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Science and Technology Facilities Council

Photo-assisted Cl^-, Br^- and I^- production in cesium sputter ion source

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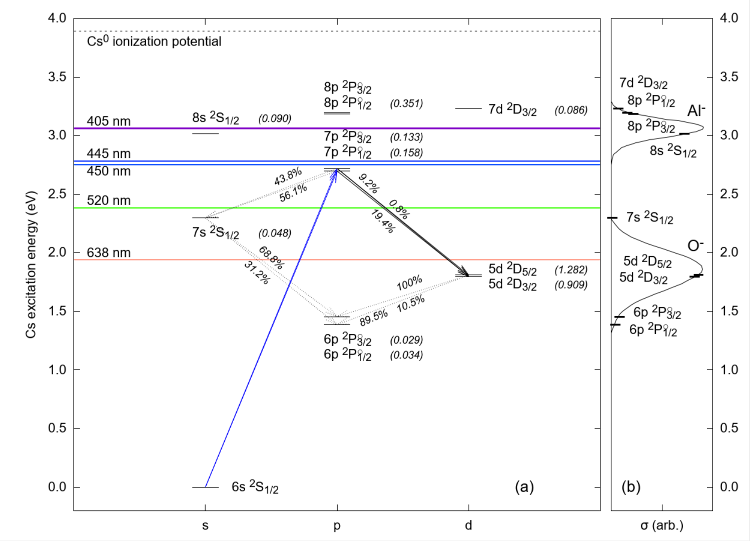
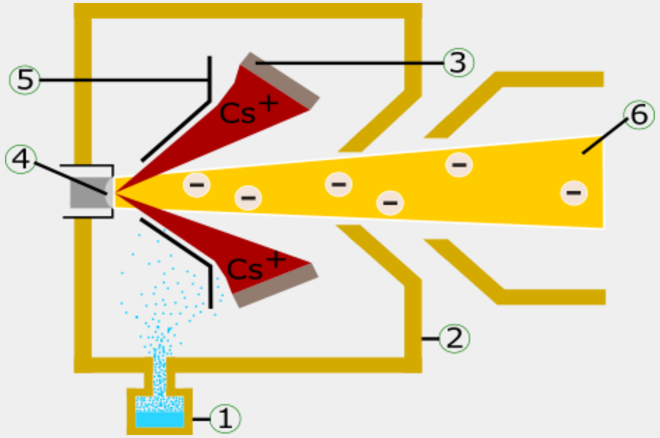
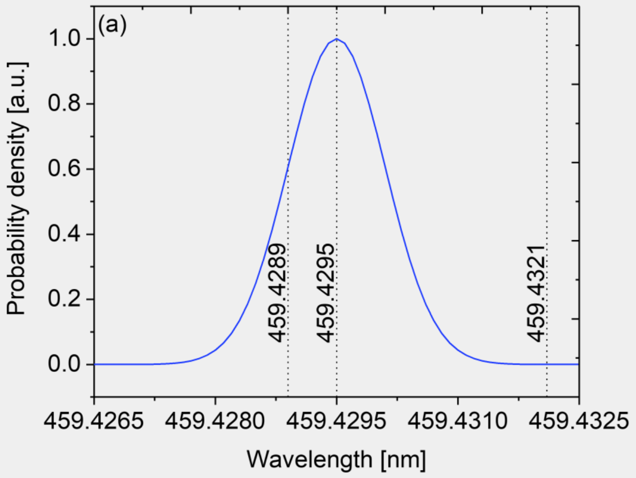
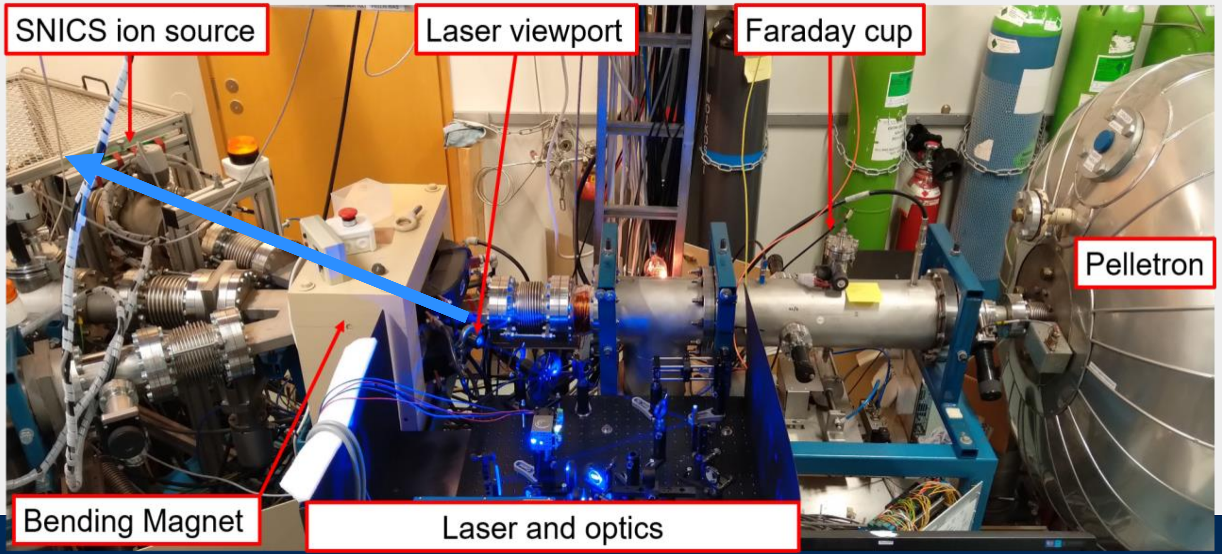
Outline: SNICS ion source and Lasers

- Motivation and background
- Previous results: Evidence of non-resonant nature
- Off-line development of the laser setup
- Laser power measurement at the SNICS setup
- Experimental results
- Conclusion









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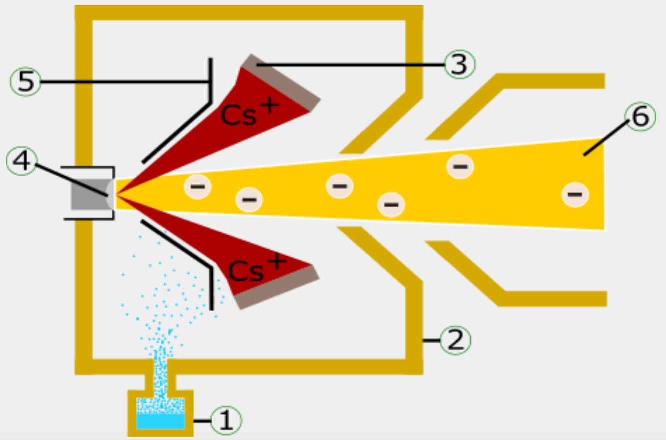
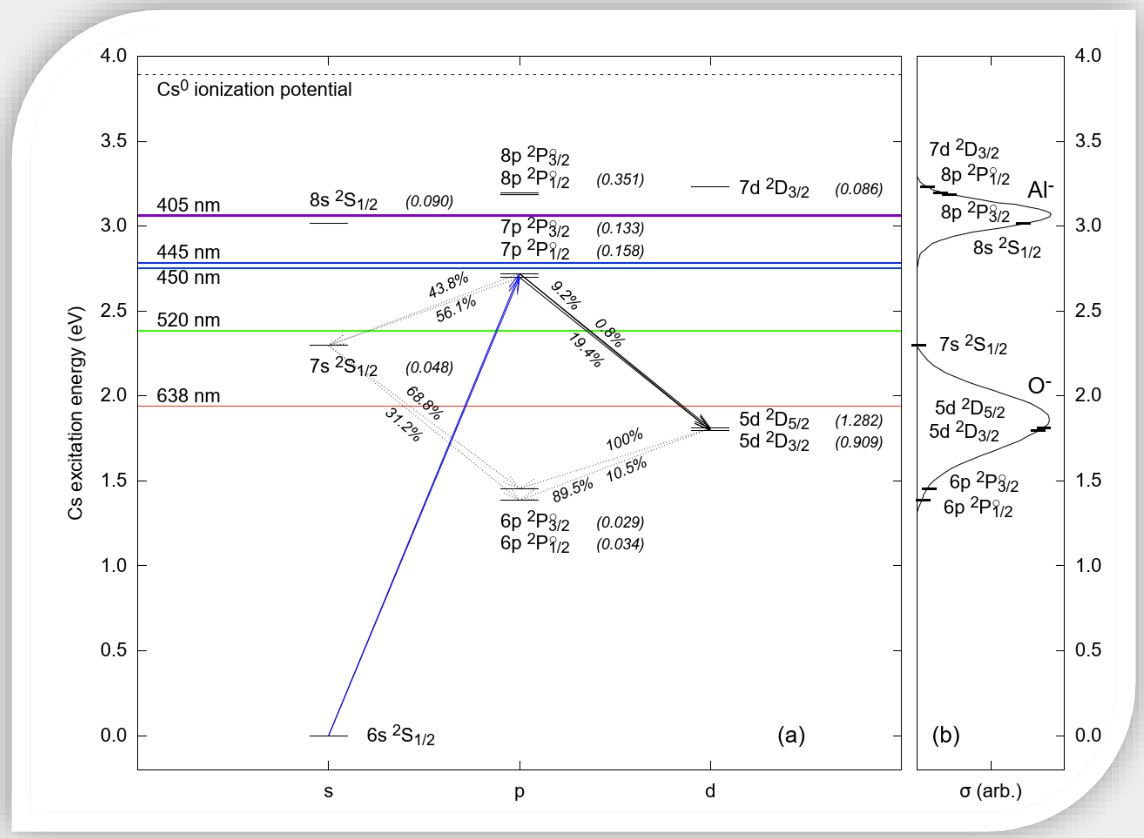
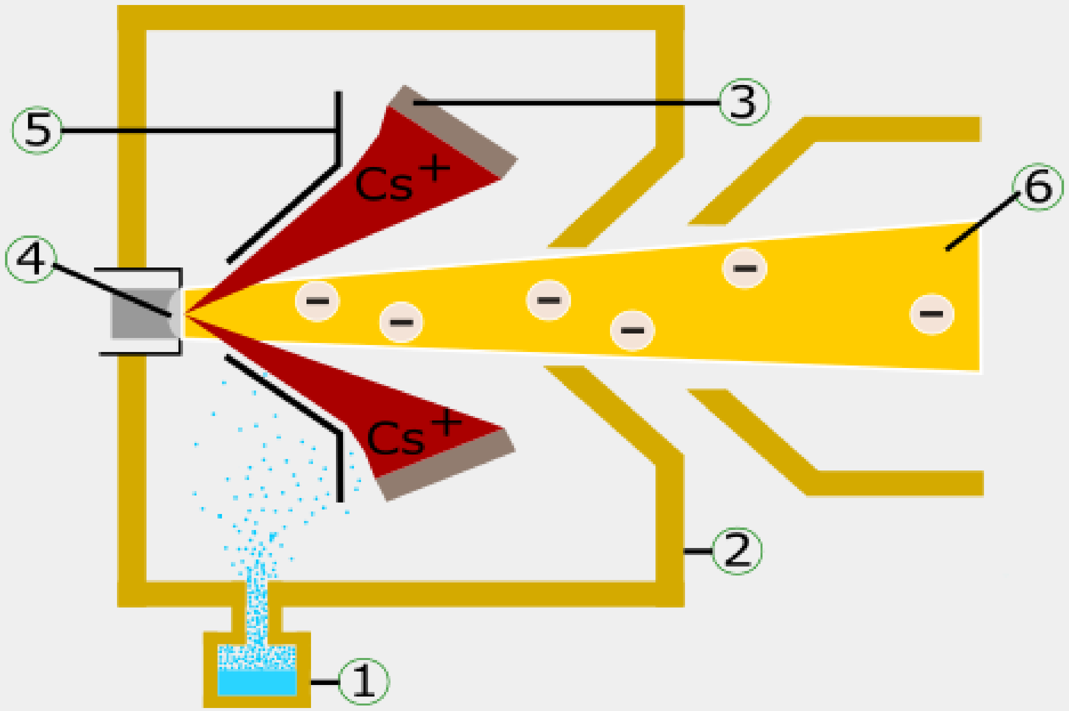
Motivation and background



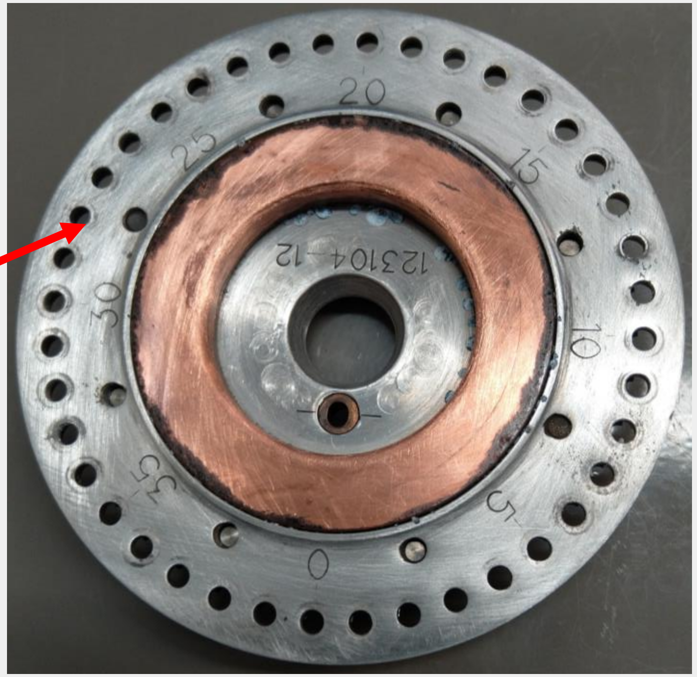


SNICS ion source



Cathode holder

Target
Ø1 mm



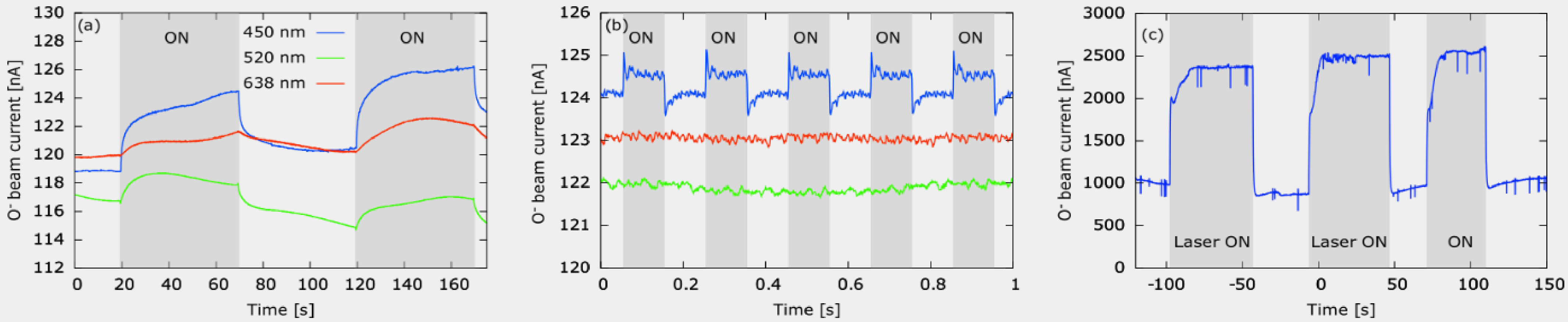
Cathode wheel (40 cathode)

Schematic drawing of the SNICS ion source:
(1) Caesium oven and transfer line, (up to the ionizer in reality)
(2) Ionisation chamber
(3) Ionizer
(4) Cathode,
(5) Focusing electrode (immersion lens) and
(6) Extraction channel and electrodes.

