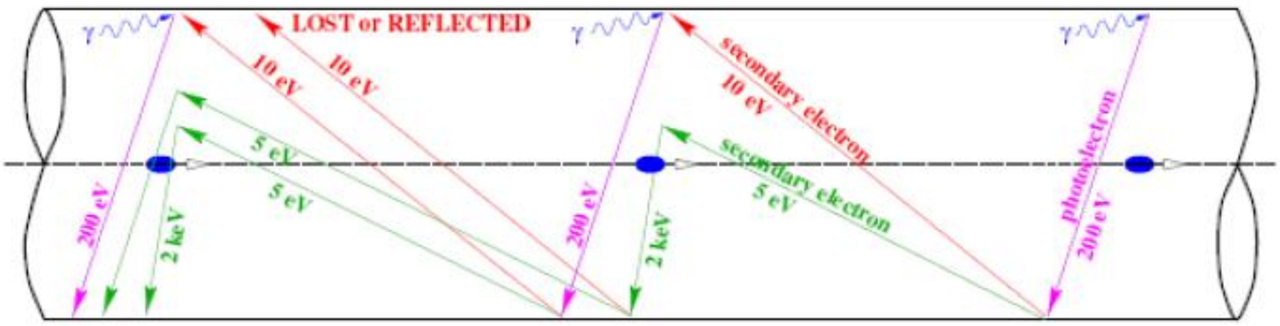
Collective effects in e+/e- colliders

T. Demma

Plan of Talk

- e-Cloud
  - Introduction
  - Analysis of the e-cloud induced instabilities @ DAFNE
  - Clearing electrodes for DAFNE dipoles and wigglers
- IBS
  - Conventional calculation of IBS
  - Multi-particles codes structure
  - Growth rates estimates and comparison with conventional theories
  - Bunch distribution evolution

Electron Cloud Effects



• The electron cloud develops quickly as photons striking the vacuum chamberwall knock out electrons that are then accelerated by the beam, gain energy, and strike the chamber again, producing more electrons.

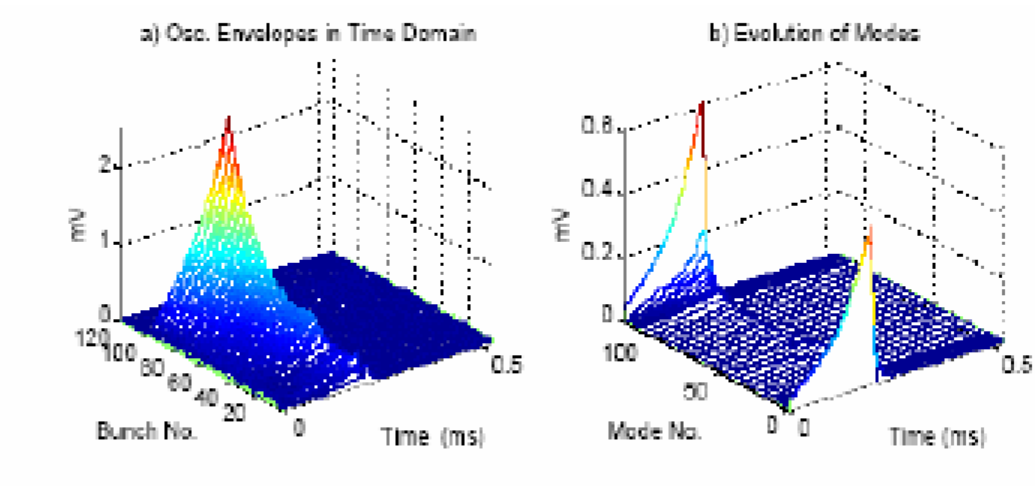
• The peak secondary electron yield (**SEY**) of typical vacuum chamber materials is >1 even after surface treatment, leading to amplification of the cascade.

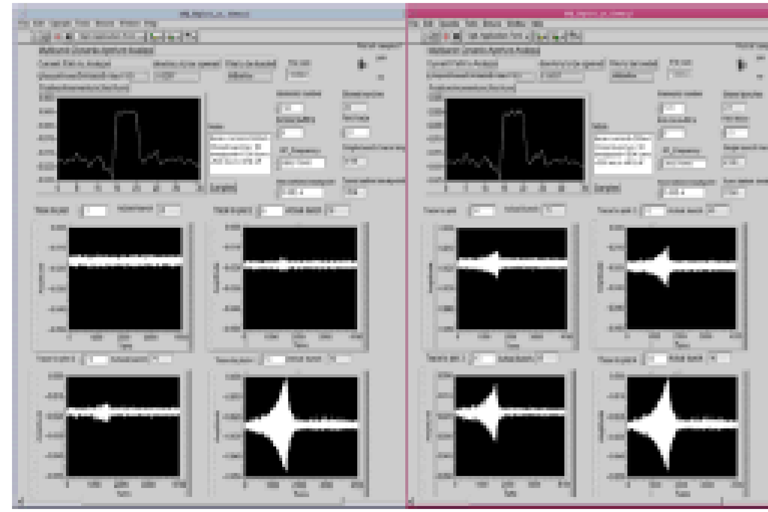
• The interaction between the electron cloud and a beam leads to the electron cloud effects such as single- and multi-bunch instability, tune shift, increase of pressure and so on.

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 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

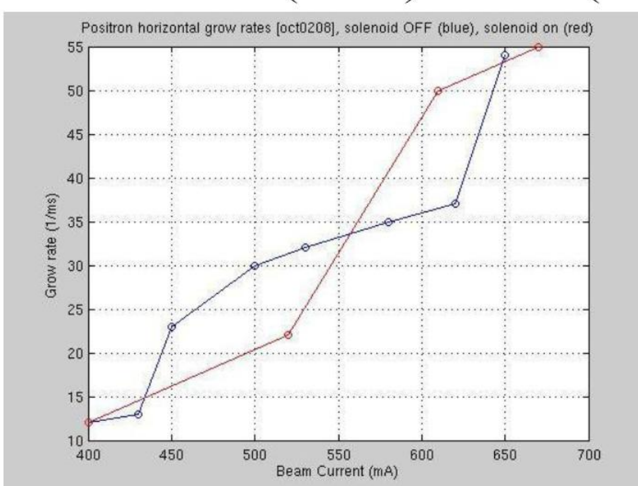
Characterization of the Horizontal Instability





Grow-damp measurements

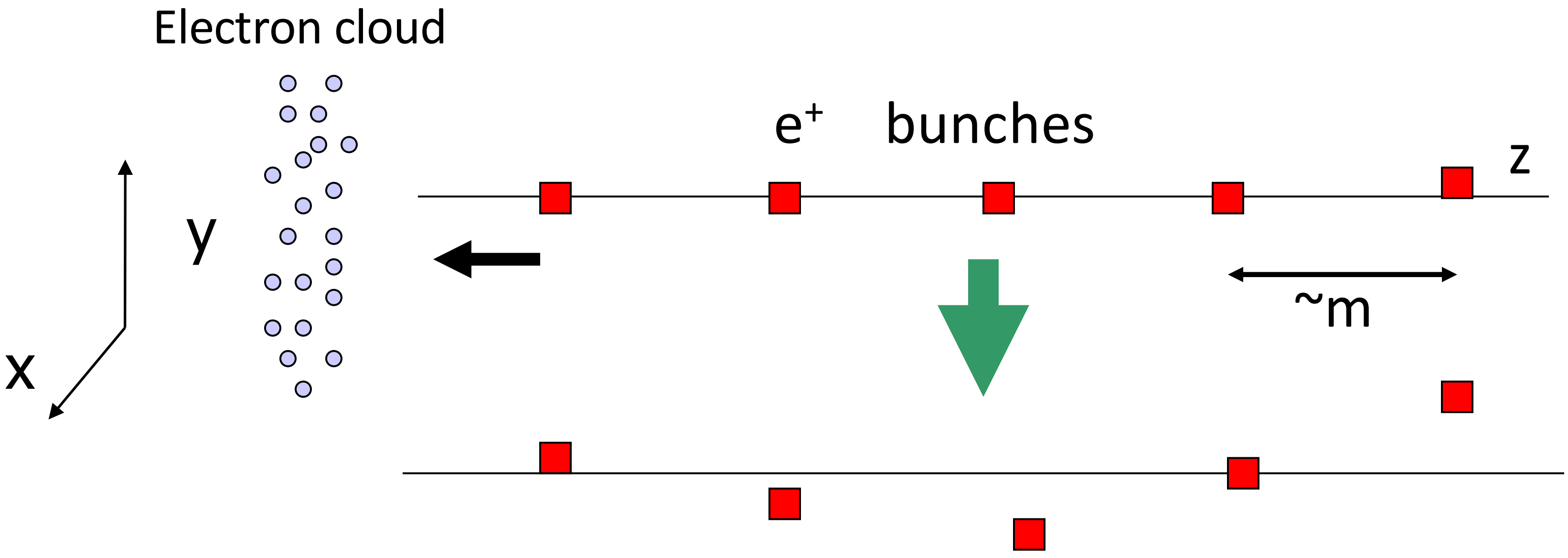
solenoids off (blue) & on (red)



- 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.

