Local energy deviations due to impedances - estimations and uncertainties

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Outline

- FCC-ee main parameters with 4 IPs
- Wakefield and impedance model
- Single bunch collective effects for Z-pole
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- Beamstrahlung and interplay between longitudinal wakefield and beam-beam
- Energy distribution under collisions
- Energy distribution at ttbar

FCC-ee main parameters (4 IPs)

Layout	PA31-1.0			
	Z	WW	ZH	$t\bar{t}$
Circumference (km)	91.174117 km			
Beam energy (GeV)	45.6	80	120	182.5
Bunch population (10^{11})	2.53	2.91	2.04	2.64
Bunches per beam	9600	880	248	36
RF frequency (MHz)	400			400/800
RF Voltage (GV)	0.12	1.0	2.08	4.0/7.25
Energy loss per turn (GeV)	0.0391	.37	1.869	10.0
Longitudinal damping time (turns)	1167	217	64.5	18.5
Momentum compaction factor 10^{-6}	28.5		7.33	
Horizontal tune/IP	55.563		100.565	
Vertical tune/IP	55.600		98.595	
Synchrotron tune	0.0370	0.0801	0.0328	0.0826
Horizontal emittance (nm)	0.71	2.17	0.64	1.49
Verical emittance (pm)	1.42	4.34	1.29	2.98
IP number	4			
Nominal bunch length (mm) (SR/BS)*	4.37/14.5	3.55/8.01	3.34/6.0	2.02/2.95
Nominal energy spread (%) (SR/BS)*	0.039/0.130	0.069/0.154	0.103/0.185	0.157/0.229
Piwinski angle (SR/BS)*	6.35/21.1	2.56/5.78	3.62/6.50	0.79/1.15
ξ_x/ξ_y	0.004/0.152	0.011/0.125	0.014/0.131	0.096/0.151
Horizontal β^* (m)	0.15	0.2	0.3	1.0
Vertical β^* (mm)	0.8	1.0	1.0	1.6
Luminosity/IP ($10^{34}/\text{cm}^2\text{s}$)	181	17.4	7.8	1.25

*SR: syncrotron radiation, BS: beamstrahlung

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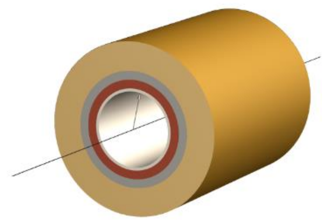
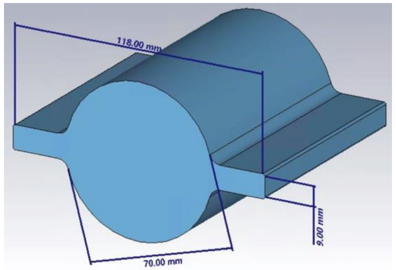
Resistive wall

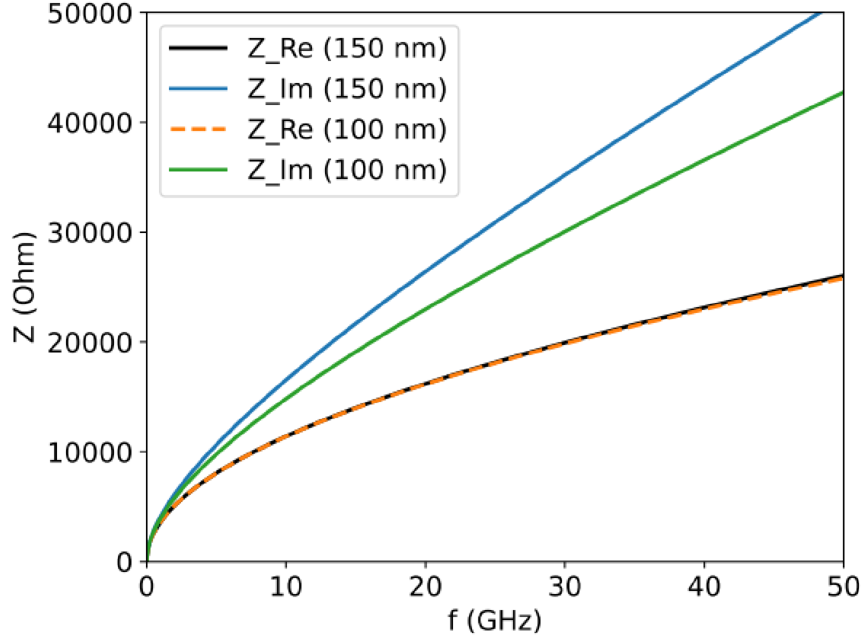


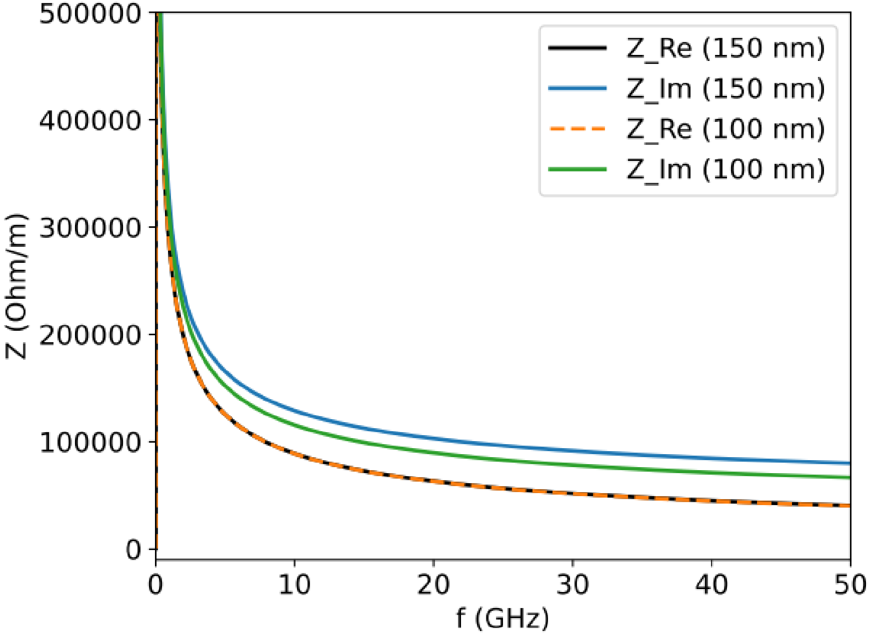
IRON	$\Delta = \infty$	$\rho = 6.89 \cdot 10^{-7} \Omega m$
DIELECTRIC	$\Delta = 6\ mm$	$\rho = 10^{-15} \Omega m$
COPPER	$\Delta = 2\ mm$	$\rho = 1.66 \cdot 10^{-8} \Omega m$
NEG	$\Delta = 150\ nm$	$\rho = 10^{-6} \Omega m$

It is the largest impedance source for FCC-ee evaluated so far. NEG coating is needed to mitigate the electron cloud build-up in the positron machine and for pumping reasons in both rings.

