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Medicis-Promed Workshop:
CARBON-11 FOR ION BEAM THERAPY
16 - 18 January 2019
Wiener Neustadt, Austria
http://medicis-promed.web.cern.ch
Organizing Committee: Thierry Stora (CERN), Claus Schmitzer (MedAustron), Andrea Mairani (CNAO), Liviu Penescu (Abstract Landscapes), Cristina Ferrari (CERN), Nicole Rauchlechner (MedAustron)

Project from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 64288.

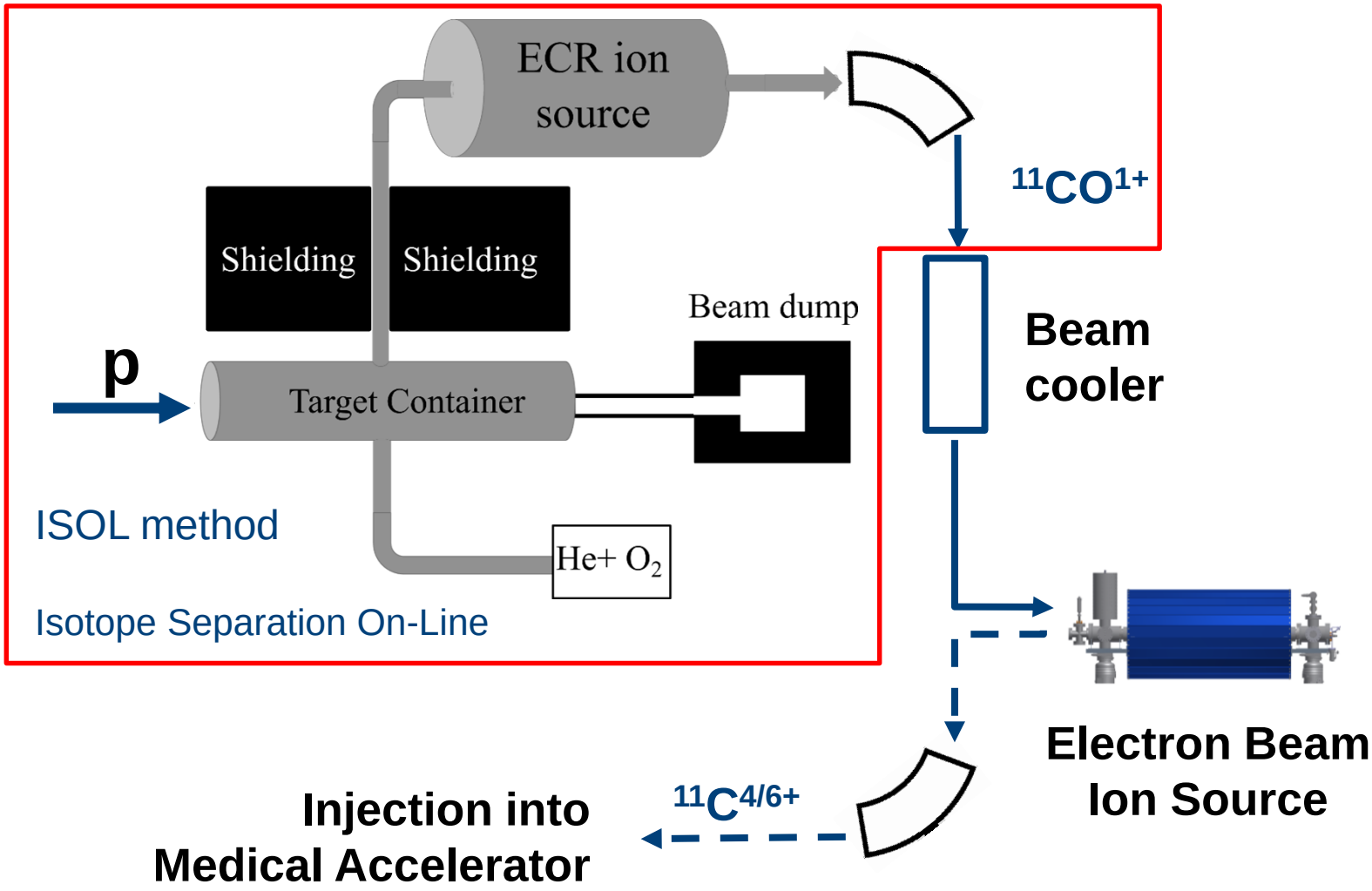
Production of intense mass separated ^{11}C beams – current status

S. Stegemann,

MEDICIS-Promed Workshop on CARBON-11 FOR ION BEAM THERAPY
16/01/2019, Wiener Neustadt, Austria

European Commission

^{11}C based hadron therapy facility (MEDICIS-Promed)



