Caesium Balance of the ISIS H^- Penning Ion Source

Olli Tarvainen
STFC Rutherford Appleton Laboratory

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Co-authors: Dan Faircloth, Scott Lawrie, Tiago Morais Sarmento, Robert Abel, John Macgregor, Christopher Cahill, Timothy Stanley, Mark Whitehead, Trevor Wood

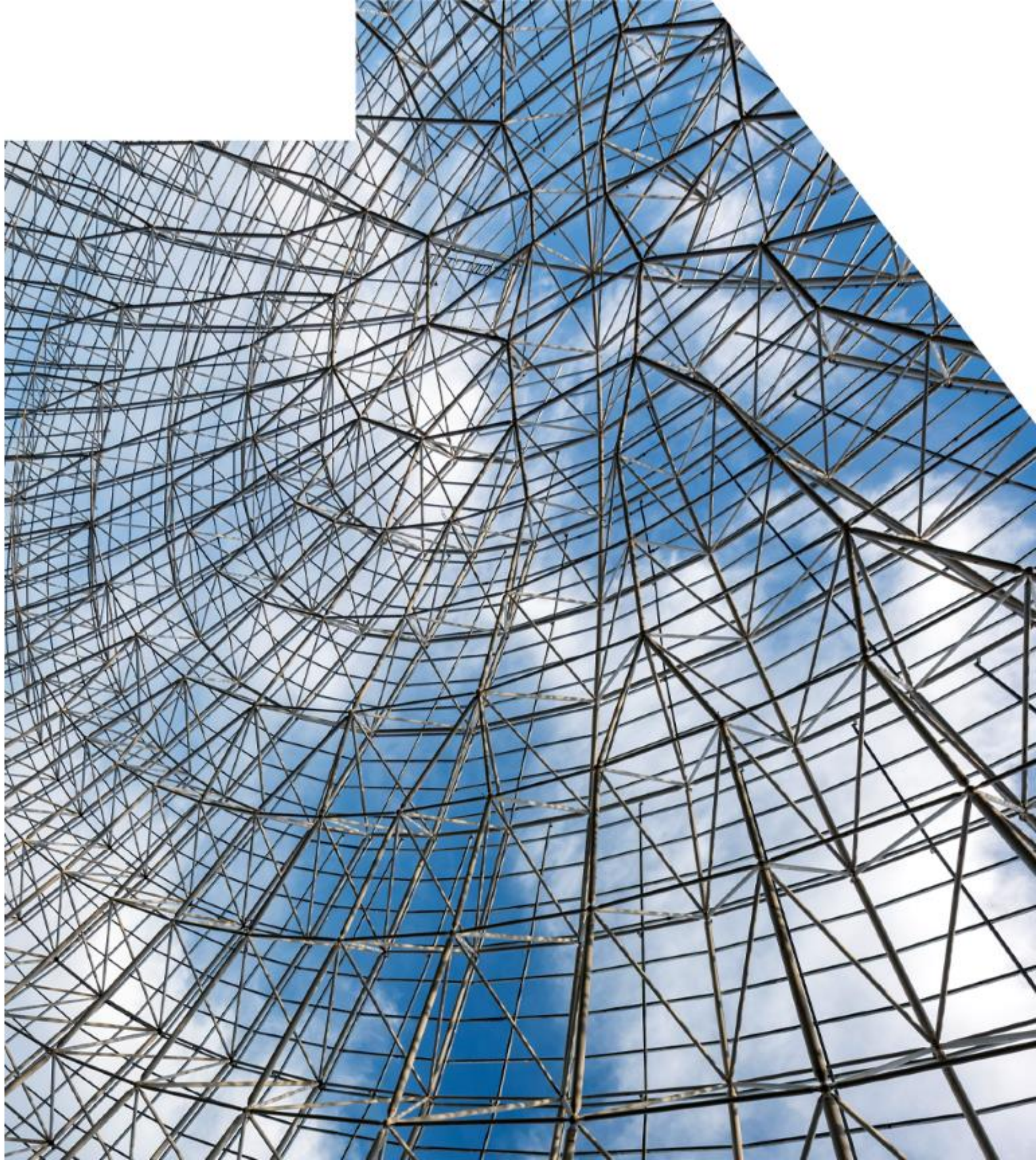
Outline

1 ISIS H^- Penning ion source

2 Caesium balance model

3 Short pulse results

4 Long pulse implications



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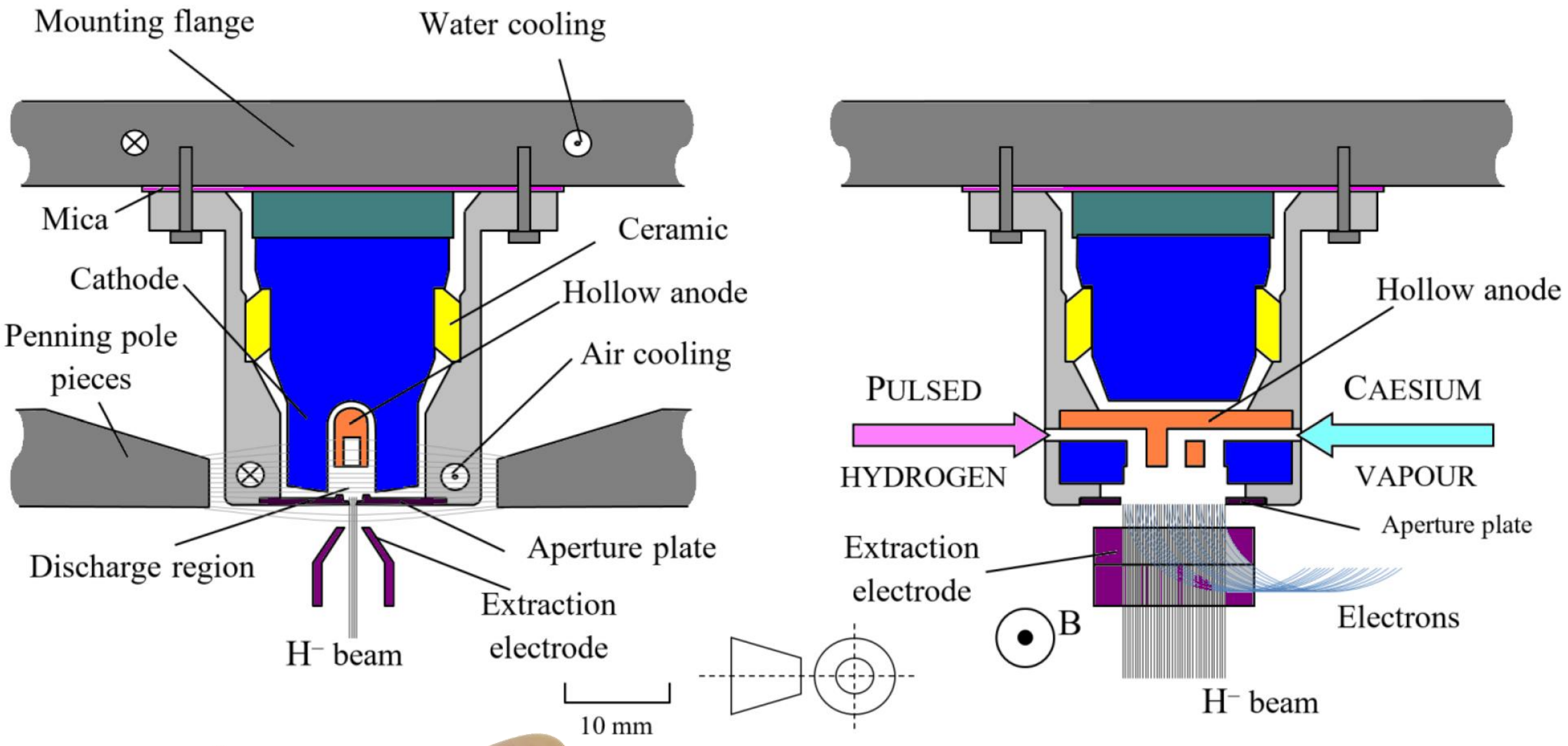
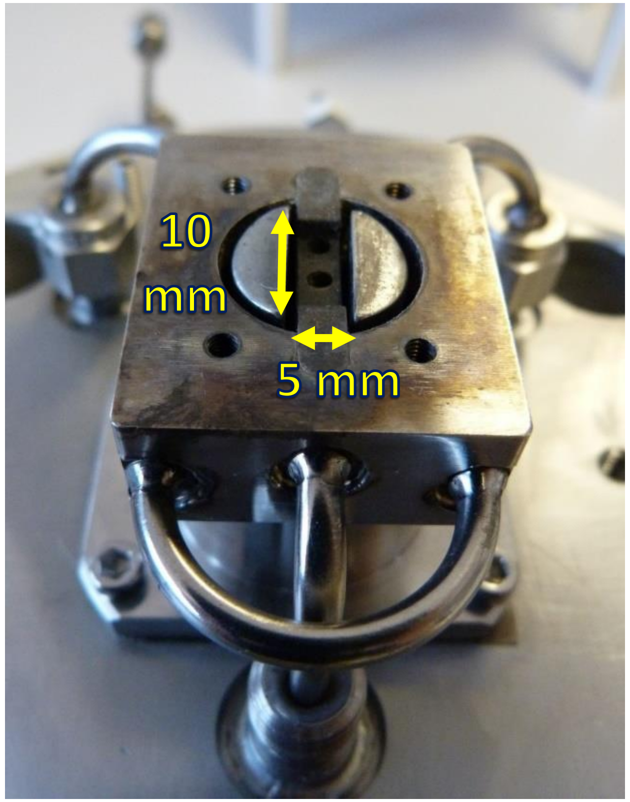
ISIS H^- Penning ion source

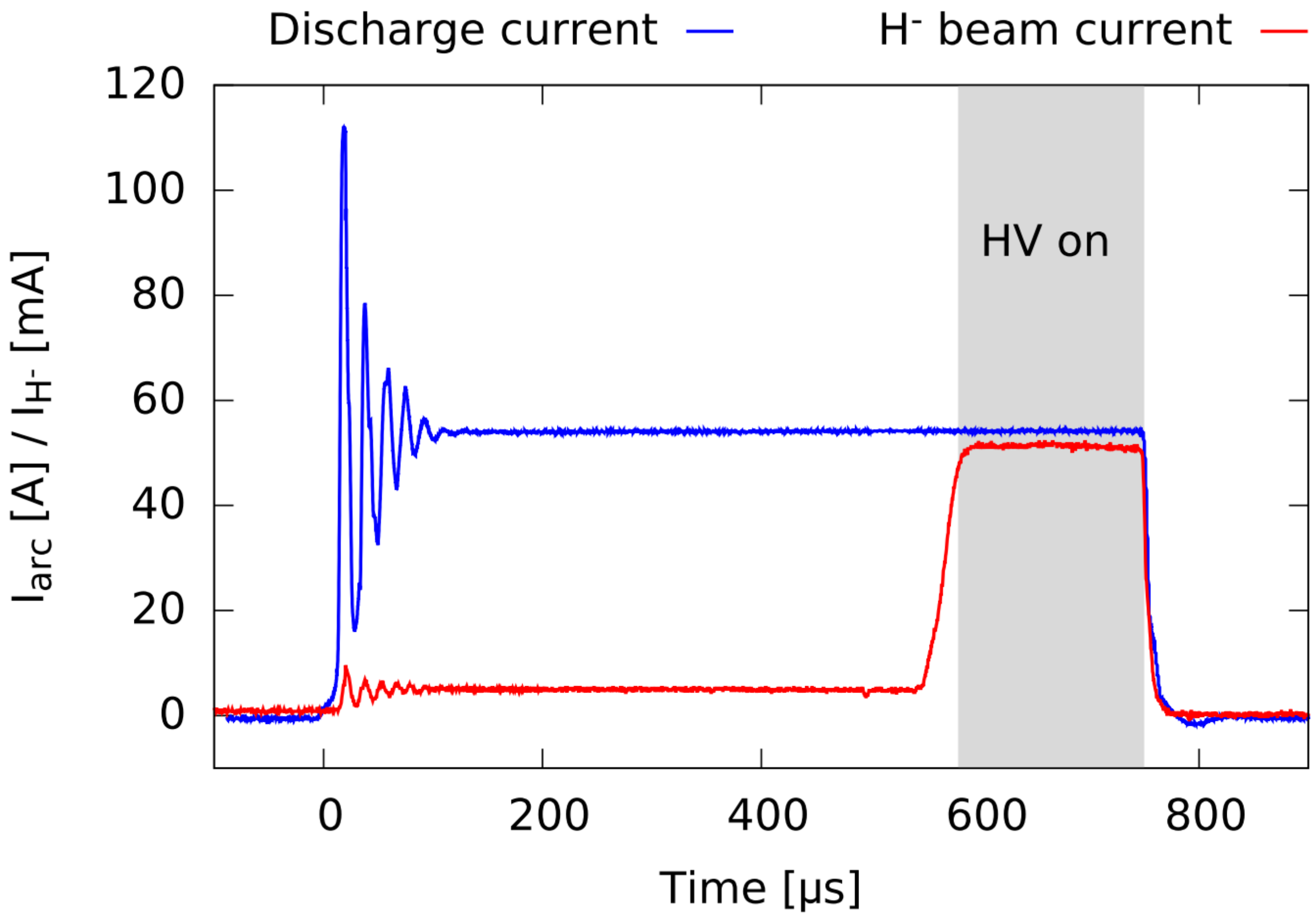
ISIS surface plasma Penning ion source





ISIS surface plasma Penning ion source

55 mA of H⁻ current with a 1.5 % duty factor at 50 Hz (300 μs pulses)



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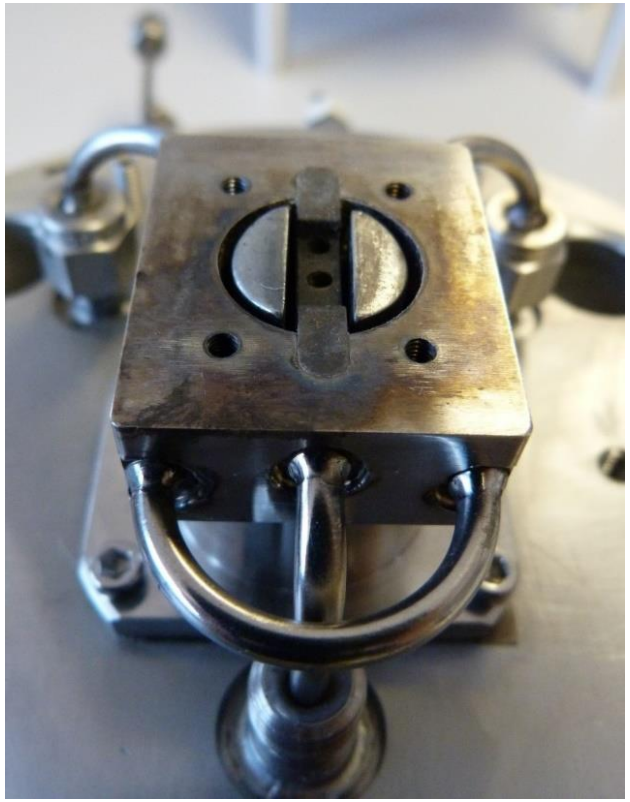
ISIS surface plasma Penning ion source



The discharge is sustained by electron emission from the cathodes and ionisation of Cs and H_2 by the "primary electrons".

