Progress of Photon Beam Stability Improvements at NSLS-II Image and Microscopy Program Beamlines

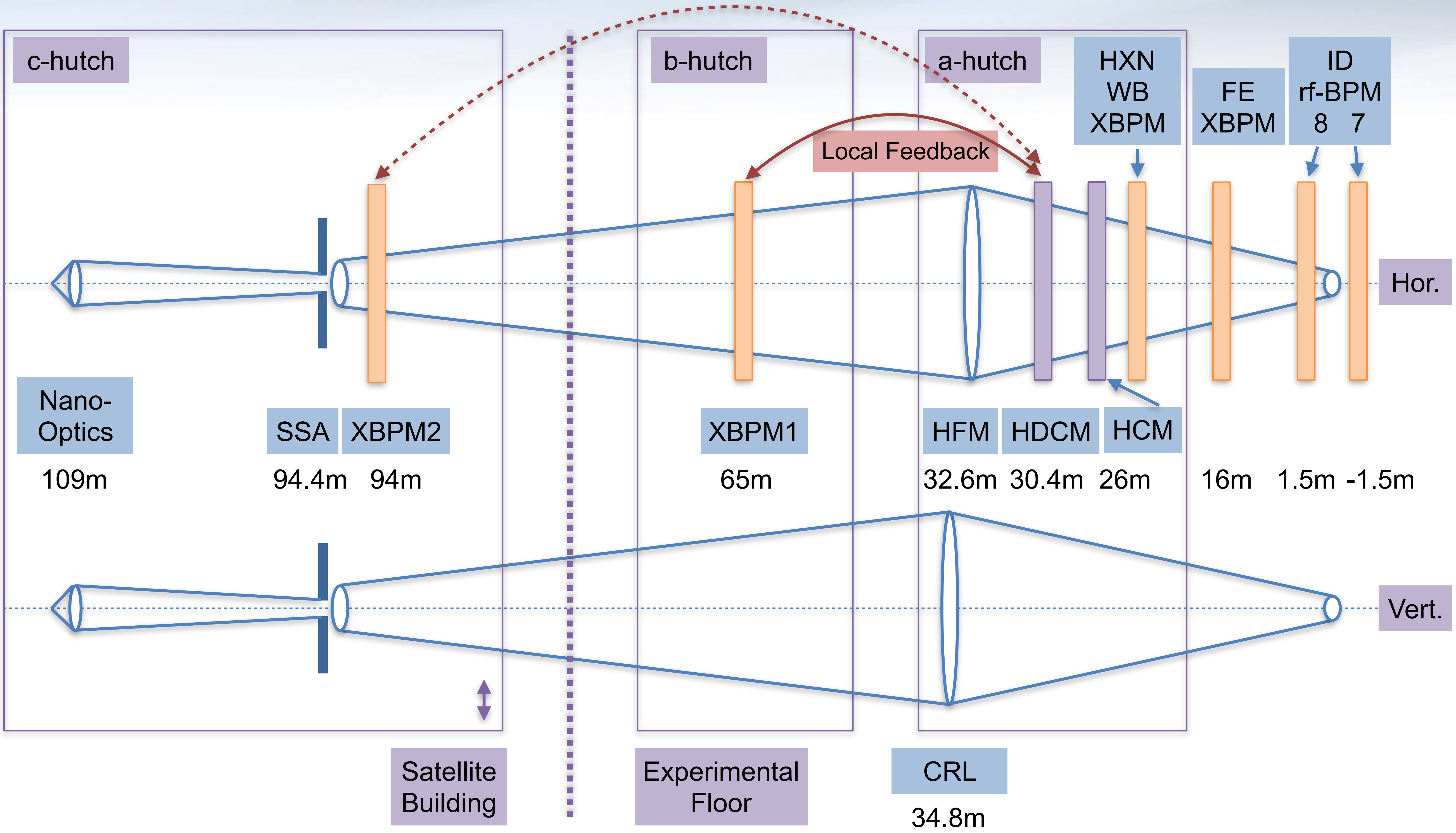
Petr Ilinski
Scientific Associate
Imaging & Microscopy Program
Photon Science Division, NSLS-II

Outline

- **Beam Stability - Recommendations**
  - Beamlines must have Local Beamline Feedback
  - Need of a Beam Stability unit at Photon Divisions to unify efforts for specifications, development, implementation, control, maintenance
  - Best if e-beam and photon beam diagnostics/beam stability units are united in one inter-division group
  - Urgent need of detector grade diamond material fabrication in the US
- **Feedback**
  - Beamline Local Feedback
  - SR Local Photon Feedback (PLFB) - great approach (BSTF), still requires further development
  - NSLS-II implementations of Beamline Local Feedback
- **Causes of instability**
  - Temperature - Long-term
    - a-hutch - 3-day temperature stabilization
    - c-hutch - day/night vertical movement of 20-40 um
    - net of sensors for ambient temperature and solar activity
  - Vibrations - Short-term
    - administrative (experimental floor activities, outdoors activities)
  - Utilities
    - Cooling water
    - DI temp, pressure
    - Dedicated chiller
  - Cryocooler
    - L1 fill pattern optimization
- **Hardware**
  - **XBPM**
    - White-beam
      - FE X-ray BPM: advantages to have, should be implemented for all beamlines, can be improved
      - Users (ID4, ID3) - not working or not in use
    - Mono-beam
      - Types
      - Resistive Diamond XBPM
  - **Electronics**
    - Electrometers
    - Feedback controllers
  - **Optical components**
- **Software**
  - Asyn Driver
  - FPGA Controller
- **Beam Stability - Planning, Coordination, Realization**
  - Defining Specifications
  - A need of coordinated efforts from multiple groups (PS, AD, Instr.Div.)
  - Currently no stake holder for entire facility
  - Better be one inter-Division group for planning coordination and realization

Feedbacks

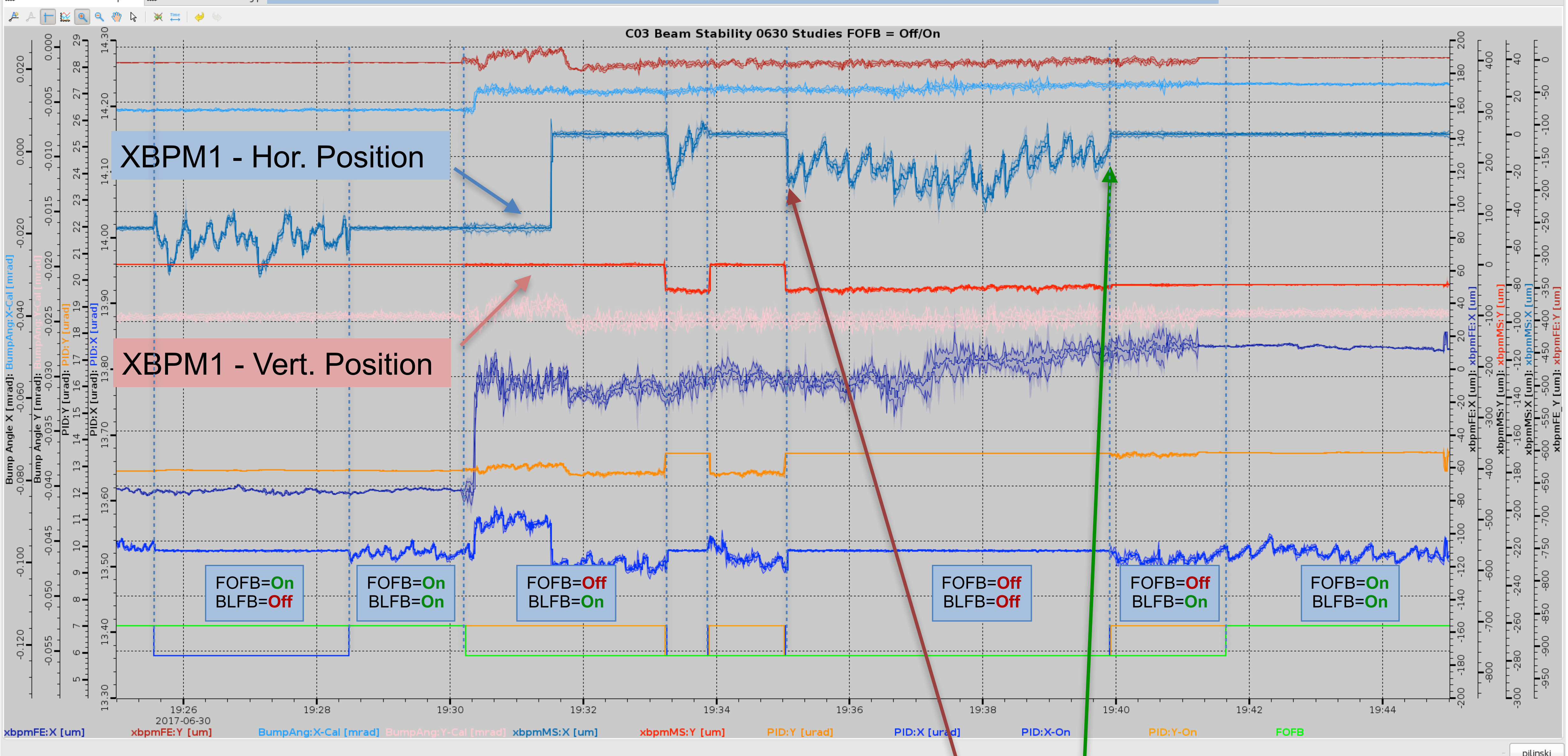
HXN Beamline Optical Layout



- Currently Beamlines have only one Optical element for correction
  - Not possible to stabilized the beam direction

HXN Beamline Local Feedback

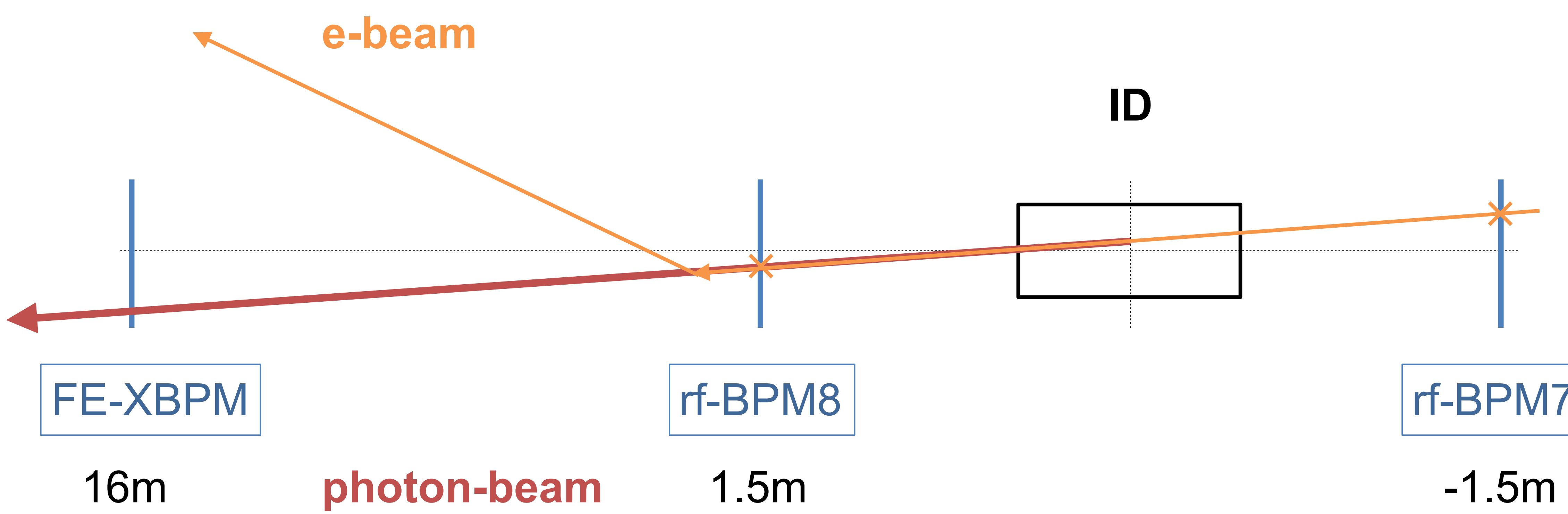
- XBPM1 - 35m downstream from monochromator
- Local Feedback - Monochromator 2nd crystal Pitch and Roll



- HXN Beamline Local Feedback (BLFB) Off and On
- HXN Cannot Operate without Beamline Local Feedback
- With Local Feedback On
  - XBPM1 Hor. Pos. rms ~ 0.6 um (18 nrad)
  - XBPM1 Vert. Pos. rms ~ 0.2 um (6 nrad)

e-beam Feedback - ID rf-BPMs and FEXBPM

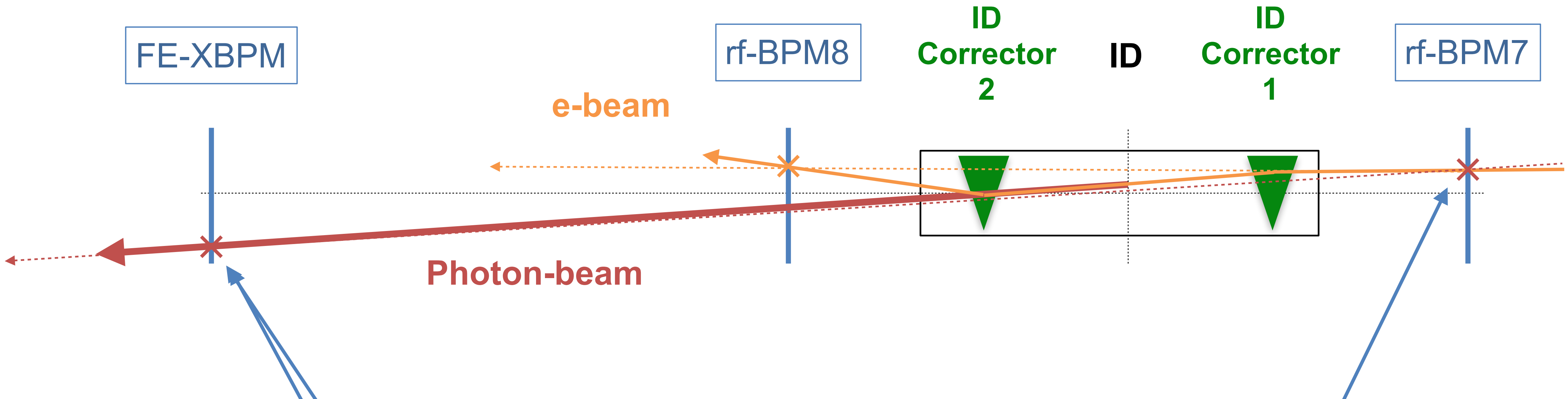
- ID rf-BPMs are located at the straight section and adjacent to the ID
- Initially ID rf-BPMs were dedicated for Active Interlock System
- ID rf-BPMs were integrated into FOFB
- Some of NSLS-II beamlines have Front End XBPMs



- Long-term Local Bump drifts are observed
- Can FEXBPM be used for e-beam Feedback?

