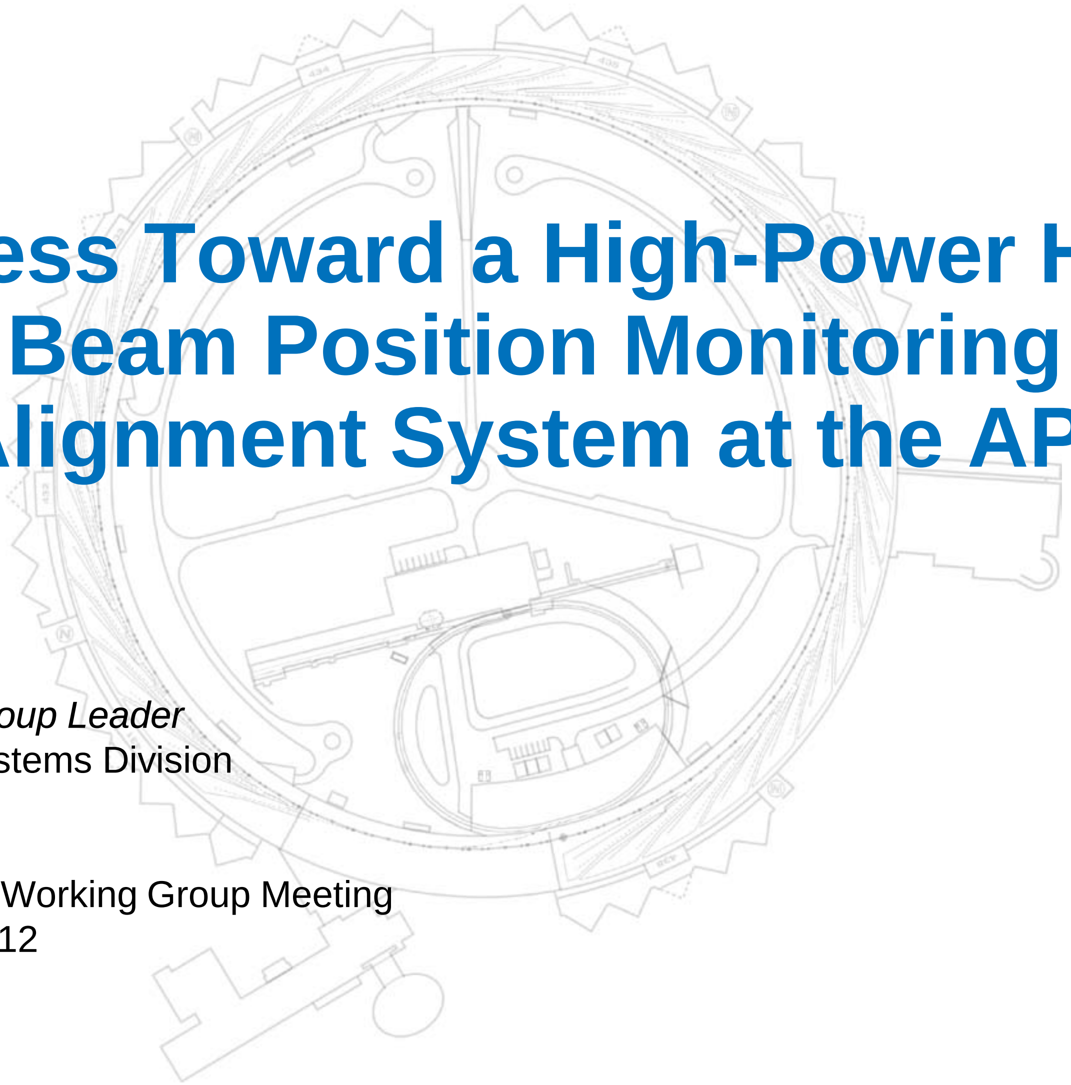


Progress Toward a High-Power Hard X-ray Beam Position Monitoring and Alignment System at the APS

Glenn Decker
Diagnostics Group Leader
Accelerator Systems Division

APS Technical Working Group Meeting
January 19, 2012

X-BPM Development Team

The presented materials the result of the XBPM Development Team:

- AES - Mechanical Engineering Group
  - Soon-Hong Lee, AES-MED Engineer
  - Pat Den Hartog AES-MED Group Leader

- ASD – Diagnostics Group
  - Bingxin Yang, Physicist
  - Glenn Decker – Accelerator Physicist, Diagnostics Group Leader

- Current issue: Integration of GRID-XBPM with APS-U front ends
  - Yifei Jaski, AES-MED Engineer
  - Mohan Ramanathan APS-U project

- Other essential help
  - Roger Dejus ASD-MD, help with undulator source programs
  - Hairong Shang ASD-AOP, help with SDDS programming
  - Josh Downey, AES-DD, designer
  - Gerd Rosenbaum – a driving force in the early days of this project

Background

- APS has the largest installed base of photon beam position monitors (bpms) continuously used in a global orbit feedback system anywhere.

-The present technology makes use of photoemission from gold-coated diamond “blades” placed edge-on to the beam.

- After many years of development, the system has reached the limit of performance: 10 to 20 microns of residual systematic errors.

GRID-XBPM* Development History

- Hard x-ray BPM development started in 2005, based on Cu-K XRF
- First XBPM using pinhole camera center-of-mass readout (March 2009)
  - Proof-of-principle test
- Present grazing-incidence XBPM approach proposed (July 2009)
  - Use grazing incidence to handle high power density.
  - Combine XBPM with the limiting aperture function.
- First XBPM designed for the 29-ID circularly polarized undulator (2010)
  - First workable solution for CPU XBPM
- First beam tests are planned with two Undulator A sources in 29-IDA
  - Starting soon – January machine startup
- Current work
  - Integration of GRID-XBPM into new high heatload front end
  - Integration of GRID-XBPM into canted undulator front end

* GRID-XBPM is an acronym for Grazing-Incidence Insertion Device X-ray Beam Position Monitor

Beam Stability Requirements

At 18 m from the source, XBPM is ideal for measuring the beam pointing angle.

APS Upgrade beam stability goals (XBPM @ z = 18.4 m)

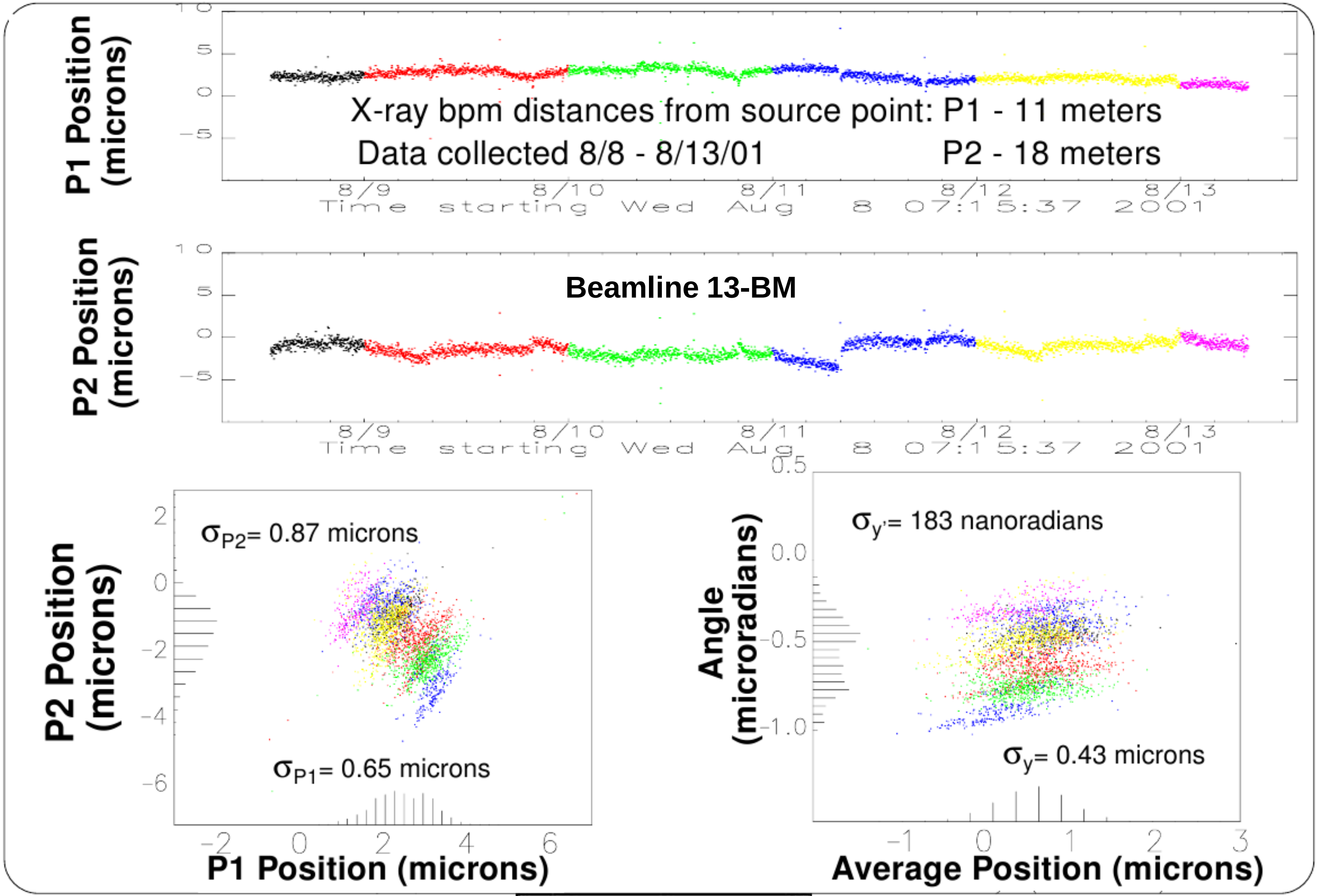
		RMS AC Motion (0.1 – 200 Hz)	RMS long term drift (1 week)
Horizontal	Angle stability goal	0.53 μrad	1.0 μrad
	X-ray beam @ 18.4 m	10.2 μm	19.1 μm
Vertical	Angle stability goal	0.22 μrad	0.5 μrad
	X-ray beam @ 18.4 m	4.1 μm	9.3 μm

