# Operational Status of the Shanghai Synchrotron Radiation Facility

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# Outline

- Introduction to the SSRF
- Operational performance
- Development and future upgrades
- Future beamlines
- Summary

# Shanghai Synchrotron Radiation Facility

- The SSRF, an intermediate energy 3rd generation light source, consists of an 150MeV linac, a full energy booster, a 3.5GeV storage ring and 7 phase-I beamlines;
- The SSRF project was launched in 2004 with the ground breaking made on Dec.25, 2004, and the first stored and accumulated electron beam in the ring was achieved on Dec.24, 2007;
- The storage ring is routinely operating at emittance of 3.9nm-rad with beam current decaying from 210mA to 140mA, the beam is refilled every 12 hours.

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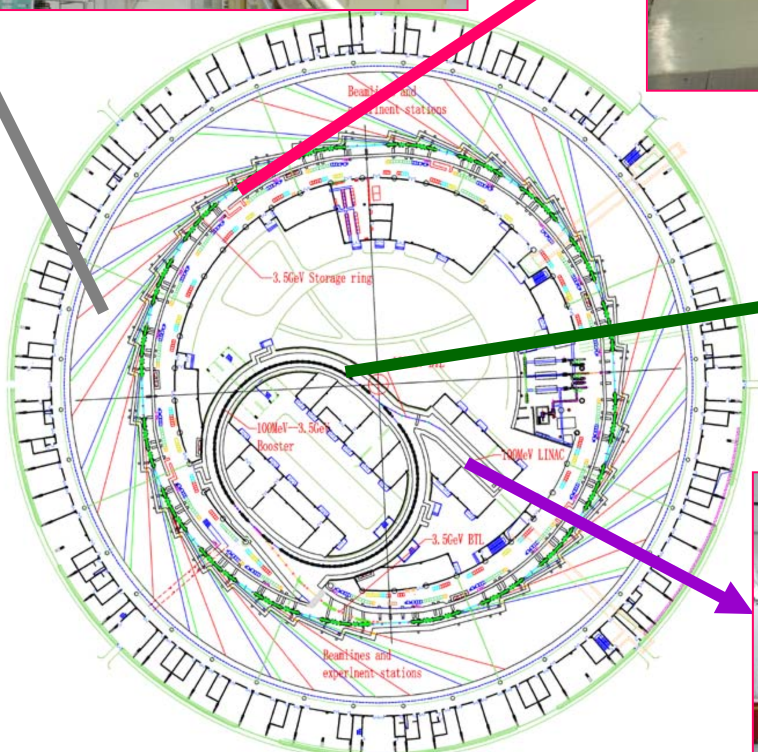
# The SSRF Complex

Beamlines number 7 in phase-I 5+24 in phase-II

Storage Ring
3.5GeV,C=432m

Booster
3.5GeV,C=180m




Electron Linac
150MeV

# SSRF Main Parameters

- Storage Ring Energy: 3.5 GeV
- Circumference: 432 m
- Natural Emittance: 3.9 nm-rad
- Beam Current: 200 ~ 300 mA
- Beam Lifetime: ~20 hrs
- Straight Sections: 4×12.0 m, 16×6.5 m
- RF Voltage: 4.0~6.0 MV
- Max. Beam Power: ~600kW

# The First SSRF Beamlines

- Macromolecular Crystallography (In-Vac Und.)
- High-Resolution X-ray Diffraction (Bend)
- X-ray Absorption Fine Structure Spectroscopy ( Wiggler)
- Hard X-ray Micro-focus and Application (In-Vac Und.)
- X-ray Imaging and Biomedical Application (Wiggler)
- Small Angel X-ray Scattering (Bend)
- Soft X-ray Microscopy (EPU)

# The SSRF Linac Performance

| | Designed | Measured |
|---|---|---|
| Energy ( MeV ) | 150 | 152 – 162 |
| Single bunch charge (nC) | 1.0 | 1.06 |
| Multi-bunch charge (nC) | 5.0 | 6.0 – 6.6 |
| Energy stability | 0.5% (rms) | 0.1 – 0.4% |
| Relative energy spread | 0.5% (rms) | 0.2 – 0.4% |
| Normalized emittance ( x) | 50 mm-mrad | 37- 46 mm-mrad |
| Normalized emittance (y) | 50 mm-mrad | 32 – 49 mm-mrad |
| Linac Frequency ( MHz ) | 2997.924 | 2997.924 |
| Rep. Rate ( Hz ) | 2 | 2 |

# The SSRF Booster Performance

| Parameter | Designed | Measured |
|---|---|---|
| Energy (GeV) | 3.5 | 3.51 |
| Circumference (m) | 180 | 180 |
| Bunch charge Single/multi (nC) | 1.0/5.0 | ~1.2 / >6.0 |
| Tunes | 8.42/5.39 | 8.41/5.27 |
| Emittance (nm-rad) | 108 | 90 - 107 |
| Rep. rate (Hz) | 2 | 2 |

The SSRF booster transmission efficiency from the LTB transport line to the BTS transport line is larger than 85%;

# The SSRF Storage Ring Performance

| Parameter | Designed | Measured |
|---|---|---|
| Beam energy (GeV) | 3.5 | 3.5008 |
| Circumference (m) | 432 | 432 |
| Beam current (mA) | | |
| Multi-bunch | 200 – 300 | >200 |
| Single bunch | 5 | 6.5 |
| Natural Emittance (nm-rad) | 3.9 | ~3.8 |
| Natural energy spread | 0.098% | ~0.1% |
| Coupling | 1% | ~0.3% |
| Betatron tunes | 22.22/11.29 | 22.223/11.293 |
| Straight No.×Length (m) | 4×12.0, 16×6.5 | 4×12.0, 16×6.5 |
| RF voltage (MV) | 4.0 | >4.2 |
| Beam lifetime (hours) | >10@200-300mA | >15@200mA |
| Orbit stability rms x/y(μm) @straight section | 5/1<br>15/5 (Phase-I) | top-up @ ~10hrs<br>2/1 |

Transport efficiency is larger than 95% ( from the booster DCCT to the ring DCCT)

# SSRF Phase-I Beamline Parameters

| | Beamline | Source | Main Parameters |
|---|---|---|---|
| 1 | Macromolecular Crystallography | In-vacuum Undulator | Energy range and resolution：5~18keV, $<2\times10^{-4}$<br>Focused spot size：~$65(H)\times25(V)\mu m^2$<br>Flux at sample：$2\times10^{12}$phs/s@12keV<br>Beam divergence: ~$0.3(H)\times0.03(V)mrad^2$ |
| 2 | Diffraction | BM | Energy range：5~20keV<br>Energy resolution: $\leqslant2\times10^{-4}$<br>Focused spot size：$\leqslant0.4(H)\times0.4(V)mm^2$<br>Flux at sample：$2.0\times10^{11}$phs/s@10keV |
| 3 | XAFS | Wiggler | Energy range：5~20keV<br>Energy resolution: $5\times10^{-5}$~$2\times10^{-4}$<br>Focused spot size：~$0.2(H)\times0.1(V)mm^2$<br>Flux at sample：$3.6\times10^{12}$phs/s@10keV |
| 4 | Hard X-ray Micro-focusing | In-vacuum Undulator | Energy range and resolution：5~20keV, $<2\times10^{-4}$<br>Focused spot size：<2μm<br>Flux at sample：$1.8\times10^{11}$phs/s@10keV |
| 5 | X-ray Imaging and Bio-medical applications | Wiggler | Energy range and resolution：9~65keV, $<2\times10^{-3}$<br>Flux density (unfocused) :$1.6\times10^{12}$phs/s/mm$^2$@20keV<br>Imaging resolution: <2μm |
| 6 | Soft X-ray spectromicroscopy | Undulator (EPU) | Energy range：200~2180 eV<br>Spectral resolution: 22000 @244eV, 2460 @1840eV<br>Flux at sample：$>2\times10^{8}$phs/s<br>Spatial resolution: < 30 nm |
| 7 | Small Angle X-ray Scattering | BM | Energy range：5~20keV<br>Energy resolution: $<6\times10^{-4}$<br>Focused spot size：~$0.4(H)\times0.5(V)mm^2$<br>Flux at sample：$4.7\times10^{11}$phs/s@10keV |

# The SSRF Construction Milestones

- Dec. 25, 2004 : Ground breaking
- Dec. 24, 2007: First synchrotron light
- Apr. 29, 2009: Dedication of the SSRF
- May 6, 2009: Start of user operation
- Jan. 19, 2010: Government acceptance

