Longitudinal phase space tomography using a booster cavity at PITZ.

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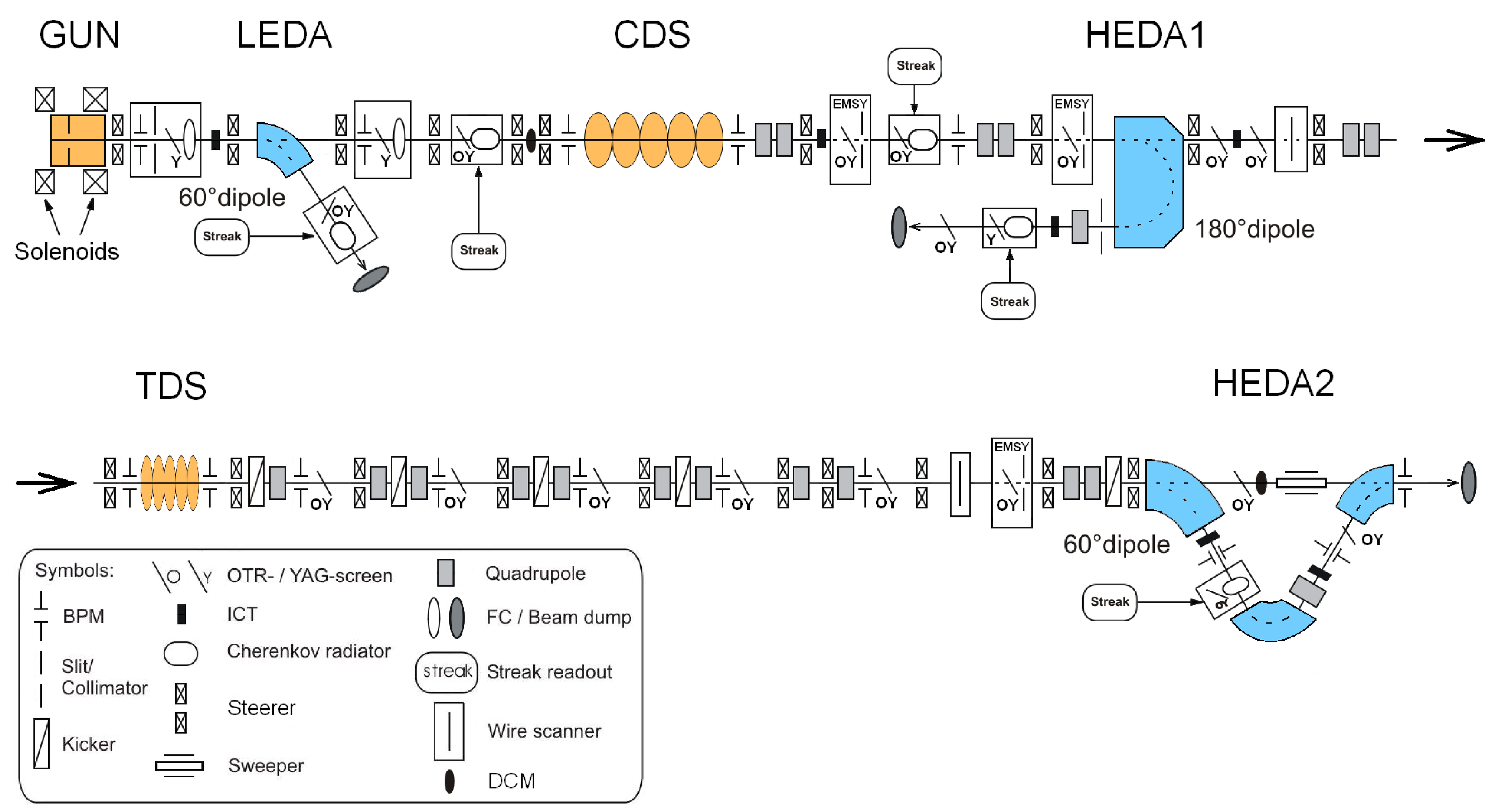
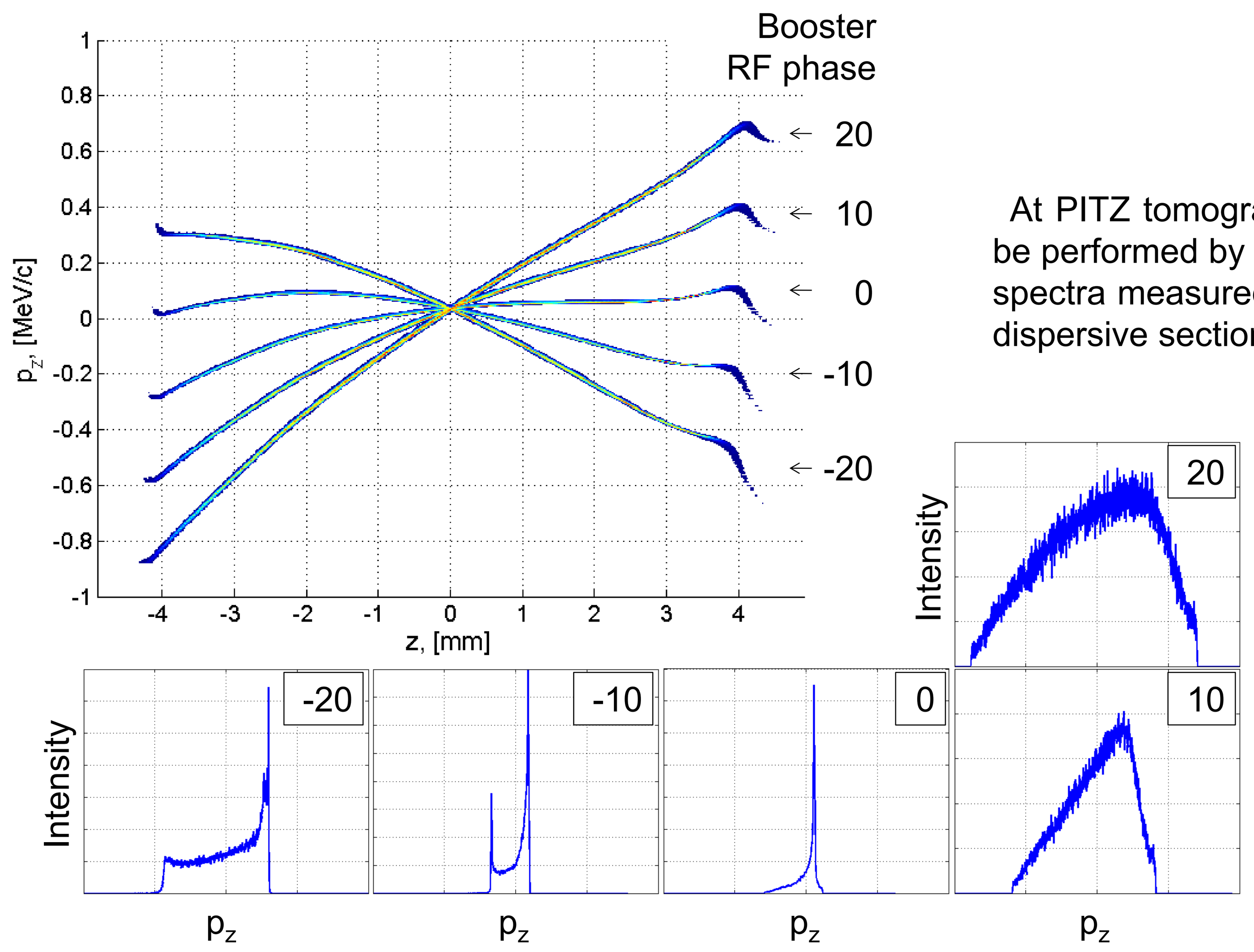
Abstract

