Simulation and Optimization of Source and Optical Elements for New Imaging Beamline Construction at ANKA

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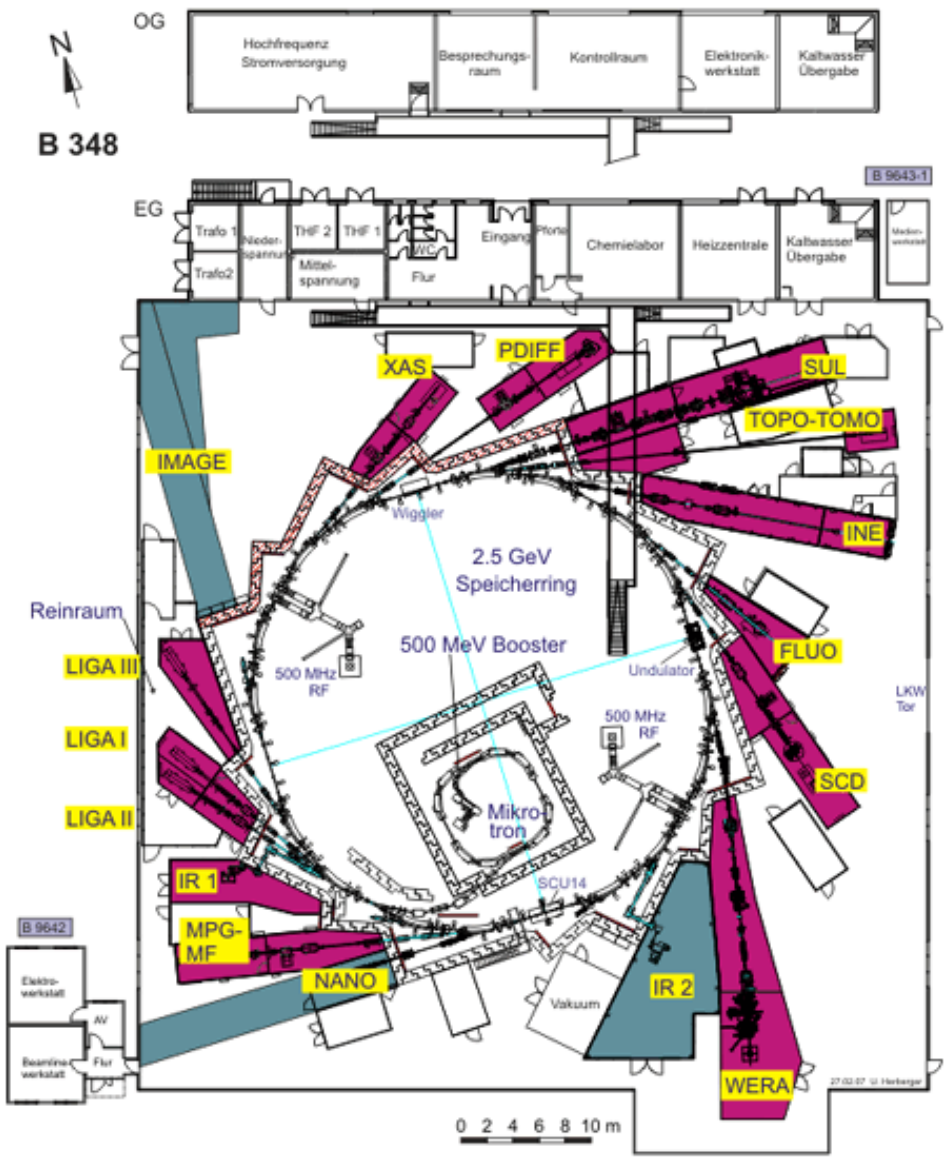
SMEXOS, 25.02.2009, Grenoble

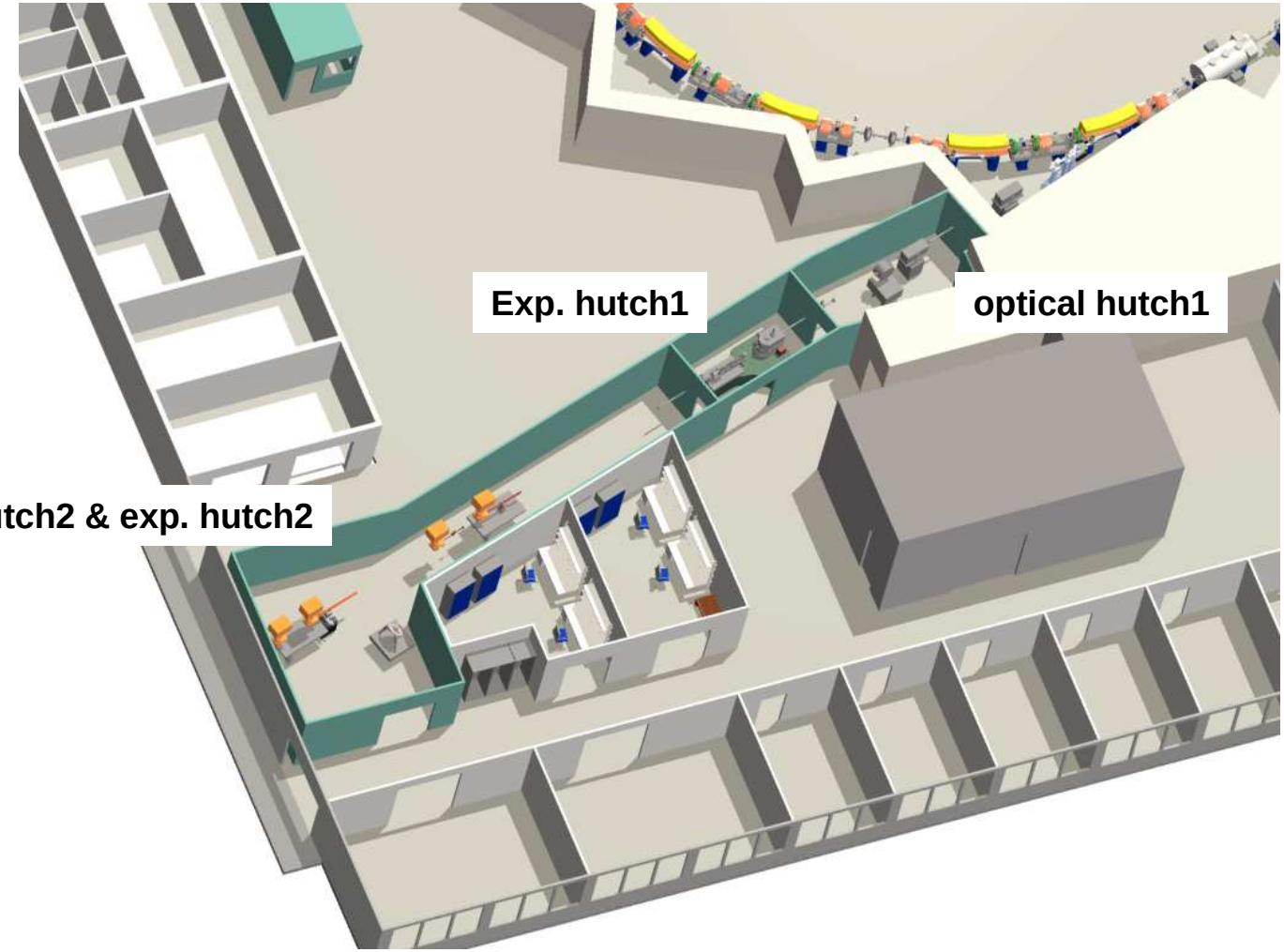
ANKA - HALLENPLAN



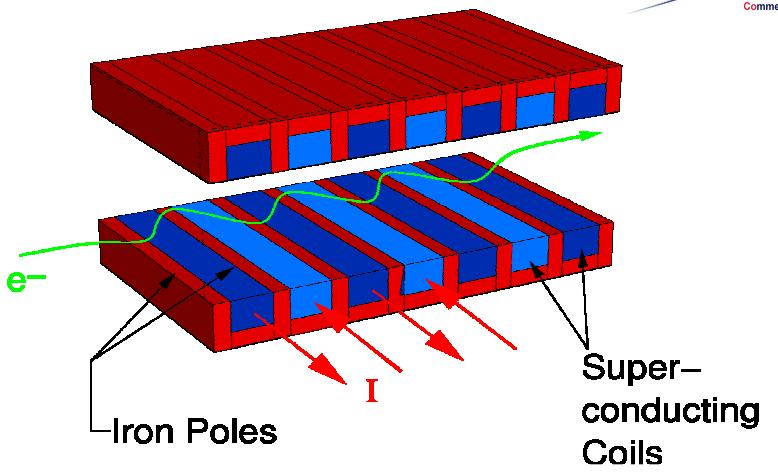
2.5 GeV
110 m
40 nmrad

Preliminary layout

wiggler & undulator source



Superconducting: SCUW
Wiggler & undulator
Switchable mode



Wiggler parameters
Period length λu [mm]: 45
Period number: 33
Deflection parameter K: 13.8
Magnetic field [T]: 3.21 T
Critical energy [keV]: 13.108

Undulator parameters
Period length λu [mm]: 15
Period number: 99
Deflection parameter K: 1.2
Magnetic field [T]: 0.86 T
Fundamental energy [keV]: 2.250