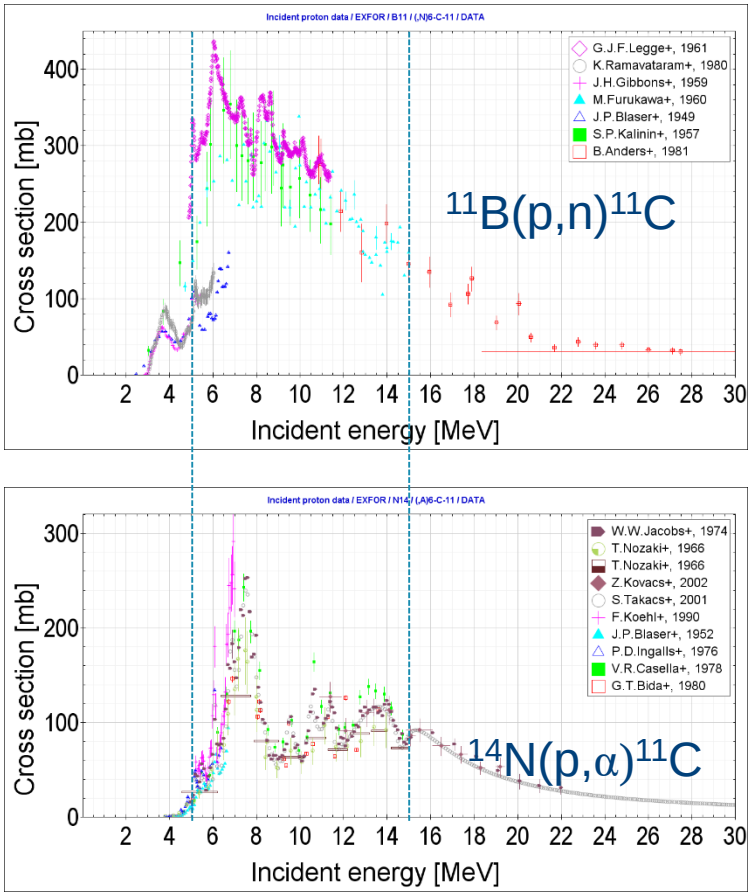
Target developments

Target material

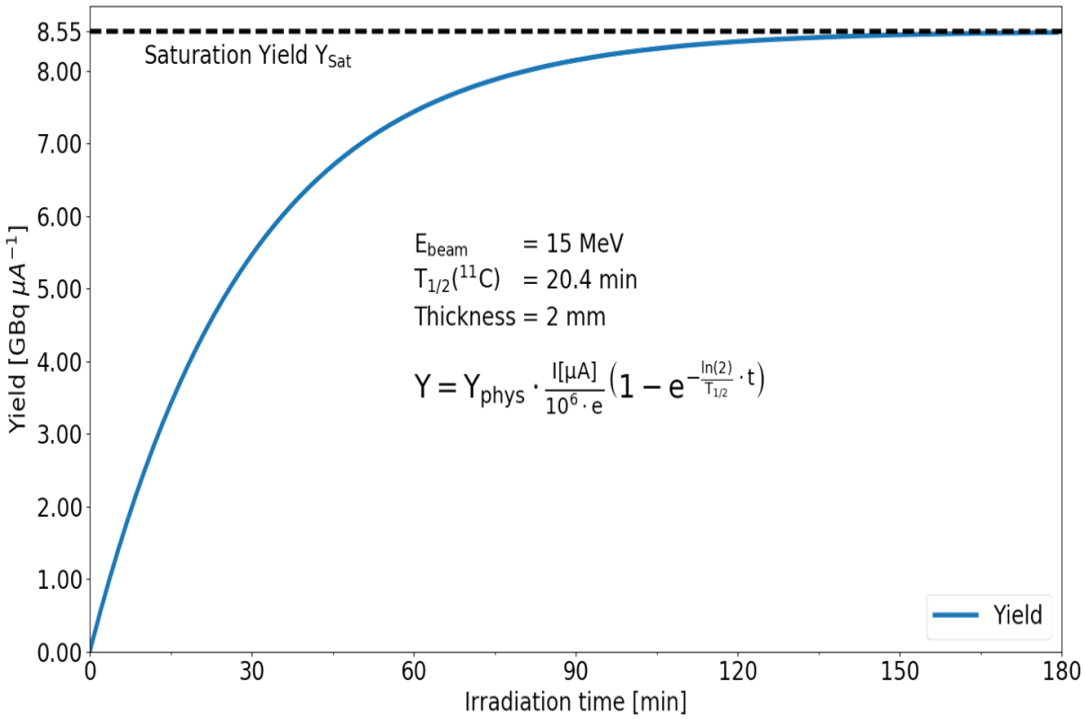
Boron nitride (BN)

$^{11}B(p,n)^{11}C$

$^{14}N(p,\alpha)^{11}C$



Calculated in-target production yield



Isotope release

Diffusion:

$D = D_0 \cdot e^{-\frac{E}{RT}}$ (Arrhenius eq.)

$\varepsilon_{diff} = \frac{3}{\pi}\sqrt{\frac{\mu}{\lambda}}$ $\mu = \frac{\pi^2 \cdot D}{G^2}$

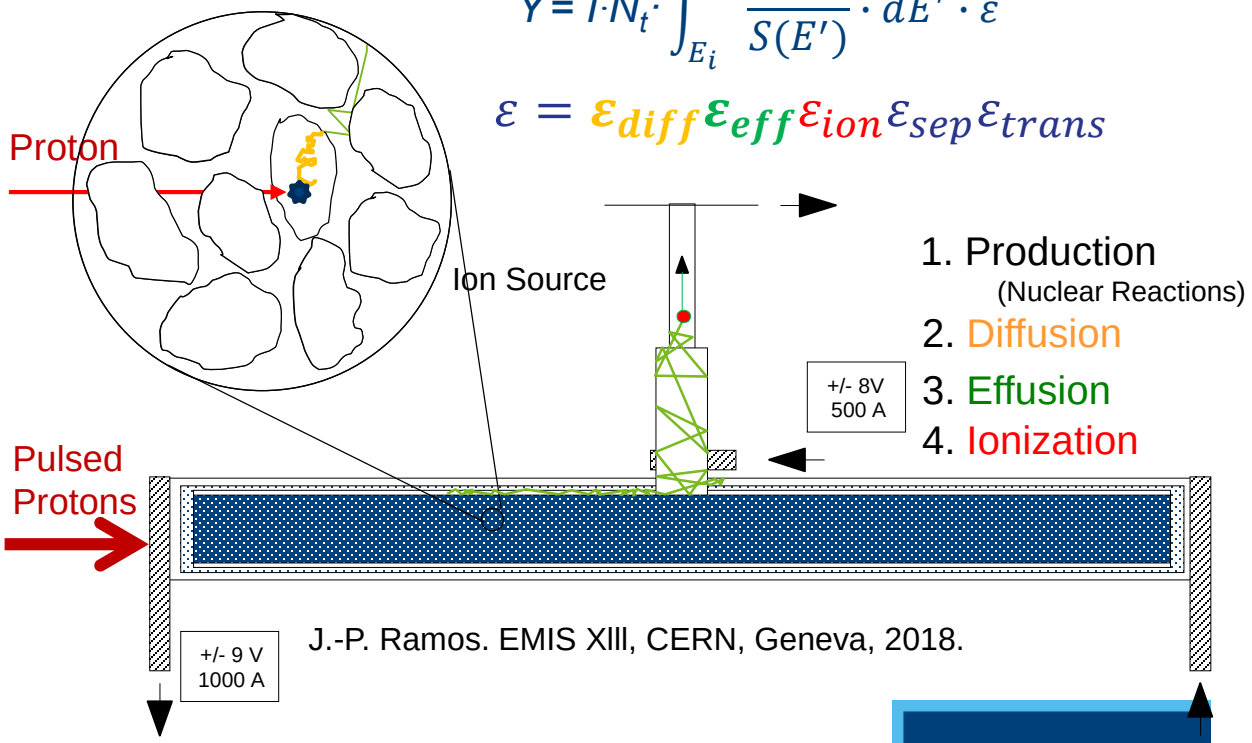
$\Rightarrow \varepsilon_{diff} \propto \frac{1}{G}$

D: Diffusion coefficient
μ : Diffusion time
λ : Decay constant
G: Grain size

Control microstructure to enhance release properties

$$Y = I \cdot N_t \cdot \int_{E_i}^{E_f} \frac{\sigma(E')}{S(E')} \cdot dE' \cdot \varepsilon$$

$$\varepsilon = \varepsilon_{diff}\varepsilon_{eff}\varepsilon_{ion}\varepsilon_{sep}\varepsilon_{trans}$$



J.-P. Ramos. EMIS XIII, CERN, Geneva, 2018.