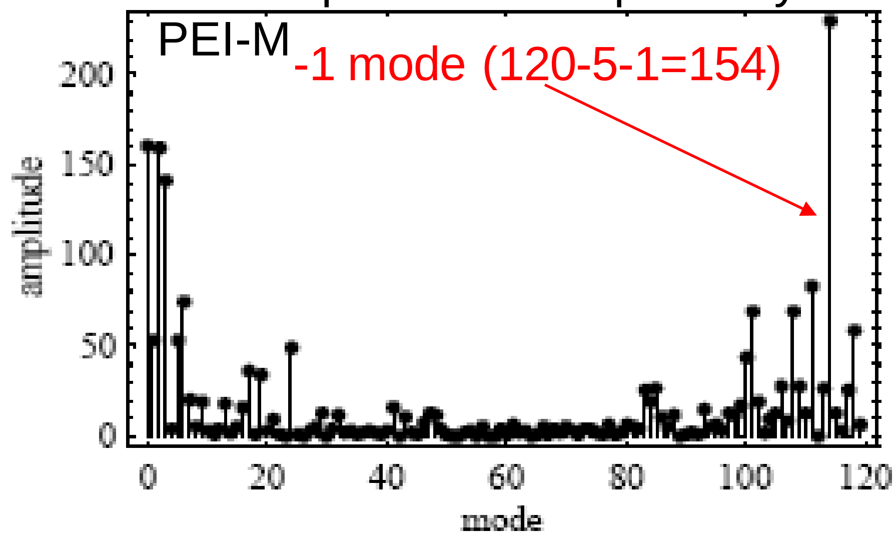
•Fourier transformation of the amplitudes gives a spectrum of the unstable mode, identified by peaks of the betatron sidebands.

e-cloud @ DAFNE

T. Demma, ''Electron cloud simulations for DAFNE'', ICFA Beam Dyn. Newslett. 48, 2009.

- Multiparticle tracking using PEI-M (K. Ohmi, KEK)
- Uniform Magnetic Field By=1.7 T

Mode Specrtrum computed by PEI-M



Input Parmeters

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

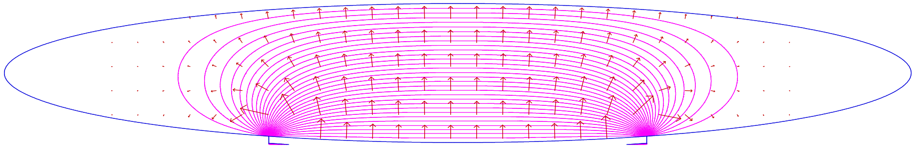
Growth Rate Comparison

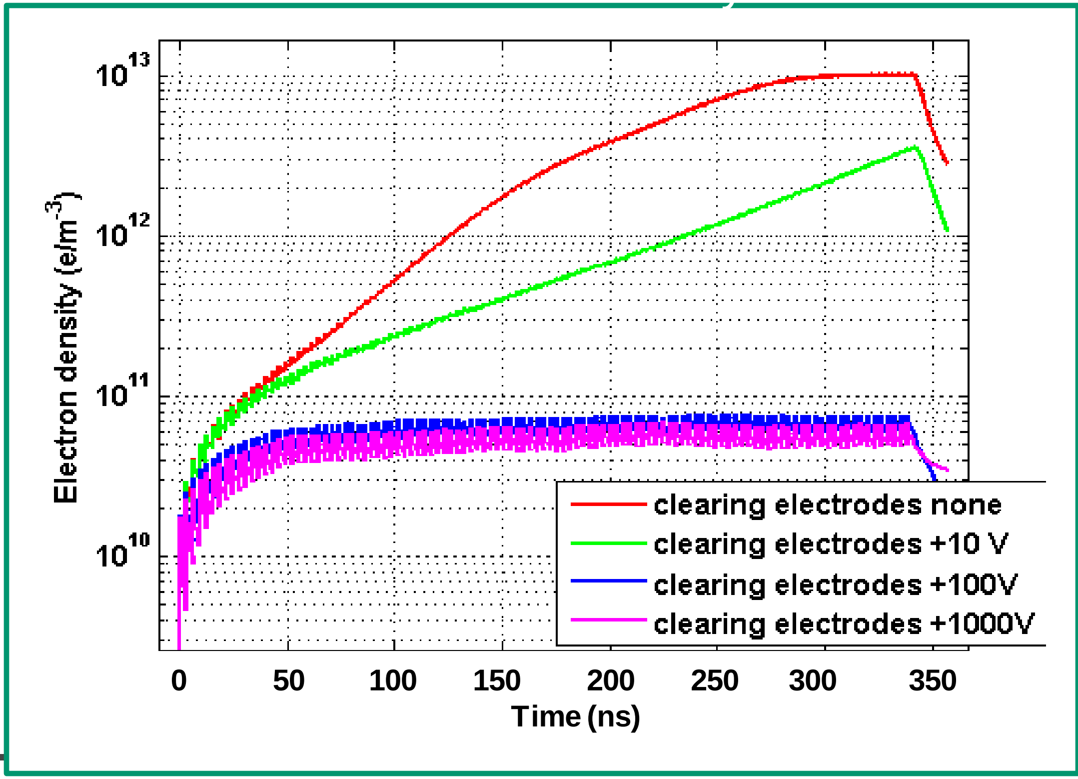
Measurment		Simulation	
I[A]/nb	τ/T_0	I[A]/nb	τ/T_0
1/105	**73**	**1.2/120**	**100**
0.75/105	56	900/120	95
0.5/105	100	600/120	130

e-Cloud @ DAFNE: Clearing Electrodes

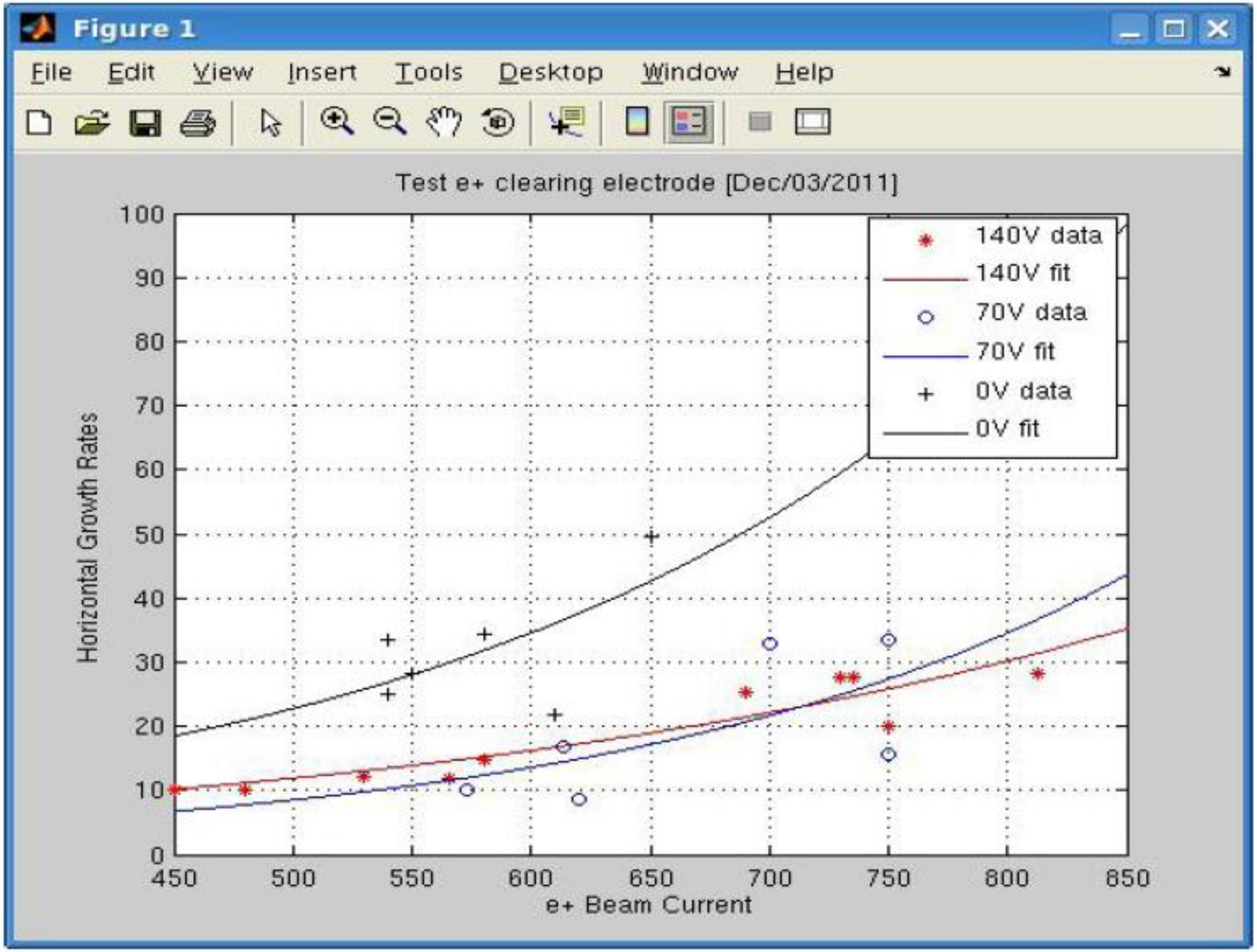
• Clearing electrodes are installed in the vacuum chambers of wigglers and dipoles of DAFNE positron ring.