XBPM1 Performance Specifications* (Including Compensation)

	RMS Resolution (0.1 – 200 Hz)	RMS long term drift (1 week)
Horizontal	7.2 μm	13.5 μm
Vertical	2.9 μm	6.5 μm

* 71% of total budget

Plots showing < 200 nanoradian rms vertical beam stability over a 5 day period
Colors indicate data for individual days



X-ray bpm distances from source point: P1 - 11 meters

P2 - 18 meters

Data collected 8/8 - 8/13/01

Beamline 13-BM

σ_{P2}= 0.87 microns

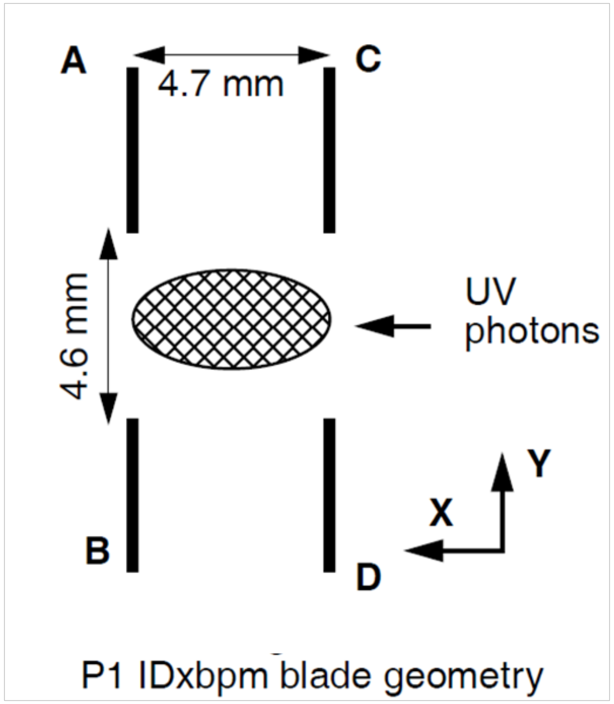
σ_{P1}= 0.65 microns

$\sigma_{y'}$= 183 nanoradians

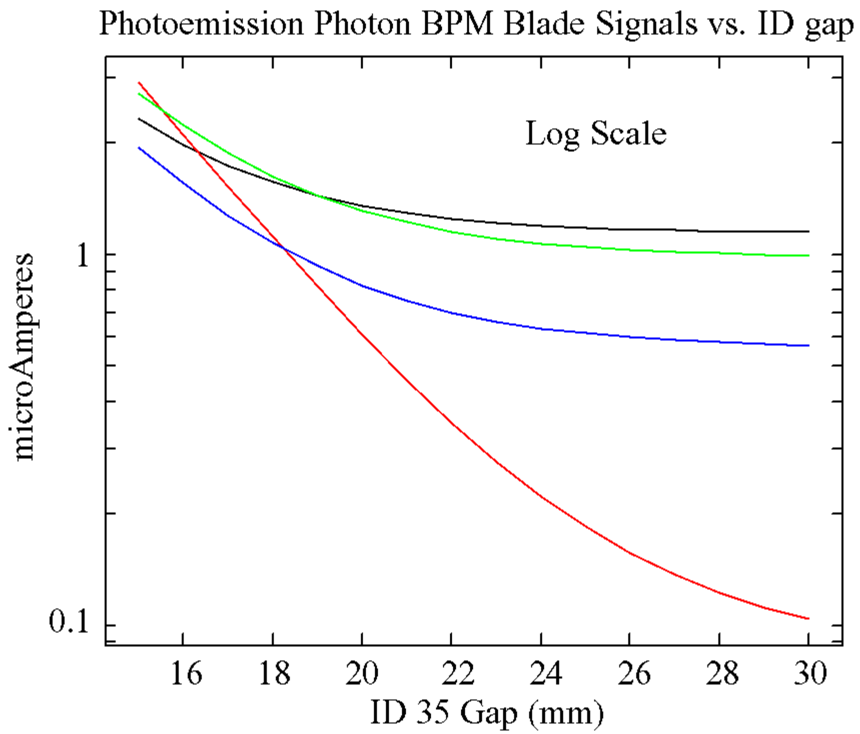
σ_{y}= 0.43 microns

Existing Photoemission-based BPM Performance

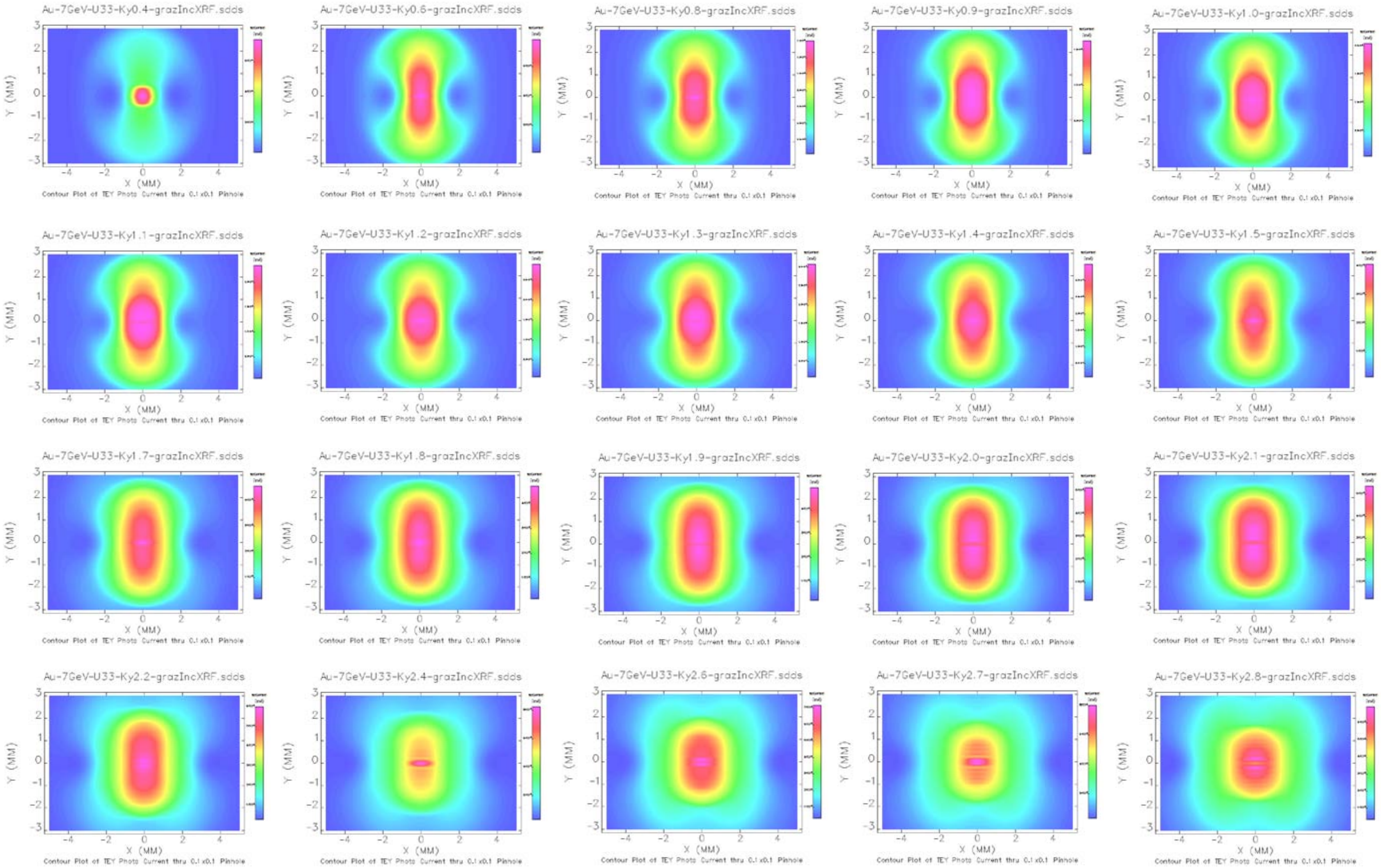
- Four blades, sensitivity down to UV, strong gap dependence.
- Not adequate for the APS upgrade specs.