H^- ions are surface produced on the cathode, accelerated by the cathode sheath, and then undergo resonant charge exchange with neutral H atoms.

$$H^-_{fast} + H(1s)_{slow} \rightarrow H(1s)_{fast} + H^-_{slow}$$

The slow H^- ions are then extracted through a slit. The extracted H^- current depends on the surface production yield.

PHYSICAL REVIEW A VOLUME 41, NUMBER 9 1 MAY 1990

Charge transfer and electron detachment for collisions of H^- and D^- with H

M. A. Huels, R. L. Champion, L. D. Doverspike, and Yicheng Wang
Department of Physics, College of William and Mary, Williamsburg, Virginia 23185
(Received 17 November 1989)

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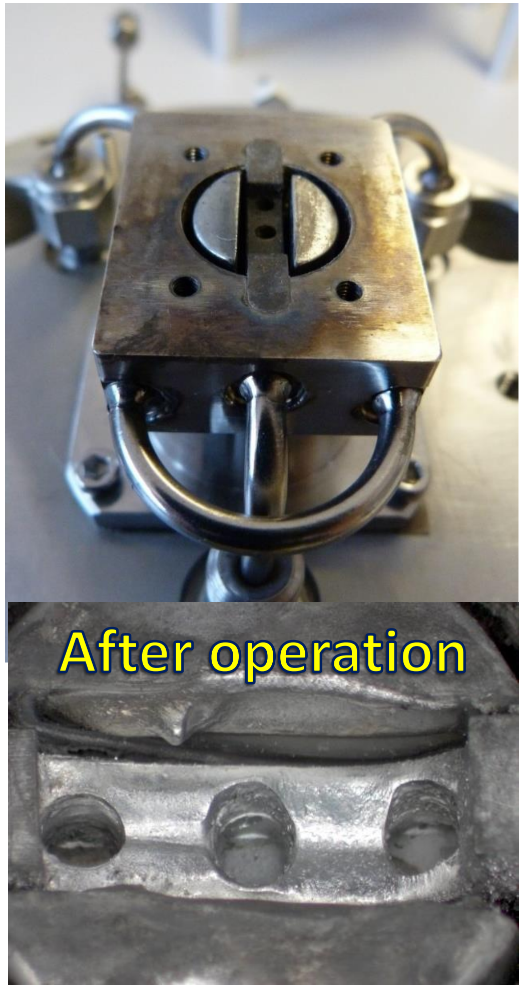
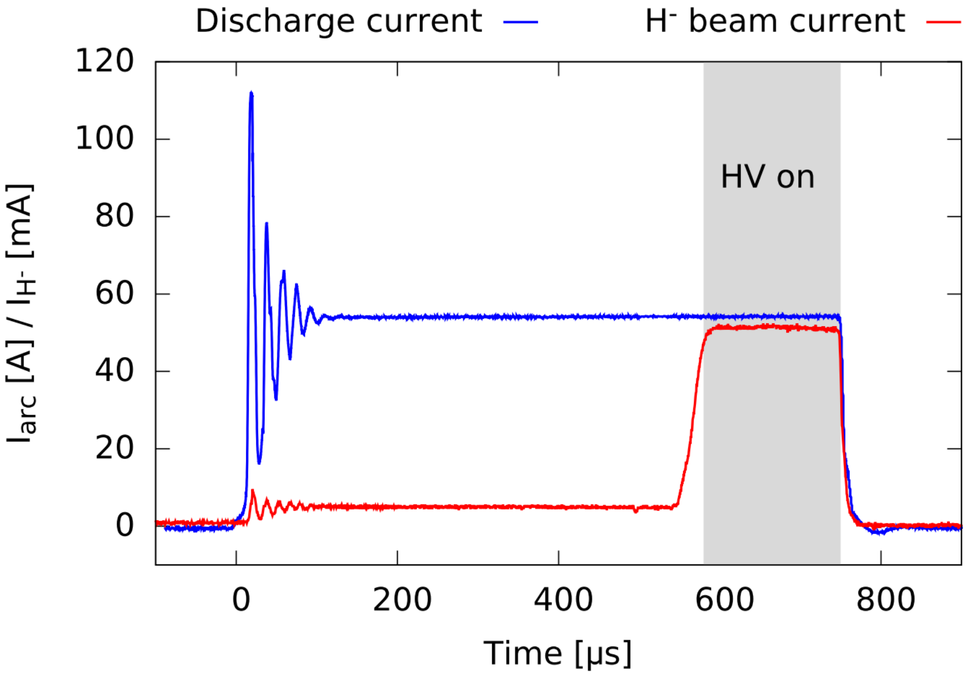
ISIS surface plasma Penning ion source



The discharge power of 2 – 4 kW (pulsed) is distributed across the 2 x 49 mm^2 surface area. That is 2-4 kW / cm^2.

Hot surfaces and significant temperature fluctuation and erosion of the cathode surface

Yet the conditions for producing the H^- beam are constant through the (up to) 1 ms discharge pulse



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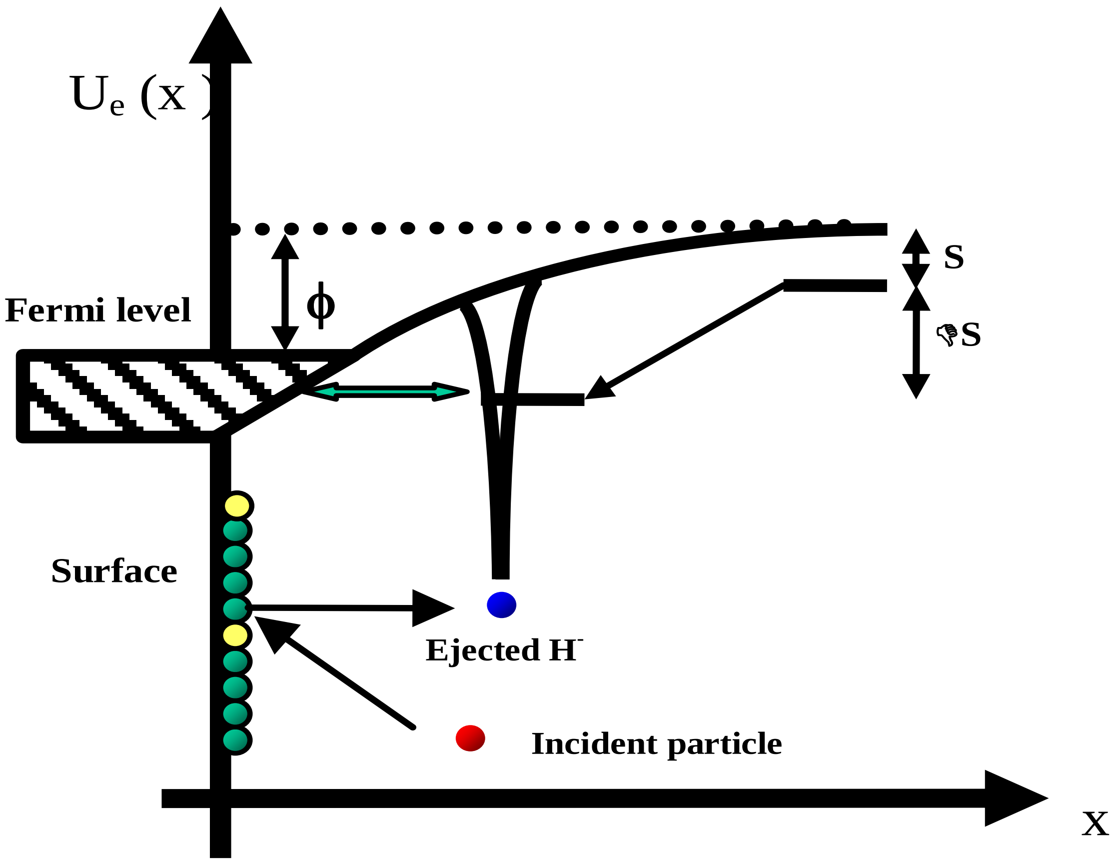
Caesium balance model

Surface ionization yield



Original figure by R.F. Welton, ICIS'07 tutorial

The resonant surface ionisation yield Y

$$Y \simeq \frac{2}{\pi} \exp\left(-\frac{\pi(\phi(\theta) - S)}{2av_{\|}}\right)$$

where

S is the electron affinity of hydrogen (0.754 eV)

a is semi-empirical constant (2-5 x 10^{-5} eVs/m)

$v_{||}$ is the negative ion escape velocity

AND $\phi(\theta)$ is the surface work function

ELSEVIER

Surface Science

Volume 118, Issue 3, 2 June 1982, Pages 697-710

Theoretical models of the negative ionization of hydrogen on clean tungsten, cesiated tungsten and cesium surfaces at low energies

B. Rasser *, J.N.M. Van Wunnik, J. Los

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Caesiated surface work function

ELSEVIER

Surface Science

Volume 175, Issue 1, 1 September 1986, Pages 226-240

Semi-empimcal mathematical relationships for electropositive adsorbate induced work function changes ☆

G.D. Alton [a]

$$\phi(\theta) = \phi_0 + \frac{6\Delta\phi_m}{(3-\theta_m)\theta_m}\theta - \frac{3\Delta\phi_m(\theta_m+1)}{(3-\theta_m)\theta_m^2}\theta^2 + \frac{2\Delta\phi_m}{(3-\theta_m)\theta_m^2}\theta^3$$

θ_m is the fractional monolayer Cs coverage corresponding to minimum work function (0.5-0-7)

$\Delta\phi_m \cong -1.24[\phi_0 - 0.5(I_A+E_A)]$ is the maximum change of the work function from clean metal.

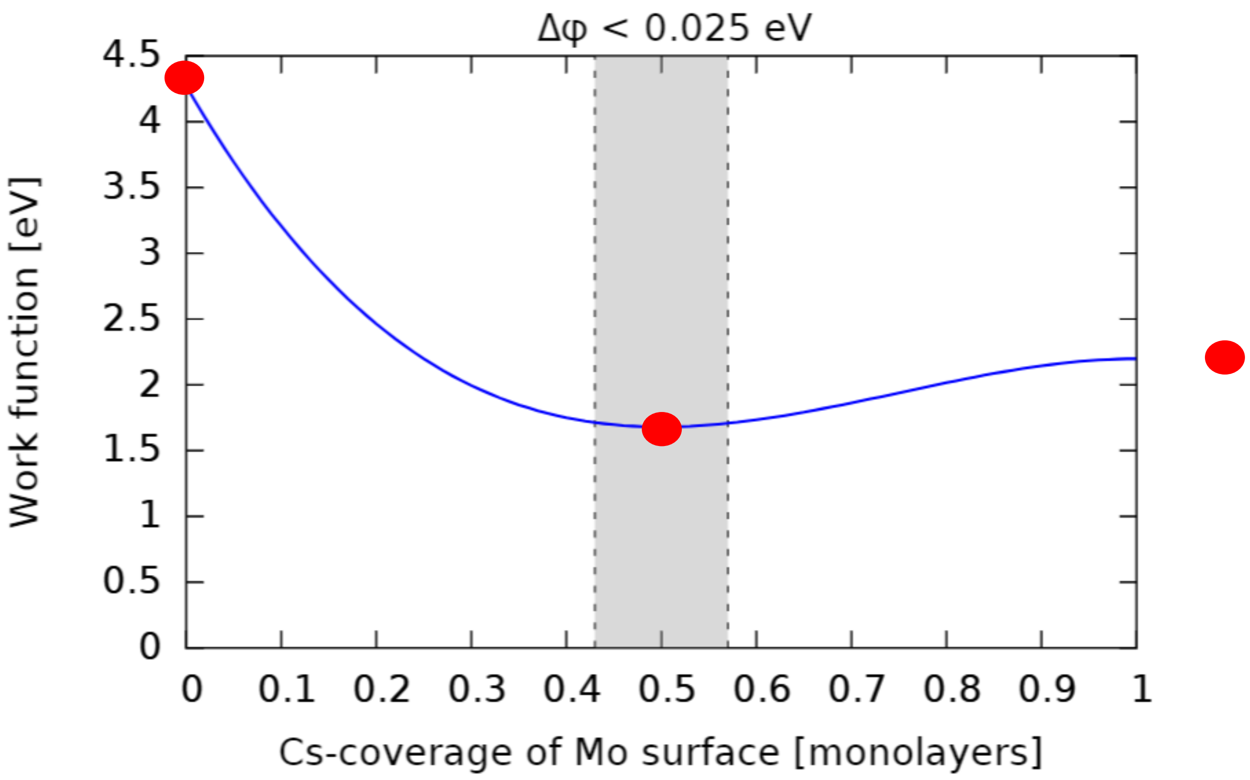
With Cs I_A of 3.89 eV and E_A of 0.47 eV we obtain $\Delta\phi_m$ = -2.59 eV for Molybdenum

Caesiated surface work function

Beam current changes < 5 % during the extraction pulse

$$\phi_{max} - \phi_{min} = -\frac{2av_{\|}}{\pi}\ln\left(1-\delta\right)$$

For δ = 0.05 that is $\Delta\phi$ < 0.025 eV



Where are we on this plot?