•Simulation using ECLOUD (CERN)





Horizontal growth rate measurements



(A. Drago, LNF-INFN)

e-Cloud Summary

- Coupled-bunch instability has been simulated using PEI-M for the DAFNE parameters. results are in qualitative agreement with grow-damp measurements.
- Clearing electrodes for DAFNE has been installed in the wigglers and dipoles of the DAFNE positron ring.
- Experience with clearing electrodes in the Dafne positron beam is largely positive: vertical dimension, tune shift and growth rates clearly indicates a good behaviour of these devices.

IBS Calculations procedure

1. Evaluate equilibrium emittances ε_i and radiation damping times τ_i at low bunch charge
2. Evaluate the IBS growth rates $1/T_i(\varepsilon_i)$ for the given emittances, averaged around the lattice, using K. Bane approximation*
3. Calculate the "new equilibrium" emittance from:

$$\varepsilon_i' = \frac{1}{1 - \tau_i / T_i} \varepsilon_i$$

- For the vertical emittance use* :

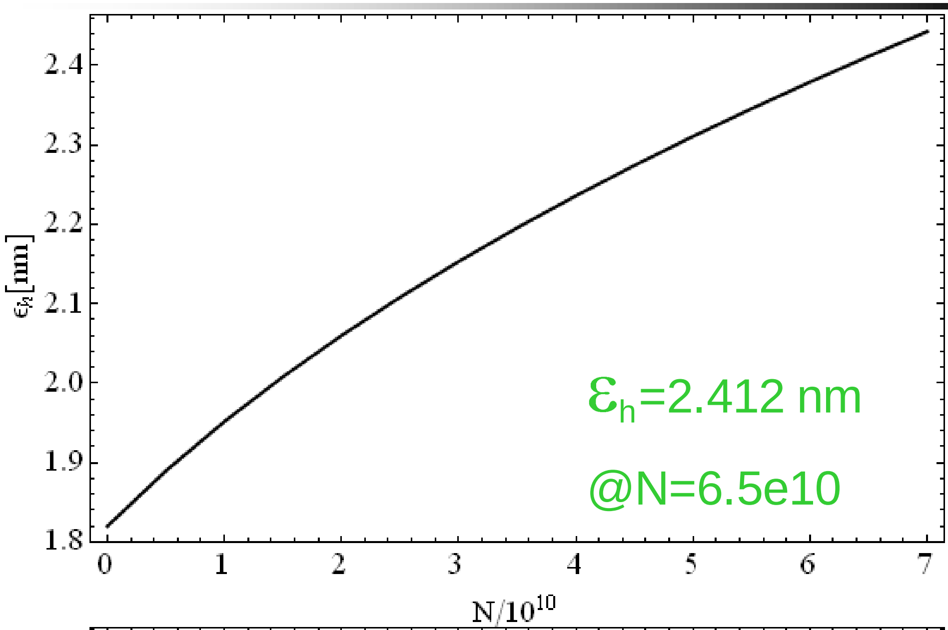
$$\varepsilon_y' = (1 - r_\varepsilon) \frac{1}{1 - \tau_y / T_y} \varepsilon_y + r_\varepsilon \frac{1}{1 - \tau_x / T_x} \varepsilon_y$$

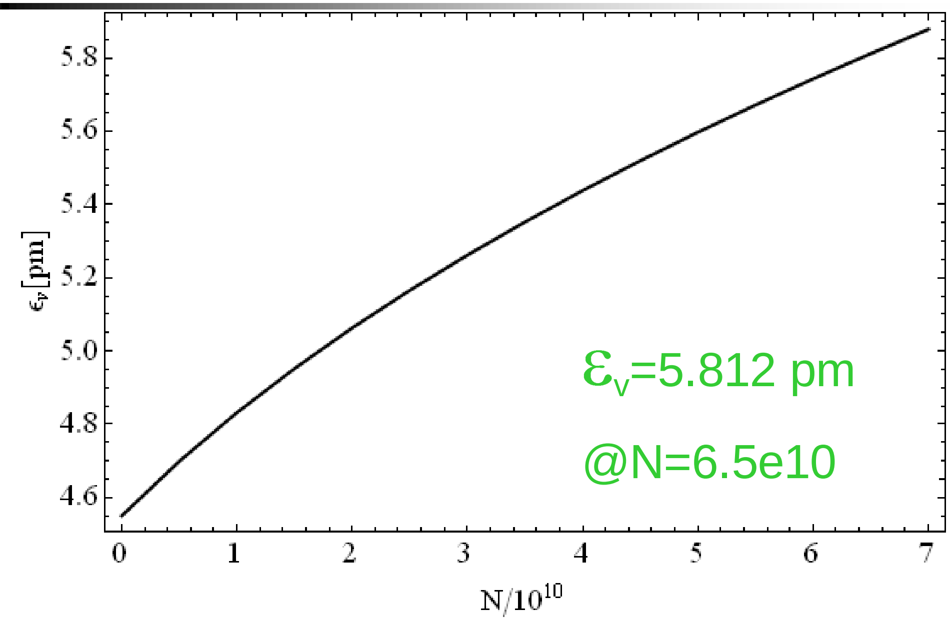
- where r_ε varies from 0 (ε_y generated from dispersion) to 1 (ε_y generated from betatron coupling)

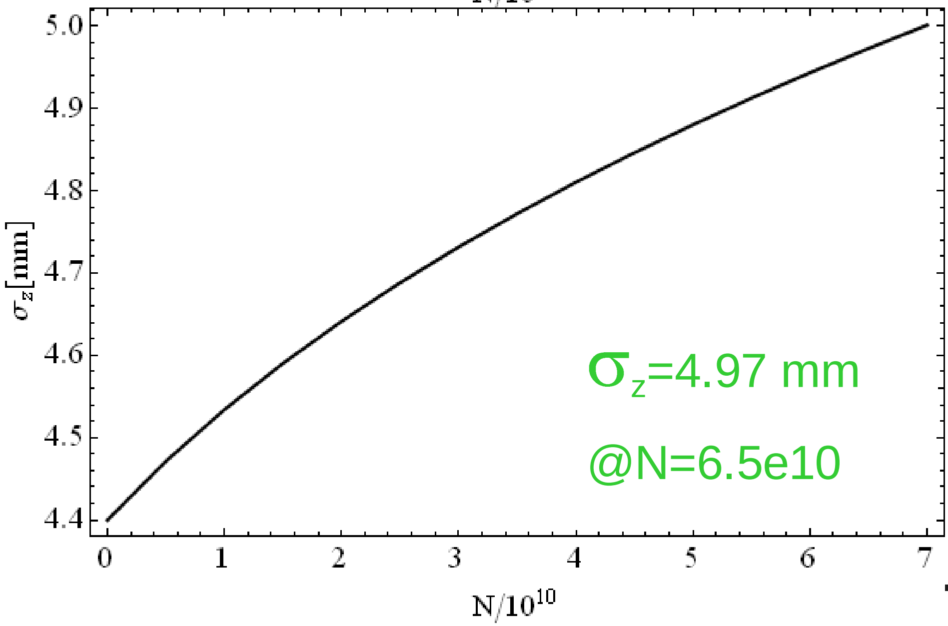
4. Iterate from step 2

* K. Kubo, S.K. Mtingwa, A. Wolski, "Intrabeam Scattering Formulas for High Energy Beams," Phys. Rev. ST Accel. Beams **8**, 081001 (2005)

IBS in SuperB LER (lattice V12)





