Low Emittance Engineering and Performance at SSRF

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For the SSRF Team

Shanghai Synchrotron Radiation Facility
2008.06.10

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Status of SSRF Project

Introduction to the SSRF Project

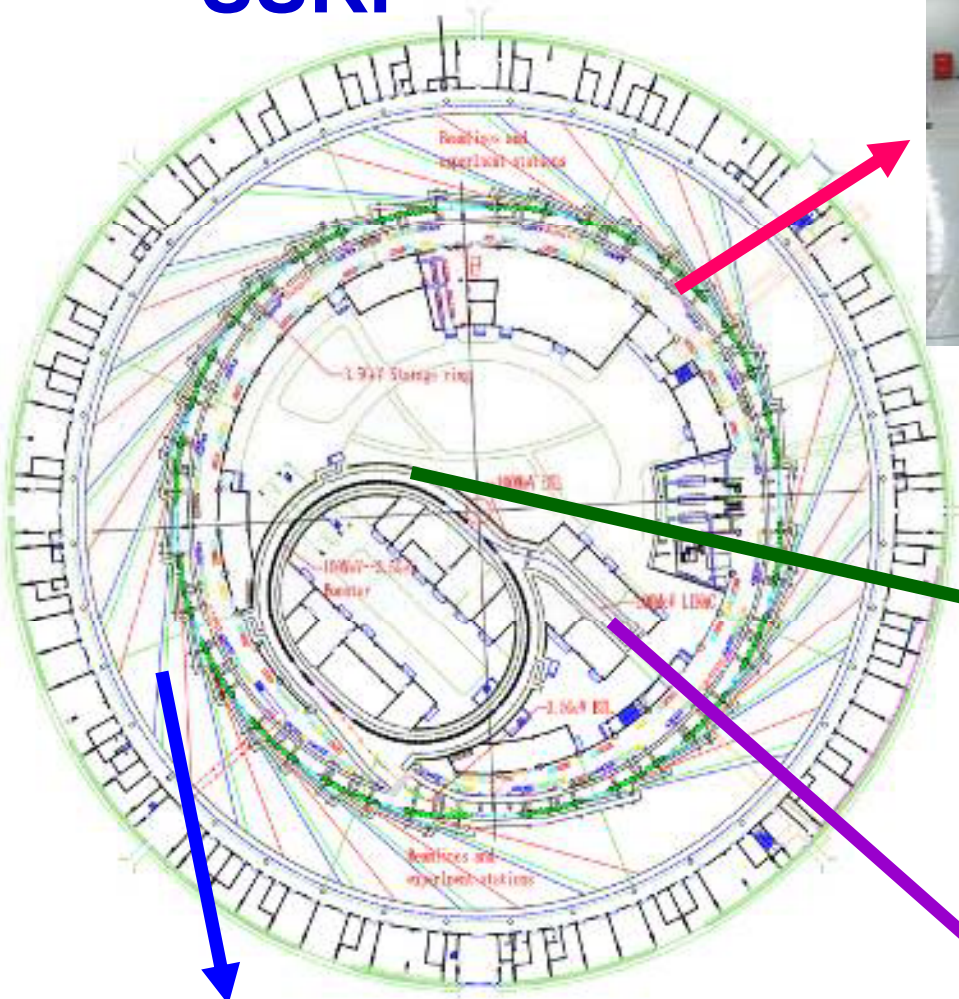
- Shanghai Synchrotron Radiation Facility (SSRF) is a 3.5GeV 3rd generation light source, it is now under construction at Shanghai Zhang-Jiang High-Tech Park;
- The project is jointly founded by central government, Shanghai local government and Chinese Academy of Sciences, its investment budget of about 150MUSD is equally shared by the three founding partners;
- The SSRF groundbreaking was made on Dec.25, 2004, and its user operation is scheduled to start from Apr. 2009;

The SSRF Construction Schedule

- Dec. 2004 ~ Sept. 2006: Building construction
- Jun. 2005 ~ Mar. 2008: Accelerator equipment and components manufacture and assembly
- Dec. 2005 ~Dec. 2008: Beamline construction and assembly
- Apr. 2007 ~ Jul. 2007: Linac commissioning
- Oct. 2007 ~ Mar. 2008: Booster commissioning
- Apr. 2008 ~ Oct. 2008: Storage ring commissioning
- Nov. 2008 ~ Mar. 2009: ID Beamline commissioning
- Apr. 2009: The SSRF operation begins

Layout of the SSRF Campus (Design)

SSRF



3.5GeV Storage Ring

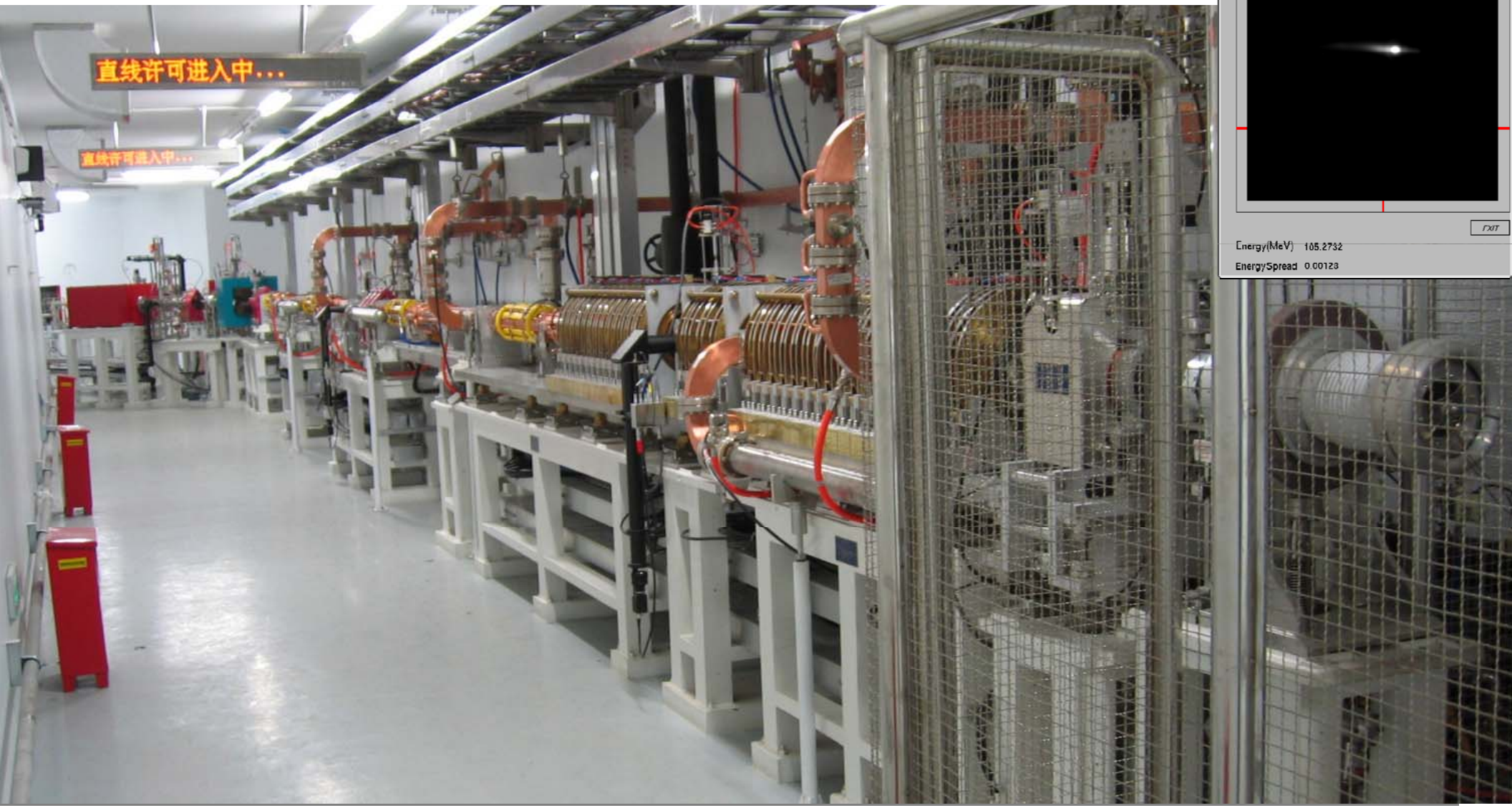
C=432m

Booster
C=180m

Beamline
and station

150MeV
Linac

150MeV Linac



May 15, 2007 Commissioning Start

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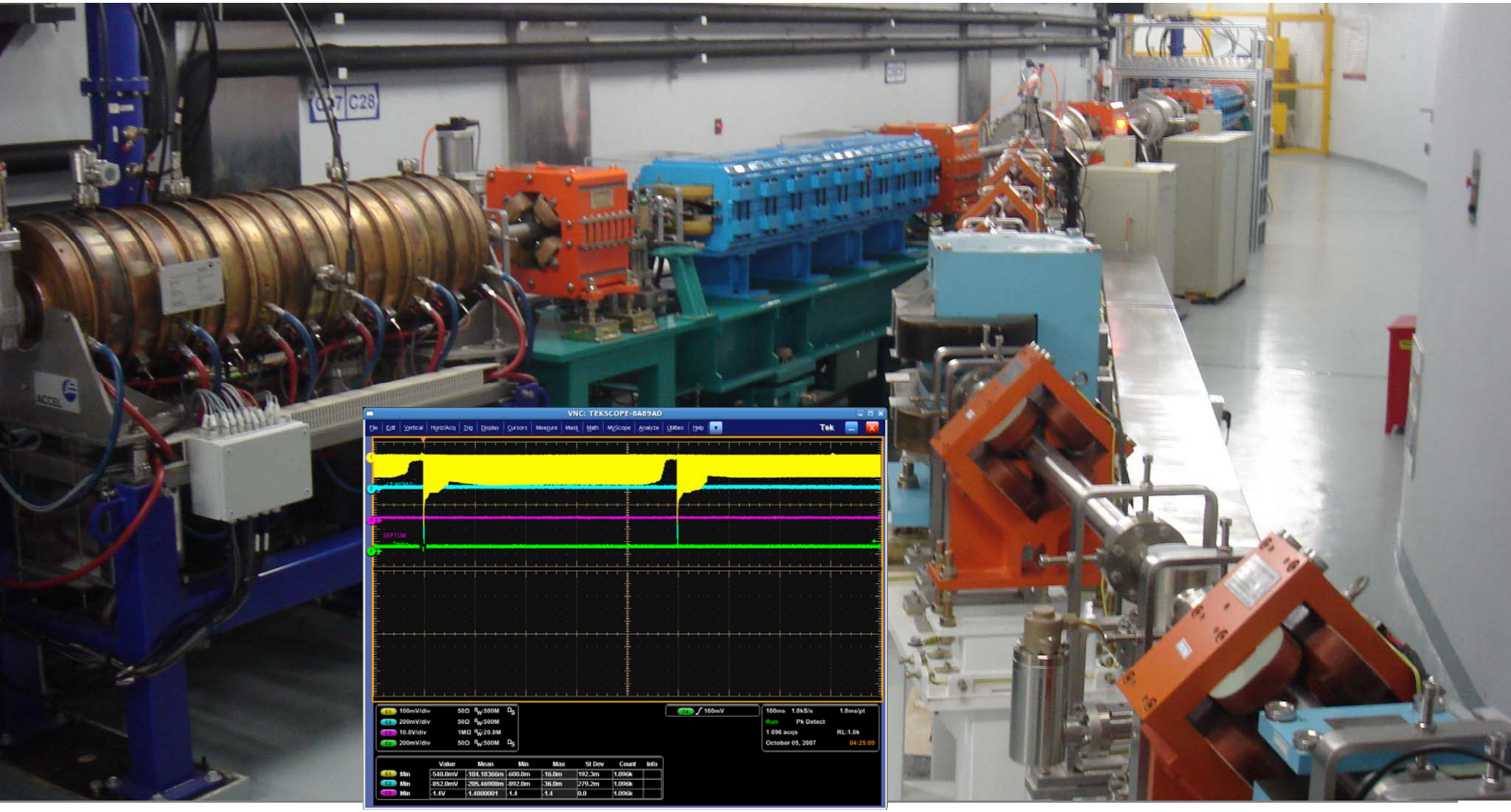
150MeV – 3.5GeV Booster



Sept. 30, 2007 Commissioning Start

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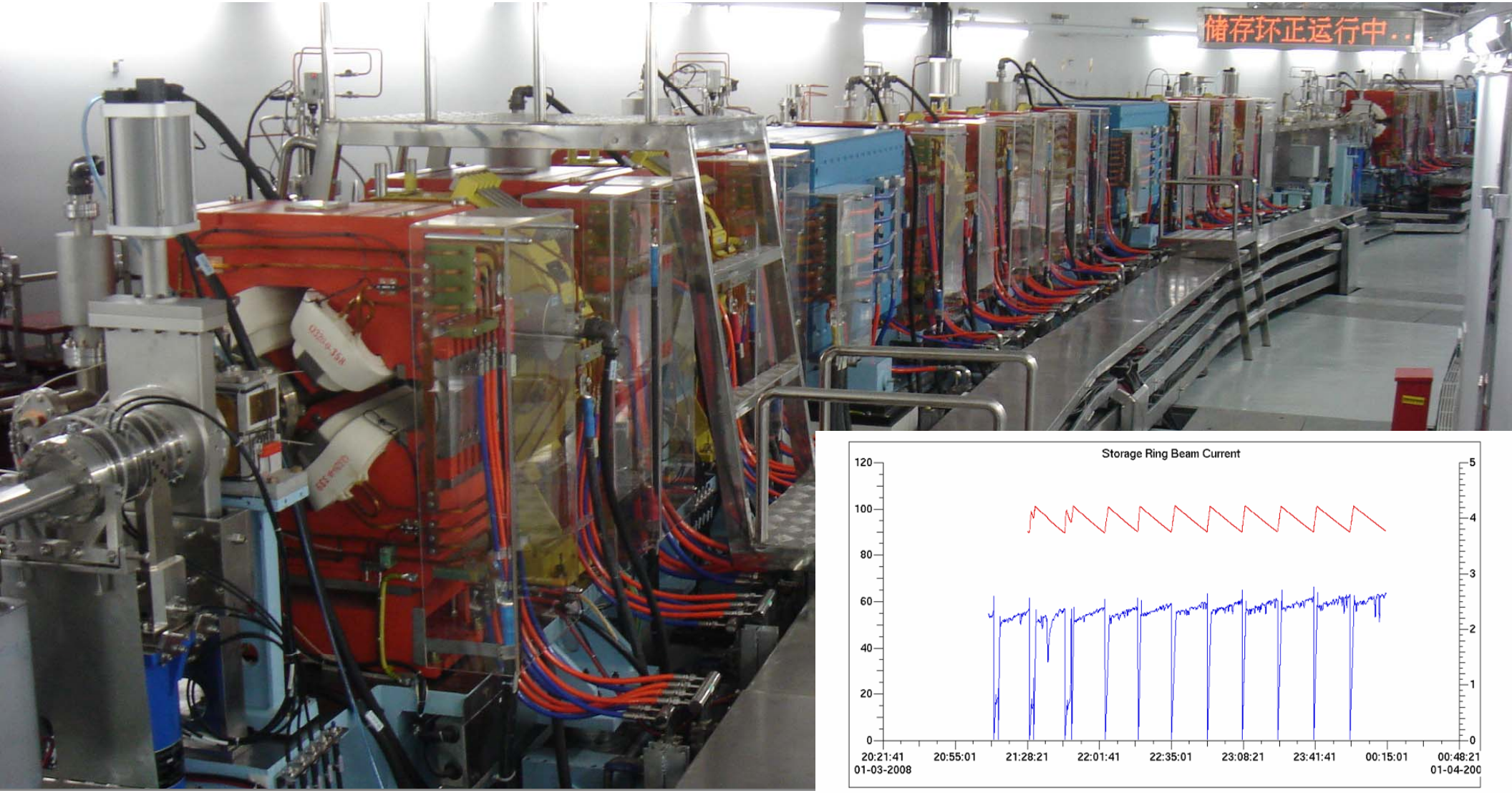
3.5GeV Storage Ring



Dec. 21, 2007 Commissioning Start

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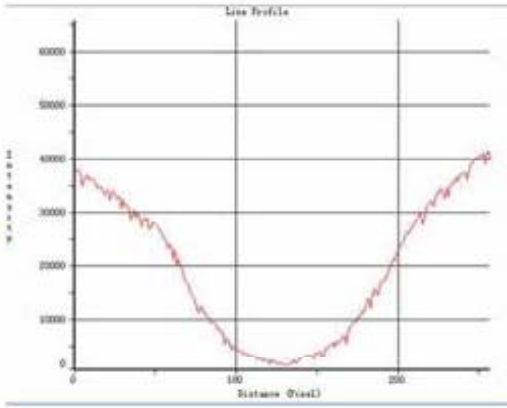
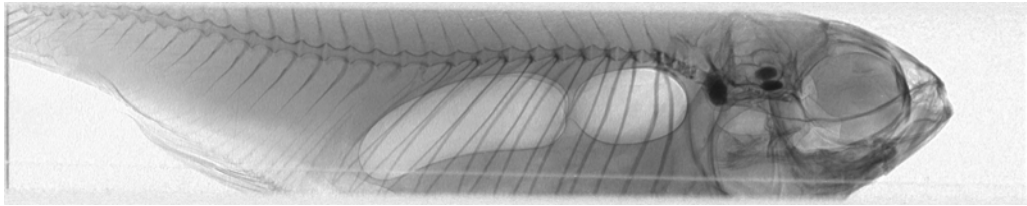
Beamlines for Phase I

- Macromolecular Crystallography (IVU.) (Dec. 2008)
- High-Resolution Diffraction
  June, 2008 Commissioning
- X-ray Absorption Fine Structure Spectroscopy (W.)
  (Oct. 2008)
- Hard X-ray Micro-focus and Application (IVU) (Dec. 2008)
- X-ray Imaging and Biomedical Application (W) (Oct. 2008)
- X-ray Scattering May, 2008 Commissioning
- Soft X-ray Microscopy (EPU) (Dec. 2008)

