# Simulation of Fast Beam-Ion Instability in ILC Damping Rings

Javier Cerrillo Moreno
Supervisor: Guoxing Xia
FLC Group
18/09/2006

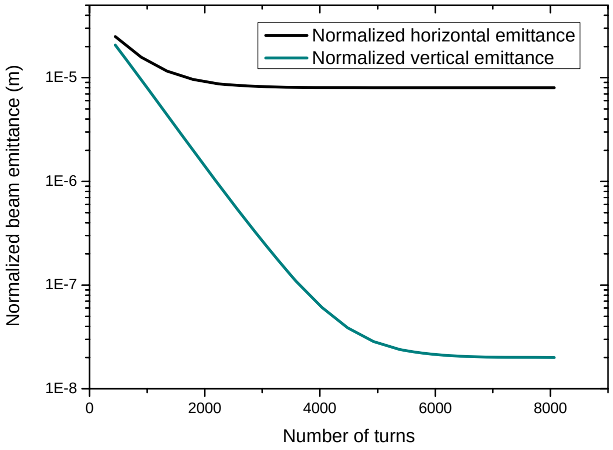
# Introduction (I)

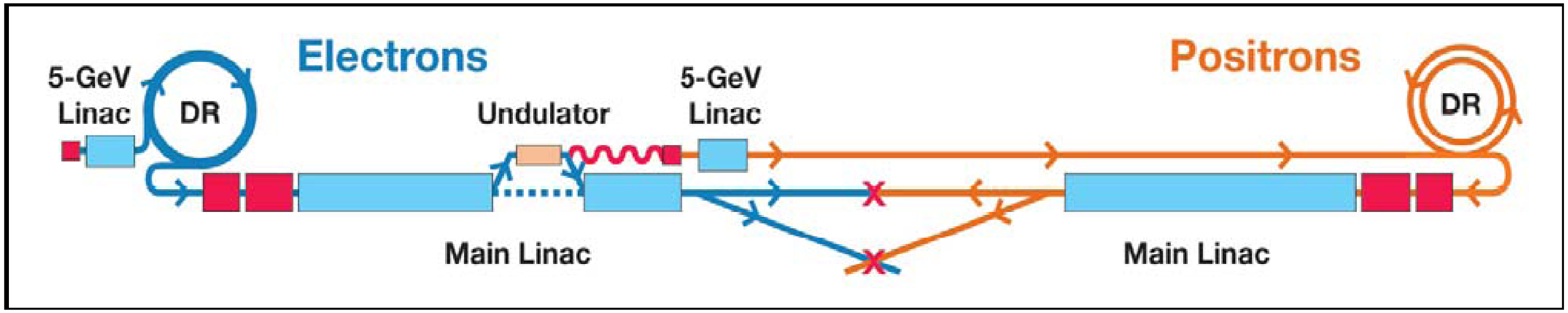
- The next electron positron linear collider needs electron beams of an extremely low vertical emittance to achieve high luminosity


$$L \propto \frac{1}{\sigma_x \sigma_y} \qquad \sigma_{x,y} \propto \sqrt{\varepsilon_{x,y}} \qquad \varepsilon_y \approx 20nm$$

