (~70g, ~140 pellets)
- Magnetic dipole PARRNe → **A** selection (M/ΔM = 1500)
- **RIALTO : laser source** → **Z** selection of elements

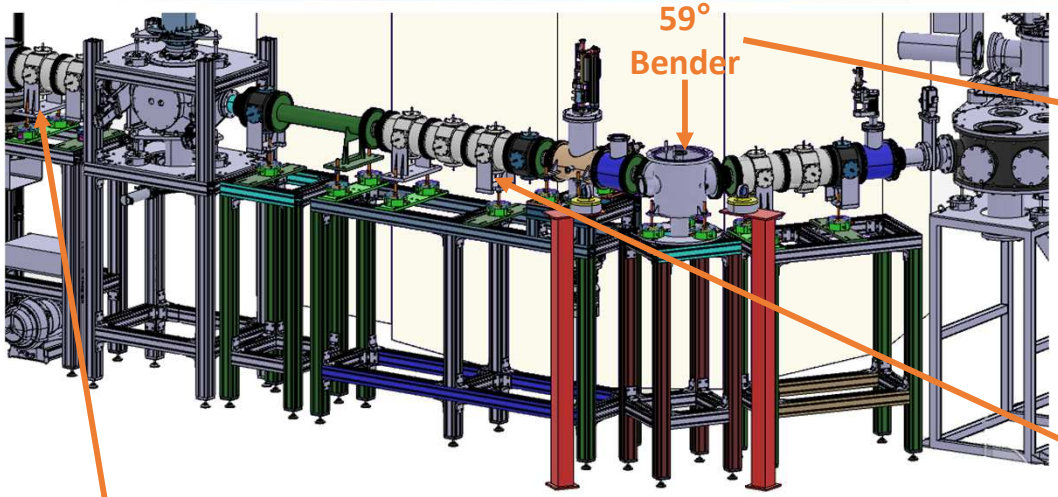


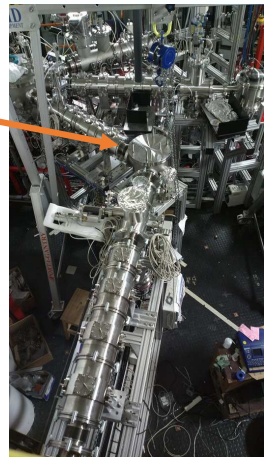
https://alto.ijclab.in2p3.fr/

MLLTRAP @ ALTO-LEB



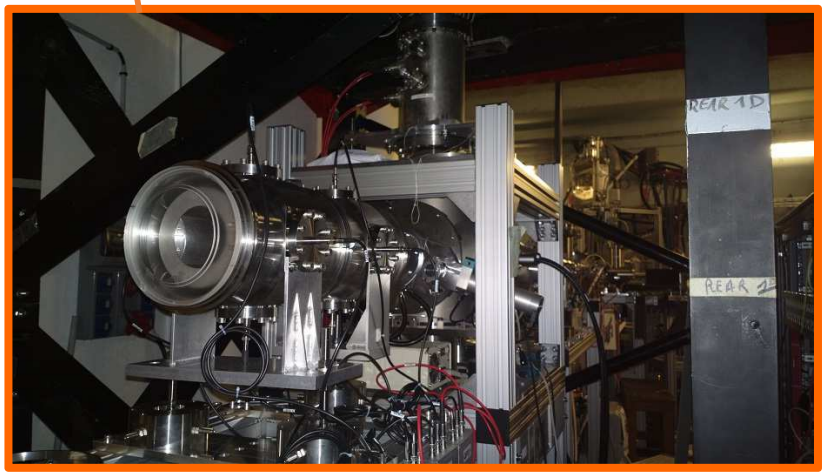
MLLTRAP @ ALTO-LEB : Beam transport





Beam transport

- Vacuum tested
- Control system ready

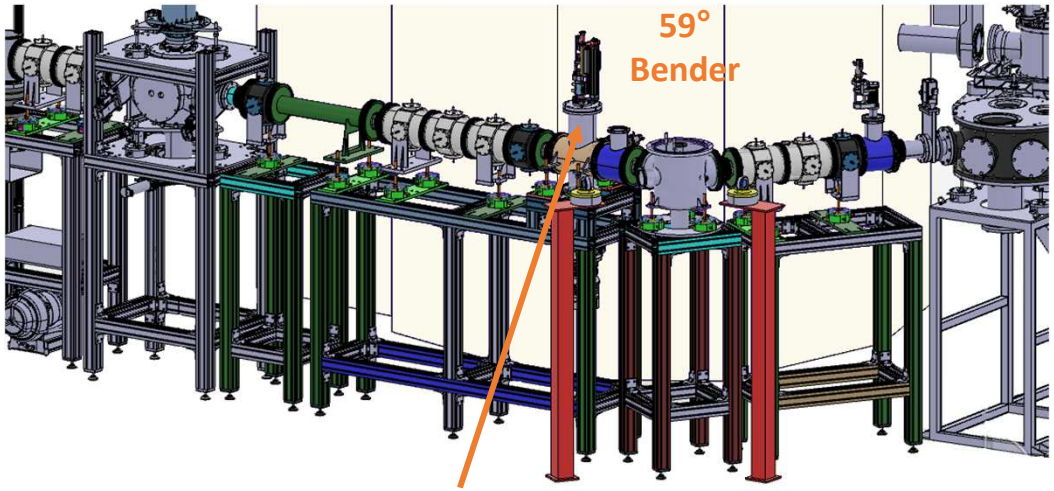


- X-Y steerers
- Electrostatics Quadrupoles

→ Based on DESIR beamlines

2022

MLLTRAP @ ALTO-LEB : Beam transport



Beam transport

Beam profile monitor from

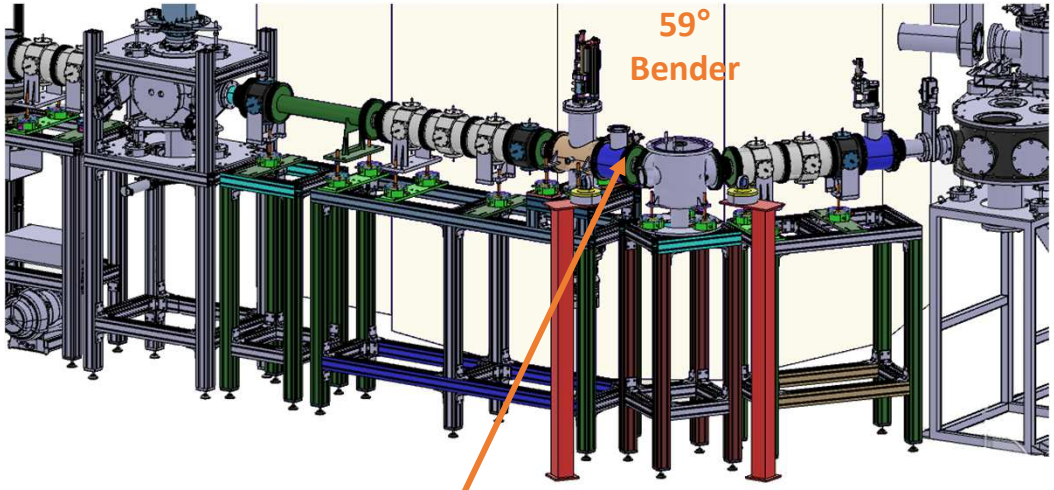