X-ray Scattering Beamline



May 9, 2008 Commissioning Start

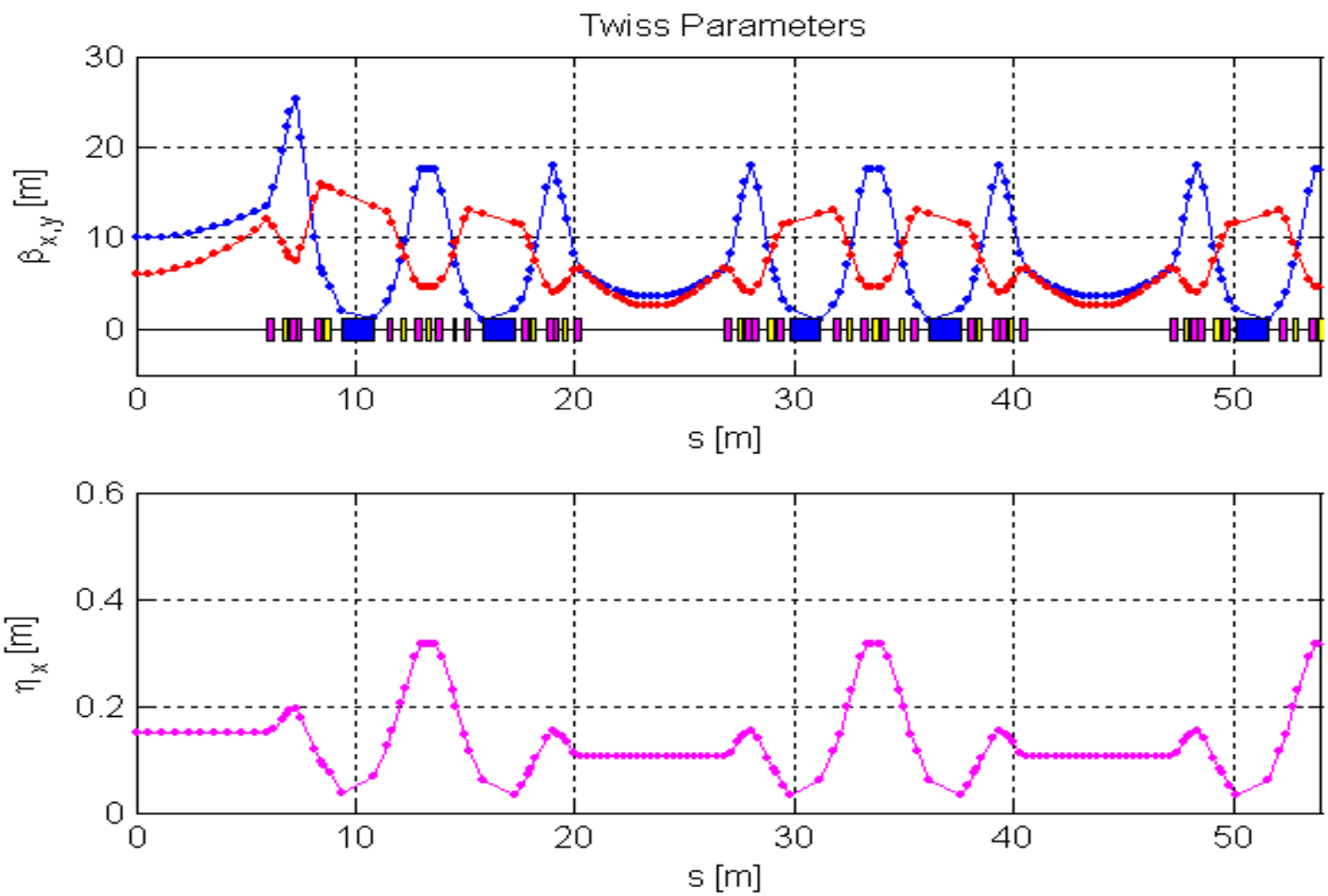


Basic Requirements for Engineering

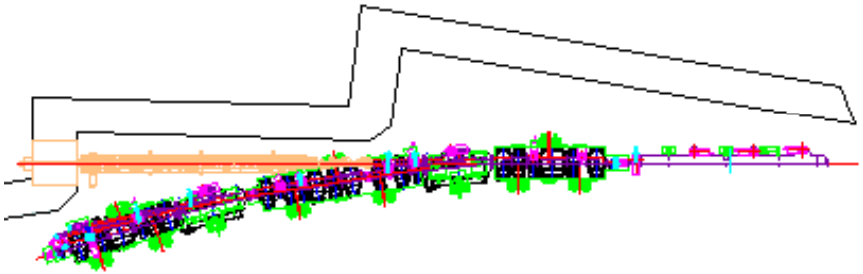
Main Parameters of Storage Ring

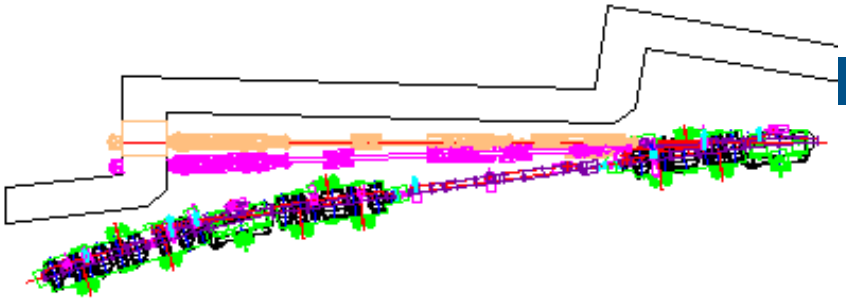
Lattice Structure	DBA	Low-emittance mode	Normal Mode
Enenrgy	GeV	3.5	3.5
Circonference	m	432	432
Natural Emittance	nm· rad	3.9	11. 2
Current：Multi-bunch（Single）	mA	200~300(5)	200~300(5)
Number of Cells		20/4	20/4
Straights: Length×Number	m	12×4、6.5×16	12×4、6.5×16
$\beta_x/\beta_y/\eta_x$ in middle of 12m straight	m	10.0/6.0/0.15	10.0/6.0/0.0*
$\beta_x/\beta_y/\eta_x$ in middle of 6.5m straight	m	3.6/2.5/0.10	3.6/2.5/0.0*
Betatron Tune Q_x/Q_y		22.22/11.32	22.22/11.32
Chromaticity ξ_x/ξ_y		-56/-19	-56/-19

Lattice Functions of SSRF Ring



Beam Sizes at Source Points





ID beamlines:

Share the front-end

BM beamlines:
Separate front-ends

Source Point	σ_x(μm)	σ_x'(μrad)	σ_y(μm)	σ_y'(μrad)
Standard Straight (6.5m)	158	33	9.9	3.95
Long Straight (12.0m)	247	20	15	2.55
1°@upstream of SS	70	114	22	1.97
3.1°@upstream of SS	53	94	22	1.97
1°@upstream of LS	77	116	23	1.79
3.1°@upstream of LS	56	96	23	1.79

Beam Stability Criteria

- **Photon**

  Photon beam intensity $\Delta I/I$: ~0.1%

  Photon energy resolution $\Delta E/E$: ~10^{-4}

- **Electron**

  Emittance control $\Delta\varepsilon_x/\varepsilon_x$: 20% (10% of beam size)

  Position stability $\Delta\sigma_x/\sigma_x$ and $\Delta\sigma_y/\sigma_y$: 10%

  Angular stability $\Delta\sigma'_x/\sigma'_x$ and $\Delta\sigma'_y/\sigma'_y$: 10%

Orbit Stability Requirement

Source Point	σ_x(μm)	σ_x'(μm)	σ_y(μm)	σ_y'(μm)
Short Straight (6.5m)	<16 μm	<3 μrad	<1 μm	<0.4 μrad
Long Straight (12.0m)	<25 μm	<2 μrad	<1.5 μm	<0.3 μrad
1°@upstream of SS	<7 μm	<11 μrad	<2 μm	<0.2 μrad
3.1°@upstream of SS	<5 μm	<9 μrad	<2 μm	<0.2 μrad
1°@upstream of LS	<8 μm	<12 μrad	<2 μm	<0.18 μrad
3.1°@upstream of LS	<6 μm	<10 μrad	<2 μm	<0.18 μrad

- **Stability goal in SSRF:**

Horizontal orbit stability < 5μm

Vertical orbit stability <1μm

Engineering Requirements for SSRF

❑ Long term

- Slab deformation at ring tunnel and experimental hall

  Δz <100μm/10m/year

  Δz <10μm/10m/day

  Δz <1μm/10m/hour

❑ Medium term

- Air temperature stability (12hours)

  Ring Tunnel: T= ~26^{0}C ; ΔT <±0.1^{0}C

  Experimental: T=22 ~26^{0}C ±2^{0}C

- Cooling water temperature stability (12hours)

  Ring tunnel: T= ~ 30^{0}C ±0.1^0

  Magnet PS: T= ~ 30^{0}C ±1^{0}C

Stability Requirements from SSRF

❑ Short term

Slab vibration amplitude (0.2 ~100Hz)

Original: Vertical: $\Delta z < 1\mu m$ (peak to peak)

Horizontal: $\Delta x < 2\mu m$ (peak to peak)

Modified to integrated rms displacement above 1Hz:

Vertical: $\Delta z < 0.15\mu m$ (quiet)

$\Delta z < 0.3\mu m$ (noisy)

Horizontal: $\Delta x < 0.3\mu m$ (quiet)

$\Delta x < 0.6\mu m$ (noisy)

Main Requirements for the Mechanical System

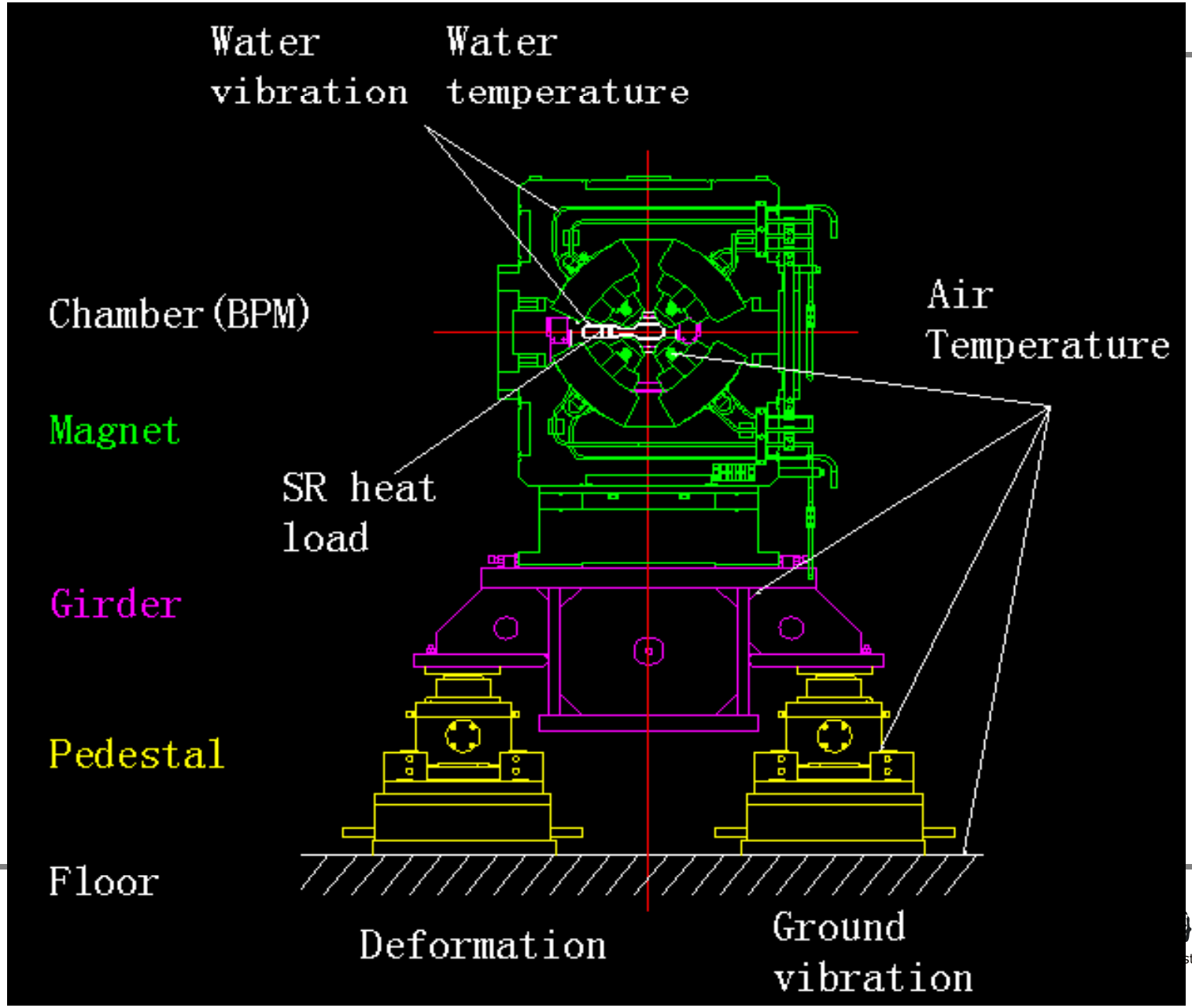
❑ Performance

- First eigenfrequency = > 30Hz
- The frequency response function value at the first eigenfrequency < =10

❑ Alignment

	Between girder	Inside girder
H	0.15mm	0.08mm
V	0.15mm	0.08mm
L	0.5mm	
R	0.2mrad	

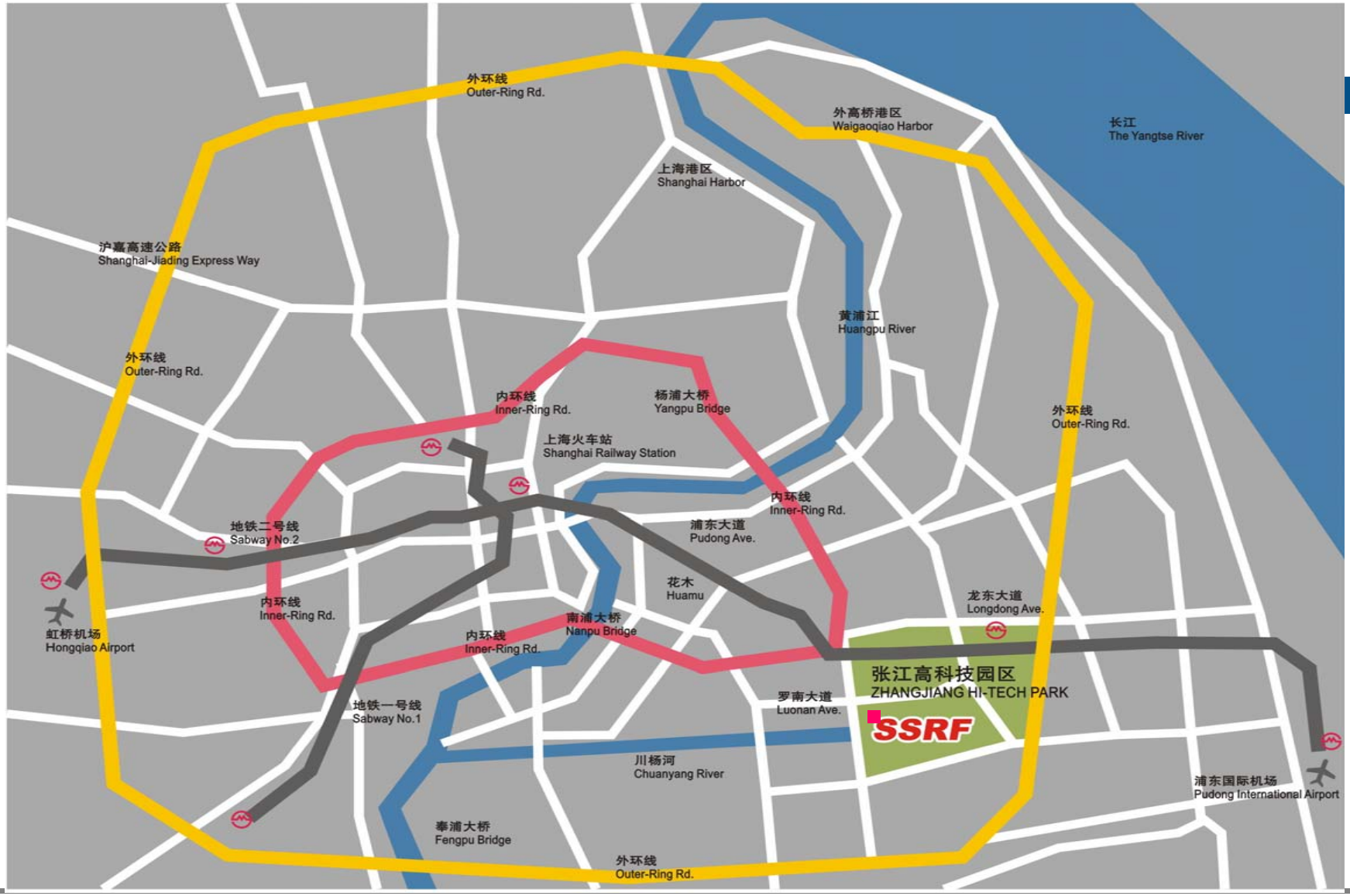
Mechanical Stability Issues



- Deformation
  - Temperature
  - Heat load
  - Ground
- Vibration
  - Source
  - Frequency
  - Damping

Site Condition, Building Design and Performance

The SSRF Site Location



- Near downtown Shanghai
- New developing area

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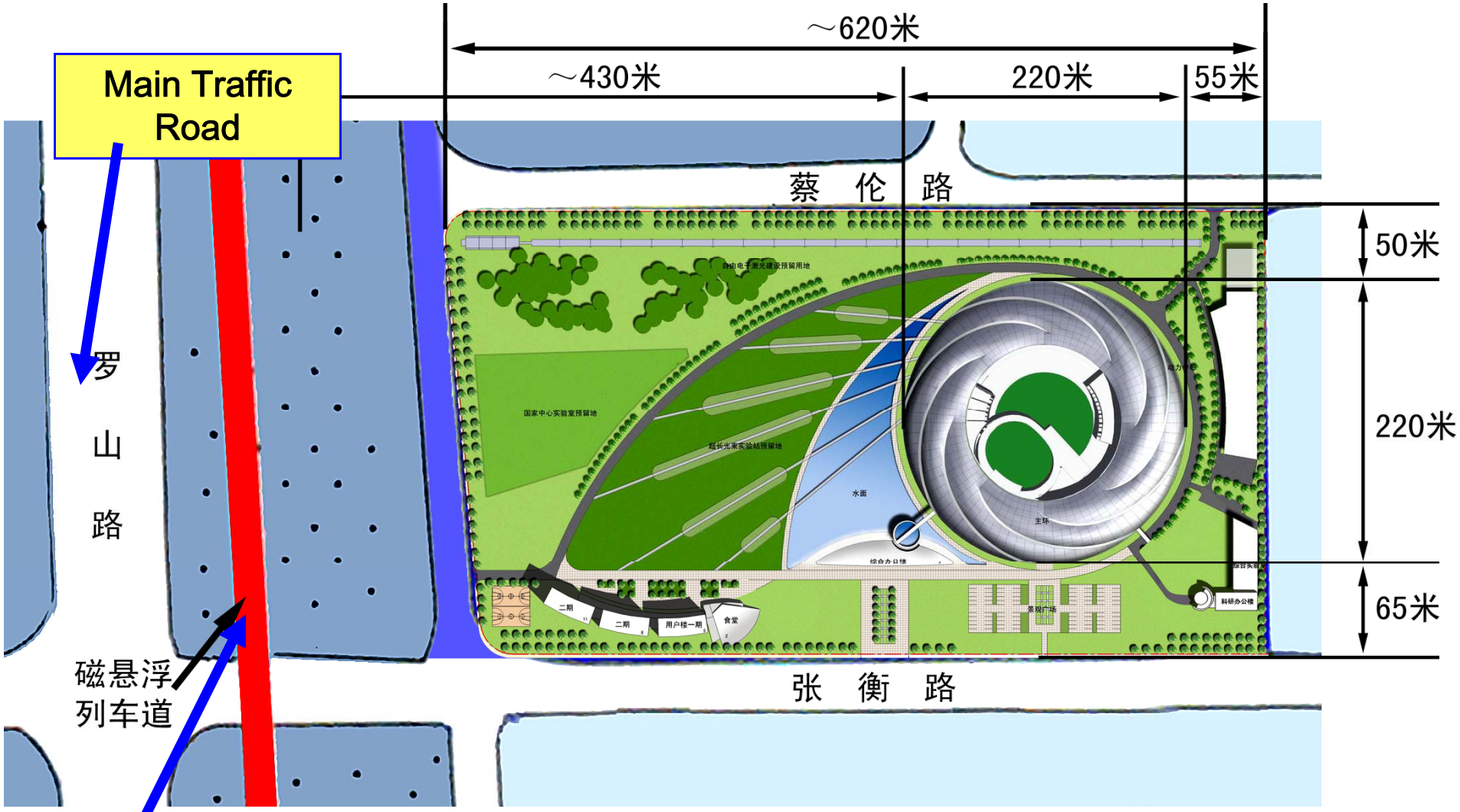
Layout of site



