Fast Ion Experiments at ATF

Junji Urakawa (KEK)

for

ATF International Collaboration

Need very flat beam and high intensity multi-bunch beam.

ATF (Accelerator Test Facility)

Energy: 1.28 GeV
Electron bunch:
- ***2×10^{10} e/bunch***
- ***1 ~ 20 bunches/train***
- ***3 trains/ring***
- ***1.56 Hz***

$\varepsilon_{x/y}$ ~ 1.5nm/4pm

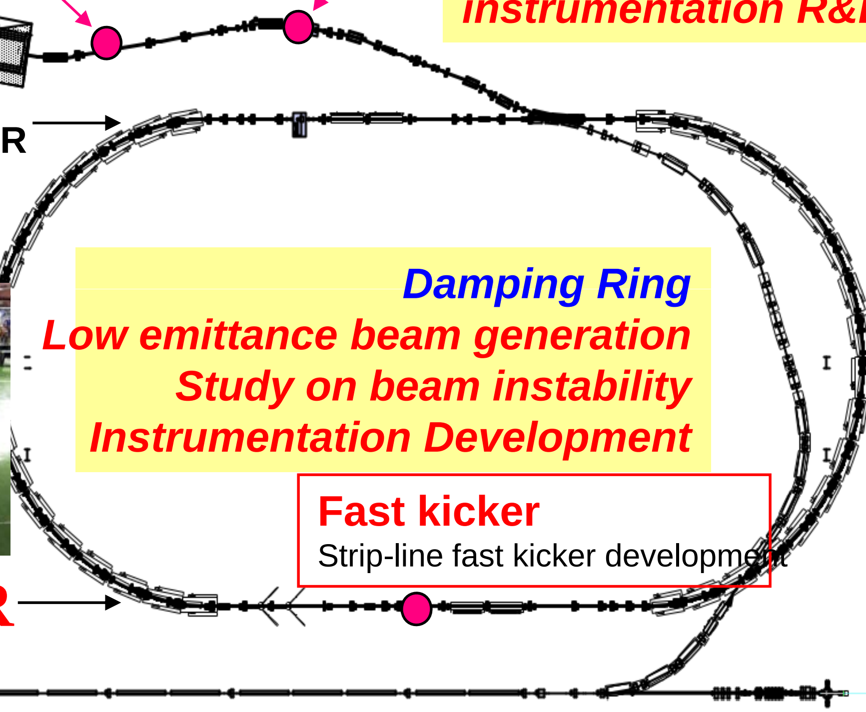
Cavity BPM
nm resolution
beam position monitor

Pulsed Laser Wire scanner
Beam size monitor

Extraction line
Beam supply for BDS Exp., instrumentation R&D

Damping Ring
Low emittance beam generation
Study on beam instability
Instrumentation Development

Fast kicker
Strip-line fast kicker development



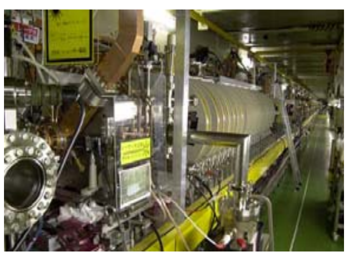
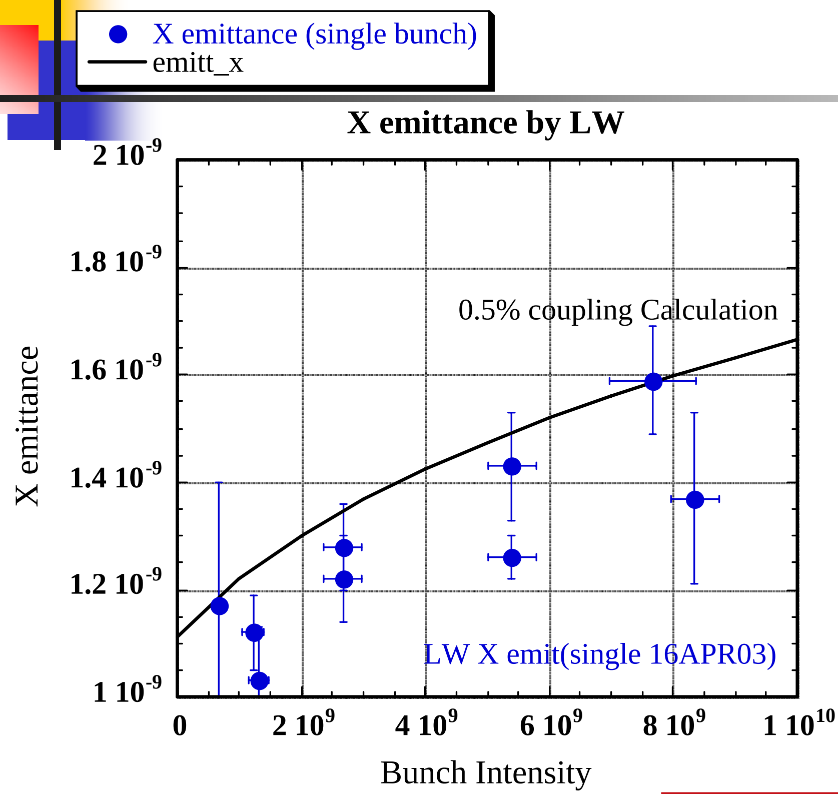
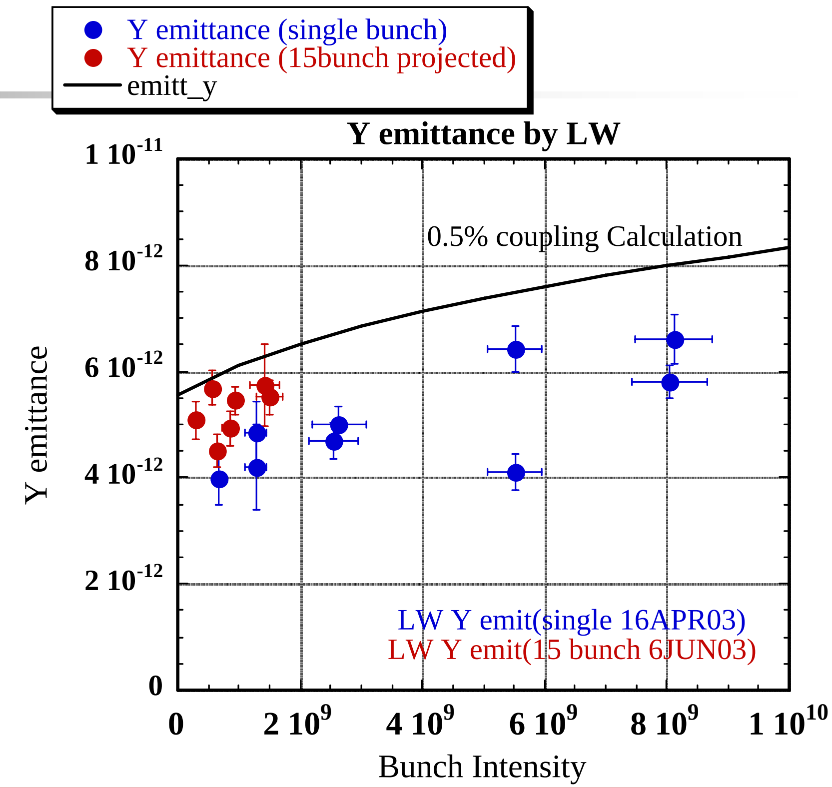


