GM/CA CAT
Dual Canted Undulator Beamlines

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What is GM/CA-CAT?

National Institute of General Medical Sciences
And National Caner Institute
Collaborative Access Team
At the Advanced Photon Source
At Argonne National Laboratory

Mission: To develop and operate a sector at the APS consisting of two independent-insertion device beamlines and one bending magnet beamline for high-through-put macromolecular crystallography for targeted research projects of NIGMS and NCI and for General Users.

GM/CA CAT Staff & Advisors

Staff

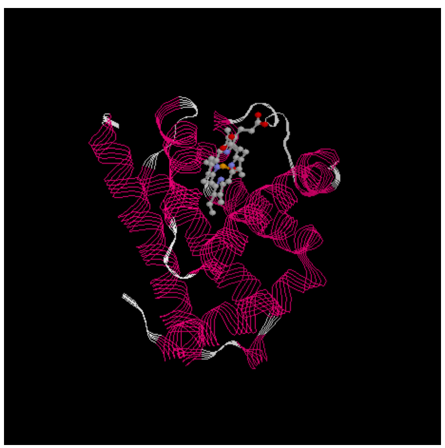
Janet L. Smith (Purdue)	CAT Director
Robert F. Fischetti	Project Manager
Sheila Rossi	CAT Administrator
Ward Smith	Protein Crystallographer
Ruslan (Nukri) Sanishvili	Protein Crystallographer
Shenglan Xu	Beamline Engineer
Rich Benn	Beamline Assistant Engineer
Sergey Stepanov	Beamline Controls Scientist
Oleg Makarov	Beamline Instrumentation Scientist
Alex Urakhchin	Programmer

Technical Advisors

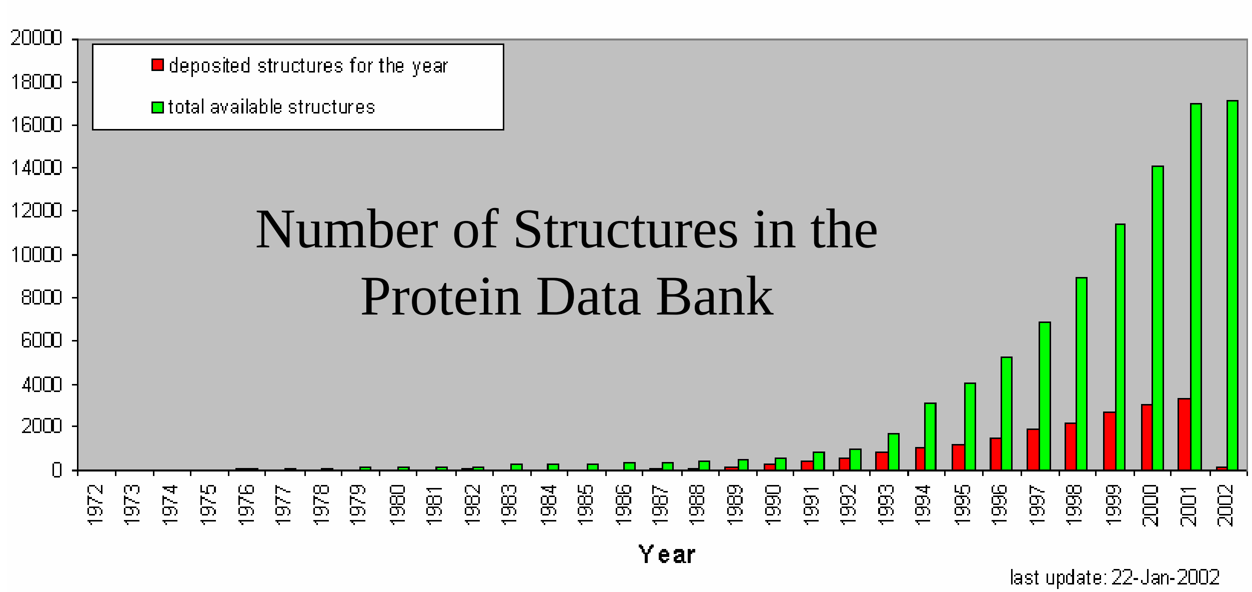
Lonny Berman	NSLS
Thomas Earnest	ALS
Peter Kuhn	SSRL, Scripps
Jim Viccaro	CARS

Why Do We Need More Beamlines?

- •Human Genome Project
- •Structure-Based Drug Design
- •Improved High-Through-Put Cloning and Expression Techniques (Robotics)
- •Recent Success with Improved Phasing Methods (Se-met)
- •Over-subscription of Existing Beamlines



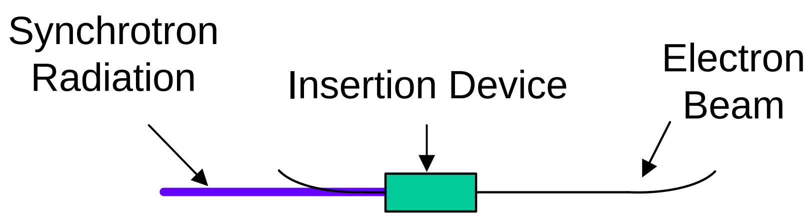
Mb, J. Kendrew 1959



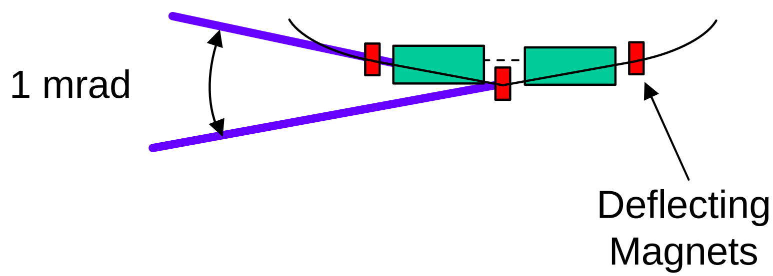
Why Dual Undulators?

- Limited number of sectors left
- Maximize use of floor space in a sector
- Increase capacity per sector and APS

Typical Single Undulator



Dual “Canted” Undulators



Impact of Various Dual Undulator Designs on Scientific Capabilities

- Two fully functional beamlines vs one fully functional and a second with slightly reduced capabilities
- Impact on experimental layout
- Technical Design Issues
  - Energy range (3.5 – 35 keV)
  - Energy resolution (dE/E ~ 1 x 10^{-4})
  - Harmonic rejection
  - Intensity (>1 x 10^{13} photons/sec/0.1%BW)
  - Energy scan rate (350 –3500 eV/sec)
  - Flexibility of focal properties
  - Focal size (100 x 200 microns)
  - Beam stability (intensity and position) and feedback
  - Beam convergence/divergence angle