# The SSRF Operation Status

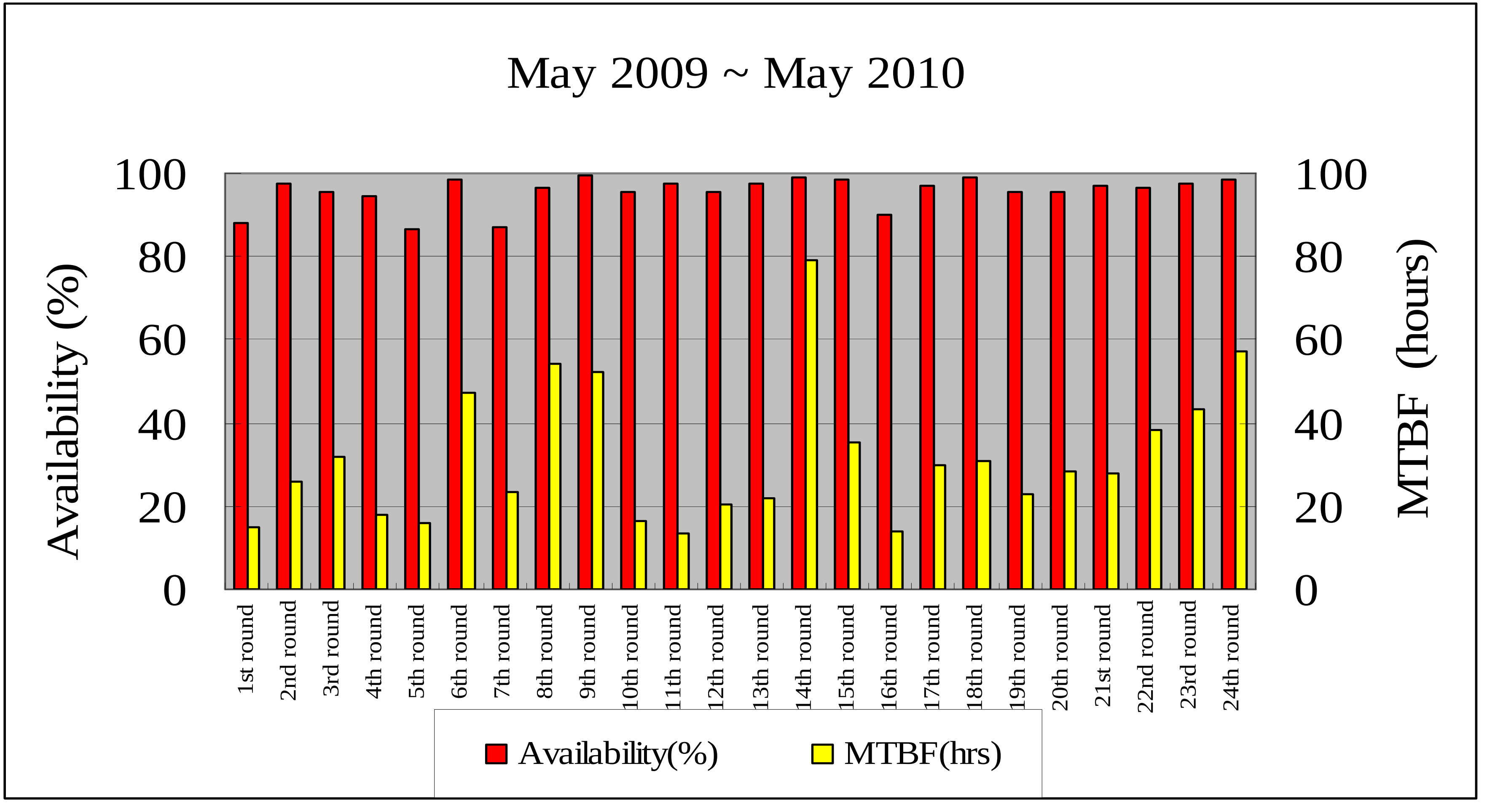
- The SSRF started its user operation with 7 beamlines on May 6, 2009, after a performance measurement from April 11 to 23, an international review on April 26 – 27 and a dedication ceremony on April 29, 2009;
- Till April 30, 2010, more than 1250 users from 114 universities and institutes in China have carried out 537 experiments at SSRF;
- The SSRF user operation time in 2009 is around 2020 hours, and the scheduled user operation time in 2010 is about 4000 hours.

# Machine Operational Performance

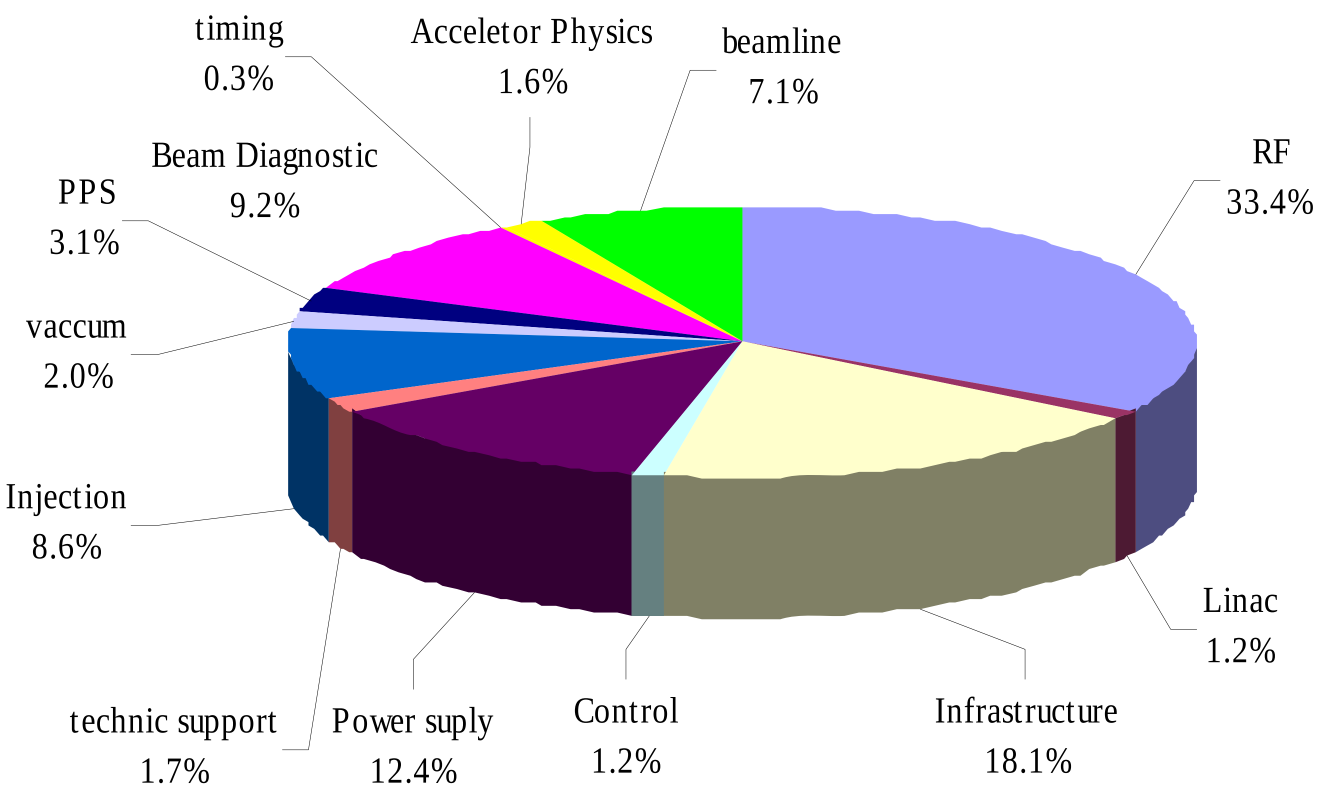
- Since May 6, 2009, more than 4000 hours of machine beam time have been delivered to user experiments.
- The injector operates reliably, the availability and MTBF of the linac are 99.8% and 38 days respectively, and the booster runs at the same availability and MTBF level.
- The total machine availability and MTBF for experiments in the passed year are about 95.6% and 31.8 hours;
- The storage ring currently operates in decay mode with beam current from 210mA to 140mA. The beam lifetime is around 30 hours at coupling about 0.8% and with 5 IDs closed, including 2 in-vacuum undulators;

