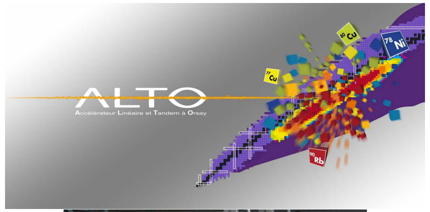
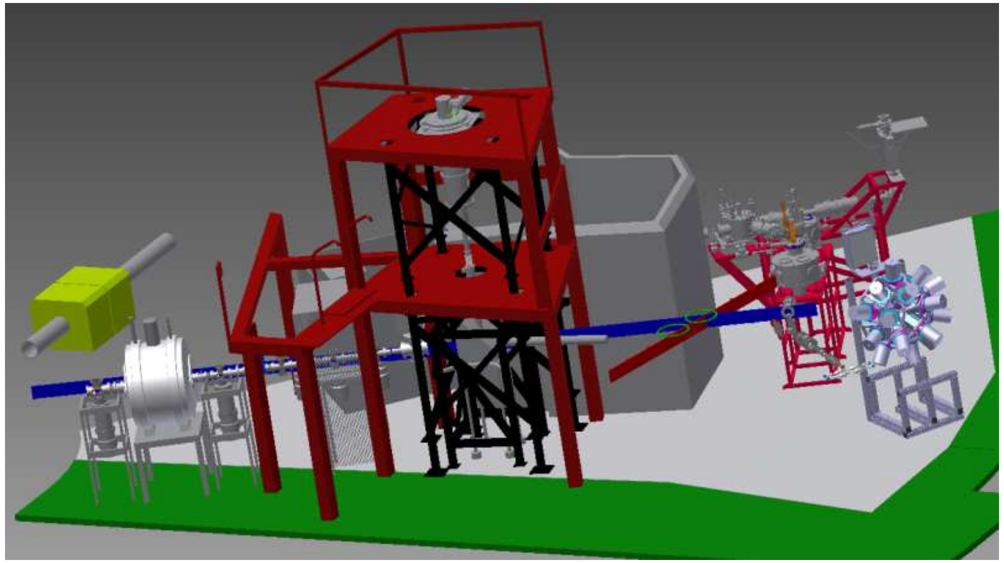
INSTITUT DE PHYSIQUE NUCLÉAIRE
ORSAY

ALTO
Accélérateur Linéaire et Tandem à Orsay

IN2P3
Les deux infinis

NUCLEAR STRUCTURE STUDIES WITH THE PENNING TRAP MASS SPECTROMETER MLLTRAP AT ALTO





Enrique Minaya Ramirez
Institut de Physique Nucléaire d'Orsay

Outline

I. Penning traps mass spectrometers

II. MLLTRAP project

III. Status of MLLTRAP@ALTO

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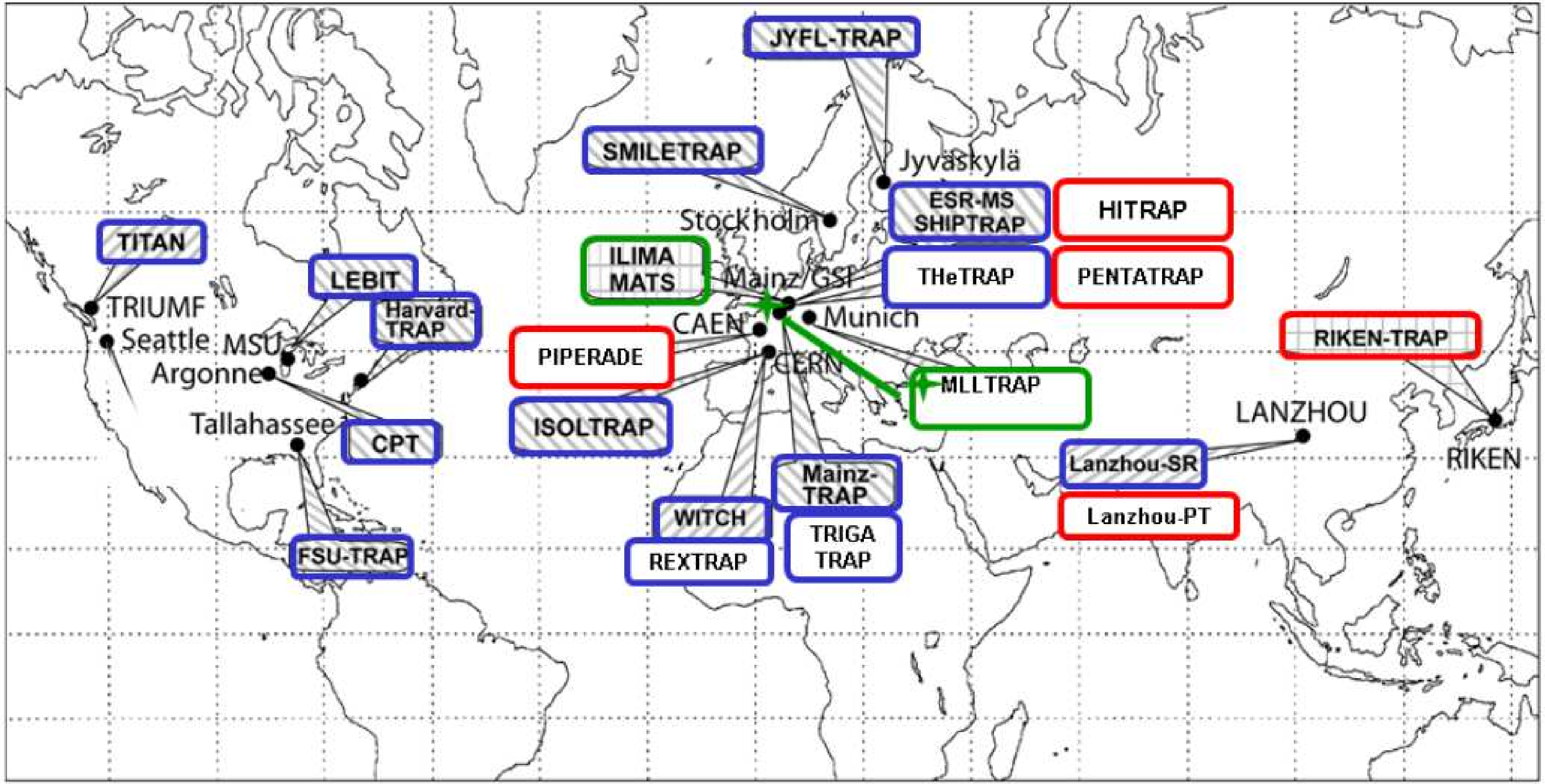
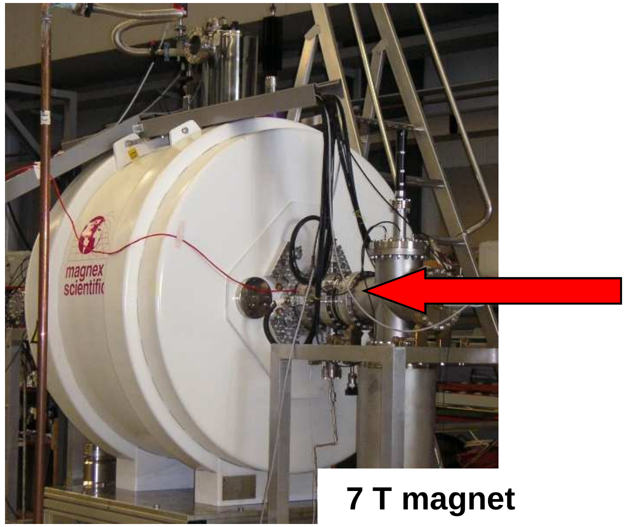
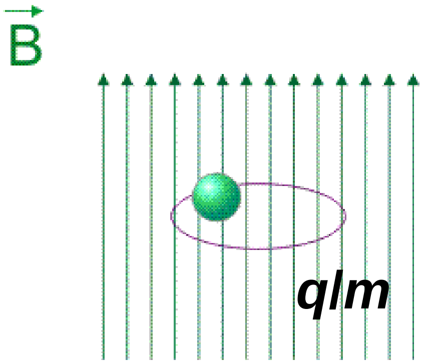
Penning traps around the world