Mag-level Train

Geologic conditions

- Alluvium area of Yangzhi river
- Rock bed is about 300m underground
- Soft soil and low ground wave velocity (110m/s)

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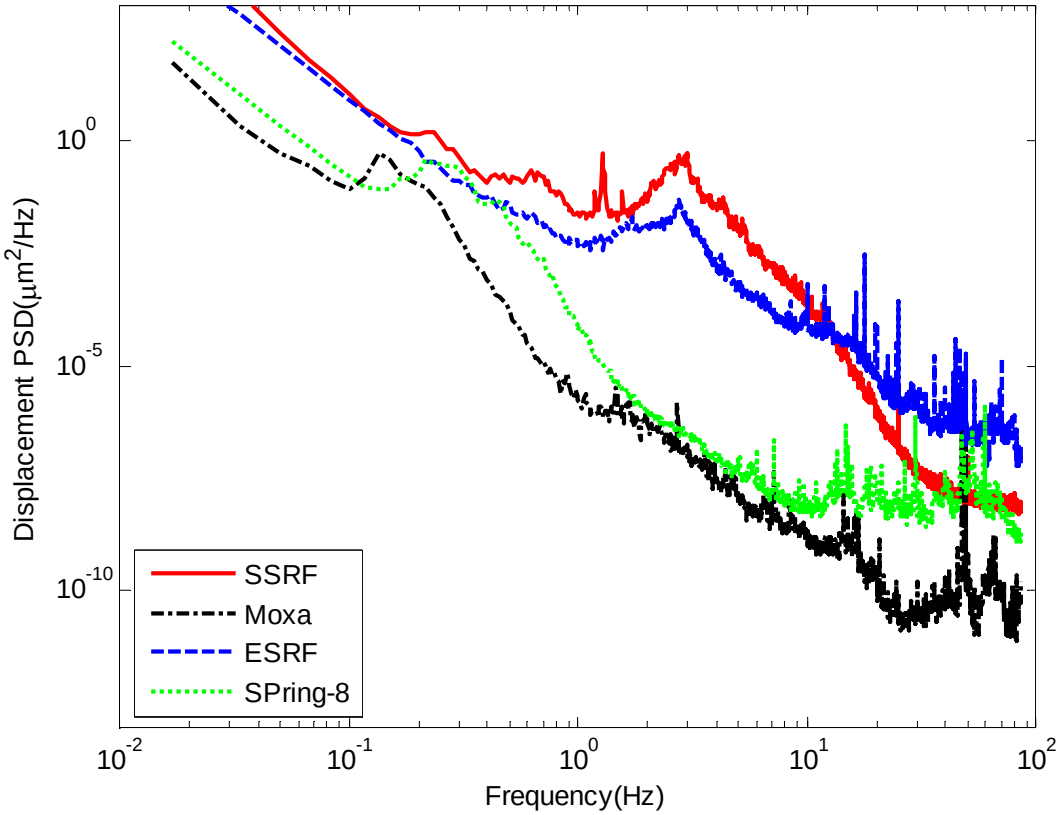
Ground Vibration

- Ground vibration is the most determinative effect !

- Minimize noise sources.

- Use various feedback.



Comparison of site vibration

Peak to Peak distribution without highest 5% Selected Data

Location	Maximum pp (nm)	FWHM (nm)	Average RMS (nm)	SD σ (nm)	Quiet RMS (nm)	Noisy RMS (nm)
1 Seismic Station Moxa	7	17	0.6	0.1	0.5	0.9
2 Salt Mine Asse	12	35	0.5	0.1	0.5	0.7
3 CERN LHC Tunnel	21	53	1.8	0.8	0.9	2.9
4 Spring-8 Harima	22	40	2.0	0.4	1.8	2.5
5 FNAL Batavia	23	49	2.9	0.9	2.2	4.0
6 LAPP Annecy	35	59	3.3	1.6	1.9	7.0
7 IHEP Beijing	49	18	8.4	0.5	8.1	9.0
8 SLAC Menlo Park	60	105	4.8	1.2	4.1	7.4
9 APS Argonne	68	56	10.5	1.0	9.8	11.0
10 ALBA Cerdanyola	87	125	18.3	9.5	9.1	42.0
11 DESY TESLA	104	160	17.4	8.4	9.3	35.9
12 DESY XFEL Osdorf	150	195	28.9	11.9	19.5	48.4
13 DESY Zeuthen	105	235	64.0	40.4	88.5	75.6
14 ESRF Grenoble	155	175	71.6	34.9	40.2	137.2
15 DESY XFEL Schenefeld	180	245	38.7	16.6	35.1	70.0
16 DESY HERA	170	200	51.8	18.9	34.8	77.0
17 KEK Tsukuba	170	210	78.0	36.0	38.0	125.1
18 BESSY Berlin	245	160	72.8	28.1	53.1	140.7
19 SSRF Shanghai	550	1000	292	164	102	444

Design of the Slab and building

- Slab for ring tunnel and experimental hall are separated with building
- Bored piles with base grouting

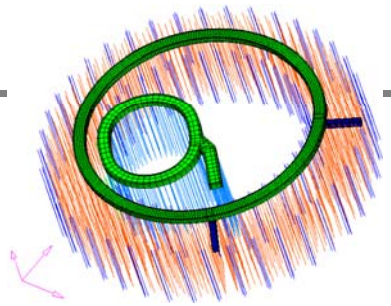
  Number: 2100

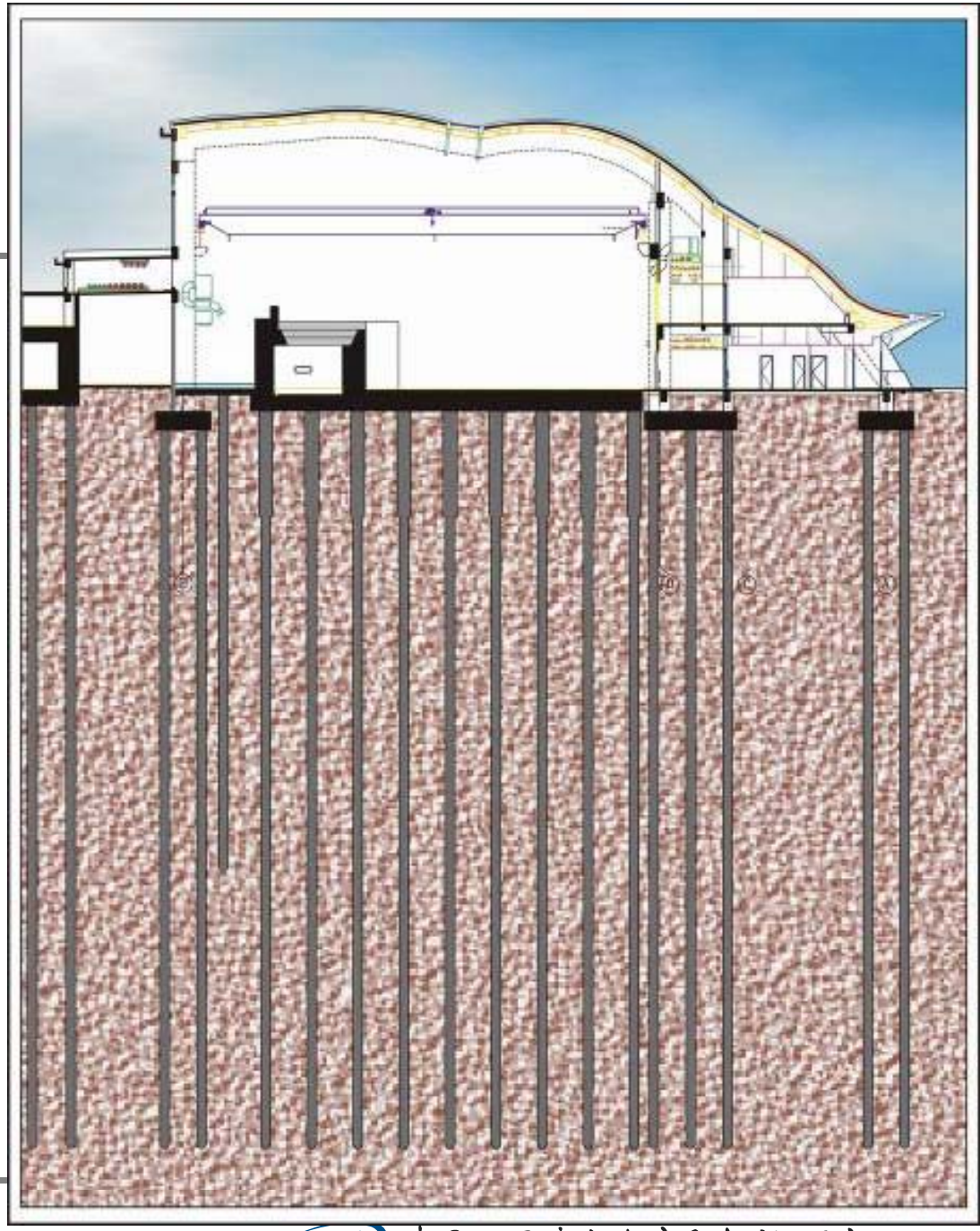
  Diameter: 0.6m (0.9m for top 7m)

  Length: 48m (To silty sand layer)
- Slab Thickness

  1.35m (experimental hall)

  1.05m (ring tunnel)





Performance of slab

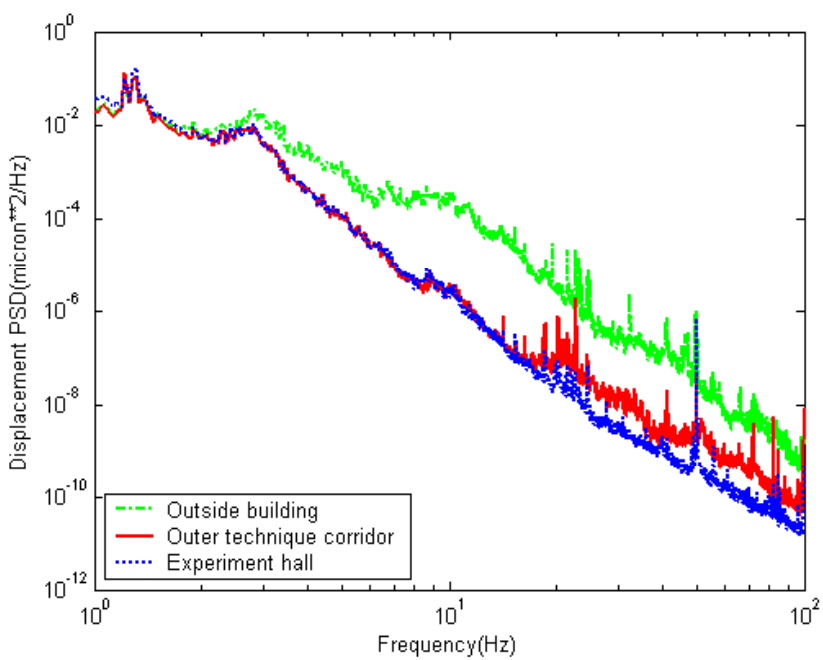
- **Orbit response to vibration**

  Vertical orbit amplification factor: ~ 4

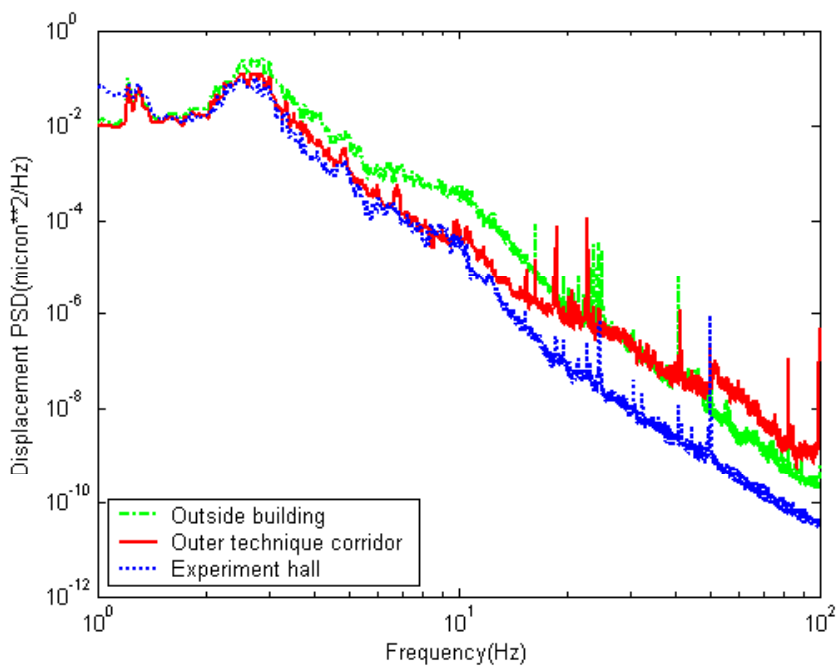
- **Slab vibration:**
  Vertical rms value
  ~0.15μm (quiet time)
  ~0.25μm (noisy time)

- **RMS value decrease about 50% in vertical direction**

PSD in Horizontal Direction

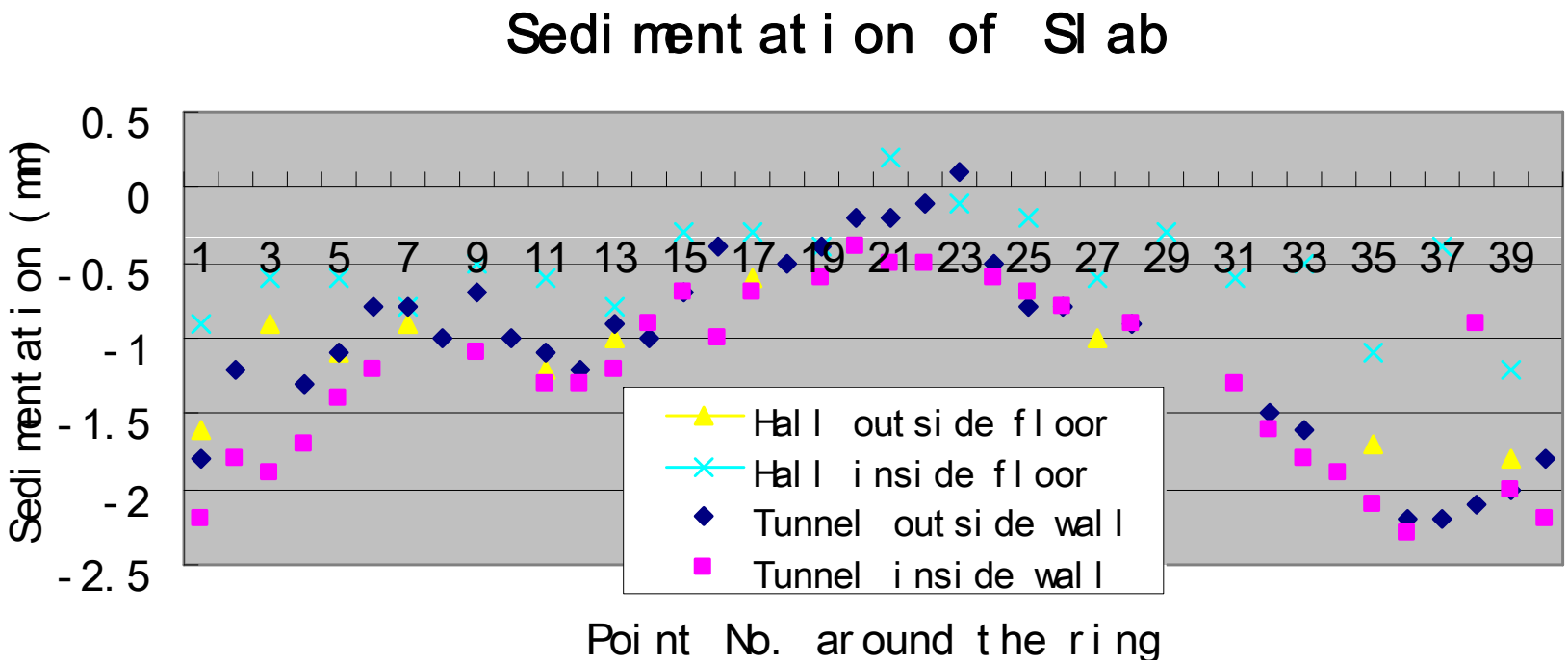


PSD in Vertical Direction



Sedimentation of the Slab

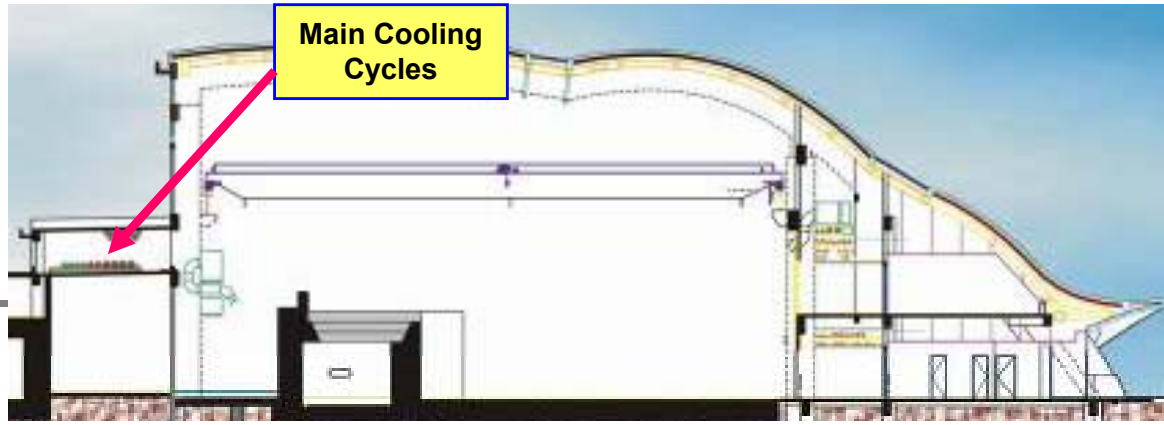
- The average sedimentation of the floor in one year is 1mm.
- The maximum relative sedimentation on the slab is ~ 2mm.

