α decay, β-delayed fission and laser spectroscopy at CERN ISOLDE - The impact of the GSI target laboratory on the ISOLDE physics program

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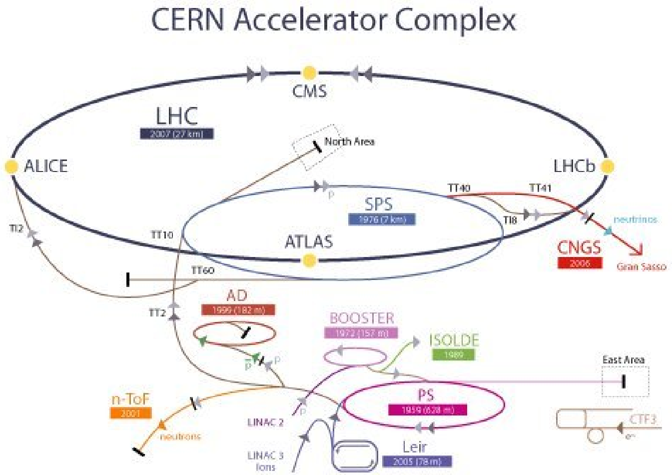
University of Manchester

April 24th 2013
Nustar Seminar - GSI

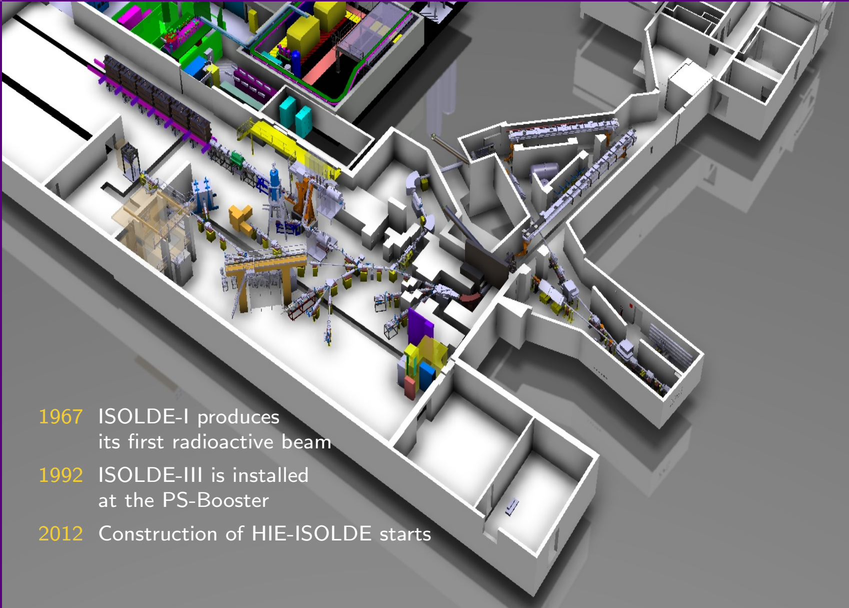
The CERN-ISOLDE Radioactive Ion Beam facility

A facility at CERN



The CERN-ISOLDE Radioactive Ion Beam facility

A big facility of small grounds



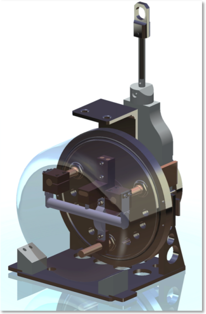
1967 ISOLDE-I produces its first radioactive beam

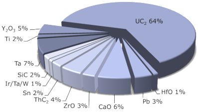
1992 ISOLDE-III is installed at the PS-Booster

2012 Construction of HIE-ISOLDE starts

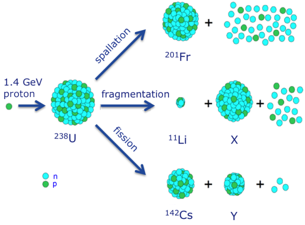
Radioactive ion beam production

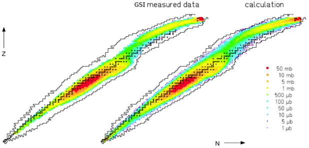
Thick targets for a small projectile





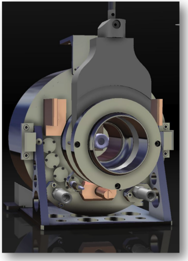
- Proton beam
  1.4 GeV
  up to 2 μA
- typical operation from Easter until Nicolaustag
- solid metal, liquid metal, oxides and carbides
  from Li up to U