# First Year Operation Status

Availability: 95.6%, MTBF:31.8 hrs



# System Failure Statistics

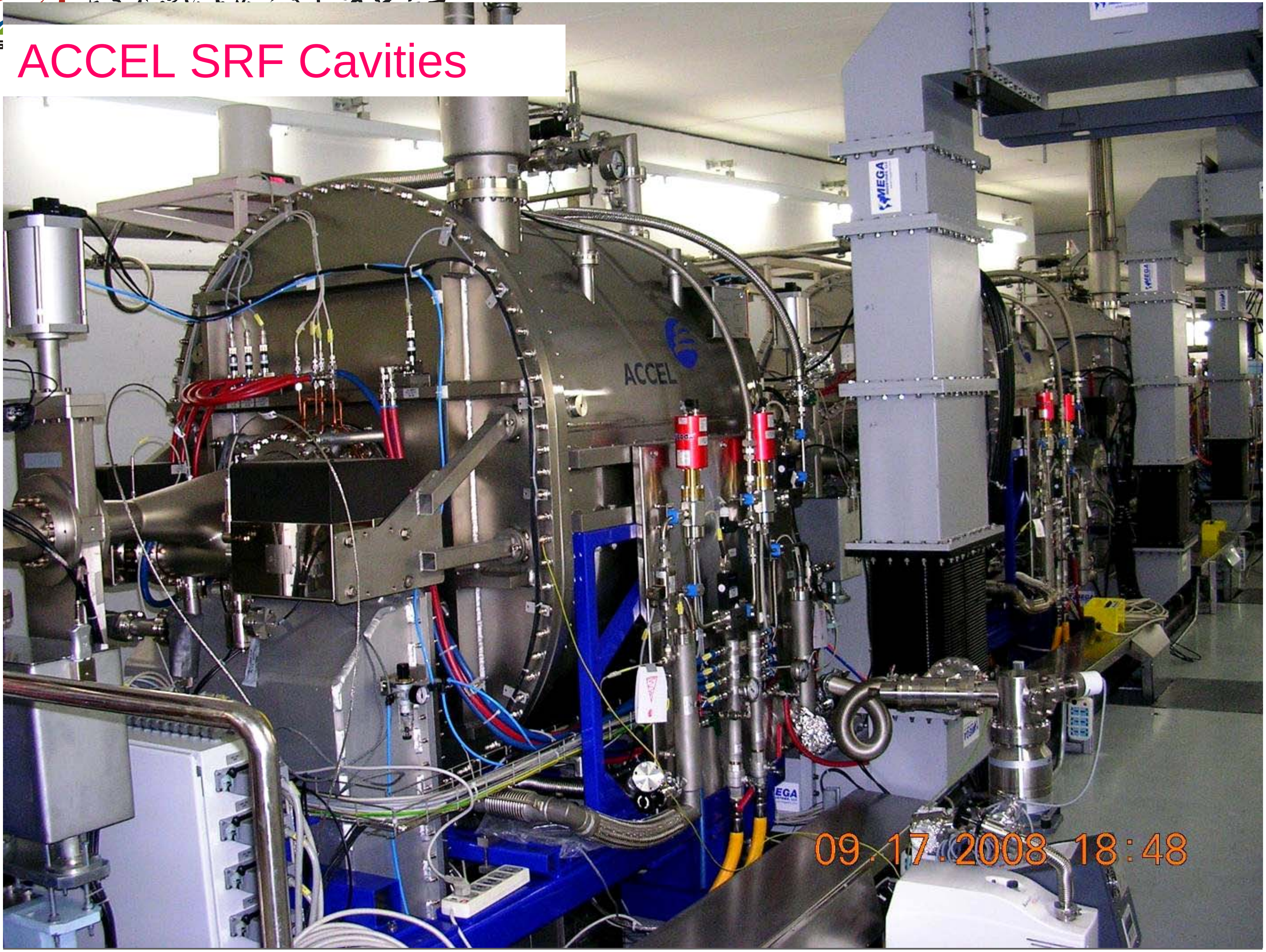


# Operation of the SSRF SRF Cavities

- The MTBF of the ring RF system is about 43 hours in the passed year, the majority trips come from SRF cavities.

- Three ACCEL SRF cavities have different operational problems, most cavity 1 trips come from the bad vacuum near the cavity window, and most cavity 3 trips may come from arc near power coupler or in input waveguide;
- One trip phenomenon we do not understand: Sometimes cavity 1 has a trip from bad vacuum (window) at high RF power, then there will be a few of trips followed for 3- 4 times in 4-5 hours interval.
- Conditioning the cavity with beam to high input RF power is an effective way to get rid of SRF cavity trips

# ACCEL SRF Cavities



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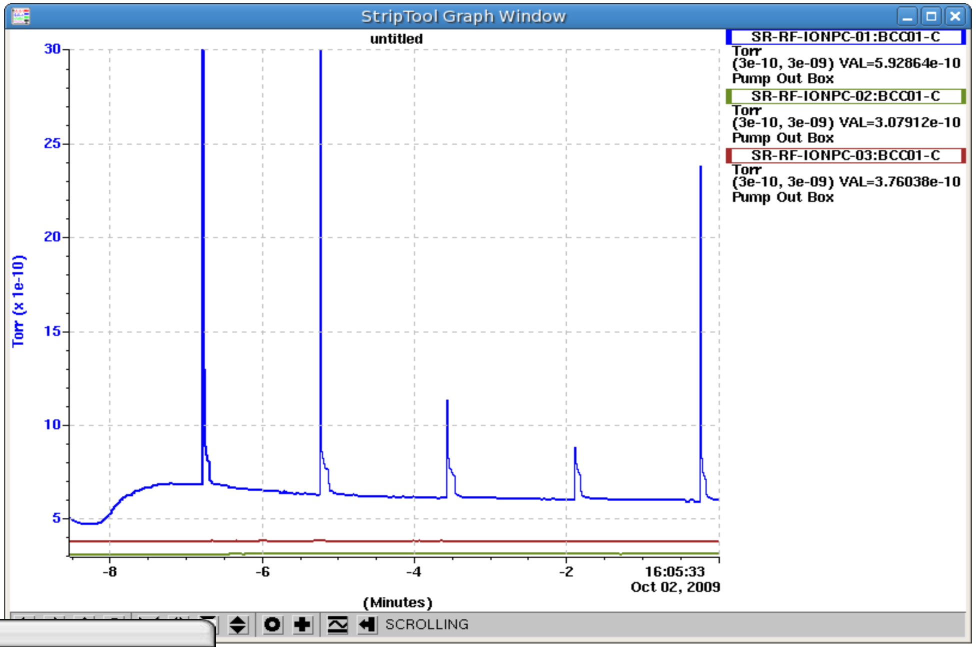
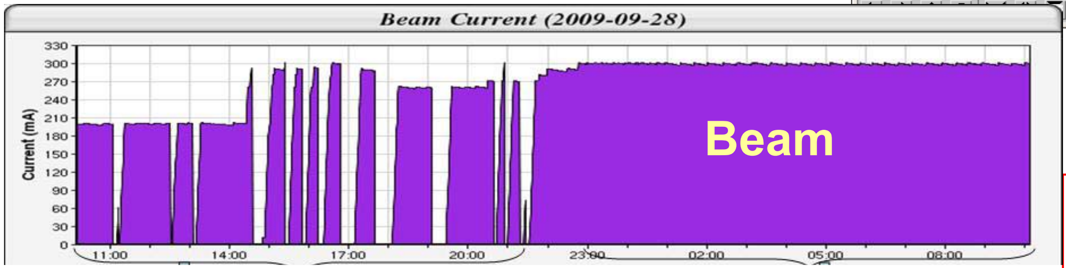
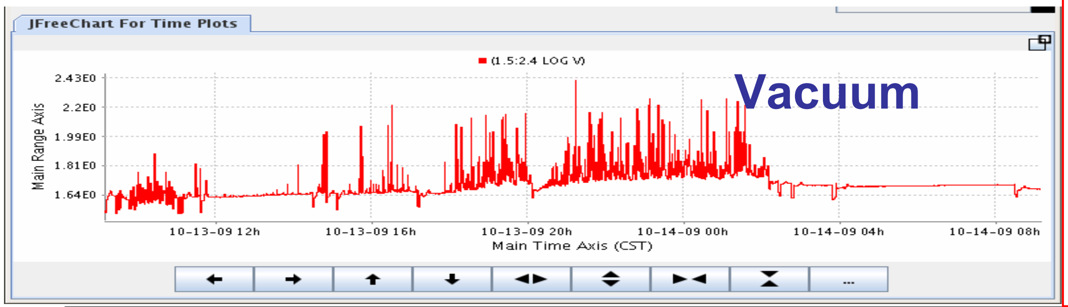
# Cavity 1

If a trip of cavity 1 happens at high input power, then degas bursts nearby the cavity window will occure periodically for a while.



