(Ab)using the QCM as a virtual cathode*

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Joe conjectured that the first cavity in the booster could be intentionally misphased to reflect the beam back upstream. The idea is that this effect should start to appear at a well-defined field amplitude, thereby enabling an accurate determination of the latter. While I don't have a sliver of a clue as to how this would work in practice (you have to separate the two beams so the viewer detecting the secondary beam won't intercept the primary beam; actually, the correctors will likely do that for you but in uncontrollable ways; horrendous things might happen to the emittance; etc.), I can give you a onedimensional prediction of the parameters very easily. No idea if these calculations are useful to anyone, but who doesn't like an academic exercise?

These calculations do not care about the transverse beam properties, and to my naïve intuition it seems like there might be prohibitive problems there. Also, I think if you try this experimentally, you're going to lose some beam or all of it on the cavity walls, though in viewer-limited mode the resulting heat load seems too low to cause a quench.

1 Approach

Let us use the same onedimensional model we used for the energy gain studies, but change the tracking algorithm such that it will not throw away the particles when their momentum gets negative. Unfortunately, now we need to use momenta rather than energies to be able to include the sign without signing up for physicists' hell. The electric field is given by

$$\begin{aligned} E_z(z,t) = {} & \cos(2\pi f_\mathrm{b} t - \phi_\mathrm{b}) A_\mathrm{b} E_\mathrm{b}(z) \\ & + \cos(2\pi f_\mathrm{QCM} t - \phi_2) A_2 E_2(z). \end{aligned} \tag{1}$$

*I'm aware that photocathode folks use an unusual definition of this term; I'm referring to a potential minimum in vacuum that reflects electrons.

As before, we use a spline interpolation of Haipeng's CST field maps for E_b and E_2. The instantaneous momentum change is

$$\frac{\mathrm{d}p_z}{\mathrm{d}t} = F_z = eE_z(z,t), \tag{2}$$

which is solved for p_z in discrete time. The other kinematic quantities follow from the usual laws.

The coordinate system is the same as in the previous studies: The center of the 2-cell cavity, i.e. the symmetry point between the cells, is located at $z = 0$.

2 Results

Figure 1 shows what the longitudinal phase space looks like at the entrance of the 2-cell cavity with my somewhat arbitrary choice of buncher amplitude, which places the focus somewhere inside the first cell.

Because I'm not exactly sure what we are trying to learn here, let's start playing around. Figure 2 shows the shape and location of the parameter contours we can use to reflect the beam. Joe is correct in intuiting that the usable phase range is fairly narrow, perhaps 10° at most, so any RMS bunch length in excess of about 2 ps will be outside the "acceptance". However, because the focusing action of the buncher trades bunch length for momentum spread and both quantities affect the sharpness of the usable parameter space, there may be a nontrivial optimization problem here, which I'm not going to think about unless challenged to.

The field amplitude needed to reflect the beam *using the first cell only* seems experimentally inaccessible and also uninteresting. In the interesting parameter regions (2 and 3 in Fig. 2), both cells contribute to a funny seesaw motion that takes about 2 ns to ultimately send the bunch back. To get a sense of what happens kinematically, we can look at the longitudinal phase space trajectories in an ensemble-average sense, see Figs. 3 and 4.

If there is anything else you would like to get out of this study, feel free to let me know; the computations and analyses are very straightforward.

