# THz Radiation Emission from Undulators and Free-Electron Lasers - TEUFEL

U. Lehnert

ELBE Radiation Source, Institute of Radiation Physics,
Helmholtz-Center Dresden-Rossendorf (HZDR), Dresden, Germany

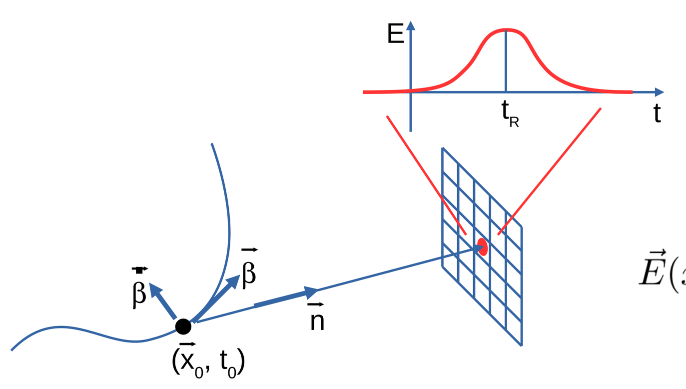
HZDR
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

## Abstract

Terahertz (THz) radiation sources are increasingly significant for many scientific frontiers. Accelerator-based light sources find increasing use at many existing and proposed facilities to deliver coherent THz radiation with high pulse energy and tunable frequency. Here we describe a simulation tool which can be used for a detailed study of the radiation production process and the properties of the emitted radiation. Several phenomena can be studied including coherent synchrotron and undulator radiation, coherent diffraction and transition radiation but also the FEL interaction in modulators and radiators. The computed radiation fields in turn can be used as lattice fields to track particles in. The computer code TEUFEL provides particle tracking under the influence of external fields and the computation of the radiation emitted by those articles. The radiation is recorded as spatially resolved time-domain waveforms with post-processing tools provided to analyze its spatial distribution and spectral content. All components of the electric and magnetic fields are computed including longitudinal components present in the near field.

## Theoretical Approach

- Import or generate initial particle distribution
- Track particles under the influence of external electromagnetic fields (magnets, RF accelerators, incident waves, …)
- Compute time-domain electromagnetic fields at several observation loactions (point, screen, meshed surface, …)
- Post-process for radiation power and spectra




$$t_R = t_O + \frac{R}{c}$$

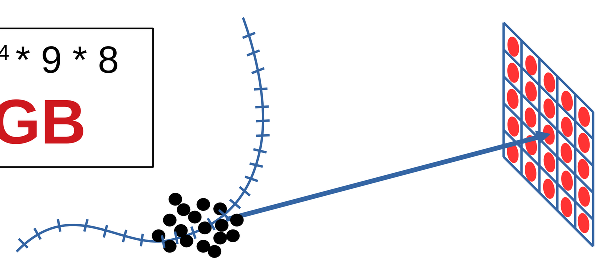
Liénard-Wiechert formula

$$\vec E(\vec x, t) = \frac{Q}{4\pi\epsilon_0}\left[\frac{\vec n - \vec\beta}{\gamma^2(1-\vec\beta\vec n)^3 R^2}\right]_{\rm ret} + \frac{Q}{4\pi\epsilon_0 c}\left[\frac{\vec n \times \left((\vec n - \vec\beta)\times\dot{\vec\beta}\right)}{\gamma^2(1-\vec\beta\vec n)^3 R}\right]_{\rm ret}$$

$$\vec B(\vec x, t) = \frac{1}{c}\left[\vec n \times \vec E(\vec x, t)\right]_{\rm ret}$$

## Computational Burden

$10^4 * 10^4 * 9 * 8$
**~7 GB**



128 * 128 * 5000 * 6 * 8
**~4 GB**

*$10^4$ particles (more are needed if one wants to compute interactions)*

*$10^4$ time steps ($\gamma$* screen time-step)*

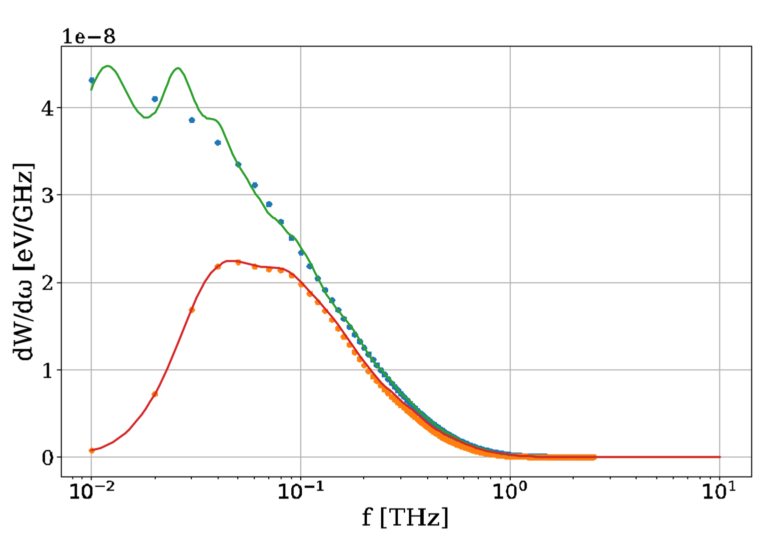
*$10^4$ pixels (can easily become $10^6$ if the screen is not perpendicular to the wave)*