P1 IDxbpm blade geometry

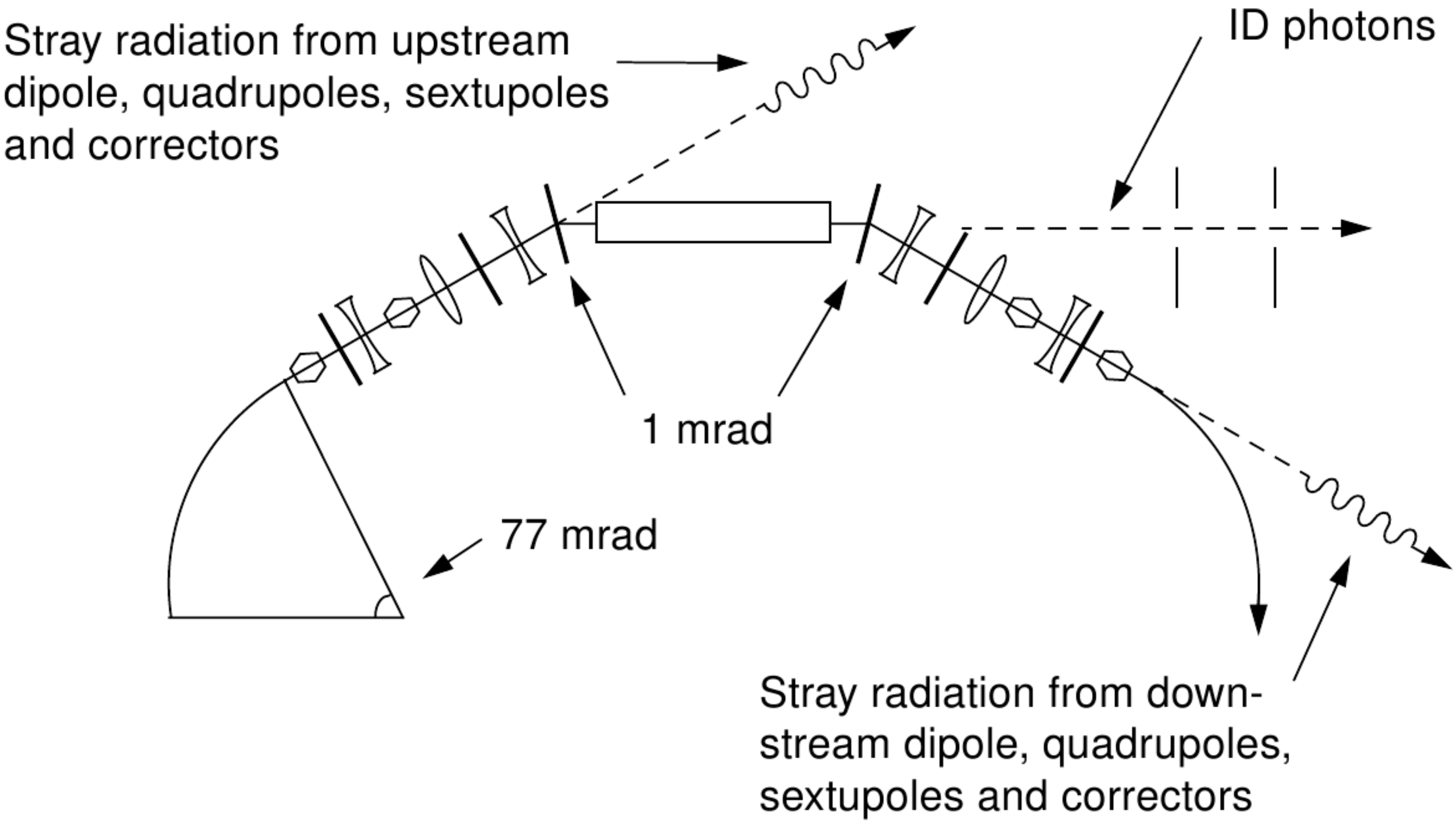


Photoemission Total Electron Yield Current Distribution Undulator U33 from Au Photocathode



Courtesy Bingxin Yang

Re-direction of Stray Photons by Girder Alignment*



Stray radiation from upstream dipole, quadrupoles, sextupoles and correctors

ID photons

1 mrad

77 mrad

Stray radiation from down-stream dipole, quadrupoles, sextupoles and correctors

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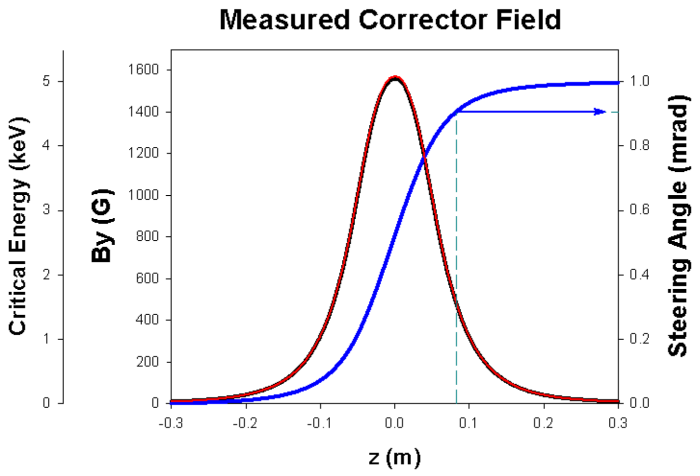
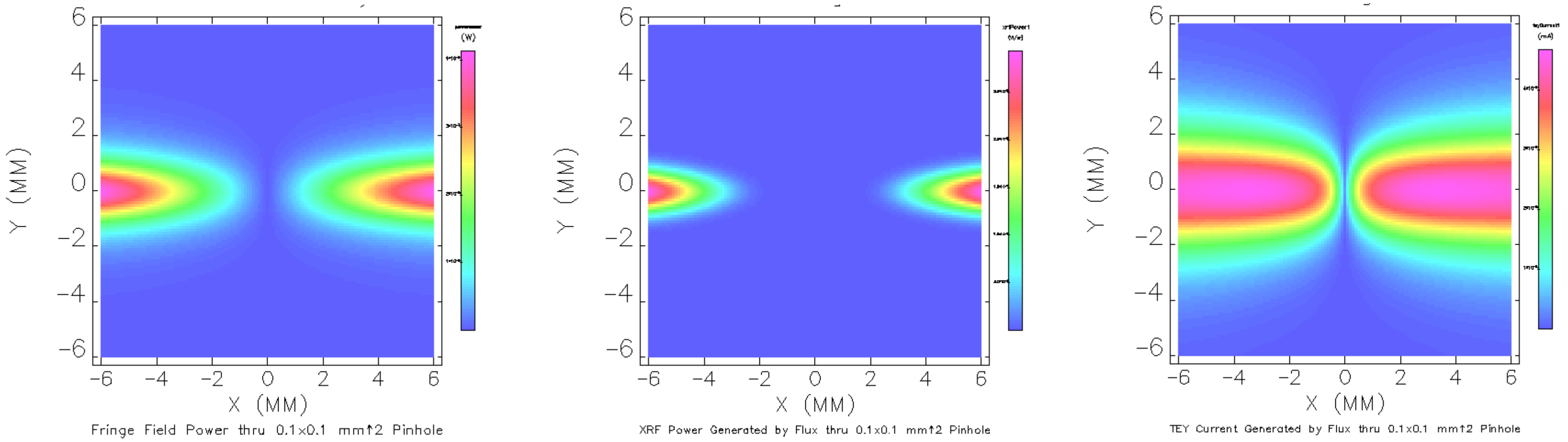
*Phys. Rev. ST Accel. Beams 2, 112801 (1999)

Stray Radiation Signal Background

- Decker Distortion Dipoles have soft magnetic edges, generating mostly soft x-rays.
- A Cu-K XRF detector is insensitive to low-energy x-ray photons (< 9 keV).



