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Introduction of the Beam Position Monitor System in HLS II Storage Ring and Application Researches

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  - Tune measurement
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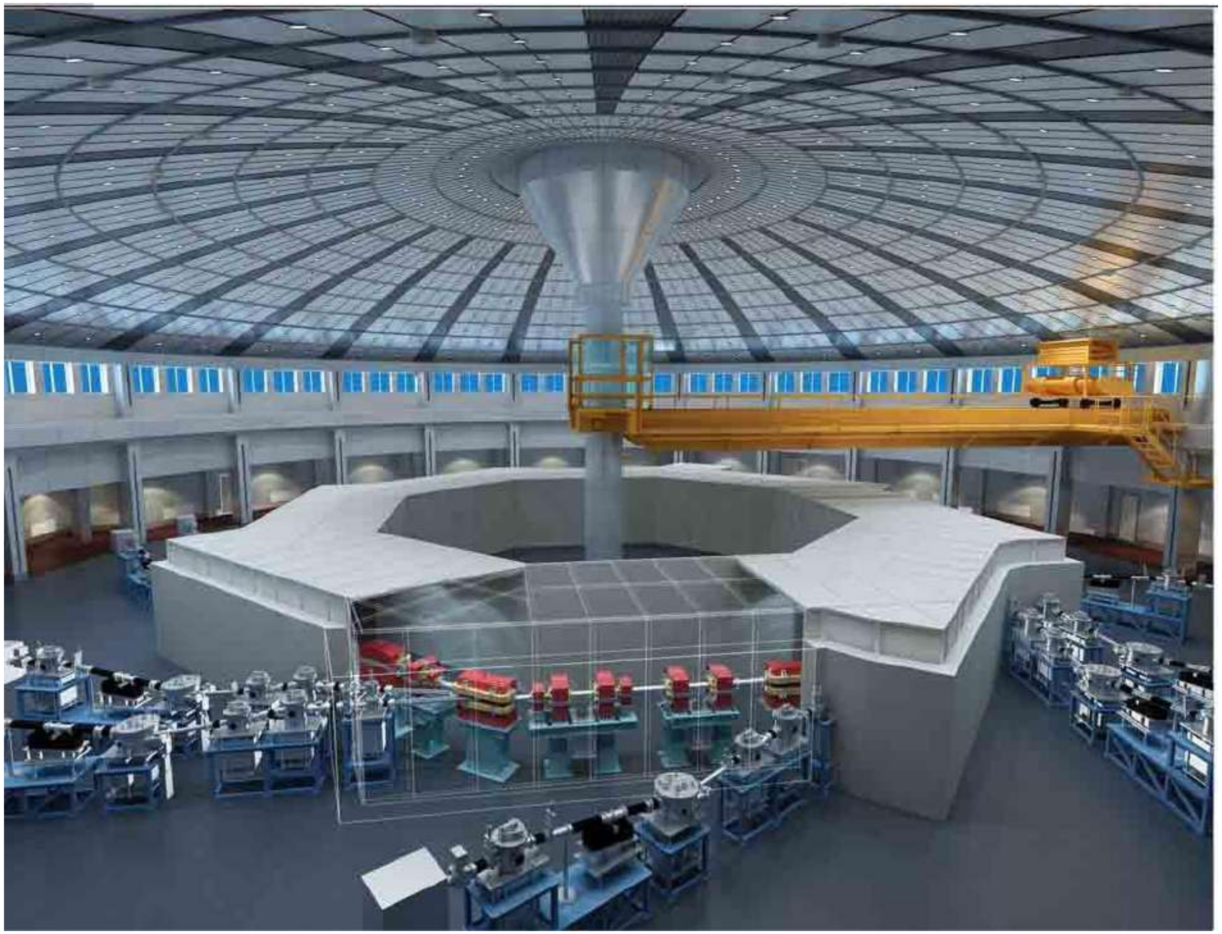
- **Summary**

HLS II updated project

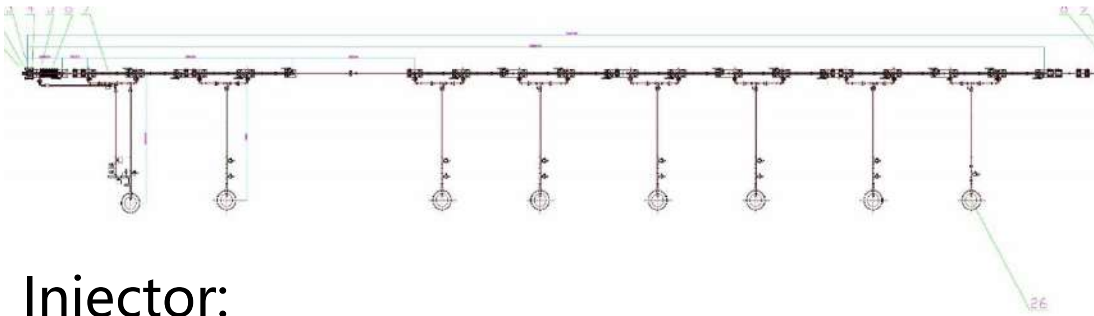
- Project schedule:
  2010.8-2014.12

- Investment:
  189.78 million yuan

- Main target:
  - Full energy injection with 800 MeV
  - Emittance of the storage ring: <40nm·rad
  - 6 inserts installed in eight straight line.



HLS II structure



- Injector:
  - Consisted of LNAC and beam transport line
  - Accelerated structure : gradient acceleration
  - Injection energy: 800 MeV

