BPM Inputs to Physics Requirements at NSLS-II

Yong HU

NSLS-2 Controls Group

EPICS Meeting@BNL, Oct. 12, 2010

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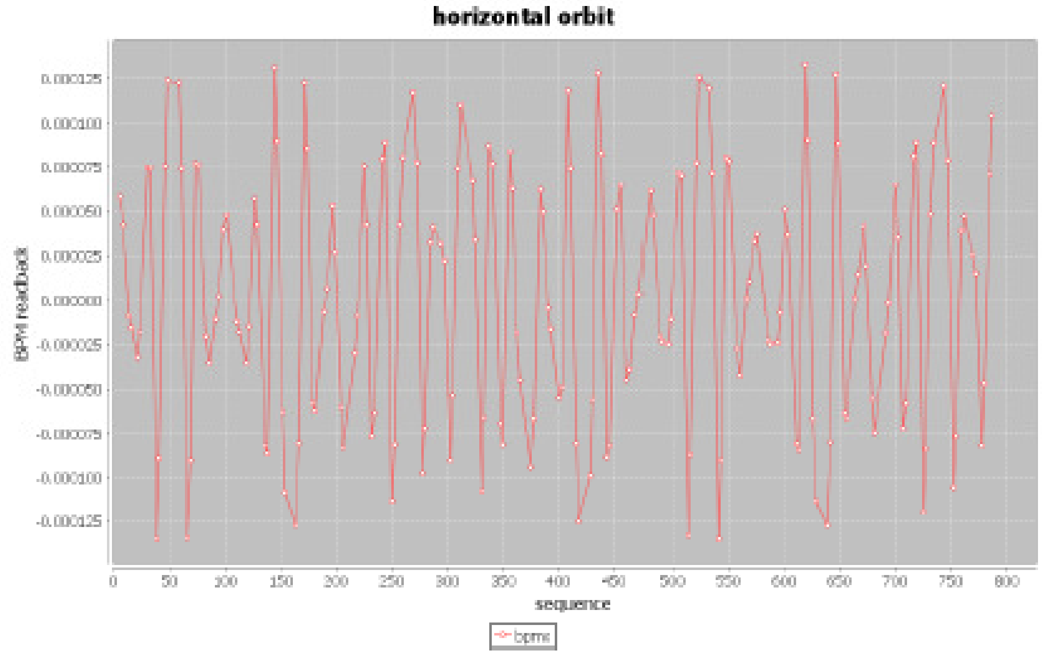
Outline

- Overview of NSLS-2 BPM (beam position monitor)
- Procedure to use BPM for fast orbit feedback (FOFB)
  1) Beam-based alignment (BBA): BPM-to-Quad offset, golden orbit;
  2) Response matrix (RM/IRM): global RM for FOFB;
  3) FOFB enable: when it's ready to go;
  4) DC shift from fast corrector to slow corrector;
  5) Disable FOFB when failures (lost communication, etc.) happen;
- BPM data associated with physics applications and requirements
  1) ADC raw data: diagnostics;
  2) TBT(turn-by-turn): very useful for machine commissioning and study;
  3) FA (fast acquisition, ~10KHz): FOFB, machine protection interlock, etc.;
  4) SA (slow acquisition, ~10Hz): very important; BBA, RM, closed orbit display;
- Controls implementation
- Conclusions

Overview of NSLS-2 BPM System (architecture)

- **BPM System:** **pick-up (i.e. button) + electronics/receiver + controls + HLA/physics(i.e. orbit server by Guobao)**

7mm / 4.47 mm button
By Igor Pinayev (physicist)



HLA: Orbit display
By Guobao Shen

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Overview of NSLS-2 BPM System (architecture)

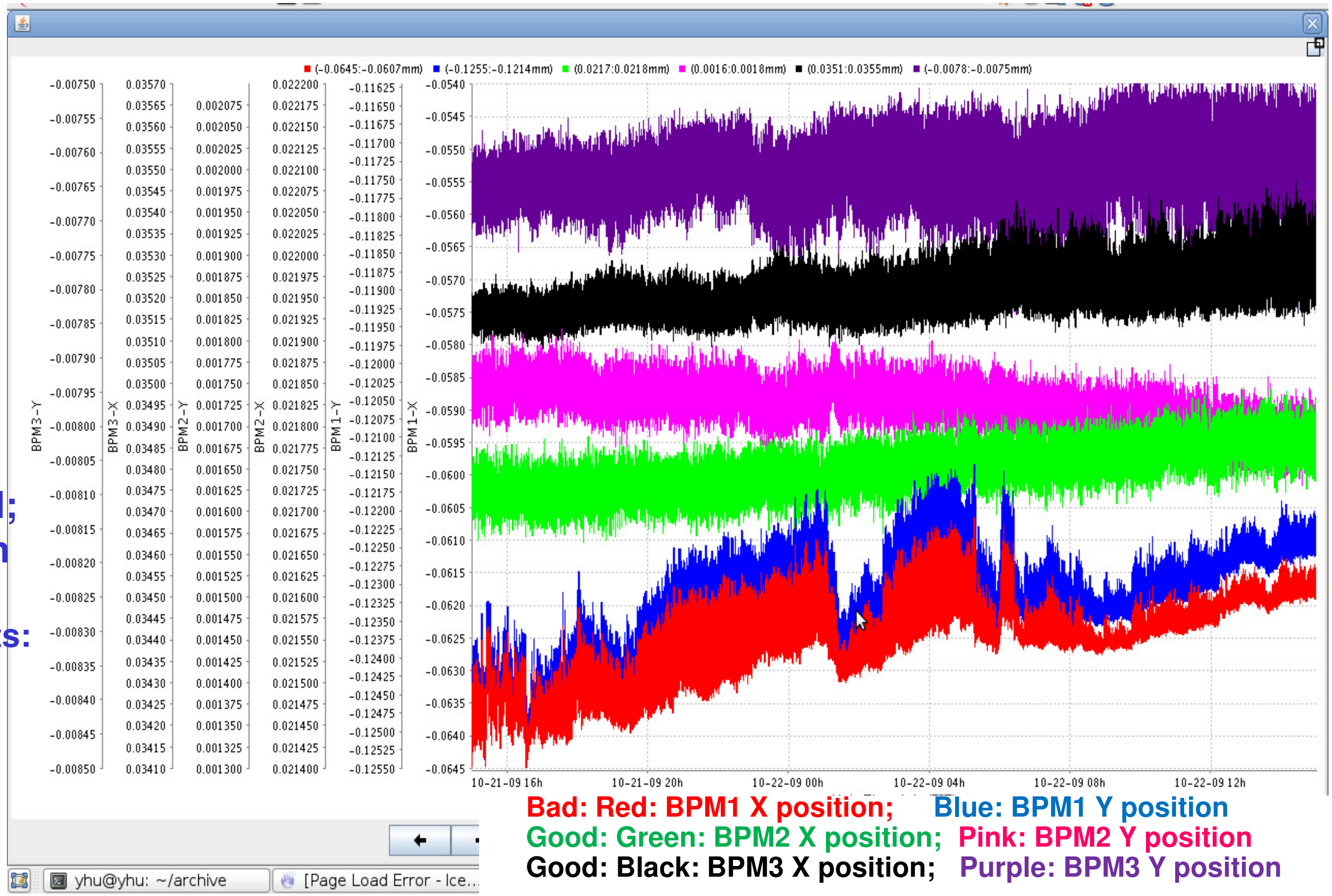
commercial BPM:
Libera Brilliance

Overview of NSLS-2 BPM System (architecture)

commercial BPM:
Libera Brilliance

Test results:
-- 1 is bad, 2 good;
-- 0.2um drift / 24h

NSLS-2 requirements:
0.2um / 8-hour



Bad: Red: BPM1 X position; Blue: BPM1 Y position
Good: Green: BPM2 X position; Pink: BPM2 Y position
Good: Black: BPM3 X position; Purple: BPM3 Y position

