LONGITUDINAL BEAM DYNAMICS IN e^- RINGS IN THE STRONG RF FOCUSING REGIME

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OUTLINE

1) Strong RF focusing in storage rings

   1.1) Proposal of a bunch length modulation experiment in DAFNE

2) SPIDER: Beam dynamics simulation code

   2.1) Beam pipe wake field model

   2.2) Coherent synchrotron radiation (CSR) wake field model

   2.3) Cavity wake field model

3) Beam dynamics simulations in the DAFNE BLM experiment

4) Conclusions

1) STRONG RF FOCUSING IN STORAGE RINGS

(Gallo & al. DAFNE TECH.NOTE G60(2003), Biscari PRST AB 8,2005)

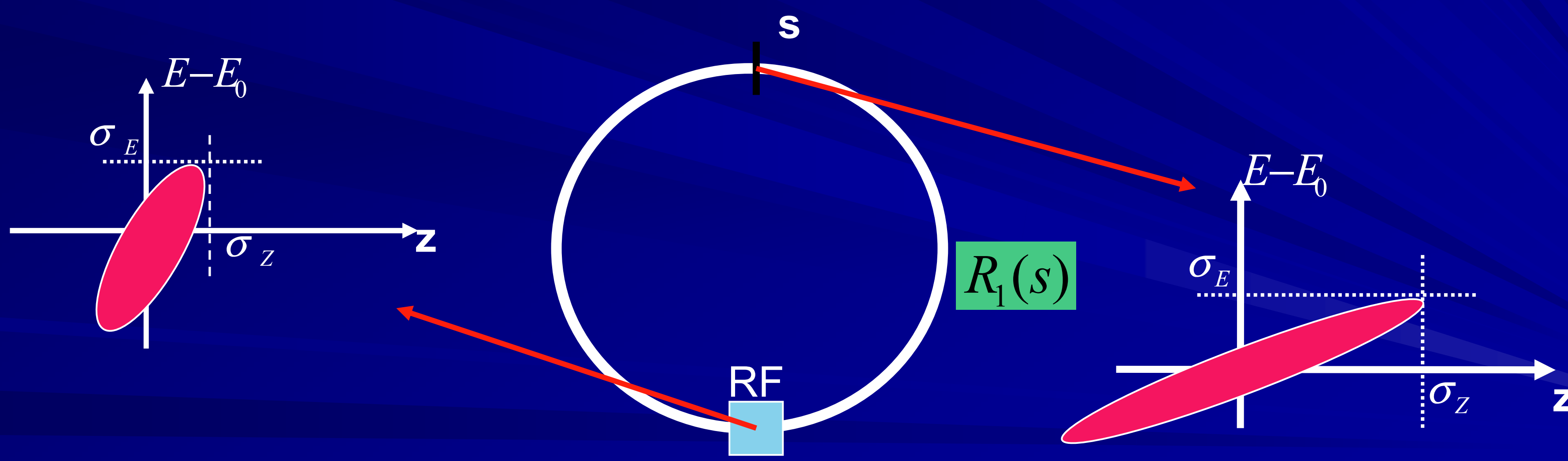
It is a way to obtain short bunches at a given position in storage rings

It can be reached by a lattice with large dispersion in dipoles and high rf gradient

$$R_1(s) = \int_{s}^{s_{RF}} \eta(s')/\rho(s')ds'$$

$$U = 2\pi\, \mathrm{V_{RF}}/(\mathrm{E_0}\lambda_{\mathrm{RF}})$$

Under these conditions and at zero current the energy spread of the bunch is constant but bunch length changes along the ring (bunch length modulation)



The bunch length modulation can be achieved with different lattices (R1 monotonic along the ring or not, obtaining different results.)

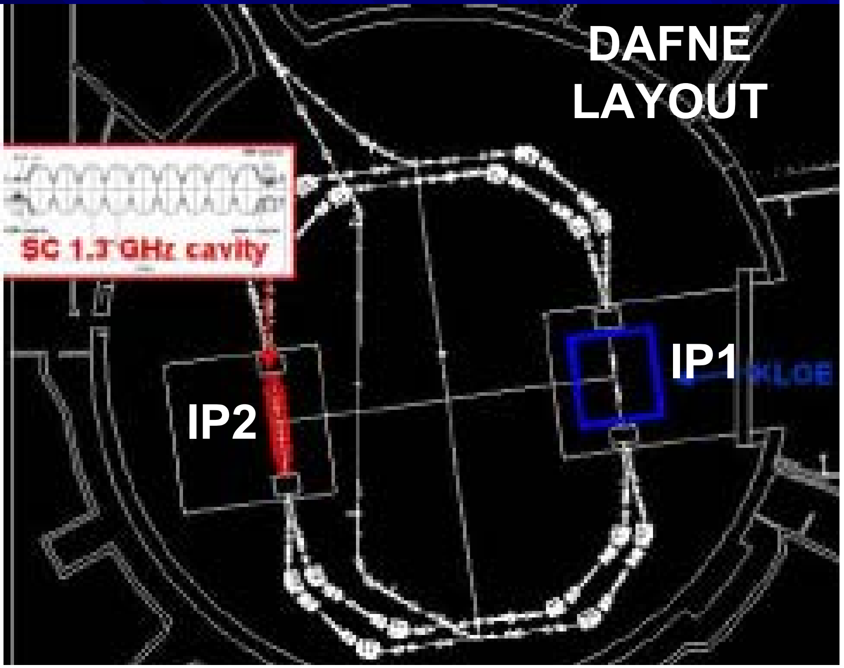
1.1) BUNCH LENGTH MODULATION EXPERIMENT IN DAFNE

(Biscari & al. PAC 2005)

In DAFNE a BLM experiment is realizable installing one additional SC RF cavity in the IP2 region. Three cases have been studied:

A: R1 monotonic;

