The 10th Continuous Wave and High Average Power RF Workshop

Status of Taiwan Light Source (TLS) and

Progress of Taiwan Photon Source (TPS)

Kuo-Tung Hsu

On behalf of the Accelerator Team

June 26, 2018

Outlines

- **TLS and TPS are in operation simultaneously since 2016.**

- **Taiwan Light Source (TLS)**
  - Operational Status

- **Taiwan Photon Source (TPS)**
  - Machine parameters and strategy of TPS development
  - Operational statistics
  - Reliability and stability improvement
  - TPS development in progress

- **Summary**

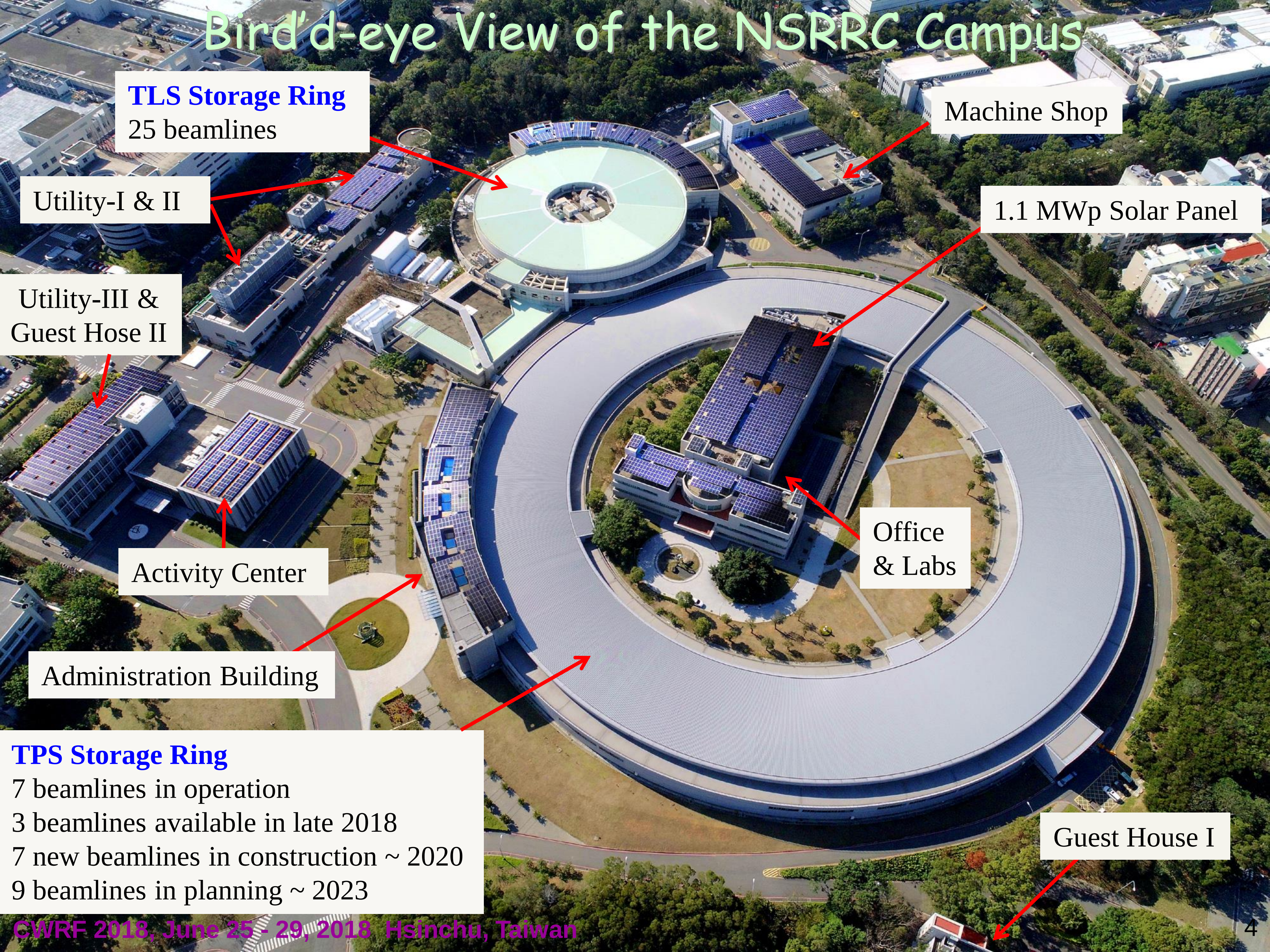
Why We Gather Here?

- You power the accelerator world! Thank you!
- All accelerator facility need powerful, reliability RF system.

Together Everyone Achieves More!

A Great Dream Requires A Great Team!

Bird'd-eye View of the NSRRC Campus



Routine Operation of TLS and TPS

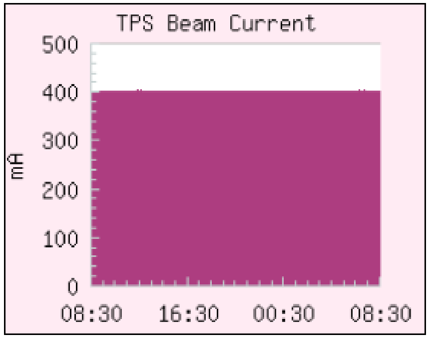
http://140.110.201.110/machinestatus/ — TPS&TLS Machine Status

TPS | TLS | TPS & TLS

2017/11/29 08:31:33

Taiwan Photon Source

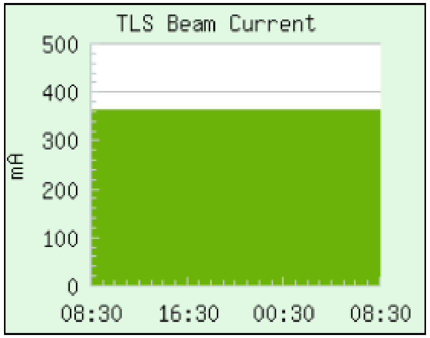
User Beam Time	
Energy	3.00 GeV
Current	400.64 mA
Lifetime	9 hr 5 min
Size X	63 µm
Size Y	40 µm



05A (IU22) g	7.28 mm
09AU (IU22) g	8.05 mm
09AD (IU22) g	40.00 mm
21A (IUT22) g	7.00 mm
23A (IU22) g	7.00 mm
25AU (IU22) g	7.00 mm
25AD (IU22) g	40.00 mm
41AU (EPU48) g	65.00 mm
41AU (EPU48) p	0.00 mm
41AD (EPU48) g	27.30 mm
41AD (EPU48) p	0.00 mm
45A (EPU46) g	25.52 mm
45A (EPU46) p	0.00 mm

Taiwan Light Source

User Beam Time	
Energy	1.50 GeV
Current	361.79 mA
Lifetime	6 hr 54 min
Size X	139 µm
Size Y	46 µm
ΔI0/I0	0.048 %



W200 g	22.42 mm
U50 g	29.91 mm
U90 g	39.22 mm
EPU56 g	44.09 mm
EPU56 p	9.90 mm
SW60	3.22 T
SWLS	5.02 T
IASW-R2	3.04 T
IASW-R4	3.04 T
IASW-R6	3.04 T

Operation Schedule

Weekly (before 2018) => Biweekly (2018)

TLS

	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T
Mar.				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31			
1-9				S	S	S	S	S	S	U	U	U	U	U	U	U	U	U	U	U	U	S	S	U	U	U	U	U	U	U	U	U	U	U			
9-17				對光		S	S	S	U	U	U	U	U	U	U	U	U	U	U	U	S	M	U	U	U	U	U	U	U	U	U	U	U	U			
17-01				S	S	S	S	S	U	U	U	U	U	U	U	U	U	U	U	U	S	S	U	U	U	U	U	U	U	U	U	U	U	U			

	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T
Apr.							1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
1-9							U	S	S	U	U	U	U	U	U	U	U	U	U	U	U	S	S	U	U	U	U	U	U	U	U	U	U	U	U	S	
9-17							S	M	U	U	U	U	U	U	U	U	U	U	U	U	S	M	U	U	U	U	U	U	U	U	U	U	U	U	S	M	
17-01							S	S	U	U	U	U	U	U	U	U	U	U	U	U	S	S	U	U	U	U	U	U	U	U	U	U	U	U	S	S	

	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T
May		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31					
1-9		S	U	U	U	U	U	U	U	U	U	U	U	U	S	S	U	U	U	U	U	U	U	U	U	U	U	U	S	S	U	U					
9-17		U	U	U	U	U	U	U	U	U	U	U	U	S	M	U	U	U	U	U	U	U	U	U	U	U	U	S	M	U	U	U					
17-01		U	U	U	U	U	U	U	U	U	U	U	U	S	S	U	U	U	U	U	U	U	U	U	U	U	U	S	S	U	U	U					

TPS

	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T
Mar.				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31			
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17-01				U	U	U	U	U	U	U	U	U	S	S	S	U	U	U	U	U	U	U	U	U	U	U	S	S	S	U	U	U	U	U			

	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T
Apr.							1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
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17-01							U	U	U	U	U	U	S	S	S	U	U	U	U	U	U	U	U	U	U	U	S	S	S	U	U	U	U	U	U	U	

	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T
May		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31					
1-9		U	U	U	U	U	S	S	S	U	U	U	U	U	U	U	U	U	U	U	S	S	S	U	U	U	U	U	U	U	U	U					
9-17		U	U	U	U	S	S	M	U	U	U	U	U	U	U	U	U	U	U	S	S	M	U	U	U	U	U	U	U	U	U	U					
17-01		U	U	U	U	S	S	S	U	U	U	U	U	U	U	U	U	U	U	S	S	S	U	U	U	U	U	U	U	U	U	U					

U : user shift (36weeks, 5184 hrs)
M : Machine maintenance
S : Machine study

Bi-weekly Operation Schedule

- 6 shifts reserved for machine study and accelerator system maintenance:

  5 shifts for accelerator test.

  (8 hours/shift)

    Machine study.

    RF conditioning.

    Machine preparation.

  1 shift for accelerator system maintenance.

    Visual inspection.

    Necessary maintenance.

Pros:

- ✓ More efficient in operation (half of the machine preparation time).
- ✓ Maintenance load of accelerator team reduced.
- ✓ Offsetting machine maintenance of TLS and TPS by one week.
- ✓ No sensible increase rate of the machine problem.

