RFTweak 5
An Efficient Longitudinal Beam Dynamics Code

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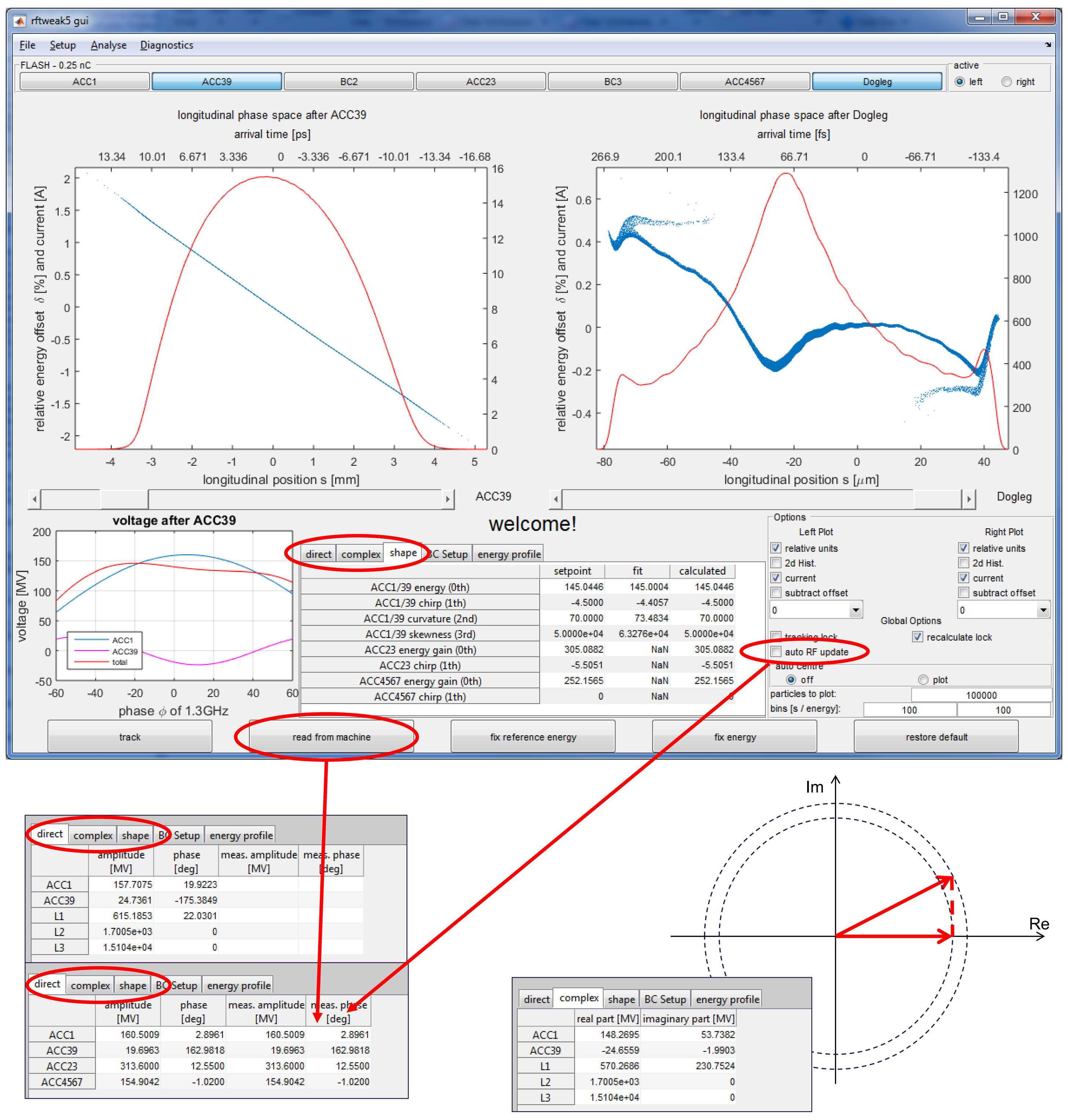
European XFEL

