The experimental facility of GSI for production and isotopic identification of radioactive beams.

(Karl-Heinz Schmidt, GSI Darmstadt)

1. **Physics goals far from stability.**
2. **Methods for producing radioactive beams.**
3. **Requirements for a versatile in-flight facility.**
4. **The components of the GSI facility.**
5. **Separation and identification.**
6. **Some representative experiments**

Some physics goals far from stability

1. Ground-state properties (masses, moments)

2. Systematics of nuclear excitations (spectroscopy)

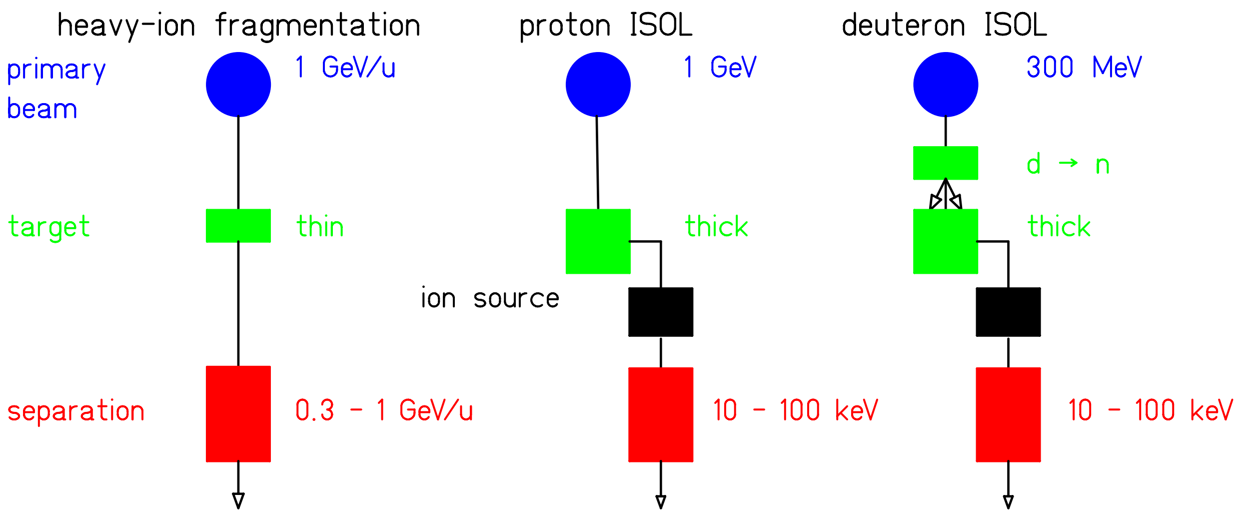
3. Nuclear structure at the extremes
   (extreme N/Z ratio, extreme deformation)

4. The continuum structure of nuclei (halos)

5. Limits of bound nuclei (driplines, superheavy elements)

6. Astrophysics (reaction rates, waiting points,
   the r-process path)

Methods for the production of secondary beams (Some examples)



Projectile fragmentation → **GSI option**

Special requirements on prim.-beam selection and energy.
Needs powerful equipment for in-flight separation.
Not restricted by radioactive decay and chemistry.
Provides high-energy radioactive beams.

Target fragmentation + ISOL

Post-acceleration decouples production and sec.-beam energy.

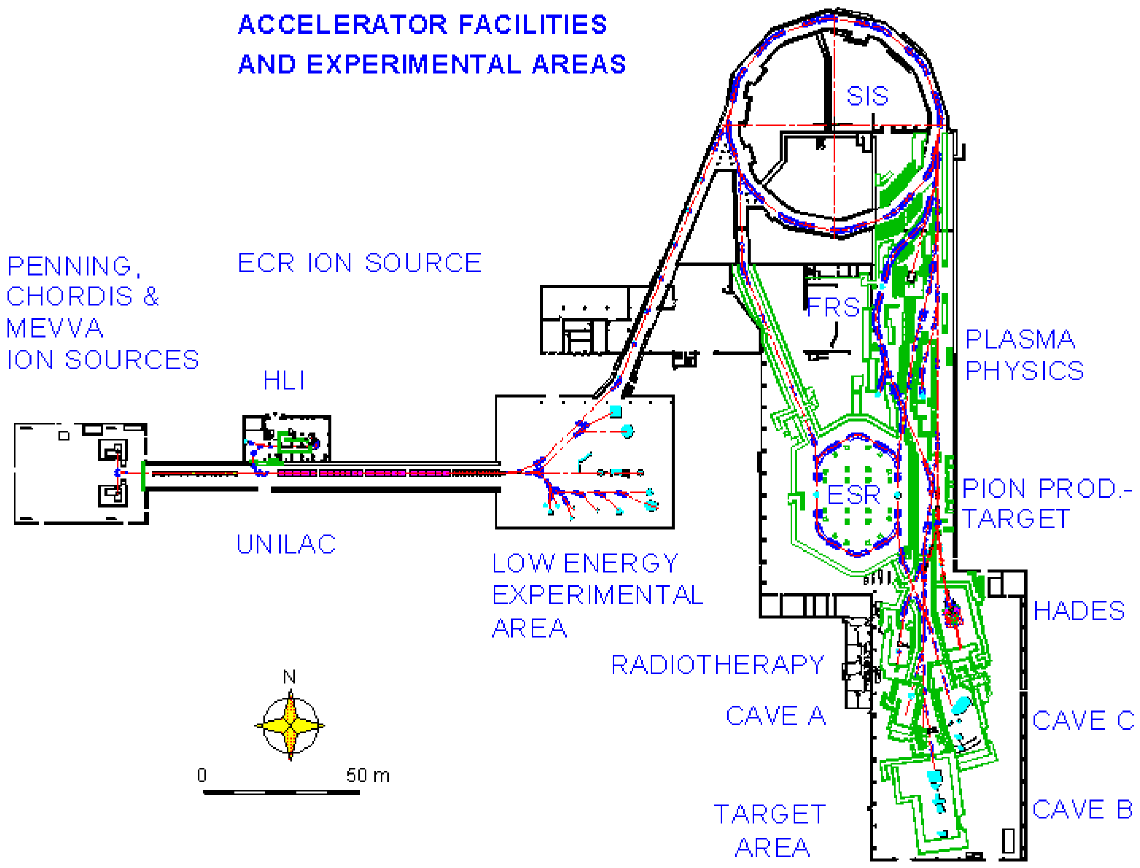
Deuteron - neutron conversion + target fragmentation + ISOL

Avoids heating by electronic energy loss in production target.