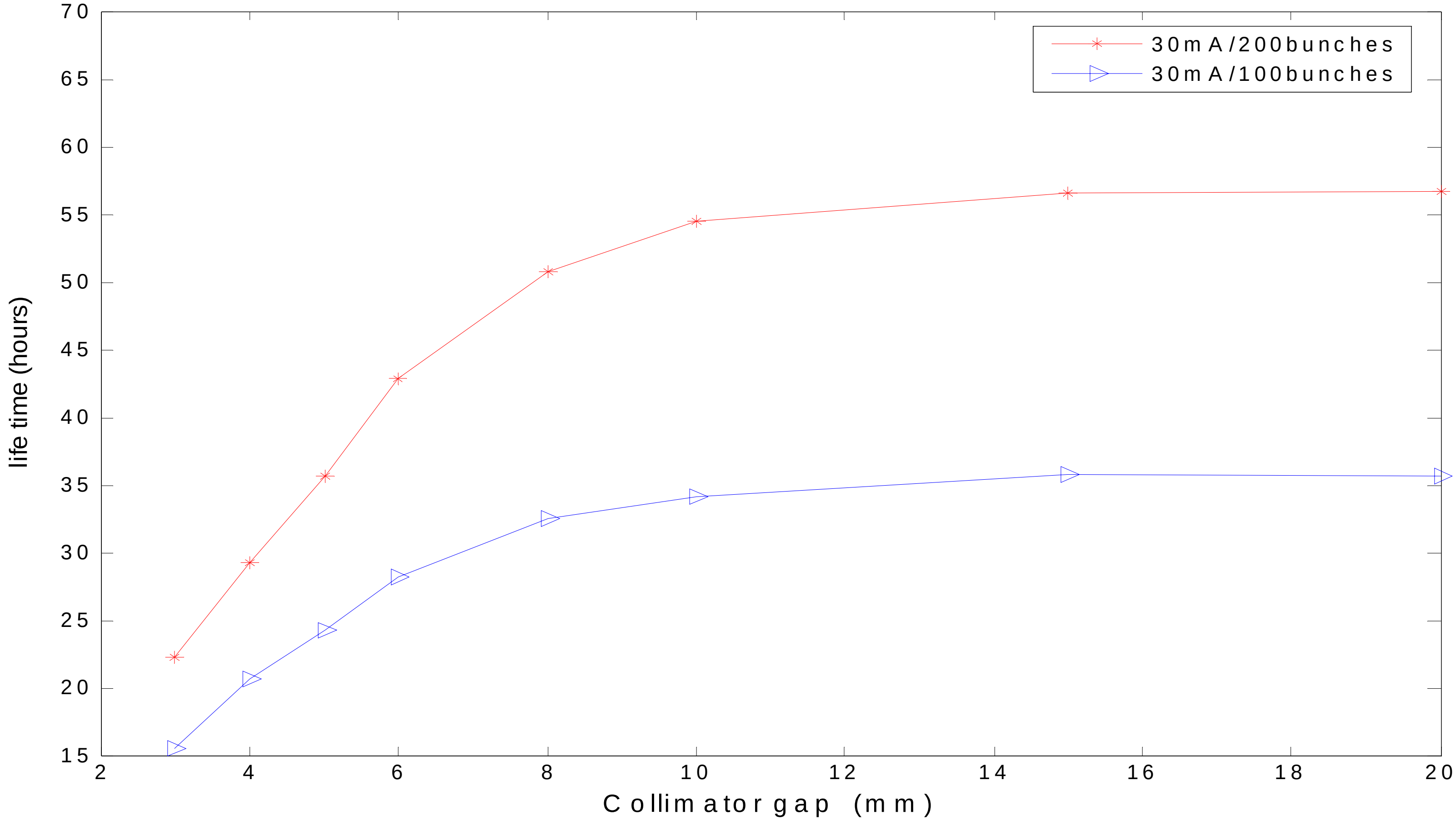




The total input RF power is a determine factor of cavity 1 trips, conditioning cavity with beam to high input power has been proved to be an effective way to get rid of trips.

# Beam Lifetime and Maximum Current

- The beam lifetime of the SSRF storage ring in operation is determined by a vertical collimator at downstream injection section, it is used to limit the electrons to hit on the magnet blocks of in-vacuum undulator.
- Beam lifetime gets short when this collimator gap is less than 10mm and drops linearly when it is less than 6mm;
- The collimator gap is set at 4.6mm during the SSRF user operation, in this case, changing the in-vacuum undulator gap has no influence to the beam lifetime;
- The maximum beam current of 300mA @3.5GeV was achieved in the SSRF storage ring on July 18, 2009.

# Lifetime and Collimator Gap



# New Developments

- Top-up operation preparation
- Low emittance lattice commissioning;
- Fast orbit feedback tests;
- New timing system;
- R&D of spare SRF cavity;
- Machine upgrade plan;
- …

# Top-up Operation Preparation

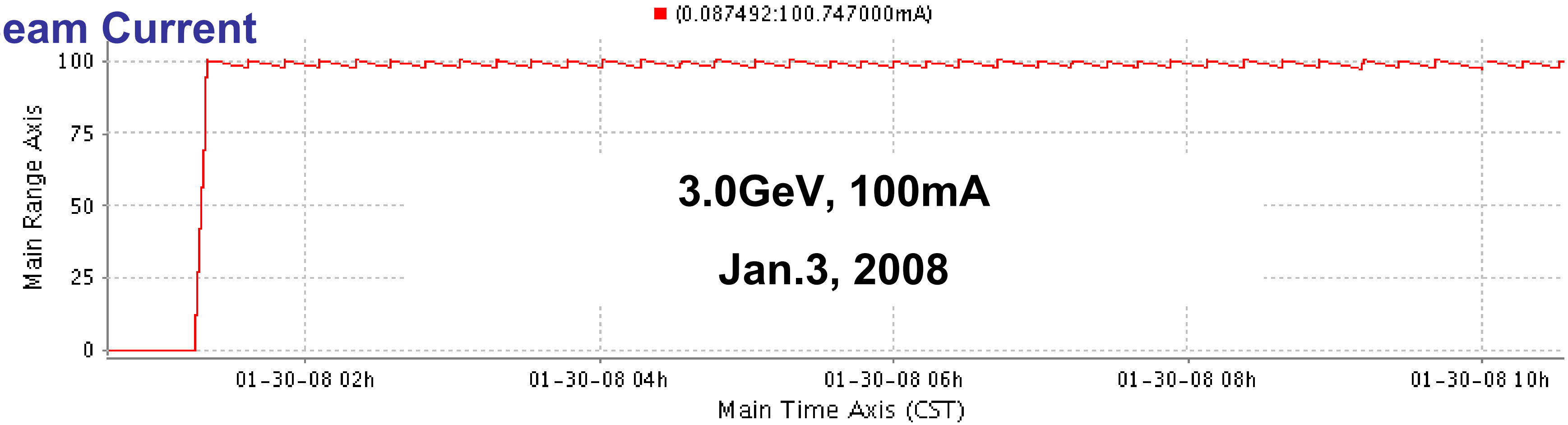
- The top-up operation was tested during machine studies and machine conditioning, top-up operation preparations including beam trace simulation, hard and soft interlocks is under way.

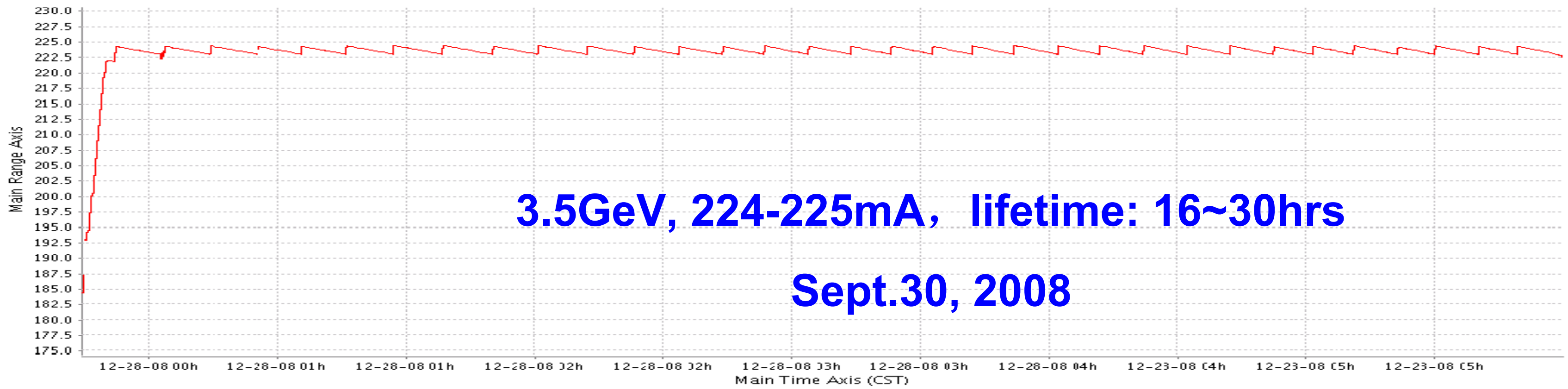
- The horizontal and vertical orbit disturbances from top up injection are suppressed to less than 100um and 30um respectively at an injection efficiency higher than 95%;