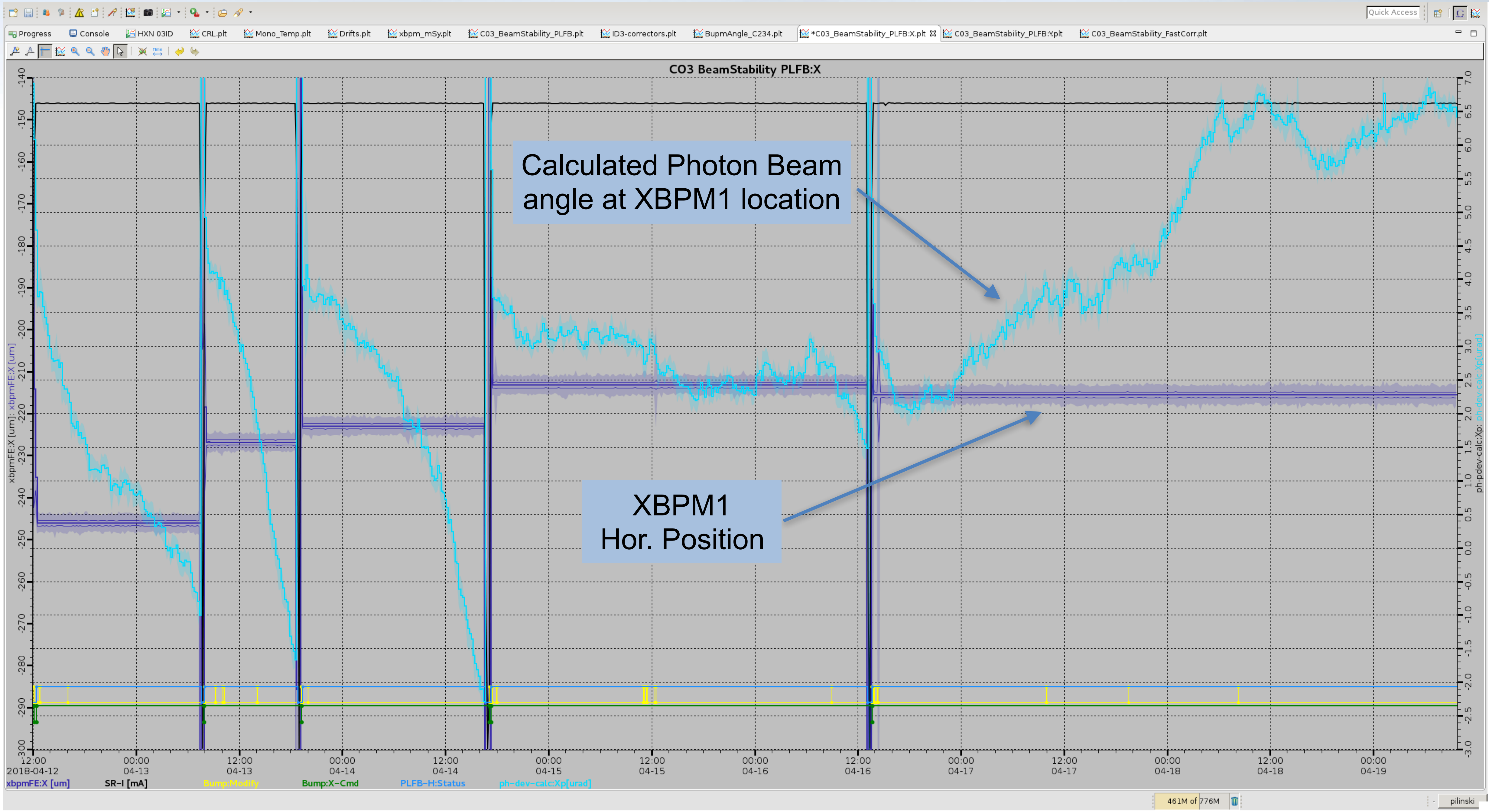
Photon Local Feedback (PLFB)

- PLFB was implemented in 2018
- PLFB employs FE-XBPM & rf-BPM7 and two ID-Correctors



- PLFB keeps positions unchanged at the FE-XBPM and BPM7
- Photon-beam can deviate at FE-XBPM pivot point by few urad

PLFB at work



- Photon-beam can deviate by few urad
- PLFB improvements
  - stabilization of the photon beam direction
  - implementation of PID loop to avoid e-beam Local Bump switching

Feedbacks Implementation at HXN and SRX

- **Feedback**
  - Beamline Local
    1. HXN - XBPM1, Fast, (100 Hz) Sydor Electrometer + PID = Mono Fine Pitch & Roll
    2. HXN - I0, Slow, (1 Hz) Setpoint for #1 Feedback = in progress
    3. HXN - XBPM2, Fast, nsls2_em Electrometer + PID = in progress
    4. HXN - Encoder, Slow (10 Hz) EPICS ePID = a-hutch mirrors
    5. SRX - XBPM, Fast CAEN Feedback commissioning = in progress
    6. SRX - Encoder, Slow (5 Hz) EPICS ePID = a-hutch mirror, mono-Pitch
  - Storage ring
    - HXN - Slow (0.5 Hz) Photon Local Feedback (PLFB) = electron beam (postponed)

