BEAMLINE FOR TIME DOMAIN PHOTON DIAGNOSTICS AT THE ADVANCED PHOTON SOURCE UPGRADE

WEP016

IBIC2023

K. P. Wootton, W. Cheng, G. Decker, N. S. Sereno, F. Westferro
Argonne National Laboratory, Lemont, IL, USA

ABSTRACT

- Time domain photon diagnostics are proposed for electron beam characterisation and operation of the Advanced Photon Source Upgrade storage ring.
- In the present work, we present updated status on the time-domain X-ray and visible photon diagnostic beamline for the Advanced Photon Source Upgrade.
- We outline design influences leading to the proposed beamline layout, in particular long-term maintenance and commonality with other beamlines at the Advanced Photon Source.

MOTIVATION

- The Advanced Photon Source Upgrade (APS-U) project is presently underway, with the goal of increasing the brilliance of photon beams to user beamlines at the Advanced Photon Source (APS) [1-3].
- A number of user programs take advantage of the fill pattern for time-resolved X-ray techniques.
- As these user programs are anticipated to continue during APS-U operations, we are providing temporal photon beam diagnostics for the optimisation and diagnostics of accelerator operations.
- In the present work, we present updated status on the time-domain X-ray and visible photon diagnostic beamline at 35-BM for the APS-U. We outline design influences leading to the proposed beamline layout, in particular long-term maintenance and commonality with other beamlines at the APS.

DESIGN INFLUENCES

- The beamline layout has matured through the design process, with subtle but notable changes since our previous work on this beamline [4]. In particular, we have made a concerted effort to utilise components standardised across APS-U bending magnet front ends and beamlines to the greatest extent possible.
- For the APS, the 35-BM front-end and beamline employed a geometry optimised for providing multiple independent photon beams for diagnostics [5,6]. The beamline featured three branch lines (X-ray, visible, X-ray) separated horizontally in angle from the bending magnet source. The visible light beamline passed a large vertical angular acceptance of $\pm 2.9\ \mathrm{mrad}$ (Fig. 1). Several practical constraints steered us away from adopting the existing 35-BM geometry directly for APS-U.
- It is envisaged that two diagnostic beamlines will be operated for routine beam diagnostics measurements for APS-U. Transverse beam sizes and emittances will be observed using the 38-AM bending magnet beamline [7-10]. Bunch length and bunch purity will be observed using visible light and X-ray diagnostics at the 35-BM beamline [4]. To meet the long-term need for time-domain diagnostics at 35-BM, a large vertical aperture is not strictly required for either the X-ray or visible light photon diagnostics. Hence rather than creating large vertical opening apertures in many components of the 35-BM front end, we instead start our design from the new bending magnet front end (BMFE) for user APS-U bending magnet beamlines [2]. The opening angle of visible synchrotron radiation and beamline apertures are illustrated in Fig. 2.
- The choice to start from the standard user BMFE design affords us opportunities to standardise many beamline components and control equipment. We anticipate that this will be beneficial for long-term maintenance of the beamline.

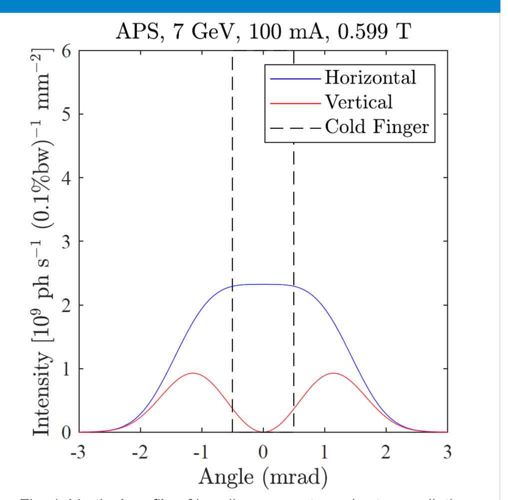

Fig. 1: Vertical profile of bending magnet synchrotron radiation accepted by 35-BM for APS storage ring. The cold finger masks synchrotron radiation over the central $\pm 0.5\ \mathrm{mrad}$.

