

New program for measuring masses of silver isotopes near the $N=82$ shell closure with MLLTRAP at ALTO



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INTERNATIONAL CONFERENCE ON ELECTROMAGNETIC ISOTOPE SEPARATORS AND RELATED TOPICS

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CERN GENEVA / SWITZERLAND / 16 - 21 SEPTEMBER 2018



ISOLDE



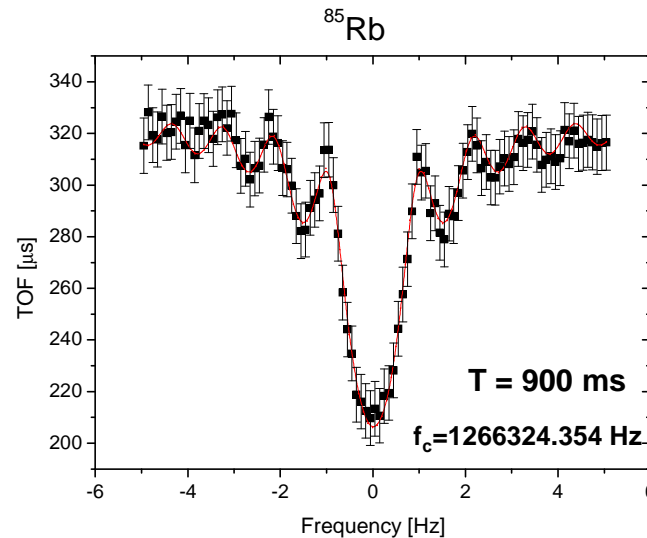
MLLTRAP project in Germany



MLLTRAP

- Penning trap mass spectrometer
- High-precision mass measurements

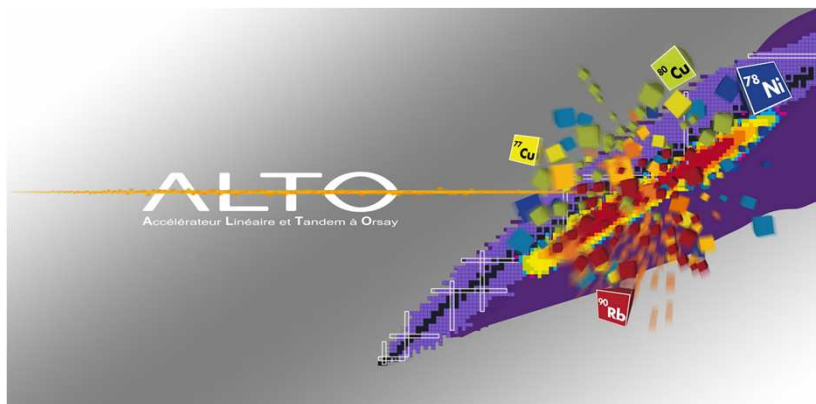
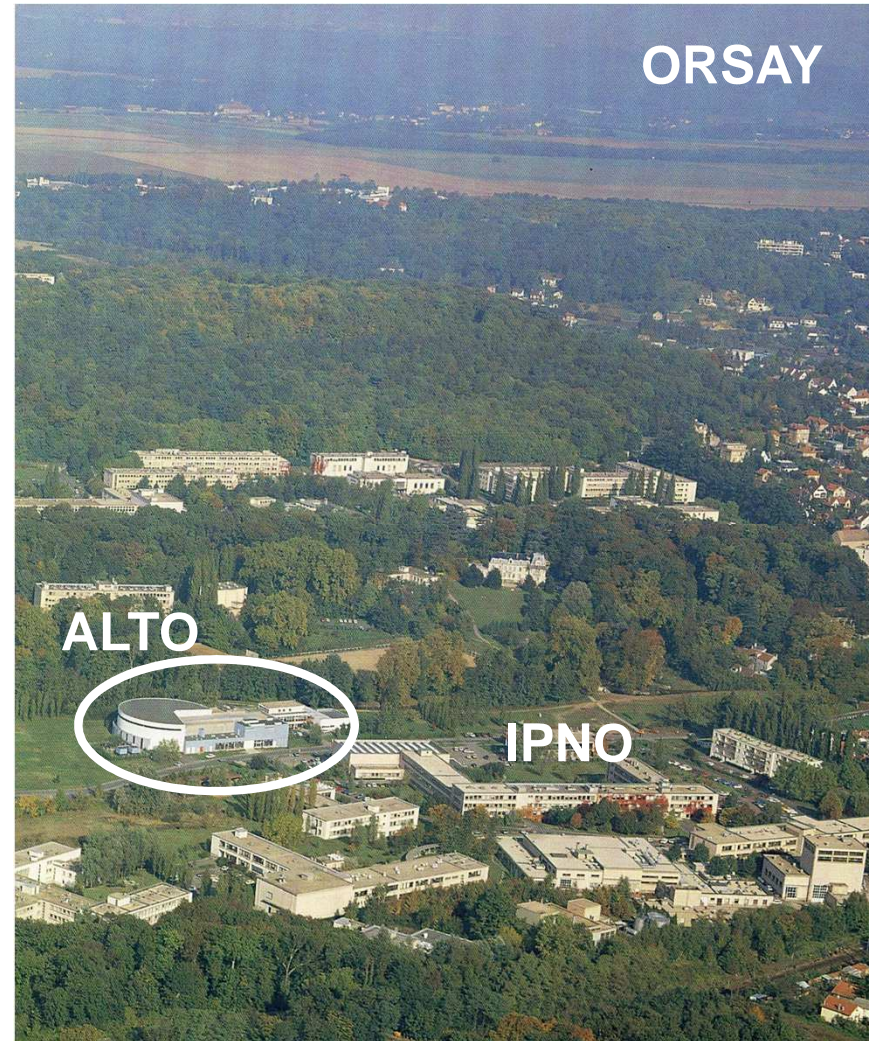
Peter G. Thirolf , Christine Weber et al.



