X-ray Beamlines for the Recirculating Linac

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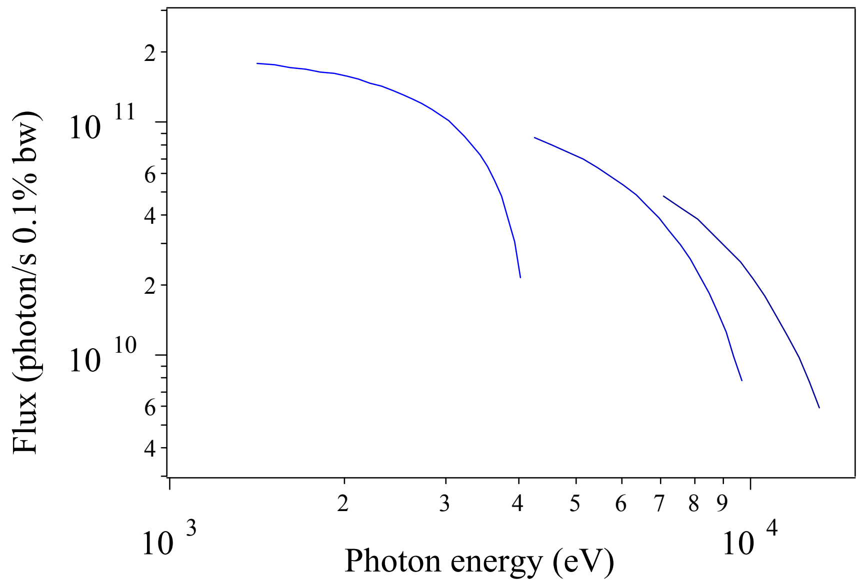
- Introduction
- Superconducting in-vacuum undulator
- X-ray pulse compression using asymmetrically-cut crystals
- Undulator beamline
- Bend magnet beamline

What is different about this x-ray source?

- Coordinate or angle correlation of the electron bunch
  - Need to use corelation to compress x-ray pulse or to display correlation onto a detector
- Single pass through photon production section
  - Can block halo of beam, use small gap undulators
- Low average current 10 μA, typical undulator power 0.2 W
  - Can use fused silica optics without cooling, cheap
  - Simpler front ends, cheap
- X-rays do not have to pass through an arc sector
  - The first optic can be close to the source, ~ 3 m
- fs laser system associated with beamlines, must be synchronized to x-ray pulses

Undulator description

- Parameters: length 2 m, λ_u 1.4 cm, B_{max} 1.5 T, gap 5 mm
- Advantage: short undulator period reaches higher photon energy at medium electron beam energy.
- Based on in-vacuum superconducting magnet design of Rossmanith. Such an undulator is under construction in Karlsruhe to be installed in the ANKA storage ring.

