E-cloud instabilities @ DAFNE and SuperB

T. Demma INFN-LNF

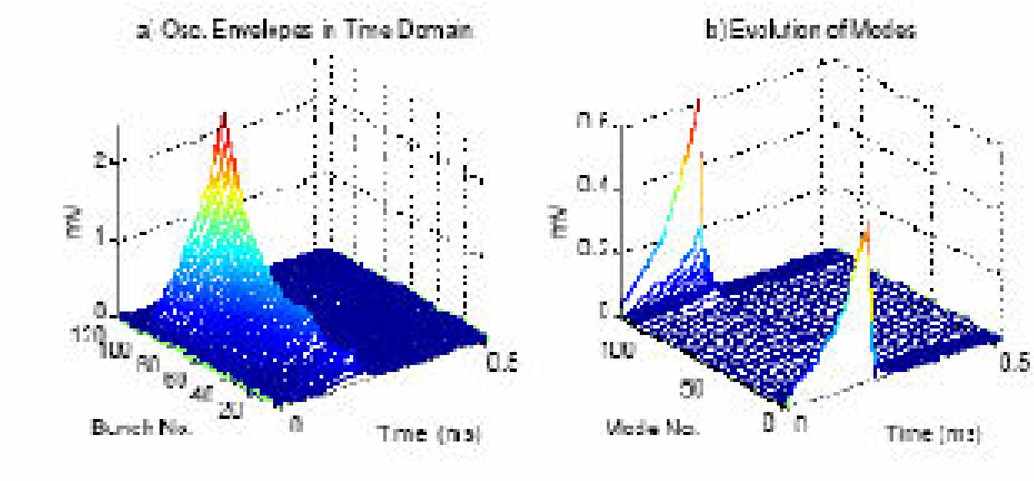
Plan of Talk

- Introduction
- Analysis of the e-cloud induced instabilities @ DAFNE
  - –Coupled bunch
  - –Single bunch
- Clearing electrodes for DAFNE dipoles and wigglers
- Electron cloud simulations for SuperB:
  - –Single bunch instability
  - –Build up simulations
- Summary

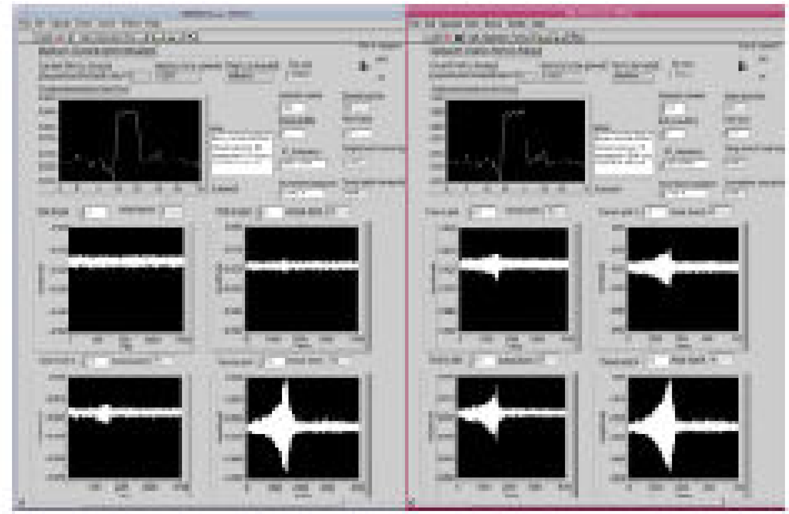
E-Cloud effects @ DAFNE

- e^+ current limited to 1.2 A by a strong horizontal instability
- Large positive tune shift with current in e^+ ring, not seen in e^- ring
- Instability depends on bunch current
- Instability strongly increases along the train
- Anomalous vacuum pressure rise has been oserved in e^+ ring
- Instability sensitive to orbit in wiggler and bending magnets
- Main change for the 2003 was wiggler field modification

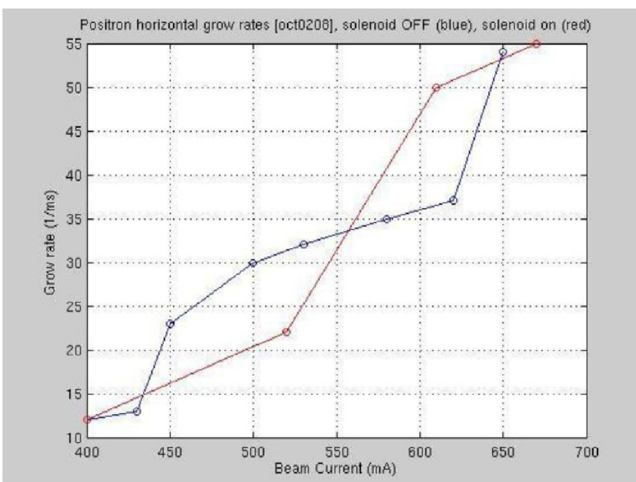
Characterization of the Horizontal Instability



Grow-damp measurements



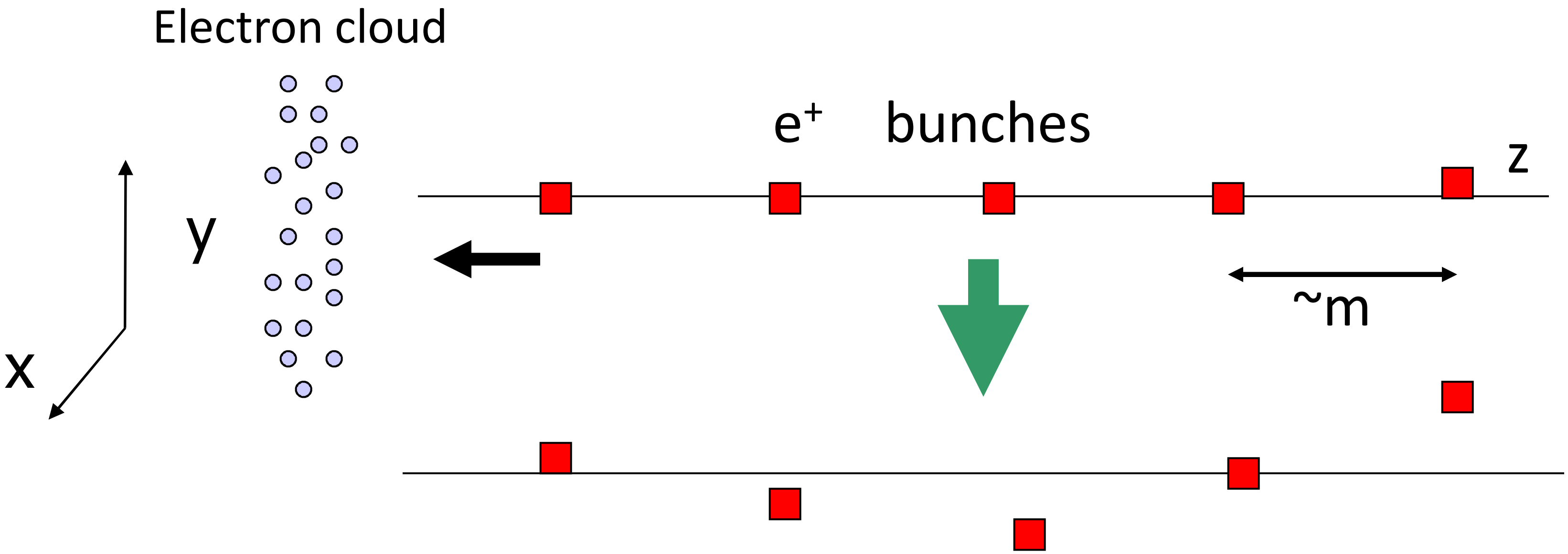
solenoids off (blue) & on (red)



- Solenoids installed in free field regions strongly reduce pressure but have poor effect on the instability
- Most unstable mode -1

PEI-M Tracking simulation

K.Ohmi, PRE55,7550 (1997),K.Ohmi, PAC97, pp1667.



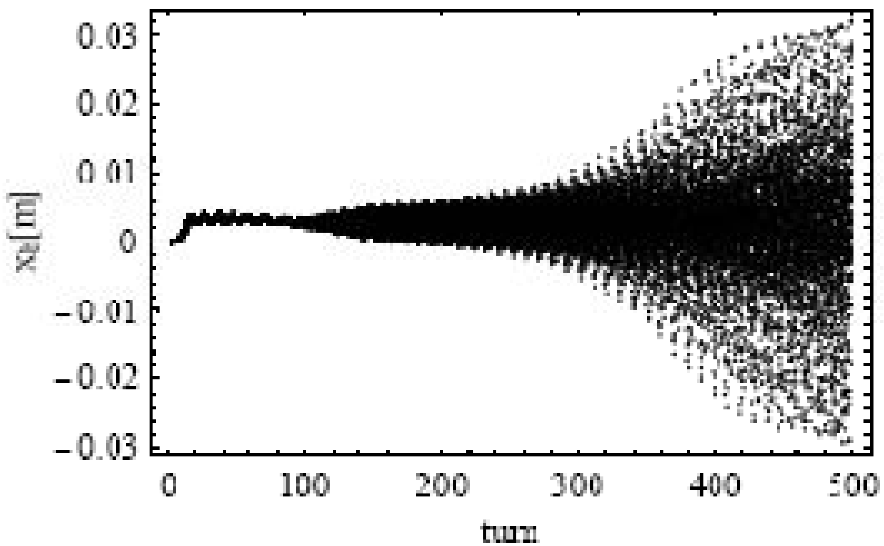
•Solve both equations of beam and electrons simultaneously, giving the transverse amplitude of each bunch as a function of time.