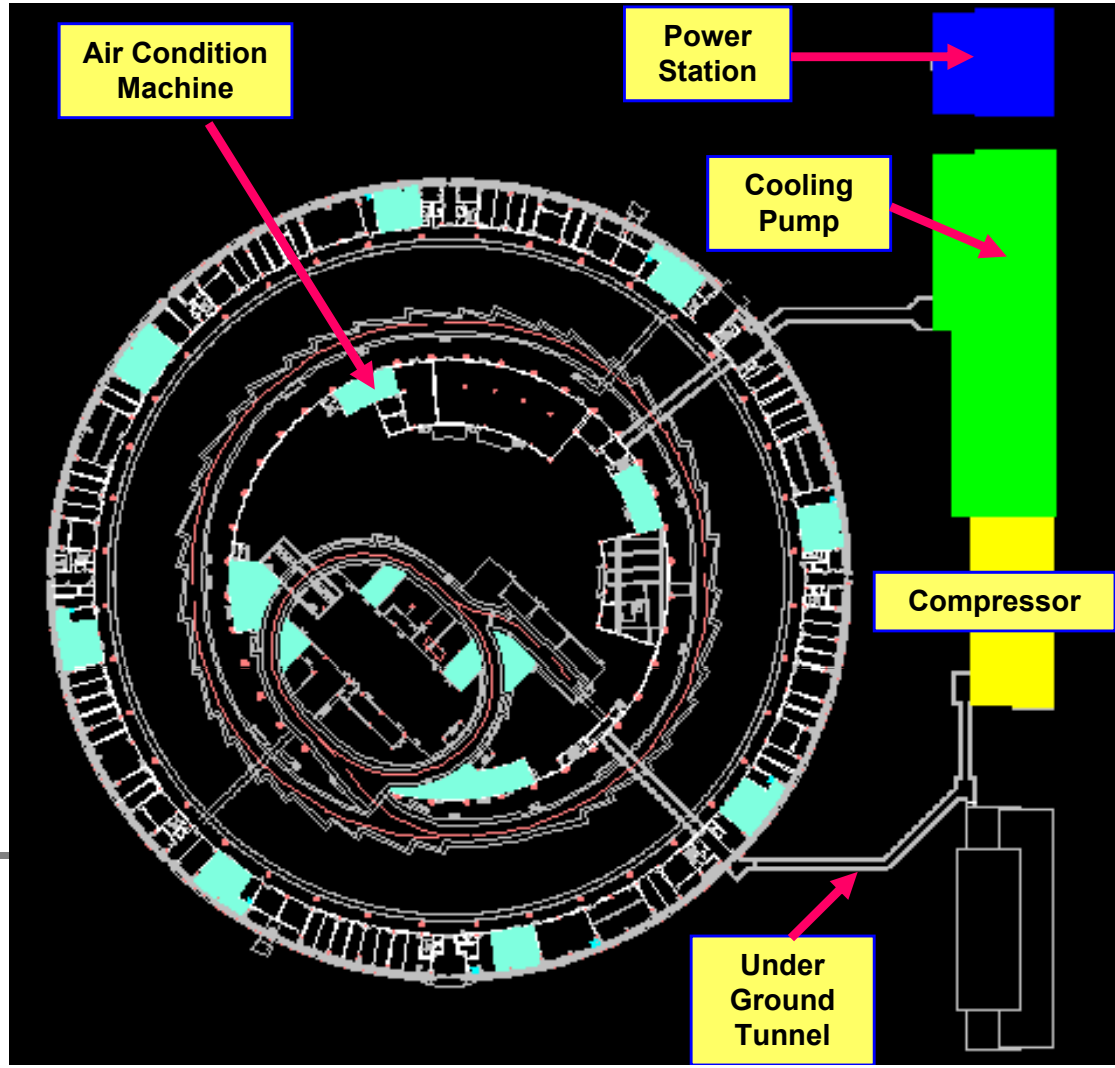


Conventional Facility

Conventional Facility Location

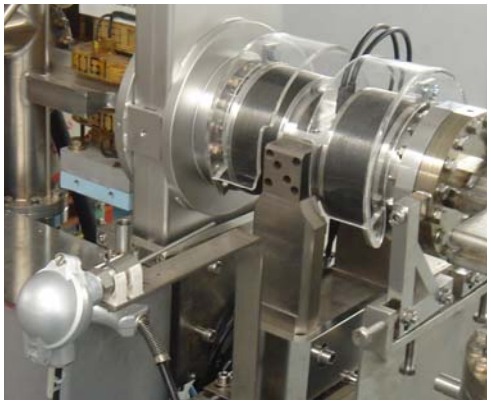
- Keep pumps and compressors far from the storage ring
- Main conventional facilities are arranged outside the main building.
- Two under ground channels for pipes and cables.
- Main cooling cycles are set in the alleyway in the main building.
- Cooling water flow rate: < 2m/s
- Air condition machines with damping are located inside the main building.





Conventional facility in tunnel

- Branches from the main cooling loop connect the machine in each cell.
- Soft pipe mechanical isolate the main pipe with accelerator components.
- Keep large curve in cooling path for components.
- Water flow rate is limited to 2m/s in magnet and absorber.
- Air flows to tunnel uniformly.
- No Air blow to machine directly.
- Temperature sensors are set near hig precision BPM.



Performance of the Conventional facility

- **Air temperature stability in Tunnel**

  Average temperature from the sensors in tunnel

  $T = 27^0C$; $\Delta T < \pm 0.2^0C$

  24Hrs

- **Cooling water temperature stability for magnets and absorbers**

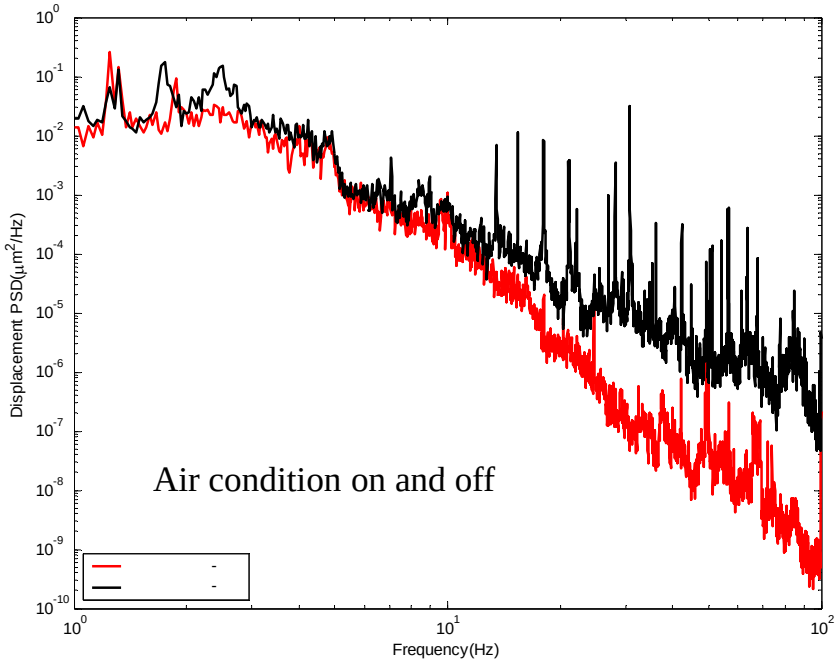
  Sensors at the downstream of the heater in main pipe are used for control.

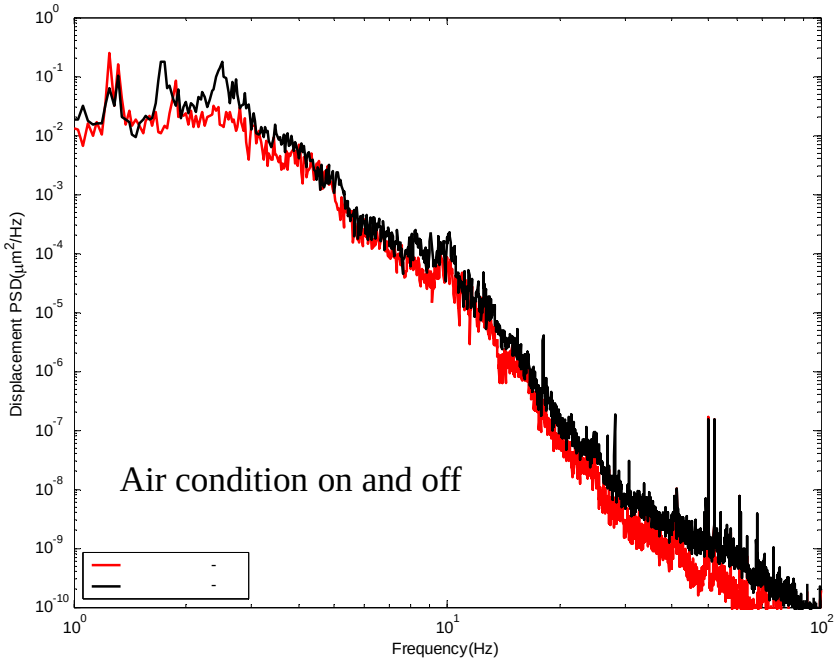
  Sensors upstream of each sector are used for monitor.

  $T = 30^0C$; $\Delta T < \pm 0.2^0C$

  24Hrs

Vibration Test for Air Condition





PSD in air condition room floor (V)

PSD in ring tunnel floor (V)

Mechanical System Design and Performance

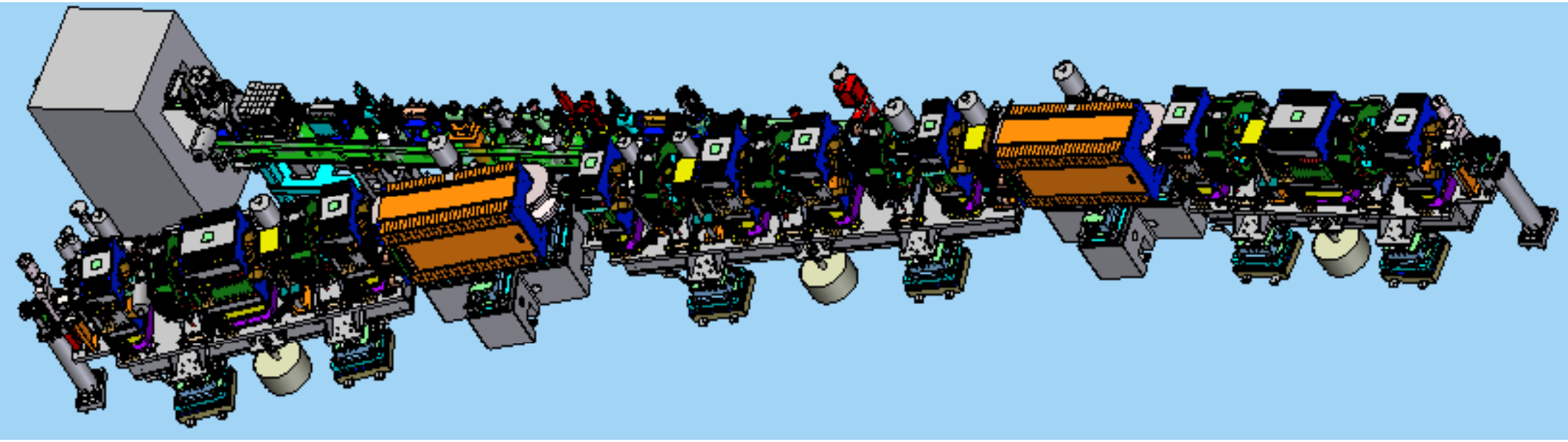
SSRF Storage Ring Mechanical System

- Double-bend achromat sector format
- 19 magnets per sector
- 3 girders and 2 pedestals per sector

  Long girder – 11 ton

  Short girder – 7 ton

  Dipole – 6 ton



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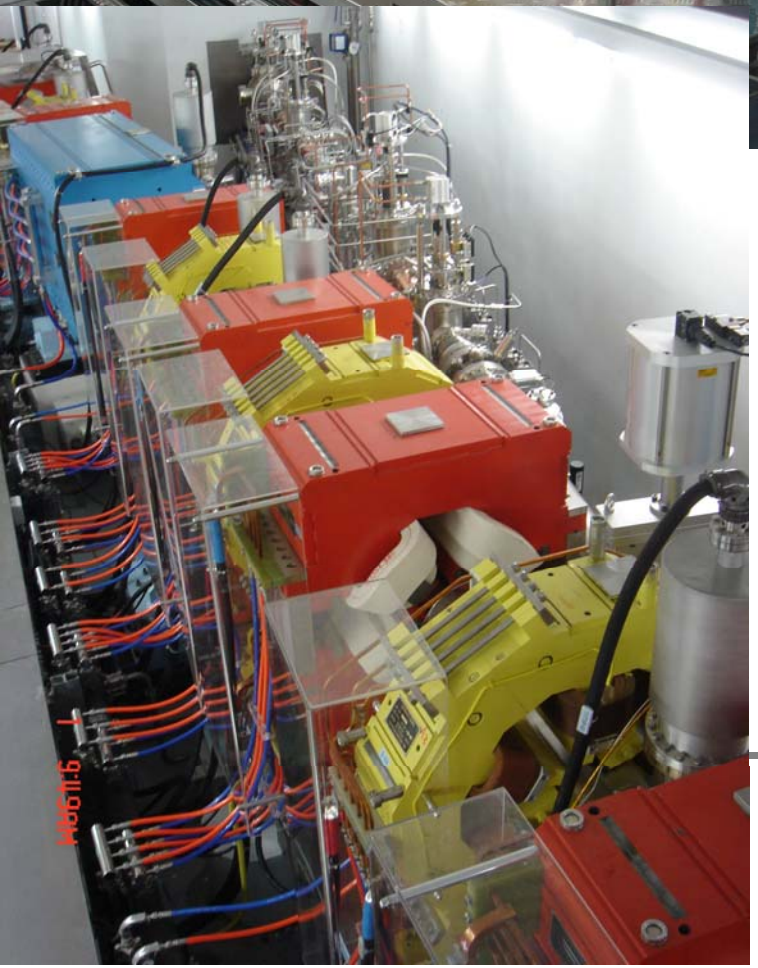

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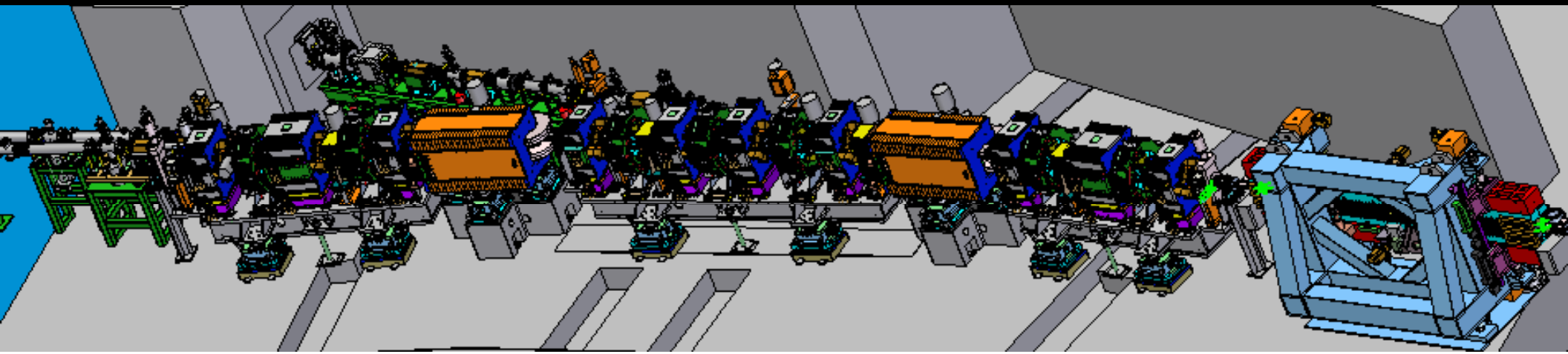
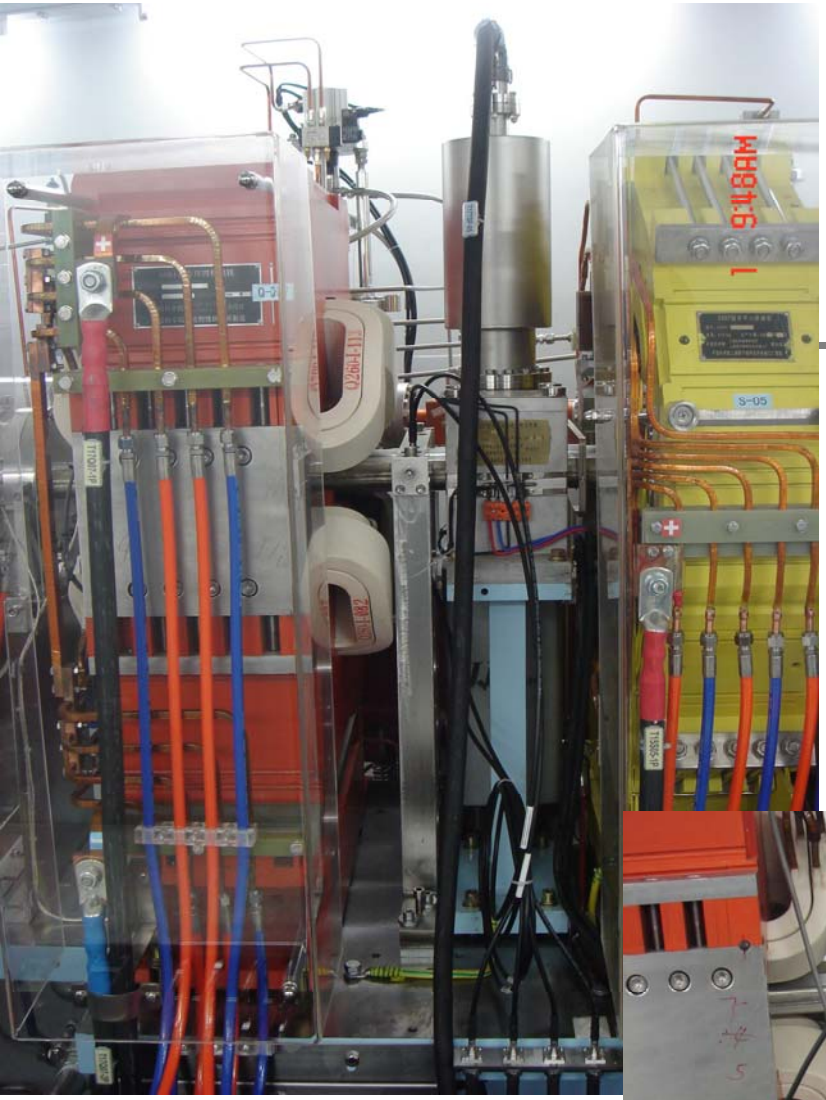
Arc Section Design

- Chamber supported on Girder, no direct contact to magnet.
- Corrector magnet, absorber and pump occupy the same space along the beam direction.
- Each magnet can be taken out without move the chamber.
- Keep minimum 8~10mm space between hardware.