Requirements for a versatile in-flight secondary-beam facility

- **Availability of all stable nuclei as primary beam.**
- **Energy of primary beam from Coulomb barrier to full stripping of uranium.**
- **Full separation and identification of secondary beams.**
- **Powerful spectrometers and other analysis devices.**

The facilities of GSI



Installations for secondary beams:

UNILAC: Universal linear accelerator (E ≤ 20 A MeV).

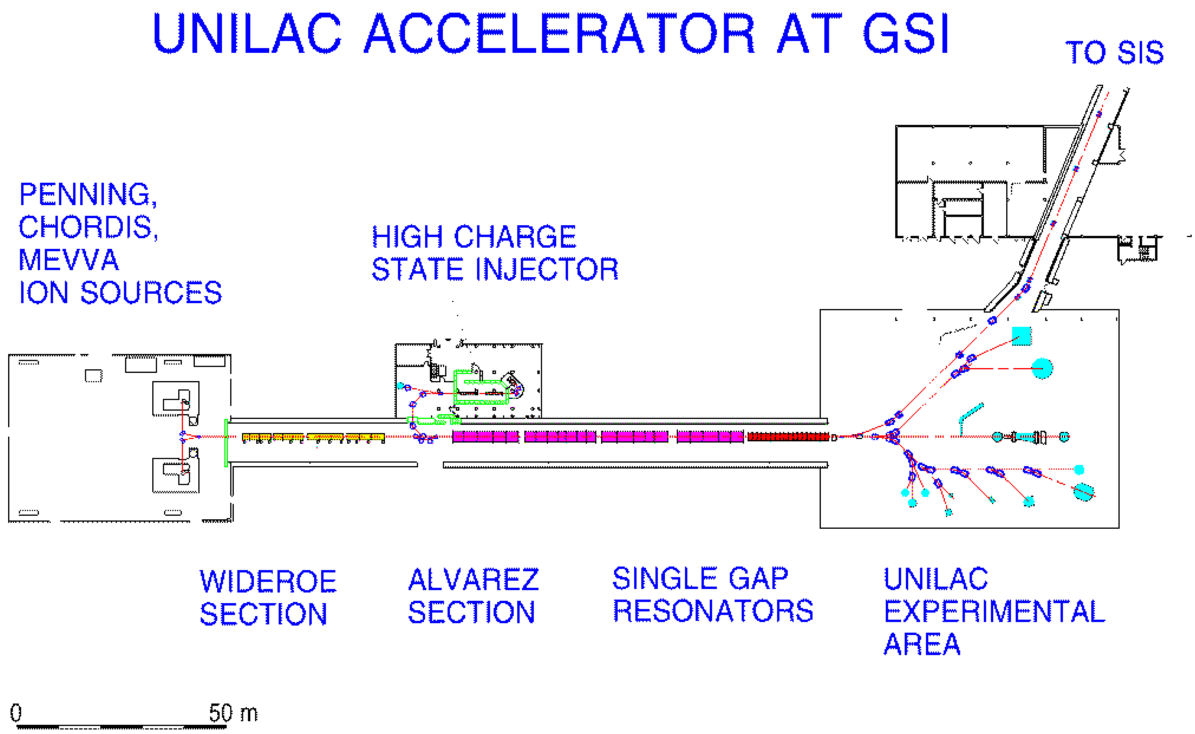
SIS18: Heavy-ion synchrotron (E ≤ 1 ... 2 A GeV).

FRS: Magnetic spectrometer for separation of radioactive beams of projectile-like residues.

ESR: Experimental storage ring.

CAVE B: Large-acceptance magnet ALADIN.

UNILAC

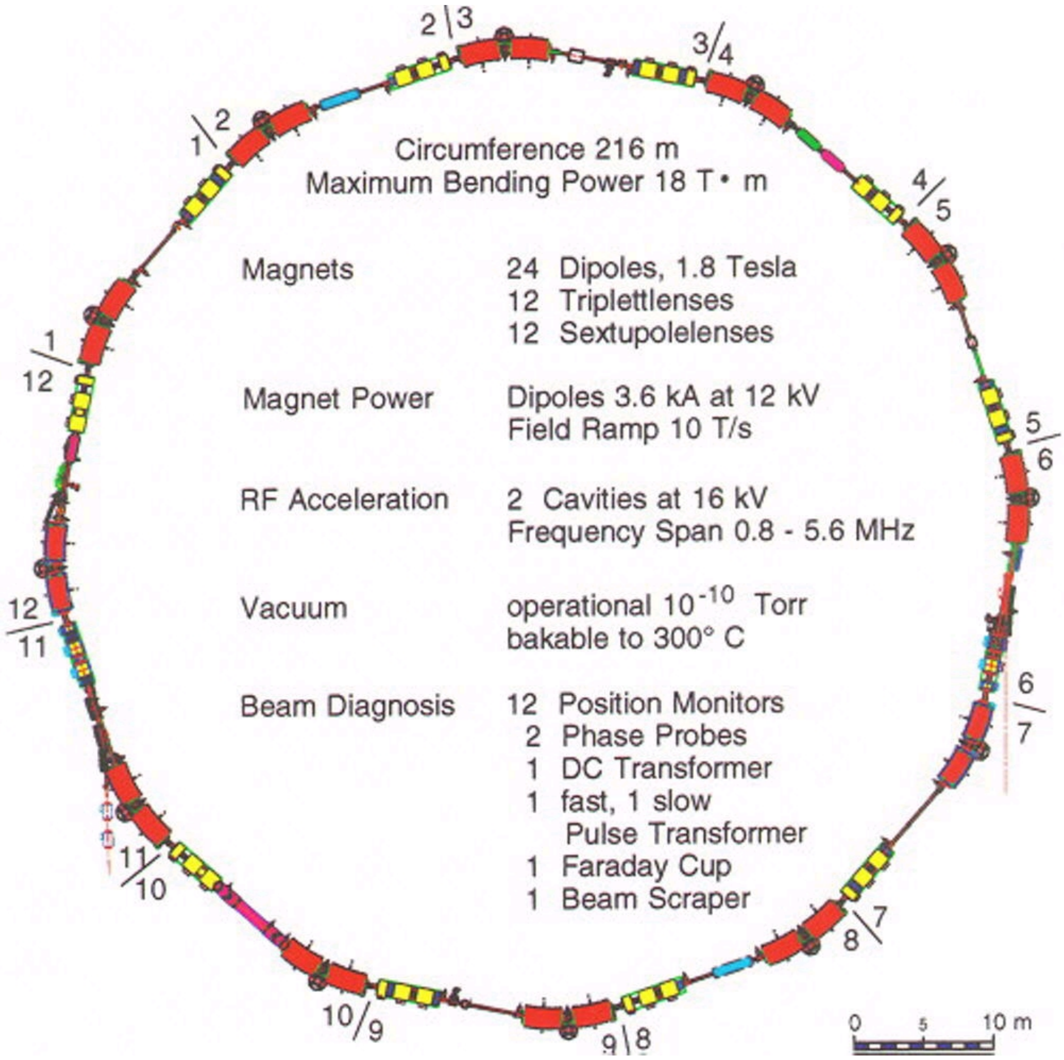


The universal linear accelerator for all stable isotopes to energies above the Coulomb barrier (energy per nucleon up to 20 MeV).