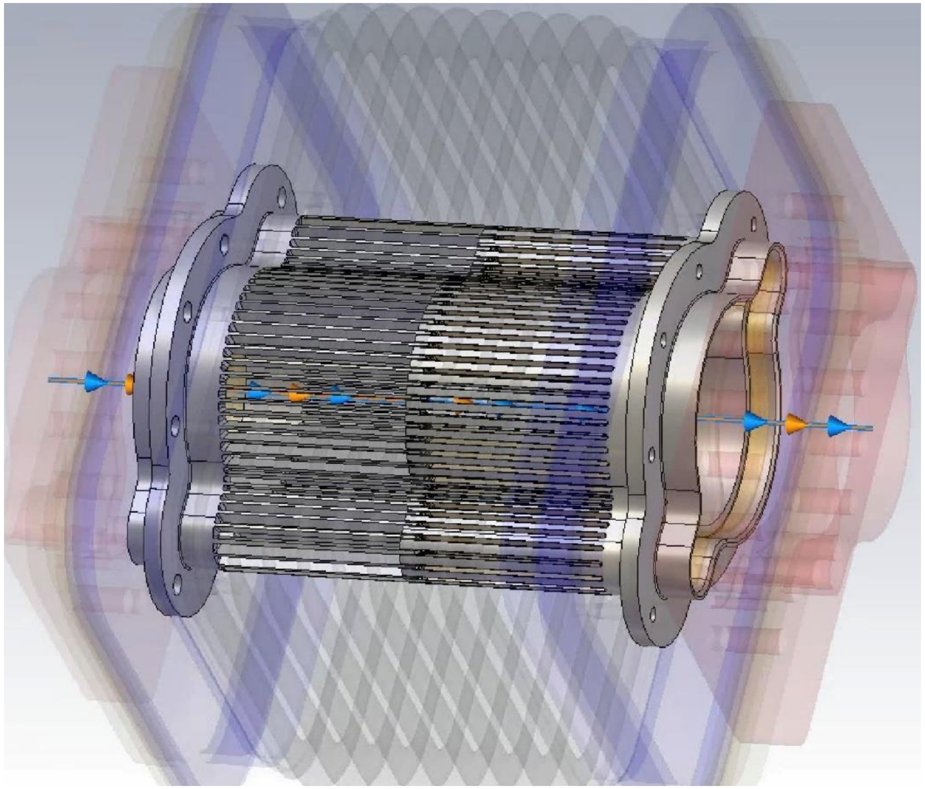


IW2D results for a circular pipe. We estimated a factor 1.1 for winglets contribution