Overview of NSLS-2 BPM System (architecture)

Motivation for Internal BPM Development

From Kurt Vetter

In-house BPM started in 09/2009

- Commercial Vendor FPGA technology at the end of its life cycle
  - Commercial vendor not willing to incorporate latest FPGA technology
  - Current hardware design completed in 2003 *(10 years old at NSLS-II commissioning)*
- Do not have access to commercial vendor FPGA or uP Source Code
  - NSLS-II completely dependent on commercial vendor for corrections, modifications, and upgrades
- High cost - $13,500 per unit (NSLS-II quantity of 250 units)
  - Projected Internally developed BPM production cost ~ $7,500 per unit (includes testing)
- Long-Term drift compensation (i.e."RF Switching") introduces transients in signal path down to 3.9KHz
  - Compensation to mitigate transients may reduce phase margin of FOFB bandwidth

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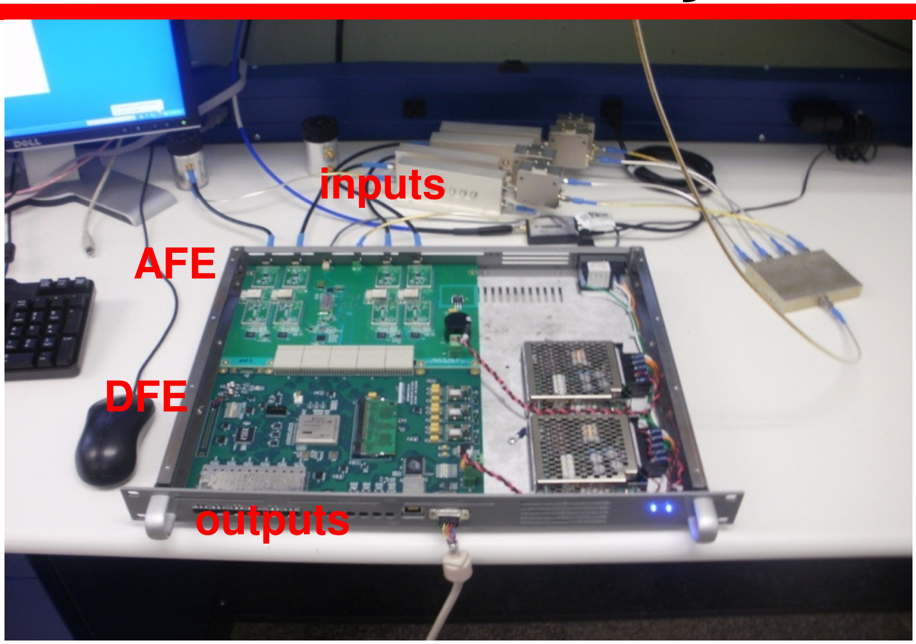
Overview of NSLS-2 BPM System (architecture)



- **In-house BPM receiver: 2 boards (AFE + DFE)**
  - Analog front-end: filters(LPF, BPF) + amplifiers + attenuators + ADCs;
  - digital front-end: FPGA + DDR2 memory + SFPs/Ethernets;
- **Outputs from BPM:**
  - Output data flows: ADC, TBT, FA, SA (more details later);
    - Ethernet ports: ADC(117MHz), turn-by-turn(380KHz), slow acquisition(10Hz);
    - SFPs/SDI: fast acquisition(~10KHz)
- **BPM team (3 dedicated engineers, ~10 involved in total):**
  - Physicists + engineers(diagnostics, controls, mechanical) + technicians;

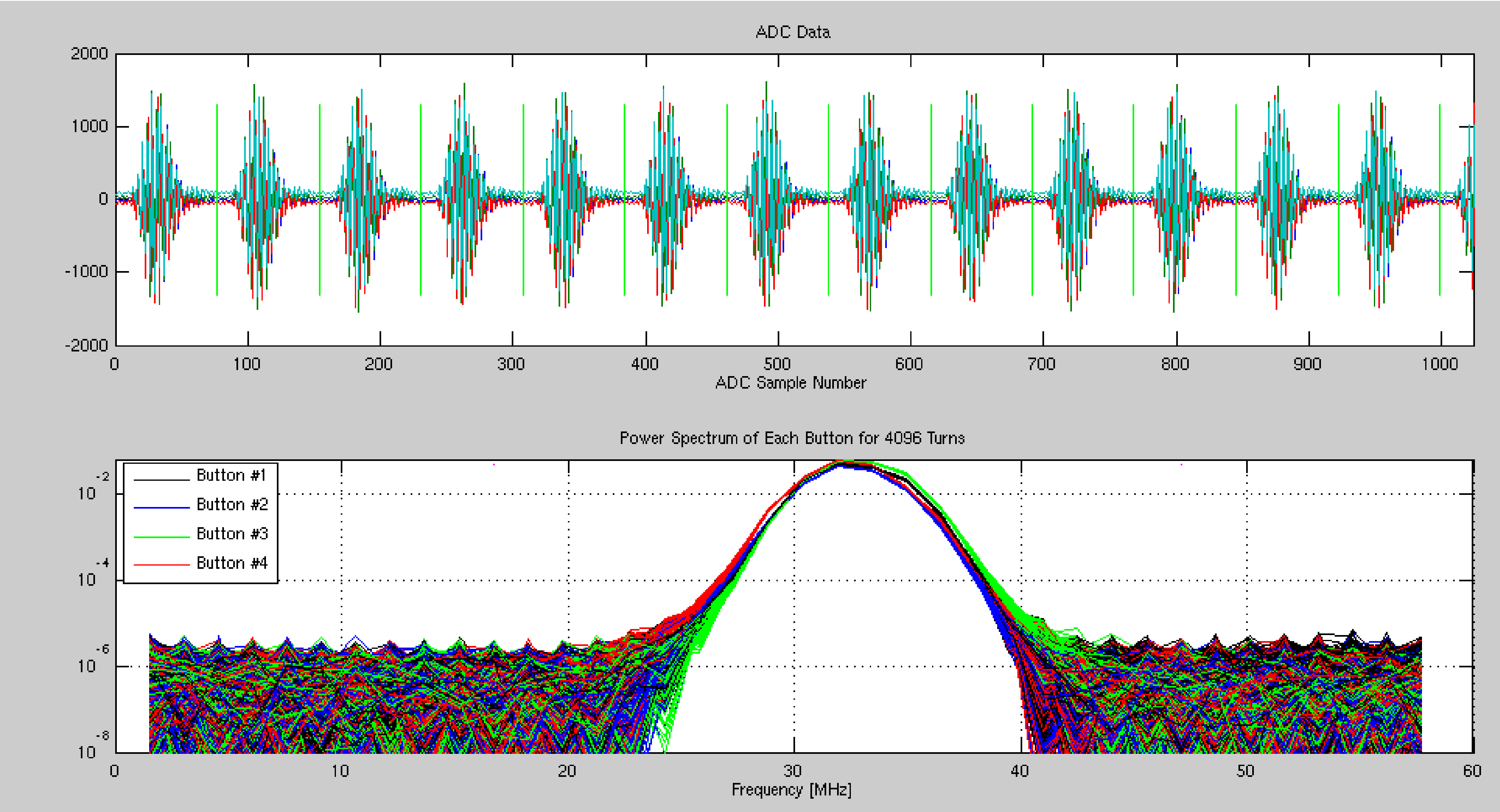
Overview of NSLS-2 BPM System (features)