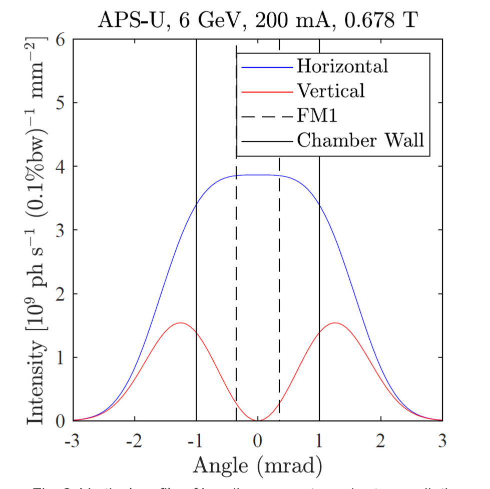

Fig. 2: Vertical profile of bending magnet synchrotron radiation accepted by 35-BM for APS-U storage ring. The vacuum chamber wall blocks synchrotron radiation at angles $\pm 1.0\ \mathrm{mrad}$. The first fixed mask (FM1) blocks synchrotron radiation at angles $> \pm 0.35\ \mathrm{mrad}$.

FRONT END

- 35-BM has been operational as a diagnostic beamline at APS for many years [5,6]. We summarise features of the front end and beamline layout for APS-U. The beamline front end for APS-U and APS is illustrated in Fig. 3.

X-Ray Path

- Figure 3 shows the scope of the changes to the front end for 35-BM. The standard BMFE is designed to pass X-rays through the the beamline (and protect the beamline when shutters are closed), so no changes to the standard BMFE are needed to accommodate X-ray beam transport to the shielded enclosures of 35-BM.

Visible Light Path

- For visible light, two essential changes are needed to the first fixed mask (FM1) and the visible light mirror. The vertical aperture of FM1 was increased by modifying a completed FM1 assembly using wire-cut electrical discharge machining. This increases the opening angle of synchrotron radiation accepted by the beamline to $\sim \pm 0.35\ \mathrm{mrad}$. The enlarged machined aperture of FM1 is illustrated in Fig. 4.
- A mirror inclined at 45° was used to reflect visible synchrotron radiation upwards. For APS [Fig. 3(b)], this mirror was at $z \approx 15\ \mathrm{m}$, while for APS-U [Fig. 3(a)], we position the new mirror at $z \approx 19.8\ \mathrm{m}$. This location was selected because it replaces the second X-ray Beam Position Monitor (XBPM2) in the standard BFME [2]. A water-cooled and vertically translatable stage for XBPM2 provide the required control for this optical mirror. The visible light mirror is shown installed in its vacuum chamber in Fig. 5.
- Thermal analysis of the visible light mirror was performed using finite element analysis. For routine beamline operations, we intend for the mirror to sit below the orbit plane of the ring, intercepting the lower fan of visible light synchrotron radiation in a manner similar to Refs. [11,12]. Using the translatable vertical stage, the mirror can be moved completely into the beam path to intercept visible light above and below the orbit plane of the ring, however this is anticipated to be used only for dedicated machine studies with very low stored beam current.
- Beyond the first mirror, visible light will be transported in air by reflecting the light using planar mirrors to the optical enclosure 35-BM-B. The optical transport is enclosed by stainless steel tubing.

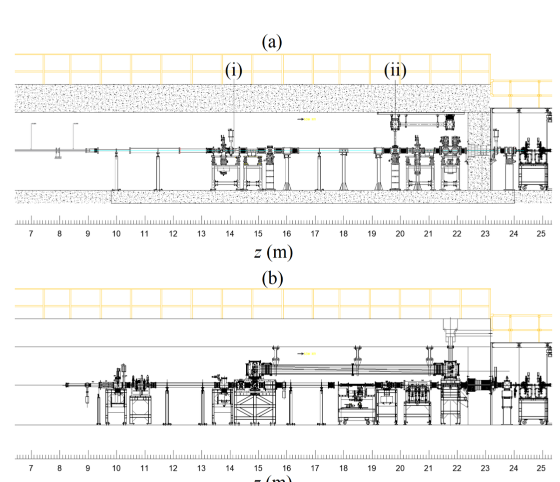

Fig. 3: Comparison of 35-BM front ends for APS-U and APS. The horizontal axis *z* is the distance from the bending magnet source in metres. (a) Front end configuration for APS-U. (i) First Fixed Mask. (ii) Visible Light Mirror. (b) Front end configuration for APS.