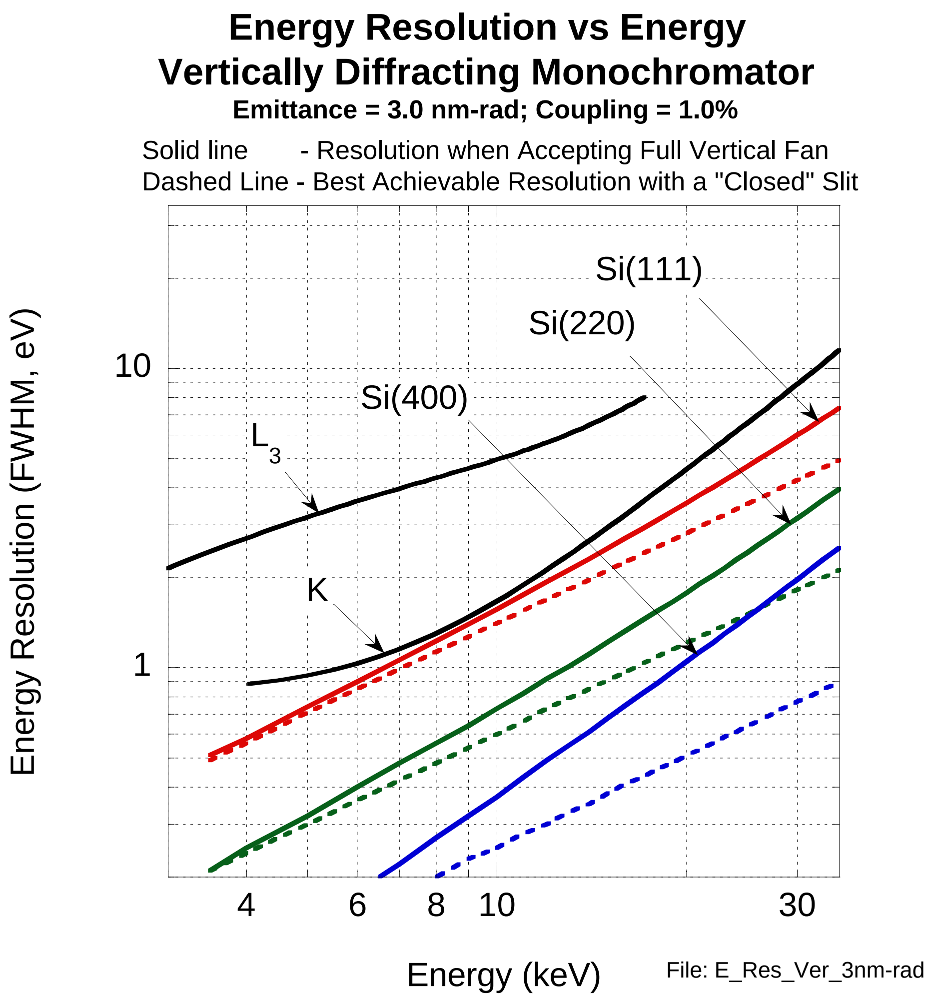
Other Design Issues

- Employ proven technology when ever possible
- Easy of use
- Independent operation (shuttering)
- Independent maintenance
- Adaptable to different source properties

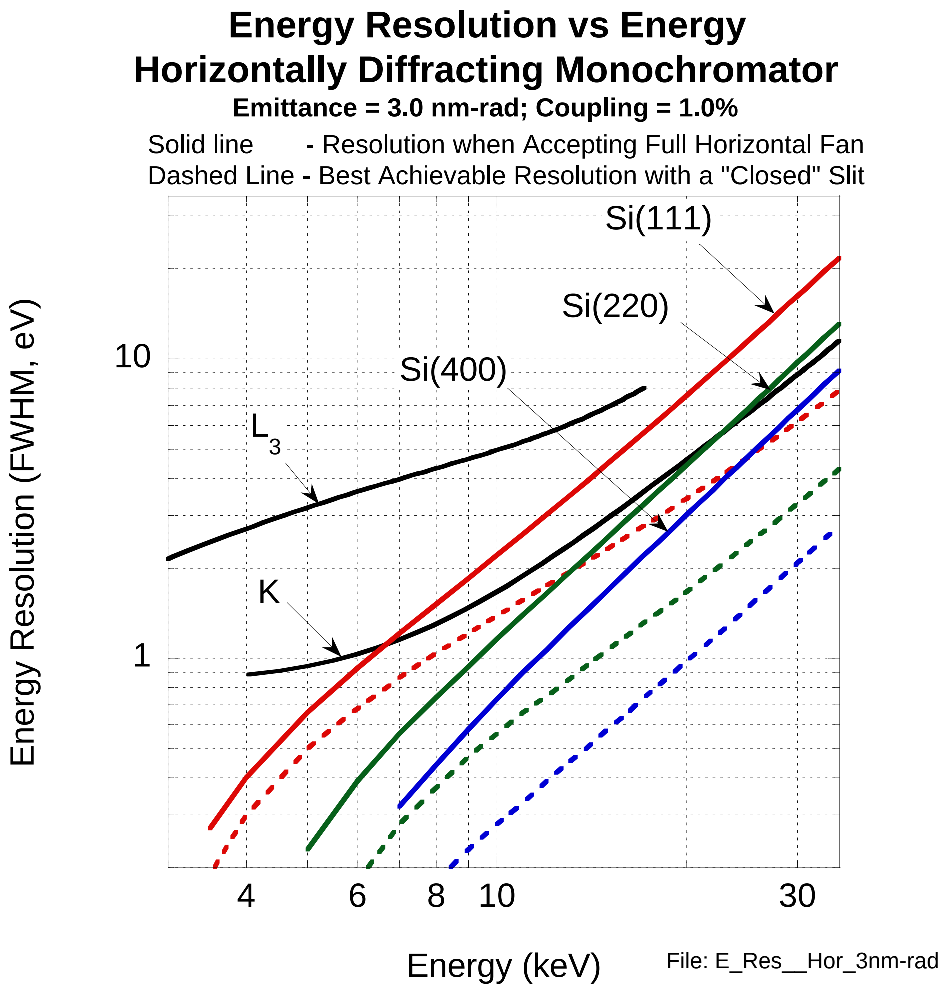
Beamline Design Options

- First Optical Component has to handle high heat load from undulator (dual undulator) source
- Preserve vertical brilliance of source
- Cryo-Cooled Si-monochromator
- Water cooled Diamond monochromator
- Water cooled white beam mirror

Vertical Diffracting Monochromator



Horizontal Diffracting Monochromator



Dual Undulator Beamlines Layout

- Option 1 – Vertical monochromator offset
- Option 2A – Outboard line deflected horizontally with monochromatic mirrors
- Option 2B – Inboard and Outboard lines each deflected horizontally with monochromatic mirrors
- Option 3 – Large horizontal offset monochromator (2 m)
- Option 4 – Horizontal deflecting white beam mirrors