PANTECHNIK
Boost Your Physics

Profiler and actuator

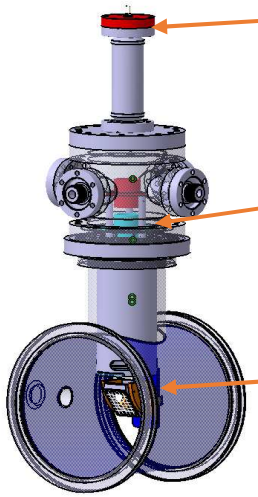
Electronic Rack 3U - 84F

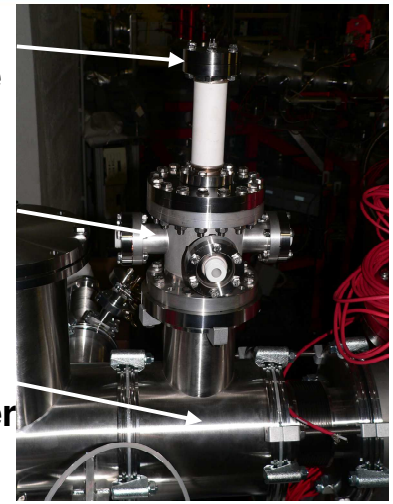
Secondary Emission Monitor (SEM) for multi-plane ion beam profile measurement (delivery expected in November 2022 → May 2023)

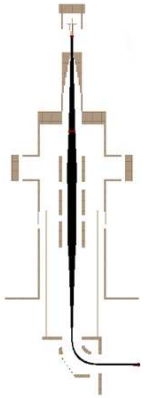
MLLTRAP @ ALTO-LEB : Beam transport

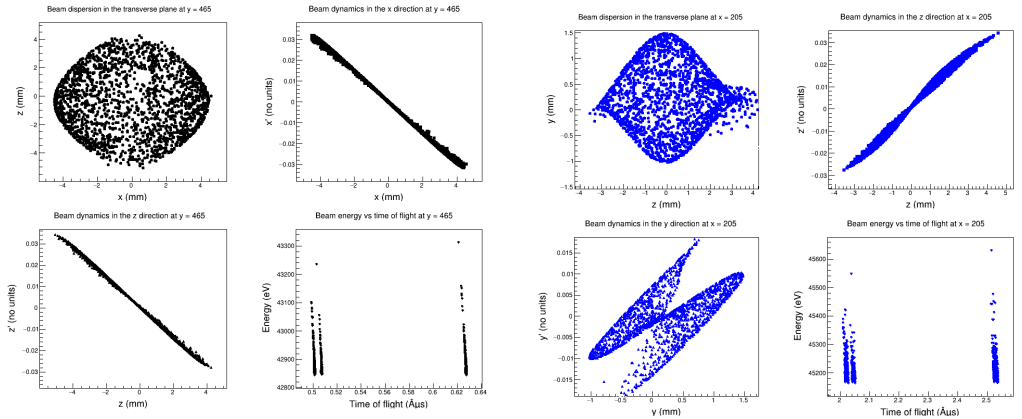


High voltage ion source



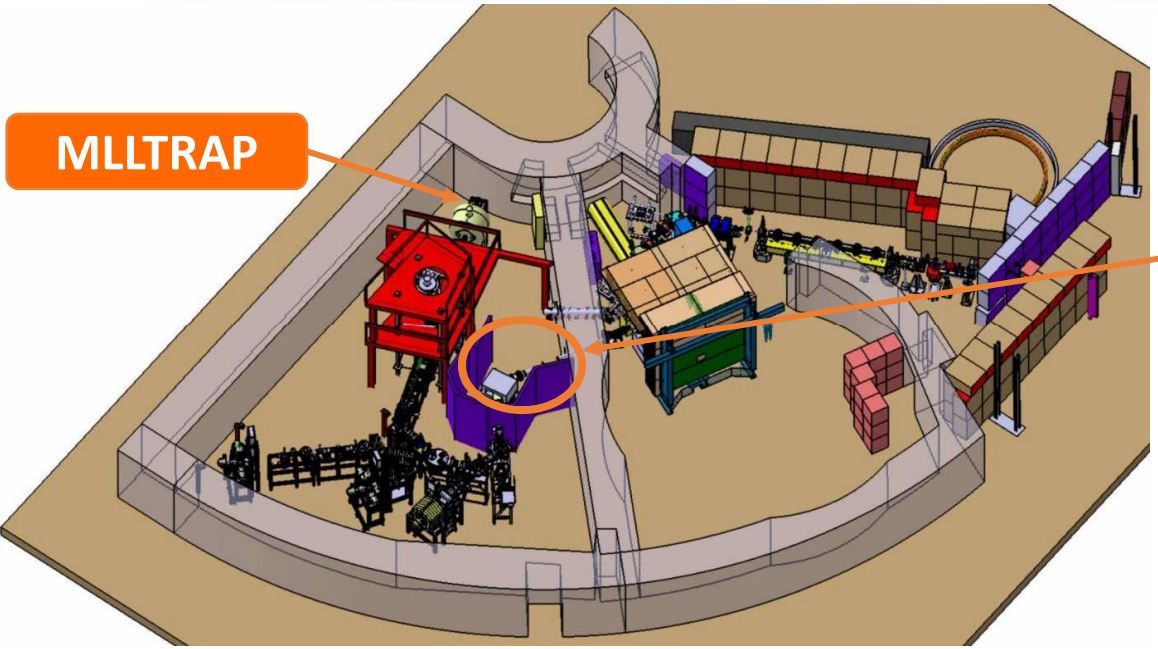


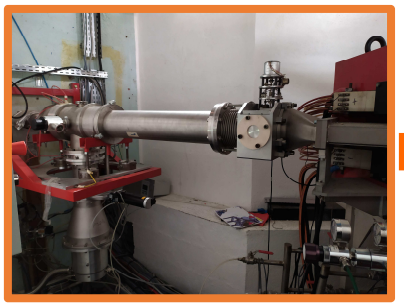




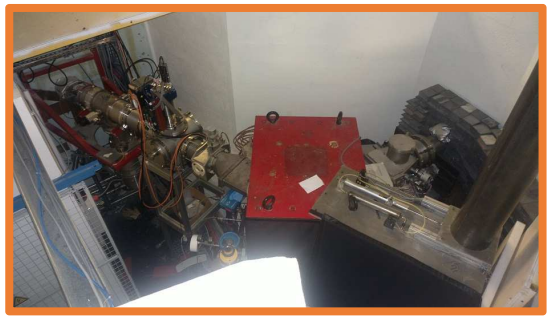
Simulation covered a large energy range : 1, 10, 30 and 50 kV were validated

