Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

DAΦNE and e-cloud: *observations and perspectives*

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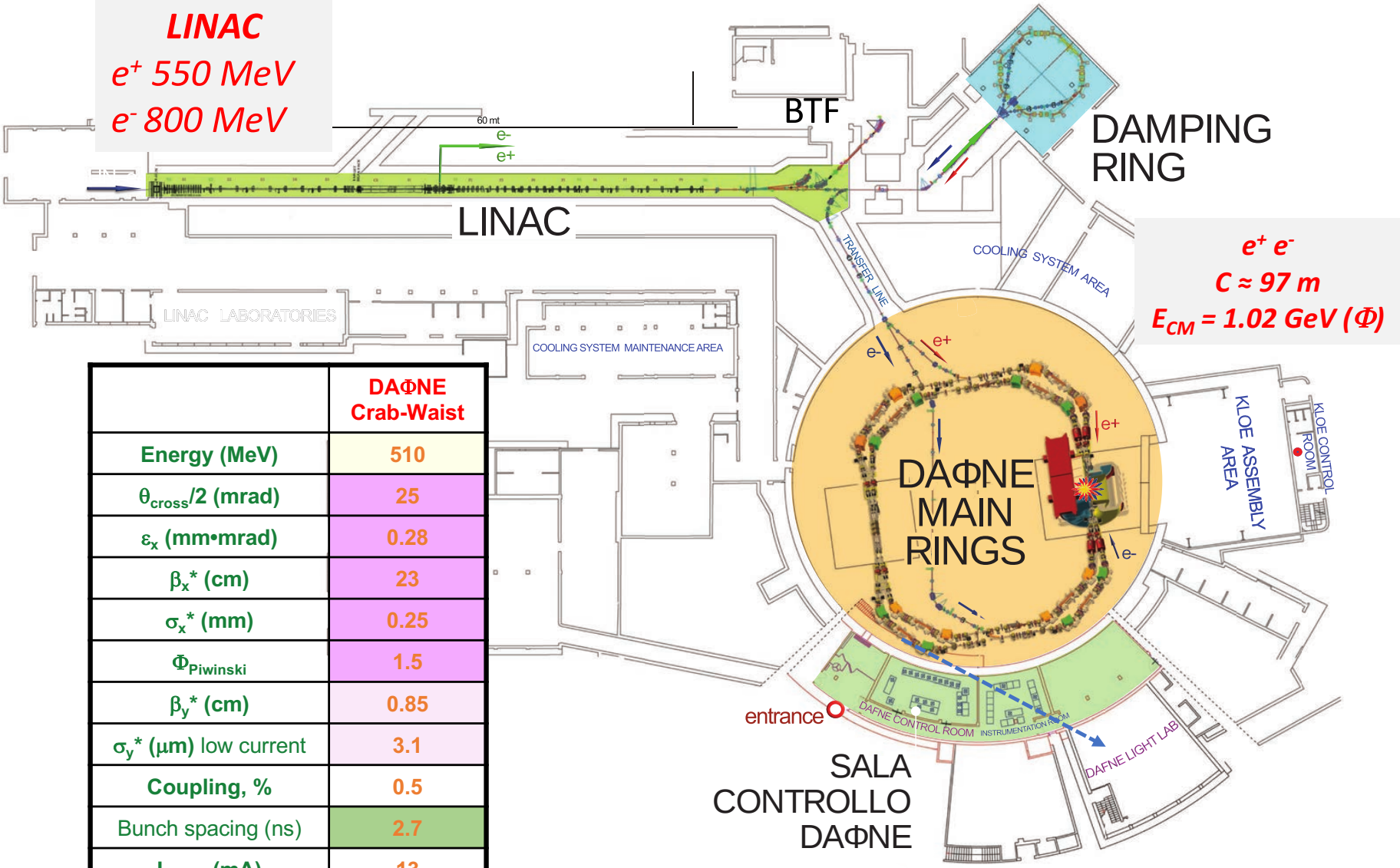
The DAΦNE Accelerator Complex

LINAC
e^+ 550 MeV
e^- 800 MeV



$e^+ e^-$
$C \approx 97$ m
$E_{CM} = 1.02$ GeV (Φ)

	DAΦNE Crab-Waist
Energy (MeV)	510
$\theta_{cross}/2$ (mrad)	25
ε_x (mm•mrad)	0.28
β_x^* (cm)	23
σ_x^* (mm)	0.25
$\Phi_{Piwinski}$	1.5
β_y^* (cm)	0.85
σ_y^* (μm) low current	3.1
Coupling, %	0.5
Bunch spacing (ns)	2.7
I_{bunch} (mA)	13
σ_z (mm)	15
N_h	120

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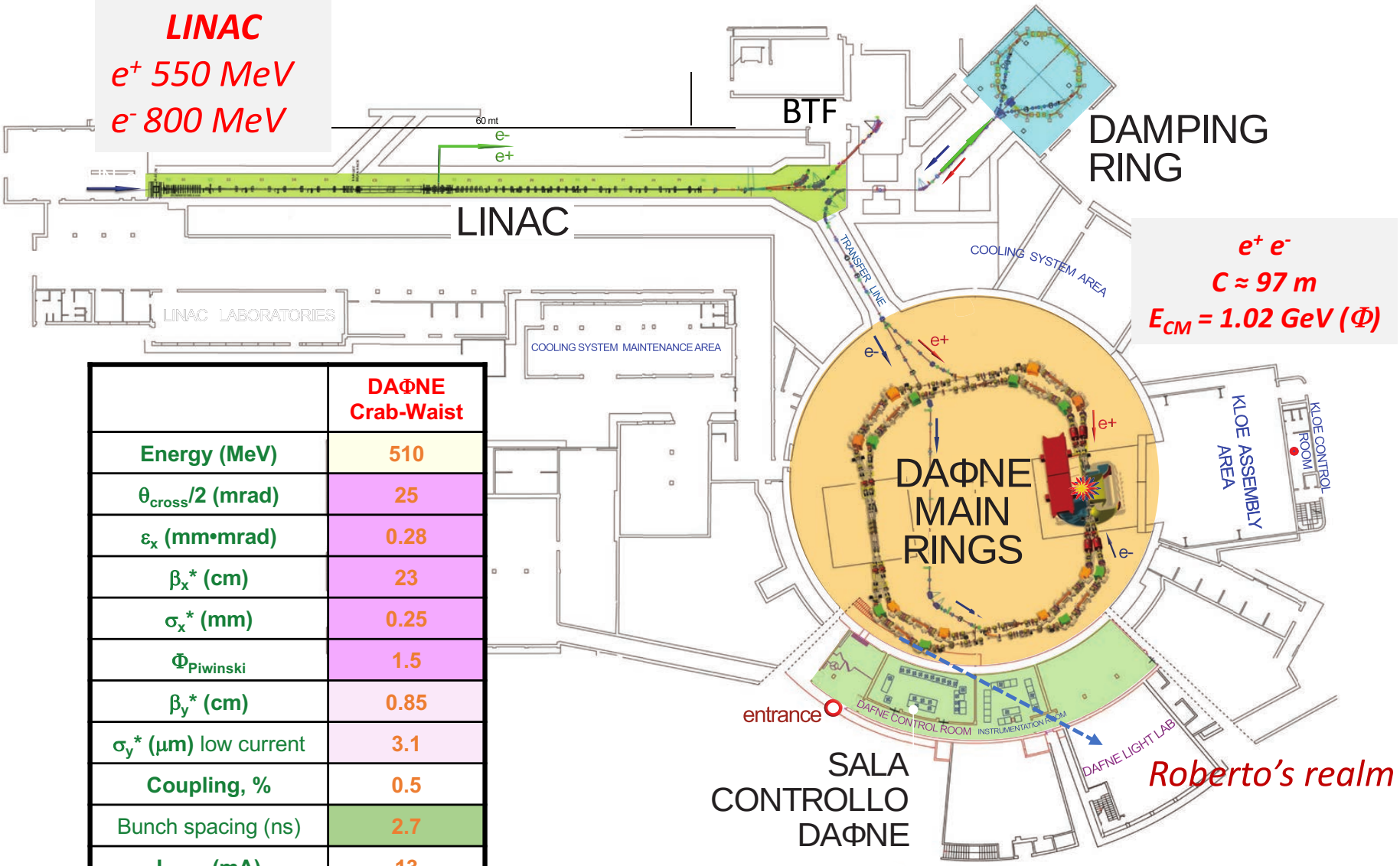

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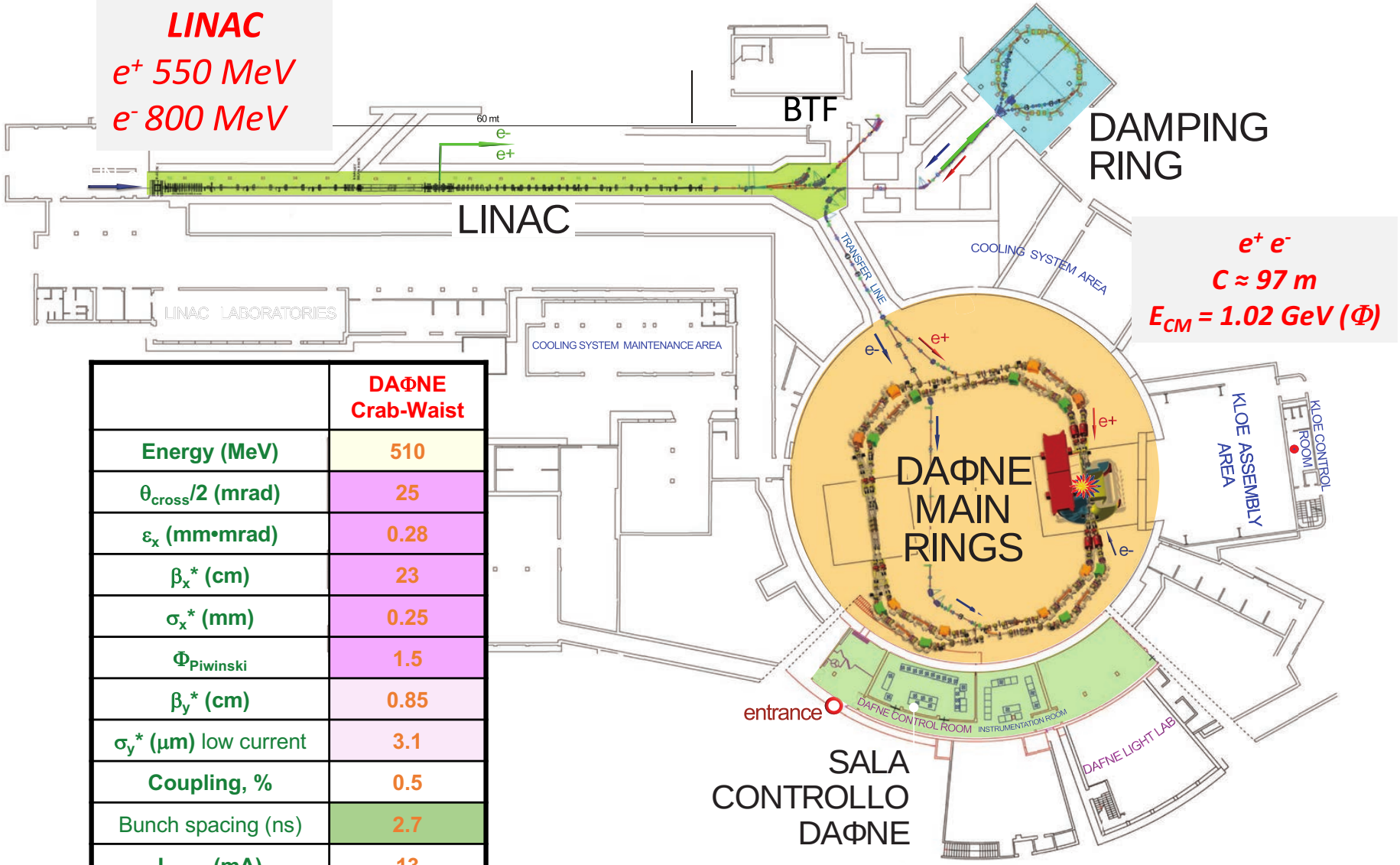

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DAΦNE implemented and tested succesfully a new approach to beam-beam interaction: the ***Crab-Waist*** **collision scheme**.

