Beam dynamics studies with a 3rd harmonic cavity for the ESRF EBS

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OUTLINE

- Touschek lifetime for ESRF Extremely Brilliant Source (EBS)
- bunch lengthening with 3rd harmonic cavity
- bunch lengthening with impedance and 3rd harmonic cavity
- optimum voltage of harmonic cavity
- effect of 3rd harmonic cavity on dynamic aperture

FILLING MODES FOR ESRF EBS

filling mode	I_{tot} (mA)	number of bunches	I_b (mA)	ε_y (pm)	delivery time
Multi-bunch	200	868	0.23	5	~70%
16 bunches	90	16	5.6	5	~25%
4 bunches	40	4	10	5	~5%

The most critical modes for the Touschek lifetime are the ones with high current per bunch (4B and 16B).

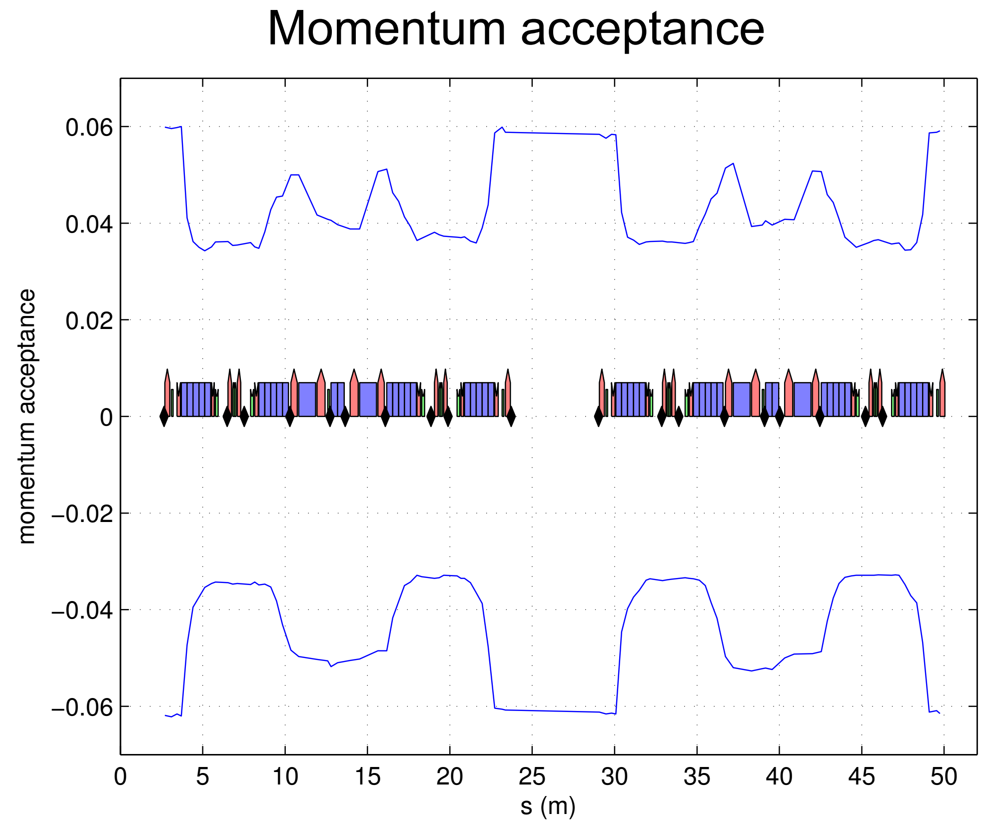
TOUSCHEK LIFETIME WITHOUT HARMONIC CAVITY

Without harmonic cavity, with impedance of 0.35 Ω, the Touschek lifetime for the three modes are:

