Volatile carbonyl compounds for new radioactive ion beams at ISOLDE

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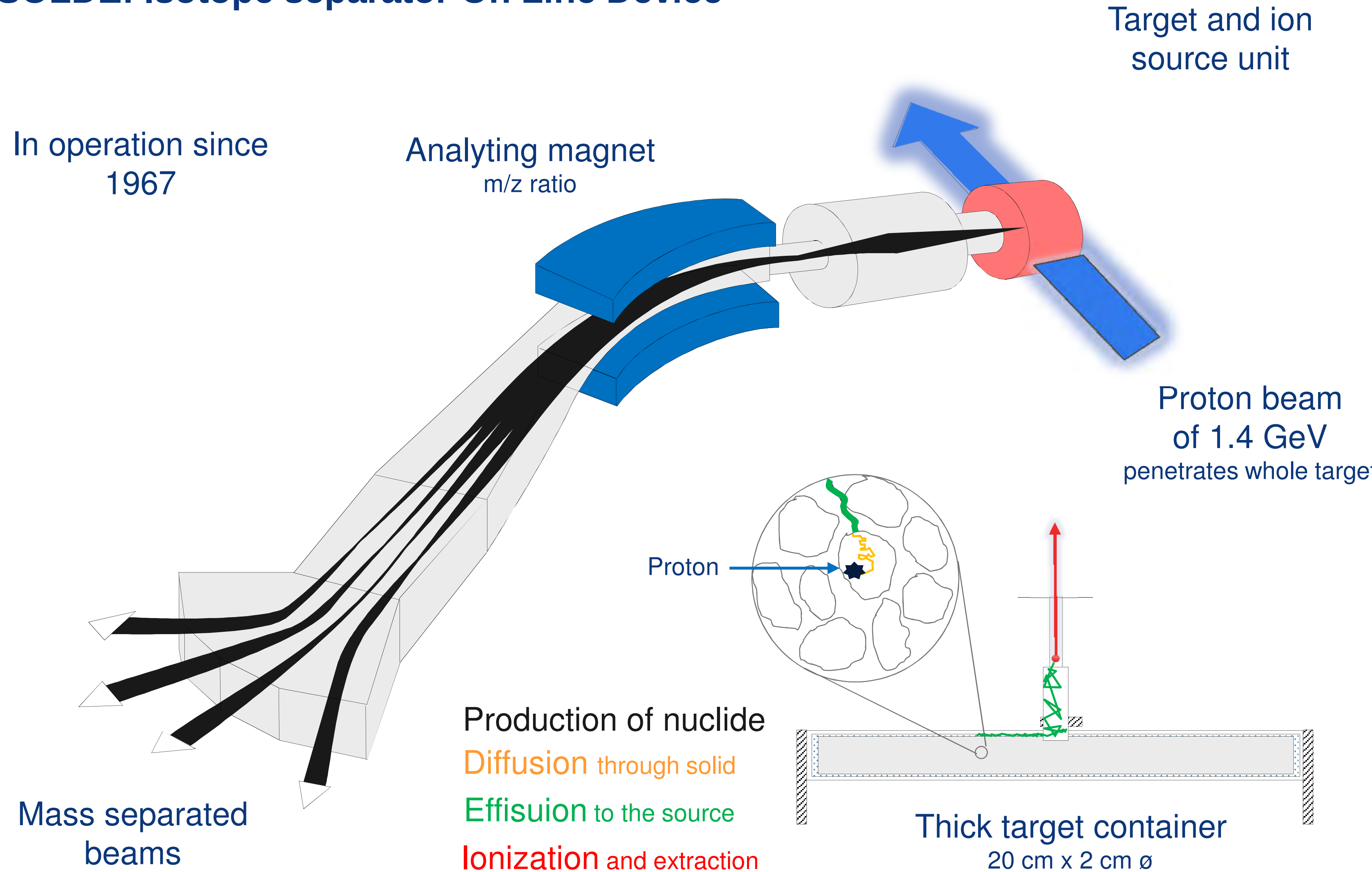
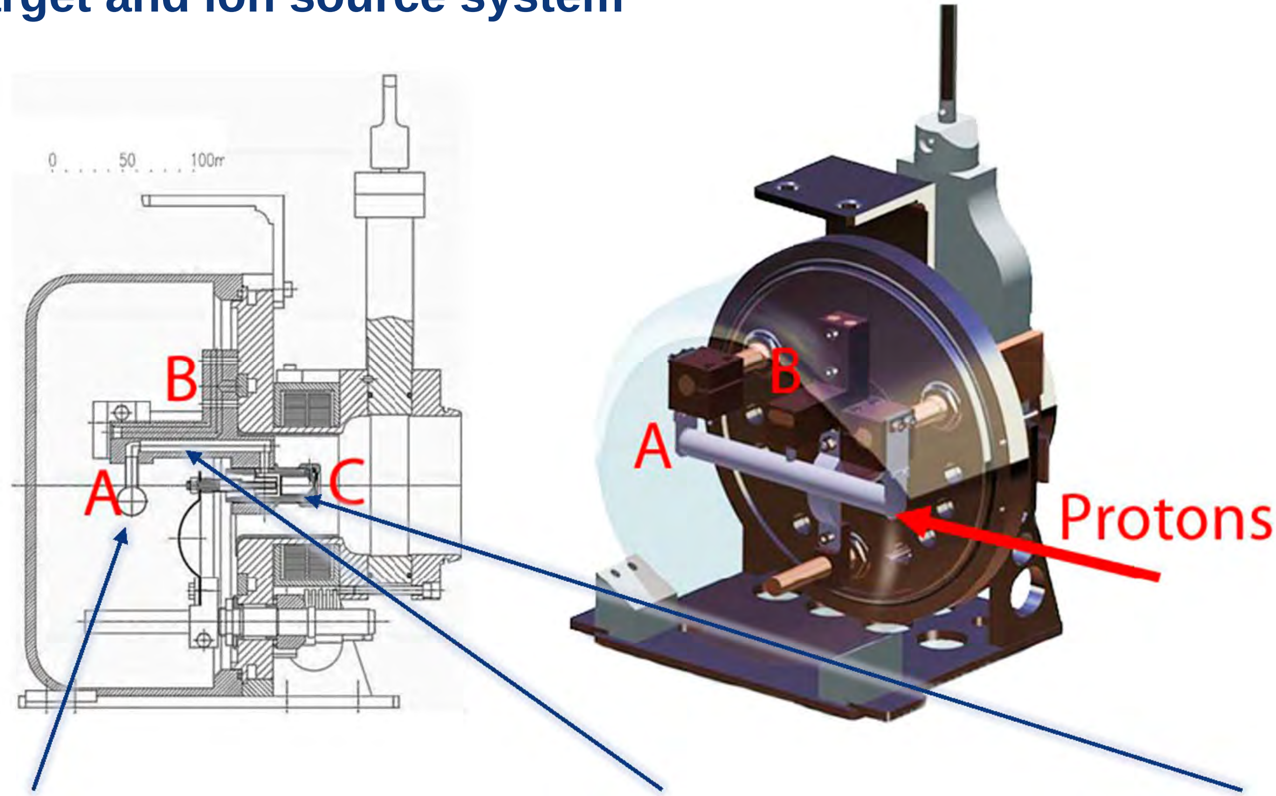
ISOLDE

