Experimental Investigations and Simulations of Dark Current in ELBE SRF gun-II

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Introduction

- **Dark current** -- "unwanted beam" not produced by the cathode drive laser, but **field emission** from the cavity and photocathode.

- Dark current can cause beam loss, increase the risk of damage to accelerator components, and create additional background for beam users.

- During operation of the ELBE SRF gun-II, the dark current has been found to correlate with the photocathode QE and life time.

Field Emission in the ELBE SRF Gun-II
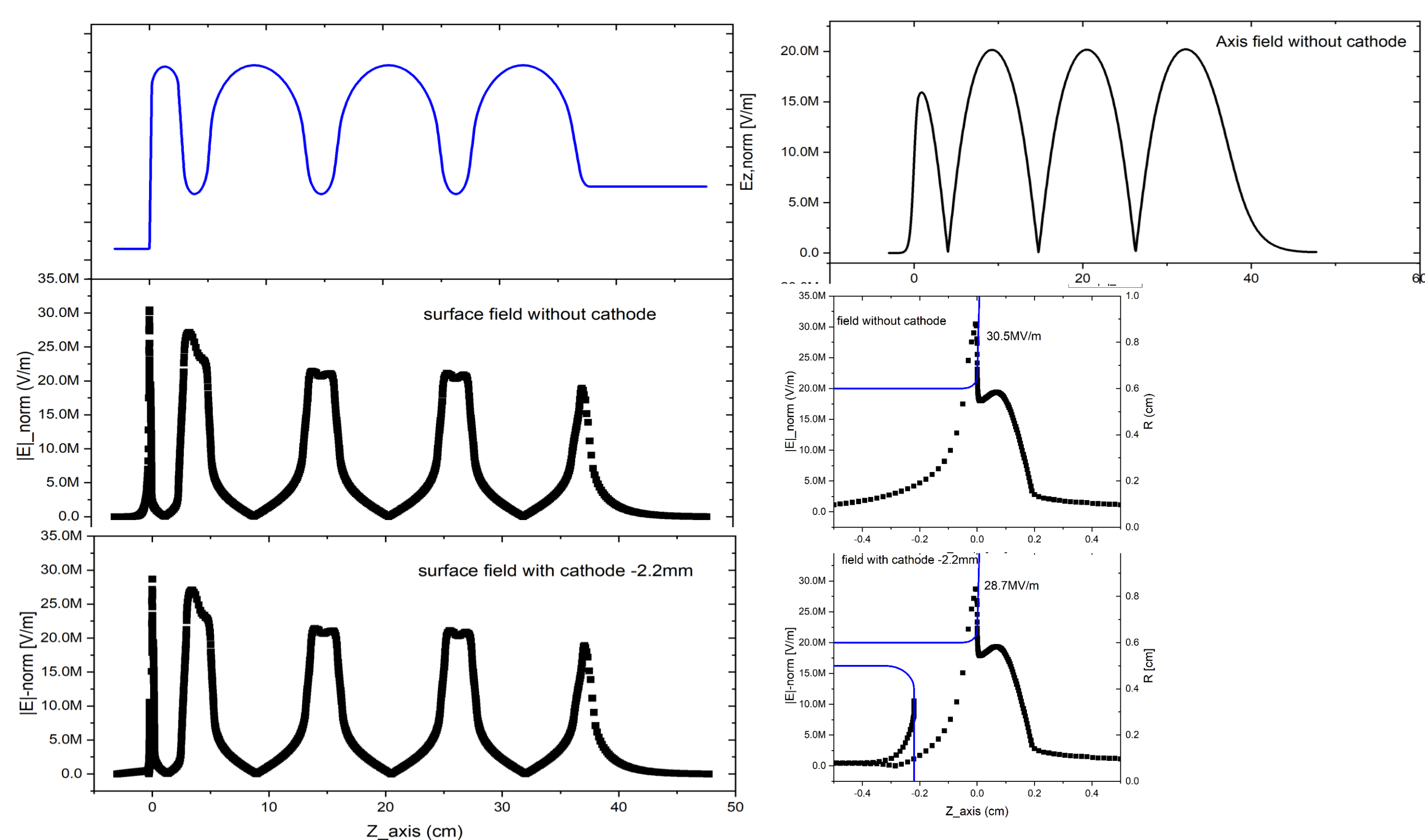
Left: Cavity shape of the ELBE SRF gun-II and the electric surface field simulated with Superfish with $E_{peak\ axis}$=20 MV/m.
Right: axis field, and the electric surface field in the zone close to the cathode.

