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

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The Role of Beam Diagnostic in the Fast Commissioning of TPS

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On behalf of the Control and Diagnostic Team
NSRRC

Outlines

- TPS Timeline and Diagnostics System
- Intensity Monitors
- Screen Monitors
- BPM System
- Feedback System
  - Orbit Feedback System
  - Bunch-by-Bunch Feedback System
- Synchrotron Radiation Monitors
  Visible Light, X-Ray Pinhole, Streak Camera, TCSPC, ...
- Beam Loss Monitor
- Summary

TPS Timeline

2007 Mar. Funding approval (230M USD Acc & Civil)
2010 Feb. Ground-breaking
2013 Oct. Phase I Accelerator installation started
2014 Aug. Phase I Accelerator system test and commissioning started
2015 Mar. Phase I Accelerator commissioning completed

up to 100 mA beam current with PETRA RF cavities & Optimization of basic machine parameters

2015 Apr. SRF, IDs and Beamline installation started
2015 Sep. Phase II commissioning with SRF, IDs and Beamline would start

up to 500 mA beam current with Superconducting RF
Insertion Devices Commissioning
Beamlines Commissioning

2016 Open to users

Beam quality control, Top-up injection, high beam intensity issues

TPS Phase I Commissioning with Petra RF cavity

Linac & LTB Commissioning

- **2011 Linac (from Research Instruments) pre-test in test-site**
- **2014 Jun. Moved to TPS site from March to June, 2014**
- **2014 Aug. Permission to test**

Booster Commissioning with hardware improvement

- **Aug. 15 Hardware improvement ex: BR power supply overheat, kicker pulse residual field (5% to 0.5%)**
- **Sep. First turn & multi-turn beam soon obtained after steering**
- **Sep.~Oct. Re-alignment of chambers & magnet, individual dipole trim install**
- **Nov. 12 Found relative permeability of pipes too large (1.2-2), uninstall for heat treatment**
- **Dec. 11 finished pipes demagnetization (permeability <1.001) More than 50 ms survival beam.**
- **Dec. 12 stored beam after RF on**
- **Dec. 15 ramping tested and ramped to 2.5 GeV**
- **Dec. 16 ramped to 3 GeV**

Storage Ring Commissioning

- **Dec. 24 extracted 3 GeV beam and found DC septum leakage field**
- **Dec. 29, accumulated beam at 1.5 GeV with kicker scan**
- **Dec. 30, extracted 3 GeV after enforcement of DC septum shielding and two more local correctors**
- **Dec. 31, 2014 5 mA stored beam, the first synchrotron light was observed**

TPS Diagnostic Devices Overview

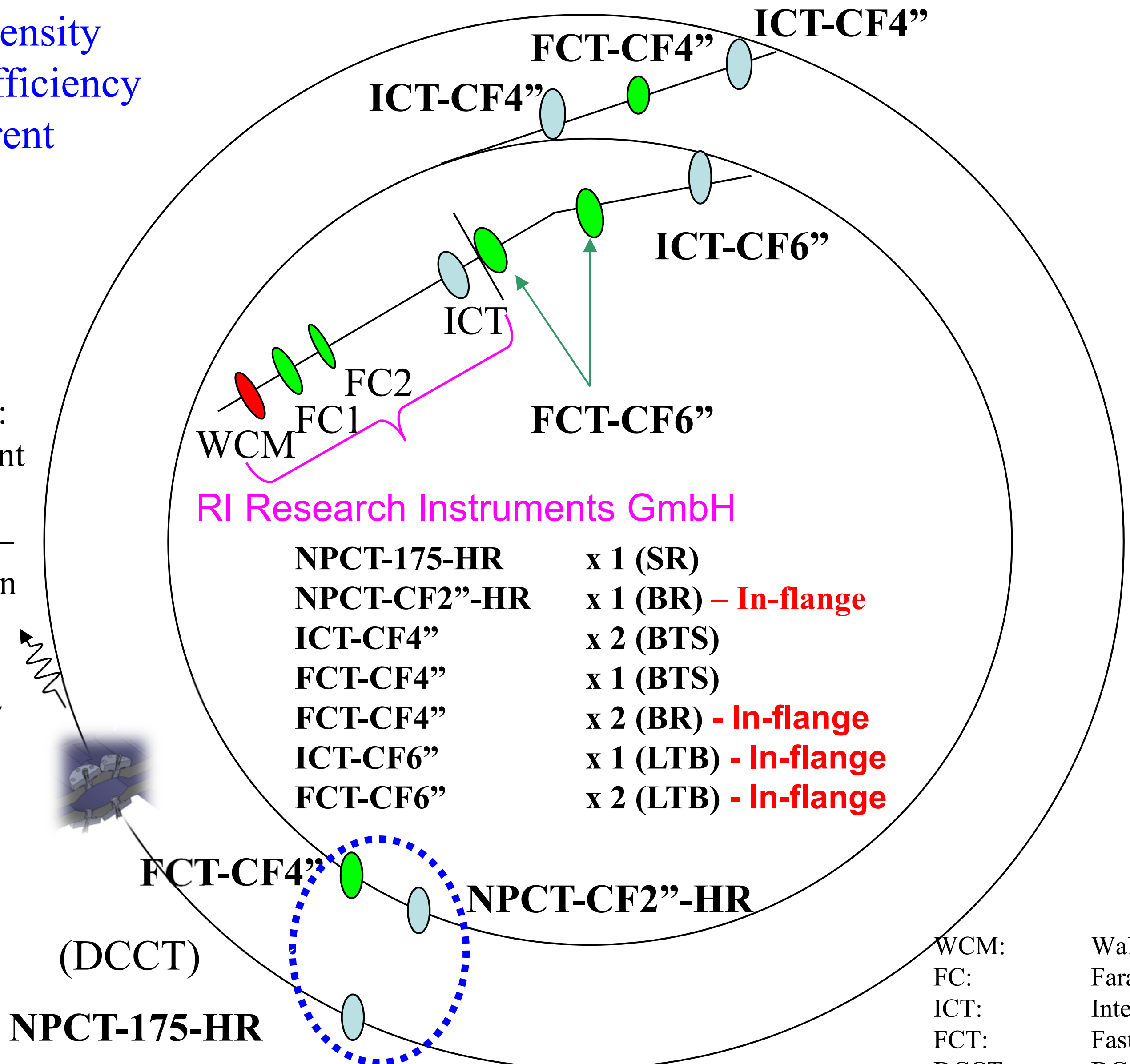
	LTB	BR	BTS	SR	Status
BPM	7	60 +1	6	167+6	
Screen Monitor	5	6	4	2+3	
SRM (Visible + X-Ray)	-	2	-	2	
NPCT	-	1	-	1	
FCT	2	1	1	-	
ICT	1		2		
Beam loss monitor		Many		Many	Work in progress (PIN diodes, RadFET, Scintillator+PMT)
Beam excitator		H x 1 V x 1		H x 1 V x 2	BR: Magnetic shaker SR: Striplines

INTENSITY MONITOR

Layout of the TPS Intensity Monitors

- Average Intensity
- Injection Efficiency
- Bunch Current

TCSPC Monitor:
1. Bunch current monitor (0.5 % accuracy – filling pattern control).
2. Isolated bunch purity (> 10^6).



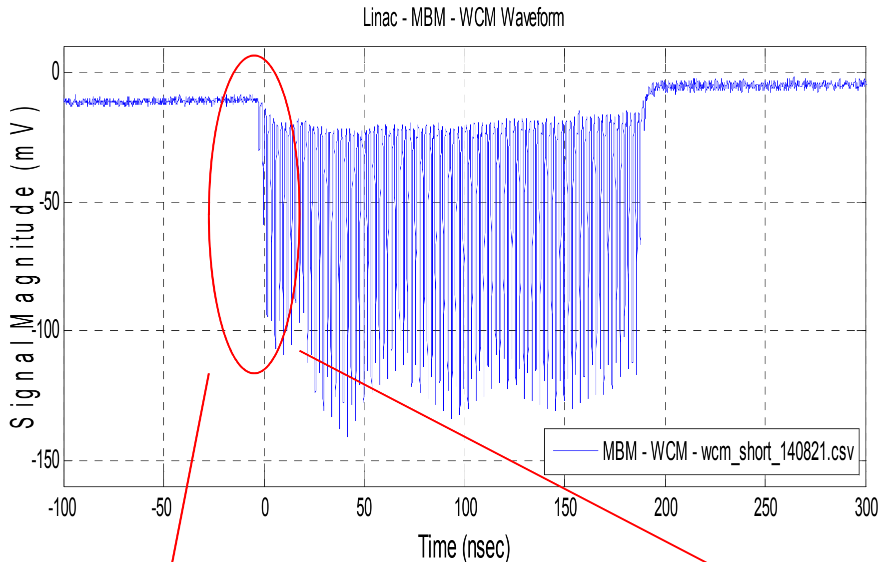
NPCT-175-HR	x 1 (SR)
NPCT-CF2"-HR	x 1 (BR) – In-flange
ICT-CF4"	x 2 (BTS)
FCT-CF4"	x 1 (BTS)
FCT-CF4"	x 2 (BR) - In-flange
ICT-CF6"	x 1 (LTB) - In-flange
FCT-CF6"	x 2 (LTB) - In-flange

BPM Based Intensity Monitor:
1. Beam current monitor (~ 5 % accuracy – interlock purpose).
2. Bunch current monitor (0.5 % accuracy – filling pattern control).

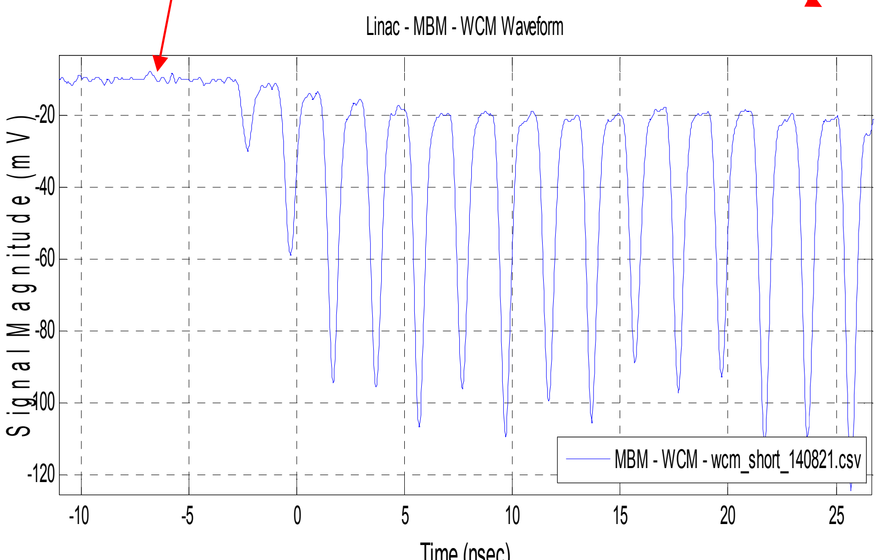
WCM:	Wall Current Monitor
FC:	Faraday Cup
ICT:	Integrating Current Transformer
FCT:	Fast Current Transformer
DCCT:	DC Current Transformer

Linac – WCM Measurement

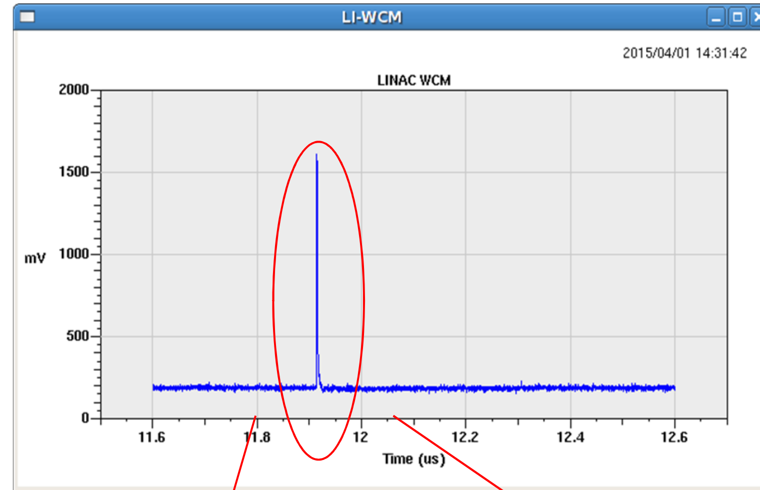
Multi-bunch



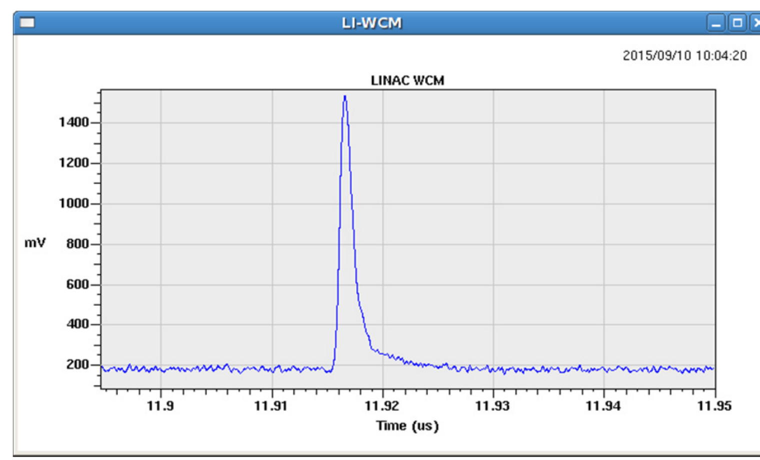
Zoom in



Single-bunch

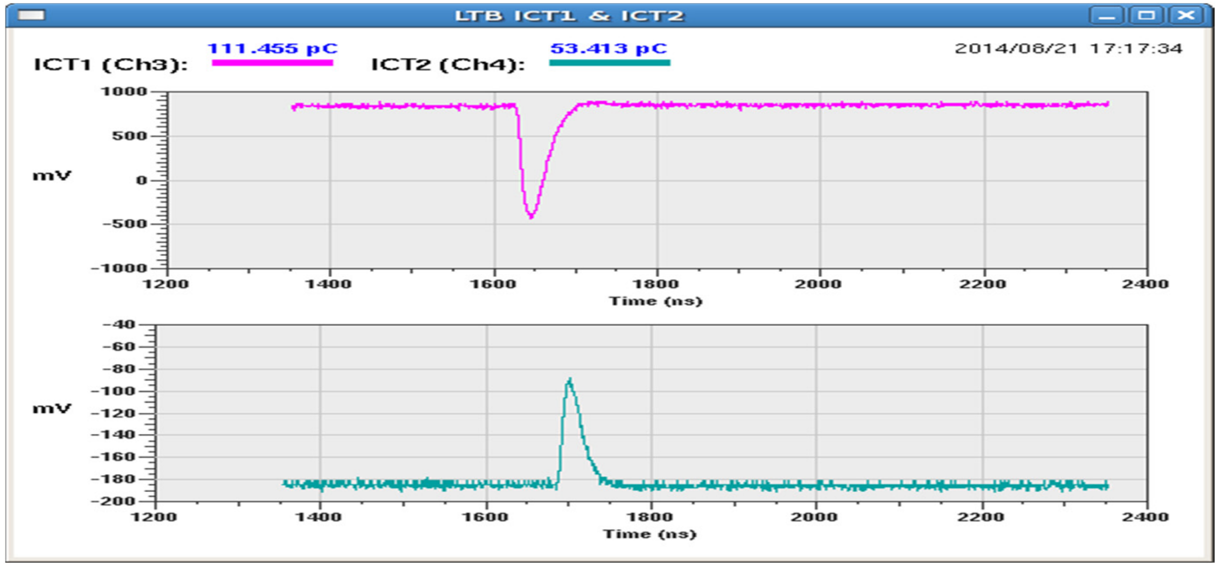


Zoom in

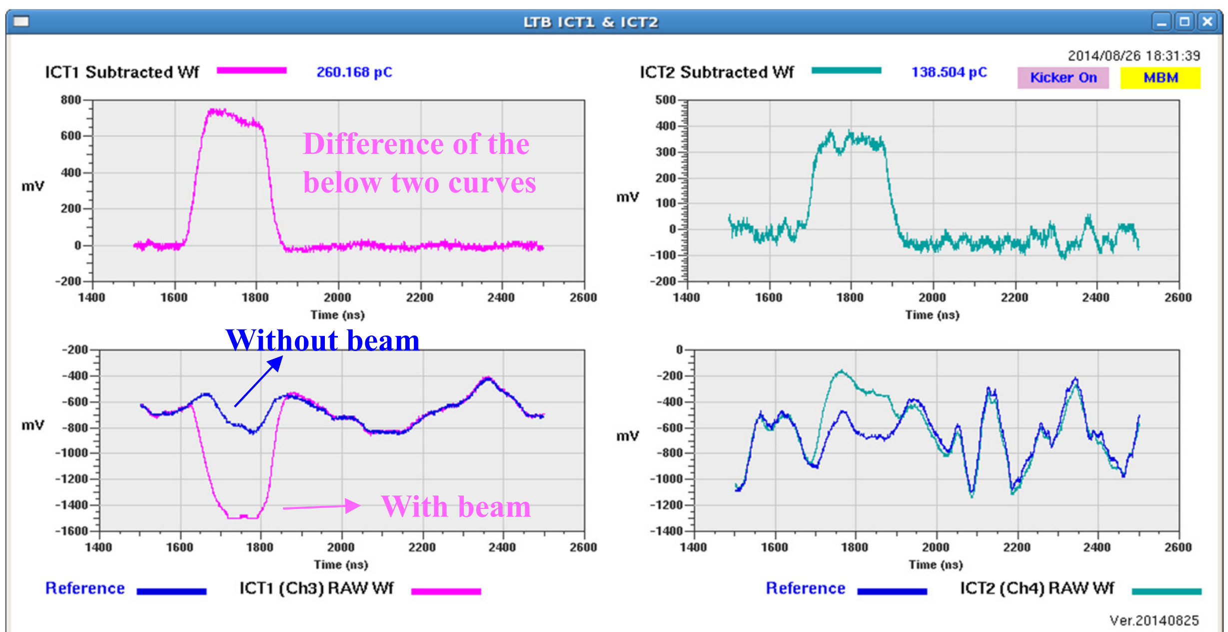


LTB ICT Beam Test

Single Bunch



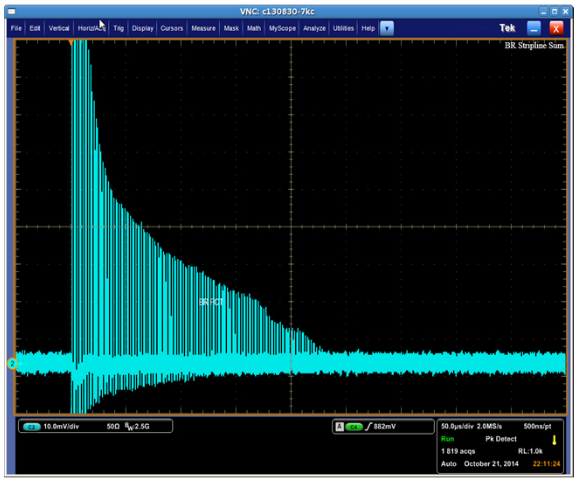
Multi Bunch (Kicker Disturbance)

