Past collective effects studies for DAFNE

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Outline

- Collective effects studies in DAFNE
  - DAFNE layout
  - Longitudinal single bunch dynamics
    - Impedance evaluation
    - Simulation code
    - Results
  - Longitudinal multi-bunch dynamics
    - HOMs evaluation
    - Longitudinal feedback system
    - Simulation code

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work done by DAFNE group

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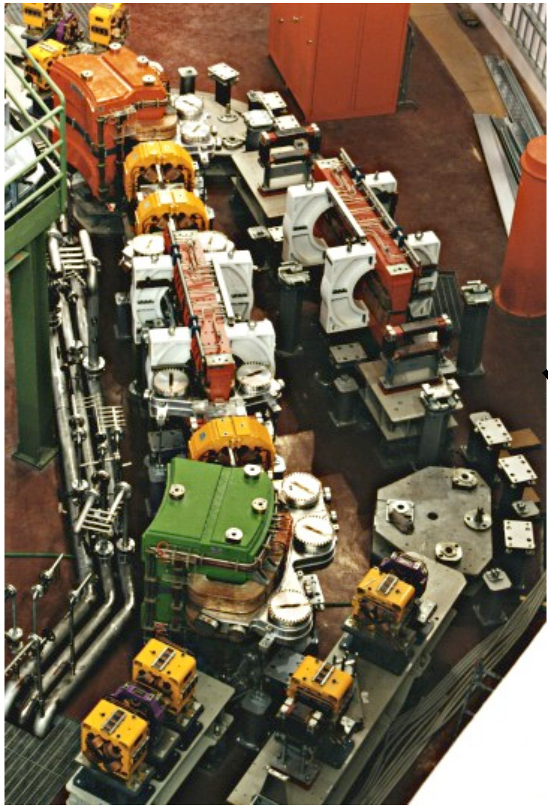
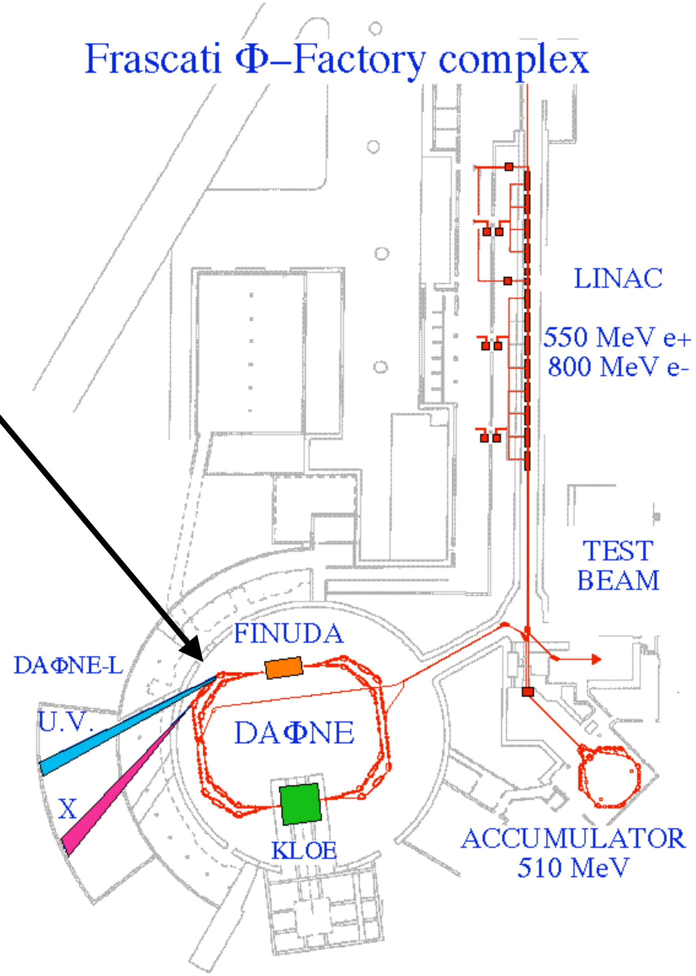
DAFNE layout





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31 Luglio 1995

Impedance evaluation

Collective Effects and Impedance Study for the DAΦNE Φ-Factory

M. Zobov, P. Arcioni[#], R. Boni, A. Gallo, A. Ghigo, F. Marcellini, M. Migliorati, L. Palumbo°, L. Perregrini[#], M. Serio, B. Spataro.

The single bunch instabilities are also of great importance for DAΦNE. In order to achieve high luminosity in a short machine the single bunch current must be high. This implies that certain single bunch thresholds must be taken into account. Indeed, for DAΦNE, the approximate criterion on the limit of the microwave longitudinal instability [2]:

$$\left(\frac{Z_L}{n}\right)_{eff} = \frac{\sqrt{2\pi}\alpha(E/e)(\sigma_{\varepsilon 0}/E)^2 \sigma_{z0}}{I_0 R} \qquad (1)$$

gives a small longitudinal impedance limit $(Z_L/n)_{eff} \approx 0.01\Omega$ and the turbulent lengthening (and widening) regime can hardly be avoided. Here σ_{z0} is the natural bunch length (4.82 mm at V_{rf}=250 kV).

The energy spread σ_ε and the bunch length are the key parameters defining Touschek lifetime, parasitic losses, luminosity, multibunch instability rise times etc. This demanded careful analysis of the broad-band impedance of the machine (short range wake fields) and simulation of the bunch lengthening process.

The transverse mode coupling does not seem to be a limiting instability for DAΦNE as it is for large machines, LEP for example [3].

Impedance evaluation

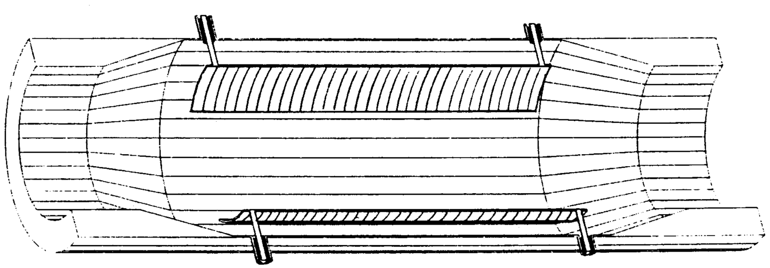
- Resistive wall $$\frac{Z_L}{L} = \frac{\omega}{c}\frac{(1+j)Z_0\delta}{4\pi b}F_0\left(\frac{b}{a}\right)$$

The longitudinal impedance estimated at the bunch spectrum roll-off n = 520 is a rather small value

$$\frac{Z_L}{n} = 0.013(1+j)\Omega$$

- Transverse feedback kicker

(2 striplines, to damp RW instability)



$$Z_L(\omega) = 2Z_s\left(\frac{\phi_0}{2\pi}\right)^2\left(\sin^2\frac{\omega l}{c} + j\sin\frac{\omega l}{c}\cos\frac{\omega l}{c}\right)$$

At frequencies $\omega / 2\pi << c / 4l = 375MHz$ eq. (8) gives for such a kicker:

$$\frac{Z_L}{n} \approx j2Z_s\left(\frac{\phi_0}{2\pi}\right)^2\frac{l}{R} = j0.064\Omega$$

Impedance evaluation

- Vacuum port screen

Lumped vacuum ports in the straight sections are screened by a mesh of rounded end 22 mm long and 8 mm wide longitudinal slots. The longitudinal distance between slots is varied randomly within ±10% in order to break the periodicity and destroy possible coherent buildup of the wave radiated by the slots [28].

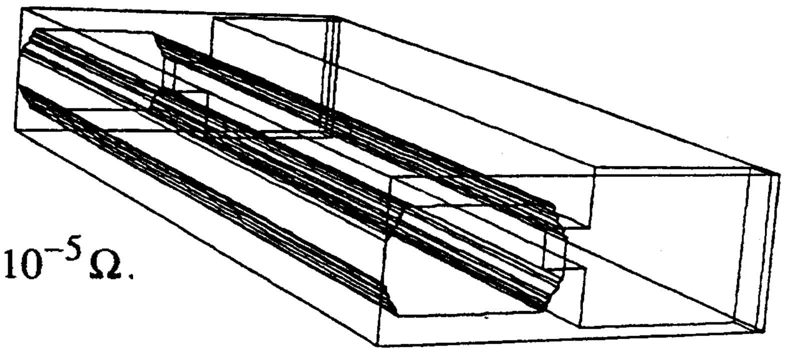
The low frequency longitudinal and transverse impedance of a slot in a circular vacuum chamber of radius b is calculated analytically [29]:

$$Z_L(\omega) = jZ_o \frac{\omega}{c} \frac{(\alpha_m + \alpha_e)}{4\pi^2 b^2}$$

For a single pump screen containing 90 slots

$$\frac{Z_L}{n} = j1.68 \cdot 10^{-3}\,\Omega$$

- Antechamber slots



Mafia calculations:

the impedance is less than $Z_L / n = j6.6 \cdot 10^{-5}\,\Omega$.