2009 → Off-line commissioning

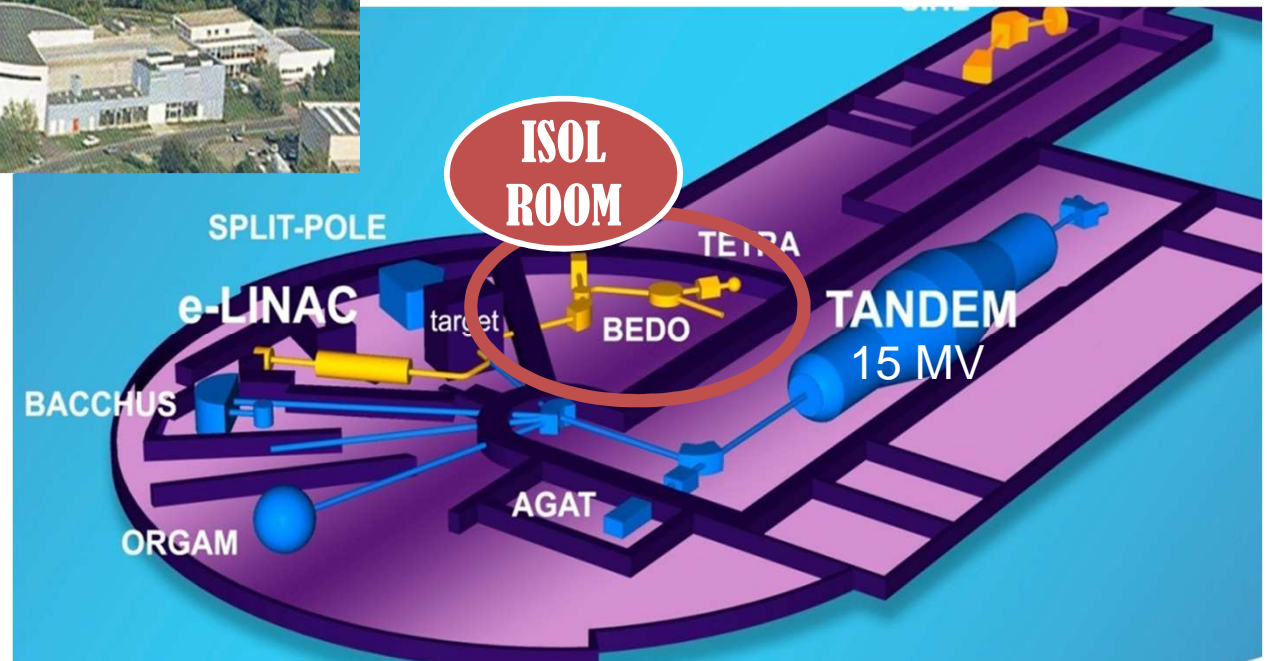
V.S. Kolhinen, et al., *Nucl. Instrum. Methods Phys. Res., Sect. A* 600 (2009) 391

MLLTRAP project in France



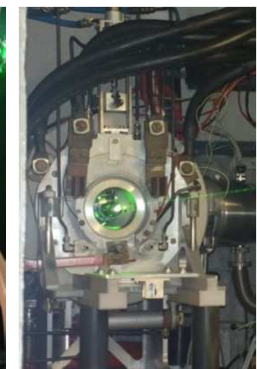
Accélérateur Linéaire auprès du Tandem d'Orsay

MLLTRAP project in France

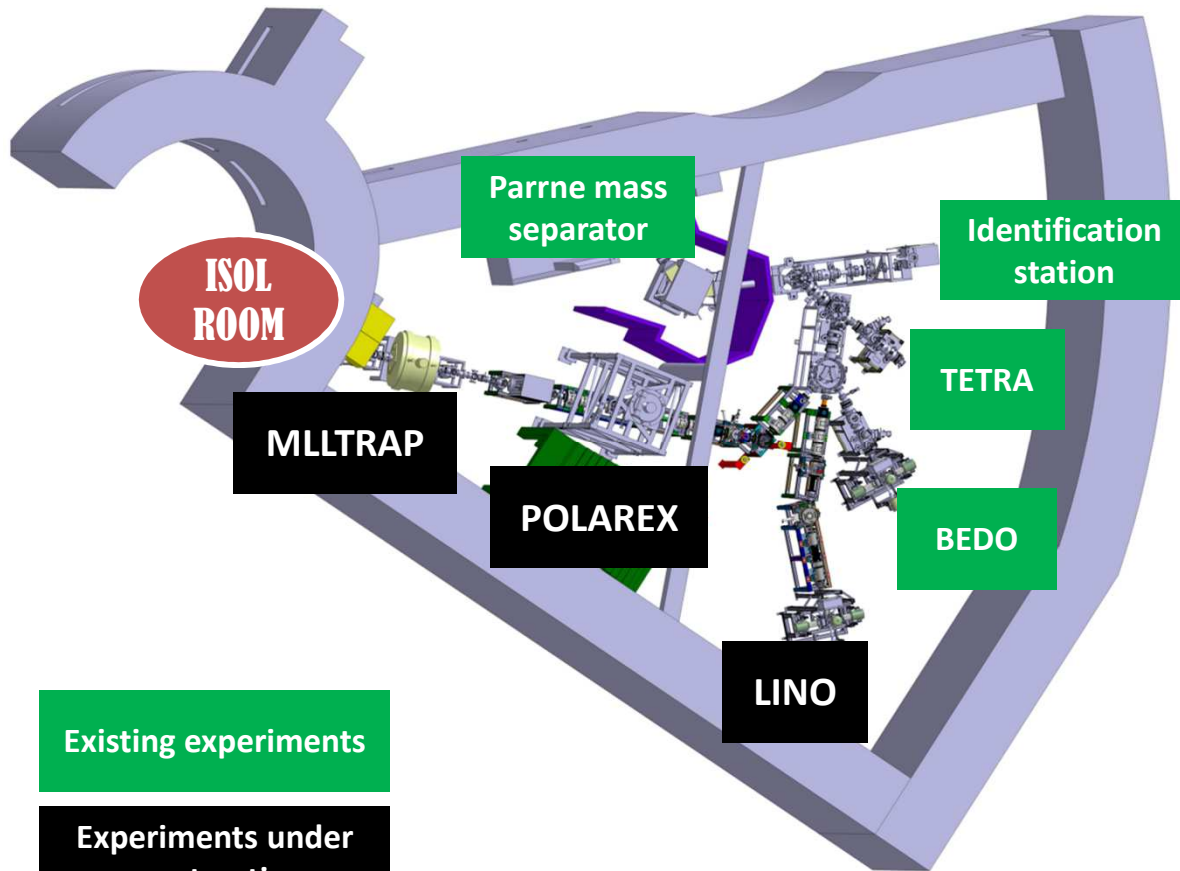


First operational RIB facility based on photo-fission → populating the GDR of ^{238}U