DAΦNE is a collider operating with high currents

Lepton Beam Currents achieved so far

	beam current I [A]	bunch population N_b [10^{11}]	rms bunch length [mm]	bunch spacing [ns]	comment
PEP-II	2.1 (e^-), 3.2 (e^+)	0.5, 0.9	12	4.2	closed
superKEKB	2.62 (e^-), 3.6 (e^+)	0.7, 0.5	7	6	commissioning
DAFNE	**2.4 (e^-), 1.4 (e^+)**	**0.4, 0.3**	**16**	**2.7**	
BEPC-II	0.8	0.4	<15?	8	
CesrTA	0.2	0.2	6.8	4	
VEPP-2000	0.2	1	33	80 (1 b)	
LHC (des)	0.58	1.15	75.5	25	
ESRF	0.2	0.04	6.0	2.8	
APS	0.1	0.02	6.0	2.8	
Spring8	0.1	0.01	4.0	2.0	
SLS	0.4	0.05	9.0	2.0	

Beam Current and Luminosity Limitations

- e^+ current limit ~ 1.4 A due to a fast horizontal instability
- vertical beam size increase
- tune spread along the batch
- anomalous vacuum pressure rise

Measurements and simulations showed how horizontal instability was triggered by the *e-cloud formation* in the *DIPOLES* in the *WIGGLERS* of the DAΦNE positron ring.

Not strange considering that:

low beam energy E = 510 MeV
Al vacuum chamber with high SEY
short bunch spacing 2.7 nsec
high current operations

Beam energy	510 [MeV]
Ring length	97 [m]
Max. e+ beam current (Kloe run)	1.4 [A]
N filled bunches	100
RF frequency	368.67 [MHz]
RF voltage	130 [kV]
Harmonic number	120
Bunch spacing	2.7[ns]
SR emitted per turn	9.7 [keV]
n per bunch @ 10 mA	$2 \cdot 10^{10}$

Suppressing the *e-cloud*

general approach

Modifying the beam pipe design and surface so to reduce the SEY

- anti-chamber
- material having low SEY
- coating
- increasing roughness by grooving and/or treating the surface

Modifying the dynamics of the electrons in the cloud by applying electric, magnetic, and electromagnetic fields

- solenoids in the straight session
- permanent magnets
- clearing electrodes used to attract or push back electrons by using static fields.

Countermeasures at DAΦNE

All Dipole and Wiggler vacuum chamber are equipped with antichamber and SR adsorbers

Devices

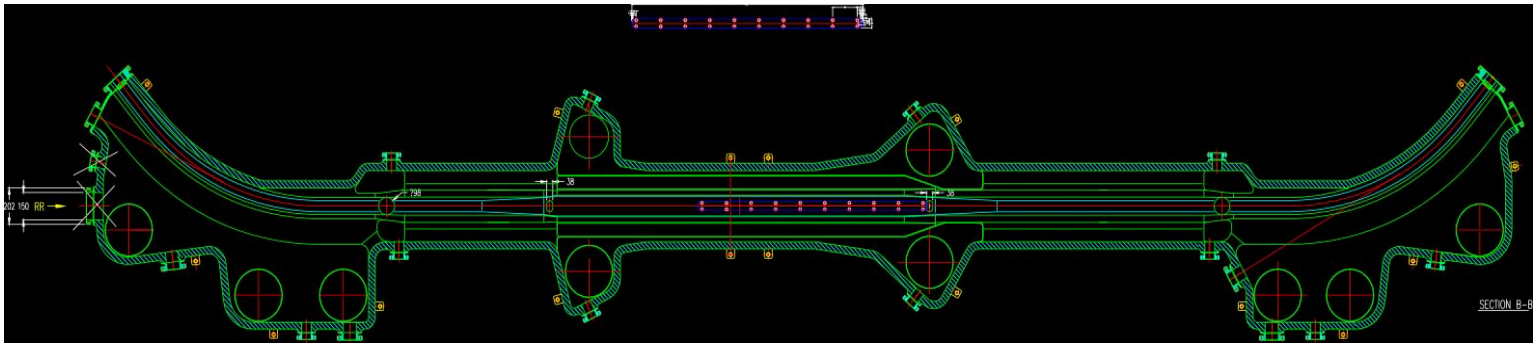
- solenoid windings
- powerful feedback system
- electrodes

Varying ring and beam parameters

- moving ξ_x ξ_y to higher positive values
- lengthening the bunch by reducing the RF voltage
- tuning octupole magnets

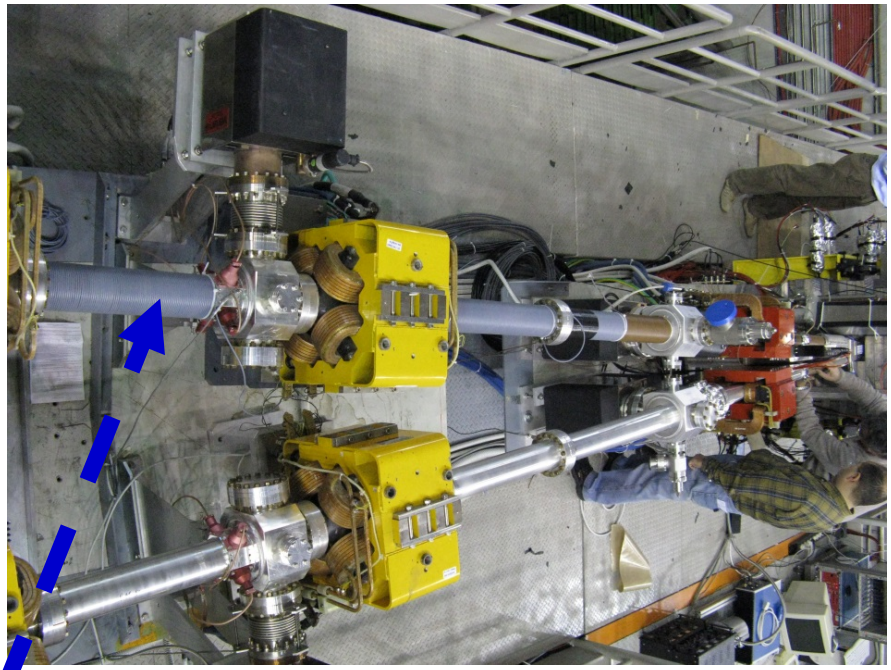
Maintaining optimal dynamic vacuum

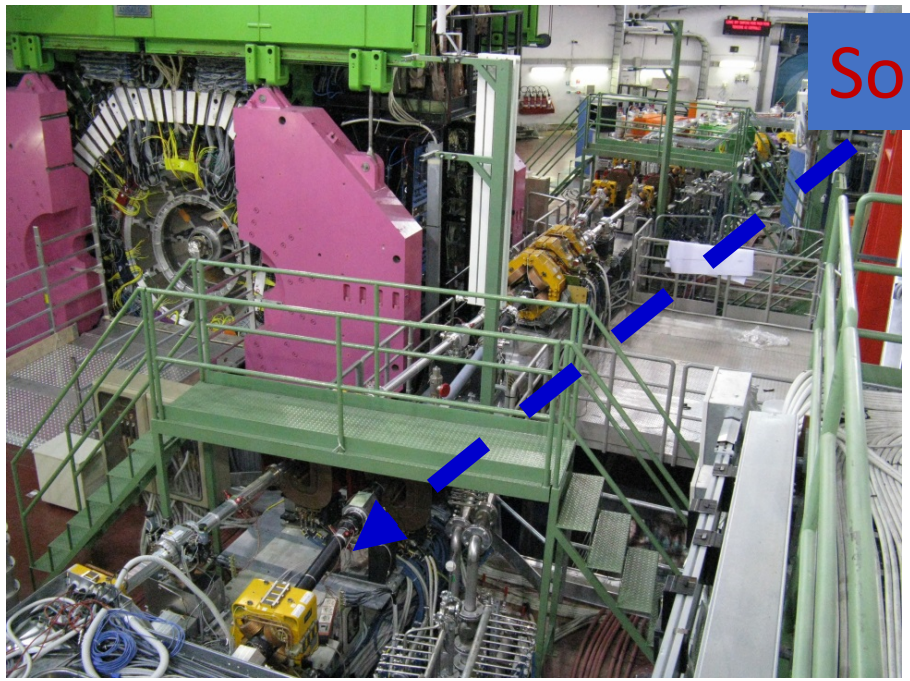
- more frequent sublimations

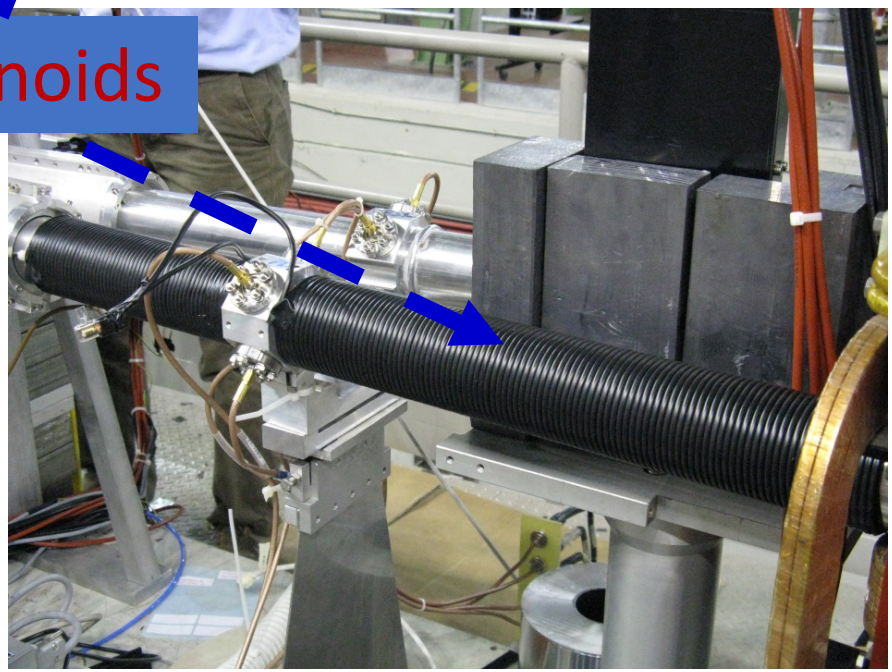


Solenoids

Solenoids have been winded around all the straight sections and connected to an external DC PS







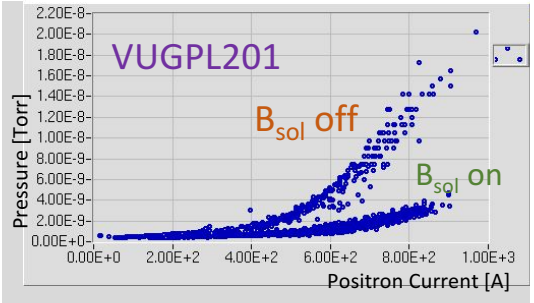
Operations with Solenoids

Solenoid currents have been initially set so to have:

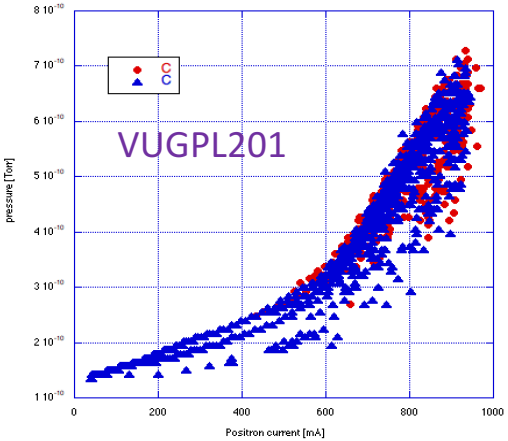
B_{sol} ~ 45 Gauss

as indicated by numerical simulations.

