High energy micron electron beam non-invasive diagnostics based on diffraction radiation

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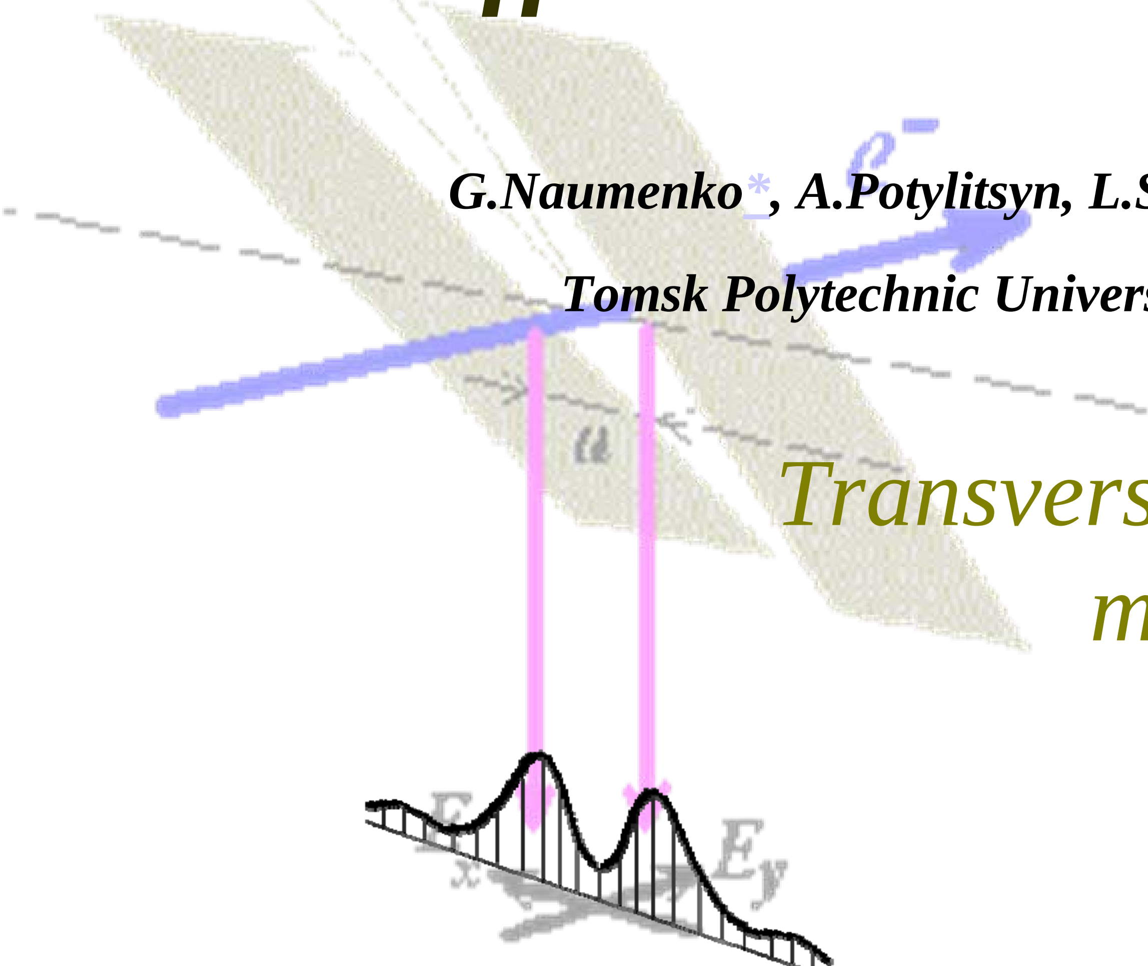