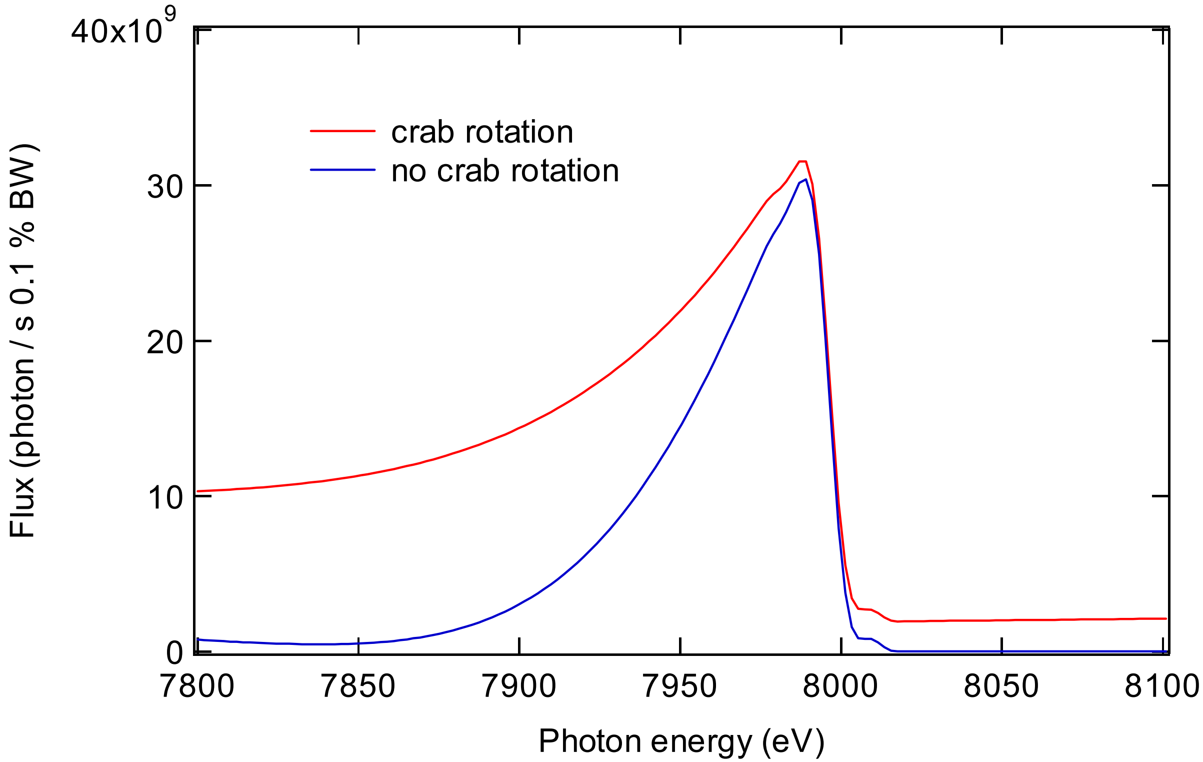


- Flux comparisons:
  Slicing bend magnet: 10^5 1/s
  Slicing undulator: 10^7 - 10^8 1/s

- Optimal flux from 100 - 8000 eV set by 2.5 GeV electron beam energy

Undulator spectrum

- Rotation of electron bunch broadens undulator harmonic, but the flux is same. Brightness is decreased by increased angular divergence (14 times).

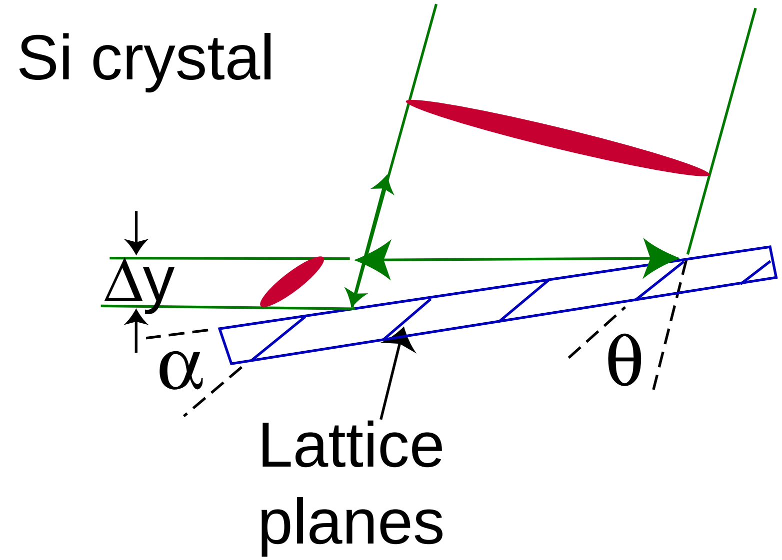


- If smaller undulator gap is possible, ~ 3 mm, could use in-vacuum permanent magnet undulator, better developed technology and cheaper