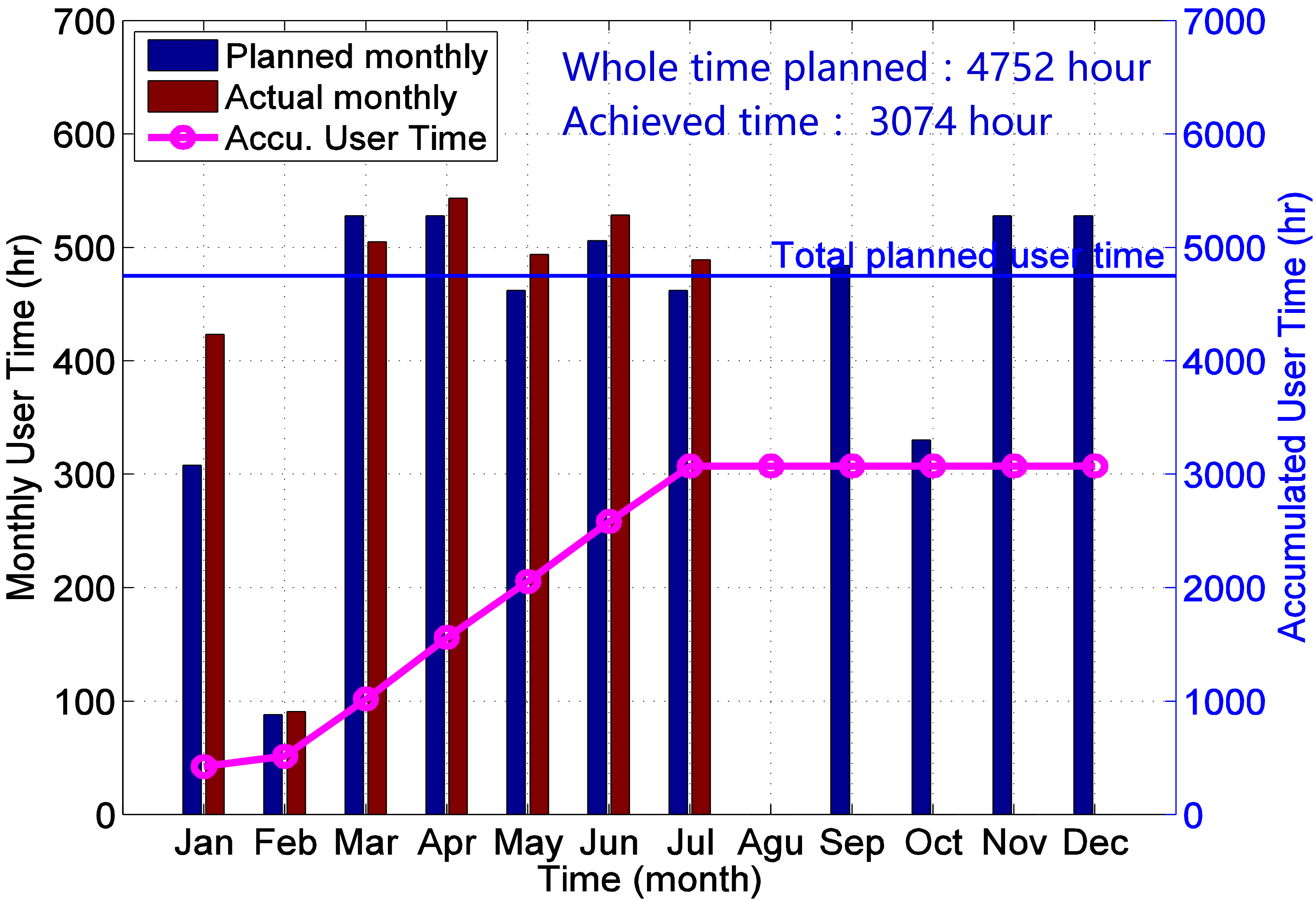
- Storage ring:
  - Beam energy: 800 MeV
  - Emittance: 38nm·rad
  - 8 straight line with 5 inserts

Operation situation

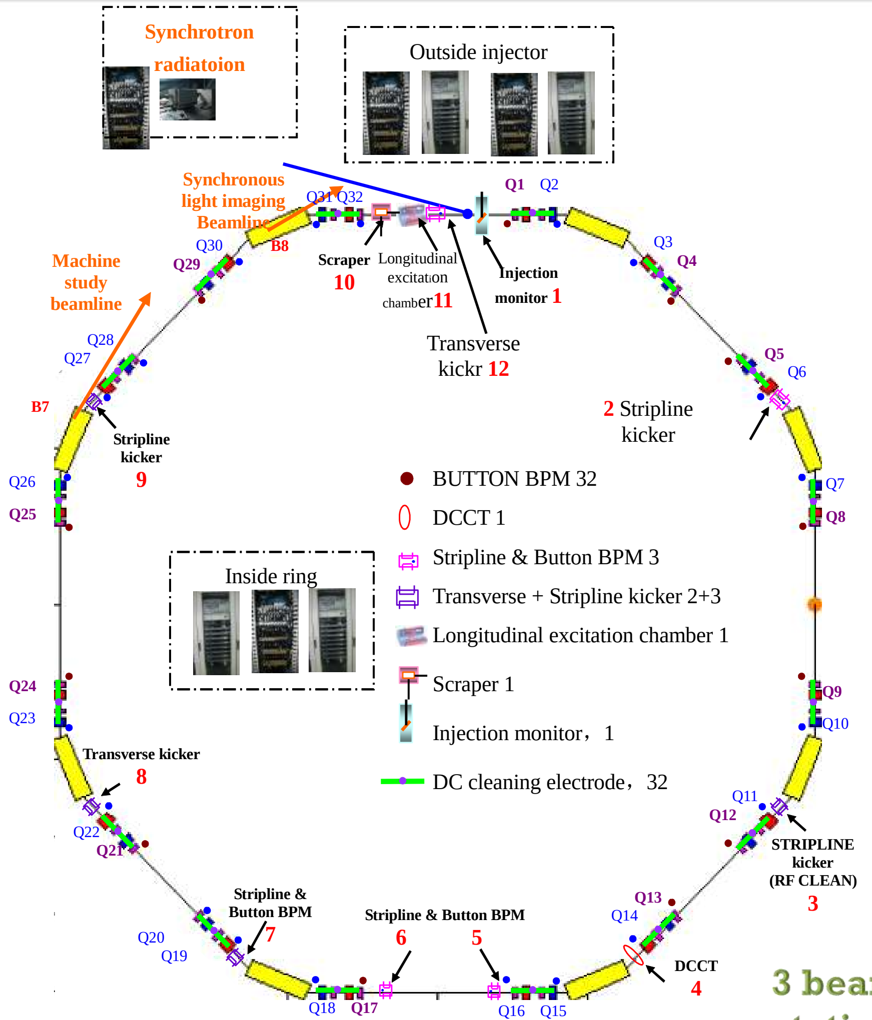
- Operation time: 9.1.2015-7.31.2016
- Operation mode: Continuous Operation with stages
- Beam Current: (300-360mA) Attenuation mode

	Total Operation time	Time distribution				
		Running time	Machine research	Injection adjustment	Routine maintenance	Debug
Planned time (hour)	4248	2882	840	262	264	<212
Actual time (hour)	4274.55	3074.13	853.4	123.86	192.92	30.53
percentage		71.91	19.96	2.90	4.51	0.71

