Coupled Space Charge and Wakefield Simulations of a TW Gun

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TECHNISCHE UNIVERSITÄT DARMSTADT

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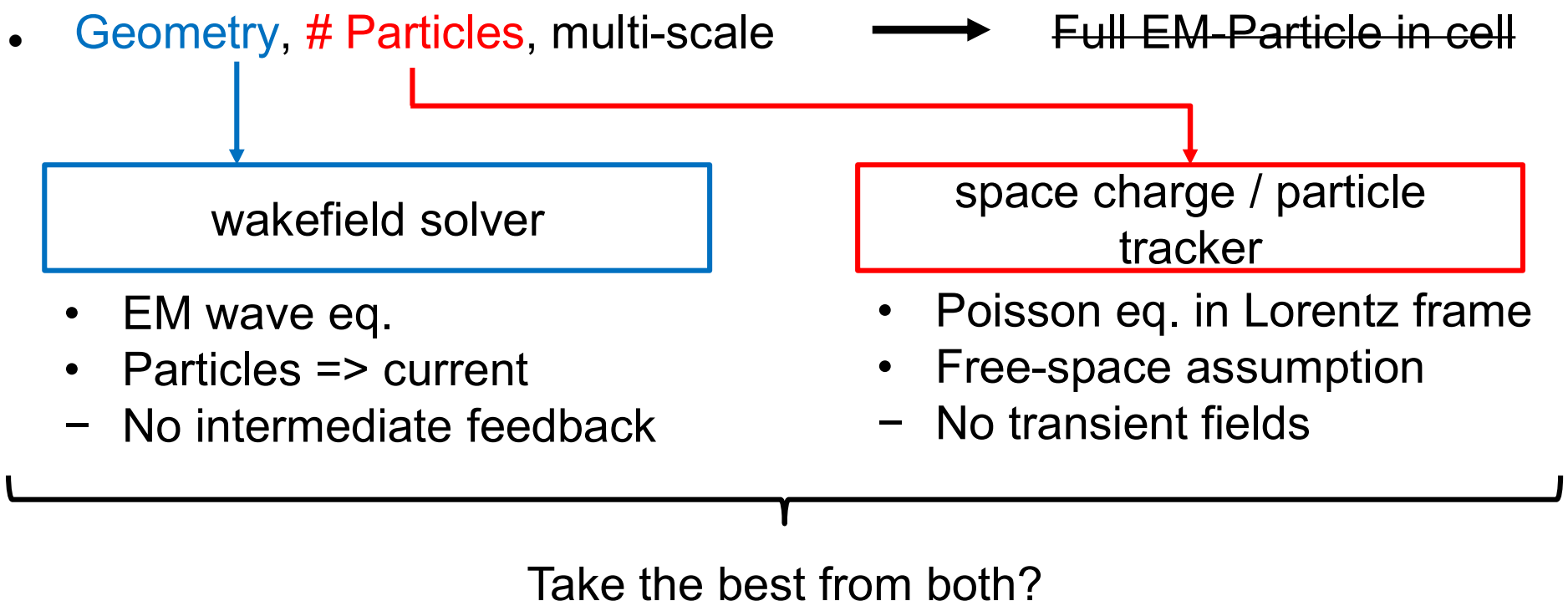
Outline

- Recap: Scattered Field Formulation
- Validation: Space Charge Impedance
- Results for Rectracted Cathode gun design
- Results for traveling wave gun @SwissFEL