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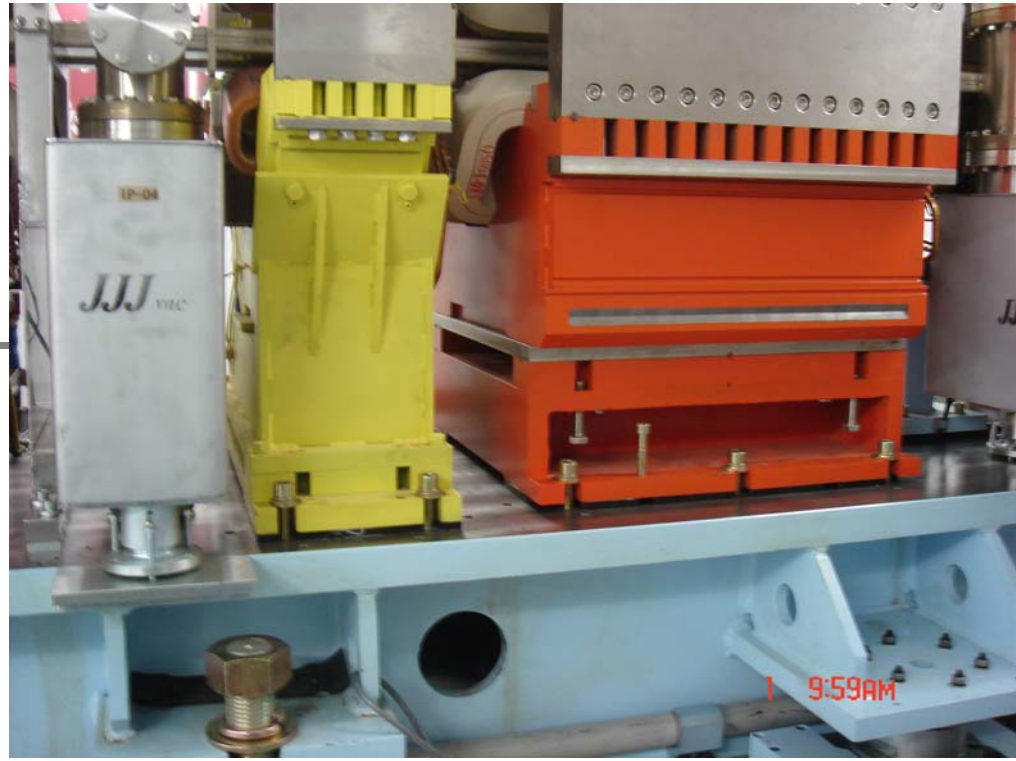
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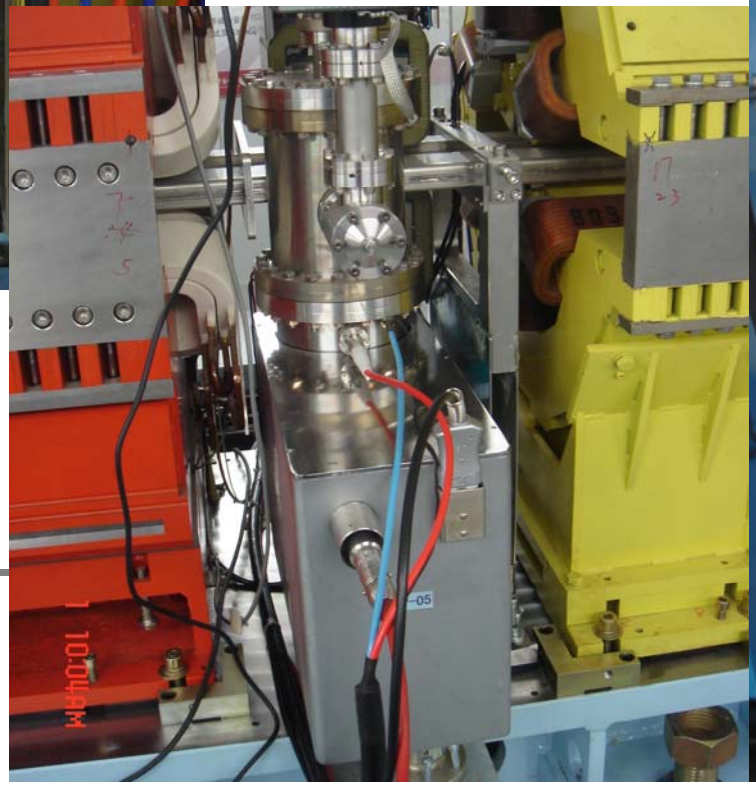
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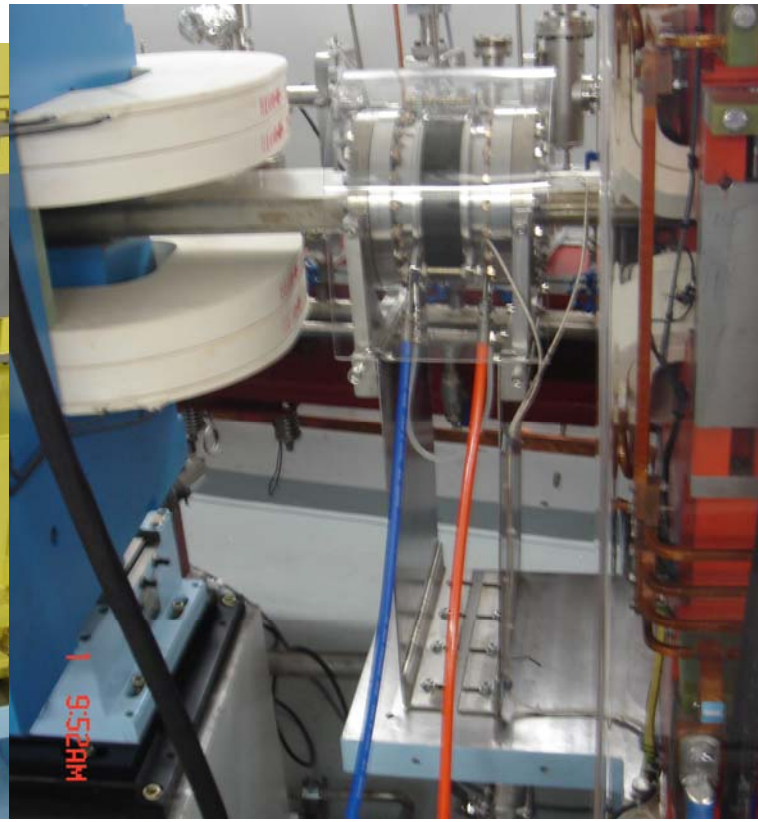
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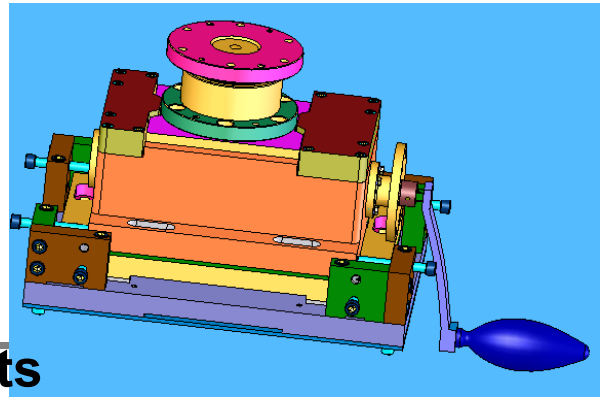
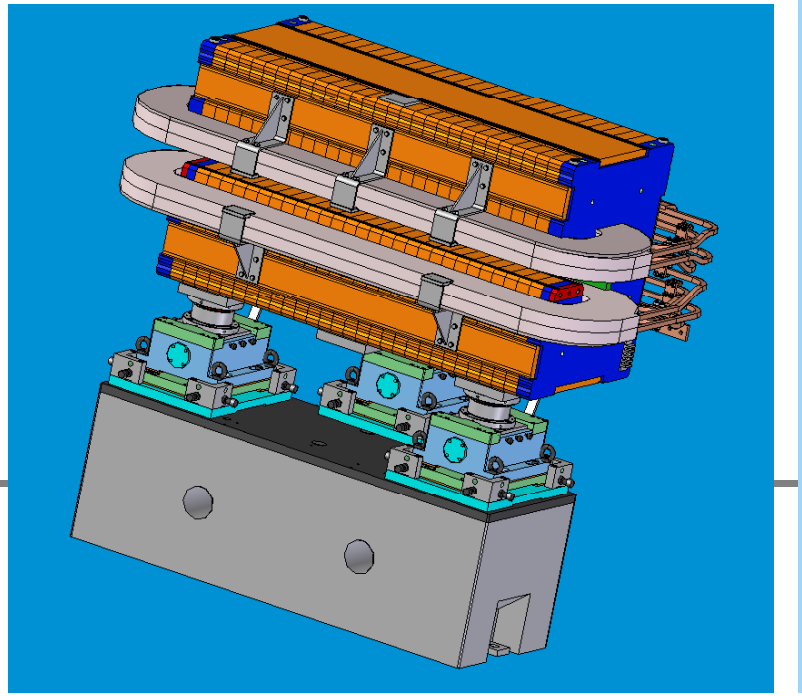
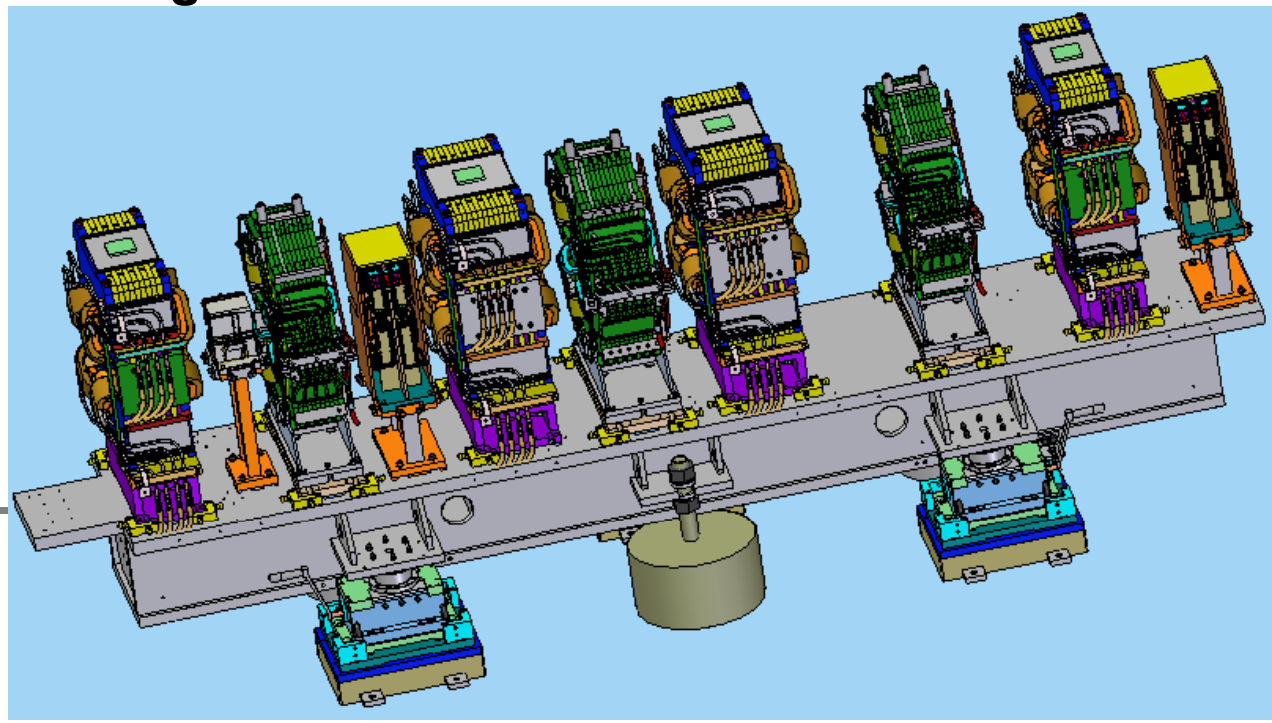
Girder Magnet Assembly



- Three point support for girder and dipole.
- The pedestals are fixed on ground by anchor bolts and filled with unshrinking concrete between them.
- Three Assistant supports are fixed on ground and reinforced with concrete.
- Wedge structure and ball bearing are used to adjust the hight.
- Magnet adjustment: Shimming and bolts





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1 9:52AM

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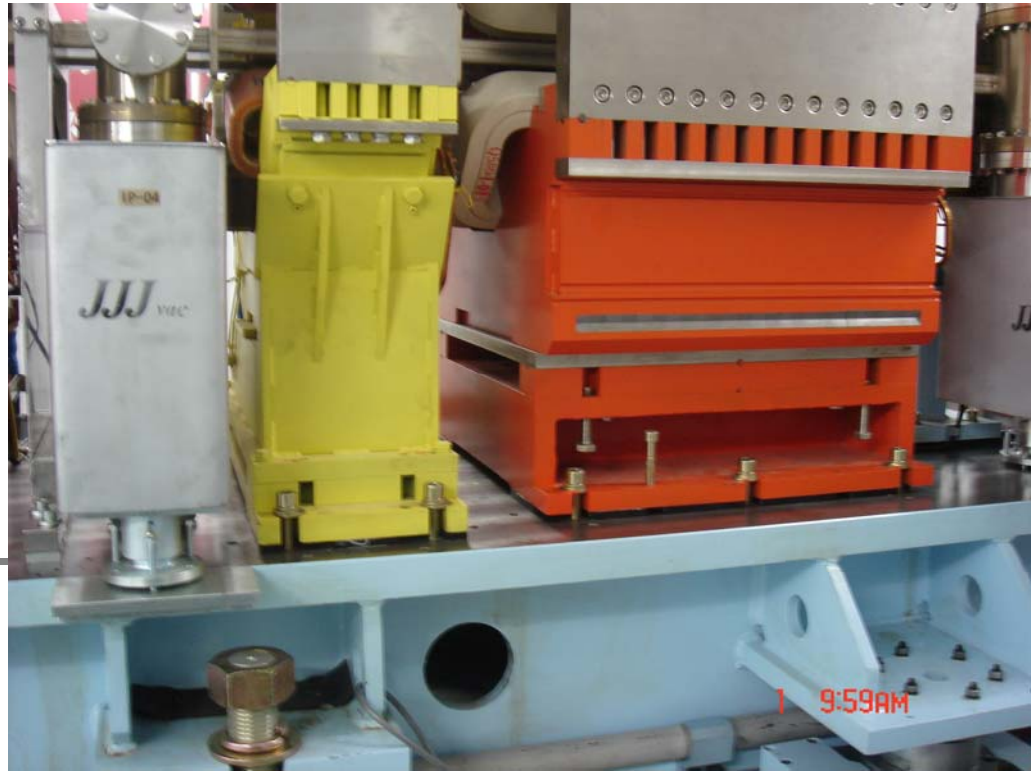
请勿靠近
1 9:55AM


JJJ
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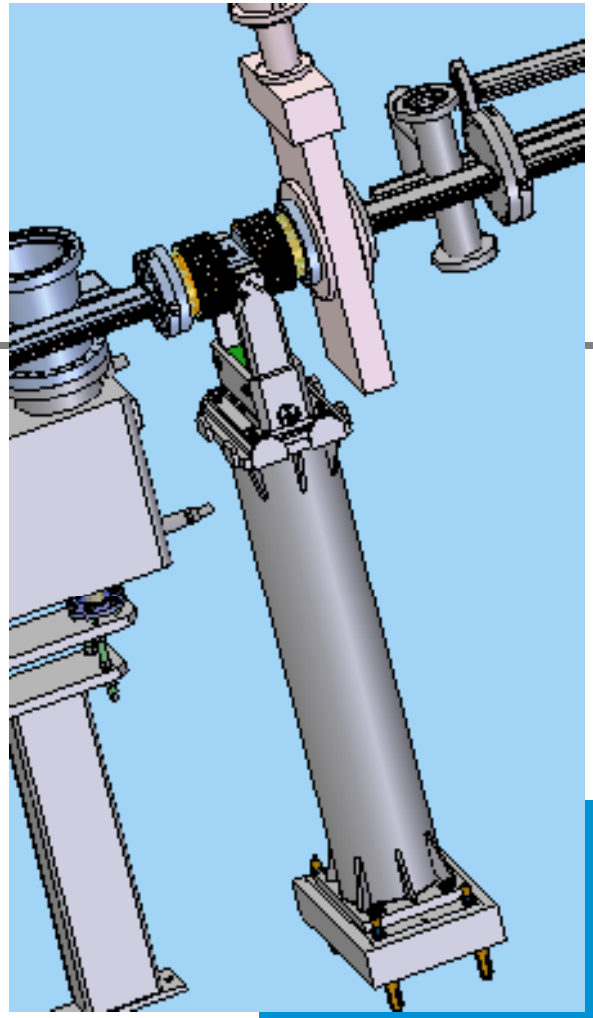
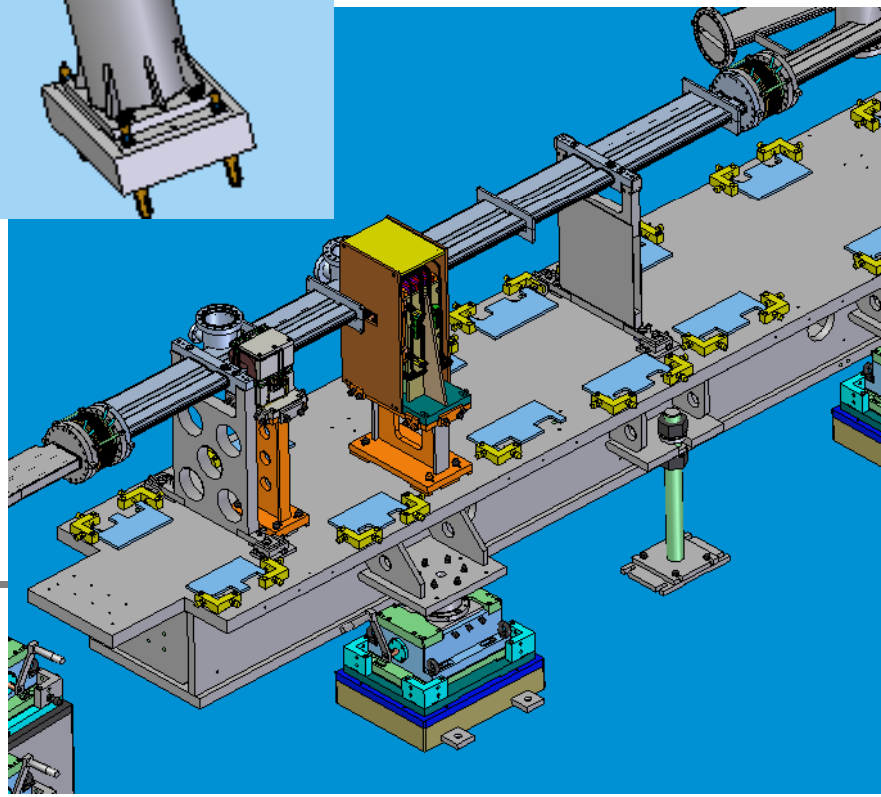
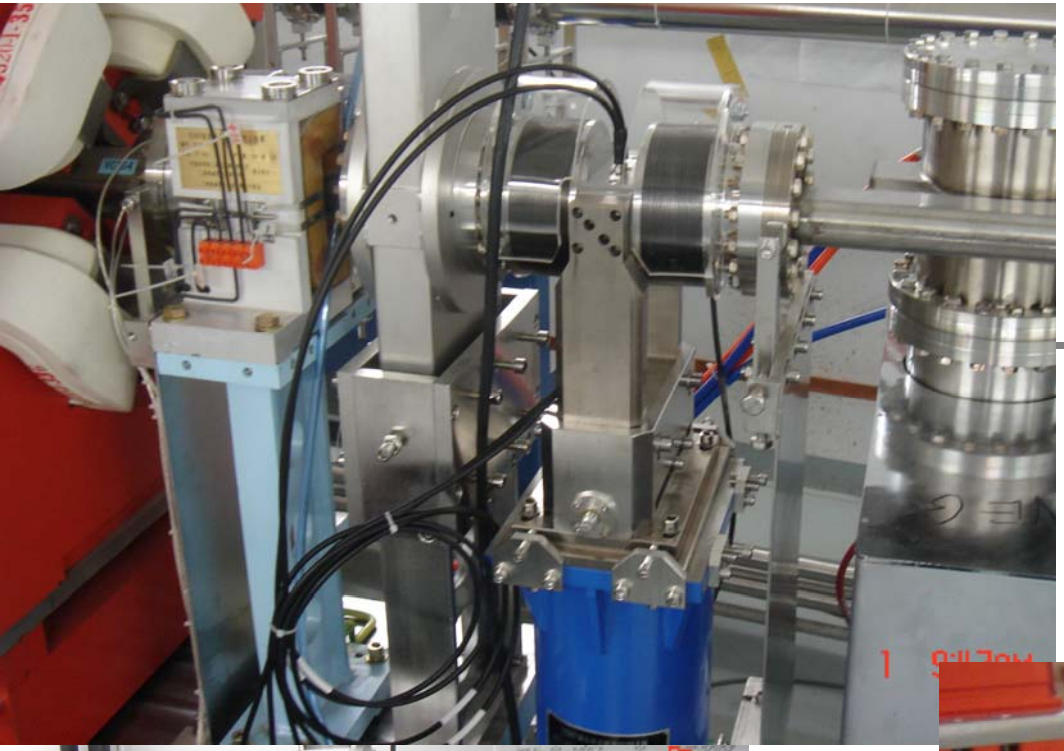
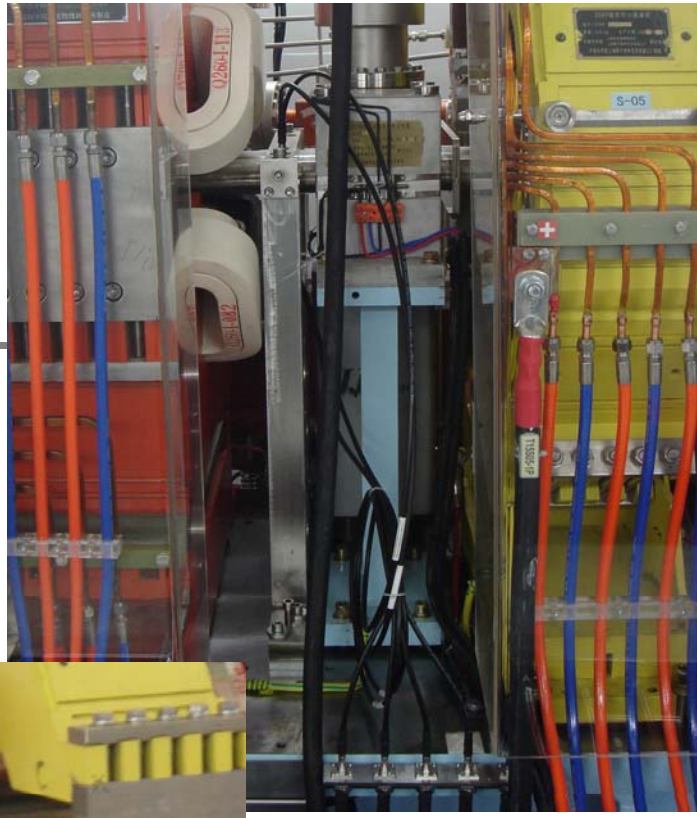
BPM Support