Acceleration in small steps in many HF cavities.

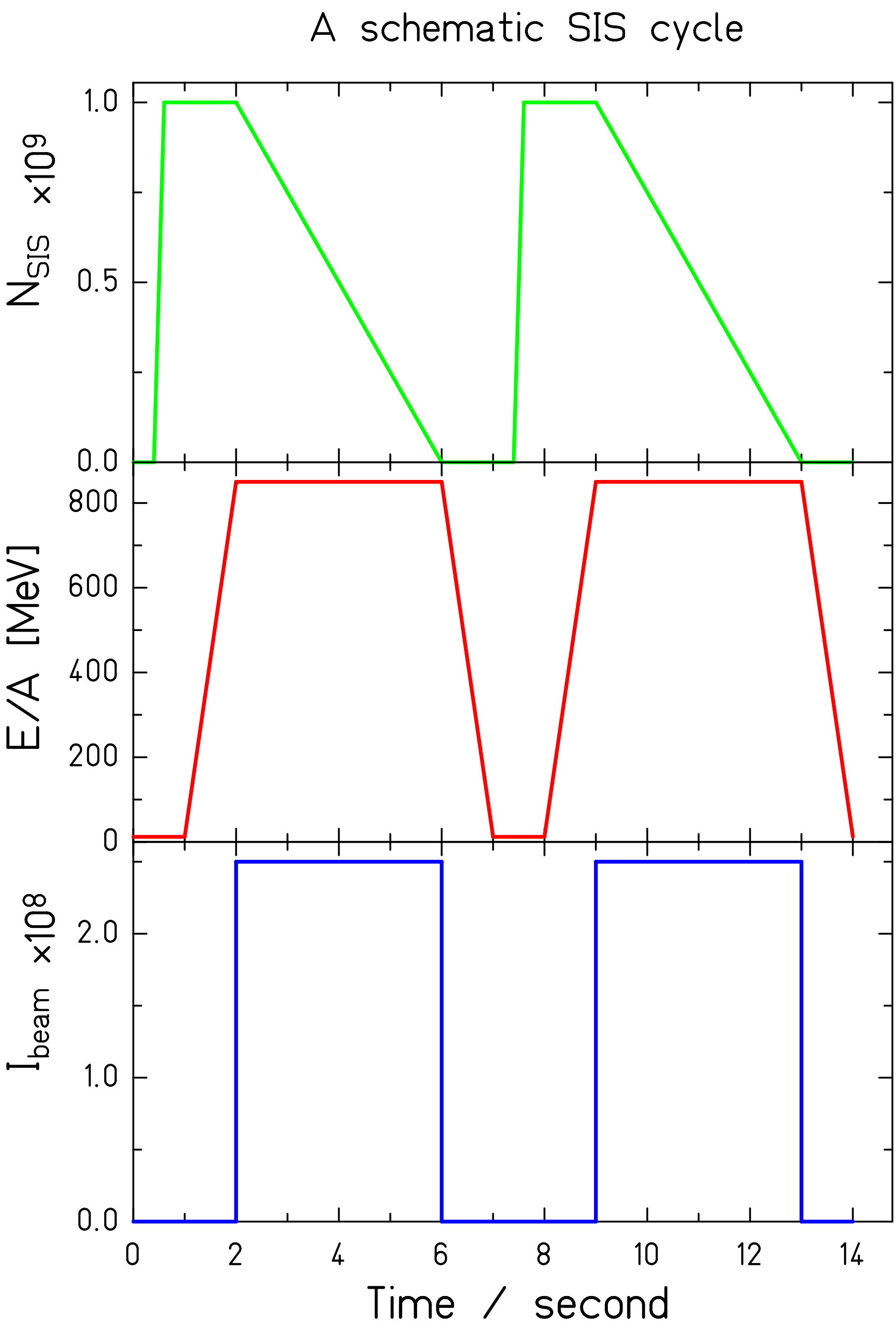
Strippers are inserted to increase ionic charge for efficient acceleration.