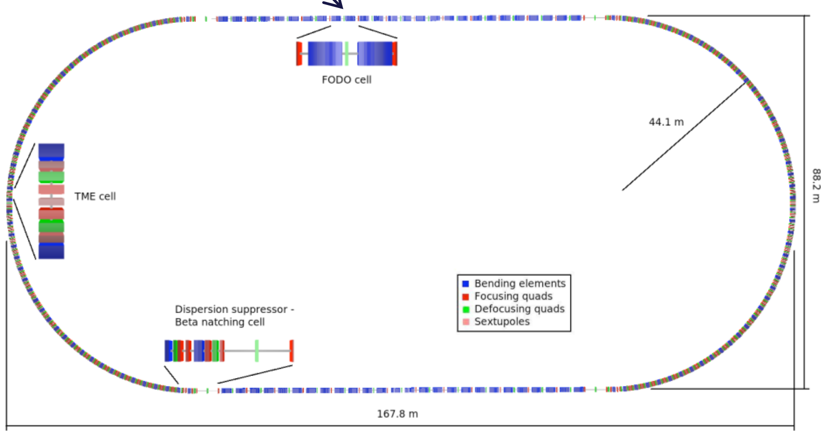


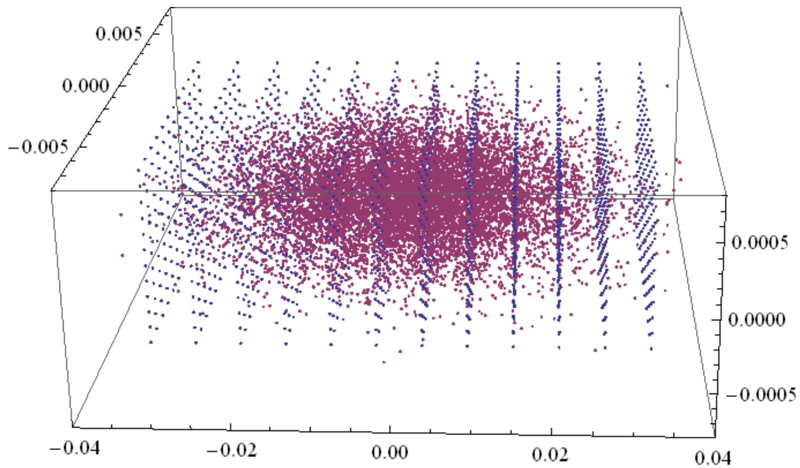
Effect is reasonably small. Nonetheless, there are some interesting questions to answer:

- What will be the impact of IBS during the damping process?
- Could IBS affect the beam distribution, perhaps generating tails?

Intra-Beam Scattering (IBS) Simulation Algorithm

IBS applied at each element of the Ring lattice

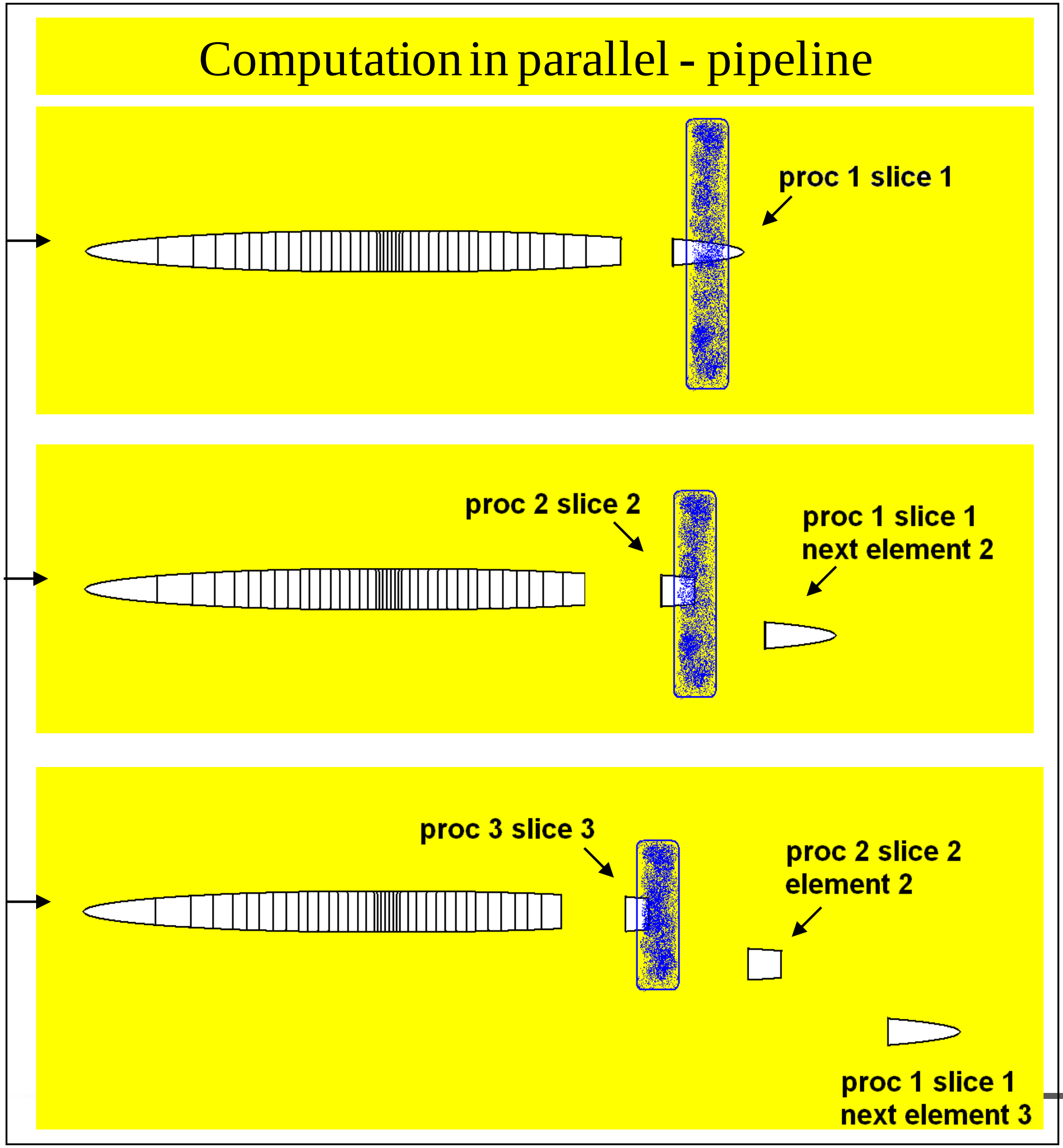


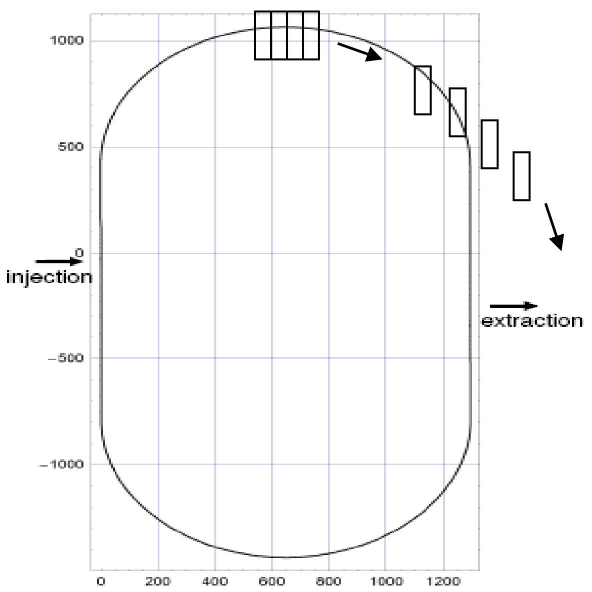


- Lattice read from MAD (X or 8) files containing Twiss functions and transport matrices
- At each element in the ring, the IBS scattering routine is called:
  - Particles of the beam are grouped in cells.
  - Particles inside a cell are coupled
  - Momentum of particles is changed because of scattering.
  - Invariants and corresponding growth rate are recalculated.
- Particles are transported to the next element.
- Radiation damping and excitation effects are evaluated at each turn.

