INTERNATIONAL CONFERENCE ON ELECTROMAGNETIC ISOTOPE SEPARATORS AND RELATED TOPICS

EMIS XVIII

CERN GENEVA / SWITZERLAND / 16 - 21 SEPTEMBER 2018

# Molecular beams in the ISOL process


Jochen Ballof[1,2]

B. Crepieux[1], Ch. E. Düllmann[2,3,4], J.P. Ramos[1], S. Rothe[1], C. Seiffert[1,5], T. Stora[1], A. Yakushev[3]

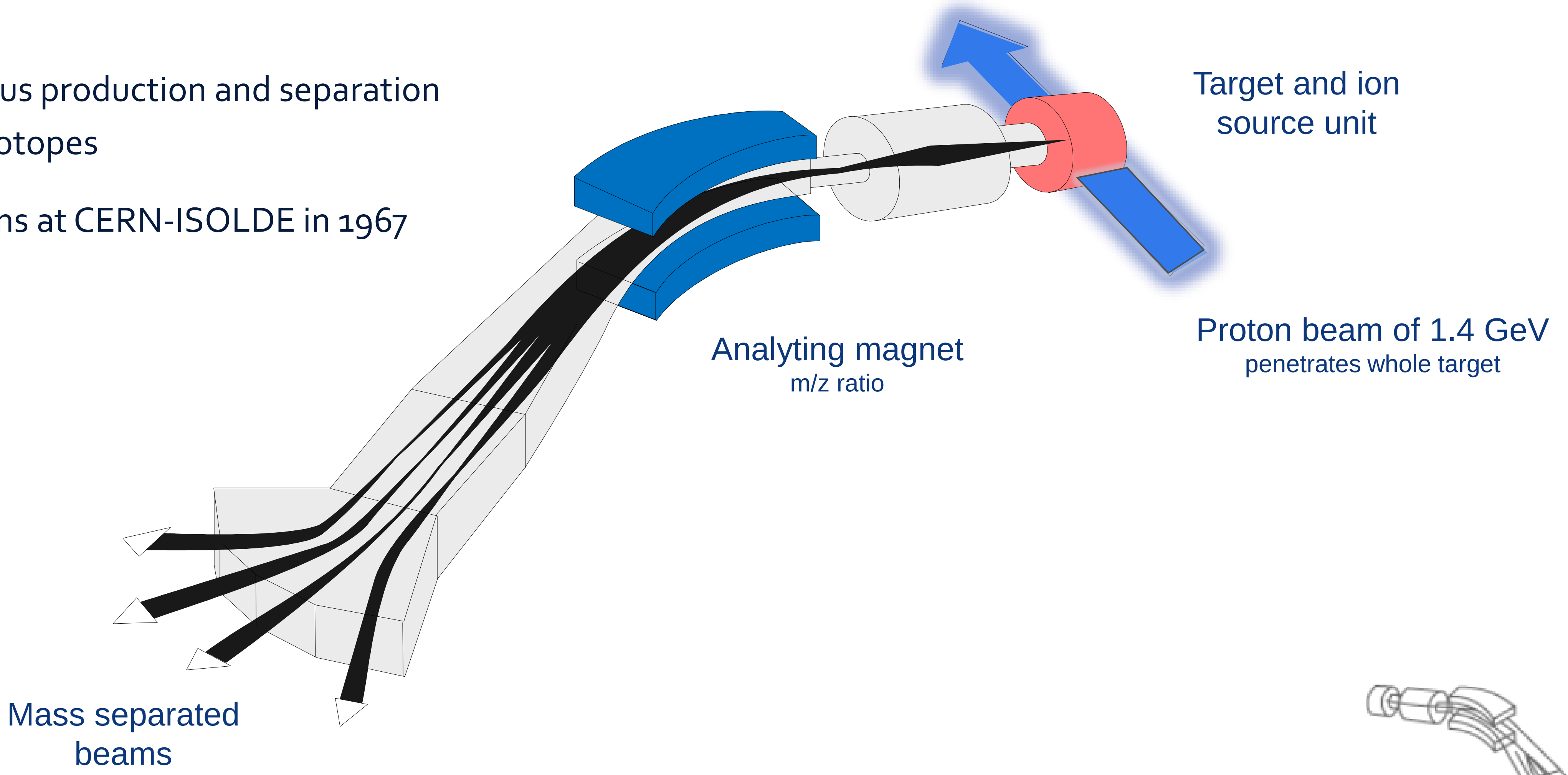
[1] CERN, ISOLDE, Switzerland
[2] Institut für Kernchemie, Johannes-Gutenberg Universität Mainz, Germany
[3] GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany
[4] Helmholtz-Institut Mainz, Germany
[5] Institut für Kernphysik, Technische Universität Darmstadt, Germany


V4

# The ISOL process

**Isotope Separation On Line**

- Simultanius production and separation of radioisotopes
- First beams at CERN-ISOLDE in 1967



