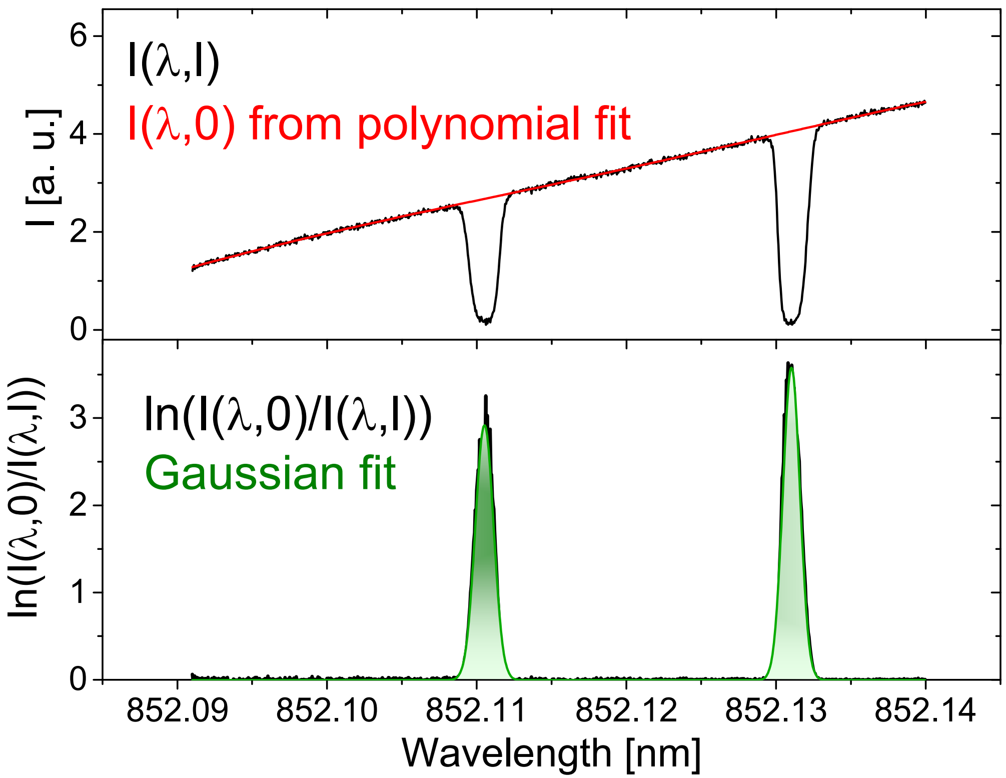
Improved understanding of the Cs dynamics in large H^- sources by combining TDLAS measurements and modelling

Christian Wimmer, Alessandro Mimo, Maria Lindauer, Ursel Fantz and IPP-NNBI-team

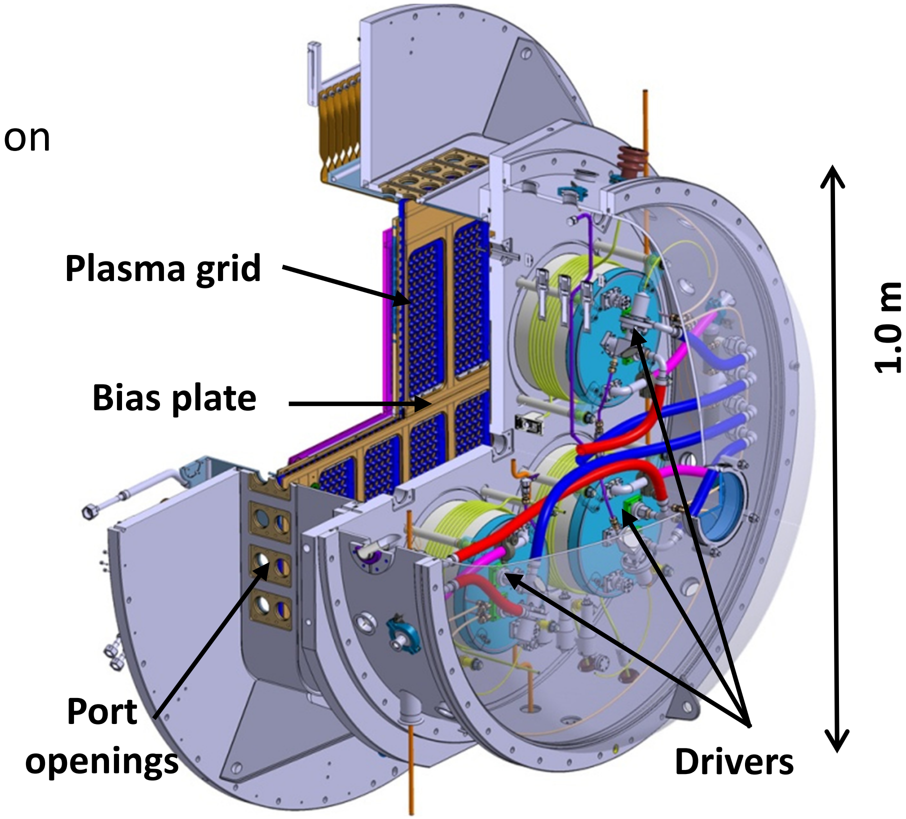


- **ELISE test facility and Cs diagnostic**
- **Cs density in short and long pulses**
- **Role of back-streaming ions**
- **Analysis of Cs line profile**

The ELISE test facility

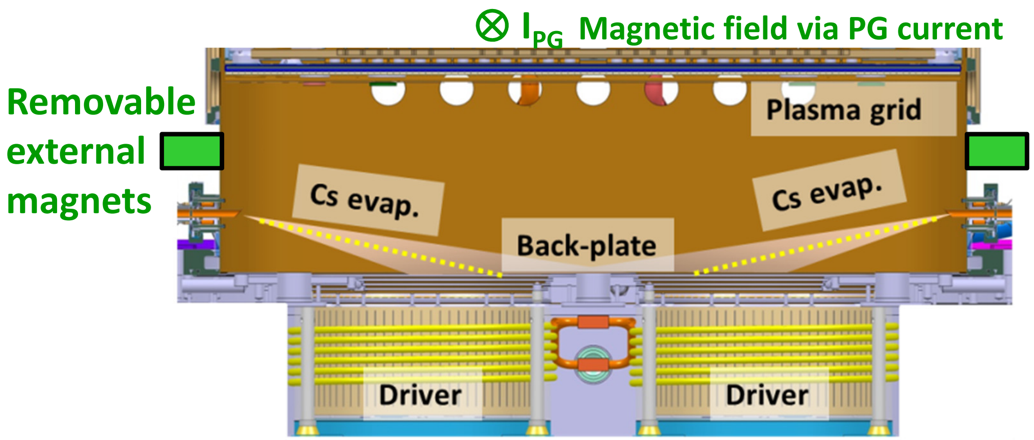
ELISE test facility with a ½-size ITER source

- **Provide input** for design, commissioning and operation of ITER NBI systems and **European test facilities**
- **Demonstrate** ITER parameters in large sources
  - Extracted currents (ions and electrons)
  - Beam homogeneity
- **Develop** most efficient source operation scenarios



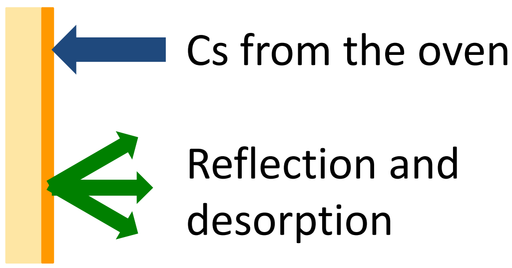
Parameter and targets

Isotope H^-, D^-
RF power = 2 x 180 kW in 4 drivers
A_{ex} = 1000 cm^2, **uniformity > 90%**
$I_{ion,acc}$ = 20 A, I_e/I_{ion} < 1 at 0.3 Pa
U_{tot} = 60 kV, U_{ex} < 12 kV
Plasma: 3600 s Beam : 10 s every 150 s (HV)



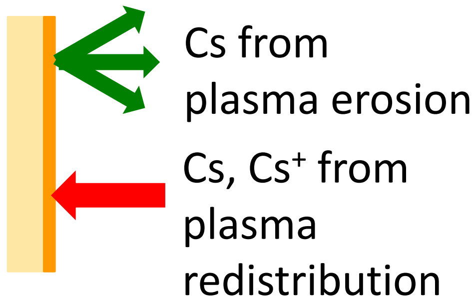
Phases of Cs dynamics and its modelling

Vacuum phase



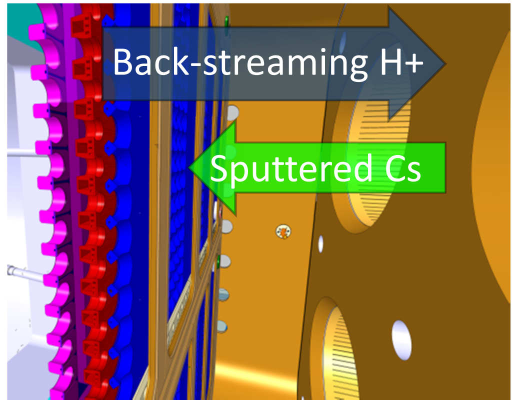
- **Pressure $10^{-5} – 10^{-4}$ Pa**
- **Ballistic transport of Cs**
  (collisions can be neglected)
- **Dynamics depends on oven evaporation and sticking coefficient**
  (temperature, impurities)