Task

- **Solve Maxwell's eqs. + Eq. of Motion:**



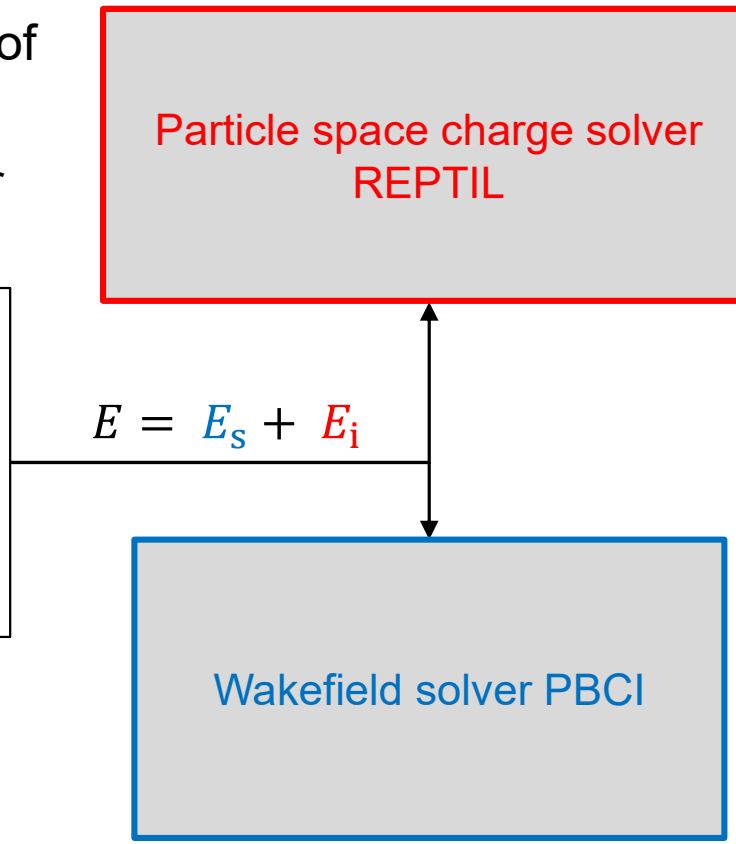
Scattered Field Formulation

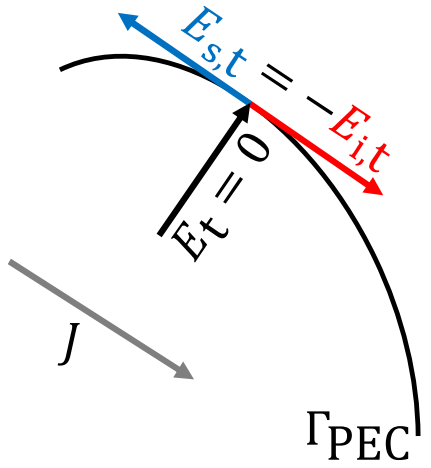
- Incident field is a matter of choice
- Fulfills Maxwell's eqs. for given current

$$\frac{d}{dt} E = \varepsilon^{-1} \operatorname{curl} H - \varepsilon^{-1} J$$

$$\frac{d}{dt} H = -\mu^{-1} \operatorname{curl} E$$

BC: $E_\mathrm{t} = 0$ on Γ_PEC

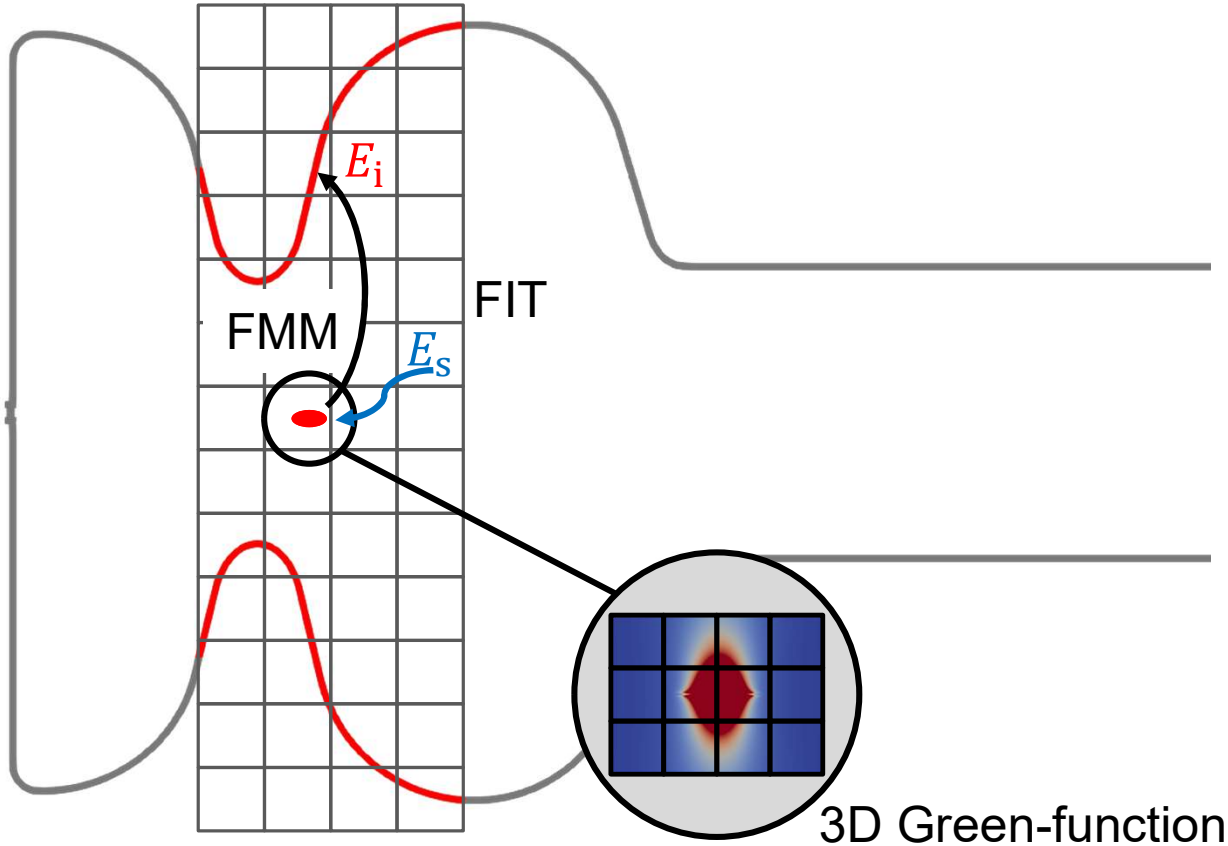




Initial conditions depend on choice of incident field:

$$E_\mathrm{s}(0) = E(0) - E_\mathrm{i}(0)$$

Coupling: PBCI + REPTIL



- Mesh-free, fast evaluation of space-charge field on boundary: FMM
- Solvers independent (grid, time step, optimization, …)
  - Arbitrary geometry
  - Arbitrary beam dynamics

