Max-Planck-Institut
für Plasmaphysik

Studies of Cs Dynamics in Large Ion Sources using the CsFlow3D Code

A. Mimo, C. Wimmer, D. Wünderlich, U. Fantz

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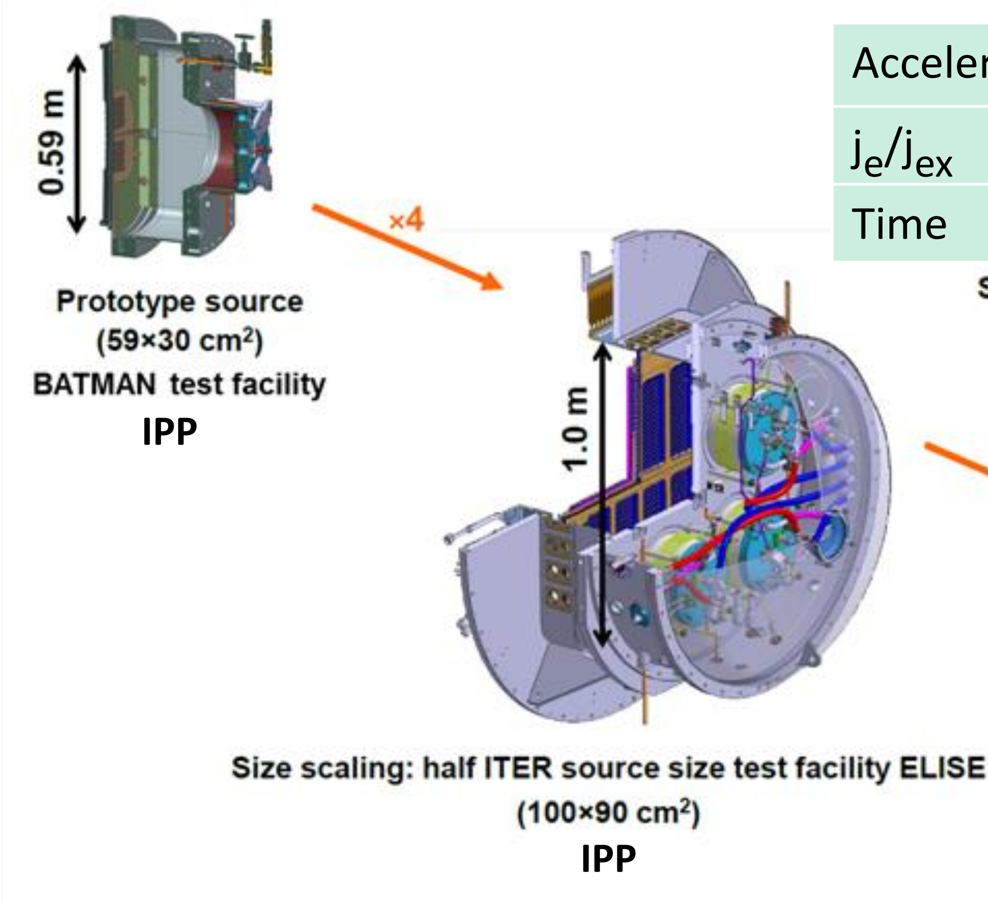
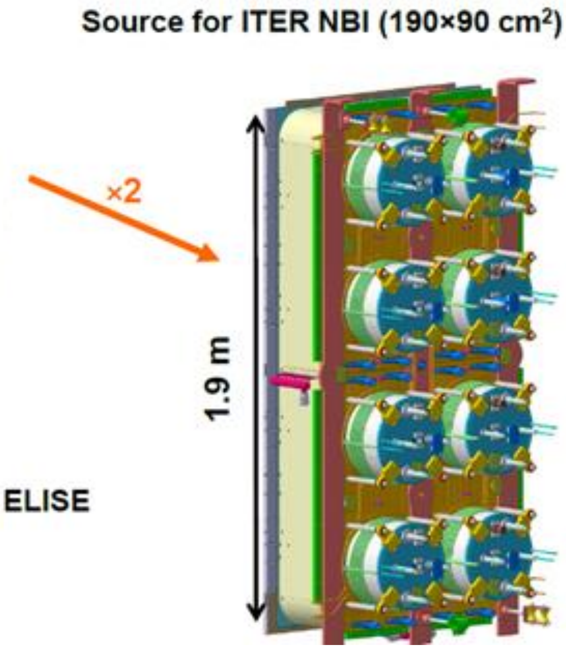
3rd - 7th September 2018

Budker INP, Novosibirsk, Russia

RF negative ion sources

Accelerated current	40 A in D^-
j_e/j_{ex}	< 1
Time	1 hour



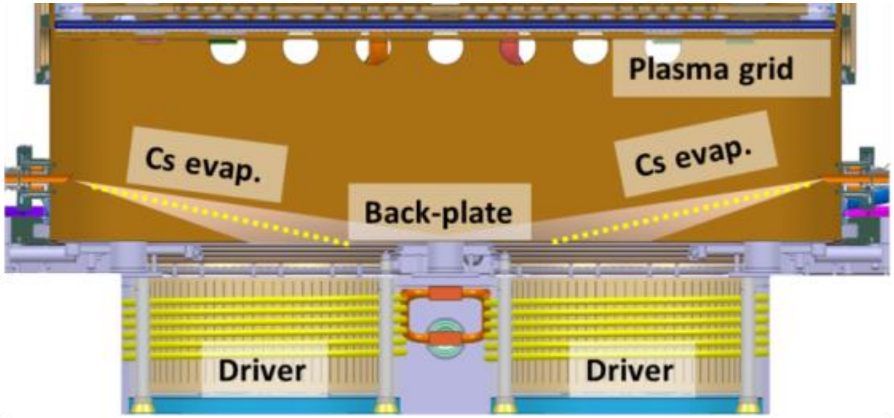


SPIDER
(Consorzio RFX)

ELISE test facility

Cs evaporation in ELISE:

- Two Cs ovens on the side of the expansion chamber
- Cs continuously evaporated during both vacuum and plasma phases



Maximum Power	360 kW
Total HV	60 kV
Plasma pulse time	up to 3600 s
Beam extraction	10 s every ≈ 150 s

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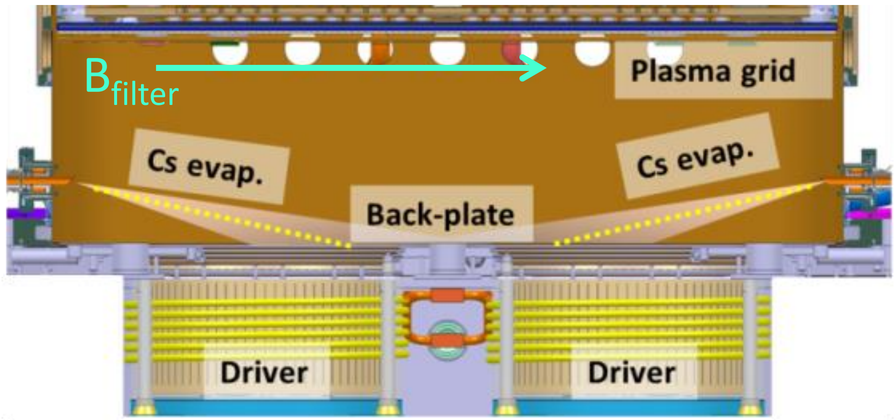

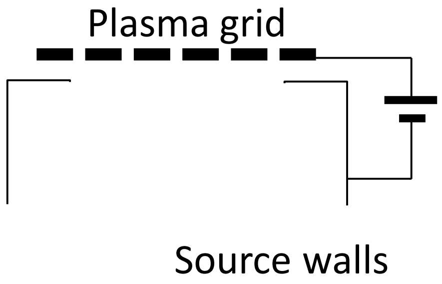

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Cs dynamics

VACUUM PHASE

- **Only neutral Cs**
- **Ballistic transport (p ≈ 10^{-4} Pa)**
- **Dynamics determined by:**
  - Oven outflow profile
  - Source geometry
  - Wall sticking probability (temperature and impurities)

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PLASMA PHASE

- **Both Cs neutrals and ions**
- **Collisions (p ≈ 0.3 Pa) :**
  - Background gas
  - Plasma
- **Cs redistribution by plasma**

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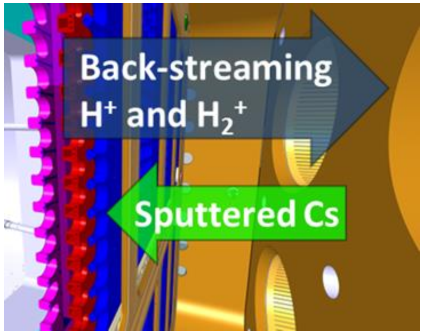
- **Cs Sputtering by back-streaming ions**



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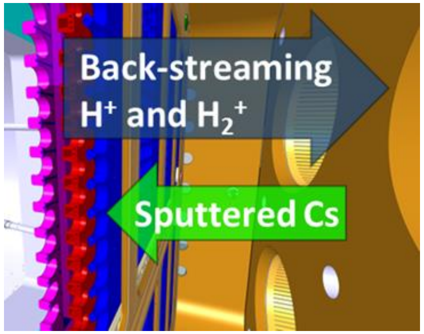

- **Stability of the work function**
- **Sufficient Cs flux** onto the grid is needed during the pulse to **counteract degradation of the work function**

INPUT

Oven nozzle
outflow profile,
position, direction

Surface
sticking probability

Plasma parameters

⇨

Monte Carlo Test Particle
Transport code

CsFlow3D

⇨

OUTPUT

Cs flux onto surfaces
(both neutrals and ions)

Energy of Cs particles

Cs **coverage**

Neutral Cs density

CsFlow3D code

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⇒

Monte Carlo Test Particle Transport code

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⇒

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Cs flux onto surfaces (both neutrals and ions)

Energy of Cs particles

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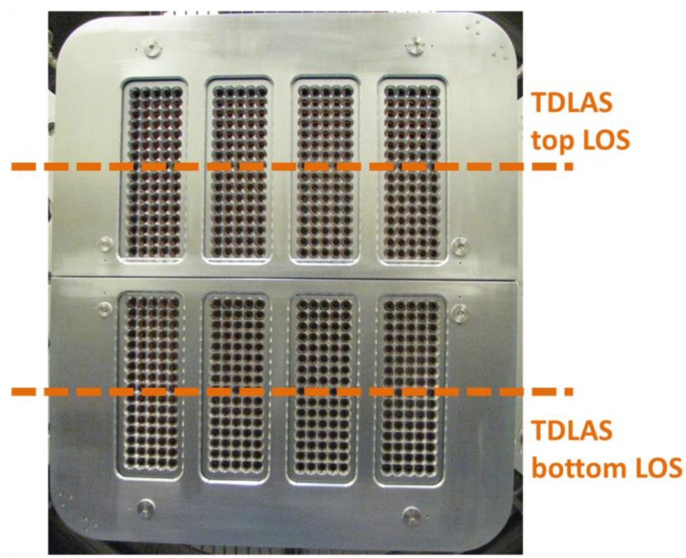
Neutral Cs density

Exp. measurements of line-averaged neutral Cs density (Laser Absorption Spectroscopy)



Investigation of Caesium dynamics

- Results of the code already benchmarked at BATMAN[1]

1. **Plasma drift** effect on neutral Cs distribution **in the larger source at ELISE**

2. **Effect of the PG bias potential on the Cs transport**,
   i.e. energy of Cs^+/Cs impinging the PG

3. **Extension to the full source,**
   simulation of conditioning and long pulses