Plasma phase



- **Pressure 0.3 Pa**
- **Both Cs and Cs^+**
- **Erosion of Cs**
  due to the plasma and redistribution via collisions

Extraction phase



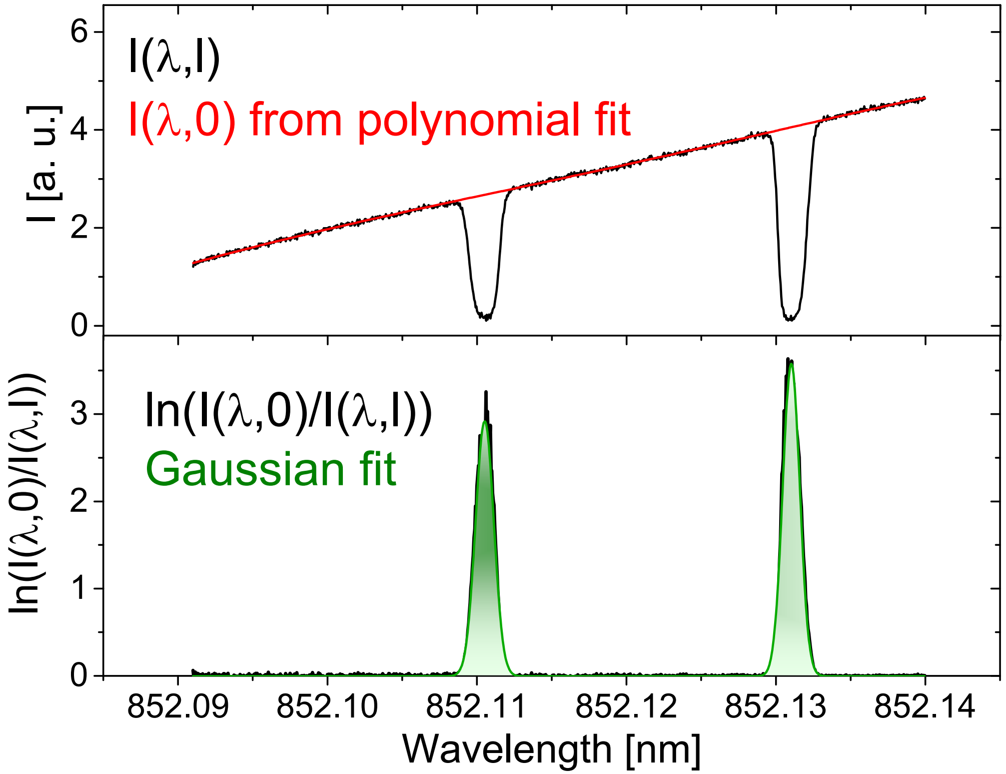
- **Additional source term of Cs and Cs^+:**
  sputtering due to back-streaming ions

CsFlow3D **Monte Carlo transport code** developed to study Cs dynamics in the source (i.e. fluxes and coverage on the surfaces). Benchmarked against the prototype source data.
Now predictions for ELISE: comparisons with experimental data from TDLAS.

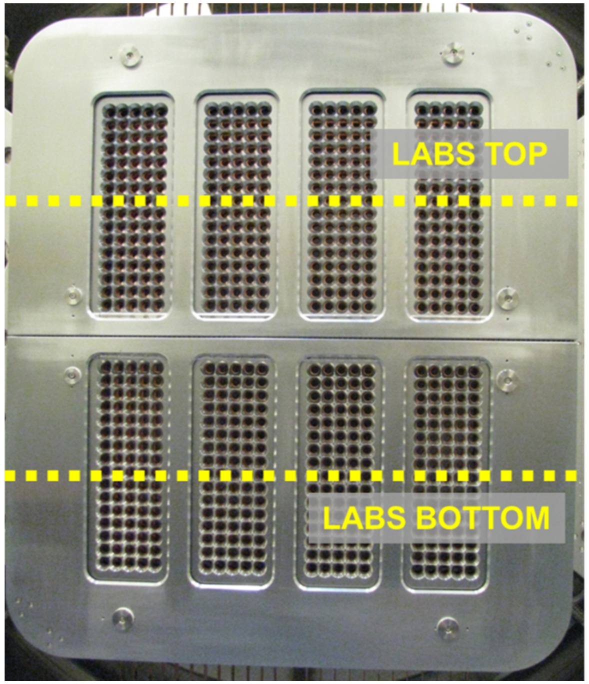
Diagnostics for Cs – Tuneable Laser Absorption Spectroscopy TDLAS

Measurement of the neutral Cs density in all 3 phases

Cs-D_2 resonant line (852 nm)



2 lines of sight close to the grid



Analysis of Doppler broadening of the absorption lines

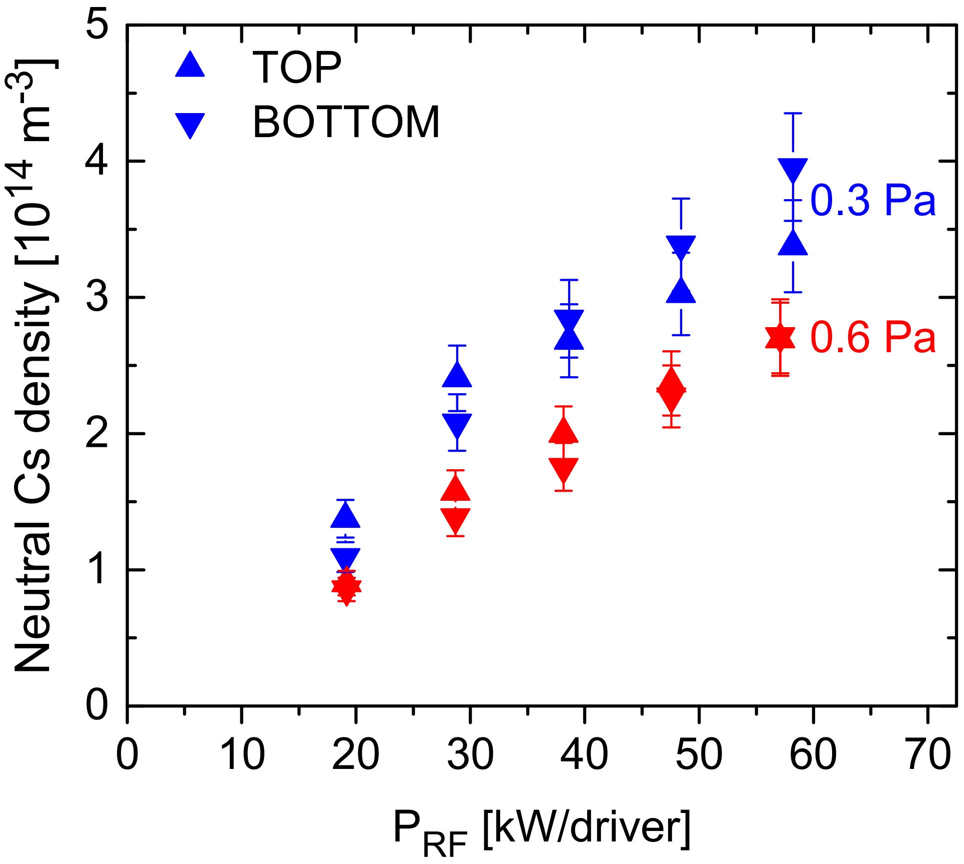
⇨ **Temperature of neutral Cs particles**

BUT: Zeeman splitting of absorption lines for high magnetic field strength

TDLAS – Measurement of Cs density and temperature of Cs particles

Cs density

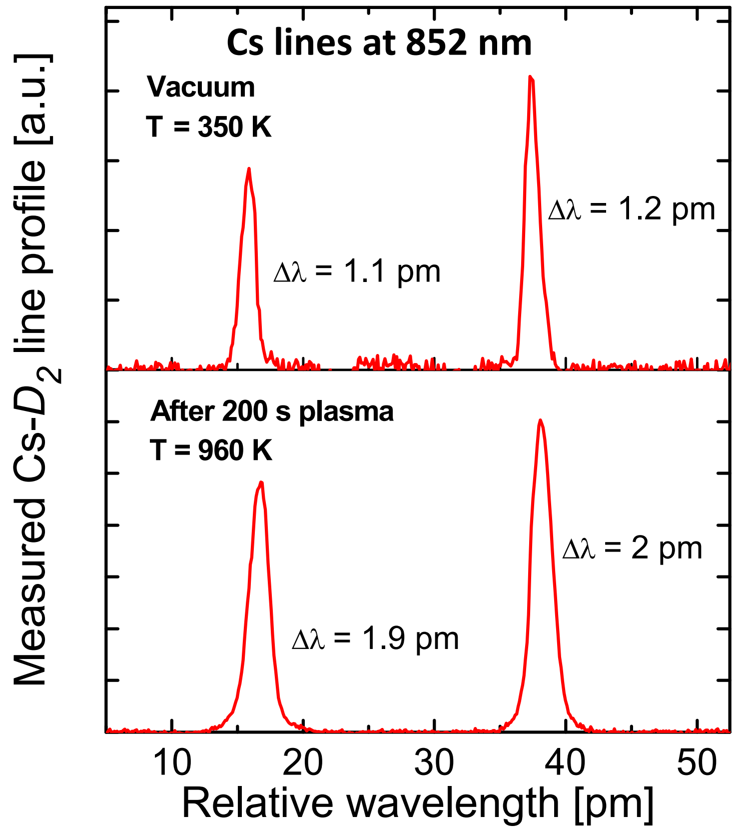
Variation of power and pressure



No significant vertical asymmetry

Temperature of Cs particles

(B-field < 40 Gauss; PG current only)