Transverse beam size measurement

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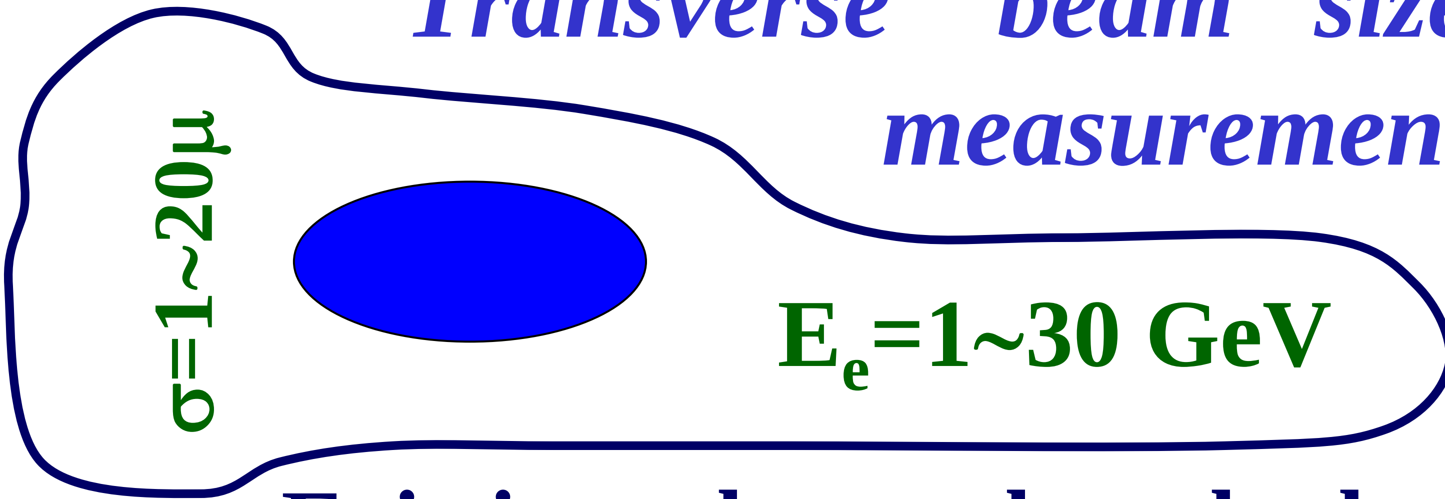


Existing advanced methods

SR - interferometer

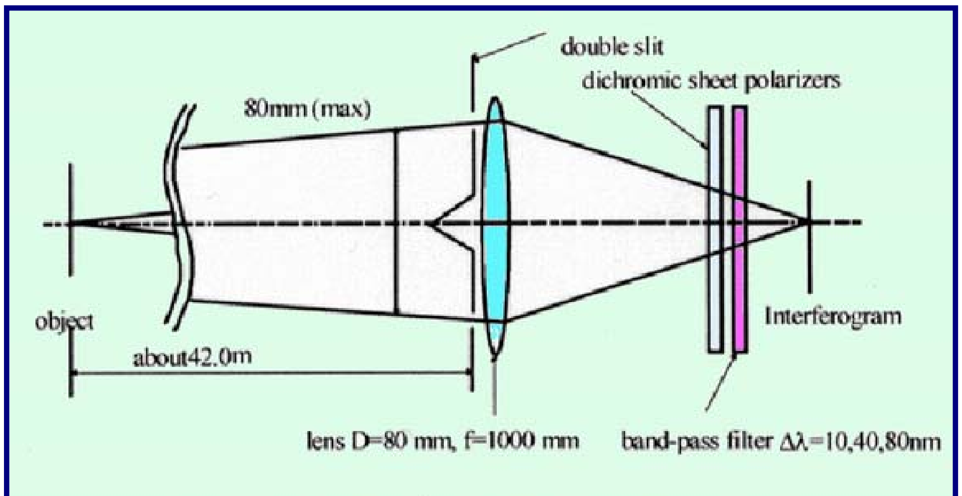


Figure 4: Set up of SR-interferometer

SakaiaY. Yamamoto, et.al., Review of Scientific instruments, 71,3 (2000)

Laser wire scanner

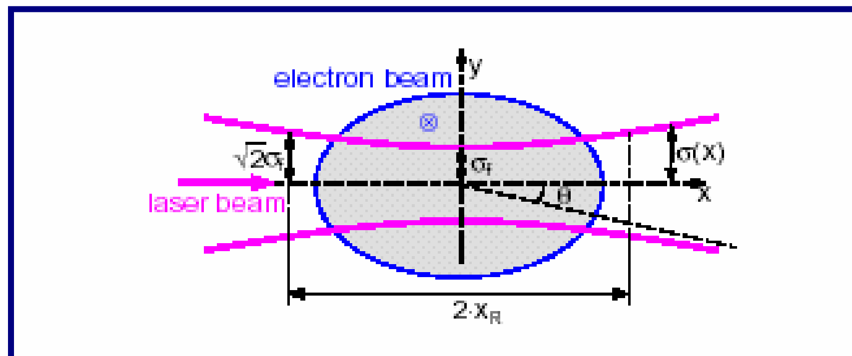


Figure 1: Scheme of a gaussian laser beam focused to its diffraction limit.