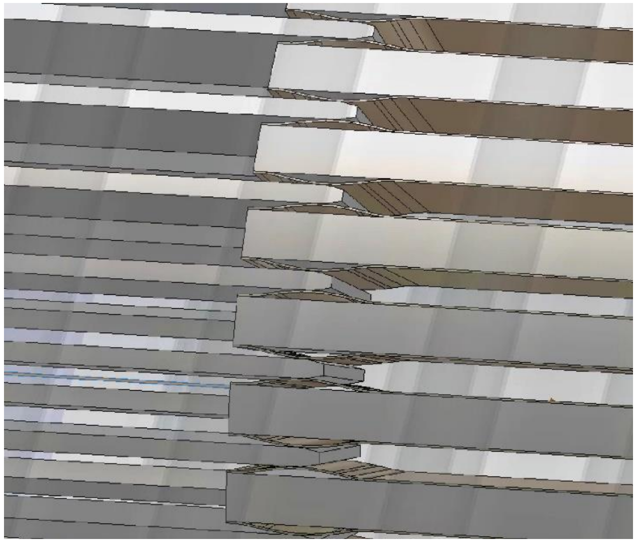




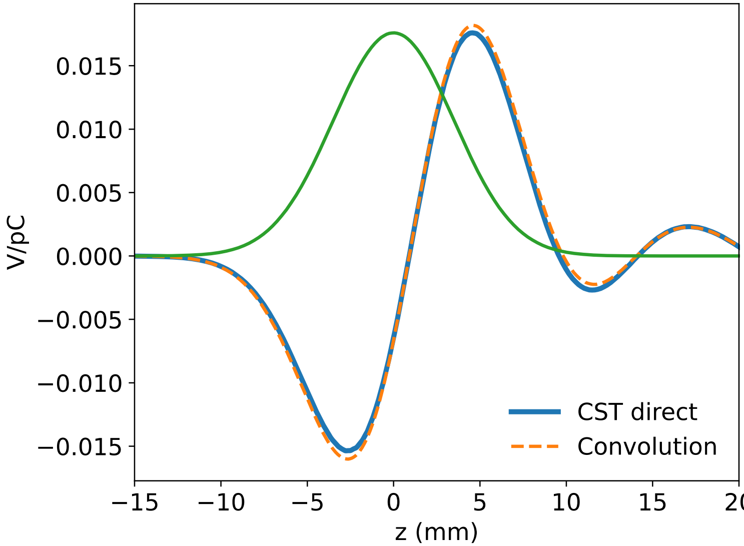
Bellows



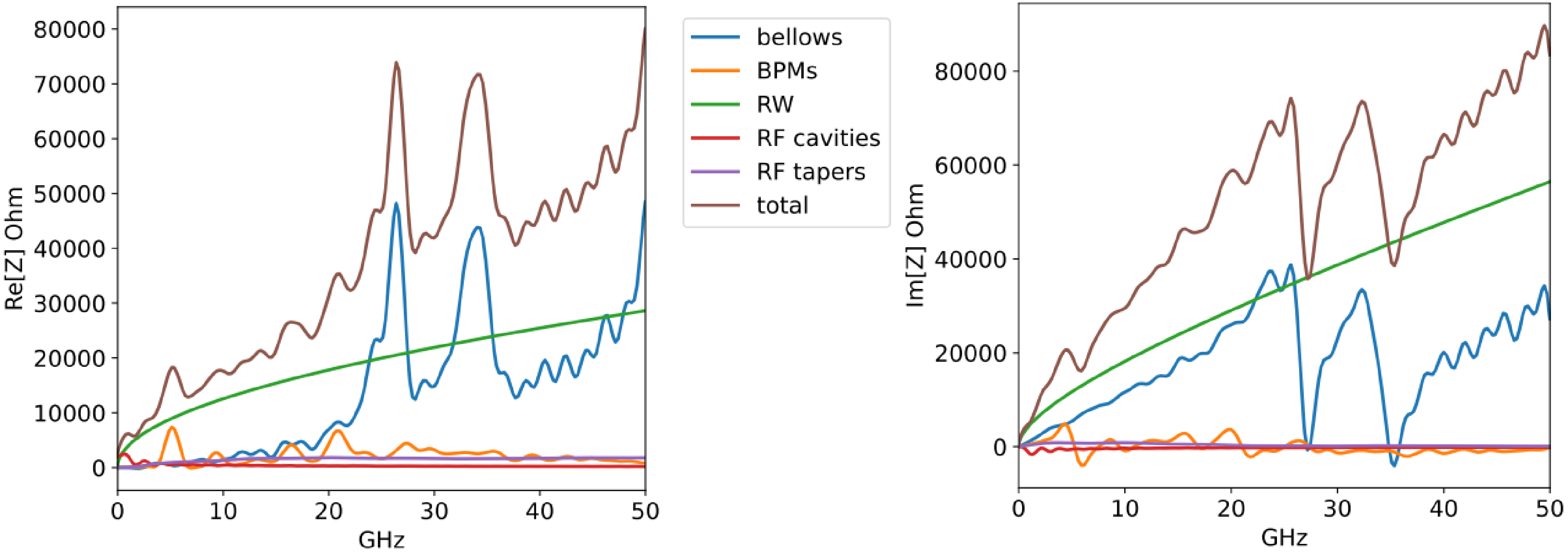
They represent the second highest impedance source. We have used an upper estimate of 20000 bellows