Target processing

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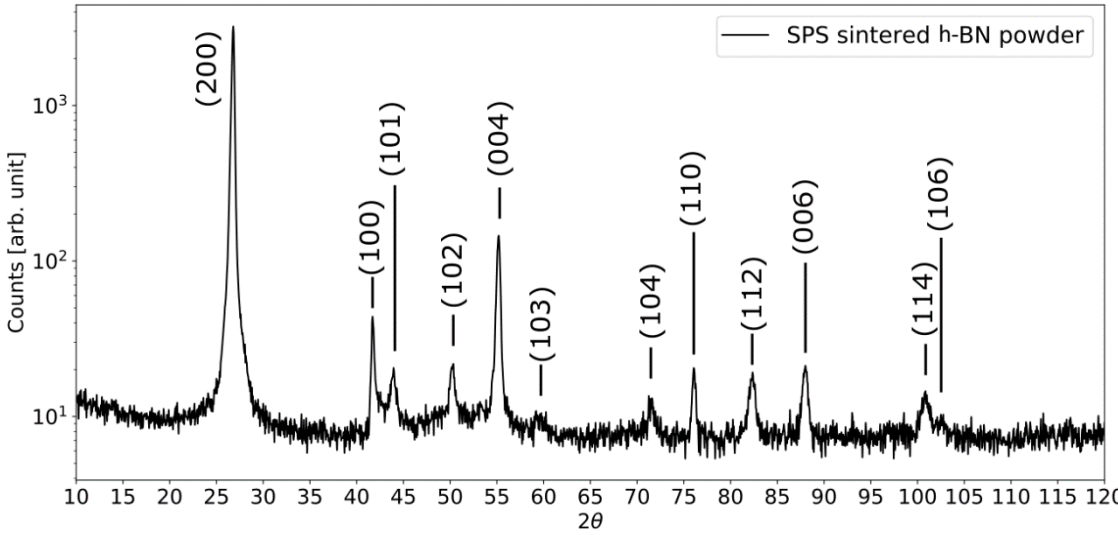
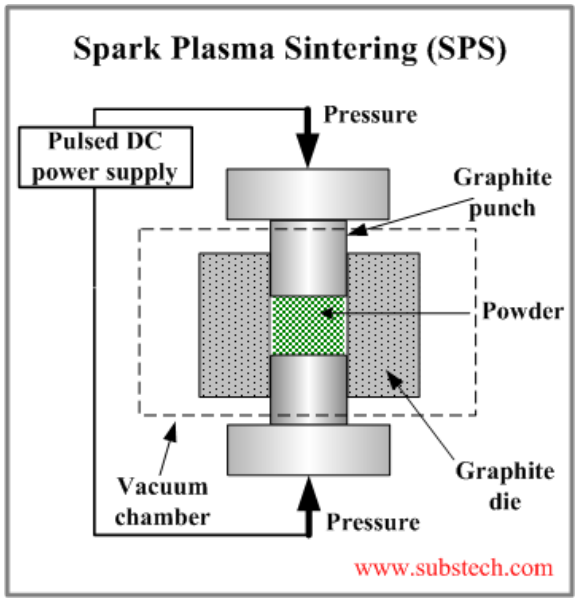
MATERIALS ENGINEERING

Spark Plasma Sintering

- High pulsed DC currents into powder compact
- High heating/cooling rates
- ➢ Minimizes grain growth at low T
- ➢ Maintaining of micro,- (nano-) structures





- 100 °C/min heating rate
- 1700 °C final sintering-temperature
- Sintering-pressure 25 MPa at 1700 °C for 5 min

- ρ_{bulk} = 1.3(1) g cm^{-3}
- Φ_{tot} = 0.40(1) total porosity
- Φ_{open} = 0.21(2) open porosity

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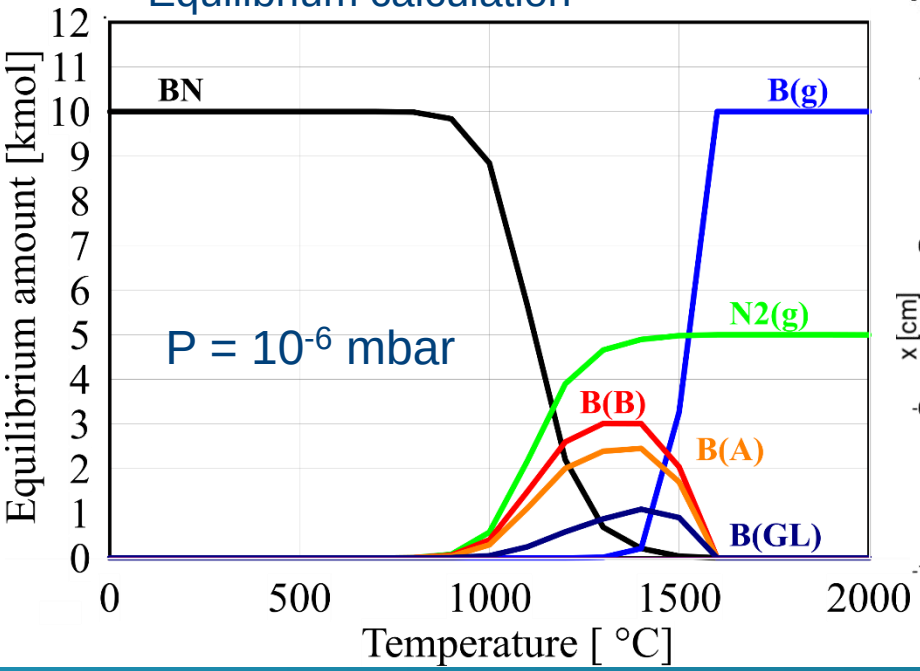
Heat management