Vacuum: typical $\Delta\lambda \approx 1.1 - 1.2$ pm

⇨ **T ≈ 350 K ± 50 K**

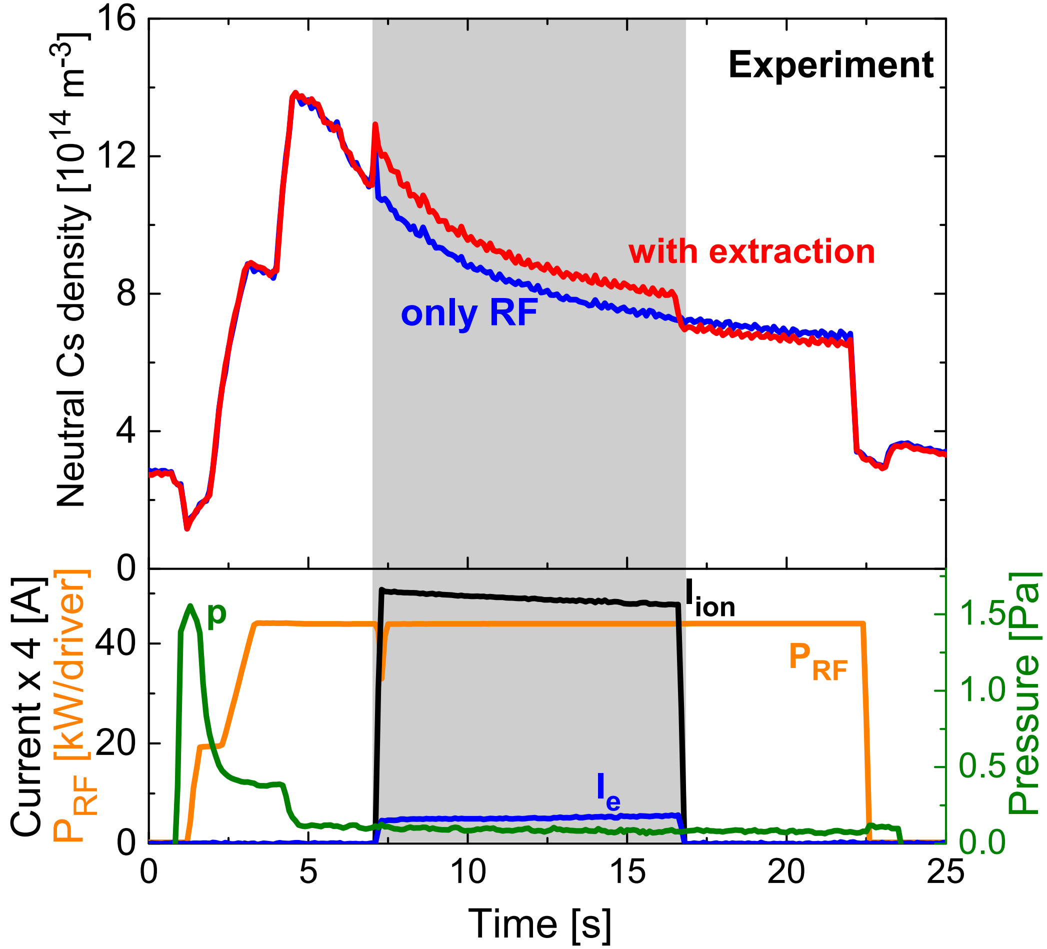
Plasma: $\Delta\lambda \approx 2$ pm

⇨ **T ≈ 960 K ± 100 K**

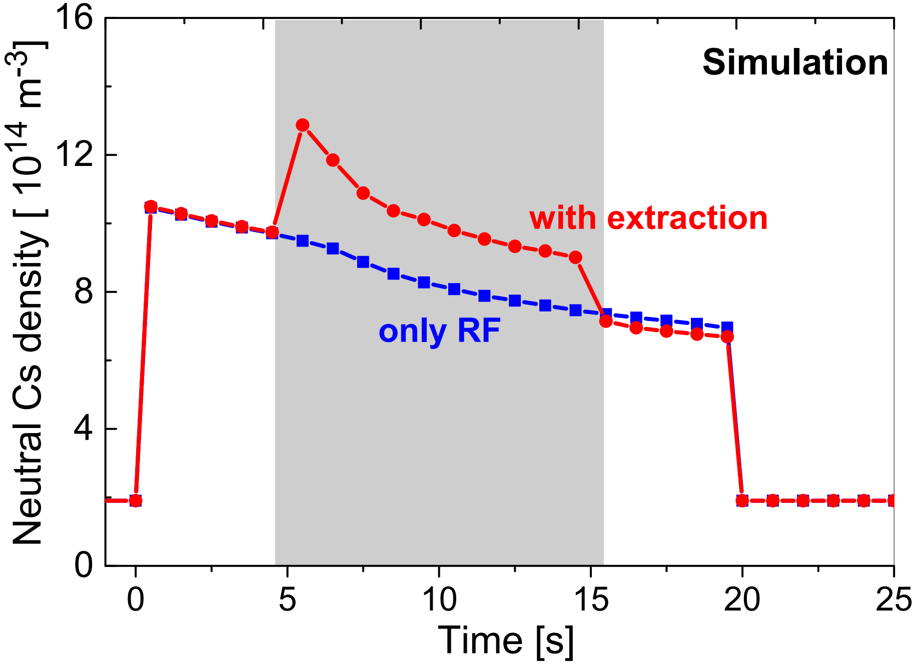
Comparisons of experiment with simulation

20 s plasma pulse with and without extraction

Experiment: 40 kW/driver at 0.3 Pa, typical Cs conditioning pulse



Simulation: 20 redistribution pulses, 200 s vacuum phase, Cs evap. 5 mg/h/oven



Calculation with and w/o contribution of Cs sputtered by back-streaming ions

using experimental data [1] as input

[1] L. Schiesko et al. (2011) Nucl. Fusion 51, 113021

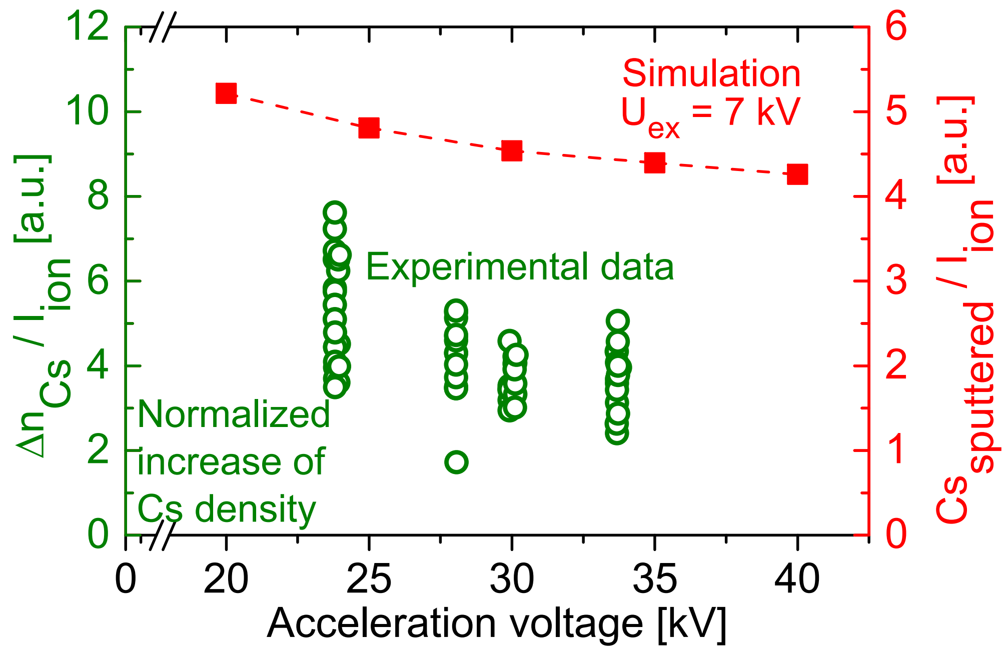
Trend and absolute values during the pulse in agreement

