Synchrotron Circulating Beam Parameters
and
Photons to Sample

Topics

- A Little about the Beam
- X-ray from Undulator and Bend (Wiggler) Magnet
- Spatial Aspects
- Propagation with/without focusing
- Flux and Brilliance
- Power
- Source Coherence

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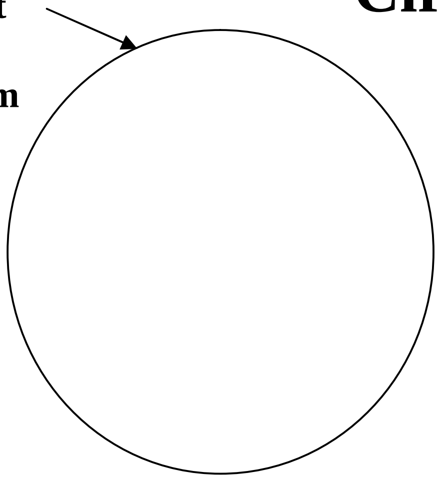
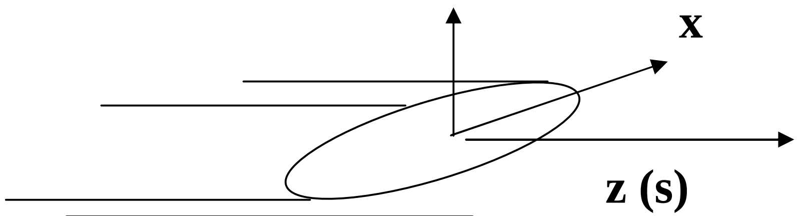
Circulating Beam

Golden Orbit (Determined by lots of beam optics)





Gaussian Beam Profile

$\sigma_x = \sqrt{\epsilon_x \beta_x \sigma'_x} = \sqrt{\epsilon_x / \beta_x}$

$\sigma_y = \sqrt{\epsilon_y \beta_y \sigma'_y} = \sqrt{\epsilon_y / \beta_y}$

Neglecting Dispersion η!

- Gaussian distribution in beam position (size) and trajectory angle around golden orbit
- Transverse -"Betatron" oscillations around orbit result in beam "Waists and Bulges"
- $\sigma_{x,y}$ and $\sigma'_{x,y}$ are functions of position on golden orbit
- Described by β_x and β_y which are functions of position on golden orbit (beta-functions)

