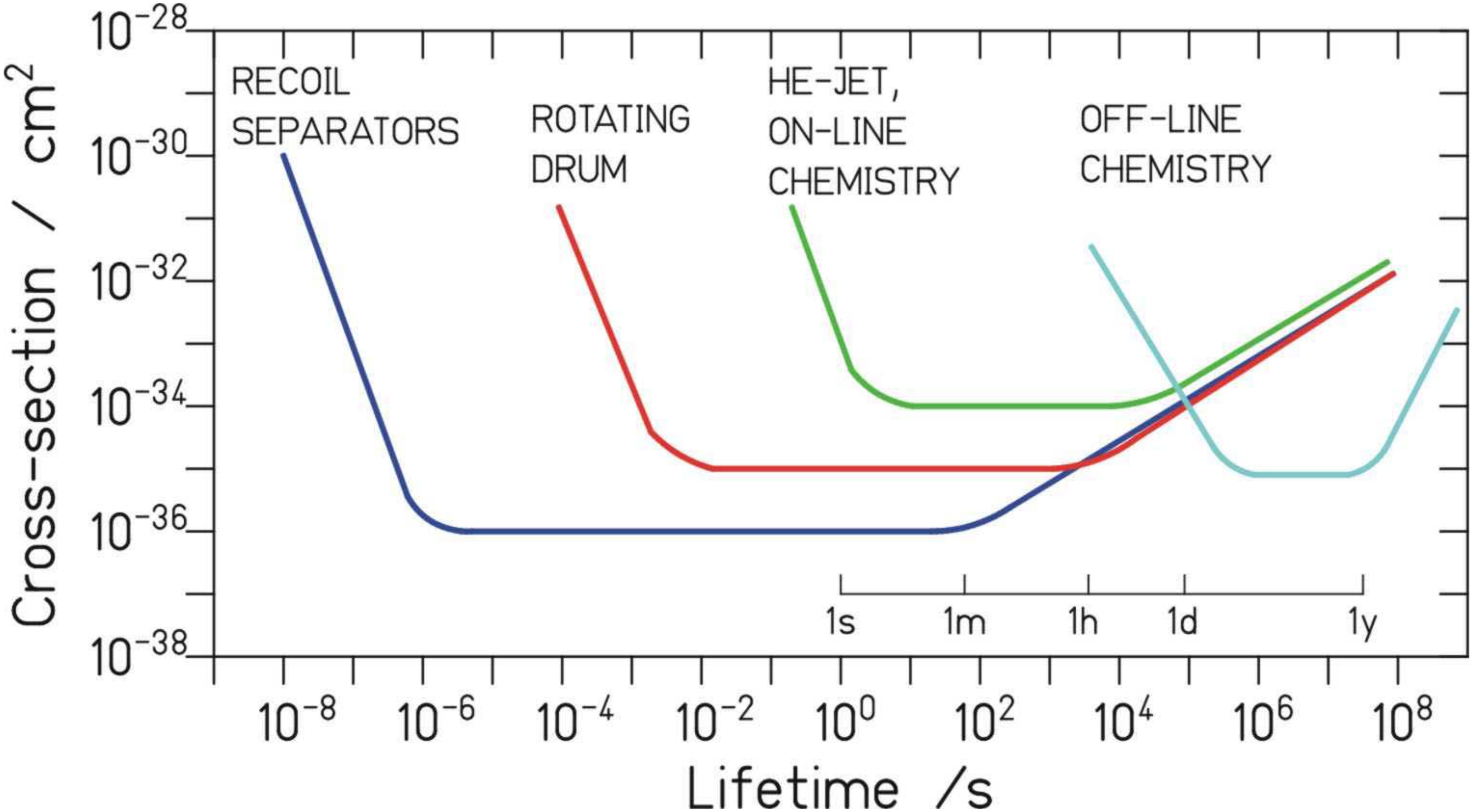
Physics with Exotic Nuclei and Exotic Atoms at Relativistic Energies

Hans Geissel
Euroschool Valencia, September 2003

- Introduction √
- Momentum Measurements, Ion Optics, √ Spectrometers
- Atomic Interaction of Heavy Ions √
- Exotic Atoms √
- **Production and Separation of Exotic Nuclei**

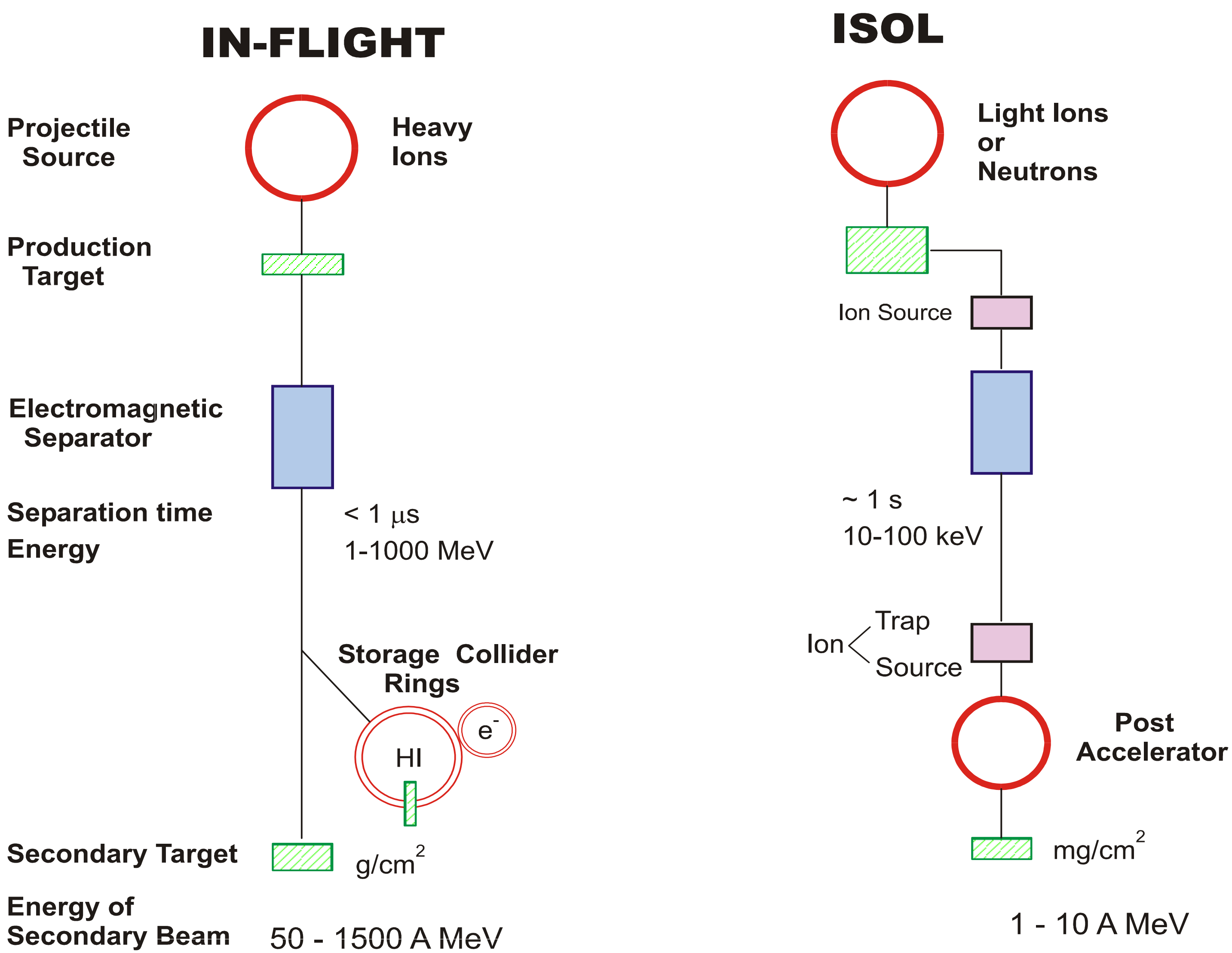
Experimental Methods to separate and to detect Exotic Nuclei