- Targets -

ISOLDE: Isotope separator On Line Device



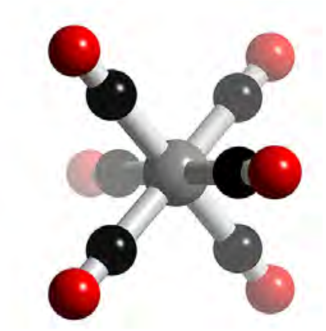
The ISOLDE target and ion source system



Target container (A)	Transfer line (B)	Ion source (C)
Typically heated ~2000 °C	Controls transport to ion source	Surface source
Pressed powders: UC_2	Usually hot 2000 °C, but also:	VADIS hot / cold
Foils: Nb, Ta, Ti, ….	Water cooled (copper)	RF heated
Molten metal or salt	Quartz line – cold / hot	Laser

Carbonyl beams

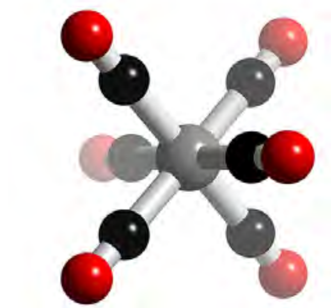
- Concepts -



Un(available) beams at ISOLDE

Principle: Mo $\xrightarrow{CO\ (g)}$ $Mo(CO)_6$

b.p. 4369 °C — volatile!



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	71 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

Available Beams

Unavailable beams

Forms Carbonyl

Carbonyle compounds
$V(CO)_6$
$Cr(CO)_6$
$Mo(CO)_6$
$W(CO)_6$
$Tc_2(CO)_{10}$
$Re_2(CO)_{10}$
$Ru(CO)_5$
$Os(CO)_5$
$Co_2(CO)_8$
$Rh_2(CO)_8$
$Ir_4(CO)_{10}$
$Ni(CO)_4$

Challenges for carbonyl beam extraction

Thermal stability

- Decomposition at ~200 °C
- Diffusion inside the target material slow at low temperatures

⟹ Common powder targets not suitable

Radiation stability

- Proton beam causes plasma inside target container
- Decomposition of molecules in plasma is expected

⟹ No direct irradiation with protons possible

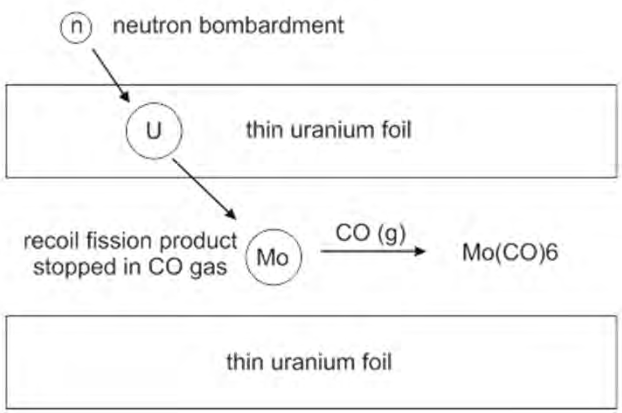
Pressure gradient

- High CO pressure in target container is favorable
- Ion source only accepts low pressure

Target design

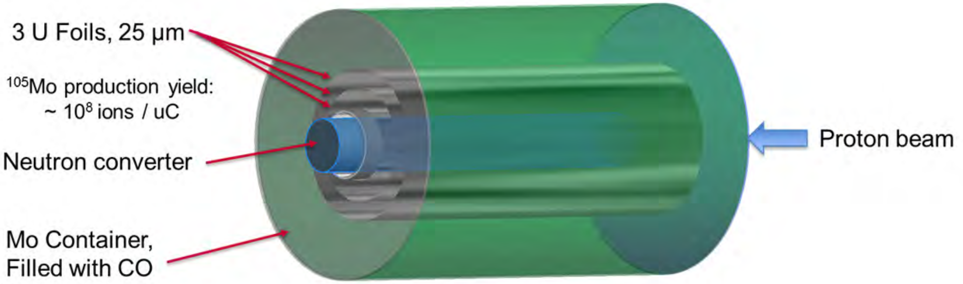
Diffusion and Effusion for refractory elements to slow.