# Introduction (II)

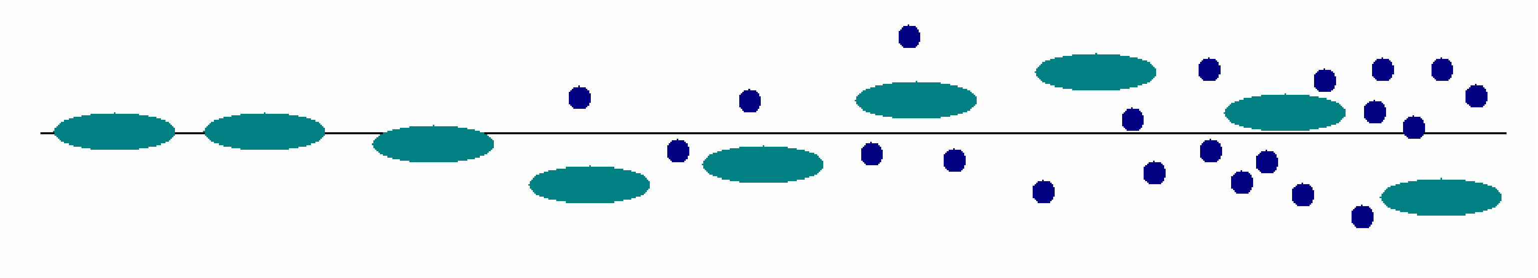
- The damping ring assures these values
- Any effect leading to instabilities in the damping ring must therefore be thoroughly studied



# Which instabilities?

- The residual gas in the vacuum chambers can be ionized by the passage of an electron bunch
- These ions can disturb the motion of the successive bunches by means of the Coulomb interaction and appear under the form of undesired oscillations

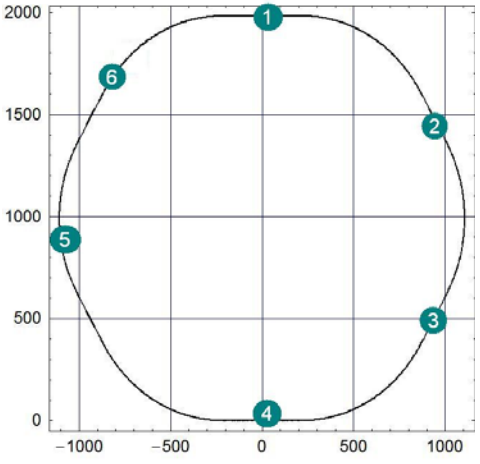


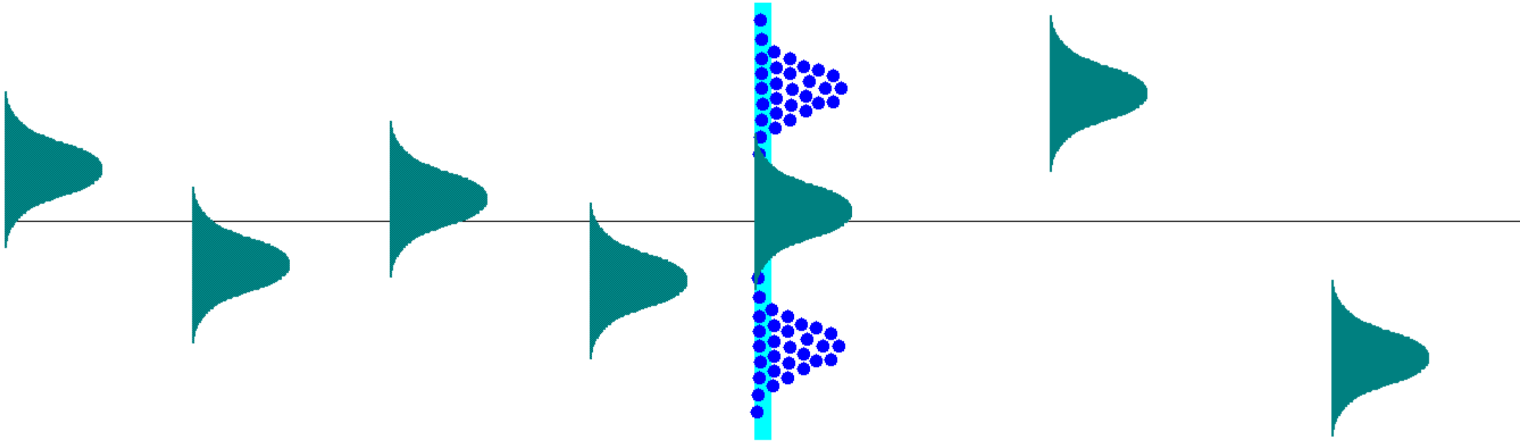
# Trapped Ion and FBII

- Ions can be trapped by the bunch itself or can be cleared out immediately after the passage of the beam bunch
- A gap between bunch trains can clear up trapped ions. Fast Beam-Ion Instability (FBII), though, still has a role within a single beam.
- In low emittance and high intensity rings, such as ILC damping ring, the growth rate of the instability is potentially high.