MLLTRAP @ ALTO-LEB : Beam transport

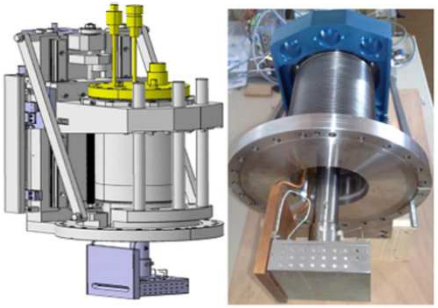


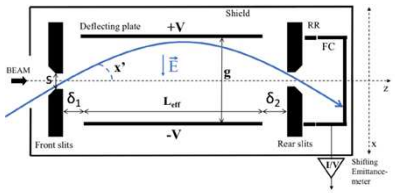


June 2022



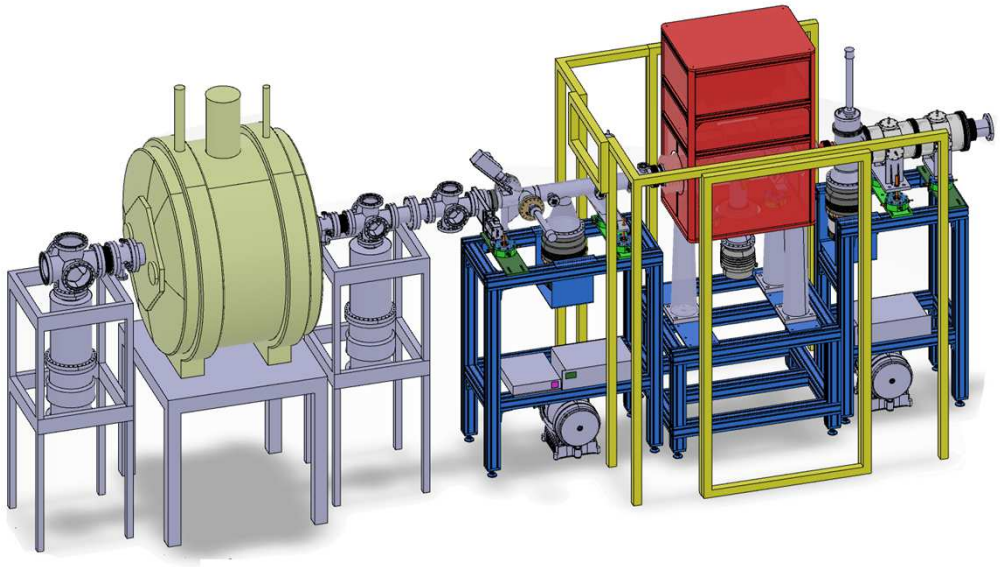
Emittance meter from

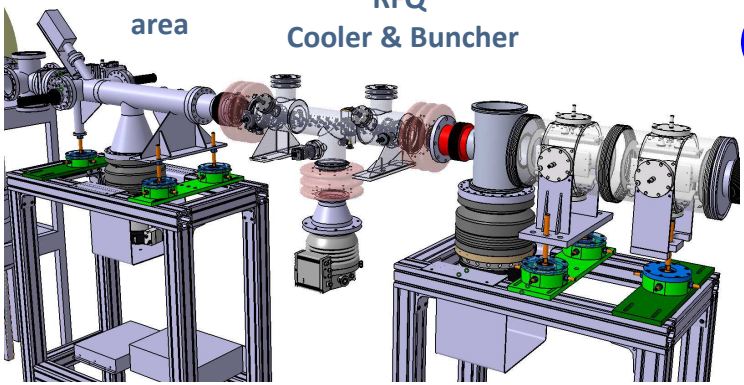




E. Bouquerel and C. Maazouzi JINST 16 (2021) T06009

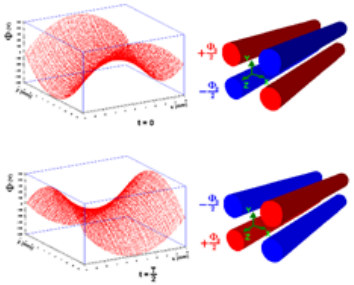
MLLTRAP @ ALTO-LEB : Beam preparation



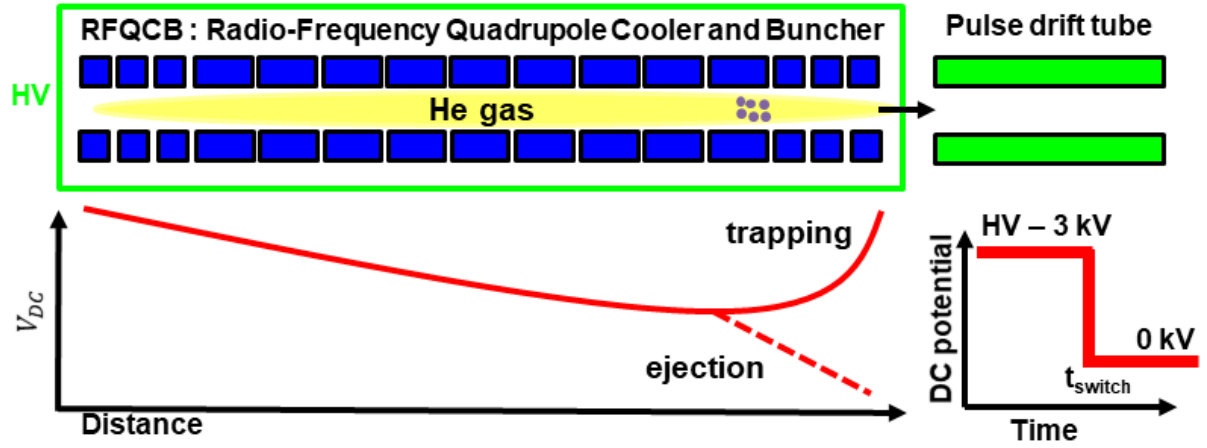


Beam preparation

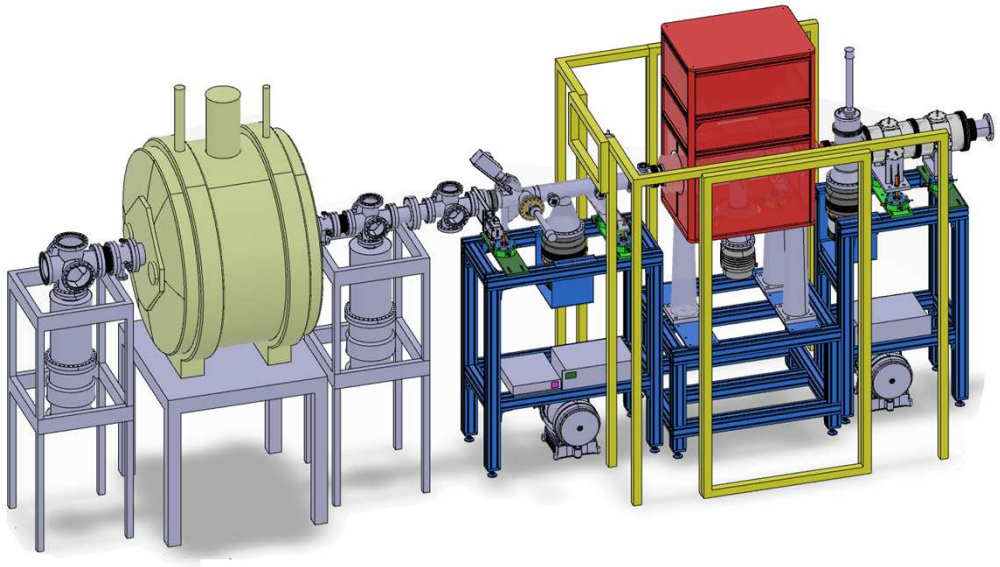
Paul trap

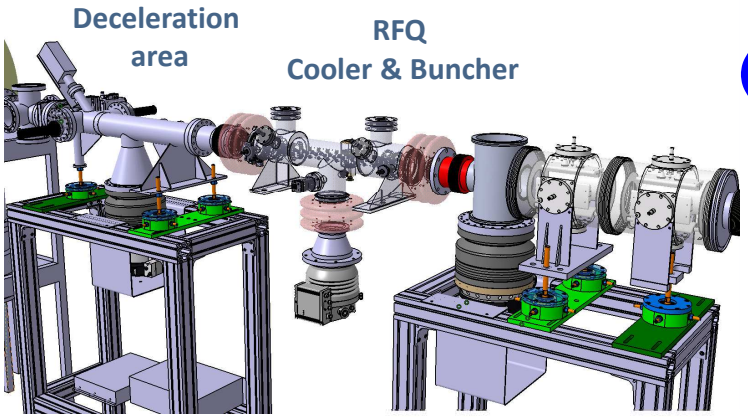