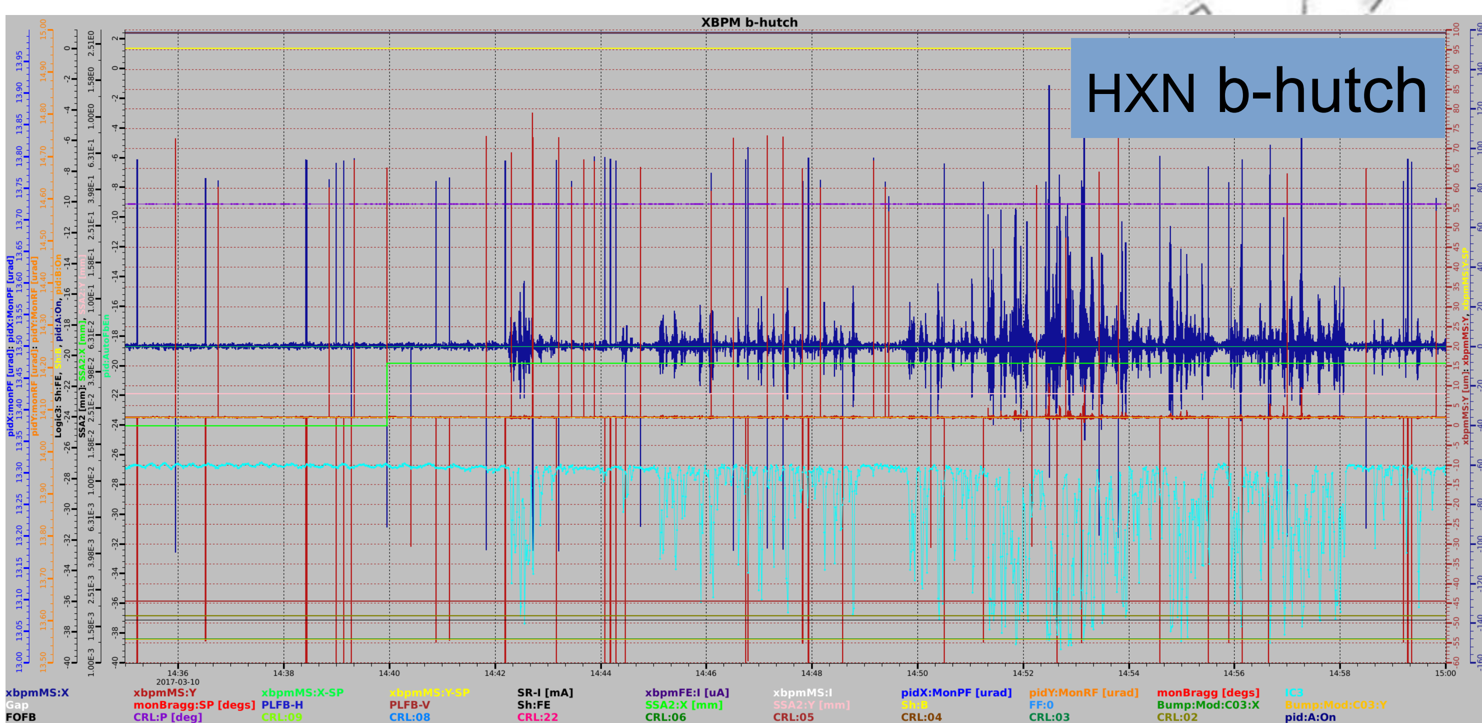
NSLS-II Local Beamlines Feedbacks

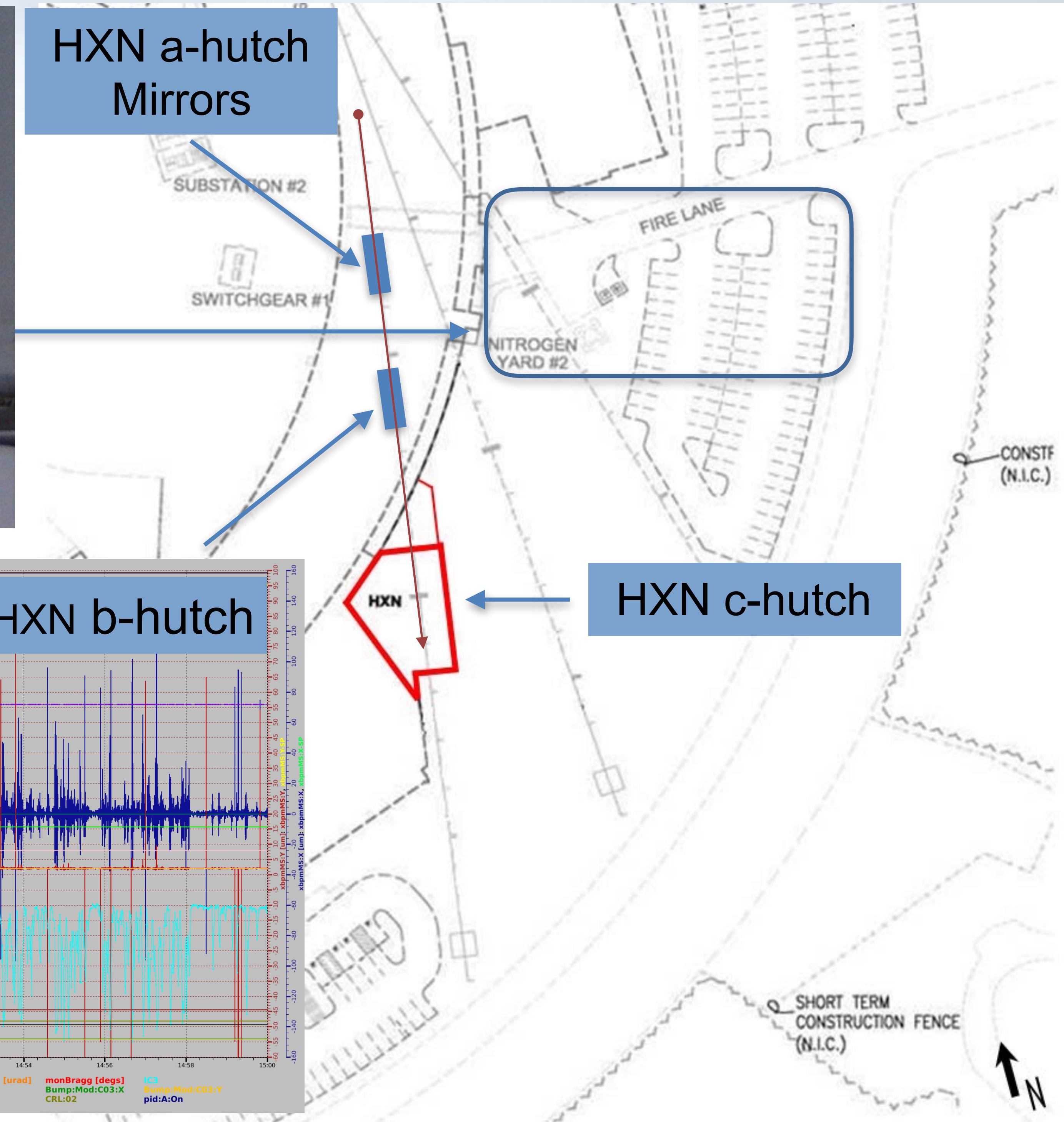
Beam line	Source	White beam XBPM	Monochromatic XBPM	Electrometer	Feedback controller	Optics DOF for feedback	Slow Feedback Status	Implem ented	Fast Feedback Status	Implem ented
HXN	3-ID	FE Blade XBPM	Sydor Quad diamond CEA Resistive diamond	Sydor Electrometer NSLS-II Electrometer nsls2_em	Sydor Electrometer epid	HDCM Second crystal pitch and roll	epidHCM epidHFM PLFB (?)	2016 2018	pidMonoPF pidMonoRF	2016
ISR	4-ID	Diamond blade	Sydor Quad diamond	Sydor Electrometer	Sydor Electrometer	DCM Second crystal pitch and roll			pidMonoPF pidMonoRF	2018
SRX	5-ID			CAEN TetrAmm NSLS-II electrometer nsls2_em	CAENels BEST nsls2_em	DCM pitch and roll	epidHFM epidMonoPitch	2018	Not commissioned	
QAS	7-BM	FE slits drain current	FOE slits drain current (pink)							
TES	8-BM	Drain current on slits	Vert: foil/mesh Hor: PIN diodes		Analog solenoid (Roll)	DCM pitch	MonoPitchFine	2018	analogMonoRoll	2018
CHX	11-ID	N	Backscatter foil		Sydor					
SMI	12-ID	N	Sydor Quad diamond	nsls2_em	nsls2_em				pidMonoPF pidMonoRF	2018
LiX	16-ID	FE Blade XBPM	Rigi quad diamond		CaenELS BEST	Mirror pitch DCM Second crystal pitch			pidMonoPF	2016
AMX	17-ID-1	FE Blade XBPM	Sydor Quad diamond Dectris Rigi quad diamond	CAEN TetrAmm	CaenELS BEST	Mirror pitch DCM crystal pitch	PLFB (electron orbit feedback with FEXBPM)	2018		
FMX	17-ID-2	FE Blade XBPM	Sydor Quad diamond Dectris Rigi quad diamond	CAEN TetrAmm	CaenELS BEST	Mirror pitch DCM crystal pitch & roll	PLFB (electron orbit feedback with FEXBPM)	2018	In progress	

- Commissioning of Beamline Local Feedbacks is not a highest priority
  - Lack of local resources or expertise

Causes of Photon Beam Instability

Vibrations - on Site

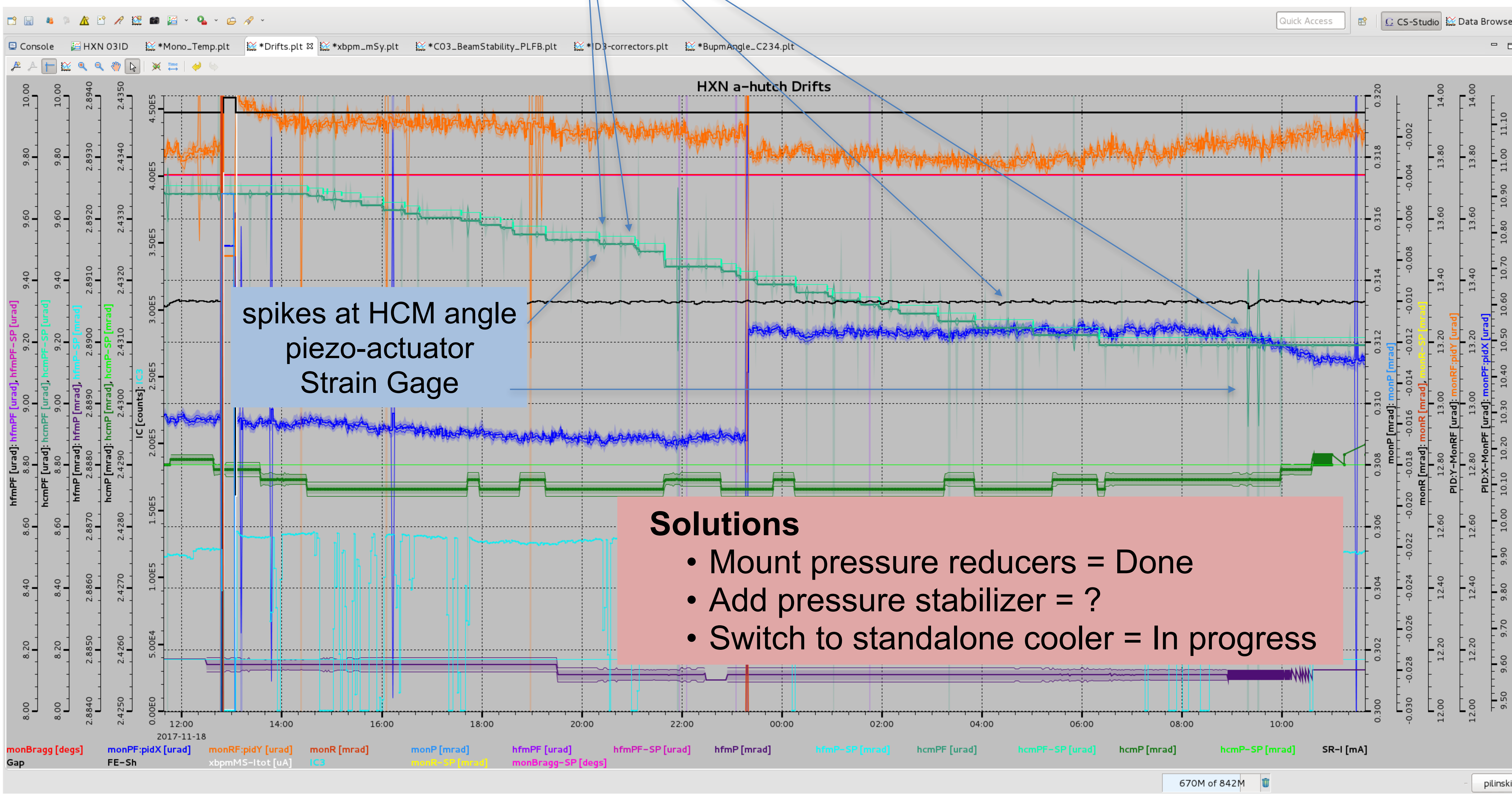




- Activities on the experimental floor and even outdoors can affect HXN operation
- Some administrative rules need to be implemented

Vibrations - Utilities

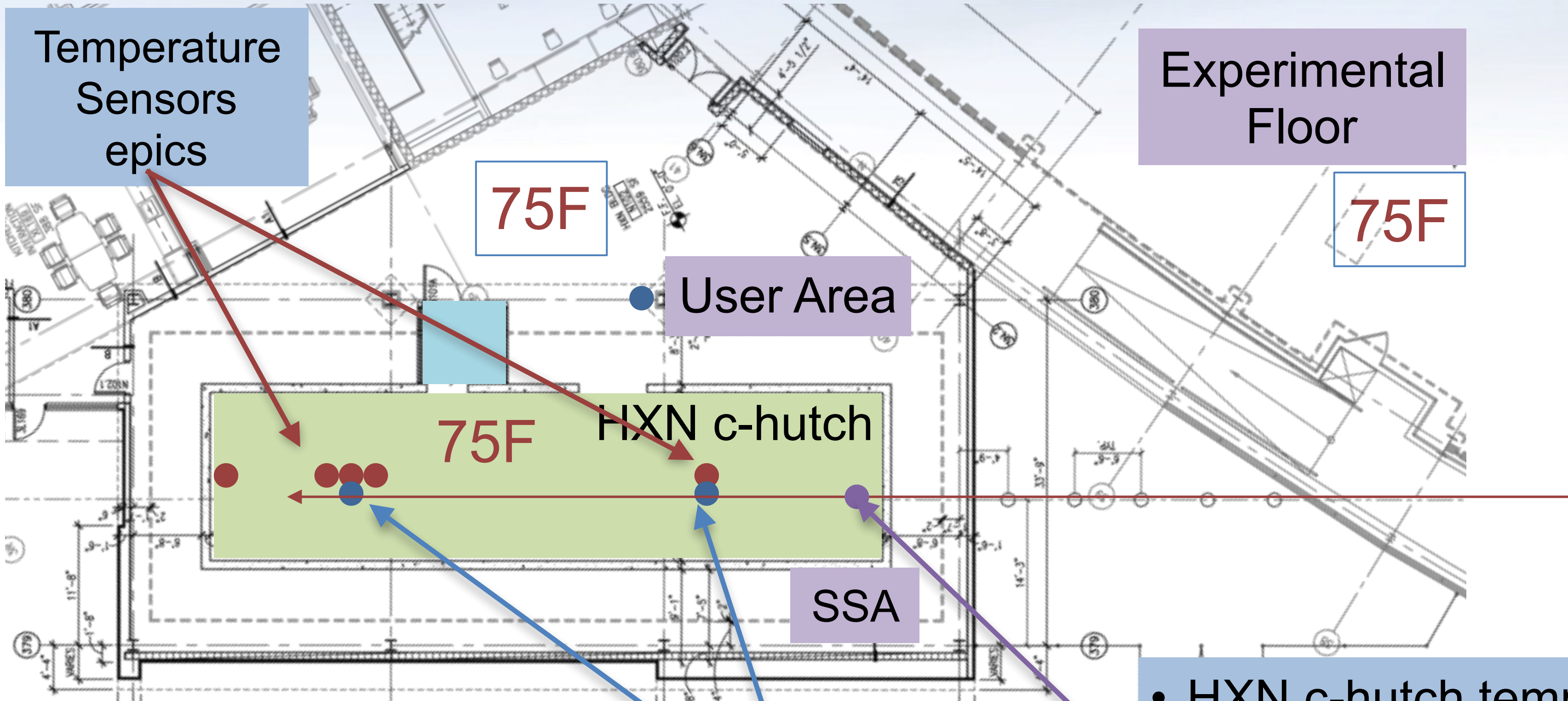
- For cooling of the FE optical components NSLS-II beamlines are sharing DI water with the Storage Ring
- a-hutch DI water Supply pressure = 80 psi, Return pressure= 30 psi
- Pressure variation can create shocks at the optical component
- DI water flow-rates are subject to change due to redistribution and clogging of DI regulator valves
- There are no remotely control DI water regulator valves



Solutions

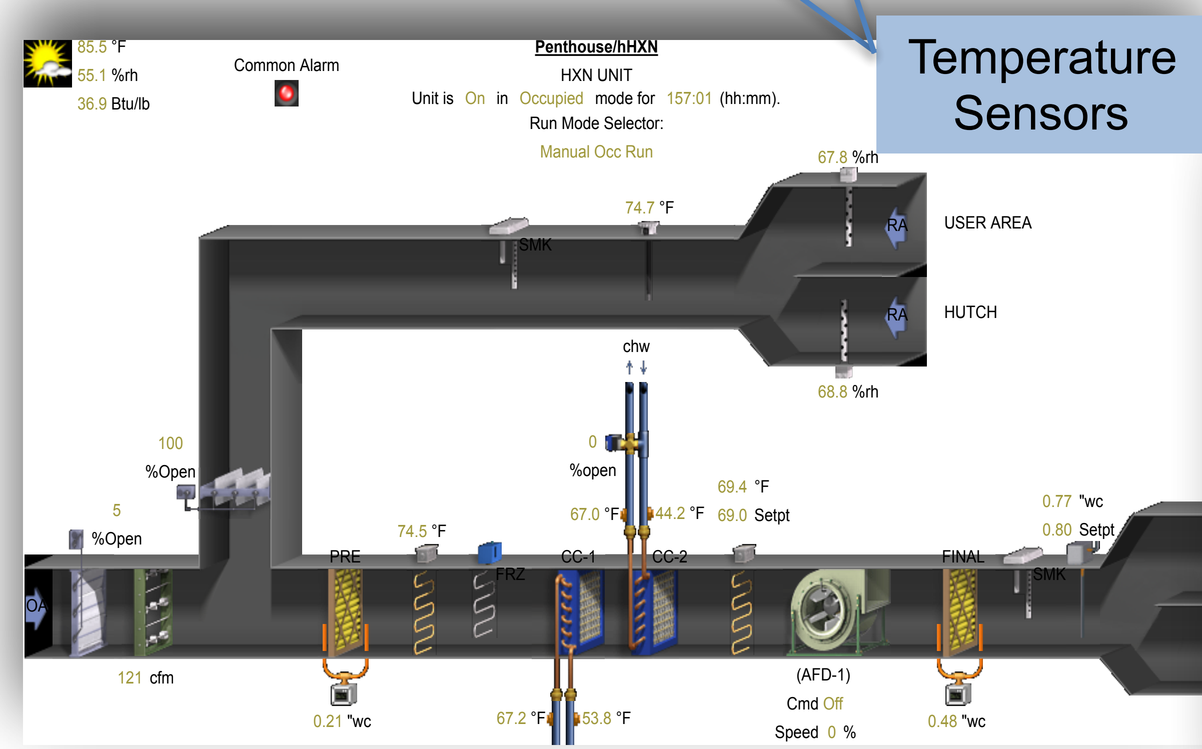
- Mount pressure reducers = Done
- Add pressure stabilizer = ?
- Switch to standalone cooler = In progress