→**High quality low-energy beams :** low emittance, low energy spread, purified samples

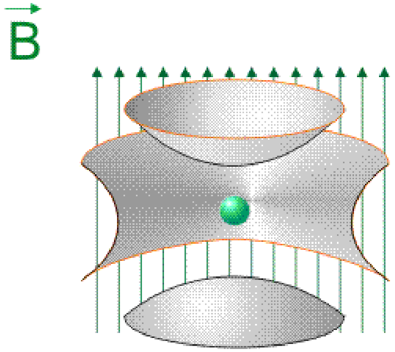


High-precision mass measurements with Penning traps





strong homogeneous magnetic field



\+ weak electrostatic field

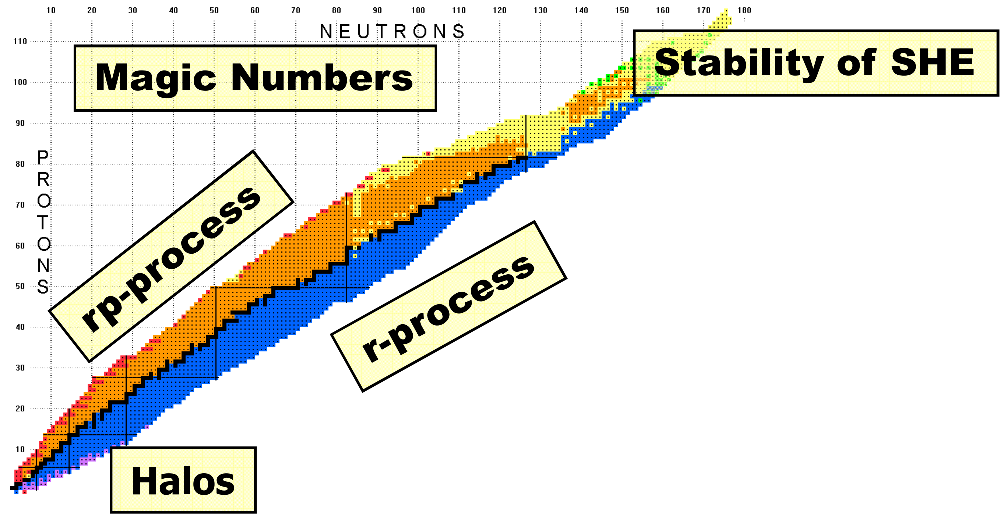
Cyclotron frequency

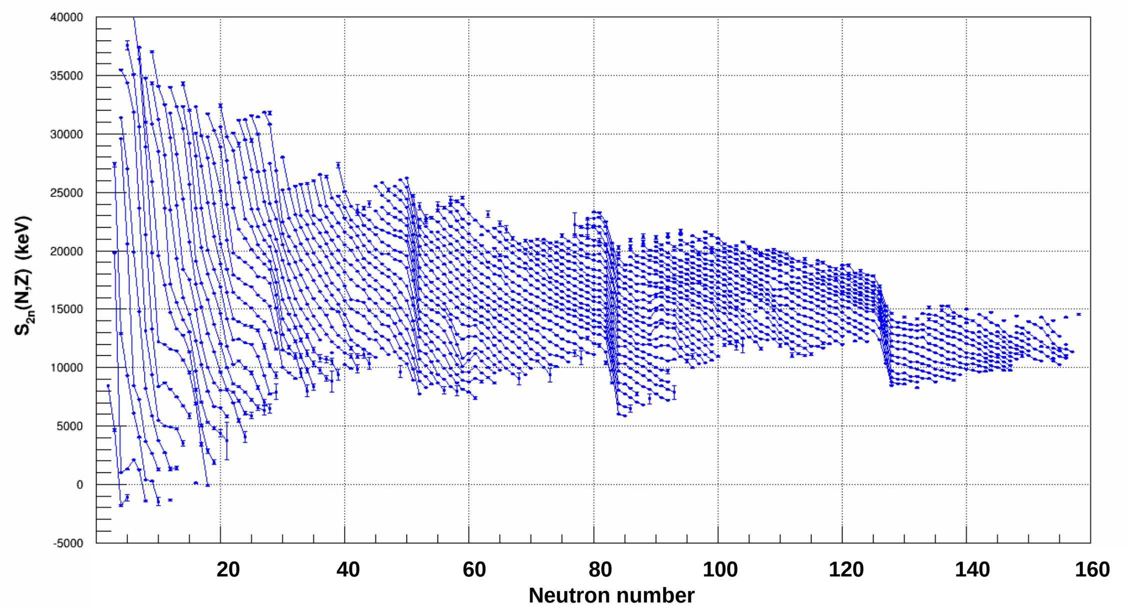
$$f_c = \frac{1}{2\pi} \cdot \frac{q}{m} \cdot B$$

High-precision mass measurements with Penning traps

Field	δm/m
Chemistry: identification of molecules	10^{-5} - 10^{-6}
Nuclear physics: shells, sub-shells, pairing	10^{-6}
Nuclear fine structure: deformation, halos	10^{-7} - 10^{-8}
Astrophysics : r-process, rp-process, waiting points	10^{-7}
Nuclear models and formulas: IMME	10^{-7} - 10^{-8}
Weak interaction studies: CVC hypothesis, CKM unitary	10^{-8}
Atomic physics: binding energies, QED	10^{-9} - 10^{-11}
Metrology: fundamental constants, CPT	$\leq 10^{-10}$

Masses and nuclear structure





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

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

- **absolute nuclear binding energy**
- **shell structure evolution**
- **Benchmark nuclear models**