Impedance evaluation

- Beam position monitors

$$\frac{Z_L}{n} = F\varphi^2 R_0 \left(\frac{\omega_1}{\omega_2} \right) \frac{j\omega_0 / \omega_2}{1 + j\omega / \omega_1}$$ **+ MAFIA**

For all BPMs $Z_L / n < 0.01 \ \ \Omega.$

- Tapers

In order to reduce the coupling impedance it is necessary to produce a vacuum chamber as smooth as possible. Long tapers, connecting vacuum chamber components, are used in DAΦNE to avoid sharp discontinuities in the vacuum chamber cross section.

Summing up the contributions from all the tapers of that kind gives $Z_L / n = j0.063 \ \ \Omega.$

The total contribution of the tapers in 4 wiggler section is $Z_L / n = j0.027 \ \ \Omega.$

(ABCI simulations)

Impedance evaluation

- Scrapers

(inside the detectors to reduce the lost particles background)

Figure 21 shows the real and imaginary part of the impedance calculated as Fourier transform of the wake field given by MAFIA. The impedance remains inductive until ~3 GHz and the low frequency contribution can be estimated as j0.0155 Ω.

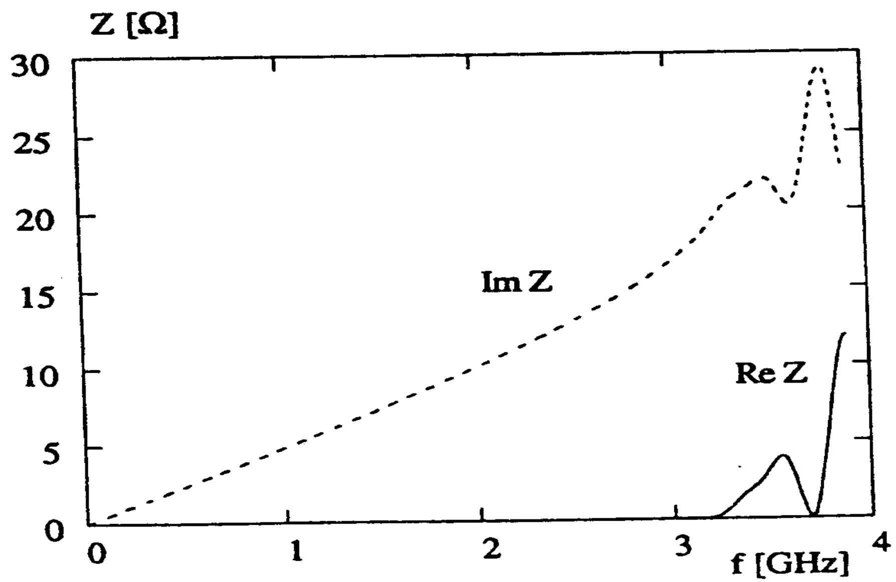


Fig. 21 - Horizontal scraper broad band impedance.

Impedance evaluation

- Bellows

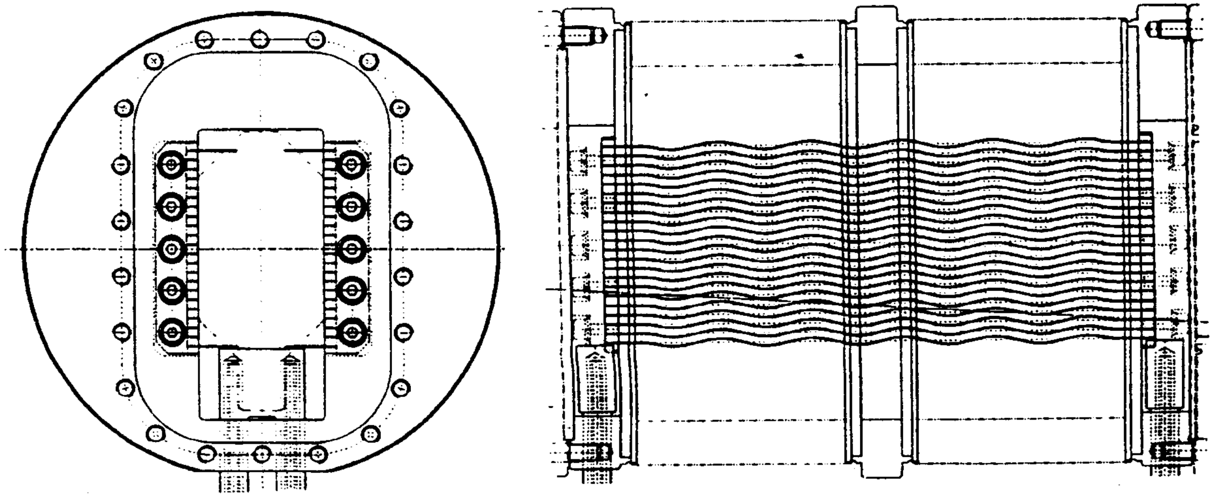


Fig. 22 - Bellows design.

Preliminary simulations with MAFIA show that the bellows are inductive at low frequency with a rather small impedance of $Z_L / n = j0.006\Omega$.

Impedance evaluation

- Other inductive elements

There is a large number of small discontinuities in the DAΦNE vacuum chamber, of different kinds, shapes and sizes. These are shallow cavities in flanges and valves, gaps in BPM assembly, slots for the synchrotron radiation monitor etc. Due to the limited space allowed, we do not show the corresponding drawings.

Despite of small sizes, the overall contribution of these elements to the inductive impedance, up to rather high frequencies, can not be neglected. We have used both the analytical expressions of [34] and numerical simulations with ABCI in order to evaluate the contribution. The overall estimated impedance Z_L/n is smaller than j0.1 Ω.

Impedance evaluation

Element	Im Z_L/n [Ω]
Tapers	0.156
Transverse feedback kickers (low frequency)	0.128
Scrapers	0.062
Bellows	0.024
Resistive wall (at roll - off frequency)	0.013
BPMs	0.01
Vacuum pump screens	0.02
Injection port	0.0031
Antechamber slots	0.0005
Synchrotron radiation	< 0.015
Space charge	-0.0021
Other inductive elements	0.1
Total	**0.53 Ω**

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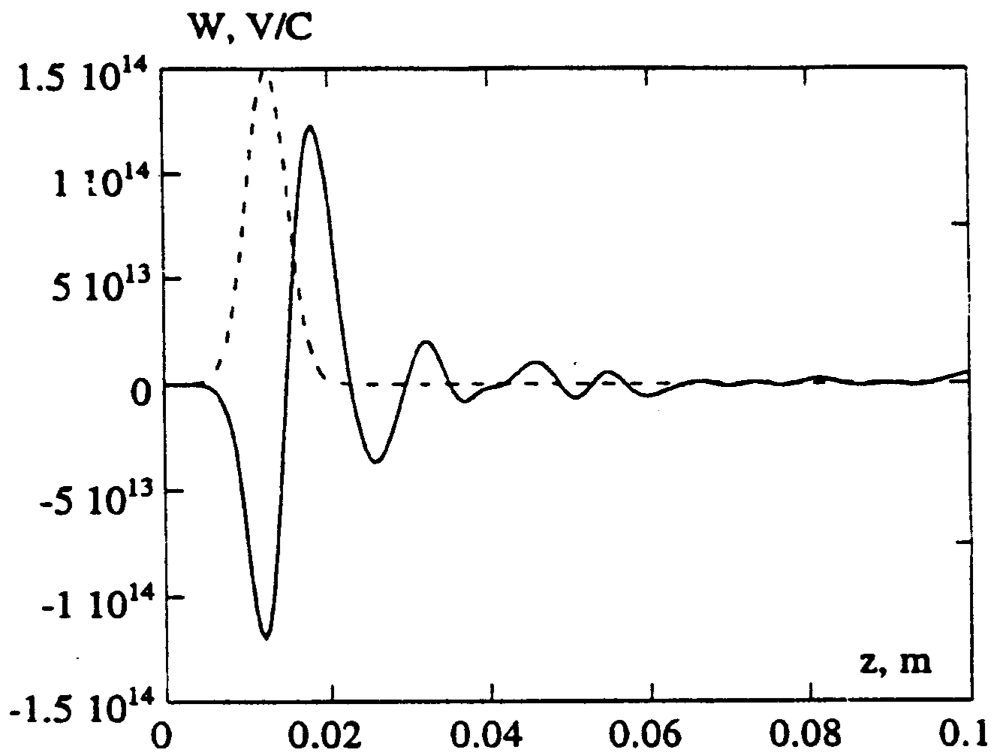
Simulation code

