國家同步輻射研究中心
National Synchrotron Radiation Research Center

ACFA/'IPAC16 Nishikawa Tetsuji Prize Presentation

"Overview of the accelerator development for light source in NSRRC"

Gwo-Huei Luo
On behalf of Accelerator Divisions

May 9-13, 2016
IPAC2016
Busan, South Korea

國家同步輻射研究中心
National Synchrotron Radiation Research Center

- Thank you Chairman and the Award Committee. It is my great honor to receive the Nishikawa Award in IPAC16.
- This award acknowledge and amplify the achievement by those who behind the project of Taiwan Photon Source.
- The project got a lot of help including friends and experts around the world as consultant, advisory committee, manufacturers accepted technical challenges, and laboratories sharing their know-how to us. We really appreciated those helps to make TPS possible.
- Thank you to those contributing to this project again.

ACFA endorsement in 2006 and government supports

ACFA Statement of support for the Taiwan Photon Source (TPS) Project in Taiwan

The 8th ACFA Statement was issued in September, 2006 at the 12th ACFA meeting.

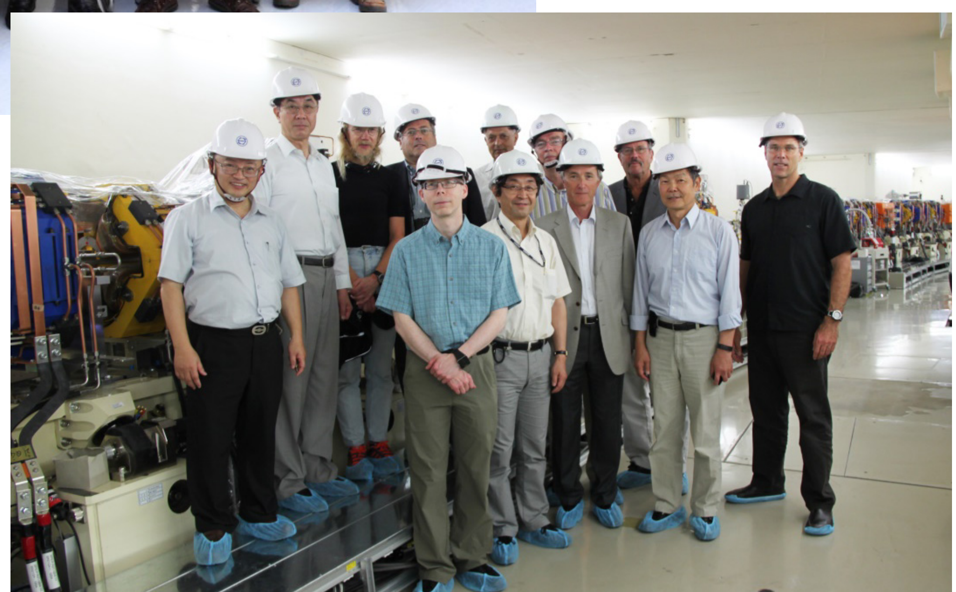
The Asian Committee for Future Accelerator (ACFA) is pleased to learn that a project is on the anvil for the construction of a low - emittance, 3 - 3.3 GeV 3rd generation synchrotron light source in Taiwan. The Conceptual Design Report of this Taiwan Photon Source (TPS) makes it clear that the creation of such a facility will greatly enhance the scientific opportunities for research teams in the Asian region and beyond, facilitate frontier research in the areas such as life, material, and environmental sciences, strengthen international cooperation and help promote new advances beneficial for the entire community.

ACFA endorses the construction of TPS and urges member countries to help this effort. ACFA feels that TPS merits the highest priority, amongst list of cooperative scientific projects envisioned in Taiwan, and recommends to local agencies to extend full funding support necessary for the construction phase.

The experts know everything about accelerators.

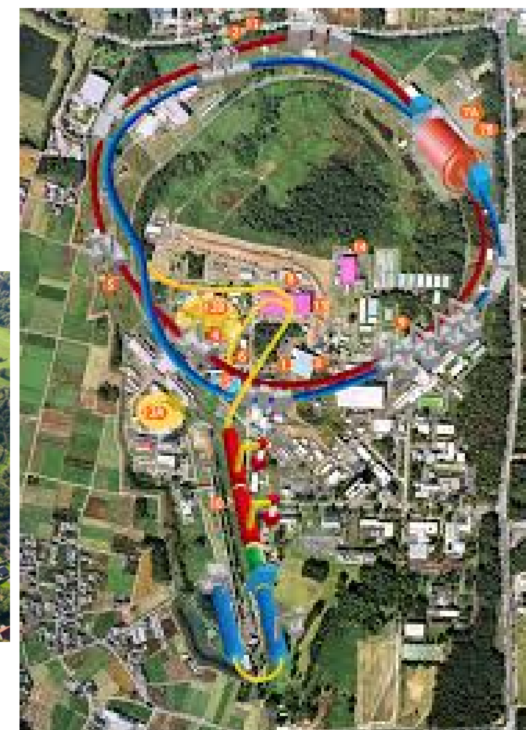
These guys almost perished…

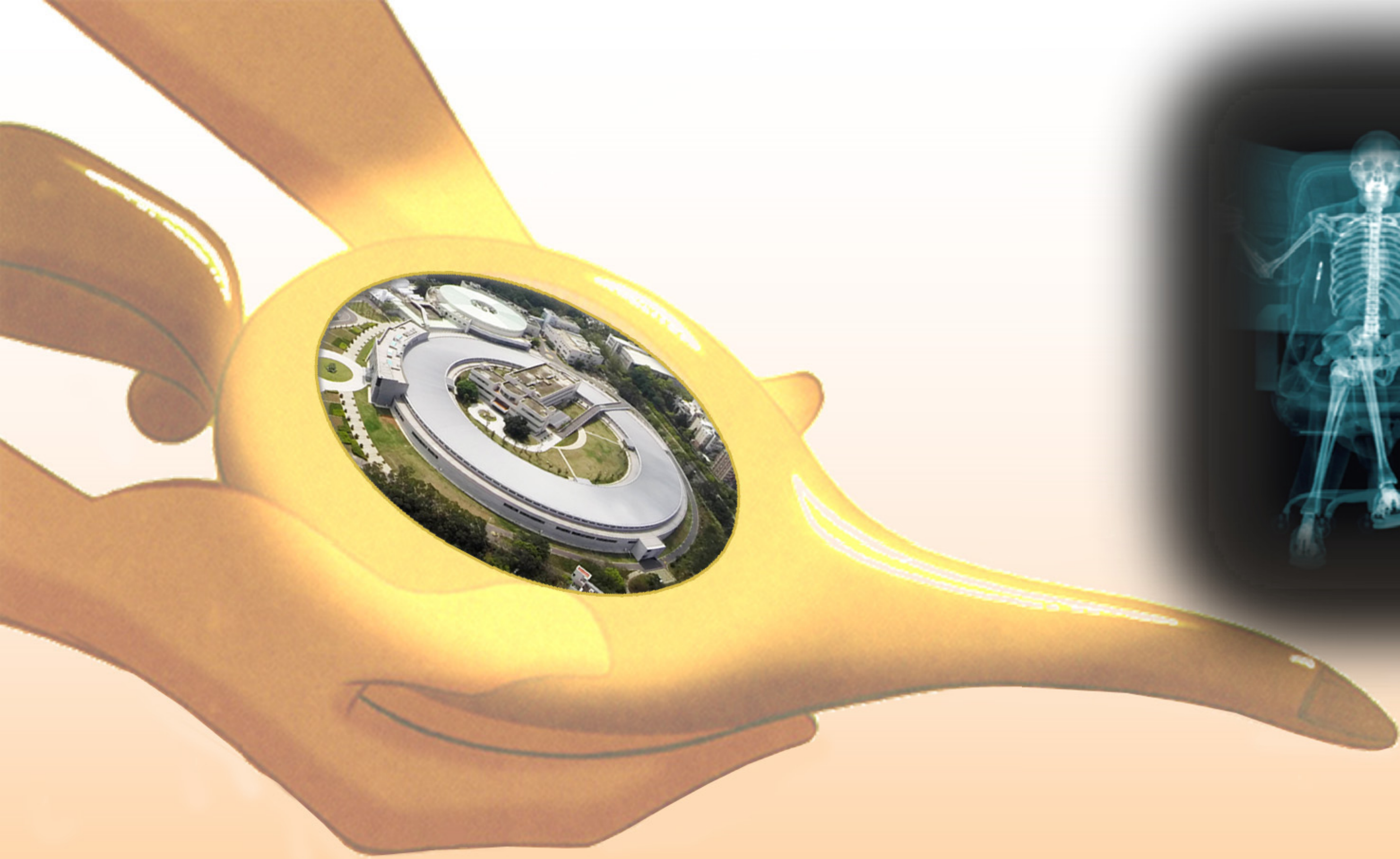
MAC 2007-2010, Chaired by H. Wiedemann

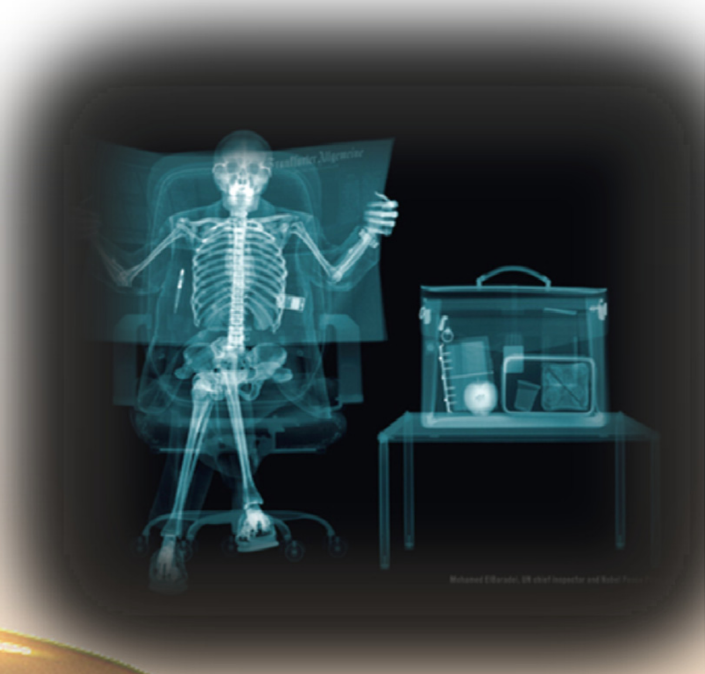


MAC 2011-2014, Chaired by Alex Chao

Laboratories supporting and/or consulting for the construction of TPS







TPS should shine as a magic lamp.

Find something that never being found.

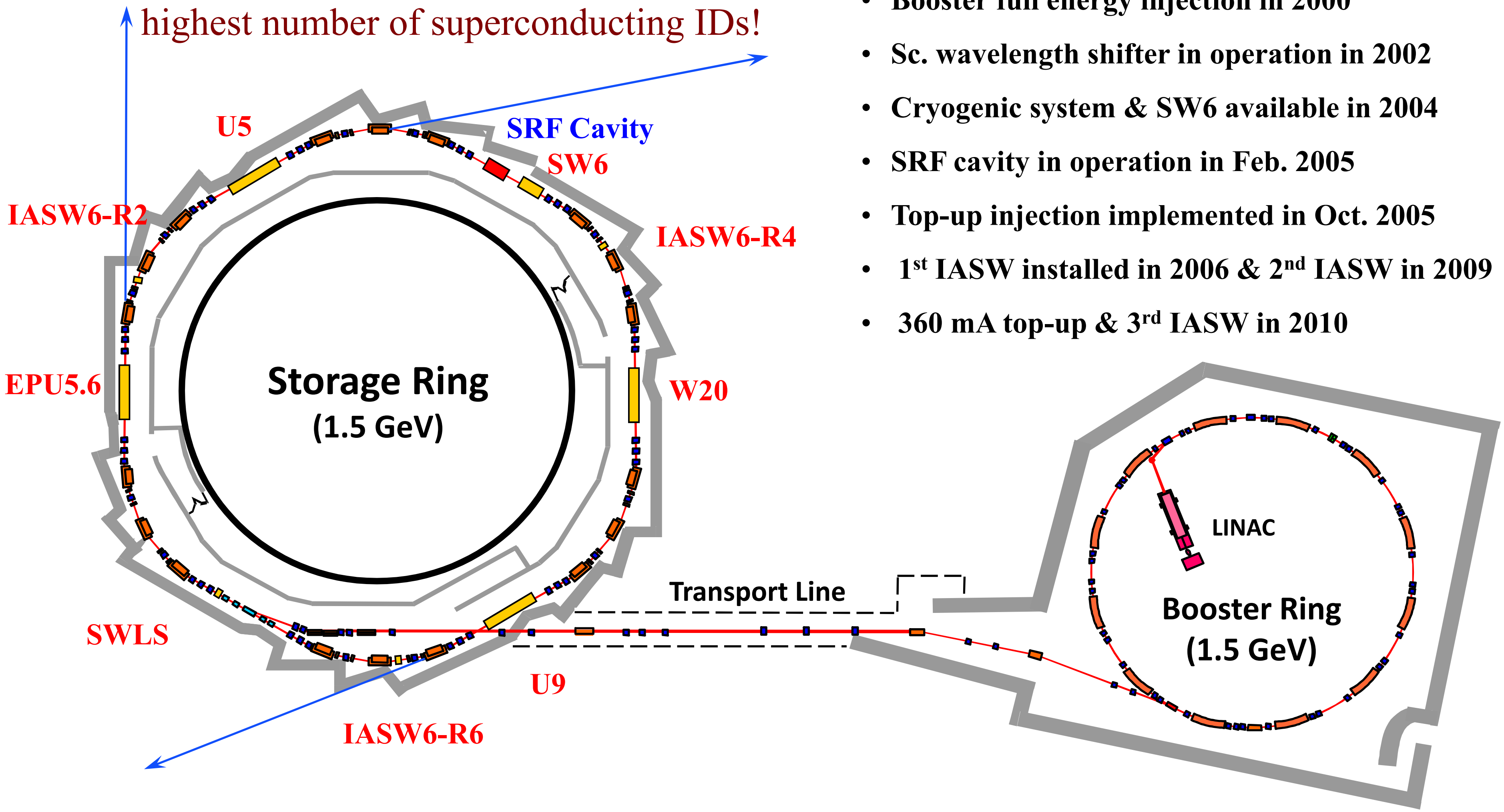
Contents

- **Taiwan Light Source**
  - Layout and milestone
  - Operation statistics
- **Taiwan Photon Source**
  - The design and layout
  - Commissioning of accelerators
  - Future Plan