MB: 20 h

16B: 1.9 h

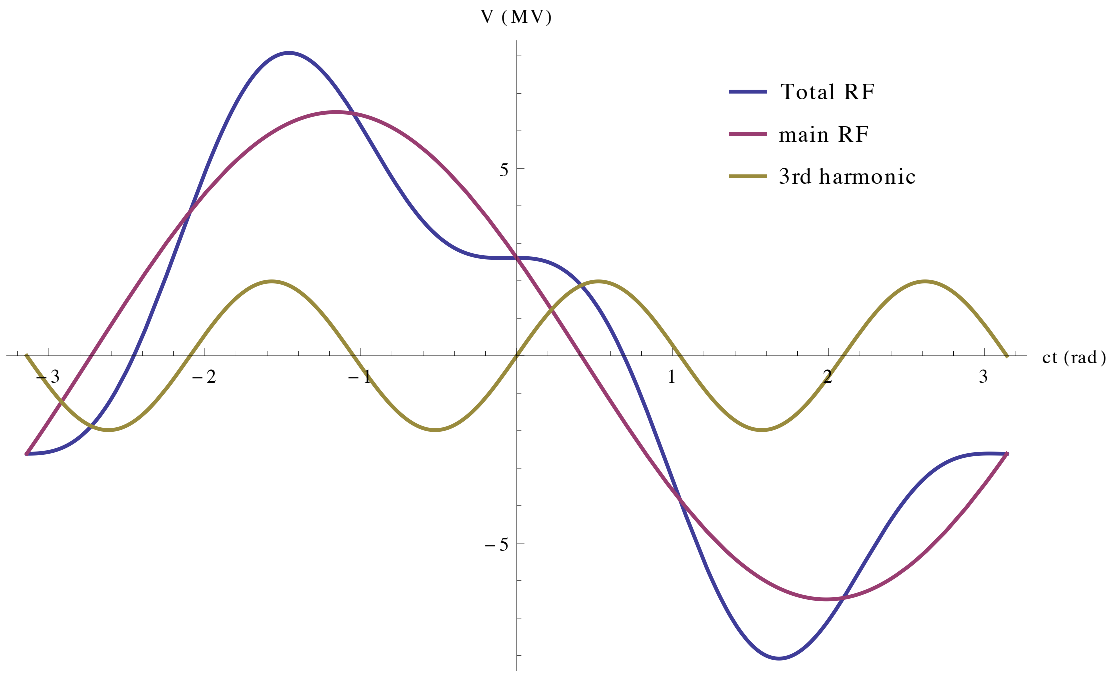
4B: 1.3 h



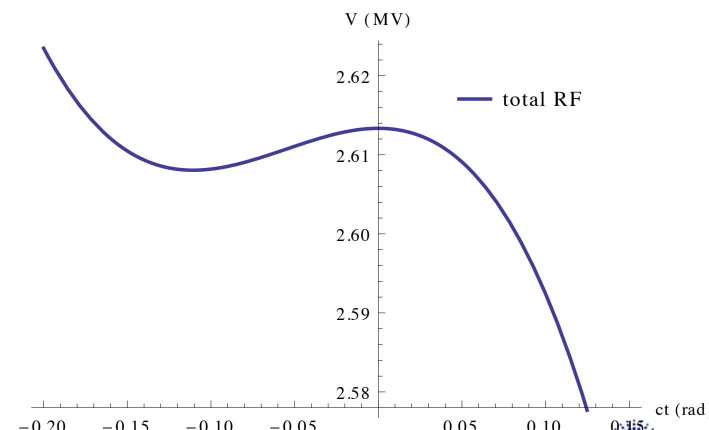
A possible upgrade of the ESRF EBS will be the installation of a third harmonic cavity to increase LT in few bunch mode.

3RD HARMONIC CAVITY: PHASE AND VOLTAGE

The superconductive harmonic cavity will be passive and almost exactly in phase with the beam. We can simulate it with the Accelerator Toolbox (AT). A small detuning with the beam is used to control the voltage of the cavity.

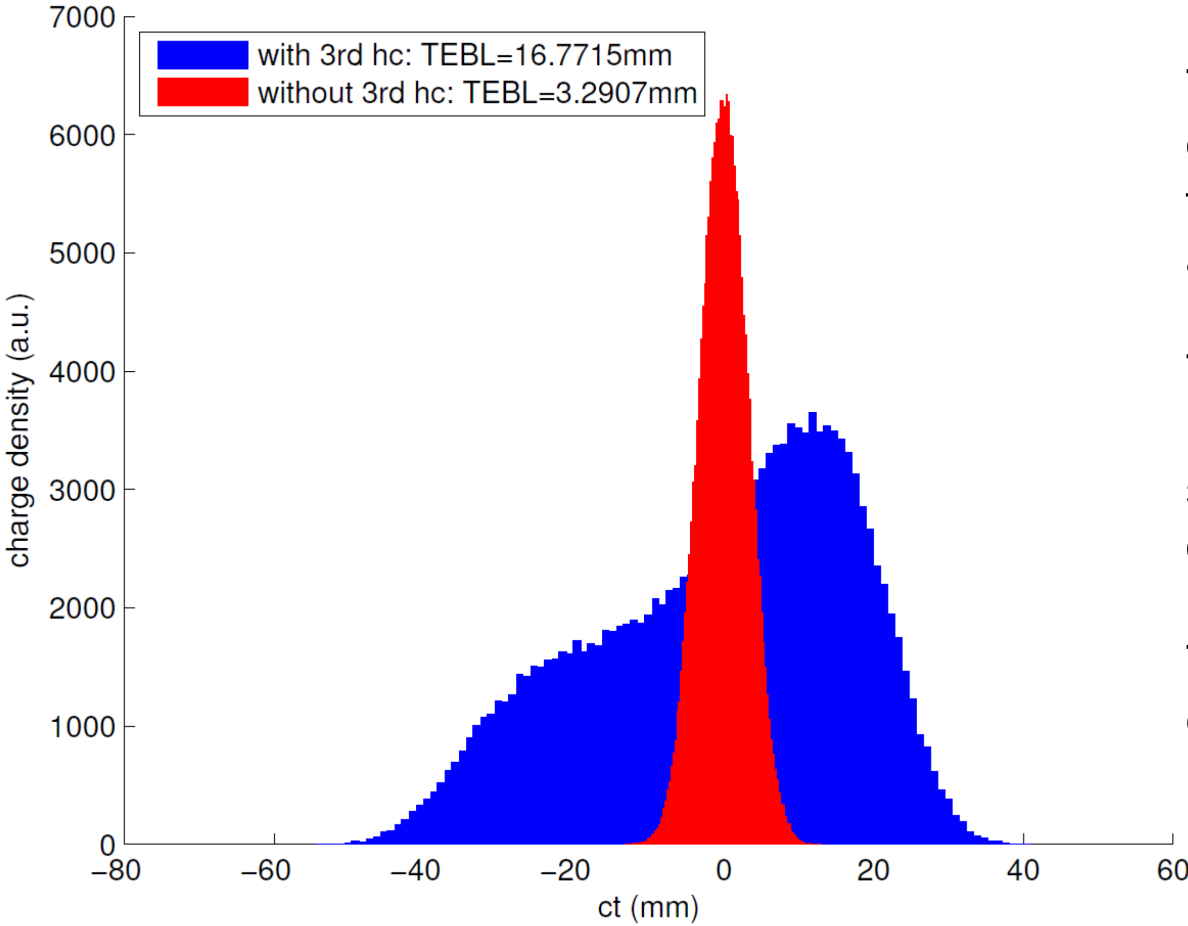


The phase of the HC is not the optimum one and the second derivative of the RF signal is not 0.



With 6.5 MV, the HC voltage is 1.98 MV

EQUILIBRIUM LONGITUDINAL BUNCH DISTRIBUTION



Tracking is done with radiation damping and quantum fluctuation, for 24000 turns and ~10^5 particles, using AT.

The equilibrium distribution is not gaussian and not symmetric, due to the not optimal phase of the HC.

The phase of the HC is set at each turn to the bunch phase.