$$\Phi_0(t) = V_{DC} - V_{RF}\cos\Omega t$$

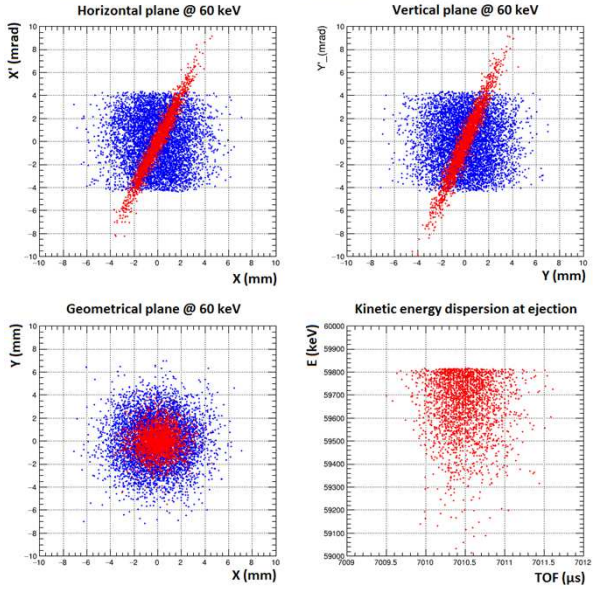


MLLTRAP @ ALTO-LEB : Beam preparation





Beam preparation

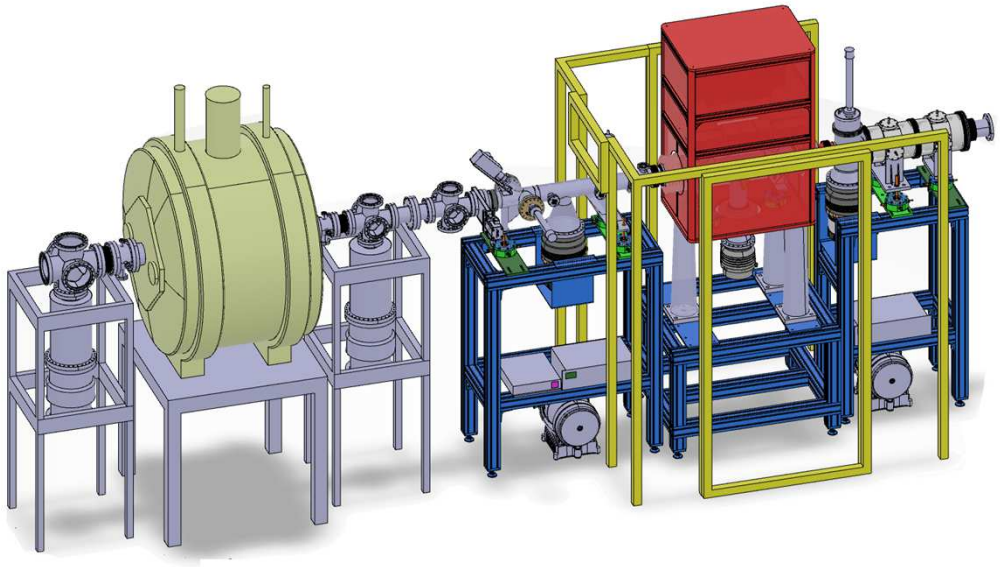


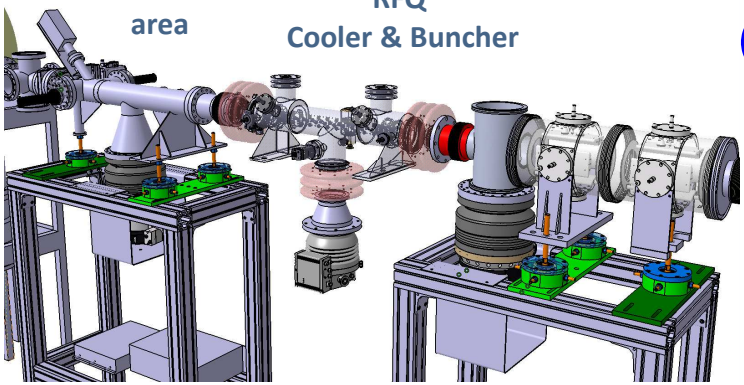
SIMION simulations at the injection point (blue color) and after having been cooled and bunched (in red).

Emittance at injection ~ 20 π.mm.mrad and ~ 3 π.mm.mrad at ejection, both at 60keV.

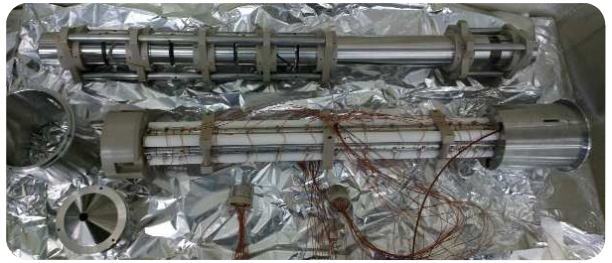
E. Minaya Ramirez et al., Nucl. Instr. Meth. B 463 (2020) 315