In order to simulate the bunch lengthening process we undertake a numerical tracking using the wake potential of a short gaussian bunch with σ_z = 2.5 mm (see Fig. 23) as the machine wake function. The computer codes ABCI [39] and MAFIA were used to calculate the wake potential for DAΦNE.

$$z_i^n = z_i^{n-1} - L_o \alpha_c \frac{\varepsilon_i^{n-1}}{E_o}$$

$$\varepsilon_i^n = \varepsilon_i^{n-1} + eV\left(z_i^n\right) - U_o - D\varepsilon_i^{n-1} - R\left(T_o\right)$$

RF + wake fields — **radiation damping** — **quantum fluctuations**



Simulation code

- Comparison with theory: potential well distortion (below microwave instability threshold)

The longitudinal motion of a particle in the bunch is confined by the potential energy due to the RF voltage and to the wake fields

$$\Psi(z) = \frac{1}{L_0}\int_0^z \left[eV_{RF}(z') - U_0\right]dz' - \frac{e^2 N_p}{L_0}\int_0^z dz' \int_{-\infty}^{\infty} \lambda_0(z'') w_{\parallel}(z'' - z')\, dz''$$

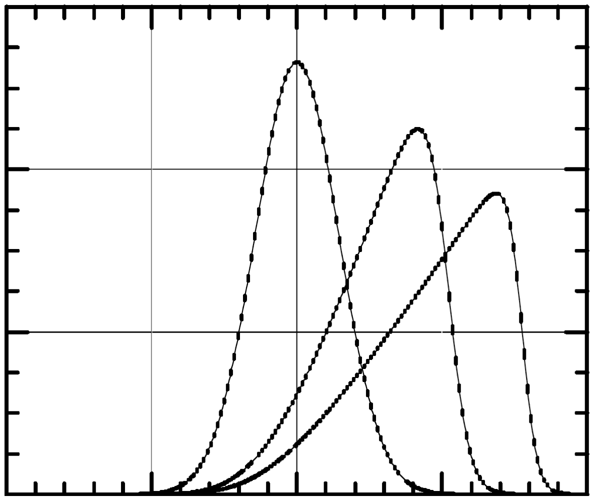
The energy distribution is Gaussian with an RMS energy spread $\sigma_{\varepsilon 0}$ not modified by the wake fields. The longitudinal distribution is described by an integral equation known as the Haissinski equation

$$\lambda_0(z) = \bar{\lambda} \exp\left[-\frac{1}{E_0 \alpha_c \sigma_{\varepsilon 0}^2}\Psi(z)\right]$$