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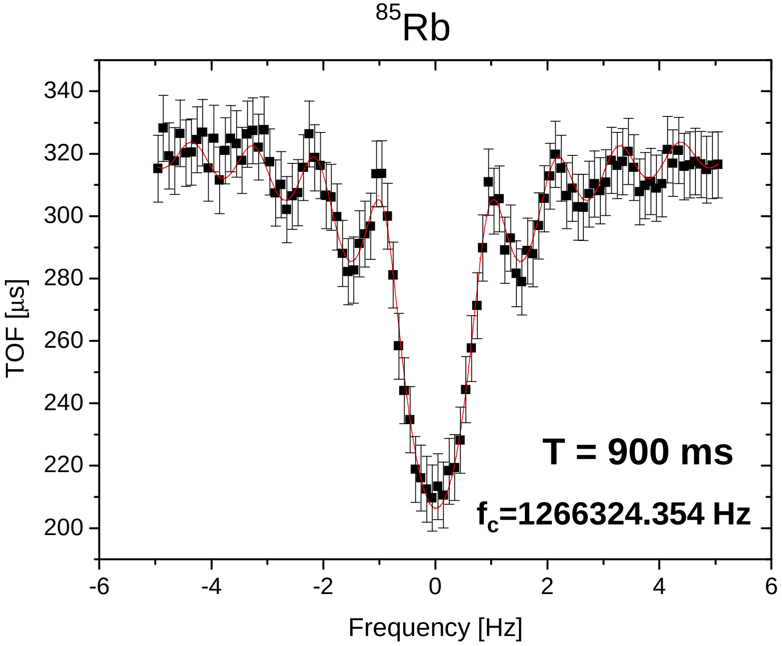
MLLTRAP project in Germany

Peter G. Thirolf , Christine Weber

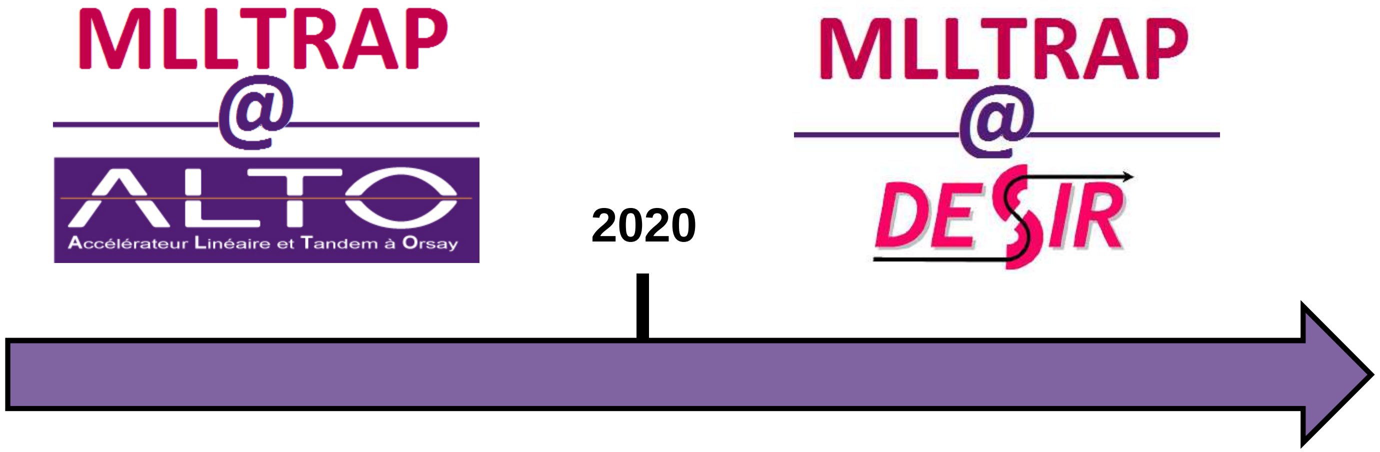


2009 → Off-line commissioning of the double Penning trap system MLLTRAP

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

MLLTRAP project in France

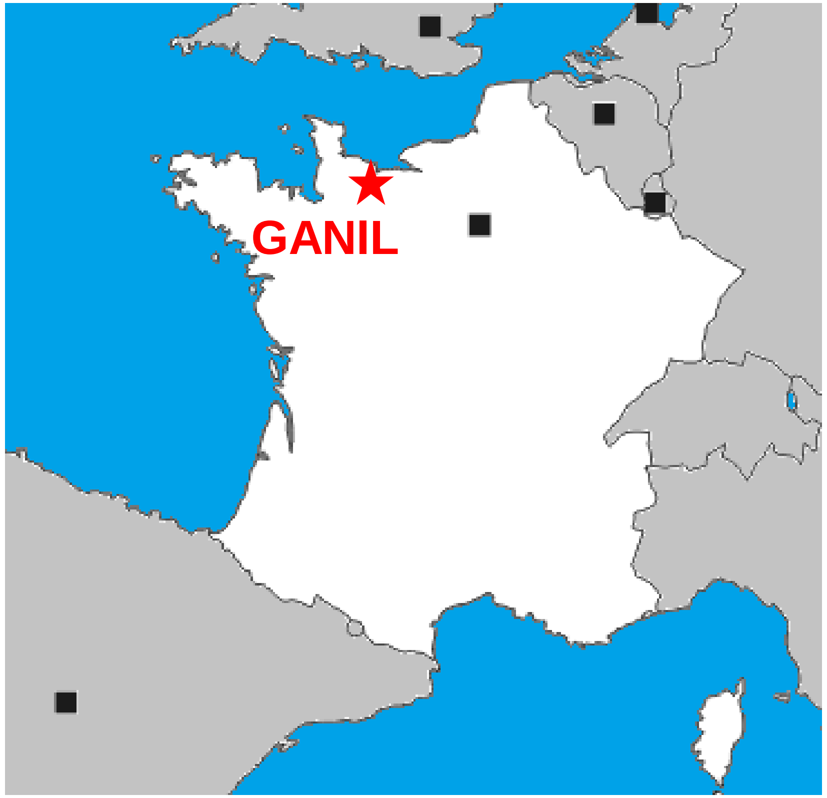
→ MLLTRAP will benefit from low energy beams from two facilities.



