The European Synchrotron

Effect of the short range wakefield on bunch lengthening

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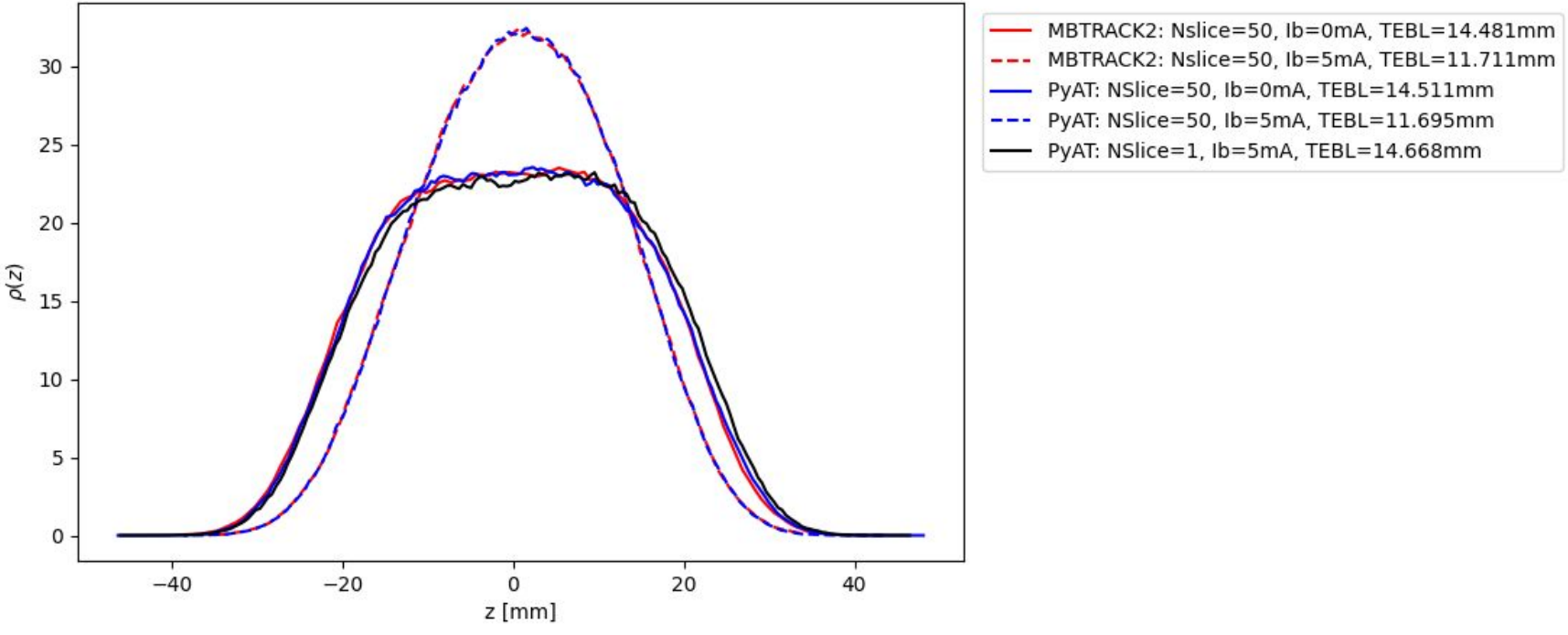
OVERVIEW

- We may recall the following plot:



- Nslice=50 has lower bunch length than Nslice=1, flat potential not achieved. Is this real?
- Sadly, yes. I will first convince you, then we can discuss the implications (which are not as severe as you may think).

