Measurement of the transverse dimensions of the beam with submicron accuracy to determine the emittance of the SKIF storage ring

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Outline

1. The SKIF storage ring design parameters
2. Features of SR from bending magnets for the SKIF storage ring
3. Conceptual design of the diagnostic system

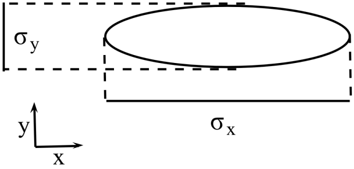
The SKIF parameters

Several design parameters of the SKIF storage ring:

Energy	3 *GeV*
Maximum beam current	400 *mA*
Circumference	476.14 *m*
Horizontal emittance (0 *mA*, no IDs)	75 *pm*
Periodicity cells	16
Number of beamlines in cell	3

Transverse beam characteristics

The emittance is a key parameter in accelerator machine



Assuming that the intensity distribution of the electron on the transverse plane is Gaussian, the beam size is defined as the standard deviation of the electron distribution

$$\Downarrow$$

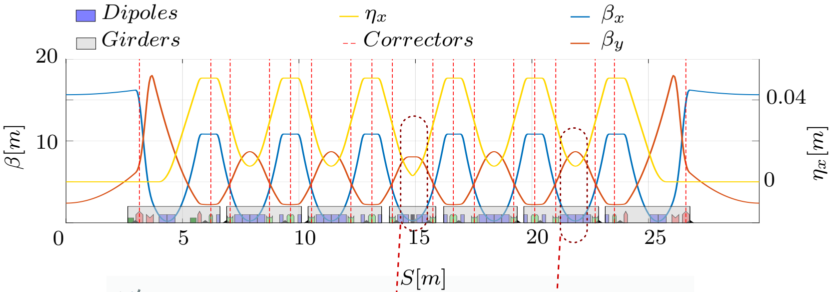
σ is measured

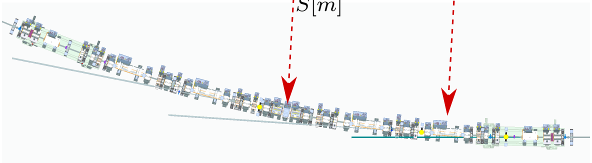
$$\Downarrow$$

$$\epsilon = \frac{1}{\beta}\left(\sigma^2 - D^2\left(\frac{\Delta E}{E}\right)^2\right)$$

Features of SR from bending magnets

Synchrotron radiation beam lines from superperiod bending magnets



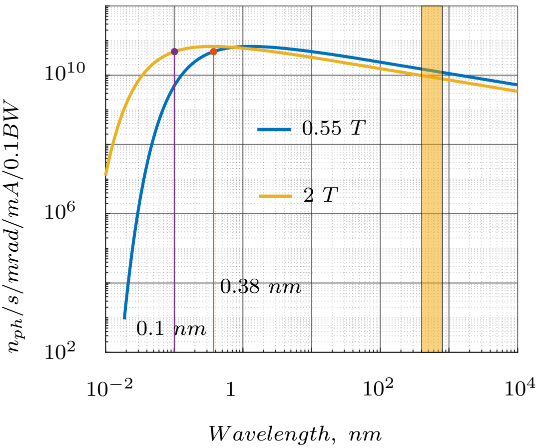


The optical part of the SR spectrum will be output from two bending magnets with «weak» and «strong» field

Features of SR from bending magnets

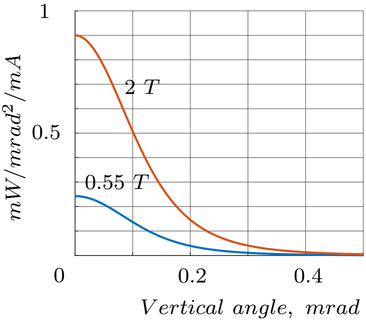
Synchrotron radiation spectrum from superperiod bending magnets

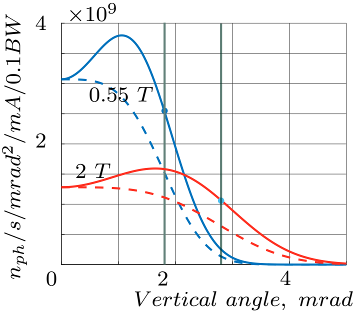
The radiation spectrum integrated from vertical angle



Features of SR from bending magnets

Features of SR from bending magnets





The total power of SR from «weak» magnet: $P_{sr} = 63\ [mW/mrad/mA]$.
The full design beam current $P_{sr}(400\ mA) = 25\ [W/mrad]$.