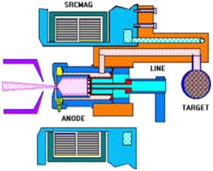




Pictures courtesy of A. Gottberg and S. Lukic *et al.*, NIMA 565(2006)784

Radioactive ion beam production
Ion sourcery





Surface ionisation

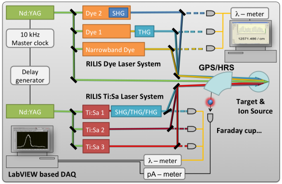
Alkali and elements with low IP (e.g. Tl)

Plasma ionisation

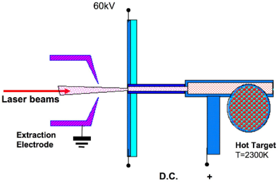
Gases

Laser ionisation

For all the rest!
Additional element selectivity
Always mixed with surface ionisation



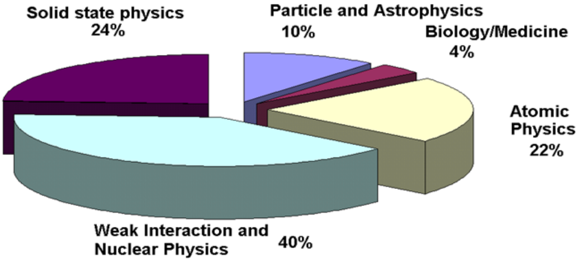
Yields depend on production cross sections, diffusion and effusion properties, ionisation efficiency, decay losses, and maybe more...



Pictures courtesy of A. Gottberg and S. Rothe

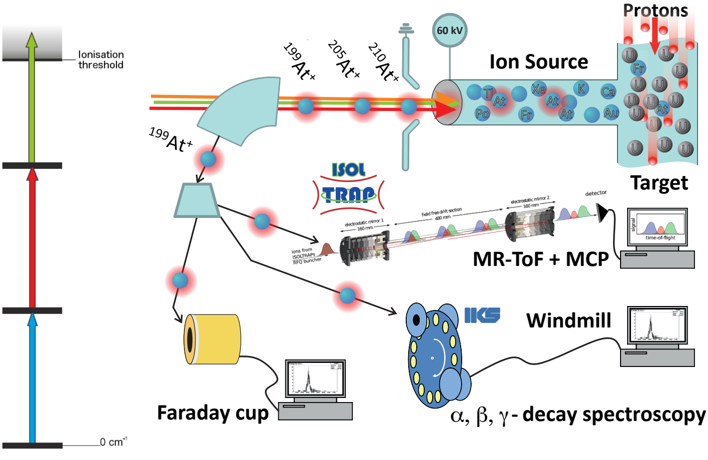
Physics at ISOLDE

Physics program



In-source laser spectroscopy

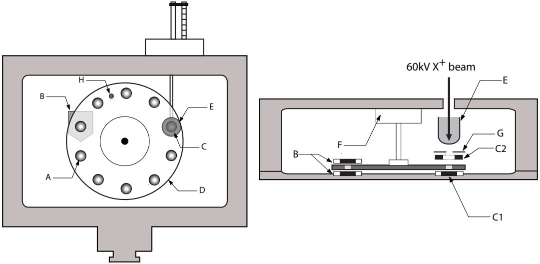
using the Resonant Ionisation Laser Ion Source

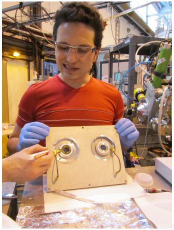


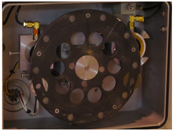
Picture courtesy of B.A. Marsh and S. Rothe