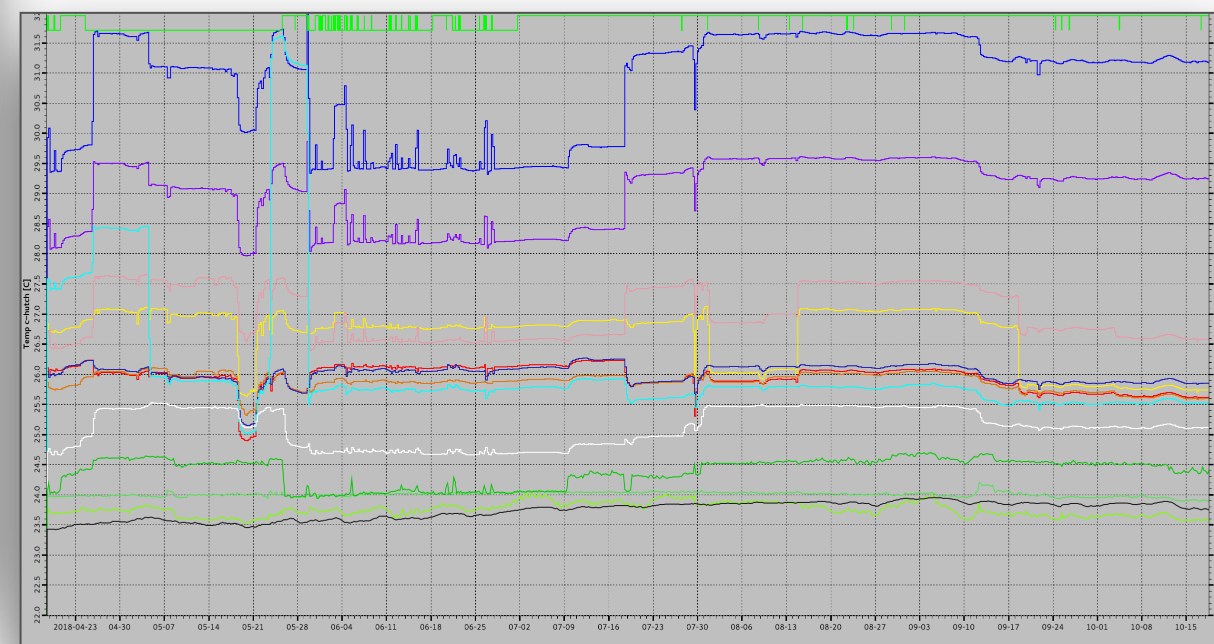
HXN c-hutch - Temperature Control



Normal ambient conditions within the Facility	
Temperature	75±1.8°F (24±1.0°C). and 75±0.9°F (24±0.5°C) over a 1 hour period.
Relative humidity	50% ±10% in summer, and, 30% ±10% in winter.
Equipment to be capable of operation in the following adverse ambient conditions	
Temperature	50°F to 100°F (10–38°C)
Normal ambient conditions within the Hutch	
Temperature	75±0.5°F (24±0.3°C) and 75±0.25°F (24±0.15°C) over a 1 hour period.

- HXN c-hutch temperature is well stabilized
- Ambient day/night variations can be a reason for SSA high variations on the order of ~ 40 um

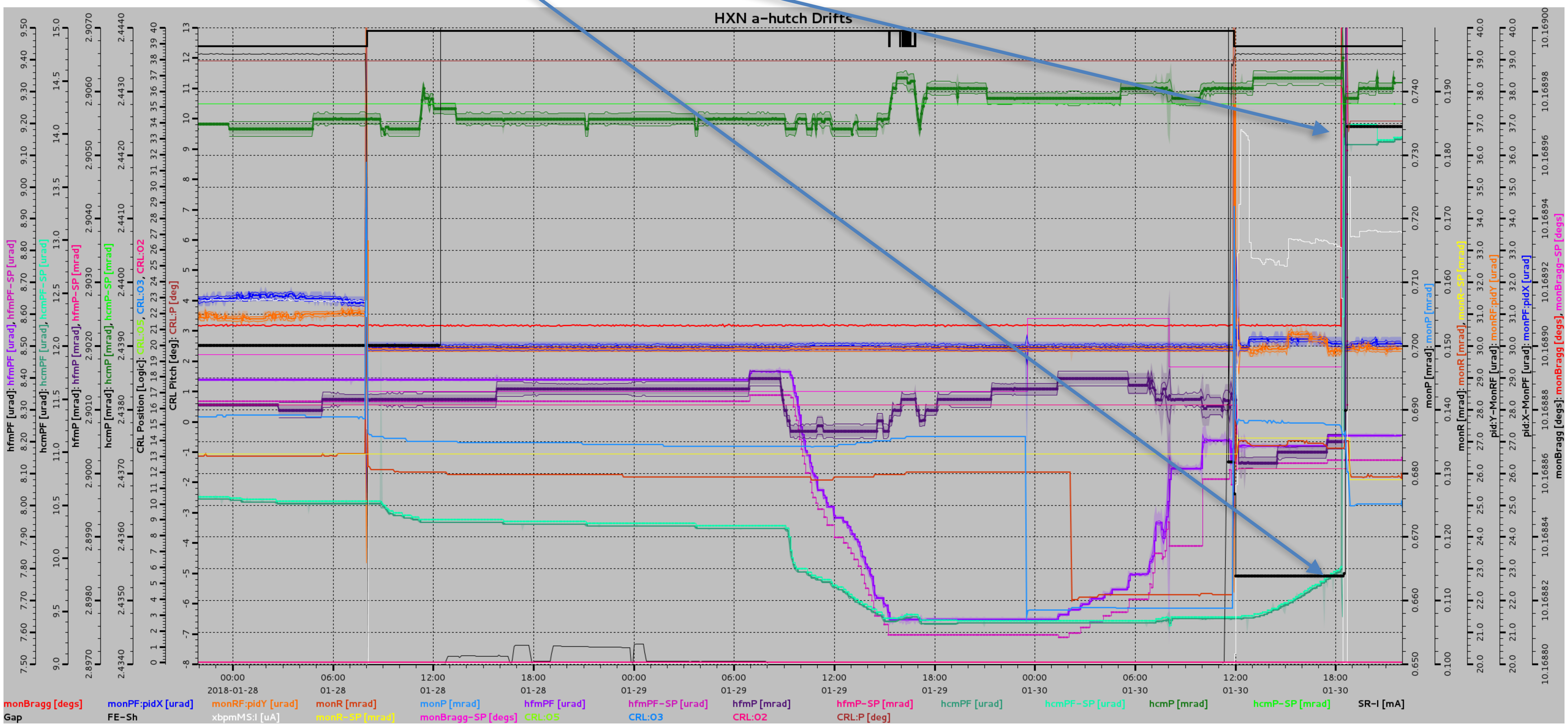




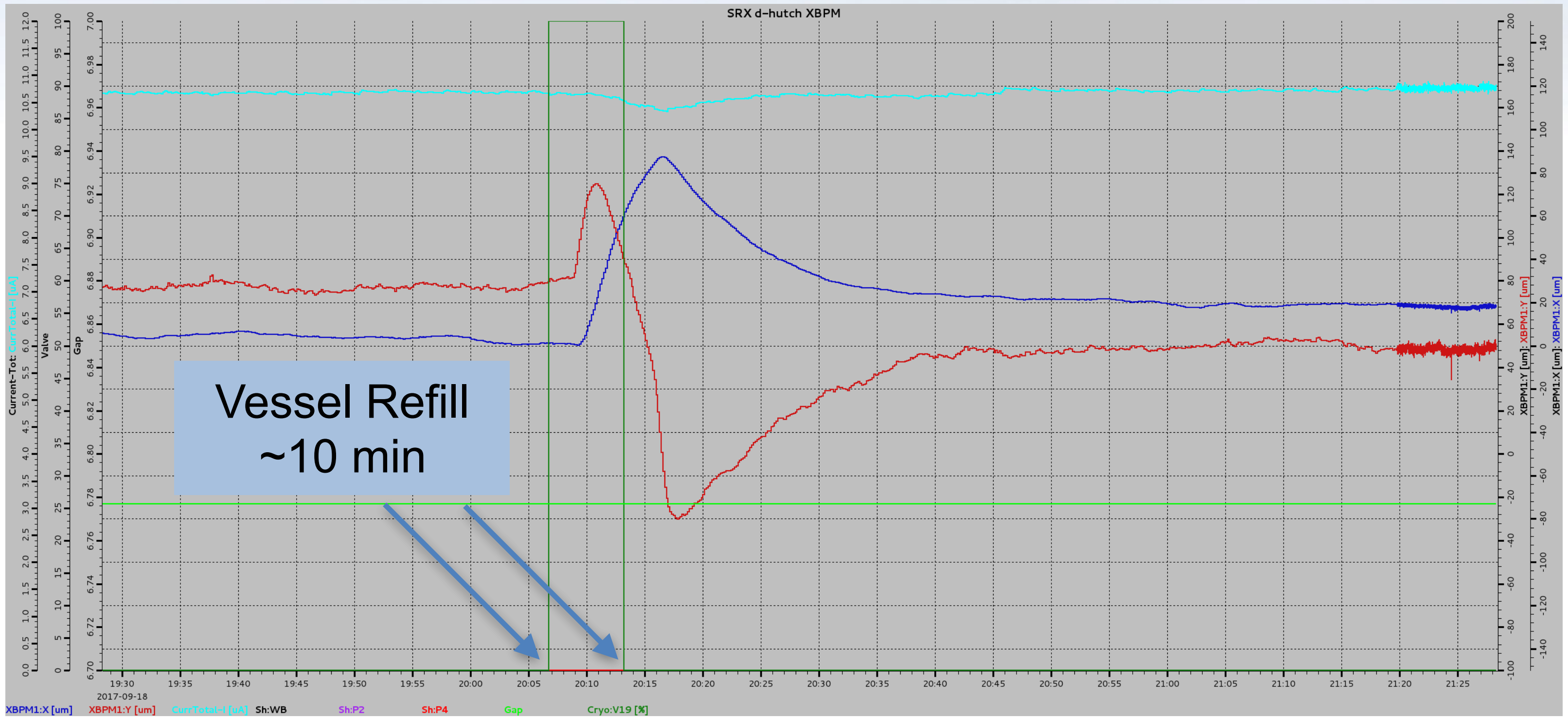
HXN a-hutch - Temperature Control

- HXN a-hutch needs 3 day to thermo-stabilized
- Thermo-load changes the mirror angle
  - HXN ID3 Gap 5.6 => 8 mm
  - hcmPF Strain Gage 8 => 13 urad