SIS18



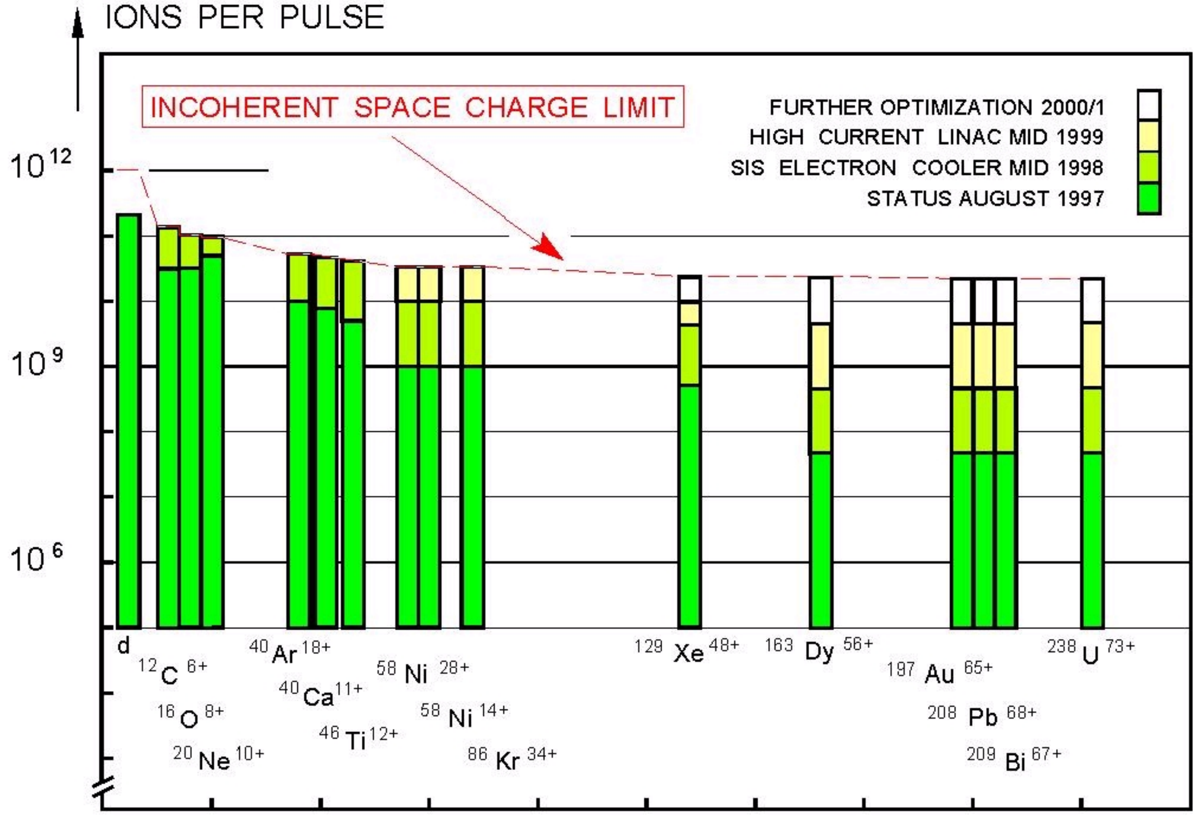
Operation cycle:
Injection - acceleration - extraction

Only short injection time.
Only 1 cavity needed for acceleration.
Ramping of magnets synchronised to acceleration.
No stripping possible.
High energy - ionic charge far from equilibrium
-> needs very good vacuum.
Fast or slow extraction.

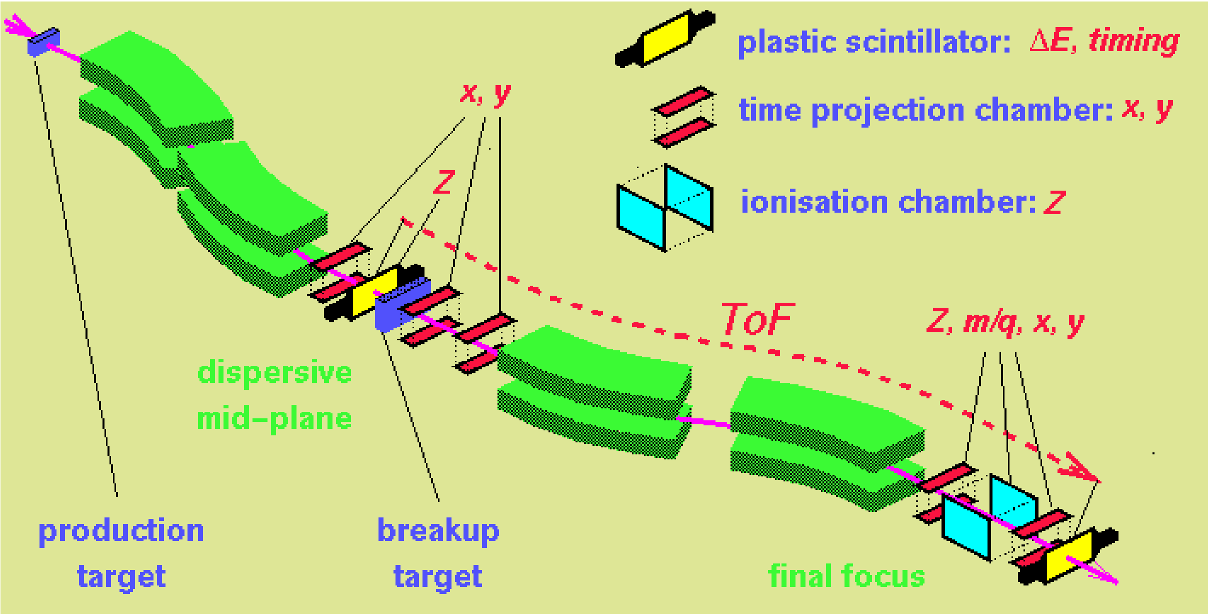


A schematic SIS cycle
N_{SIS} ×10⁹
1.0
0.5
0.0
E/A [MeV]
800
600
400
200
0
I_{beam} ×10⁸
2.0
1.0
0.0
0
2
4
6
8
10
12
14
Time / second

Intensities of ion beams from SIS



Fragment Separator

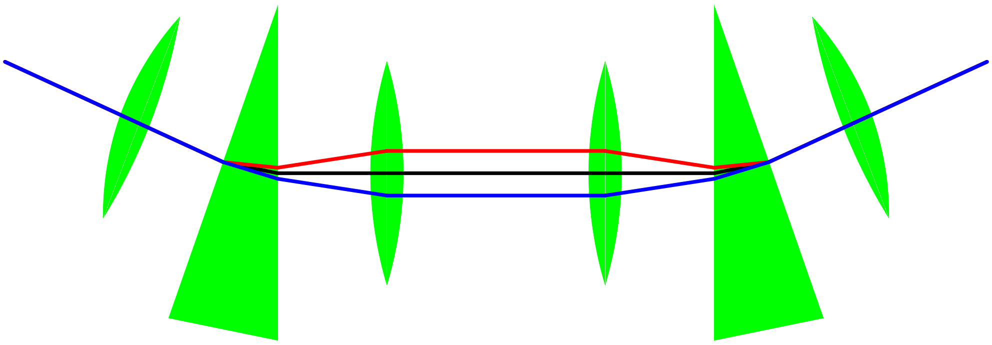


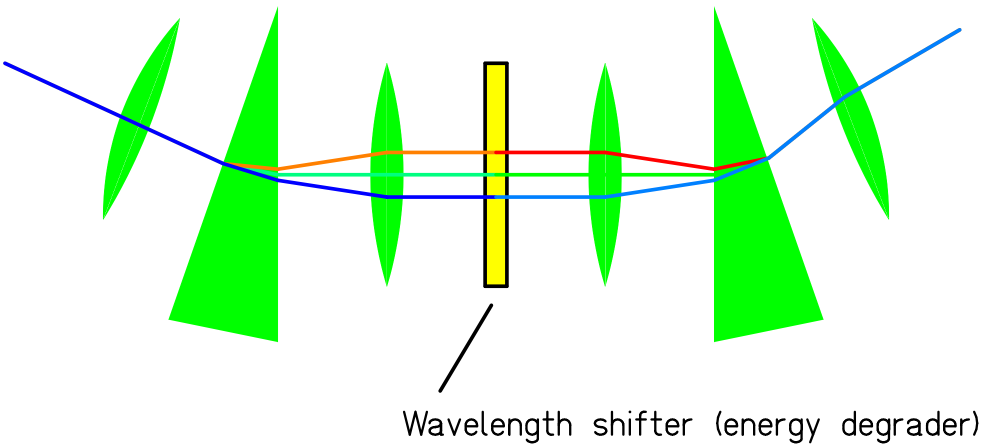
A two-stage magnetic spectrometer with

- **dispersive intermediate image plane and**
- **achromatic final image plane.**

Analogon of energy-loss spectrometer

(Only central trajectories are shown.)





