ISOLDE
CERN

# Fission fragment beams at ISOLDE

**Workshop on decay spectroscopy**

**Oak Ridge, 19 August 2003**

Ulli Köster

ISOLDE CERN

# Volatility of the elements

- T (p vapor > 0.01 mbar) < 100 °C
- T (p vapor > 0.01 mbar) < 400 °C
- T (p vapor > 0.01 mbar) < 1000 °C
- T (p vapor > 0.01 mbar) < 2000 °C
- T (p vapor > 0.01 mbar) > 2000 °C

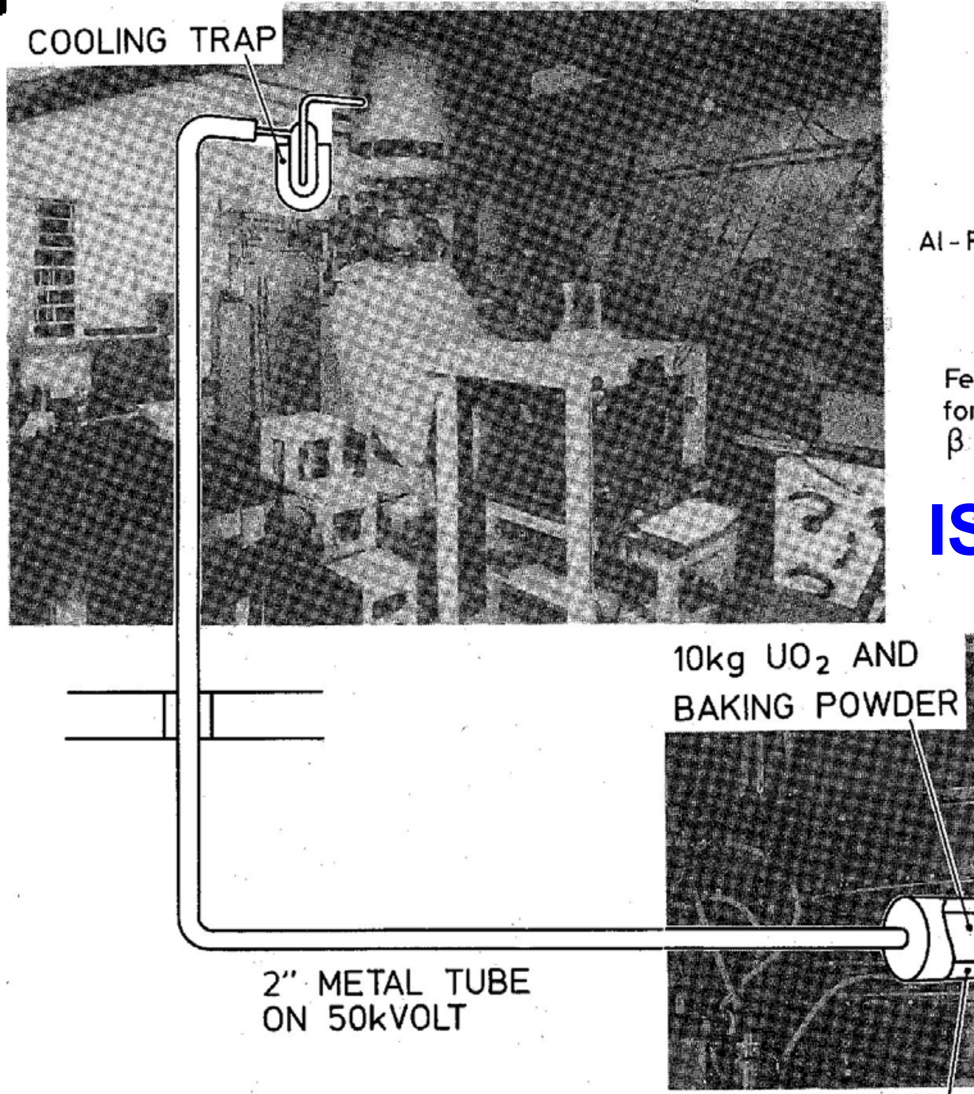
| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 H | | | | | | | | | | | | | | | | | 2 He |
| 3 Li | 4 Be | | | | | | | | | | | 5 B | 6 C | 7 N | 8 O | 9 F | 10 Ne |
| 11 Na | 12 Mg | | | | | | | | | | | 13 Al | 14 Si | 15 P | 16 S | 17 Cl | 18 Ar |
| 19 K | 20 Ca | 21 Sc | 22 Ti | 23 V | 24 Cr | 25 Mn | 26 Fe | 27 Co | 28 Ni | 29 Cu | 30 Zn | 31 Ga | 32 Ge | 33 As | 34 Se | 35 Br | 36 Kr |
| 37 Rb | 38 Sr | 39 Y | 40 Zr | 41 Nb | 42 Mo | 43 Tc | 44 Ru | 45 Rh | 46 Pd | 47 Ag | 48 Cd | 49 In | 50 Sn | 51 Sb | 52 Te | 53 I | 54 Xe |
| 55 Cs | 56 Ba | 57 La | 72 Hf | 73 Ta | 74 W | 75 Re | 76 Os | 77 Ir | 78 Pt | 79 Au | 80 Hg | 81 Tl | 82 Pb | 83 Bi | 84 Po | 85 At | 86 Rn |
| 87 Fr | 88 Ra | 89 Ac | 104 Rf | 105 Db | 106 Sg | 107 Bh | 108 Hs | 109 Mt | 110 | 111 | 112 | | | | | | |

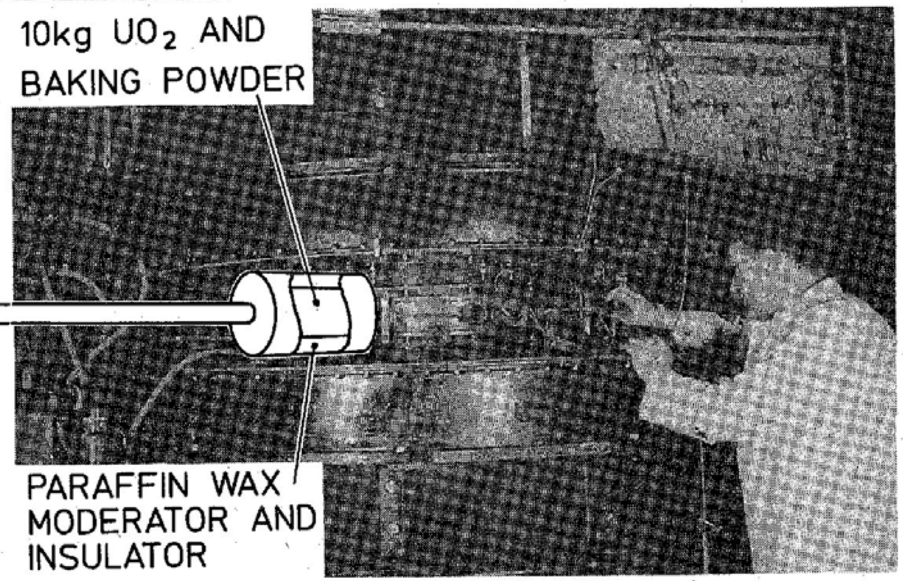
| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 58 Ce | 59 Pr | 60 Nd | 61 Pm | 62 Sm | 63 Eu | 64 Gd | 65 Tb | 66 Dy | 67 Ho | 68 Er | 69 Tm | 70 Yb | 71 Lu |
| 90 Th | 91 Pa | 92 U | 93 Np | 94 Pu | 95 Am | 96 Cm | 97 Bk | 98 Cf | 99 Es | 100 Fm | 101 Md | 102 No | 103 Lr |

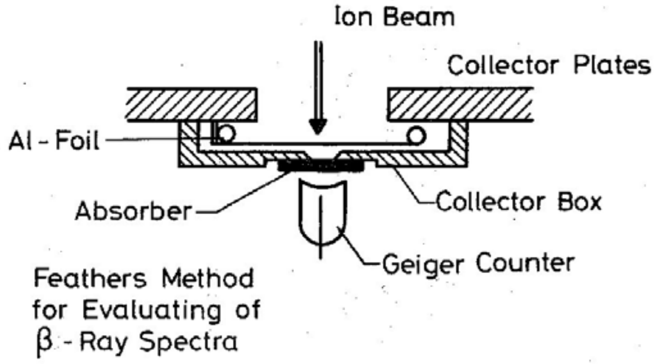
Ulli Köster

ISOLDE CERN

# 1951: The first ISOL experiment



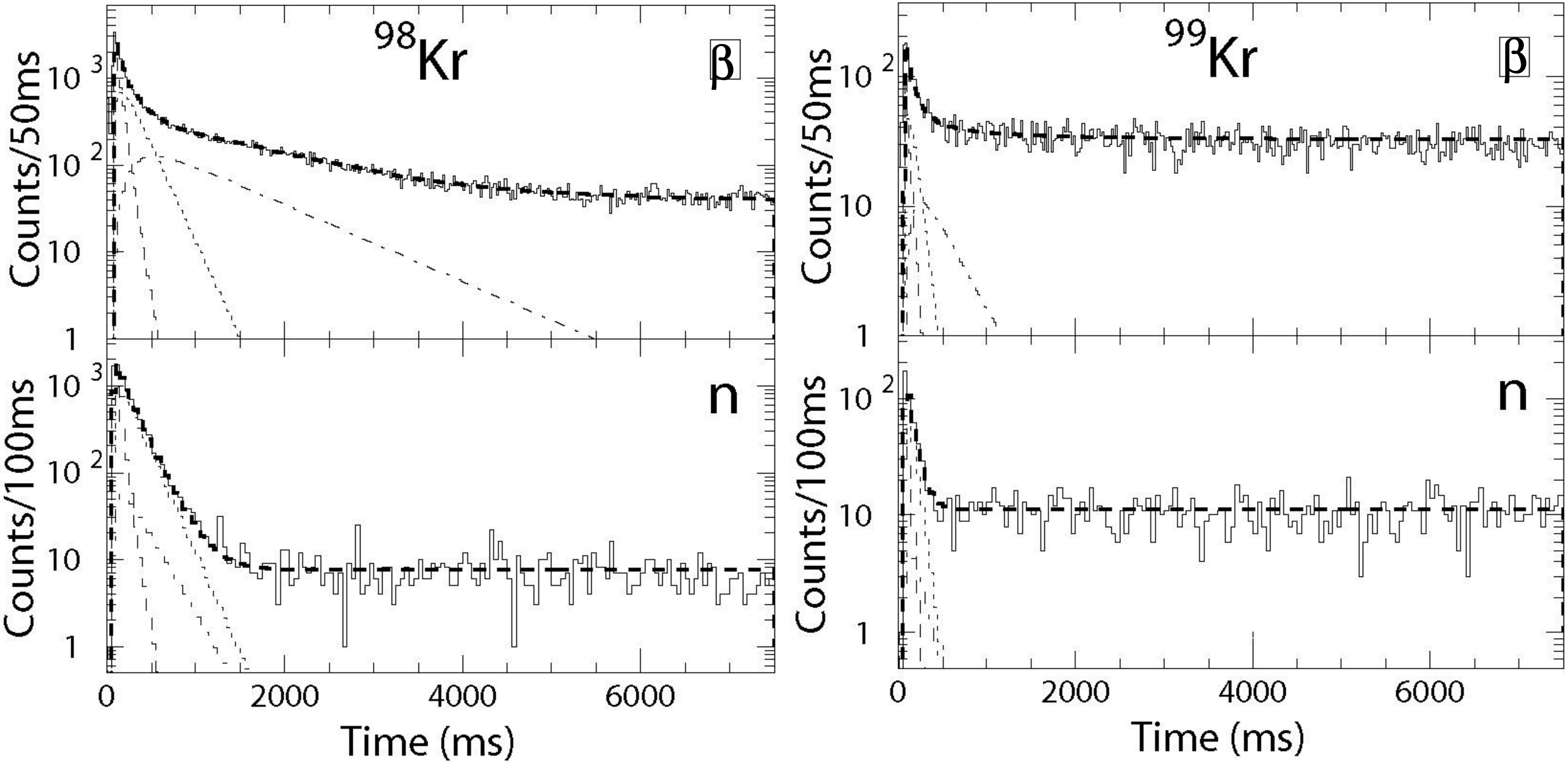




**ISOL beams of $^{89-93}$Kr**

*O. Kofoed-Hansen and K.O. Nielsen,*

*Mat. Fys. Medd. Dan. Vid. Selsk. 26, Nr. 7 (1951).*

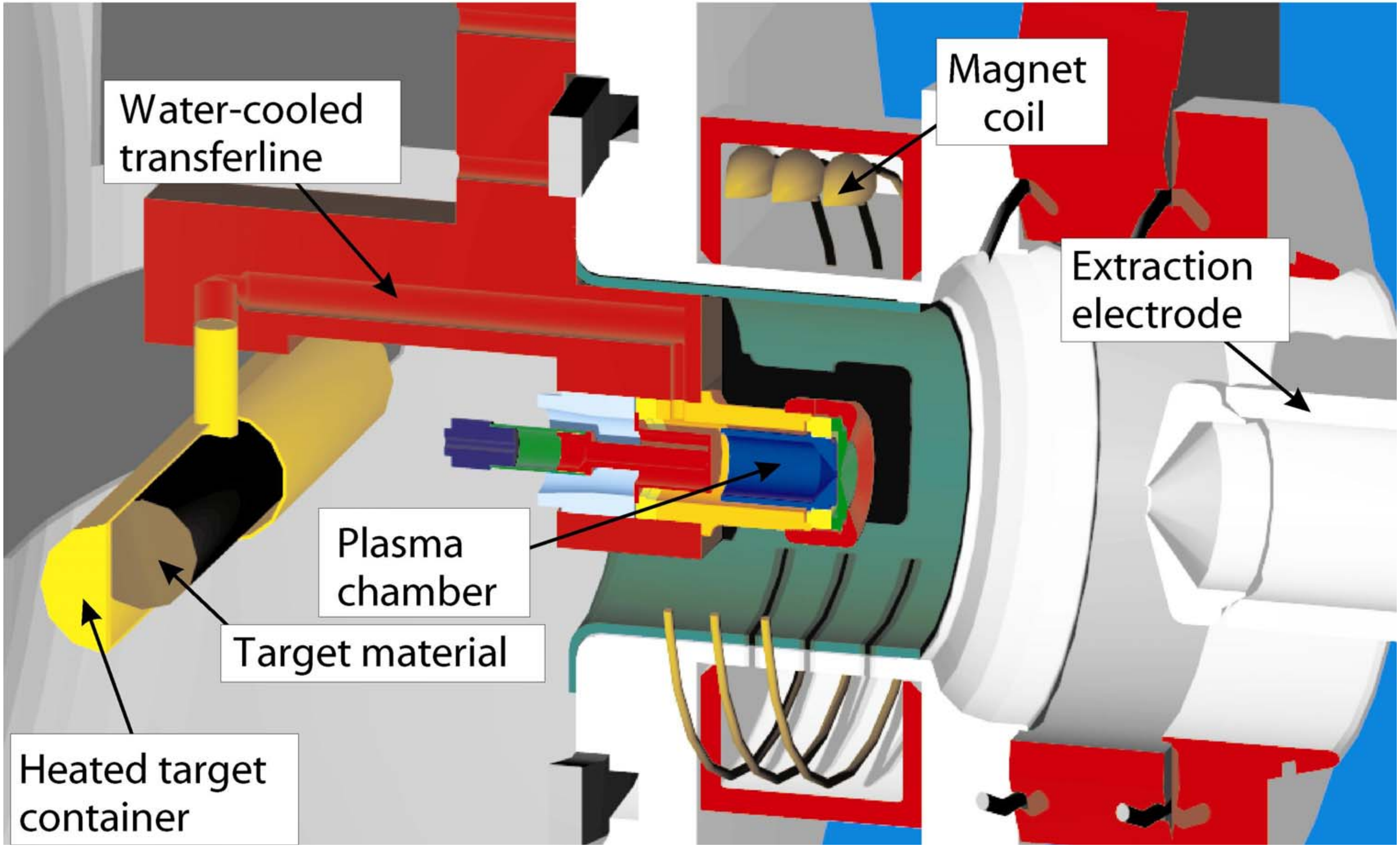
# 2001: $^{94-99}$Kr decay studied at ISOLDE