*$10^4$ time steps (20 steps per cycle, radiation arrives late at the corners)*

**$10^{12}$** searches for retardation condition computations of the Liénard-Wiechert formula

## Diffraction Radiation

20 mm diameter diffraction screen with 2 mm hole
backward diffraction radiation from 100 pC charge at $\gamma$=20

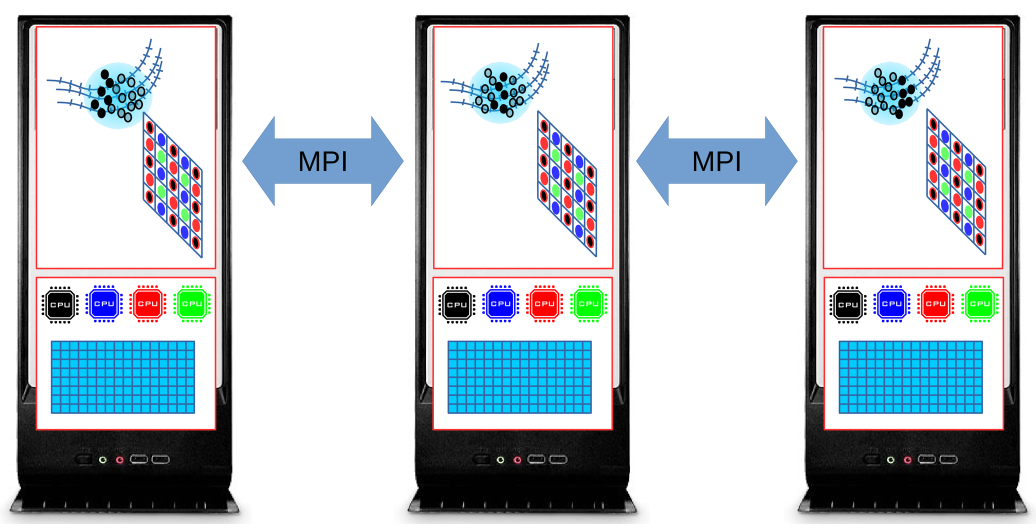



***Radiation Spectrum:***
*The solid lines are from Fig. 12 of [1] and Eq. 31 integrated over the solid angle. The dots are the spectral intensities computed by TEUFEL on the diffraction screen (blue) and on an observation screen in 3m distance (red). The finite size of that screen yields a low-frequency cut-off near 0.03 THz.*

*[1] S. Casalbuoni. et. al., TESLA report 2005-15*

## Parallel Computation

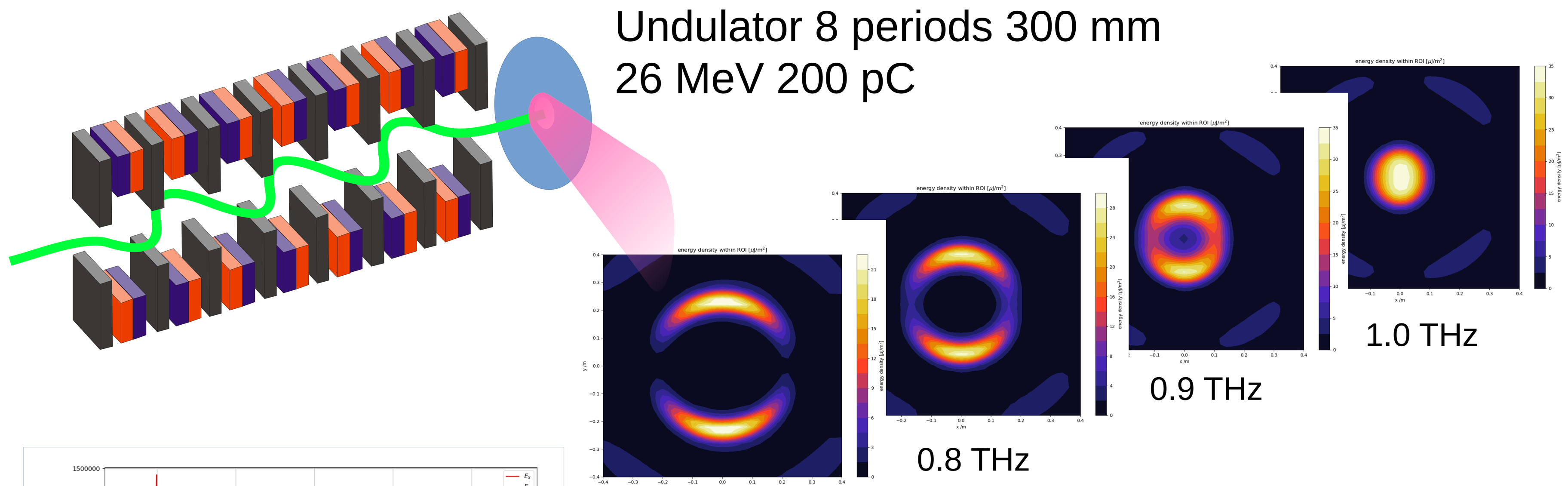
The code was developed to run on a cluster of CPU nodes communicating with MPI (message passing interface) and using shared memory parallelism (OpenMP) on the node.
See **https://github.com/lehnertu/TEUFEL**

