EXPERIMENTAL MEASUREMENTS AND SIMULATION OF AN ECRIS CALCIUM OVEN

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TUXZO03

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Outline

Motivation

Oven Design

Measurements

Simulation

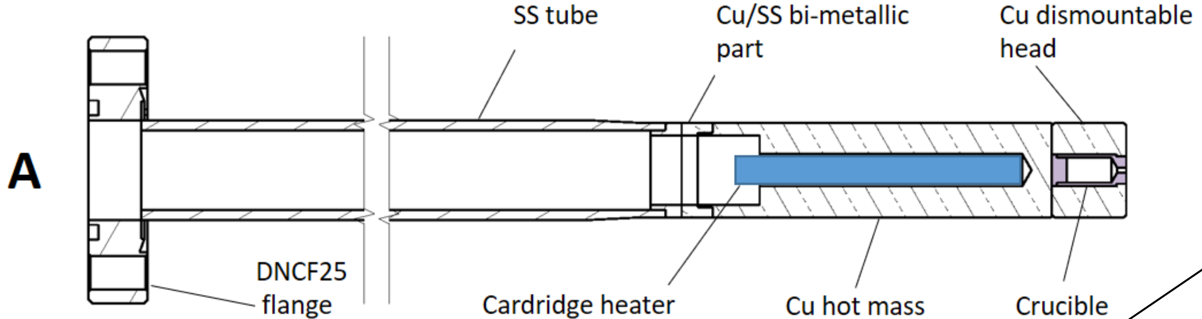
Conclusion

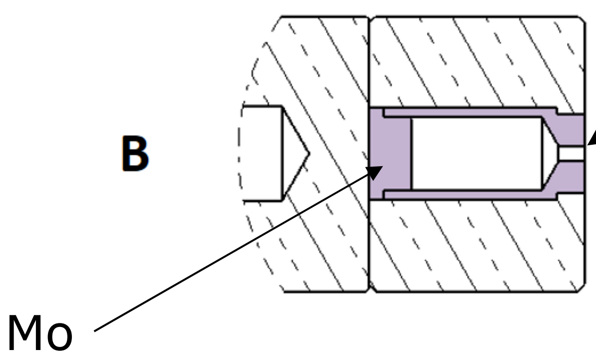
Motivation

- In ECRIS, atom to ion oven efficiency ranges from a few % to 20%, sometimes up to ~70% with wall recycling
- ^{48}Ca is > 200k€/g : it is worth trying to optimize the atom to ion conversion efficiency
- How atoms are spatially distributed outward an oven? Can this distribution be optimized?
- Can simulation reproduce experimental measurements?

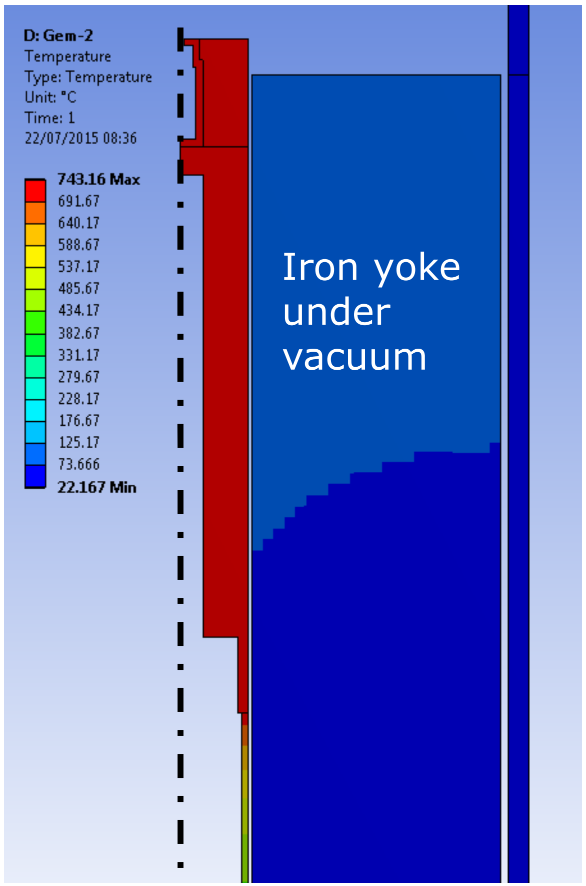
Calcium oven

- Derived from LBL design
  - Massive oven, suitable for operation with high power RF heating
  - 200W ~ 650°C