For a «strong» magnet $P_{sr} = 234\ [mW/mrad/mA]$
and $P_{SR}(400\ mA) = [93\ W/mrad]$.

SR imaging monitors

Limits on resolution

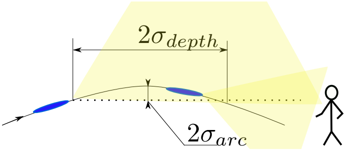
$$\sigma_{diff} \approx 0.25\sqrt[3]{\frac{\pi}{6}\lambda^2\rho},$$

$$\sigma_{arc} \approx \frac{1}{2}\sqrt[3]{\left(\frac{3}{4}\frac{\lambda}{\pi}\right)^2\rho},$$

$$\sigma_{depth} \approx \sqrt[3]{\left(\frac{3}{4}\frac{\lambda}{\pi}\right)^2\rho},$$

$$\sigma_{rad} = \sqrt{\sigma_{arc}^2 + \sigma_{diff}^2 + \sigma_{depth}^2},$$

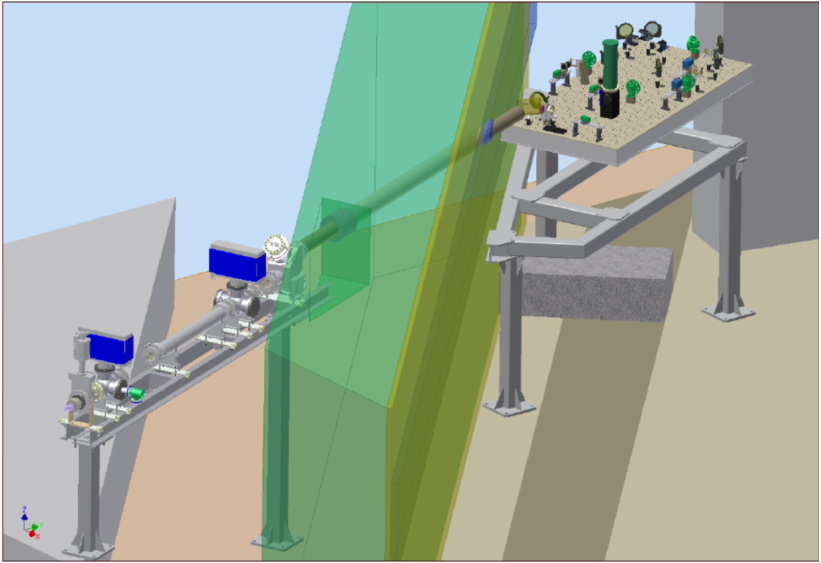
$$\sigma_{vert} = \sqrt{\sigma_{diff}^2 + \sigma_{depth}^2}.$$



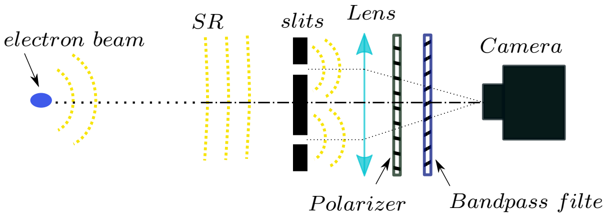
The SR imaging limits (for wavelength 450 nm)

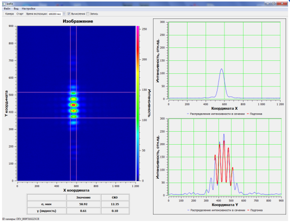
Limits in μm	«weak» magnet	«strong» magnet
σ_{diff}	31	20
σ_{arc}	30	19
σ_{depth}	59	38
σ_{rad}	73	47
σ_{vert}	67	43

Optical observation system of the Kurchatov acceleration-storage complex



SR Non-imaging: interferometer



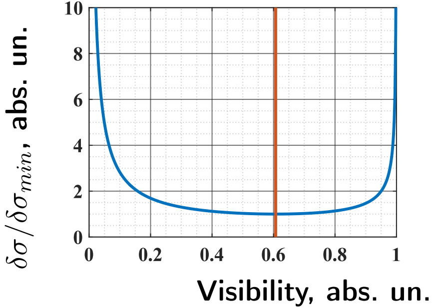


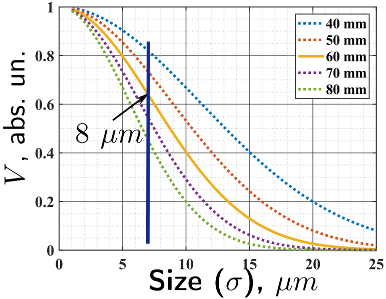
- Double slit Young interferometer adapted for beam size measurements by T. Mitsuhashi (see WEIC02)
- Successfully used on the Kurchatov acceleration-storage complex (ASC) (optical observation system of the «Siberia-2» accelerator)

$$\sigma = \frac{\lambda L}{\pi D}\sqrt{\frac{1}{2} ln\left(\frac{1}{V}\right)},$$

