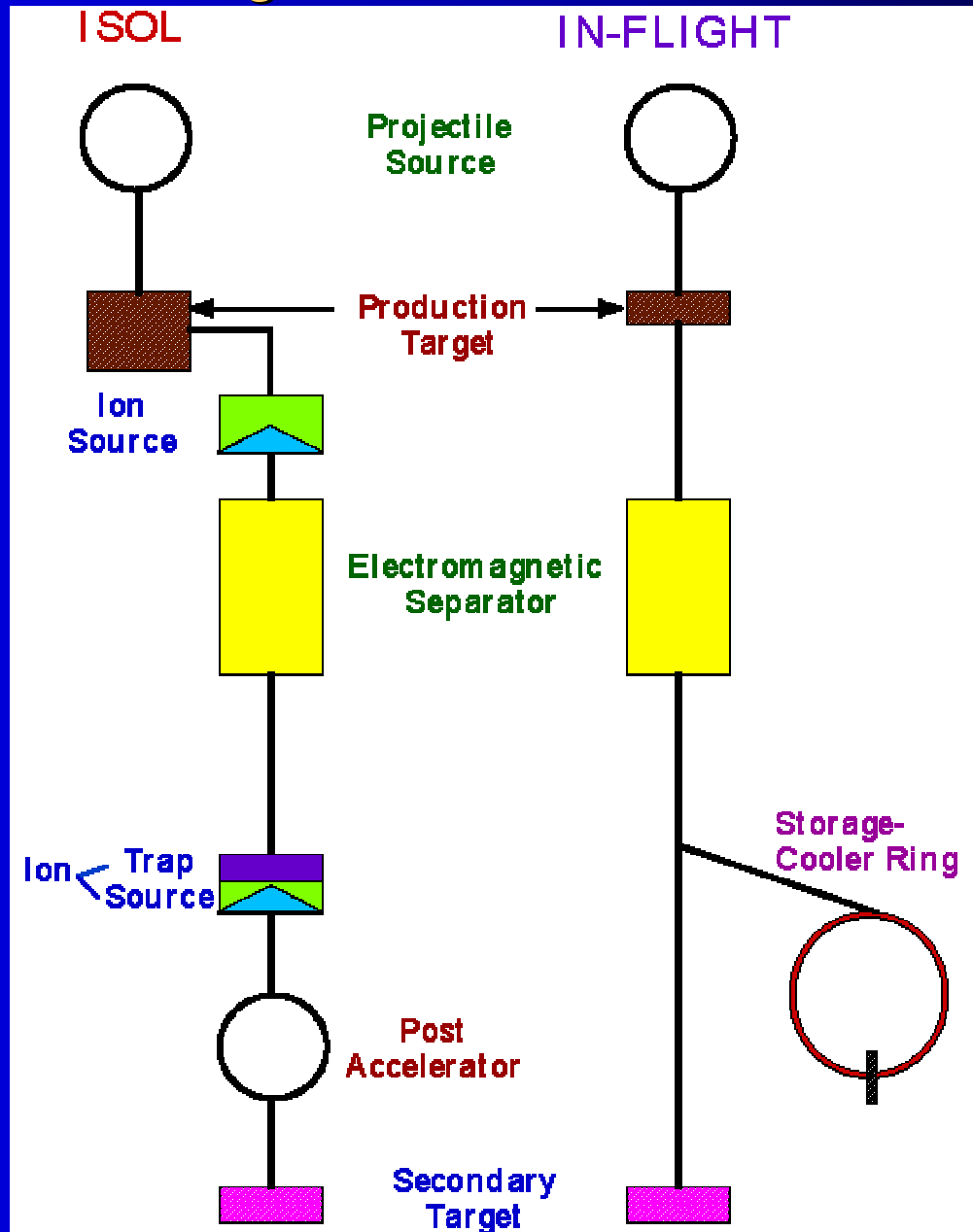
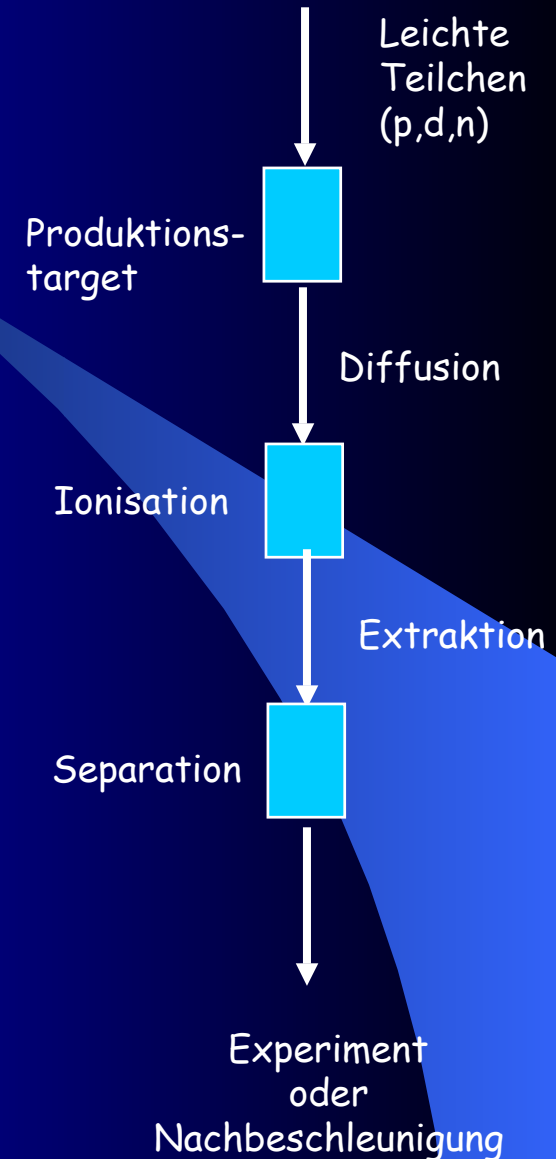


# Produktion kurzlebiger radioaktiver Strahlen



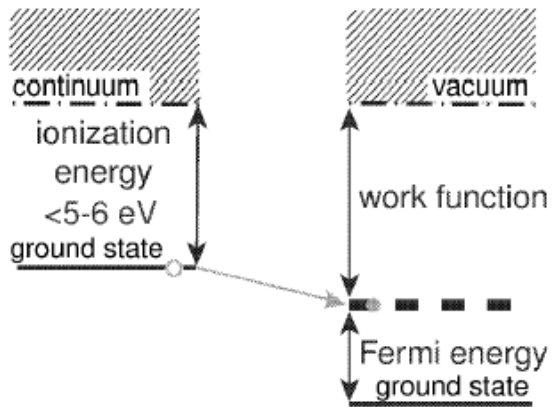
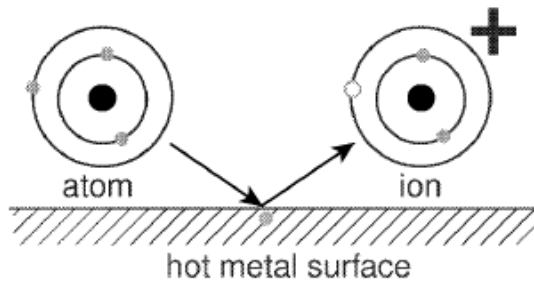
# ISOL Schema

- **leichte Ionen (n,p,d) induzieren Reaktionen im Target:**
  - Spaltung von Uran Targets
  - Spallation verschiedener Targetmaterialien
  - Fusionsreaktionen
  - Fragmentation
- **Radioaktive Produkte**
  - diffundieren aus dem Target heraus
  - werden einfach ionisiert
  - werden beschleunigt (30-60 kV)
  - werden elektromagnetisch separiert
- **Niederenergie-Experimente mit 30-60 keV Ionen**
  - Massen, Laserspektroskopie,  $\beta$ -Zerfall
- **Beschleunigung der Ionen in zweitem Beschleuniger auf 5-10 MeV/u**
  - Coulomb-Anregung
  - Transfer
  - Fusionsreaktionen

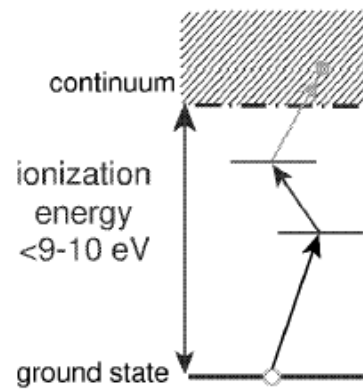
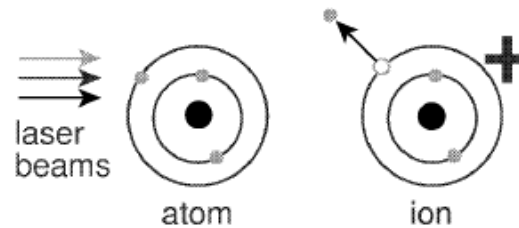


# Ionisationsmethoden

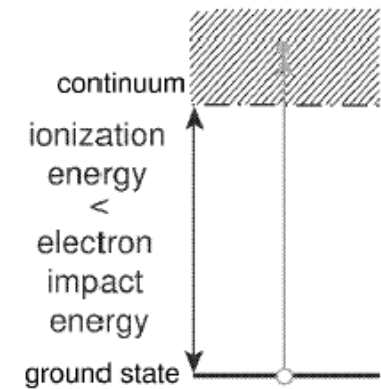
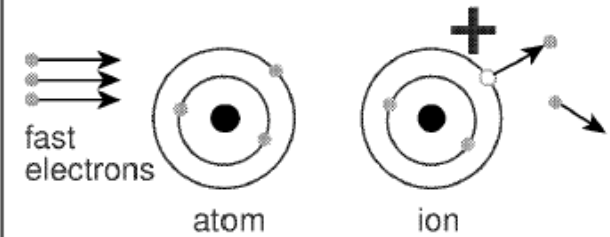
## Surface ionization



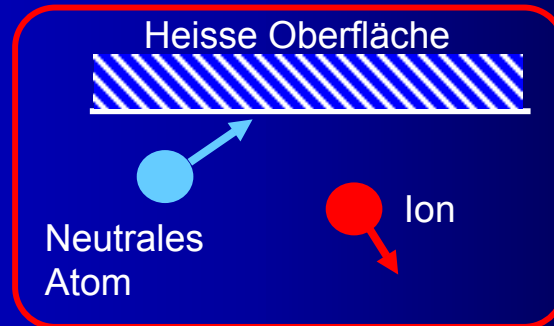
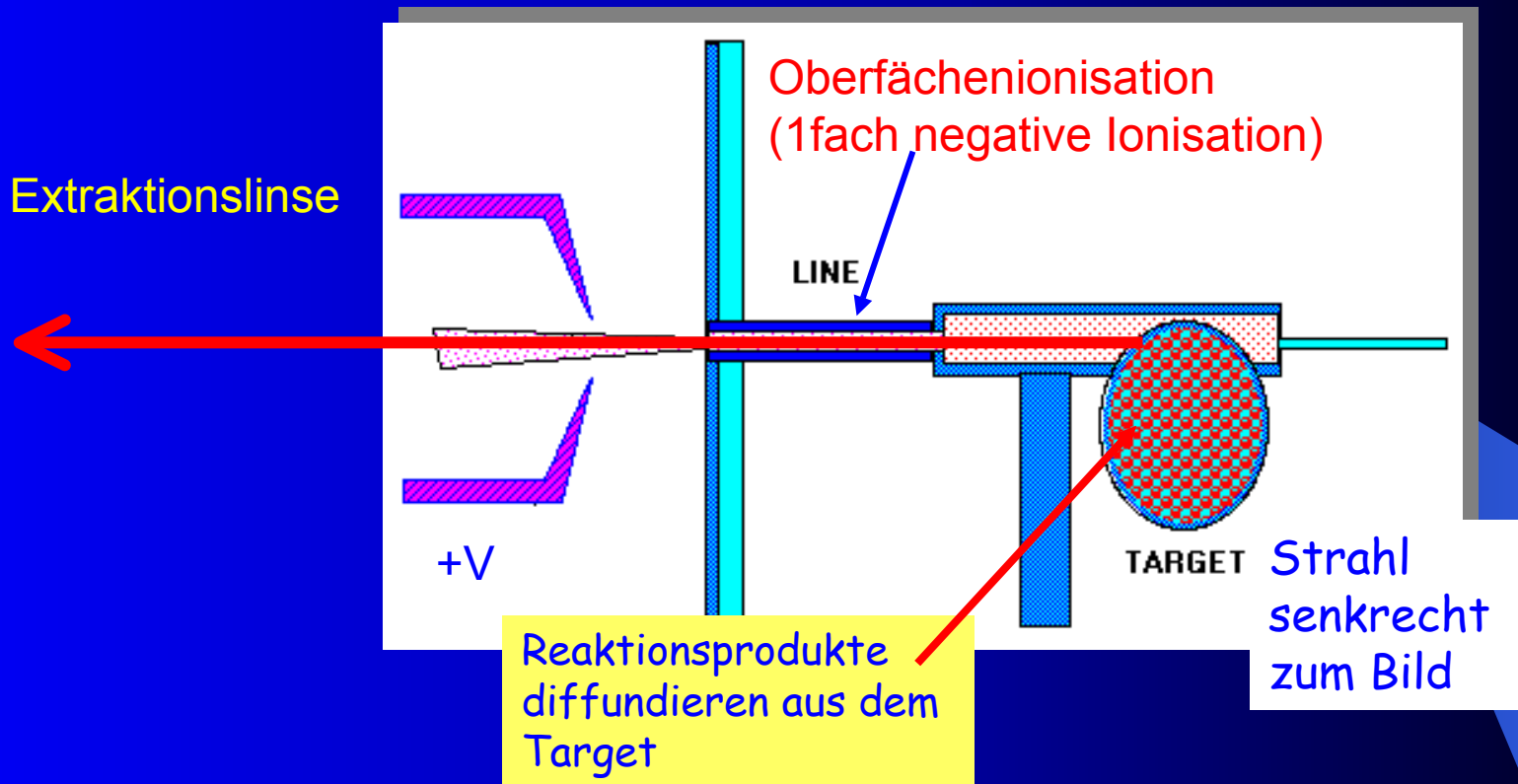
## Laser ionization



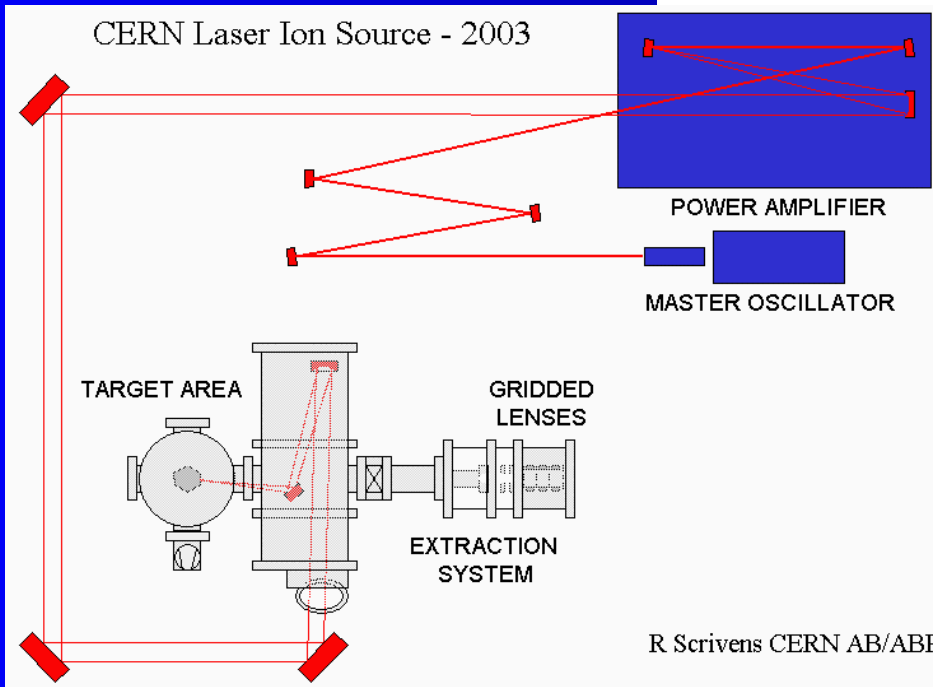
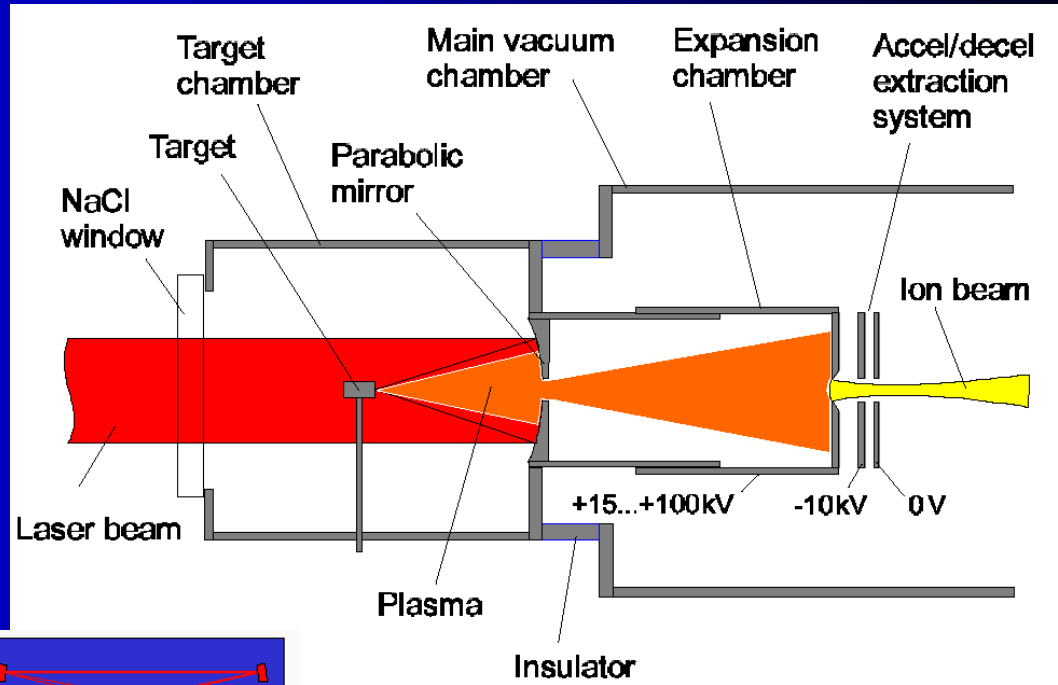
## Ionization by electron impact



