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Experimental Measurements of e-Cloud Mitigation using Clearing Electrodes in the DAΦNE Collider

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OUTLINE

-The DAΦNE collider and the e-cloud effects

-Clearing electrodes:

design, realization, installation and beam coupling impedance

-Measurements of electrodes effects on beam dynamics:

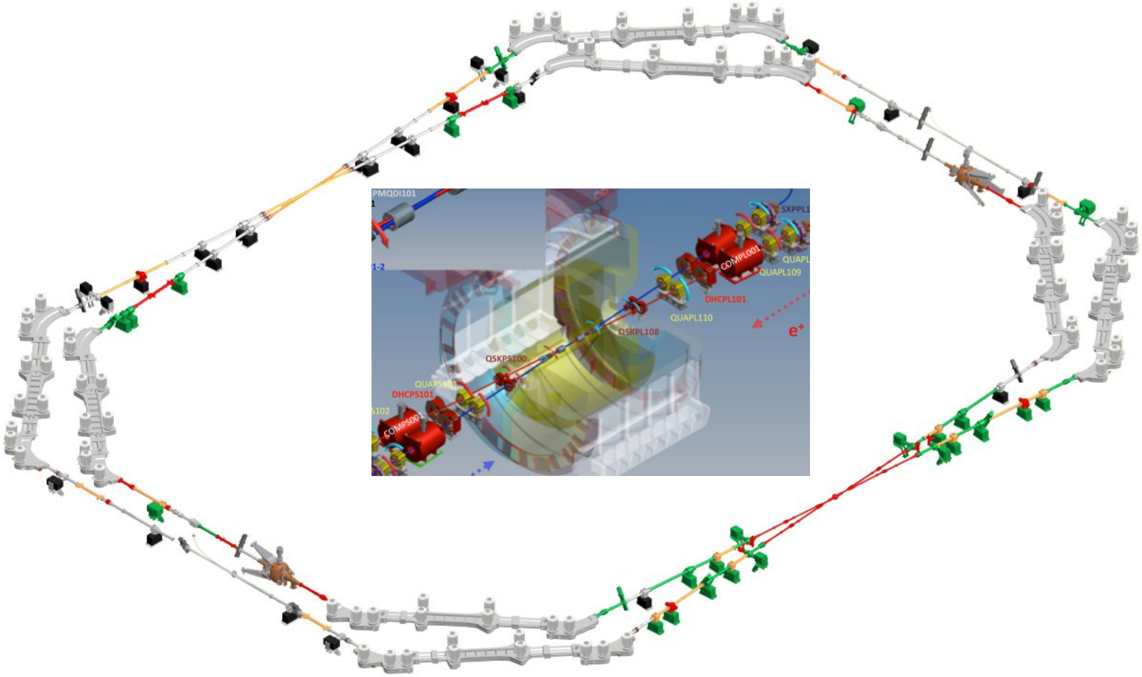
-Shift and spread of betatron tunes
-Growth rate of the horizontal instability
-Beam dimension variations
-Vacuum chamber RF resonance shifts
-Current delivered by voltage generators

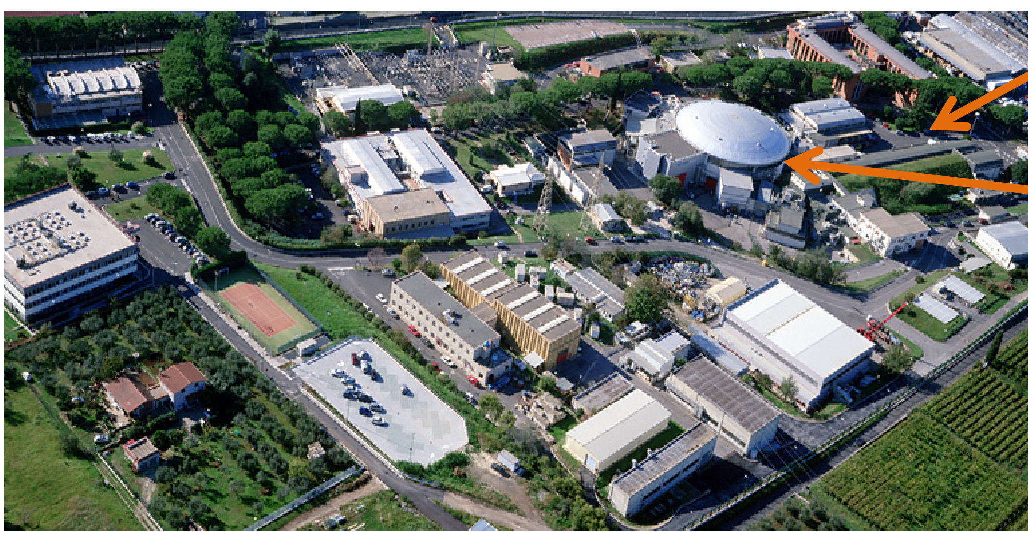
-Conclusions

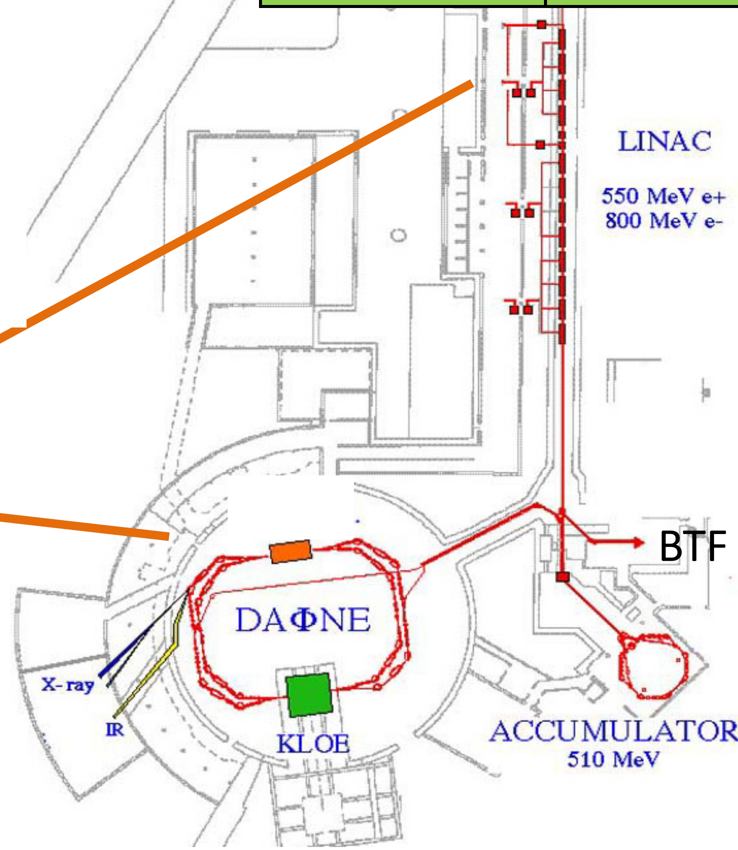
The DAΦNE collider

The Frascati Φ-factory DAΦNE is an e^+e^- collider operating at the energy of Φ-resonance (1.02 GeV c.m.).