Windmill 1.4

A selective counting station





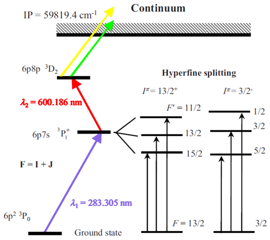


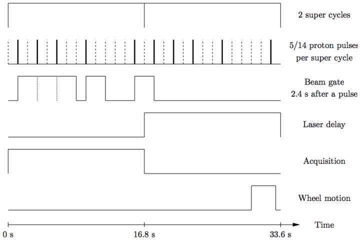
- A GSI-made C foil ($20\mu g/cm^2$).
- B 2 Si detector surrounding an off-axis point to observe unperturbed decay.
- C 2 Si detectors surrounding the implantation point on the beam axis to monitor short-lived activity.
  The upstream Si detector (C2) has a hole to let the beam through.
- D Rotatable wheel with 10 positions.
  The motion from on-axis to off-axis takes up to 1 second.
- E Retractable Faraday cup for beam monitoring and beam tuning.
- F Stepping motor.
- G Collimator to protect the annular Si detector.

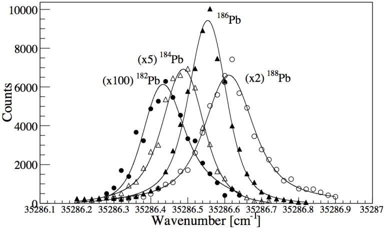
Pictures courtesy of B.A. Marsh and C. Van Beveren

In-source laser spectroscopy

As easy as lead







- 30 s sampling per point
- FWHM ∼ 4 GHz (Doppler broadening)
- Sensitivity to below 1 atom per s

H. De Witte et al., PRL 98 (2007) 112502.

M.D. Seliverstov et al., EPJA 41 (2009) 315.

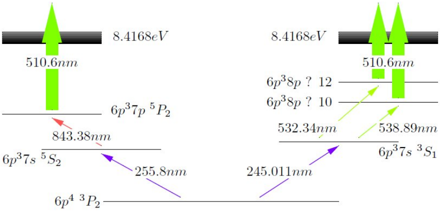
In-source laser spectroscopy

Not that easy anymore

Unknown atomic structures

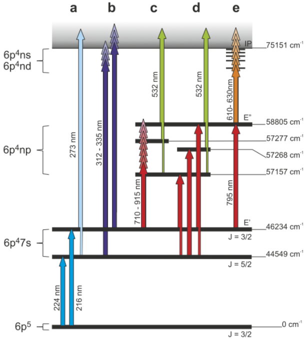
Due to their lack of naturally occurring stable isotopes, few elements have only limited information available, e.g. Po, At.

Atomic spectroscopy first had to be performed online to search for efficient ionisation schemes that would also be sensitive to the nuclear observables of interest.



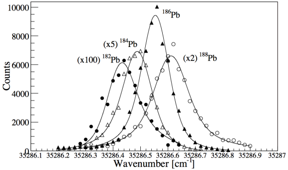
Po: T.E. Cocolios, B.A. Marsh et al., NIMB 266 (2008) 4403.

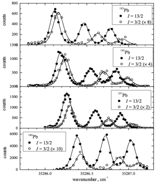
At: S. Rothe et al., Nature Communications, in print.



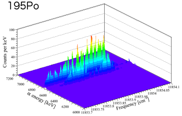
The University of Manchester
MANCHESTER 1824

Even-Z nuclei
A wealth of data

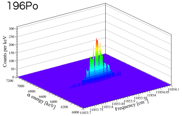




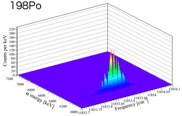
195Po

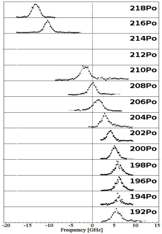


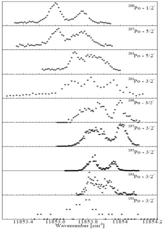
196Po

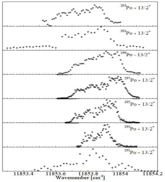


198Po



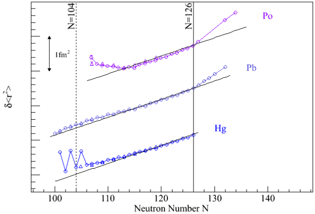


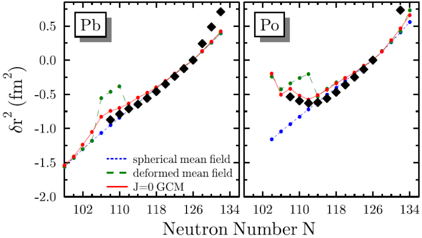




Even-Z nuclei

Shape coexistence around $Z = 82$





- Pb follows spherical droplet predictions
- Po departs early and steadily from spherical droplet predictions
- BMF calculations reproduce the trends and point towards an ill-defined shape, yet spherical on average