Cs density higher during extraction phases

Measurement – Cs release due to back-streaming ions

Dependence on acceleration voltage

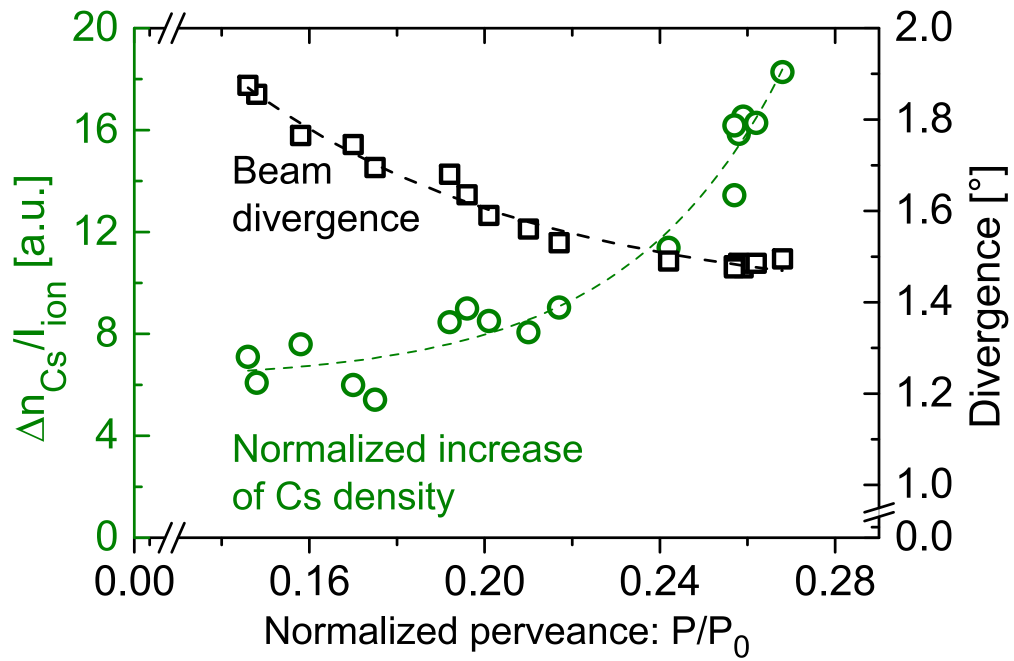
- Measurements indicate a weak dependence
- 1D model calculation for production of H^+, H_2^+ and Cs sputtering confirms the weak dependence



Dependence on beam optics

- Strong dependence on perveance
- Role of optics of H^+,H_2^+ ions ? [2]

⇨ **More investigations needed!**

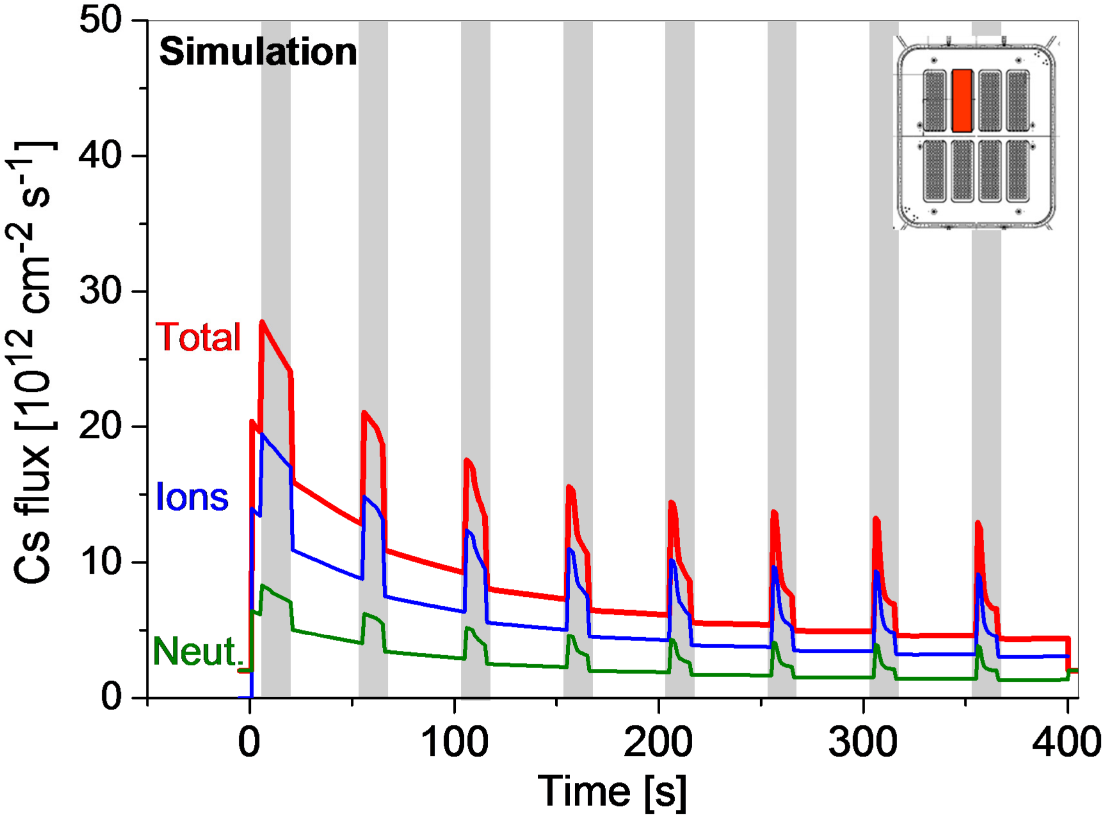


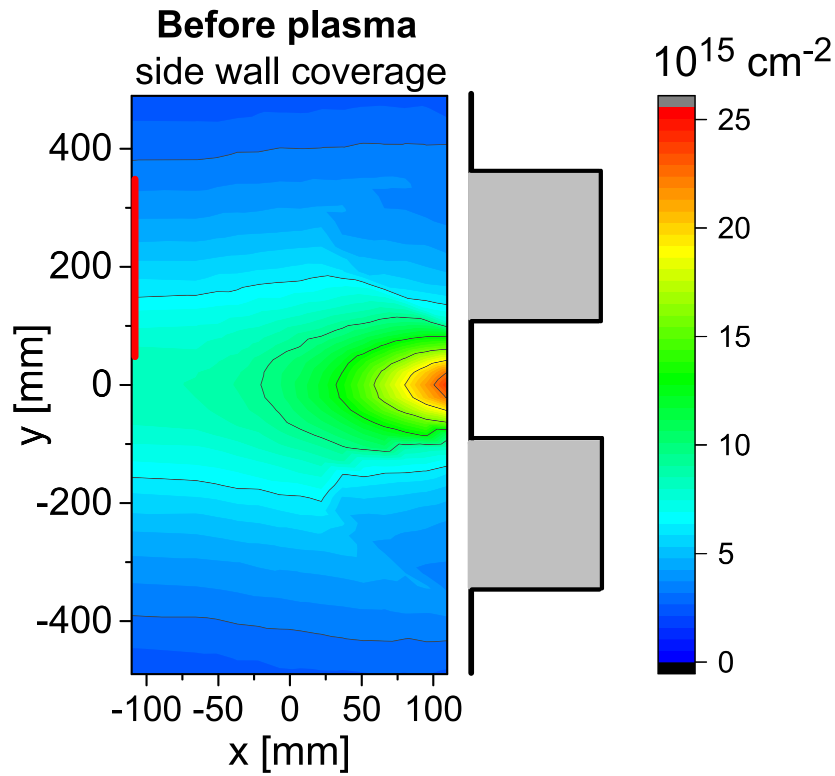
[2] K. Ikeda et al. (2017) AIP Conf. Proc. 1869, 050004

CsFlow3D – Simulation of long pulses

Simulation of the average Cs flux onto one beamlet group

- **Several beam blips** (10 s every 50 s) during 400 s plasma
  - Cs ions dominate the total flux with 70%
  - Fast decrease with time but back streaming ions provide additional Cs





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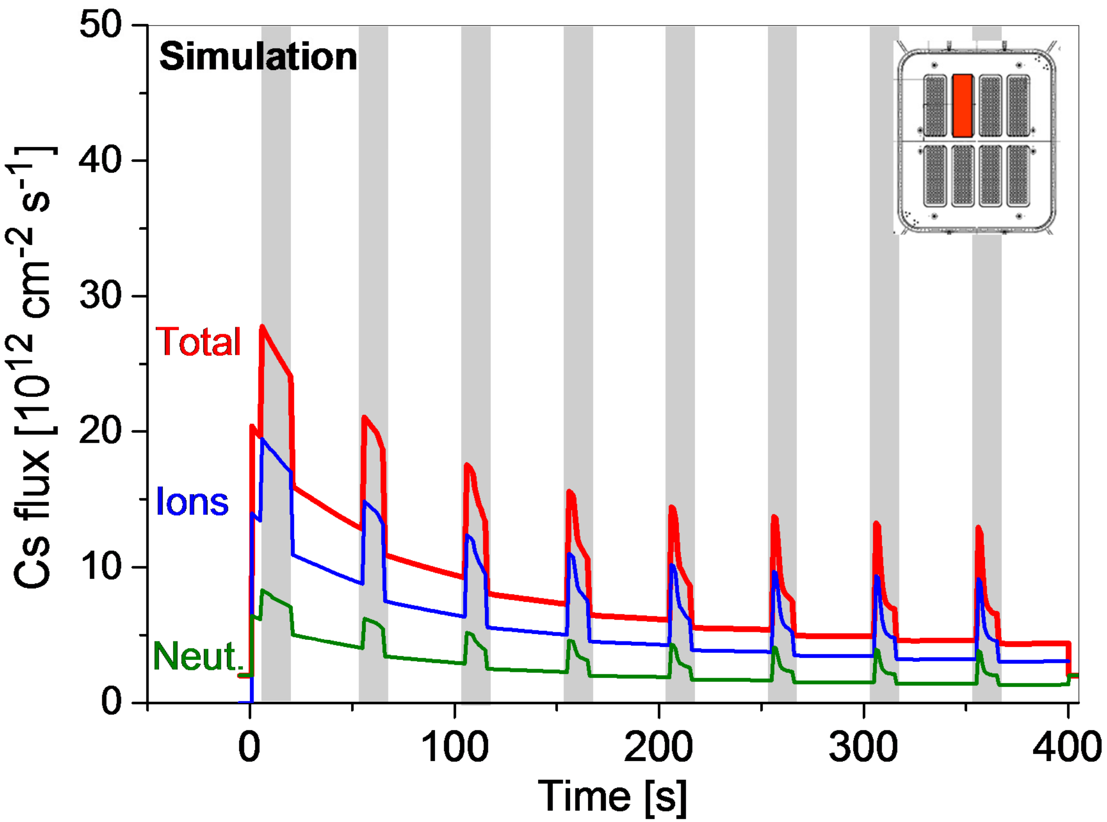