Accumulation time of offering light



Beam diagnostic system of the storage ring



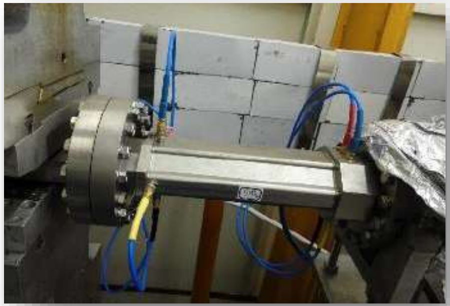
Layout of the storage ring

Subsystems

- Beam position measurement
- Beam orbit measurement
- Beam current measurement
- Tune measurement
- Synchrotron radiation parameters measurement
- Digital Bunch-by-Bunch feedback system
- Injection monitor
- Beam loss monitor

3 beam diagnostic stations

FCT

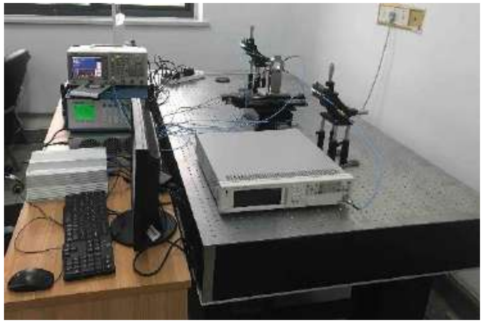


Stripline BPM

Button BPM

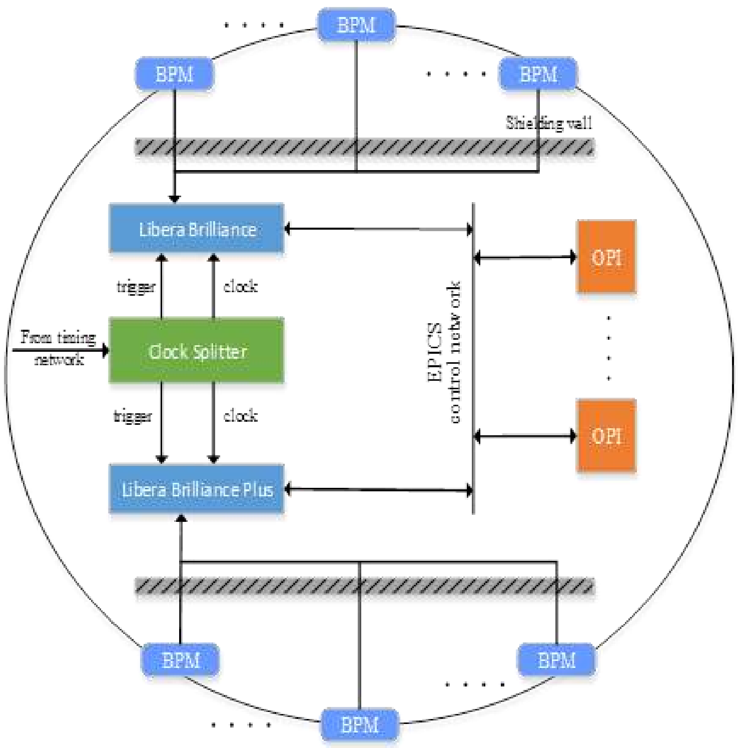
Diagnostic station

Libera Brillianceplus



BPM offline calibration platform

BPM system



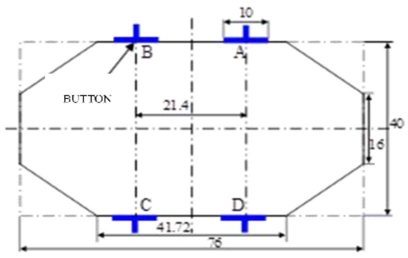
BPM system structure for the HLS II electron storage ring.

IOC embedded in BPM processor is used for platform management and algorithms application and it supports EPICS protocol.

The main functions and performance of the BPM system :

1. Beam closed orbit measurement: resolution 1μm;
2. First Turn beam position measurement: resolution 50μm;
3. Turn-by-turn position measurement: resolution 15μm;
4. Storage ring closed track correction and feedback: closed-circuit stability to 10% of the beam spot size;
5. Beam Based Alignment (BBA): technology for quadrupole magnetic center measurement, to find the optimal reference orbit.

Button BPM



(a) Schematic diagram

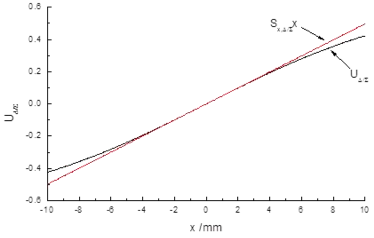
(b) Electrode assembly

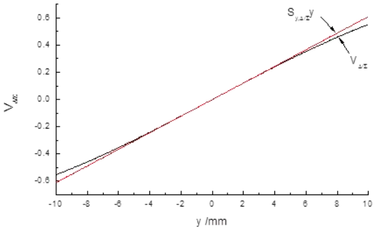
Button BPM of the HLS II storage ring.

parameters	values/mm
Button diameter	10
Button thickness	2
Gap between button and chamber	0.3

The transverse normalized electronic position signal of the beam is denoted as (U, V), corresponding to the horizontal and vertical directions:

$$U_{\Delta/\Sigma}=\frac{(Q_A+Q_D)-(Q_B+Q_C)}{(Q_A+Q_B+Q_C+Q_D)},\quad V_{\Delta/\Sigma}=\frac{(Q_A+Q_B)-(Q_C+Q_D)}{(Q_A+Q_B+Q_C+Q_D)}$$

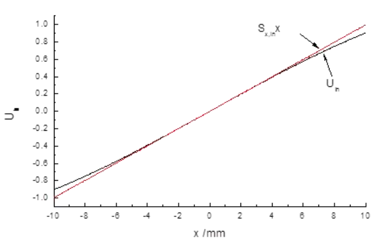


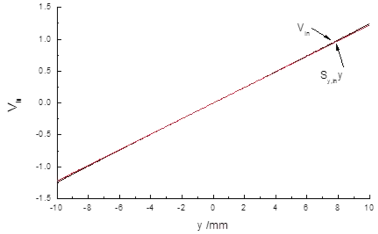


Sx=0.0498 mm^{-1}, linear deviation 5% at x=5.45 mm

Sy=0.061 mm^{-1}, linear deviation 5% at y=7.2 mm

$$U_{\ln}=\ln\frac{(Q_A+Q_D)}{(Q_B+Q_C)},\quad V_{\ln}=\ln\frac{(Q_A+Q_B)}{(Q_C+Q_D)}$$