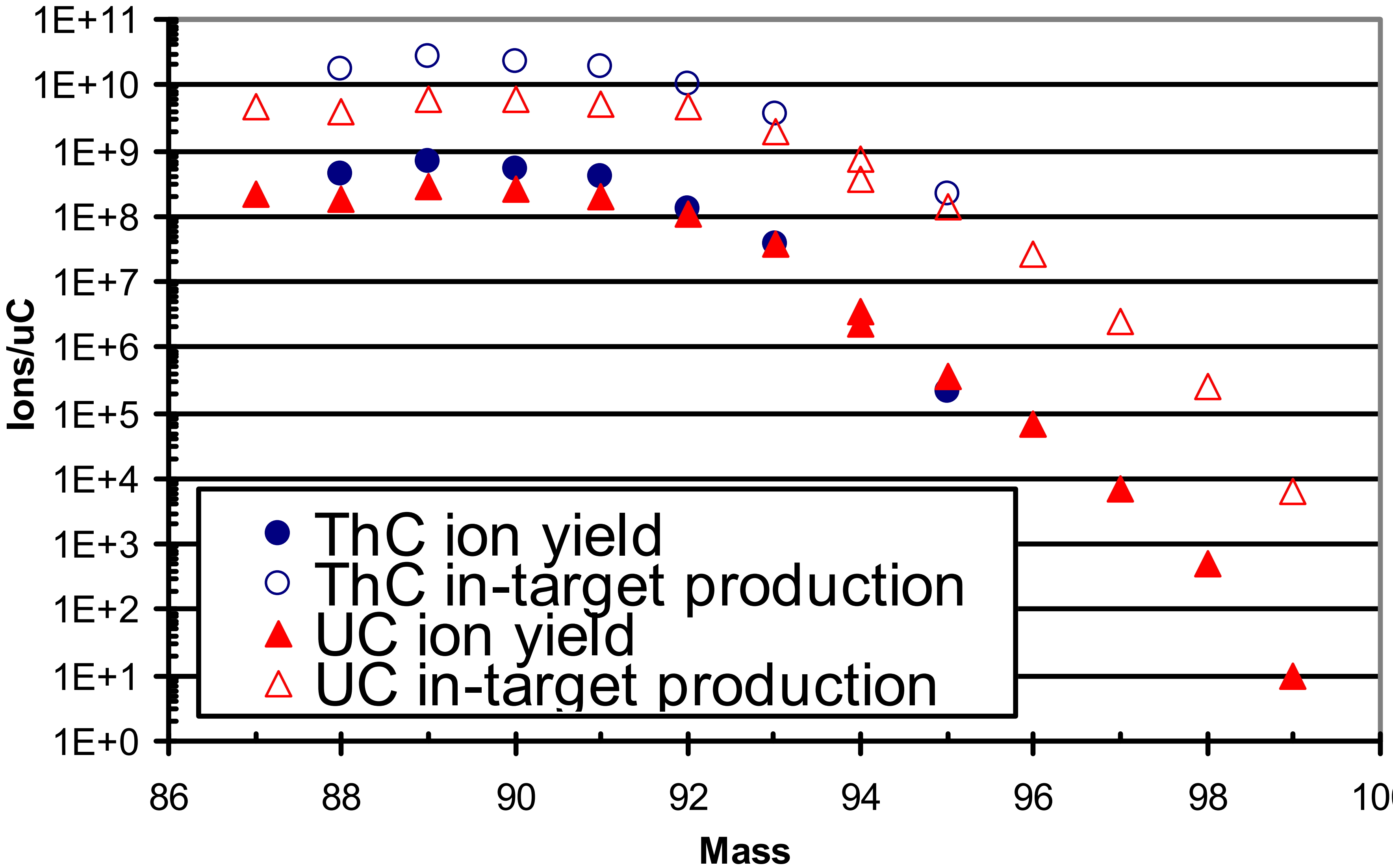

*U.C. Bergmann et al., NPA 714 (2003) 21.*

Ulli Köster
ISOLDE
CERN

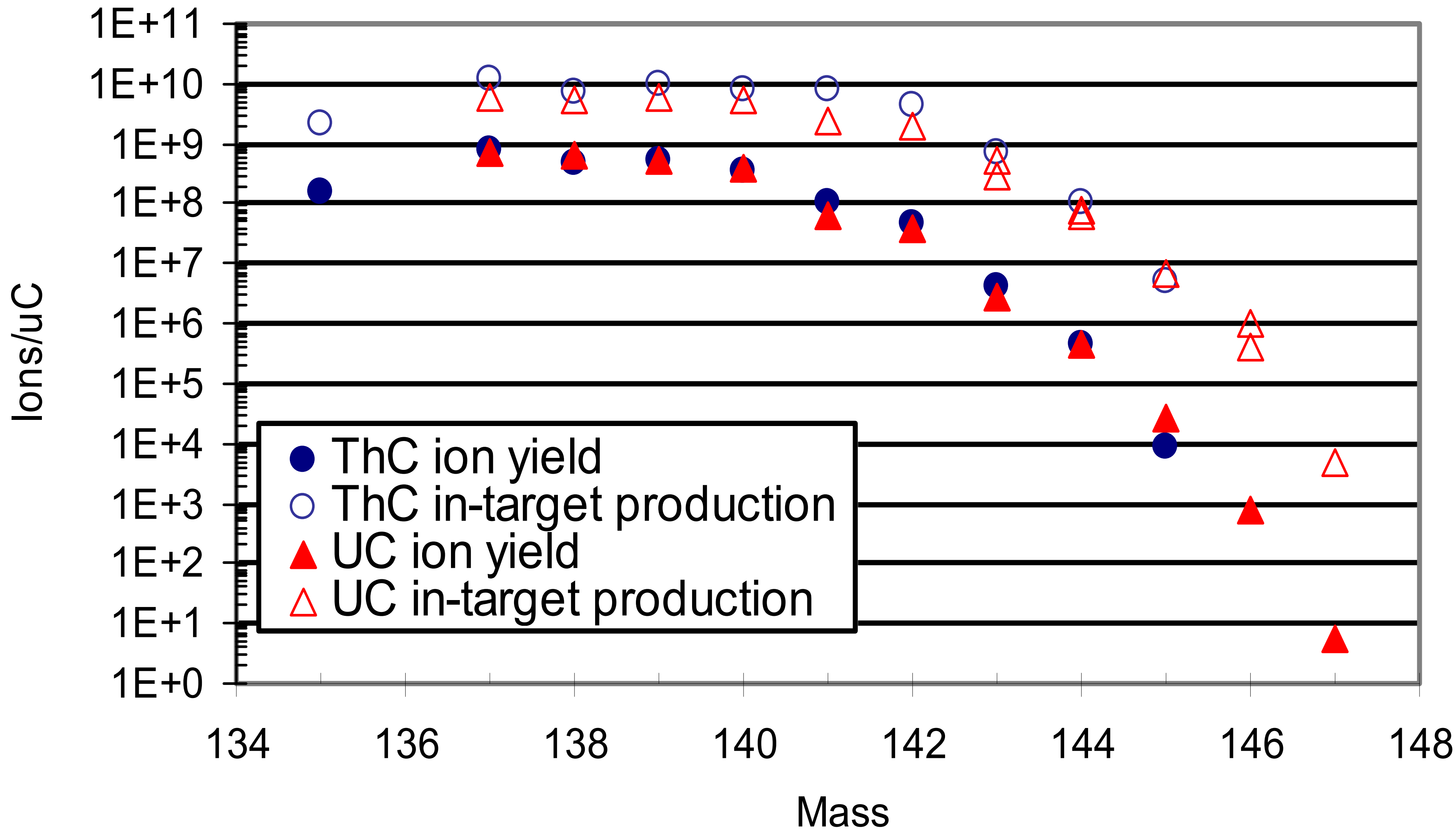
# Isothermal chromatography at ISOLDE



# Krypton yields



# Xenon yields



Ulli Köster

ISOLDE CERN

# Noble gases

pure Kr beams already separated in first ISOL experiment

use of MK7 gives very pure noble gas beams

half-lives and $P_n$ values measured up to $^{99}$Kr and $^{147}$Xe

Coulex planned at REX on $^{88}$Kr (mixed symmetry states, P172) and $^{138}$Xe (magnetic moments, IS415)

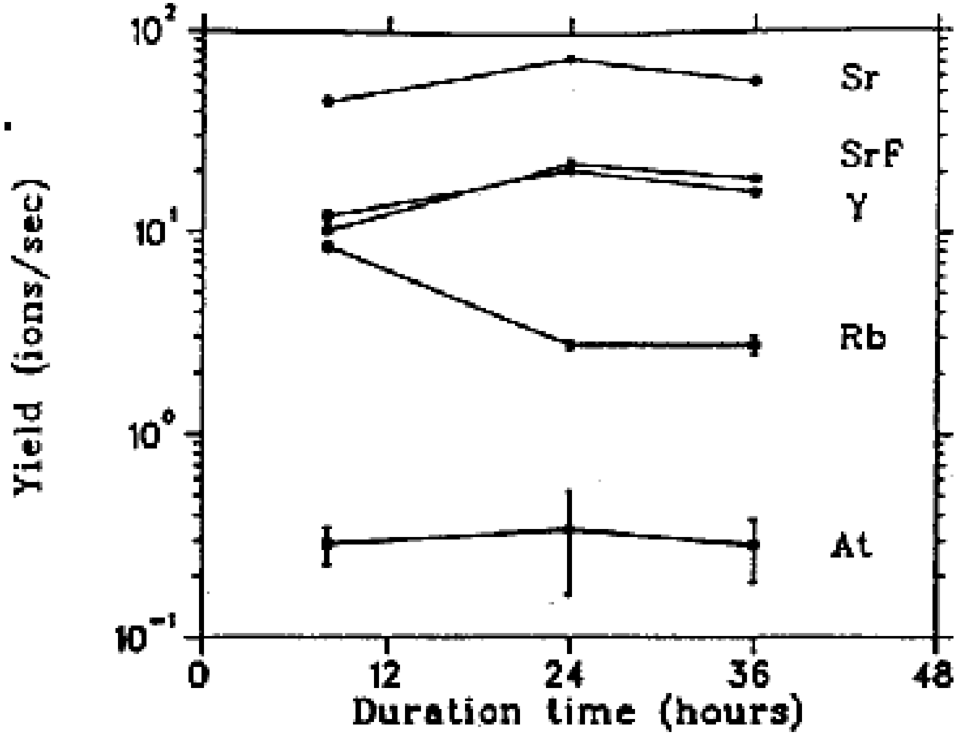
Outdiffusion from tape causes uncertainty in half-life measurements. Problem could be solved by deeper implantation (into sandwich target?) after postacceleration.

⇒ post-accelerator could help decay spectroscopy

# Alkali metals

(Relatively) clean alkali beams are produced by surface ionization.

Far from stability significant admixture of alkaline earth isobars.




**Rubidium:**

Up to $^{102}$Rb for βγ spectroscopy

*G. Lhersonneau et al.,*

*Z. Phys. A 351 (1995) 357.*

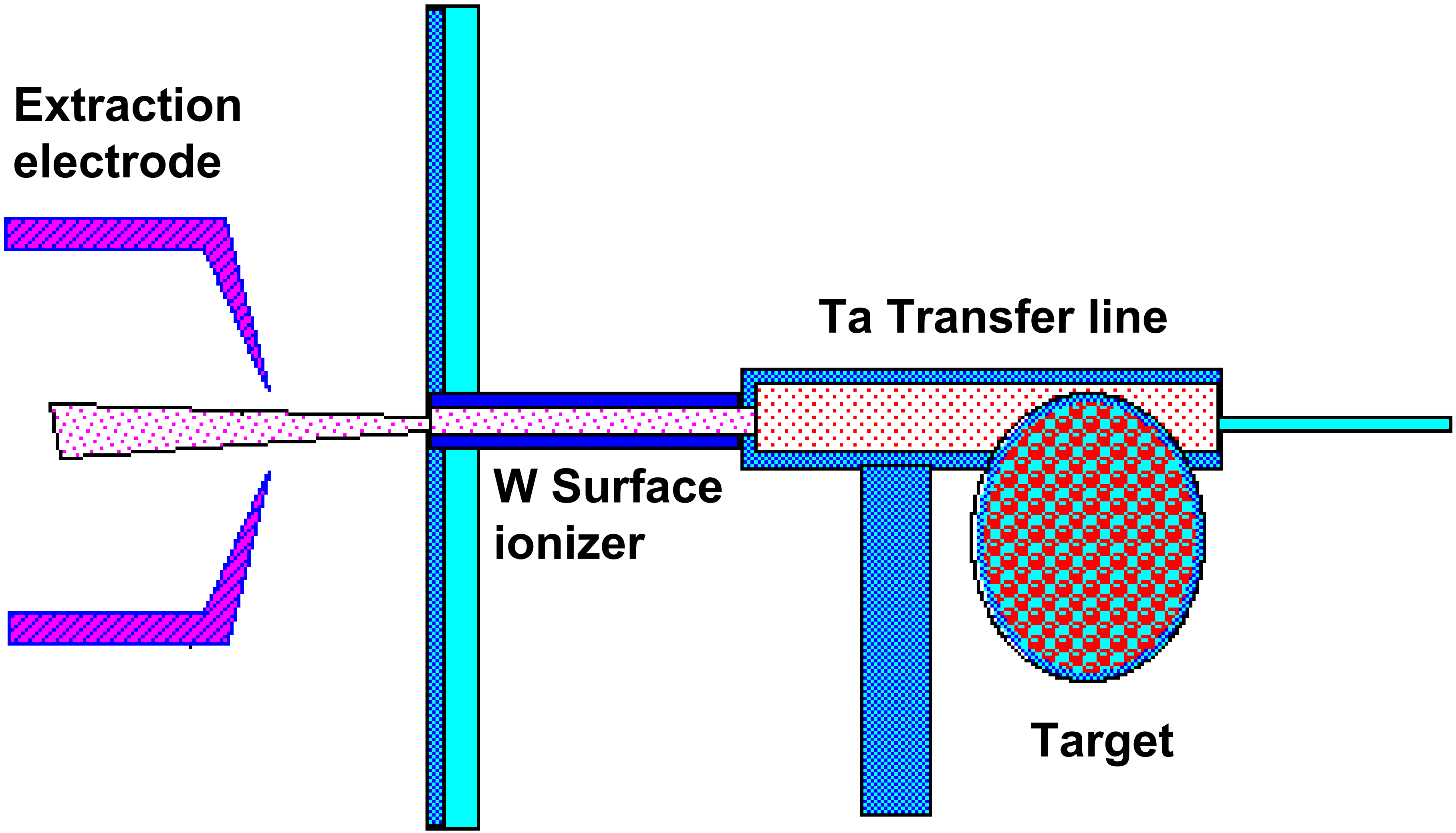
**Cesium:**

Up to $^{150}$Cs measured

Half-lives measured for $^{149,150}$Cs

Alkalis are easily surface ionized and an omnipresent background!

# Surface ionization source



Ulli Köster

ISOLDE
CERN

# Ionization potentials of the elements

Ionization potential: < 5 eV

Ionization potential: 5.0 - 5.8 eV

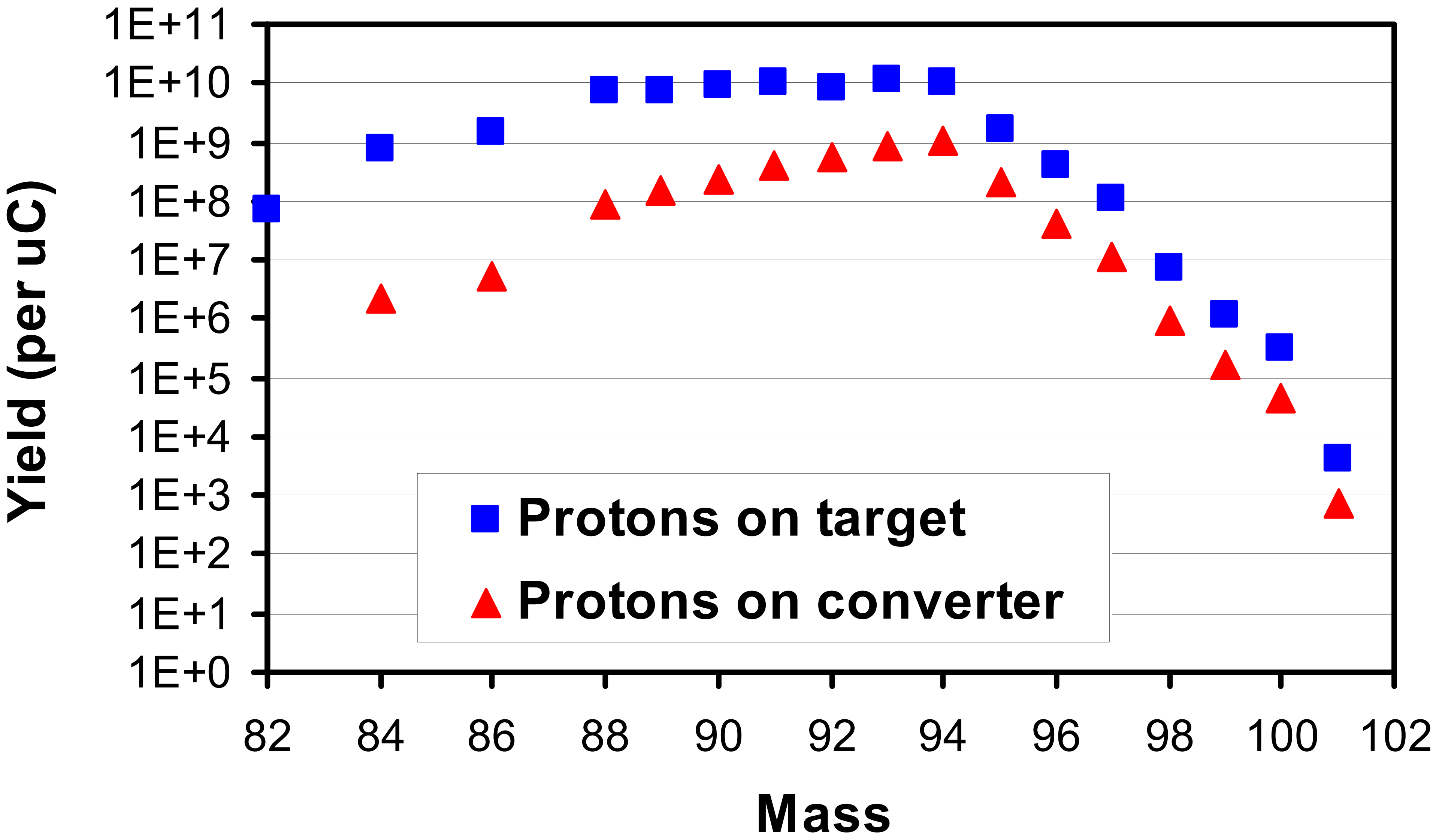
Ionization potential: 5.8 - 6.5 eV

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 H | | | | | | | | | | | | | | | | | 2 He |
| 3 Li | 4 Be | | | | | | | | | | | 5 B | 6 C | 7 N | 8 O | 9 F | 10 Ne |
| 11 Na | 12 Mg | | | | | | | | | | | 13 Al | 14 Si | 15 P | 16 S | 17 Cl | 18 Ar |
| 19 K | 20 Ca | 21 Sc | 22 Ti | 23 V | 24 Cr | 25 Mn | 26 Fe | 27 Co | 28 Ni | 29 Cu | 30 Zn | 31 Ga | 32 Ge | 33 As | 34 Se | 35 Br | 36 Kr |
| 37 Rb | 38 Sr | 39 Y | 40 Zr | 41 Nb | 42 Mo | 43 Tc | 44 Ru | 45 Rh | 46 Pd | 47 Ag | 48 Cd | 49 In | 50 Sn | 51 Sb | 52 Te | 53 I | 54 Xe |
| 55 Cs | 56 Ba | 57 La | 72 Hf | 73 Ta | 74 W | 75 Re | 76 Os | 77 Ir | 78 Pt | 79 Au | 80 Hg | 81 Tl | 82 Pb | 83 Bi | 84 Po | 85 At | 86 Rn |
| 87 Fr | 88 Ra | 89 Ac | 104 Rf | 105 Db | 106 Sg | 107 Bh | 108 Hs | 109 Mt | 110 | 111 | 112 | | | | | | |