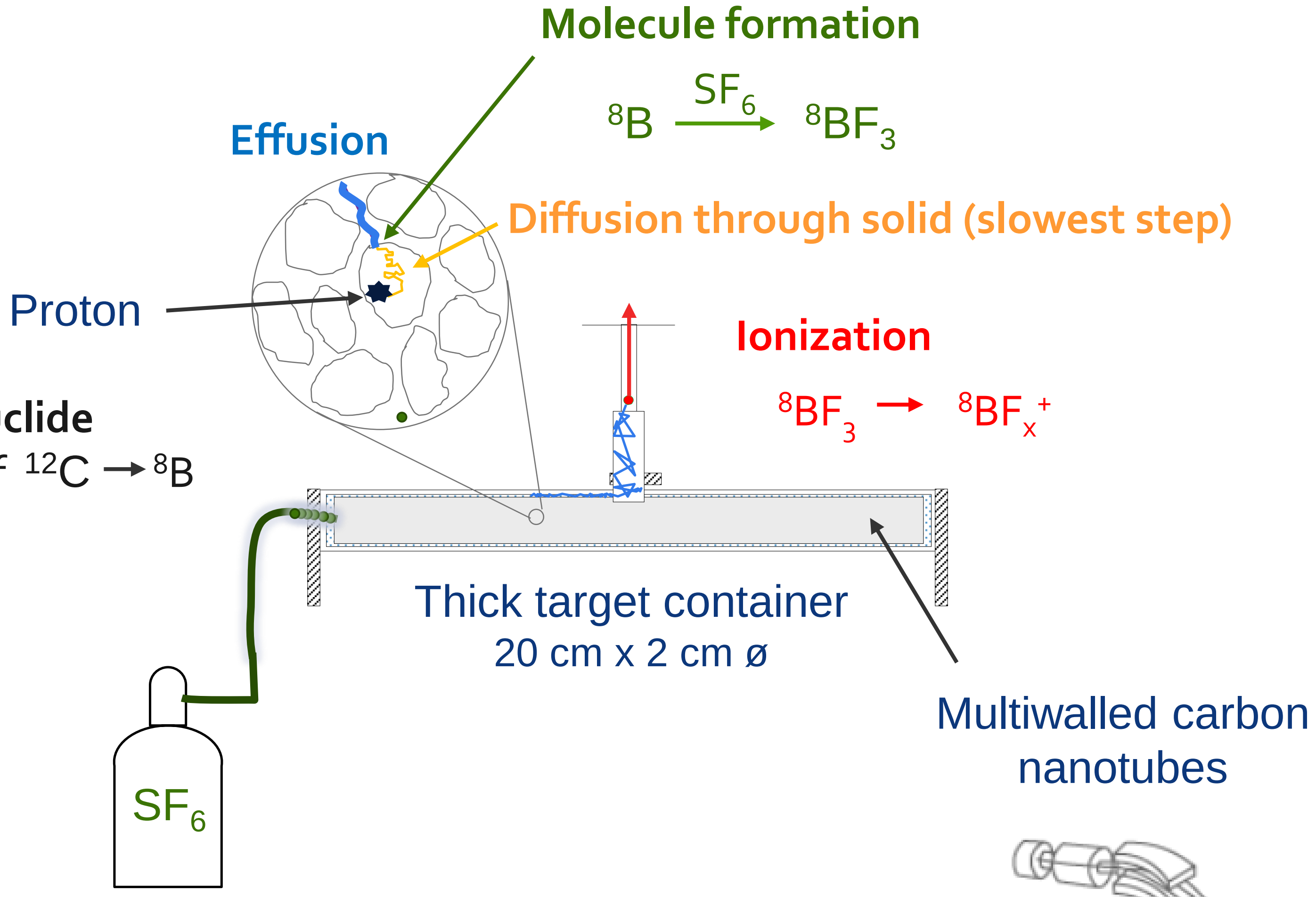
# The ISOL process

**Molecular beam extraction taking the example of $^{8}BF_2$**

- Boron is refractory and reactive
- Can't be extracted as atom -> more volatile molecule needed

**Production of nuclide**
Fragmentation of $^{12}C \rightarrow {}^{8}B$

Yield = $N_0 \times \varepsilon_{release}(T_{1/2}) \times \varepsilon_{form} \times \varepsilon_{ion} \times \varepsilon_{other}$



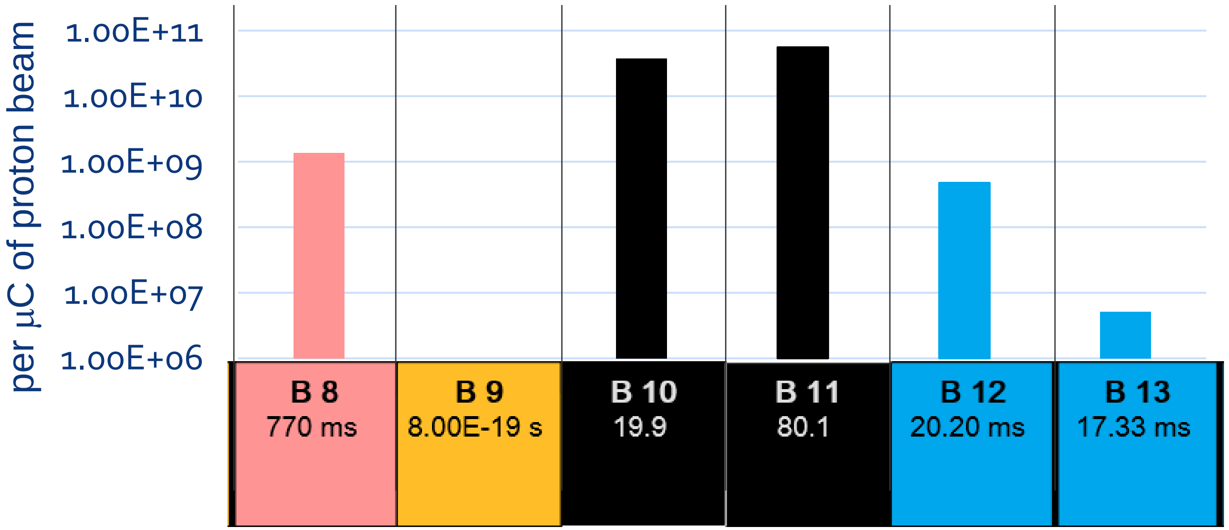
# Boron beams

Boron isotopes

in-target production from multiwalled carbon nanotubes by 1.4 GeV protons

FLUKA / ABRABLA

Yield = $N_0 \times \varepsilon_{release}\,(T_{1/2}) \times \varepsilon_{form} \times \varepsilon_{ion} \times \varepsilon_{other}$




ISOLDE:
typical. max. intensity:
2 µA

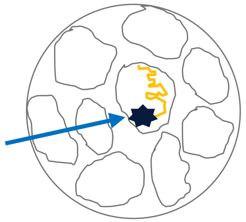
Simulations:
Joao-Pedro Ramos, Christoph Seiffert