•Fourier transformation of the amplitudes gives a spectrum of the unstable mode, identified by peaks of the betatron sidebands.

Input parameters for DAFNE simulations

Bunch population	N_b	2.1; (4.2 x10^{10})
Number of bunches	n_b	120; (60)
Missing bunches	N_{gap}	0
Bunch spacing	L_{sep}[m]	0.8;(1.6)
Bunch length	σ_z [mm]	18
Bunch horizontal size	σ_x [mm]	1.4
Bunch vertical size	σ_y [mm]	0.05
Chamber Radius	R [mm]	40
Hor./vert. beta function	β_x[m]/β_y[m]	4.1/1.1
Hor./vert. betatron tune	ν_x/ν_y	5.1/5.2
Primary electron rate	$d\lambda/ds$	0.0088
Photon Reflectivity	R	100% (uniform)
Max. Secondary Emission Yeld	Δ_{max}	1.9
Energy at Max. SEY	E_m [eV]	250
Vert. magnetic field	B_z [T]	1.7

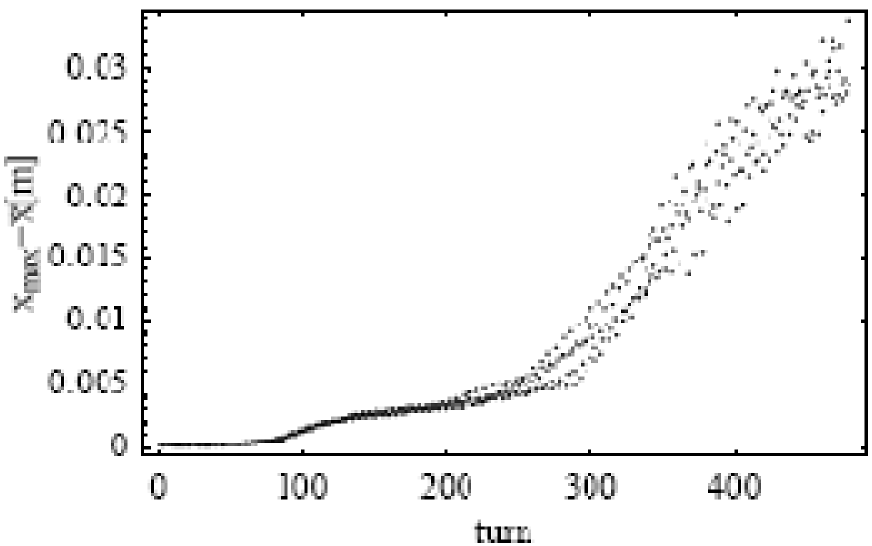
Mode spectrum and growth rate



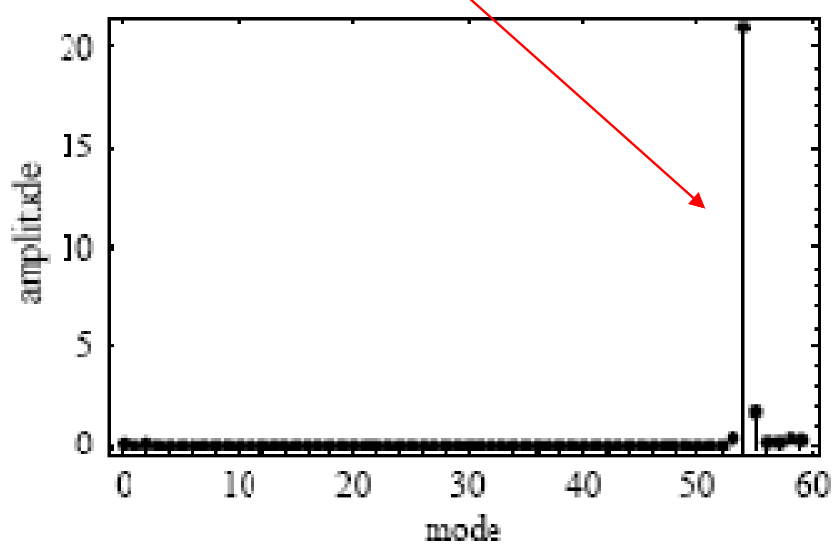
60 equispaced bunches

Beam current 1.2 A

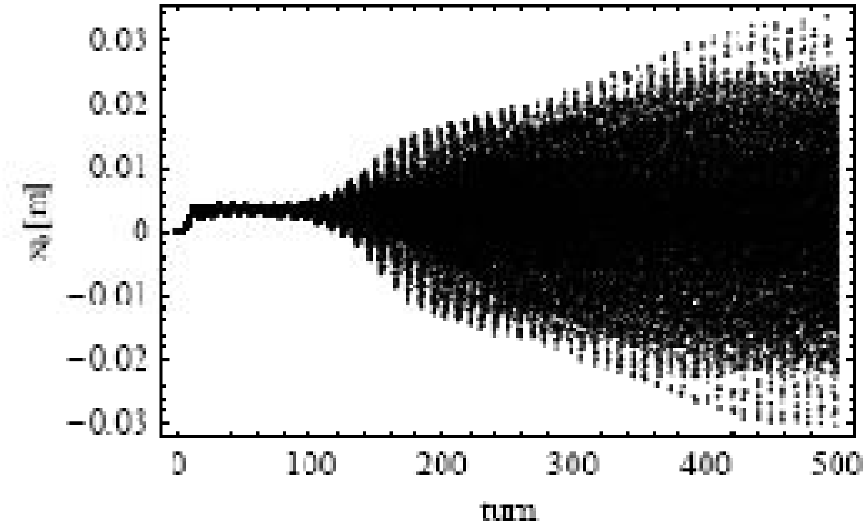
Growth time ~ 100 turn

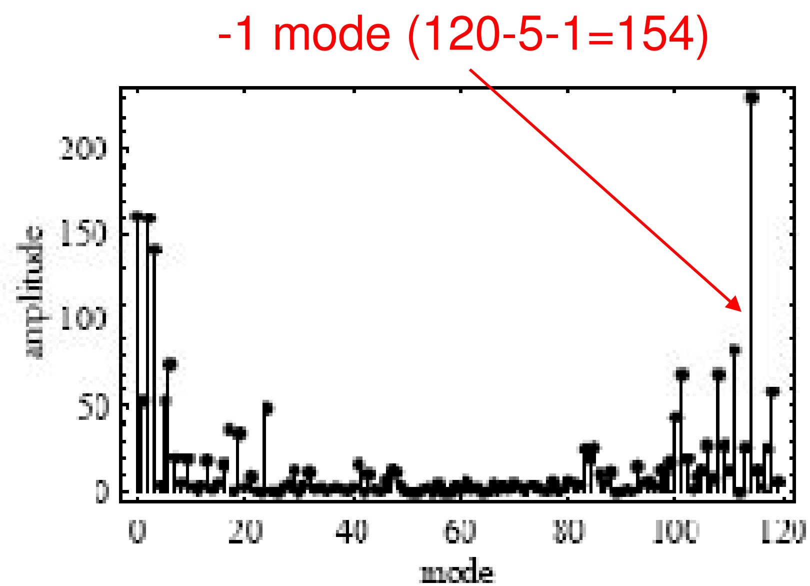


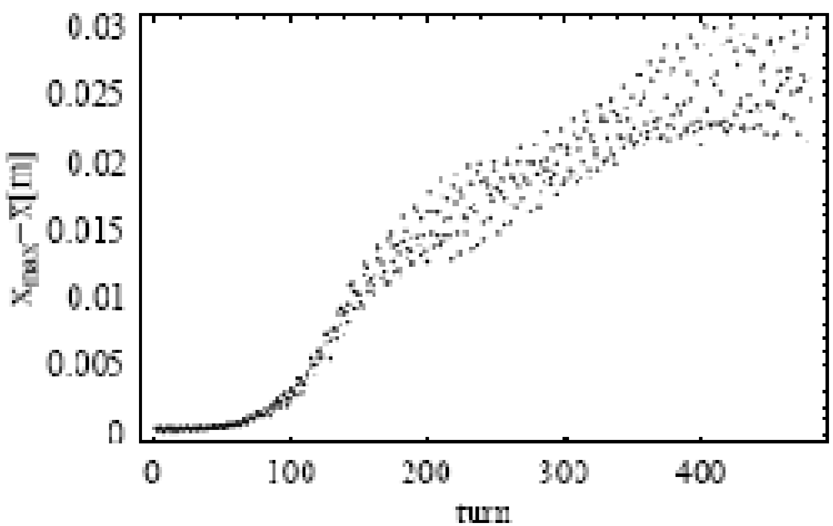
-1 mode (60-5-1=54)