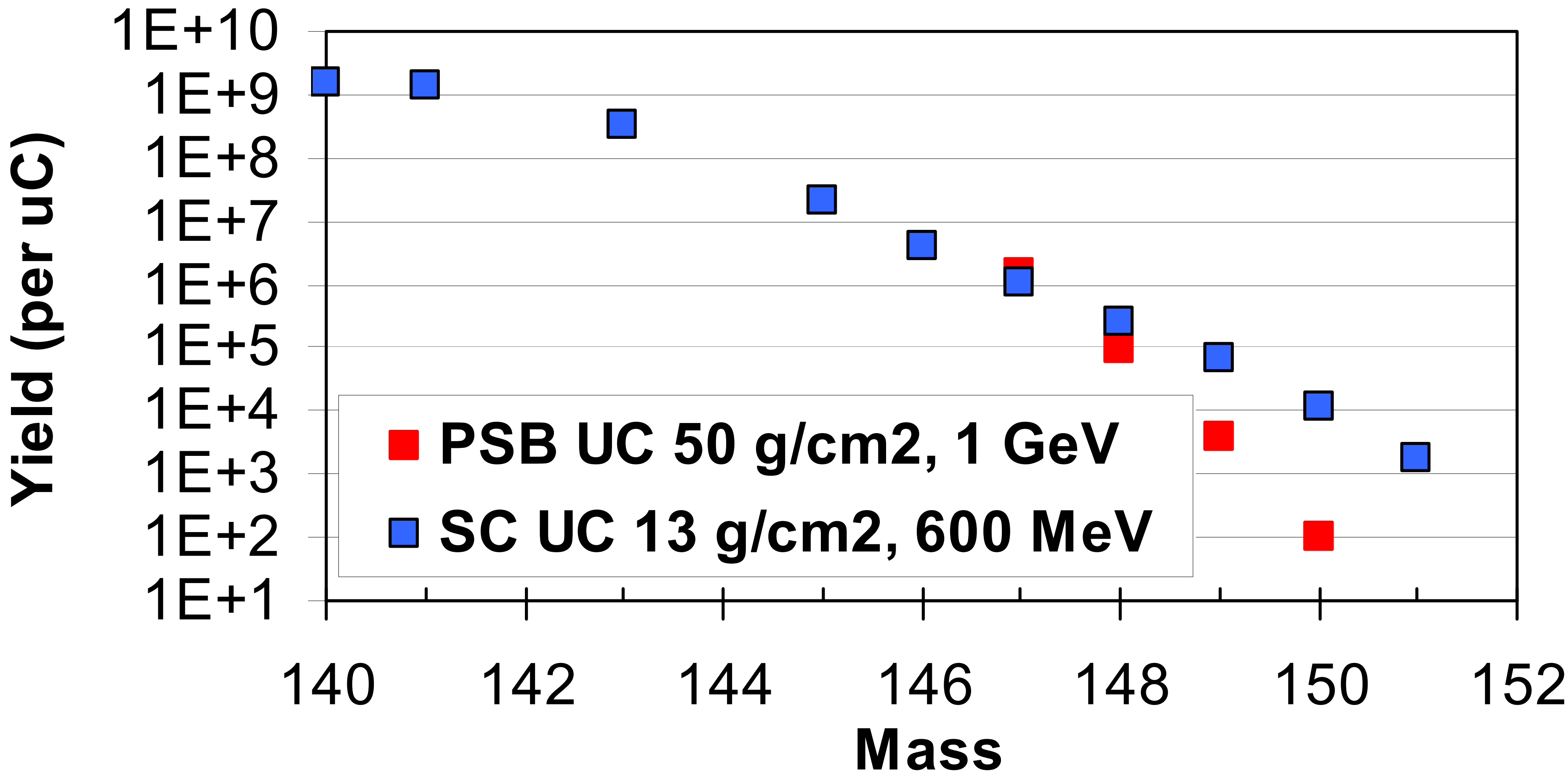
| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 58 Ce | 59 Pr | 60 Nd | 61 Pm | 62 Sm | 63 Eu | 64 Gd | 65 Tb | 66 Dy | 67 Ho | 68 Er | 69 Tm | 70 Yb | 71 Lu |
| 90 Th | 91 Pa | 92 U | 93 Np | 94 Pu | 95 Am | 96 Cm | 97 Bk | 98 Cf | 99 Es | 100 Fm | 101 Md | 102 No | 103 Lr |

Ulli Köster
ISOLDE
CERN

# Rubidium yields



# Cesium yields



ISOLDE CERN

# Halogens

Production of pure halogen beams at ISOLDE-SC with $LaB_6$ negative surface ion source. Use of $ThO_2$ targets to avoid surface poisoning.

Up to $^{94}Br$ used for βn and βγ spectroscopy at ISOLDE-SC

*K.L. Kratz et al., ZPA 330 (1988) 229.*

Up to $^{142}I$ observed at ISOLDE-SC

No request for pure halogen beams since move to PSB (>10 years)!

Negative ions incompatible with charge-breeding concept, use instead molecular ions, e.g. $AlBr^+$.

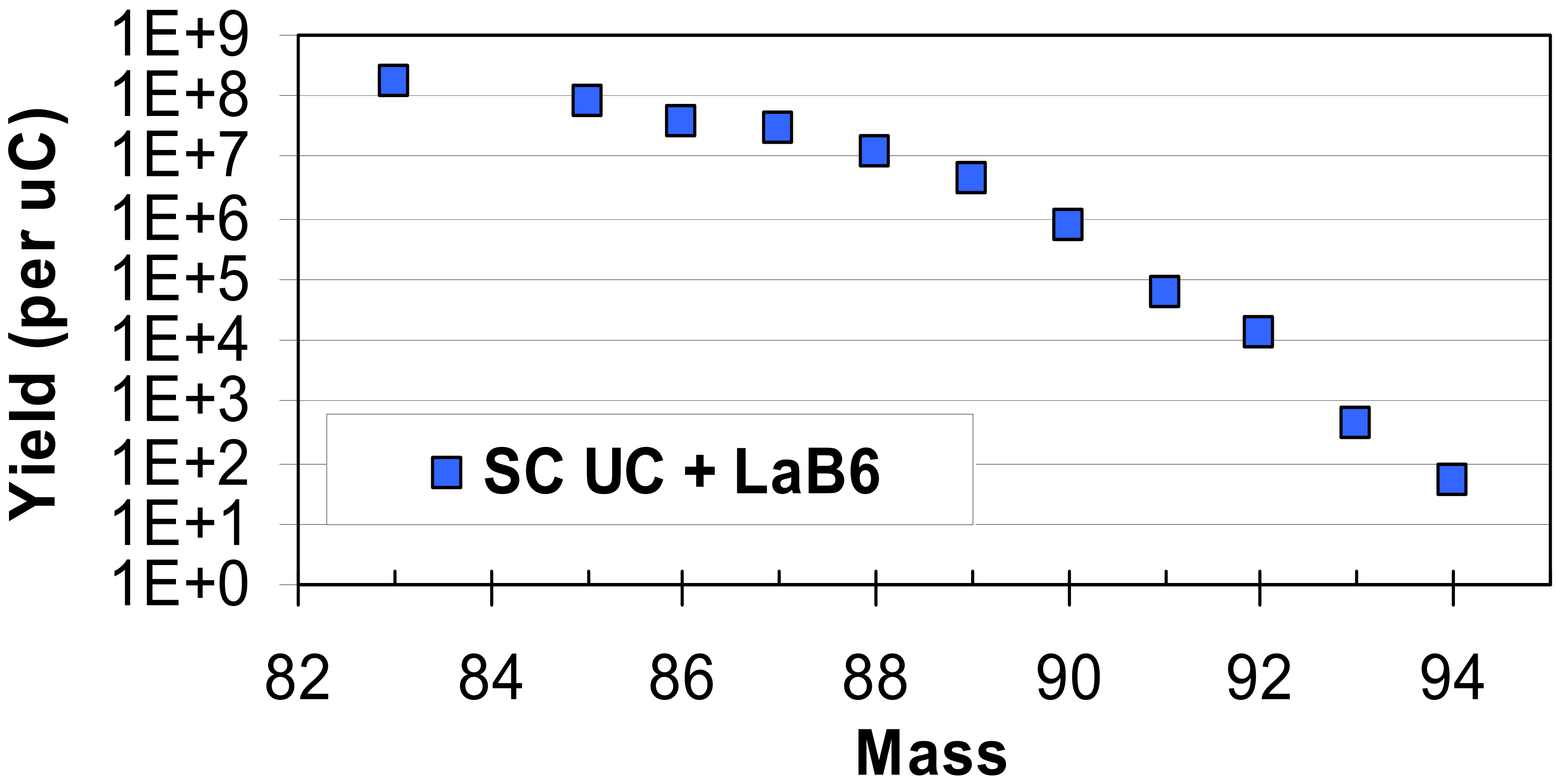
Halogenide ions cause frequently background:

$^{A}X^{19}F^+$ with X=Ca, Sr, Ba, Ln (fluorine emanating from Ta container)

$^{A}Br^{27}Al^+$, $^{A}Br^{40}Ca+$, $^{A}Br^{134\text{-}138}Ba^{+,}$ etc.

Complete removal of molecular background is possible (see below)!

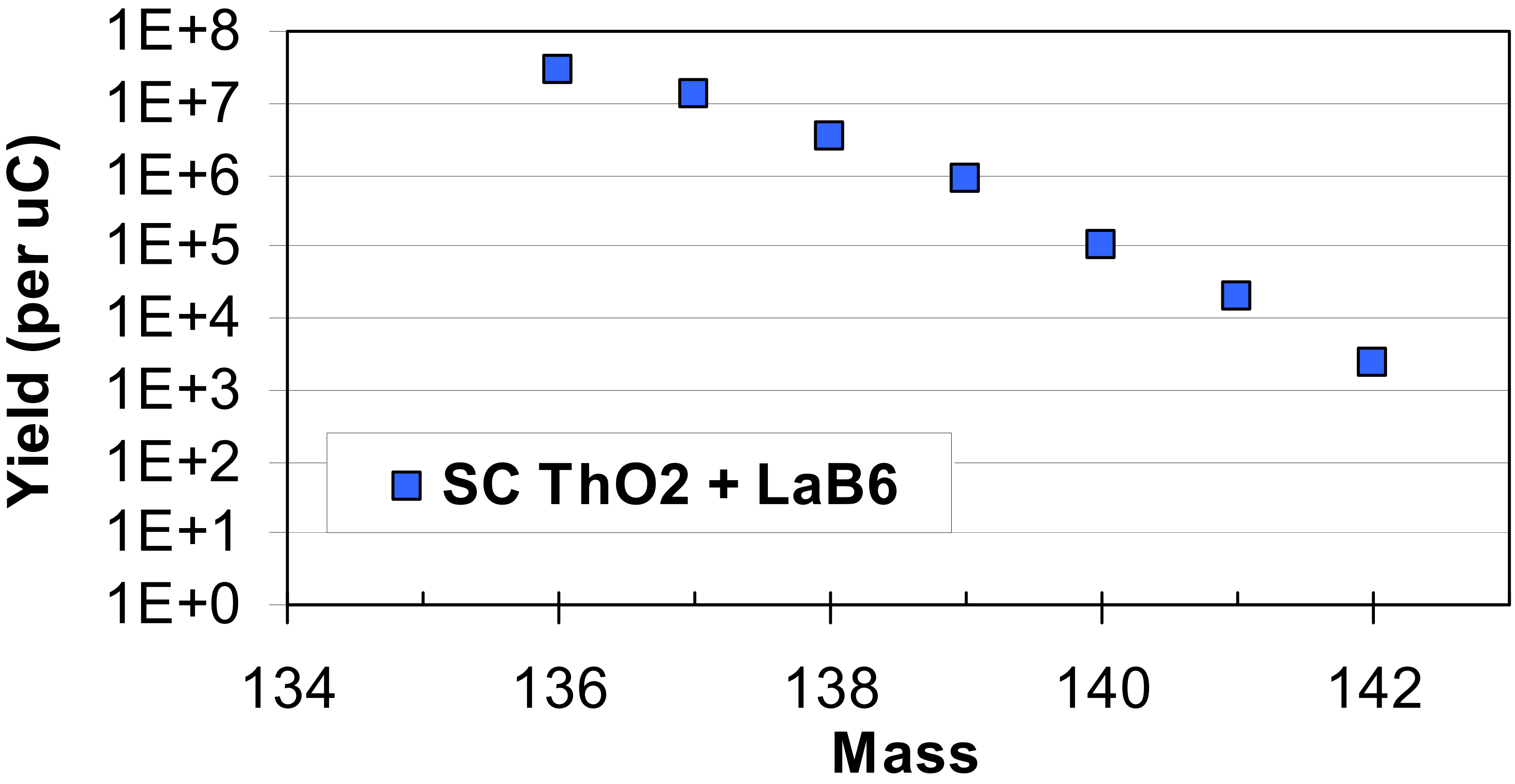
# Bromine yields



Ulli Köster

ISOLDE CERN

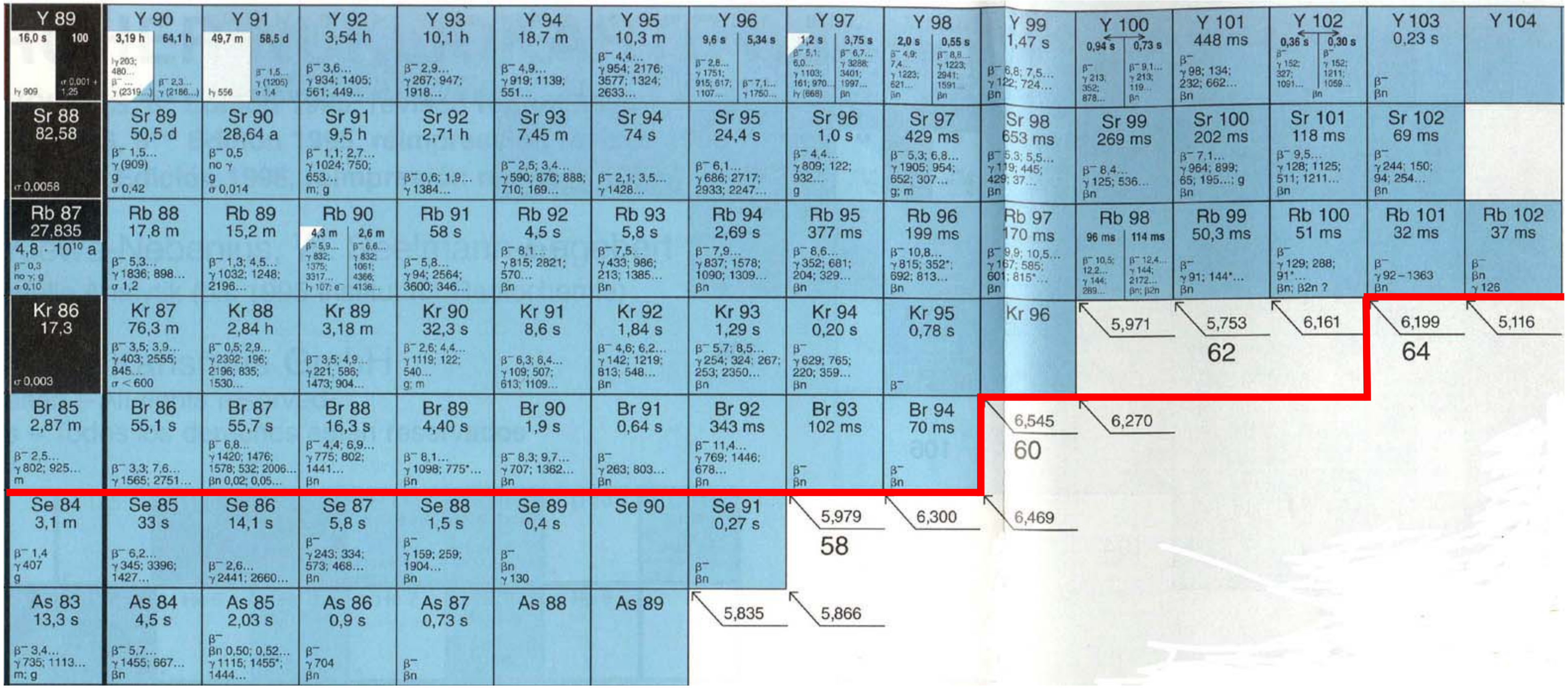
# Iodine yields



Ulli Köster

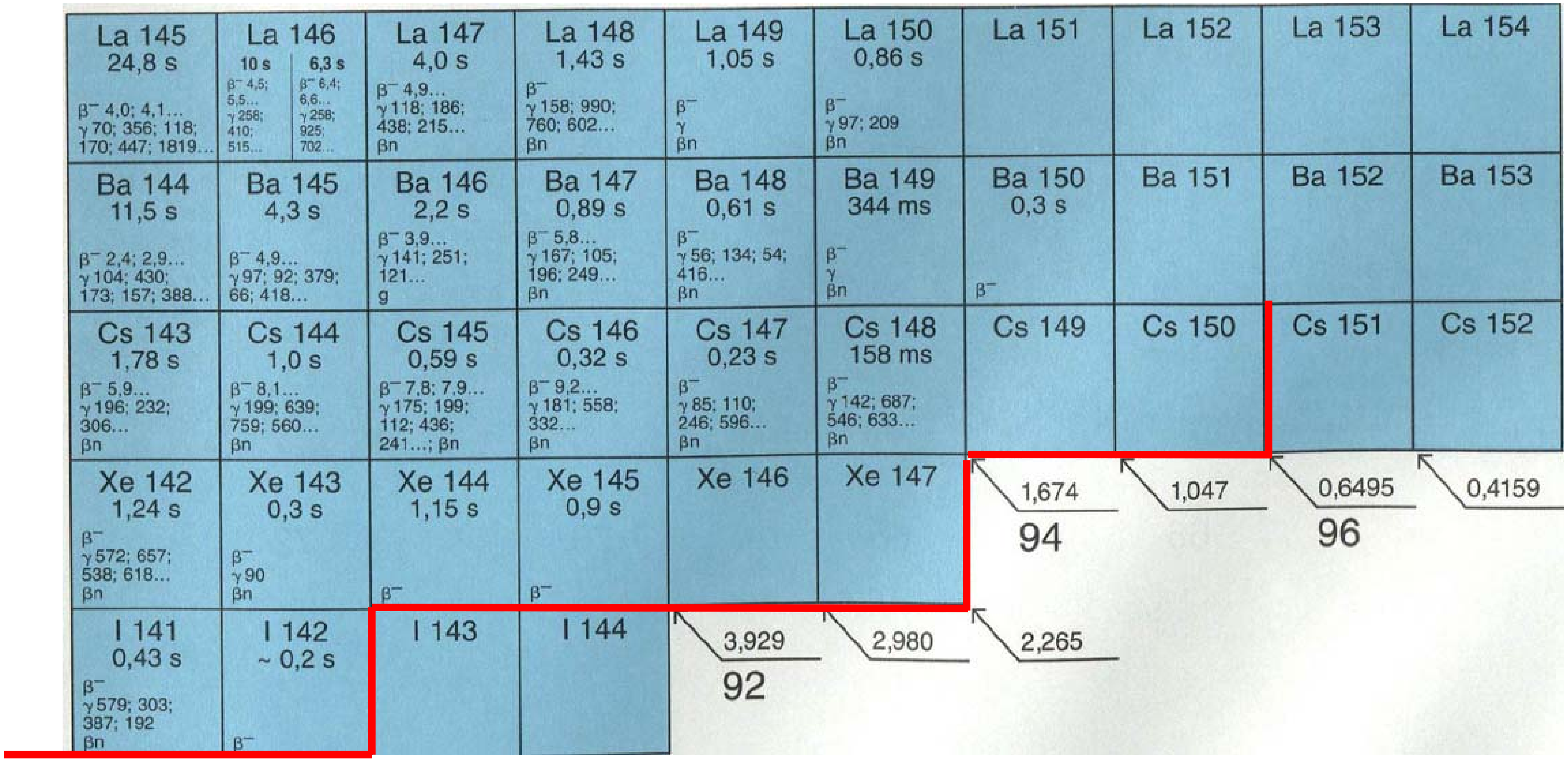
ISOLDE CERN

# N=50 to N=65



Ulli Köster
ISOLDE
CERN

# Up to N=95



Ulli Köster

ISOLDE
CERN

# Volatility of the elements

- T (p vapor > 0.01 mbar) < 100 °C
- T (p vapor > 0.01 mbar) < 400 °C
- T (p vapor > 0.01 mbar) < 1000 °C
- T (p vapor > 0.01 mbar) < 2000 °C
- T (p vapor > 0.01 mbar) > 2000 °C

