Predicting the Trajectories of Relativistic Electron Beams for External Injection in Plasma Wakefield Acceleration

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Abstract:

The AWAKE project aims to accelerate electrons through proton driven plasma wakefields. The transverse extend of the wakefields is given by the plasma density and is of the order of one millimeter. With external injection, the exact position of the electron bunch in the wakefields determines the acceleration energy and the captured charge. The pointing jitter of the electron beam is of the order of the size of the wakefields, so single event analysis is desired. After the last two beam position monitors (BPMs) the electrons propagate in vacuum. Ballistics can be used to propagate the trajectory to determine the position of the beam with respect to the proton bunch. The co-propagating proton bunch interferes with the electron BPMs readings and they cannot be used to determine the electron trajectory for these common events. Therefore, we have to use BPMs upstream of the common line. We use a model based on beam-optics to propagate the electron bunch before and towards the plasma and predict its point of closest approach to the proton bunch. This method is used to investigate the measured accelerated charge from event to event.

Motivation

Fig. 1 shows that BPMs in the common line are affected by the presence of the proton bunch.

We use a model to propagate the beam from the electron beam line to the plasma source

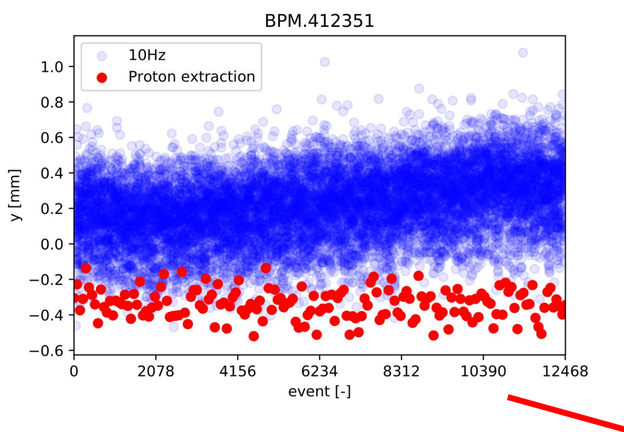


Fig. 1: Readings of BPM for events without protons (blue) and with protons (red)

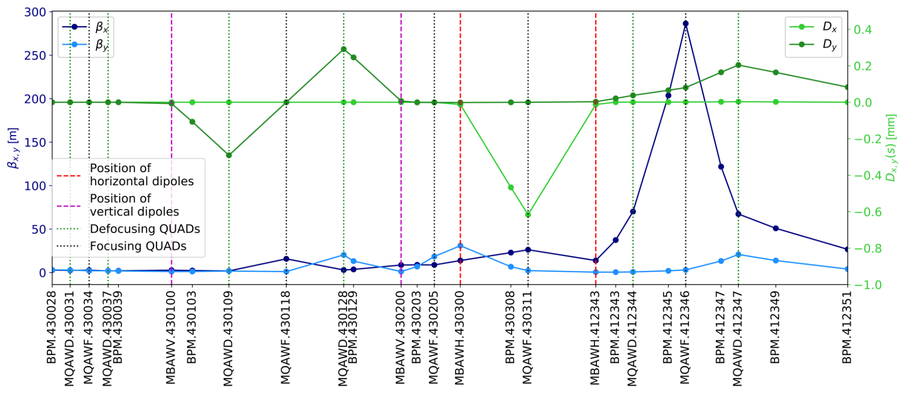


Fig. 2: Dispersion function (D) and amplitude function (β) along the beamline

Fig. 3: Layout of the AWAKE-Experiment at CERN

Model

1. Assumption: $$y_{BPM_i}(s_i) = \overbrace{\underbrace{\sqrt{\beta(s_i)}}_{\text{amplitude function}}\ \underbrace{y_\beta(s_i)}_{\text{betatron oscillation}}}^{\text{betatron contribution}} + \overbrace{\underbrace{D_y(s_i)}_{\text{dispersion function}}\ \underbrace{\delta_p}_{\text{momentum offset}}}^{\text{dispersion contribution}}$$

2. Using two BPMS: $$\delta_p = \frac{\sqrt{\beta_1}\cdot y_{BPM_2} + \sqrt{\beta_2}\cdot y_{BPM_1}}{\sqrt{\beta_1}\cdot D_{y_2} + \sqrt{\beta_2}\cdot D_{y_1}}$$

