Simulation Studies for the PITZ THz SASE FEL

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DESY-TEMF Meeting

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Structure

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III. Modeling of Radiation Recoil

IV. Summary and Outlook

Introduction
THz SASE FEL at DESY PITZ

Motivation:

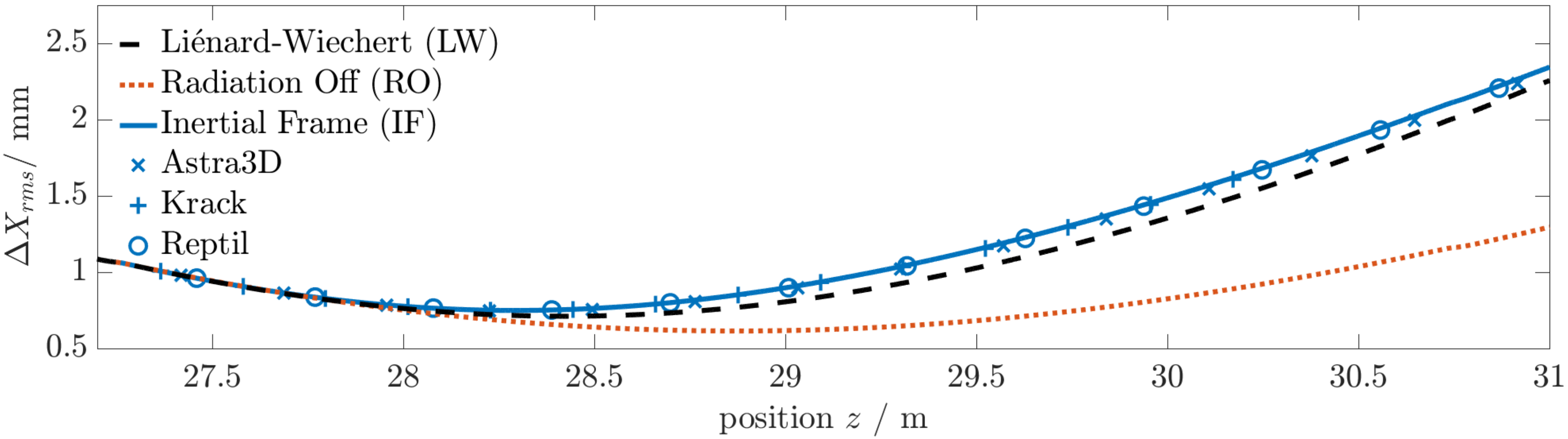
Development of a high power, tunable THz source for European XFEL

⇒ THz radiation at $\lambda \sim 100\ \mu\text{m}$, $\sim 6\ \text{ps}$ pulse length, and $\sim 38\ \text{MW}$ peak power

M. Krasilnikov et al., „Start-to-End Simulations of THz SASE FEL Proof-of-Principle Experiment at PITZ", ICAP'18, Key West

THz-FEL Parameters:

Electron beam with $Q_b \sim 4\ nC$ bunch charge and $E_b \sim 16.7\ MeV$ beam energy



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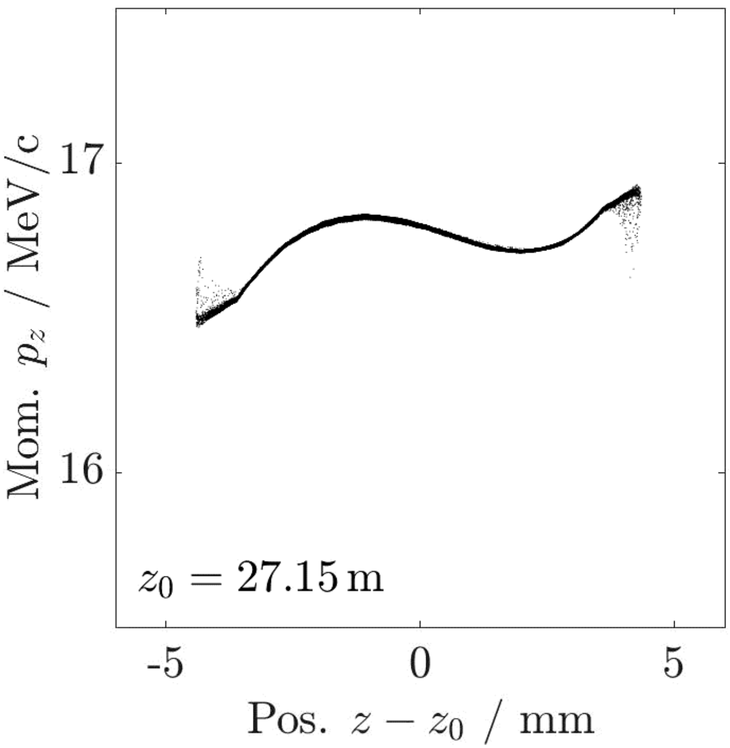
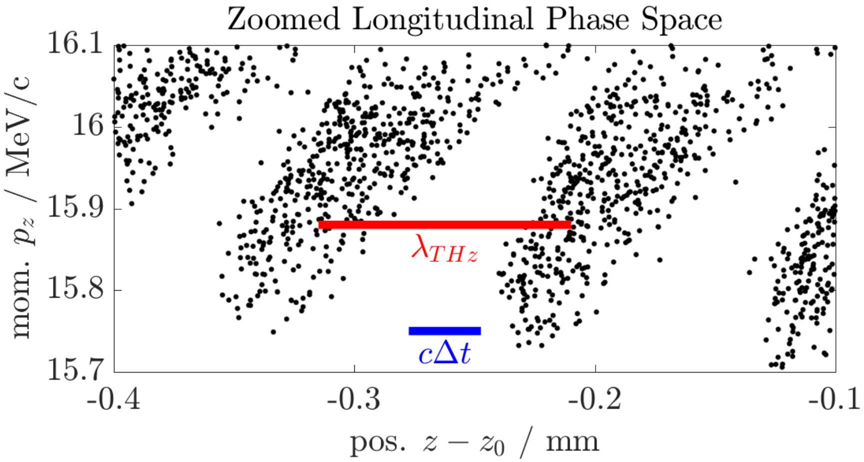
Longitudinal Phase Space:



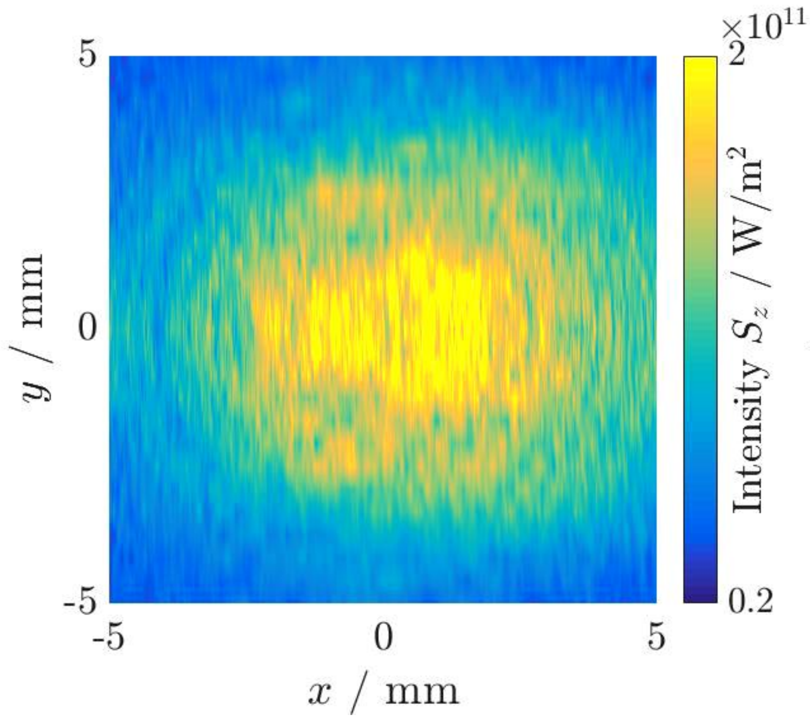


THz-Wavelength $\lambda_{THz} = \frac{\lambda_U}{2\,\gamma^2}\left(1 + \frac{K^2}{2}\right) \approx 105\ \mu\text{m}$

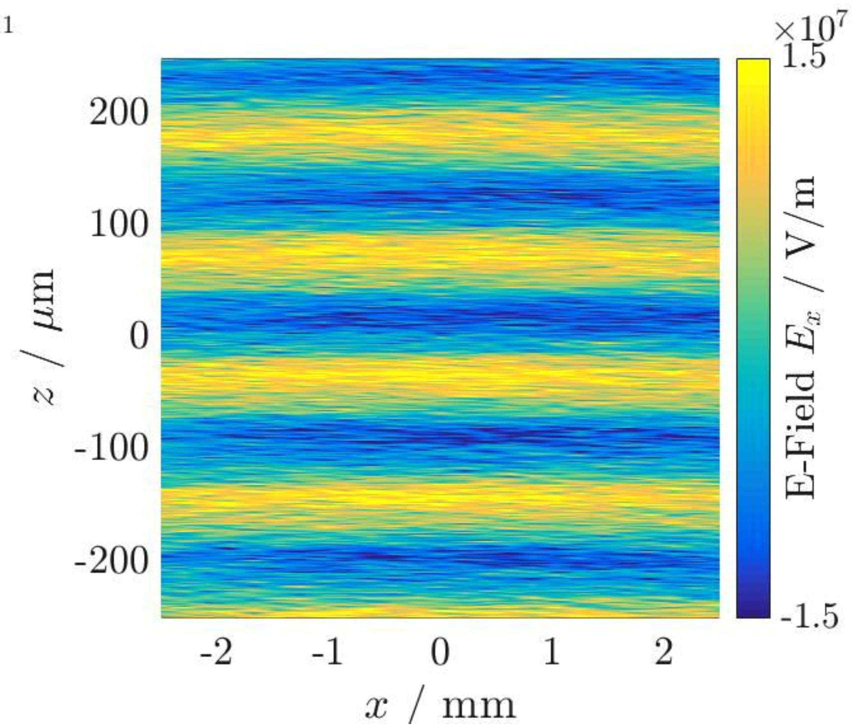
$\Rightarrow$ Micro-bunching consistent with λ_{THz}

THz Radiation Studies
EM-Field Monitor at Undulator Exit

Vertical Plane Monitor



Horizontal Plane Monitor



⇒ spatial analysis

⇒ spectral analysis

THz Radiation Studies
Spectrum at Undulator Exit

Fourier Analysis of Radiation Field:

8 different random realizations of particle phase space at undulator entrance

⇒ Shot noise characteristic of initial distribution slightly influences THz spectrum