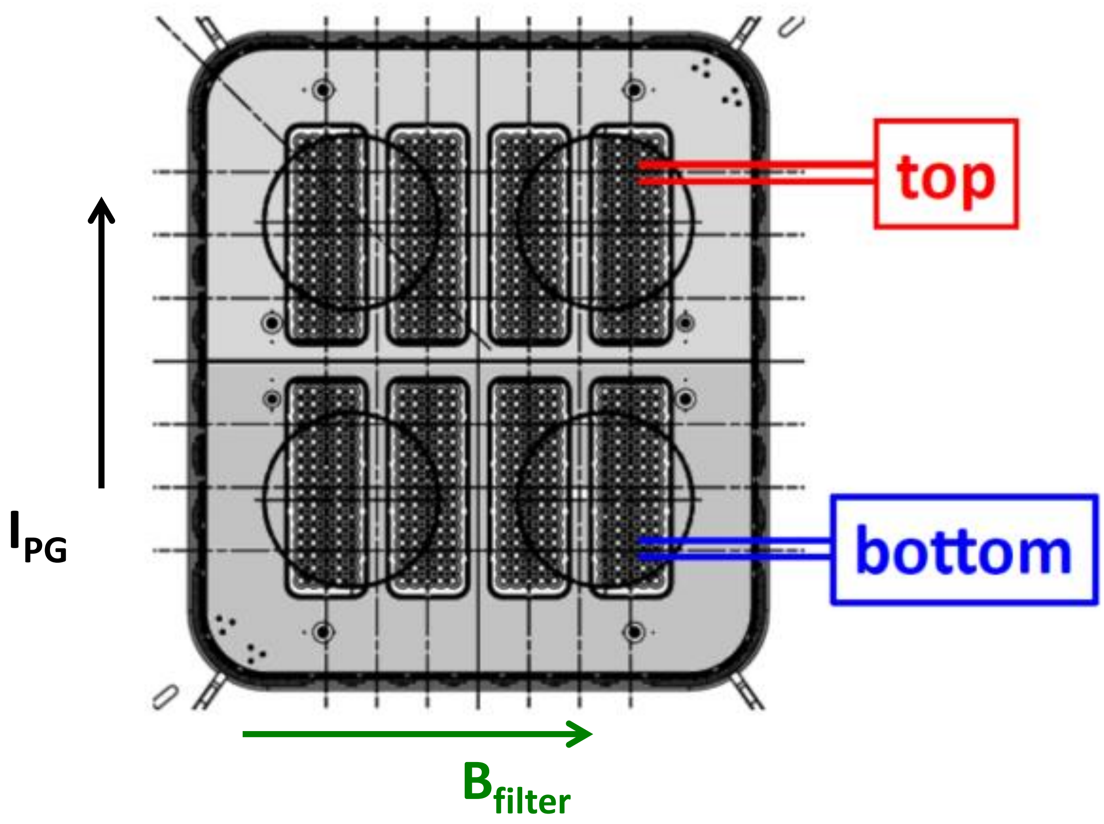
[1] A. Mimo, AIP Conf. Proc. 1869, 030019 (2017)

Effect of the plasma drift at ELISE

Plasma drift at ELISE:

- At I_{PG} = 2 kA $\frac{n_{plasma,TOP}}{n_{plasma,BOTTOM}} \approx 2$

C. Wimmer (Mon04)



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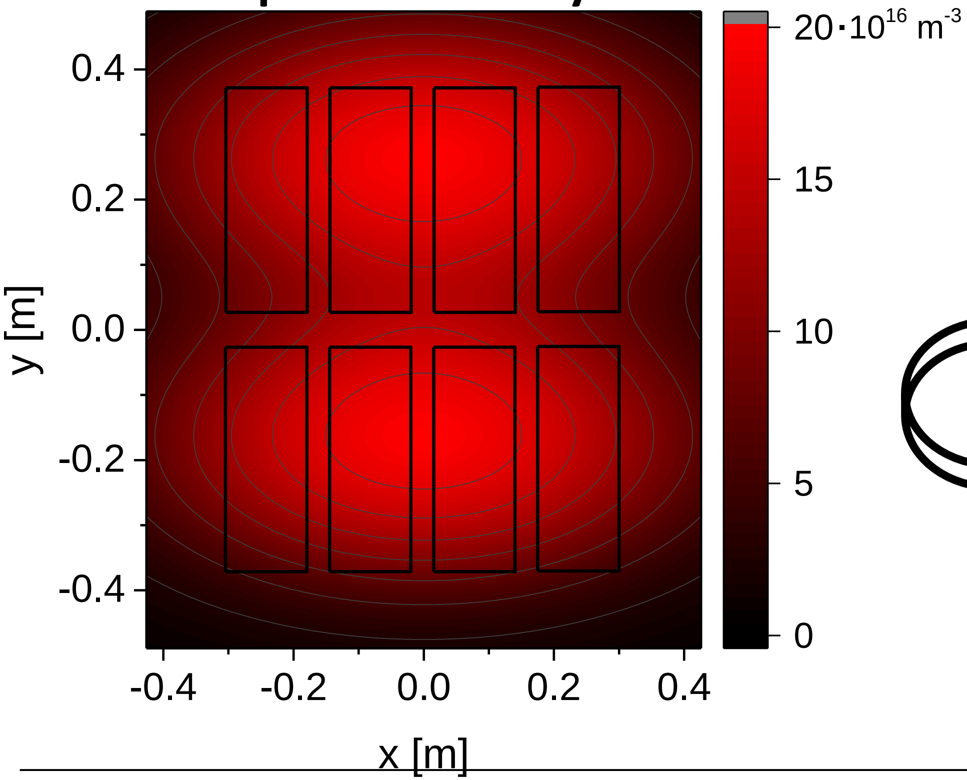
CsFlow3D input plasma density



SIMULATION

20 consecutive pulses (conditioning):

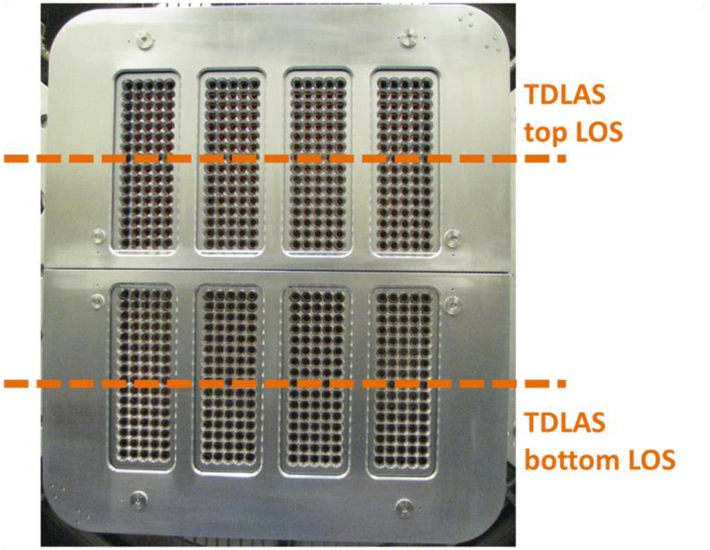
20 s plasma phase

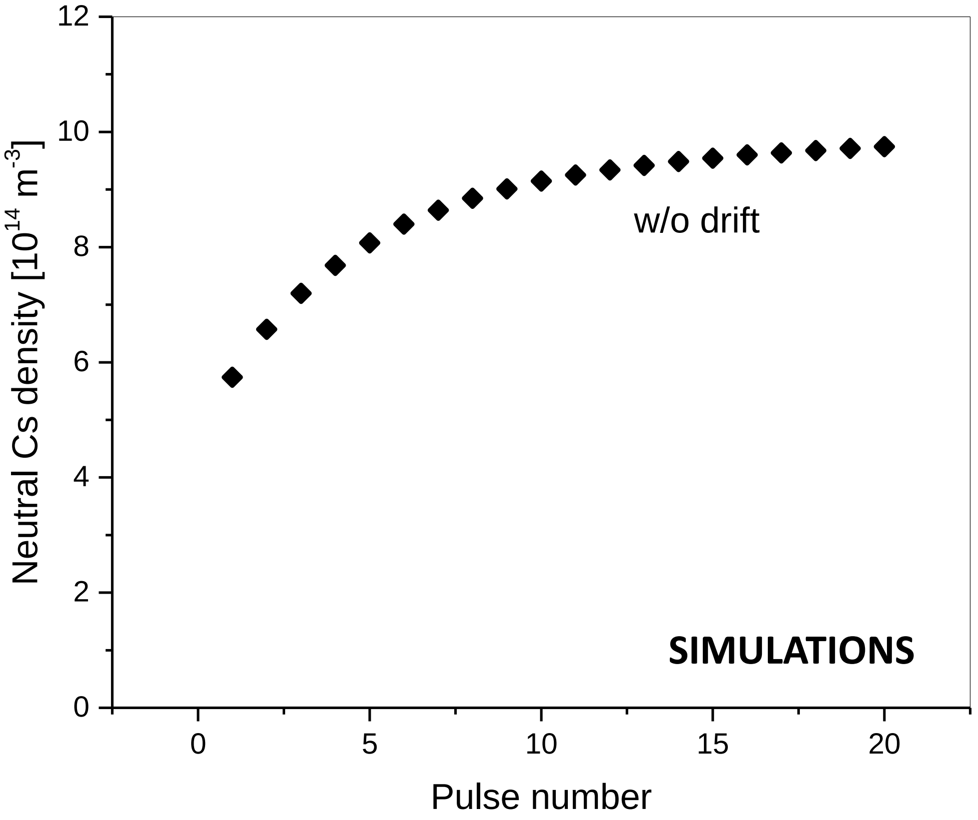
200 s vacuum phase

Cs evap. rate 10 mg/h (5mg/h/oven)