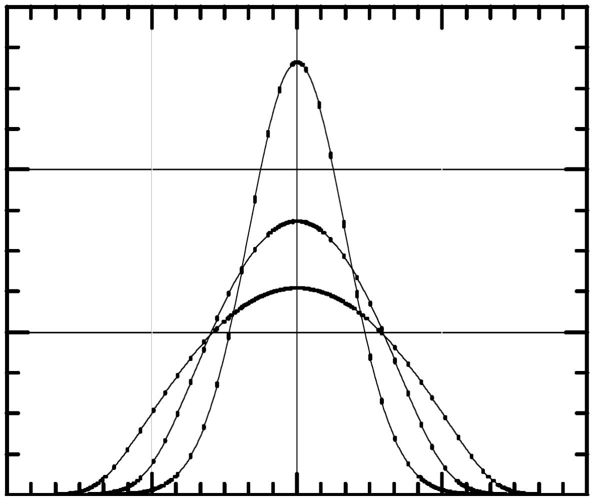
Simulation code

- Particular solutions of Haissinski equation

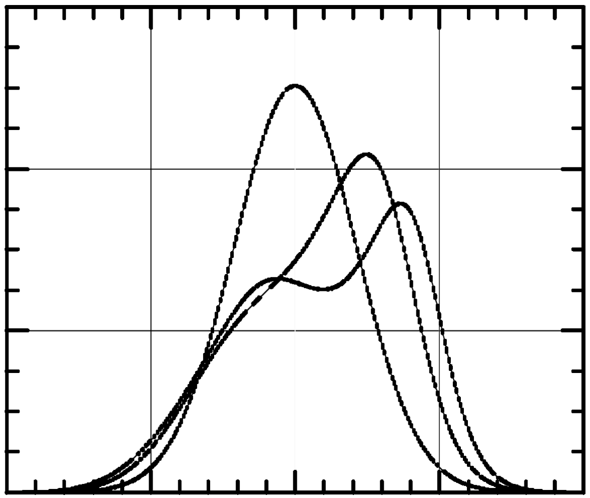
Pure resistive impedance



Pure inductive impedance

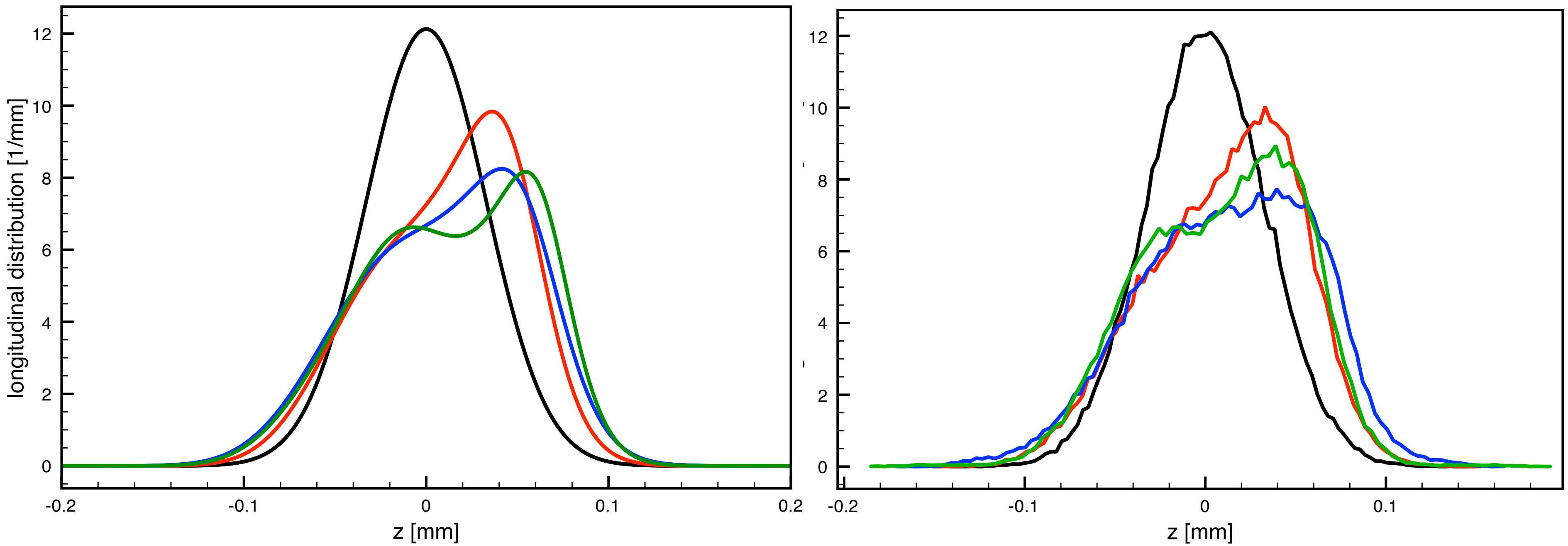


Broad band resonator



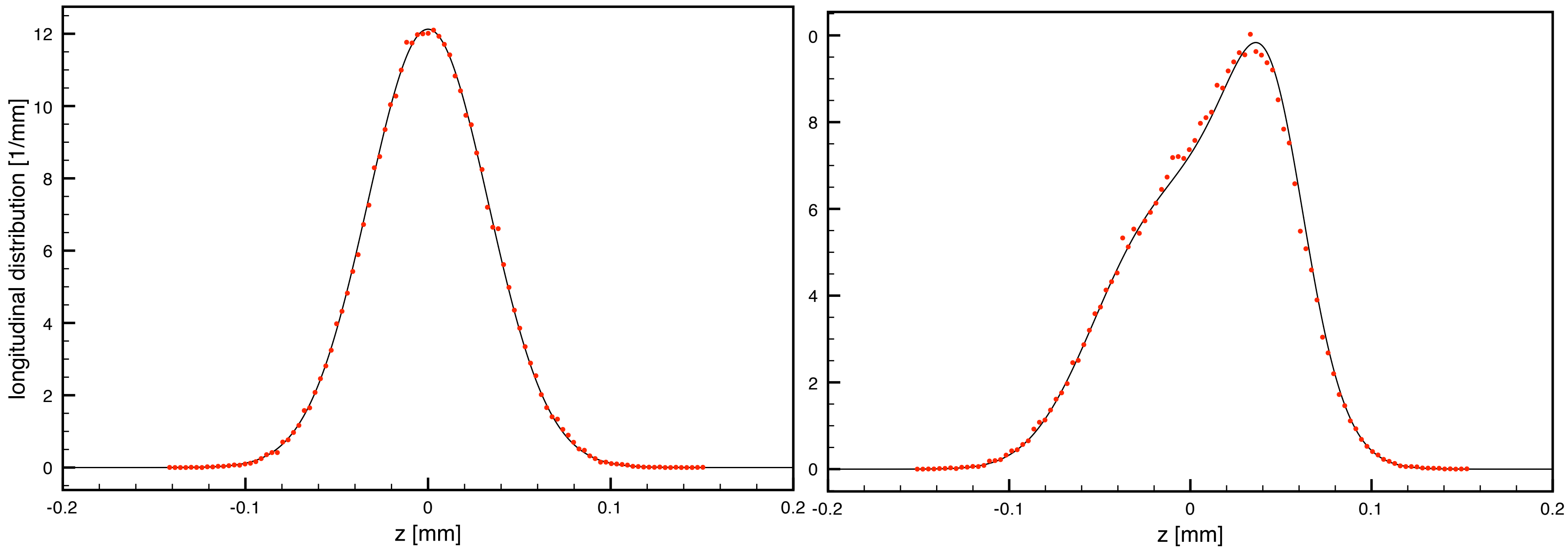
Simulation code

- Example of comparison with theory: BBR impedance



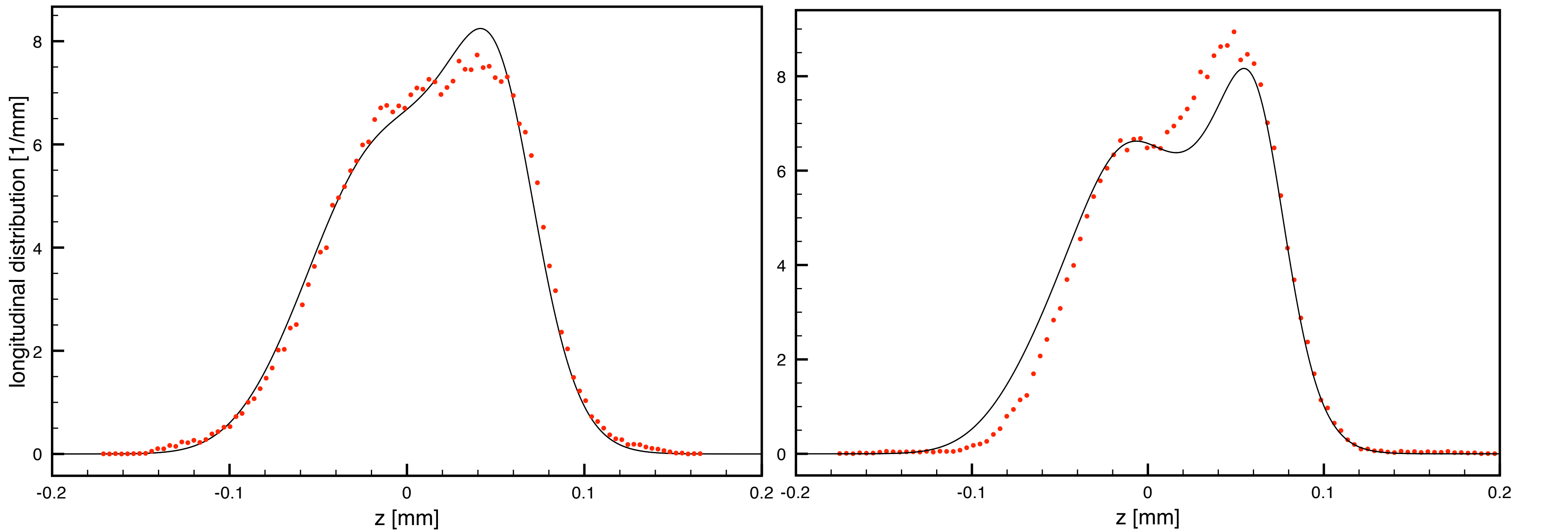
Simulation code

- Example of comparison with theory: BBR impedance



Simulation code

- Example of comparison with theory: BBR impedance



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Results

- Application to DAFNE Main Rings (positron ring)

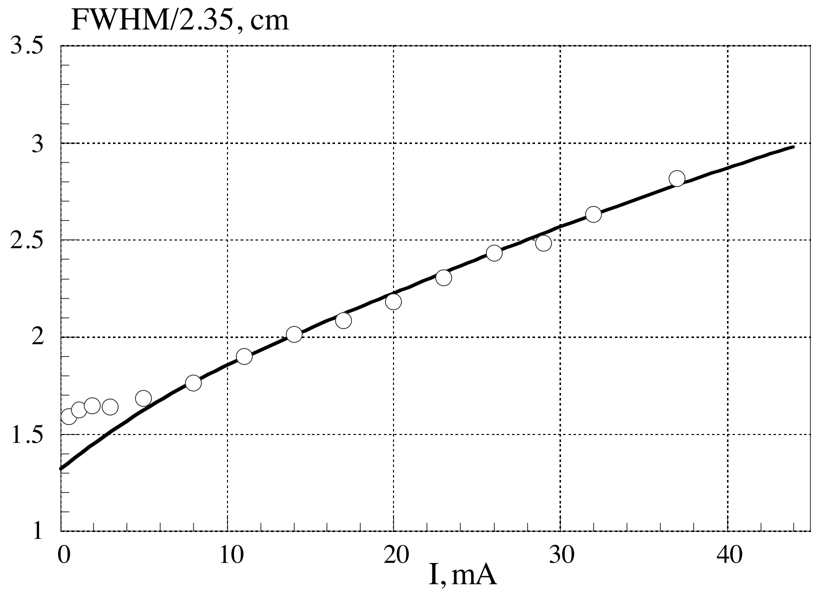


Figure 12: Bunch lengthening (FWHM) at 100 kV RF voltage. Solid line - numerical calculations; circles - measurement results.

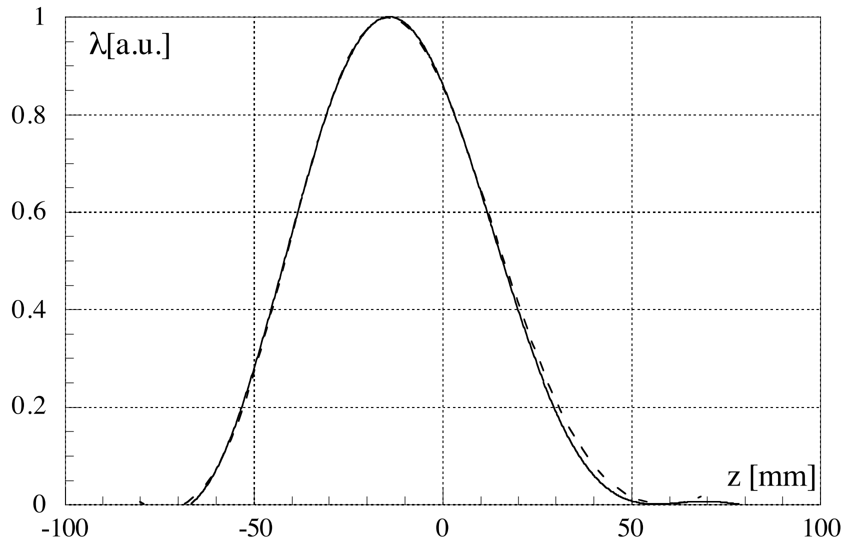
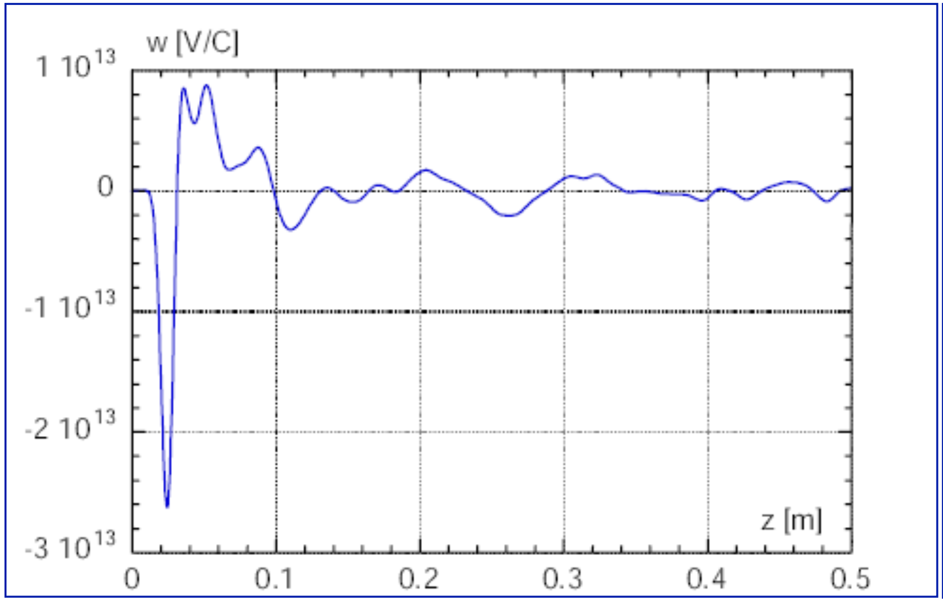