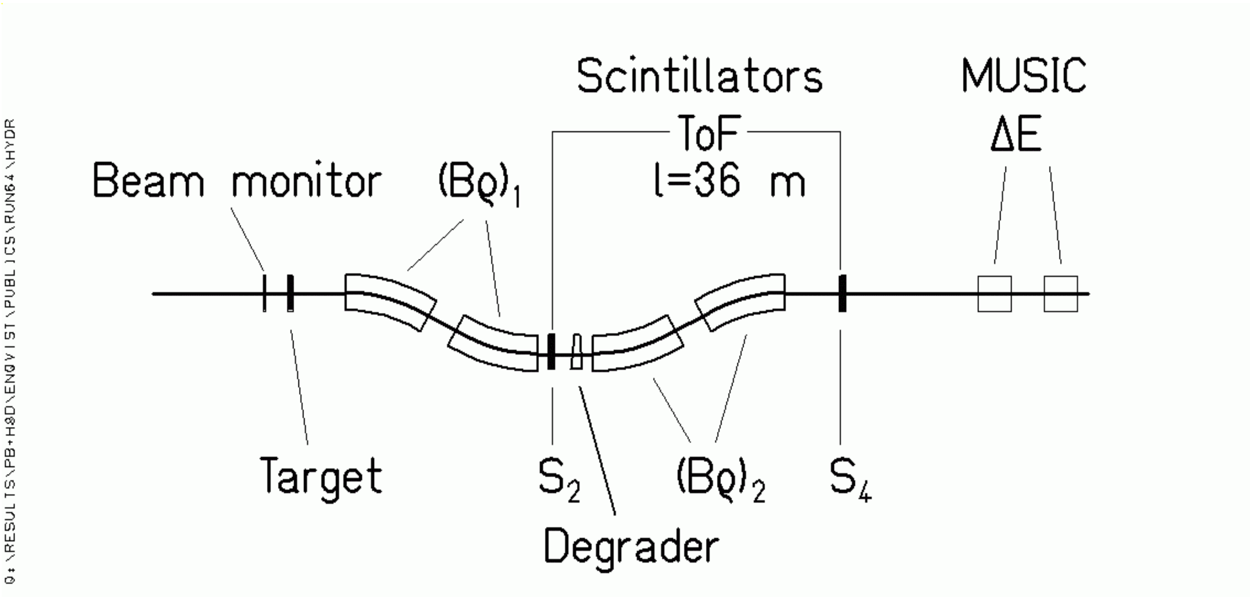
Position in central plane → wavelength

(in FRS: $p/q \approx A/Z$)

Position in exit plane → wavelength shift

(in FRS: $\Delta E \approx Z^2$)

The Fragment Separator



Projectile-like fragments:

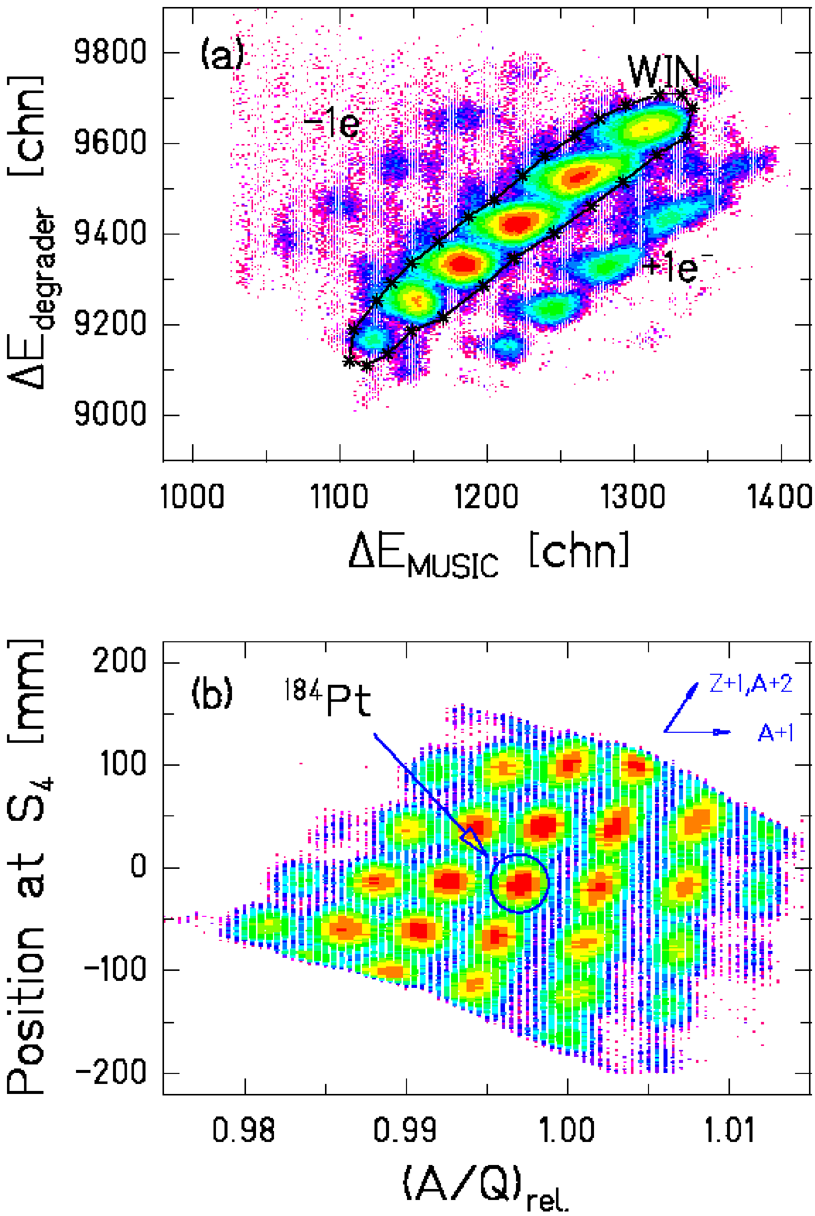
Transmitted with $\Delta B\rho / B\rho$ = 3% and Θ_{max}=15 mr.