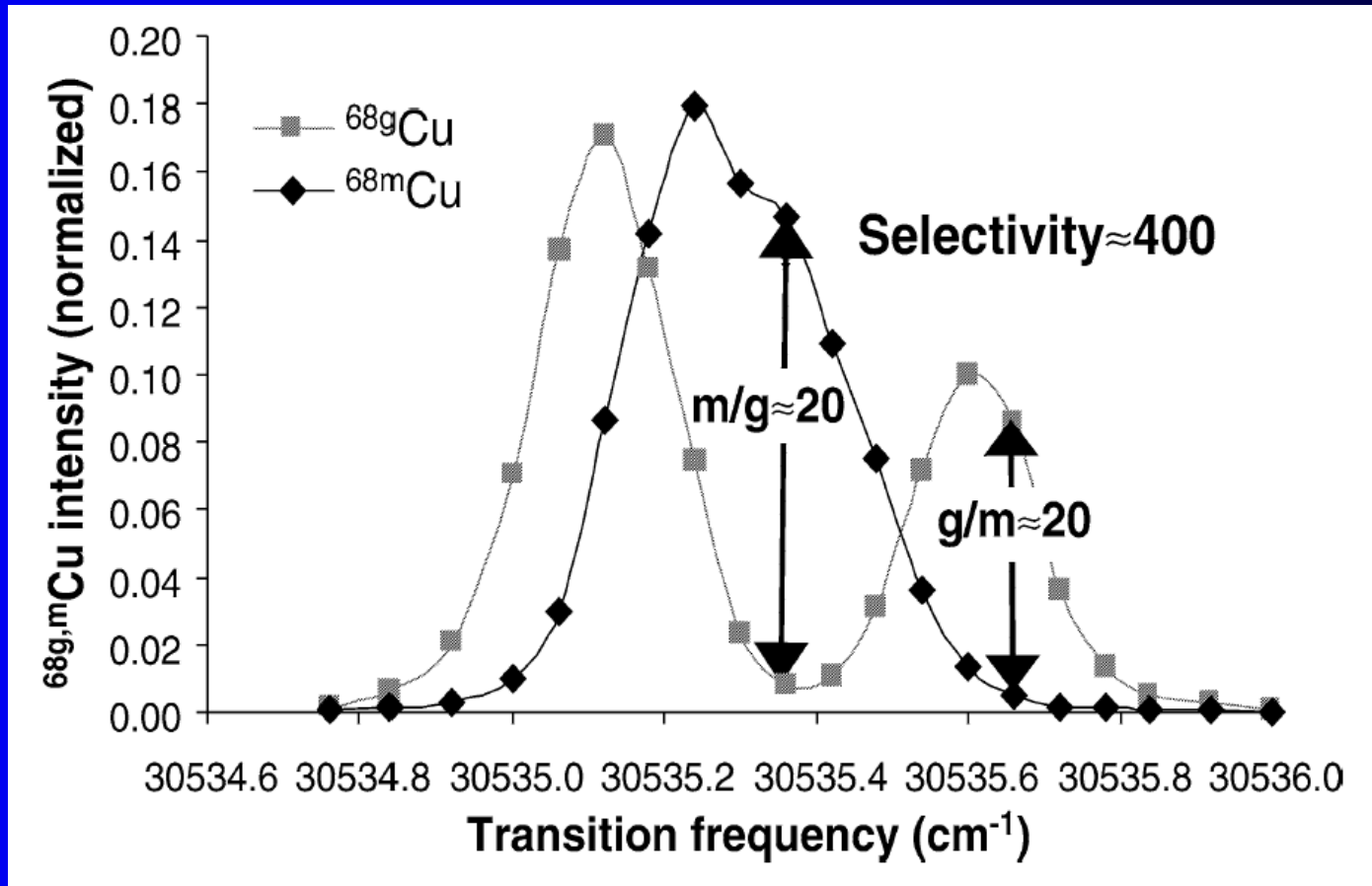
# Oberflächenionisation



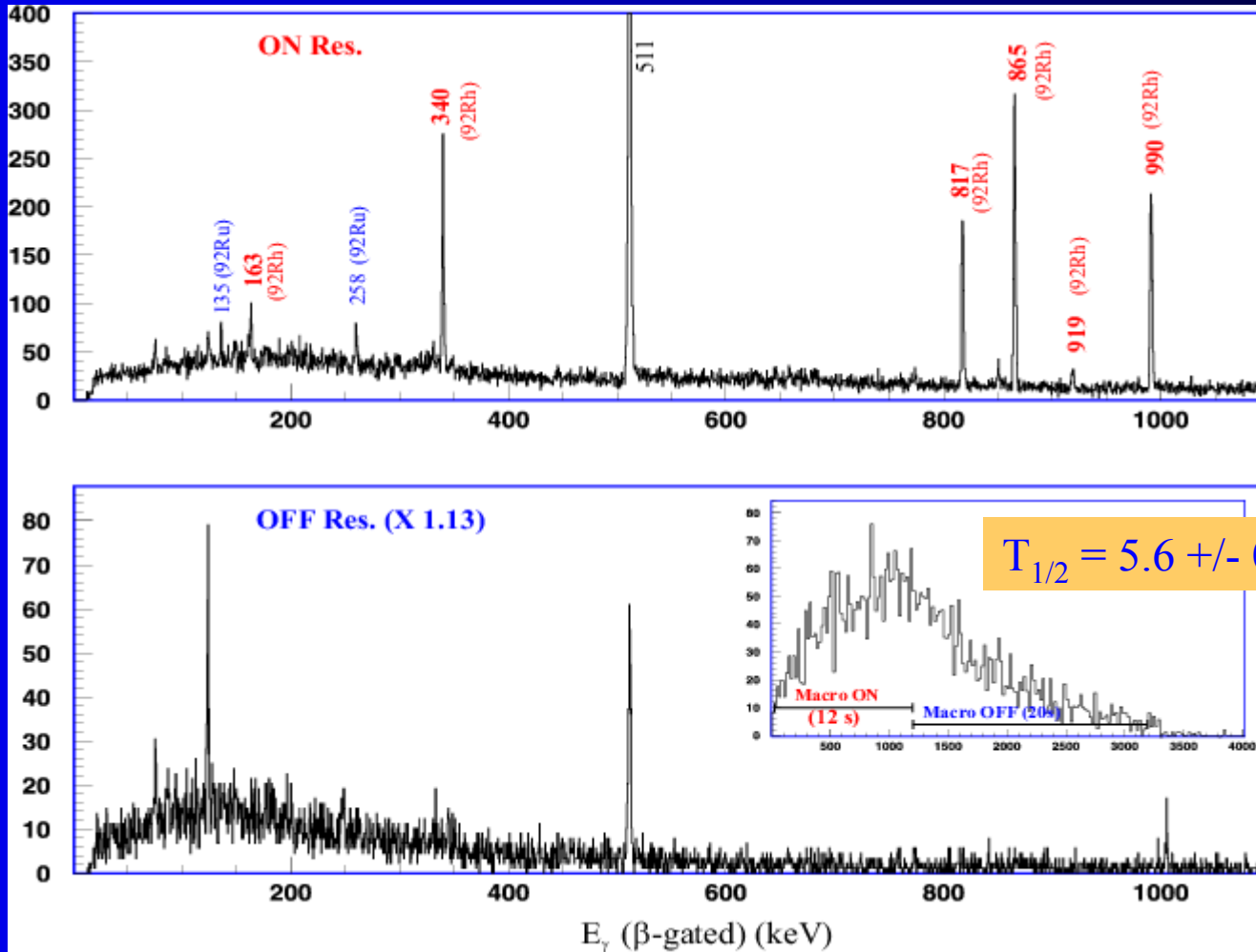
# Laserionisation



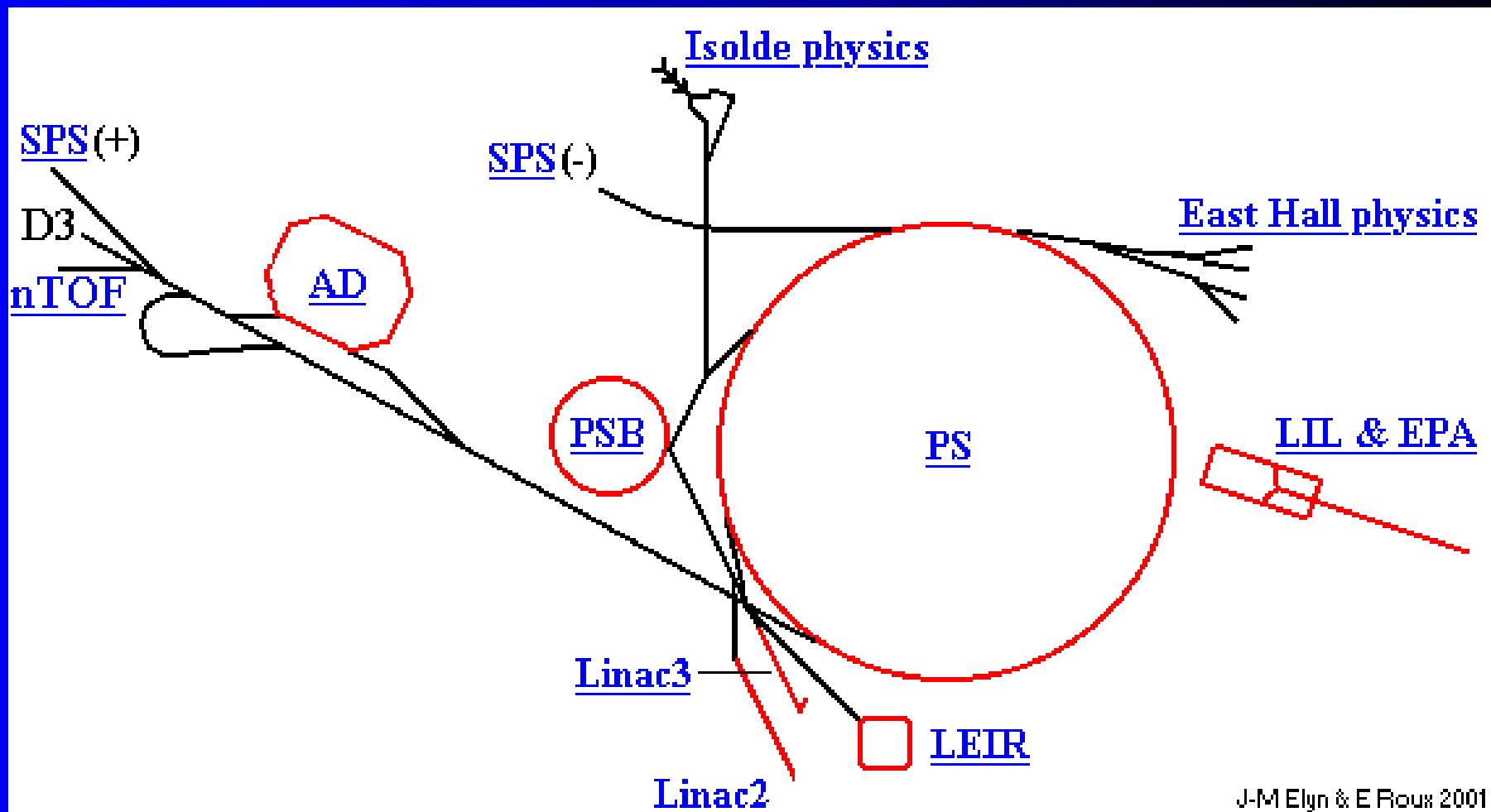
# Selektivität der Laser Ionisation 1



# Selektivität der Laser Ionisation 2

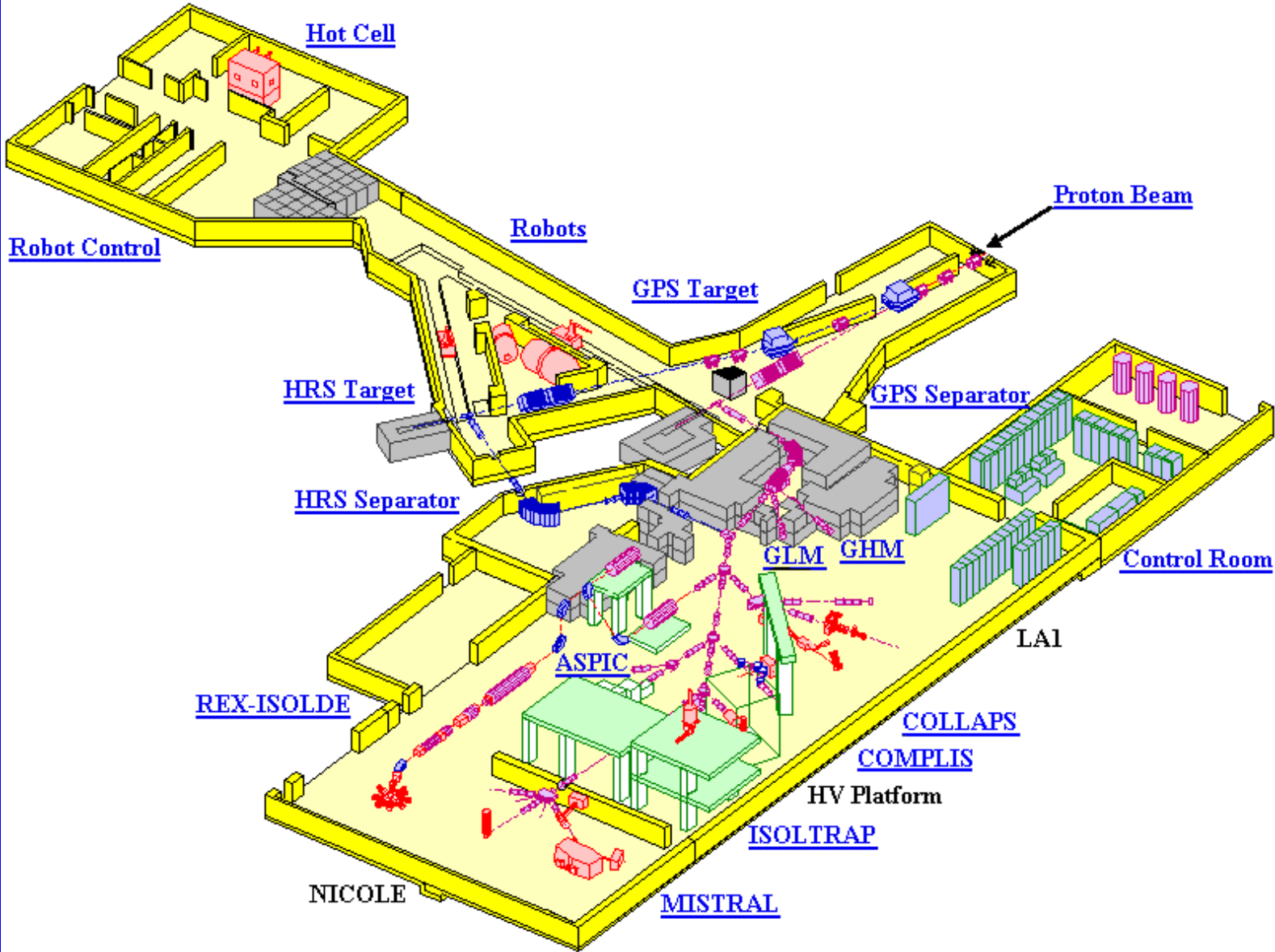


# ISOLDE am PS Booster des CERN

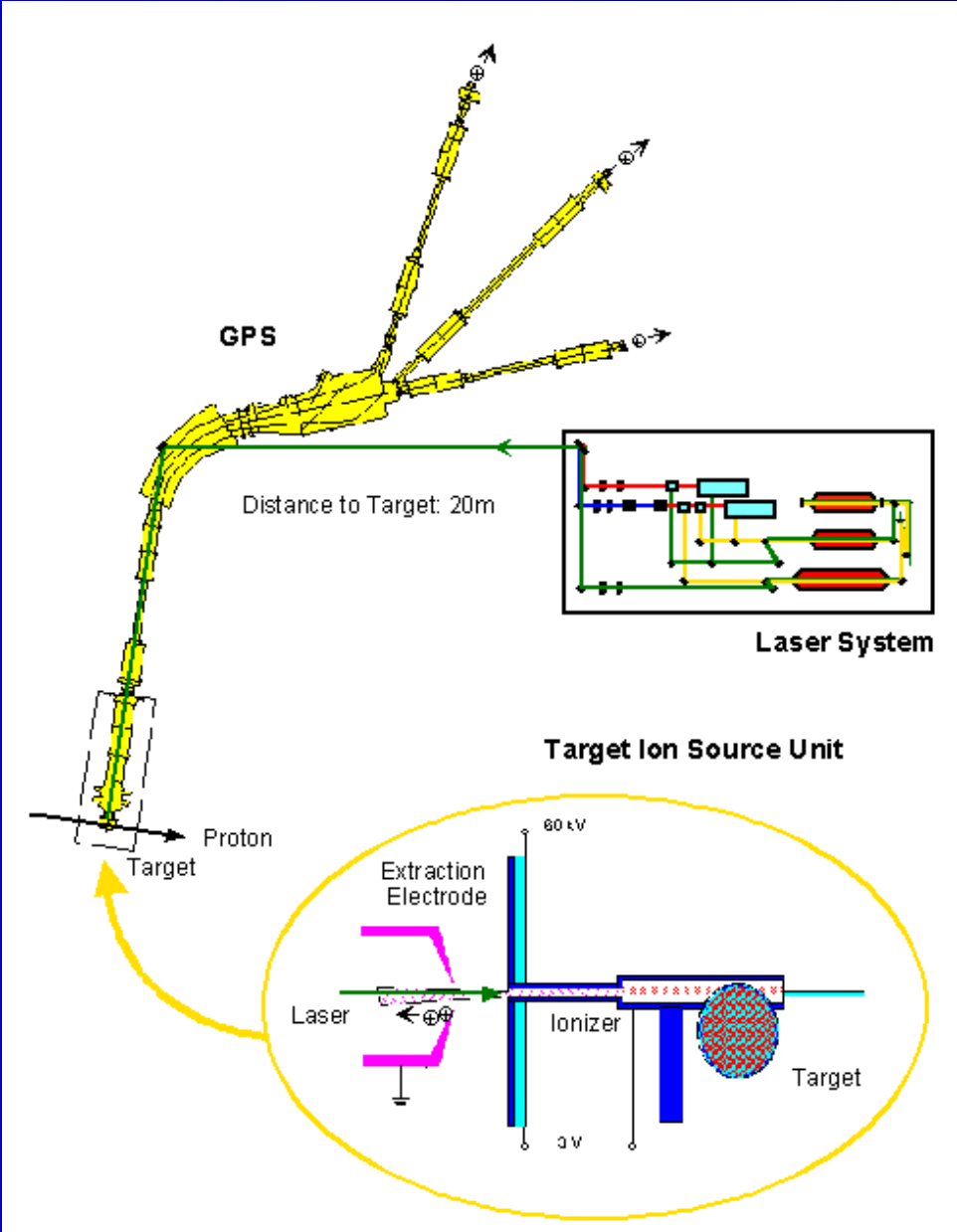