Effect of the plasma drift at ELISE

Simulated neutral Cs density with and w/o the vertical plasma drift





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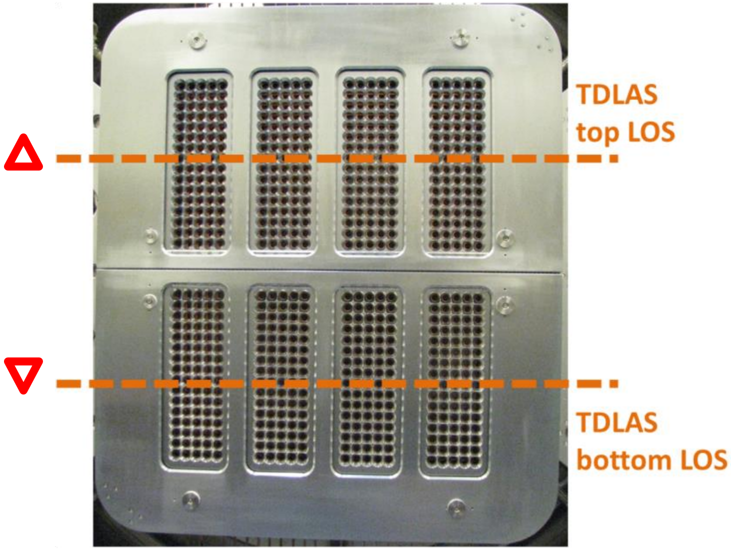
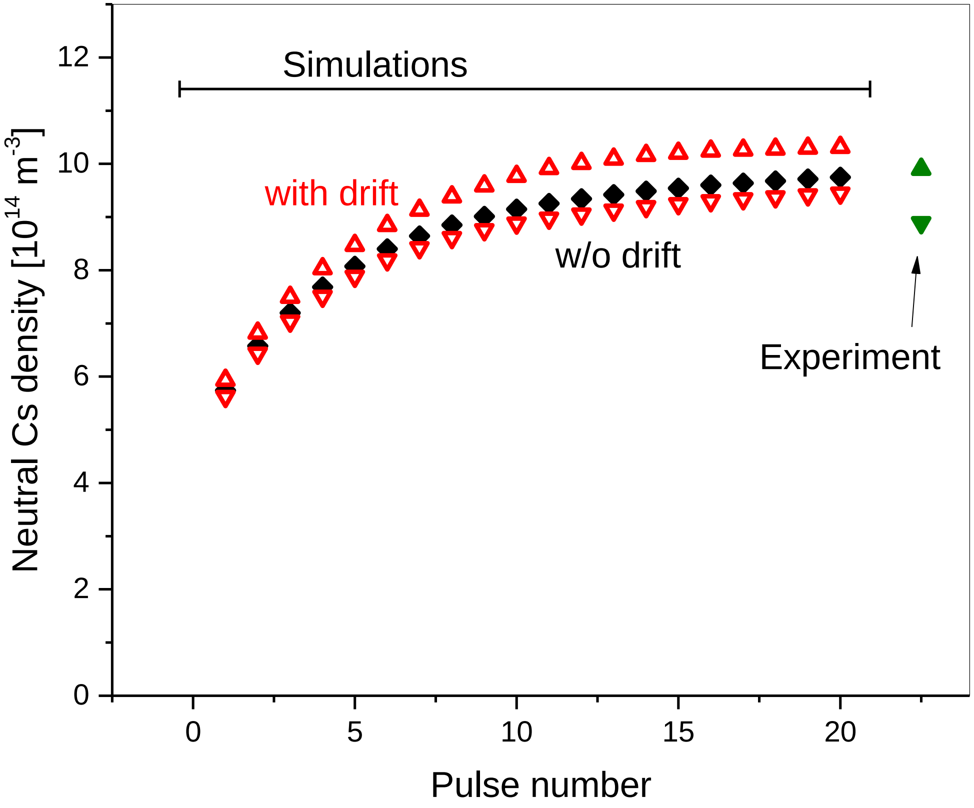
Neutral Cs is symmetric both in simulation and experiment

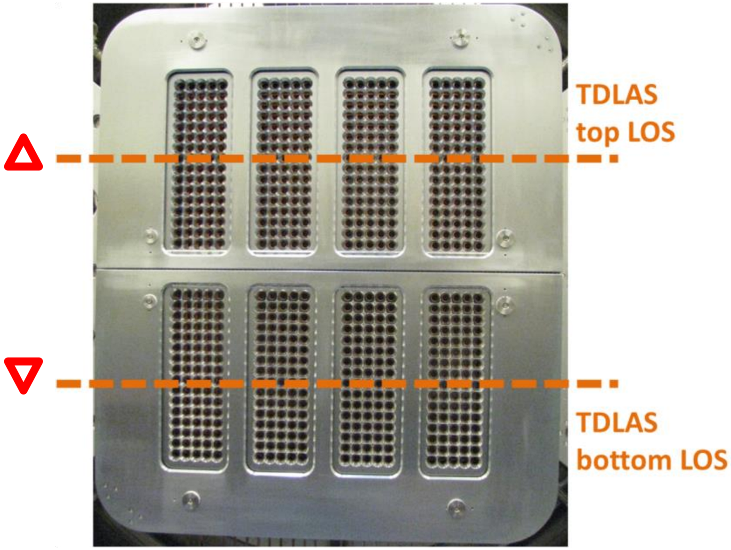


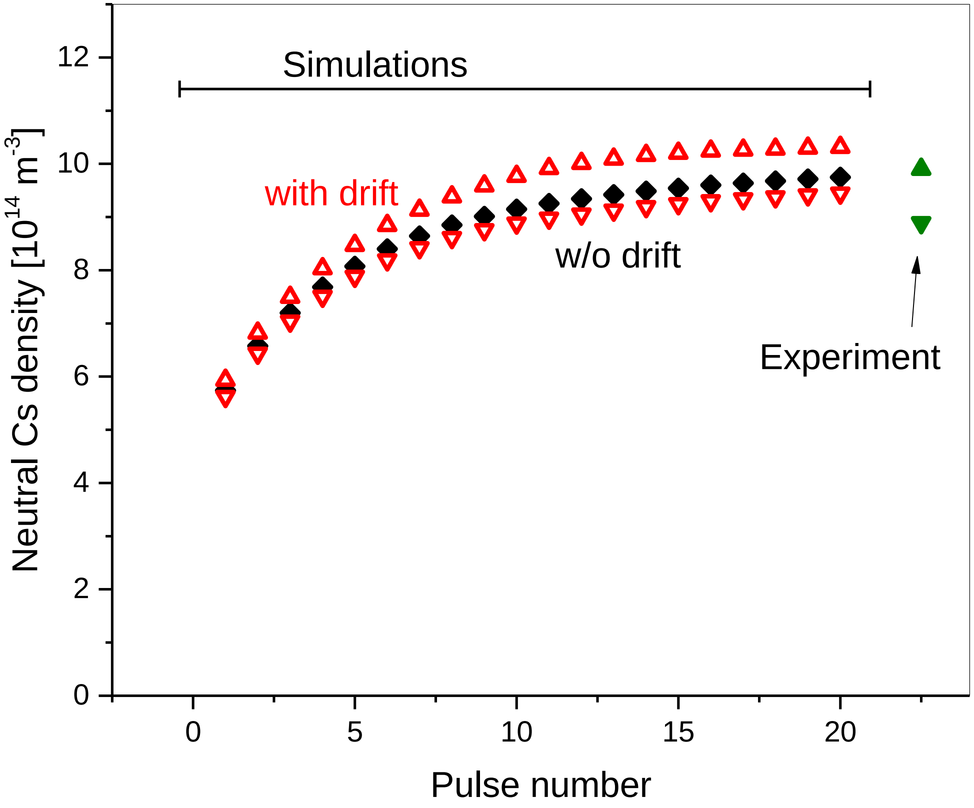


Effect of the plasma drift at ELISE

Simulated neutral Cs density with and w/o the vertical plasma drift

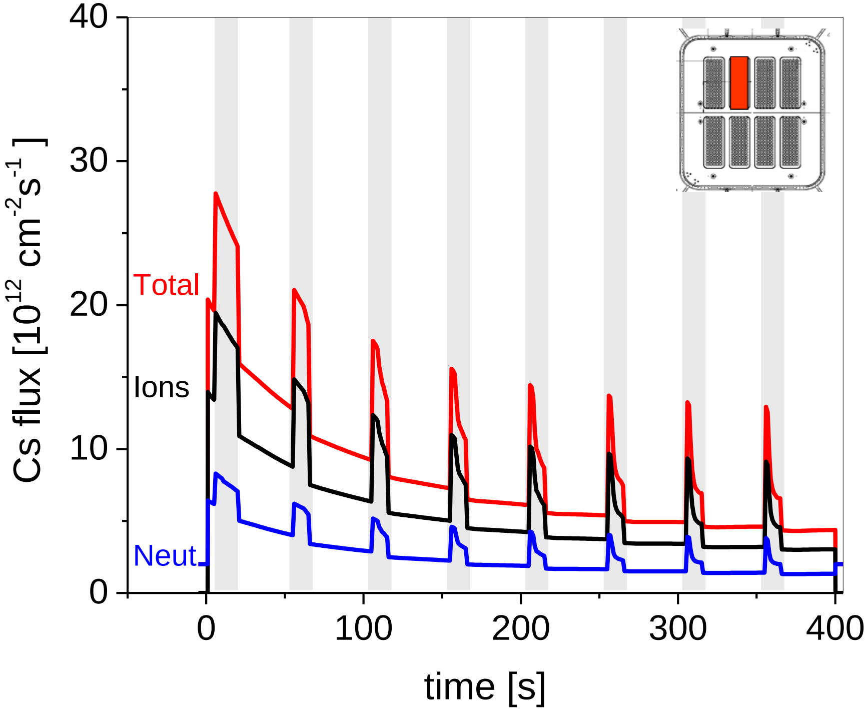
Neutral Cs is symmetric both in simulation and experiment
But this is not necessarily true for the Cs ions…

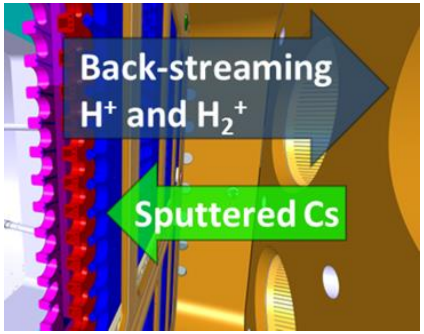




Effect of the PG bias voltage on Cs flux

- Simulation of a long pulse at ELISE with pulsed extraction: Cs flux consists mostly of ions (up to 70%)





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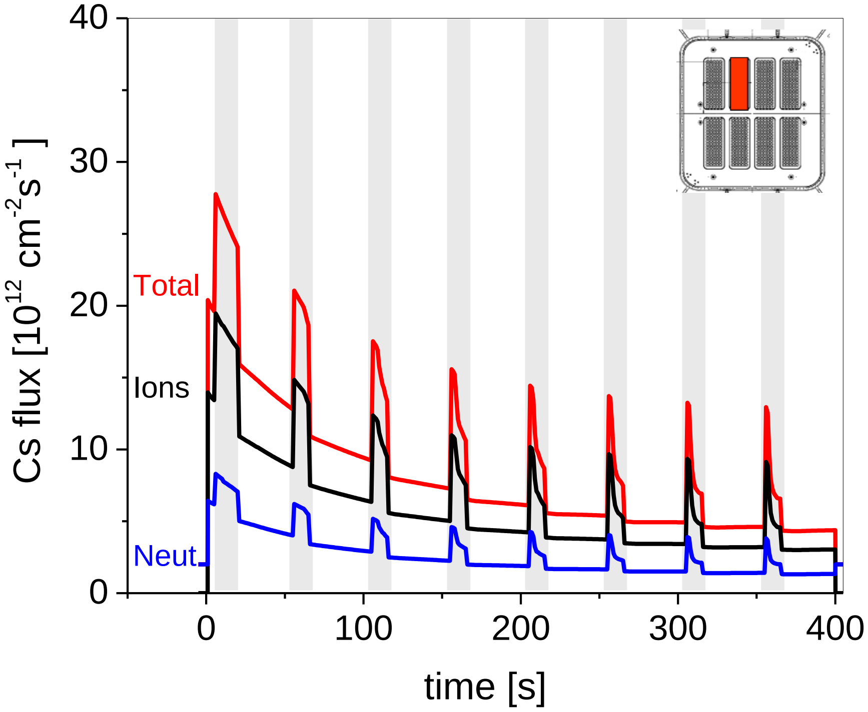
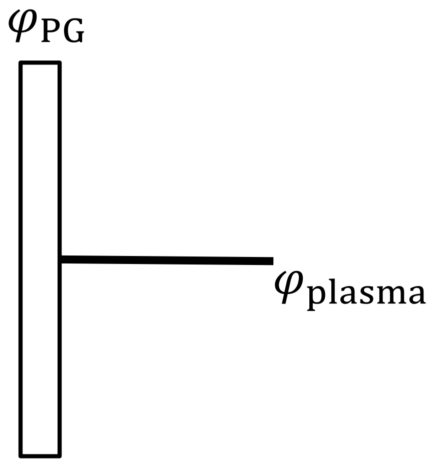


Calculation performed for: $$\Delta\varphi = \varphi_{\text{plasma}} - \varphi_{\text{PG}} = 0\ V$$