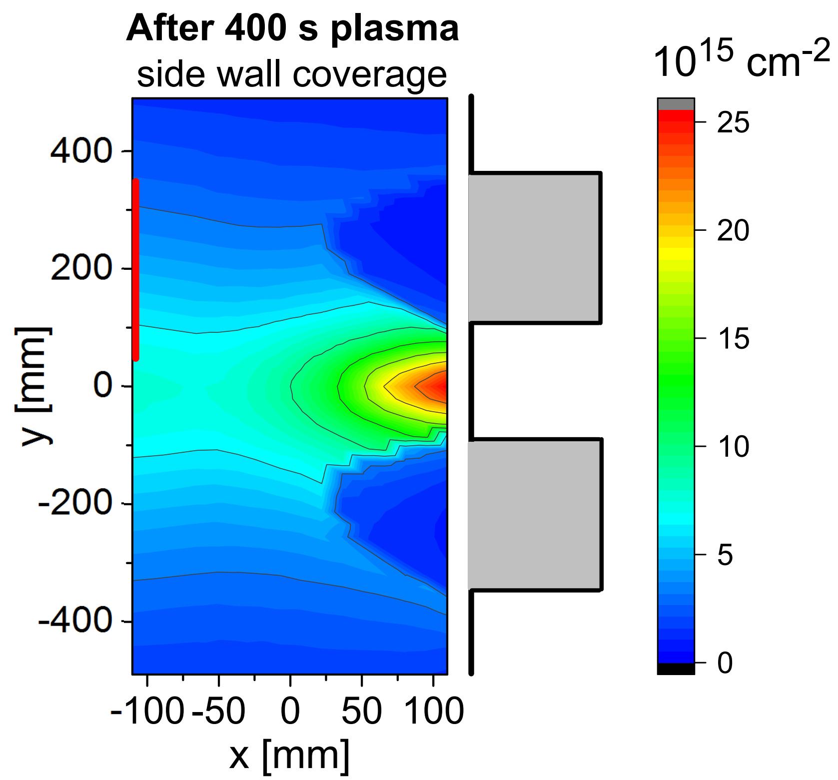

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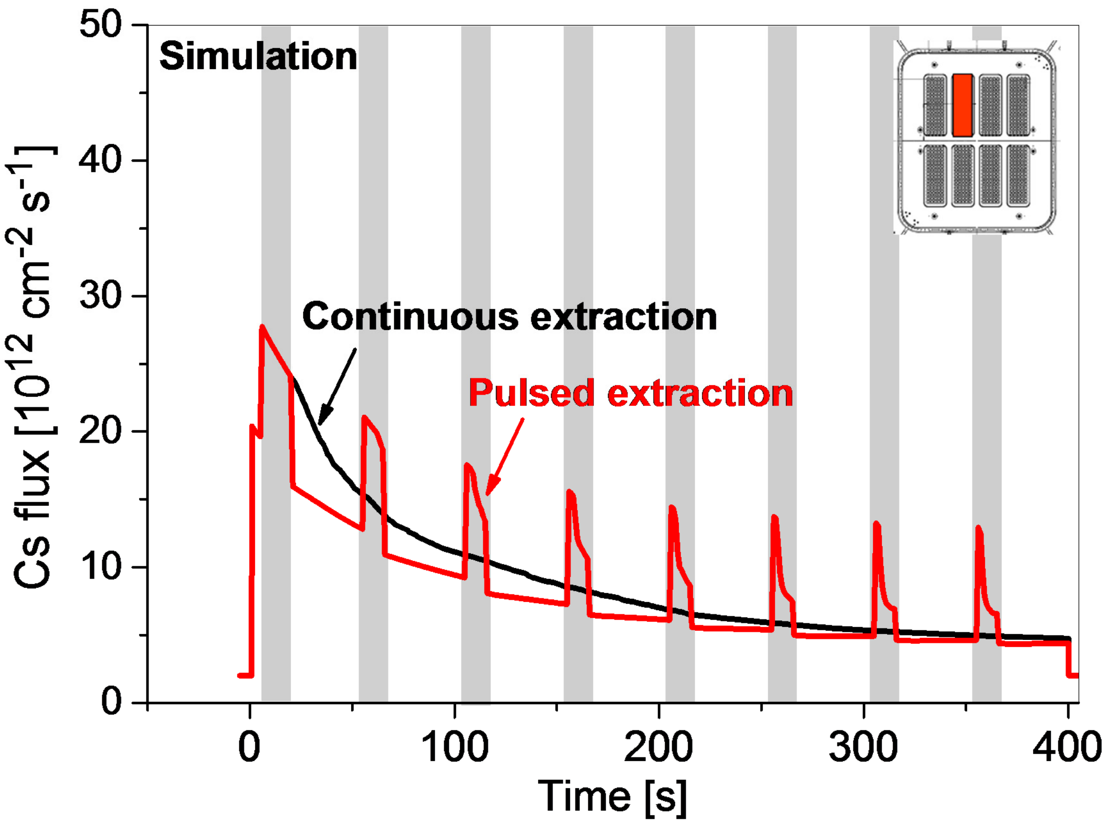