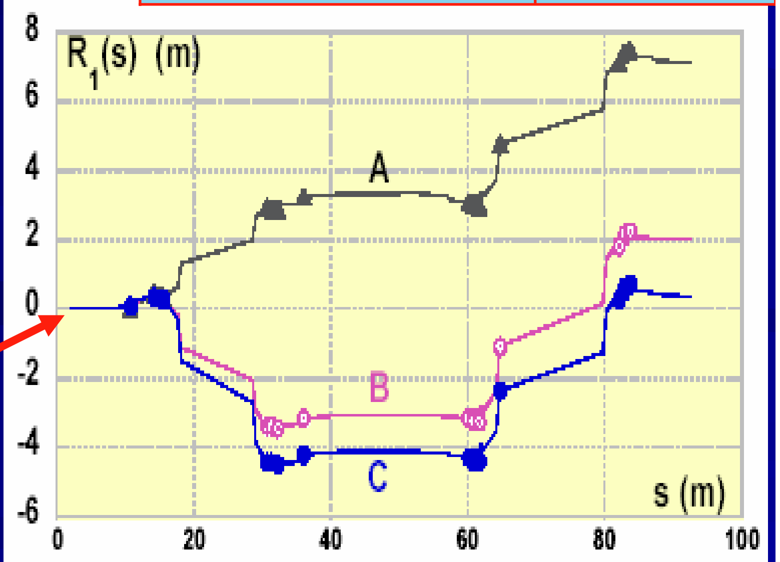
B and C: R1 non-monotonic

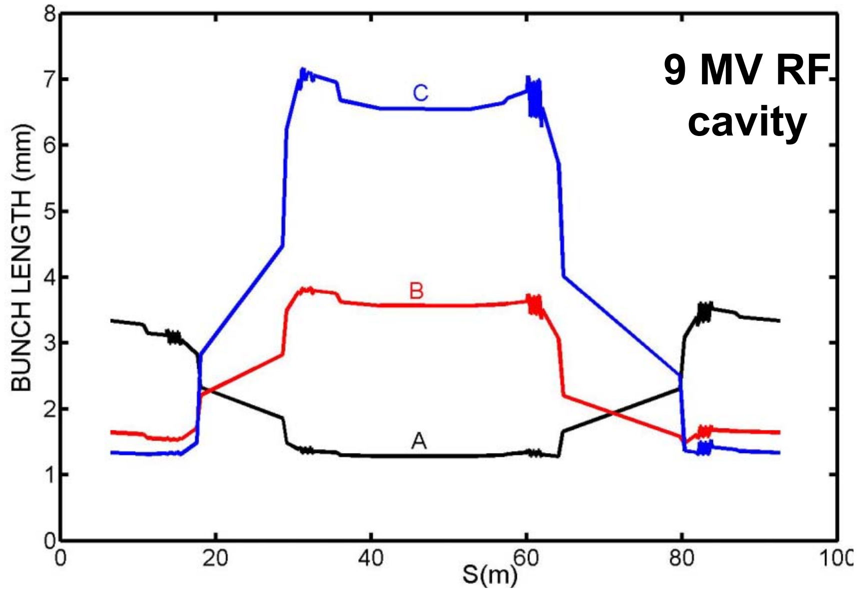


Parameters of the BLM lattices in DAFNE

Energy	510 MeV
length	97.69 m
Momentum compaction factor	0.073(A) 0.02(B) 0.004(C)
SC RF voltage (TESLA-like cavity)	up to 9 MV
SC RF frequency	1.3 GHz
Harmonic number	423

SC RF cavity position



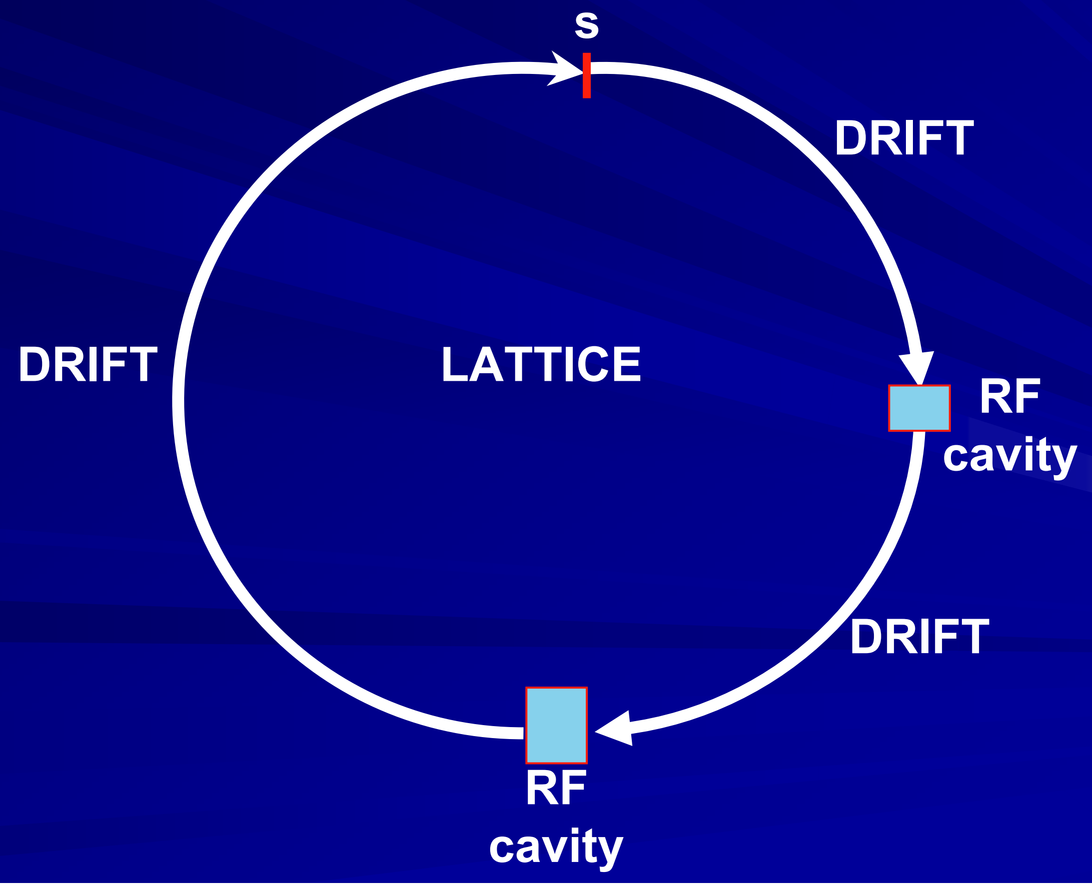


2) SPIDER CODE (1/3)