Energy per beam	510 [MeV]
Machine length	96 [m]
Max. ach. beam current (KLOE-2 run)	1.5(e-) 1(e+) [A]
# of colliding bunches	100
RF frequency	368.67 [MHz]
RF voltage	200[kV]
Harmonic number	120
Bunch spacing	2.7[ns]
Max ach. Luminosity (KLOE-2 run)	$1.5 \cdot 10^{32}$ [$cm^{-2}s^{-1}$]

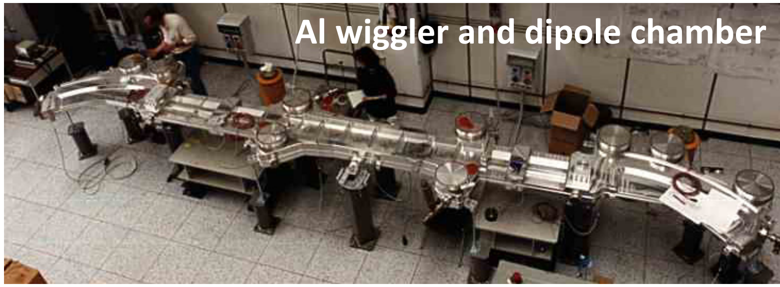




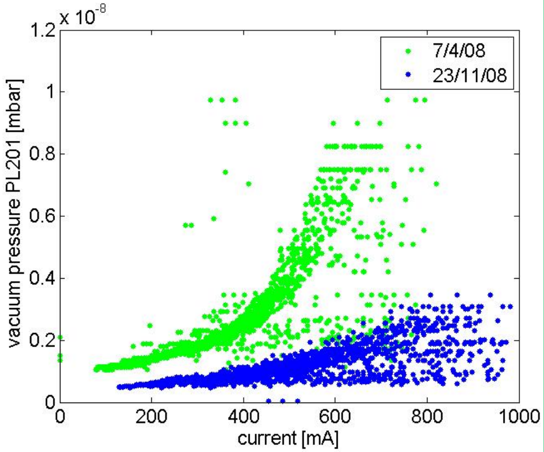


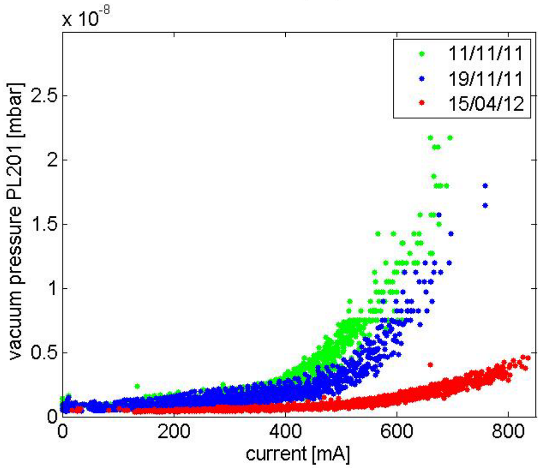
E-cloud @ DAFNE

After the 2003 shutdown, and some optics and hardware modifications (especially in wigglers poles), the appearance of a **strong horizontal instability for the positron beam at a current (I>500mA)**, triggered the study of the **e-cloud effect in the DAΦNE** collider (the only way to fight the instability was a strong increase of feedback power). The experimental observation could be summarized as follow:

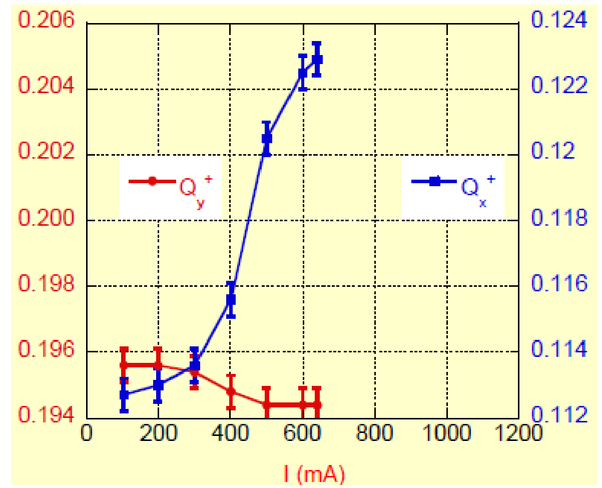


anomalous vacuum pressure rise with beam current and scrubbing

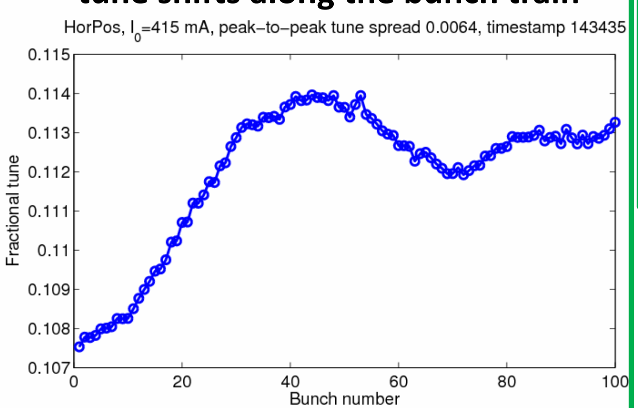




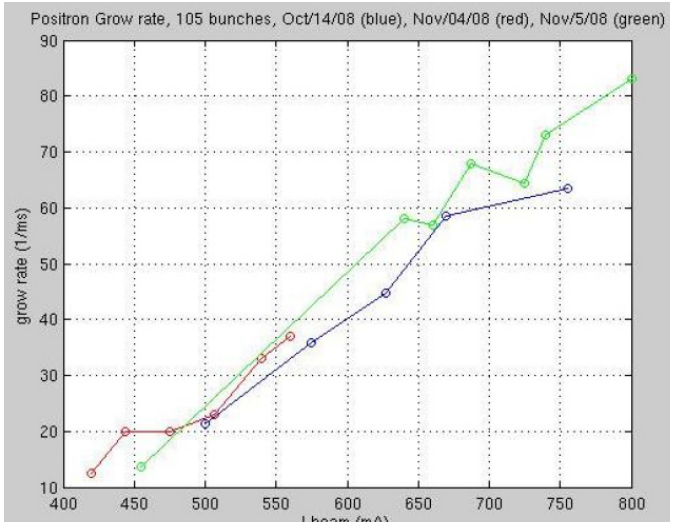
larger positive tune shift induced by the e^+ beam current