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Caesium adsorption and desorption fluxes

The caesium adsorption flux from kinetic gas theory

$$\Gamma_a = \frac{1}{4} n_{\mathrm{Cs}} v = \frac{p_{\mathrm{Cs}}}{\sqrt{2\pi k T_{eq} m_{\mathrm{Cs}}}}$$

Semi-empirical expression for the caesium desorption flux from refractory metals

$$\Gamma_d = \Gamma_{d,0} \exp\left(\frac{-e(3.37 - 2.78\theta)}{kT_s}\right)$$

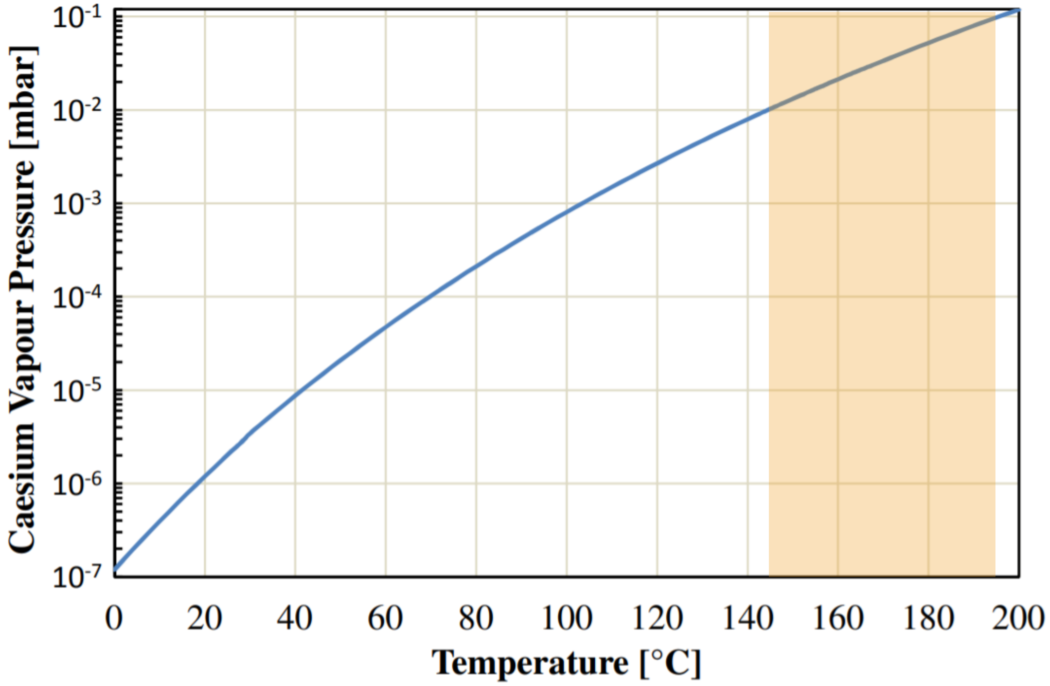
AIP | Journal of Applied Physics

A model for the stationary cesium coverage on a converter surface in a cesium seeded hydrogen discharge

P. W. van Amersfoort, Ying Chun Tong, and E. H. A. Granneman

Citation: Journal of Applied Physics **58**, 2317 (1985); doi: 10.1063/1.335953

Caesium pressure of the ISIS ion source?



145 – 195 °C oven temperature implies 1-10 Pa caesium pressure

5 g caesium ampoule is consumed in approx. 50 days, which equates to 1.2 µg/s escaping through the 0.6 mm x 10 mm extraction slit.

Using $$\Gamma_a = \frac{1}{4} n_{\mathrm{Cs}} v = \frac{p_{\mathrm{Cs}}}{\sqrt{2\pi k T_{eq} m_{\mathrm{Cs}}}}$$

results in 0.115 Pa caesium pressure, which is supported by quartz microbalance measurements suggesting 0.1 – 1 Pa.

0.1 – 10 Pa used for the model

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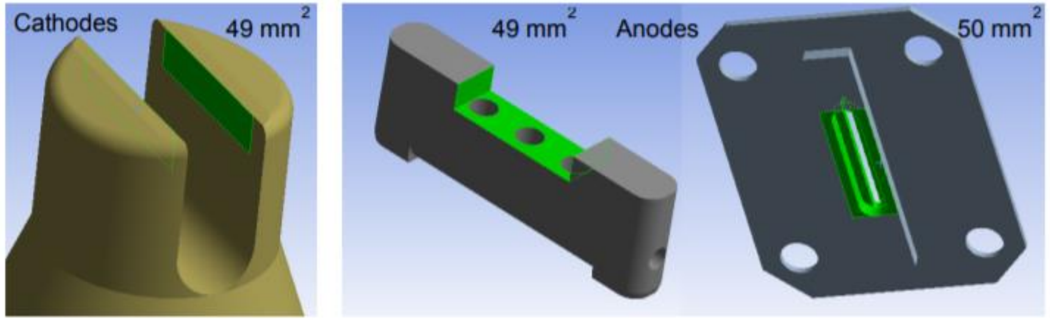
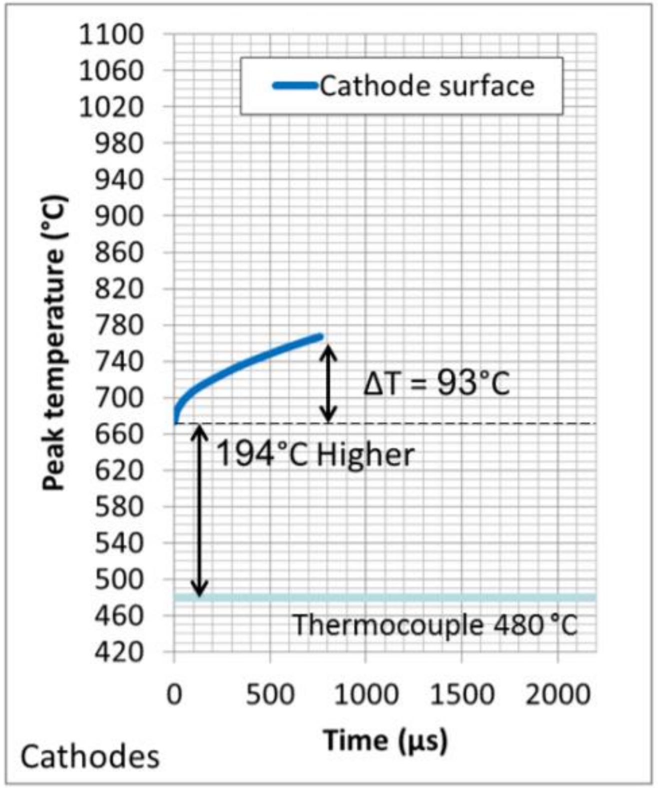
Cathode temperature of the ISIS ion source?

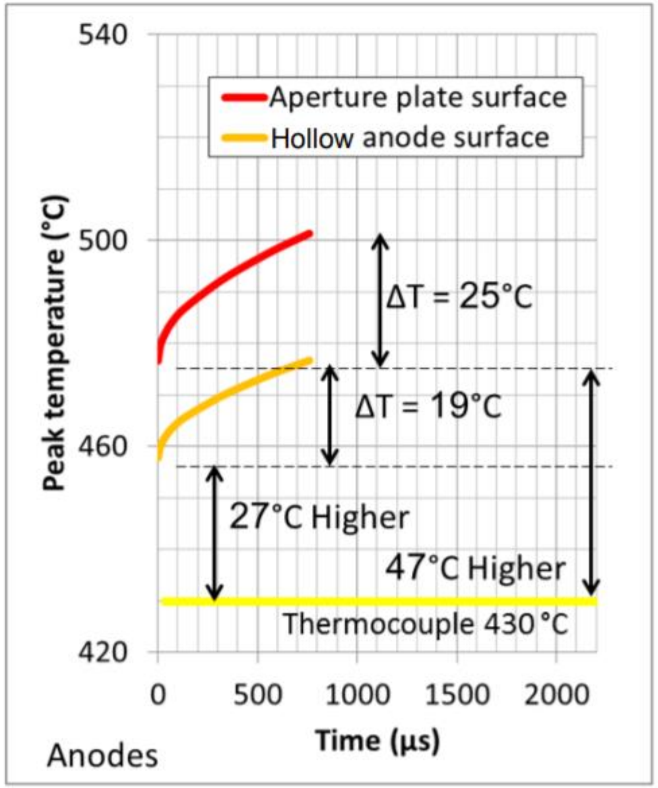
Operational and theoretical temperature considerations in a Penning surface plasma source

Cite as: AIP Conference Proceedings **1655**, 030013 (2015); https://doi.org/10.1063/1.4916440
Published Online: 14 April 2015

D. C. Faircloth, S. R. Lawrie, H. Pereira Da Costa, and V. Dudnikov







With 760 µs / 55 A discharge pulses the expected cathode surface temperature is 670 – 770 °C.

In real life there is ± 100 °C variation in cathode temperature between sources producing the same beam current.