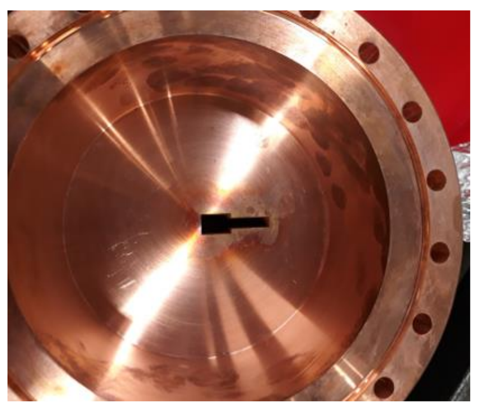

Fig. 4: Machining of FM1 vertical aperture to increase the vertical aperture for visible light propagation. The narrower slot (at right) is used to pass X-rays through to the X-ray beamline enclosures. The beam direction in this figure is into the page.

Fig. 5: Visible light mirror. The beam direction in this figure is into the page.

BEAMLINE

- The beamline layout on a standard APS sector is illustrated in Fig. 6. From the perspective of the X-ray beamline, the most significant change between the APS and APS-U machine is the lateral offset of 42 mm inboard of the new X-ray source point [2]. As a result, the new beamline centerline is 42 mm inboard of the previous beamline. Fortuitously, 35-BM features a unique shielded X-ray transport passing through the 35-BM-B hutch. The beam transport is actually two separate beam transport tubes, separated horizontally. As a result, we are able to configure the beamline to employ the inboard beam transport with minimal changes to the beamline components. Beamline components are illustrated in profile view in Fig. 7.

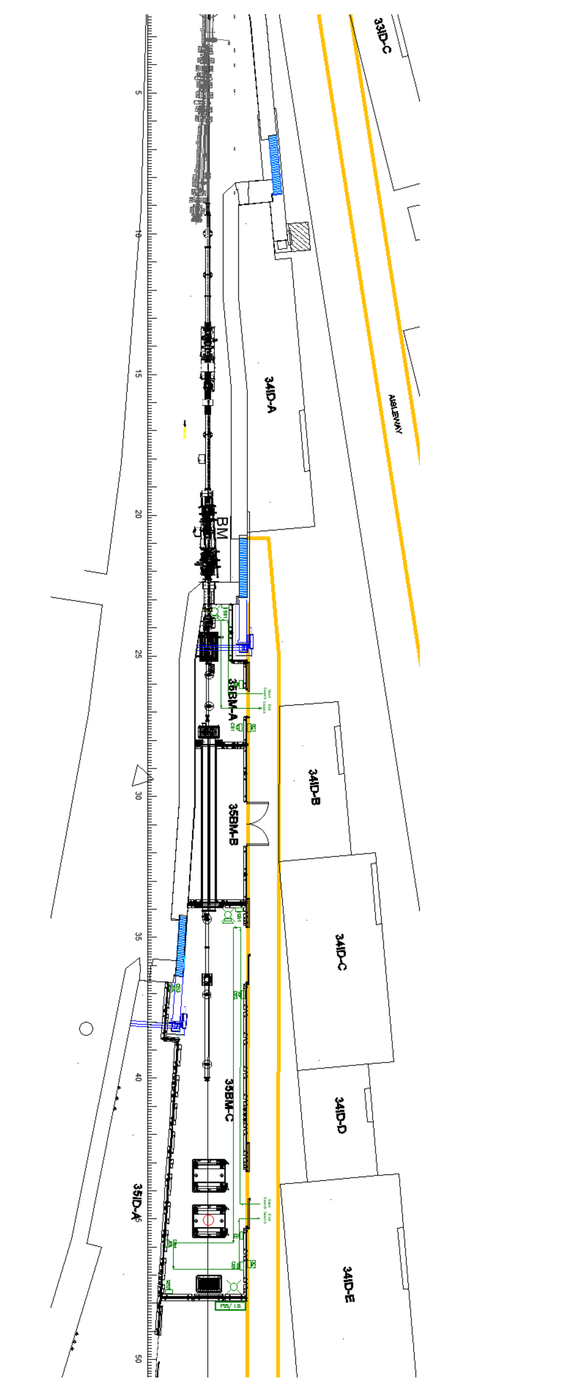

Fig. 6: Illustration of 35-BM beamline layout for APS-U operations. The horizontal axis *z* is the distance from the bending magnet source in metres. The beam direction in this figure is from top to bottom.