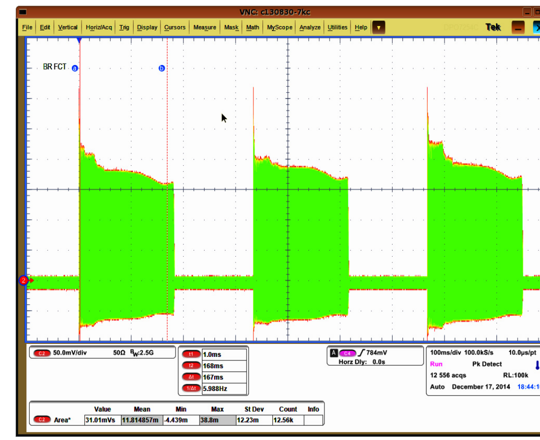


Booster Beam Intensity Observation by FCT

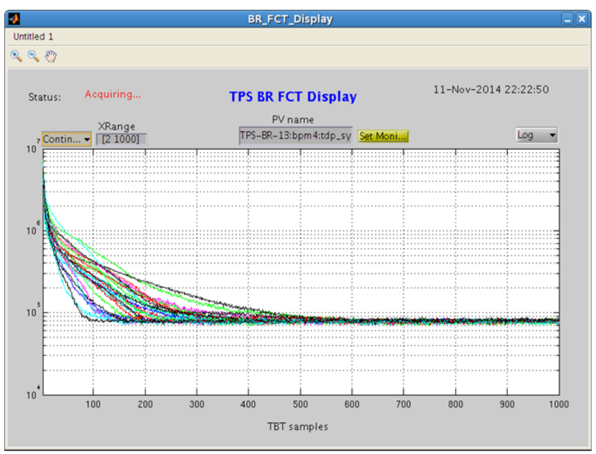
un-annealed chamber

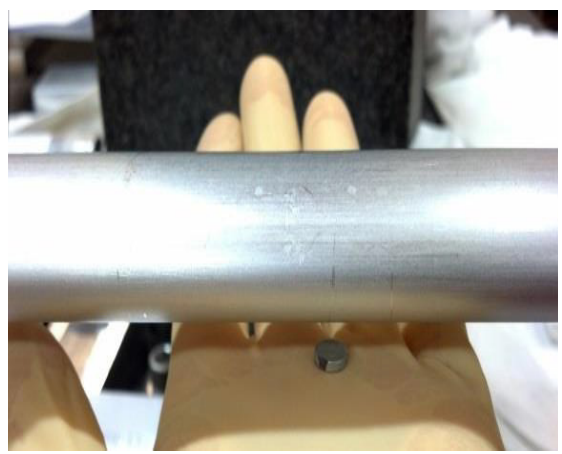
annealed chamber

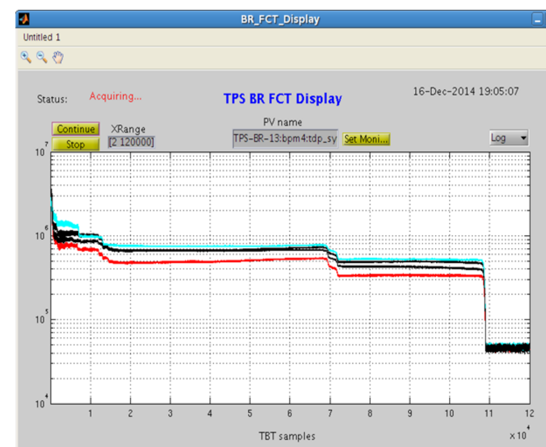




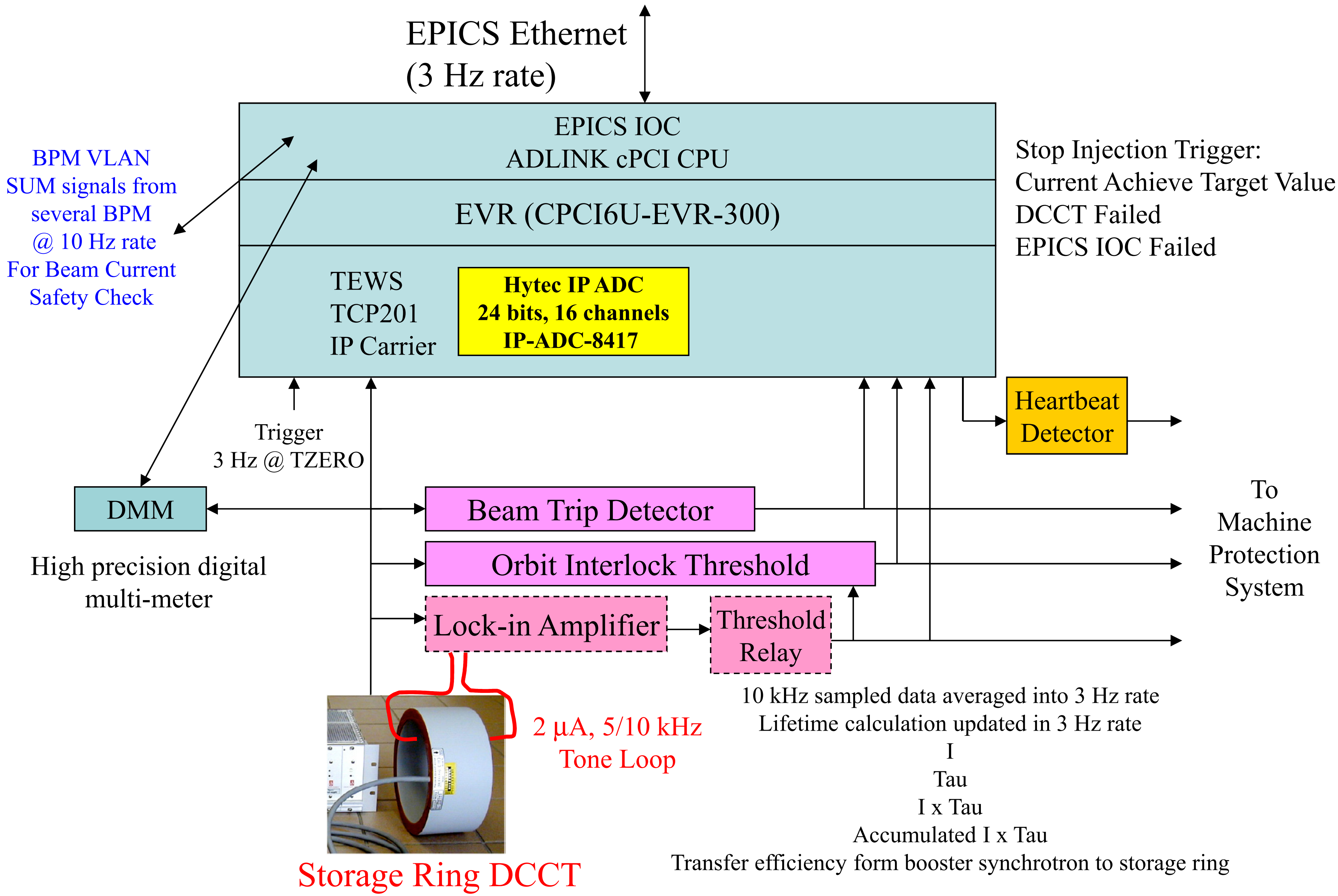
NbFeB magnet



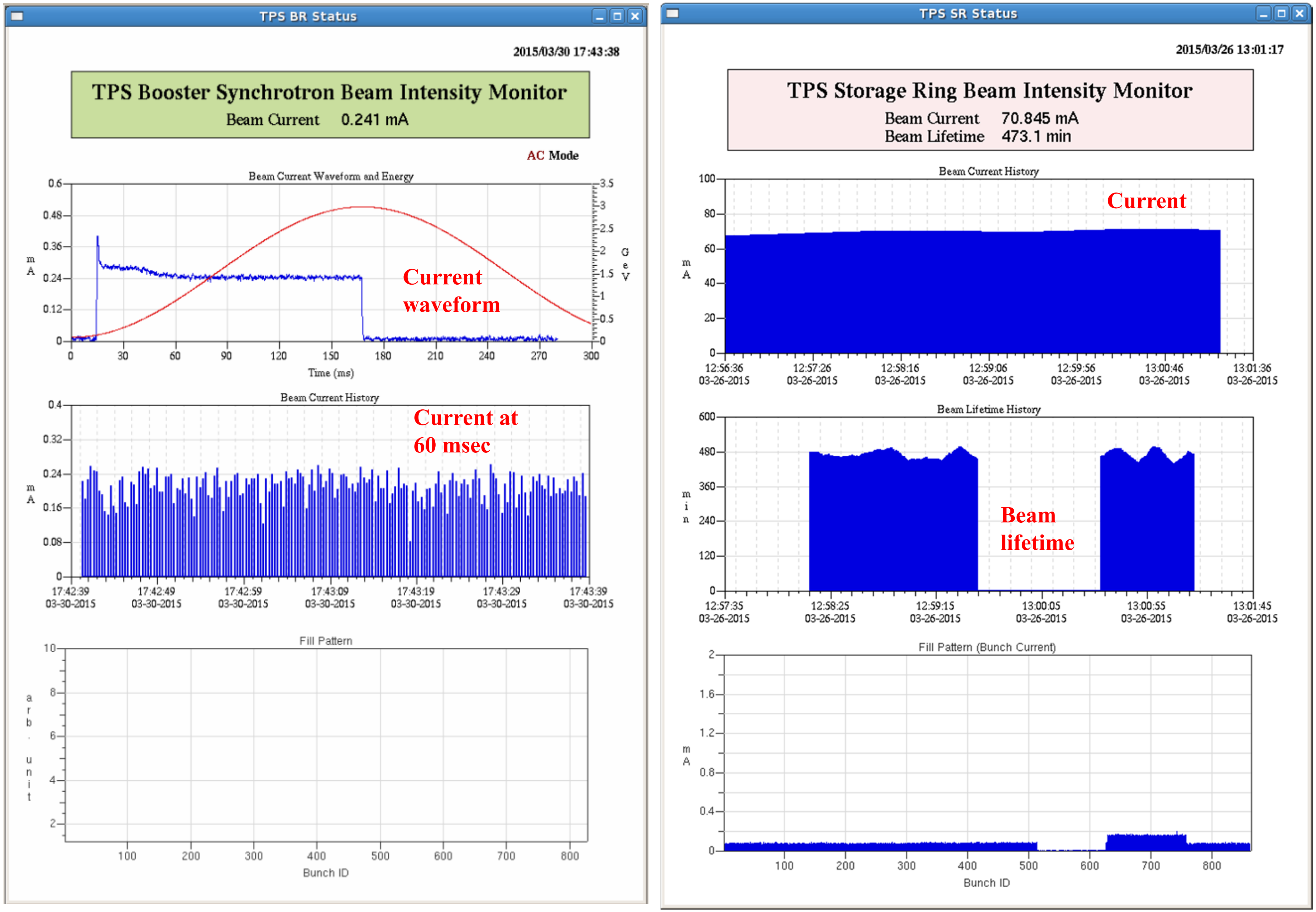




Implementation of the DCCT IOC



Current Measured from DCCT



Filling Pattern (Bunch Current) Diagnostics and Control

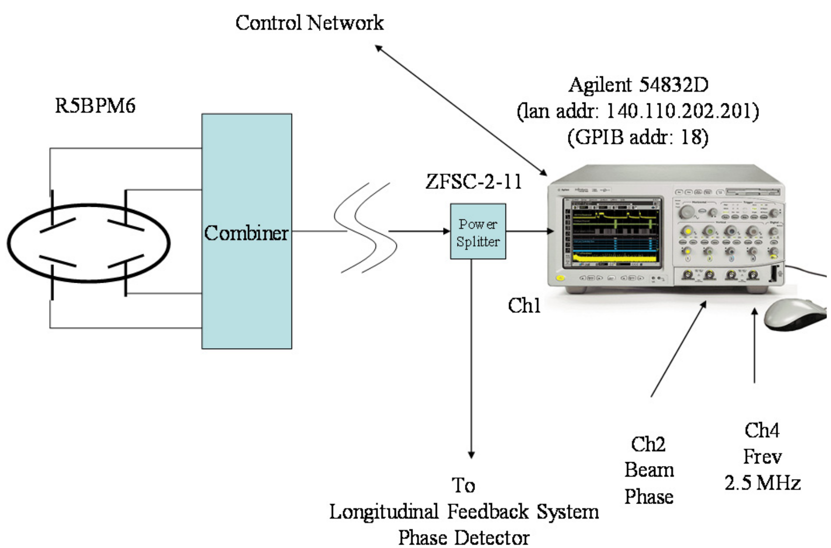
- Filling Pattern

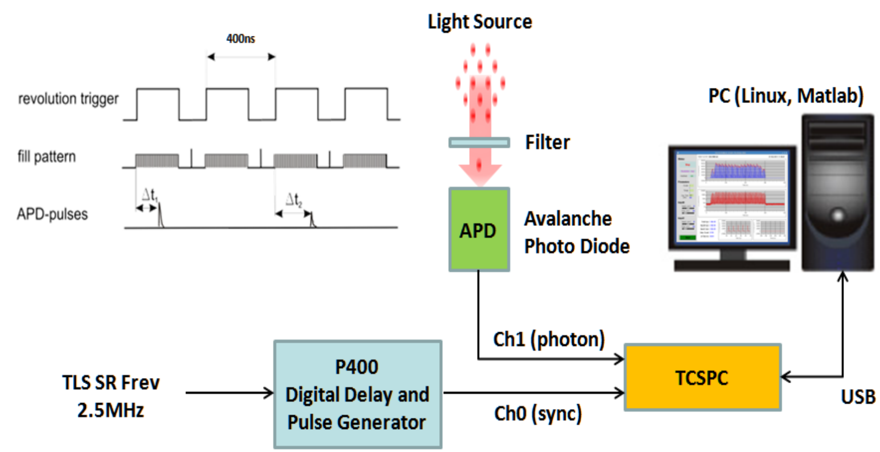
  BPM Pickups - Button Pick-up + Fast Digitizer (Oscilloscope, etc.)
  (Better than 1 %)

  Visible Light or X-ray: APD + TCSPC (>10^6 Dynamic Range for Isolated Bunch)

- Filling Pattern Control

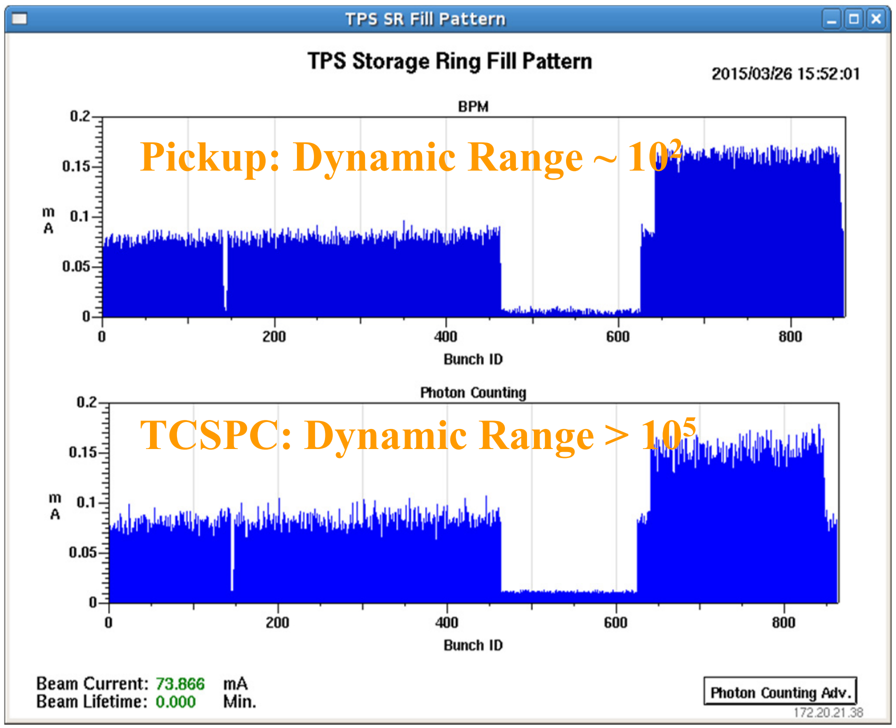
  Integrated with Control System for Filling Pattern Control

