# Ion Instability Issue in Electron Rings

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# Brief History of Fast Beam-Ion Instability (FBII)

1. T. O. Raubenheimer and F. Zimmermann: Prediction of FBII by simulation. Theoretical treatment.

   Phys. Rev. E 52, 5487 (1995).

2. J. Byrd et al. : First observation of FBII at ALS.

   Phys. Rev. Lett. 79, 79 (1997).

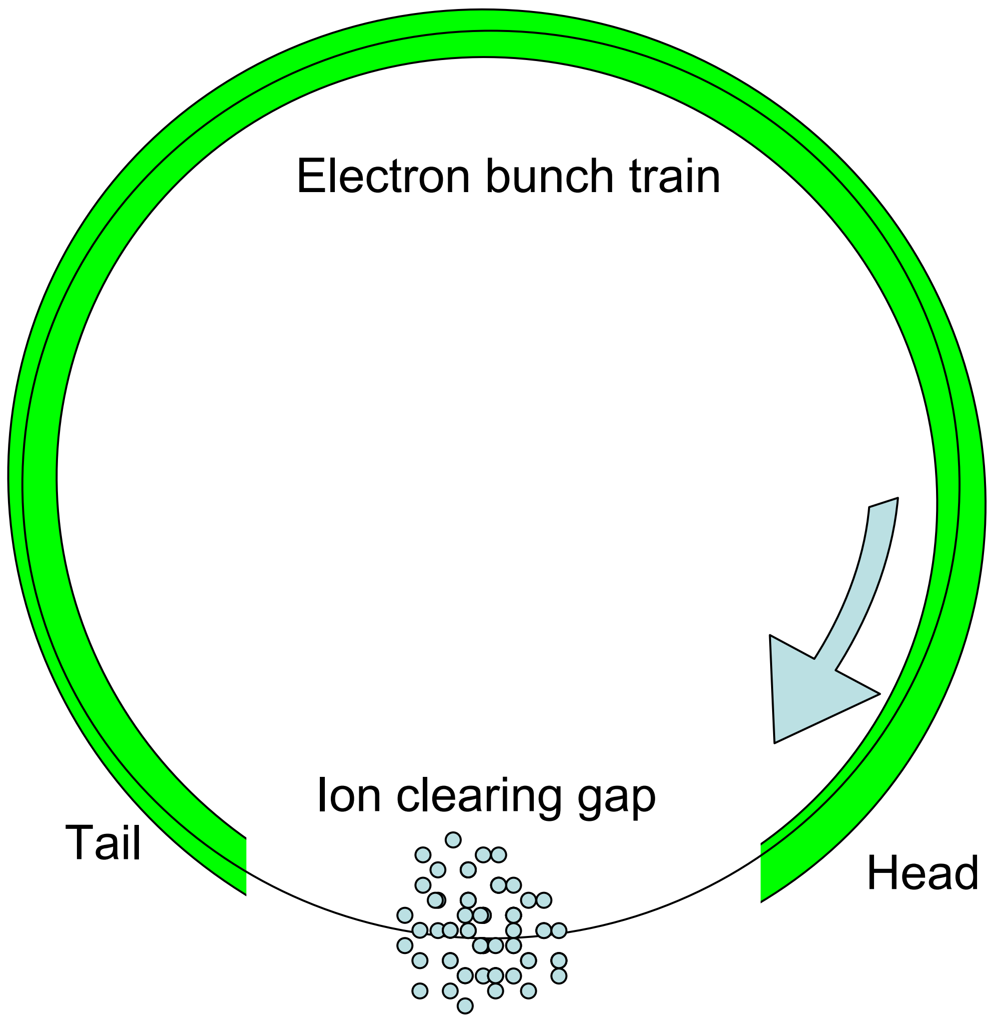
3. Observation of FBII at PLS: Streak camera images of FBII.

   Phys. Rev. E 55, 7550 (1997). Phys. Rev. Lett. 81, 4388 (1998). This experiment was prepared for the B-factory, which was under construction.

4. But it turned out that FBII was not harmful on B-factories. FBII was almost forgotten.

5. Interests in FBII has been revived because of the ILC damping ring.

# Fast Beam-Ion Instability




Ions are created by passing electrons and cleared after the final bunch.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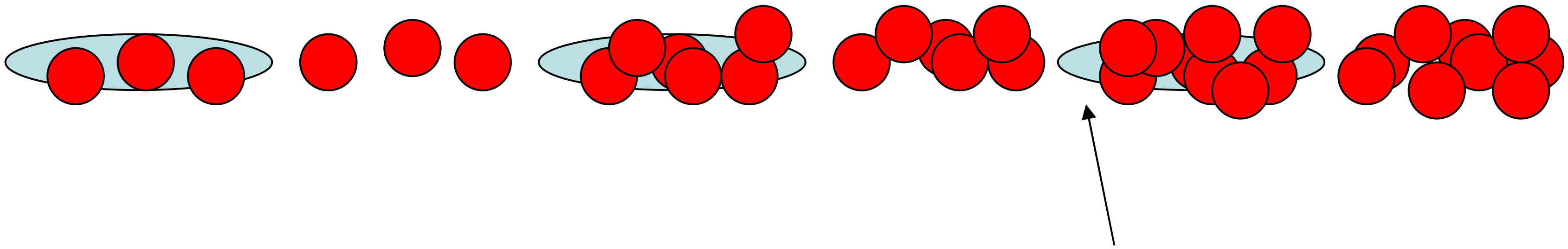
# Fast Beam-Ion Instability

The number of ions grow along the bunch train.



Attractive linear force between electron bunches and ions. It depends on beam sizes.

$$f \propto \frac{1}{\sigma_y(\sigma_x + \sigma_y)}$$

This is beam-beam interaction not an ion-an electron interaction.

Extremely low beam emittance may cause FBII.