➡ use fission recoil effect

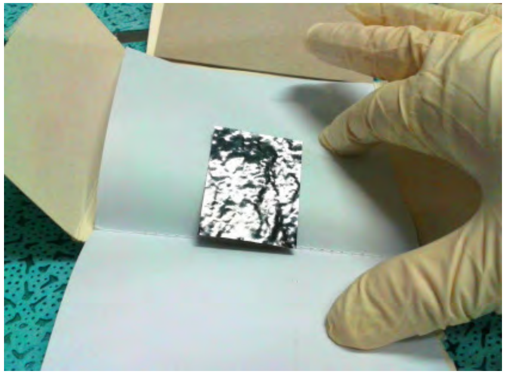


Protons induce plasma and destroy compounds

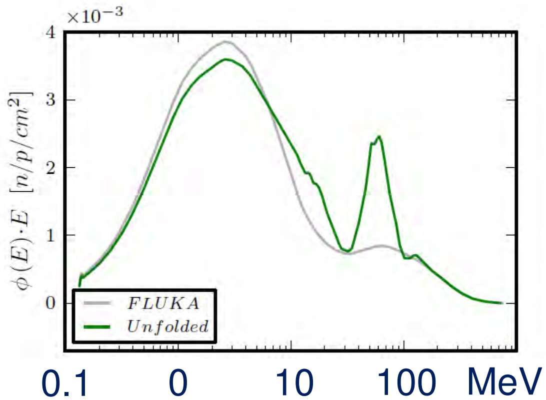
➡ use neutrons



Uranium foil



Neutron energy spectrum

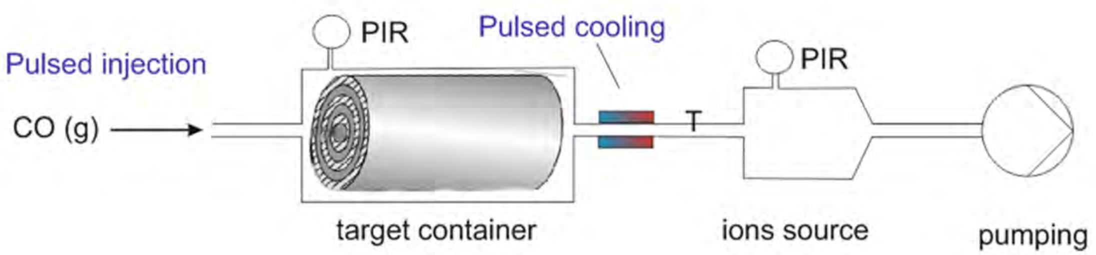


Stora et. al, EPL, 98 (2012) 32001

Gas separation

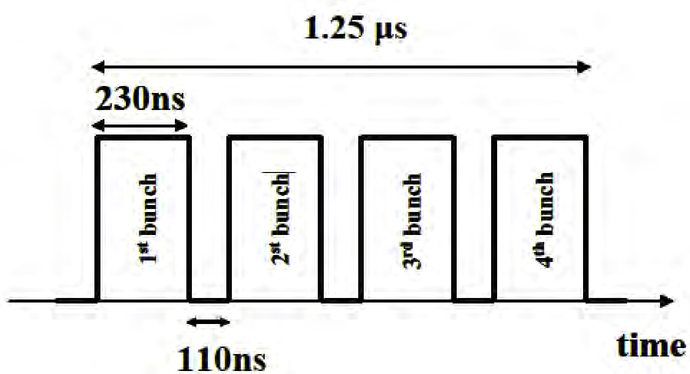
Stopping of fission recoils in gas needs pressures in the order of bars
Ion sources operate in the region of 10e-3 mbar or less

- Option 1: Removal of excess gas (cryogenic gas separation)
  "Batch mode"



see e.g. Katagiri *et al.* Rev. Sci. Instrum. **86**, 123303 (2015)

- Option 2: Pulsed injection



PSB pulse structure

Protons are delivered by the
Proton Synchrotron Booster (PSB)

Higher pressure is only needed for 1.25 µs every ~3 seconds.

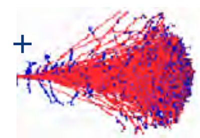
Project overview

New set of technologies needs to be developed

Carbonyl production

FLUKA
- Production cross sections
- Heat deposition
- Dose rates

SRIM + MCS



- Propagation through foil
- Stopping in gas

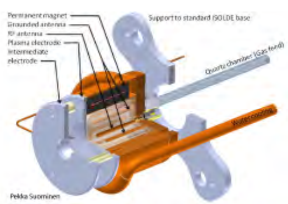
MEDICIS
Irradiation experiment

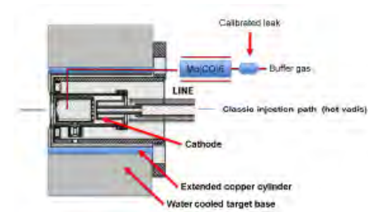
- Carbonyl production
- and survival at ISOLDE
(planned)

Adsorption MC (Zvara)
Gas flow calculations

Gas separation

COMIC
(tested)



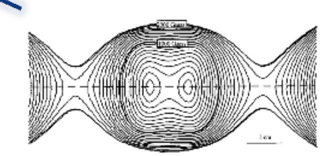


VADIS
(tested)

Ionization

Laser breakup
(tested)

HELICON
(tests ongoing)



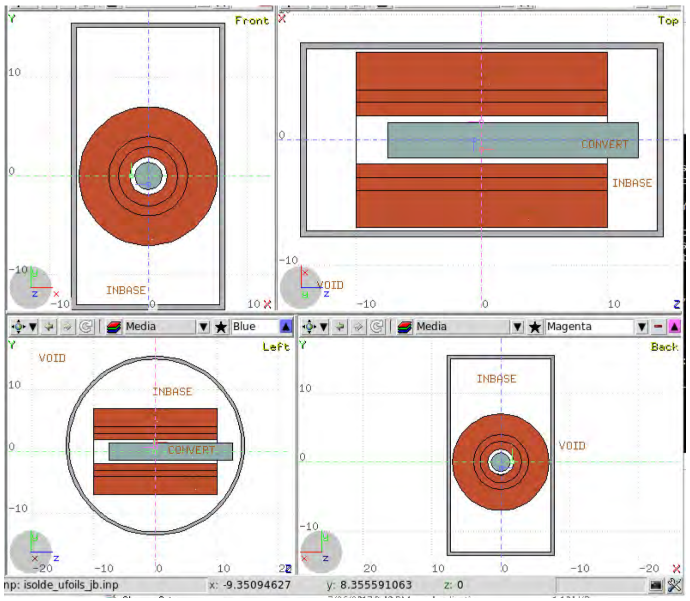
MINIMONO
(planned)

Carbonyl beams

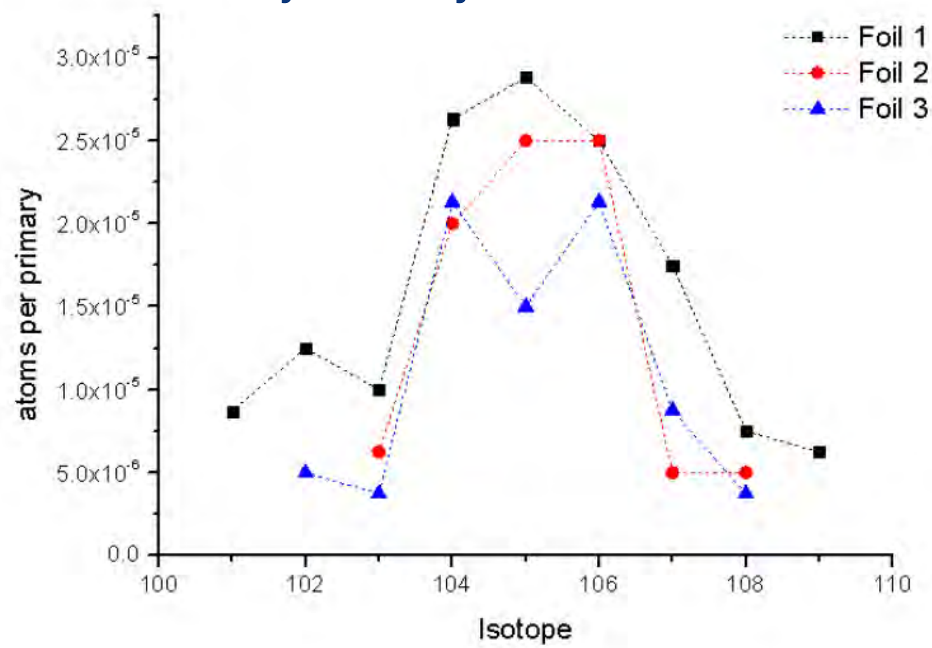
- Production -

Carbonyl Production   1. In-Target production

Geometry



Molybdenum yields



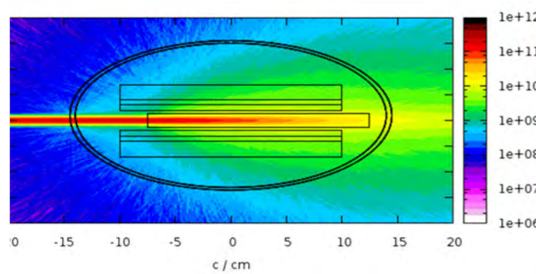
Parameters used:

- gas container 140 mm
- 3 concentric 25 µm depleted uranium foils (d= 38, 60, 80 mm)
- tungsten neutron converter 28 mm

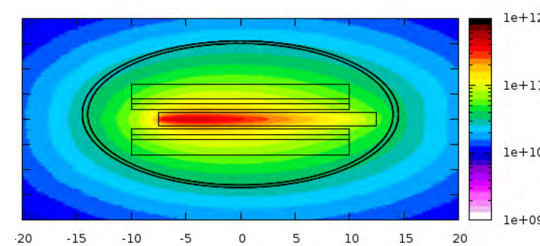
Results:

- ca. 10^8 atoms ^{105}Mo / µC of protons
- proton current typical 1 – 2 µA

Proton fluence /cm2 /uC

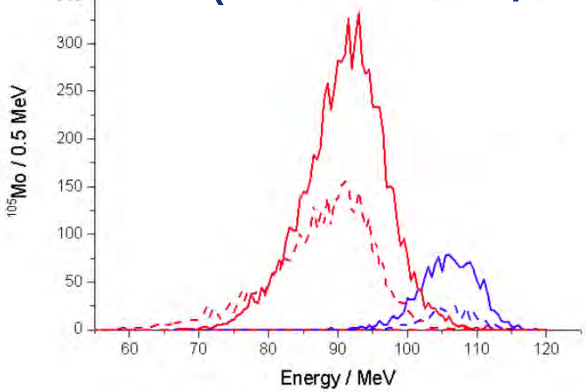


Neutron fluence /cm2 /uC



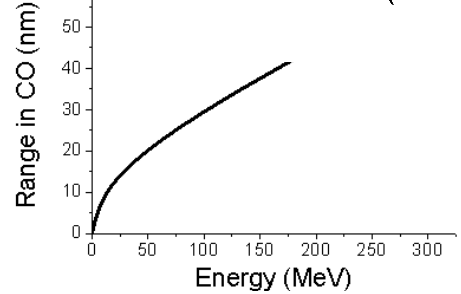
Carbonyl Production 2. Stopping of the recoils

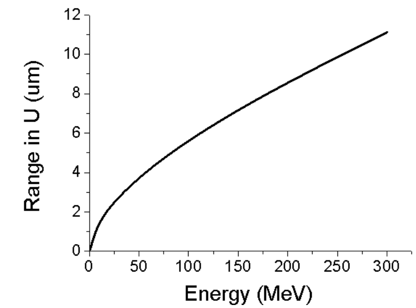
Fission – Recoil energy of Mo fragment: ca. 90 MeV (ABRABLA Code)



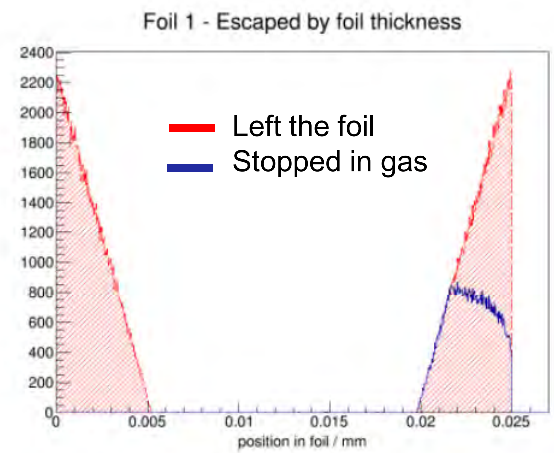
SRIM: Fitted Range in CO and U foil:

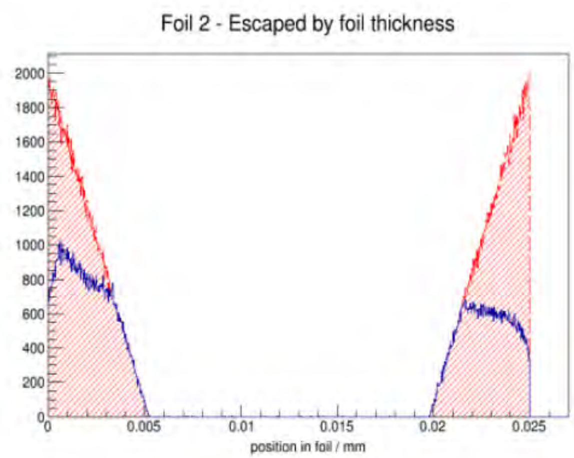
Range of ^{105}Mo fission recoil in ^{238}U foil is about 5 µm and 25 mm in CO (1 bar)

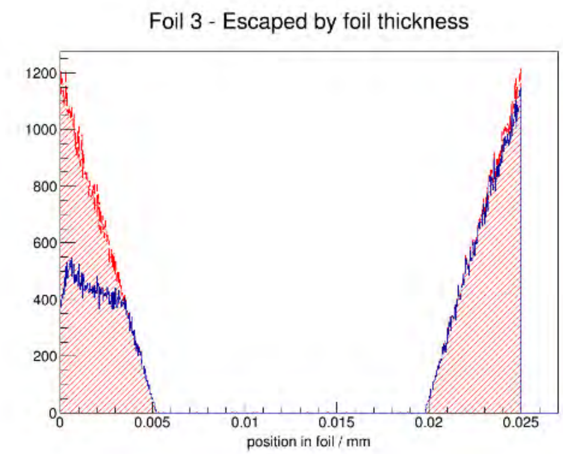




Geometry covered with Monte-Carlo-Simulation.



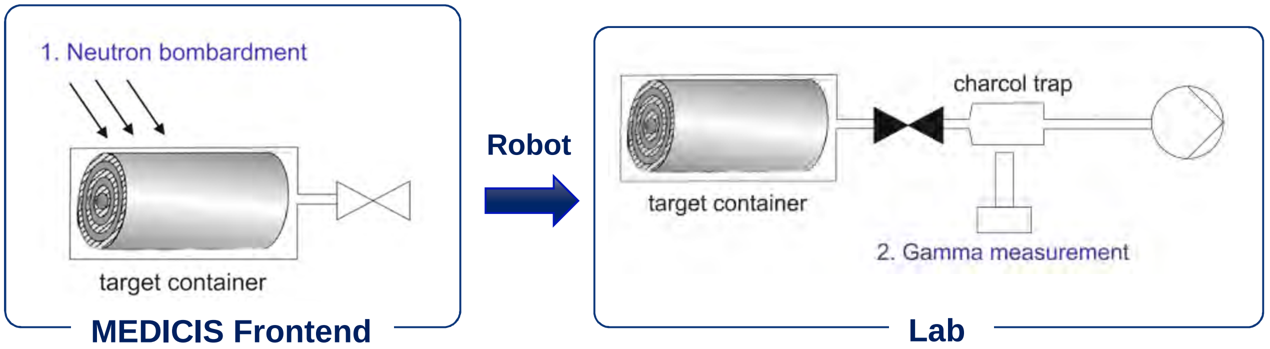




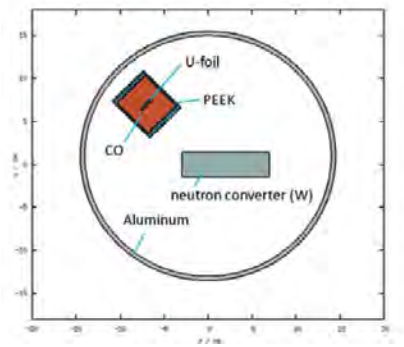
11% of the fragments recoil out of the foil
51% of these are stopped in the gas