TOUSCHEK EFFECTIVE BUNCH LENGTH (TEBL)

We need to compute the effective bunch length for the Touschek lifetime when the bunch is not gaussian, assuming no correlation between longitudinal and transverse distribution.

In Piwinski formula:

$$\frac{1}{\tau} \propto \int \rho^2(x,y,z)dxdydz$$

For a gaussian beam:

$$g(z) = \frac{1}{\sqrt{2\pi}\sigma_z} e^{-\frac{z^2}{2\sigma_z^2}}$$

$$\int g(z)dz = 1$$

$$\frac{1}{\tau} \propto \frac{1}{8\pi^{\frac{3}{2}}\sigma_x\sigma_y\sigma_z}$$

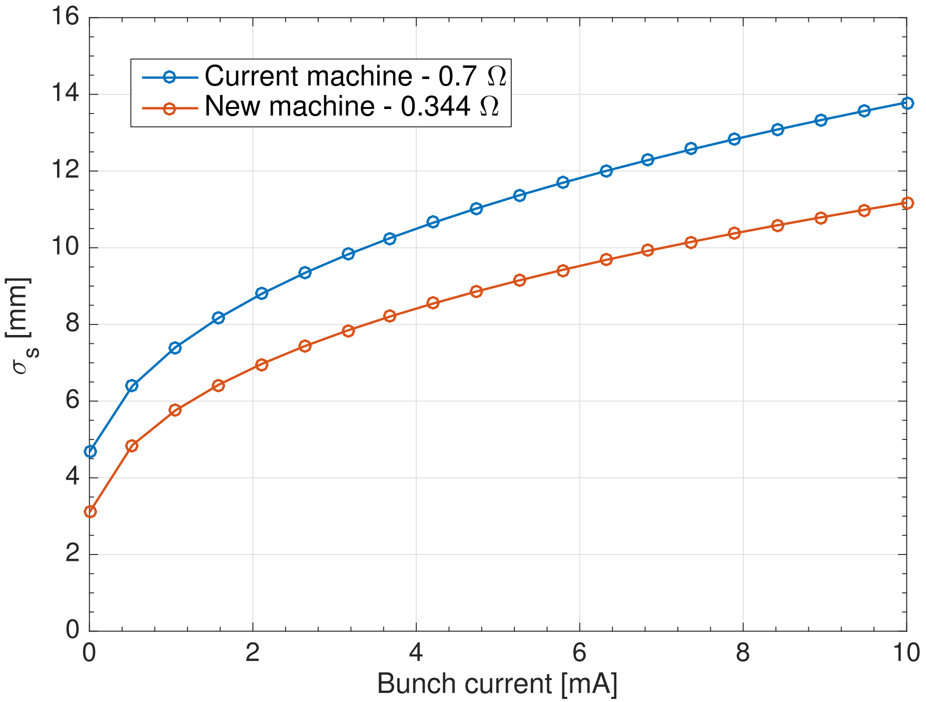
If g(z) is an arbitrary f(z):

$$\frac{1}{2\sqrt{\pi}\sigma_z} \Rightarrow \int f^2(z)dz$$

$$\boxed{\sigma_{zTE} = \frac{1}{2\sqrt{\pi}\int f^2(z)dz}}$$

Courtesy of B. Nash

BUNCH LENGTHENING DUE TO IMPEDANCE

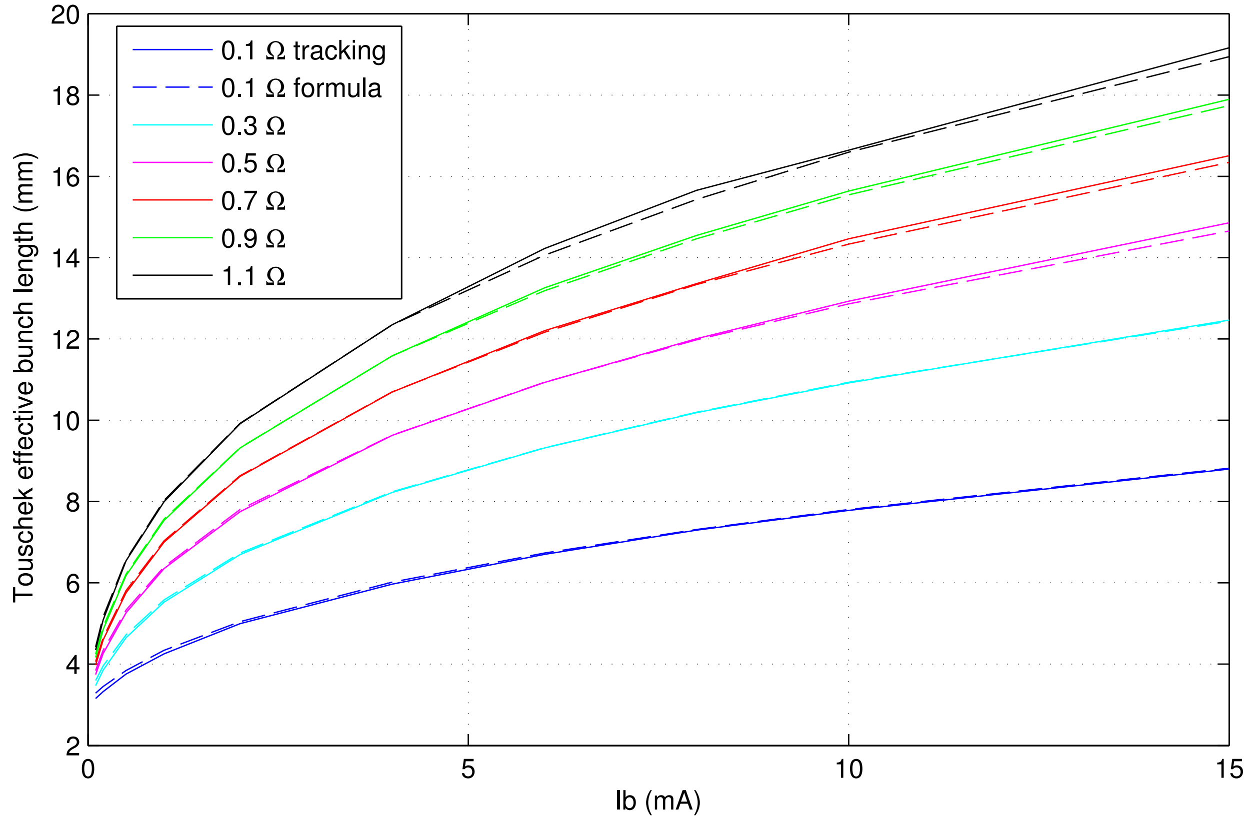


The bunch length with impedance of ESRF-EBS is always shorter than in the present machine, due to smaller impedance and shorter zero-current bunch length.