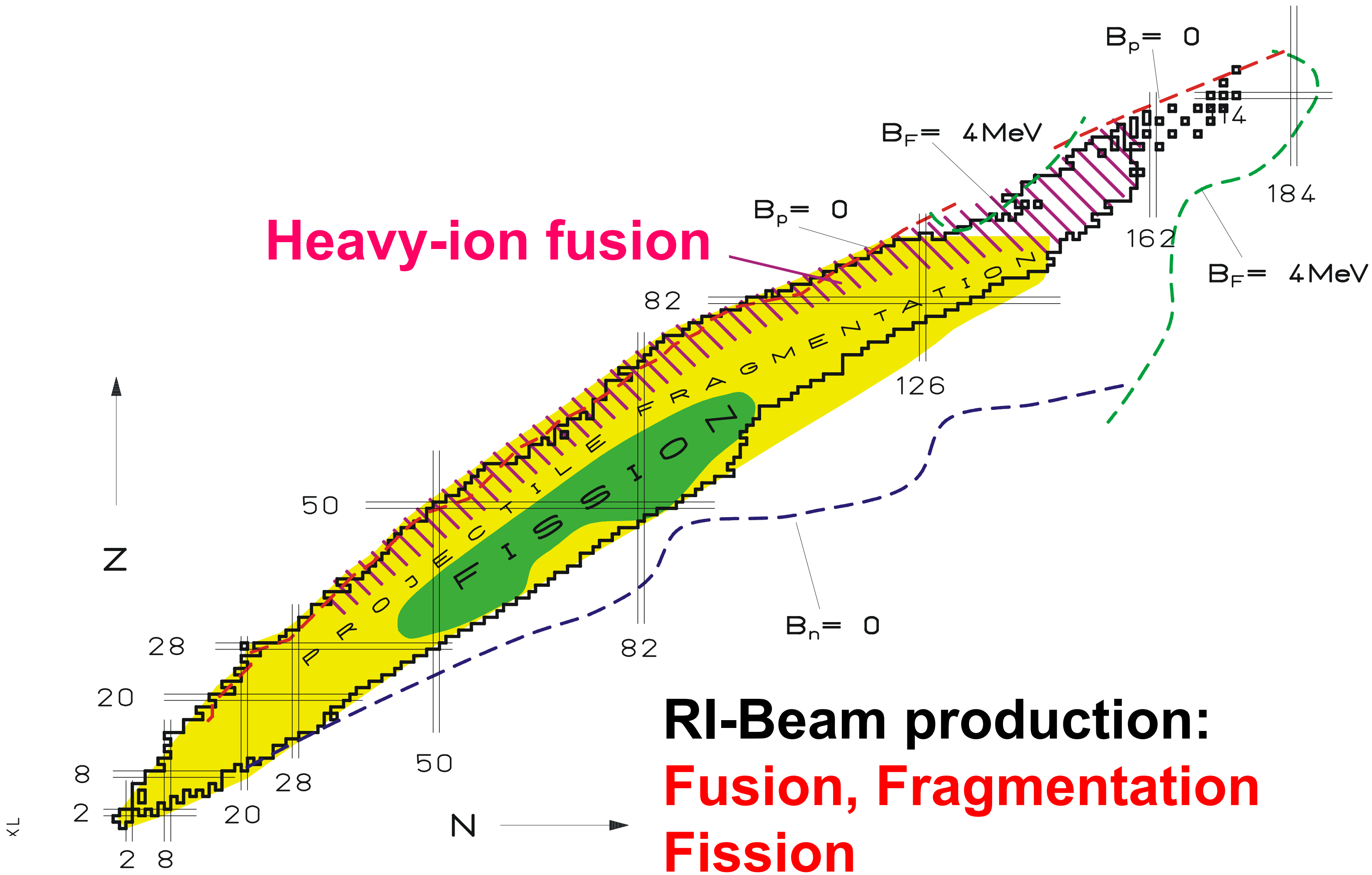
G. Münzenberg
Rep. Prog. Phys. 1988 51 57

Production and Separation Schemes

Ann. Rev. Nucl. Part. Sci. 45 (1995) 163



Production of Energetic Exotic Nuclei



RI-Beam production:
Fusion, Fragmentation
Fission

Characterization of Nuclear Reactions

de Broglie wavelength: $\lambda = \frac{h}{p} = \frac{hc}{[2mc^2\ E + E^2]^{1/2}} = \frac{1239.86\ MeV\ \ fm}{[2mc^2\ E + E^2]^{1/2}}$

.

for a proton:

E (MeV)	p(MeV/c)	λ(fm)
1	43.2	28.7
10	136.8	9.1
100	443.0	2.8
1000	1692.0	0.7

Nuclear radius:

R=1.13 fm $A^{1/3}$

$\lambda \geq$ **R:**

Reactions determined by nuclear potential and binding energies

Fusion, Fission

$\lambda \leq$ **range of nuclear force (≈ 1 fm):**

Collisions with individual nucleons (t_{coll}=r/v≈10^{-23} s, v(1000MeV/u)=2.62 10^8m/s)

Fragmentation

The fusion cross section: two step process fusion-survival

The **production** of a certain isotope is

$$\sigma_{\mathrm{ER}} = \sigma_{\mathrm{fus}}(E_{\mathrm{p}} - E_{\mathrm{B}}, \ell)^{*} w_{x}(E^{*}, \ell)$$

The **fusion cross section** is

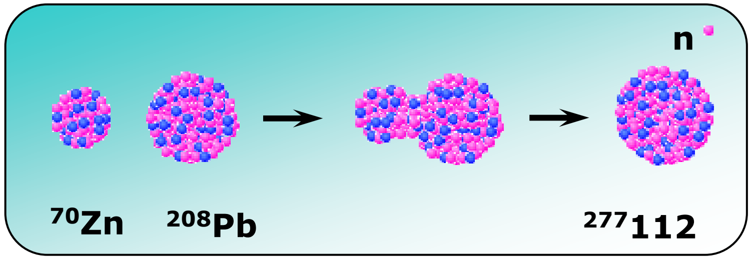
$$\sigma_{\mathrm{fus}} = \pi \lambda\!\!\!^{-2} \sum_{\ell=0}^{\ell_{\mathrm{lim}}} (2\ell + 1)^{*} T_{\ell}(E_{\mathrm{p}} - E_{\mathrm{B}})$$