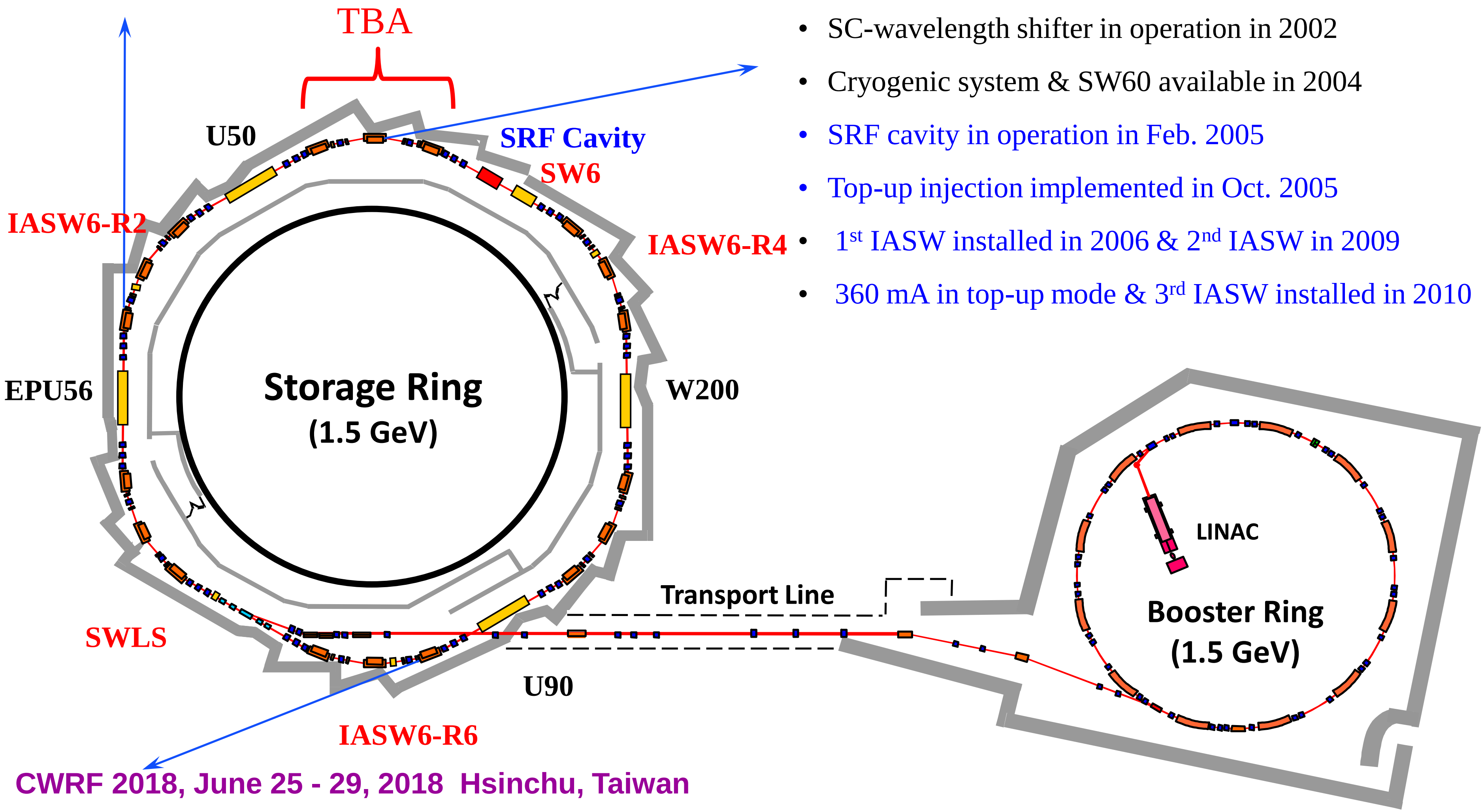
Cons:

- ✓ If non-critical problems happened, it requires one-week waiting for the action.
- ✓ If crane is needed for new beamline construction, it is essential to synchronize with user beam time.
- ✓ Increase loading of beamline supports.

Status of the TLS

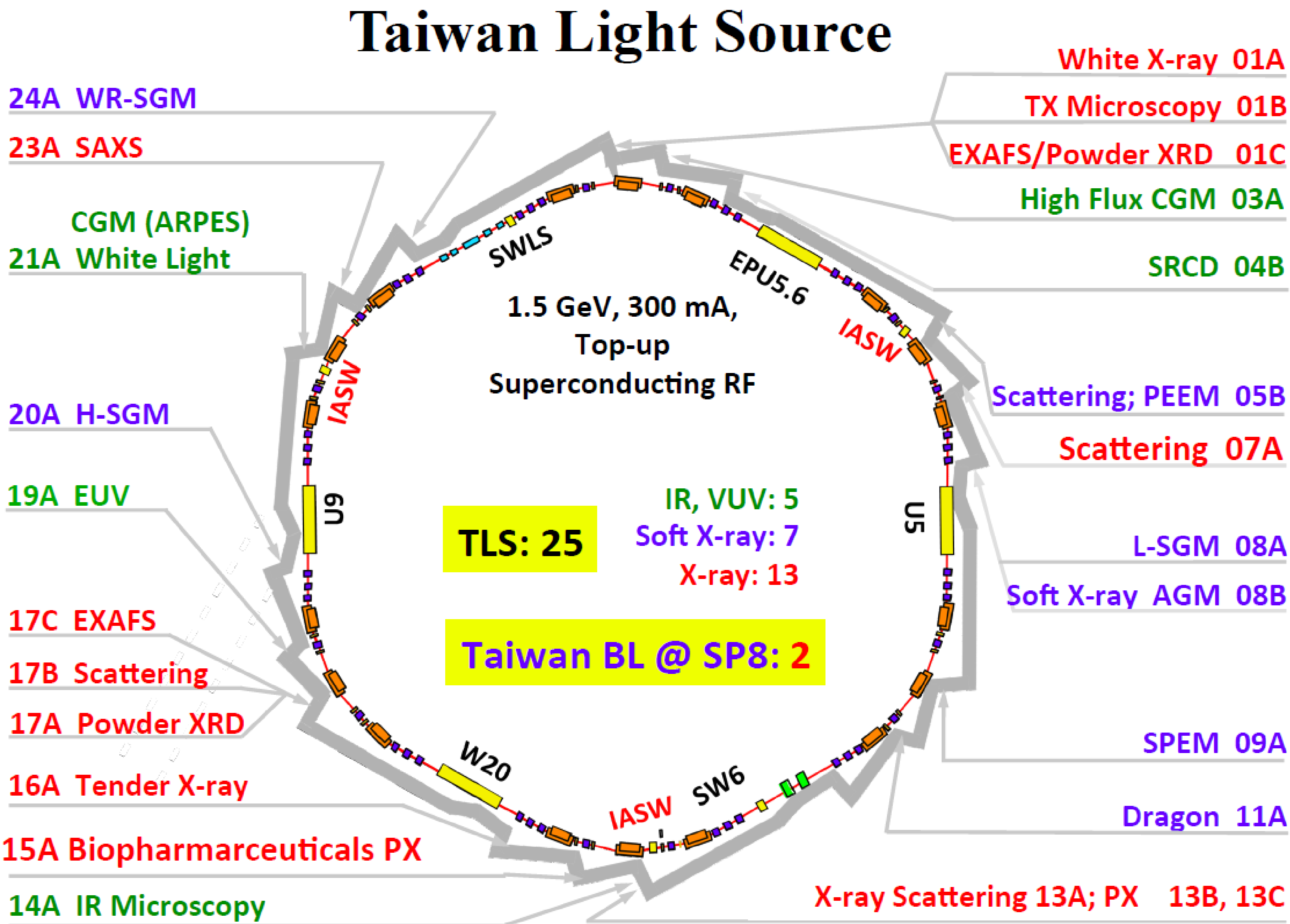
TLS Accelerator Layout and Key Milestones

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

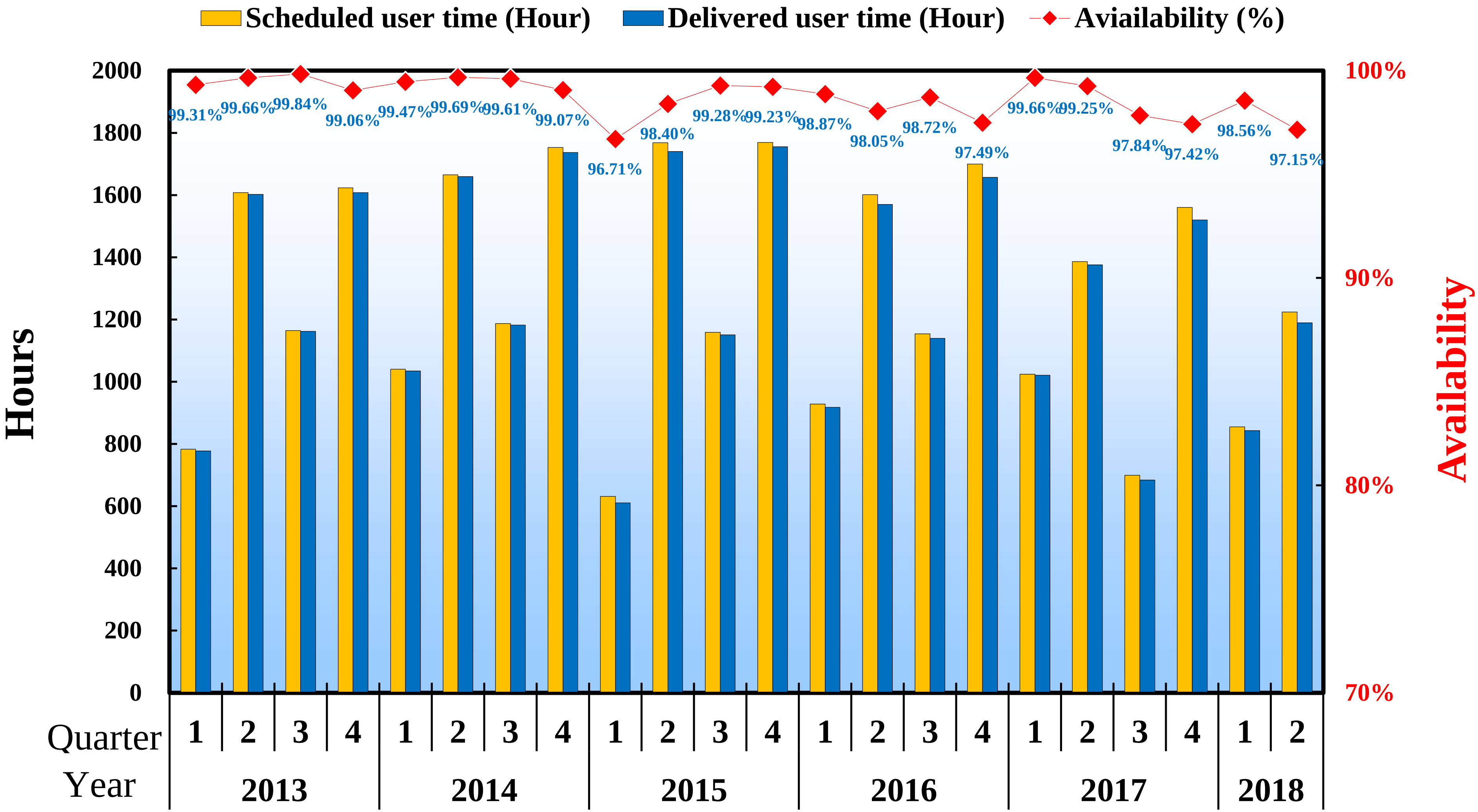


- Commissioned in Apr. & opened to users in Oct. 1993
- 1.3 to 1.5 GeV ramping in operation in 1996
- Operational beam current at 240 mA in 1996
- Booster in full energy injection in 2000
- SC-wavelength shifter in operation in 2002
- Cryogenic system & SW60 available in 2004
- SRF cavity in operation in Feb. 2005
- Top-up injection implemented in Oct. 2005
- 1st IASW installed in 2006 & 2nd IASW in 2009
- 360 mA in top-up mode & 3rd IASW installed in 2010

TLS Beamlines



TLS Operational Statistics



2016: Delivered: 5,526 hrs; Availability: 98.2%; MTBF: 100.5 hrs

2017: Scheduled user time ~ 4,680 hrs (36 weeks); Delivered user time 4,669 hrs (Jan. ~ Dec.); Availability: 98.5%; MTBF: 259.4 hrs

2018: Scheduled user time ~ 5,184 hrs; Delivered user time 2,032 hrs (Jan. ~ May)

TLS Operational Status

- Near 25 years user service since late 1993.
- Deliver high availability and high beam stability for users.
- Maintain a smooth operation for user service.
- Upgrade subsystems gradually which are difficult to maintain or least reliable.