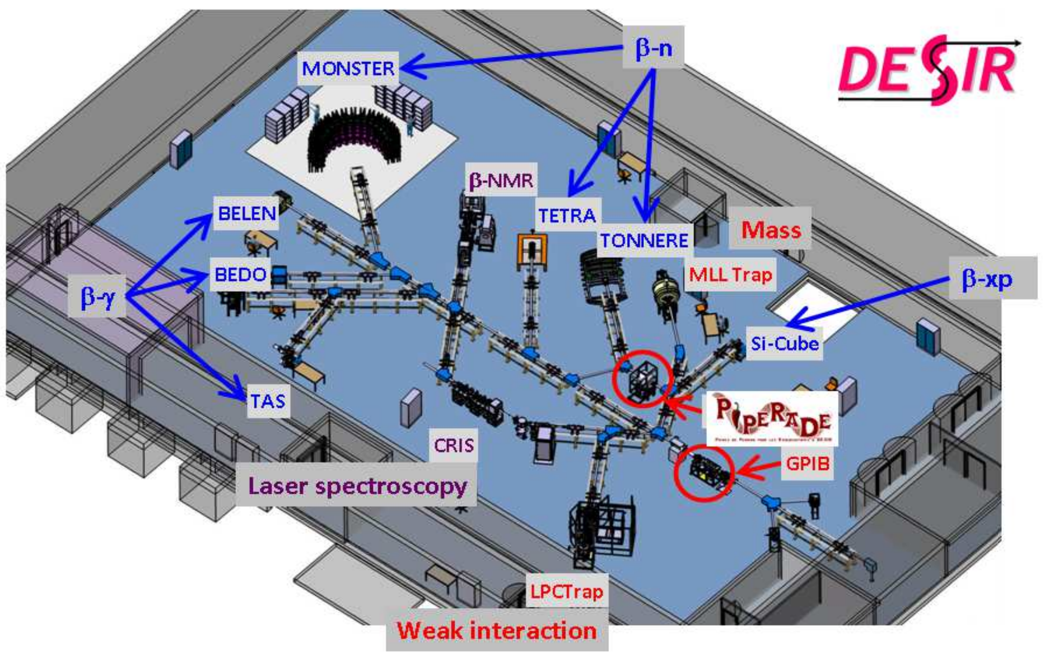
MLLTRAP project in France

The DESIR facility at GANIL-SPIRAL2 :

- β decay spectroscopy
- Laser Spectroscopy
- High-precision mass measurements



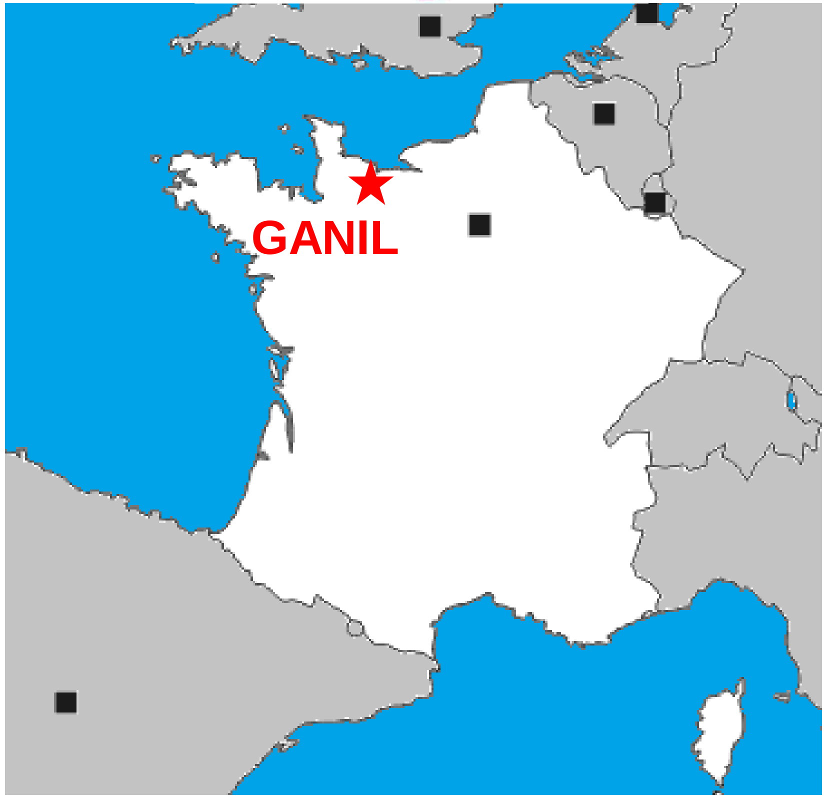
DESIR (Désintégration, Excitation et Stockage d'Ions Radioactifs



MLLTRAP @ DESIR

MLLTRAP project in France

MLLTRAP @ DESIR



Day 1 SPIRAL2 Phase 2
(RIB in DESIR & GANIL Experimental Area)

Title:
The mass of ^{100}Sn and the extraordinary binding of $N = Z$ nuclides

Spokespersons (if several, please use capital letters to indicate the name of the contact person):
D. Lunney (spokesperson), P. Thirolf (contactperson)

Day 1 SPIRAL2 Phase 2
(RIB in DESIR & GANIL Experimental Area)

Title:
Study of quantum phase transitions around $A = 100$ from the nuclear mass surface

Spokespersons (if several, please use capital letters to indicate the name of the contact person):
D. Lunney, CSNSM-Orsay (spokesperson), P. Thirolf, LMU-Munich (contactperson)

Day 1 SPIRAL2 Phase 2
(RIB in DESIR & GANIL Experimental Area)

Version 10/12/2010

Title: Precision mass measurements of nuclei with Z ~ 104 from S^3 with MLLTRAP at DESIR

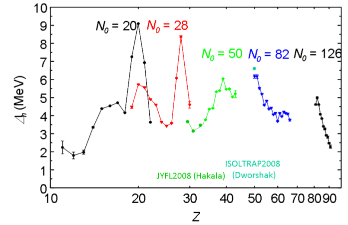
Spokespersons (if several, please use capital letters to indicate the name of the contact person):
P.G. Thirolf

Address of the contact person: Faculty of Physics, LMU Munich, Am Coulombwall 1, 85748 Garching/Germany

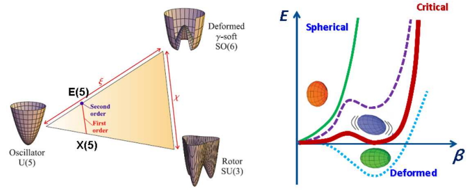
Phone: 0049-89-28914064	Fax: 0049-89-28914072	E-mail: Peter.Thirolf@lmu.de

Other Participants or Organisations: H. Savajols (GANIL), C. Weber (LMU), B. Blank (CENBG), M. Gerbaux (CENBG), J. Giovinazzo (CENBG), S. Grevy (CENBG), D. Lunney (CSNSM), E. Minaya Ramirez (GSI)