# Simulation model (I)

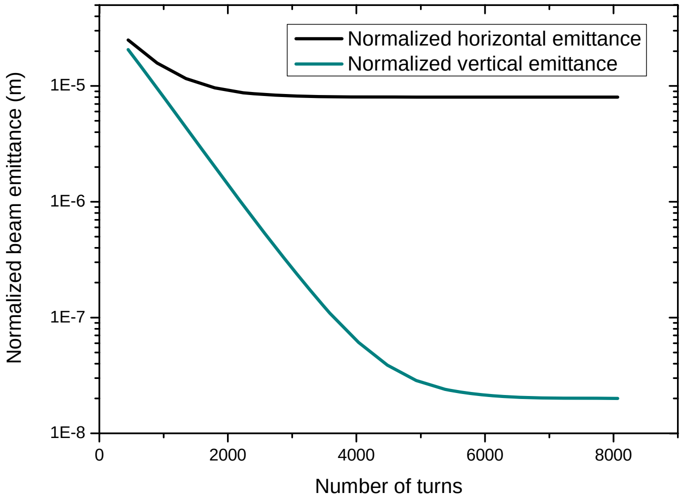
- *Strong-strong* or *weak strong*?
- Weak-strong model (rigid Gaussian-like bunches and ion macroparticles)
- No longitudinal structure
- Only barycentre transverse motion is considered
- 6 Ionization points



# Simulation model (II)

- Horizontal emittance is much larger than vertical emittance → Only vertical instability is studied
- 4000 turns have to be tracked
- First bunch slightly displaced from ideal orbit




| | |
|---|---|
| Circumference [m] | 6695.057 |
| Energy [GeV] | 5.0 |
| Harmonic number | 14516 |
| Arc cell type | TME |
| Transverse damping time [ms] | 25.7 |
| Natural emittance [nm] | 0.515 |
| Norm. natural emittance [µm] | 5.04 |
| Horizontal initial emittance [nm] | 4.599 |
| Vertical initial emittance [nm] | 4.599 |
| Horizontal equilibrium emittance [nm] | 0.8176 |
| Vertical equilibrium emittance [pm] | 2.044 |
| Natural bunch length [mm] | 6.00 |
| Natural energy spread [$10^{-3}$] | 1.28 |
| Average current [mA] | 402 |
| Mean horizontal beta function [m] | 13.1 |
| Mean vertical beta function [m] | 12.5 |
| Bunches per train | 2820 |
| Particles per bunch | $2 \times 10^{10}$ |
| Bunch spacing [m] | 1.8 |

# Equations

- Kick:

$$\Delta v_{y,i} + i\Delta v_{x,i} = -2N_b r_e c \frac{m_e}{M_i} f(x_{ie}, y_{ie})$$