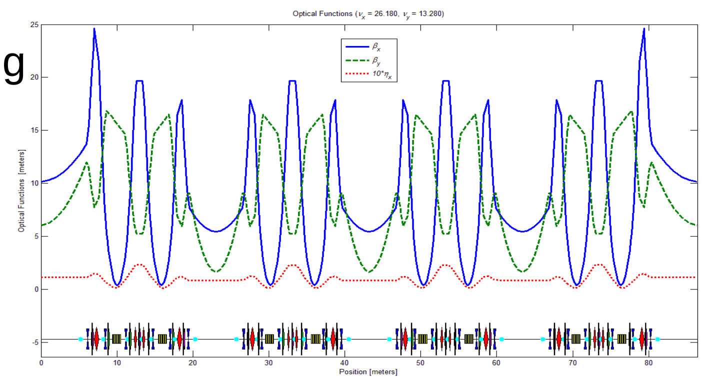
Status of the TPS

Major Parameters of Taiwan Photon Source

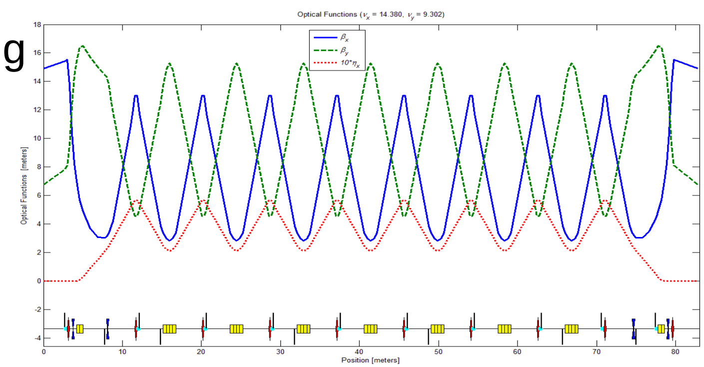
Energy	3 GeV (maximum 3.3 GeV)
Current	500 mA at 3 GeV (Top-up injection)
SR circumference	518.4 m (h = 864 = $2^5 \cdot 3^3$, dia.= 165.0 m)
BR circumference	496.8 m (h = 828 = $2^2 \cdot 3^2 \cdot 23$, dia.= 158.1 m)
Lattice	24-cell DBA
Straight sections	12 m x 6 (σ_v = 12 μm, σ_h = 160 μm) 7 m x 18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



TPS Milestone

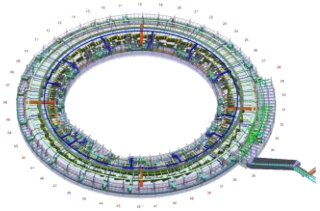





Install 2 SRF cavity and 10 IDs

First light delivered to the experimental station (port 5A) on Nov. 19, 2015


Available for users



Design

2007

Construction

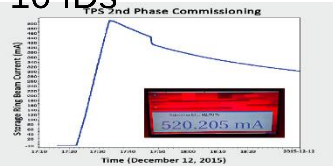
2010

1st SR from the TPS
(3 GeV, 1 mA)
Dec 31, 2014

Phase I Commissioning up to 100 mA (with two 5-cell PETRA Cavity)

Q4 2014 - Q1 2015

Q3/Q4 2015



Up to 520 mA (*Dec 12, 2015)*

Phase II Commissioning (with two SRF Cavity)

Q4 2015

Mar. 2016

300 mA Top-up

May 2016

Vacuum Improvement

Q3 2016

Phase-II IDs

400 mA Long-term Test Run

Feb. 2017

400 mA Top-up

Nov. 2017

SRF #3 Project

2018

Strategies for TPS Accelerator System Development

- **Short-term: Improvements**
  - Increase stored beam current: 300 mA (May 2016)=> 400 mA (late 2017) for routine operation, further test for 500 mA in future.
  - Improve reliability:

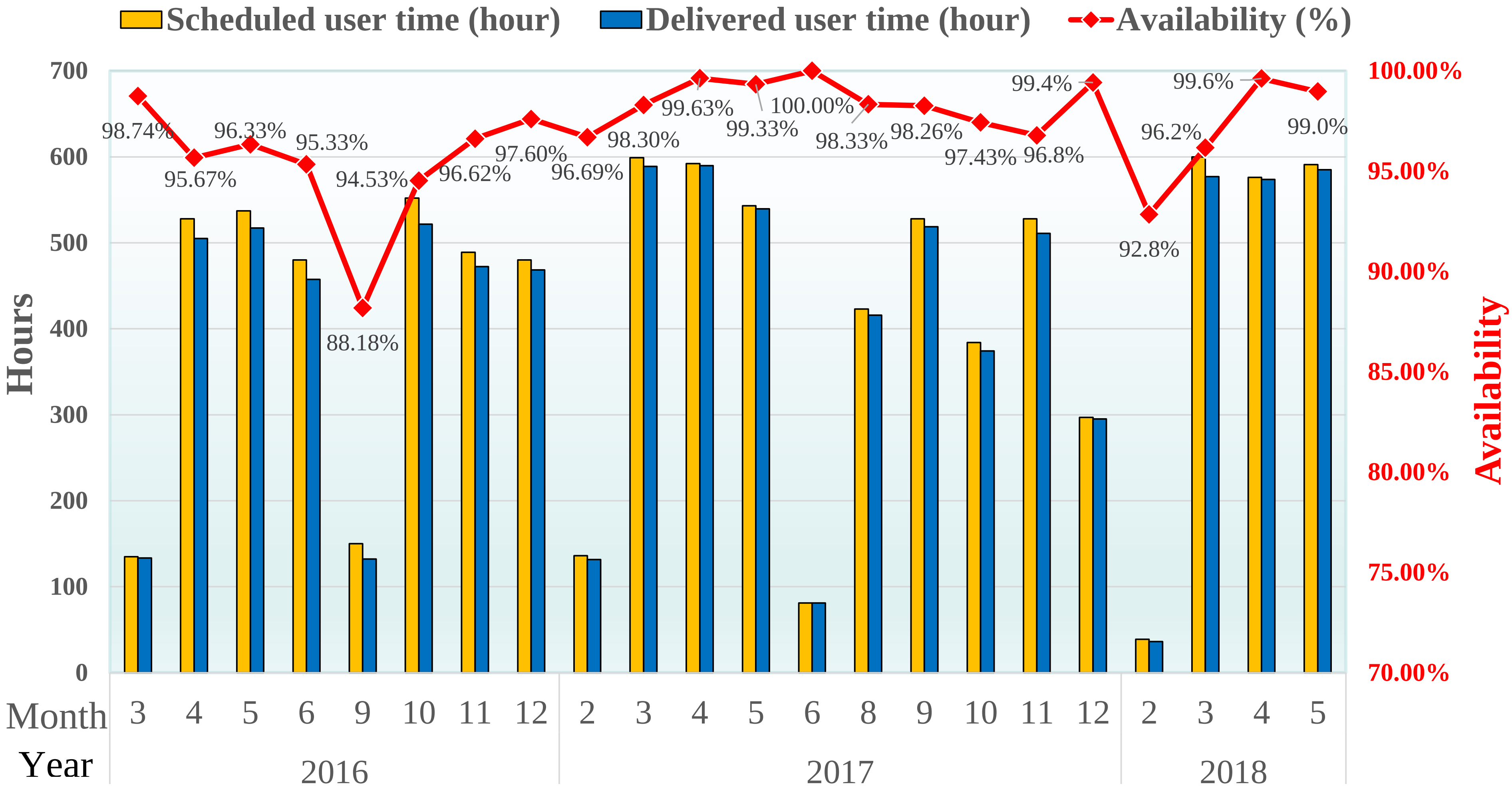
    Software bug elimination, improvement of the latest reliable subsystem, post-mortem diagnostics, minimized trip rate.
  - Improve stability: Noise source identification, reduce, remove and active feedbacks, Injection transient minimization.
  - Improve compatibility of storage ring and beamlines/end-stations.

    Orbit reproducibility, stability, long-term drift, …etc.
  - Explore methods for energy saving without the sacrifice of accelerator operation performance.

- **Mid-term: SRF #3, Phase-II and Phase-III beamlines projects**
  - Various subsystem enhancement and development:

    Solid-state pulser, digital LLRF, solid-state RF power amplifier , novel IDs R&D, …
  - 3rd SRF system to support Phase-III ID project.
  - Phase-II and Phase-III ID construction.
  - Explore feasibility for short bunch mode.
  - Investigation methods of how to reduce emittance to less than 1000 pm-rad.

TPS Operation Statistics



Delivered beam time: 1,615 hrs | 1,595 hrs | 4,046 hrs | 1,772 hrs

Beamline Commissioning & Pilot Experiments

User Service

2017: Scheduled user shift ~ 4,111 hrs (33 weeks); Delivered user time 4,046 hrs (Jan. ~ Dec.)

2018: Scheduled user time ~ 4,488 hrs; Delivered user time 1772 hrs (Jan. ~ May)

Reliability and Stability

- More than 98.5% availability were achieved.

- Short-term stability satisfy requirements of most of users. Continuous effects are on-going.