Mode spectrum and growth rate

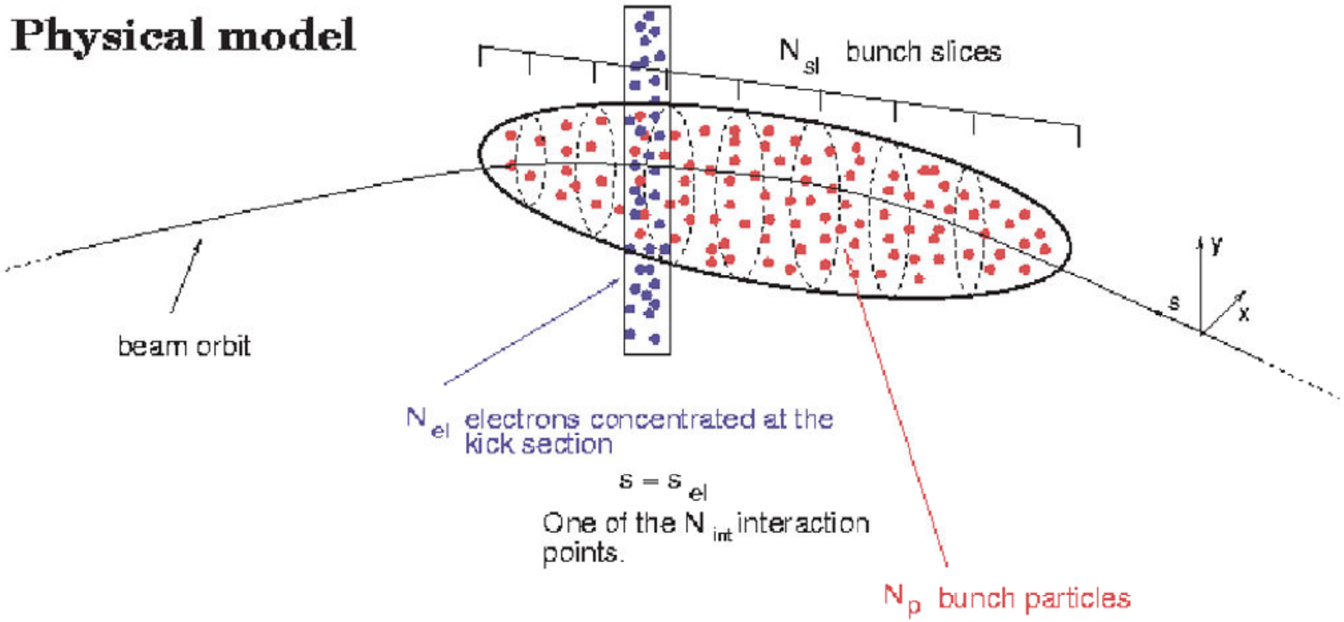






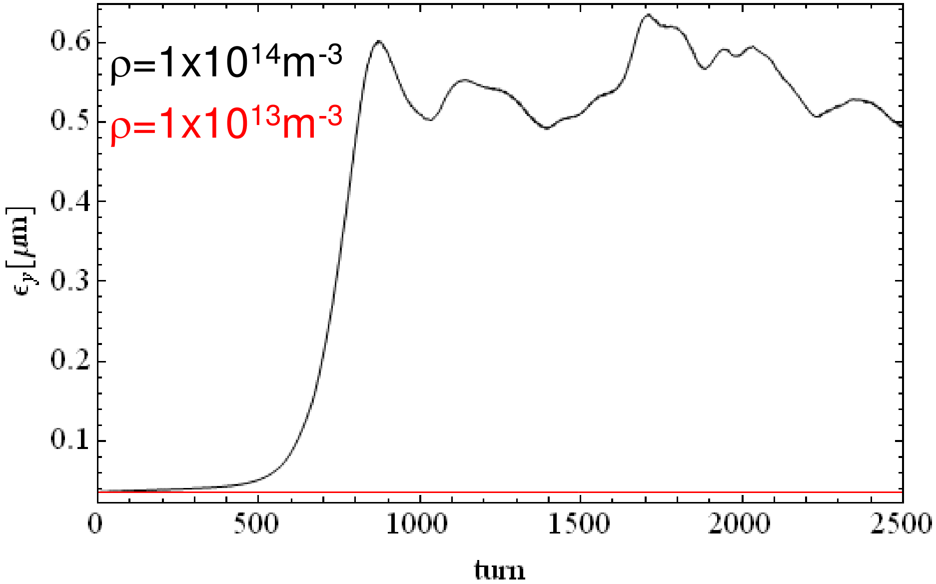
Measurment		Simulation	
I[A]/nb	τ/T_0	I[A]/nb	τ/T_0
1/105	**73**	**1.2/120**	**100**
0.75/105	56	900/120	95
0.5/105	100	600/120	130

Simulation of single-bunch instability

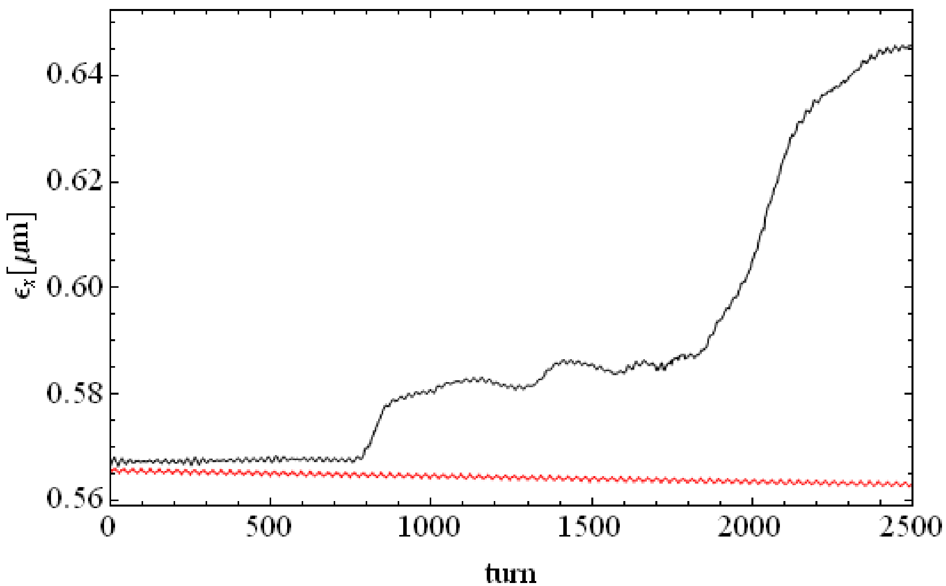


- Simulations were performed using CMAD (M.Pivi,SLAC):
  - –Tracking the beam (x,x',y,y',z,δ) in a MAD lattice by 1st and 2nd order transport maps
  - –MAD8 or X "sectormap" and "optics" files as input
  - –Apply beam-cloud interaction point (IP) at each ring element
  - –Parallel bunch-slices based decomposition to achieve perfect load balance
  - –Beam and cloud represented by macroparticles
  - –Particle in cell PIC code 9-point charge deposition scheme
  - –Define at input a cloud density level [0<r<1] for each magnetic element