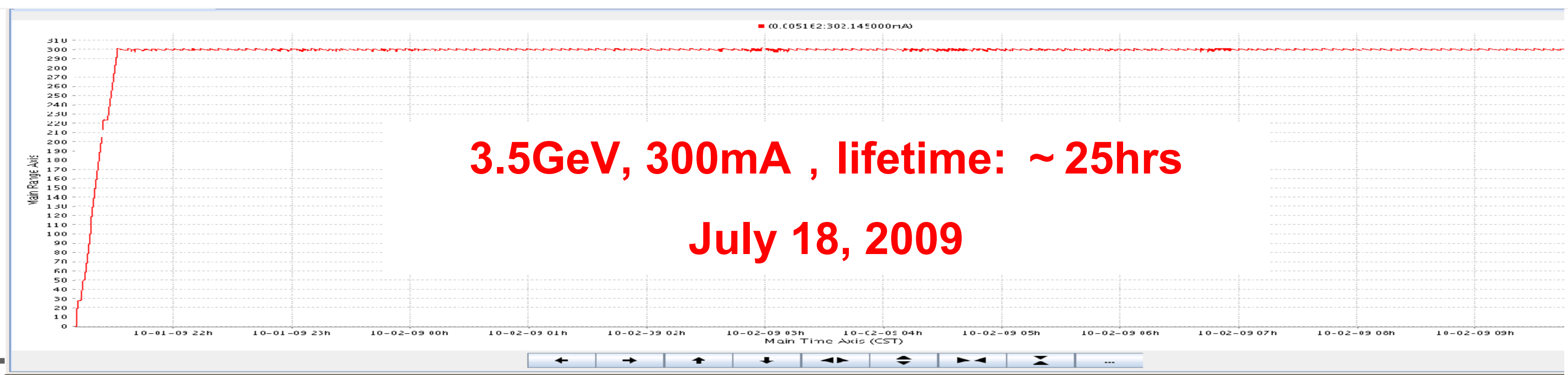
- Beam trace simulation is being carried out against every possible condition in the SSRF storage ring;

- The main interlocks include stored beam current, injecting beam energy, injection efficiency, radiation dose control level in hutches. Collimators are considered to be limiters.

# Beam Current



# Commissioning of Lower Emittance Lattice

- A lower emittance lattice has been optimized by increasing horizontal tune from 22.22 to 23.31, the emittance can be reduced by 10%. This lower effective emittance lattice has been commissioned to a beam current about 200mA.

| | Nominal optics | Lower-emitt. optics |
|---|---|---|
| Beam energy / GeV | 3.5 | 3.5 |
| Circumference / m | 432 | 432 |
| Beam current /mA | 200 – 300 | ~200 |
| Tune (H/V) | 22.22/11.29 | 23.31/11.23 |
| $\beta_x/\beta_y/\eta$ @ the center of the long and standard straight section | 10/6/0.15<br>3.6/2.5/0.10 | 10/6/0.13<br>3.0/2.0/0.09 |
| Natural emittance / nm.rad | 3.9 | 3.5 |
| Effective emittance @ center of the standard straight section | 5.2 | 4.6 |
| Momentum compaction factor | $4.27\times10^{-4}$ | $4.03\times10^{-4}$ |
| Natural energy spread | $9.84\times10^{-4}$ | $9.84\times10^{-4}$ |

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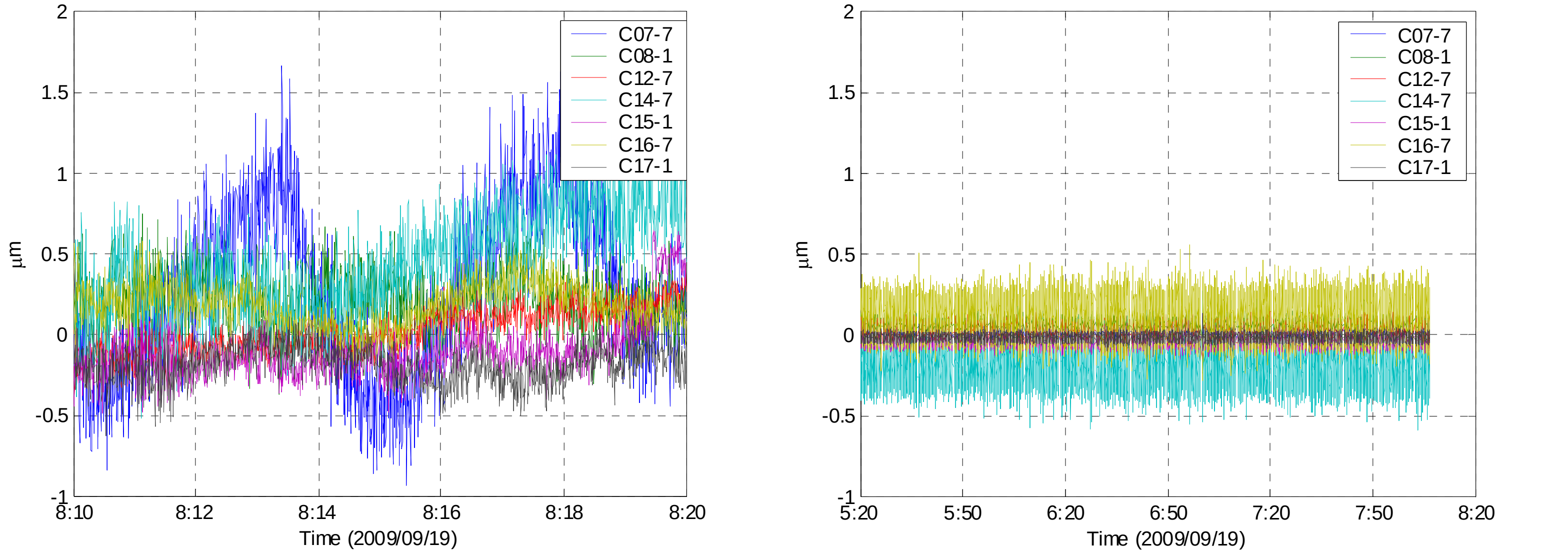
# Fast Orbit Feedback System

## Orbit noise suppression test in time domain



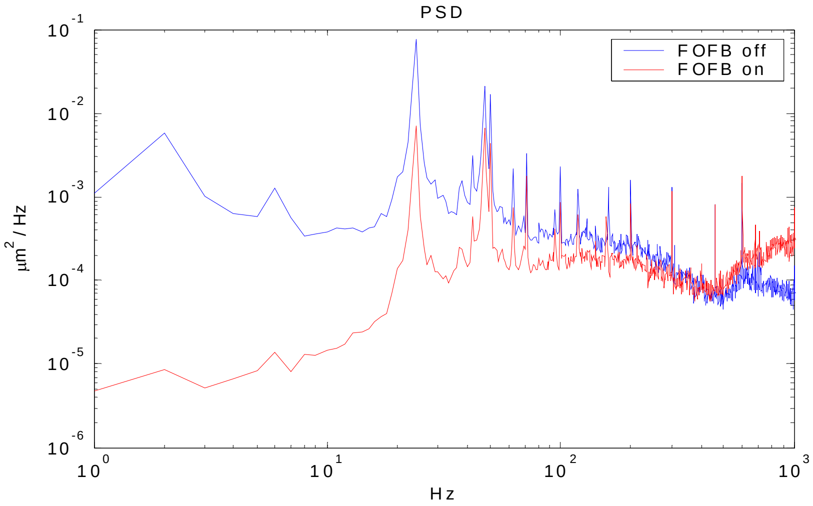

*** measured on Sep 18, 2009**

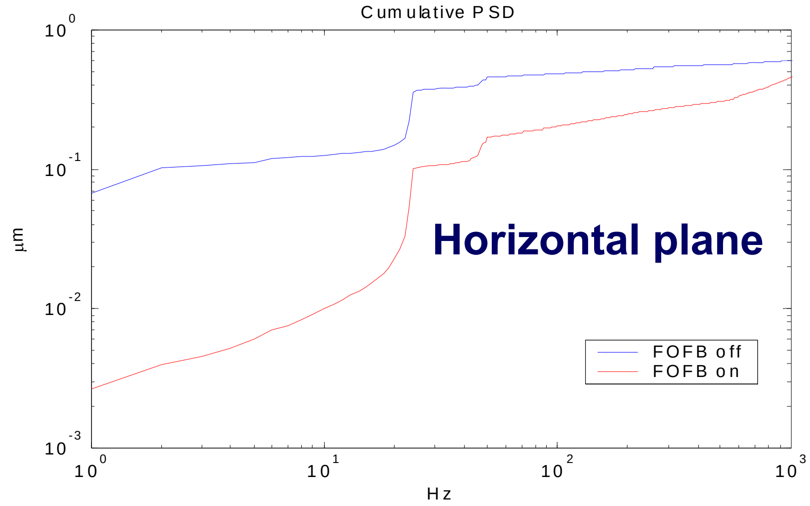
*** orbit (vertical plane) is acquired by Libera SA channel (BW@10Hz)**