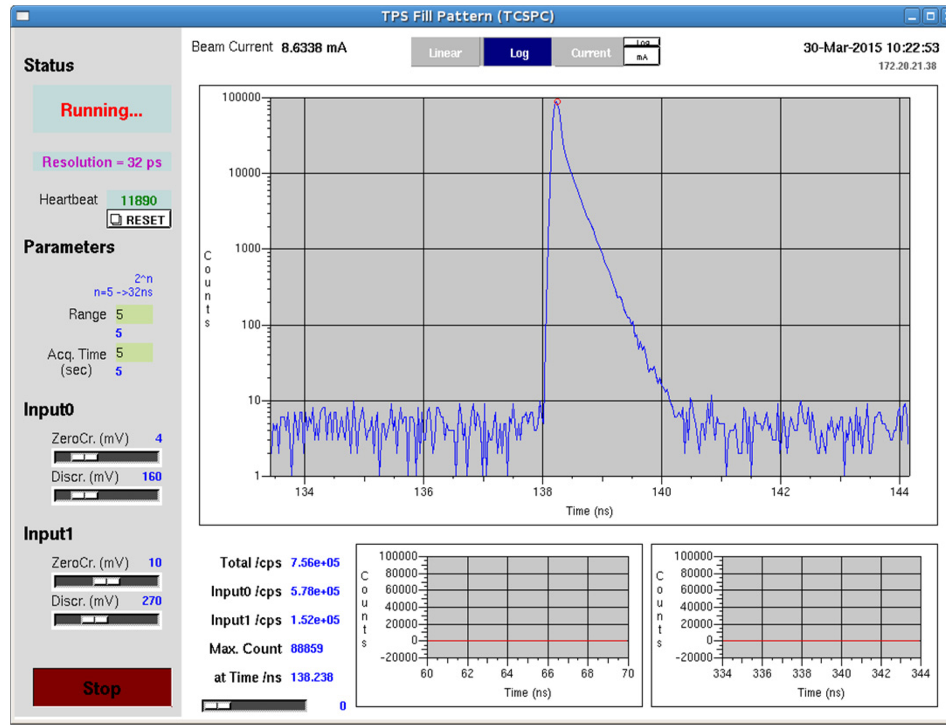




Filling Pattern Measurement at TPS

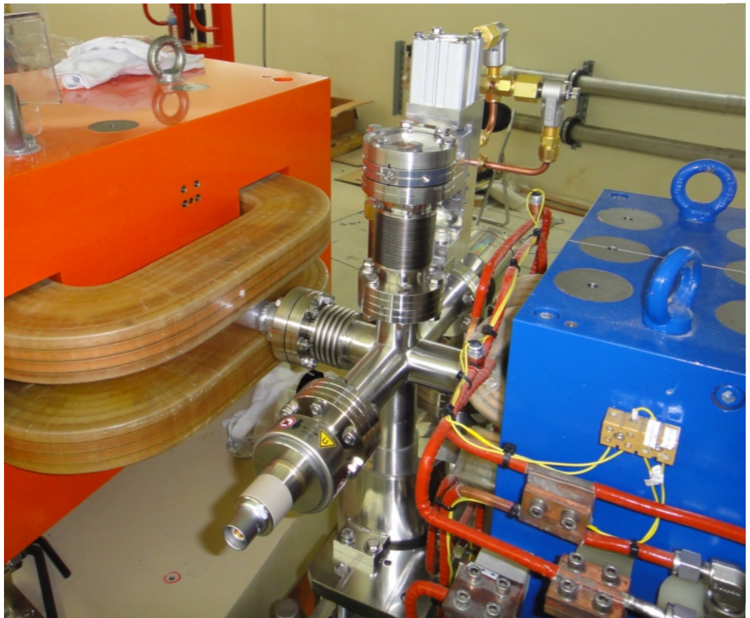
TCSPC for Bunch Purity Measurement

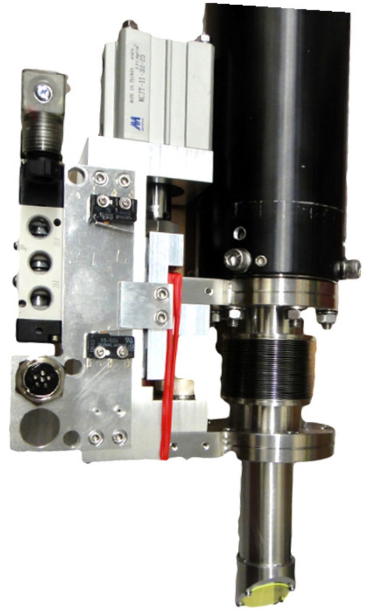


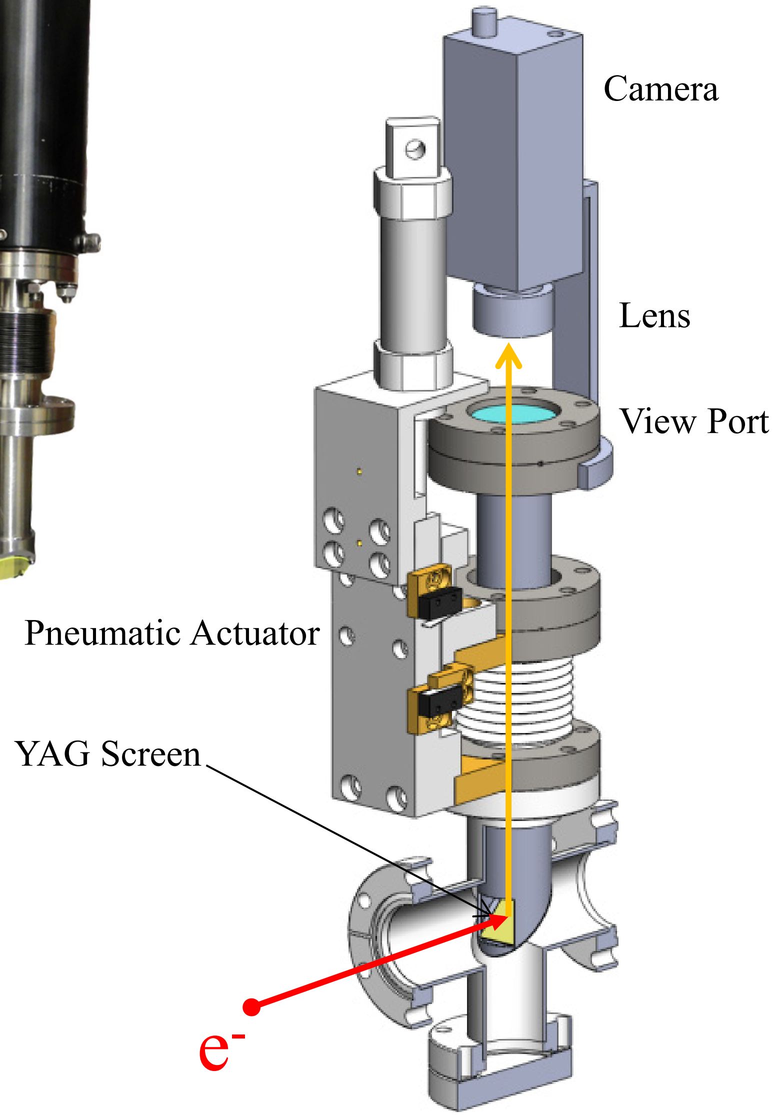


SCREEN MONITOR

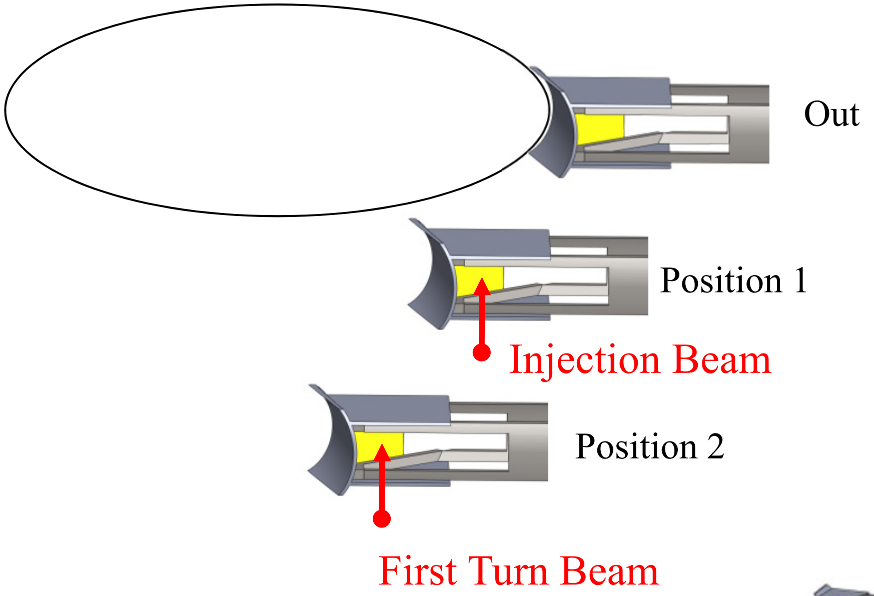
Screen Monitor – LTB, Booster Synchrotron, BTS

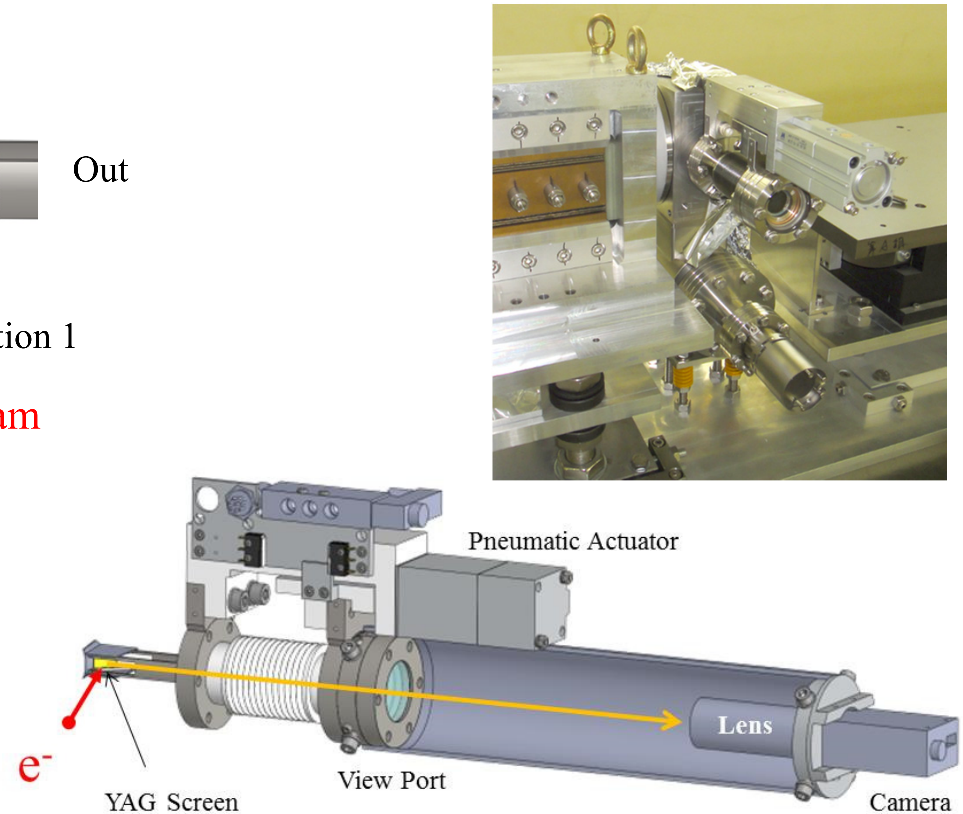


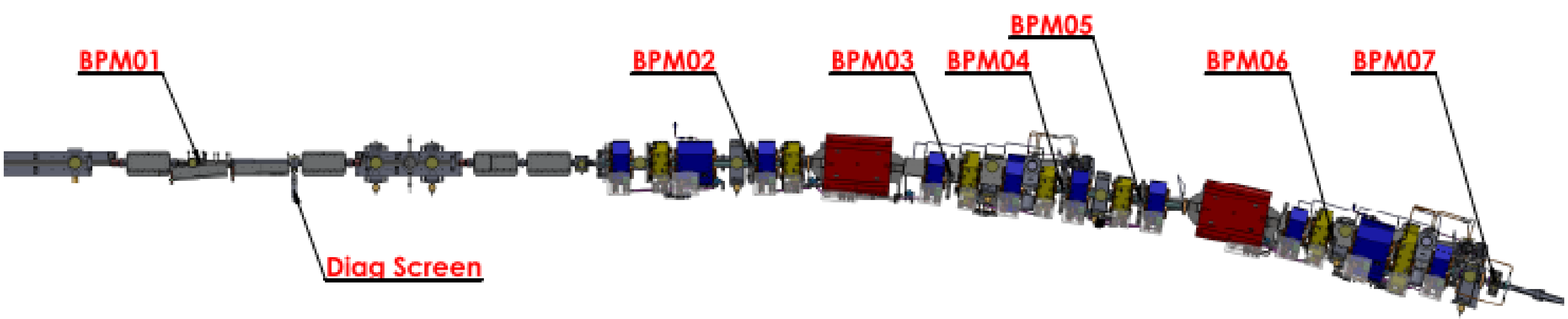




Screen Monitor – Storage Ring

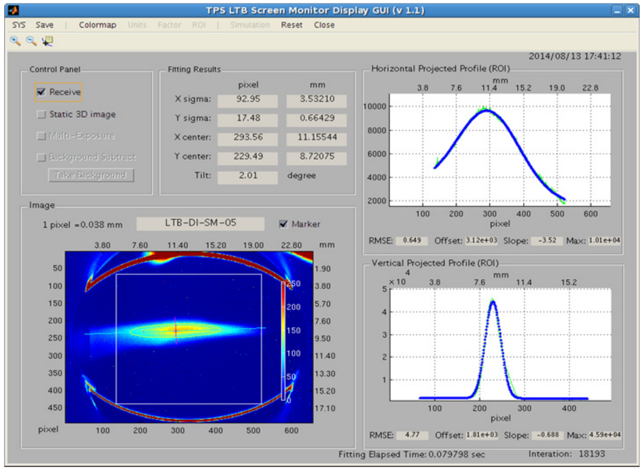




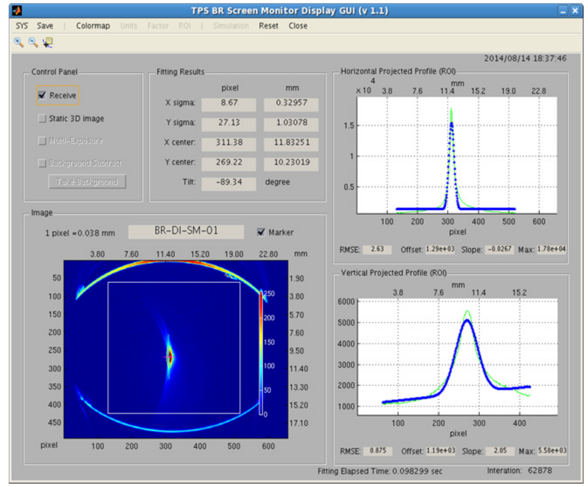


Screen Monitor Images

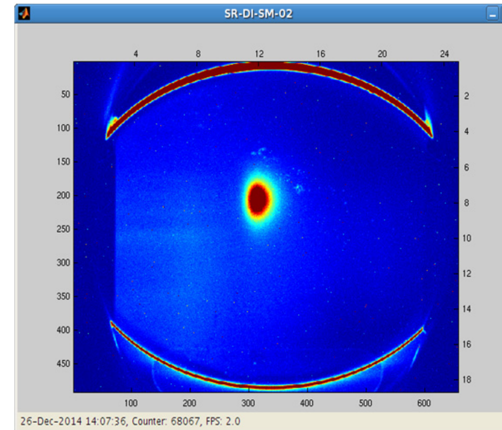
Screen image at Linac



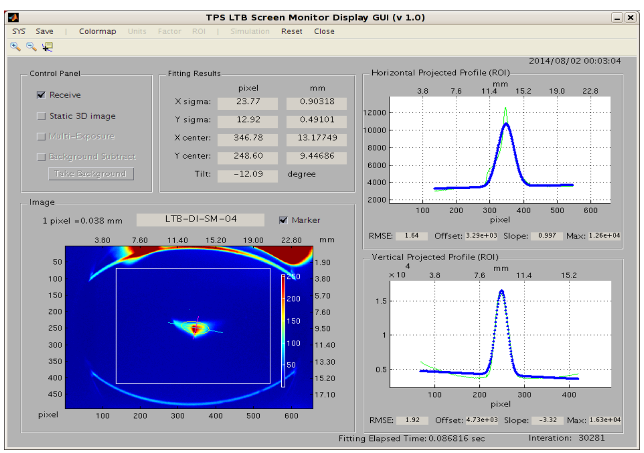
Screen image at Booster



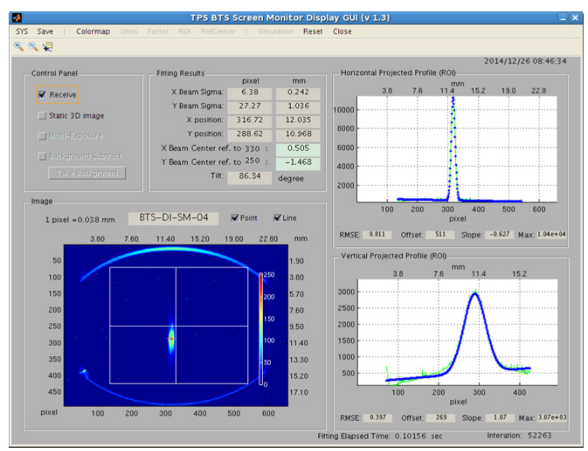
Screen image at SR scn4



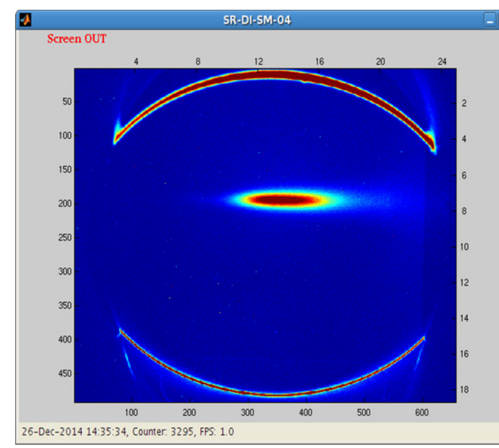
Screen image at LTB



Screen image at BTS

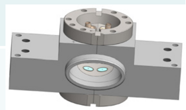
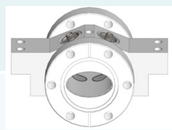
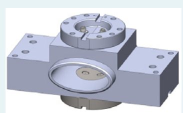
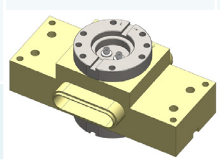


Screen image at SR scn4



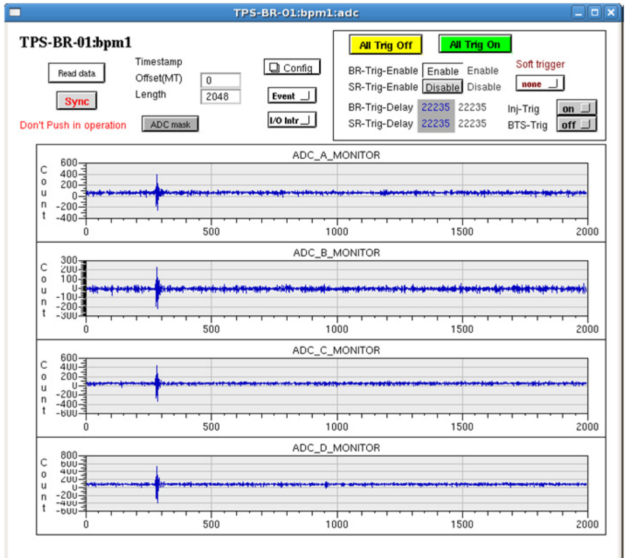
BPM SYSTEM

Summary of the BPM Types Used in TPS Project

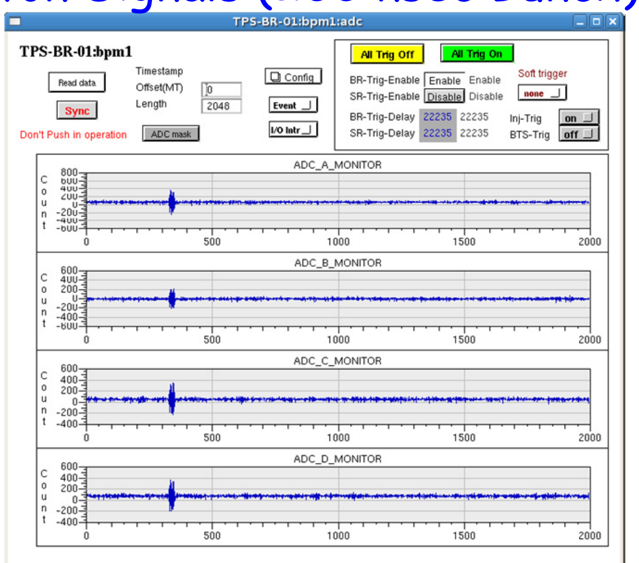
		Chamber profile	Size (mm)	ϕ button (mm)	Kx/Ky (mm)	Remarks
Linac (0)		-	-	-		
LTB (7)		Elliptical	56 x 28	10.2	15.20/10.95	Libera Single Pass Brilliance
Booster (60)		Elliptical	35 x 20	10.7	8.25/9.66	Libera Brilliance Plus
BTS (6)		Elliptical	35 x 20	10.7		Libera Single Pass Brilliance
Storage Ring -Standard BPM (120 + 3)		Elliptical	68 x 30	7.4	13.8/12.73	Libera Brilliance Plus
Storage Ring -Primary BPM (46 - 3)		Racetrack	64 x 16	7.4	6.58/8.89	
IU22 (2 + 1)			68 x 20	7.4	8.99/9.63	
EPU48 (1)			68 x 8	< 5	~ 4/4	