# ISOLDE am CERN



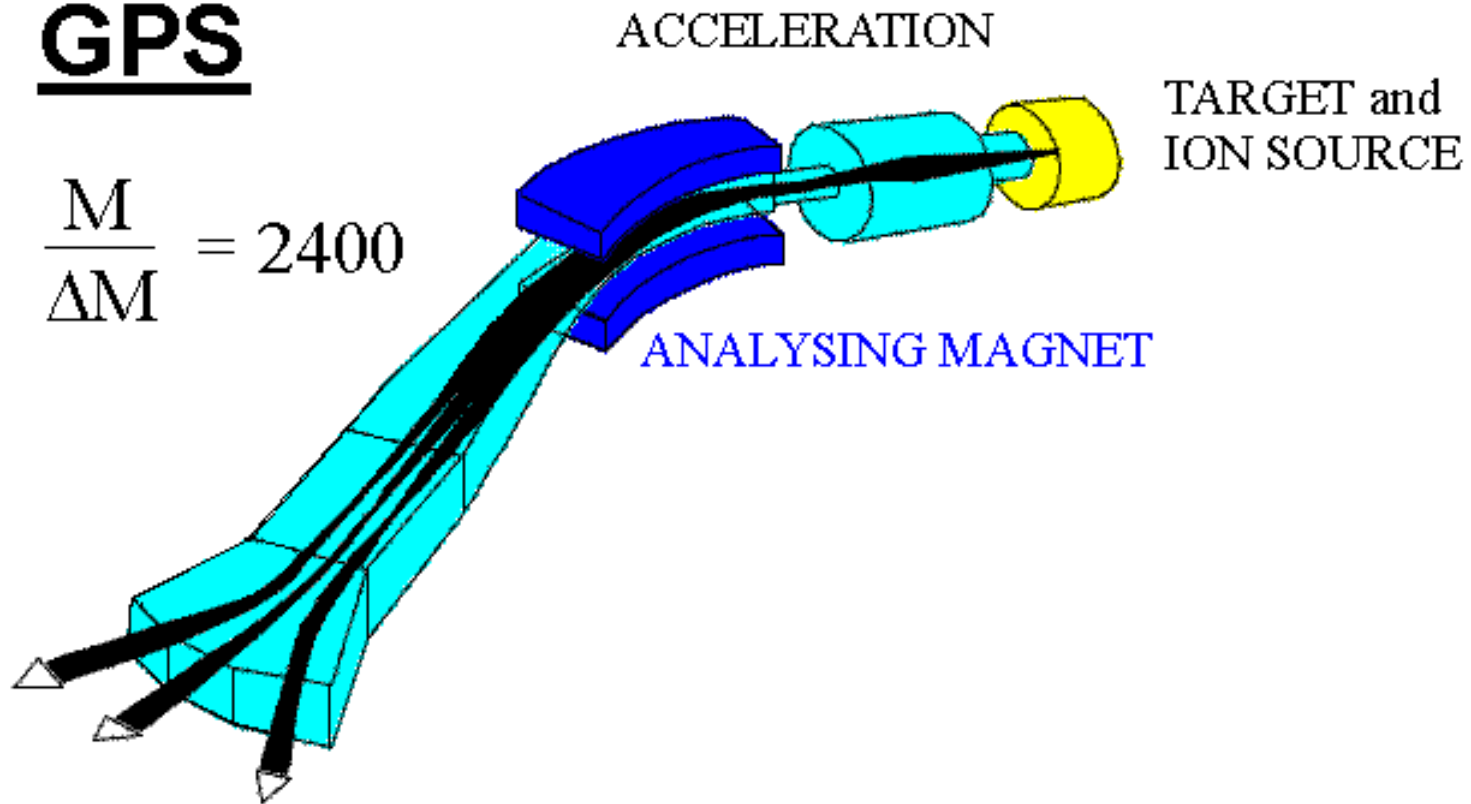
# Laserionisation an ISOLDE



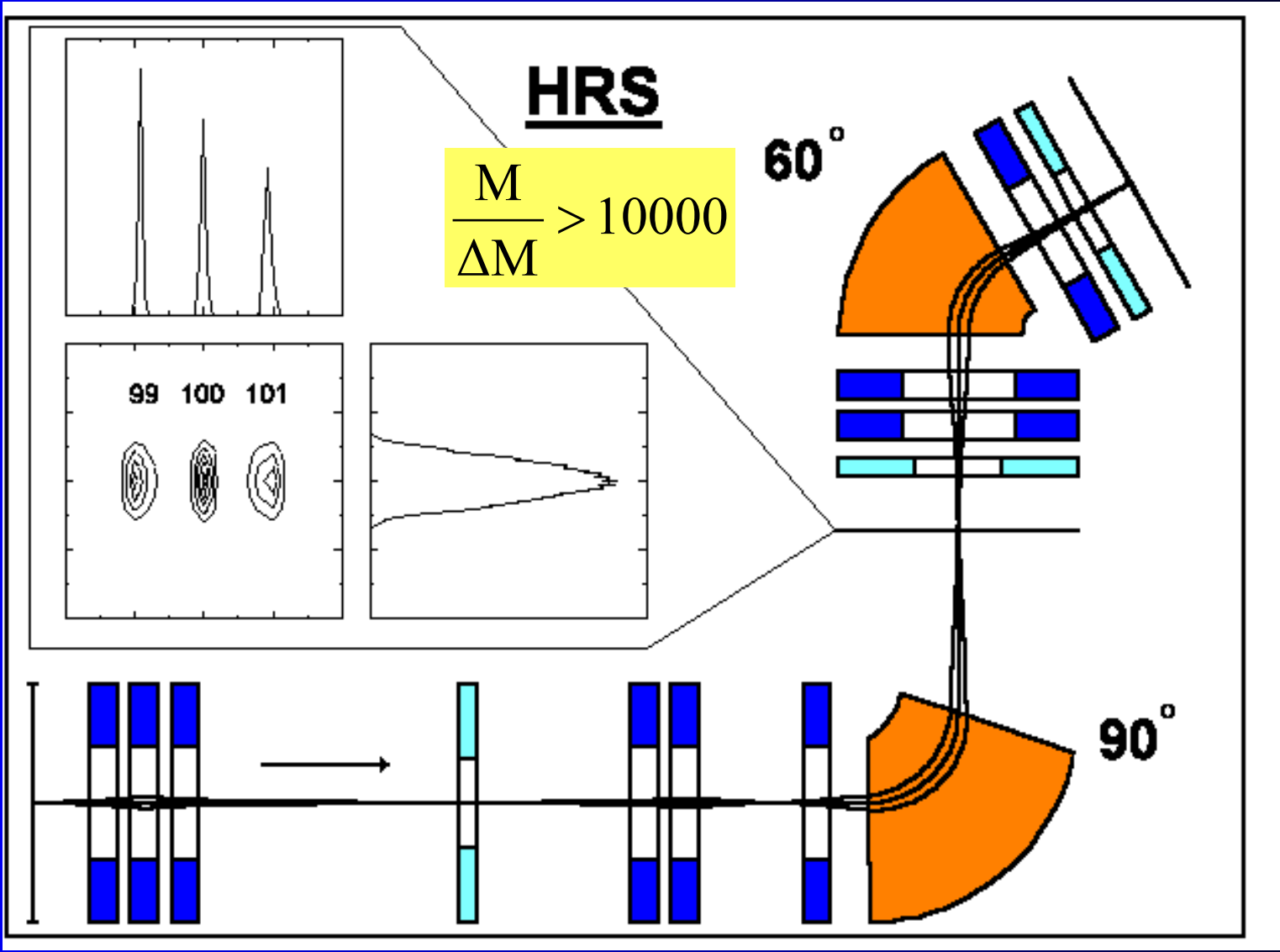
# Mass separation with dem General Purpose Separator

**GPS**

$$\frac{M}{\Delta M} = 2400$$

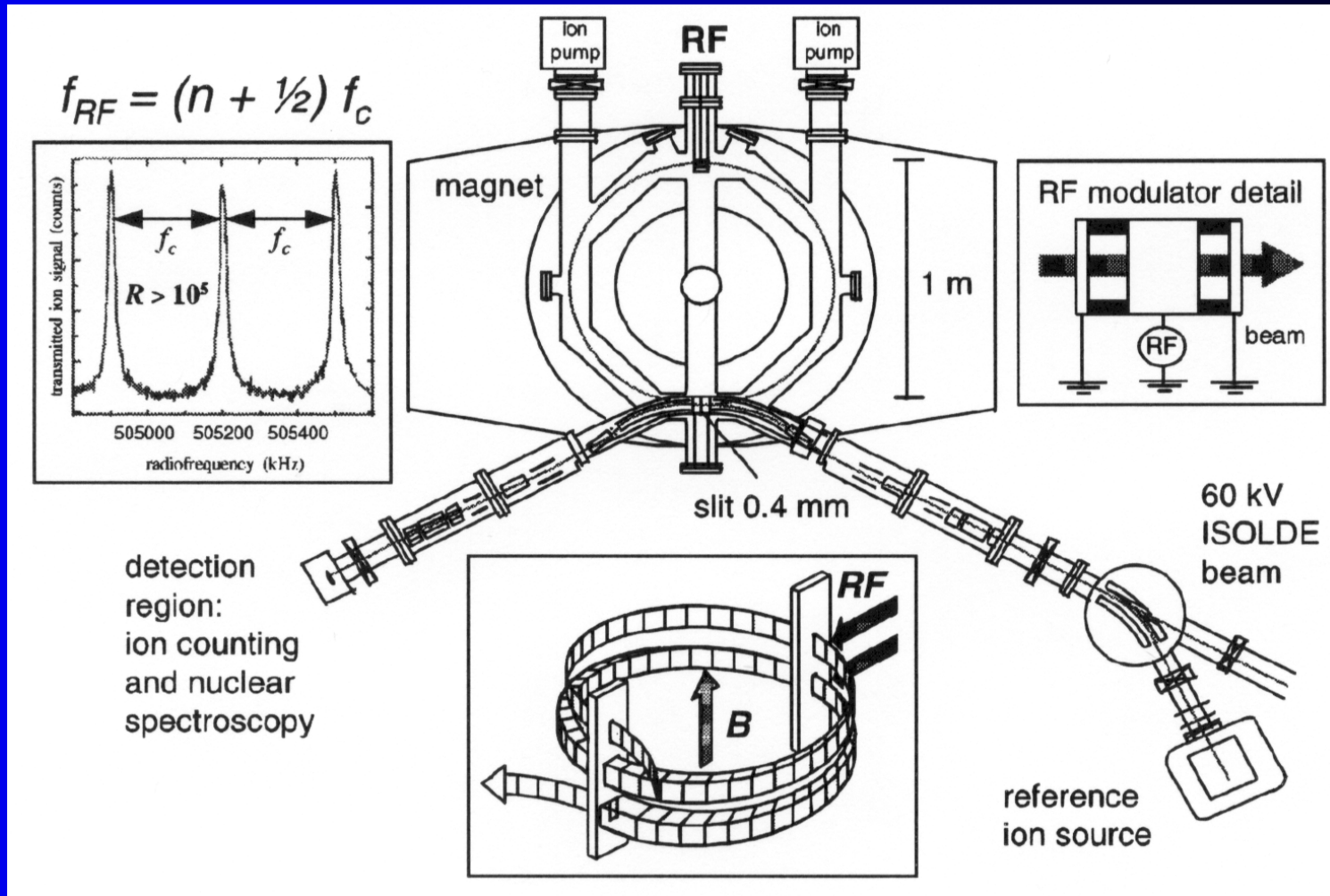


# Hochauflösender Massenseparator an ISOLDE



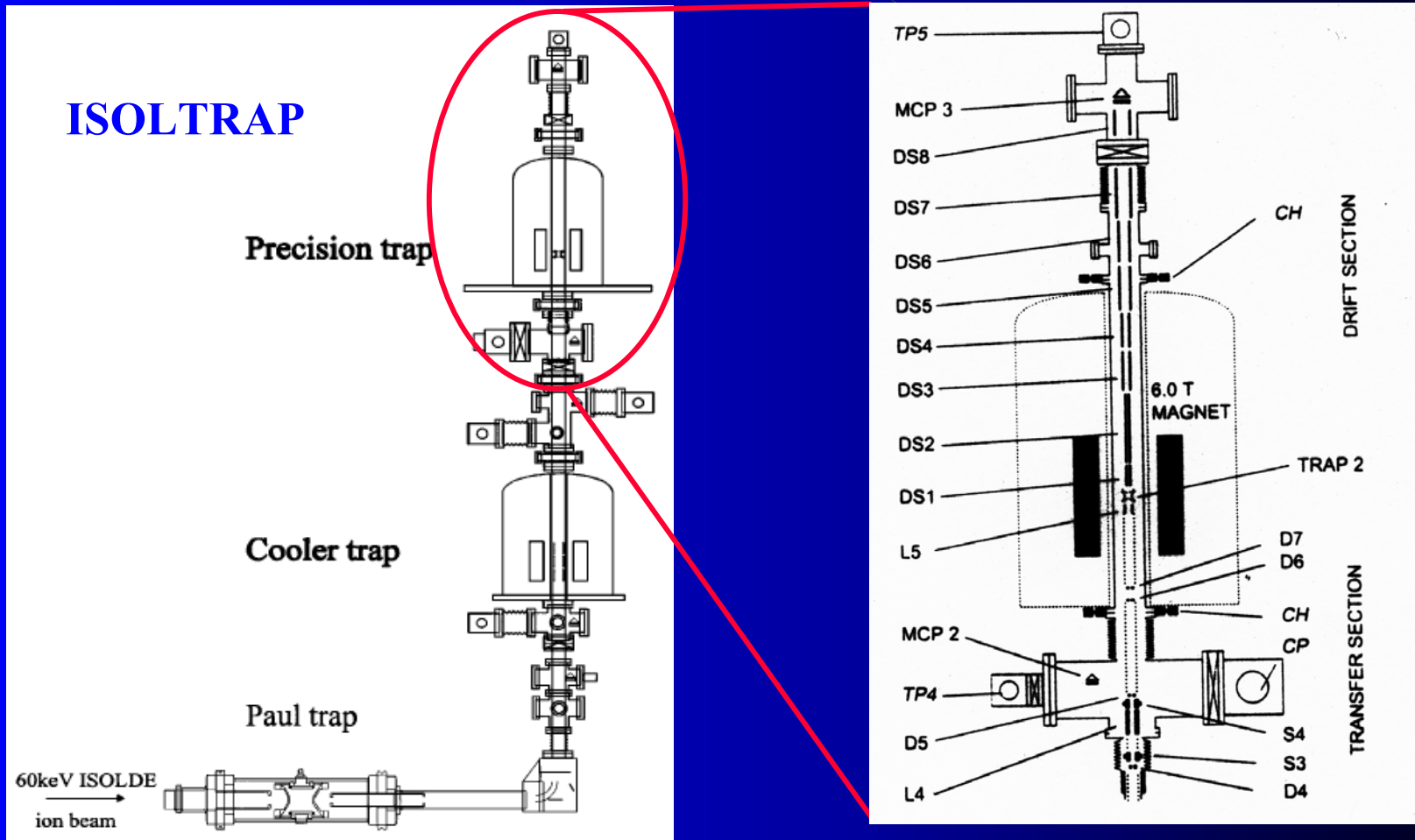
# MISTRAL – Massen durch Radiofrequenzmessung