H. De Witte et al., PRL 98 (2007) 112502.
M.D. Seliverstov et al., EPJA 41 (2009) 315.

T.E. Cocolios et al., PRL 106 (2011) 052503.
M.D. Seliverstov et al., PLB 719 (2013) 362.

Even-Z nuclei

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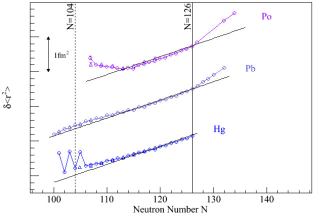
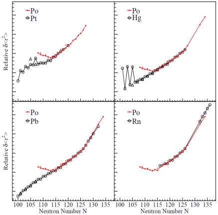
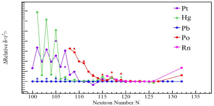




- relative $\delta\langle r^2\rangle$ take away the atomic systematic effects
- all isotopic chains agree extremely well close to $N = 126$
- departure from sphericity is very different in all cases



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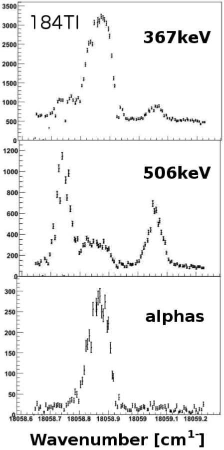
T.E. Cocolios et al., PRL 106 (2011) 052503.
M.D. Seliverstov et al., PLB 719 (2013) 362.

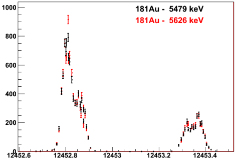
Odd-Z nuclei

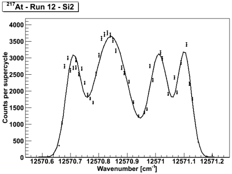
New data

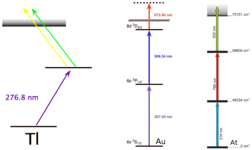
2011-2012 data

A new series of campaigns has been performed in 2011 and 2012 on $_{79}$Au, $_{81}$Tl and $_{85}$At. The use of the ISOLTRAP MR-ToF-MS has brought new possibilities to bridge the gap between FC detection and decay tagging. The analysis is still on-going.





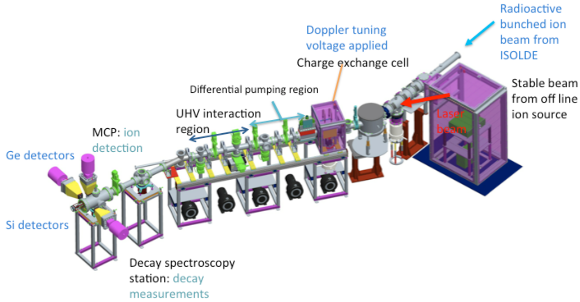




ISOLTRAP's MR-ToF-MS: R.N. Wolf et al., NIMA 686 (2012) 82.

Collinear Resonant Ionisation Spectroscopy

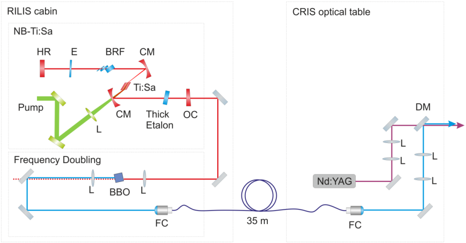
Recovering the resolution in-flight

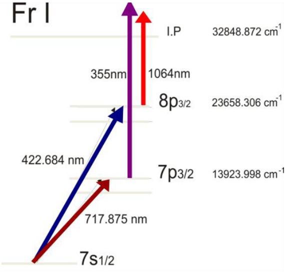


Layout of the CRIS beam line

- Bunches are delivered from the ISOLDE HRS ISCOOL at 30 to 50 keV;
- Ions are (Doppler-tuned and) neutralized in a K charge exchange cell operated at 10^{-6} mbar;
- Non-neutralized ions are deflected away while the atoms drift through the interaction region, maintained at $< 10^{-9}$ mbar;
- Lasers are sent through the interaction region;
- Re-ionized isotopes are deflected towards an MCP or an α-decay station.