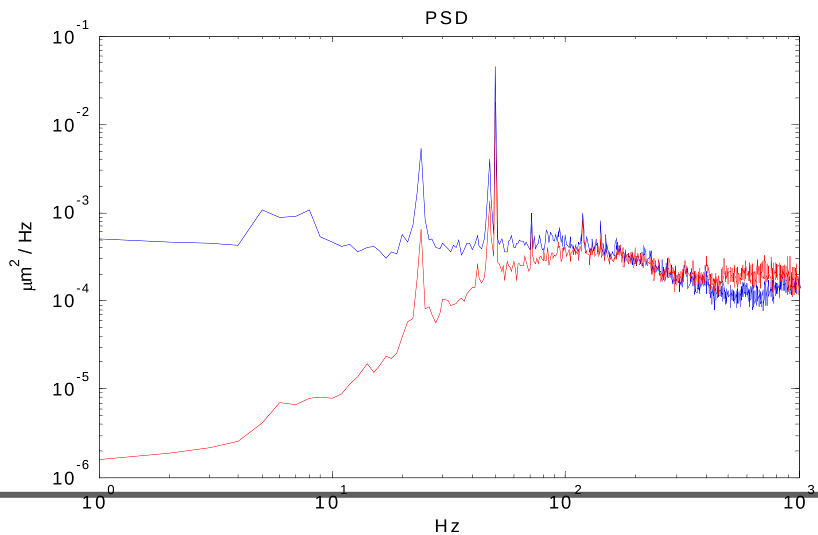
*** right figure: FOFB on; left figure: FOFB off**

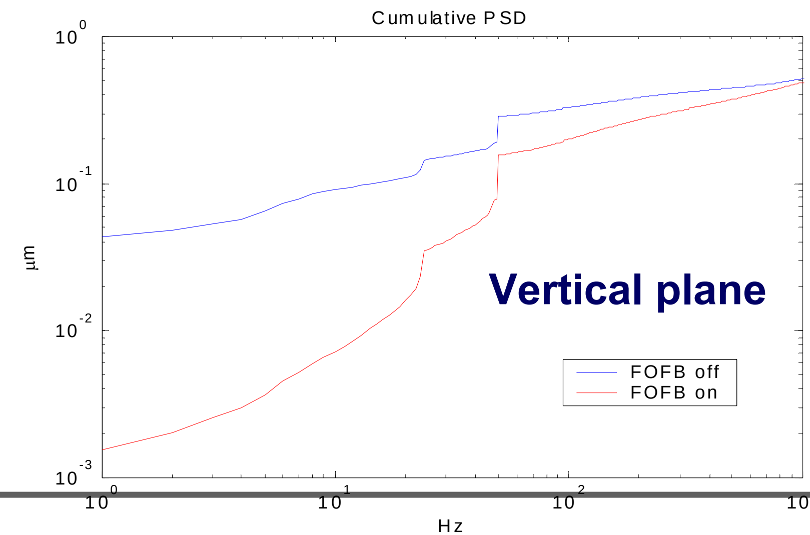
*** zero = 0.9; gain = 0.05**

# Fast Orbit Feedback Tests (Frequency Domain)



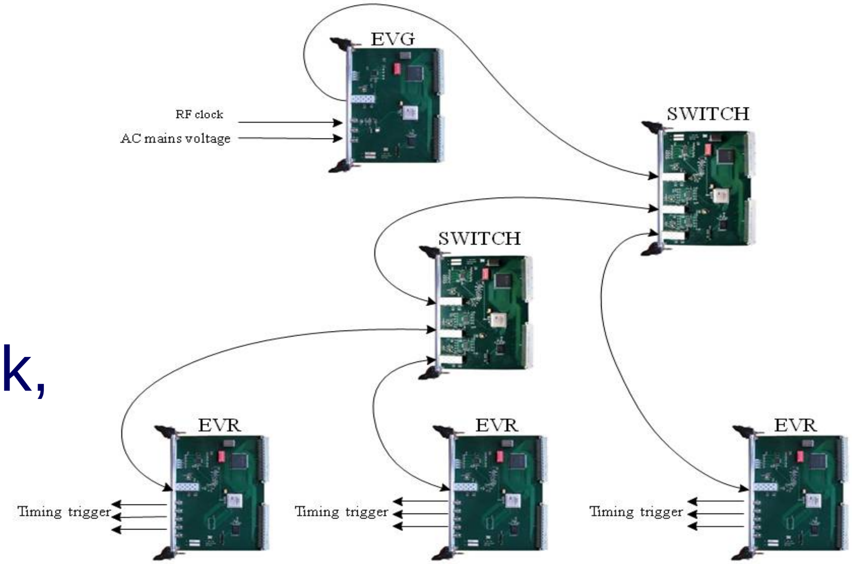



# New Timing System Development

- A new timing system based on real-time synchronized data bus, which is fully compatible with present event timing system, is developed at SSRF, its rms jitter respect to RF clock is less than 10ps.

- New timing system can be used to distribute event trigger and exchange data and integrate orbit feedback, interlock and timing into a uniform system.



# R&D of Spare SRF Cavity

- Three ACCEL SRF cavities SSRF purchased are all in routine operation at the storage ring, at least one spare cavity is needed to assure a reliable user operation;
- A R&D based on KEK SRF cavity technology is being carried out, aiming at knowing the technical details to lead a high stable operation besides constructing a SRF cavity;
- Niobium cavities are manufactured by deep-drawing and welded by EBW to validate the technology availability in China;
- After BCP and high pressure rinsing, two niobium cavities are ready to go vertical test.

# R&D of SRF Spare Cavity

Half cell deep-drawing

Half cells and transition parts

Coupler and pick-up ports on SBP

Cavities after EBW

High pressure pure water rinsing (HPR) after BCP

Cavity hung on vertical test facility after Indium seal, waiting for pumping

# Machine Upgrade Plan

- Top-up operation is of high priority in the machine performance upgrades, it is planed to be implemented before summer of 2011;
- The storage ring is routinely operating with slow orbit feedback and RF frequency feedback. The fast orbit feedback will be implemented right after top-up operation;
- First canted undulators for new protein crystallography beamlines will be installed in two years;
- Superconducting wiggler (~5T) will be built and installed;
- A third harmonic cavity system for controlling the bunch length is planed to install at the storage ring;

# Beamlines for National Protein Science Facility

- Three Protein crystallography beamlines
  - Protein micro-crystals: membrane proteins etc.
  - Crystals with large unit cell: macromolecular complexes and assemblies
  - High throughput crystal screening and structural determination
- Small angle X-ray scattering beamline(Bio-SAXS)
  - High performance (very small angle X-ray scattering) beamline for the studies of protein dynamics and interaction
- IR Beamline with two end-stations
  - Time-resolved spectroscopy for protein dynamics and interaction
  - Micro-spectroscopy and imaging for structural and functional studies of cell, tissue and organisms

# SSRF Phase-II Beamlines

- 24 SSRF phase-II beamlines have been proposed to the government, they will be constructed and commissioned from 2011 to 2016;
- Some of new beamlines will make full use of the brilliant beam and the partial coherence to achieve high spatial resolution, high energy resolution and high time resolution;
- Detailed discussions and studies on the phase-II beamlines and experimental stations is under way;

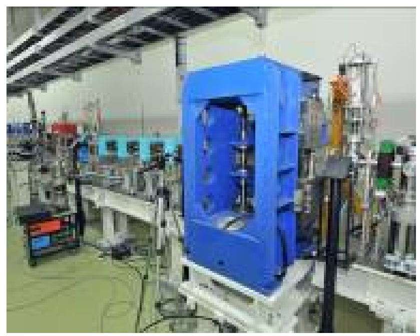
In addition, there are some beamlines to be constructed by using other funding sources

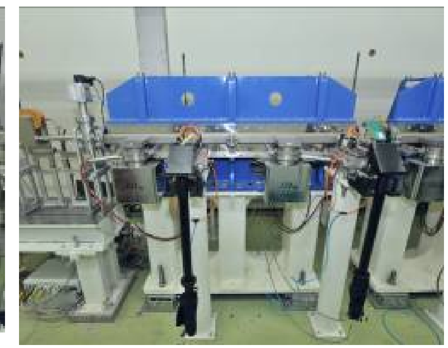
# Summary

- Since May 6, 2009, the SSRF has delivered more than 4000 hours beam time to SR experiments and served more than 1250 users to perform experimental studies;
- The machine availability and MTBF are 95.6% and 31.8 hours respectively for the passed year, and they will be continually improved in the following years;
- Top-up operation and fast orbit feedback are the next major upgrades of the SSRF machine performance;
- About 30 beamlines will be constructed and commissioned at SSRF in the following 5-6 years.

