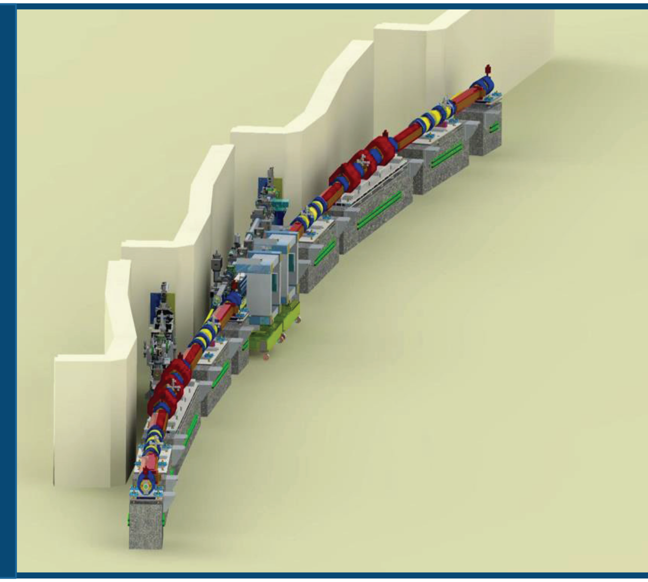
NEXT GENERATION X-RAY BPM DEVELOPMENT FOR THE ADVANCED PHOTON SOURCE UPGRADE



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Future Light Source 2018, Shanghai, China
March 5, 2018

Outline

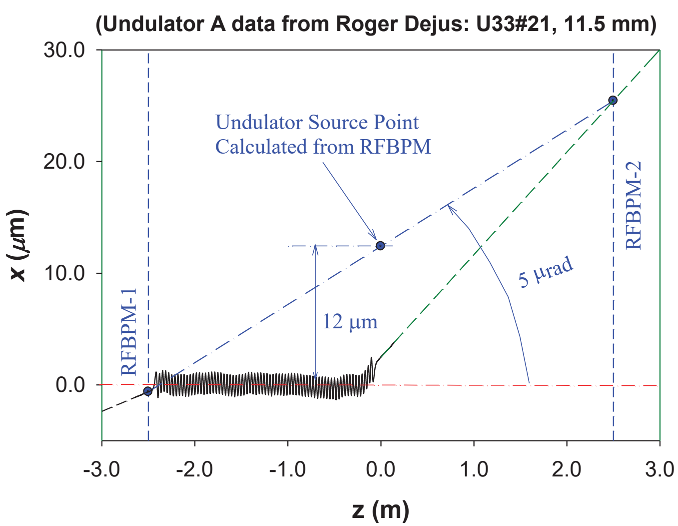
- Introduction: undulator x-ray beam position monitors
- Challenge of reliable white-beam undulator XBPMs
- The APS solution: GRID-XBPM and its performance
- Improving XBPM for APS Upgrade
  - Optimizing individual readout detectors
  - Array readout detectors and optics
  - Compton XBPM for low-power undulators
  - XBPM electronics
- Summary

Intro: Use of undulator beam XBPM

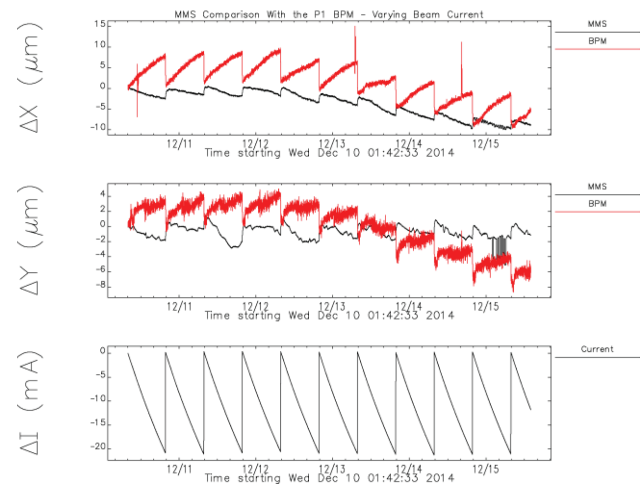
Main use of XBPM: Maintain long-term x-ray beam **angle stability** for user beamlines in the time scale of 1 second to 1 week.

Causes of beam motion, even with good RFBPM in feedback:

- From RFBPM: mechanical motion of chamber/XBPM, BPM bunch pattern dependence and other electronics artefacts, …
- Other factors: undulator steering, uneven air and water temperature changes, tidal / seasonal motion of ground, building structures, …



Electron trajectory in an undulator



Chamber RFBPM motion with current.

Intro: APS-U XBPM Requirements

The APS-U beam stability goal (10% of the x-ray beam size)

	Plane	RMS AC motion (0.01 – 1000 Hz)		RMS long term drift (7 days)	
APS-Upgrade goals	Horizontal	1.3 μm	0.25 μrad	1.0 μm	0.6 μrad
	Vertical	0.4 μm	0.17 μrad	1.0 μm	0.5 μrad

XBPM beam stability requirements (Z = 20 m)

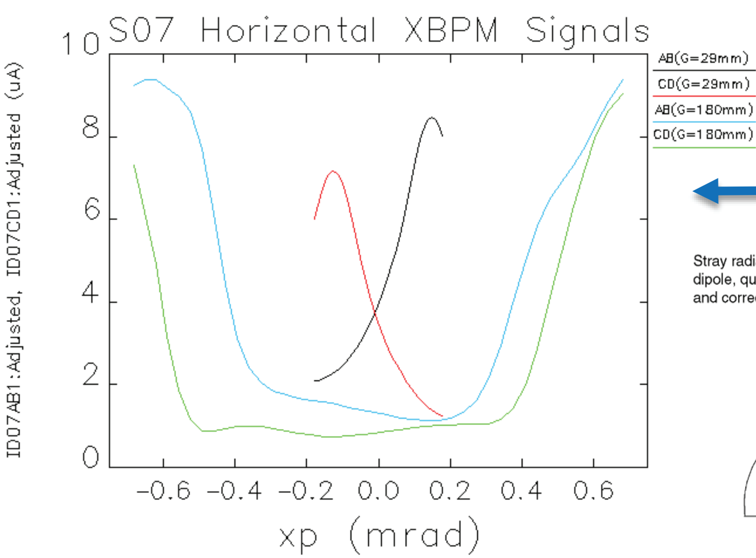
	Plane	RMS AC motion (0.01 – 1000 Hz)	RMS long term drift (7 days)
X-ray beam position tolerance	Horizontal	5.2 μm	12.0 μm
	Vertical	3.4 μm	10.0 μm
XBPM error budget (~70%)	Horizontal	3.5 μm	7.9 μm
	Vertical	2.2 μm	6.2 μm

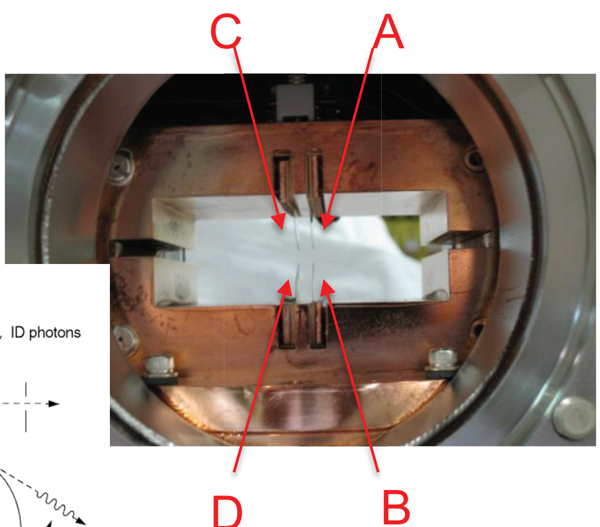
Existing photoemission XBPM not good: gap dependence 100's μm, after correction 10's μm!

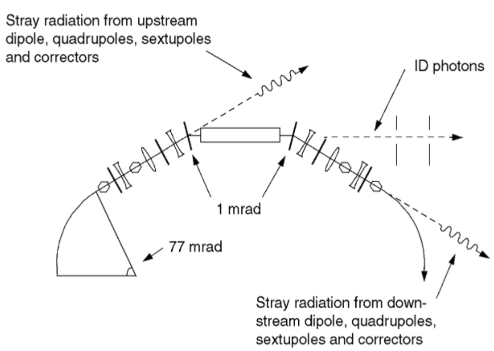
Challenge: problems with old APS XBPM

Old XBPM characteristics:

- Photoemission (PE) signal: Diamond blades with gold coating. Blades are far from beam center from reducing power load.
- Strong bend magnet background: with low threshold energy, PE current is nearly independent of magnet fields. At K = 0.5, the BM background is up to 10-times of the signal ➔ The XBPM is useful only at high undulator power levels (K > 1).