MLLTRAP @ ALTO-LEB : Beam preparation





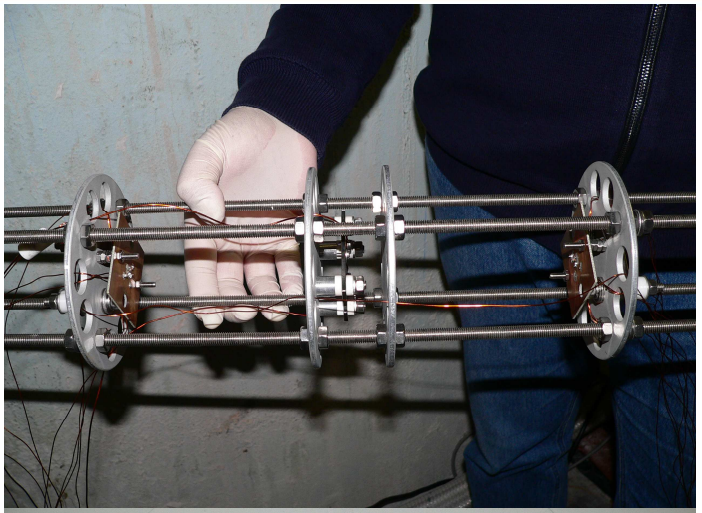
Beam preparation

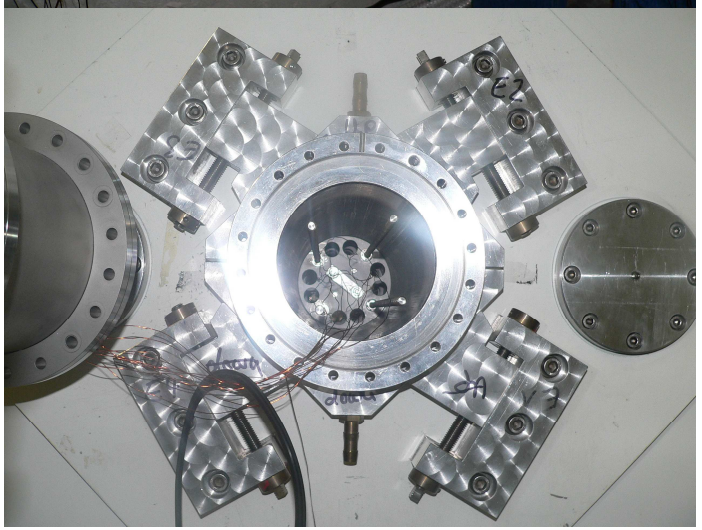


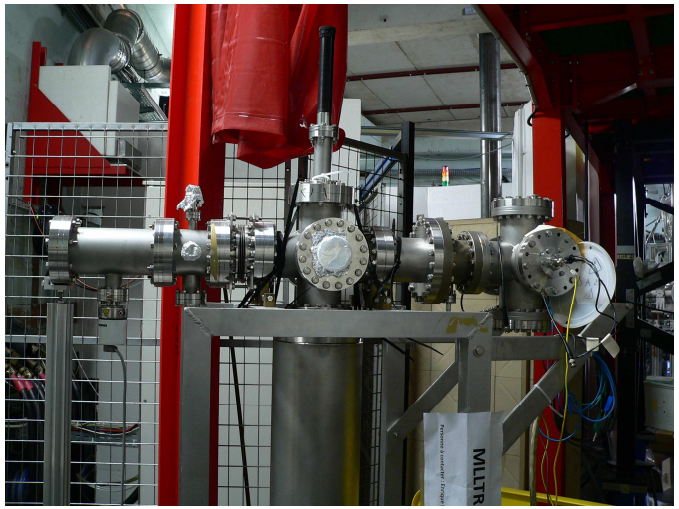
- Electronics and pumping material received with a large delay.
- All the mechanical parts have been delivered. The assembly of the different parts are in progress.
- The alignment of the supports are currently in progress at ALTO

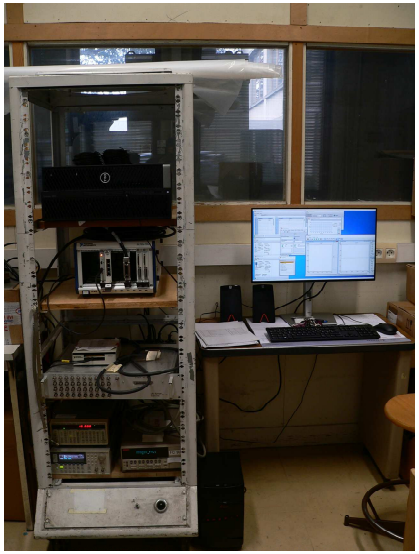
MLLTRAP @ ALTO-LEB : Beam manipulation

- Alignment of the vacuum tube axis with magnetic field lines was impacted by the installation and validation of the magnetic probe. The alignment is now finished (misalignment angle : 1.1 ± 0.1 mrad)
- Bender, injection electrodes and diagnostic system (faraday cup and microchannel plate) operational (tested with an alkali ion source).
- Upgrade of the control system in progress. Coupled with the installation of the MCP delay line (for PI-ICR).
- Installation of Penning traps in progress.





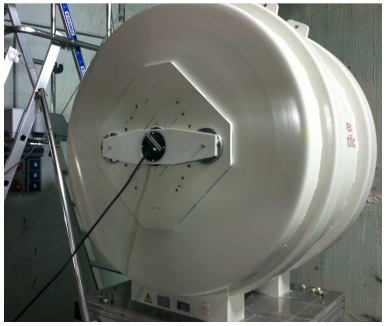


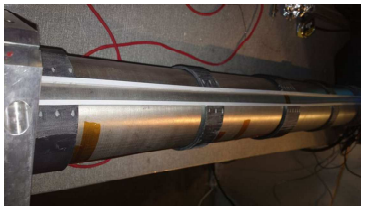


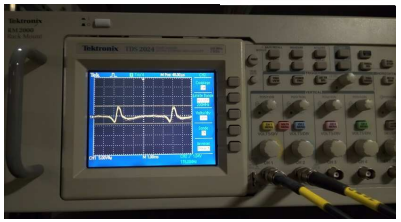
MLLTRAP @ ALTO – Beam manipulation

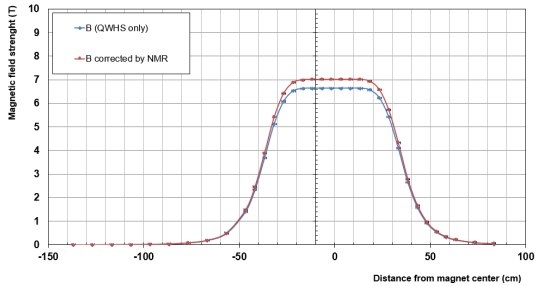
- **Probe developed by Caylar to track magnetic field evolution in real time.**
- **Probe located in the gap between bore's magnet and the vacuum tube.**
  → non-linear field drifts during long measurements

