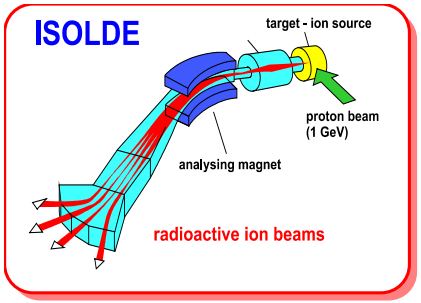
# Extending and Refining the Mass Surface around $^{208}$Pb

High-Precision Penning-Trap Mass Spectrometry with ISOLTRAP

Susanne Kreim
February 2nd 2011




Overview
Technical Possibilities
Physics Aims

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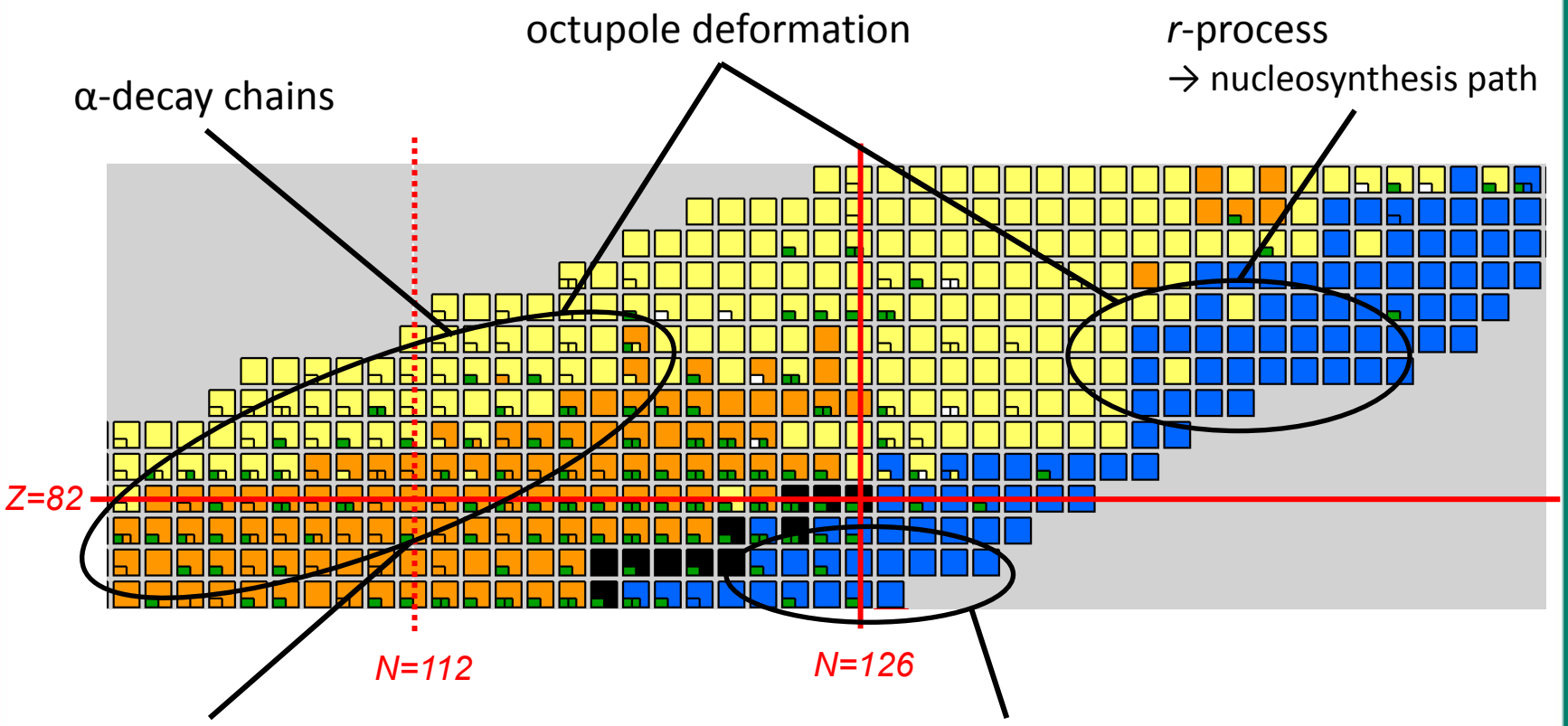
# Physics Interest