Comparison of 2-D intensity distribution of BM radiation from corrector magnets: XRF map @ 20 m has a clean center



(A) Power

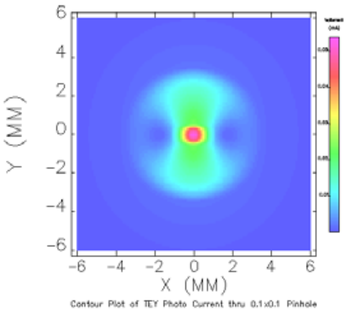
(B) X-ray fluorescence

(C) Total Electron Yield

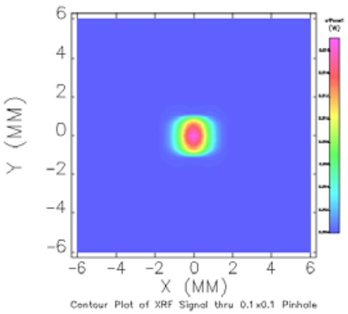
Seeking an optimal XBPM: a summary

Our optimal XBPM will use x-ray fluorescence (XRF) signal due to its clean background. In order to succeed, we need two additional key technical elements:

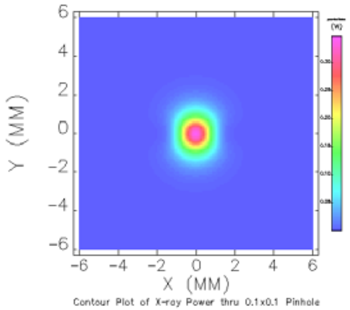
A. Place XRF target (mask) as close to the beam center as possible (< 1 mm)



(A) Total Electron Yield (Au)



(B) X-ray fluorescence (Cu)

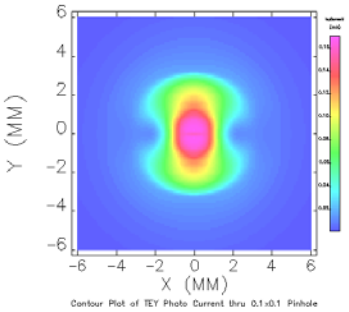


(C) Power

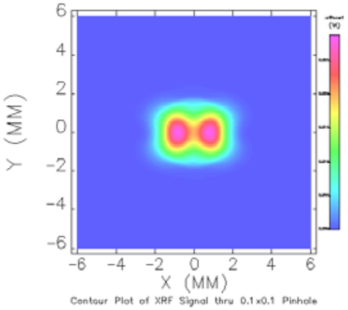
K = 0.4

G ~ 30 mm

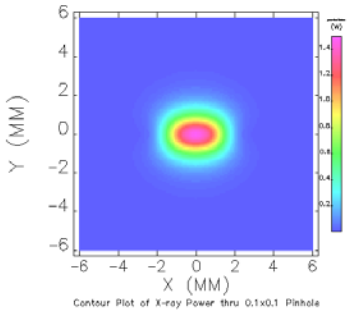
B. Use Center-of-mass detectors in the horizontal plane



(A) Total Electron Yield (Au)



(B) X-ray fluorescence (Cu)



(C) Power

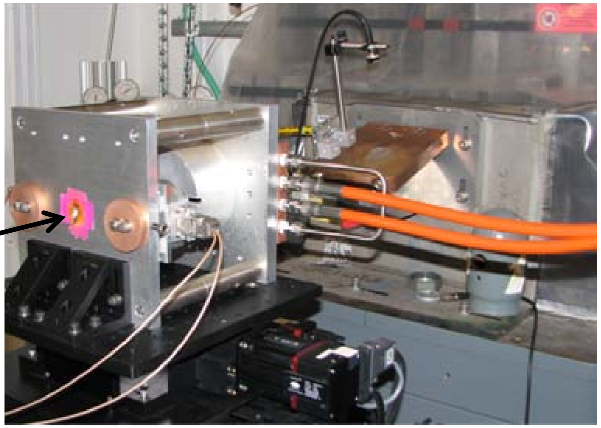
K = 1.1

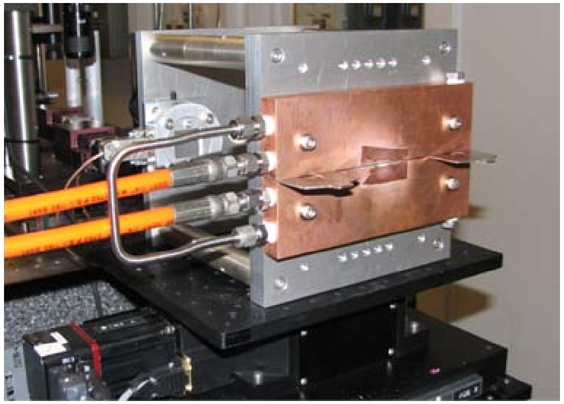
ε_1 ~ 8.8 keV

Proof-of-principle test of single-slot XBPM (2009)

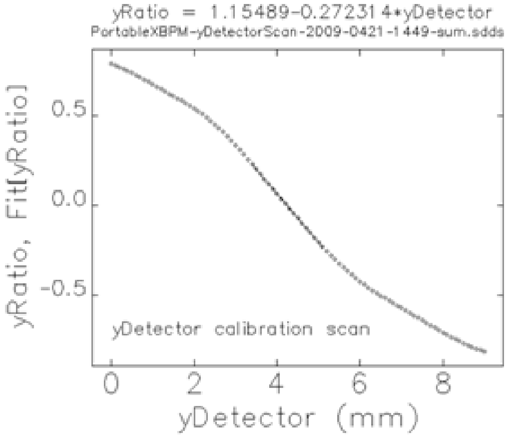
- Normal incidence model: Copper plate slot XBPM.
- Position readout: 2-D Center-of-Mass detector.

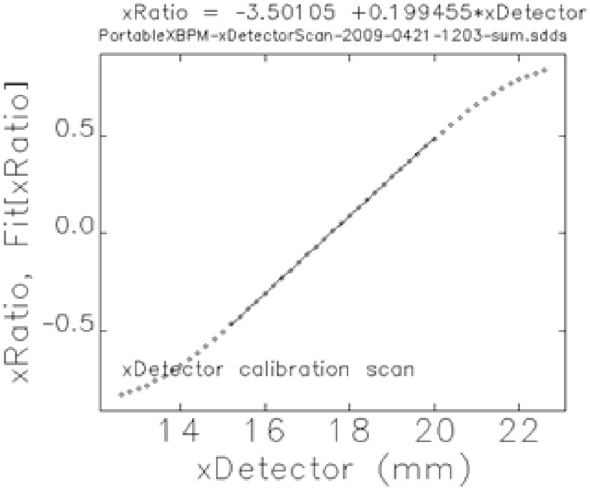
X-rays

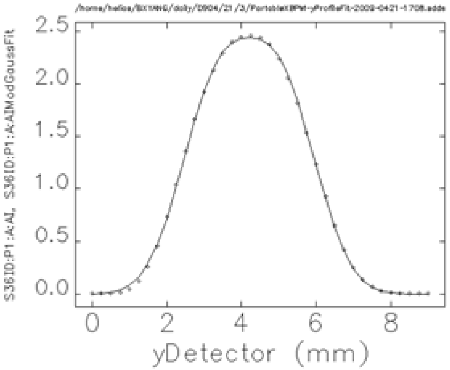




Looking Upstream



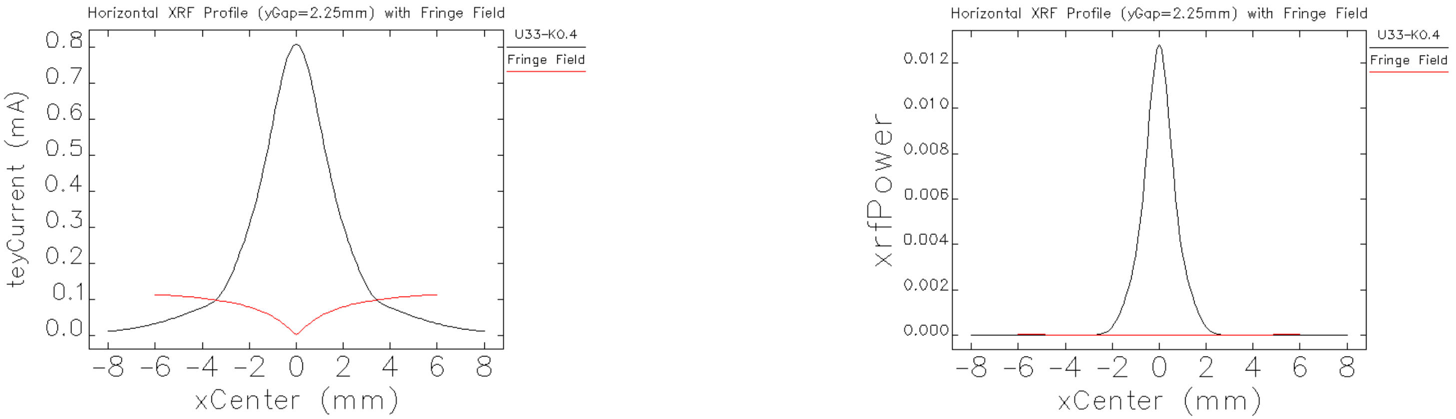




Mod-Gaussian Fit to S36ID:P1:A:AI

Compare XBPM signals and background

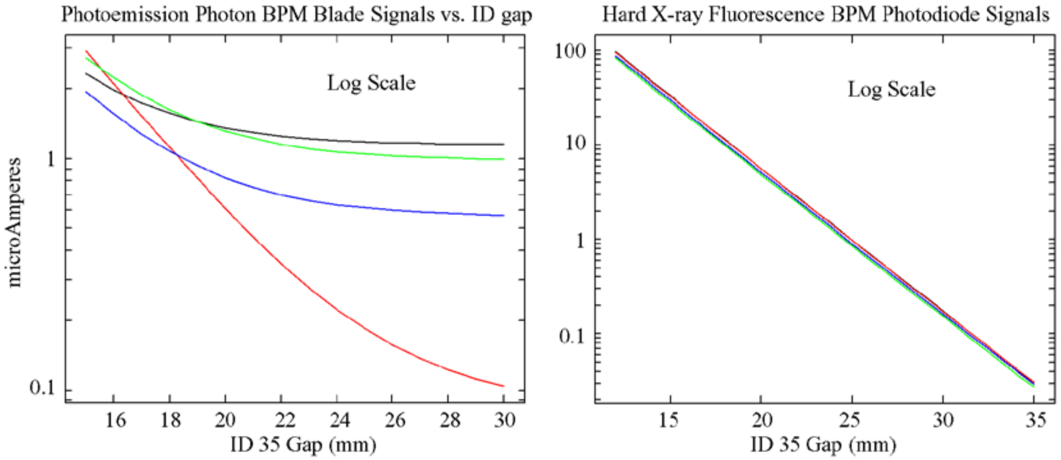
Vertically-integrated intensity profiles show > 10-times improvement (calculation).