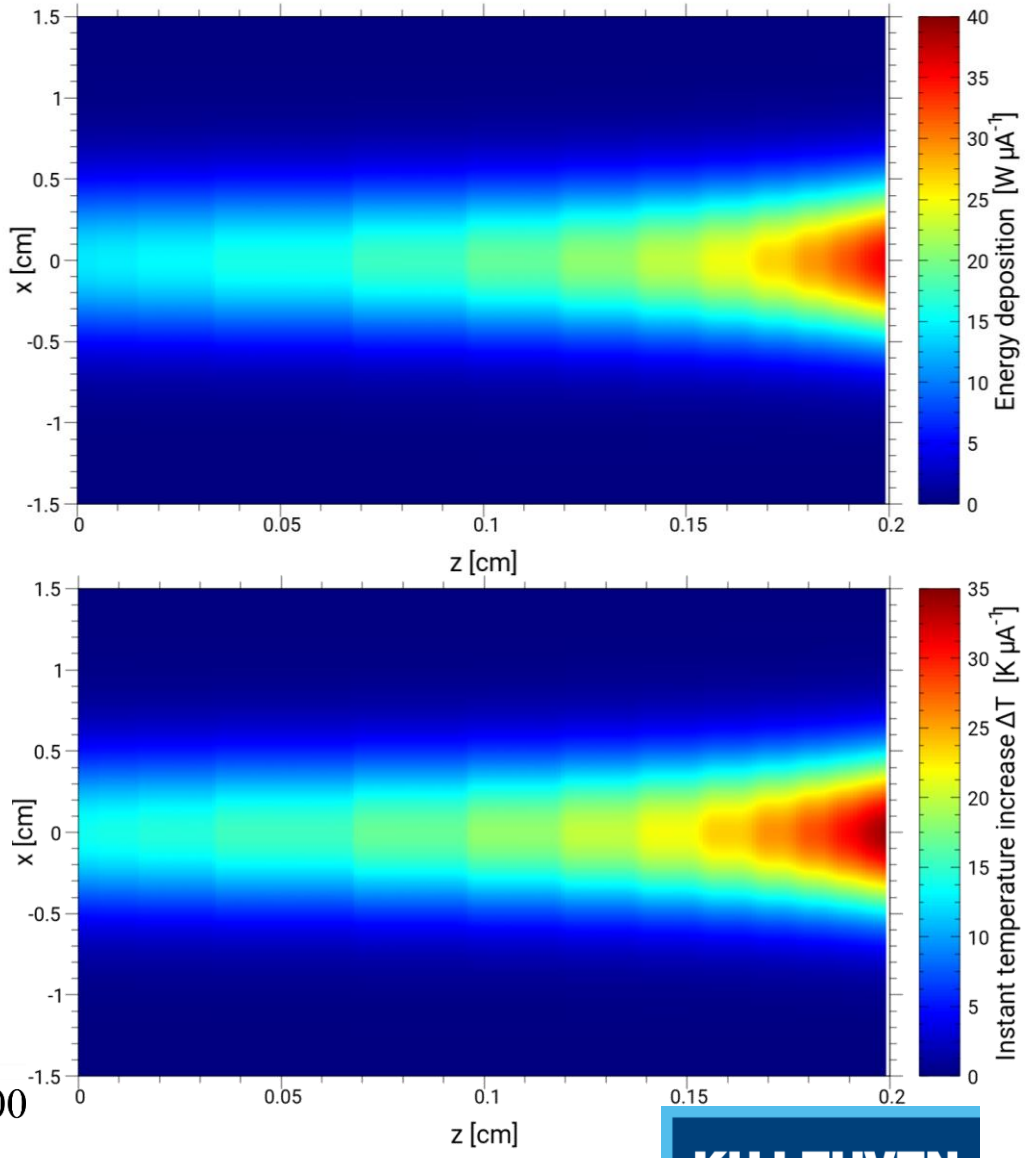
$$Y_{Prod} = I \cdot N_t \cdot \int_{E_i}^{E_f} \frac{\sigma(E')}{S(E')} \cdot dE'$$