T. Demma, M. Boscolo, M.Biagini (INFN), M. Pivi , A. Chao (SLAC)

Bunch-slice parallel decomposition

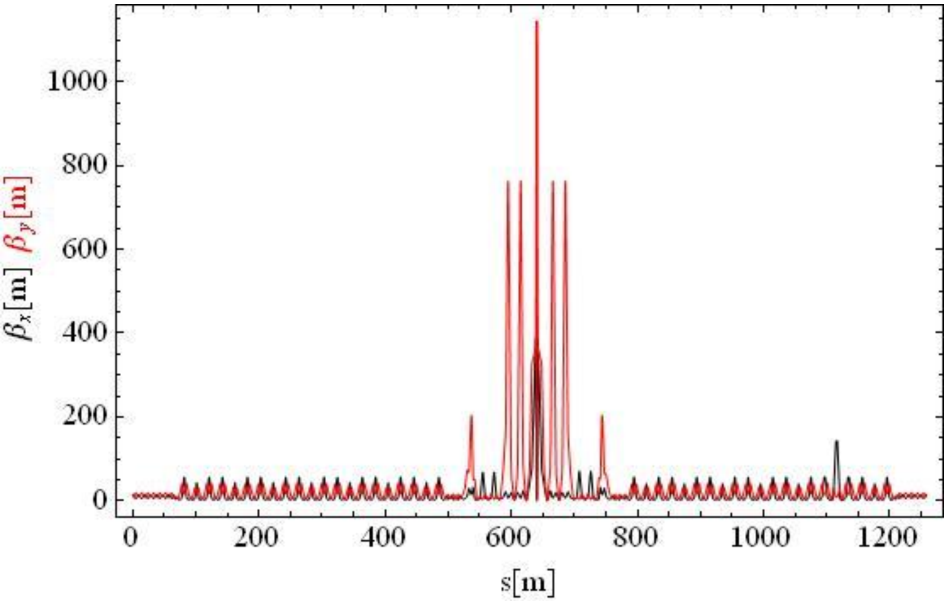




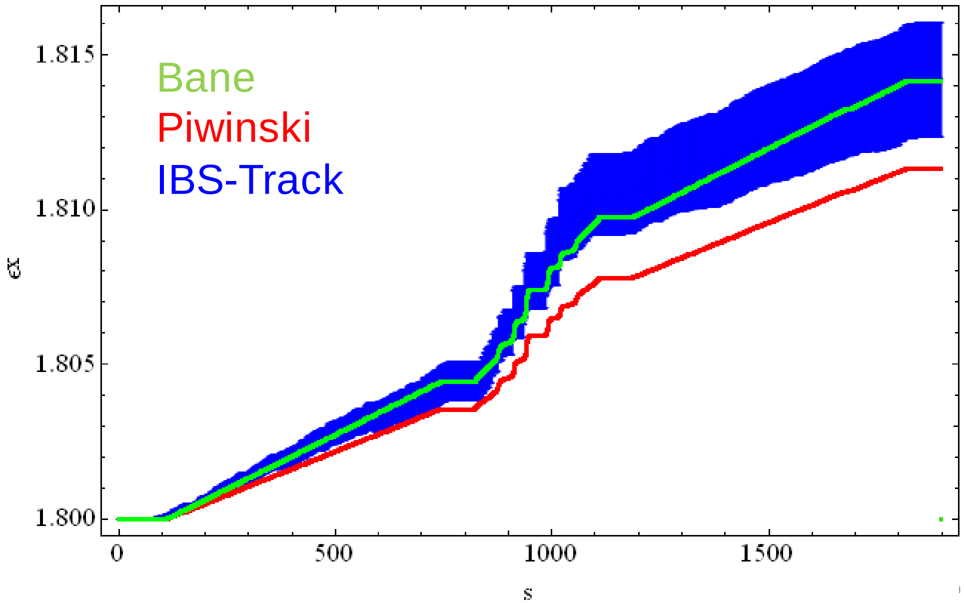
Each processor deals with the bunch-slice, then send information to the next in the pipeline. The last processor print out the beam information. At each turn, 1 processor gathers all particles and compute Radiation Damping and Quantum Excitation.

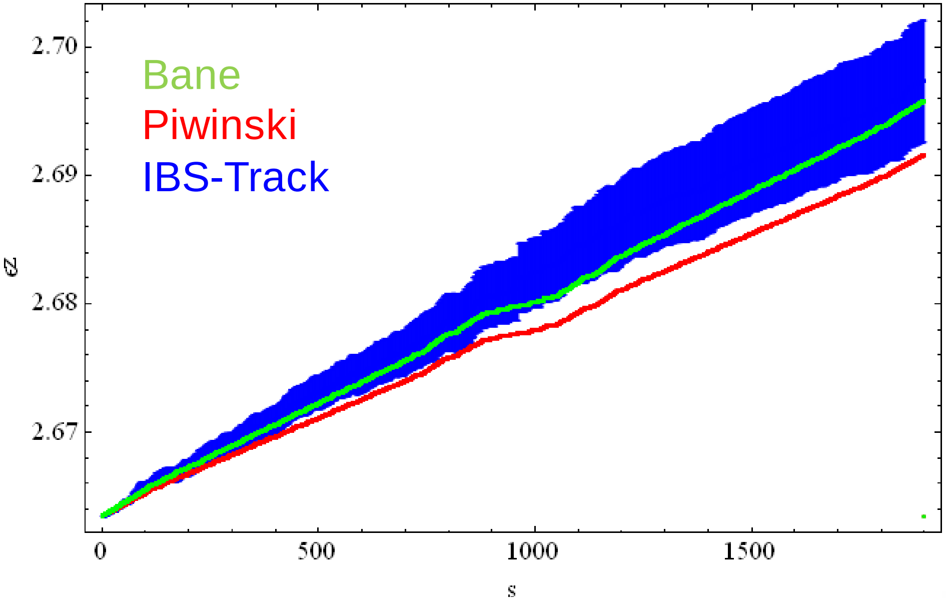
M. Pivi (SLAC)

Intrabeam Scattering in SuperB LER



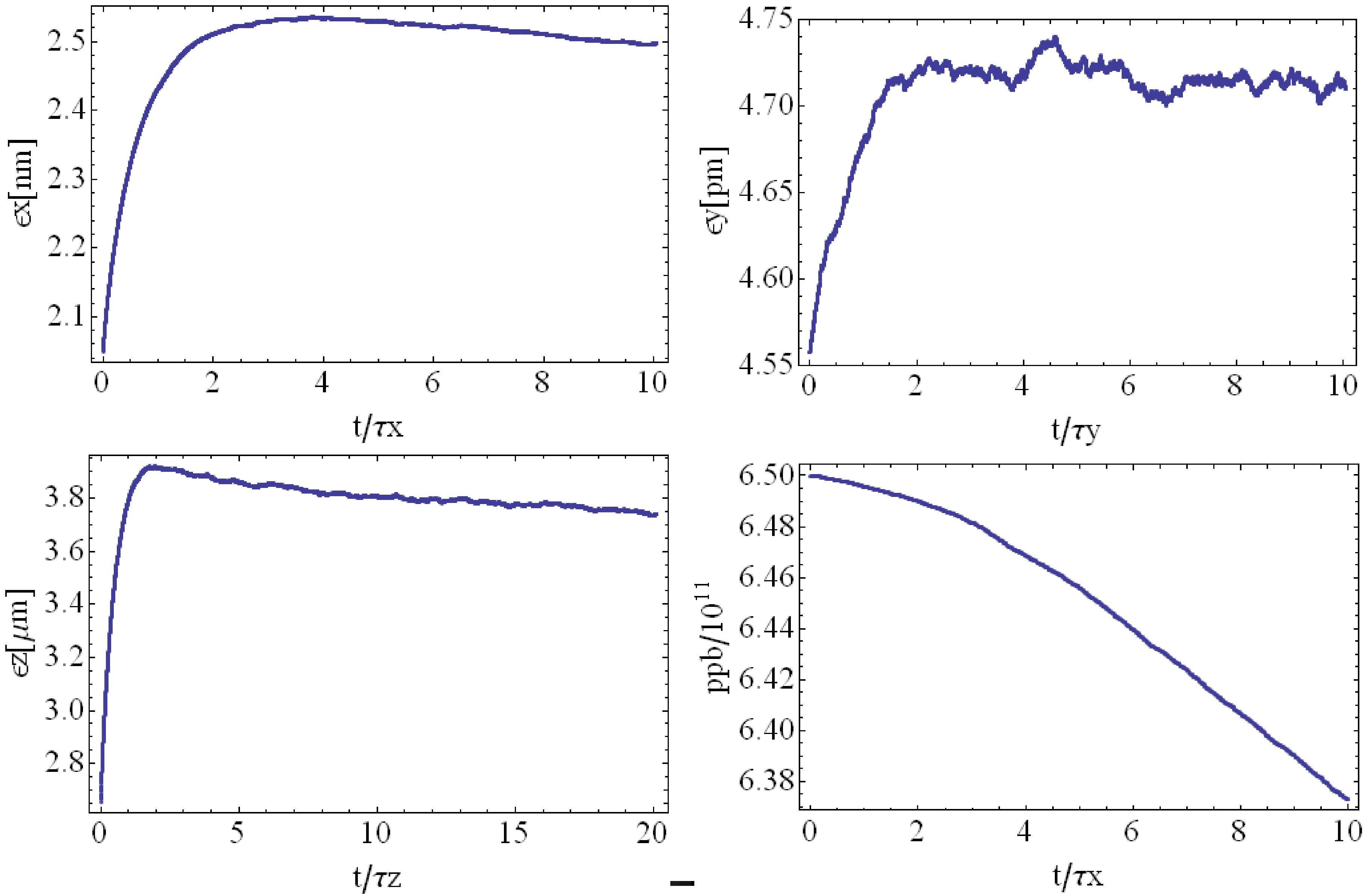
Parameter	Unit	Value
Energy	GeV	4.18
Bunch population	10^{10}	6.5
Circumference	m	1257
Emittances (H/V)	nm/pm	1.8/4.5
Bunch Length	mm	3.99
Momentum spread	%	0.0667
Damping times (H/V/L)	ms	40/40/20
N. of macroparticles	-	10^5
N. of grid cells	-	64x64x64