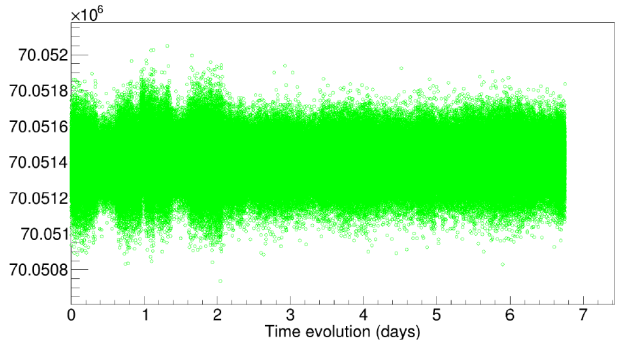
Beam manipulation





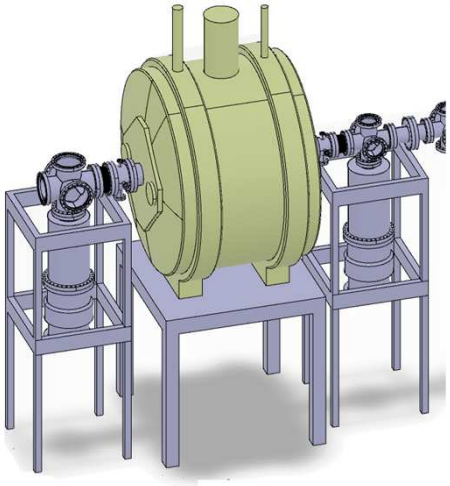


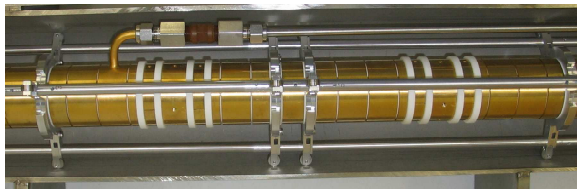


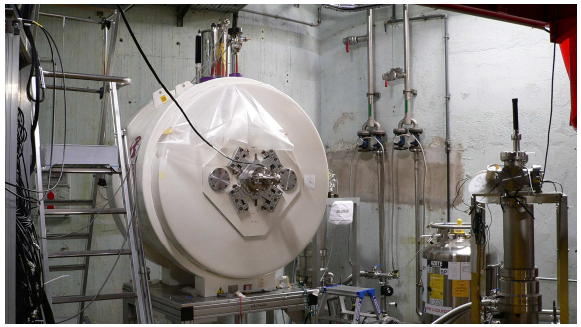


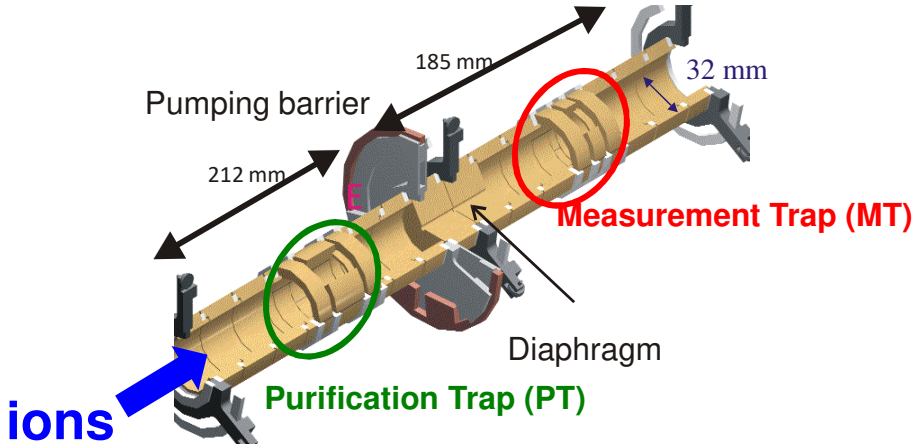
- First probe developed between (2018-2019) → miniaturized probe validated in September 2020.
- Coupled to the bore temperature. Currently 10^{-7} precision.

MLLTRAP @ ALTO-LEB : Beam manipulation

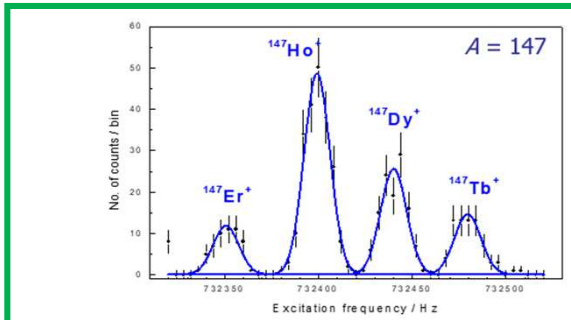




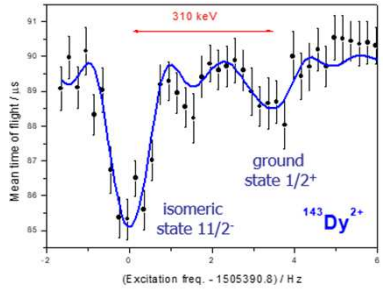




Beam manipulation



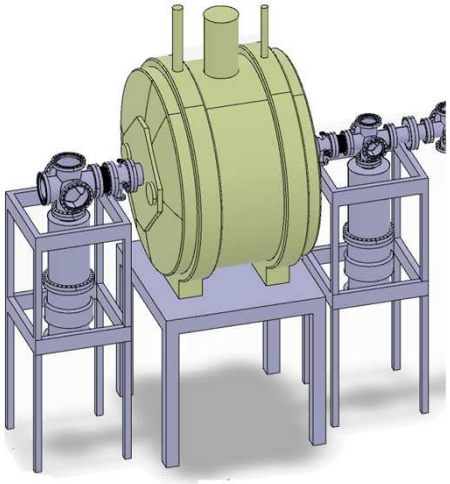
Mass resolving power of 100 000
→ separation of isobars

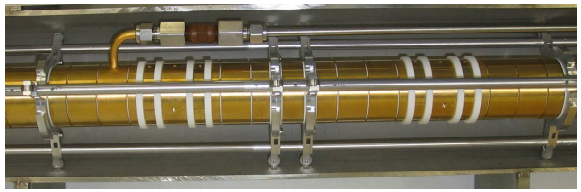


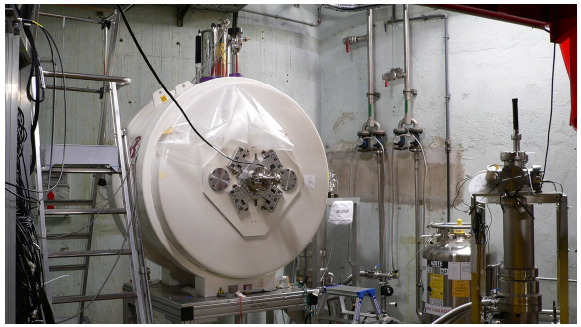
Mass resolving power of 1 000 000
→ separation of isomers

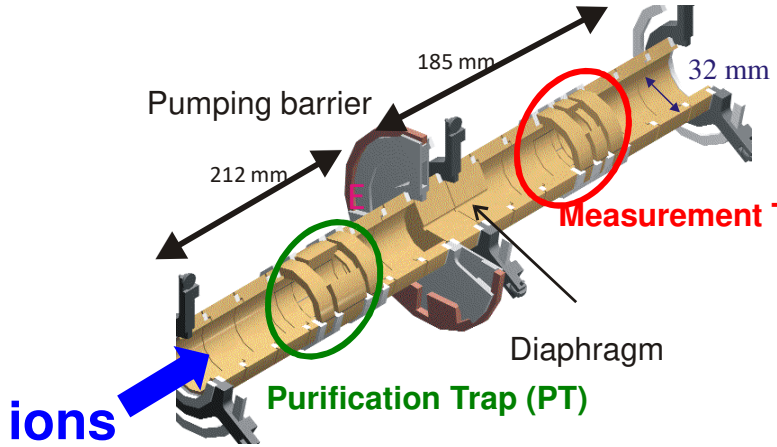
Time of Flight Ion-Cyclotron-Resonance (TOF-ICR)