# Boron beams

Release Efficiency: Fraction of isotopes not decayed before release

Yield = $N_0 \times \varepsilon_{release}\ (T_{1/2}) \times \varepsilon_{form} \times \varepsilon_{ion} \times \varepsilon_{other}$

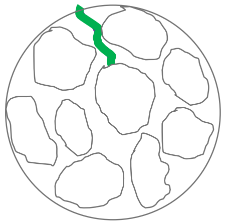
1. Diffusion in the solid



- Slow process
- Was investigated in offline experiments
- Long heat treatment times necessary ~ 30 min
- Simple model: Fick's 2nd law

➡ **Characteristic diffusion time** $\tau_D$ = 862 *s*

2. Effusion through open space

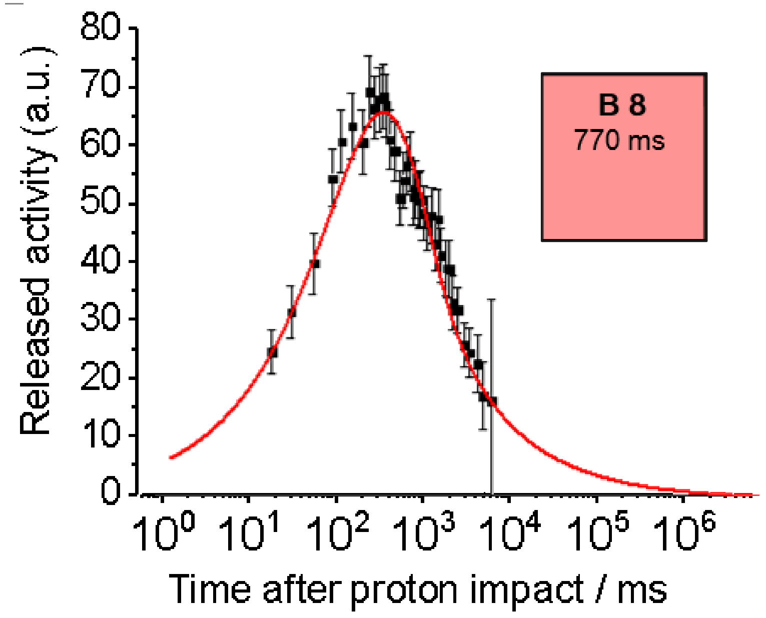


- Fast process
- Best investigated online

➡ **Effusion time constant** $t_{eff}$ = 339 *ms*

Offline mobility studies: Christoph Seiffert

Online release curve fitted with release model measured on $^{8}B$ and corrected for decay




Model for release of a stable isotope:

$$p(t) = \frac{1}{A_K} \sum_{m=1}^{\infty} \frac{e^{-c_m t/\tau_D} - e^{-t/t_{eff}}}{\tau_D - c_m t_{eff}}$$

with $c_m = (j_{0,m}/\pi)^2$, $j_{0,m}$ $m^{th}$ positive root of Bessel function of order 0, $A_K$ normalization constant

# Boron beams

Release Efficiency

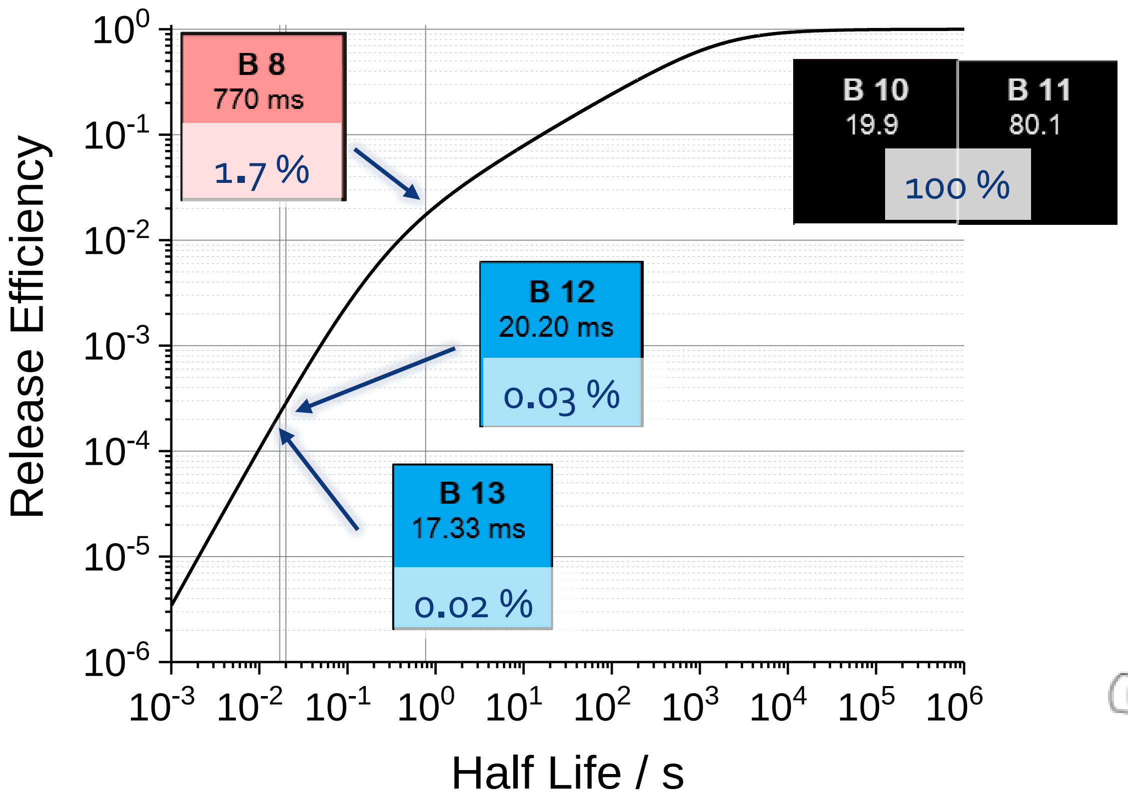
Yield = $N_0 \times \varepsilon_{release}(T_{1/2}) \times \varepsilon_{form} \times \varepsilon_{ion} \times \varepsilon_{other}$

Release efficiency can be obtained from release curve:

$$\varepsilon_{release}(T_{1/2}) = \int_0^\infty p(t)\, e^{-\ln(2)\, t/T_{1/2}}\, dt$$

Function holds for all isotopes of the same chemical elements.