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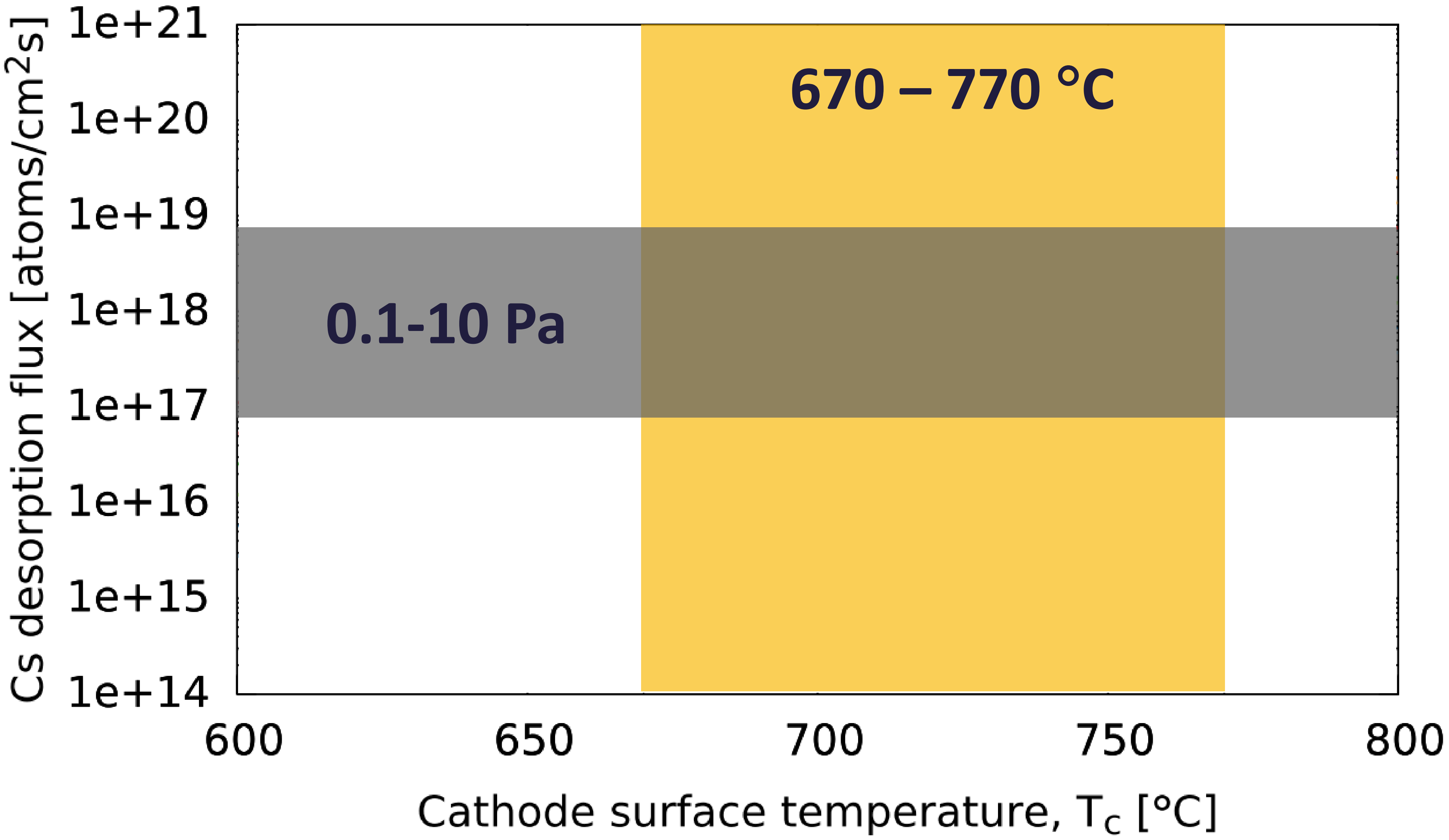
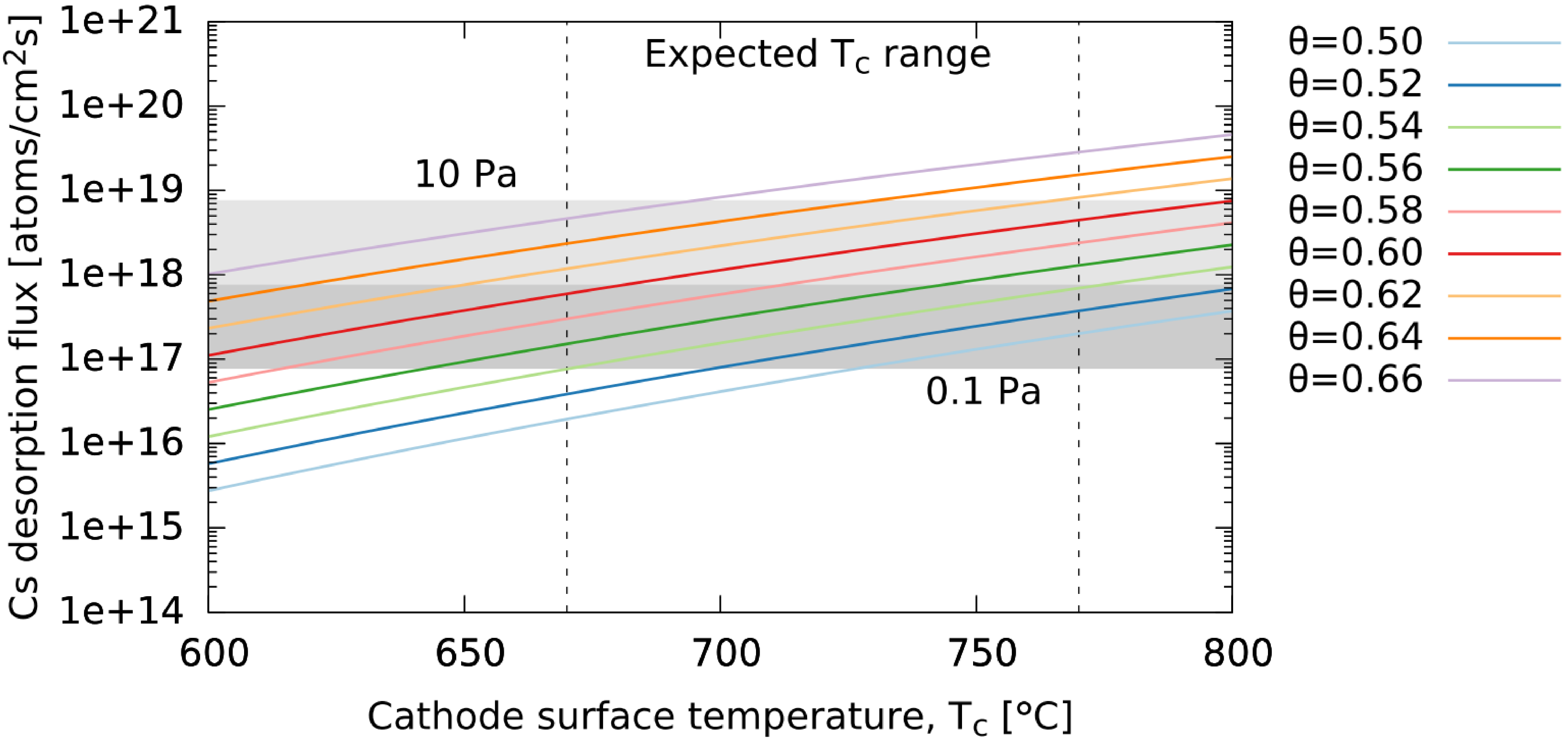
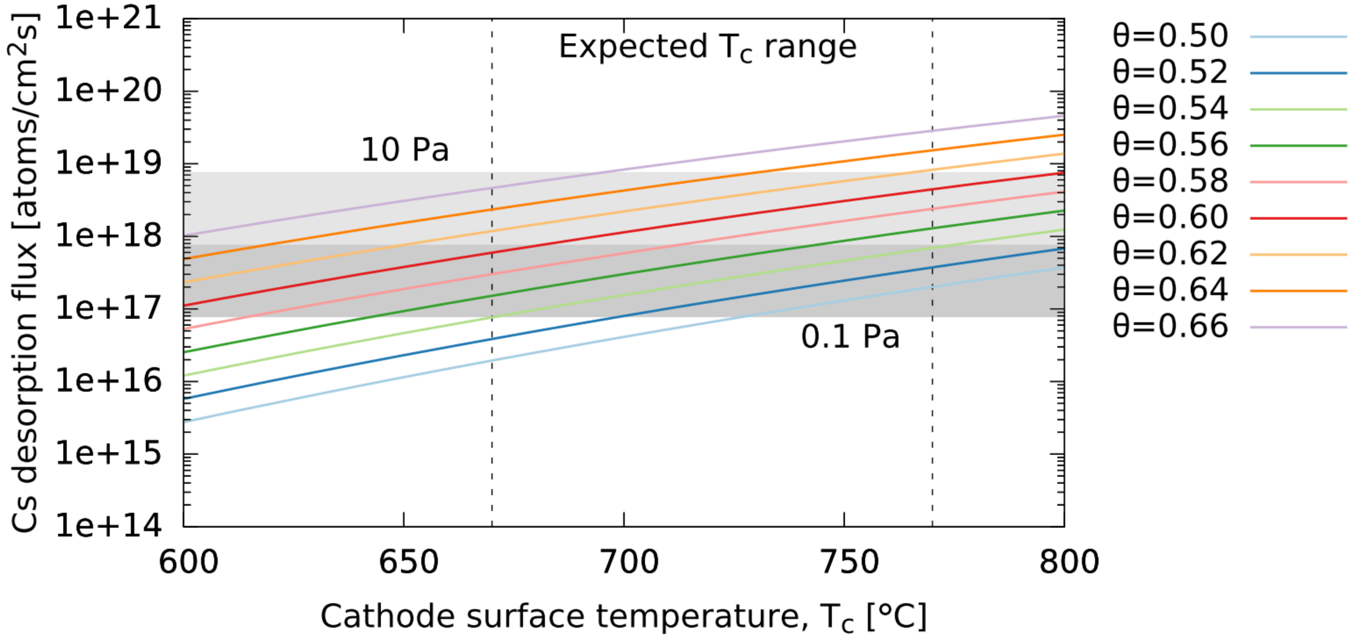
Equlibrium caesium coverage of the cathode

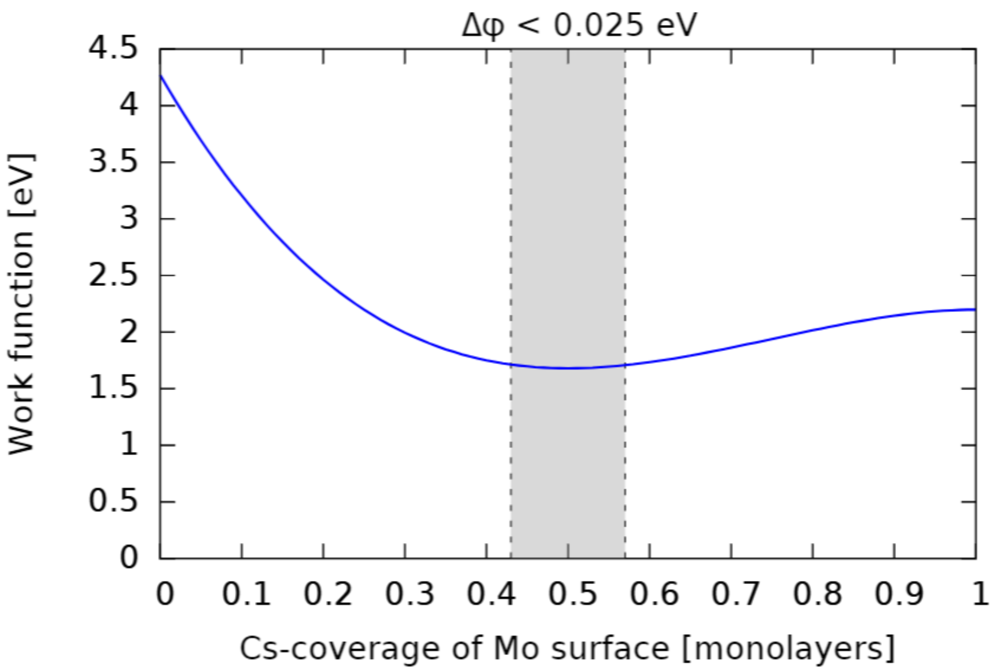


Equlibrium caesium coverage of the cathode



Equlibrium caesium coverage of the cathode



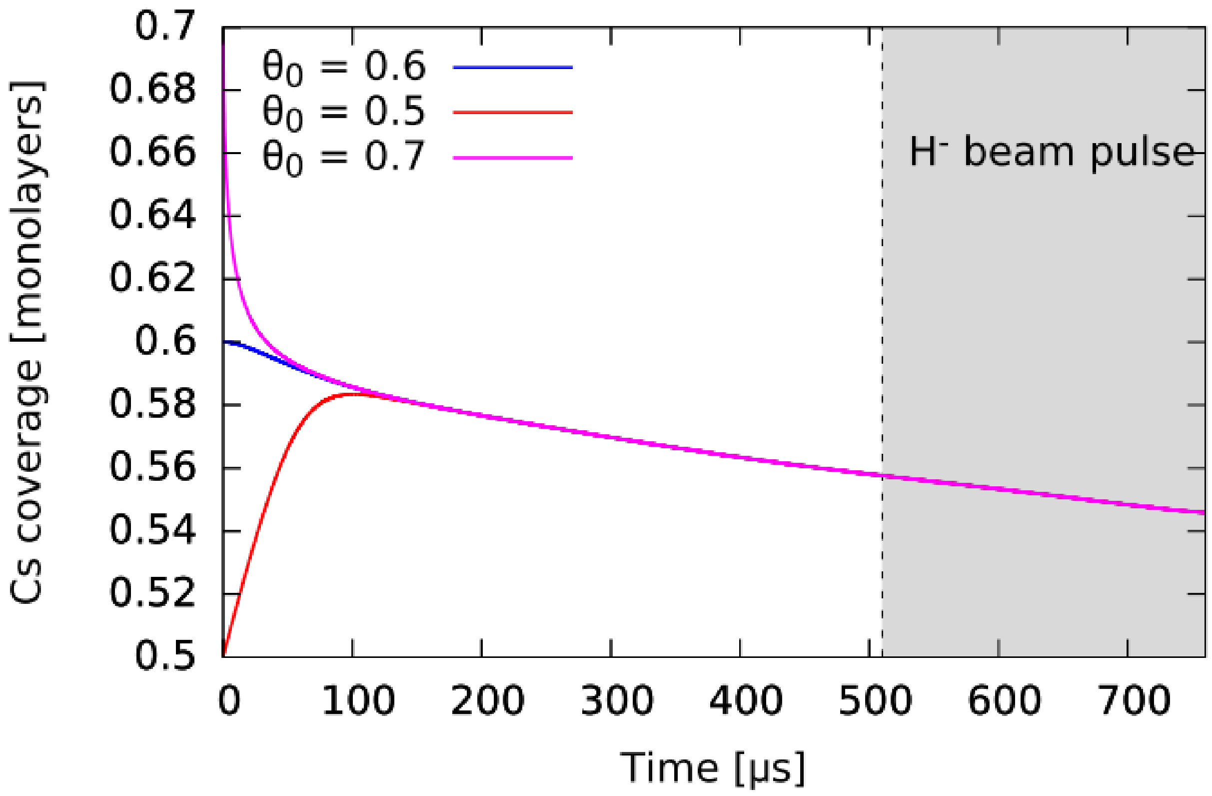


The expected caesium coverage is remarkably close to the optimum. TOO GOOD TO BE TRUE?

The ISIS Penning source can be operated only in a certain temperature – Cs pressure window.

Caesium balance of the cathode surface

We can model the cathode surface caesium balance by calculating the change of the caesium coverage in time step dt using the dynamic cathode surface temperature together with desorption and adsorption fluxes at certain caesium pressure. The free parameter is the caesium coverage in the beginning of the discharge pulse.