CRIS@ISOLDE
The laser system





Pictures courtesy of R.E. Rossel & S. Rothe

RILIS + CRIS

- 10kHz 422nm light from the RILIS Ti:Sa laser system with a bandwidth of $\sim$ 1GHz is fibre-coupled to the CRIS experiment;
- 30Hz 1064nm light from a Nd:YAG laser is mixed with the blue light at the CRIS experiment and is delivered to the beam line.

CRIS@ISOLDE

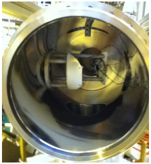
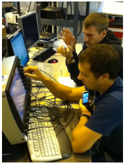
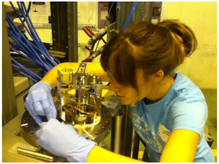
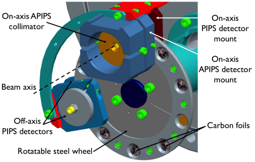
Counting ions

MCP counting

- The ions are sent onto a biased copper plate;
- Secondary electrons are guided to an MCP and recorded;
- The MCP signal is processed in a digital scope, triggered by the Nd:YAG laser in order to accept signals in sync with the ion bunch passing through the experiment.

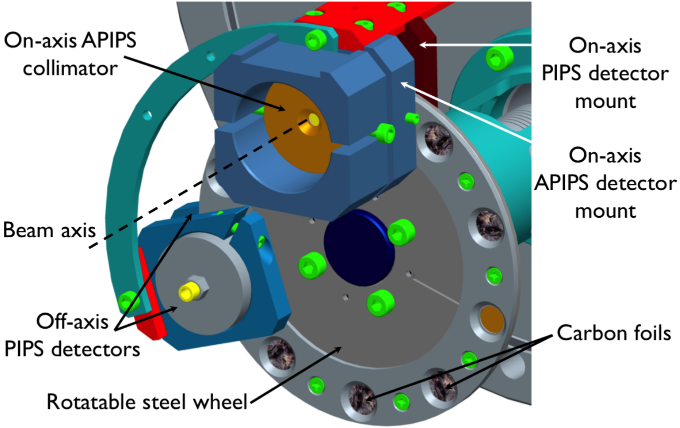
α counting

- The ions are implanted in 1 of 9 C foil (20μg/cm^2);
- 2 Si detectors surround the C foil;
- up to 3 Ge detectors can be placed around the DSS.
- To identify the respective components of mixed hyperfine structures;
- To perform decay spectroscopy on ultra-pure samples.

CRIS@ISOLDE

Counting ions



2012 experimental campaign

Study of the francium isotopic chain

One successful test beam time (Aug'12) and one successful beam time (Oct'12) have allowed to study 17 hyperfine structures, including 9 new isotopes and 4 isomers.

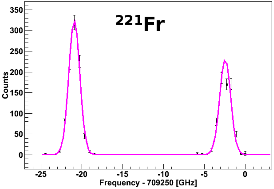
High efficiency

- Neutralization efficiency of 1:2;
- Total efficiency for resonant ions of 1:60 has been reached in Fr;
- ^{202}Fr has been effortlessly measured with 100 ions per second.

High purity

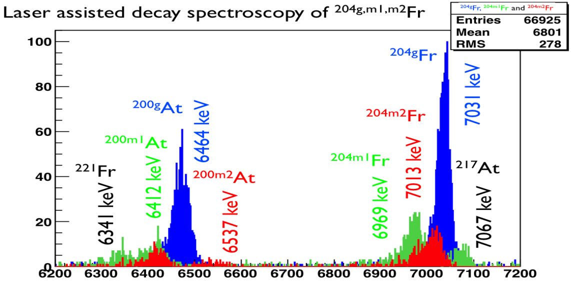
- Total collisional background efficiency of 1:300 000 at a pressure of $8 \cdot 10^{9}$mbar;
- Background-free measurement in the most exotic cases (e.g. ^{202}Fr);

⇒ 99.98% purity on isomer selection.