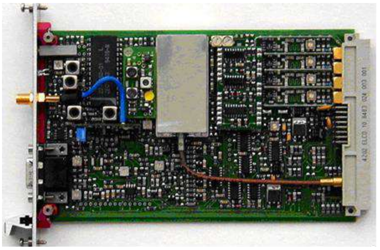




Sx=0.0996 mm^{-1}, linear deviation 5% at x=7.25 mm

Sy=0.1222 mm^{-1}, linear deviation 1.8% at y=10 mm

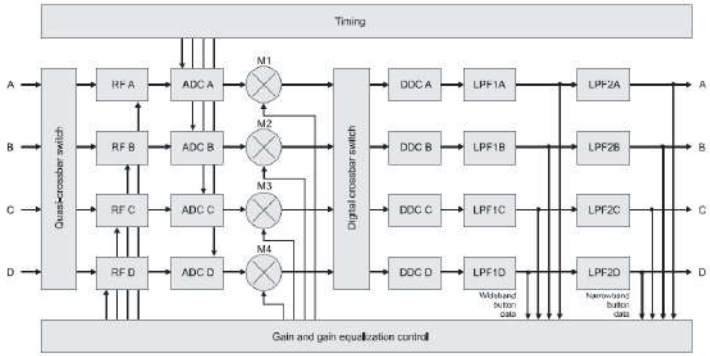
BPM processor



Bergoz MX-BPM Analog Electronics

Libera Brilliance

Libera Brillianceplus



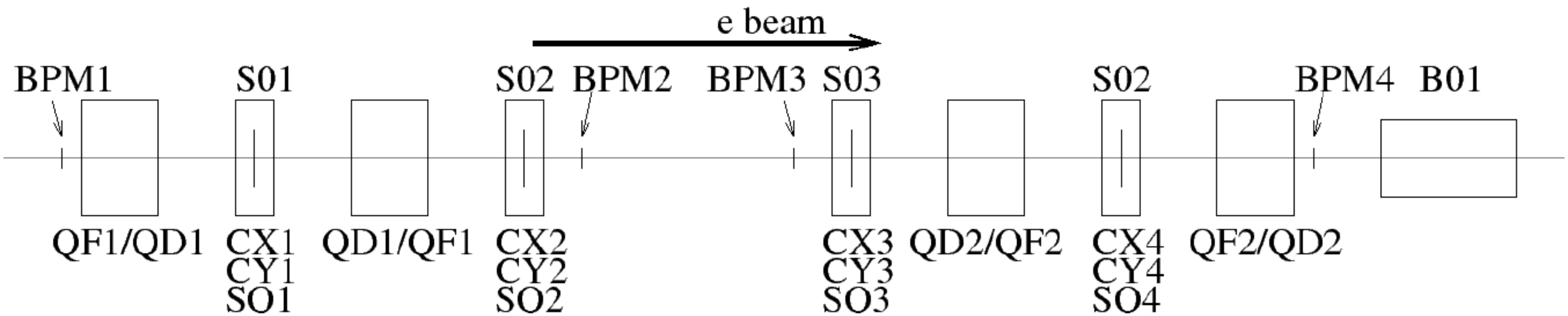
Architecture of Libera Brillianceplus.

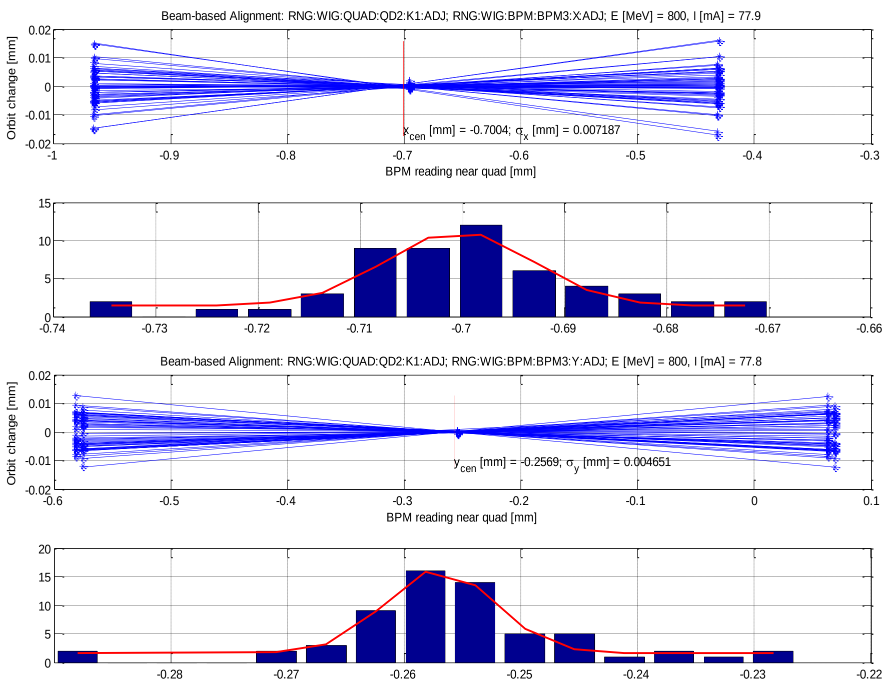
Four modules in one machine, better optimization algorithm.

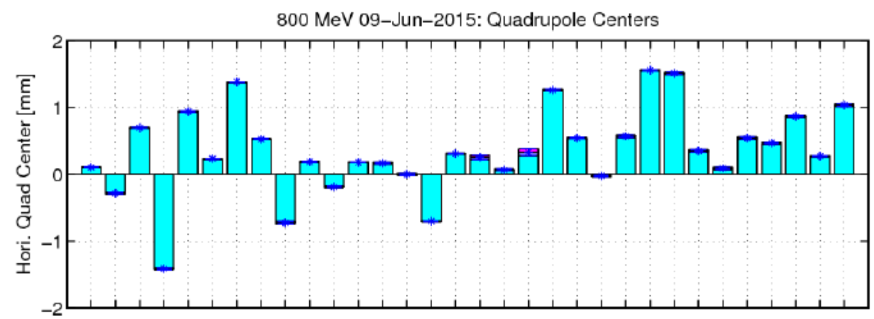
DATA MODES: ADC, TBT, FA, SA.

Interface of the BPM control system and OPI for one module of the Libera Brillianceplus coded by edm.