Photo-cathode RF gun

S-band Linac

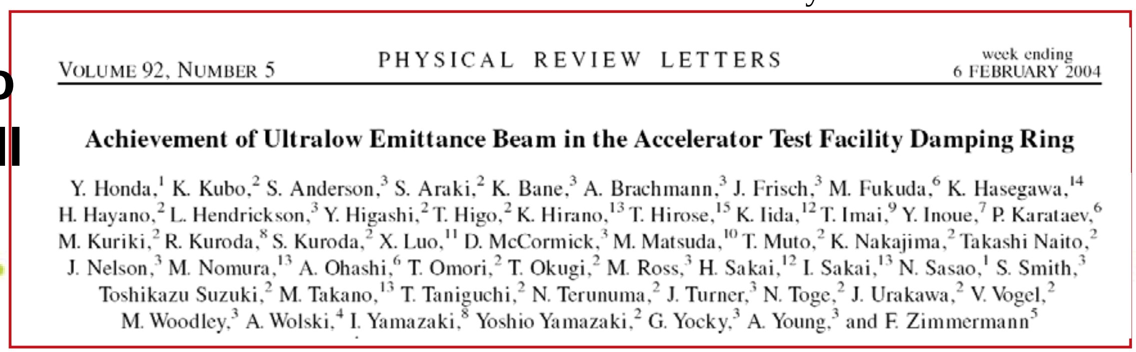
Emittance measured by CW Laser wire





< 0.5% y/x emittance ratio

Y emittance =4pm at small intensity

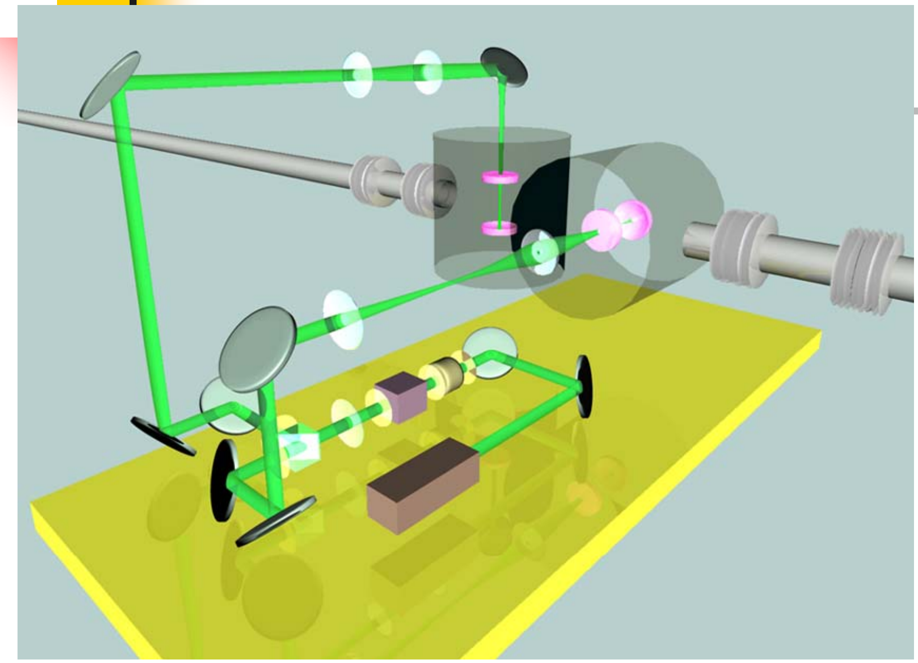


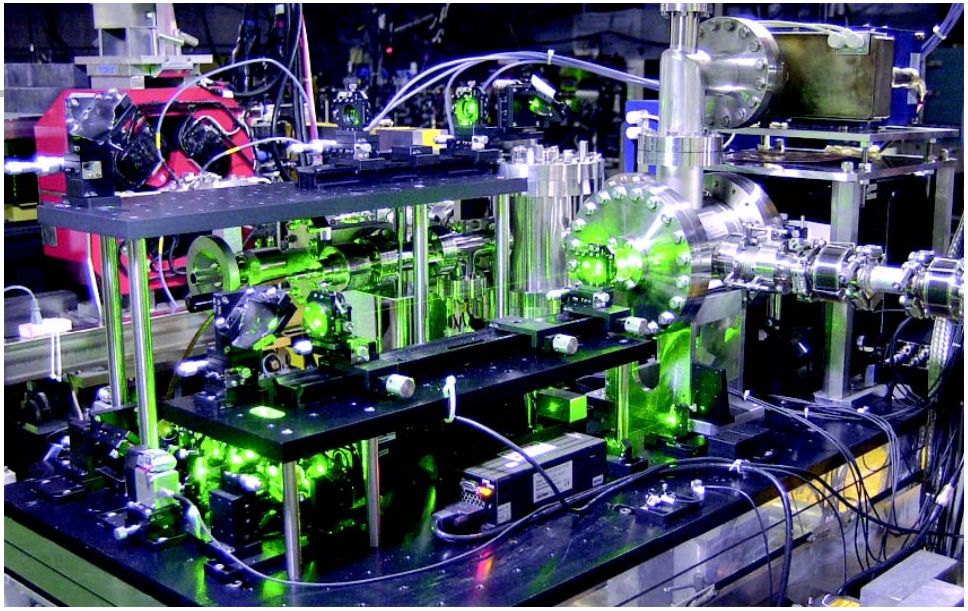
VOLUME 92, NUMBER 5 PHYSICAL REVIEW LETTERS week ending 6 FEBRUARY 2004

Achievement of Ultralow Emittance Beam in the Accelerator Test Facility Damping Ring

Y. Honda,[1] K. Kubo,[2] S. Anderson,[3] S. Araki,[2] K. Bane,[3] A. Brachmann,[3] J. Frisch,[3] M. Fukuda,[6] K. Hasegawa,[14] H. Hayano,[2] L. Hendrickson,[3] Y. Higashi,[2] T. Higo,[2] K. Hirano,[13] T. Hirose,[15] K. Iida,[12] T. Imai,[9] Y. Inoue,[7] P. Karataev,[6] M. Kuriki,[2] R. Kuroda,[8] S. Kuroda,[2] X. Luo,[11] D. McCormick,[3] M. Matsuda,[10] T. Muto,[2] K. Nakajima,[2] Takashi Naito,[2] J. Nelson,[3] M. Nomura,[13] A. Ohashi,[6] T. Omori,[2] T. Okugi,[2] M. Ross,[3] H. Sakai,[12] I. Sakai,[13] N. Sasao,[1] S. Smith,[3] Toshikazu Suzuki,[2] M. Takano,[13] T. Taniguchi,[2] N. Terunuma,[2] J. Turner,[3] N. Toge,[2] J. Urakawa,[2] V. Vogel,[2] M. Woodley,[3] A. Wolski,[4] I. Yamazaki,[8] Yoshio Yamazaki,[2] G. Yocky,[3] A. Young,[3] and F. Zimmermann[5]

Laser wire beam size monitor in DR





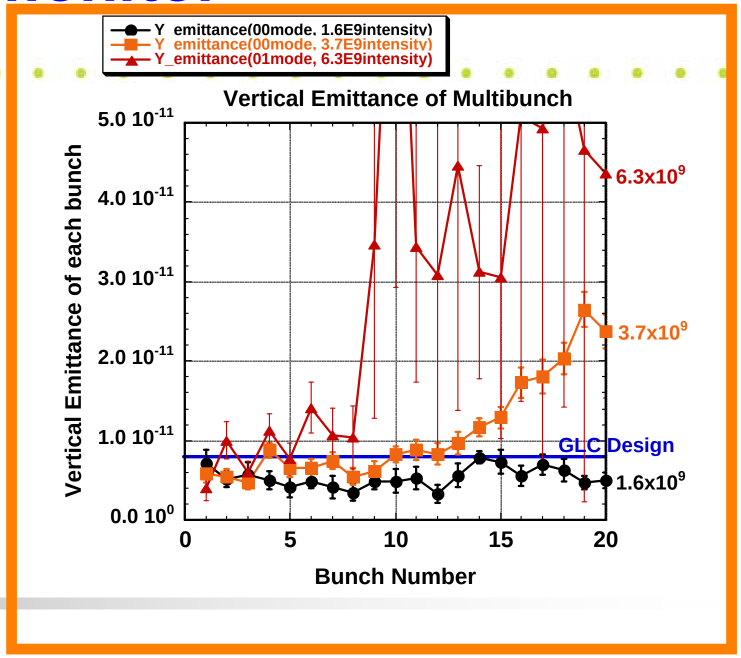
300mW 532nm Solid-state Laser fed into optical cavity

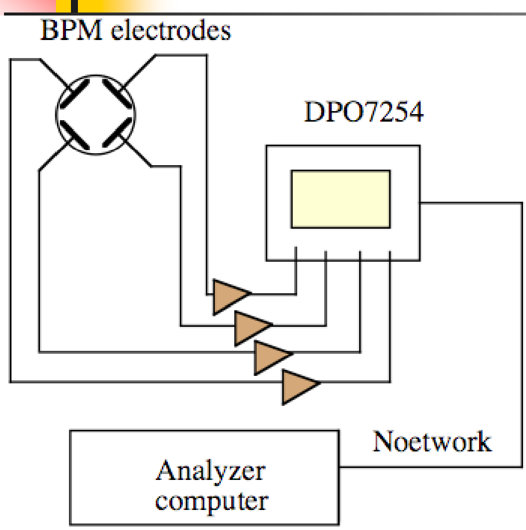
14.7μm laser wire for X scan
5.7μm for Y scan
(whole scan: 15min for X, 6min for Y)

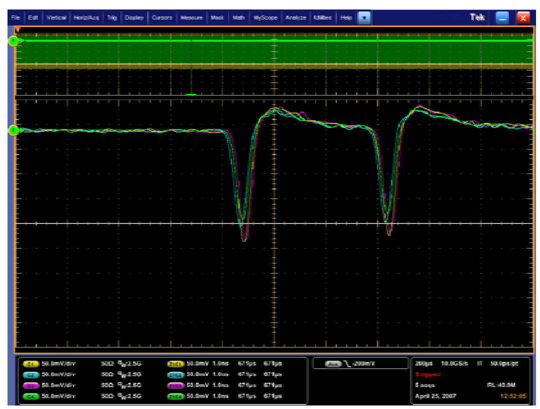
Multi-bunch Turn-by-turn monitor

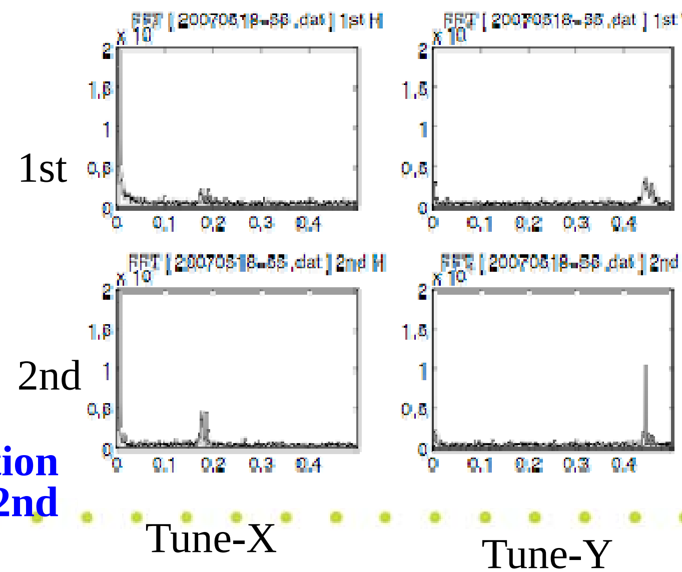
T. Naito (KEK)

The beam blowup at tail bunches was measured by the laser wire in ATF, which is assumed coming from FII effect. In order to observe the individual beam oscillation in the multi-bunch beam, multi-bunch turn-by-turn monitor has been developed. This monitor consists of front end circuits(amplifier and filter) and DPO7254 scope. The scope can store the waveform up to 2ms with 100ps time resolution.