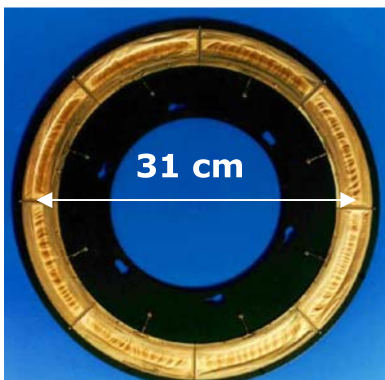
where $\lambda\!\!\!^{-2} = \hbar^{2} / (2\mu E_{\mathrm{p}})$ denotes the reduced deBroglie wavelength

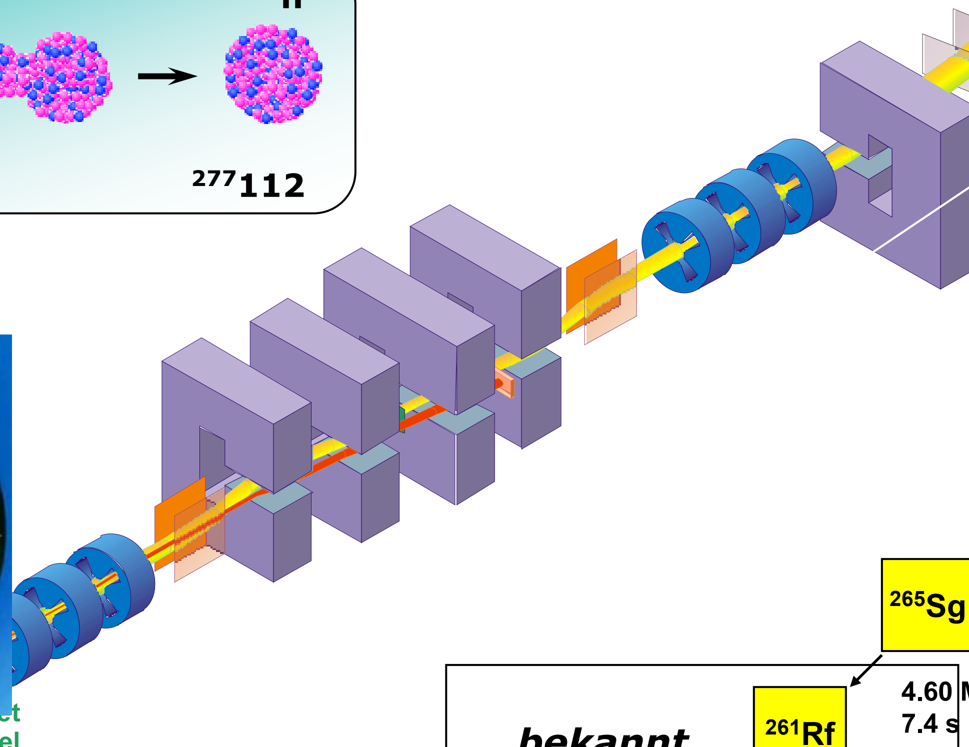
The **survival probability** is determined by the neutron evaporation-to-prompt-fission competition

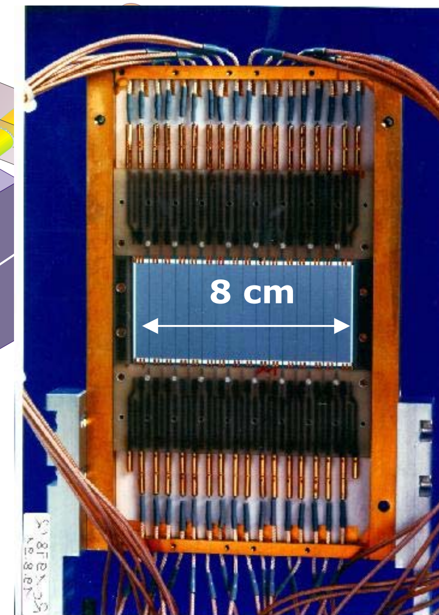
$$w_{x}(E^{*}, \ell) = \prod_{i=1}^{x} \frac{\Gamma_{n}(E^{*}, \ell)}{\Gamma_{n}(E^{*}, \ell) + \Gamma_{\mathrm{f}}(E^{*}, \ell)} \approx \left(\frac{\Gamma_{n}}{\Gamma_{\mathrm{f}}}\right)^{x}$$