tune shifts along the bunch train

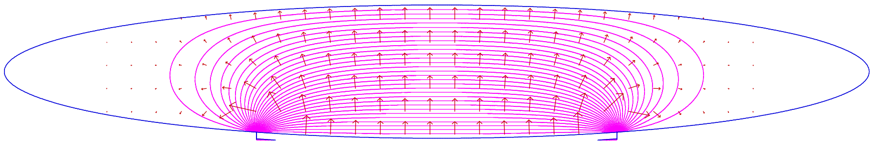


Very **fast horizontal instability** not explainable by parasitic HOMs

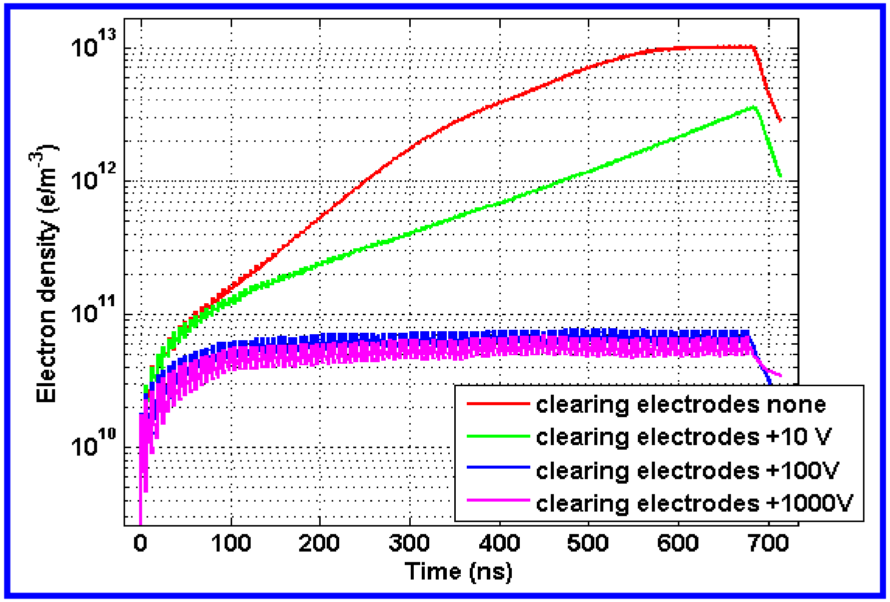


Clearing electrodes design

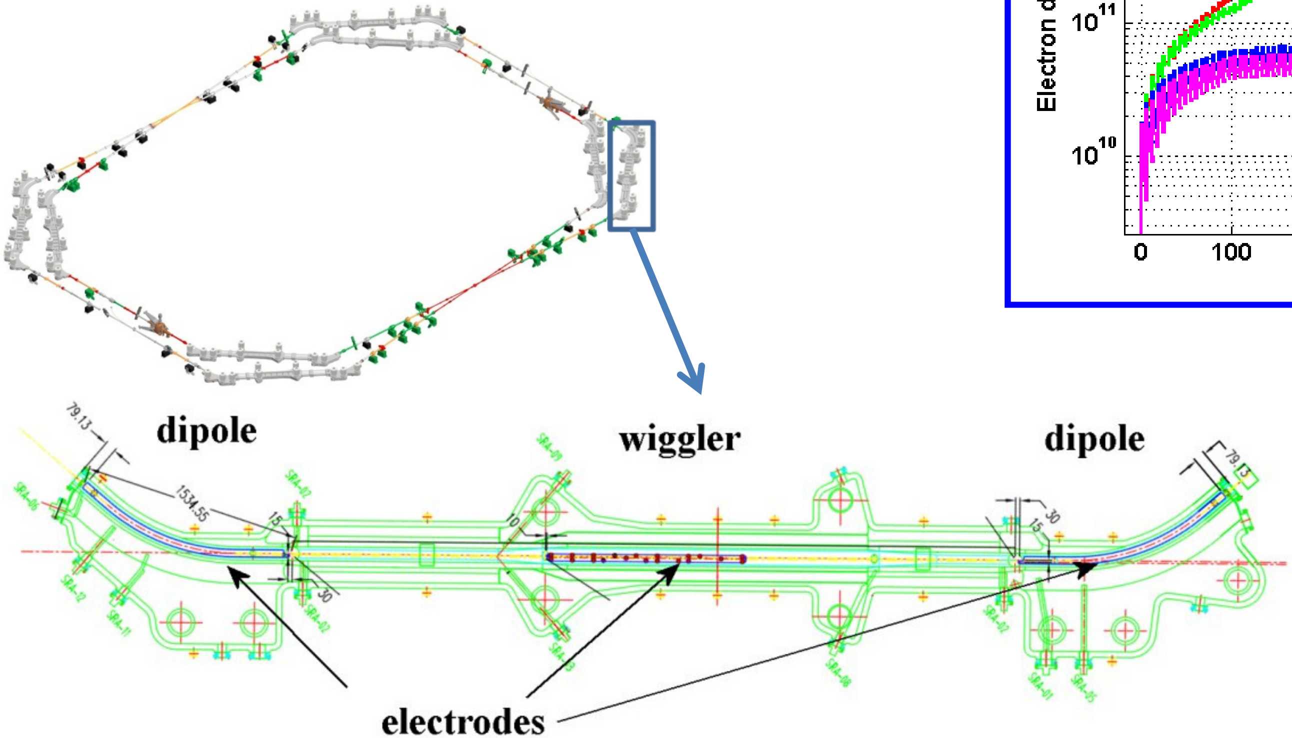
To mitigate the e-cloud instability **copper electrodes have been inserted in all dipole and wiggler chambers** of the machine and have been connected to external dc voltage generators in order to absorb the photo-electrons. The dipole electrodes have a length of 1.4 or 1.6 m depending on the considered arc, while the wiggler ones are 1.4 m long . Simulations of the e^- cloud density and instability threshold with and without the voltage applied to the electrodes have been done. **With a dc voltage of 100-500 V applied to each electrode we expected a reduction of such density** by two orders of magnitude that will contribute to reduce substantially the source of the instability.