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 H | | | | | | | | | | | | | | | | | 2 He |
| 3 Li | 4 Be | | | | | | | | | | | 5 B | 6 C | 7 N | 8 O | 9 F | 10 Ne |
| 11 Na | 12 Mg | | | | | | | | | | | 13 Al | 14 Si | 15 P | 16 S | 17 Cl | 18 Ar |
| 19 K | 20 Ca | 21 Sc | 22 Ti | 23 V | 24 Cr | 25 Mn | 26 Fe | 27 Co | 28 Ni | 29 Cu | 30 Zn | 31 Ga | 32 Ge | 33 As | 34 Se | 35 Br | 36 Kr |
| 37 Rb | 38 Sr | 39 Y | 40 Zr | 41 Nb | 42 Mo | 43 Tc | 44 Ru | 45 Rh | 46 Pd | 47 Ag | 48 Cd | 49 In | 50 Sn | 51 Sb | 52 Te | 53 I | 54 Xe |
| 55 Cs | 56 Ba | 57 La | 72 Hf | 73 Ta | 74 W | 75 Re | 76 Os | 77 Ir | 78 Pt | 79 Au | 80 Hg | 81 Tl | 82 Pb | 83 Bi | 84 Po | 85 At | 86 Rn |
| 87 Fr | 88 Ra | 89 Ac | 104 Rf | 105 Db | 106 Sg | 107 Bh | 108 Hs | 109 Mt | 110 | 111 | 112 | | | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 58 Ce | 59 Pr | 60 Nd | 61 Pm | 62 Sm | 63 Eu | 64 Gd | 65 Tb | 66 Dy | 67 Ho | 68 Er | 69 Tm | 70 Yb | 71 Lu |
| 90 Th | 91 Pa | 92 U | 93 Np | 94 Pu | 95 Am | 96 Cm | 97 Bk | 98 Cf | 99 Es | 100 Fm | 101 Md | 102 No | 103 Lr |

ISOLDE CERN

# Group 12

**Beam purification by medium-temperature transfer line or/and RILIS.**

**Zinc:**

**Up to $^{81}$Zn observed at ISOLDE-SC** ***K.L. Kratz et al., ZPA 340 (1986) 419.***

**RILIS used for n-deficient Zn beams, but not yet for n-rich ones**

**Coulex with $^{72,74,76}$Zn beams at REX scheduled for September (IS412)**

**Cadmium:**

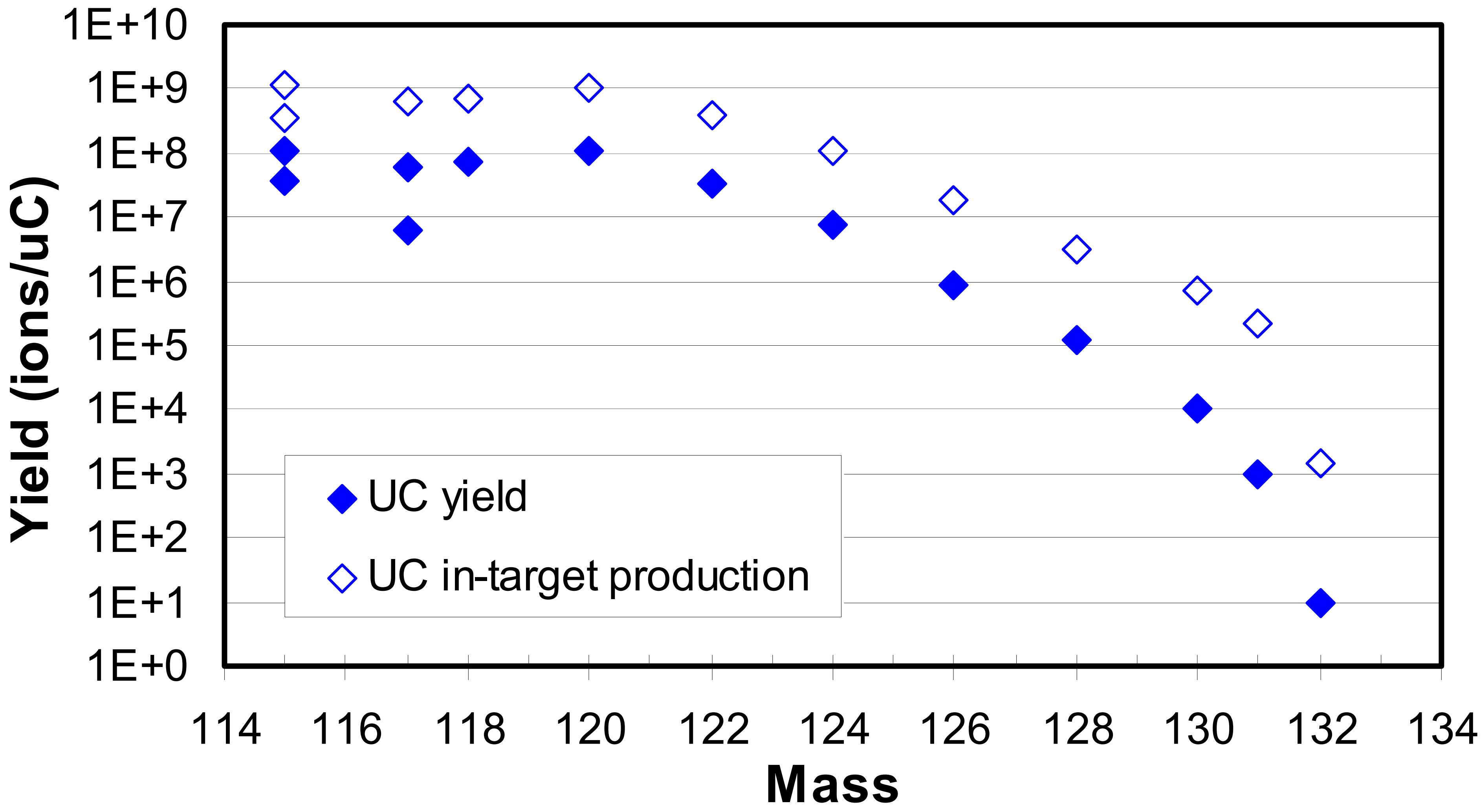
**Up to $^{130}$Cd observed at ISOLDE-SC**

***K.L. Kratz et al., ZPA 325 (1986) 489.***

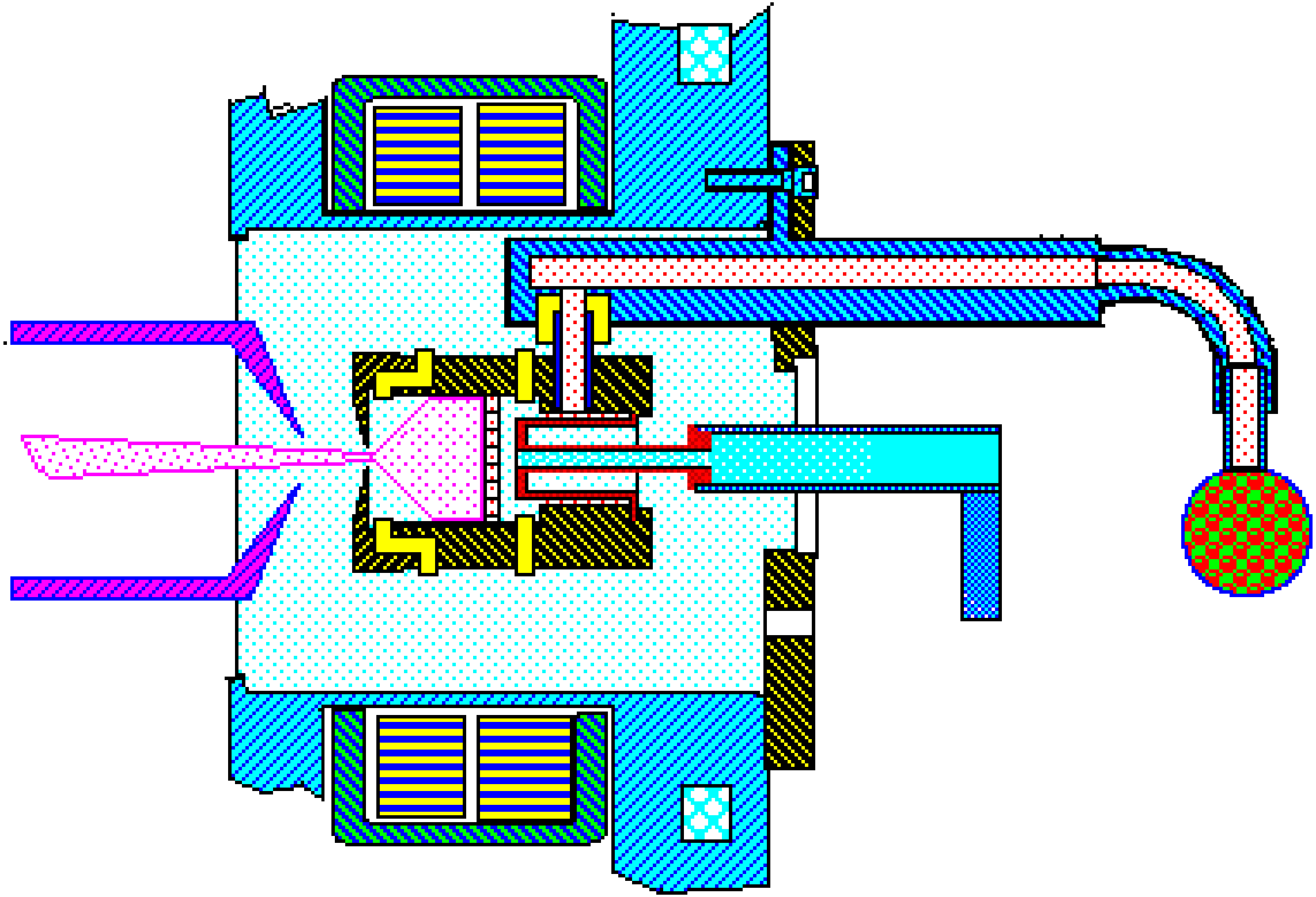
**PSB: half-lives and Pn values of $^{131,132,133}$Cd and βγ spectroscopy of $^{130}$Cd** ***M. Hannawald et al., PRC 62 (2000) 054301.***

Ulli Köster
ISOLDE
CERN

# Cd yields



# Medium-temperature transfer line



# Silver

**Up to $^{129}$Ag observed with RILIS**

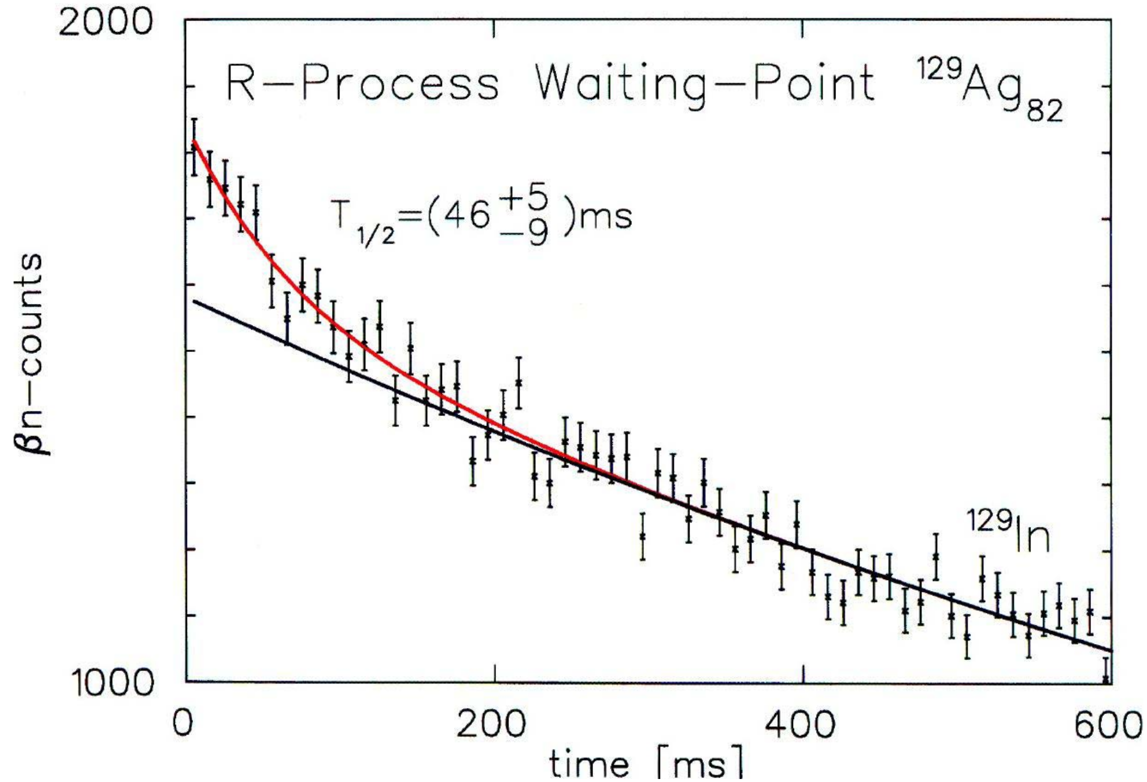
*K.L. Kratz et al., Conf. on Fission..., Sanibel Island, 1997, World Scientific.*

**First 2$^{+}$ and 4$^{+}$ states in $^{126,128}$Cd identified by βγ spectroscopy,**

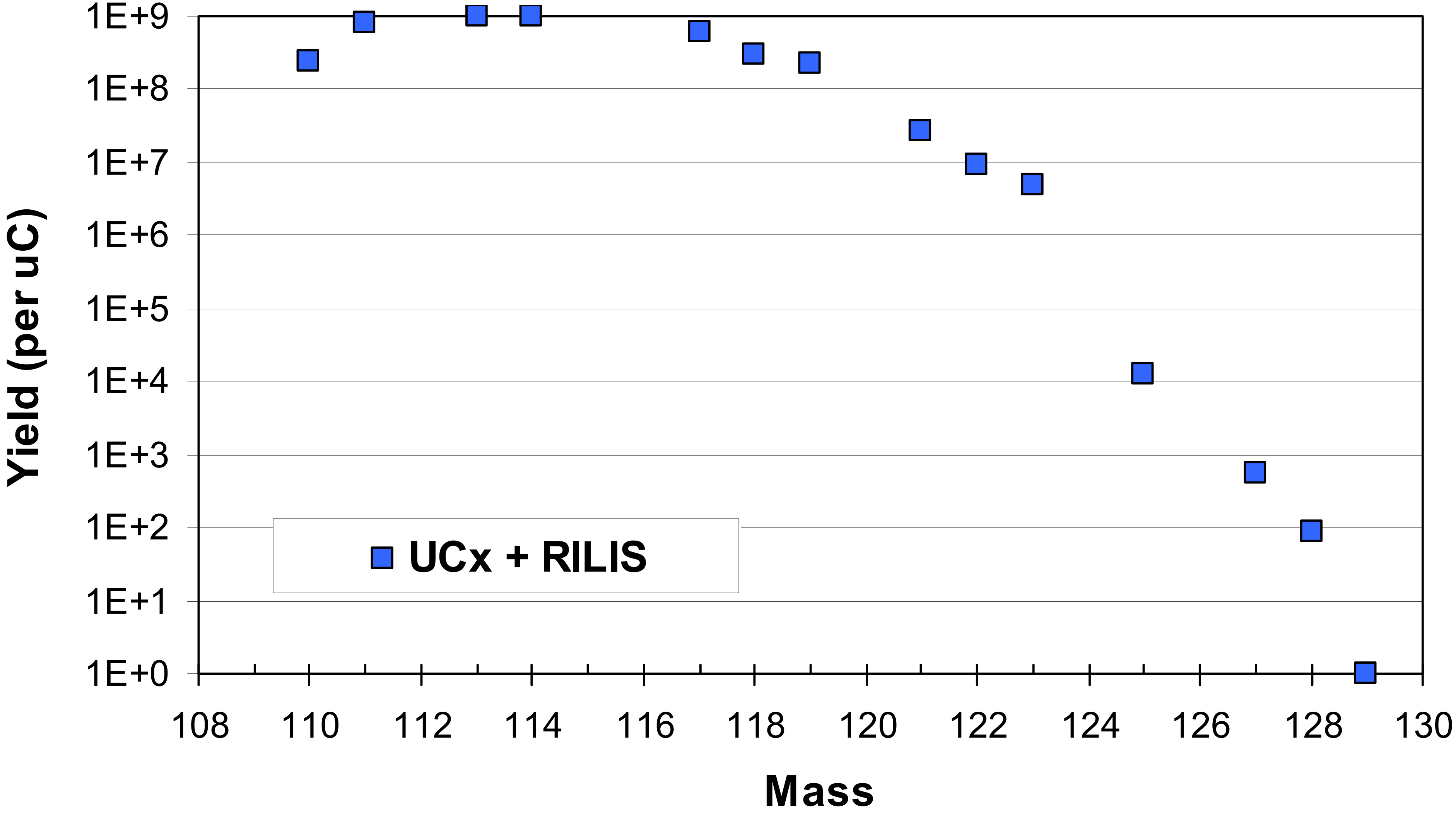
*T. Kautzsch et al., EPJA 9 (2000) 201.*