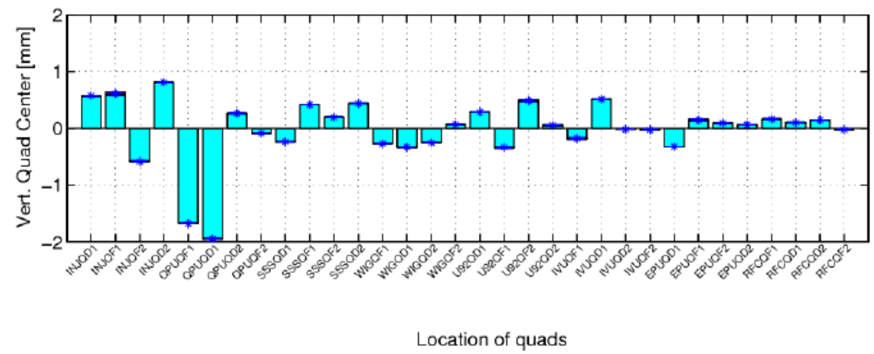
Beam based alignment



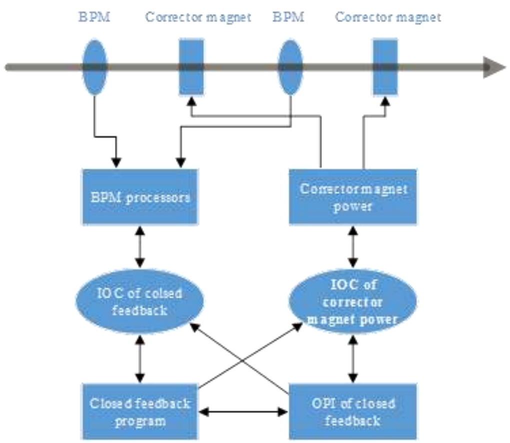




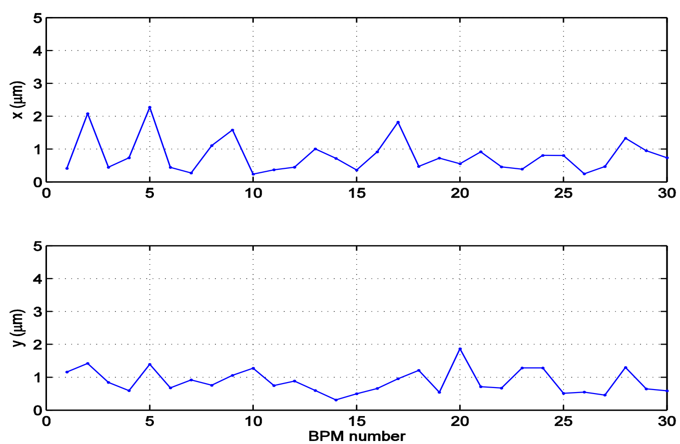
BPM center compared to Quadrupole center: [-2mm , 2mm]



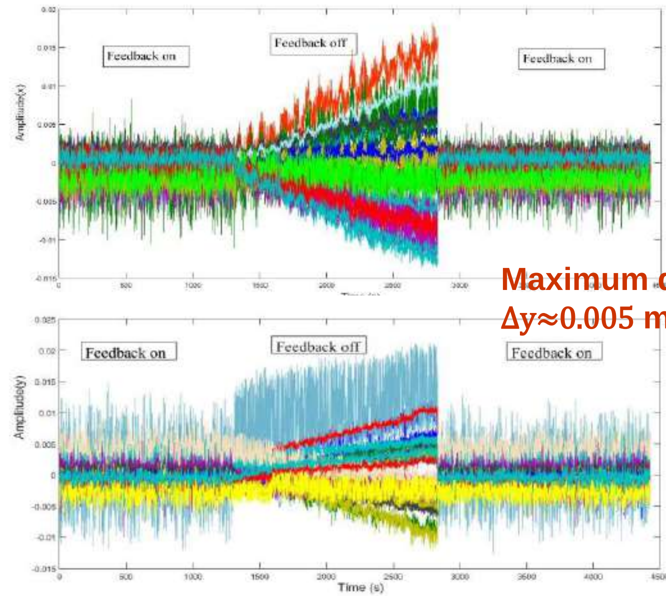
Beam closed orbit feedback system



System diagram of the Closed orbit feedback for the HLS II storage ring.