FROM RF VOLTAGE TO BUNCH DISTRIBUTION

- We know that the combination of generator and beam voltage give the cavity voltage when beam loading is well compensated.

$$V_{rf}(z) = V_g \sin(kz + \psi + \phi_s) - V_b \sin(kz + \psi)$$

$$U_{pot}(z) = -\frac{1}{C}\int_{zs}^{z} (eV(z') - U_0)dz'$$

$$\lambda(z) = K \exp\left(-\frac{U_{pot}(z)}{E_0 \alpha_c \sigma_\delta^2}\right)$$

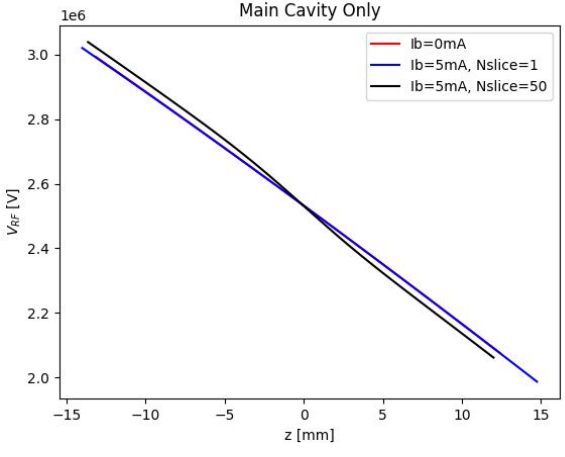
- In most other codes, and most analytical expressions, Vb is a fixed number for the whole bunch (implying Nslice=1), and form factors are used to take into account the distribution.

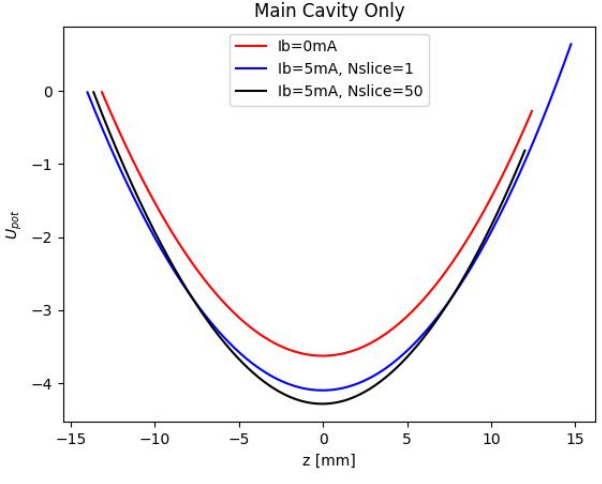
- Here, when we compute the beam induced voltage for multiple slices, Vb*sin(kz+psi) becomes Vb(z)

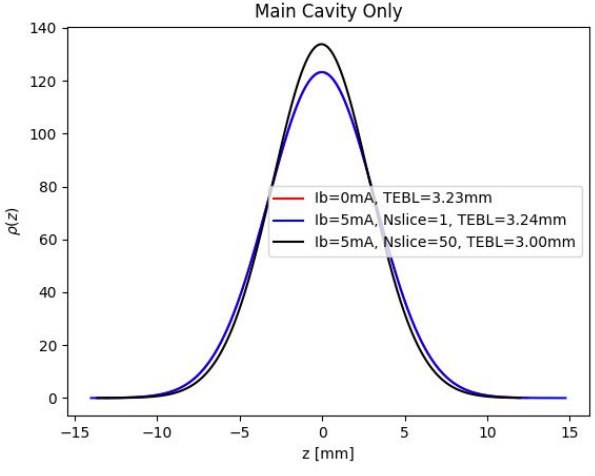
SINGLE HARMONIC

- **Question 1:**
- **Does the short range wakefield modify the potential in the single harmonic case?**

- **Method:**
  - Run a tracking simulation to obtain the equilibrium distribution, the generator voltage, the detuning angle etc.
  - Compute the voltage induced on the bunch by Nslice=1 and Nslice=50
  - For each case, reconstruct the total rf voltage, compute the potential and compute the expected distribution.





