

# Comprehensive investigation of the decay losses in the ISOL extraction method

KP2 Seminar, 15.02.2006

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# [ Outline ]

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- ISOL method and yields
- In-target production
- Results of the comparison
- Conclusions

# [ ISOL method ]

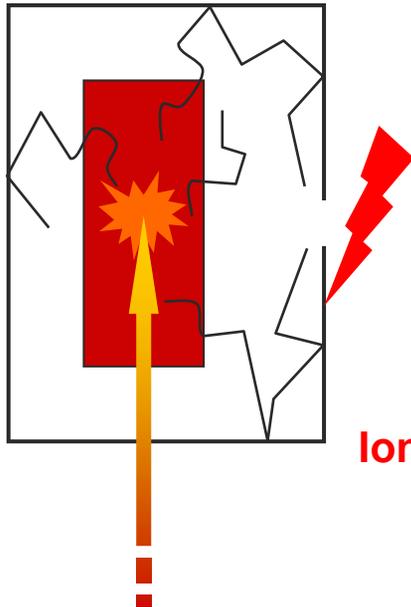
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- Isotope Separation OnLine – nuclide production in a thick target + extraction and mass separation
- High in-target production rates
- Quality low-energy RIB
- It was first employed in 1951, at Niels Bohr Institute (Copenhagen)

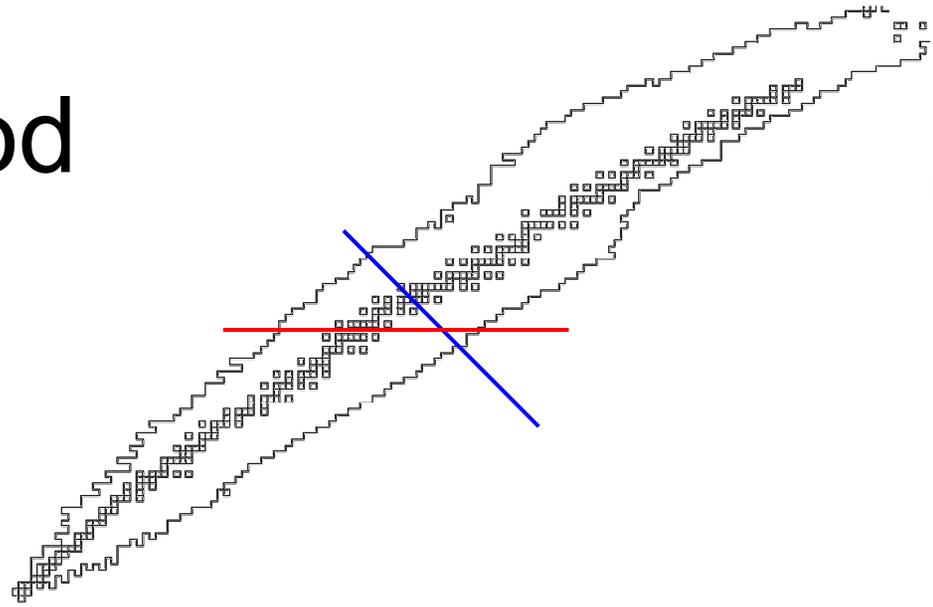
# [ ISOL method ]

❖ Production:  
nuclear reactions

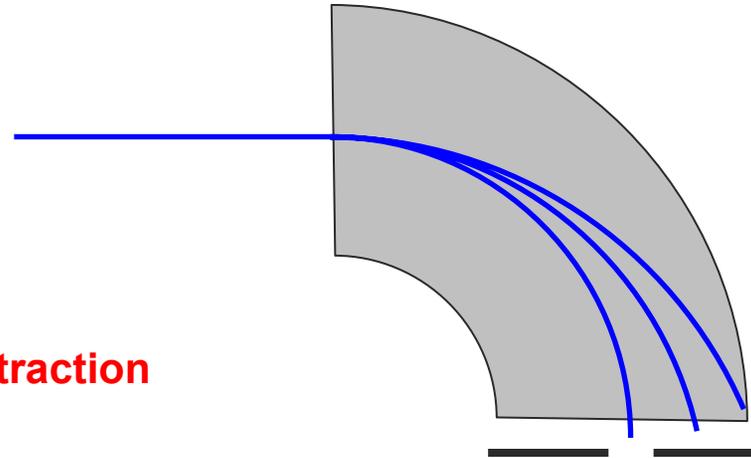
❖ Thermal diffusion  
(chemical properties)