Booster BPM: ADC

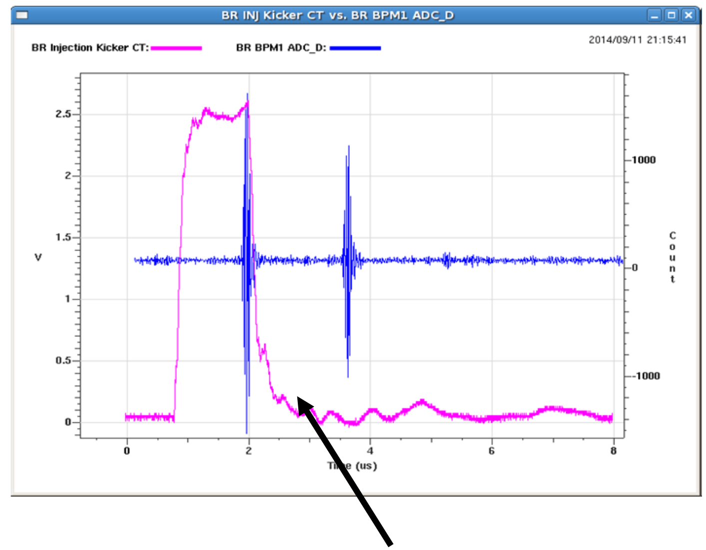
Button Signals (Single Bunch)



Button Signals (200 nsec Bunch)

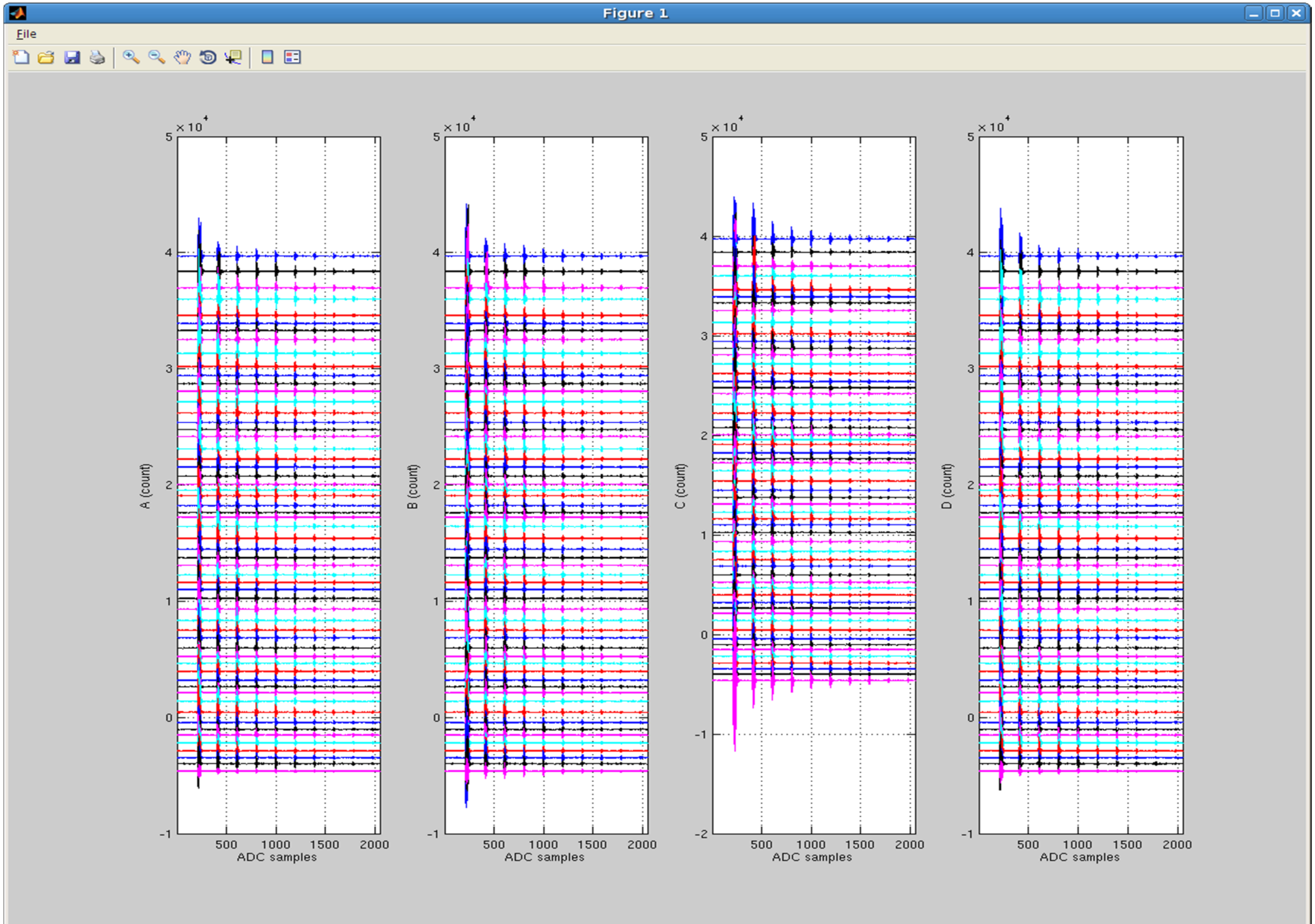


Adjust kicker trigger delay so that the 2nd turn of beam would not overlap on the kicker residual tail



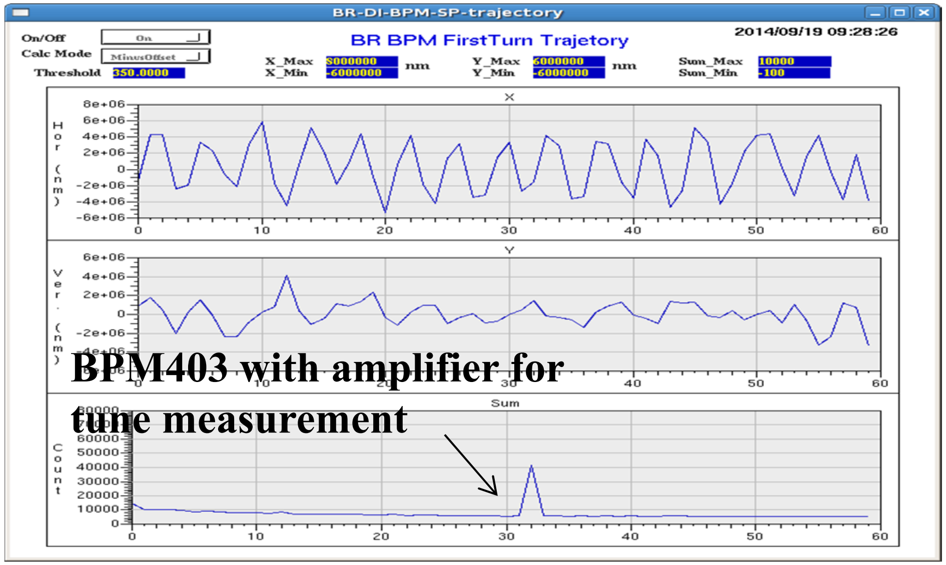
Residual field tail

Booster BPM ADC data after Phase Alignment



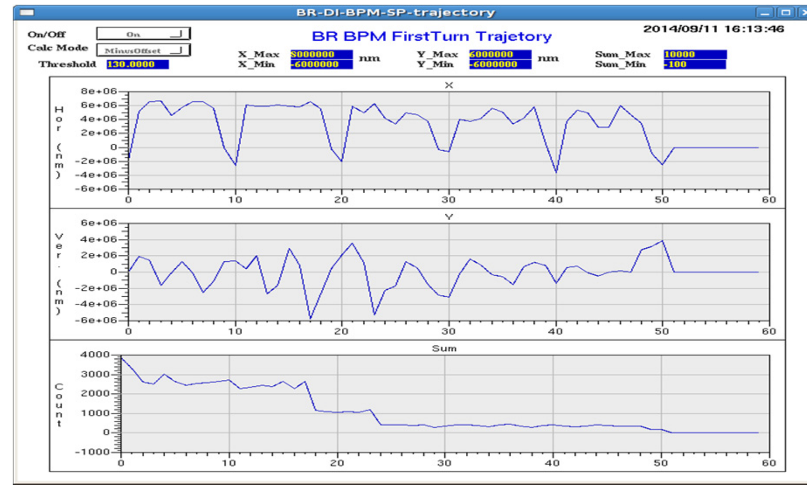
First turn & Multi-turn

First-turn display GUI

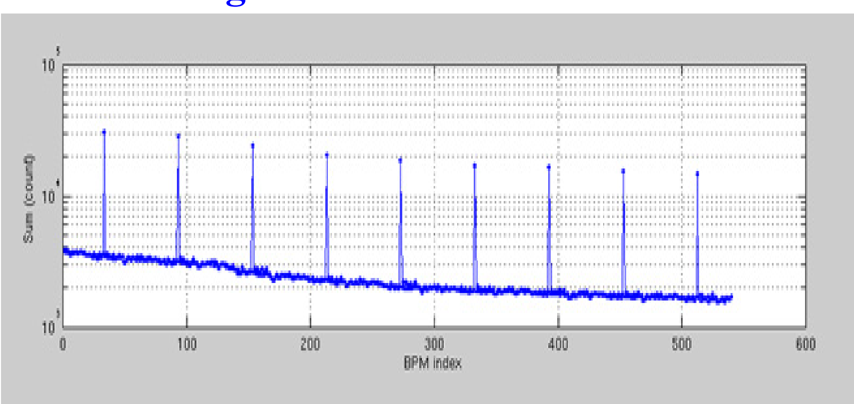


BPM403 with amplifier for tune measurement

At early commissioning, linac modulator was not stable, energy drift could be observed from the first turn trajectory in horizontal.



9 turns sum of all BPMs.
Beam loss along booster chamber uniform before demagnetized.

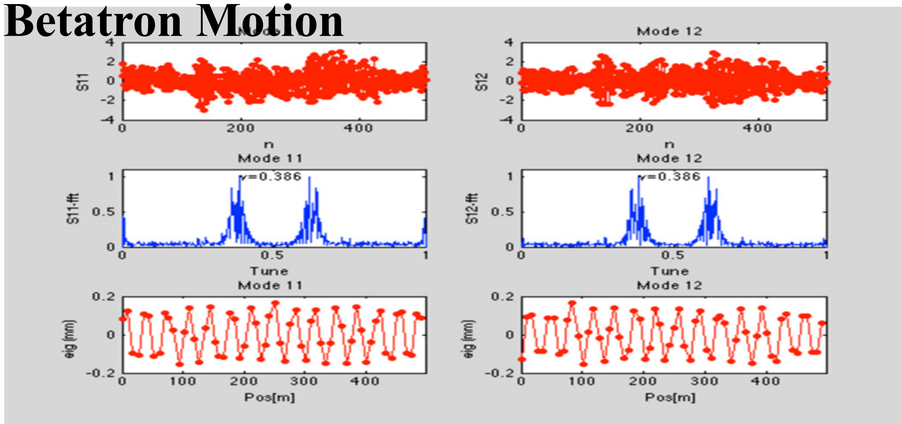


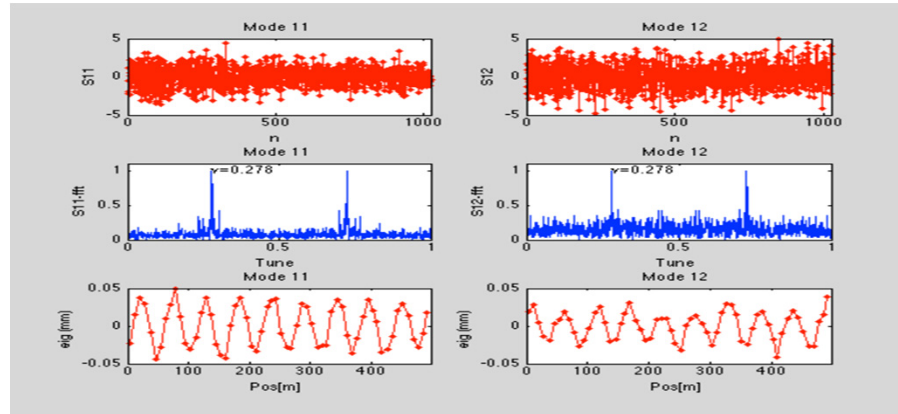
Cable phase match :±3°
Cable loss diff: less 0.1 dB

Booster BPM: TBT Data & Analysis

Horizontal **Vertical**

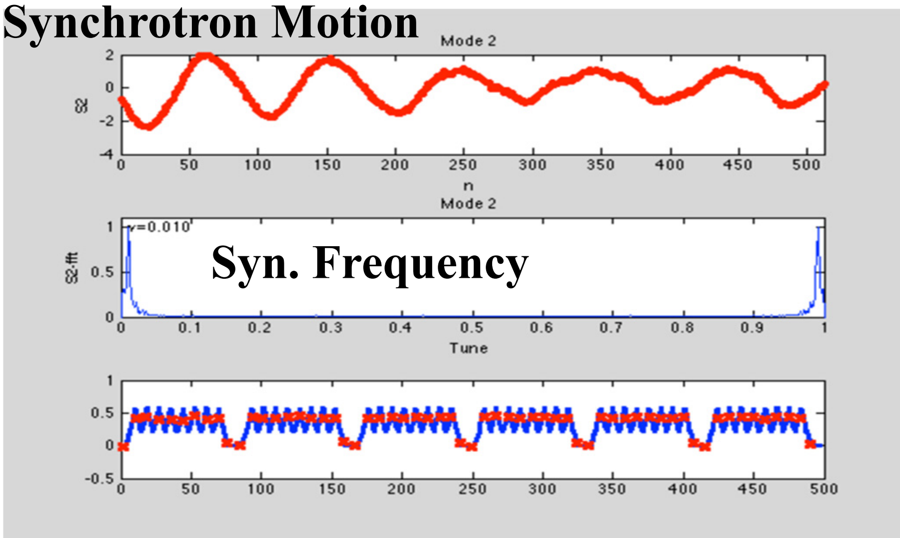
Betatron Motion

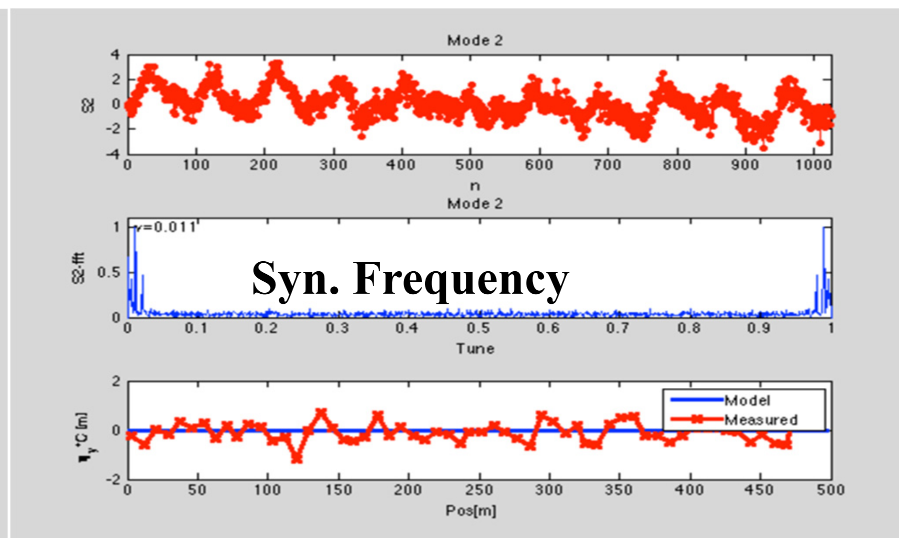




Measured beta Functions in both planes.

Synchrotron Motion



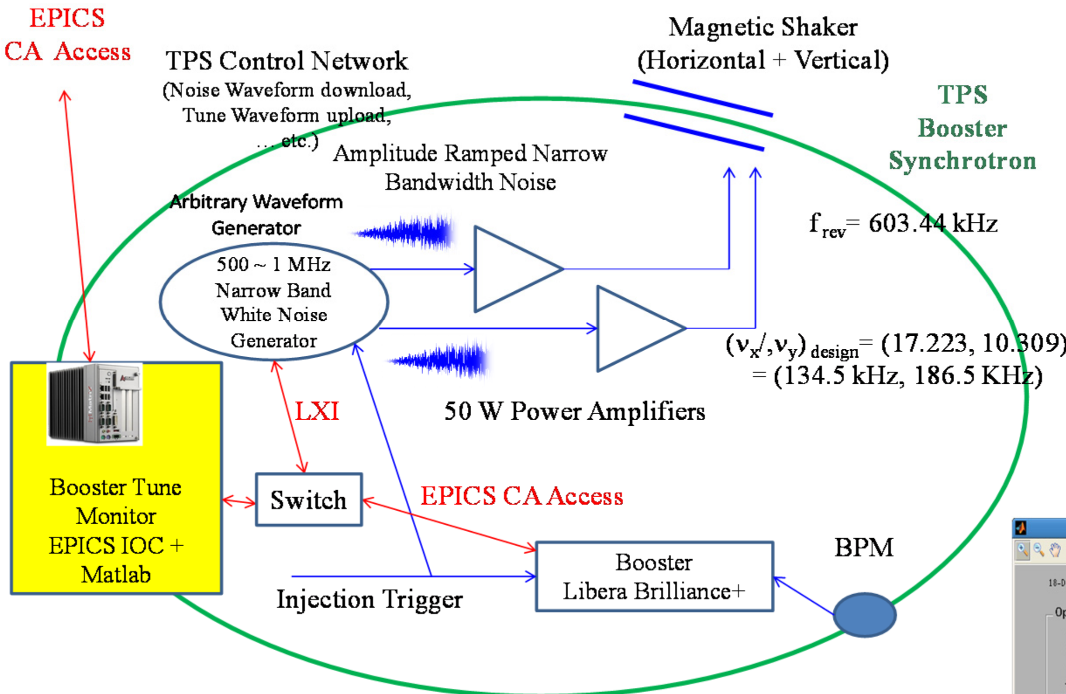


Dispersion Measured by Turn-by-Turn Data.