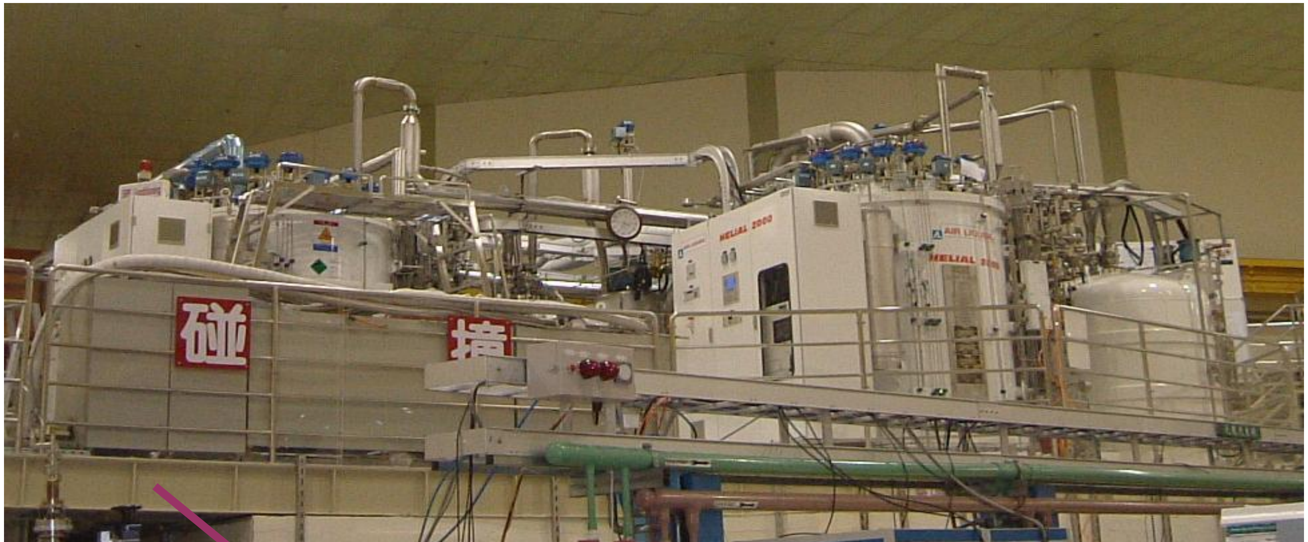
TLS accelerator layout and key milestones

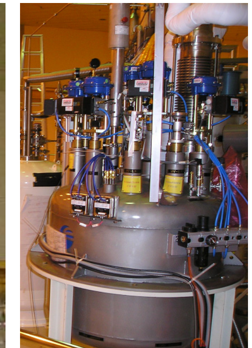
- The 1st 3rd G light source in Asia (1993)
- The 2nd LS using SRF cavity (2005)
- The 3rd LS full time top-up injection (2005)
- The most densely-packed SR ring with the highest number of superconducting IDs!

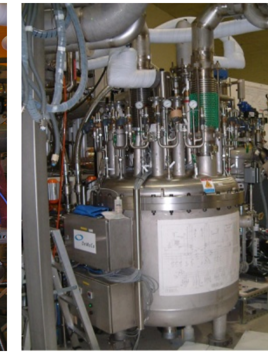
- Commission in Apr. & open to users in Oct. 1993
- 1.3 to 1.5 GeV ramping in operation in 1996
- 240 mA operation beam current in 1996
- Booster full energy injection in 2000
- Sc. wavelength shifter in operation in 2002
- Cryogenic system & SW6 available in 2004
- SRF cavity in operation in Feb. 2005
- Top-up injection implemented in Oct. 2005
- 1st IASW installed in 2006 & 2nd IASW in 2009
- 360 mA top-up & 3rd IASW in 2010



The Largest Cryo-plants (2x460W) in Taiwan







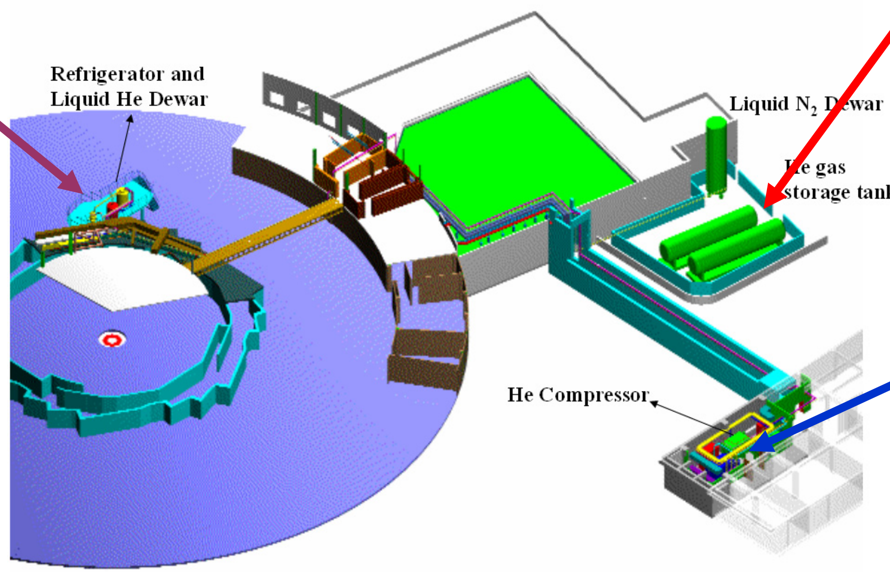
Cryo. Sys. Operation Cost

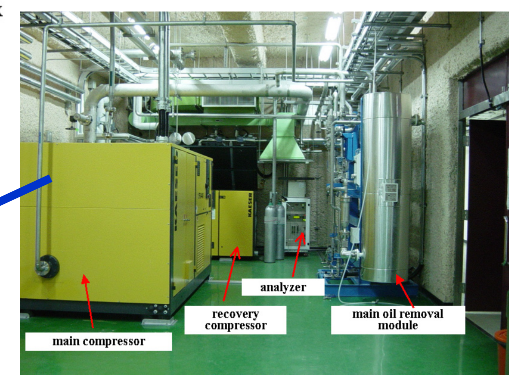
Maintenance (cryogenic system)
Safety/Inspection

Maintenance (utility)

Electricity (335 kW/350days)

Total: 8,982 kNT

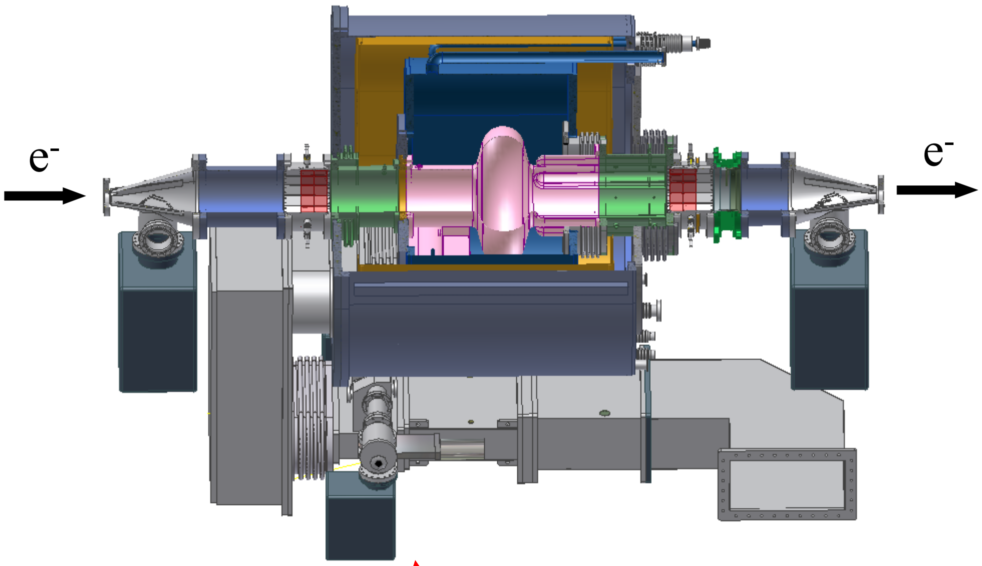


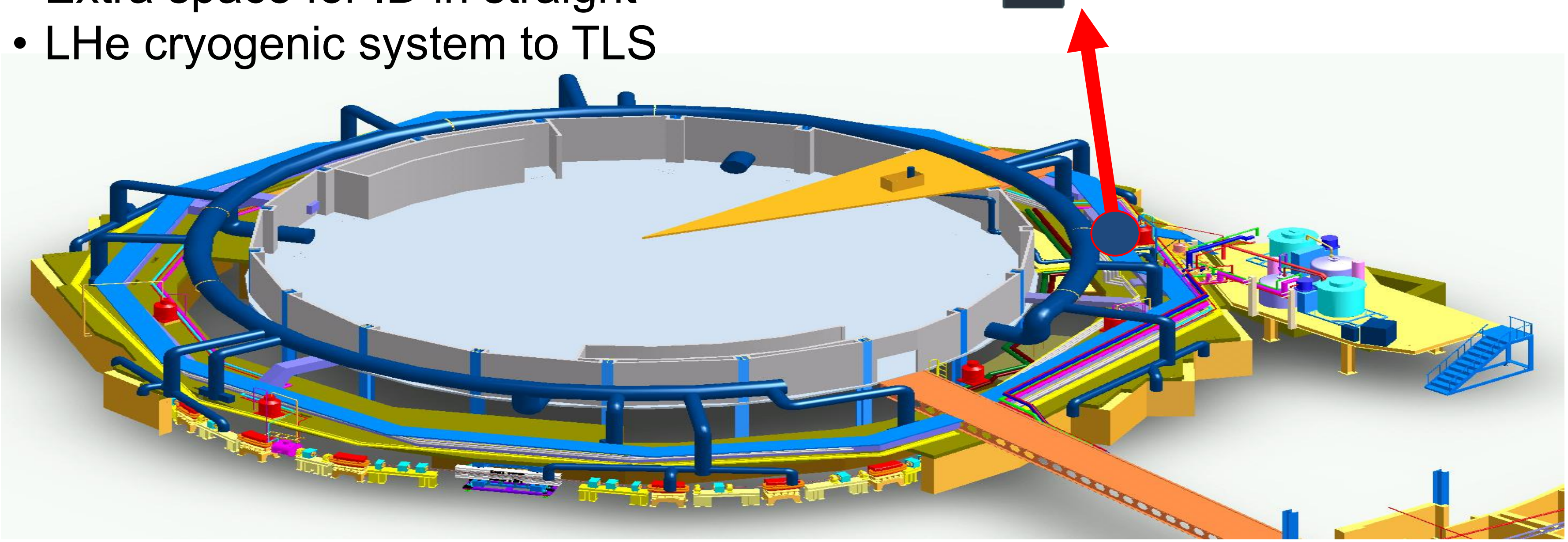


Superconducting RF (SRF) project

Goals：

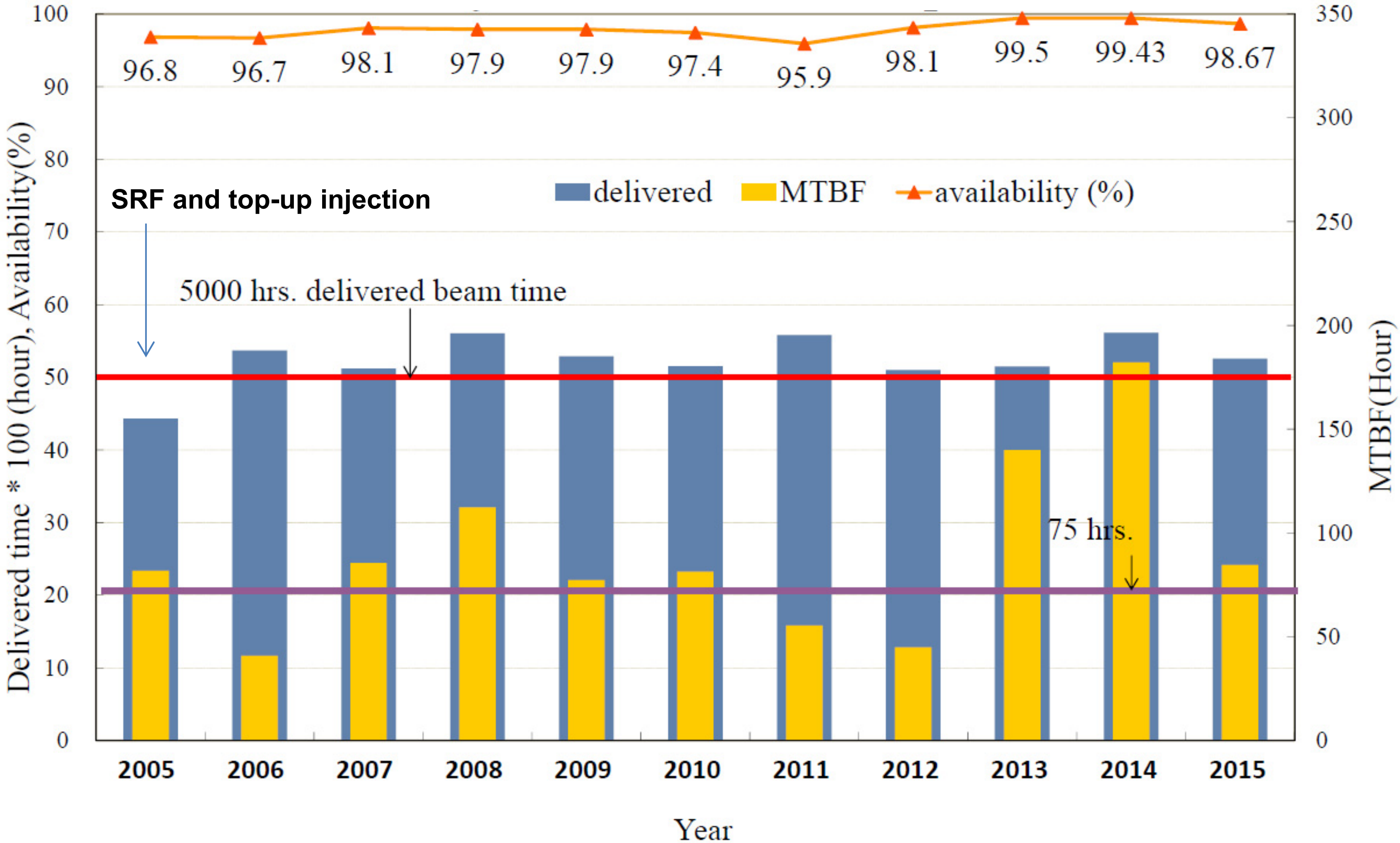
- Increase the stored beam current and photon flux
- Eliminate beam instabilities by higher-order-modes (HOMs) free cavities
- Reduce the number of RF transmitters and cavities
- Extra space for ID in straight
- LHe cryogenic system to TLS





TLS運轉

Annually delivered > 5,000 hrs. to users with availability 96~99%



Delivered: 5,256 hrs.; Availability: 98.67%; MTBF*: 84.56 hrs.