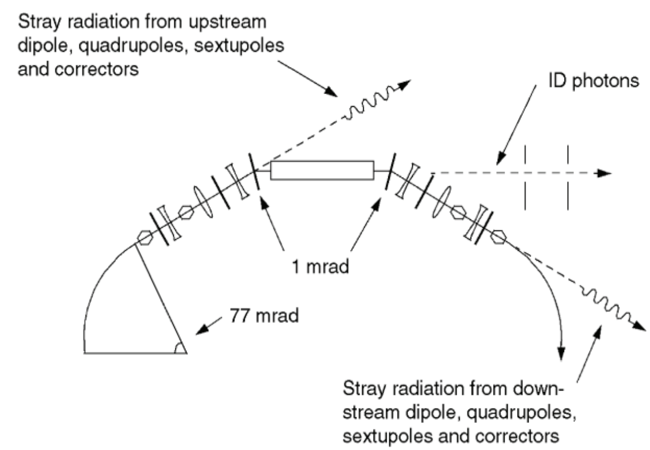


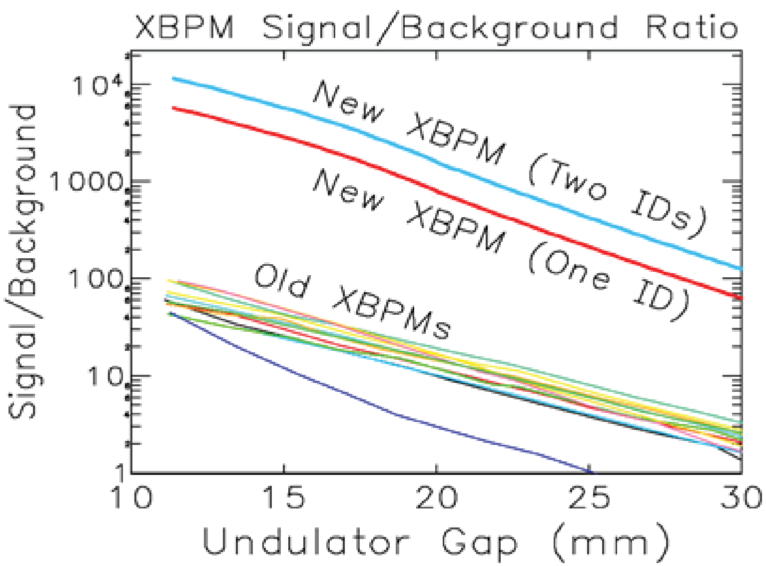
PE-XBPMs do not meet MBA requirement due to BM background.

Solution: Decker Distortion and new XBPM

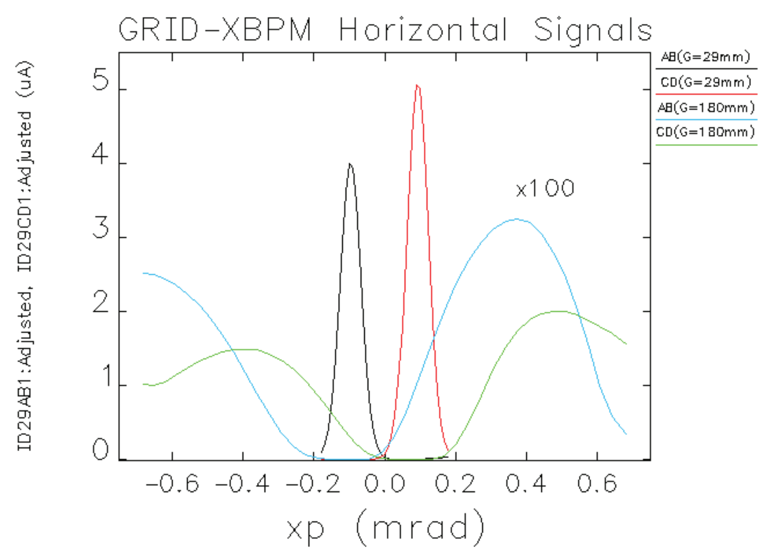
Two major parts in the APS approach for x-ray beam stability:

- Decker distortion ➔ simplify / reduce / soften BM background
- Hard x-ray beam position monitor ➔ insensitive to low-energy x-rays





Undulator signal / BM background ratio

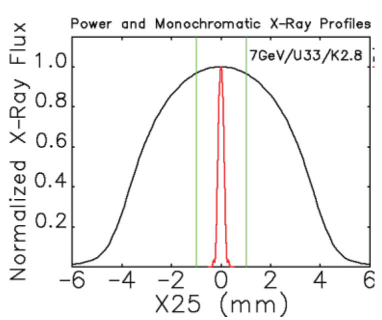


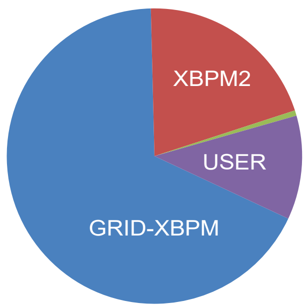
Next generation hard x-ray BPM has dramatically reduced BM background

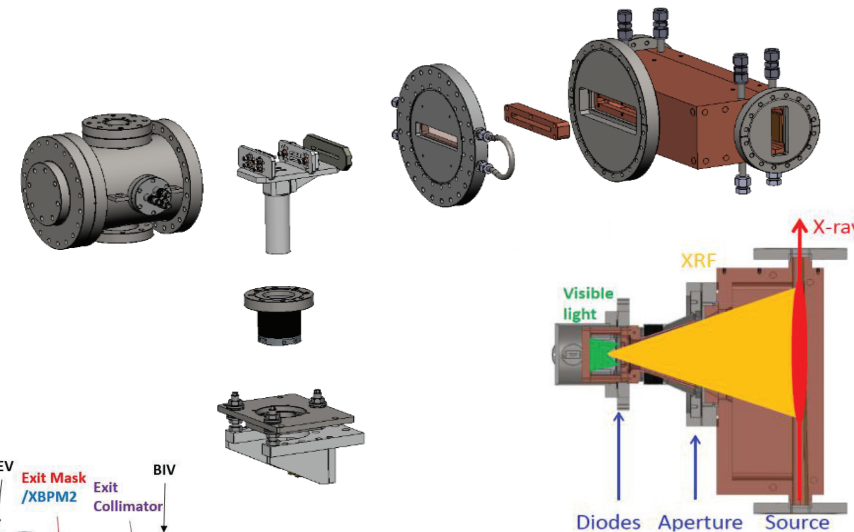
First unit: full test in 27-ID front end

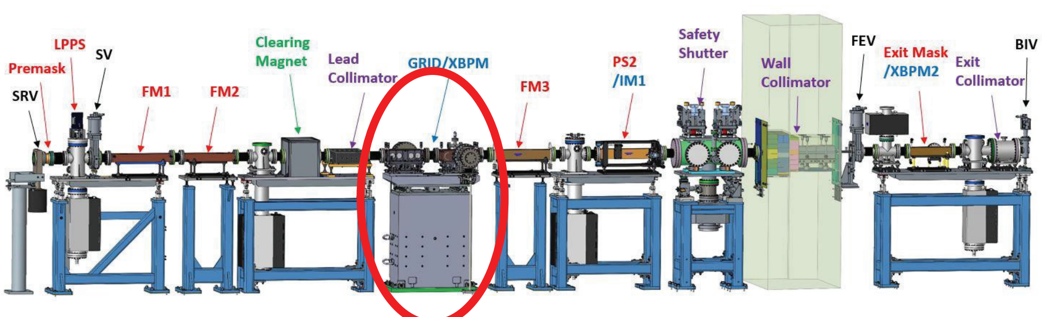
In the front end, most intercepted power falls on the two XBPM's. Design features of the Grazing Incidence Insertion Device XBPM (XBPM1):

- GlidCop absorber takes most beam power at min gap (14 kW/22 kW).
- Independently supported imaging slits and detector.
- Granite support for mechanical stability.
- Position monitored by mechanical motion sensor with hydrostatic level.