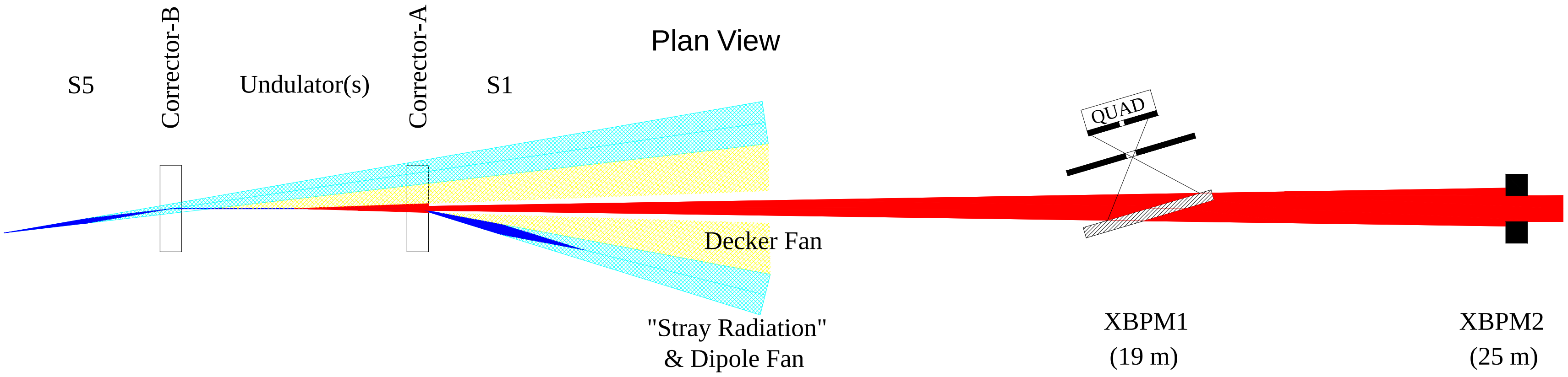
(A) Total Electron Yield (K = 0.4, Au)

(B) X-ray fluorescence (K = 0.4, Cu)

Experimental confirmation: Fringe field XRF background is almost negligible.



Current plan for HHL-FE GRID-XBPM (single element)

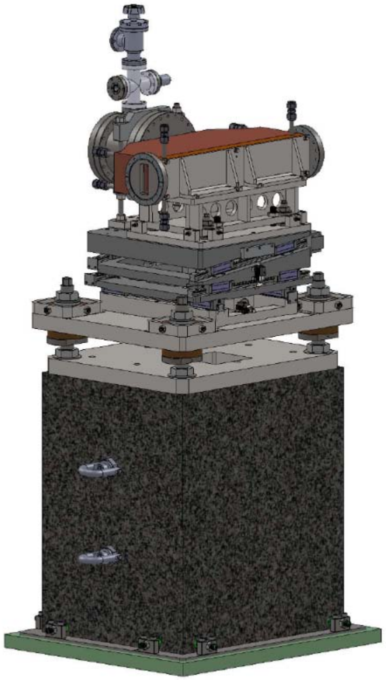


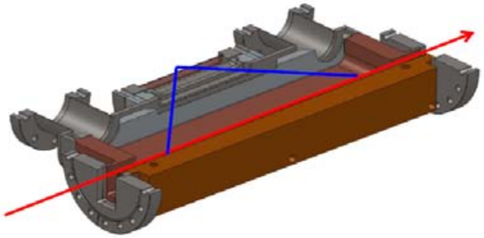
XBPM-1 Design features:

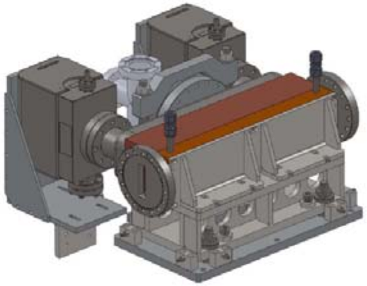
- Target geometry = a single slot in grazing incidence. Lower cost, less space.
- Simple one-pinhole “imaging” detector scheme
- Lack of symmetry enhances systematic errors:
  - Thermal bump up to > 50 μm is gap dependent;
  - Powder diffraction and Compton scattering favor forward direction, resulting additional offset errors;
  - Software compensation planned.
  - Luckily, the horizontal direction has larger tolerance

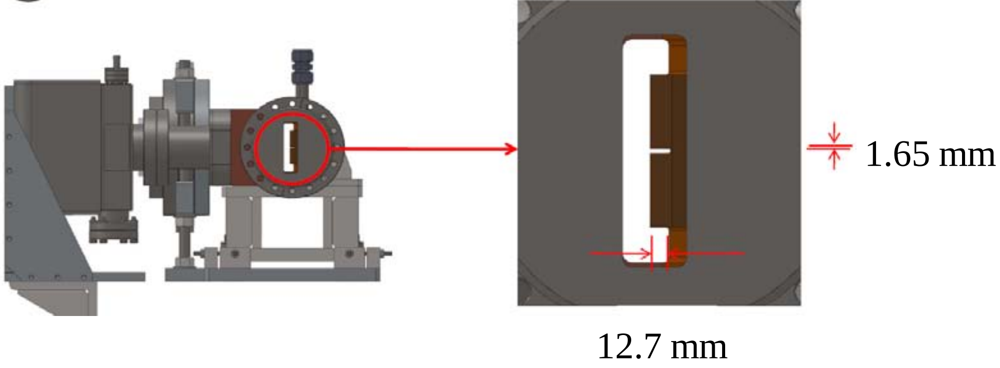
This is our current plan for HHL-FE GRID-XBPM