Simulation using ECLOUD code of electron cloud build-up and suppression with clearing electrodes.

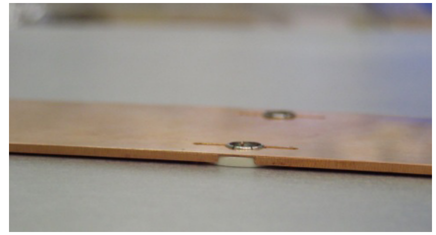


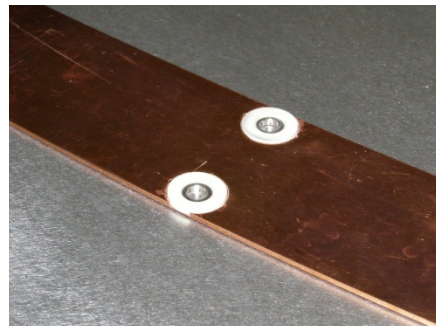
Bunch population	2.1×10^{10}
Bunch spacing L[ns]	2.7
Bunch length σ_z [mm]	18

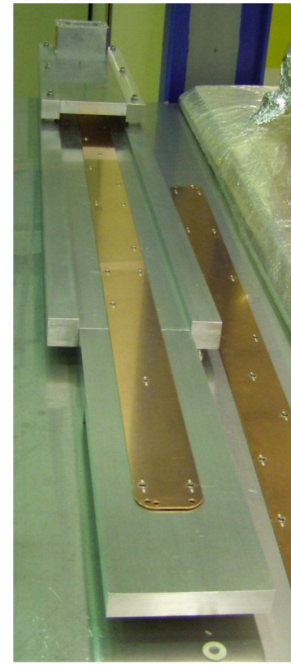


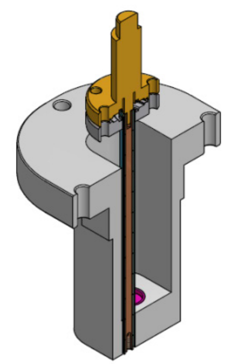
Clearing electrodes realization

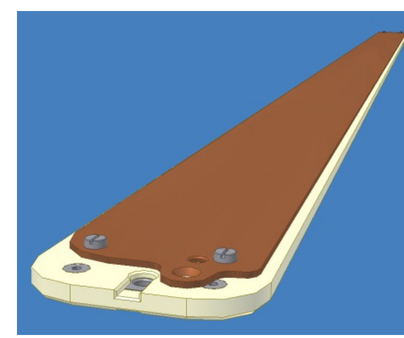
The electrodes have a **width of 50 mm, thickness of 1.5 mm and their distance from the chamber is about 0.5 mm.** This distance is guaranteed by **special ceramic supports** (made in SHAPAL), distributed along the electrodes. This ceramic material is also thermo-conducting in order to partially dissipate the power released from the beam to the electrode through the vacuum chamber. The supports have been designed to minimize the beam coupling impedance and to simultaneously sustain the strip. The distance of the electrode from the beam axis is 8 mm in the wigglers and 25 mm in the dipoles.











The electrodes have been inserted in the vacuum chamber using a dedicated tool allowing the electrode to be inserted without damages the Al chamber. They have been connected to the external dc voltage generators modifying the existing BPM flanges.

Electrode impedance evaluation

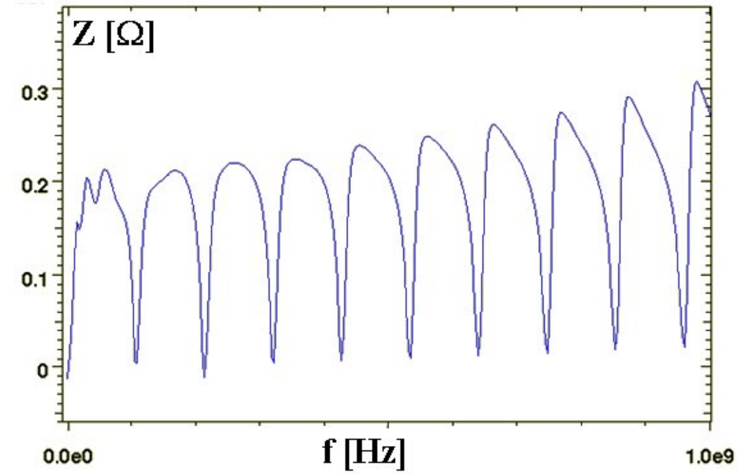
Resistive wall

It is due to a finite conductivity of the electrode. Wiggler case: **112 W/m²**. Such power density would result in electrode heating under vacuum up to **50⁰-55⁰ C**.

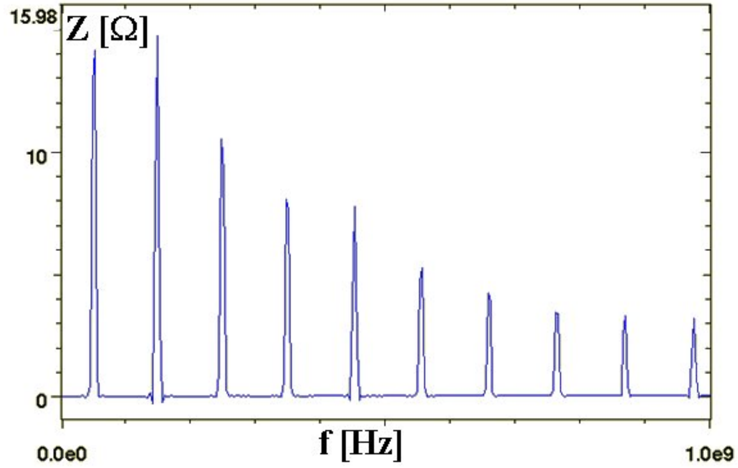
Strip-line Impedance

Two extreme cases have been simulated:

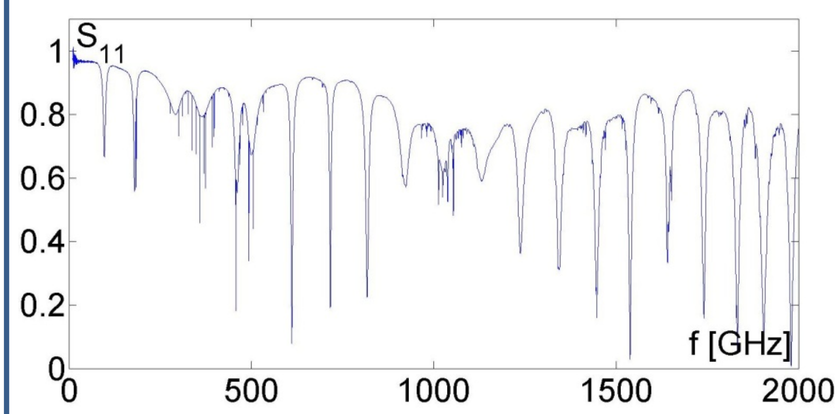
Perfectly matched: broad-band impedance, in this case the loss factor can be used for the power loss evaluation. Loss factor (≈1.6×10^9 V/C) is a factor 3 higher than that of the resistive walls but part of power is dissipated in the external load.