New features of NSLS-2 BPM (compared with Libera Brilliance)

- **Latest FPGA technology**: Vertex-5 / Vertex-6;
- **Deep DDR2 memory(256MB):** ADC data(~3.8K turns), TbT data(>1M turns);
- **Embedded FFTs:** spectrum of 10KHz FA data, TbT for tunes measuring, etc;
- **No crossbar switching noise:** use pilot tone for active calibration;
- **Easy programming:** Matlab/Simulink/System Generator for VHDL coding;
- **Embedded event receiver for timing:** better synchronization, global time-stamp;
- **Seamless FOFB integration:** Cell Controller shares the DFE board of BPM;
- **Open hardware & software**: the DFE with FPGA code will be open;
- **In-house expertise:**
  - big difference: jump from how to use DBPM to how to make it;
  - good for system maintenance, future upgrades, etc.

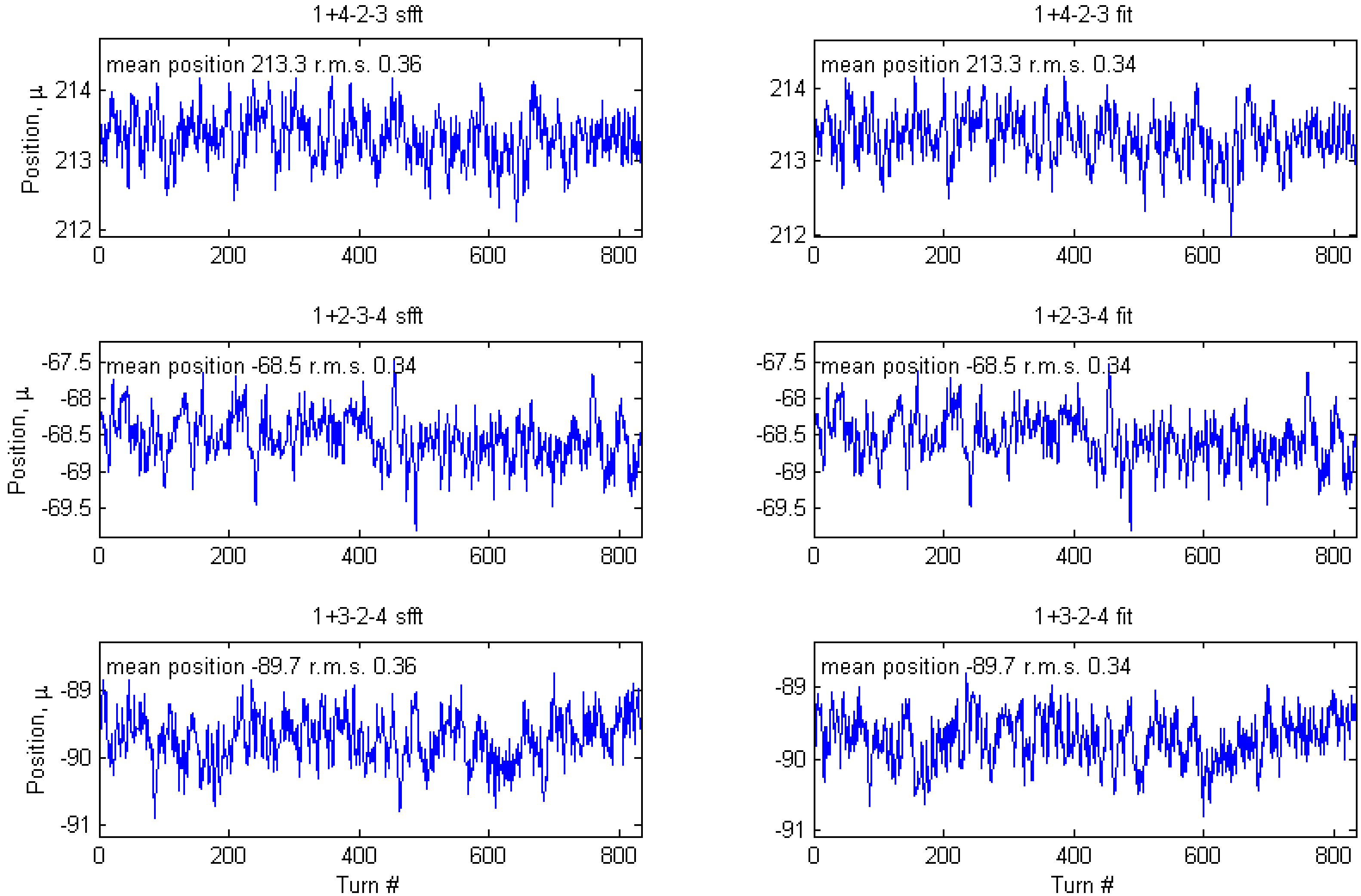
Overview of NSLS-2 BPM System (progress)

ADC raw data: tested at ALS, 77samples/turn **From Kurt Vetter**



Overview of NSLS-2 BPM System (progress)

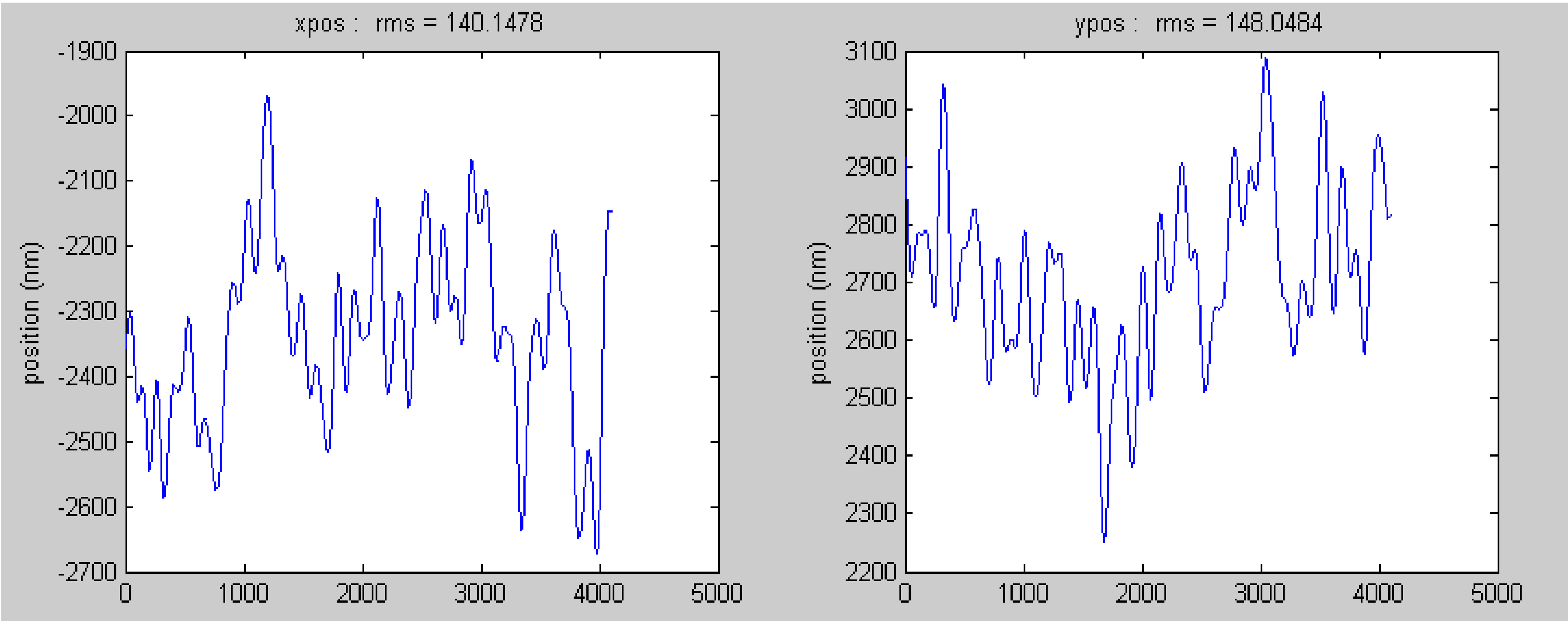
Turn-by-turn(~340nm RMS noise / resolution): tested at ALS **From Kurt Vetter**