Identification in *Z* and *A* by magnetic deflection in FRS, tracking, *ToF* and ΔE.

$$B\rho = m_0 A c \beta \gamma / (e Z)$$

$$\Delta E \propto Z^2 / v^2$$

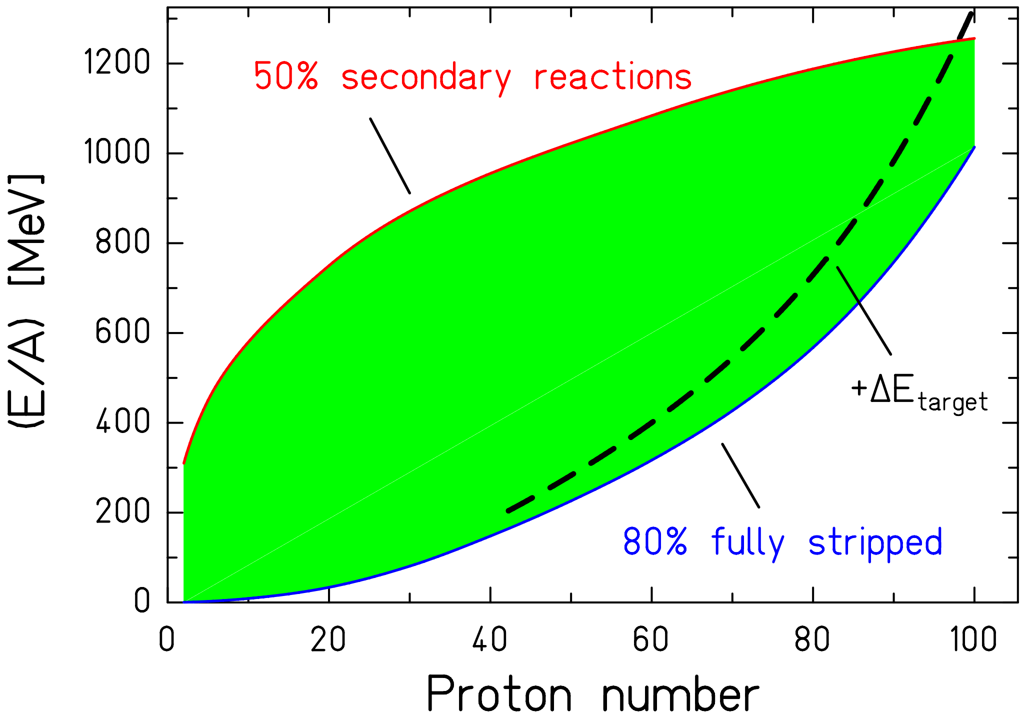
Isotopic identification



Suppression of ionic charge states (above) and isotopic identification (below).

(Data: ^{208}Pb (1 A GeV) + ^{1}H, Timo Enqvist)

Operation domain of the FRS



Green area: Energy limits in the first half of the FRS.
Lower limit: 80% fully stripped in a Nb target stripper.
Upper limit: 50% secondary reactions in an Al degrader.

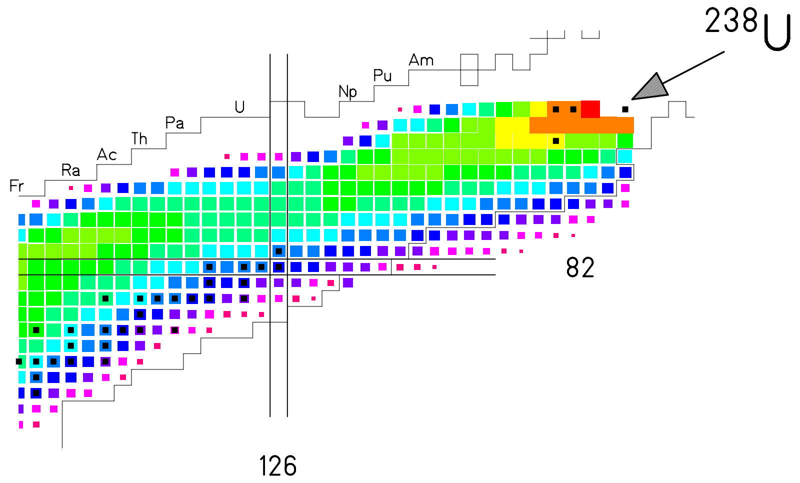
Dashed line: Energy in front of Be target (30% range of projectile).

Conclusion: 1 A GeV is required for uranium.

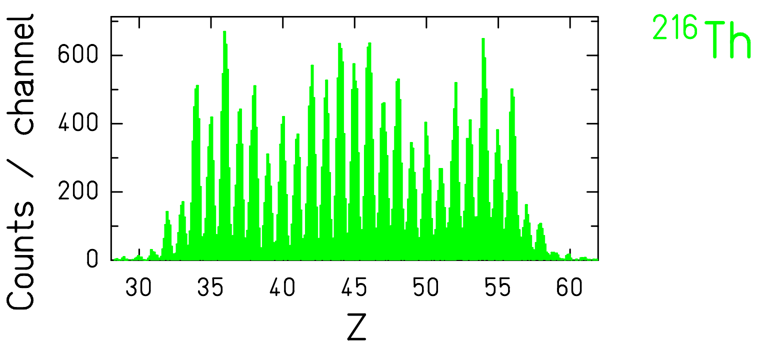
Nuclear-fission experiments at GSI

Major advantages:

- *Secondary beams give access to several 100 short-lived isotopes*



- *Good Z resolution due to inverse kinematics*



Research topics:

- *Shells at large deformation (e.g. $\beta \approx 0.6$)*
- *Viscosity of nuclear matter*