- **Emittance**

$\epsilon_{x,y} \sim \sigma_{x,y} \times \sigma'_{x,y}$

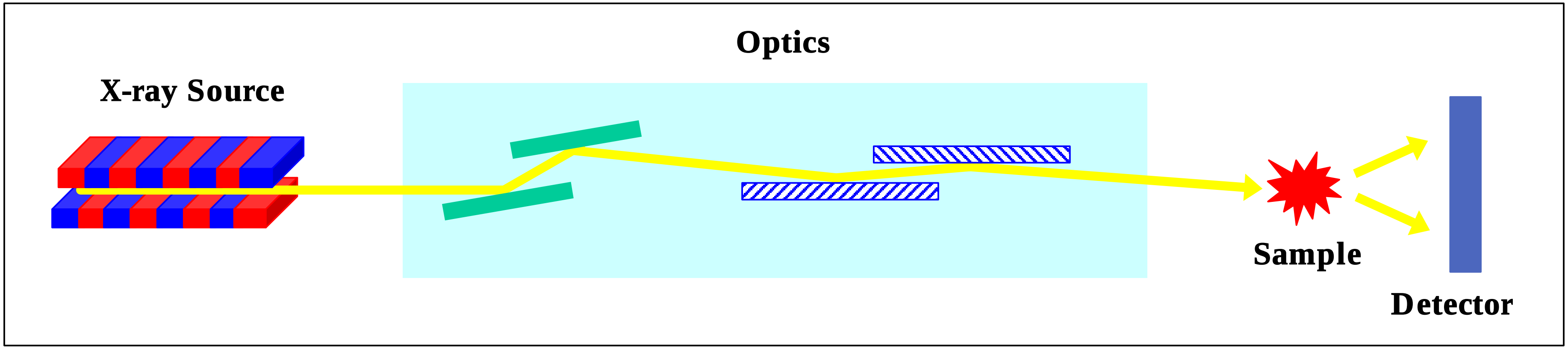
Constant Over Orbit

- ϵ_x and ϵ_y Invariant
- $\epsilon_x = (1-k)\epsilon$

$\epsilon_y = k\epsilon$

k is coupling parameter

Source, Optics, Sample



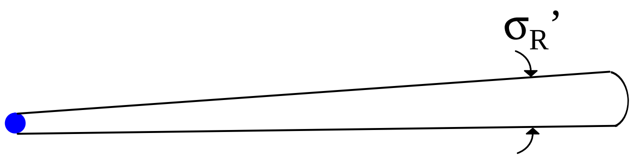
Insertion device (ID) x-ray source: Periodic structure of magnetic poles resulting in a periodic magnetic field over its length. The ID is characterized by the "deflection parameter", $K = 0.934\lambda_o B_o(T)$, with peak field, B_o, and magnetic period, λ_o.

The so-called wigger regime (broadband output) is characterized by $K \geq 5$ and the undulator regime (polychromatic output), by $K \leq 2$.

- Source required and beam delivery driven by science and experiment/sample
- Sample presents a "sample acceptance" determined by:
  - The effective area (sample size, apertures, etc.)
  - The angular convergence required over the effective area
  - The spectral purity ($\Delta E/E$) required
  - The required rate of Photons within the acceptance
- Sample acceptance related to **source** and **brilliance**

X-ray Source Properties

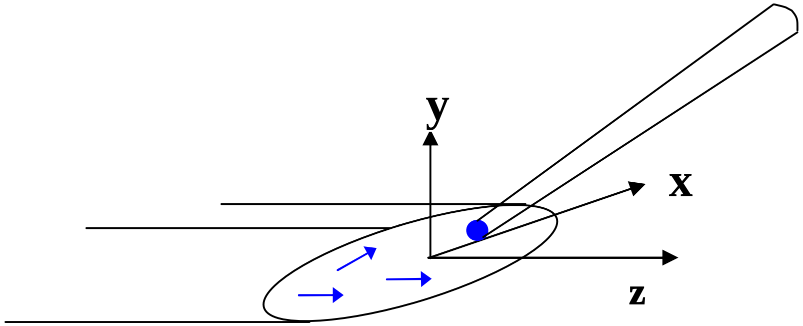
Single Particle Radiation



σ_R Radiative source size ~ 0 σ_R' Radiative angular divergence

Bend / Wiggler σ'_R ~ $1/\gamma$ ~ 73 μrad Undulator A σ_R' ~ 6 μrad

Coupling with Particle Beam Statistics



Particle beam parameters $\sigma_{x,y} = \sqrt{\varepsilon_{x,y}\,\beta_{x,y}}\quad \sigma'_{x,y} = \sqrt{\varepsilon_{x,y}/\beta_{x,y}}$

Radiative source parameters $\Sigma_{x,y} = \sqrt{\sigma_{x,y}^2 + \sigma_R^2}$ $\Sigma'_{x,y} = \sqrt{\sigma'^2_{x,y} + \sigma'^2_R}$

Some Numbers

Emittance: 3.0nm-rad; Coupling ~2%

	ID	**BM**
Source Size		
$s_{\mathbf{x}}$	239.5 µm	102.8 µm
$s_{\mathbf{y}}$	15.4 µm	35.1 µm
Divergence		
$s'_{\mathbf{x}}$	14.4 µrad	60 µrad
$s'_{\mathbf{y}}$	3.9 µrad	2.1 µrad
Beta Functions		
$b_{\mathbf{x}}$	14.40 m	1.94 m
$b_{\mathbf{y}}$	3.95 m	20.55 m

See http://www.aps.anl.gov/aps/frame_operations.html
For current APS storage ring operating parameters