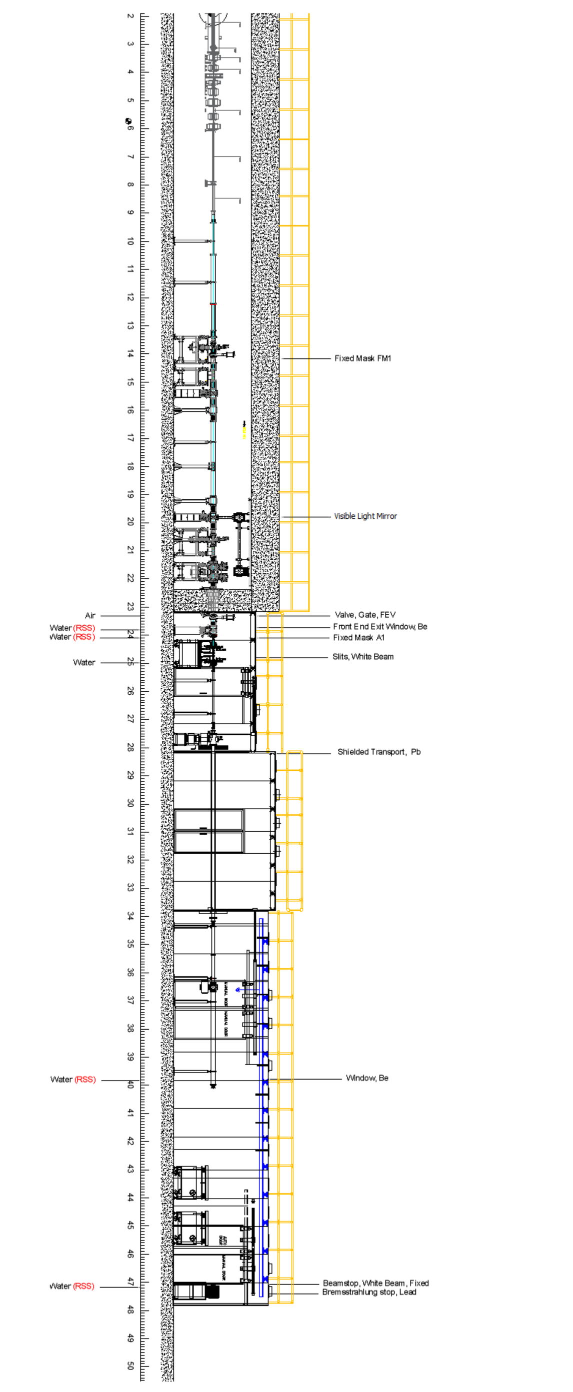

Fig. 7: Illustration of 35-BM beamline profile for APS-U operations. The horizontal axis *z* is the distance from the bending magnet source in metres. The beam direction in this figure is from top to bottom.

OUTLOOK

- The principal long-term purpose of the X-ray beamline configuration is to preserve X-ray beam transport from the 35-BM-A through to 35-BM-C hutches, for use with the bunch purity monitor diagnostic [13,14].
- However the beamline can also be used as configured for an X-ray pinhole camera for beam size measurements. Four blades of white-beam slits (z=24 m) can be closed to form a rectangular pinhole aperture.
- A scintillator and optical microscope can be positioned near the end of the beamline (z=45 m) in order to image the electron beam in the APS-U storage ring with an X-ray pinhole magnification 21/24=0.875. Parameters of the electron beam and pinhole camera in the horizontal plane are summarised in Table 1.

Table 1: Pinhole Camera Parameters.

Parameter	Symbol	Value
Beta function	β_x	0.84 m
Emittance	ε_x	42 pm rad
Energy spread	δ	0.156%
Dispersion	η_x	3.67 mm
Beam size (source)	σ_x	8.3 µm
Pinhole magnification	M	0.875
Beam size (scintillator)	Σ_x	7.2 µm

- We anticipate that the spatial resolution needed to image an X-ray spot size of Gaussian distribution $\Sigma_x = 6.2\ \mu\mathrm{m}$ is challenging, but not beyond technical feasibility. We anticipate that few-$\mu\mathrm{m}$ resolution may be achievable by using a $20\ \mu\mathrm{m}$ thick single-crystal scintillator such as Cerium-doped Yttrium Aluminium Garnet imaged by an optical microscope with numerical aperture between 0.4–1.0 [15].

SUMMARY

- In the present work, we have presented updated status on the time-domain X-ray and visible photon diagnostic beamline for the Advanced Photon Source Upgrade.
- We have outlined design influences leading to the proposed beamline layout, in particular long-term maintenance and commonality with other beamlines at the Advanced Photon Source.
- Beyond its primary use as a time-domain diagnostic, we additionally outline potential use of the beamline to image the electron beam distribution in the horizontal plane.