wakefield of 3.5 mm Gaussian bunch

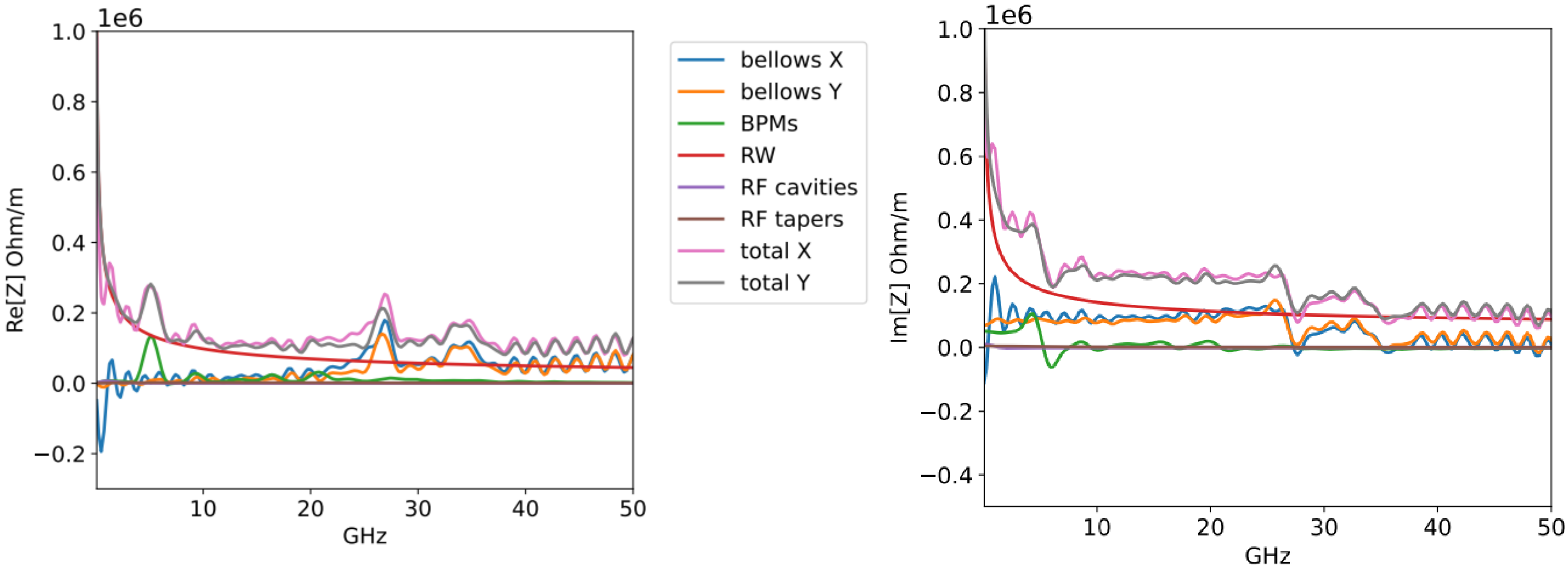


Total impedance: longitudinal

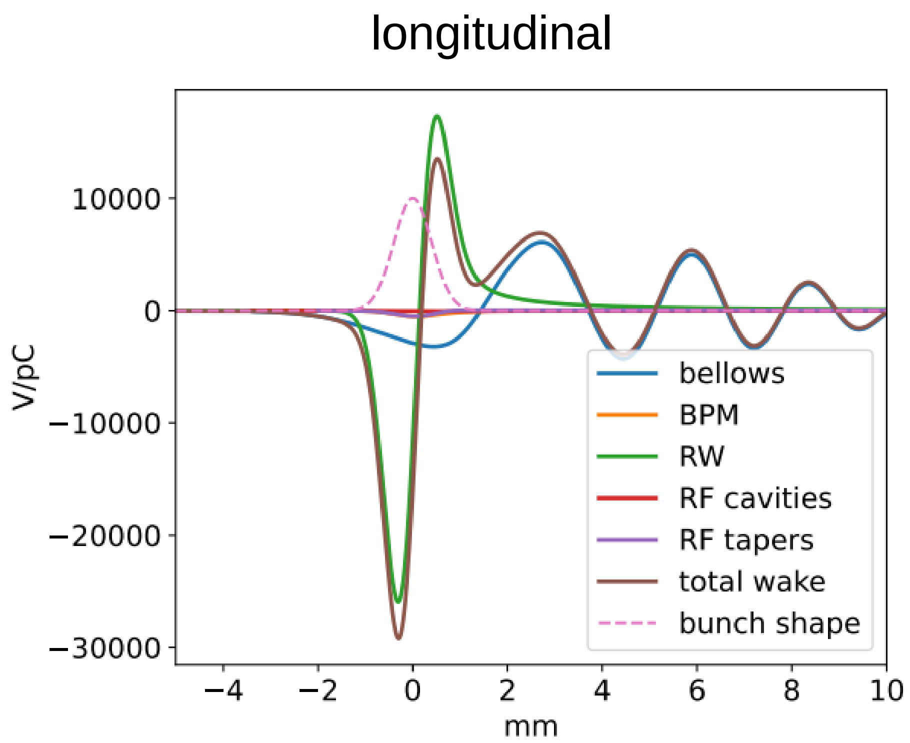


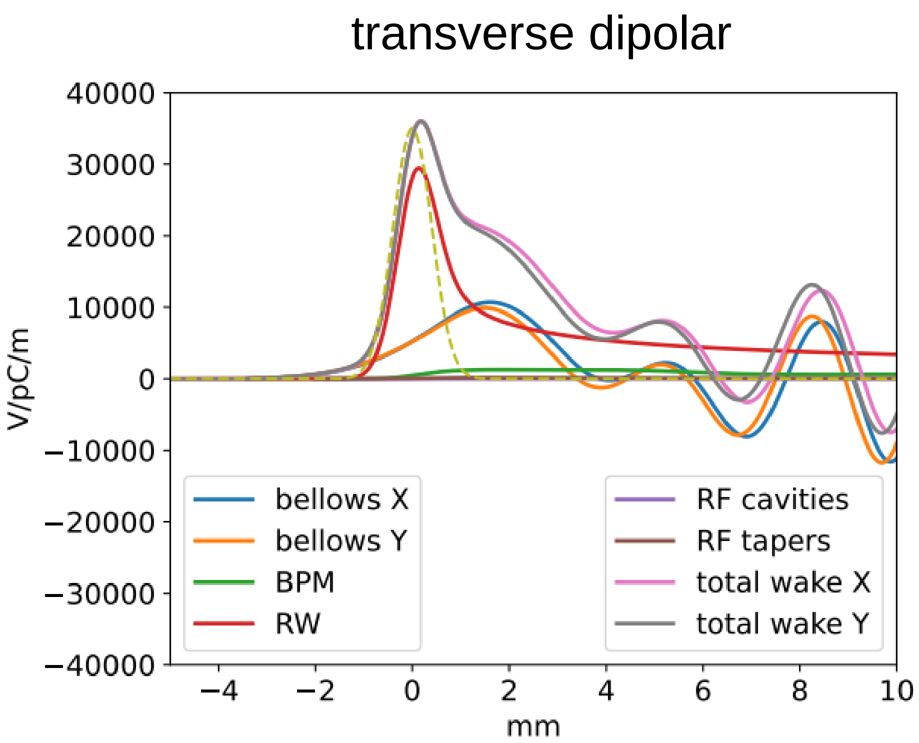
The main sources of longitudinal impedance, responsible of the energy change, are the RW and the bellows, which are distributed uniformly around the machine → there is no strong localized impedance that can change the bunch energy (and its distribution) in a particular position of the machine: the energy change is an almost uniform process along the machine

Total impedance: transverse dipolar



Wake potential of 0.4 mm Gaussian bunch





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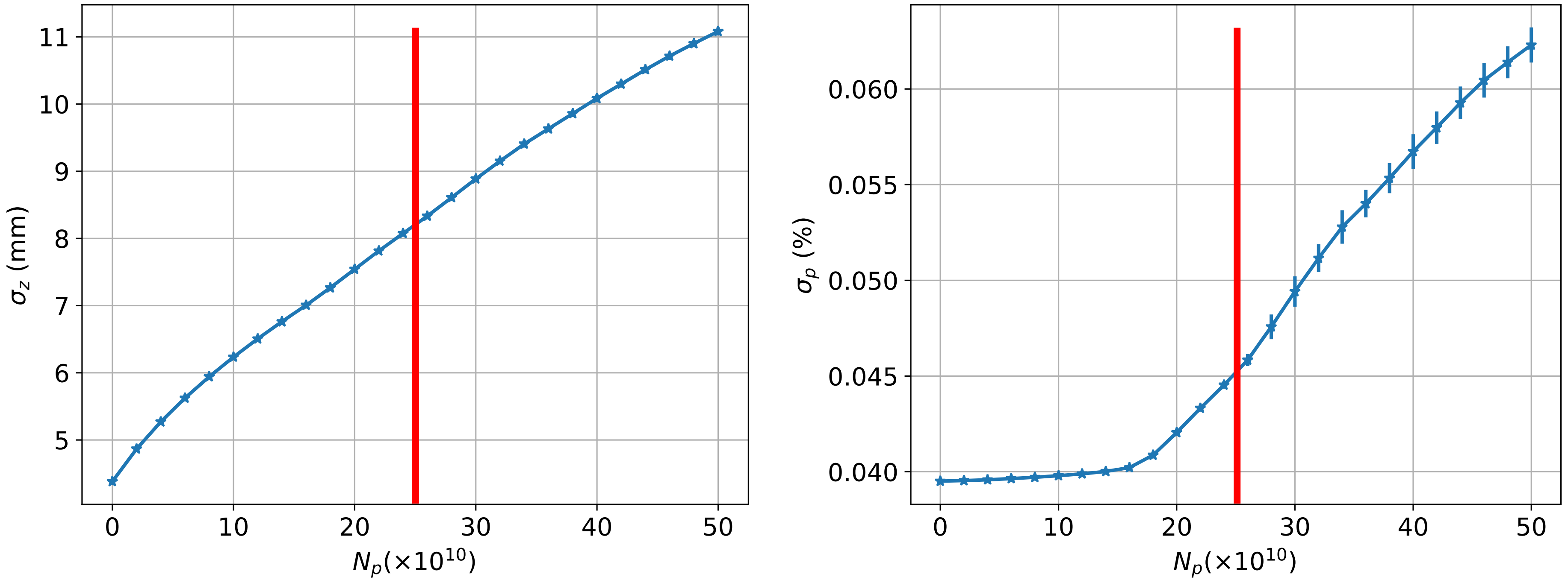
Some comments on the impedance budget and collective effects

- FCC-ee is still an ongoing project, and, as we evaluate and add new devices, the total machine impedance increases more and more
- We are still missing several important devices, such as the collimation system, vacuum flanges, …
- On the other hand, the impedance evaluated so far already demonstrates how this machine can become critical due to collective effects
- The distributions shown in the following will change based on the new impedance contributions that will gradually be added.
- In this talk we discuss only the longitudinal effects, in particular the energy distribution
- Since, so far, we have not observed strong localized longitudinal impedances, the energy lost due to wakefield is almost uniformly distributed along the machine. The minimum bunch energy is before the RF system