Short-circuited: situation less predictable. The released power can be much higher in this case if one of the narrow peaks coincides with one of the RF frequency harmonics. Electrode length has been properly chosen. Moreover we used thermo-conducting dielectric material as supports (SHAPAL).



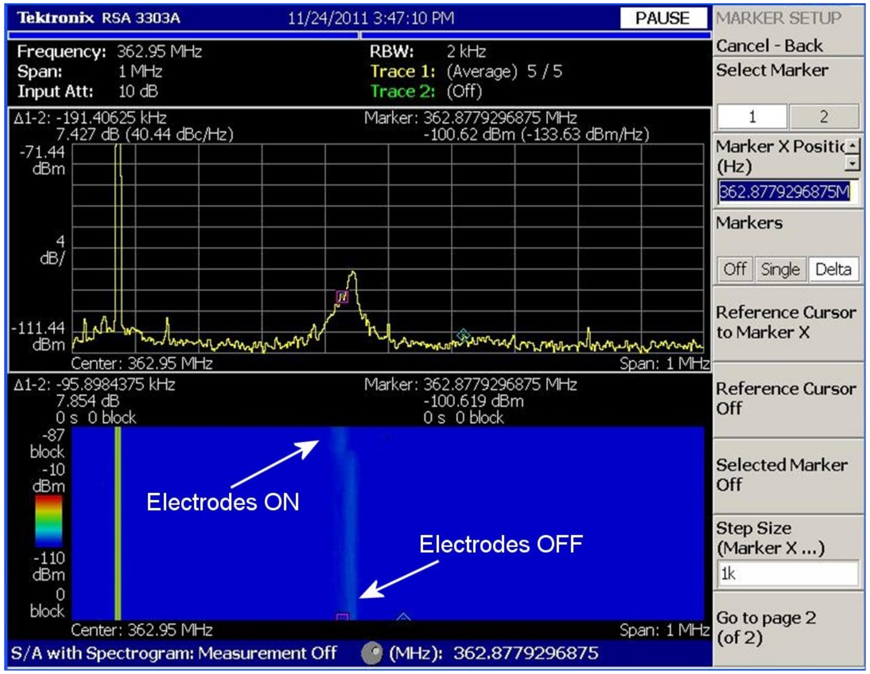
RF measurements have been performed allow estimating the resonant frequencies of the strip



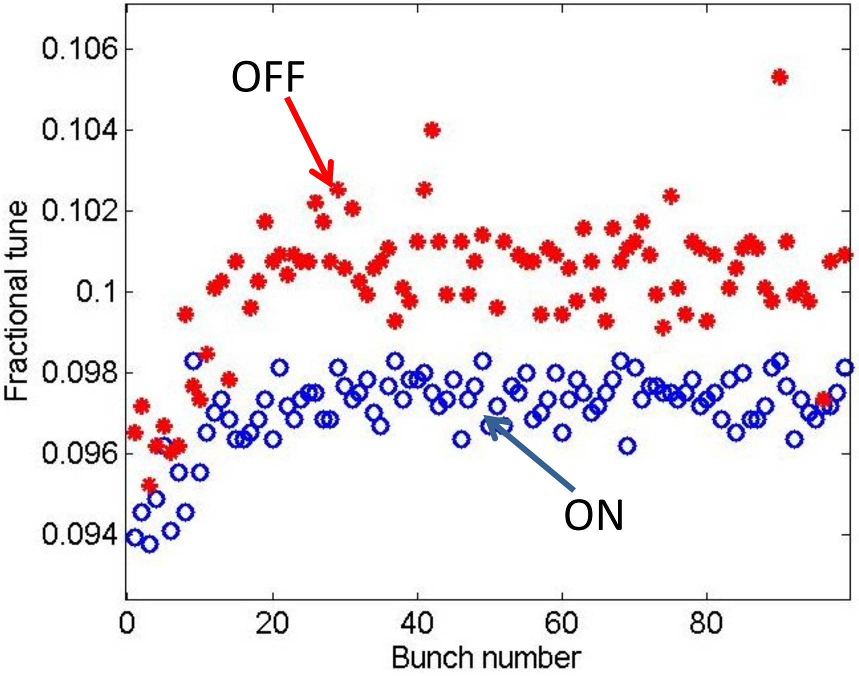
Measurements of electrodes effects on beam dynamics: shift and spread of betatron tunes

The **electrodes effectiveness** in absorbing the e-cloud has been verified by **several measurements**.

Horizontal tune shift measurements with electrodes on and off (in figure the case of 550 mA). The frequency shift of the horizontal tune line switching off all electrodes is ≈20 kHz which correspond to a difference in the **horizontal tune of ≈0.0065**.