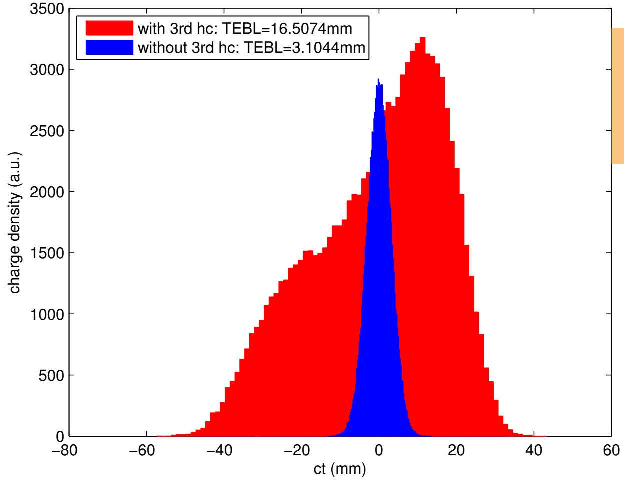
BUNCH LENGTHENING DUE TO IMPEDANCE: AT PASS METHOD

We want to simulate the bunch lengthening with both the effect of impedance and the effect of the harmonic cavity.

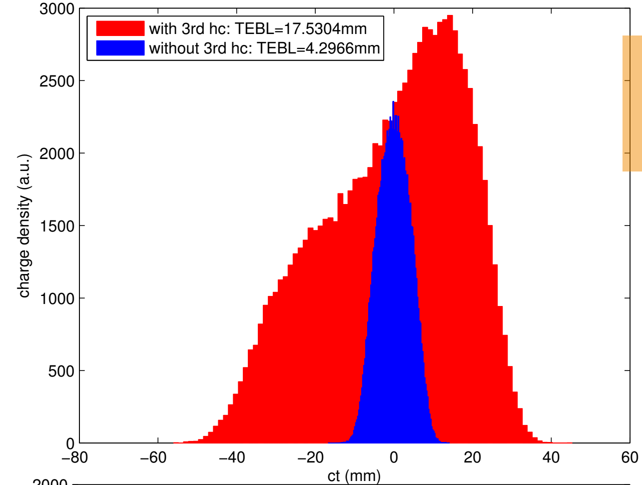
S. White has implemented an inductive impedance element for the Accelerator Toolbox, which agrees with Haissinski equation.



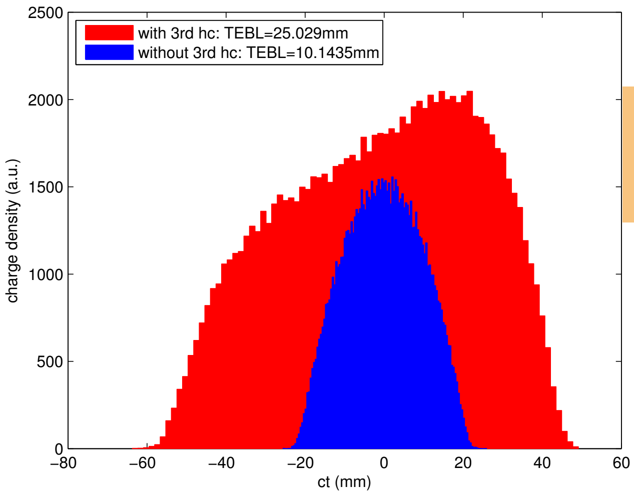
3RD HARMONIC CAVITY AND 0.35 Ω IMPEDANCE