1. Ions oscillate with given frequency due to the force.

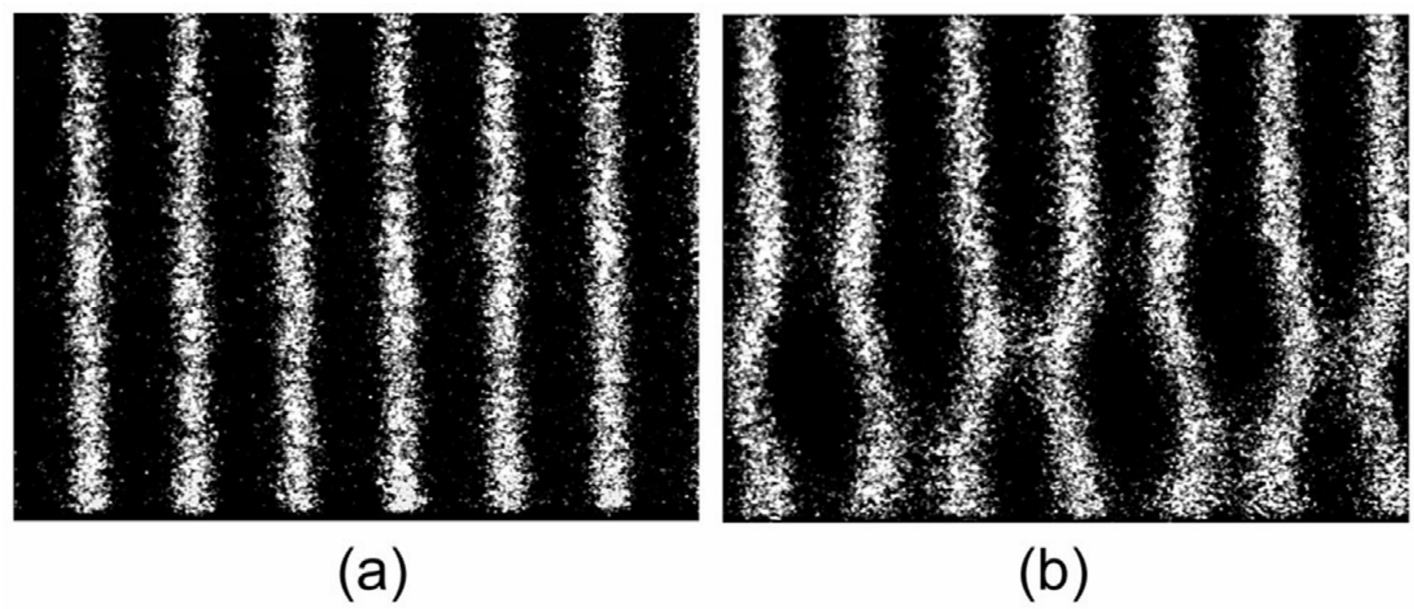
$$w_i = [\frac{N}{\sigma_y(\sigma_x + \sigma_y)A}]^{1/2}$$

2. Electrons, which execute betatron oscillations, show more complicated motion. But in the frame moving with electrons, bunch centroids oscillate with the ion frequency coherently.

3. The number of ions grows along the electron bunch train.

4. The oscillation amplitude grows along the bunch train.

# PLS Experiment in 1997




Normal vacuum pressure

0.16 nTorr

Ion pumps turned off

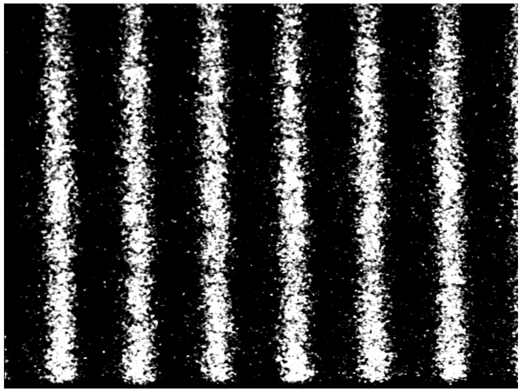
2.2 nTorr

Induced by CO-ions

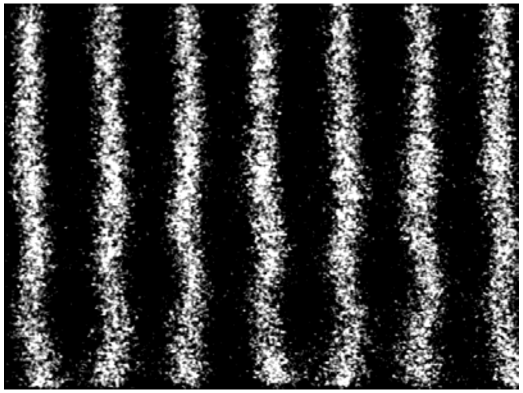
FBII has never been observed in existing rings of normal vacuum pressure.

# PLS Experiment in 1997

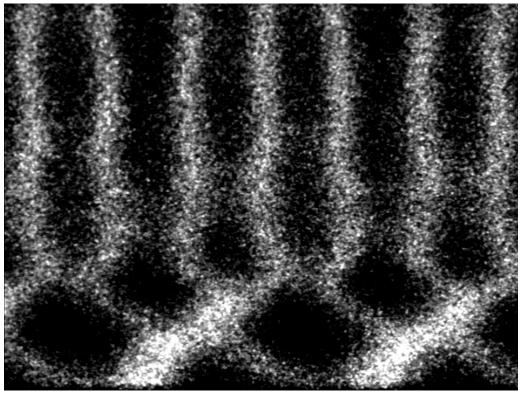
Instability was also excited by Helium gas injection in one place