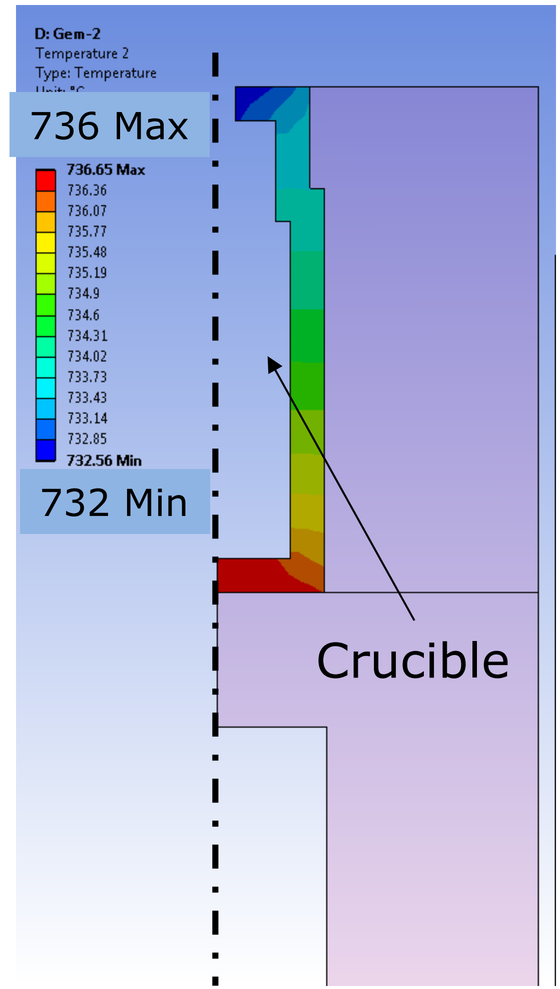
Oven thermal simulation



ANSYS

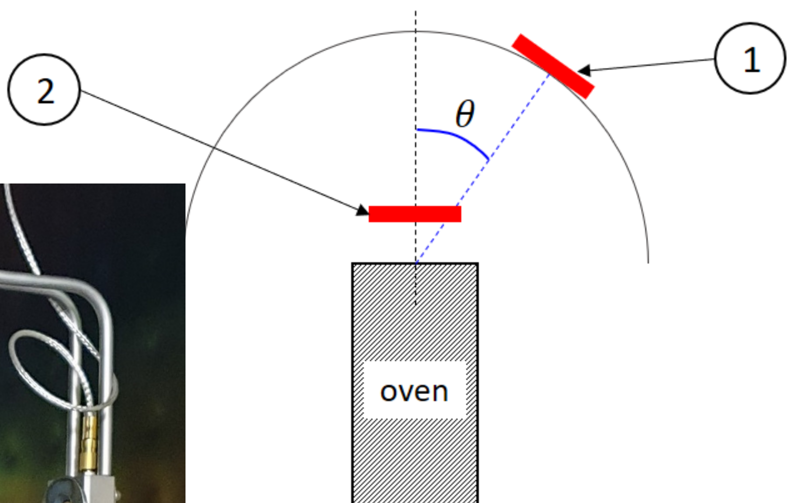
Application to PHOENIXV3 ECRIS

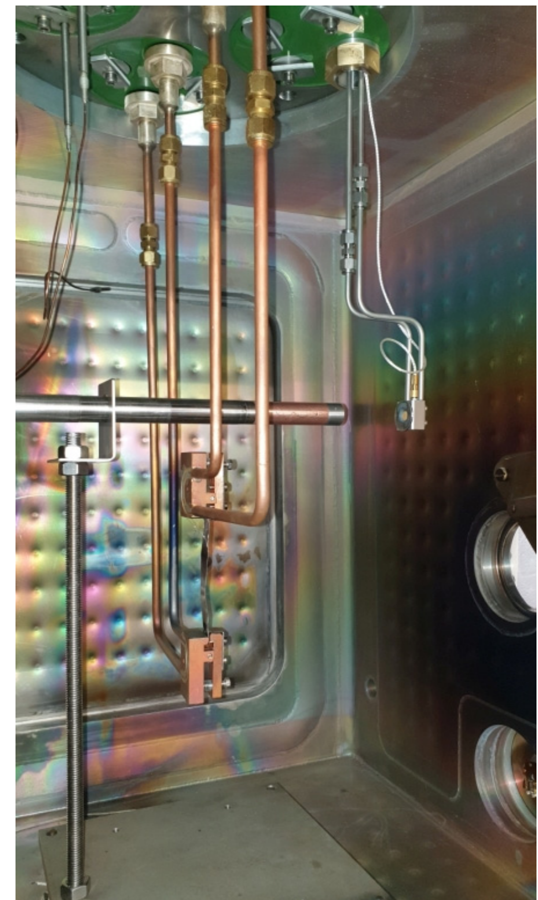
- Oven is ~isothermal
- Water cooled iron Yoke <80 °C



Experimental setup

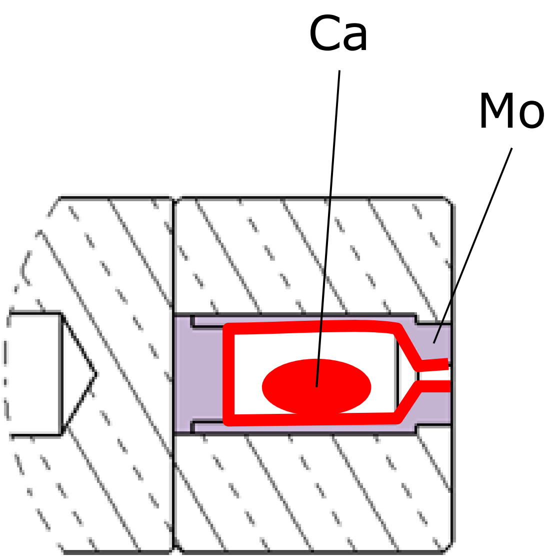
- AUDA6 Neyco quartz microbalance @3 MHz
- Heater cartridge thermocouple to monitor the temperature
- Atom flux measurement vs angle (1) and vs Temperature (2)
  - Active balance diameter : 8.1 mm
  - Distance 1 : 60 mm
  - Distance 2 : 10 mm
  - $P_0 \sim 10^{-7}$ mbar





Oven Chemistry

- Sticking time (Frenkel) : $\tau = \tau_0 e^{\frac{H}{kT}}$
- Small aperture => Pressure builds up to the saturating vapor pressure:
  - (Antoine's law) $\log_{10} P = A - \frac{B}{T}$
- Evaporation mass flow (Hertz-Knudsen) :
  - $\dot{M} = P\sqrt{\frac{m}{2\pi kT}}s$
- Ca evaporation in a Mo crucible
  - Mo-Ca enthalpy >> Ca-Ca enthalpy
  - Build up of a strongly bound layer of Ca on Mo
  - Next Ca re-evaporates on fresh Ca layer
- Ca surface of evaporation includes the crucible's
  - Calcium sample surface : $s_{Ca} \approx 0.8 \pm 0.2\ cm^2$
  - Crucible surface $s_c = 2.8\ cm^2$
  - Mass flow Hysteresis in operation



Experimental results (1)