But it does not matter…

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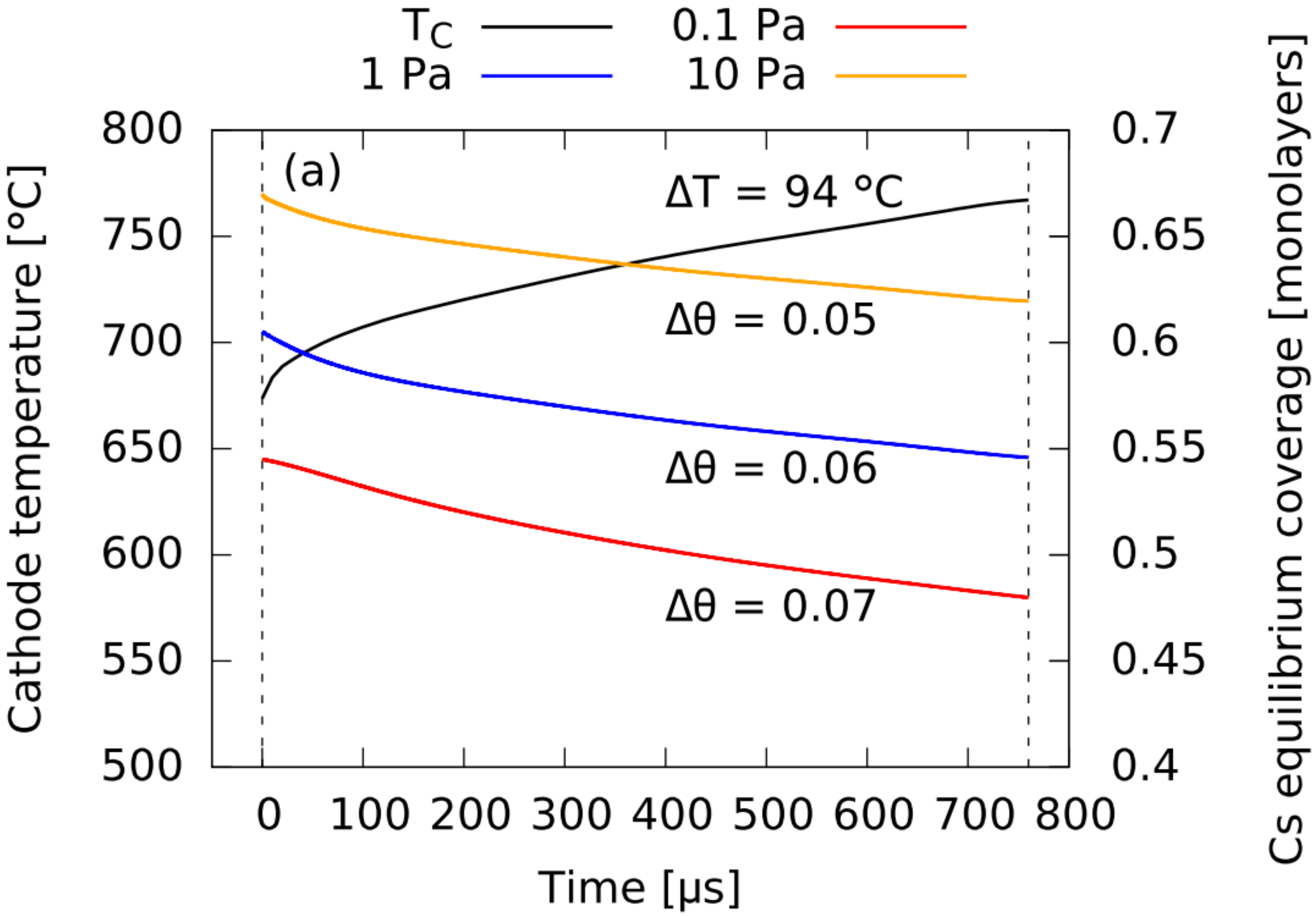
Short pulse results

Cathode Cs coverage vs Cs pressure



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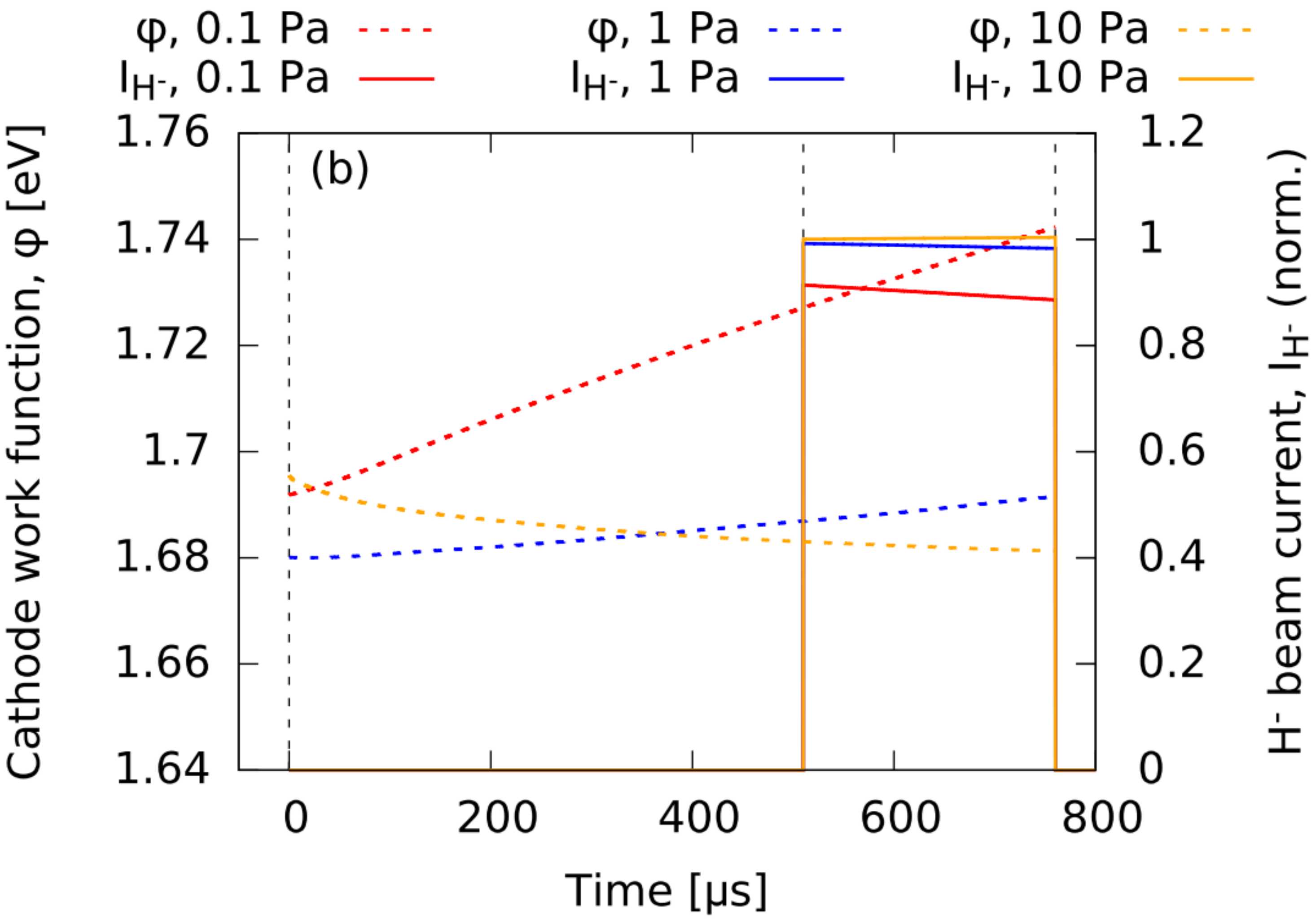
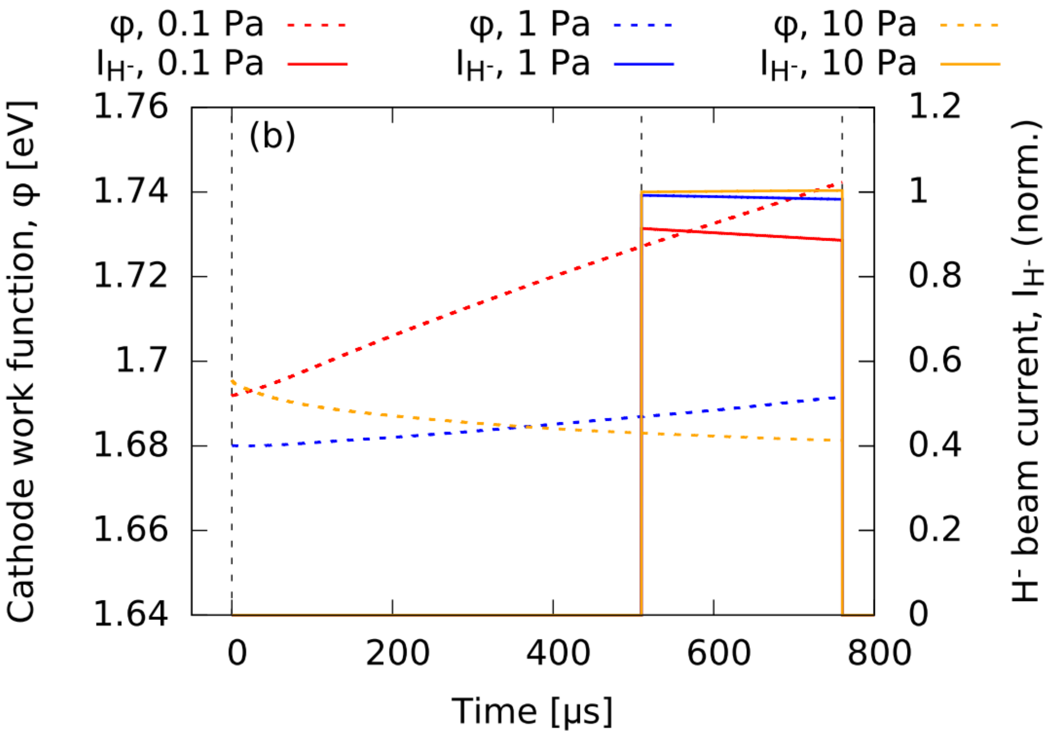
Cathode work function and H⁻ beam current vs Cs pressure



Model vs Experiment (Cs oven temperature)



10-15 % lower H^- current at low Cs pressure

20 % lower H^- current at low Cs pressure

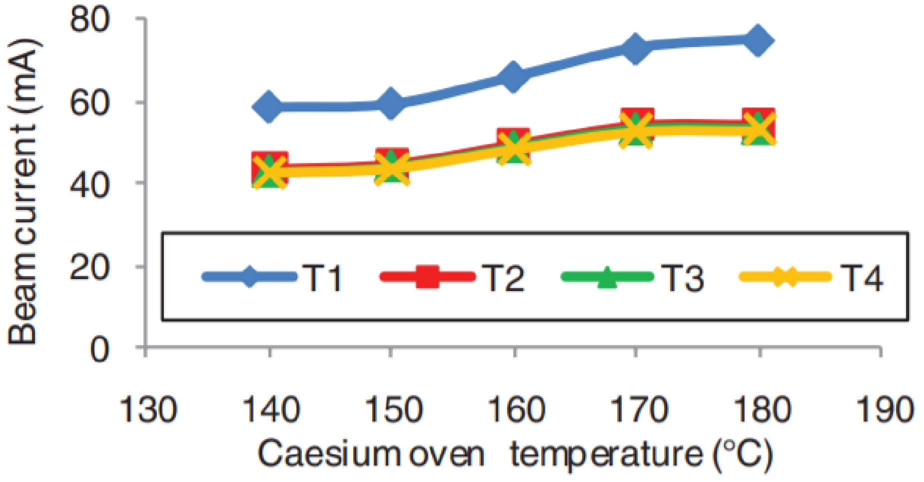


FIG. 7. (Color online) H^- beam currents vs caesium oven temperature for a 55 A discharge.