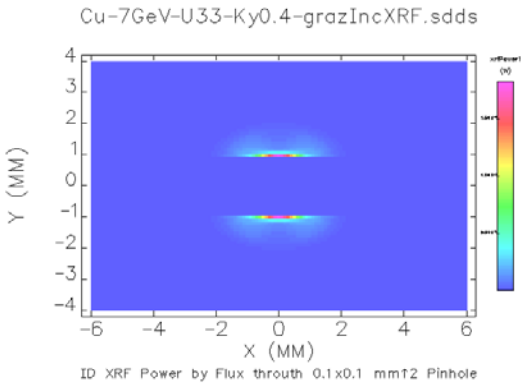
HHL front end XBPM-1 design



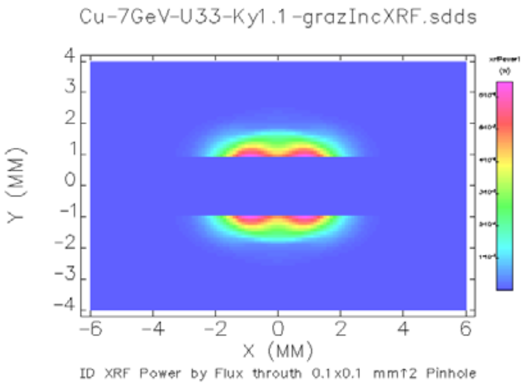




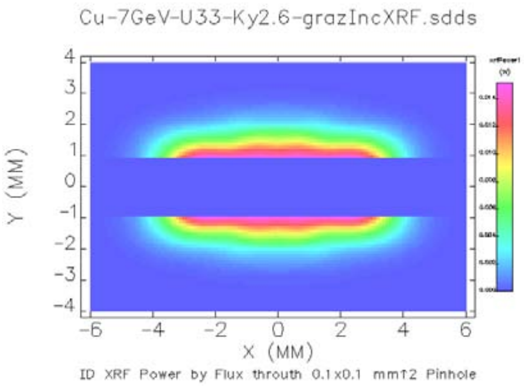




K = 0.4

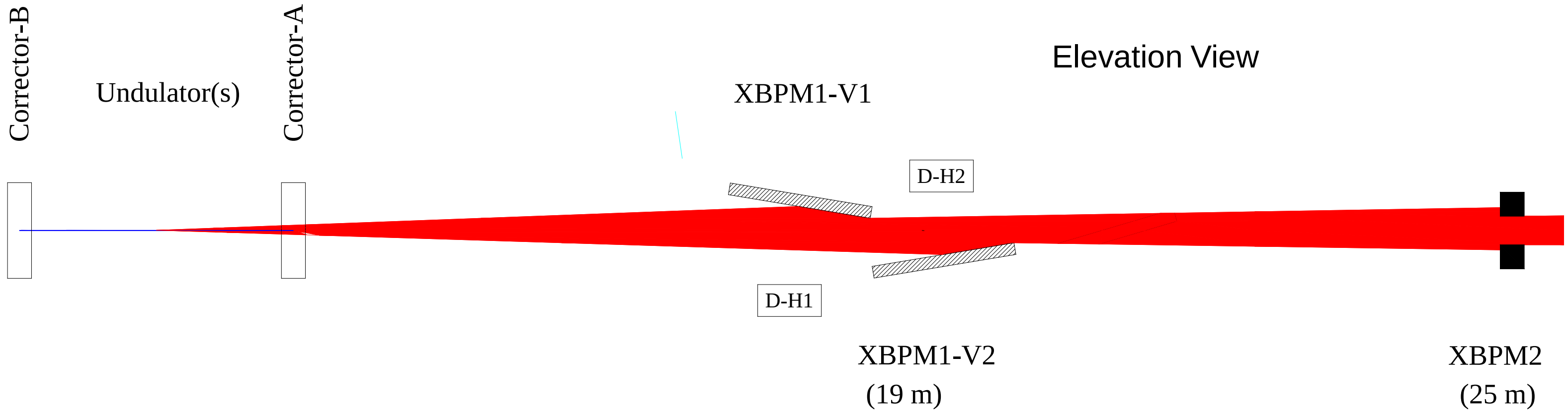


K = 1.1



K = 2.6

Current plan for CU-FE GRID-XBPM (two-element)



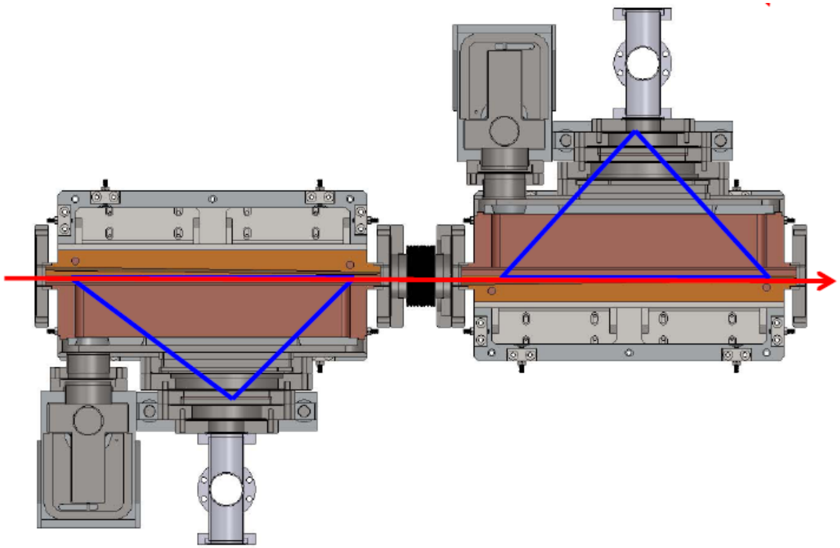
XBPM-1 Design features:

- Two flat plates sample both undulator beams simultaneously.
- Symmetry allows better cancellation of spurious background signals in the vertical direction
  - Thermal bumps
  - Powder diffraction
  - Compton scattering
- XBPM-2 uses upstream apertures as pinhole for (4-pixel) “imaging”.

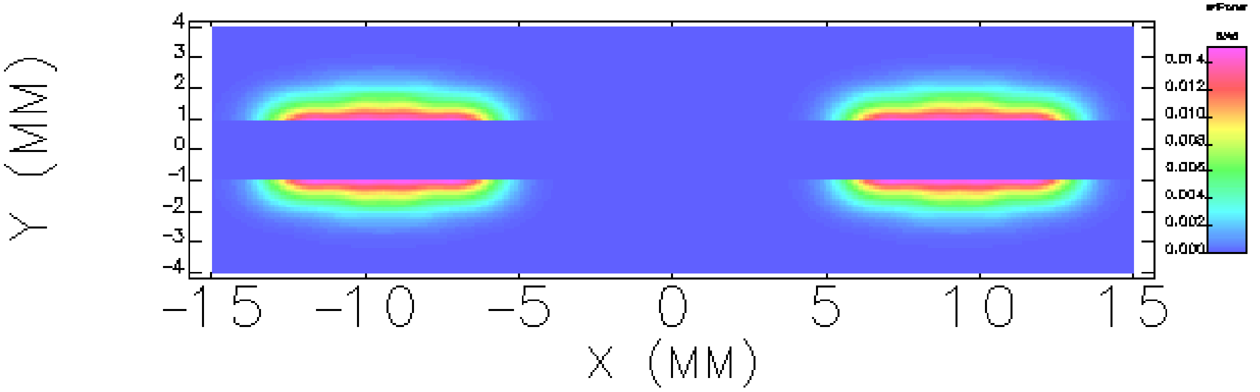
This is our current plan for Canted Undulator GRID-XBPM

Canted undulator front end XBPM design concept

XBPM Absorber Arrangement (side view)



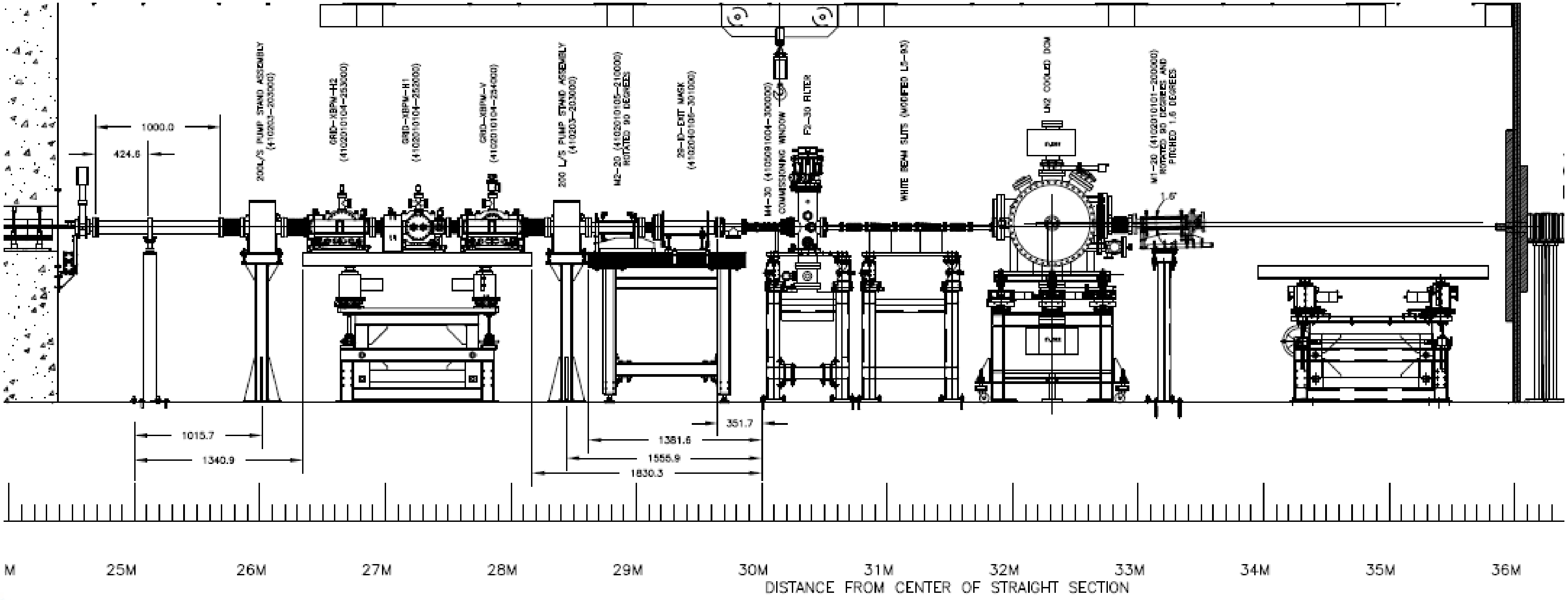
Intercepted pattern for Ky1 = Ky2 = 2.6 (gaps closed)