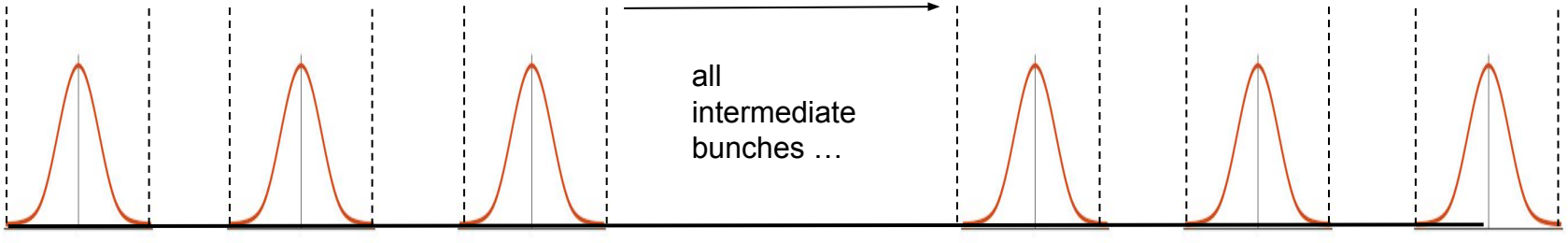


ITERATIVE DISTRIBUTION SOLVER

- **Question 2:**
- **Can we prove this using only formula and without using tracking?**
- **This would be a beneficial tool to have as it would allow a fast computation of the beam distribution, ignoring stability issues!**

- **Introducing a new haissinski solver: IterativeDistributionSolver (IDS)**

- **Method (part 1):**
  - Define a maximum and minimum position around each bucket central position and the number of slices per bunch to use.
  - Define a full beam distribution (with as many bunches in whatever buckets you want) with a starting guess of the beam distribution (sigma_z=3mm for example).
  - Slice this beam distribution.