α tagging

Identifying hyperfine components with the DSS

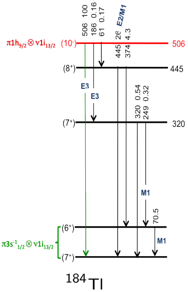


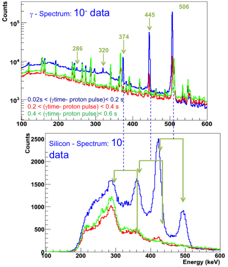
Isomeric beams

- Scans on the MCP revealed many components;
- Each component was sent to the DSS to observe the respective α decay;
- The peaks in the hyperfine structure can then be associated with their respective states.
- Additionally, purified beams of isomer corresponding with a mass resolving power $M/\Delta M \sim 5 \cdot 10^6$ have been produced.

β decay on pure samples

Combining the selectivity of RILIS and ISOLDE

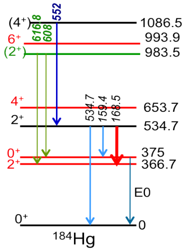


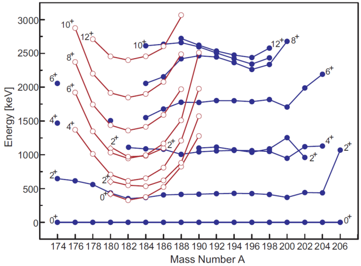


Internal transitions and β decay

Ratio of isomers within the beam can be manipulated so as to create pure spectra of the different states. This allows the construction of accurate decay schemes.

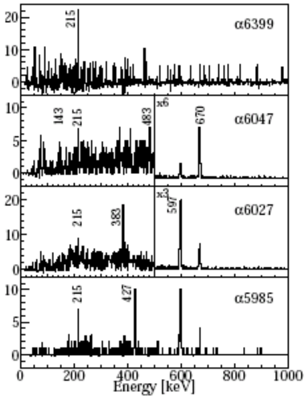
Pictures courtesy of E. Rapisarda and J. Elseviers et al., PRC 84 (2011) 034307.

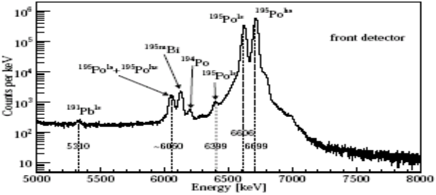


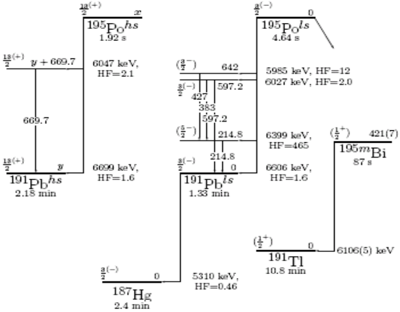


α decay on pure samples

^{195}Po with RILIS



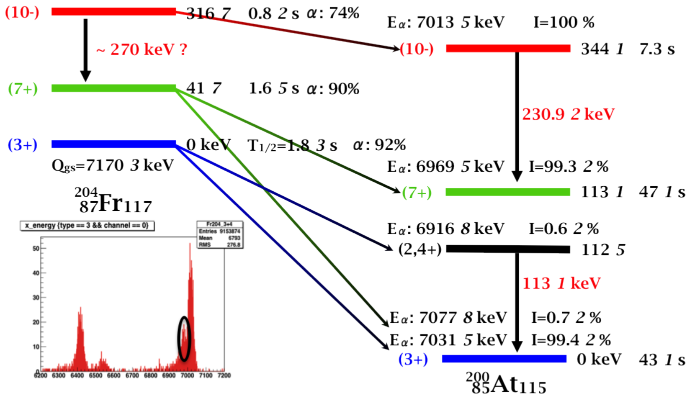




T.E. Cocolios et al., JPG 37 (2010) 125103.