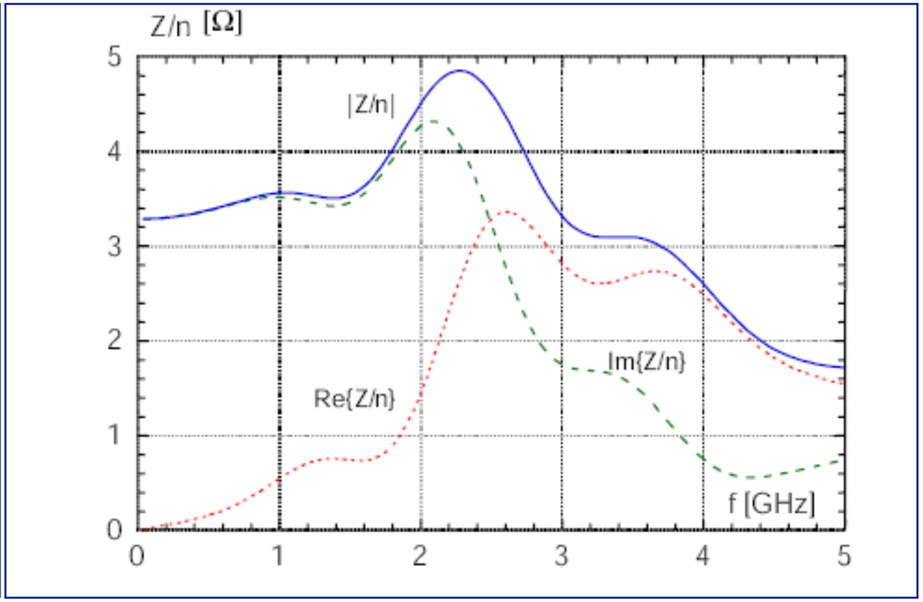
Figure 13: Bunch current distribution at 100 kV (I = 26 mA). Solid line - measured signal; dotted line - numerical simulation.

Numerical simulations performed in the design phase, before the measurements

Results

- Application to DAFNE Accumulator Ring





DAΦNE accumulator wake potential of a 2.5 mm Gaussian bunch.

Results

ELSEVIER   Nuclear Instruments and Methods in Physics Research A 418 (1998) 241–248   NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

- DAFNE Accumulator Ring

DAΦNE accumulator ring coupling impedance measurements

R. Boni, A. Drago, A. Gallo, A. Ghigo, F. Marcellini, M. Migliorati, F. Sannibale, M. Serio, A. Stella, G. Vignola, M. Zobov*

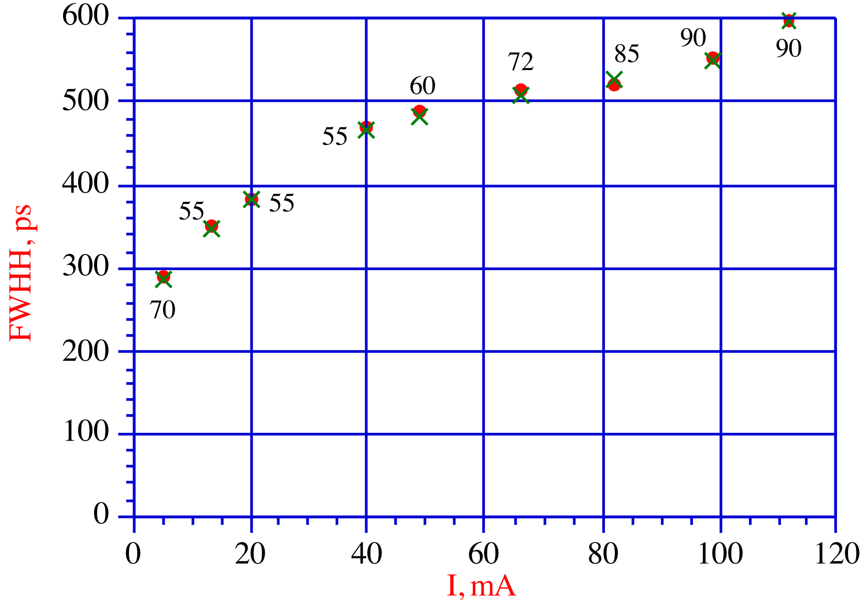


Fig. 6 - Bunch length at different voltages (full width at half maximum): dots - measurement results; crosses - numerical simulation; numbers - RF voltage.

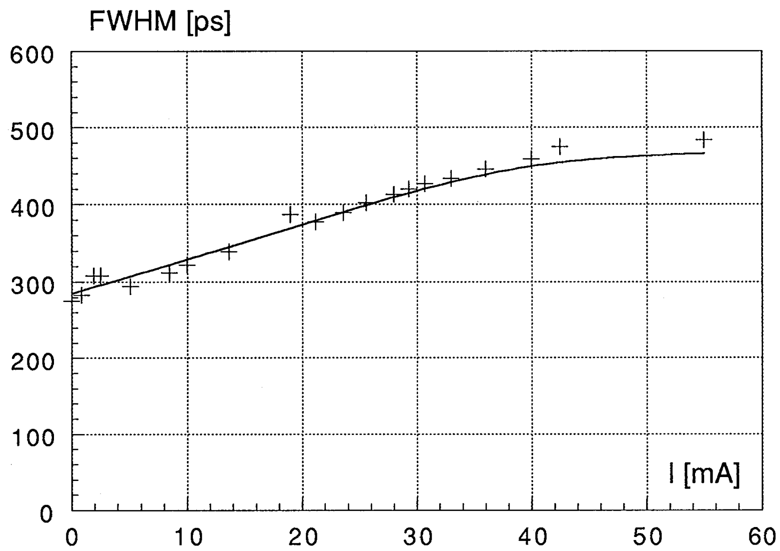


Fig. 8. Bunch length at $\hat{V}_{rf} = 60$ kV: crosses – measurement results; solid line – numerical simulations.

Results

- DAFNE Accumulator Ring impedance model

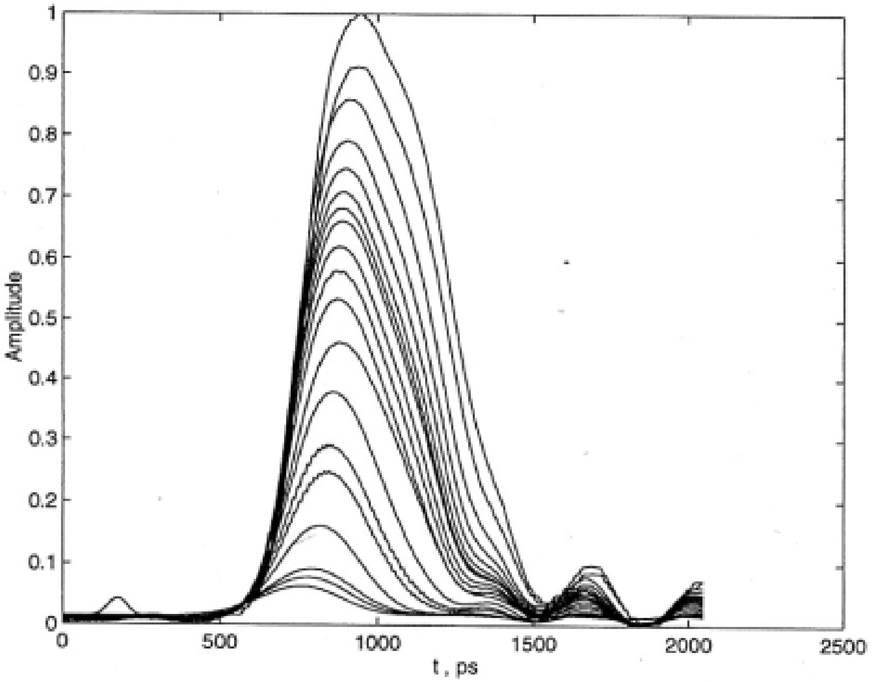
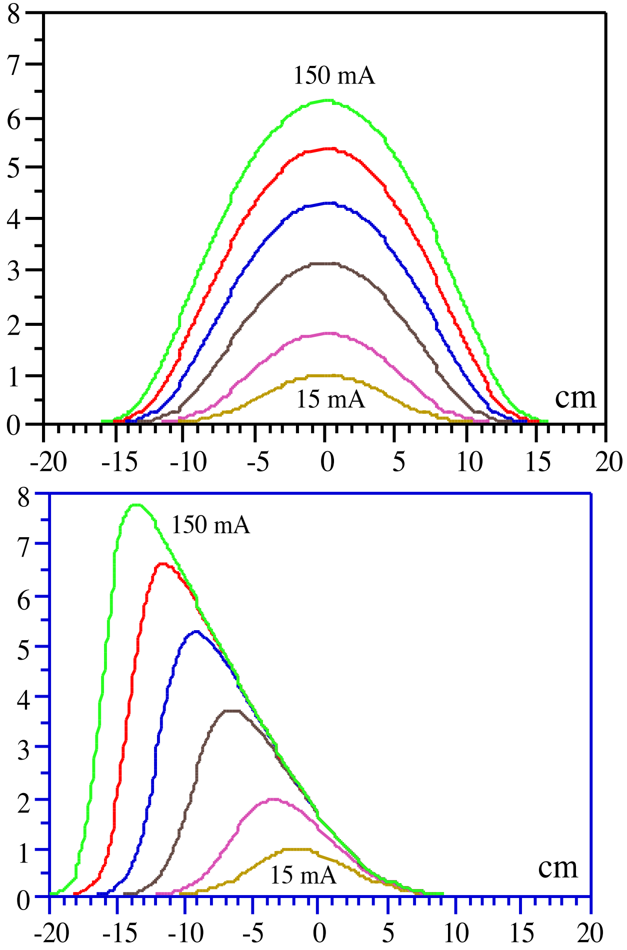