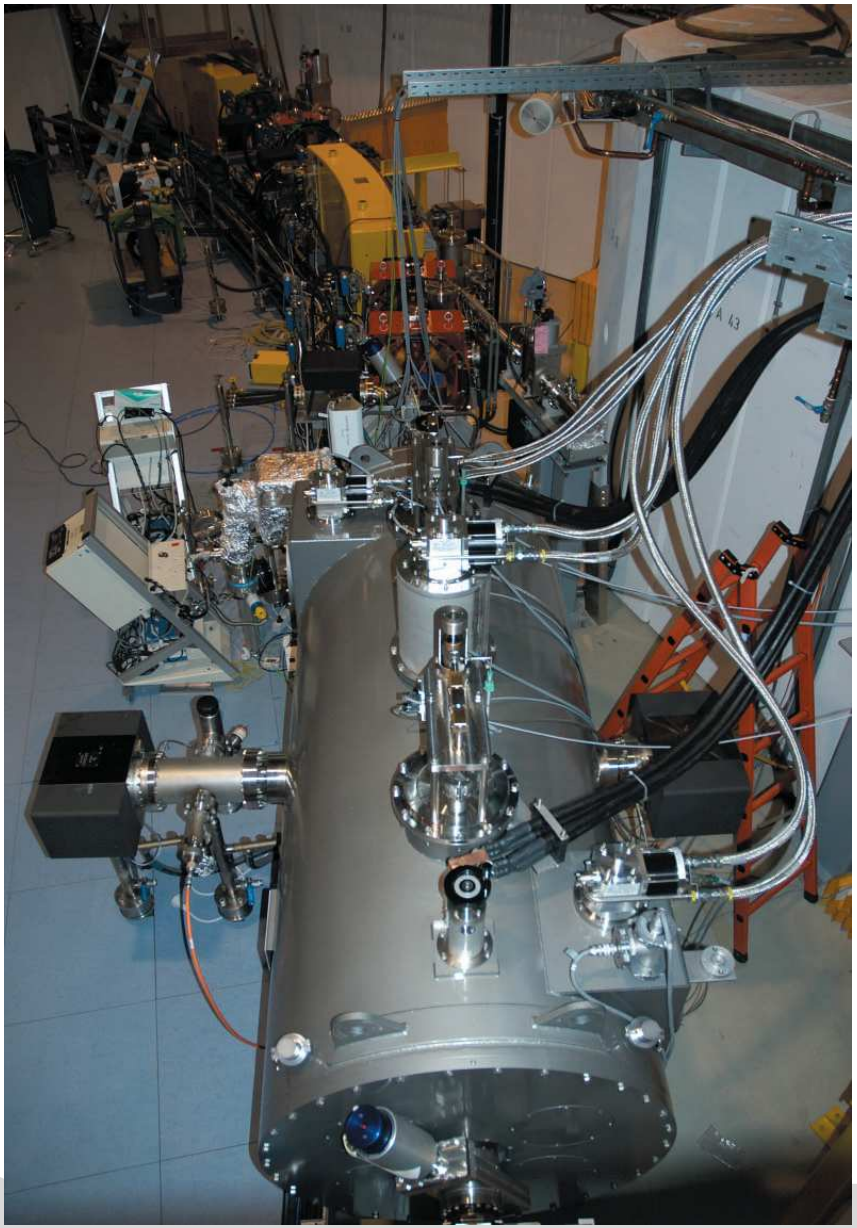
Wiggler mode

Energy keV	Source size, $\sigma_H \times \sigma_V$ mm²	Divergence, $\sigma_H' \times \sigma_V'$ mrad²
8	1.05×0.072 2.47×0.17 (FWHM)	1.45×0.158 3.41×0.37 (FWHM)
25	0.99×0.045 2.33×0.106 (FWHM)	1.18×0.090 2.77×0.212 (FWHM)

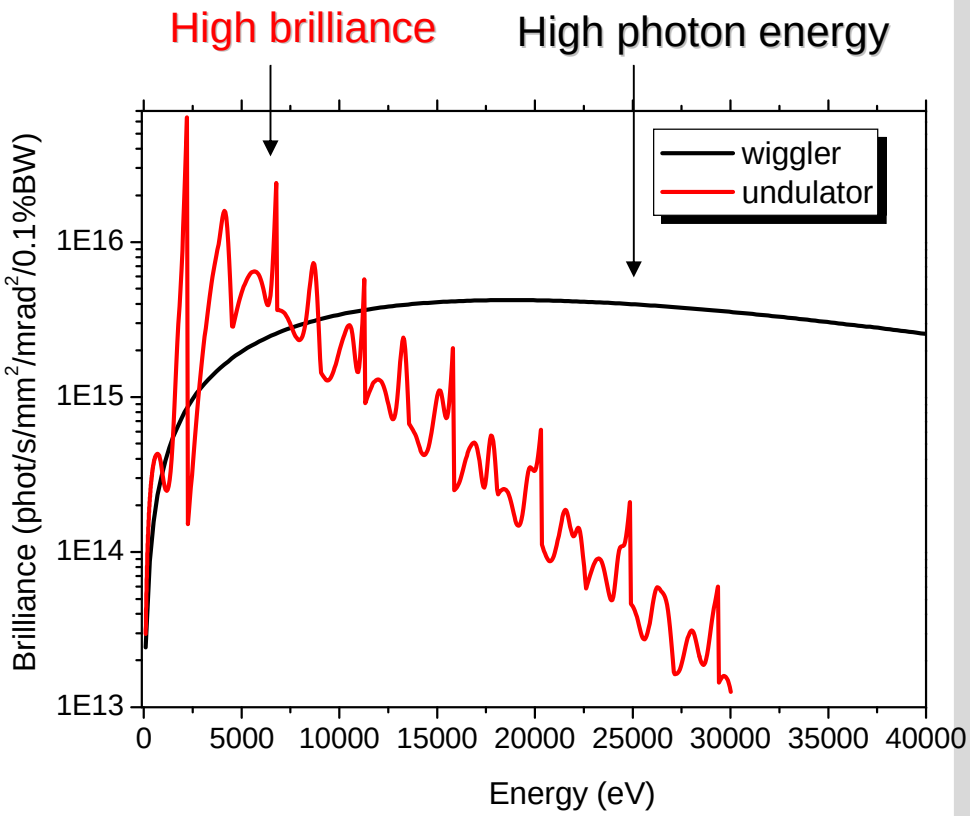
Undulator mode

Source size, $\sigma_H \times \sigma_V$ mm²	Divergence, $\sigma_H' \times \sigma_V'$ mrad²
0.85×0.024 1.90×0.056 (FWHM)	0.056×0.017 0.13×0.040 (FWHM)

SPECTRA, T. Tanaka



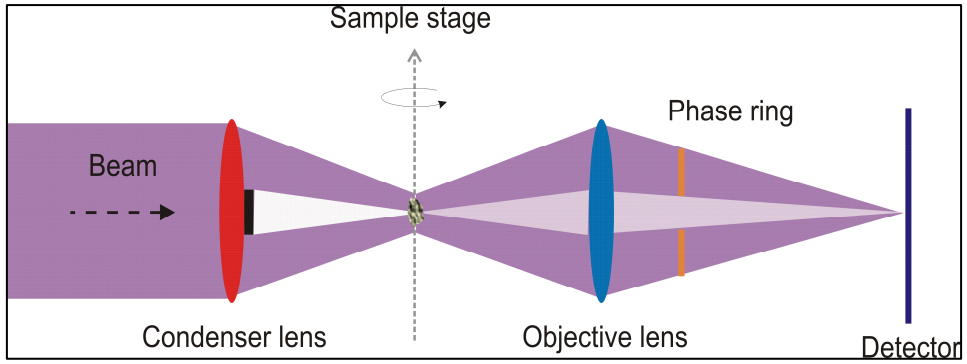
SCU14 -demonstrator installed on February 28th, 2005, ANKA