**Cs suppressed by neutron converter.**

**Detailed βγ decay spectroscopy of $^{124-128}$Ag planned (IS421)**



# Silver yields



# Copper

**Up to $^{79}$Cu observed at ISOLDE-SC**

*K.L. Kratz et al., ZPA 340 (1986) 419.*

**With RILIS separation of isomers and measurement of magnetic moments by laser scanning of HFS**

**Discovery of new isomer in $^{70}$Cu**

**"Exclusion" of β-decaying isomers in $^{72,76}$Cu**

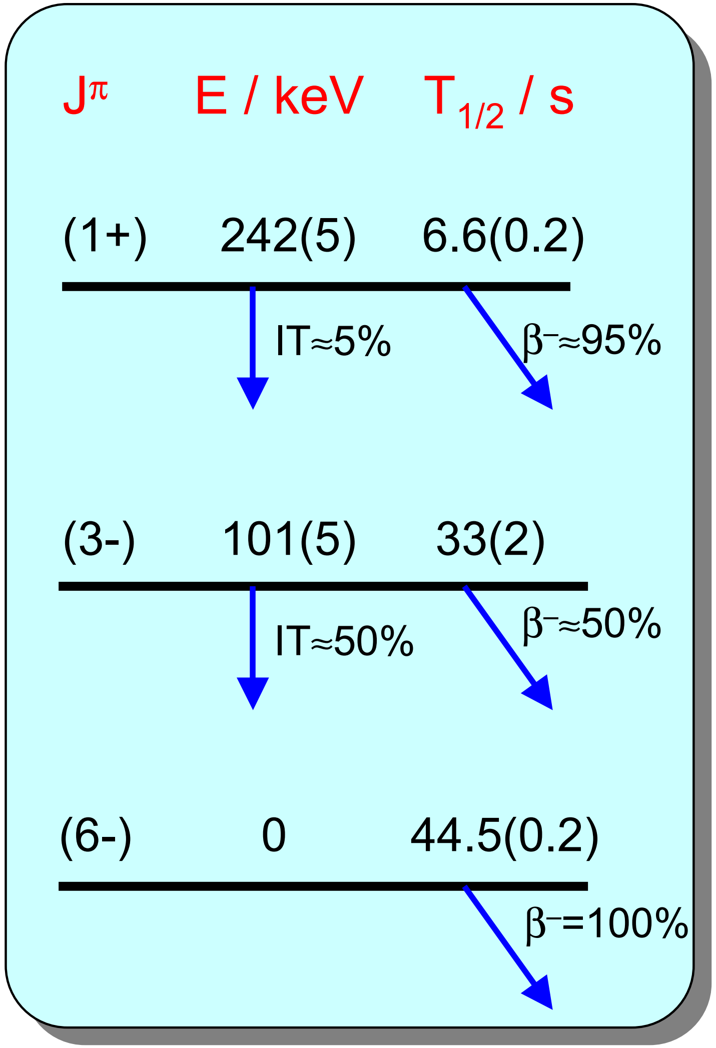
**Rb suppressed by neutron converter**

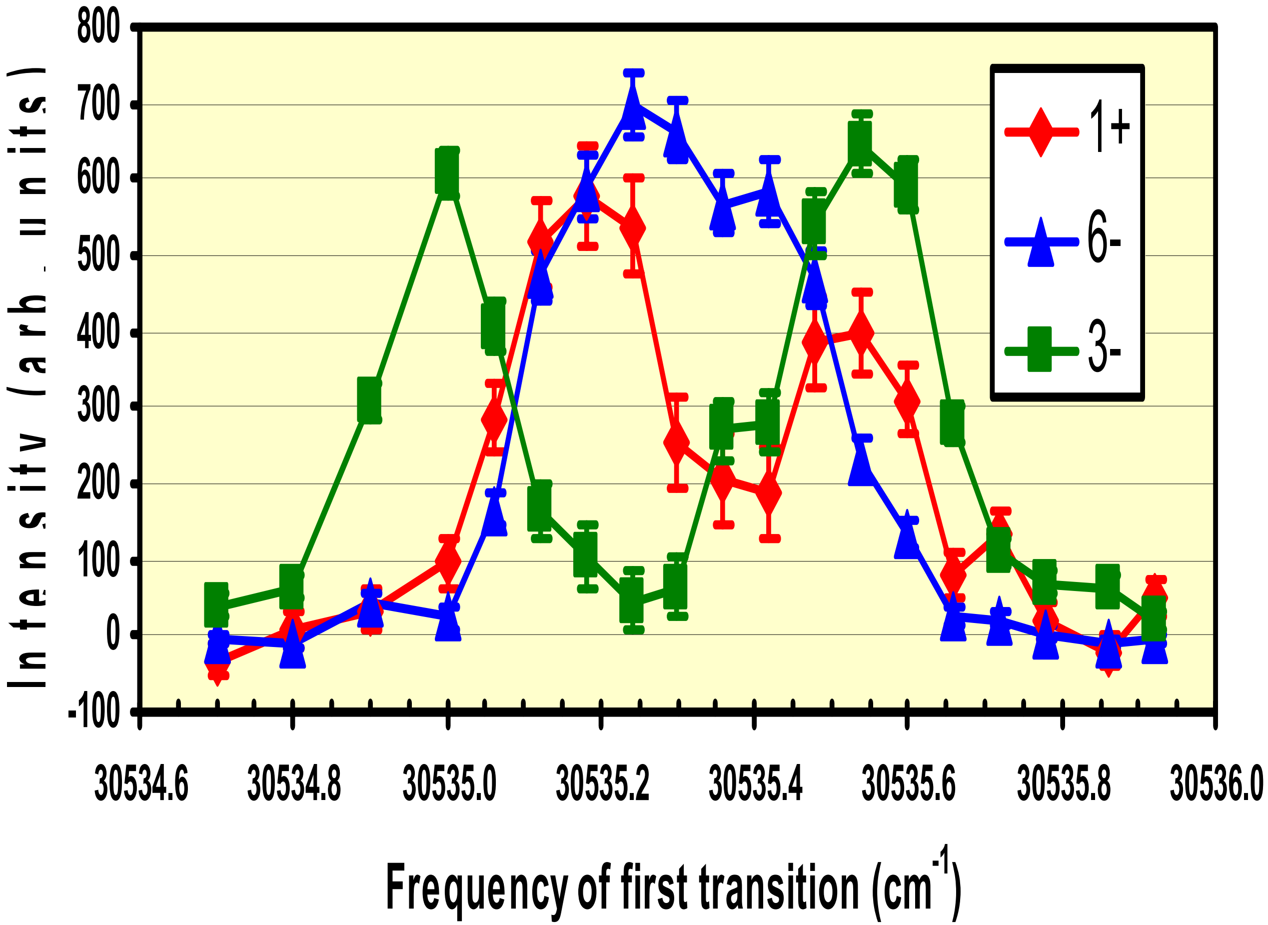
**First observation of $^{78}$Cu βγ decay**

**very detailed decay spectroscopy data for $^{71-77}$Cu**

Ulli Köster
ISOLDE
CERN

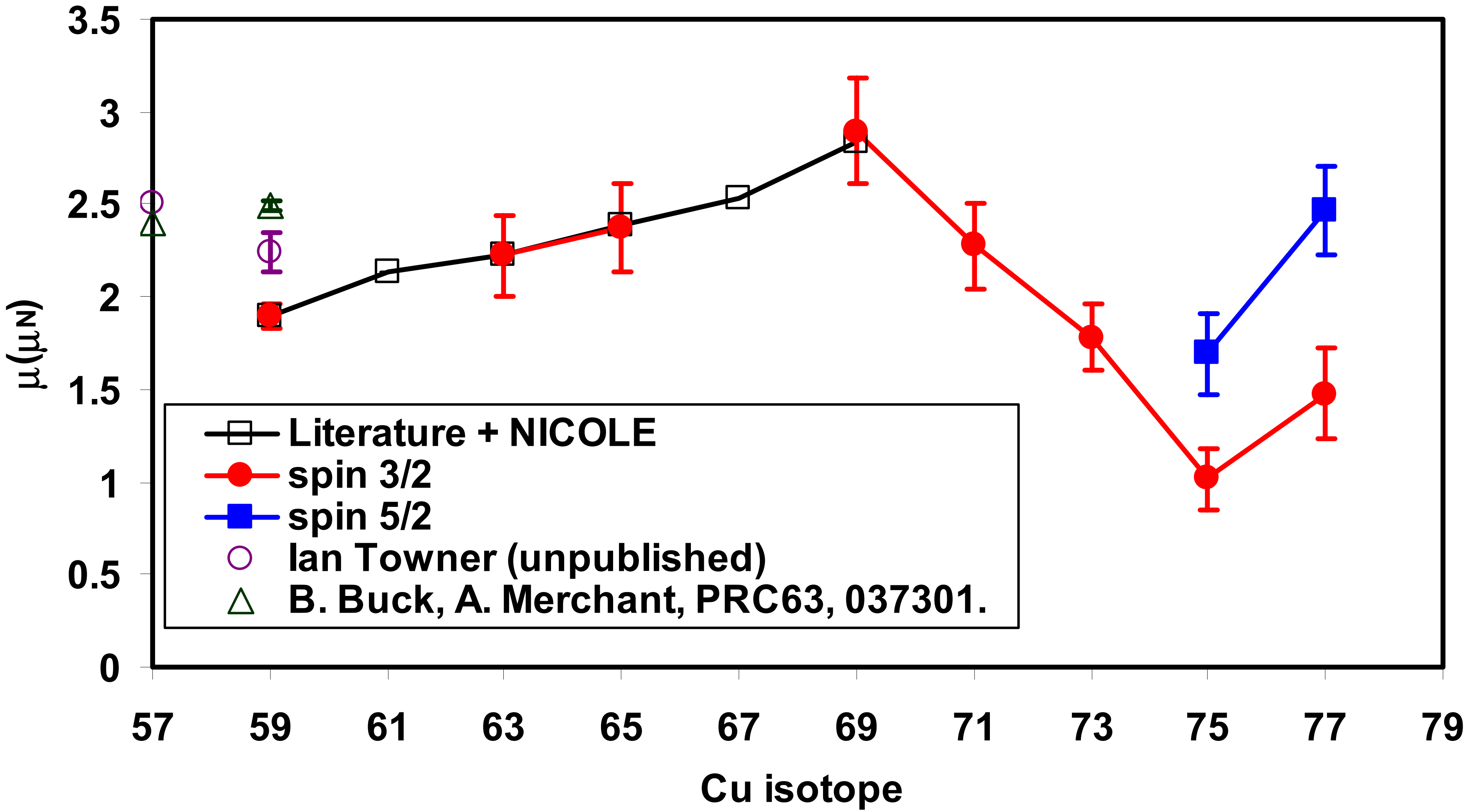
# $^{70}$Cu isomers separated



ISOLDE CERN

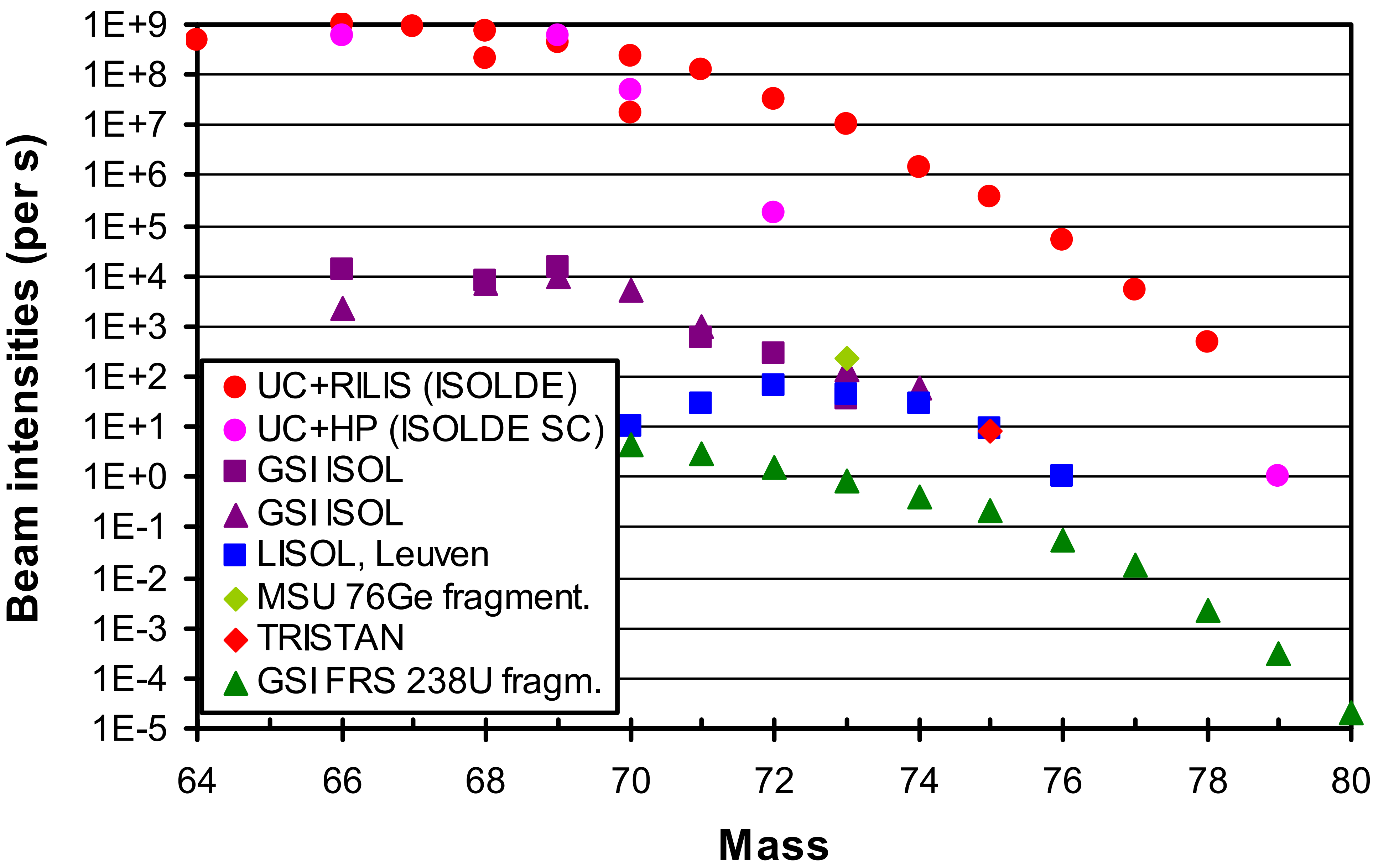
# Magnetic moments of Cu isotopes



Ulli Köster

ISOLDE CERN

# Copper beam intensity



# Suppression of surface-ionized background

**Fast beam chopper:**
**selectivity gain 10 for Be, <6 for Cu, <4 for Ag, but intensity loss**

**Reduced line temperature:**
**works best with low-work-function surface, enhances delay**

**Low work-function surface:**
**counter-acted by cavity effect, may degrade over longer period**

**Inverse electric field gradient in transfer line: delays Rb, Cs; also used with FEBIAD. Needs to be combined with back-extraction.**

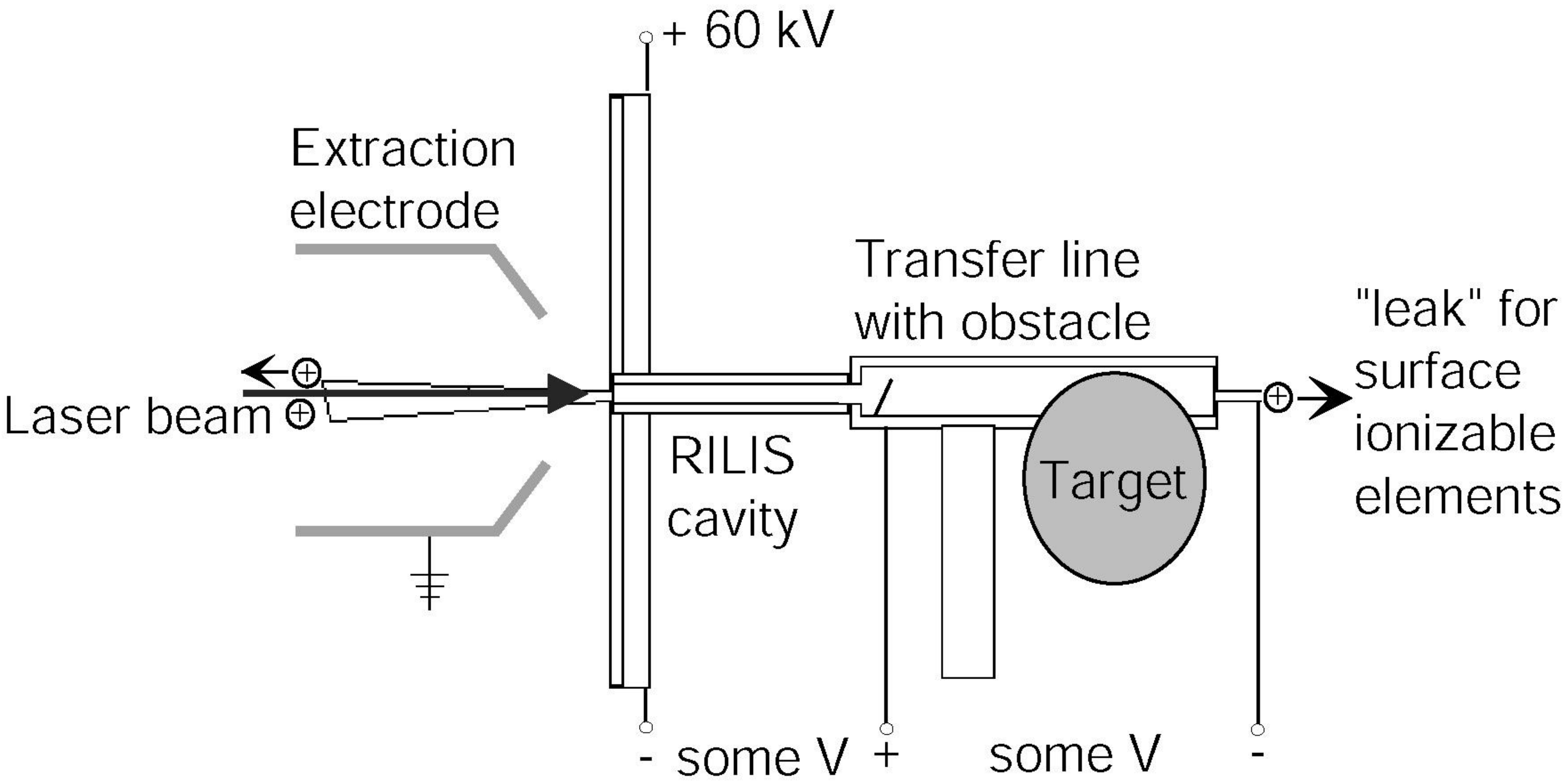
**Back-extraction of ions: intensity loss proportional to orifice ratio**