Normal condition



0.2 nTorr Helium



3.34 nTorr Helium

Induced by He-ions

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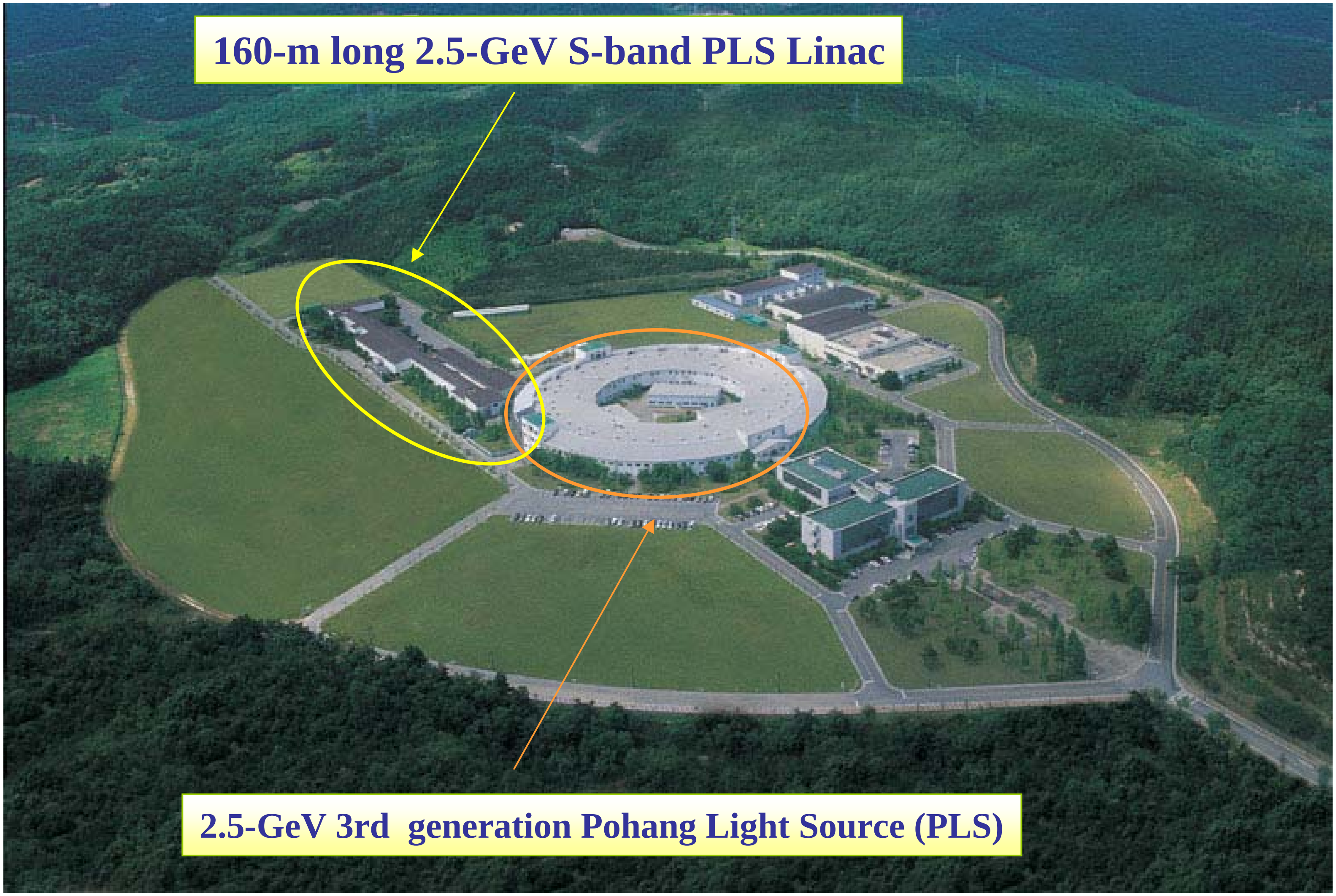
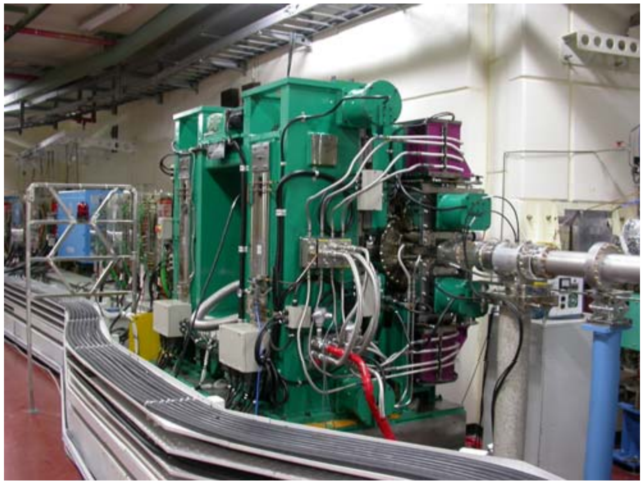


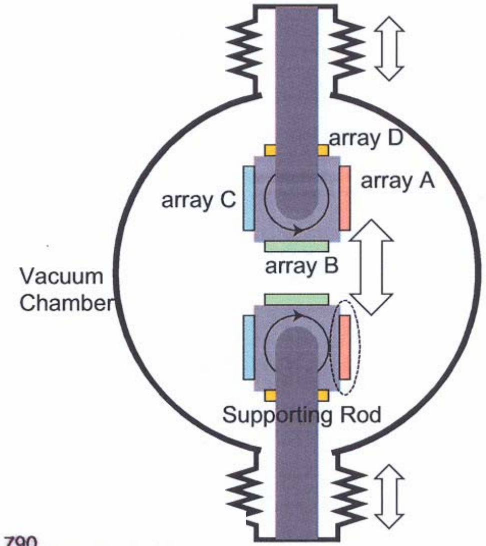
# New PLS Experiemnt (2005-2006)

## Motivation

1. PLS has a Revolver In-Vacuum X-ray UNdulator (RIVXUN). The minimum gap is 5 mm. The length is 1.2 m
2. If the beam orbit is distorted when the RIVXUN gap is lowered, the vacuum pressure of the undulator area is increased up to one order of magnitude higher. (Undulator SR hits internal structure).
3. It is possible to control the local pressure step by step.
4. Good for an FBII experiment.

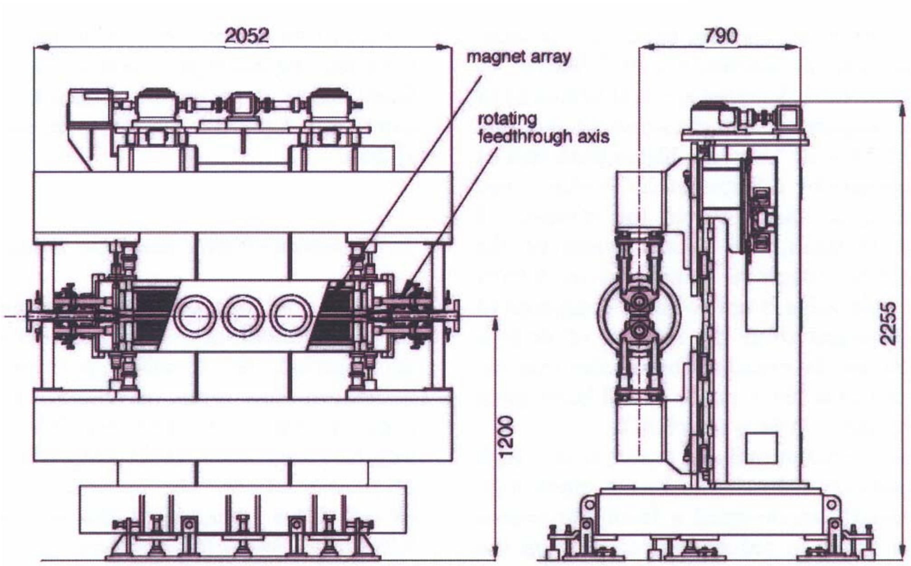
# RIVXUN: Revolver In-Vacuum X-ray UNdulator