E-cloud induced emittance growth in DAFNE: solenoids on

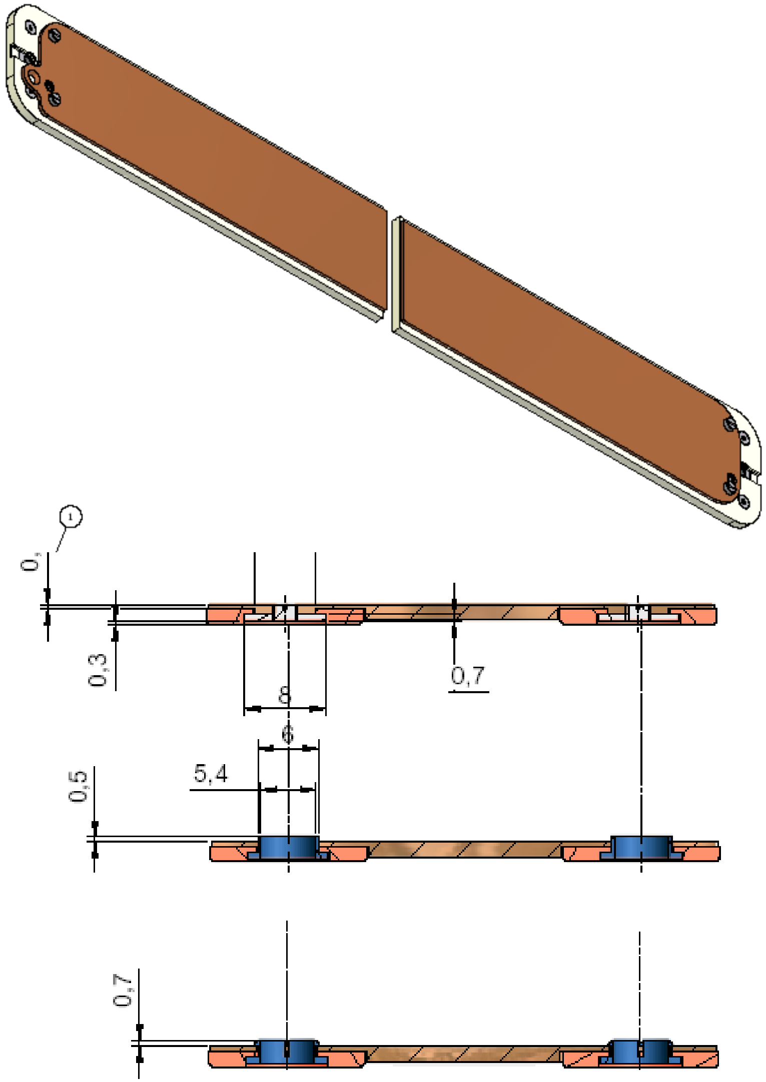


- Beam is tracked using a DAFNE MADX lattice model that matches quite well beam measurements (C.Milardi).
- Applying beam-cloud kicks in dipoles and wigglers only: assume e-cloud in field free Drift regions is mitigated by solenoids.
- Threshold well above the current estimated e-cloud density for DAFNE ($<10^{13} e^-/m^3$)



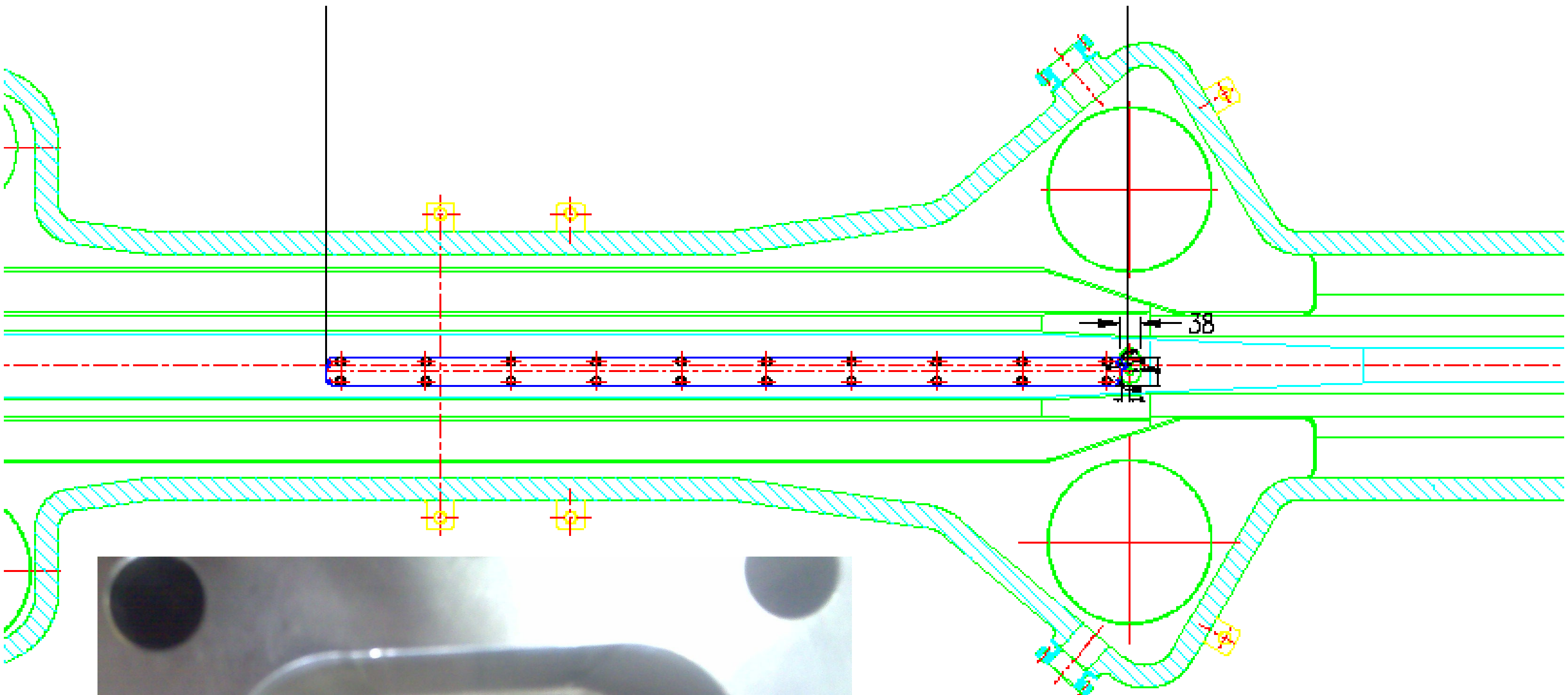
Beam energy E[GeV]	0.51
circumference L[m]	97.588
bunch population N_b	2.1×10^{10}
bunch length σ_z [mm]	12
horizontal emittance ε_x[um]	0.57
vertical emittance ε_y [um]	0.035
hor./vert. betatron tune Q_x/Q_y	5.1/5.2
synchrotron tune Q_z	0.012
hor./vert. av. beta function	6/5

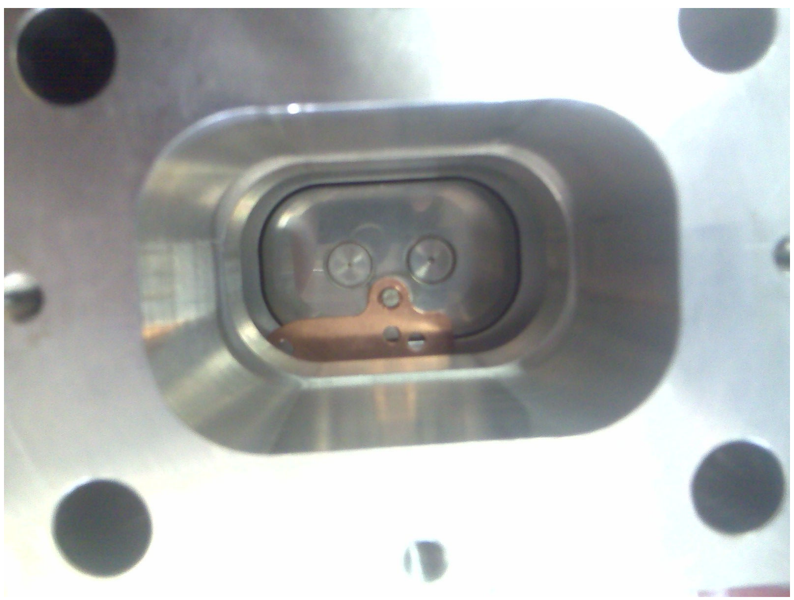
Clearing electrodes for DAFNE

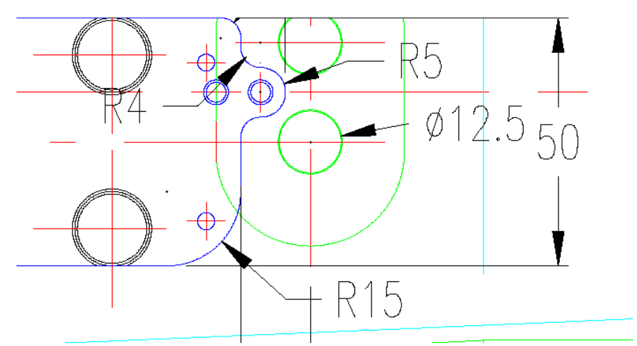


D.Alesini, M. Zobov, A.Battisti, R. Sorchetti, V. Lollo (LNF)

