Extending and Refining the Mass Surface around $^{208}$Pb

High-Precision Penning-Trap Mass Spectrometry with ISOLTRAP

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Overview
Technical Possibilities
Physics Aims
Physics Interest

- Octupole deformation
- R-process → nucleosynthesis path
- α-decay chains

- Z = 82
- N = 112
- N = 126

- Mid-shell behavior → shape coexistence
  → octupole correlations
  → isomerism

- Robustness of shell closure → residual interaction
  → shell gap
Current Performance of ISOLTRAP

- Accuracy $\approx 1 \cdot 10^{-8}$ achievable via frequency measurement to extract wanted mass
- Half-life $\approx 60$ms
- Production yield $\approx 100$ ions per second
- Efficiency $\approx 1\%$
- Resolving power for isobar separation $\approx 10^5$
- Contamination ratio $\approx 10^4:1$ plus $\approx 10^3:1$
- Resolving power for isomer separation $\approx 10^7$
- Time-of-flight detection via “Ramsey method”


Installed 2010
### Technical Achievements

- **N-rich Au**: newly developed RILIS scheme available
  - Suppression of Hg and Pb achievable

- **Hg and Pb isotopes**:
  - Tl and Fr suppressed by quartz transfer line due to further development
  - For n-deficient Hg and Pb current state-of-the-art targets sufficient

- **At isotopes**: RILIS ionization scheme successfully tested in 2010
  - Fr contamination for $A \geq 203$ removable by ISOLDE
  - Required resolving power and contamination ratio of Fr, Ra and Tl (n-deficient) lie well within the demonstrated capability of the MR-ToF mass separator

- **Fr isotopes**:
  - Separation of isobars possible due to improvement in selectivity at ISOLTRAP
# Beam Time Requests

<table>
<thead>
<tr>
<th>Nuclei</th>
<th>Shifts</th>
<th>Target</th>
<th>Ion Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>185m,190m Au</td>
<td>8</td>
<td>UCx</td>
<td>RILIS or hot plasma</td>
</tr>
<tr>
<td>202,204,205 Au</td>
<td>10</td>
<td>UCx</td>
<td>RILIS</td>
</tr>
<tr>
<td>183m Hg</td>
<td>2</td>
<td>Molten Pb</td>
<td>VADIS</td>
</tr>
<tr>
<td>185m,189m Pb</td>
<td>4</td>
<td>UCx</td>
<td>RILIS</td>
</tr>
<tr>
<td>194m,196,197,198,202,220-223 At</td>
<td>26</td>
<td>UCx</td>
<td>RILIS</td>
</tr>
<tr>
<td>200,201,202,206,226-234 Fr</td>
<td>26</td>
<td>UCx</td>
<td>RILIS</td>
</tr>
</tbody>
</table>

- Half-lives between 50ms and 10m
  - 5 cases not known or extrapolated
- Mass uncertainty between 30 and 400keV
  - 40% extrapolated or not known
- Yield between $10^0$ and $10^9$ ions/µC
  - measured and extrapolated, already demonstrated at ISOLTRAP
- MR-ToF mass separator calibration 0.3 shifts per A → 9 additional shifts
Nuclear Structure

- Evolution of shell strength -- Au, Hg
  - Test mean field approaches
  - Going beyond the mean field
  - Input for shell model calculations

- Mid-shell behavior -- At, Fr
  - Study isotopic chains to look for transitional regions
  - Onset of deformation accessible due to smaller uncertainties
  - Higher-order nucleon interaction
  - Adjustment of mass models, e.g. HFB-13

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R-Process and Deformation

- **r-process -- At, Fr**
  - Modeling of nucleosynthesis path
  - Consolidate nucleosynthesis path with additional data

- **Octupole Deformation -- At, Fr**
  - Shape parametrization within FRDM
  - Map evolution of changes in energy
Isomerism

- Isomerism -- Au, Hg, Pb, At, Fr
  - Low-lying isomeric states paired with shape coexistence or transformations
    - shape coexistence in $^{186}$Pb
    - shape staggering of Hg isotopes
  - Unambiguous identification with ISOLTRAP as input for spectroscopy experiments
  - States can be resolved with Penning-trap mass spectrometry using the time-of-flight detection technique

![Graph showing time of flight vs frequency for $^{194}$Tl isomer and ground state](image-url)
Priorities

- **2011 high priority (unknown or extrapolated masses / half-lives)**
  - r-process / octupole deformation
    - $^{226-228}$Fr, $^{231-234}$Fr, $^{221-223}$At
    - 21 shifts + 3 shifts
  - Shell strength
    - $^{202, 204, 205}$Au
    - 10 shifts + 1 shift

- **2011/2012 medium-high priority**
  - Shell strength
    - $^{207, 209, 210}$Hg
    - 0 shifts
  - Study of Isomerism
    - $^{185m, 190m}$Au, $^{183m}$Hg, $^{185m, 190m}$Pb, $^{198m}$At, $^{200m, 202m}$Fr
    - 18 shifts + 3 shifts

- **2012 medium priority**
  - Mid-shell behavior
    - At and Fr isotopes
    - 27 shifts + 3 shifts
The ISOLTRAP Collaboration

Thank you!

Missing: S. Eliseev, S. George, A. Herlert, S. Naimi, D. Neidherr, S. Schwarz
Future Developments

- N-deficient Au:
  - RILIS or hot plasma ion source because of higher yields
  - Target and ion source development (TISD) in cooperation with ISOLTRAP needed

- Hg and Pb isotopes:
  - Couple technical development of beam extraction to physics of this proposal
  - Outcome of Au measurements to be used towards ThO target development

- At isotopes: RILIS ionization scheme successfully tested in 2010
  - ISOLTRAP used as monitoring tool for TISD regarding yield enhancement

- Fr isotopes:
  - Yield of Ra contamination not higher than Fr
  - Separation possible due to improvement in selectivity at ISOLTRAP
Achievements and Aims

Not shown:
- Rn isotopes
- Tl isotopes (IS 463)
- Po isotopes (INTC-P-293)

Status 2002:
- Accuracy 1·10^{-7}
- Resolving power 3.7·10^6

N=126

Z=82

Fr
At
Bi
Tl
Au

N=112

N=126
Auxiliary Isobaric Purification

- Mass resolving power of MR-ToF mass separator of about $R=200,000$
- Bradbury-Nielsen beam gate used to select the wanted species
- $\alpha$-decay chains -- Pb, At, Fr
  - Small uncertainty of $Q_\alpha$-value