Permanent magnet structure is a revolving type with four arrays, which provides 4 different undulator periods of 10, 15, 20, and 24 mm.

| Array | Undulator Period [mm] | Number of period |
|---|---|---|
| C, c | 10 | 101 |
| B, b | 15 | 67 |
| A, a | 20 | 50 |
| D, d | 24 | 42 |



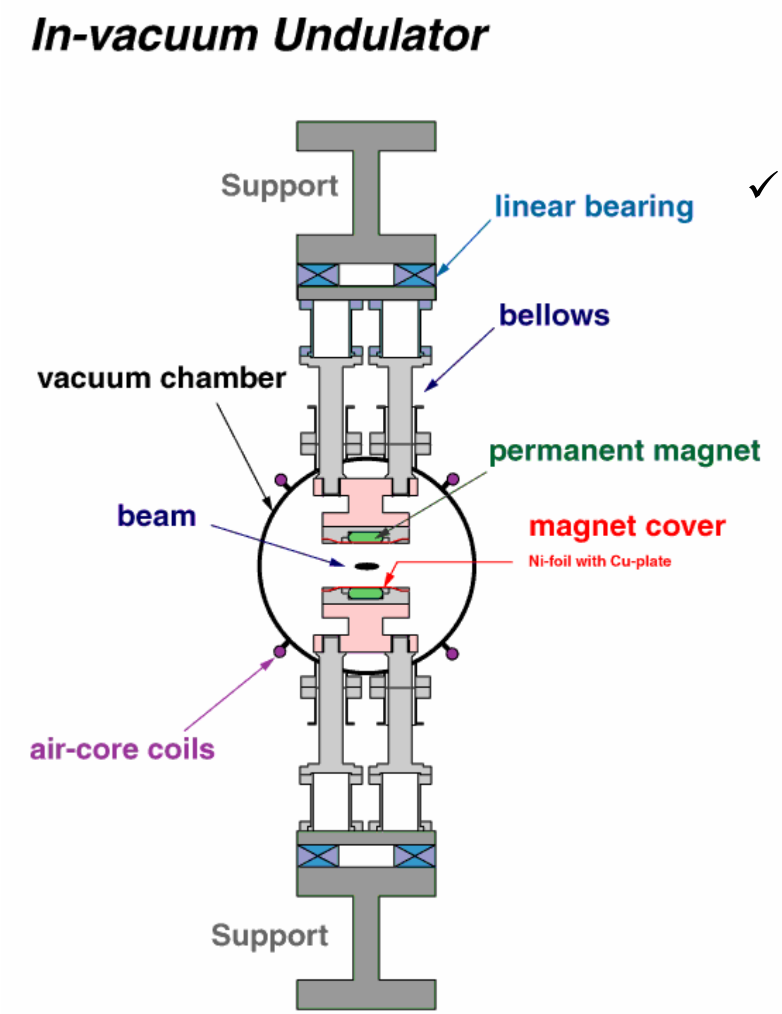

Undulator magnet length is 1.2 meter

***Magnet material*** **: Nd2Fe14B**

***designed at Spring-8***

**Kitamura et al. NIMA 467, 110 (2001)**

# Gas Desorption by Photons




- ✓ To reduce the resistive wall impedance, the permanent magnet array is covered with a **50 μm-thick Cu sheet coated with 50 μm-thick Ni**.
- ✓ The bakeout temperature for
  - the vacuum chamber: 200°C
  - the magnet arrays: 125°C

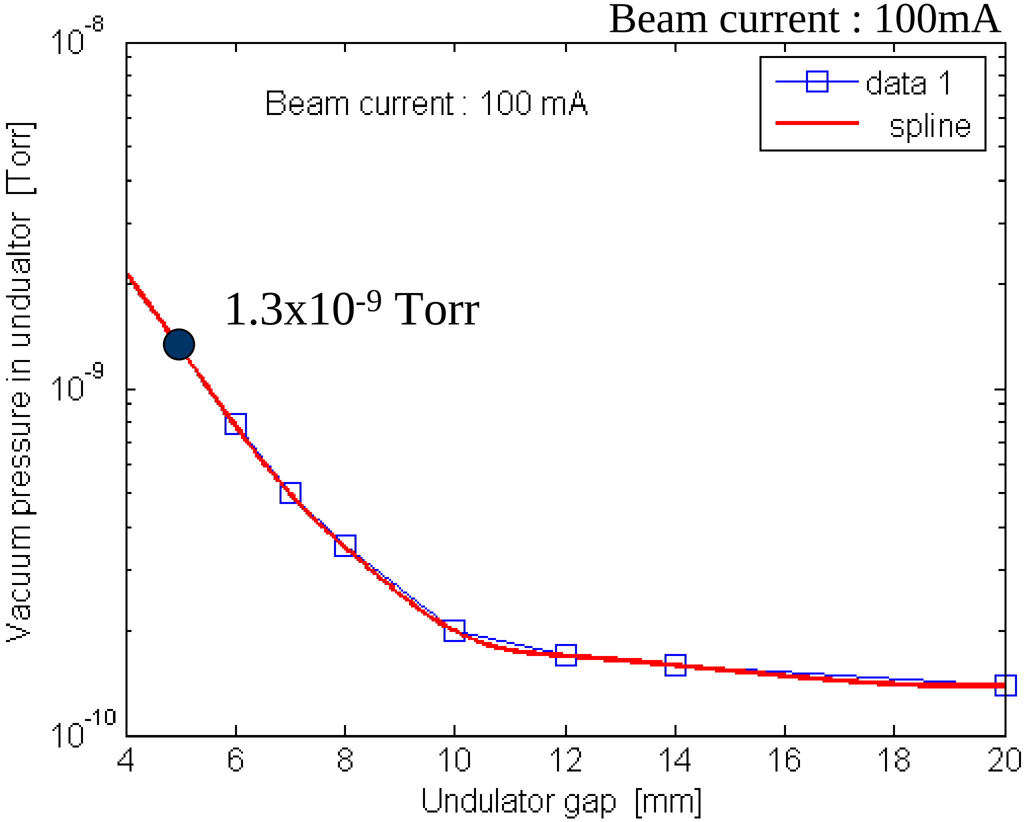
- ✓ Synchrotron radiation should be blocked by photon stops
- ✓ Gas desorption by stray photons
  - Photon desorption
  - Electron-stimulated desorption
- ✓ Pre-cleaning by stray photons: Aging process

| | Out-vacuum | In-vacuum |
|---|---|---|
| Aging by stray photons | Enough : Continuous | Not enough: Intermittent |
| Gas desorption by photons | weak | strong |