SNICS:
- Beams from H to U
- AMS (C14, etc) usage and IBA
- Molecule beams available
- Gaseous targets also possible (CO2)
- Beam currents up to ~400 uA (Carbon)

Motivation and background

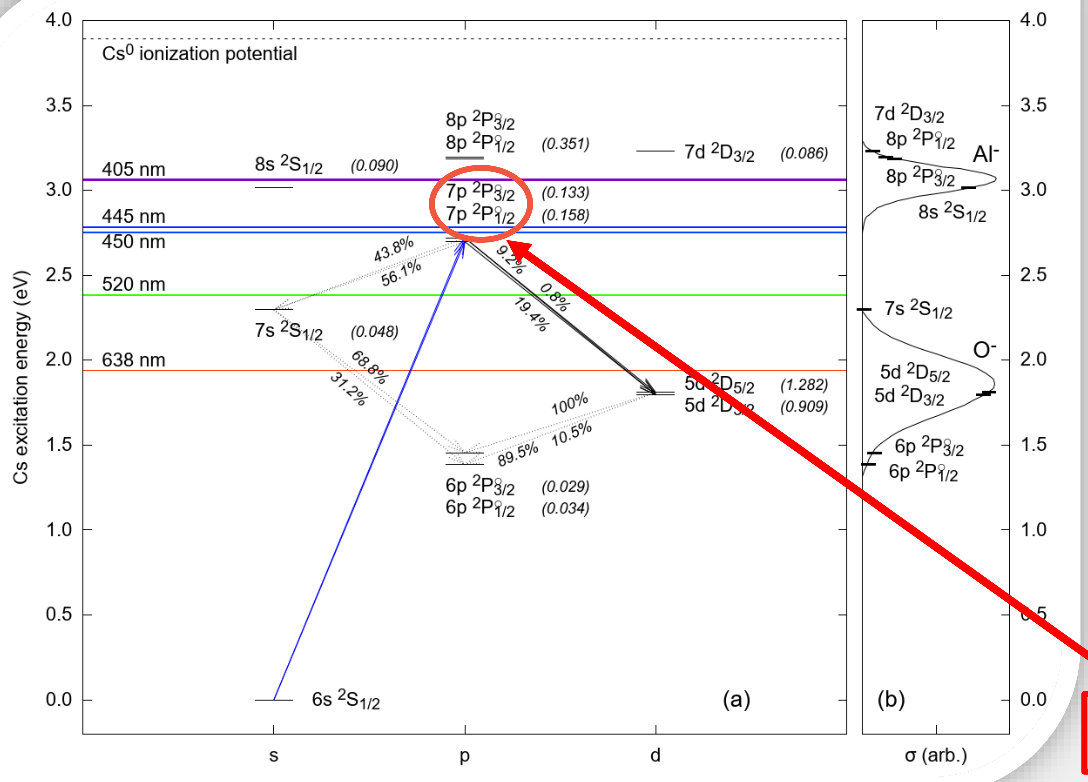
- Vogel: **Resonant Ion Pair Production** (2018) [1]
- JYFL-ACCLAB and the UK Science and Technology Facilities Council, STFC: **Negative ions can be provoked by any laser** (2020) [2]
- JYFL-ACCLAB and STFC: **Beam current enhancement does not depend on the resonant ion pair production**, extracted beam current can be enhanced by a factor >2 (2022) [3]
- Experiments with Cl^-, Br^- and I^- : All have similar Cs-matrix material + usage in Ion Beam Analysis (IBA)



The effect of (a) 50 s and (b) 100 ms laser pulses at 450 nm / 1.6 W, 520 nm / 1.0 W and 638 nm / 0.7 W wavelengths / powers on the O^- beam current. The best recorded example of the (c) 445 nm, 6 W laser on the O^- beam current. [2]

[1] J. S. Vogel, "Lasis: The laser assisted sputter ion source," NIMB 438, 89–95 (2019).
[2] O. Tarvainen, R. Kronholm, M. Laitinen, M. Reponen, J. Julin, V. Toivanen, M. Napari, M. Marttinen, D. Faircloth, H. Koivisto, and T. Sajavaara, "Experimental evidence on photo-assisted O^- ion production from Al2O3 cathode in cesium sputter negative ion source," Journal of Applied Physics 128, 094903 (2020).
[3] A. Hossain, O. Tarvainen, M. Reponen, R. Kronholm, J. Julin, T. Kalvas, V. Toivanen, M. Kivekäs and M. Laitinen
Photo-enhanced O-, H- and Br- ion production in caesium sputter negative ion source-no evidence for resonant ion pair production, J. Phys. D: Appl. Phys. (2022).

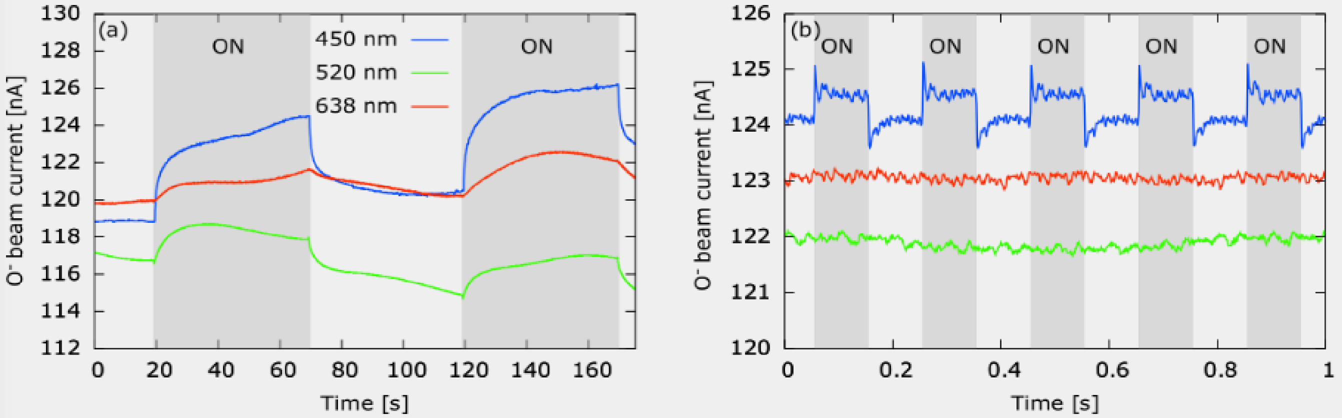
Previous results:
Evidence of non-resonant nature ?



Resonance expected by Vogel

Fig: Multiple probed laser wavelengths and energy levels.

2 different phenomena recognized:



Long-term "heating" effect and **short-term** prompt effect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PAPER

Photo-enhanced O⁻, H⁻ and Br⁻ ion production in caesium sputter negative ion source—no evidence for resonant ion pair production

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References

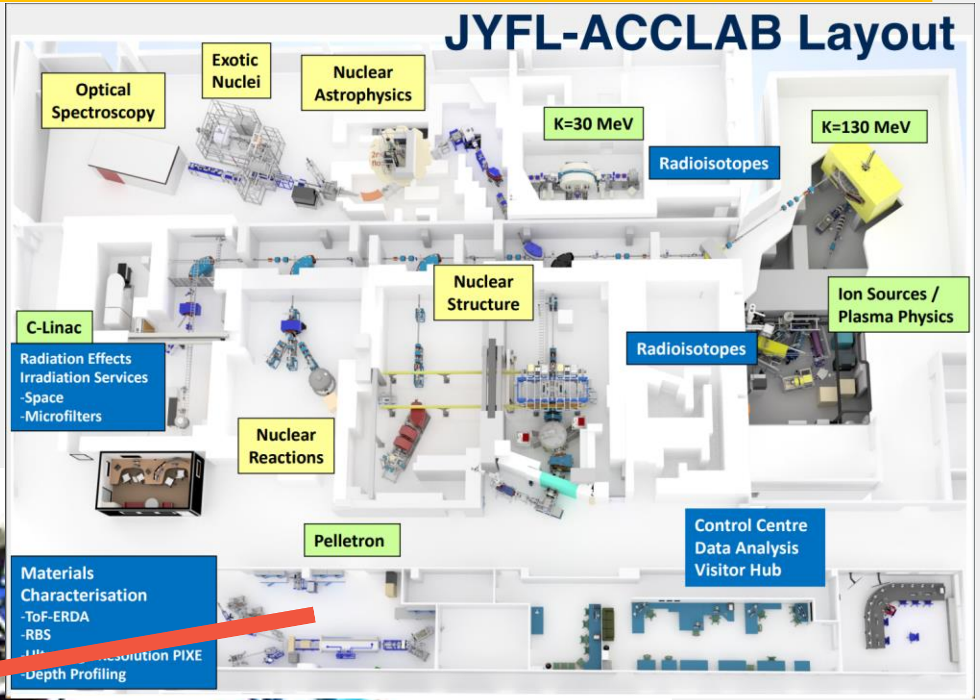
+ Article information

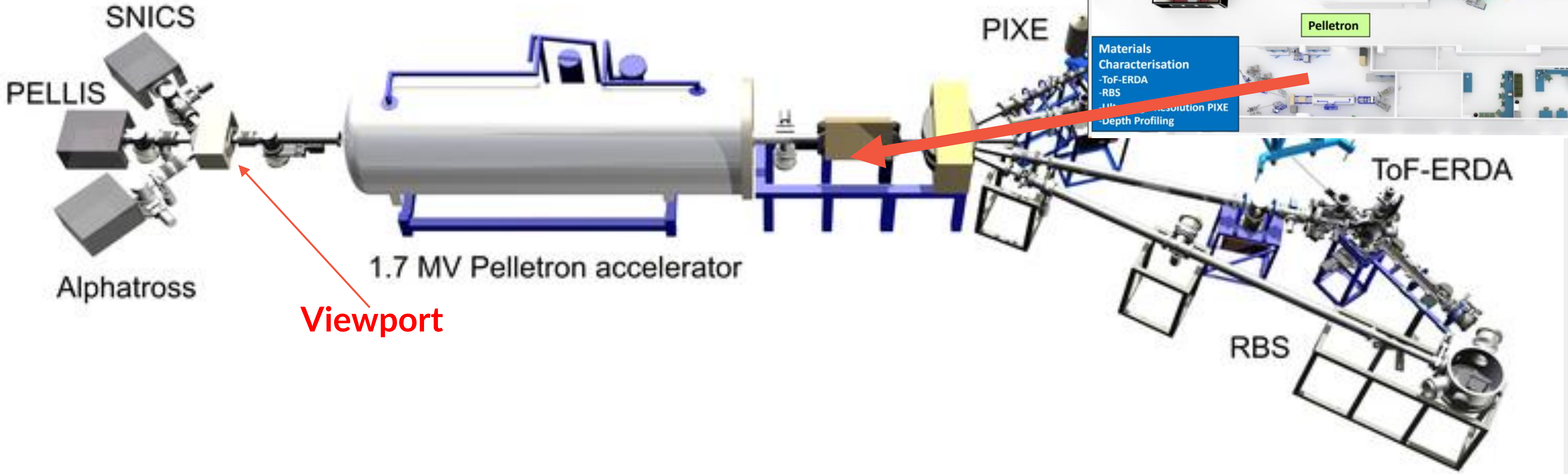
O. Tarvainen, R. Kronholm, M. Laitinen, M. Reponen, J. Julin, V. Toivanen, M. Napari, M. Marttinen, D. Faircloth, H. Koivisto, and T. Sajavaara, "Experimental evidence on photo-assisted O⁻ ion production from Al2O3 cathode in cesium sputter negative ion source," Journal of Applied Physics 128, 094903 (2020).

Accelerator Laboratory of the University of Jyväskylä

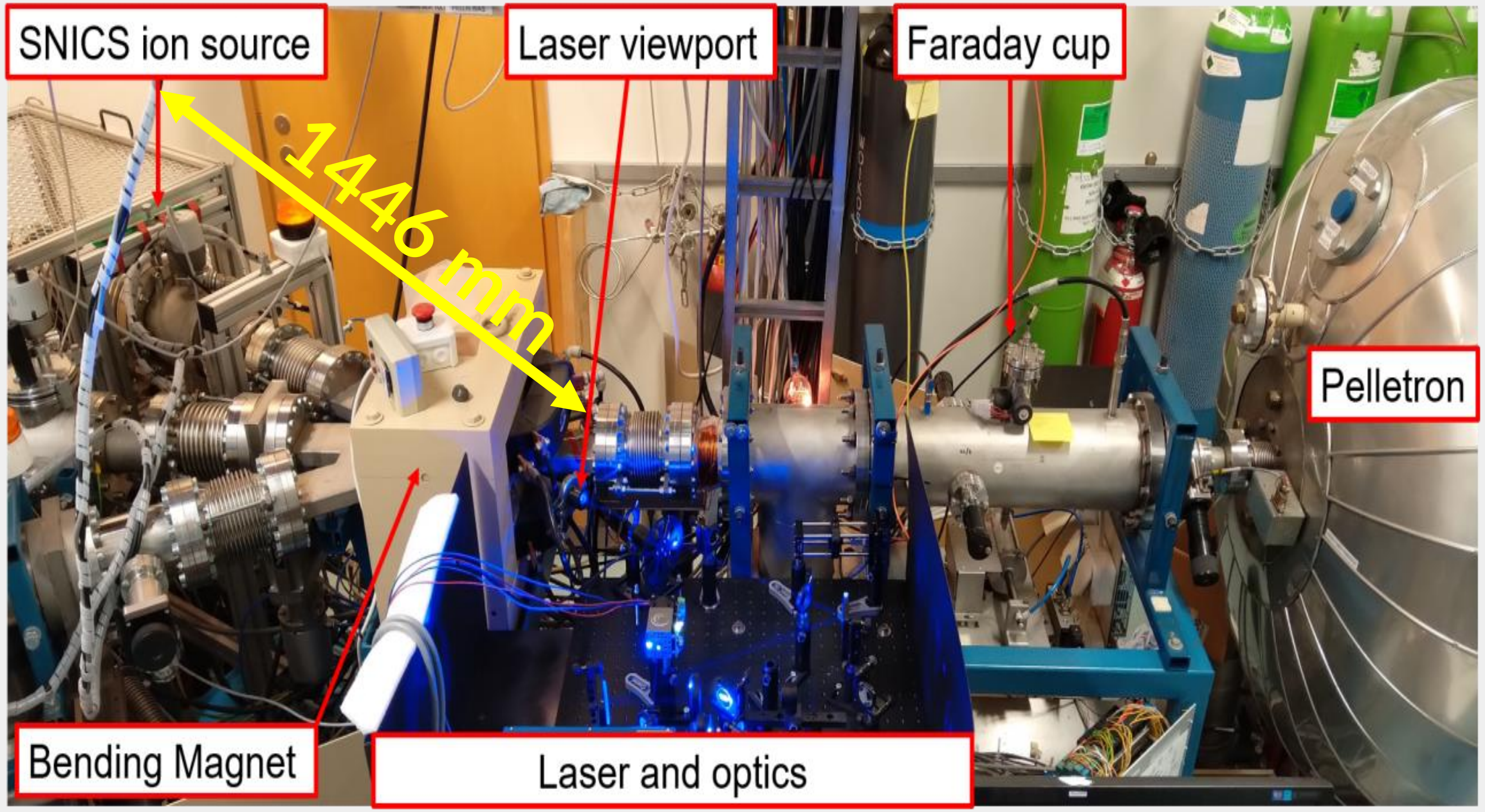
- Large scale nuclear physics-based infrastructure
- Versatile support from ion source, laser, IBA experts available