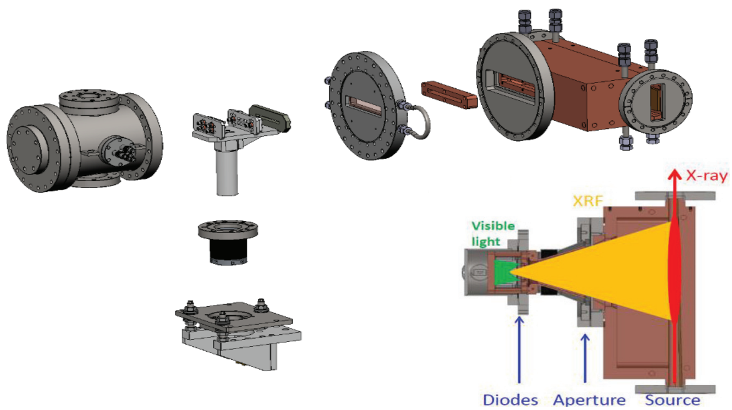


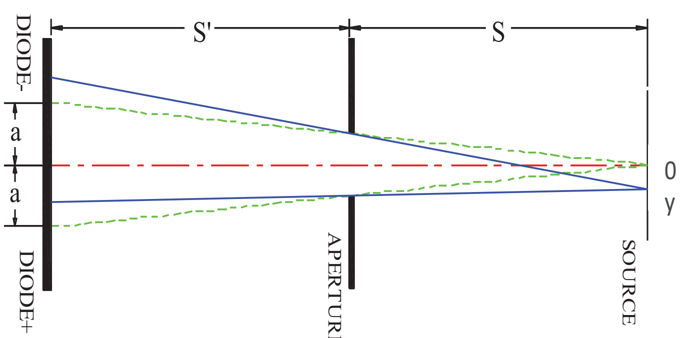


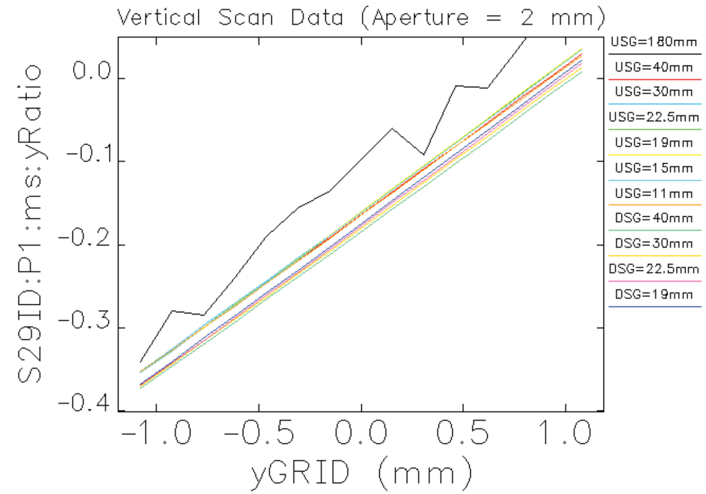


GRID-XBPM: vertical plane readout optics

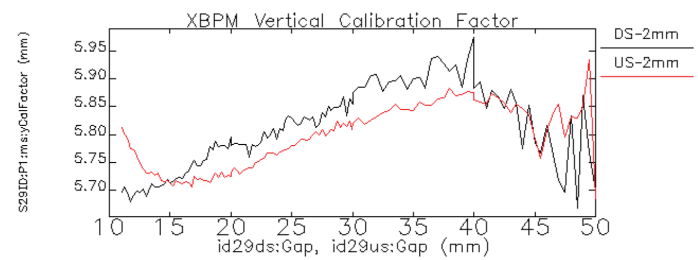
Pinhole optics + Two PIN diodes ➔ Measure center-of-mass position in vertical plane: calibration independent of the undulator gap.

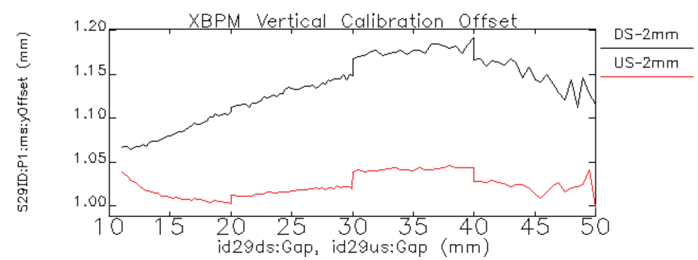






Raw Delta/Sum data

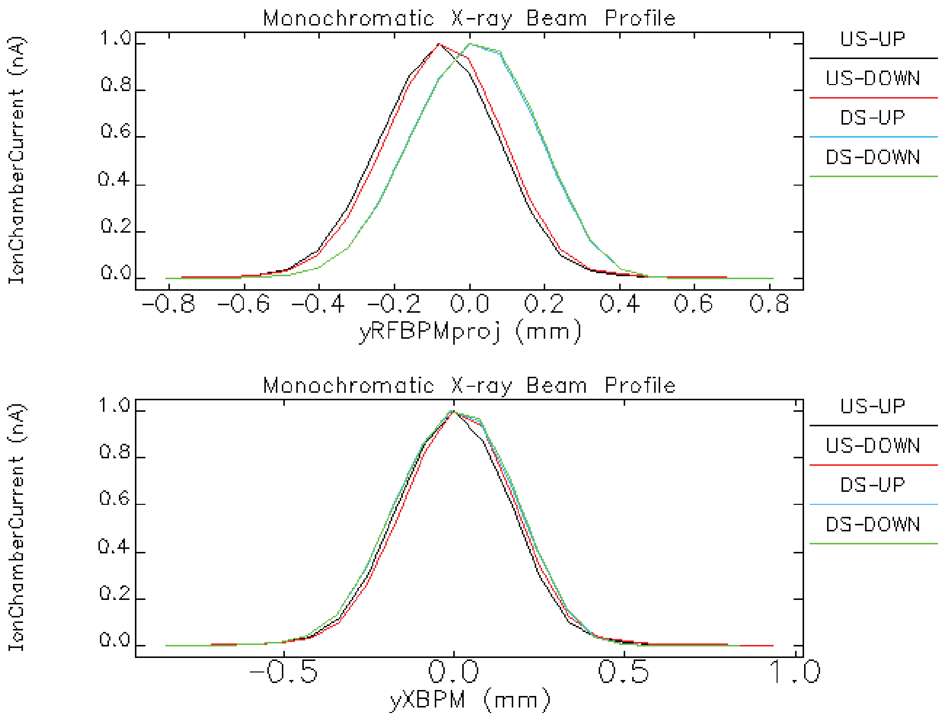


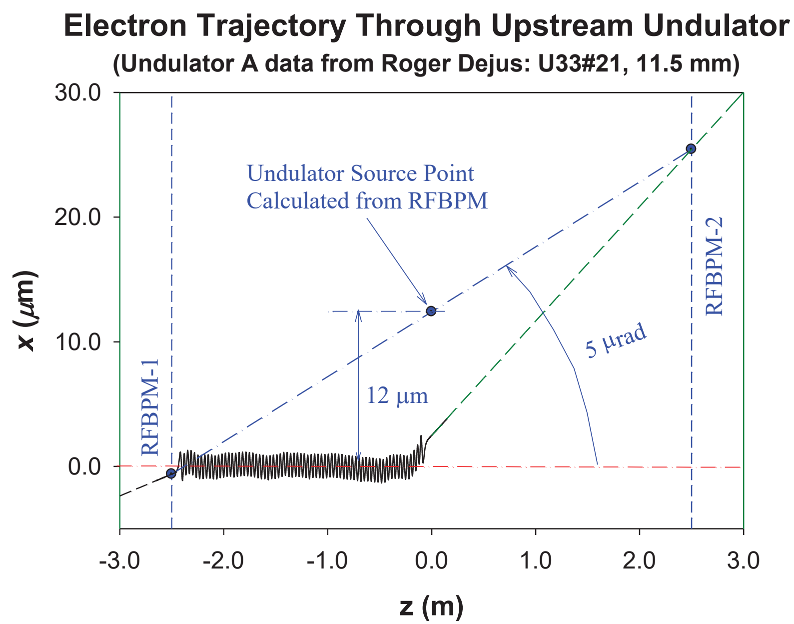


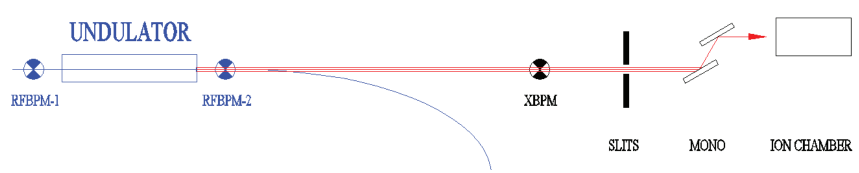
Calibration/Offset vs. gap

Hard XBPM is more accurate than RFBPM

GRID-XBPM demonstrated that the hard x-ray BPM is more accurate in predicting monochromatic x-ray beam (central cone) position than the RFBPM since the latter cannot account for undulator steering.