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

robustness of shell closure
→ residual interaction
→ shell gap



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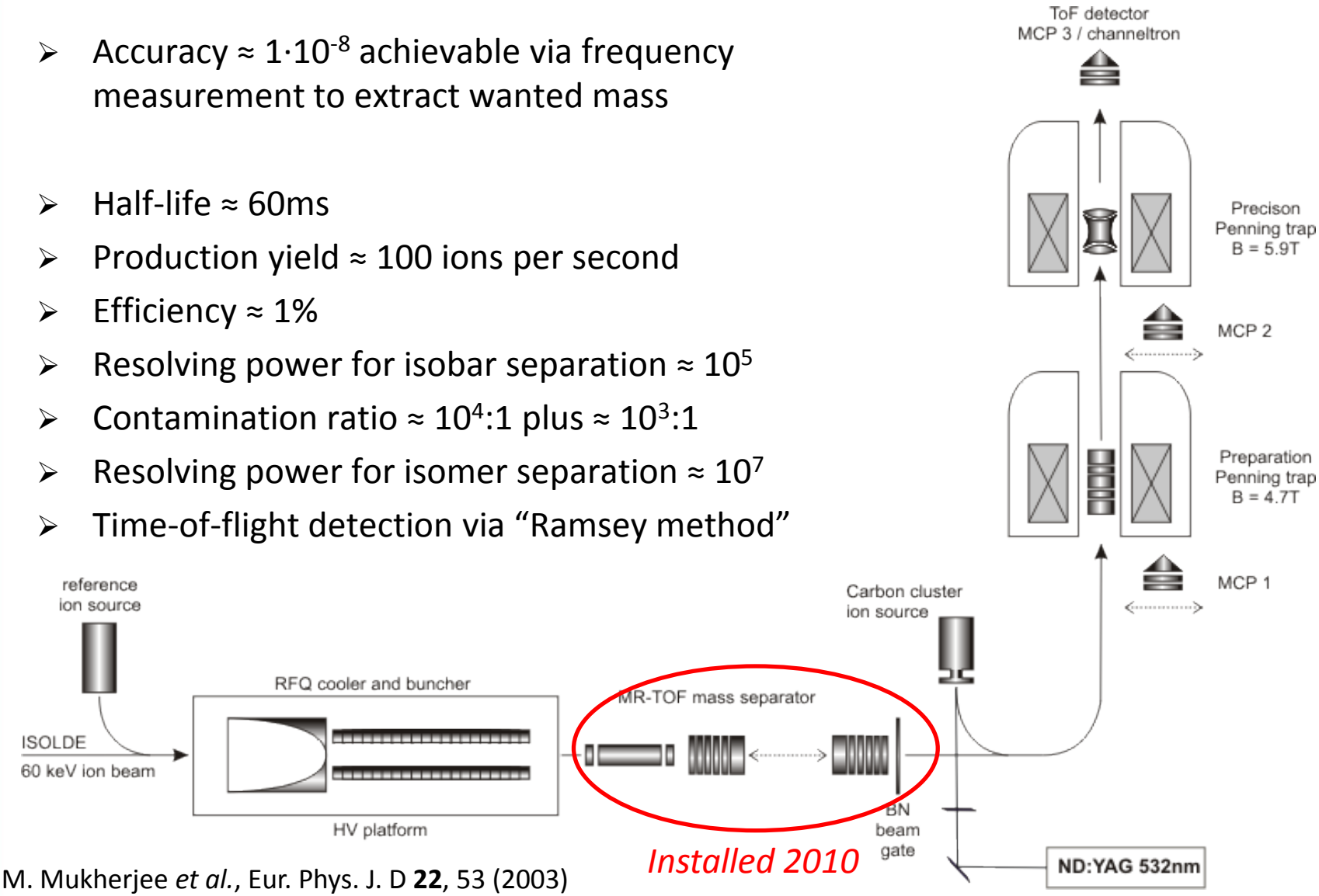
# Current Performance of ISOLTRAP

- Accuracy ≈ $1 \cdot 10^{-8}$ achievable via frequency measurement to extract wanted mass

- Half-life ≈ 60ms
- Production yield ≈ 100 ions per second
- Efficiency ≈ 1%
- Resolving power for isobar separation ≈ $10^5$
- Contamination ratio ≈ $10^4$:1 plus ≈ $10^3$:1
- Resolving power for isomer separation ≈ $10^7$
- Time-of-flight detection via "Ramsey method"