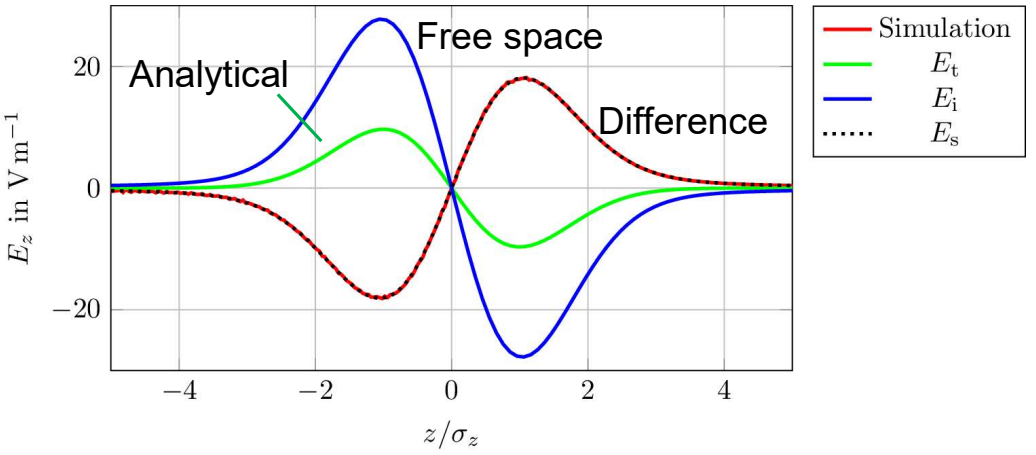
Validation: Space Charge Impedance

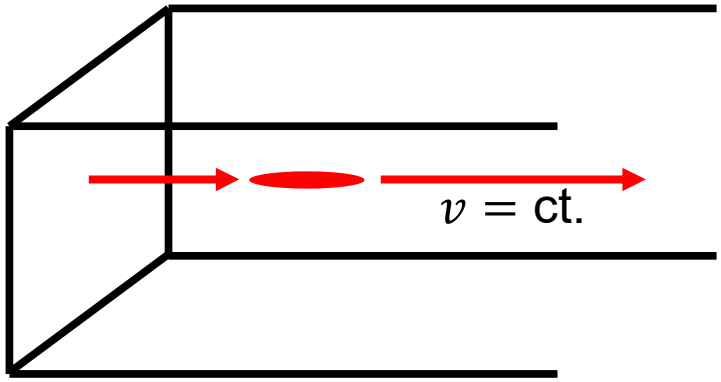
- Analytical estimate for field in beam pipe (space charge impedance)

$$E_z(z) = \frac{-Q}{2\pi\varepsilon_0\gamma^2}\Lambda\frac{d\lambda(z)}{dz}$$

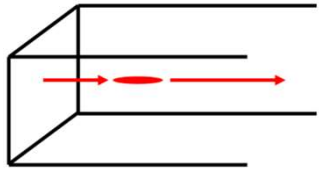
  - Neglects space charge, valid only for $\sigma_z\gamma \gg$ height, …

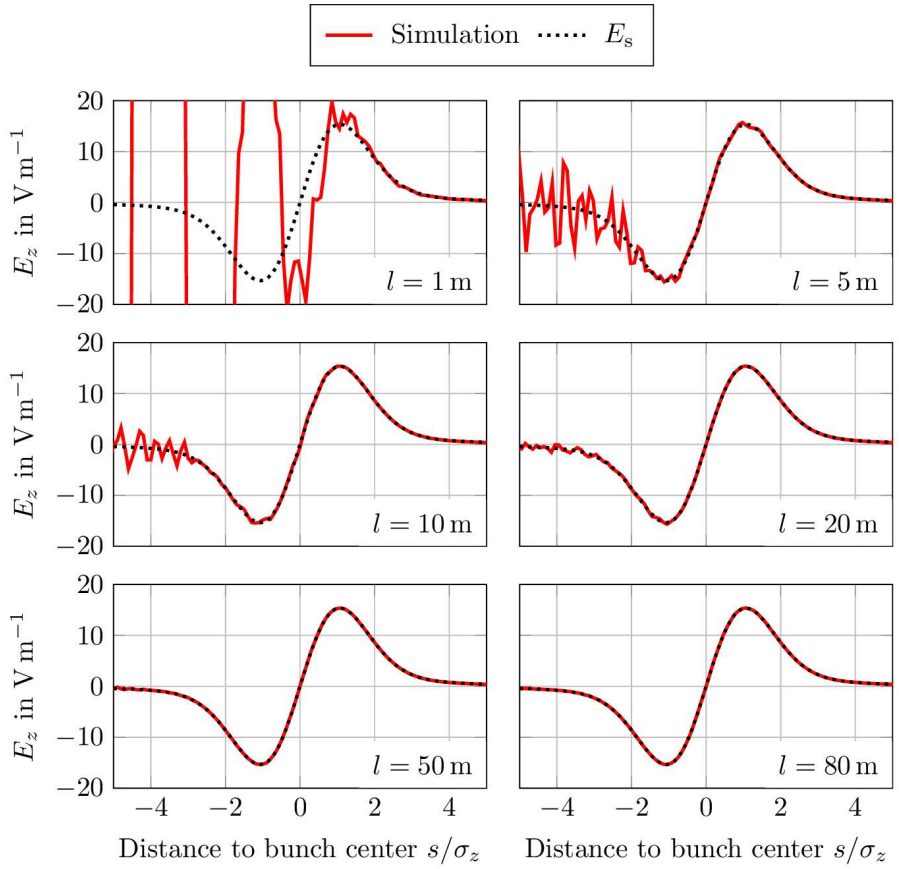
- Simulation: emission into beam pipe
  - Initial modes get damped over time