X-ray pulse compression with asymmetrically-cut crystals

- Optical path length Δl varies linearly with position Δy on the crystal:

$$\Delta l = 2\,\Delta y\,\frac{\sin\theta\,\sin\alpha}{\sin(\theta+\alpha)}$$

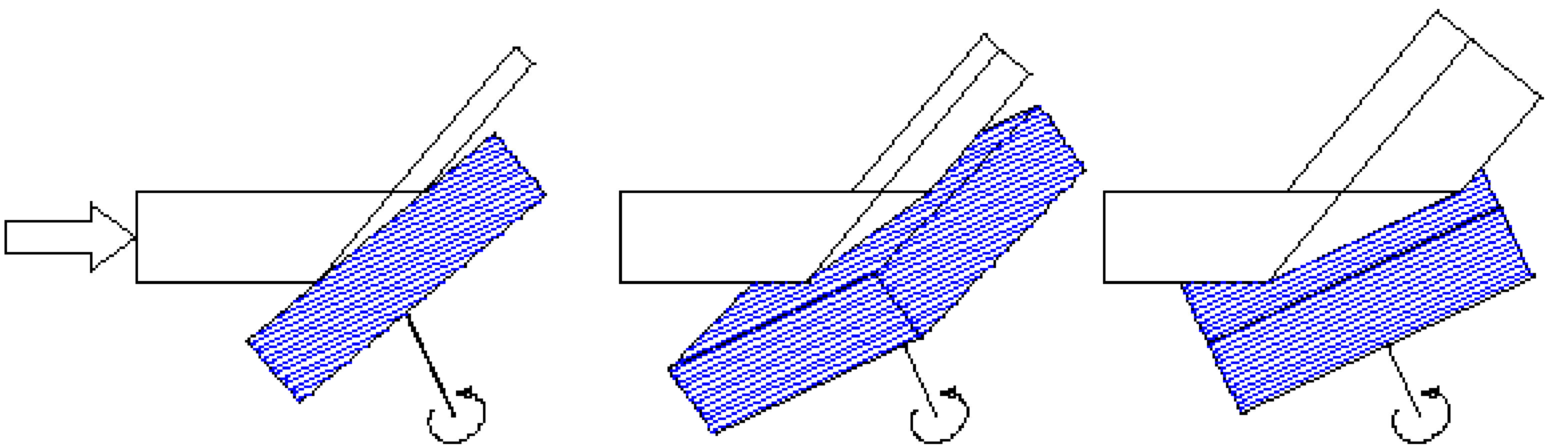


Crystals	λ	Δy	θ	α	Δl
Si(111)	1.5 A	1.5 mm	14.309°	2.1°	0.3 mm (1 ps)