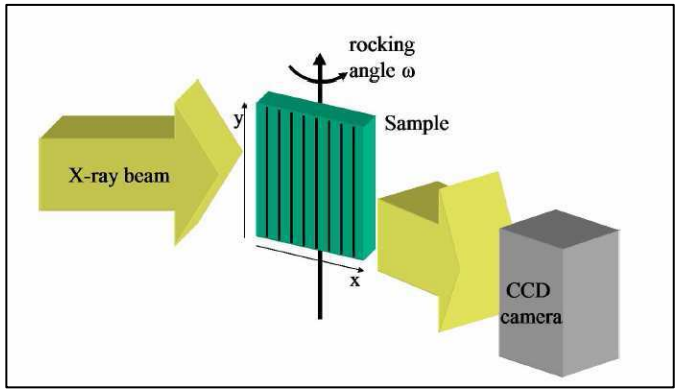
SPECTRA

Experimental stations

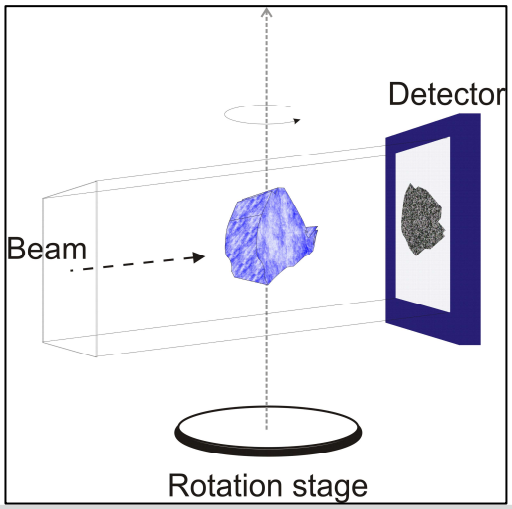
Full-field microscopy



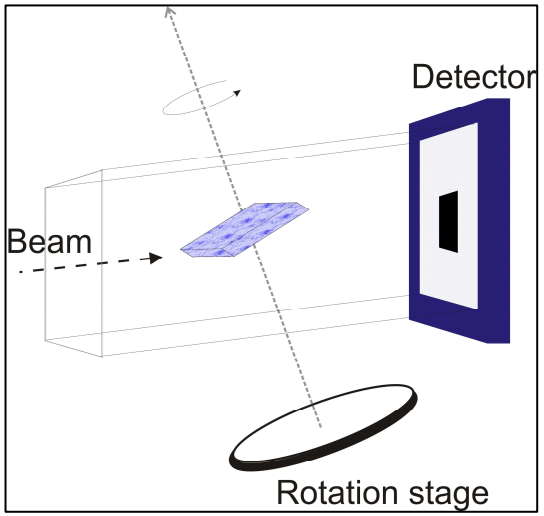
Rocking Curve Imaging



Tomography



Laminography

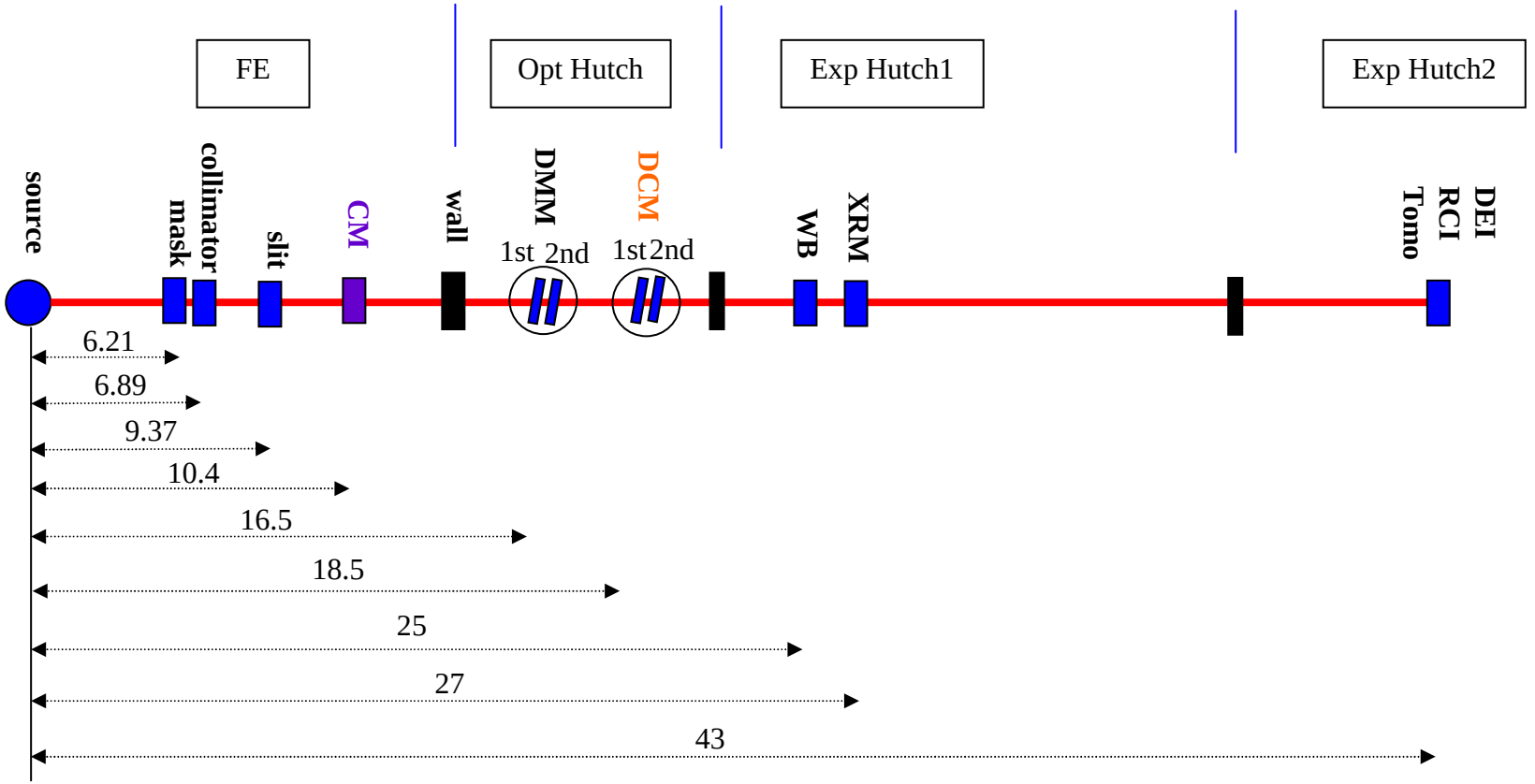


D. Pelliccia

Imaging requirements

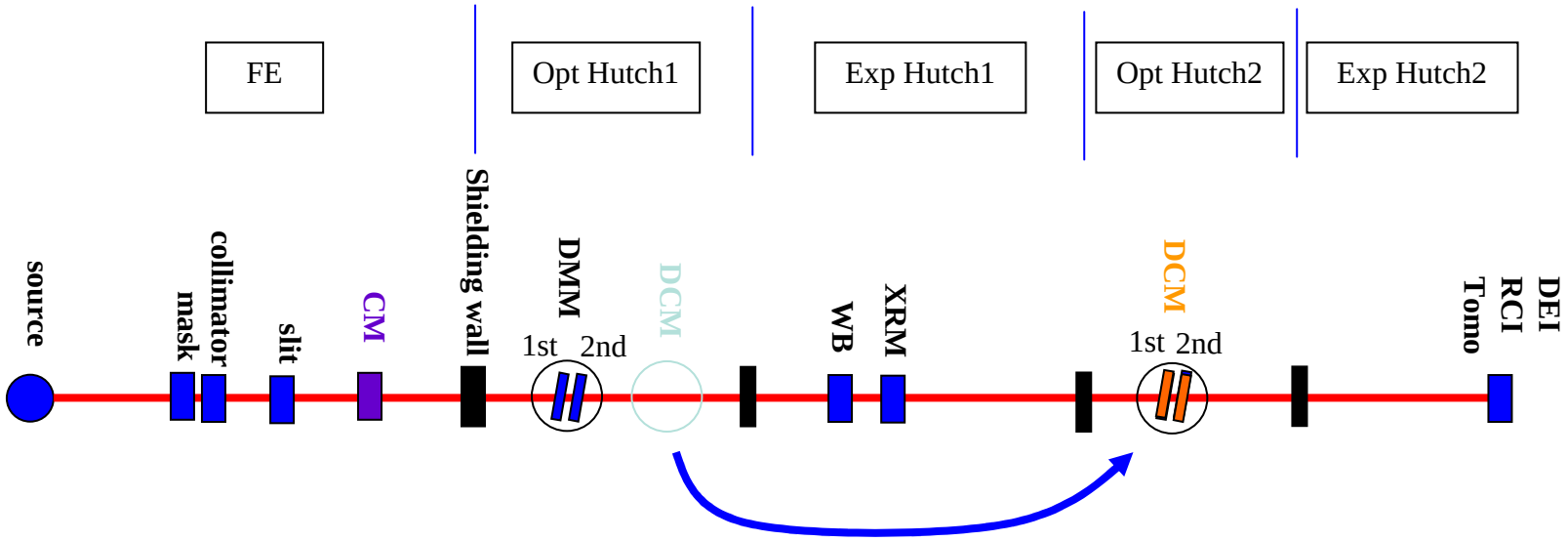
XRM	focused beam, high brilliance, intermediate energy
Tomography & radiography	large beam size, high energy photon, high flux
Coherence imaging	Coherence, high flux
Diffraction enhanced imaging Rocking curve imaging	High energy resolution, high brilliance, focused beam

Optical Layout, option 1



Mask:50×0.5cm^2
Collimator: 20×0.3cm^2

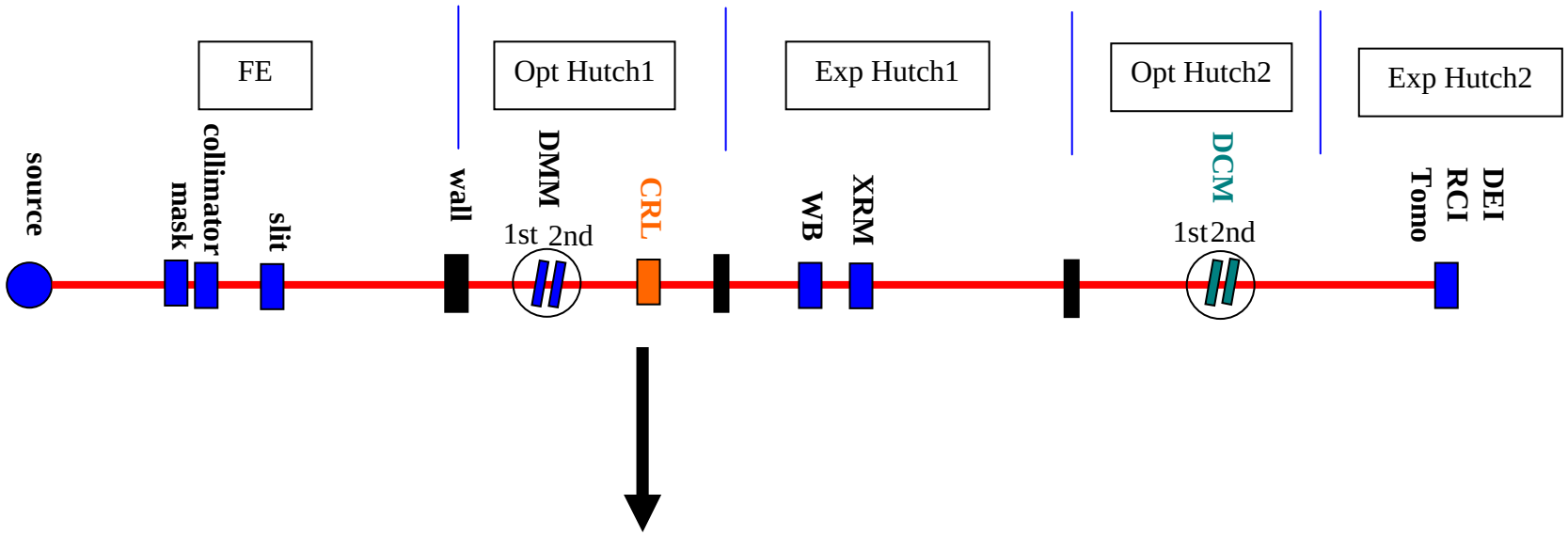
Optical Layout, option 2



coherence length at 43m: ξ_x=2.8μm, ξ_z=29.2 μm (direct beam)

vertical beam instability from DCM ~ 100 nmrad=0.1μrad
DCM at 35m: $8*10^6 \times 0.1*10^{-6}$ =8 μm
DCM at 18.5m: $24.5*10^6 \times 0.1*10^{-6}$=24.5 μm — kill the coherence!