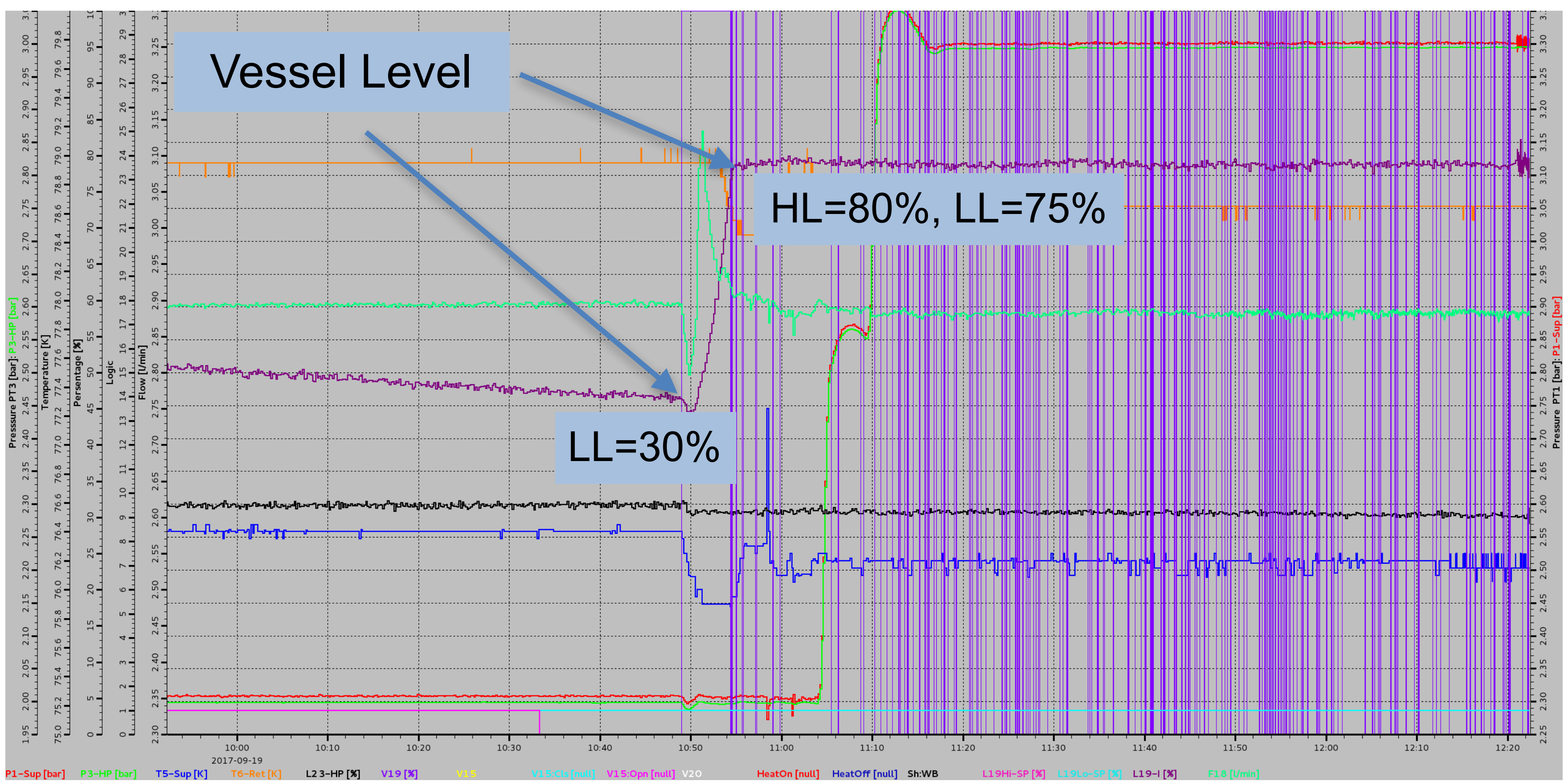
- **Solutions**
  - Limit a-hutch access
  - epid Feedback loops for a-hutch mirrors
    - HCM
    - HFM



Cryocoolers



SRX Cryo vessel refill
- took 40 min to stabilize beam
- Yp, Yp are changed by 1 urad



Solutions
- "Constant" Vessel refill
- Increasing High Pressure level

Beam Stability - Utilities, Environment

- **Environment - Control and Stabilization**
  - Temperature
    - HXN - c-hutch & User Area Temperature Stabilization
    - HXN - Microscope Temperature Monitoring
    - HXN - FE, a-hutch - 1Wire temperature sensors = in progress
  - Water-cooling
    - HXN - a-hutch Mirror1, DI Water Pressure/Flow Stabilization = in progress
    - HXN - a-hutch Mirror1, Chiller installation = in progress
  - Cryocooler
    - HXN - upgrade to FMB-O Cryocooler XV (5 bar)
    - SRX - optimization of the Cryocooler parameters

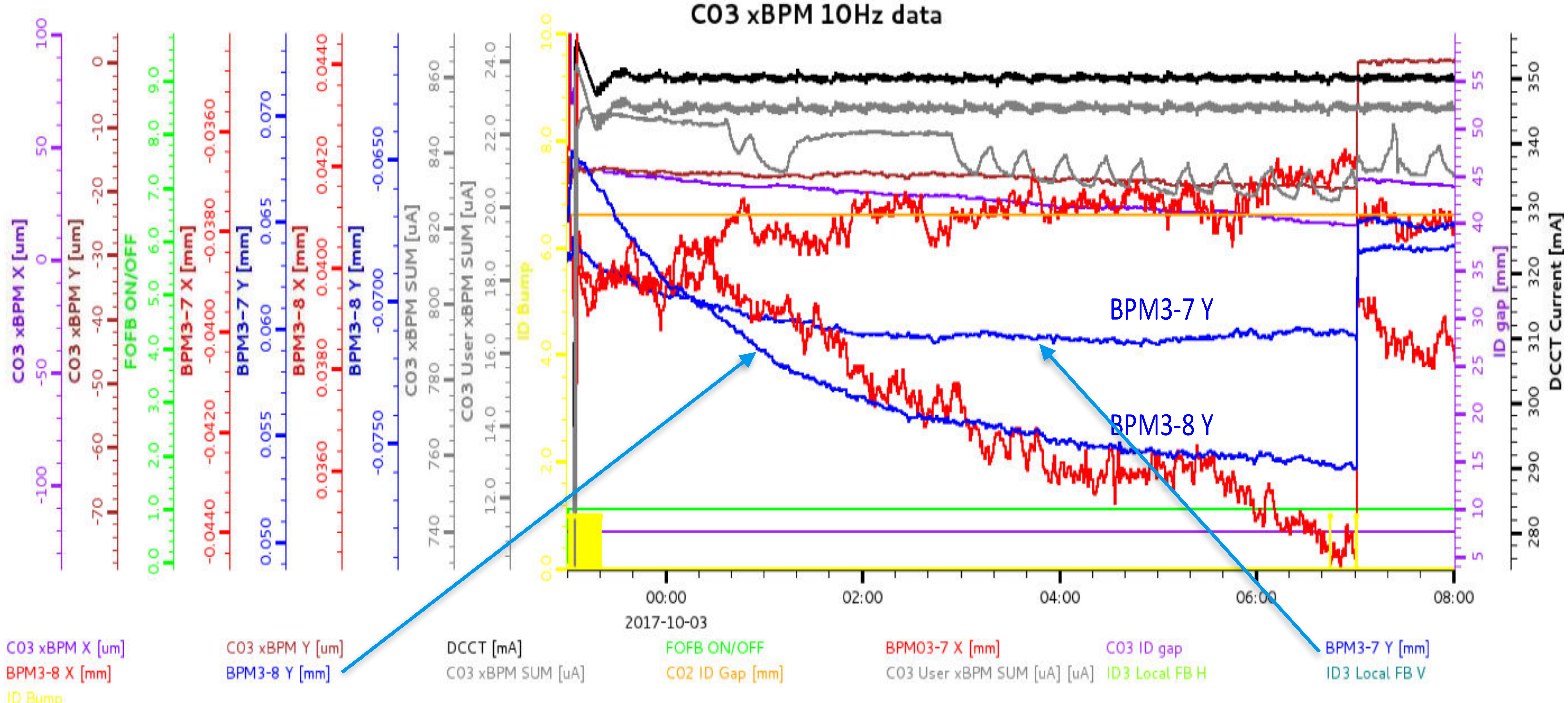
Feedbacks Hardware

White Beam X-ray BPMs Consideration

- **Redundancy**
  - Complimentary to e-BPMs
  - May help to detect and compensate e-BPMs systematics
- **Better angular resolution**
- **True Photon Beam position**
  - e-BPMs are not sensitive to the photon beam position changes due to the trajectory bumps within undulator
- **Compensate slow e-BPMs drift**
- **Optimal number of BPMs for orbit feedback**

C03 BPM8 & BPM7 Drifts after Beam Dump

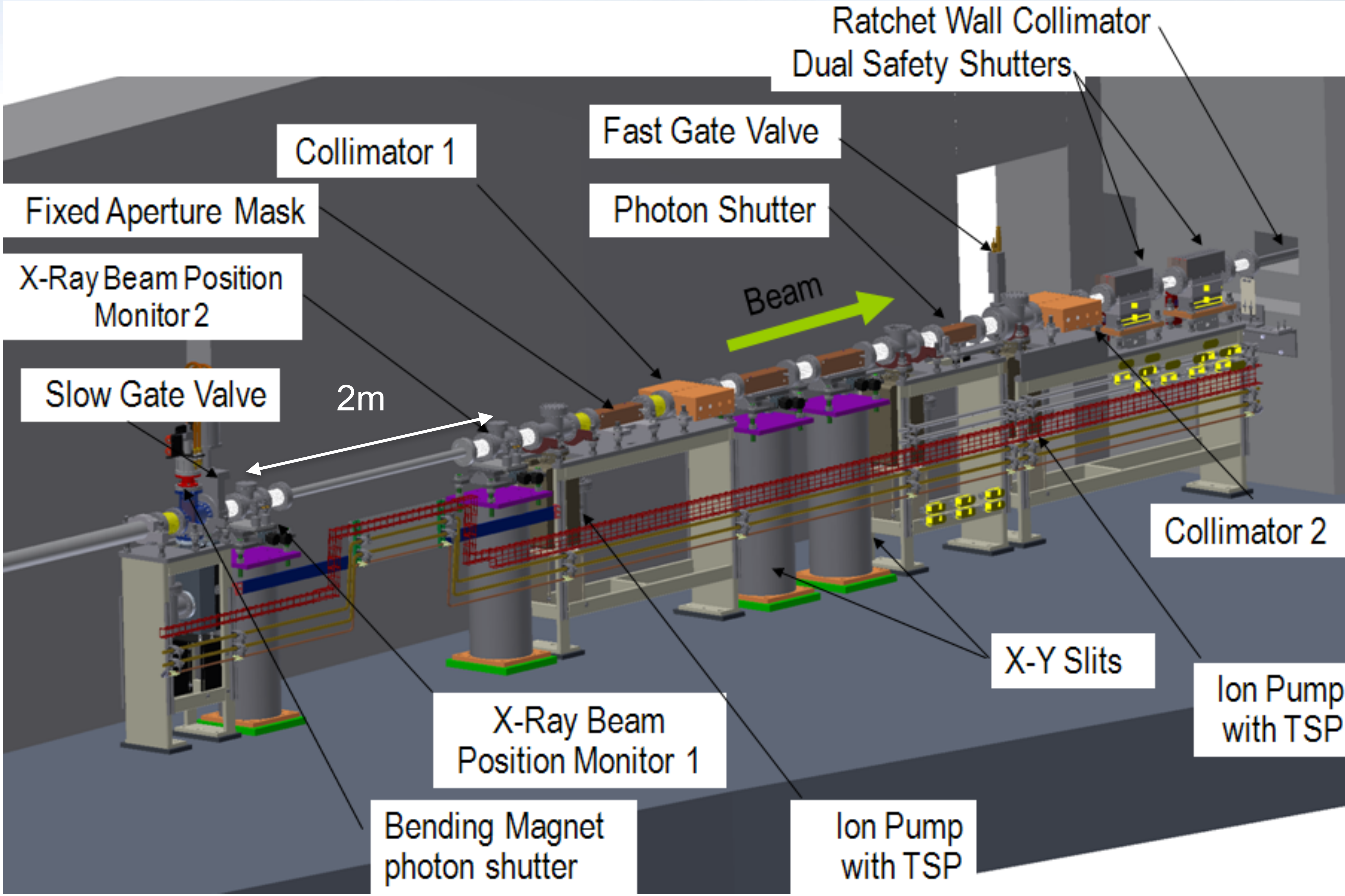
W. Cheng, Diagnostics Group, AD



Noticed significant BPM readings drift, especially at ID BPMs after refill.

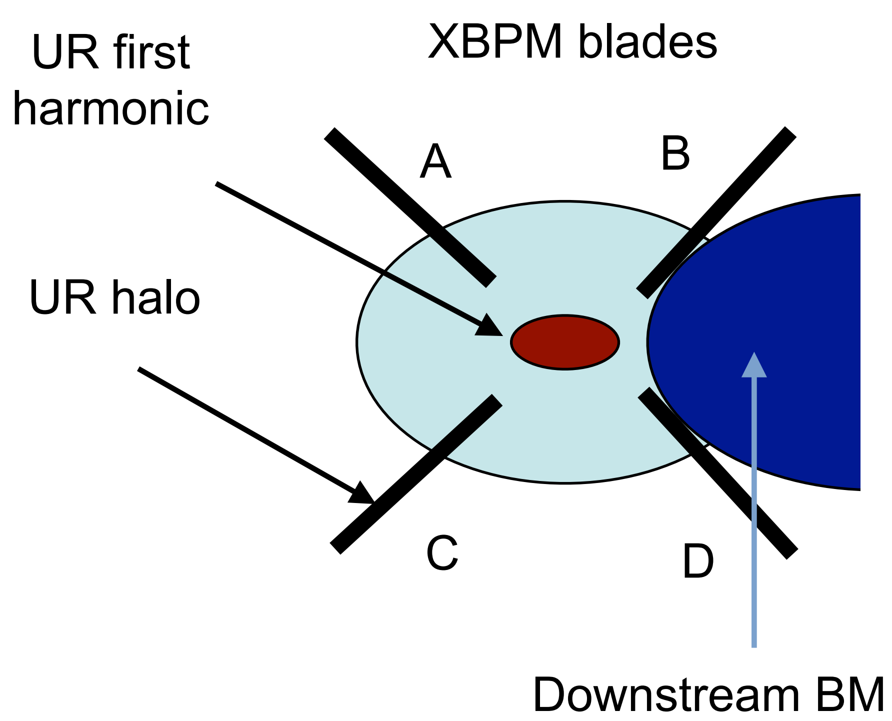
For example, BPM3-8 drifted more than 10um within several hours.