M. Mukherjee *et al.*, Eur. Phys. J. D **22**, 53 (2003)

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# 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 ≥ 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:
  - ✓ Sepration of isobars possible due to improvement in selectivity at ISOLTRAP

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# Beam Time Requests

| Nuclei | Shifts | Target | Ion Source |
|---|---|---|---|
| $^{185m,190m}$Au | 8 | UCx | RILIS or hot plasma |
| $^{202,204,205}$Au | 10 | UCx | RILIS |
| $^{183m}$Hg | 2 | Molten Pb | VADIS |
| $^{185m,189m}$Pb | 4 | UCx | RILIS |
| $^{194m,196,197,198,202,220-223}$At | 26 | UCx | RILIS |
| $^{200,201,202,206,226-234}$Fr | 26 | UCx | RILIS |

- 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

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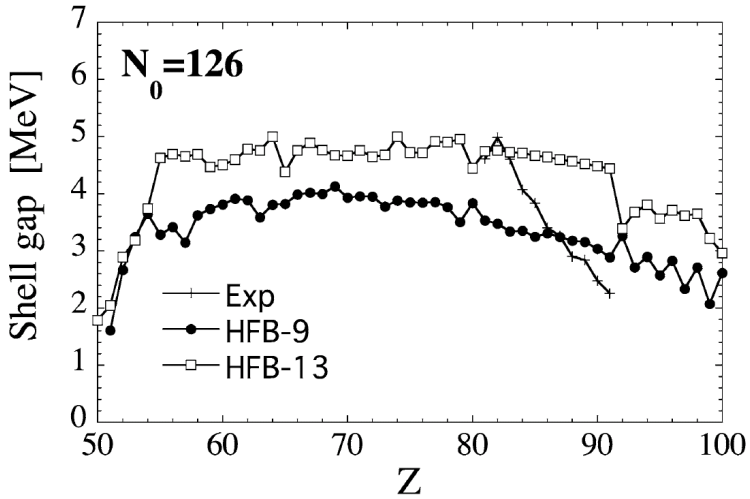
# Nuclear Structure

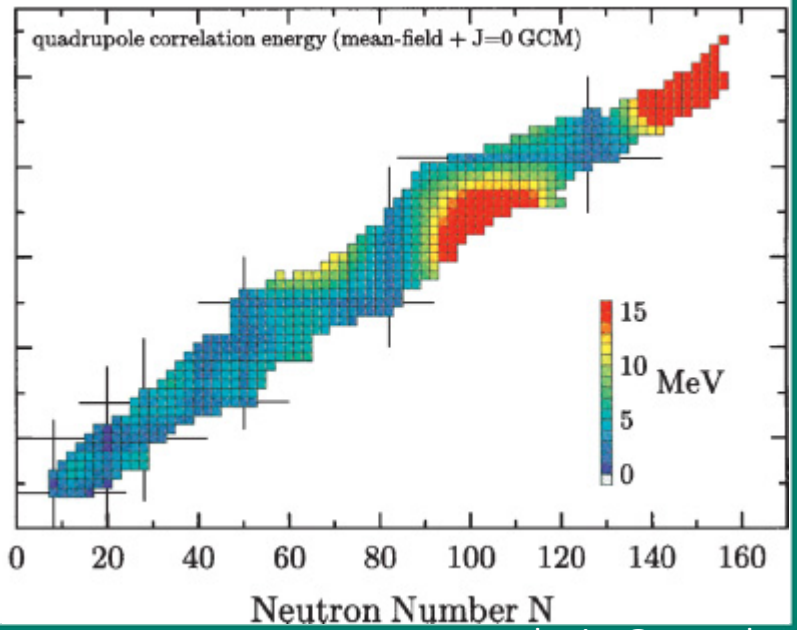
- Evolution of shell strength -- Au, Hg
  - ✓ Test mean field approaches

    S. Goriely *et al.*, Nucl. Phys. A **773**, 279 (2006)
  - ✓ 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 acessible due to smaller uncertainties

    M. Bender *et al.*, Phys. Rev. C **73**, 034322 (2006)
  - ✓ Higher-order nucleon interaction
  - ✓ Adjustment of mass models, e.g. HFB-13