- ❑ 30-kV platform
- ❑ mass separator ($A/\Delta A = 1500$)
- ❑ $10 \mu\text{A}$, 50 MeV e- beam
- ❑ $10^{11} - 4 \times 10^{11}$ fissions/s



MLLTRAP @ ALTO



MLLTRAP
@
ALTO
Accélérateur Linéaire et Tandem à Orsay



2016



“Charting Terra Incognita of Exotic Nuclei”

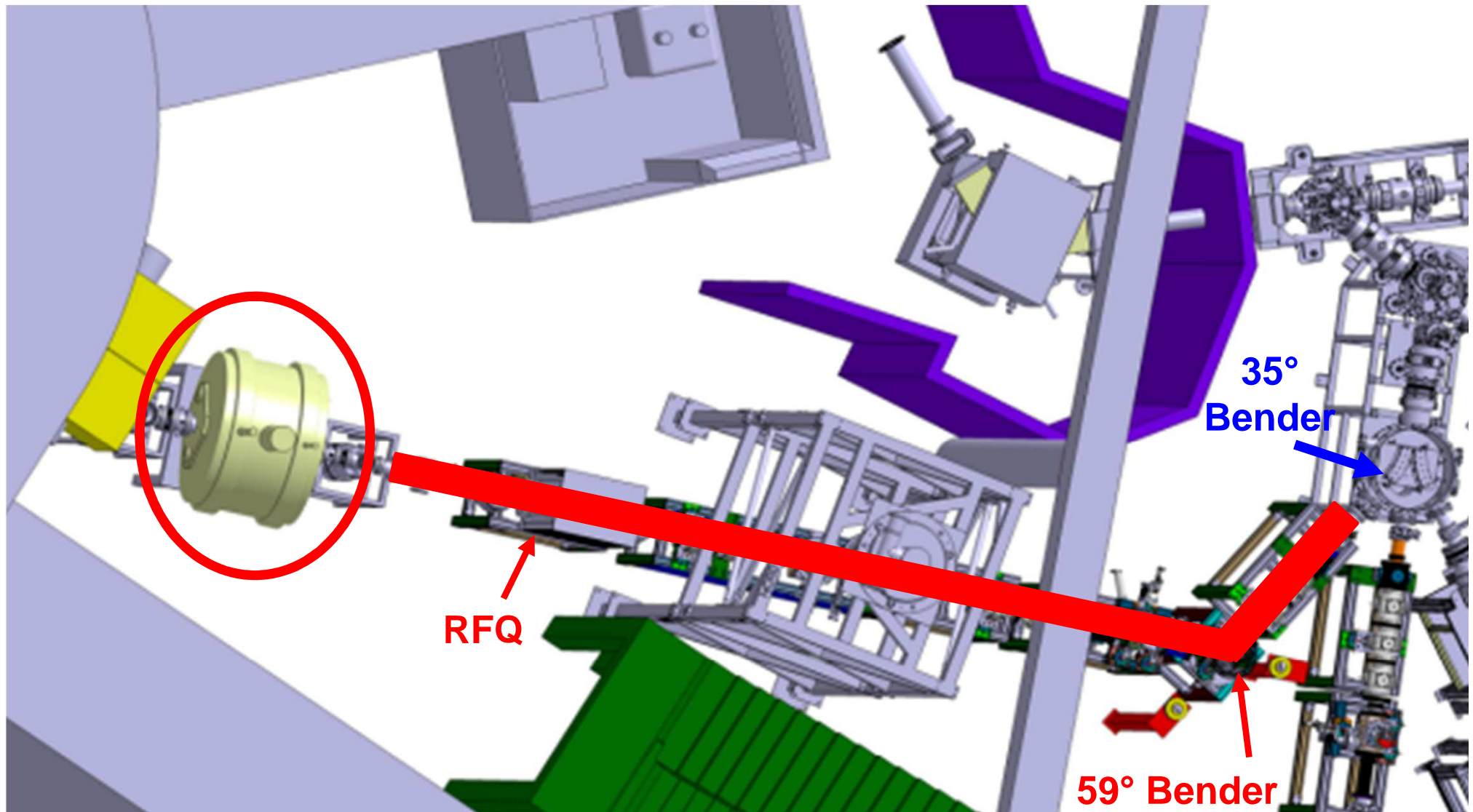
2017

île de France

SESAME

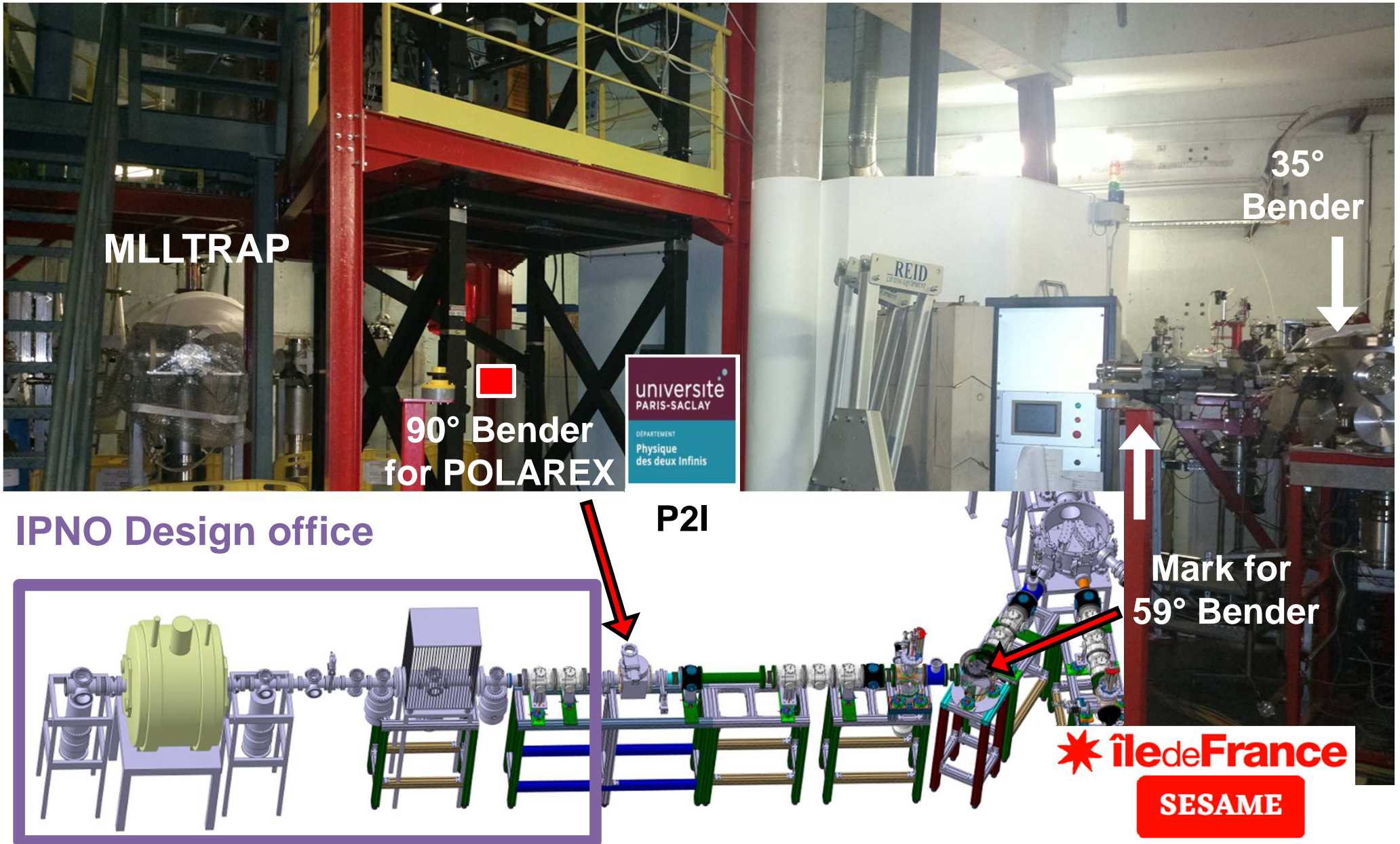
“Reaching Terra Incognita of Exotic Nuclei”

Status of MLLTRAP@ALTO



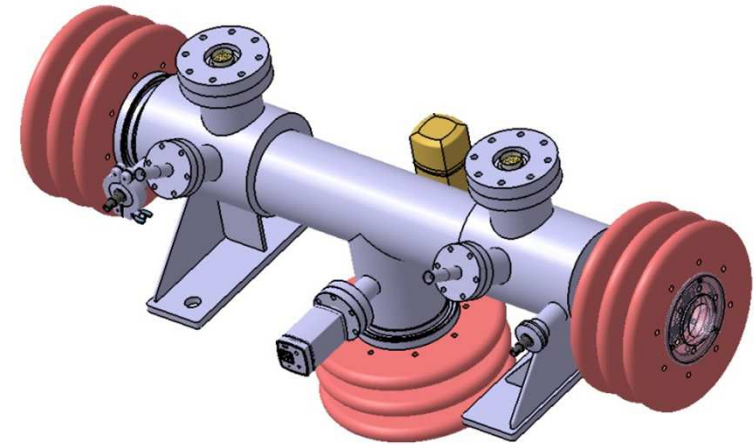
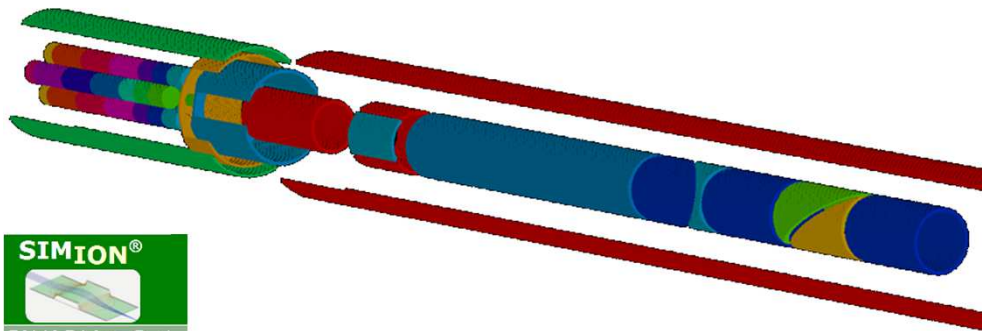
- New area rehabilitated
- 7 T superconducting magnet with 2 homogenous regions
- Energized in November 2017