The effects of the wake fields and CSR in case of BLM have been studied by dedicated simulation code SPIDER (Simulation Program for Impedances Distributed along Electron Rings) C. In the code

a) ***The machine is divided into an arbitrary number of longitudinal drift spaces between RF cavities***

b) ***Impedances are localized in each section***



SPIDER CODE (2/3)

c) The bunch is described by N ***macroparticles*** **(N =** $1.5 \cdot 10^5$ **);**

For each turn and for each section (drift space or RF cavity) the longitudinal phase space coordinates:

$\varepsilon = E - E_0$ and *z: displacement from the synchronous particle*

of each macroparticle are calculated under the effect of the incoherent and coherent synchrotron radiation and the pipe wakefield;

$z(s_1); \varepsilon(s_1)$ → RF CAVITY → $z(s_2); \varepsilon(s_2)$

$$\begin{cases} z(s_2) = z(s_1) \\ \varepsilon(s_2) = \varepsilon(s_1) + V_{cav}(z(s_2)) + V_{RF}\cos(\phi - 2\pi f_{RF} z(s_1)) \end{cases}$$

$V_{cav}(z(s_2))$	Energy loss due to cavity wake
ϕ	Synchronous phase
V_{RF}	RF cavity peak voltage
f_{RF}	RF cavity frequency

SPIDER CODE (3/3)

$z(s_1);\varepsilon(s_1)$

DRIFT SPACE

$z(s_2);\varepsilon(s_2)$

$$\begin{cases} z(s_2) = z(s_1) - R_1(s_2;s_1)\varepsilon(s_1)/E_0 \\ \varepsilon(s_2) = \varepsilon(s_1) + V_{CSR}(z(s_2)) + V_{pipe}(z(s_2)) - U_0(s_2;s_1) - D(s_2;s_1)\varepsilon(s_1) + G\sigma_E(s_2;s_1)\sqrt{2D(s_2;s_1)} \end{cases}$$

Contribution of incoherent synchrotron radiation

$R_1(s_2;s_1) = \int_{s_1}^{s_2} \eta(s')/\rho(s')ds'$ Drift function

$U_0(s_2;s_1) = 1.4 \cdot 10^{-32} E_0^4 I_2(s_2;s_1)$ Energy radiated by synchronous particle

$D(s_2;s_1) = 1.4 \cdot 10^{-32} E_0^3 \left(2I_2(s_2;s_1) + I_4(s_2;s_1)\right)$ Damping factor

$\sigma_E(s_2;s_1) = 1.2 \cdot 10^{-12} E_0^2 \sqrt{\dfrac{I_3(s_2;s_1)}{2I_2(s_2;s_1) + I_4(s_2;s_1)}}$ Natural energy spread without BLM in the section

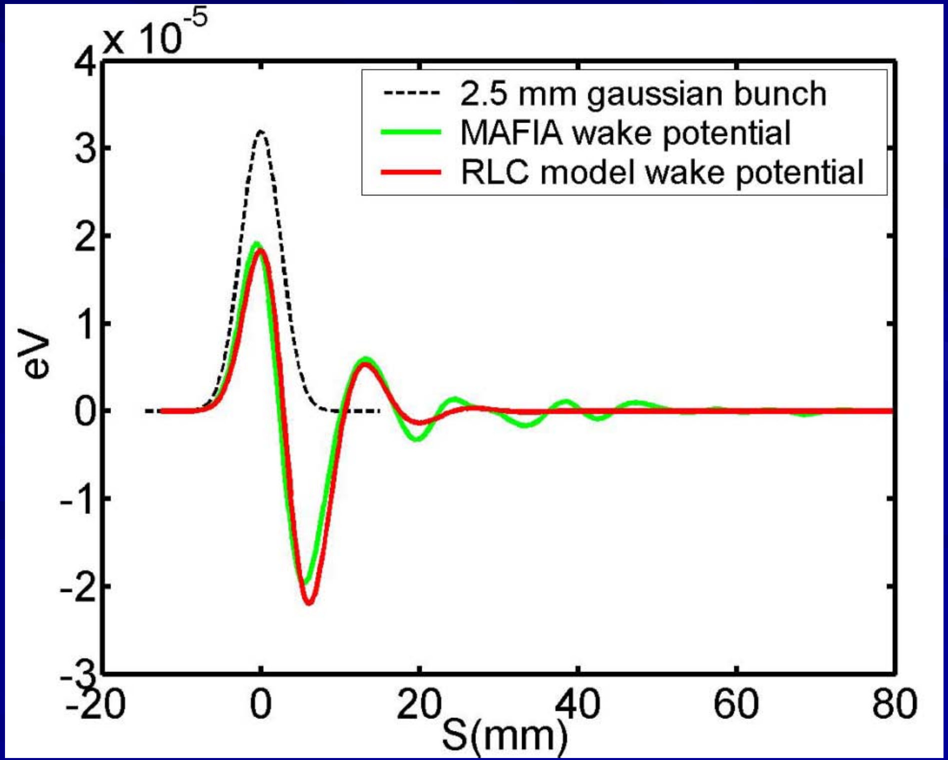
G=Random gaussian number with r.m.s.=1

$V_{pipe}(z(s_2))$ Energy loss due to pipe wake

$V_{CSR}(z(s_2))$ Energy loss due to CSR wake

2.1) BEAM PIPE WAKE FIELD MODEL

- The ***wake function of DAFNE*** has been calculated by numerical codes as the wake potential of a 2.5 mm gaussian bunch *(Zobov & al.,LNF-95/041,1995)*
- Since in the case of BLM the bunch length is comparable with 2.5 mm, the wake function of each section has been ***approximated by an RLC*** equivalent model. The R,L,C parameters have been found by fitting the wake potential of the 2.5 mm bunch.