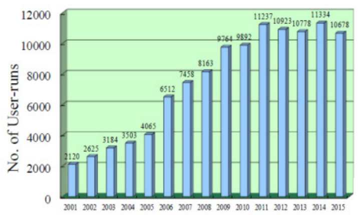
(updated to Jan. 1, 2016)

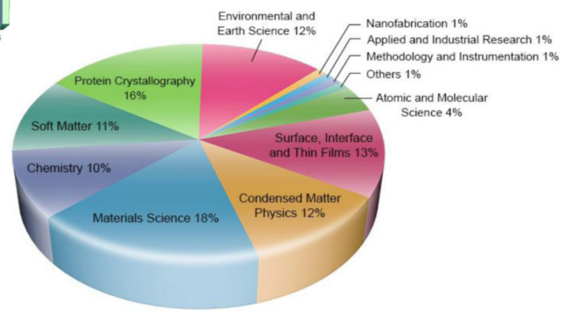
*** MTBF: Mean Time Between Failures**

TLS Operation Statistics

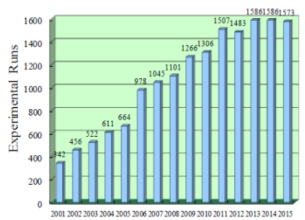
Number of experiments and user-runs

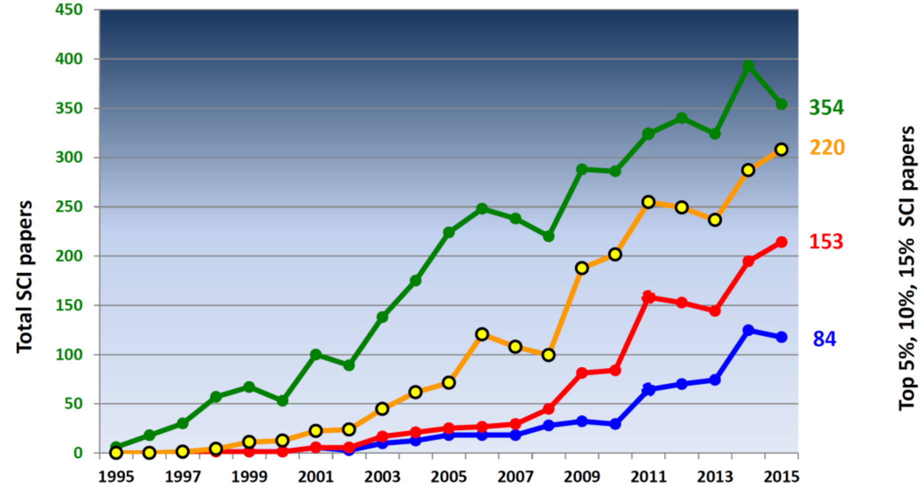
International User-run: 9.5%





International Proposals: 13 %

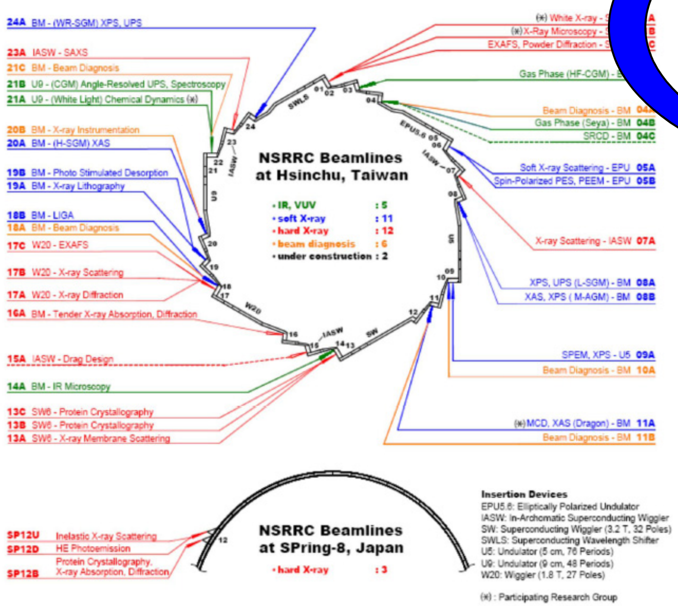




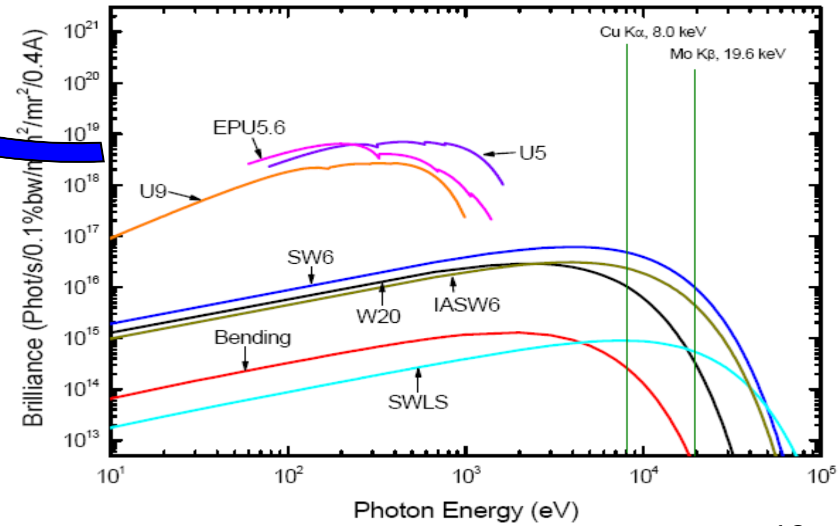
…I.F. ≥ 6.0 for physical science; I.F. ≥ 9.0 for life science.
…p 10%: I.F. ≥ 4.5 for physical science; I.F. ≥ 6.0 for life science.
3. Top 15%: I.F. ≥ 3.5 for physical science; I.F. ≥ 4.8 for life science.

(updated on 105.04.08)

Beamlines in TLS and SPring-8



Brilliance of TLS IDs

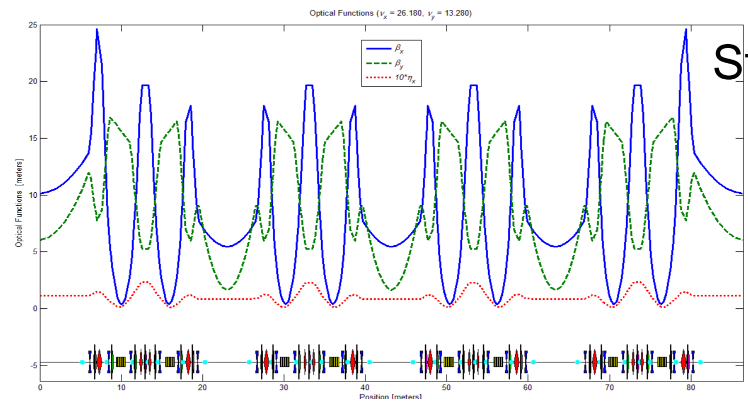


Taiwan Photon Source

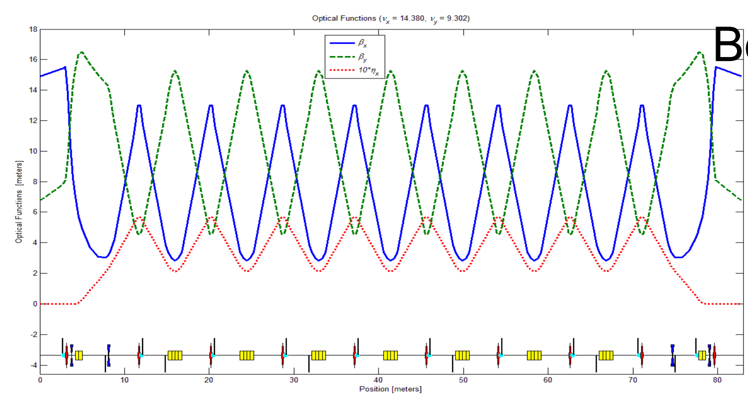
Major parameters of Taiwan Photon Source

Energy	3 GeV (maximum 3.3 GeV)
Current	500 mA at 3 GeV (Top-up injection)
SR circumference	518.4 m (h = 864 = $2^5 \cdot 3^3$, dia.= 165.0 m)
BR circumference	496.8 m (h = 828 = $2^2 \cdot 3^2 \cdot 23$, dia.= 158.1 m)
Lattice	24-cell DBA
Straight sections	12 m x 6 (σ_v = 12 μm, σ_h = 160 μm) 7 m x 18 (σ_v = 5 μm, σ_h = 120 μm)

Storage Ring Circumference (m)	518.4
Energy (GeV)	3.0
Beam current (mA)	500
Natural emittance (nm-rad)	1.6
Straight sections (m)	12 (x6) + 7 (x18)
Radiofrequency (MHz)	499.654
Harmonic number	864
RF voltage (MV)	3.5
Energy loss per turn (dipole) (keV)	852.7
Betatron tune	26.18 /13.28
Momentum compaction (α_1, α_2)	2.4×10^{-4}, 2.1×10^{-3}
Natural energy spread	8.86×10^{-4}
Damping time (ms)	12.20 / 12.17 / 6.08
Natural chromaticity	-75 / -26
Synchrotron tune	0.00609
Bunch length (mm)	2.86



Storage Ring



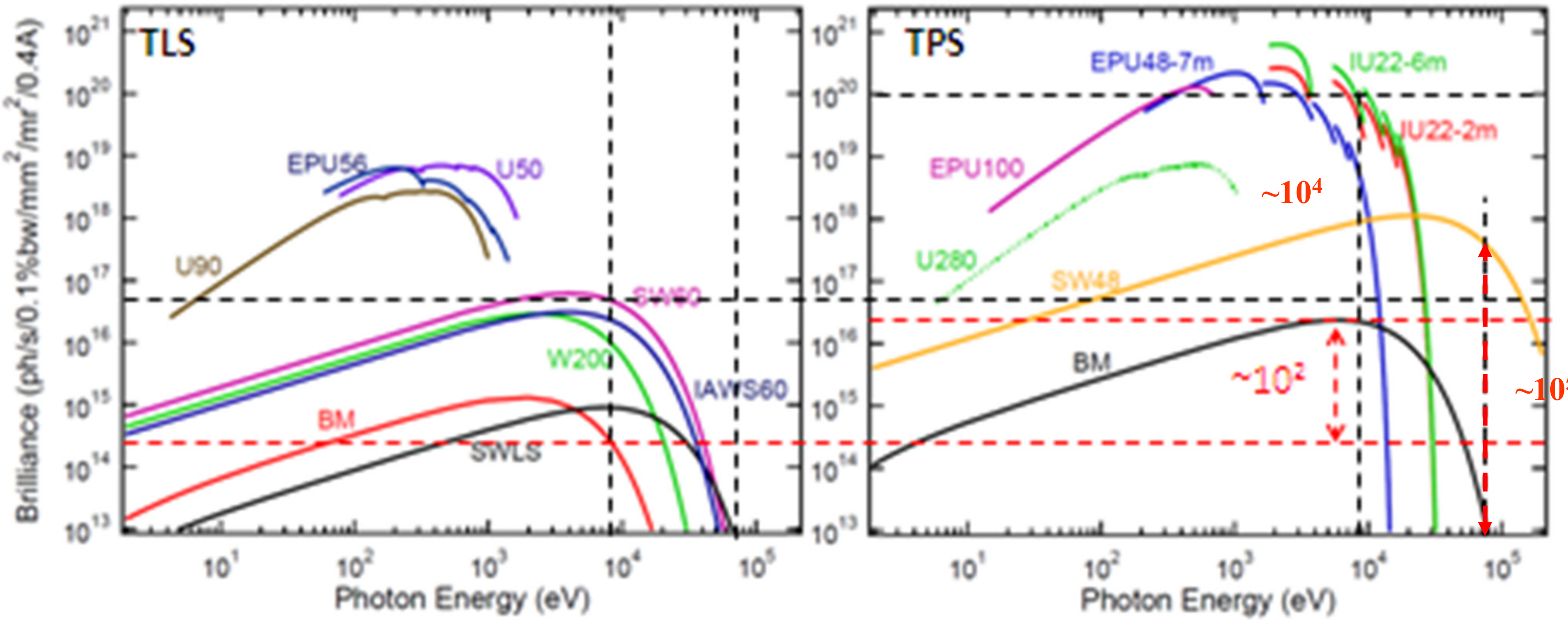
Booster Ring

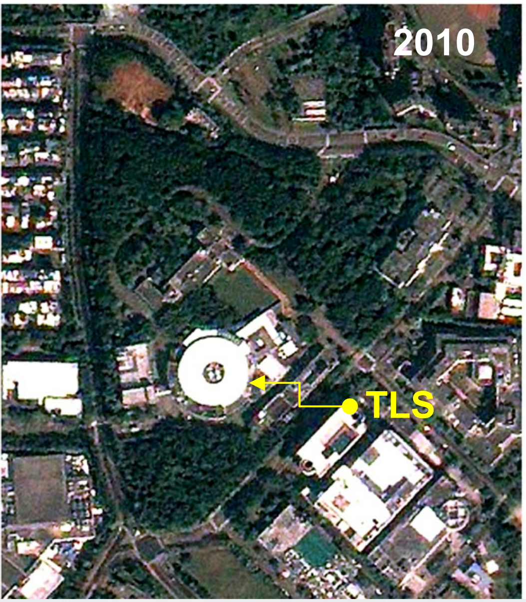
Comparison of brightness between TLS and TPS

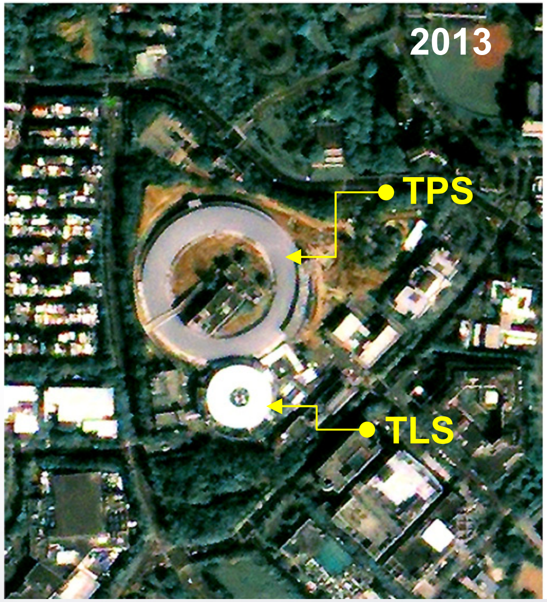
The X-ray spectrum (photon energy 8 keV ~ 70 keV):

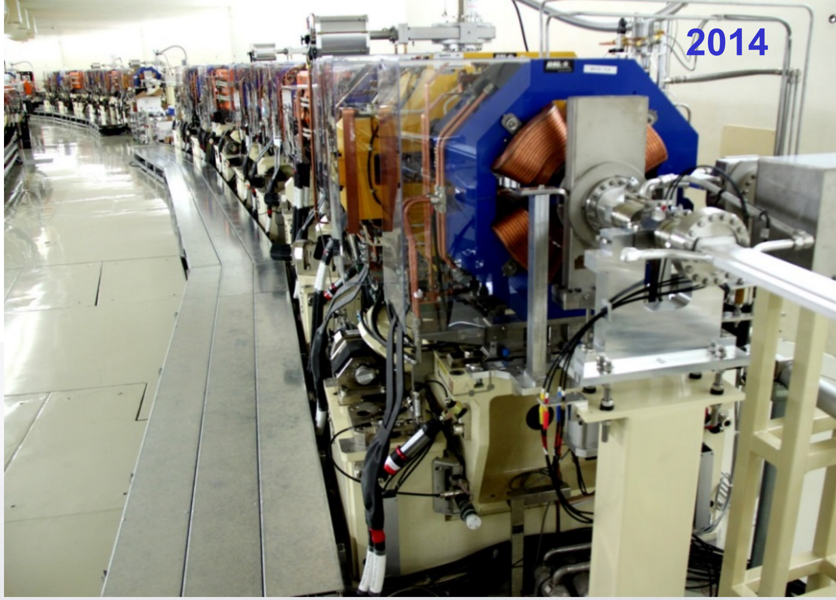
the brightness of bending magnet $>10^2$.

the brightness of IDs: 4~6 orders of mag.