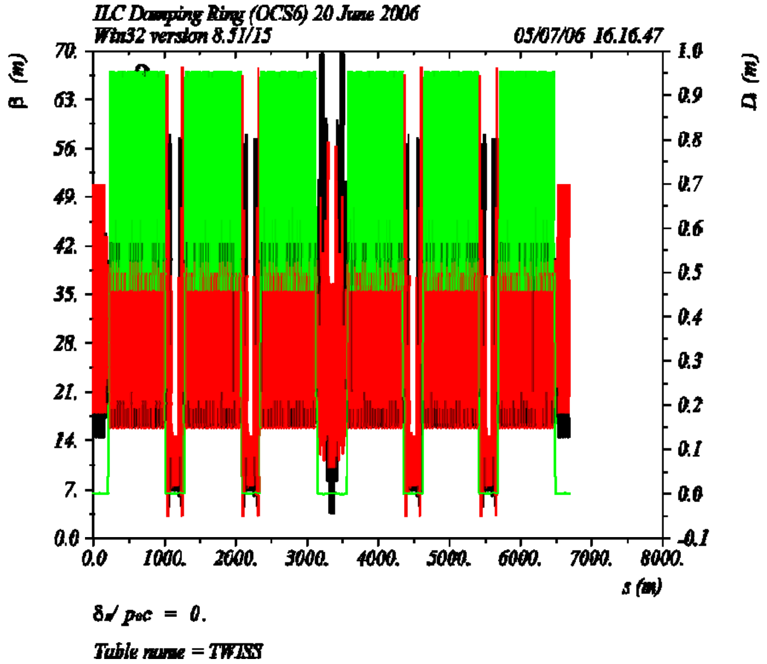
$$\Delta y' + i\Delta x' = \frac{2r_e}{\gamma} \sum_i N_i f(x_{ie}, y_{ie})$$

$$f(x,y) = -\sqrt{\frac{\pi}{2(\sigma_x^2 - \sigma_y^2)}} \left[ w\left( \frac{x+iy}{\sqrt{2(\sigma_x^2 - \sigma_y^2)}} \right) - \exp\left( -\frac{x^2}{2\sigma_x^2} - \frac{y^2}{2\sigma_y^2} \right) w\left( \frac{x\frac{\sigma_y}{\sigma_x} + iy\frac{\sigma_x}{\sigma_y}}{\sqrt{2(\sigma_x^2 - \sigma_y^2)}} \right) \right]$$

$$w(z) = \exp(-z^2)[1 - \mathrm{erf}(-iz)]$$

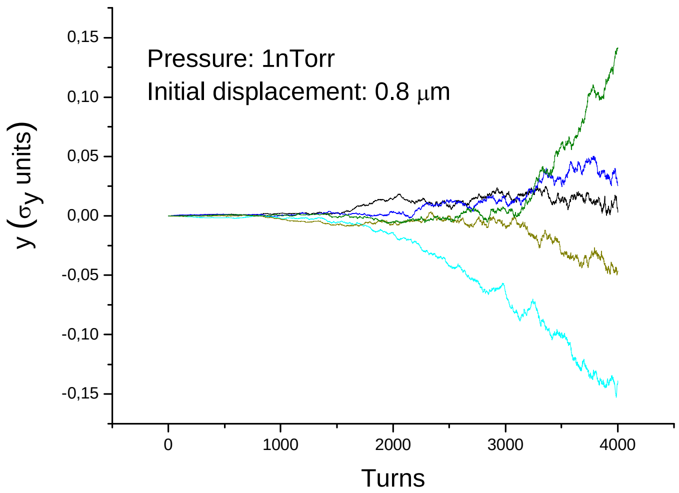
# Beam optics

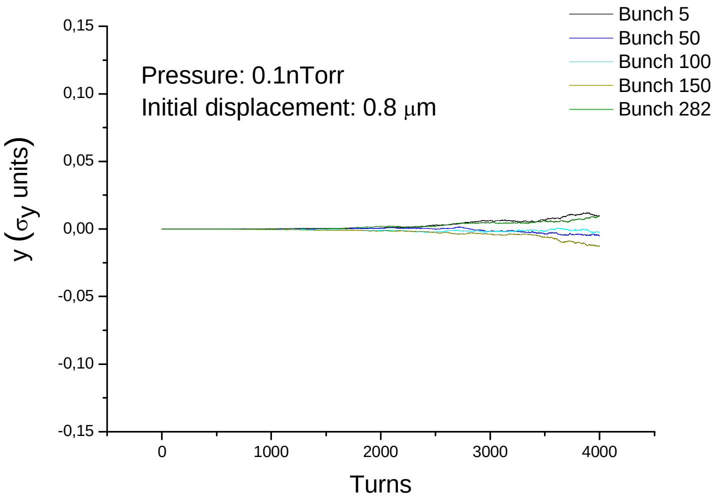
- Translation of the electron bunch between adjacent ionization points

