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

Enrique Minaya Ramirez
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Outline

I. Penning traps mass spectrometers

II. MLLTRAP project

III. Status of MLLTRAP@ALTO
Outline

I. Penning traps mass spectrometers

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III. Status of MLLTRAP@ALTO
Penning traps around the world

→ **High quality low-energy beams**: low emittance, low energy spread, purified samples
High-precision mass measurements with Penning traps

Cyclotron frequency

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

strong homogeneous magnetic field

+ weak electrostatic field
### High-precision mass measurements with Penning traps

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

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MLLTRAP project in Germany

Peter G. Thirolf, Christine Weber

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

MLLTRAP project in France

→ MLLTRAP will benefit from low energy beams from two facilities.
The DESIR facility at GANIL-SPIRAL2:
- β decay spectroscopy
- Laser Spectroscopy
- High-precision mass measurements
### MLLTRAP project in France

#### 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)

**Title:** Precision mass measurements of nuclei with $Z \sim 104$ from $S^2$ with MLLTRAP at DESIR

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

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

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**N=Z nuclides up to $^{100}$Sn**

**N=60, A = 100**

**Superheavies**

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Enrique MINAYA RAMIREZ

Adelaide, 15th of September 2016

INPC 2016
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

**Isol : mass separator and low-energy RIB lines**

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

**Users**

<table>
<thead>
<tr>
<th>Year</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Users</td>
<td>200</td>
<td>135</td>
<td>143</td>
</tr>
<tr>
<td>Beam-time</td>
<td>2983 h</td>
<td>2297 h</td>
<td>2736 h</td>
</tr>
</tbody>
</table>

**373 UT 287 UT 342 UT**

**Shape coexistence in the $^{78}$Ni region:**

MLLTRAP project in France

24/03/2016 → Project funded from the French Investments program LabEx (laboratory of Excellence) P2IO
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Move of MLLTRAP from MLL to Alto

February – April 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

COLETTE : RFQ cooler and buncher

2r₀ = 14 mm
L = 40 mm (9 segments - center)
L = 20 mm (6 segments - first and last)

MLLTRAP@ALTO (room 110)
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 $m/\Delta m \approx 20\,000\,000$


MLLTRAP for high precision mass measurements

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Mass resolving power of $m/\Delta m \approx 100\,000$
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Octupolar resonance $m/\Delta m \approx 20\,000\,000$

$\Rightarrow$ Phase Imaging Ion Cyclotron Resonance (PI-ICR)

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

$\Delta v = \frac{\Delta \phi}{2\pi} = \frac{\Delta R}{\pi R}$

$\rightarrow$ 40 fold gain in resolving power
$\rightarrow$ 5 fold gain in precision
$\rightarrow$ 25 faster than the Ramsey TOF-ICR

Delay-Line Detector by Roentdek GmbH

compared to standard technique:


S. Eliseev et al., APB 114 (2014)
MLLTRAP for in-trap nuclear decay-spectroscopy experiments

In-trap Decay Spectroscopy developed @ MLL


TRAPPED SHORT-LIVED ISOTOPE
EMITS \( \alpha \) PARTICLE AND ELECTRONS

DETECTOR TRAP OF Si-STRIP SENSORS
DRIFT SECTION
POSITION-SENSITIVE ELECTRON DETECTOR

7 T
~ 7 mT

MAGNETIC FIELD STRENGTH ALONG THE TRAP AXIS
MLLTRAP for in-trap nuclear decay-spectroscopy experiments

In-trap Decay Spectroscopy developed @ MLL

- ‘detector trap’: $\alpha$-detectors act as trap electrodes
- customized $\alpha$ detectors were developed and characterized for the cryogenic and UHV-conditions (single-sided Si-strip detector, active area 30x30 mm², 30 strips, $\alpha$-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 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 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