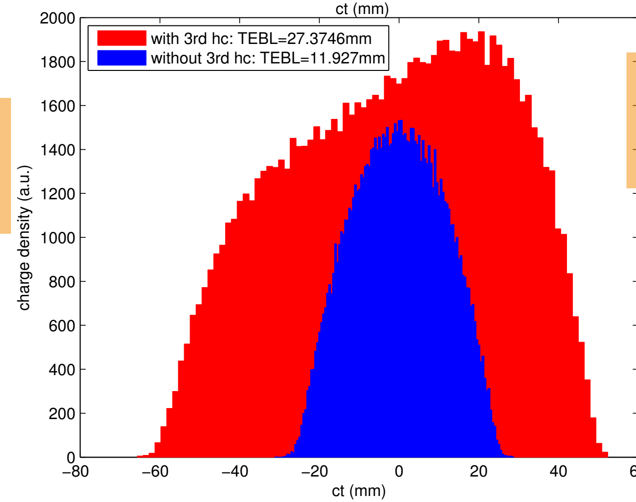
0 current
σ_{HC}=5.3 σ_{noHC}



MB current
σ_{HC}=4.1 σ_{noHC}

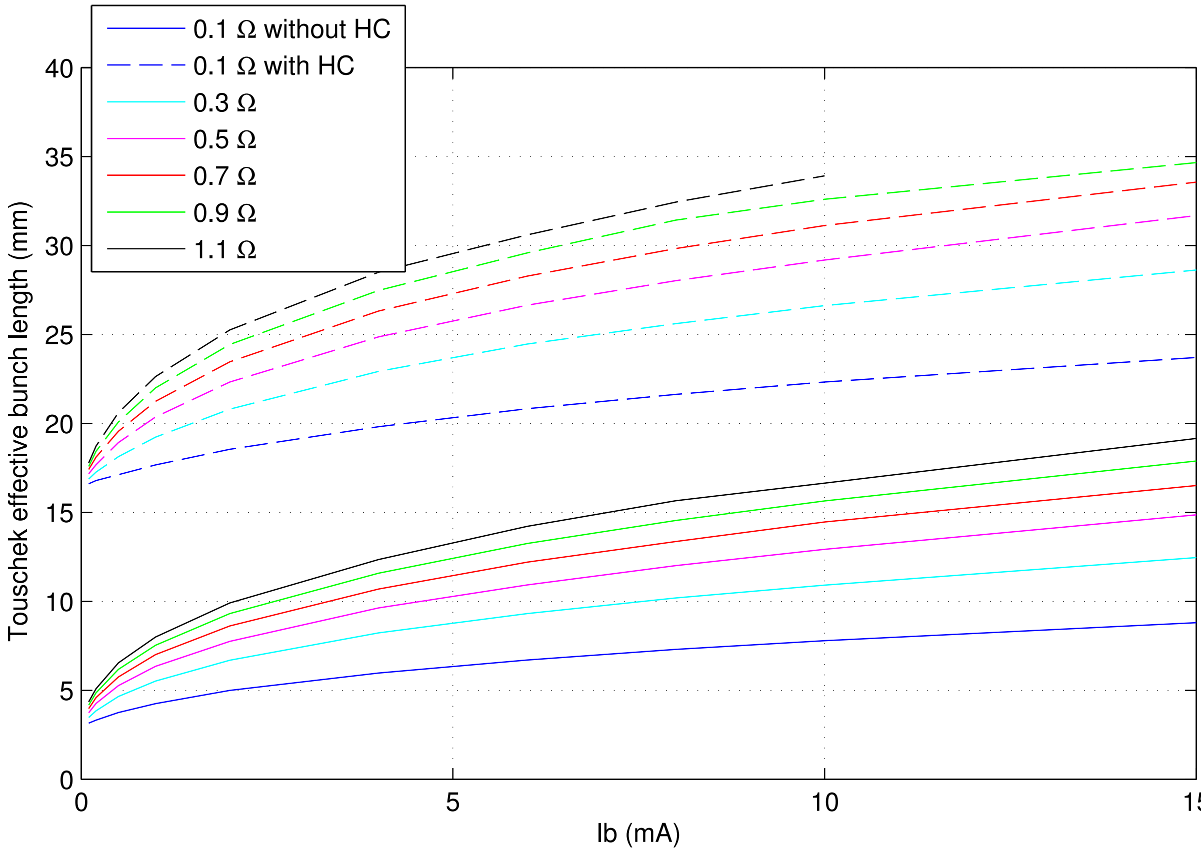


16B current
σ_{HC}=2.5 σ_{noHC}

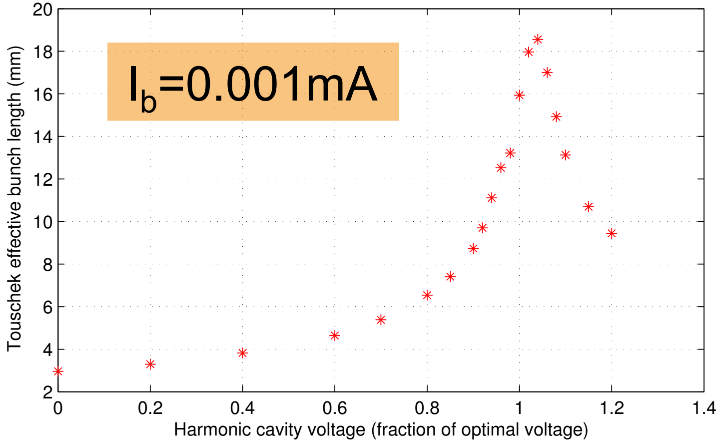


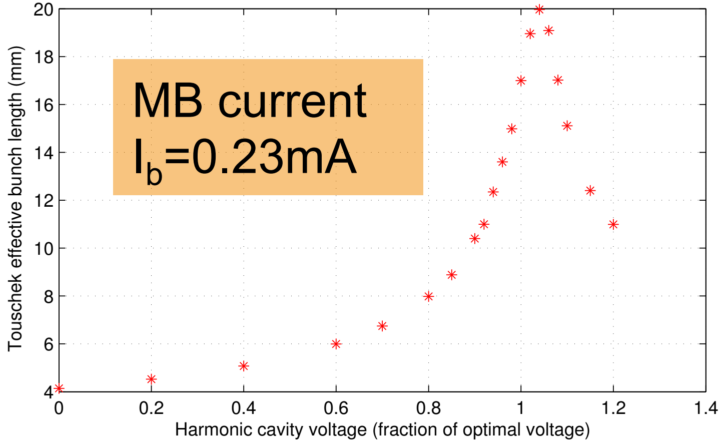
4B current
σ_{HC}=2.3 σ_{noHC}

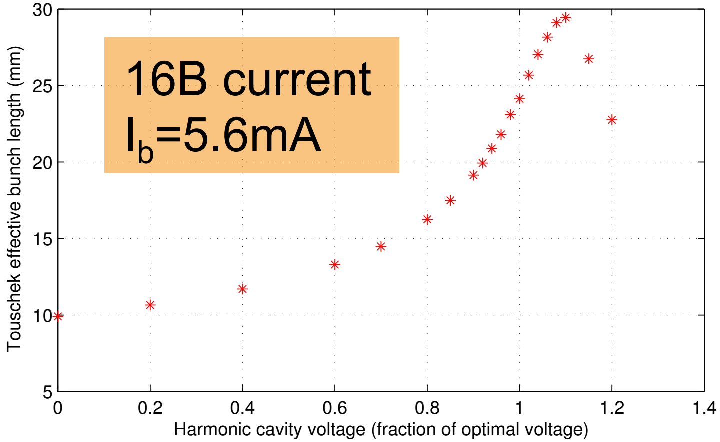
The gain in Touschek effective bunch length with the harmonic cavity is smaller if there is also bunch lengthening due to impedance.