Longitudinal microwave instability

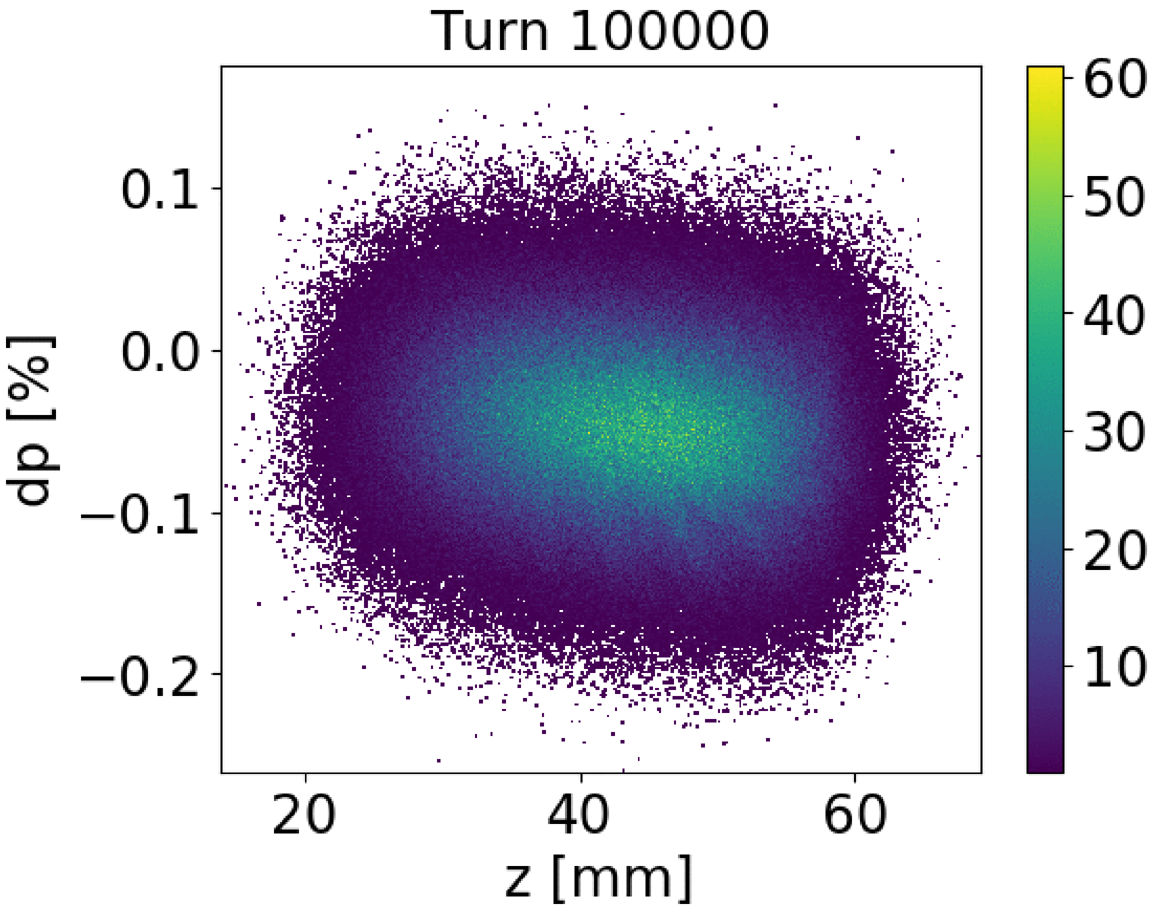


no collision → no beamstrahlung effect

The inclusion of beamstrahlung effect changes the bunch behaviour

Longitudinal microwave instability

Longitudinal phase space at $N_p = 26 \times 10^{10}$



The microwave instability makes the phase space longitudinal distribution to oscillate → the energy distribution is not constant over time

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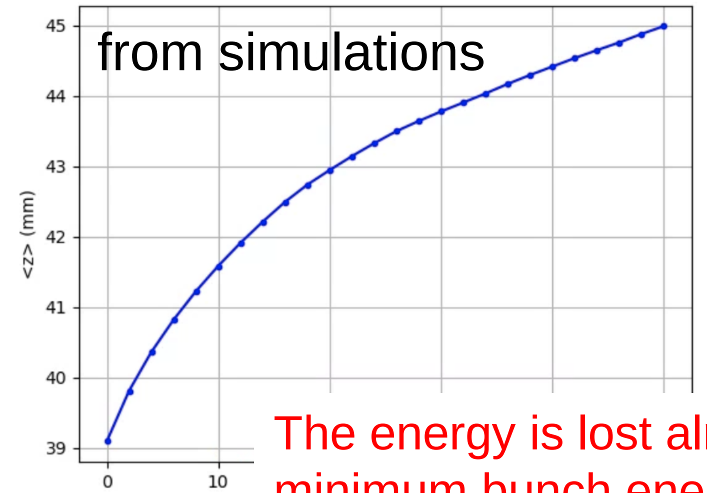
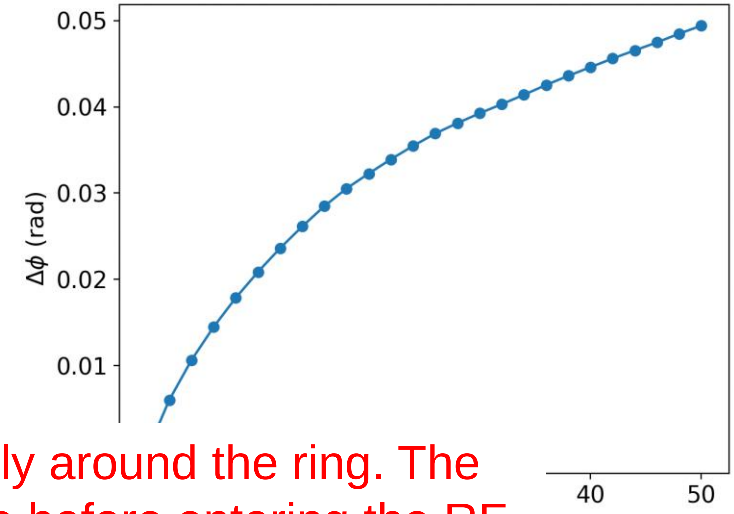
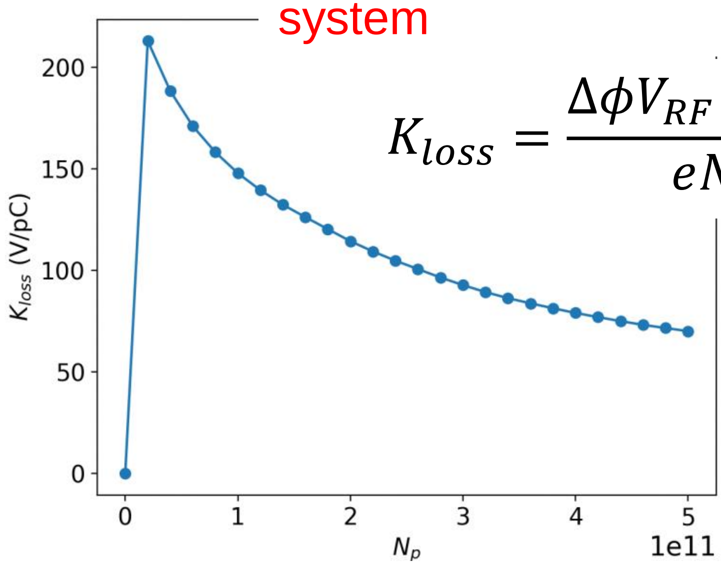
Loss factor and energy lost due to impedance