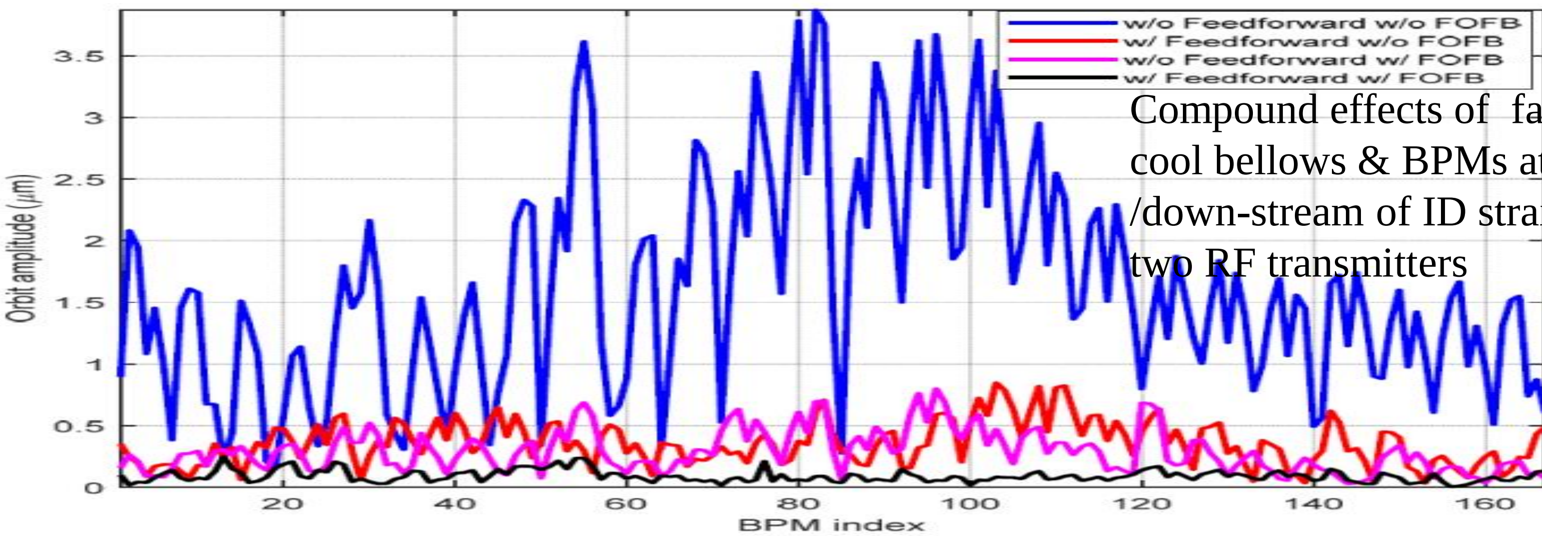
- Long-term drift can be controlled within acceptable range without unintentional beam trip happened.

- Orbit reproducibility of each refill less than 5 μm/μrad at ID center.
  - * Further investigation/improvement is required.
    => Operation procedures and/or hardware improvement.
  - * Improve machine reliability are highly helpful to minimize the impact.

- Injection transient cannot be accepted by strict beamline requirements. Real-time gating in data acquisition during injection or post processing to remove deteriorate data is the current reality.

An Example: 60 Hz Orbit Motion Study

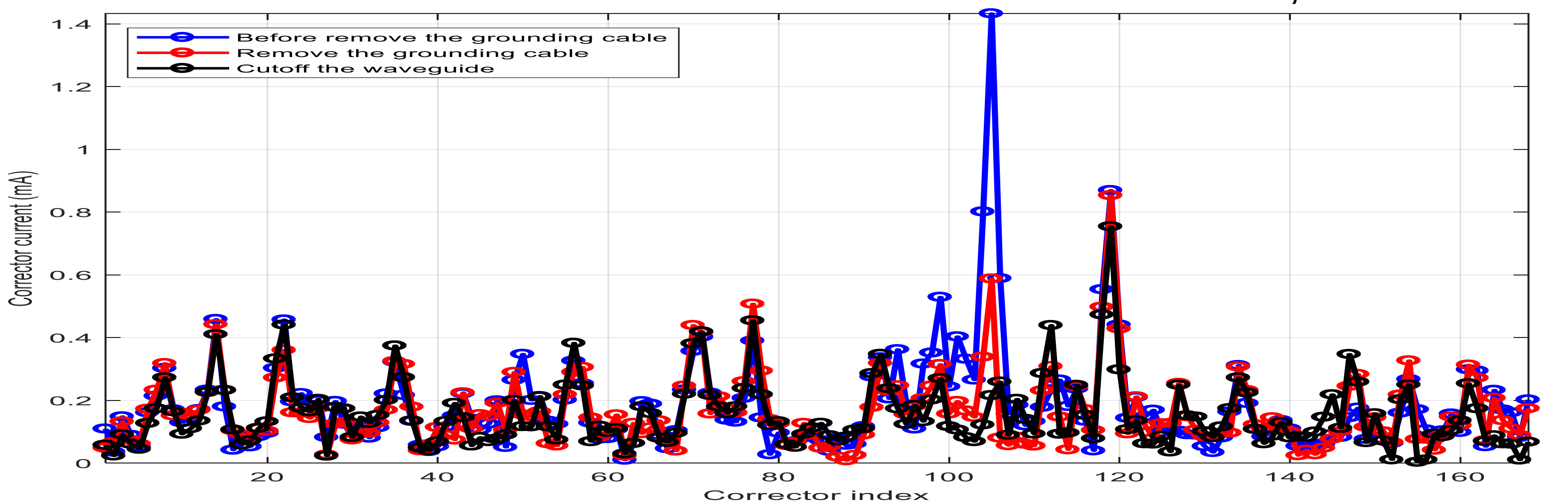
Feedforward and feedback to correct 60 Hz beam motion (Vertical)



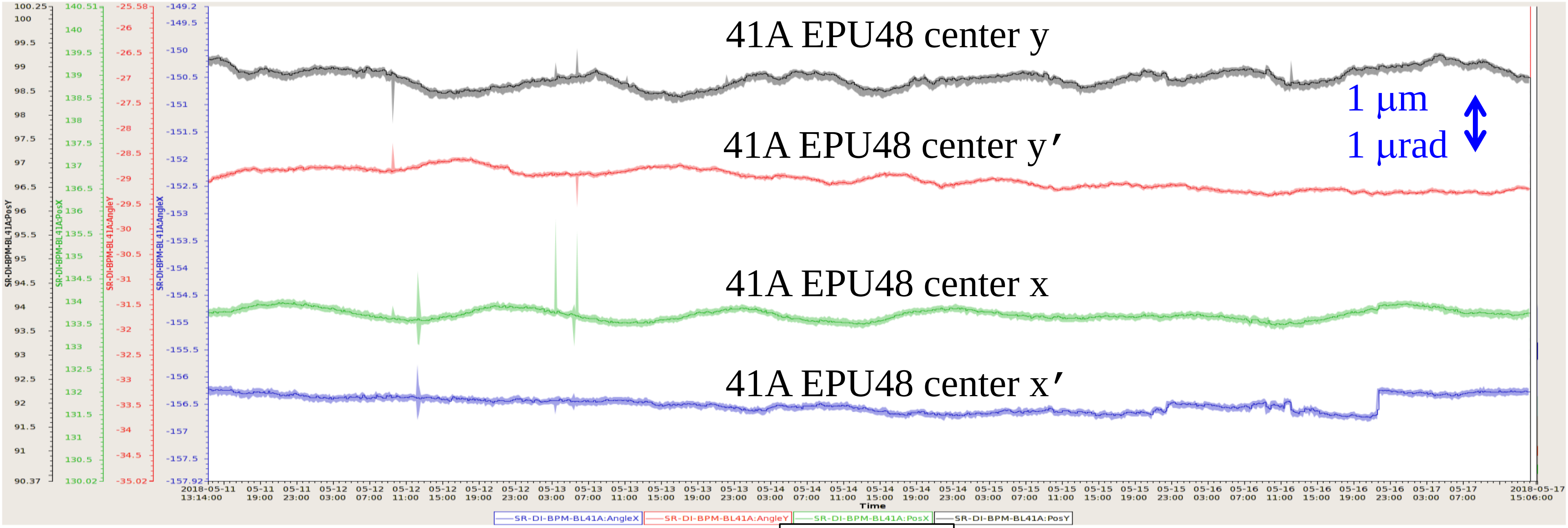
Compound effects of fans to cool bellows & BPMs at up-/down-stream of ID straight and two RF transmitters

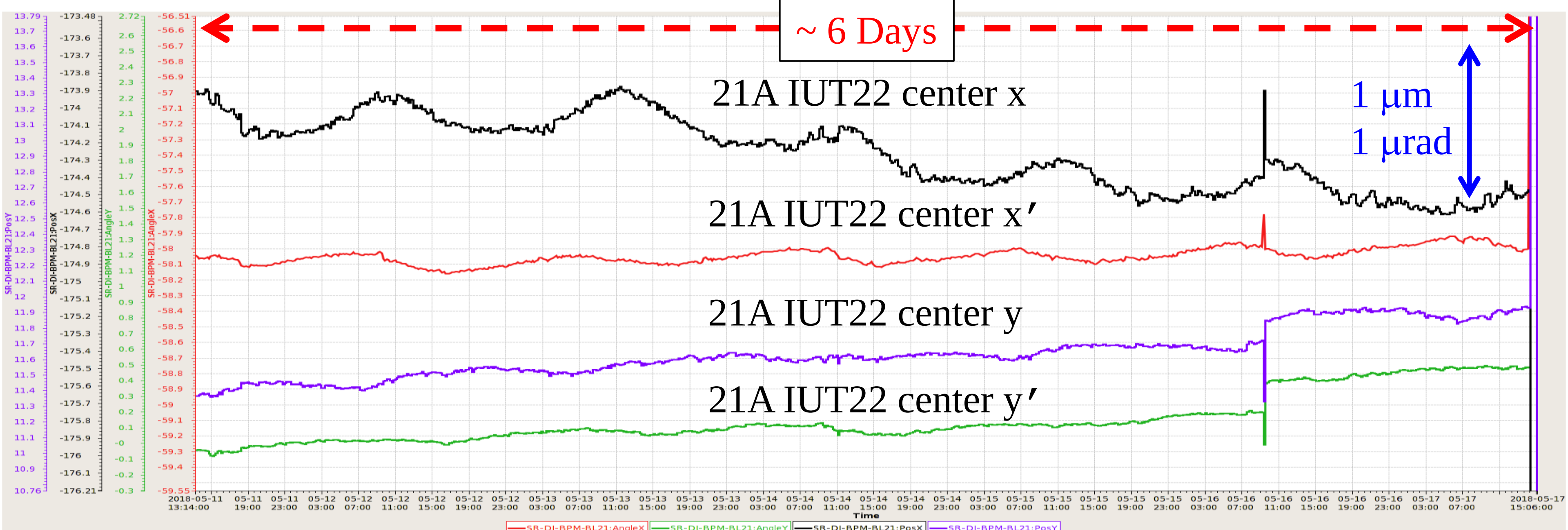
An Example: Source locating for 60 Hz beam motion