Clearing electrodes installation: Wigglers







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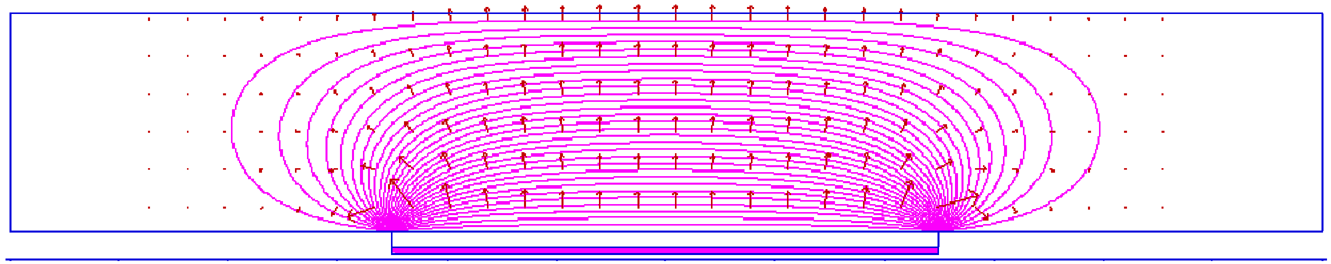
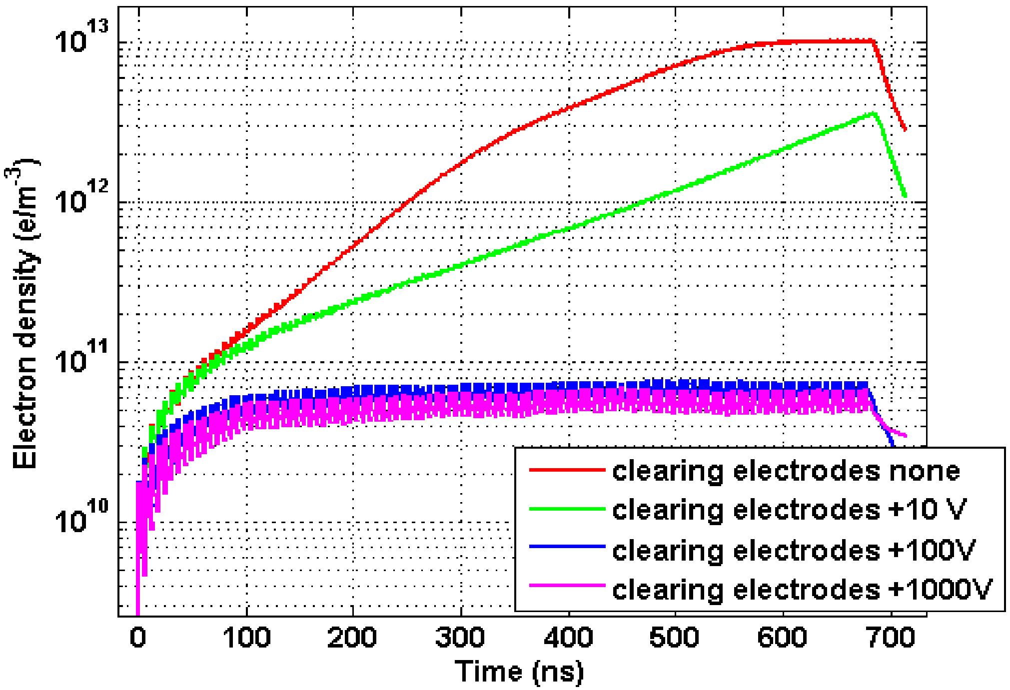
Electrodes Field and e-Cloud build-up



Simulation unsing POSINST code of electron cloud build-up and suppression with clearing electrodes.

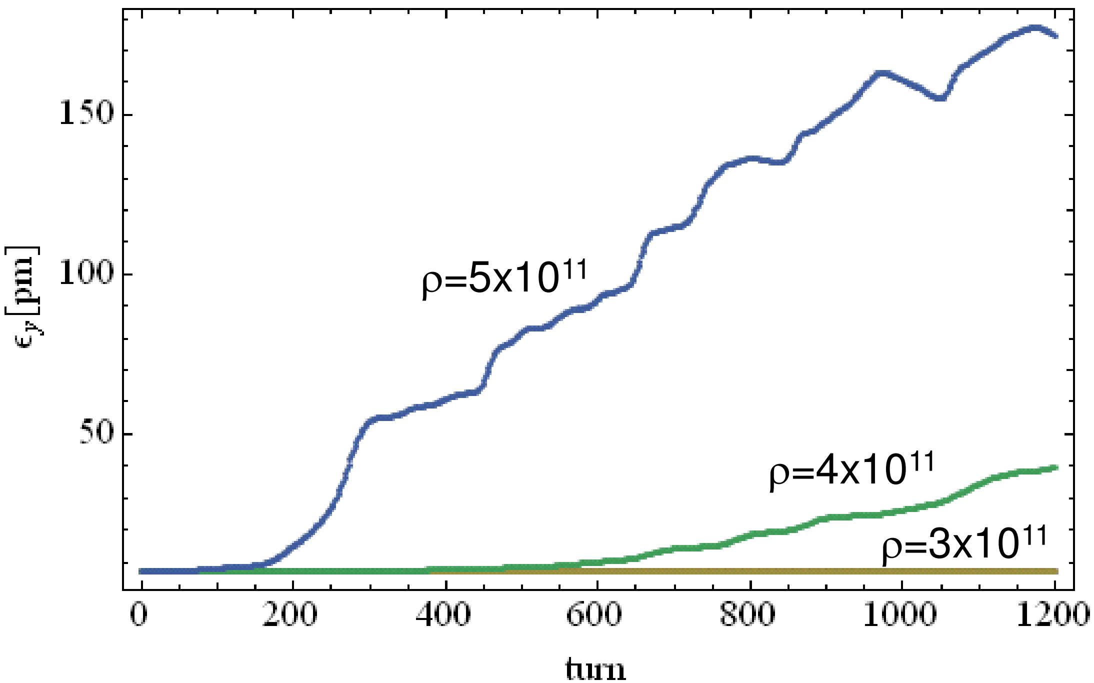
Bunch population	2.1×10^{10}
Bunch spacing L[m]	0.8
Bunch length σ_z [mm]	18
Primary electron rate	0.0088
Photon Reflectivity	100%
Max. SEY	1.9



SuperB configuration options

LER/HER	Unit	June 2008	Jan. 2009	March 2009	LNF
E+/E-	GeV	4/7	4/7	4/7	4.18/6.7
L	$cm^{-2} s^{-1}$	$1x10^{36}$	$1x10^{36}$	$1x10^{36}$	$1x10^{36}$
I^+/I^-	Amp	1.85 /1.85	2.00/2.00	2.80/2.80	2.80/2.80
N_{part}	$x10^{10}$	5.55 /5.55	6/6	4.37/4.37	6.33/4.06
N_{bun}		1250	1250	2400	928
I_{bunch}	mA	1.48	1.6	1.17	1.17
$\theta/2$	mrad	25	30	30	30
β_x^*	mm	35/20	35/20	35/20	20/20
β_y^*	mm	0.22 /0.39	0.21 /0.37	0.21 /0.37	0.2 /0.37
ε_x	nm	2.8/1.6	2.8/1.6	2.8/1.6	1.6
ε_y	pm	7/4	7/4	7/4	4
σ_x	μm	9.9/5.7	9.9/5.7	9.9/5.7	5.7/5.7
σ_y	nm	39/39	38/38	38/38	28/28
σ_z	mm	5/5	5/5	5/5	5/5
ξ_x	X tune shift	0.007/0.002	0.005/0.0017	0.004/0.0013	
ξ_y	Y tune shift	0.14 /0.14	0.125/0.126	0.091/0.092	
RF stations	LER/HER	5/6	5/6	5/8	
RF wall plug power	MW	16.2	18	25.5	
Circumference	m	1800	1800	1800	

Emittance growth due to fast head-tail instability (LNF conf.)



Input parameters for CMAD

Beam energy E[GeV]	6.7
circumference L[m]	1200
bunch population N_b	4.06×10^{10}
bunch length σ_z [mm]	5
horizontal emittance ε_x [nm rad]	1.6
vertical emittance ε_y [pm rad]	4
hor./vert. betatron tune Q_x/Q_y	40.57/17.59
synchrotron tune Q_z	0.01
hor./vert. av. beta function	25/25
momentum compaction α	4.04e-4

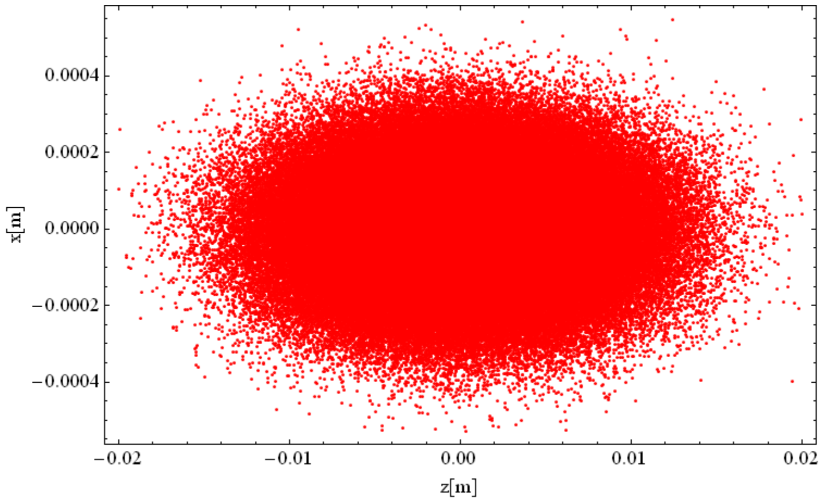
The interaction between the beam and the cloud is evaluated at 40 different positions around the SuperB HER (LNF option) for different values of the electoron cloud density.