- Beispiel: MISTRAL am CERN

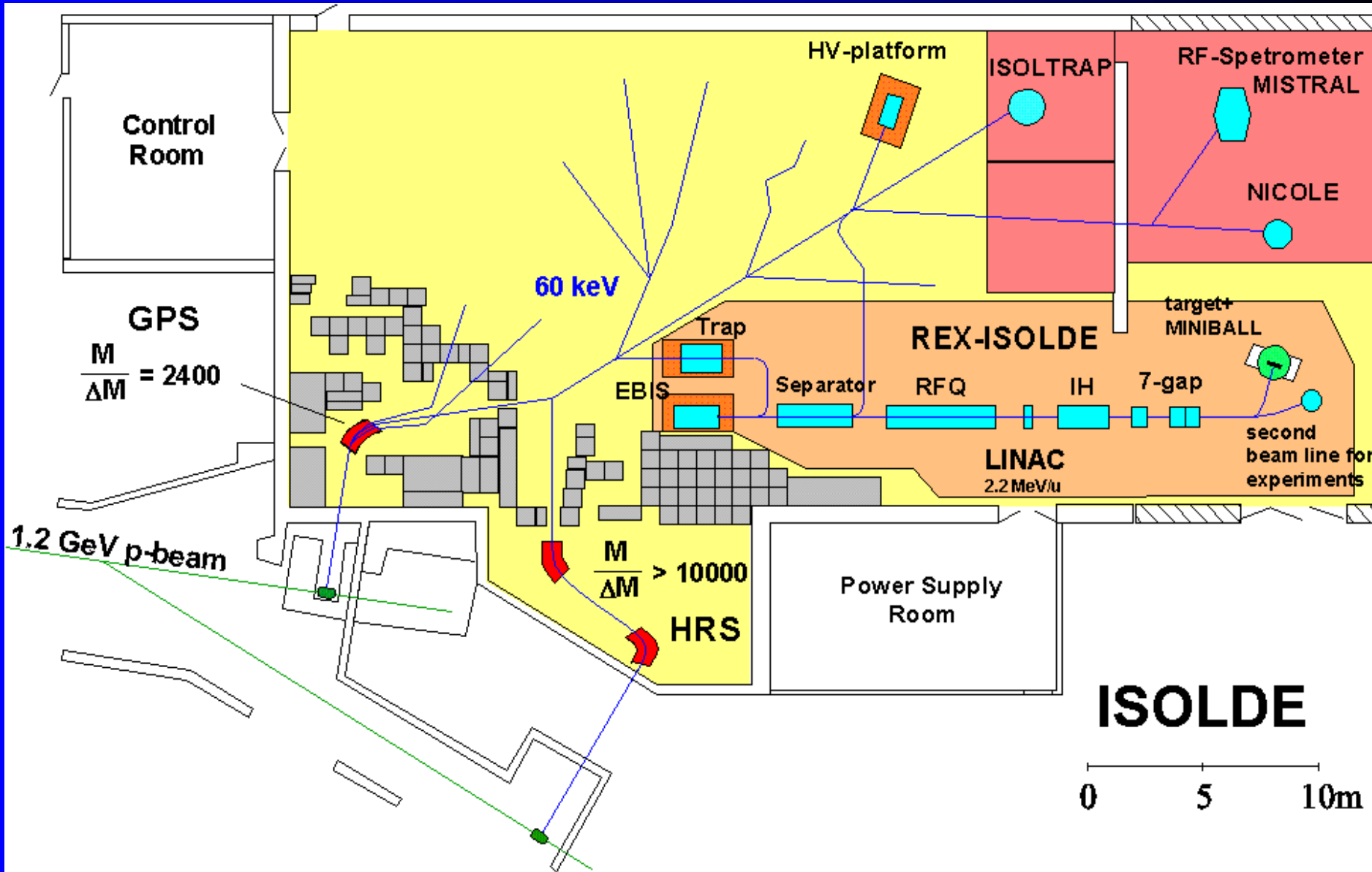


# ISOLTRAP – Penning Falle zur Massenmessung

- Beispiel: ISOLTRAP am CERN



# REX-ISOLDE

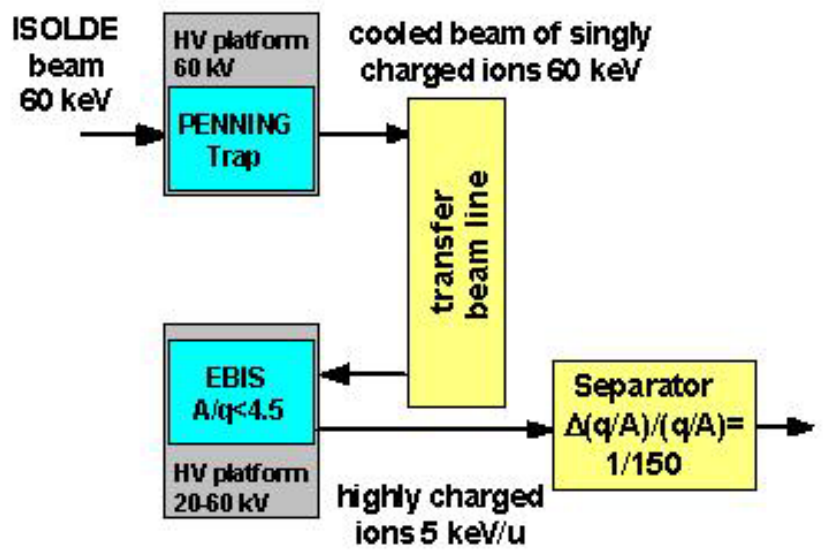


## ISOLDE

0 5 10m



# The REX-ISOLDE charge state breeder



|                               |                 |
|-------------------------------|-----------------|
| breeding time ( $q/A > 0.2$ ) | < 20 ms         |
| beam intensities              | < $10^9$ /s     |
| efficiency one charge state   | < 30%           |
| efficiency REXTRAP            | 50%             |
| UHV operation                 | $10^{-11}$ mbar |

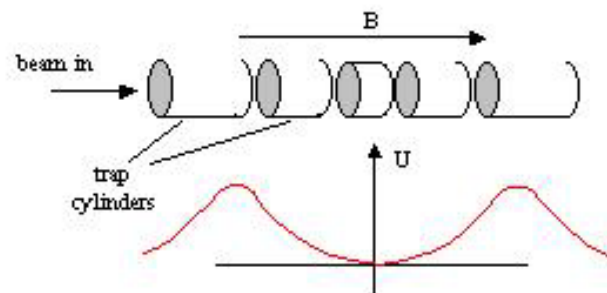
q/A-selector

REXTRAP



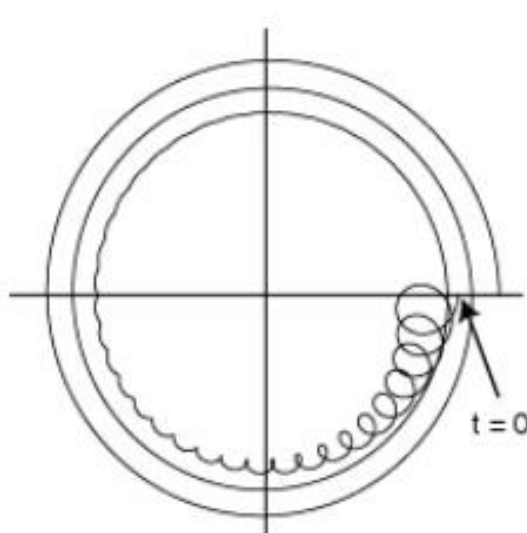
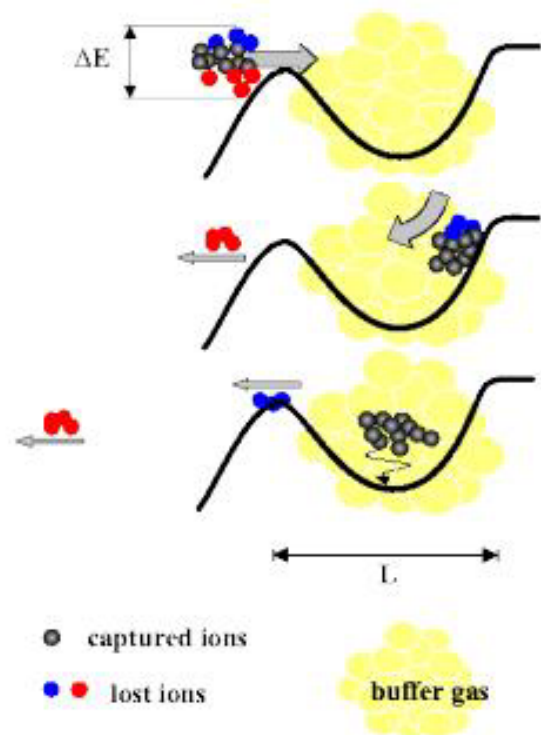


# REXTRAP principle

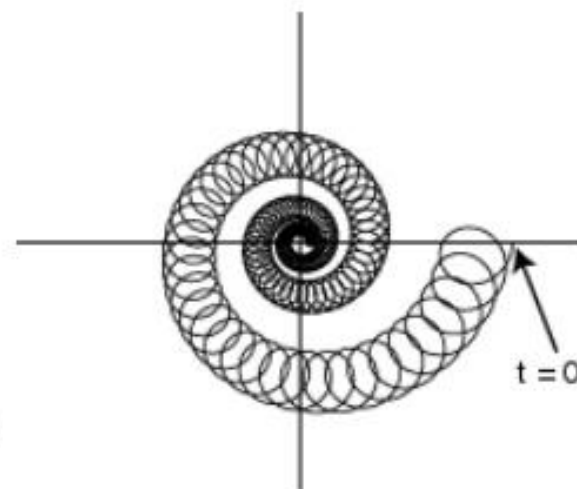


|                     |                |
|---------------------|----------------|
| magnetic field      | 3 T            |
| cycle time          | 10 ms          |
| buffer gas pressure | $10^{-3}$ mbar |

## sideband cooling method



Buffer gas



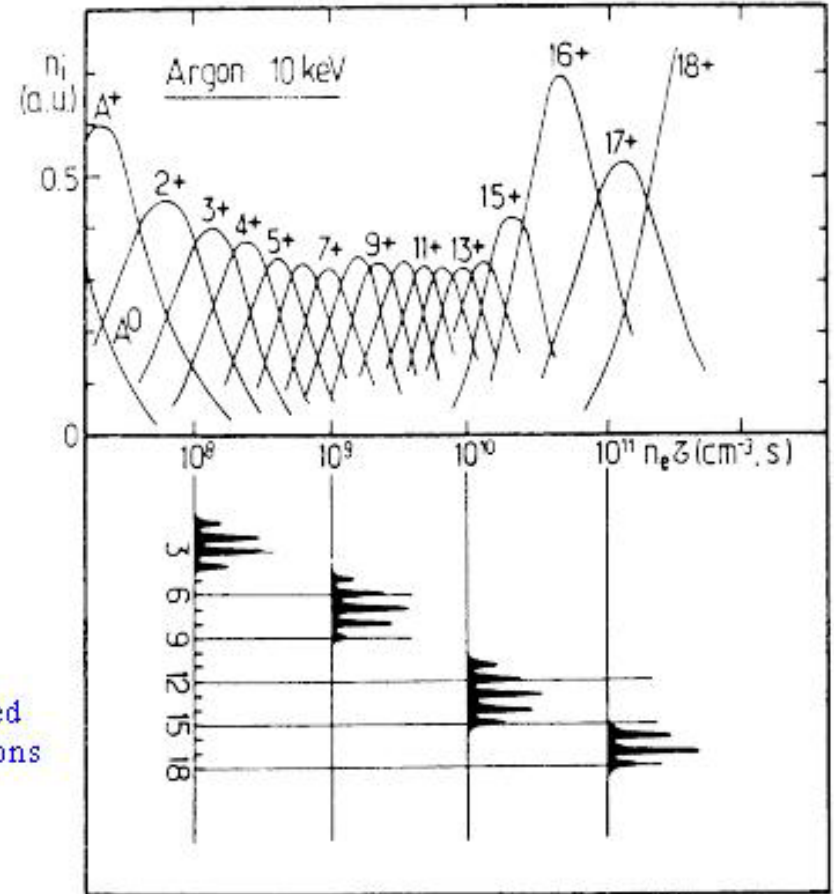
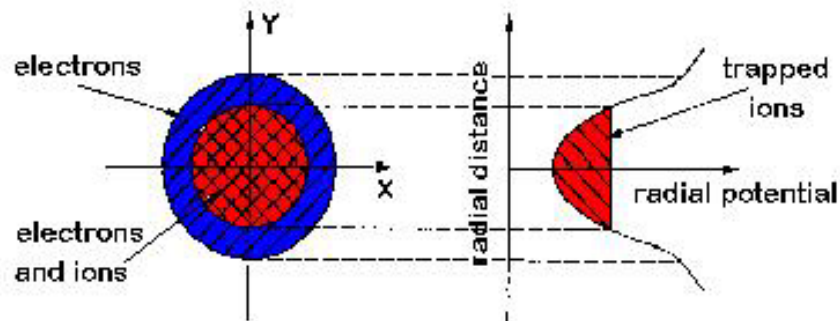
Buffer gas+ rf-field



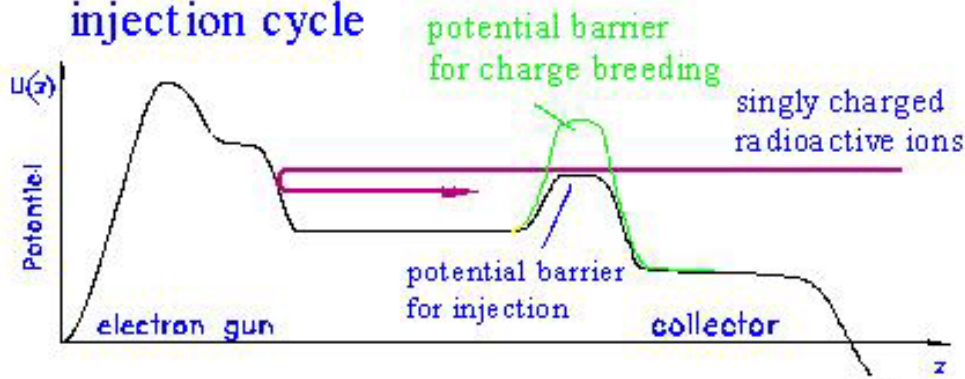
# The Electron Beam Ion Source



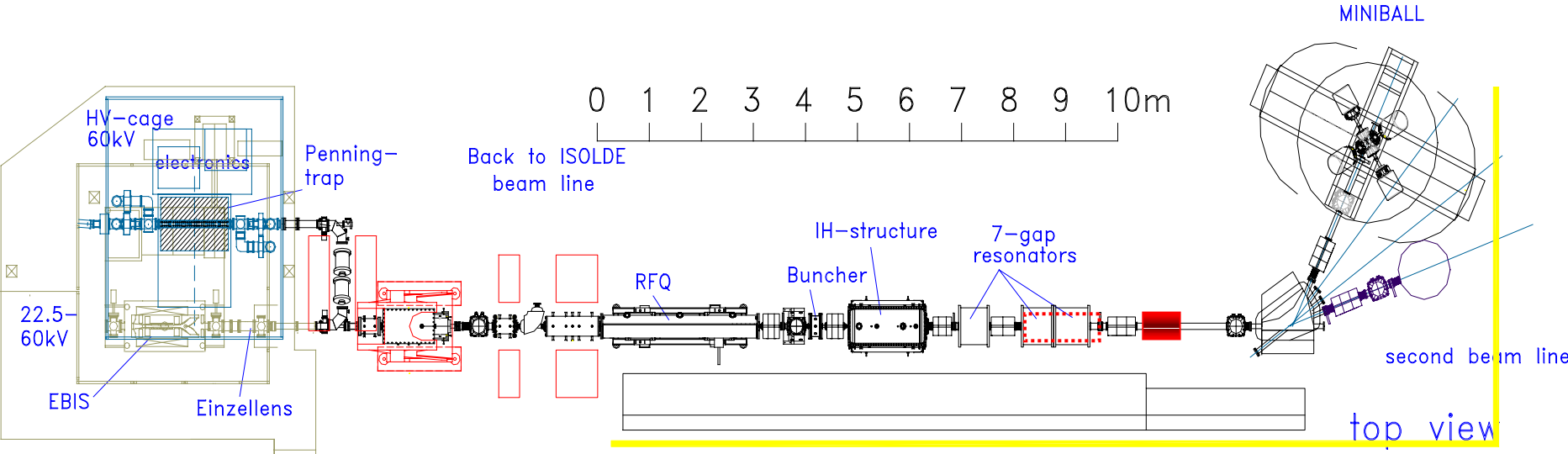
|                       |                       |
|-----------------------|-----------------------|
| Magnetic field        | 2 T                   |
| electron beam current | 190 mA                |
| electron beam energy  | 5 keV                 |
| current density       | 150 A/cm <sup>2</sup> |
| emittance             | 10-20 $\pi$ mm mrad   |