Overview of NSLS-2 BPM System (progress)

10KHz FA data: tested at Lab, <200nm RMS noise / resolution

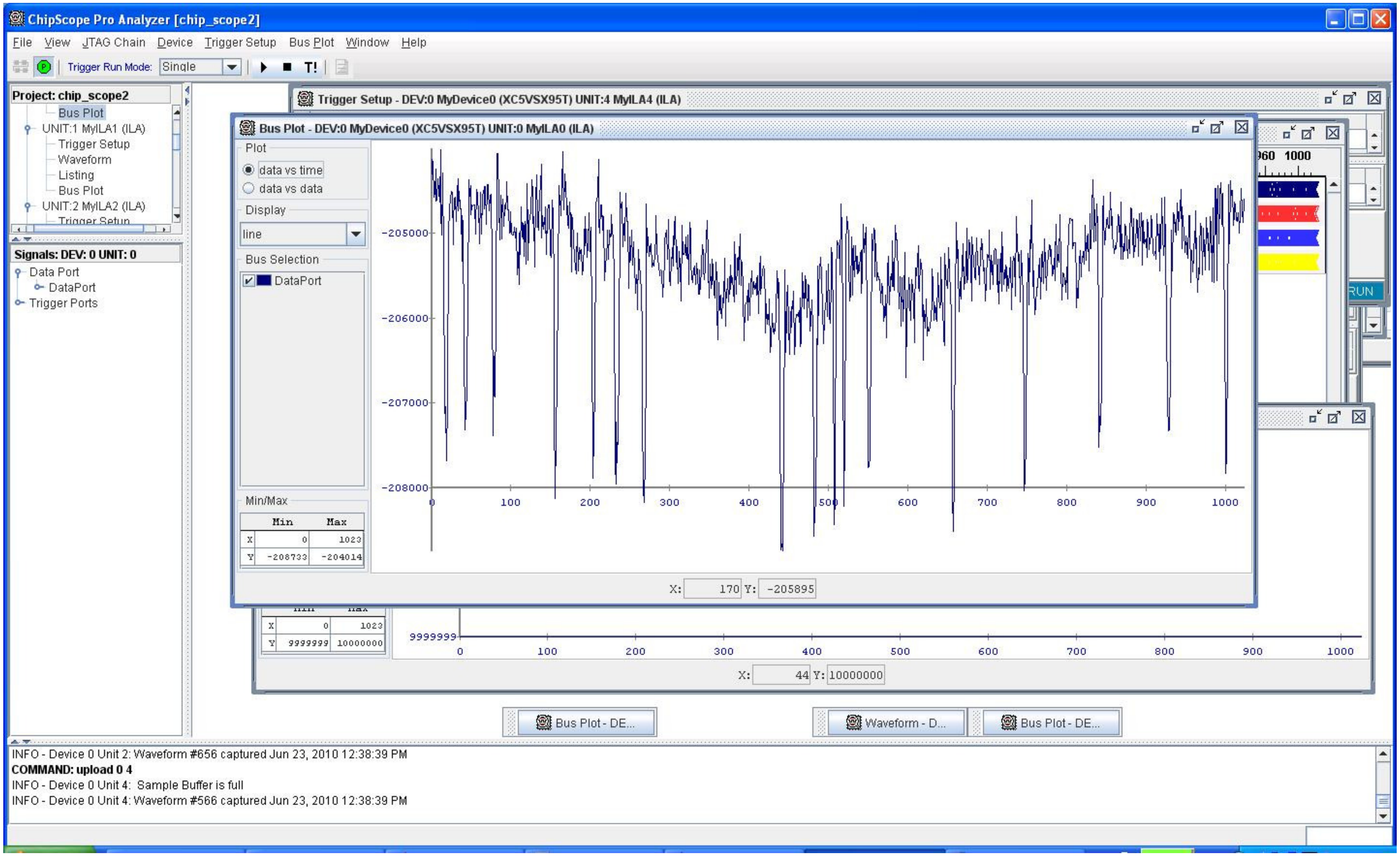
From Joe Mead



Overview of NSLS-2 BPM System (progress)