SRF2 Transmitter On, SRF3 On

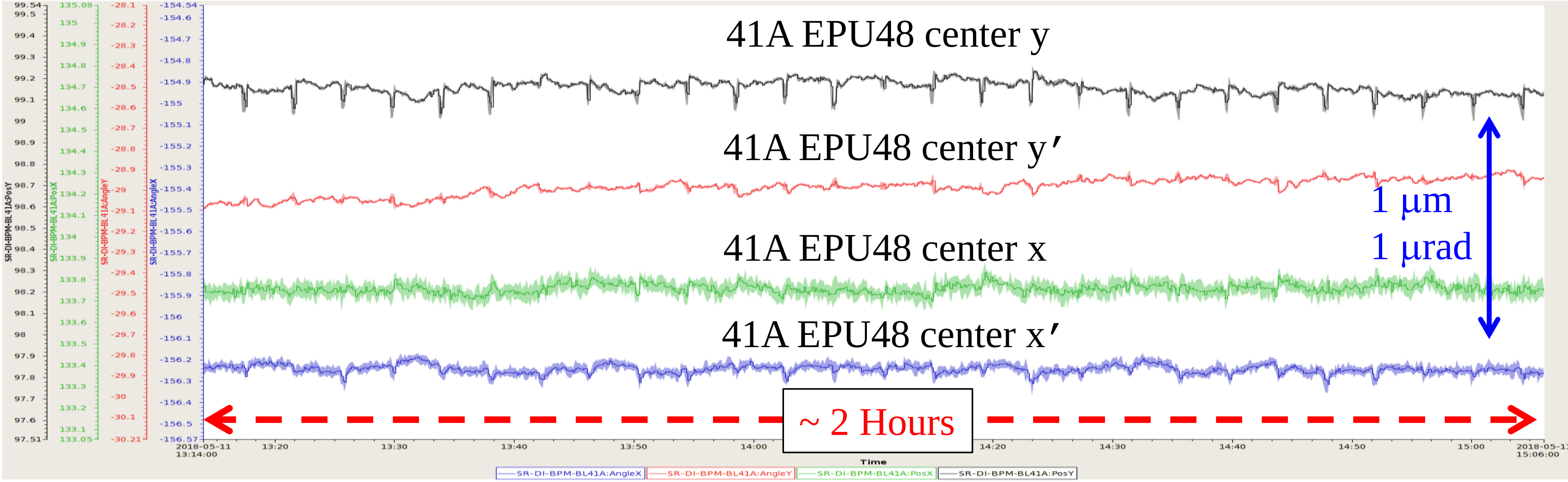


Long-term Stability of Position and Angle at ID Center

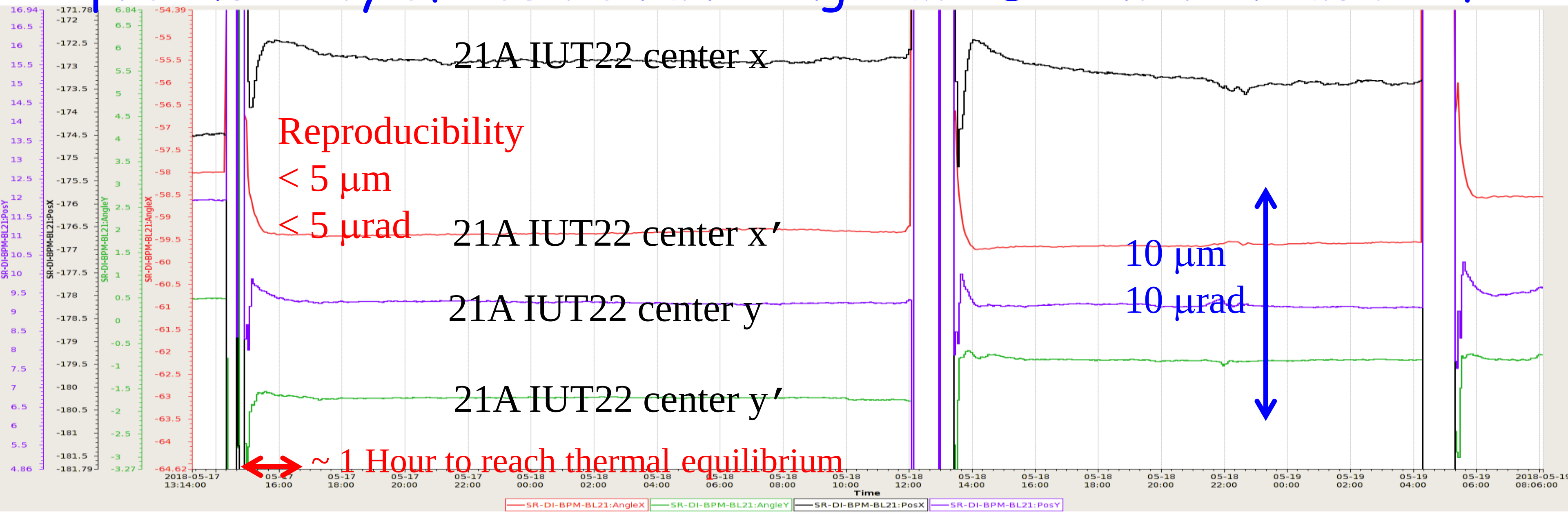




Short-term Stability of Position and Angle at ID Center

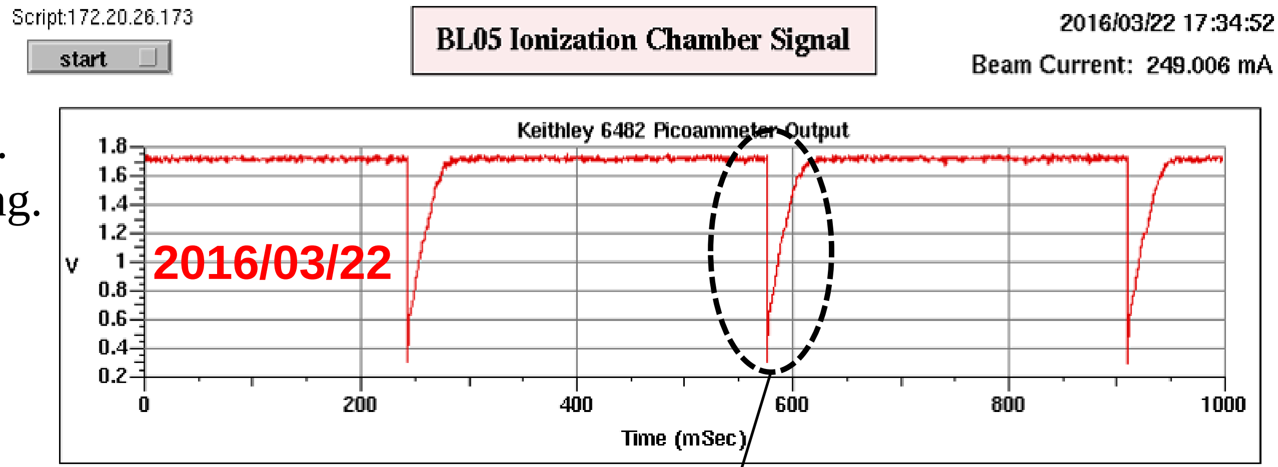


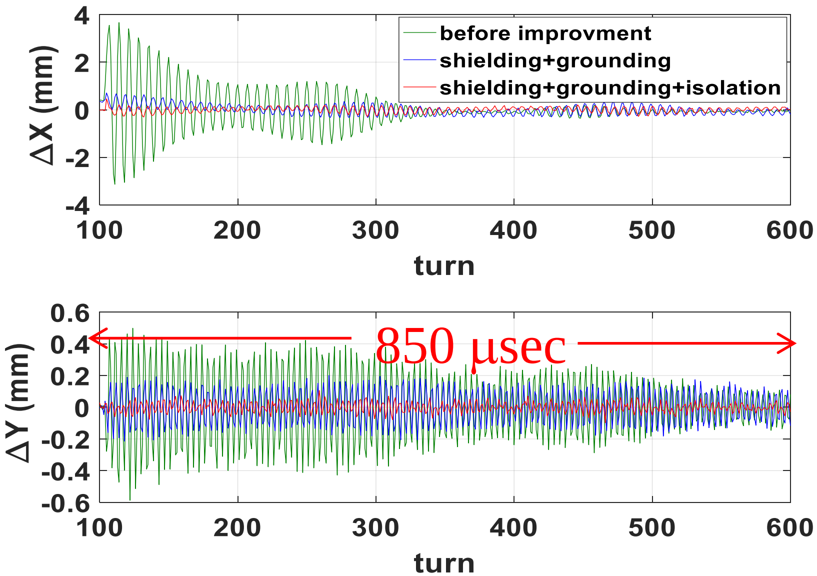
Reproducibility of Position and Angle at ID Center in each Refill



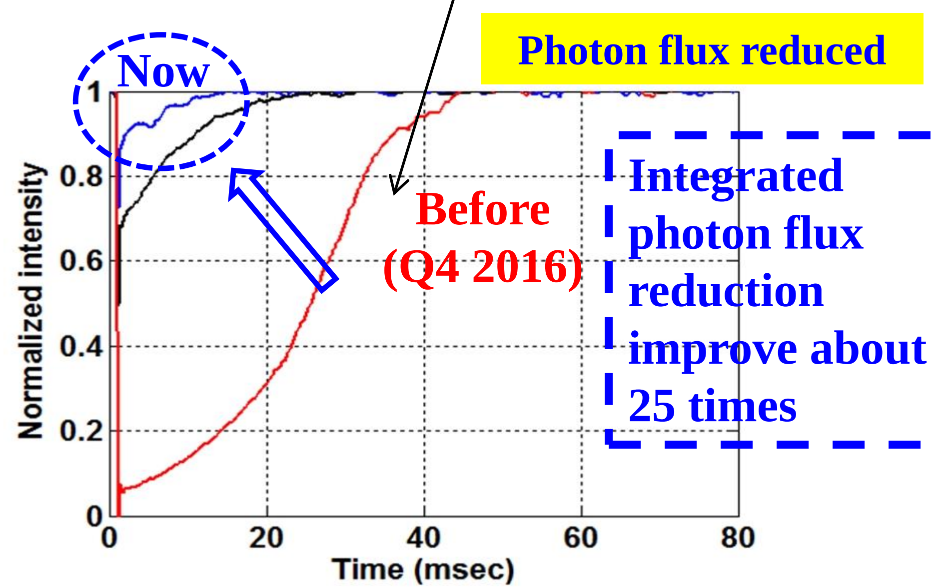
Mitigate Effects of the Injection Transient

- Improve kickers matching.
- Improve magnetic shielding.
- Grounding and isolation.





Centroid motion of the electron bunches observed by beam position monitor



Photon flux observation by QBPM #2 (after DCM) of TPS 05A

TPS Development in Progress

3rd SRF System(2018~2022)

Goals:

- Deliver sufficient power for Phase-III beamlines running at 500 mA.
- Provide option to reduce power level of each RF station to increase reliability.
- Provide sufficient beam current (~ 300 mA) when one system in trouble.
- Project timeframe : 2018-2022.