Conceptual Design Issues

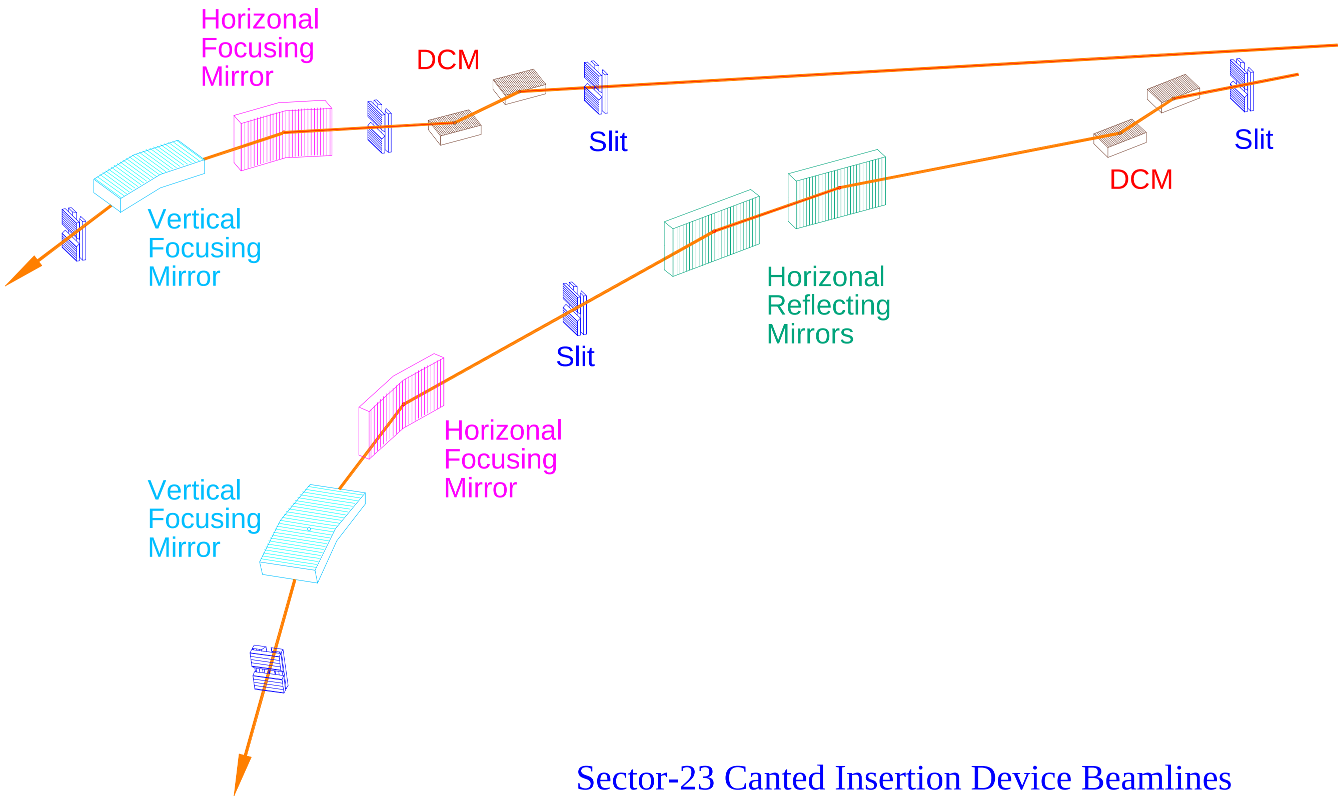
Conceptual Layout Summary

- Inboard ID-line – best possible ID-beamline, vertical offset monochromator, K-B mirrors, performance specifications
- Outboard ID-line – vertical offset monochromator, horizontal deflecting mirrors, K-B mirrors, performance specifications
- Bending magnet line – collimating mirror, monochromator, focusing mirror, performance specifications

Design Issues

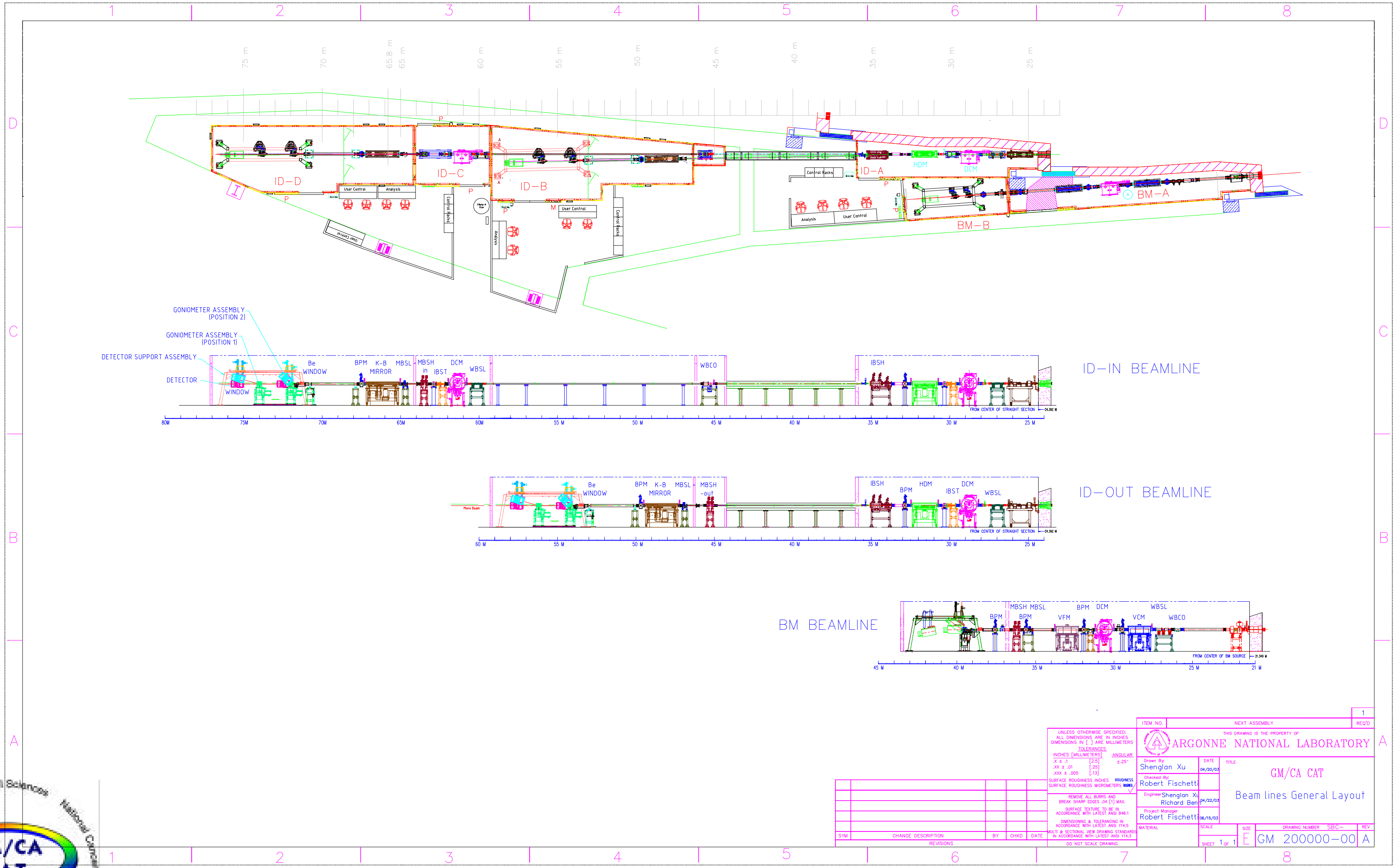
- Sufficient vertical separation to introduce horizontal mirrors
- Monochromator, precision, reproducibility, stability (tune and position)
- Monochromator Cryo-crystals, first and ideally second
- Compton scatter shield
- Focusing mirrors – highly demagnifying, mirror length
- Beam transport – joint or separate
- Independent operation/shuttering of ID-lines