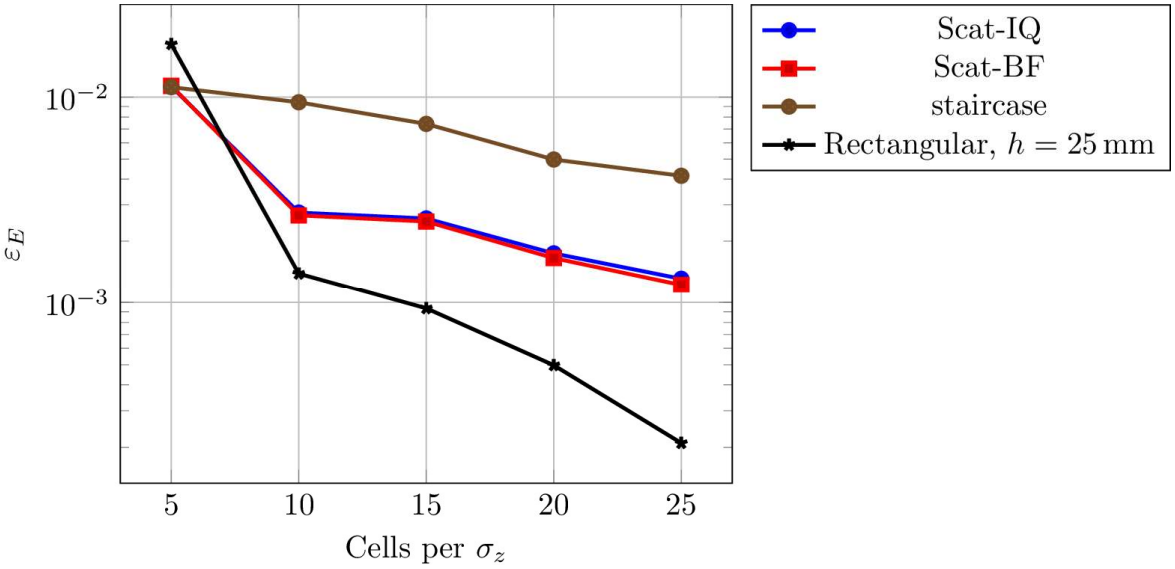




Convergence







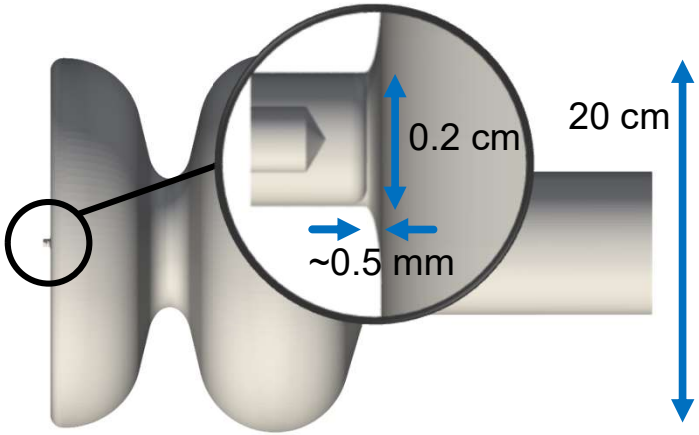
- Convergence: rectangular and cylindrical beam pipe

→ Formulation validated

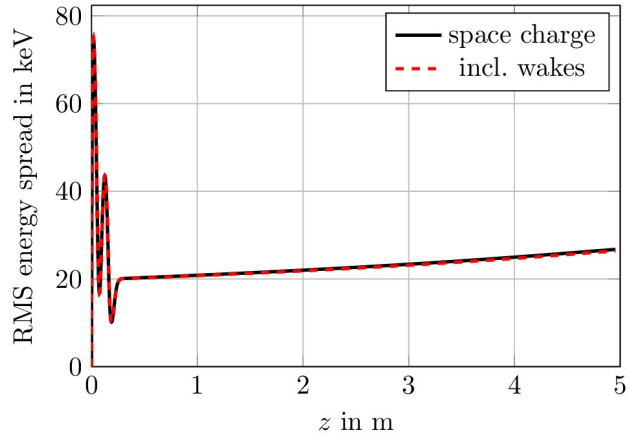
Results for Retracted Cathode Gun

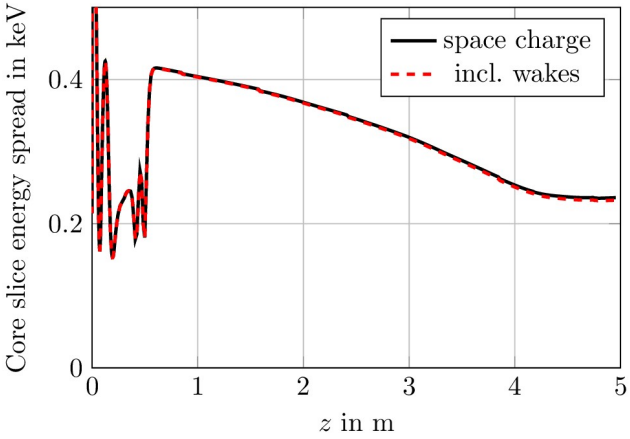
- Retracted cathode for RF focusing
- Slight deviations due to space charge impedance in beam pipe
- No significant impact from wakefields in gun

