Beam dynamics study of a CW L-band SRF gun for the High Duty Cycle EuXFEL

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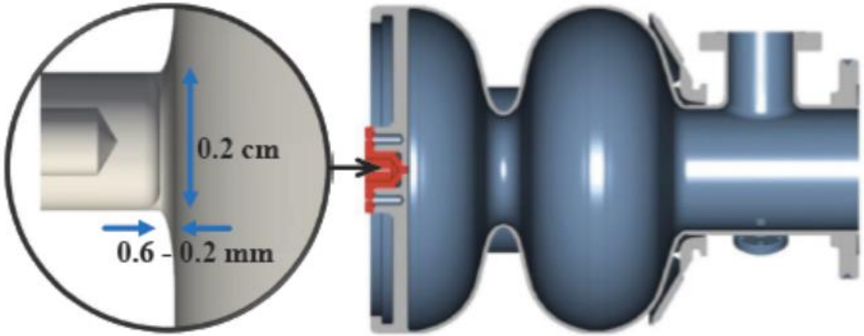
SRF Gun

- **Retracted cathode gun geometry**



Idea of the new gun:

- Flexible cathode replacement and processing
- RF-based emittance compensation

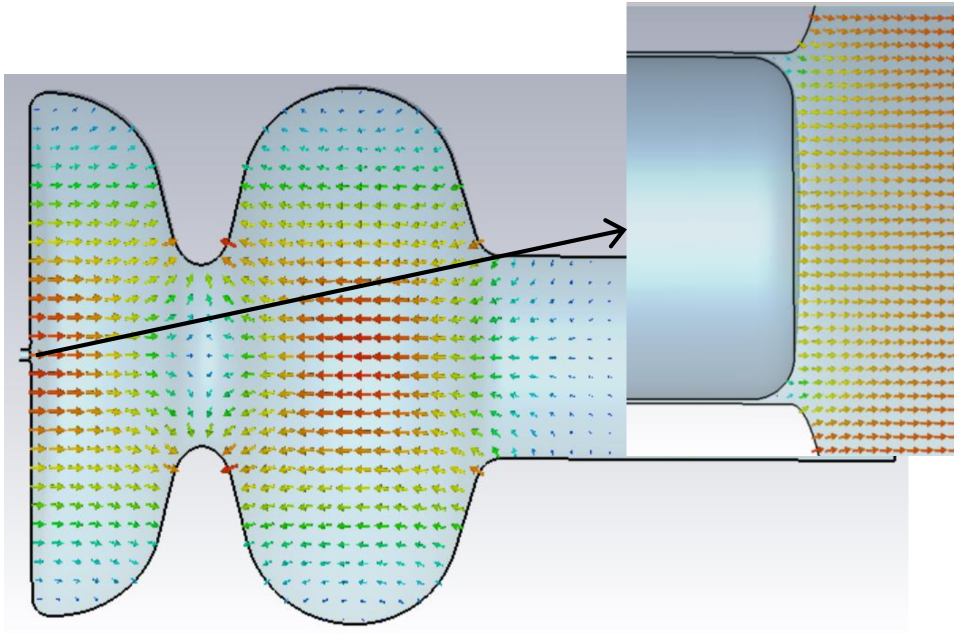
Goals of this investigation:

- Is there an emittance compensation effect?
- How large is this effect?
- What are the optimum gun parameters?
- What is the optimum plug position?
- Impact of cathode plug misalignments on the beam dynamics?