MLLTRAP @ ALTO-LEB : Beam manipulation

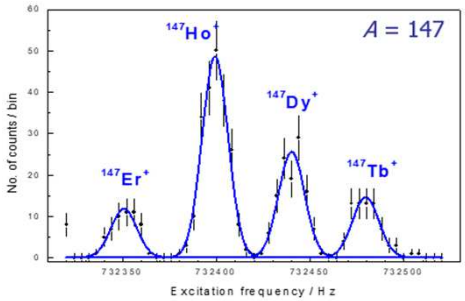




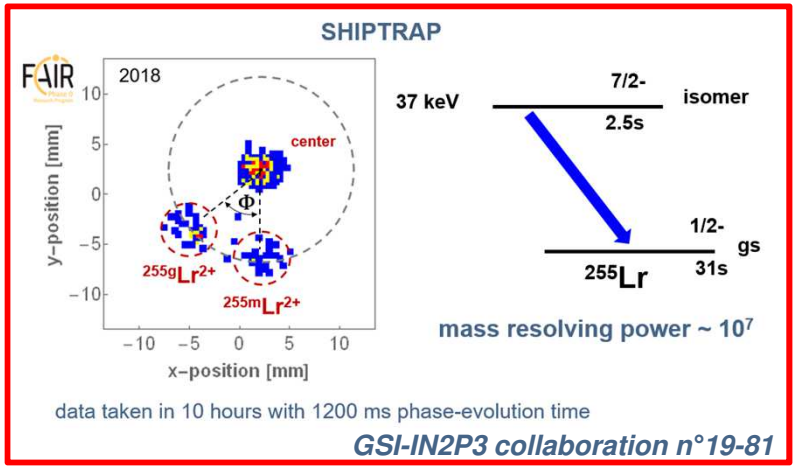




Beam manipulation



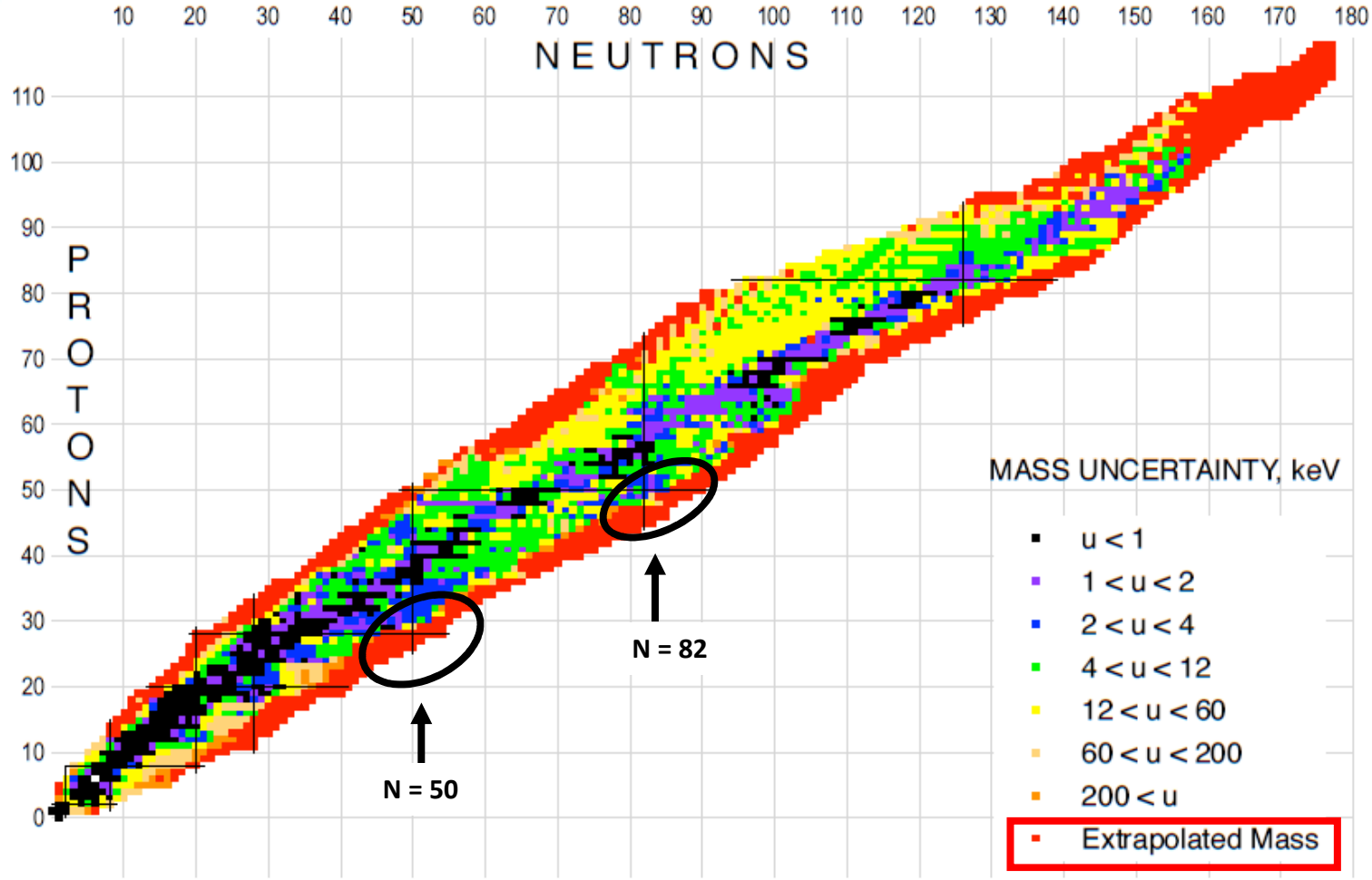
Mass resolving power of 100 000
→ separation of isobars



Phase Imaging Ion-Cyclotron-Resonance (PI-ICR)

$$\varphi + 2\pi n = 2\pi\nu t \qquad \Delta\nu = \frac{\Delta\varphi}{2\pi t} = \frac{\Delta R}{\pi t R}$$

High-precision mass measurements at ALTO



AME (Atomic Mass Evaluation)

F.G. Kondev et al, Chinese Phys. C 45 (2021) 030001

Study of *N* = 82 shell closure with silver isotopes at ALTO

^{118}Ag	^{119}Ag	^{120}Ag	^{121}Ag	^{122}Ag	^{123}Ag	^{124}Ag	^{125}Ag	^{126}Ag	^{127}Ag	^{128}Ag	^{129}Ag
2.5	15	4	12	40	30	250	430	200#	200#	300#	400#

Nuclear astrophysics

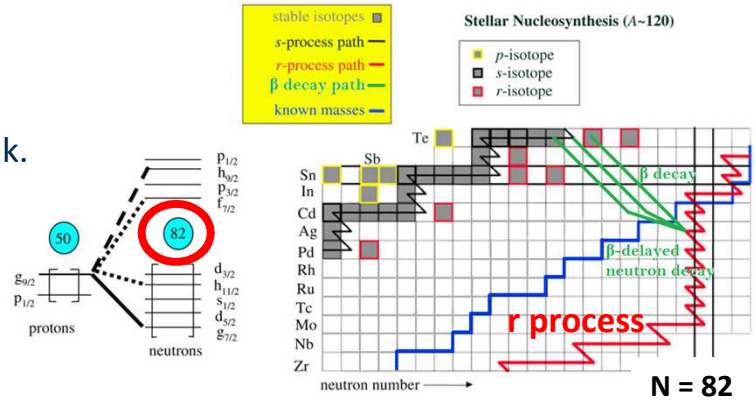
Inputs for r-process path evolution models

N = 82 could be linked to A = 130 abundance peak.

Nuclear structure

- Evolution of S2n.
- Shell gaps evolution.