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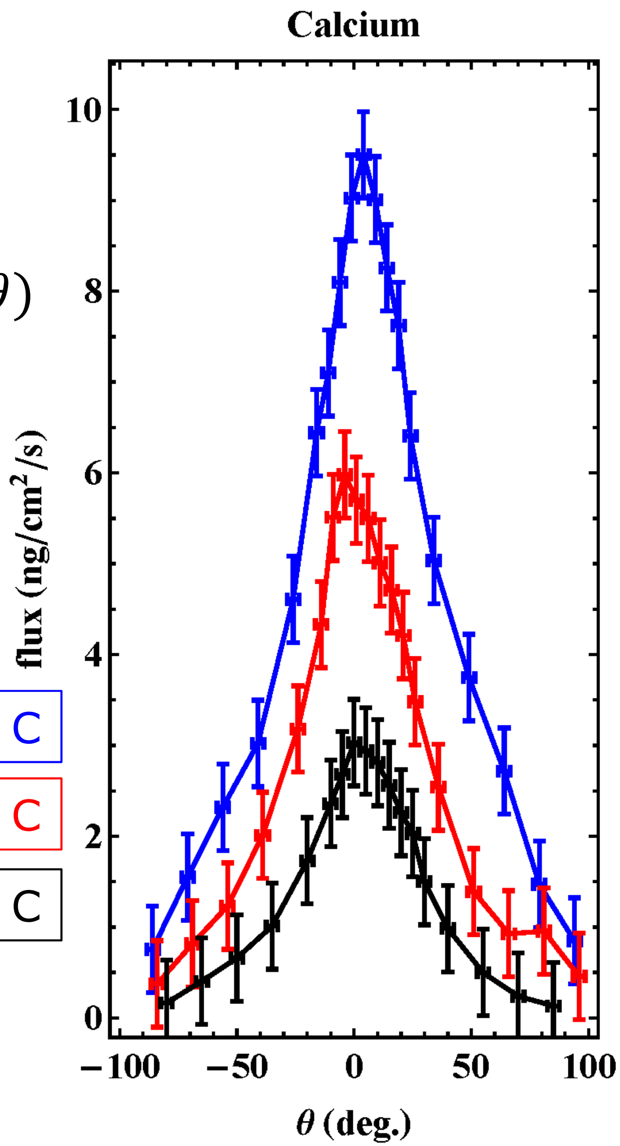
GANIL spiral2
laboratoire commun CEA/DRF CNRS/IN2P3

$$\frac{d\dot{m}}{dS}(\theta)$$



625° C	~900 K
600° C	~875 K
575° C	~850 K

r=60 mm

Calcium diff. flux vs angle of detection

- Time of integration : 180s
- Range of measurement > 575°C
- No signal below this temperature

Experimental results (2)

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GANIL Spiral2 — laboratoire commun CEA/DRF CNRS/IN2P3

Absolute Calcium flux vs temperature

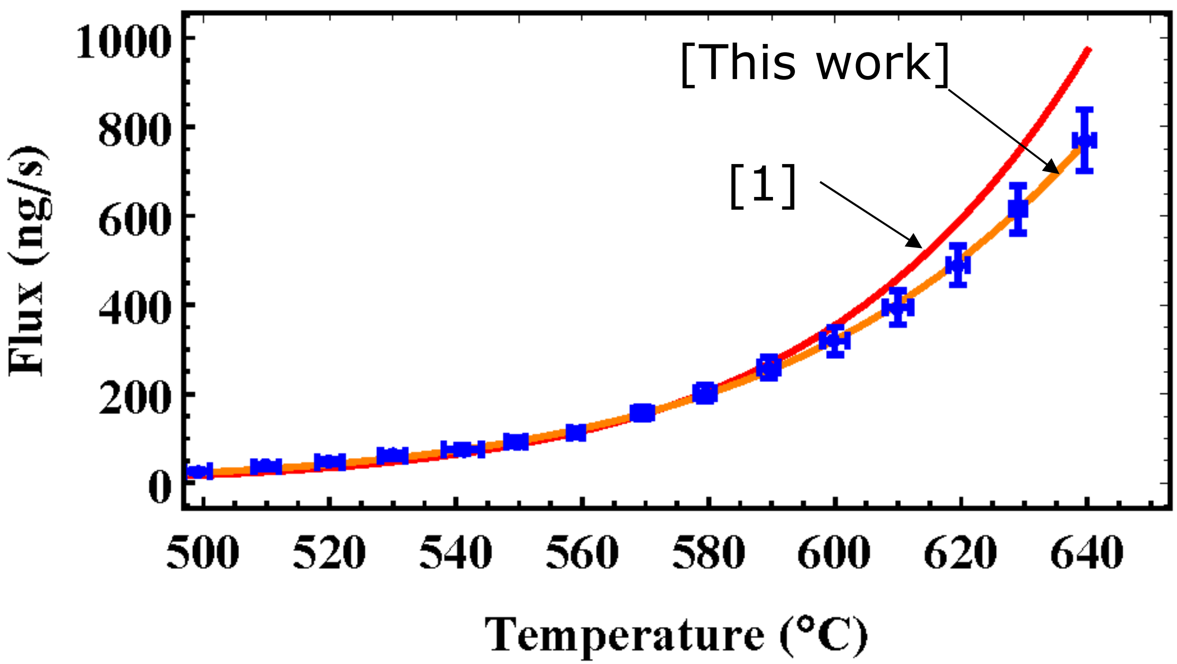
- $\frac{d\dot{m}}{d\omega}(\theta)$ Data from pos. (1) used to calculate the total flux in pos. (2) :
- $\dot{M} = 2\pi r^2 \int \frac{d\dot{m}}{d\omega}(\theta).d\Omega$
- Compared to :
  Hertz Knudsen eq. + Antoine's law
- Good fit, provided:
  $s = s_{Ca} + s_c$