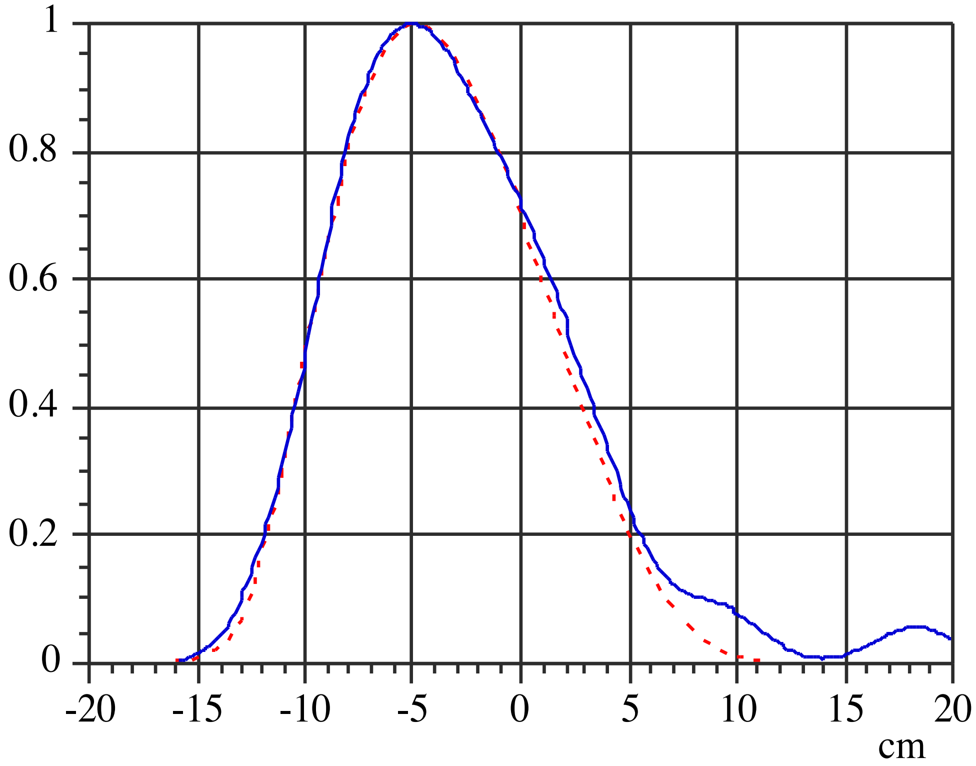
Fig. 8 - Bunch shape for different average bunch currents

$$Z(\omega) = j\omega L + R$$



Results

- DAFNE Accumulator Ring impedance model



$$Z(\omega) = \left(600 + j6.2E - 8\omega\right)\Omega$$

Results

- The simulation code has been used for studying the option of a third harmonic cavity to lengthen the bunch for DAFNE (cavity prototype realized and measured)

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS, VOLUME **6**, 074401 (2003)

Longitudinal beam dynamics in the Frascati DAΦNE e^+e^- collider with a passive third harmonic cavity in the lengthening regime

David Alesini, Alessandro Gallo, Susanna Guiducci, Fabio Marcellini, and Mikhail Zobov
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(Received 3 February 2003; published 8 July 2003)

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS, VOLUME **7**, 092001 (2004)

Third harmonic cavity design and RF measurements for the Frascati DAΦNE collider

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(Received 19 December 2003; published 7 September 2004)

Results

- The single bunch simulation code has been used to obtain an impedance model for SUPER ACO and ELETTRA

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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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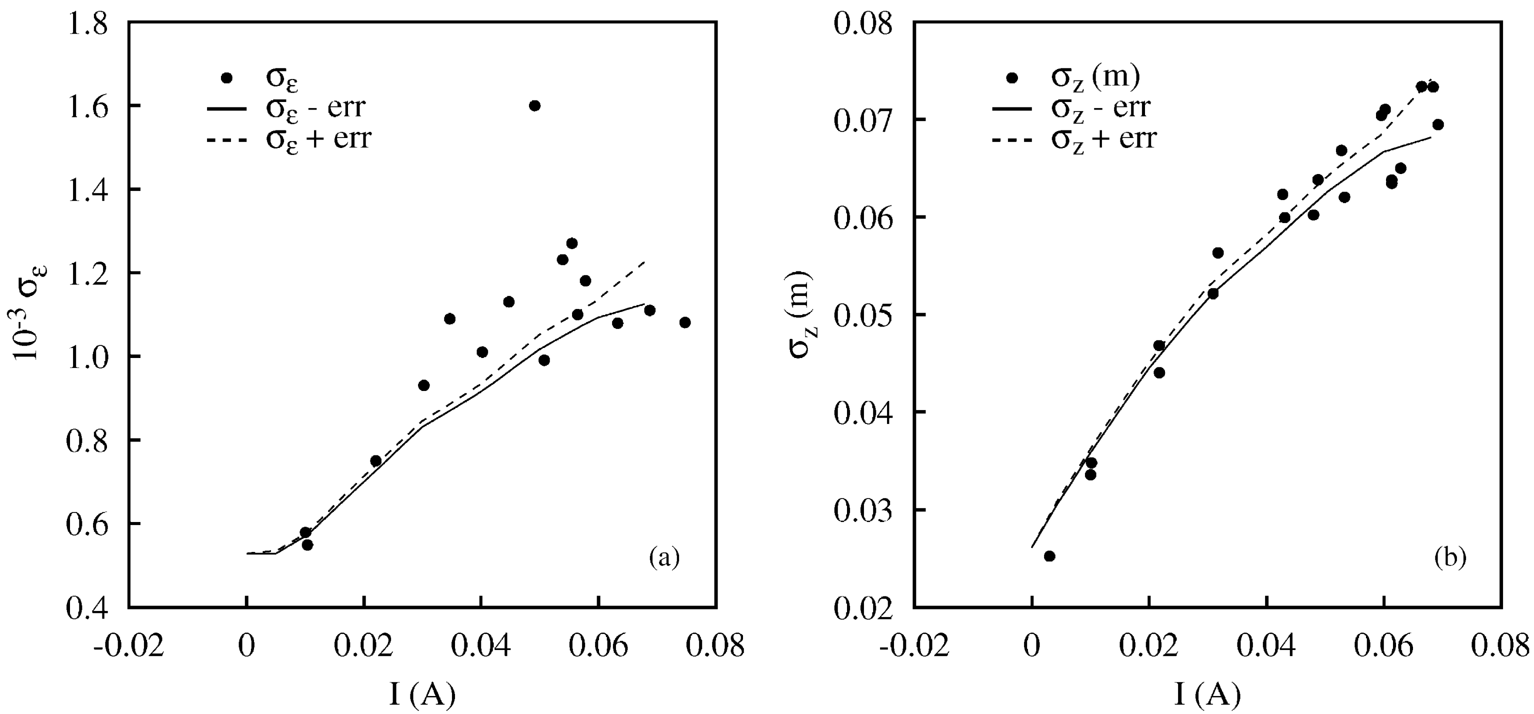
Electron beam properties and impedance characterization for storage rings used for free electron lasers

G. Dattoli[a,*], L. Mezi[a], M. Migliorati[b], A. Renieri[a], M.E. Couprie[c,d], D. Garzella[c,d], D. Nutarelli[c,d], C. Thomas[c,d], G. De Ninno[c,d], R. Walker[e]