XRF Power by CU Flux throuth 0.1x0.1 mm↑2 Pinhole

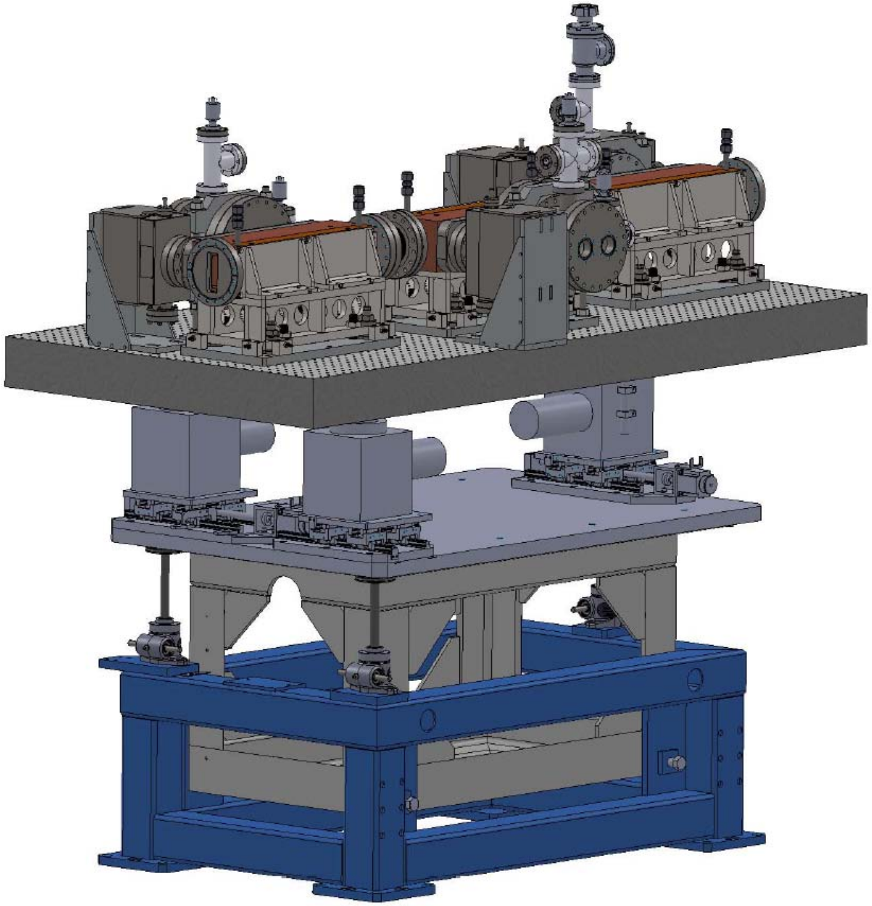
Full power XBPM test with dual Undulators A (29-IDA)

- First high-power test is planned for Run 2012-1 in the 29-ID-A two inline undulator A U33 sources.
  - Study high-heat-load performance: temperature, distortion, displacement, …
  - Investigate out-of-vacuum detector geometry experimentally
- Test both one-element and two-element configurations.

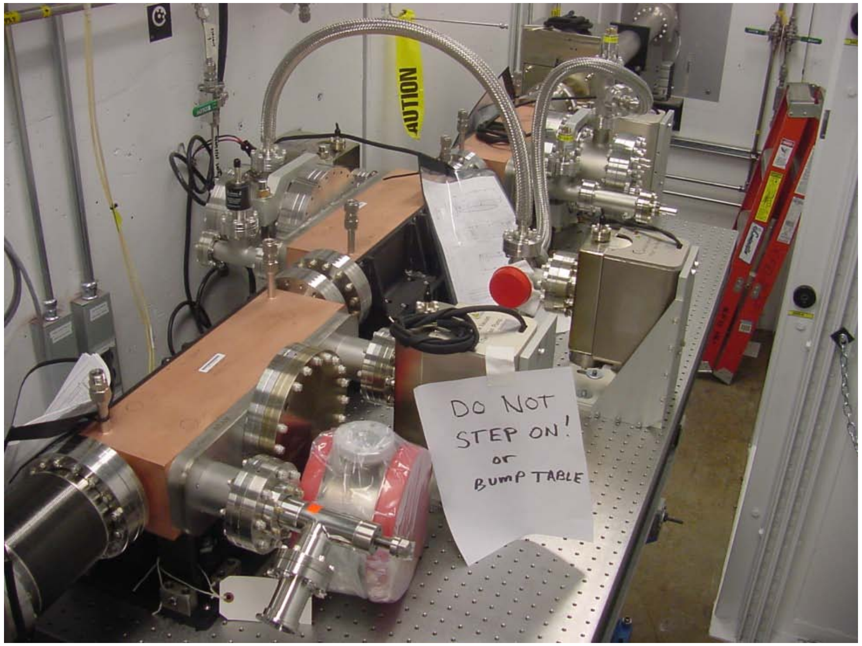


29-IDA XBPM preparation

- Hardware installation near completion for first beam next week during machine startup.



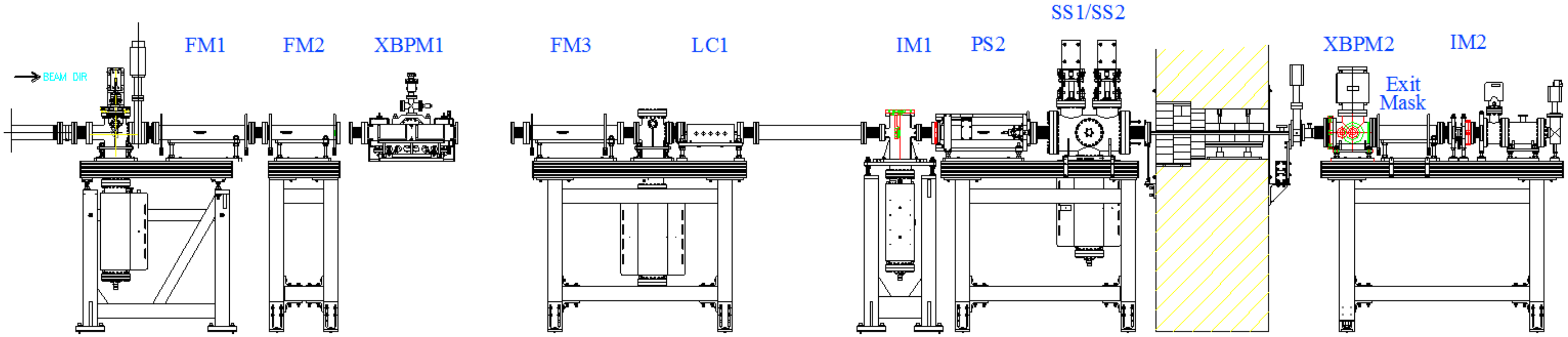
Installation at 29-ID FOE, 1/16/2012



Other components of the XBPM system

Key to optimal performance: The XBPM has zero gap dependence only when the white beam is at the aperture center.

- **Alignment aid**
  - Function: help position the white beam at the aperture center
  - First Beam Intensity Monitor (IM1)
  - Second Beam Intensity Monitor (IM2)
- **XBPM-2**
  - Function: real-time monitor of beam position stability
  - Integral design with Exit Mask



Summary

- A five-year effort to develop an x-ray fluorescence-based hard x-ray beam position monitor has resulted in the possibility of dramatic improvements in x-ray beam stability.

- By integrating these concepts into new high-heat load and canted undulator front ends, x-ray position reproducibility will be enhanced significantly.

- First full-scale high-power tests with two 3.3 cm period undulator A magnets start next week…