The field emission at higher gradient can be estimated based on the Fowler-Nordheim equation [J.W. Wang and G.A. Loew, SLAC-PUB-7684]

$$I(E) = \frac{5.7 \times 10^{-12} \times 10^{4.52\phi^{-0.5}} A(\beta E_0)^{2.5}}{\phi^{1.75}} \exp\left(-\frac{6.53 \times 10^9 \times \phi^{1.5}}{\beta E_0}\right)$$

$$\frac{d\left(\frac{\log_{10} I}{E^{2.5}}\right)}{d\left(\frac{1}{E}\right)} = -\frac{2.84 \times 10^9 \phi^{1.5}}{\beta}$$

I : time-averaging current (A)
Φ: work function (eV)
E : instantaneous electric surface field (V/m)
A: emitter size (m^2)
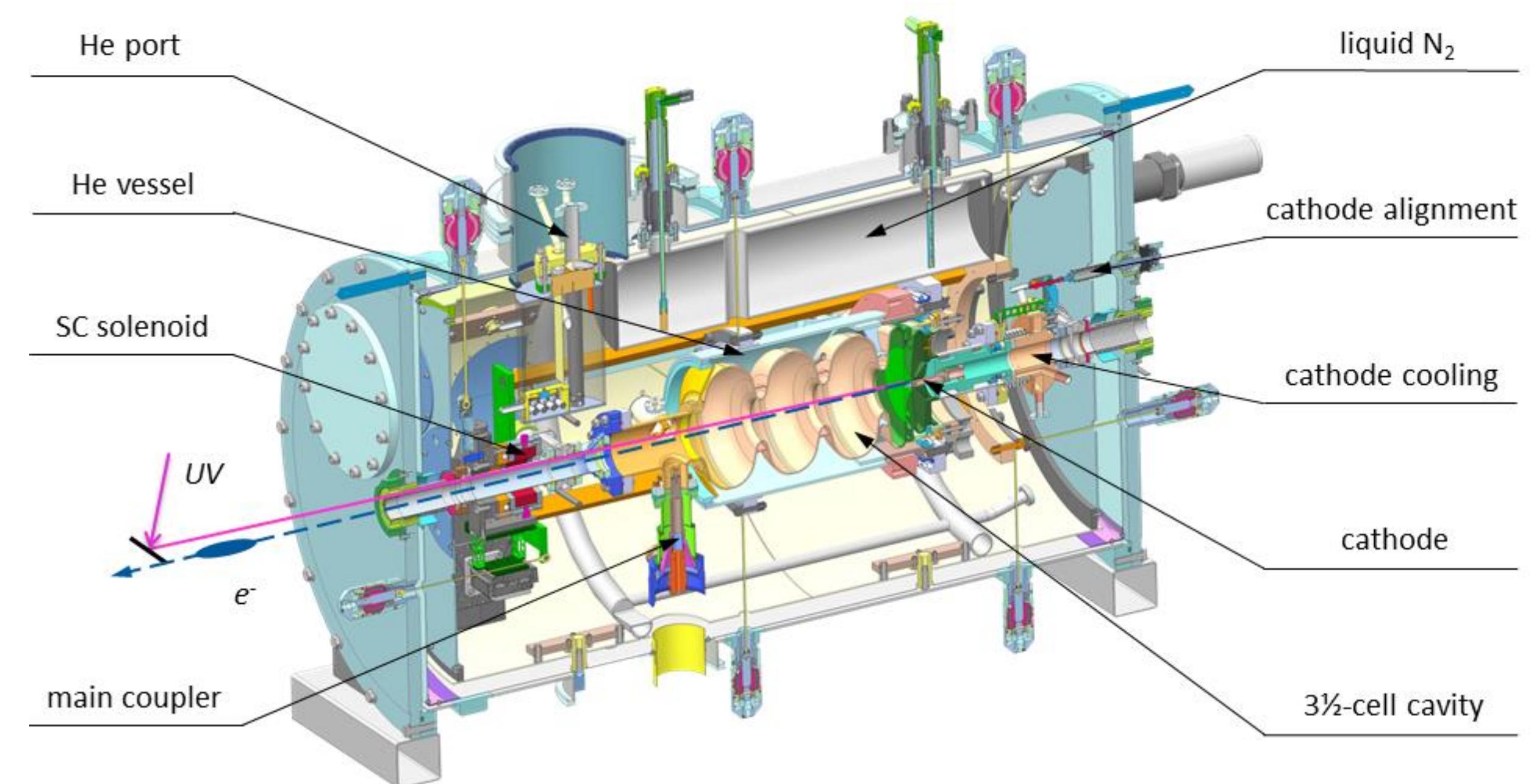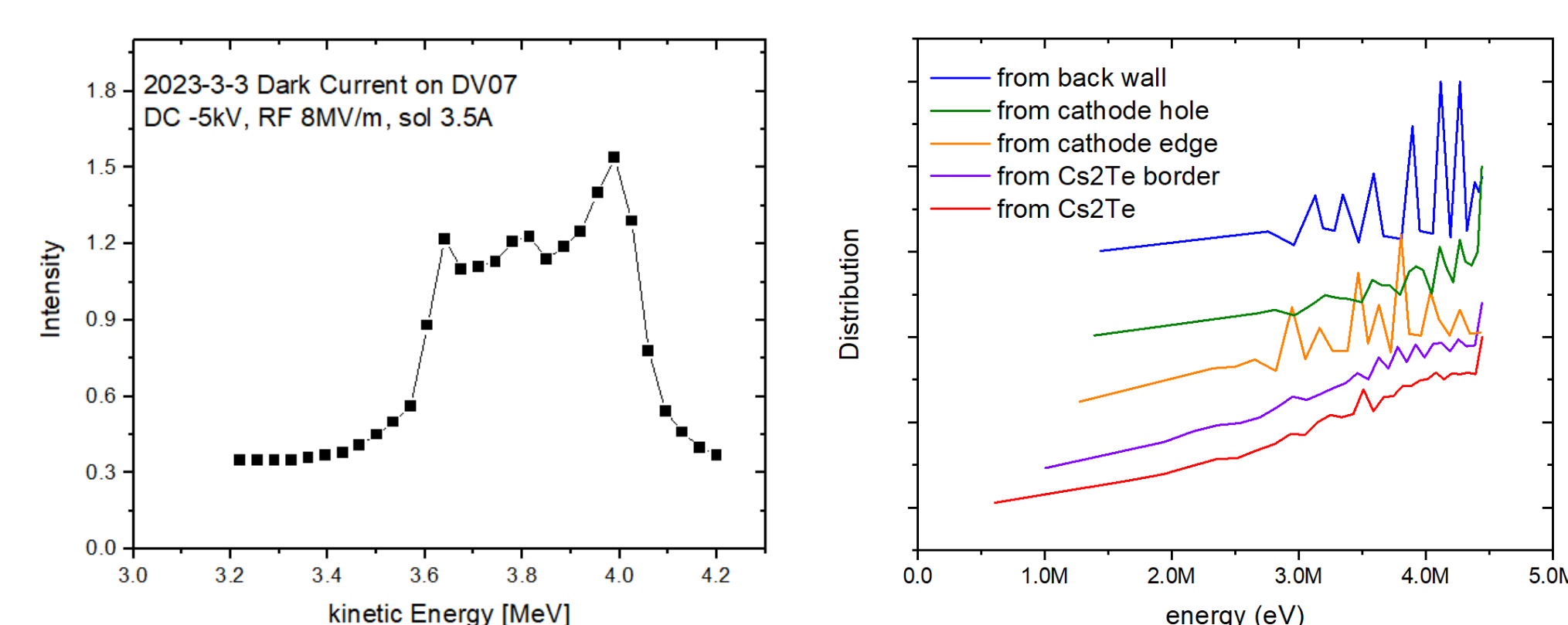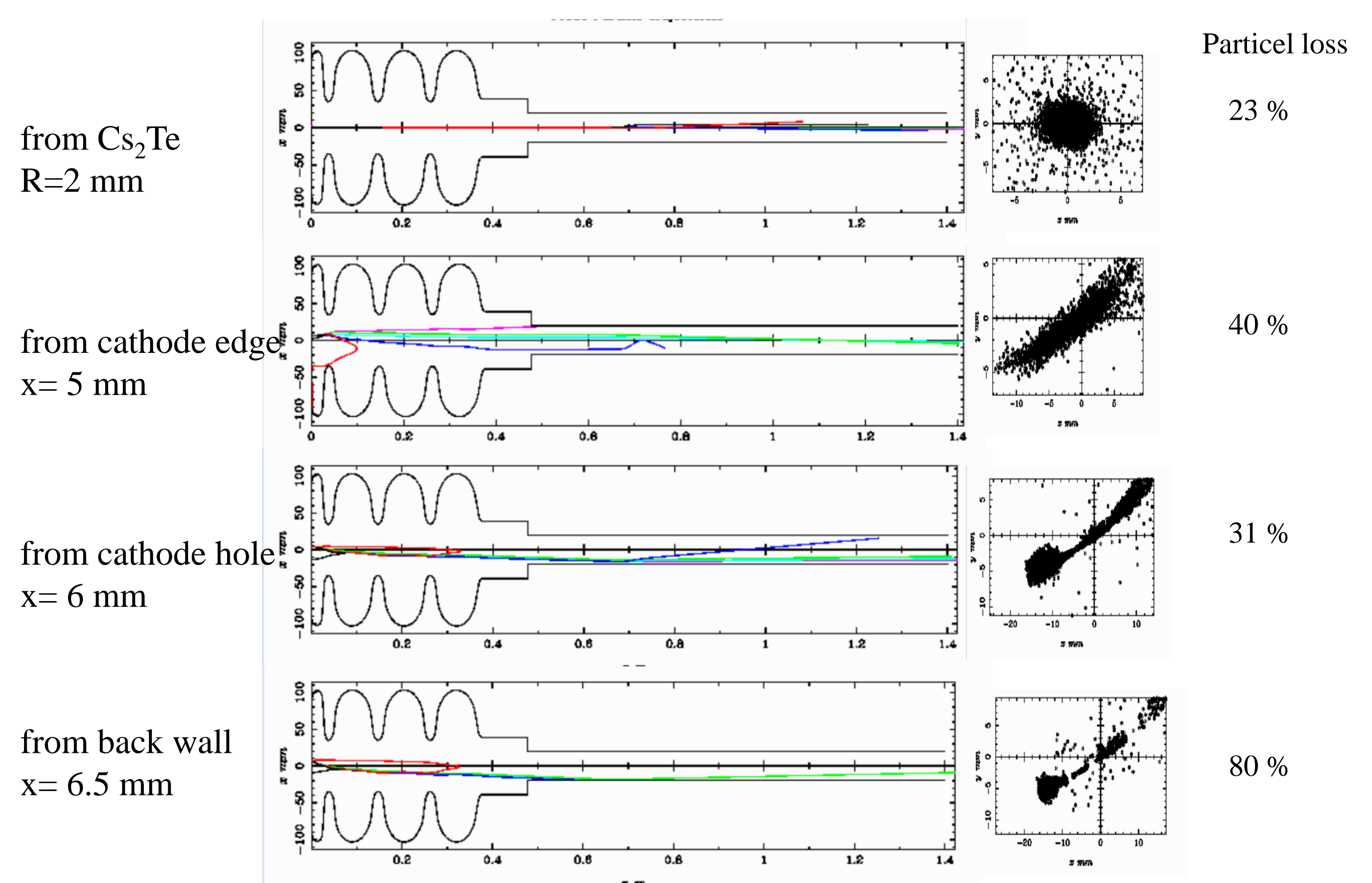