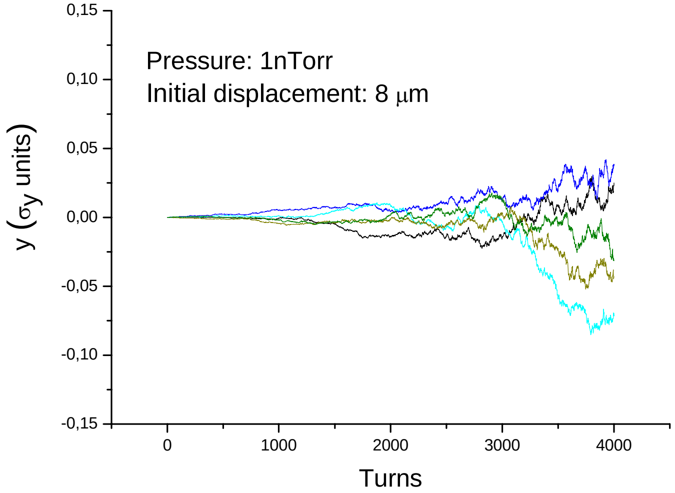


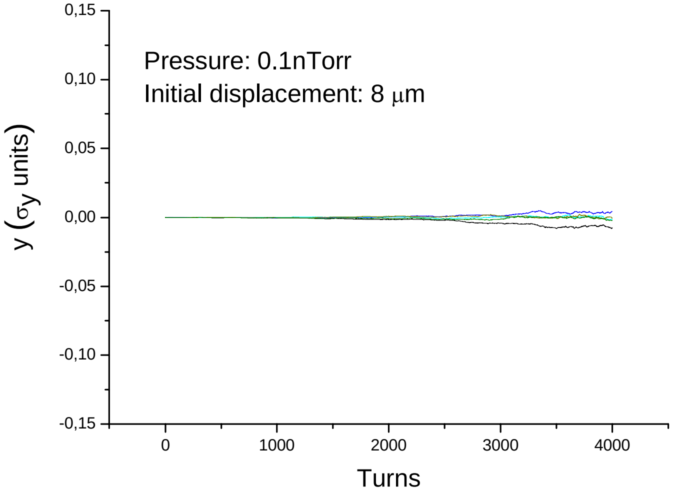

$$\begin{pmatrix} z_2 \\ z'_2 \end{pmatrix} = \begin{bmatrix} \sqrt{\frac{\beta_2}{\beta_1}}(\cos\psi + \alpha_1 \sin\psi) & \sqrt{\beta_2\beta_1}\sin\psi \\ \frac{\alpha_1 - \alpha_2}{\sqrt{\beta_2\beta_1}}\cos\psi - \frac{1+\alpha_1\alpha_2}{\sqrt{\beta_2\beta_1}}\sin\psi & \sqrt{\frac{\beta_1}{\beta_2}}(\cos\psi + \alpha_2 \sin\psi) \end{bmatrix} \begin{pmatrix} z_1 \\ z'_1 \end{pmatrix}$$