Fusion and Identifikation of Super-heavy Elements at SHIP









^{265}Sg
9.23 MeV
19.7 s

bekannt

^{261}Rf
4.60 MeV (escape)
7.4 s

^{257}No
8.52 MeV
4.7 s

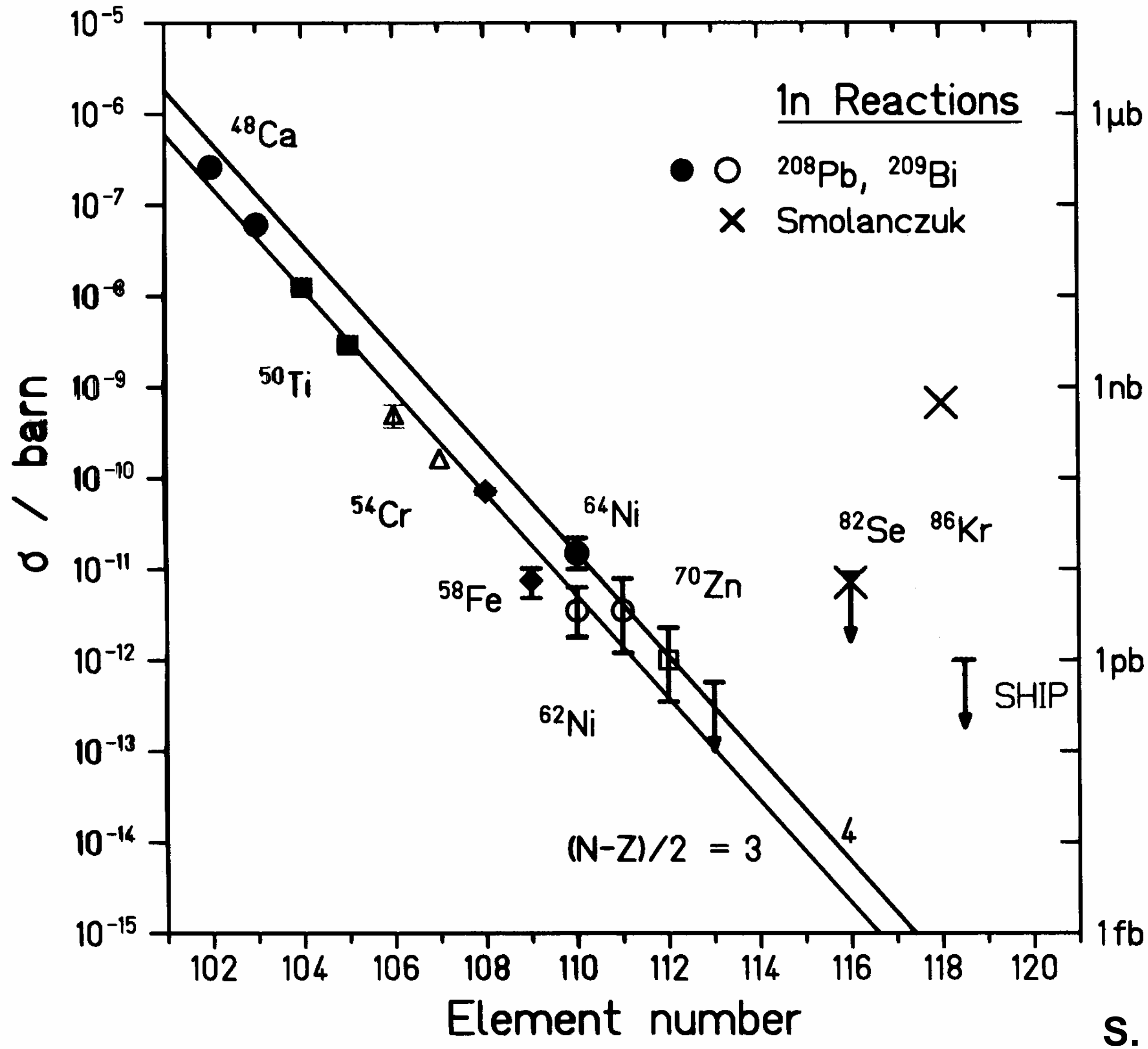
^{253}Fm
8.34 MeV
15.0 s

Date: 09-Feb-1996
Time: 22:37 h

Identification via α-α Correlations down to known Isotopes

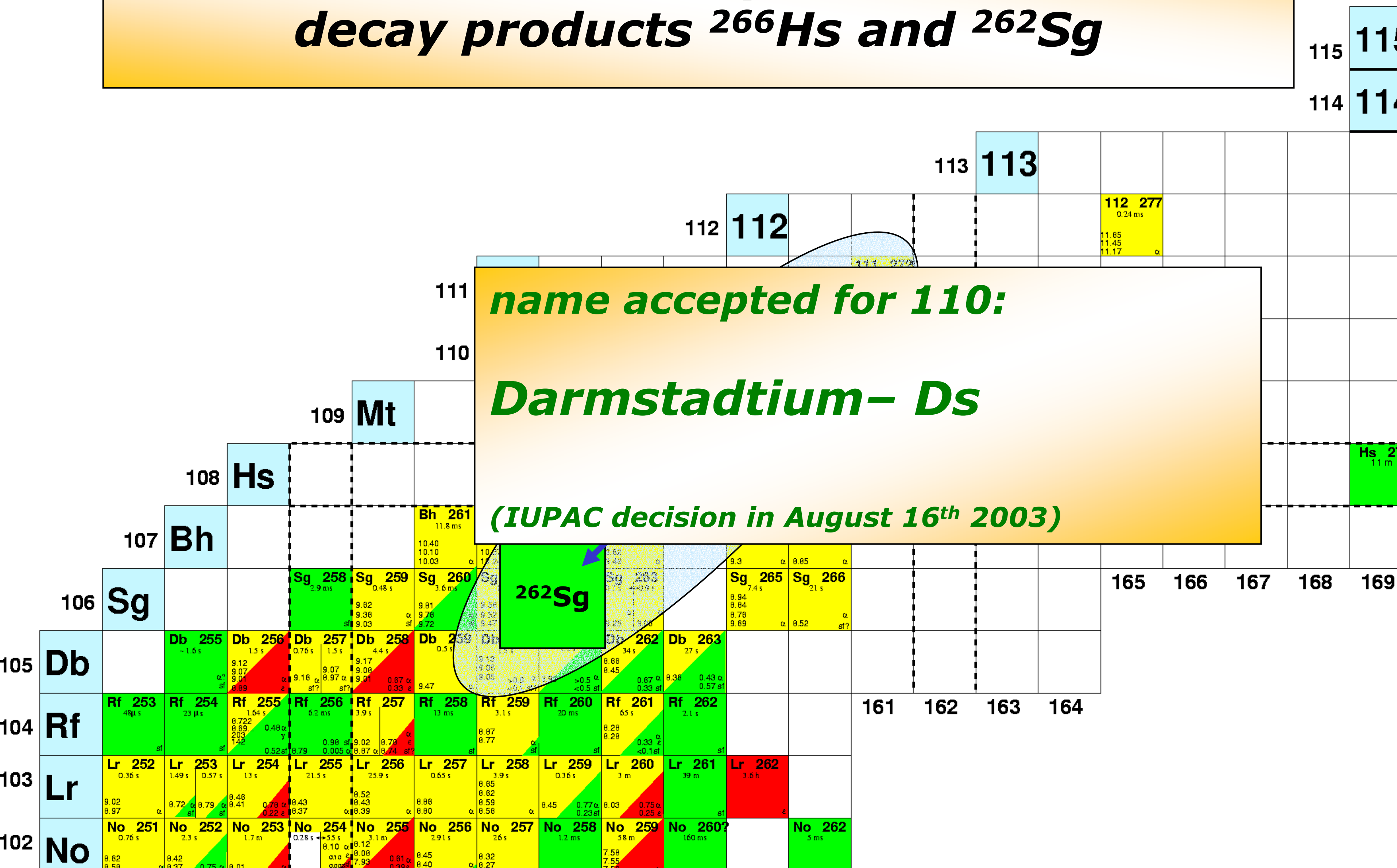
G. Münzenberg, S. Hofmann

Measured Cross Sections for the Heaviest Elements



S. Hofmann et al.

The even-even isotope ^{270}110 and its decay products ^{266}Hs and ^{262}Sg



name accepted for 110:

Darmstadtium– Ds

(IUPAC decision in August 16th 2003)

Principle of a Gas-filled Separator

Magnetic Rigidity:

$$B\rho = \frac{mv}{q} \quad (1)$$

Mean Charge State:

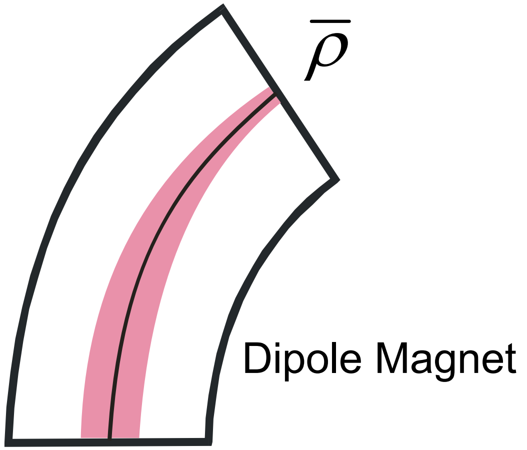
Populated during atomic collisions in gases

(Bohr Formula)