➡ Allows prediction of yields for more exotic isotopes $^{12}B$, $^{13}B$




EMIS XVIII

# Boron beams

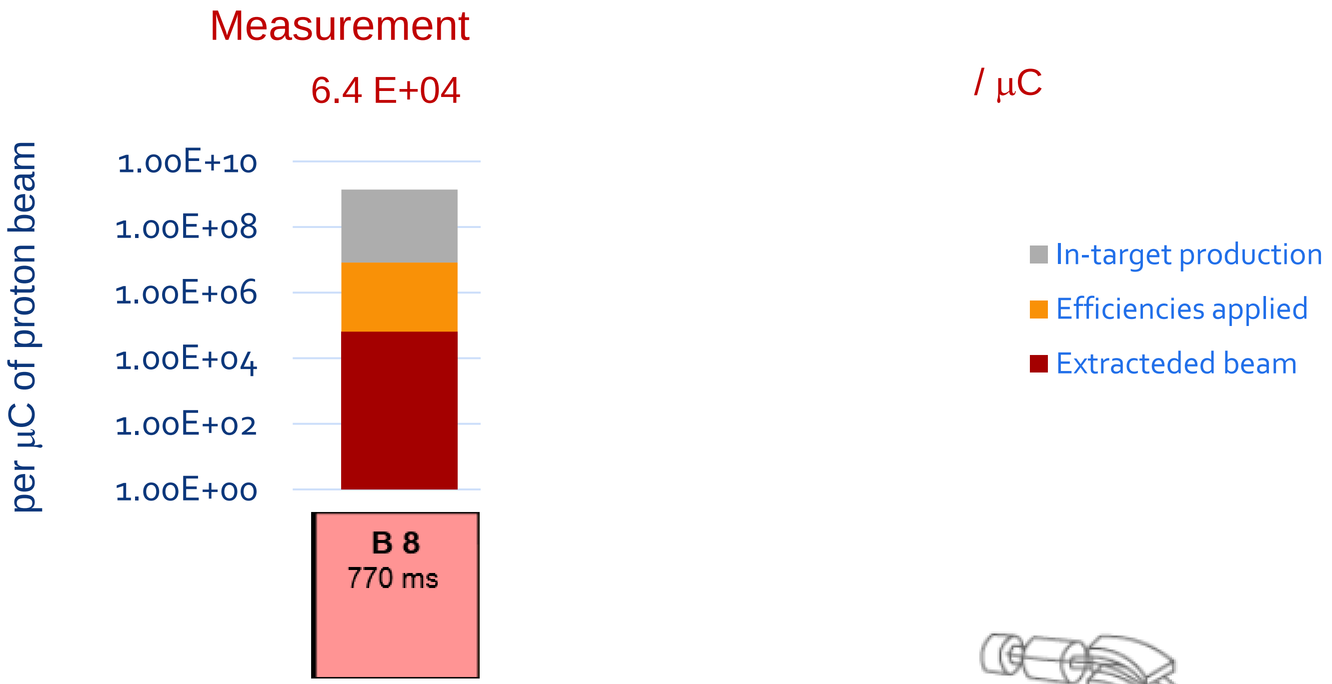
Putting it all together

Yield = $N_0 \times \varepsilon_{release}(T_{1/2}) \times \varepsilon_{form} \times \varepsilon_{ion} \times \varepsilon_{other}$

- Other efficiencies are typically assumed to be independent of the half life
- Can be calculated, if …
  - the **yield** of one isotope was measured
  - $N_0$ is known from simulations
  - $\varepsilon_{release}(T_{1/2})$ was calculated
- Or measured offline

Measured yield on $^{8}BF_2$: $6.4 \times 10^4$ / μC

➡ $\varepsilon_{form} \times \varepsilon_{ion} \times \varepsilon_{other} = 0.6$ %