2.2) CSR WAKE FIELD MODEL (1/2)

⇒ there are ***different models*** for the CSR wake;

⇒ each model needs the ***derivative of the distribution***: the numerical derivative is obtained with a ***SAVITZKY-GOLAY filter***.

To set the parameters without introducing unreal microbunching, tests suggested in *(Borland,PRST AB, 2001)* were made.

a) ***Dipole CSR models***

The code includes:

-Steady state CSR wake field model *(Stupakov & al., PRST AB 5, 2002)*

-Model including the entrance and exit transients *(Stupakov & Emma,Proc. EPAC 2002)*

-Model including the pipe shielding *(Murphy & al.,Part.Acc. 57,1997)*

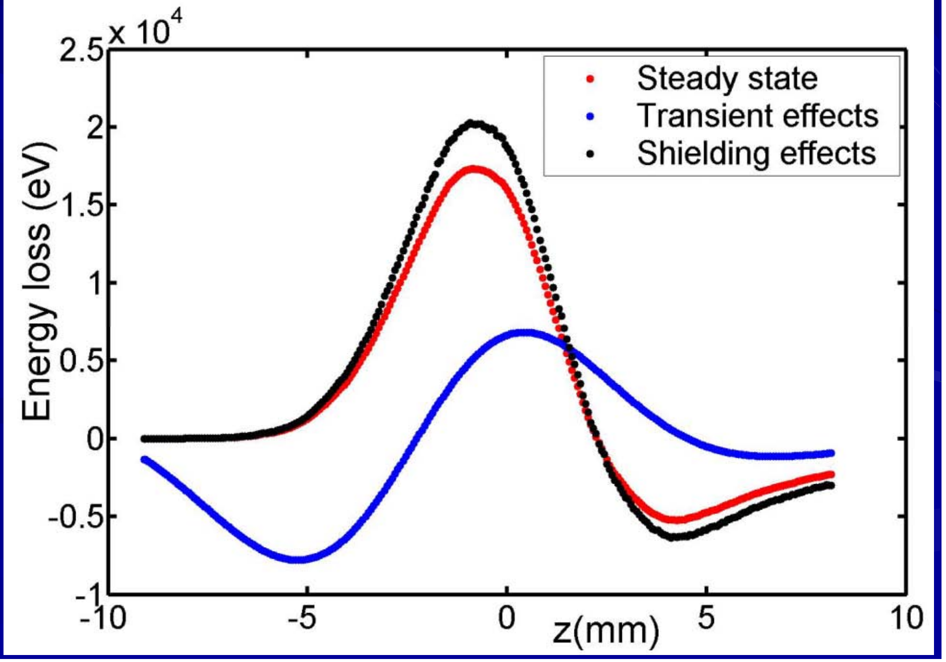
2mm,1nC gaussian bunch

Dipole features:

Length: 1 m

Bending radius: 1.4 m

Pipe gap: 53 mm

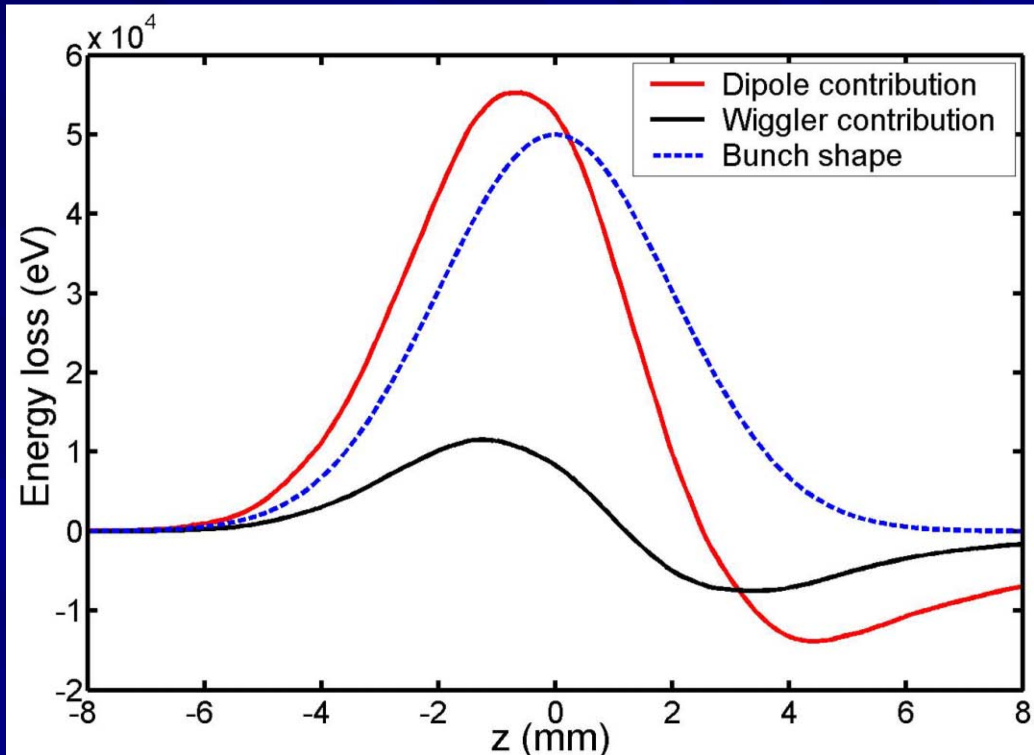


CSR WAKE FIELD MODEL (2/2)