3. Compute $y_\beta(s) = R\cdot\cos(2\pi\mu(s)+\phi)$ for the common line

4. Fit $y_\beta(s)$

5. Compute y_{BPM_i} for downstream BPMs

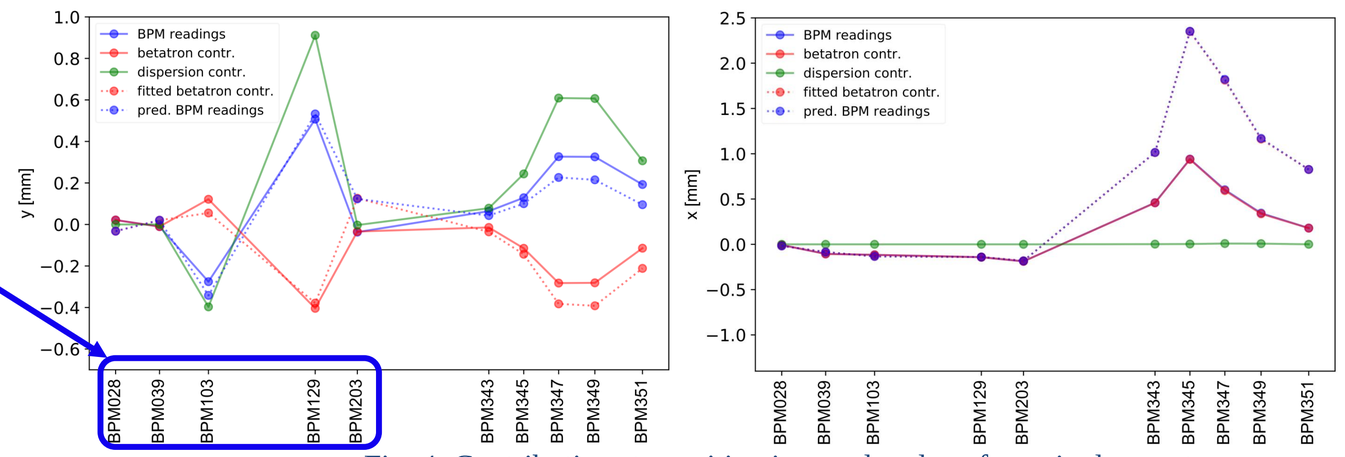
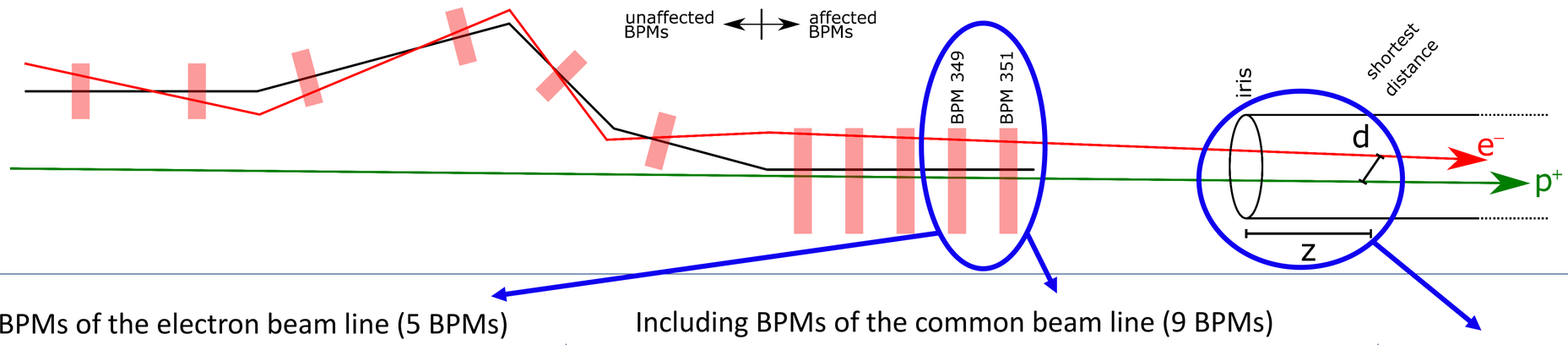


Fig. 4: Contributions to position in x and y plane for a single event



Results

Using BPMs of the electron beam line (5 BPMs)