*J. Ballof, C. Seiffert et. al, submitted to EPJA (2018)*

# Boron beams

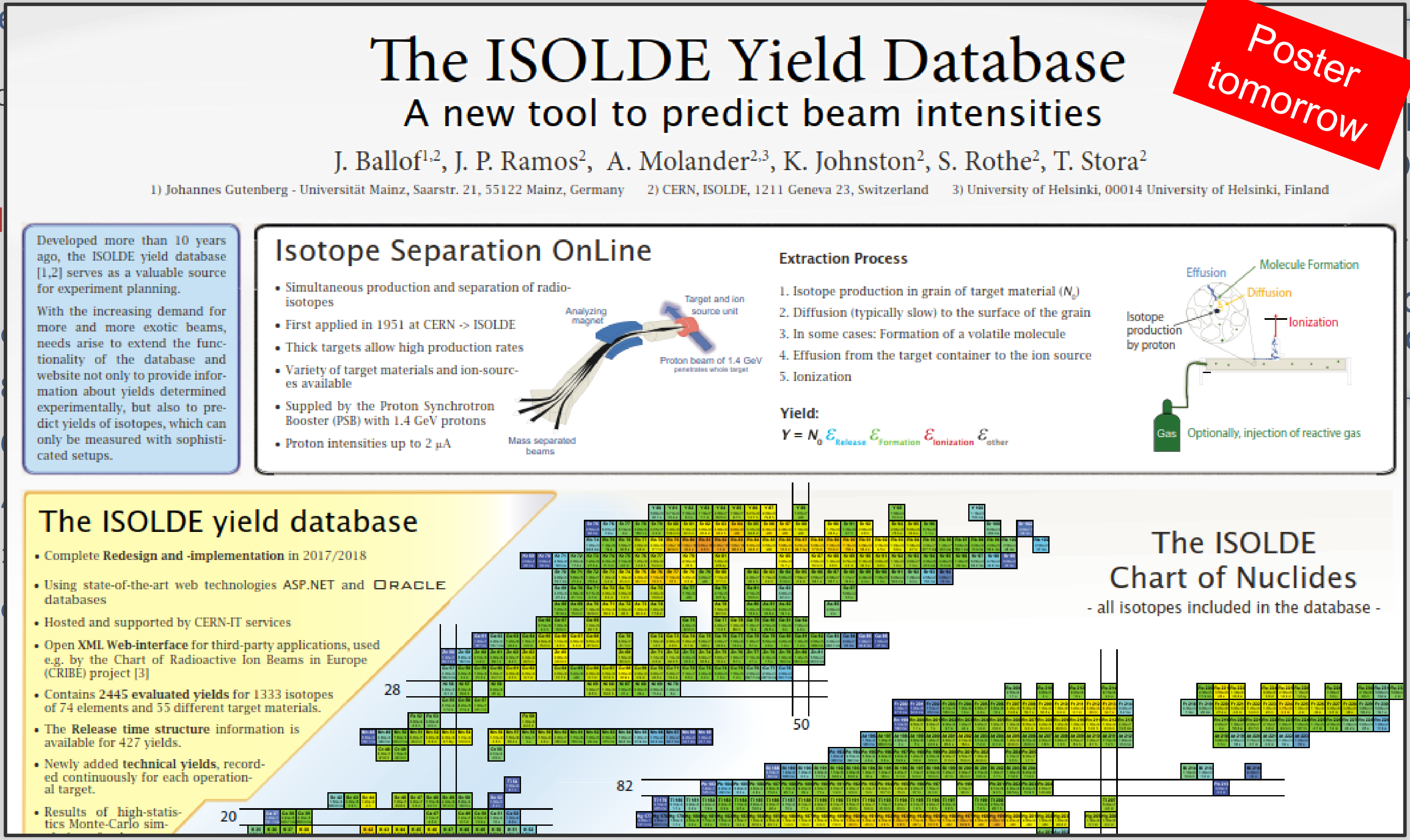
Testing the

Yield = N$_0$

M

per μC of proton beam

1.00E+1
1.00E+0
1.00E+0
1.00E+0
1.00E+0
1.00E+0




Poster tomorrow

Preliminary

LDE
S)
C
García Borge,
GISOL)



EMIS XVIII

# More molecular beams - Posters

Today!

**Prospects for the production of $^{100}Sn$ ISOL beams at HIE-ISOLDE**

F. Boix Pamies, R. Catherall, S. Malbrunot, G. Neyens, J.P. Ramos, S. Rothe, T. Stora
CERN, CH-1211 Geneva 23, Switzerland


➡ Extraction as $SnCl_x$

Tomorrow

**Infrastructure for the Production and Development of Targ... CERN-ISOLDE**

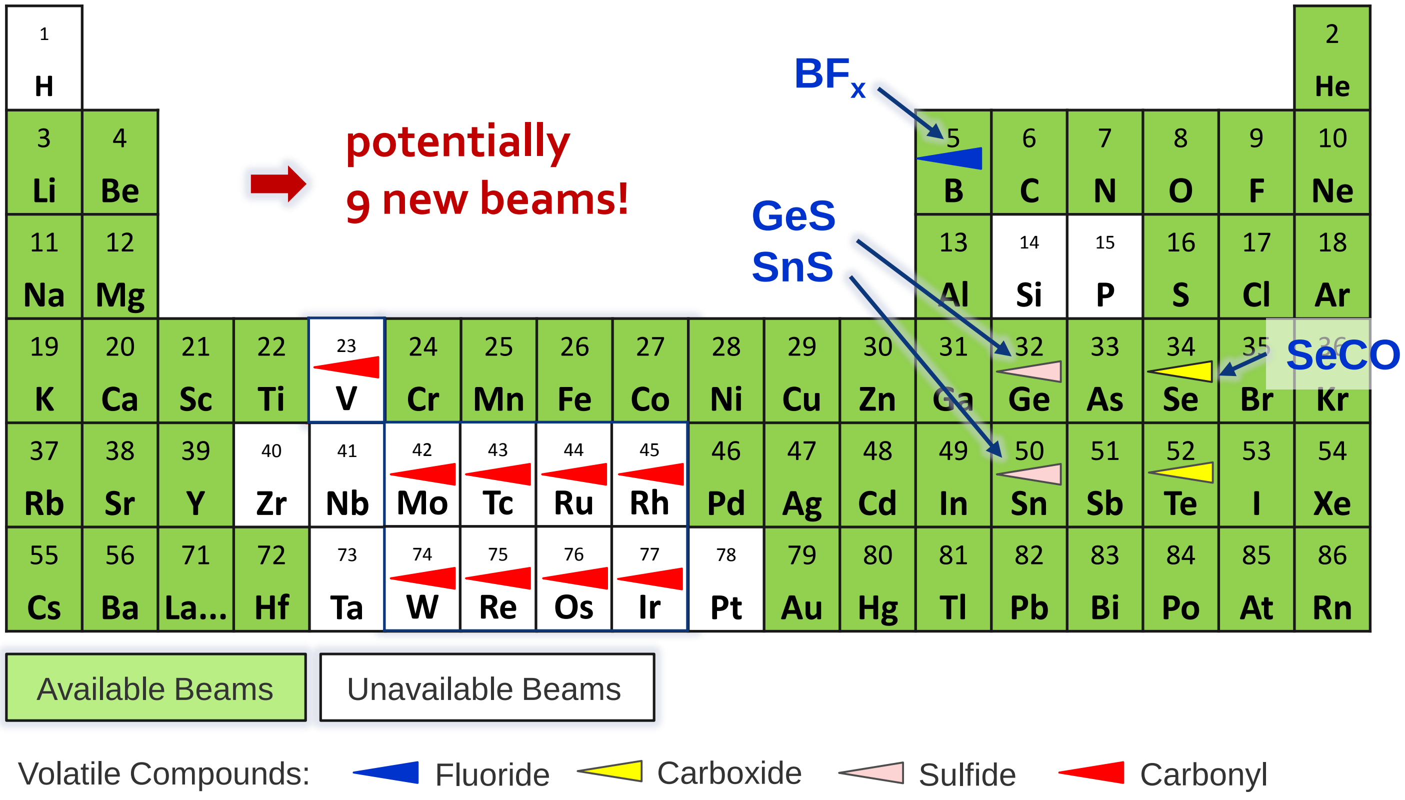
Sebastian Rothe[1], Jochen Ballof[1,3], Ermanno Barbero[1], Ferran Boix Pamies[1], Richard Catherall[1], Katerina Chrysalidis[1,2], Bernard Crepieux[1], Kevin Develle[1], Paul Harwood[1], Reinhard Heinke[2], David Leimbach[1,2], Annie Ringvall-Moberg[1,4], Bruce Marsh[1], Michael Owen[1], João Pedro Ramos[1], Ralf Erik Rossel[1], Thierry Stora[1], Andres Suarez[1], Nhat-Tan Vuong[1,5], Shane Wilkins[1]