# Ion Instability: Measured vacuum pressure in Revolver

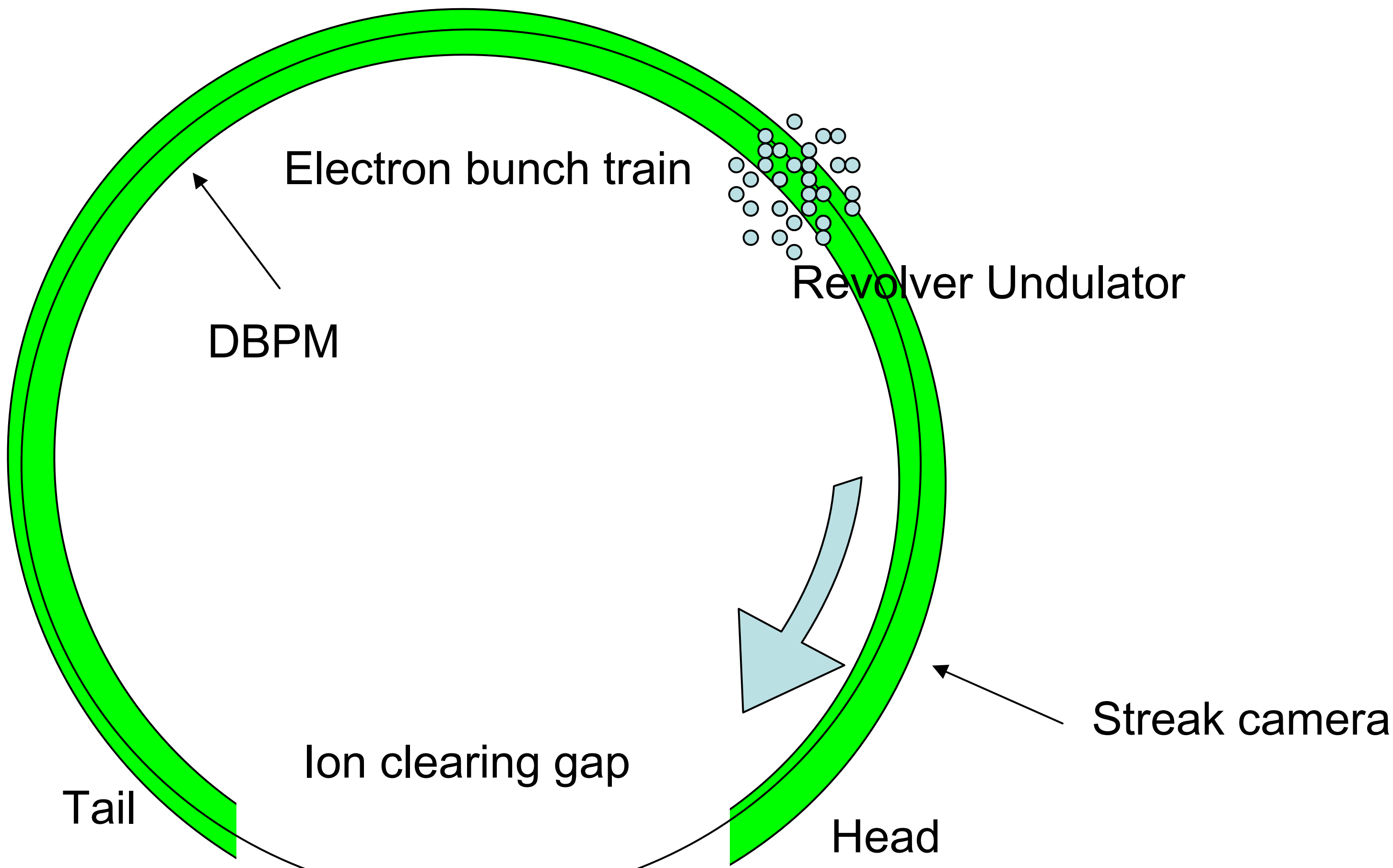
1. The Revolver vacuum pressure increased by 10 times when the gap was reduced from 20mm to 6mm.
2. **Even this local high vacuum pressure gives rise to FBII**

Beam current : 100mA




Average vacuum pressure in the ring:
$5.0 \times 10^{-10}$ Torr

# FBII Experiment in an In-aVacuum Undulator

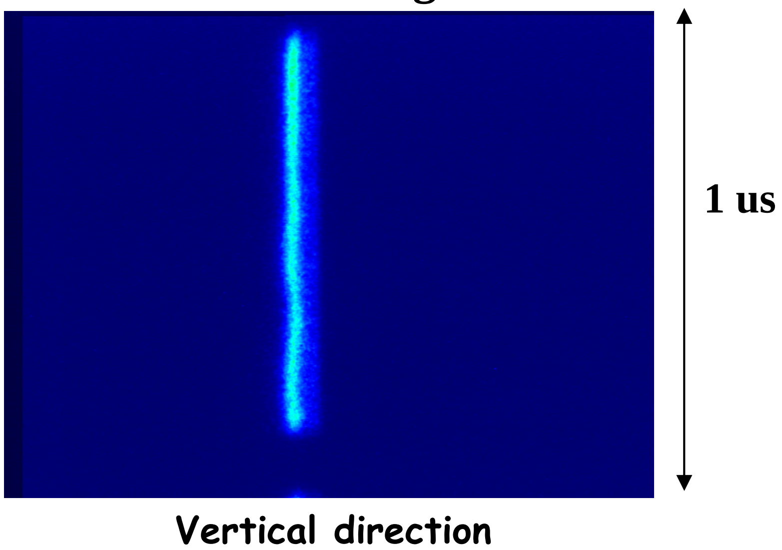



Shorter ion clearing gap is enough.