Schematic View of the Canted ID-Beamlines

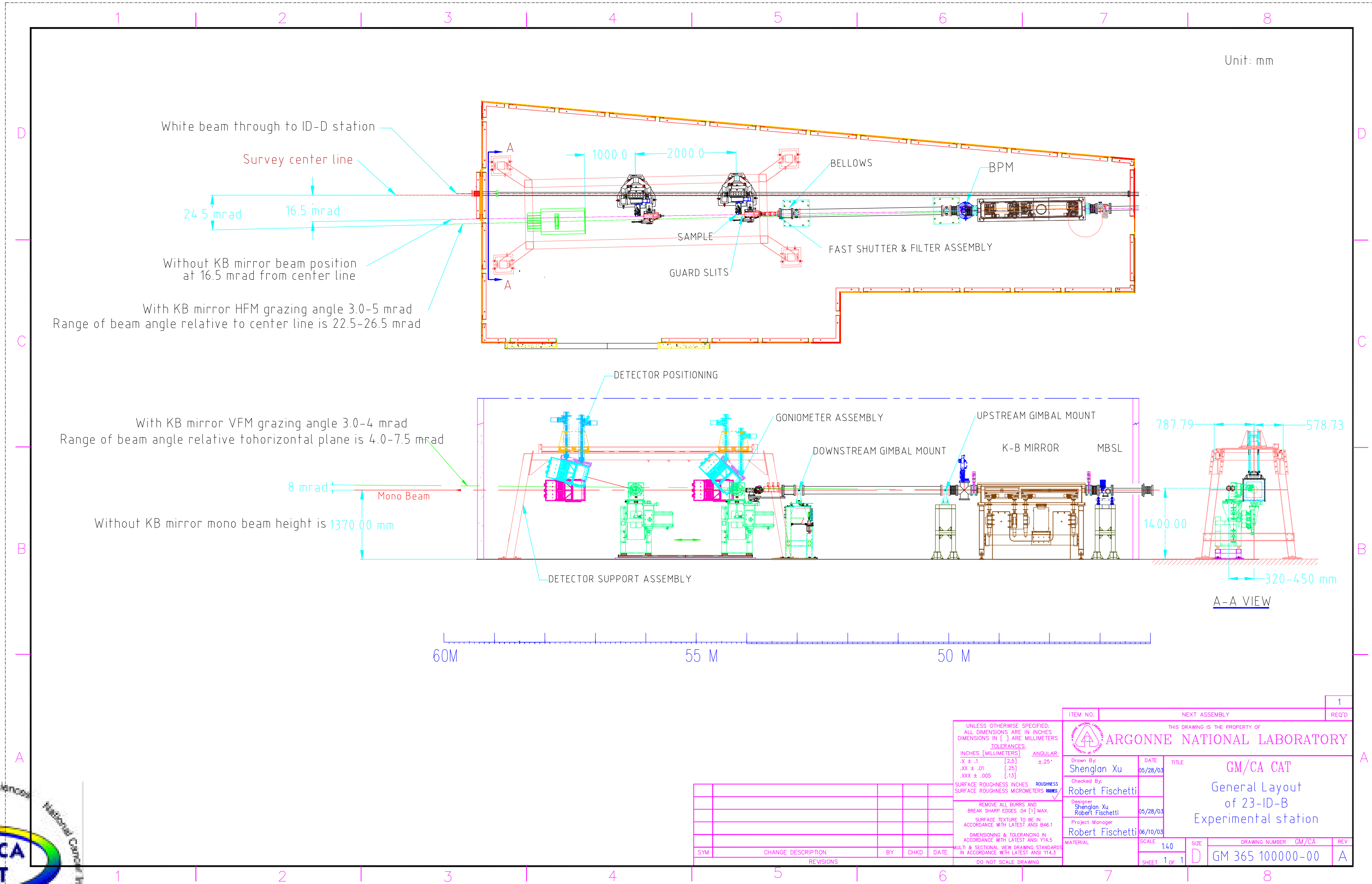


Sector-23 Canted Insertion Device Beamlines

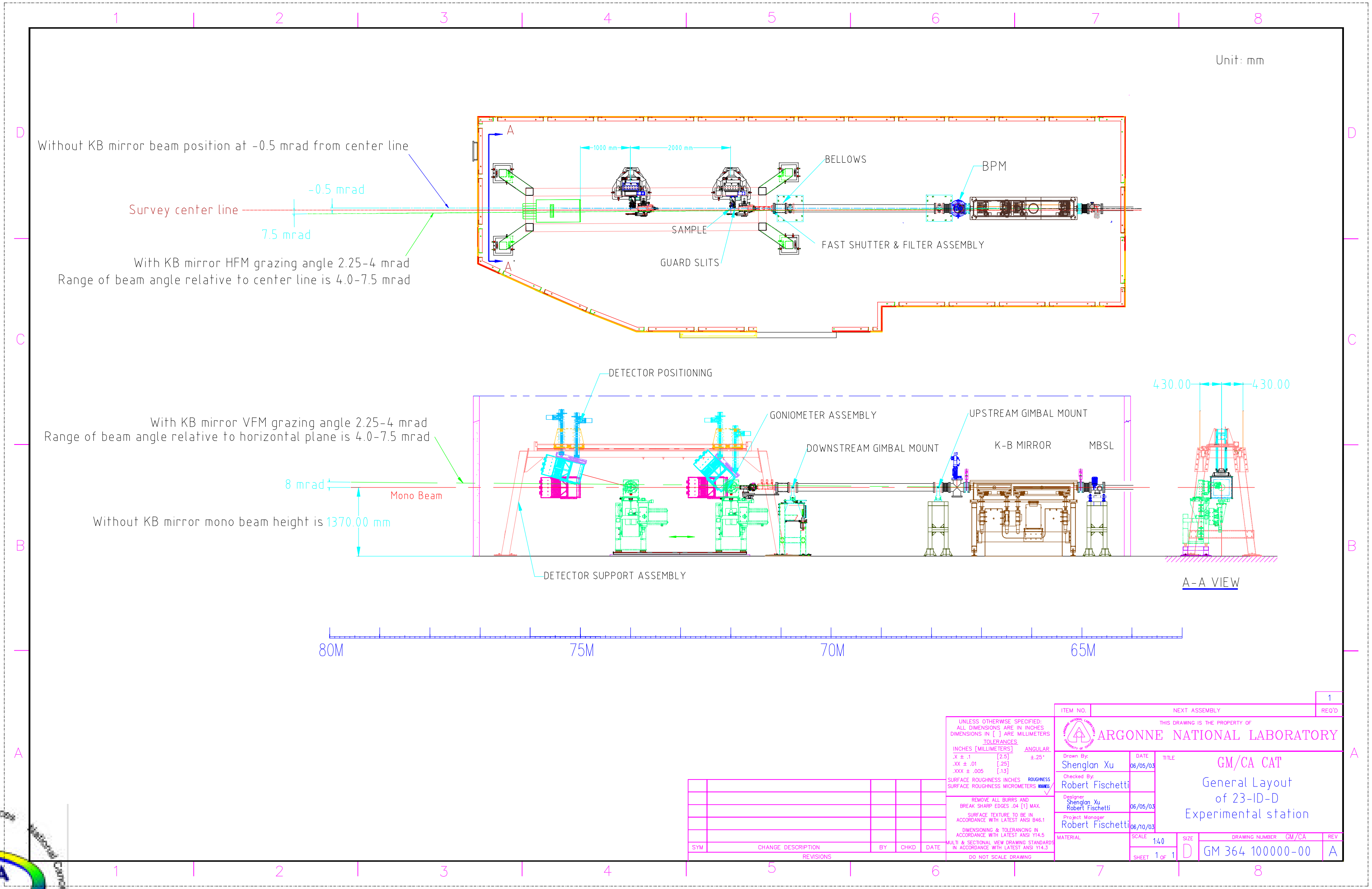
GM/CA CAT Sector Layout



GM/CA ID_out Experimental Station



GM/CA ID_in Experimental Station



Beam Separation vs High Energy Cut Off

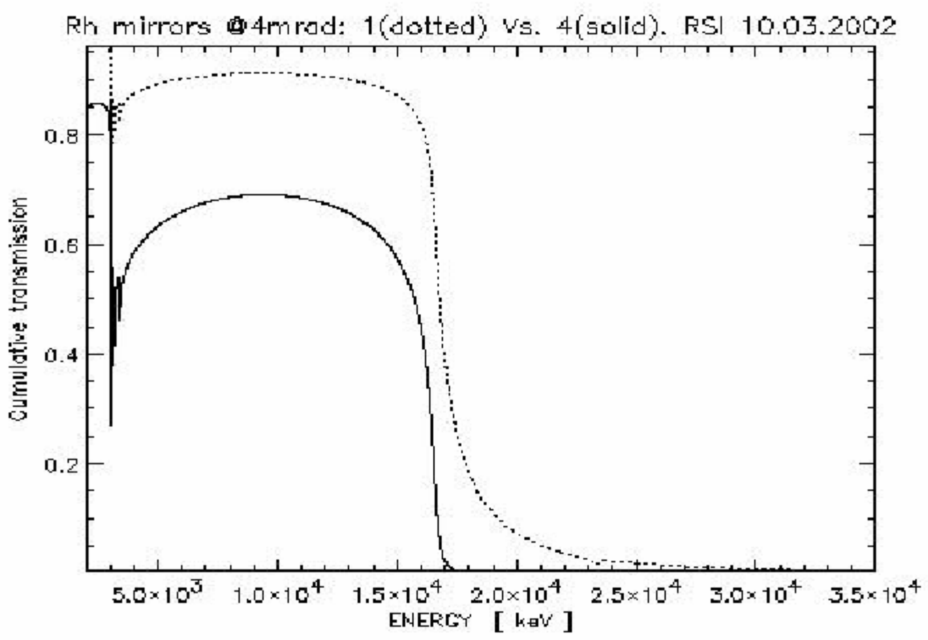
Based on Option 2A

		Mirror Surface						
		Si	**Cr**	**Ni**	**Rh**	**Pd**	**Pt**	**Au**
E*Theta at 8 keV	keV*mrad	3.276E-02	5.537E-02	6.151E-02	7.081E-02	6.928E-02	8.902E-02	8.457E-02