# Simulation Results: Vertical Displacement



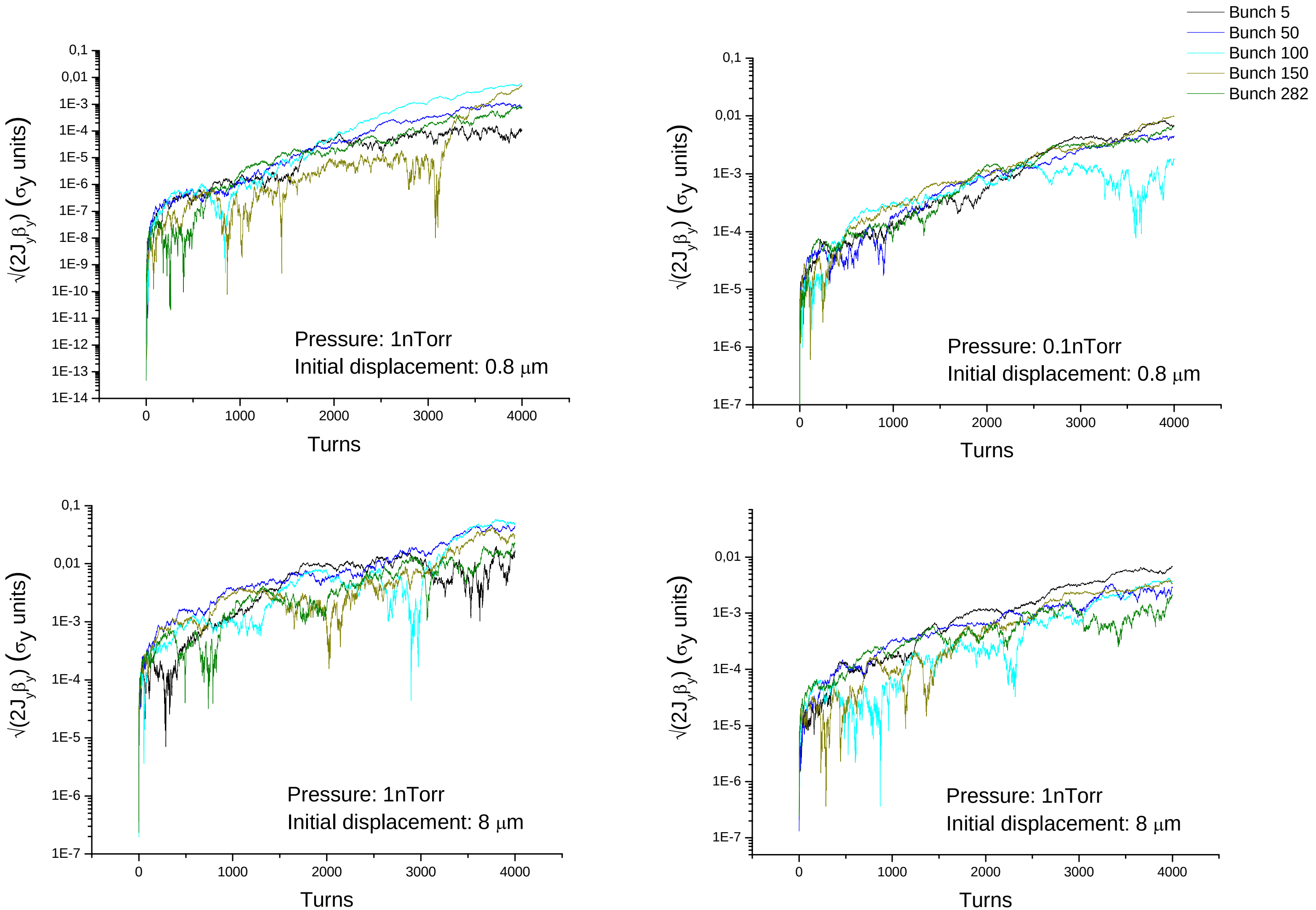



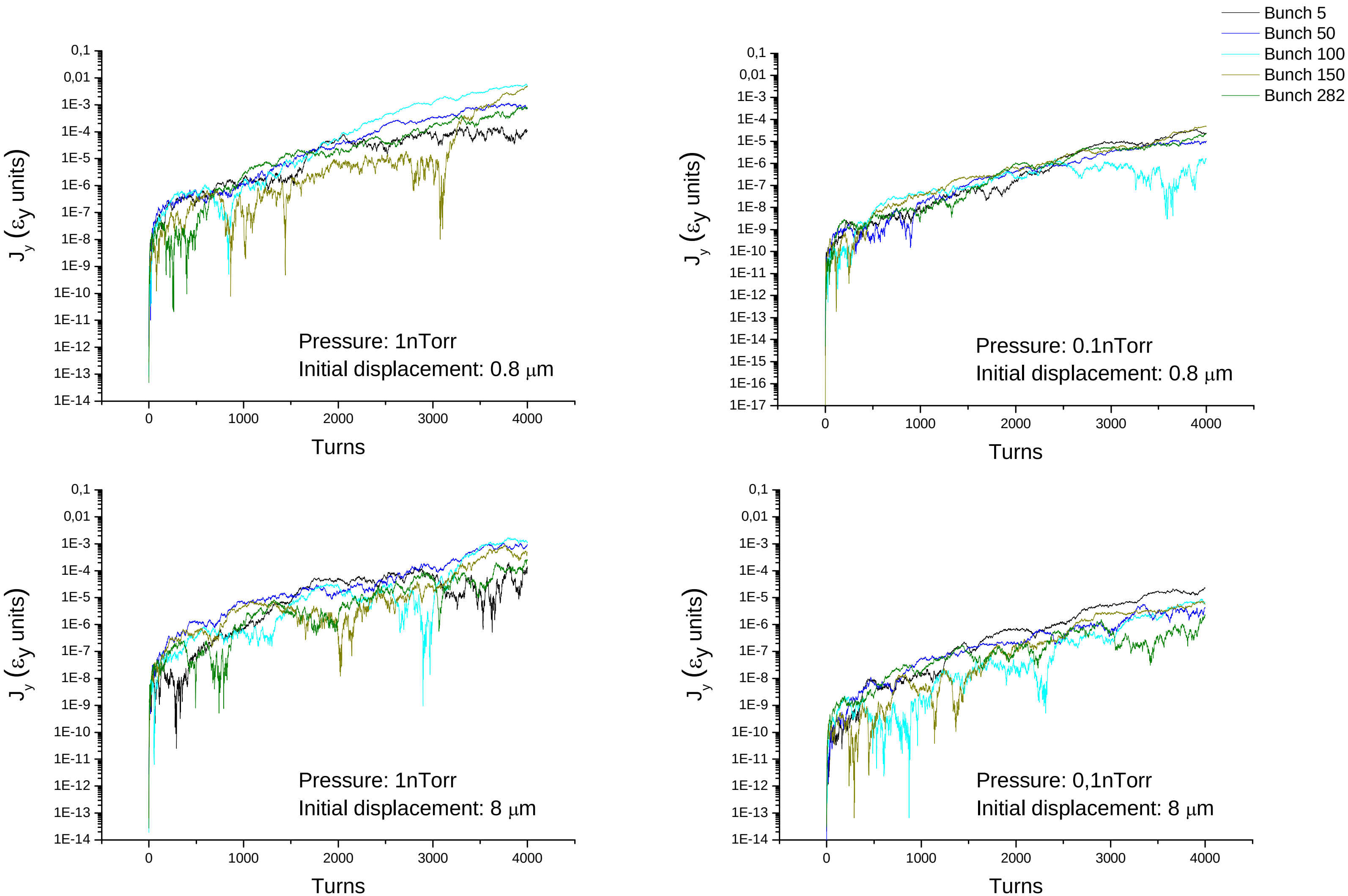
# Simulation Results: Oscillation Amplitude

$$J_y = \frac{1+\alpha^2}{\beta} y^2 + 2\alpha y y' + \beta (y')^2$$



# Simulation Results: Vertical Action

$$J_y = \frac{1+\alpha^2}{\beta} y^2 + 2\alpha y y' + \beta (y')^2$$



# Conclusions and Summary

- FBII: potential limitation for ILC DR performance
- Instability decreases at 0.1 nTorr
- Not serious FBII in any of the studied cases
- Other results predict high FBII at 1nTorr
- Further discussion