Friday Talks:
(08:30 ~ 10:00) Chaoen Wang
(09:30 ~ 10:00) Zong-Kai Liu

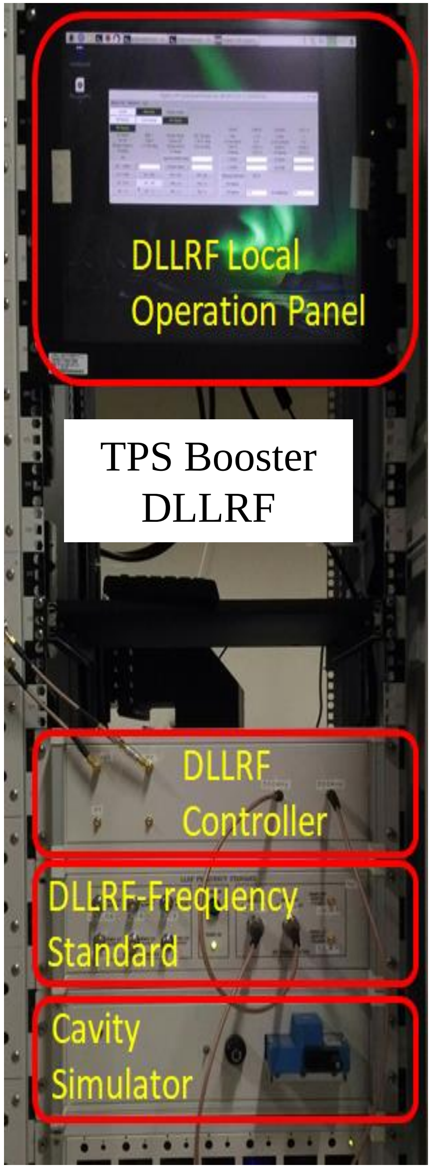
Features:

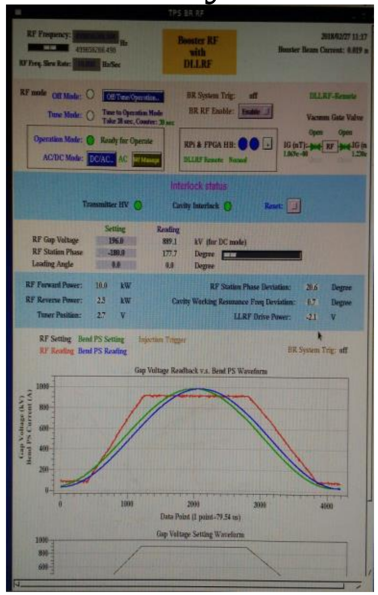
- Same KEKB type SRF cavity as previous two SRF stations.
  - System integration at NSSRC labs.
  - Good training chance to enhance maintenance capability.
- DLLRF to enhance performance and functionality.
  - Loop optimization is simple.
  - Rich diagnostics functionality.
  - Lower noise.
- In-house manufactured supporting system as much as possible (include DLLRF) to enhance capability and to avoid obsolesce of components.
  - Up-to-date design.
  - Spare units.

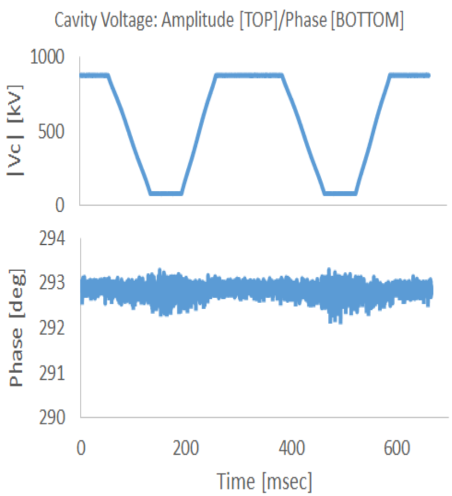
Digital Low Level RF (DLLRF) and Solid-State Amplifier (SSA) Development

Tuesday Talk
(13:30 ~ 14:00)
Tsung-Chi Yu

DLLRF Test at TPS Booster Synchrotron

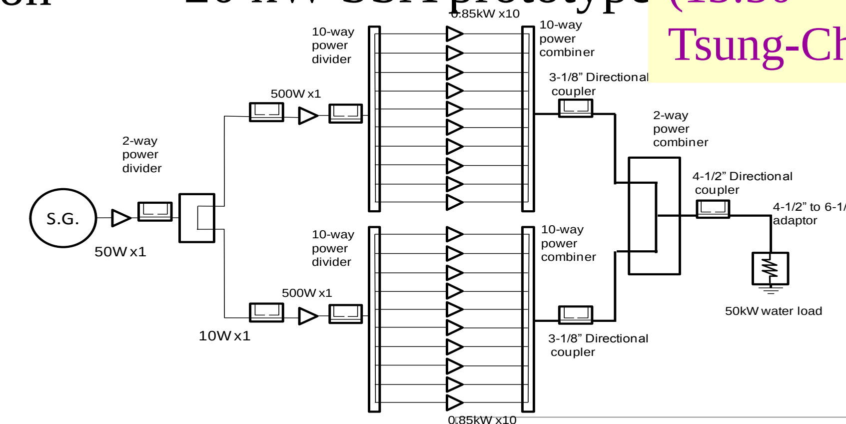


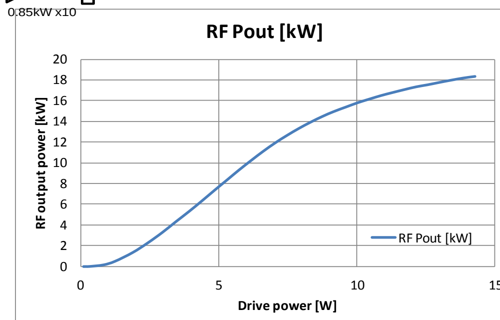


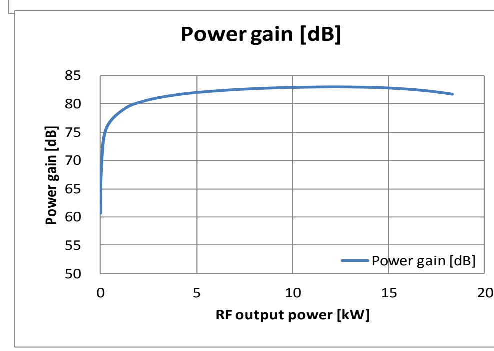


Amplitude: 0.32 %
Phase: 0.01°

20 kW SSA prototype

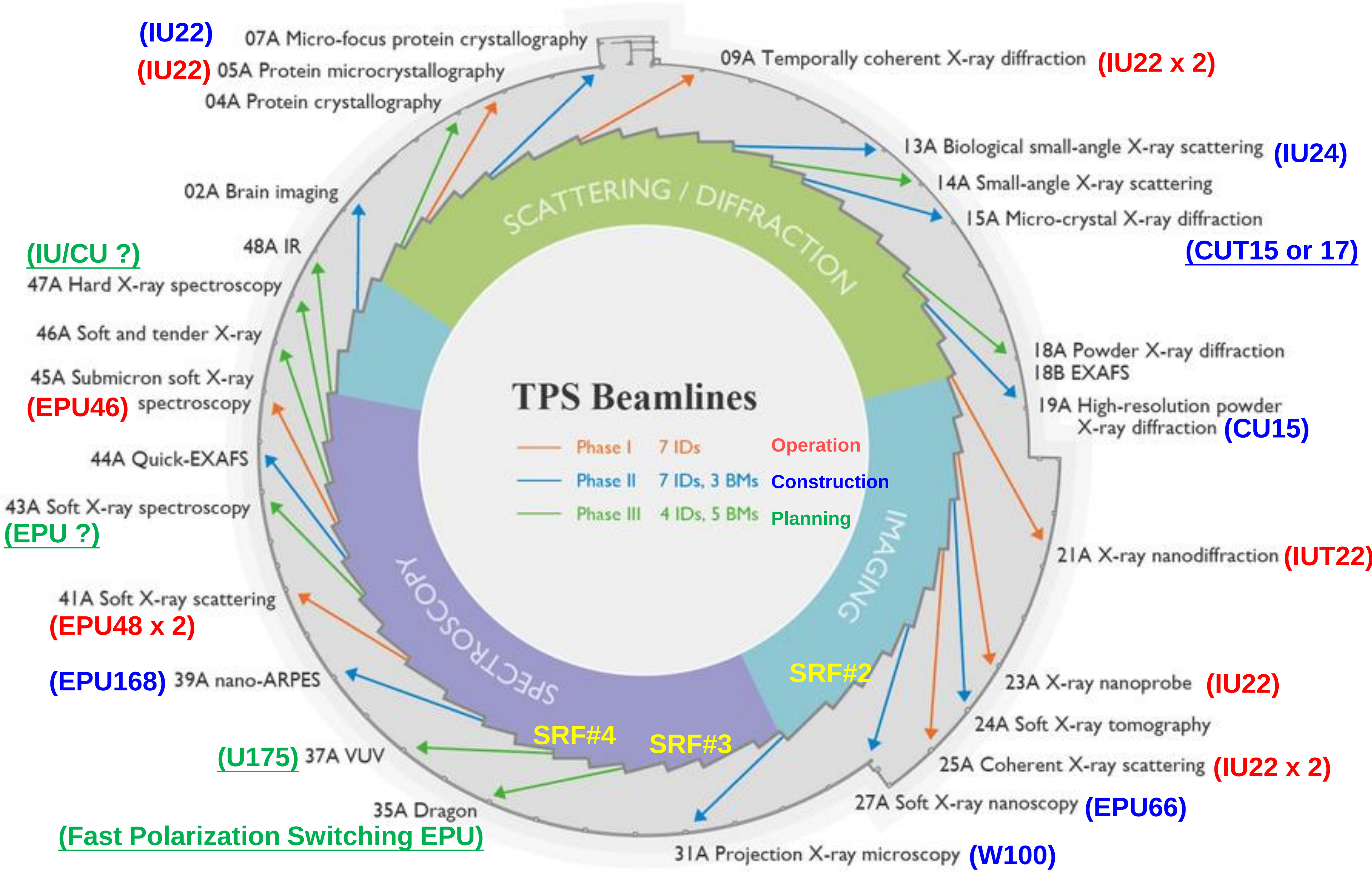






- 80 kW prototype will be available in early of 2019.
- 300 kW SSA in evaluation.

TPS Beamlines and Insertion Devices

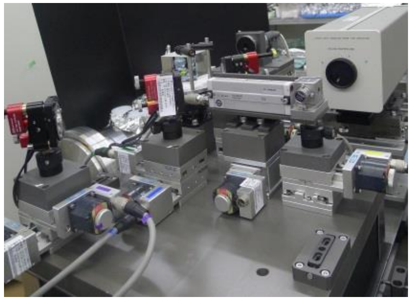


Status of IDs for TPS Phase-II Beamlines

- 07A IU22: Installation is in progress (June 2018)。
- 13A IU24: Due to ball screws and linear guides are in short supply, delivery will be postponed for 3 months (Due 2019/3/25)。 Installation will be scheduled during 2019～2020.
- 15A CUT15: Specifications in preparation.
- 19A CU15: In final integration and measurement phase at NSRRC lab.
  - 77K Cryo-cooler vibration reduction.
  - Field measurement at operation temperature.
  - Installation will be scheduled in 2019.
- 27A EPU66: Magnetic block and mechanical frame in procurement process.
- 31A MPW-W100: Magnetic and mechanical design in progress.
- 39A EPU168: Mechanical design in progress.