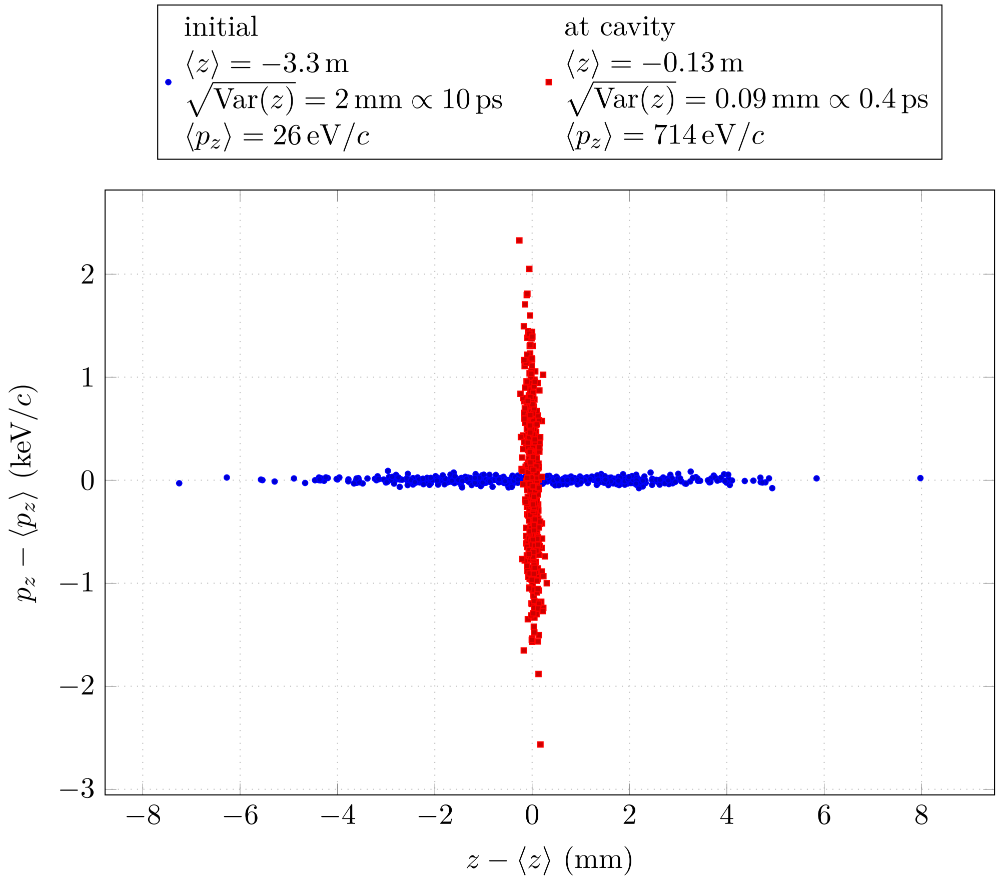

Figure 1: Longitudinal phase space at the beginning of tracking and at the entrance of the 2-cell cavity. The buncher focus is set to $z_\mathrm{f} = -0.09\,\mathrm{m}$, inside the first cavity cell (measured with the 2-cell off). By showing the Monte-Carlo-ness of the approach, I am hoping for Hannes' approval to call it a simulation.