H. Sakai, et.al., Phys.Rev.ST Accel.Beams 4:022801,2001.

Transition Radiation Monitor

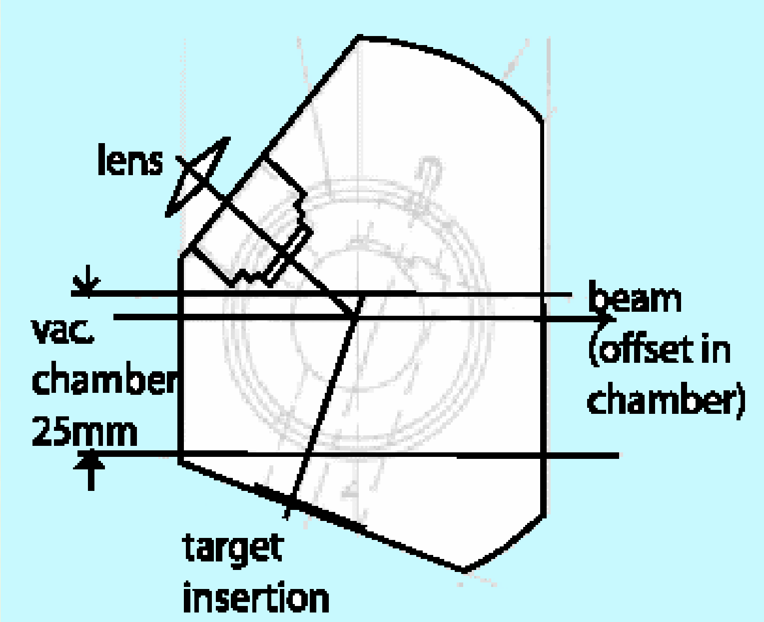


Figure 3: High-resolution optical transition radiation monitor tested at ATF/KEK. The monitor is displaced when the target is inserted in order to bring the beam close to the lens.

M. Ross, et.al., 2001 IEEE Particle Accelerator Conference, Chicago, IL, 2001.

Laser interferometer

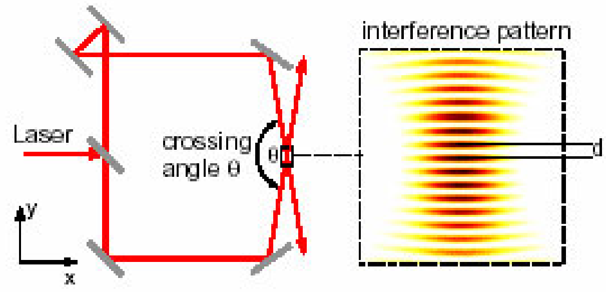


Figure 2: Schema of the generation of an interference pattern using a split laser beam. d is the fringe spacing.

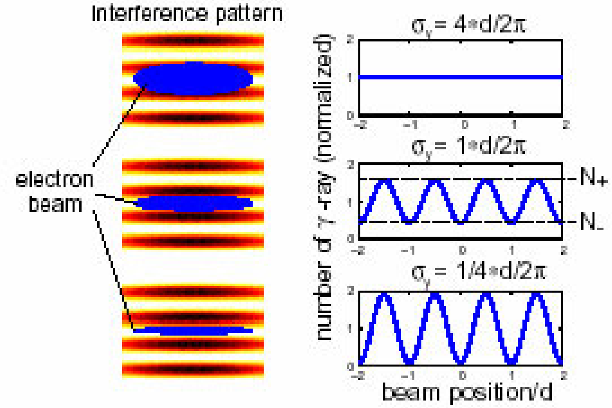


Figure 3: Modulation of Compton scattered photons as a function of the vertical electron beam position for different beam sizes (top large, center medium, bottom small)

H. Sakai, et.al., Phys.Rev.ST Accel.Beams 4:022801,2001.

What about a non-invasive single bunch diagnostics?

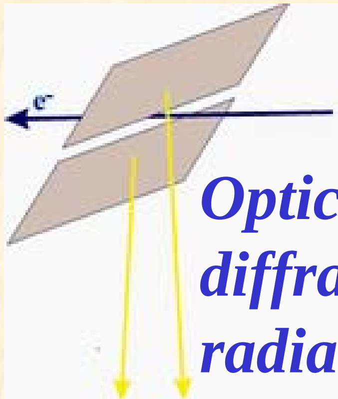
	Non invasive	Single bunch measurement
SR - interferometer	yes	no
Laser wire scanner	yes	no
Transition Radiation Monitor	no	yes
Laser interferometer	yes	no
?	yes	yes