**Neutron-converter: shifts fission peak towards neutron-rich side**

**Medium temperature transfer line: only for volatile elements: Zn, Cd**

**Alkali-retaining target or transfer line: oxides, glass**

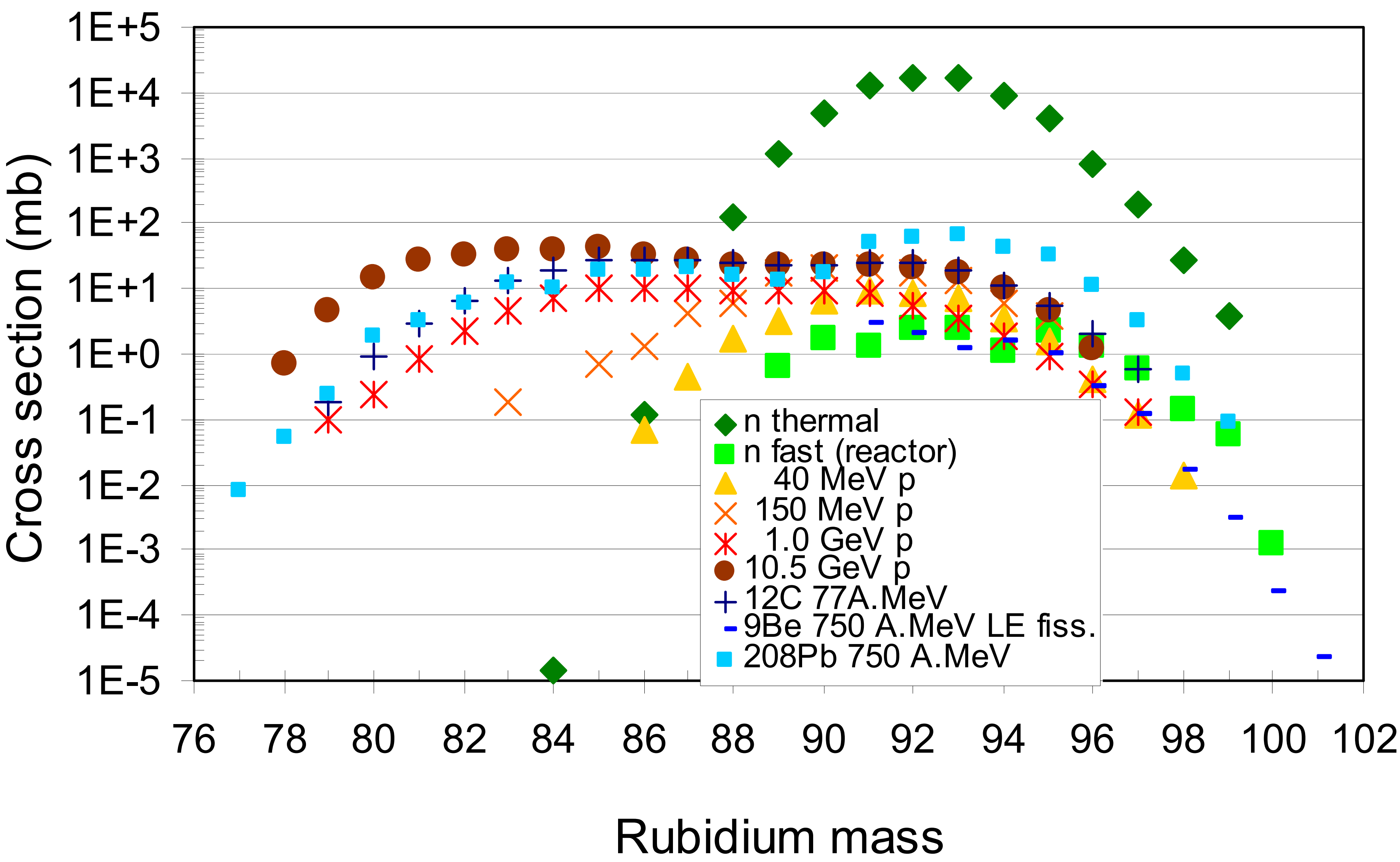
# "Back-extraction"



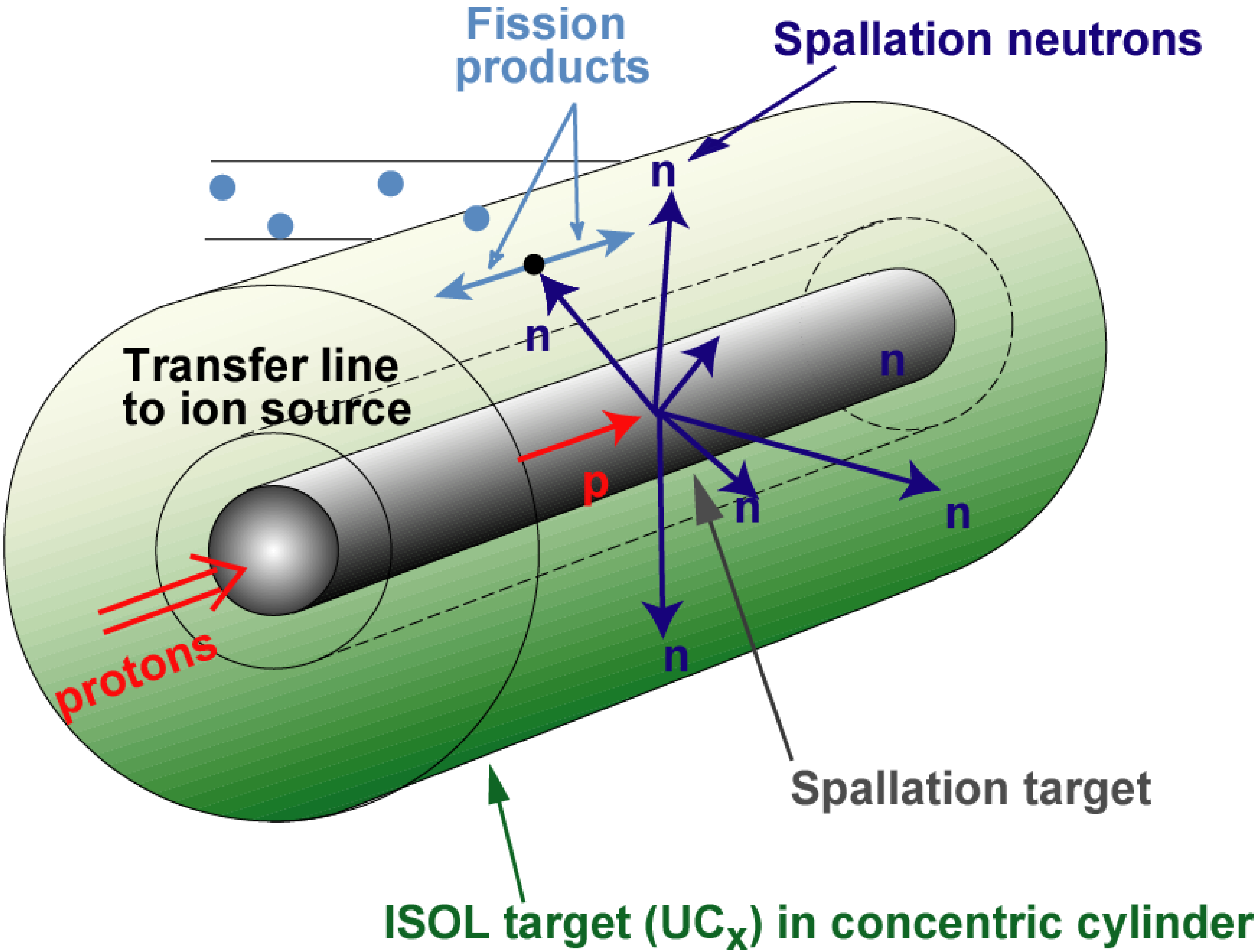
Ulli Köster

ISOLDE CERN

# Fission yields



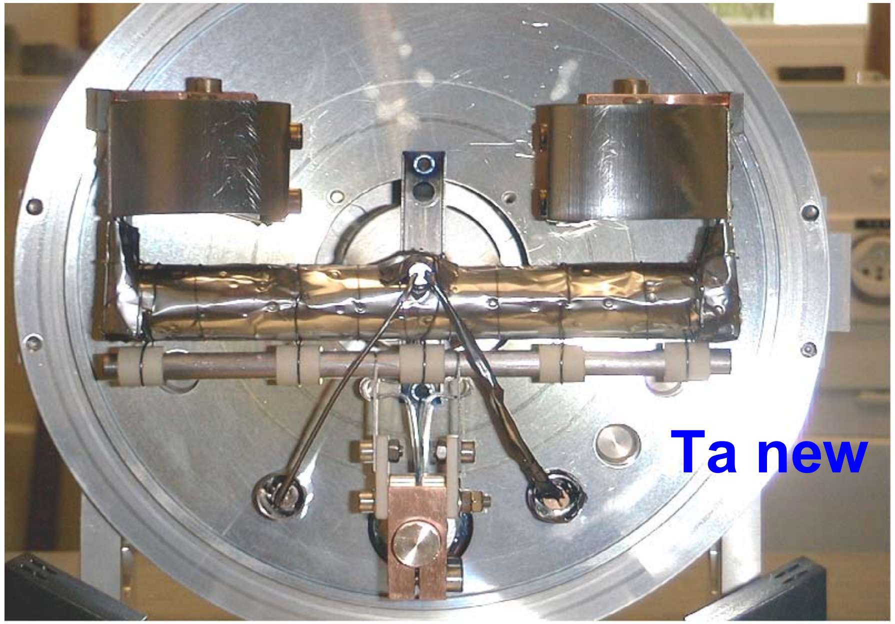
# The neutron converter (principle)

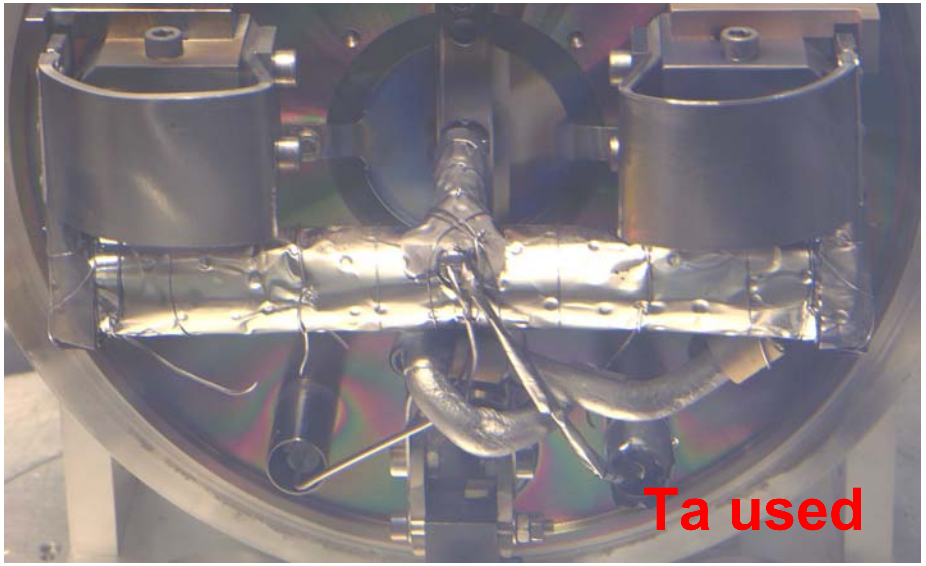


Ulli Köster

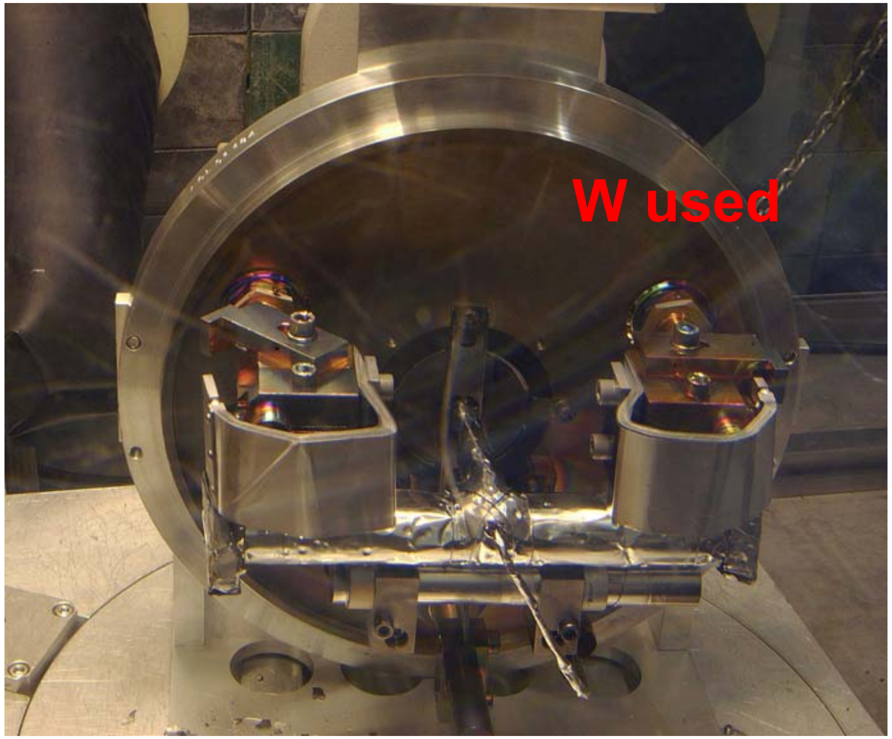
ISOLDE CERN

# Neutron converters in praxi







# Group 13

## Gallium:

yields boosted by factor 20-30 with RILIS versus W SI

converter suppresses Rb background

Up to $^{86}$Ga observed, decay spectroscopy of $^{84,85}$Ga

## Indium:

yields boosted by factor 7 with RILIS versus W SI

converter suppresses Cs background

$^{135}$In studied by $\beta$n spectroscopy,

*I. Dillmann et al., EPJA 13 (2002) 281.*

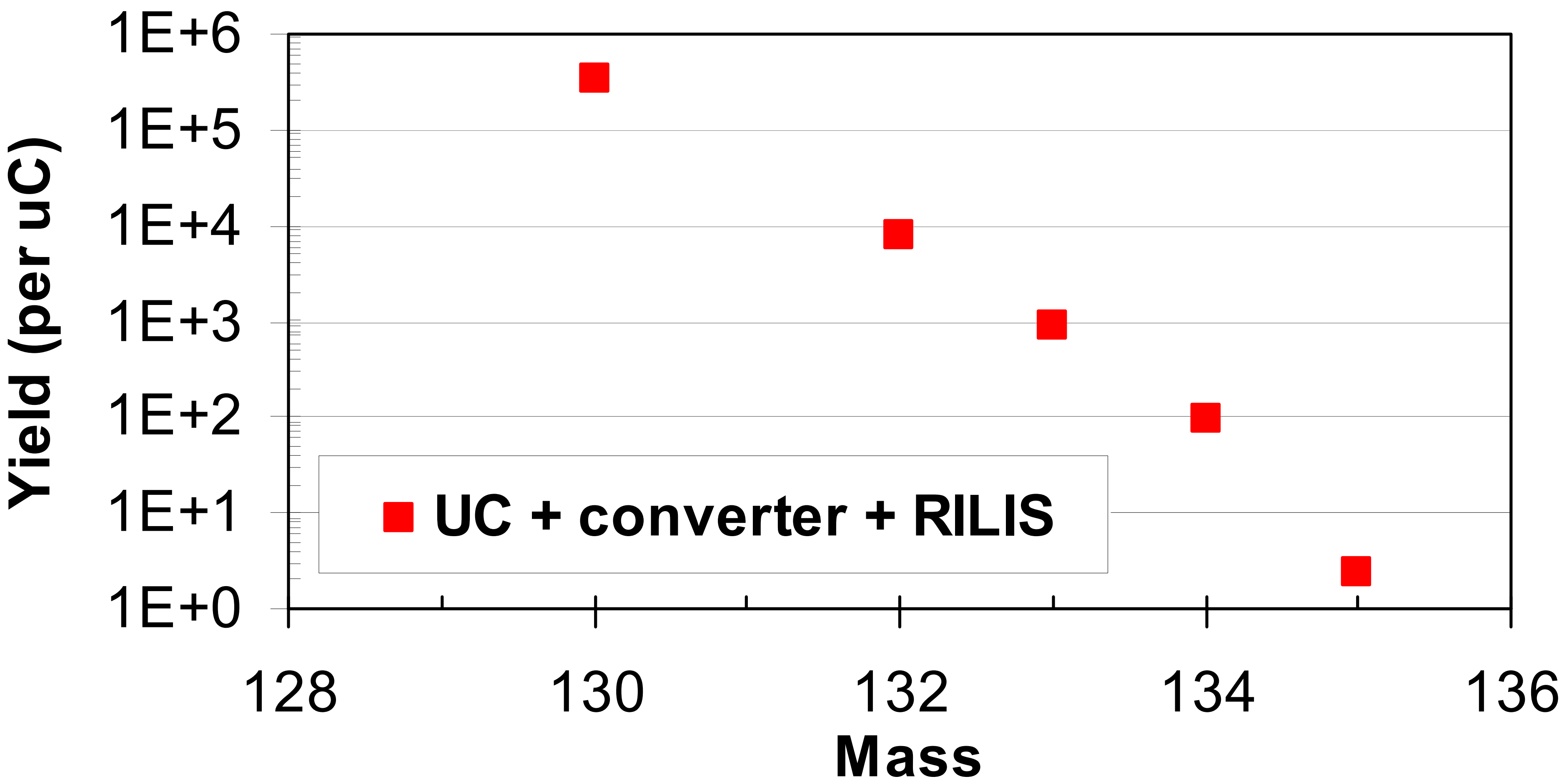
Ga and In are surface ionized and can present a background.