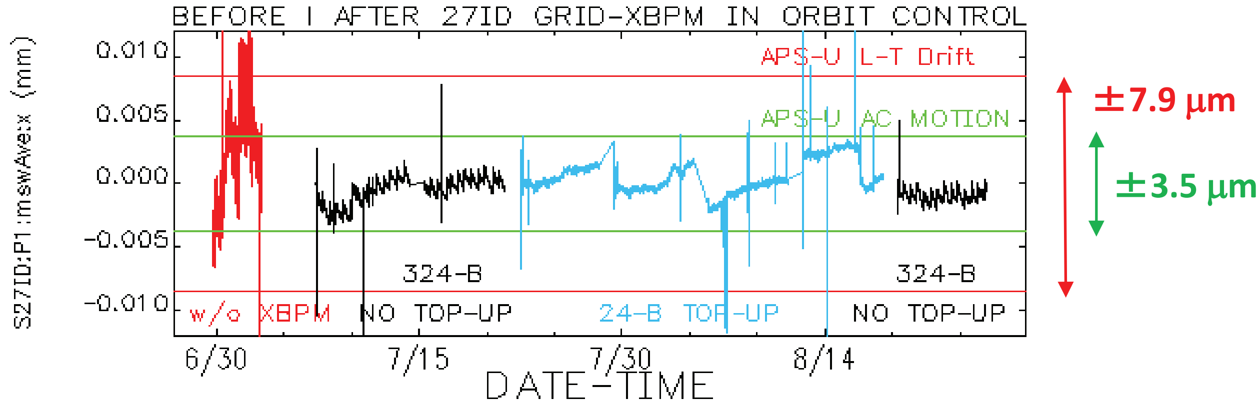


GRID-XBPM correctly reads the x-ray beam position in the beamline!

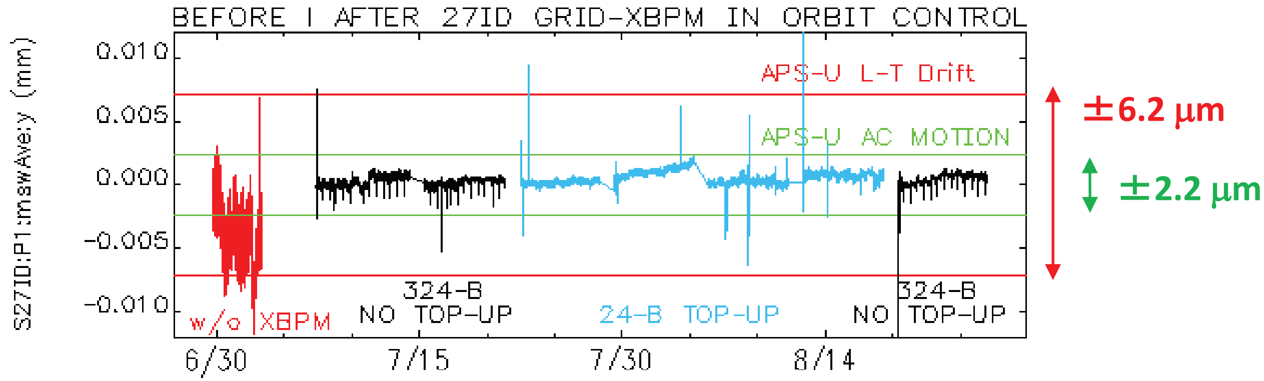
Stable operations in orbit control (27-ID)

After verifying the accuracy of the GRID-XBPM, we tested the x-ray beam stability during user operations. It did significantly improve the angular stability of 27-ID undulator beam.

Horizontal beam positions in 60-days of User Operations



Vertical beam positions in 60-days of User Operations



Date in Run 2015-2

This GRID-XBPM met the APS-U specifications in both planes.

XBPM R&D for APS Upgrade

Since the first article proved the advantage of the hard x-ray XBPM, we started several R&D projects to further improve the XBPM:

(1) High-current, radiation resistant readout detector:

[Motivation] Increased S/N ratio and wider band width

[Conclusion] CVD diamond works but its noise is also higher.
YAG + Si-PIN combos are chosen as the final winner.

(2) Array readout detectors and new electronics

[Motivation] Characterize strong BM background to reduce subtraction error

[Status] On-going

(3) Compton XBM development

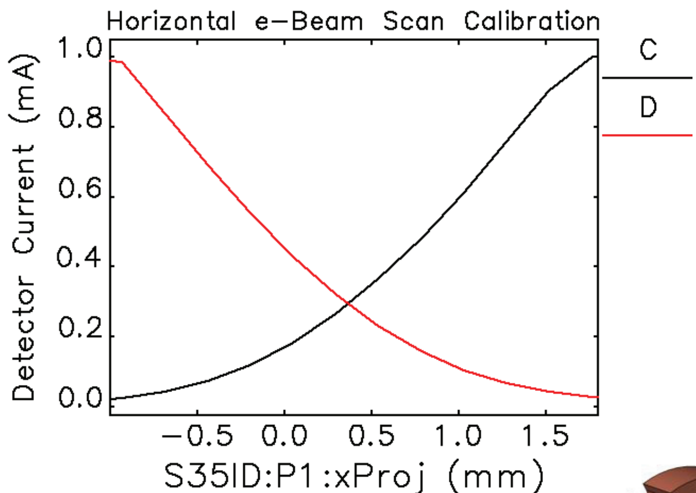
[Motivation] Independent steering for canted beamlines, lower cost.

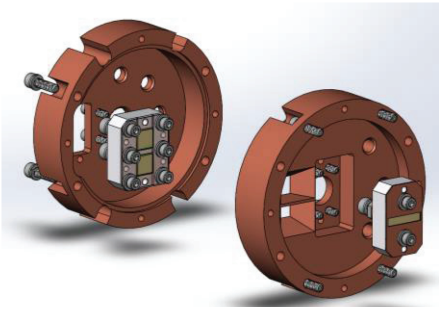
[Status] Prototype XBPM worked well for one APS undulator (5.5 kW), but failed when the second undulator beam is applied.

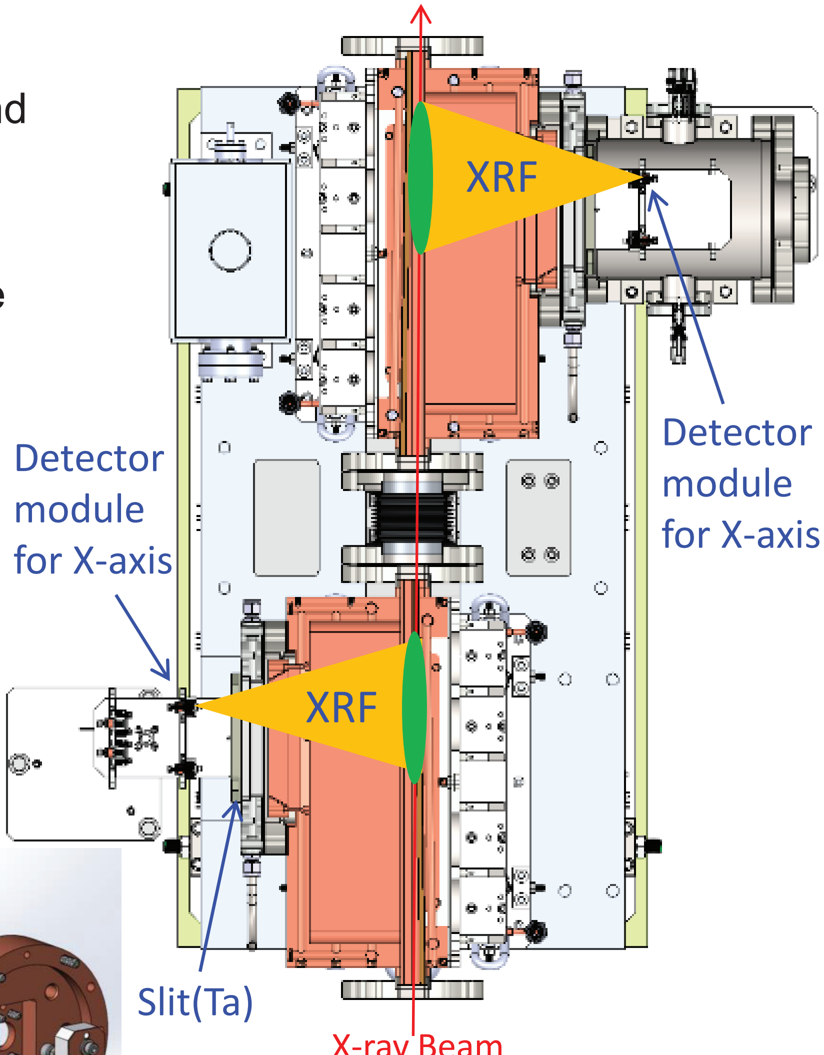
Diamond readout detector in GRID-XBPM

A set of diamond detectors were installed in 35-ID GRID-XBPM:

- CVD diamond 10 mm × 10 mm x 0.5 mm and 20 mm × 5 mm x 0.5 mm
- Both sides Au-plated. DC bias 150 – 300 V
- Obtained detector current up to 1-mA, at the limit of the APS XBPM electronics.