$$E_{dep} \propto I$$

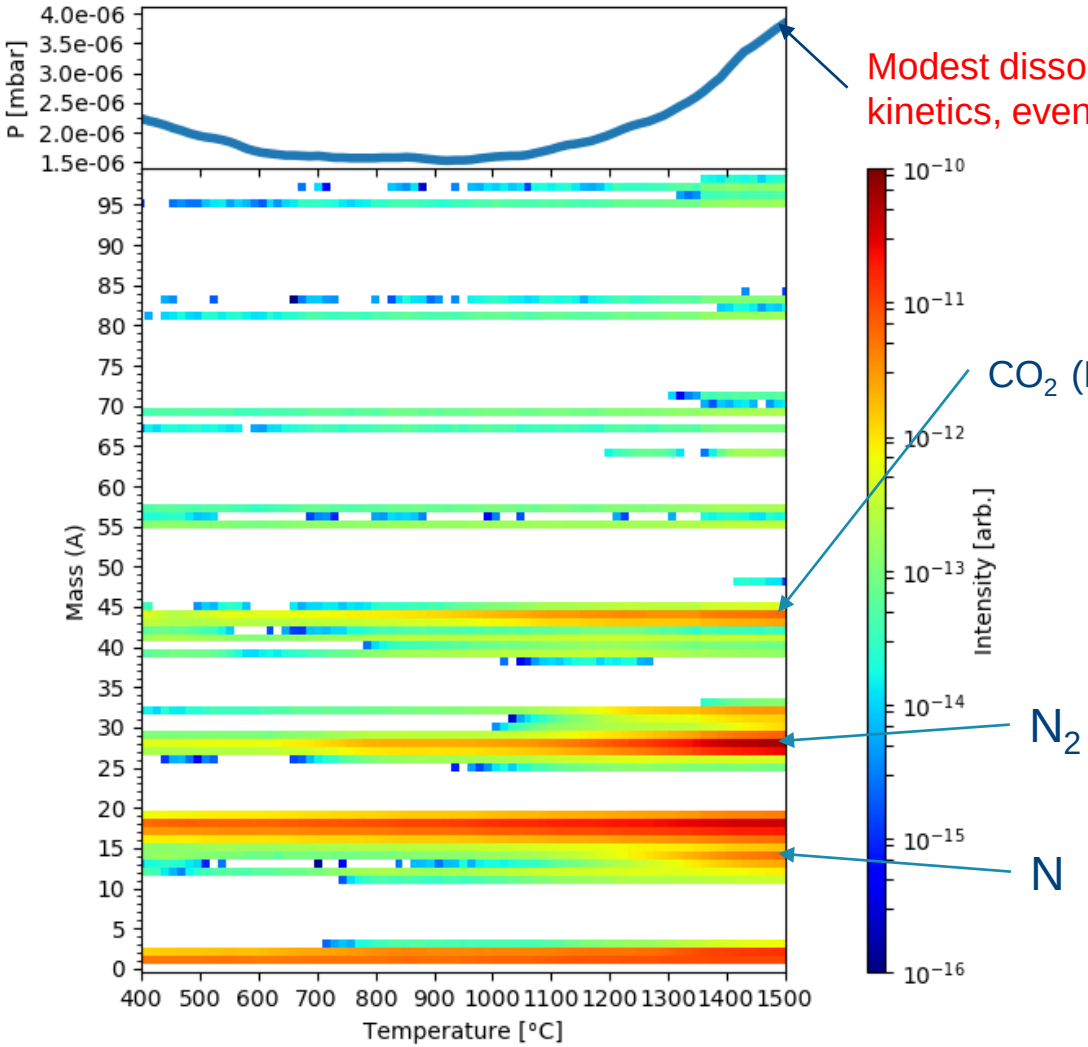
$$D = D_0 \cdot e^{-\frac{E}{RT}}$$

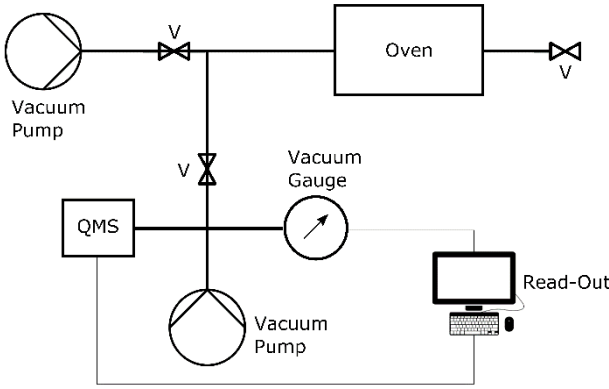
Equilibrium calculation





High-temperature measurements





$2BN = 2B + N_2(g)$

- Low dissociation rate!
- BN can ce applied with 1500 °C!

To further improve ^{11}C release

…

Molecular ^{11}C release

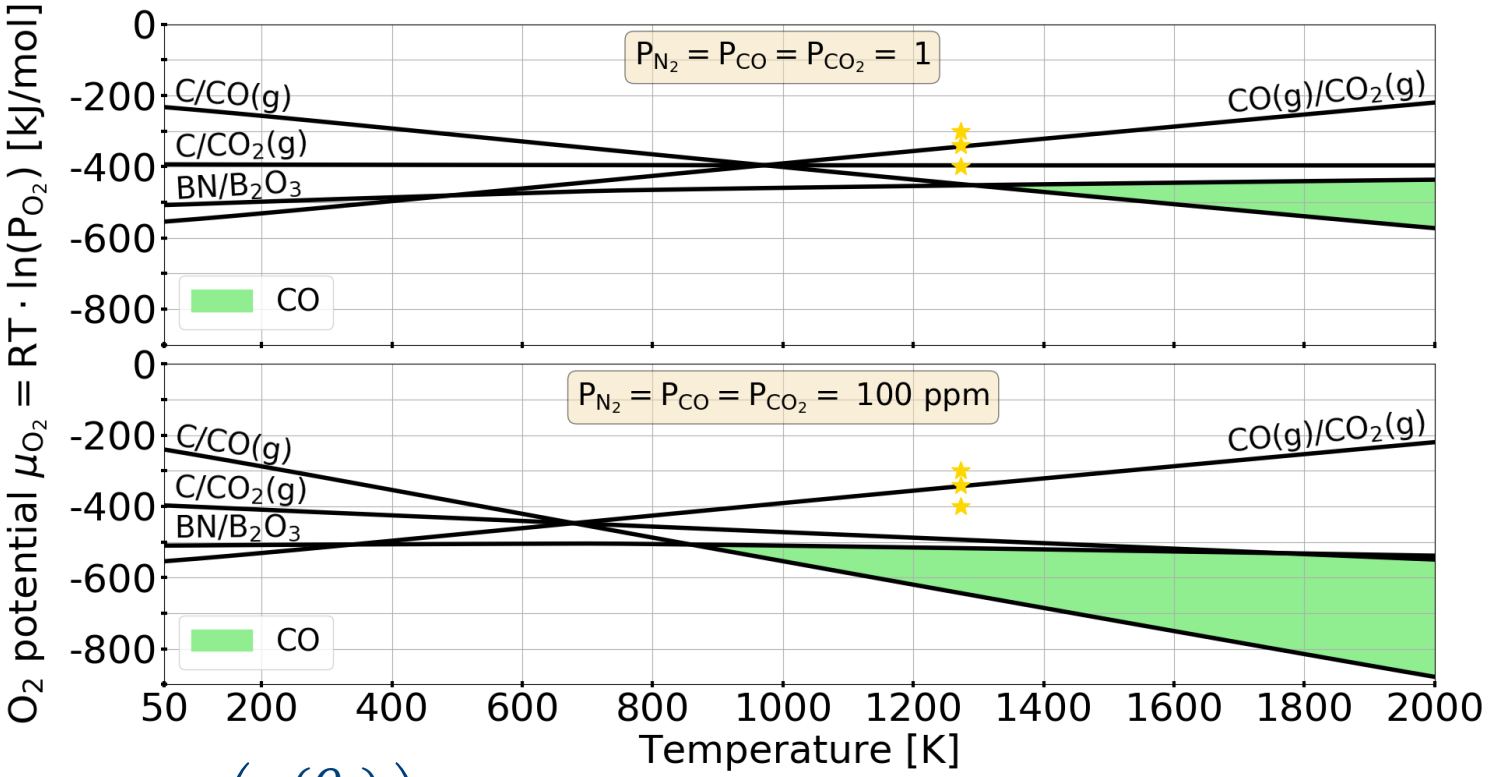
- C is refractory and forms strong bonds with hot metal surfaces

➢ Release in molecular form (CO)

But: BN is sensitive to oxidation!

➢ Need operation conditions where formation of carbon oxides in favored.

Ellingham diagram



$$\Delta G = R * T * ln\left(\frac{p(O_2)}{p(O_2)^*}\right)$$

⇒ Control gas composition

ΔG : Oxygen potential
$p(O_2)$: Oxygen partial pressure
$p(O_2)^*$: Standard-state pressure

<u>High-T oxidation of BN:</u>

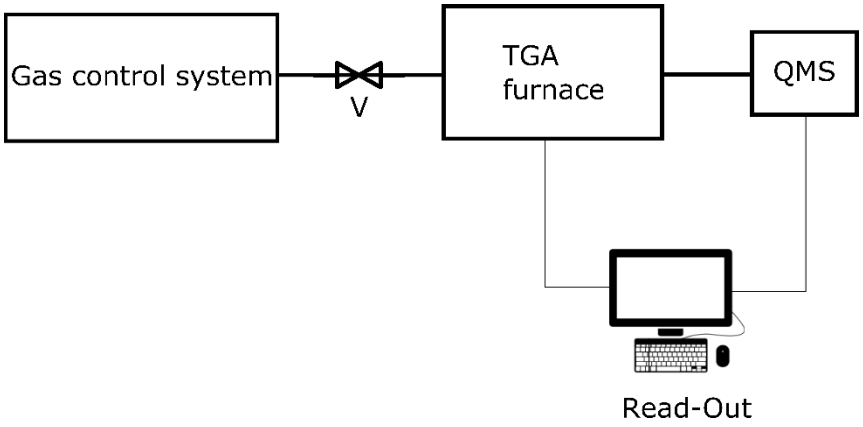
$2BN + \frac{3}{2}O_2 \leftrightharpoons B_2O_3 + N_2$