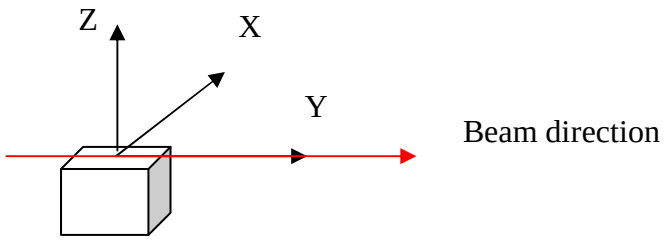
Optical Layout, option 3



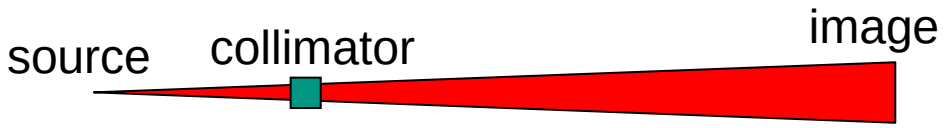
Compound refractive lens used as a beamline component for collimating & focusing

Ray-tracing simulations (XOP2.1, shadow1.0)

- Simulations for wiggler and undulator source, separately.
- Beam spot size is given in x×z dimension (cm).
- x' and z' are divergence (mrad) in x and z.
- Intensities are given relative to source intensity, 25000.
- Monochromator: infinite dimensions.
- Collimating mirror: 100cm×20cm



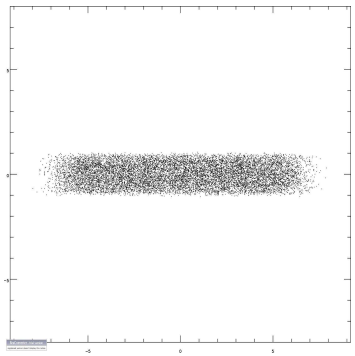
Direct beam



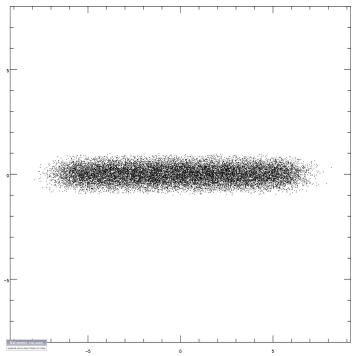
No	Source	energy eV	Source x×z	image x×z	image x'×z'
1	wiggler	8000±15	0.247×0.017 25000	**12.3×1.69** **12666**	2.82 ×0.39
2	wiggler	25000±80	0.232×0.011 25000	**11.9×0.99** **17555**	2.75×0.22
3	Undulator 3rd	7152±6	0.201×0.055 25000	**0.58 ×0.36** **25000**	0.12 ×0.08
4	Undulator 5th	11000±10	0.205 ×0.055 25000	**0.69 ×0.58** **2500**	0.16 ×0.14

High coherence
Large beam profile

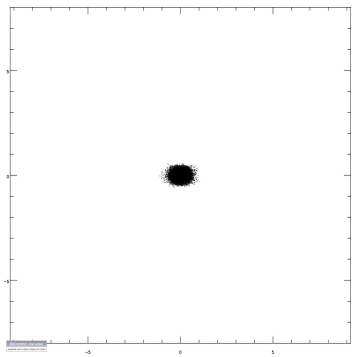
Beam profile at 43m



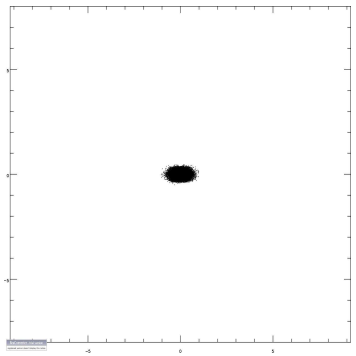
8keV, wiggler



25keV, wiggler

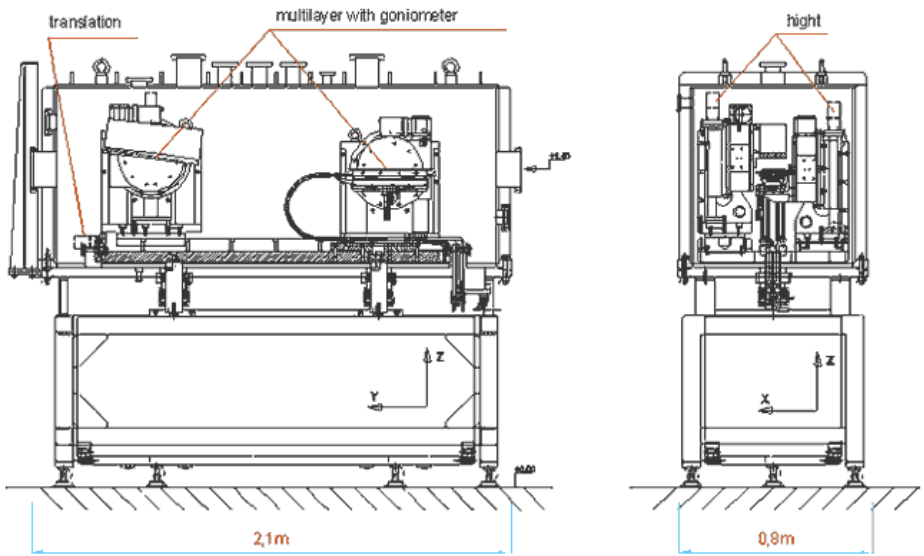


7keV, undulator

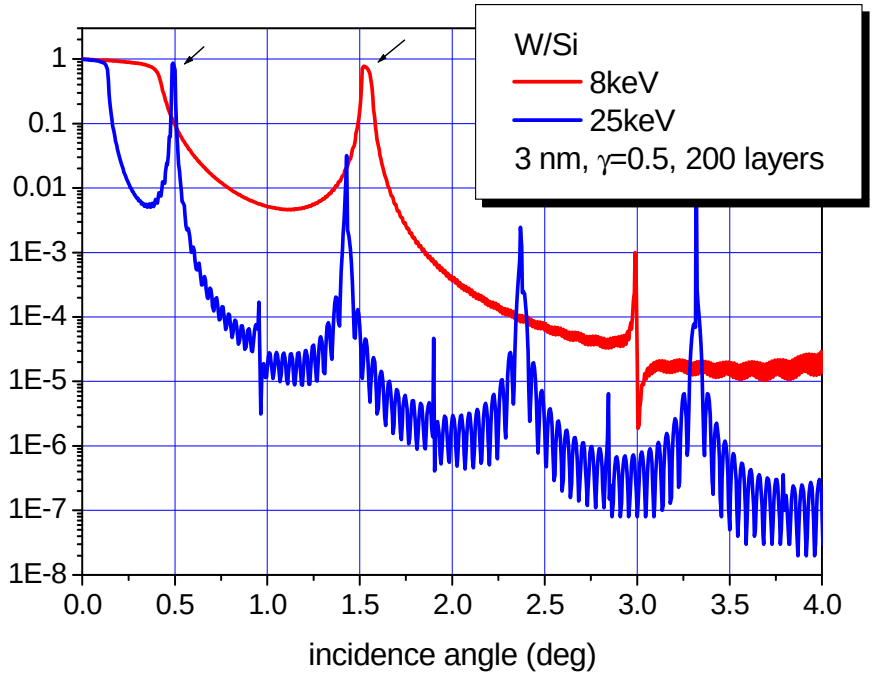


11keV, undulator

DMM



W/Si DMM, http://www.accel.de



Standard DMM
Bandwidth: 10^{-2}, Mo/B4C, W/C
d-spacing =2.7~ 3 nm, N~200
High resolution DMM
Bandwidth: 10^{-3}, Mo/B4C
d-spacing =1.5 nm, N=600

Energy (keV)	DMM	grazing angle (°)	reflectivity
8	W/Si	1.54	0.72
25	W/Si	0.49	0.80

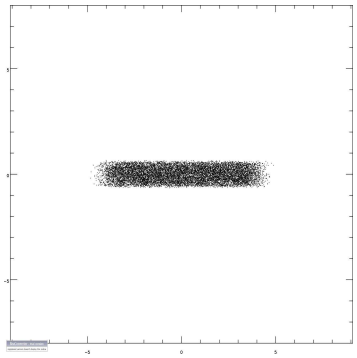
J. Synch Rad. (2006). **13**, 204

DMM

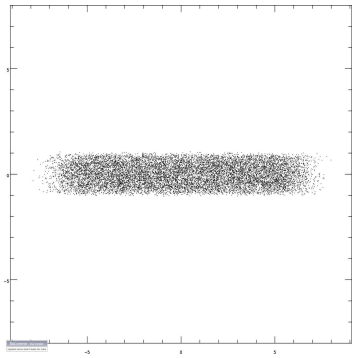
wiggler source, W/Si, 3nm, 200 layers

No	energy (eV)	Image dist M	image x×z	image x'×z'	Resolution eV	Bandwidth %
1	8000±200	10.5	7.70×1.07 4265	2.84×0.39 4265	214	2.7%
2	8000±200	26.5	12.4×1.66 4265	2.84×0.39 4265	214	2.7%
3	25250±750	10.5	7.52×0.57 5707	2.75×0.22 5707	730	2.9%

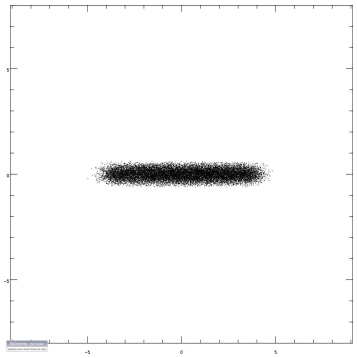
Beam profile xz at 27 m
or 43m



1: 8keV, wiggler



2: 8keV, wiggler



3: 25keV, wiggler

DCM

Energy resolution

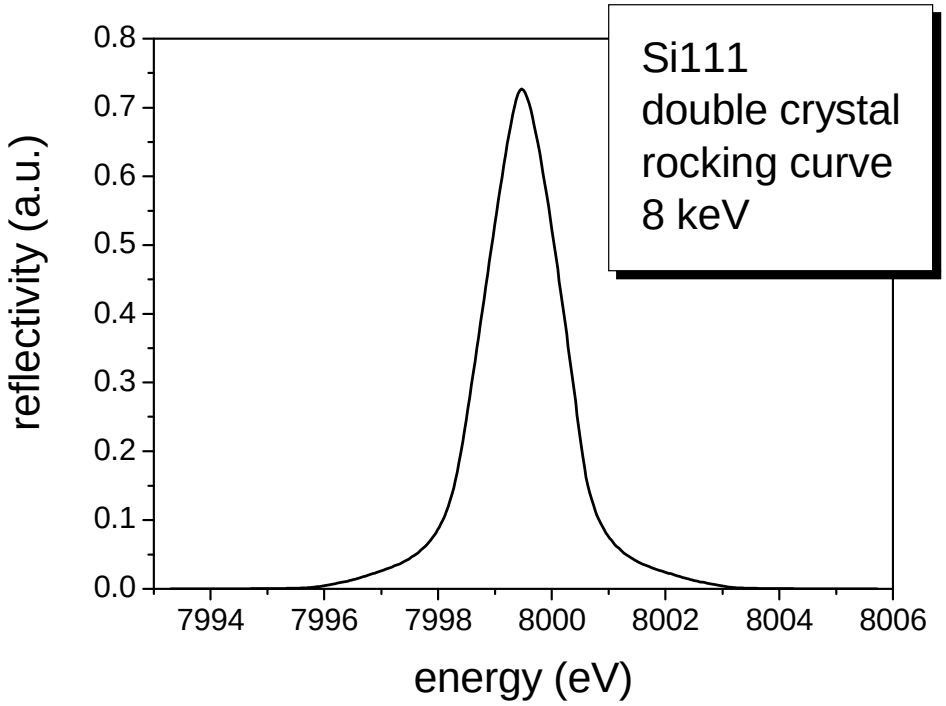
$$\frac{\Delta E}{E} = \sqrt{\Delta\theta_s^2 + \Delta\theta_d^2 + \Delta\theta_m^2} \times \cot\theta$$