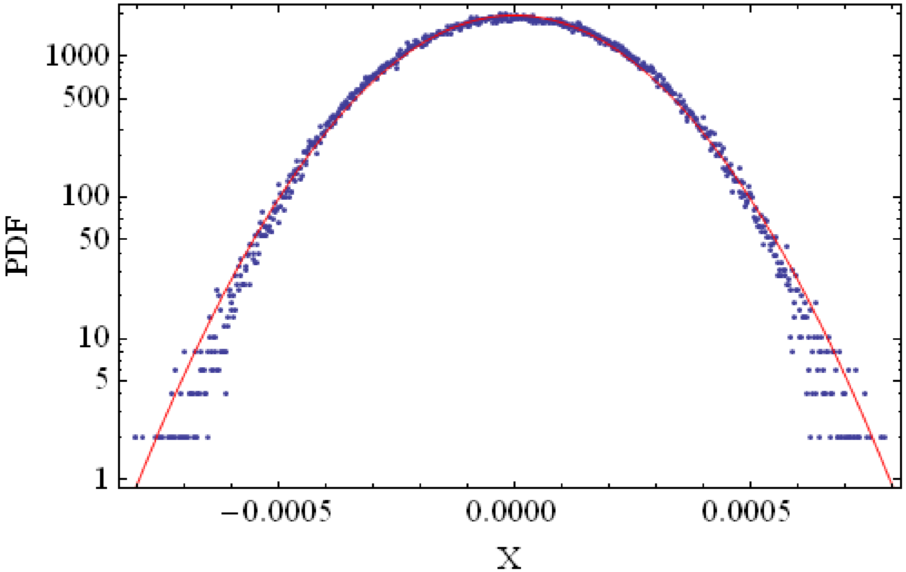
CPU time ~ 15 sec per turn (64CPU)

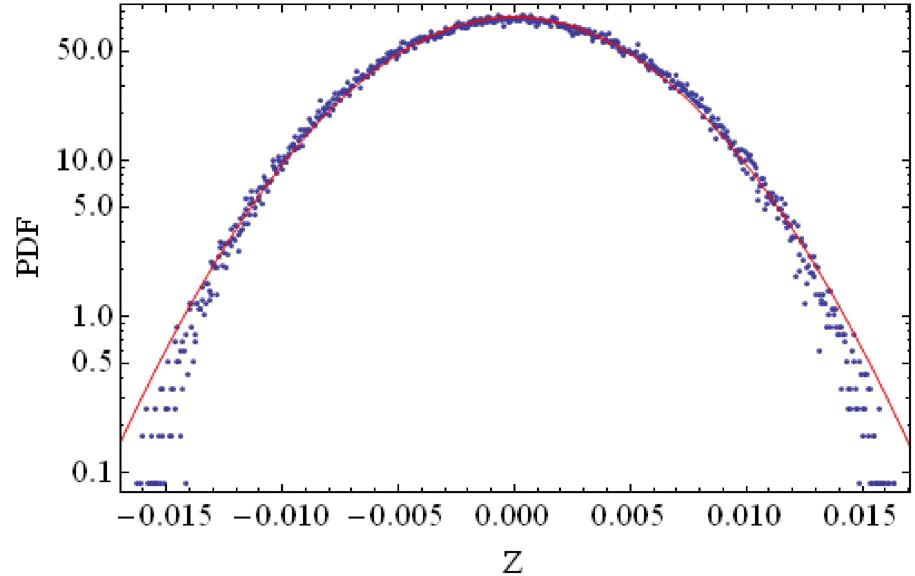
Emittance Evolution in SuperB LER

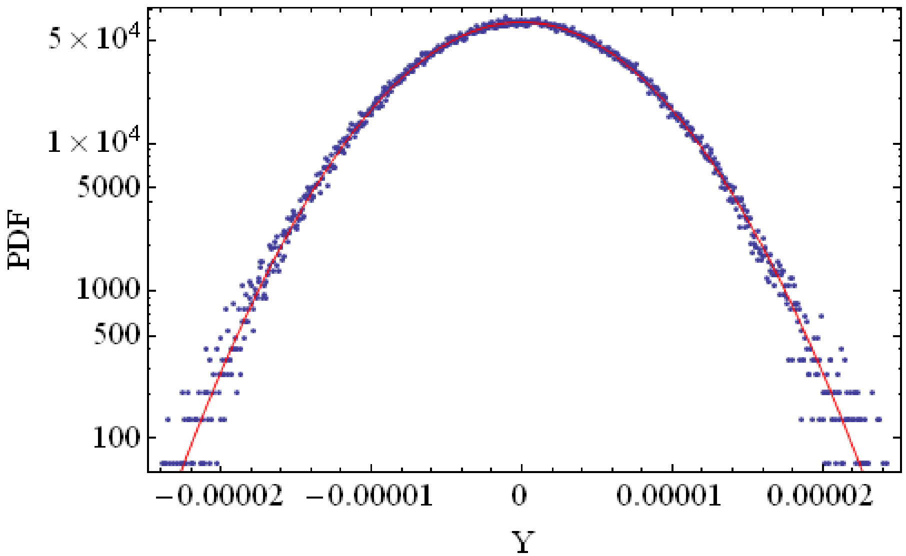


M. Pivi (SLAC), T. Demma (INFN)

IBS Distribution Studies







$$p_k(\xi_k) = \frac{1}{\sqrt{2\pi}\sigma_k} e^{-\frac{\xi_k^2}{2\sigma_k^2}}$$

Parameter	χ^2_{799}	Confidence
Z	1857.56	<1e-6
X	1455.68	<1e-6
Y	778.228	0.6920

M. Pivi (SLAC), T. Demma (INFN)

IBS Summary

•Interesting aspects of the IBS such as its impact on damping process and on generation of non Gaussian tails may be investigated with a multiparticle algorithm.

•Two codes implementing the Zenkevich-Bolshakov algorithm to investigate IBS effects have been developed:

– Benchmarking with conventional IBS theories gave good results

–Evolution of the particle distribution shows deviations from Gaussian behaviour due to IBS effect

• Parallel implementation of the algorithm is ready :

–IBS routines included in CMAD (thanks to M. Pivi).

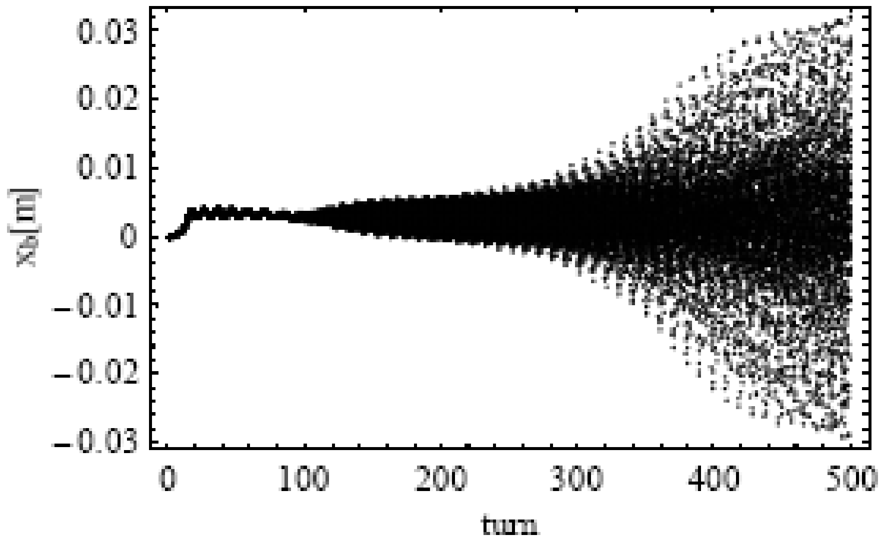
•Comparison of the code results with measurements at SLS and/or Cesr-TA would provide the possibility of

•Benchmarking with real data

•Tuning code parameters (number of cells, number of interactions, etc.)

•Revision of the theory or theory parameters (Coulomb log, approximations used, etc.)