2010
TLS


2013
TPS
TLS


2014


March, 2015
TLS
TPS

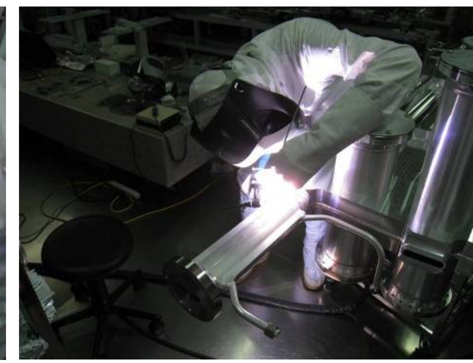
Process welding of BC in Chu-Tung

Upper and lower leaf of BC

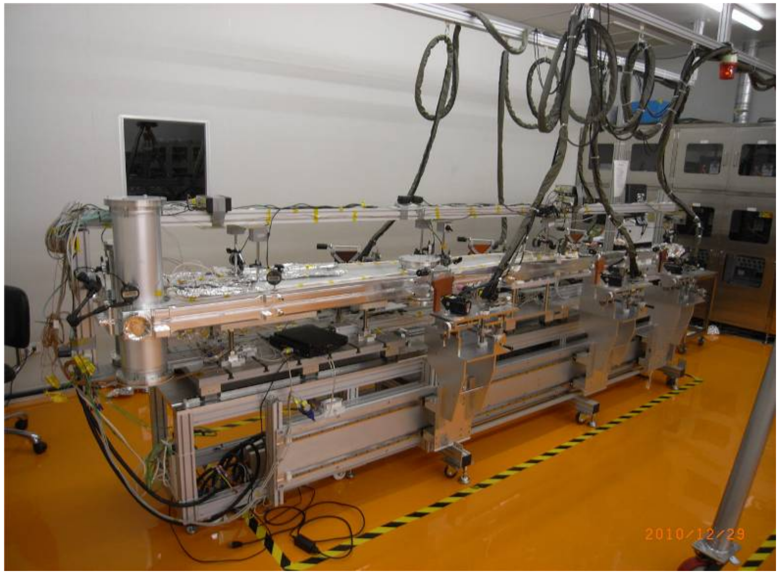
Welding pumping port

Alignment for the bending chamber

Bending chamber in auto-welding stage



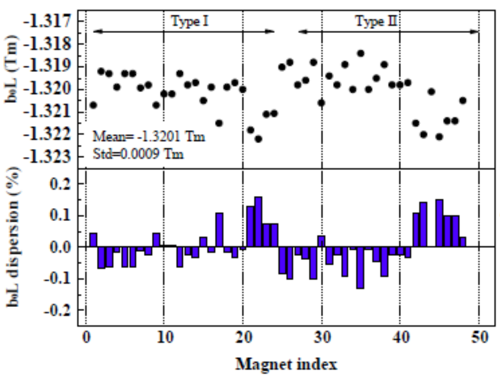
Assembly of pedestals, girders and vacuum system in Chu-Tung

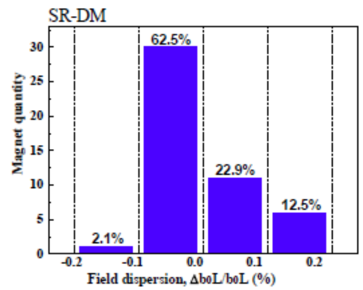


Field qualification of SR and BR magnets

SR dipole magnet

Field dispersion



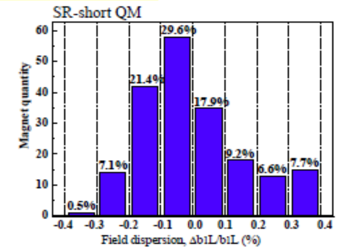


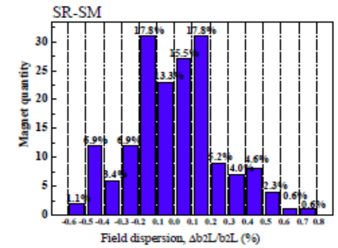
48 SR-DM:

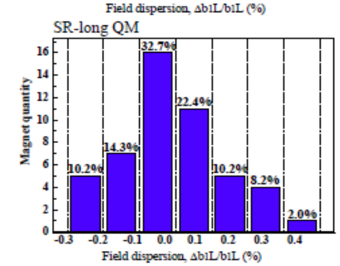
- The mean value of b_0L is -1.3201 Tm.
- The standard deviation of b_0L is 0.0009 Tm (0.07%).
- The b_0L dispersion is better than 0.16%. (85.4% of magnet are better then ±0.1%).

SR quadrupole/sextupole magnet

Field dispersion





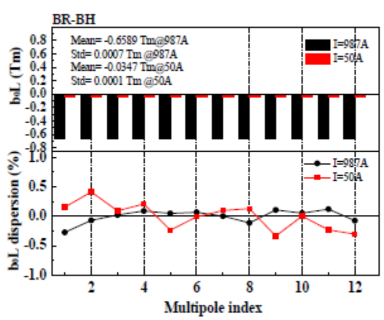


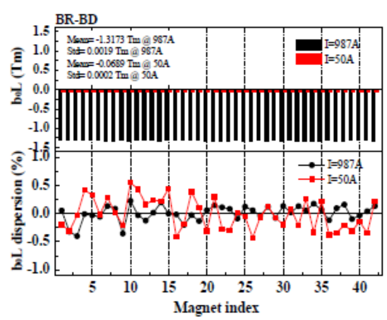
SR-QM/SM:

- The b_1L of Short-QM and Long-QM are better than ±0.4%.
- The b_2L dispersion of 95.4% of SM are better than ±0.5%.
- The integral field strength of QM/SM magnet will be fine-tuned with an independent power supply.

BR-dipole magnet

Field dispersion



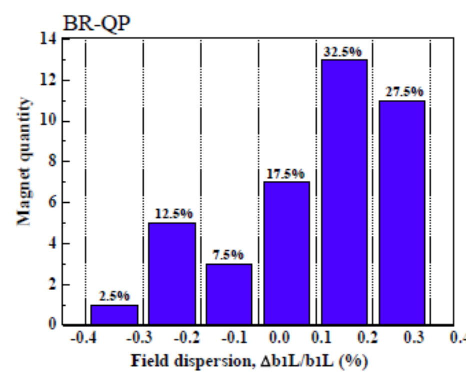


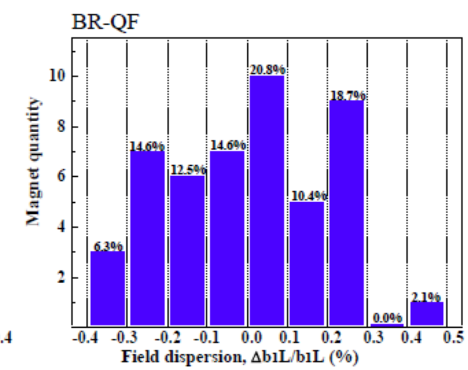
12 BH and 42 BH:

- The mean value of BH and BD is -0.6586 Tm and -1.3173 Tm with 987A charged respectively.
- The standard deviation of BH and BD is 0.0007 Tm (0.11%) and 0.0019 Tm (0.14%) with 987A charged, respectively.

BR-quadrupole magnet

Field dispersion





BR-QM:

- The b_1L dispersion of BR-QP is better than ±0.4%.
- The b_1L dispersion of BR-QF is better than ±0.5%.

Integration of magnets, vacuum chambers and girders

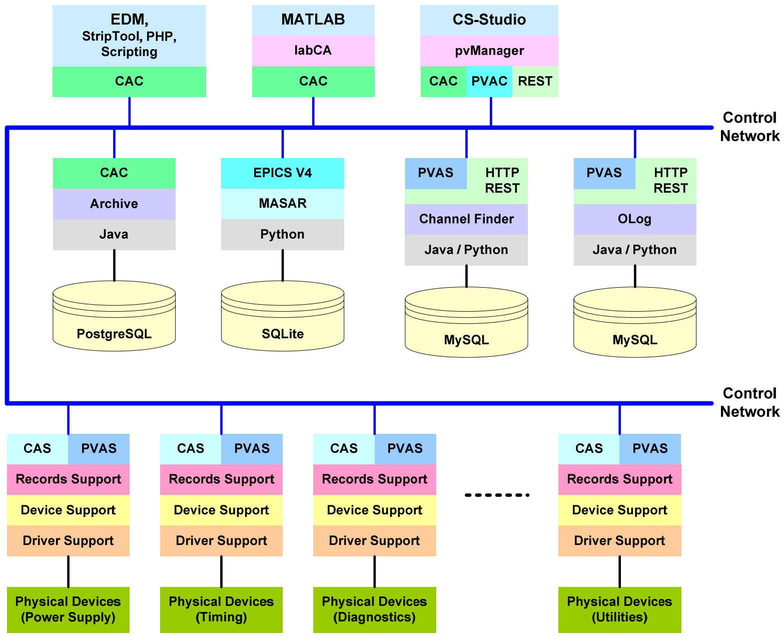
Installation of a 14 m vacuum cell on the girders.

Anchor the 14 m vacuum cell on the girders.

Assembling of a 14 m vacuum cell with magnets in the tunnel

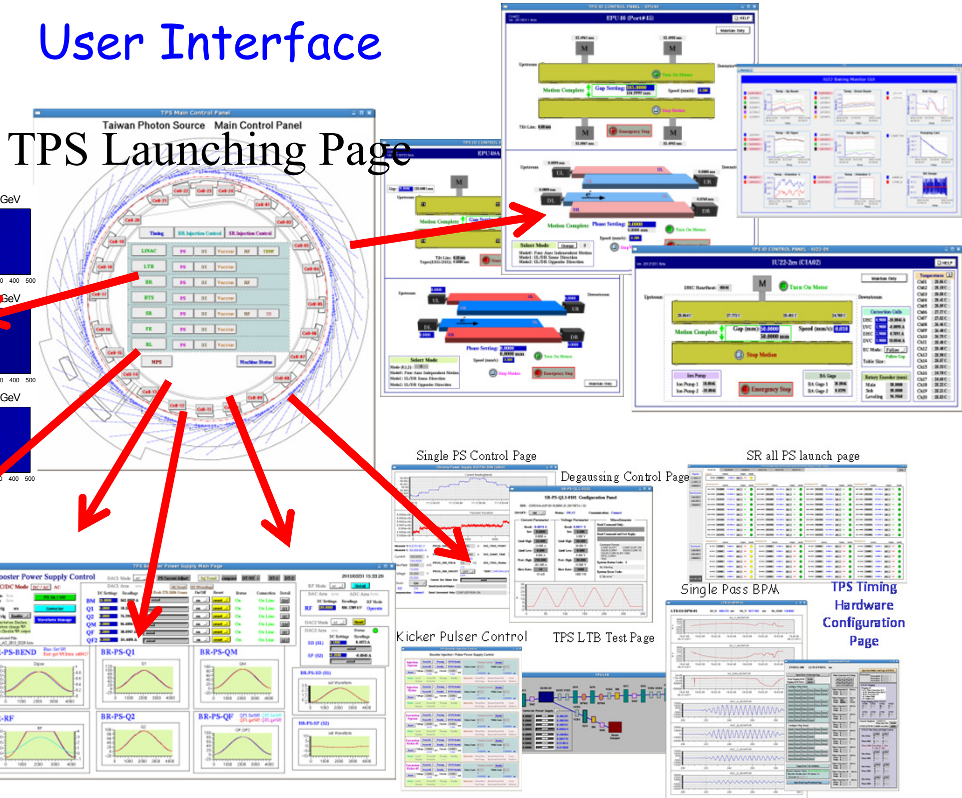
Installation of the vacuum system for the 1/12 section of booster.