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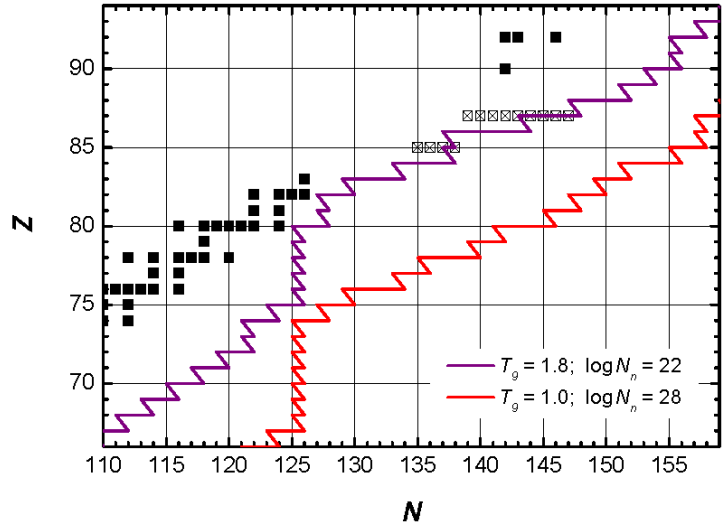
# R-Process and Deformation

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

    D. Neidherr *et al.*, Phys. Rev. Lett. **102**, 122503 (2009)

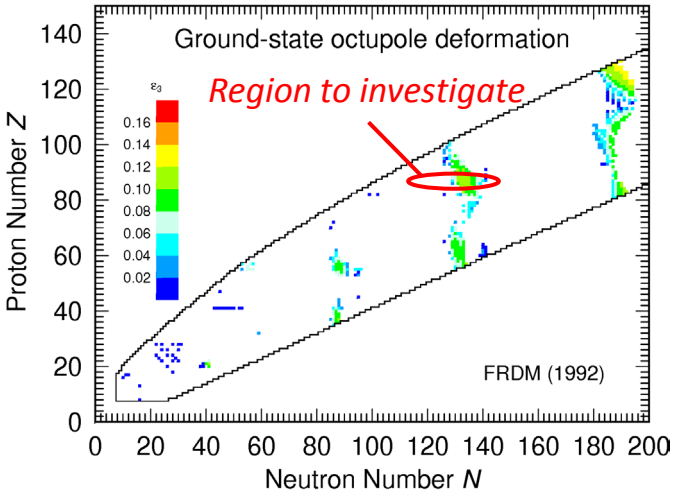



- Octupole Deformation -- At, Fr
  - ✓ Shape parametrization within FRDM

    P. Möller *et al.*, Atomic D. and Nucl. D. T. **59**, 185 (1995)
  - ✓ Map evolution of changes in energy

    D. Neidherr *et al.*, Phys. Rev. Lett. **102**, 122503 (2009)

    D. Neidherr *et al.*, Phys. Rev. C **80**, 044323 (2009)

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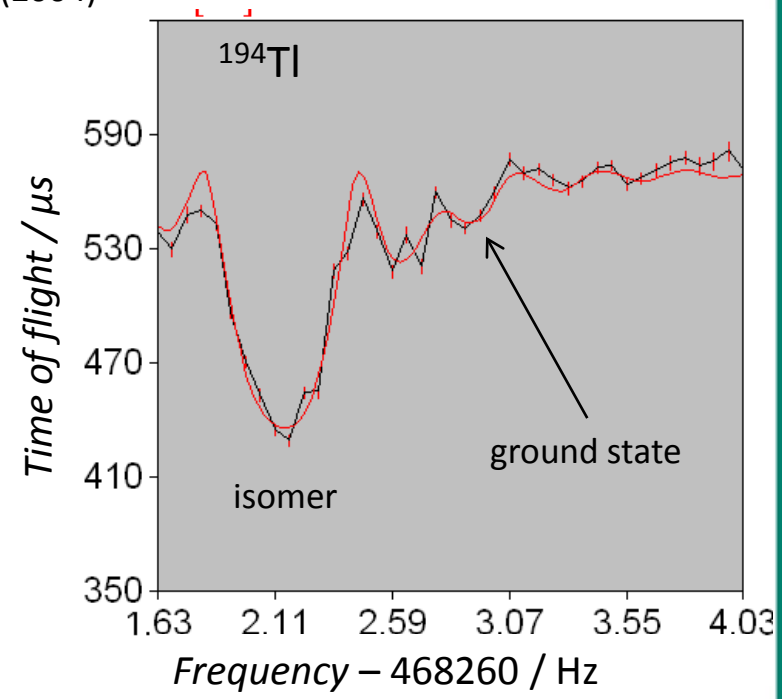
# Isomerism