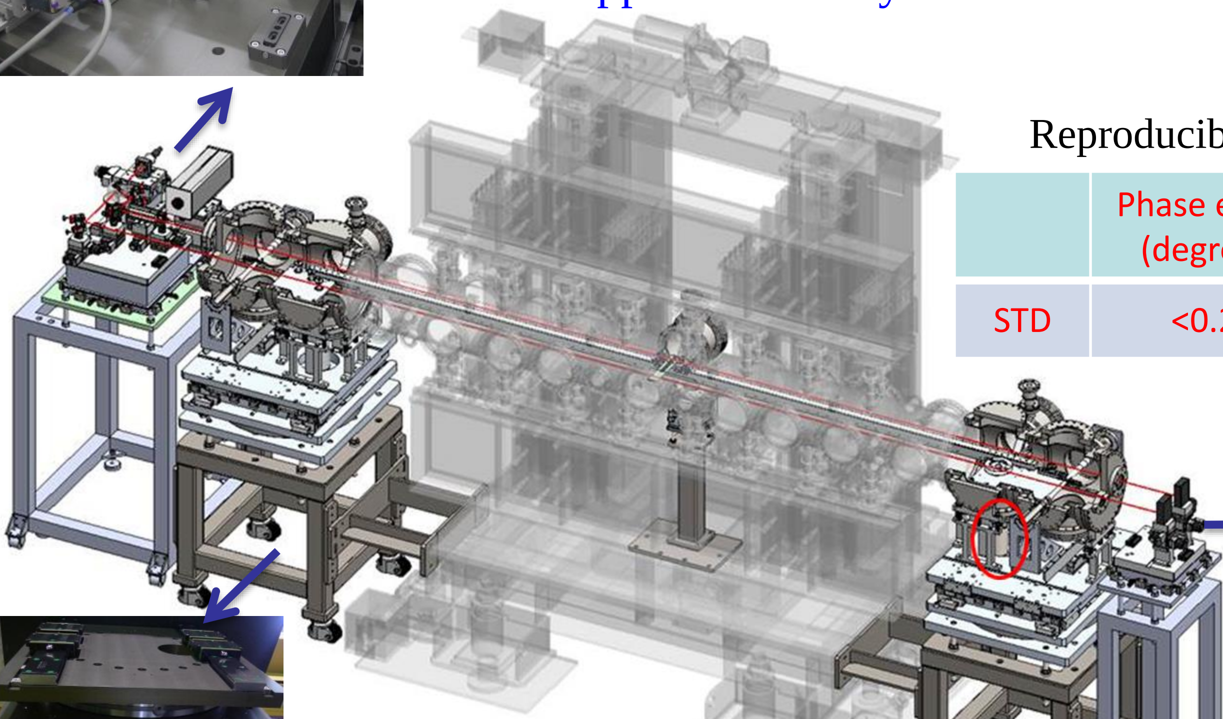
CU/CUT in Vacuum and in-situ fielding mapping Setup

Laser System



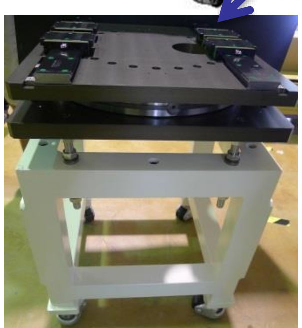
Features

- In-situ field mapping.
- Support small gap (3 mm) measurement.
- Dynamic monitor and correction for position of the Hall probe.
- Support on-the-fly measurement.



Reproducibility of the measurement system

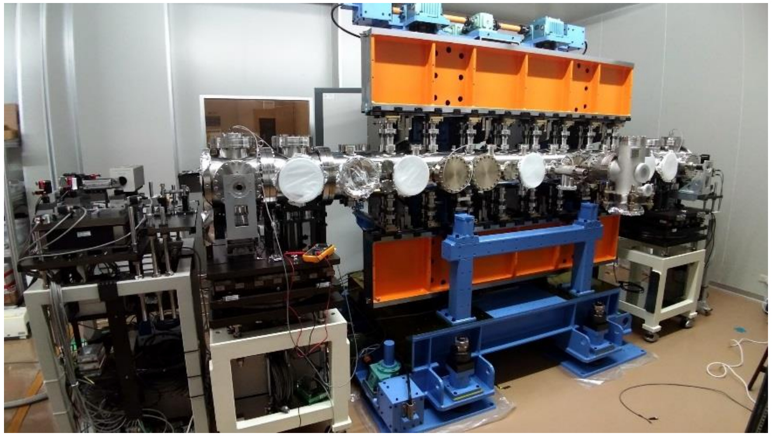
	Phase error (degree)	Half integral deviation (%)	Peak field deviation(%)
STD	<0.2	<0.1	<0.02

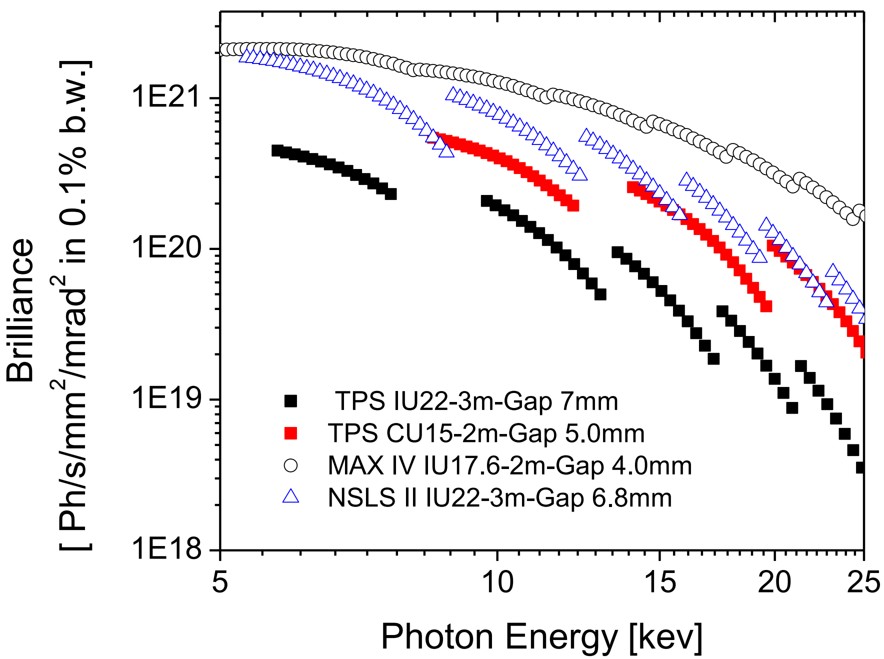


Multi-axes Rotating Stage

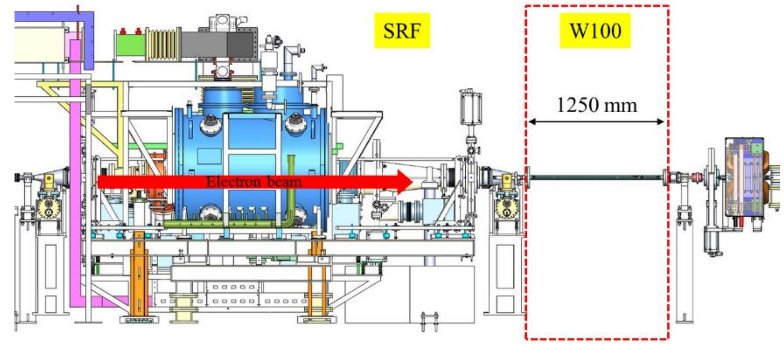
Position Sensitive Detector

CU15 (19A)
In final integration phase

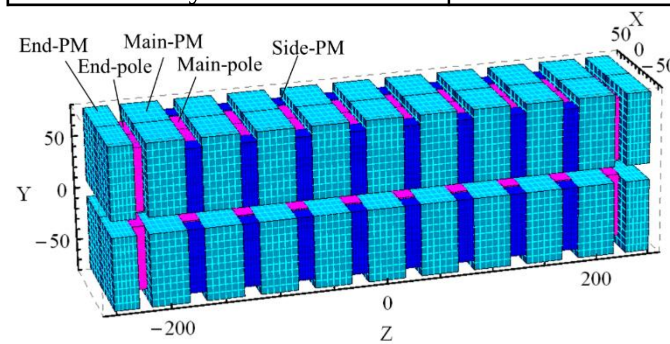




W100 (31A)
Magnetic and mechanical design in progress



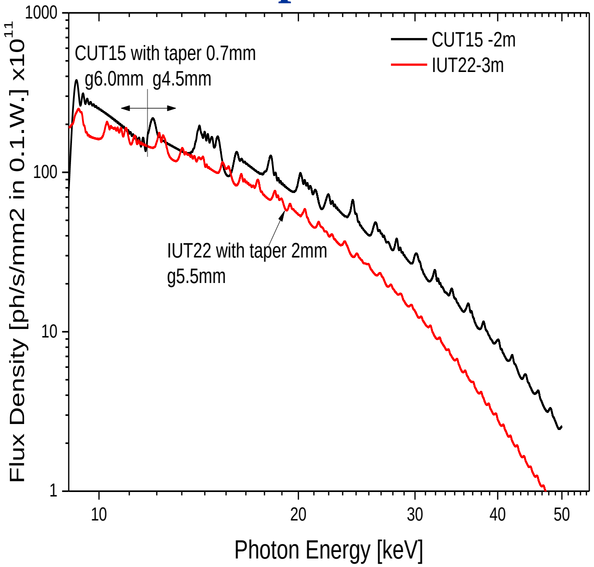
W100 parameters	
	4 periods
Peak field strength	1.81T
Period length	100 mm
Number of periods (main pole)	4
Magnet length array length	< 600 mm
Pole gap	14 mm
Deflection parameter, k	16.91
Critical Energy	10.8 keV
Photon energy	5-50 kev
Total radiation power	3.7 kW
Power density	3.11 kW/mrad^2



Taper Undulator CUT15 (15A)

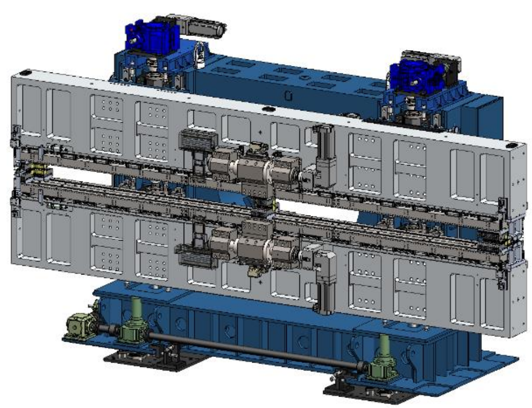
Schedule	
Design	3 months
Mechanical frame +magnet manufacturing	12 months
Manufacturing of the cryogenic system ,vacuum system and temperature control system	-- (include. Above)
Acceptance Test (include field measurement)	3
Assembly work	3
Cooling test and vacuum test	1
Field measurement and final tuning	2
Total	~ 24 months

