5th Annual SSRL School on Synchrotron X-ray Scattering
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\textbf{Beam Line Optics at SSRL}

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Beam Line Optics at SSRL

- **Synchrotron Radiation Sources**
- **Beam Line Optical Elements**
- **Beam Stabilizing Feedback Systems**
- **Flux vs. Energy Resolution**
Generic Synchrotron Components

photon beam line

bending

e-beam focusing elements

vacuum chamber

rf-cavity

injection system

Insertion device beam line

Courtesy of Tom Rabedeau
**Typical Beam Line Optical Concept**

- **Your Sample**
- **Mono Entrance Slits**
  - Variable vertical aperture defines mono acceptance.

- **Monochromator**
  - Double crystal
  - Si(111) or Si(220)
  - LN or water cooled

- **Mirror**
  - Cylindrical or toroidal figure
  - Rhodium-coated silicon
  - Harmonic rejection, power filter, collimating or focusing

- **Mirror Slits**
  - Variable gap
  - Defines BL acceptance.

- **Source**

- ~12 meters

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**SSRL**
**X-Ray Beam Line Sources**

**Bending Magnets** - a “sweeping searchlight”,
BLs 1, 2, 8, 14  $\varepsilon_c = 7.78$ keV

**Wiggler** - incoherent superposition of radiation from an array of magnet poles
BL6 $\varepsilon_c = 5.39$ keV,  BL7 $\varepsilon_c = 12.2$ keV

**Undulator**
- quasi-monochromatic spectrum consisting of fundamental and higher harmonics
- intensity $\sim (N_{\text{poles}})^2$
- narrow horizontal emission cone

**Bend Magnets & Wigglers**
- continuous spectrum with half-power point “critical energy”

$\varepsilon_c(\text{keV}) = 0.665 B(T) E^2 (\text{GeV})$
- intensity $\sim N_{\text{poles}}$
- broad horizontal fan
Source Characteristics (bends/wigglers):

- **source size:**
  - typical ID - 700um x 70um fwhm
  - bend - 380um x 120um fwhm

- **angular divergence:**
  - horizontal divergence is defined by slits to 1-3milliradians
  - vertical divergence is energy dependent - typical x-ray divergence ~250urad fwhm

- **broad energy spectra**

- **stability** - ~20um horz x ~5um vert (rms)

- **polarization** – dominantly horizontal

- **Frequent Fill coming June 7, 2010**
X-ray optical elements:

- Focusing and Collimating Mirrors
- Monochromators
- Apertures
- Filters
- associated Mechanical Alignment Systems

engineered, designed, assembled and installed by SSRL.
Fabricated by specialized optics shops in the United States, Japan, Germany, France.....
Focusing Mirrors

BL11-1 1.0m Si flat, side-cooled m0 mirror

BL10-2 1.2m Si vertically and horizontally focusing cylindrical m0 mirror
BL 7-2 m0 Vertically Collimating/Focusing Mirror

1.2 m long, central 0.8 m with optical figure and cooling
X-ray Mirrors
Reflectivity vs. Angle

Rh coated mirror surface

Adjustable low-pass filter for harmonic rejection.
Mirrors are either polished or bent to obtain desired figure.

- **elliptical figure provides point to point focusing**
- **parabolic figure collimates beam from source point or focuses parallel beam to a point**

BL mirrors at SSRL fall into two classes:

- **flats bent to approximate an ellipse or parabola to provide one dimensional beam shaping** (eg., BL7-2 & BL11-3)
- **cylinders bent into a toroidal figure to provide two dimensional beam shaping** (eg., BL2-1)

**Typical radii of curvature:**

- \( R_{tangential} = 2-8 \text{ km} \)
- \( R_{sagittal} = 35-100 \text{ mm} \)
Select a narrow energy band pass from the broad spectrum synchrotron source; typical crystal mono energy resolution $\sim 1e^{-4}$ (or better)

above left - LN mono crystal mount plate
above right – side scattering mono
lower right – LN mono first crystal with cooling channel bundle
Features of a Double Crystal Monochromator:

• Exit beam is parallel to entrance beam.
• Exit beam is tunable to reduce harmonic content by pitching the second crystal with respect to the first by ~10 microradians.
• Exit beam height varies sinusoidal with energy. Consequently, hutch table or downstream optics need to compensate for beam motion.
• Roll misalignment between the first and second crystal results in beam horizontal motion with energy.
X-ray Crystal Monochromators:
Improving Energy Resolution

• employ higher index monochromator crystal (e.g., Si(111) >> Si(220))
• use a collimating mirror upstream of monochromator to reduce vertical angular spread (e.g., BL7-2 M0 mirror can be used to collimate the beam at the expense of vertical spot size)
• reduce horizontal angular acceptance if monochromator is preceded by toroidal focusing mirror (e.g., BL2-1)
• reduce monochromator vertical angular acceptance by reducing monochromator entrance slit gap.
• **Mirror Pitch Feedback**
  Compensates for floor and beam line support frame motion driven by diurnal temperature changes and tidal forces.