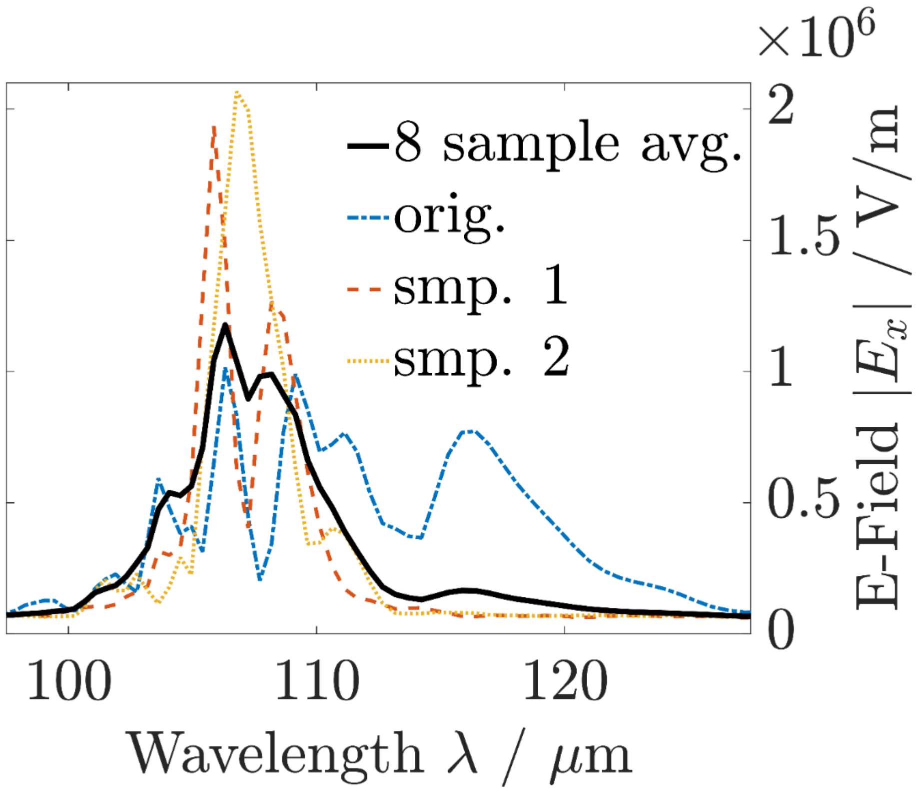
Averaged spectrum is centered at

$$\lambda_{THZ} \approx 108.5\ \mu\text{m}$$

and has a spectral width of

$$\sigma_{FWHM} \approx 4.8\ \mu\text{m}.$$

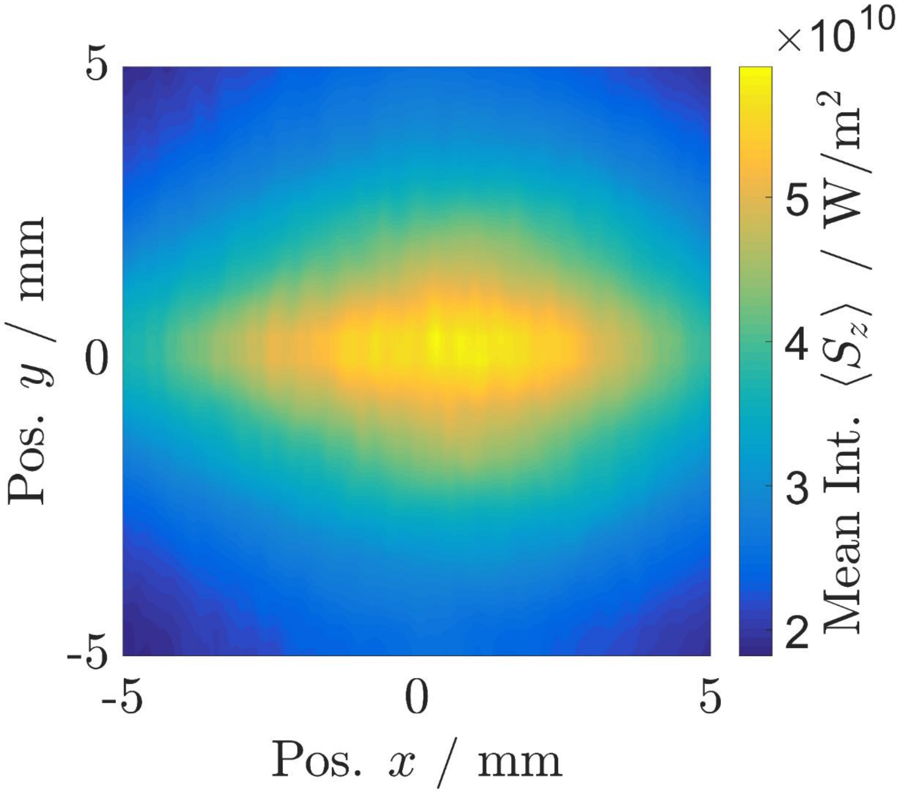
⇒ Good agreement with GENESIS 1.3



THz Radiation Studies

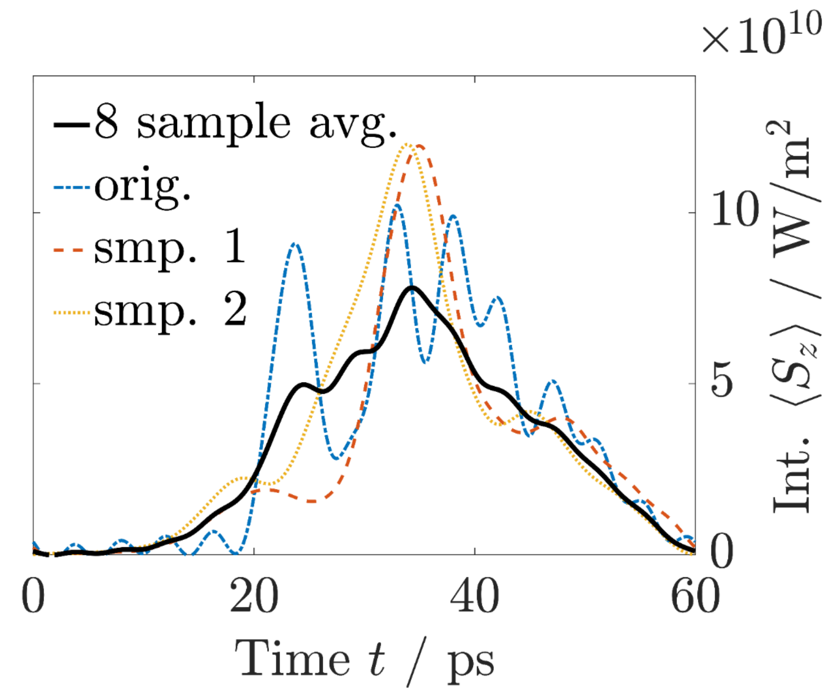
Intensity / Pulse Profile at Undulator Exit

Time-Averaged THz Intensity:



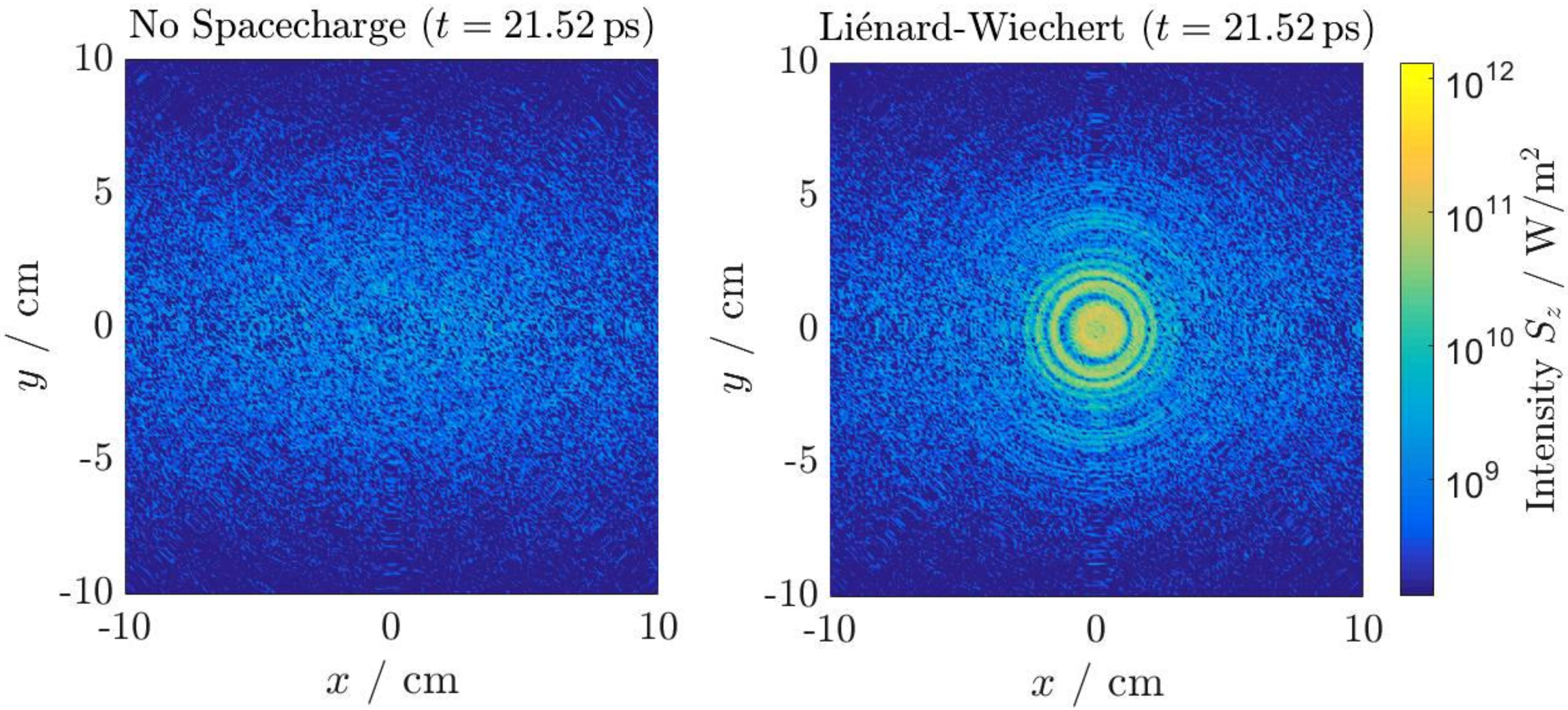
⇒ Vertical asymmetry of bunch shape

Temporal THz Pulse Profile:



⇒ Particle noise influences pulse shape

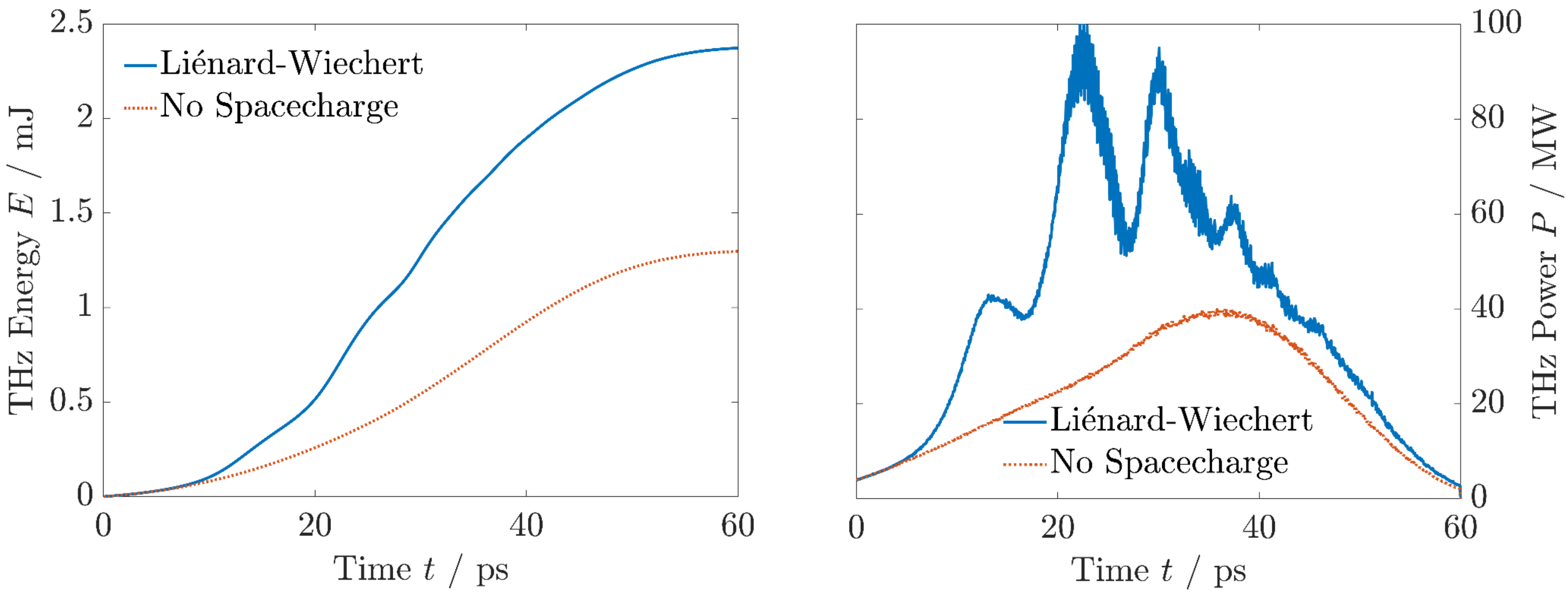
THz Radiation Studies
Intensity Monitor at Undulator Exit