From Joe Mead

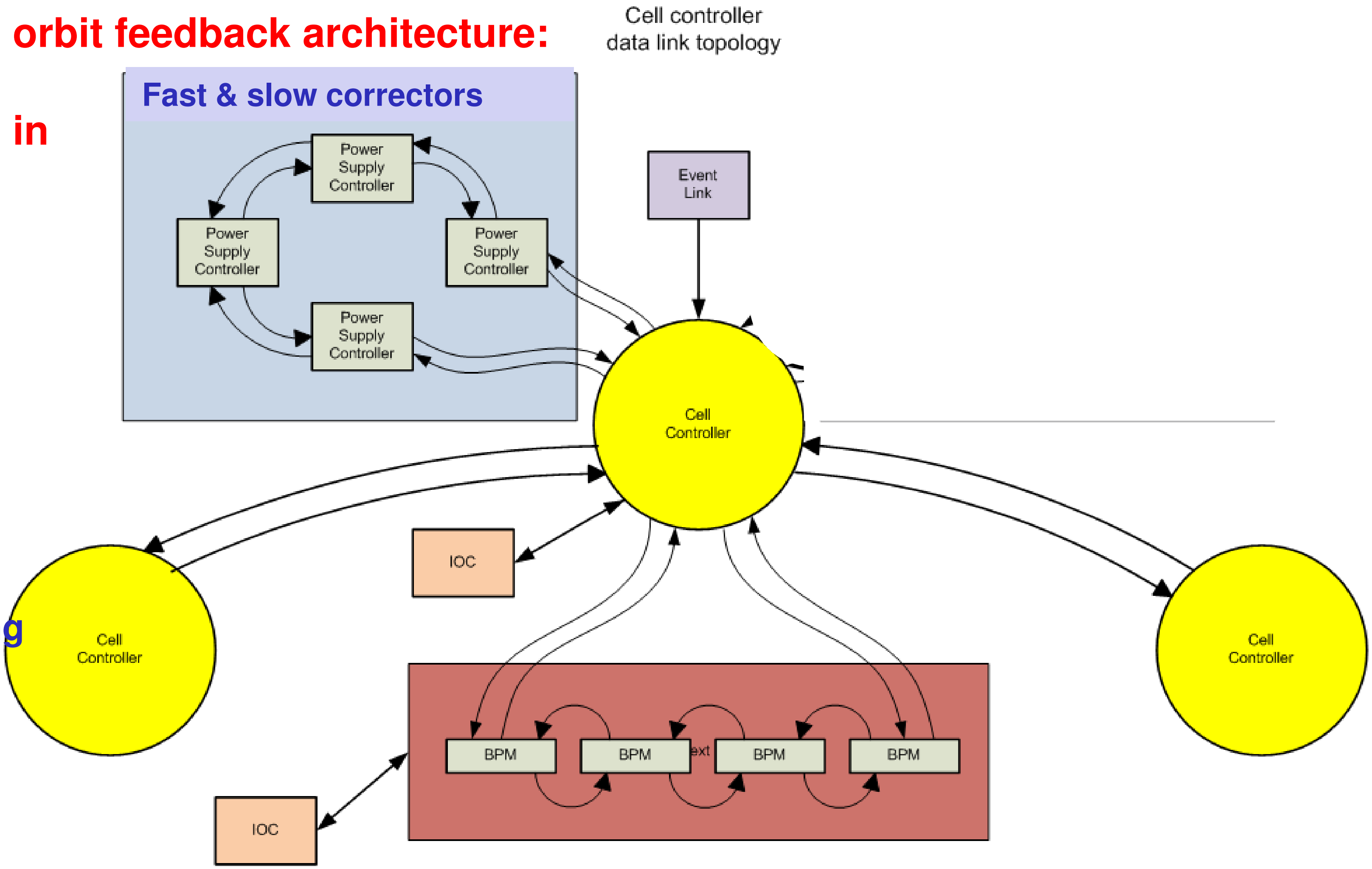
10Hz SA data: glitch issue;
the cause is found: unstable amplifier, second-version AFE started;



Procedure to use BPM for FOFB (architecture)

NSLS-II Fast orbit feedback architecture:

more details in Yuke's talk

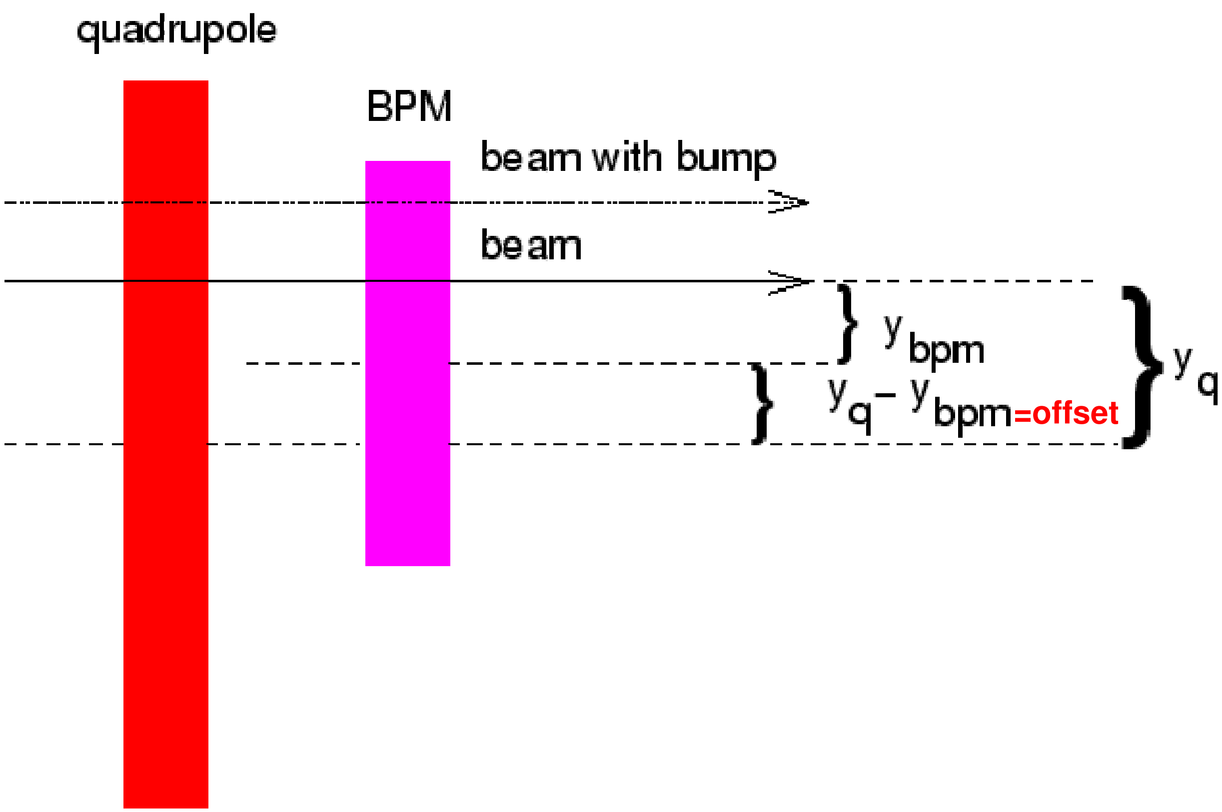


By Joe DeLong

- **Local BPMs 10KHz data at each cell → Cell Controller (data concentrator, algorithm computation, communication link / SDI) → neighboring CCs → global BPMs data for global orbit feedback**

Procedure to use BPM(first step: beam based alignment)

- **Why do BBA: get BPM-to-Quad offsets and use them for position calculations**
  - **X/Y = Kx/y * ((Va+Vd)-(Vb+Vc))/(Va+Vb+Vc+Vd) – X/Yoffset;**
  - **Golden orbit is the offset in a sense;**
  - **Golden orbit(offsets) will be integrated into NSLS-II IRMIS;**



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- **What BPM data used: 10Hz SA**
  - **10Hz data will be averaged to lower rate (i.e. 1Hz) with higher resolution;**
  - **Resolution requirement: the higher the better, 0.2um RMS noise is good;**
  - **Since centering one Quad only takes short time(1-min), no position drift issue;**

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- **Who/how do it: HLA, physics group, physicists know how;**
  - Physicists play with BPM SA data, slow correctors and quadrupoles, etc.;
  - Principle: steer beam to pass through the magnetic center of individual quad:

- **When do it: time consuming (several hours)**
  - not frequently, commissioning, start of each run

Procedure to use BPM (beam based alignment)