Optimizing the front end test stand high performance H− ion source at RAL

D. Faircloth, S. Lawrie, C. Gabor, A. Letchford, M. Whitehead et al.

Citation: Rev. Sci. Instrum. **83**, 02A701 (2012); doi: 10.1063/1.3655526
View online: http://dx.doi.org/10.1063/1.3655526

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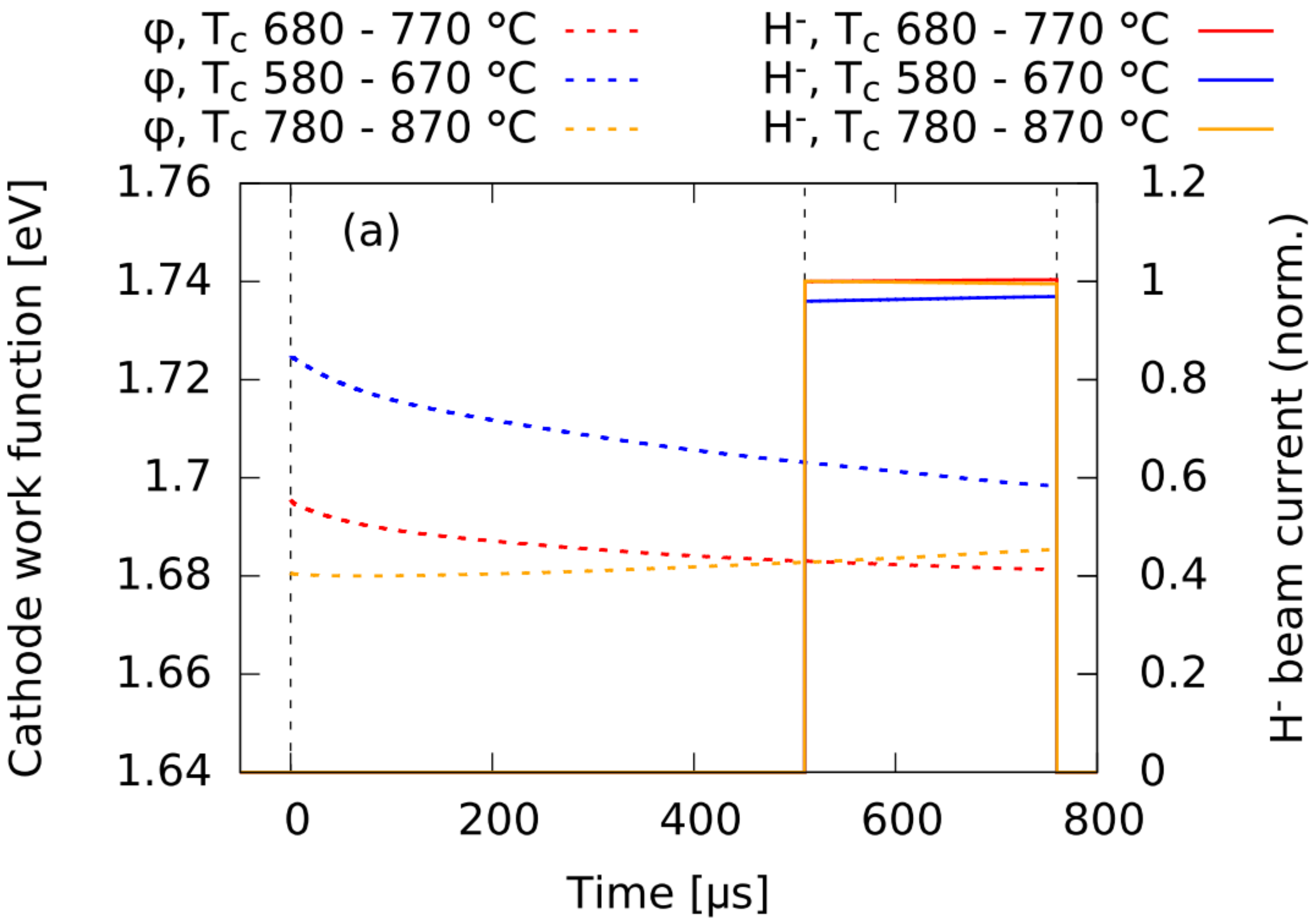
Cathode work function and H⁻ beam current vs Cathode temperature



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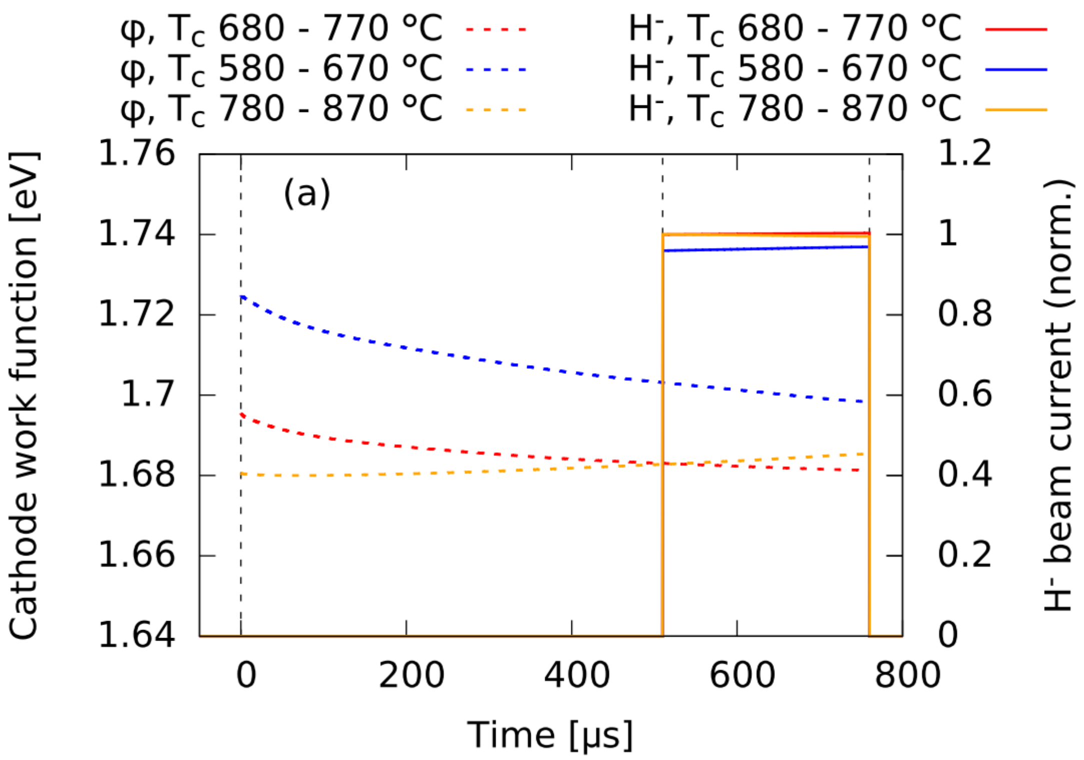
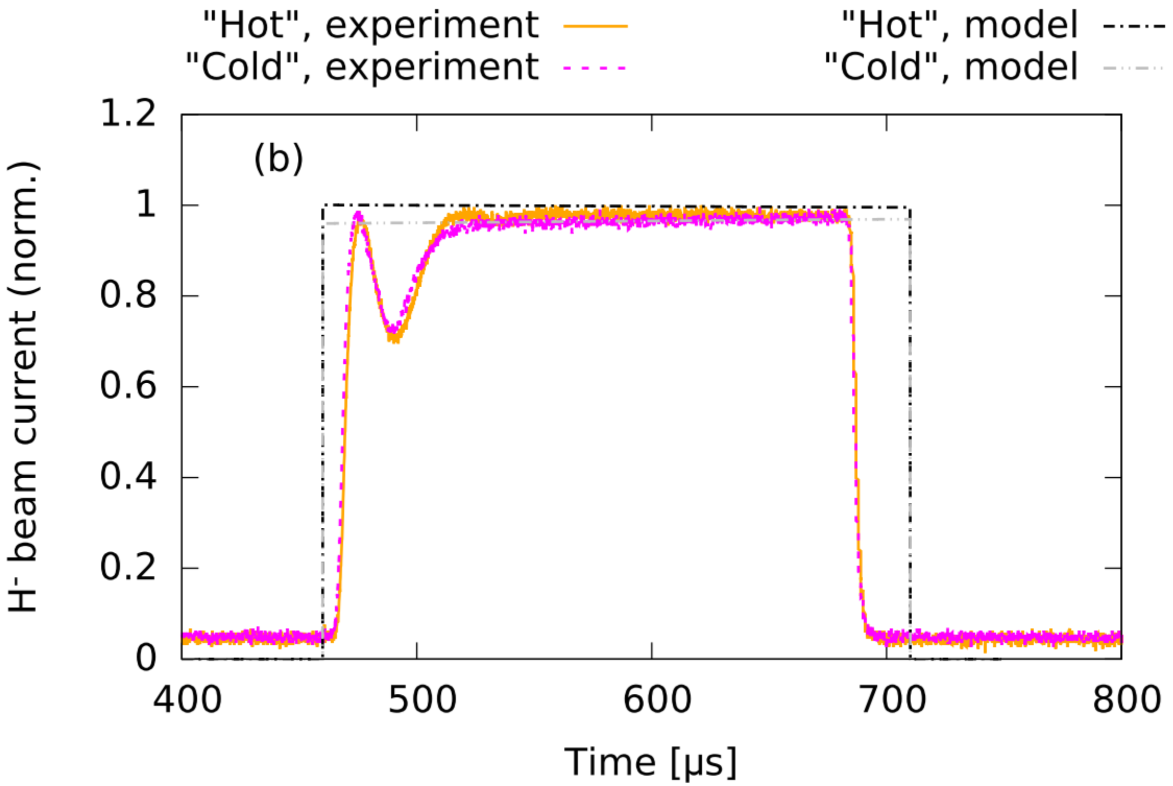
Model vs Experiment (cathode temperature)





< 5 % lower H^- current at low cathode temp.

Negligible difference in experiment with 200 °C thermocouple reading variation

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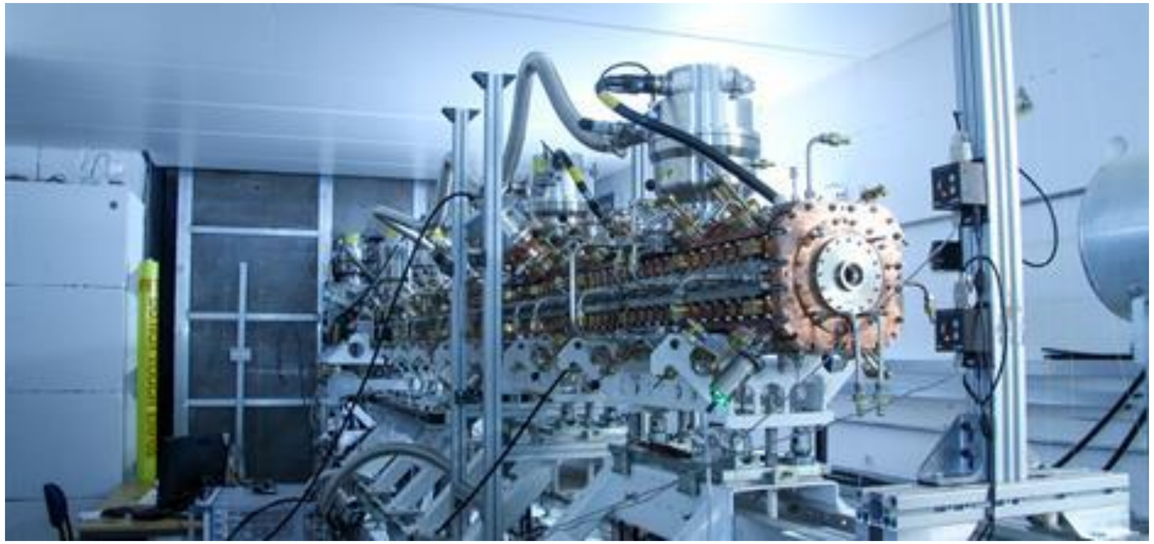
Long pulse results and implications

Motivation for long H^- beam pulses

The Front End Test Stand at RAL expects 60 mA / 2 ms H^- beam pulses at 50 Hz



https://www.ppd.stfc.ac.uk/Pages/FETS.aspx

Penning source considered for ESSνSB-project requiring 70 mA / 3 ms H^- beam pulses at 14 Hz
https://essnusb.eu/about-us/

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Successful long pulse experiments

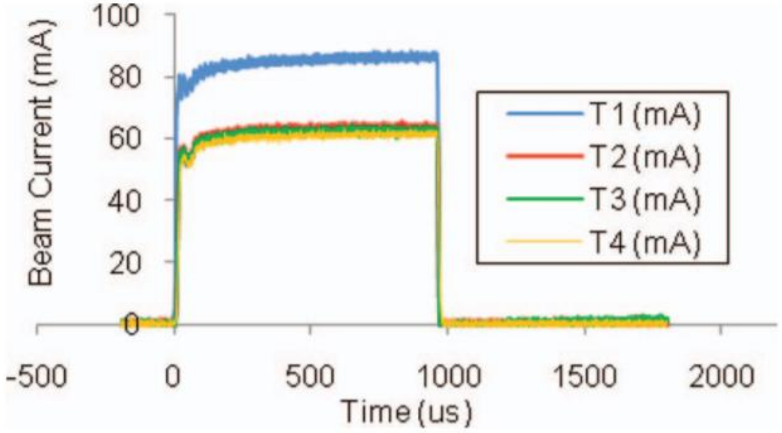

FIG. 8. (Color online) Beam current profiles of 62 mA at 50 Hz 1 ms (1.2 ms, 60 A discharge, 19.6 kV extraction voltage, 65 keV beam, 180 °C caesium oven, 16 mLmin^{-1} H_2.)

180 °C

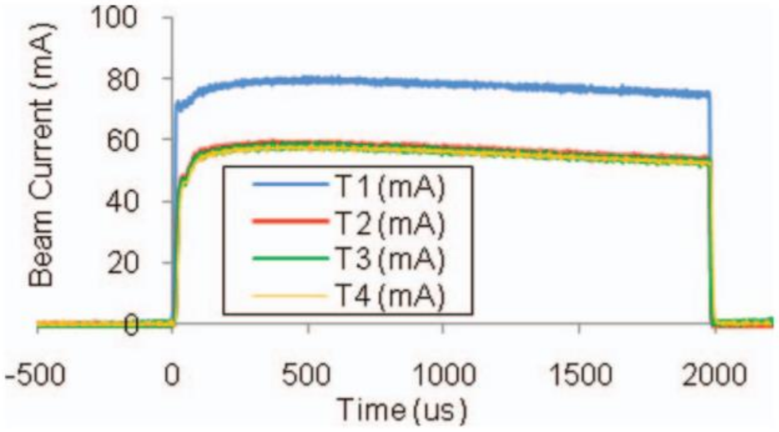

FIG. 9. (Color online) Beam current profiles of 60 mA at 25 Hz (2.2 ms, 64 A discharge, 19.6 kV extraction voltage, 65 keV beam, 190 °C caesium oven, 16 mLmin^{-1} H_2.)