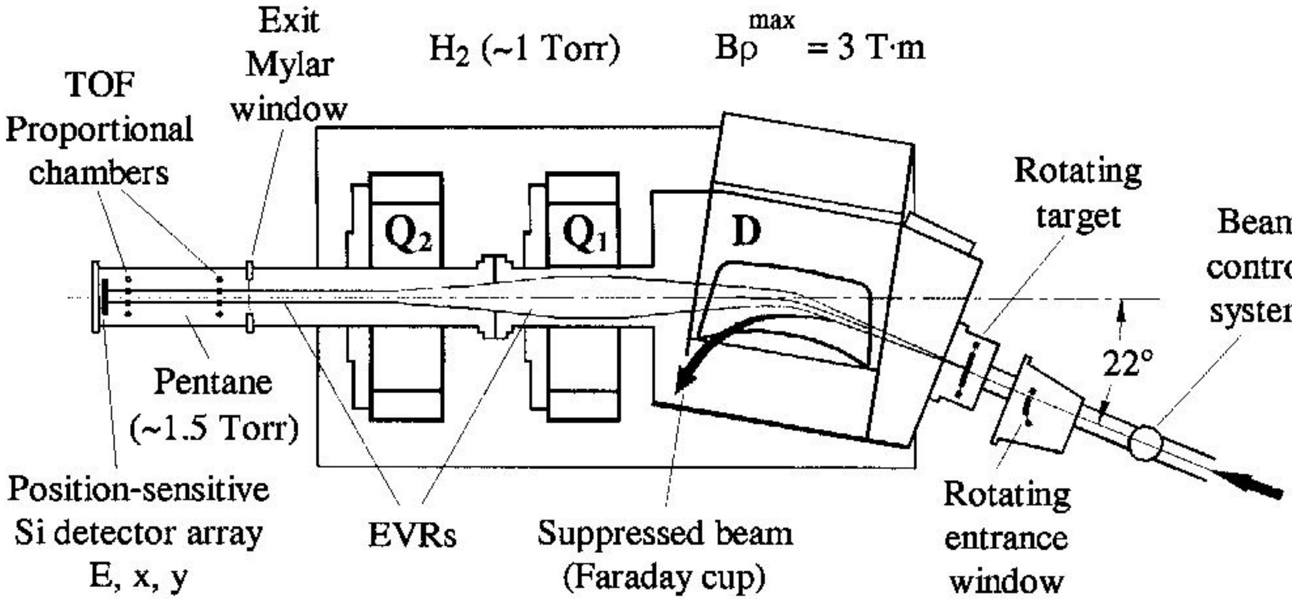
$$\overline{q} = \frac{Z^{1/3} v}{v_0} \quad (2)$$

Mean Bending Radius:

$$\overline{\rho} = \frac{m v_0}{B} Z_1^{1/3} \quad (3)$$



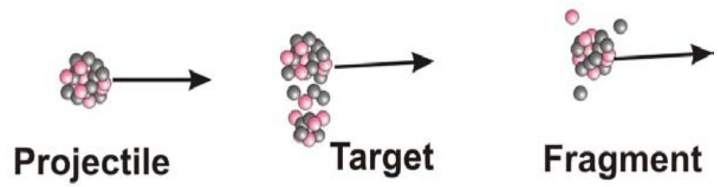
Gassfilled Separator GFRS at JINR- FLNR in Dubna, Russia