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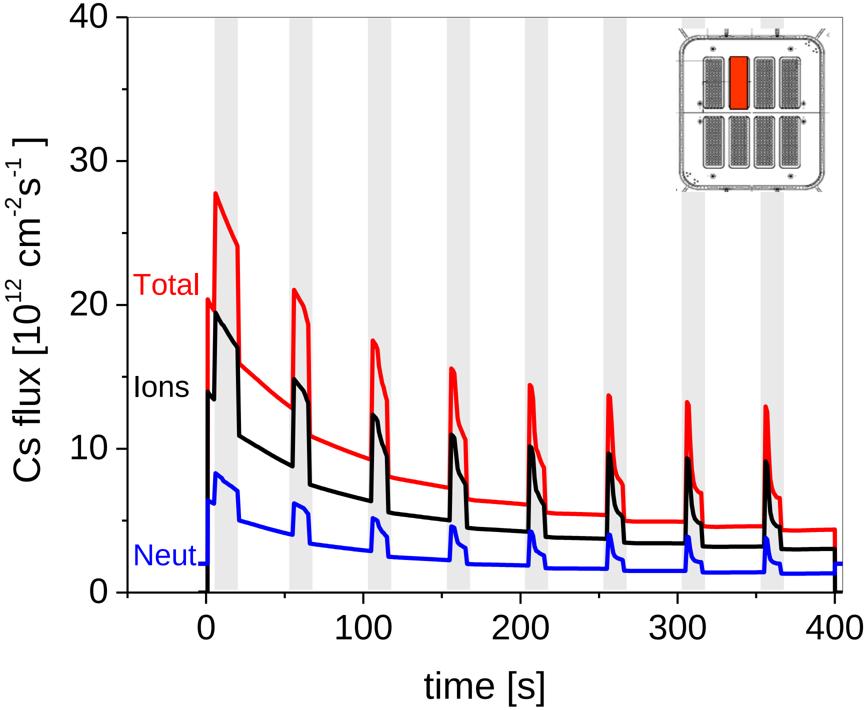

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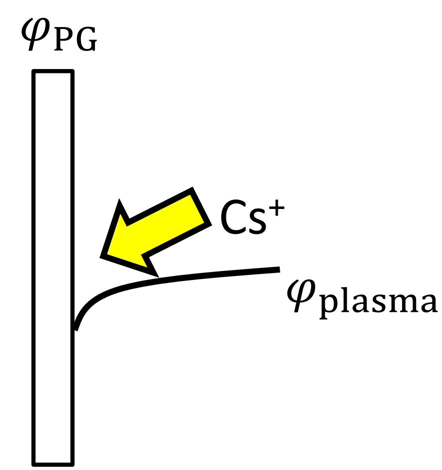

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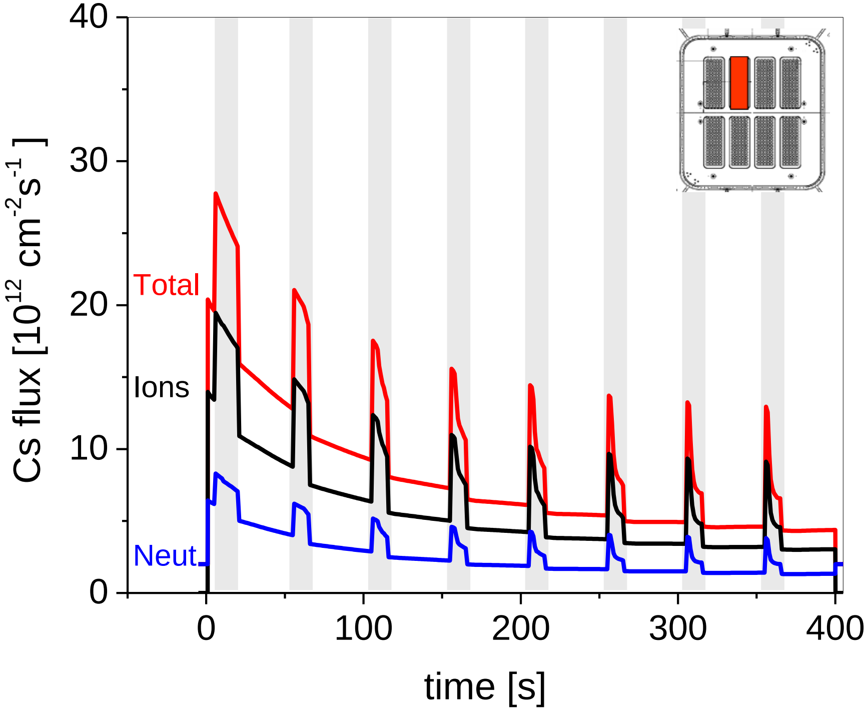

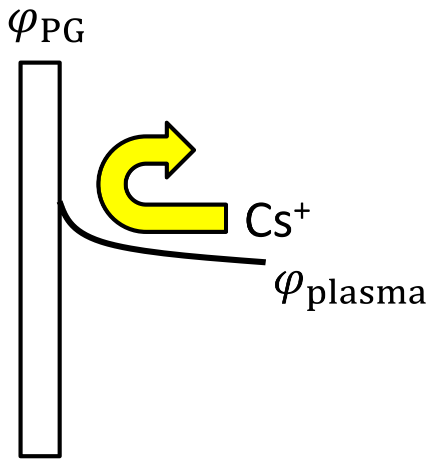

Calculation performed for: $$\Delta\varphi = \varphi_{\mathrm{plasma}} - \varphi_{\mathrm{PG}} < 0\ V$$

Effect of the PG bias voltage on Cs flux

- **Energy distribution of Cs^+ ions** onto a sample surface element of the PG **during plasma phase**

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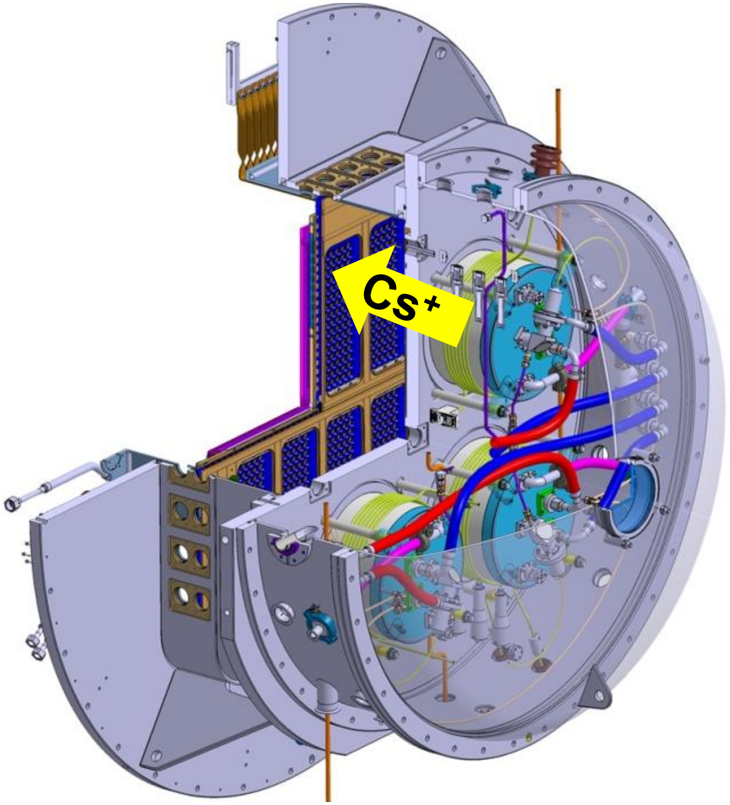

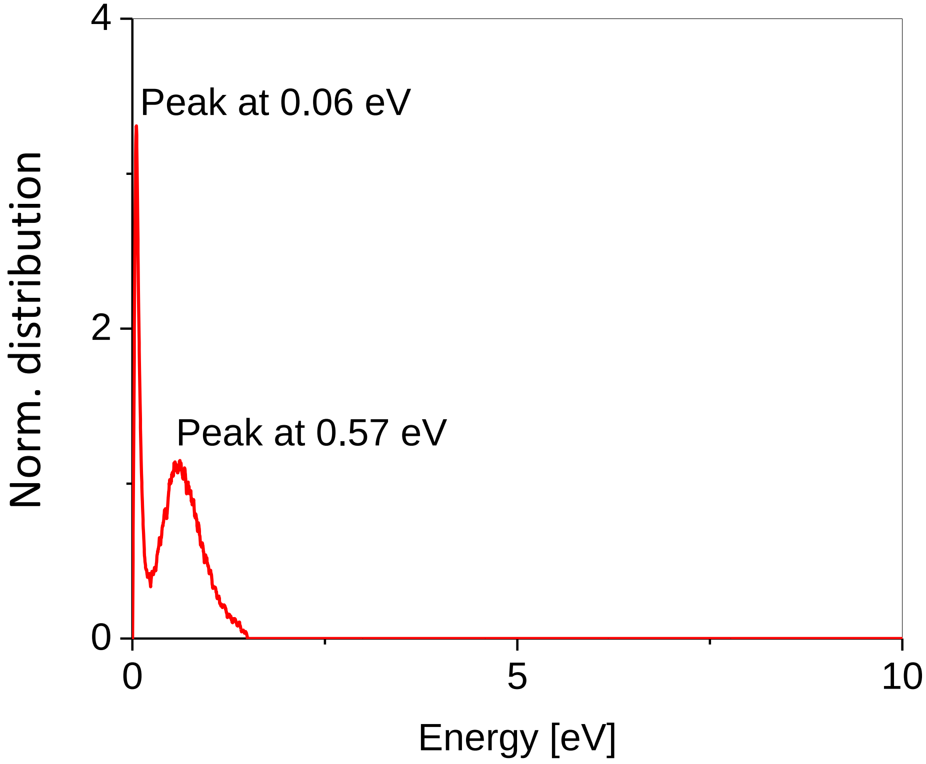

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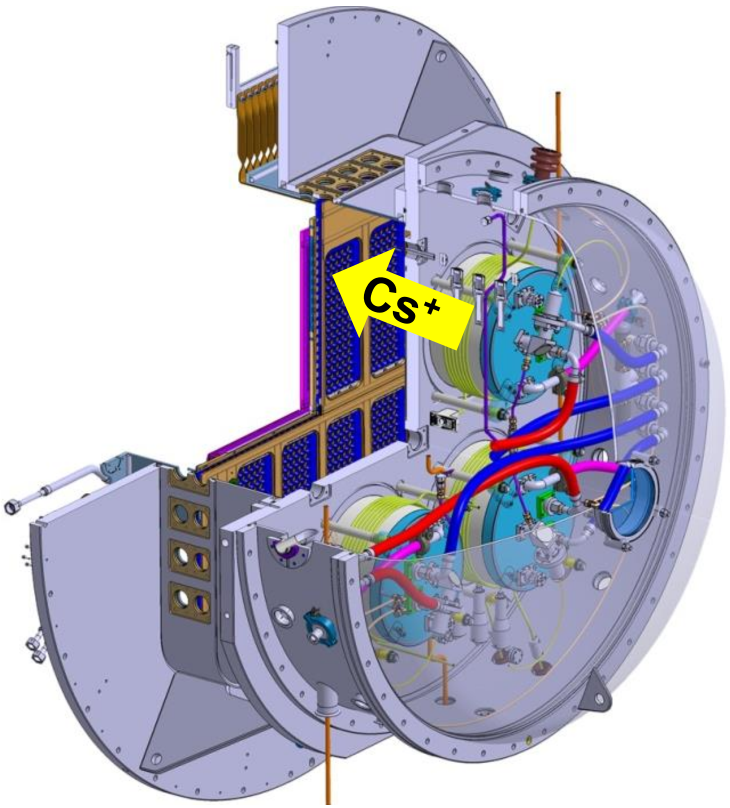