- 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 istotopes
  - ✓ Unambiguous identification with ISOLTRAP as input for spectroscopy experiments
    S. Schwarz et al., Nucl. Phys. A 693, 533 (2001)
    J. van Roosbroeck *et al.*, Phys. Rev. Lett. **92**, 112501 (2004)
  - ✓ States can be resolved with Penning-trap mass spectrometry using the time-of-flight detection technique

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# 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

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# The ISOLTRAP Collaboration


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

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GSI

ISOLDE

CERN

KATHOLIEKE UNIVERSITEIT LEUVEN

UNIVERSITÉ PARIS-SUD 11

MICHIGAN STATE UNIVERSITY

TECHNISCHE UNIVERSITÄT DRESDEN

ERNST MORITZ ARNDT UNIVERSITÄT GREIFSWALD

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# 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
  - ✓ Sepration possible due to improvement in selectivity at ISOLTRAP

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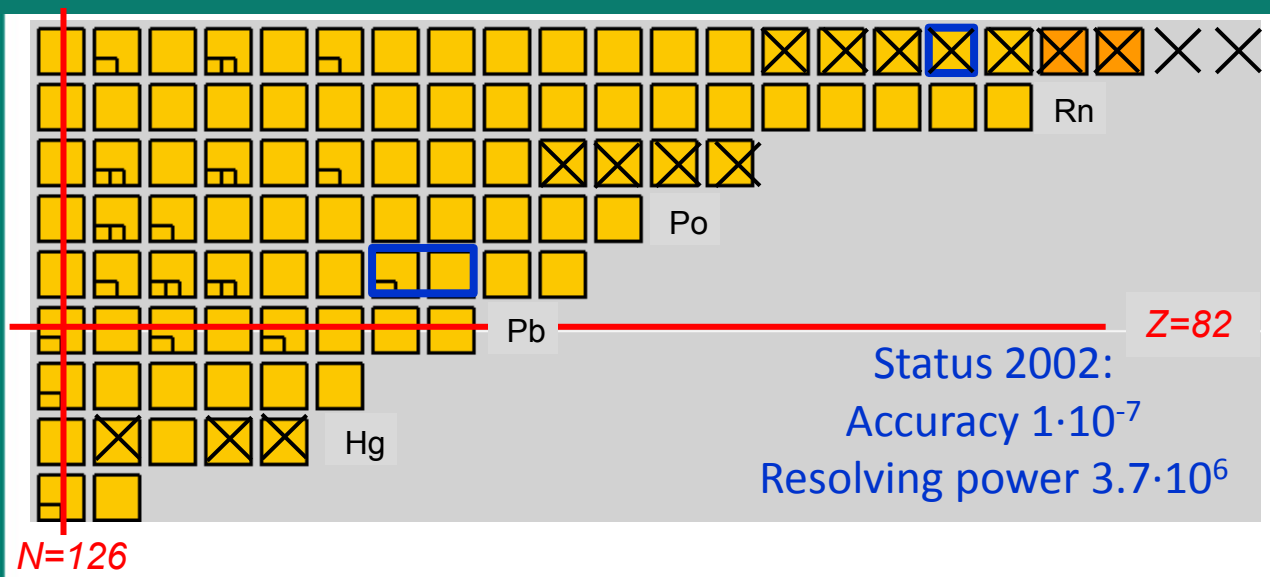
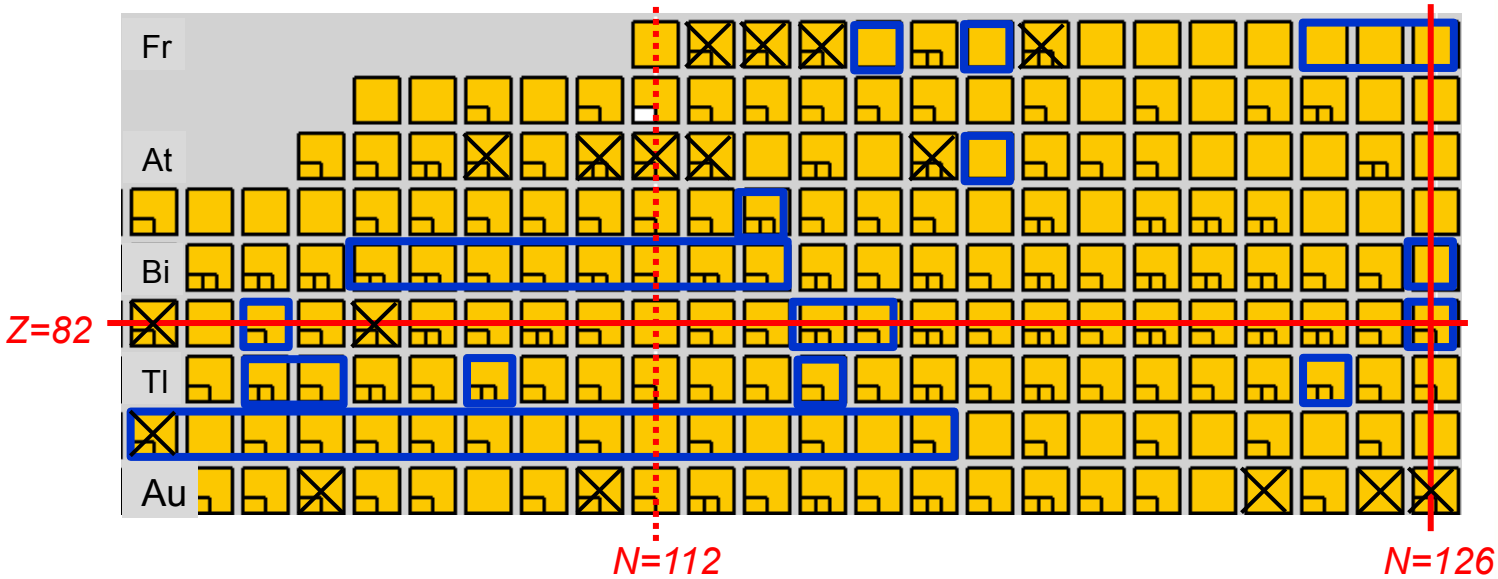
# Achievements and Aims