Yu.Ts. Oganessian, Nature, vol. 400, July 1999

Production of Exotic Nuclei at relativistic Energies

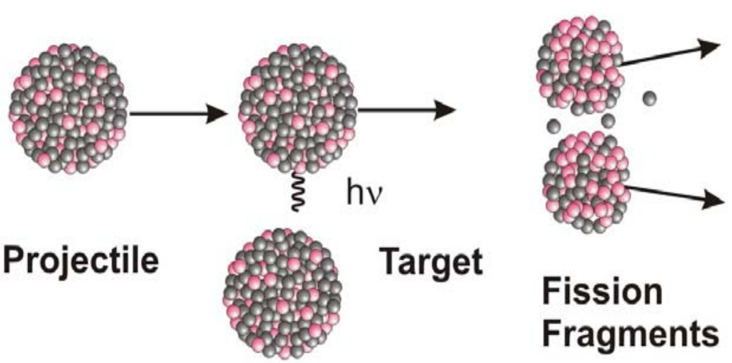
Projectile Fragmentation



Nucleon-nucleon collisions, abrasion, ablation

$$\vec{v}_f \approx \vec{v}_p$$

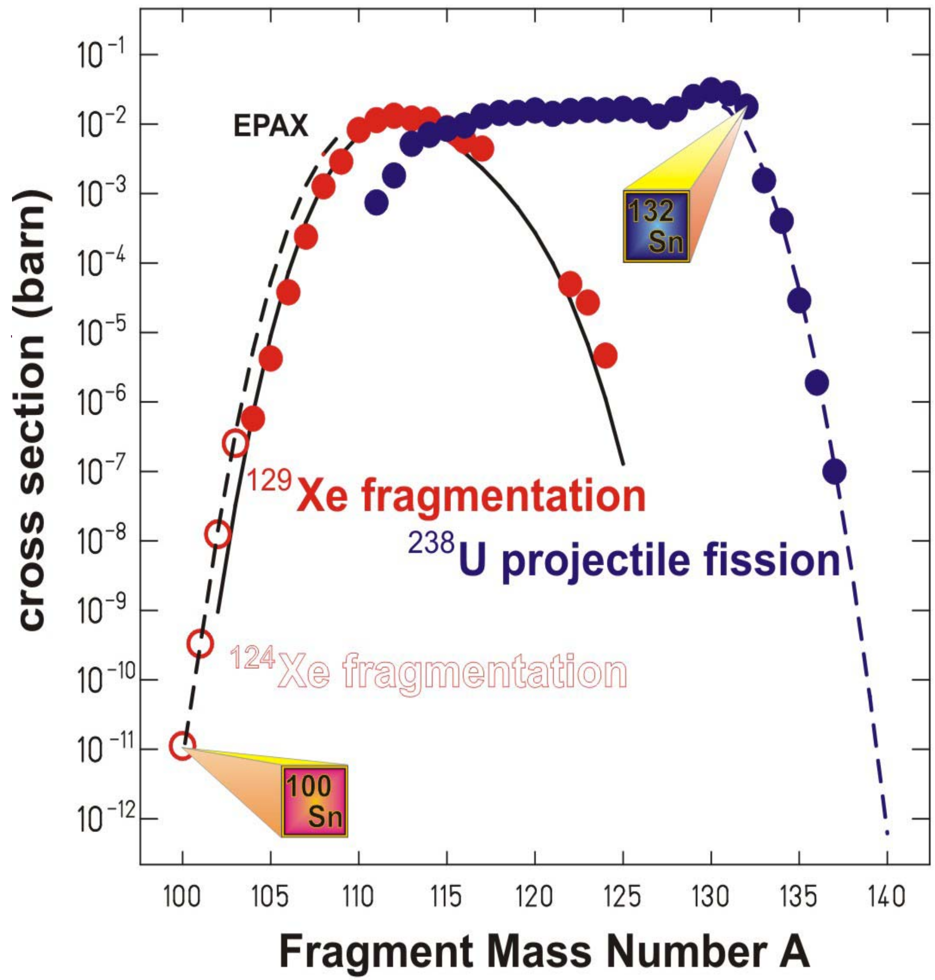
Projectile Fission



Electromagnetic excitation, fission in flight

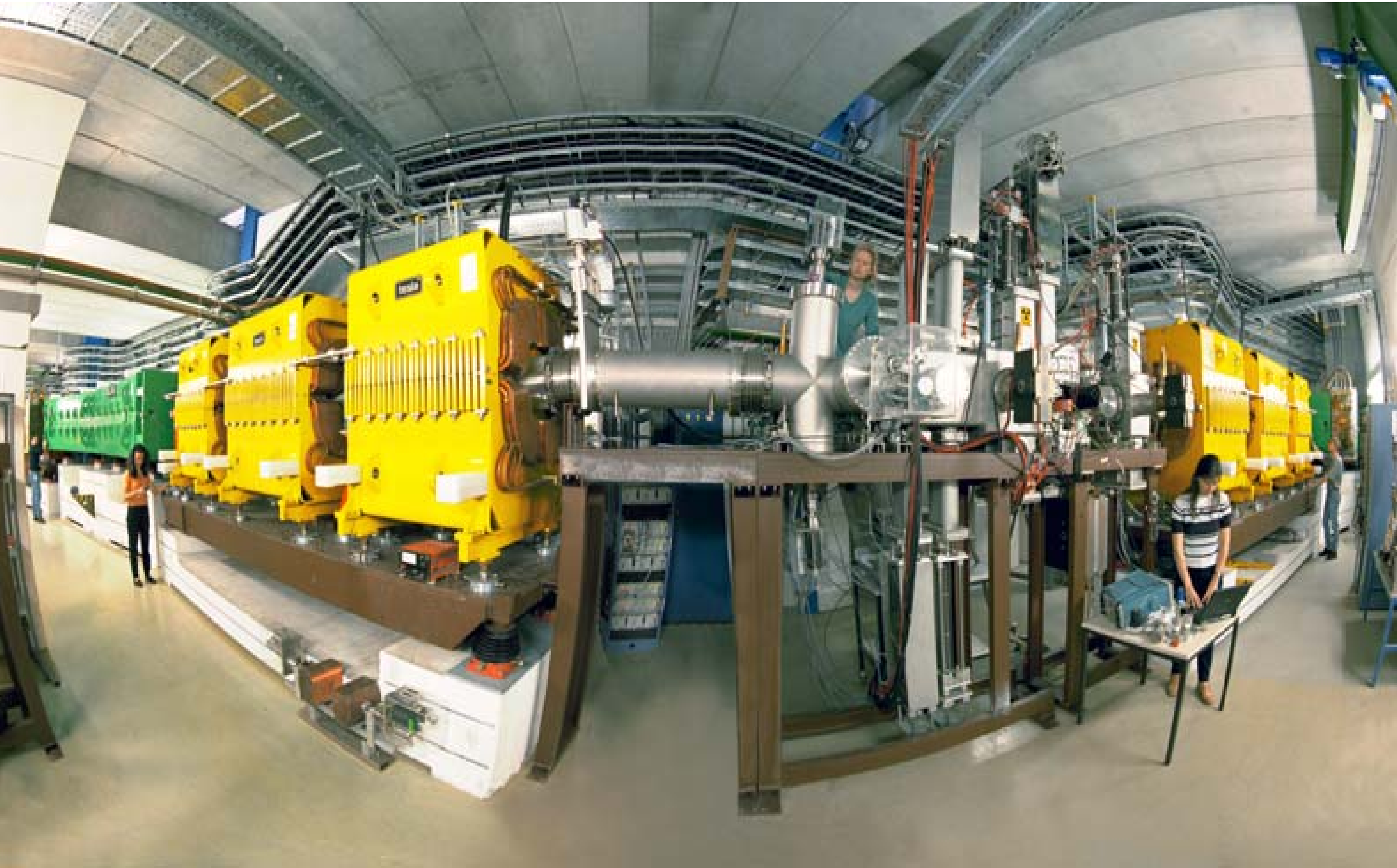
$$\vec{v}_f \approx \vec{v}_p + \vec{v}_{fission}$$