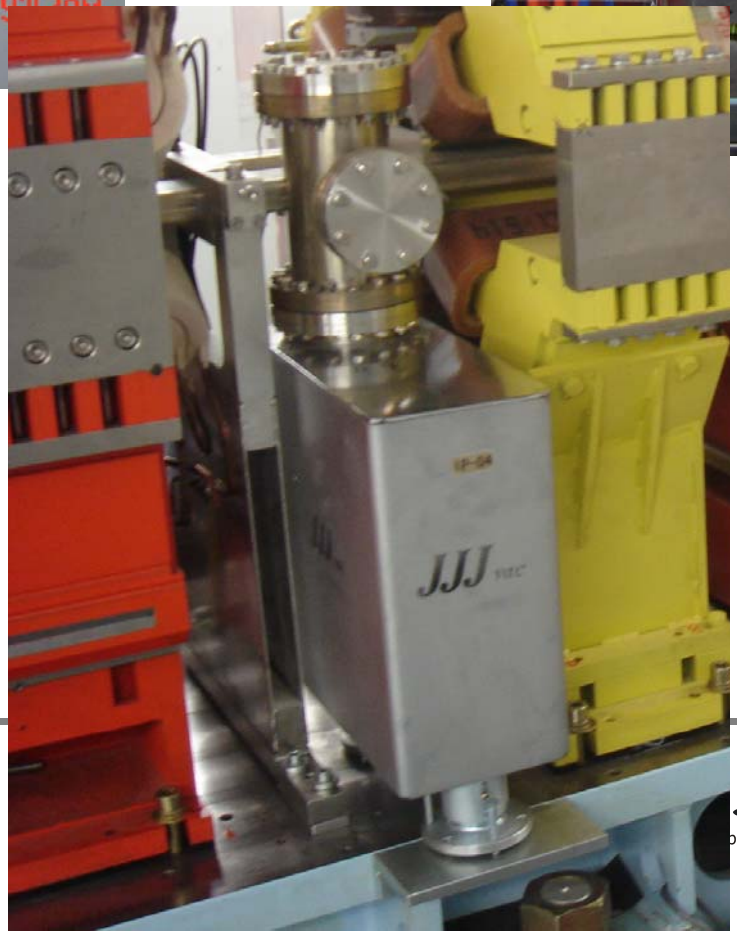
- ➢ **High precision BPM**
- • **Supported on ground with Invar cylinder**
- • **Mechanical isolated to chamber by bellows**
- • **No cooling in BPM block**
- ➢ **Normal BPM**
- • **Supported on girder**
- • **Each chamber has one fixed point in BPM block**
- • **Others supported by leaf spring**











上海应用物理研究所

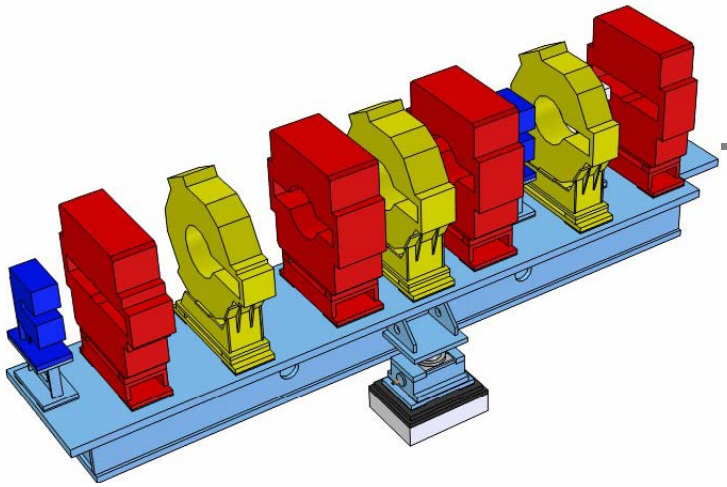
Applied Physics, Chinese Academy of Sciences

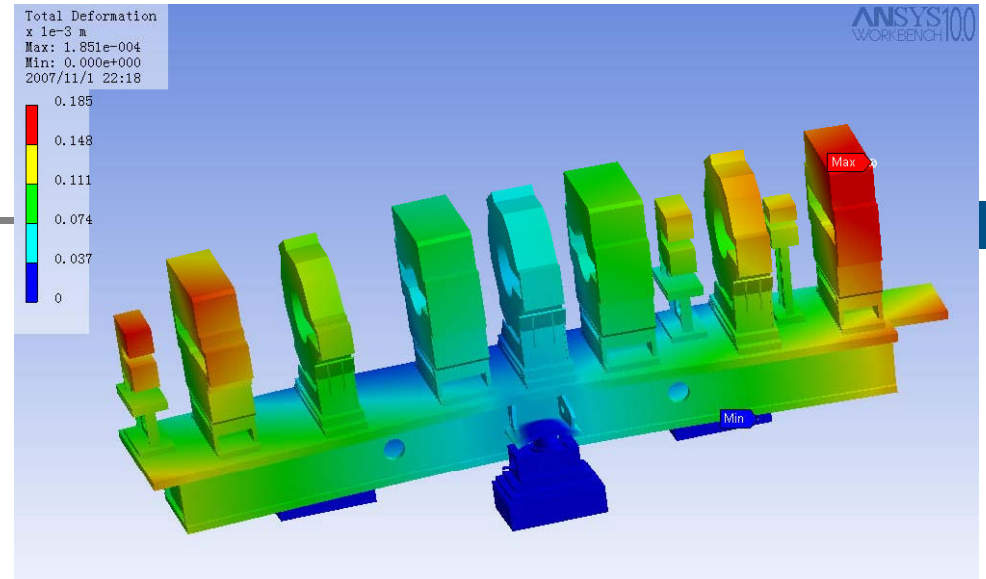
Dynamic Performance

Many simulations and tests have been carried out during the design, construction and commissioning phase.

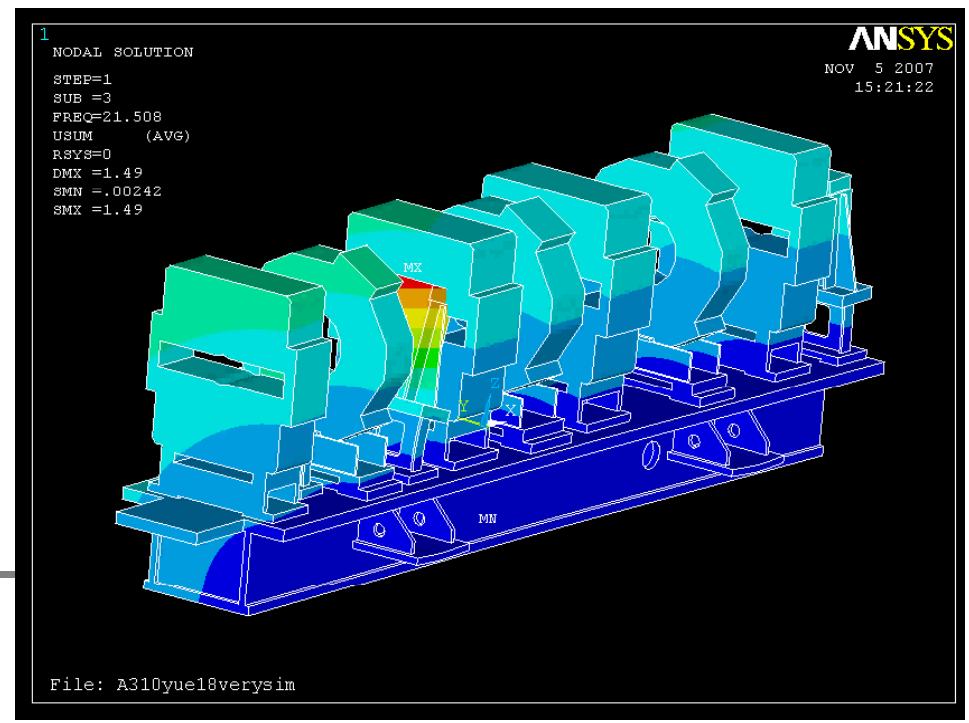
- Simulation 2005
- Prototype test 2006.05
- First sector test 2007.03
- Machine test 2008

Design Simulation



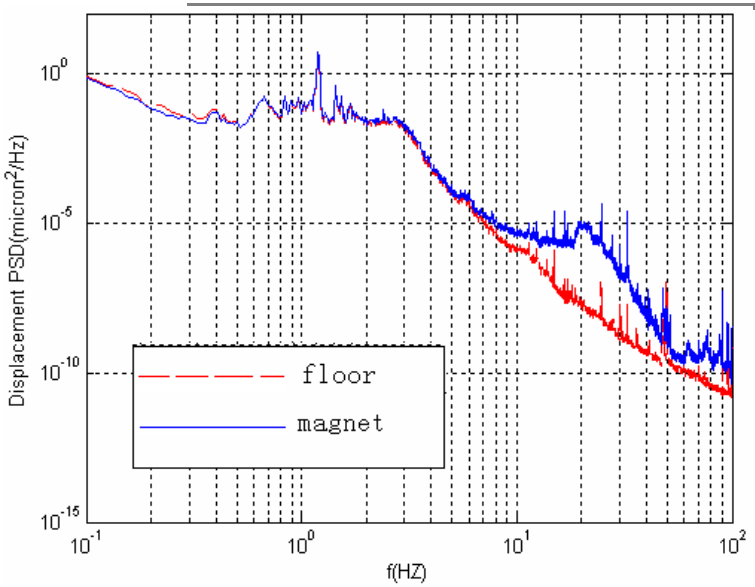


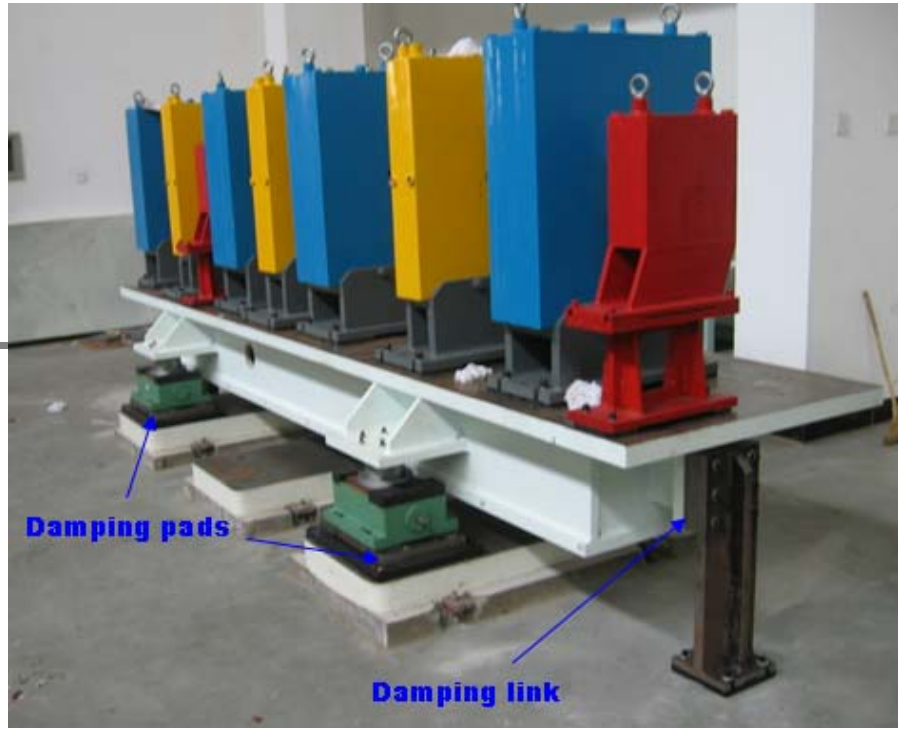
Mode	Frequency	Mode Shape
1	21.9 Hz	Girder translation
2	23.57 Hz	Girder roll
3	34.4Hz	Girder roll
4	40.43Hz	Girder translation
5	47.2Hz	SM yaw
6	47.86Hz	
7	52.24Hz	
8	58.74Hz	
9	59.79Hz	QM yaw
10	69.09Hz	SM yaw



Prototype Test

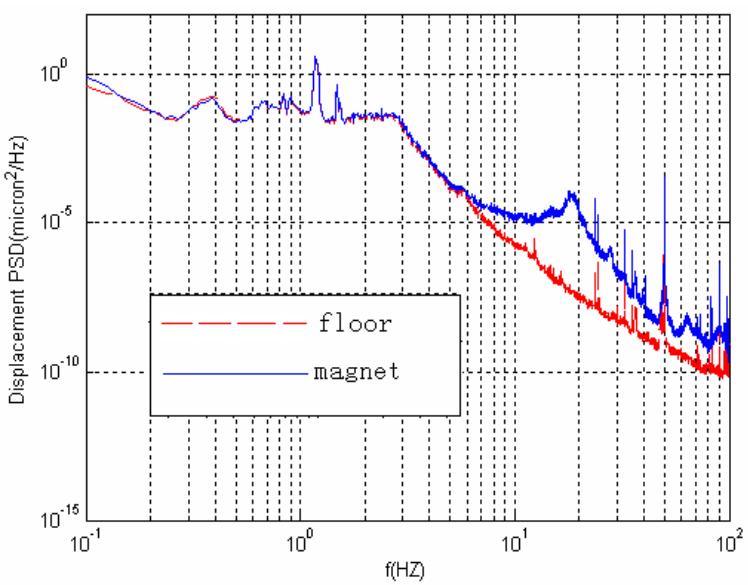
Four-point support (H)





- To confirm the simulation results.
- To compare and decide the support structure for GMA.

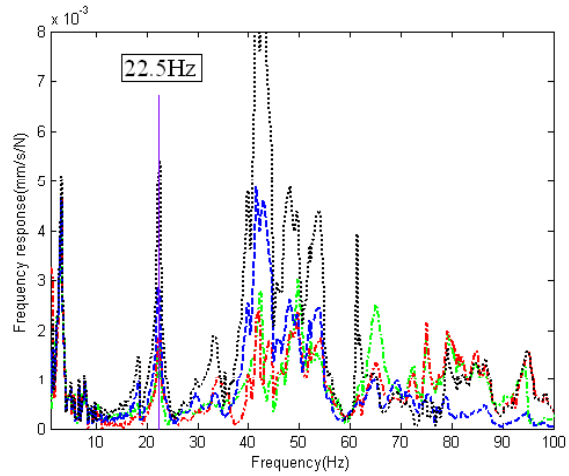
Three-point support (H)



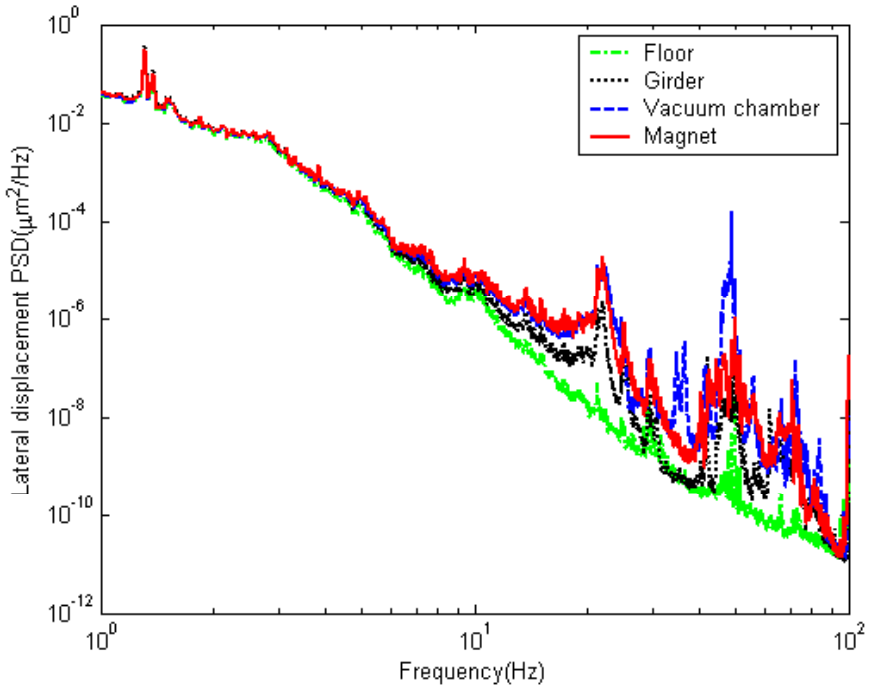
		Floor	Quadrupole magnet	Ratio
Three-point support	Lateral	0.01411	0.01828	1.30
	vertical	0.02738	0.03267	1.19
Four-point support	Lateral	0.01845	0.02273	1.23
	vertical	0.03081	0.03464	1.12
Bad-four-point support	Lateral	0.02885	0.06532	2.26
	vertical	0.03201	0.04508	1.41
Five-point support	Lateral	0.02681	0.03195	1.19
	vertical	0.02828	0.03058	1.08

Test for Machine

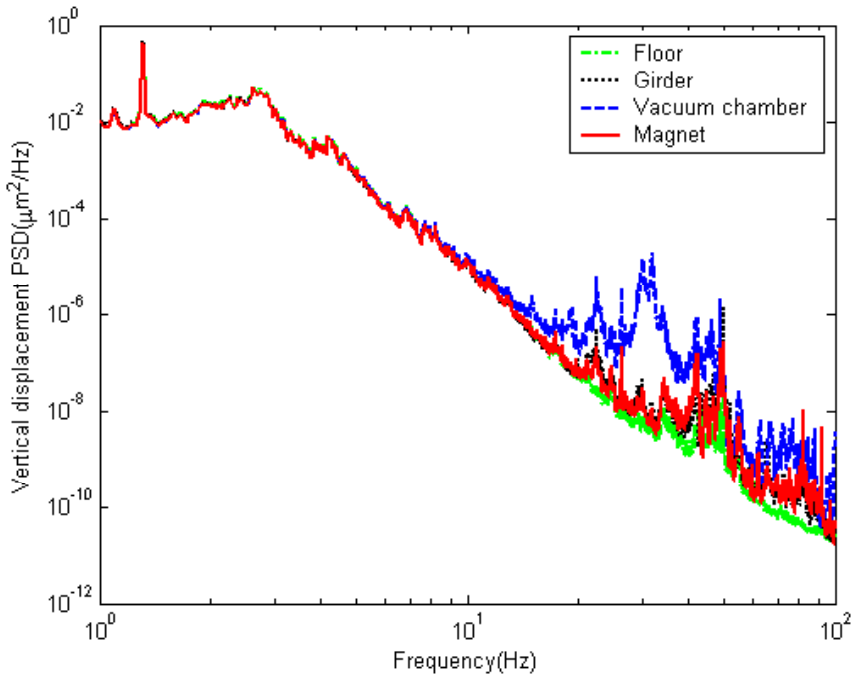
- The first eigenfrequency
  21.9Hz (H)
  22.5Hz (V)
- Response of quadrupole to floor vibration in first eigenfrequency
  34.8 (H); 1.6 (V)
- The first eigenfrequency can be improved to 27.7Hz with assistant support.