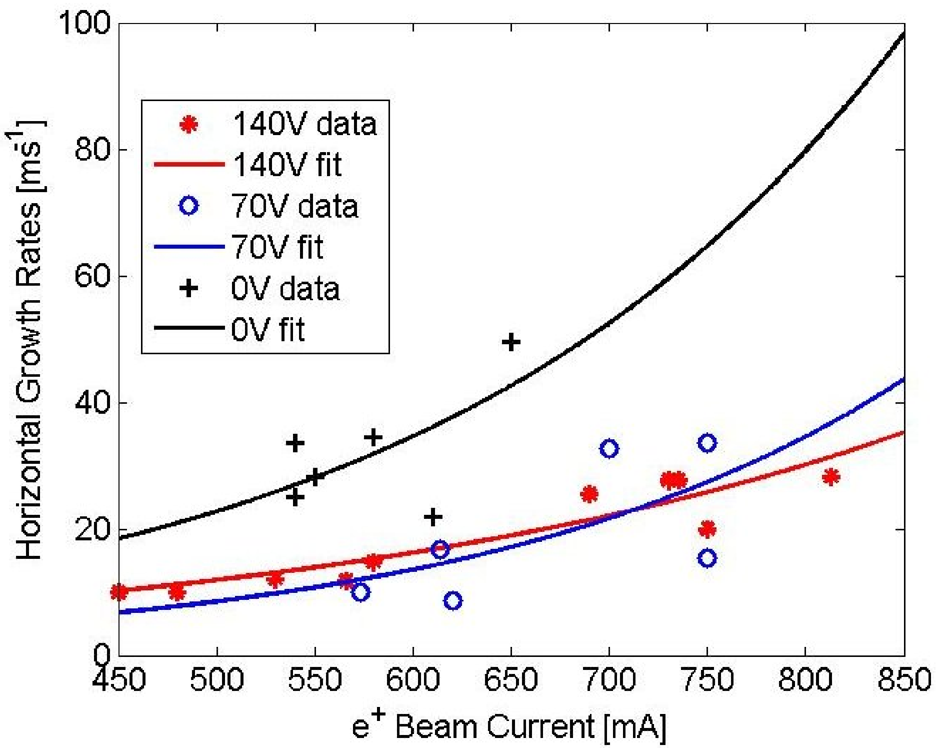
Off-line analysis of the **signals acquired by the bunch-by-bunch transverse feedbacks** allows measuring the fractional tunes of each bunch along the train. Results are given in Figure for the horizontal plane (bunch #1 is the first in the batch). In this case the measurements have been done turning off the four wigglers electrodes and two (over eight) dipole electrodes.



The average tune shift and the tune spread, measured in the vertical plane, are a factor ten lower than the corresponding values in the horizontal one

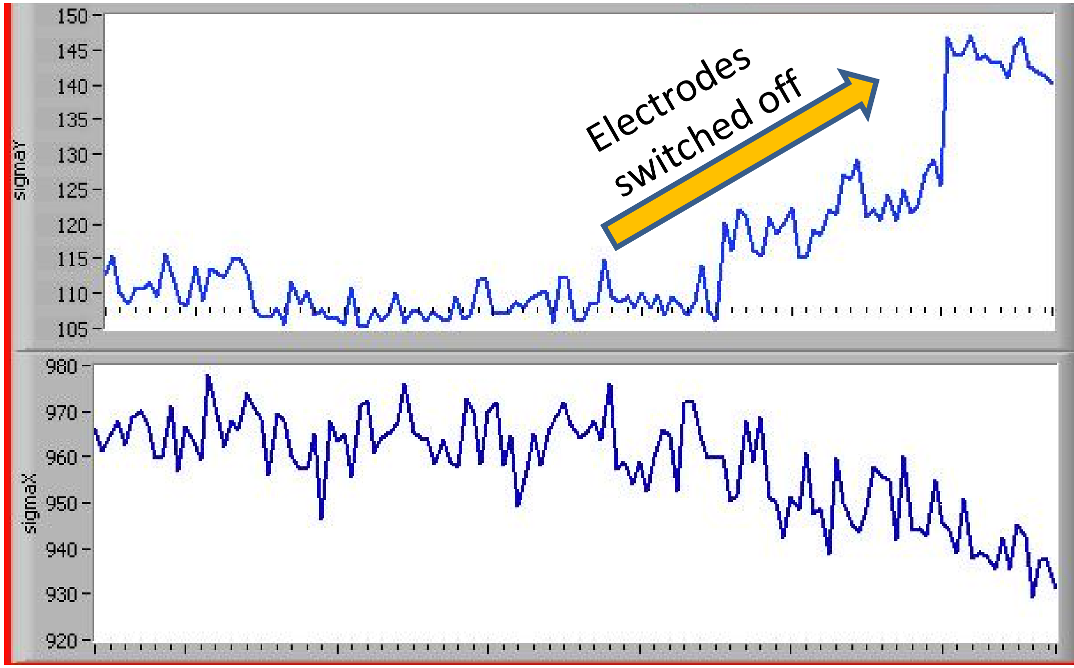
Growth rate of the horizontal instability

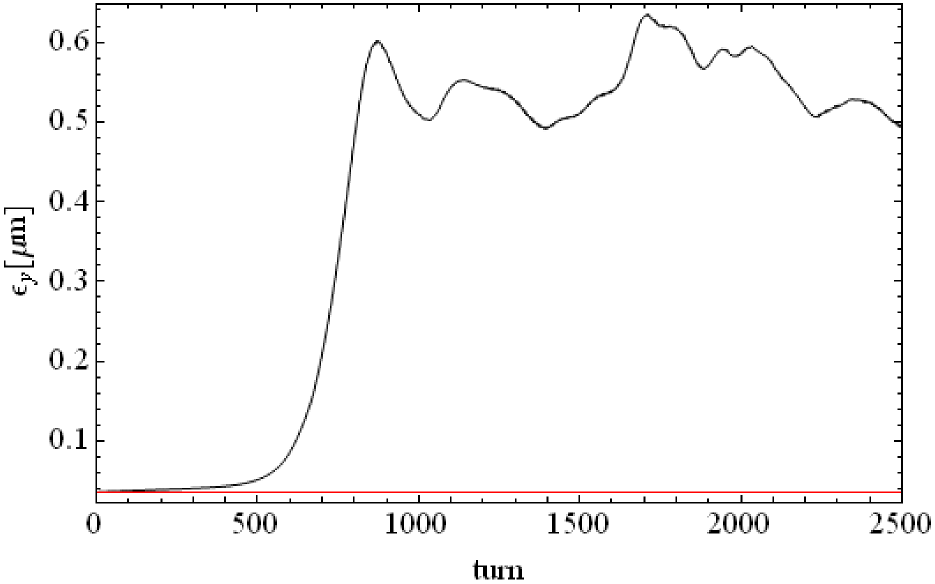
Growth rates measurements of the coupled bunch instabilities can be performed by means of the bunch by bunch transverse feedbacks. With ***electrodes OFF,*** the growth rate of the horizontal instability at 650 mA exceed 50 ms^{-1} and the measurements above this current becomes quite difficult since the beam is strongly unstable. With ***electrodes ON***, these growth rates are strongly reduced and it is possible to store a higher stable current.



Beam dimension variations

The transverse beam dimensions (in μm) measured at the synchrotron light monitor (SLM) **turning off, progressively, all electrodes** are given in the figure. The beam vertical size goes from less than 110 μm with electrodes on to more than 145 μm with electrodes off.