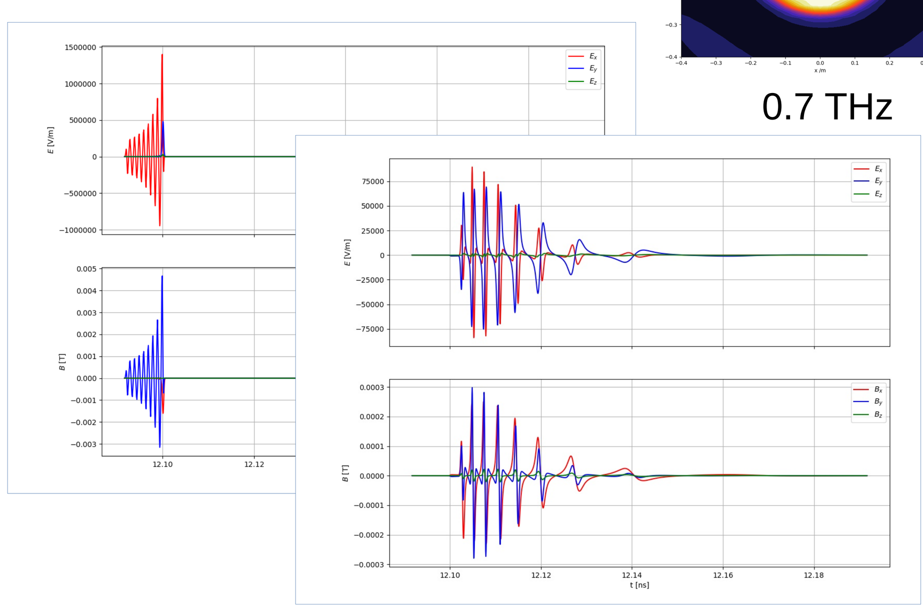



1) The head node initializes the particles.
2) Particles are distributed over the nodes.
3) Every node tracks a subset of the particles. After every tracking step the particle coordinates are synchronized between the nodes, so all nodes „know“ all particles (for potential p-p interaction). For tracking a single core per node is sufficient.
4) After tracking all particle trajectories are gathered onto the head node for storage.
5) All nodes compute the observed fields for a subset of the particles one by one (a single trajectory fits into the CPU cache memory). All cores share the load by computing different observation points. The complete radiation field is held in memory only once per node.
6) After one observer is finished, the fields are summed up onto the head node for storage.
7) For post-processing a number of Python scripts and Jupyter notebooks are provided.

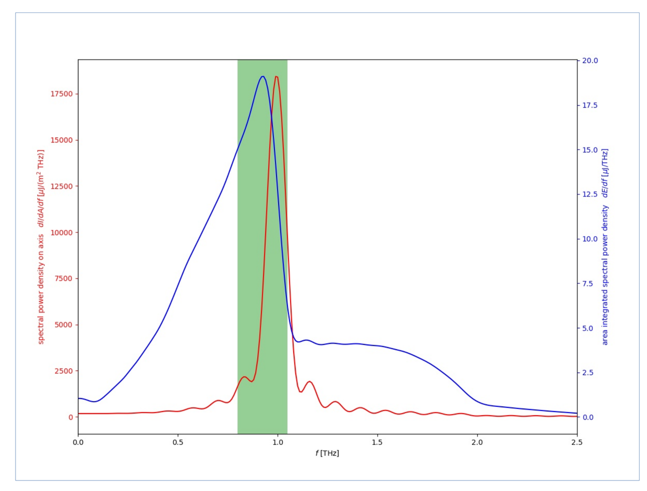
## Undulator Radiation

Undulator 8 periods 300 mm
26 MeV 200 pC



*Time-domain waveforms near center and near the edge of the mirror*



*Radiation spectrum on axis and integrated over the full screen area*