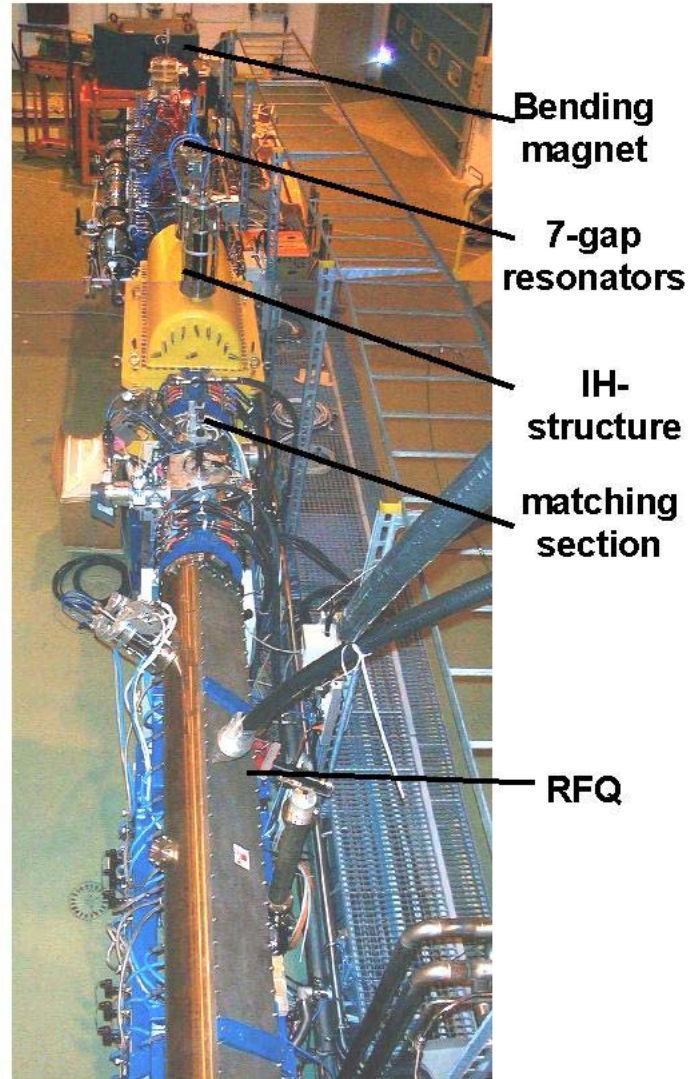
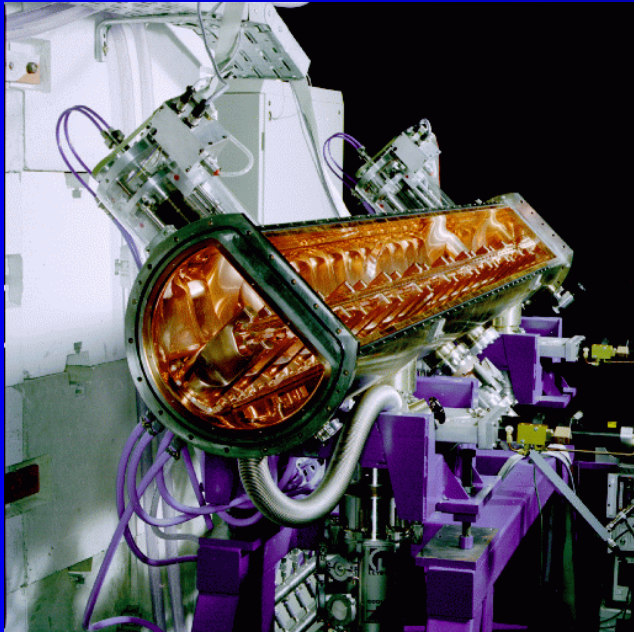
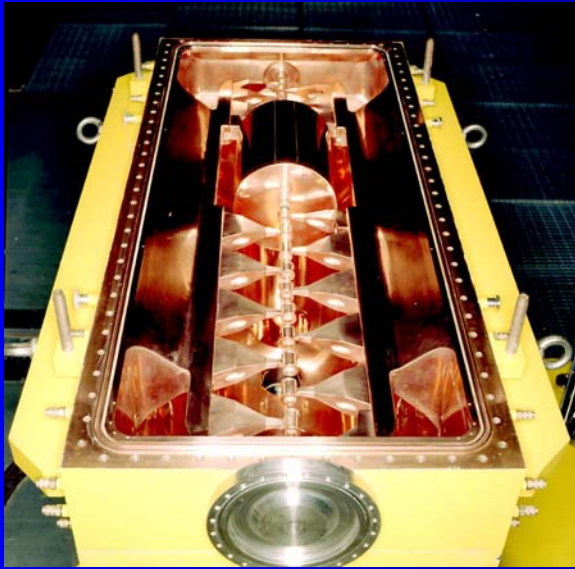
## injection cycle



# REX-ISOLDE



# REX- Beschleunigerstrukturen



Bending magnet

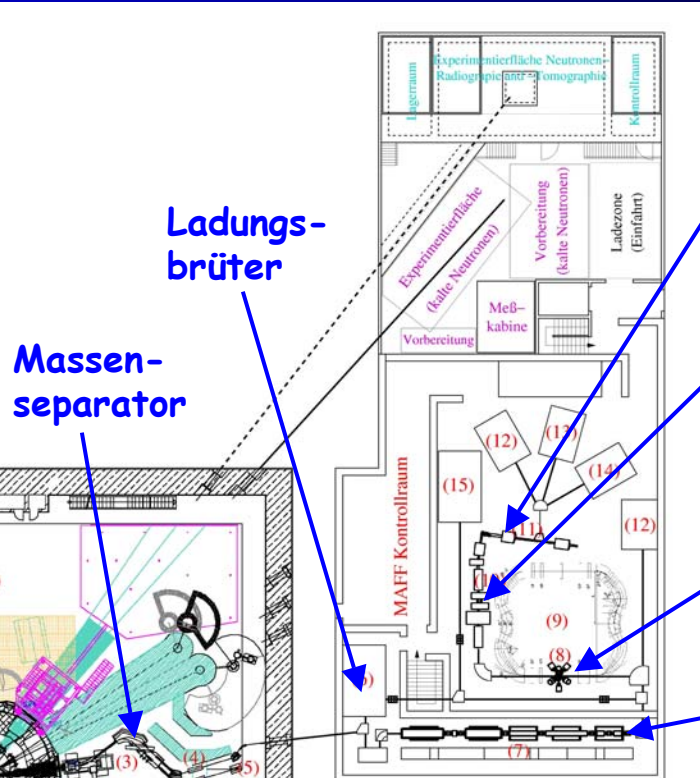
7-gap resonators

IH-structure

matching section

RFQ

# MAFF am FRM II in Garching



MAFF-Trap

Magnet-Separator

Gamma-Spektrometer

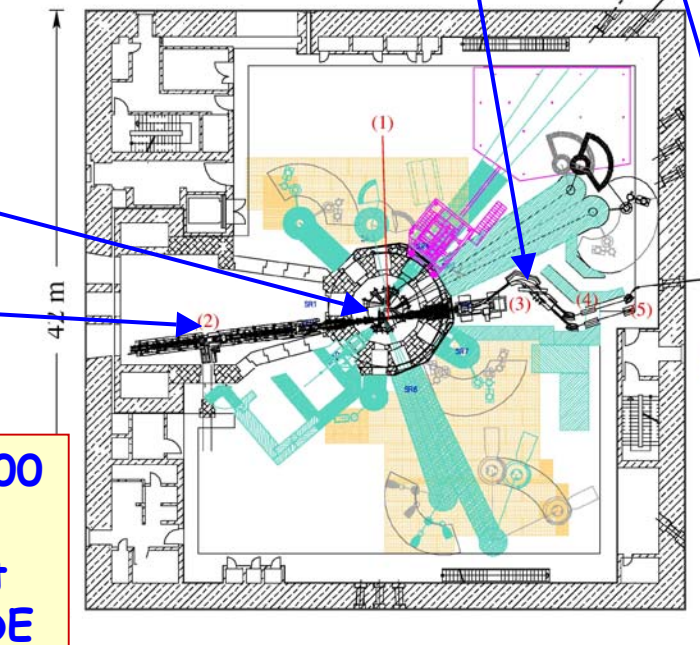
~5 MeV/u  
LINAC

Ladungsbrüter

Massenseparator

Spaltquelle  
 $10^{14}$  Spalt./sec

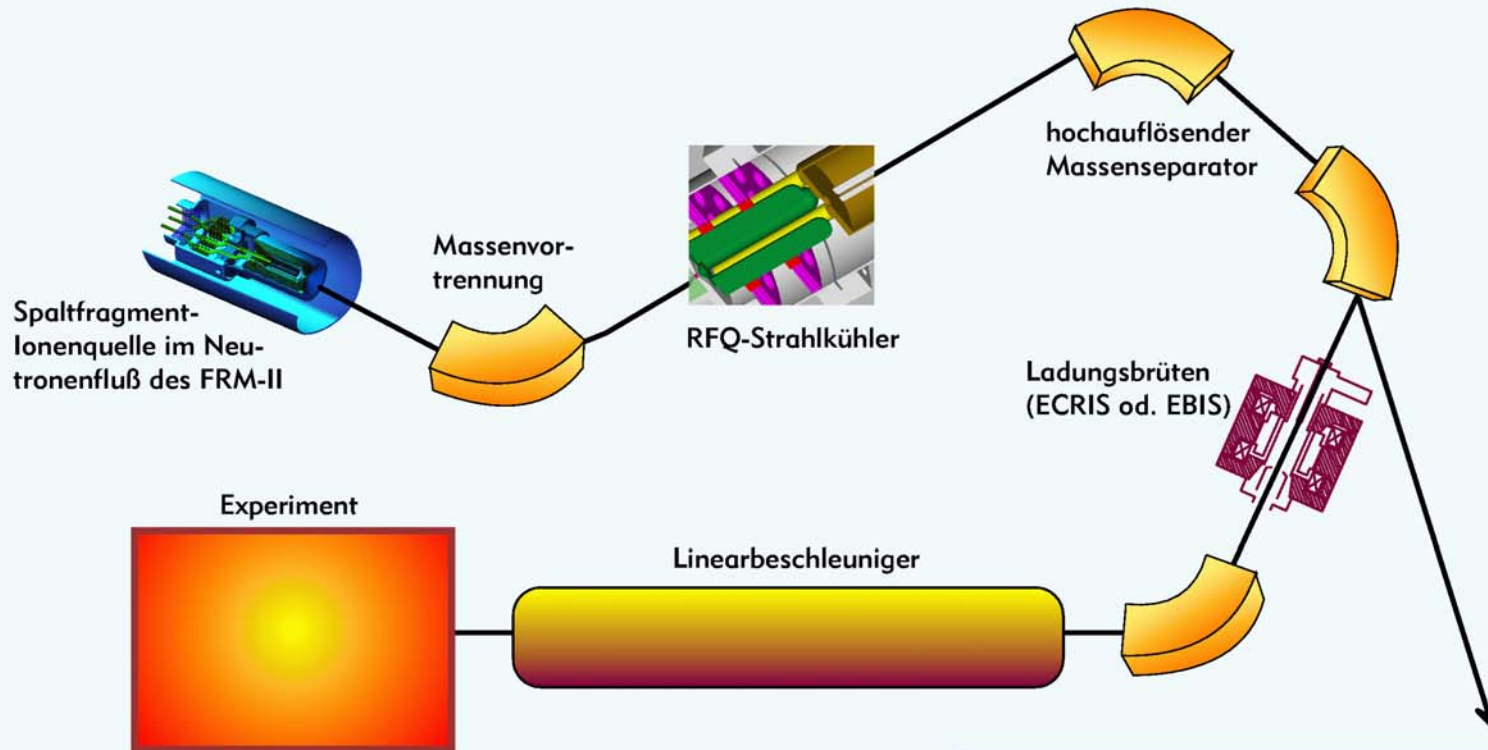
Quellenwechsler



Faktor 100-1000  
höhere  
Strahlintensität  
als REX-ISOLDE



# Prinzip des Münchner Spaltfragmentbeschleunigers (MAFF)



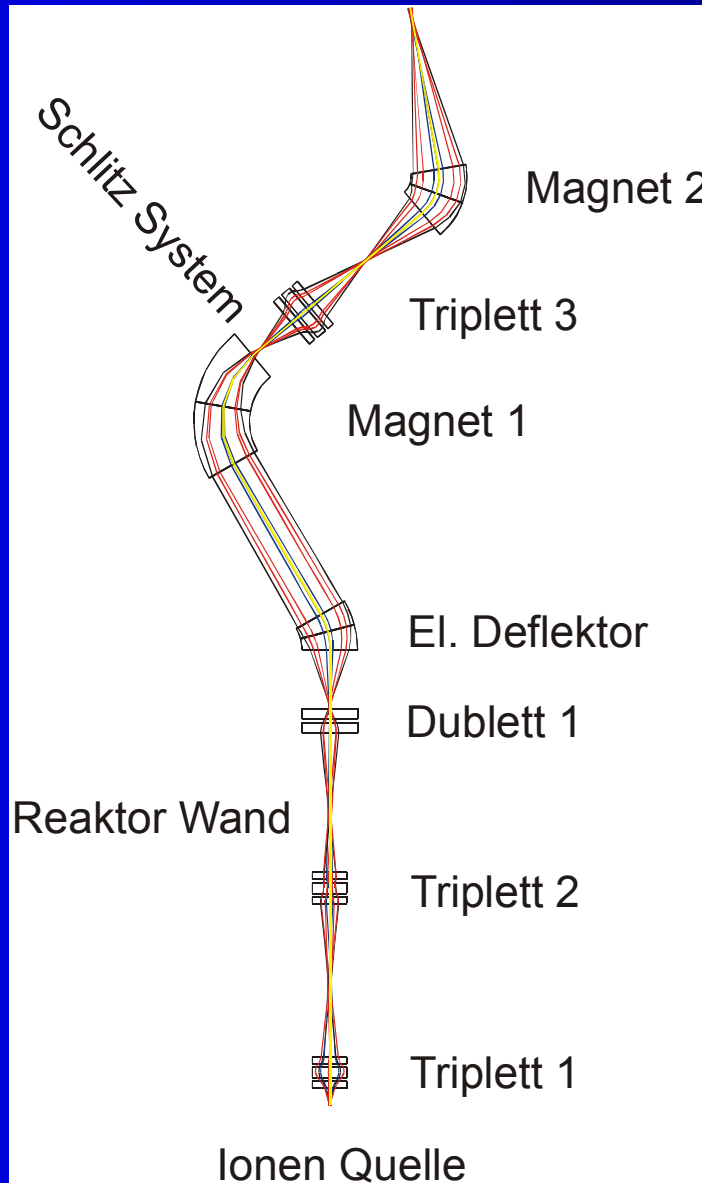
## Hochenergiestrah:

- Herstellung langlebiger, superschwerer Elemente ( $T_{1/2}$  bis zu 30 Jahre):
- Kernphysik: Blasenförmige Atomkerne
- Chemie: Schrumpfung der inneren Elektronenschalen durch relativistische Effekte