Ulli Köster

ISOLDE
CERN

# Towards 78Ni

# Indium yields




Factor 3 gain from RILIS tuning possible!

Ulli Köster

ISOLDE CERN

# Carbon group

## Tin:

up to $^{138}$Sn ionized by RILIS, *J. Shergur et al., PRC 65 (2002) 034313.*

improved beam purity (removal of Cs contamination) and faster release by using $SnS^+$ separation

on-line 5% in $SnS^+$ sideband with little $SO_2$ addition

off-line 40% in $SnS^+$ sideband with increased $SO_2$ addition

lanthanide background (far asymmetric fission) can be reduced with the converter

use of isotopically enriched $^{32}$S or $^{34}$S to avoid ambiguities

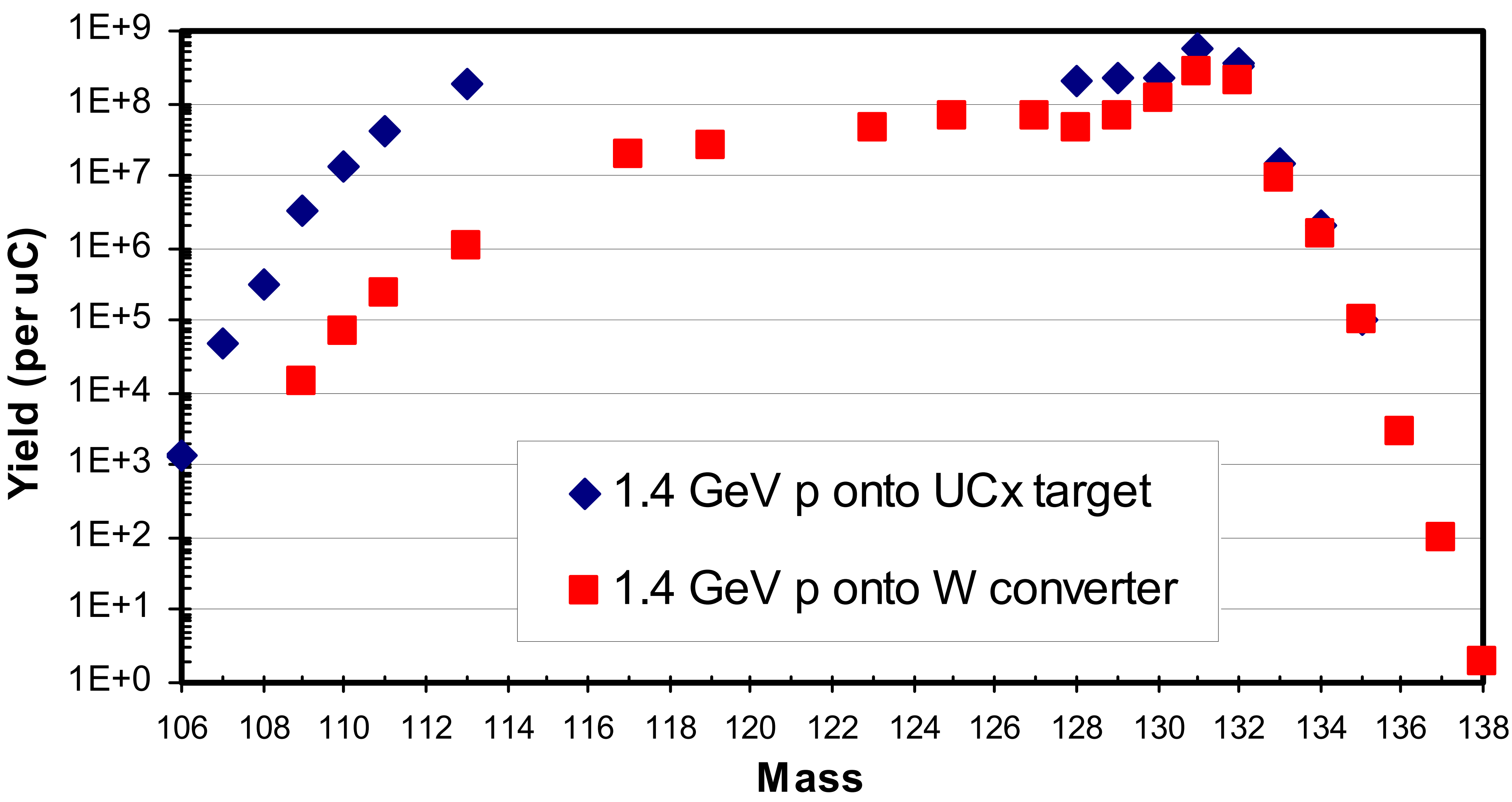
## Germanium:

off-line test of $GeS^+$ separation: 65% in $GeS^+$ sideband

Ulli Köster

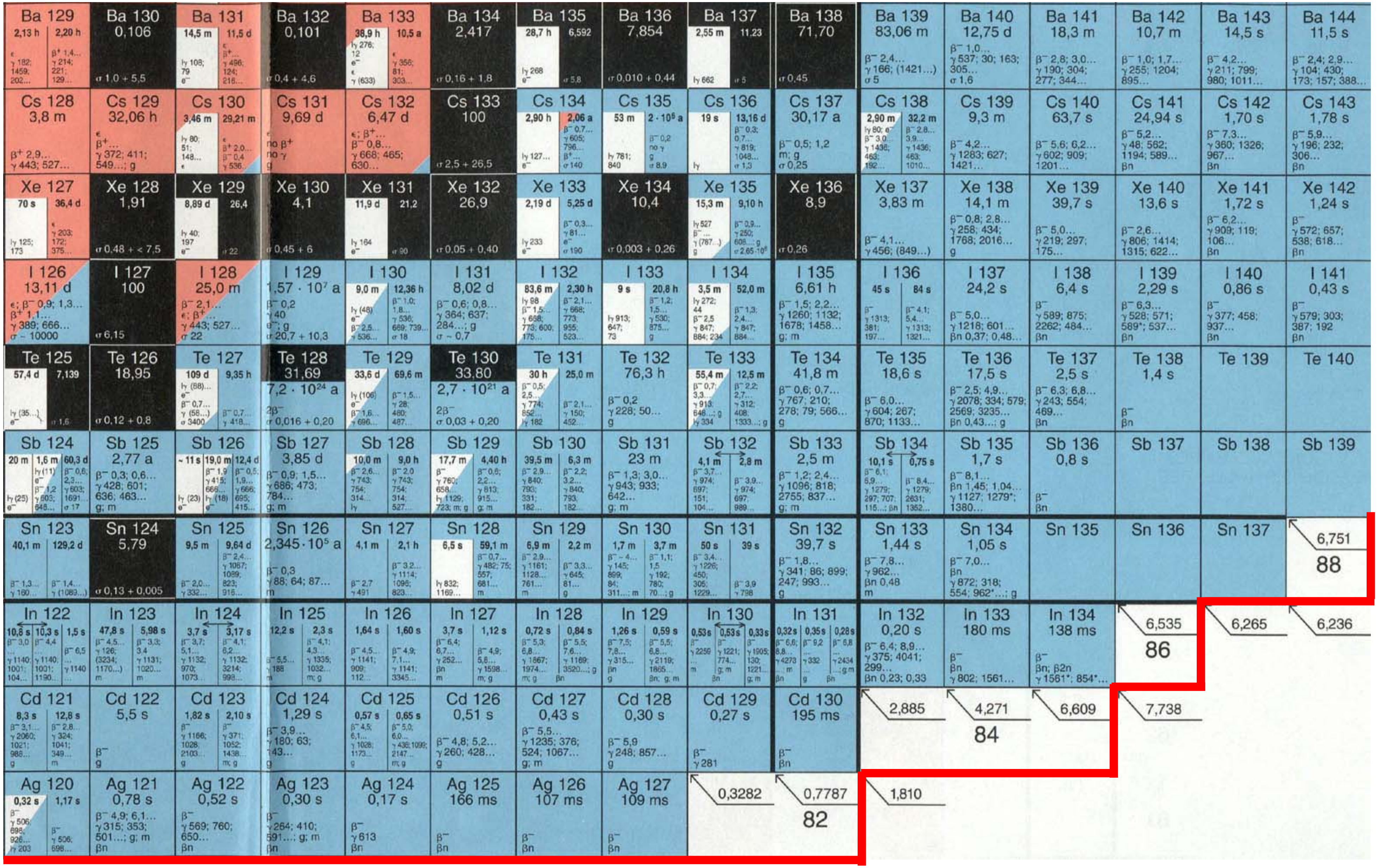
ISOLDE CERN

# Tin yields



Ulli Köster
ISOLDE
CERN

# Around 132Sn



ISOLDE CERN

# Manganese

high intrinsic beam purity with RILIS (no surface ionized isobars)

$^{57}$Mn routinely used for Mößbauer spectroscopy

Up to $^{69}$Mn observed and first excited states in $^{64,66}$Fe found

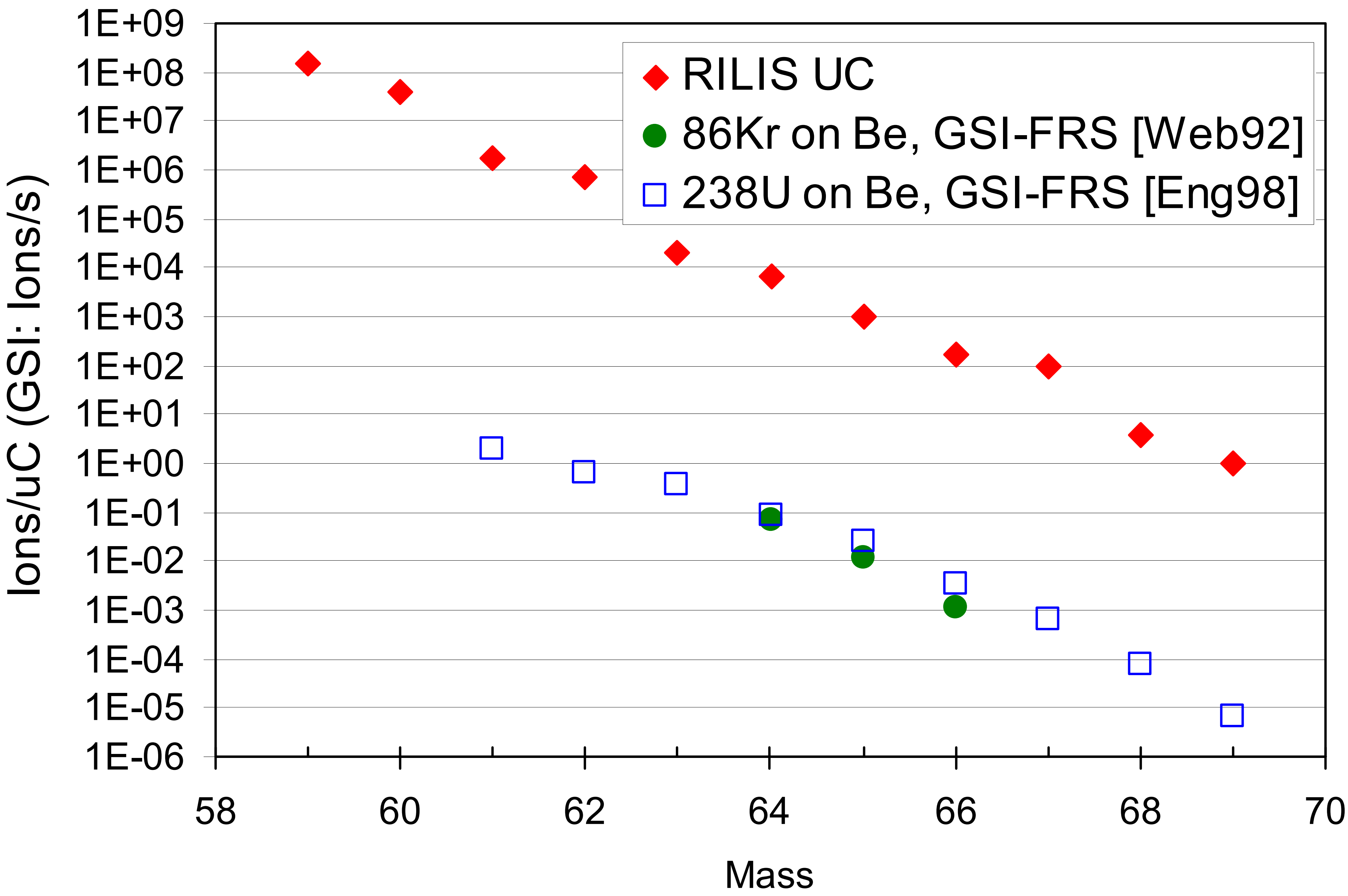
*M. Hannawald et al., PRL 82 (1999) 1391.*

far asymmetric fission favored by high-energy protons

$\Rightarrow$ further gain with 1.4 GeV protons

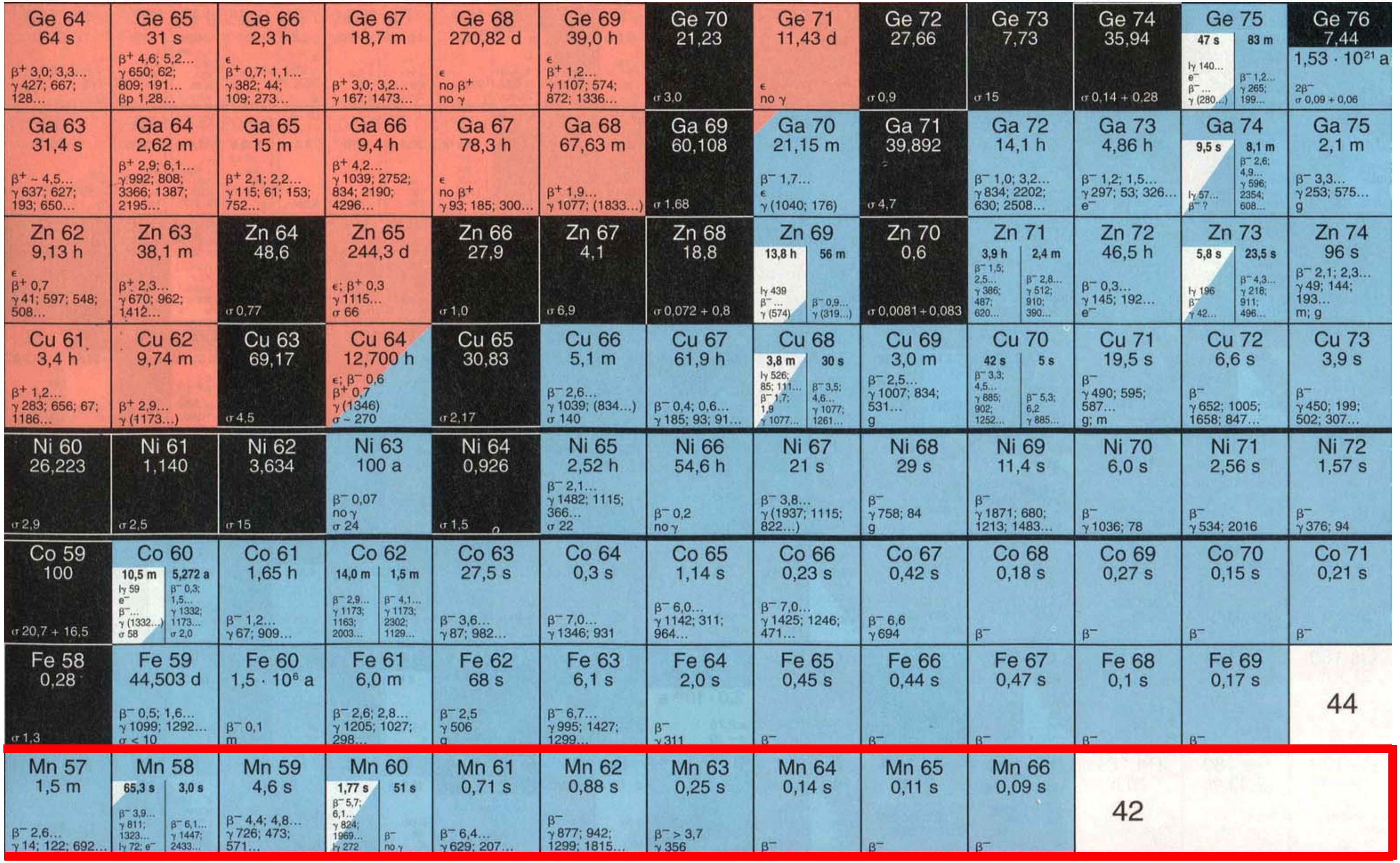
Ulli Köster
ISOLDE CERN

# Manganese yields



Ulli Köster
ISOLDE
CERN

# Neutron-rich Mn and isobars



# Nickel

Beams observed up to $^{70}Ni$

Very slow release (Fe and Co expected to be similar)

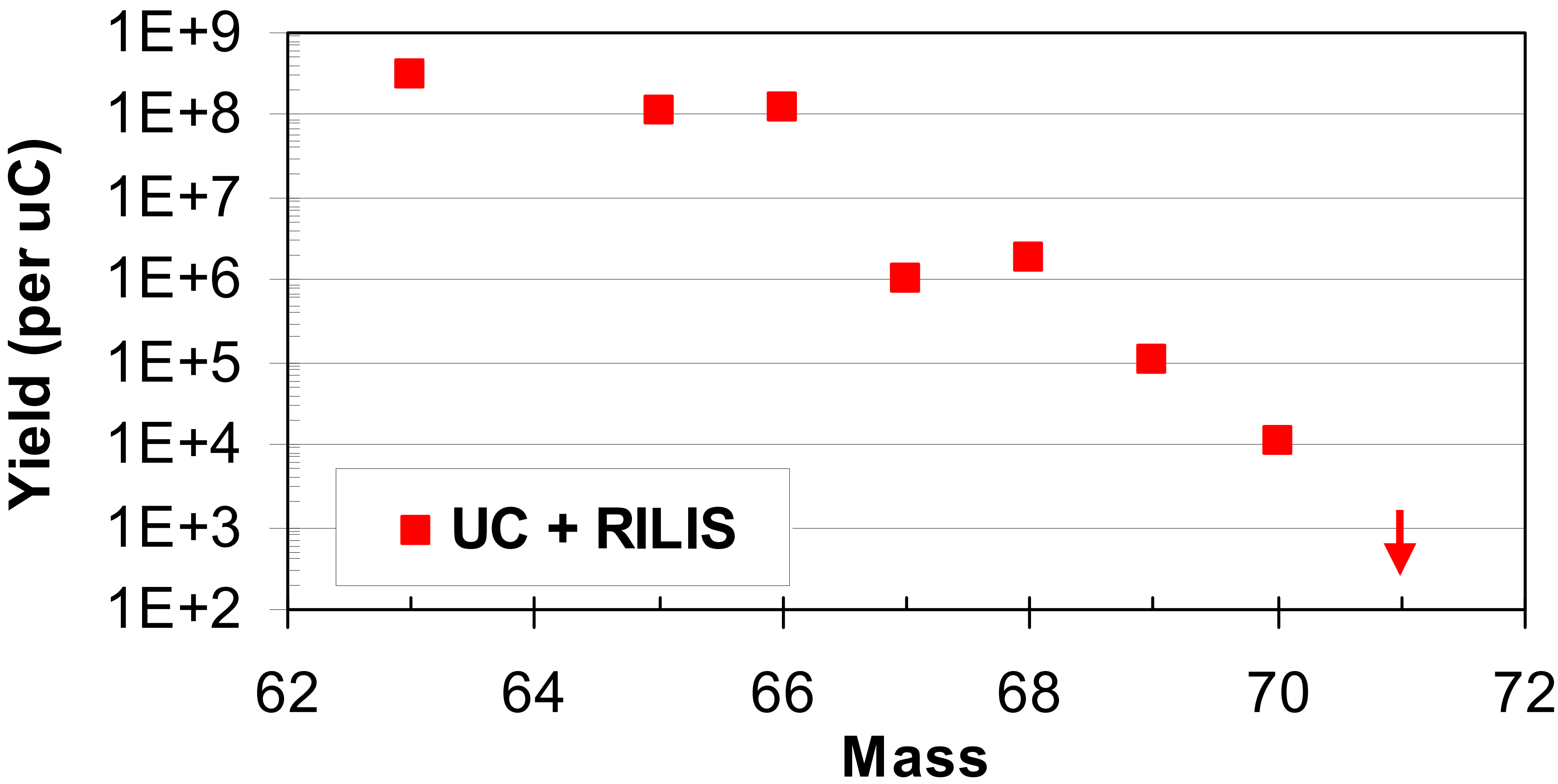
Delay mainly due to slow desorption from metallic surfaces.