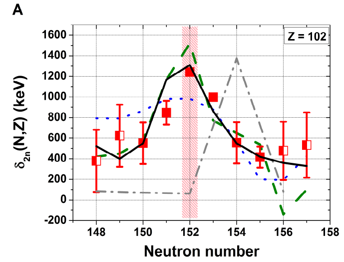
N=Z nuclides up to ^{100}Sn

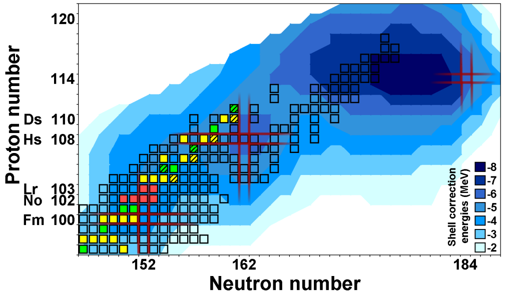


N=60, A = 100



Superheavies



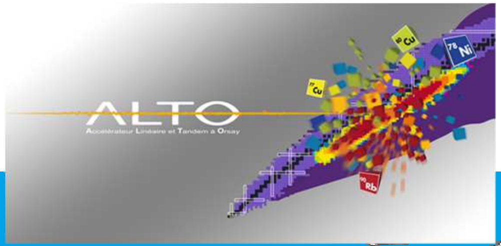


MLLTRAP project in France

MLLTRAP
@
ALTO
Accélérateur Linéaire et Tandem à Orsay

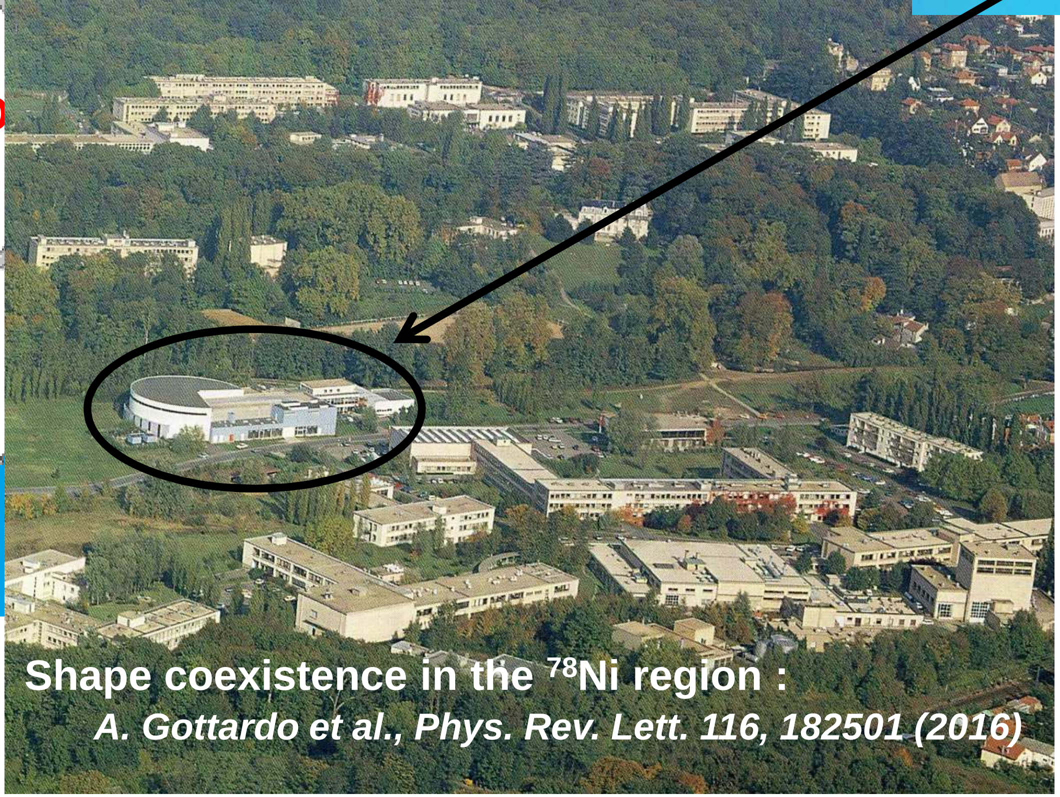
MLLTRAP project in France

The ALTO facility

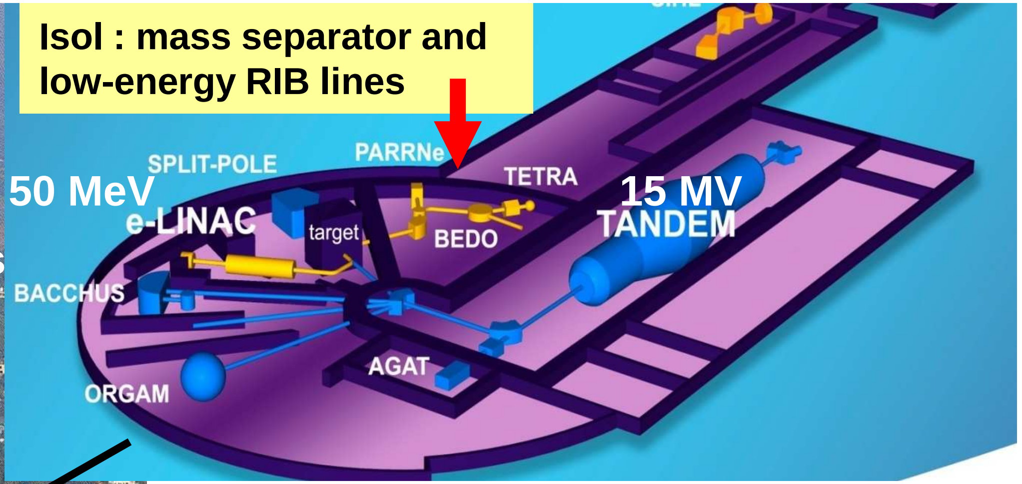


- ► Stable and Radioactive beam facility
- ► R&D on ISOL & RIB
- ► low-energy physics program based on photo-fission
- ► R&D and physics at ALTO a step towards a next-generation ISOL RIB facility

- ► Resonance ionization laser ion source
- ► on-line isotope separator PARRNe



Shape coexistence in the ^{78}Ni region :
A. Gottardo et al., Phys. Rev. Lett. 116, 182501 (2016)



- ❑ 30-kV platform
- ❑ mass separator (A/ΔA = 1500)
- ❑ 10 μA, 50 MeV e- beam
- ❑ 10^{11} – 4 x10^{11} fissions/s

	2013	2014	2015
Users	200	135	143
Beam-time	2983 h	2297 h	2736 h
	373 UT	287 UT	342 UT

ENSAR CHANDA cnrs IN2P3 Les deux infinis IPN INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY UNIVERSITÉ PARIS SUD

MLLTRAP project in France

MLLTRAP @ ALTO

Accélérateur Linéaire et Tandem à Orsay

24/03/2016 → Project funded from the French Investments program LabEx (laboratory of Excellence) P2IO

INVESTISSEMENTS D'AVENIR

P2IO Physique des 2 Infinis et des Origines

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Move of MLLTRAP from MLL to Alto