α decay on pure samples

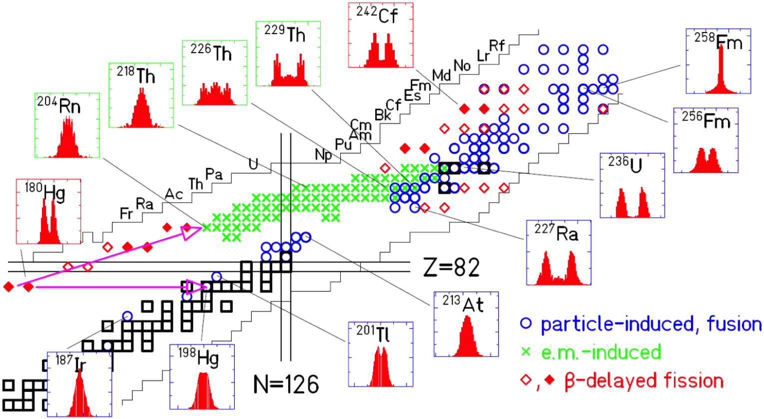
^{204}Fr with CRIS



Picture courtesy of K.M. Lynch.

β-delayed fission

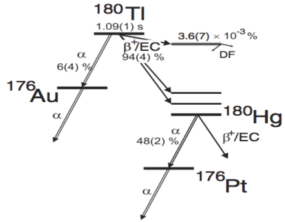
A rare nuclear decay mechanism

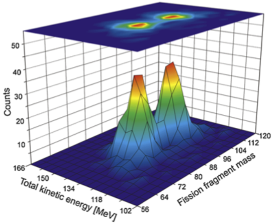


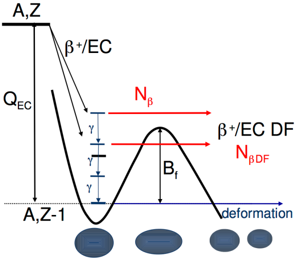
Picture courtesy of A.N. Andreyev and L. Ghys.

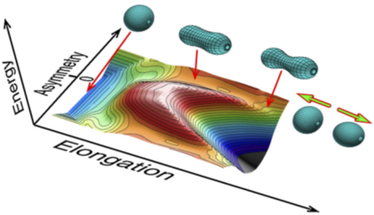
β-delayed fission

Asymmetric fission in ^{180}Tl





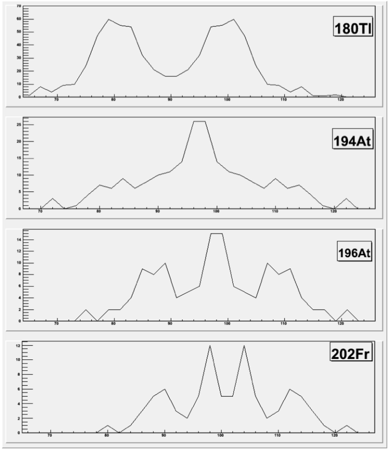




A.N. Andreyev, J. Elseviers et al., PRL 105 (2010) 252502.

β-delayed fission

Mixed fission in At and Fr

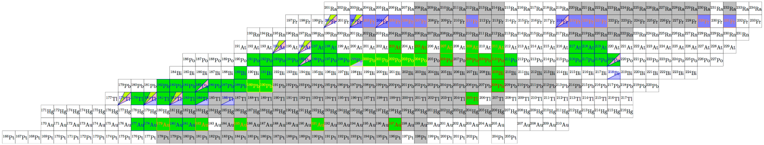


Picture courtesy of A.N. Andreyev and L. Ghys.

On-going analysis

New data has been collected on ^{194,196}At and ^{200,202}Fr. The analysis is still on-going but points to a smooth transition between symmetric and asymmetric fission. Isomeric beams, using RILIS (At) or CRIS (Fr) are required to disentangle the decay patterns and identify a possible spin dependence on the process.

Summary



Conclusion

- An extensive program around shape coexistence and β-delayed fission is currently being undertaken at ISOLDE.
- The low-energy studies make use of Windmill setups with silicon detectors for the study of α decay and fission.
- Upgrades and new designs are currently being investigated.
- New proposals are in preparation.

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