Tuneability of x-ray pulse compression with photon energy

- Add rotation about axis normal to Bragg planes φ to rotation of Bragg angle θ

  ⇒ Variation of crystal asymmetry α keeping pulse compression fixed



φ = 0°
α = 15°

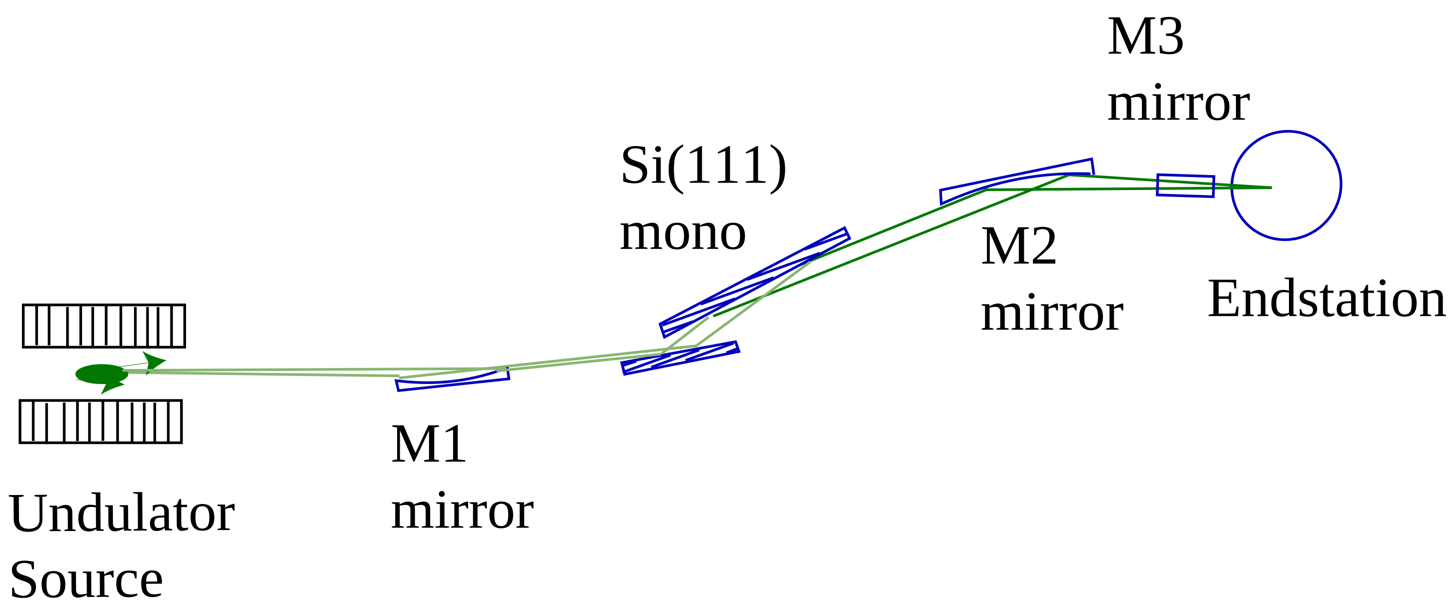
φ = 45°
α = 11°

φ = 90°
α = 0°

Limits to x-ray pulse duration

- Number of slices in angular correlation:
  - » bunch rotation 130 μrad / electron beam divergence 9 μrad = 14 slices (70 fs fwhm)