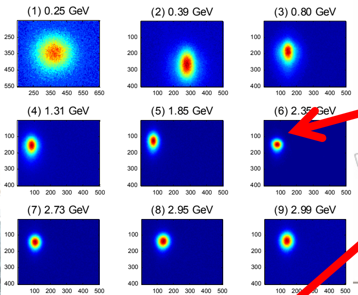
Software Architecture

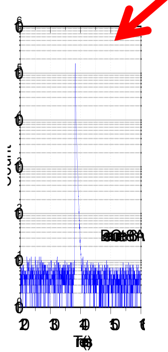


Control Room

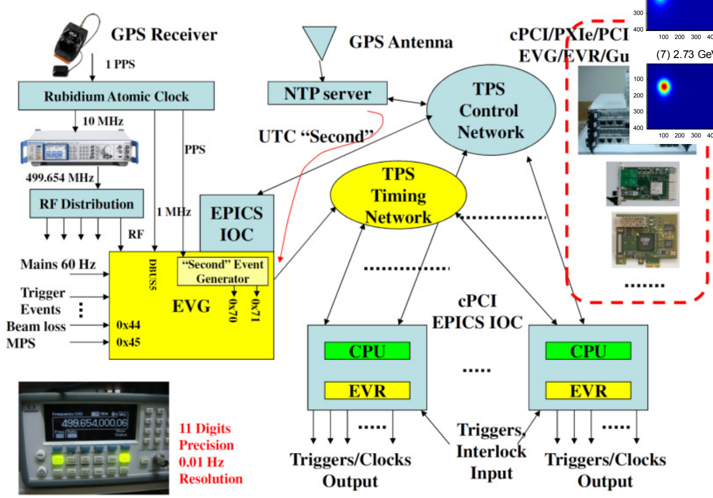
User Interface







Timing System

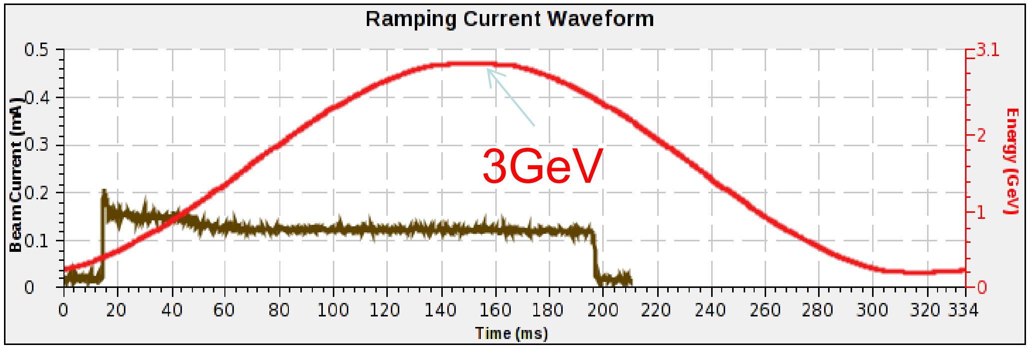


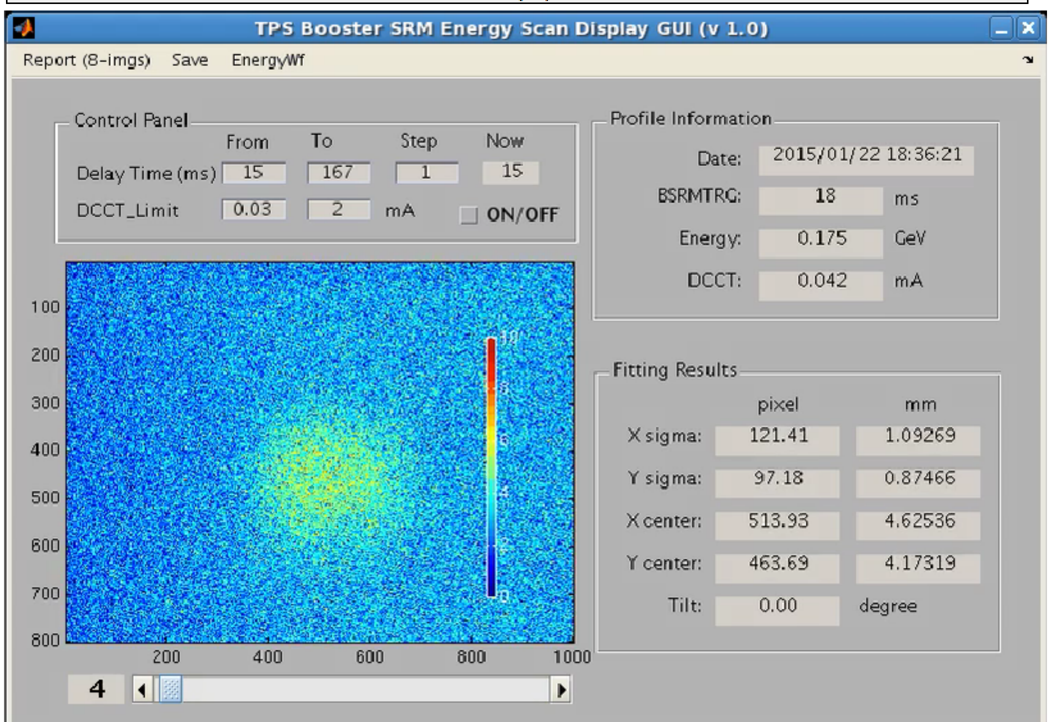
Commissioning of Accelerators

Booster commissioning

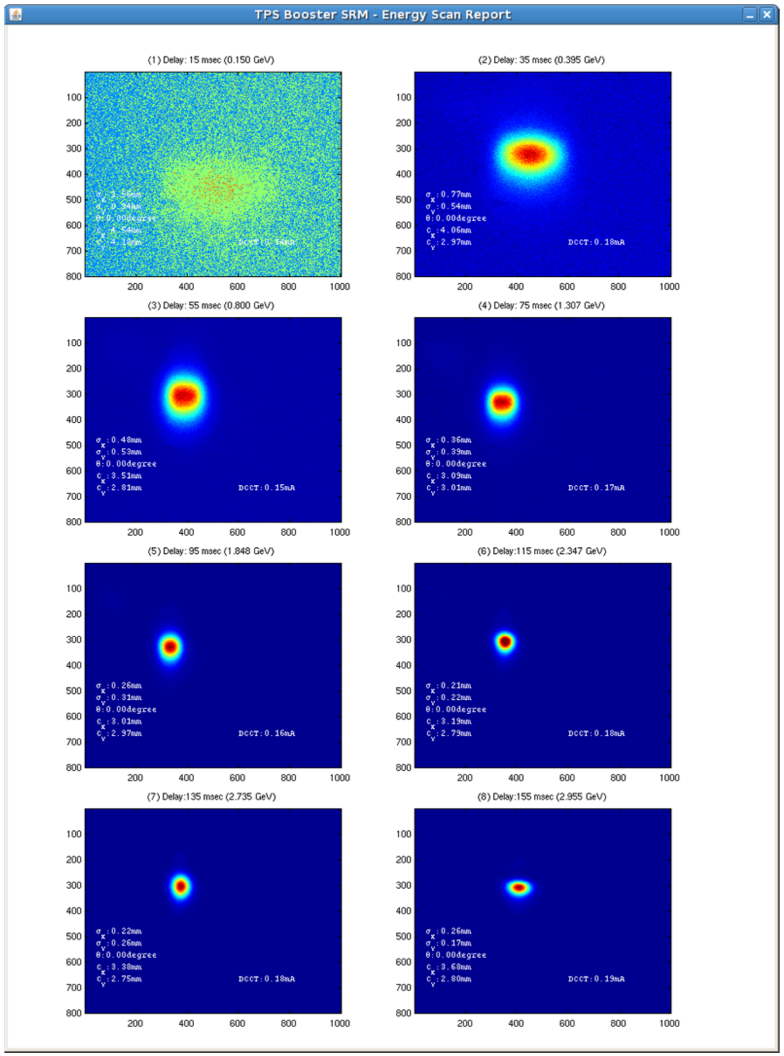
Booster beam commissioning started on 12 Dec. 2014, successfully ramped to 3 GeV on 16 Dec. 2014

Beam Current (peak): 0.16 mA at 3 GeV



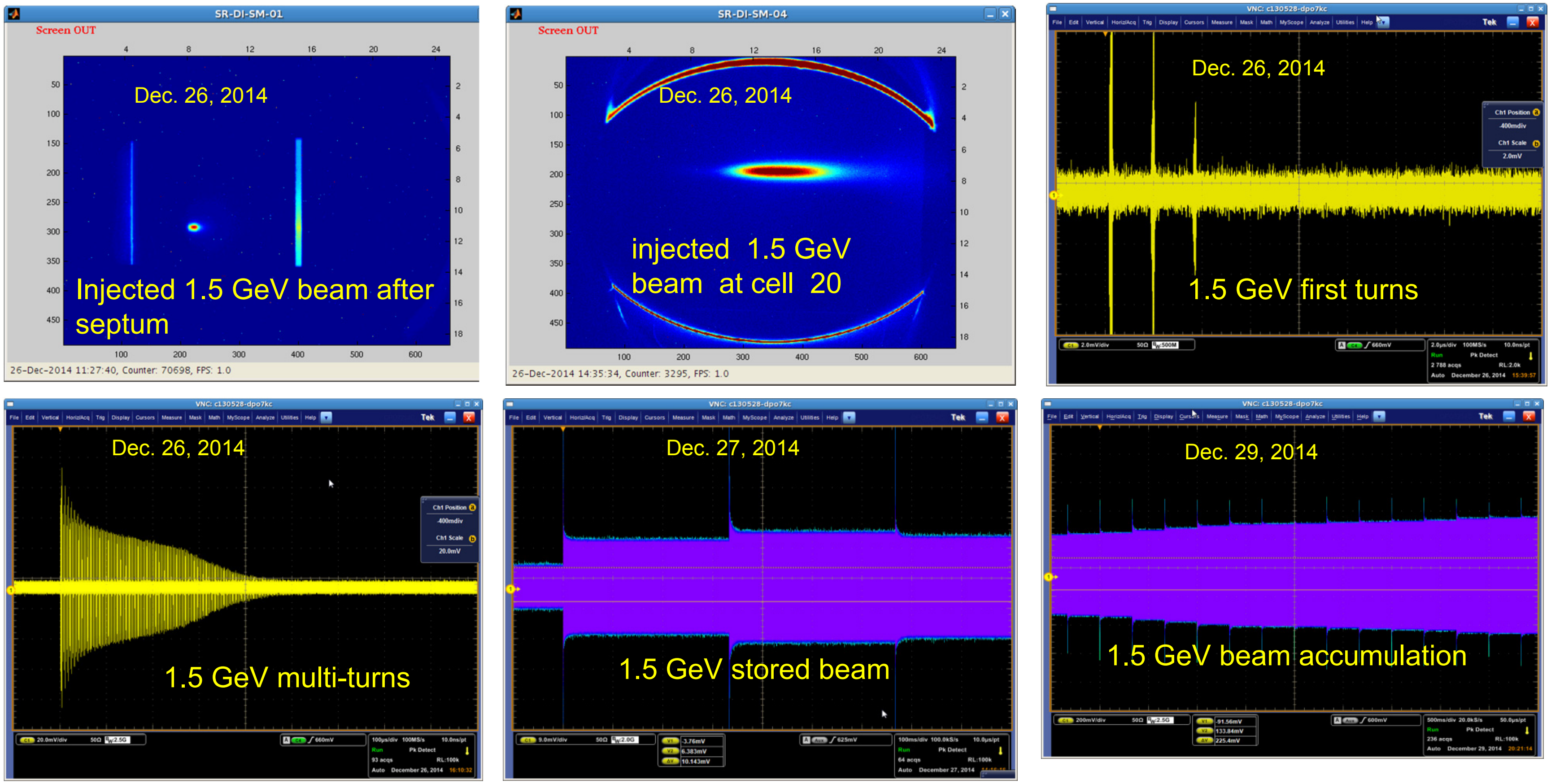


Beam profile measured by synchrotron light monitor



Storage Ring Commissioning at 1.5 GeV

- **Dec. 24, extracted 3 GeV beam but DC septum leakage field affected booster**
- **Dec. 26, 1.5 GeV beam injected, multi-turn with one H corrector**
- **Dec. 27, stored beam with sextupoles and RF on. RF, sextupole, and quad scan**
- **Dec. 29, accumulated beam with kicker scan**

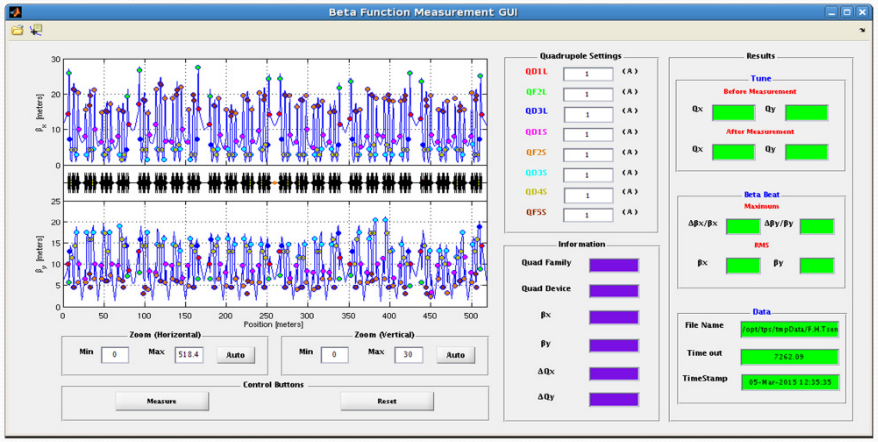


The first synchrotron light from TPS storage ring at 3GeV, 1mA

December 31, 2014

Before Optics Correction

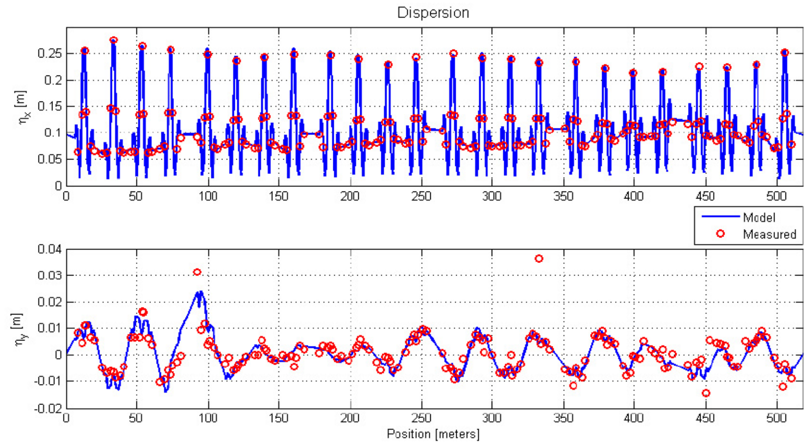
(Beta function)



Blue line is LOCO fitting result

Before Optics Correction

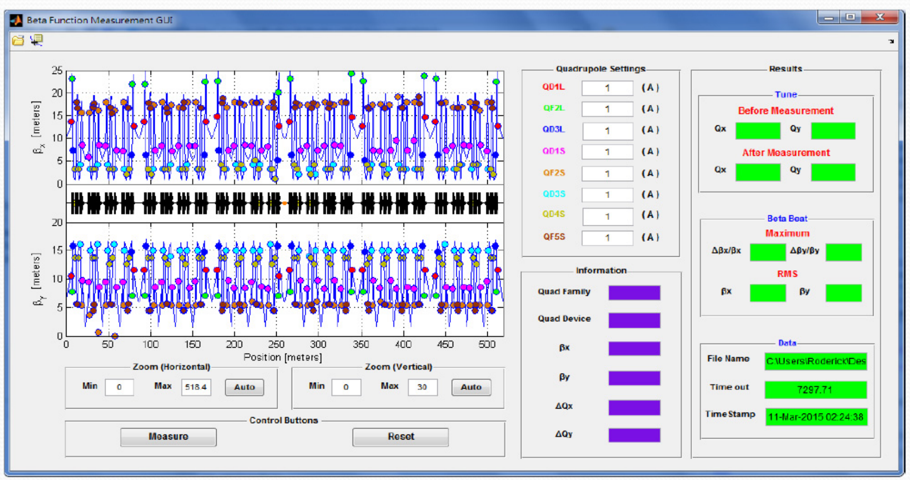
(Dispersion function)