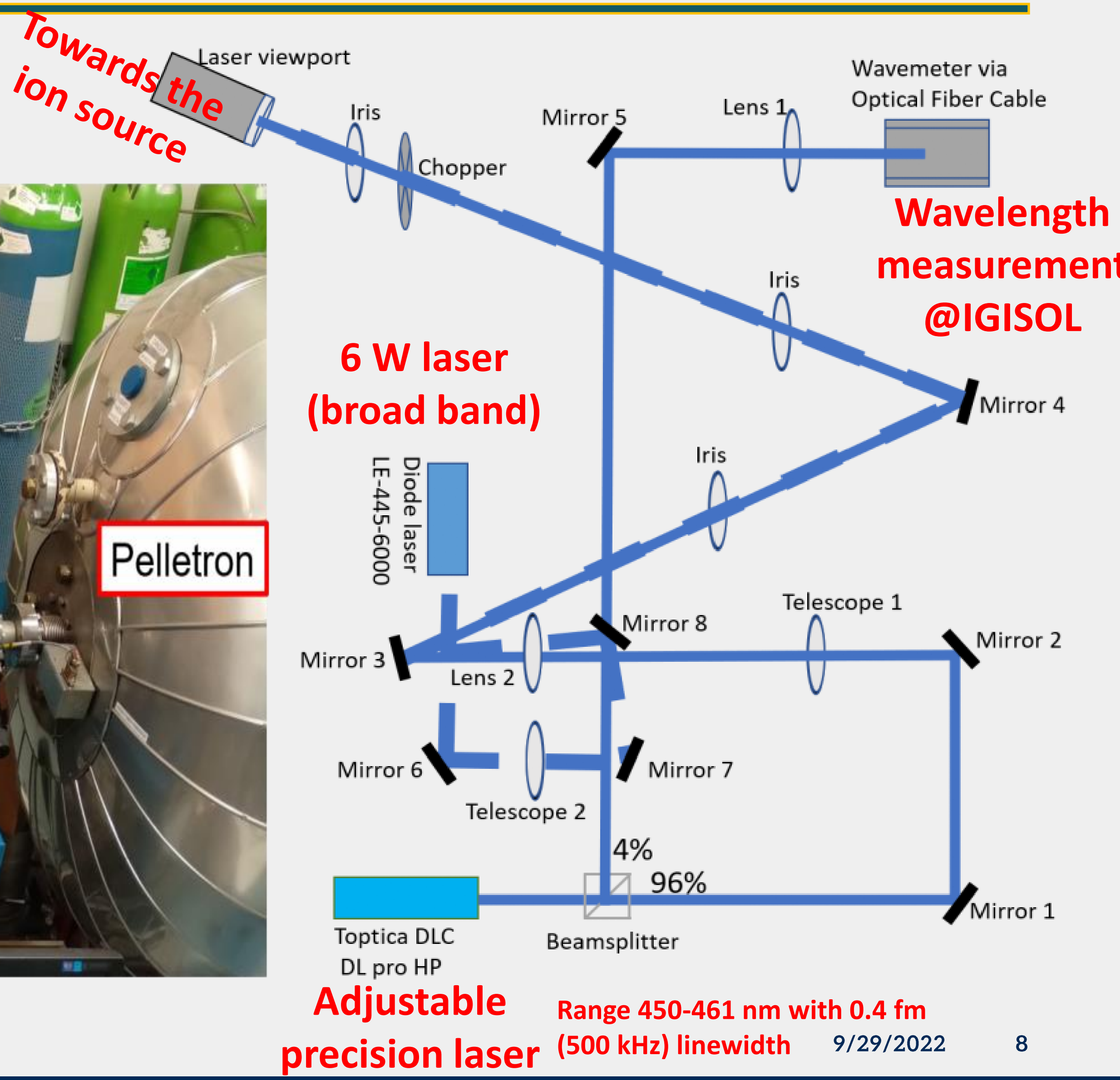
- Experiments done at Pelletron lab:
  Using NEC made 40 cathode MC-SNICS source, where
  Laser input has been through the viewport at the magnet





Experimental Setup for non(?)-resonance measurements





A. Hossain, O. Tarvainen, M. Reponen, R. Kronholm, J. Julin, T. Kalvas, V. Toivanen, M. Kivekäs and M. Laitinen Photo-enhanced O-, H- and Br- ion production in caesium sputter negative ion source-no evidence for resonant ion pair production, J. Phys. D: Appl. Phys. (2022).

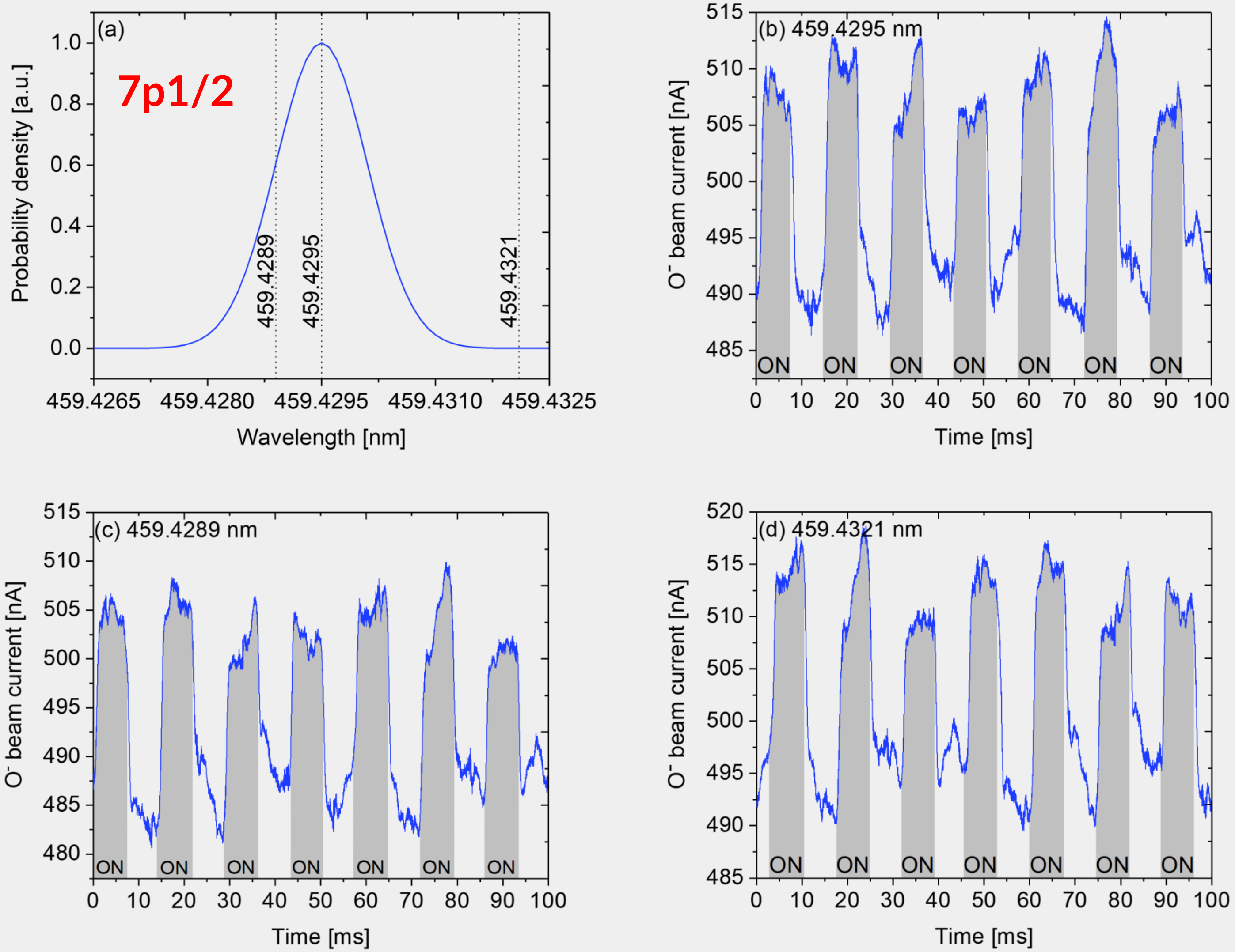
Laser powers for resonance measurements

The output power of the two lasers, the power at the cathode and corresponding efficiency

Toptica DLC DL pro HP			LE-445-6000 diode laser		
Output power [mW]	Power at the cathode [mW]	Efficiency [%]	Output power [W]	Power at the cathode [mW]	Efficiency [%]
0.03	0.01	33.3	0.3	8.8	2.9
0.06	0.02	33.3	0.7	21.1	3.0
4.8	1.6	33.3	1.0	30.3	3.0
12.0	3.6	30.0	1.3	38.8	3.0
19.5	6.3	32.3	1.7	50.3	3.0
26.7	8.2	30.7	2.2	62.2	2.8
34.5	11.4	33.0	2.3	64.4	2.8
41.7	14.8	35.5	3.0	79.0	2.6
49.0	16.0	32.7	3.6	77.2	2.1
56.0	17.4	31.1	4.2	71.3	1.7
62.6	21.6	34.5	4.7	70.7	1.5
70.9	23.2	32.7	5.0	68.5	1.4
79.7	28.0	35.1	5.2	64.2	1.2
85.4	28.8	33.7	-	-	-
94.1	33.2	35.3	-	-	-
100.1	33.7	33.7	-	-	-
111.9	39.7	35.5	-	-	-
116.9	41.3	35.3	-	-	-

Maximum power delivered to the cathode (1 mm):
- **Precision laser: 41 mW**
- ”High” power laser: 79 mW (optics were optimized for precision laser measurements)

Evidence of non-resonant nature



Beam intensity change was similar amount for broad range of wavelengths (>10) scanned over the expected resonance frequencies of the neutral Cs.

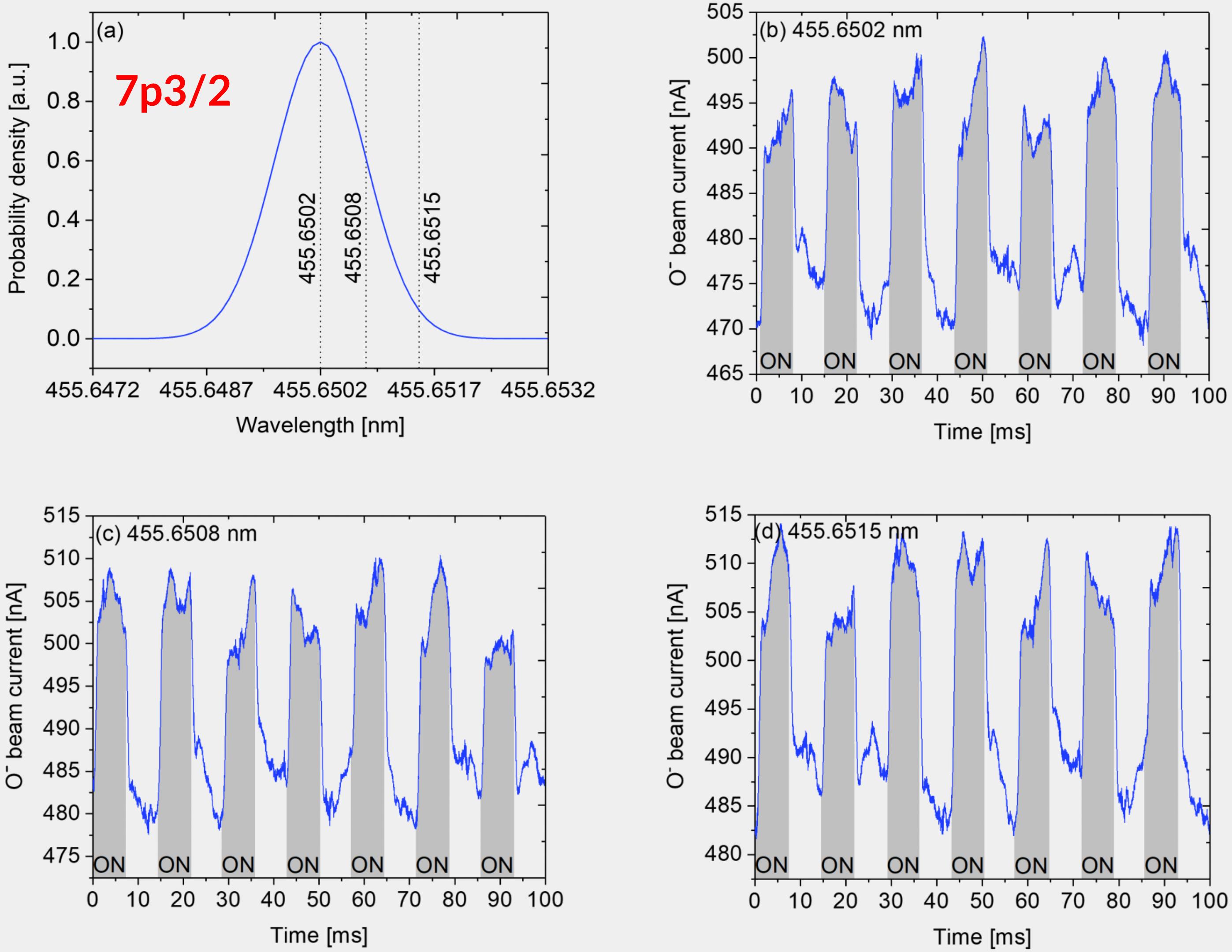
->> not a resonance effect

(at least for these states)

Wavelength selection for the excitation of the 7p1/2 electronic state of neutral Cs: (a) shows the expected maximum Doppler broadening of the absorption line and the laser wavelengths used for probing the putative ion pair production.

The prompt effect of the laser exposure on the O− beam current with different wavelengths: (b) in-vacuum resonance at 459.4295 nm, (c) 459.4289 nm within the maximum Doppler broadening, and (d) 459.4321 nm outside the maximum Doppler broadening.

Evidence of non-resonant nature



Beam intensity change was similar amount for broad range of wavelengths (>10) scanned over the expected resonance frequencies of the neutral Cs.

->> not a resonance effect

(at least for these states)

Wavelength selection for the excitation of the 7p3/2 electronic state of neutral Cs: (a) shows the expected maximum Doppler broadening of the absorption line and the laser wavelengths used for probing the putative ion pair production.

The prompt effect of the laser exposure on the O− beam current with different wavelengths: (b) in-vacuum resonance at 455.6502 nm, (c) 455.6508 nm within the maximum Doppler broadening, and (d) 455.6515 nm outside the maximum Doppler broadening.