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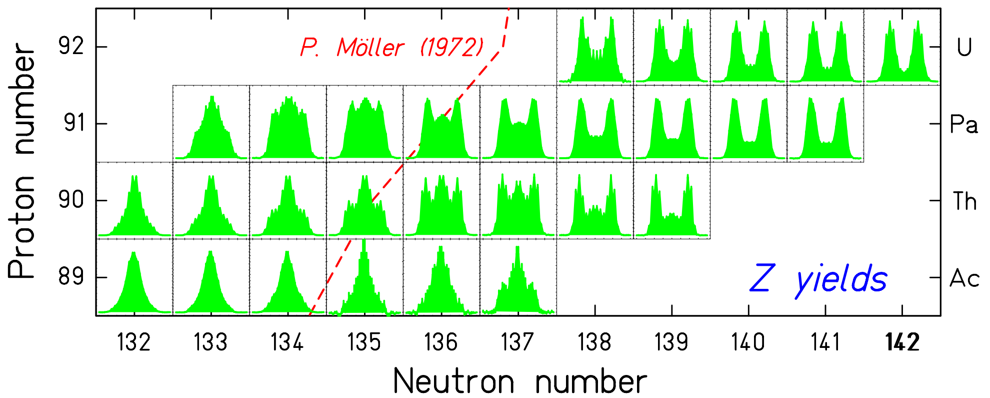
Nuclear shells at large deformation

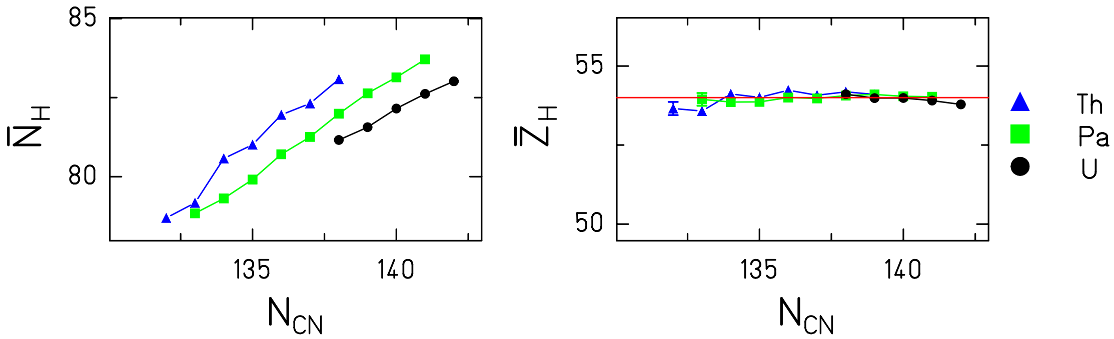
Experimental information on shells at large deformation (β>0.3) obtained from fission

Actual puzzles:

- Transition from symmetric to asymmetric fission



- Position of the fission channels



Future plans:

- Measuring Z, N and neutrons with R^3B
  - → Position of neutron and proton shells
  - → Deformation of shells