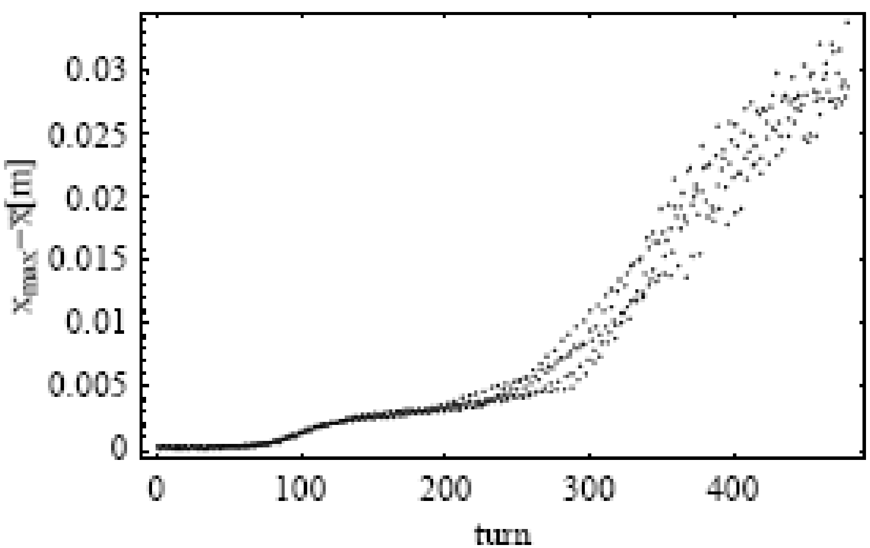
Mode spectrum and growth rate



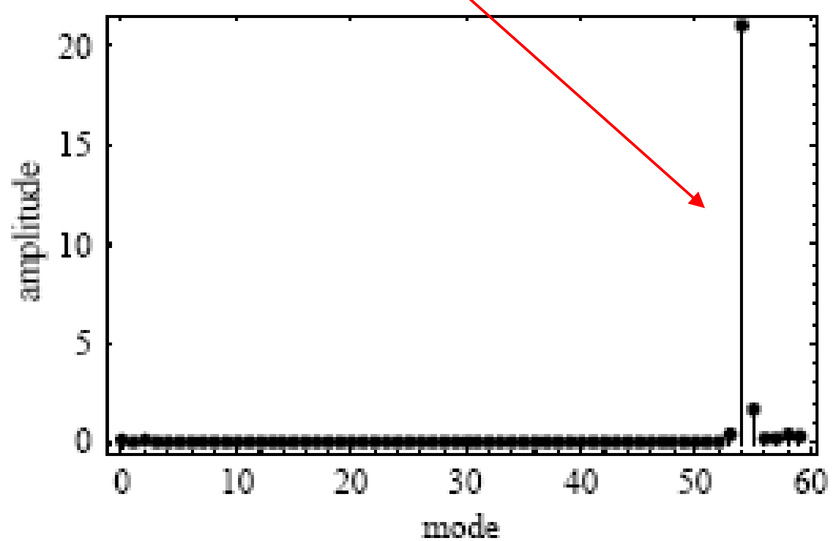
60 equispaced bunches

Beam current 1.2 A

Growth time ~ 100 turn



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



Piwinski

$$\frac{1}{T_p} = A\left\langle \frac{\sigma_H{}^2}{\sigma_p{}^2} f(a,b,q) \right\rangle$$

$$\frac{1}{T_x} = A\left\langle f\left(\frac{1}{a},\frac{b}{a},\frac{q}{a}\right) + \frac{H_x{}^2 \sigma_{\mathrm{H}}{}^2}{\varepsilon_x} f(a,b,q) \right\rangle$$

$$\frac{1}{T_y} = A\left\langle f\left(\frac{1}{b},\frac{a}{b},\frac{q}{b}\right) + \frac{H_y{}^2 \sigma_{\mathrm{H}}{}^2}{\varepsilon_y} f(a,b,q) \right\rangle$$

$$\frac{1}{\sigma_{\mathrm{H}}{}^2} = \frac{1}{\sigma_p{}^2} + \frac{H_x{}^2}{\varepsilon_x} + \frac{H_y{}^2}{\varepsilon_y}$$

$$a = \frac{\sigma_H}{\gamma}\sqrt{\frac{\beta_x}{\varepsilon_x}}, \qquad b = \frac{\sigma_H}{\gamma}\sqrt{\frac{\beta_y}{\varepsilon_y}}, \qquad q = \sigma_H \beta \sqrt{\frac{2d}{r_0}}$$

$$f(a,b,q) = 8\pi \int_0^1 du \frac{1-3u^2}{PQ}\left\{ 2\ln\left[\frac{q}{2}\left(\frac{1}{P}+\frac{1}{Q}\right)\right] - EulerGamma \right\}$$

$$P^2 = a^2 + (1-a^2)u^2, \qquad Q^2 = b^2 + (1-b^2)u^2$$

Bane's high energy approximation

- Bjorken-Mtingwa solution at high energies
- Changing the integration variable of B-M to $\lambda' = \lambda\sigma_H^2/\gamma^2$

- Approximations
  - a,b<<1 (if the beam cooler longitudinally than transversally)→ The second term in the braces small compared to the first one and can be dropped
  - Drop-off diagonal terms (let ζ=0) and then all matrices will be diagonal

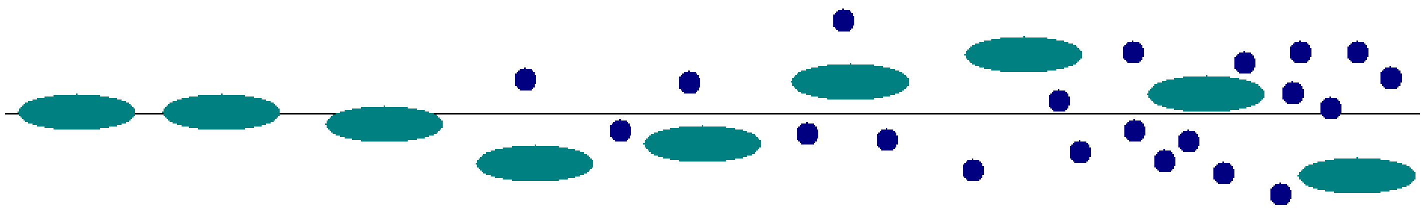
$$(L + \lambda' I) = \frac{\gamma^2}{\sigma_H^2}\begin{pmatrix} a^2+\lambda' & -a\zeta_x & 0 \\ -a\zeta_x & 1+\lambda' & -b\zeta_y \\ 0 & -b\zeta_y & b^2+\lambda' \end{pmatrix}$$

$$\zeta_x = \phi_{x,y}\sigma_H\sqrt{\frac{\beta_{x,y}}{\varepsilon_{x,y}}}$$

$$\frac{1}{T_p} \approx \frac{r_0^2 cN(\log)}{16\gamma^3\varepsilon_x^{3/4}\varepsilon_y^{3/4}\sigma_s\sigma_p^3}\left\langle \sigma_H g(a/b)(\beta_x\beta_y)^{-1/4}\right\rangle$$

$$\frac{1}{T_{x,y}} \approx \frac{\sigma_p^2\langle H_{x,y}\rangle}{\varepsilon_{x,y}}\frac{1}{T_p}, \qquad g(a) = \frac{2\sqrt{a}}{\pi}\int_0^\infty \frac{du}{\sqrt{1+u^2}\sqrt{a^2+u^2}}$$

Fast Ion Instability



Characteristics of FII

- The residual gas in the vacuum chambers can be ionized by the single passage of a bunch train
- The interaction of an electron beam with residual gas ions results in mutually driven transverse oscillations
- Ions can be trapped by the beam potential or can be cleared out after the passage of the beam
- Multi-train fill pattern with regular gaps is an efficient and simple way to remedy of FII

Simulation of FII

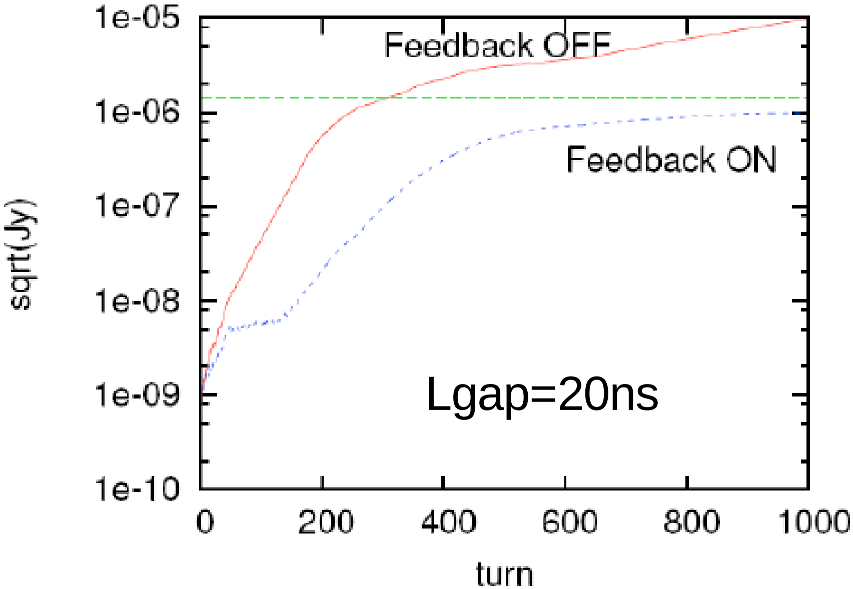
IONTR developed by Ohmi san

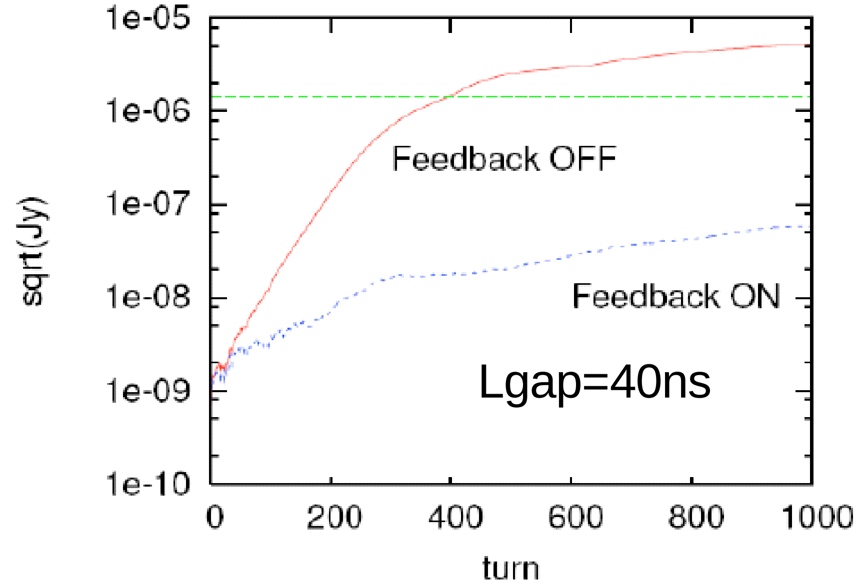
- •Weak-strong approximation
- •Electron beam is a rigid gaussian
- •Ions are regarded as Marco-particles
- •The interaction between them is based on Bassetti-Erskine formula
- • β function variation are taken into account
- • The effect of a bunch-by-bunch feedback system is included (damping time 50 turns)
- •Assumptions for SuperB:
  - CO ions
  - N_i[m-1]=0.046xP[Pa]xppb
  - P=0.3x10^{-8} Pa