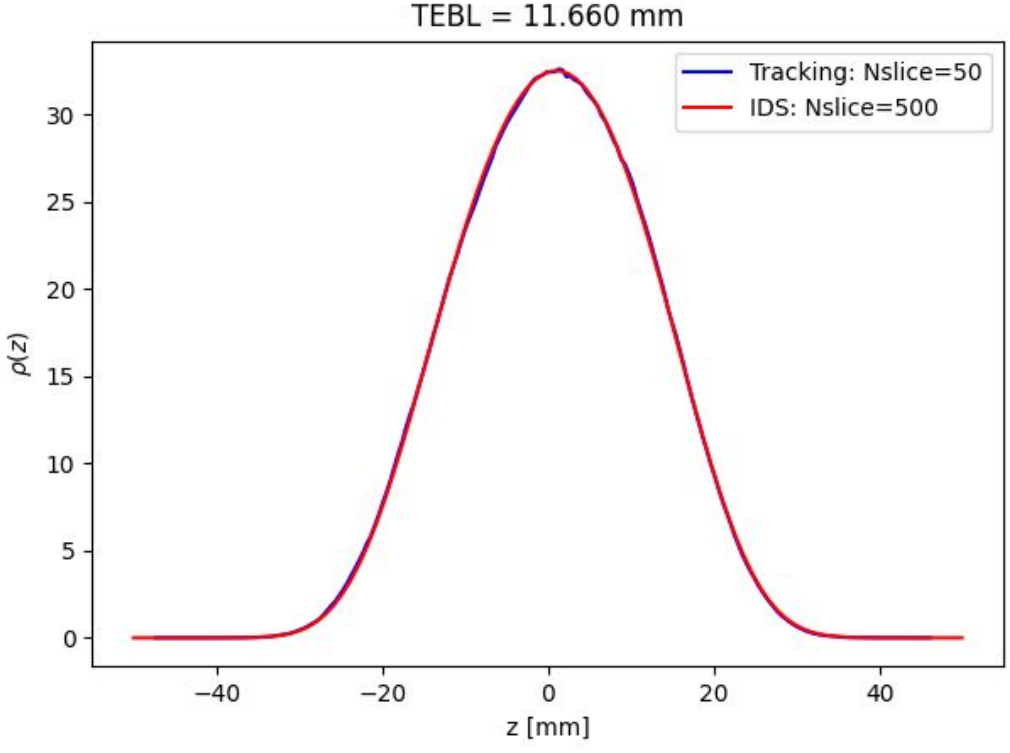
ITERATIVE DISTRIBUTION SOLVER

- **Method (part 2):**
  - Compute the beam induced voltage on each slice in your fixed slicing window. (For a given Nturns which is well chosen based on cavity Q, assuming fixed distribution for all turns).
  - Recompute the generator voltage and detuning angle to ensure beam loading compensation.
  - Sum all of the voltages taking into account:
    Full standard formula for generator voltage
    Numerically computed beam induced voltage as a function of slice
    (Note that these above points can be considered easily for any number of cavities!)
  - Compute the potential for each bunch.
  - Compute the distribution for each bunch.
  - Recompute the beam induced voltage…
  - Iterate until convergence.

- **This method is very fast compared to tracking simulations.**
- **Nbunches=1, Nslices=1000 takes about 4 seconds to reach convergence.**
- **NBunches=16, Nslices=200*16 takes about 10 seconds.**

ITERATIVE DISTRIBUTION SOLVER

- Here we compare the results of the tracking simulation (as shown on slide 2), with the results of the IDS for Nbunches=1, Nslices=50, 500 (tracking, IDS), I0=5mA.
- Beam loading in main. No beam loading in harmonic cavity.



THINKING OUT LOUD

- So it's real. But why has this not been seen before?
- Well, it has. Except people have been doing simulations a bit differently.

- First, all other labs plan for or have a passive harmonic cavity. Short range effect like this depends only on single bunch current. Probably not been seen before by other simulations.

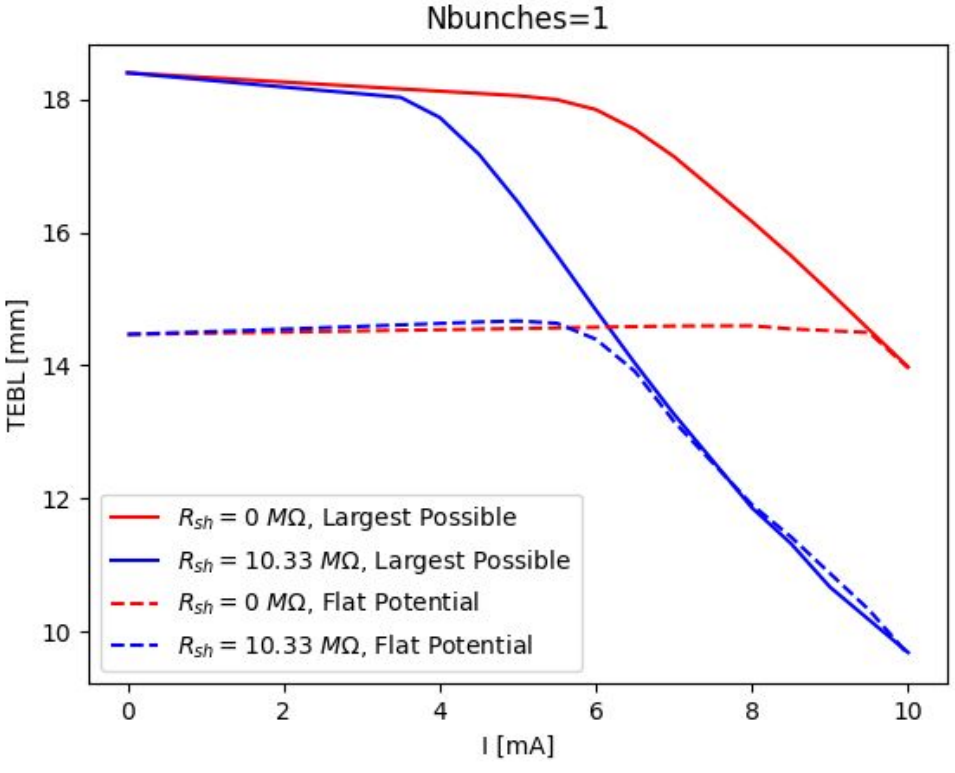
- What about the work done in the past by Vincent and Nicola? They both modelled beam loading and it's compensation with Nslice=1 which is perfectly valid. Then they added the full machine wake potential which is modelled with Nslice>1 and **contains the cavity short range wake.**