Non-invasive diagnostics based on the Optical Diffraction Radiation

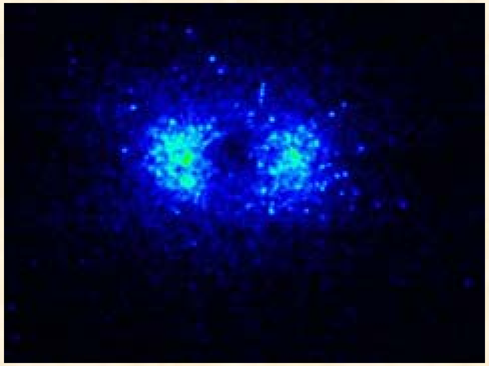
Short prehistory

Start: **KEK ATF 2000**

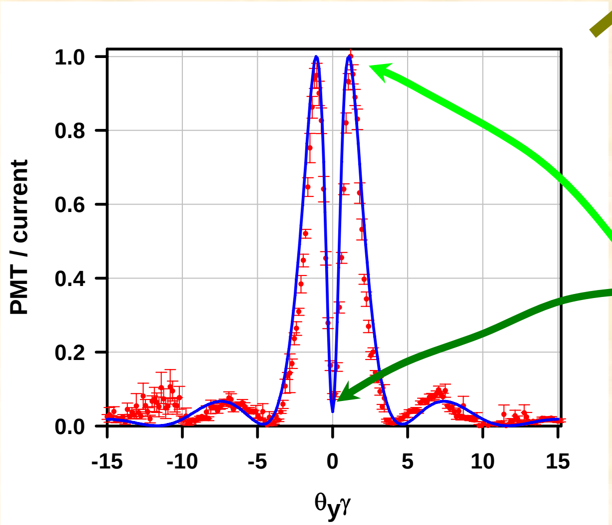
Flat slit target



Optical diffraction radiation



2003



Measured ODR angular distribution

P. Karataev S. Araki et.al, NIM B 227 (2005)

At 2004 the 10μ beam size has been measured

$$\frac{W_{\min}}{W_{\max}} = f\left(\sigma_e\right)$$

P. Karataev, S. Araki et.al., PRL 93, 244802 (2004)

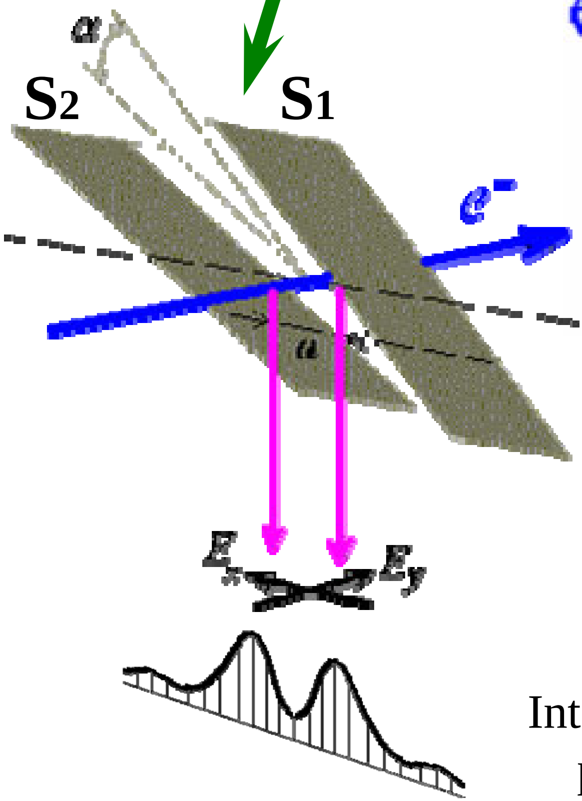
Method limitation

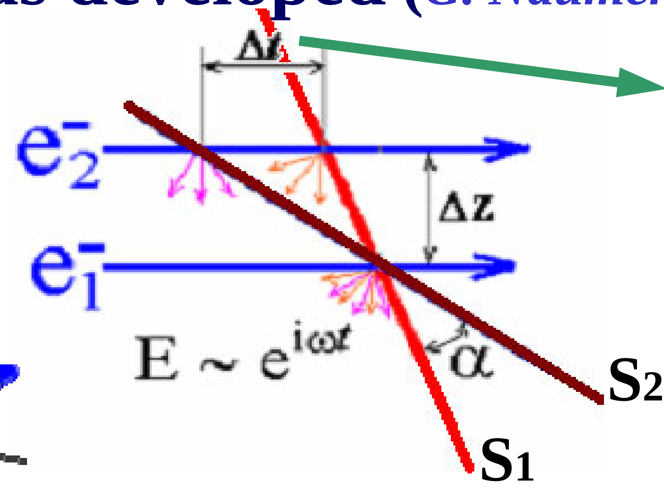
For $E_e \approx 1$ GeV method sensitivity limit was reached for beam size $\approx 10\ \mu$.