Bunch:	
Charge	0.1nC
Length	~2mm
Size	<2mm
Energy	5MeV at gun exit



Credit: Bazyl, Vennekate





Note error in data scale in last presentation

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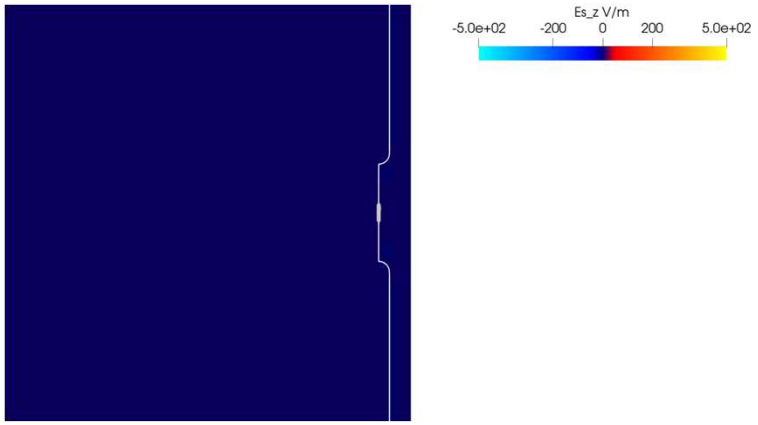

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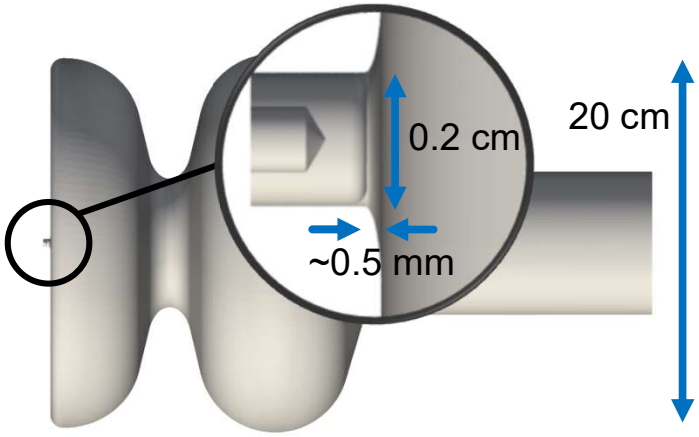

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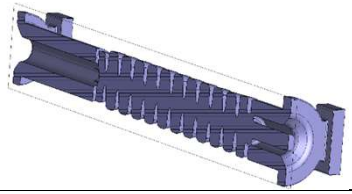
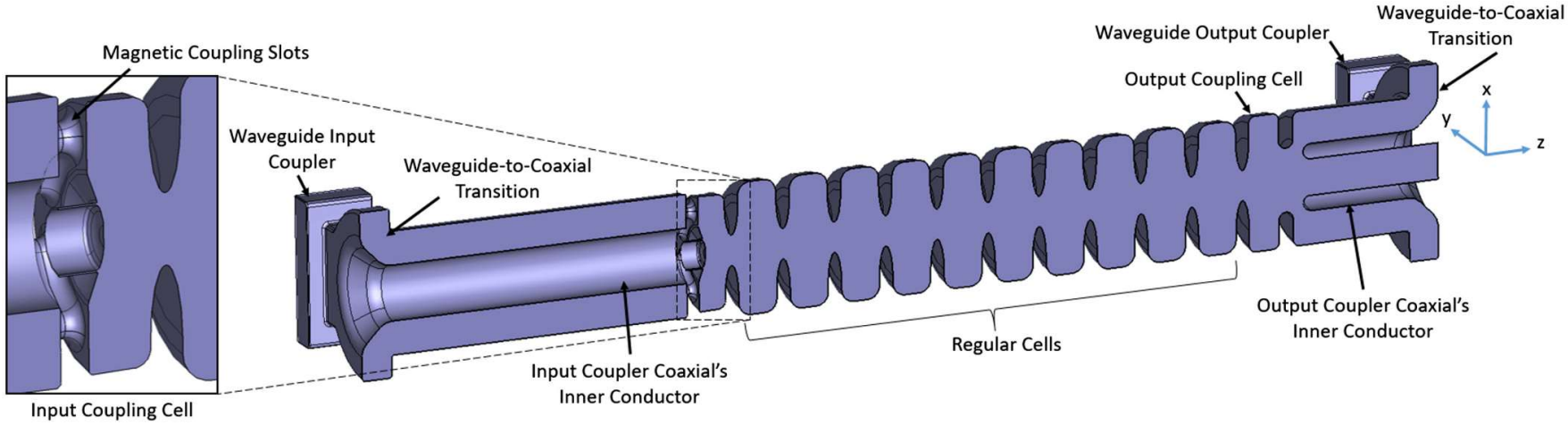
Traveling Wave Gun Model