Such value has then been tuned experimentally



Impact of solenoid windings (May 2012)



Red and blue dots refer to two different values of the B_{sol} in a given section at the end of the optimization process

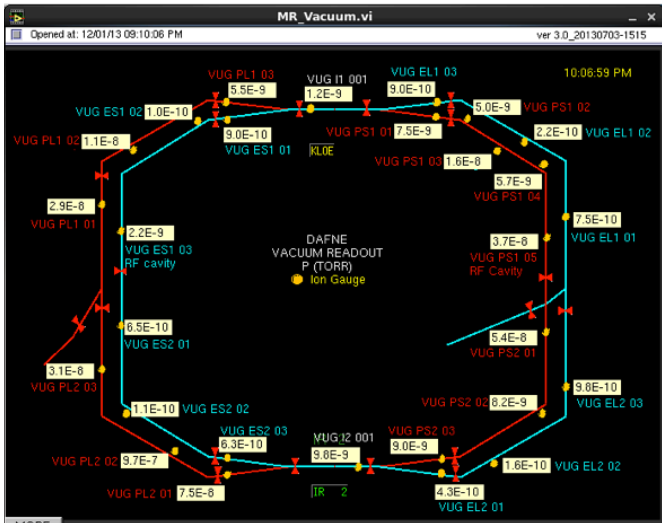
Blue dots exhibit different trends corresponding to different values of the RF voltage.

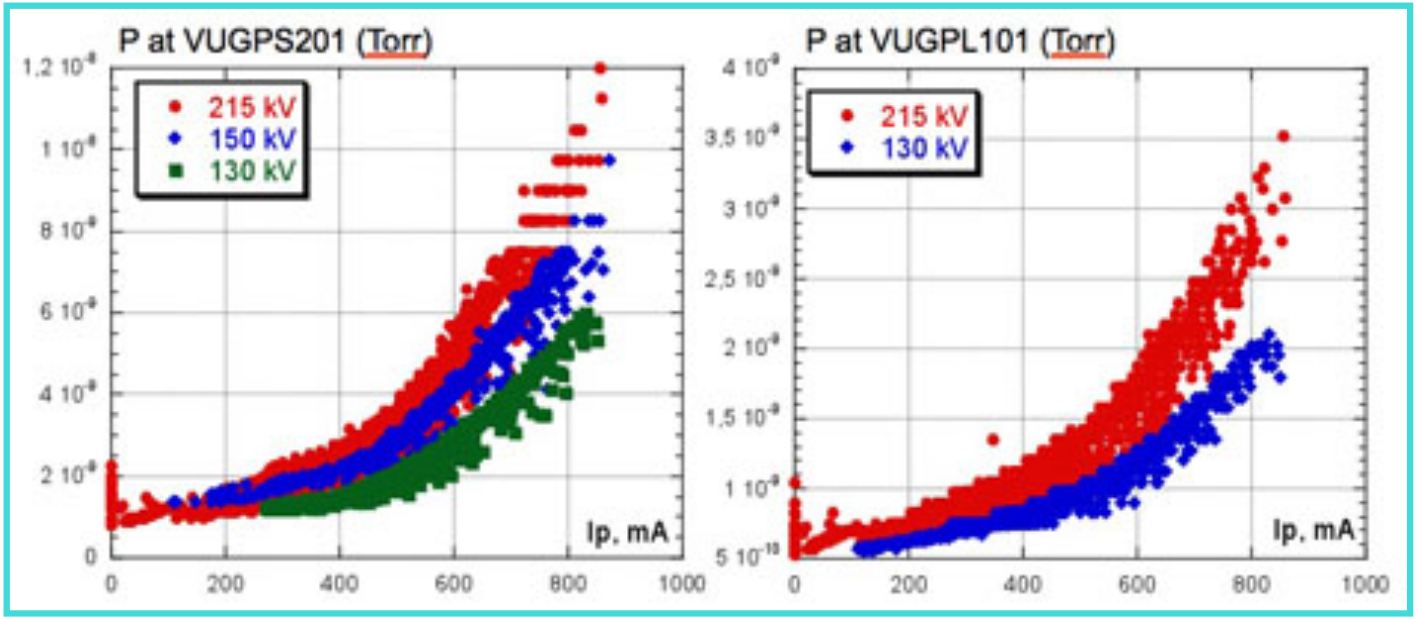
Solenoids are also effective in:

- reducing the transverse instability rise time
- boosting the action of the transverse feedbacks
- keeping under control the growth of the beam transverse size

Tuning Bunch Length

e-cloud induced effects have been mitigated also by lengthening the bunch by reducing the RF cavity voltage





Electrodes for DAΦNE e^+ ring

E**-cloud **C**learing **E**lectrodes **ECE

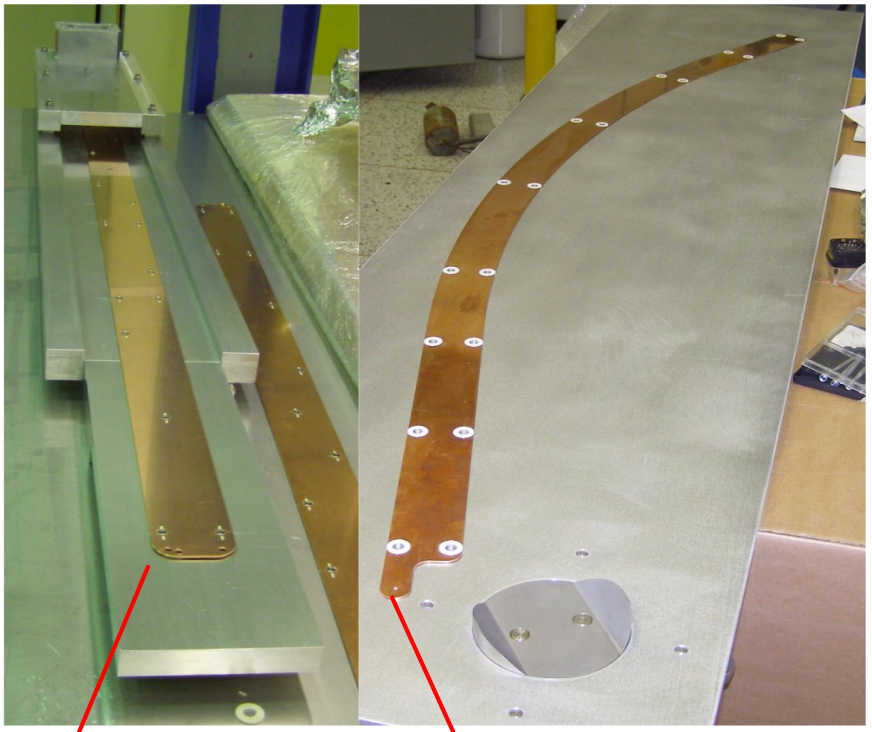
A new type of electrode never used before has been installed and tested on the DAΦNE positron ring

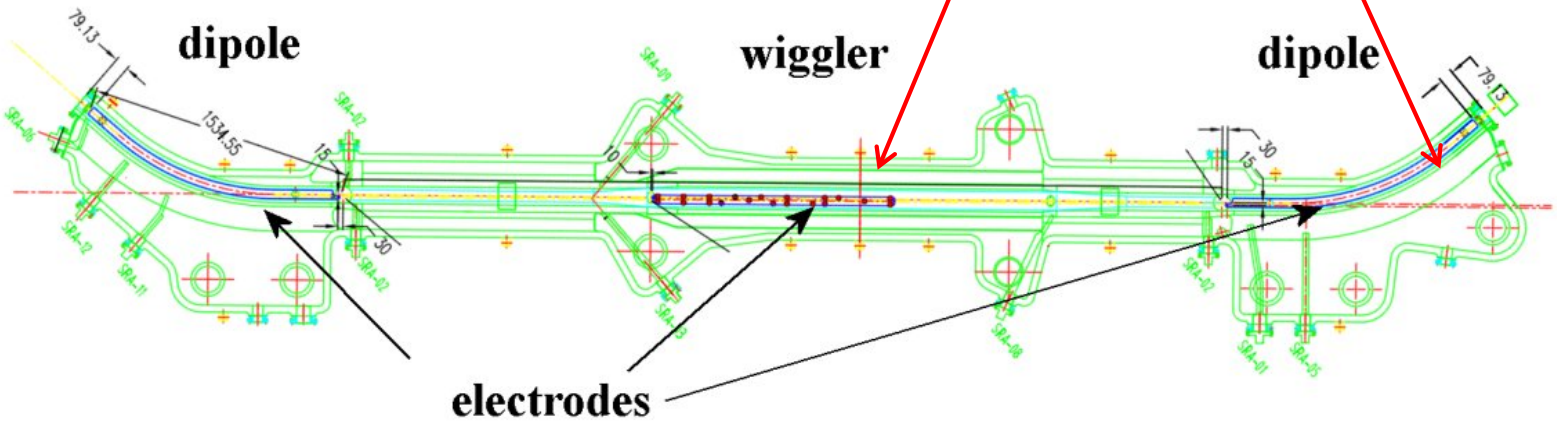
Copper electrodes

$L_{WGL} = 1.4$ m

$L_{SDIP} = 1.6$ m

$L_{RDIP} = 1.4$ m

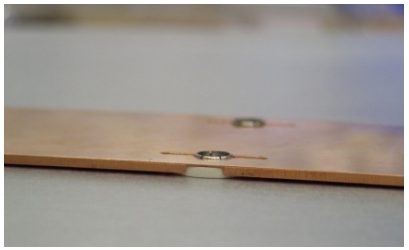


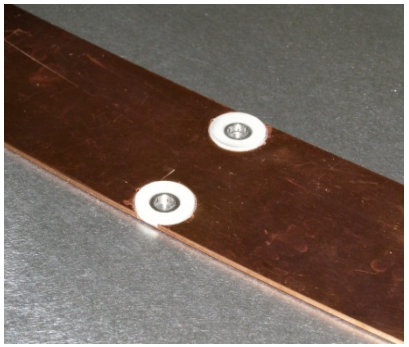


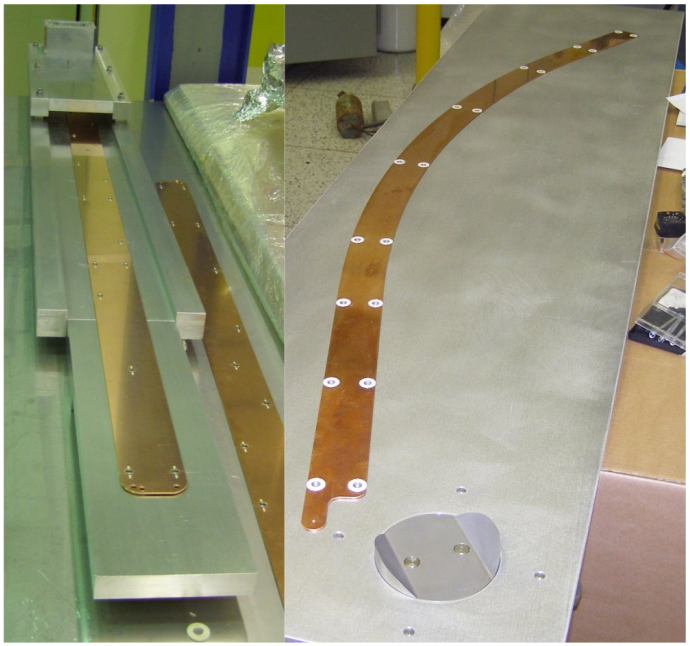
Electrodes Design & Installation

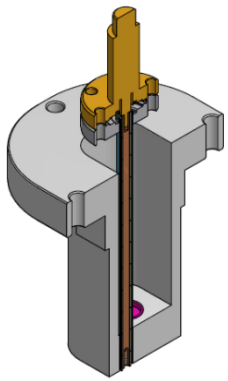
DAΦNE electrodes:

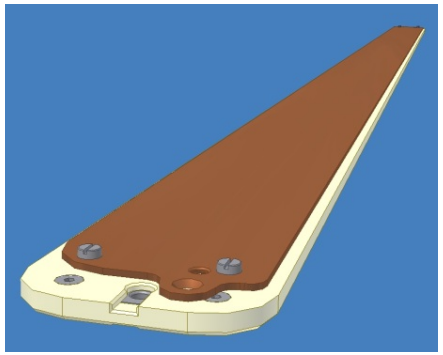
- 50 mm width
- 1.5 mm thickness
- ~ 0.5 mm *ceramic supports* (made in *SHAPAL*), optimized to minimize the beam coupling impedance
- electrode distance from the beam axis is 8 mm in the wigglers and 25 mm in the dipoles.