Carbonyl Production 3. Medicis irradiation experiment

to validate the simulation results and investigate possible carbonyl decomposition



Geometry

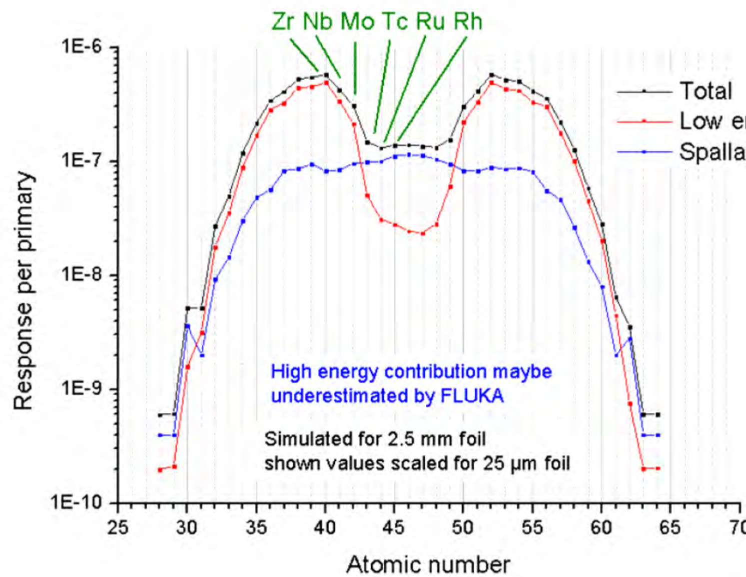


Parameters used:

- 1 uranium foil 4.7 x 3.5 cm²
- 10 min Irradiation @ 1e13 pps
- 30 min cooling

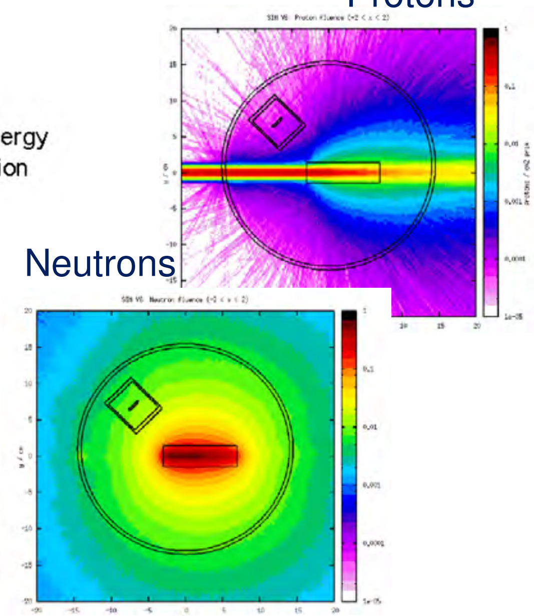
Results:

- Mo 99, 101 and 102 > 1e4 gamma events / 10 min expected



Protons

Neutrons



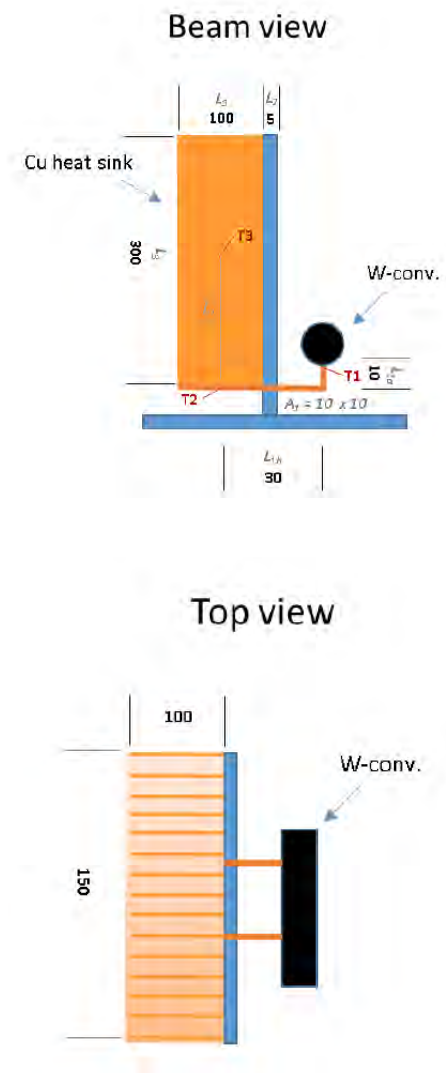
Challenges:

1. Heat dissipation

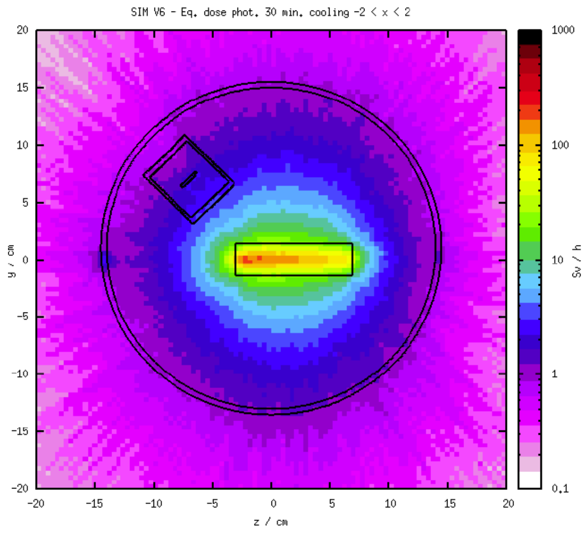
no watercooling available at MEDICIS, beam power on converter: 360W

➡ Heat sinks necessary to dissipate heat.