For $E_e \approx 30$ GeV the sensitivity decrease catastrophically.

ODR method modification

Beam size measurement technique using ODR from crossing target was developed (*G. Naumenko, KEK report, Nov. 2003*)

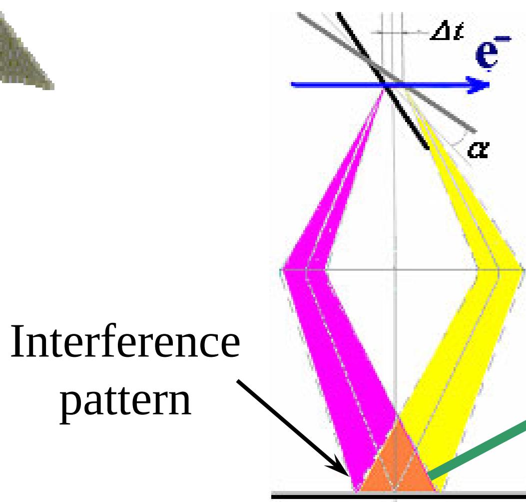




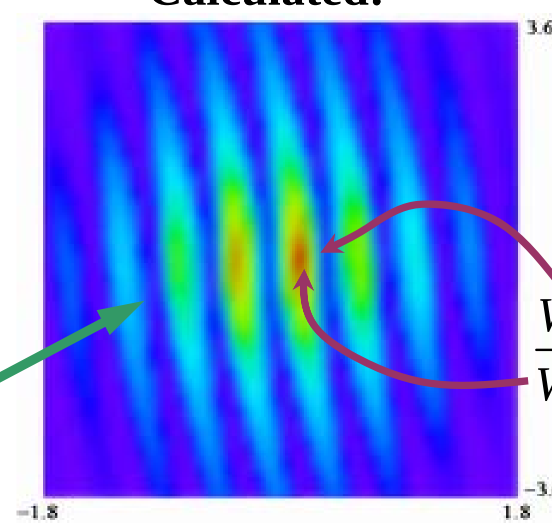
Phase shift:

$\Delta\varphi = i \cdot \omega \cdot \Delta t =$

$= i \cdot 4\pi \cdot \alpha \cdot \Delta z / \lambda$



Calculated:

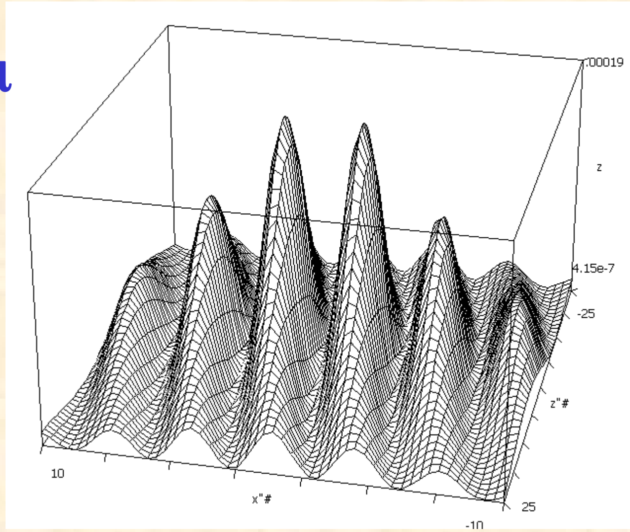


$$\frac{W_{min}}{W_{max}} = f(\sigma_e)$$

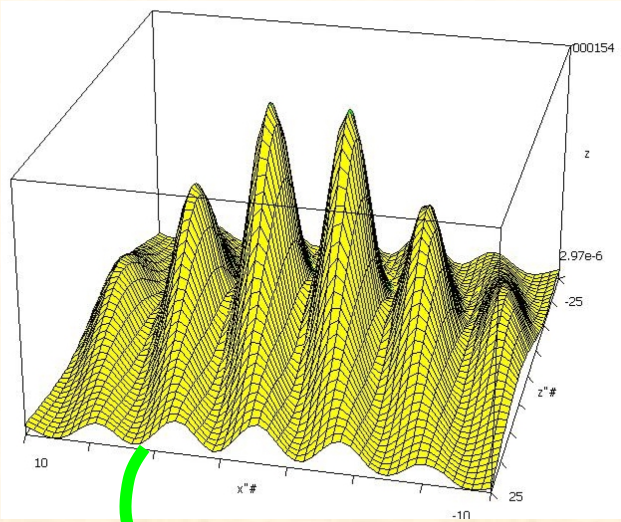
Example for γ=2500, α=5.6mrad

Interference pattern after the integration over a Gaussian electron beam profile:

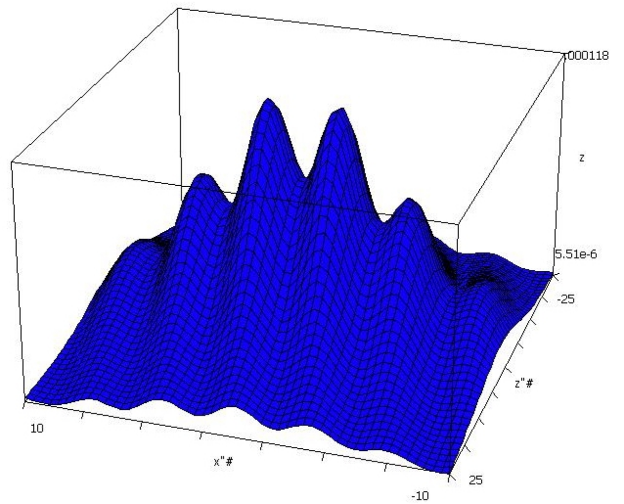
σ_e= 2μ

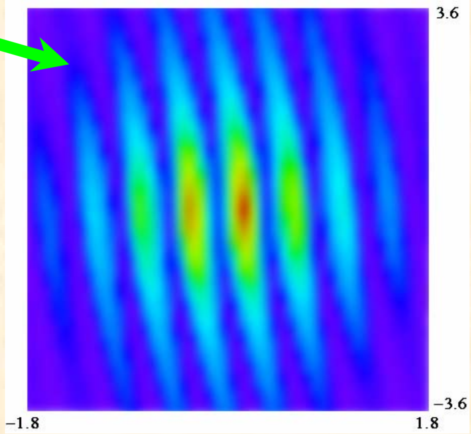


σ_e= 6μ



σ_e= 10μ

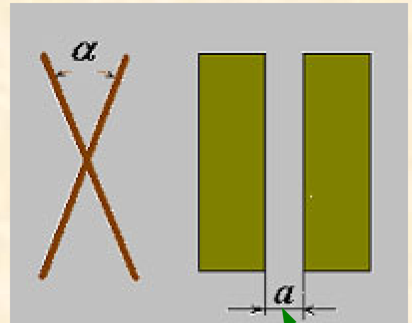




Single bunch measurement

Example:

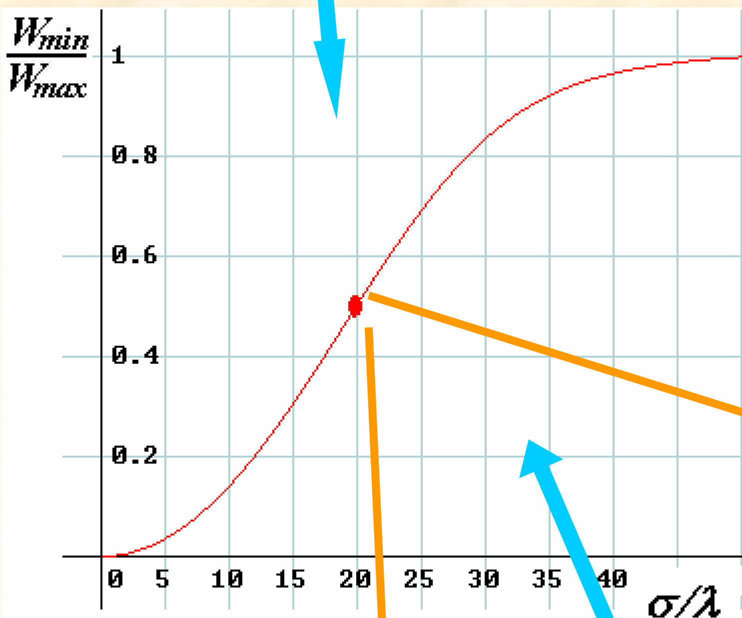
α=5.6 mrad



$$W_{max} \propto e^{-\pi \frac{a}{\gamma\lambda}}$$

γ is the Lorenz-factor

$$if \quad a \ll \gamma\lambda, \quad W_{max} \approx W_{OTR}$$



For λ=0.5mcm and γ=60000
γλ=3cm. $a \ll \gamma\lambda$ **is possible**

For λ=0.5mcm σ=10mcm

No dependence on the Lorenz-factor in far field zone

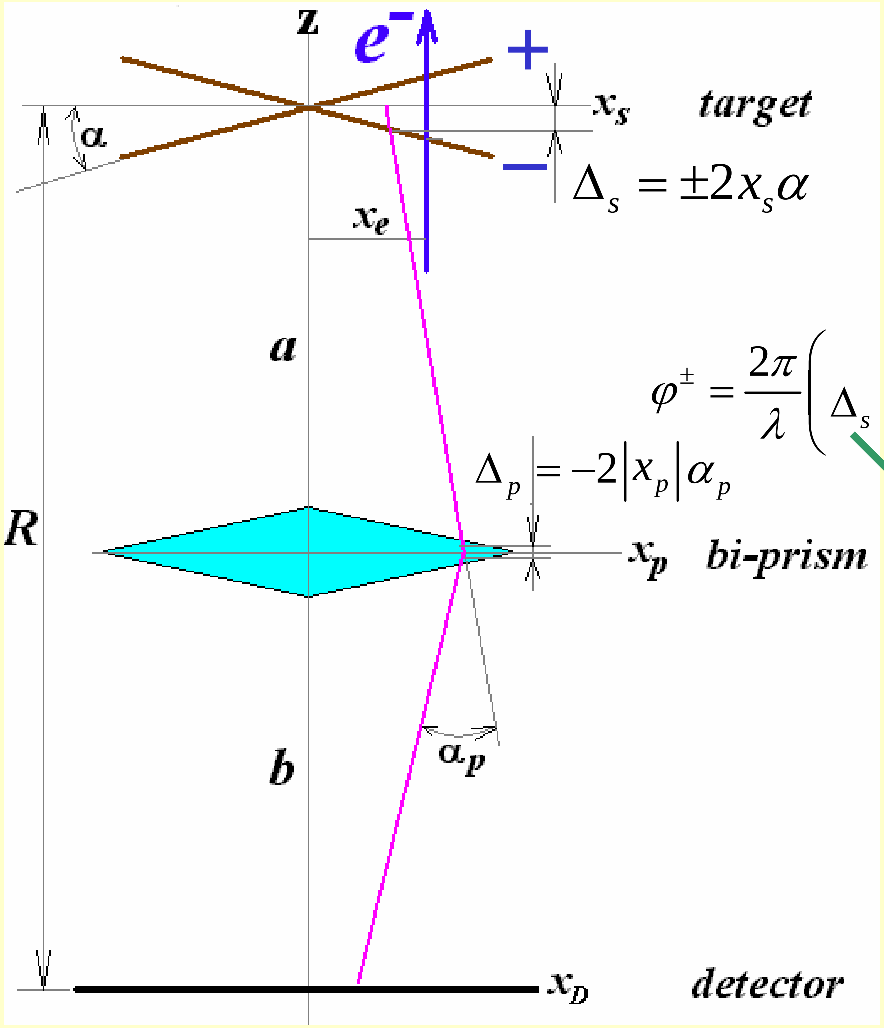
Beam size effect is of the order of OTR intensity, which was measured using CCD from a single bunch.

Problem of beams together bringing

Pseudo-photon reflection approach

$$E_y^{\pm}(x_D, y_D) = \iint dx_s dy_s \iint dx_p dy_p \frac{1}{R}\left(\frac{-2e}{\gamma\lambda} \frac{y_s}{\sqrt{(x_s - x_e)^2 + y_s^2}} K_1\left(\frac{2\pi}{\gamma\lambda}\sqrt{(x_s - x_e)^2 + y_s^2} \right) \cdot e^{i\varphi^{\pm}} \right)$$

Bessel function



$$W_y = \left| E_y^{+}(x_D, y_D) + E_y^{-}(x_D, y_D) \right|^2$$

$$\frac{x_s, x_p, x_D, y_s, y_p, y_D}{a, b} << 1$$

$$\varphi^{\pm} = \frac{2\pi}{\lambda}\left(\Delta_s + \frac{(x_p - x_s)^2 + (y_p - y_s)^2}{2a} + \Delta_p + \frac{(x_D - x_p)^2 + (y_D - y_p)^2}{2b} \right)$$