Electrodes have been inserted in the vacuum chamber using a dedicated tool
They have been connected to the external *dc voltage* modifying the existing BPM flanges.

Electrode impedance evaluation

Resistive wall

It is due to a finite conductivity of the electrode.

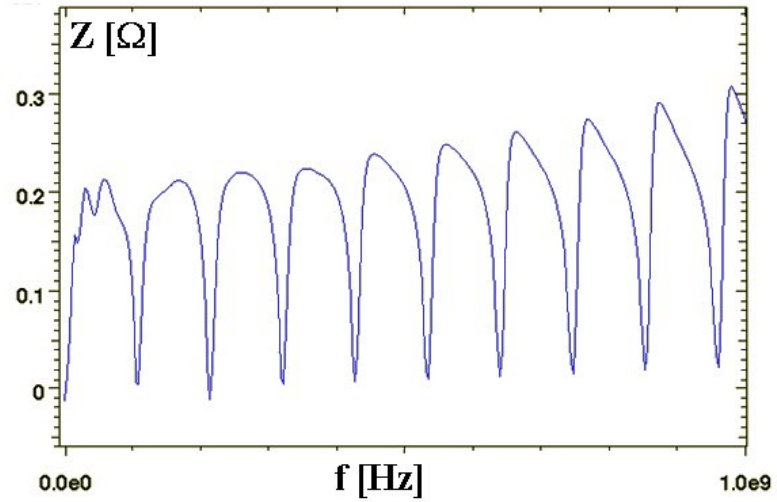
Wiggler case: **112 W/m²**, such power density would result in electrode heating under vacuum up to **50^0-55^0 C**.

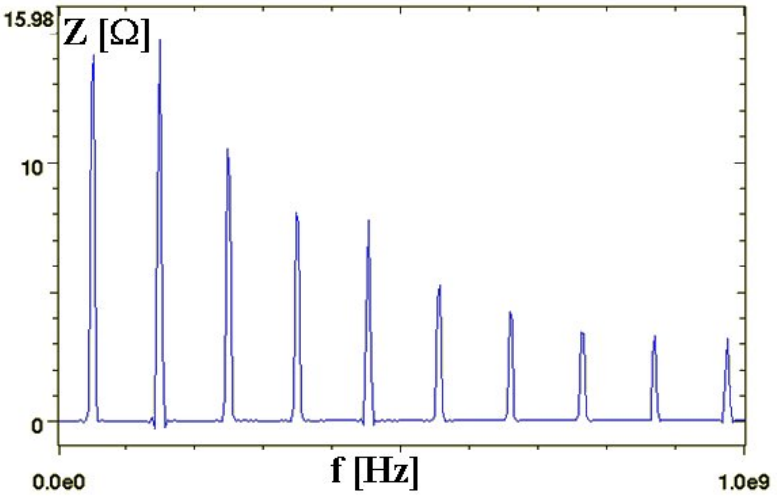
Strip-line Impedance

Two extreme cases have been simulated:

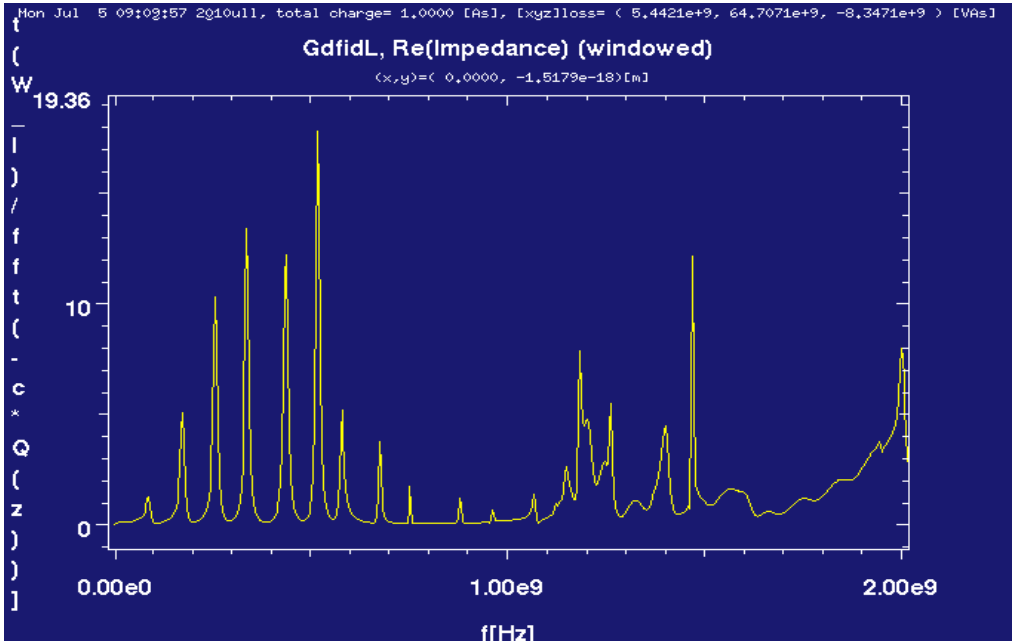
Perfectly matched: broad-band impedance, in this case the loss factor can be used for the power loss evaluation. Loss factor (≈1.6x10^9 V/C) is a factor 3 higher than that of the resistive walls but part of power is dissipated in the external load.

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 and thermo-conducting dielectric material as supports (SHAPAL) has been used.