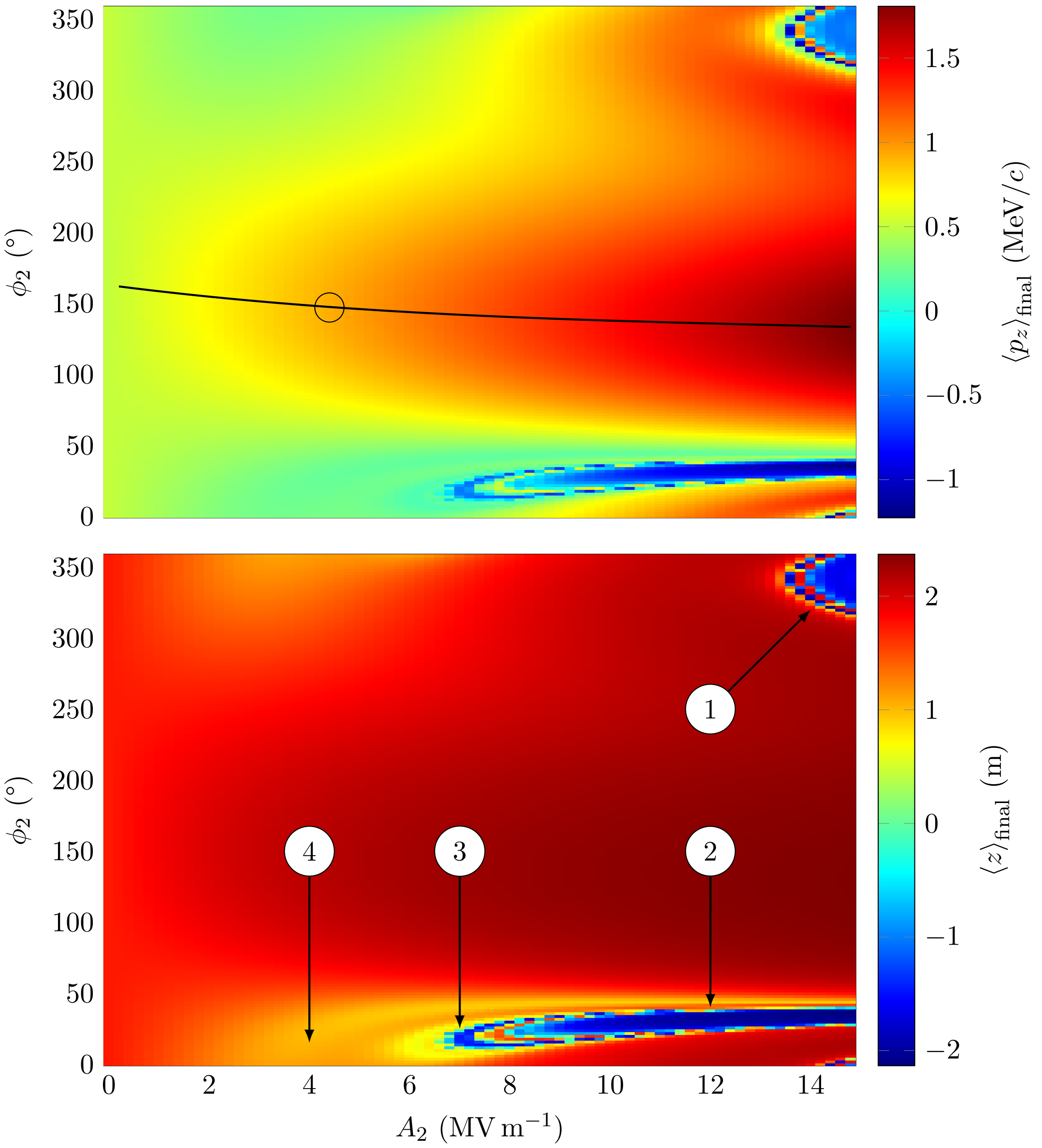

Figure 2: Final bunch momentum and longitudinal position in the $[A_2, \phi_2]$ parameter space. The black line in the momentum plot is the contour of maximum energy gain; the circle denotes the point at which the energy gain is 330 keV, corresponding to a final momentum of 0.91 MeV/c. In this amplitude range, there are three regions in which the beam is distinctly reflected (1, 2, 3) and a fuzzy one in which the momentum is so low that the beam isn't quite sure what to do (4). Region 1 is most likely experimentally inaccessible. Regions 2 and 3 are not the same because there is a small region of acceleration in between. The "final" time is chosen such that we look at the bunch before it gets a chance to travel backward through the buncher.