Results

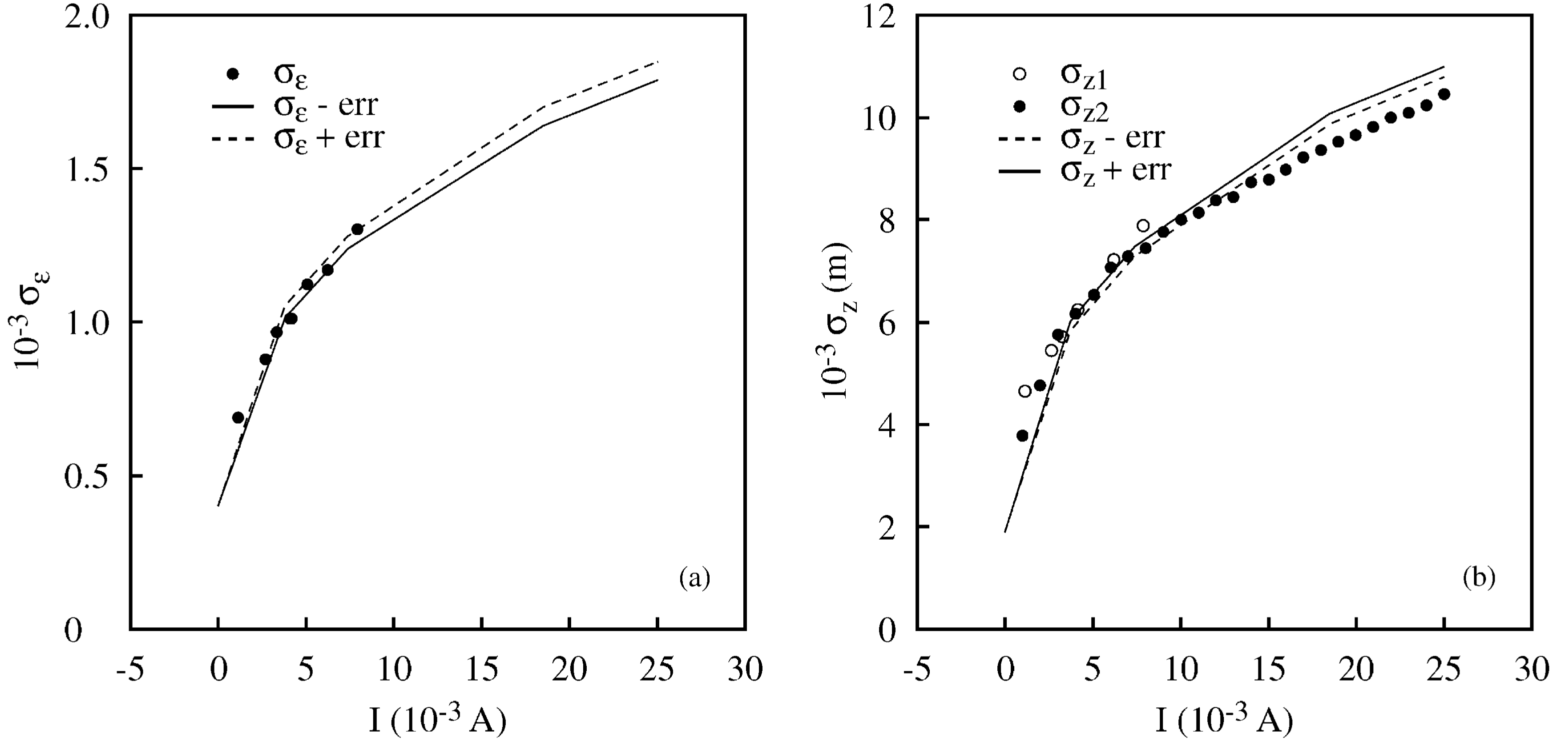
- SUPER ACO



- BBR model with R_s=6.5 kΩ, ω_r=30 GHz, Q=1

Results

- ELETTRA



- RL impedance model $Z(\omega) = j\omega L + R$ $\begin{cases} R = 0.6\,\mathrm{k}\Omega \\ L = 3 \times 10^{-8}\,\mathrm{H} \end{cases}$

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HOMs evaluation

The basic design choice of achieving the required luminosity with a large total current, distributed over a large number of bunches, makes the operation very critical with respect to coupled bunch instabilities. These instabilities have been identified since the very beginning of the project as a potentially severe limit on the ultimate achievable luminosity. For this reason, one of the primary goals in the machine design was to reduce to a minimum the number of vacuum chamber elements creating parasitic high order modes (HOMs) capable to drive the multibunch instability and to develop means for damping both the HOMS and the instabilities. This task is accomplished by properly designing the RF cavity and by coupling off the HOMs through loops or wave-guides to extract energy from the resonant fields, thus reducing at the same time the quality factor Q and the shunt impedance R. The residual excitation of beam oscillations is damped by means of a bunch-by-bunch digital feedback system.

HOMs evaluation

- RF cavity

The choice of the cavity shape has been matter of a long debate. The goal was to reduce both the shunt impedance R and the (R/Q) of the cavity HOMs in order to increase the longitudinal instability thresholds.

The basic ideas to reduce the HOM impedances were to provide large and long tapered cavity beam tubes to let the parasitic modes propagate along them and to couple out the HOM energy by means of waveguides (WG) [4].

The tapered tubes are used as a gradual transition from the cavity iris to the ring vacuum pipe. A careful analysis of the longitudinal wake potentials made with the code TBCI [5] has shown that in a long taper cavity the loss factor of the HOMs is significantly lower than that of a cavity with short tubes [6]. This means that, on the average, the R/Q values of the parasitic modes are reduced.

HOMs evaluation

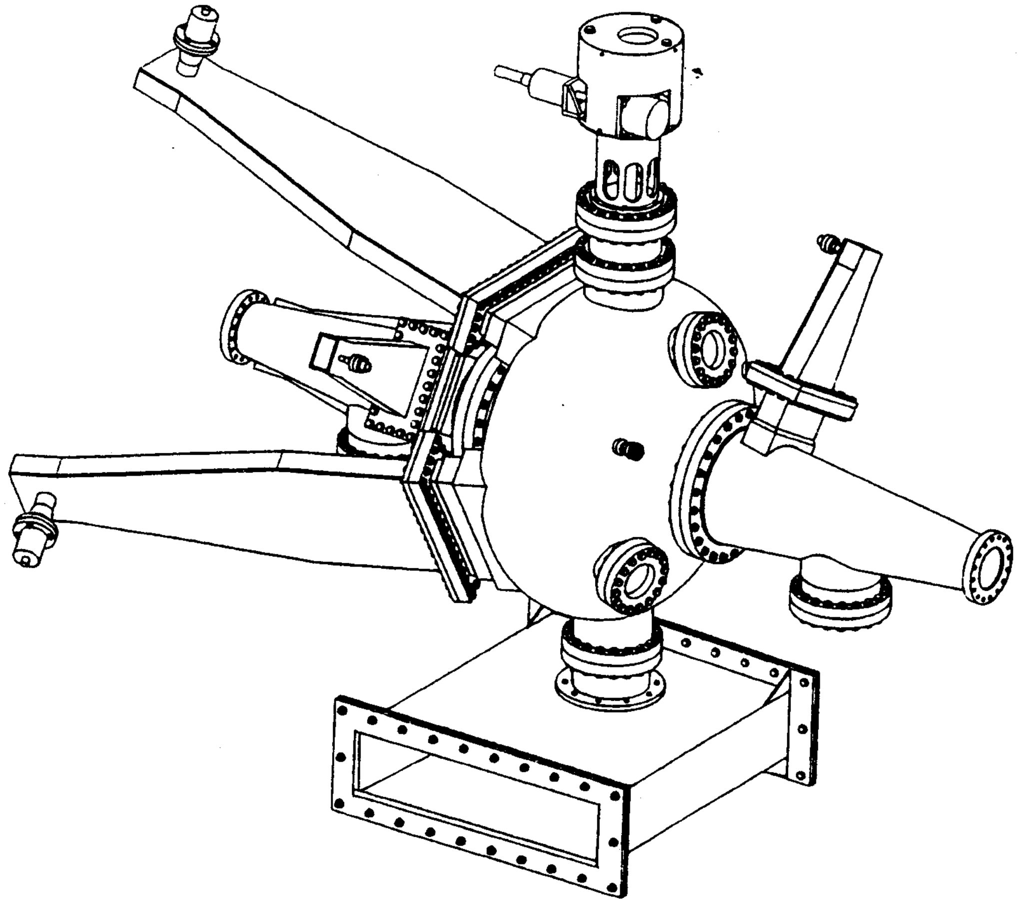

FIG. 5 - Sketch of DAΦNE resonator equipped with HOM waveguides, tuning system and main RF coupler.

