Progress of Coupled Space Charge and Wakefield Simulations

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DESY-TEMF Collaboration Meeting
Dec 4 2023, Hamburg, Germany

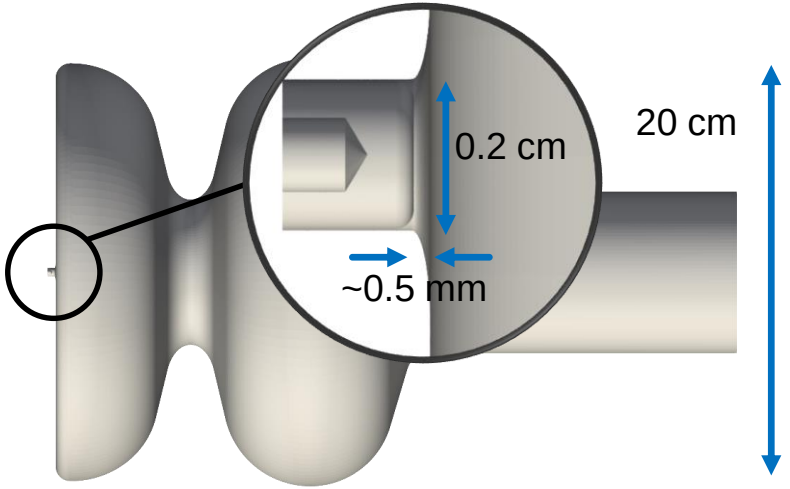
The work of J. Christ is supported by the DFG through the Graduiertenkolleg 2128 ”Accelerator Science and Technology for Energy Recovery Linacs” (AccelencE).

Outline

- Retracted Cathode
- Scattered Field Formulation
- Coupling to Beam Dynamics
- Results

Retracted Cathode

- **Idea of retracted cathode: built-in RF focusing for emittance compensation**
  - Strong coupling between wakefields and space-charge interaction
  - Kick-wise application of wakefields is inaccurate
  - Full-scale EM PIC not feasible



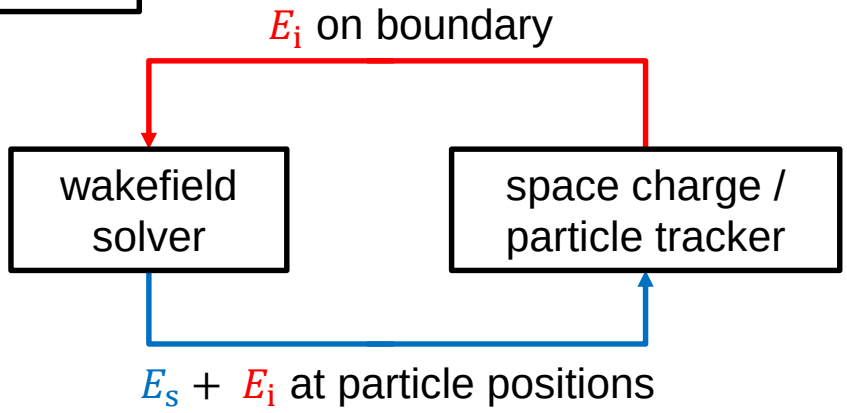
Credit: Bazyl, Vennekate

Idea

- **Strong coupling of space-charge and wakefield calculations**

  → Scattered field formulation: $E = E_\mathrm{i} + E_\mathrm{s}$

- Employ available specialized solvers
  - Space-charge: Green function in rest frame
  - Wakefields: FIT in moving window
- For arbitrary particle dynamics
- Avoids current interpolation step (in PIC)
- Allows better resolution of space-charge fields (than PIC)