[1]CERN, Geneva, Switzerland
[2]Institut für Physik, Johannes Gutenberg-Universität, Mainz, Germany
[3]Institut für Kernchemie, Johannes Gutenberg-Universität, Mainz, Germany
[4]Department of Physics, Gothenburg University, Gothenburg, Sweden
[5]Doctoral School of Chemistry and Chemical Engineering, EPFL, Lausanne, Switzerland

EN Engineering Department

# Refractory Metal Carbonyl beams

## Un(available) beams at ISOLDE and selected sidebands

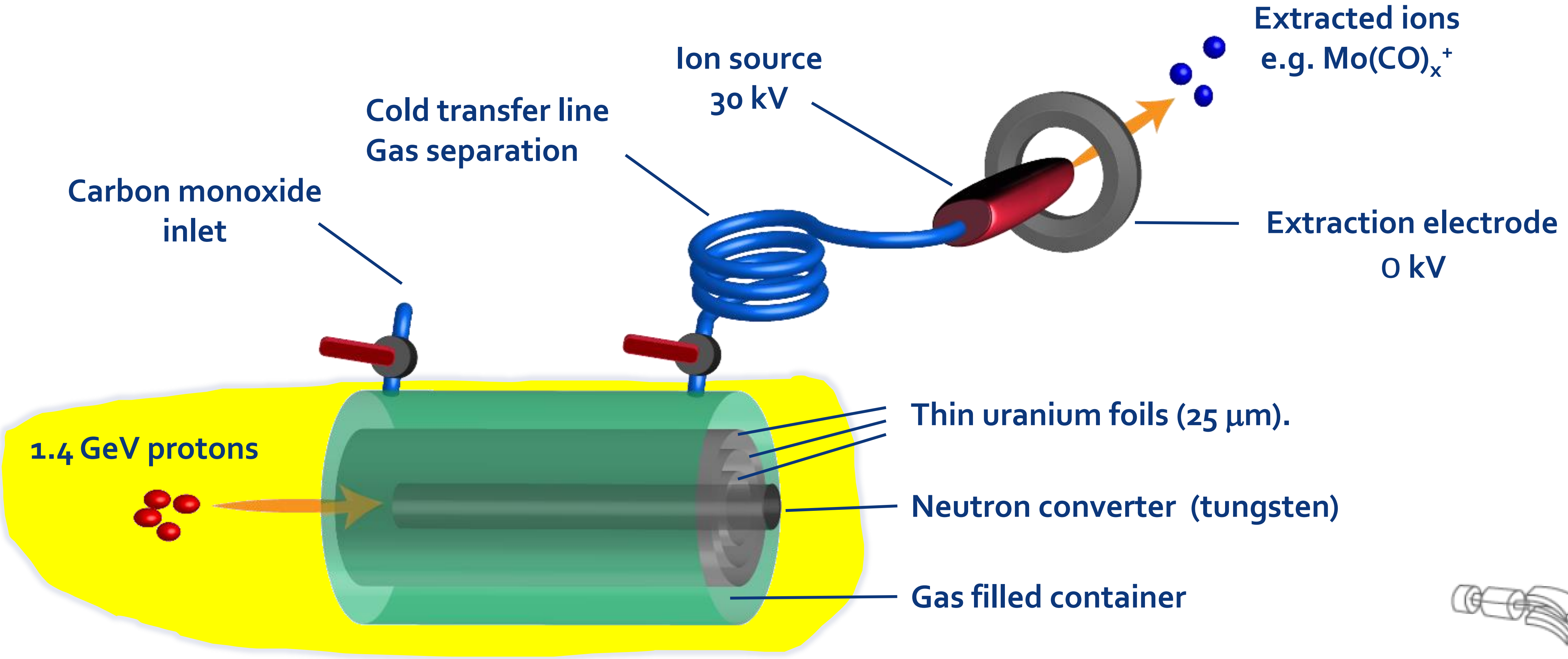