## Niederenergiestrah:

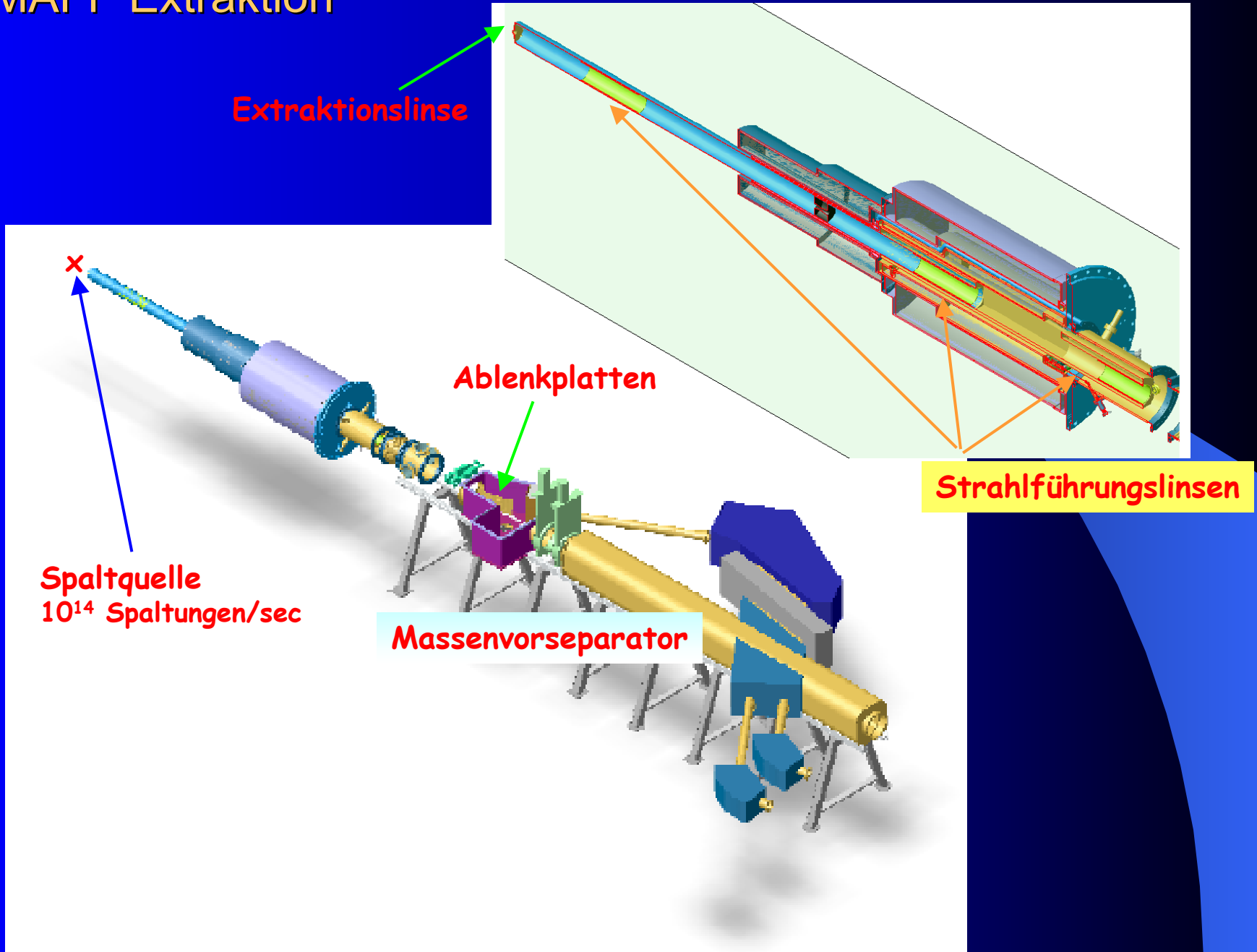
- Kernspektroskopie:  
Untersuchung der Elementsynthese bei Supernova-Explosionen
- Nuklearmedizin:  
Trägerfreie Isotope f. Diagnostik u. Therapie
- Migration von Spaltprodukten:  
Endlagerung radioaktiver Abfälle

# MAFF Extraktion



Triplet-Prototyp

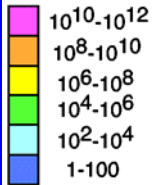
# MAFF Extraktion



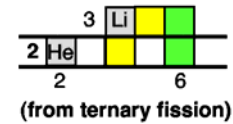
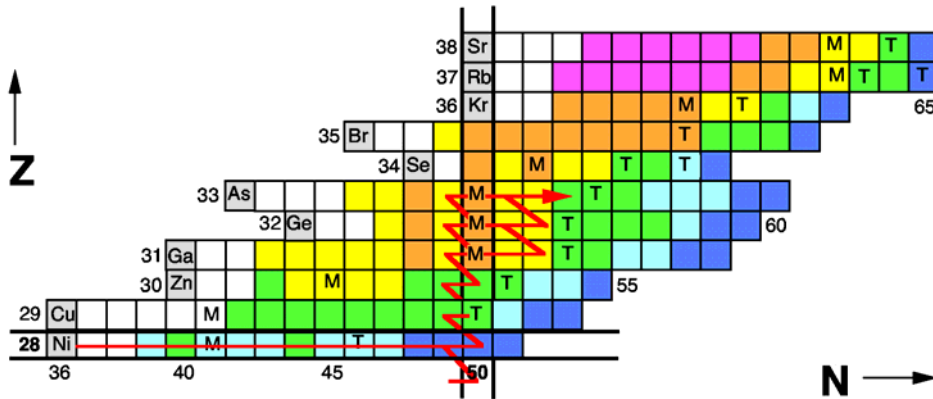
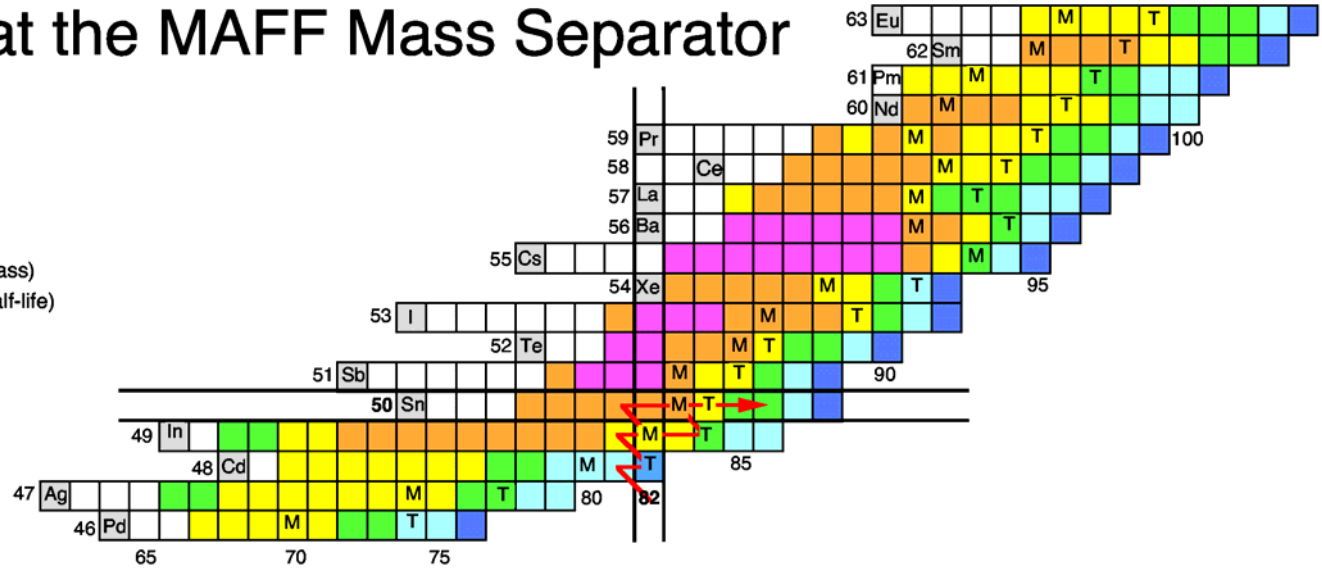


# Beam Intensities at the MAFF Mass Separator

$1^+ \text{-Ions (s}^{-1}\text{)}$



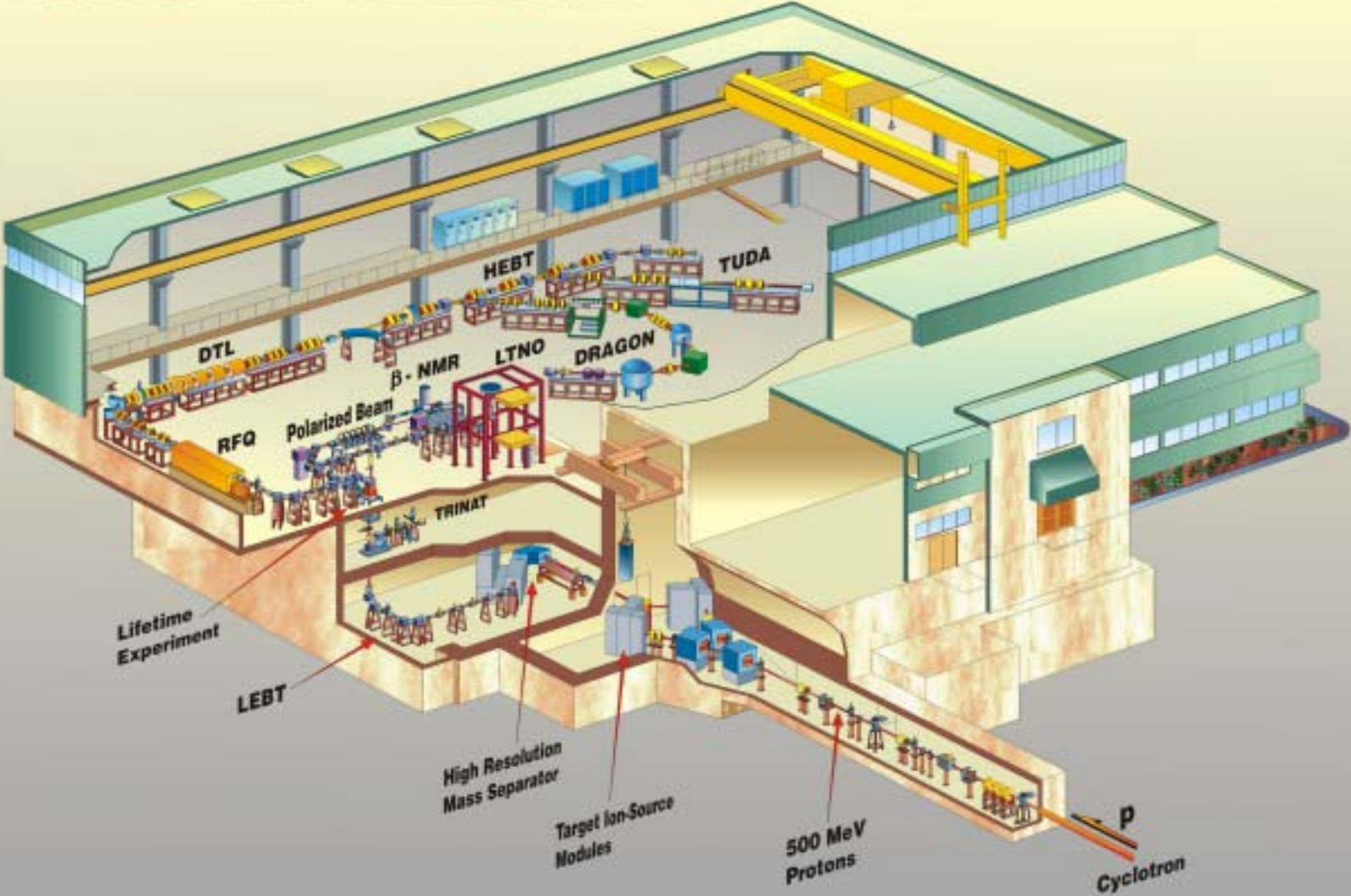
- Limit of stable nuclei
- M Limit of known nuclei (Mass)
- T Limit of known nuclei (Half-life)