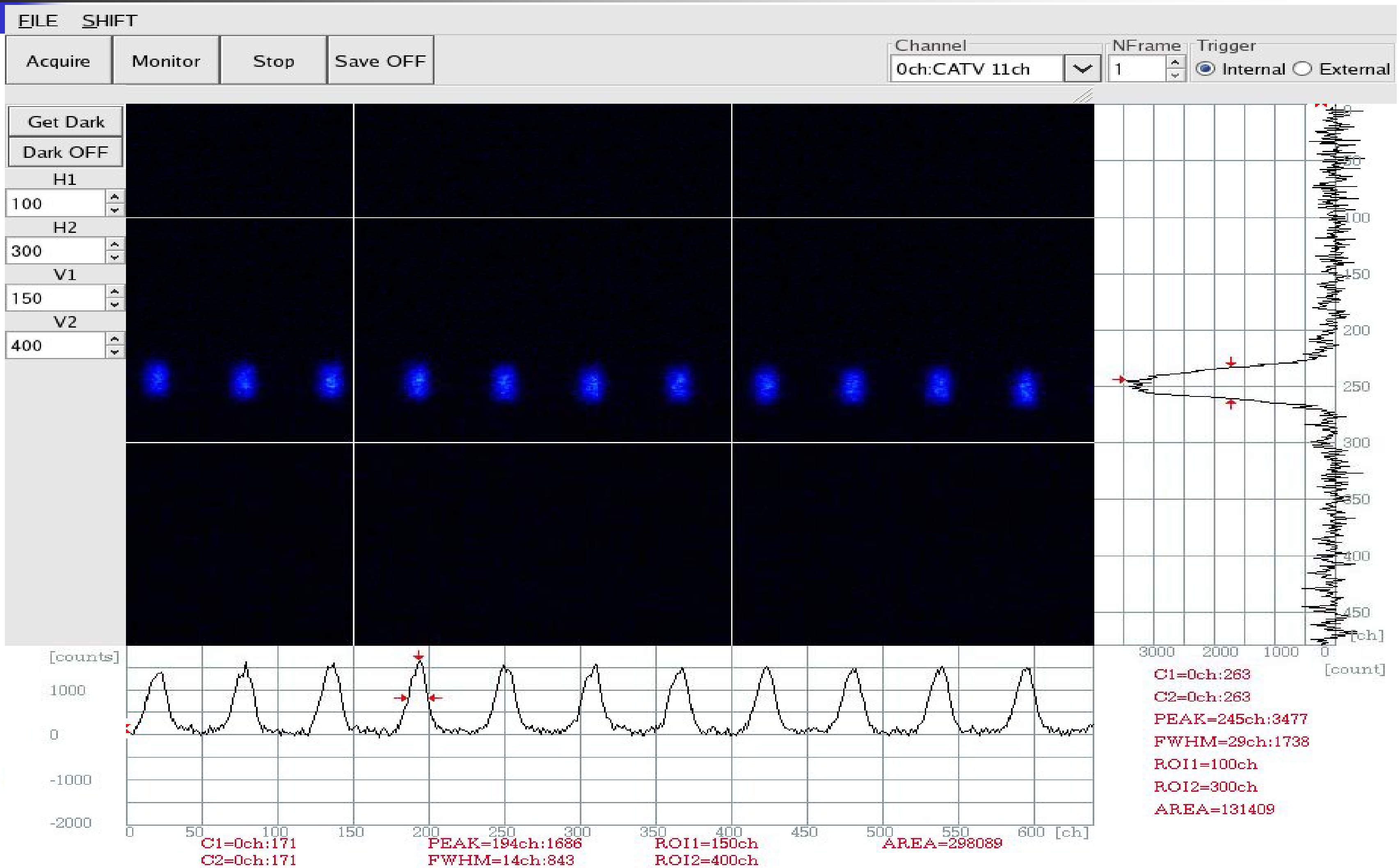






The preliminary results shows the different oscillation amplitude of the tune-X and the tune-Y for the 1st and 2nd bunches at just after injection.

Bunch Length Measurement (Synchronized Streak Camera)



Last few bunches show the oscillation in a train.

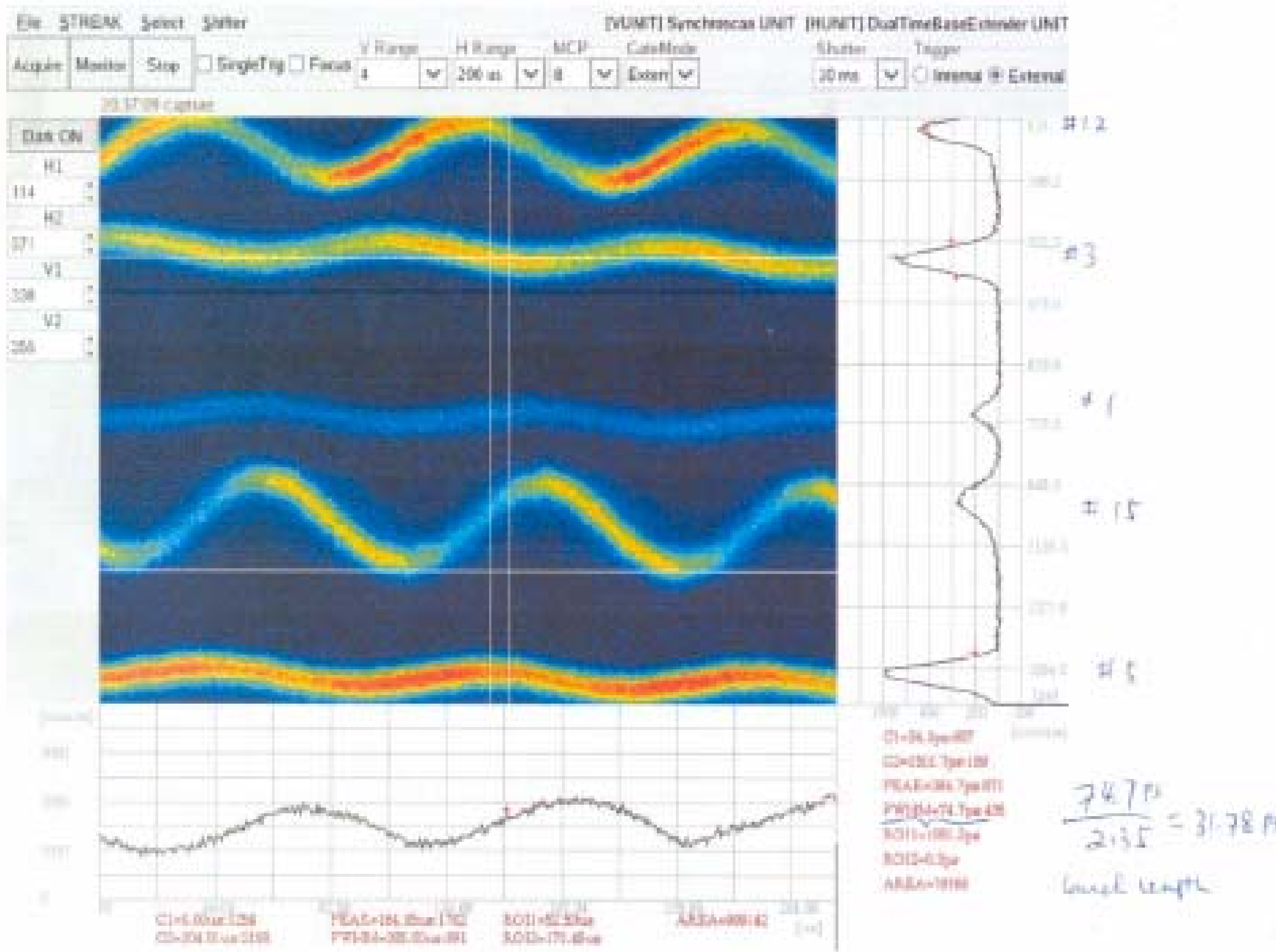
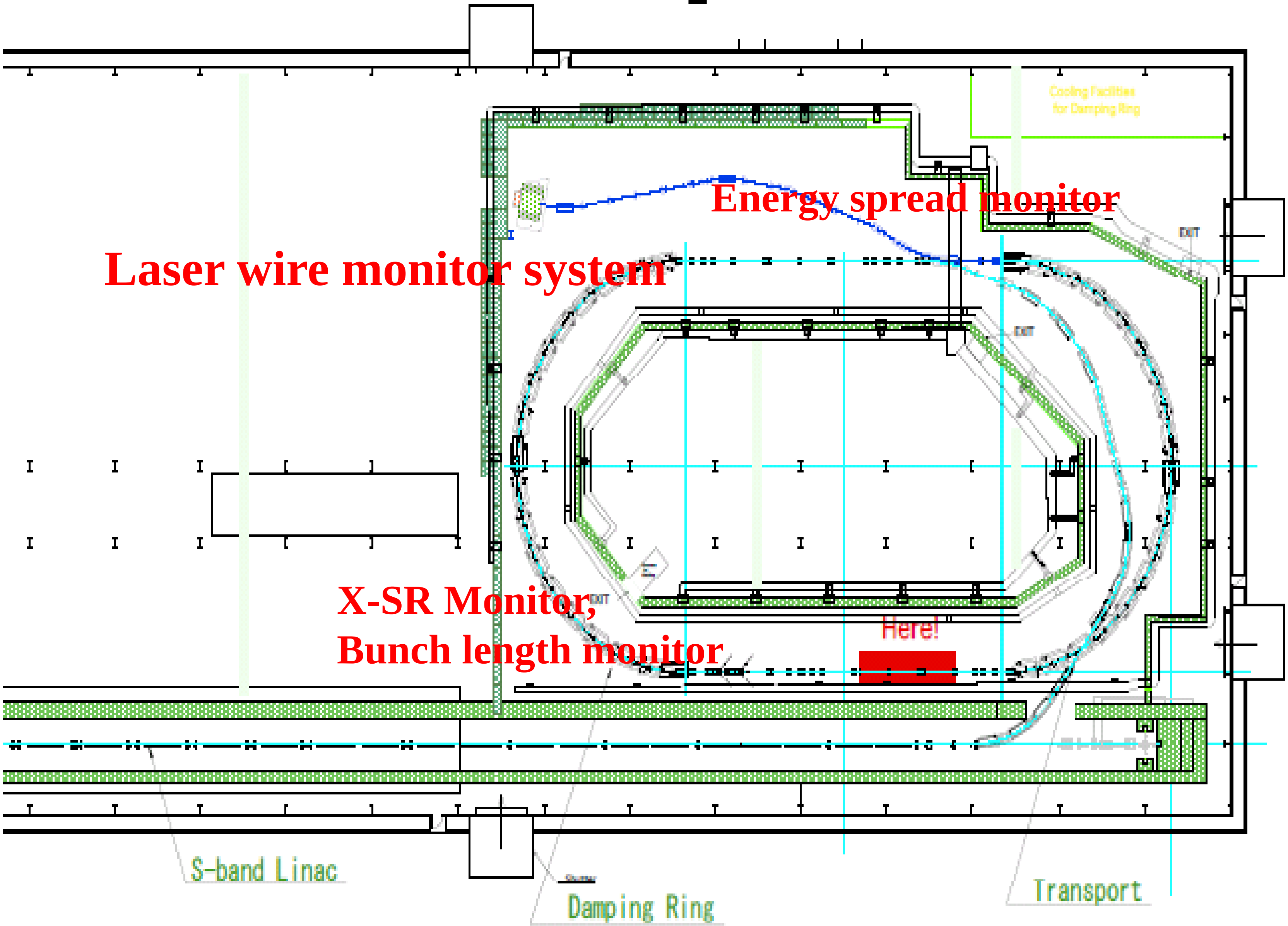


Figure 6: The bunch oscillation information from streak camera.