Status of MLLTRAP@ALTO



Status of MLLTRAP@ALTO

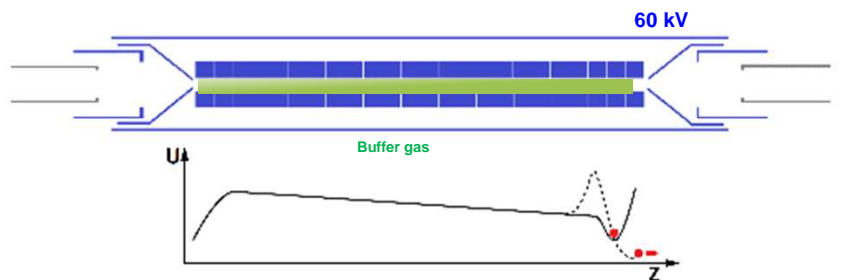
RFQ cooler and buncher



$2r_0 = 14 \text{ mm}$
 $L = 503.5 \text{ mm (15 segments)}$

Transverse emittance : $\sim 20 \pi \cdot \text{mm} \cdot \text{mrad}$ @ 1 keV

Longitudinal emittance : $\sim 10 \text{ eV} \cdot \mu\text{s}$



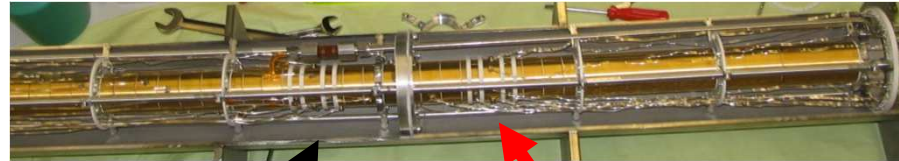
RFQ COLETTE @ 30 keV

T. Beyer et al., Appl. Phys. B 114 (2014) 129

MLLTRAP setup ALTO



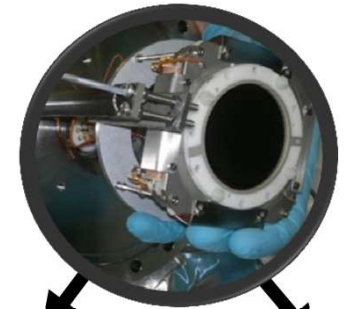
High-precision mass measurements



Purification Trap

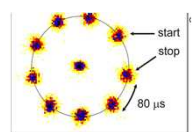
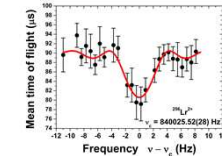
Measurement Trap