$$\log_{10} P = A - \frac{B}{T}$$

$$\dot{M} = P\sqrt{\frac{m}{2\pi kT}}\, s$$

Antoine's coeff. For Ca

	A	B
[1]	10.34	8,94x10³
This work	8.98	7,79x10³

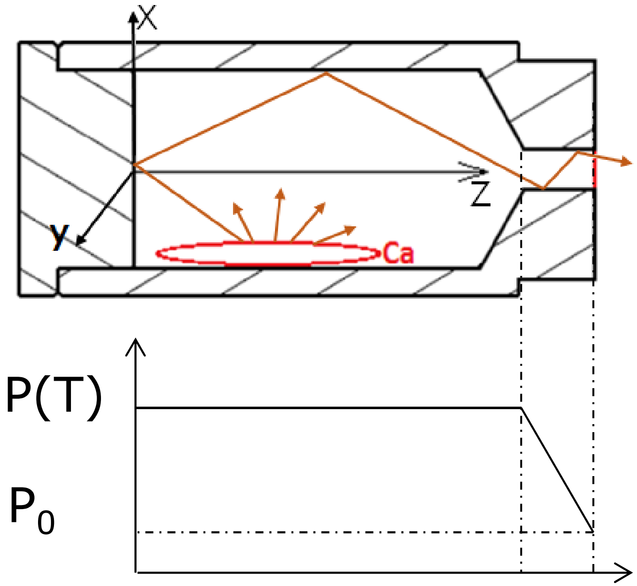


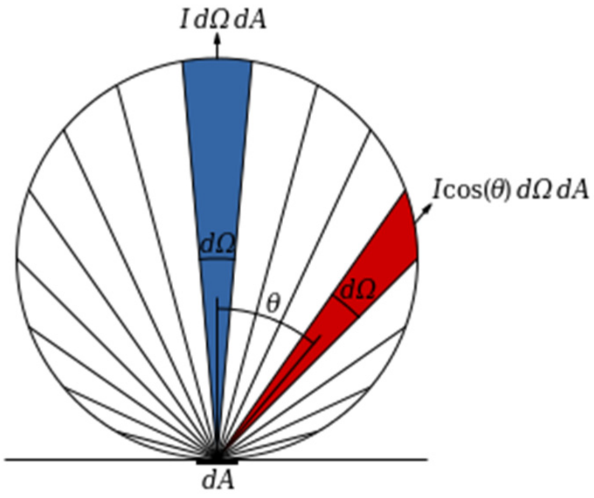
[1] S. DUSHMAN and J/M. LAFFERTY – Scientific foundationsof vacuum technique. 806 p., 2nd ed. New York, Wiley andSons (1962).

Simulation

3D Monte Carlo code

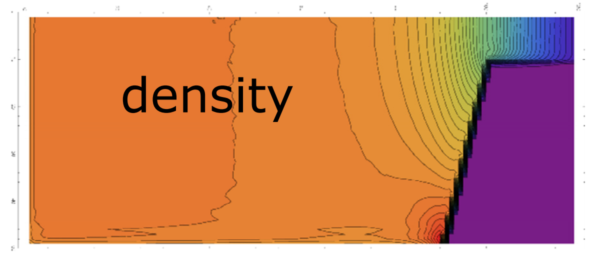
- Oven Temperature as a parameter
- Atoms generated at the bottom of the crucible
- Lambert's cosine law emission from surface
- Volume collision considered
  - density profile imposed in the crucible
  - output density profile cross checked a posteriori => validated
- Mean thermal atom velocity considered





Collision MFP:

$$\lambda = \frac{kT}{\sqrt{2}\pi P d_{atom}^2}$$



Calcium gaz regime

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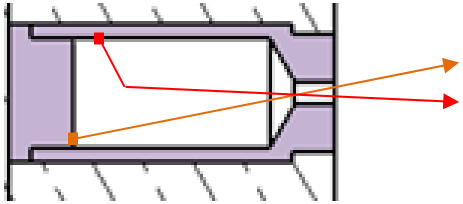
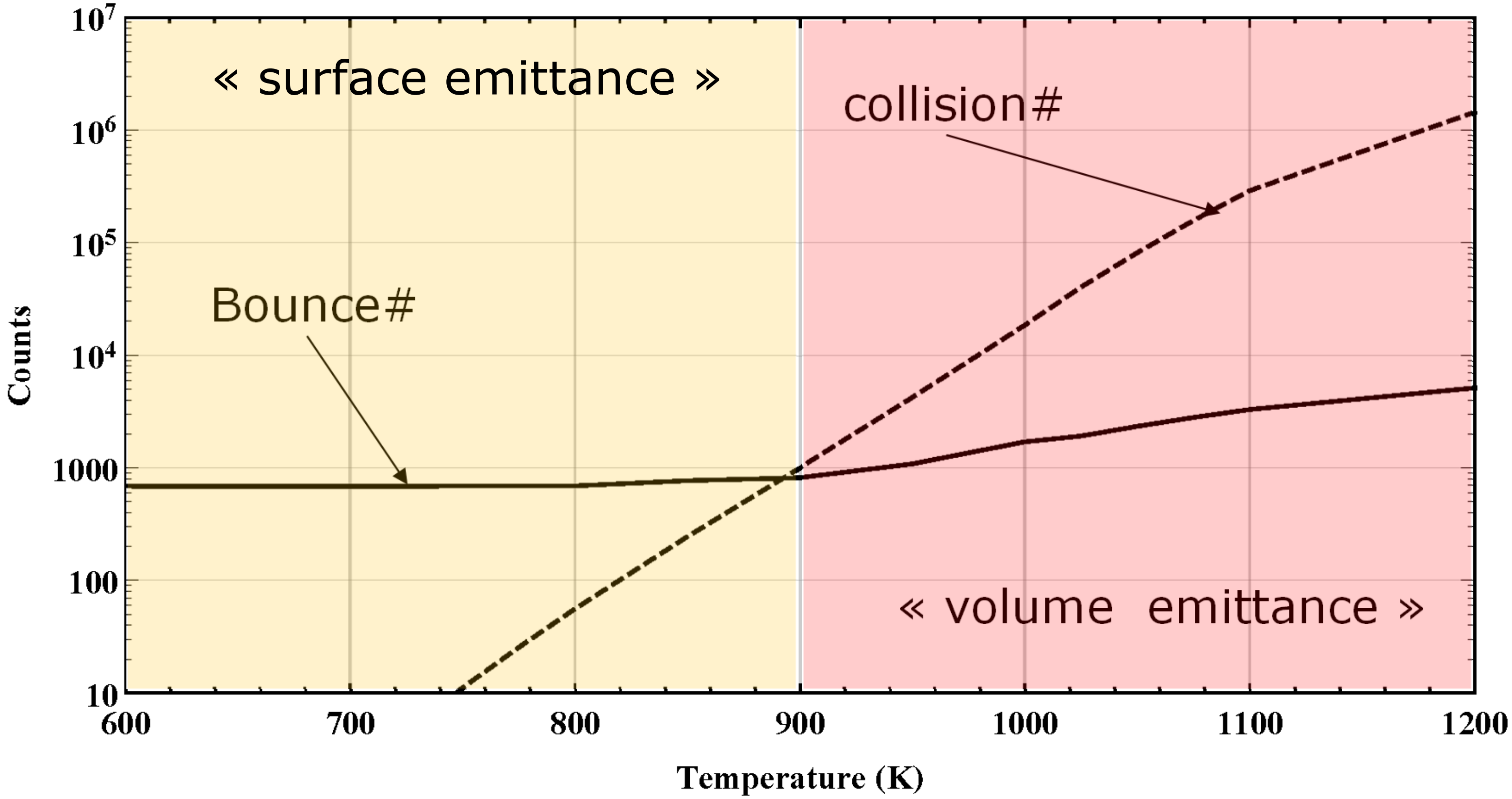
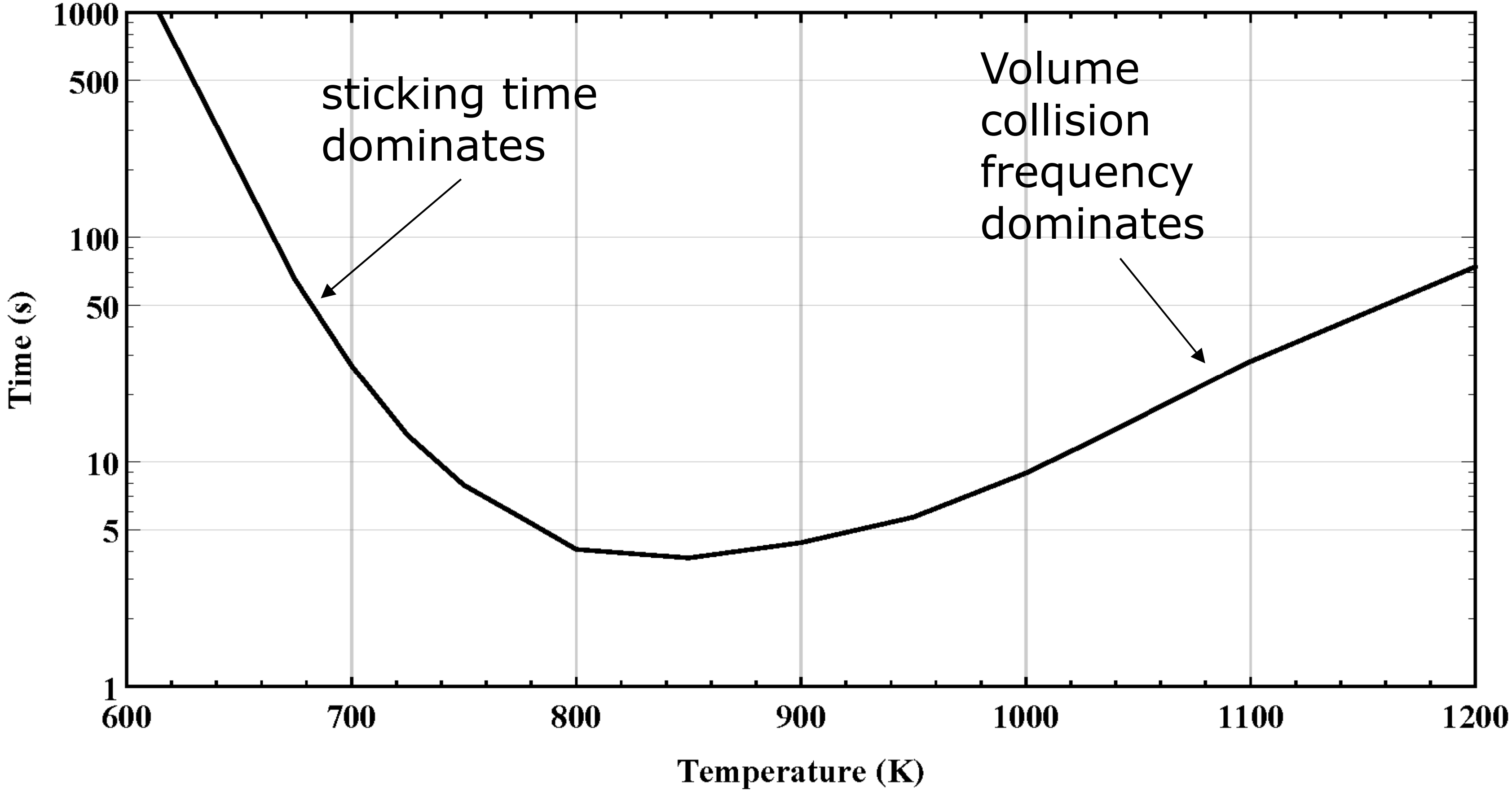
- Ca gaz is non collisional up to 900K (625° C)
  - T<900K: atoms extracted directly coming from walls
  - T>1000K : atoms coming from the volume
  - T~900K-1000K : transition