⇒ Radiation field evaluated at fixed positon with $z_0 = 30.8$ m

THz Radiation Studies

Intensity Monitor at Undulator Exit

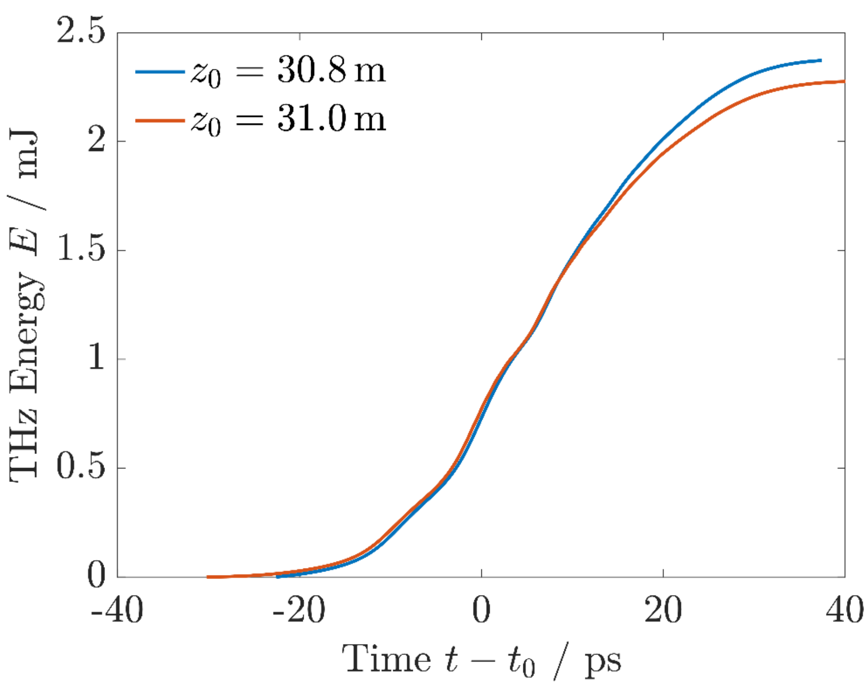


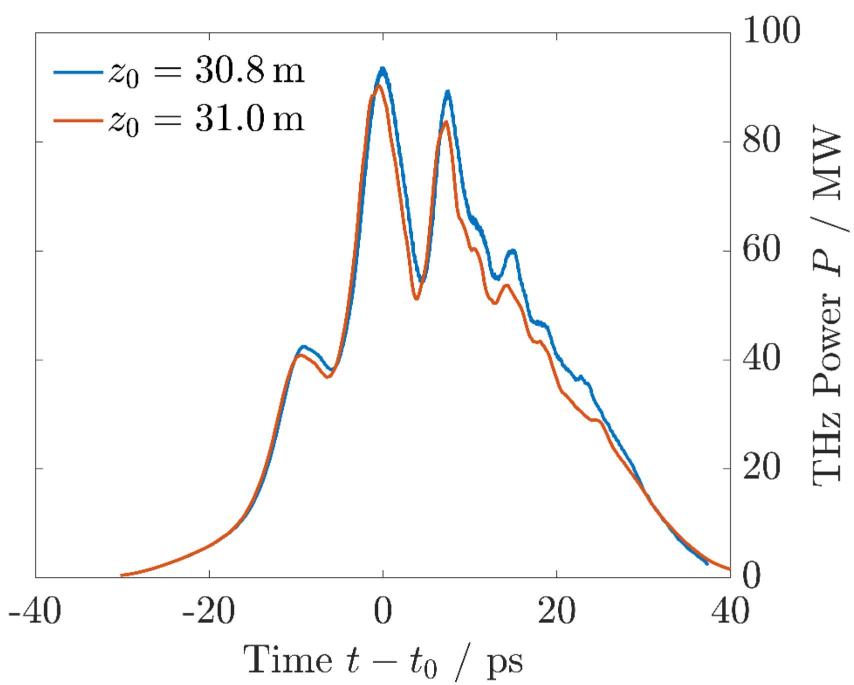
⇒ Liénard-Wiechert interaction generates interference patterns on radiation monitor

⇒ Radiated energy / power increases compared to reference simulation

⇒ Intensity monitor shows near- and far-field properties of THz bunch

THz Radiation Studies
Intensity Monitor at Undulator Exit



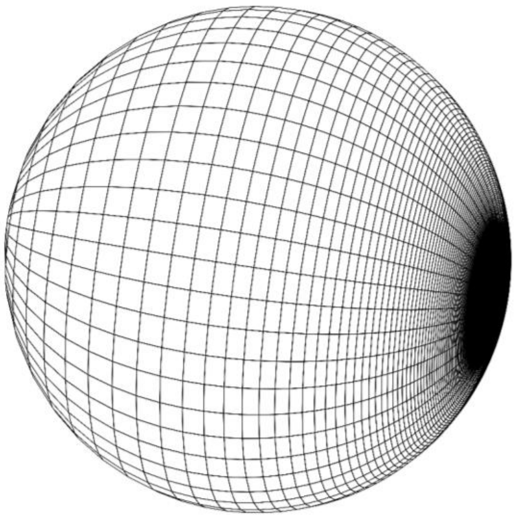


⇒ Total power flux through monitor area decreases for larger distance (z_0)

⇒ Influence of near-field properties at THz pulse tail less pronounced

THz Radiation Studies
Angular Profile Inside Undulator

Adaptive Mesh:



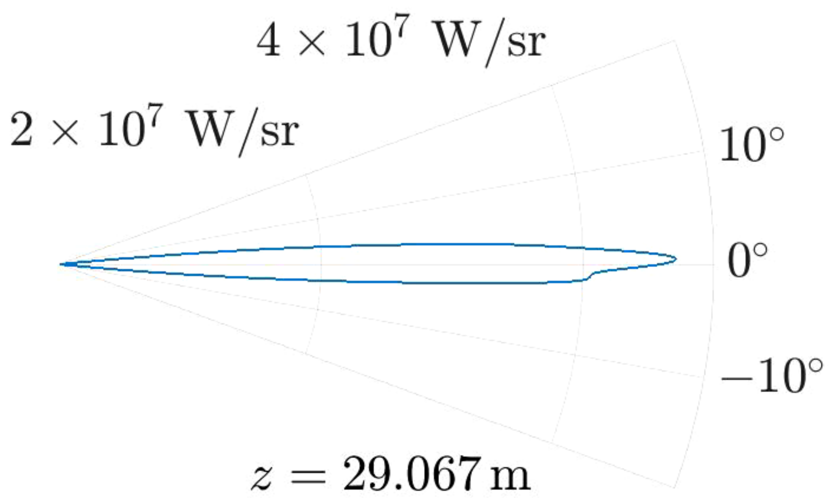
$$\boldsymbol{n} \parallel \begin{pmatrix} cos(\phi)\sin(\theta) \\ sin(\phi)\sin(\theta) \\ \gamma\, cos(\theta) + \gamma\,\beta \end{pmatrix},$$

$$\phi \in [0,2\pi), \theta \in [0,\pi],\ \mathbf{n}(0,0) \parallel <\boldsymbol{\beta}>$$

Larmor Formula:

$$\frac{dP_{rad}}{d\Omega} = \frac{q^2}{16\pi^2\,\epsilon_0\,c_0}\frac{\left|\boldsymbol{n} \times \left[(\boldsymbol{n}-\boldsymbol{\beta}) \times \dot{\boldsymbol{\beta}}\right]\right|}{(1-\boldsymbol{\beta}\cdot\boldsymbol{n})^5}$$