X-ray Source Properties

Propagation and Focusing

- **For Bending Magnet (and Wiggler)**

  Propagation depends on σ'_R , $\sigma_{x,y}/R$, and $\sigma'_{x,y}$ and orbit (horizontal)

  $\sigma'_R \sim 1/\gamma \sim 73$ μrad much larger that beam parameters in vertical direction and dominates propagation

  For **Focusing**,

  beam 'size' σ_x and σ_y (nearly) determine focal spot size at sample and

  σ'_R (and focal element distance/angle) determine coverage AND final divergence of focused beam

- **For Undulator on APS**

Beam and undulator radiative properties are relevant

$$\Sigma_{x,y} \sim \sigma_{x,y} \sim 240\ \mu \text{ and } 15\ \mu$$

$$\Sigma'_x = \sigma'_x \quad \text{for the APS}$$

$$\Sigma'_y = \sqrt{\sigma'^2_y + \sigma'^2_R}$$

For **propagation** w/ no focusing, divergence **dominates**

For **focusing**

Beam size determines the **focal spot size**

Total **divergence** determines coverage and final divergence of focused beam

X-ray Source Properties

Some Numbers

Radiative (Diffraction Limited) Undulator Divergences

$$\sigma'_R = \sqrt{\lambda/2L}\ ,\quad \lambda \text{ is x-ray wavelength}$$

Harmonic (keV)	(1^{st}) 8	(3^{rd}) 24	(1^{st}) 12	(3^{rd}) 36
σ'_R (μrad)	6	3.5	4.6	2.7

Compare to

$\sigma'_x \sim 14$ μrad and

$\sigma'_y \sim 3.9$ μrad

In vertical direction, e-beam divergence ‘important’ only for higher harmonics.

X-ray Source Properties

Flux and Brilliance

- Flux, F, and On-Axis Brilliance (Brightness), B(0,0)

  Invariant under linear (good optics) transformations

- Related

  $B(0,0) = F/(4\pi^2 \Sigma_x \Sigma_y \Sigma'_x \Sigma'_y)$ in ph/(s mm^2 mrad^2 0.1%BW)

  Source Phase-Space Volume

X-ray Source Properties
Power

Spatial distribution of power depends on

$1/\gamma$ vertical

e-beam orbit horizontal

Very little dependence on ring emittance except for special cases of low-K undulators (weak field)

For bend magnet and wiggler,

x-ray and power envelopes approximately same

For undulator, x-ray envelope

$1/(10\gamma)$ vertical (approximately)

depends on e-beam orbit horizontal

Power management possible on undulator

With minimal loss of usable x-ray!

Coherence

Coherence between

A and B: Longitudinal determined by the spectral purity $\Delta\lambda/\lambda$

B and C: Transverse determined determined by source phase space volume

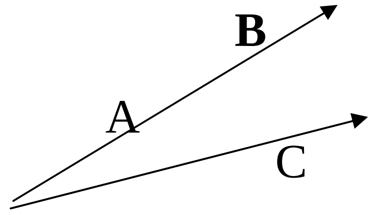
For an extended source of size σ and divergence σ' the largest phase volume which can emit with full spatial coherence is

$$V \sim 2\pi\, \sigma_R \sigma'_R = \lambda/2 \quad \text{For } \lambda \sim 1\ \text{Å},\ V \sim 5\ 10^{--11}\ \text{m-rad}$$

The coherent fraction of a beam, in one dimension, is given by

$$f \sim \lambda/(4\pi\, \Sigma_x \Sigma_{x'}) \sim \lambda/(4\pi\, \sigma_x \sigma_{x'})$$

Current parameters for Undulator A are



σ_x = 240 microns σ_y = 15 microns

$\sigma_{x'}$ = 14 microradians $\sigma_{y'}$' = 3 ~ 5 microradians

y coherence fraction ~ 0.1 ! (a lot)

x coherence fraction ~ 0.001

The smaller the $\varepsilon_{x,y}$ the larger the coherence factor!