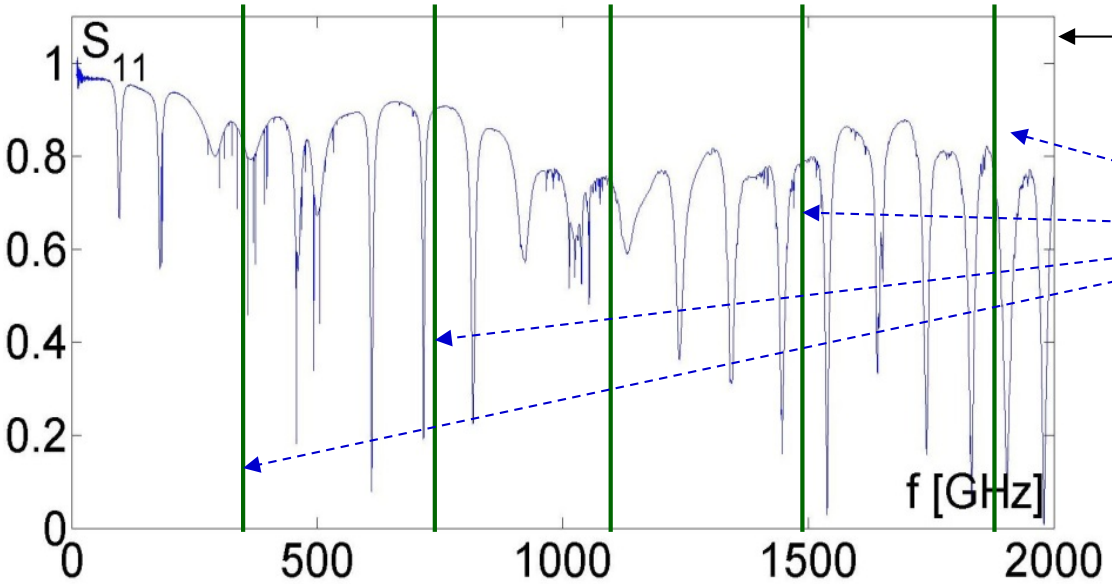




Impedance Simulation and Measurements



Numerical Simulations

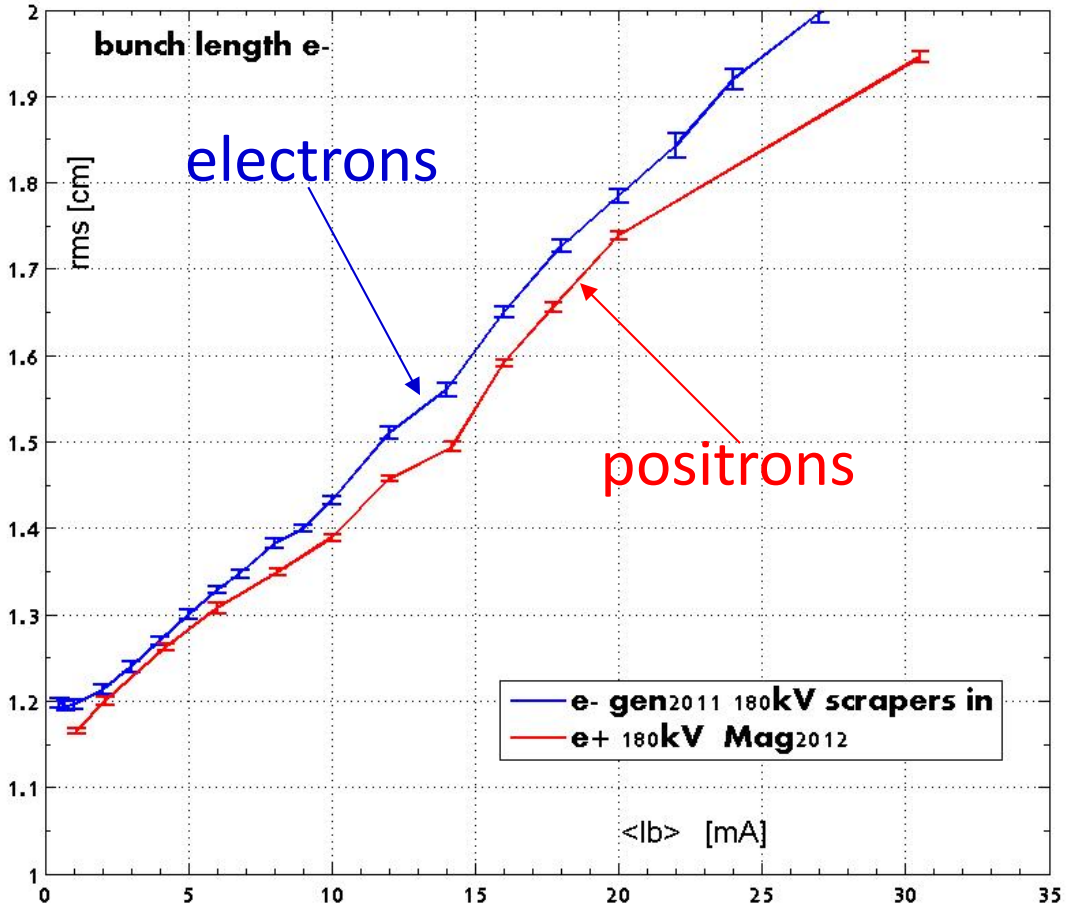


Bench Measurements

RF harmonics

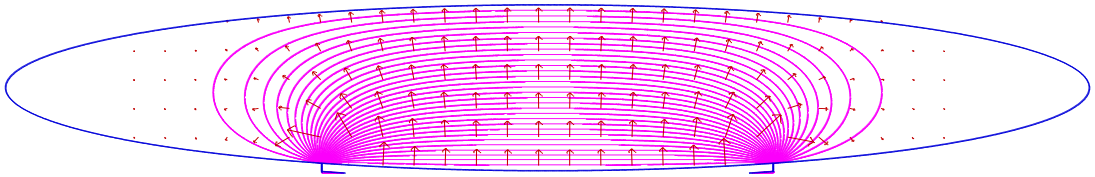
Bunch Length Measurements

extimated Z/n ~ 0.003

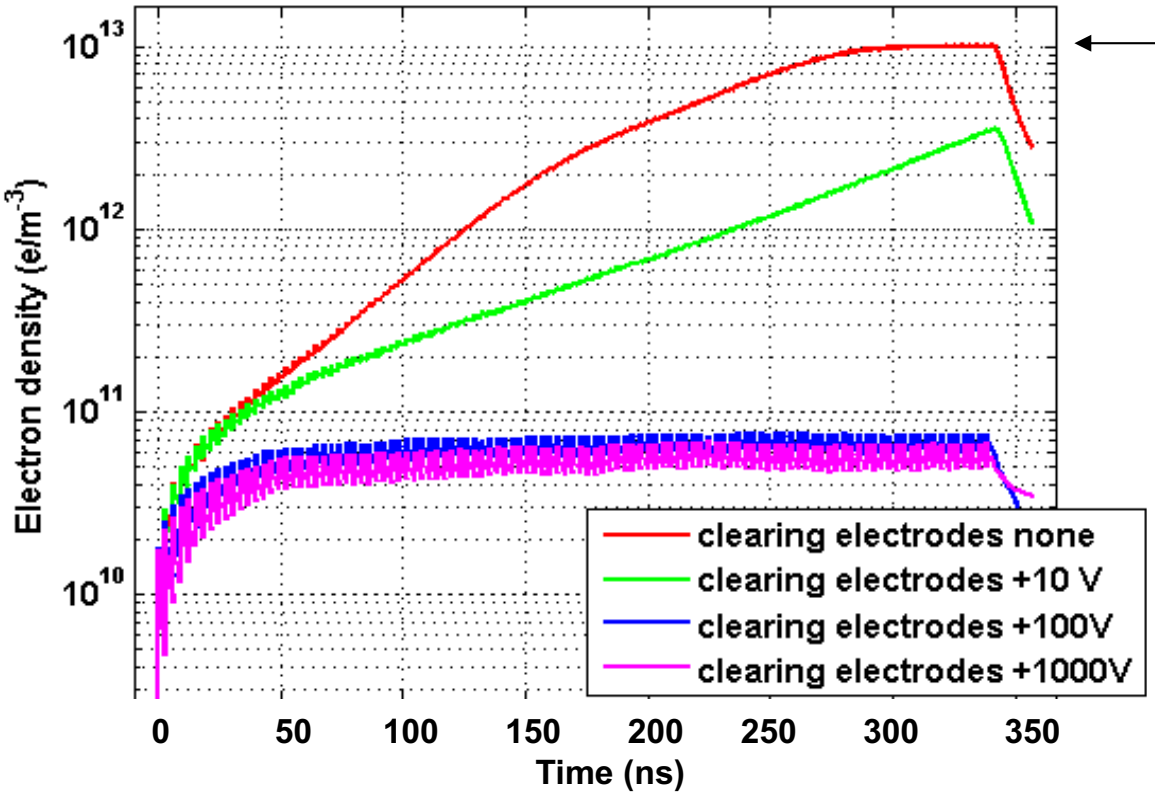


Electrode contribution to the ring impedance (inductive part) is negligible.
Bunch lengthening with current is lower in the e+ ring t than in the e- one where there are no electrodes.

e-Cloud Simulation



Electric field as computed by POISSON

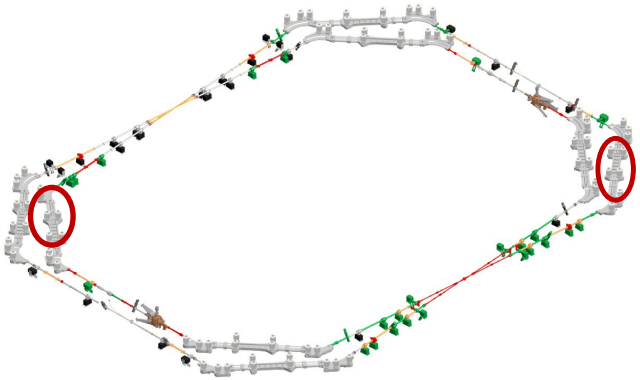


Simulation of electron cloud evolution using ECLOUD (CERN)

With a dc voltage of 100-500 V applied to each electrode we expected a reduction of the electron cloud density by two orders of magnitude !

Electrode polarized by Positive Voltage

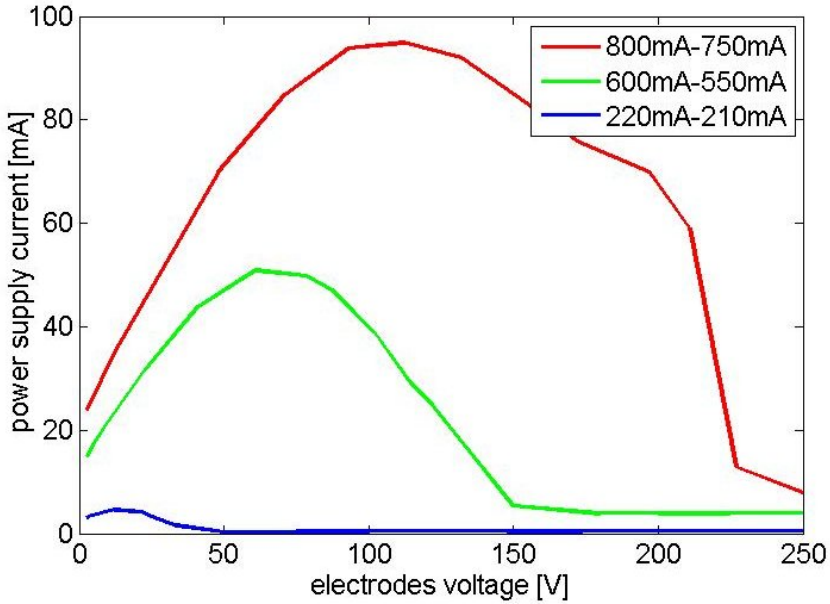
Electrodes have been installed in the e^+ ring in 2010
They have been originally tested by polarizing the stripline with a positive voltage in the range 0 ÷ *250 V*
The voltage generators connected to the electrodes absorbs the photo-electrons



since installation two out of the four WIGGLER electrodes have been short-circuited since they had faulty behaviour

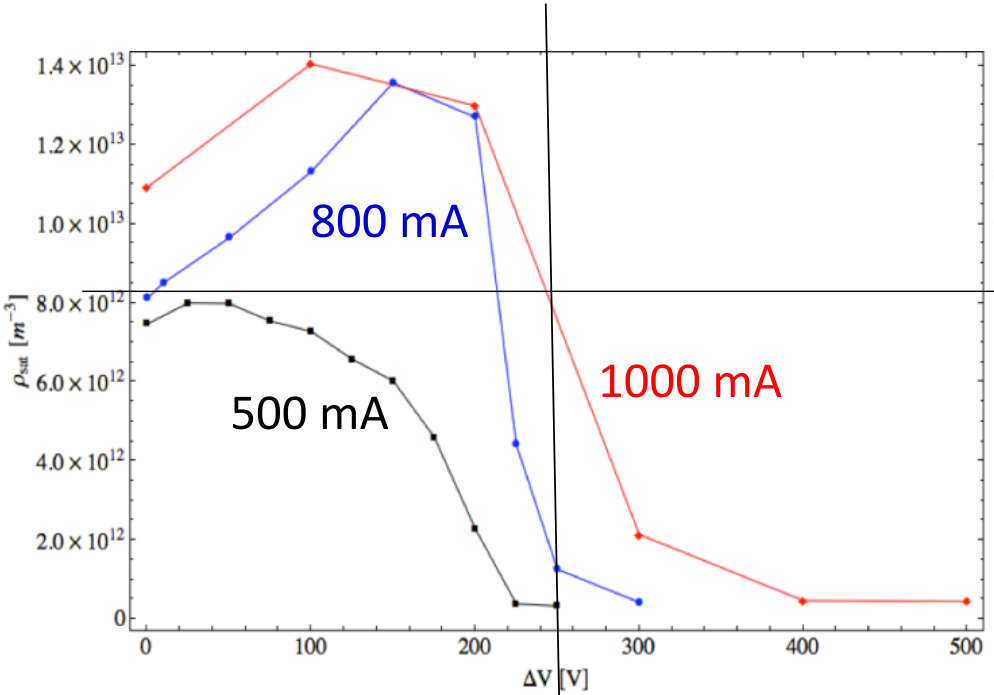
In the initial layout one voltage generator is connected to three electrodes of one arc (i.e. one wiggler and two dipoles).

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

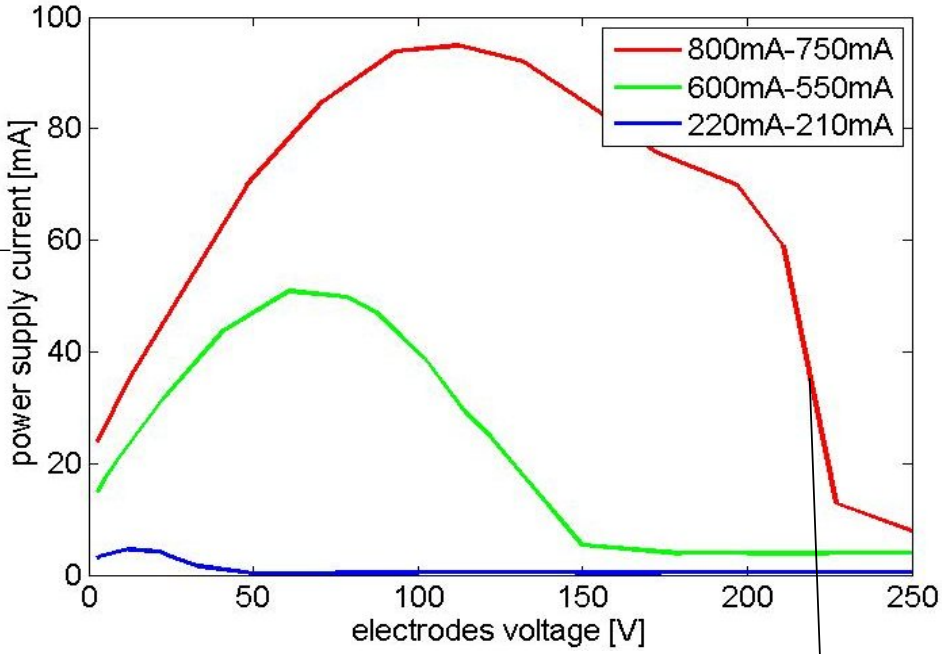


Effectiveness of e-cloud Clearing Electrodes

E-cloud density simulations



Measured absorbed e-cloud current



At the maximum voltage of 250 V the electrodes are effective up to a positron current of 800-900 mA . For higher beam currents higher voltages are required

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 $\boldsymbol{I \propto V_{DC} \cdot I_B - \beta V^2_{DC}}$.

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.***

Electrode polarized by Negative Voltage

In 2013 the HV power supplies polarising the e-cloud clearing electrodes have been replaced with devices providing twice the original voltage (500 V) and having negative polarity.

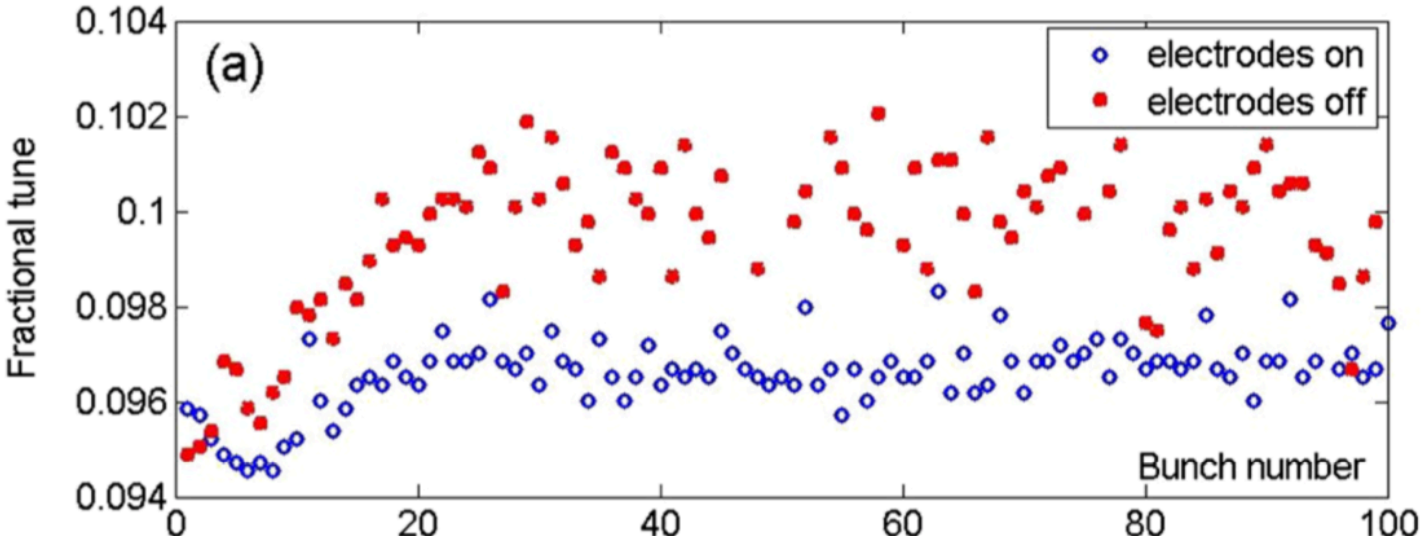
This in order to:

- achieve complete neutralization of the e-cloud generated by a positron current of the order of ~1. A
- avoid damages to the electrodes from the electron bombardment and to the voltage generator from the reversed current

Electrodes made possible many interesting measurements about e-cloud induced effects

DAΦNE experience confirmed that the electrode effectiveness does not depend on the sign of the stripline polarization voltage.