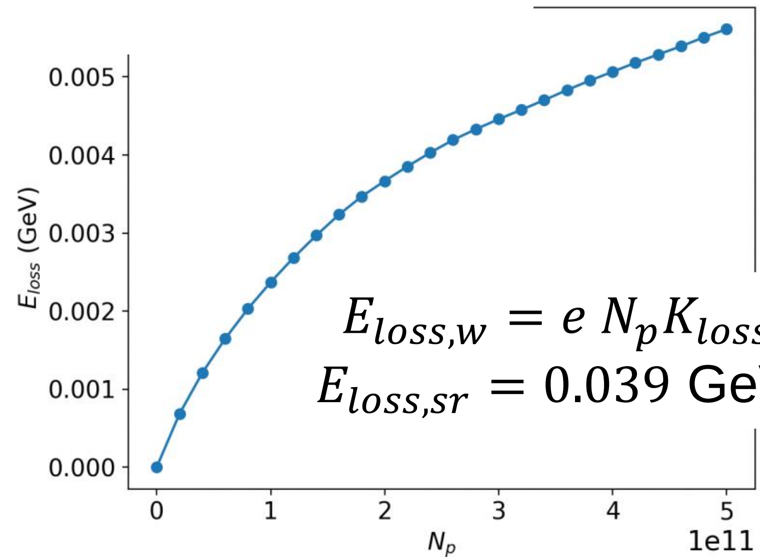




The energy is lost almost uniformly around the ring. The minimum bunch energy should be before entering the RF system

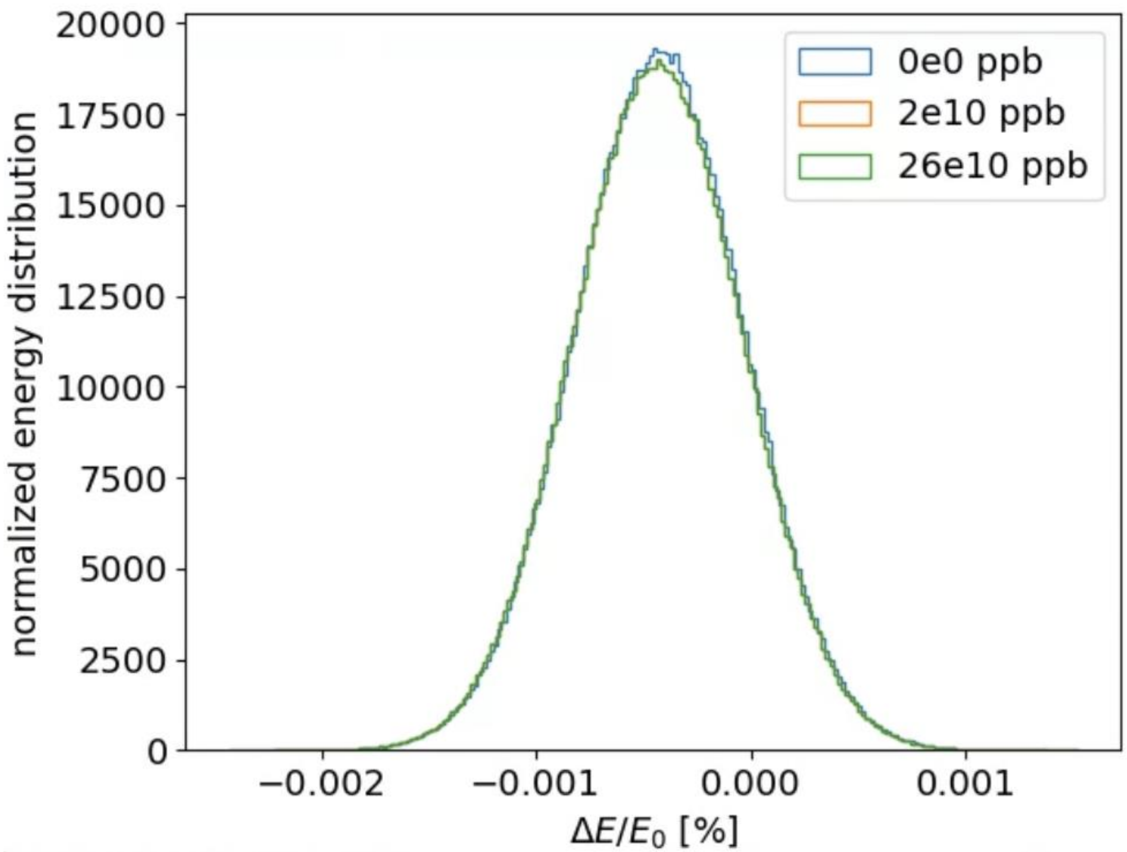


$$K_{loss} = \frac{\Delta\phi V_{RF} \cos\phi_s}{e N_p}$$



$$E_{loss,w} = e\, N_p K_{loss}$$
$$E_{loss,sr} = 0.039 \text{ GeV}$$

Energy distribution



NB: $E_{loss,w} \ll E_{loss,sr}$

The energy distribution, up to 26e10 ppb, is essentially not affected by the longitudinal wake, even if a weak microwave instability and small oscillations are observed.

The energy distribution is not centred around zero because PyHT considers the RF located at half of the machine, where only half of the energy lost by synchrotron radiation is considered.

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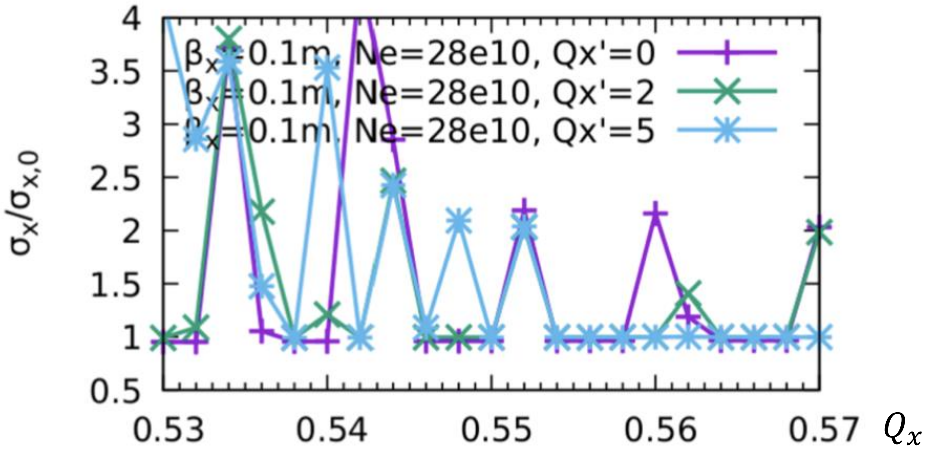
Beamstrahlung and longitudinal wakefield

Under collision the single bunch regime is different from that of single beam. No microwave instability is observed up to the nominal intensity, but there is an increase of the energy spread due to the beamstrahlung.

