X-ray Diagnostics

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U.S. DEPARTMENT OF ENERGY

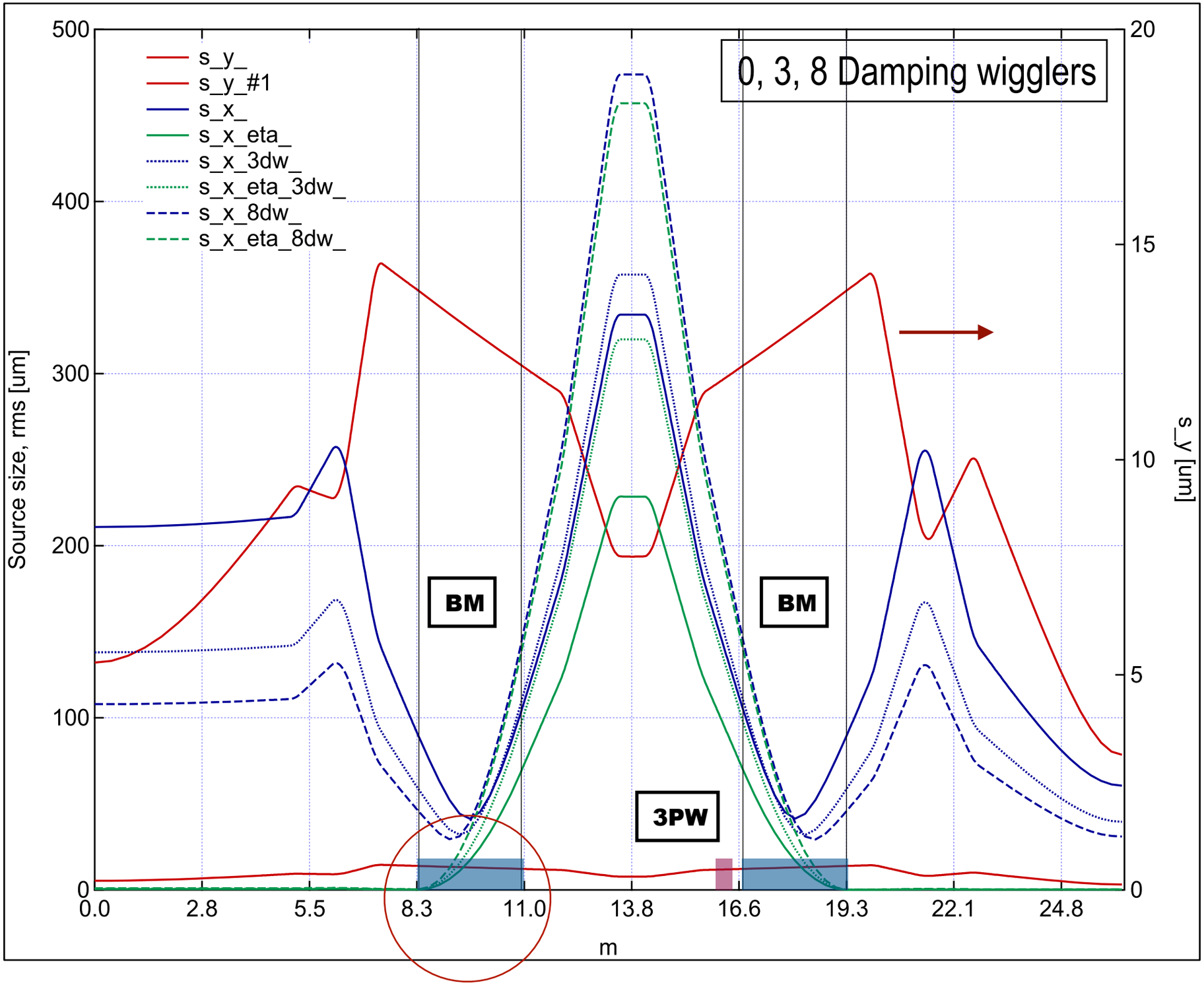
BROOKHAVEN NATIONAL LABORATORY
BROOKHAVEN SCIENCE ASSOCIATES

X-ray diagnostics objectives

- **e-beam**
  - emittance
    - source size measurements
      - pinhole
      - CRL
  - particles energy spread
- **Photon beam**
  - commissioning
    - ID radiation centering
  - position monitors
    - feedback

e-beam Diagnostics

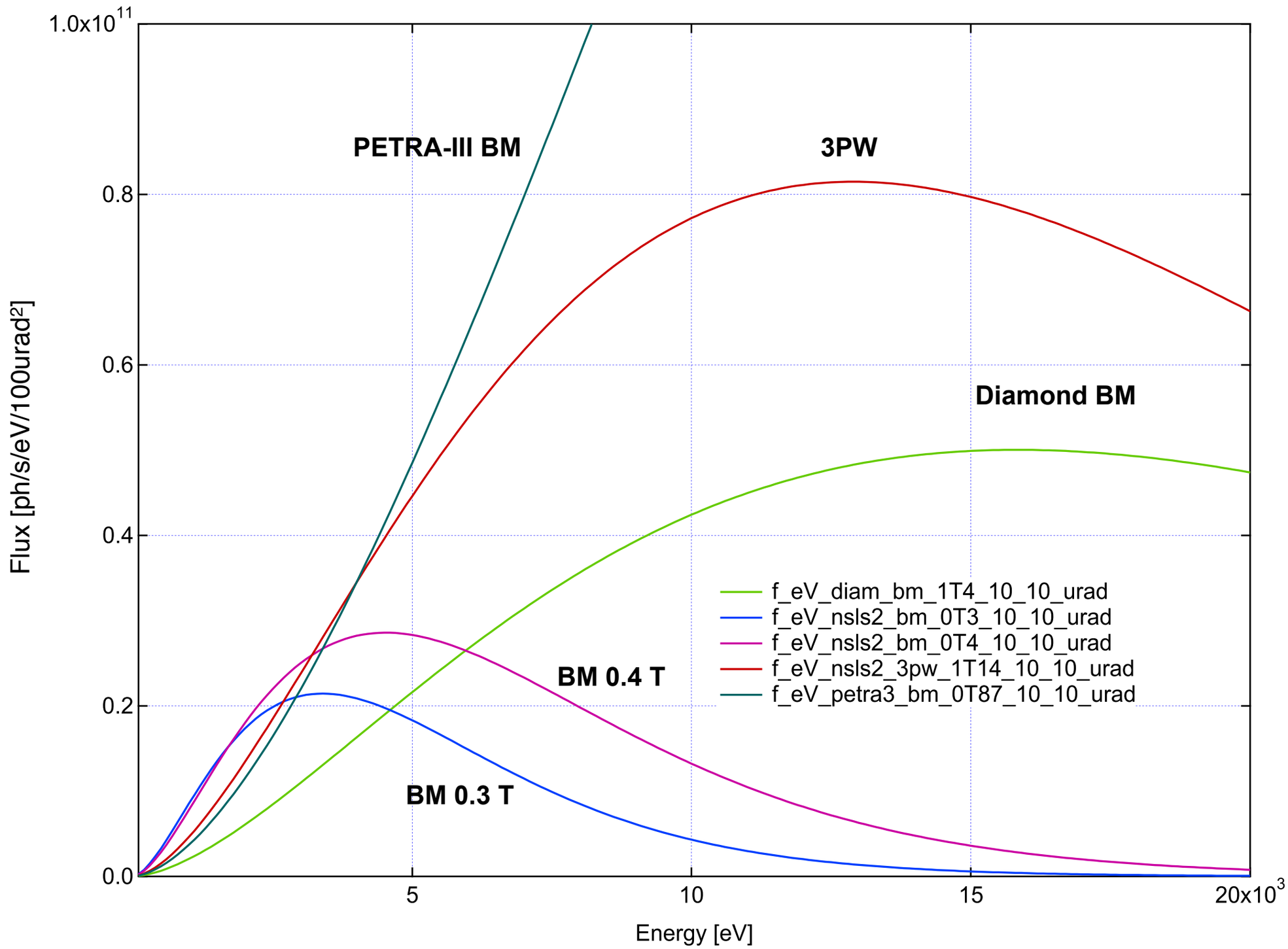
e-beam Source Size



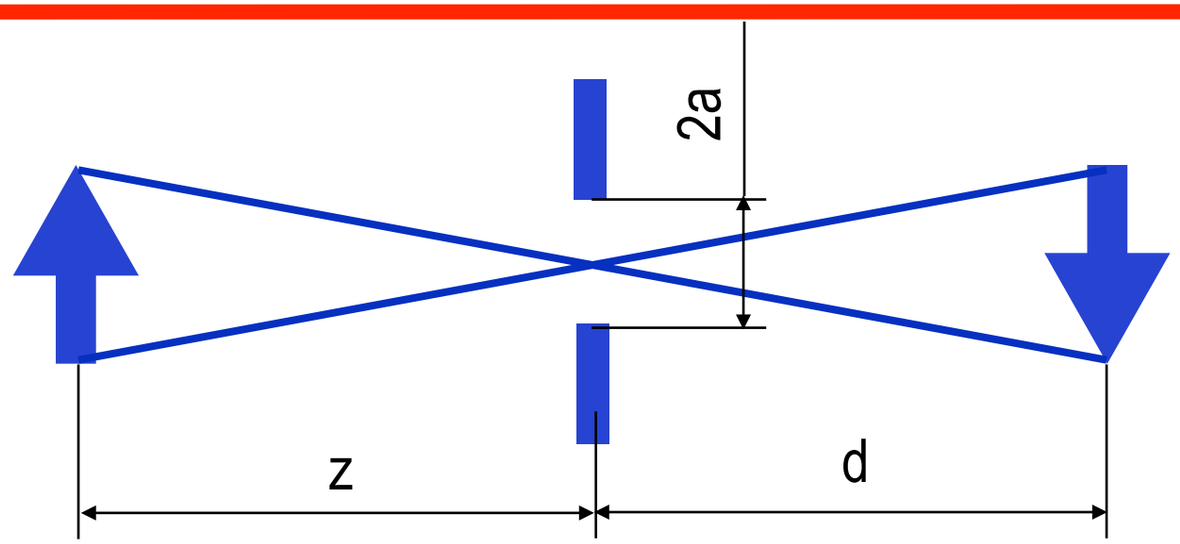
e-beam / Radiation

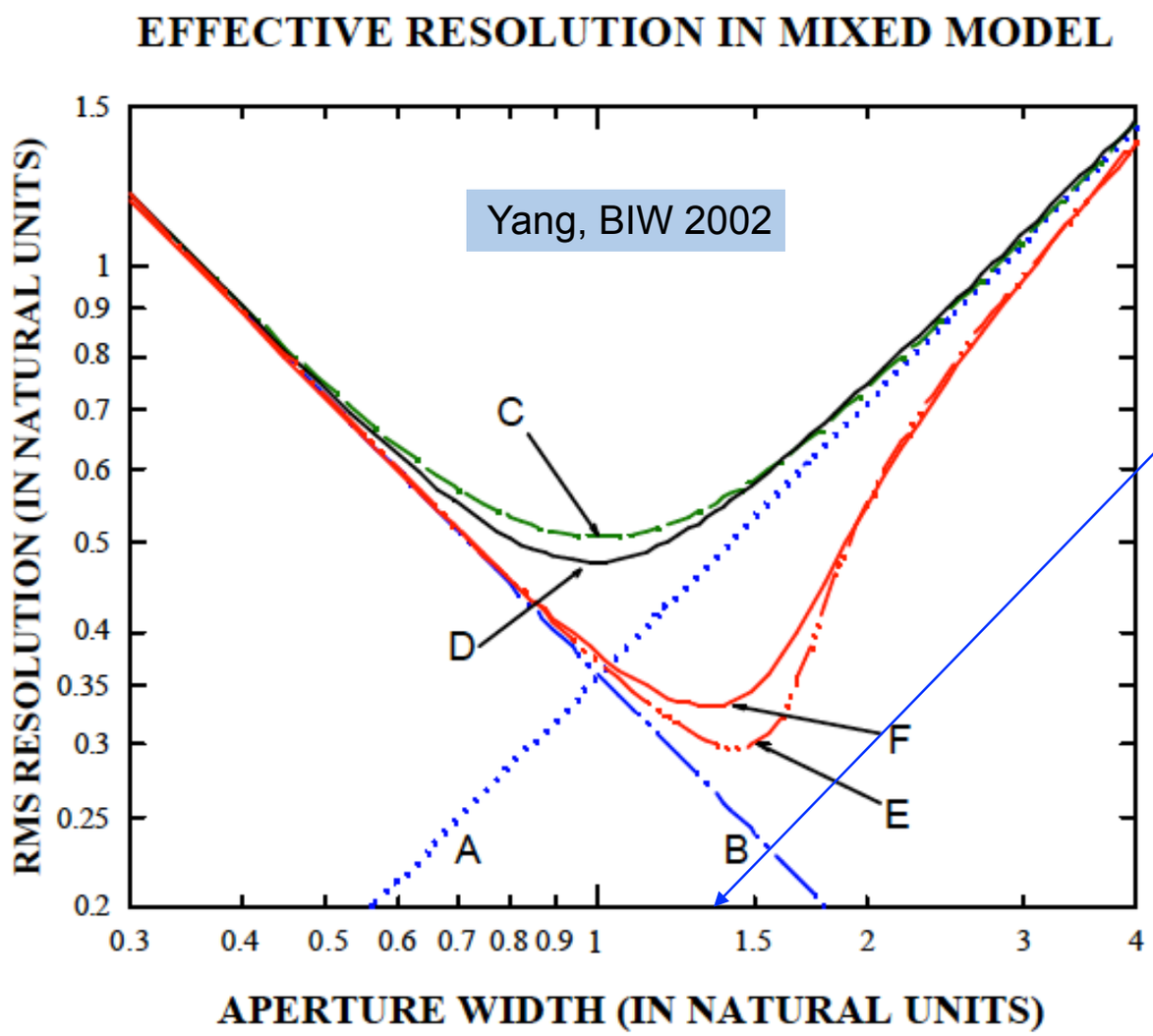
	BM	3-pole wiggler
σ_x [μm]	75	140
σ_y [μm]	14	12
$\sigma_{x'}$ [μrad]	56	77
$\sigma_{y'}$ [μrad]	0.8	0.9
B [T]	0.4	1.14
E_c [keV]	2.4	6.8
$\sigma'_{ph} \sim 1/\gamma$ [μrad]	170	170
σ_{ph} [μm]	0.24	0.09
L_f [mm]	4.3	1.5