HOMs evaluation

- Measurements on a prototype

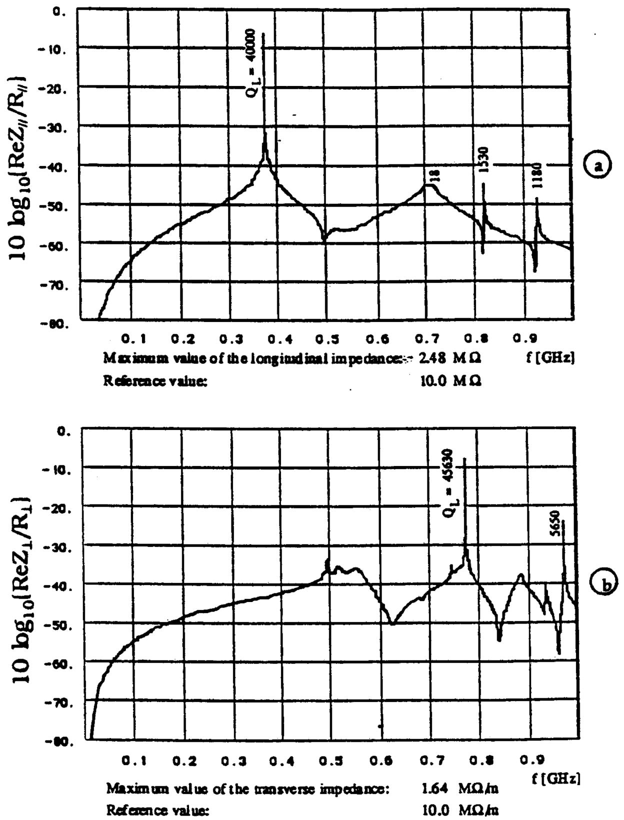

FIG. 3 - Longitudinal and transverse coupling impedances of DAΦNE cavity in the 0 - 1000 MHz frequency band (without waveguide dampers).

Table 3. Cavity Prototype Modes

Mode	Freq. (MHz)	R/Q (Ω)	Undamped Q	WG damped Q	τ (ms)
0-EM-1	357.2	61	25000	22000	
0-MM-1	745.7	16	24000	70	1.4
0-EM-2	796.8	0.5	40000	210	14.9
0-MM-2	1023.6	0.9	28000	90	17.5
0-EM-3	1121.1	0.3	12000	300	15.4
0-MM-3	1175.9	0.6	5000	90	25.6
0-EM-4	1201.5	0.2	9000	180	38.4
0-EM-5	1369.0	2.0	5000	170	4.1
0-MM-4	1431.7	1.0	4000	550	2.6
1-MM-1 a	490.0	5.1*	30500	650	3.0
1-MM-1 b	491.3	5.1*	28500	830	2.4
1-EM-1 a	523.5	14.0*	31500	150	4.5
1-EM-1 b	549.7	14.0*	32000	50	13.1

Simulations

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Longitudinal feedback system

Even though the HOMs in the accelerating cavity are heavily damped, the probability for a damped HOM to cross a coupled bunch mode frequency is high and, due to the large total current, the growth rate of unstable modes can be substantially stronger than the natural damping rate

The required additional damping is provided via a time domain, bunch by bunch feedback system [16] based on digital signal processors (DSPs).

The feedback has been designed in collaboration with SLAC-LBL PEP-II group (J. Fox et al.).

Longitudinal kicker

The stripline longitudinal kicker was very rich in HOMs content with the risk of introducing further instabilities instead of damping them.
A new broad band RF cavity kicker loaded with waveguides to broaden the fundamental mode bandwidth and to damp the cavity HOMs was designed.

Longitudinal feedback system

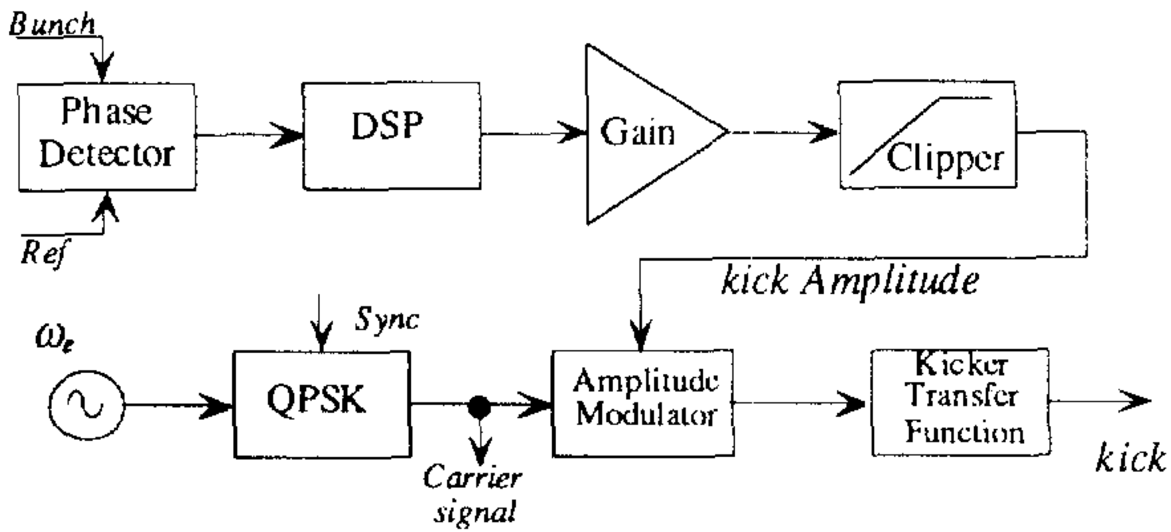

Fig. 1. Block diagram of the bunch-by-bunch longitudinal feed-back system.

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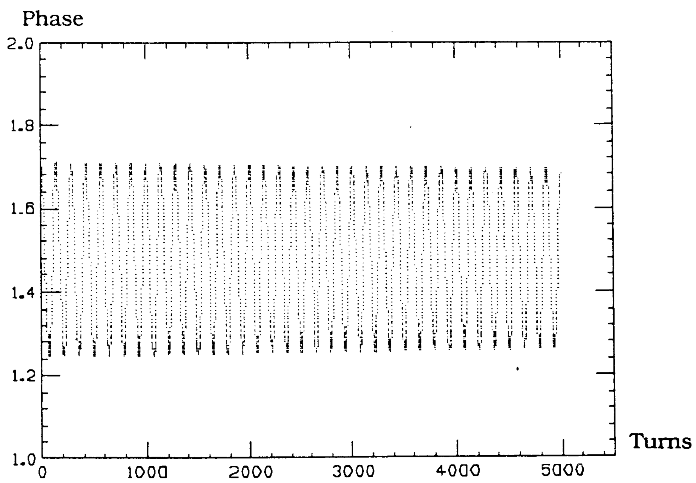
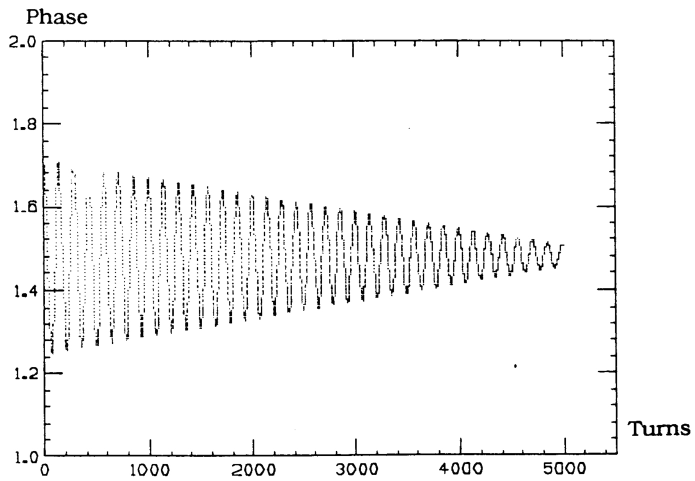
Simulation code

- A time domain simulation code has been developed to investigate the effect of the bunch-by-bunch feedback system on the multi-bunch longitudinal dynamics.
- The code tracks the longitudinal dipole motion of all the bunches and it includes the bunch-by-bunch feedback, the effects of the HOMs, the synchrotron radiation, the fast RF feedback …
- The core of the algorithm can be divided into four main parts:
- 1) propagation of all the bunches in the ring
- 2) bunch-by-bunch feedback effect
- 3) beam-cavity interaction
- 4) RF feedback

Simulation code

- The bunch-by-bunch feedback is simulated in all its parts.
- It is possible to modify the system configuration and the feedback gain
- Different digital filters, as delay line, high and low pass, derivative and sinusoidal filters have been investigated
- It has been possible to evaluate the power needed to cure the mode coupling instability





- Thank you for your attention