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

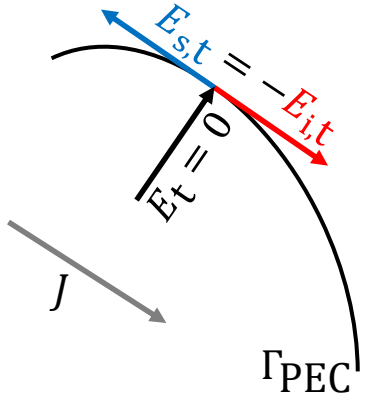
$$E = E_\mathrm{s} + E_\mathrm{i}$$

$$\frac{d}{dt} E_\mathrm{i} = \varepsilon^{-1} \operatorname{curl} H_\mathrm{i} - \varepsilon^{-1} J$$
$$\frac{d}{dt} H_\mathrm{i} = -\mu^{-1} \operatorname{curl} E_\mathrm{i}$$

arbitrary BC

$$\frac{d}{dt} E_\mathrm{s} = \varepsilon^{-1} \operatorname{curl} H_\mathrm{s}$$
$$\frac{d}{dt} H_\mathrm{s} = -\mu^{-1} \operatorname{curl} E_\mathrm{s}$$

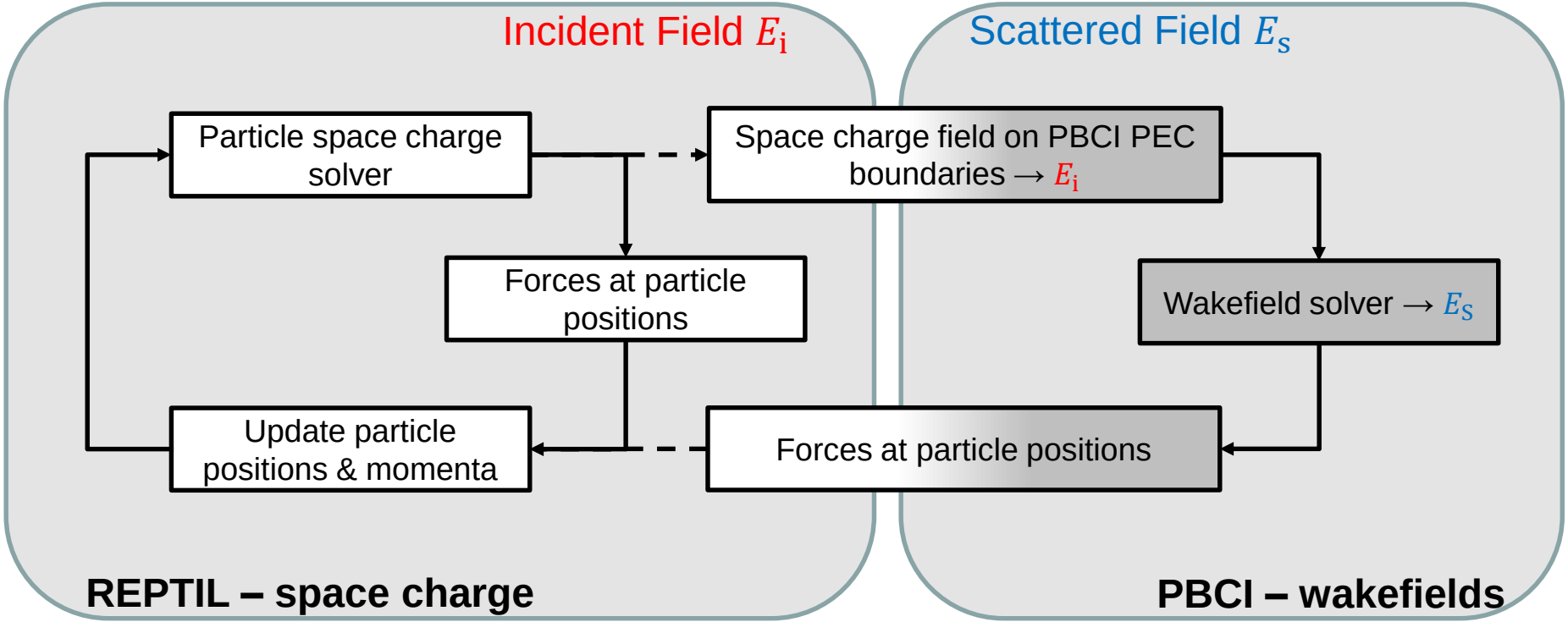
BC: $E_{\mathrm{s,t}} = -E_{\mathrm{i,t}}$ on Γ_PEC