**Ionization and extraction**



**Mass separation**



# [ ISOL facilities ]

## ■ Present:

- CERN – ISOLDE
- GANIL – SPIRAL
- GSI – ISOL
- TRIUMF – ISAC
- ORNL – HRIBF
- RIB project at Louvain-la Neuve
- Many other...

## ■ Future:

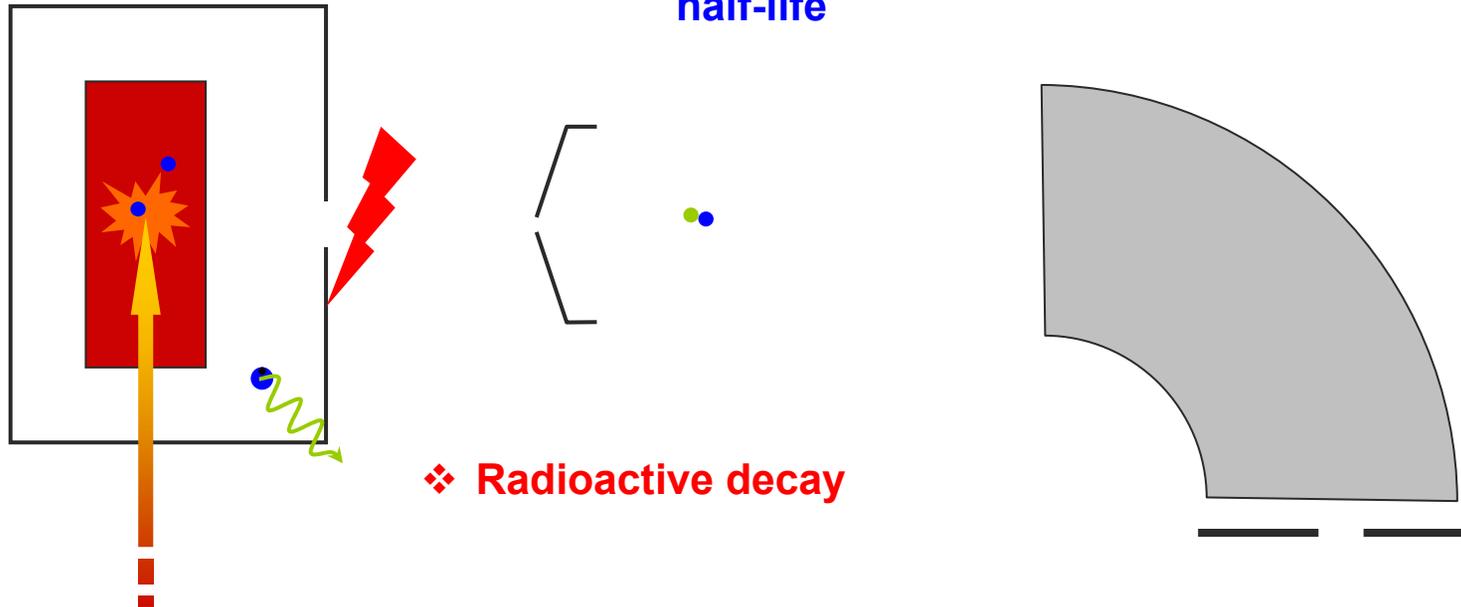
- EURISOL
- SPIRAL2
- RIA
- and others...

# ISOL method – nuclide losses

- ❖ Sticking to a wall
- ❖ Escaping ionization
- ❖ Chemical reactions

All these losses are difficult to directly estimate.