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

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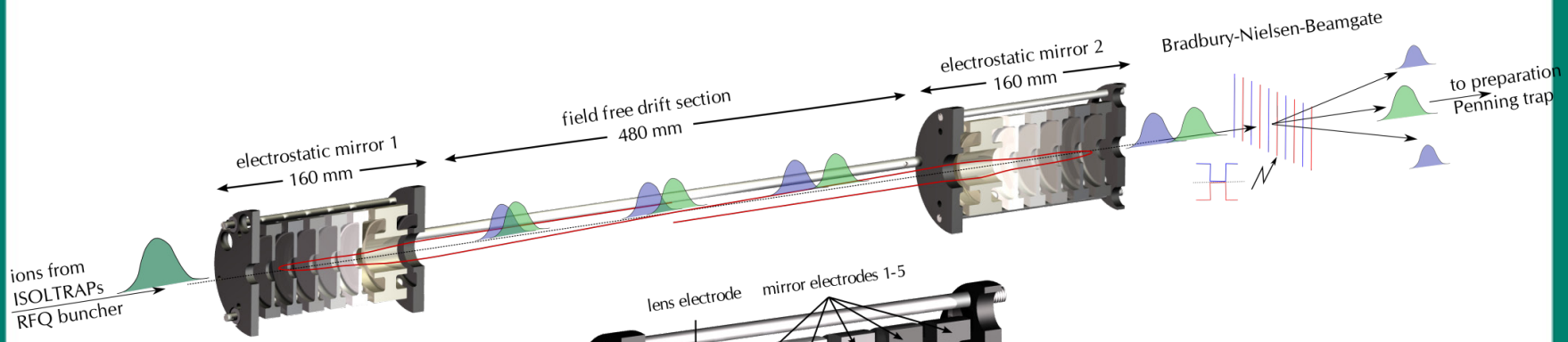
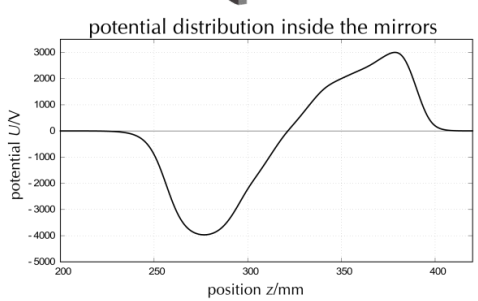
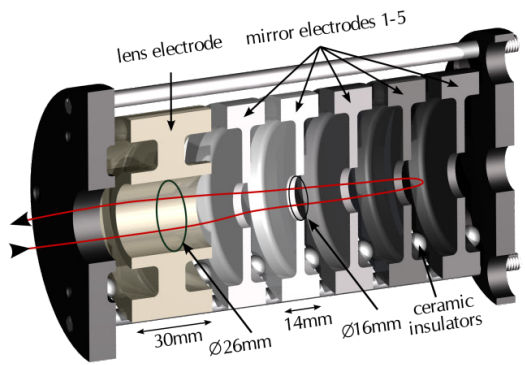
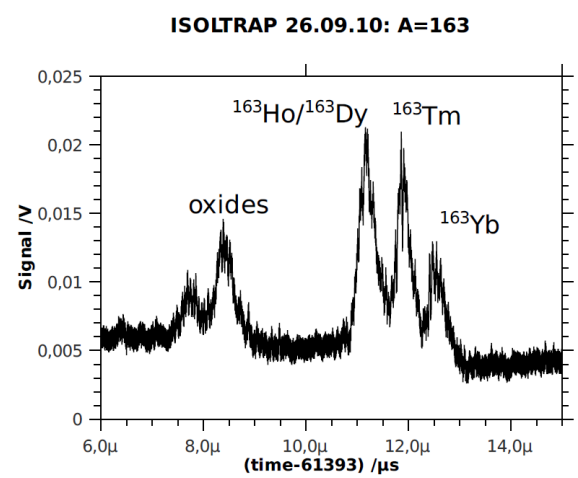
# Auxiliary Isobaric Purification