February – April 2016








July 2016

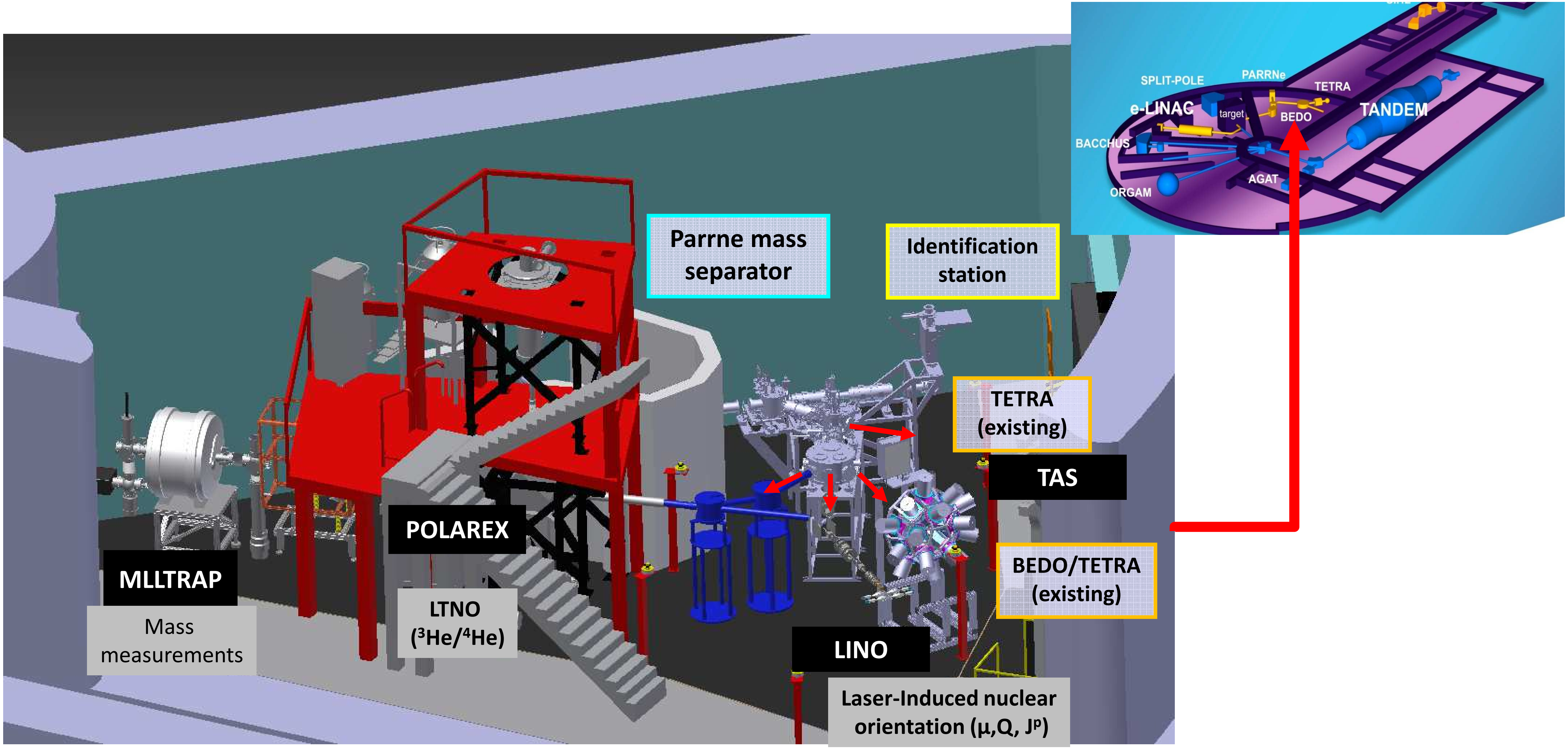


*The truck left MLL the **14th of July 2016***




MLLTRAP is now at ALTO

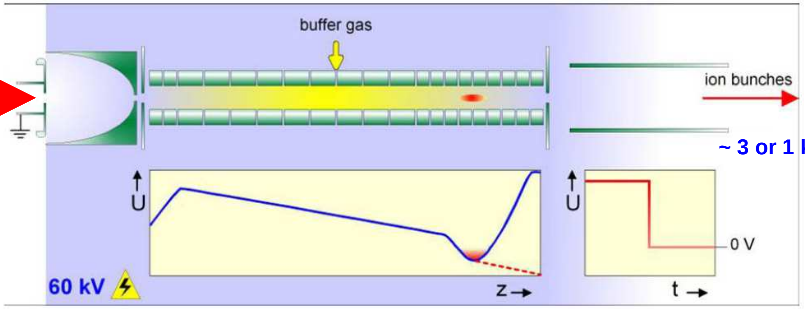
High-precision mass measurements at ALTO