For practical applications (i.e. design of new ISOL facilities, like EURISOL) the information on overall losses is important...  
...particularly in function of the isotopic half-life



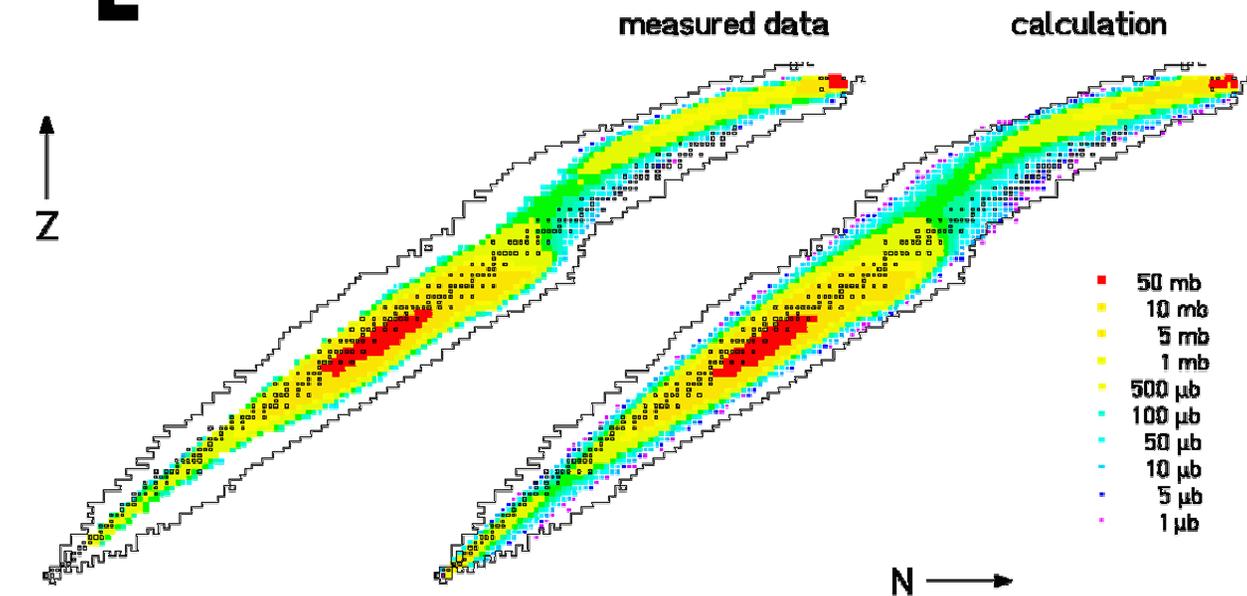
# [ ISOL method – nuclide losses ]

- Depending on the element, the efficiency for long-lived nuclides ranges from <math><0.1\%</math> to 100%. Some elements can not be extracted at all.
- Very short-lived isotopes are even more difficult to extract
- At ISOL facilities worldwide, more than 80 elements are available, with half-lives down to ~ms.

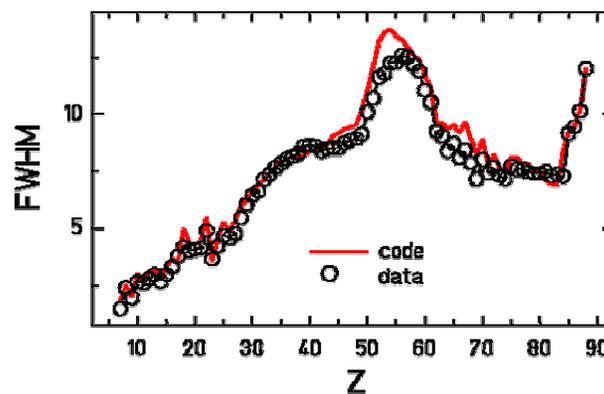
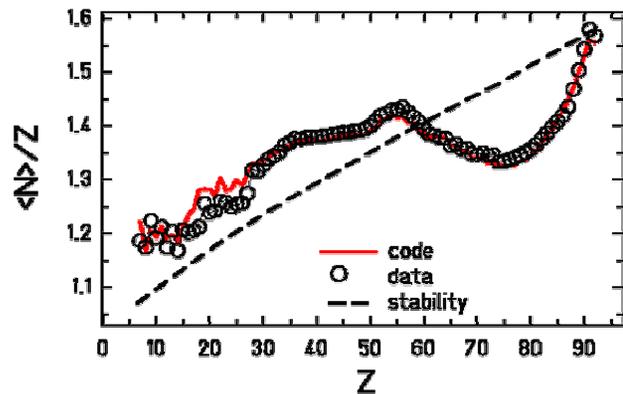
# [ ISOL method – yields ]