Proposed new design to keep temperature on converter below 150 °C:

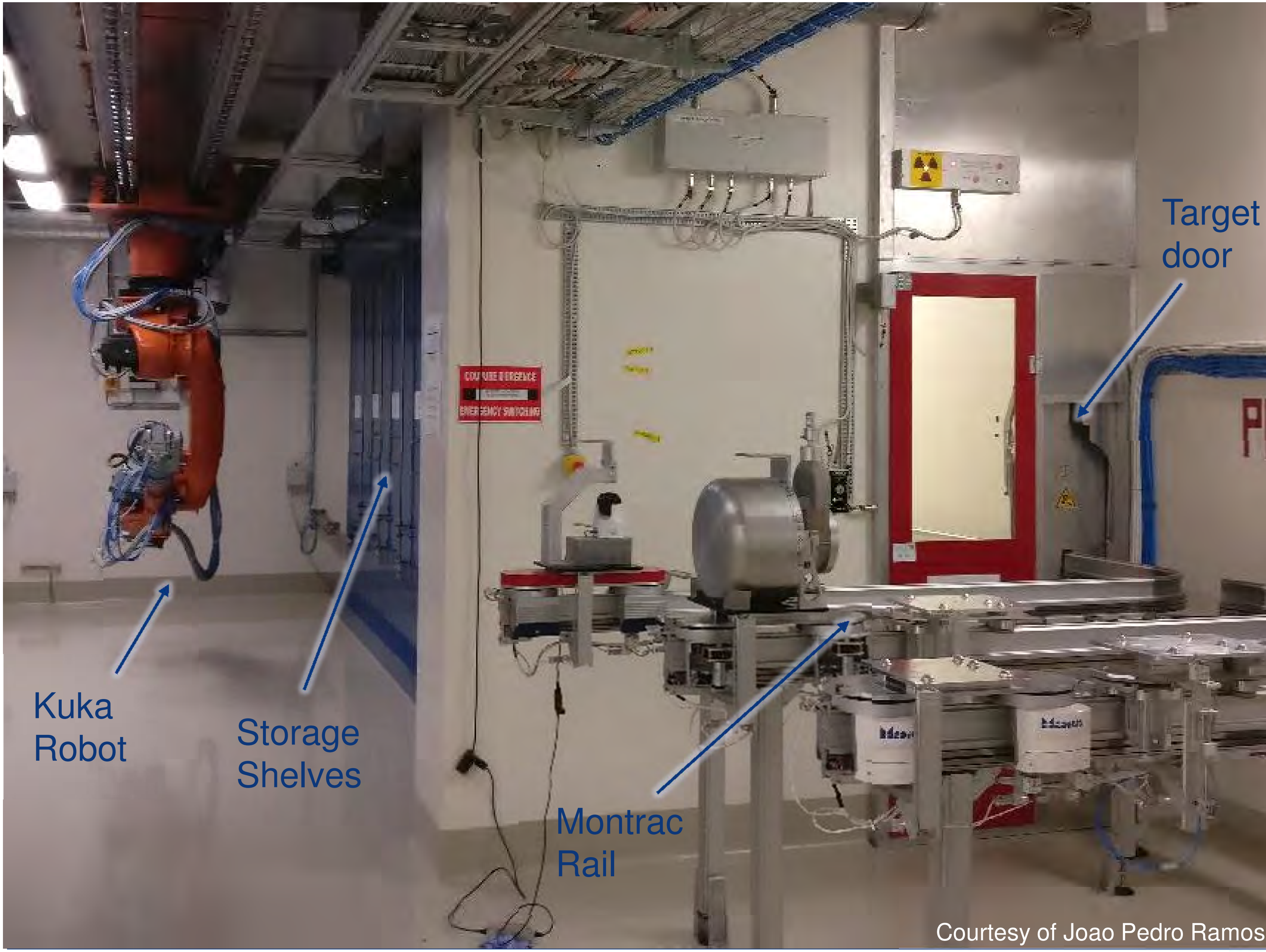


2. Radiation



Dose rate ca. 1 Sv / h on contact of cover after 30 minutes of cooling

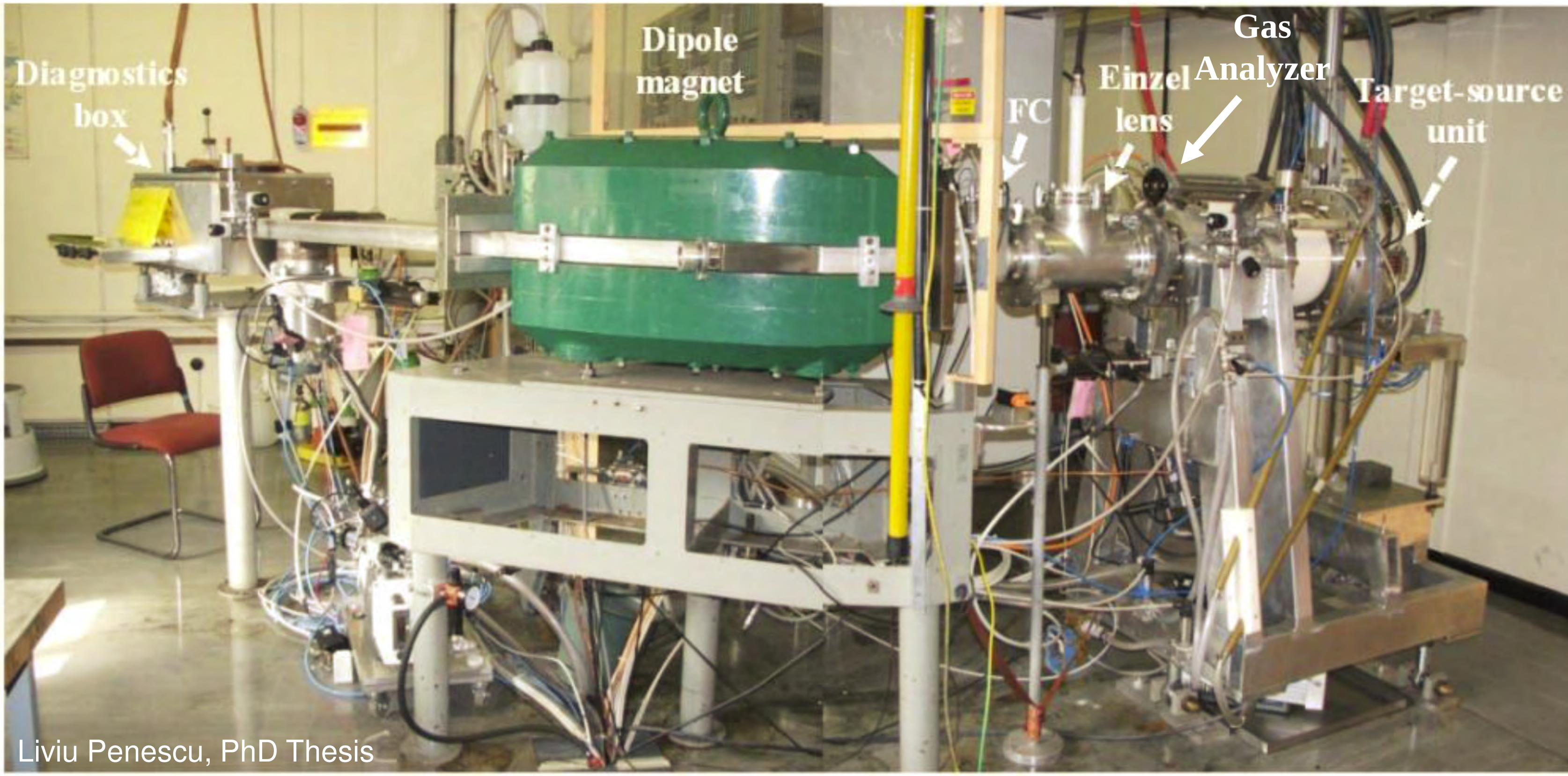
➡ Remote handling necessary


Target door
Kuka Robot
Storage Shelves
Montrac Rail
Courtesy of Joao Pedro Ramos

Carbonyl beams