Blue line is LOCO fitting result

After Optics Correction

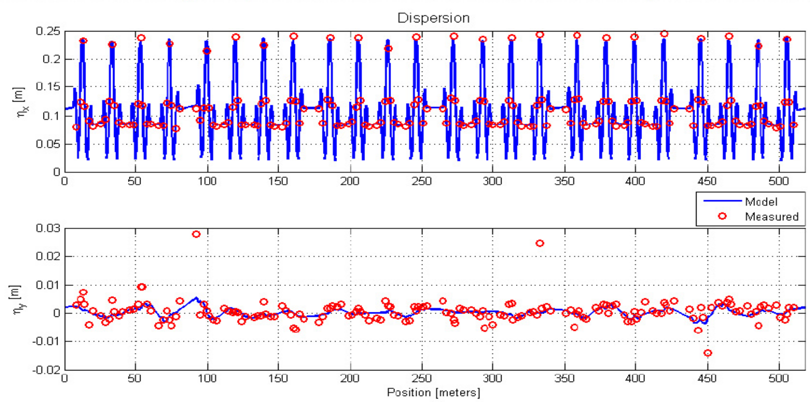
(Beta function iteration 3)



Blue line is LOCO fitting result

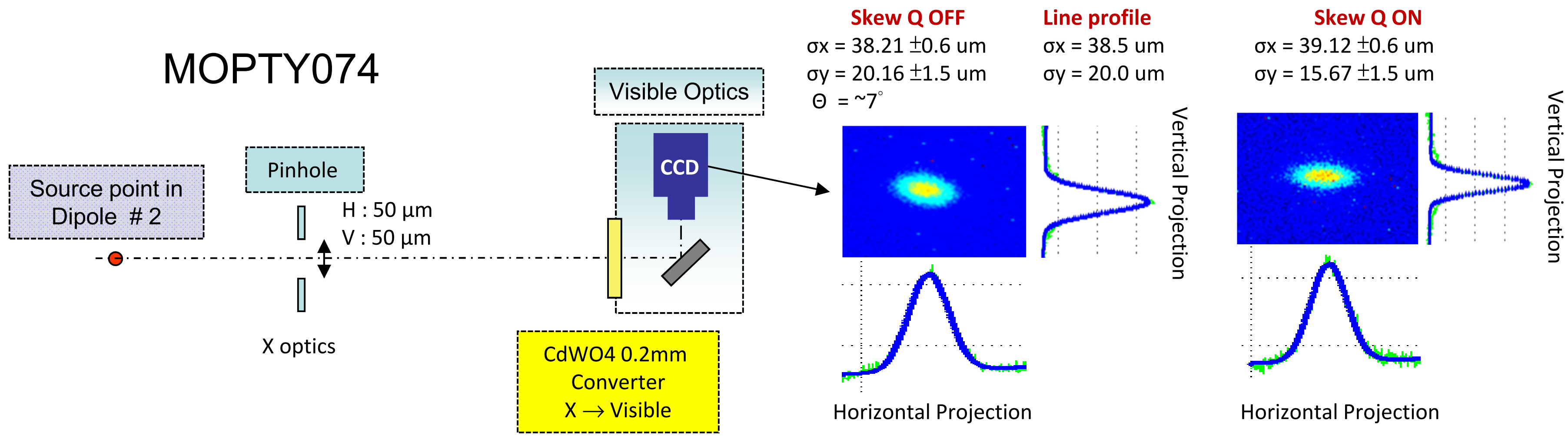
After Optics Correction

(Dispersion function iteration 3)



Blue line is LOCO fitting result

Coupling Ratio and Emittance



Pinhole camera	without skew quad	with skew quad
H. Emittance (nm.rad)	1.55	1.64
V. Emittance (pm.rad)	25.6 ±3	15.7 ±3
Emittance ratio (%)	1.65	0.96

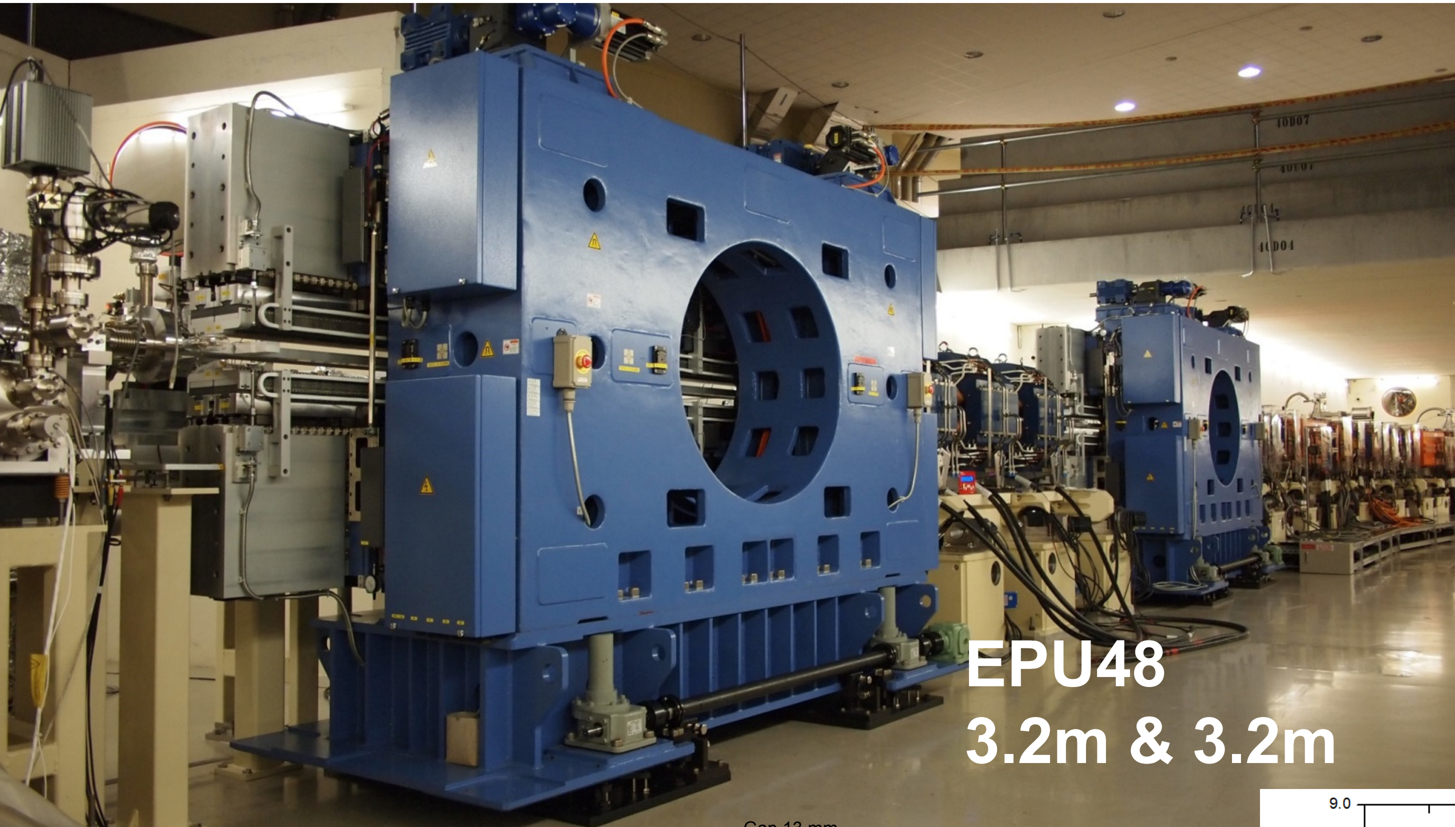
Estimated Emittance ratio (%)	without skew quad	with skew quad
Betatron Coupling	0.170	0.001
Vertical Dispersion	0.156	0.038

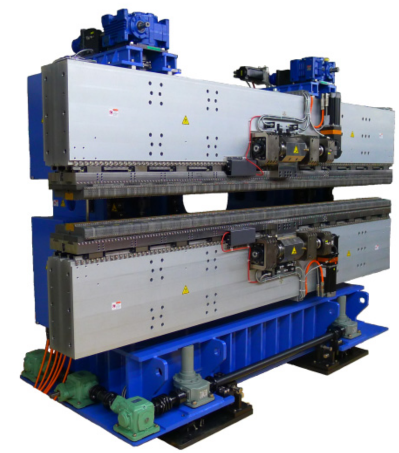
Discrepancy: Orbit noise, instabilities, resolution in instrument

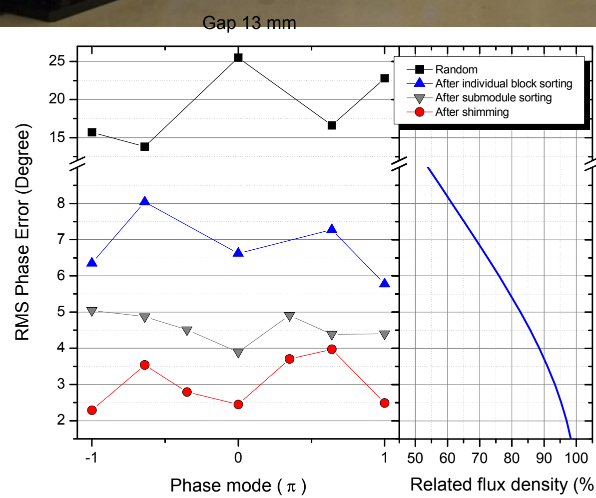
Design Natural Emittance ε_{x0} ***= 1.6 nm.rad***

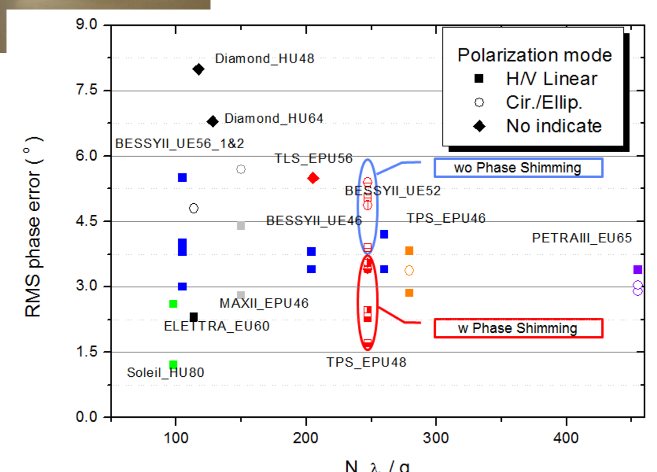
Installation of IDs, SRF cavities and Other Hardware

Elliptical Polarized Undulators at long straight



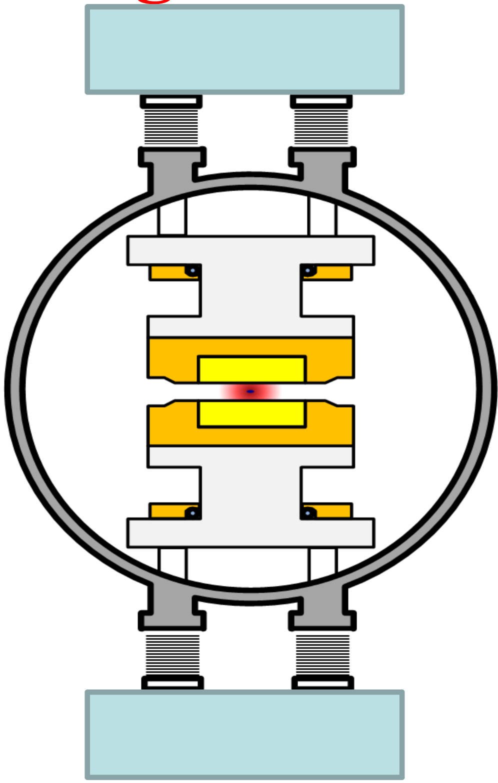


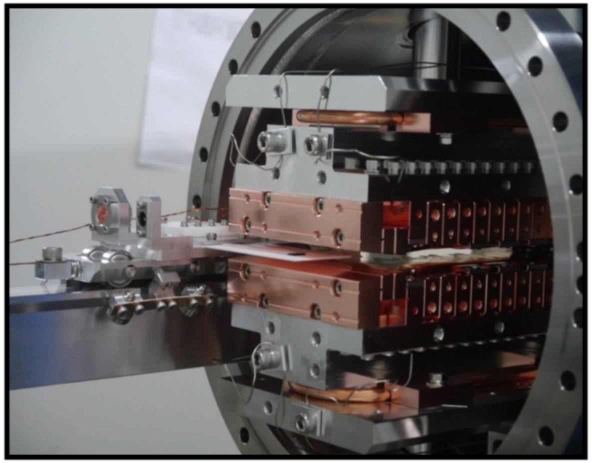


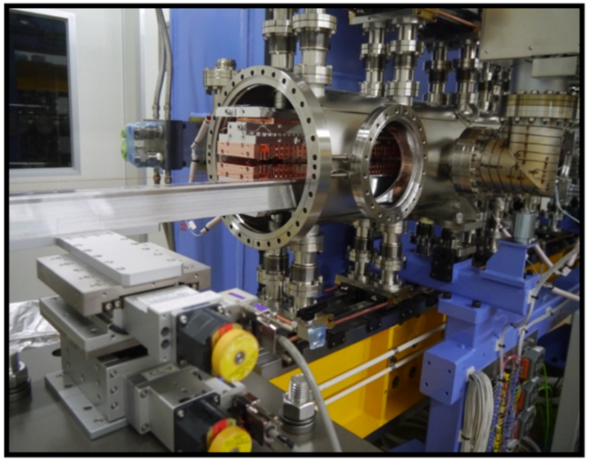


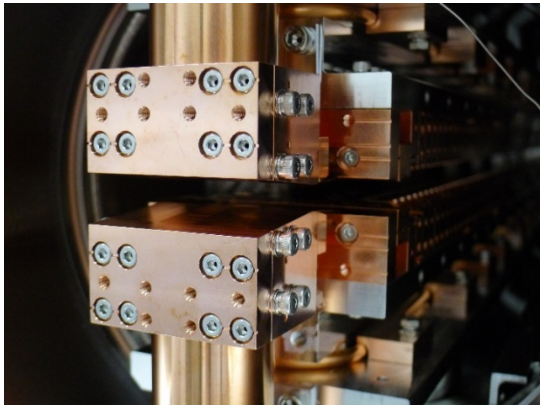
N_p : number of period; λ_p : period length; g : gap; $L = N_p \lambda_p$