190 °C

Optimizing the front end test stand high performance H− ion source at RAL

D. Faircloth, S. Lawrie, C. Gabor, A. Letchford, M. Whitehead et al.

Citation: Rev. Sci. Instrum. **83**, 02A701 (2012); doi: 10.1063/1.3655526

View online: http://dx.doi.org/10.1063/1.3655526

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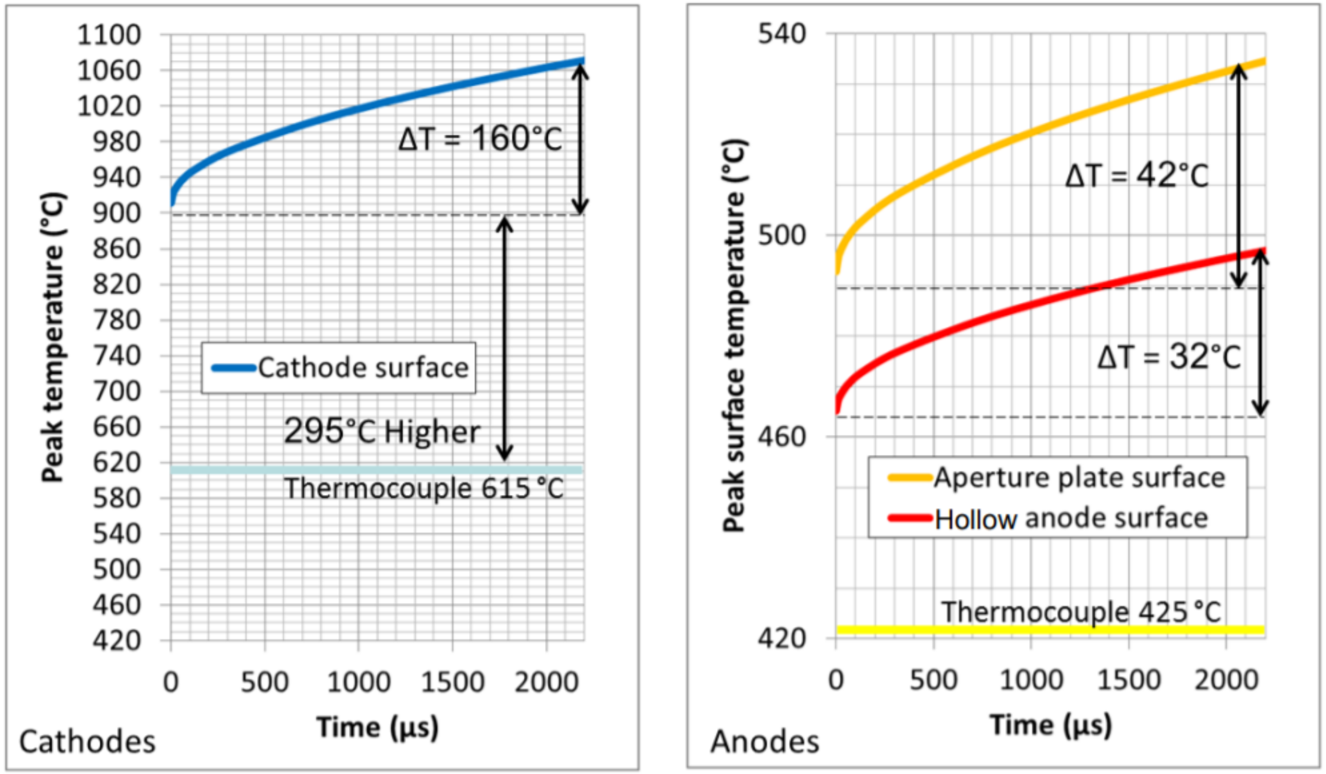
Long pulse model

2.2 ms discharge pulse at 25 Hz



Operational and theoretical temperature considerations in a Penning surface plasma source

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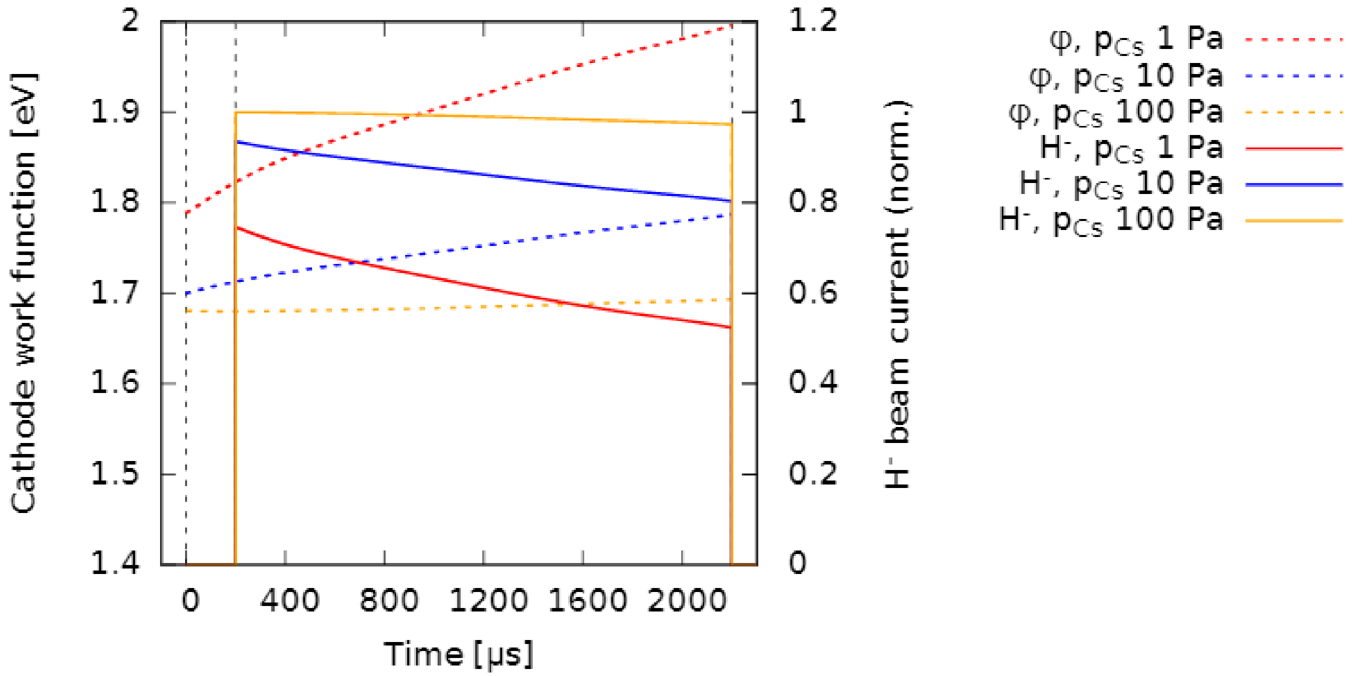
Long pulse model vs experiment



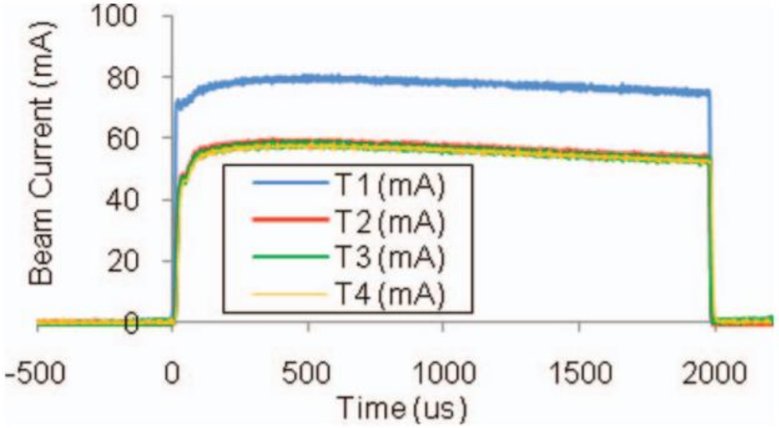


FIG. 9. (Color online) Beam current profiles of 60 mA at 25 Hz. (2.2 ms, 64 A discharge, 19.6 kV extraction voltage, 65 keV beam, 190 °C caesium oven, 16 mLmin^{-1} H_2.)

2.2 ms discharge pulse at 25 Hz

Long pulses at elevated Cs pressure

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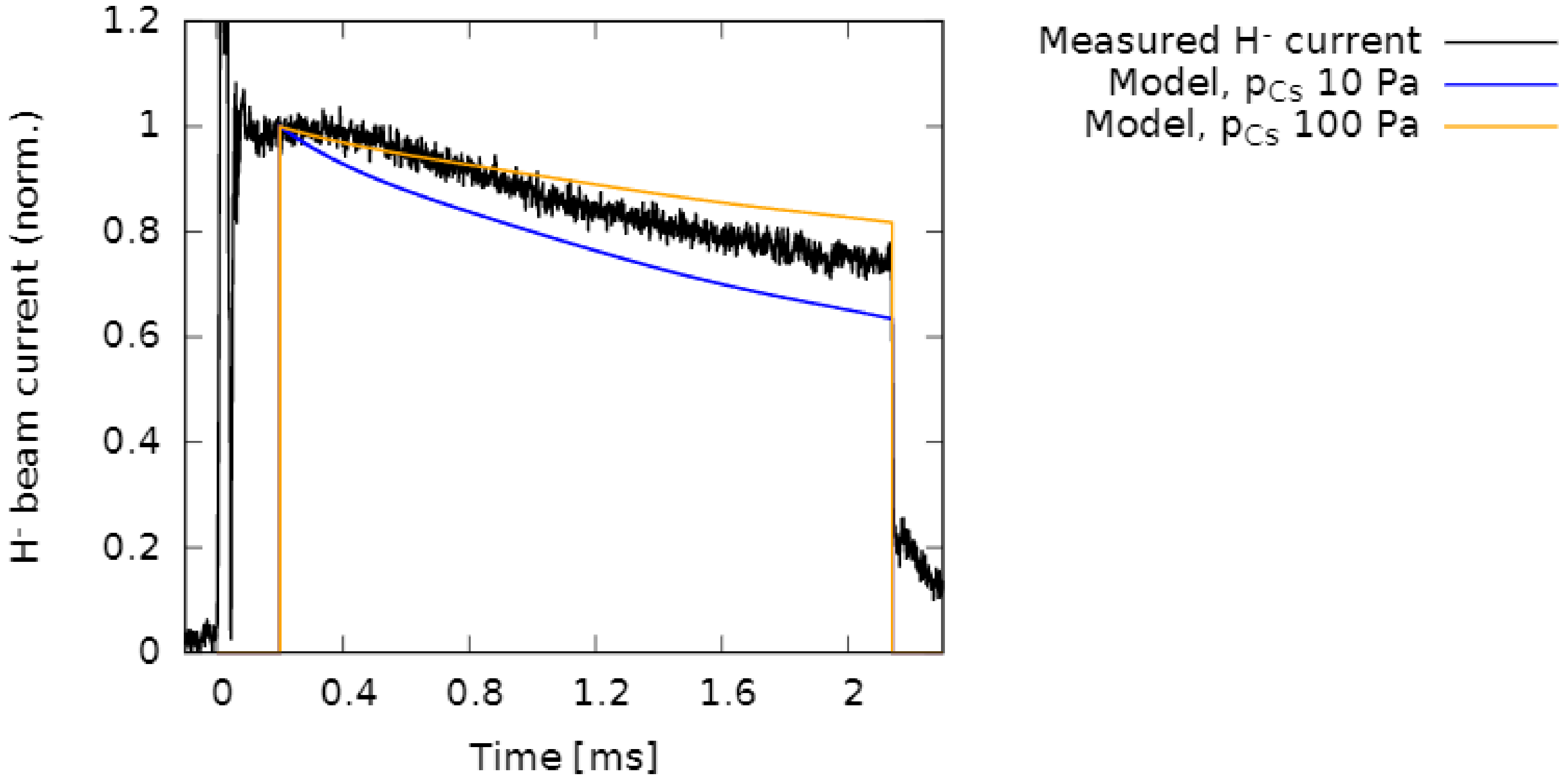
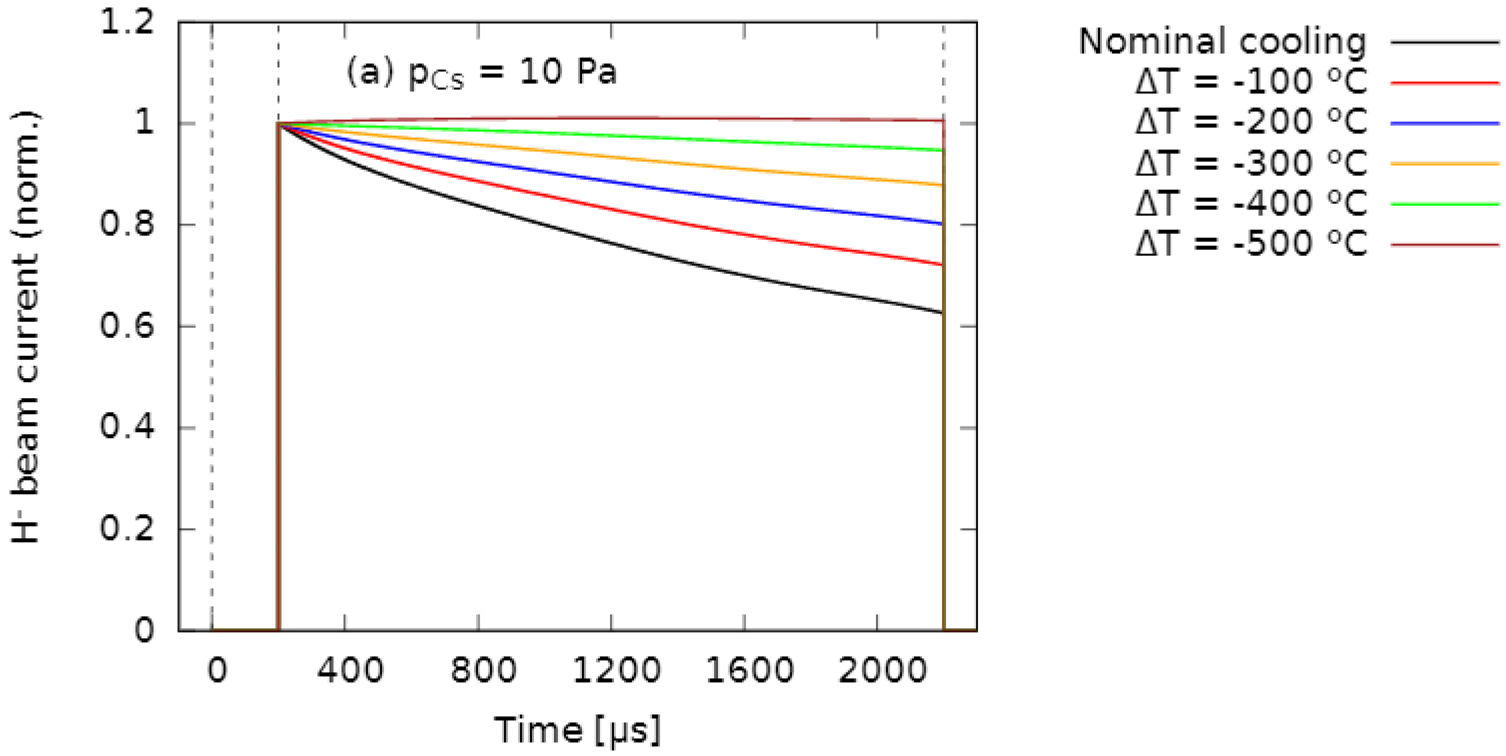
Long pulse model vs experiment