Radiation Sources - Spectral Flux



Imaging with Pinhole





$$Pinhole\ diameter = 2a$$

$$\frac{1}{f} = \frac{1}{z} + \frac{1}{d} \qquad \frac{1}{f} = \frac{(1+M)^2}{LM}$$

$$L = z + d \qquad z = L/(1+M)$$

$$M = d/z \qquad d = ML/(1+M) \qquad M = \frac{L}{z} - 1$$

$$F = \frac{a^2}{\lambda f}$$

- For an optimal $F = 0.7$

$$a = \sqrt{0.7\,\lambda\, LM/(1+M)}$$

and PSF (w=WFHM) at

Image Plane:

$$w \simeq 2\sqrt{\frac{\lambda}{2\pi}\frac{d^2}{f}}$$

$$w \simeq \frac{2}{\sqrt{2\pi}}\sqrt{\lambda\, M\, L}$$

Source Plane:

$$w \simeq 0.7\sqrt{\lambda\, L/M}$$

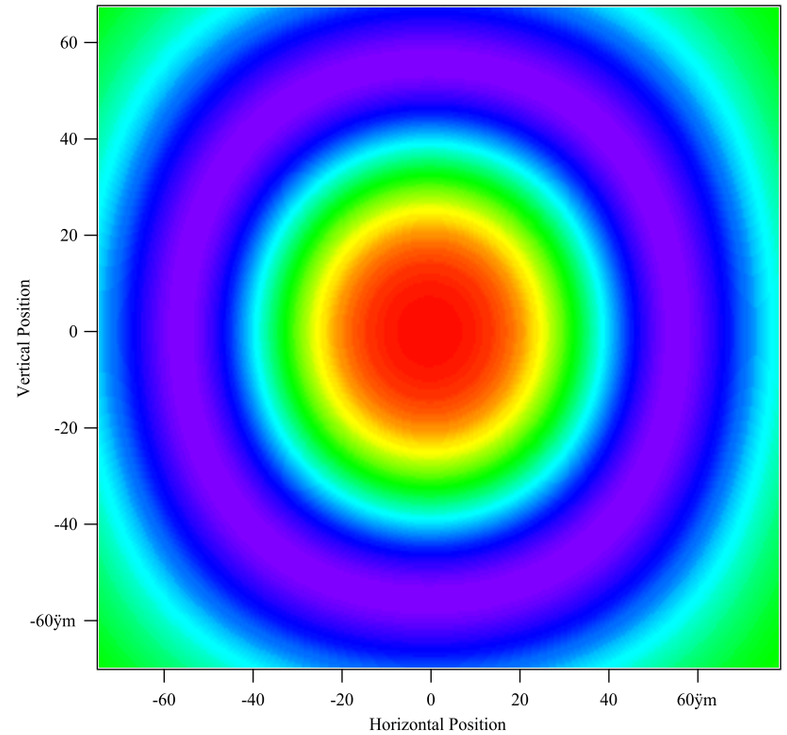
$$\sigma \simeq 0.3\sqrt{\lambda\, L/M}$$

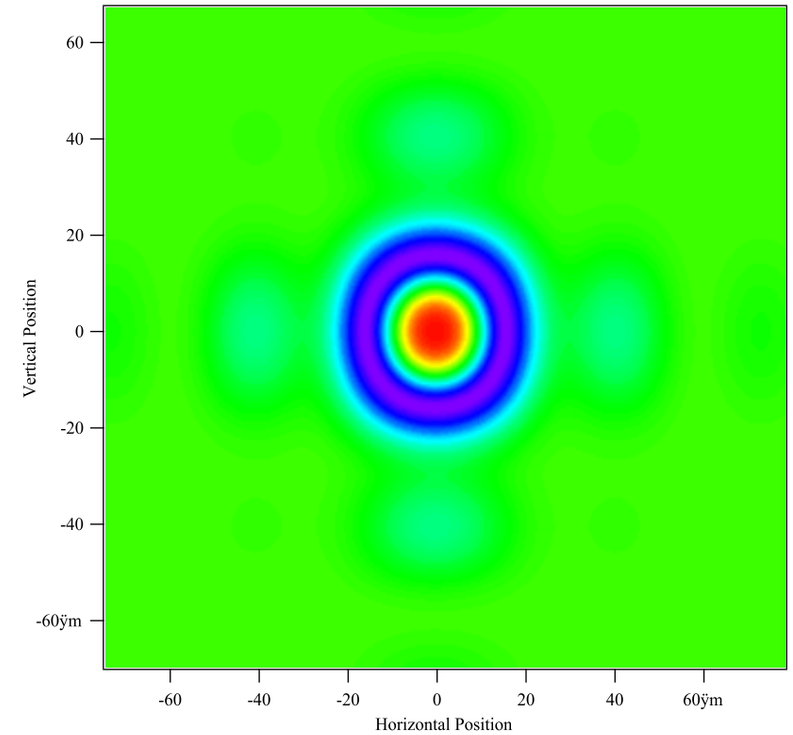
$$\sigma \simeq 0.3\sqrt{\lambda\, Lz/(L-z)}$$