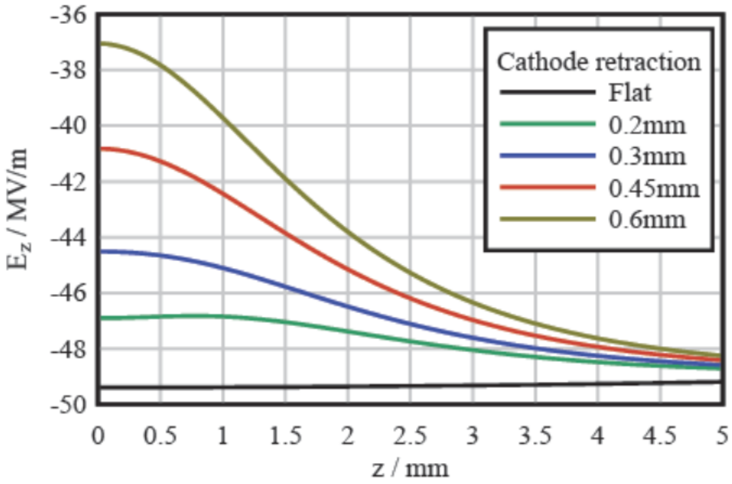
1. H. Qian, E. Vogel, Overview of CW RF guns for short wavelength FELs, FEL2019, WEA01
2. H. Vennekate, at al., Emittance compensation schemes for a superconducting rf injector, PRAB 21 (2018), 093403
3. E. Gjonaj, D. Bazyl, IPAC2023, WEPA054

Analysis

- **Accelerating mode @1.3GHz**



- Small focusing component at the cathode
- Accelerating field strength is decreased



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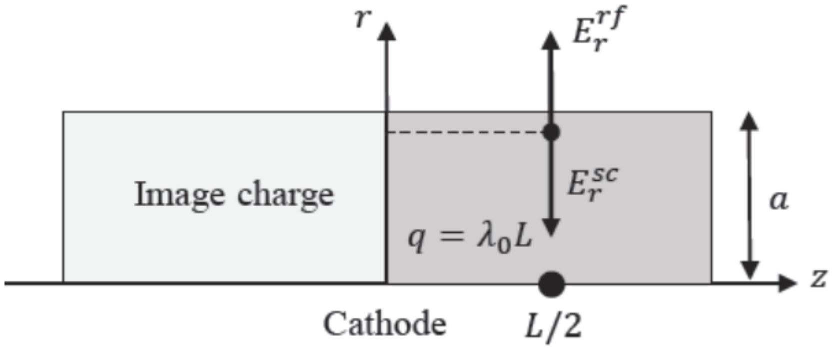
Analysis

- **Force balance at the cathode**

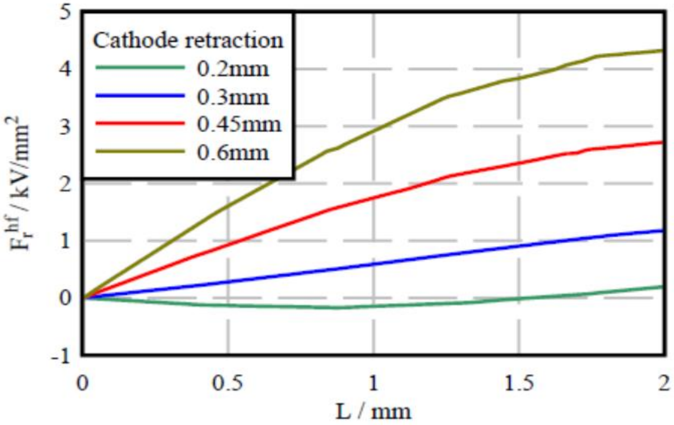


Fields at the center of cylindrical bunch with constant line charge density at any given emission stage

$$(Q = 100pC,\ L_0 = 2mm, \sigma_r = 2a = 0.16mm)$$

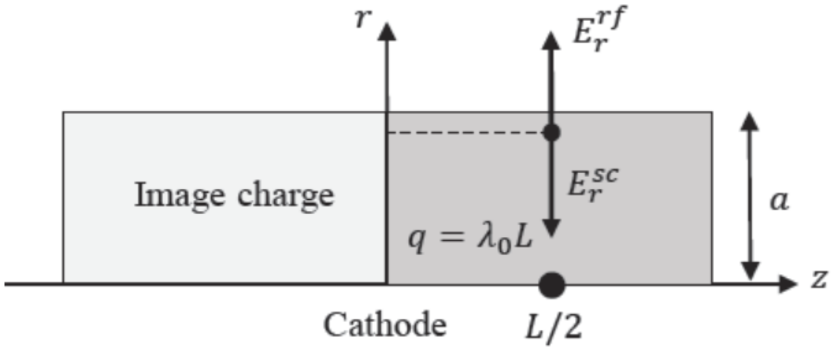
$$E_r^{rf}(r,z,t) = -\frac{\partial E_z^{rf}(0,z,t)}{\partial z} r + O(r^3)$$