Provided by H. J. Tsai

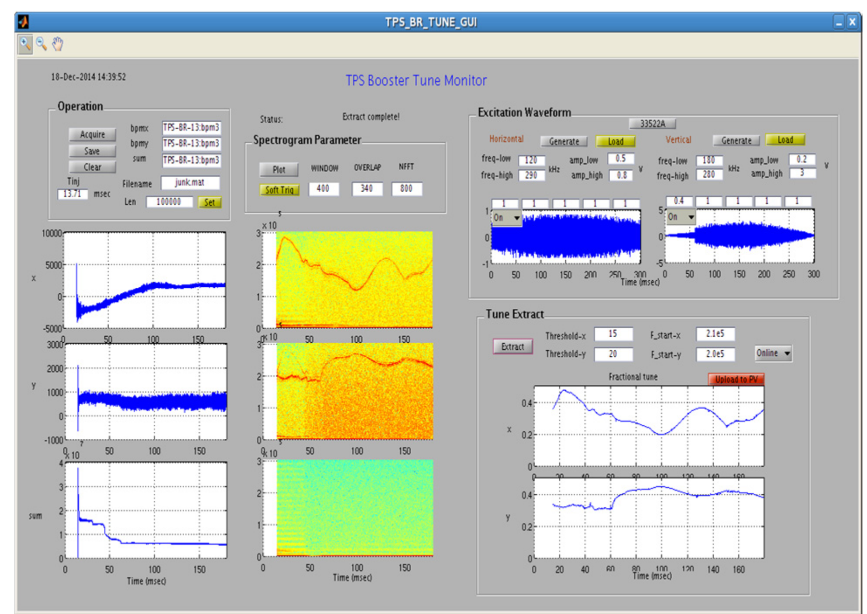
Booster Tune Monitor and GUI

Booster Tune Monitor Block Diagram

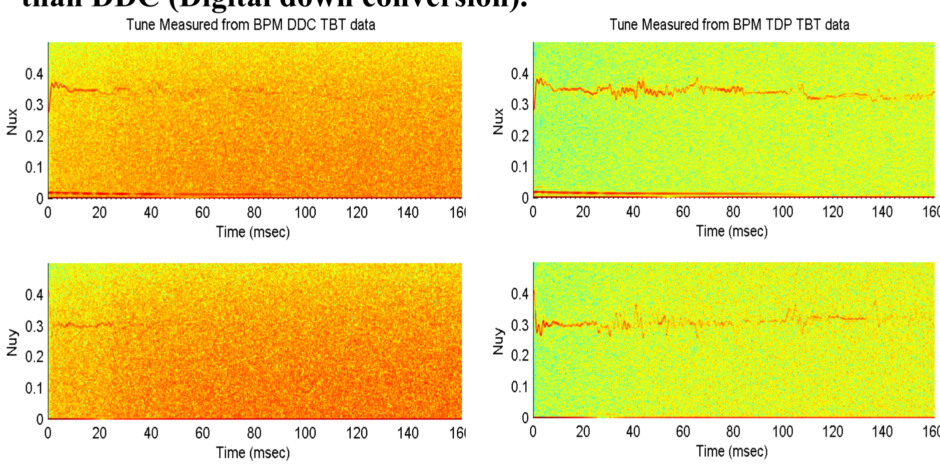


Implemented on an dedicated EPICS IOC
Add waveform generator, excitation on/off control, Data, Time, ……
Select BPM source,
Average, subtraction, persistence display , fraction tune, frequency, ….

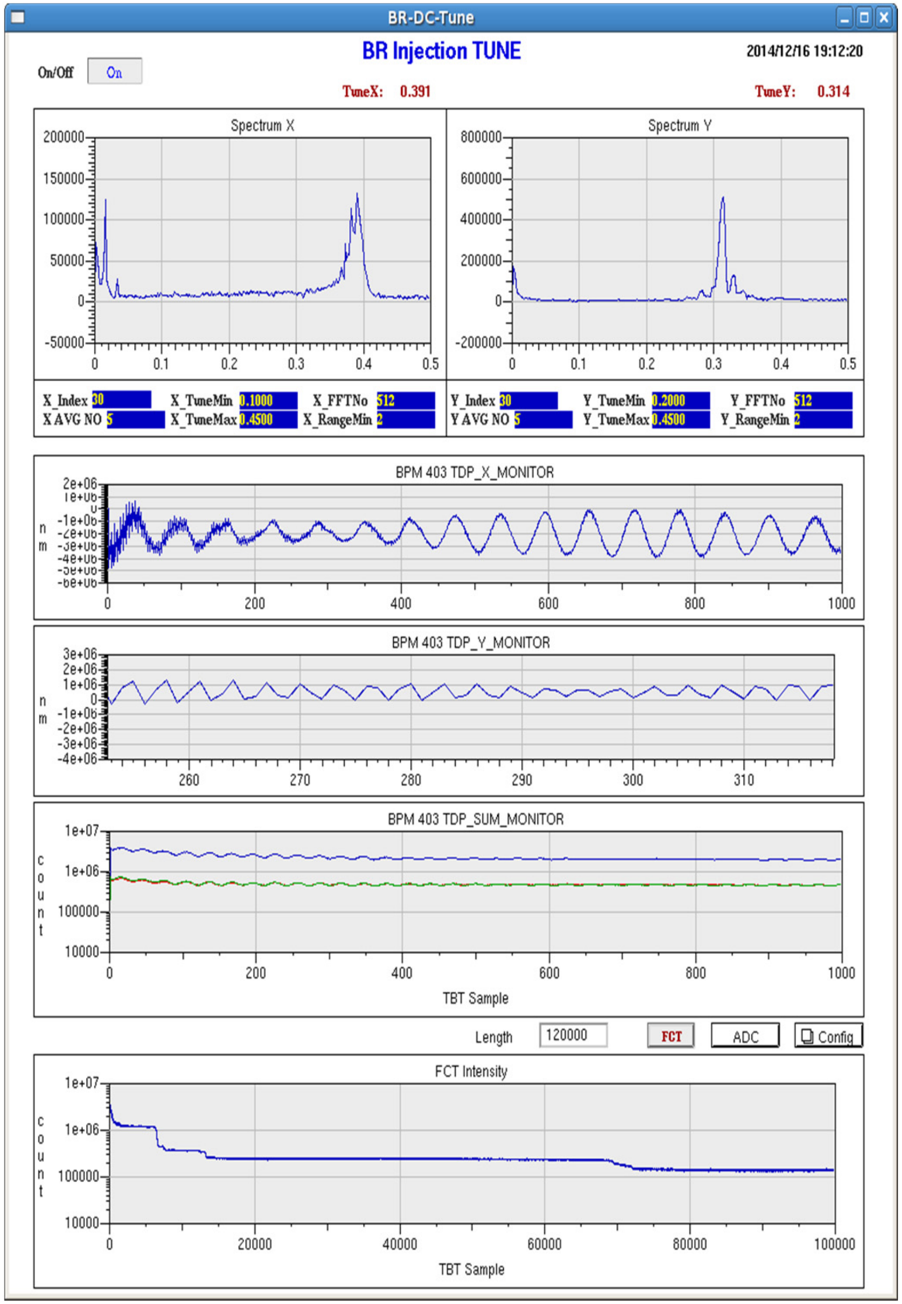
Booster Tune Monitor



Tune resolution of TDP (Time domain processing) better than DDC (Digital down conversion).

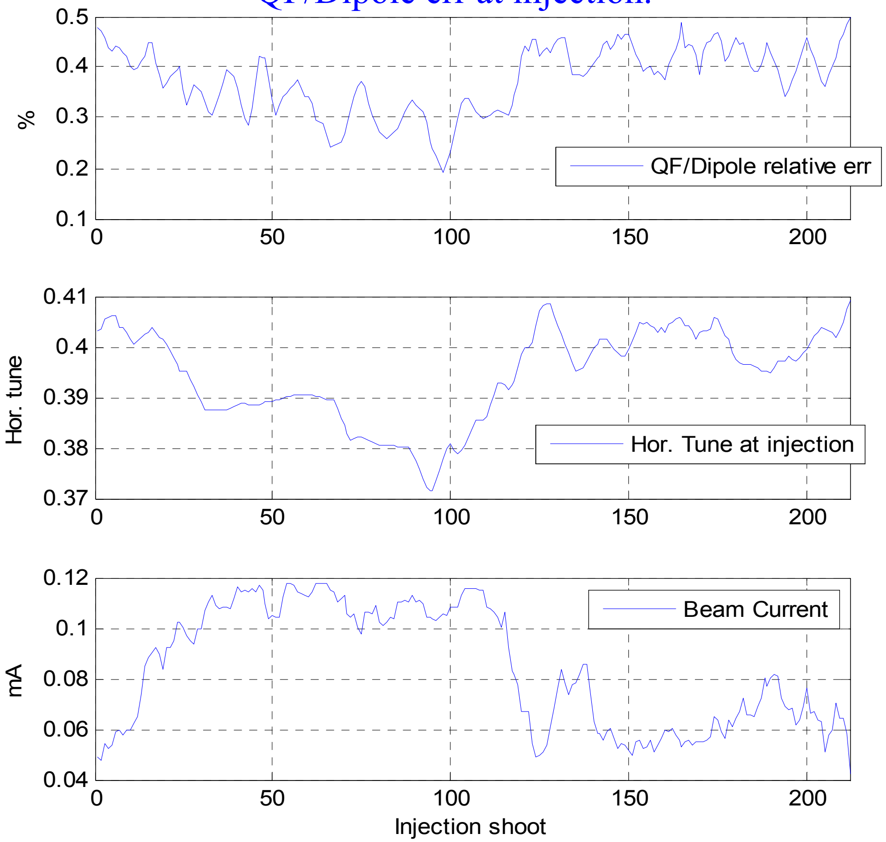


Booster tune monitor at injection

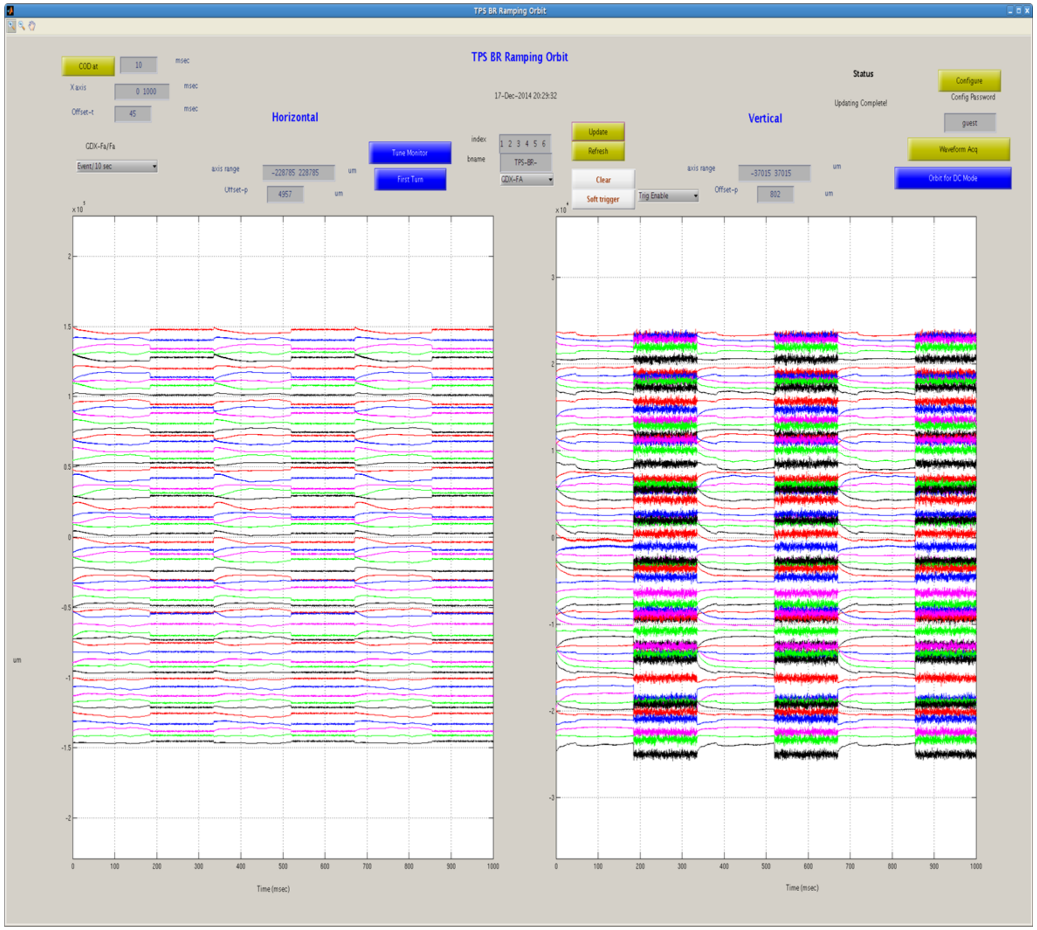


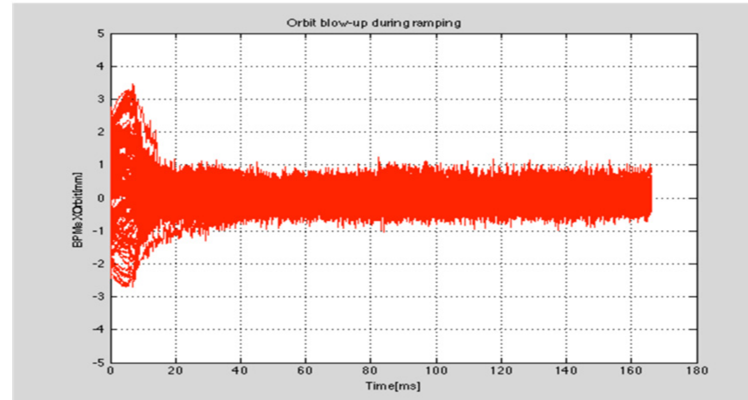
Stability of booster main power supply improved from 0.5% to 0.2% at low current.

Relation between beam survival rate, tune and QF/Dipole err at injection.

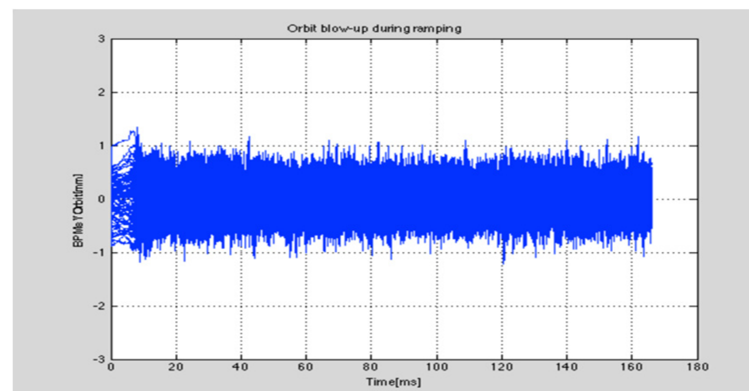


Booster Orbit during Ramping observed from BPM 10kHz data – 141218





150MeV → 3GeV



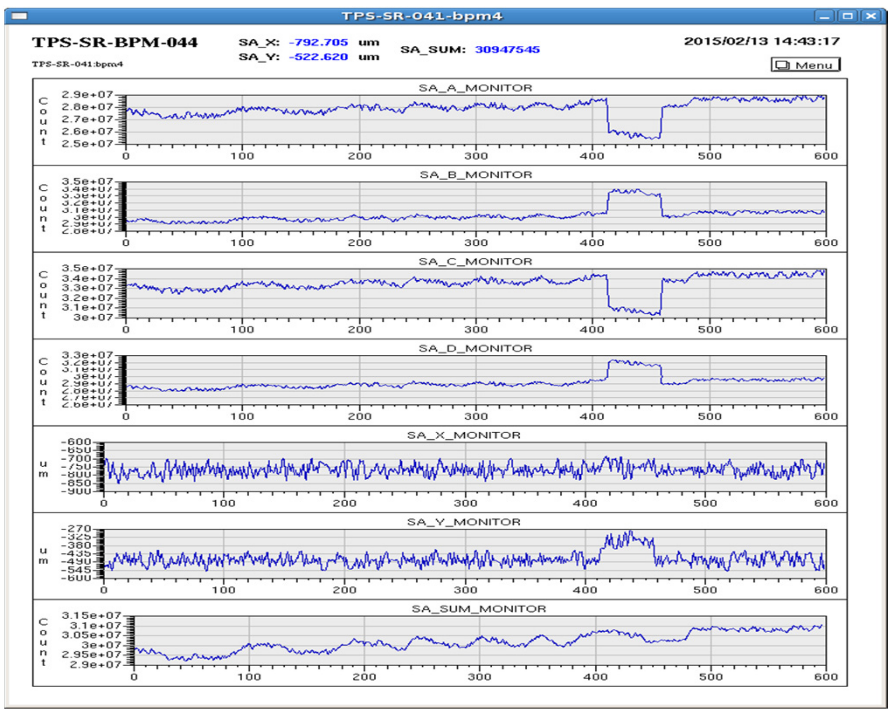
orbit brow-up +4/-2 mm in X-plane and +/- 1 mm in Y-plane during ramping

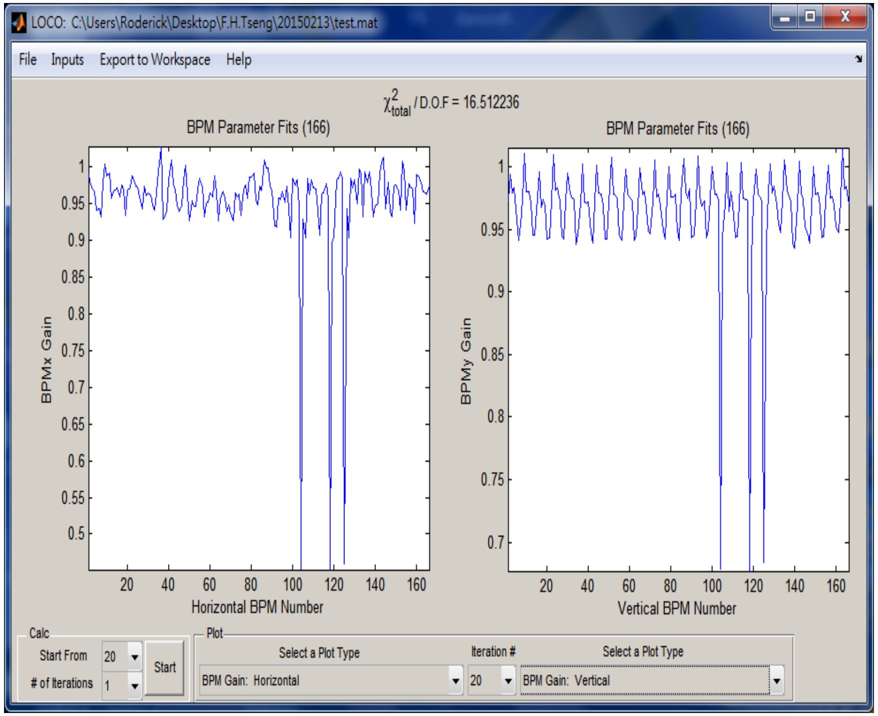
Orbit correction during ramping would be done in phase II commissioning