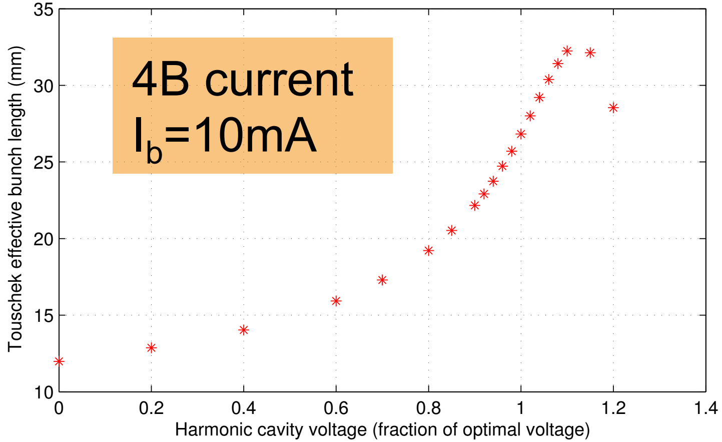


OPTIMUM VOLTAGE OF THE HARMONIC CAVITY



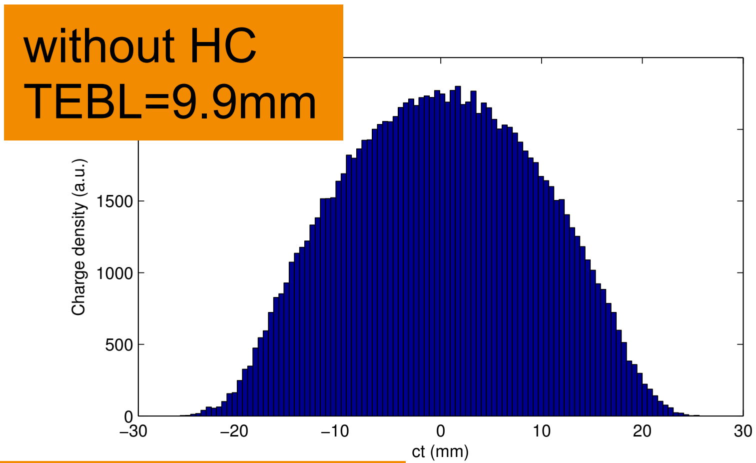


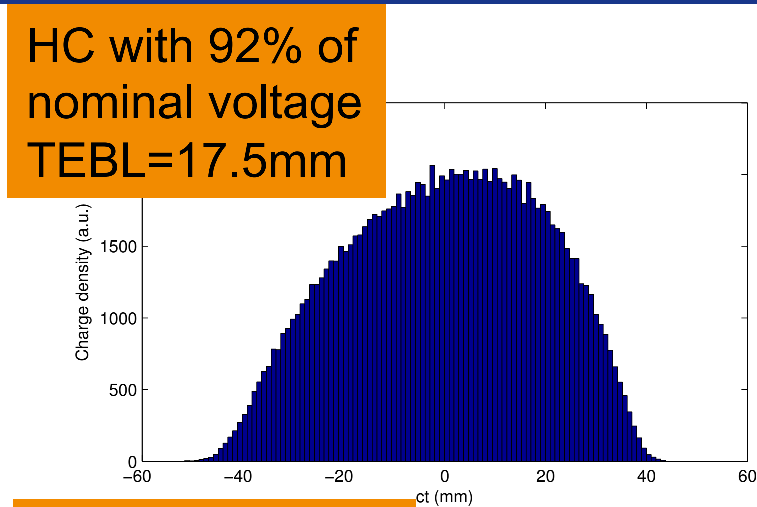


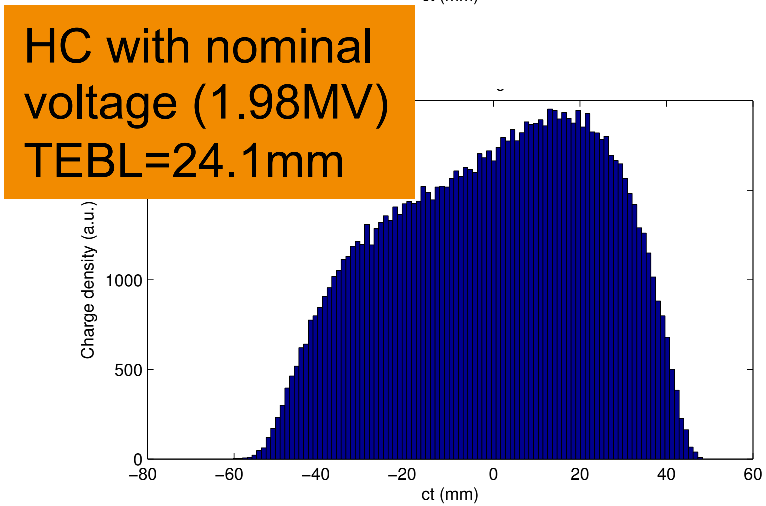


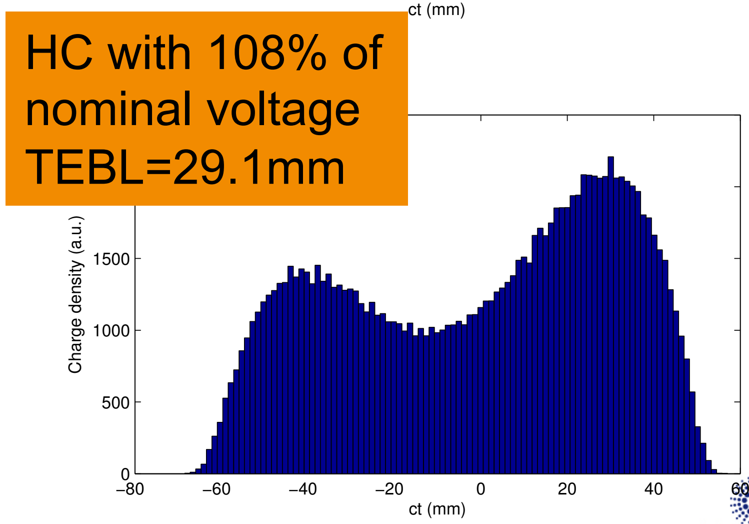
The nominal voltage for 6.5 MV in the main cavities is 1.98MV.

