Optical Diffraction Radiation Diagnostics

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Introduction

Measuring both the beam size and position close to the interaction point in a collider is very useful in order to achieve a reasonable luminosity which requires that both beams are centered on one another. In addition, a beam size measurement in the interaction region is very useful in correcting optical errors in this region and achieving the desired spot size at the interaction point. Therefore, it is extremely necessary to control the beam size at every stage of an accelerating process. Optical diffraction radiation is a good candidate to measure these properties in a noninvasive manner.

Optical Diffraction Radiation

There is a great interest in the ability to monitor high energy particle beams transverse size in a non-intercepting manner:

- Modern accelerators preclude the use of invasive techniques like transition radiation monitors due to a significant emittance growth

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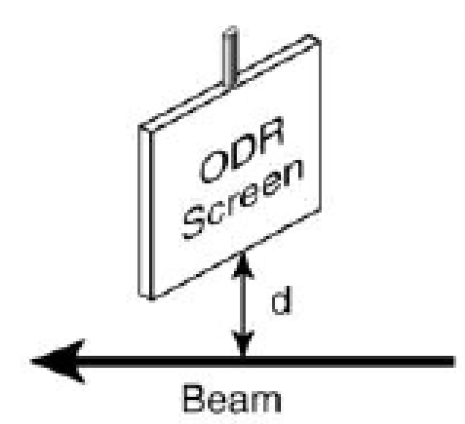
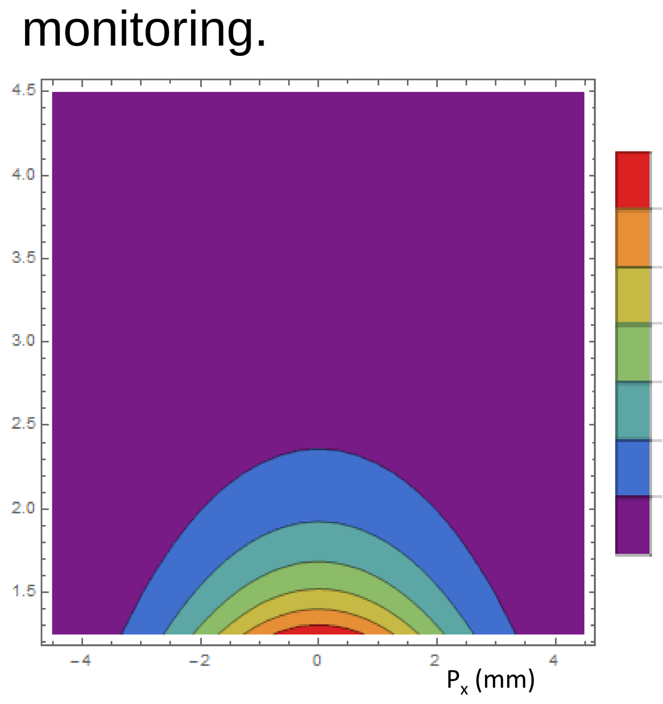
- Successful operation of next generation high energy machines depends on a low damage due to the beam. Material degradation would limit target lifetime.

What is ODR? A particle moving close to the edge of a metal plate induces currents changing in time producing radiation. Optical diffraction radiation is the radiation emitted when a particle moves near the edge (at a distance *d* from the beam center) of a conducting material without directly interacting with it. This is an effect that can be used for beam size monitoring.





Differential spectral intensity from a given point in the target.

$$\frac{dI}{d\omega} = \frac{\eta}{2\pi\sigma_x\sigma_y}\iint K_1^2(\alpha\rho)e^{-x^2/2\sigma_x^2 - y^2/2\sigma_y^2}dxdy$$

$$\eta = \frac{q^2\alpha^2 N}{\pi^2\beta^2 c} \qquad \alpha = \frac{2\pi}{\gamma\lambda} \qquad \rho = \sqrt{(p_x - x)^2 + (p_y - y)^2}$$

(x,y) = position in the beam — σ_x, σ_y are beam sizes

(p_x,p_y) = position in the target — ϒ = Lorentz factor

K_1 is the modified Bessel function — λ = wavelength

What are the advantages of using ODR to measure beam properties? If feasible, this would be a complementary method of measuring important beam properties in present and future accelerators. Since the particles do not directly interact with the target does not disturb the beam.

Where do we want to use ODR? Experimental study has been performed on the ODR at the 7-GeV beam of the Advanced Photon Source and elsewhere. We want to use this technique to find both vertical and horizontal beam sizes with APS parameters and try to use the results in a future high energy proton collider (FCC-hh). Key condition 2πd/ϒλ < 1.