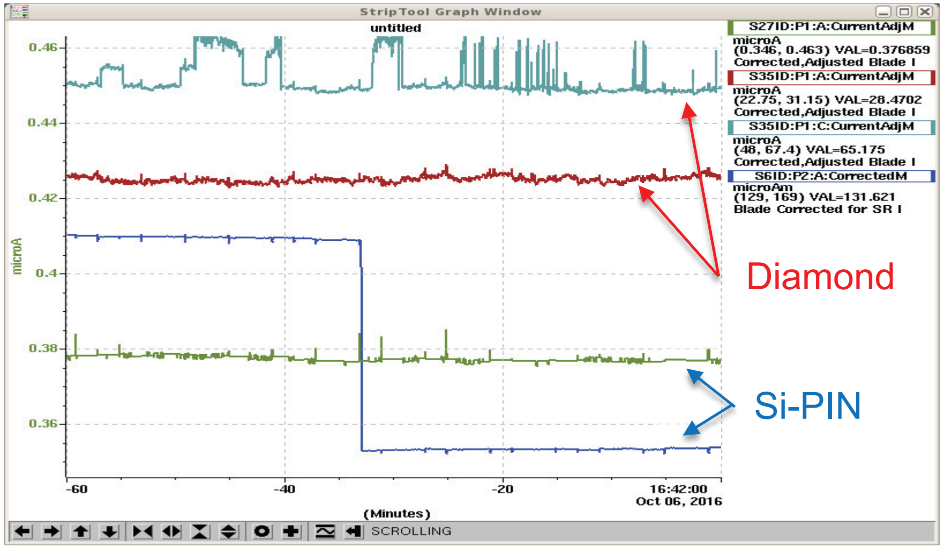


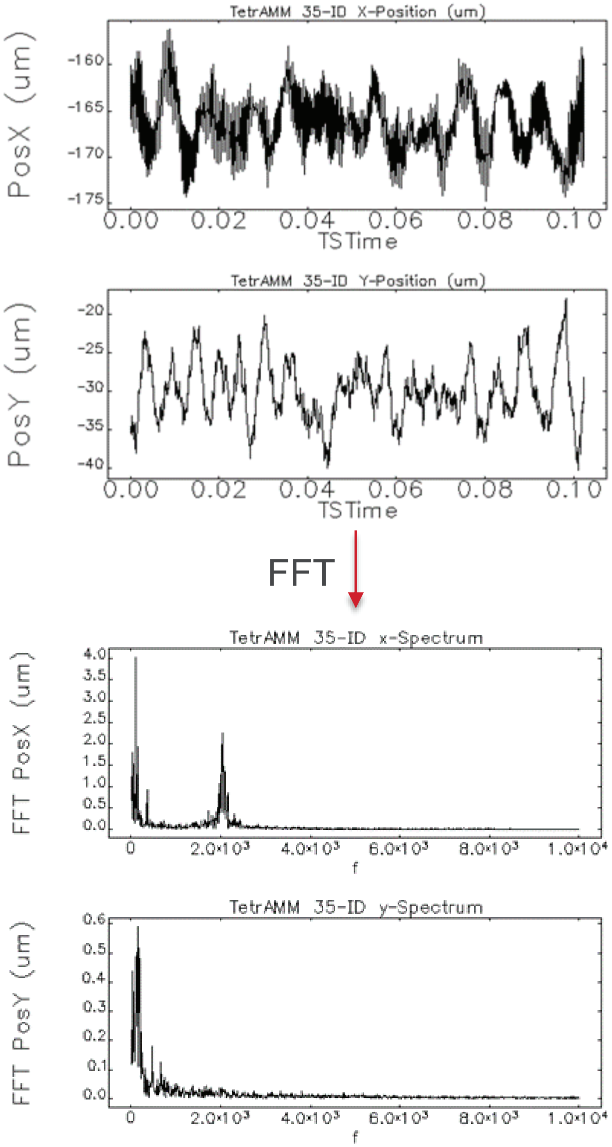
Diamond readout detector: high bandwidth

Diamond detector in the GRID-XBPM monitors observes fast beam motion using a TetrAMM from CAEN.

[Bad news]

CVD detector shows charge / efficiency bursts!



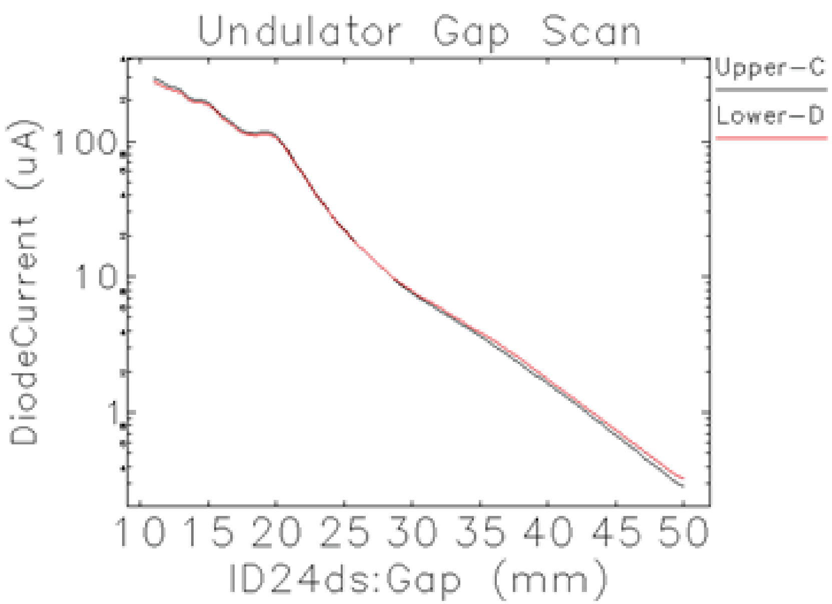


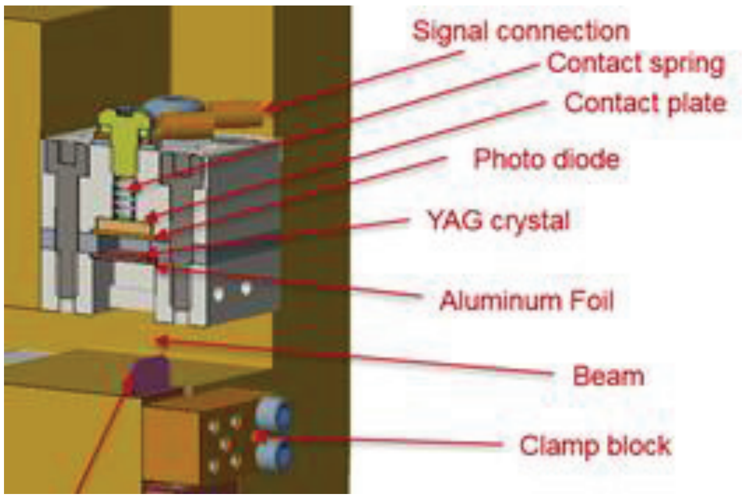
Crystal diamond detector should be better. But the cost of a 10x10mm^2?!

YAG + Si-PIN readout detectors

[Final Winner]

- YAG + Si-PIN combos are chosen as the standard readout detectors.
- High current Si-PIN photodiode may go up to 2 mA according to the maker.
- Undoped YAG has similar performance as the Ce-doped scintillator, maybe just slightly better, with higher signal at the highest x-ray flux and lower one at the lowest flux level. (Still needs confirmation)