Horizontal Tune Spread



Measured by feedback system frontend

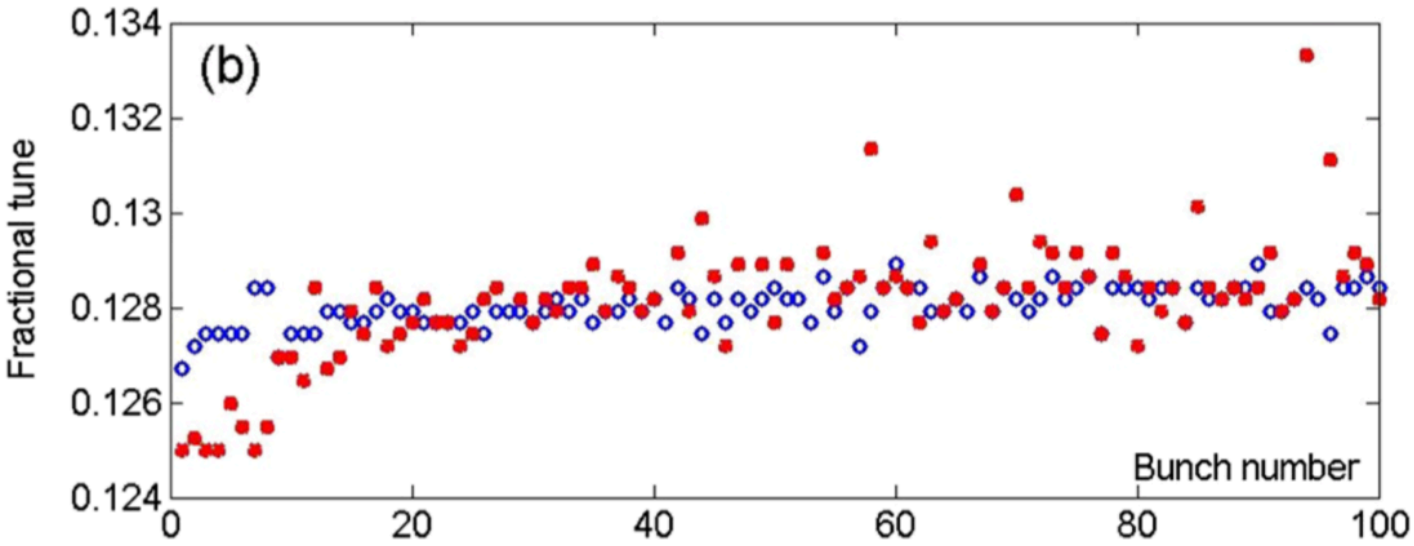
Electrodes off

- The fractional tunes progressively increase and reaches a steady state regime after ~ %20 bunches.
- Horizontal head-tail tune spread is about 0.006–0.008.
- According simulations this tune shift should correspond to an e-cloud density in the wiggler sections of 10^{14} m^{-3}
- since average density is of the order of 10^{13} m^{-3} -> density in the vacuum chamber center in the vicinity of the beam trajectory is by an order of magnitude higher.

Electrodes on

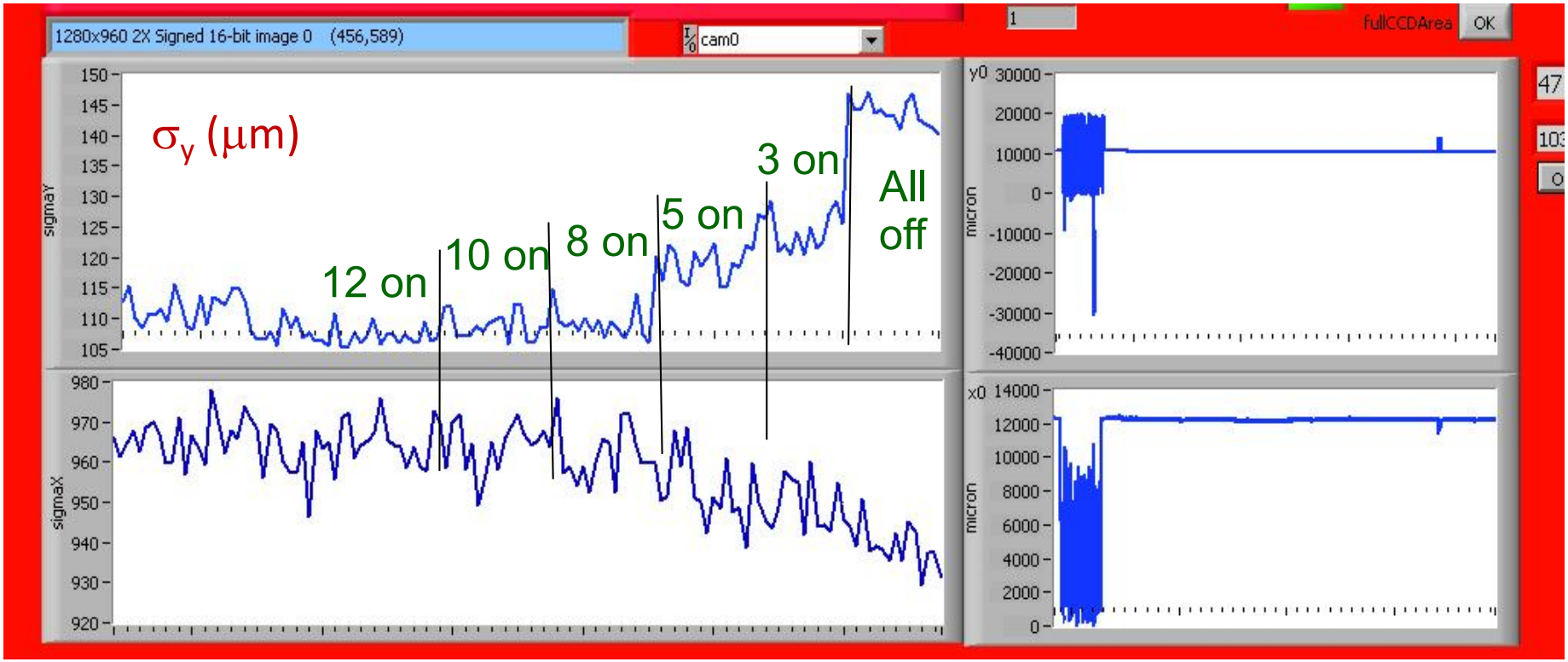
tune shift reduces by a factor of 2–3, but they do not cancel completely the tune spread. This is probably due to the fact that the electrodes in the wigglers cover only 67% of their total length.

Vertical Tune Spread



Vertical tune spread is much smaller than the horizontal one and is almost completely cancelled by the electrodes.

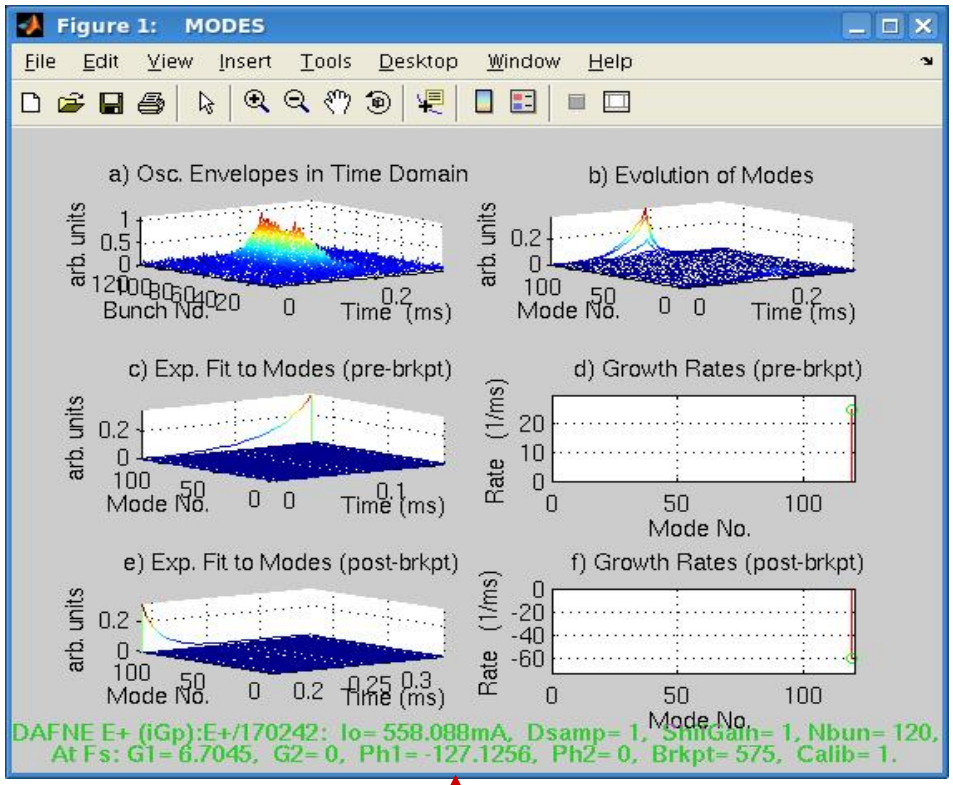
Vertical Beam Size Variation



Vertical beam size enlargement is clearly observed by the Synchrotron Light Monitor while turning progressively off clearing electrodes