# FBII at 6.4 mm Undulator Gap

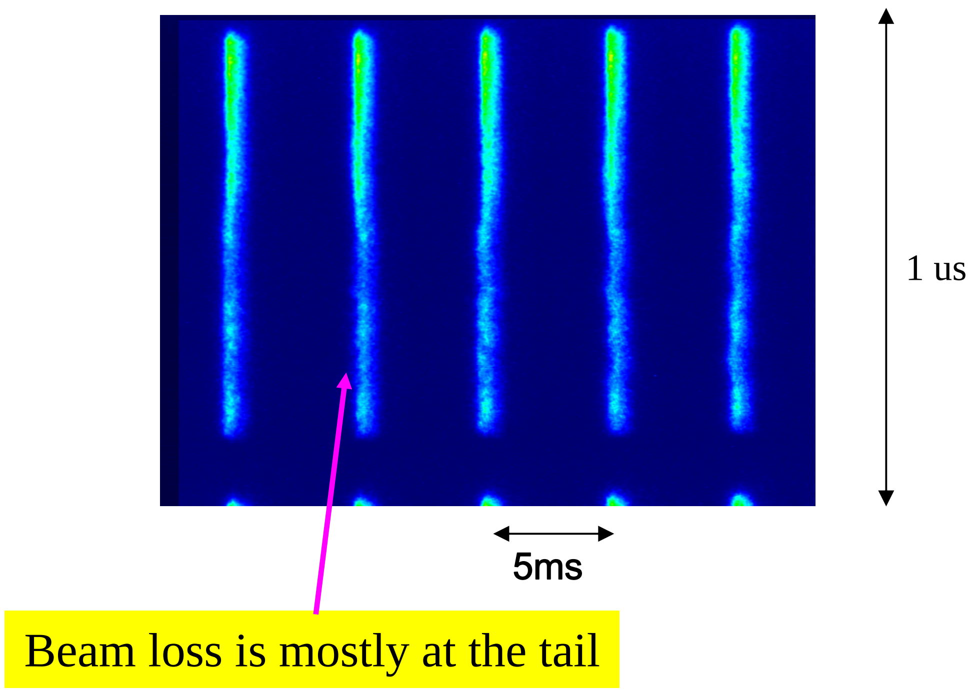
1. Streak camera IMAGES shows FBII: the tail part of a long bunch train oscillates vertically.

2. There was no appreciable difference at the different fill patterns, because of localized ions.



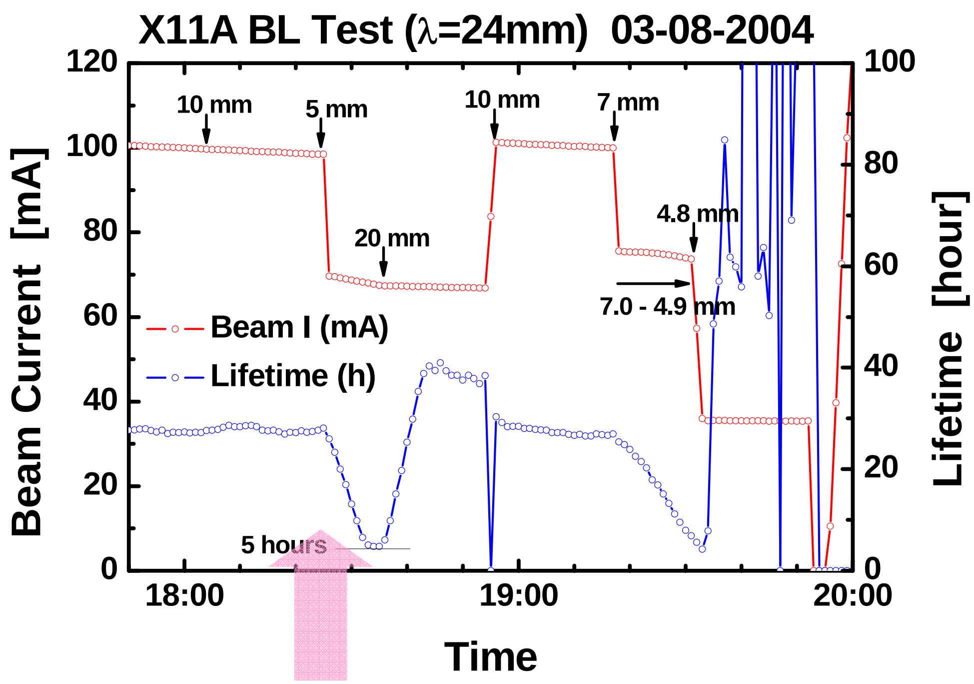

**The tail part of the bunch train is oscillating vertically.**

# FBII at 5mm Undulator gap



# Ion Instability during the revolver gap change

1. Above gap 7mm, no instability and no lifetime change
2. Below gap 6.4mm, transverse ion instability appeared and then beam loss occurred.