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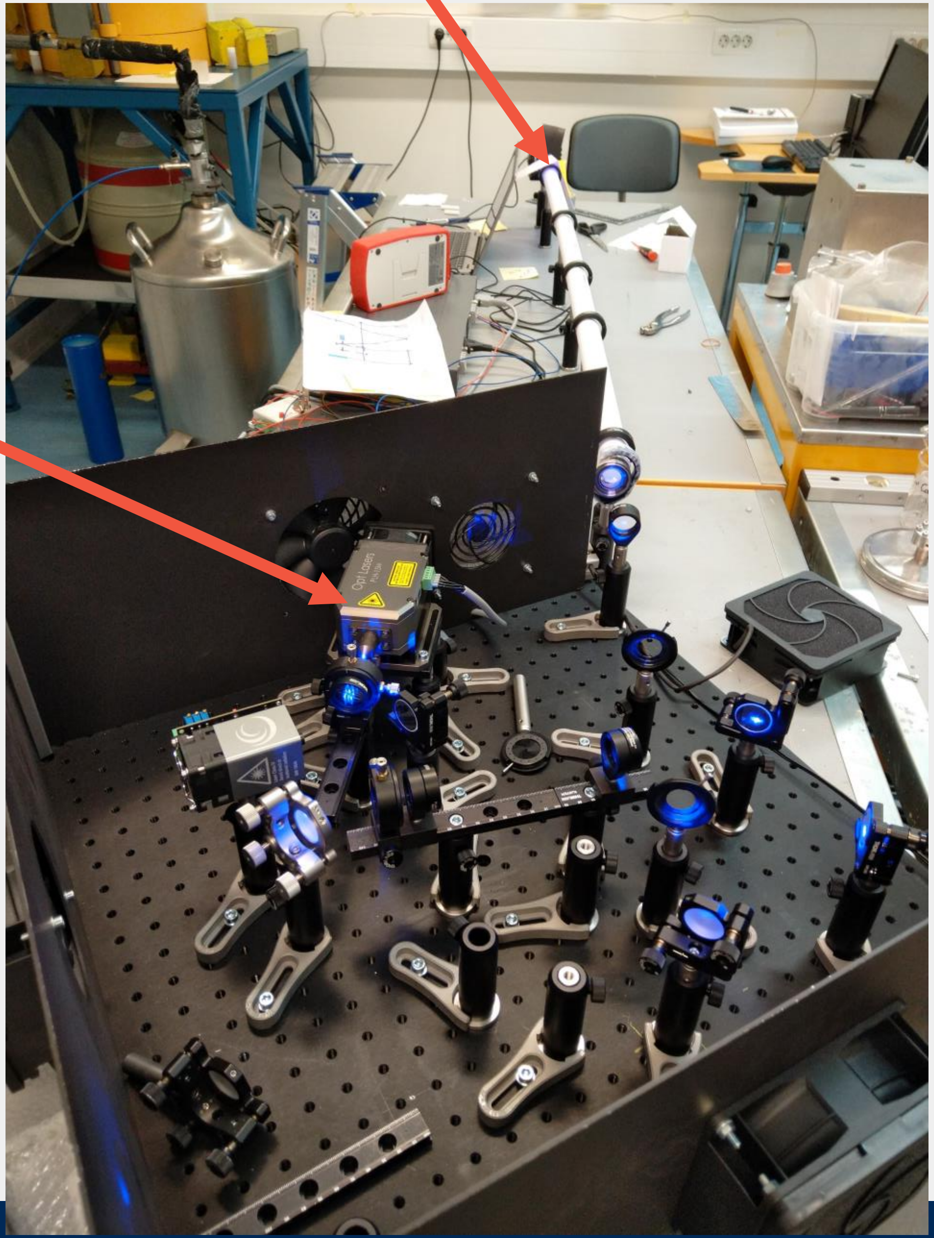
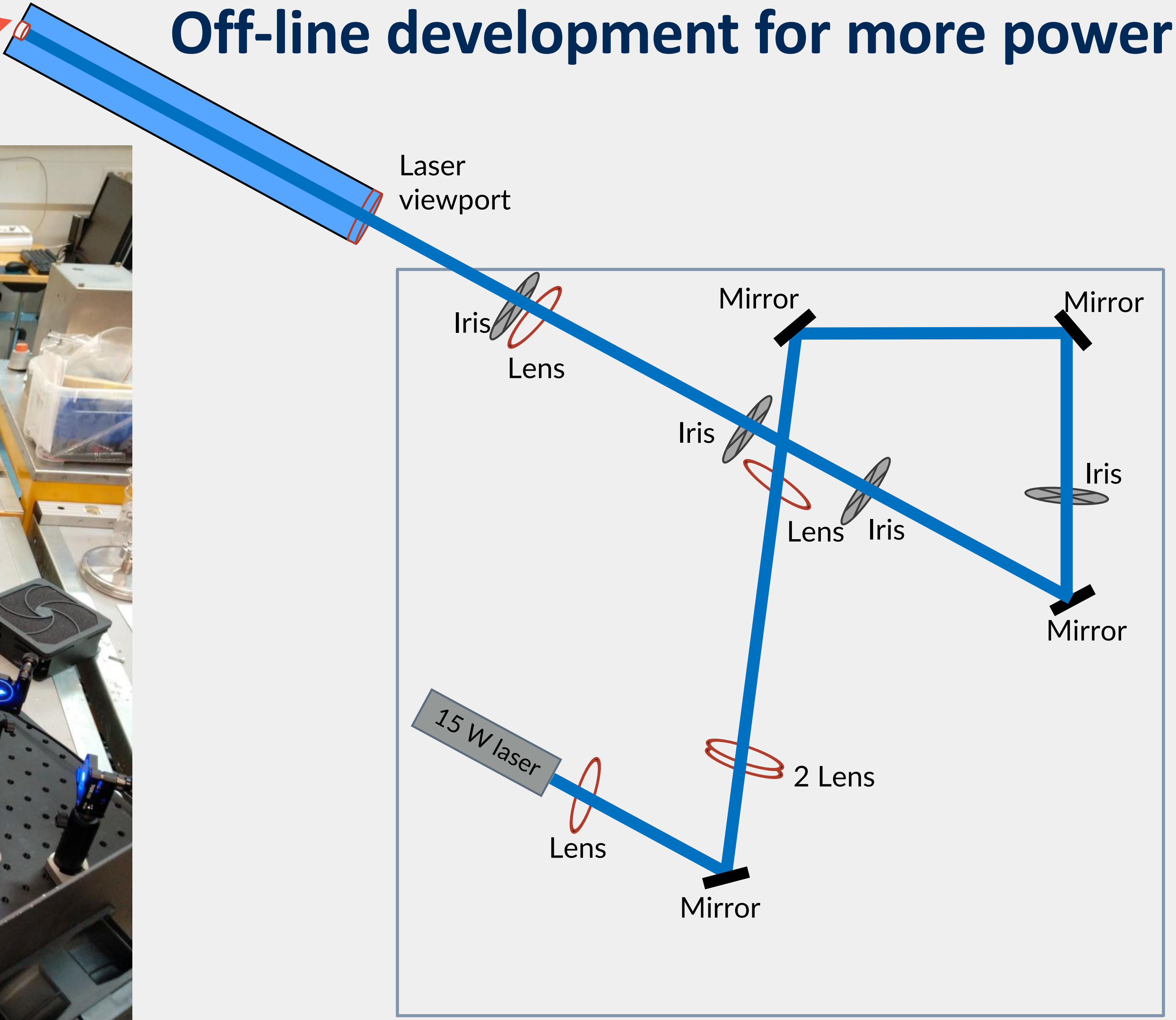
Off-line development of the laser setup
-
How about MORE POWER !?

Off-line development for more power

Cathode position

15 W laser



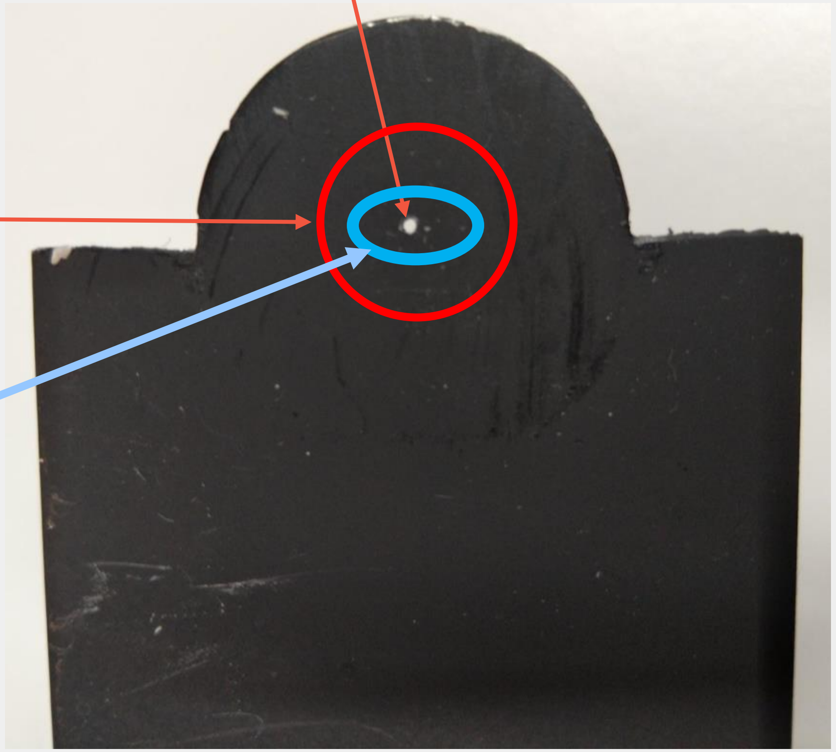


Off-line development for more power

Thermal power sensor

1 mm aperture hole simulating the cathode

Ionizer opening ~6.5 mm

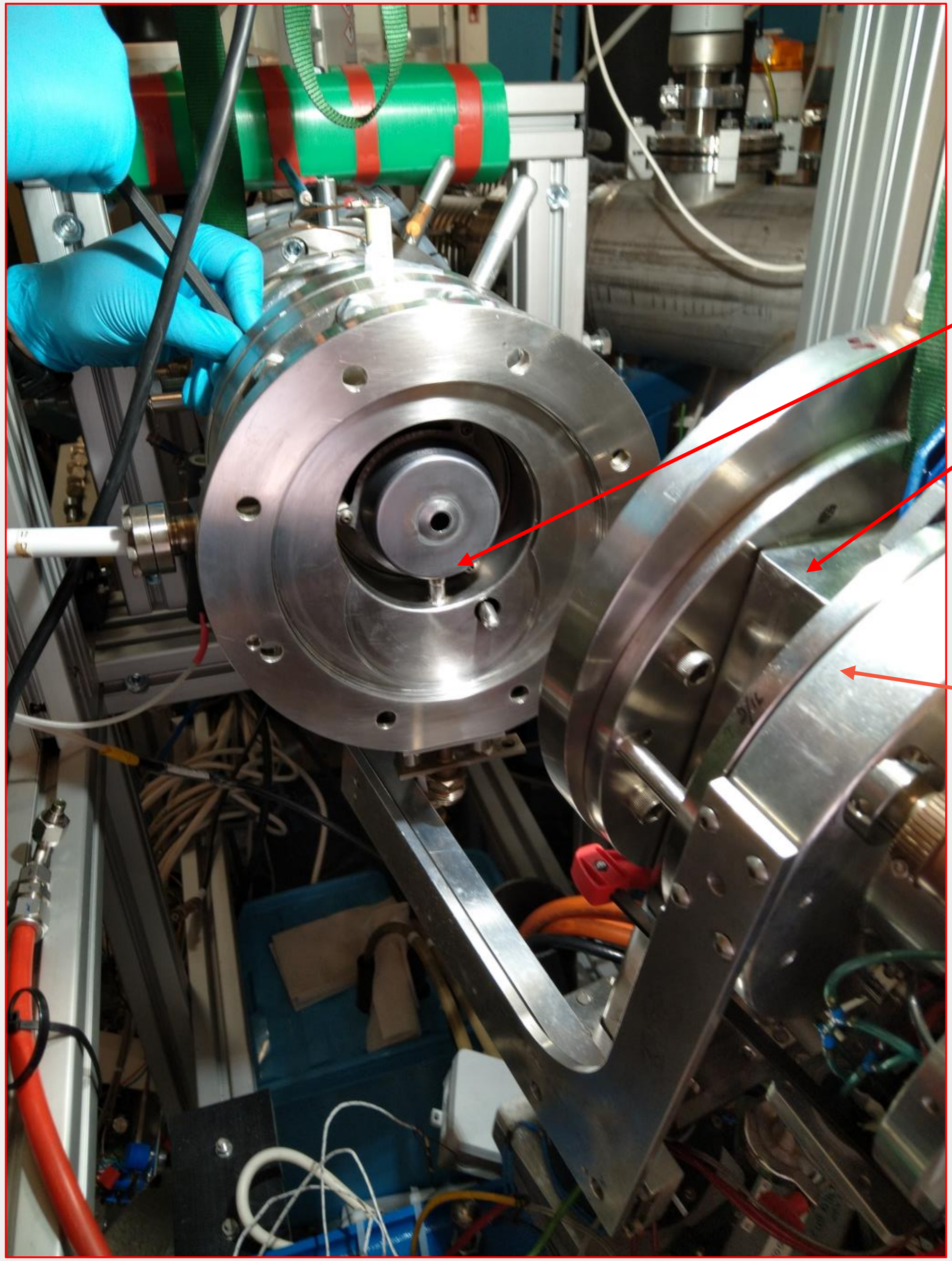


Off-line measured (high intesity) beam spot: 3.9 × 1.6 mm^2

beam spot measured off-line 3.9 × 1.6 mm^2

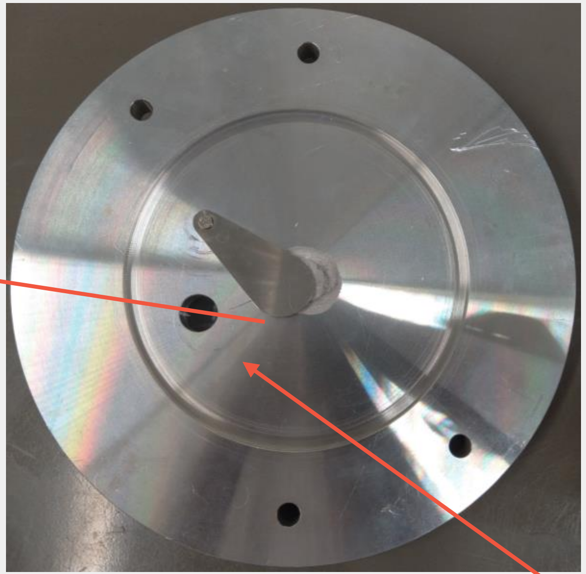
From previous maximum of <100mW to **> 600 mW** at the cathode position Ø1 mm

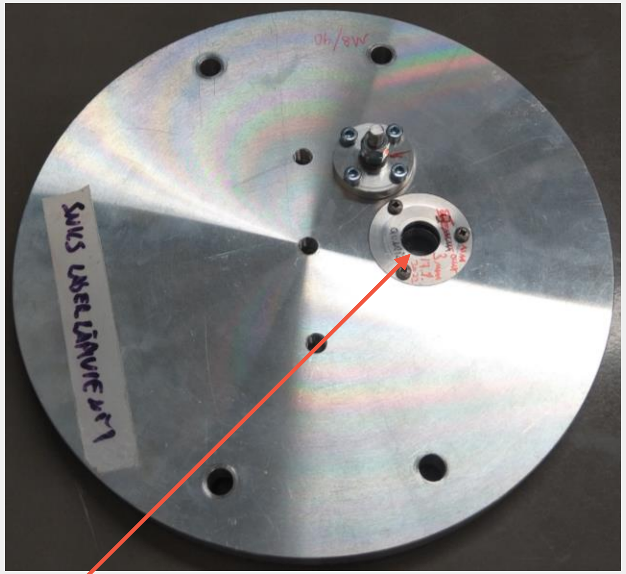
Laser power measurement at the SNICS ion source cathode position