NSLS-II Front End Configuration



Blade Photoemission XBPM

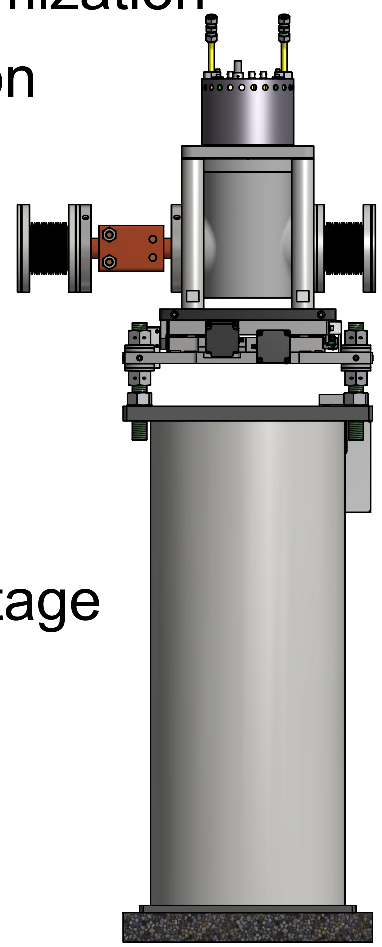
Standard type at 3d generation SR

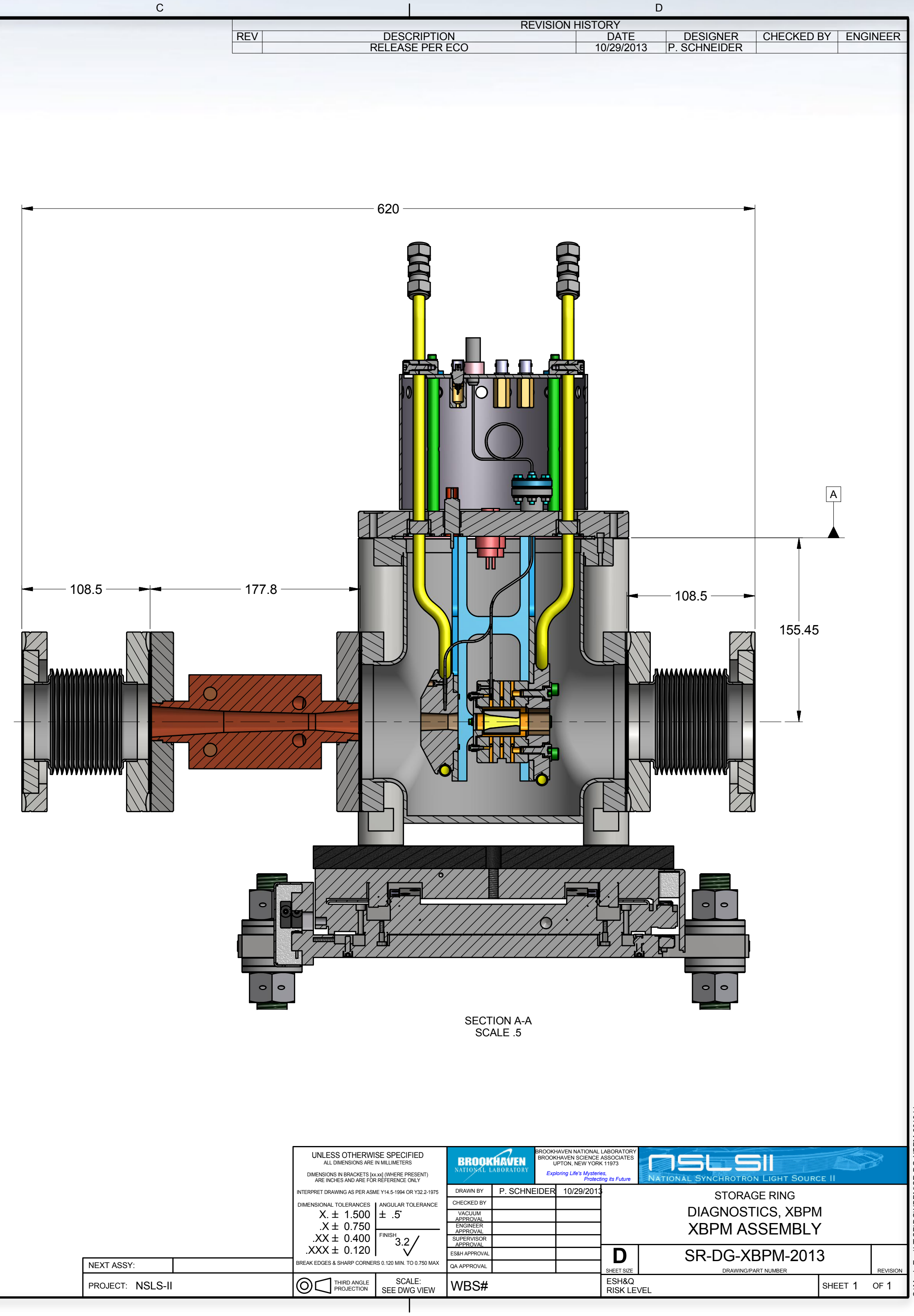


- **Operation**
  - Photo-emission
- **Pro**
  - Non-invasive
  - Good spatial resolution (in general)
- **Drawbacks**
  - Signal contamination from BM and Focusing Optics
  - Undulator gap dependent
  - Total electron yield depends on surface conditions
  - Limited linear range
  - Do not provide absolute position - calibration

Development of the NSLS-II XBPM

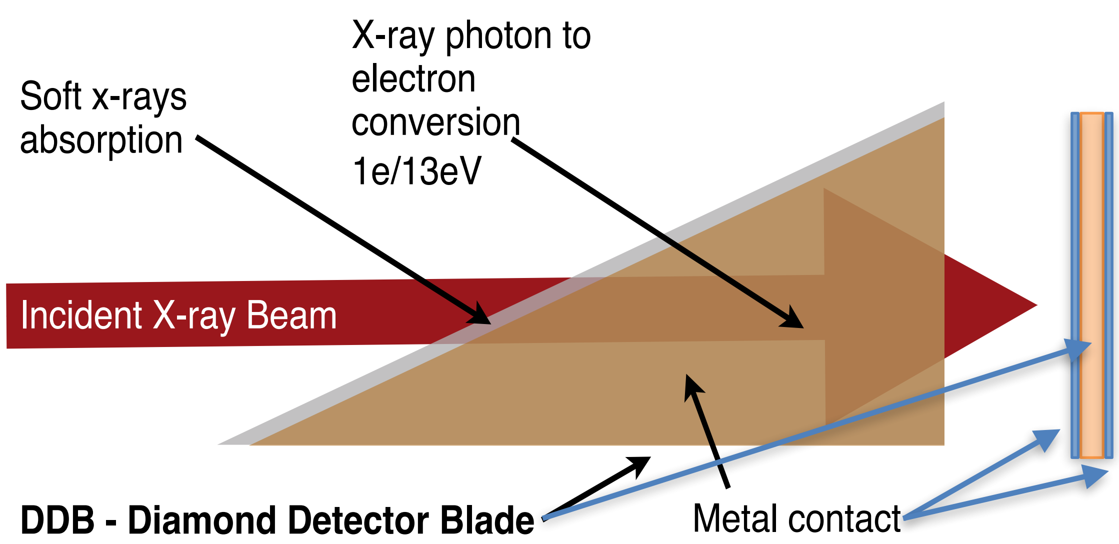
- Interaction with radiation halo
  - Photo-emission XBPMs
    - Blade material
- Optimization/Improvements
  - Signal spatial distribution
    - Blades position optimization
    - Sensitivity calculation
  - Mechanical
    - Thermo-stability
    - Vibrational stability
      - mechanical
      - water-cooling
      - removable XY-stage
  - Production
    - FMB-Berlin
    - NSLS-II

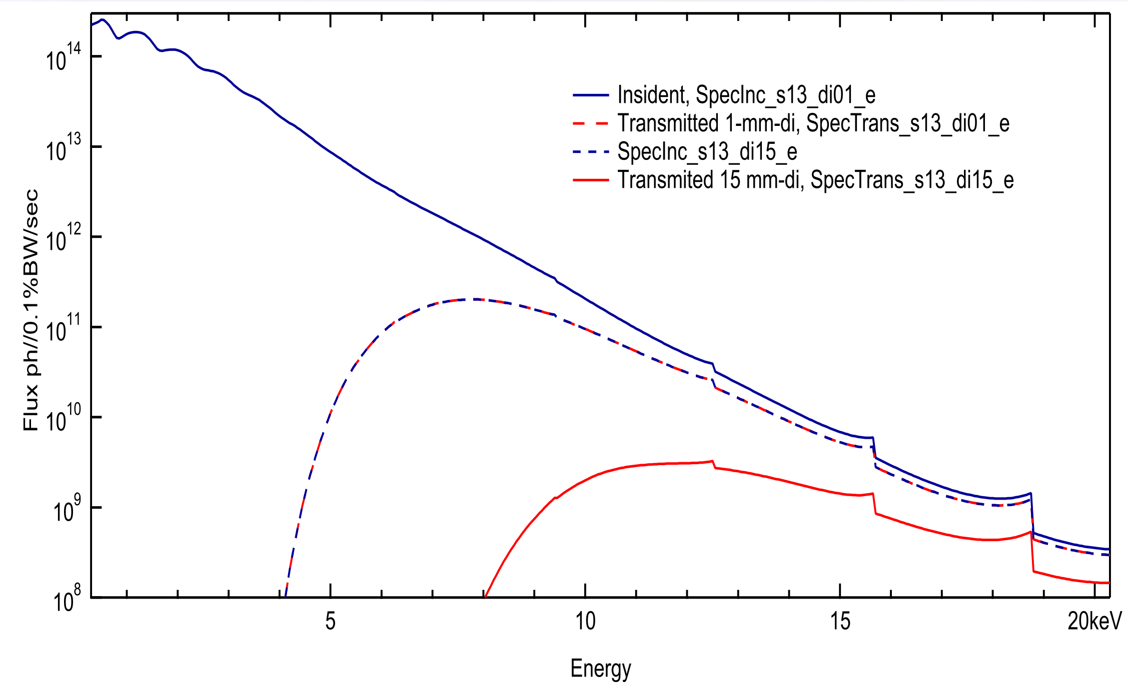


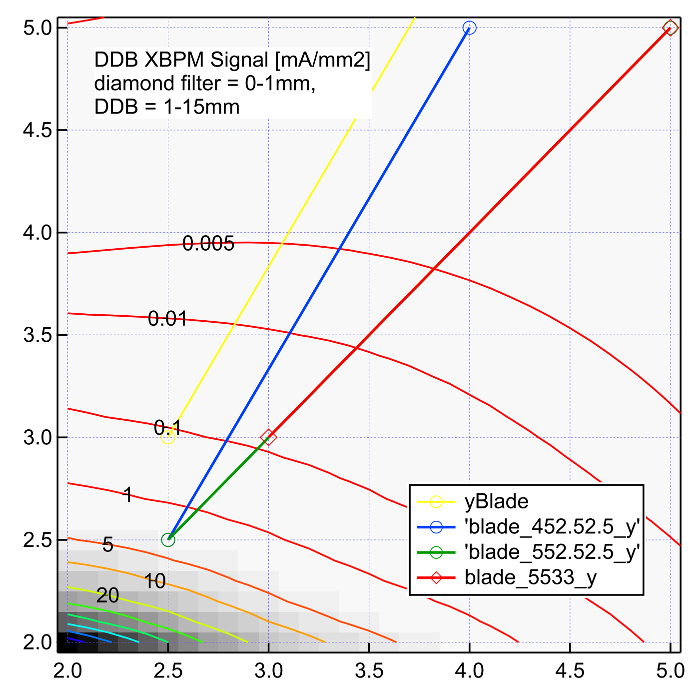


Diamond Detector Blade (DDB) XBPM

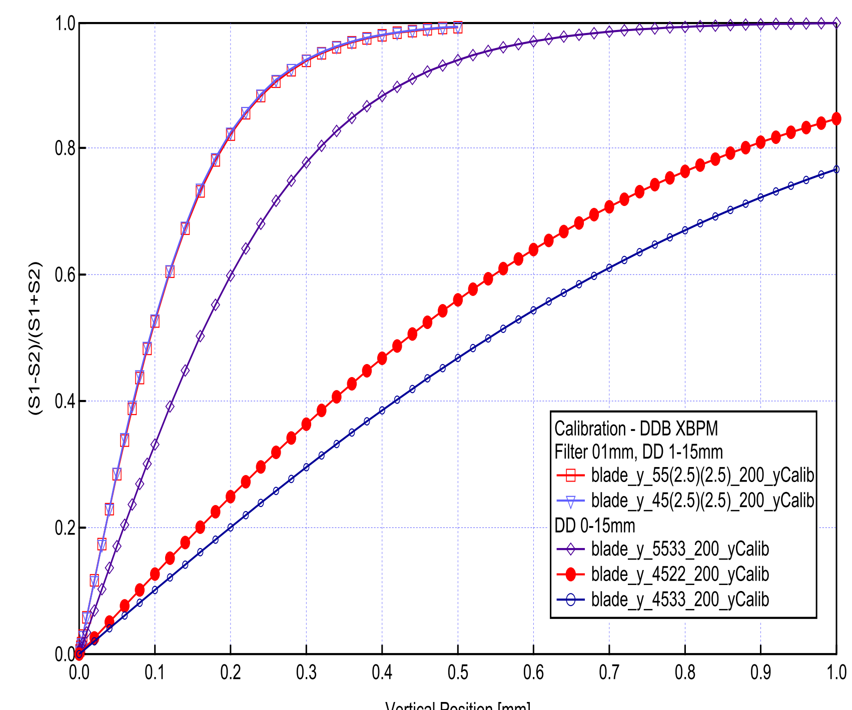
P. Ilinski, *Optimization of NSLS-II Blade X-ray Beam Position Monitors: from Photoemission type to Diamond Detector,* Journal of Physics: Conference Series 425 (2013)