- X-ray divergence
  - » 9 μrad at 8 keV (100 fs fwhm total), increases with $\lambda^{1/2}$
- Penetration of x-rays into crystal:
  - » $N \lambda \sim 1$ μm (3 fs) for Si(111) at 8 keV

Undulator beamline layout



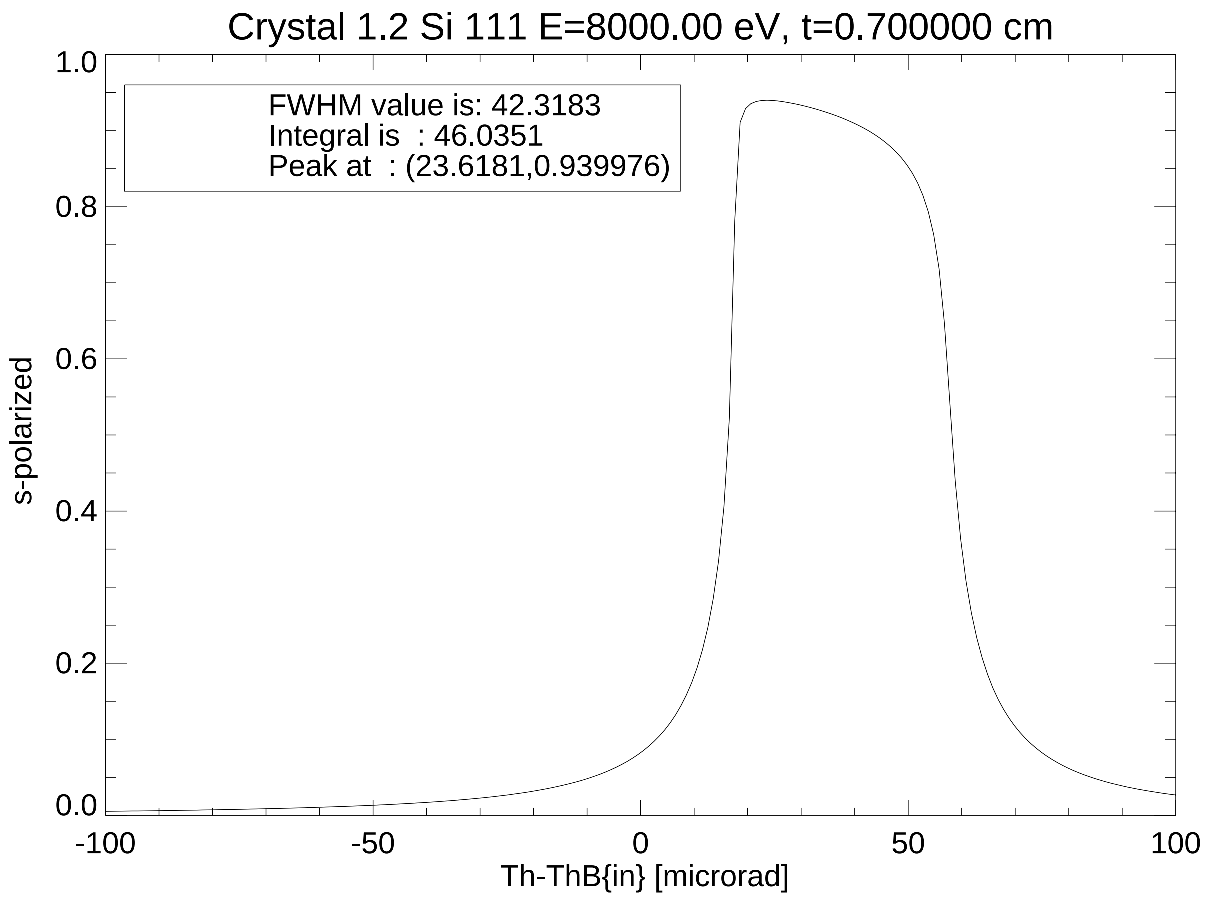
- Undulator source with angle correlation
- Collimating mirror produces spatial correlation at crystals
- Photon energy range 1 - 10 keV