Vertical beam divergence: 0.371 mrad

Non-aberration optics, 0

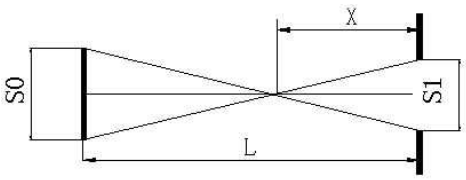
Darwin width (Si111 double crystal, 8 keV): 0.0499 mrad

ΔE = 11.7 eV at 8keV



Divergence at 8 keV

Source, mrad		Collimator, mrad	
h	v	h	v
3.41	0.371	3.06	0.681



$$\Delta\theta_s = \frac{s_1 + s_0}{L}$$

DCM

$$m\lambda = 2d\sin\theta_0(1-\frac{\delta(\lambda)}{\sin^2\theta_0})$$

$$\tilde{n} = 1-\delta(\lambda)-i\beta$$

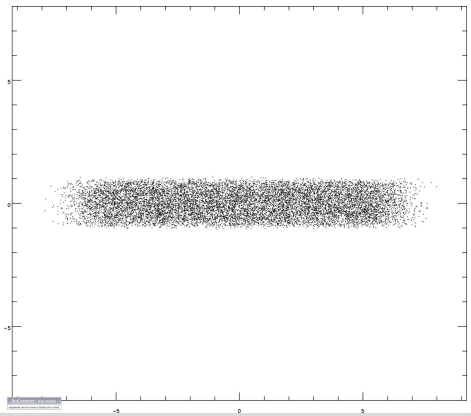
Fixed exit
4°~40°
Si111, Ge111: 3.2~25keV
Si311: 6~50keV

Crystal plane	Si111				Si311			Ge111			
Energy (keV)	3.2	8	15	25	6	25	50	3.2	8	15	25
Bragg angle (°)	38.2	14.3	7.57	4.54	39.1	8.71	4.34	36.4	13.7	7.27	4.35
Darwin width (μrad)	109.2	35.0	17.9	10.6	23.9	4.32	2.13	247.0	77.2	41.9	25.4
Footprint (cm)		5.55		9.85		5.15			5.78		10.3

DCM

wiggler source

No	energy (eV)	Crystal	source dist m	image x×z	image x'×z'	resolution eV
1	8000±15	Si111	35	11.2×1.66 388	2.38×0.39 388	11.6
2	25000±80	Si111	35	10.8×0.916 395	2.50×0.240 395	55.0
3	25000±80	Si311	35	9.69×1.18 79	2.43×0.166 79	30.6
4	**8000±15**	**Ge111**	**35**	**12.5×1.56 694**	**2.65×0.37 694**	**12.6**

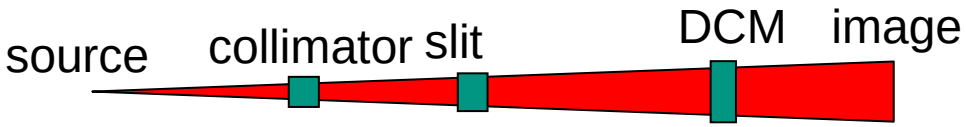


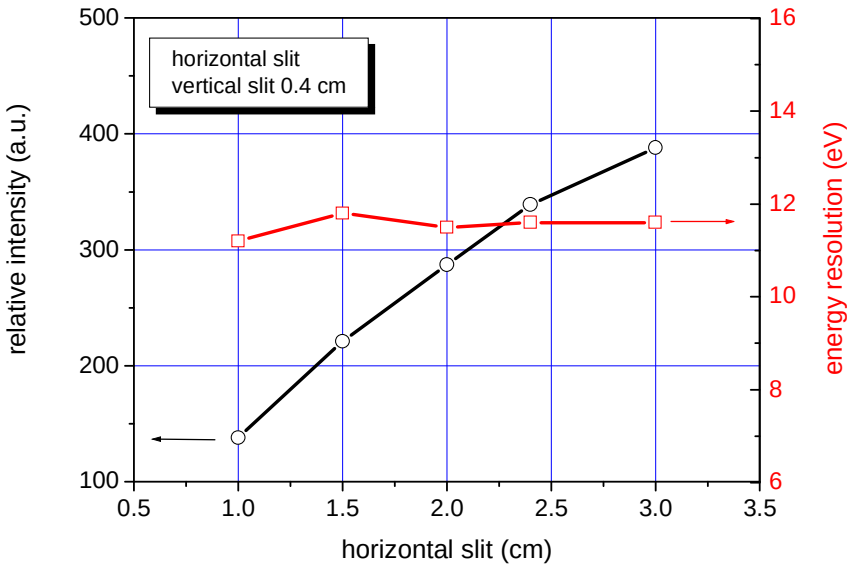
Ge 111 has higher flux, comparable energy resolution with Si111

8keV, wiggler, S111

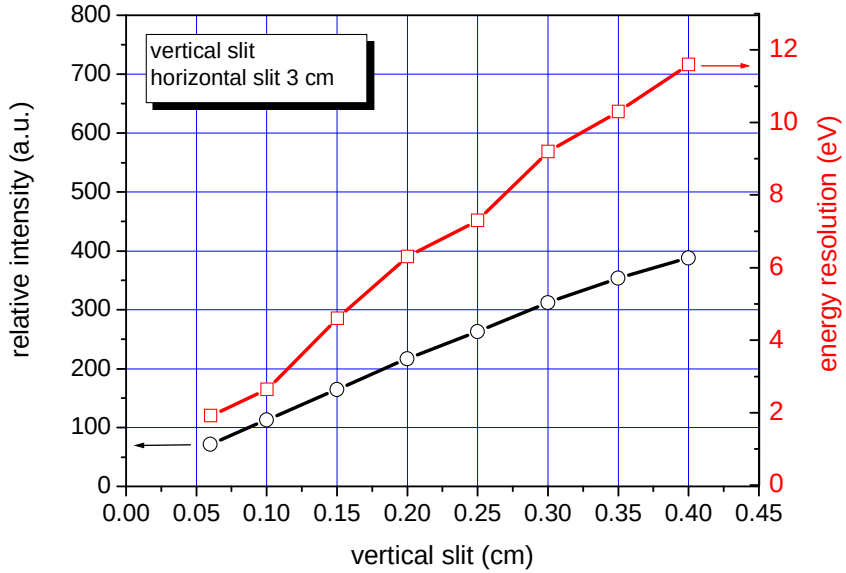
DCM: combined with front Slit

wiggler source





Horizontal

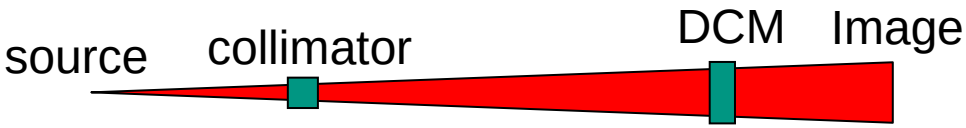


Vertical

Results from ray-tracing

High energy resolution
For DEI, RCI

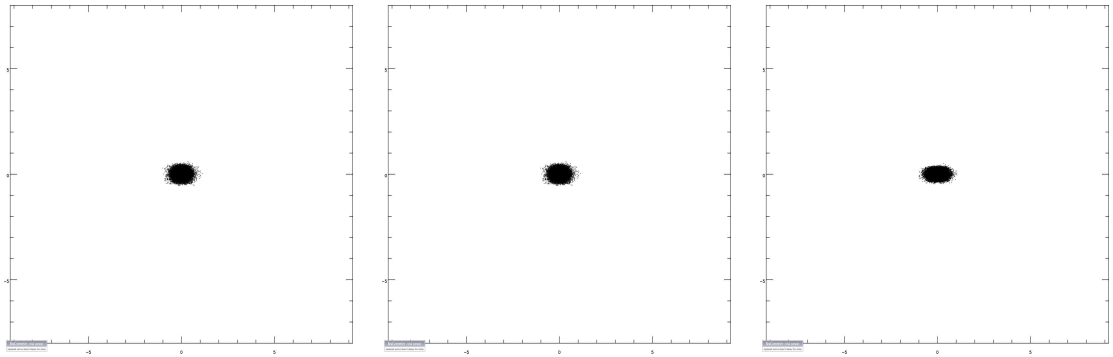
DCM



undulator source

No	Harmonic	energy (eV)	mono	image x×z	image x'×z'	resolution eV
1	3	7152 ±6	DCM Si111	0.561×0.348 1628	0.116×0.083 1628	2.00
2	3	7152 ±6	DCM Ge111	0.607×0.337 2962	0.120×0.082 2962	2.59
3	5	11000 ±10	DCM Si111	0.538×0.303 1753	0.235×0.143 1753	2.00