PSD in lateral direction



PSD in vertical direction



RMS Displacement (micron)

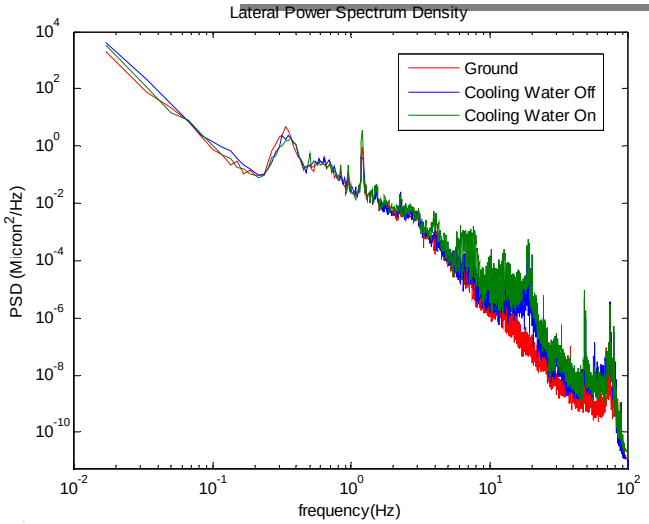
Lateral direction

	2 ~ 50Hz		3 ~ 50Hz		4 ~ 50Hz	
	Quiet	Noisy	Quiet	Noisy	Quiet	Noisy
Floor	0.05620	0.11093	0.02288	0.04534	0.00941	0.01773
Girder	0.05908	0.11668	0.02532	0.04907	0.01100	0.01996
Chamber	0.06152	0.12007	0.02794	0.05220	0.01336	0.02264
Magnet	0.06271	0.12108	0.03177	0.05556	0.01911	0.02731
Q-F Ratio	1.11	1.09	1.39	1.23	2.03	1.54

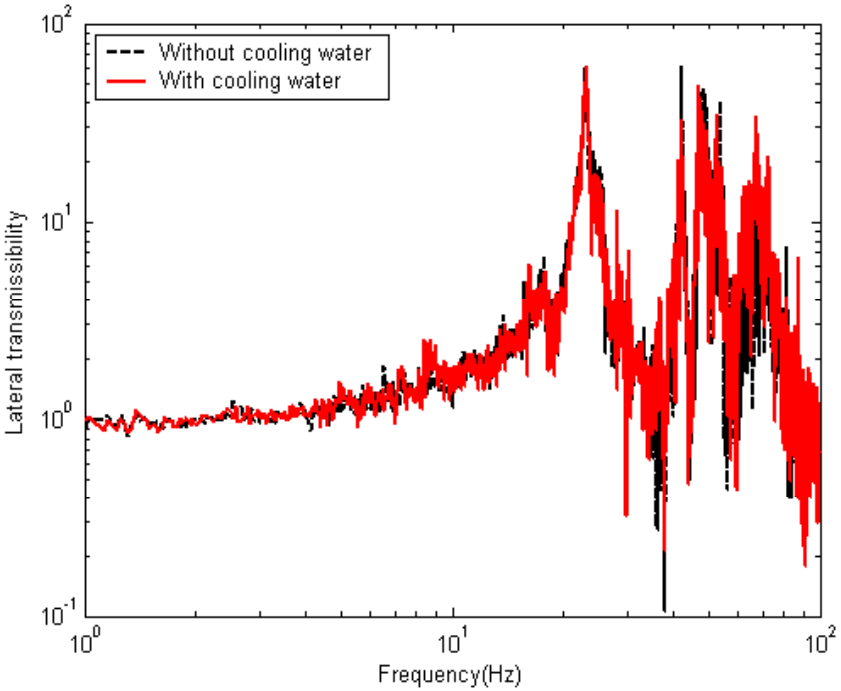
Vertical direction (Quiet)

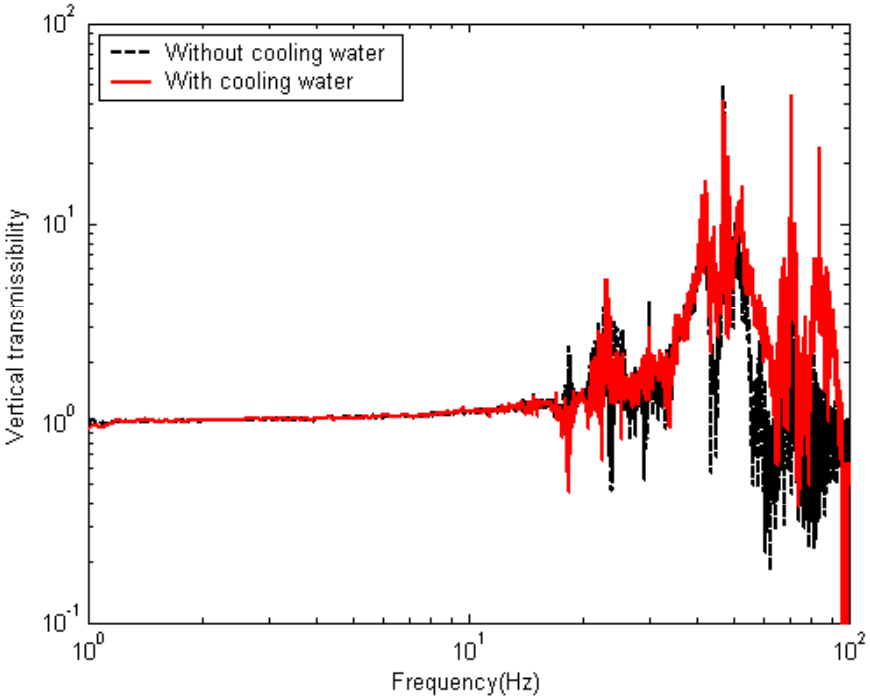
	1 ~ 50Hz	2 ~ 50Hz	3 ~ 50Hz	4 ~ 50Hz
Floor	0.47085	0.11700	0.06636	0.02182
Magnet	0.51190	0.12052	0.06812	0.02284
Q-F Ratio	1.087	1.03	1.03	1.05

Response of Magnet to Cooling Water

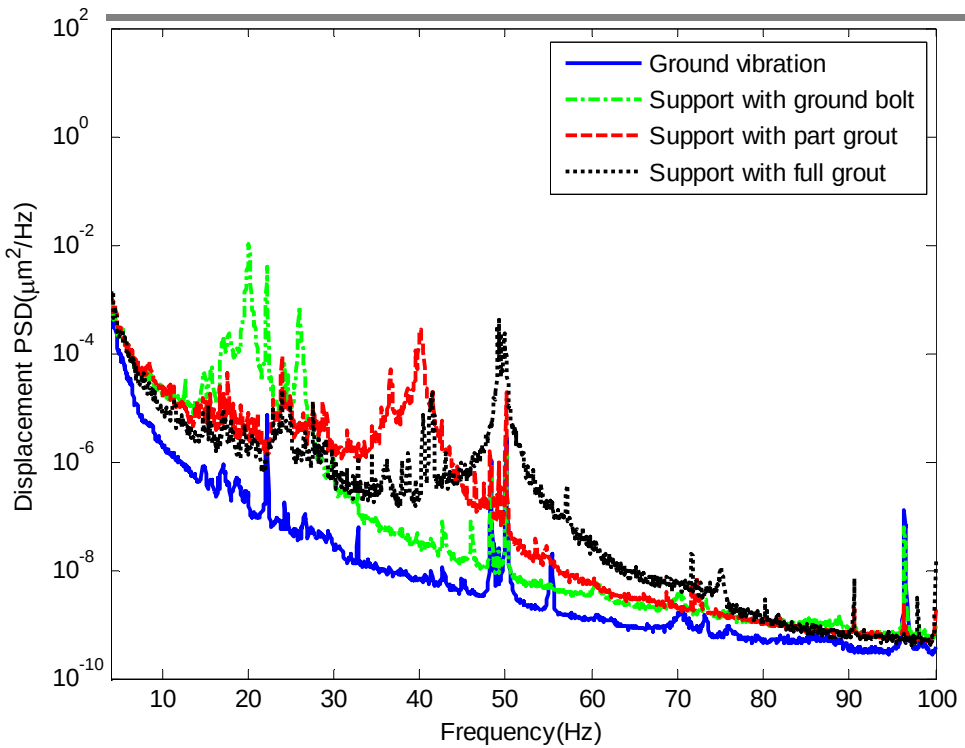


- 4 QM+3 SM
- Pressure drop: 0.65MPa
- Cooling water velocity in magnet coil: 1.8m/s





High Precision BPM Test



- **The first eigenfrequency in lateral direction : 49Hz**
- **The amplification ratio (4~50Hz) : 1.23**

Machine Commissioning

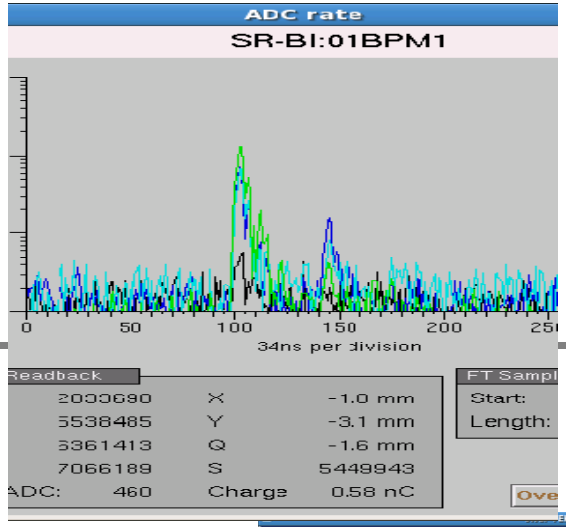
Commissioning Schedule

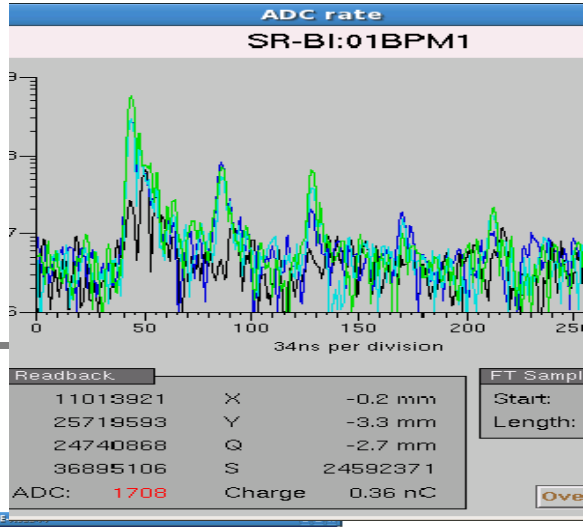
- Dec. 21, 2007 Start, First turn and multi turns
- Dec. 24 Storage
- Dec. 25 5mA
- Jan. 3, 2008 100mA
- Feb. 29 COD 80μm (rms)
- Mar. 16 COD 50μm (rms)

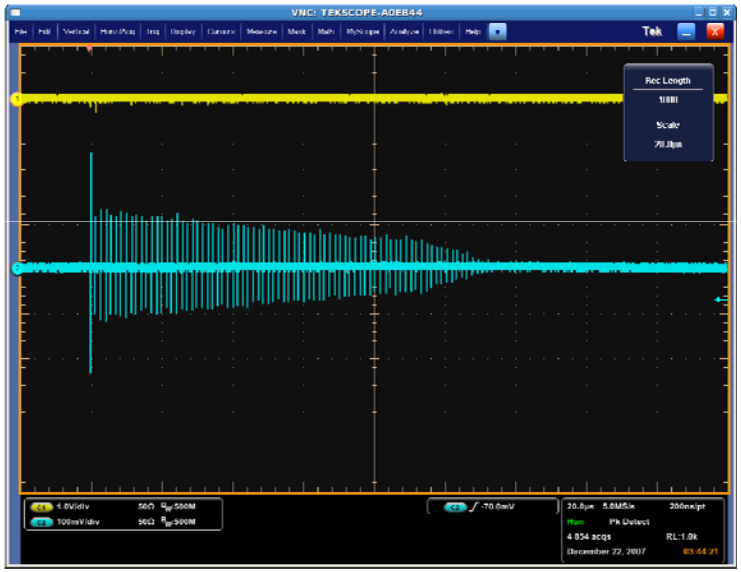
Beam Performance

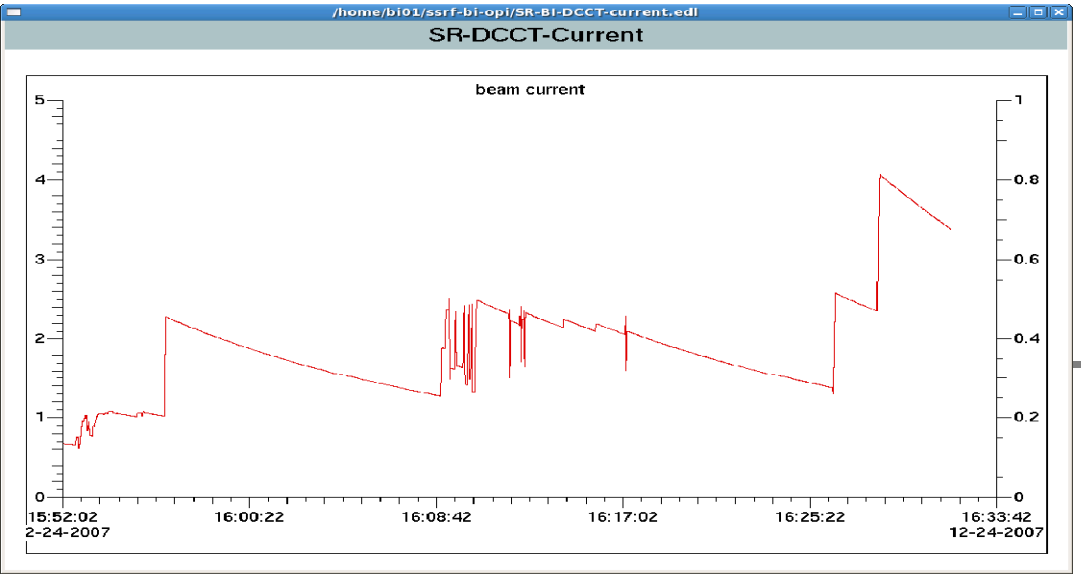
- 3.0GeV, 100mA with 3 RF cavities
- Injection rate: 0.5~0.8mA/s
- Emittance: 2.83nm.rad
- Beam Dose: 140A.h
- Beam life time: ~15h @ 100mA
- Closed orbit distortion: 50μm (RMS) @ 100mA
- Beam stability: ~100μm without feedback
  1~2μm with slow feedback