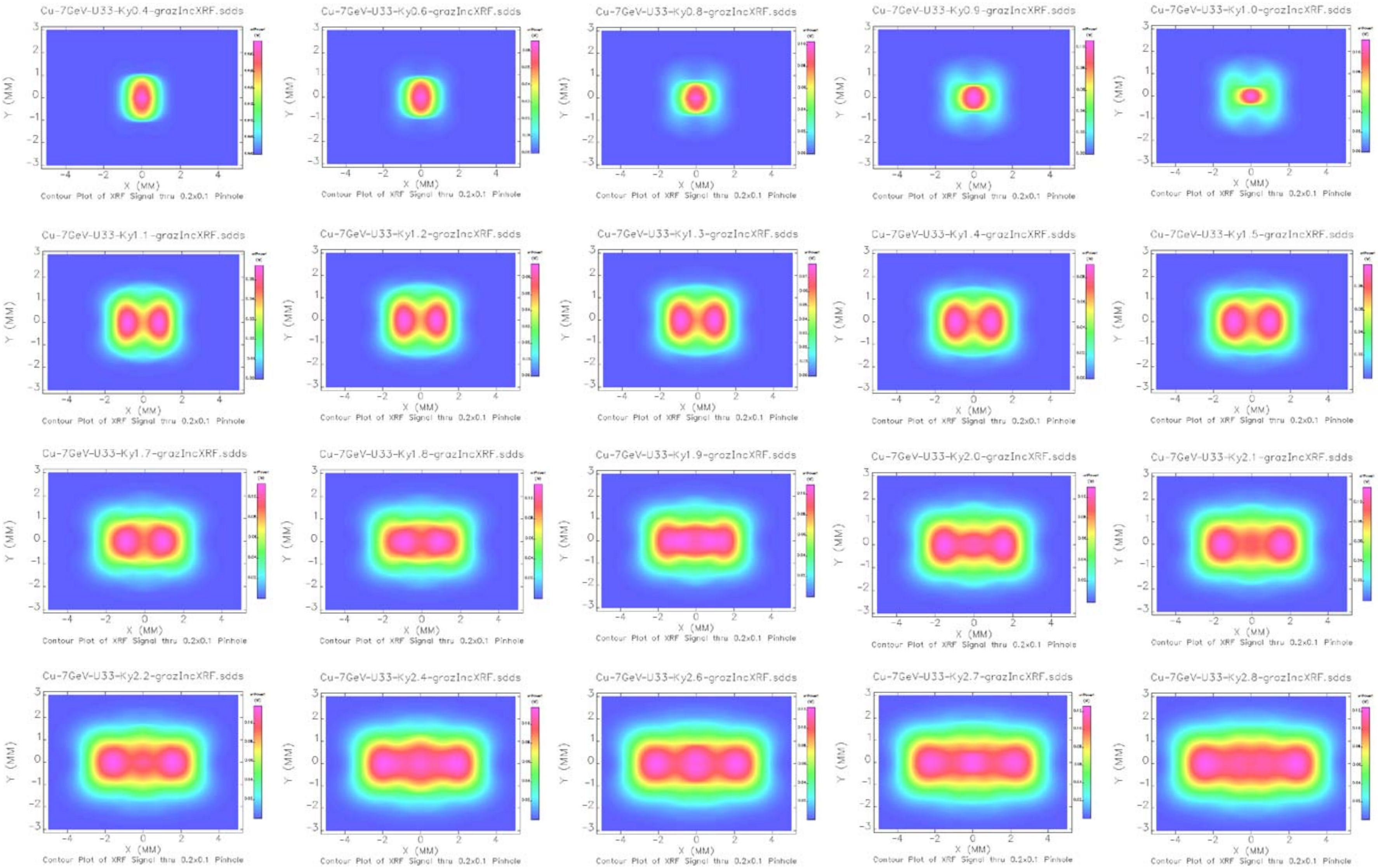
- So wish us luck.

End of Presentation

Spare Slides Next

X-Ray Fluorescence Intensity Distribution, U33

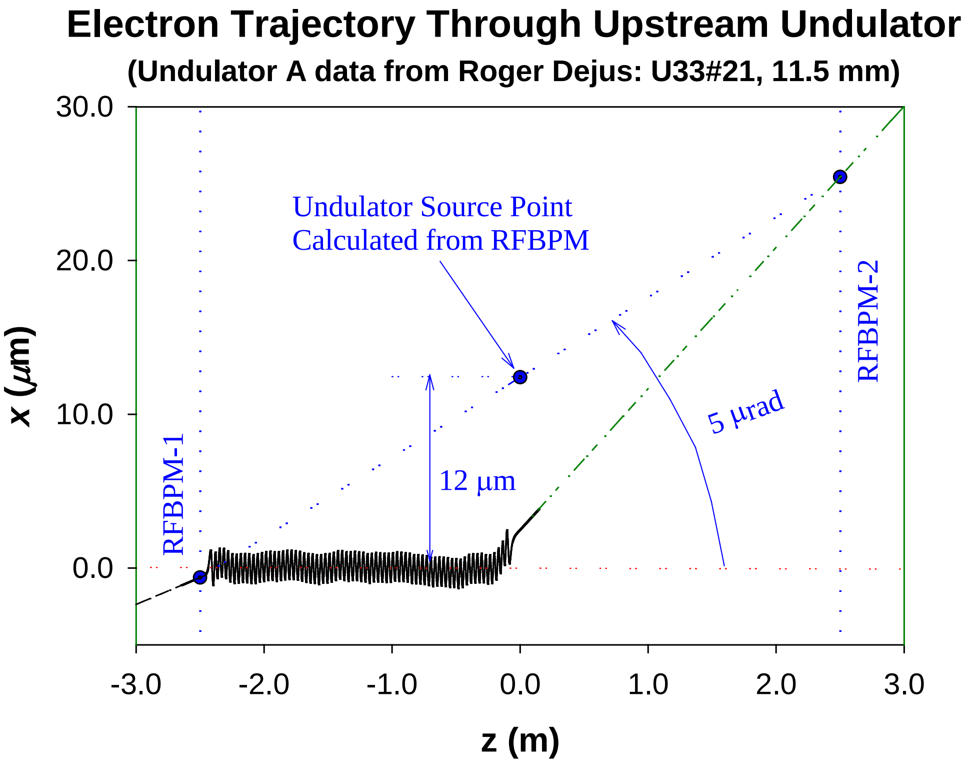
$E_1(K=\mathbf{1.07}\ ) = 2E_1(K=\mathbf{2.07})\ ) = 3E_1(K=\mathbf{2.73}) = 8.98\ \text{keV (Cu-}K\text{)}$



Position/angle shift in the undulator

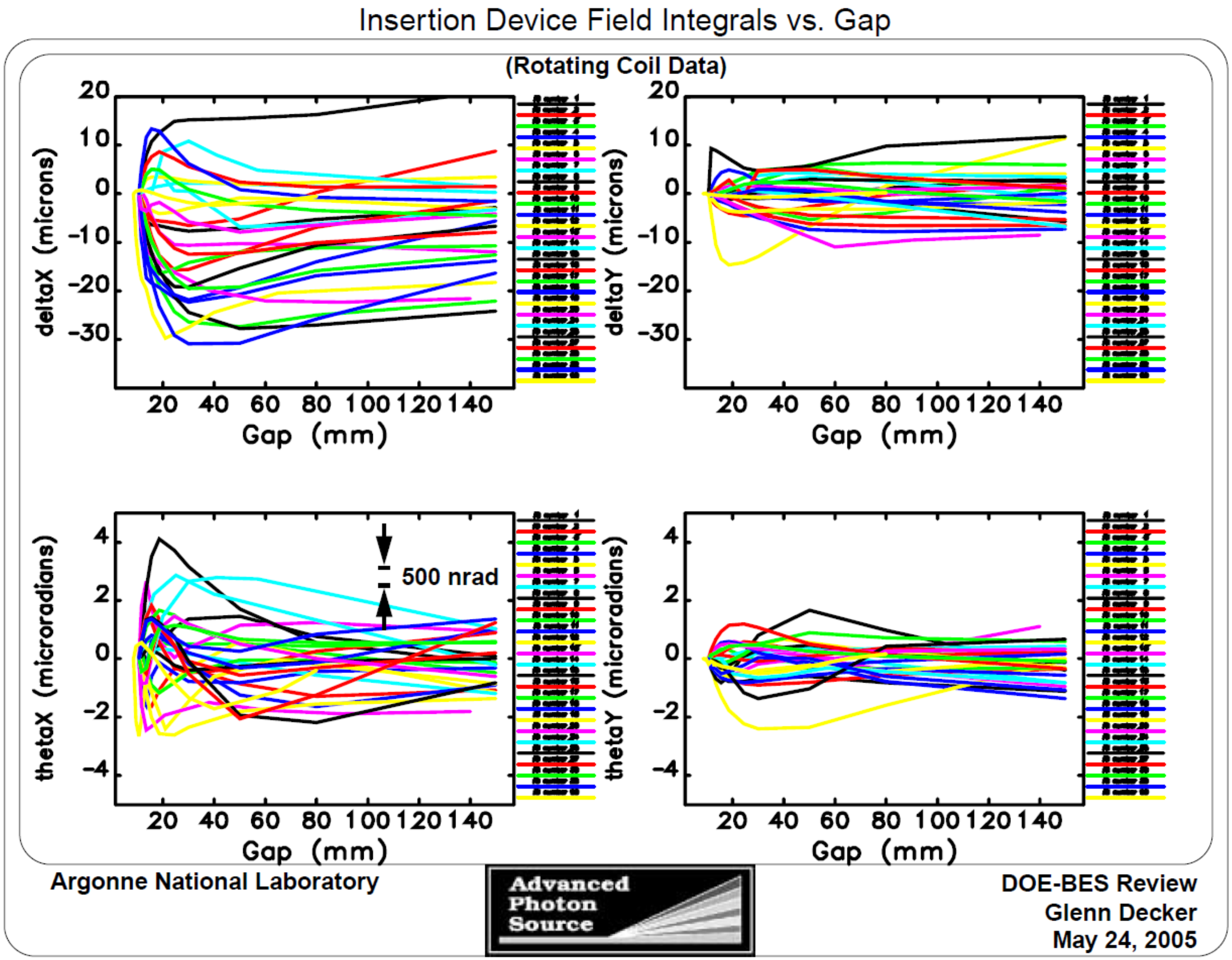
Undulator end segments steer the electron beam

- For a typical undulator: effective source point may shift by > 10 μm; effective beam angle may differ by more than 5 μrad.
- Steering depends on undulator gap (field).



Solution: Directly measure the x-ray source position and beam angle!

Gap-dependence of position/angle shift (G. Decker)



Insertion Device Field Integrals vs. Gap

(Rotating Coil Data)

Argonne National Laboratory

DOE-BES Review
Glenn Decker
May 24, 2005

Conclusion: Good XBPM is essential for beam stability.