Beam closed orbit at each BPM when closed orbit feedback is on

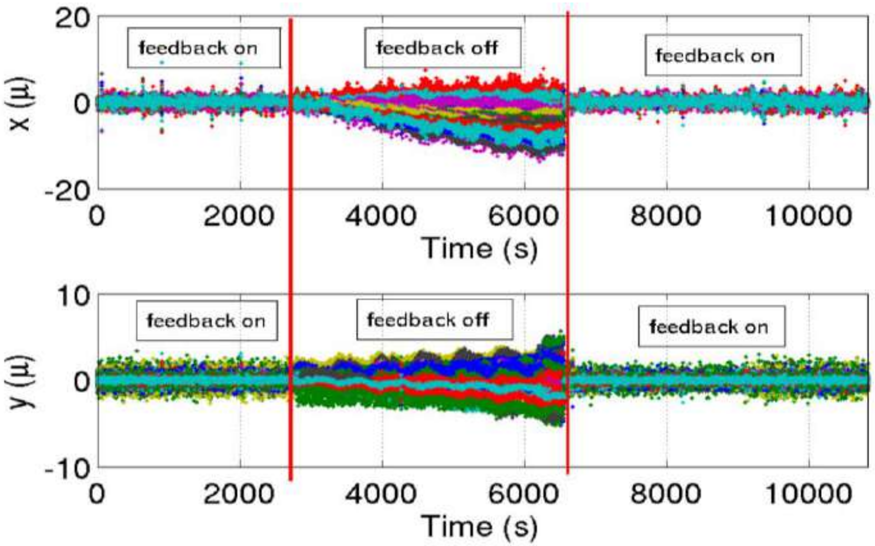


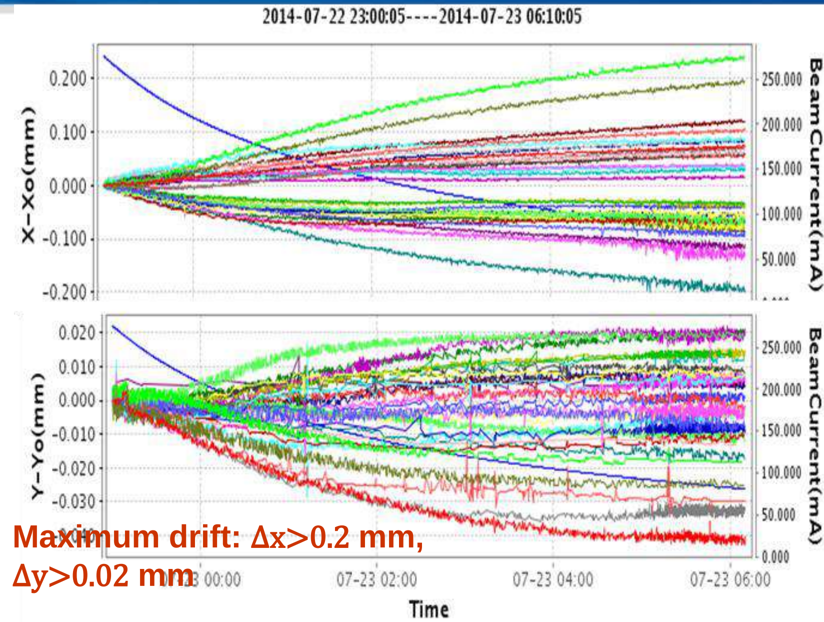
Maximum drift: Δx≈0.02 mm, Δy≈0.005 mm

Beam orbit stability when the closed orbit feedback system is on and off.

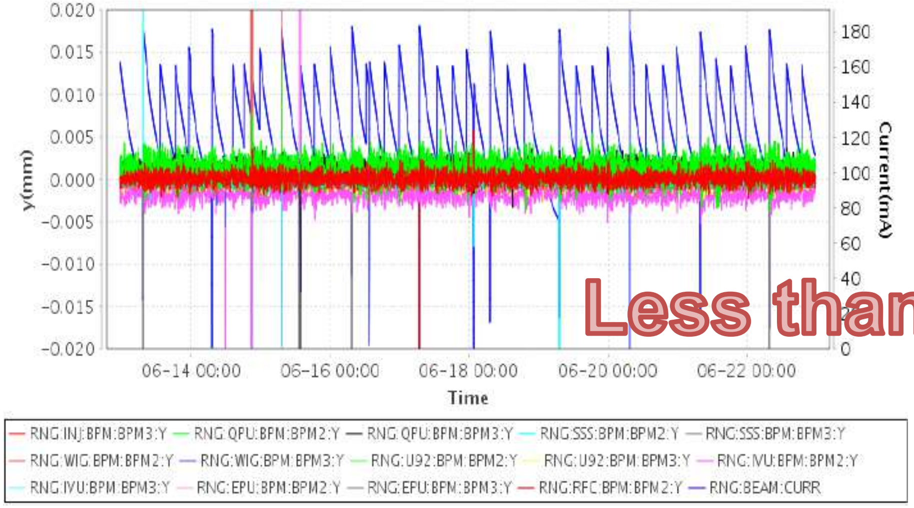
Closed orbit feedback is an effective way to obtain high beam orbit stability which can meet the needs of user experiments.

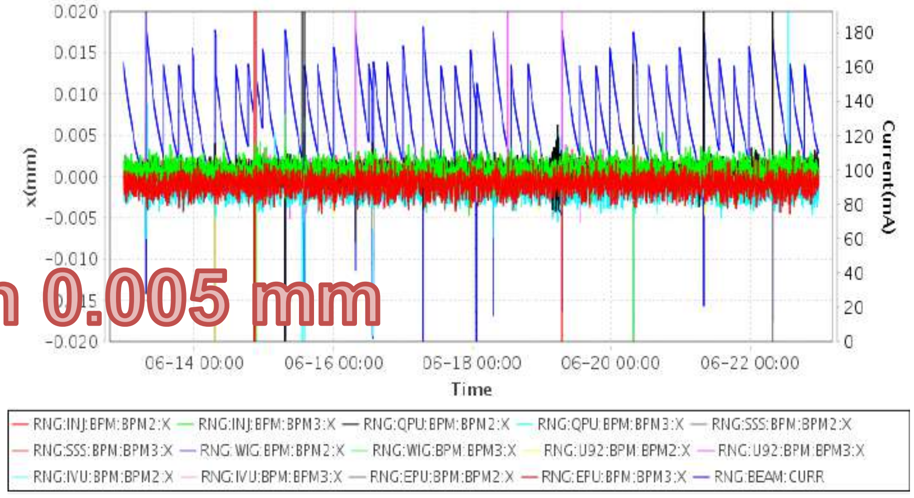
Closed orbit feedback stability





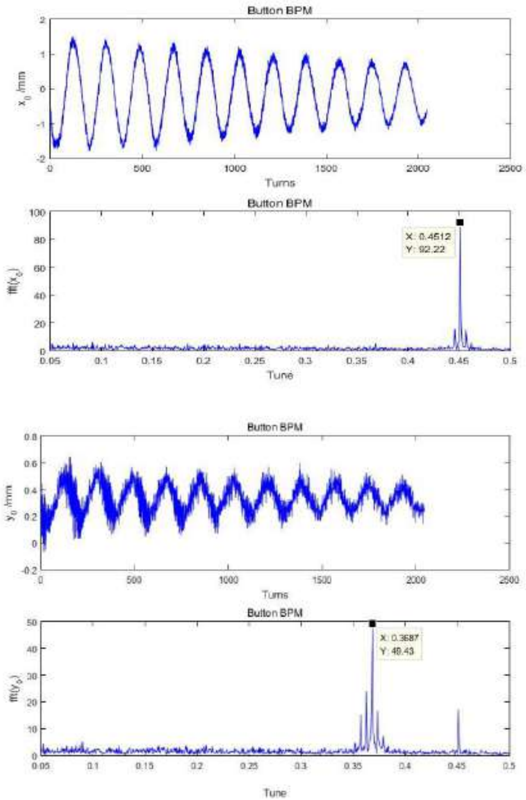
Maximum drift: Δx>0.2 mm, Δy>0.02 mm





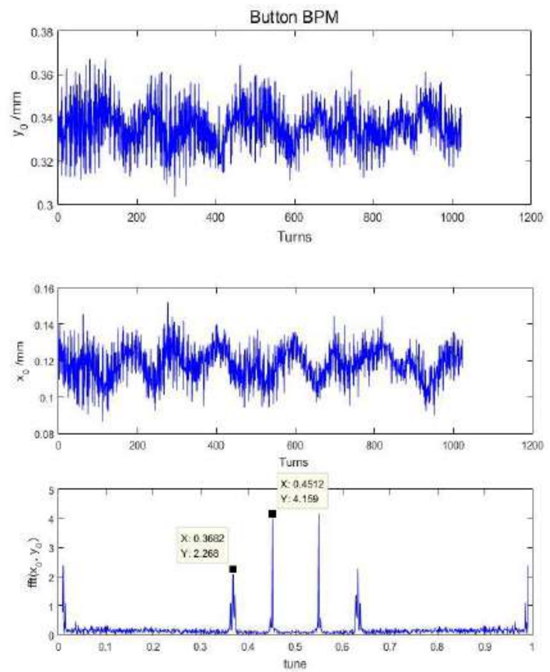
Less than 0.005 mm

Tune measurement (1)