RF-focusing strength: $F^{rf}(L) = -\left.\frac{\partial E_z^{rf}(0,z,0)}{\partial z}\right|_{z=L/2}$



Analysis

- **Force balance at the cathode**

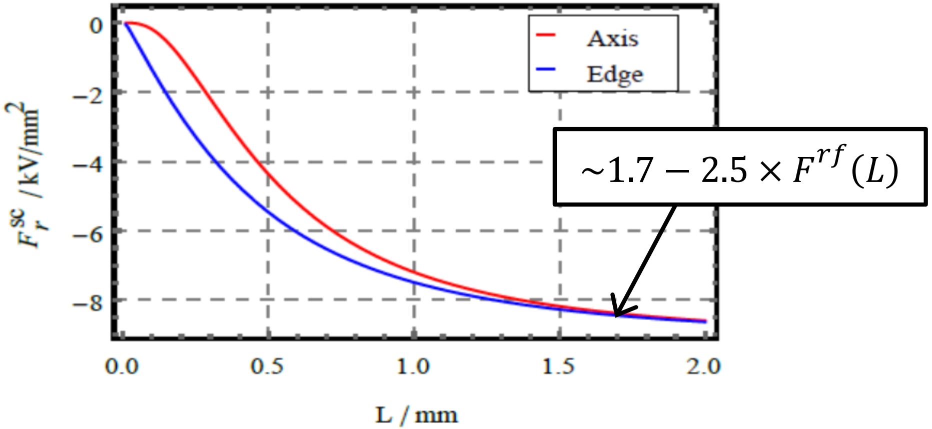


Fields at the center of cylindrical bunch with constant line charge density at any given emission stage

$(Q = 100pC,\ L_0 = 2mm, \sigma_r\ = 2a = 0.16mm)$

$$E_r^{sc}\left(r, z - \frac{L}{2}\right) = \frac{\lambda_0}{2\pi\epsilon_0}\int_0^{\pi} d\phi \cos\phi \log\left(\frac{R_- - z_-}{R_+ - z_+}\right)$$

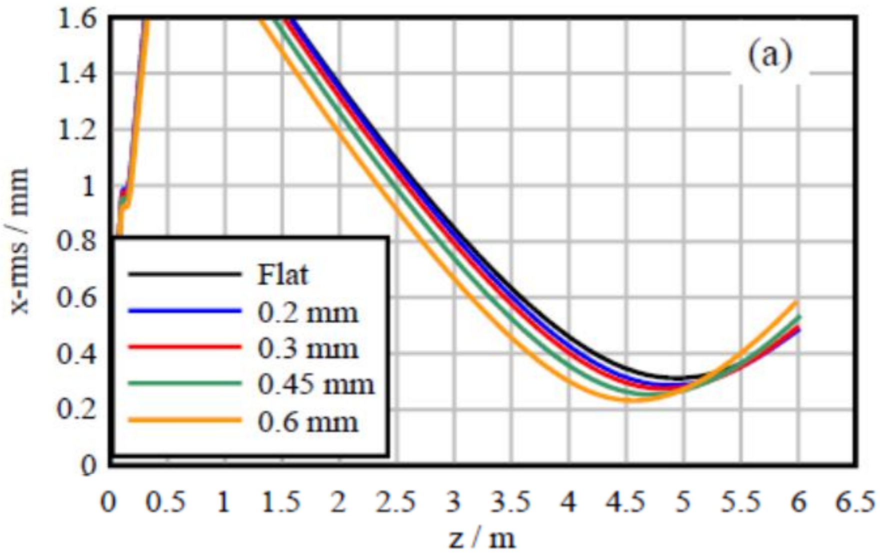
SC-defocusing strength: $F^{sc}(r, L) = \frac{E_r^{sc}(r,0)}{r}$