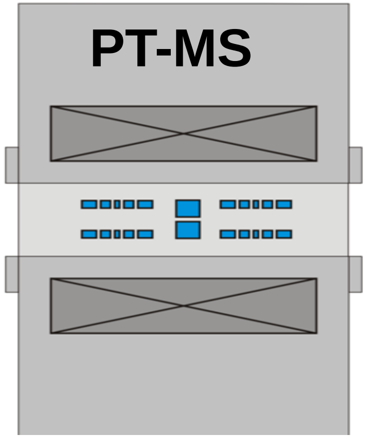


Installation of MLLTRAP @ ALTO

Continuous Beam from ALTO @ 30 / 60 KeV

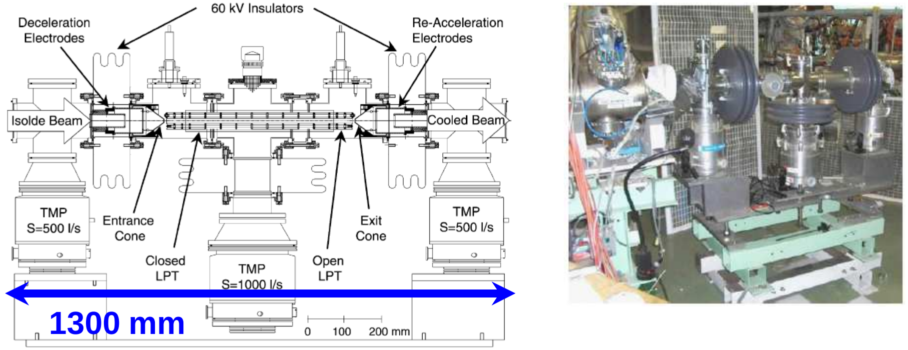
RFQ Cooler and buncher



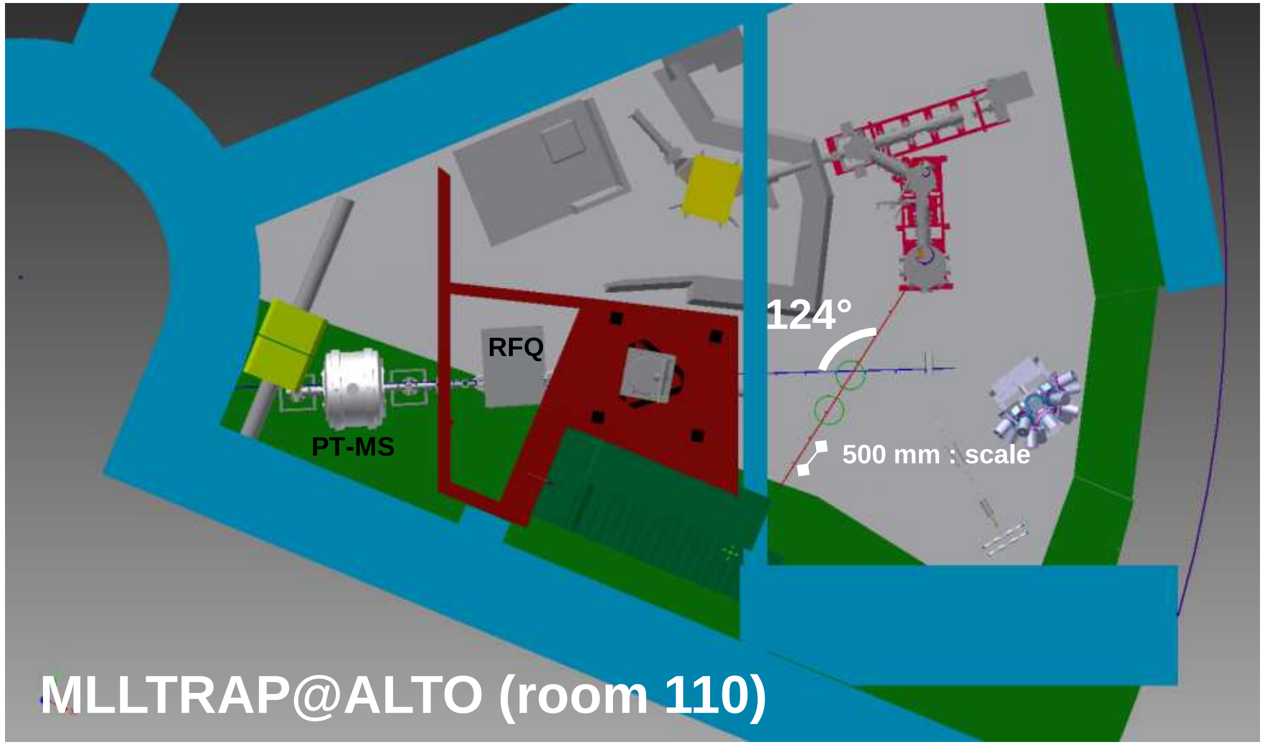


MCP

COLETTE : RFQ cooler and buncher



$2r_0$ = 14 mm
L = 40 mm (9 segments - center)
L = 20 mm (6 segments - first and last)



MLLTRAP for high precision mass measurements

First trap (purification trap)

Mass resolving power of **$m/\Delta m \approx$ 100 000**

$\Rightarrow$ separation of isobars

Second trap (measurement trap)

Quadrupolar resonance **$m/\Delta m \approx$ 1 000 000**

$\Rightarrow$ separation of isomers

Octupolar resonance **$m/\Delta m \approx$ 20 000 000**

S. Eliseev et al., Phys. Rev. Lett. 107 (2011) 152501

E. Minaya et al., Nucl. Instr. Meth. B 317 (2013) 501

MLLTRAP for high precision mass measurements

First trap (purification trap)

Mass resolving power of **m/Δm ≈ 100 000**
⇒ **separation of isobars**

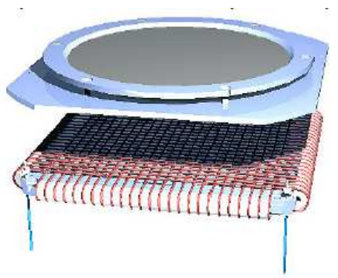
Second trap (measurement trap)

Quadrupolar resonance **m/Δm ≈ 1 000 000**
⇒ **separation of isomers**

Octupolar resonance **m/Δm ≈ 20 000 000**

S. Eliseev et al., Phys. Rev. Lett. 107 (2011) 152501
E. Minaya et al., Nucl. Instr. Meth. B 317 (2013) 501

→Phase Imaging Ion Cyclotron Resonance (PI-ICR)



Delay-Line Detector
by Roentdek GmbH

$$\phi + 2\pi n = 2\pi \nu t$$

$$\Delta \nu = \frac{\Delta \phi}{2\pi t} = \frac{\Delta R}{\pi t R}$$

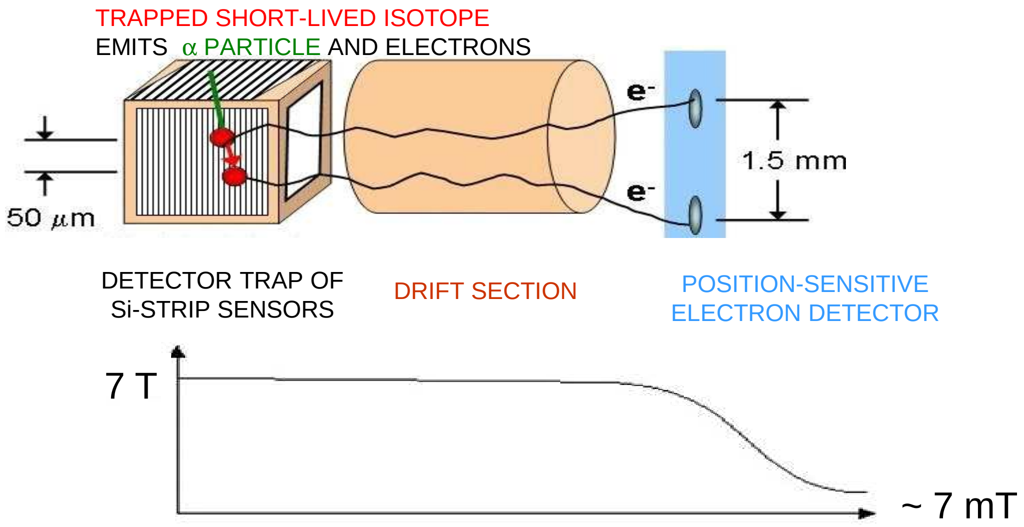
compared to standard technique:
→ 40 fold gain in resolving power
→ 5 fold gain in precision
→ 25 faster than the Ramsey TOF-ICR