Abstract

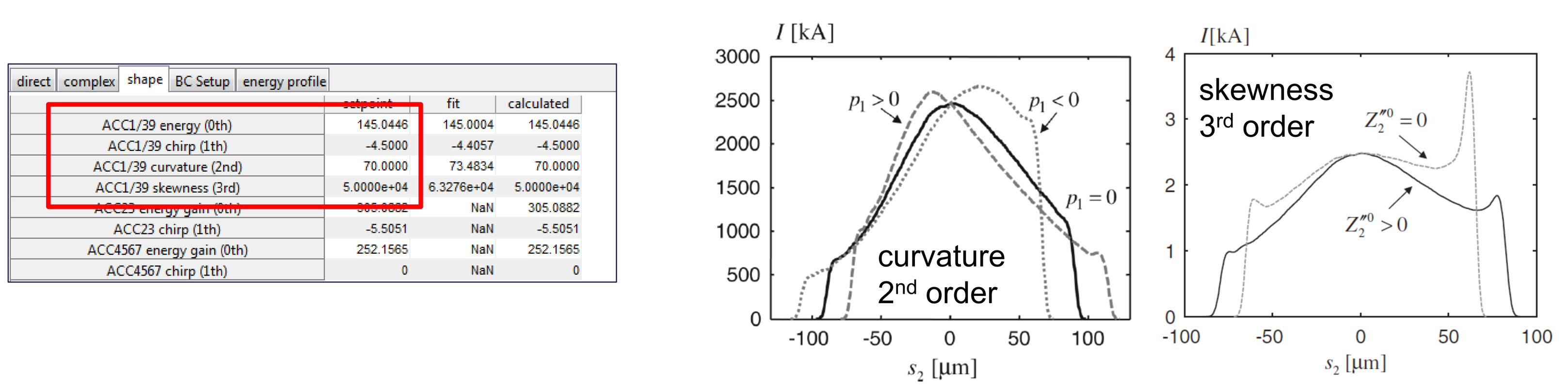
The shaping of the longitudinal phase space in bunch compression systems is essential for efficient FEL operation. RF systems and self-field interactions contribute to the overall phase space structure. The design of the various facilities relies on extensive beam dynamics simulations to define the longitudinal dynamics. However, in everyday control room applications such techniques are often not fast enough for efficient operation, e.g. for SASE tuning. Therefore efficient longitudinal beam dynamics codes are required while still maintaining reasonable accuracy. Our approach is to pre-calculate most of the required data for self-field interactions and store them on disc to reduce required online calculation time to a minimum. In this paper we present the fast longitudinal tracking code RFTweak 5, which includes wakes, space charge, and CSR interactions. Lattice and impedance models for FLASH and European XFEL are implemented but the code can be applied to other machines as well.

Graphical User Interface



Different RF Setup Methods

1. Direct input or machine readout of phase and amplitude settings
2. Complex definition of RF parameters – The energy is given by the real part while the chirp is controlled by the imaginary part.
3. Abstract beam physics based knobs like chirp and energy as well as higher orders to control the shape.



Problem:

$$\begin{pmatrix} 1 & 0 & 1 & 0 \\ 0 & -k & 0 & -nk \\ -k^2 & 0 & -(nk)^2 & 0 \\ 0 & k^3 & 0 & (nk)^3 \end{pmatrix}\begin{pmatrix} \blacksquare \\ \blacksquare \\ \blacksquare \\ \blacksquare \end{pmatrix} = \frac{1}{e}\begin{pmatrix} \boxed{E_1} - E_0 \\ \boxed{E_1\alpha_1} - E_0\delta_0' \\ \boxed{E_1\alpha_2} - E_0\delta_0'' \\ \boxed{E_1\alpha_3} - E_0\delta_0''' \end{pmatrix}$$

ACC1 ACC39

$$V_i = |X_i + iY_i|, \qquad \varphi_i = \arg(X_i + iY),$$
$$X_i = V_i \cos\varphi_i, \qquad Y_i = V_i \sin\varphi_i.$$

Solution:

$$\blacksquare = \frac{F_3 + F_1(kn)^2}{k^2(n^2-1)}, \qquad \blacksquare = -\frac{F_4 + F_2(kn)^2}{k^3(n^2-1)}$$
$$\blacksquare = -\frac{F_3 + F_1k^2}{k^2(n^2-1)}, \qquad \blacksquare = \frac{F_4 + F_2k^2}{k^3 n(n^2-1)},$$
$$F_1 = \boxed{\bar{E}_1} - \bar{E}_0, \qquad F_i = \boxed{\bar{E}_1\alpha_{i-1}} - \bar{E}_0\frac{\partial^{i-1}\delta_0}{\partial s^{i-1}}$$
$$i = 2, 3, 4.$$

Igor Zagorodnov and Martin Dohlus
Semianalytical modeling of multistage bunch compression with collective effects
Phys. Rev. ST Accel. Beams 14, 014403 (2011)

Tracking Overview

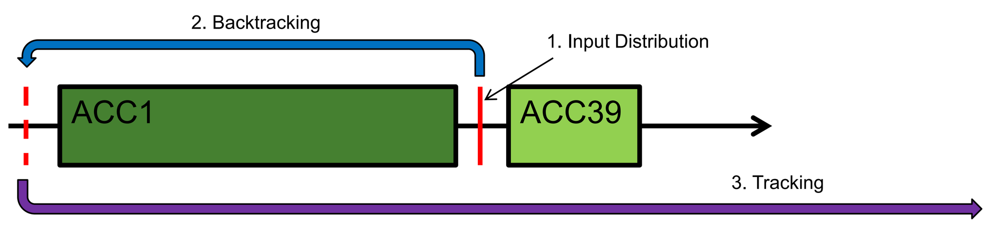
- Two types of alternating tracking steps:
  - Longitudinal offset is constant but energy is not