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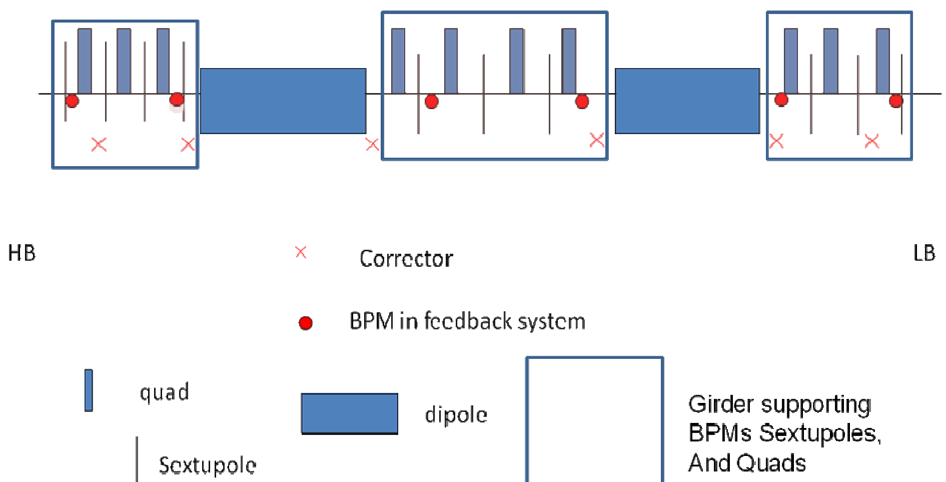
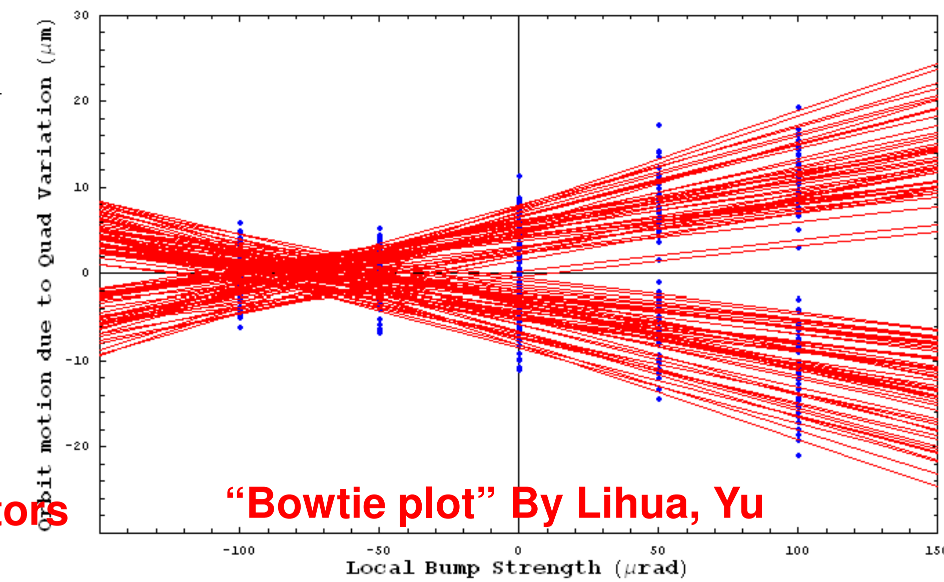


Latest layout of BPMs, Quads, correctors for FOFB, By Lihua, Yu



“Bowtie plot” By Lihua, Yu

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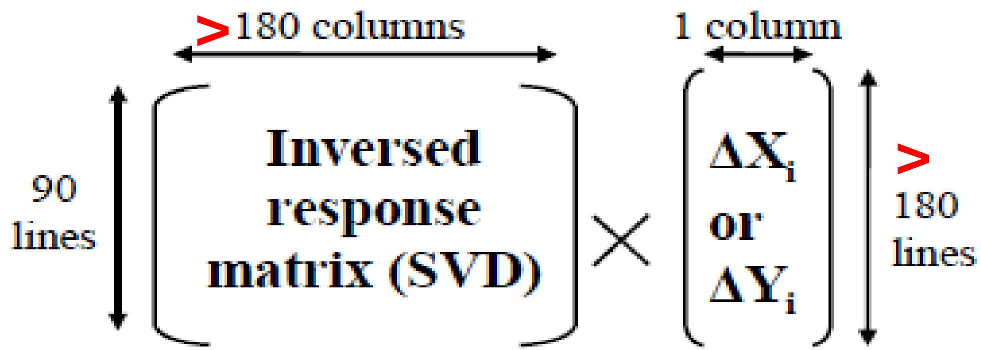
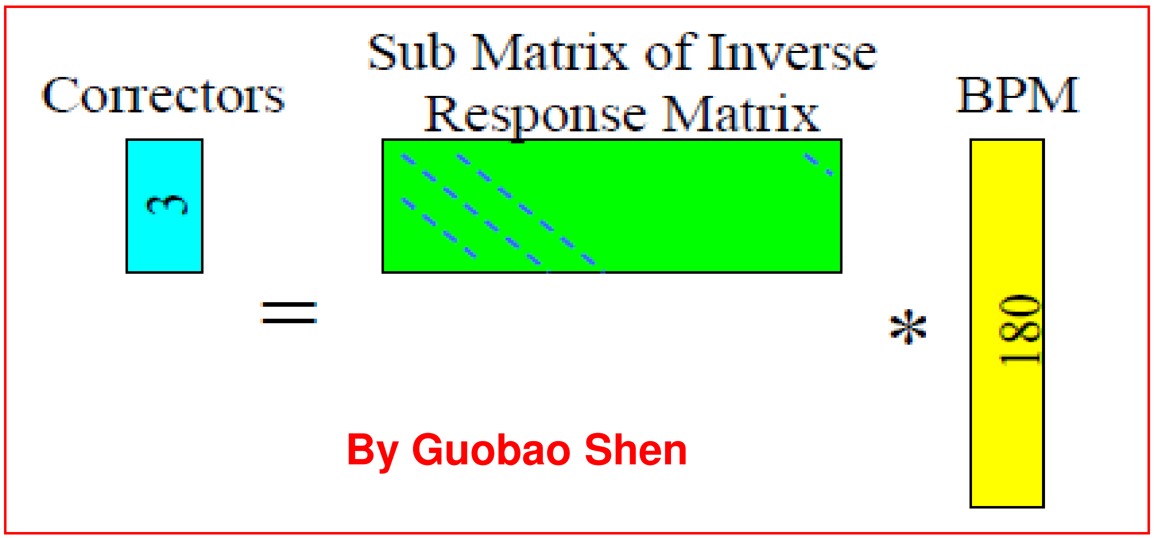
Procedure to use BPM (second step: response matrix)

- Why need global RM (IRM/SVD): for FOFB algorithm which is implemented inside Cell Controller FPGA;





By Guobao Shen

Procedure to use BPM (Response Matrix)

- Why need global RM (IRM/SVD): for FOFB algorithm which is implemented inside Cell Controller FPGA;

- What BPM data used: still 10Hz SA
  - 10Hz data will be averaged to lower rate (i.e. 1Hz);
  - Resolution: the higher the better, 0.2um RMS noise is good;
  - Again, no position drift issue;
  - All BPMs' data should be globally synchronized;

- Who/how do it: HLA, physics group, physicists know how;
  - Physicists play with BPM SA data, fast correctors, etc.;

- When do it: time consuming (several hours)
  - not frequently, commissioning, start of each run

Procedure to use BPM (enable FOFB)

When to turn on FOFB:

1) **Load our measurement data into BPM & cell controller FPGAs:**
   - **BPM coefficients(Kx/y) into BPMs: determined by BPM geometry;**
   - **Beam-base Alignment data into BPMs: golden orbit (offsets);**
   - **Response Matrix data into cell controller: for FOFB;**
   - **All these data can be treated as constants;**
   - **Loaded during FPGAs initialization;**
2) **All BPMs & cell controllers communicate well: no broken nodes;**
3) **Beam current (measured by Bergoz DCCT) >= threshold (?mA);**
4) **During initial filling (injection from zero to full, 1Hz): FOFB is off;**
5) **It's the time: after initial filling, enable FOFB for top-off injection (1-min);**