Ion Source as opened,
Ionizer (behind the Cs focus electrode) and Cs tube visible

Gate valve for cathode wheel exchange purposes





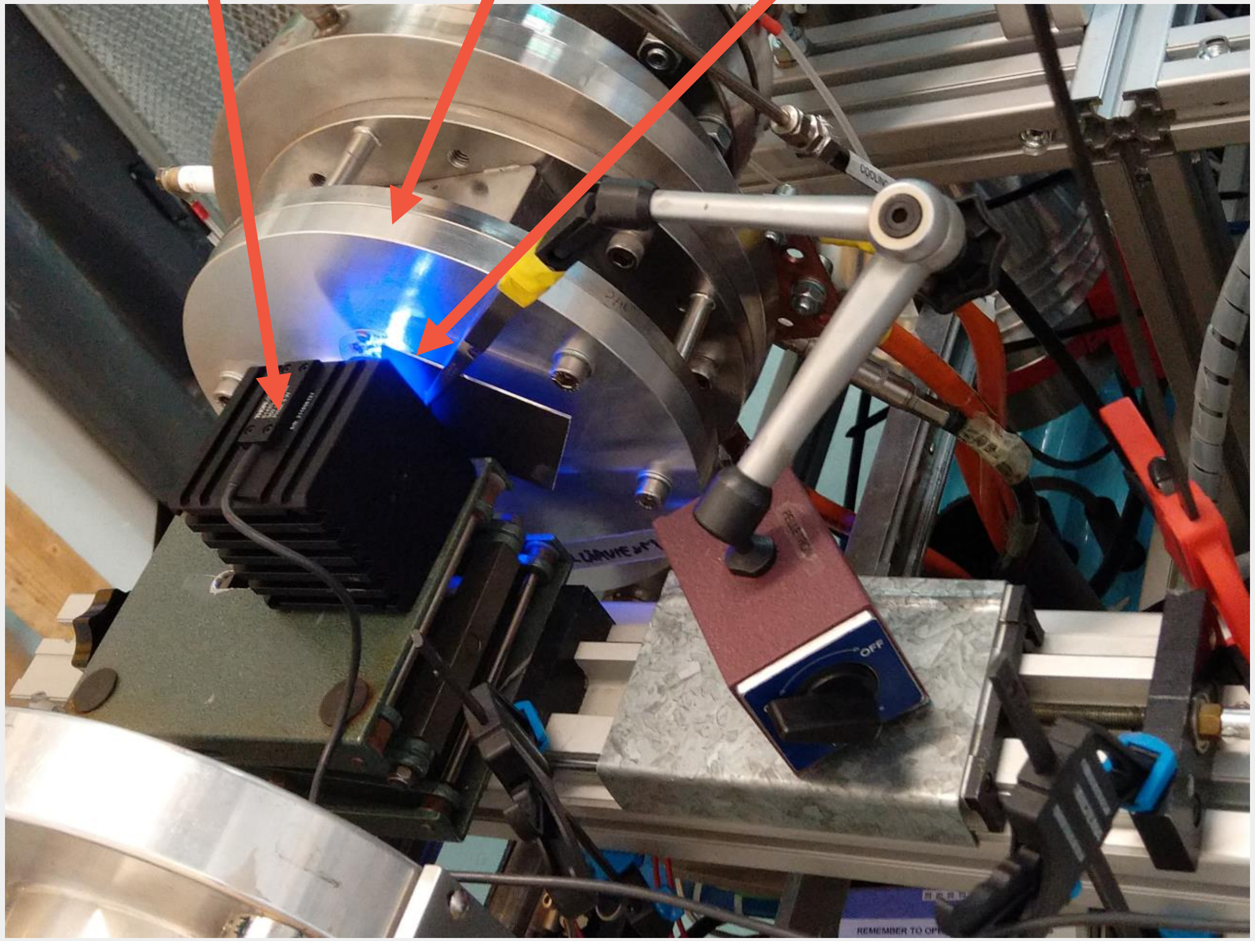
Quartz window flange,
for laser power measurement at the target/cathode position

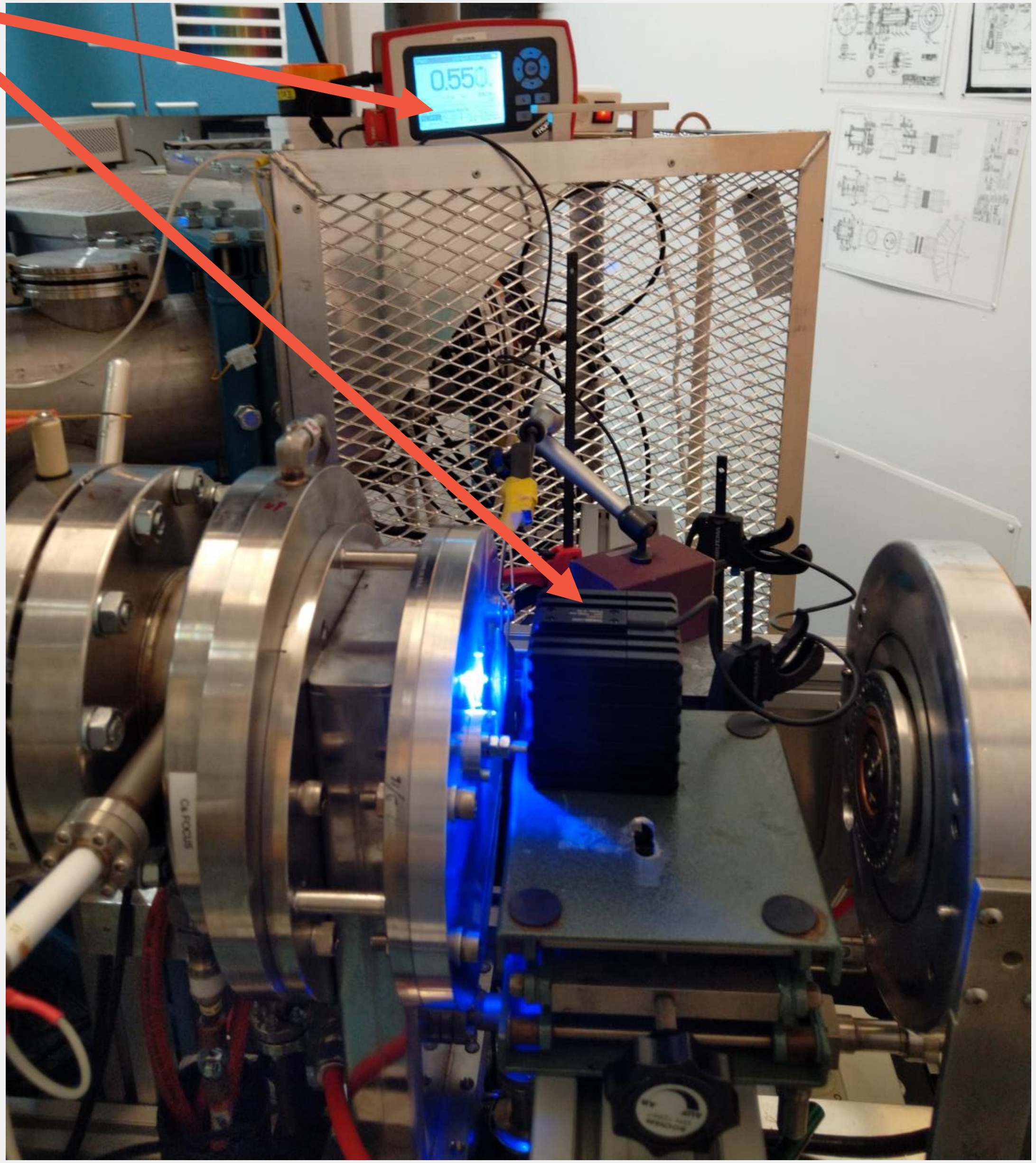
Thermal Power sensor

Quartz window-flange

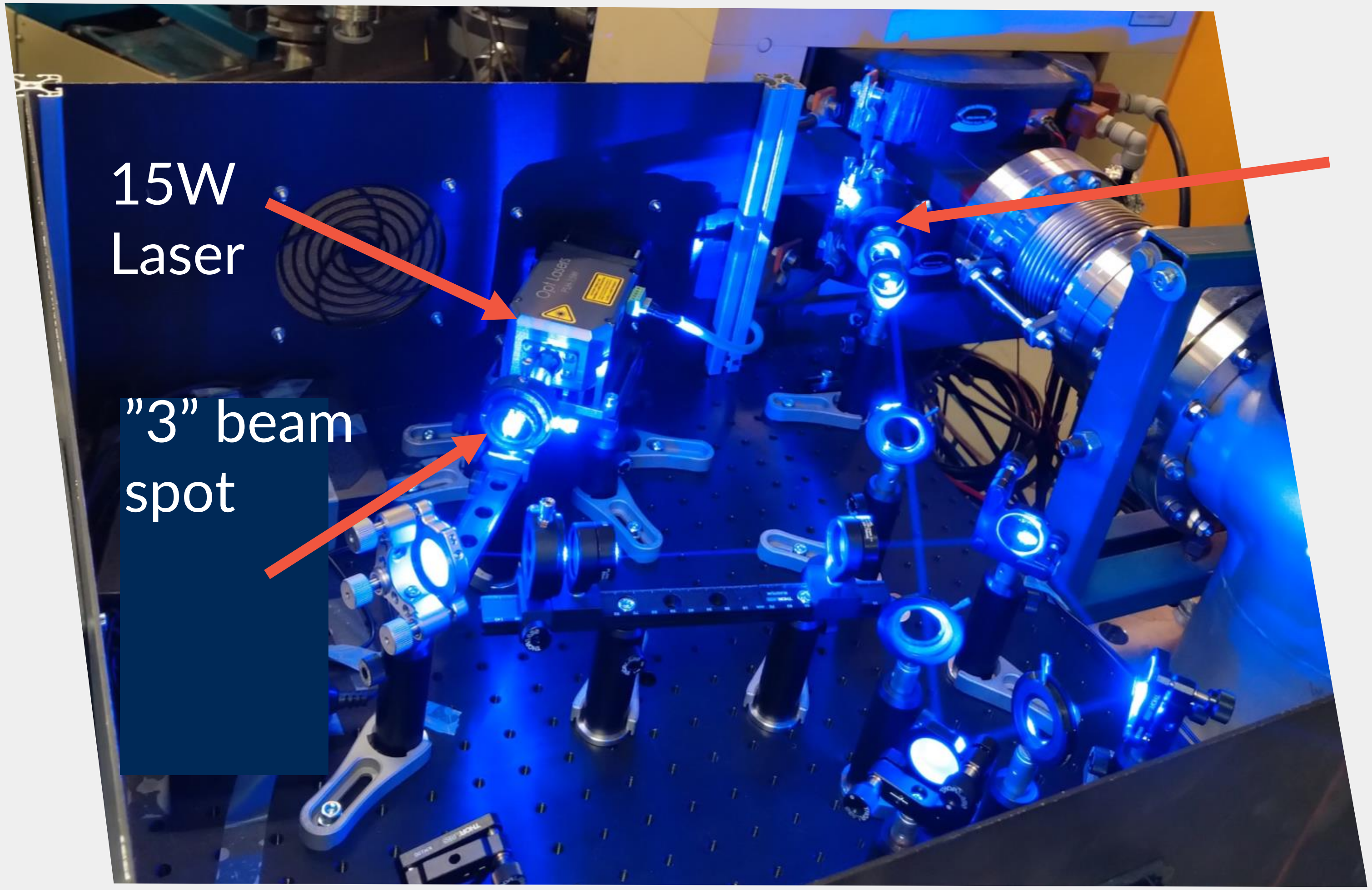
1 mm diameter collimator @ cathode position

Power Measurement





Optical Setup



Vacuum
Viewport

Power measurement

Output Power [W]	Power at the cathode [mW]	Efficiency [%]
1.09	40	3.67
2.64	100	3.79
4.19	150	3.58
5.71	240	4.2
7.22	295	4.09
8.68	390	4.49
10.11	470	4.65
11.50	540	4.70
12.80	605	4.73

Maximum power delivered to the cathode (1 mm)

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Experimental results

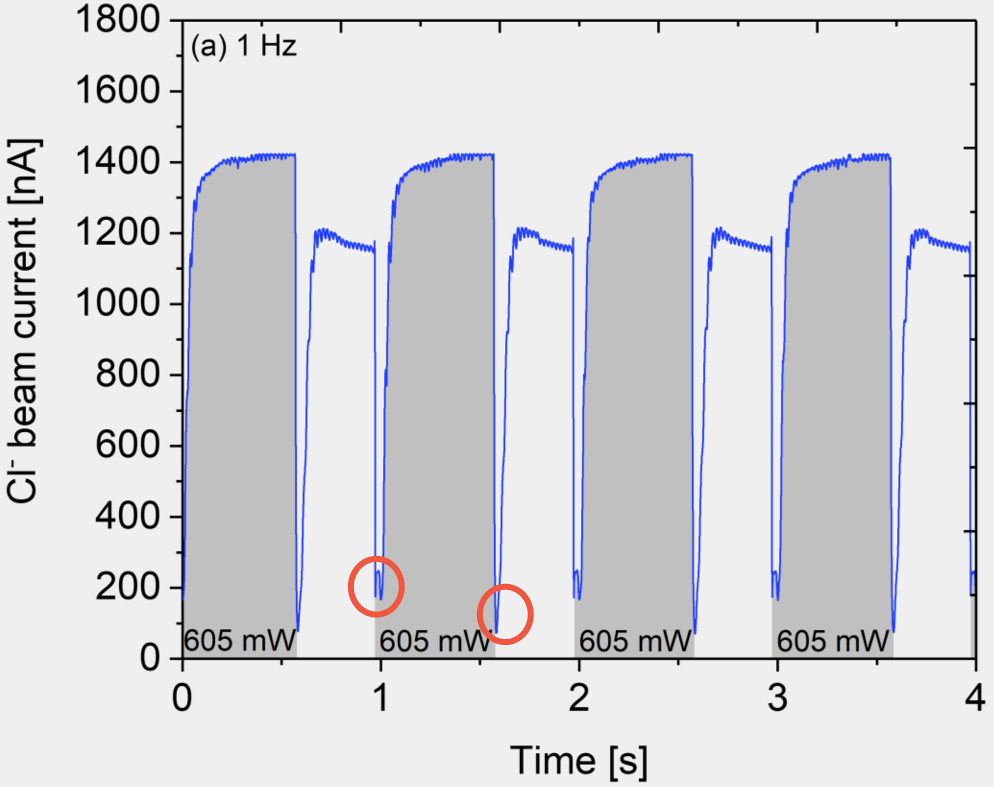
Effect of the laser repetition rate on the beam current