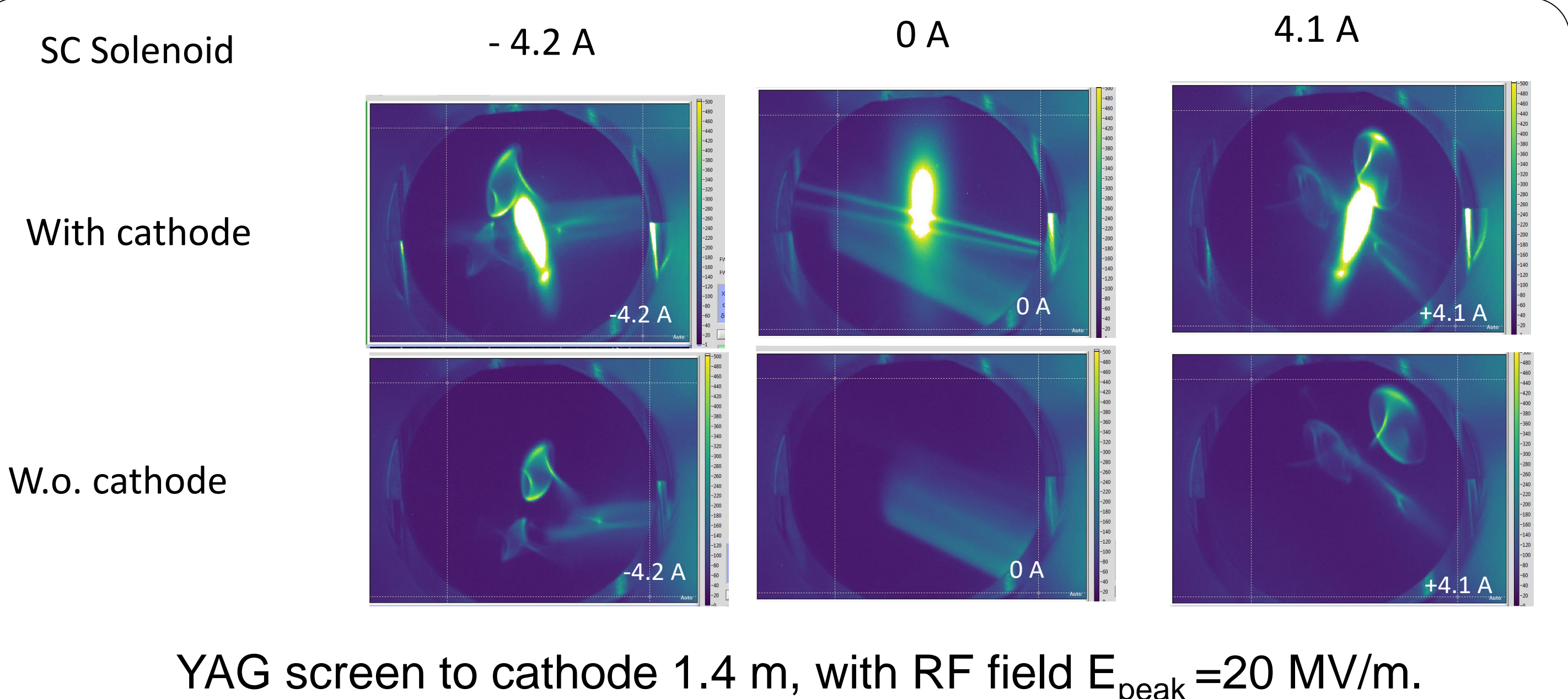β: field enhancement factor
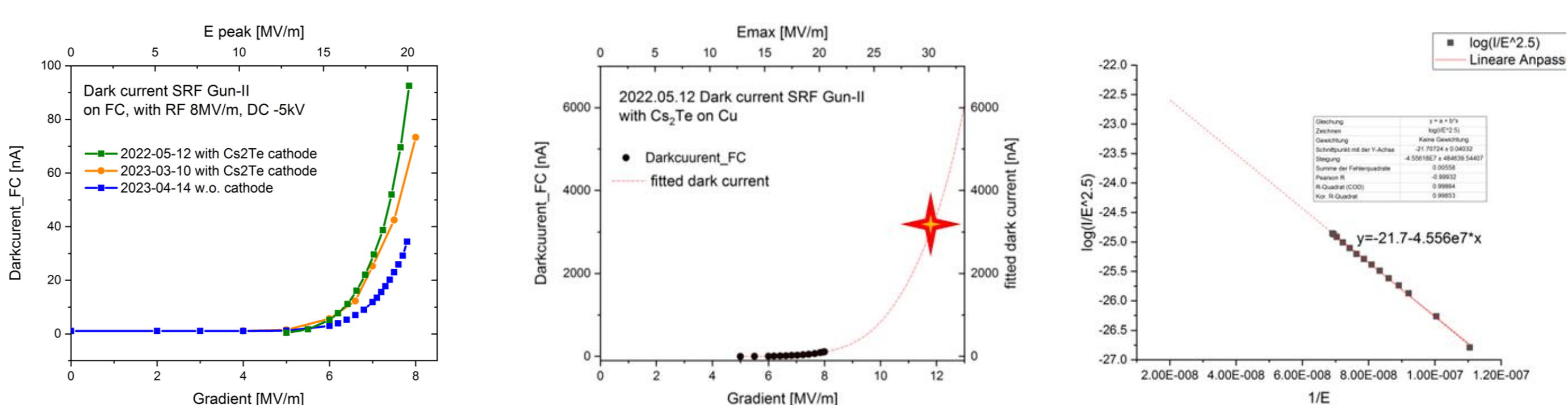
References

1. R. Xiang, et al., Phys. Rev. Accel. Beams 17, 043401 (2014).
2. J.W. Wang and G.A. Loew, SLAC-PUB-7684.
3. R. Xiang, et al., proceeding of IPAC2022, THPOPT022.
4. J. Teichert, et al., Phys. Rev. Accel. Beams 24, 033401 (2021)
5. A. Arnold, et al., Proceedings of SRF'21, TUPTEV001.

ELBE SRF Gun-II at HZDR

- 3.5 cell 1.3 GHz Nb cavity, E_{acc} = 8 MV/m, $E_{cathode}$ =14 MV/m
- Superconducting solenoid 70 cm downstream from cathode
- Reliable and stable user operation since 2019
- Routinely 4 MeV CW beam with 200 - 250 pC bunch charge

Dark Current Image and Astra Simulation

YAG screen to cathode 1.4 m, with RF field E_{peak} =20 MV/m.

	Particel loss
from Cs$_2$Te R=2 mm	23 %
from cathode edge x= 5 mm	40 %
from cathode hole x= 6 mm	31 %
from back wall x= 6.5 mm	80 %

Energy spectrum of dark current and the possible field emission sources