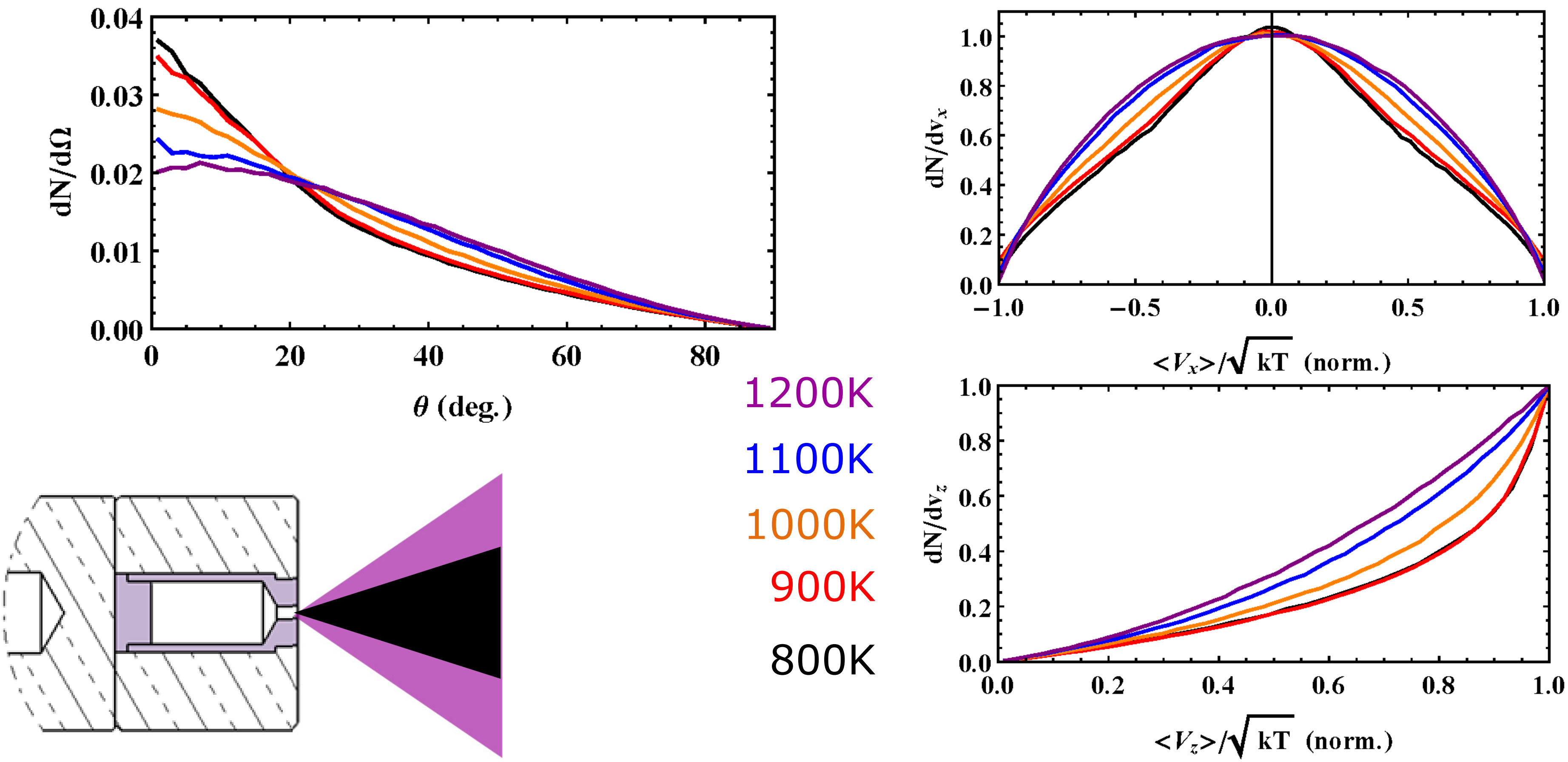
Atom extraction time

➢ A balance between sticking time and collision frequency



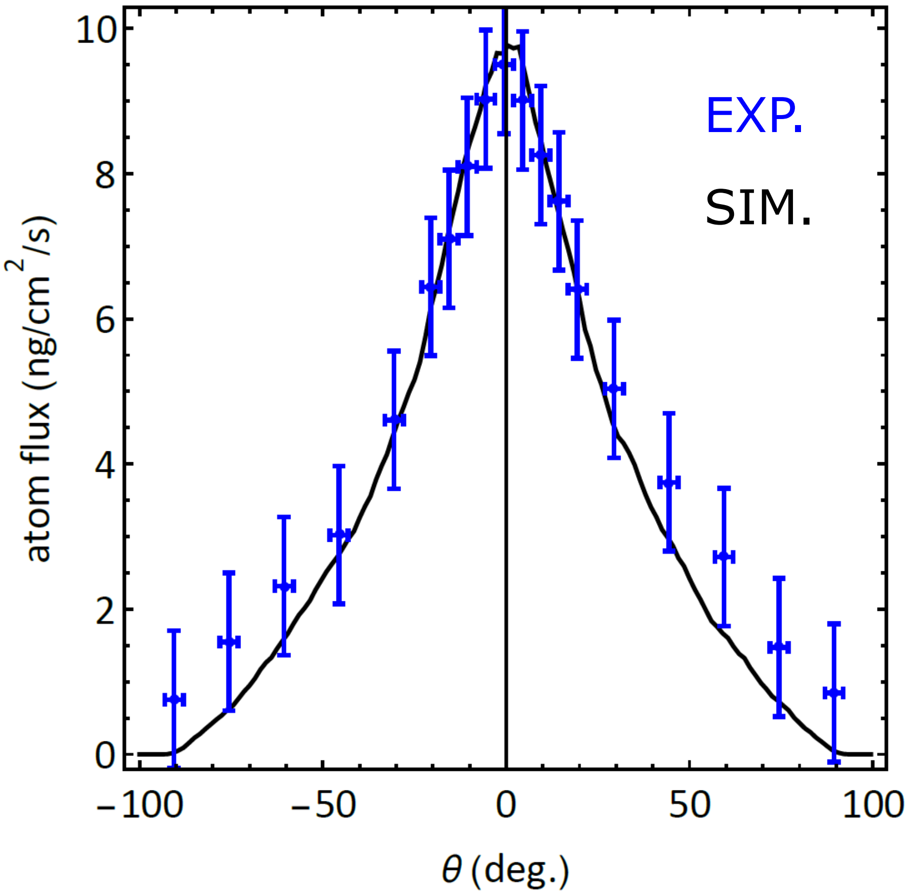
Simulation results

- Atom Emittance depends on the temperature
  - The exit channel drives the emittance up to T ~ 900 K
  - Volume collision spreads the beam above 900K



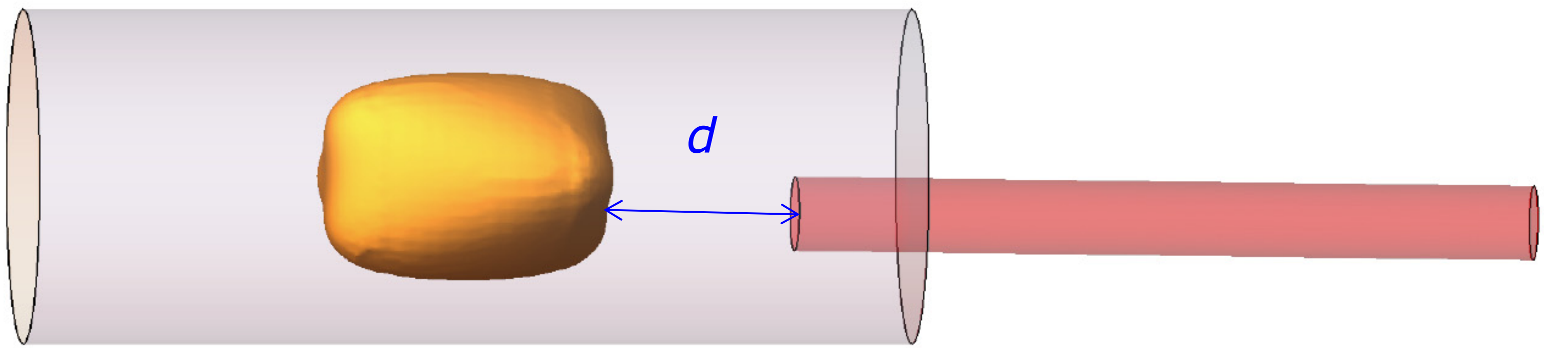