b) ***Wiggler CSR model:***

Steady state solution *(Saldin & al.,Nucl.Instr.Meth. in Phys.Res. A 417,1998)*

Steady state CSR contribution for a 2 mm gaussian bunch



In these simulations CSR is dominated by dipole contribution

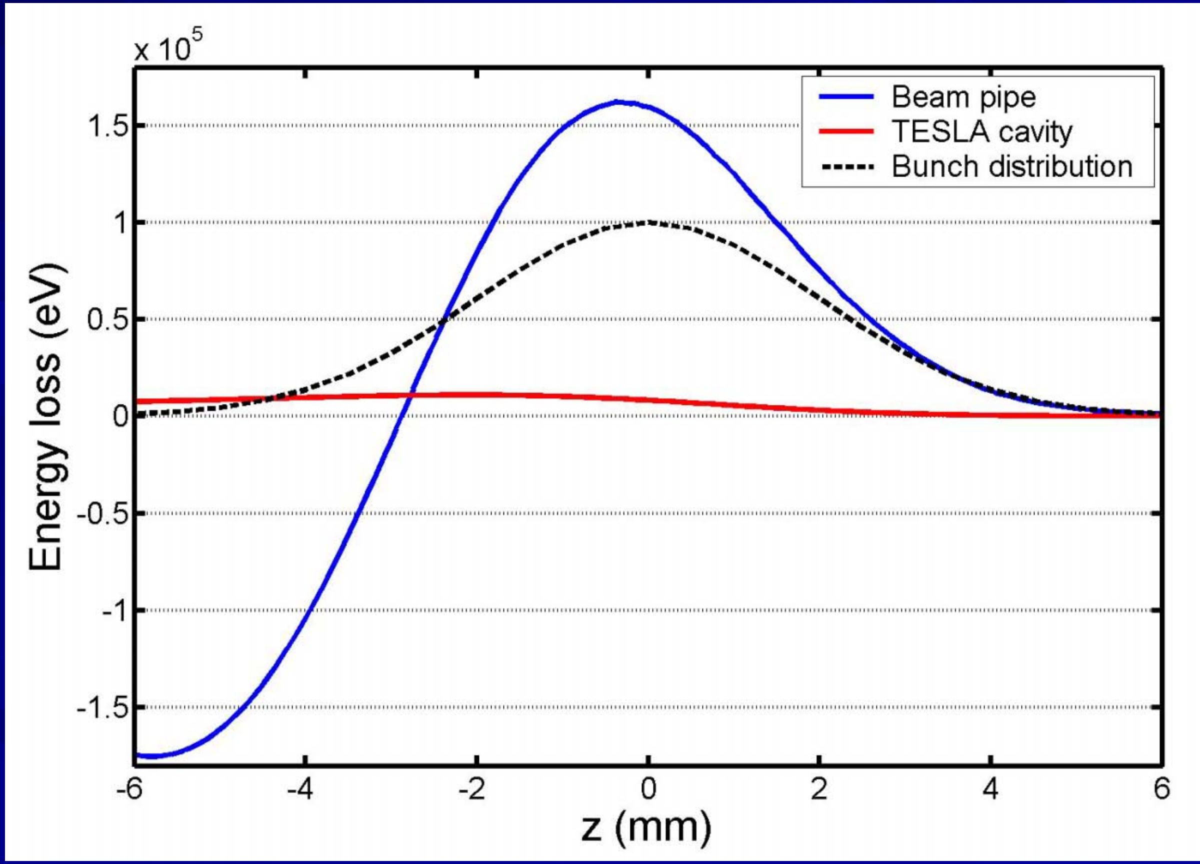
2.3) Cavity wake field model

It was used the analytic approximation for a wake function per unit length

(*Edwards, TESLA 95-01,1995*)

$$w(z) = 38.1\left[\frac{V}{pC \cdot m}\right]\left(1.165 \cdot \exp\left(-\sqrt{\frac{z}{3.65mm}}\right) - 0.165\right)$$

Simulations showed that even with a short bunch in the cavity, cavity wake effect gives negligible contribution

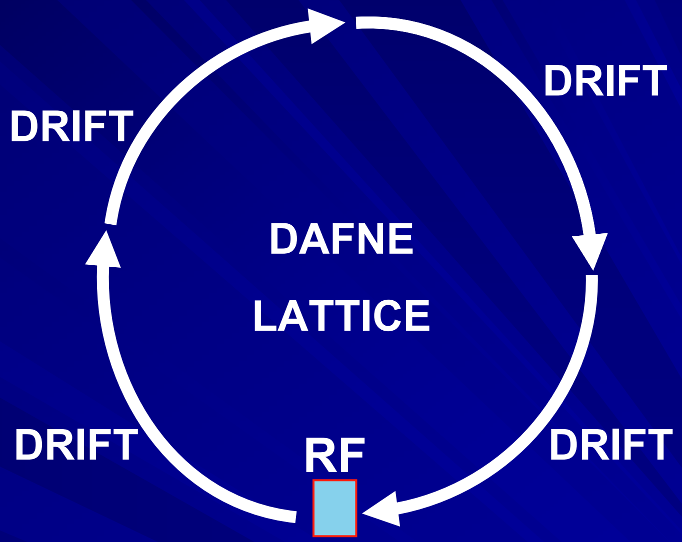


3) BEAM DYNAMICS SIMULATIONS IN THE DAFNE BUNCH LENGTH MODULATION EXPERIMENT

Simulations have been performed dividing the rings in 5 parts:

- 1 SC RF cavity;
- 4 longitudinal drift sections 25 meters long according to R1 trend.

CASE A **Monotonic α=0.073**	**V=3 MV** **V=9 MV**	**Qs=0.18** **Qs=0.38**
CASE B **Nonmonotonic α=0.02**	**V=3 MV** **V=9 MV**	**Qs=0.09** **Qs=0.16**
CASE C **Nonmonotonic α=0.004**	**V=3 MV** **V=9 MV**	**Qs=0.04** **Qs=0.07**