λ – SR wavelength; D – slits distance; V – visibility; L – Distance from the source.

SR Non-imaging: interferometer





$$V = \frac{I_{max} - I_{min}}{I_{max} + I_{min}},$$

$$\Delta\sigma(V) = \frac{\lambda L}{\pi D} \frac{1}{V \cdot \sqrt{8 \cdot ln\left(\frac{1}{V}\right)}} \cdot \Delta V.$$

$$D = \frac{\lambda L}{2\pi\sigma_y} = \frac{450\ [nm] \cdot 7\ [m]}{2\pi \cdot 8\ [\mu m]} \approx 60\ [mm],$$

$$D^w_{max}(L) \approx 2\psi_{rms} \cdot L \approx 25\ [mm],$$

$$D^s_{max}(L) \approx 2\psi_{rms} \cdot L \approx 40\ [mm],$$

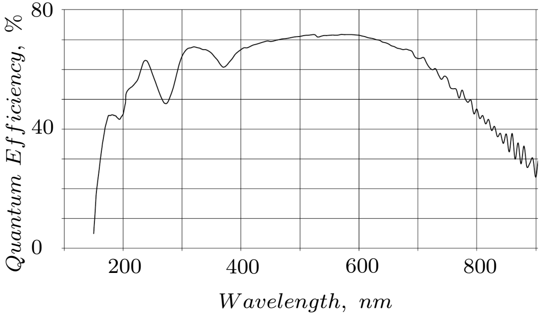
$$D = \frac{\lambda L}{2\pi\sigma_y} = \frac{250\ [nm] \cdot 7\ [m]}{2\pi \cdot 8\ [\mu m]} \approx 35\ [mm]$$

Imaging Monitors

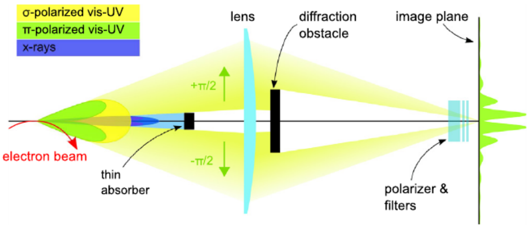
Technical characteristics of the UV CMOS camera (Photon Focus MV4-D1280U-H01-GT)

Free run frame rate, full resolution	up to 140 fps, 10 bit with 10 GigE
Optical area	9.47×7.58 mm, 12.13 mm diagonal
Active Pixels	1280(h)×1024(v)
Spectral response	150 – 1020 nm

The sensitivity of the sensor allows recording both deep ultraviolet and visible wavelength range.



SR Non-imaging: Vertical Polarization Monitor



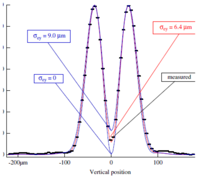


Fig. 8. Measured (marks) and predicted (three solid lines) vertical image profiles. $\lambda = 364$ nm; acceptance angles 3.9 mrad$_H$/9.0 mrad$_V$. Machine conditions: 400 mA in top-up operation; tuned skew quads.

A. Andersson et al., Nuclear Instruments and Methods in Physics Research A 591 (2008) 437–446

- Essentially an interferometer, but using the vertical polarization component;
- Weaker than horizontal polarization component, BUT has natural zero at center, due to phase reversal, at all wavelengths;
- Double-lobed structure of vertical component provides a «natural» double-slit interferometer even with no limiting aperture;
- Resolution limit in principle similar to that of SR interferometer;
- Beam size measurements of 6 microns demonstrated at Swiss Light Source.

Conclusion

• It is impossible to measure the transverse dimensions of the beam from its image in the visible SR range;
• SR interferometer will be used to accurately determine the transverse dimensions of the beam;
• To ensure reliable measurements, SR with a short long wave is used;
• Measurements of the vertical beam size will be duplicated by the SR π monitor.

Thank You for attention!