# SDUV-FEL Tests

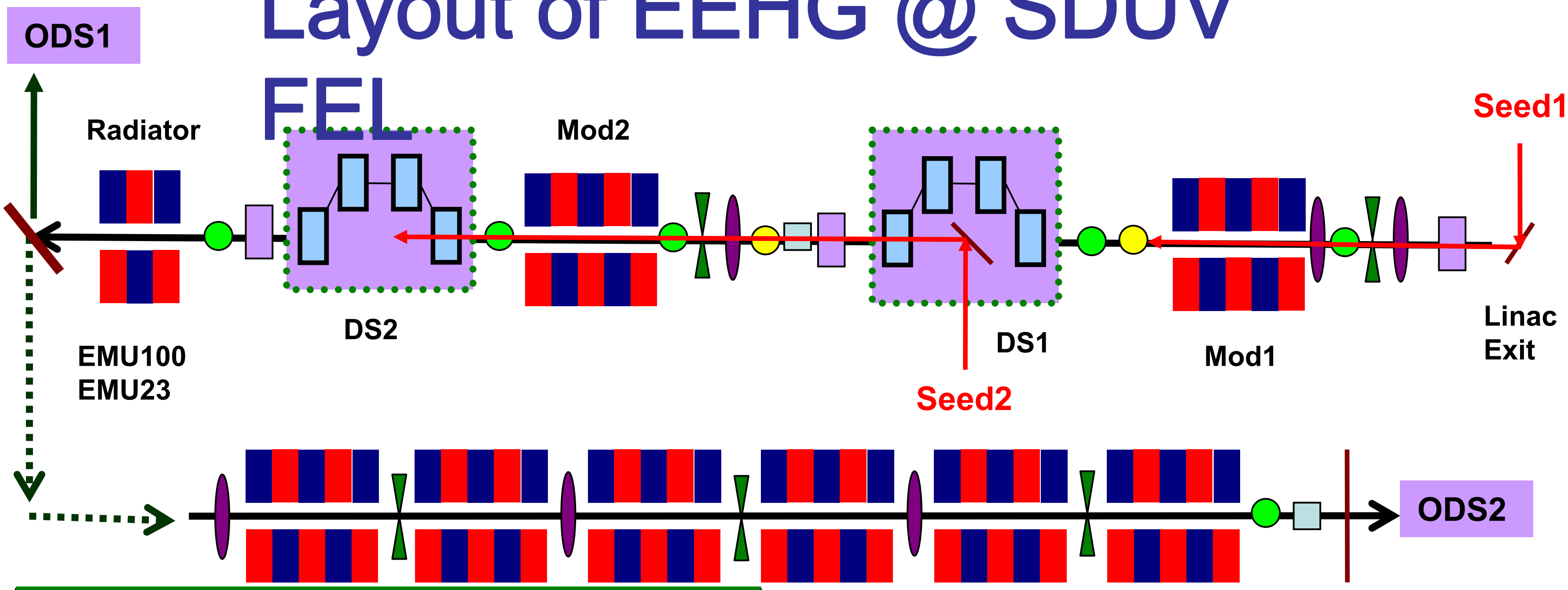
- SASE
- HGHG
- EEHG
- Cascading





**ODS=Optical Diagnostics Station**

# Layout of EEHG @ SDUV FEL



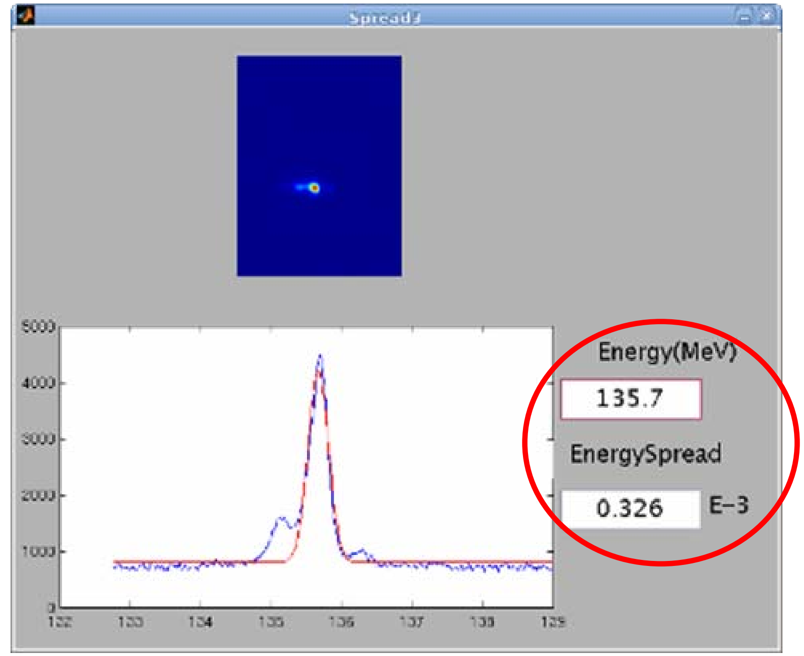

| Parameters | Measurement |
|---|---|
| Beam energy | 136MeV |
| Beam energy spread (projected) | ~0.03% |
| Normalized emittance | 4~5mm-mrad |
| Bunch charge | 100~200pC |
| Seed laser wavelength | 1047nm |
| Seed laser pulse length | 8ps |
| Seed laser power (1, 2) | 0~15MW |
| Modulator1 (EMU65) | 10*6.5cm |

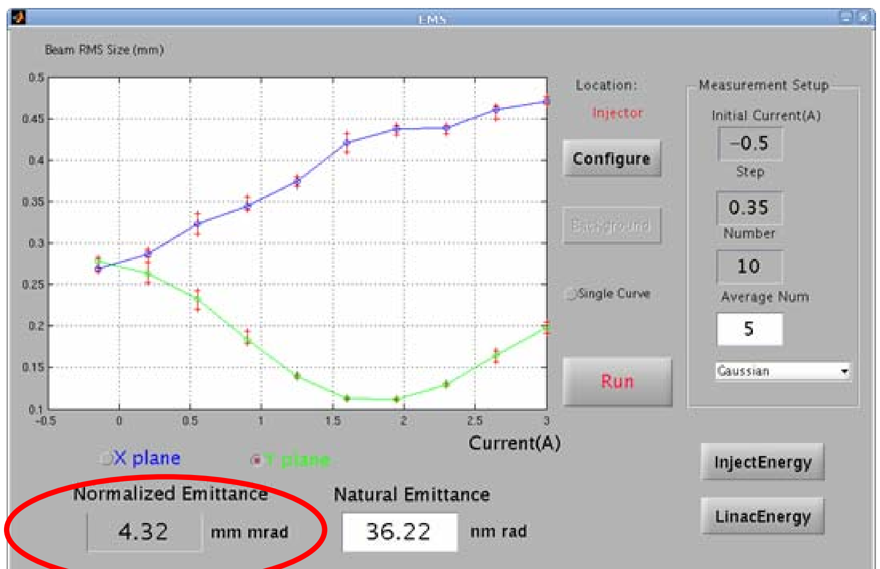
| Parameters | Measurement |
|---|---|
| Modulator2 (PMU50) | 10*5cm |
| R56 of dispersion section 1 | 0~70mm (16A) |
| R56 of dispersion section 2 | 0~1mm (2.2A) |
| Radiator1: EMU100 (1, 2) | 2*10cm |
| Radiator2: EMU23 | 10*2.3cm |
| Radiator3: PMU25 | 6*60*2.5cm |