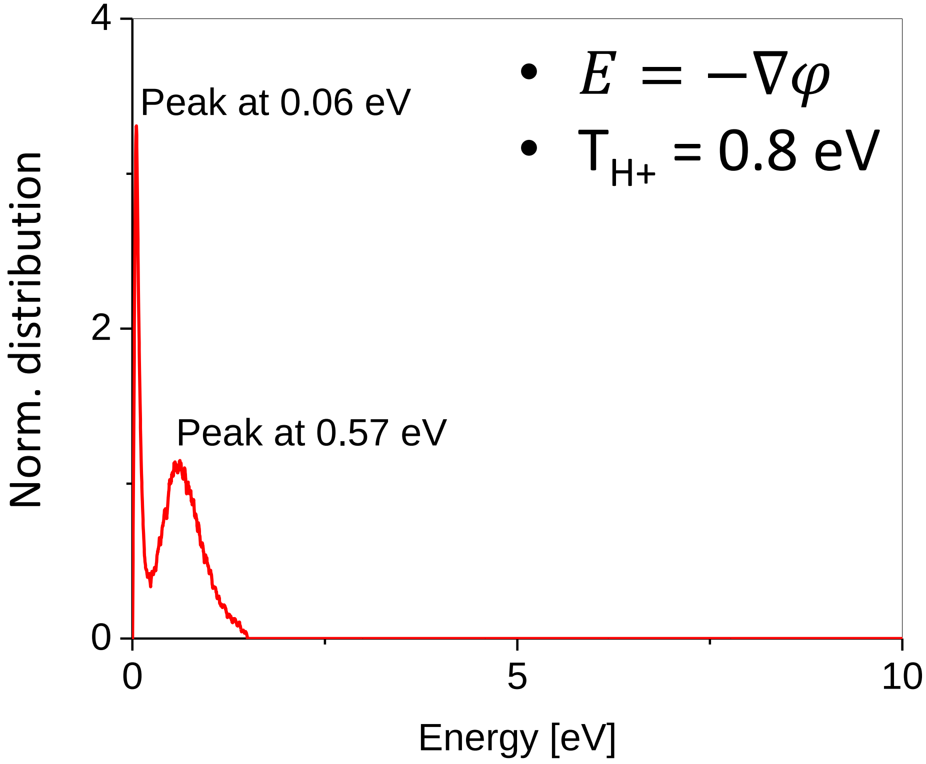

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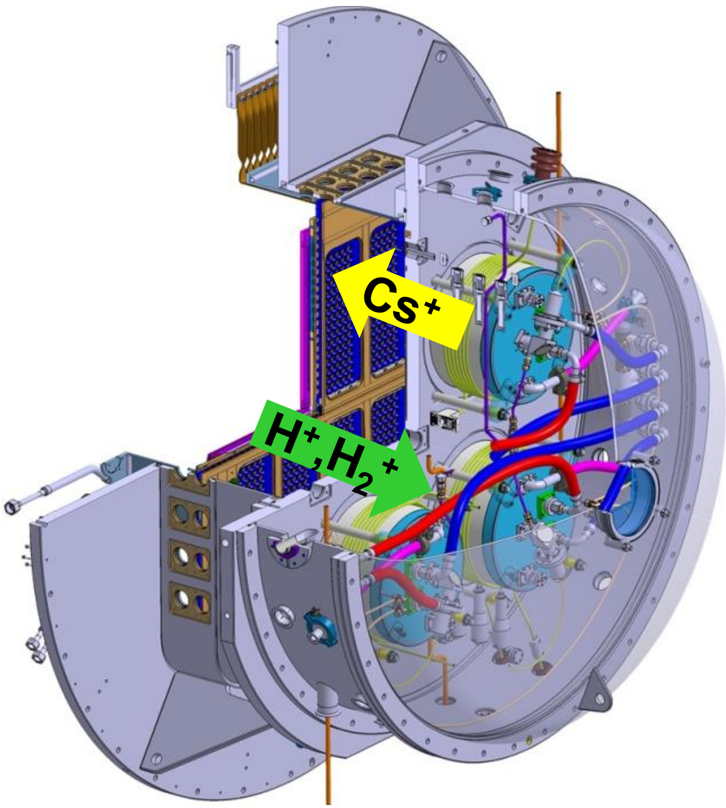
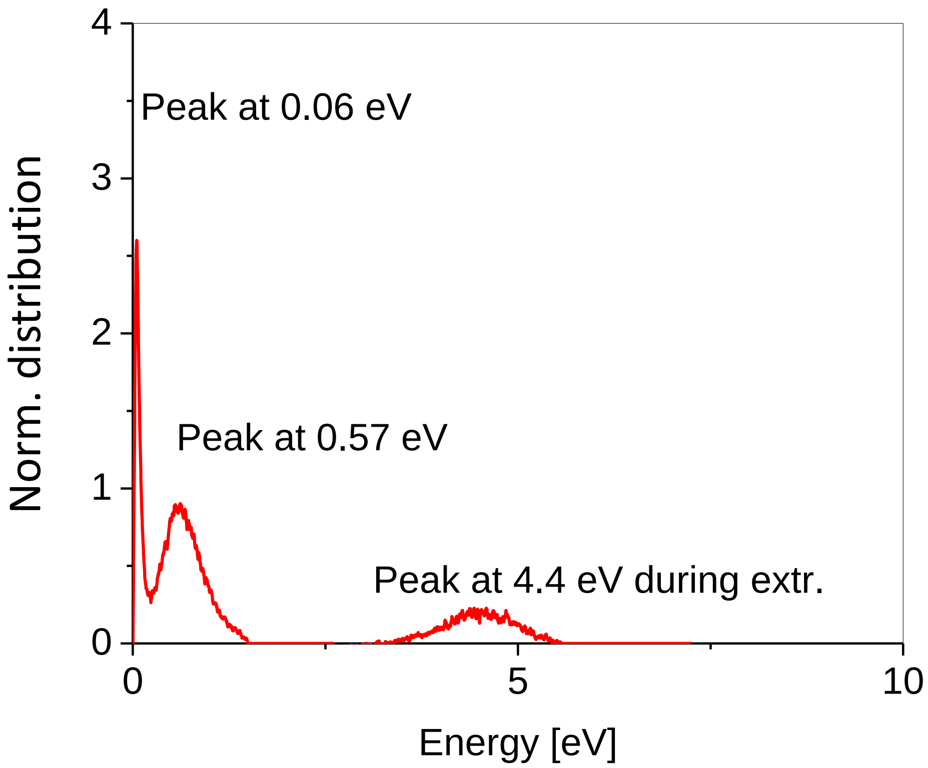
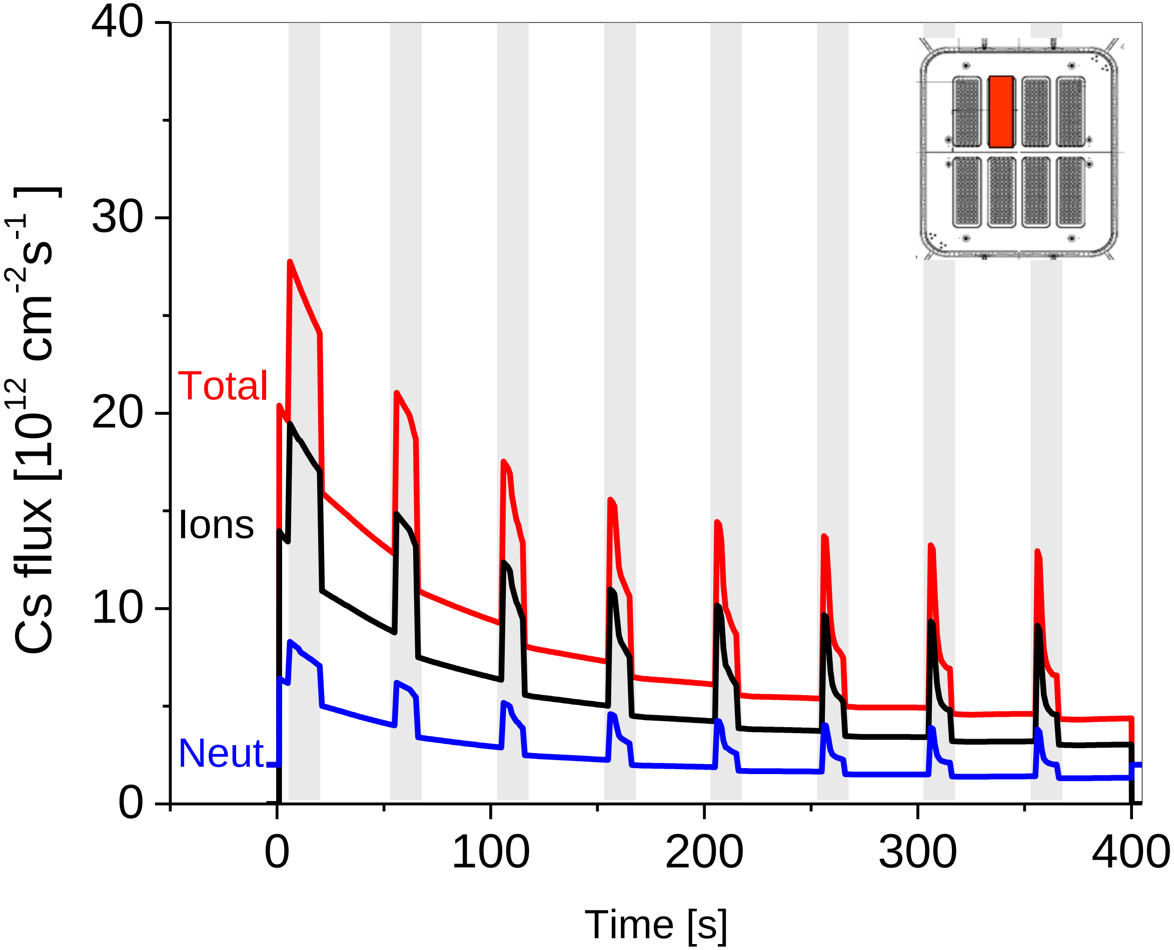




Influence of PG bias potential on Cs flux

- Cs ion flux onto the PG for different $\Delta\varphi = \varphi_{\text{plasma}} - \varphi_{\text{PG}}$