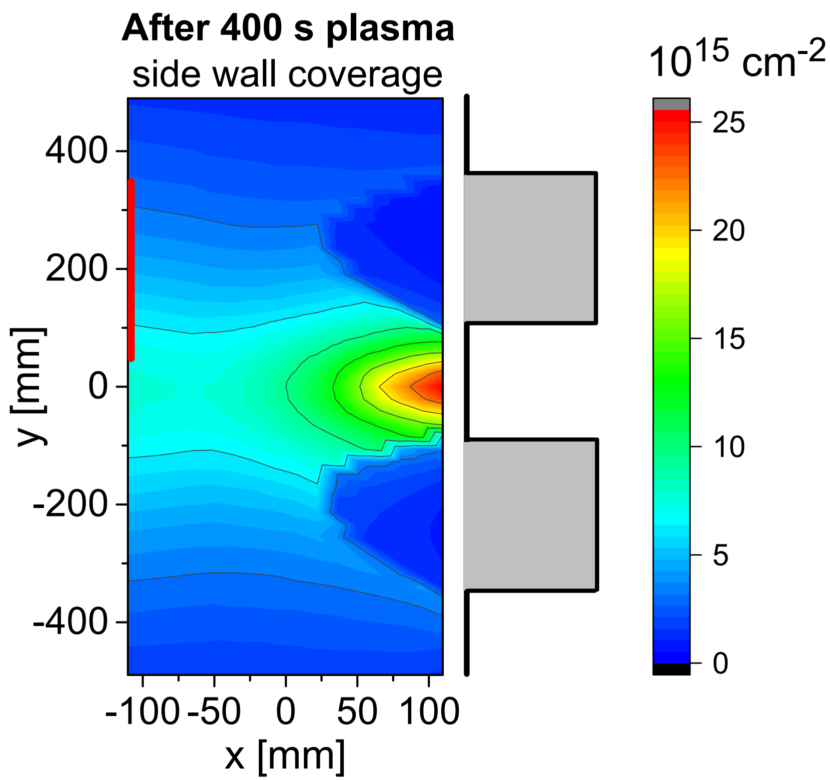

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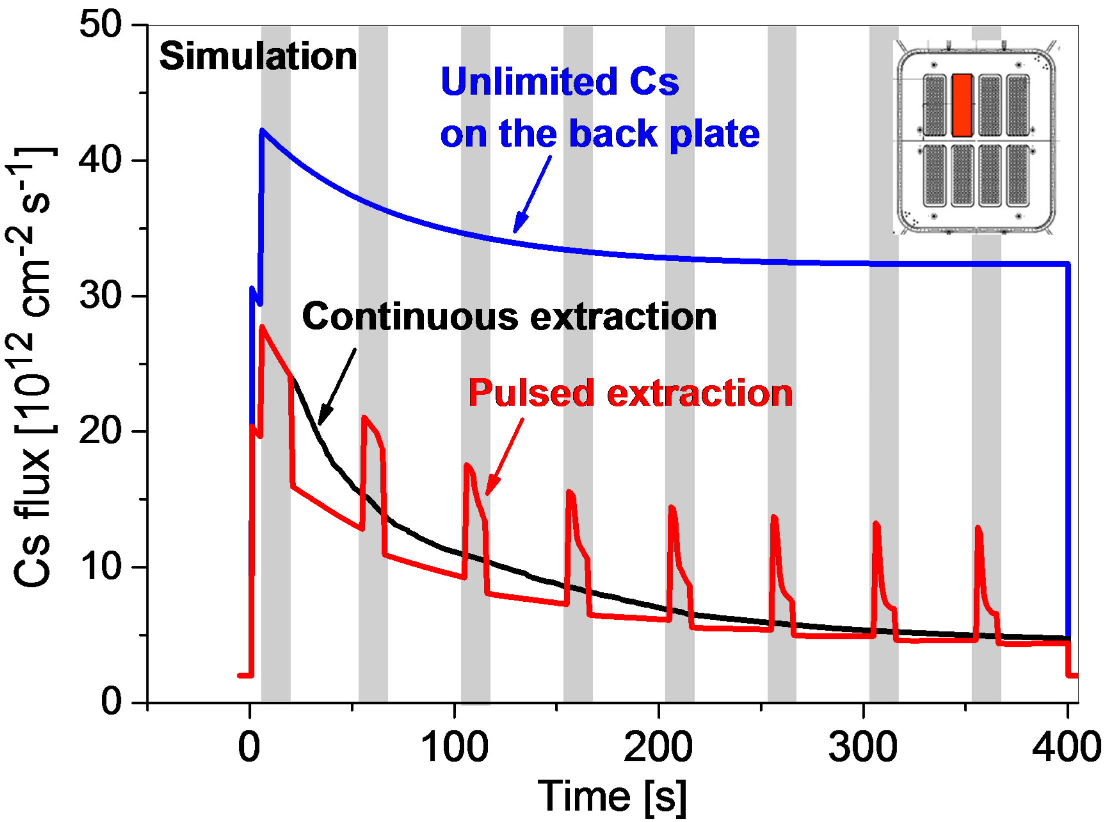
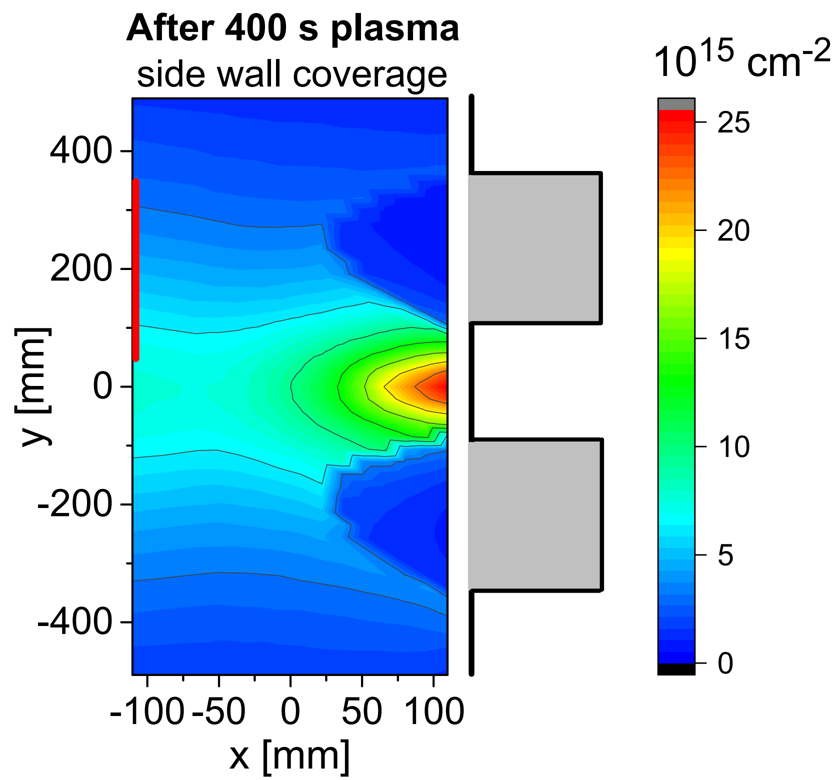
- **Continuous extraction ⇨ still not sufficient to stabilize Cs flux**
- **Unlimited Cs reservoirs in the back-plate: higher and stable flux**

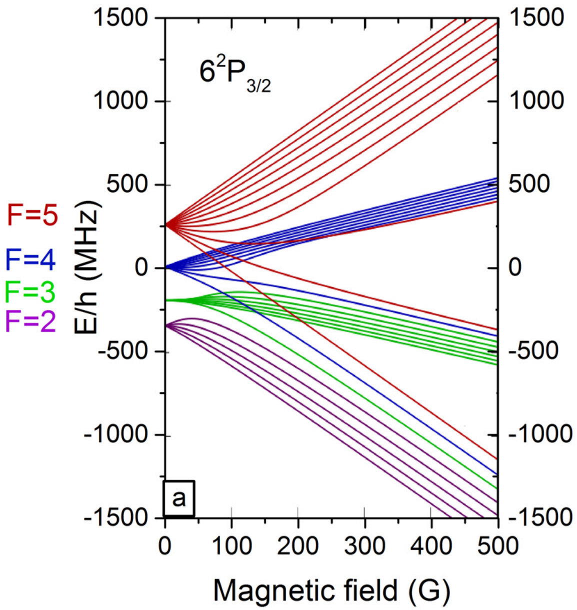


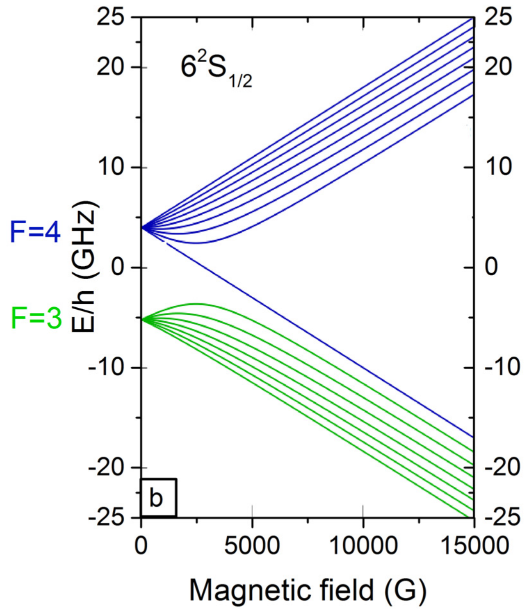


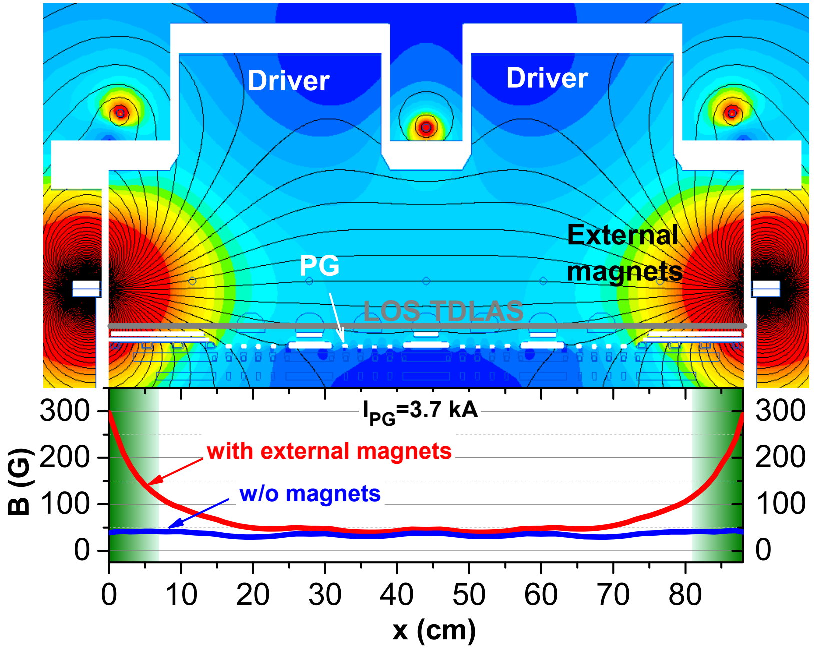
Experiment – Cs line profile during long pulses