Beam profile
xz at 43m

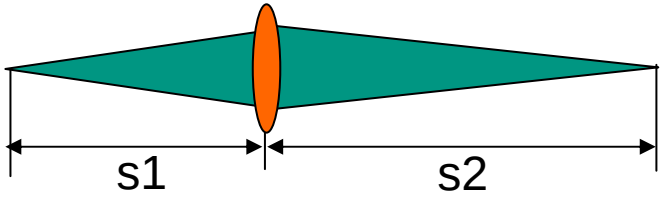


1 2 3

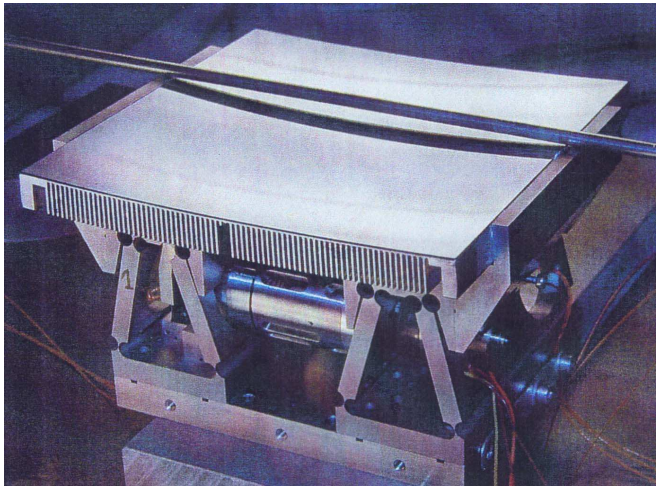
DCM: Sagittal Focusing

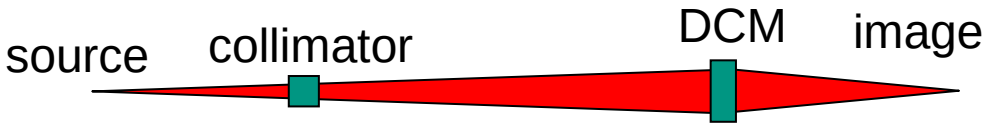
Horizontal focusing

second crystal, Bragg angle θ at E



$$\frac{1}{s_1}+\frac{1}{s_2}=\frac{2\sin\theta}{R}$$





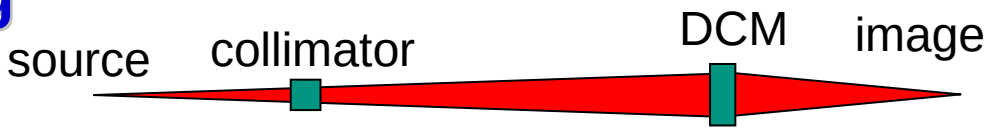
Sagittal Radius

S1=35m S2=8m

S1=18.5m S2=24.5m

energy(keV)	2nd crystal	R1, cm	R2, cm
4	Si111	643	1041
5	Si111	515	834
8	Si111	322	521
20	Si111	129	208
20	Si311	246	399
25	Si311	197	319
35	Si311	141	228
4	Ge111	617	999
5	Ge111	494	780
8	Ge111	308	499
20	Ge111	101	164

DCM: Sagittal Focusing



wiggler source

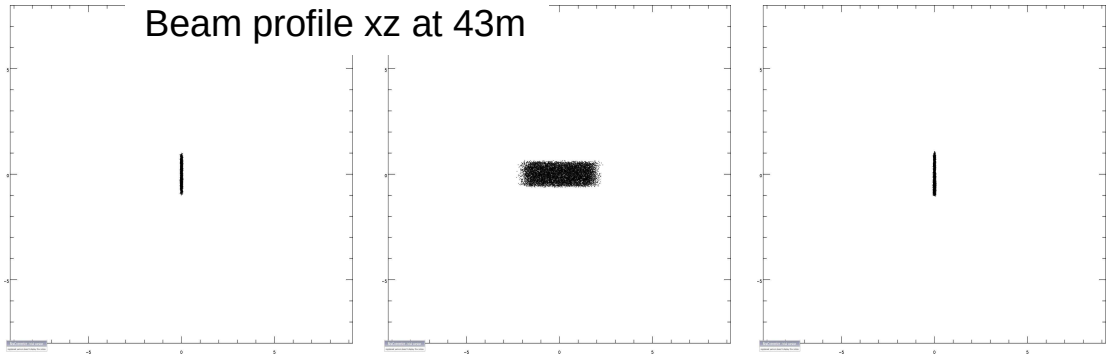
No	energy (eV)	mono	s1 m	M	image x×z, cm	image x'×z', mrad	E eV
1	8000±15	DCM Si111	35	0.23	0.047×1.66 376	11.2×0.386 376	11.6
2	8000±15	DCM Si111	18.5	1.32	3.10×1.02 362	2.08×0.394 362	11.6
3	25000±80	DCM Si311	35	0.23	0.050×1.02 40	3.00×0.172 40	33.3

Optimal magnification for sagittal focusing (large divergence source):

$$M = \frac{s_2}{s_1} = \frac{1}{3}$$

M. Sanchez del Rio, SPIE, 3448, 230-245, 1998

Beam profile xz at 43m



Optimal location for DCM: 32m from source point at 43m imaging point

CM

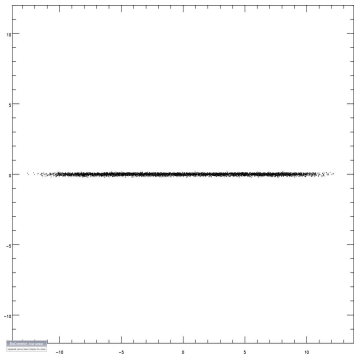
wiggler source, 1m long CM, 2.1mrad incident angle, Pt

No	energy (eV)	mono	image x×z	image x'×z'	E eV
1	8000±15	DCM Si111	20.0×0.175 186	2.96×0.010 186	1.1
2	25000±10	DCM Si311	16.6×0.182 422	2.49×0.078 422	1.7

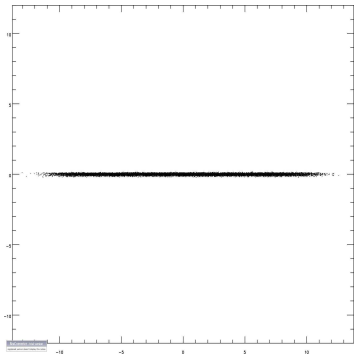
High energy resolution, high energy & high harmonics cut off Coherence deterioration, Beam vertical offset (9cm at 43m)

A correlation for horizontal and vertical size?

Beam profile xz at 43m



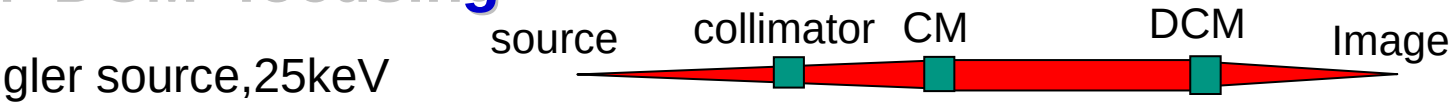
8keV

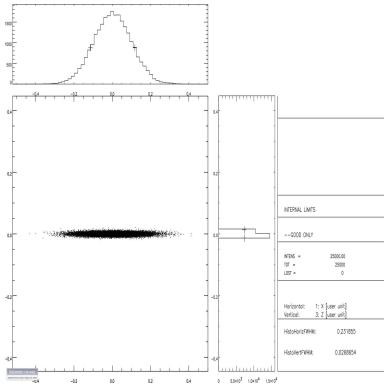


25 keV

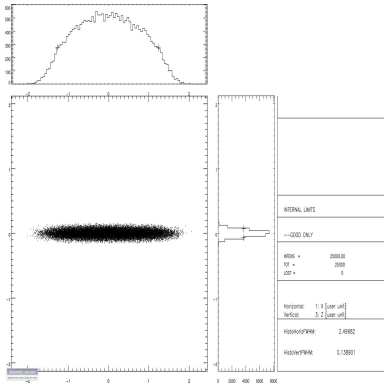
Source+CM+DCM+focusing

wiggler source,25keV

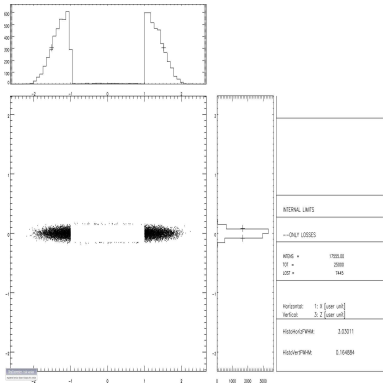




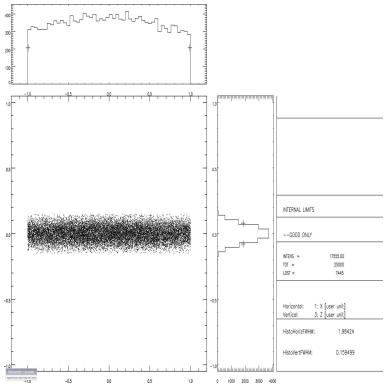
Beam profile xXz at source



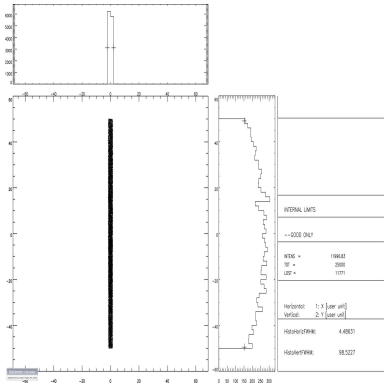
Beam profile xXz at pre-mask



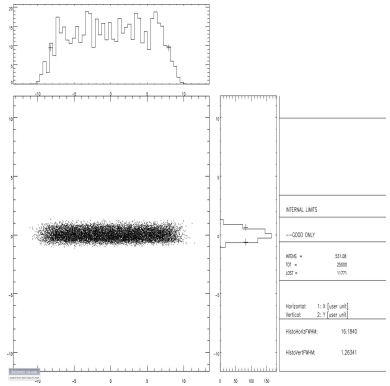
Beam profile xXz cut off by collimator (2.0×0.30 cm^2).



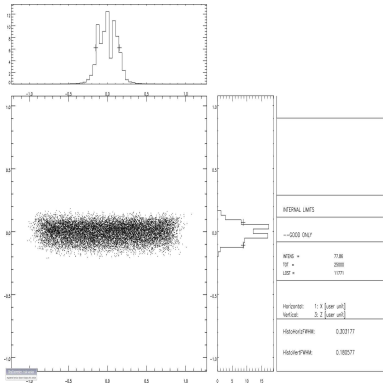
Beam profile xXz passing through collimator (2.0×0.30 cm^2).