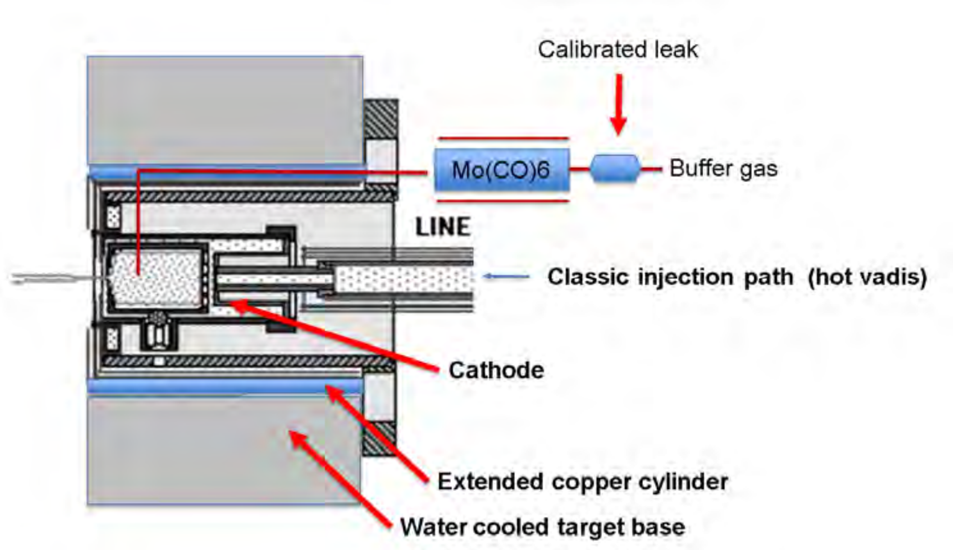
- Ionization -

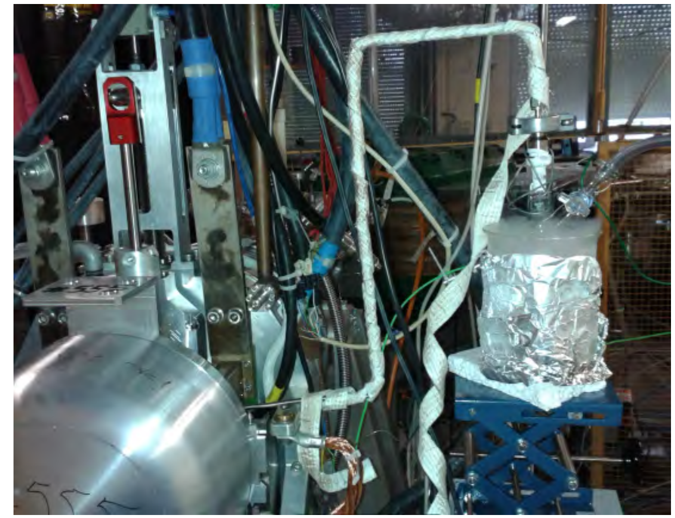
The ISOLDE offline mass separator



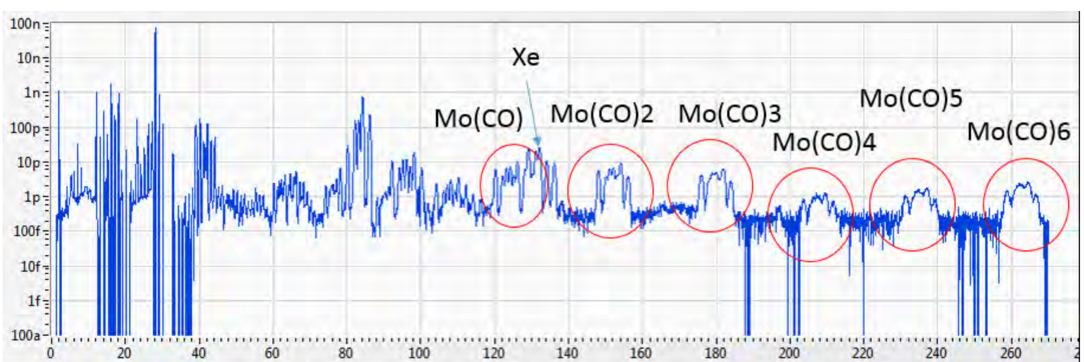
Ionization

A modified VADIS source





Mass scan

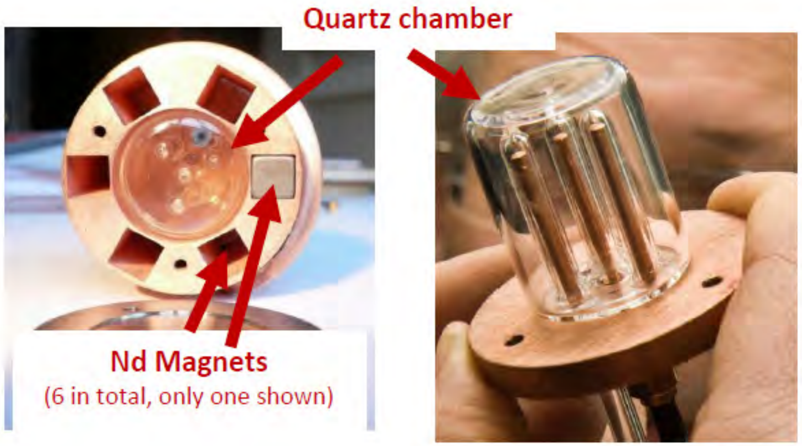


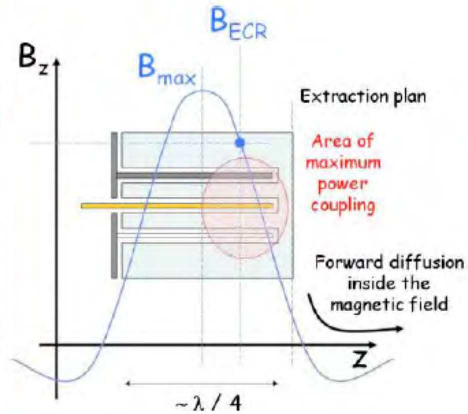
➡ Ionization is feasible, but ionization efficiency is very low.