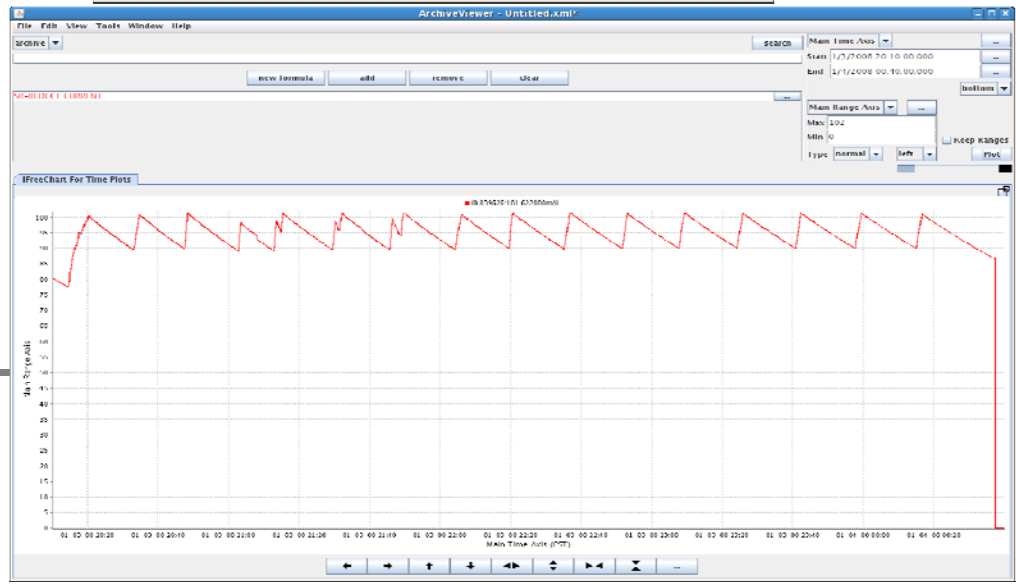
From Injection to Storage









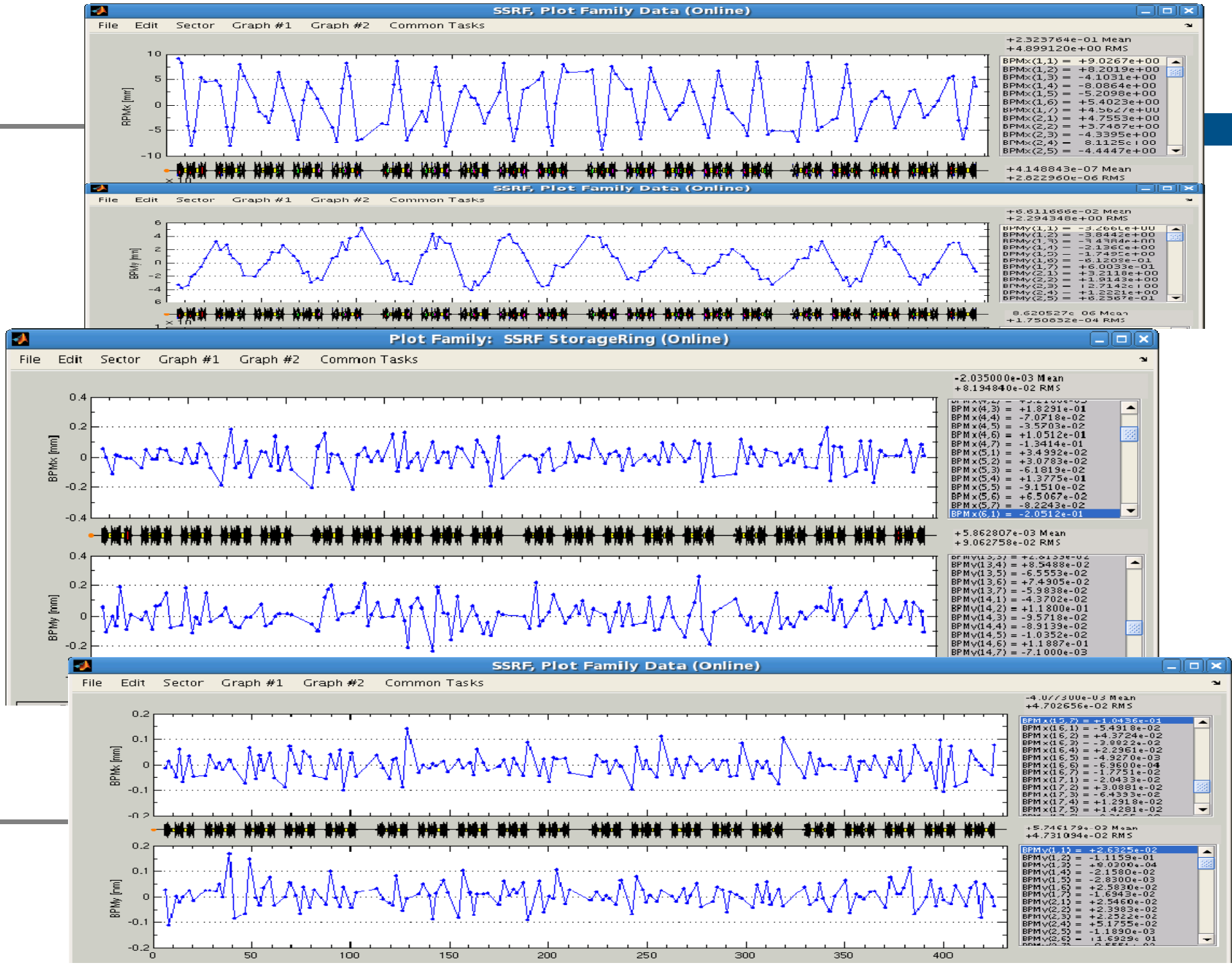


Closed Orbit Distortion

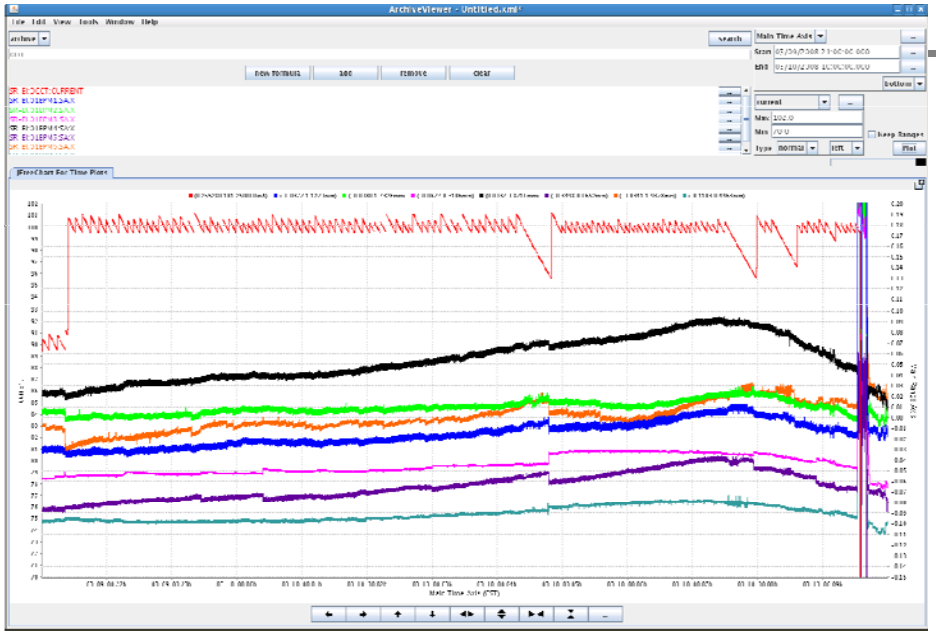
Bare Orbit

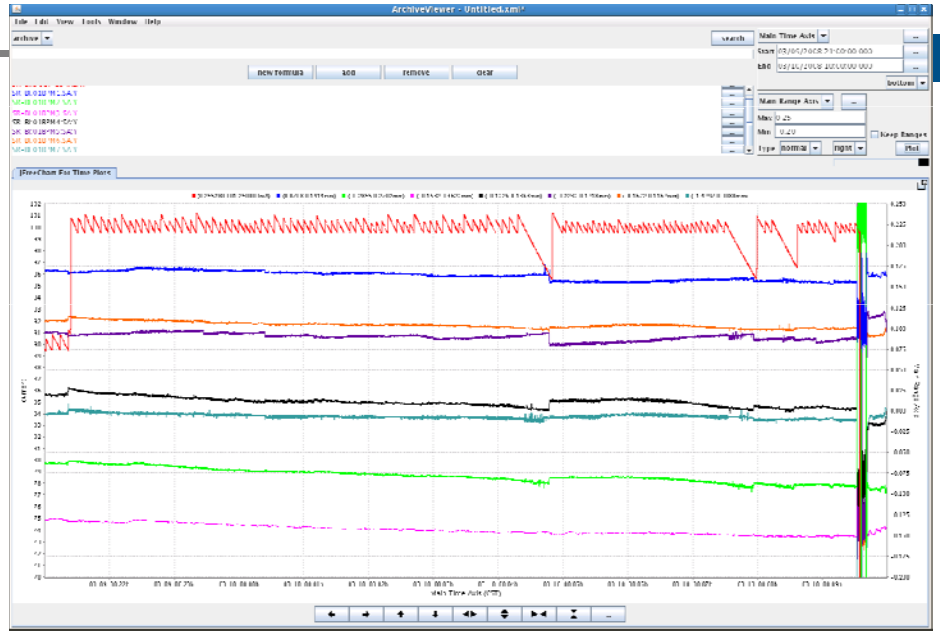
80μm COD

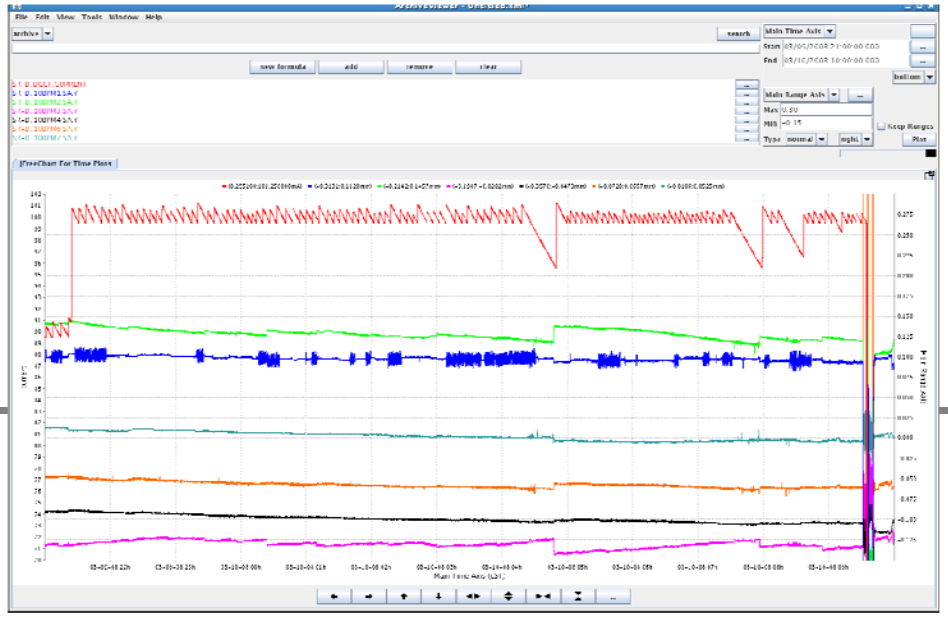
50μm COD

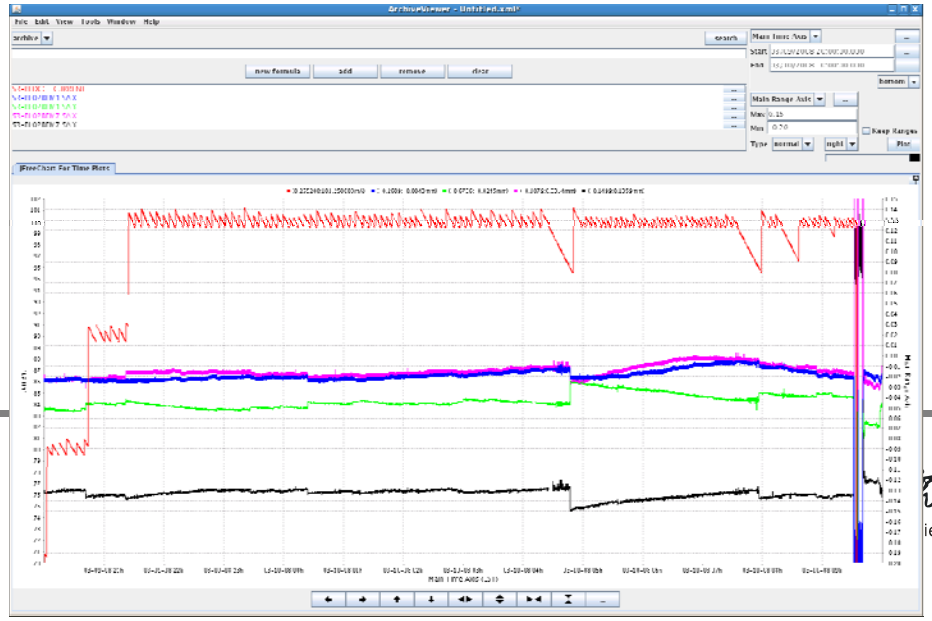


Beam Orbit Stability with and without SOFB

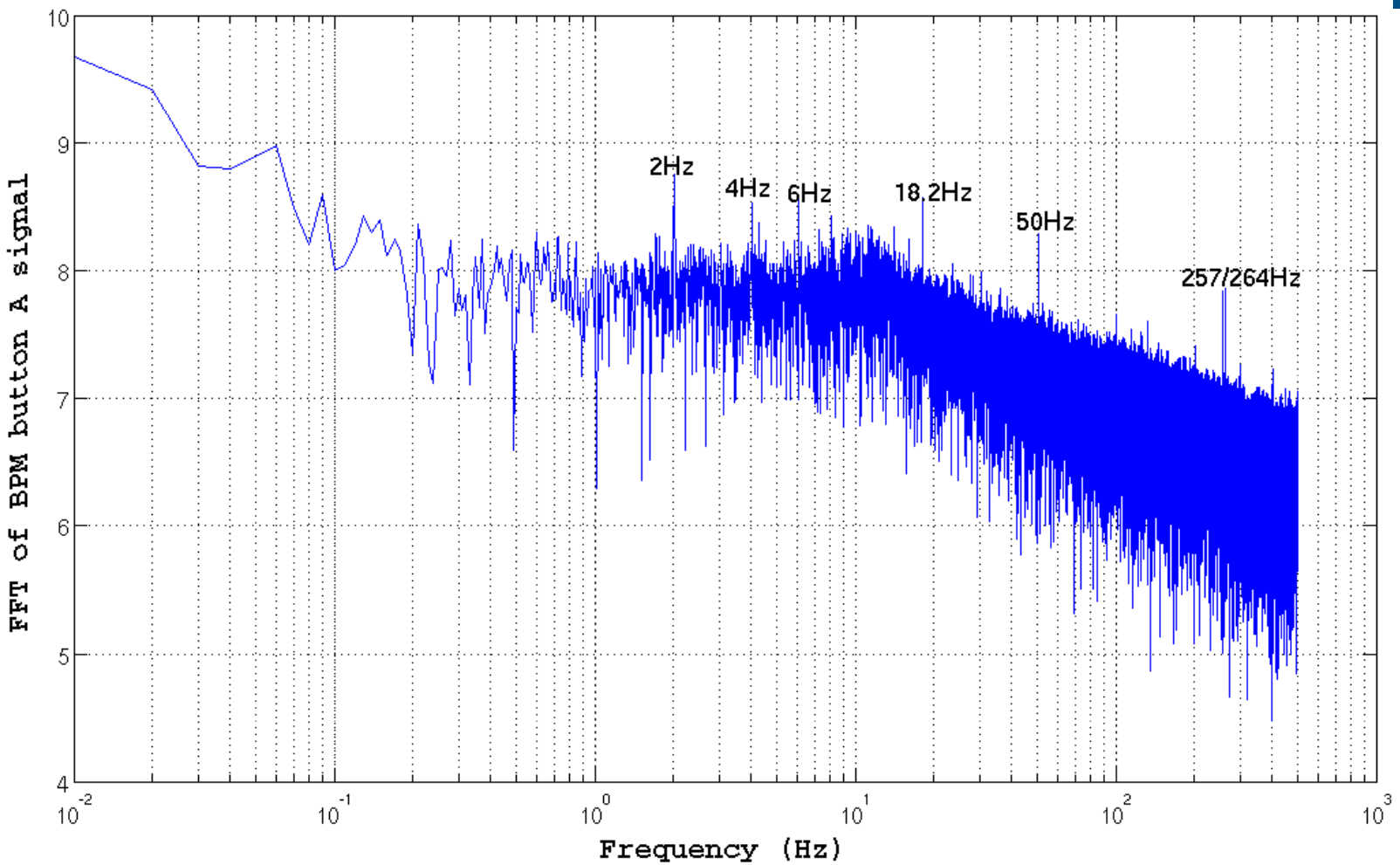








BPM Single Spectrum



Commissioning Plan

- First stage: Dec. 2007 ~ May, 2008
  3.0GeV, 100mA with 3 RF cavities.
  Beam lines from bending magnet.

- Second stage: July, 2008 ~ Aug. 2008
  3.5GeV, with 2 SC RF cavities.

- Third stage: Sept. 2008 ~ Mar. 2009
  3.5GeV, >200mA, with 2 SC cavities.
  Beam lines from ID.

Conclusion

- Some strategies are adopted in the design of the slab and the building to suppress the higher vibration of the site.
- Conventional facility is located outside of the main building to isolate the vibration generated by mechanism.
- A series of simulation and test were performed for the GMA to optimize the mechanical structure and decrease the vibration of the key components.
- Detail investigation and optimization for the engineering are doing along with the commissioning of the accelerator and the beam lines to realize the beam stability goal for SSRF.

Acknowledgment

Thanks to experts for the discussion and the suggestion on the mechanical engineering during the design and construction of SSRF Project.

- F. Wei, L. Schulz, PSI
- S. Sharma, APS
- L. Zhang, ESRF
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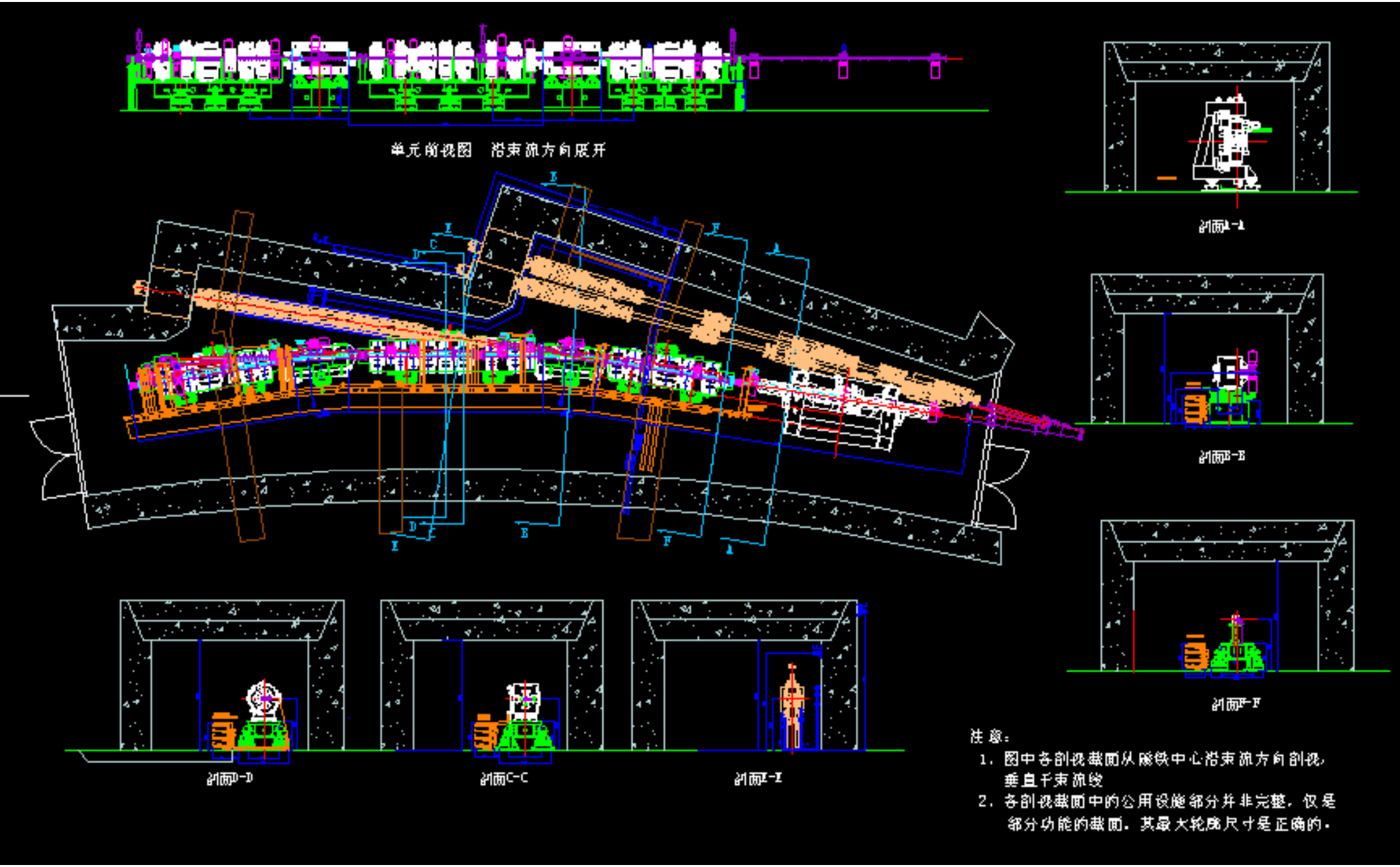
- H, Ehrlichmann, DESY
- K. Tsumaki, SPring8
- J. Chen, D. Wang, SRRC
- K. Haga, KEK
- C. Kim, PAL

Thank you ！


单元前视图 沿束流方向展开
剖面A-A
剖面B-B
剖面F-F
剖面D-D
剖面C-C
剖面E-E
注意：
1. 图中各剖视截面从隧道中心沿束流方向剖视，垂直于束流线
2. 各剖视截面中的公用设施部分并非完整，仅是部分功能的截面。其最大轮廓尺寸是正确的。