Optical elements of undulator beamline

	Type	Coating and blank material	Dimensions (mm)	Radius (m)	Incidence angle(	Distance from source (m)	Slope error (µrad) Roughness (Å)
M1	Plane parabolic mirror	Pt-coated silicon	600 x 60	2000	89.7135	5	1 µrad 5 Å
X1, X2	Crystal	Silicon (111)	60 x 60	∞	75.6912 $\alpha = 2.1$	6	
M2	Plane parabolic mirror	Pt-coated silicon	1200 x 75	2000	89.7135	7	1 µrad 5 Å
M3	Plane elliptical mirror	Pt-coated silicon	300 x 60	228	89.7135	11.4	5 µrad 5 Å
Endstation						12	

- Length of beamline: 12 m

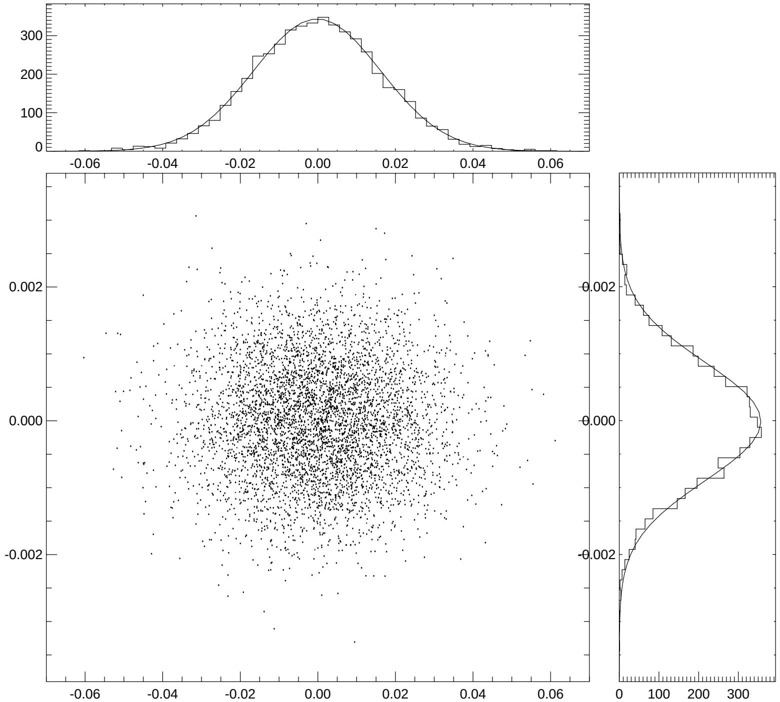
Asymmetric crystals

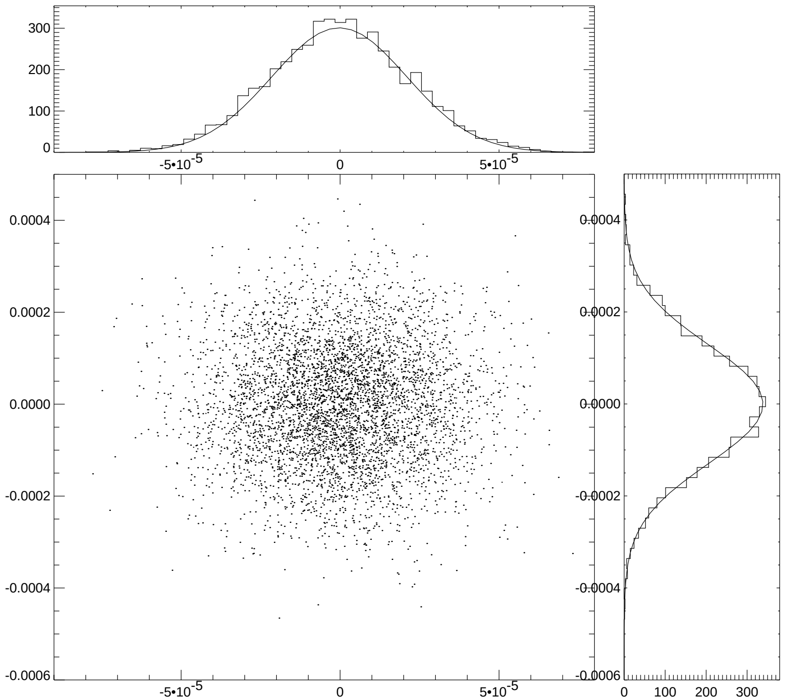


b = 0.75

ΔE = 1.3 eV

Source

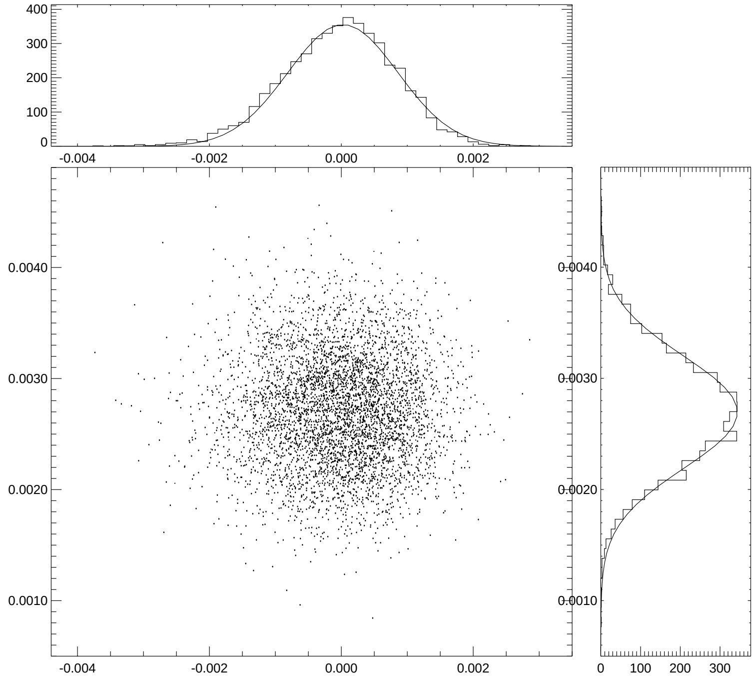


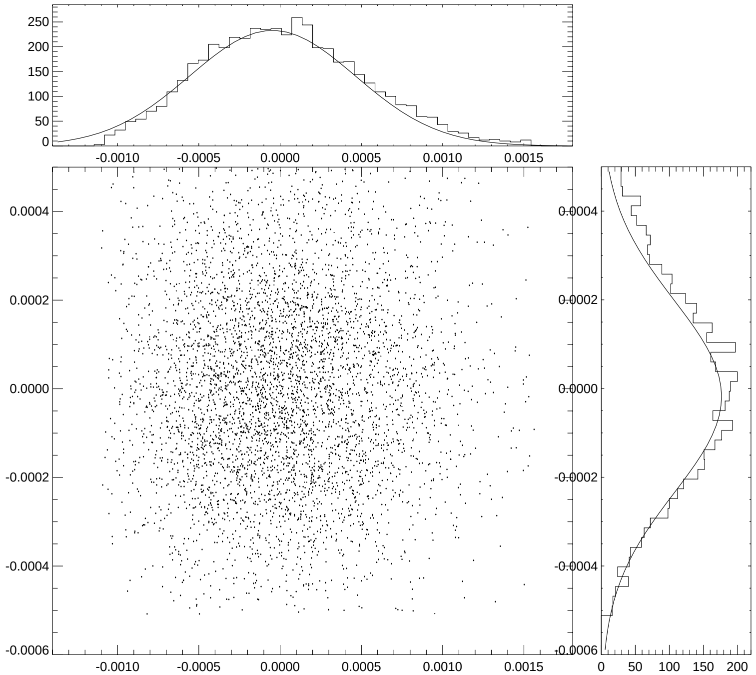