LONGITUDINAL BUNCH DISTRIBUTION WITH DIFFERENT HC VOLTAGE 16B CURRENT







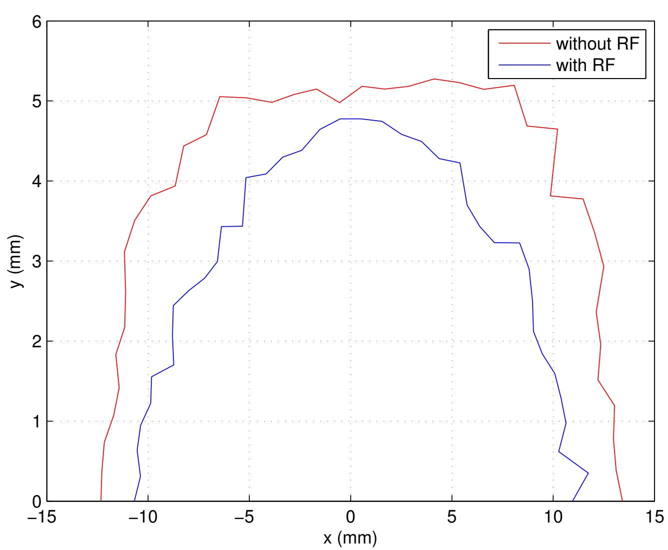


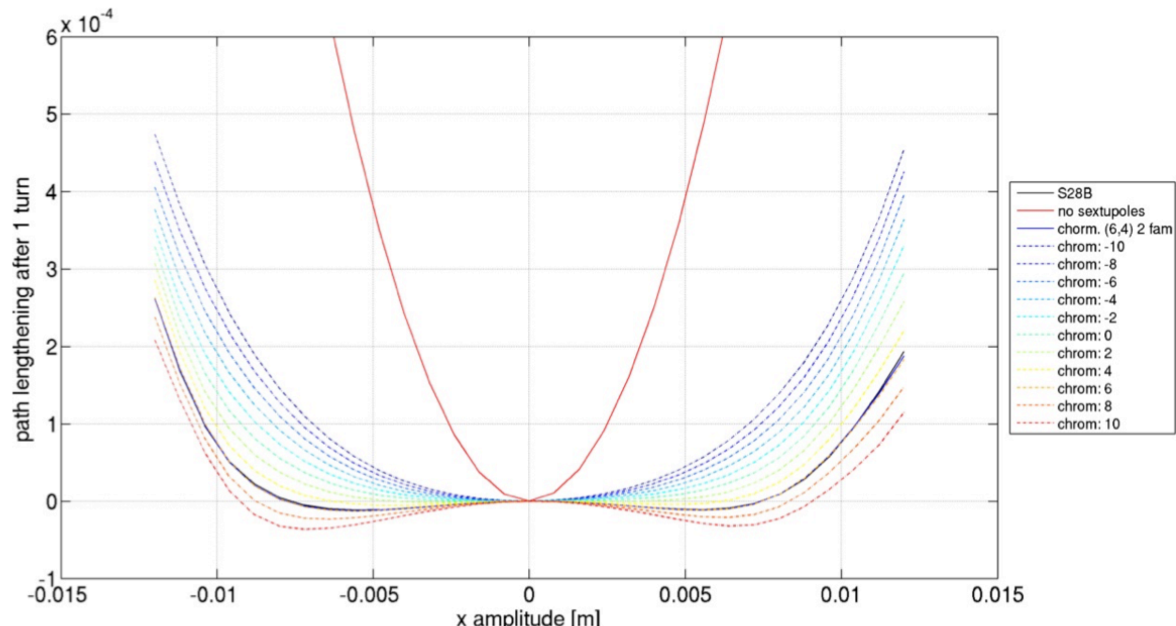
PATH LENGTHENING WITH AMPLITUDE AND CHROMATICITY

On-energy dynamic aperture is substantially smaller if the RF cavity is on.