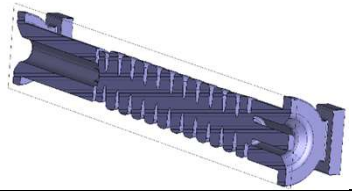
- 12-cell TW gun under design at SwissFEL (Lucas)
- Narrow, long geometry: 5mm iris radius, ~22cm acceleration path length

Bunch:	
Charge	0.2nC
Length	~0.5mm
Size	~1mm
Energy	13MeV at gun exit



Lucas 2023, DOI: 10.1103/physrevaccelbeams.26.103401

Traveling Wave Gun Model



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- 12-cell TW gun under design at SwissFEL (Lucas)
- Narrow, long geometry: 5mm iris radius, ~22cm acceleration path length
- Video: fields build up over time

Bunch:	
Charge	0.2nC
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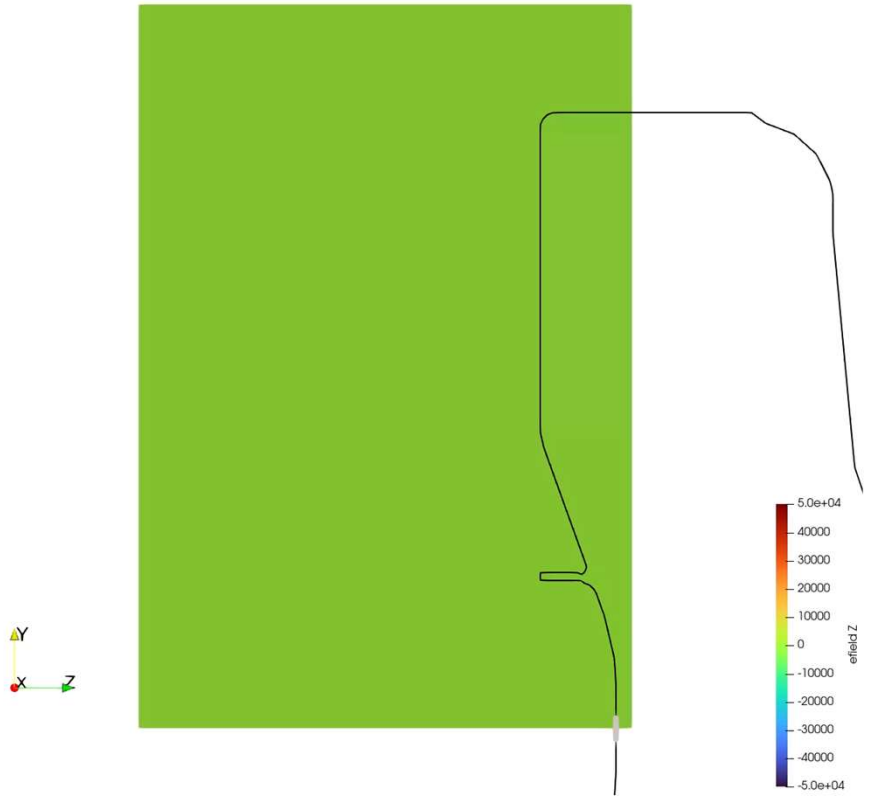
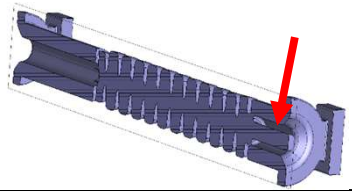