Square Pinhole - PSF

E=12 keV, z=6m, d=10m

5 x 5 μm²

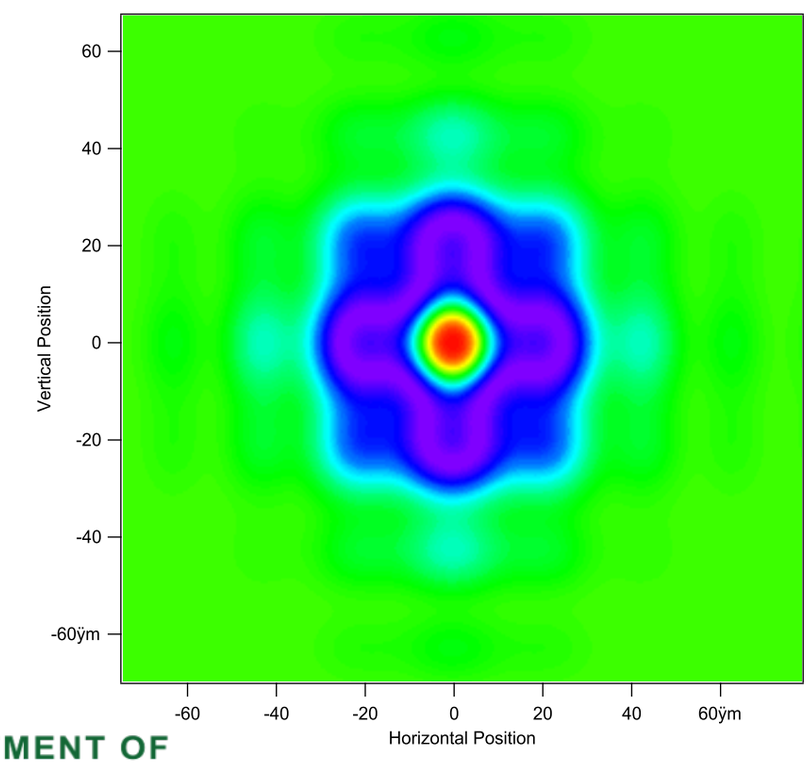


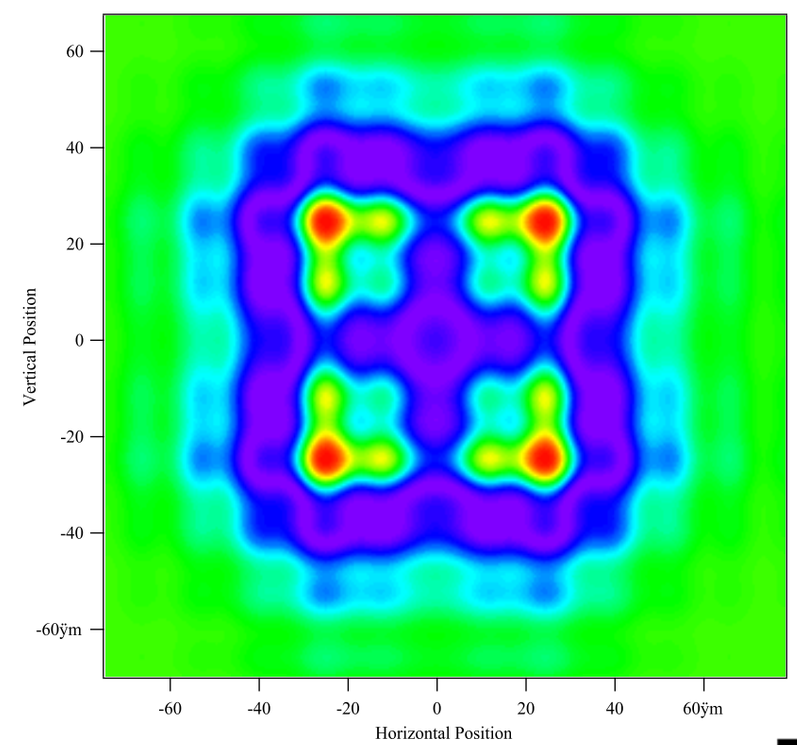


10 x 10 μm²

33 x 33 μm²

Optimal

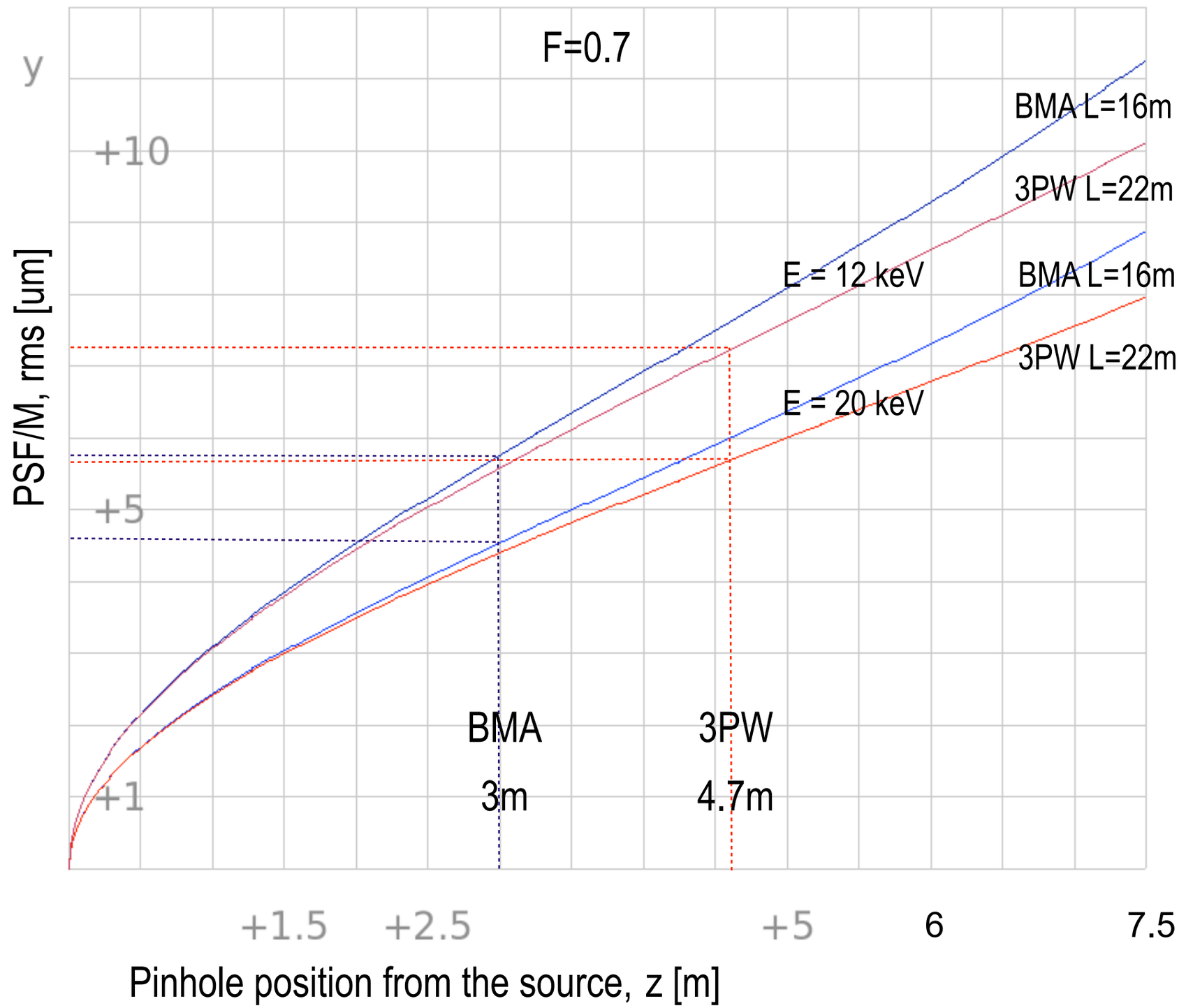




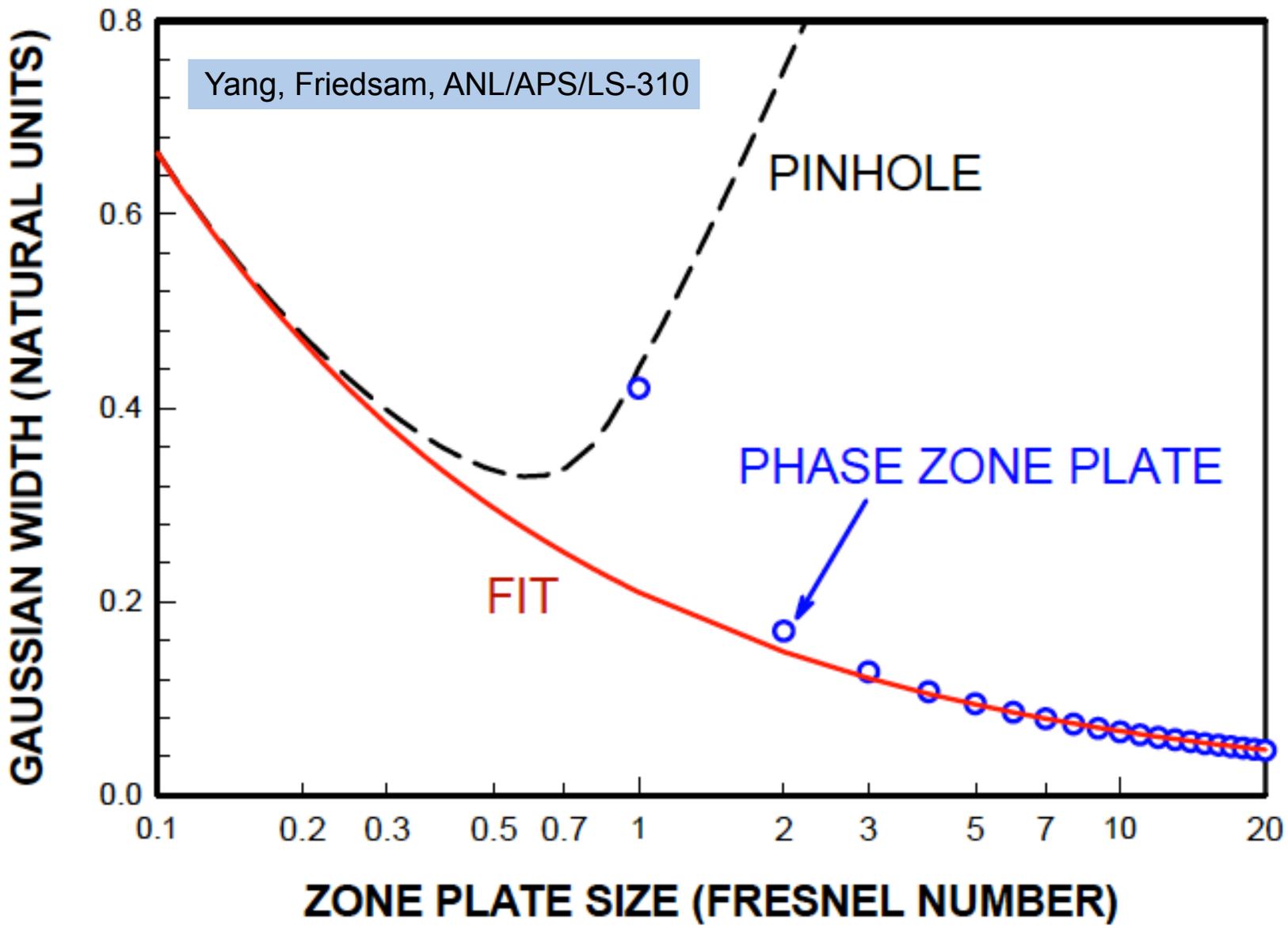
100 x 100 μm²

Pinhole setup optimization

Resolution (PSF WFHM) vs. Pinhole position from the source



X-ray Optics - Resolution



Larger NA allows to increase spatial resolution

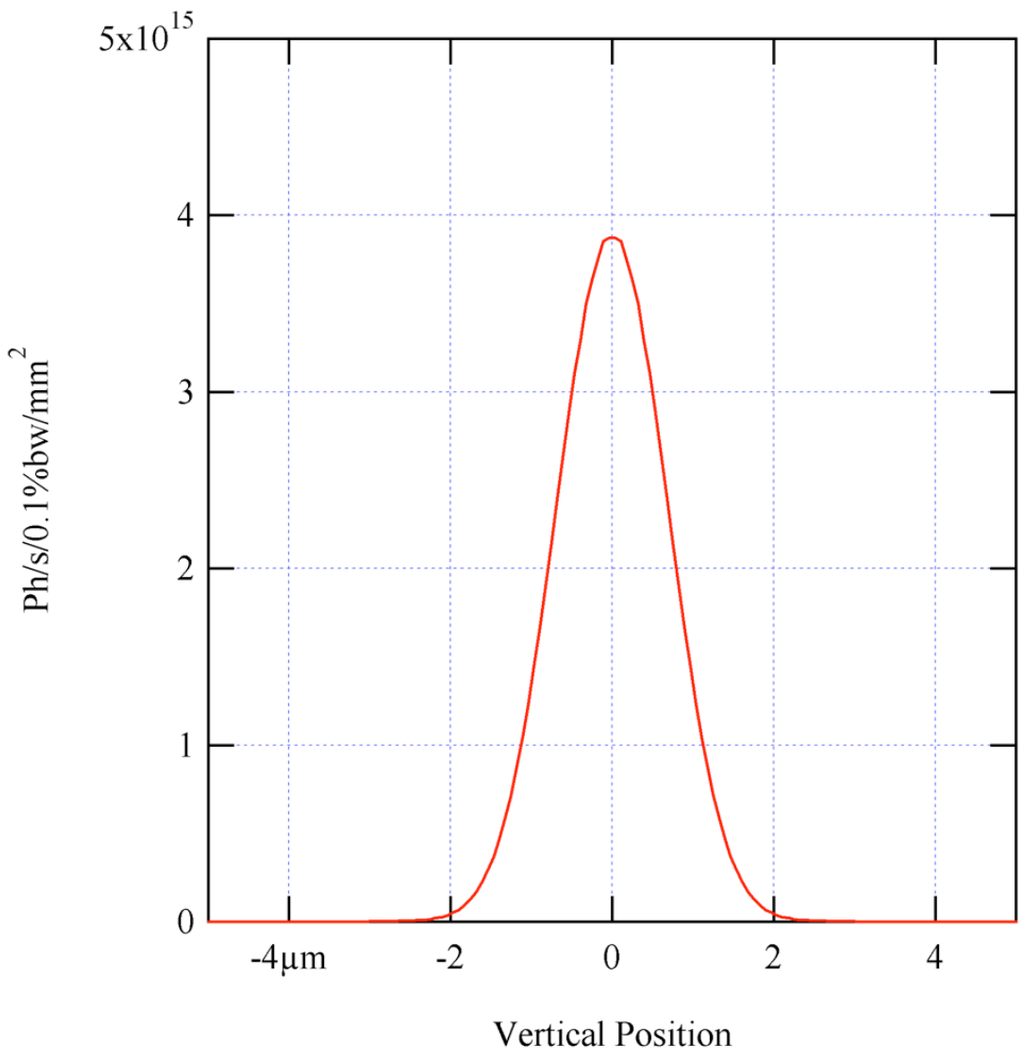
A Compound Refractive Lens (CRL) optics will be used for high resolution setup

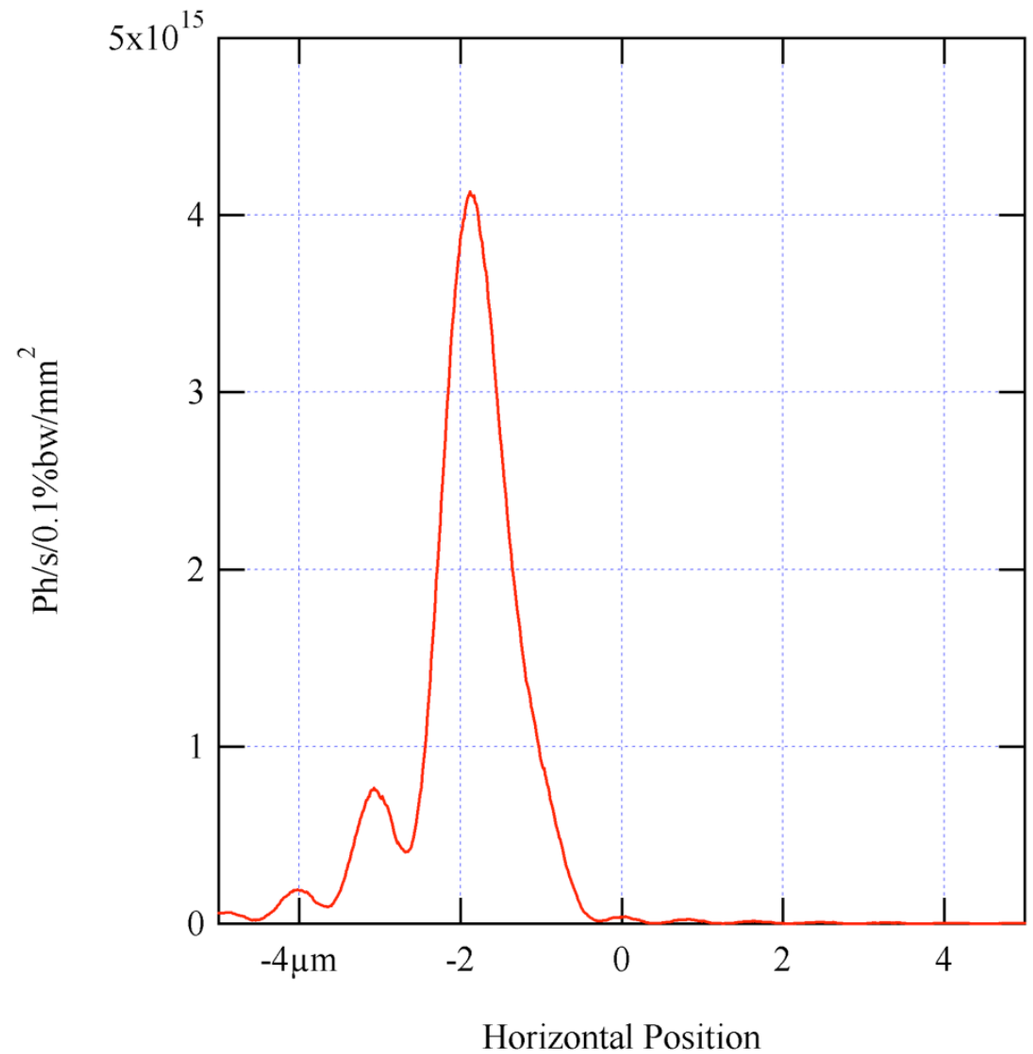
Compound Refractive Lens (CRL) - PSF

Calculated Point Spread Functions (PSF)

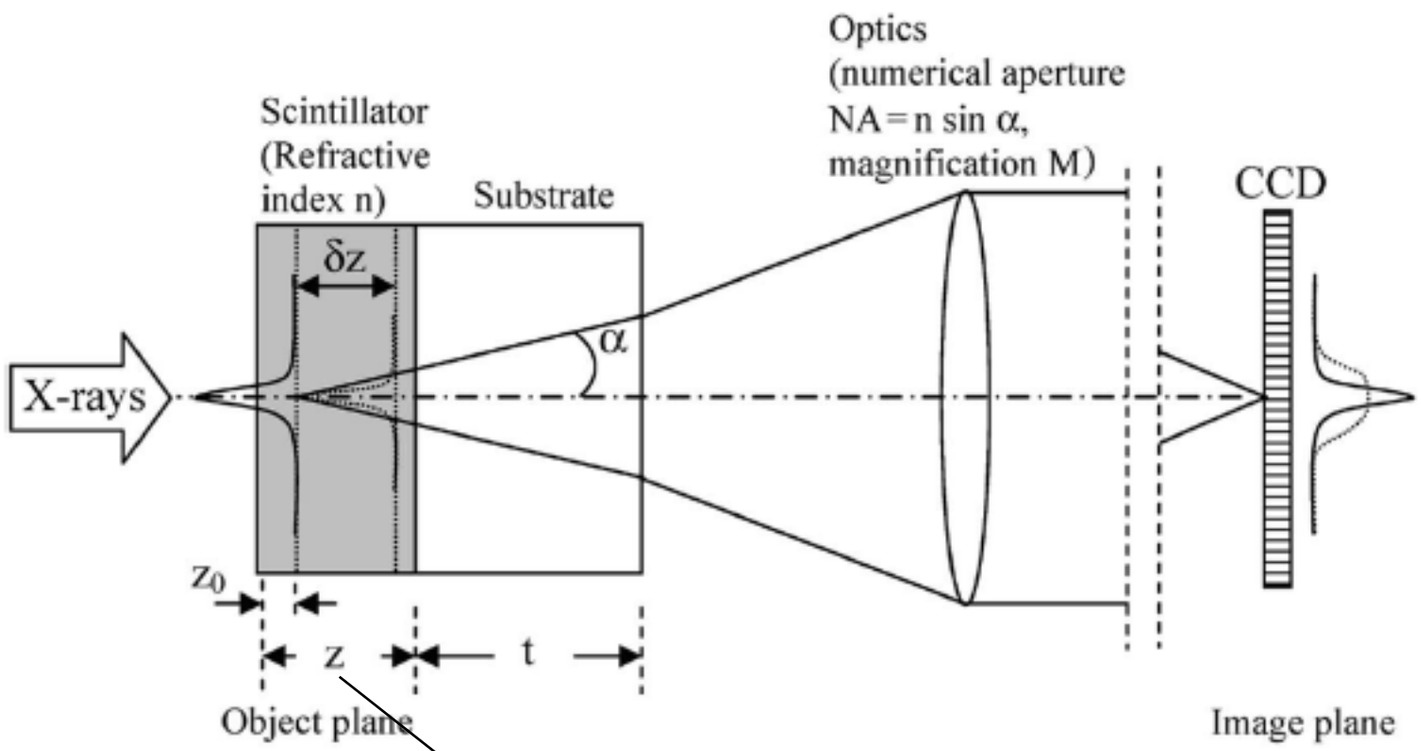
BM radiation, 0.4T, single electron, E_{ph}=20 keV, σ'=0.05 mrad

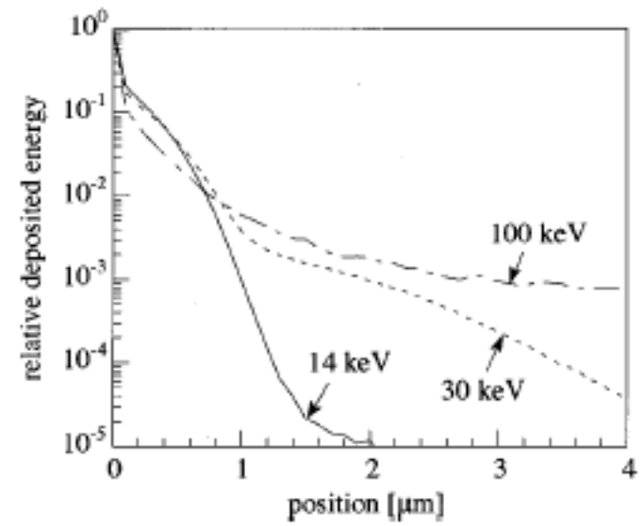
CRL - 12 Be lenses, 1-mm-diam, R=50um, z=3.02m, d=12.98m, M=4.3

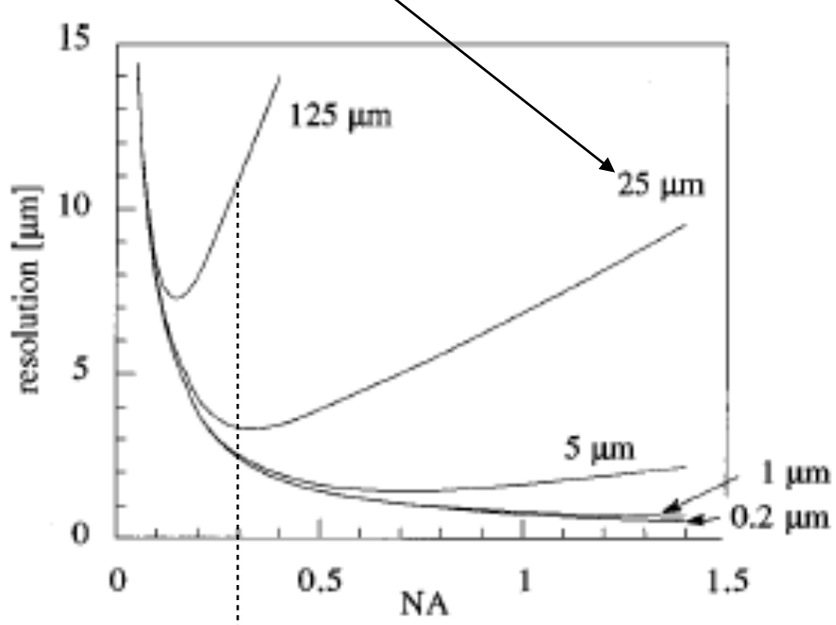




X-ray Detection - PSF







x10 objective

Spatial resolution is limited by:

- Diffraction: $R \sim \lambda/NA$
- Depth of focus: $R \sim \delta z \cdot NA$
- Spherical aberrations of substrate: $R \sim t \cdot NA^3$
- Photoelectron range

Koch et al, J.Opt.Soc.Am. A, Vol. 15, p.1940, 1998

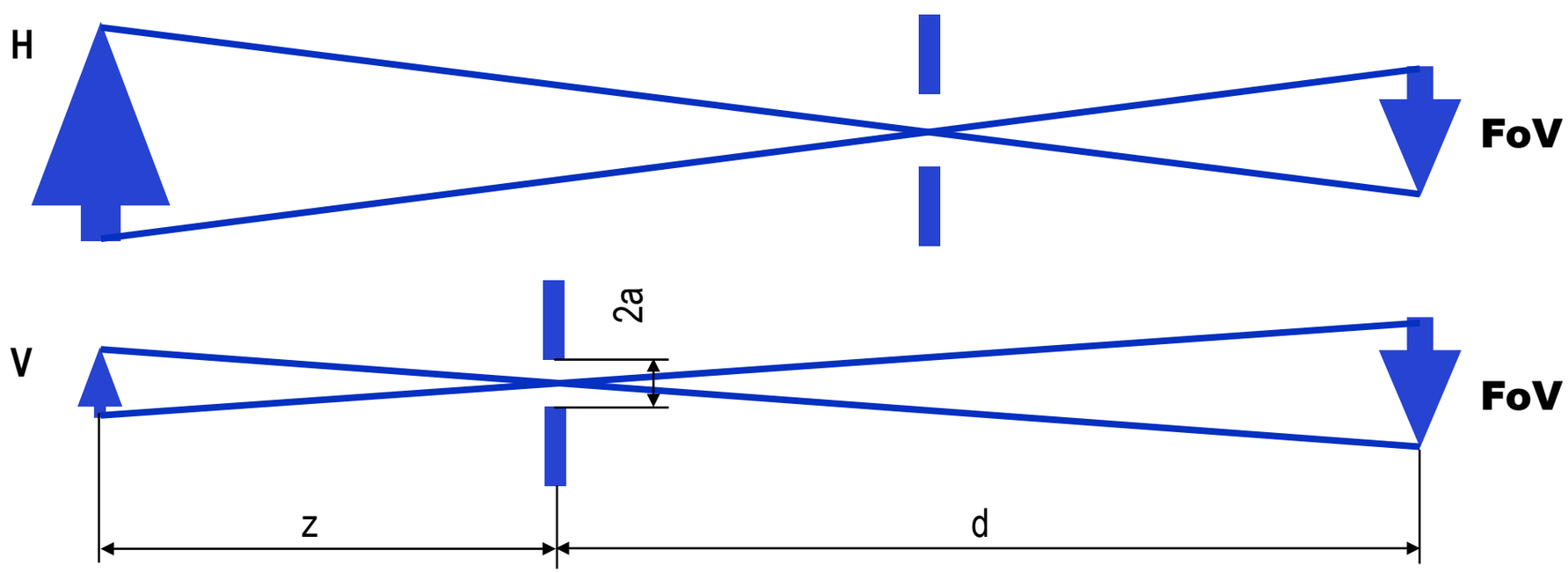
X-ray Detection - beamline setup

- Required spatial resolution
  - 2-3 μm
- Field of View (FoV)
  - is defined by source size, required resolution, objective magnification, CCD dimensions
  - source is highly asymmetric
  - FoV needs to be 2÷3 times of the image size (6σ)
- FoV vs. Resolution
  - Different magnification for Horizontal and Vertical directions allows to achive required resolution with standard CCD
  - Horizontal and Vertical slits
  - Linear CRL for imaging in Horizontal and Vertical planes

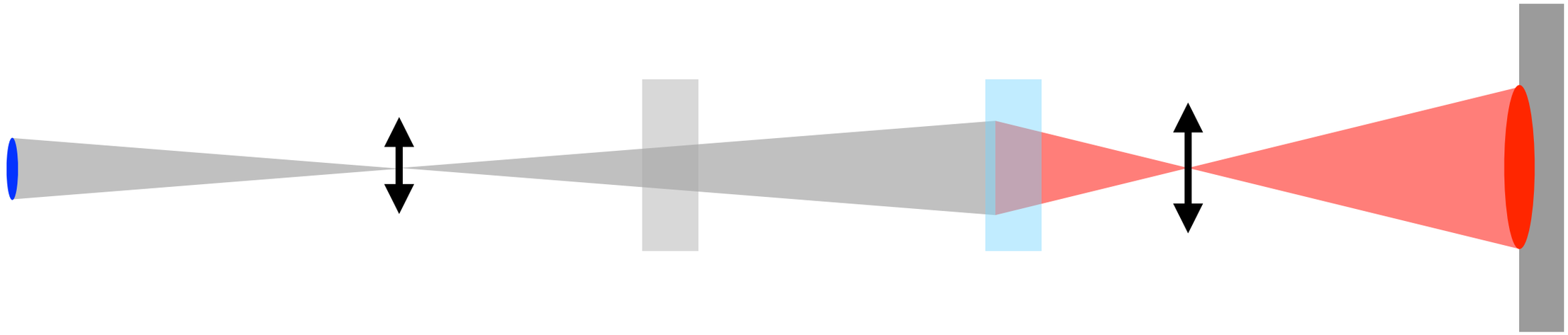
Optical Layout - Resolution, FoV

	Units	BM	BM 3-DW	BM 8-DW	3PW	3PW 3-DW	3PW 8-DW
Source size V	um	14	14	14	12	12	12
Source size H	um	75	49	39	133	137	138
Aspect ratio H/V		5	4	3	11	11	12

Optical Element	Material	Delta	BL	Energy	D_eff	R	N	f	z	d	L= z +d	PSF	M= d/z	PSF /M	Source Size Hor	Source Size Vert	FoV= 6s*2*M Hor	FoV= 6s*2*M Vert	CCD FoV	CCD # pixels	CCD pixel size	Objective M	Objective Resolution	CCD pixel size/ M
CRL				keV	um	um		m	m	m	m	um		um	rms um	rms um	mm	mm	mm		um	x	um	um
V-CRL	Be	8.5E-7	BM	20	420	50	12	2.45	3.02	12.98	16	1.0	4.3	0.2	75	14	3.9	0.7	0.9	1000	9.0	10	0.9	0.9
H-CRL	Be	8.5E-7	BM	20	428	50	8	3.68	10.28	5.72	16	0.6	0.6	1.1	75	14	0.5	0.1	0.9	1000	9.0	10	0.9	0.9
V-CRL	Be	8.5E-7	3PW	20	430	50	7	4.20	5.66	16.34	22	1.8	2.9	0.6	140	12	4.9	0.4	0.9	1000	9.0	10	0.9	0.9
H-CRL	Be	8.5E-7	3PW	20	428	50	8	3.68	17.33	4.67	22	0.5	0.3	1.9	140	12	0.5	0.0	0.9	1000	9.0	10	0.9	0.9
Slit																								
V-Slit			BM	20	20				2.85	13.15	16	20.1	4.6	4.5	75	14	4.2	0.8	1.8	1000	9.0	5	2.0	1.8
H-Slit			BM	20	26				6.00	10.00	16	12.4	1.7	7.3	75	14	1.5	0.3	1.8	1000	9.0	5	2.0	1.8
V-Slit			3PW	20	25				4.69	17.32	22	20.1	3.7	5.6	140	12	6.2	0.5	1.8	1000	9.0	5	2.0	1.8
H-Slit			3PW	20	31				10.00	12.00	22	12.0	1.2	10.0	140	12	2.0	0.2	1.8	1000	9.0	5	2.0	1.8