External magnets at the lateral walls gives field strengths up to 300 G

- Absorption lines affected by Zeeman splitting







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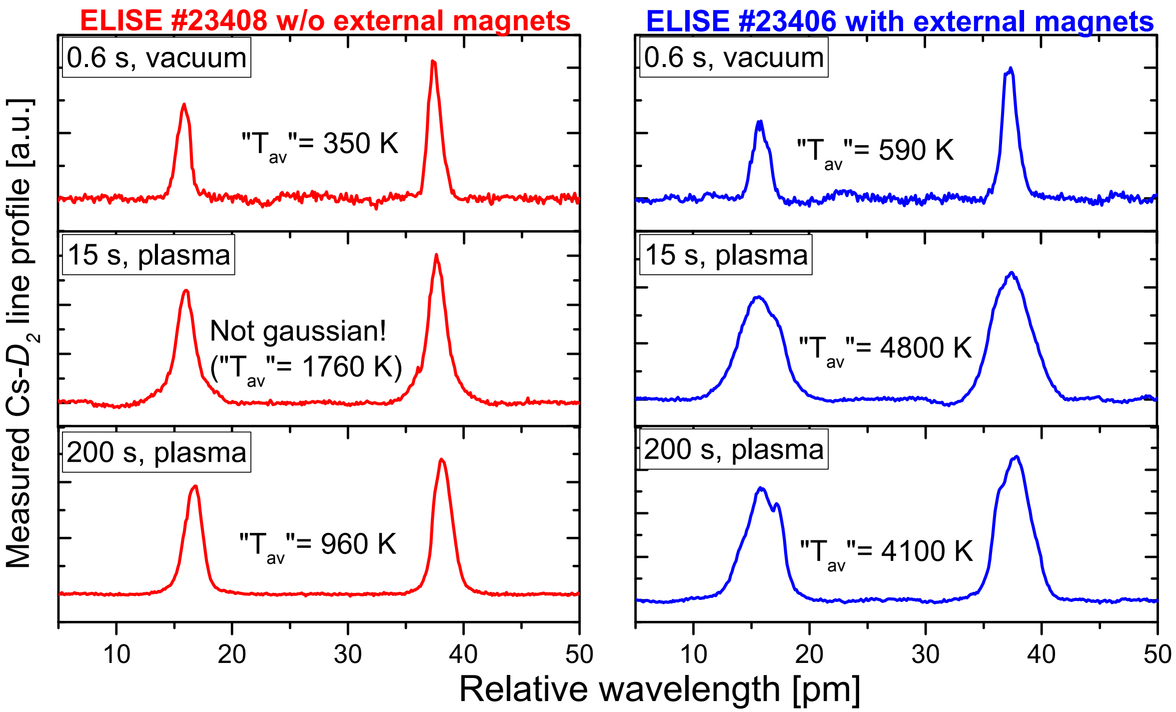
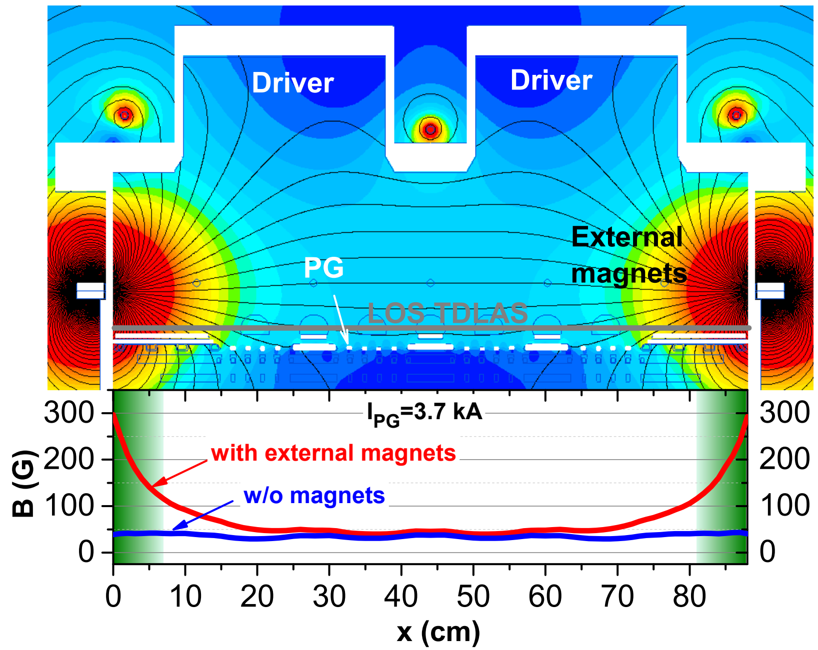
- Absorption lines affected by Zeeman splitting
- Comparisons of absorption spectra with and w/o external magnets
  - ⇨ **Line splitting is evident in long pulses with magnets**





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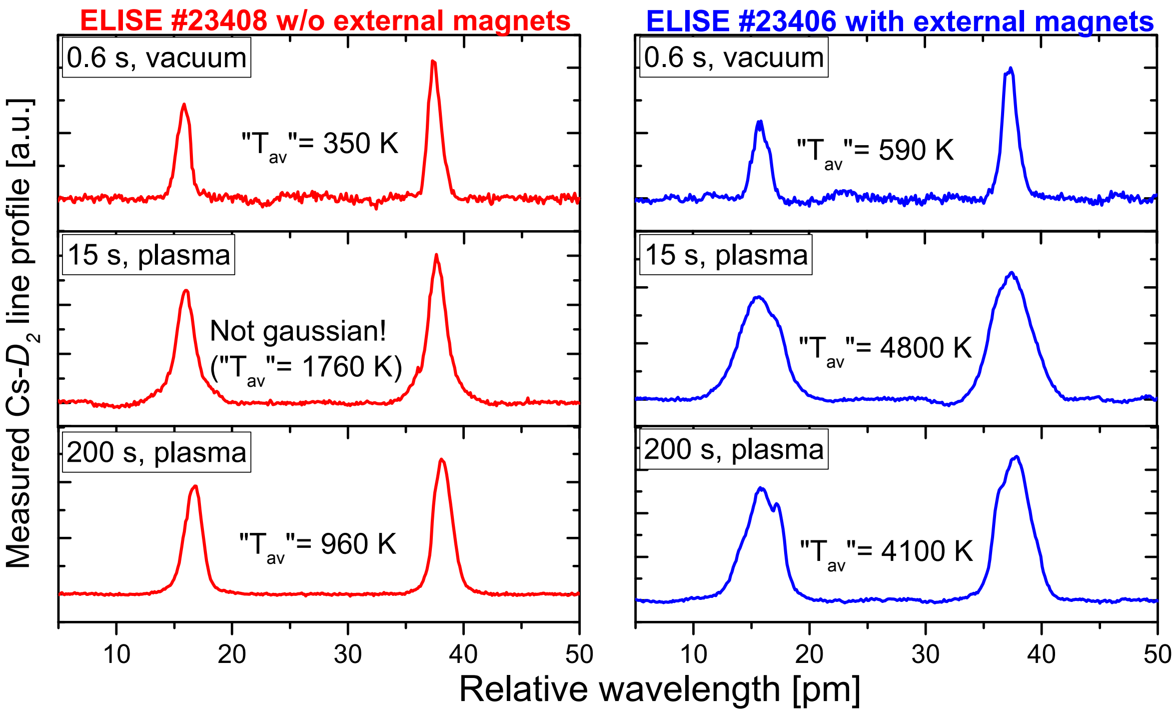
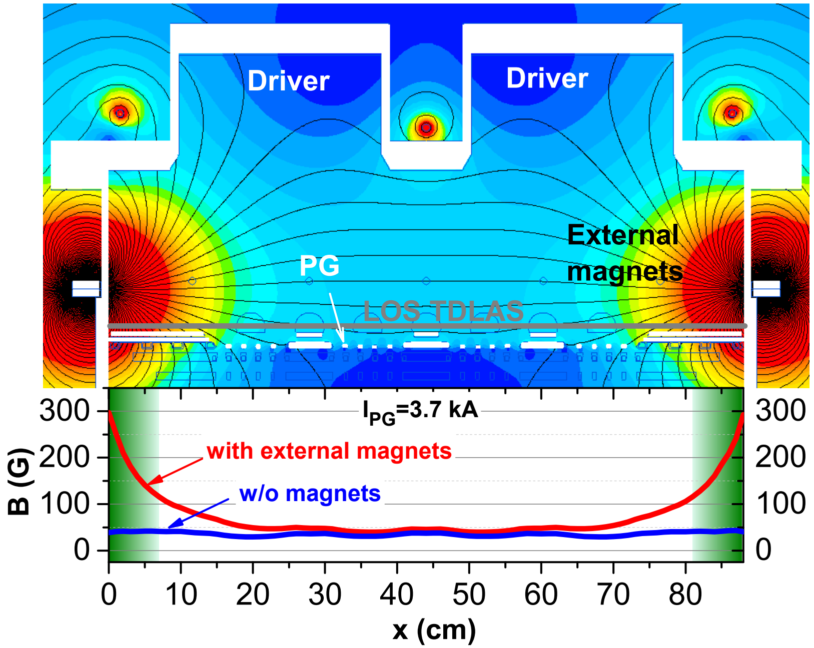