TPS Storage Ring BPM-Problems

- Cabling Problem
  1. Button B and C of two BPMs 04_4 & 17_7 were cross connected.
  2. The cables of BPM 24_4 and 24_6 were in wrong order.
- Calibration Problem:

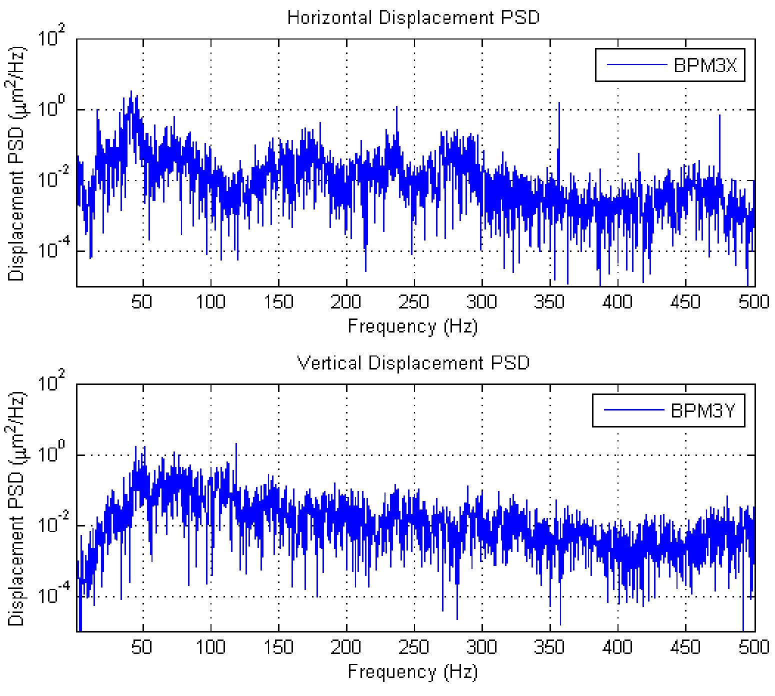
  The BPM sensitivity factors were incorrectly set to the configuration of the primary type BPM while they should have set to standard type configuration.

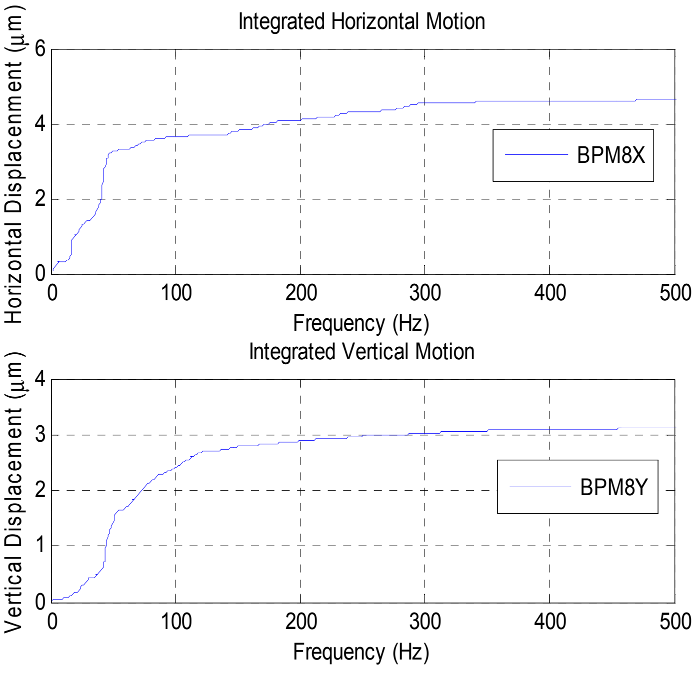




TPS Storage Ring Beam Stability from FA data

Before turbo-pumps turned off, 29 Hz dominated—girder vibration
After turning off the pumps, the noise level was much decreased.
Water turbulence in vacuum chambers is another source of noise.



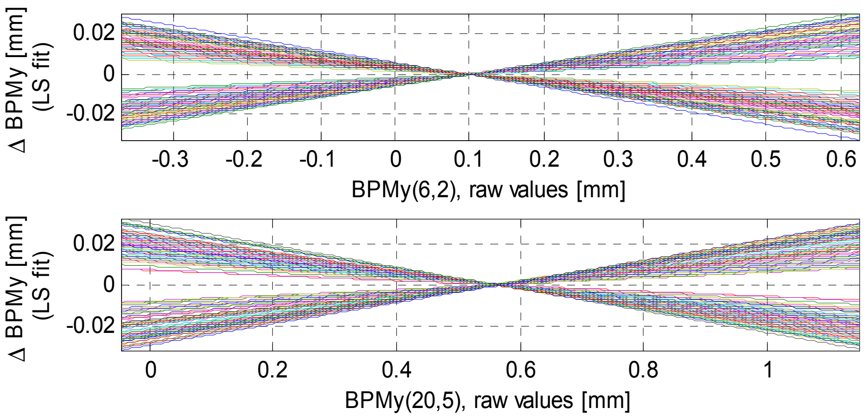


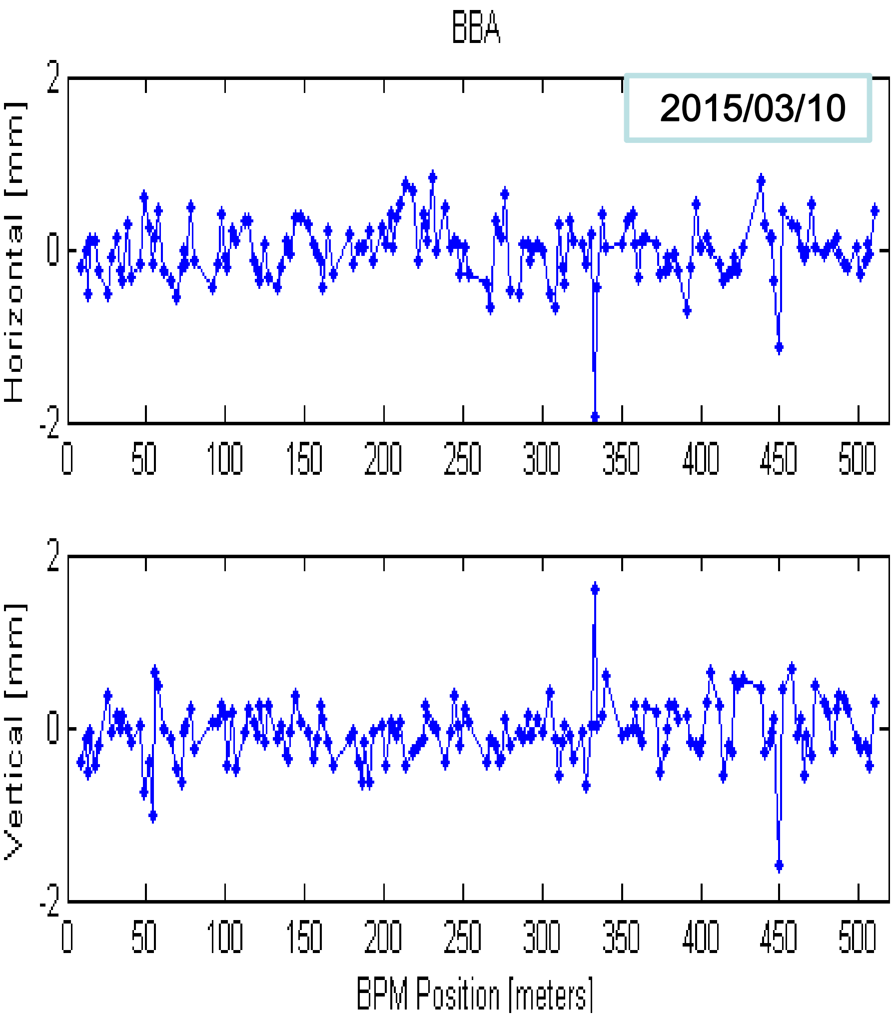
Beam Based Alignment (BBA)

- **By using any corrector magnet to position the electron beam at different position in quadrupole magnet.**
- **Determine the position which minimizes the orbit distortion when the quadrupole field is varied. (BPM-Quad center offset—BBA)**

$$f(\theta_{cm}) = \frac{1}{166}\sum_{i=1}^{166}(x_i(+\Delta k) - x_i(-\Delta k))^2$$

θ_{cm} : the strength of the corrector magnet
$x_i(\Delta k)$: orbit after changing the quadrupole by Δk
i : BPM index



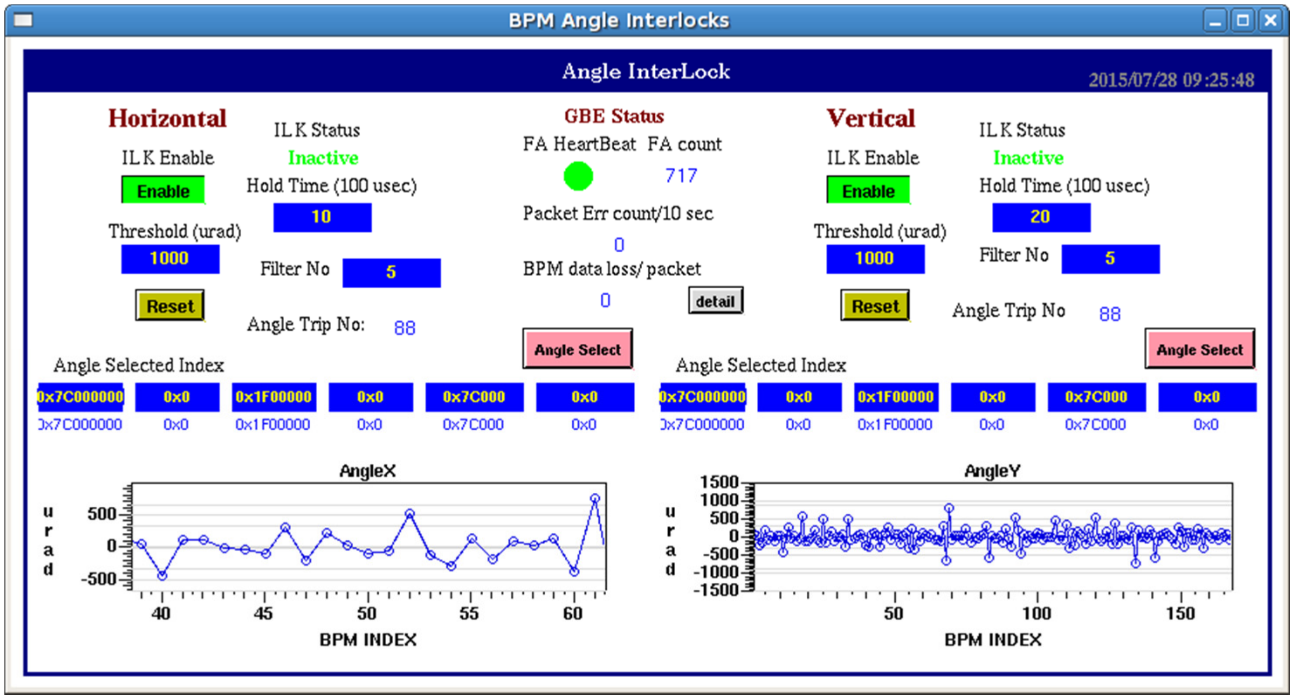


X: 0.344 mm (rms)
Y: 0.346 mm (rms)

Provided by C. C. Kuo

Interlock

- BPM 10 kHz data used for interlock including position and angle
- 7 long straight line (EPU & IU) required first
- Interlock activate condition under discussion
- Functionalities test 4th quarter 2015



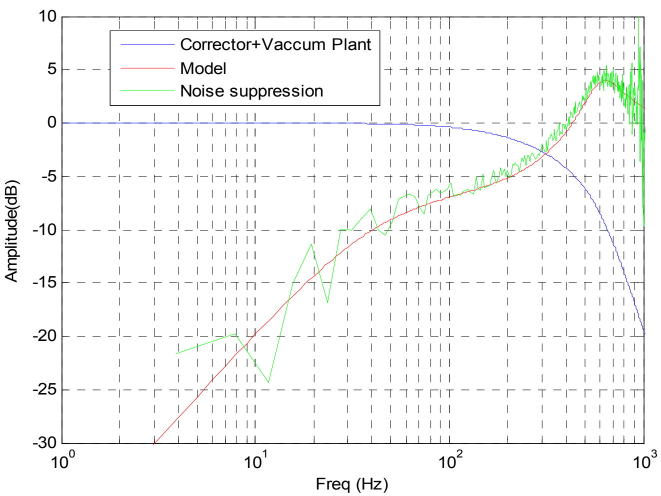
FEEDBACK SYSTEM

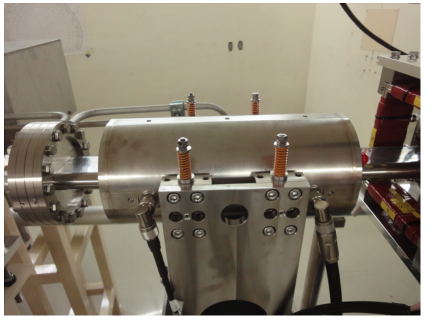
Feedbacks

Kind of Feedbacks	Status
SOFB	Apply during 4th quarter 2015 with ID commissioning Updating rate at 10Hz
FOFB	Fast corrector installed in June 2015 Firmware under modification and test Planned to operate in 2016
Bunch-by-bunch	Preliminary beam test at January 2015. Hor. and Ver. kickers installed in June 2015 Commissioning on 4th quarter 2015 .

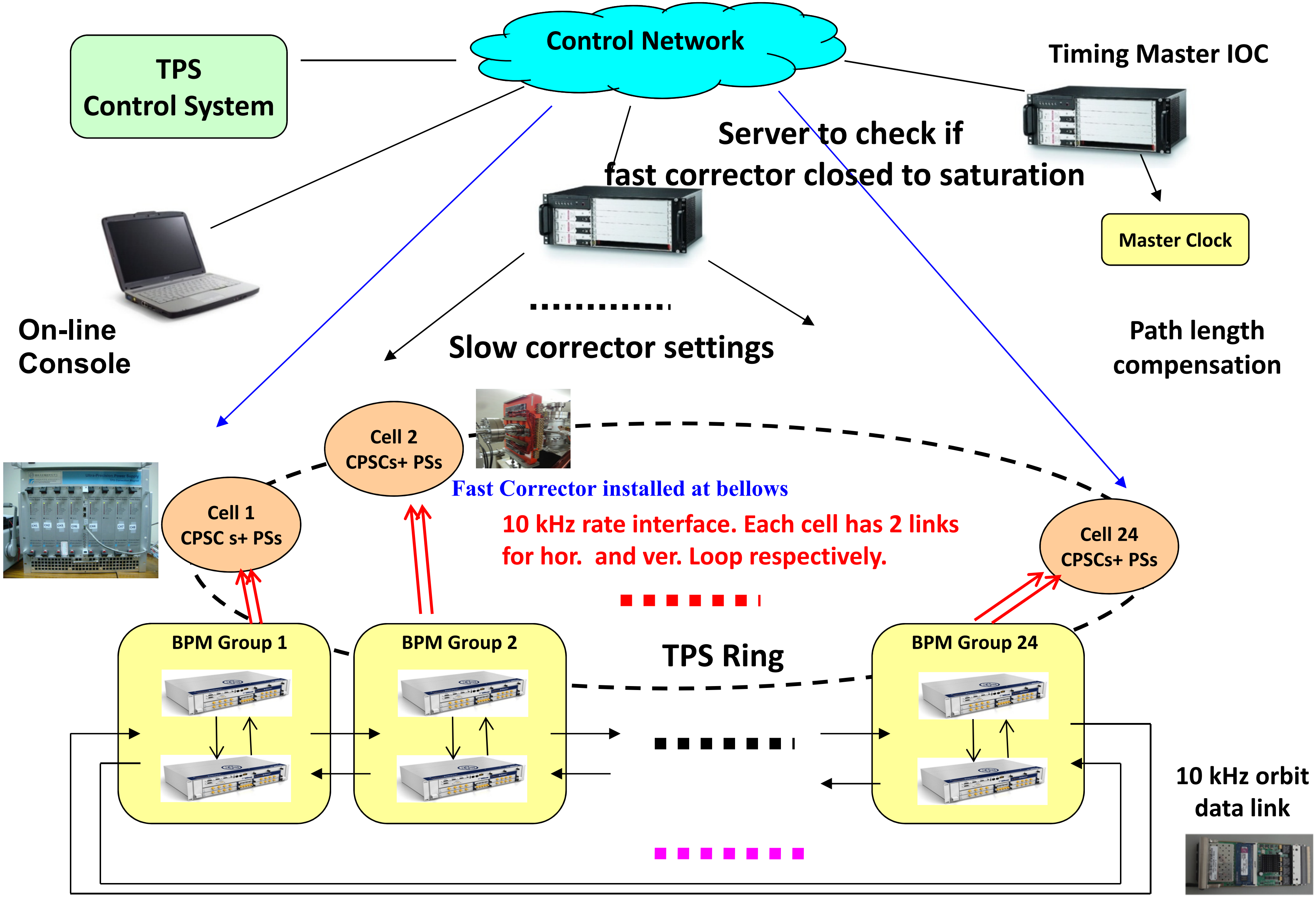
FOFB parameters:

- Corrector bandwidth ~ 300 Hz
- Vacuum Chamber bandwidth ~ 500 Hz
- Noise suppression bandwidth ~300 Hz.