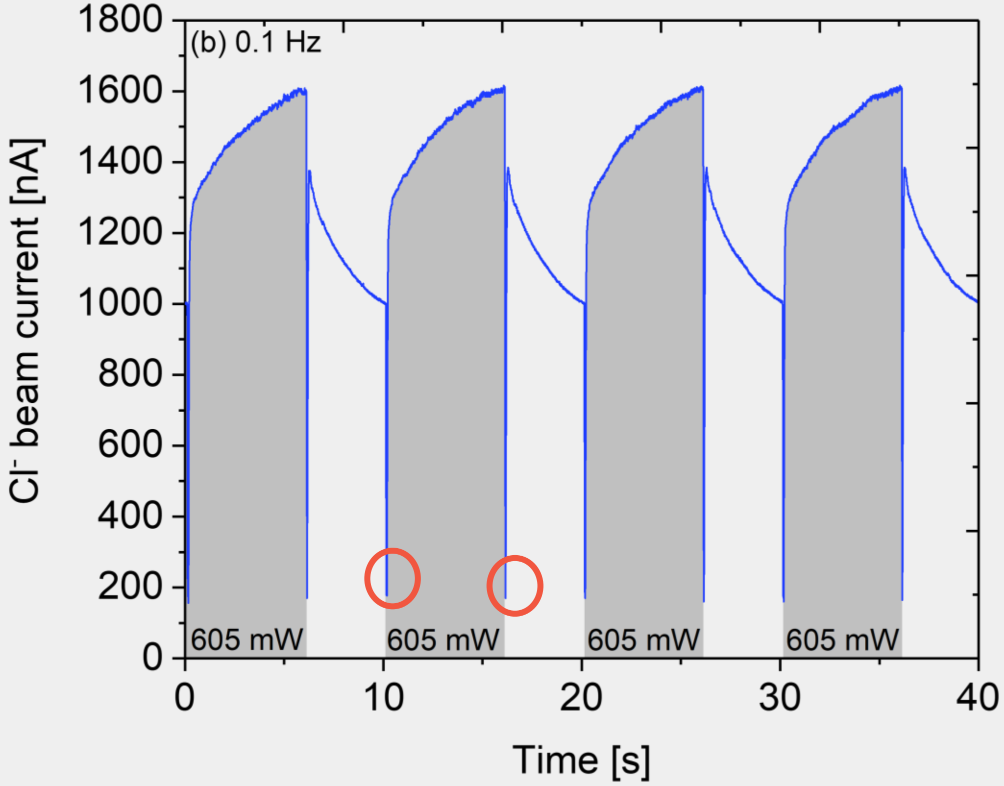
NOTE: Highly depleted Cs conditions!

- Fresh (cleaned) ion source,
- Cs oven temperature: 140 °C.
  BUT..
- Tube heater was room temp (heater failure after maintenance).

- Experiments were done with very little of Cs in the source and only fraction of normal beam intensity could be extracted also after these measurements (from non-Cs containing compounds).

Different time scale: Cathode Material: CsCl



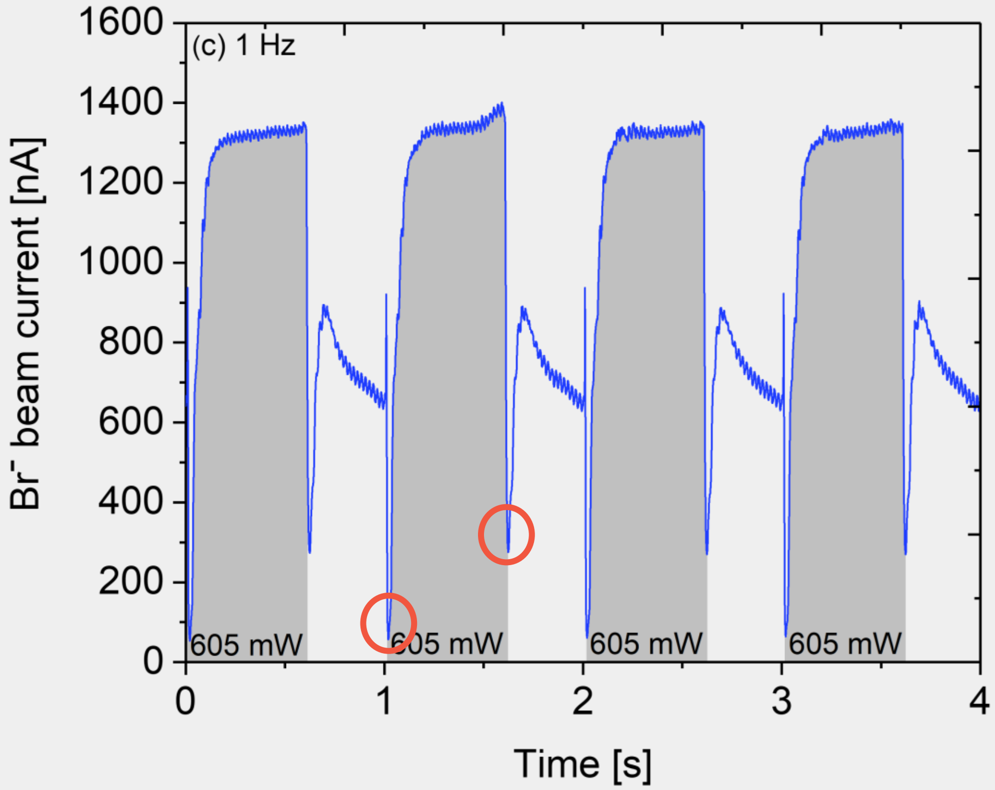


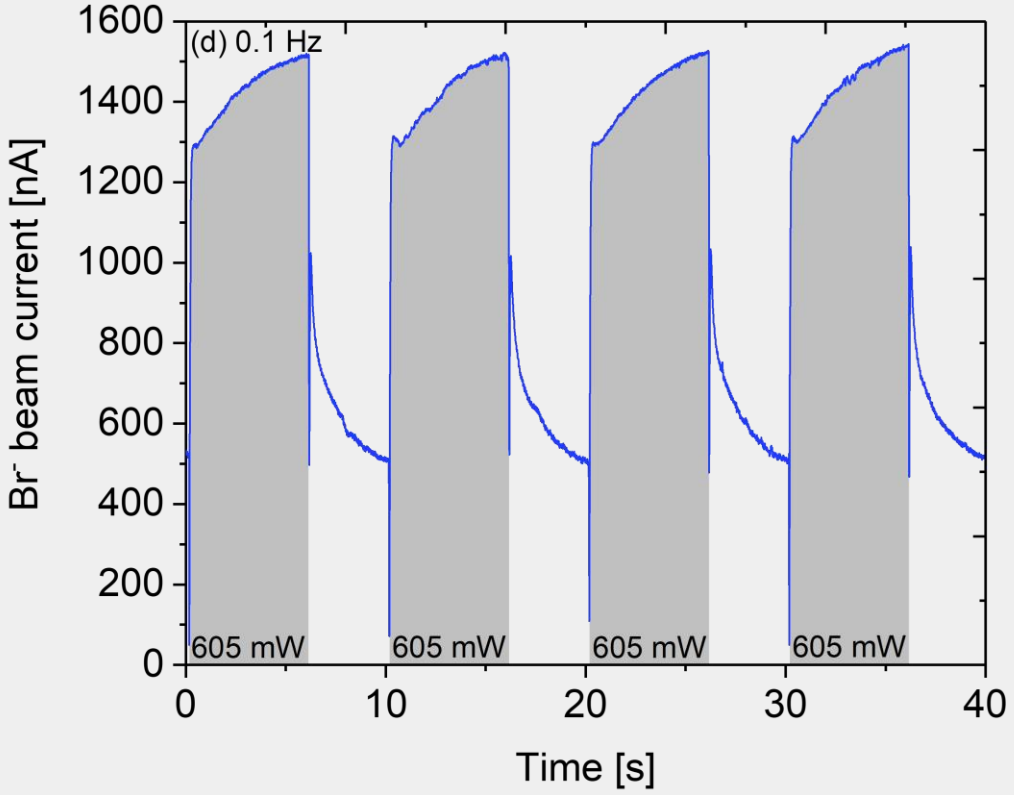
The effect on the Cl^- beam current with 605 mW laser output power at nominal 445 nm wavelength incident on the cathode. The laser pulse period is (b) 1 s and (c) 10 s with 60% duty factor.

Longer the pulse, more beam seemed to be available.

Gap Lens HV power supply issue limited the fast measurements. (and steered the beam off)

Different time scale: Cathode Material: CsBr

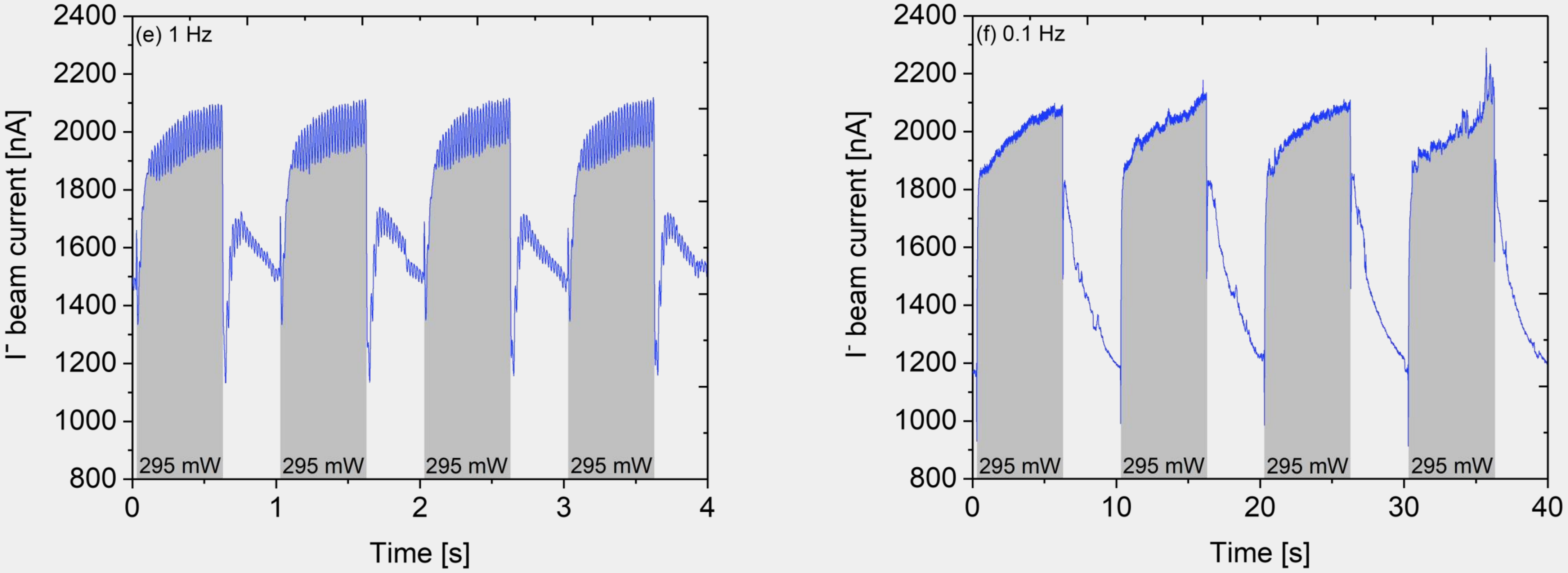




The effect on the Br^{-} beam current with 605 mW laser output power at nominal 445 nm wavelength incident on the cathode. The laser pulse period is (b) 1 s and (c) 10 s with 60% duty factor.
Longer the pulse, more beam seemed to be available.

Gap Lens HV power supply issue limited the fast measurements. (and steered the beam off)

Different time scale: Cathode Material: CsI



The effect on the I^- beam current with 295 mW laser output power at nominal 445 nm wavelength incident on the cathode. The laser pulse period is (b) 1 s and (c) 10 s with 60% duty factor.

Longer the pulse, more beam seemed to be available.

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Experimental results

Experiments with different laser power

NOTE: Highly depleted Cs conditions!

- Fresh (cleaned) ion source,
- Cs oven temperature: 140 °C.
  BUT..
- Tube heater was room temp (heater failure after maintenance).

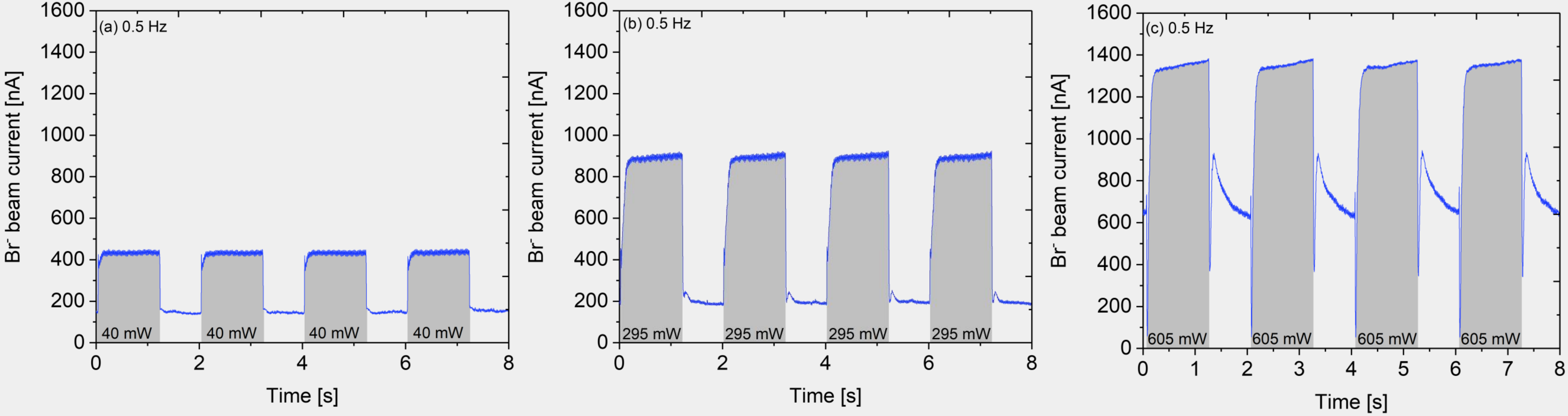
- Experiments were done with very little of Cs in the source and only fraction of normal beam intensity could be extracted also after these measurements (from non-Cs containing compounds).

Different laser power on the CsBr cathode

40 mW

295 mW

605 mW



200 nA as base beam current before and after for all measurements.
The effect on the Br^- beam current with (a) 40 mW, (b) 295 mW and (c) 605 mW laser output power at nominal 445 nm wavelength incident on the cathode. The laser pulse period is 2 s with 60% duty factor.
Enhancement: (a) 110%, (b) 350% and (c) 550%.