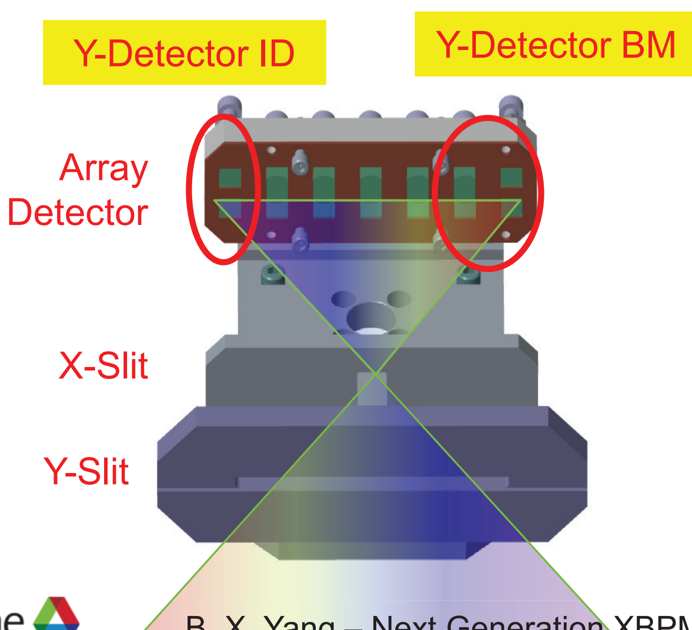


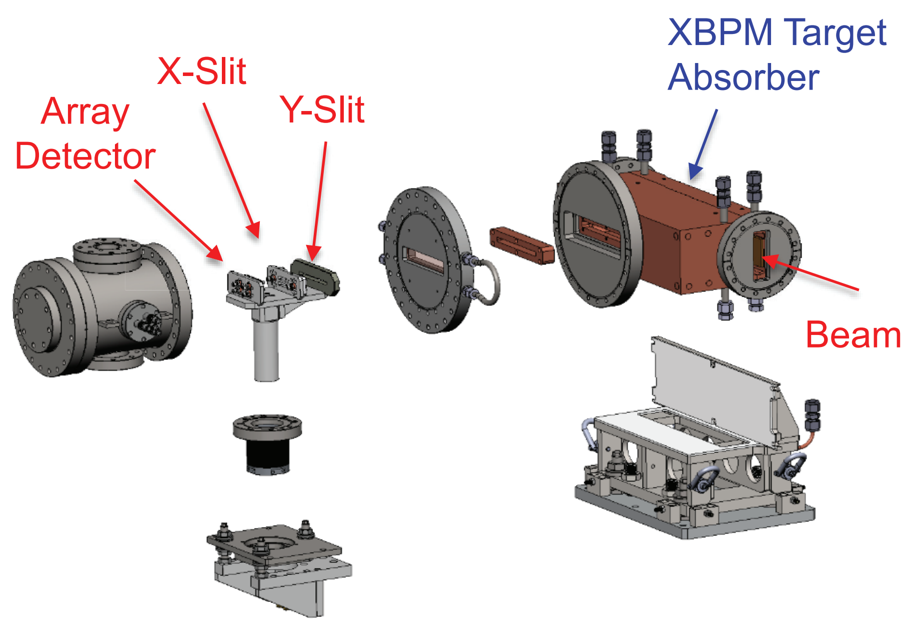
Compare Ce-doped and undoped YAG scintillators using x-rays scattered by diamond blade.

Array Detectors for GRID-XBPM

Array detector has been considered for some time, but adopted only recently:

- The APS XBPM benefits greatly from the “Decker Distortion.” By end of 2016, it was clear that similar soft-tail magnet would not be available for the APS-U.
- New array detector approach for handling the strong BM background:
  - Four detectors for Y-plane on the outboard absorber: Two inner detectors for the ID beam and two outer ones for the BM background
  - 14 detectors for horizontal XRF distribution: effective subtraction of BM background
- XBPM electronics need 16-channel input and new data processing algorithm

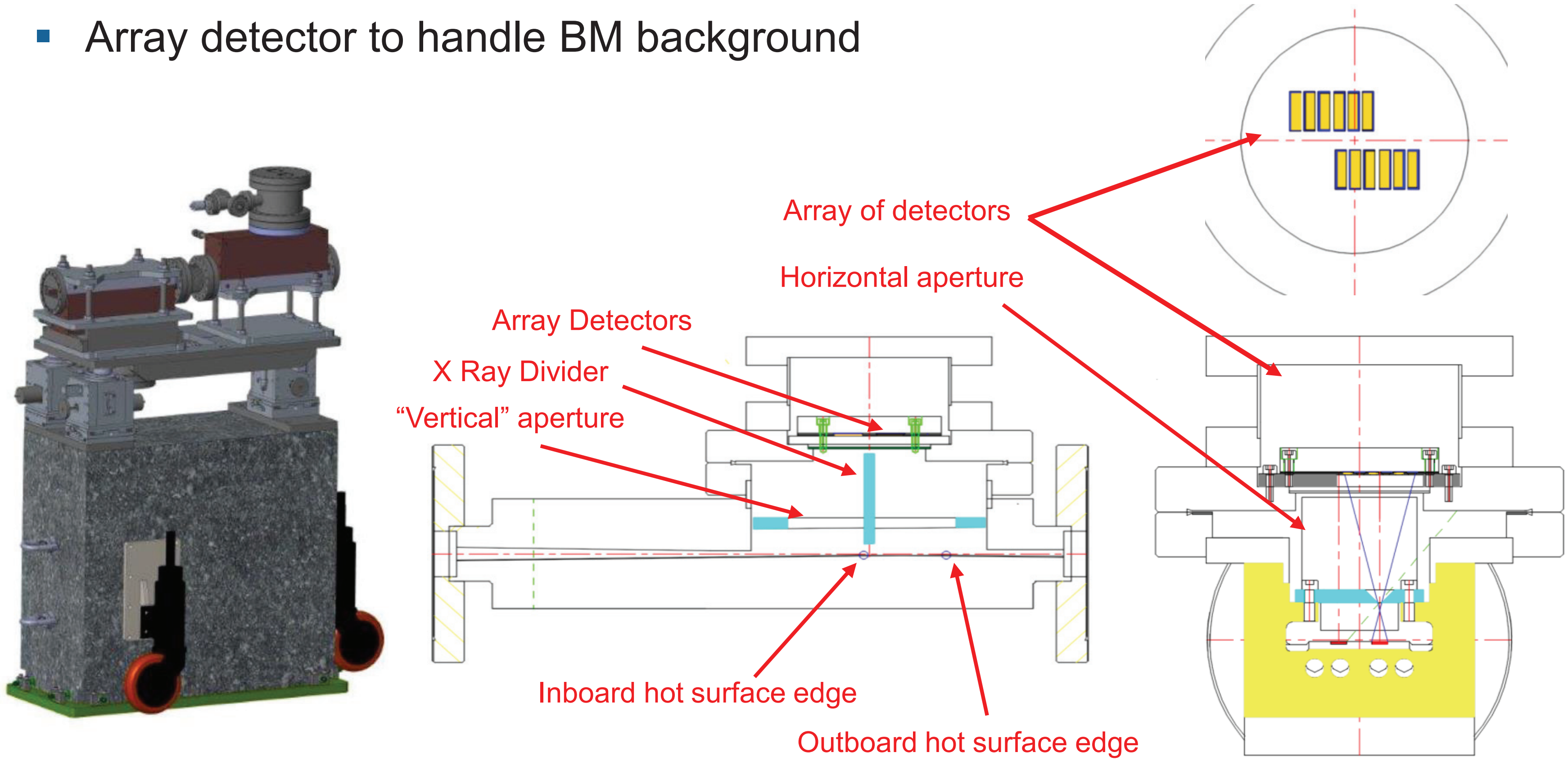




Canted undulator GRID-XBPM

[Design features]

- Two absorbers: One above and one below beam
- Sheared absorber: absorber surface for inboard undulator is displaced from that for the outboard device by 60-mm along beam axis
- Separate readout detector and optics
- Array detector to handle BM background



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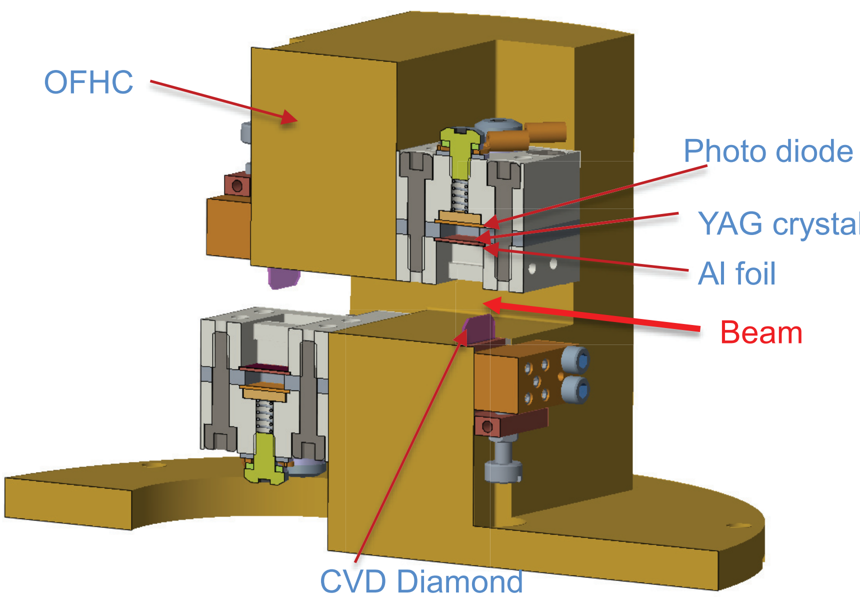
Developing Compton-scattering XBPM