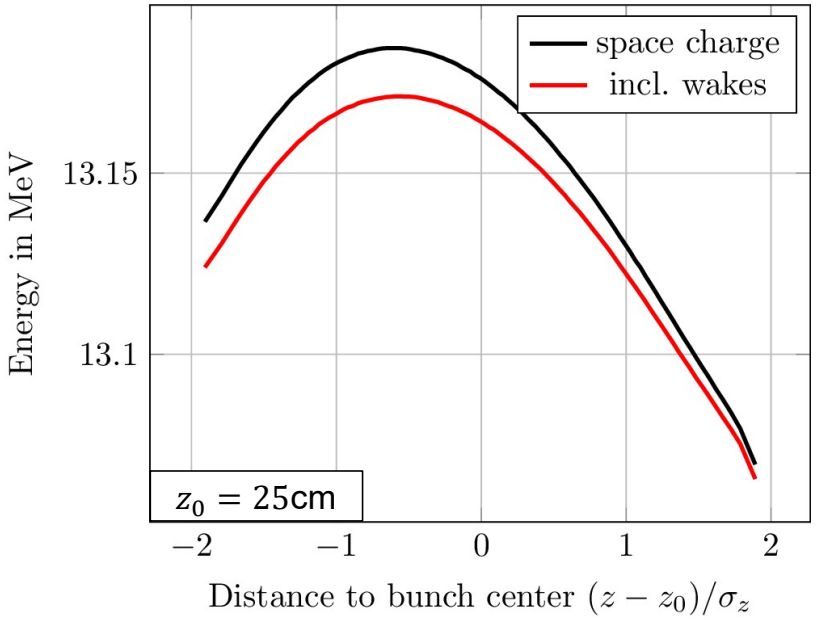
ACCELENCE

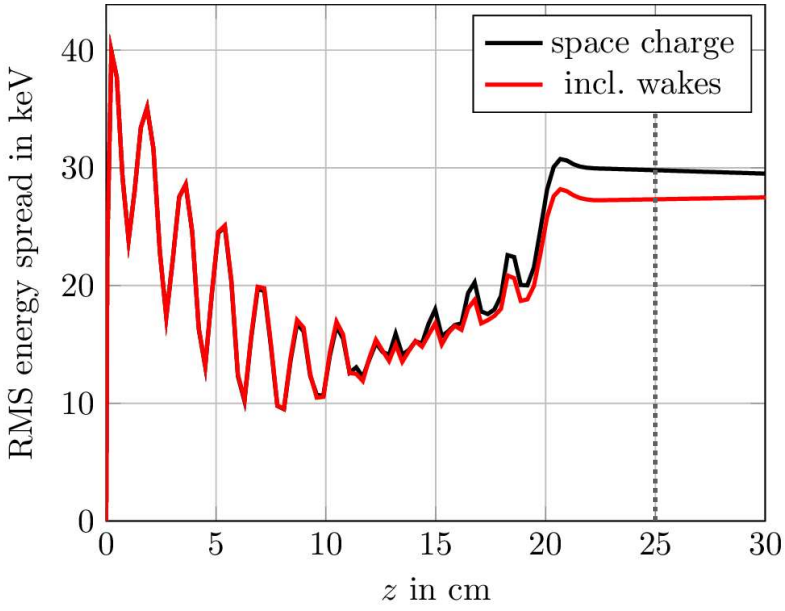
TEMF

Energy Chirp

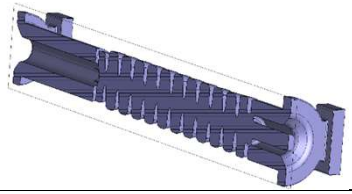


- Wakefields reduce energy chirp in gun
  - Wakes reach tail first
- ~10% RMS energy spread reduction at end of gun





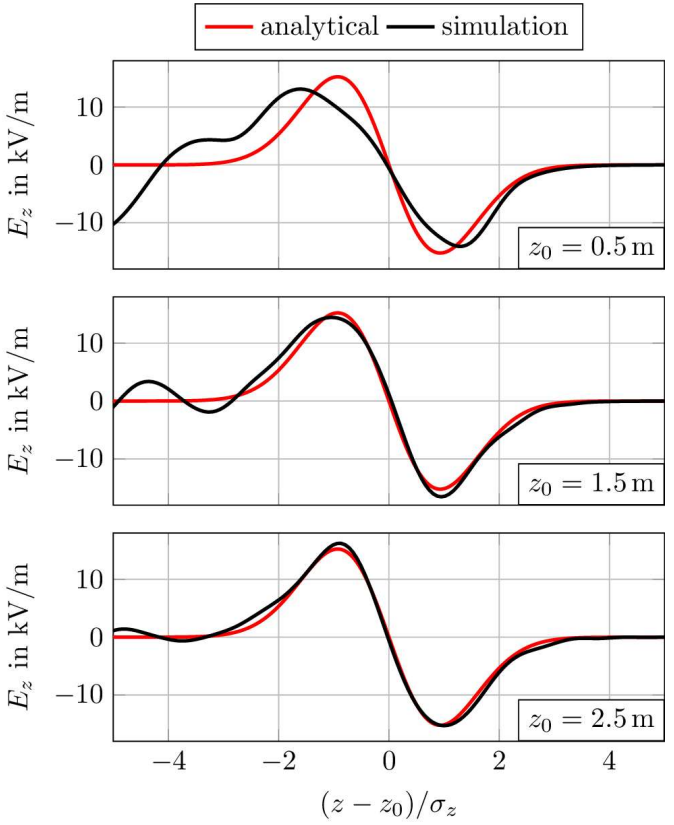
Full Injector Line Simulation I



- Field in beam pipe approaches space charge impedance field

  → Weak coupling of wakefields to beam pipe and downstream sections

  → Include wakefields up to first accelerating section, continue with space charge solver only



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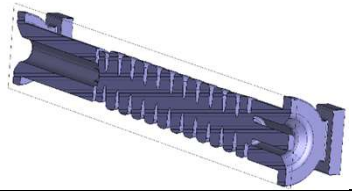