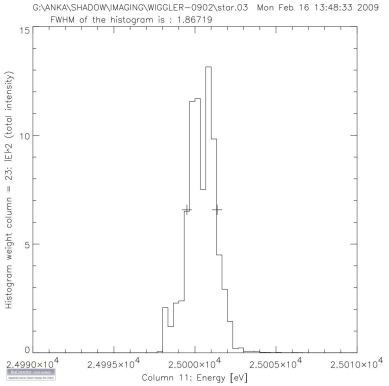
Footprint xXy on CM



Footprint xXy on DCM



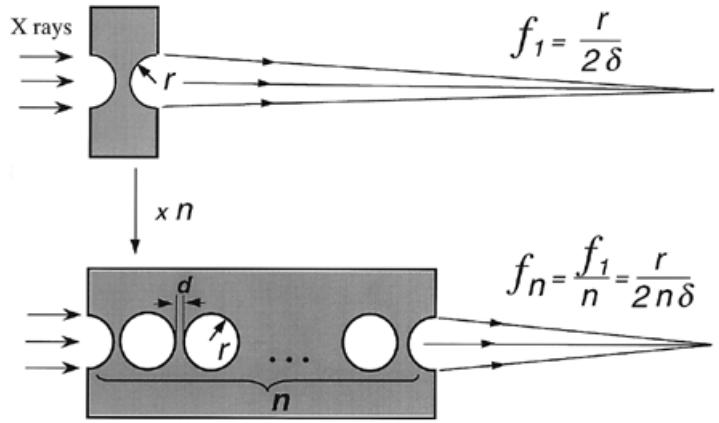
Focused beam profile xXz at 43m

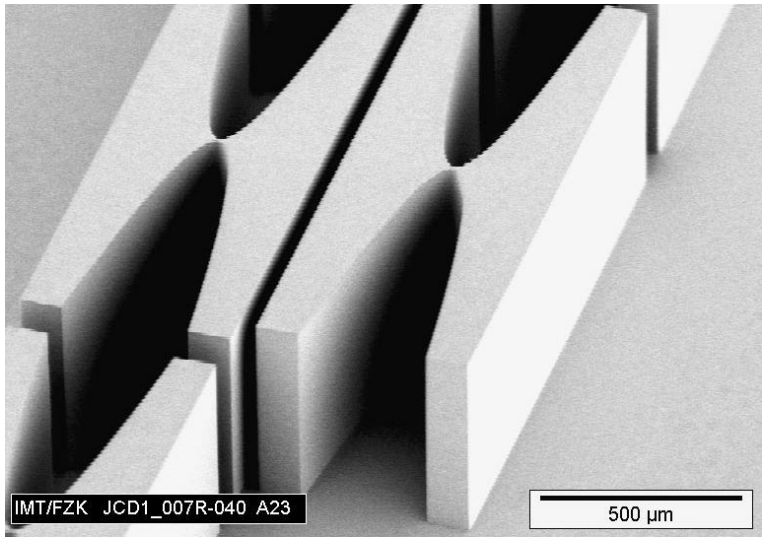


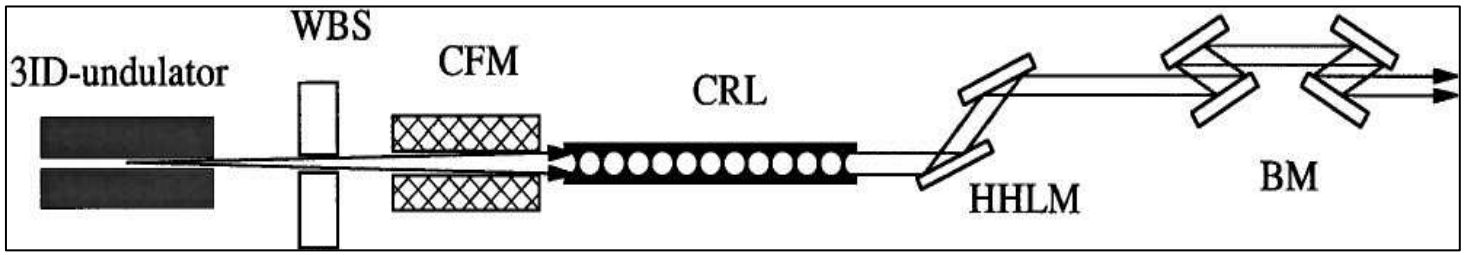
Energy resolution at 43m

Compound Refractive Lens (CRL)

CRL: Focusing, collimating and energy filtering



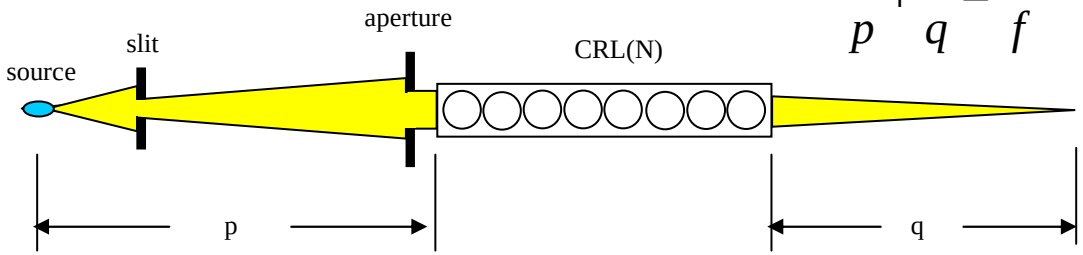


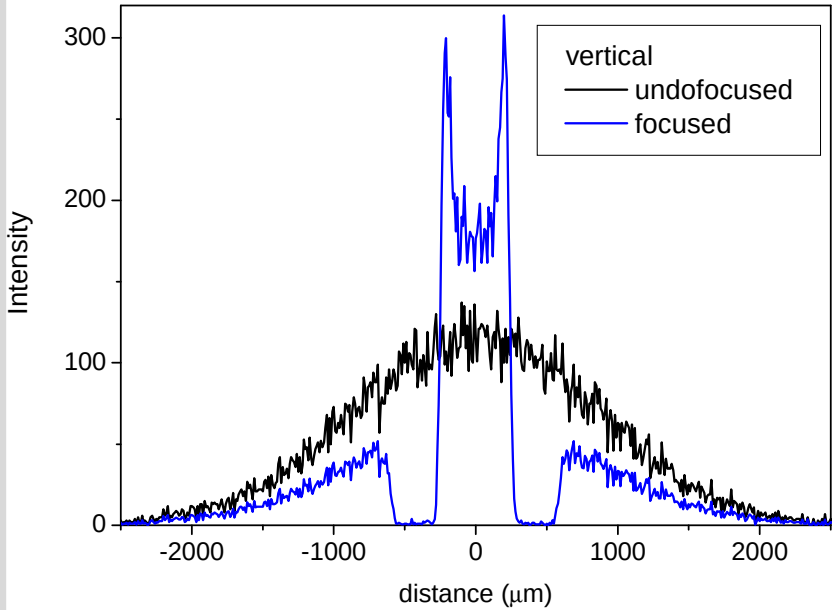


3ID undulator beamline, SRI-CAT, APS.
WBS: white beam slits; BM: brilliance meter; HHLM: high heat-load- monochromator.
CRL is combined with water-cooled collimating fixed mask (CFM). (Zhao et al, 2002)

CRL as a collimator or focusing element

$$\frac{1}{p}+\frac{1}{q}=\frac{1}{f}$$





XOP

Source size RMS: 0.045mm, 25keV
CRL: R=0.4mm, Be, d=0.1mm, p (source-CRL distance)=18m

Collimating
N=20, q=∞
focusing
N=61, q=9m

High energy resolution

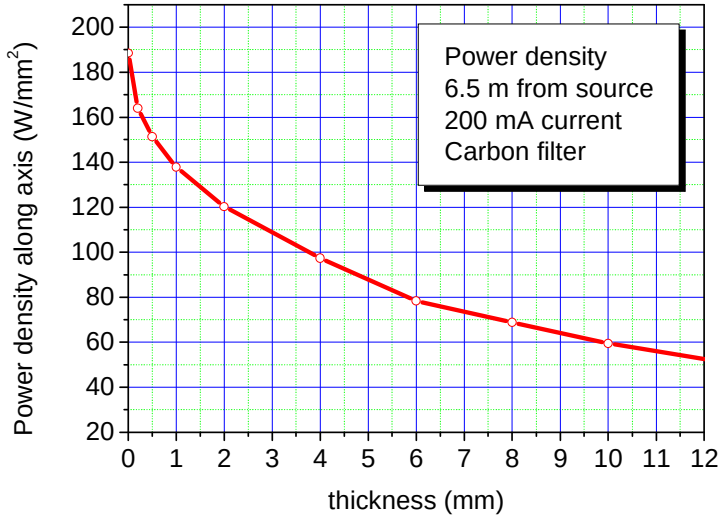
microscopy

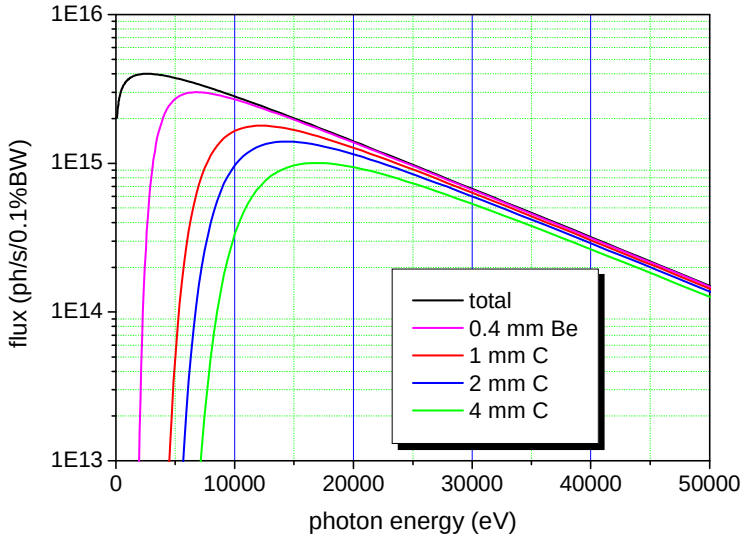
q=9m, Focused FWHM: 0.66mm, unfocused FWHM: 1.82 mm, nor. Intensity: 50%

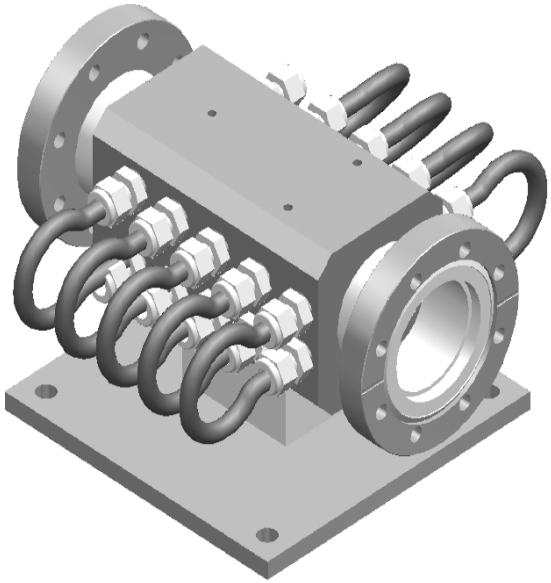
Water-cooling?