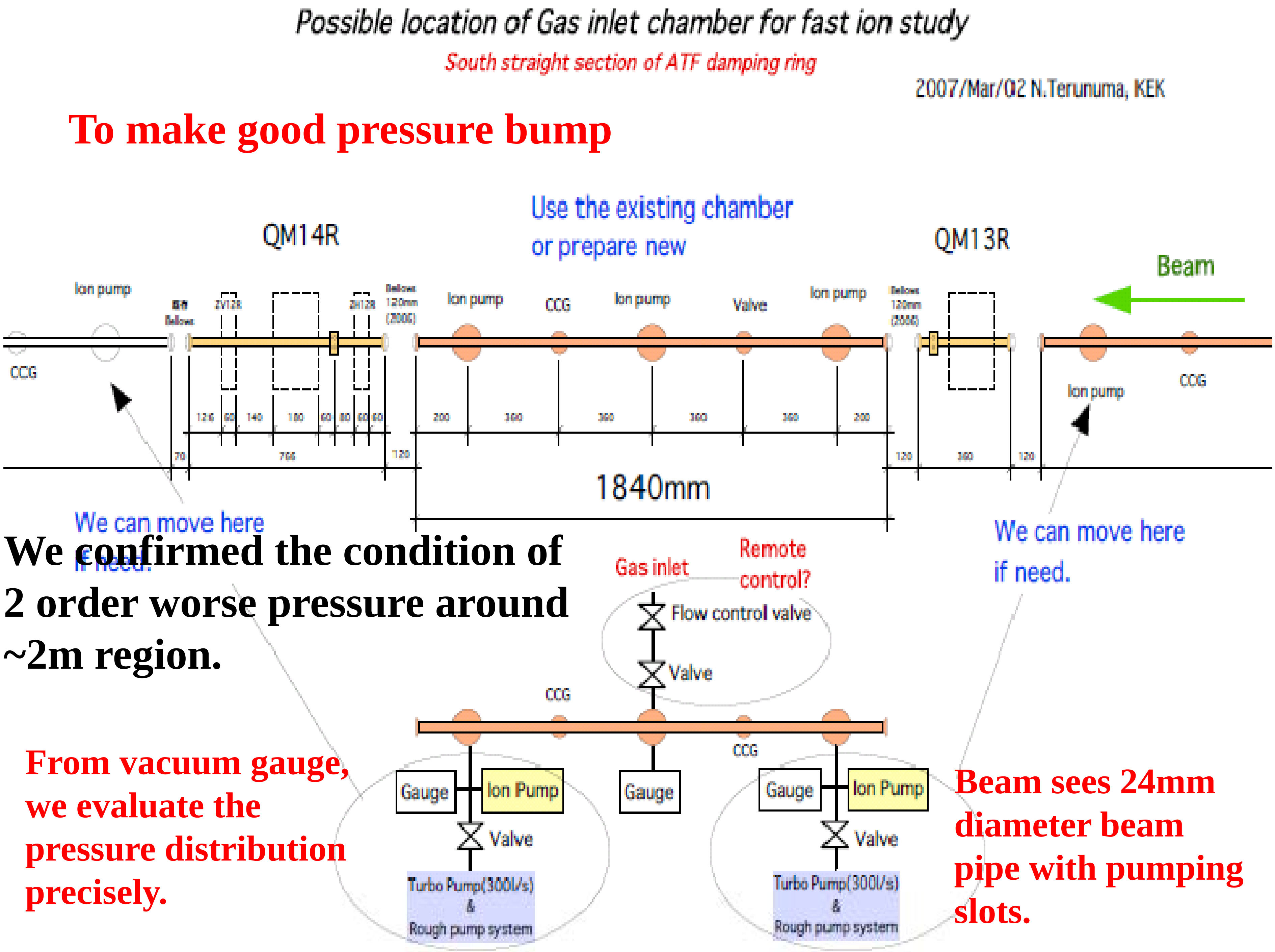
Posssible location for Fast Ion Study

Gas Inlet Chamber : N_2 etc.

2007/Mar/02 N.Terunuma, KEK



To make good pressure bump

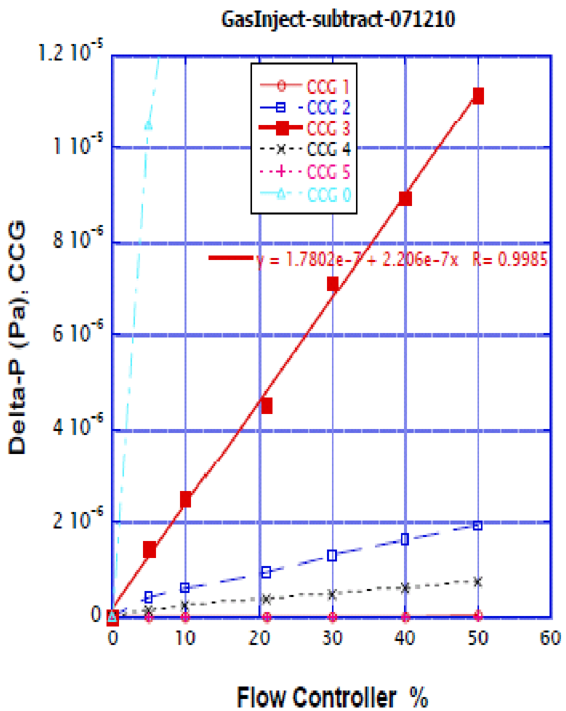


We confirmed the condition of 2 order worse pressure around ~2m region.

From vacuum gauge, we evaluate the pressure distribution precisely.

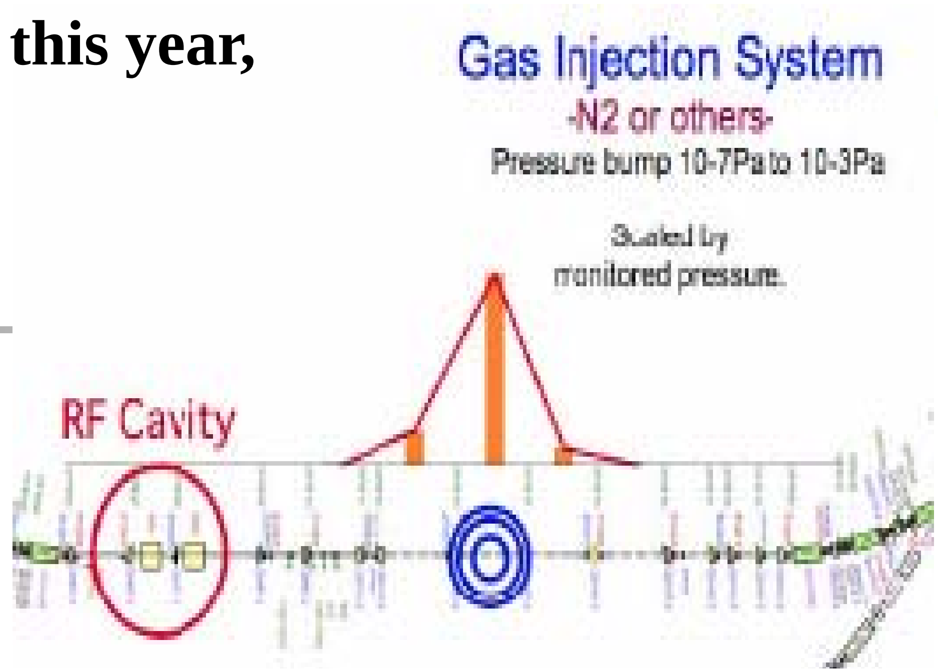
Beam sees 24mm diameter beam pipe with pumping slots.

From the report in this year, by G. Xia (DESY).



(Data come from measurement on Dec 10, 2007)

Gas flow controller in ATF DR



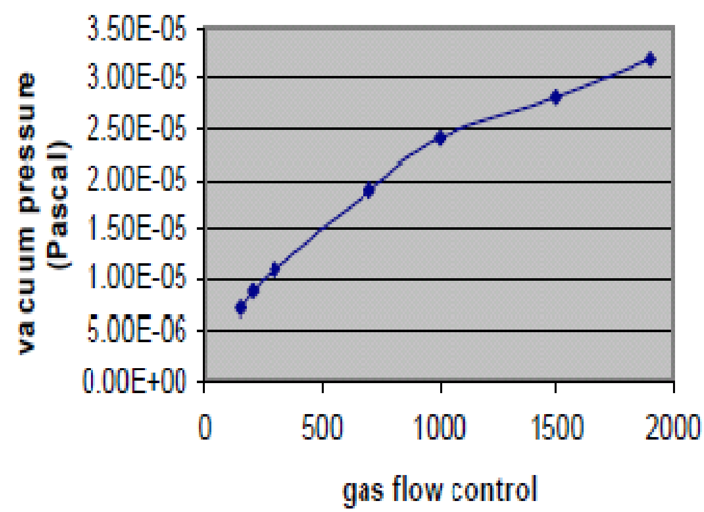


Figure 3: Change the flow controller (Data come from measurement on Dec 14, 2007)

The ultimate goal is to ensure that the design (including specification of feedback system, vacuum levels, and bunch train patterns) is such that the damping rings will be capable of delivering a beam with the required quality.