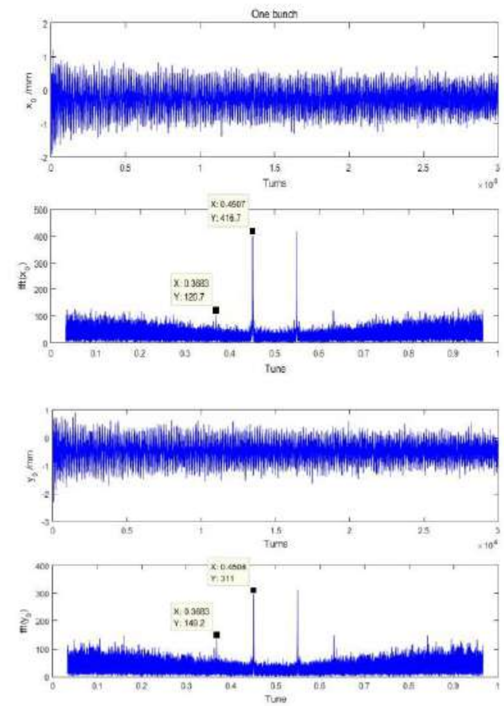
Tune measurement by FFT.

υ_x= 0.4512; υ_y=0.3687.



Tune measurement by interpolated FFT.

υ_x= 0.4512; υ_y=0.3682.

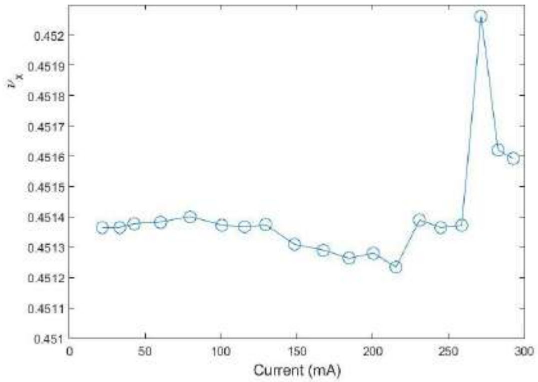


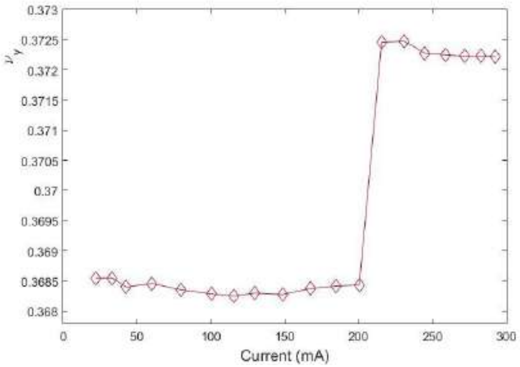
Tune measurement by interpolated FFT of one bunch.

υ_x= 0.4505; υ_y=0.3683.

Tune measurement (2)

When beam is injected into the storage and bunch-by-bunch feedback system is closed, beam itself is unstable, we can obtain the tune directly by analyzing the beam position data sampled by Libera Brilliancepluse without additional excitation .



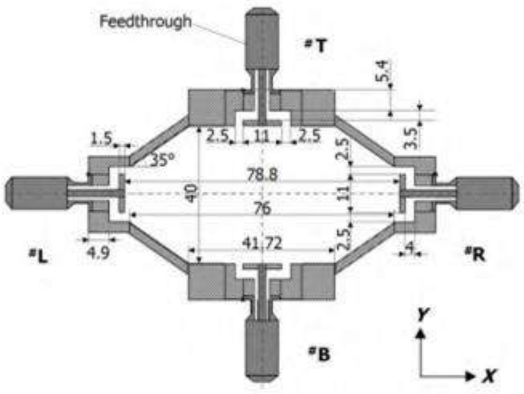


Tune x and tune y change with the injection beam current.

$\Delta\upsilon_x = 0.041$, $\Delta\,\upsilon_y = 0.052$

The tunes of x and y have a drift during the injection. Generally, it requires that the drift range must avoid the resonance line at least below third order, otherwise it will cause the beam oscillation and affect beam stability.

Offline measurement of the electrode gains



The cross-section of the stripline BPM .

WHY WE NEED TO MEASURE ELECTRODE GAINS ?

The response to the beam will vary among the four electrodes due to differences in electronic gain and misalignment. This variation in the response of the BPM electrodes will couple real horizontal offset to apparent vertical position, and introduce spurious measurements of coupling and vertical dispersion. To alleviate this systematic effect, a beam based technique to measure the relative response of the four electrodes has been developed to calibrate the gain.

D. L. Rubin, *et al*, *Beam based measurement of beam position monitor electrode gains.*

The quadrupole component for axially symmetric stripline BPM with difference/sum method:

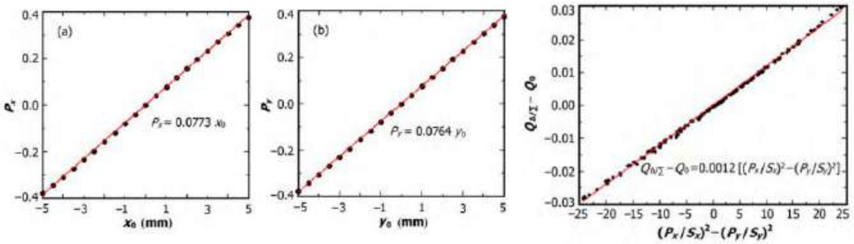
$$Q_{\Delta/\Sigma} - Q_0 = S_Q\left[\left(\frac{P_x}{S_x}\right)^2 - \left(\frac{P_y}{S_y}\right)^2 + \sigma_x^2 - \sigma_y^2\right]$$

Q_0: Non-zero component. Because the horizontal electrodes' distance differs from vertical electrodes'.