MCP delay line



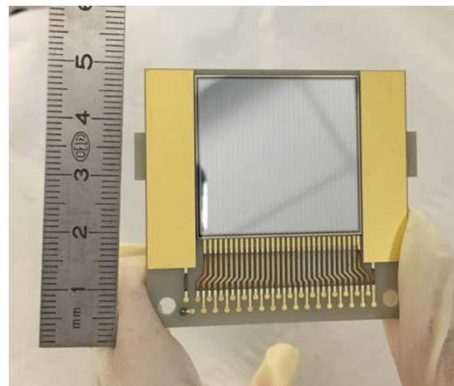
TOF-ICR

PI-ICR

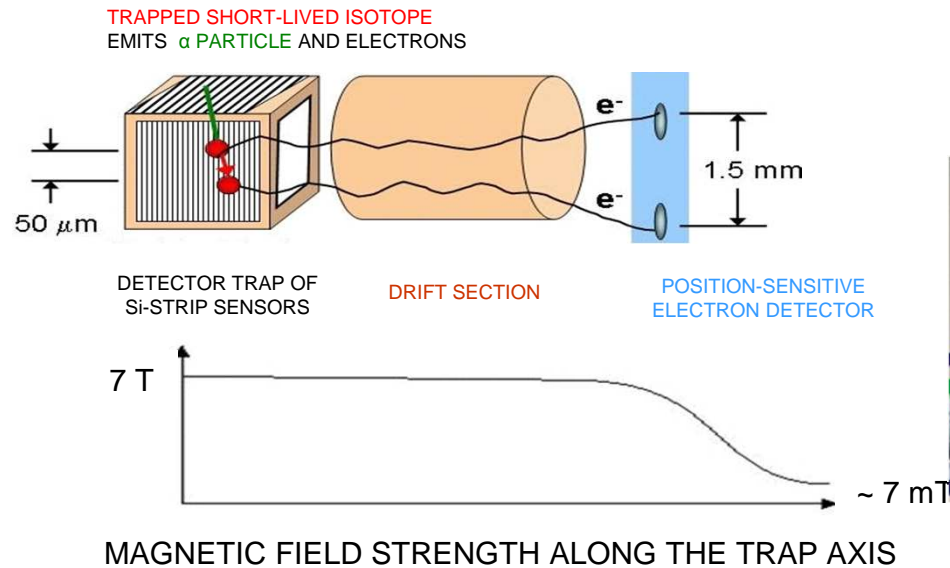


In-trap decay spectroscopy

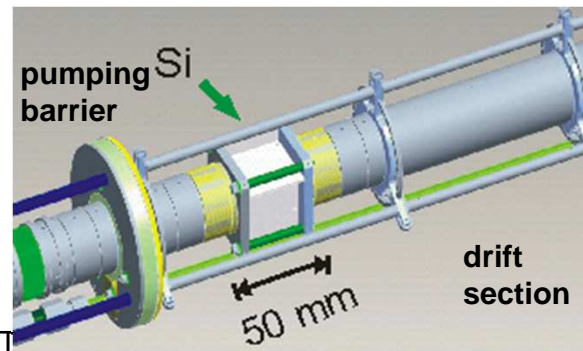
Detector Trap



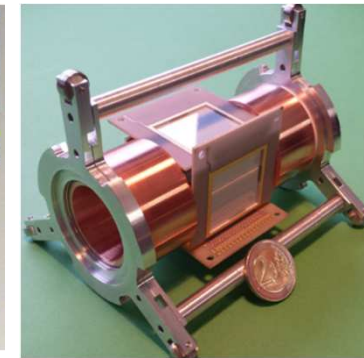
In-trap decay spectroscopy for MLLTRAP



C. Weber et al., *Int. J. Mass Spectrom.* 349-350, 270 (2013)
C. Weber et al., *Nucl. Instr. Meth. B* 317, 532 (2013)



Conceptual layout



Detector trap



- 'detector trap': α -detectors act as trap electrodes
- customized α detectors were developed and characterized for the cryogenic and UHV-conditions (single-sided Si-strip detector, active area 30x30 mm², 30 strips, α -energy resolution ~ 20 keV)

Advantages:

- 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.

Physics Goals :

- From lifetime measurements of the first excited 2⁺ states in heavy nuclei, nuclear quadrupole moments Q_0 can be derived
- Similar experiments on 0⁺ states allow for a determination of E0 decay strengths r^2 (E0)
- Shape coexistence of 0⁺ configurations as present in mid-shell regions around magic proton numbers

In-trap decay spectroscopy for MLLTRAP

IN-TRAP DECAY SPECTROSCOPY AND NUCLEAR LEVEL LIFETIME MEASUREMENT WITH MLLTRAP

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¹ Centre de Sciences Nucléaires et de Sciences de la Matière
² Institut de Physique Nucléaire d'Orsay
³ Ludwig-Maximilians-Universität München



Weber et al., *Int. J. Mass Spectrom.* 349-350, 270 (2013)
 Weber et al., *Nucl. Instr. Meth. B* 317, 532 (2013)

INTRODUCTION

MLLTrap is a double Penning trap incased in a 7-T superconducting magnet designed at the Maier Leibnitz Laboratory for high-precision mass measurements and currently installed at ALTO [1]. Instead of the conventional double-trap electrode system, another electrode assembly is being studied in which the second trap has been replaced with a cubic arrangement of silicon strip detectors for in-trap decay spectroscopy and nuclear level lifetime measurement.