- Field in beam pipe approaches space charge impedance field

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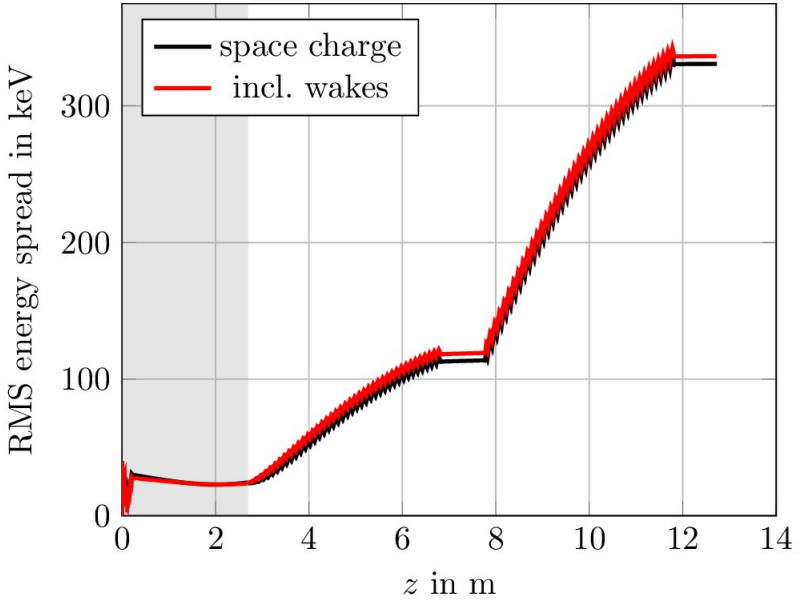
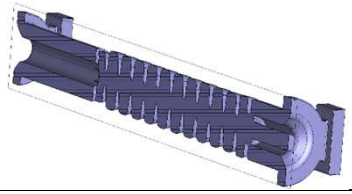
- Difference in RMS energy spread:

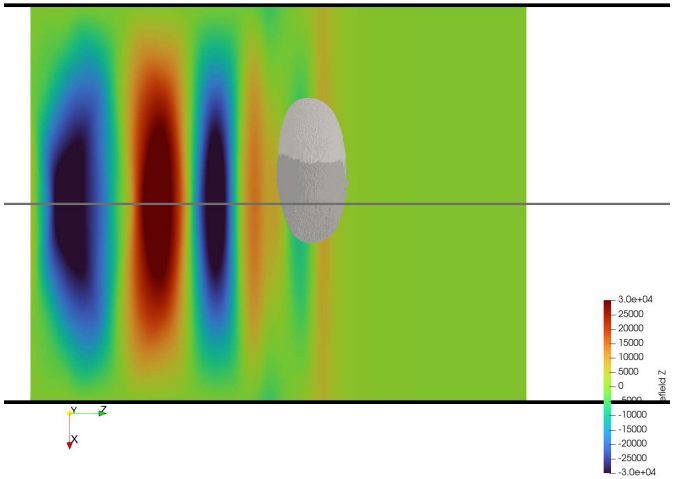
  5.5keV (simulated), 7.1keV (analytical)

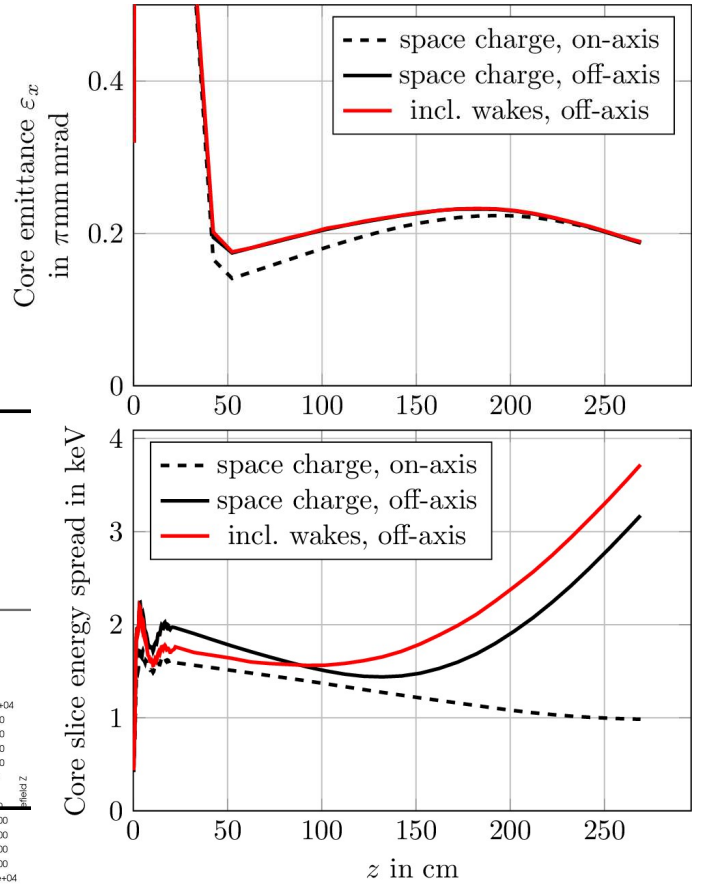


Impact on Core Slice



- Little effect on core slice values for on-axis emission
- Laser misalignment of 0.5mm causes transverse wakefields
- Radial dependency of $E_{s,z}$ affects energy distribution





Discussion & Outlook

- Validation of coupled simulation approach
- Multi-Cell TWT (SwissFEL):
  - Effect of wakes on energy chirp
  - Limited coupling to downstream section
- Outlook
  - Bunch with >1nC: PITZ and quasi-TW (~KEK)
  - CSR wakefields in the bunch compressor