Finalized specifications



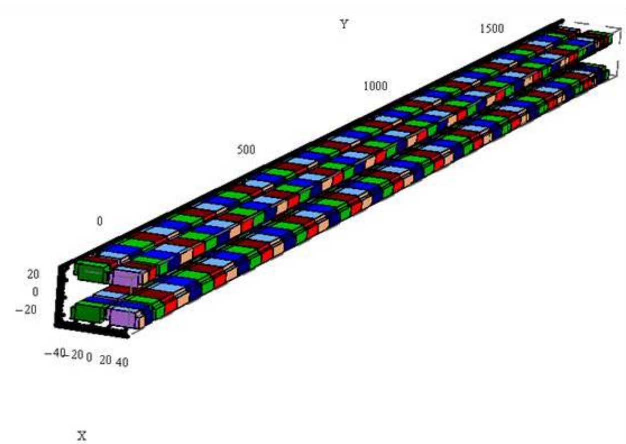
EPU66 (27A) Parts procurement in progress

	EPU66 parameters	
Type	APPLE-II	
Period length	66	mm
Number of period	62	
Minimum gap	16.8	mm
Max K_y, Min E1 at H.L.	5.3, 84	,eV
Max K_y=K_x, Min E1 at C.P.	3.2, 117	,eV
Max K_x, Min E1 at V.L.	3.9, 149	,eV



EPU168 (39A) Magnetic and mechanical design in progress

	EPU168 parameters	
Type	APPLE-II	
Period length	168	mm
Number of period	23	
Minimum gap	28	mm
Max K_y, Min E1 at H.L.	8.1, 15	,eV
Max K_y=K_x, Min E1 at C.P.	3.5, 39	,eV
Max K_x, Min E1 at V.L.	3.5, 72	,eV



Vacuum System progress to Support TPS Phase II Beamlines

Update of the vacuum chamber:

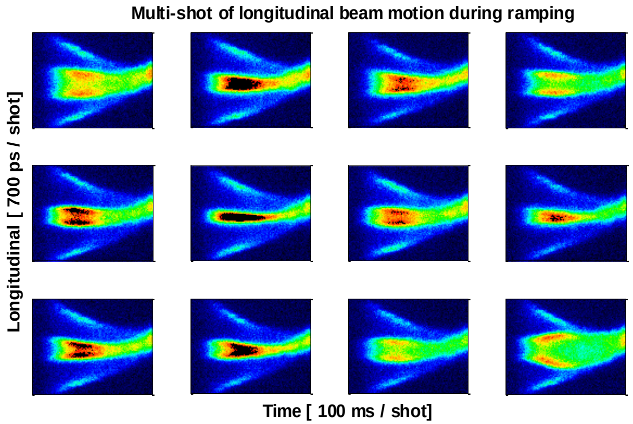
- Storage ring SR14 and SR20 vacuum chamber modification to support (EPU66 、 EPU168).
- TPS-EPU66/EPU168 vacuum chamber design and construction.

Front-end construction:

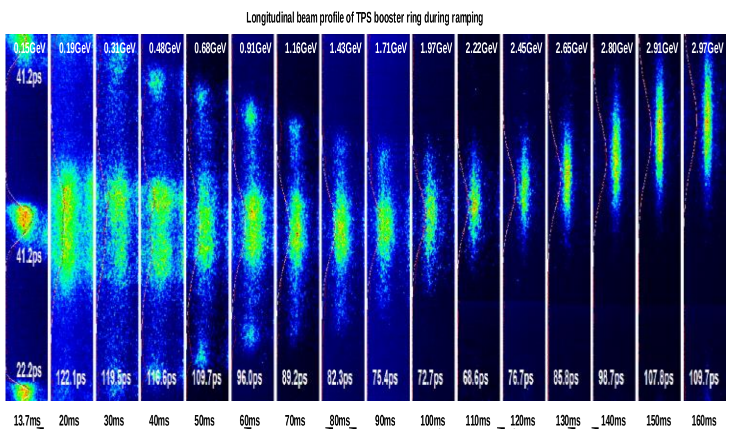
- 19A (CU15) high-resolution powder X-ray diffraction.
- 31A (W100) projection X-ray microscopy.
- 07A (IU22) micro-focus protein crystallography.
- 27A (EPU66) soft X-ray nanoscopy.

Accelerator Related R&D

Booster Beam Capture Study

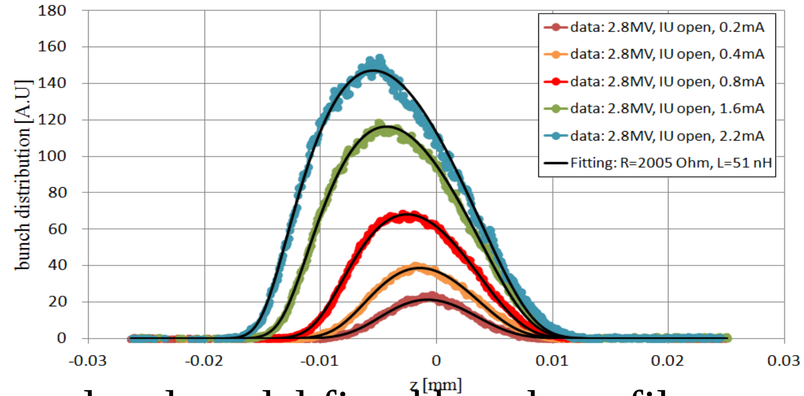


Multi-shot of longitudinal beam motion. The synchrotron oscillation due to the energy variation was observed.

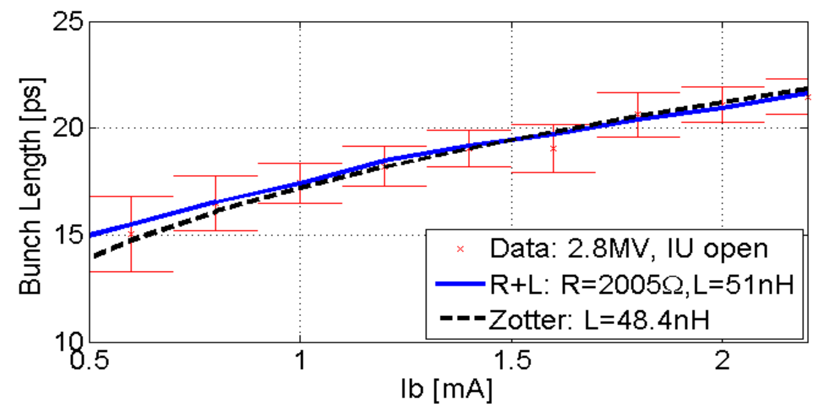


The accumulated longitudinal beam profile and Gaussian fit of the center bunch during ramping.

Storage Ring Impedance Study



Measured and model fitted bunch profiles at varied bunch current below the threshold of microwave instability for the case with RF voltage 2.8 MV and IU gaps open.

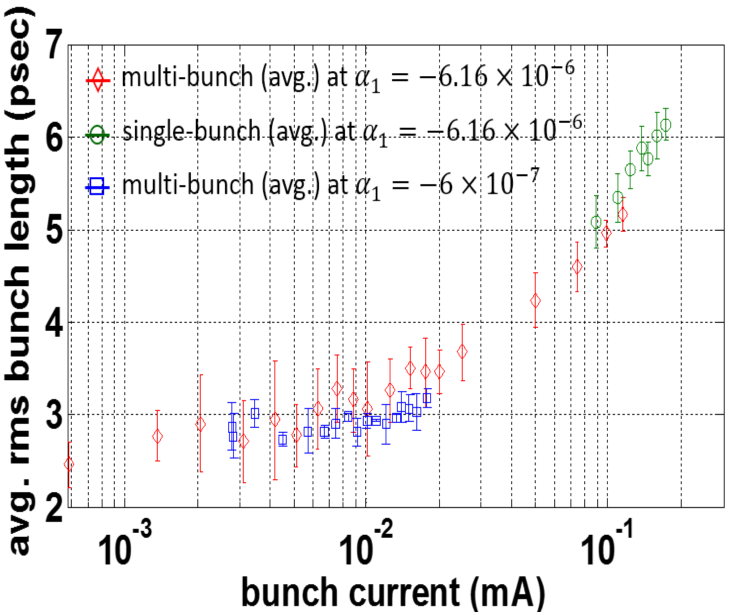


Measured and model fitted bunch length as a function of bunch current at the TPS storage ring below the threshold of microwave instability.

Accelerator Related R&D - Cont.

Low-alpha mode R&D

- Short X-ray pulse (a few picosecond)
- Coherent THz/IR radiation



Bunch length measurements in high emittance, low alpha lattices, where the linear momentum compaction factor is α_1= -6.16×10^{-6} (red and green) and -6×10^{-7} (blue).

Other efforts

- Lattice optimization
- IDs alignment
- ID commissioning and optimization
- Compatibility between accelerator and beamlines
- Beam-based modeling
- Operation automation
- Fault diagnostics
- Beam lifetime/losses study
- Feasibility study toincrease FOFB bandwidth
- Thermal effect study
- Tidal effect study
- MBA lattice study
- …
- … etc.

Efforts for TPS

Continuous Efforts:

- Improve machine reliability.
- Improve stability.
  - Beam noise suppression.
  - Reduce orbit drift.
  - Improve orbit reproducibility of each-refill.
  - Minimize effects of injection transient. Further R&D is ongoing.
  - Increase FOFB bandwidth to ~1000 Hz range (now is 300 Hz).
- Continuous ID commissioning and lattice optimization.
- Advanced beam physics study
- Develop various beam-based optimization algorithm
- Develop tool to assist machine operation and problem diagnostic by latest technologies.

Efforts for TPS - cont.

Key Missions in Progress

- Development of the 3rd SRF system.
    - Third SRF module
    - Solid-state high power RF transmitter.
    - Digital Low Level RF (DLLRF) control system
- Phase-II IDs: IU22 (07A), IU24 (13A), EPU168 (39A), EPU66 (27A), CU (19A), CUT (15A), W100 (31A).
- Phase III insertion devices: Fast Polarizing Switching EPU (35A), U175 (37A), …etc.

Machine Development and Feasibility Study

- Minimized injection transient study.
- Novel insertion devices development.
- Low α mode in storage ring.
- Study feasibility to adopt Robinson wigglers to reduce beam emittance.
- Use harmonic cavity to increase bunch length and lifetime.
- Investigate possibility to upgrade TPS to delivery diffraction limited hard X-ray with new lattice in 2030s.

Summary

Taiwan Light Source

- Smooth operation for user service.
- Upgrade subsystems which are difficult to maintain or least reliable gradually .

Taiwan Photon Source

- Smooth operation of TPS for last two years.
- Reliability and stability improved significantly since its start operation. Both are the common goals to improve for short- and long-term efforts.
- 300 mA top-up operation since late May, 2016. 400 mA stored beam operation since November 2017.
- Improve compatibility of the storage ring and beamlines are current focus.
- The 3rd SRF system project and Phase-II and III beamlines are the highest priority short-term goals.
- Various machine development plans are in progress.

Thank you for your attention!