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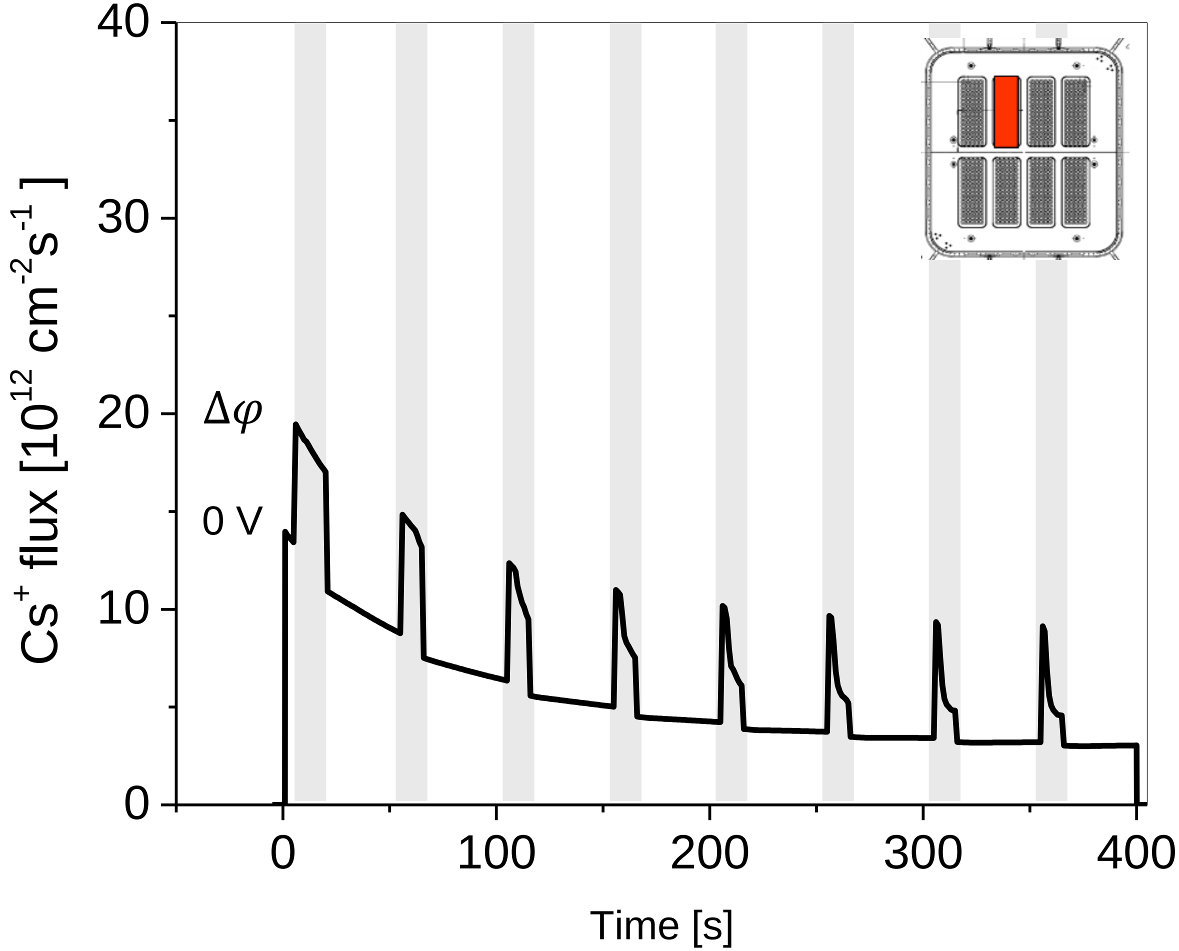

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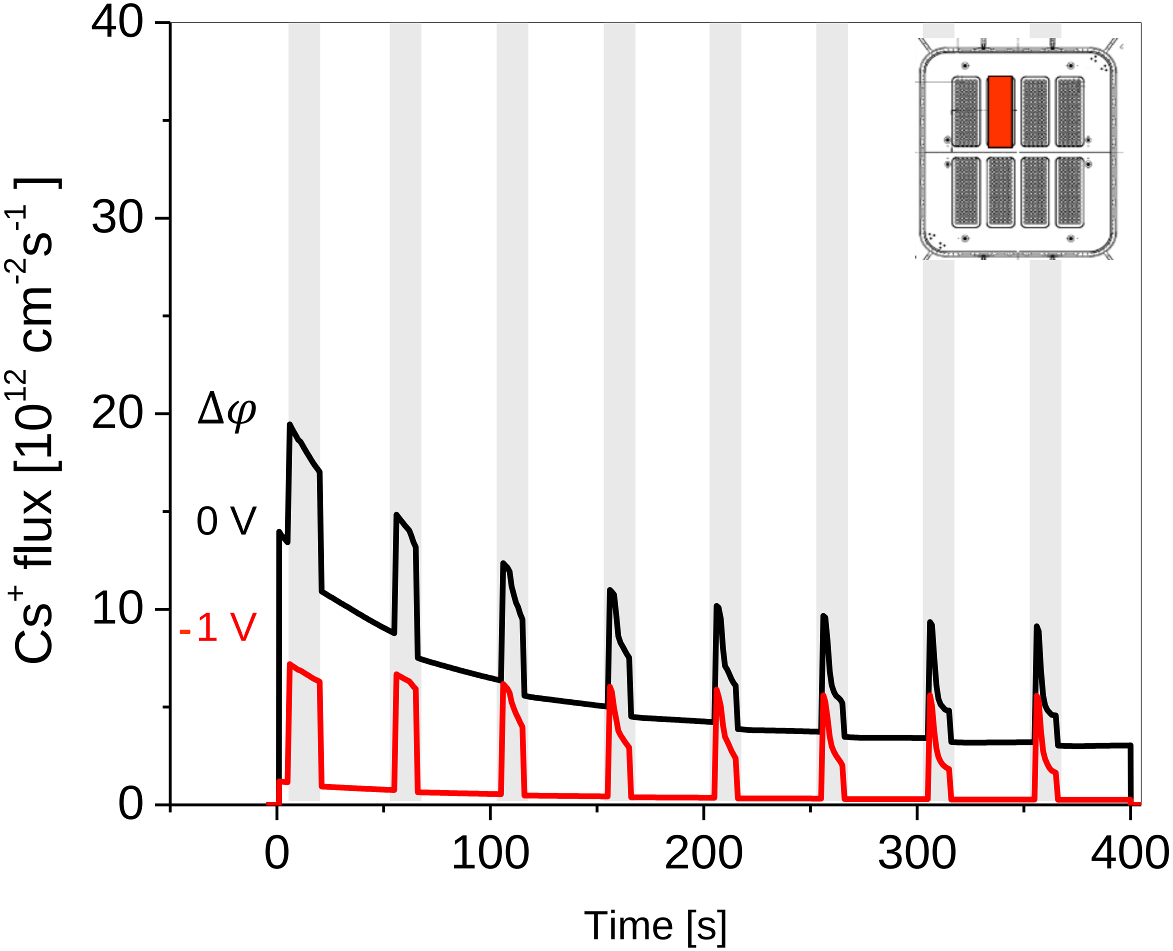

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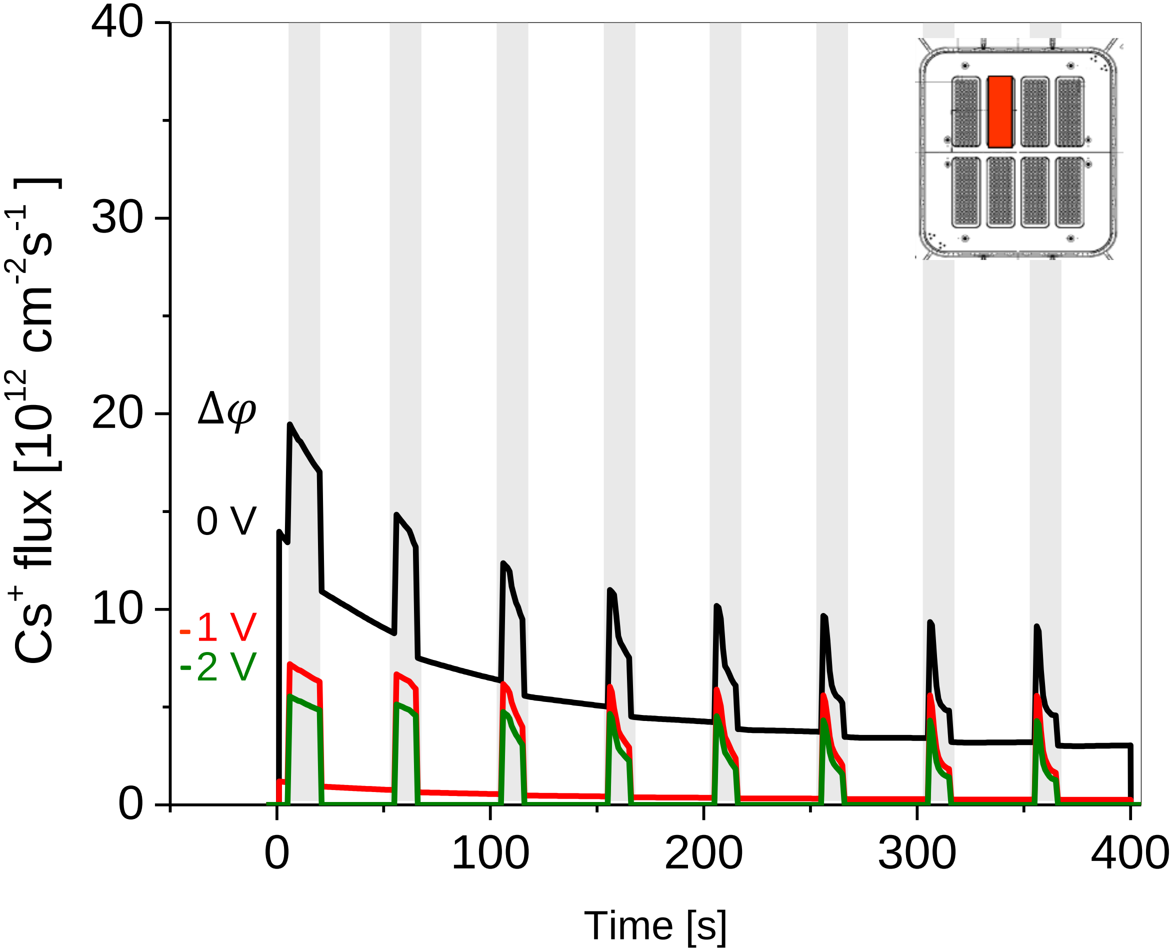

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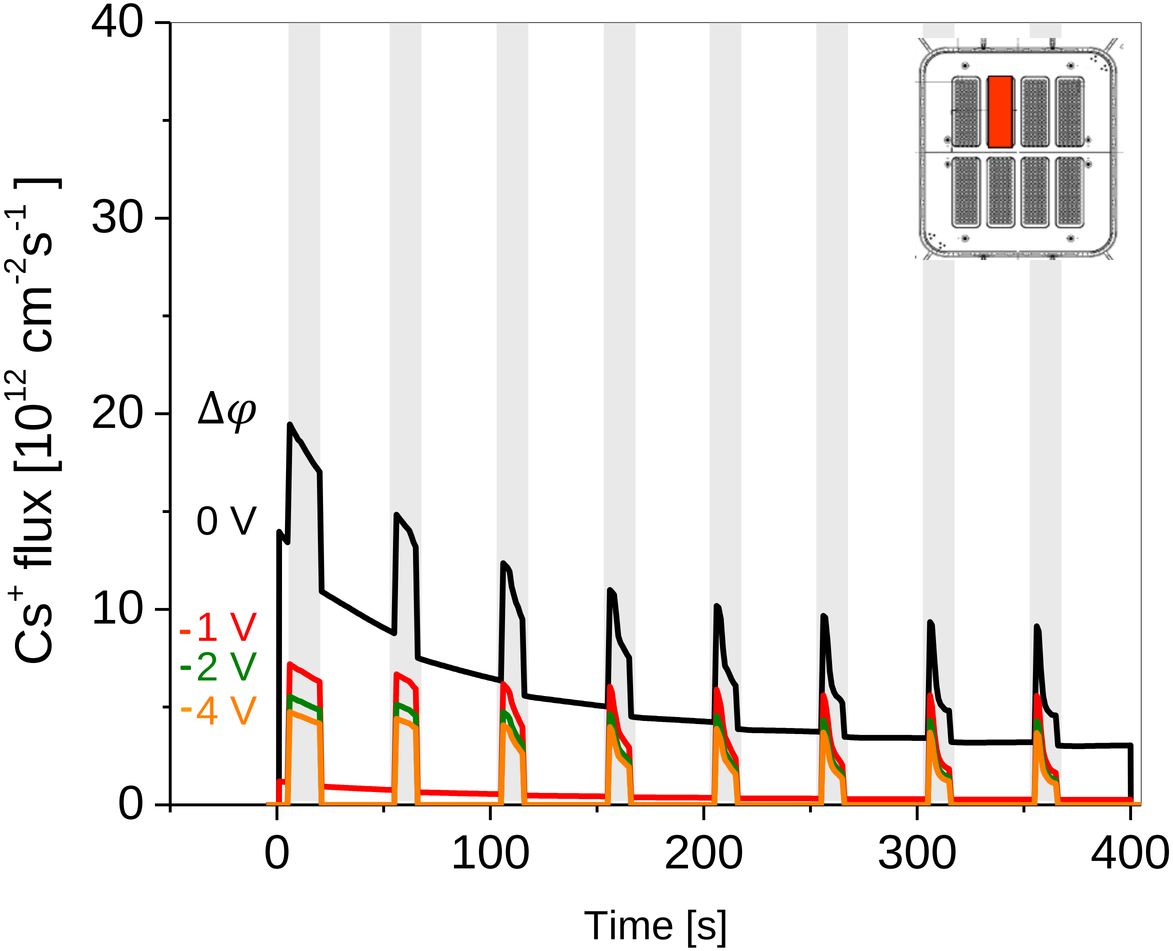