$B_2O_3 + H_2O \leftrightharpoons 2HBO_2$

$2H_2 + O_2 \leftrightharpoons 2H_2O$

High-T oxidation kinetics (TGA-MS)

SCK•CEN



Examined high-T oxidation kinetics of BN and BN-C ([C] = 0.01, 0.1, 1, 5%)

TGA coupled with QMS (thermogravimetric analysis)

Measured: for T = 1000 °C; ΔG = -400, -340, -300 kJ mol^{-1}

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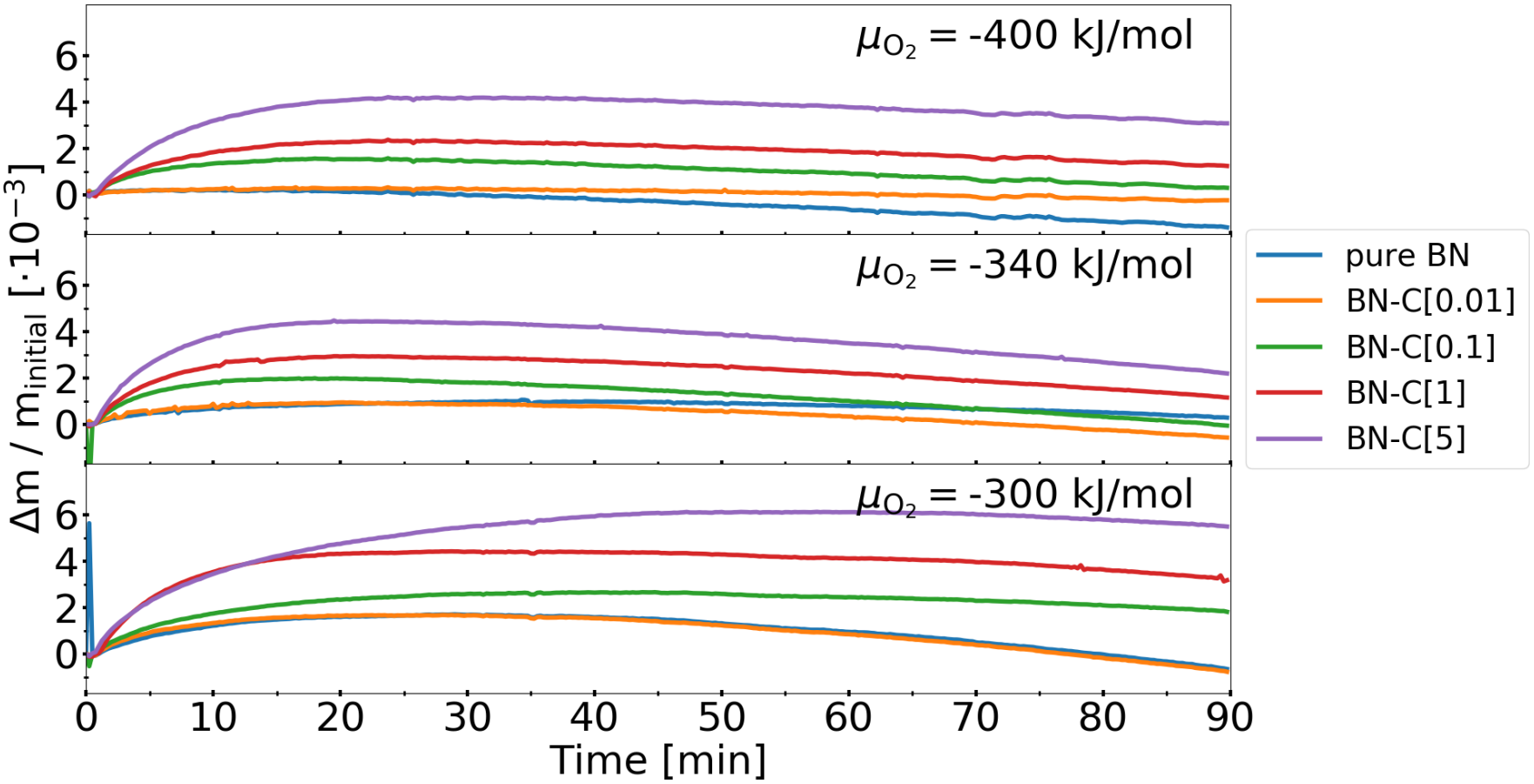


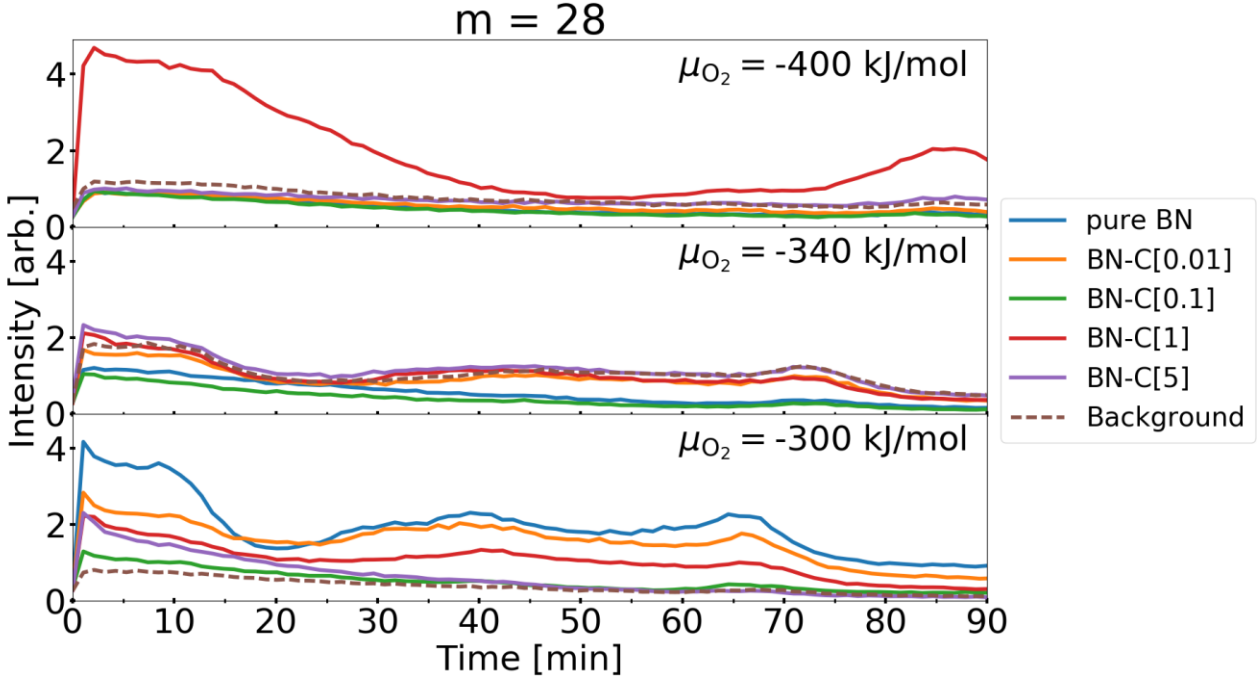
- No, or very modest oxidation of BN
- Samples obey paralinear kinetics