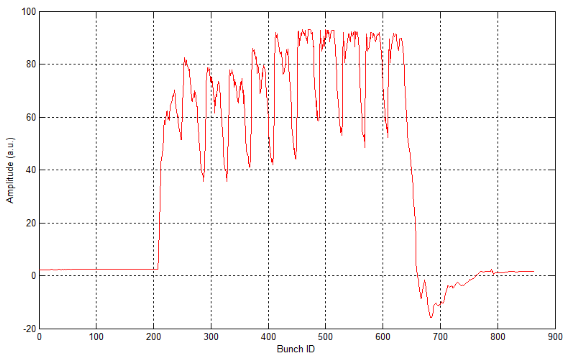


Infrastructure for FOFB

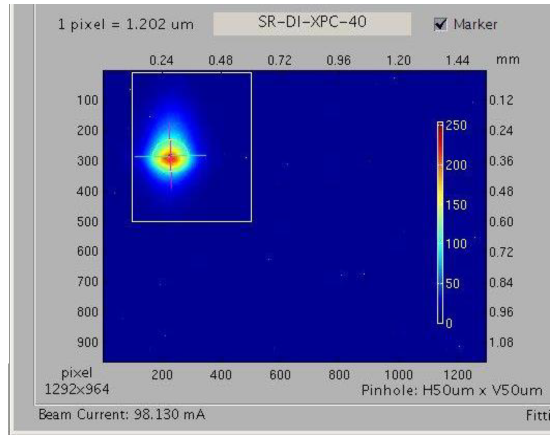


Prototype Bunch-by-Bunch Feedbacks

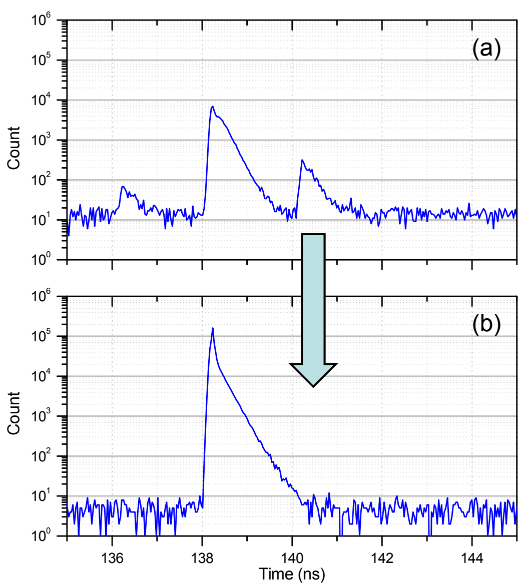
Filling Pattern



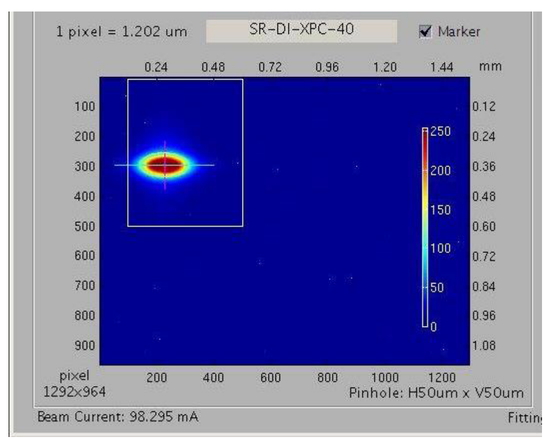
Feedback OFF



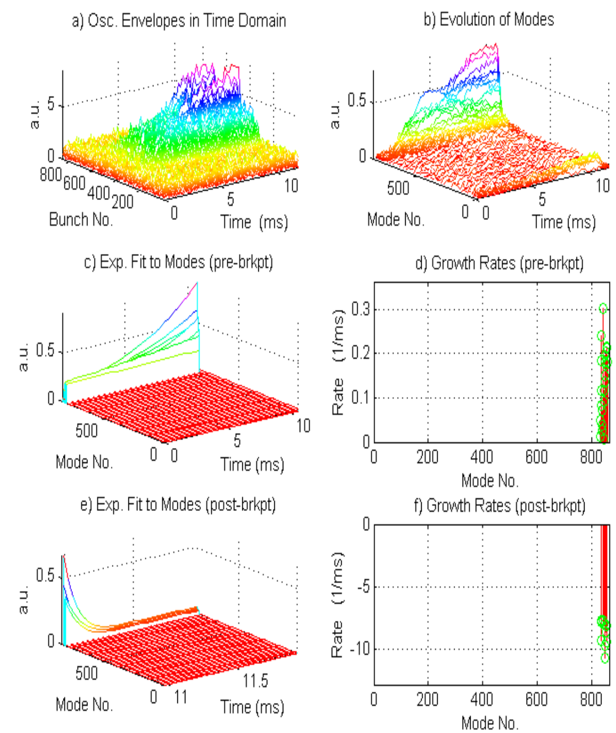
Bunch cleaning by feedback



Feedback ON



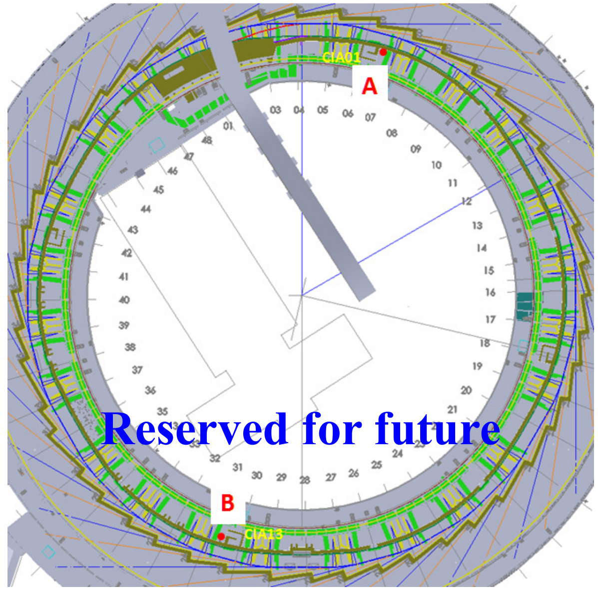
growth/damping experiment at 90 mA



SYNCHROTRON RADIATION MONITOR

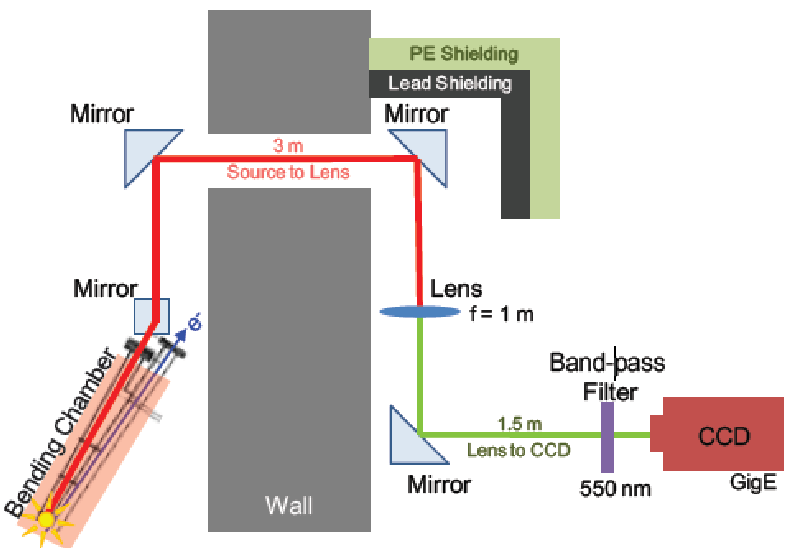
Layout of the Booster SRM Station

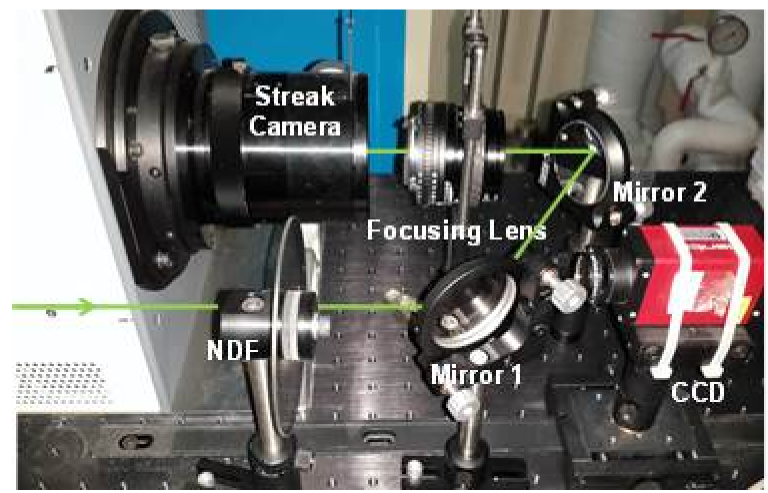
Energy (GeV)	0.150	3
ε_x (nm-rad)	167	9
ε_y (nm-rad)	167	1
σ_x (mm)	**0.7**	**0.15**
σ_y (mm)	**1.5**	**0.1**



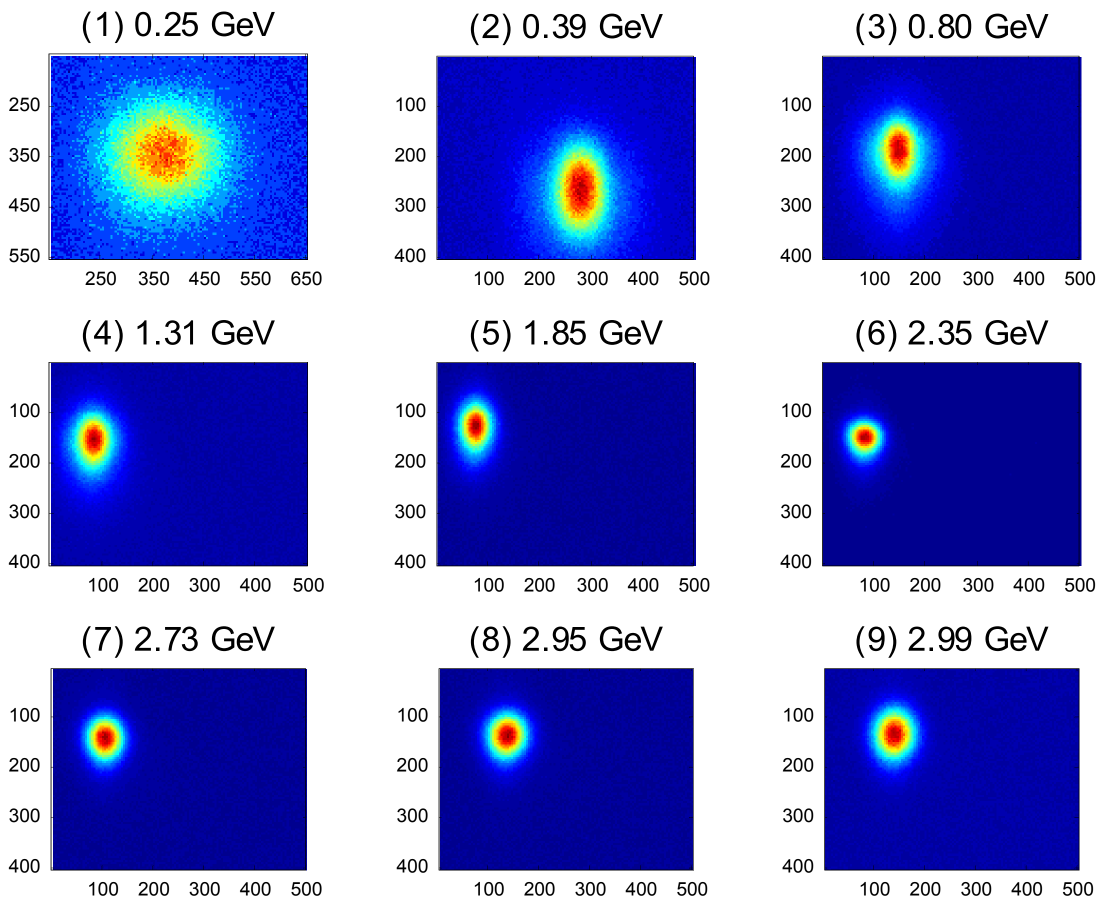
SRM port A:
Streak camera & CCD to measure visible light

Side-view of SRM port A

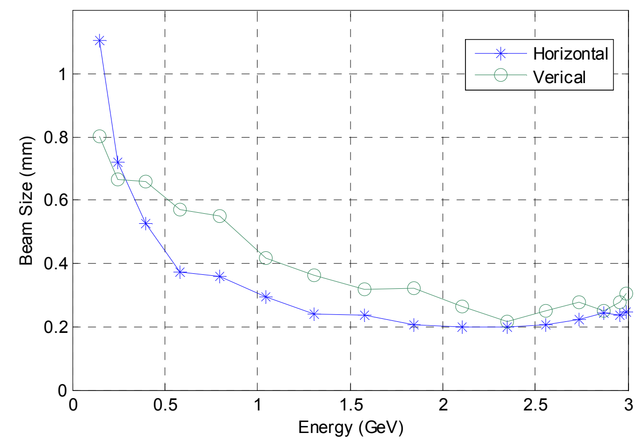




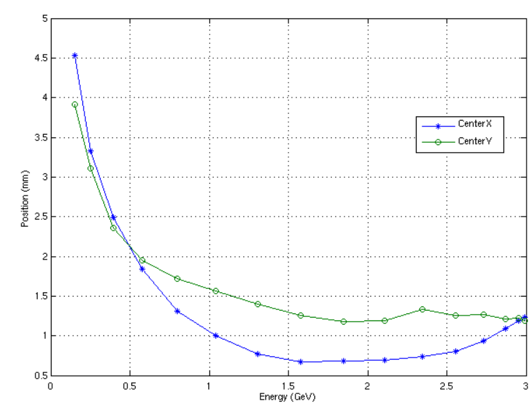
TPS booster synchrotron radiation profiles during energy ramping



Beam size change during ramping

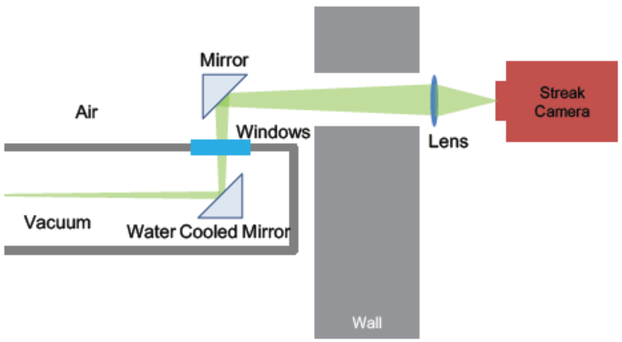


Beam position change during ramping



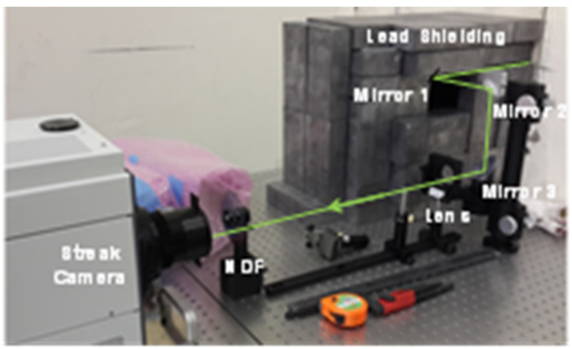
Layout of the Storage Ring SRM Station

Top view of streak camera

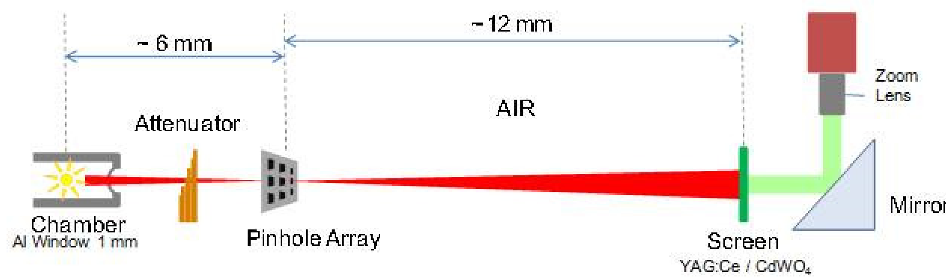


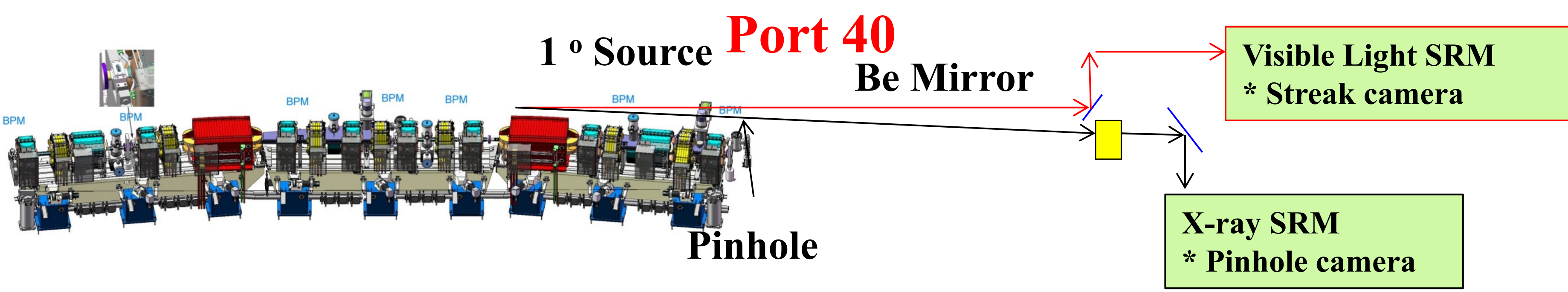
Beam size $\sigma_{x,y}$ and beam divergence $\sigma_{x',y'}$ for 1 % coupling. Natural horizontal emittance is 1.6 nm-rad.