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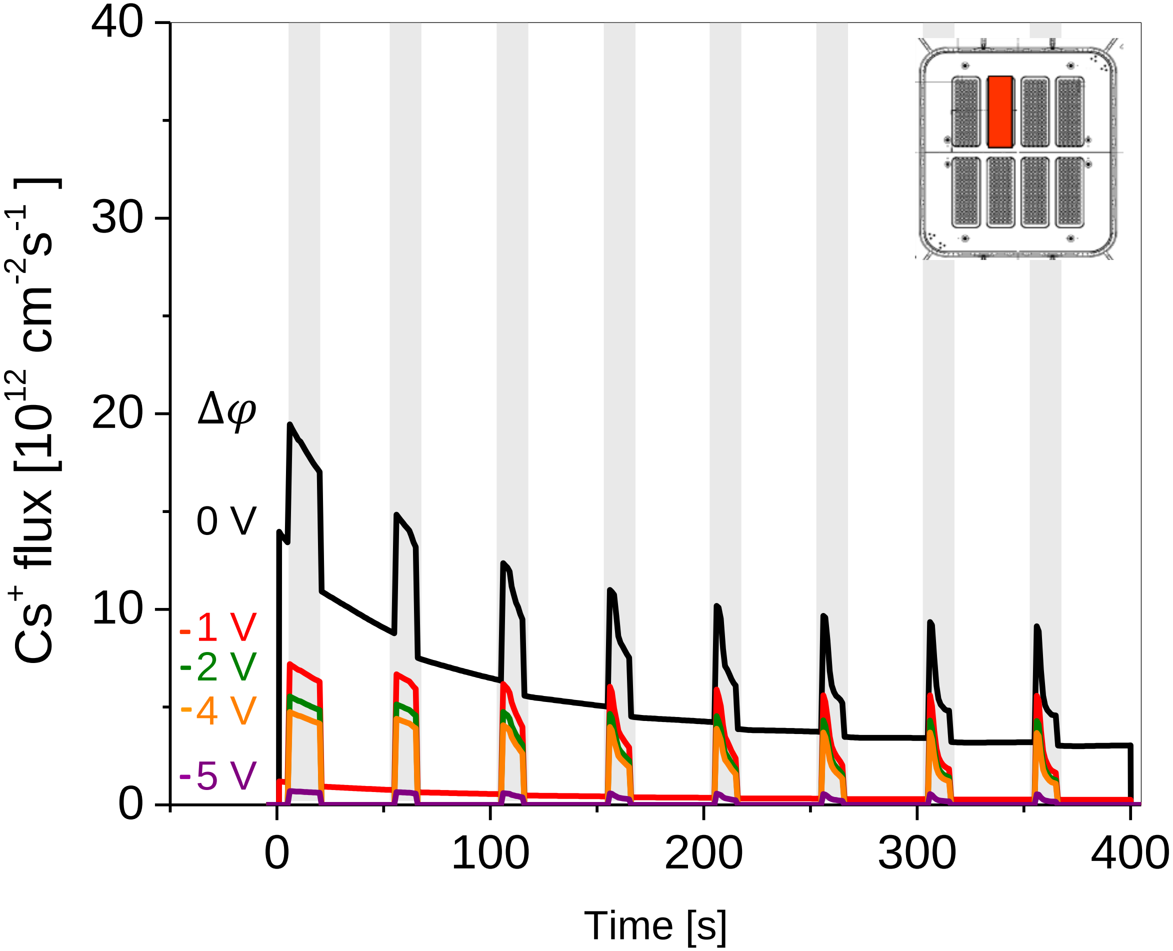
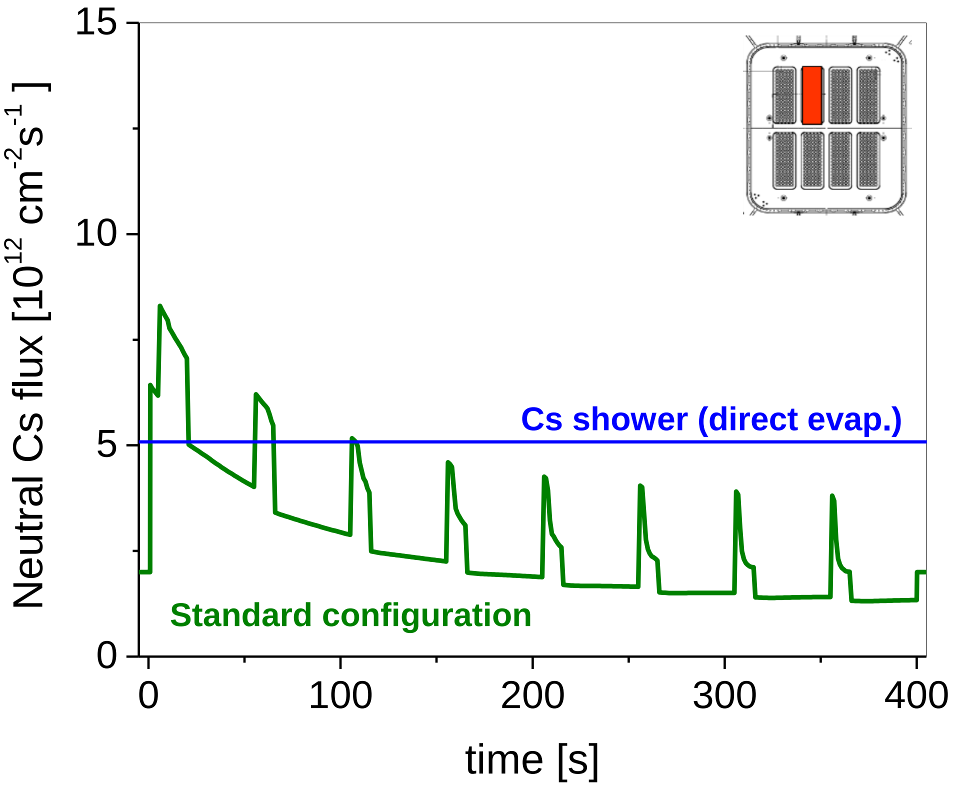
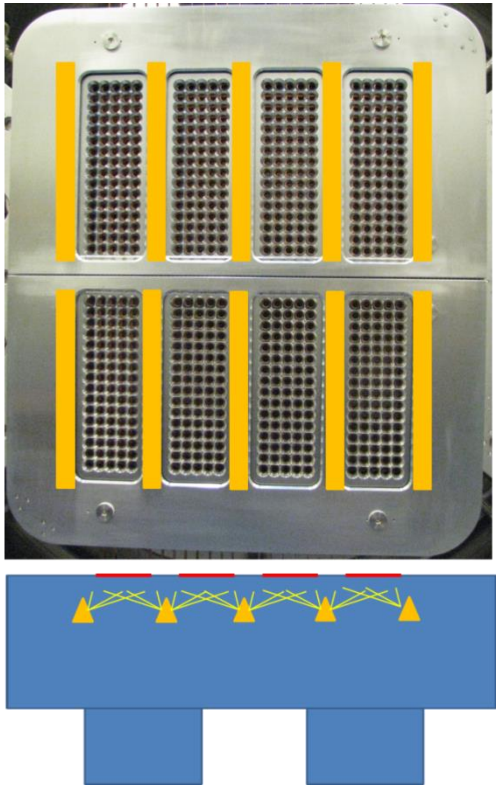


Evaporation close to the PG

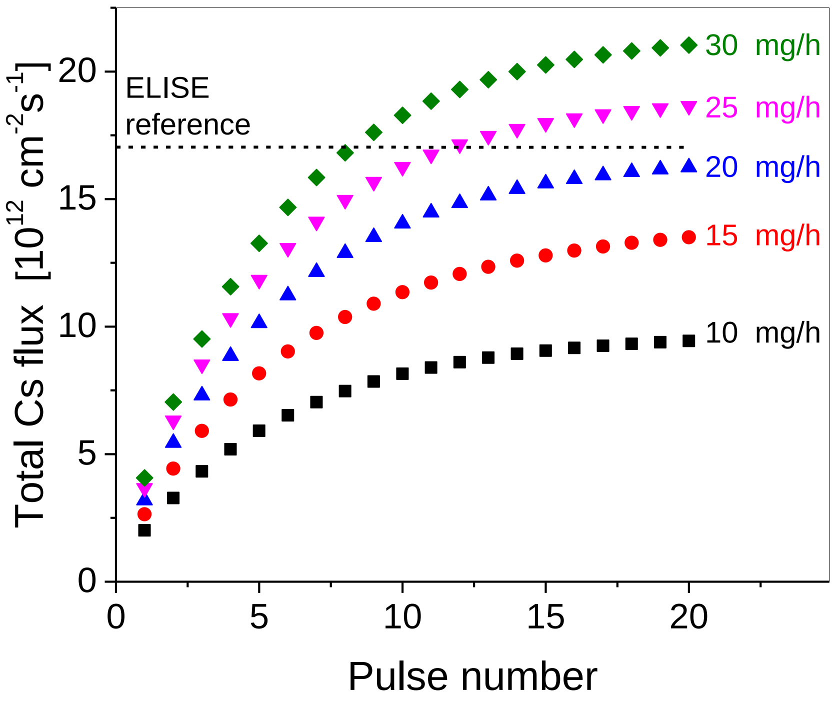
- **Evaporation** close to the plasma grid:
  - Limit Cs ionization due to low T_e close to the PG (almost **70 % of the flux is neutral**)
  - **Direct control of PG caesiation**, not relying on plasma assisted redistribution