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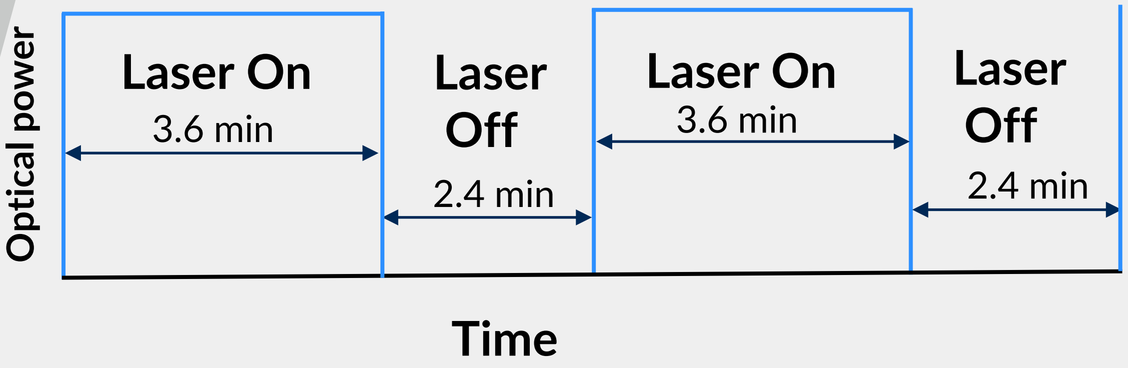
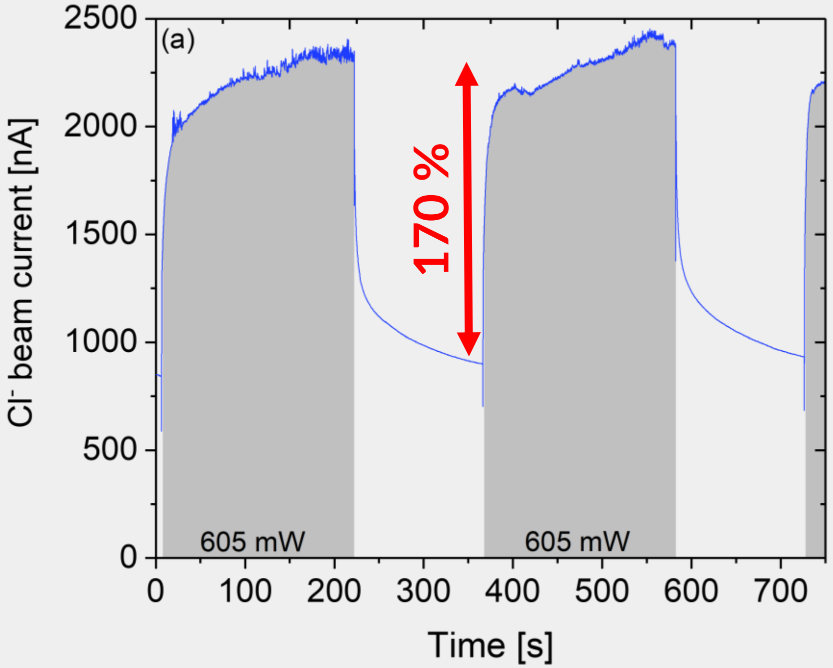
Experiment with 6 min laser pulse, 60% duty factor

NOTE: Highly depleted Cs conditions!

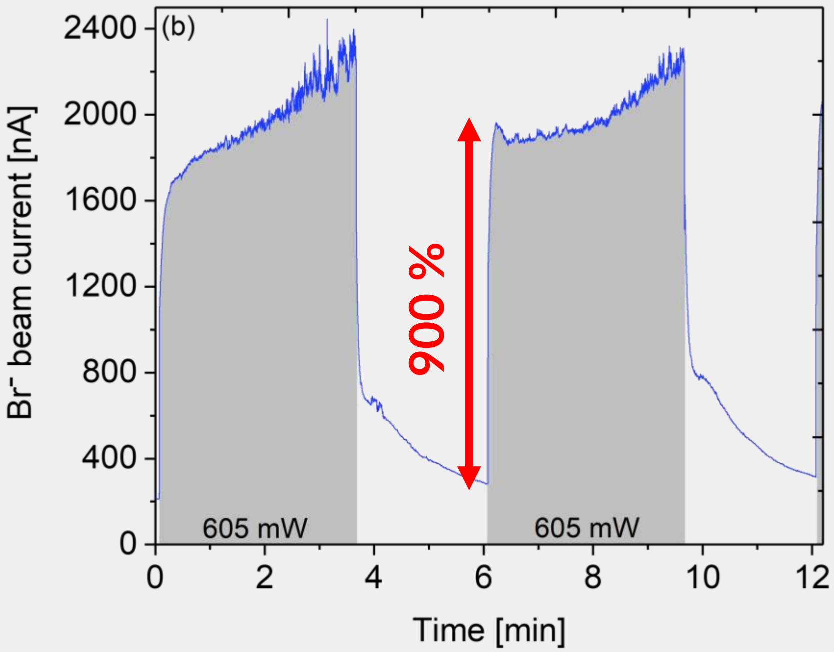


Comparing different target materials

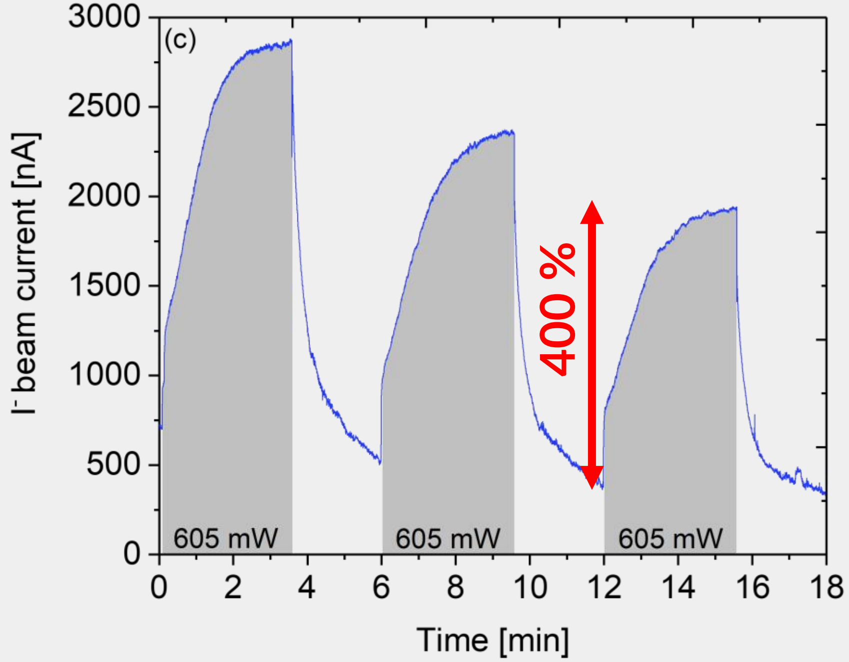
CsCl cathode material



CsBr cathode material



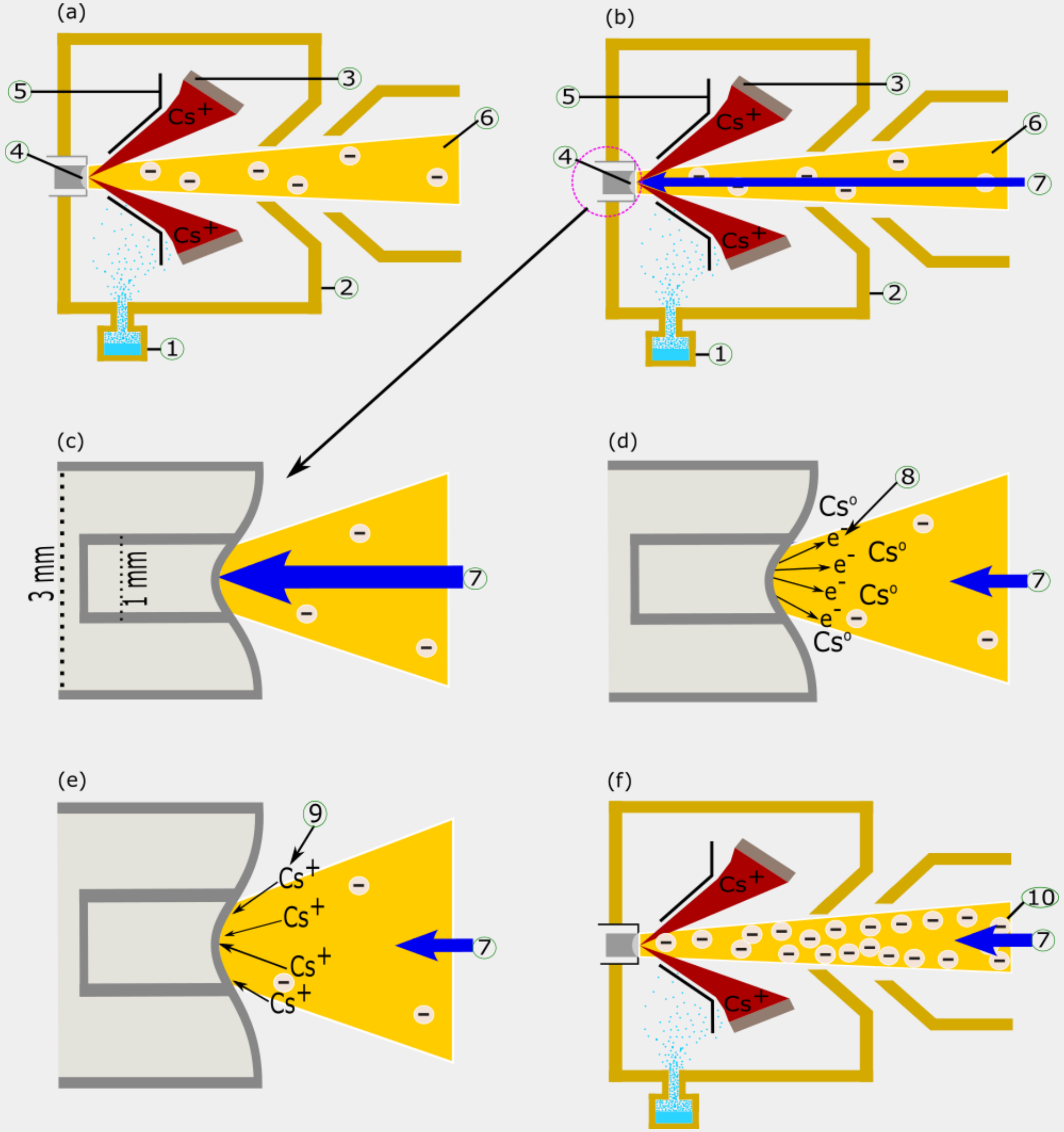
CsI cathode material



Longer pulses tend to produce more beam, and the intensity is more stable than for short pulses.
Stabilization of the Cs surface condition? Are we removing the “extra” Cs or depleting the Cs layer too much ?

The effect on the Cl^-, Br^- and I^- beam current with 605 mW laser power on the cathode. The laser pulse period is 6 min with 60% duty factor. Enhancement approximately: (a) 170 % , (b) 900% and (c) 400% (based on 3rd pulse).

One of the PROPOSED MECHANISM



Photoelectric emission of electrons, which causes prompt Cs ionization and increased sputtering.

A schematic drawing of the SNICS ion source (a) and the illustration of the proposed photo-assisted negative ion production mechanism (b)-(f).
The applied laser beam (c) induces photoelectron emission from the cathode (d) resulting in volumetric ionization of the Cs vapor (e). The labeling refers to the following:
(1) caesium oven and transfer line, (2) ionization chamber, (3) ionizer, (4) cathode, (5) focusing electrode (immersion lens), (6) extraction channel and electrodes, (7) laser beam, (8) emitted photoelectrons, (9) ionised Cs+ and (10) increased negative ion yield.

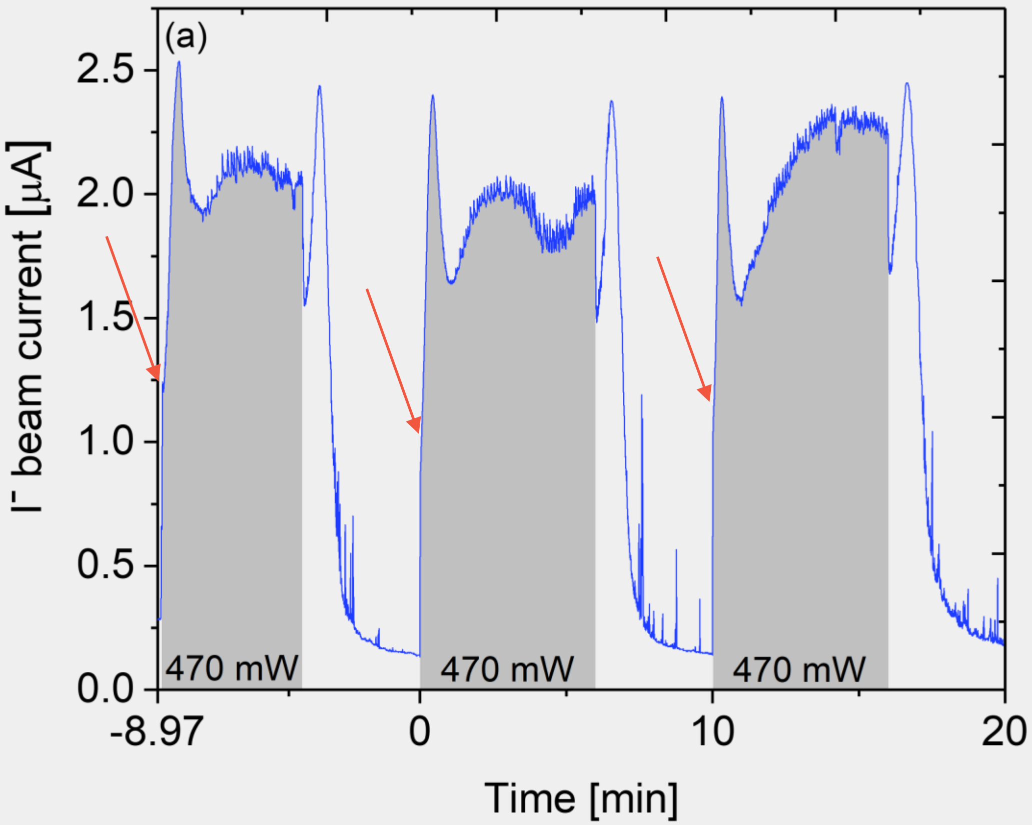
Long laser pulses and measuring the cathode current
-
Can we quantify the photoelectrons ?