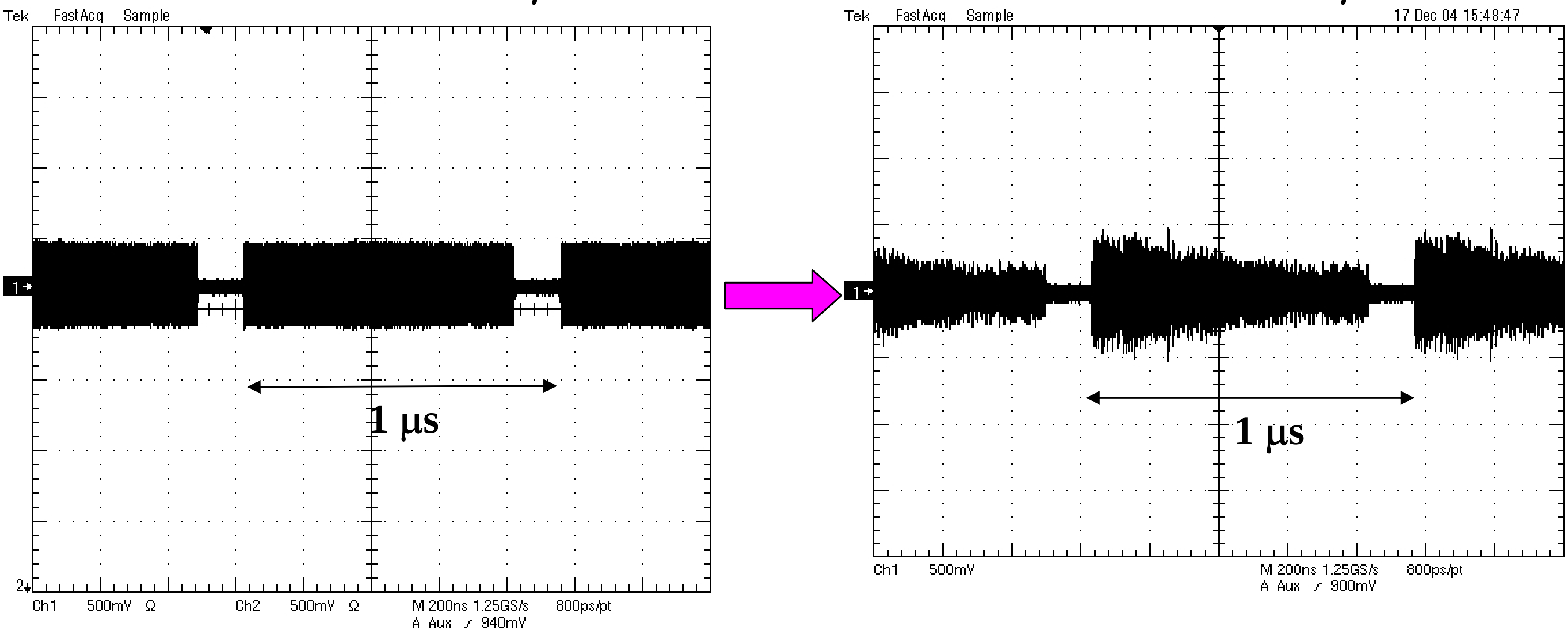



**Beam loss occurred as well as lifetime decreased rapidly**
**~ 5 Hours Electron Beam Lifetime @ 5 mm Undulator Gap !**

# Ion Instability: **Bunch Current**

Before the instability

After the ion instability

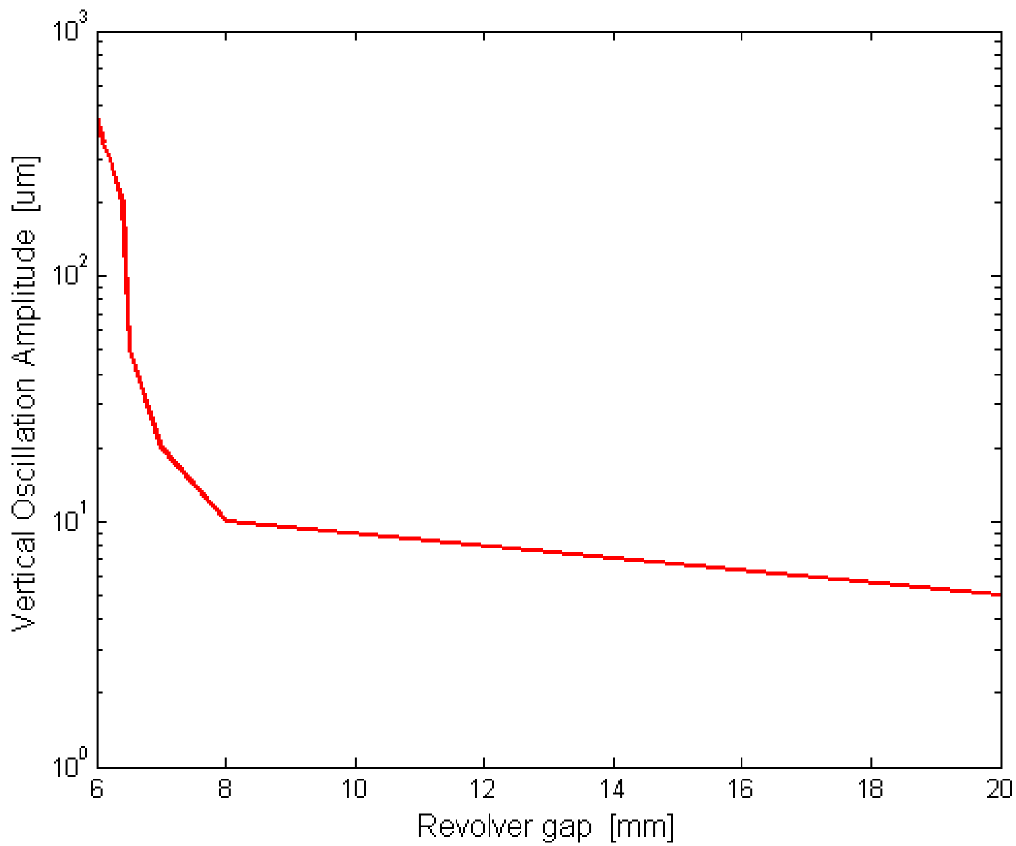



- ✓ The bunch current of long bunch train was scraped off to a triangular shape.
- ✓ The physical aperture of the storage ring reduced to the Revolver gap.