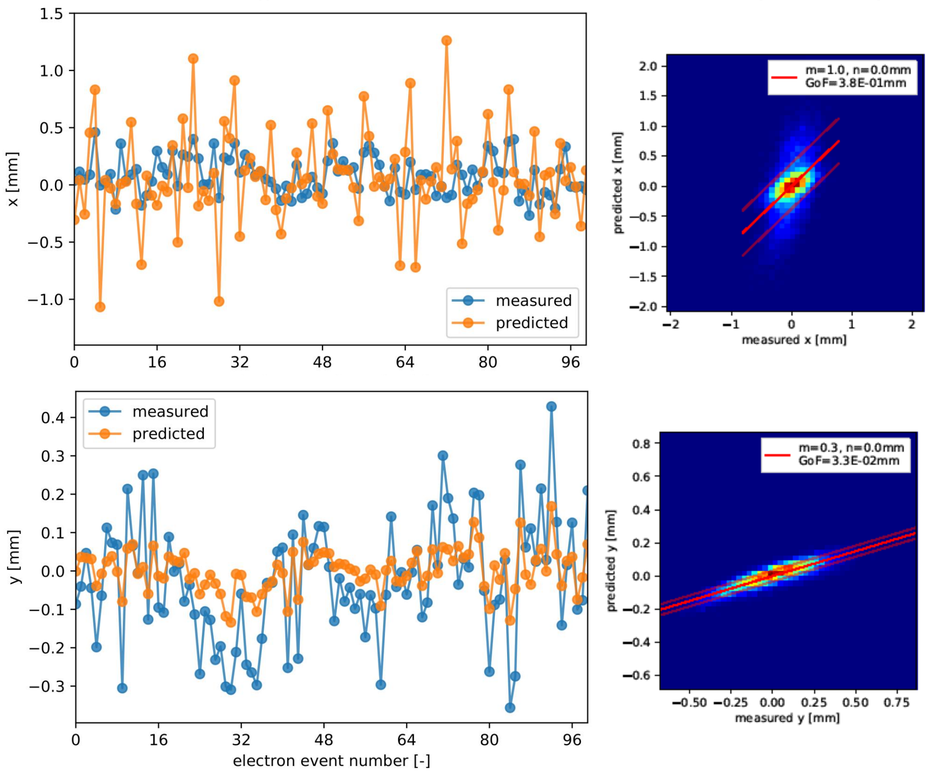


Fig. 5: (Using 5 BPMs) Positions over time for BPM 351 (left), histogram of predicted and measured values (right)

Including BPMs of the common beam line (9 BPMs)

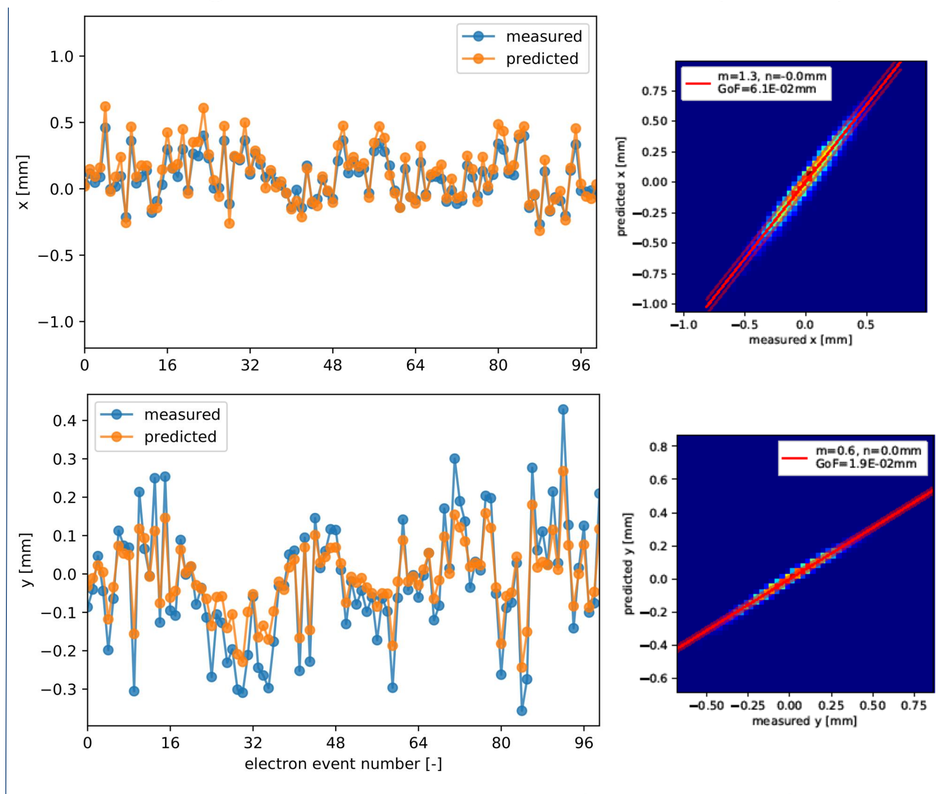


Fig. 6: (Using 9 BPMs) Positions over time for BPM 351 (left), histogram of predicted and measured values (right)

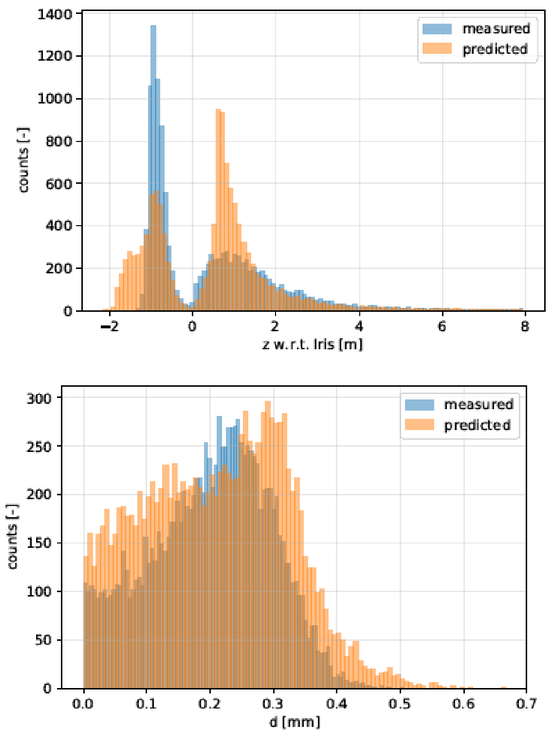


Fig. 7: Positon of closest approach in z and closest distance d