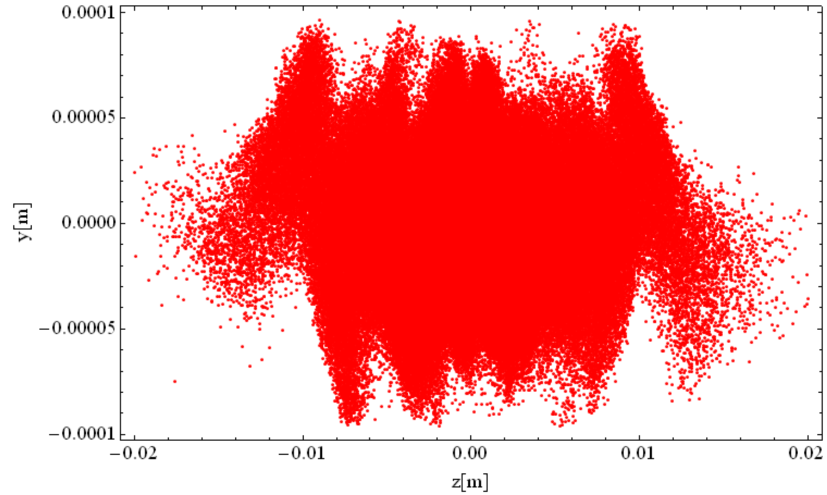
The threshold density is determined by the density at which the growth starts:

$$\rho_{e,th} = 4 \times 10^{11} \ m^{-3}$$

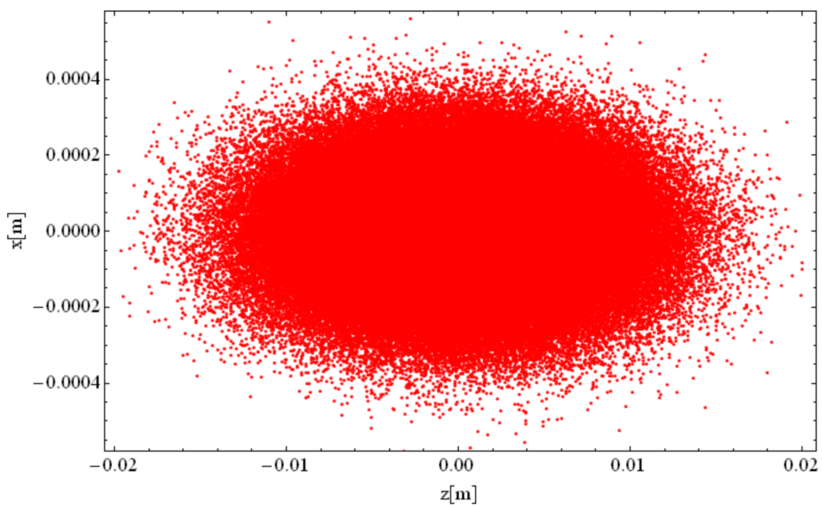
Bunch shape at last turn

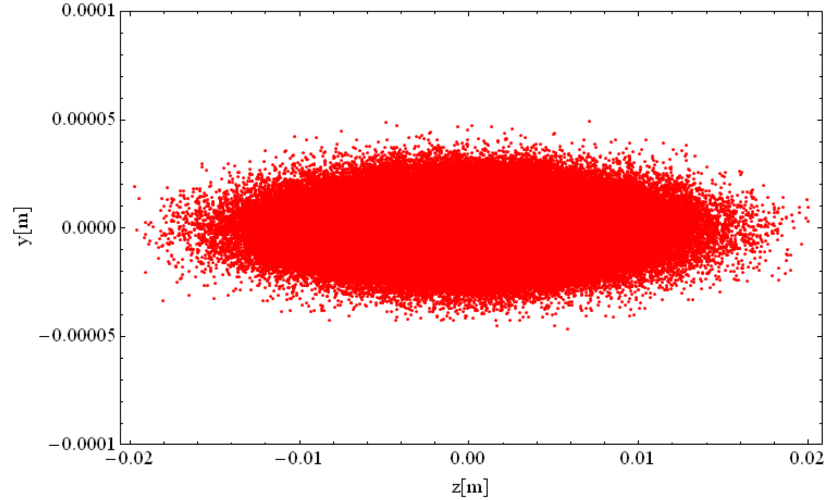
Above instability threshold





Below instability threshold





Electron cloud buildup simulation

- Cloud buildup was calculated by code “ECLOUD” developed at CERN.
- Assumptions:

  - Round or elliptical Chambers
  - Uniform production of primary electrons on chamber wall.
  - A reduced number of primary electrons is artificially used in order to take into account the reduction of electron yield by the ante-chamber:

$$e^- / e^+ / m = dn_\gamma / ds \cdot Y \cdot (1-\eta)$$

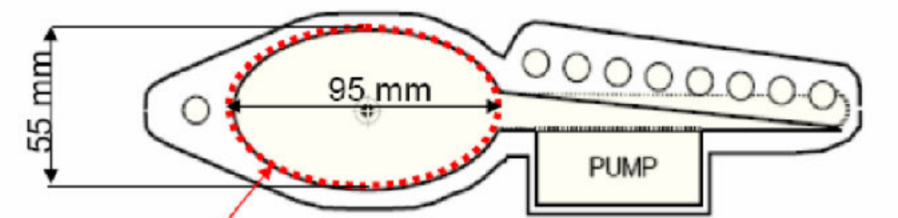
where: dn_γ/ds is the average number of emitted photons per meter per e^+, Y is the quantum efficiency, and η is the percentage of photons absorbed by the antechambers.

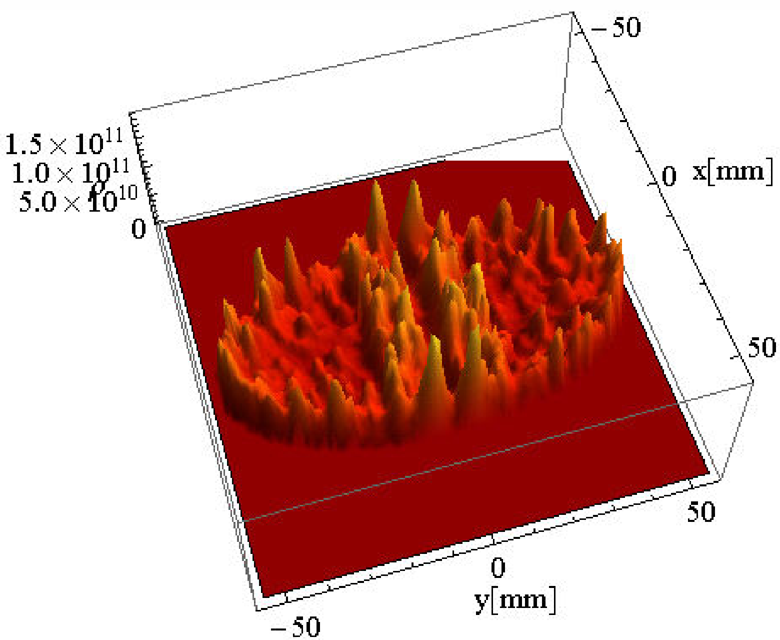
Build Up Input Parameters for ECLOUD

Bunch population	N_b	5.7x10^{10}
Number of bunches	n_b	500
Bunch spacing	$L_{sep}[m]$	1.2
Bunch length	$\sigma_z [mm]$	5
Bunch horizontal size	$\sigma_x [mm]$	0.3
Bunch vertical size	$\sigma_y [mm]$	0.012
Photoelectron Yield	Y	0.2
Photon rate (e^-/e^+/m)	dn_γ/ds	0.72
Photon Reflectivity	R	100%
Max. Secondary Emission Yeld	δ_{max}	1.0-1.2
Energy at Max. SEY	$E_m [eV]$	250
SEY model	Cimino-Collins $(\delta(0)=0.5)$	

Buildup in the SuperB arcs: Dipoles

LER dipole vacuum chamber (CDR)

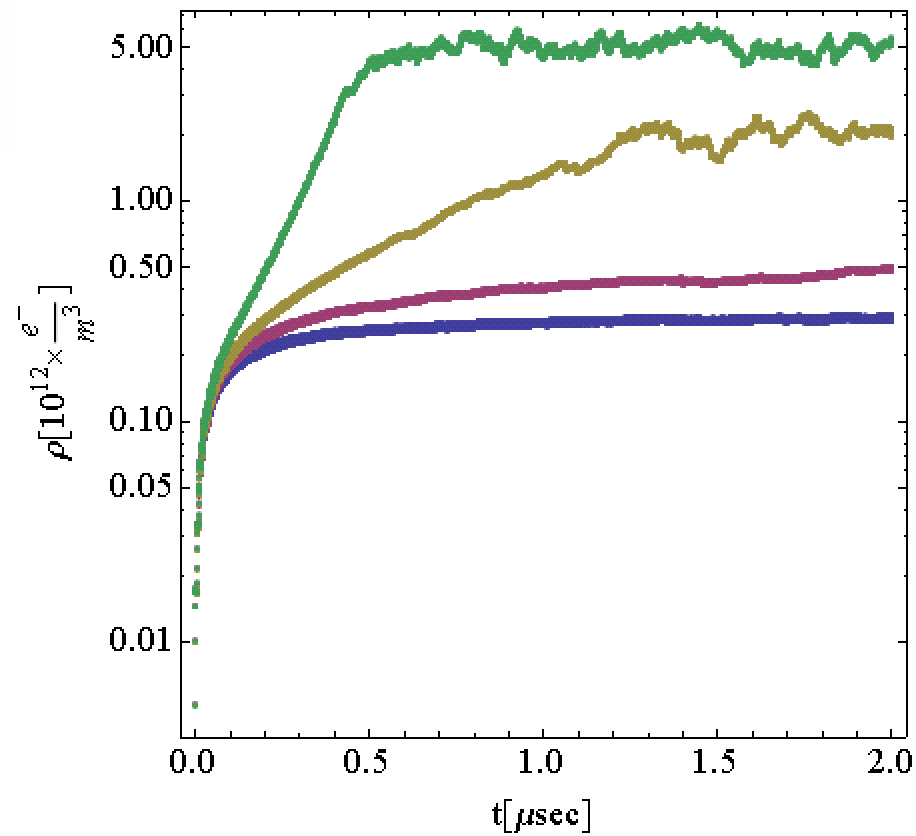




Snapshot of the electron (x,y) distribution
"just before" the passage of the last bunch