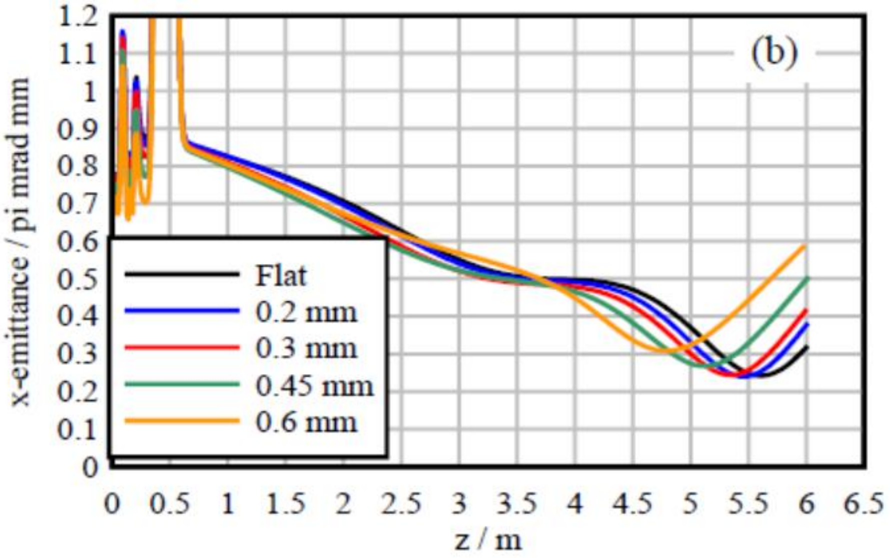


Simulations

- **Tracking with nominal parameters**

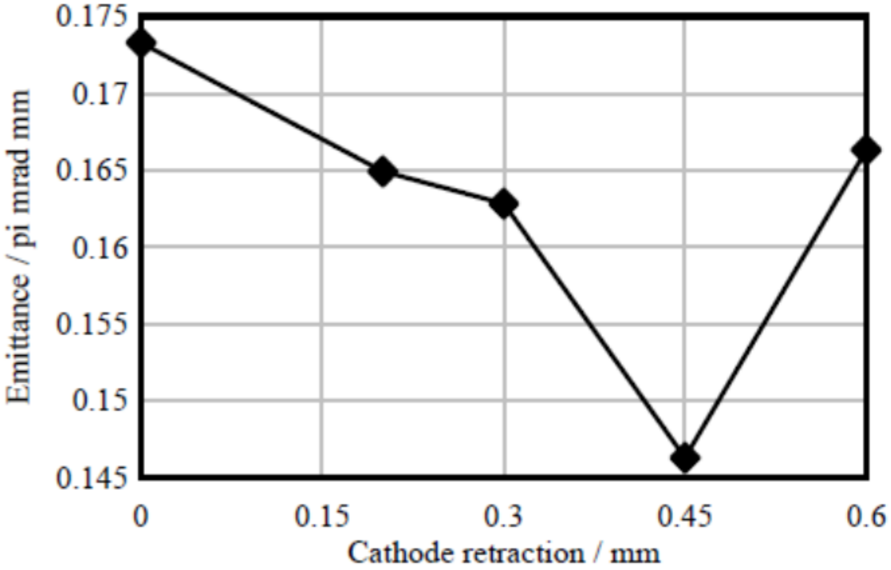
$$Q = 100\text{pC},\ \ \sigma_t = 7.3\text{ps},\ \ \sigma_r = 0.16\text{mm},\ \ \sigma_{E0} = 5.5\text{eV},\ \ \sigma_{\varepsilon 0} = 0.13\text{mm mrad}, B_{max} = 0.184\text{T}$$