[Motivation (2015)]

- Canted beamlines have two beams separated by 1 mrad with 10-kW power in each beam. **Independent steering could be request by the user?**
- Attempt to develop an alternate to GRID XBPM to reduce cost using existing supports and vacuum housing ($150K vs $30K each, Qty = 13).
- Explore the idea of Compton scattering as a method of detecting the signal to determine the position for each beam

[Principle of Operation]

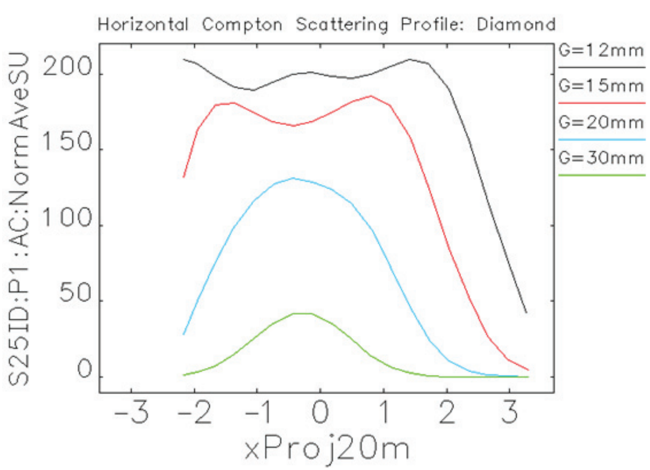
- Beam strikes a pair of CVD diamond or pyrolytic graphite blades and scatter from them.
- Compare upper and lower detector signals to determine vertical beam position.
- Compare inboard and outboard detector signal to determine horizontal beam position.



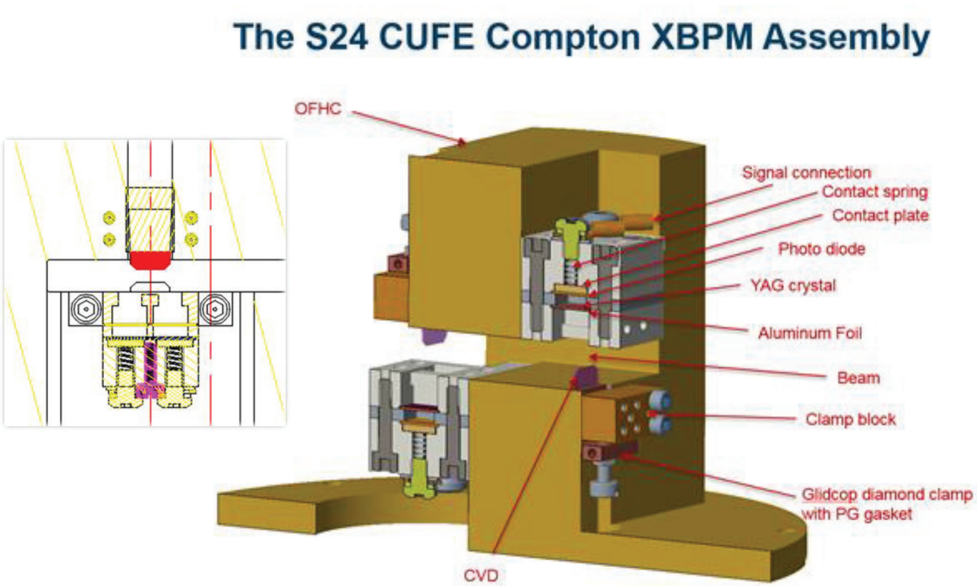
Compton XBPM: Design

Design features:

(1) Replace existing PE XBPM "core," reuse chamber and support tables
(2) Scattering blades: normal-incidence diamond or pyrolytic graphite
(3) Wide blades are used to sample the multi-peak horizontal profiles
(4) Collimator-optics: **horizontal** CofM measurements for small beam
(5) Upper and lower blades: Diff/Sum for **vertical** position measurements
(6) Readout detector: YAG + SiPIN



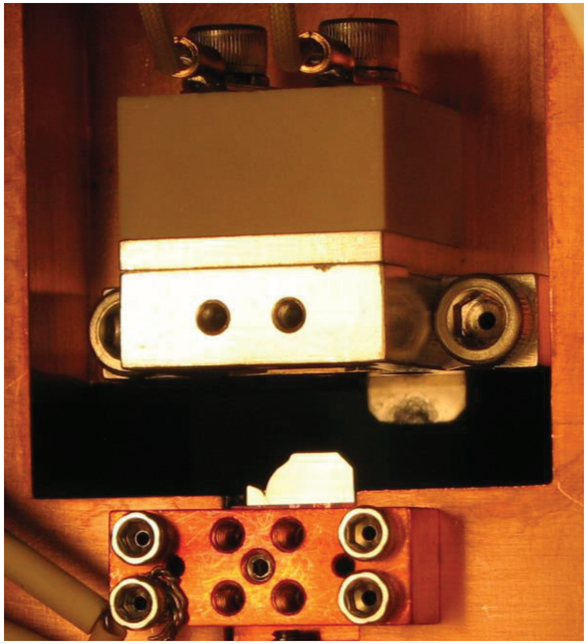
Horizontal signal profiles of the white beam Compton XBPM.



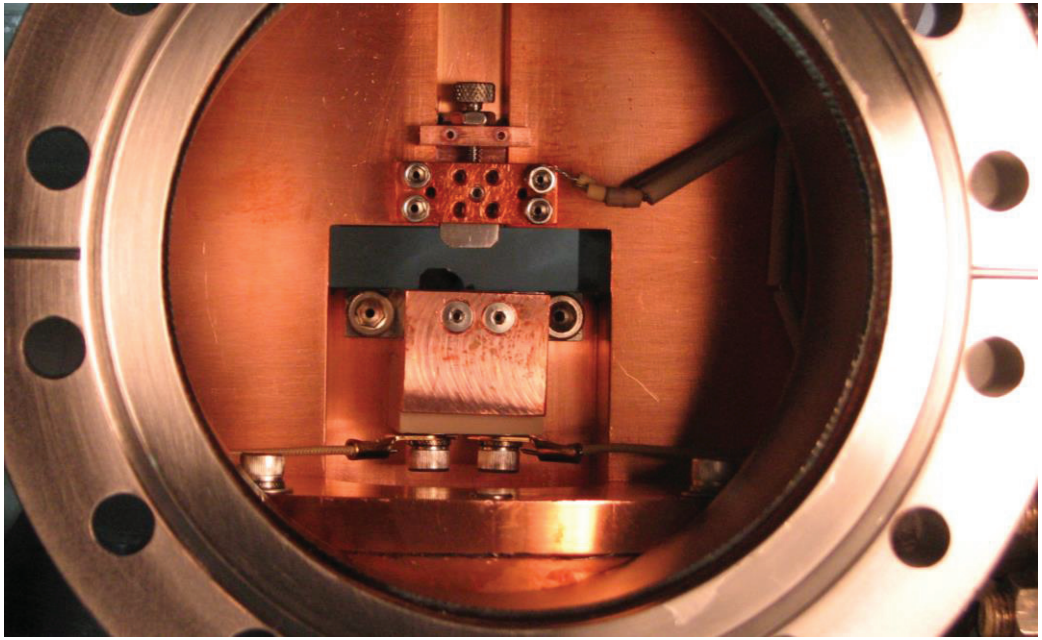
Compton XBPM: blade damage tests

Damage tests: Center the undulator beam at the edge of the blade and slowly close the undulator gaps in steps: Power of two inline APS Undulators A is equivalent to one APS-U canted undulator.

- Both diamond and graphite blades survived one undulator beam (5.5 kW)
- Both are damaged when the second undulator adds 1.0 kW power.
- The diamond blade cracked and splintered.
- Layers of the graphite blade sublimated.



Upstream view



Downstream view

Compton XBPM R&D: Conclusion

1. Compton-scattering XBPMs work well when the blade gaps are set properly.
2. In the front end, at normal incidence, the XBPM survived direct hits by a 5.5-kW beam from a single APS undulator U33.
3. This design will not survive direct hits in the front end by the APS-U canted undulator beam at 10 kW power.
4. These XBPMs can be used in the APS-U beamlines downstream of the front end.
5. The readout detector combo, YAG + Si-PIN, was tested successfully and produced signal current up to 0.7 mA.

Summary

- The Next Generation XBPMs are expected to play important roles in the beam stabilization systems in the APS-U.
- A properly designed hard x-ray BPM intercepts the beam outside of the core but correctly infers the position of the central cone.
- For front ends for high-power undulator sources up to 22 kW, we have successfully developed a GRID-XBPM with proven performance. New readout detectors are expected to improve the XBPM bandwidth. However, without the Decker Distortion, we will use array detectors to handle the BM background.
- For canted undulator front ends, the XBPMs are still being developed based on grazing incidence GlidCop absorbers.
- Normal-incidence Compton-scattering XBPM was developed but will only be used for user beamlines on the experimental floor.