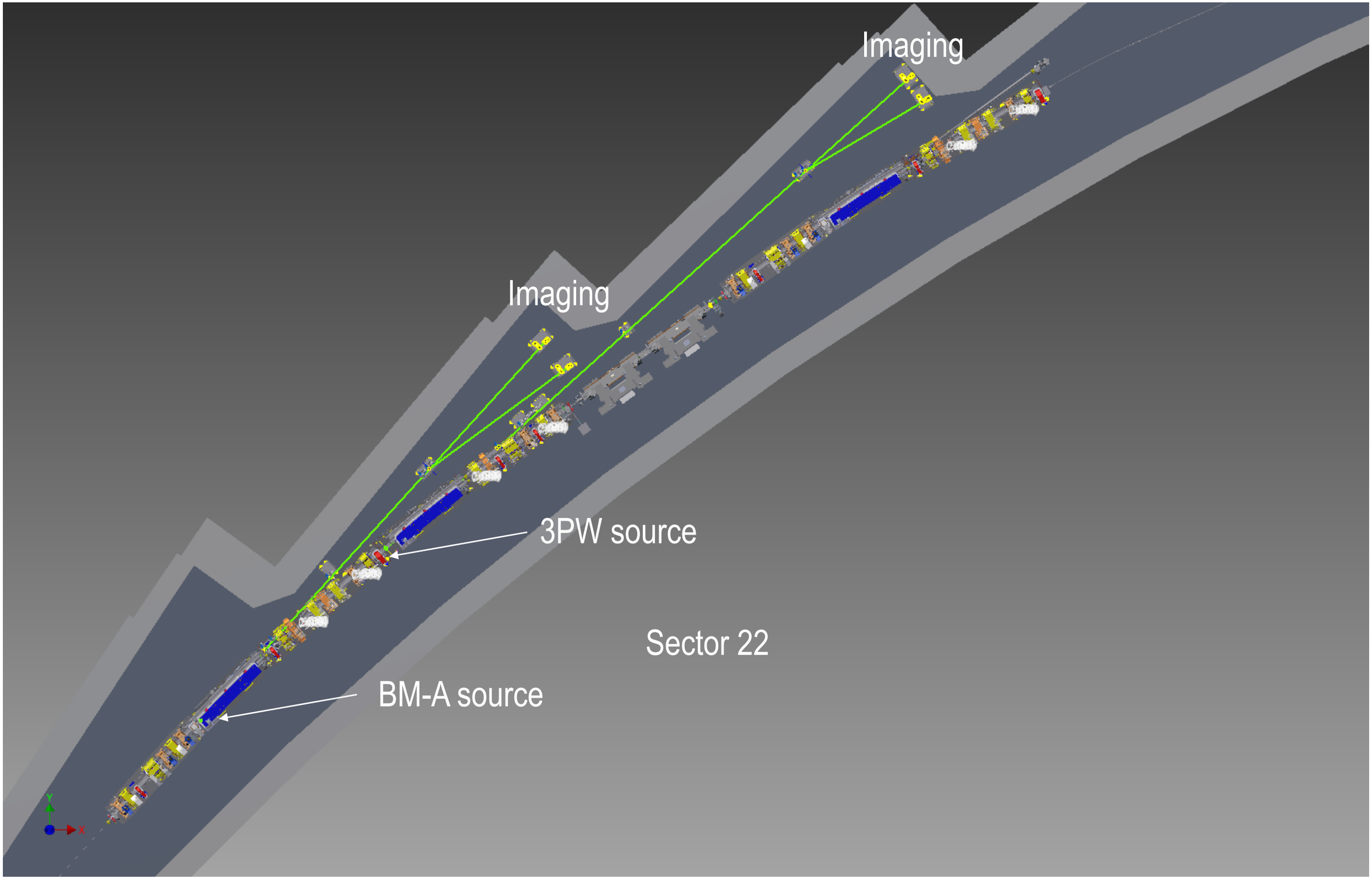


Flux Budget

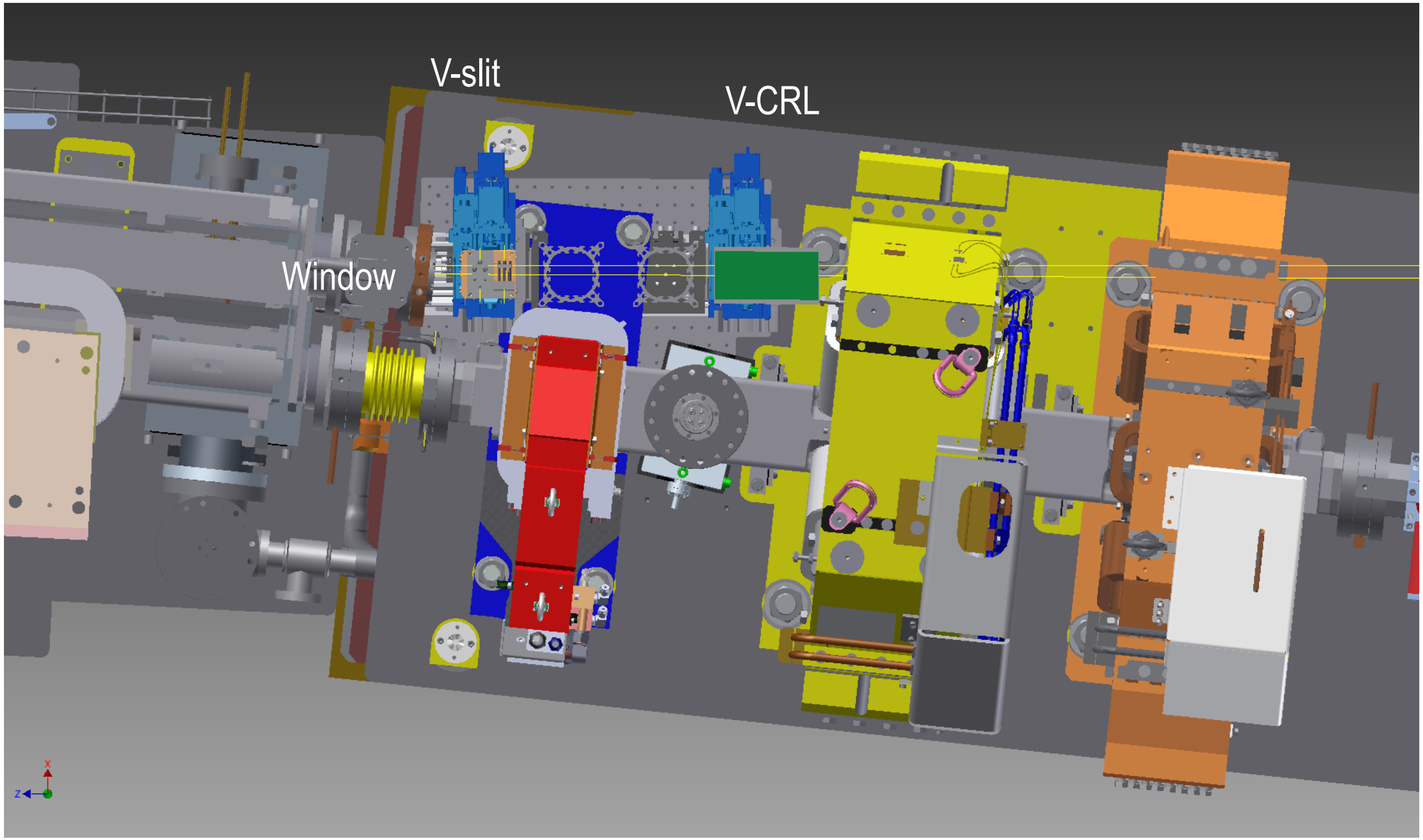


Source	I	H	V	Energy	BW	X-ray Flux	Window	Filter	X-ray Flux	Scintillator	Scint thick ness	V-ph Flux	Objec tive	V-ph Flux	spot size H	spot size V	V-ph Flux/ pixel
	mA	urad	urad	keV	eV	ph/s			ph/s		um	ph/s	NA	ph/s	pixels	pixels	ph/s/px
BM 0.3T	500	10	10	all	all	1.4E+14	-	N2 10m	1.6E+12	CdWO4	100		0.3		300	300	
BM 0.3T	500	10	10	all	all	1.4E+14	Al 1mm	N2 20m	2.4E+11	CdWO4	100	2.6E+14	0.3	1.2E+12	300	300	1.3E+7
BM 0.3T	500	10	10	20	20		Al 1mm	N2 20m		CdWO4	100	4.4E+11	0.3	2.0E+9	300	300	2.3E+4
BM 0.3T	1	10	10	20	20		Al 1mm	N2 20m		CdWO4	100	8.8E+8	0.3	4.1E+6	300	300	4.5E+1
BM 0.3T	500	10	10	all	all		Al 1mm	N2 20m		CdWO4	10	9.3E+13	0.3	4.3E+11	300	300	4.8E+6
BM 0.3T	500	10	10	20	20		Al 1mm	N2 20m		CdWO4	10	1.2E+11	0.3	5.6E+8	300	300	6.2E+3
BM 0.3T	1	10	10	20	20		Al 1mm	N2 20m		CdWO4	10	2.4E+8	0.3	1.1E+6	300	300	1.2E+1
BM 0.4T	500	10	10	all	all	2.5E+14	-	N2 10m	1.0E+13	CdWO4	100		0.3		300	300	
BM 0.4T	500	10	10	all	all	2.5E+14	Al 1mm	-	5.0E+12	CdWO4	100		0.3		300	300	
BM 0.4T	500	10	10	all	all	2.5E+14	Al 1mm	N2 20m	2.5E+12	CdWO4	100	3.0E+15	0.3	1.4E+13	300	300	1.5E+8
BM 0.4T	1	10	10	all	all	5.0E+11	Al 1mm	N2 20m	5.0E+9	CdWO4	100	6.0E+12	0.3	2.8E+10	300	300	3.1E+5
BM 0.4T	500	10	10	20	20		Al 1mm	N2 20m	4.4E+9	CdWO4	100	5.5E+12	0.3	2.6E+10	300	300	2.8E+5
BM 0.4T	1	10	10	20	20		Al 1mm	N2 20m	8.8E+6	CdWO4	100	1.1E+10	0.3	5.1E+7	300	300	5.7E+2
3PW	500	10	10	all	all	2.0E+15	-	N2 20m	9.6E+14	CdWO4	100		0.3	4.6E+15	300	300	5.1E+10
3PW	500	10	10	20	20	1.3E+12	-	N2 20m	8.7E+11	CdWO4	100		0.3	3.3E+13	300	300	3.7E+8
3PW	1	10	10	20	200	2.6E+09	-	N2 20m	1.7E+09	CdWO4	100		0.3	6.6E+10	300	300	7.3E+5
3PW	500	10	10	all	all	2.0E+15	Al 1mm	N2 20m	6.0E+14	CdWO4	100	8.3E+16	0.3	3.9E+14	300	300	4.3E+9
3PW	500	10	10	20	20	1.3E+13	Al 1mm	N2 20m	3.9E+11	CdWO4	100	4.8E+14	0.3	2.2E+12	300	300	2.5E+7
3PW	1	10	10	20	20	2.6E+10	Al 1mm	N2 20m	7.8E+08	CdWO4	100	9.6E+11	0.3	4.5E+9	300	300	5.0E+4

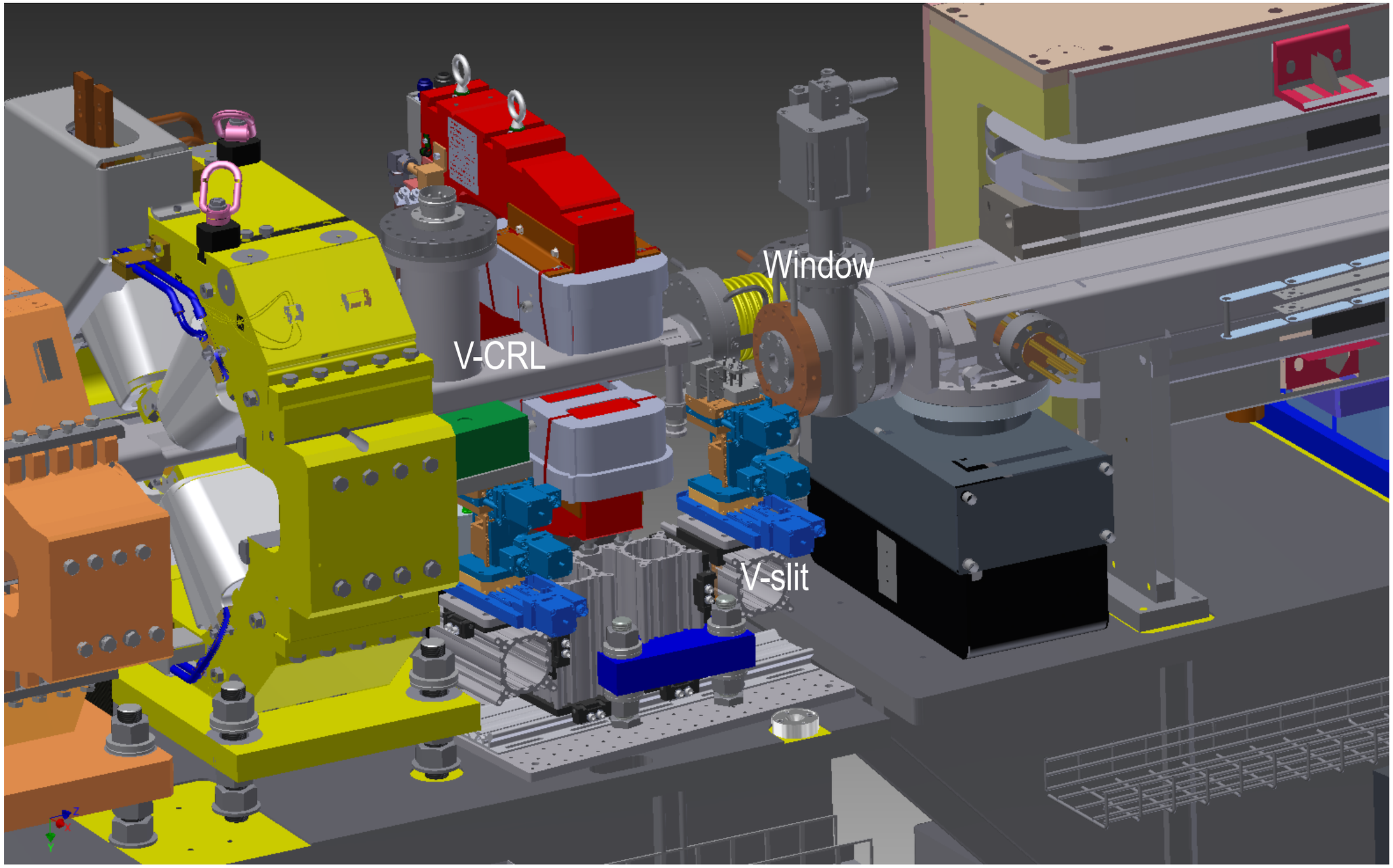
X-ray Diagnostics Beamlines Layout



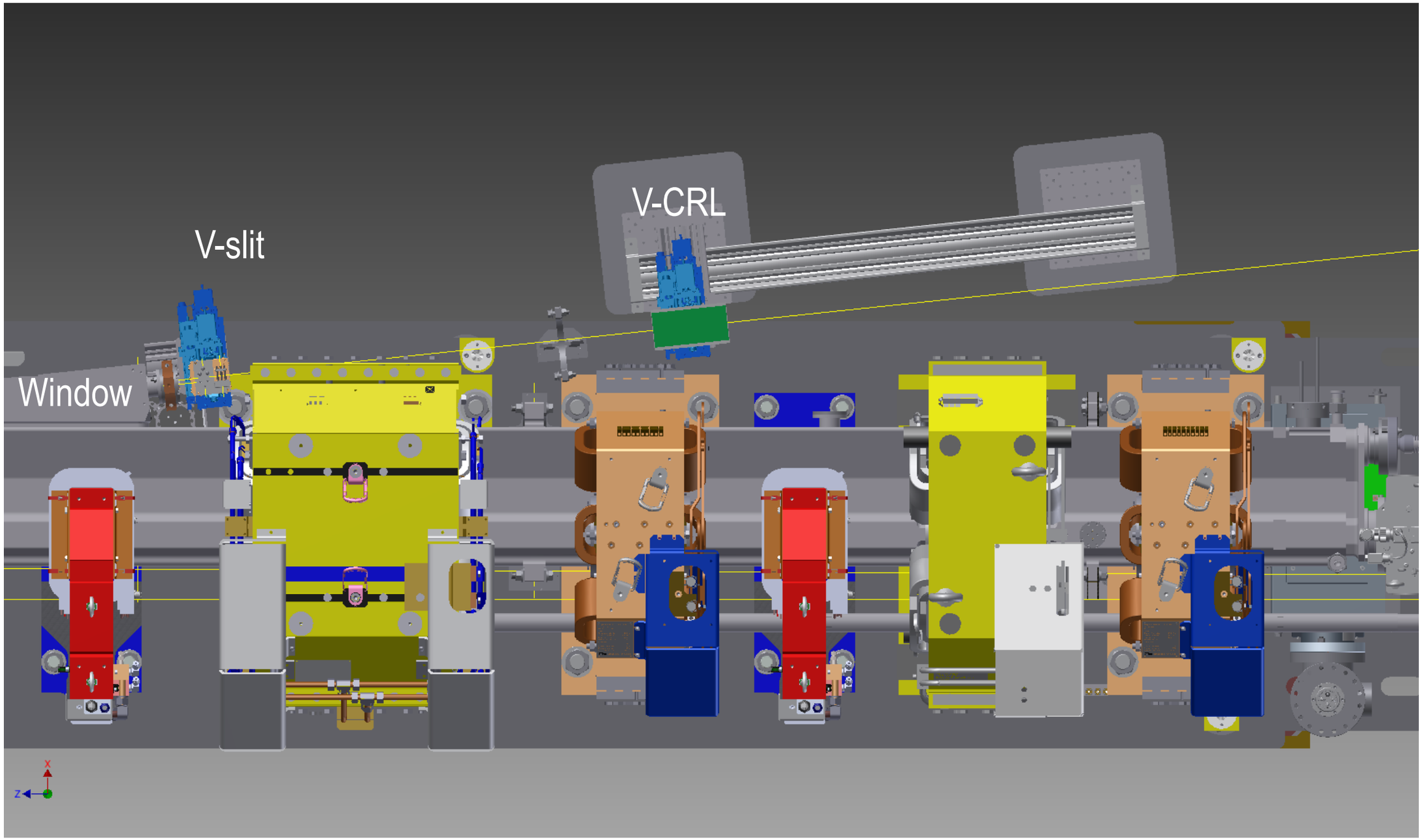
BM-A Layout (girder)



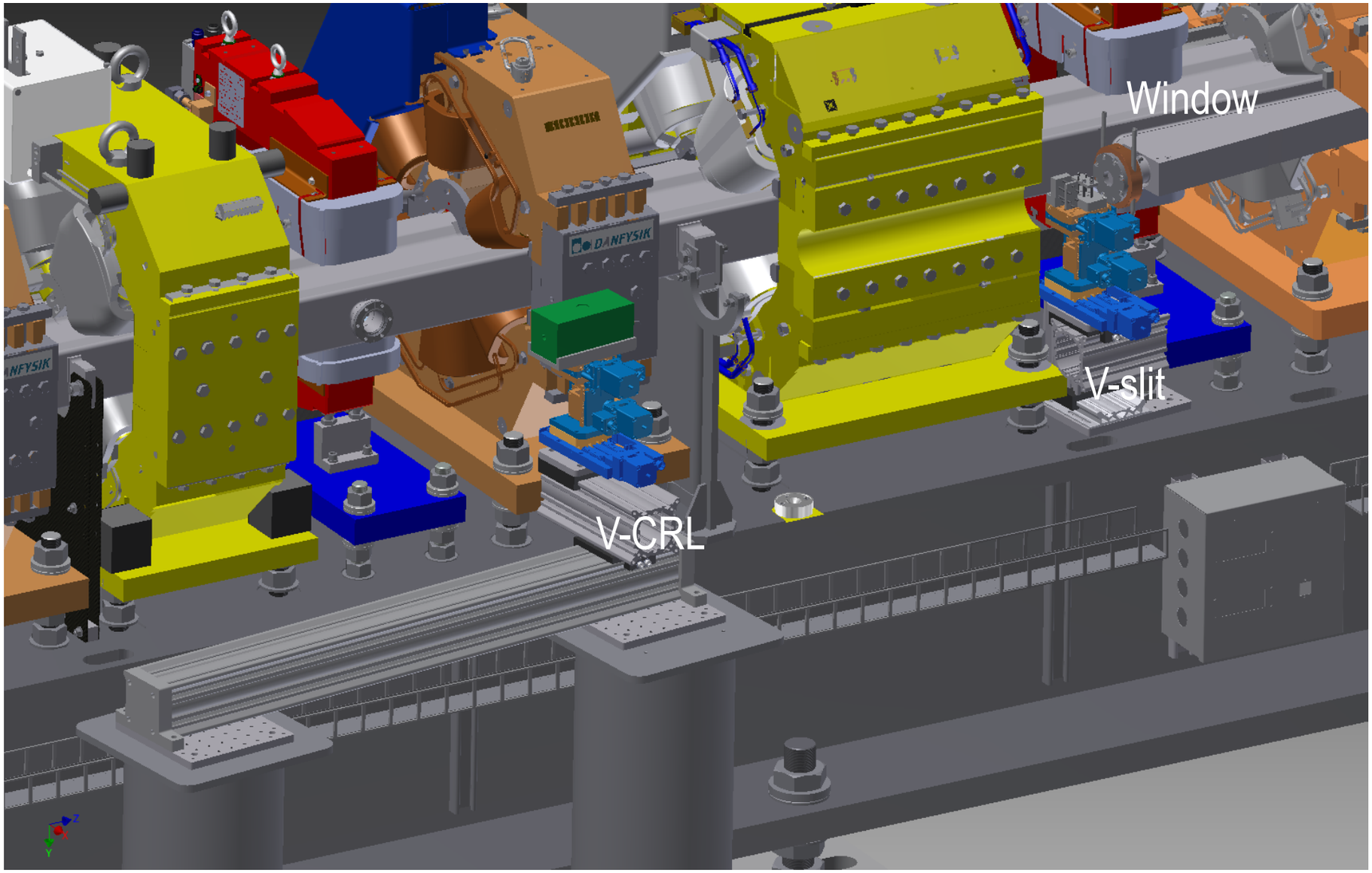
BM-A Layout (girder)