Graphite or oxide surfaces might help to speed up the release.

Coulex of $^{68,70}Ni$ planned with REX (IS412)

ISOLDE
CERN

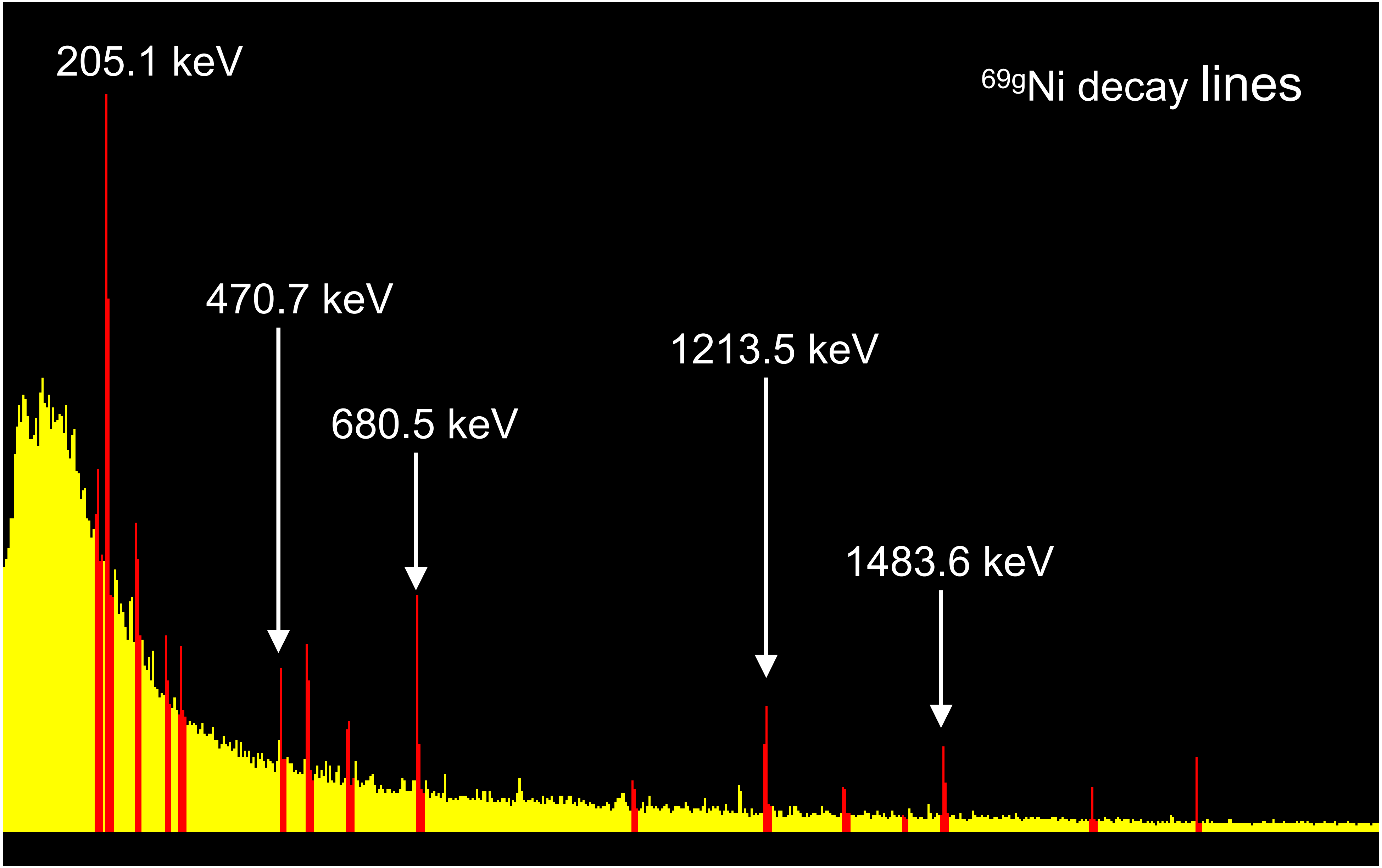
# Nickel yields



Ulli Köster

ISOLDE CERN

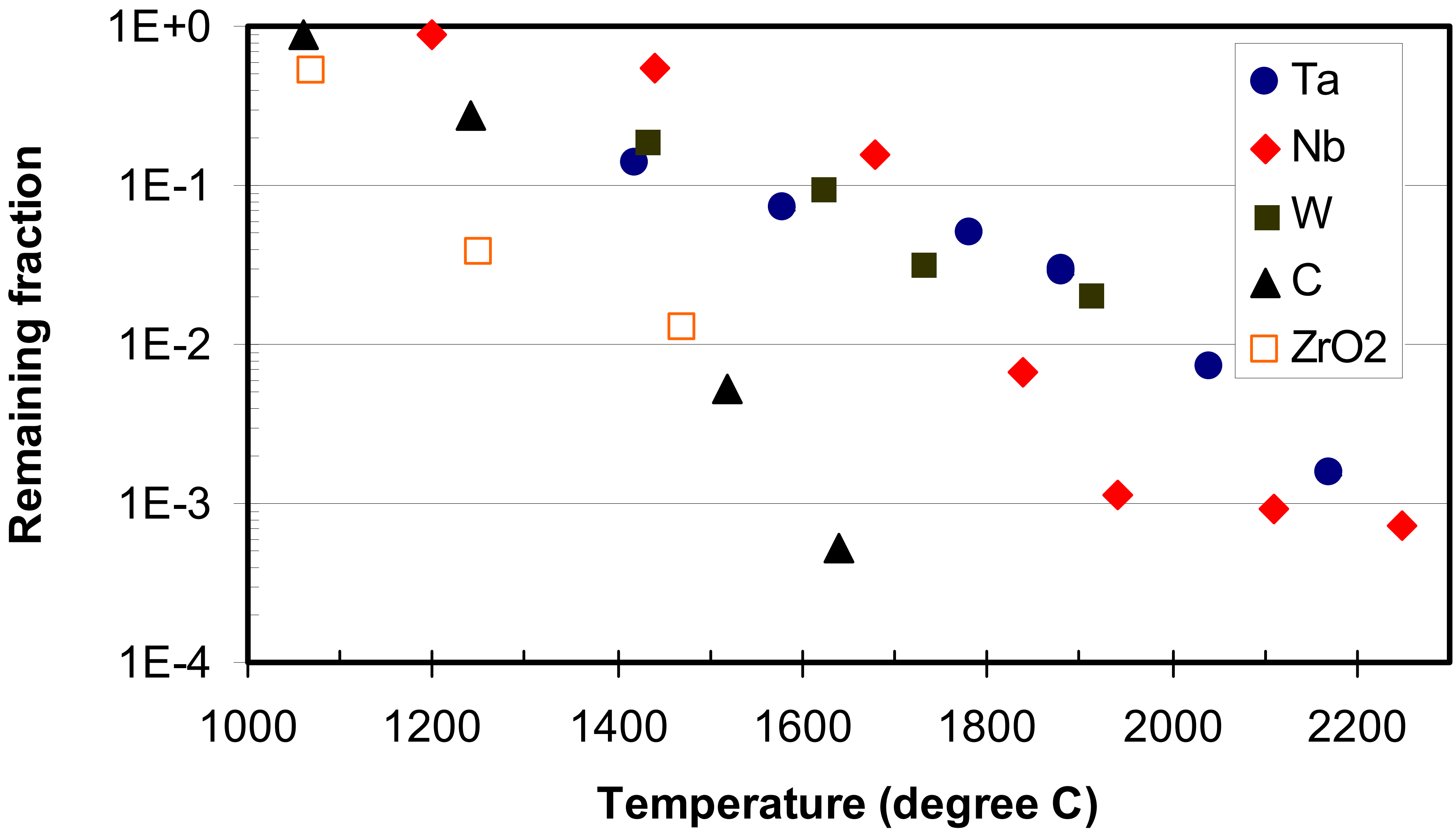
# $^{69}$Ni decay γ-ray spectrum



Ulli Köster

ISOLDE CERN

# Nickel desorption



# Chalcogenes

## Selenium:

**Off-line: oxide target favorable for release of Se**

**On-line: ca. 60% in molecular sideband $SeCO^+$**

## Tellurium:

**little population of molecular sideband $TeCO^+$:**
**(>) 0.7% on-line measured in sideband**

**Clean Te beams required to measure magnetic moments of Coulomb excited $2^+$ states of $^{132,134,136}Te$ (IS415)**

**Produce clean Te beams rather by isothermal chromatography: desorption data measured in TARGISOL-Mainz-Rossendorf experiment presently under evaluation**

# Other metals

RILIS schemes for Co, Y, Sb, Tb, Tm, Yb have been tested off-line (or on-line with non-actinide target).

RILIS schemes for Sr, La, Nd, Sm, Eu, Gd, Ho are known.

On request these elements could be ionized with the RILIS.

Off-line release studies of Fe, Mo, Tc, Ru, Pd and others within TARGISOL (EU-RTD project for the systematic improvement of ISOL targets involving ISOLDE, PSI, GANIL, GSI, LMU Munich and IEM Madrid.)

Ulli Köster

ISOLDE
CERN

# RILIS schemes (for CVL)

elements ionized with ISOLDE RILIS

tested ionization scheme

possible ionization scheme (untested)

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 H | | | | | | | | | | | | | | | | | 2 He |
| 3 Li | 4 Be | | | | | | | | | | | 5 B | 6 C | 7 N | 8 O | 9 F | 10 Ne |
| 11 Na | 12 Mg | | | | | | | | | | | 13 Al | 14 Si | 15 P | 16 S | 17 Cl | 18 Ar |
| 19 K | 20 Ca | 21 Sc | 22 Ti | 23 V | 24 Cr | 25 Mn | 26 Fe | 27 Co | 28 Ni | 29 Cu | 30 Zn | 31 Ga | 32 Ge | 33 As | 34 Se | 35 Br | 36 Kr |
| 37 Rb | 38 Sr | 39 Y | 40 Zr | 41 Nb | 42 Mo | 43 Tc | 44 Ru | 45 Rh | 46 Pd | 47 Ag | 48 Cd | 49 In | 50 Sn | 51 Sb | 52 Te | 53 I | 54 Xe |
| 55 Cs | 56 Ba | 57 La | 72 Hf | 73 Ta | 74 W | 75 Re | 76 Os | 77 Ir | 78 Pt | 79 Au | 80 Hg | 81 Tl | 82 Pb | 83 Bi | 84 Po | 85 At | 86 Rn |
| 87 Fr | 88 Ra | 89 Ac | 104 Rf | 105 Db | 106 Sg | 107 Bh | 108 Hs | 109 Mt | 110 | 111 | 112 | | | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 58 Ce | 59 Pr | 60 Nd | 61 Pm | 62 Sm | 63 Eu | 64 Gd | 65 Tb | 66 Dy | 67 Ho | 68 Er | 69 Tm | 70 Yb | 71 Lu |
| 90 Th | 91 Pa | 92 U | 93 Np | 94 Pu | 95 Am | 96 Cm | 97 Bk | 98 Cf | 99 Es | 100 Fm | 101 Md | 102 No | 103 Lr |

# Two-stage separation of molecular sidebands

Molecular sidebands are often very pure for n-deficient isotopes:

$SrF^+$, $BaF^+$, $YF_2^+$, $AlBr^+$, $SeCO^+$, $GeS^+$, $SnS^+$, $LaO^+$, …

Problems for neutron-rich beams from actinide target:

A. non-monoisotopic carrier (e.g. 4.2% $^{34}S$ and 0.02% $^{36}S$) causes admixture of more abundant lighter isotopes
 $\Rightarrow$ Solution: use enriched isotopes as carrier

B. molecular sidebands end up in region with other background

 $\Rightarrow$ Solution: two-stage separation

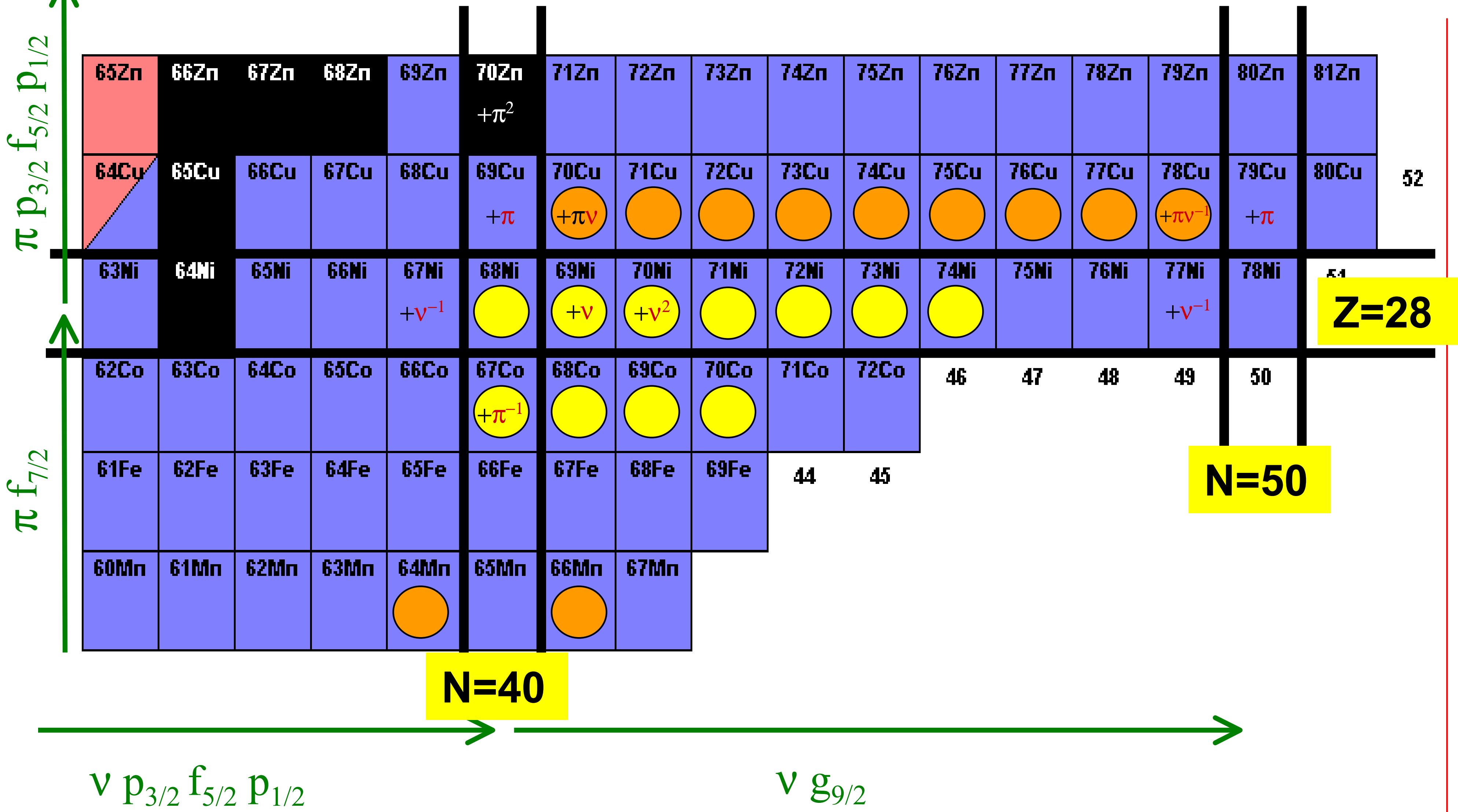
1. use molecular sideband $AX^+$ to separate from “real isobars”
2. break molecule $AX^+ \rightarrow A^+ + X$ (by stripping, charge breeding or in gas cell)
3. perform additional mass-separation to remove “new isobars”

 $\Rightarrow$ Post-accelerator could help decay spectroscopy!

Ulli Köster

ISOLDE CERN

# LISOL and ISOLDE complementary




- (orange) $\beta\gamma$-decay of Mn and Cu at ISOLDE — Phys. Rev. Lett. 82 (1999) 1391 and IS365 to be published
- (yellow) $\beta\gamma$-decay of Co and Ni at LISOL — Phys. Rev. Lett. 81 (1998) 3100 and Phys. Rev. Lett. 83 (1999) 3613