2.2 ms discharge pulse at 50 Hz

Significant droop even at very high Cs pressure

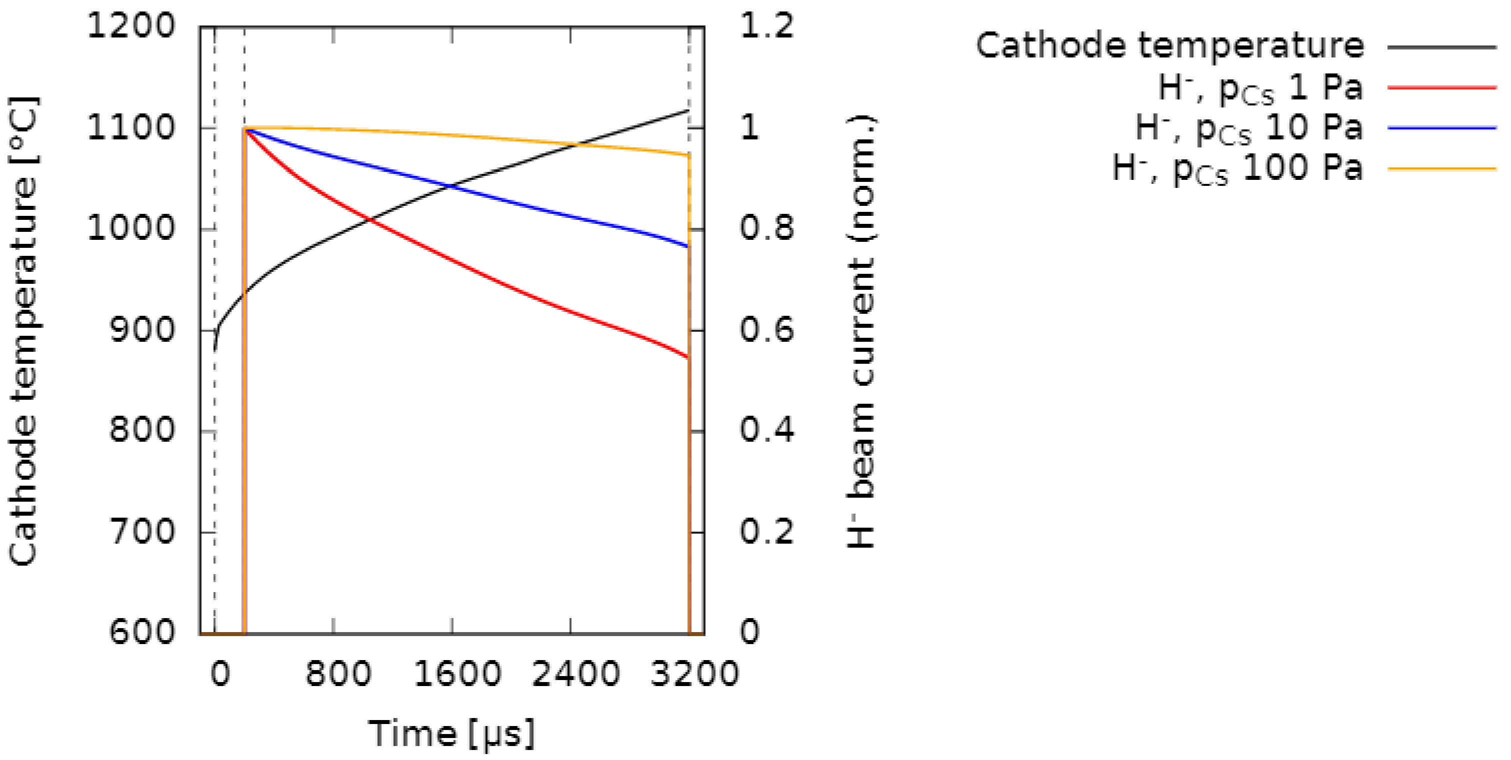
Long pulse model prediction



2.2 ms discharge pulse at 50 Hz

Works only at reasonable Cs pressure if the cathode cooling can be improved (2X source, redesign of the cooling,…)

Long pulse model prediction



3 ms discharge pulse at 14 Hz (ESSνSB), Iarc 70 A to make 70 mA H^- current

Works only at very high Cs pressure (escape flux probably unacceptable)

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Conclusion

We have developed a semi-empirical model for the cathode Cs balance.

The model reproduces experimental results (qualitatively) for short and long discharge pulses.

The model can be used for guiding ion source development towards long pulse / high duty factor.

Need to consider released Cs vs sputtered Mo and compare Cs release predictions to OES data.

Thank You for your attention

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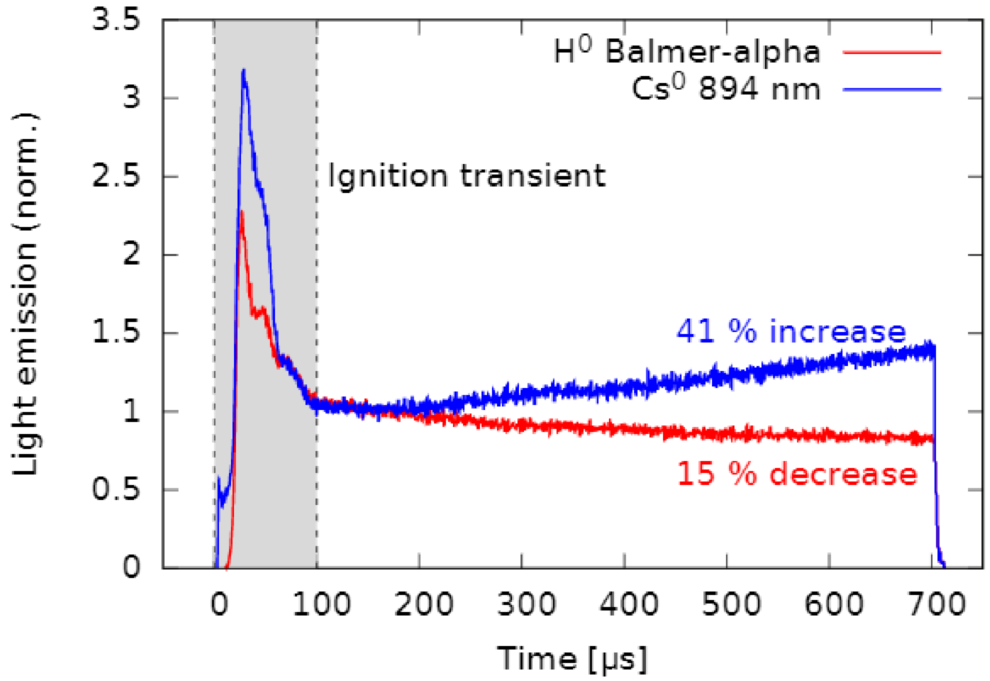
Extra slides

Table 2: The change of Cs coverage on the Penning ion source electrode surfaces during 760 µs discharge pulses at 50 Hz.

Electrode	Area [mm^2]	Temp. [°C]	Cs coverage [atoms]	Cs atoms released
Cathode	2×49	670–770	$3.17\text{–}2.91 \cdot 10^{14}$	$0.26 \cdot 10^{14}$
Anode	49	460–480	$1.87\text{–}1.84 \cdot 10^{14}$	$0.03 \cdot 10^{14}$
Aperture plate	44	480–505	$1.65\text{–}1.62 \cdot 10^{14}$	$0.03 \cdot 10^{14}$
Discharge	**Vol. [mm^3]**	**Cs pres. [Pa]**	**Cs density [atoms/mm^3]**	**Cs atom number**
1X Penning	105	10	$8.3\cdot10^{11}$	$0.87\cdot10^{14}$

37 % increase of Cs density



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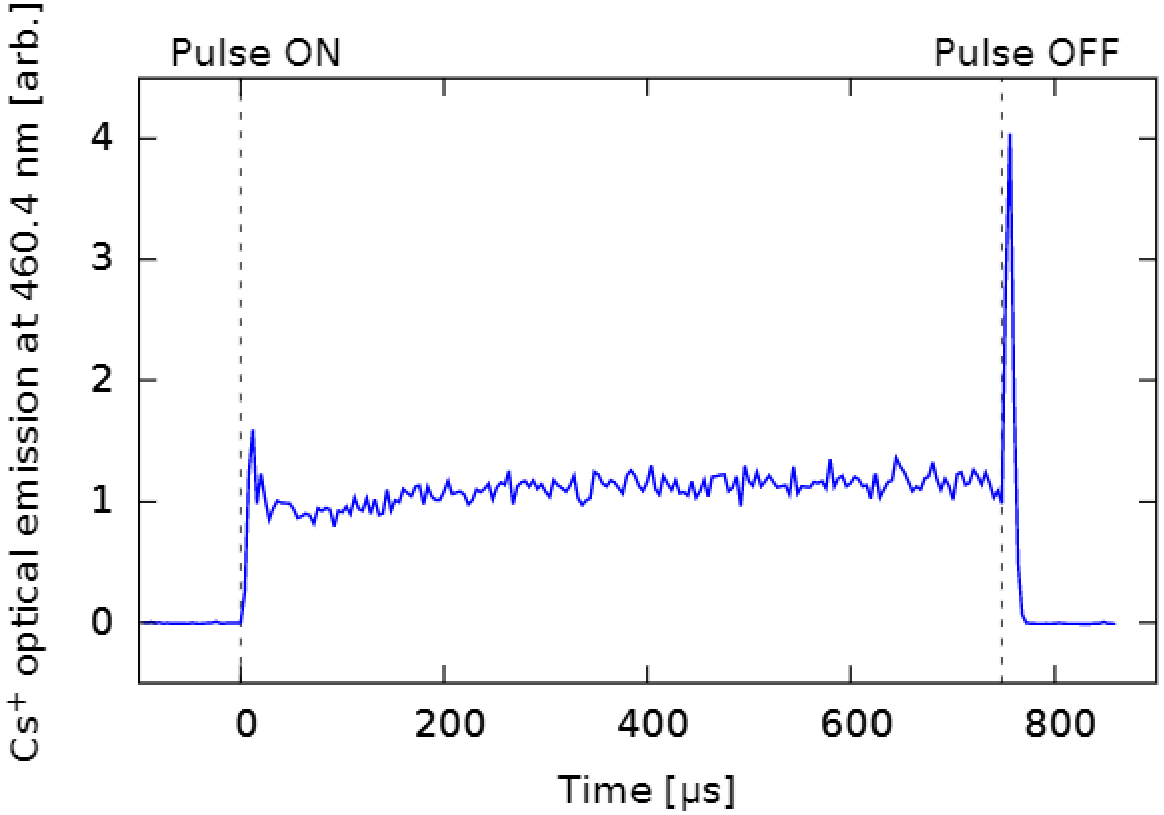
Extra slides

$$P_{\text{ion}} = \frac{1}{1 + \frac{g^0}{g^+} \exp\left(\frac{I_p - \phi}{kT_S}\right)}$$

Surface ionised Cs cannot escape the cathode



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