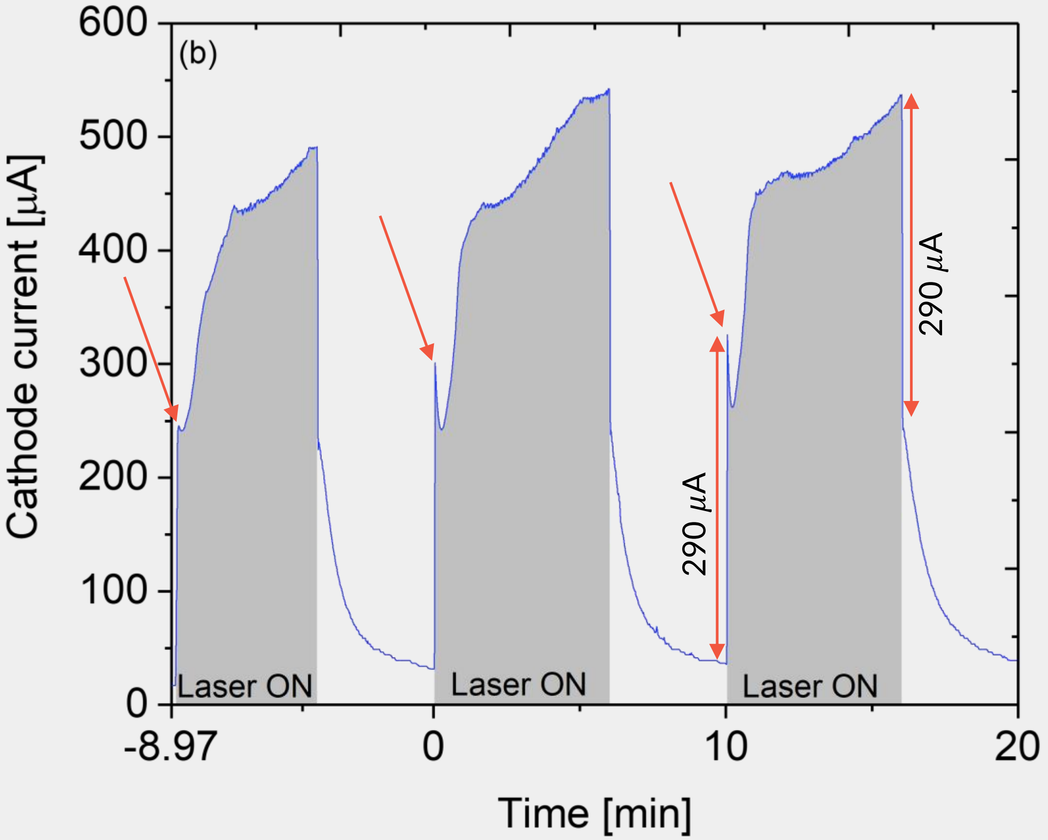
NOTE: Highly depleted Cs conditions!
- Fresh (cleaned) ion source,
- Cs oven temperature: 140 °C. BUT..
- Tube heater was room temp (heater failure after maintenance).

- Experiments were done with very little of Cs in the source and only fraction of normal beam intensity could be extracted also after these measurements (from non-Cs containing compounds).

Photoelectrons and the Cs balance?

I^- Beam current vs. Cathode current

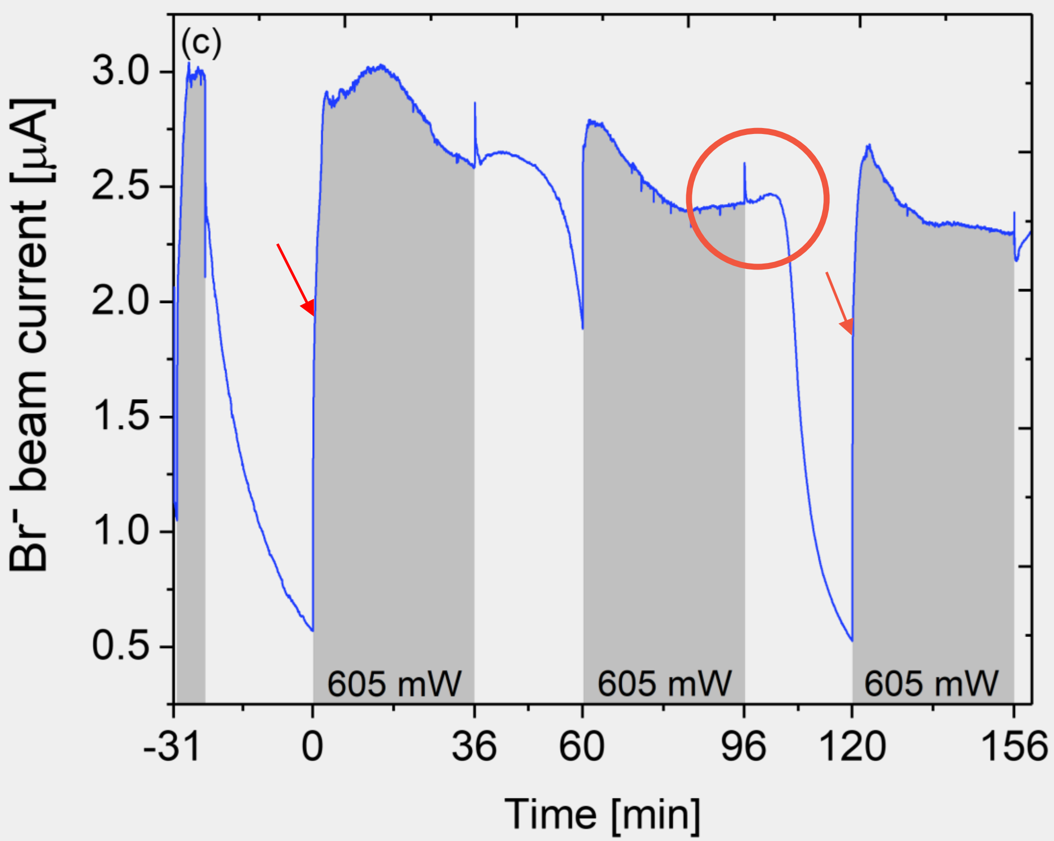


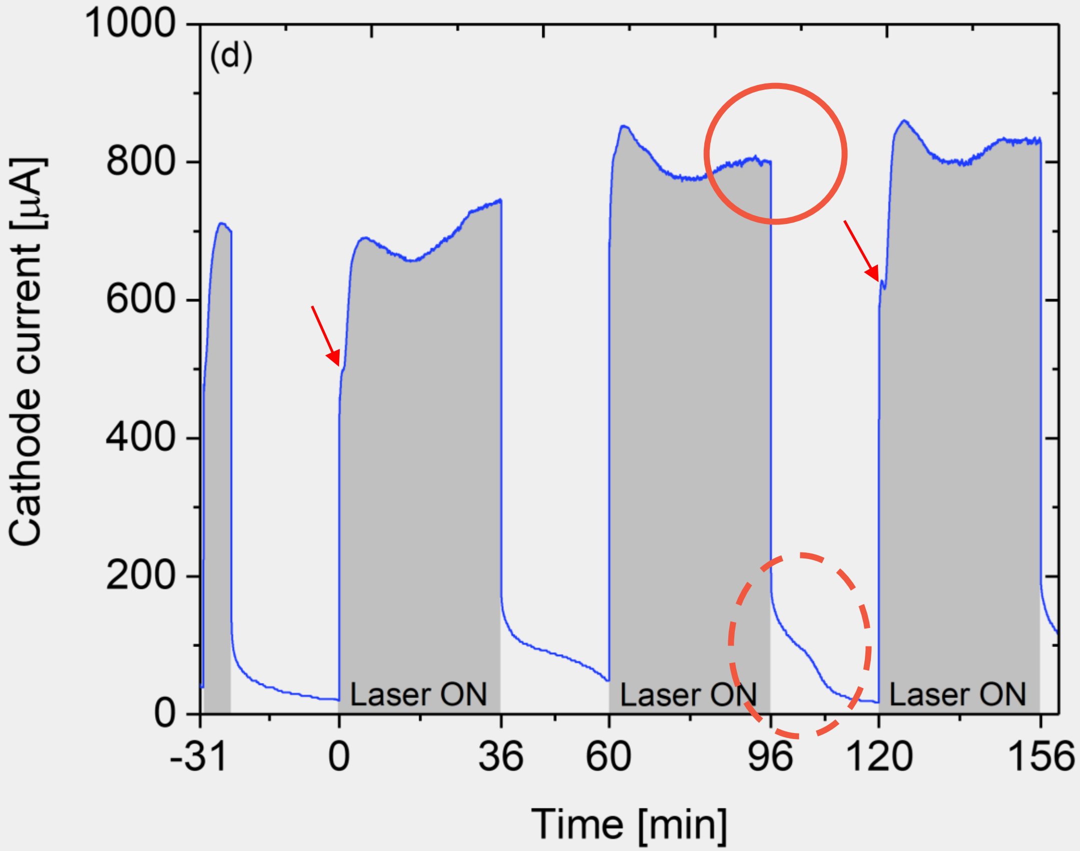


The effect on the (a) I^- beam current with 470 mW laser power on the cathode and corresponding (b) cathode current. The laser pulse period is 10 min with 60% duty factor. Enhancement approximately: (a) 700%.

Photoelectrons and the Cs balance?

Br^- Beam current vs. Cathode current





The effect on the (a) Br^-beam current with 605 mW laser power on the cathode and corresponding (b) cathode current. The laser pulse period is 60 min with 60% duty factor. Enhancement approximately: (a) 350% (Based on 3rd pulse).

Conclusions

- Beam current enhancement depends on the
  - Applied laser power
  - Wavelength
  - Pulse length and
  - The ion source conditions.

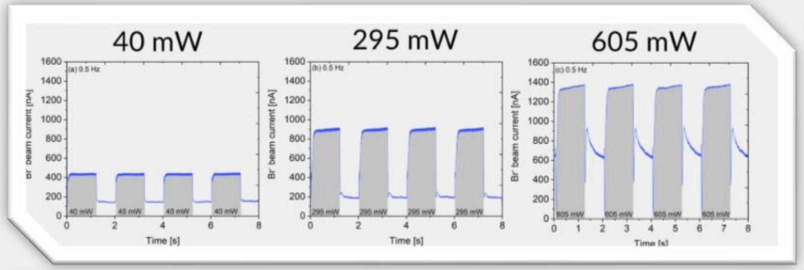
- The extracted beam current can
  be enhanced by a factor up to 9 or more.

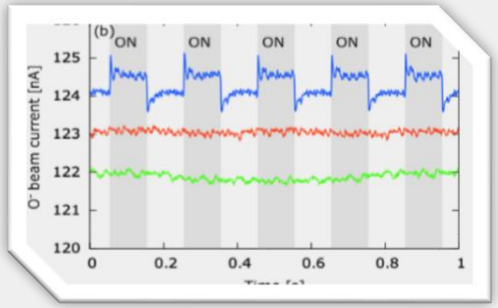
- Resonant ion pair production does not
  play a role on the beam current enhancement.

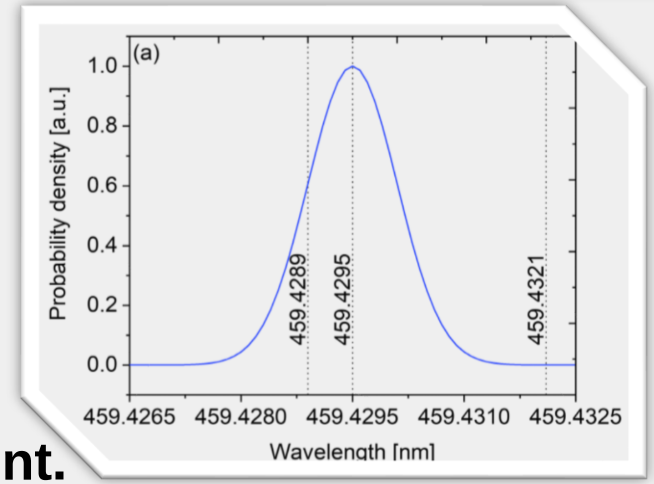
- We suggest a qualitative explanation for the observed effect

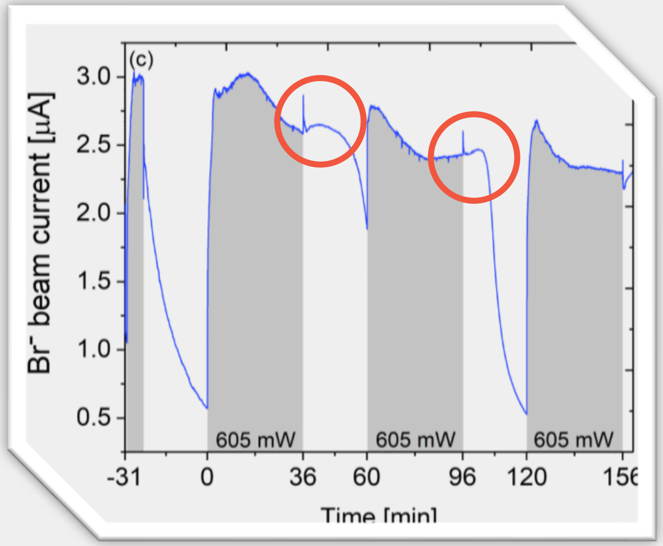
  I. Photoelectron emission

  II. Cs coverage on the cathode surface









Future plan

- Cathode voltage pulsing with/without the laser
- “High performance” tests at Helsinki AMS lab
- Where does the effect relate, does if have a molecule effect? (LiO vs Li2O)
- Ionizer effect tested independently to Cs condition (by the oven)
- Continuation of the measurement through multiple materials and target
- Photoelectric effect: changing the cathode holder material for same target material
- … a lot of possiblities
- Patent pending…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Pulsed operation of a SNICS ion source – ionization efficiency and ion current output

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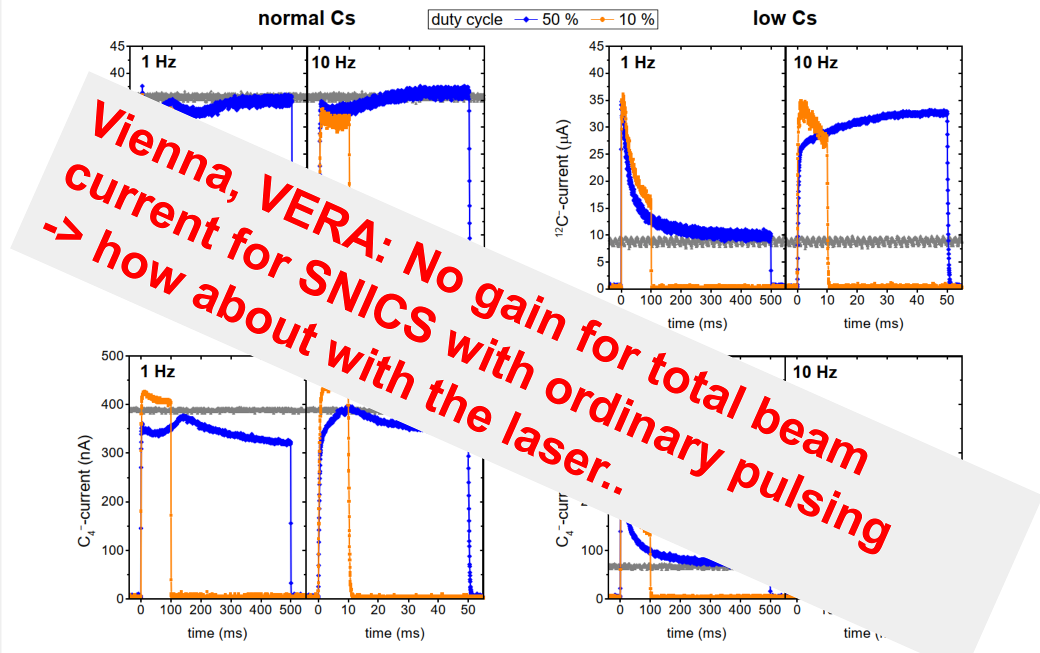

Fig. 5. Ion currents of C^- and C_4^- as a function of time recorded at normal and low Cs conditions both at 1 Hz and 10 Hz repetition rate. Only under s-scarcity, significant ion current enhancement on the order of a factor 4 is observed in pulsed mode: After supposedly accumulating Cs during the idle-period, the ion current pulse reaches almost the DC-current-level achieved with sufficient Cs supply, i.e. under standard AMS source conditions.

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Thank you for your attentation

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