- Mass resolving power of MR-ToF mass separator of about R=200,000
- Bradbury-Nielsen beam gate used to select the wanted species

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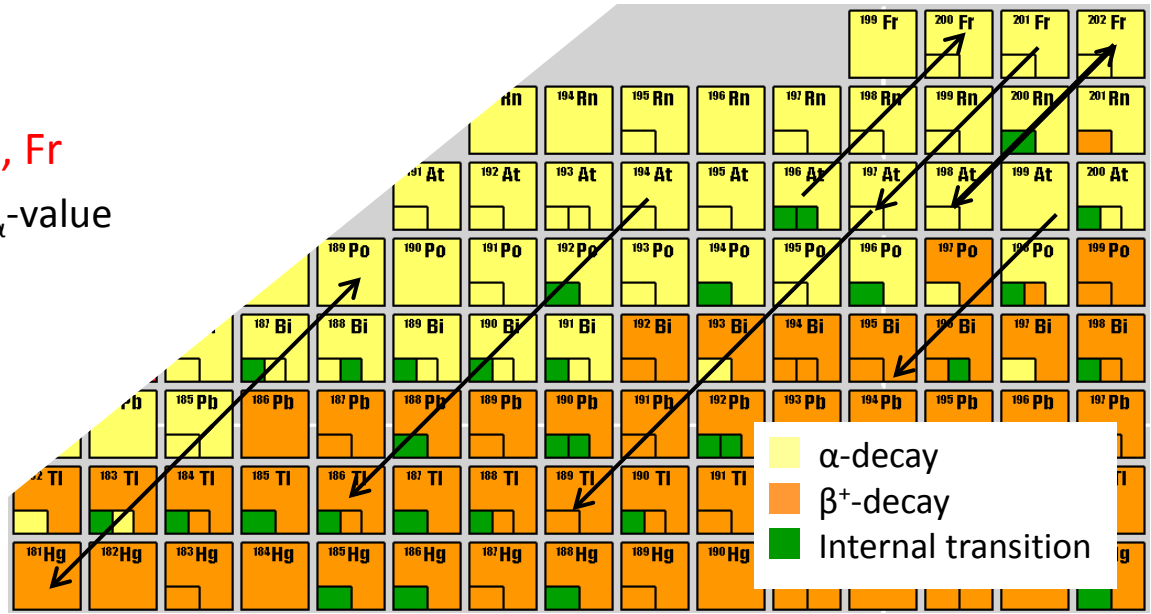
# α-Decay

- α-decay chains -- Pb, At, Fr
  - ✓ Small uncertainty of $Q_\alpha$-value

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