Sample:
ca. 100 mg $Mo(CO)_6$

Ionization COMIC source

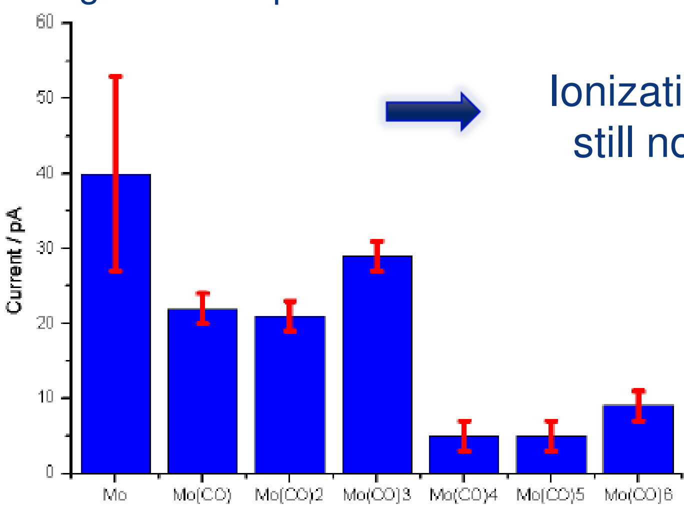
Microwave heated cold plasma source (2.45 GHz)





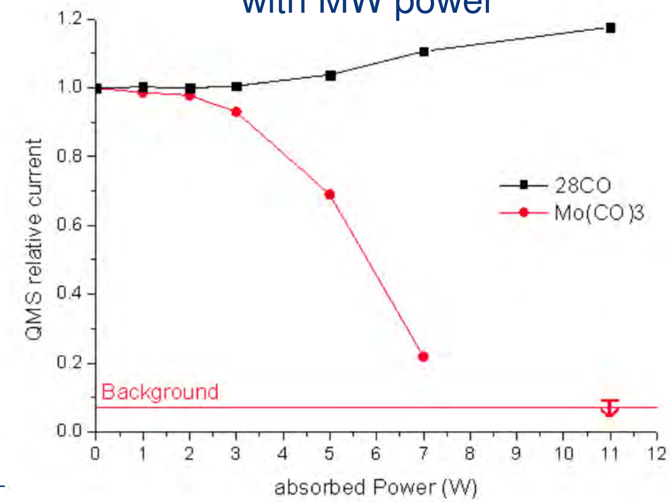
Chamber after the tests

Fragmentation pattern

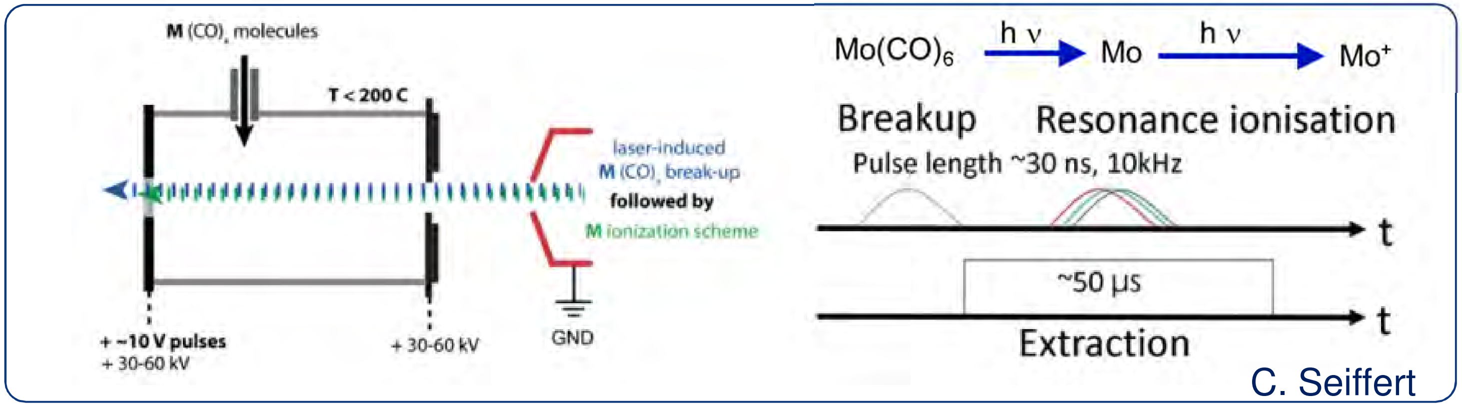


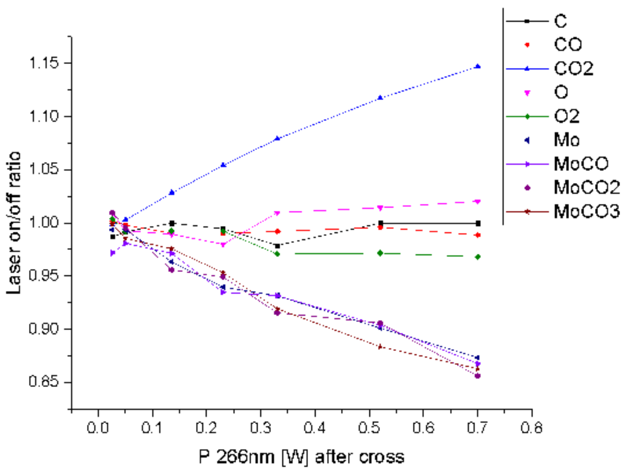
Ionization efficiency still not satisfying

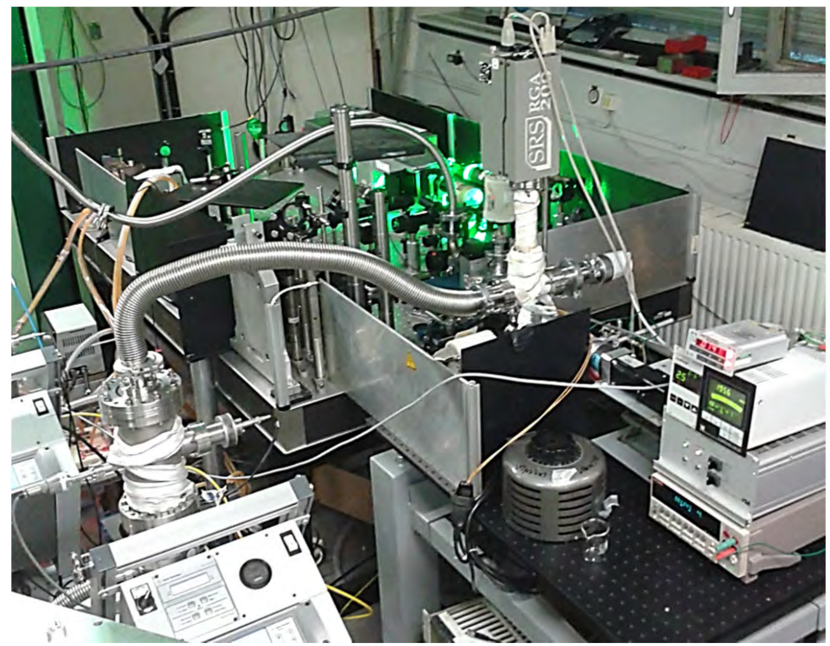
Carbonyl decomposition with MW power



Ionization Laser breakup







- Mo Ionization scheme developed by RILIS in 2016 (K. Chrysalidis)
- Breakup successfully tested with RGA at 266 nm.

Thanks!

CERN