One of the ways to measure the longitudinal phase space of the electron bunch in a linear accelerator is a tomographic technique based on measurements of the bunch momentum spectra while varying the bunch energy chirp. The energy chirp at PITZ can be controlled by varying the RF phase of the CDS booster – the accelerating structure installed downstream the electron source (RF gun). The resulting momentum distribution can be measured with a dipole spectrometer downstream. As a result, the longitudinal phase space at the entrance of the CDS booster can be reconstructed.

The present PITZ beamline layout is shown on the right side. The main components are: a photocathode laser system, an RF photo-electron **gun** (first accelerating structure) surrounded by main and a bucking solenoids, a second accelerating structure – Cut Disk Structure (**CDS**) which is also called booster cavity; and three dipole spectrometers. One spectrometer is located in the low energy section downstream the gun (Low Energy Dispersive Arm – **LEDA**), a second one in the high energy section downstream the booster (the first High Energy Dispersive Arm – **HEDA1**), and the third one in the end of the PITZ beamline (the second High Energy Dispersive Arm – **HEDA2**). Additionally there are three Emittance Measurement Stations (**EMSY**s) and a transverse deflecting structure (**TDS**).

PITZ beamline layout





Longitudinal phase space tomography

At PITZ tomographic measurements of the longitudinal phase space can be performed by varying the RF phase of the CDS booster. The momentum spectra measured downstream the booster at the HEDA1 or at the HEDA2 dispersive sections can be used to feed the tomographic reconstruction.

Bunch momentum chirp

The bunch momentum chirp k induced by an accelerating structure can be calculated as a first time derivative of the beam momentum:

$$k = -\frac{dp}{dt} = V\omega \cdot \sin(\varphi), \qquad (1)$$

where $\omega = 2\pi f$ and f is the RF frequency in the structure.

Bunch length estimation

The electron bunch length can estimated from the momentum phase scan as:

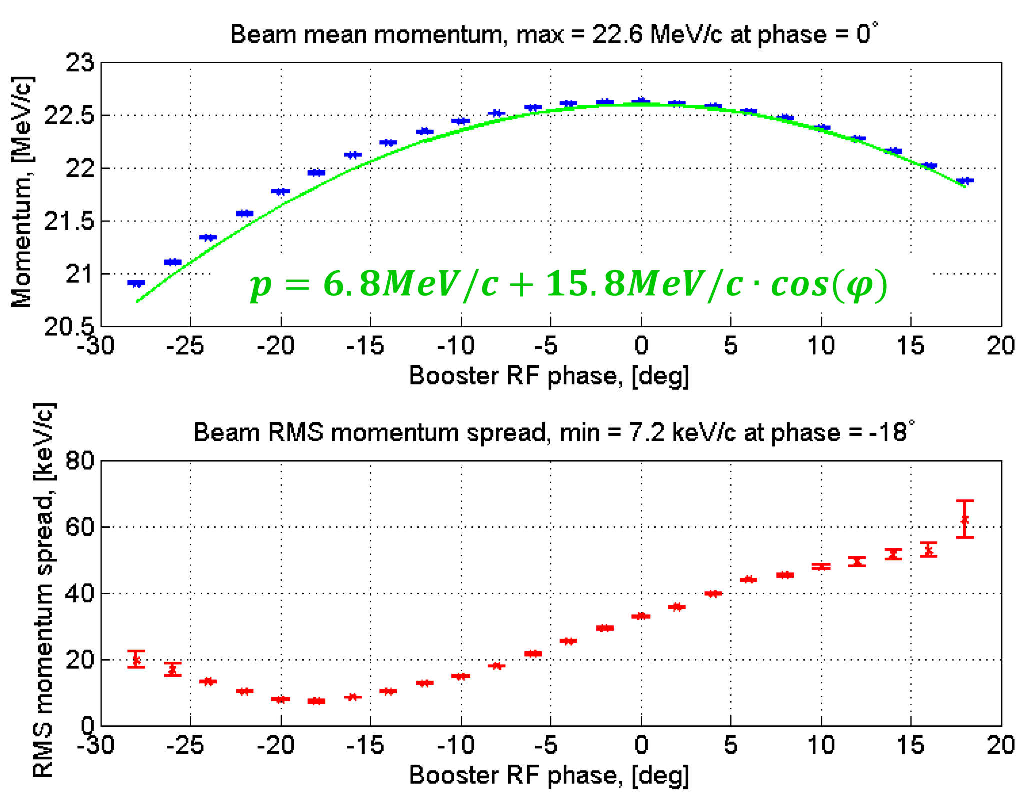
$$\delta_l = \frac{\delta_p}{k_0 + k_1} c, \qquad (2)$$