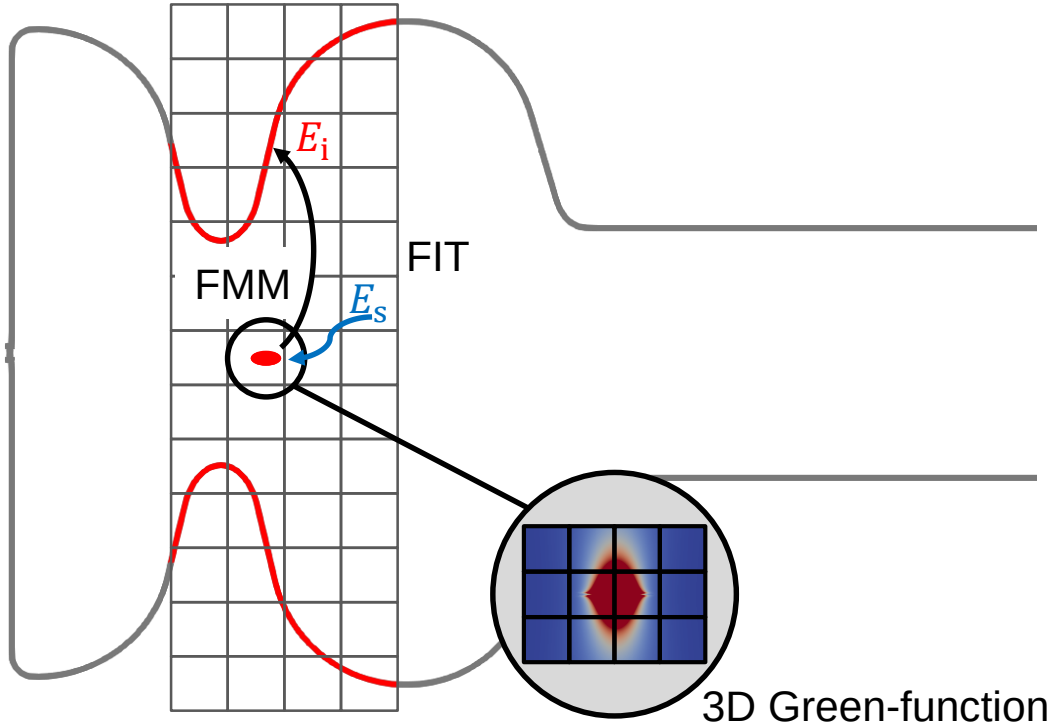
Initial conditions depend on choice of incident field:

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

Coupling: PBCI + REPTIL



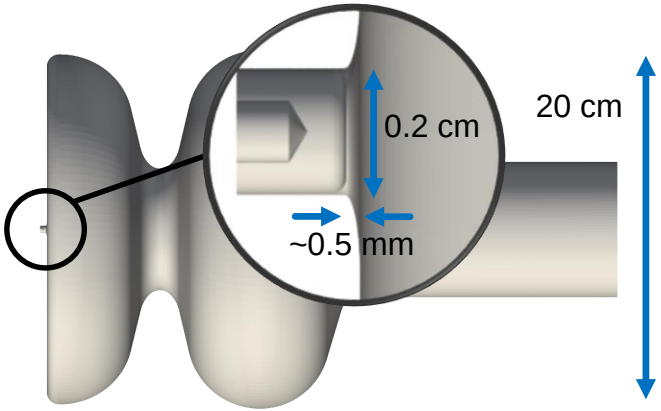
Coupling: PBCI + REPTIL II

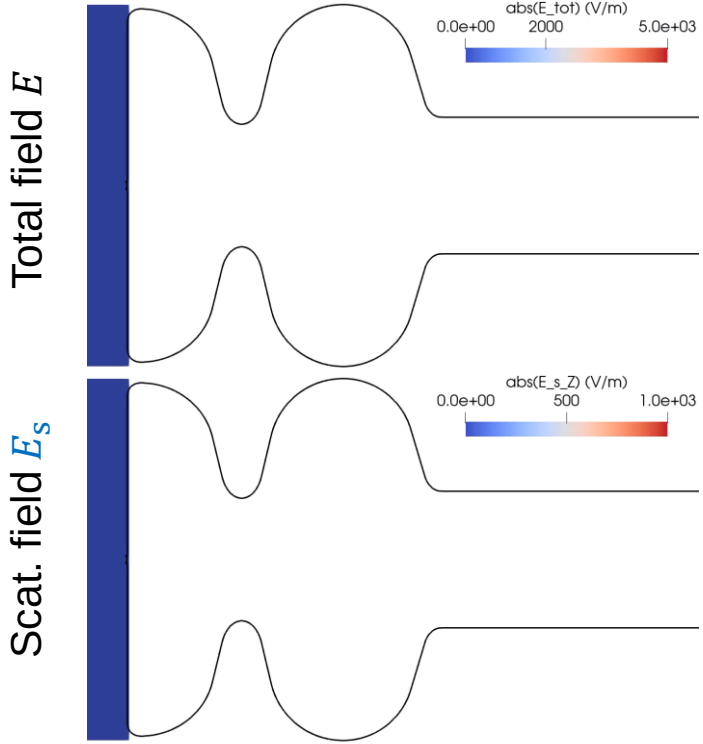


- Mesh-free, fast evaluation of space-charge field on boundary: FMM
- Solvers independent (grid, time step, optimization, …)
  - Arbitrary geometry
  - Arbitrary beam dynamics

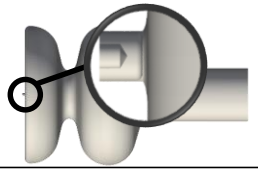
Gun with Retracted Cathode

- **Idea: built-in RF focusing to compensate space-charge forces**
  - Shaping of acceleration field by retraction of emission plug





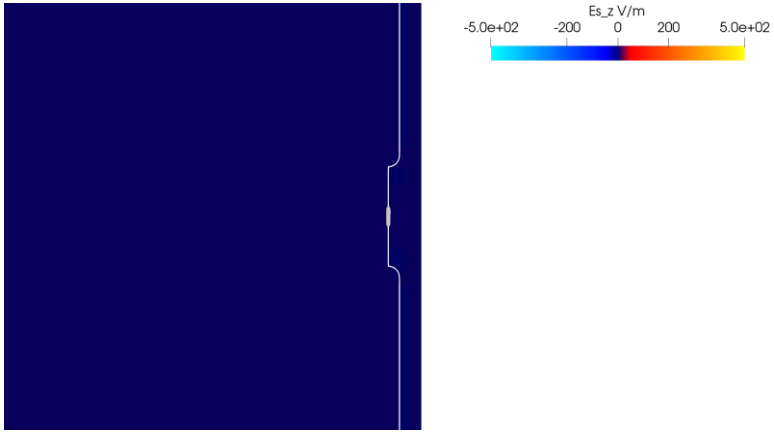
Results: Retracted Cathode



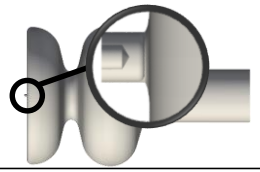
- **Cathode with retraction by 0.45 mm**
  - Here: No back-coupling on trajectory
  - Particle-wise momentum kick computation

$$d\vec{p}_i = q_i \int \vec{E}_s + \vec{v}_i \times \vec{B}_s \, \mathrm{d}t$$

  - Bunch analysis using $\vec{p}_i + d\vec{p}_i$
  - Simulation: gun cavity, solenoid, beam pipe (5m)
  - Comparison: emission in beam pipe