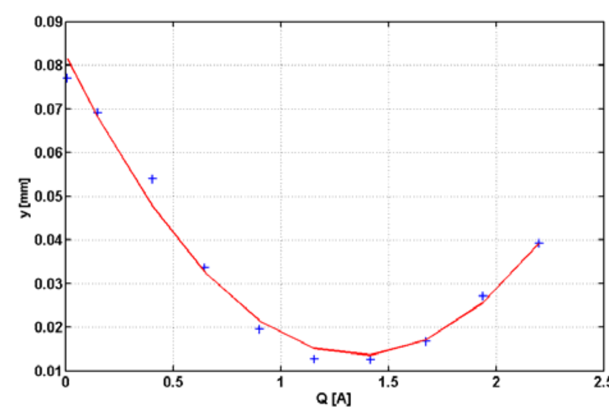
ODS=Optical Diagnostics Station

# Linac Commissioning Results

- 136MeV
- Energy spectrometer
- Emittance measurement
- ……



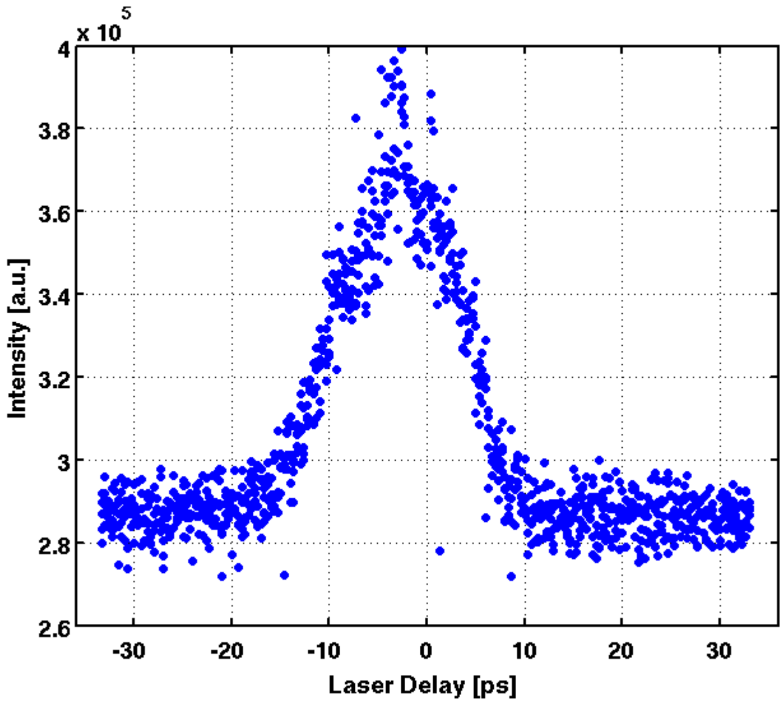



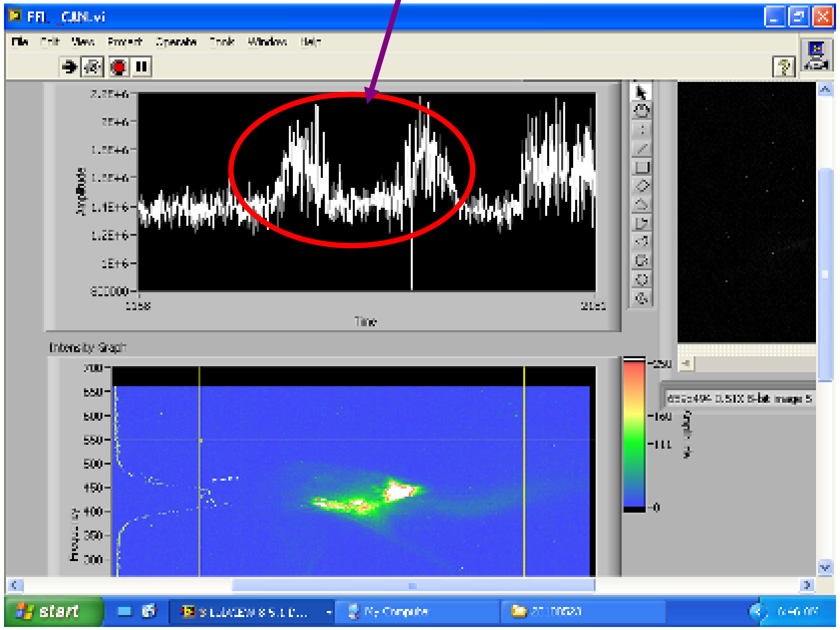
# Modulators Commissioning

- Laser pulse: 8ps (FWHM)
- electron beam: ~10ps
- Timing jitter is NOT an issue

**CUR Enhancement from small radiator EMU100**



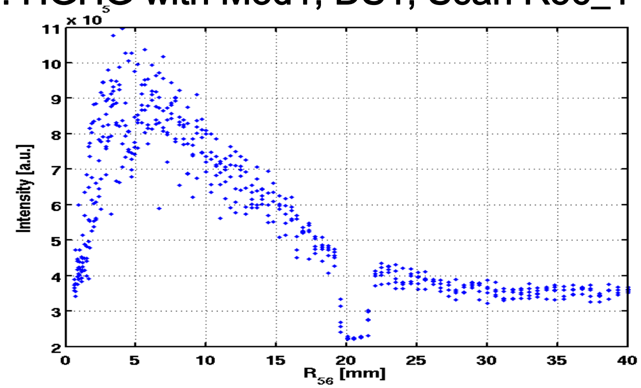

**modulator1**



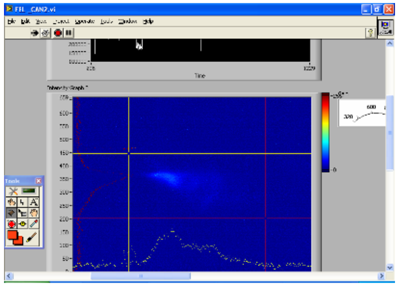

**modulator2**

# How to separate HGHG with EEHG

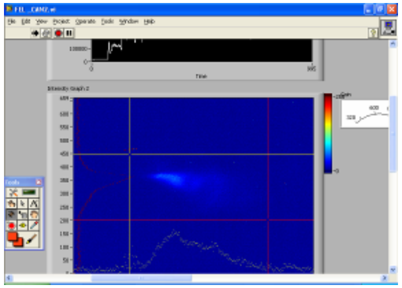
Step 1: HGHG with Mod1, DS1, Scan R56_1




Increase the R56_1 to NO Enhancement

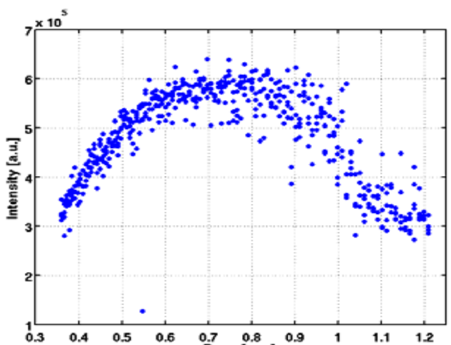


Seed Laser1 OFF



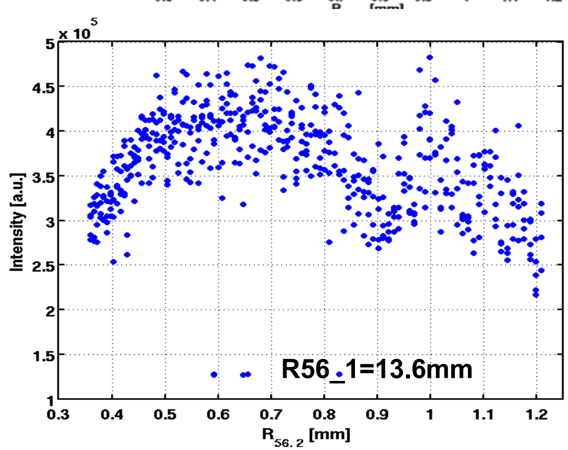
Seed Laser1 ON

Step 2： Turn off Mod1, DS1,
Turn on Mod2, DS2, HGHG, Scan R56_2

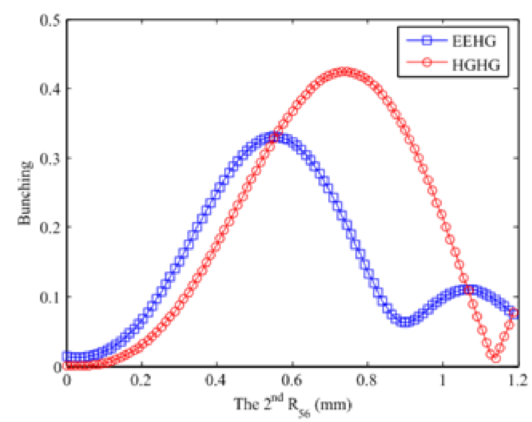



•"Double peaks"are observed with EEHG setup, which agrees with echo theory.

Step 3: Turn on Mod1, DS1, EEHG, Scan R56_2, See double peaks




Simulation results



# Summary of Echo experiment

- EEHG Proof-of-Principle experiment has been carried out in SDUV FEL at SINAP.
- So far, it seems that experimental results agree well with predictions of echo theory, with typical echo effect (‘double peaks’) observed?

Plans for near future:

- EEHG FEL saturation at 3rd harmonics
- Higher harmonic bunching with EEHG


Thank you for your attention


谢谢！