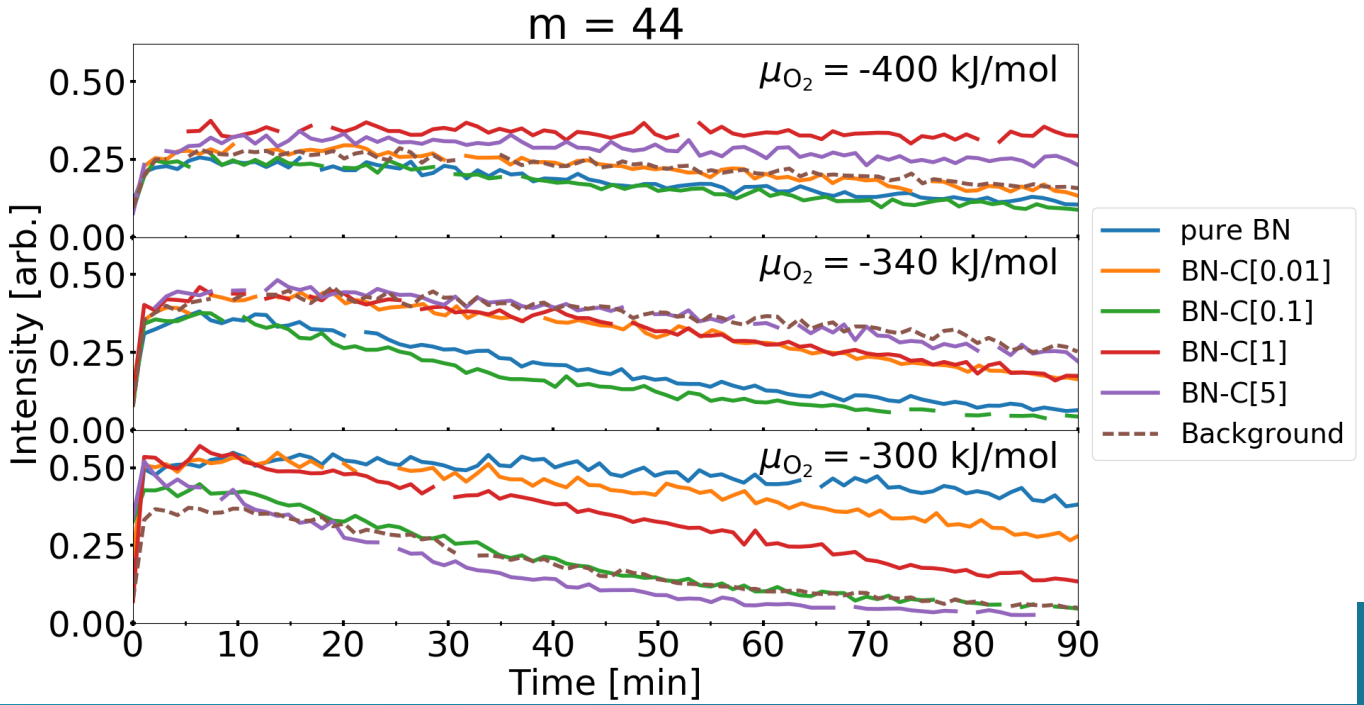
➢ Uptake O_2 (parabolic);

volatilization HBO_2 (linear)

- Increasing [C] → Increasing O_2 uptake
- But: No conclusive information from MS data