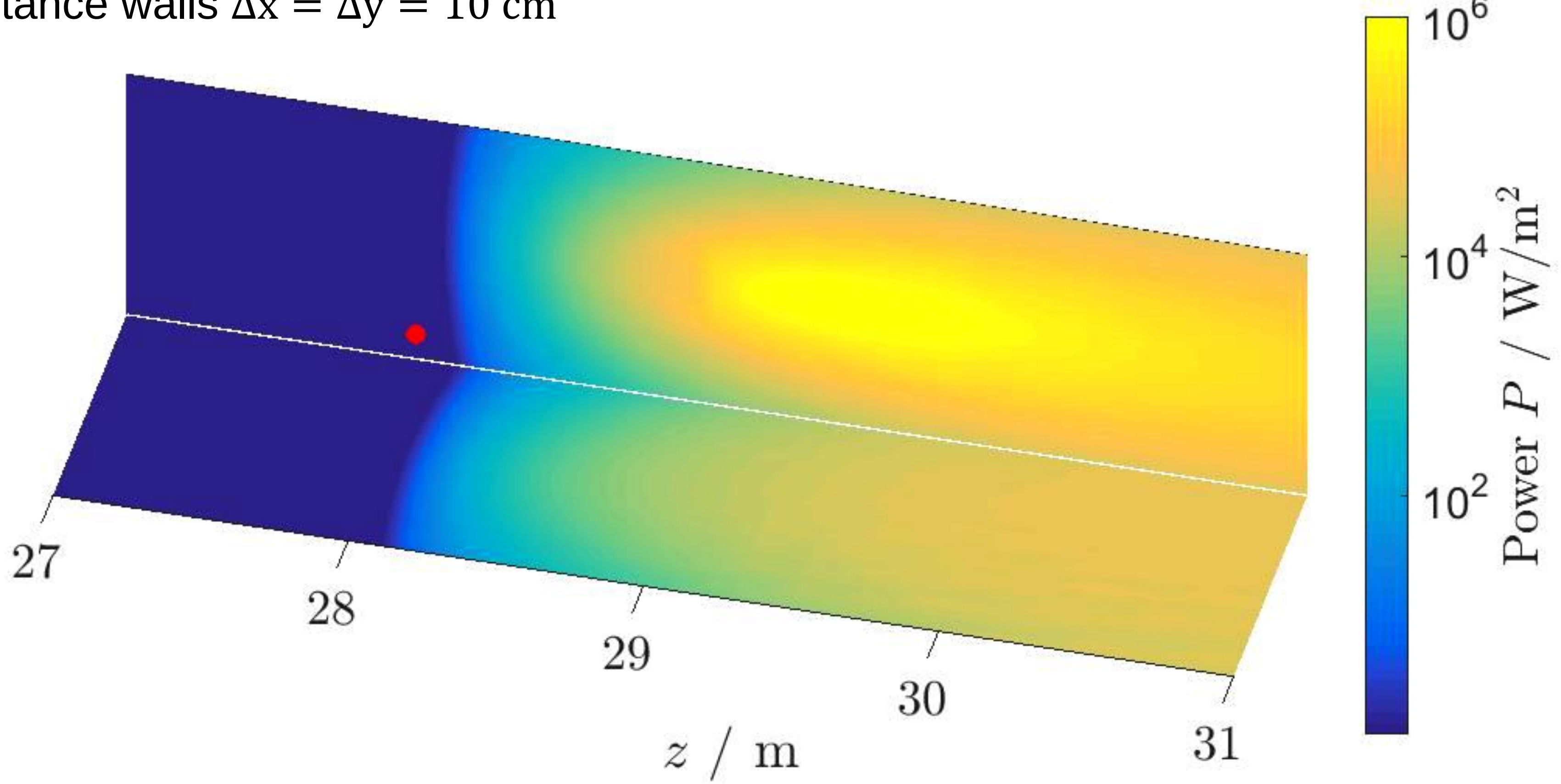
Horizontal Radiation Profile:



THz Radiation Studies
Losses Inside Undulator

Power Loss on Beampipe:

Distance walls $\Delta x = \Delta y = 10\ \text{cm}$

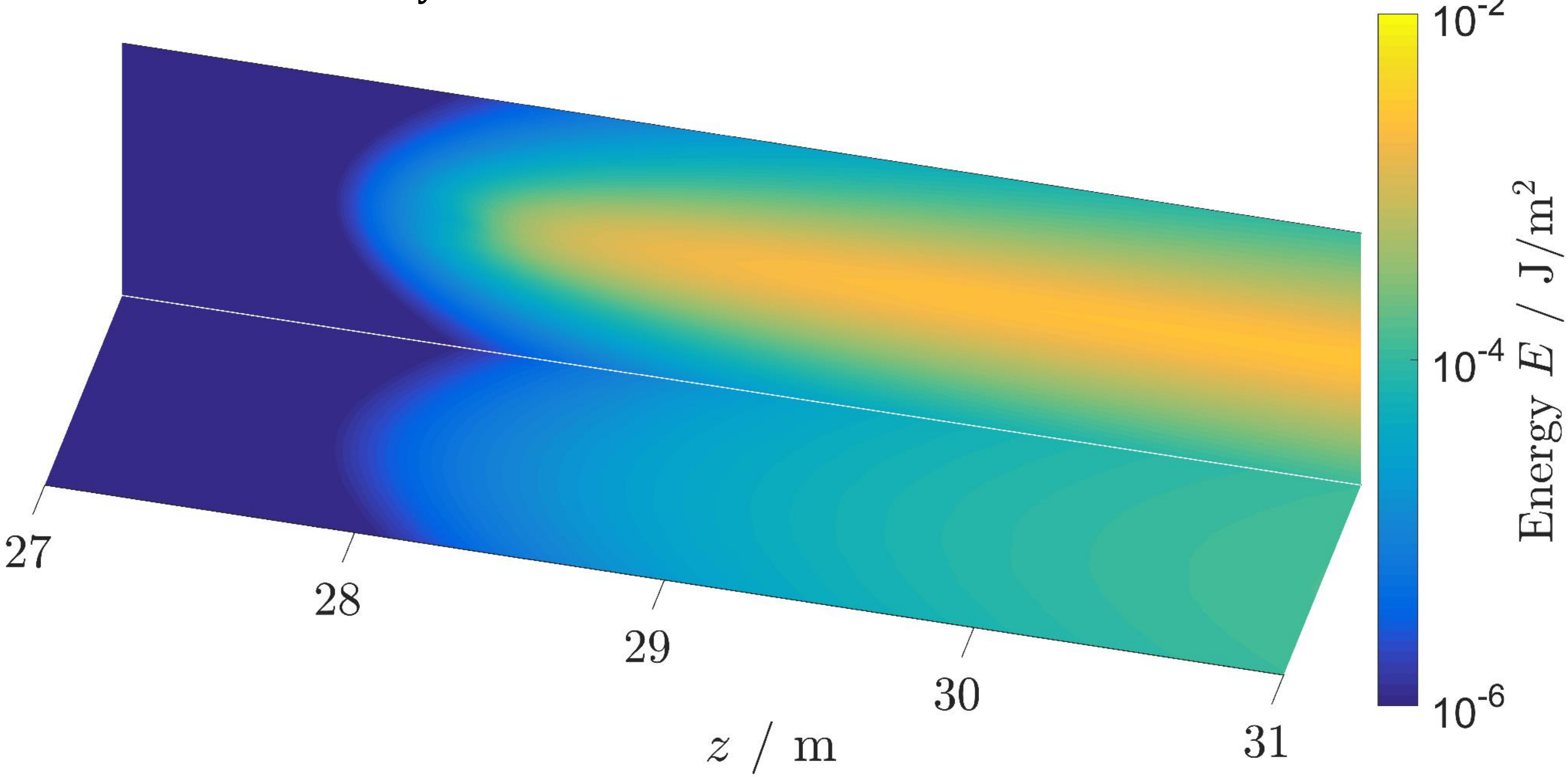


THz Radiation Studies

Wall Losses Inside Undulator

Integrated Energy Loss on Beampipe:

Distance walls $\Delta x = \Delta y = 10$ cm



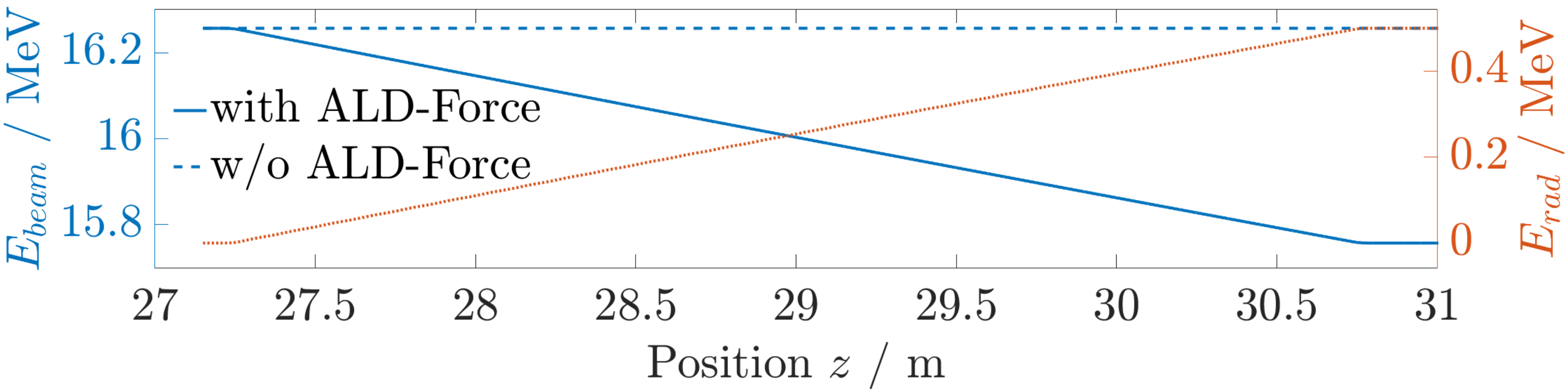
Modeling of Radiation Recoil

Abraham-Lorentz-Dirac Force

Radiation Recoil Force:

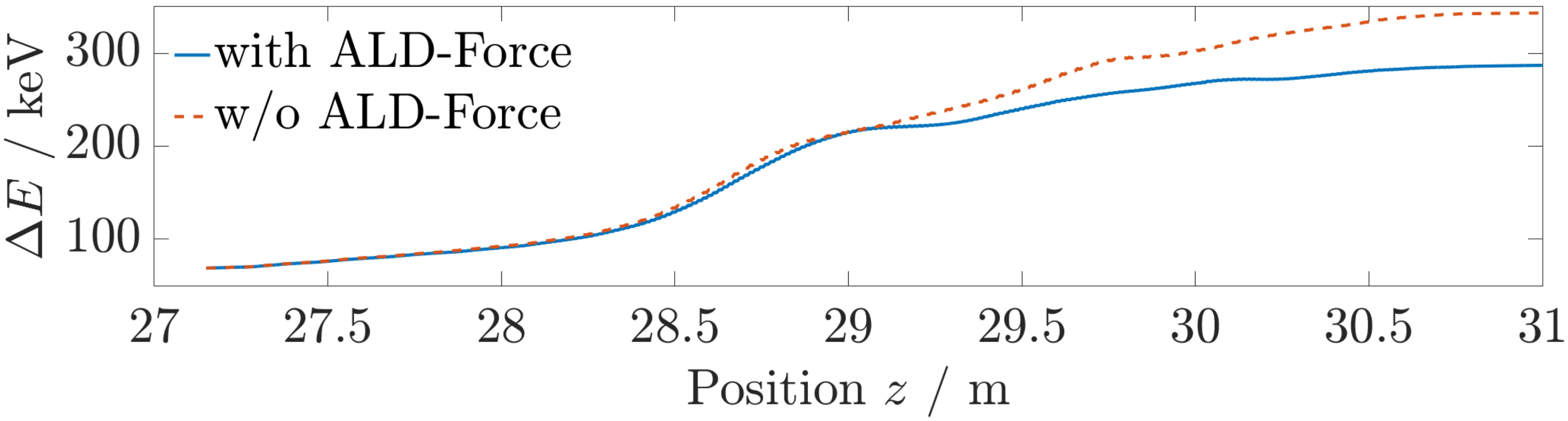
$$\boldsymbol{F_{rec}} = \frac{q^2\gamma^2}{6\pi\,\epsilon_0\,c^2}\left\{\ddot{\boldsymbol{\beta}} + \gamma^2\left(\beta\cdot\ddot{\beta}\right)\boldsymbol{\beta} + 3\,\gamma^2\left(\beta\cdot\dot{\beta}\right)\left[\dot{\boldsymbol{\beta}} + \gamma^2\,\boldsymbol{\beta}\right]\right\}$$