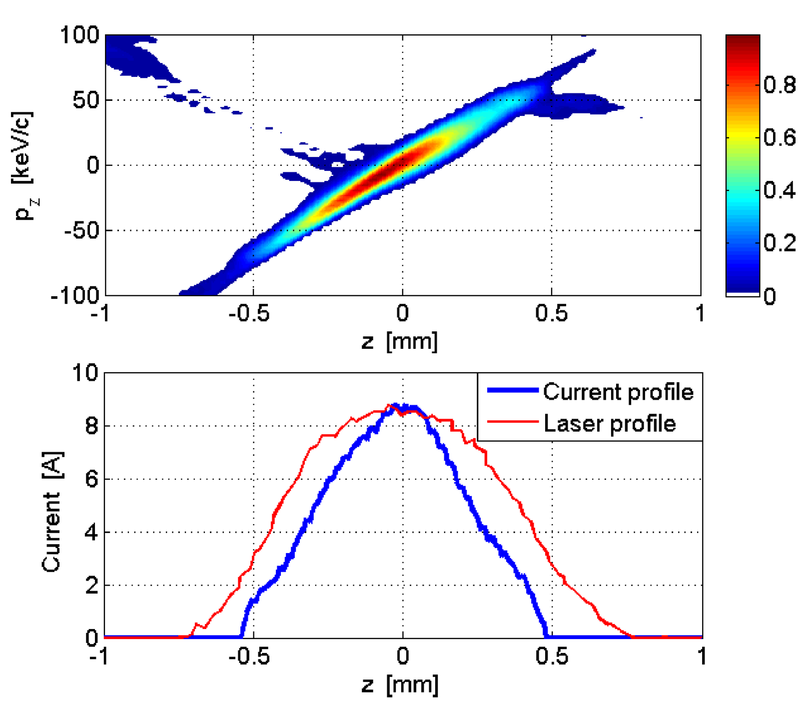
where δ_l is the RMS bunch length, δ_p is the RMS momentum spread, k_0 is the initial momentum chirp (upstream the booster), k_1 is the momentum chirp induced by the booster cavity at the maximum measurable momentum spread and c is the speed of light. k_0 can be estimated using Eq. (1) with inverse sign at the phase with minimum momentum spread.

Experimental results for 20 pC bunch charge

The photo cathode laser had a **Gaussian temporal profile** with FWHM length of **2.8 ps**. On the right side the measured mean beam momentum and RMS momentum spread in the HEDA1 section are shown as a function of the booster RF phase.

The result of the longitudinal phase space reconstruction using the ART algorithm is shown in picture below. Lower, the comparison of the bunch current profile with the measured laser temporal profile is shown.