➢ C enhances O_2 uptake, but CO could not be measured





No conclusive information from TGA-MS study on C-doped BN targets

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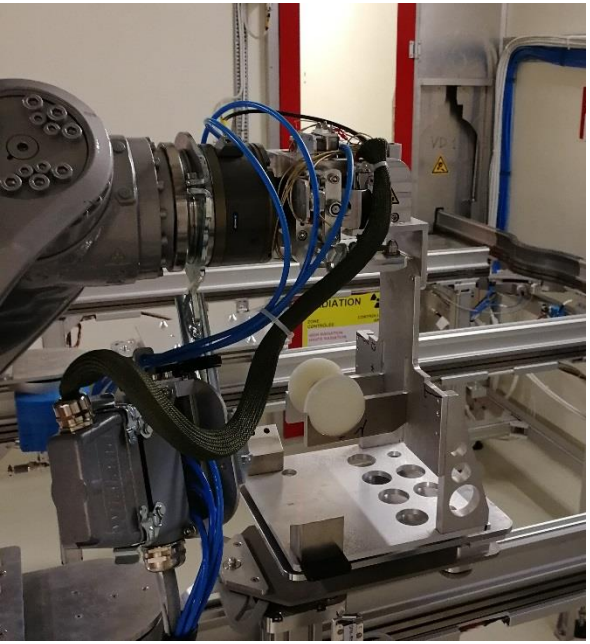
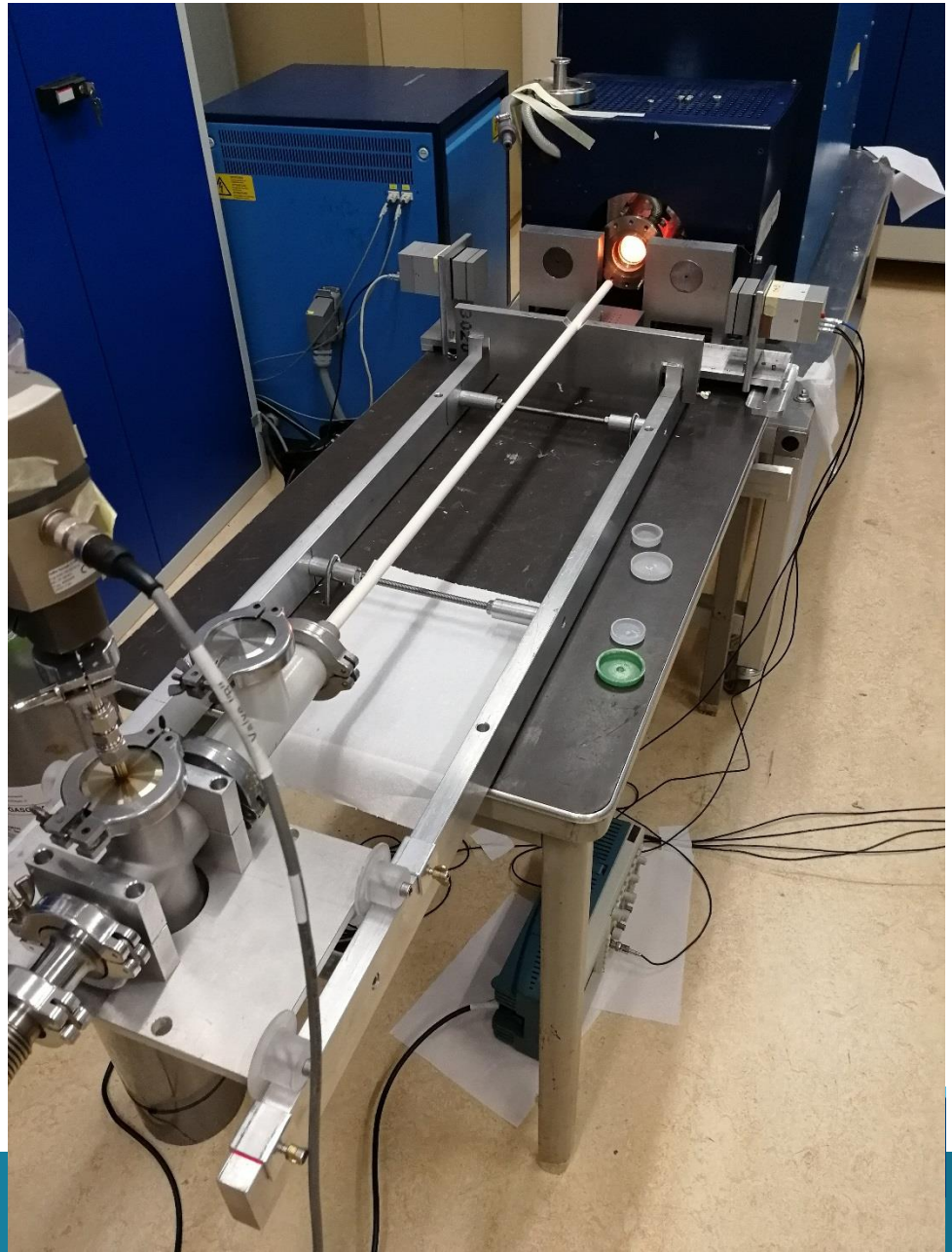
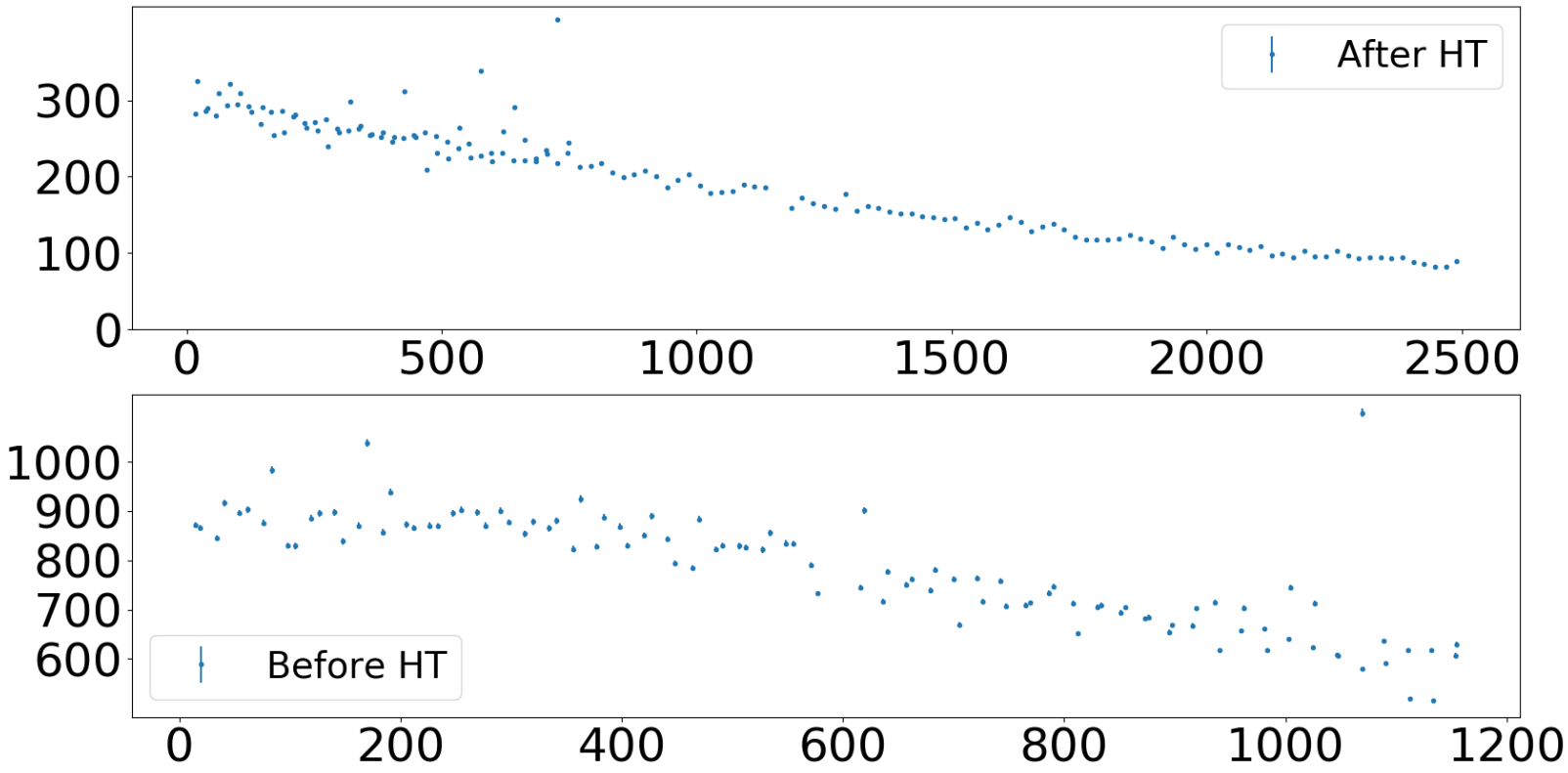
Most recently

^{11}C release study at CERN MEDICIS






After HT
300
200
100
0
0
500
1000
1500
2000
2500
1000
900
800
700
600
Before HT
0
200
400
600
800
1000
1200

Thank you.
Questions, comments?

This research project has been supported by a Marie Skłodowska-Curie Innovative Training Network Fellowship of the European Commission's Horizon 2020 Programme under contract number 642889 MEDICIS-PROMED.

Outlook

- Release efficiency study