Parameter	APS	FCC-hh
	Electron	Proton-Proton
Energy	7 GeV	50 TeV
ϒ	13 700	53 300
2πd/ϒλ	0.68	0.21

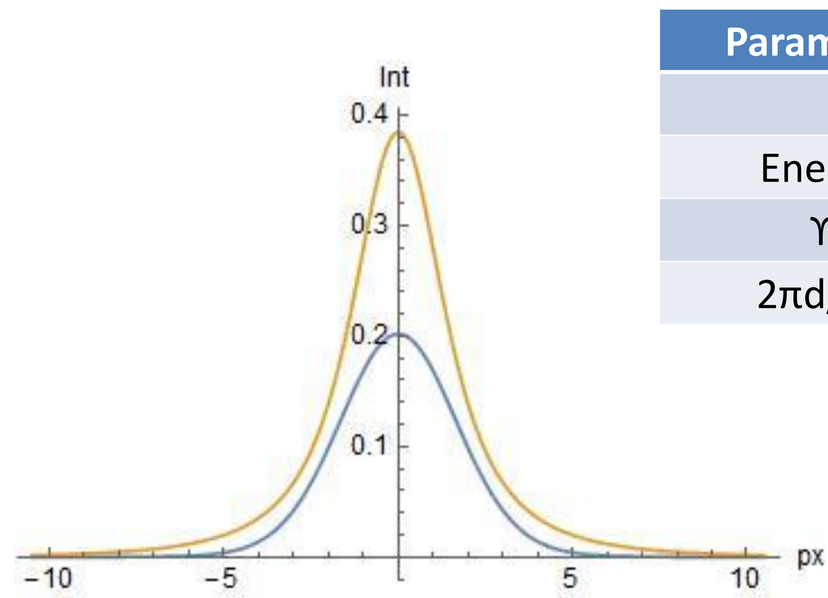
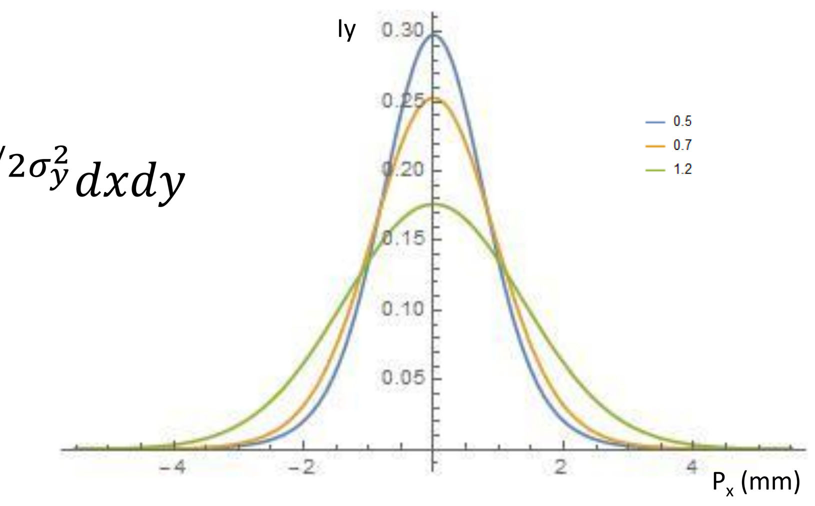


Figure shows the comparison between the total intensity with APS parameters (blue) and FCC-hh (orange).

Fitting The Perpendicular Component To A Gaussian

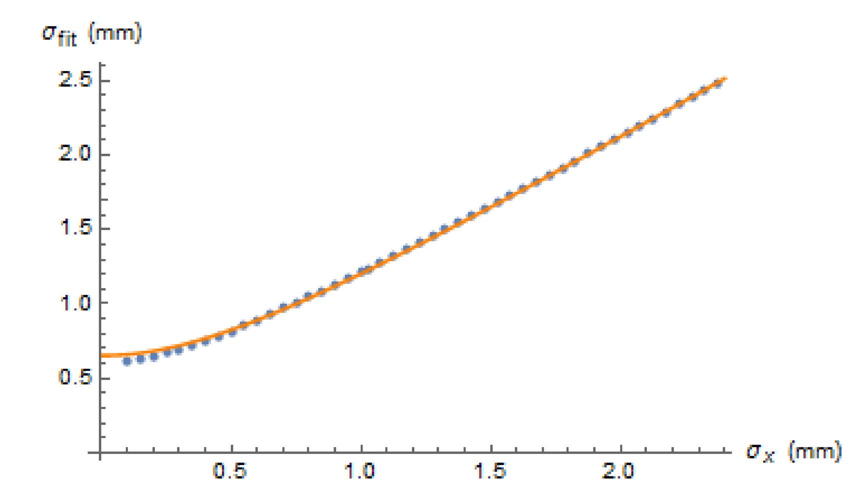
Perpendicular polarization of the intensity:

$$I_y = \frac{\eta}{2\pi\sigma_x\sigma_y}\iint \frac{(d-y)^2}{\rho^2}K_1^2(\alpha\rho)e^{-x^2/2\sigma_x^2 - y^2/2\sigma_y^2}dxdy$$



Perpendicular component is shown to the right for σ_y = 0.2mm and three different values of σ_x. This component can be fitted to a Gaussian, whose rms is sensitive to the impact parameter *d* and to both beam sizes as:

$$\sigma_{fit}^2 = \sigma_x^2 - k(d)\sigma_y^2 + \sigma_0^2(d)$$



Plot above shows σ_{fit} as a function of σ_x for APS parameters with σ_y = 0.2mm and d = 1.25mm