3PW Layout (girder)

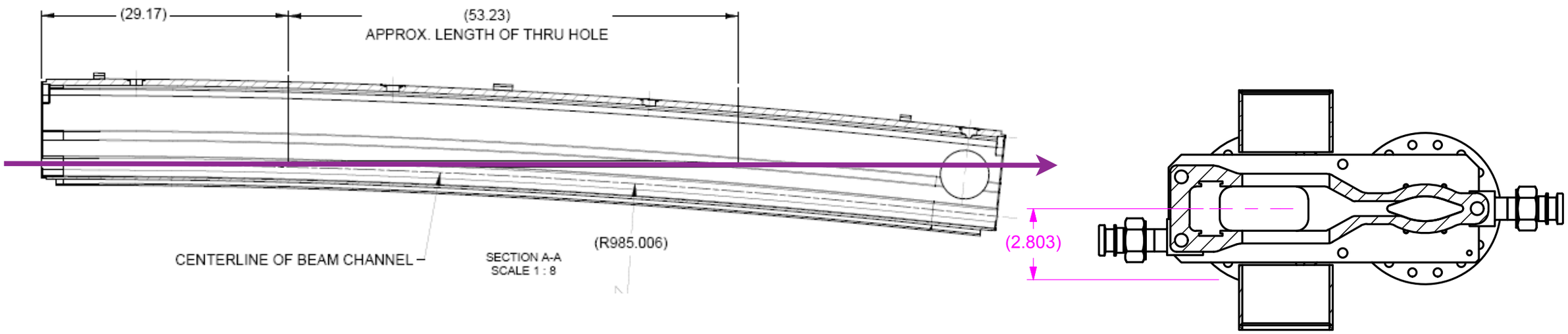


3PW Layout (girder)

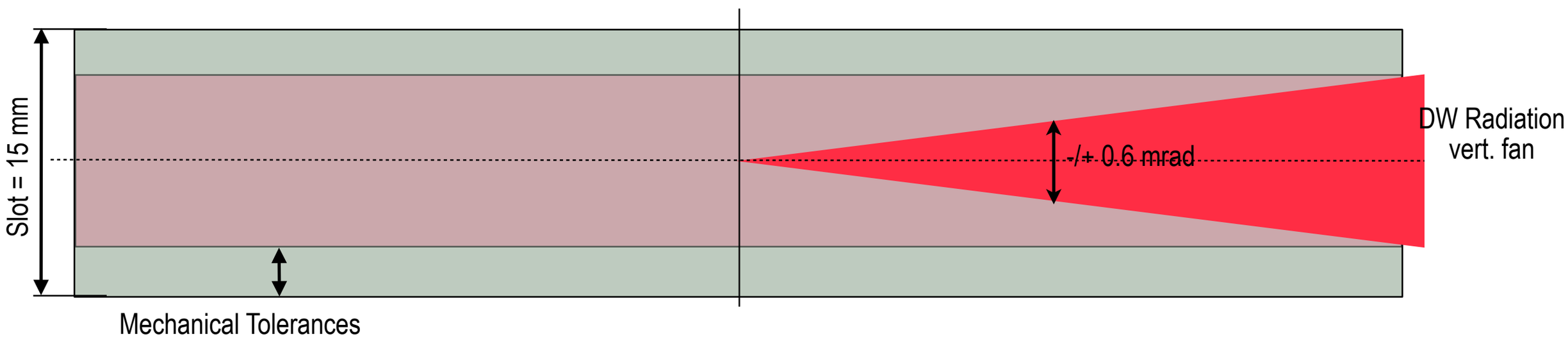


Insertion Devices Commissioning

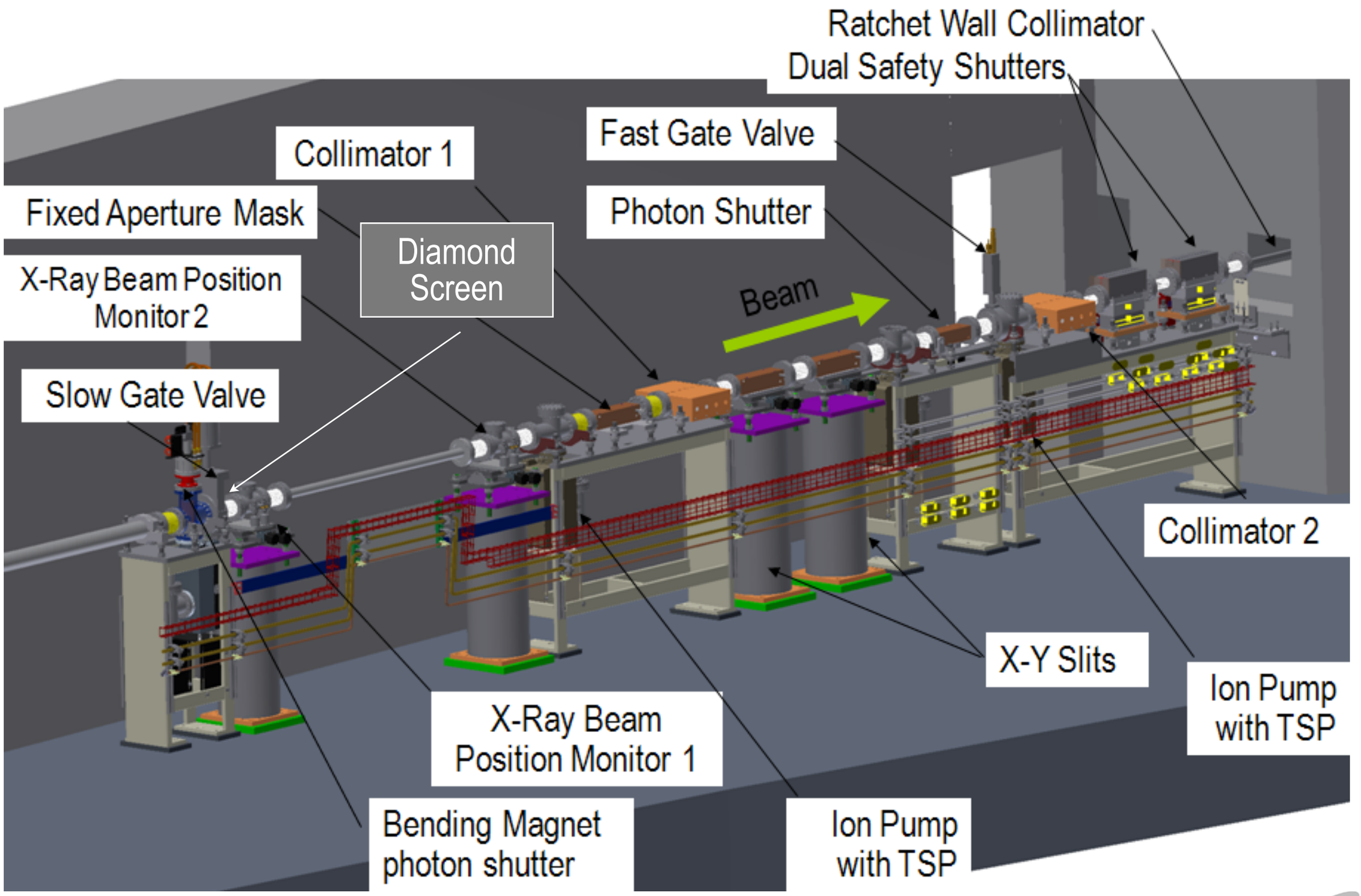
ID radiation - Dipole Chamber



Vertical cross-section



Diamond Screens for NSLS-II commissioning



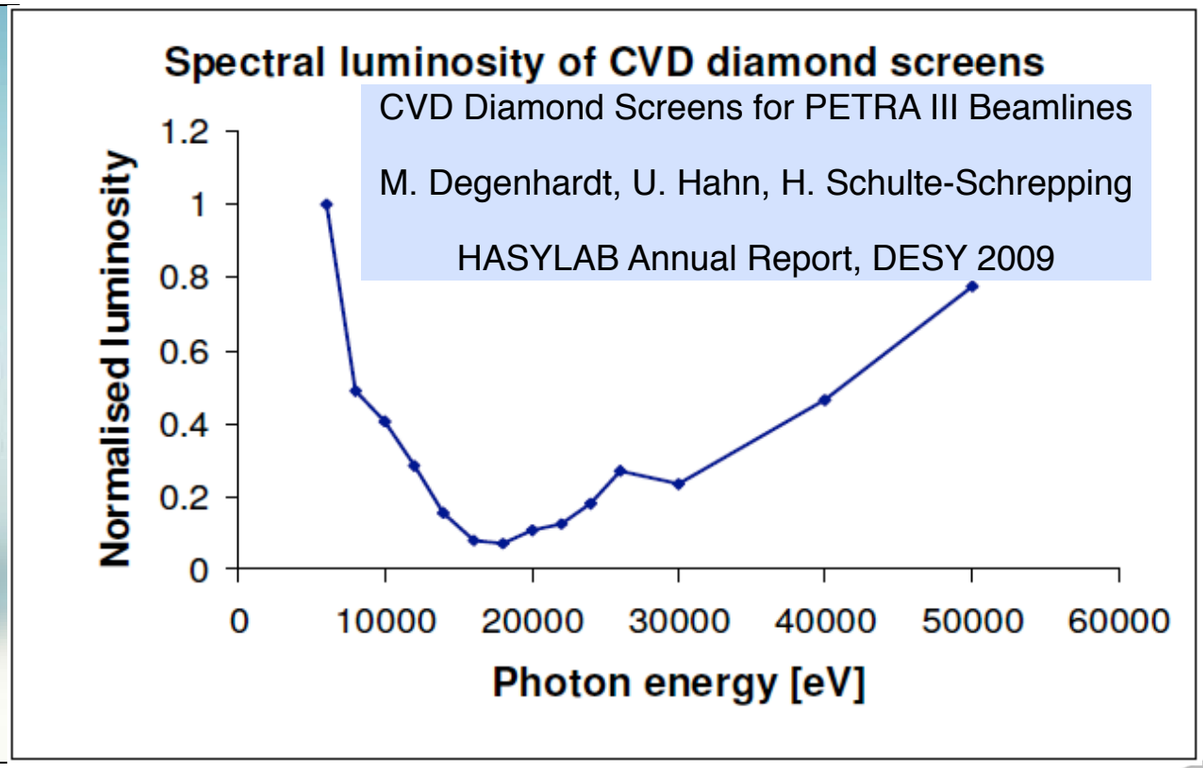
Diamond Luminescent Screens

Diamond X-ray beam monitors

Diamond Materials, Freiburg, Germany

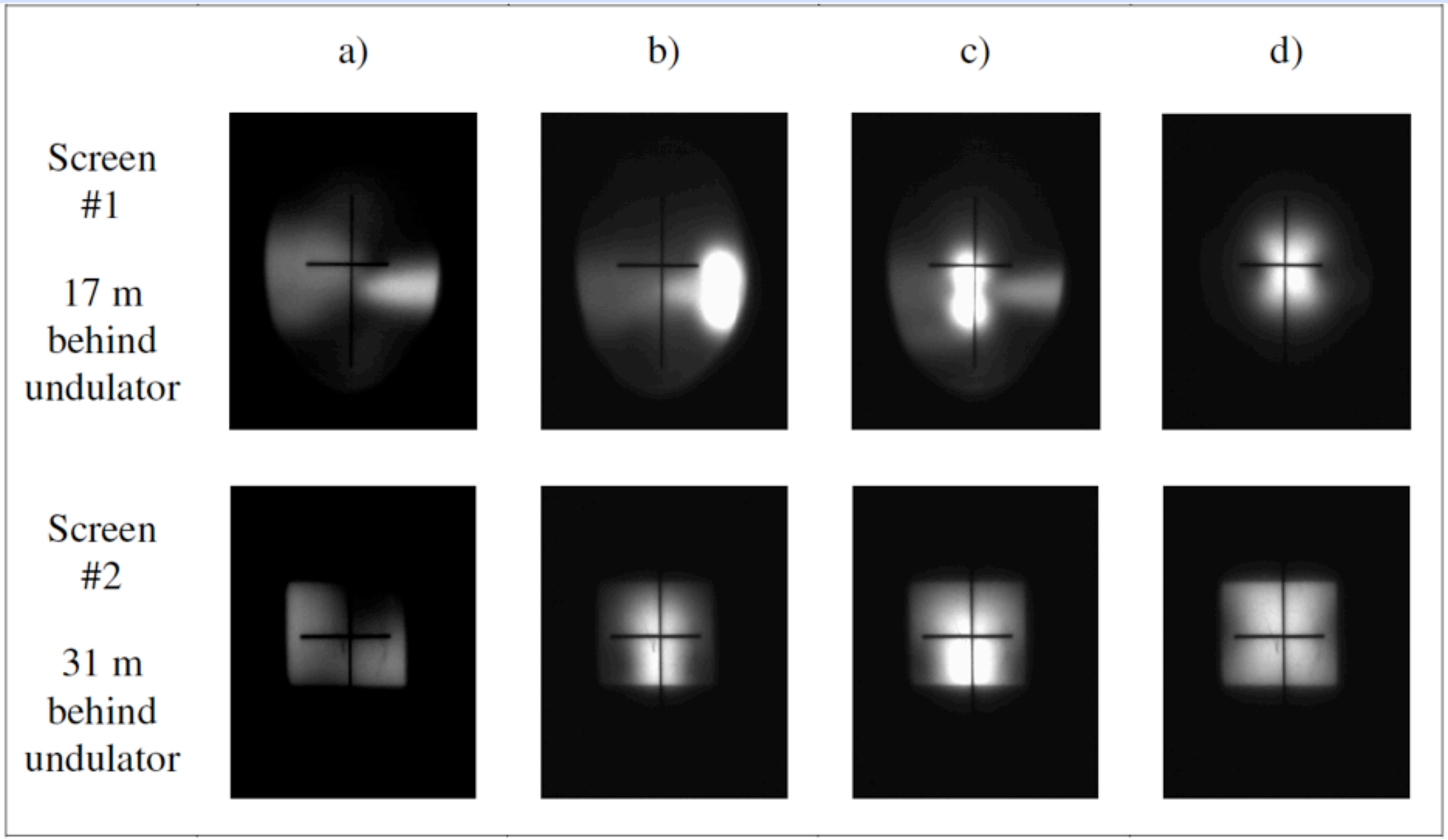
Available options:

Type	Free-standing diamond fluorescence screen
Options	Defined sub-micron surface roughness to scatter the light from laser
Material	Optical transparent diamond, doped for increased fluorescence yield
Thickness	> 20 μm
Size	Up to 75 mm; rectangular, circular or elliptical



Diamond Luminescent Screens at PETRA-III

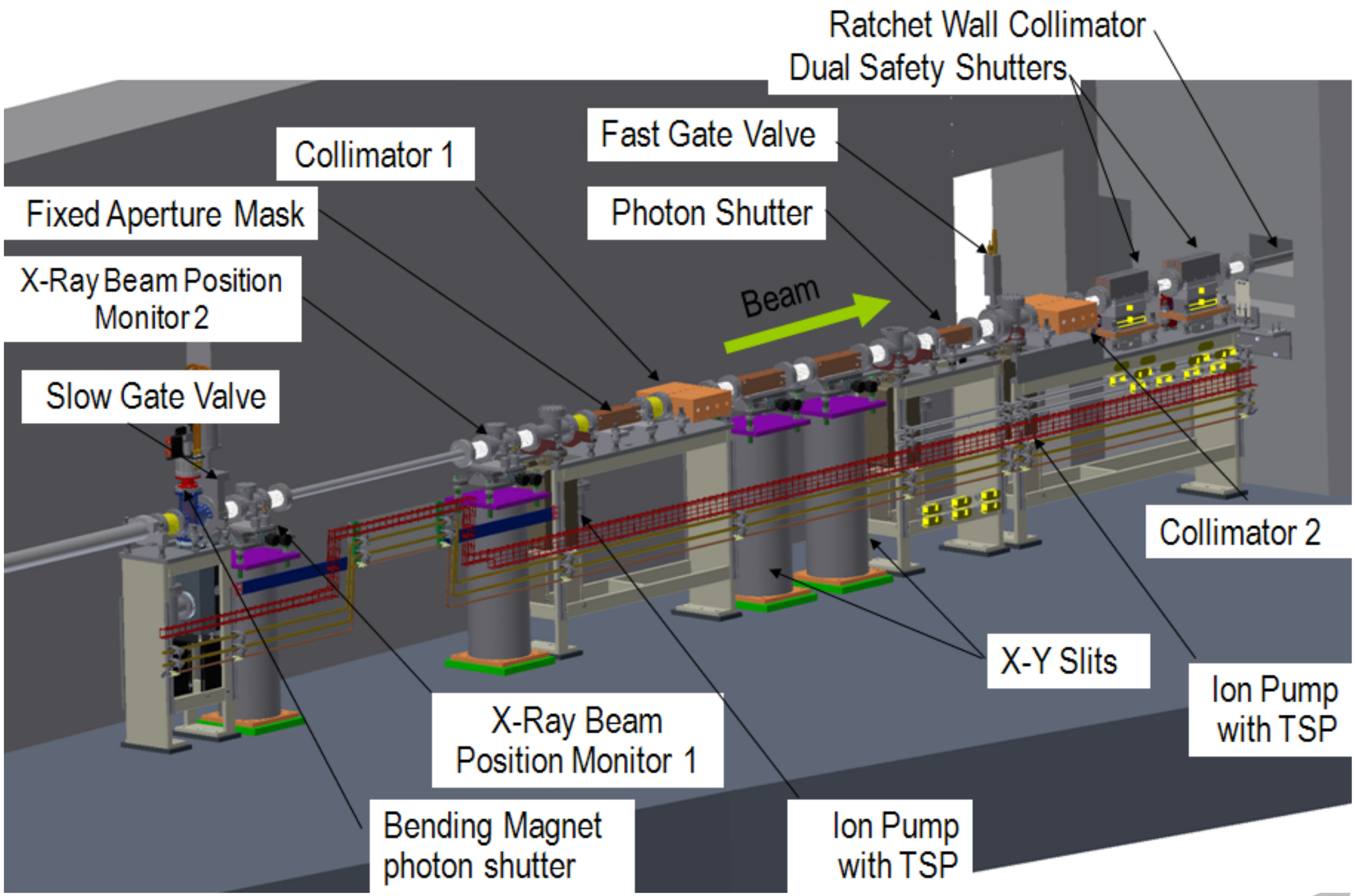
CVD Diamond Screens for PETRA III Beamlines
M. Degenhardt, U. Hahn and H. Schulte-Schrepping
HASYLAB Annual Report, DESY 2009



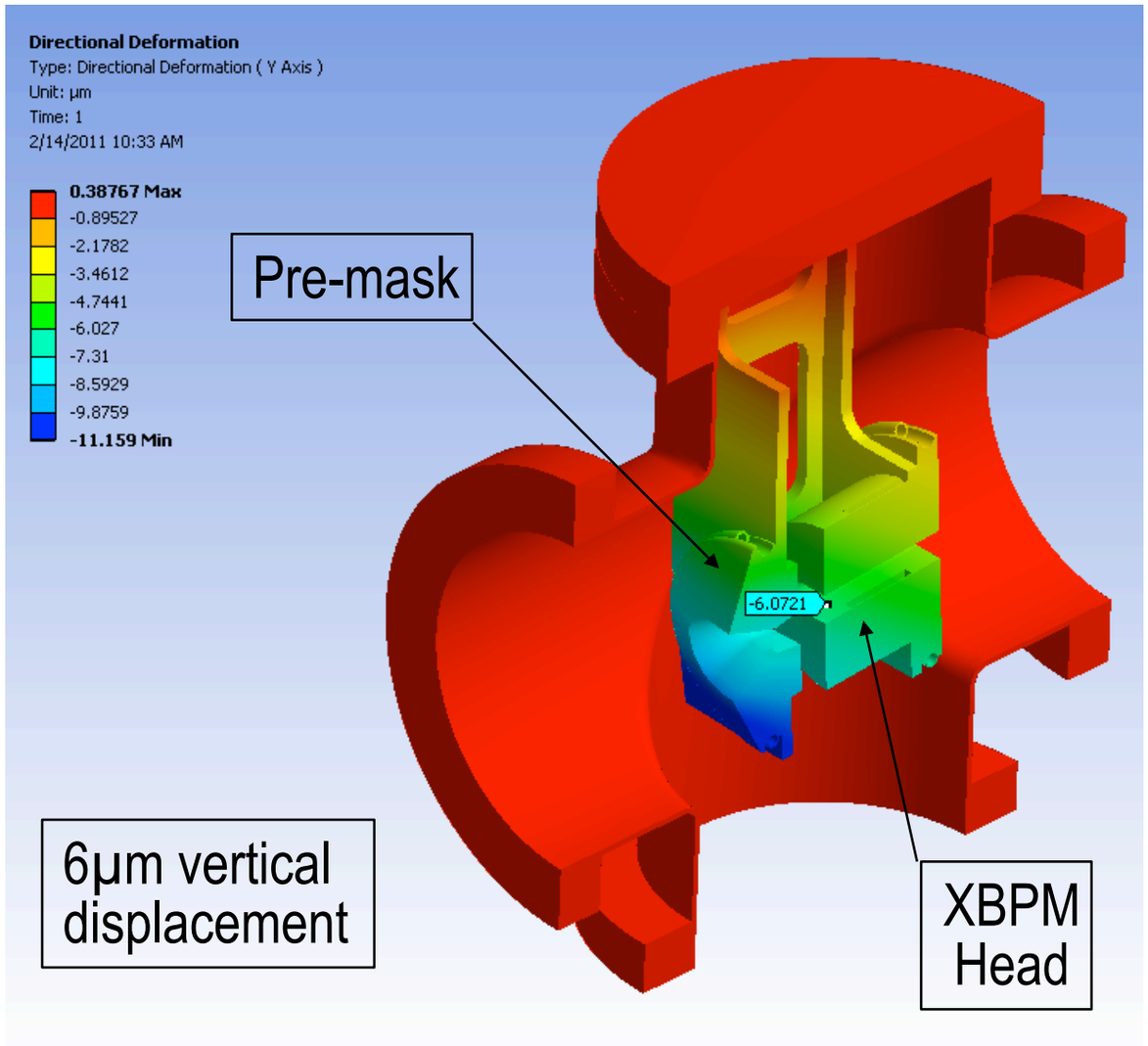
Alignment of the PETRA-III undulator beam in the pre-aligned front-end of beamline P09
a) Bending magnet radiation, b) Bending magnet and undulator radiation,
c) ongoing alignment, d) properly aligned undulator beam

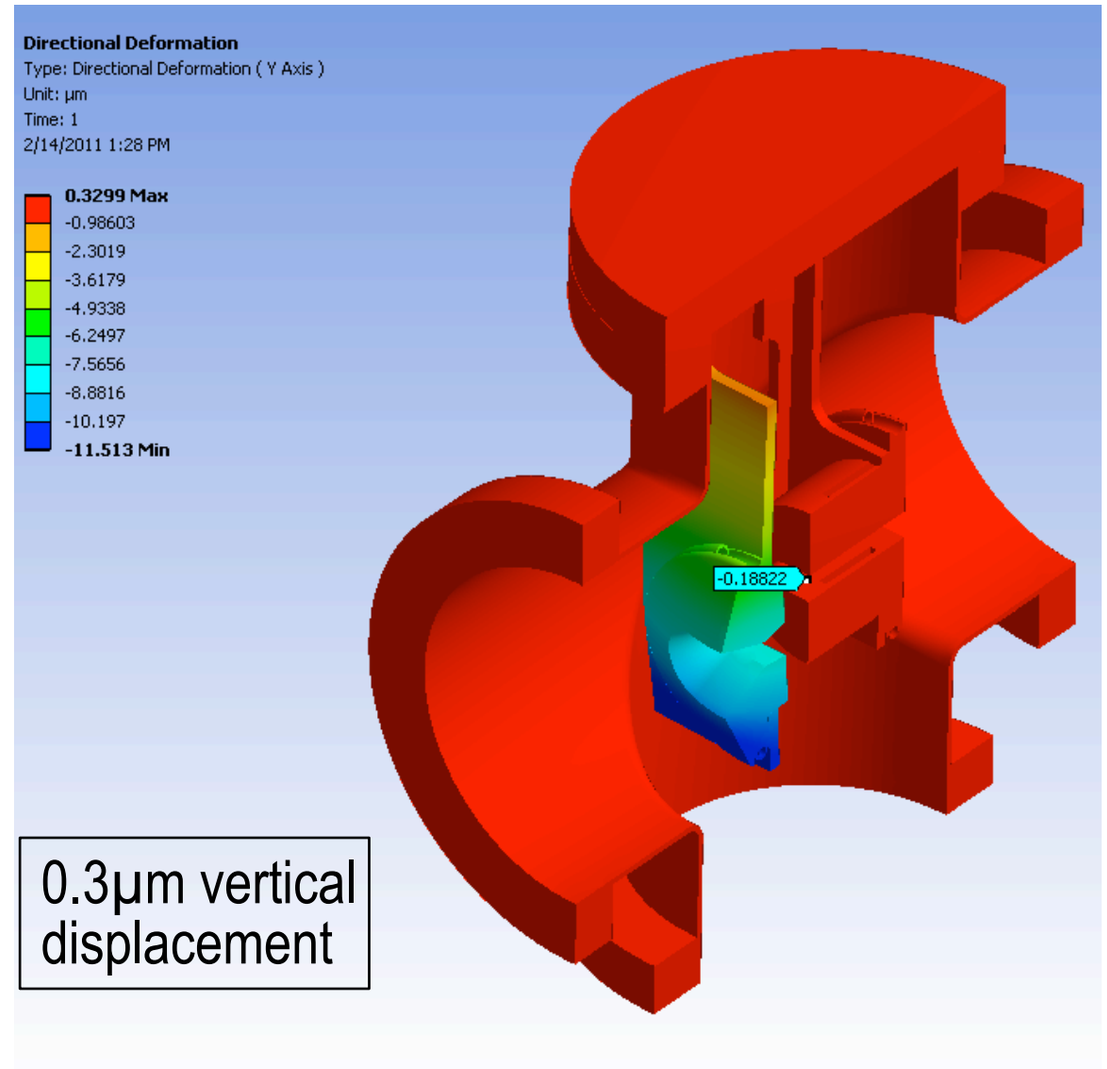
X-ray Beam Position Monitors

Typical NSLS-II Front End Configuration



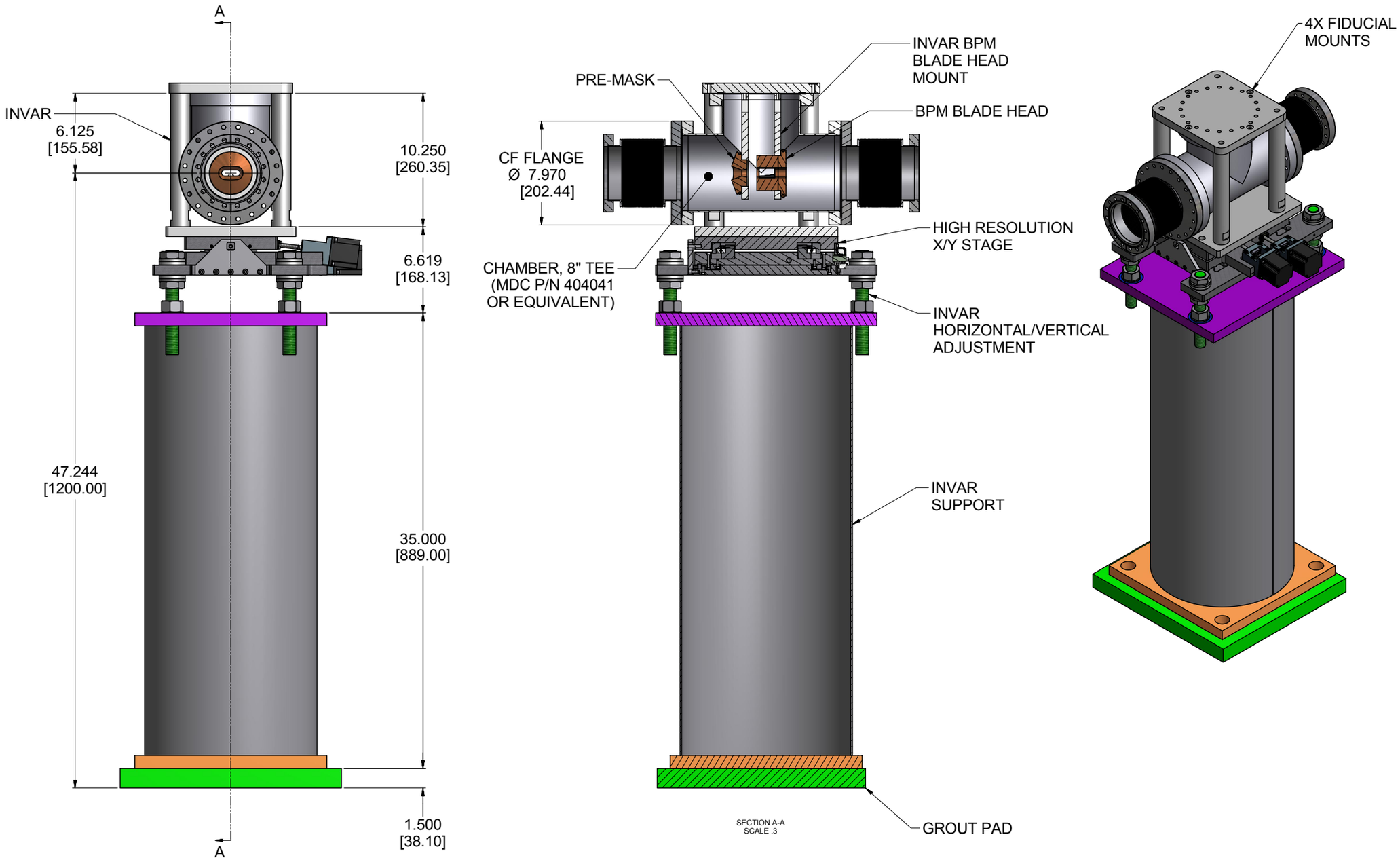
Thermal Stability of XBPM Head





100 watts applied to pre-mask Common support structure (thermally coupled)	100 watts applied to pre-mask Separate support structures (thermally de-coupled)