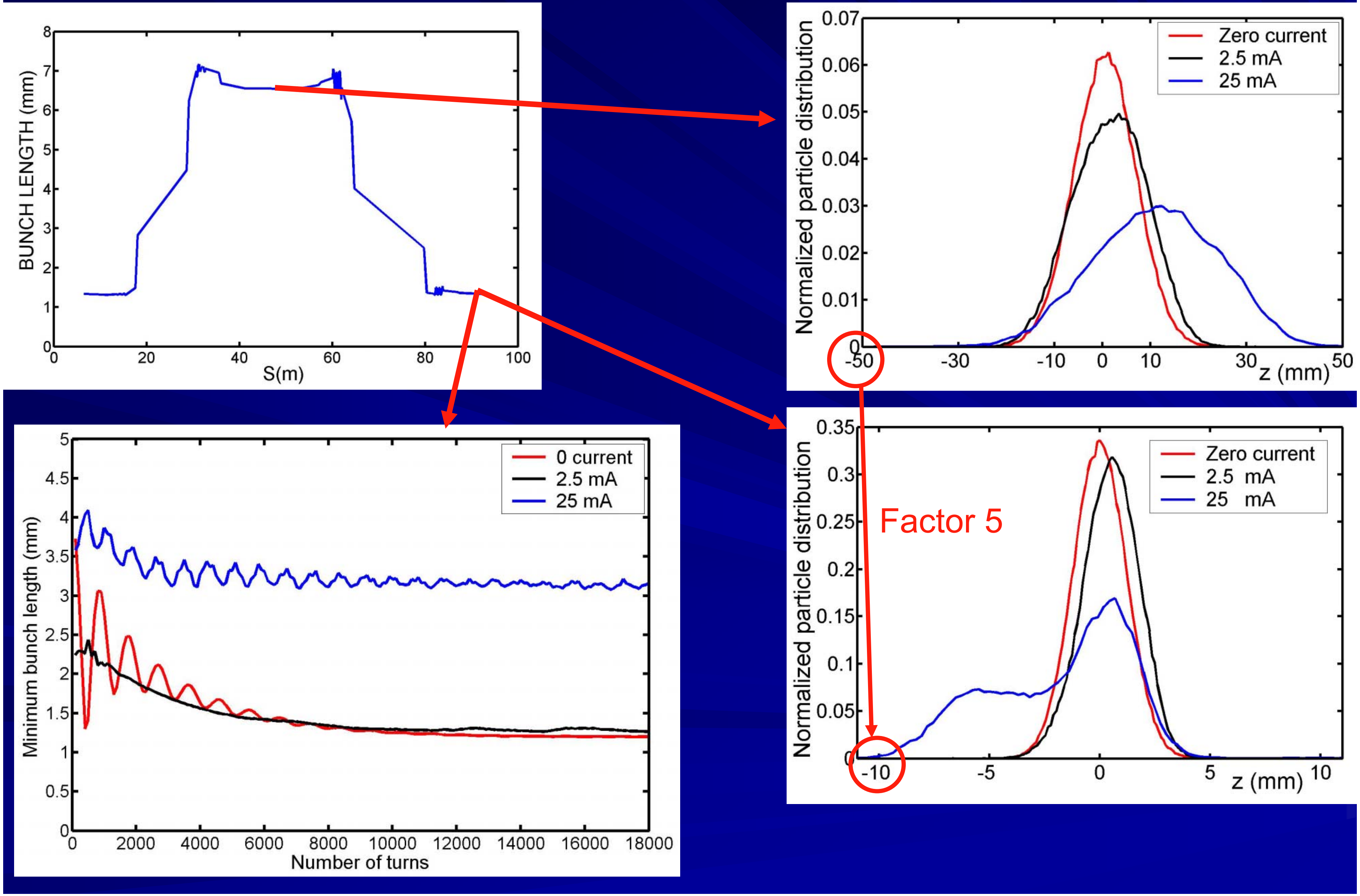
For the cases A, B and C with 3 and 9 MV voltage, the longitudinal distributions of the bunch were studied for different bunch currents (0 to 25 mA):

1. ***With beam pipe wake;***
2. ***With CSR wake;***
3. ***With CSR and pipe wake;***
4. ***With CSR, pipe and SC cavity wake.***

As a comparison it was studied a case without length modulation with very low momentum compaction (0.004) with natural length 1.6 mm

a) Example of SPIDER results

CASE C 9MV (Zero current)



b) SPIDER results for the BLM experiment (1/2)

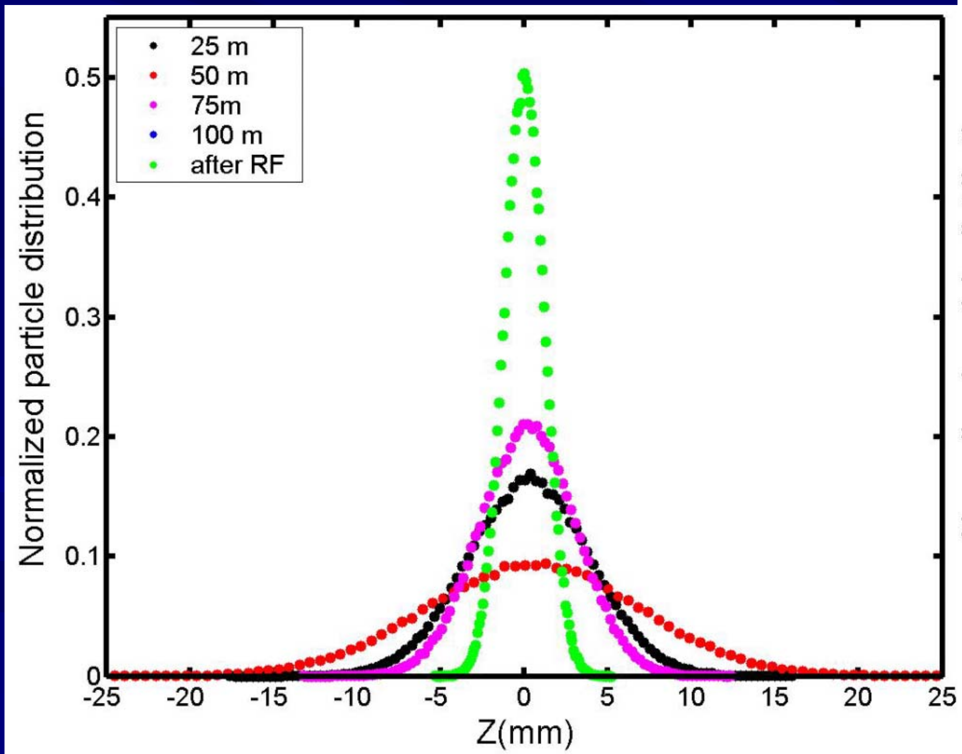
1) 0 current (no wake):