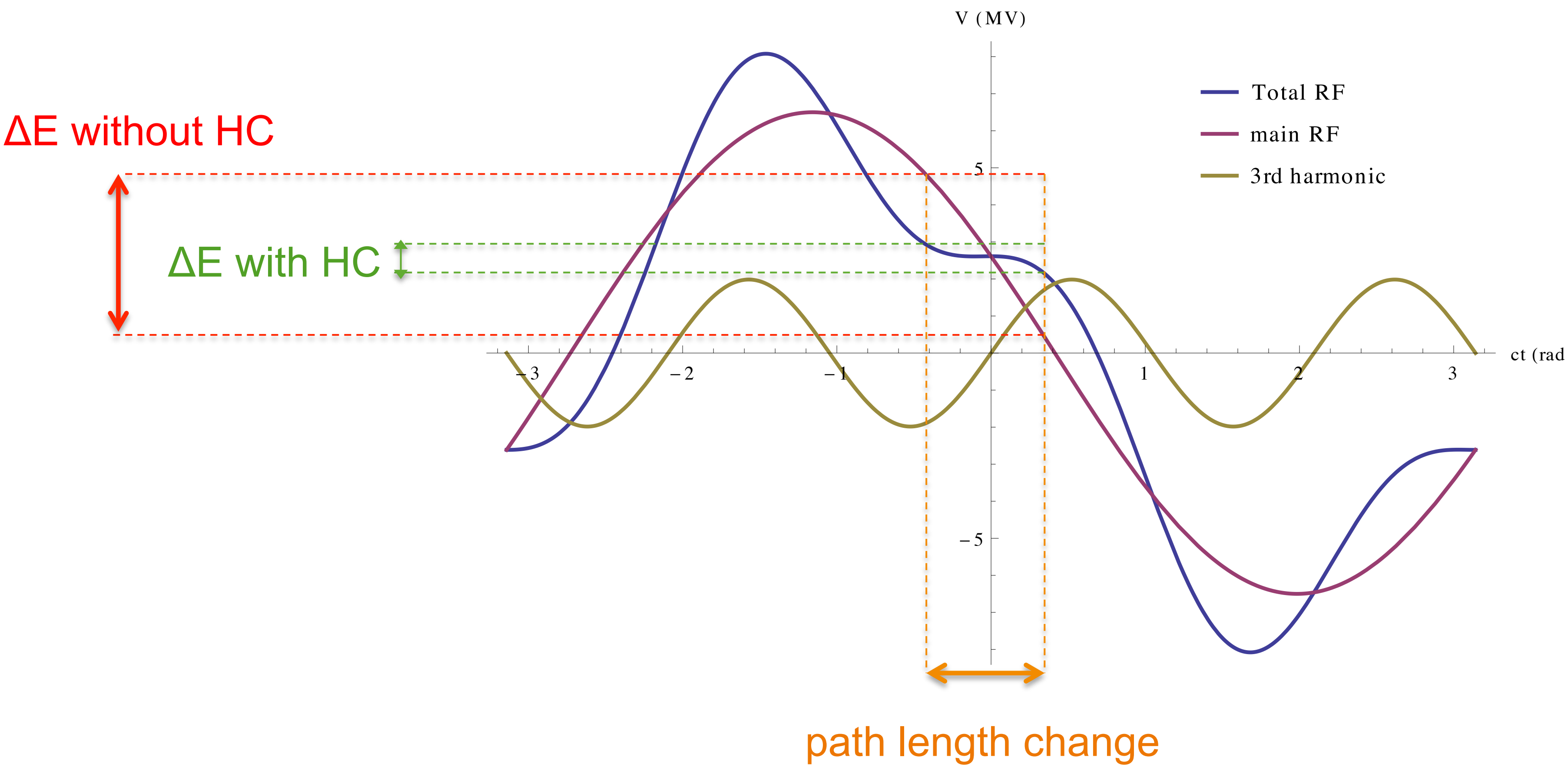
Particles with large amplitude have a longer trajectory and arrive later to the cavity, so they change their energy.

The effect can be reduced changing the chromaticity: high chromaticity is beneficial to reduce the path lengthening with amplitude in ESRF EBS lattice.

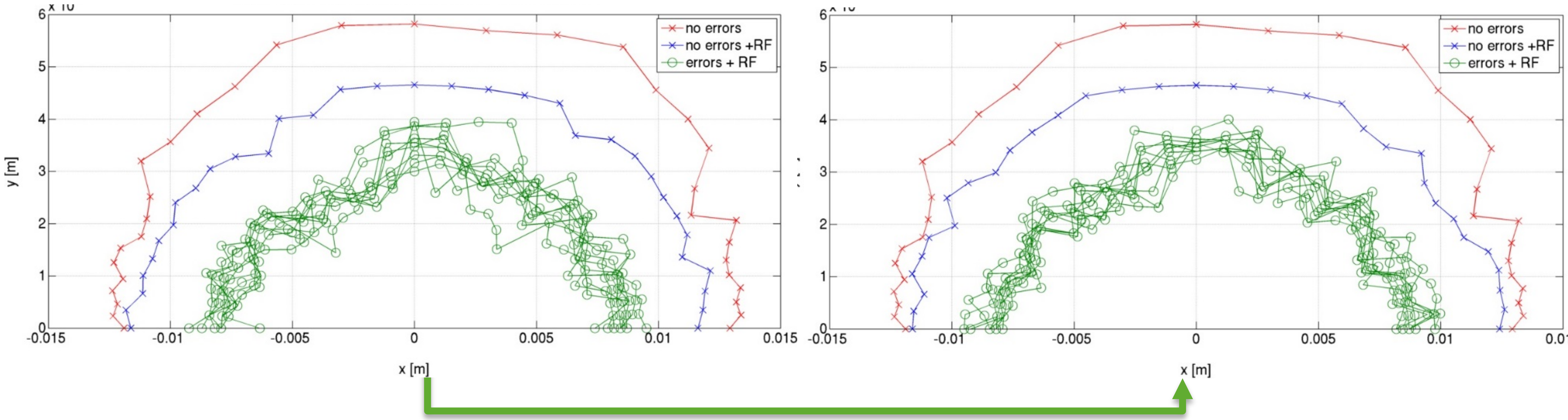




PATH LENGTHENING AND HARMONIC CAVITY



EFFECT OF THE HARMONIC CAVITY ON THE DYNAMIC APERTURE



Harmonic cavity 3rd order

	D.A.	Injection efficiency		
		(120,5) nm	(60,5) nm	(30,30) nm
Nominal	-8.2 +/- 0.4	63.8	85.6	95.4
+ Harmonic Cavity	-8.7 +/- 0.6	87.8	98.3	99.6

Courtesy of S. Liuzzo

CONCLUSION

- **Touschek lifetime for ESRF EBS can be increased with a harmonic cavity, that increases the Touschek effective bunch length, by a factor**

  - 2.3 for 4B mode

  - 2.5 for 16B mode

  - 4.1 for MB mode

- **the gain could be larger if we accept a doubled peak bunch**
- **the harmonic cavity increases the on-energy dynamic aperture and the injection efficiency**


MANY THANKS FOR YOUR ATTENTION