Measurement	Detector(s)
Alpha spectroscopy	In-trap SSDs
CE spectroscopy	Outside Si detector
Lifetime measurement	In-trap SSD + position-sensitive MCP
Mass measurement	MCP

- 1-TRAP: cylindrical electrodes (Fig. 1a)
- 2-TRAP: segmented rings for dipolar/quadrupolar excitation (gas filled for mass selective cooling (purification) + resolving power > 10⁴)
- 4 Si detectors of 30 strips each (Fig. 1b, c, d)
- trapping potential set by the detectors
- UHV for extended trapping time (~1s)
- PCB-mounted electrodes for correction/excitation

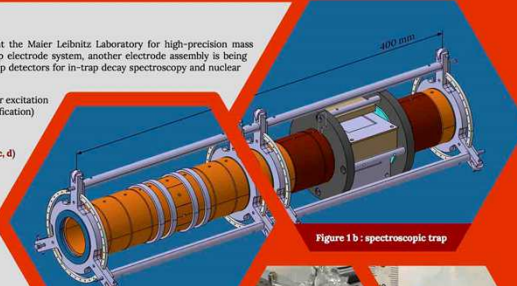


Figure 1 b : spectroscopic trap

OPTIMIZATION & SIMULATION

3D potential maps and charged particle trajectories calculated with SIMION 8.1.

Typical cycle: RFQCB | bunch creation → First trap | Cooling → Second trap | Excitation-ejection (FT-ICR) | Simple trapping (α-spectroscopy)

Penning trap equations are only valid in a quadrupolar field, i.e. $V(x, y, z) = V(0,0,0) + x^2 + y^2 - 2z^2$
 $-H = [V(x, y, z) - V(0,0,0)] / (x^2 + y^2 - 2z^2) \cdot [V_x - V_y]$ must be constant over the trap volume

Optimizing field	minimizing α_x/H	α_x/H	Max mass precision
Cylindrical trap	Potentials from [2]	0.94E-3	2.3E-7
	Optimized potentials	1.58E-3	0.9E-8
Square trap	Optimized potentials and geometry	4.17E-3	1.6E-7

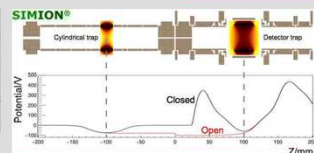


Figure 2 : electrodes and potential map of the double trap

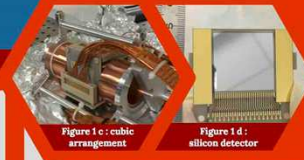
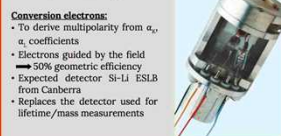


Figure 1 c : cubic arrangement

Figure 1 d : silicon detector

SPECTROSCOPY

- Alpha:
- For nuclear structure
 - In-trap detector developed and tested by C. Weber et al [3]
 - 4 detectors of 30 strips (1mm), $\Delta E_\alpha = 20-25$ keV
 - Circuit board, contacts, connectors and cable are all compatible with UHV and cryogenic conditions.
 - Tested inside and outside the magnet at MLL
 - Pending commissioning at ALTO



- Conversion electrons:
- To derive multipolarity from α_x , α_y coefficients
 - Electrons guided by the field
 - 50% geometric efficiency
 - Expected detector Si-Li ESLB from Canberra
 - Replaces the detector used for lifetime/mass measurements

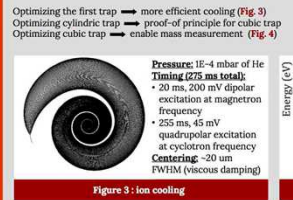


Figure 3 : ion cooling

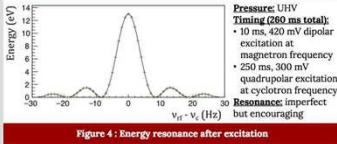


Figure 4 : Energy resonance after excitation

LIFE-TIME MEASUREMENT

α -decay leads to a reorganization of the electronic shells, often ejecting a few low-energy electrons. For heavy even-even nuclei, the probability to populate the 2+ state of the daughter nucleus is 10-30%. While in this state the daughter nucleus recoils before decaying mostly through internal conversion, releasing a second cloud of electrons due to the relaxation of the atomic shell. These two electron clouds mark the population and decay of the 2+ state. Thus the distance between those clouds is proportional to the lifetime of this state [3]. The small recoil distance is magnified in the fringe field then its azimuthal projection is measured in a position-sensitive detector (Fig. 5). The polar angle is finally deduced from the position of the alpha particle in the SSD. Simulations have confirmed the feasibility of the method (Fig. 6).

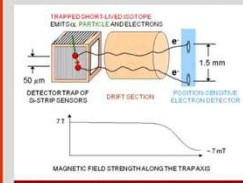


Figure 5 : recoil distance measurement [3]

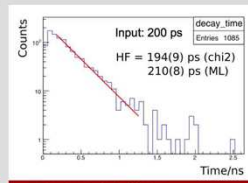


Figure 6 : simulating lifetime measurement

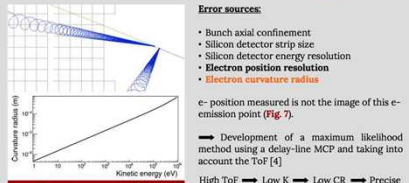


Figure 7 : curvature radius

Error sources:

- Bunch axial confinement
- Silicon detector strip size
- Silicon detector energy resolution
- Electron position resolution
- Electron curvature radius

e^- position measured is not the image of this emission point (Fig. 7).
 Development of a maximum likelihood method using a delay-line MCP and taking into account the ToF [4]

High ToF → Low K → Low CR → Precise

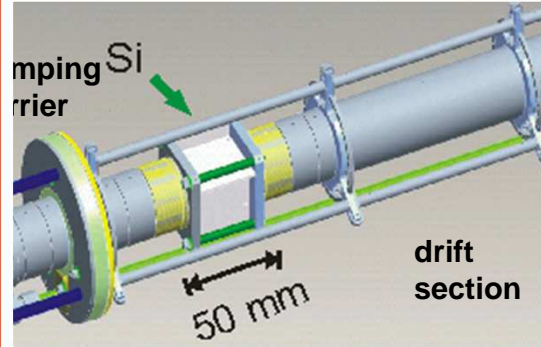
OUTLOOK

Extensive simulations have proven the feasibility of mass and lifetime measurements and new methods are being developed to improve the latter. We are currently preparing to test the in-trap SSDs outside and then inside the magnet. The recoil distance measurement could first be tested offline with a ²¹⁰Pb ($T_{1/2} = 114.4$ d) source α -decaying into ²¹⁰Bi ($T_{1/2} = 4$ s) and then into ²¹⁰Po. Though ALTO does not yet produce α -emitters, a fusion-evaporation target/ion source system is being studied, and a ⁴⁰Ar beam could be produced for online commissioning of the double trap.