				Mirror Surface							
	Beam Separation			**Rh**		**Pd**		**Pt**		**Au**	
Mirror Angle	**Hor**	**Ver**	**Diag**	**E_critical**	**E_max**	**E_critical**	**E_max**	**E_critical**	**E_max**	**E_critical**	**E_max**
mrad	mm	mm	mm	keV	keV	keV	keV	keV	keV	keV	keV
2.00	298.5	77.4	308.3	35.4	28.7	34.6	28.1	44.5	36.1	42.3	34.3
2.50	358.4	84.2	368.2	28.3	22.9	27.7	22.4	35.6	28.8	33.8	27.4
3.00	418.4	91.1	428.2	23.6	19.1	23.1	18.7	29.7	24.0	28.2	22.8
3.50	478.3	97.9	488.2	20.2	16.4	19.8	16.0	25.4	20.6	24.2	19.6
4.00	**538.3**	**104.7**	**548.4**	**17.7**	**14.3**	17.3	14.0	**22.3**	**18.0**	21.1	17.1
4.50	598.2	111.6	608.5	15.7	12.7	15.4	12.5	19.8	16.0	18.8	15.2
5.00	658.2	118.4	668.8	14.2	11.5	13.9	11.2	17.8	14.4	16.9	13.7
			Edges	E(keV)		E(keV)		E(keV)		E(keV)	
			M(II)					3.027		3.148	
			M(I)					3.296		3.425	
			L(III)	3.004		3.173		11.564		11.919	
			L(II)	3.146		3.330		13.273		13.734	
			L(I)	3.412		3.604		13.880		14.353	
			K	23.220		24.350		78.395		80.725	

Reflectivity of Multiple Mirror Surfaces

Reflection from 1 and 4 Rh surfaces each at 4.0 mrad

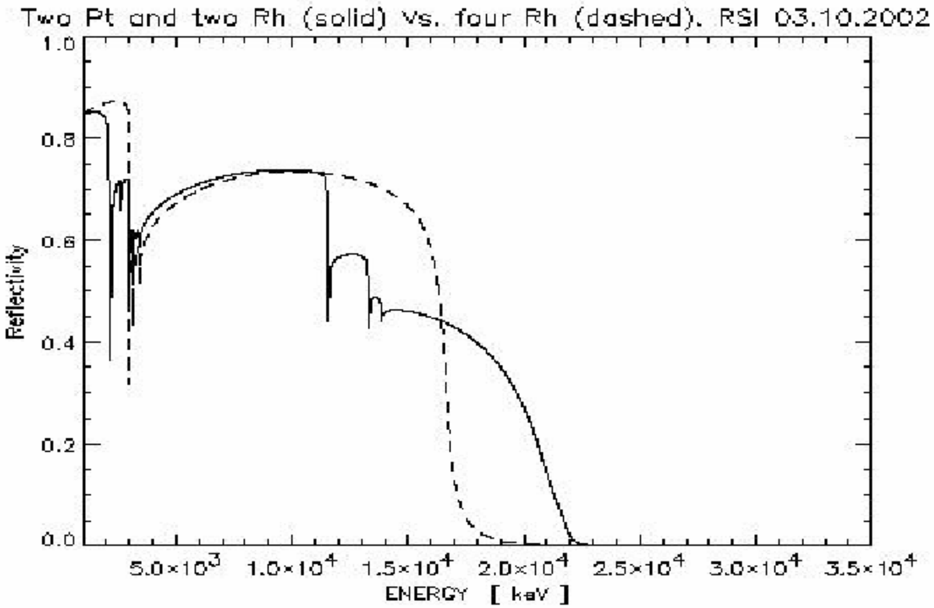


Reflectivity of Multiple Mirror Surfaces

Reflection form 2-Pt at 4.0 mrad and 2-Rh at 3.0 mrad

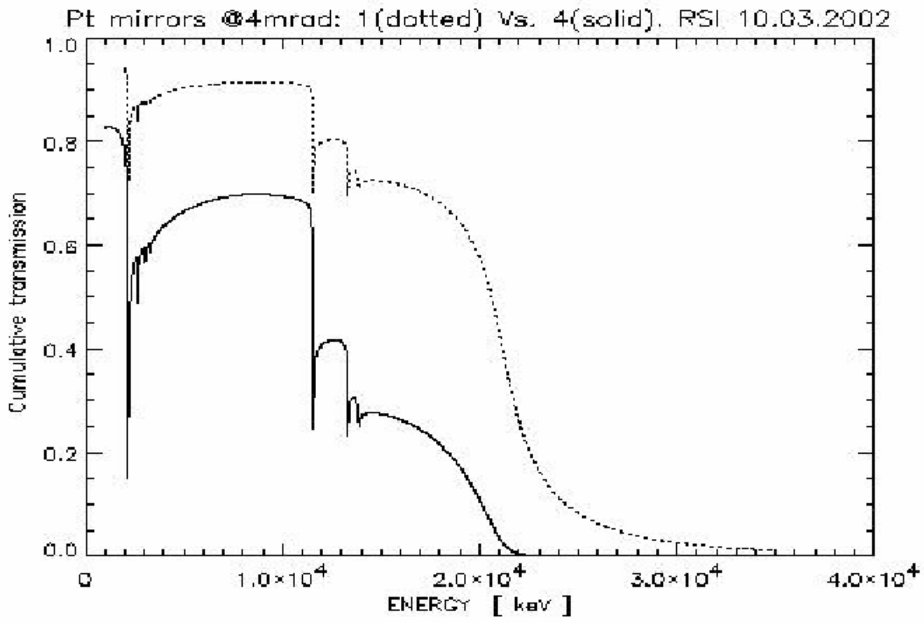
vs

2-Rh at 4.0 mrad and 2-Rh at 3.0 mrad



Reflectivity of Multiple Mirror Surfaces

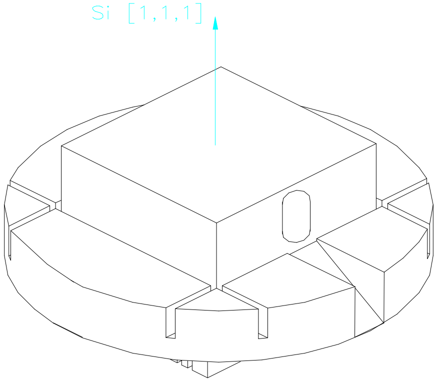
Reflection form 1 and 4 Pt surfaces each at 4.0 mrad