Also the bunch length is much longer in collision for the same reason. As a consequence, we also expect that the loss factor is lower. This kind of studies cannot be performed with PyHT.

In collision a critical aspect is the coherent X-Z instability, and a proper stable working point has to be found



Normalised horizontal beam size σ_x/σ_{x0} as a function of the horizontal tune for a bunch population of $Np = 2.8 \times 10^{10}$ (different chromaticities

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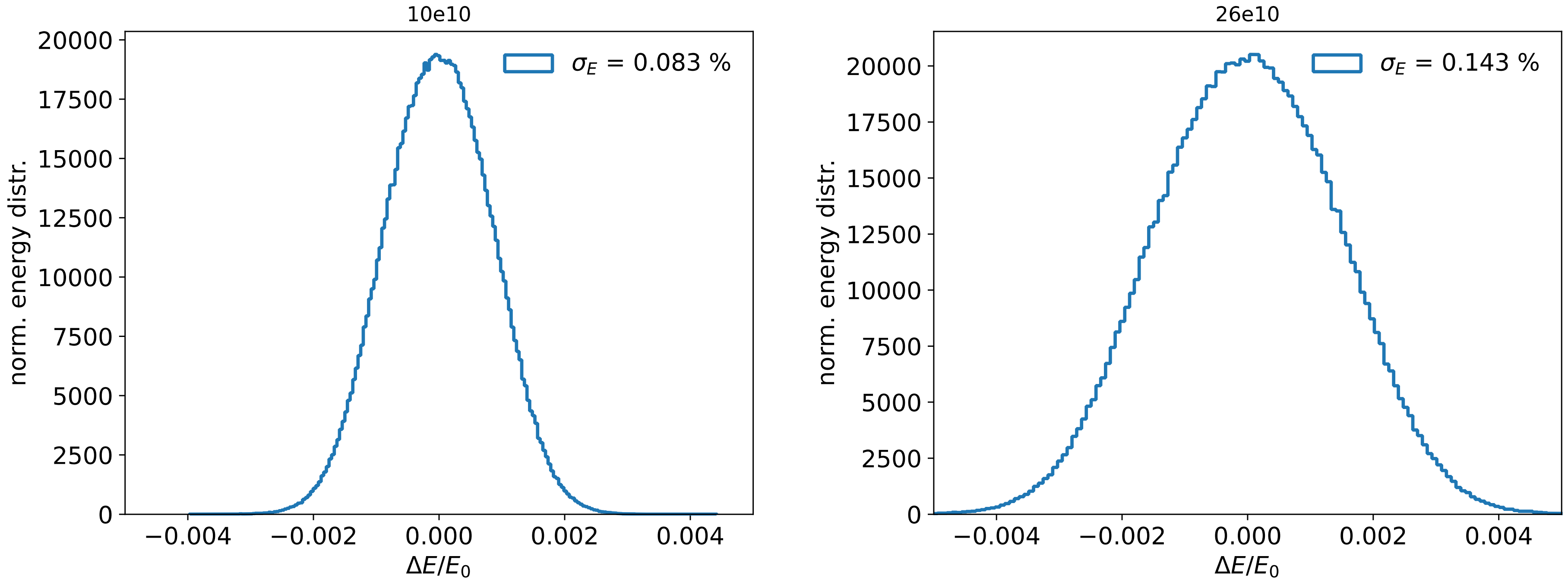
Energy distribution under collision

Nominal energy spread with beamstrahlung and without wakefield: 0.13%



Summary for Z-pole

	Pilot bunch (3×10^{10} ppb)	**Nominal intensity (2.6×10^{11} ppb)**	**Nominal intensity and beamstrahlung (2.6×10^{11} ppb)**	**SR**
Energy spread	0.039 %	0.045 %	0.143 %	0.039 %
Energy loss	0.8 MeV	4.2 MeV	~ 1.6 MeV	39 MeV
Bunch length	5 mm	8.3 mm	17.2 mm	4.4 mm

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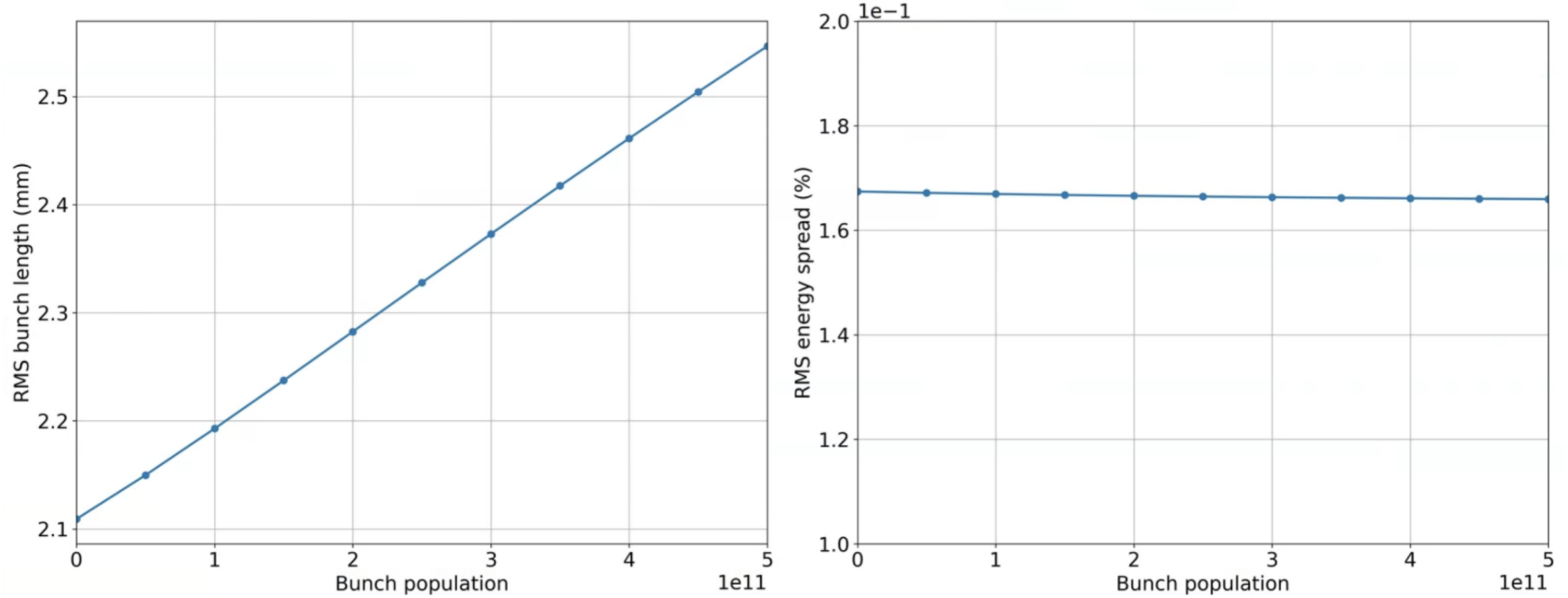
Energy distribution at ttbar