By=0.3 T; η=95%

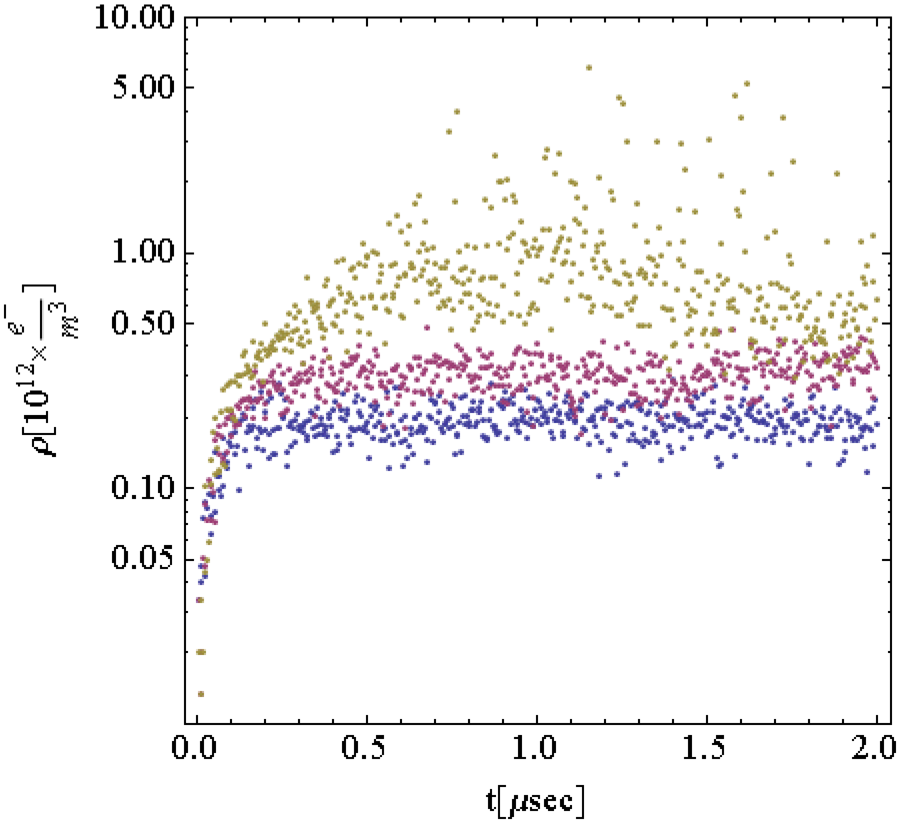
SEY=1.1 SEY=1.2 SEY=1.3 SEY=1.4



Electron Cloud Density at Center of Beam Pipe

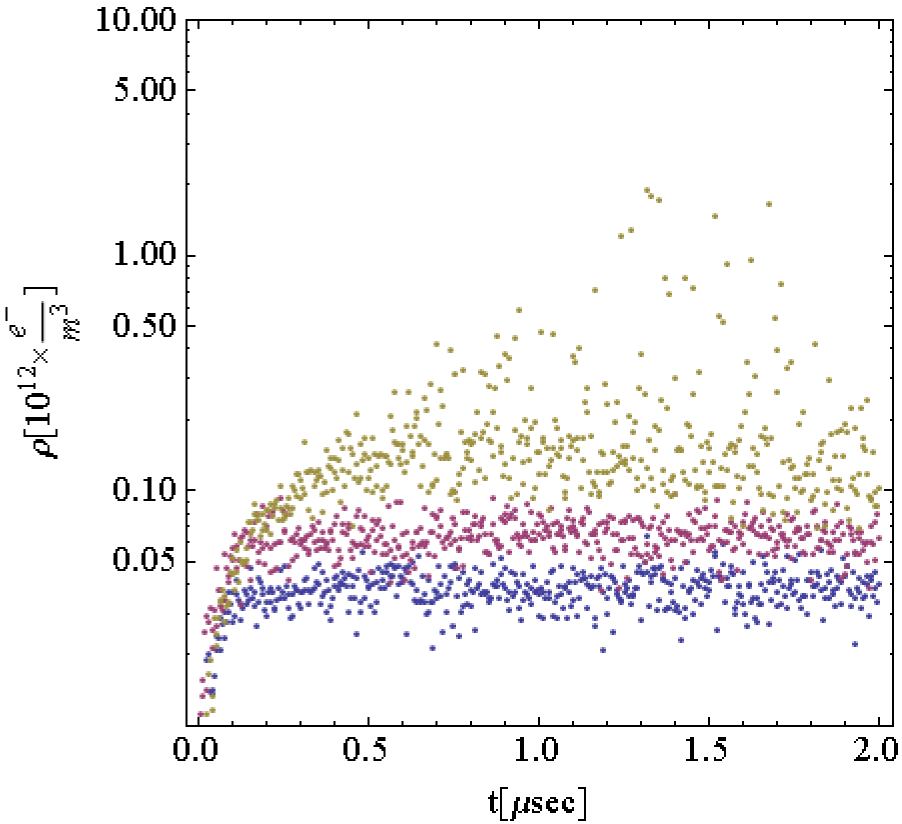
Center e-cloud density for η=95%

SEY=1.1 SEY=1.2 SEY=1.3



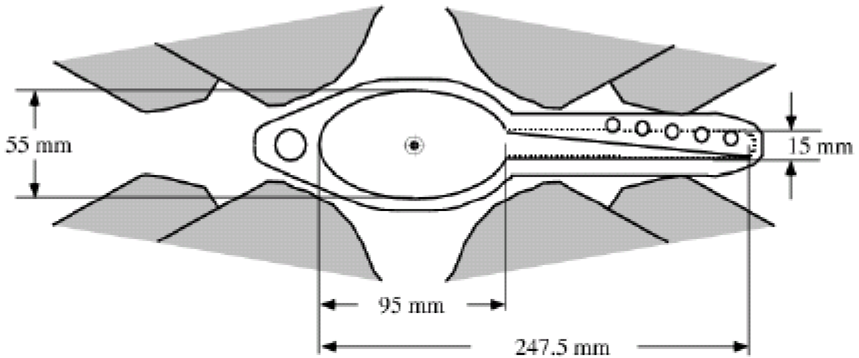
Center e-cloud density for η= 99%

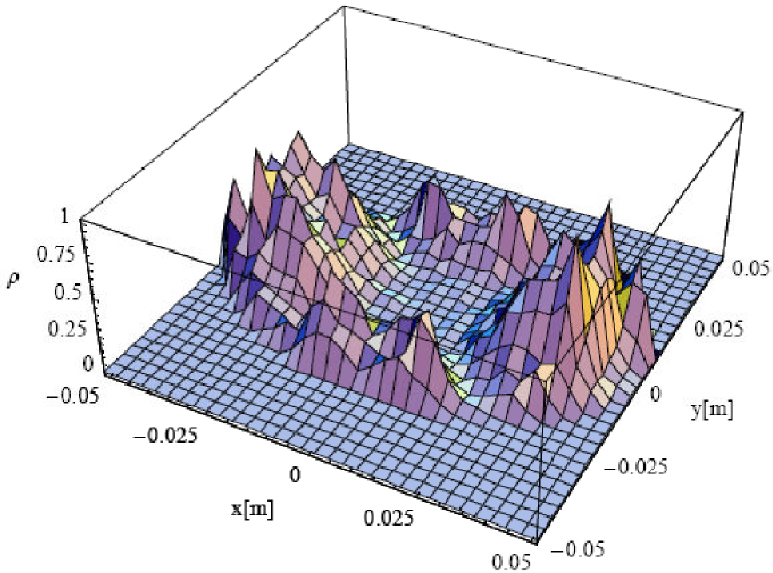
SEY=1.1 SEY=1.2 SEY=1.3



Buildup in the SuperB arcs: Quadrupoles

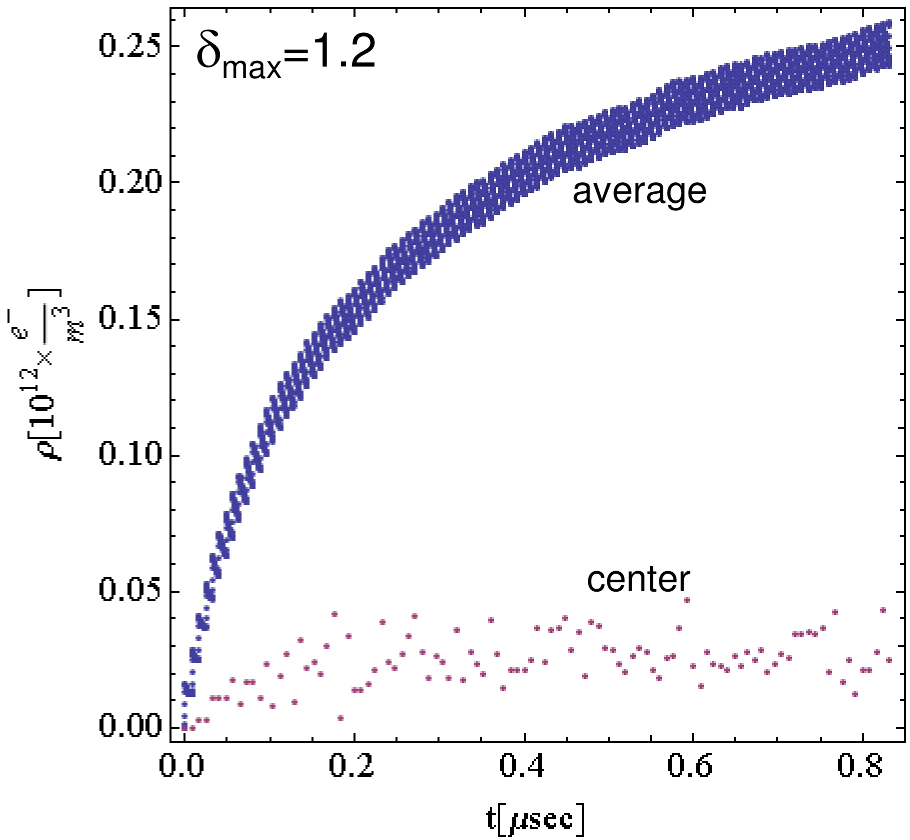
LER Arc quadrupole vacuum chamber (CDR)





Snapshot of the electron (x,y) distribution
“just before” the passage of the last bunch

dB_y/dx=2.5T/m, η=99%



Head-Tail Instability Threshold

		June 2008		January 2009		March 2009		LNF conf.
		ρ_{int} [$10^{15}m^{-2}$] solenoids	ρ_{int} [$10^{15}m^{-2}$] no solenoids	ρ_{int} [$10^{15}m^{-2}$] solenoids	ρ_{int} [$10^{15}m^{-2}$] no solenoids	ρ_{int} [$10^{15}m^{-2}$] solenoids	ρ_{int} [$10^{15}m^{-2}$] no solenoids	ρ_{int} [$10^{15}m^{-2}$] solenoids
SEY=1.1	95%	**0.06**	**2.1**	**0.09**	**2.5**	**0.22**	**2.7**	**0.1**
	99%	**0.02**	**0.25**	**0.04**	**0.3**	**0.04**	**0.7**	**0.07**
SEY=1.2	95%	**0.22**	**2.8**	**0.27**	**3.2**	**0.45**	**6.5**	**0.3**
	99%	**0.045**	**0.71**	**0.06**	**0.82**	**0.07**	**2.4**	**0.1**
SEY=1.3	95%	**2.7**	**20.2**	**2.9**	**25.7**	**5.4**	**25**	**2.0**
	99%	**0.94**	**3.2**	**1.3**	**4.1**	**4.5**	**13**	**0.7**

Instability occurs if:

$$\rho_{\text{int}} = \int_{drift} \rho_{cent.} ds + \int_{dipoles} \rho_{cent.} ds + \int_{quads} \rho_{cent.} ds \geq \int_{L_{tot}} \rho_{e,th} ds = \begin{matrix} 0.9\times 10^{15} m^{-2} \\ 0.5\times 10^{15} m^{-2} \end{matrix}$$

where $\rho_{cent.}$ and $\rho_{e,th}$ are obtained from simulations.

LNF conf.

Summary

DAFNE:

- Coupled-bunch instability has been simulated using PEI-M for the DAFNE parameters. results are in qualitative agreement with grow-damp measurements.
- Single-bunch instability has been simulated with CMAD tracking the beam through a realistic ring optics model. Preliminary results indicate a threshold well above the current estimated e-cloud density for DAFNE.
- Clearing electrodes for DAFNE has been designed and their effect on beam will be tested during next run.

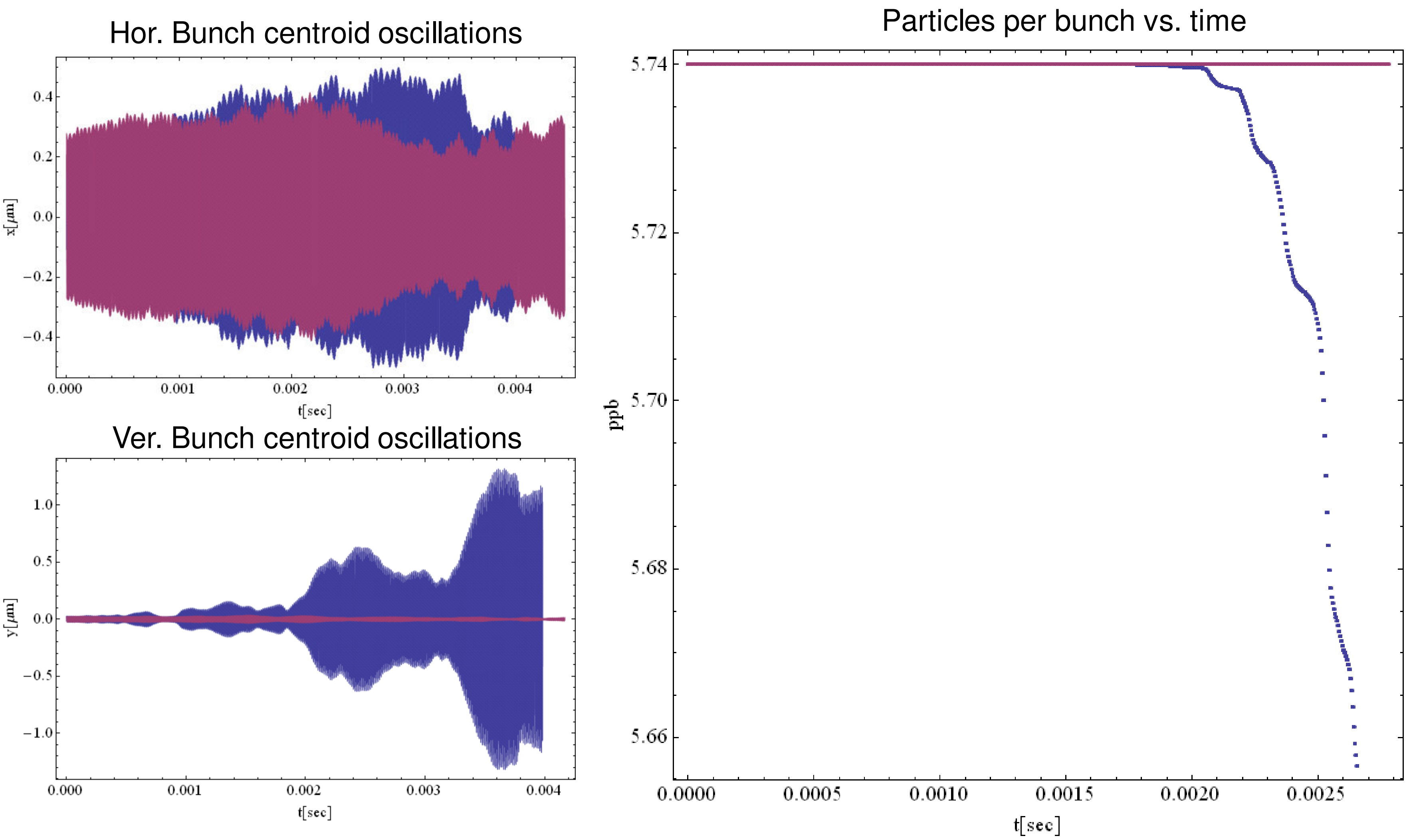
SuperB:

- Simulations indicate that a peak secondary electron yield of 1.2 and 99% antechamber protection result in a cloud density close to the instability threshold.
- Planned use of coatings (TiN, ?) and solenoids in SuperB free field regions can help.
- Ongoing studies on mitigation techniques (grooves in the chamber walls, clearing electrodes) offers the opportunity to plan activity for SuperB.

- Work is in progress to:

  estimate other effects: multi-bunch instability, tune-shift, ...

Beam losses



$\rho=3\times10^{11}e^-/m^{-3}$; $\rho=7\times10^{11}e^-/m^{-3}$