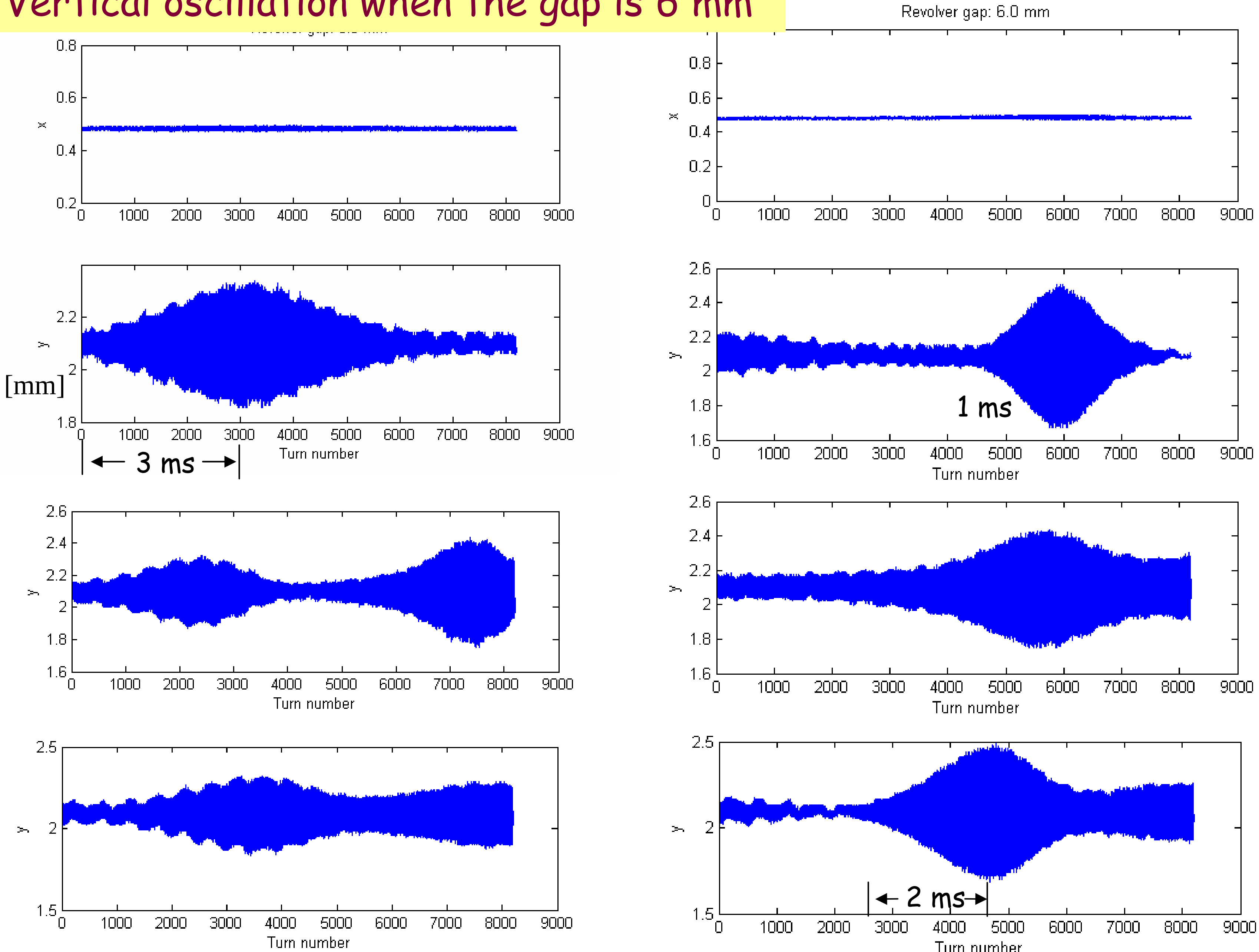
# Measurement of Beam Oscillation with turn by turn DBPM

[illegible]

400 um



# Vertical oscillation when the gap is 6 mm




Growth time of instability : 2 – 3 ms
Transverse damping time of PLS: 8 ms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# Summary of the New PLS Experiment

1. Elevation of the pressure only in a small part of the PLS ring (an in-vacuum undulator, approximately 1/200 of the ring) can cause FBII.
2. Streak camera image and DBPM data were obtained in low vacuum positions.
3. The measured oscillation amplitude was approximately 200 um.
4. The measured growth time was 2-3 msec in this set up.
5. If the pressure had been high all over the ring, crude scaling of the above growth time would have given around 10 usec.
6. The experiment demonstrates clearly the threshold (6.4 mm gap) above which FBII is excited.

# ILC Damping Ring

1. FBII is a potential danger to the ILC electron damping ring, because of the extremely small beam emittance and high bunch current.
2. The linear interaction on the n-th electron bunch and ions is given by

$$f(n) = K \frac{PNn}{\sigma_y(\sigma_x + \sigma_y)}$$

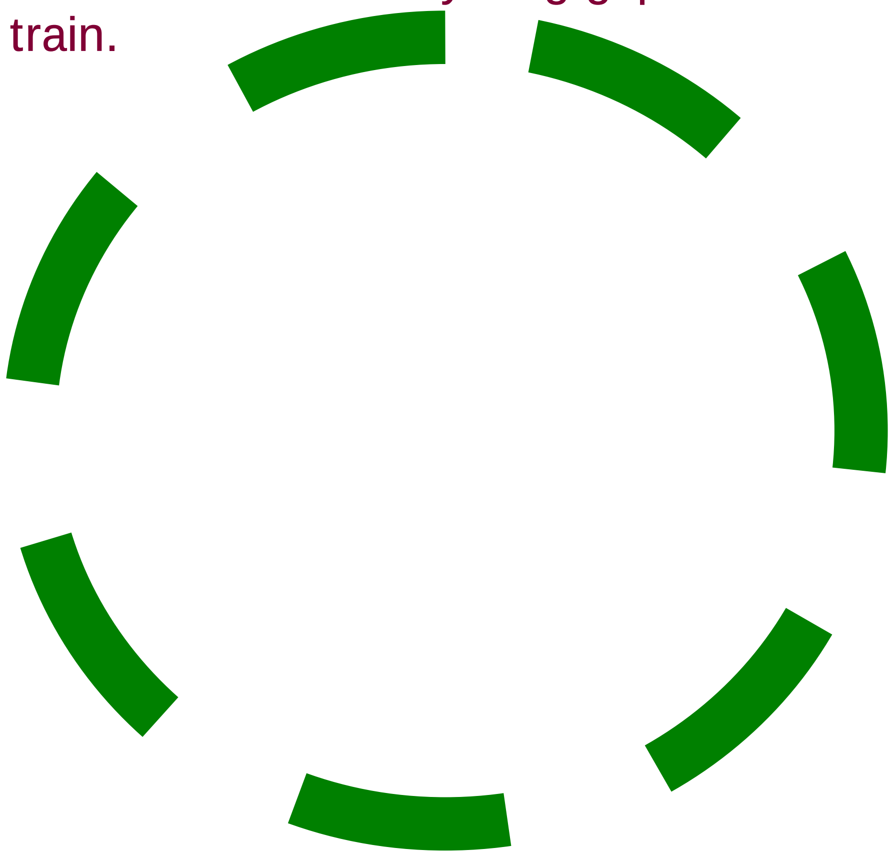
N: number of electrons in a bunch, P: vacuum pressure,

K: overall constant.

3. To suppress FBII, f(n) should be minimized. P should always be kept low. N should be kept high to give high luminosity.
4. The best parameter to choose is n, the number of bunch train. Note that n=1, ..., a few thousands, depending on the ring circumference.

# How To Suppress FBII

1. Reducing n is very effective in a large ring such as the ILC damping ring.
2. Hence, the current design of ILC damping ring considers many minitrains of electron bunches with sufficiently long gaps between them instead of a very long bunch train.



# Summary

1) FBII is such that it is not observed in any existing ring of normal operation condition. It has been observed only with deliberate vacuum pressure elevation.

2) The recent PLS experiment shows that FBII can be excited by high pressure localized only in a small area of a ring. This indicates that FBII is potentially more dangerous than previously thought.

3) An effective way to suppress FBII in a large ring is to use many minitrains of bunches with sufficient gaps between them instead of a long bunch train.

Thank You For Your Attention!