The APS NG-XBPM Team

Mechanical design and installation

- Soonhong Lee (GRID-XBPM & Compton XBPM)
- Frank Westferro (XBPM2, IM1, IM2, Compton XBPM)
- Yifei Jaski (front end integration)
- Sam Oprondek (array detector)

Data acquisition and motion control

- Michael Hahne, Adam Brill, Bob Lill (XBPM electronics)
- Jim Stevens (motion control)
- Frank Lenkszus, Shifu Xu (XBPM data processing in IOC)

X-ray physics & experimental measurements

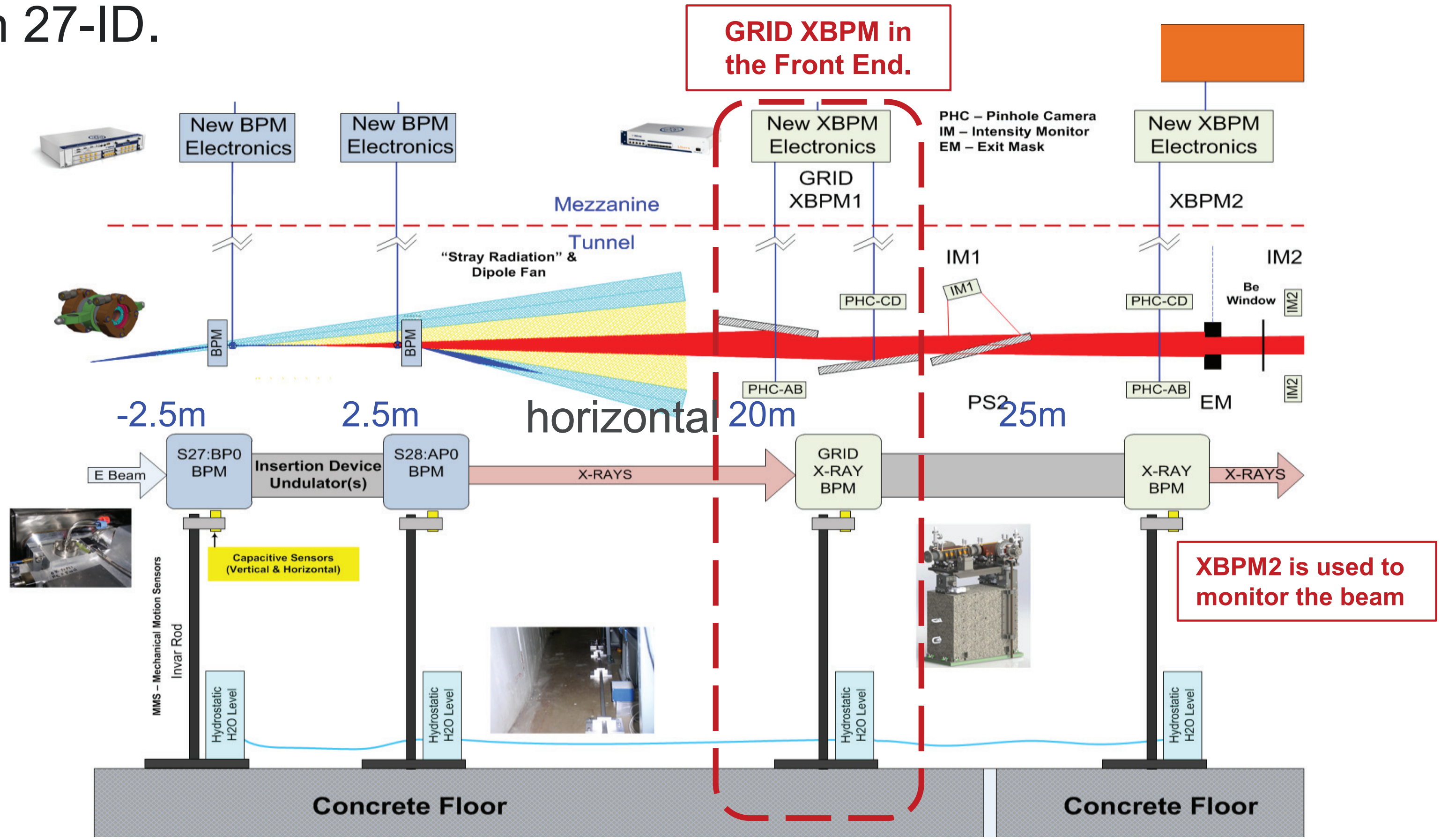
- Glenn Decker (initial development and continued participation/support)
- Mohan Ramanathan
- Nick Sereno
- Bingxin Yang

Plus help from many people in APS

Spare slides

The APS-U Beam Stabilization System

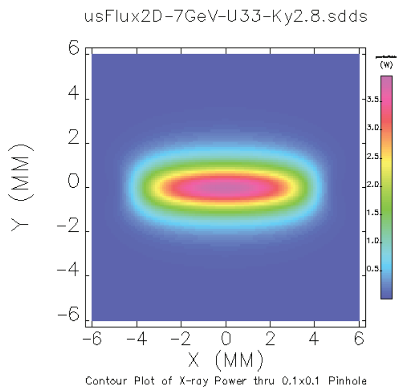
The beam stabilization system planned for the APS-U was developed and tested in 27-ID.



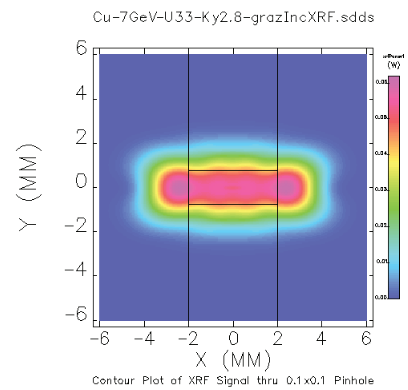
The long lever arm (along with using the x-rays) results in better capabilities for XBPM over RF-BPM

Revisit XBPM physics: response maps

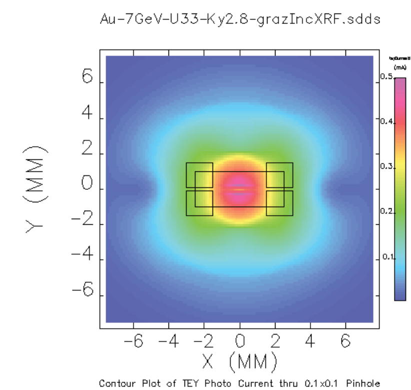
Understand the multi-peak horizontal profiles: response maps depend strongly on the secondary product collected and detection geometry. See following example for APS Undulator A (7GeV/U33/N70x2/K2.8).



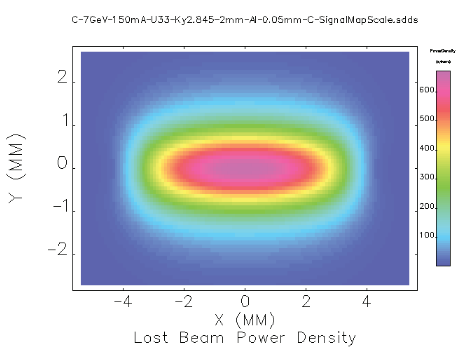
Total Power



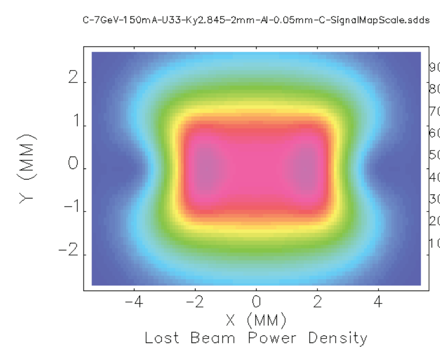
Copper K-edge XRF



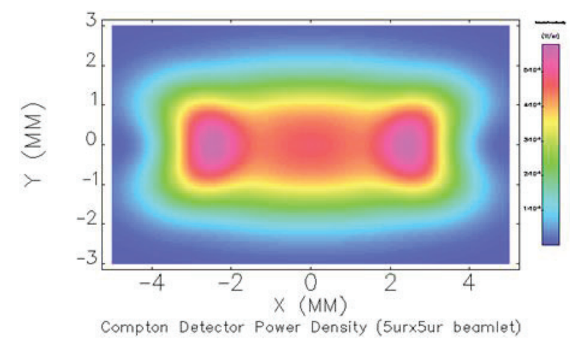
Photoemission (Au, TEY)



Total Power



Diamond Absorbed Power



Diamond X-ray Scattering