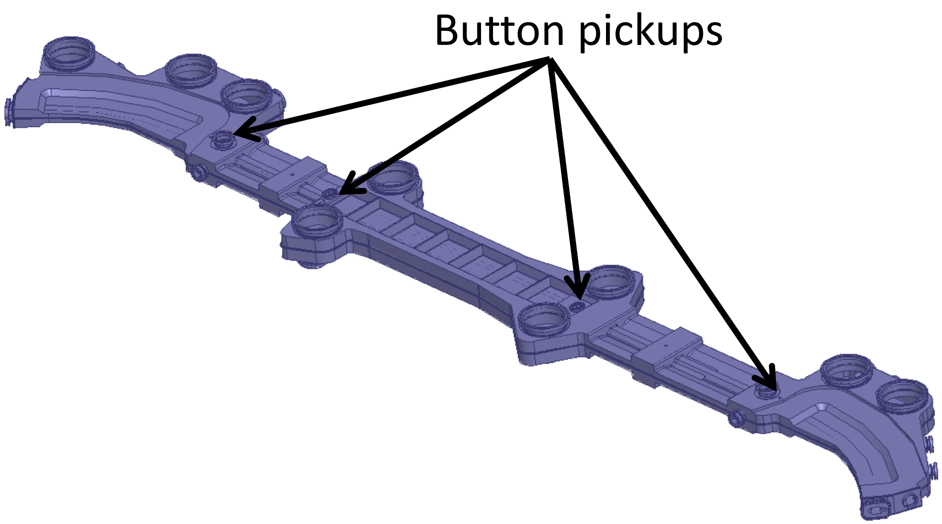


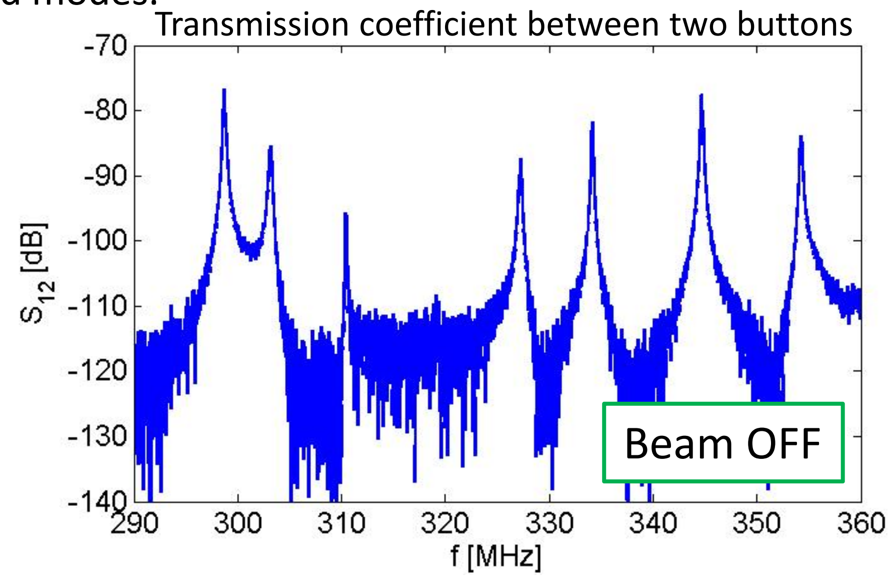


BUT: Simulated threshold well above the current estimated (simulated) e-cloud density for DAΦNE ($<10^{13}e^-/m^3$).

Vacuum chamber RF resonance shifts: measurement setup

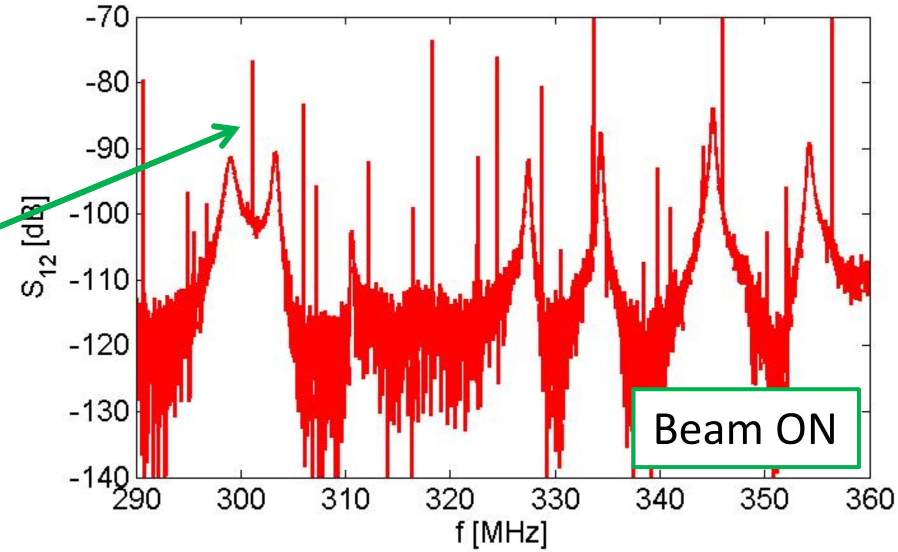
The ***e-cloud plasma can interact with RF waves*** transmitted in the vacuum chamber changing the phase velocity of such waves. A ***similar approach can be used in case of resonant waves*** in the vacuum chamber. Even in this case the e-cloud changes the electromagnetic properties of vacuum and this can result in a ***shift of the resonant frequencies of vacuum chamber*** trapped modes.





Resonant TE-like modes are trapped in the DAΦNE arcs and can be excited through button pickups. The lower modes have frequencies between 250 and 350 MHz.