MASS ACCURACY (keV)
- u < 1
- 1 ≤ u < 2
- 2 ≤ u < 4
- 4 ≤ u < 12
- 12 ≤ u < 60
- 60 ≤ u < 200
- 200 ≤ u
- Extrapolated Mass

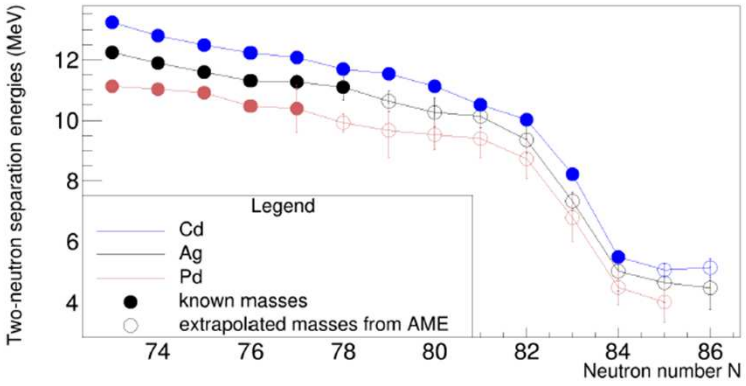


N = 82

Important nuclei from sensitivity studies

***ISOLTRAP** : V. Manea et al., Phys. Rev. Lett. 124 (2020) 092502*

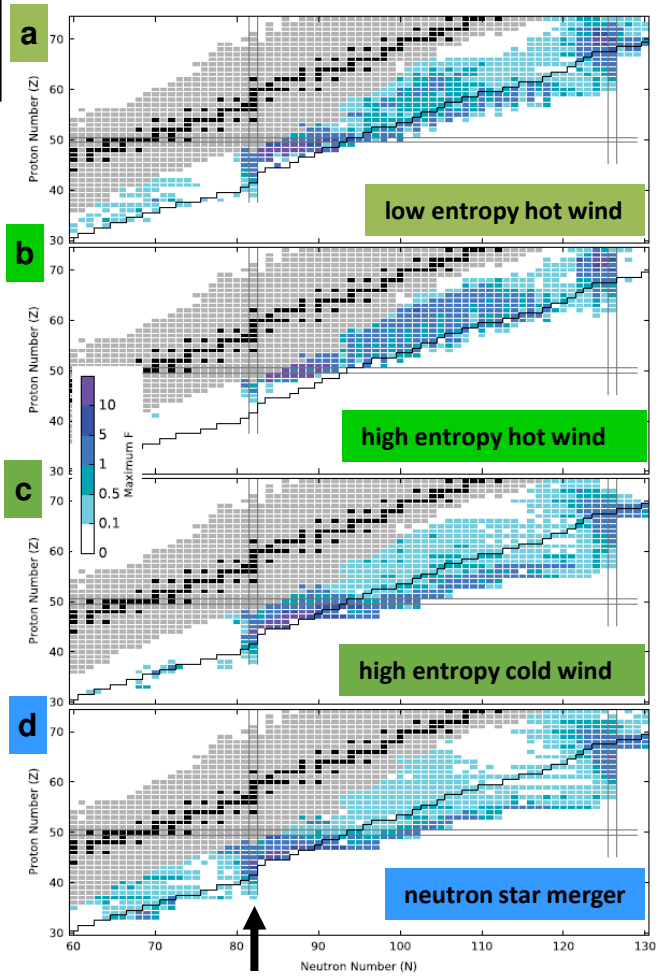
***JYFLTRAP :** A. Kankainen et al., Hyperfine Interact. 241 (2020) 43*



Nuclear mass (silver isotopes)

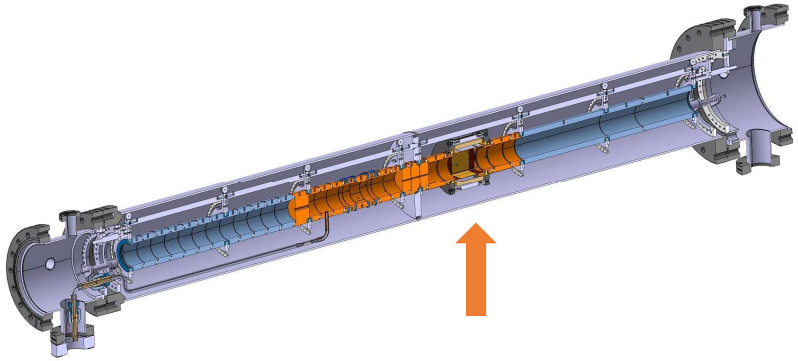
mass	a	b	c	d
126	0.05	*	0.15	1.28
127	0.11	0.02	0.22	1.68
128	**2.22**	**3.51**	1.23	**2.89**
129	1.92	0.71	1.18	**2.90**
130	**12.54**	0.04	0.68	**3.03**

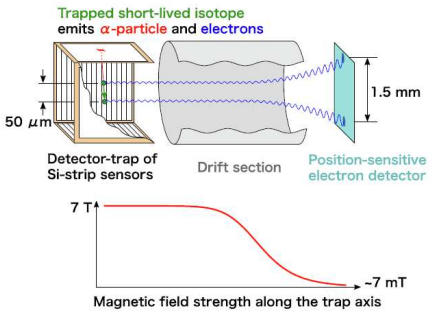
M.R. Mumpower et al., PPNP86 (2016) 86

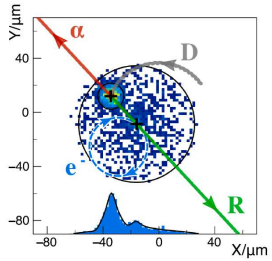


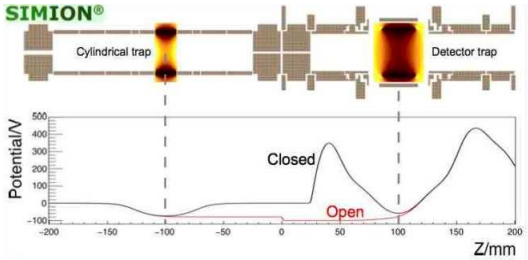
N = 82

MLLTRAP @ ALTO – R&D for Beam manipulation









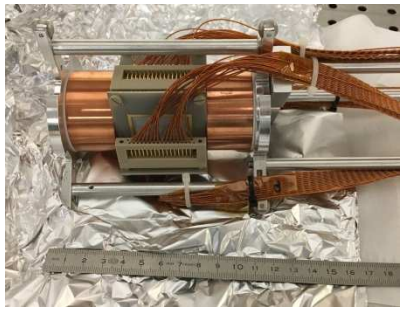
In-trap decay spectroscopy for MLLTRAP

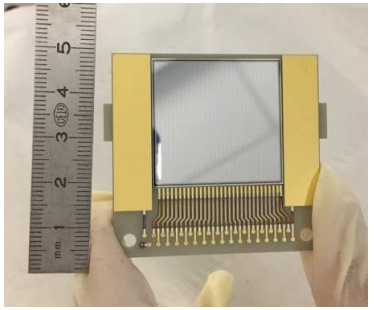
- Decay experiments with carrier-free particles stored in a Penning trap enable studies on ideal ion samples.
- The improved energy resolution can be exploited for high-resolution α- and electron-decay spectroscopy.

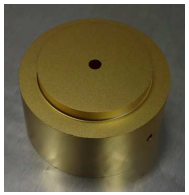
→ Design fixed, all mechanical parts and insulators received in 2020.

→ Gold plating of all the electrodes performed in October 2022

→ The next step is the mechanical assembly







P. Chauveau et al., NIMB 982 (2020) 164508
P. Chauveau et al., NIMB 463 (2020) 371

Thank you for your attention !