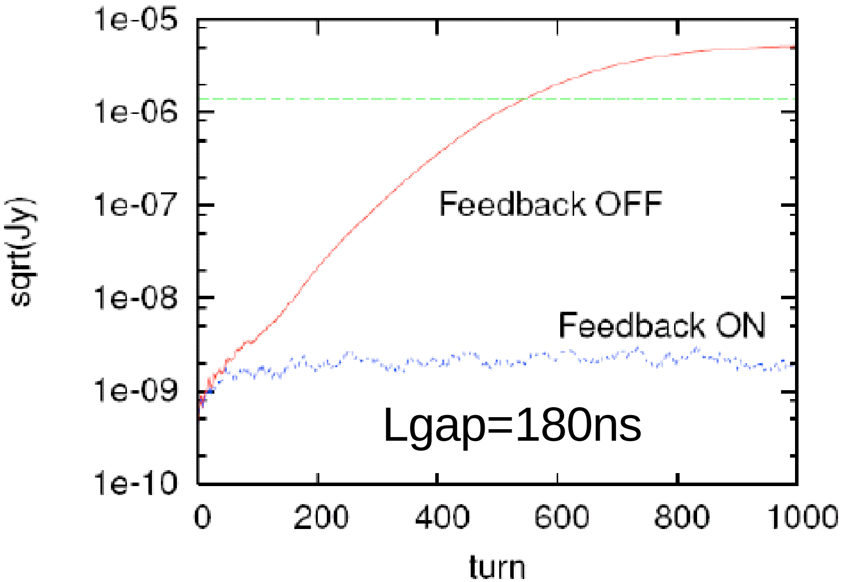
SuperB LER

Circumference [m]	1258.4
Energy [GeV]	4.18
Harmonic number	1998
Trans. damping time [ms]	40
Horizontal emittance [nm]	2.4
Vertical emittance [pm]	6.15
Natural bunch length [mm]	5.00
Natural energy spread [10^{-4}]	6.68
Bunches per train	978
Particles per bunch	5.5 x 10^{10}
Bunch spacing [ns]	4

Simulation of FII (4)





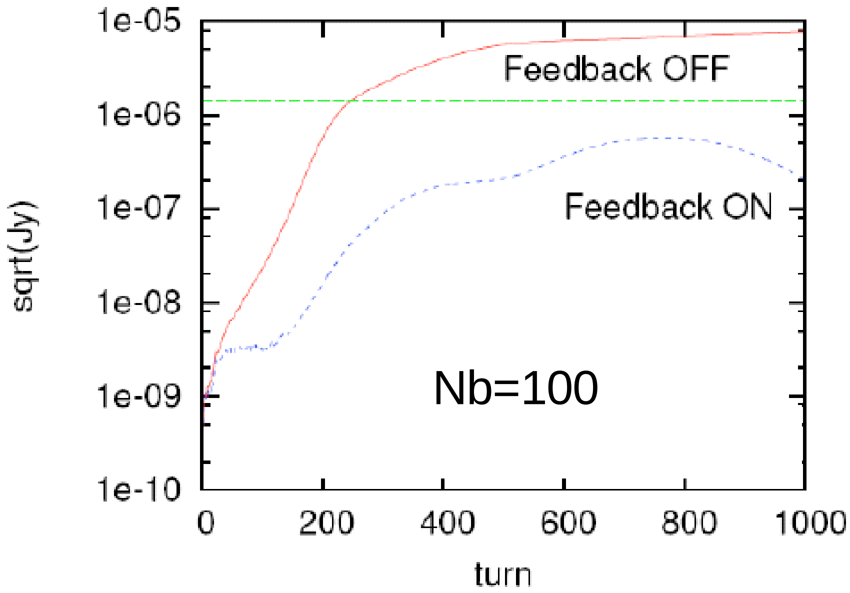


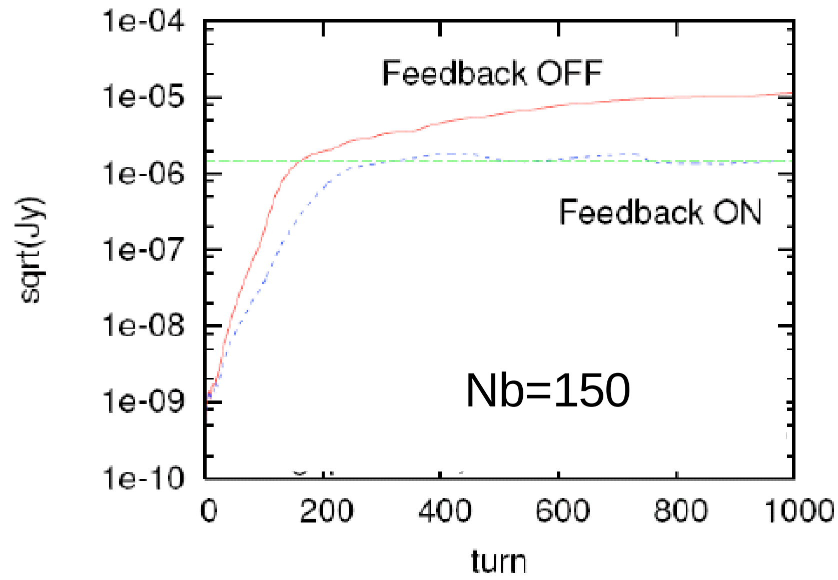
Ntrain=5

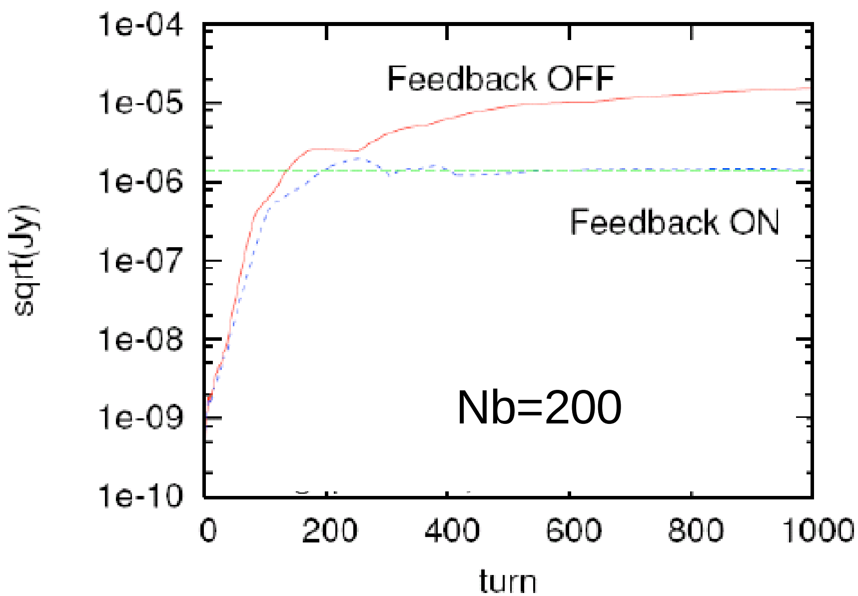
Nb=50

Lsep=4ns

Simulation of FII (5)







Ntrain=2

Lgap=40ns

Lsep=4ns

Fast Ion Instability Summary

- Fast Ion Instability has been simulated for SuperB updated parameters using Ohmi san code iontr
- Preliminary results show that:
  - Beam oscillations are suppressed by the feedback system for *Lgap* ≥ *40 ns*, while considerable residual oscillation remains for *Lgap* ≤ *20 ns*.
  - With Lgap= 40 ns, the instability is suppressed by the feedback system for Nb = 100, but it is not suppressed for longer trains, *Nb* ≥ *150*.