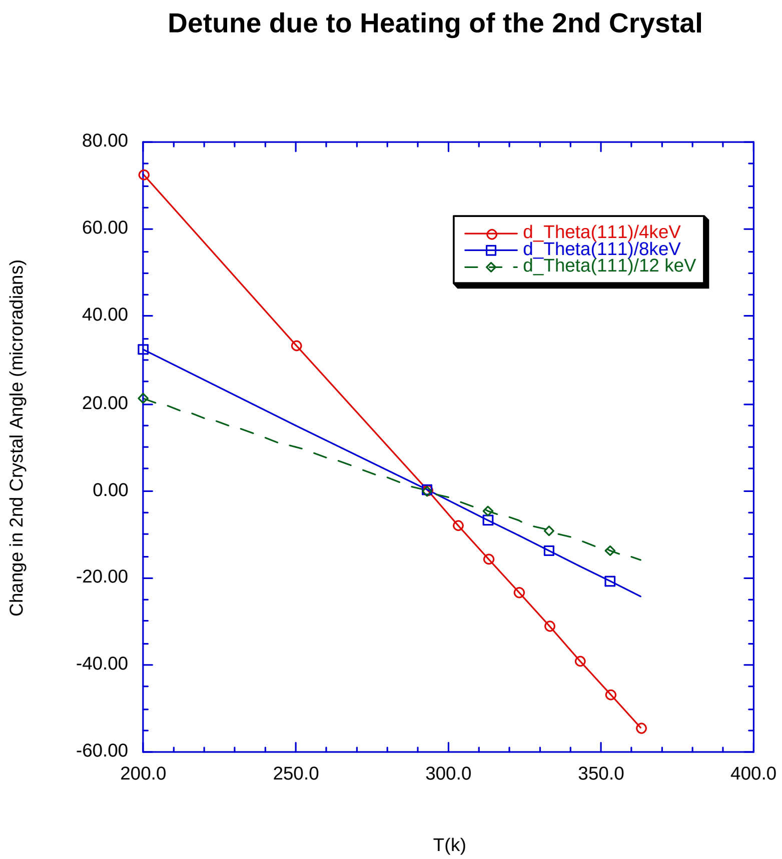
Beamline Characteristics

	ID		BM	
Energy Range (keV)	3.5 - 16, 3.5 - 35		3.5 - 35	
Energy Resolution (%, for all energies, full vertical opening angle of incident beam) *	<0.02		<0.02	
Flux @12 keV (photons/s/100 mA/0.02% BW)	$> 1.0 \times 10^{13}$		$> 1.0 \times 10^{11}$	
Harmonic contamination (%)	<0.01		<0.01	
Rate of energy change (eV/sec)** at 6.5 keV	350		350	
at 20 keV	3500		3500	
Beam positional stability for 100 eV change (% of beam size)	<5		<5	
Beam positional stability for 1000 eV change (% of beam size)	<10		<10	
	Vert	Hor	Vert	Hor
Beam size at crystal (microns) *	50	200	100	200
Beam divergence at crystal (mrad) *	0.05	0.25	0.25	2.0

Hockey Puck Cryo-Crystal

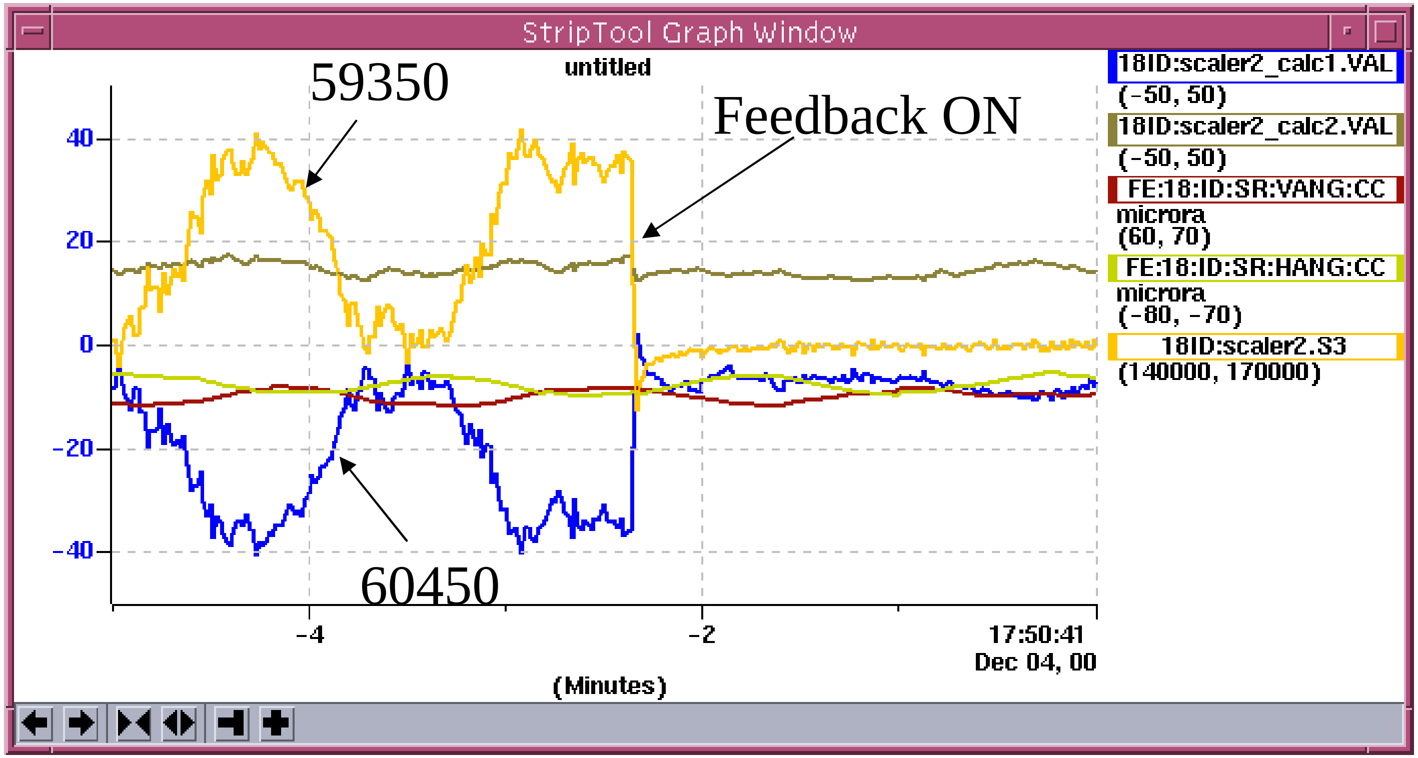


Thermal Effect on 2nd Crystal



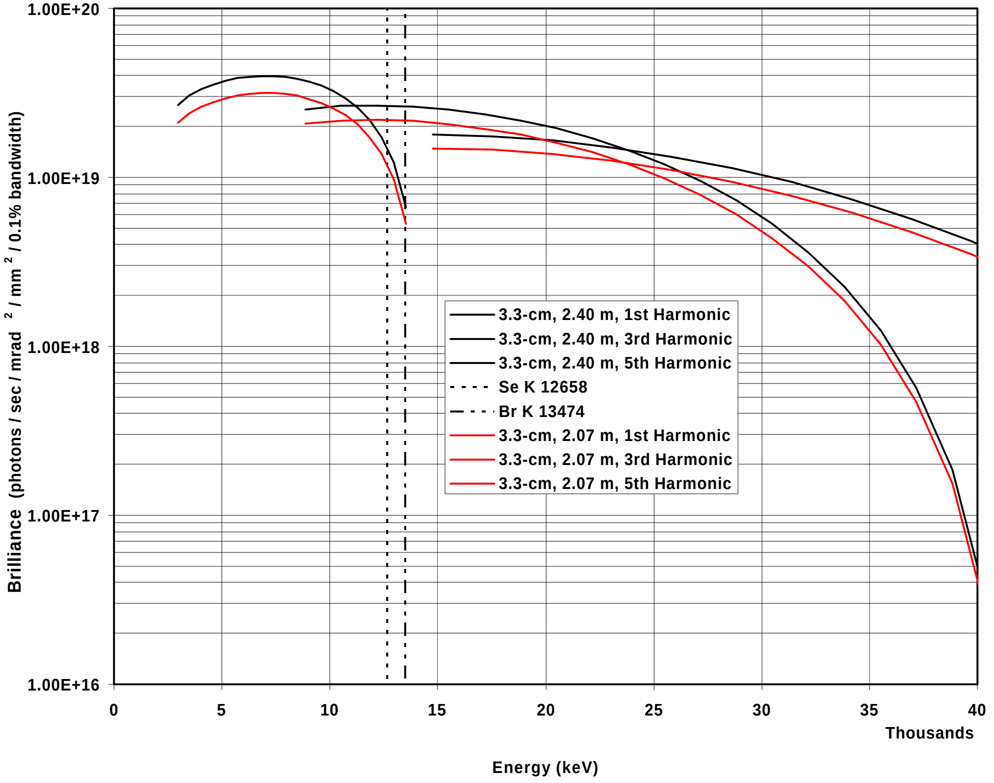
Closed Loop Positional Feedback

BPM at 59350 mm drives angle of second crystal
BPM at 60450 mm records position further downstream