Beam power spectrum lines



Vacuum chamber RF resonance shifts: results

The analysis of data, up to now, gave the following results:

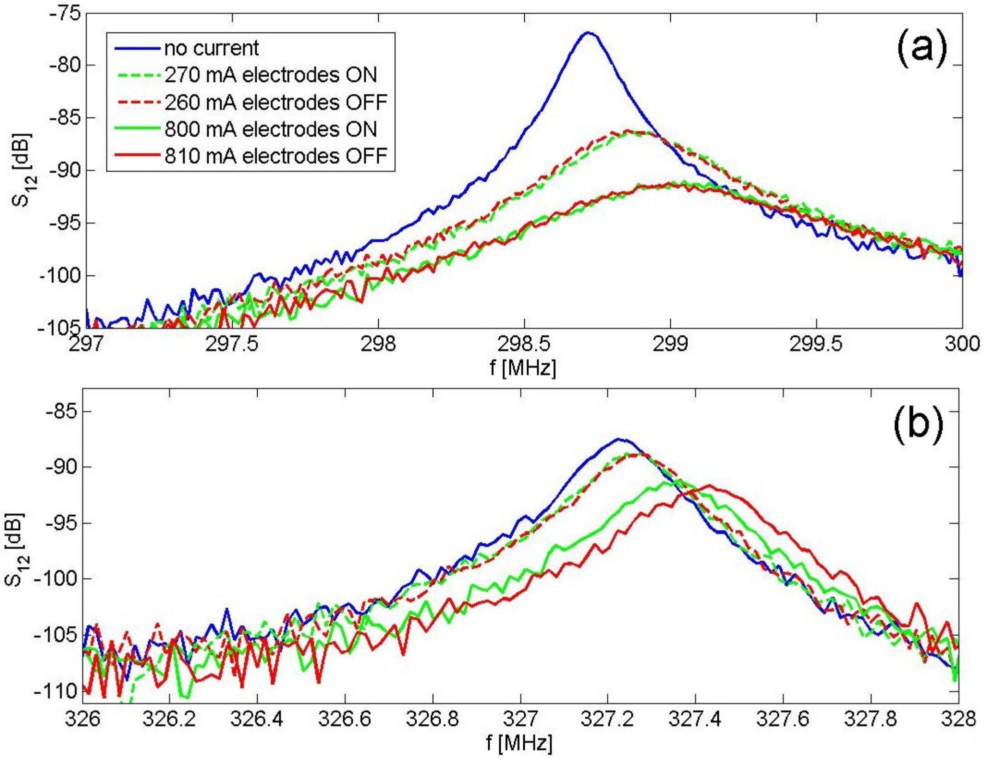
(a) ***all modes have a positive frequency shift*** as a function of the positron beam current and, with 800 mA, it is between 100 and 400 kHz depending on the modes we are considering;

(b) for almost all modes we can ***partially cancel the frequency shift*** switching on the electrodes;

(c) the ***quality factor of the modes decreases with positron current***;

(d) The fact that for some modes the shift does not depend on the electron voltage could depend by the fact that ***these modes are localized in different places of the arc*** and also in regions not covered by electrodes.

(e) In principle, from these shifts it is possible to ***evaluate the e-cloud density***. Applying the formula given in [J. Sikora et al., MOPPR074] it is possible to estimate an average e-cloud density of about **(1-5)·10^{11}e/m^3**.



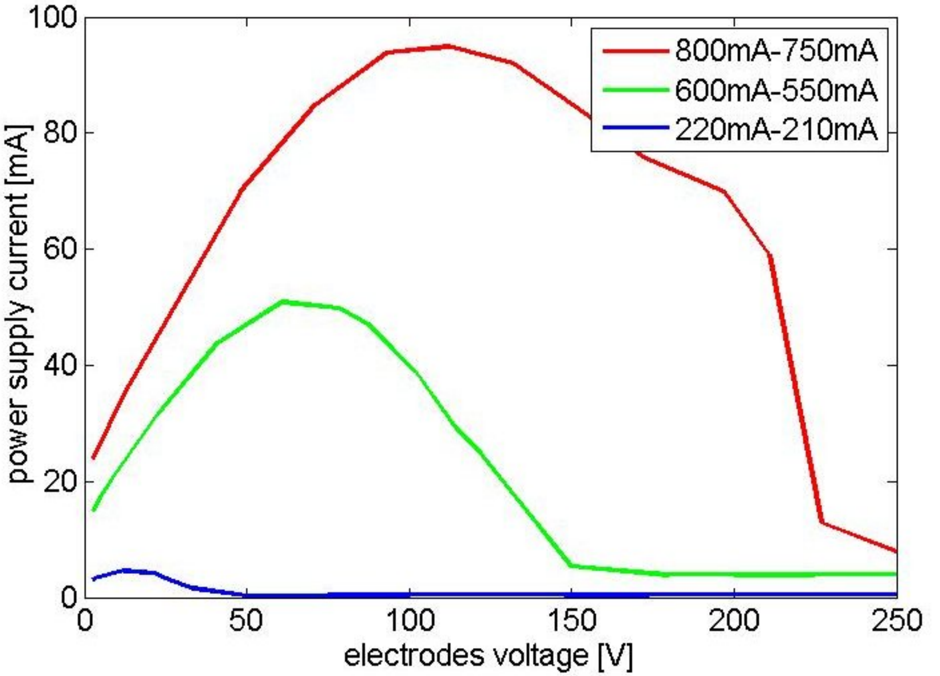
(f) An identification of resonant mode location is still in progress and is not trivial due to the complex 3D geometry of the arc chamber

Current delivered by voltage generators

The voltage generators connected to the electrodes absorbs the photo-electrons.

In the present layout one voltage generator is connected to three electrodes of one arc (i.e. one wiggler and two dipoles).

The ***current delivered by the generator has been measured as a function of the generator voltage and for different beam currents***.



Possible explanation

Current supplied by the generator $I \propto V_{DC} \cdot n_{e-}$

e-cloud density $n_{e-} \propto I_B - \beta V_{DC}$.

Combining the two previous relations we obtain that $I \propto V_{DC} \cdot I_B - \beta V^2_{DC}$,

The e-cloud is completely absorbed when $I \approx 0$. In all other situations there is still an e-cloud density. Fitting these curves and scaling their behaviour up to currents >1A, one discover that a voltage of the order of 250 V is no longer adequate to completely absorb the e-cloud when I_B>1A. ***So the applied voltage has to be increased.***

Conclusions

1. ***Special metallic electrodes have been recently installed*** in the vacuum chamber of all dipoles and wigglers of the DAΦNE positron ring.

2. They were expected to ***absorb the e-cloud*** that limited the positron beam dynamics and the overall collider performances.

3. ***Experimental measurements*** of the effectiveness of the electrodes in the mitigation of the e-cloud effects have been shown:

   the electrodes allow reducing the vertical beam size increase
   the growth rate of transverse instabilities
   the tune shifts induced by the e-cloud.

4. ***Frequency shifts measurements*** of the vacuum chamber resonances switching on and off the electrodes have also been done. This measure allows calculating, to the first order, the e-cloud density and the effects of the clearing electrodes.

5. We have also shown the measurements of the ***current delivered by the voltage generators*** that is related to the effectiveness in absorbing the e-cloud.