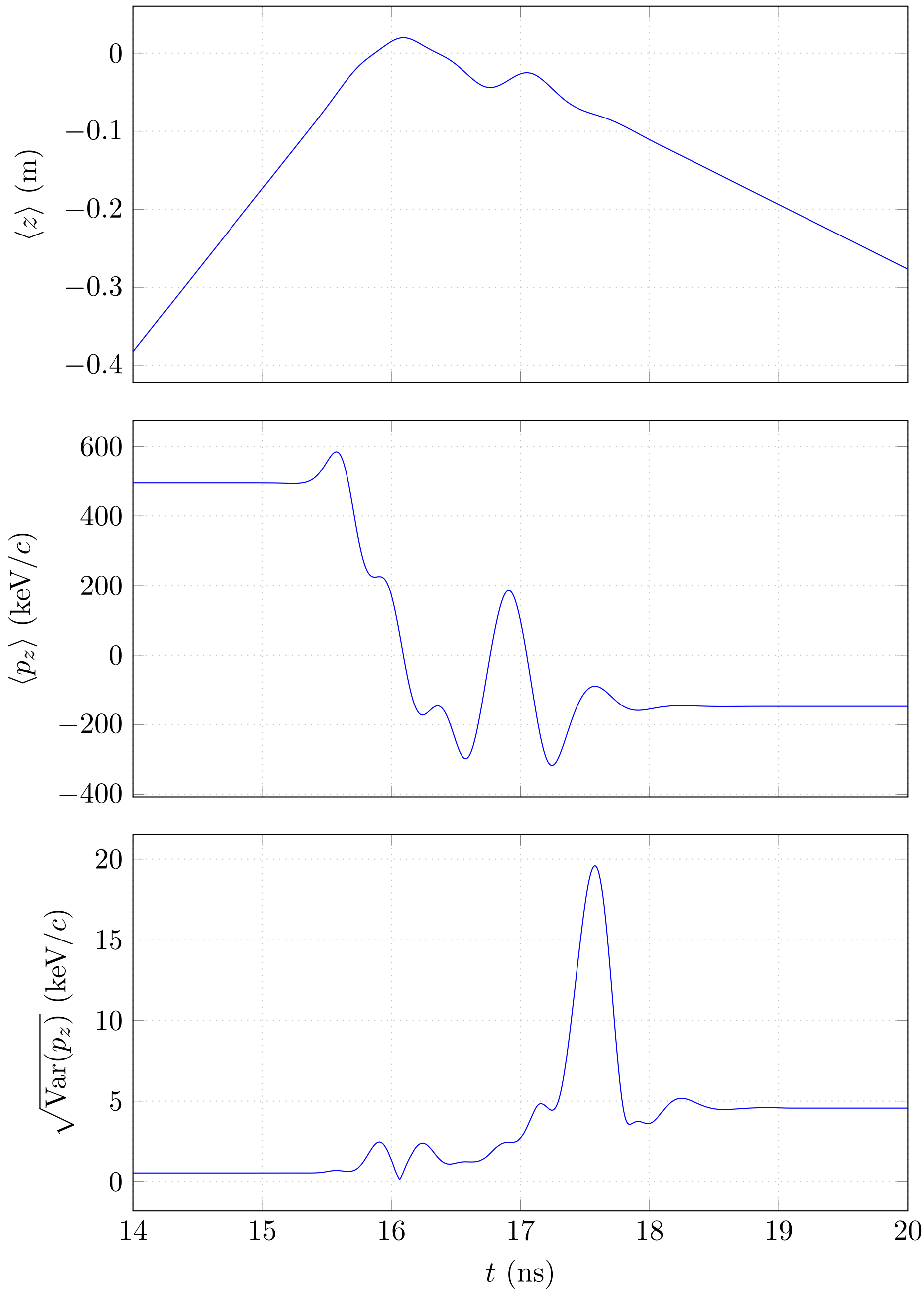

Figure 3: Ensemble average of the trajectory through the booster in region 2, right at the tip of the inner prolate structure. $\phi_2 = 23°$, $A_2 = 8.1\,\mathrm{MV\,m^{-1}}$. The bunch gets reflected in the *second* cell.