- At ISOLDE, isotopic yields for 64 different elements were documented during its operation with the SC proton beam in CERN (196? – 1992)
- Yield uncertainties:
  - isobaric and molecular contaminations of ISOLDE beams
  - unknown fraction of nuclides of a certain type that are produced in isomeric states
- In general, the accuracy is estimated to be within a factor of 2-3 close to stability, and up to one order of magnitude far-off stability

# In-target production - ABRABLA



Benchmarked  
against GSI  
nuclide-production  
cross-sections



# In-target production – thick target

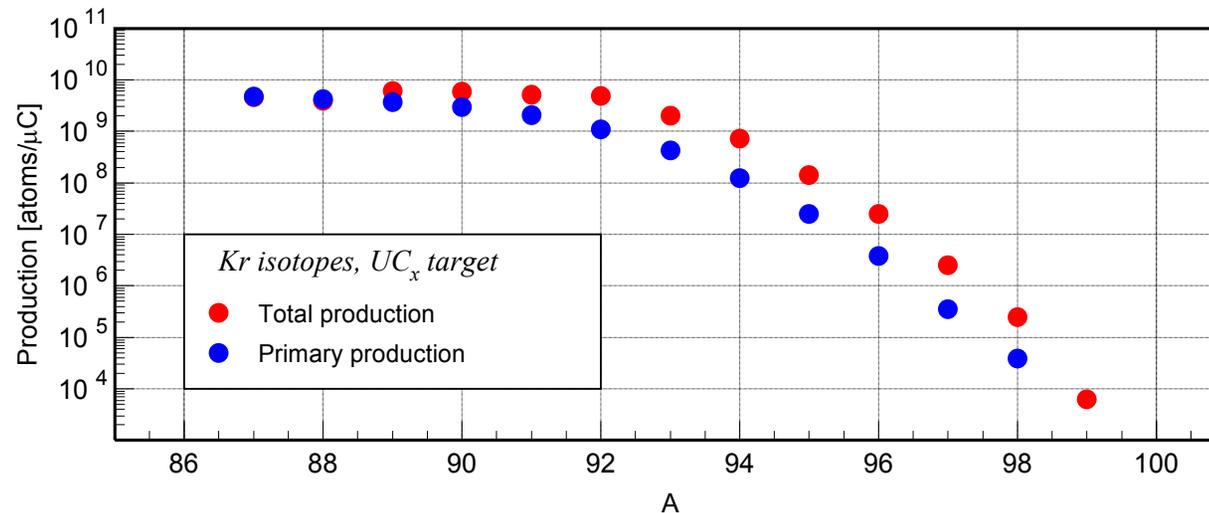
- Energy loss
- Beam attenuation
- Secondary reactions