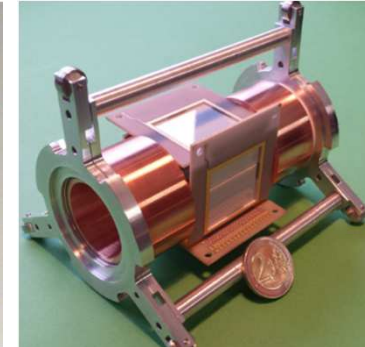
REFERENCES

- [1] E. Minaya Ramirez, EMIS 2018 talk
- [2] V. S. Kolhinen et al, NIM A 600 (2009) 391-397
- [3] C. Weber et al, IJMS 349-350 (2013) 270-276
- [4] P. Chauveau et al, to be published

Funded by



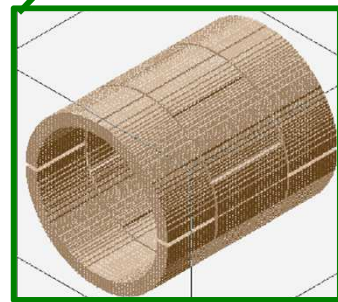
Conceptual layout



Detector trap



See poster #28 by Pierre Chauveau

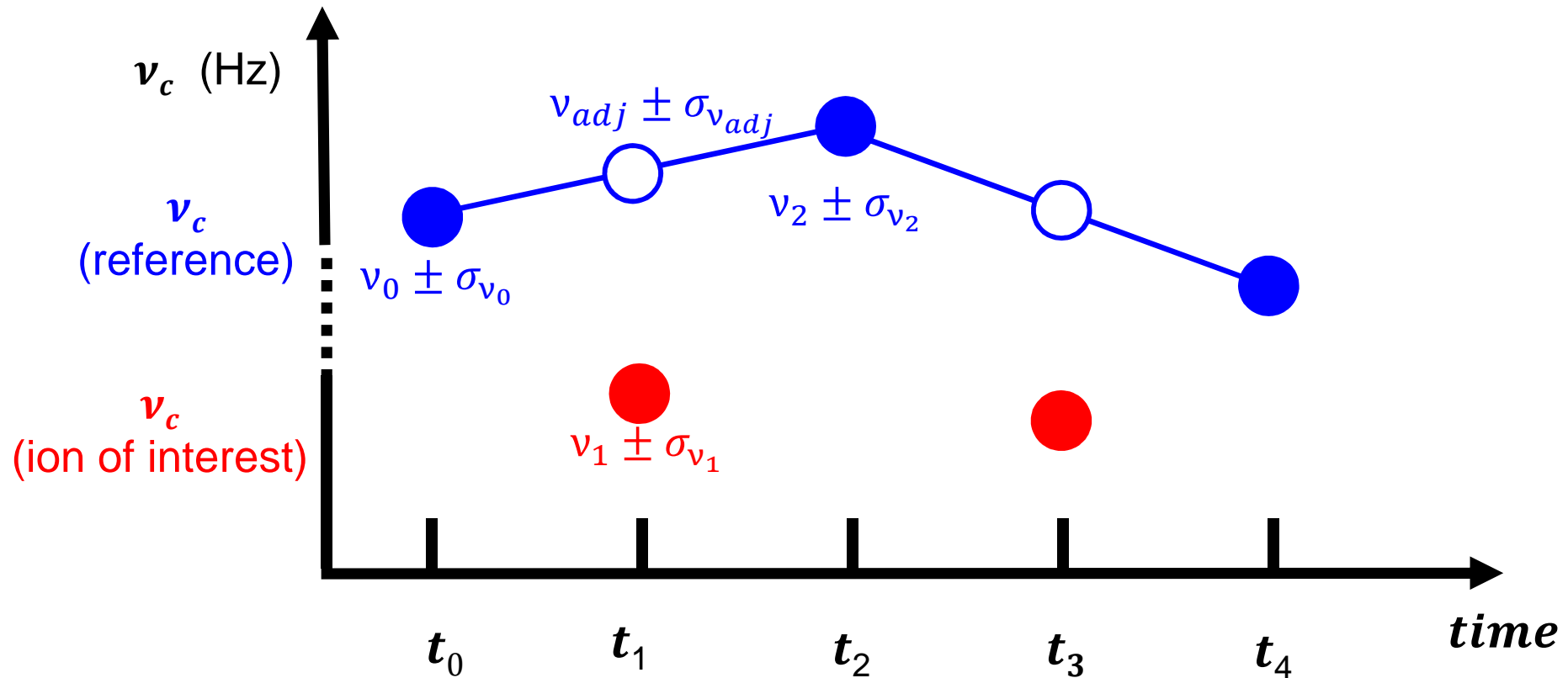


First Trap:

- Gas filled
- For mass-selective cooling
- Built



Magnetic field calibration



→ keep track of magnetic field variations during on-line measurements

→ Probe developed by Caylar (company nearby Orsay)

→ Measurements performed during the last months



✳ île de France

SESAME

High-precision mass measurements at ALTO

ALTO

**Letter of Intent for Day 1
MLLTRAP experiments**

PAC session :

March 2017

EXP # (Do not fill in):

Title: High-precision mass measurement of silver isotopes ($A=113 - 129$) towards the $N=82$ shell closure with MLLTRAP at ALTO

Is it a follow up experiment? [Yes/No]: **No** If yes, experiment number:

Spokespersons (if several, please use capital letters to indicate the name of the contact person):

Enrique Minaya Ramirez

Address of the contact person:

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¹*Centre d'Etudes Nucléaires de Bordeaux-Gradignan, France*