Source point	σ_x (μm)	$\sigma_{x'}$ (μrad)	σ_y (μm)	$\sigma_{y'}$ (μrad)
Straight center	165.1	12.4	9.8	1.6
Long straight center	120.8	17.2	5.1	3.1
Dipole (1 degree source point)	39.7	76.1	15.8	1.1



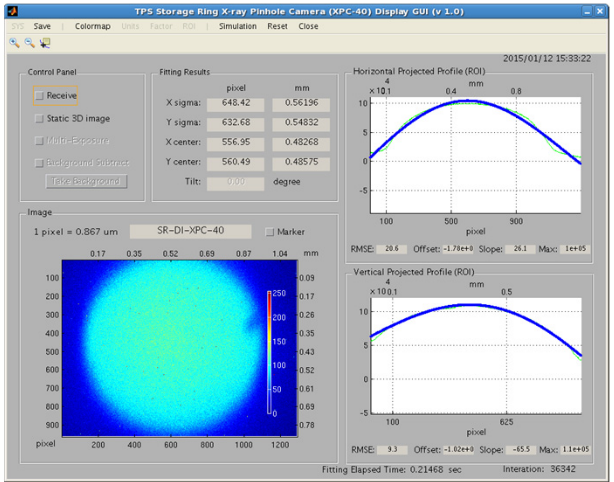
Side view of X-ray pinhole camera





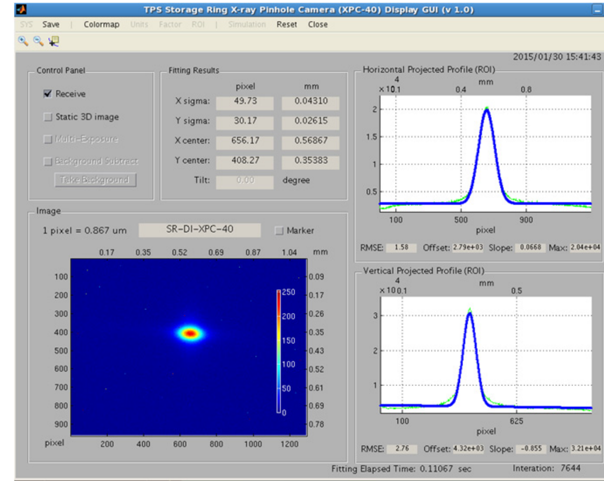
X-ray Pinhole Camera Test for SR

Beam size larger then expected

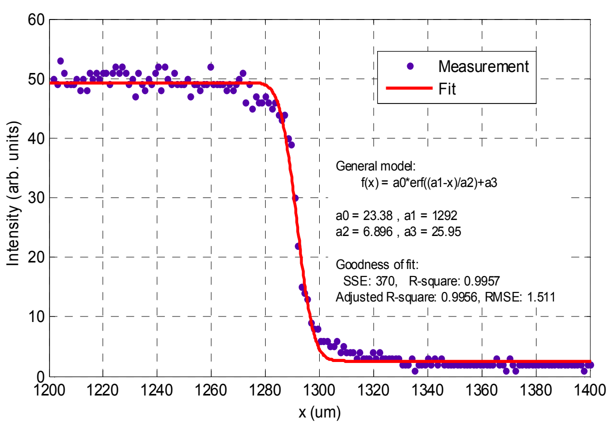


Found that the mirror was moved so that focal length changed

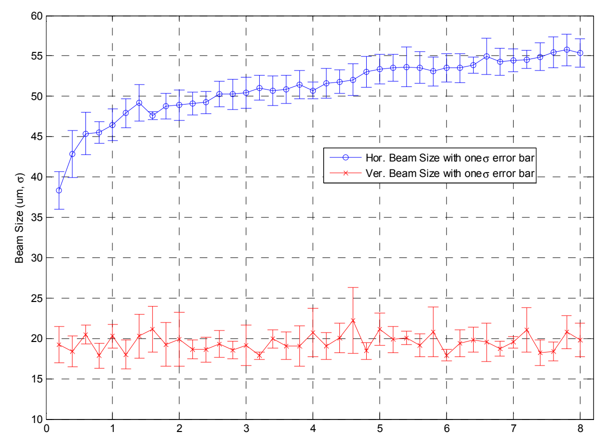
After focus adjustment



Resolution measure by knife edge test ~ 5 um



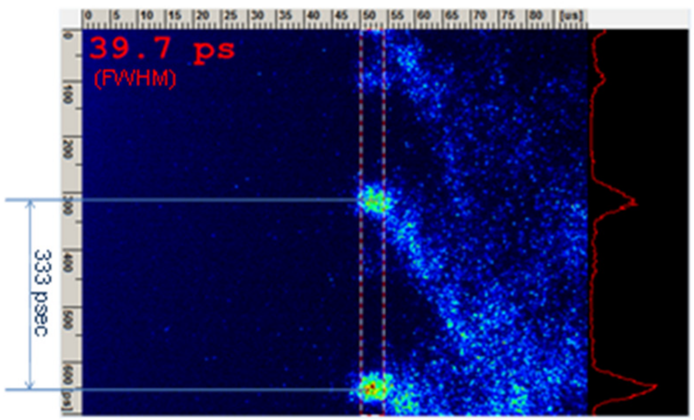
Beam size change as beam current increased



Booster Beam – Streak Camera Observation

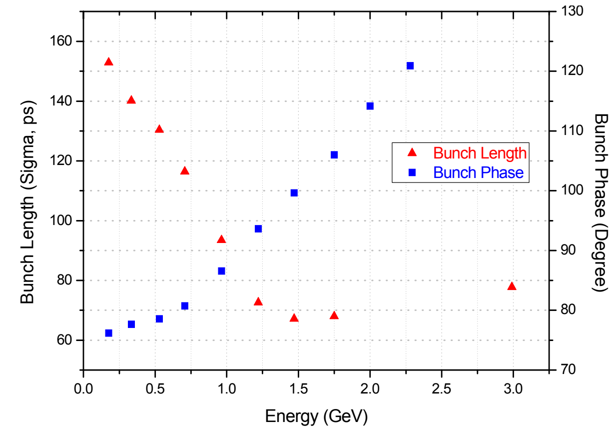
Before Linac optimization, side bunches (3 GHz) were observed. They would merge for synchrotron motion.

100 us

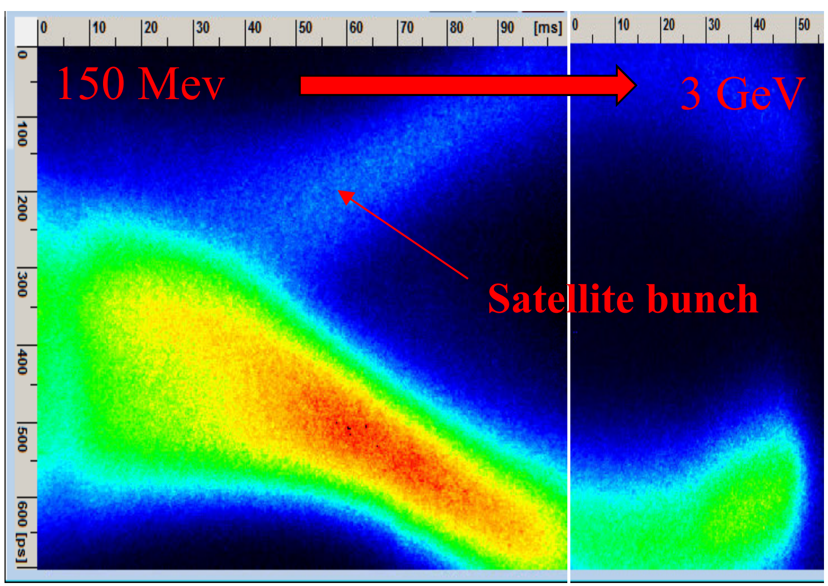


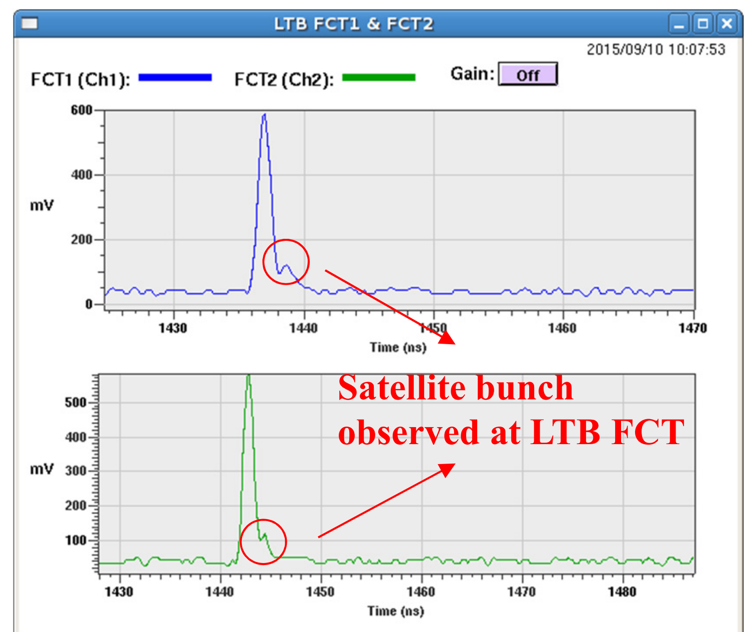
Single Bunch Mode

Bunch length and phase variation during the energy ramping process. Bunch length changes around 85 psec, bunch phase change around 45 degree.



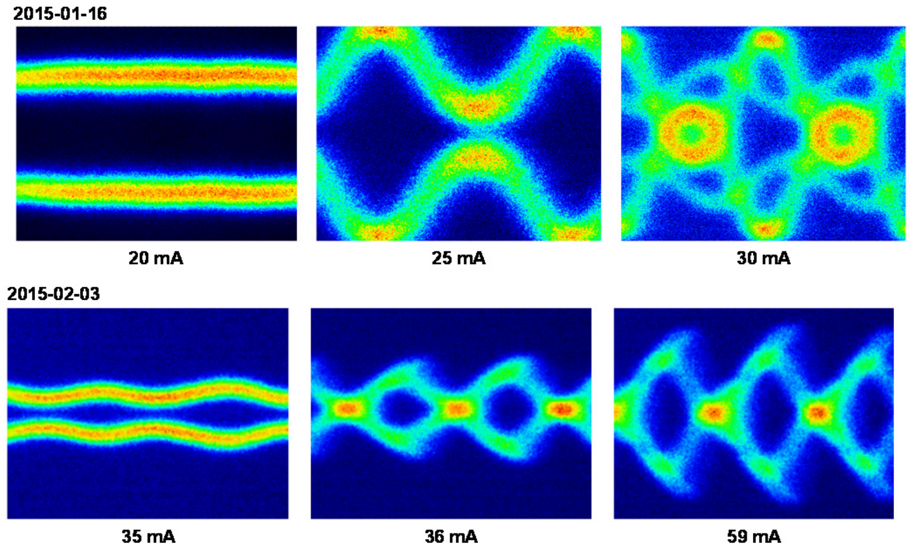
700 ps



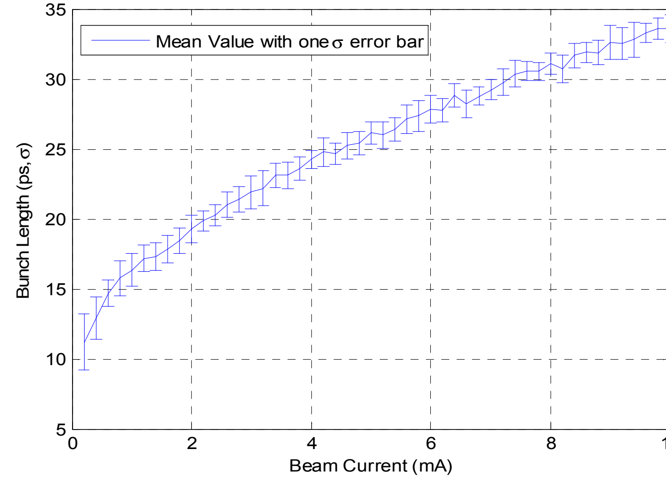


Storage Ring - Streak Camera Observation

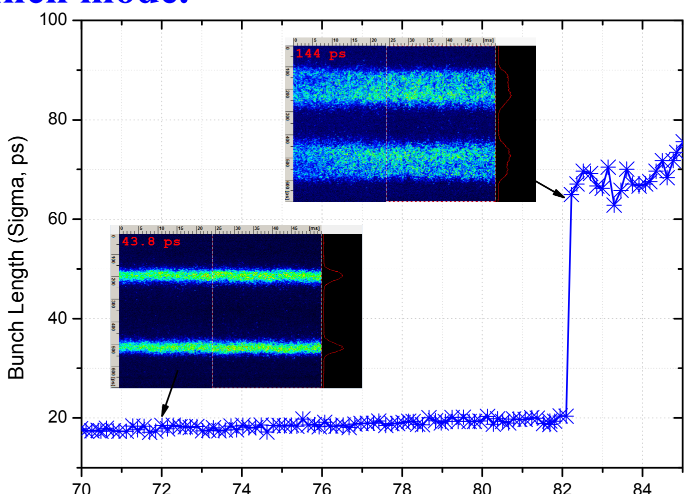
Longitudinal instability before RF problem of amplitude loop found.



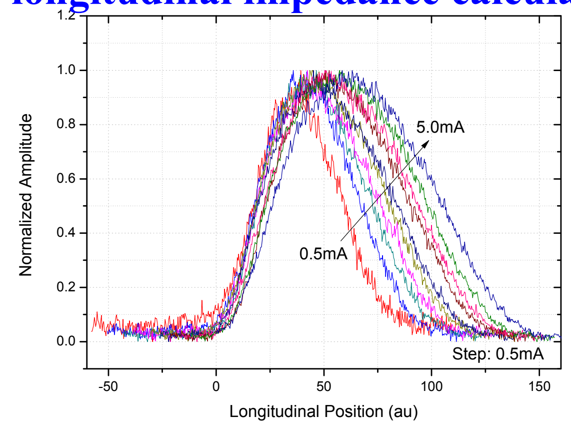
Bunch length as function of bunch current



Longitudinal instability happened ~82 mA in multi bunch mode.



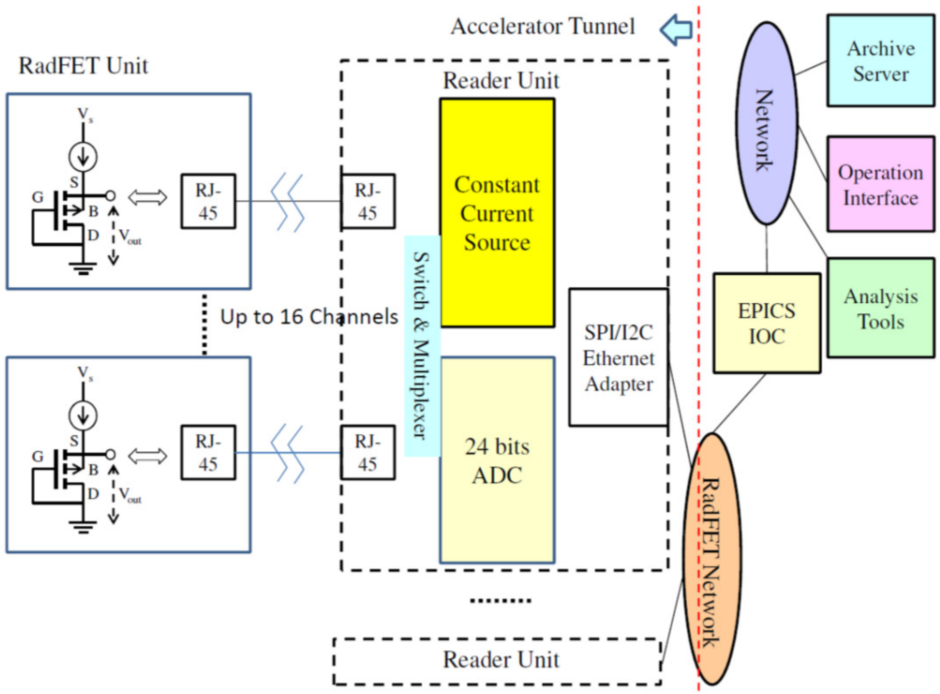
Single bunch profile distortion for longitudinal impedance calculation.



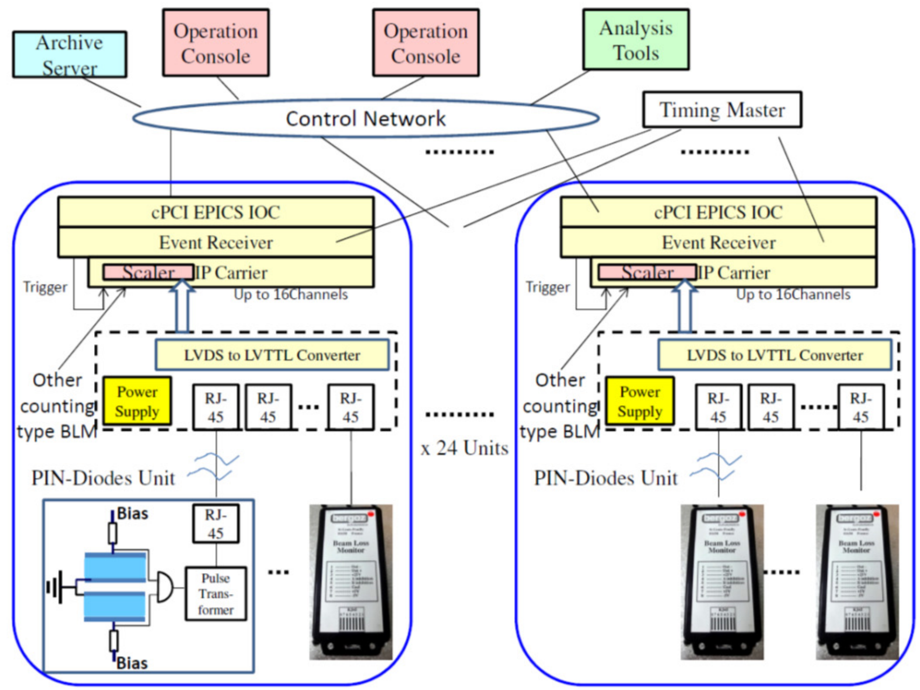
BEAM LOSS MONITOR

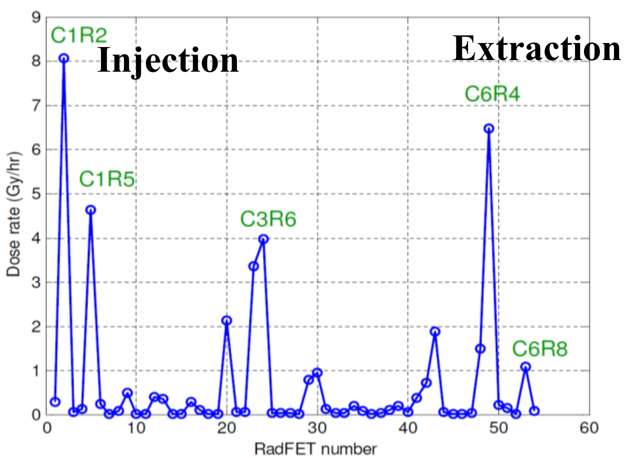
Beam Loss Monitor (BLM)

Configuration of RadFET BLM system



Configuration of dual PIN-diode BLM system





Beam loss pattern of booster ring.

Summary

Work in progress

1. Phase II commissioning with SRF before delivery to users.
2. Final check of the interlock functionalities.
3. Prepare for bunch by bunch feedback system
4. Slow orbit feedback would be first provided this 4th quarter.
5. System integration test and firmware debug of the fast orbit feedbacks continues.

Summary

1. Diagnostics helps to improve subsystem, optimize machine and accelerate TPS commissioning.
2. Further modification and expansion continues during Phase II commissioning.

Acknowledgement

Many helps direct or indirect from diagnostics communities. IBIC2015 is the best occasion to express our deepest appreciations to You.

Especially help from
Jean-Claude Denard, Gunter Rhem (DLS), Ubaldo Iriso (ALBA), T. Nakamura (SPring-8), Bob Hettel (SLAC), …

Help from NSRRC machine groups is a key to success!