At ttbar, due to the high energy, the effect of longitudinal wakefield is much lower. Here we suppose to be without collision

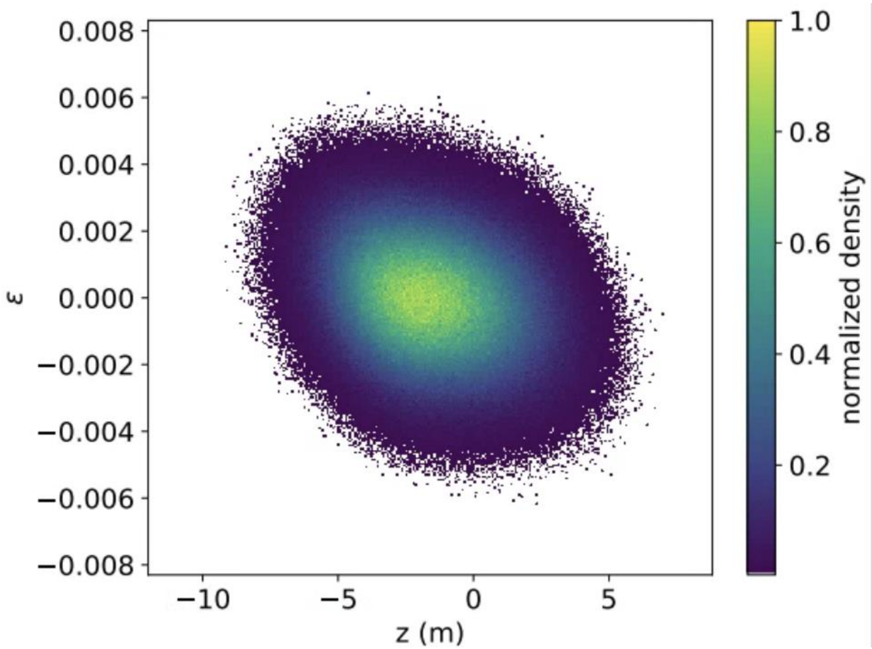


No microwave instability threshold is observed up to 50e10 ppb and the energy spread remains the same as the nominal one.
NB: simulations give a natural energy spread a bit higher than that of the parameter list: 0.167 % instead of 0.157 %, maybe due to some approximation in the damping time.

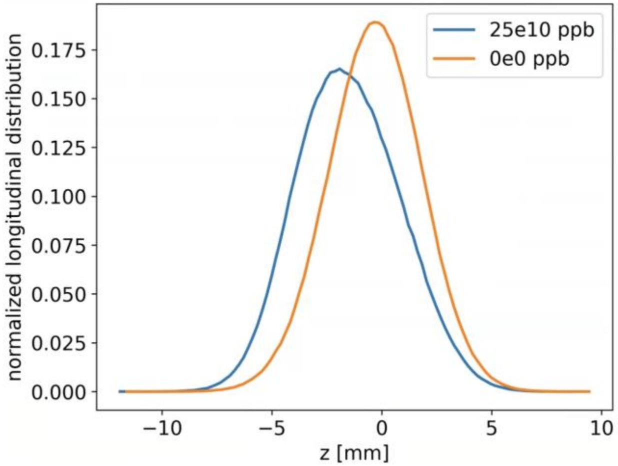
Energy distribution at ttbar

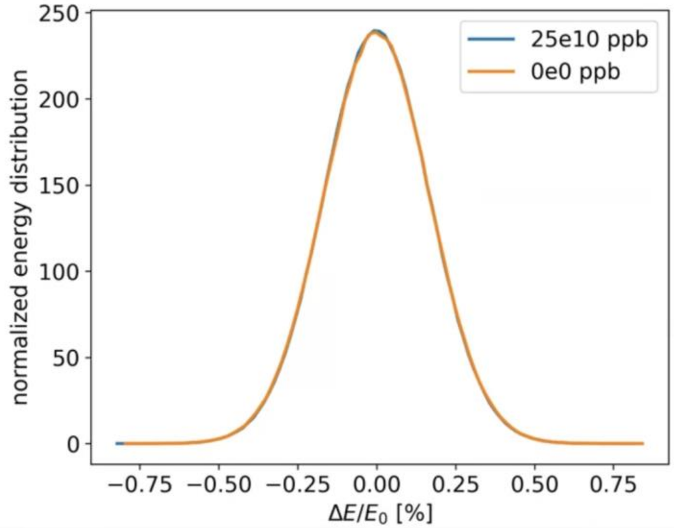
$N_p = 25 \times 10^{10}$ ppb

The bunch centre of mass changes by about 1.2 mm. This has to be compared with 4.5 mm of the Z-pole
$\rightarrow E_{loss,w} \ll E_{loss,SR}$



Phase space is a bit distorted due to the potential well distortion





The energy spread is unchanged

Conclusions

- We have not found important sources giving rise to strong localized longitudinal impedances
- The main sources, so far, are the RW and the bellows uniformly distributed
- The energy loss due to the interaction of the beam with the real part of the impedance is almost linear along the machine, and it is about a factor 10 lower than that due to the synchrotron radiation (at nominal intensity)
- With single beam, at nominal intensity, we have found a weak microwave instability that makes the bunch to oscillate a bit, also in energy
- The increase of energy spread, so far, is almost negligible with respect to the nominal one
- In collision, the beamstrahlung, which is influenced by the longitudinal wakefield, changes the energy distribution, which depends on the bunch population
- A study of energy spread, bunch length and loss factor vs intensity in collision cannot be performed with PyHT
- At ttbar the effect of the longitudinal wakefield, so far, is almost negligible
- All the results can change since the longitudinal wakefield is not complete, yet

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Thank you for your attention