# In-target production – secondary reactions

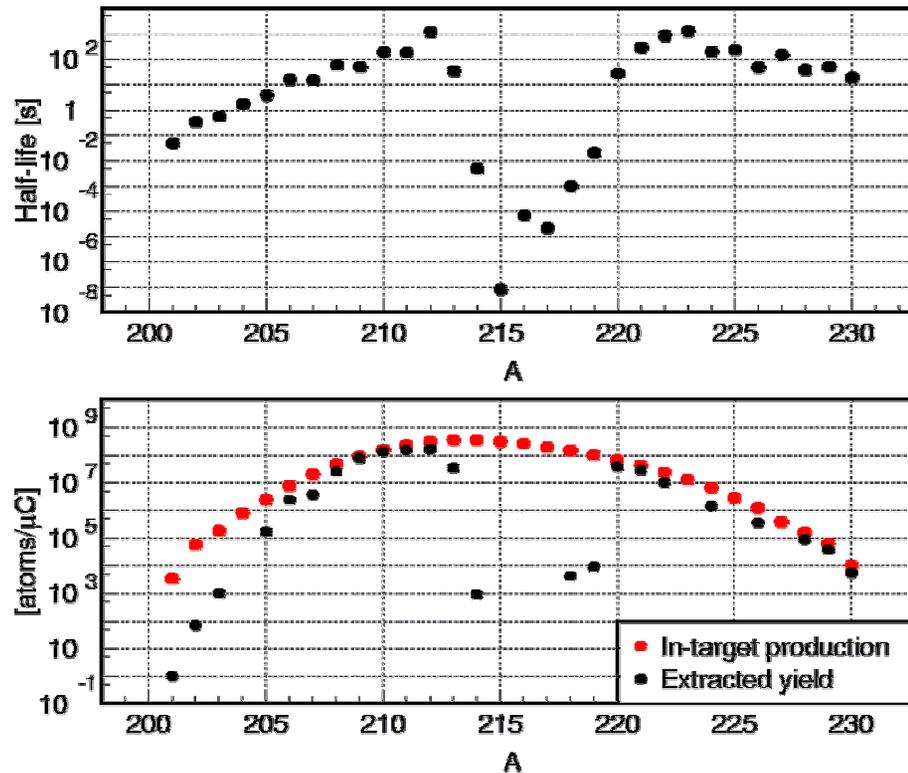
- Secondary neutrons
  - higher production cross-section than for charged particles
  - Longer range
  - Higher reaction cross-sections
- Mean neutron energy in (p +  $^{238}\text{U}$ ):  
2 MeV → mostly low energy fission

# In-target production – secondary reactions

- Comparison of the total in-target production for Kr isotopes in  $UC_x$  (ISOLDE, EURISOL report) with calculated primary production rates in a target of the same geometry
- Difference almost entirely due to low-energy fission induced by neutrons
- This difference was used to estimate the secondary neutron capture rate
- ABRABLA used to calculate the nuclide production from the formed compound nucleus  $^{239}\text{U}$  with excitation energy  $E^* = E_{sp} + \langle E_n \rangle \approx 7 \text{ MeV}$

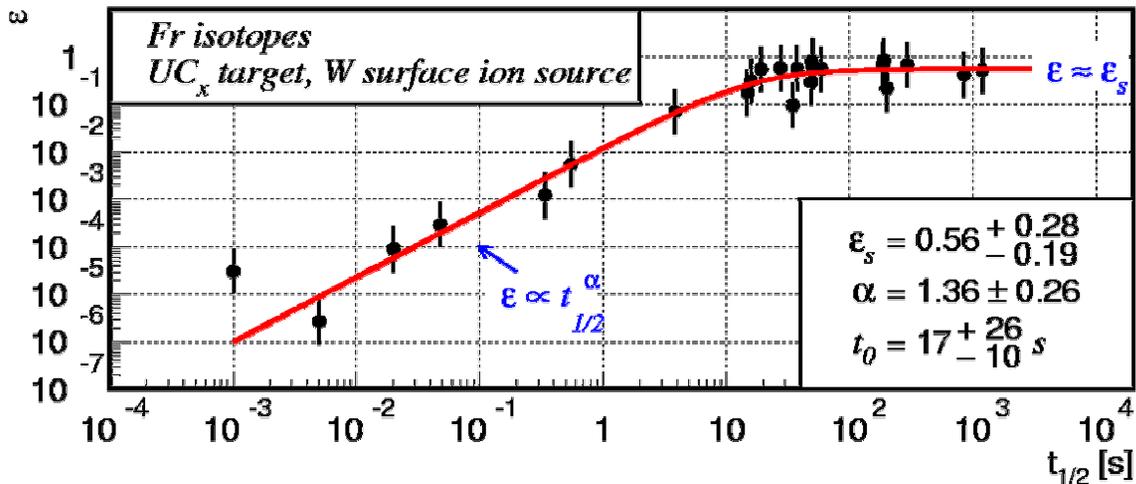


# Results – francium



- Non-uniform dependence of half-lives with the mass number
- Clear correlation of the extraction efficiency with the half-life