Procedure to use BPM (DC shift)

- **No slow orbit feedback at NSLS-II:**
  - **NSLS-II FOFB correction bandwidth goes from DC to 200Hz**
  - **NSLS-2 orbit feedback is named Fast Feedback with Slow Correctors**

- **Why we still need slow correctors (SC)?**
  - **The fast corrector(FC) might saturate after long-term drift;**
  - **Shift DC components from FC to SC;**
  - **Rate of DC shift is flexible, i.e.10 second;**

Procedure to use BPM (disable FOFB)

- **When to turn off FOFB (conditions):**
  - **Initial filling;**
  - **Machine physics study: BBA, RM, etc;**
  - **BPM / Cell controller broken;**
  - **Machine protection system (MPS) triggered;**

- **But don't dump the beam while disabling FOFB:**
  - **The machine should be alive for a while without FOFB;**
  - **BPM protection interlock signal can be used to dump the beam;**
  - **Other diagnostic monitors might be used for MPS: DCCT, beam losses;**

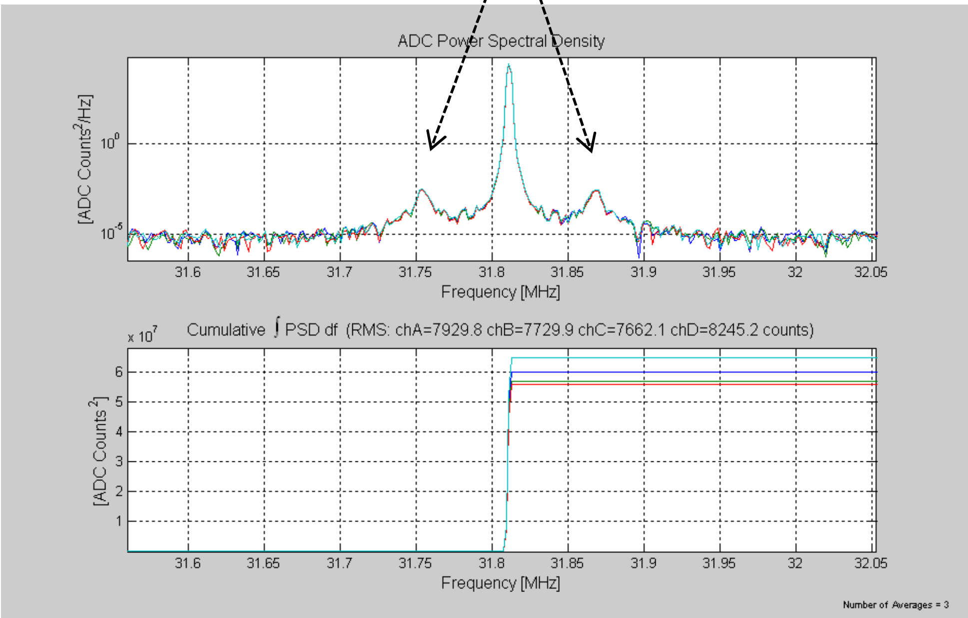
BPM data & applications/requirements

1) ADC raw data (~117MHz, ADC sampling frequency):

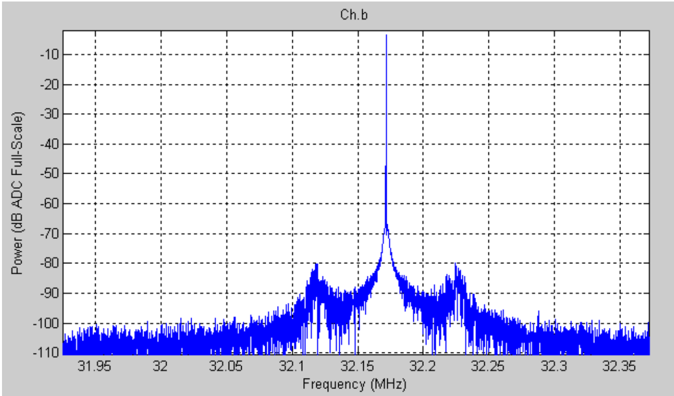
- Useful for diagnostics/debugging;
- Data length requirement: 10 ms (~3.8K turns, 3 turns in Libera) should be OK;

Noise investigation: Power supply /regulator

From Kurt Vetter



1M pt. FFT Using BPM SDRAM



BPM data & applications/requirements

2) Turn-by-turn data(~380KHz, revolution frequency):

- Very useful and attractive to physicists;
- Many applications: tunes, phase advance, injection damping, etc.;
- Requirements:
  - i. Circular buffer: TBT data are continuously written into circular memory at revolution frequency. The arrival of a timing event stops the writing (freeze the buffer), then EPICS IOC reads out the buffered data;
  - ii. All BPMs' TBT data should be synchronized: a counter for each turn;
  - iii. Resolution: 1 um is good;
  - iv. 1-second-length (~380K samples) TBT is enough for physics applications;

TBT data for tunes measurement:

a) Traditional solution: spectrum analyzer-based (NSLS-2 has it in baseline)

- More sensitivity: can detect small betatron oscillation

b) Another solution: FFT TBT data inside our BPM / FPGA (not available from Libera)

- 0.01% frequency resolution requirement: $1/(2N) < 0.01\%$ → $N > 5*1024$ (samples)

BPM data & applications/requirements

3) Fast acquisition (FA) data (~10KHz):

- FOFB;
- Machine protection: if the FA positions (X, Y) are out of range;
- Spectral analysis by FFT inside our BPM / FPGA (not available from Libera);
- Requirements:
  i. Globally synchronized 10KHz data;
  ii. Resolution: 0.4um RMS noise;

4) Slow acquisition (SA) data (~10Hz): very useful and attractive to physicists:

- BBA (beam-base alignment);
- RM (response matrix);
- Live orbit display;
- Beam life-time measurement (Bergoz DCCT will also be used for life-time);
- Requirements:
  i. Globally synchronized and time-stamped;
  ii. Resolution: 0.2 um RMS noise;