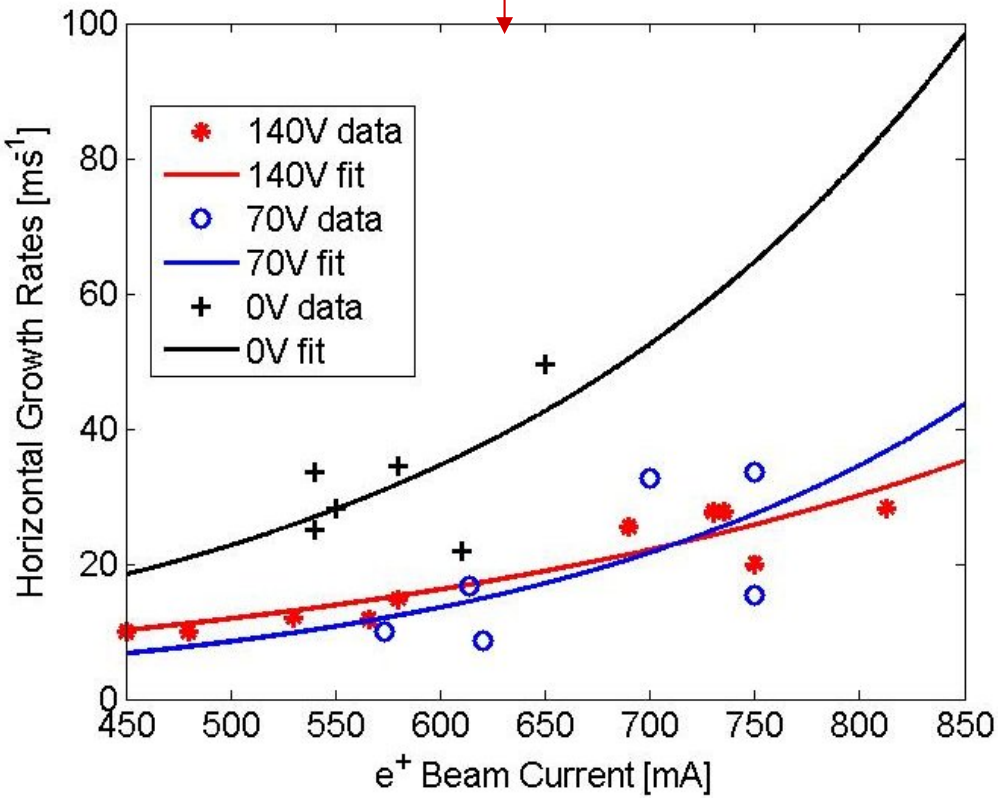
Horizontal Instability Growth Rate

Measurements Using Bunch-by-Bunch Feedback



Mode = -1 is unstable

Applied voltages were 0V, 70V and 140V

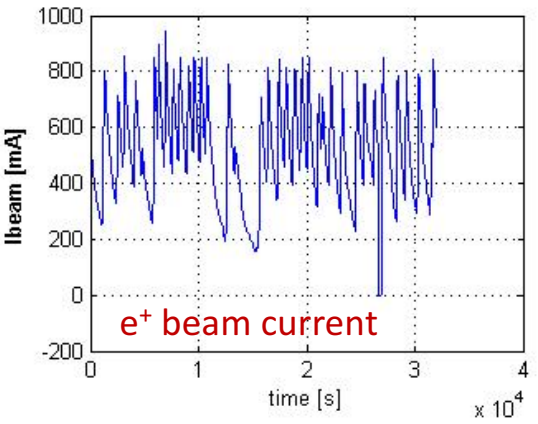


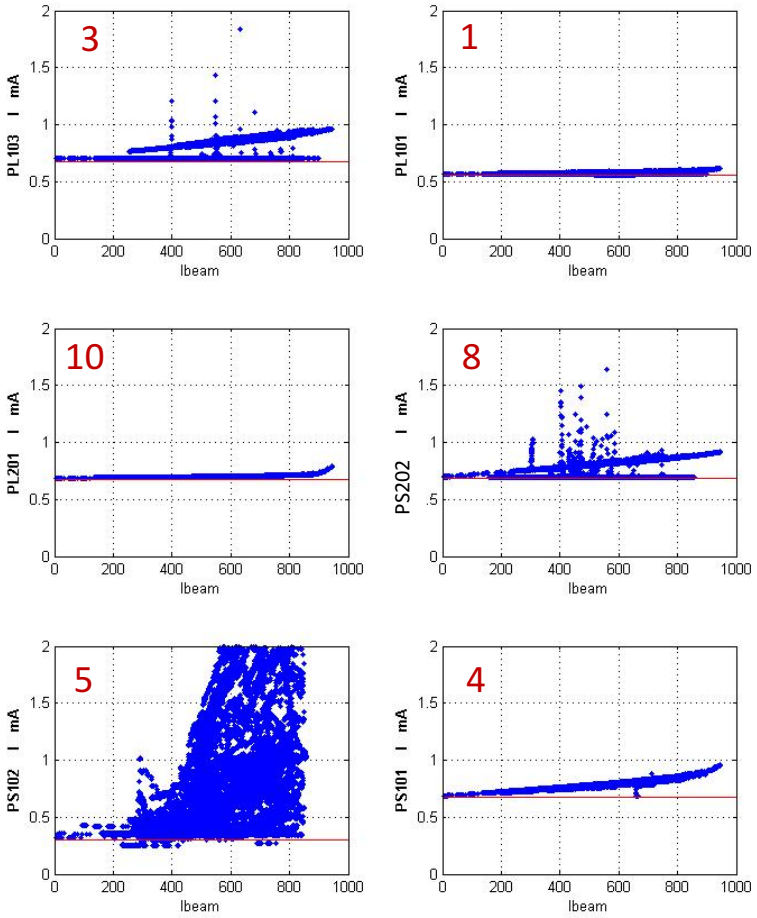
Operations with e-cloud Electrodes

ECE have been fundamental in order to achieve high e^+ currents mostly in the first stage of operations

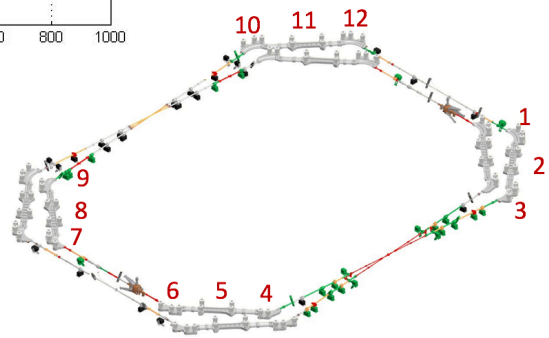
During the activity several criticalities appeared:

- sudden variation of the e^+ beam orbit have been observed concurrently with large variation of the current delivered by some voltage generators
- many ECE stopped working





Current delivered by some ECE voltage generators over 3h operations with e^+ beam

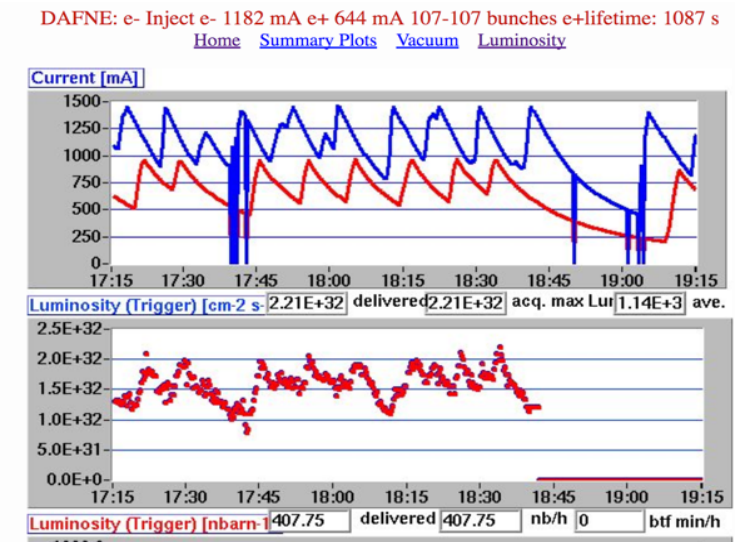


Operations with e-cloud Electrodes

At the end of the 40 months run only 2 out of the 12 ECE were working properly, none of them was in the wigglers

A posteriori analysis to explain the ECE behavioue is under way

However it was still possible to run the collider at peak performances

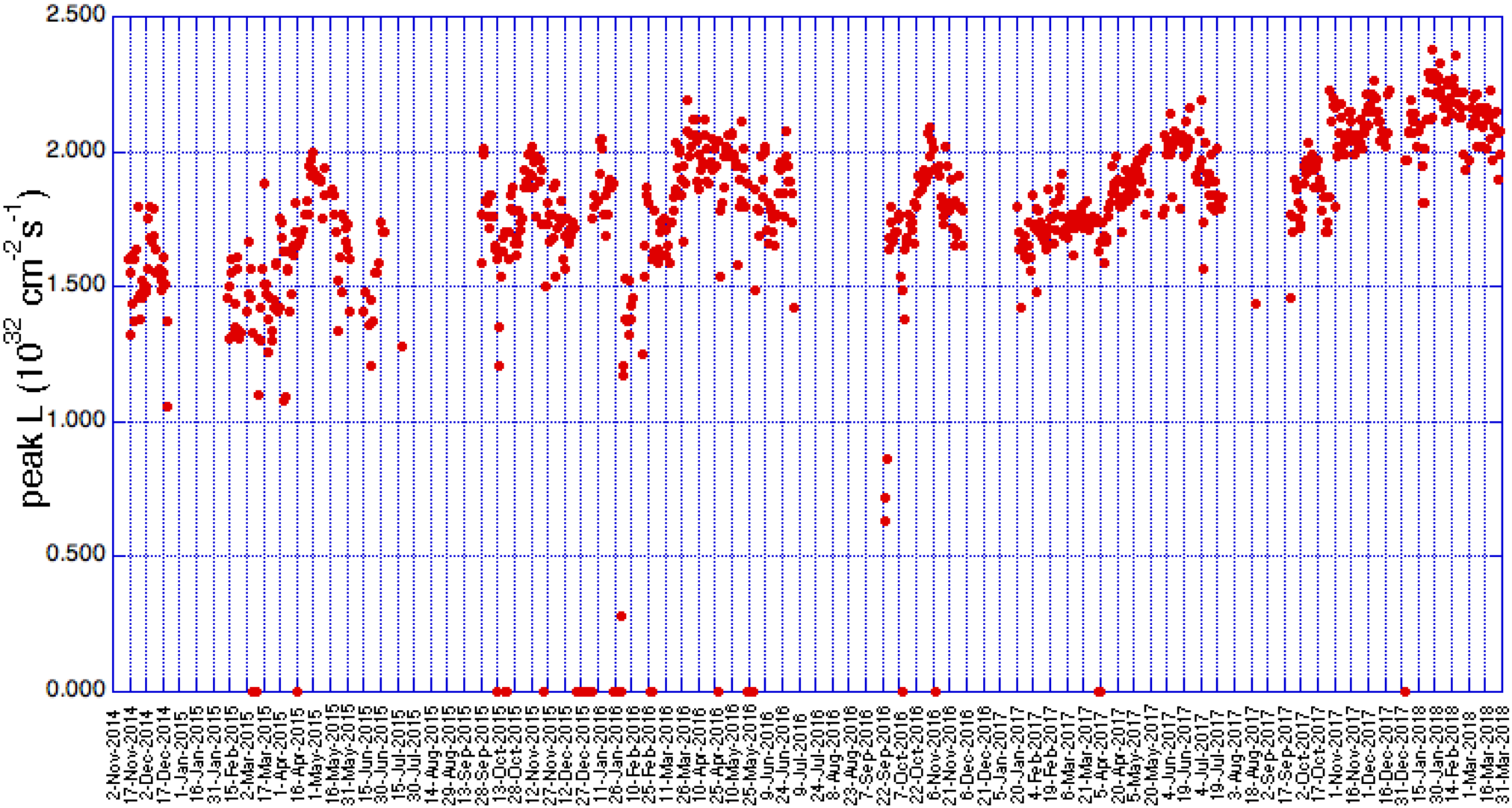


$L_{peak} = 2.21 \cdot 10^{32}$ $cm^{-2}s^{-1}$

$I^{+} \leq 1$ A

with 2 ECE only

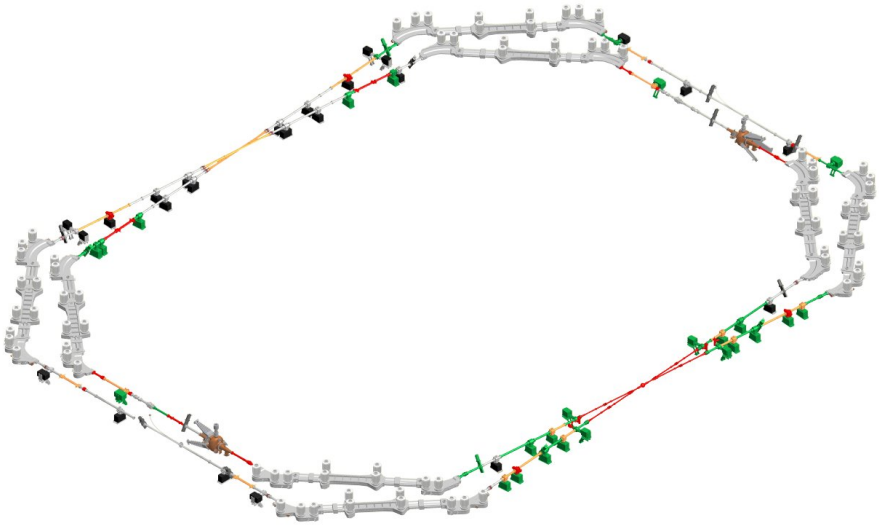
Instantaneous Luminosity during the KLOE-2 run



scrubbing may be??