Simulation vs Experiment

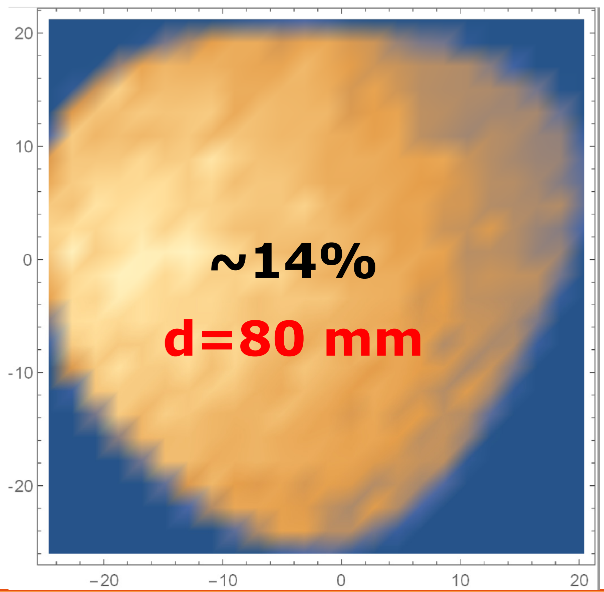
- Quite good agreement
  - Underestimation of large angle flux by simulation
  - But result compatible with uncertainties

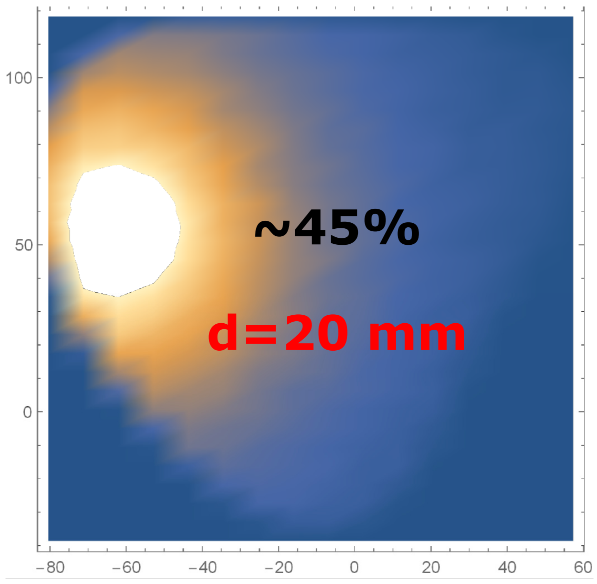


Atom to ion conversion yield in ECRIS

- Simulated with PHOENIX V3 ECRIS
  - Oven Temperature T~425°C (700K)