S. Eliseev et al., APB 114 (2014)

MLLTRAP for in-trap nuclear decay-spectroscopy experiments

In-trap Decay Spectroscopy developed @ MLL

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



MAGNETIC FIELD STRENGTH ALONG THE TRAP AXIS

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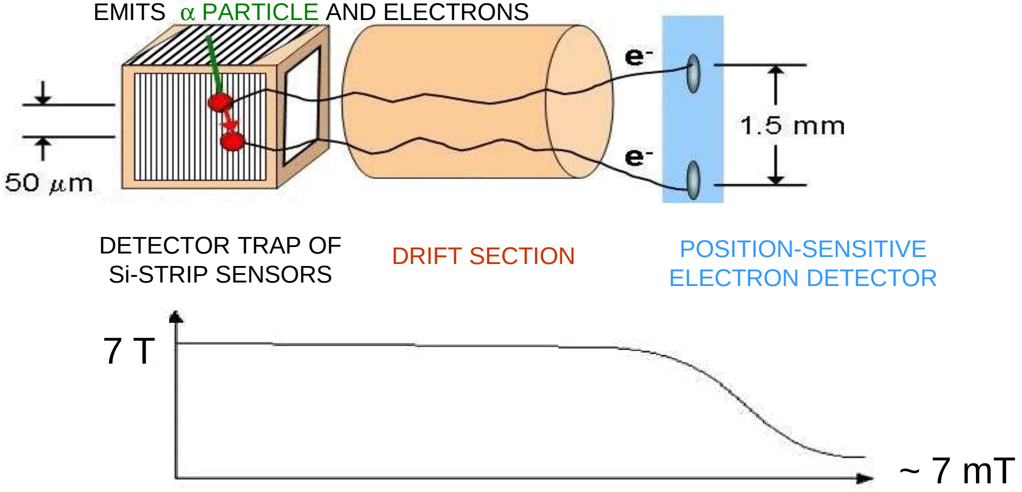
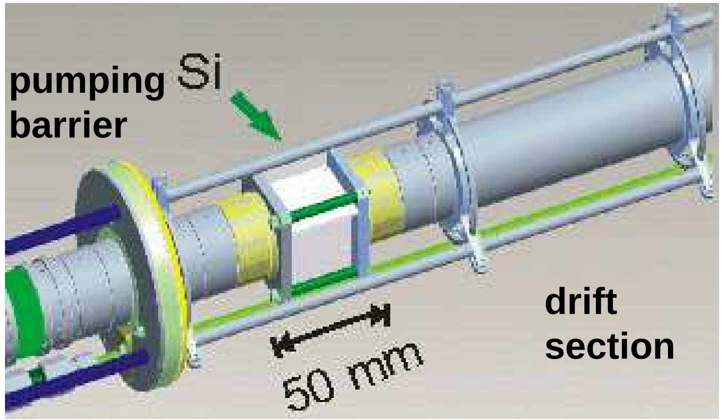
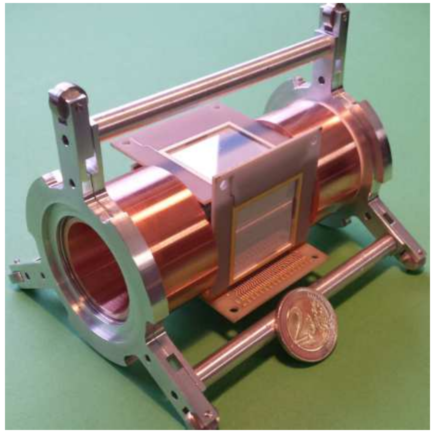


MAGNETIC FIELD STRENGTH ALONG THE TRAP AXIS



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)

MLLTRAP for in-trap nuclear decay-spectroscopy experiments

In-trap Decay Spectroscopy developed @ MLL

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

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 a- and electron-decay spectroscopy.

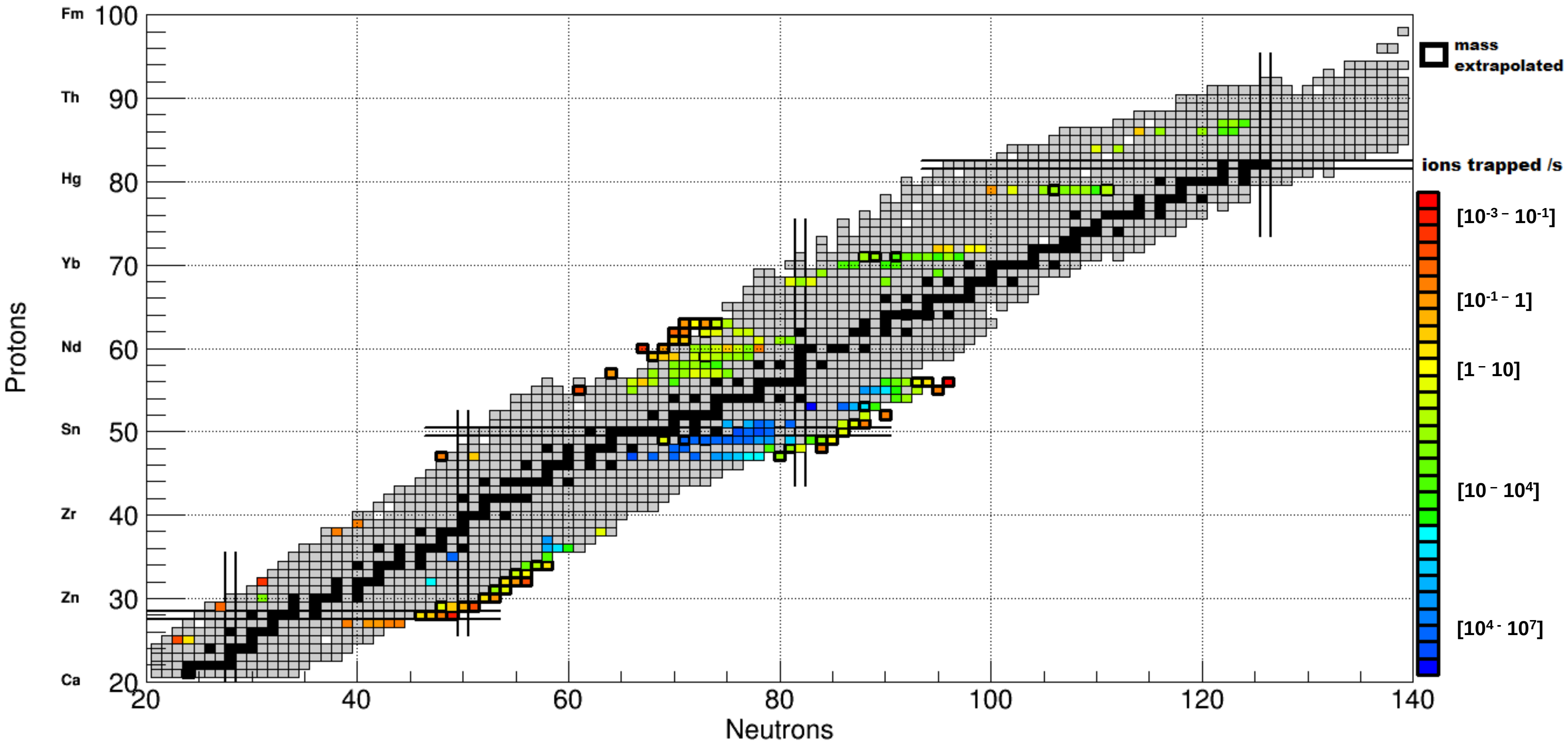
Physics Goals:

- 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

High-precision mass measurements at ALTO



- δm > 10 keV
- $T_{1/2}$ > 80 ms
- Trapped ions in 10h > 100

+ Fusion evaporation cases

- High-precision mass measurements in the region of the magic numbers 50 and 82 are of high interest for nuclear astrophysics (r and rp process)

- Masses of neutron-rich Ag and In isotopes would allow to investigate a possible weakening of the shell gap for Z < 50 and its impact on the A = 130 r-process abundances

Thank you for your attention!

Serge Franchoo, Marion MacCormick, Enrique Minaya Ramirez,
Karl Hauschild, Joa Ljungvall, Araceli Lopez-Martens, David Lunney
Bertram Blank, Jean-Charles Thomas,
Peter G. Thirolf , Christine Weber