DDB XBPM Signal density distribution

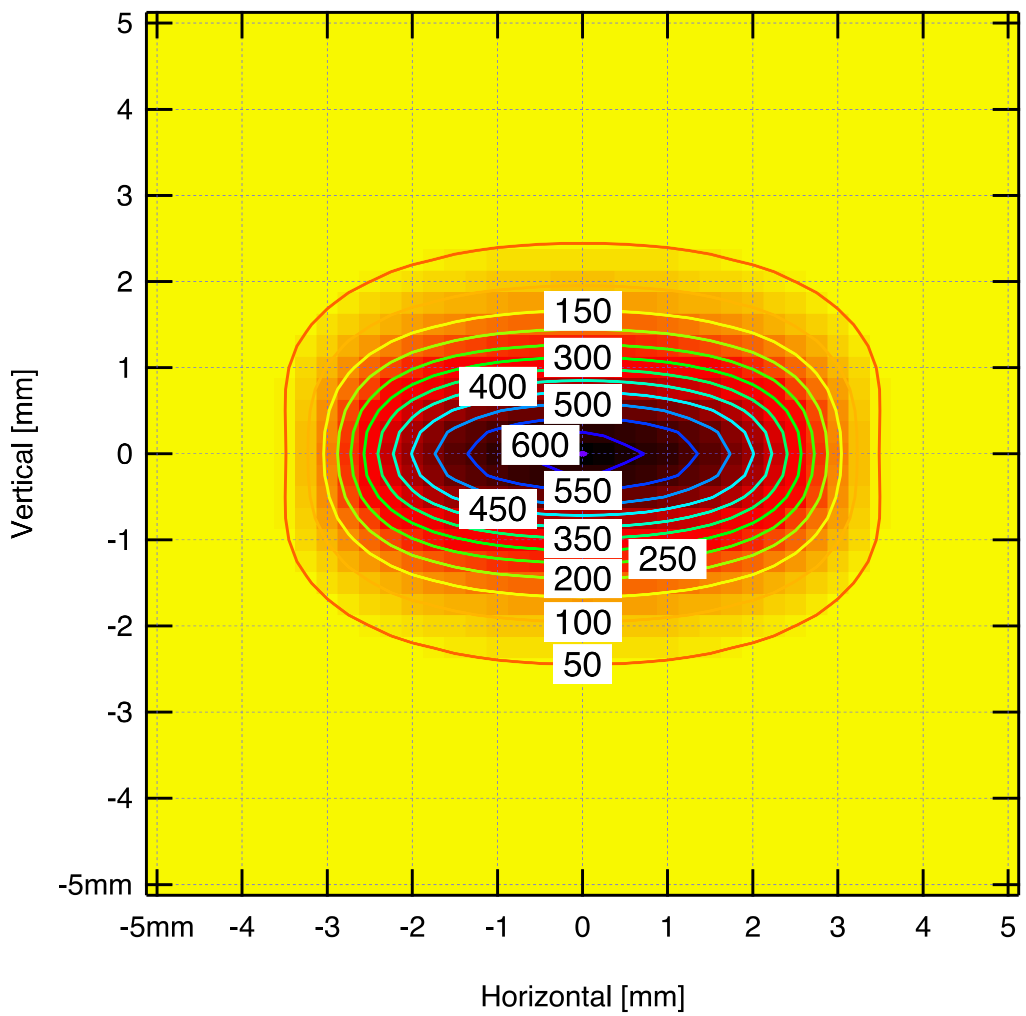


DDB XBPM Calibration Curves

XBPM Signal

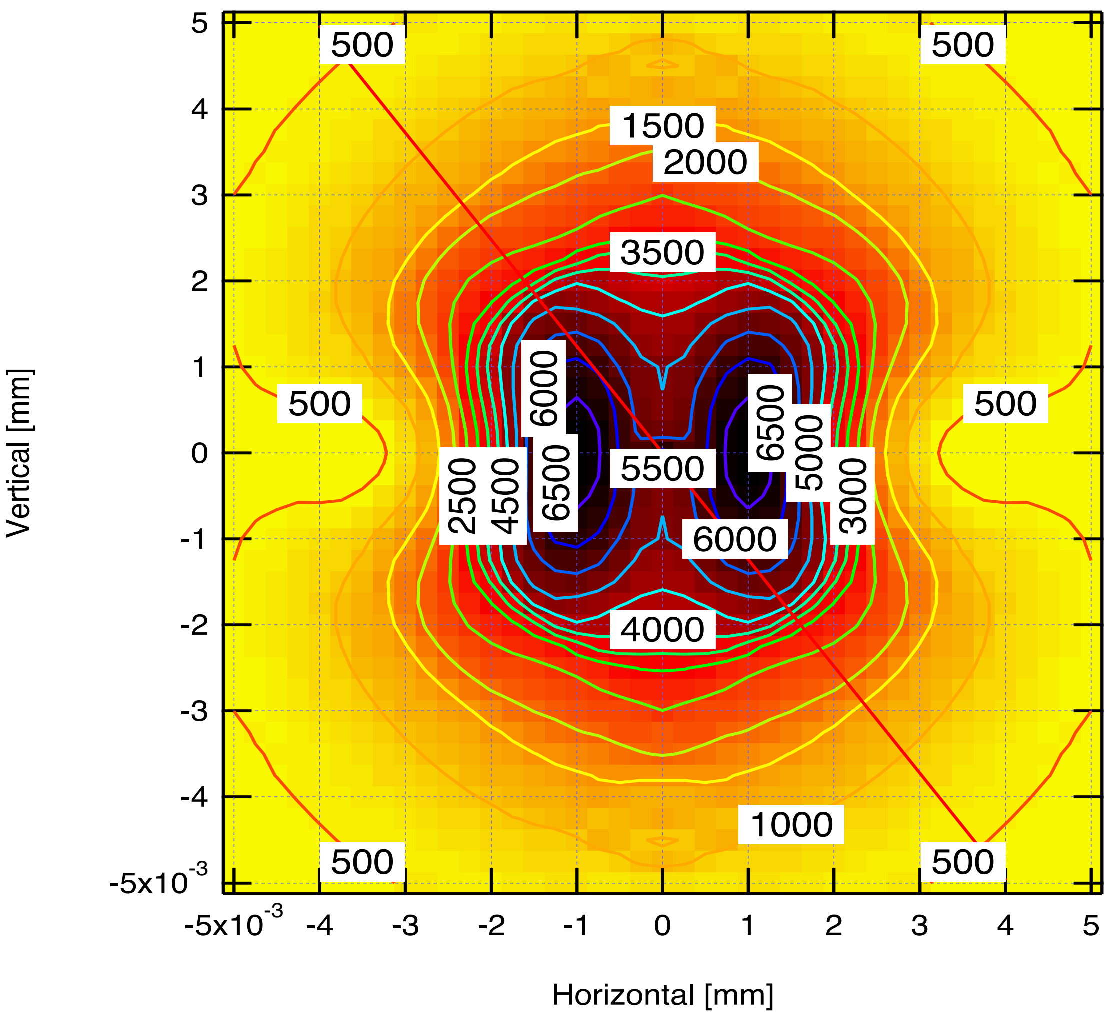
DDB XBPM Signal will be proportional to Incident Power

Incident Power density [W/mm2] (vs. x,z)



NSLS-II IVU-20, 10m, K=1.8, Tungsten Blades

XBPM signal density distribution [uA/mm2] (vs. x,z)



Diamond Detector Blade XBPM Summary

- **Operation**
  - Photoionization (12 eV/electron)
- **Pro**
  - Perfect thermo-load capabilities
  - Self-discrimination for low-energy photons
  - May have a varied thickness front diamond filter
  - Existing FE Blade XBPMs can be refurbished into DDB XBPM
  - Plenty of signal - good resolution
  - No contamination of signal
- **Drawbacks**
  - Single source (E6) for single polycrystal diamond detector grade material
  - Need development and testing
- **Development**
  - Resistive contacts for energy discrimination
  - Single counting with energy discrimination

White XBPMs Summary

- FE XBPM is a valuable photon beam diagnostics tool
- FE XBPM was integrated into e-beam Photon Local Feedback
- Development
  - Best, if FE XBPM can be combined with Pre-Mask and Fixed Mask into one component
  - APS GRID-XBPM
  - Diamond Detector Blade XBPM

Mono XBPM Types

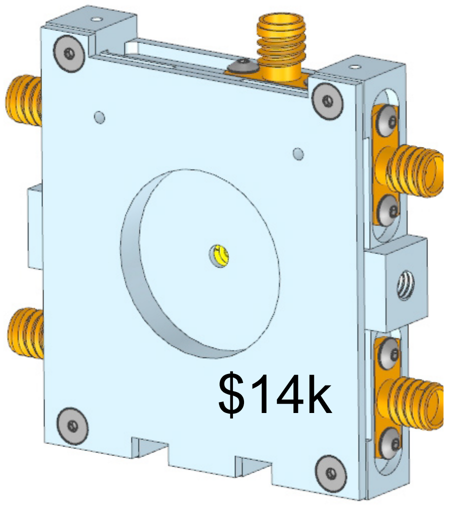
- **Interaction with radiation halo**
  - Photo-emission XBPMs
  - Fluorescence XBPMs
- **Interaction with radiation central cone**
  - Solid state (filter, window, mirror, crystal)
    - Photoionization - solid state ion chamber
      - **Single Crystal Diamond**
    - Luminescence
    - Scattering
  - Gas (residual, high pressure)
    - Photoionization
    - Luminescence

Mono XBPMs Consideration

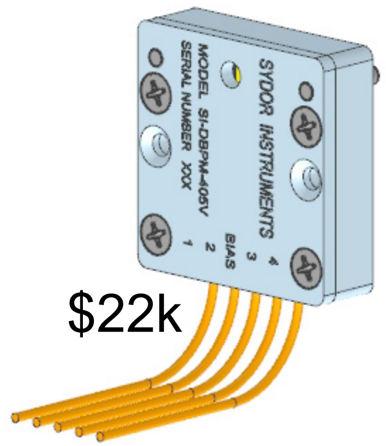
- **Invasive - choice of interaction matter**
  - the uniformity of the response can be an issue with XBPM thickness decrease
  - 1-um-thick metal foil (pioneered at APS)
  - 6-um-thick Si PSD (BESSY)
  - 10-um-thick polycrystalline diamond Quad (SLS)
  - 4÷40-um-thick diamond single detector grade crystal - Quad (BNL)
  - 10÷40-um-thick diamond single detector grade crystal - Duo-lateral (SOLEIL)
- **Resolution vs. FoV, Fast vs. Slow**
  - Quadrant (lock-in)
  - PSD - resistive, imaging
- **HXN and SRX XBPMs**
  - 1-um-thick Cu and Ti foils (need to exchange foils, position is not reproducible)
  - 40-um-thick diamond single detector grade crystal - Quad (Sydor $22K)
  - 40-um-thick diamond single detector grade crystal - Duo-lateral (CEA, Euro6K)

Commercial Diamond XBPM

SYDOR Technologies had partnered with BNL (SBIR) to commercialize
Diamond Beam Position Monitors and Readout