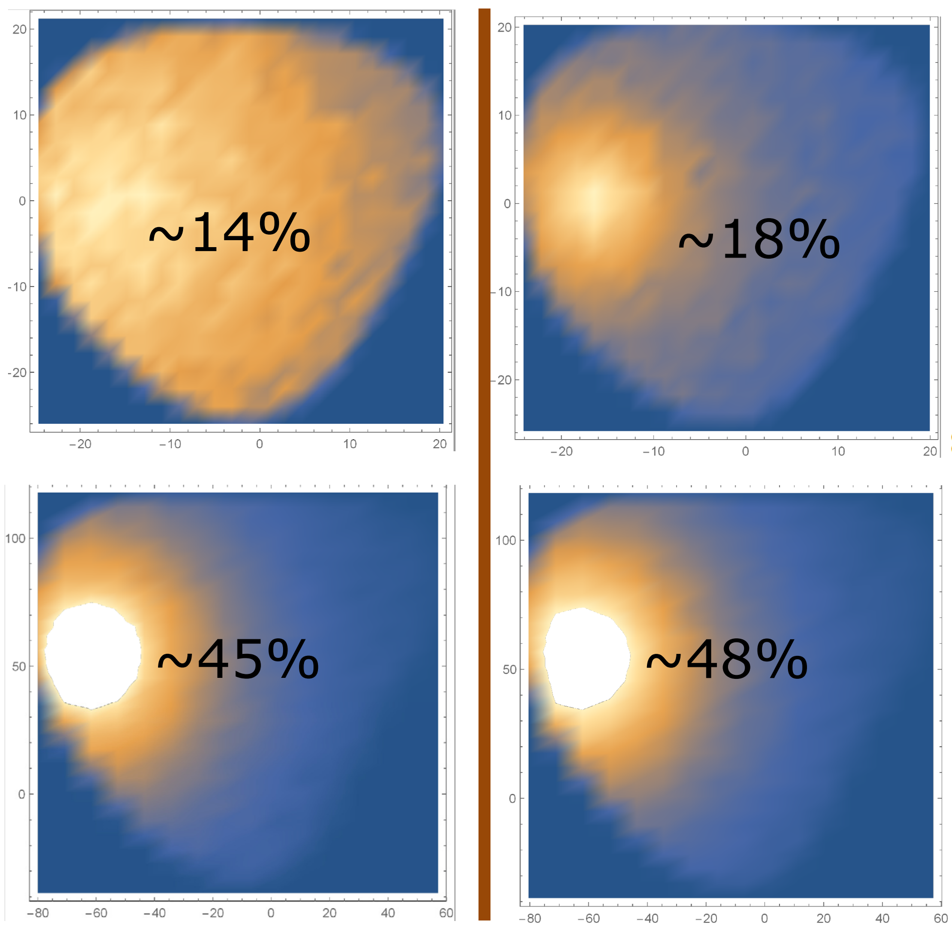
Effect of the exit channel geometry

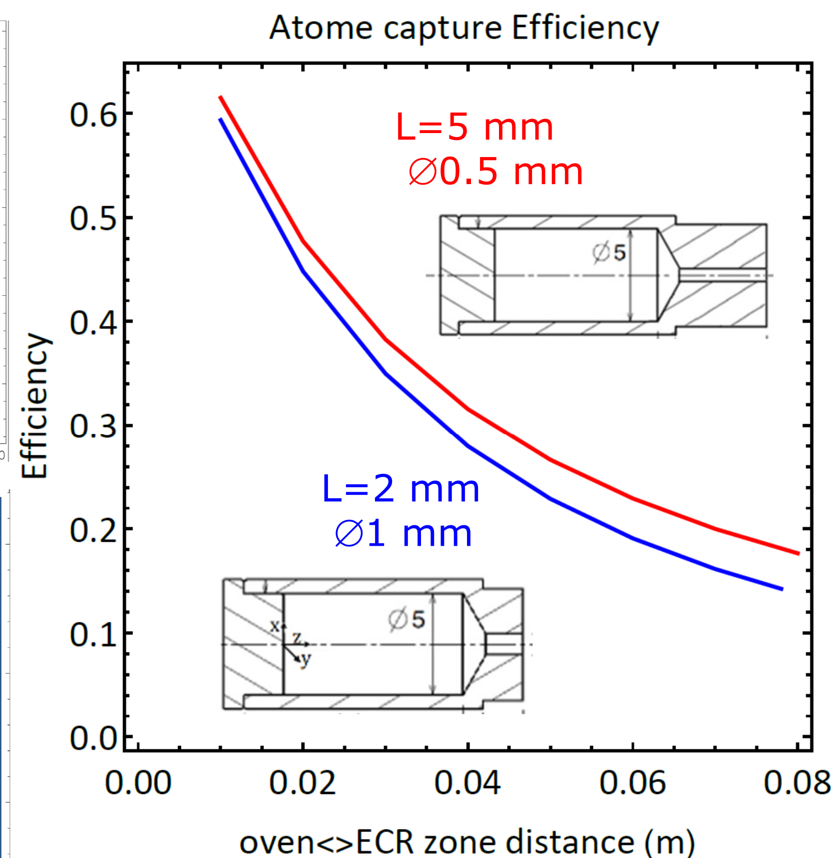
- Yield enhancement with the nozzle geometry is secondary with respect to the oven distance to the ECR zone

∅=1 L=2 mm ∅=0.5 L=5 mm

d=80 mm

d=20 mm





Conclusion

- Calcium oven behaviour is well understood
  - A Ca layer covers the Mo walls
  - the surface of evaporation includes the crucible surface
- Absolute Ca mass flow gave new measurements of Antoine's law equation parameters
- Simulation reproduces fairly well the differential mass flow measurements
- Atom to ion conversion strongly depends on the distance to the ECR zone. It ranges between 14% and 45%
- Exit channel geometry does not change significantly the atom to ion yield
  - Provided the oven aims at the ECR zone
  - To be cross checked experimentally

THANK YOU FOR YOUR ATTENTION

The webinar saved ~40.000 kg of CO_2, which is great for our kids!