Simulations

- **Parameter Optimization**



Optimal parameters for different cathode retractions

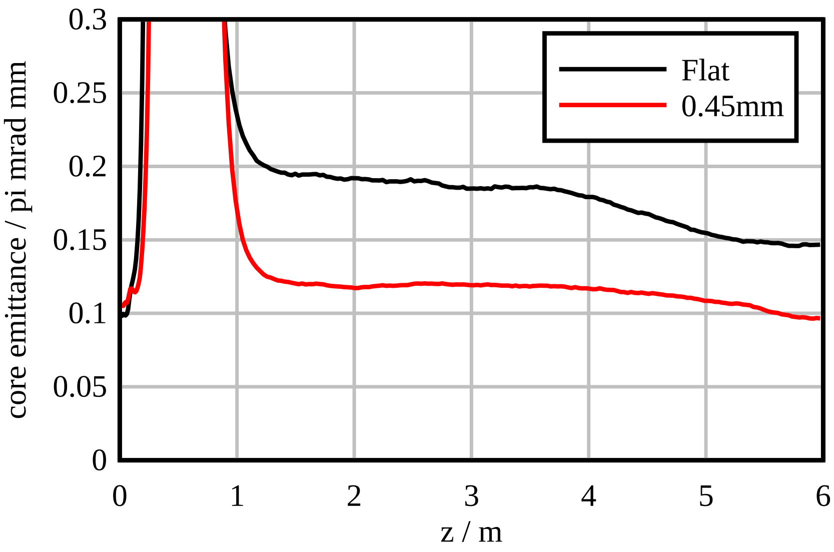
Δ(mm)	σ_r(mm)	σ_t(ps)	B(T)	Z_B(m)	ϕ_{rf}(°)
Flat	0.107	10	0.18	0.46	1.33
0.2	0.089	12.5	0.18	0.46	1.76
0.3	0.098	12.4	0.18	0.48	1.55
0.45	0.108	12.7	0.17	0.52	1.28
0.6	0.116	13.6	0.18	0.52	1.7

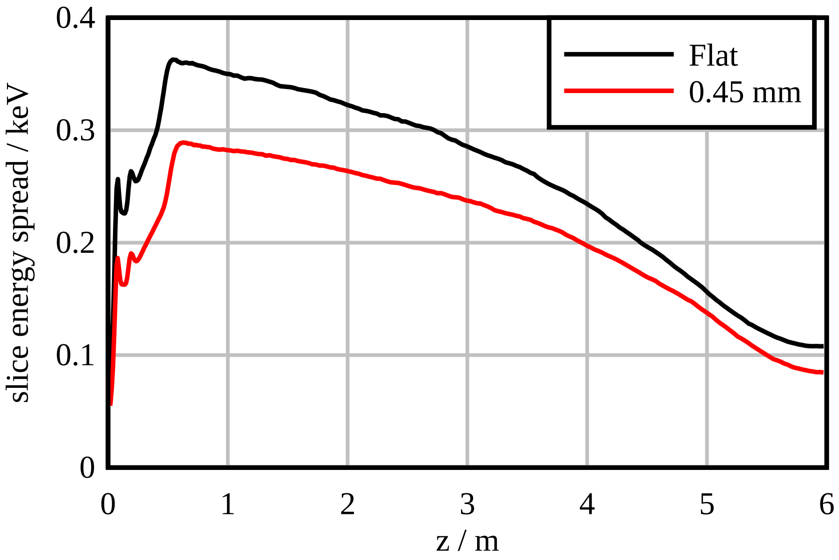
- **~20% emittance reduction at the optimum**
- **Relevant parameter is the laser pulse length**

Simulations

- **Parameter Optimization**

Core emittance and slice energy spread at the optimum





Conclusions

- Weak RF-compensation effect
- About 20% emittance reduction at the gun exit – compatible with the analytical estimation
- But, the optimum emittance is very close to the thermal emittance of the gun
- The optimal cathode retraction is at ~0.45mm
- Slightly longer laser pulses are needed for a retracted cathode gun
- No deterioration of the overall beam quality due to cathode retraction
- Simulations with 3D-field maps (not shown here) reveal no impact on the beam dynamics for radial misalignments of up to 50um of the cathode plug