Sn isotopes from projectile fragmentation and projectile fission

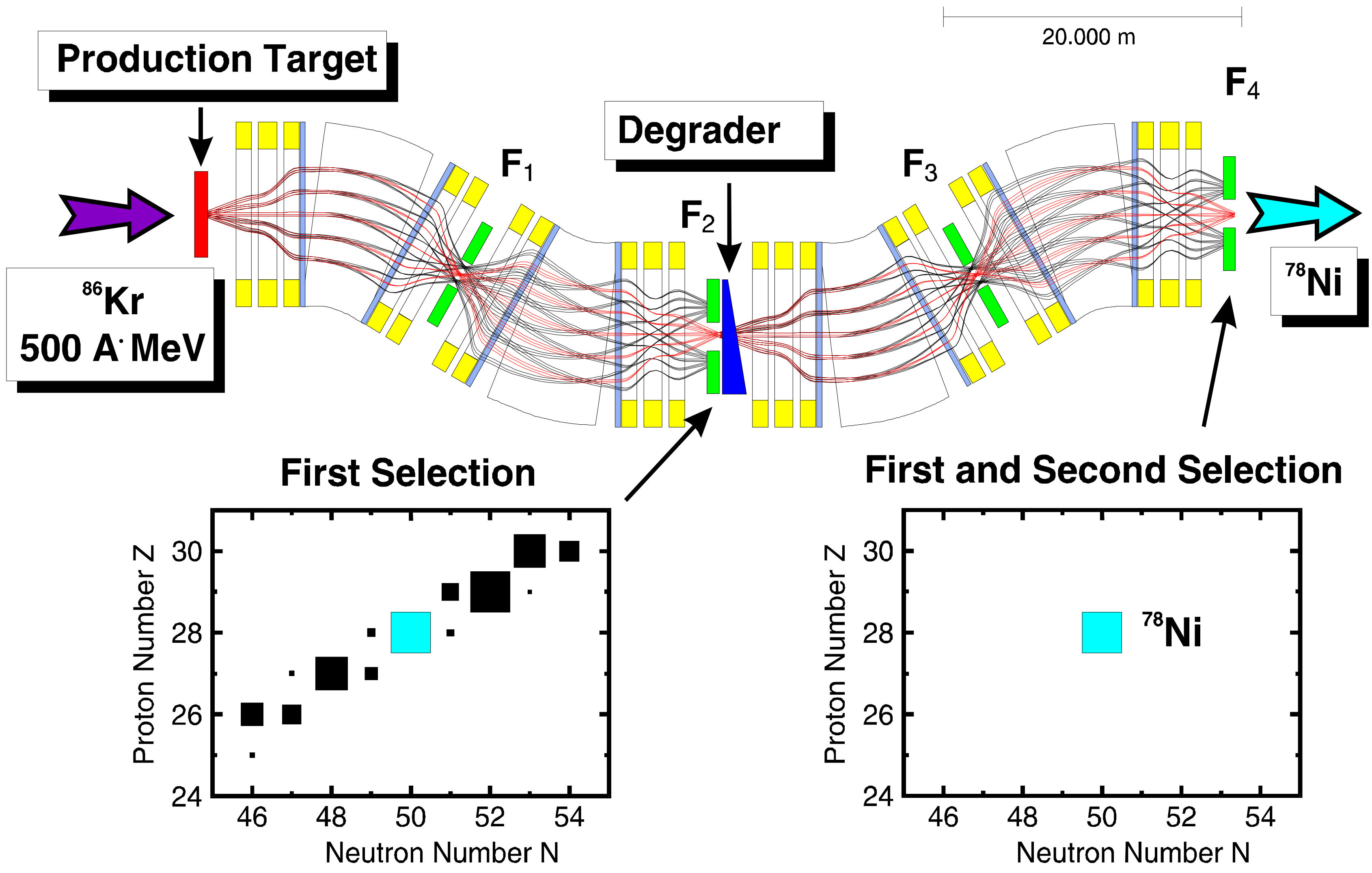


K.Sümmerer

The Fragment Separator FRS



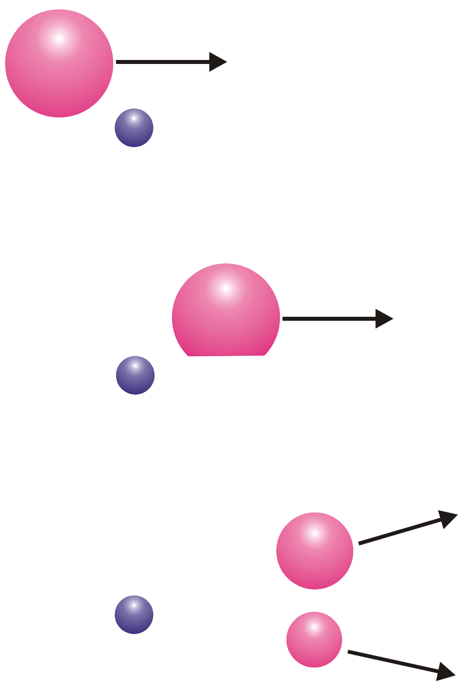
Bρ - ΔE - Bρ Separation Method

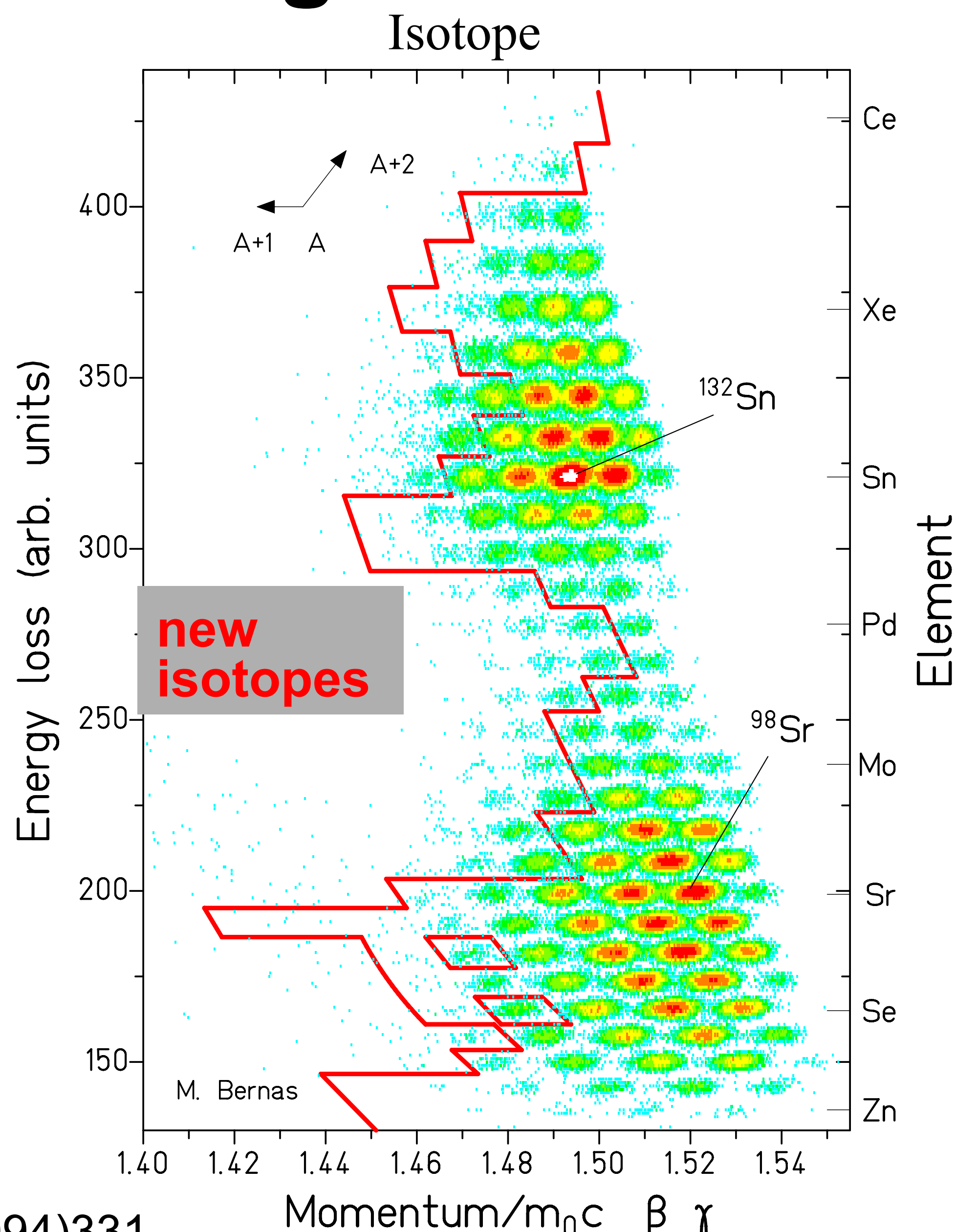


H.G. 1.7.02

^{238}U Fission In-flight

^{238}U at 1 A GeV on Be

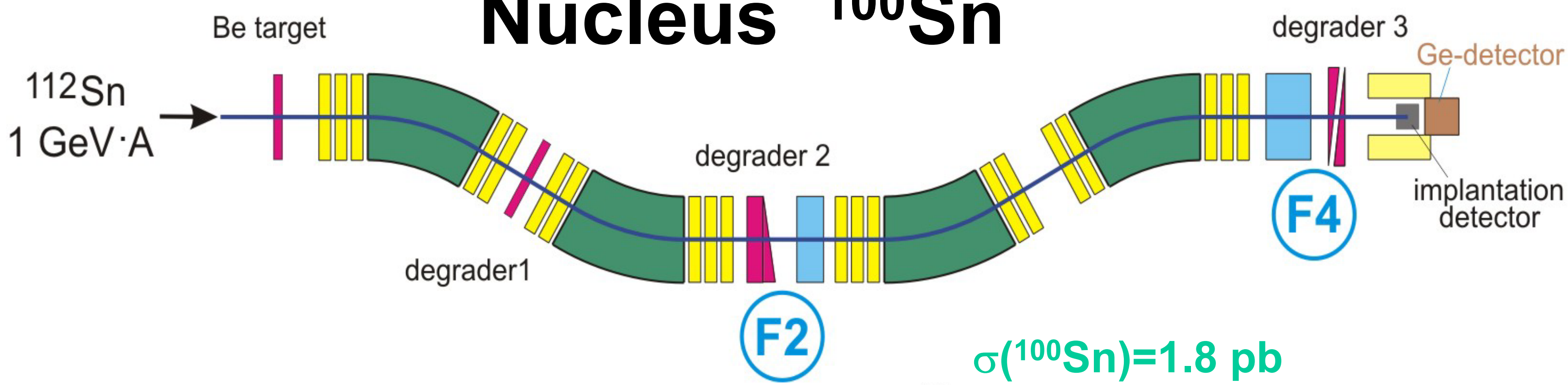


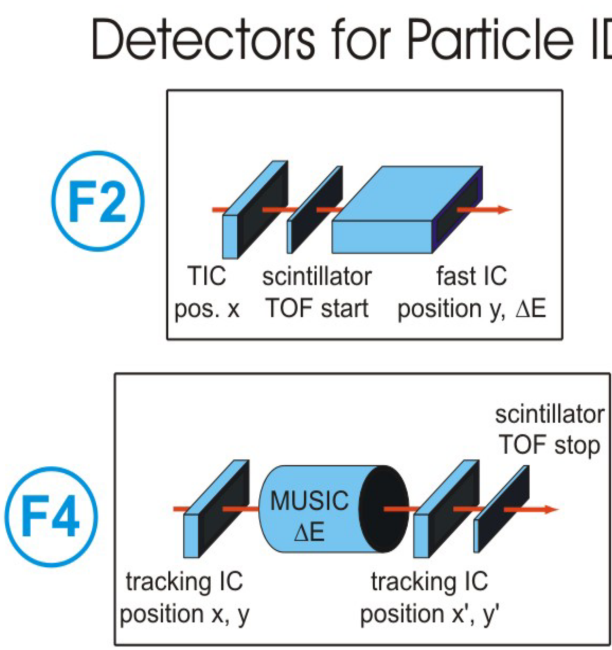


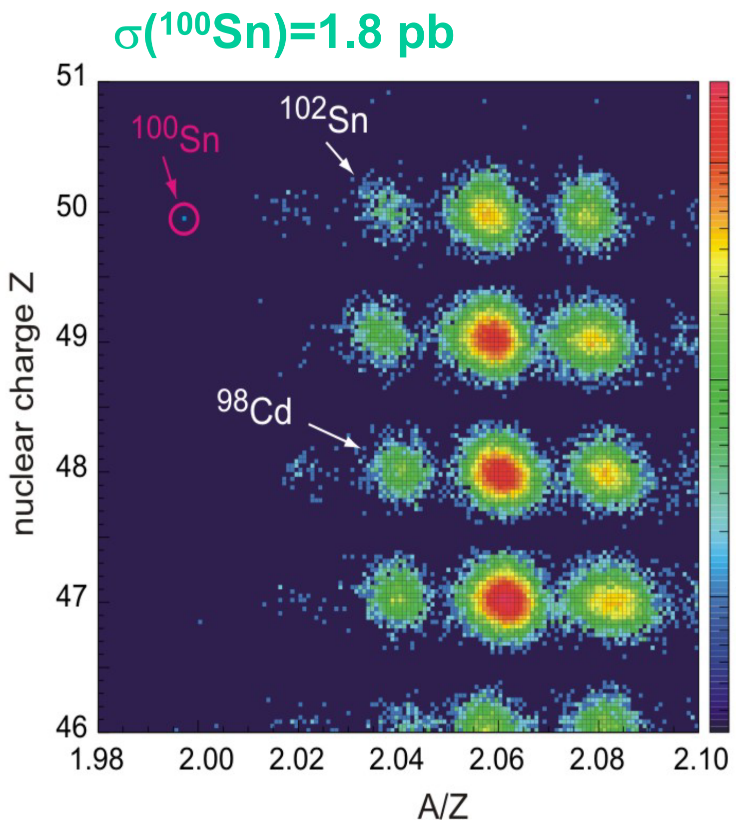