# Results – francium



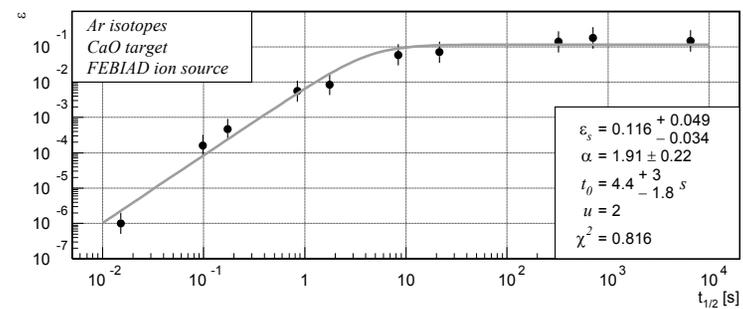
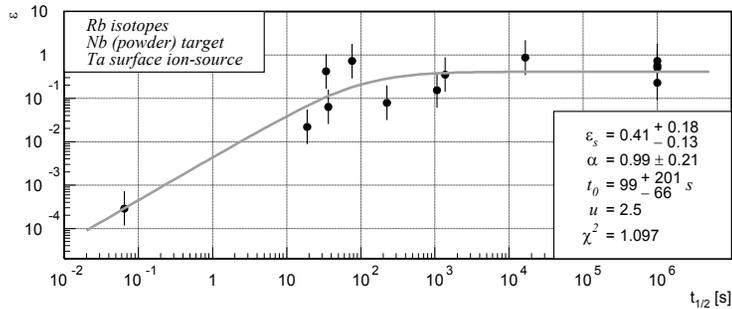
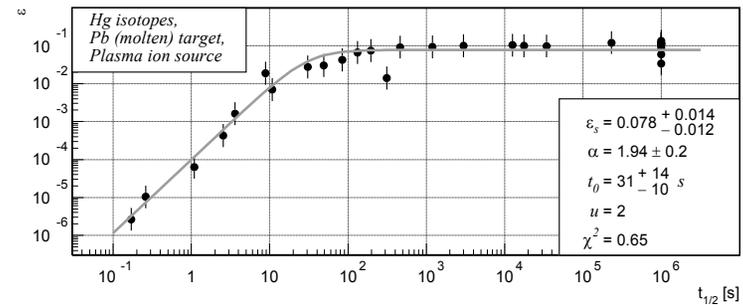
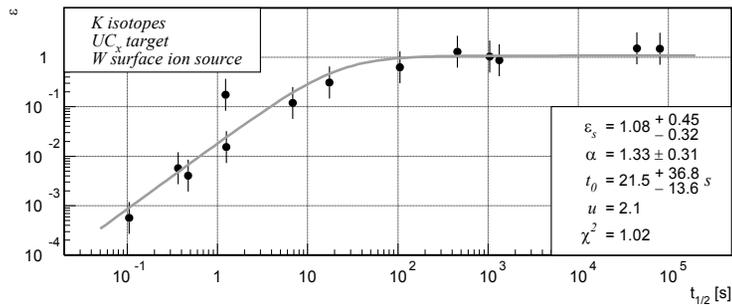
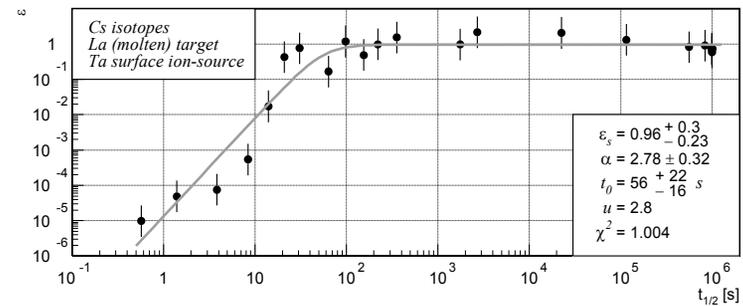
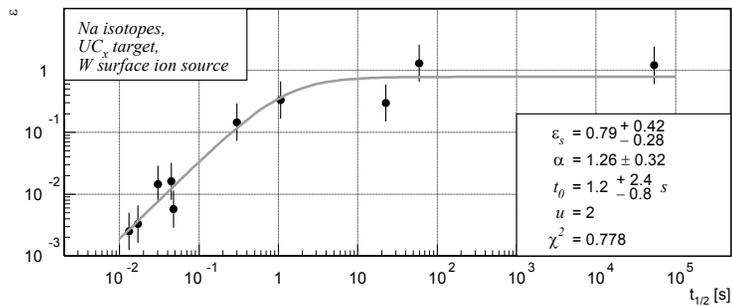
- Same general behavior in many different cases:

- Constant efficiency for long half-lives
- Power-function behavior for short half-lives

- Parameterization:

$$\varepsilon\left(t_{1/2}\right) = \frac{\varepsilon_s}{1 + \left(\frac{t_{1/2}}{t_0}\right)^{-\alpha}}$$

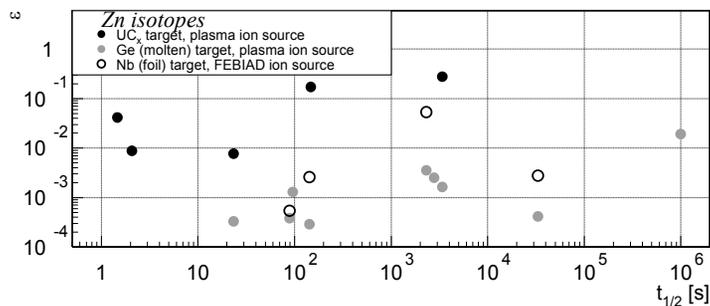
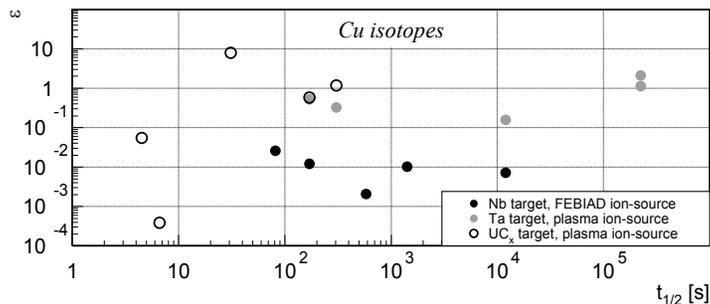
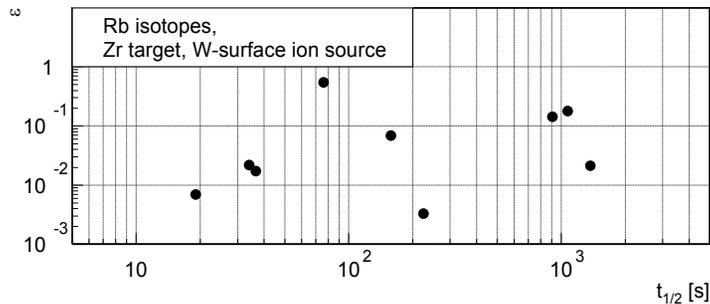
# Results – more examples



# [ Results – uncertainties ]

- Uncertainties come from:
  - difficulties to precisely calculate cross sections at the steep outer slopes of isotopic distributions far off stability
  - isobaric and molecular contaminations of ISOLDE beams
  - side feeding
  - unknown fraction of nuclides of a certain type that are produced in isomeric states
- Sometimes, these effects are so large that...

# Results – cases that "don't work"



- In ~30% of cases, no apparent correlation of efficiencies with half-lives

# Conclusions

- Measured ISOLDE yields have been compared with new and high-quality information on the nuclide-production cross sections in proton-induced reactions.
- Essential properties of the overall ISOL efficiencies have been quantified for a wide variety of isotopic chains from different target and ion-source systems. :
  - The parameter  $\varepsilon_s$  – extraction efficiency in the limit of long half-lives – directly indicates the overall losses that occur apart from the decay losses.
  - The parameters  $t_0$  and  $\alpha$  describe the effect of the decay losses with short half-lives
- This information helps completing our understanding of the efficiencies of the ISOL method, as well as identifying the issues that need most attention in the process of ISOL target and ion-source development
- This kind of study is, in principle, applicable across the entire table of elements and for all target and ion-source systems.