Comparison of Undulator A and Short-Undulator A

Low Emittance Mode (3.0 nm-rad, 1% coupling, 7 GeV, 100 mA)



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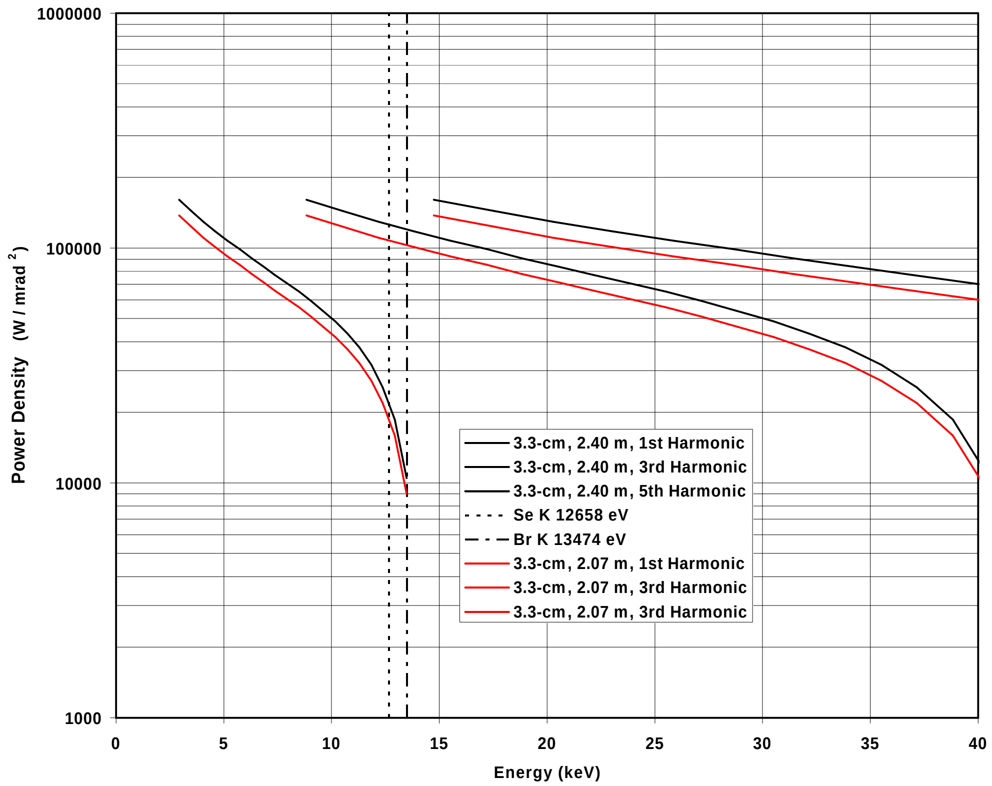

Comparison of 3.0-cm and 3.3-cm Short Undulators

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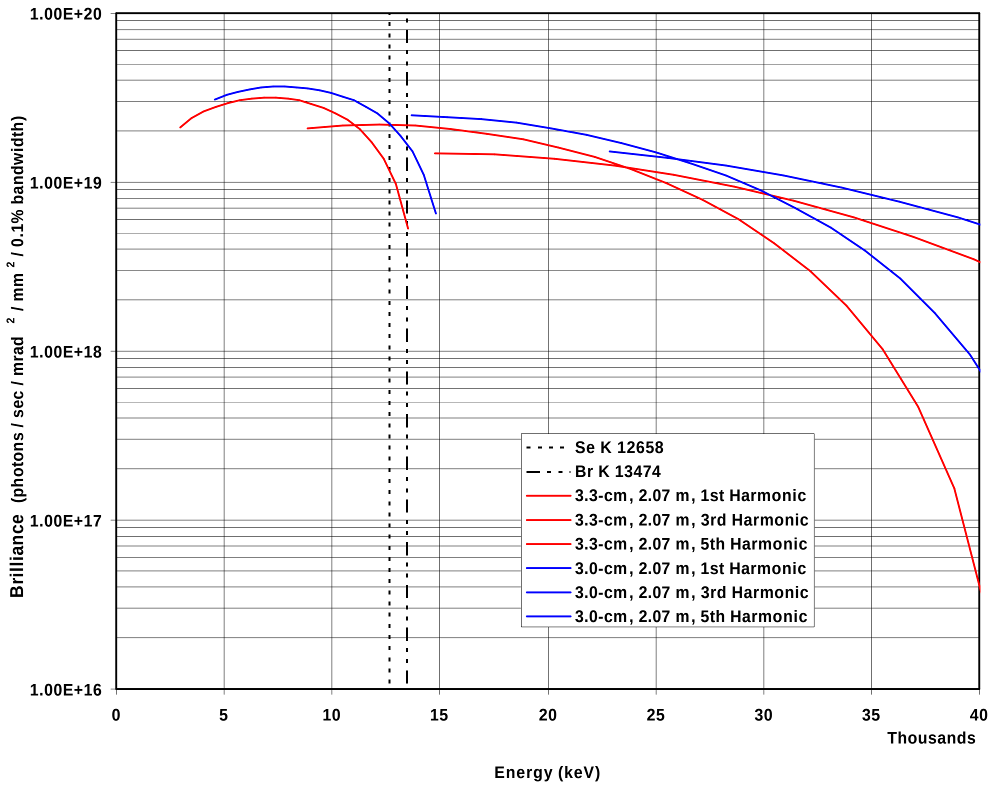

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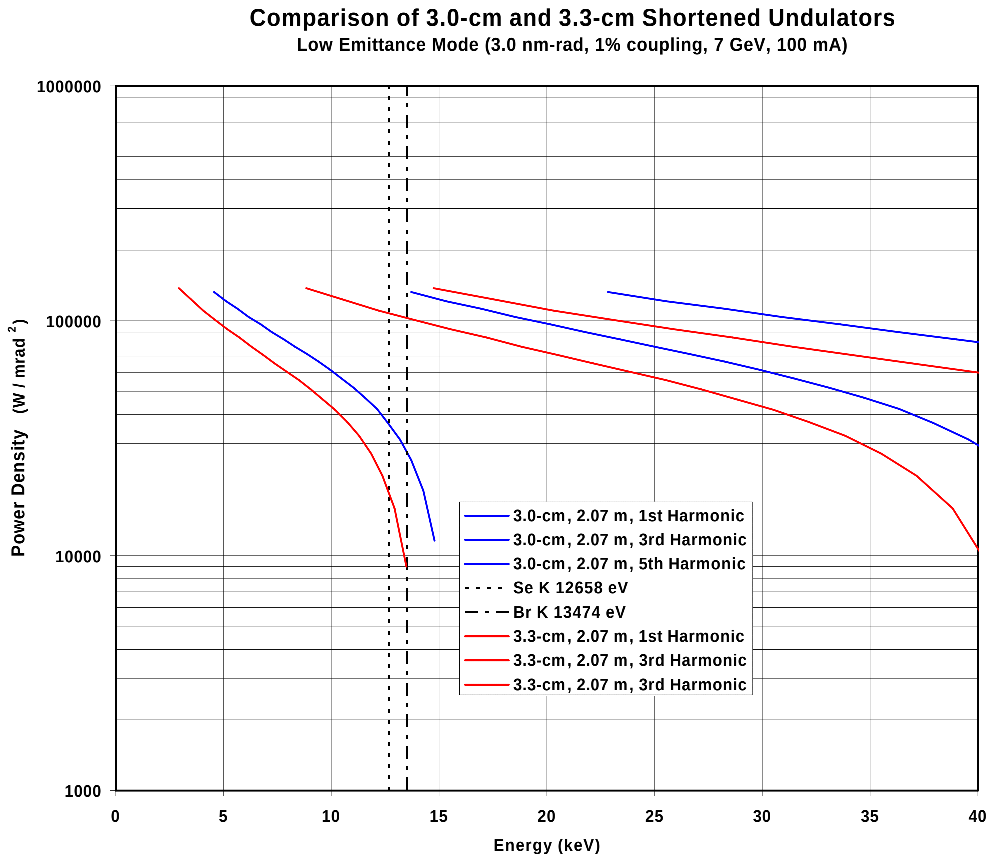