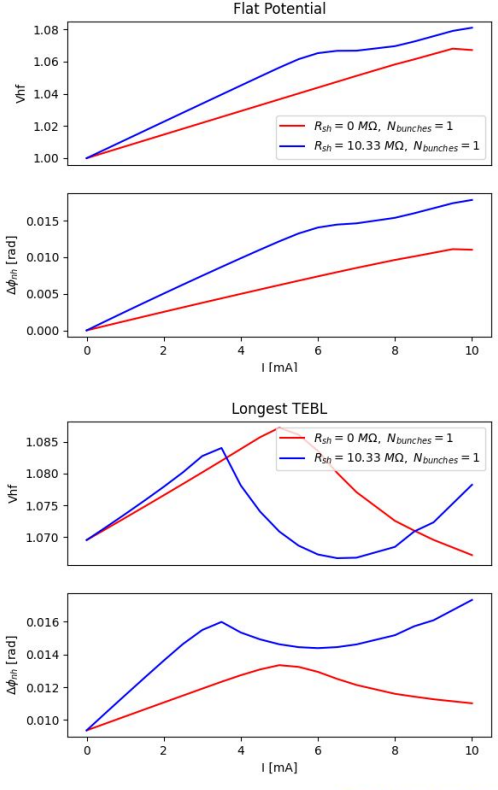
- I have heard many times: you will never see factor 5 bunch lengthening at high current. But I always assumed it was coming from the full machine impedance. Actually, the short range wake of the cavity beam loaded system itself is enough to modify strongly the bunch lengthening.

- First we have to add the machine wake to the IDS, it to compute the beam distribution very quickly, and perform many scans to really understand and optimize the bunch length for the realistic case.

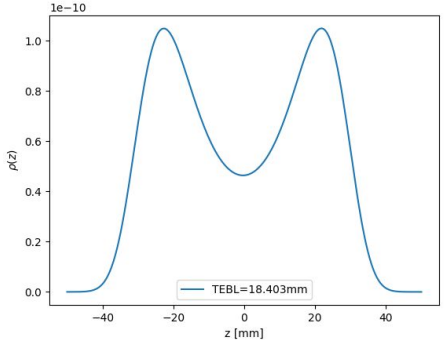
SINGLE BUNCH DISTRIBUTIONS

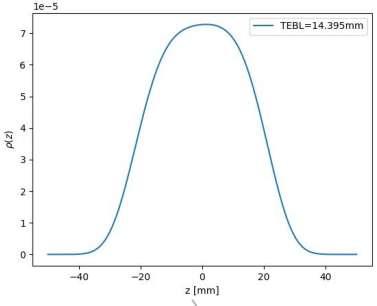
- Now we can do some more systematic studies.
- What is the maximum bunch lengthening achievable for only a single bunch in the presence of the short range wakes from the cavities?