EMIS XVIII

# Refractory Metal Carbonyl beams

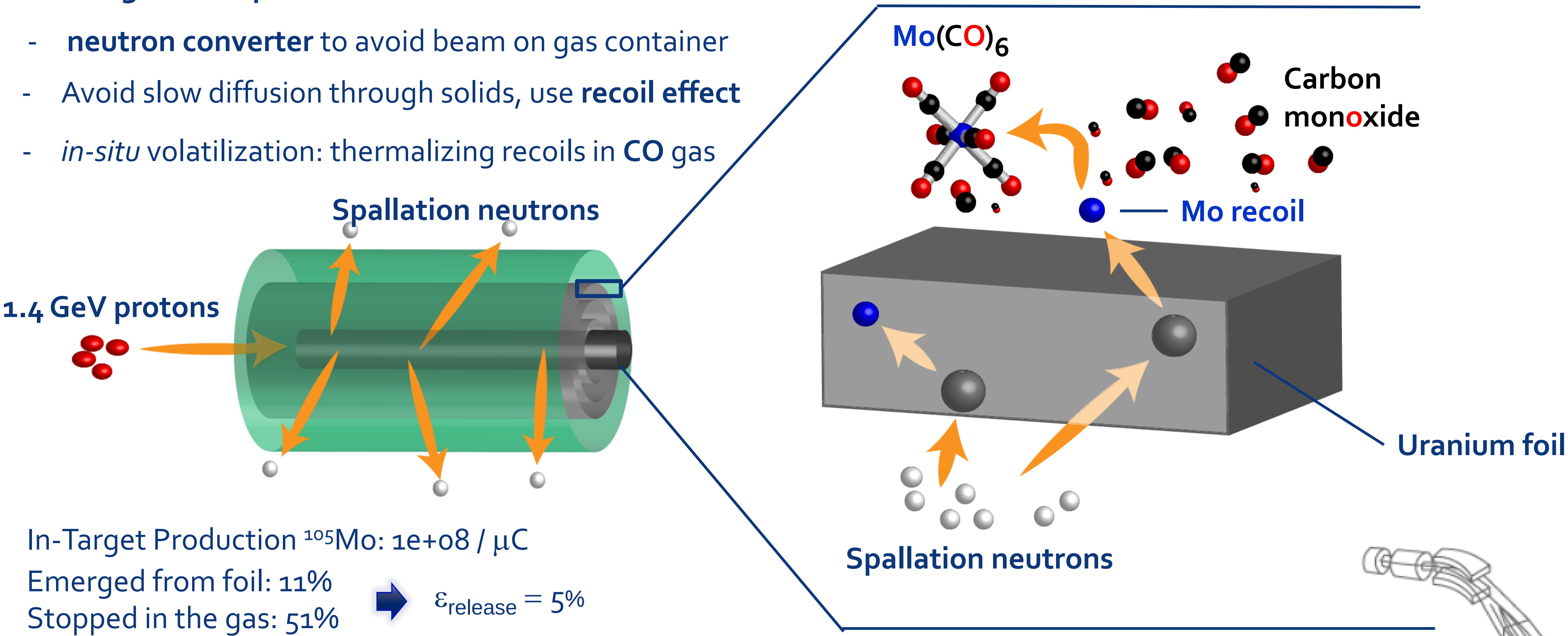
The target concept



# Refractory Metal Carbonyl beams

**The target concept**

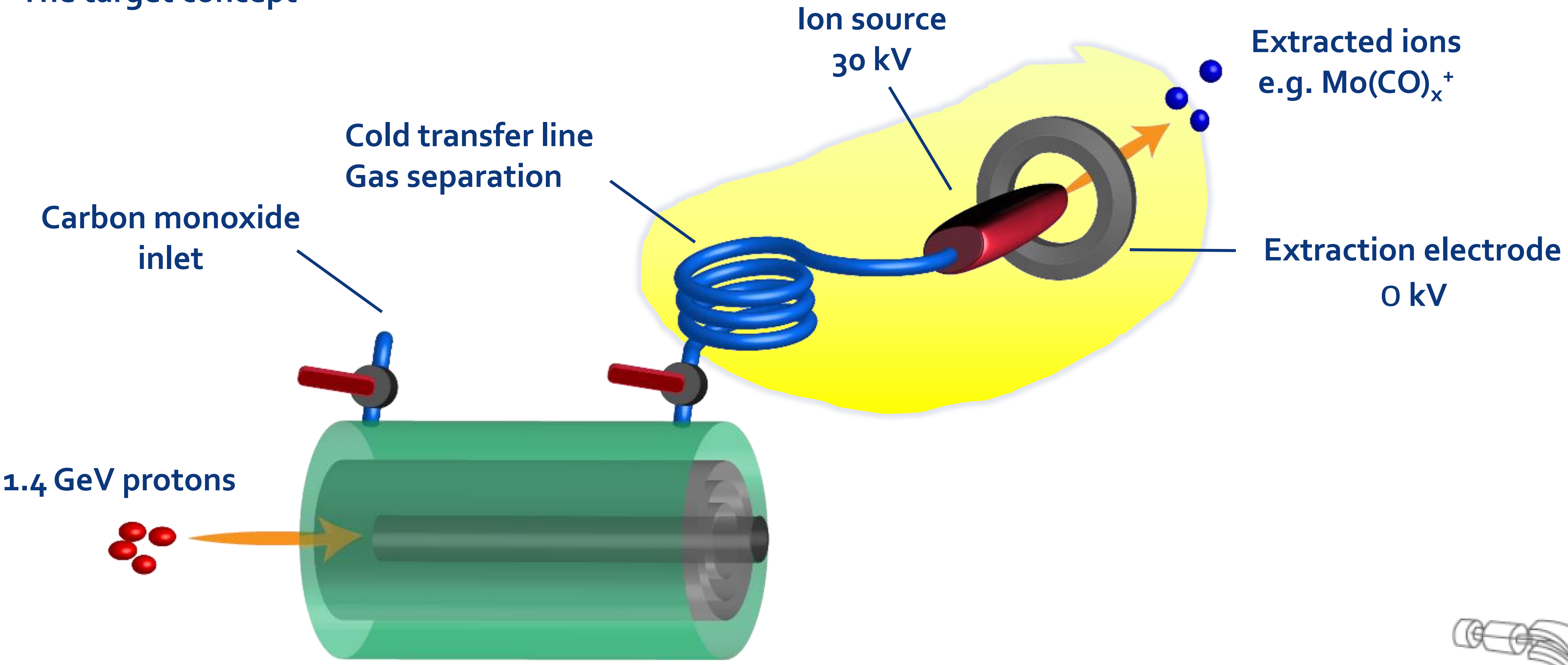
- **neutron converter** to avoid beam on gas container
- Avoid slow diffusion through solids, use **recoil effect**
- *in-situ* volatilization: thermalizing recoils in **CO** gas