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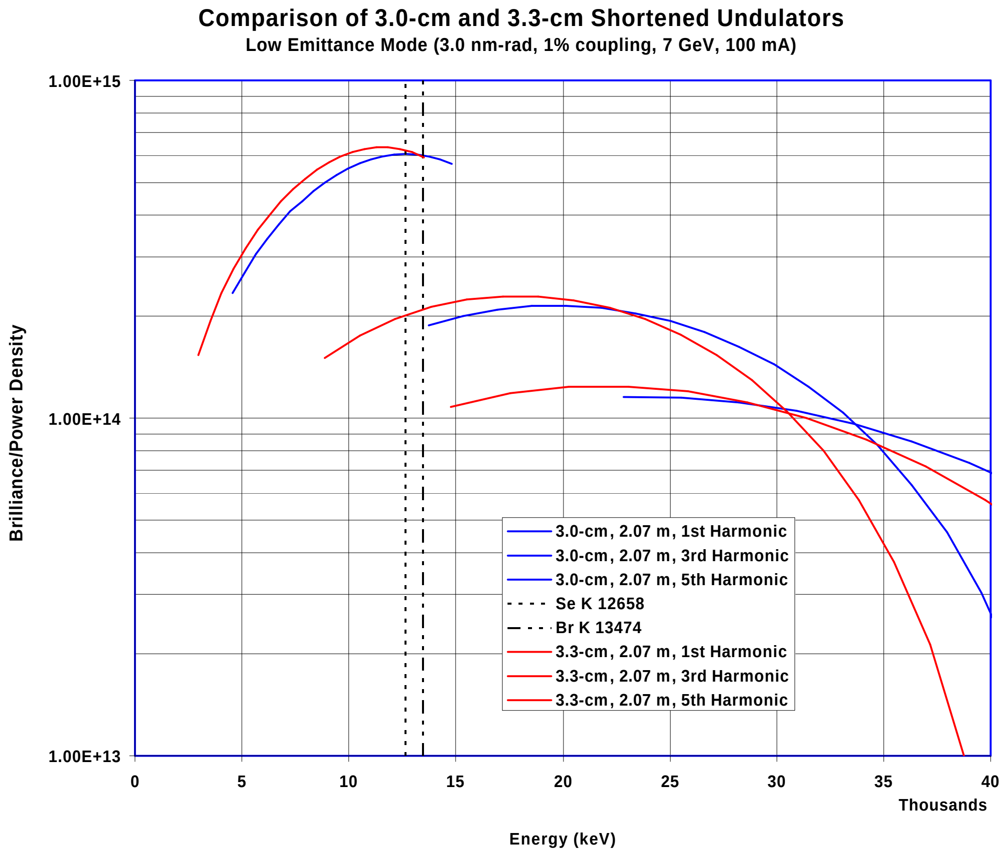

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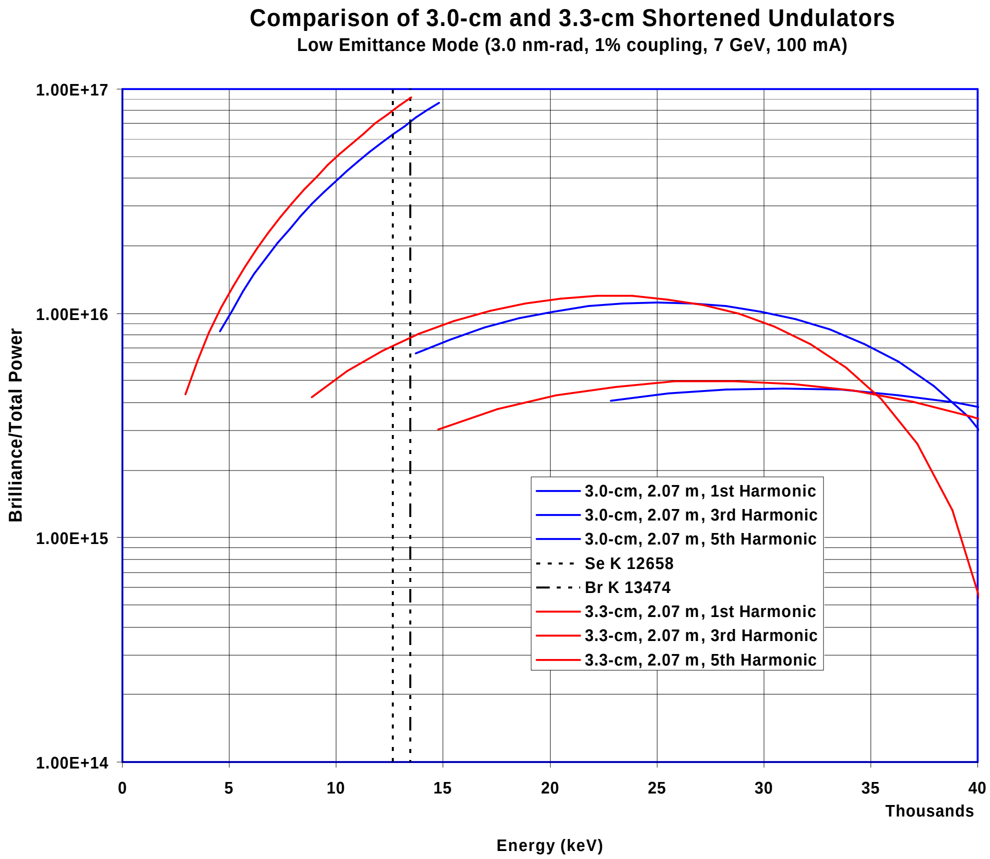

Properties of Synchrotron Sources

Particle Beam Properties	APS ID, July 1999	APS ID, Low Emittance	APS BM, July 1999	ESRF High Beta	ESRF Low Beta	ESRF Bending Magnet	
Natural Beam Emittance, ε	8.18E-09	3.00E-09	8.18E-09	4.00E-09	4.00E-09	4.00E-09	m-rad
Coupling Constant, k_{xy}^{2}	0.01	0.01	0.01	0.01	0.01	0.01	
Horizontal Beam Emittance, ε_x	8.10E-09	2.97E-09	8.10E-09	3.96E-09	3.96E-09	3.96E-09	m-rad
Vertical Beam Emittance, ε_y	8.10E-11	2.97E-11	8.10E-11	3.96E-11	3.96E-11	3.96E-11	m-rad
Horizontal Beta function, β_x	15.90	15.90	1.64	35.60	0.50	2.20	m
Vertical Beta function, β_y	5.30	5.30	15.90	2.50	2.73	34.90	m
Horizontal Beam Size, σ_x	358.85	217.32	115.25	375.49	44.50	93.34	microns
Vertical Beam Size, σ_y	20.72	12.55	35.89	9.95	10.40	37.18	microns
Horizontal Beam Divergence, $\sigma_{x'}$	22.57	13.67	6000.00	10.55	89.00		micro-rad
Vertical Beam Divergence, $\sigma_{y'}$	3.91	2.37	47.00	3.98	3.81		micro-rad
Undulator Length (end poles omitted)	2.40	2.40		1.6	1.6		m
the Straight Section	-1.25	-1.25		0	0		m
ID X-ray Source Properties from WEB Document							
Horizontal Beam Size, Σ_x	359.00		145.00				microns
Vertical Beam Size, Σ_y	21.00		36.00				microns
Horizontal Beam Divergence, $\Sigma_{x'}$	23.00		6000.00				micro-rad
Vertical Beam Divergence, $\Sigma_{y'}$	3.90		47.00				micro-rad