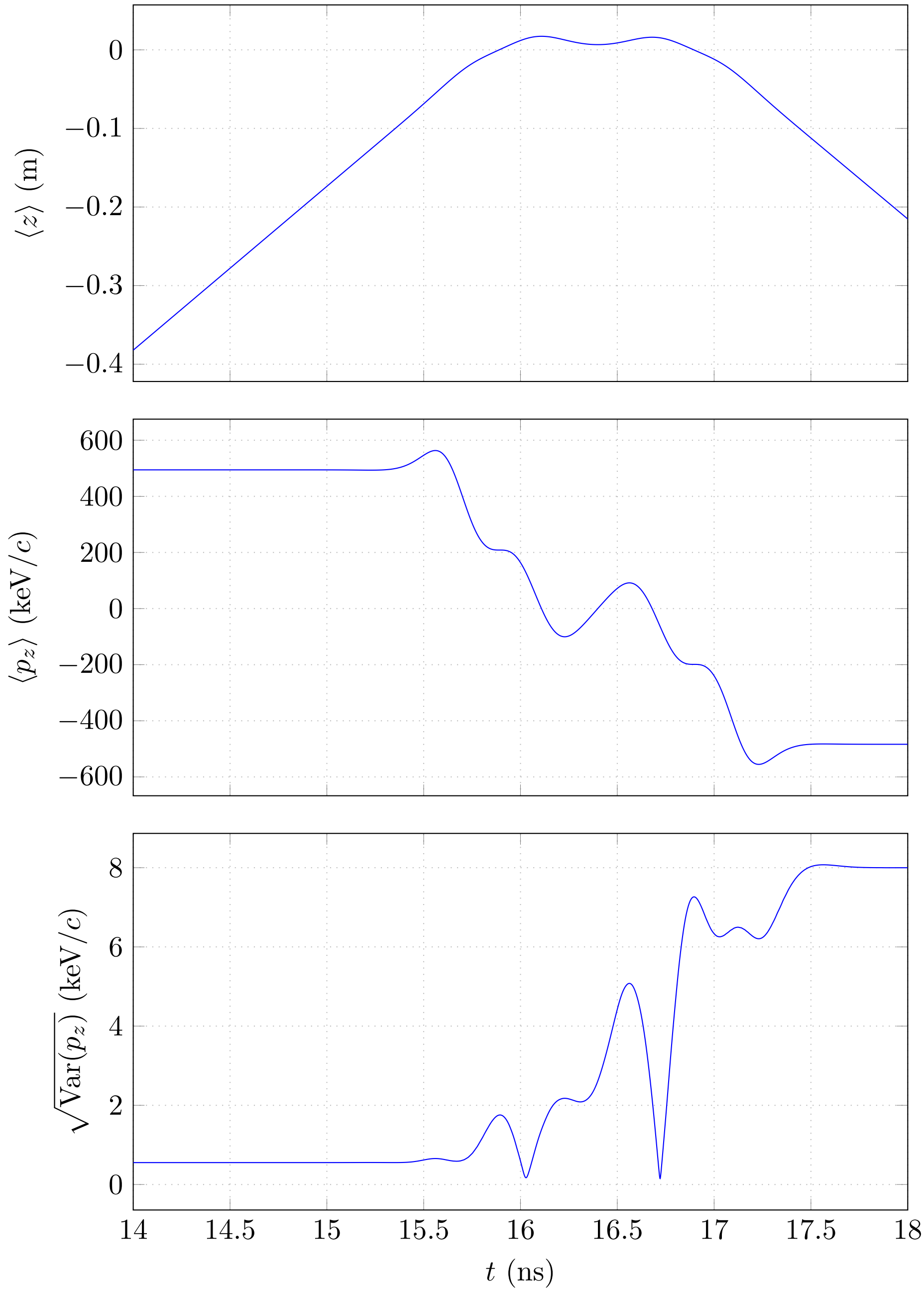

Figure 4: Ensemble average of the trajectory through the booster in region 3. $\phi_2 = 16°$, $A_2 = 7.2\,\mathrm{MV\,m^{-1}}$. The bunch gets reflected in the *second* cell.