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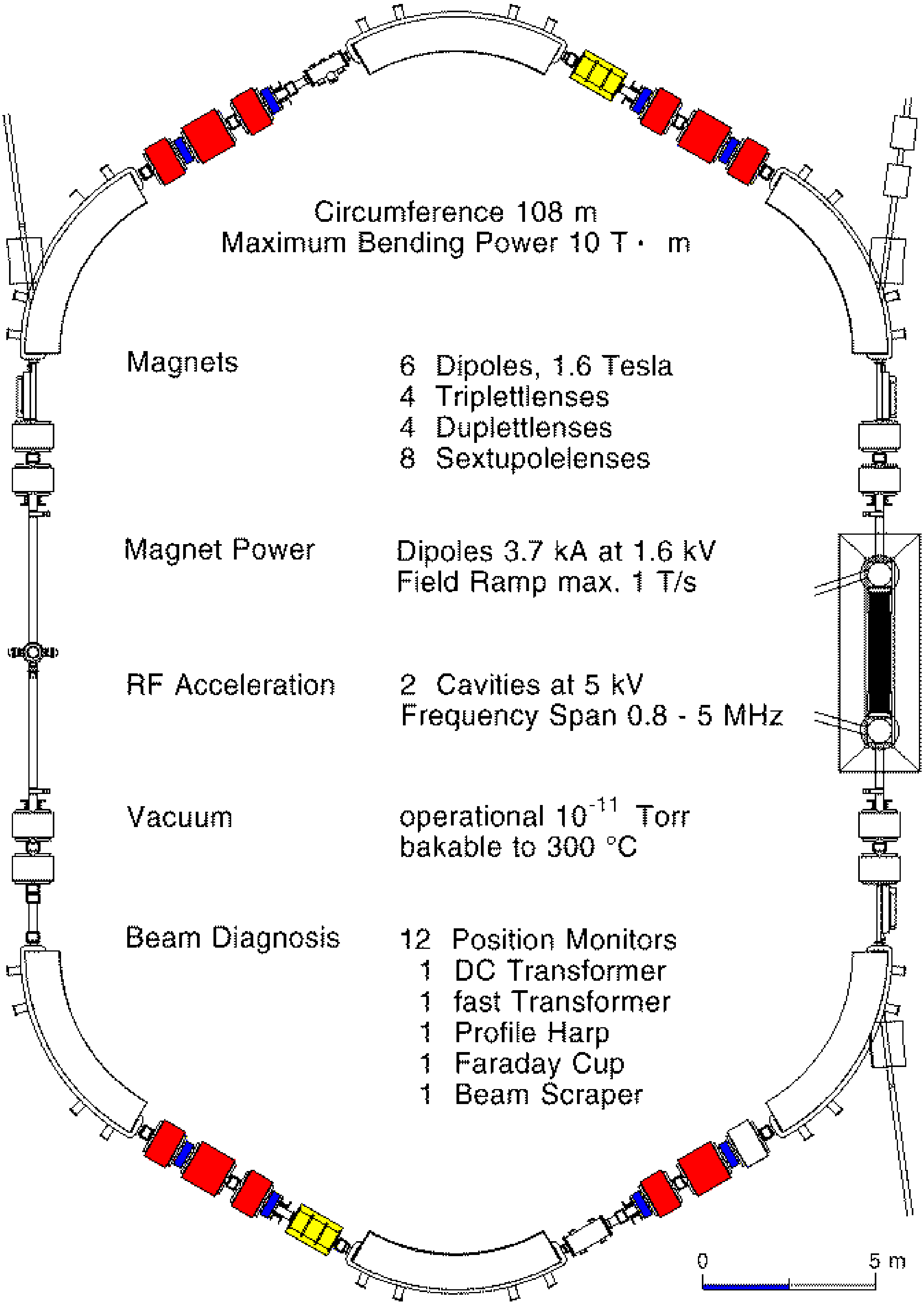
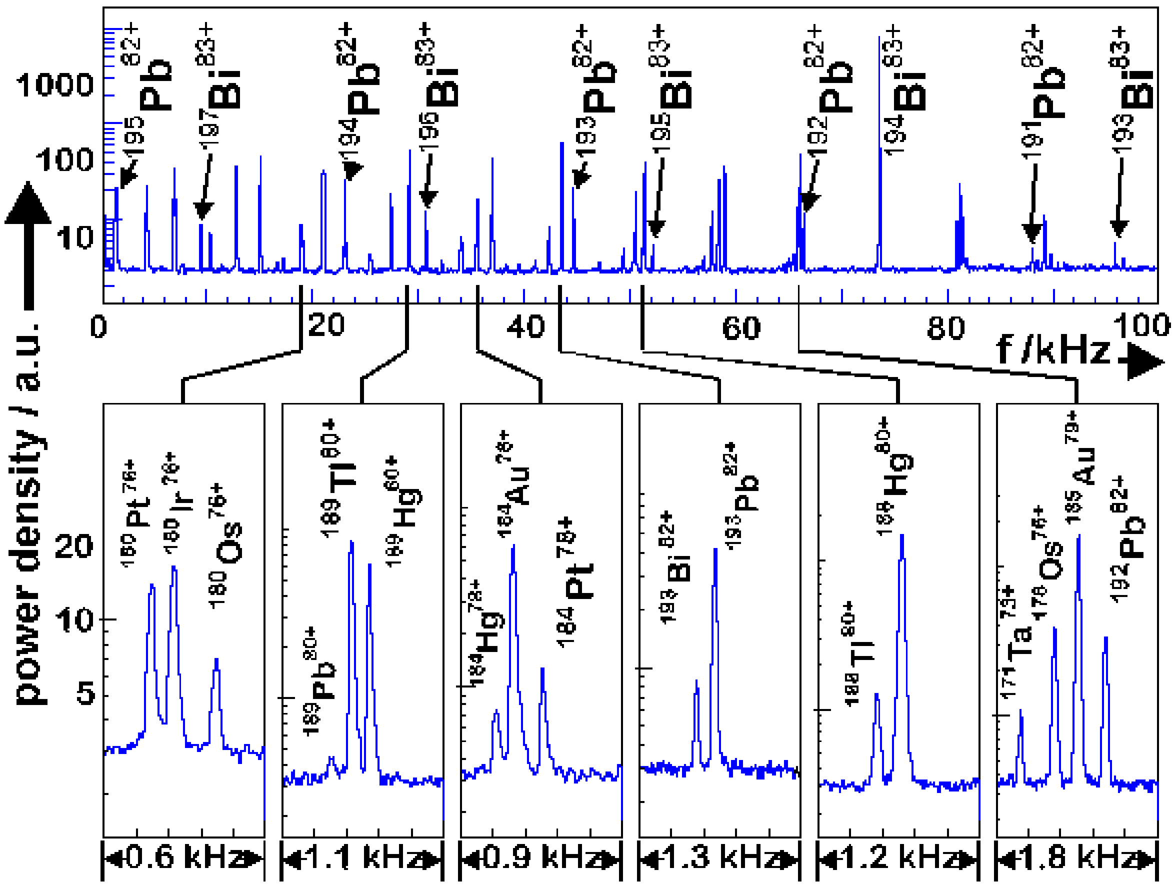
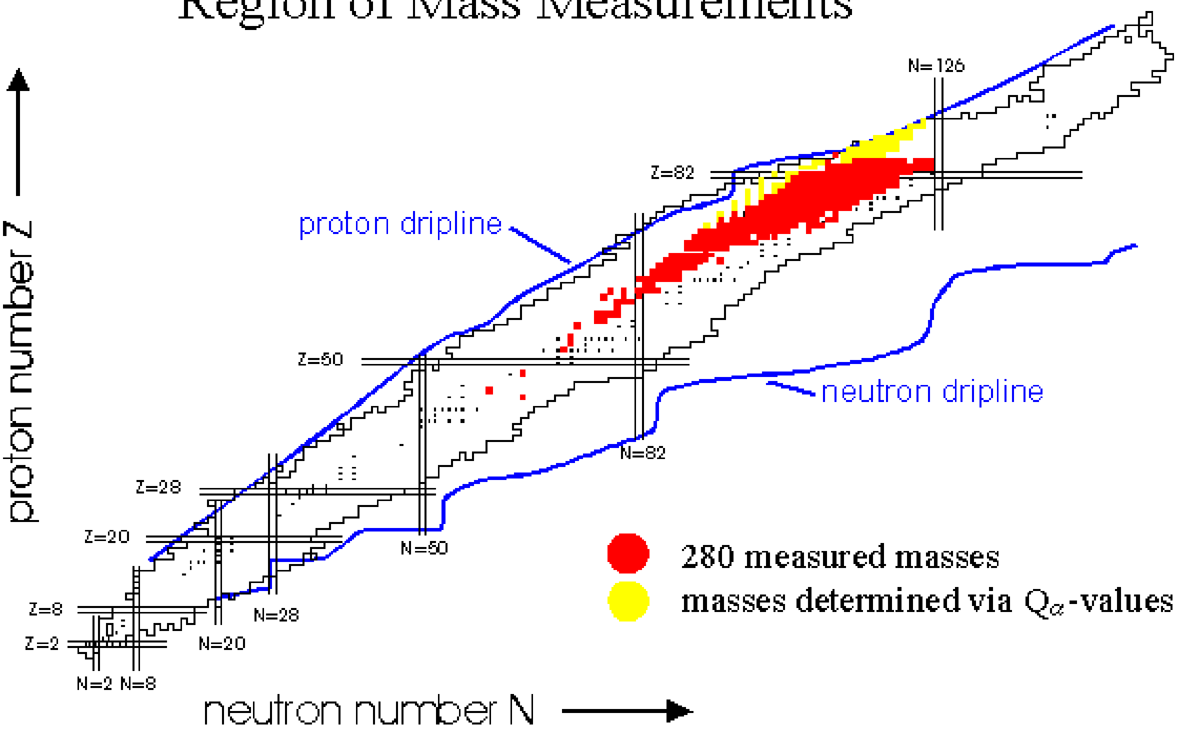
Experimental Storage Ring (ESR)



Mass measurements by Schottky Scan in ESR



Region of Mass Measurements



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