- Acess to n-rich nuclei
- high energy

M. Bernas et al. Phys. Lett. B331(1994)331

Identification of the Doubly Magic Nucleus ^{100}Sn

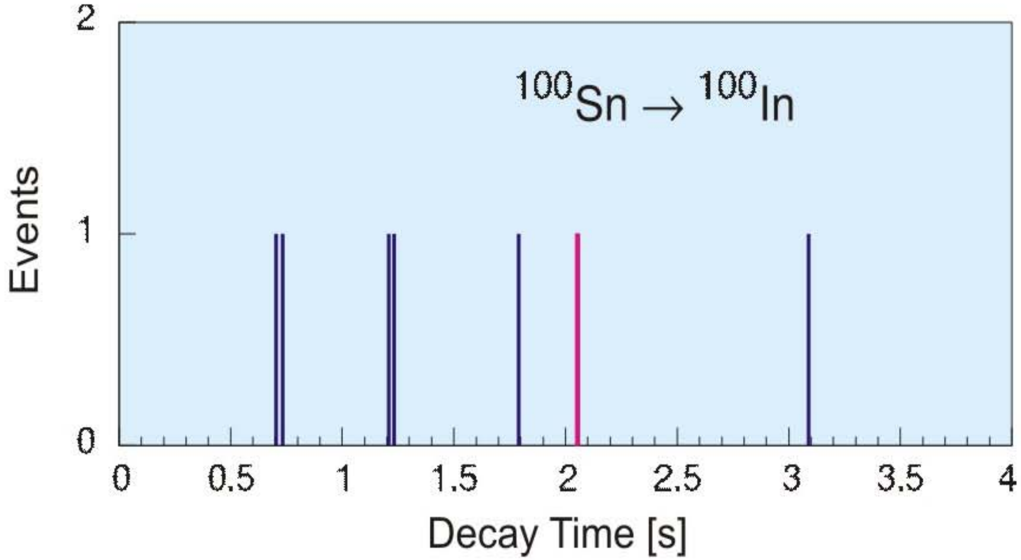






A. Stolz (TUM)

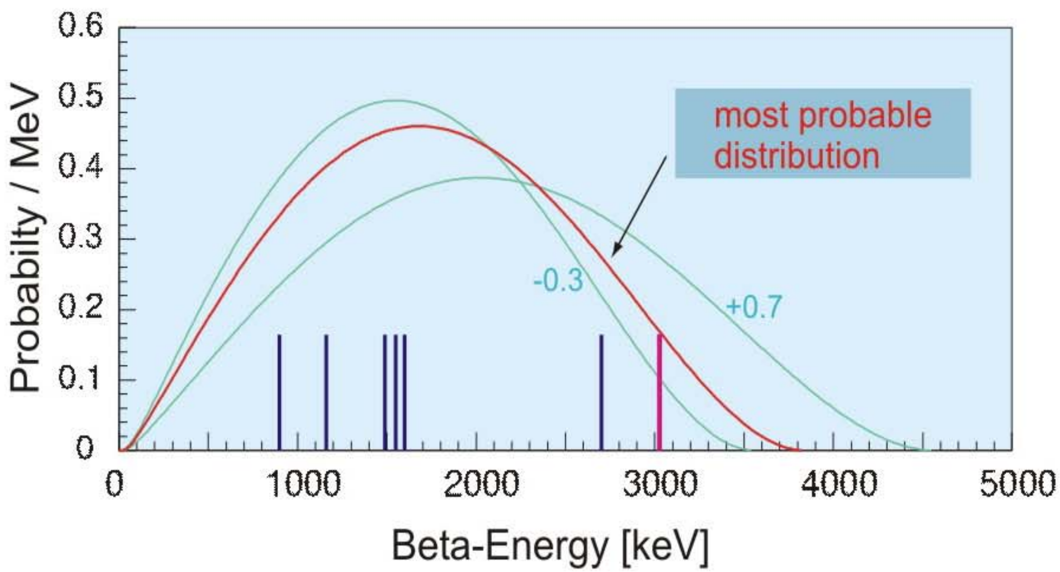
Beta Decay of ^{100}Sn



Results from 7 decays of ^{100}Sn
(6 atoms experiment '94,
1 atom experiment '98)

Half-life

$T_{1/2} = 1.00 \,^{+0.52}_{-0.26}$ s



Beta-Endpoint-Energy

$E_{\beta_0} = 3.8 \,^{+0.7}_{-0.3}$ MeV

A. Stolz