REFERENCES

[1] T. E. Fornek, “Advanced Photon Source Upgrade Project Final Design Report”, Argonne National Laboratory, Lemont, IL, USA, Rep. APSU-2.01-RPT-003, May 2019. doi:10.2172/1543138
[2] T. E. Fornek, “Advanced Photon Source Upgrade Project Preliminary Design Report”, Argonne National Laboratory, Lemont, IL, USA, Rep. APSU-2.01-RPT-002, Sep. 2017. doi:10.2172/1423830
[3] M. Borland *et al.*, “The Upgrade of the Advanced Photon Source”, in Proc. 9th Int. Particle Accelerator Conf. (IPAC’18), Vancouver, Canada, Apr.-May 2018, pp. 2872–2877. doi:10.18429/JACoW-IPAC2018-THXGBD1
[4] K. P. Wootton *et al.*, “Time Domain Photon Diagnostics for the Advanced Photon Source Upgrade”, in Proc. IBIC’21, Pohang, Korea, Sep. 2021, pp. 356–360. doi:10.18429/JACoW-IBIC2021-WEPP02
[5] B. Yang and A. H. Lumpkin, “The Planned Photon Diagnostics Beamlines at the Advanced Photon Source”, AIP Conf. Proc., vol. 333, pp. 252–258 (1995). doi:10.1063/1.48048
[6] A. Lumpkin, and B. Yang, “Status of the synchrotron radiation monitors for the APS facility rings”, in Proc. 16th Particle Accelerator Conf. (PAC’95), Dallas, TX, USA, May 1995, paper MPQ09, pp. 2470–2472. doi:10.1109/PAC.1995.505587
[7] B. X. Yang *et al.*, “High-Energy X-Ray Pinhole Camera for High-Resolution Electron Beam Size Measurements”, in Proc. IBIC’16, Barcelona, Spain, Sep. 2016, pp. 504–507. doi:10.18429/JACoW-IBIC2016-TUPG66
[8] B. X. Yang and S. H. Lee, “Planned x-ray diffraction diagnostics for APS Upgrade emittance measurements”, presented at Topical Workshop on Emittance Measurements for Light Sources and FELs, Barcelona, Spain, Jan. 2018, unpublished.
[9] K. P. Wootton, W. X. Cheng, G. Decker, S. H. Lee, and B. X. Yang, “X-Ray Beam Size Monitor Enclosure for the Advanced Photon Source Upgrade”, in Proc. IBIC’20, Santos, Brazil, Sep. 2020, pp. 34–36. doi:10.18429/JACoW-IBIC2020-TUPP05
[10] K. P. Wootton *et al.*, “Design of the X-Ray Beam Size Monitor for the Advanced Photon Source Upgrade”, in Proc. IPAC’21, Campinas, Brazil, May 2021, pp. 956–959. doi:10.18429/JACoW-IPAC2021-MOPAB303
[11] J. C. Bergstrom, J. M. Vogt, “The optical diagnostic beamline at the Canadian Light Source”, Nucl. Instrum. Methods Phys. Res., Sect. A, vol. 562, pp. 495–512, Jun. 2006. doi:10.1016/j.nima.2006.02.200
[12] M. J. Boland *et al.*, “X-ray and Optical Diagnostic Beamlines at the Australian Synchrotron Storage Ring”, in Proc. EPAC’06, Edinburgh, UK, Jun. 2006, paper THPLS002, pp. 3263–3265.
[13] W. E. Norum and B. X. Yang, “A Novel FPGA-Based Bunch Purity Monitor System at the APS Storage Ring”, in Proc. 22nd Particle Accelerator Conf. (PAC’07), Albuquerque, NM, USA, Jun. 2007, paper FRPMN115, pp. 4384–4386. doi:10.1109/PAC.2007.4440014
[14] B. X. Yang, W. E. Norum, S. E. Shoaf, and J. B. Stevens, “Bunch-by-Bunch Diagnostics at the APS Using Time-Correlated Single-Photon Counting Techniques”, in Proc. 14th Beam Instrumentation Workshop (BIW’10), Santa Fe, NM, USA, May 2010, paper TUPSM044, pp. 238–242.
[15] T. Martin, A. Koch, “Recent developments in X-ray imaging with micrometer spatial resolution”, J. Synchrotron Radiat., vol. 13, pp. 180–194, Jan. 2006. doi:10.1107/S0909049506000550

U.S. DEPARTMENT OF ENERGY
Argonne National Laboratory is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC.

Argonne NATIONAL LABORATORY