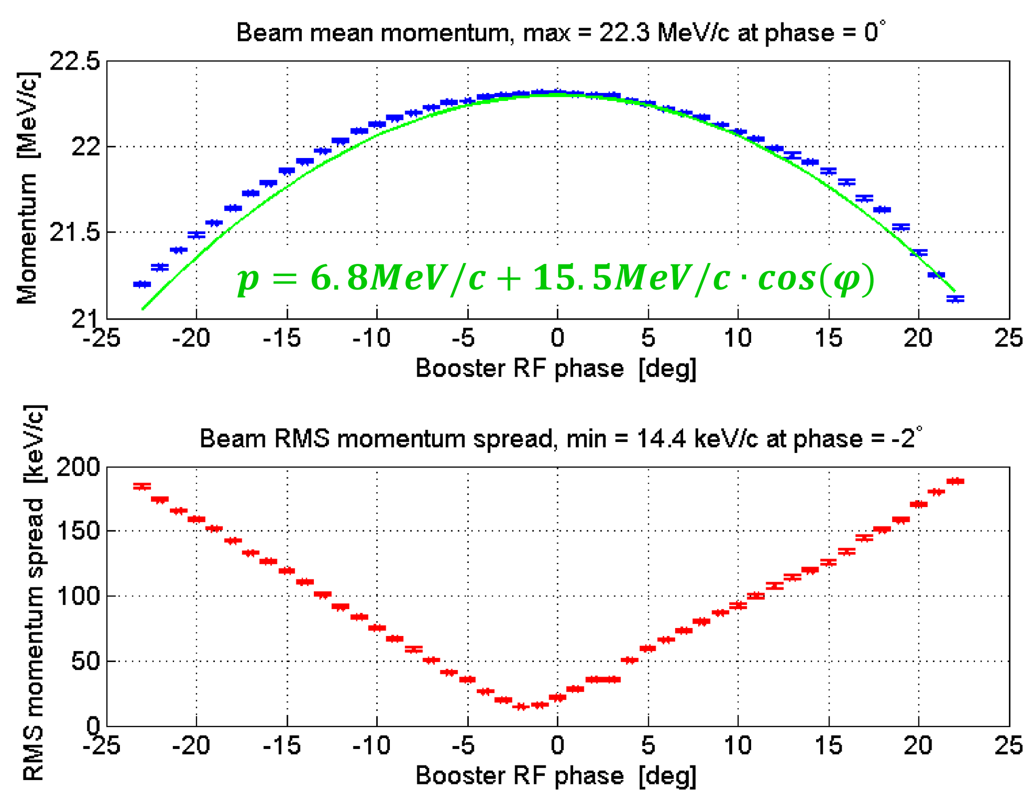


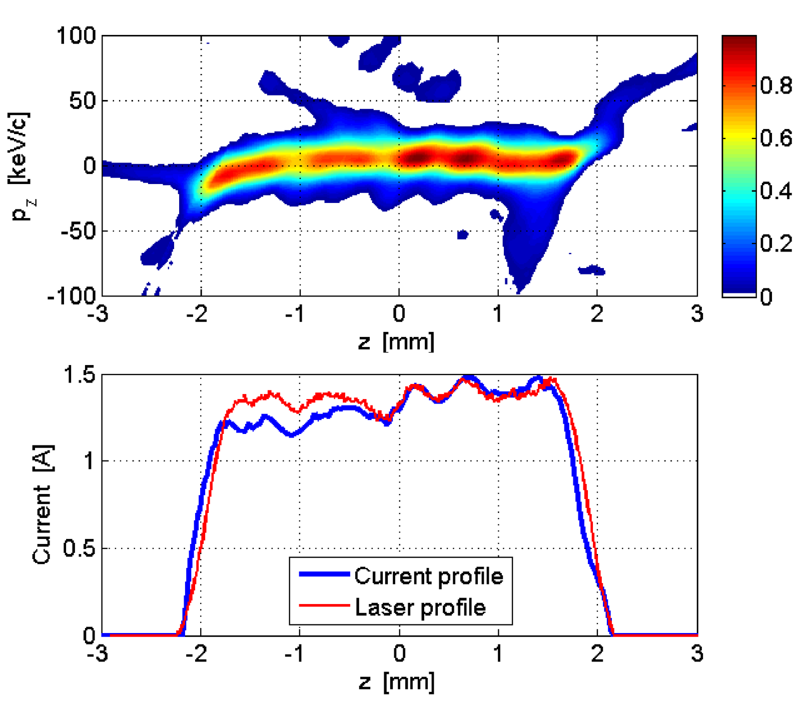
The current profile was calculated applying **15% charge cut** to the reconstructed phase space in order to remove reconstruction artifacts. The calculated current profile is shorter than the laser profile (**0.56 mm vs 0.86 mm** at FWHM).

The RMS bunch length calculated from the reconstruction is **0.22 mm**. The rough estimation from the momentum phase scan (upper graph) using Eq. (2) gives **0.23 mm**.

The laser had a **flat-top temporal profile** with a FWHM length of **17.4 ps**. On the right side the measured beam mean momentum and RMS momentum spread in the HEDA1 section are shown as a function of the booster RF phase.

The reconstructed longitudinal phase space and the comparison of the current profile with the laser profile is shown in pictures below. The laser profile was squeezed longitudinally to have the same length and scaled vertically to have the same amplitude as the current profile for better comparison.





The RMS bunch length calculated from the reconstruction is **1.1 mm**. The rough estimation from the momentum phase scan (upper graph) using Eq. (2) gives the same number.

Conclusion

The longitudinal phase space of the electron bunch can be measured using a tomographic technique. Temporal density modulations of the laser profile can be seen in the reconstructed longitudinal phase space. The bunch length can be quickly estimated from the momentum phase scan.

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