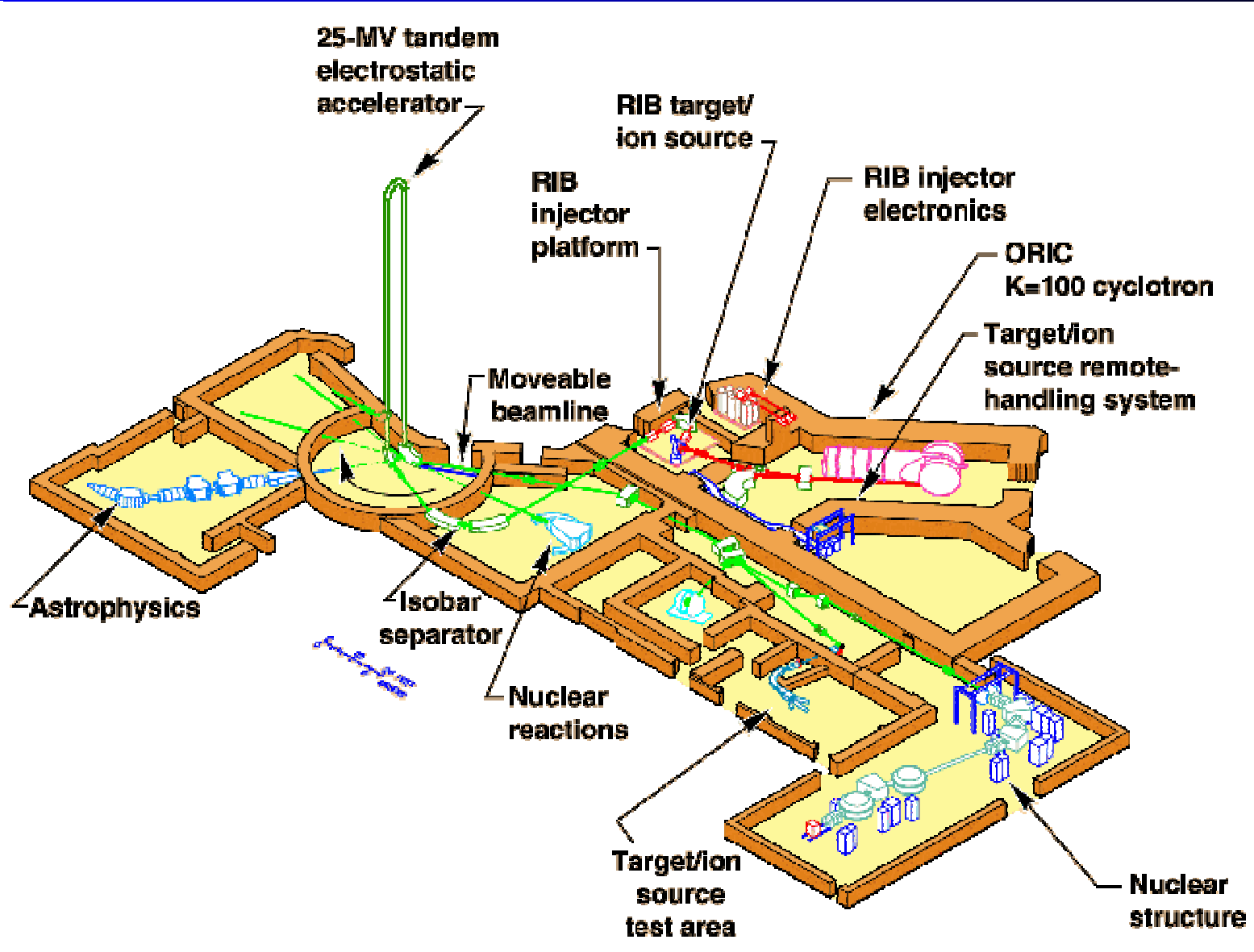
**N** →

# Kanadische ISOL Facility

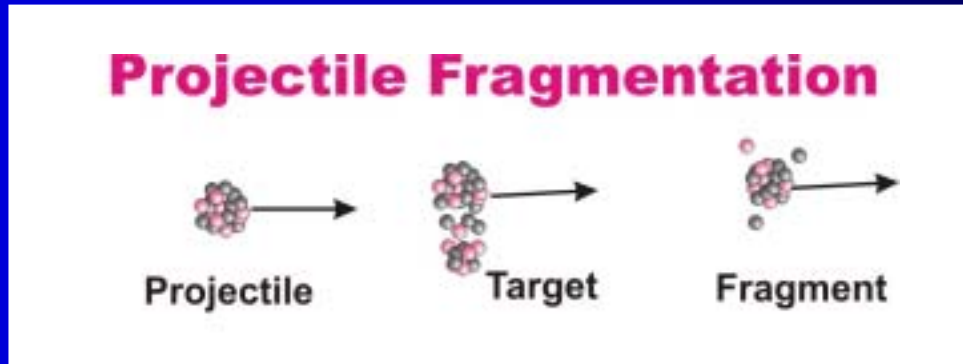
## ISAC at TRIUMF



# ISOL Facility at Oak Ridge National Laboratory, USA

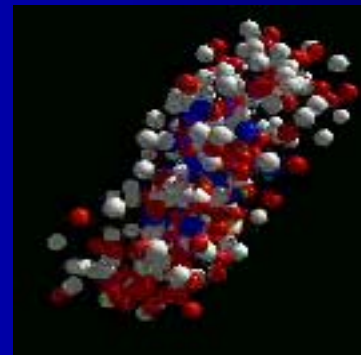
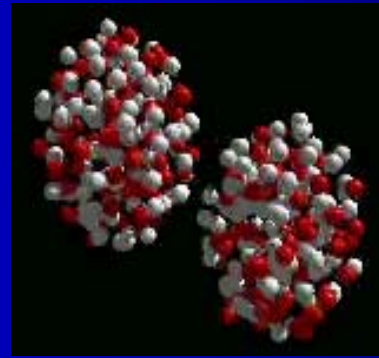
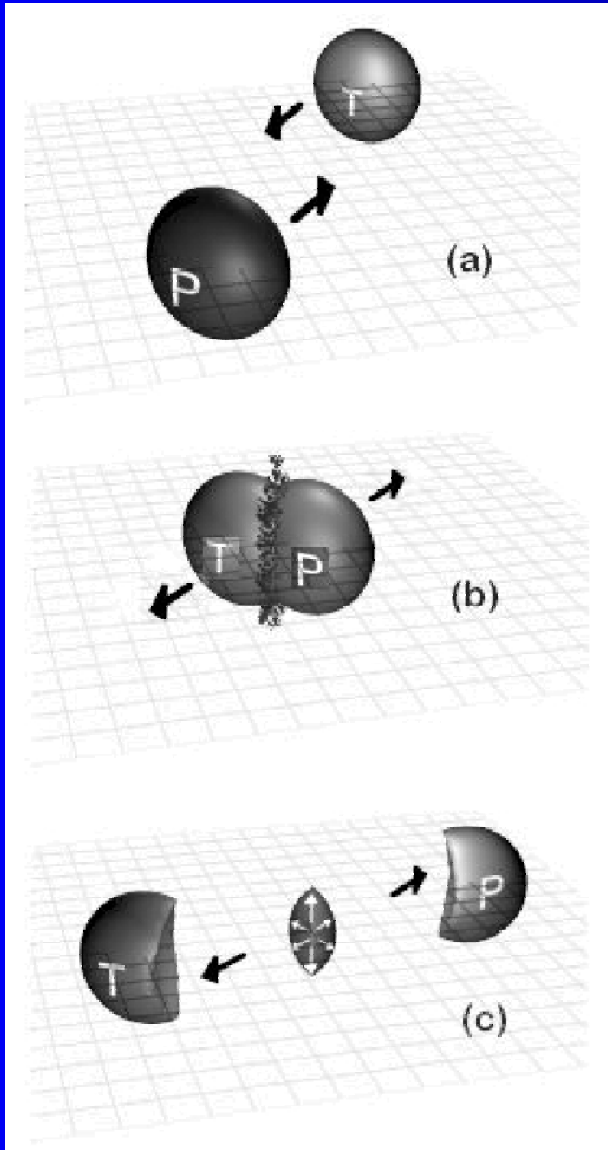


# Fragmentation



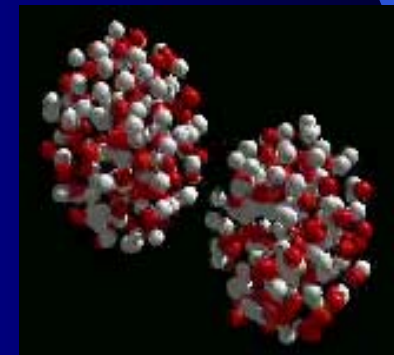
- Schwere Ionen werden zu hohen Energien beschleunigt (50 – 1000 MeV/u)
- Fragmentation oder Spaltung der Strahlteilchen an einem Target (Be, Pb)
- Fragmente fliegen mit Strahlgeschwindigkeit weiter
- Magnetische Separation der gewünschten Produkte

# Projektilfragmentation anschaulich

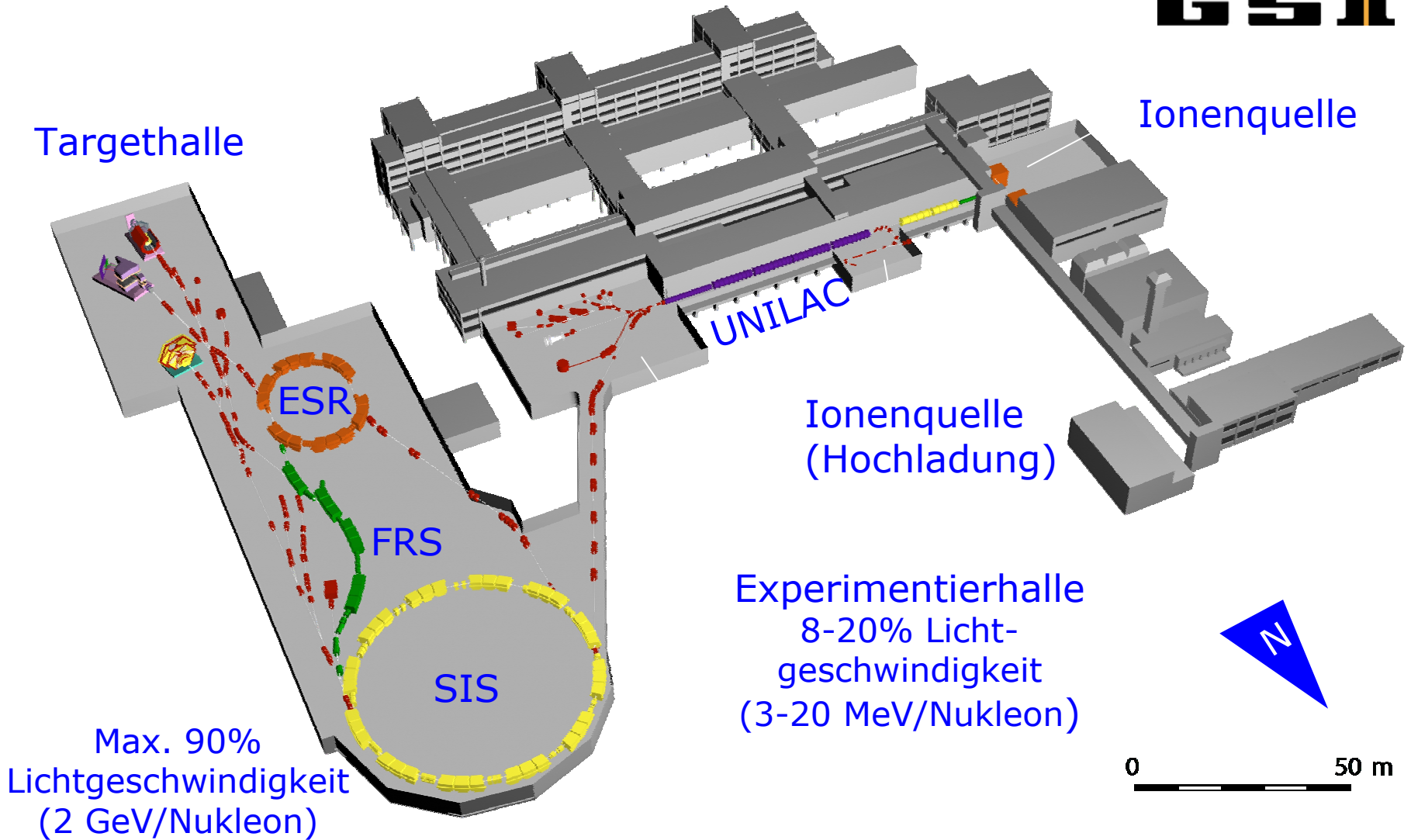


Spektatoren, und  
Reaktionszone

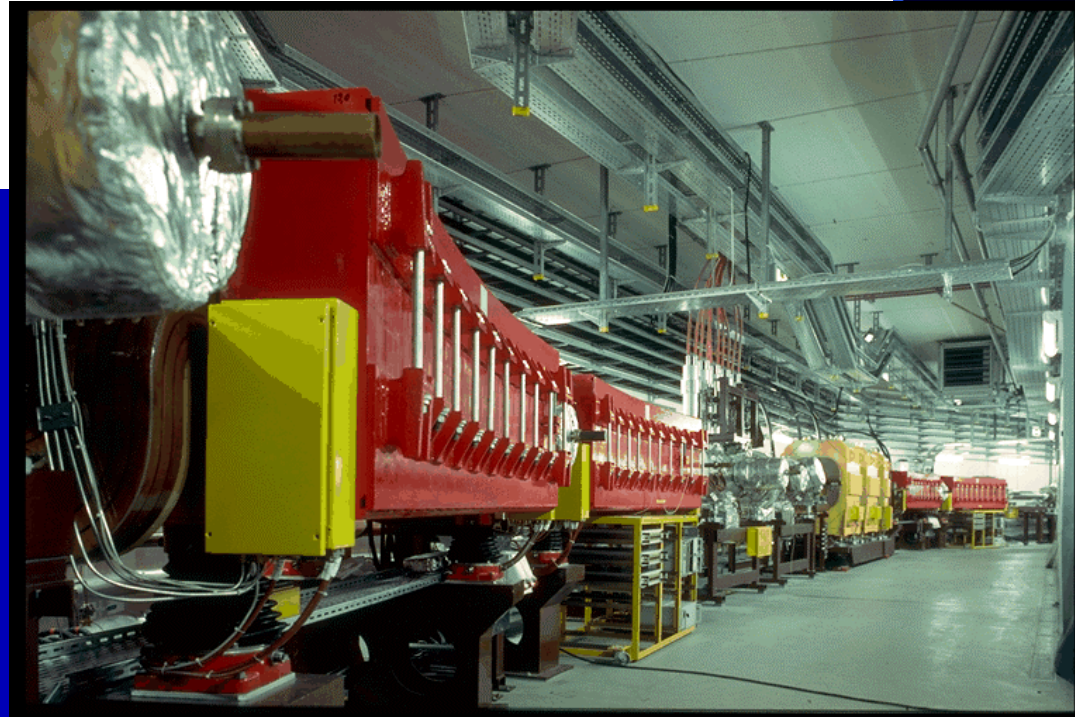
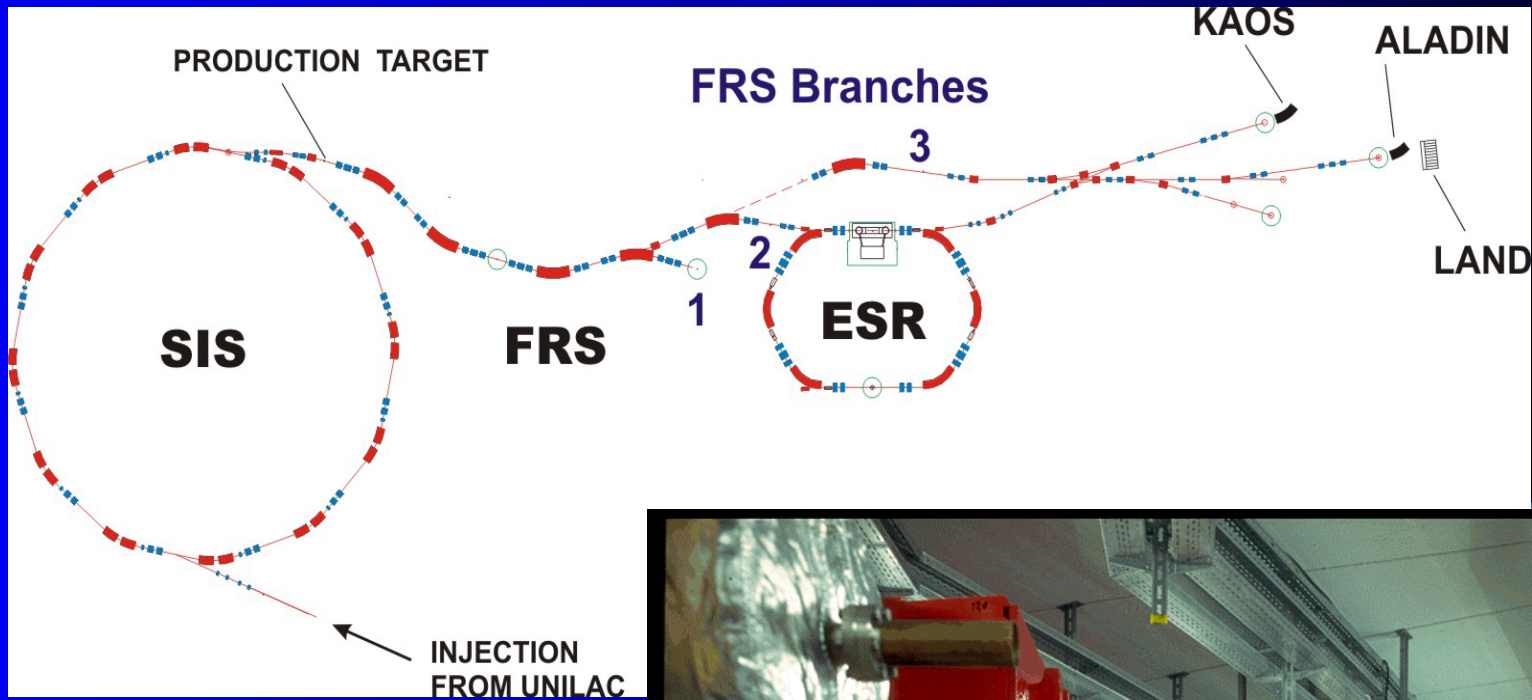
Beide sind  
hochangeregt  
und dampfen  
Neutronen ab