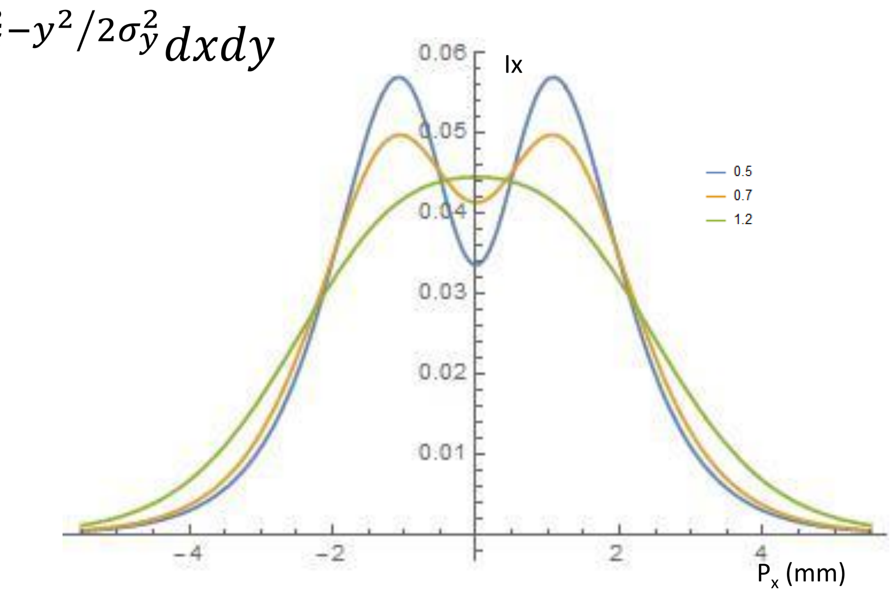
Where *k* is a parameter depending on *d* and σ_0 is the minimum resolution of the method, determined by the point spread function (PSF) that is, when σ_x and σ_y tend to zero. In this case the I_y profile is given by:

$$I_{y,PSF} = \frac{d^2K_1^2(\alpha\sqrt{p_x^2 + d^2})}{p_x^2 + d^2}$$

Taking The Ratio I_{min}/I_{max} In The Parallel Component

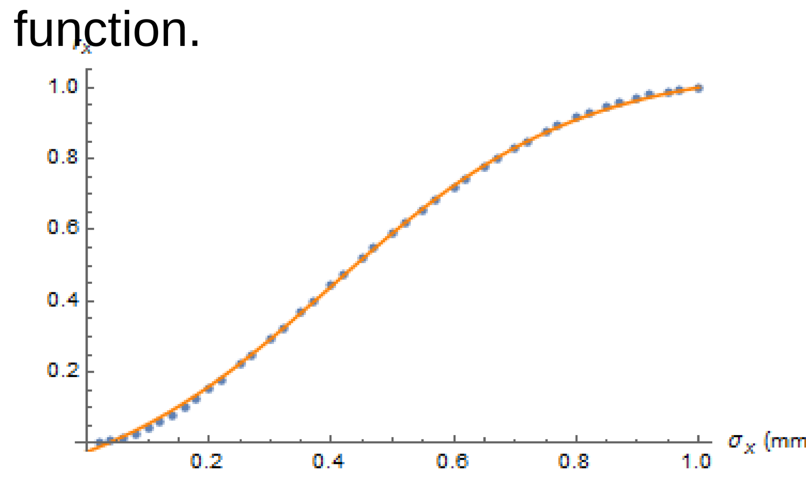
Parallel polarization of the intensity:

$$I_x = \frac{\eta}{2\pi\sigma_x\sigma_y}\iint \frac{(p_x - x)^2}{\rho^2}K_1^2(\alpha\rho)e^{-x^2/2\sigma_x^2 - y^2/2\sigma_y^2}dxdy$$



Parallel component is shown to the right for three different values of σ_x. This profile has two symmetrical peaks and one local minimum at p_x = 0 when σ_x < 1mm. For larger σ_x both peaks join in a central one. When there is a minimum at the center we take the ratio $r_x = I_{min}/I_{max}$ for different values of σ_x and fit them to a hyperbolic function.

$$r_x = p(\sigma_y) + a\tanh[q(\sigma_y)\sigma_x + b\sigma_y^2 + c]$$



Where *p* and *q* are second and fourth order polynomials on σ_y respectively, and *a, b, c* are parameters that depend on *d*. Figure shows the results for values of *d* = 1.25mm and σ_y = 0.2mm.

Conclusions

ODR seems to be a good method for beam diagnosis in a noninvasive manner for present colliders and a future very large hadron collider. Our key results were:

- We found a relation between σ_0, σ_x, σ_y and σ_{fit} from the perpendicular profile.
- We found a relation between r_x, σ_x and σ_y from the parallel profile.
- Both beam sizes can be measured with a single target.
- ODR Intensity in hadron collider will be larger than in the APS.

References

A. H. Lumpkin *et al.*, Near-field imaging of optical diffraction radiation generated by a 7-GeV electron beam, Phys. Rev. ST Accel. Beams **10**, 022802 (2007).

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