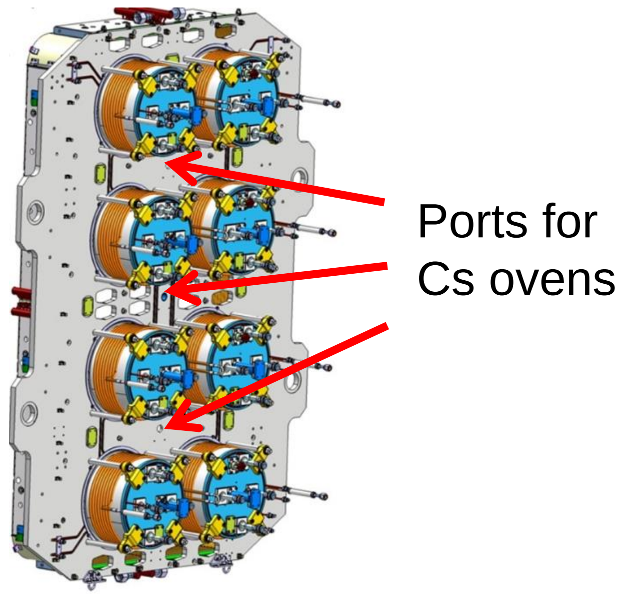


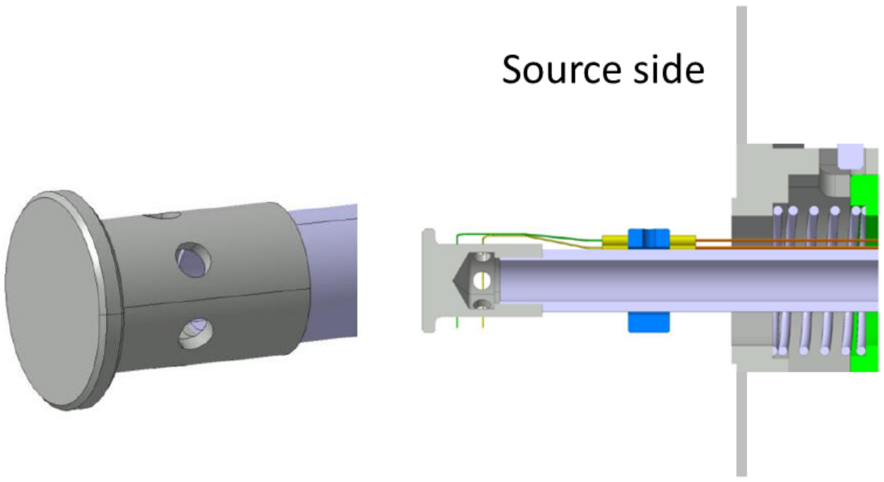


Towards the full size source: conditioning at SPIDER

- Simulation of SPIDER:
  - 20 pulses (20 s plasma + 200 s vacuum phase)
  - Different Cs oven configuration
- Total Cs evap. rate to reach ELISE flux: 20 mg/h

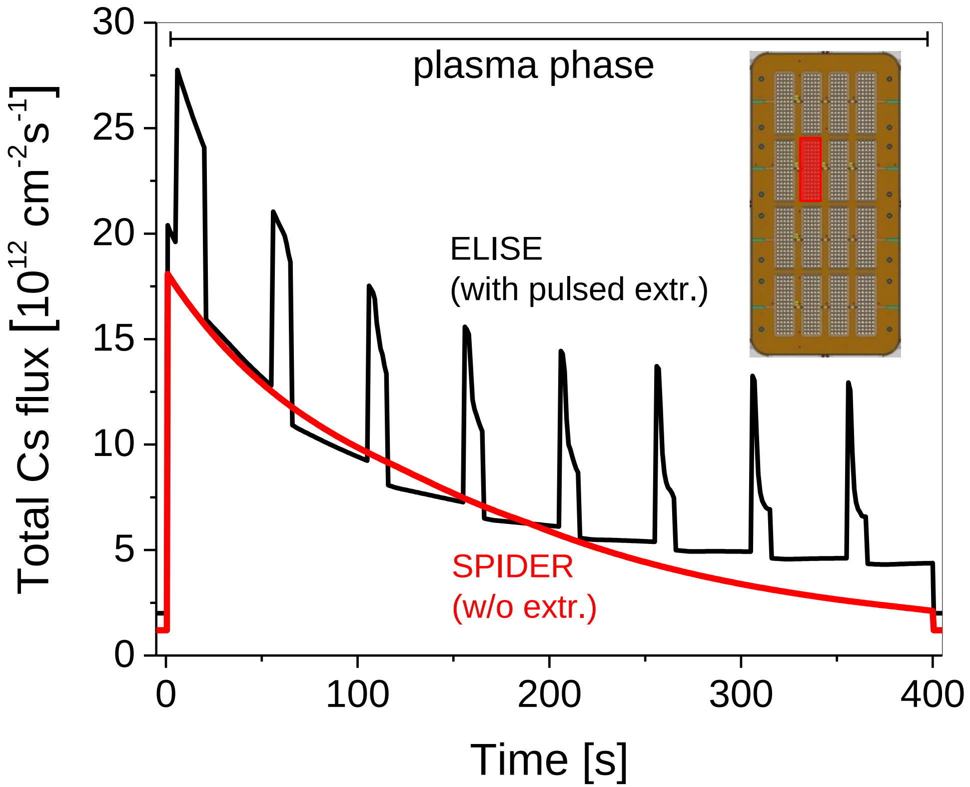






Towards the full size source: long pulses at SPIDER

- Long pulses at SPIDER compared with ELISE: 20th pulse after conditioning → Long pulse of 400 s
- Depletion of Cs flux during the long pulse also observed, but much stronger than in ELISE
- Effect of back-streaming ion sputtering not increase the flux, but not enough to compensate the depletion.



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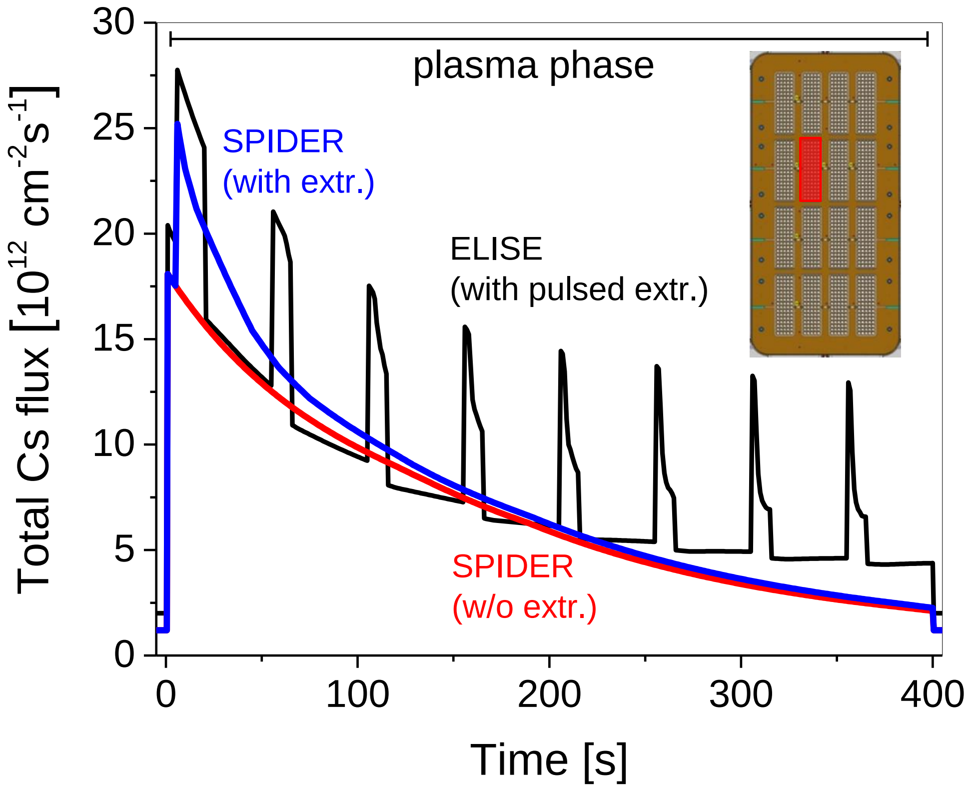


Summary and conclusions

- Plasma drift does not induce asymmetry for the neutrals, but this is not necessarily true also for the ions

- Cs^+ ions mostly affected by the PG bias voltage:

  - **Cs^+ ion flux onto PG can be locally different due to locally different values of $\Delta\varphi$**

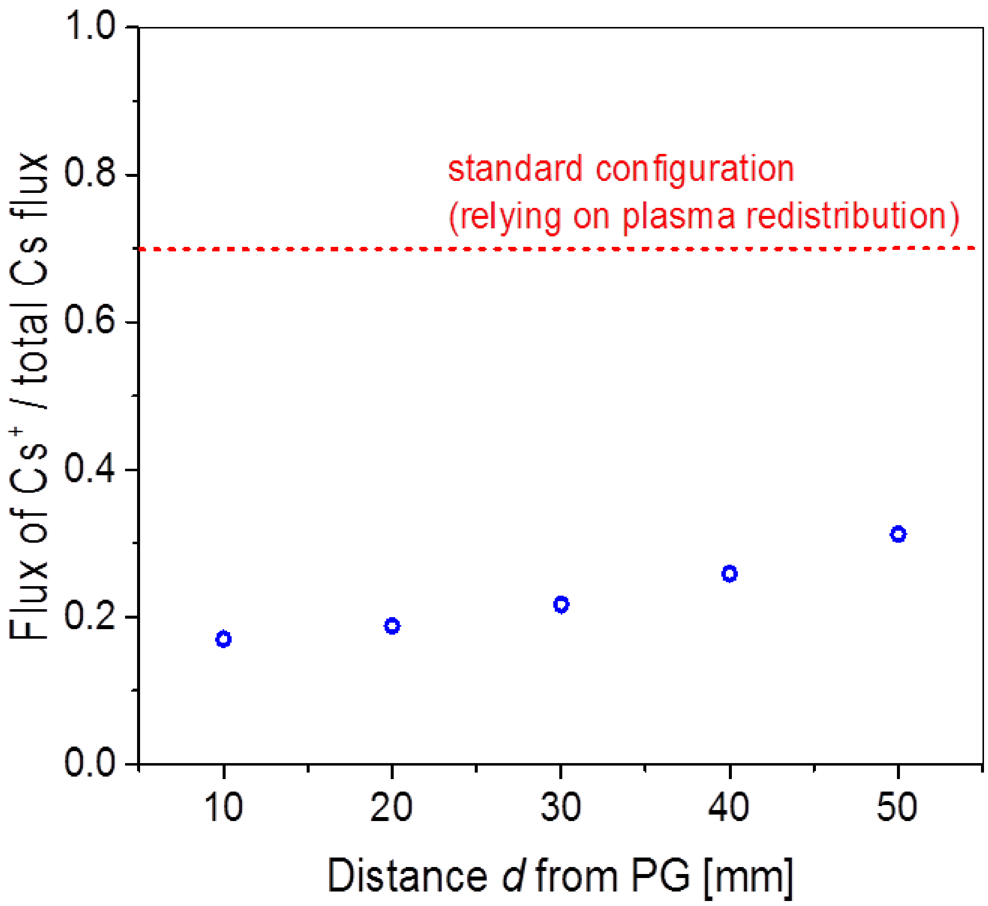
  - Cs^+ released **by back-streaming ions** reach **higher energy** (≈ 4.7 eV)

  - **Evaporation** close to the grid beneficial for having mostly neutral Cs flux (control of the caesiation **independently from plasma parameters**)

- **Simulation of the full source at SPIDER**:

  - **Depletion of Cs flux during long pulses** stronger than in ELISE, (not compensated by the Cs released by back-streaming ion sputtering)

  - Cs density measurements during **continuous extraction** will be very helpful


1.0
0.8
0.6
0.4
0.2
0.0
Flux of Cs+ / total Cs flux
standard configuration
(relying on plasma redistribution)
10
20
30
40
50
Distance d from PG [mm]