# Fragmentation in Darmstadt – Gesellschaft für Schwerionenforschung



# Der Fragmentseparator (FRS) der GSI

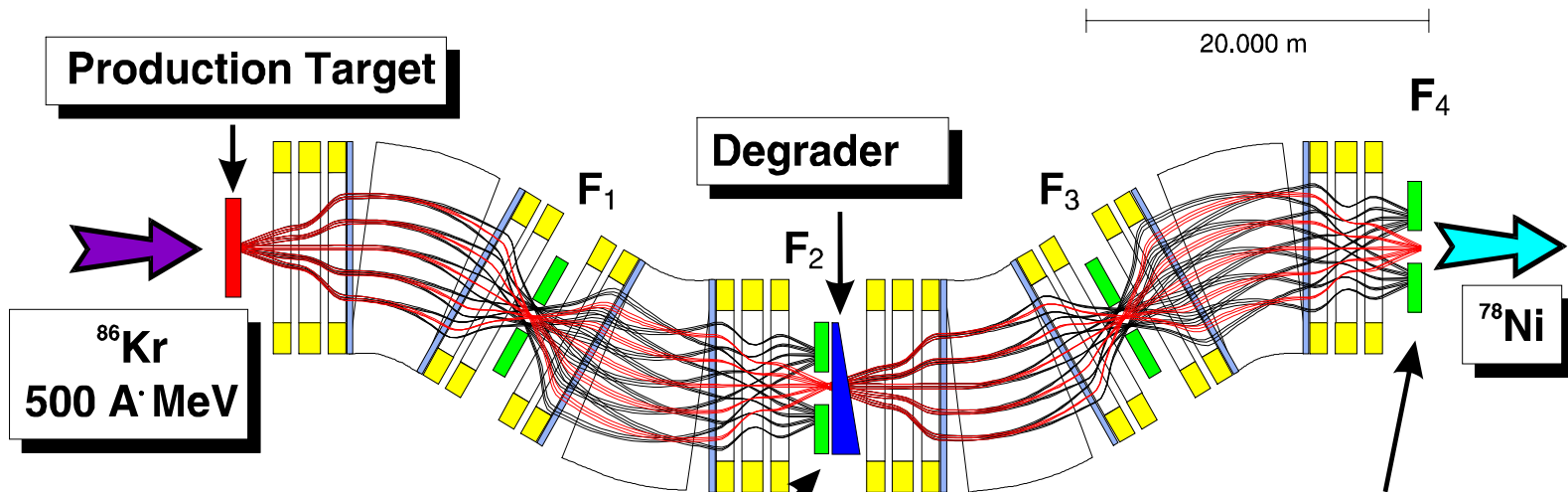




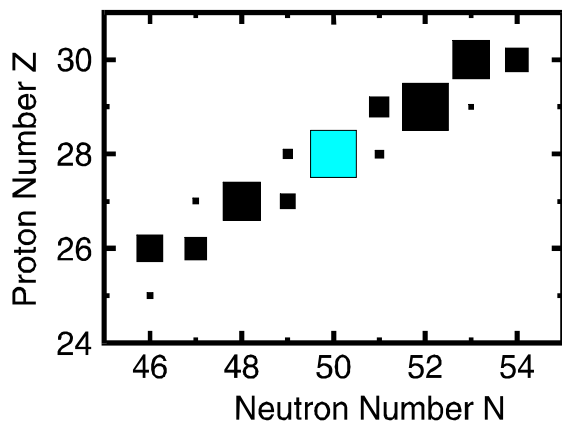


# Separationsprinzip bei der Fragmentation

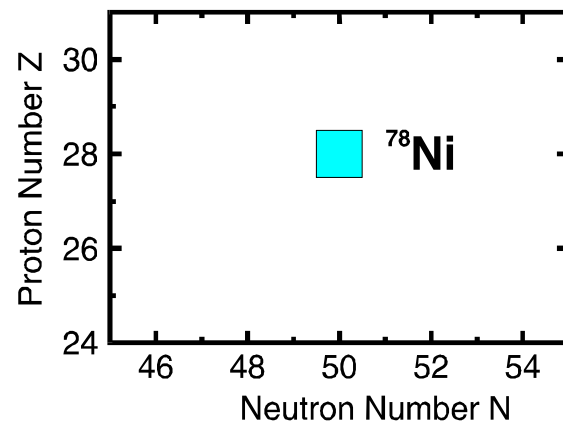
## THE FRAGMENTSEPARATOR AT GSI



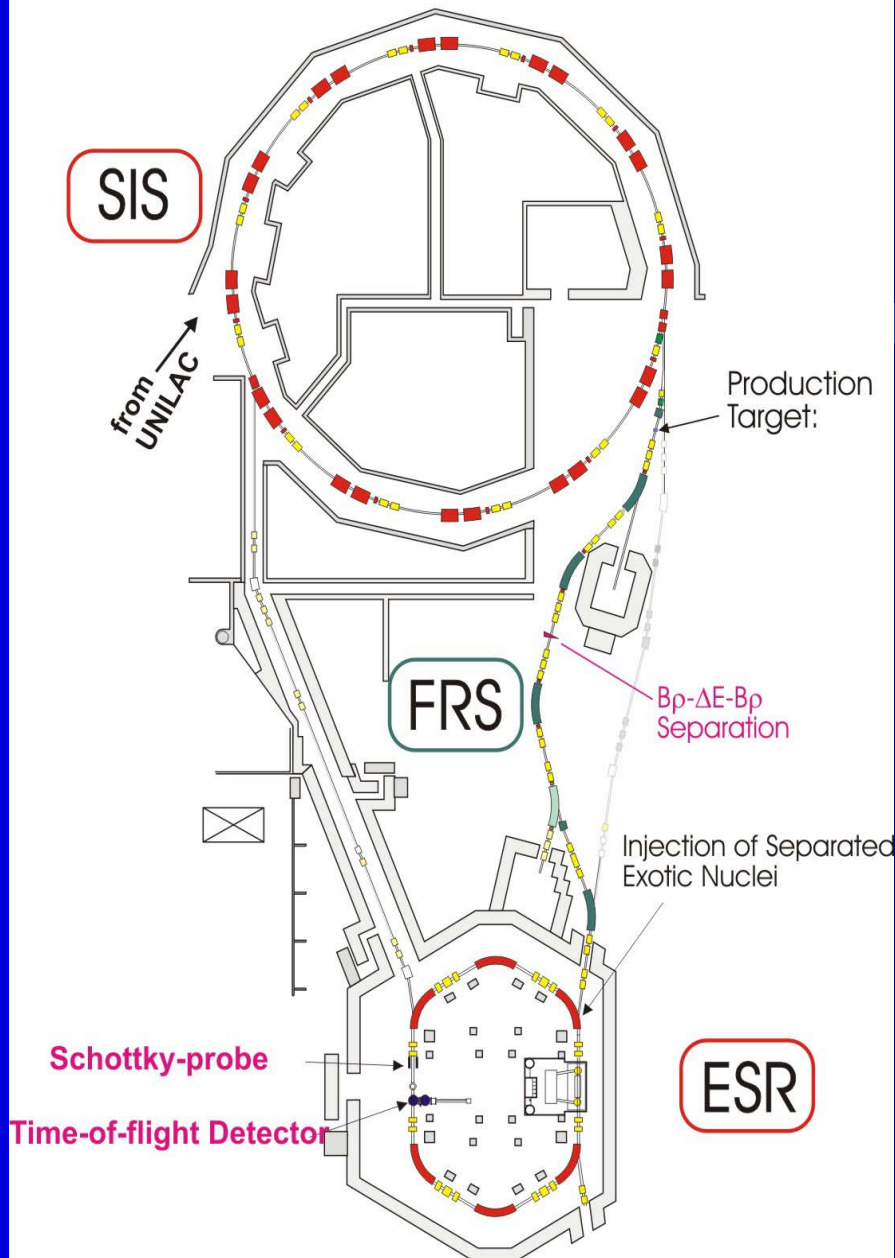
First Selection



First and Second Selection

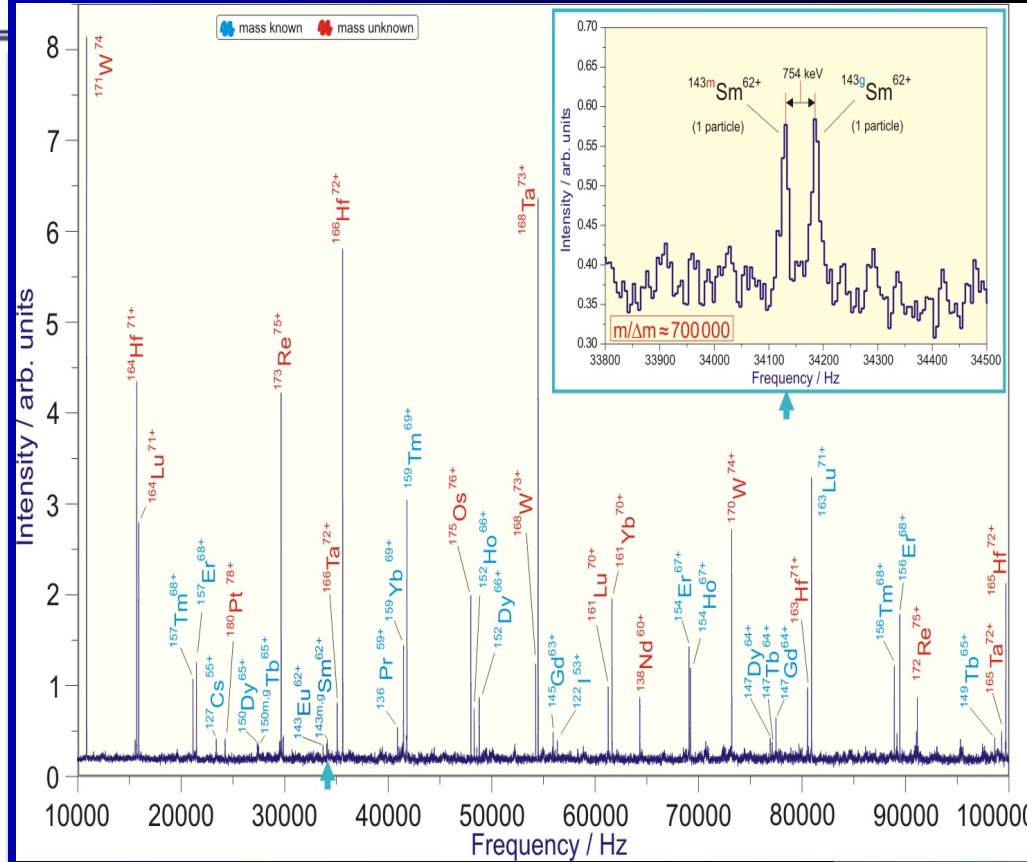
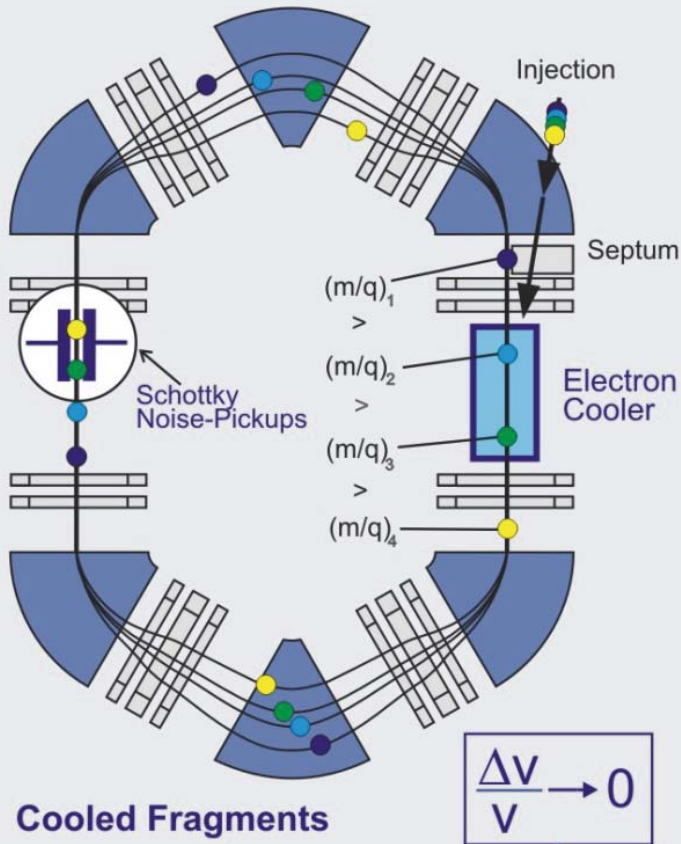


# Precision Experiments with the combination of the FRS and the ESR

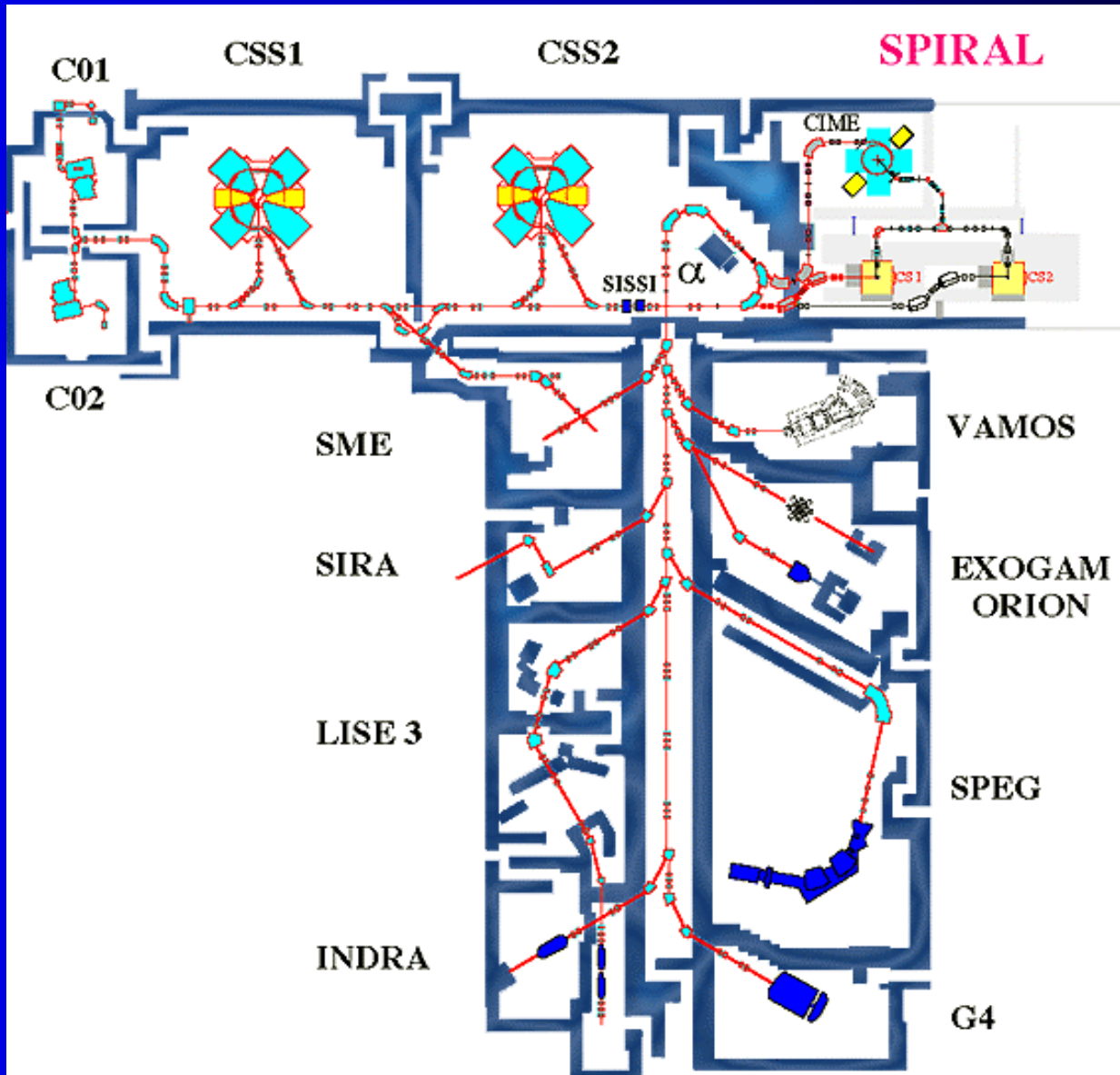


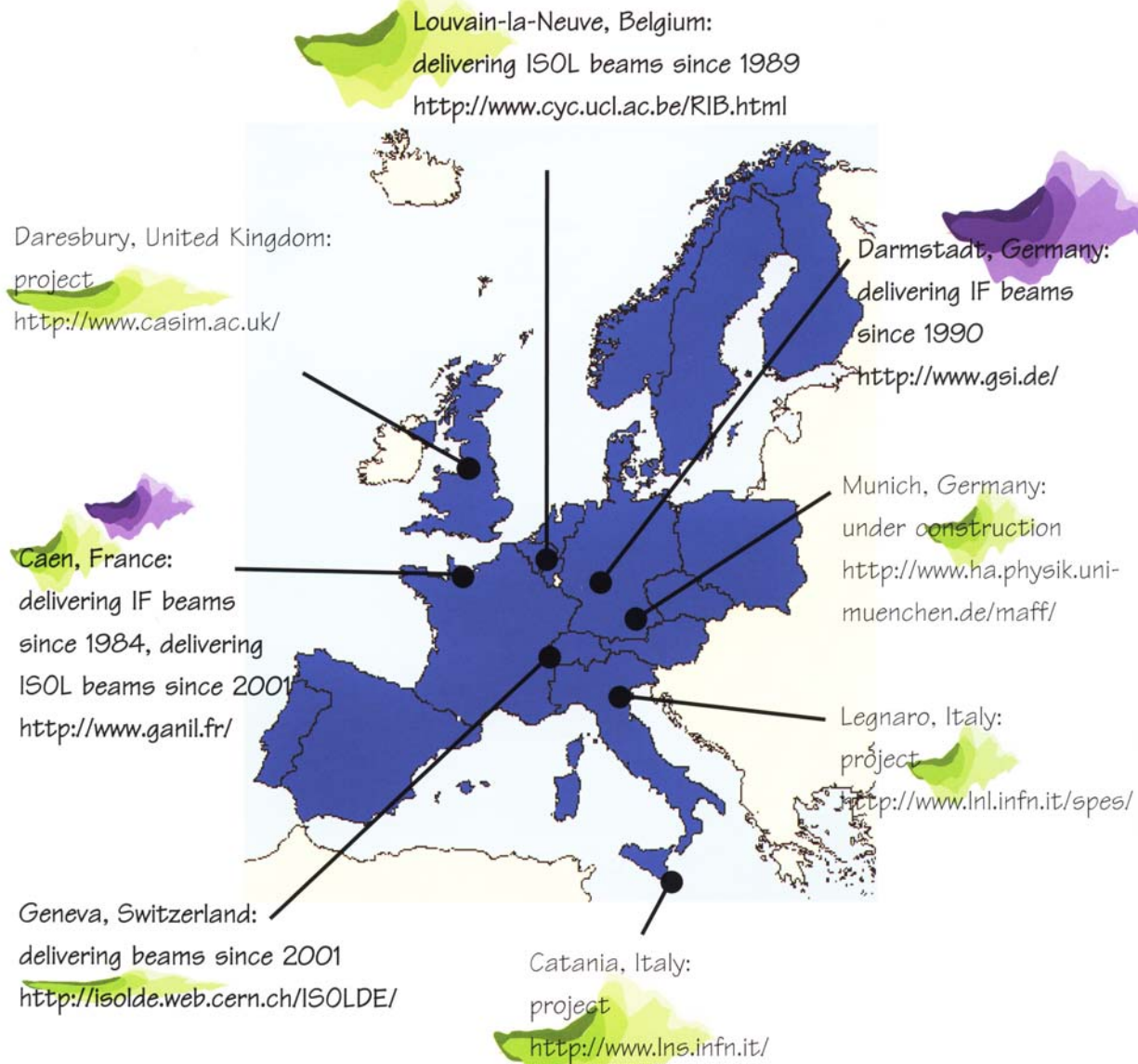
# Massenmessungen am Speicherring (mit einzelnen Ionen)

## SCHOTTKY MASS SPECTROMETRY



# Fragmentation und ISOL in GANIL, Frankreich





NuPECC member countries are in blue, ISOL facilities in green and IF in purple.