DAΦNE Beam Pipe Composition

The 8 large vacuum chamber of the arcs are in **AL 5083 H321** (Al - Mg)



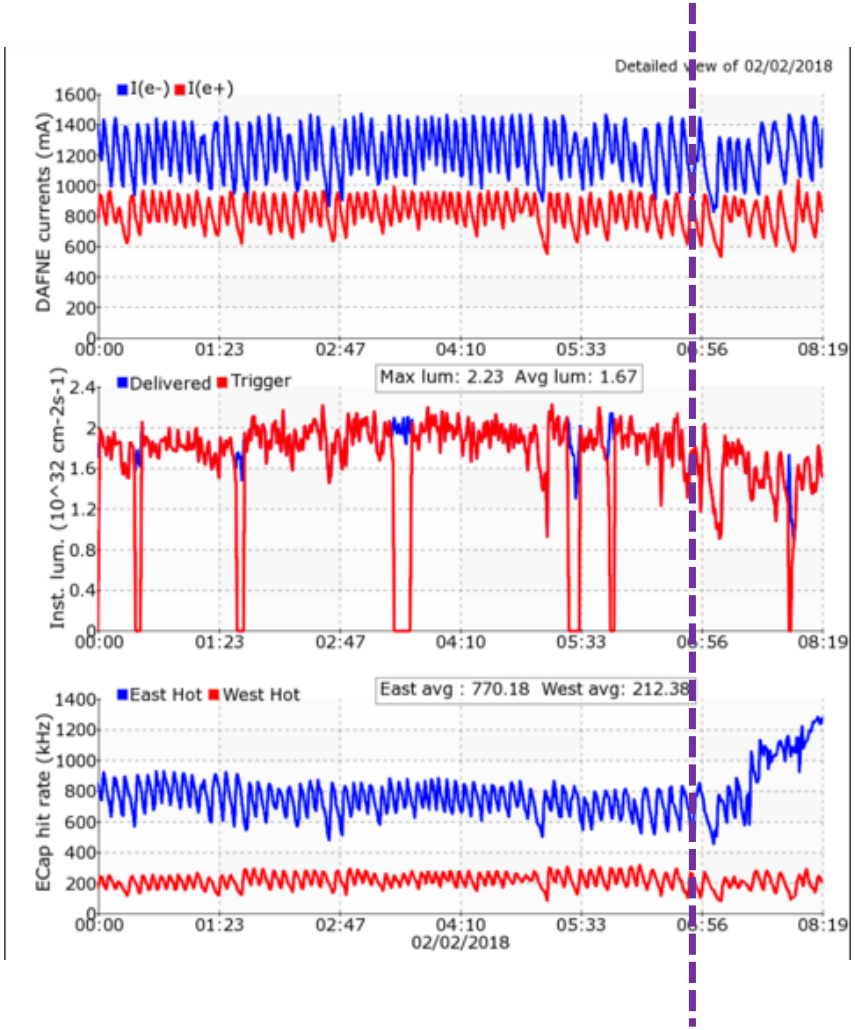
Property Results

Chemistry Data : [top]

Aluminum	Balance
Chromium	0.05 - 0.25
Copper	0.1 max
Iron	0.4 max
Magnesium	4 - 4.9
Manganese	0.4 - 1
Remainder Each	0.05 max
Remainder Total	0.15 max
Silicon	0.4 max
Titanium	0.15 max
Zinc	0.25 max

Straight section beam pipes are made by **AL 6082 T6** (Al - SI)

Operations with e-cloud Electrodes



All ECE (four) off due to a CS fault:

- larger σ_y -> lower ***L***
- lower injection efficiency for the e+ beam
- higher background on the detector

DAΦNE Timeline

March 31st 2018

end of the KLOE-2 Run

April ÷ September

KLOE-2 roll-out and SIDDHARTA-2 IR installation

September ÷ December 2018

DAΦNE commissioning and SIDDHARTA setup

In year 2019

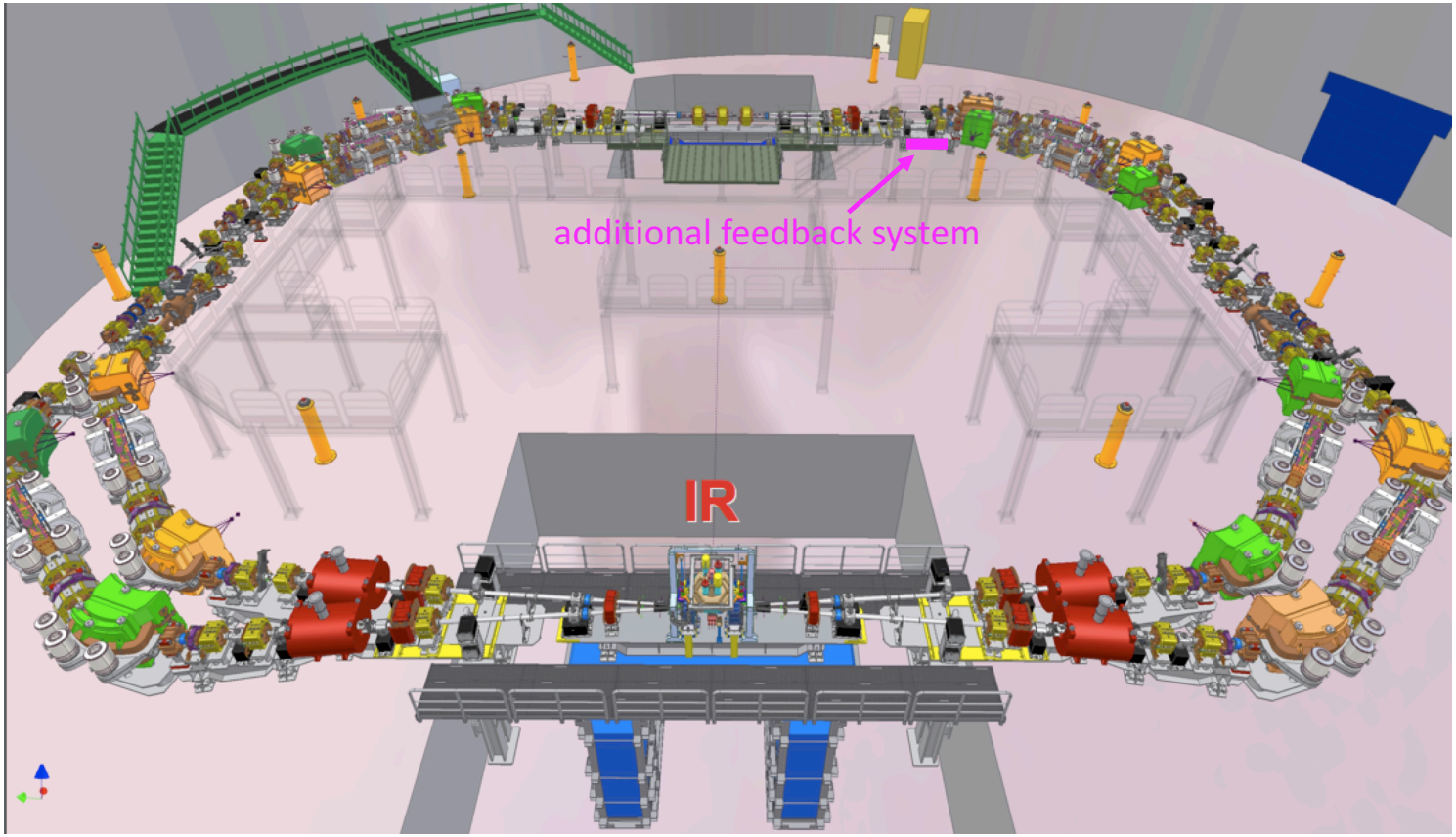
SIDDHARTA-2 data taking

Starting from 2020 DAΦNE might be transformed in a test facility:

DAΦNETF

SIDDHARTA run

Faulty electrodes will not be replaced
an additional horizontal feedbak system will be installed in the e^+ ring



DAΦNE as bench test accelerators

Insertion devices
Vacuum components
Vacuum chambers even at cryogenic temperatur (preliminary contacts with CERN and ANKA)

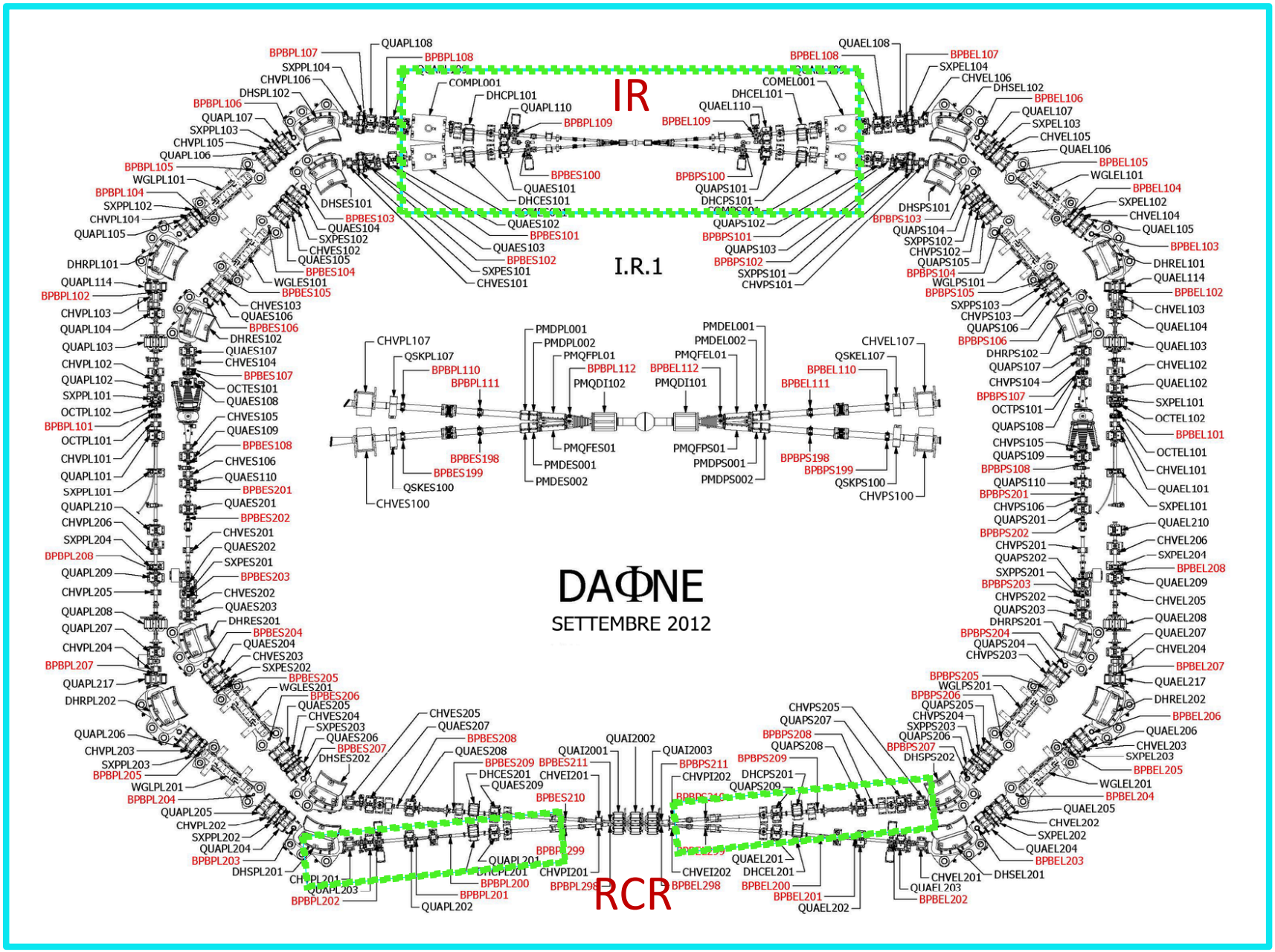
Vacuum chamber coating to reduce desorbtion and SEY
- carbon coating
- laser ablation … (preliminary activities with MALYSHEV and VALIZADEH)

Experimental tests about:
- Impedance & HOMs for specific devices:
  - bellows
  - kickers
  - diagnostic elements
  - special vacuum chambers
  - transition sections

Diagnostics tools

Development and test of Feedback system components (see A. Drago talk)

Possible test stations



Conclusion

Positron beam current at DAΦNE is clearly limited by *e-cloud induced effects* determining:

- anomalous vacuum pressure rise
- transverse beam size growth
- fast multibunch horizontal instability

Several countermeasures have been devised and succesfully implemented

- ring optics and beam parameter optimization
- feedback
- solenoid windings
- electrodes
  - *DAΦNE is the first and only collider to operate routinely with and thanks to the electrodes for e-cloud mitigation*

In less than two years time DAΦNE will stop to operate as a collider and could be efficiently used as a *test facility finalized to R&D studies in the particle accelerator field* with special attention to e-cloud related topics.

Thank you for your attention