High power heat load

Total power
Wiggler: 12 kW, undulator: 850W







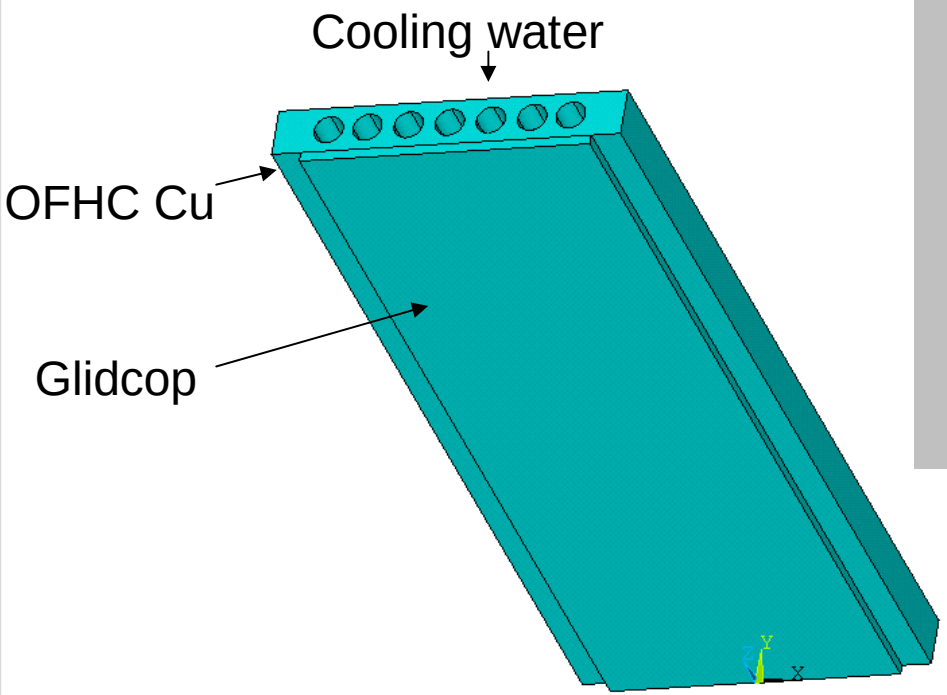
CVD diamond window,
NANO beamline, ANKA

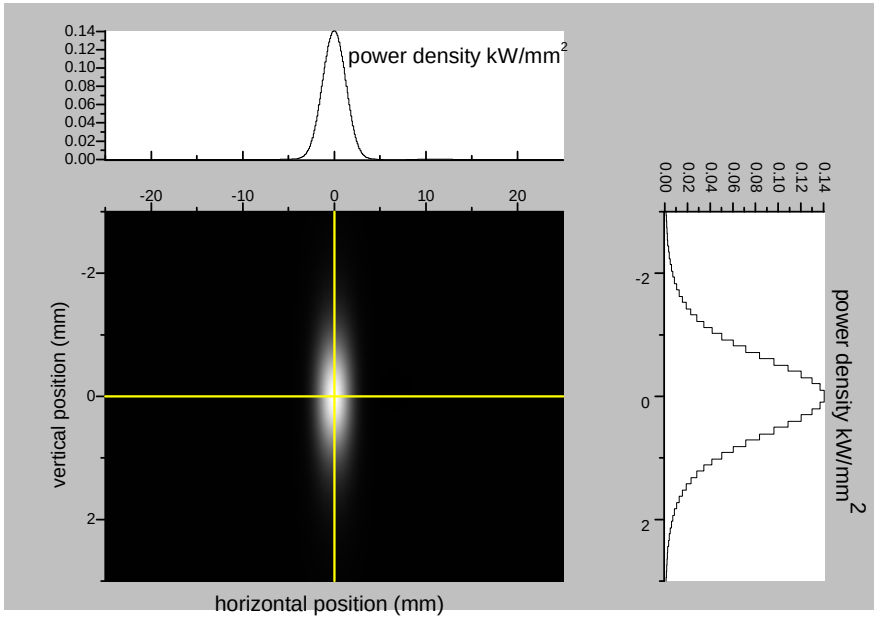
XOP

Photon shutter: Finite element analysis

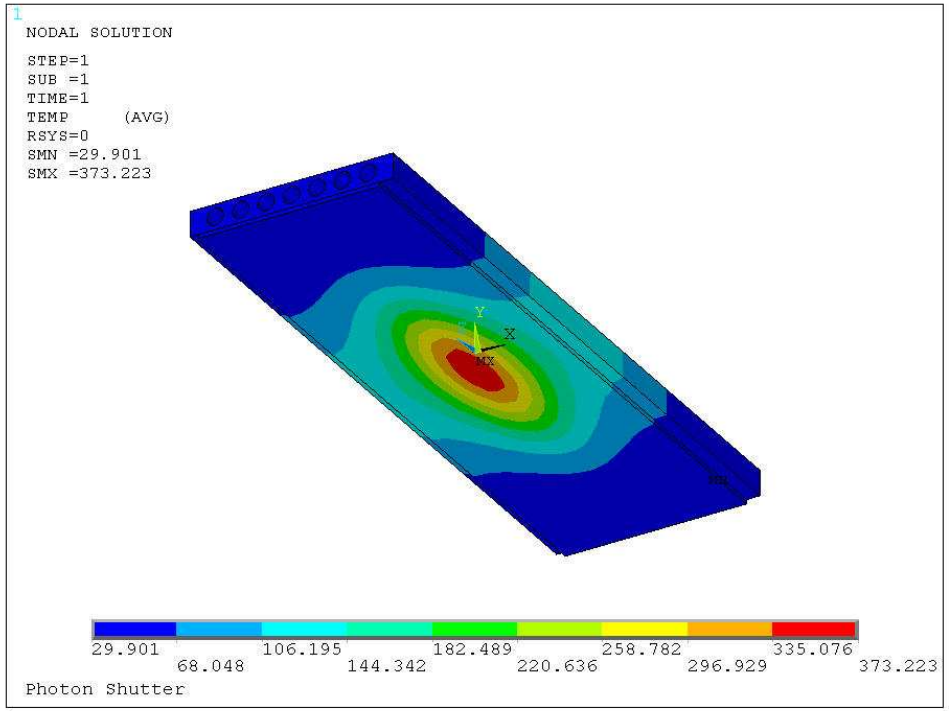
Power density: 150 w/mm^2, Gaussian function

Standard component at APS front end

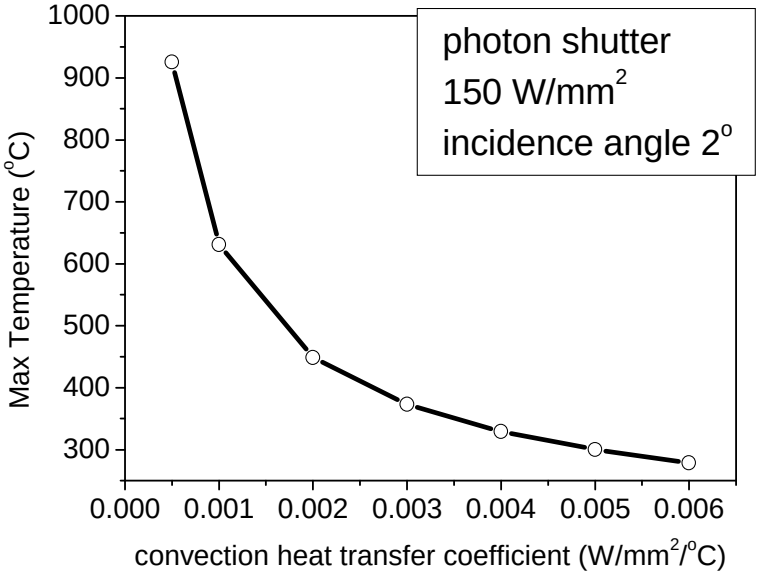


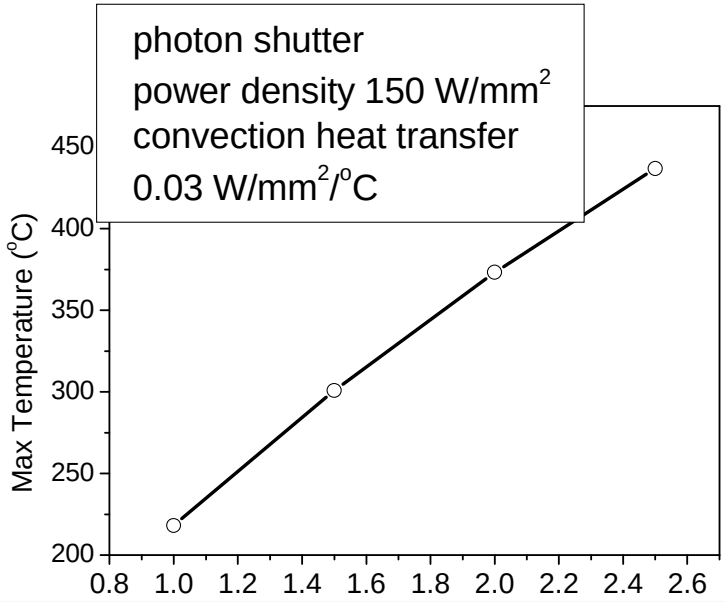


Photon shutter: FEA



ANSYS 11.0





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