• **Mirror Cooling Water Temperature Feedback**
  0.6 degree C temperature change in mirror cooling water is enough to degrade image quality. Feedback system holds to +/- 0.1 degrees C
Mirror Pitch Feedback at SSRL

Concept

- error signal obtained from position sensitive detector located near beam focus
- error signal used to control piezo high voltage via PI algorithm
- piezo provides mirror fine pointing control with typical full range of motion +/-~30urad
Mirror Pitch Feedback
Detector Cross Section

- 50V

Bias Electrodes

Beryllium w/Ti Coating

Stainless Steel Entrance/Exit Aperture
3mm vertical x 8mm wide

I to V

Upper Blade “A”

I to V

Lower Blade “B”
Mirror Pitch Feedback
Detector Mechanical Model
Mirror Pitch Feedback
LabView Control Panel
Mirror Pitch Feedback in Action Today
BL2-1 m0 Mirror

82.7 microns/volt
6.50 microradians/volt
Mirror Pitch Feedback in day-to-day operation

- **BL12-2**  
  Protein Crystallography- diurnal & foot-traffic motion.

- **BL2-1**  
  **2-Circle Diffractometer - 300um p-p diurnal motion.**

- **BL7-2**  
  6-Circle Diffractometer - 300um p-p diurnal motion.

- **BL4-2**  
  SAS – 400um p-p diurnal motion.

- **BL6-2**  
  Transmission X-Ray Microscope - “squirrelly” beam motion

- **BL10-2**  
  XAS Fluorescence Imaging - keep 150um vertical fwhm beam centered in 50 pin hole.

Mirror Pitch Feedback Future:

- **VUV Beam Lines**  
  In-vacuum MPF detector schemes currently in development, and implementation planned for November.
Mirror Cooling Water Temperature Feedback system developed by Valery Borzents of the Experiment Support Group
### Beam Line Flux and Energy Calculator

**Source:**
- Energy (GeV): 3.0
- Current (mA): 100.0
- Beam line:
  - Beam center (mm): 0
  - Beam horiz accept (mm): 1.5

**Calculated Flux:**
- Photon energy (eV): 8980
- Flux (cps/0.1%bp): 6.36E+12
  
  *(Wiggler/bend only!)*

**Filters:**
- He (mm): 16000, 0.935
- Be (um): 546, 0.922
- N2 (mm): 0, 1.000
- C (um): 15, 0.990
- Al (um): 0
- Cu (um): 0
- Ar (mm): 0
- N2 (mm): 0
- Cu (um): 0
- Air (mm): 100, 0.921
- Total transmission thru filters: 7.85E-01

**Si Monochromator:**
- d (rlu): 1
- k (rlu): 1
- l (rlu): 1
- Bragg theta (deg): 12.7147
- Theta cor in (deg): 12.7147
- Theta cor exit (deg): 12.7147
- Temperature (K): 393

**Vertical Acceptance:**
- Lim. vert. aperture (mm): 3.500
- Vert. accept. (ur): 333.3
- Aperture z (mm): 10500.0
- Frac. accept.: 0.9124

**Ion Chamber:**
- Ion cham length (mm): 17
- Gas 1 (He, N2, Ar, Al): 1, 1.0000
- Gas 2 (He, N2, Ar, Al): 0
- Ion cham current (A): 1.00E-07
- Gas 1 abs length: 236316.8
- Gas 1 abs: 1675.96
- Gas 2 abs length: 71.37
- Gas 2 abs: 71.37
- Air abs length: 1207.5
- E/Ec: 1.2003
- Sig_y' (urad): 97.5840

**Calculate Flux Corrected for Filters, Mono, & Accept.:**
- 5.43E+11 cps  ==> 5.43E+09 cps / mA
- Flux incident on ion chamber (from IC current): 2.41E+11 cps  ==> 2.41E+09 cps / mA

*Created by Tom Rabedeau and John Bagnasco of SRRL Beam Line Development Group*

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