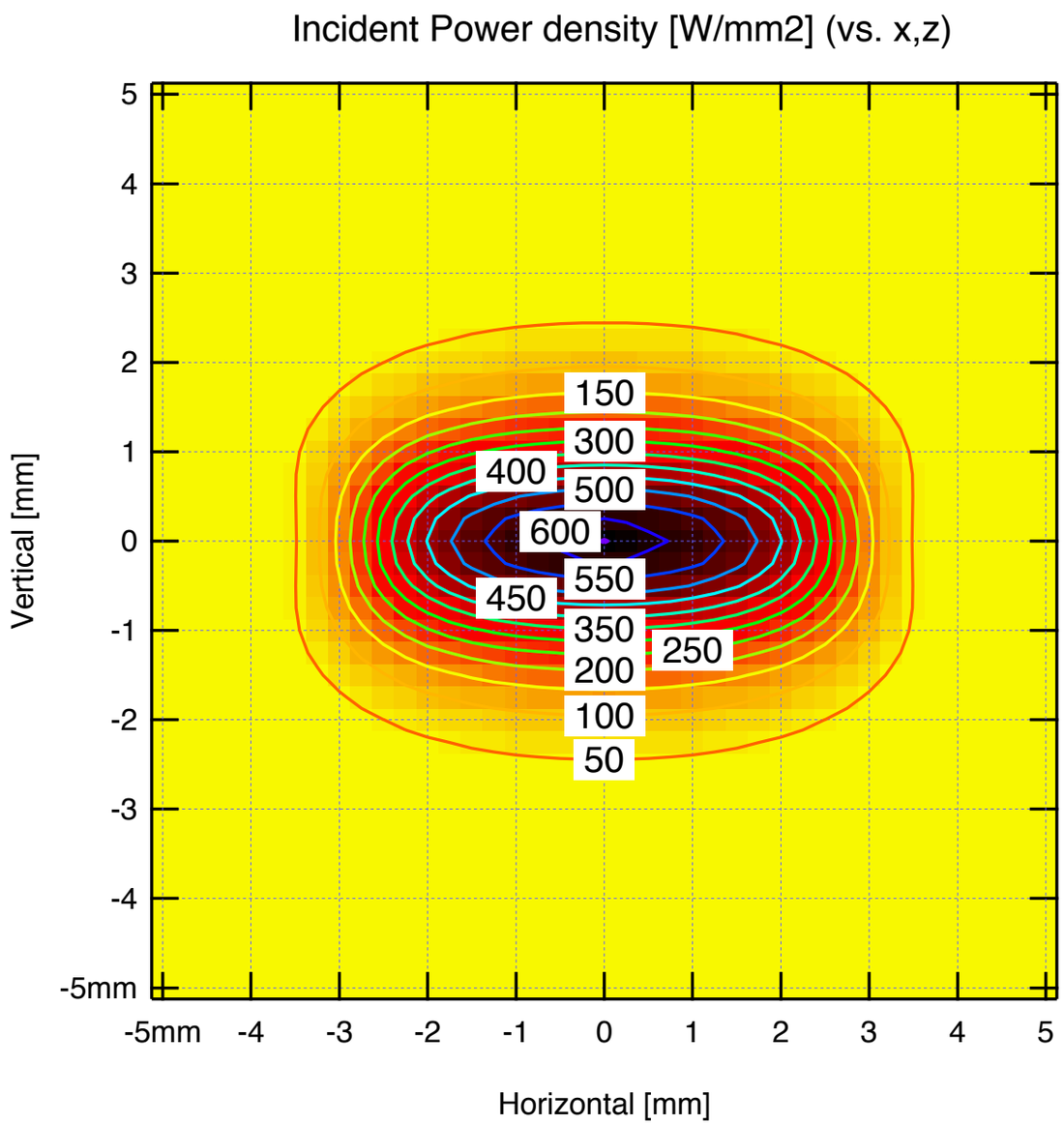
XBPM Assembly Layout

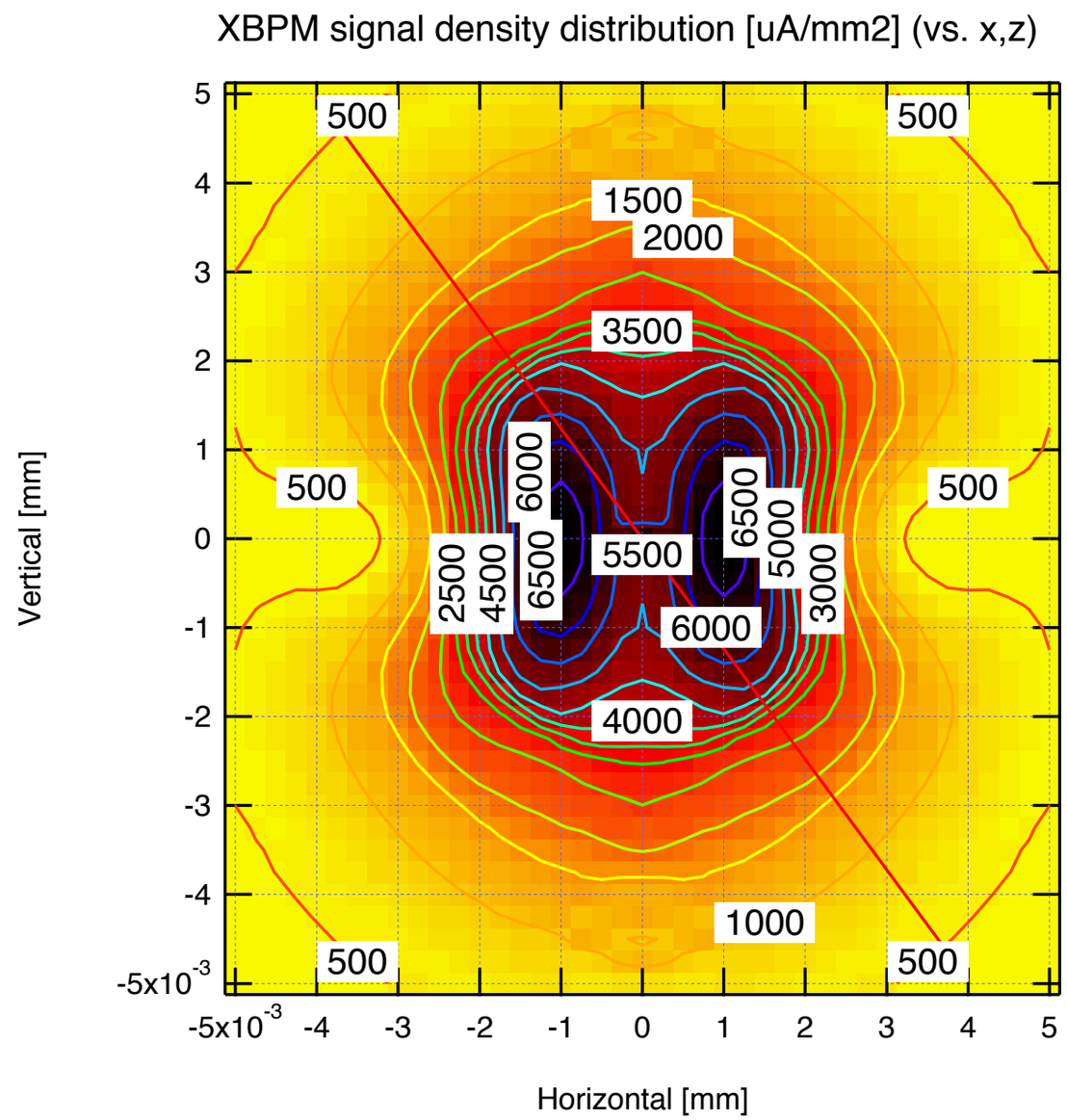


Invar slit stand	inches	mm	change degrees C	change degrees F	MATERIAL	in/in/deg F	EXPANSION inches	EXPANSION mm	EXPANSION microns
top and bottom plates	2.0	50.8	0.2	0.36	INVAR	7.2E-07	5.2E-07	1.3E-05	0.00
stand tube	35.3	895.4	0.2	0.36	INVAR	7.2E-07	9.2E-06	2.3E-04	0.23
stage	3.5	88.9	0.2	0.36	ALUMINUM 6061	1.3E-05	1.6E-05	4.2E-04	0.42
slit body	1.8	44.5	0.2	0.36	COPPER	9.8E-06	6.2E-06	1.6E-04	0.16
threaded rods	3.5	88.9	0.2	0.36	INVAR	7.2E-07	9.1E-07	2.3E-05	0.02
									0.83

Power density and XBPM Signal distribution

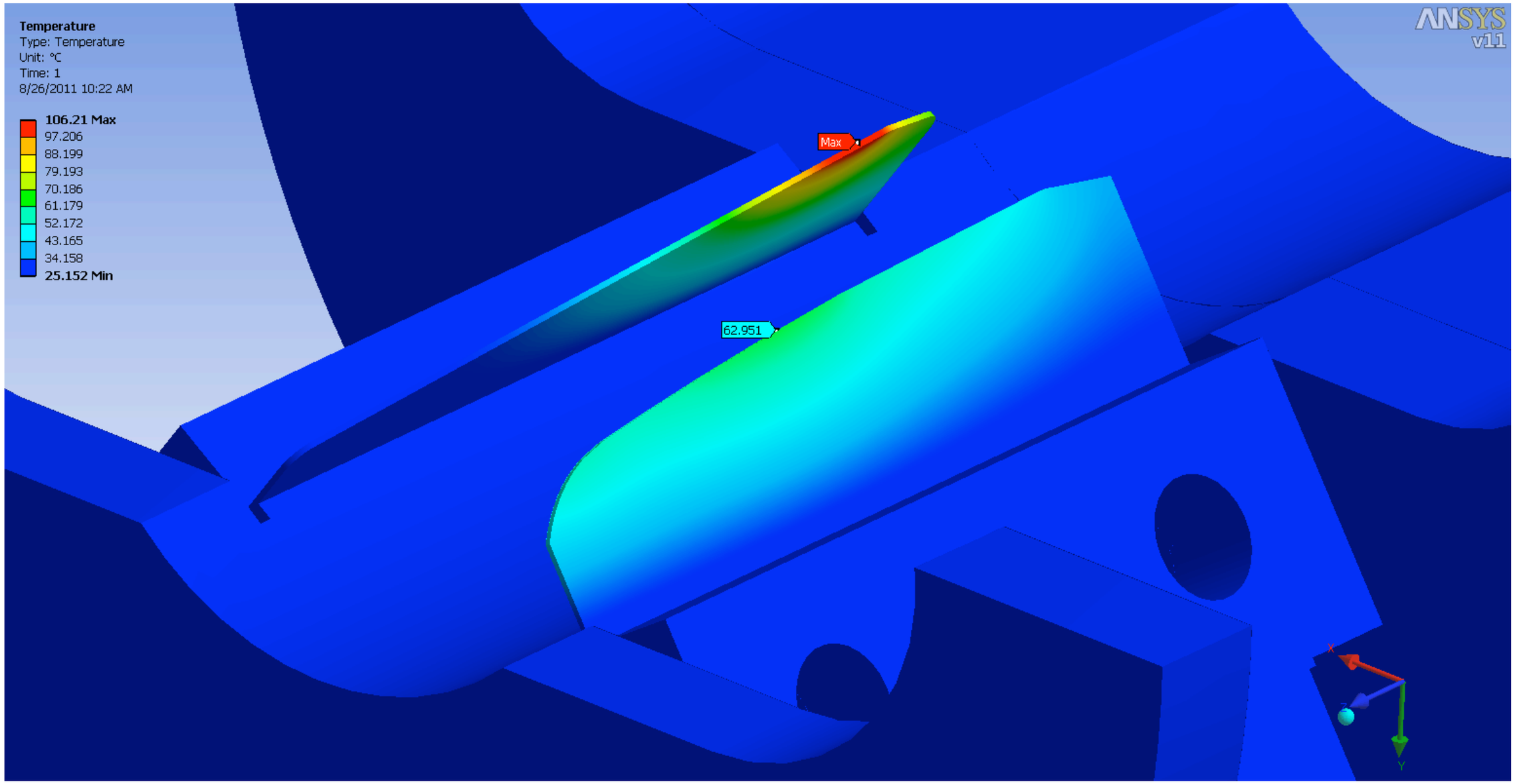
NSLS-II IVU-20, 10m, K=1.8, Tungsten Blades





Blade Temperature Distribution

Blade Optimization
Tungsten, 0.2mm FBM, 0.2mm BNL



Conclusions

- **e-beam diagnostics beamlines**
  - research - completed
    - two interchangible setups (pinhole/CRL)
  - beamline design - 80% completed
- **Diamond Luminescent Screens**
  - PETRA-III blueprints
- **X-ray BPMs**
  - optimization - ongoing
  - assembly - in design
  - FMB - in contact