X05 Package
Compact Offset



X00 Package
Post Mounted

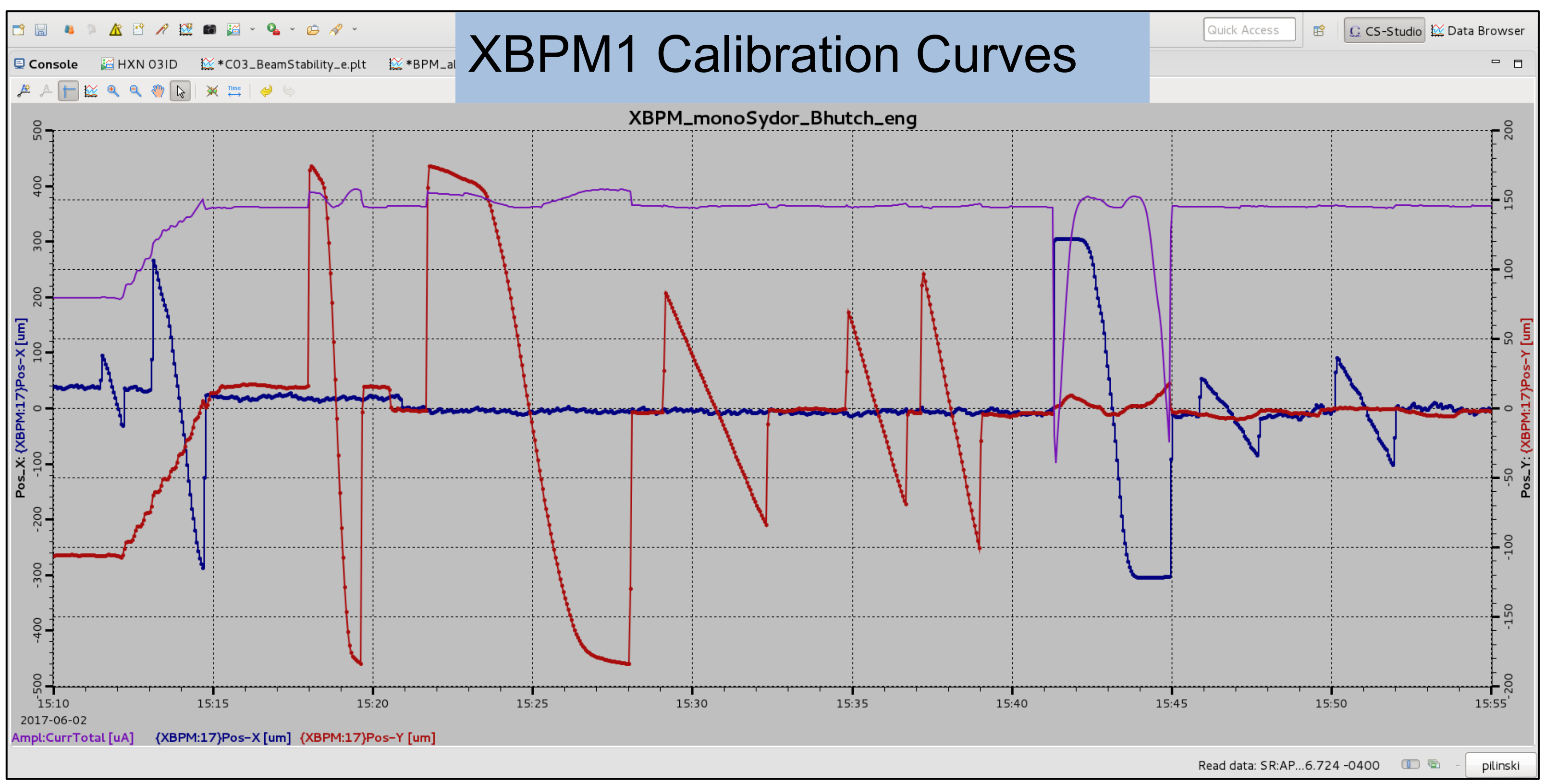
SYDOR Diamond XBPM

- 40-um-thick single crystal CVD diamond (Element-6)
- Quadrants electrodes - 40-nm-thick Pt

SYDOR EP-A3P Electronics Module $25K

- NSLS-II FE XBPM Electrometer
- Bias
- PID board (SBIR)

XBPM1 Calibration Curves



Beam Size @ XBPM1
~ 600x300 um (HxV)

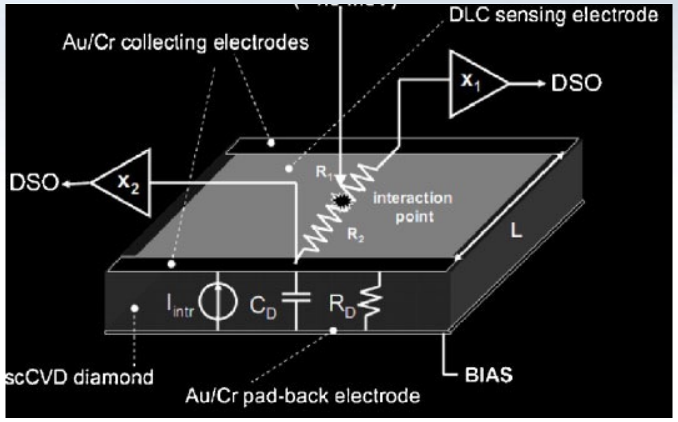
- Spatial resolution and Linearity Range depends on the beam size
- Needs X,Y re-centering

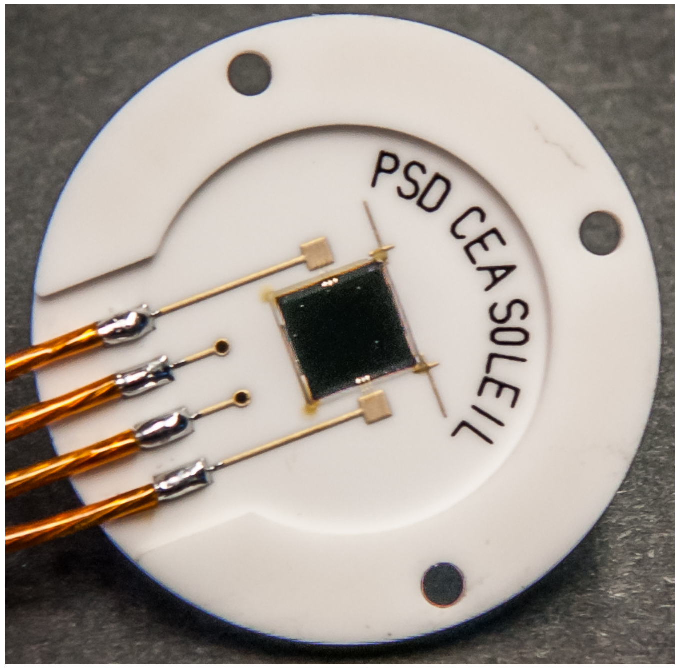
Diamond Resistive XBPM

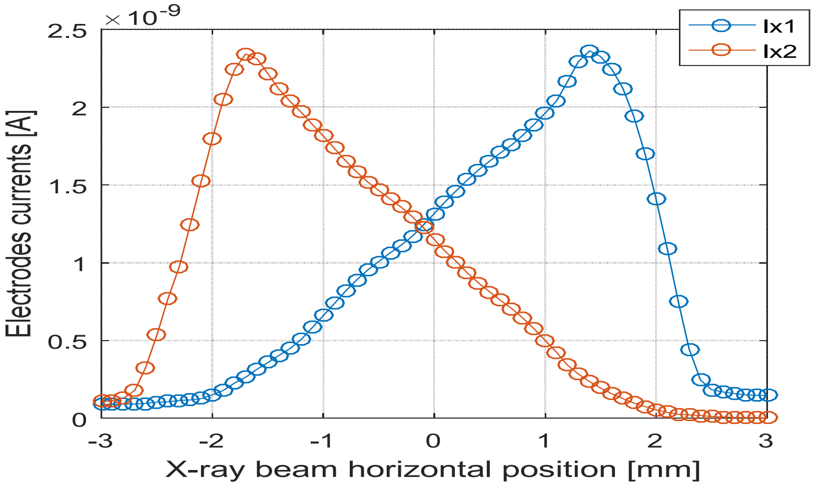
- Position Sensitive Detector (PSD)
  - A duo-lateral PSD XBPM made of a single crystal CVD diamond with restrictive diamond-like carbon planar electrodes
- Development/Production
  - Diamond Sensors Laboratory, CEA-LIST, France
- Operation
  - SOLEIL, France

Diamond plate	4.5 mm x 4.5 mm Single Crystal CVD diamond electronic grade Type, with <5 ppb of nitrogen impurities from Element Six Ltd.
Diamond plate thickness	40 µm
Active area	3.5 mm x 3.5 mm

- Pros
  - Large linear working area (no need to recenter)
  - Sensitivity can be tuned by resistivity
- Cons
  - Slower response, compare to Quadrant type
- Note
  - Need to adjust resistivity to signal range
  - Needs electrometer with different Bias inputs







Diamond XBPM Summary

- **Operation**
  - Photoionization (12 eV/electron)
- **Pro**
  - Low absorption
  - High efficiency (plenty of signal) - good resolution
  - Very fast
- **Drawbacks**
  - Single source (E6) for production of detector grade single crystal diamond
  - Metal (Pt, Ag) Quad contacts
    - non-uniform transmission or phase contrast
    - slit/edge diffraction
- **Development**
  - Diamond XBPMs with resistive electrodes were developed at CEA, France
  - Need the development and production of resistive type diamond XBPMs
  - Diamond XBPM with p-i-n structure can be advantages

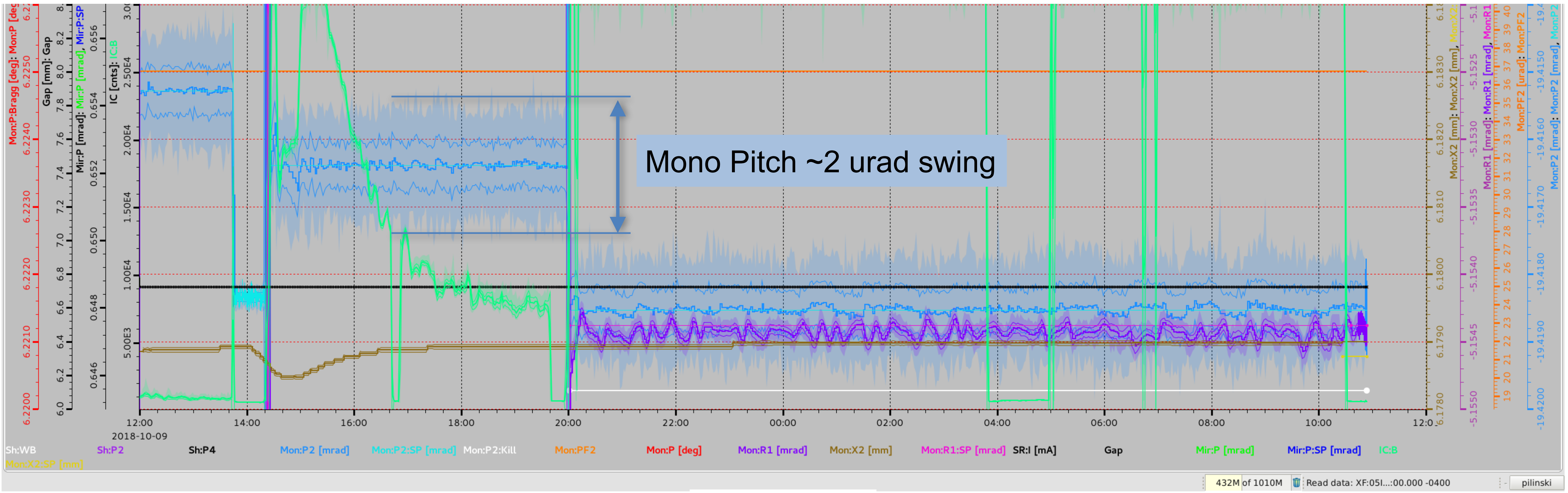
Beamline Local Feedback Systems at HXN and SRX

- **Feedback Controllers**
  - FPGA Controller
    1. Sydor Electrometer+PID (based on NSLS-II FEXBPM Electrometer), $22K
    2. CAEN BEST, >$40K
    3. NSLS2_EM Electrometer+PID, $1.5K (PicoZed FPGA, J. Mead, Instr. Div., BNL)
  - PID Feedback implementation
    1. Linux, C++, 1 kHz (Sydor): proprietary
    2. FPGA, 100kHz (CAEN): proprietary
    3. Linux, Fast (10 kHz) - Asyn driver, Slow (10 Hz) - EPICS ePID: M. Rivers, APS

- Diverse choice of the Feedback Controllers
  - Need of unification
- Luck of software developers
  - Hard to improve and modify software/firmware

Optical Components - Design Considerations

- Feedback for Axis with course (stepper motors) and fine motion (piezo-actuator)
    - piezo-actuator may not need the sensor in case if total encoder has high resolution (SRX HFM)
- Angle flexures can bee too soft, which makes it difficult to implement any feedback (SRX Mono)



- Slow epid Feedback to change Setpoint of the Mono 2nd crystal Pitch Fast Feedback
    - Feedback bandwidth may not be sufficient
- Install damper for Mono 2nd crystal Pitch
- Consideration at the stage of component design

Summary

- **Beam Stability**
  - Depends on many parameters
  - Needs coordinated efforts of multiple groups (PS, AD, Instr.Div.)
  - Better be a single inter-division group responsible for beam stability
- **Feedback**
  - Beamline Local Feedback is a necessity
  - SR Local Photon Feedback - great approach (BSTF), needs improvement
- **XBPM**
  - White-beam FE X-ray BPM
    - should be implemented for all beamlines
    - development - can be upgraded to DDB XBPM
  - Mono-beam BL X-ray BPM
    - Shortage of the detector grade single diamond crystals
    - Currently expansive
    - Resistive diamond XBPM - preferred choice
- **Hardware**
  - NSLS2_EM - preferred choice
  - NSLS2_EM modification for Resistive Diamond XBPM - in progress
- **Staff Expertise**
  - Asyn Driver - support, modifications
  - FPGA Controller - FPGA programing

Beam Stability Group Objectives

- **Consolidate Specifications**
  - site vibrations/temperature/geographic
  - e-beam
  - photon beam
- **Beam Stability**
  - Define best approaches and practices
  - Implement e-beam and photon beam feedbacks
  - Monitor
  - Support
- **XBPM**
  - white-beam FE x-ray BPM
    - maintenance
    - development
  - mono-beam BL x-ray BPM
    - maintenance
- **Hardware**
  - specs for optical components feedbacks
  - maintenance
- **Resources**
  - e-beam, photon beam diagnostics scientists
  - accelerator scientist (engineer) - orbit feedback
  - controls engineers - epics, FPGA support

Supplemental

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FPGA Programming

CAENels BEST IRR filter