In-Target Production $^{105}$Mo: 1e+08 / μC
Emerged from foil: 11%
Stopped in the gas: 51% ➡ $\varepsilon_{release} = 5\%$

# Refractory Metal Carbonyl beams

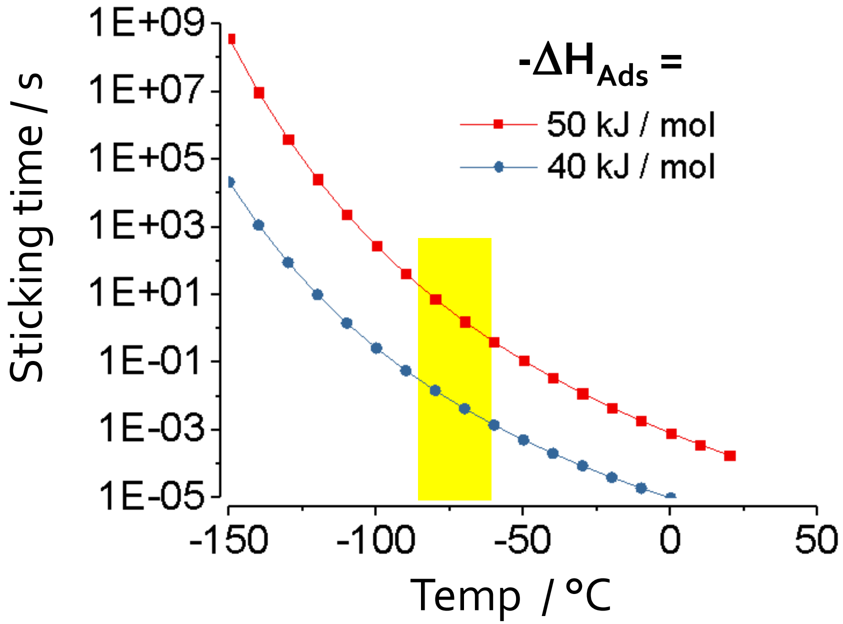
The target concept



# Refractory Metal Carbonyl beams

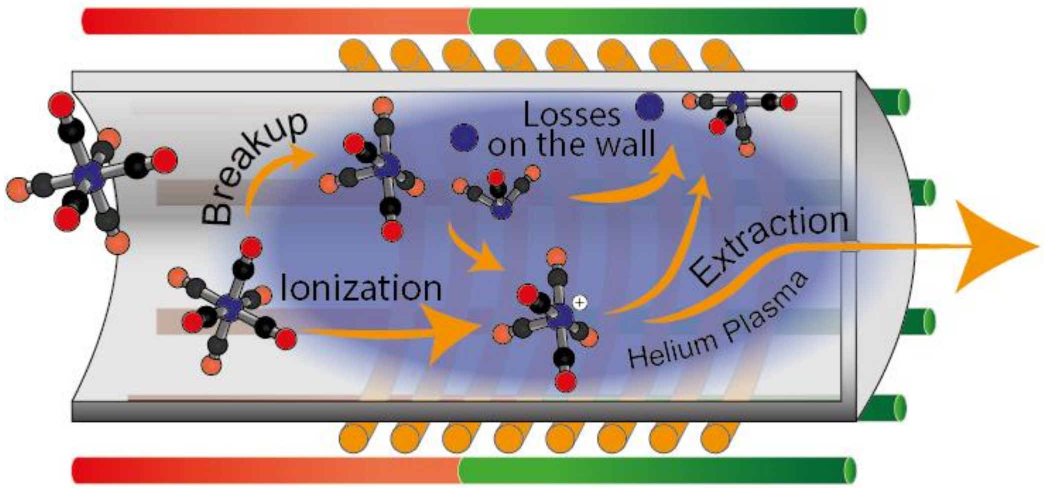
## Gas separation

- $Mo(CO)_6$ retained on cooling trap while gas is pumped
- Adsorption enthalpies on quartz surfaces known
  *-> Even et. al, Radiochim. Acta 2014*
- Similar set up for gas separation tested
  *-> Katagiri et. al, Rev. Sci. Instr. 2014*




## Ionization

- Ion sources should be cold, $Mo(CO)_6$ decomposes easily
- Ionization tested with RF-Sources (HELICON, COMIC) and FEBIAD type sources
- Ionization feasible, but efficiency (so far) too low for radioactive beams.



# Summary

## First boron beams from thick ISOL targets

| B 8 | B 12 | B 13 |
|---|---|---|
| 770 ms | 20.20 ms | 17.33 ms |

- Measurement of yield and release properties for $^{8}BF_2$ (4.6 e+04 / µC)
- Prediction of the extraction of exotic $^{12}B$ and $^{13}B$

## History

- 2015: First successful prototype
- 2016: HIE-ISOLDE Tests
- 2017: First low energy beam to users
- 2018: First accelerated beam to users

## Concept for the extraction of the most refractory metals

| | | | |
|---|---|---|---|
| Mo | Tc | Ru | Rh |
| W | Re | Os | Ir |

- Extraction from target foils by fission recoil effect
- *in-situ* volatilization by carbonyl formation
- cryogenic gas separation
- Ionization in ECR or Laser-based ion source

## Outlook

- Irradiation experiments planned to study carbonyl formation and survival at ISOLDE
- Investigation of ECR ion-sources

# Thanks for your attention!

Special thanks to

Ermanno Barbero, Vincent Barozier, Ana-Paula Bernardes, Ferran Boix Pamies, Richard Catherall, James Cruikshank, Melanie Delonca, Katerina Chrysalidis, Maria Garcia Borge, Paul Harwood, Karl Johnston, David Leimbach, Razvan Lica, Miguel Madurga Flores, Bruce Marsh, Tania Mendonca, Michael Owen, Yisel Martinez Palenzuela, Julien Riegert , Andres Suarez, Olof Tengblad, Miranda Van Stenis, Andree Welker and Shane Wilkins