Achieving the Objectives will involve the following tasks:

1. Validate existing theoretical models and simulation tools for the fast ion instability by carrying out suitable measurements in available storage rings.
2. Refine existing simulation tools beyond their current state or develop new tools if necessary to achieve acceptable agreement with the experiments.
3. Demonstrate the existence of viable machine designs capable of meeting the specifications for beam quality and stability, and show experimental feasibility of these designs using existing machines if possible.
4. Explore the effectiveness of a variety of mitigation techniques (such as clearing electrodes), if necessary.

The main deliverables will be:

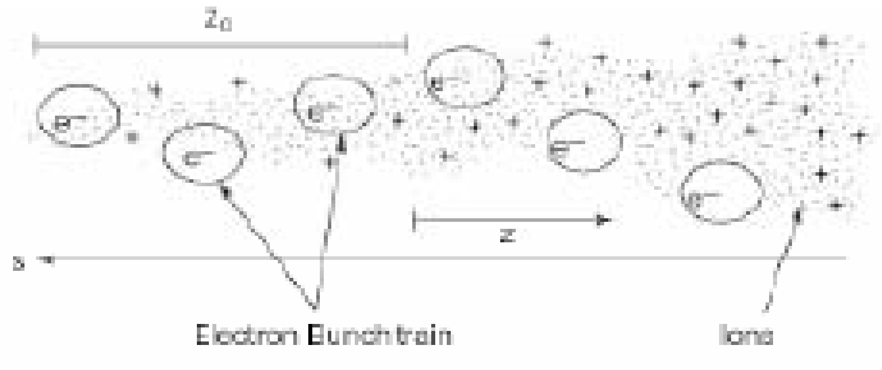
Experimental validation of theoretical models and simulation tools for the fast ion instability.

Indication of machine design parameters (including bunch filling patterns, lattice optics, feedback and vacuum specifications) capable of delivering a beam with the required quality and stability without limitations from ion effects.

Guidance for optimization of design of vacuum and feedback systems, and optimization of the optics design, to avoid limitations from ion effects.

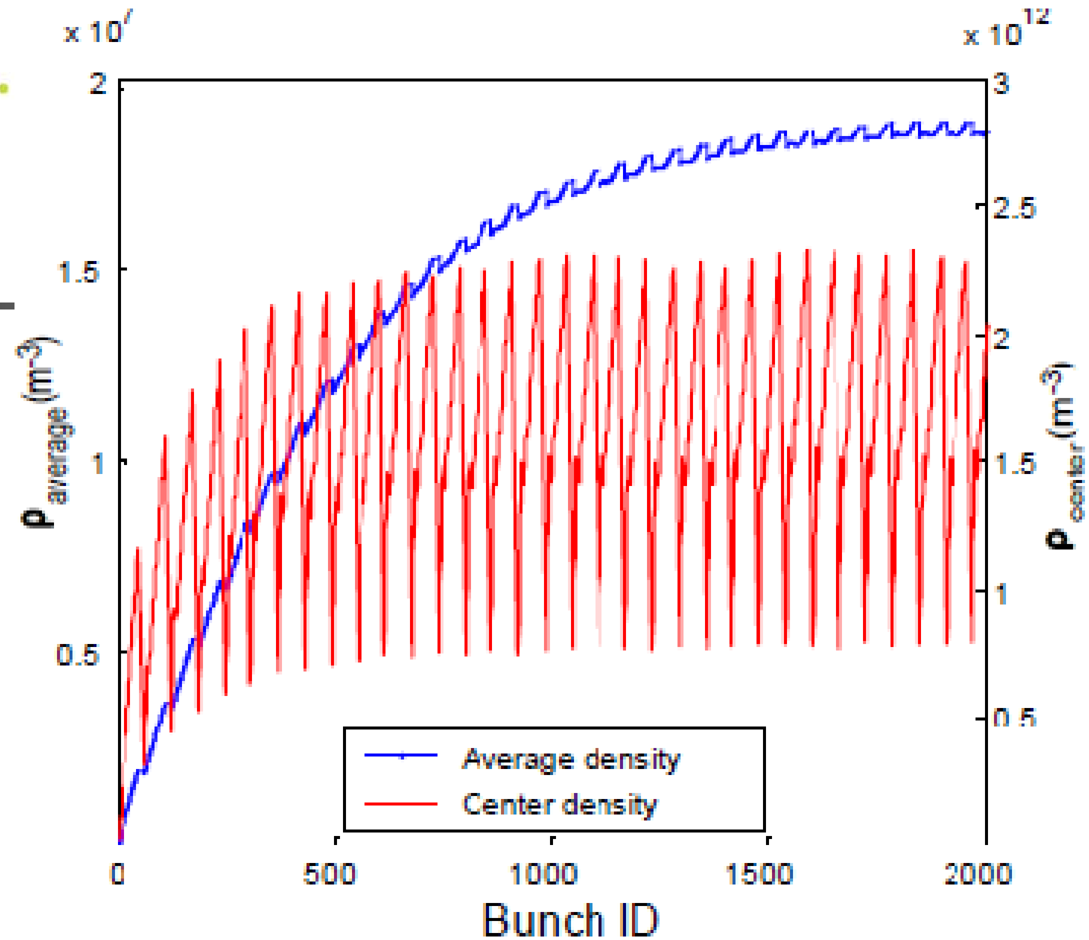
If the Objectives are not met, the ability to deliver the required beam specifications at extraction could be compromised, resulting in reduced luminosity.

Brief review of RDR



Schematic of the Fast-Beam Ion Instability

- Critical issues : ion-induced beam instability and tune shifts due to ultra-low vertical emittance.
- For mitigating bunch motion, a low base vacuum pressure less than 10^{-7} Pa and bunch-by-bunch feedback systems with a damping time of about 0.1 ms are necessary.
- To reduce the core ion density, mini-gaps in the train are essential.



The simulated growth time is 280μs.

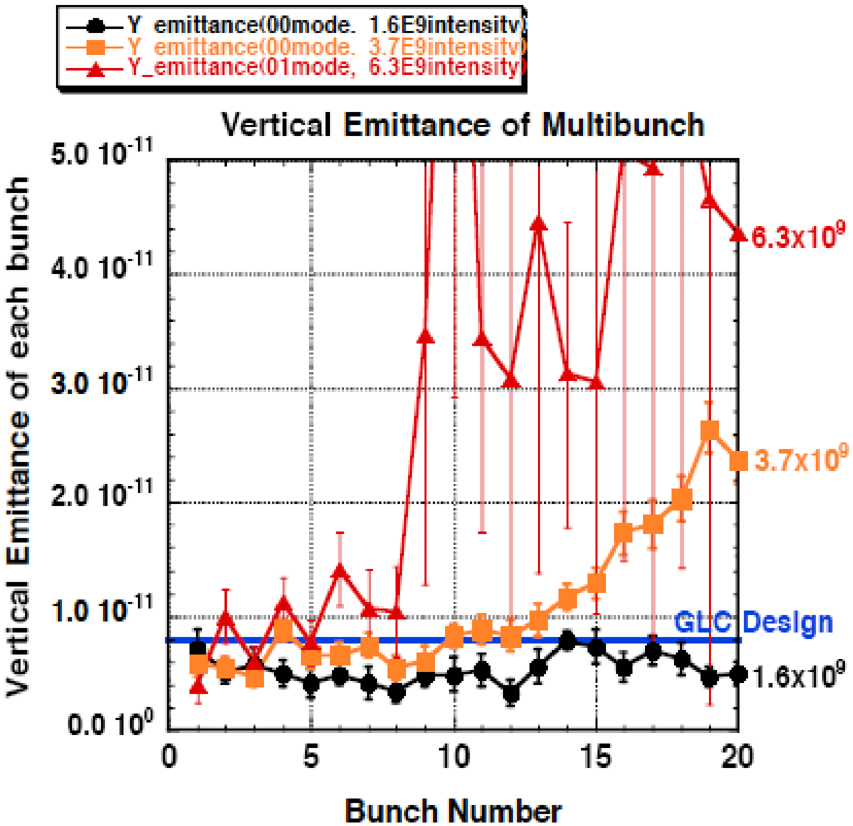
Build-up of CO^+ ion cloud at extraction. The total number of bunches is 5782 (118 trains with 49 bunches per train). The beam has a bunch separation of two RF bucket spacings, and a train gap of 25 RF bucket spacings. There are 0:97 x 10^{10} particles per bunch, and the partial vacuum pressure is 1 nTorr.