⇒ Idea: Radiation energy losses reduce kinetic energy of particle



⇒ Beam energy reduced by radiated THz energy

Modeling of Radiation Recoil
Abraham-Lorentz-Dirac Force

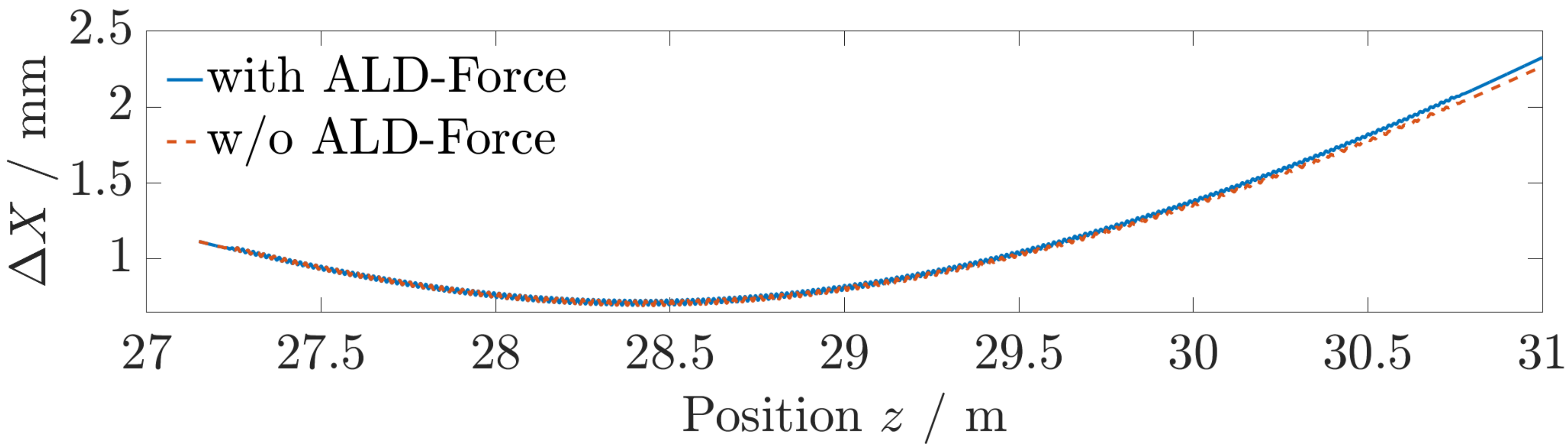


Effect on Beam Dynamics:

Reduction of energy spread ΔE

⇒ Faster particles loose more energy than slower particles

Modeling of Radiation Recoil
Abraham-Lorentz-Dirac Force



Effect on Beam Dynamics:

Reduction of energy spread ΔE

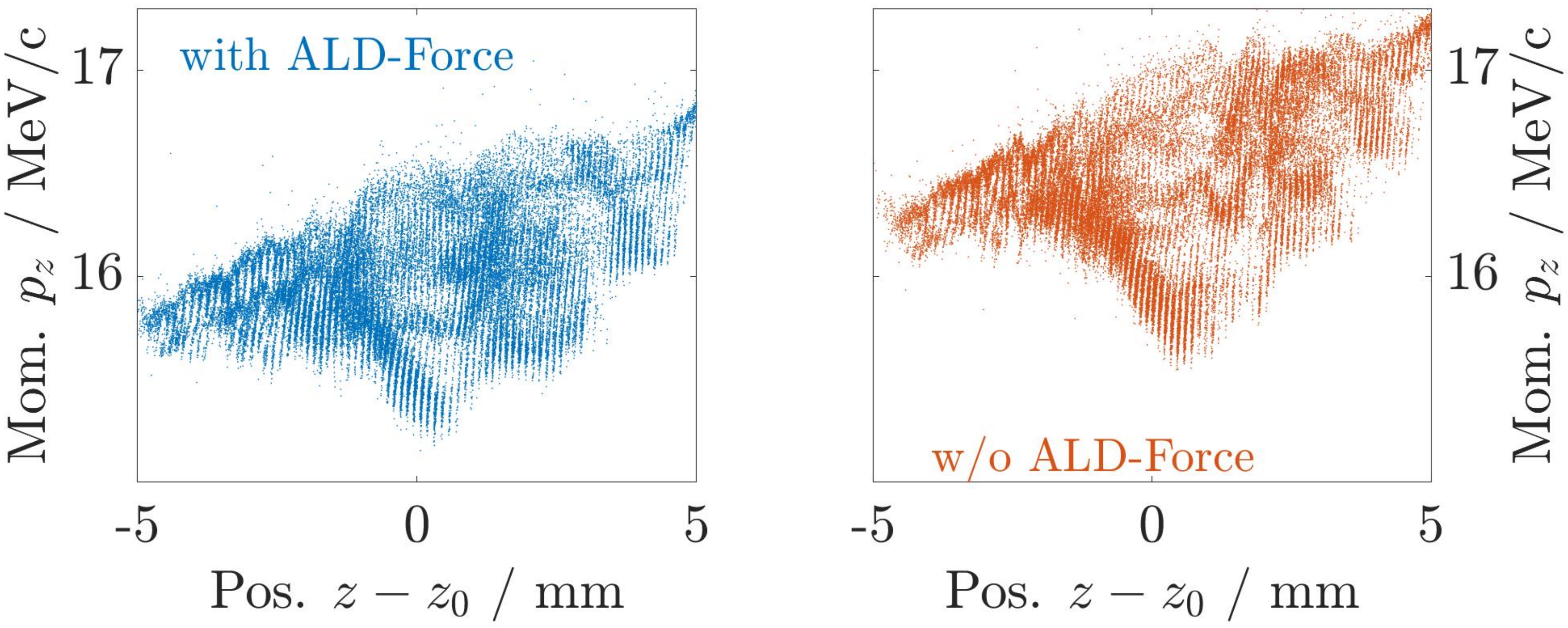
⇒ Faster particles loose more energy than slower particles

Slightly increased transverse divergence ΔX

⇒ Increased space charge interaction due to reduced beam energy

Modeling of Radiation Recoil
Abraham-Lorentz-Dirac Force

Particle Phase Space at Undulator Exit:



Summary & Outlook

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Summary:

⇒ Beam dynamics and THz radiation simulation study based on LW-model
⇒ Angular THz pulse profile and radiation power losses inside the Undulator
⇒ Investigation of radiation recoil effect on beam dynamics

Outlook:

⇒ Investigation of intensity distribution on far-field monitor
⇒ Thermal modeling of radiation induced beampipe heating
⇒ Investigate influence of radiation recoil effect on THz radiation generation