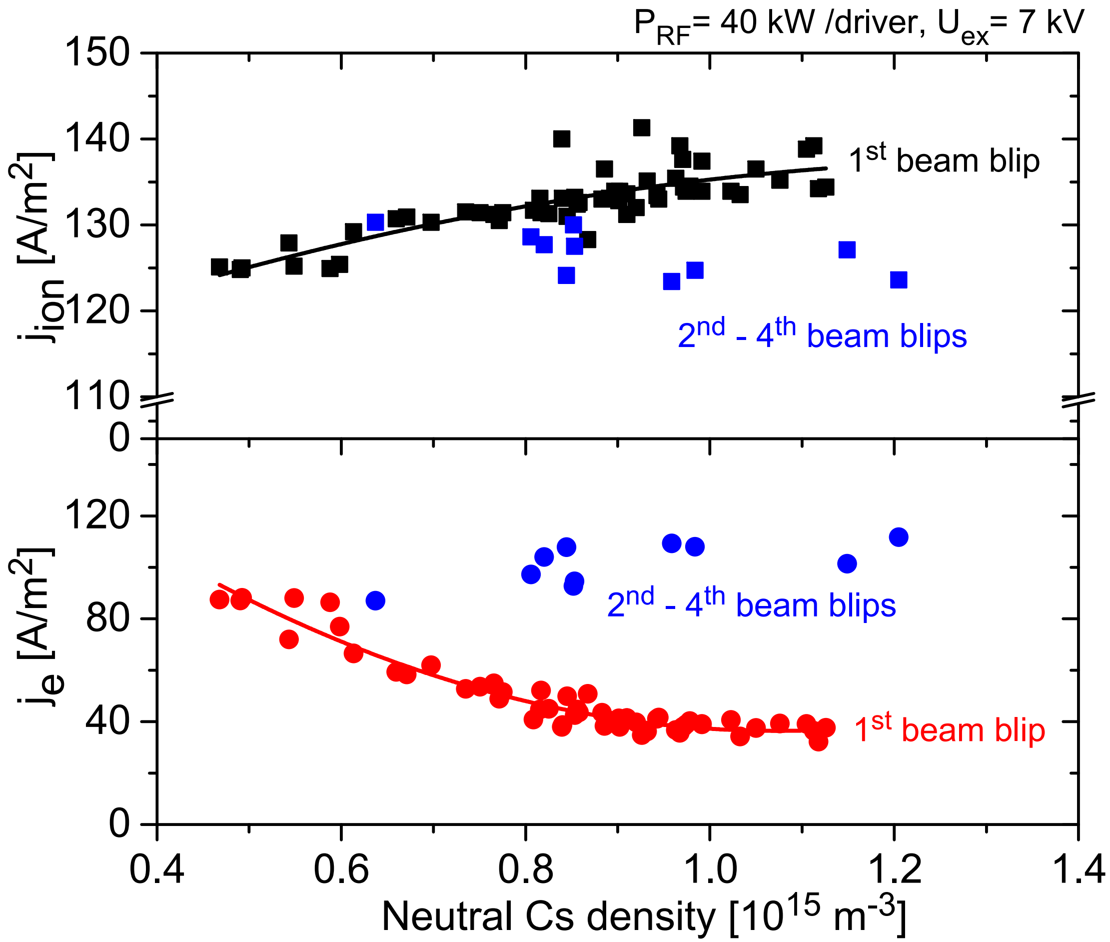


Zeeman effects gives a spatial resolution along the lines of sight

Majority of Cs is situated close to the lateral wall ⇨ effect on the performances?

Experiment – Cs line profile during long pulses

Zeeman effect gives a spatial information along the lines of sight



First beam blip (< 20 s) correlates well with detected neutral Cs

BUT > 1 beam blip: correlation lost as neutral Cs is located near the walls.

⇨ **Depletion of neutral Cs in front of the grid !**

Conclusions

New insights in Cs dynamics for large sources

- ✓ **No significant vertical asymmetry** of Cs distribution
- ✓ Influence of the **wall temperature** (strong reactivity of Cs with impurities)
- ✓ **Back-streaming ions** can be a relevant Cs source term: are they affected by the optics?
- ✓ **Neutral Cs temperature** in vacuum (≈ 350 K) and in plasma (≈ 1000 K)
- ✓ With external magnets: **Zeeman effect gives a spatial resolution** along the line of sights.
- ✓ Comparisons with simulations: **CsFlow3D can be used as a predictive tool**

↓

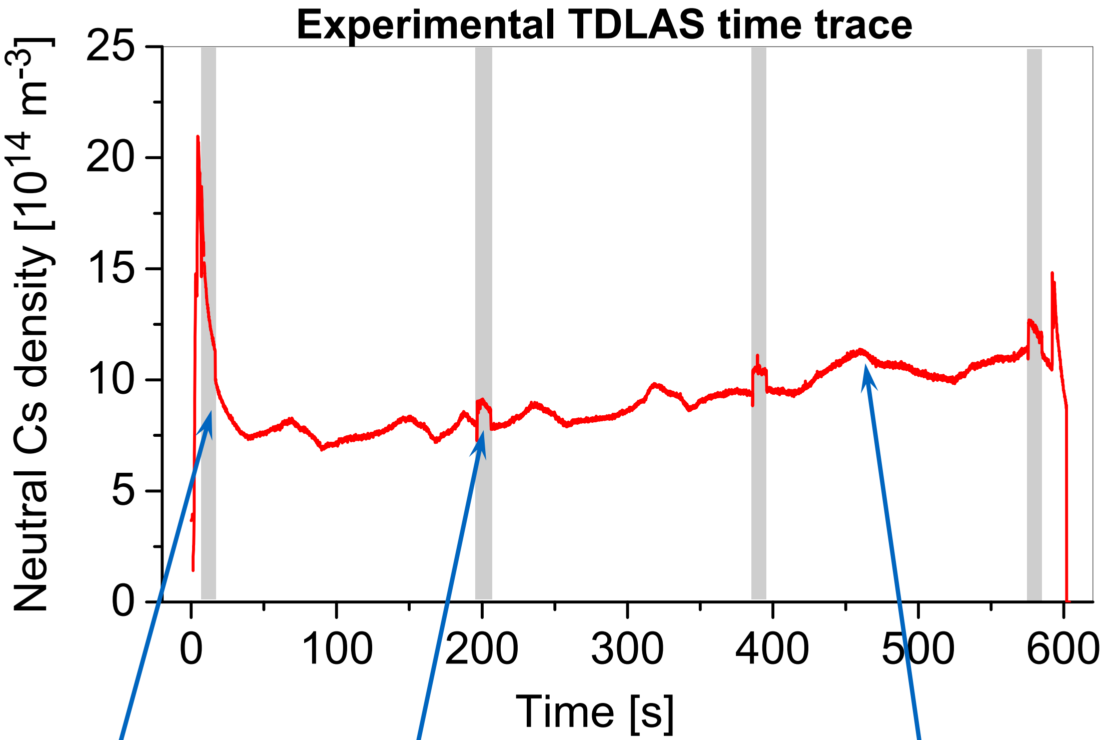
TDLAS shows a depletion of neutral Cs in the center of the source...

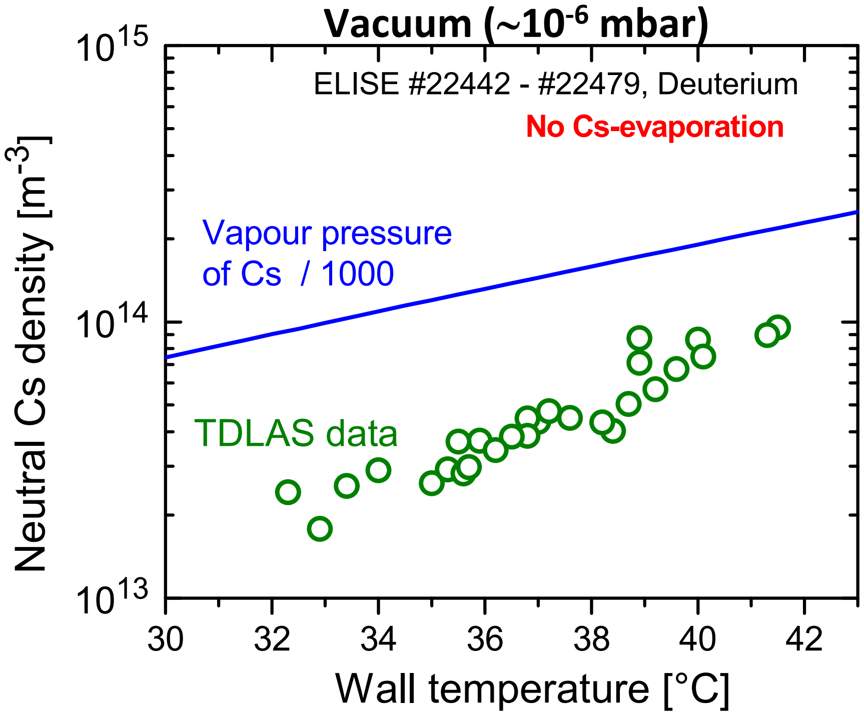
How to bring Cs/Cs+ onto the large PG during long pulses?

Alternative solutions need to be identified, since Cs evaporation cannot be increased further (already at the operative limit for breakdowns).

Experiment – Long pulse behaviour

General trends of the Cs density during long pulses





Fast decrease of neutral Cs density during the beginning of the pulse (≈ factor 3 in ≈ 50 s)

Oscillations ⇨ **Temperature effects**

- Cs density correlates with wall temperature
- Density > 10^3 times lower than predicted (Cs vapor pressure)
  ⇨ **Strong reactivity with impurities**

Back-streaming ion effect during the extraction phases