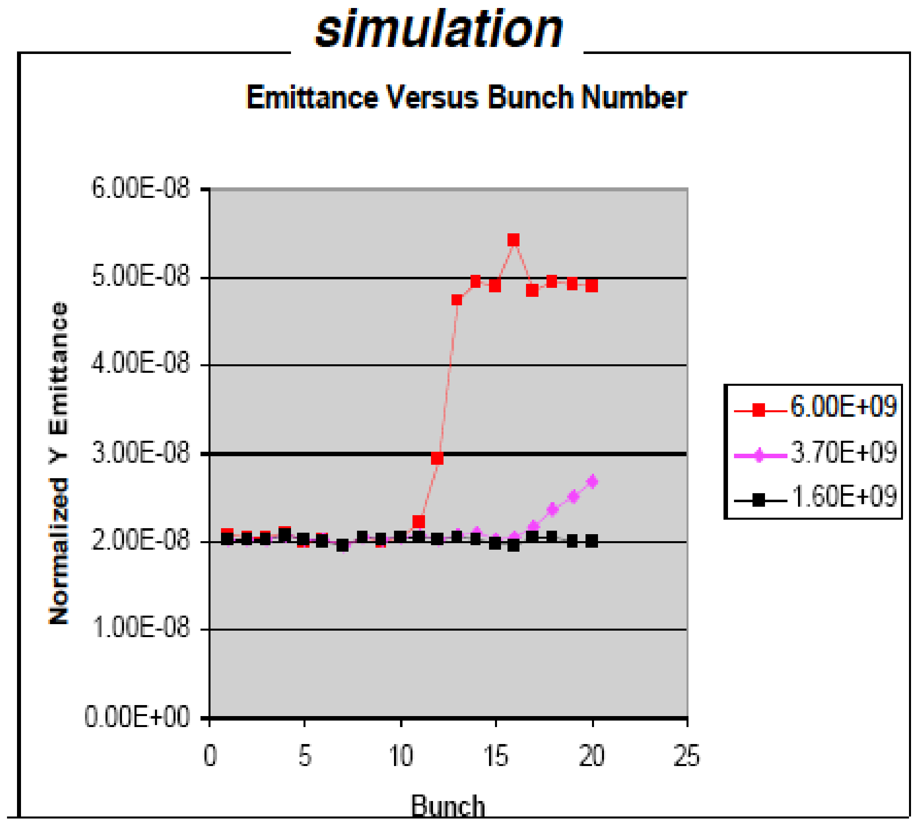
Plan for fast ion instability study at ATF

- Required information : ion density (related parameters include vacuum pressure, average beam line density, emittance, betatron function and beam fill pattern), bunch train gap, detail data to benchmark simulations with experiment.
- Deliverables : reliable simulation codes to evaluate the vacuum level, fill pattern and bunch-by-bunch feedback system.
- Resources : SLAC, LBNL, KNU, DESY, KEK

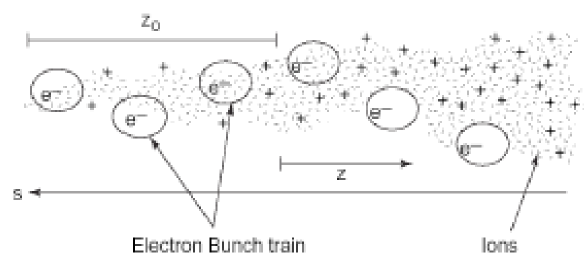
Preliminary result of Fast Ion Instability simulation

Results obtained in 2004





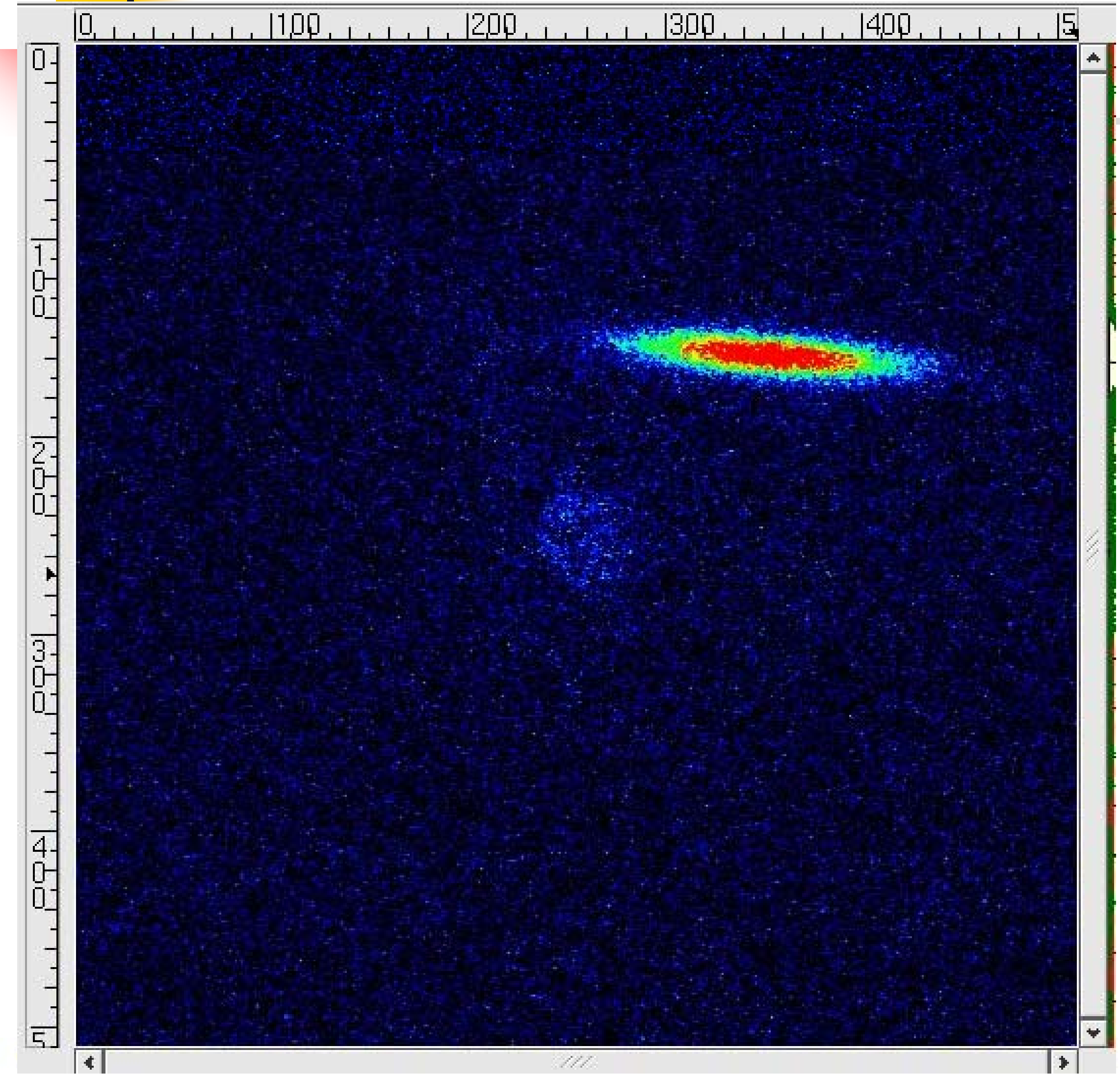
Behavior of Y emittance is very similar.



Schematic of the Fast-Beam Ion Instability

Problems: meas. of vacuum pressure,
Unknown gas species, extraction kicker heating

Measured beam profile by XSR monitor in normal vacuum condition in 2007 March



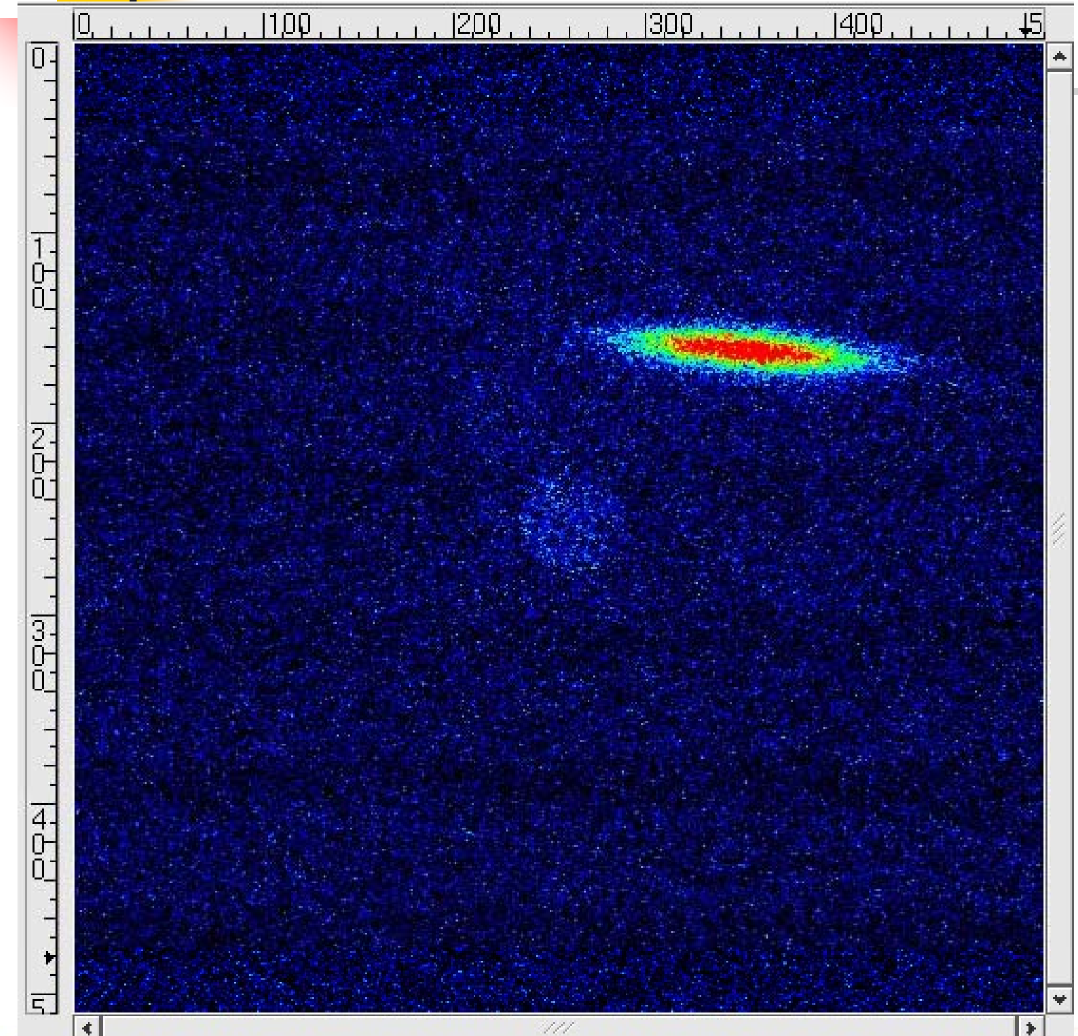
Single bunch/single train
2×10^{10} bunch/train

Ave: 2×10^{-7} Pa

X : 49.5 ± 2.3 μm
Y : 8.1 ± 0.7 μm

This profile was appeared on normal beam operation

Measured beam profile by XSR monitor in the vacuum condition with north ion pump off