$$\delta_{E_{i,n+1}} = \delta_{E_{i,n}} + A + Bs_n^i + C{s_n^i}^2 + \ldots$$

  - Energy is fixed but the longitudinal offset is modified

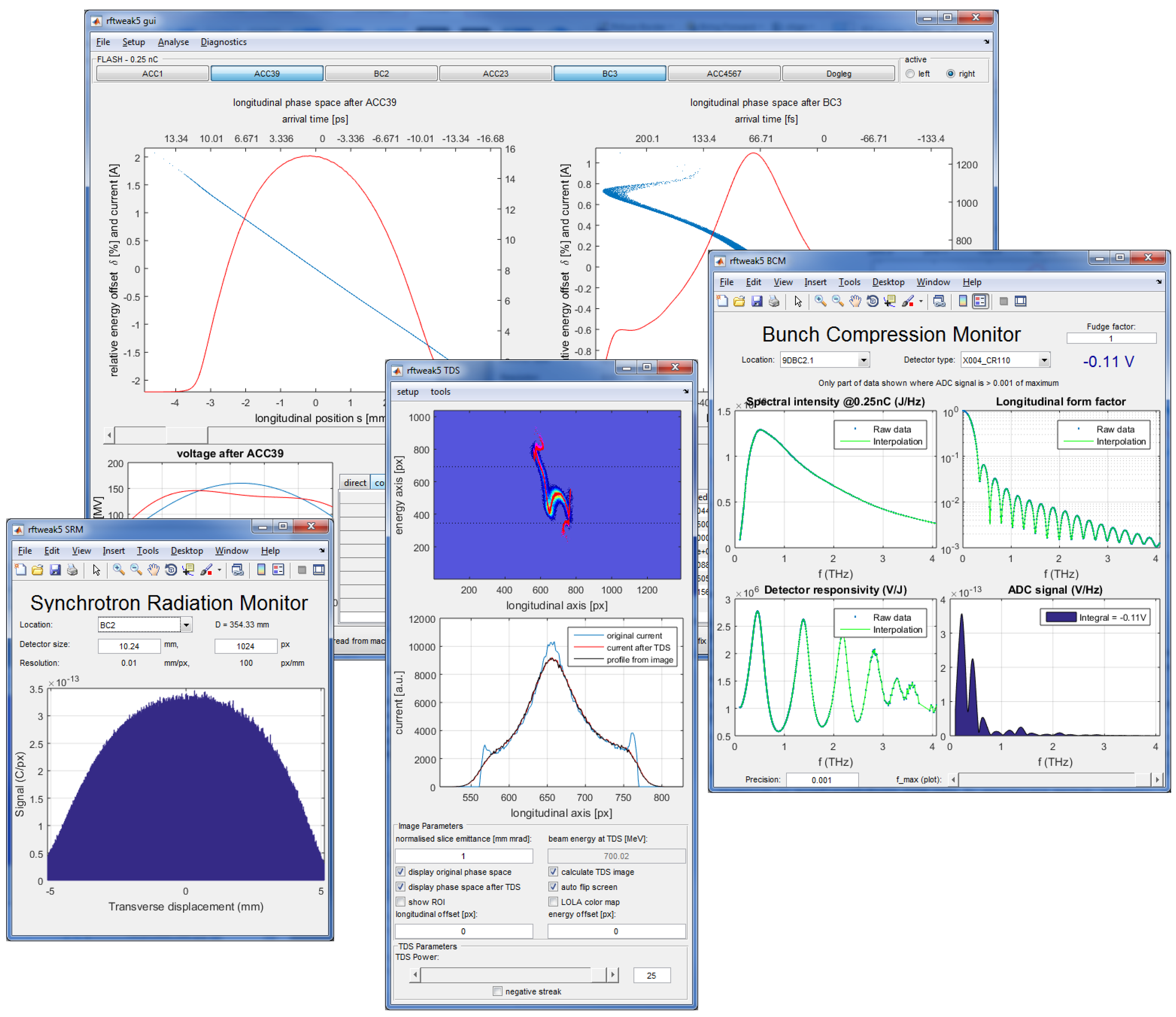
$$s_{n+1}^i = s_n^i + R_{56}\delta_{E_{i,n}} + T_{566}{\delta_{E_{i,n}}}^2 + \cdots$$

- The Taylor-coefficients are defined as the components of the longitudinal dispersion or the series expansion around the working point, e.g. the RF curvature in the cavities.
- Wakes, longitudinal space charge and CSR effects are applied in the energy modifying steps.
- ASTRA dumps downstream of ACC1 are accepted as input
- Chirp generated by ACC1 is implemented by backtracking



- Fast self field calculations are possible by pre-calculated wake kernel tables which are stored to disk
  - Energy independent CSR kernels (about 4GB for XFEL)
  - Energy dependent tables for wakes and longitudinal space charge (about 150MB each)
  - Recalculation required if energy profile changes on a percent level about 2 minutes time for recalculation
  - Results are stored to disk so following tracking runs with the same energy do not require this preparation
- Example:
  - Full XFEL 1D tracking with 1M particles, wakes on, longitudinal space charge on, in less than 5 seconds
  - Switching CSR on in the final BC increases tracking time to only a minute on a standard notebook

Simulated Signals for Longitudinal Diagnostics



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