Results: Retracted Cathode II



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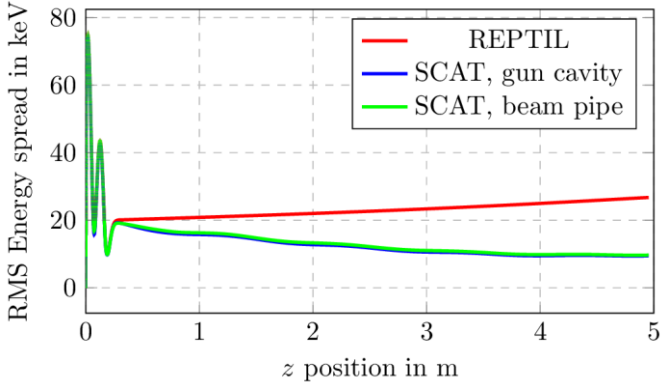
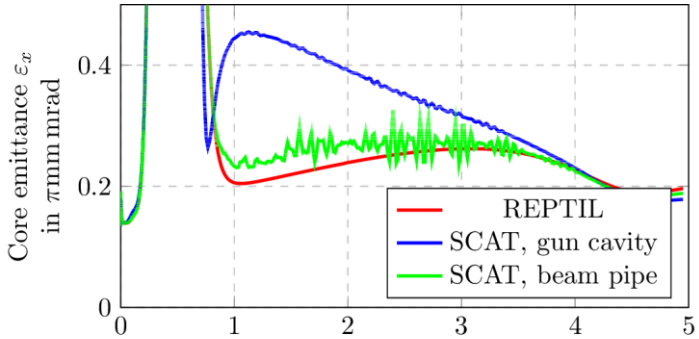
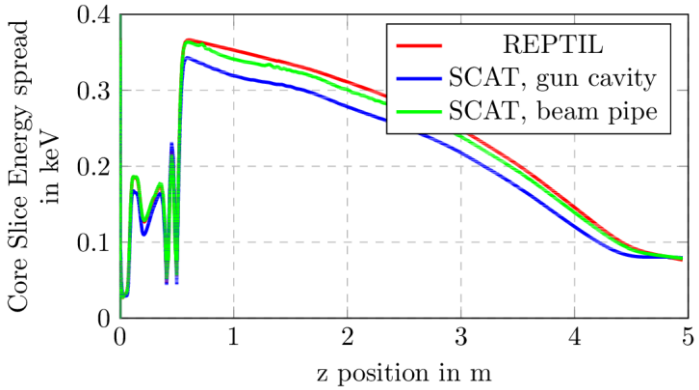
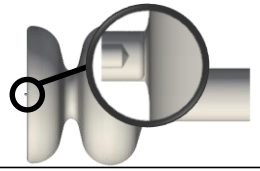
- Large reduction in RMS energy spread
- Slight (~10%) intermediate reduction in core SES
- Intermediate increase of transverse core emittance



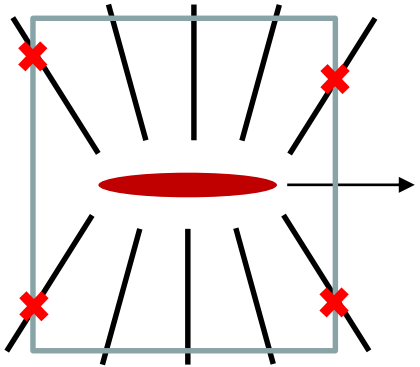




Ongoing Work

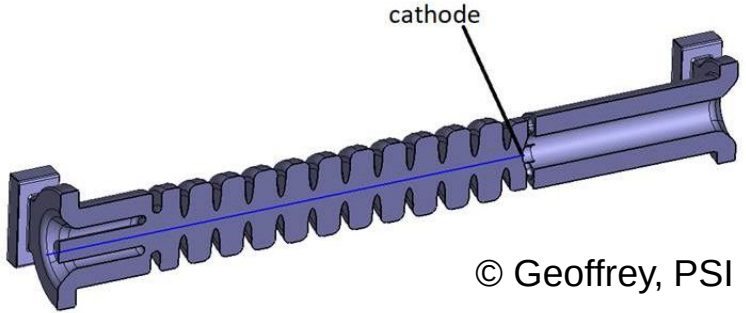


- Comparison with analytical estimation of beam pipe impedance and wakefields
- Quantify influence of wakefield causes: Retraction, iris, transition to pipe, coupler
- Develop open boundary conditions in moving window
  - Excitation in BC?



Discussion & Outlook

- Scattered field formulation for FIT
- Successful implementation in wakefield code PBCI, coupled with space charge solver REPTIL
- First results for retracted gun and beam pipe
- Outlook
  - Open boundaries in moving window
  - Surface impedance BC
  - CSR wakefields in the bunch compressor
  - Multi-cell TWT (Swiss FEL)



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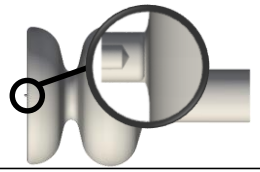
Appendix / Backup

Results: Retracted Cathode III



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- Slight reduction in RMS transverse emittance
- Slight reduction in slice transverse emittance