In-vacuum undulators at 12 m straight



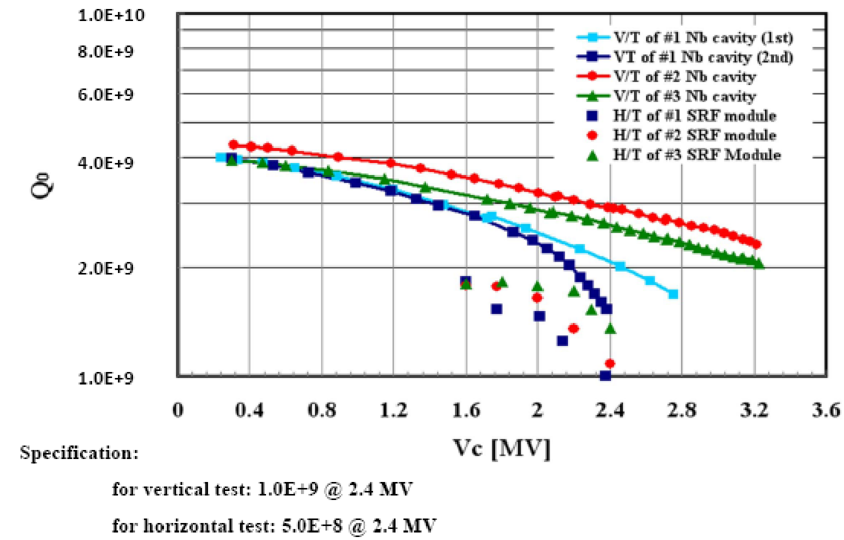






Major RF sub-system

Low-level system for RF transmitter



Performance of SRF modules 2.4 MV: $Q_0 > 5*10^8$

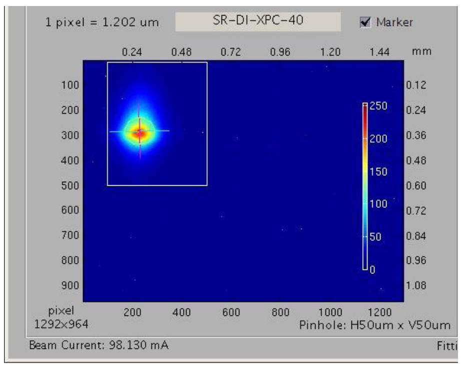
Installed 5-cells Petra cavities for phase-I

SRF cavity installed in tunnel

Instabilities in transverse and longitudinal directions

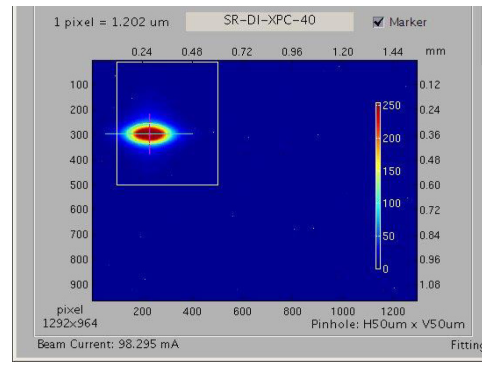
- **Transverse instability suppressed by adequate chromaticity setting and by bunch-by-bunch feedbacks (BBF) in vertical planes.**
- **Stabilized beam up to 500 mA without problem.**
- **No longitudinal instability observed.**

Vertical BBF "OFF"



Beam profile image @ 100 mA

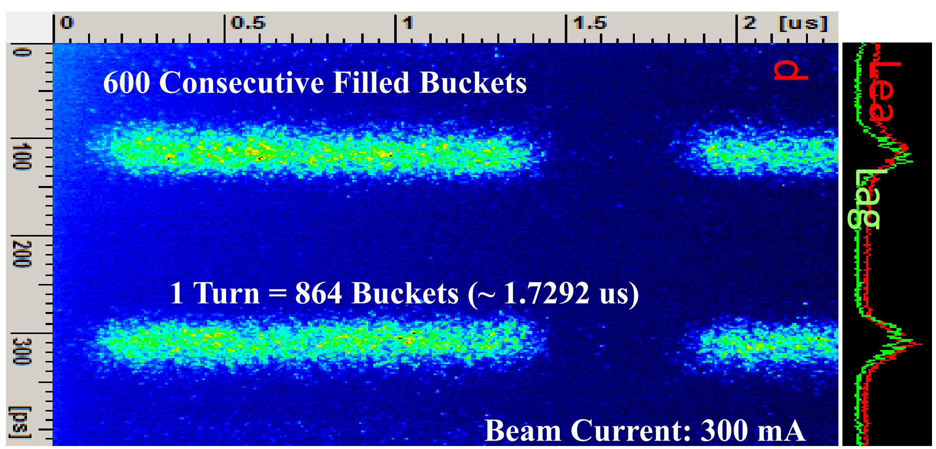
Vertical feedback "ON"



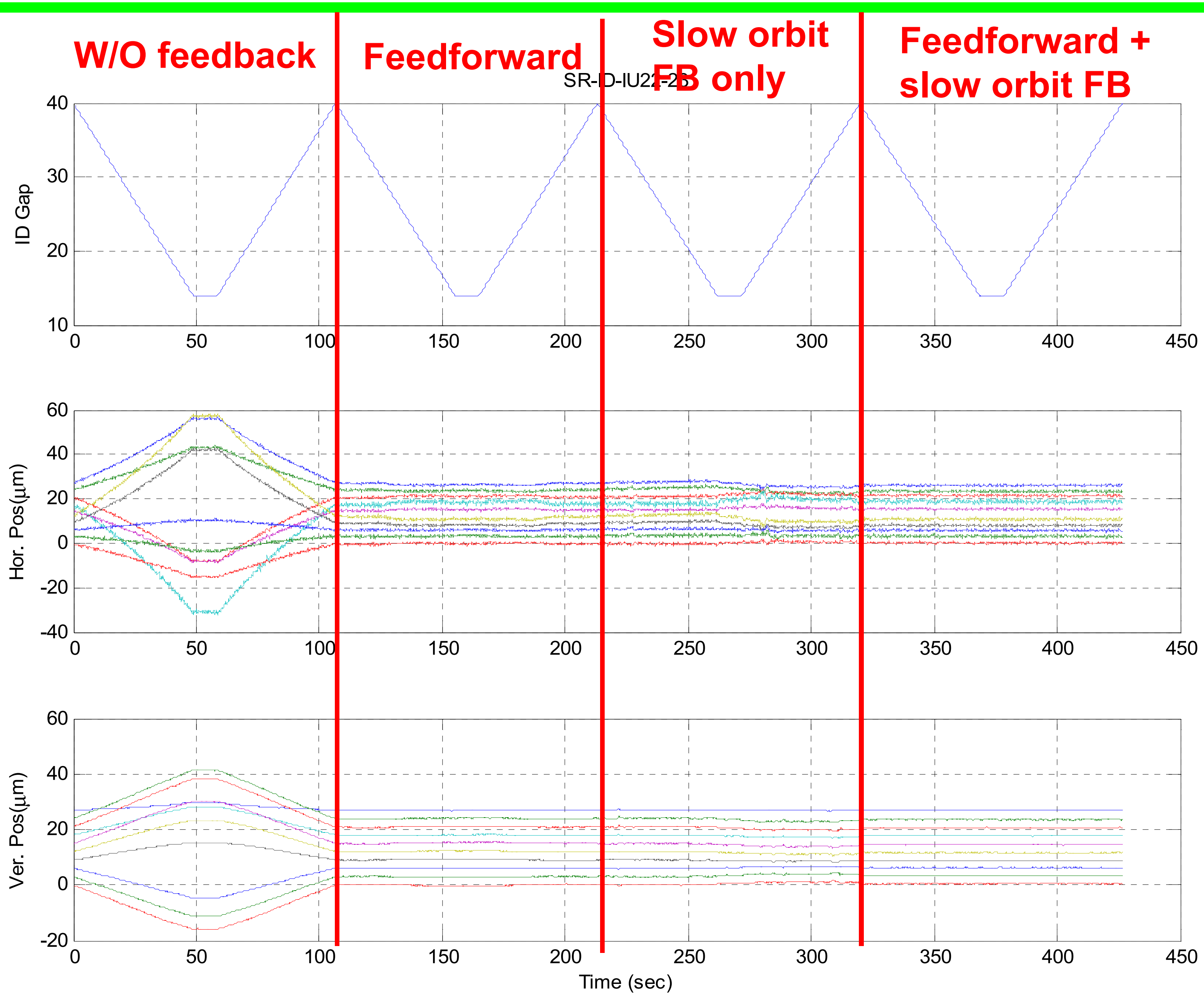
Longitudinal Stable Beam @ 300 mA

Odd Bunches

Even Bunches

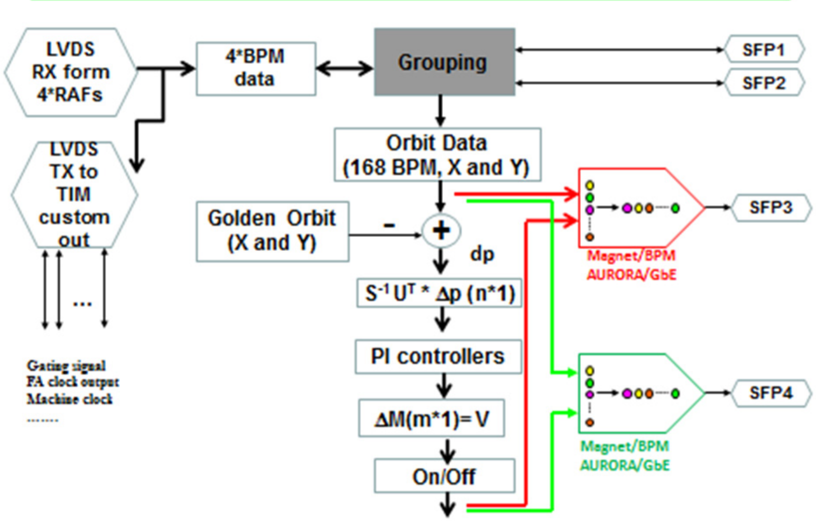


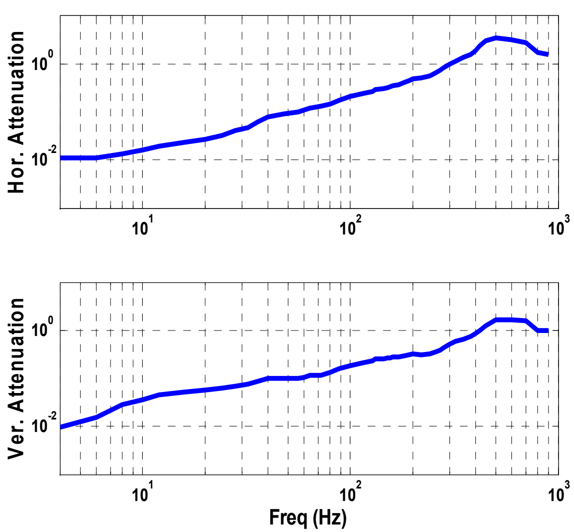
IU22-23 Measured on 2015/11/18



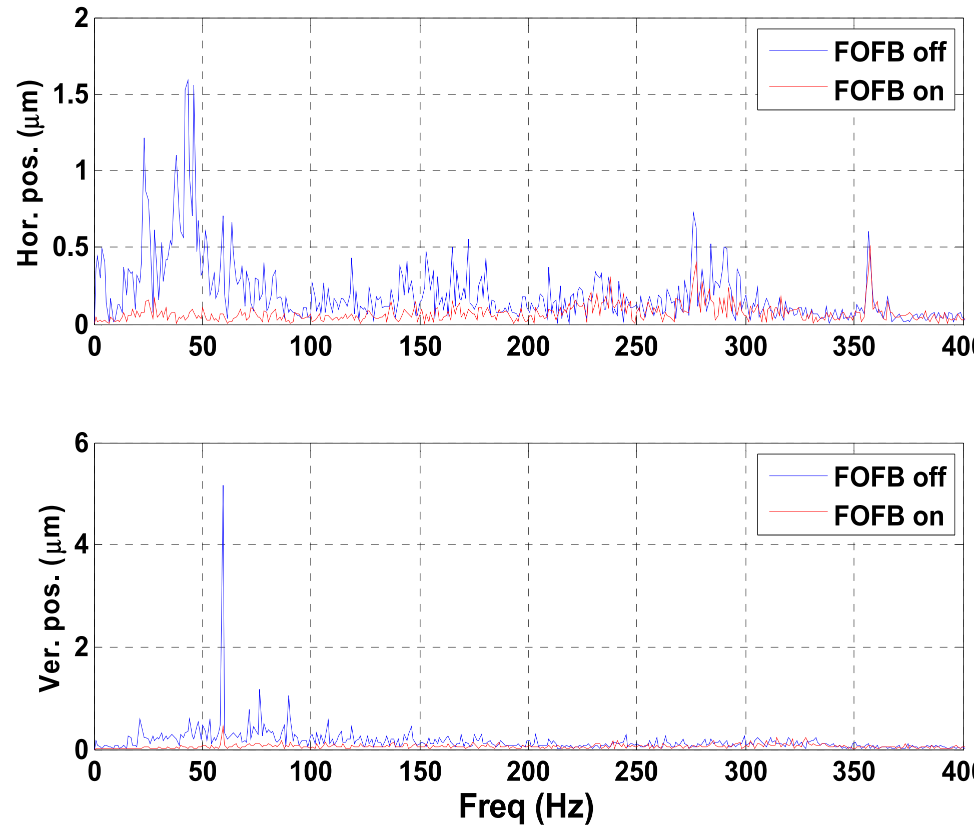
Performance of fast orbit feedback system