The theoretical natural values were perfectly reproduced

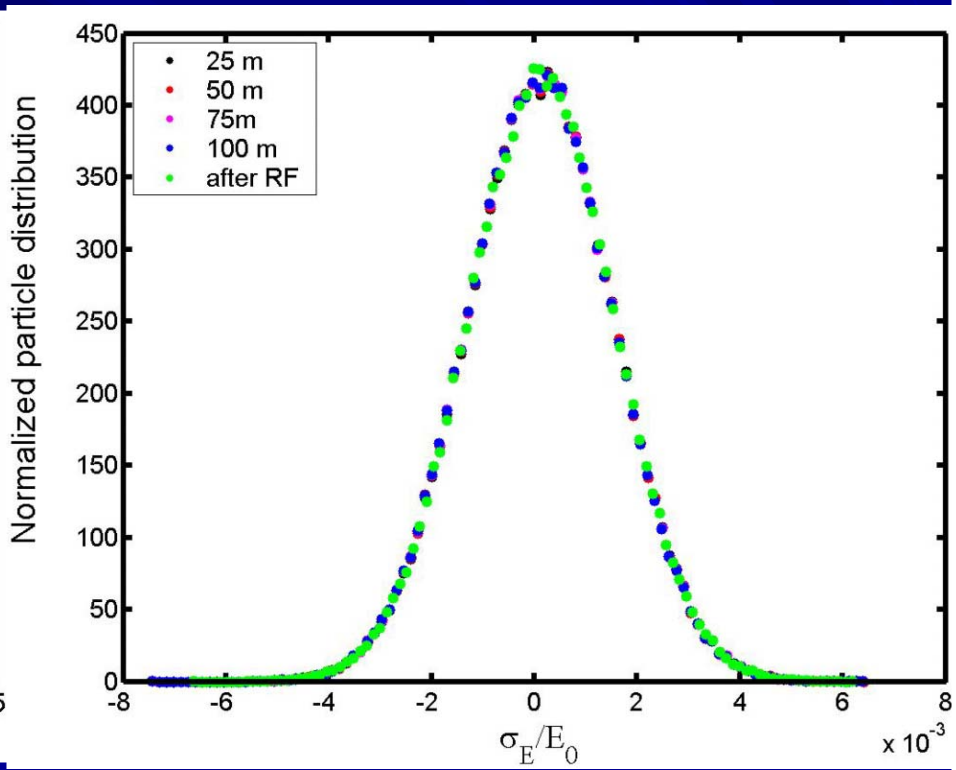
EXAMPLE:

CASE C(R1 non monotonic, very low momentum compaction)
9 MV RF cavity

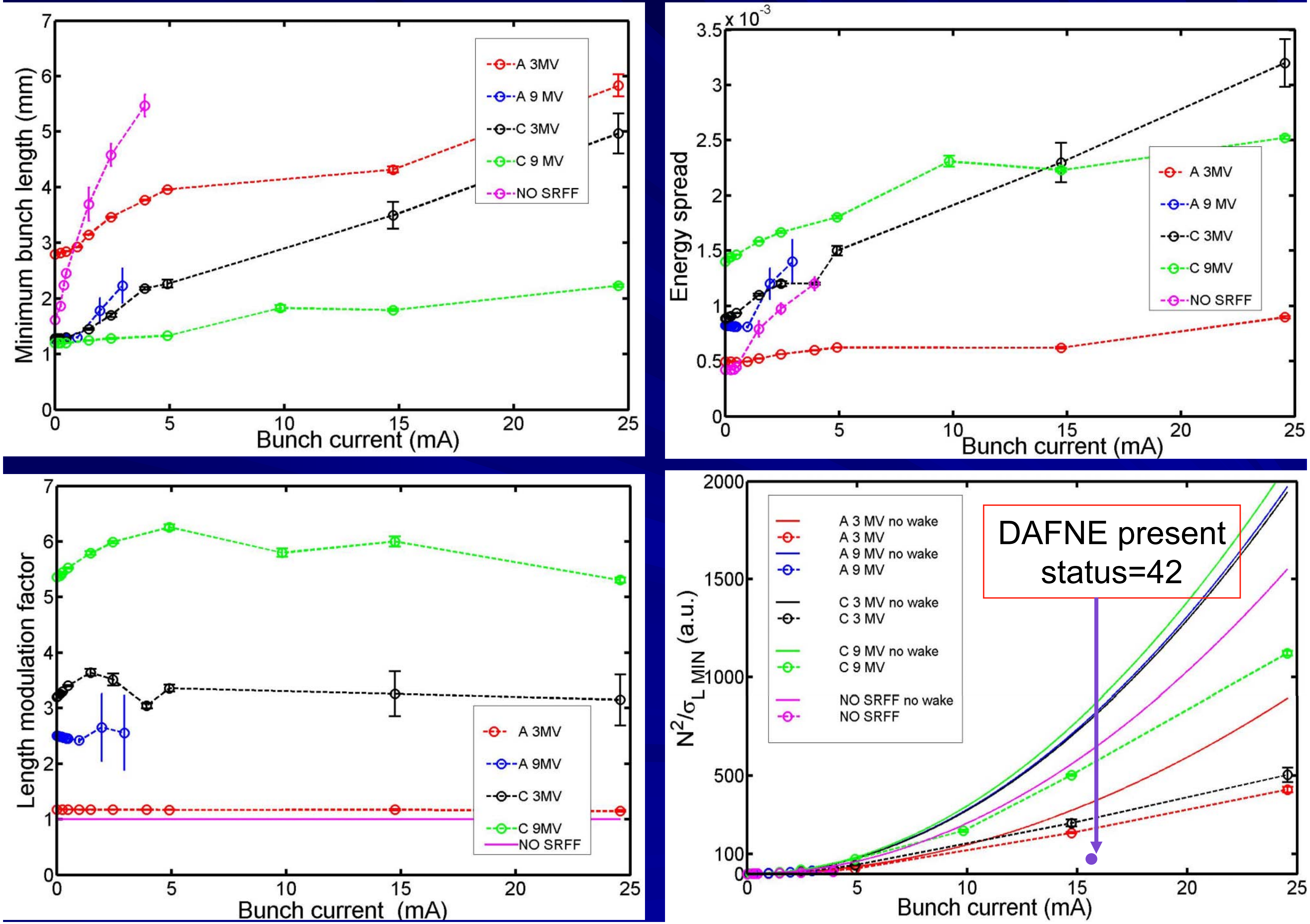
Bunch length distribution



Energy spread distribution



b) SPIDER results for the BLM experiment (2/2)