BPM data & applications/requirements

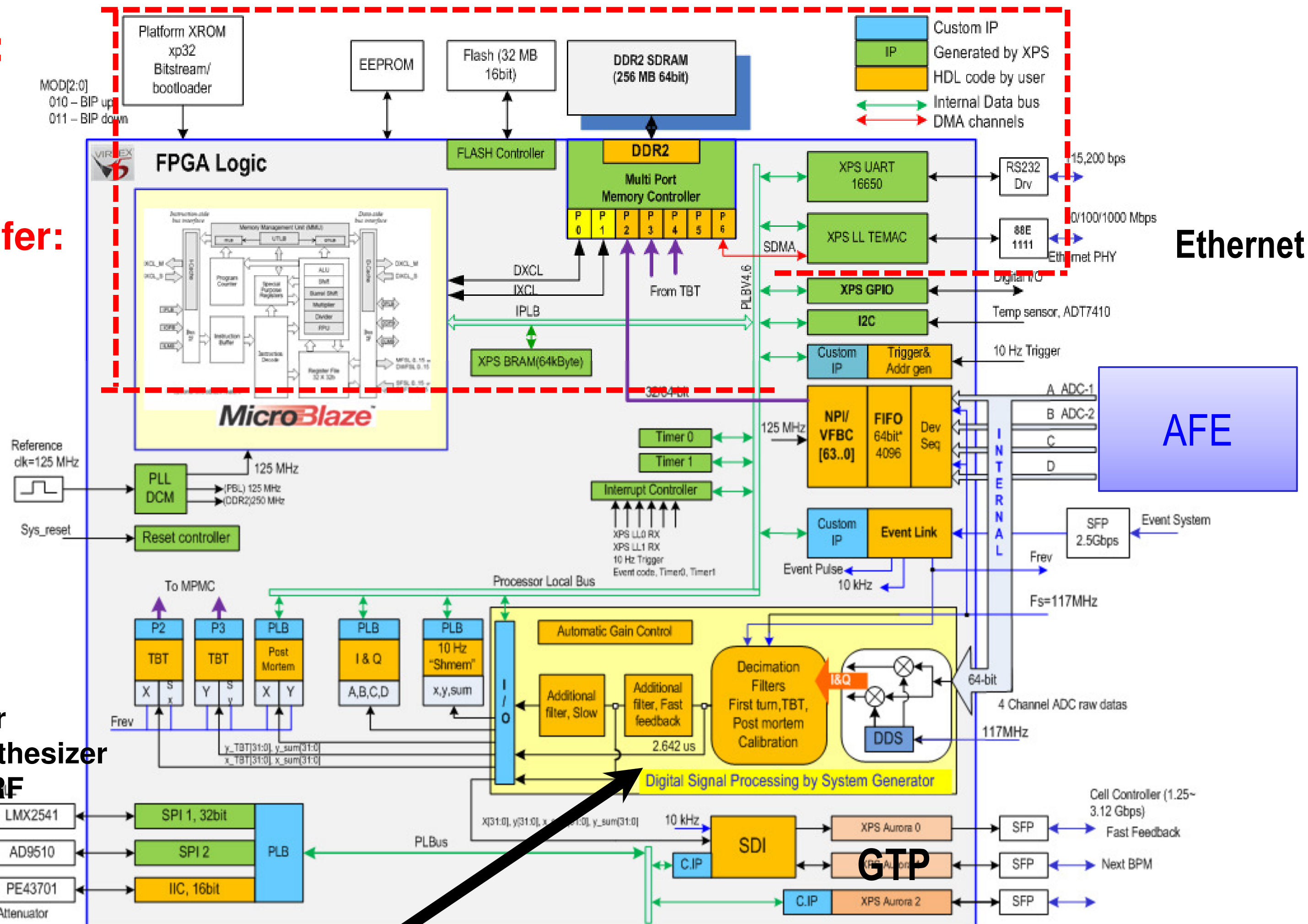
data flow	Data Rate	Applications	Requirements
ADC Raw Data	117 MHz	diagnostics, debugging	on demand; ~ 3.8K samples
Turn-by-turn	378 kHz	tunes, phase advance, injection damping, etc.	on demand; 1 um resolution; ~ 380K samples; synchronization
Fast Acquisition	10 KHz	fast orbit feedback, machine protection	continuous; 0.4um resolution; synchronization
Slow Acquisition	10 Hz	beam-based alignment, response matrix, closed orbit, life-time	continuous; 0.2um resolution; synchronization

Controls Implementation for Physics apps

- **2-layer architecture for BPM data usages:**
  - **Low-level controls(Kiman, Yong, etc.): make BPM data as EPICS PVs**
  - **High-level applications (Guobao, Lingyun, etc): play with the EPICS PVs**

Low-level controls:
MicroBlaze + MPMC + DDR2 + Ethernet

Large array data transfer: (ADC, TBT)
-- Modbus TCP/IP;
-- TFTP;



✓**Attenuator**
✓**Clock synthesizer**
✓**Pilot ton RF**

DSP module

By Kiman Ha

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Controls Implementation for Physics apps

- **2-layer architecture for BPM data usages:**
  - **Low-level controls(Kiman, Yong, etc.): make BPM data as EPICS PVs**
  - **High-level applications (Guobao, Lingyun, etc): play with the EPICS PVs**

- **Basic implementations: external IOC (1 PC/Linux or VME/RTEMS for one Cell)**

1) **ADC raw data:**
   - **4 EPICS waveform records with 1M (max.) elements each: 4-button(A,B,C,D);**
   - **Data on-demand / upon timing event;**
2) **TBT/PM data:**
   - **5 waveform records with 1M (max.) elements each: A,B,C,D, Counter;**
   - **Another 4 waveforms (X,Y,S,Q) are calculated in IOC from A,B,C,D;**
   - **Data on-demand / upon timing event;**
3) **FA 10KHz continuous data: currently not available from EPICS IOC;**
4) **SA data: 10Hz continuously, 5 longin for A,B,C,D,S and 3 ai records for X,Y,Q**
5) **Misc: diagnostics, i.e. temperature, BPM/CC health, IOC CPU/memory usages, etc.**

Conclusions

- **NSLS-II BPM receiver is in good progress;**
  - **Digital board (DFE) 100% operational;**
  - **AFE 2nd version has started to solve glitch issue;**
- **The data flows are enough for physics applications;**
  - **BBA, RM. FOFB, tunes, phase advance, injection damping, life-time, live orbit display, machine protection, post-mortem, etc.**
- **If we beat Libera in terms of stability, we'll be good;**
  - **Long-term drift: SA 10Hz data;**
- **Special thanks to my colleagues: K. Vetter, K. Ha, J.DeLong, J.Mead, G-B. Shen, L-H.Yu, Y-K.Tian!**

Thanks ALL!

Backup

TBT: very useful and attractive to physicists:

- Too many applications, do whatever physicists want to do: tunes, phase advance, injection damping, etc.;
- Requirements:

  i. Data captured on trigger: receive a trigger, then acquire ~400K (1 second) samples to the DDR-2(buffer) and stop acquiring (freeze the buffer);

  ii. All BPMs' TBT should be synchronized: a counter for each turn;

  iii. Resolution: 1 um is good;

Backup

Challenging:

- AFE design;
- Stability,
- Calibration;
- Controls: transfer large array data (ADC raw data, TBT)

BPM data & applications/requirements

2) Turn-by-turn data(~380KHz, revolution frequency):

- Very useful and attractive to physicists;
- Many applications: tunes, phase advance, injection damping, etc.;
- Requirements:
  - i. Circular buffer: TBT data are continuously written into circular memory at revolution frequency. The arrival of a timing trigger stops the writing (freeze the buffer), then EPICS IOC reads out the buffered data;
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a) Traditional solution: spectrum analyzer-based (NSLS-2 has it in baseline)

- More sensitivity: can detect small betatron oscillation

b) Another solution: FFT of TBT data inside FPGA (not available from Libera)

- 0.01% frequency resolution requirement: $1/(2N) < 0.01\%$ → $N > 5K$ (samples)

3) First turn (1 sample per injection trigger): like single-pass, different from TBT, directly calculated from ADC raw data;

BPM data & applications/requirements

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b) Another solution: FFT TBT data inside our BPM FPGA (not available from Libera)
   - 0.01% frequency resolution requirement: $1/(2N) < 0.01\%$ → $N > 5*1024$ (samples)

Post-mortem data:

- the same buffer as the TBT data;
- Different from TBT: PM is acquired from history before PM trigger occurred;
- PM Source: global machine protection interlock (MPS);

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