Block of FOFB computation modules

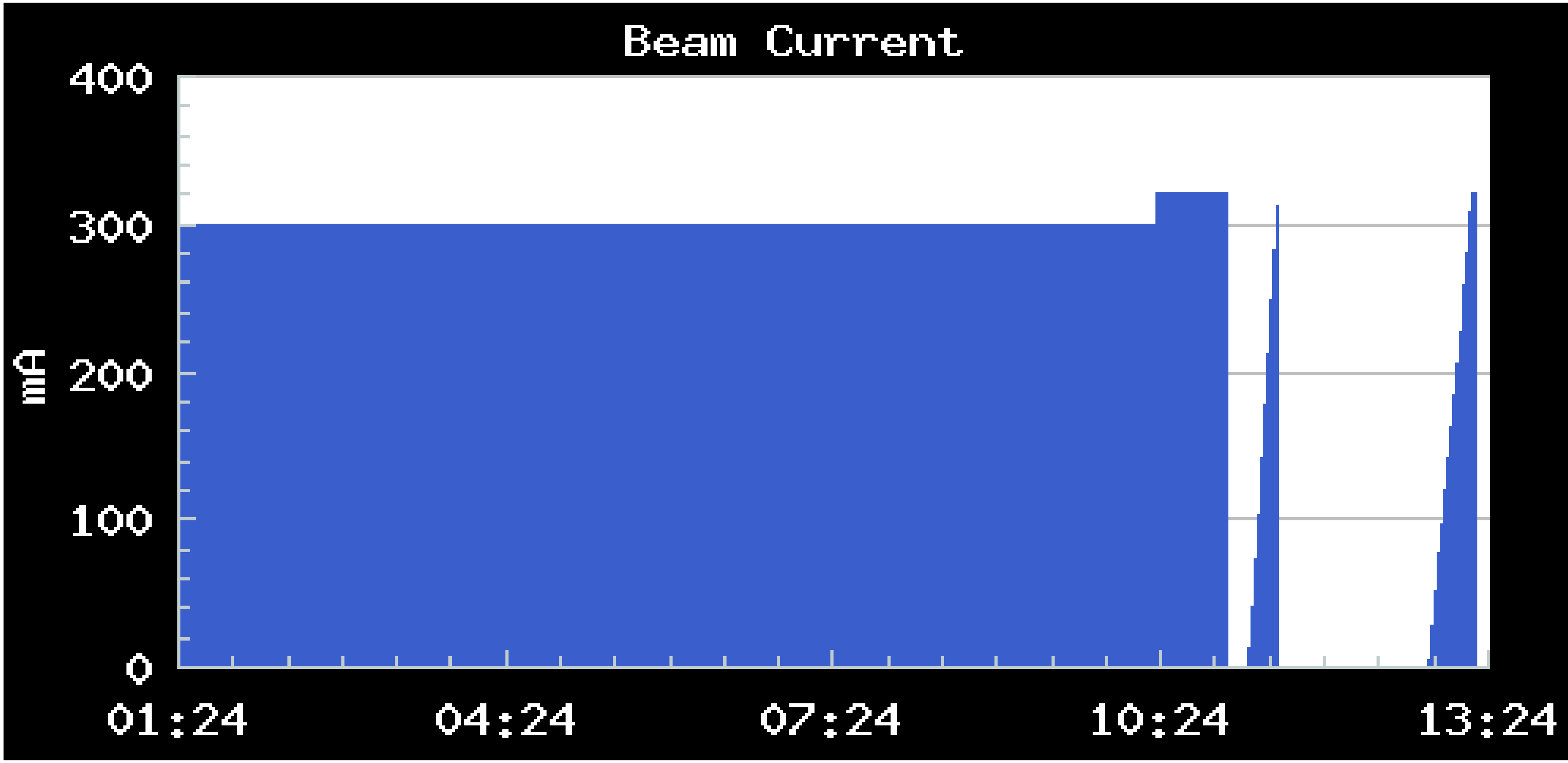




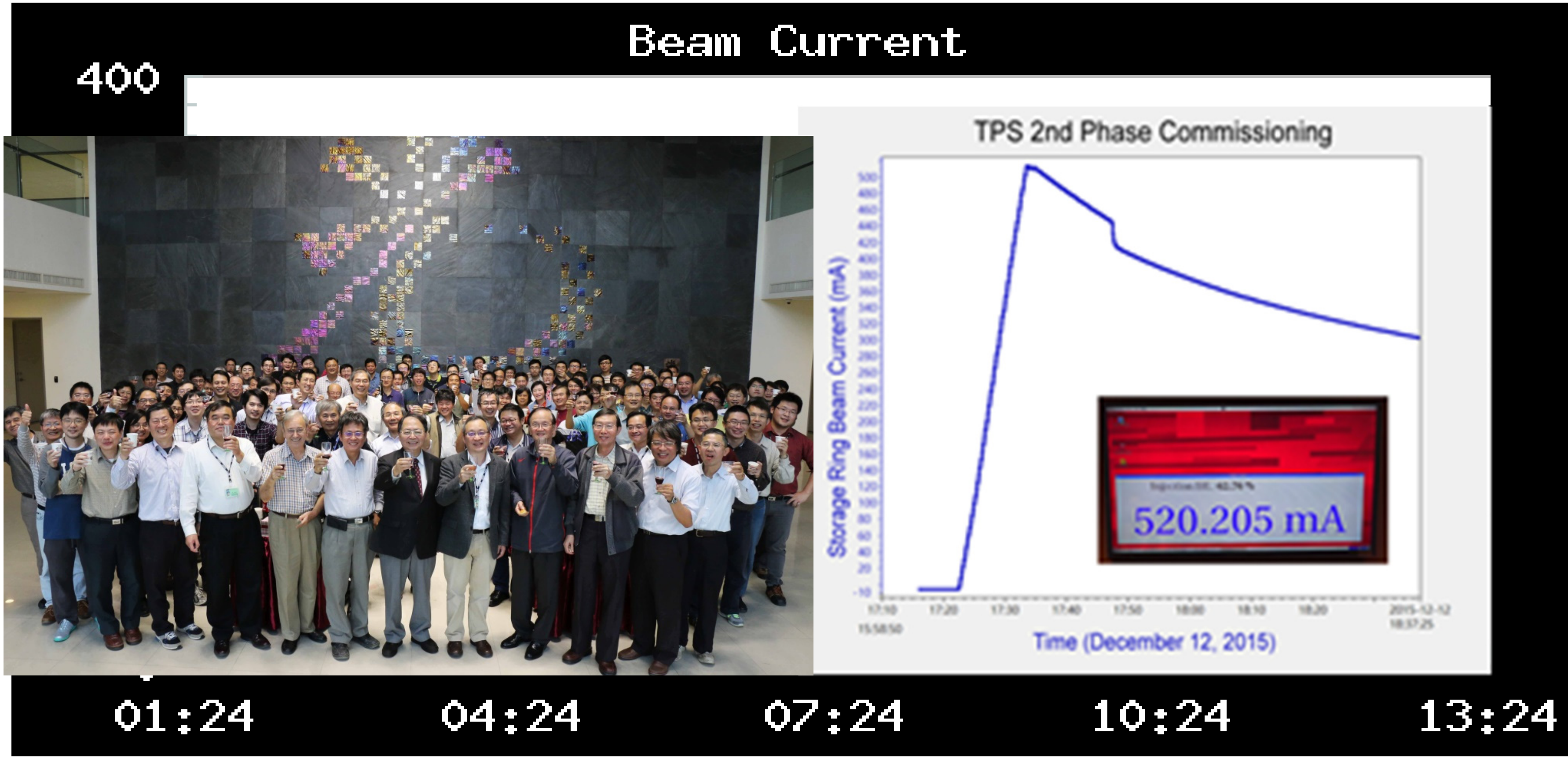
The measured bandwidth of FOFB. Horizontal around 250Hz and vertical around 300 Hz.



Beam Spectrum (no booster power supply ramping)



- Replace the B-Chamber of Cell#2, curing abnormal vacuum burst as I >230 mA. Top-up injection with stored current 300 mA on 12/6/2015。
- Stored beam current exceed design goal 500 mA, I > 520 mA, on Dec. 12, 2015.



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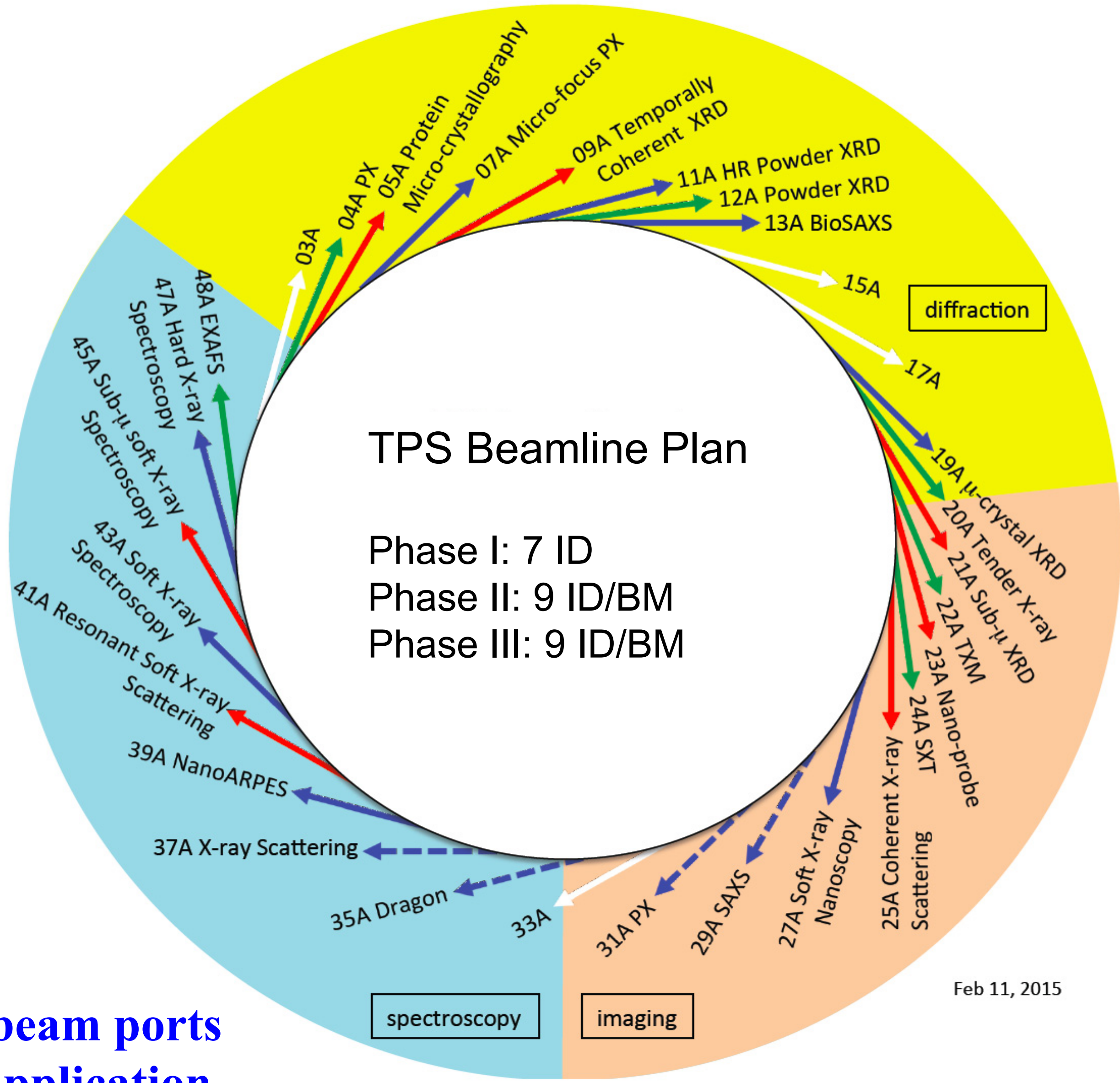
TPS Beamlines construction plan and priority



Reserved 19 beam ports

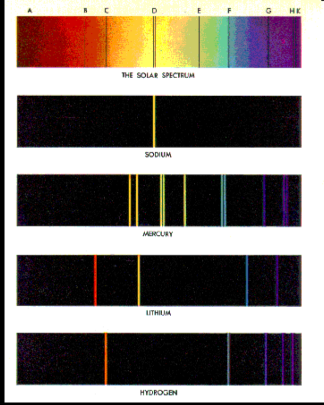
1.Industrial application

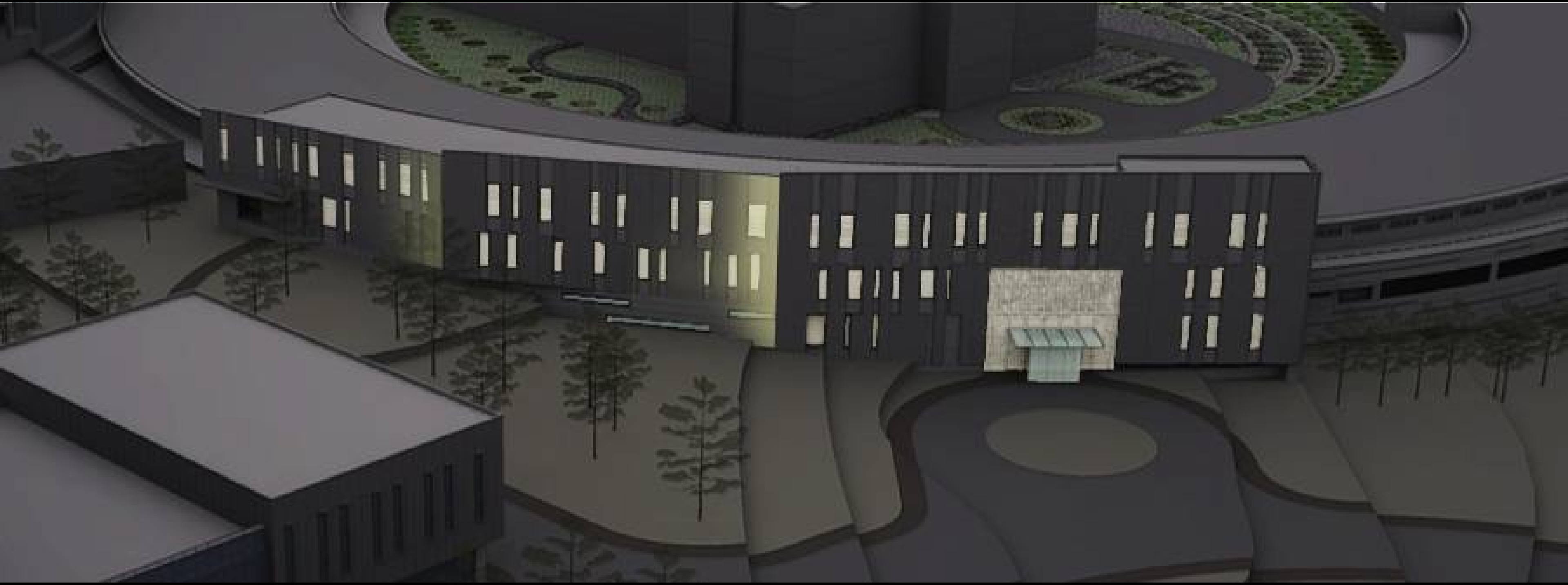
2.International collaboration

Summary

- **Taiwan Light Source**
  - 1.5 GeV beam energy provides 5000~ 5500 hrs with 360 mA top-up to users. Photon energy can be up to ~30 keV by SC wigglers.
  - Beamlines in SPring-8 provide hard x-ray to users.
  - From MOST's point of view, the long term-strategy about TLS fate needs to be planned with the operation of TPS.
- **Taiwan Photon Source**
  - Ten insertion devices and two SRF cavities installed in Q2 and Q3, 2015.
  - Double mini-βy lattice and phase-I BLs commissioning in Q4, 2015.
  - Stored beam current exceeded 500 mA design goal, $I > 520$ mA, in 2015.
  - 3 GeV, 300 mA top-up injection as users operation mode in Sept. 2016.
  - Single bunch and Hybrid operation mode will be planned.
  - Robinson damping wiggler under investigation, potentially can reduce emittance by ~50% with increase of energy spread.

Taiwan Photon Source (**TPS**)





Thank you for your attention!