The electrical position (Px , Py) :

Tungsten wire: $\sigma_x = \sigma_y = 0.2$ mm

$$P_x = (V_R - V_L)/(V_R + V_L) = S_x x_0,$$
$$P_y = (V_T - V_B)/(V_T + V_B) = S_y y_0.$$

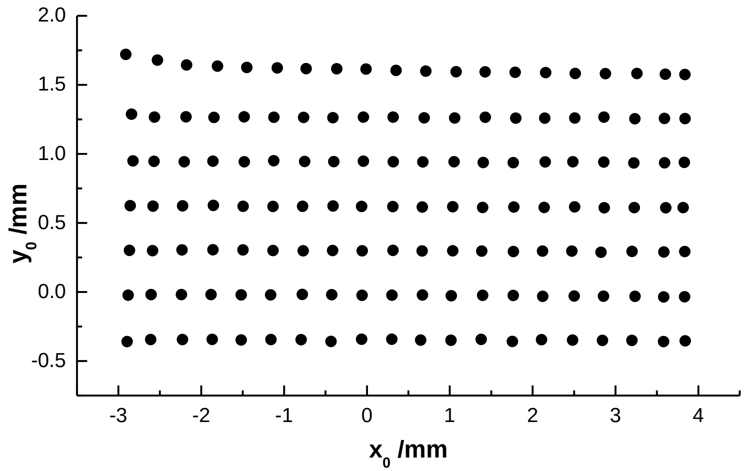


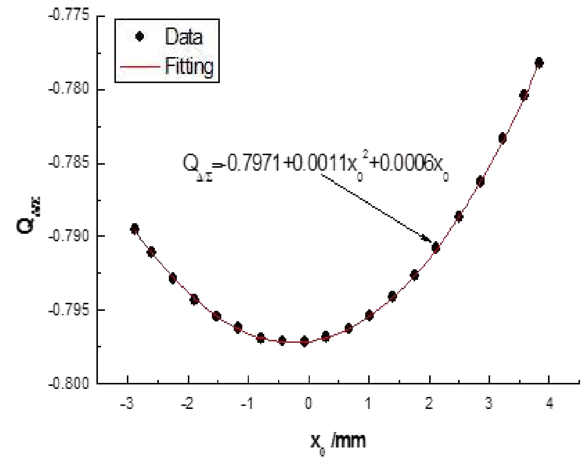
S_x=0.0773 mm^{-1}, S_y=0.0764 mm^{-1} , S_Q =0.0012mm^{-2}

Merit function to be minimized:

$$\chi^2 = \sum_{i=1}^{n}\left[\left(\frac{g_R V_R^i + g_L V_L^i - g_T V_T^i - g_B V_B^i}{g_R V_R^i + g_L V_L^i + g_T V_T^i + g_B V_B^i} - Q_0\right) - c\cdot S_Q \cdot \left[\left(\frac{1}{S_{x\,\Delta/\Sigma}}\frac{g_R V_R^i - g_L V_L^i}{g_R V_R^i + g_L V_L^i}\right)^2 - \left(\frac{1}{S_{y\,\Delta/\Sigma}}\frac{g_T V_T^i - g_B V_B^i}{g_T V_T^i + g_B V_B^i}\right)^2\right]\right]$$

Online measurement of the electrode gains





Relationship between $Q_{\Delta/\Sigma}$ and x_0 when beam was moved on the horizontal center axis

Local bump method can be used to move beam in a grid of a certain range in the stripline BPM and four electrode induced signals at each grid point are obtained. When beam current was 25 mA, Beam positions in the stripline BPM (HLS II SR-BD-STLB1) produced with local bump.

According to the fitting relationship:

$$Q_0 = -0.7971 - S_Q\left(\sigma_x^2 - \sigma_y^2\right) = -0.7979$$

(σ_x, σ_y): (0.827mm, 0.036mm)

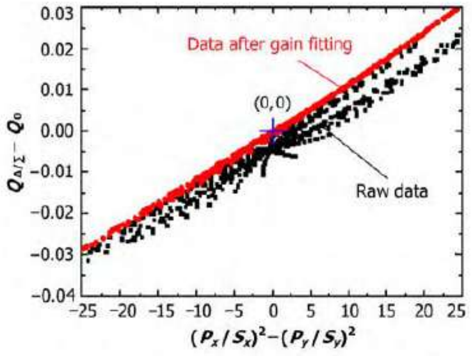
Merit function to be minimized:

$$\chi^2 = \sum_{i=1}^{n}\left[\left(\frac{g_R V_R^i + g_L V_L^i - g_T V_T^i - g_B V_B^i}{g_R V_R^i + g_L V_L^i + g_T V_T^i + g_B V_B^i} - Q_0\right) - c\cdot S_Q \cdot \left[\left(\frac{1}{S_{x\,\Delta/\Sigma}}\frac{g_R V_R^i - g_L V_L^i}{g_R V_R^i + g_L V_L^i}\right)^2 - \left(\frac{1}{S_{y\,\Delta/\Sigma}}\frac{g_T V_T^i - g_B V_B^i}{g_T V_T^i + g_B V_B^i}\right)^2 + \sigma_x^2 - \sigma_y^2\right]\right]$$

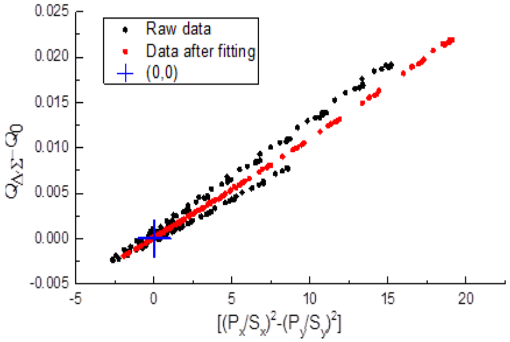
Electrode gains result

The results of online electrode gains measurement

	g_R	g_L	g_T	g_B
First time	1	0.92	0.94	0.98
Second time	1.08	1	1.02	1.06
Third time	1.06	0.98	1	1.04
Fourth time	1.02	0.94	0.96	1
Averaged result	1.04	0.96	0.98	1.02



Offline



Online

The fitting results for raw data and corrected data based on calculated electrode gains.

Results comparation between online and offline calibrated gains

	g_R	g_L	g_T	g_B
Online fitted gains	1.04	0.96	0.98	1.02
Offline fitted gains	1.07	0.96	0.96	1.02

The data corrected by online fitted gains is linear and passes through zero. Online and offline calibrated electrode gains are compared and the results are basically consistent.

Summary

- The BPM system play an important role in the beam diagnostic system, and the Libera Brilliancepluse processor play an important role in the BPM system.
- Many researches had been done base on the BPM system, such as tune measurement, Beam Based Alignment, BPM electrode gains measurement.
- We hope that more new products manufactured by Instrumentation Technologies Company will help us to solve more beam diagnostic problems and do further researches.

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THANK YOU！