Source dimensions:
390 µm (h) x 20 µm (v)

Source divergence:
50 µrad (h) x 300 µrad (v, rotated)

Focus at the endstation



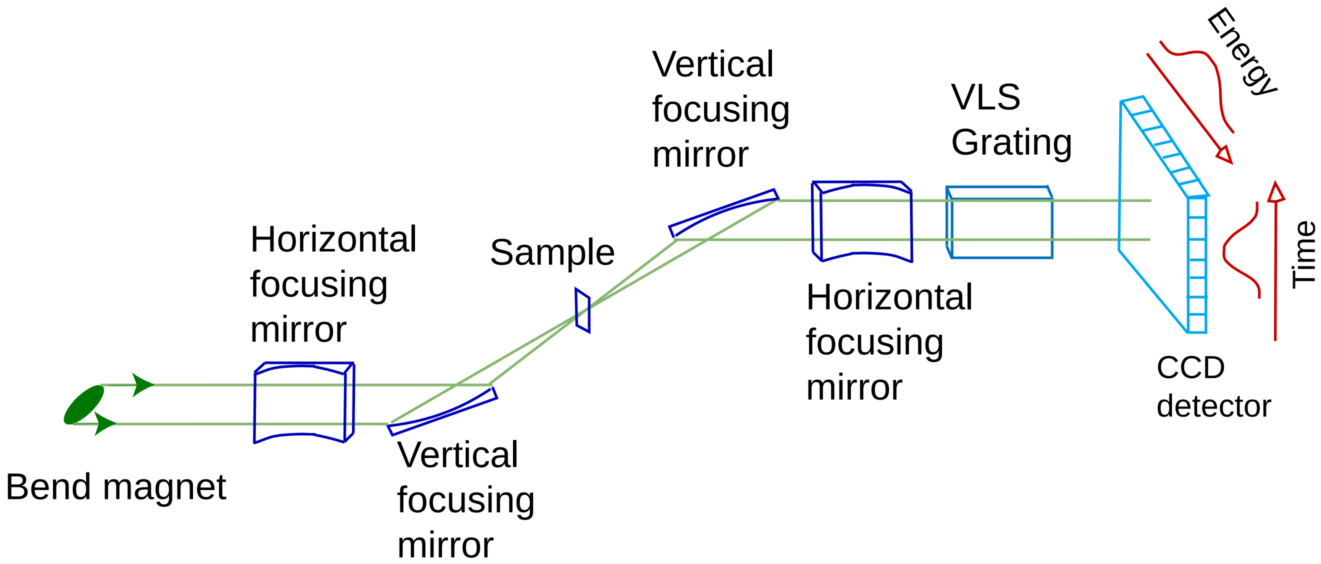


Focus dimensions:
20 µm (h) x 12 µm (v)

Focus divergence:
1.2 mrad (h) x 500 µrad

Bend magnet beamline layout

- Bend magnet source with spatial correlation
- Photon energy range 100 eV - 2 keV
- Flux 6 x 10^8 photon /s 0.1% BW



Future Work

- What is minimum gap for undulators?
- Quantitative evaluation of pulse broadening from crystals
  - » J. Wark has done diffraction calculations including time
- Reduction of x-ray pulse duration
- Completion of bend magnet beamline design
- Wiggler in arc sector: intense white beam source, time resolution ~ 1-2 ps