Conclusions

In Strong RF focusing regime bunch length changes along the ring

A simulation code was written to study the effect of the wake fields in BLM regime

The code was applied to the experiment of BLM in DAFNE with 3 examples of lattices (CASE A, CASE B, CASE C with 3 and 9 MV)

Bunch lengthening was studied under the effect of:

- Beam pipe wake, CSR wake, Tesla-like cavity

The instability threshold is higher in the monotonic case (A) but the instability grows faster than in the non monotonic cases (case B and case C):
Low momentum compaction allows higher maximum currents at a given minimum length thanks to a greater modulation factor

CSR is not dominant but its contribution can not be neglected

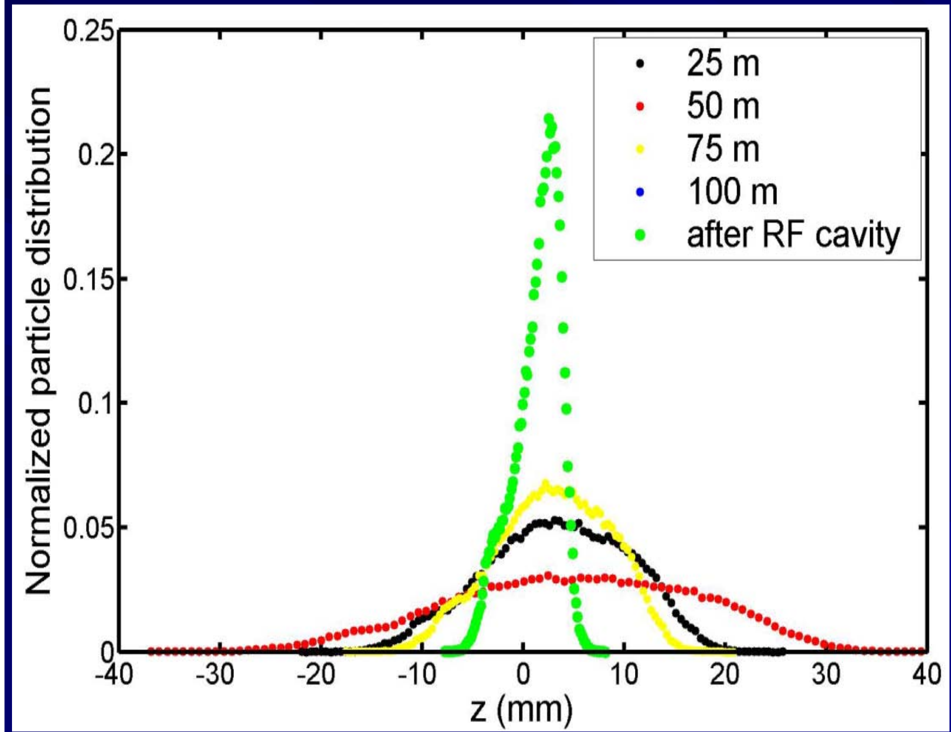
SC Cavity wake gives negligible effects even when the bunch is short in the cavity

Because of wake effects energy spread is no longer constant along the ring

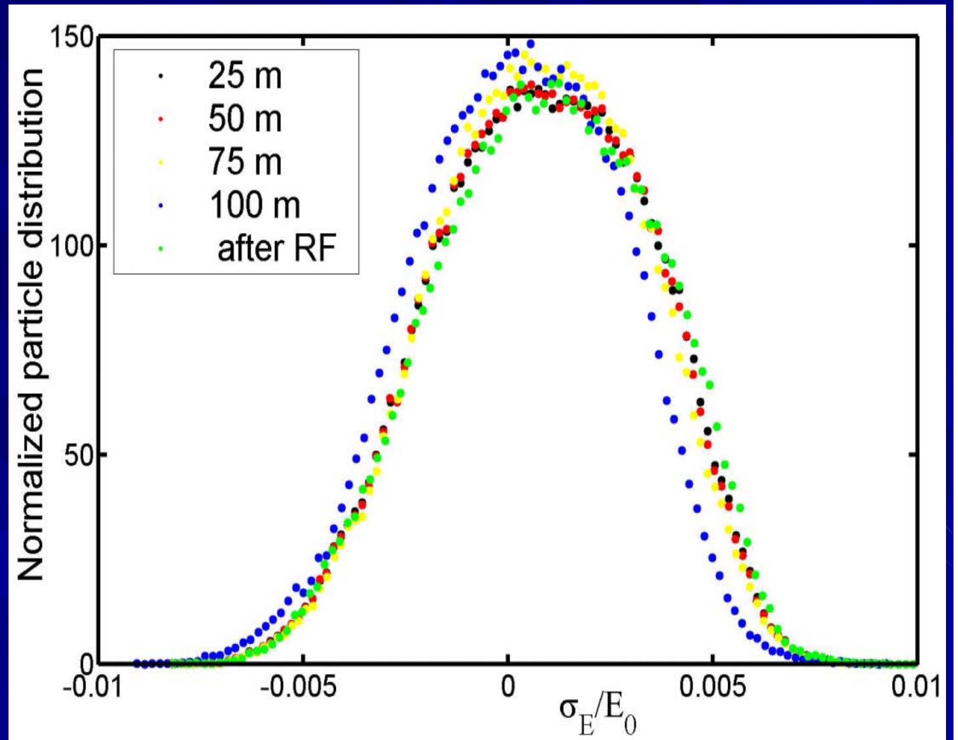
This analysis involves only longitudinal dynamics but the cases with critical dynamic apertures are critical also from this point of view

CASE C, 9 MV: 25 mA

Bunch length distribution



Energy spread distribution



Under the effect of the wakefields energy spread is no more exactly constant along the ring