Single bunch/single train
2×10^{10} bunch/train

Ave: 2×10^{-6} Pa (Maybe)

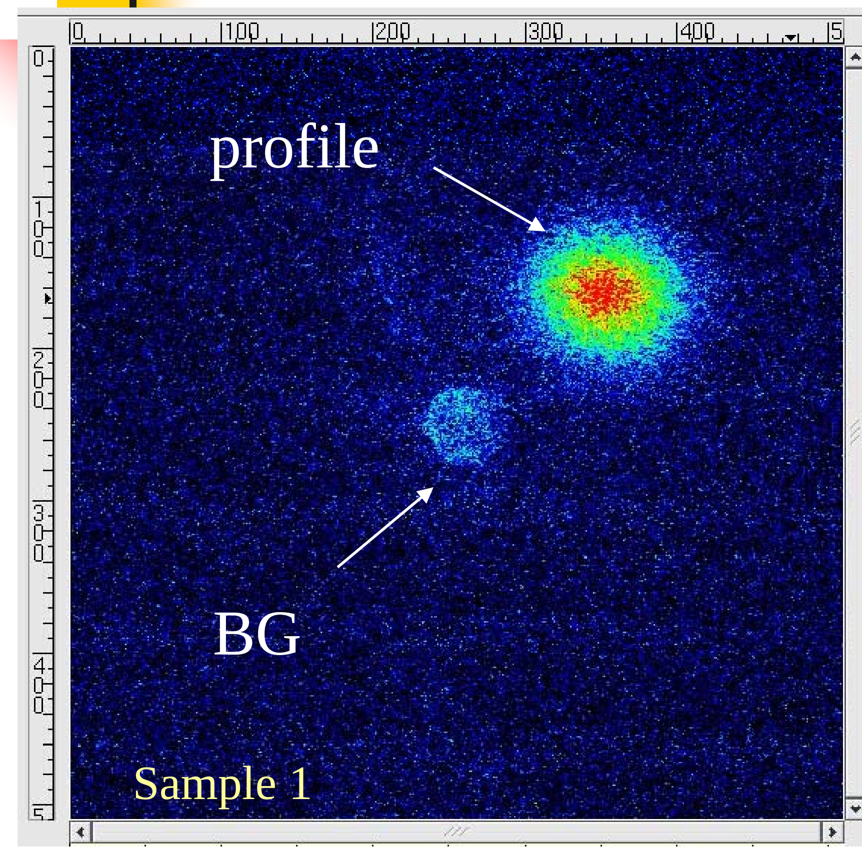
X : 46.8 ± 2.9 μm
Y : 8.4 ± 0.8 μm

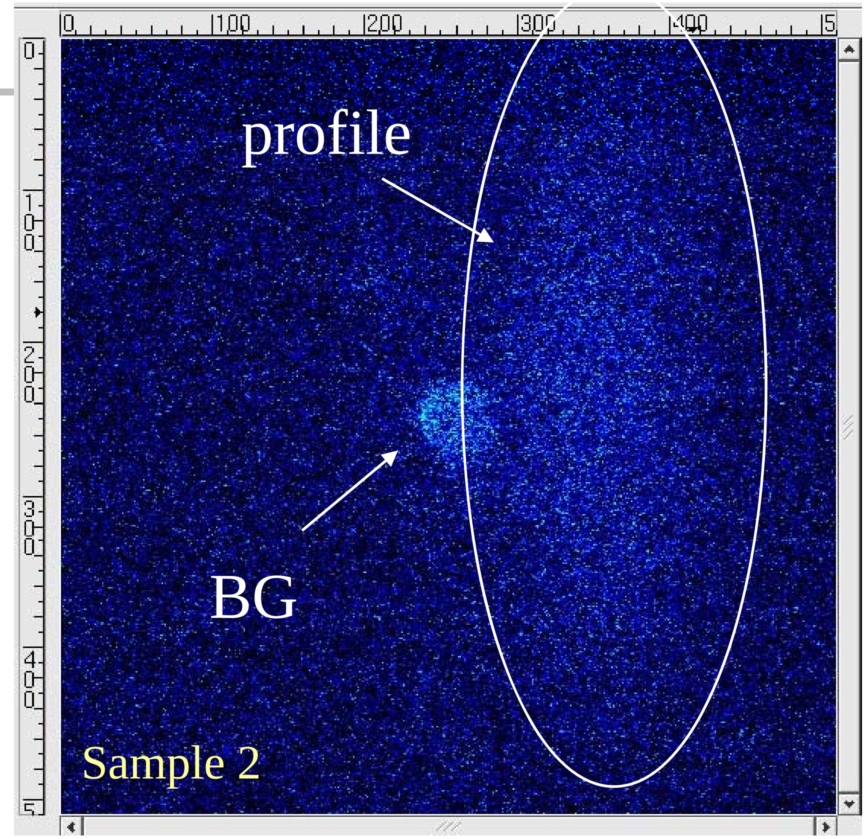
We have not found vertical beam size blow-up in this vacuum condition

Change 3train mode

Measured beam profile by XSR monitor on 3 train mode

Vacuum : 1×10^{-5} Pa

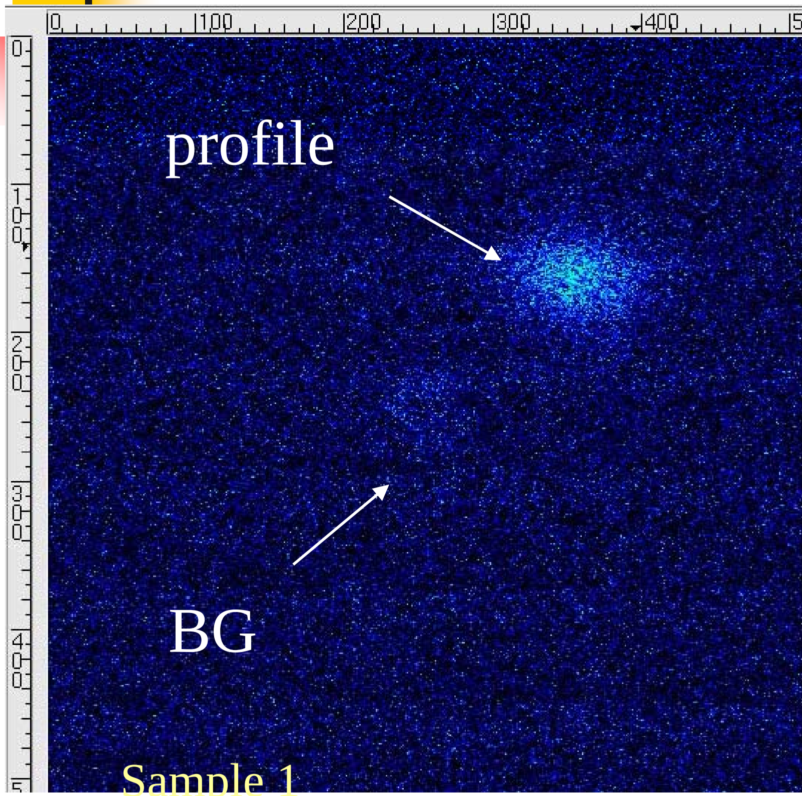


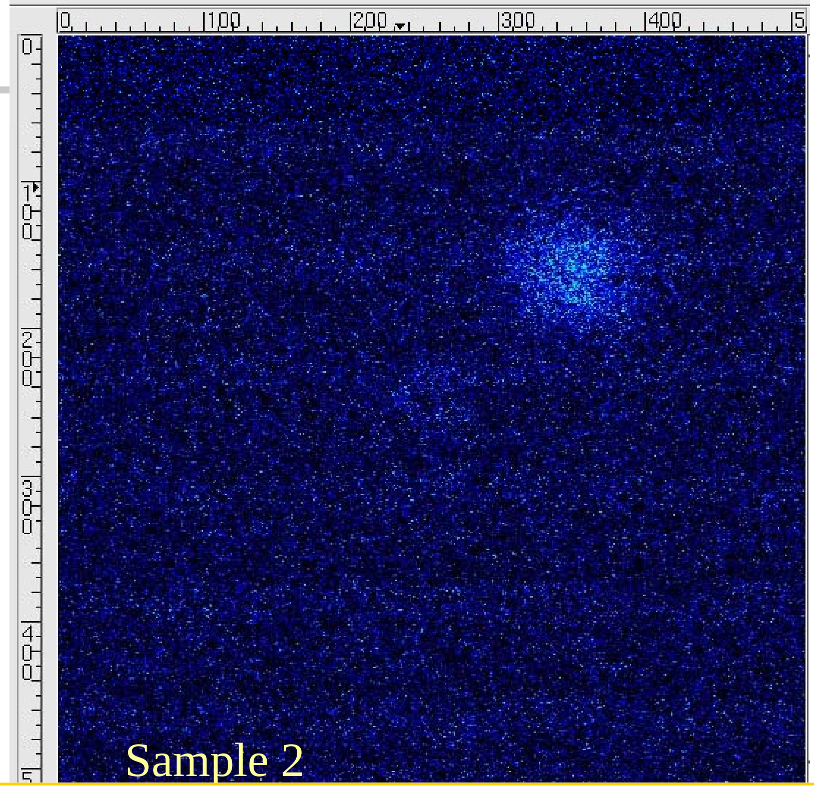


On a 3 train mode at 2×10^{10} /bunch, sudden large vertical beam blow-up appeared. On XSR monitor, measured vertical beam size was not fixed on same sizes. We also see a vertical beam oscillation by turn-by-turn monitor. **This is not FII?**

Measured beam profile by XSR monitor on 3 train mode (2)

Vacuum : 2×10^{-6} Pa





On a 3 train mode at 2×10^{9} /bunch (1/10 reduction than before), vertical beam blow up also appeared. But this amplitude was reduced on XSR monitor. The measured beam sizes were <u>32.5±0.9 μm</u> horizontally and 24.7±4.7 μm vertically. After changing single train, we did not find this vertical beam blow-up.