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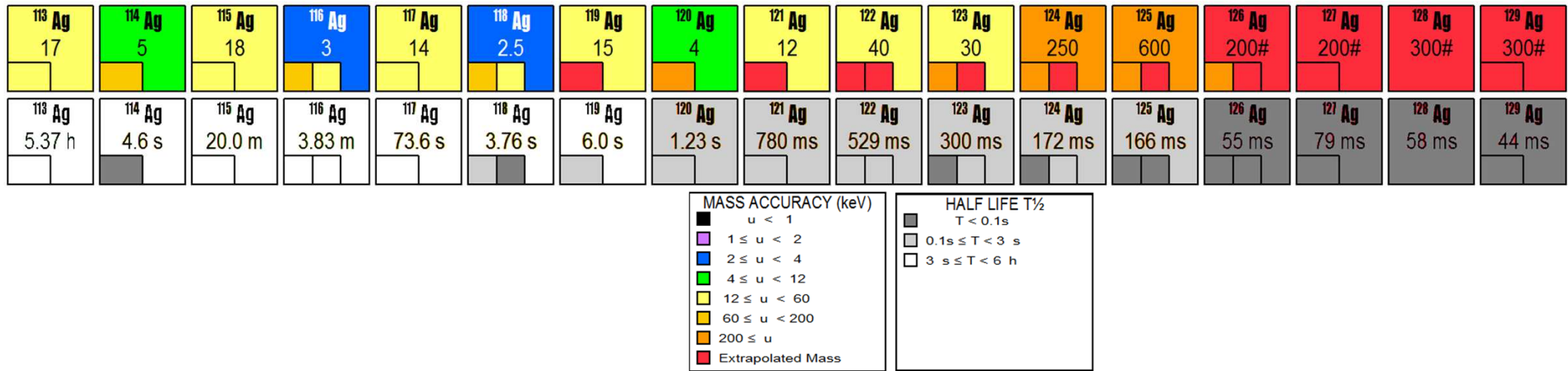
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⁴*Institut de Physique Nucléaire d'Orsay, France*

⁵*University of Jyväskylä, Department of Physics, Finland*

⁶*Ludwig-Maximilians-Universität München, Garching, Germany*

High precision mass measurements of silver isotopes



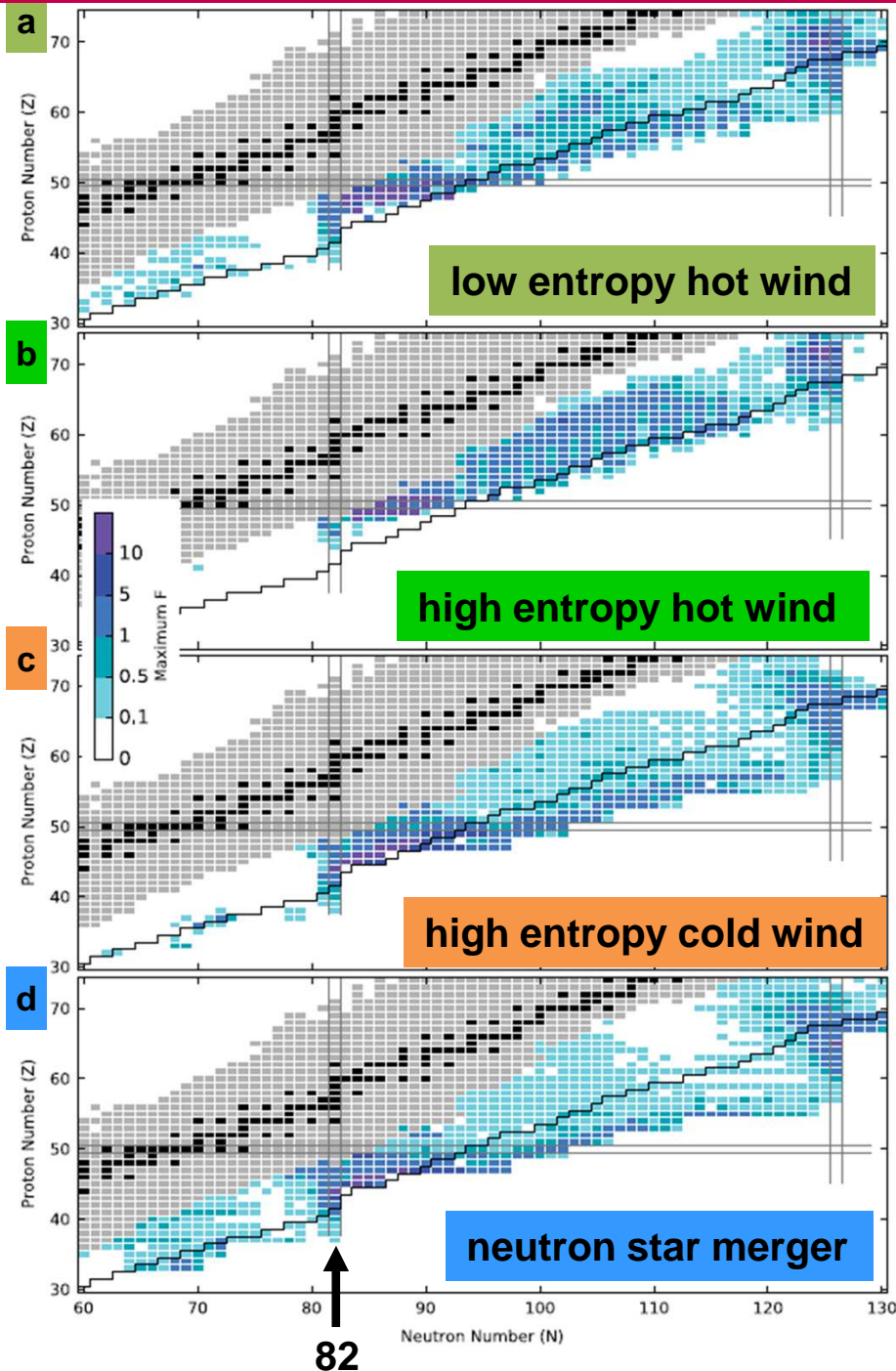
^{113,115,118}Ag : Characterize the performance of the full detection system

¹²³⁻¹²⁵Ag : Sensitivity of MLLTRAP to ions with short half-lives and low statistics

¹²⁶Ag and above : evolution of the shell gap at N= 82 (PI-ICR)

Masses for nuclear astrophysics studies

Important nuclei from sensitivity studies



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

Thank you for your attention!