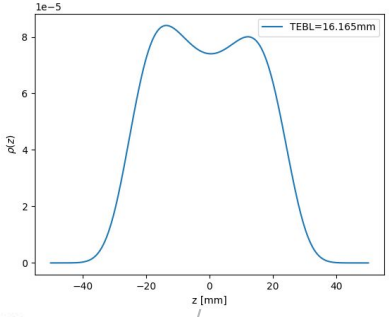


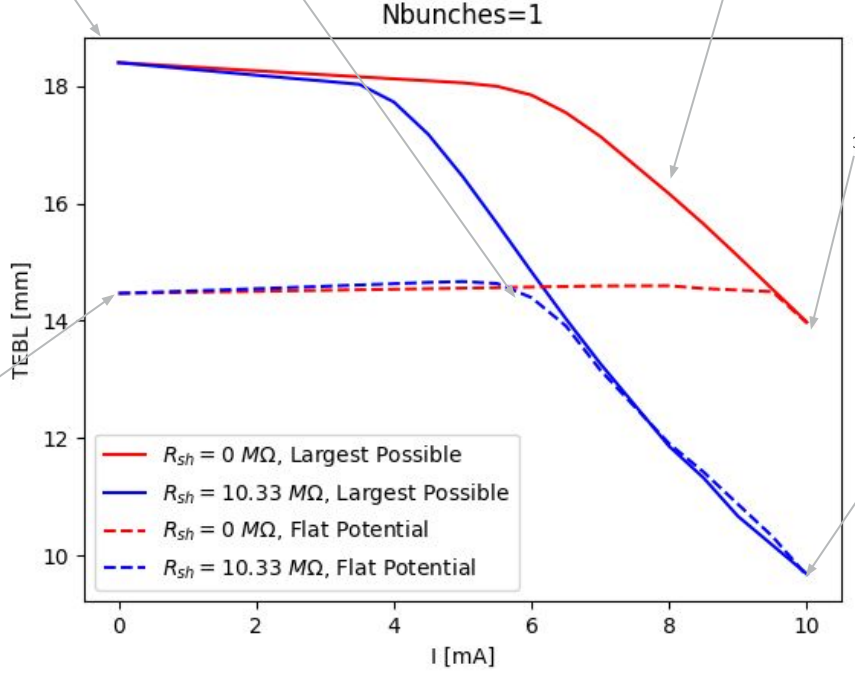


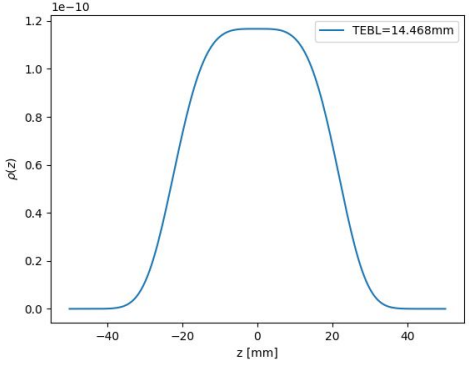
SINGLE BUNCH DISTRIBUTIONS

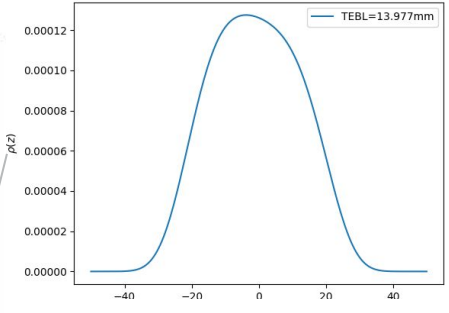


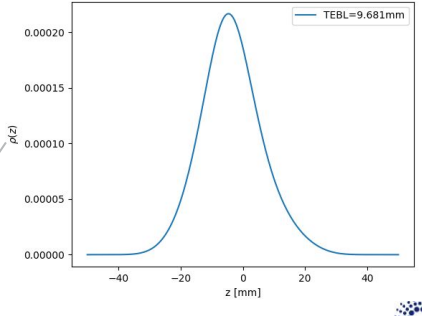












DISTRIBUTIONS IN 4B

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DISTRIBUTIONS IN 16B

SOME DEVELOPMENTS

- Some ideas from Alex
- Each cavity will also have beam loading of the HOMs -> easy to include into the distribution solver
- For filling modes with Nbunches>=16, the bunch spacing is smaller than the cavity filling time, so the model may not be accurate in this case. Some formulas in the wilson paper need to be looked at.

BUNCH LENGTH DIAGNOSTICS

- Streak camera
- Spark sum signals are sensitive to bunch length
- 10GHz cavity
- Striplines to measure beam response at different frequencie
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