Experimental Condition in 2007 April

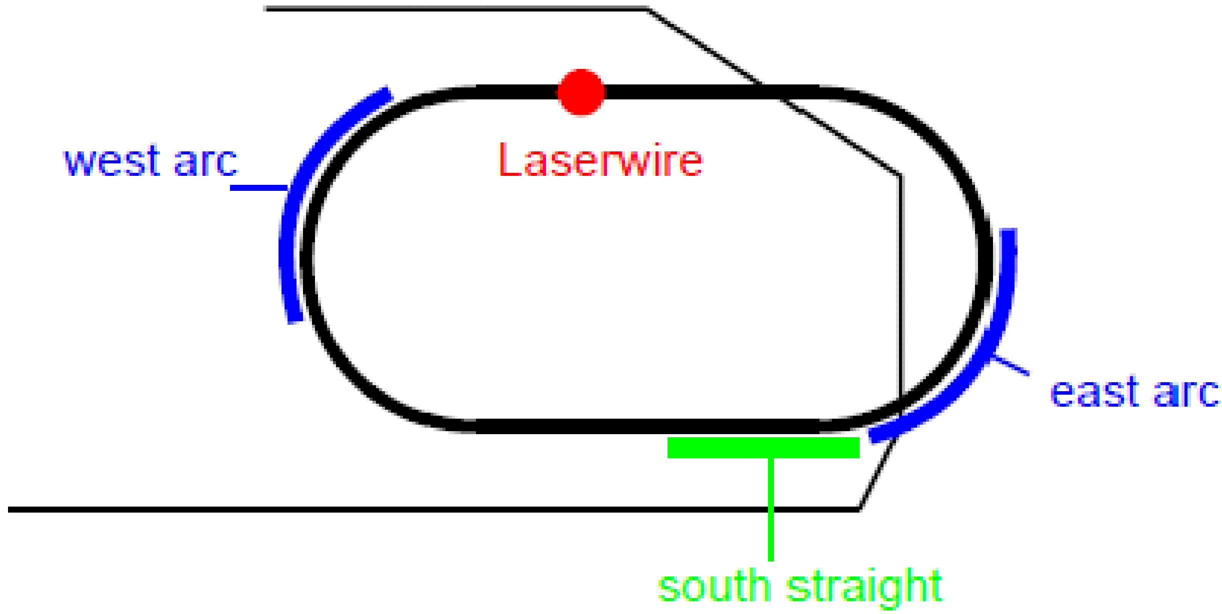


Figure 3: Sections that ion pumps were turned off in this experiment

Table 1: vacuum pressure in the measurements

ion pump status	5mA	10mA	20mA
normal	4.6×10^{-7} Pa	5.9×10^{-7} Pa	1.0×10^{-6} Pa
south straight OFF	2.0×10^{-6} Pa	2.7×10^{-6} Pa	5.5×10^{-6} Pa
both arcs and south straight OFF	3.4×10^{-6} Pa	5.2×10^{-6} Pa	

Experimental Results measured by laser wire in DR

Table 2: vacuum pressure in 2004

ion pump status	11mA	26mA	31mA
normal	4.0×10^{-6} Pa	6.0×10^{-6} Pa	6.5×10^{-6} Pa

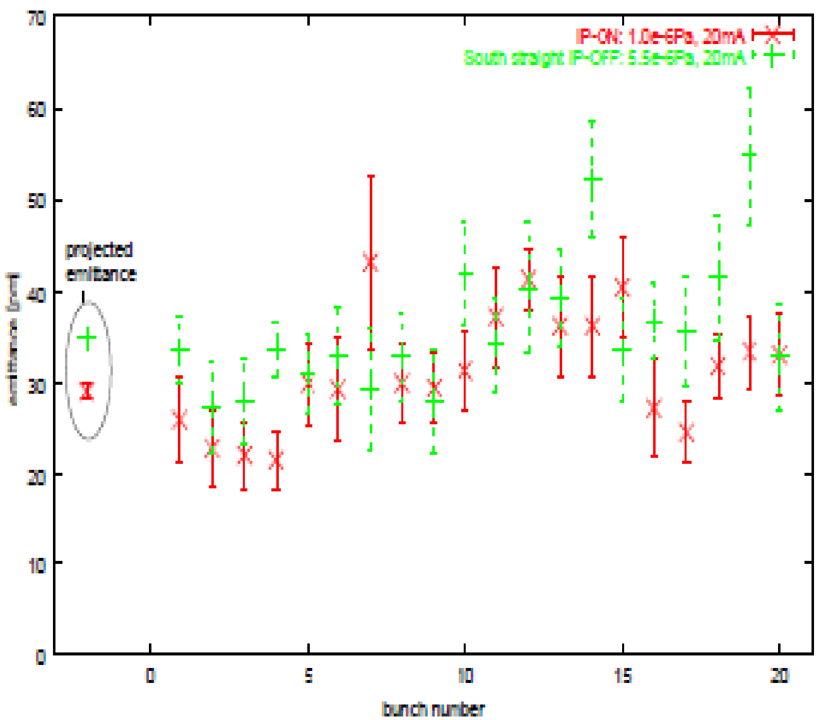


Figure 9: emittance of multi-bunch beam at 20mA/20bunches

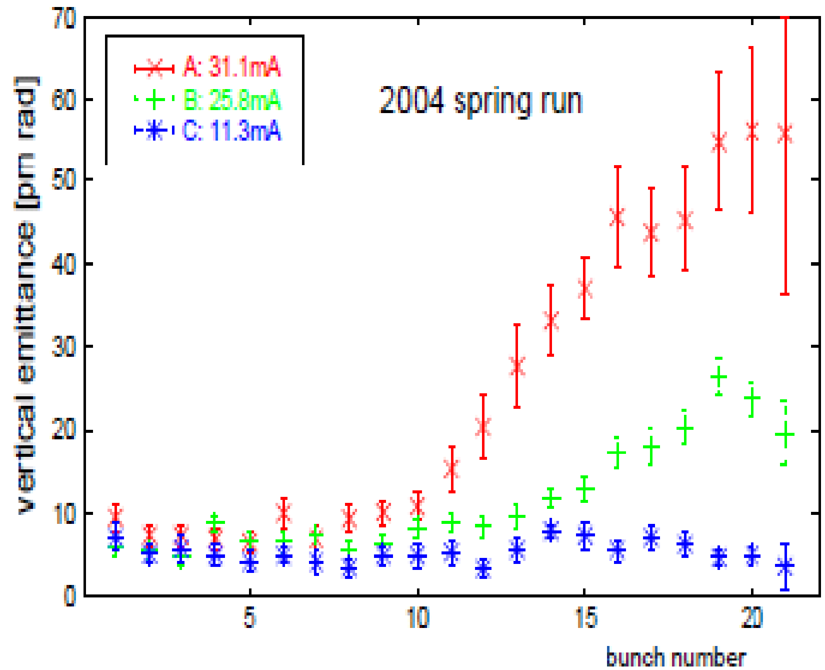


Figure 10: data taken in 2004

Study from Feb. to April in 2007.

- **We found the vertical beam blow-up at 3 train mode above 2×10^{-6} Pa between 2×10^{9} and 2×10^{10} /bunch.**
- **We did not find the vertical beam blow-up at single bunch/ single train mode below 2×10^{-6} Pa.**
- **We measured vertical emittance of each bunch in a 20bunches train with a laser wire monitor. Even if we turned off ion pumps of several section of the DR to enhance ion effects, no clear blow-up in a train was seen up to 20mA/train beam current. One of the reason may be the bigger vertical emittance compared with the data taken 2004.**

Summary of Spring preliminary experiment for fast ion instability at ATF

Our conclusion is that we need more total stored current than 20mA/train and should generate 5pm vertical emittance like 2004 beam experiment in order to realize the beam blow-up due to the fast ion instability.

Since reliable data for the study of FII are necessary, we continue this experiment from 2007 Nov. operation with the installation of the Gas (N_2) inlet system.

Necessary preparation and good maintenance

- Multi-bunch energy compensation system in ATF Linac (We need energy margin.)
- Ready laser wire and X-SR monitor
- 10GHz signal sampling system in DR
- Tuning for high quality beam injection

(beam stability, high current injection more than 70mA/train)

Goals of the experiment

(according to Two proposals)

(G. Xia, E. Elsen, L. Wang and T. Raubenheimer)

- **Distinguish the two ion effects: beam size blow-up and dipole instability.**
- **Quantify the beam instability growth time and tune shift. The growth rate is related to the ion density (vacuum pressure, average beam line density, emittance, betatron function and so on).**
- **Quantify the bunch train gap effect**
- **Provide detailed data to benchmark simulations with experiment.**

Detailed Experimental plan

A. Measurement of vacuum pressure and the main components of gas species.

B. Effects of pressure and bunch current:

With different pressure conditions (2.0×10^{-5} Pa in pressure bump) by injecting nitrogen gas);

With different beam: 1 train, N of bunch =2~20, $5 \times 10^{9} \sim 2 \times 10^{10}$/bunch

C. Gap effect

- repeat B with 2 and 3 bunch trains,
- repeat B with different length of gaps.
- repeat above with a different emittance (emittance ratio :changed by skew quads from 0.5% to 10%.)

To make efficient international collaboration

ATF Web is involving and making international data communication page.

- 5th Joint meeting of TB and SGCs on Dec. 21 at KEK last year
- Call for new R&D proposals at ATF
- Studies about the Fast Ion Instability
  - This is a starting point for data sharing within the collaboration of the fast-ion R&D program. Therefore we have no tools converting the internal data format into your environment at present. Raw data are distributed in some computers at ATF because the developments of monitors are done by several groups. Each beam-monitor system has their own format on the different operating system, 8, 16, 32 or 64 bits. It is very difficult to gather them in a server at present. Your help or work to establish the data sharing tools for near future is necessary. Anyway, we will keep to upload the results for your works.

    by Nobuhiro Terunuma, March 1st, 2007.
  - Data and Summary
  - *Logging into the ATF web system is required. If you have no account on the ATF web system, please visit the user registration page .* (http://atf.kek.jp/collab/)
  - 2007/Feb/23, 28 -----2007/April
  - 2008/March/7, 2007/Dec/14 , 2007/Dec./10