$$x_s = x_e + x_s'$$

$$\pm 2 x_e \alpha \qquad \mp 2 x_e \alpha$$

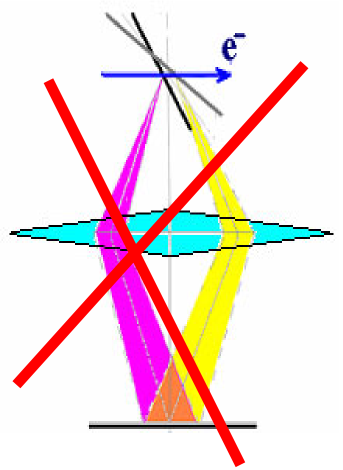
$$0$$

Not any dependence on an electron position and beam size

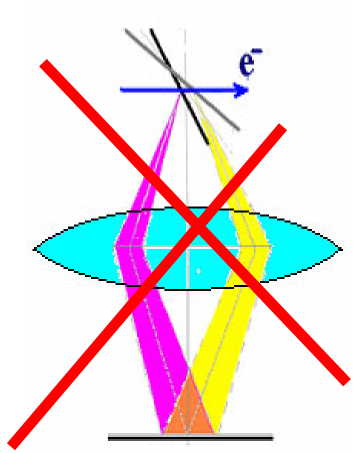
Moreover

The same results may be shown for:

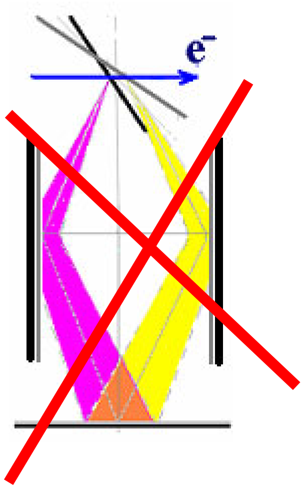
Bi-prism



Lens



Mirrors



Is a beam size measurement possible?

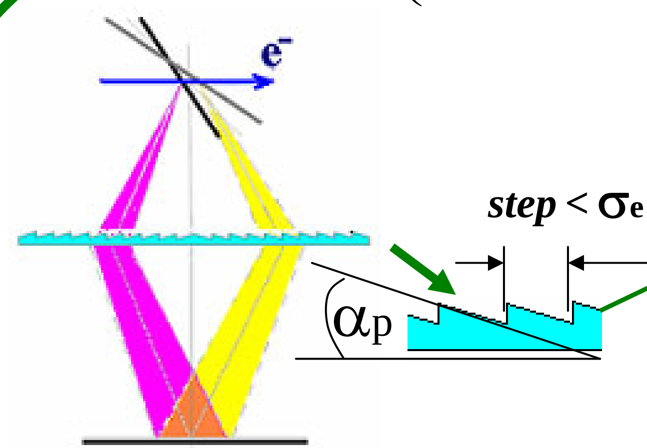
Frenel prism

Based on Frenel lens technology

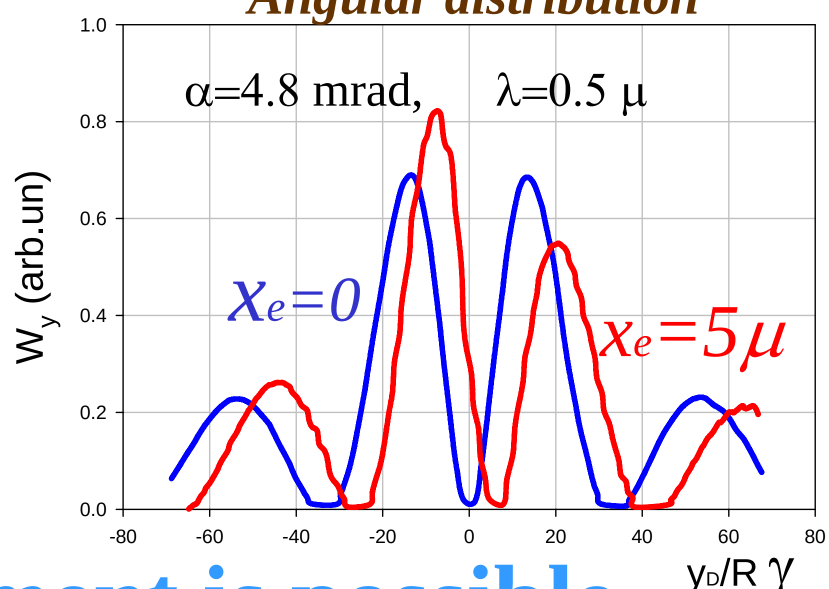
Phase

$$\varphi^{\pm} = \frac{2\pi}{\lambda}\left(\Delta_s + \frac{(x_p - x_s)^2 + (y_p - y_s)^2}{2a} + \Delta_p + \frac{(x_D - x_p)^2 + (y_D - y_p)^2}{2b}\right)$$

$$\Delta_p = \frac{step \cdot x_p}{|x_p|} \cdot frac\left|\frac{x_p}{step}\right| \cdot \alpha_p$$



Angular distribution

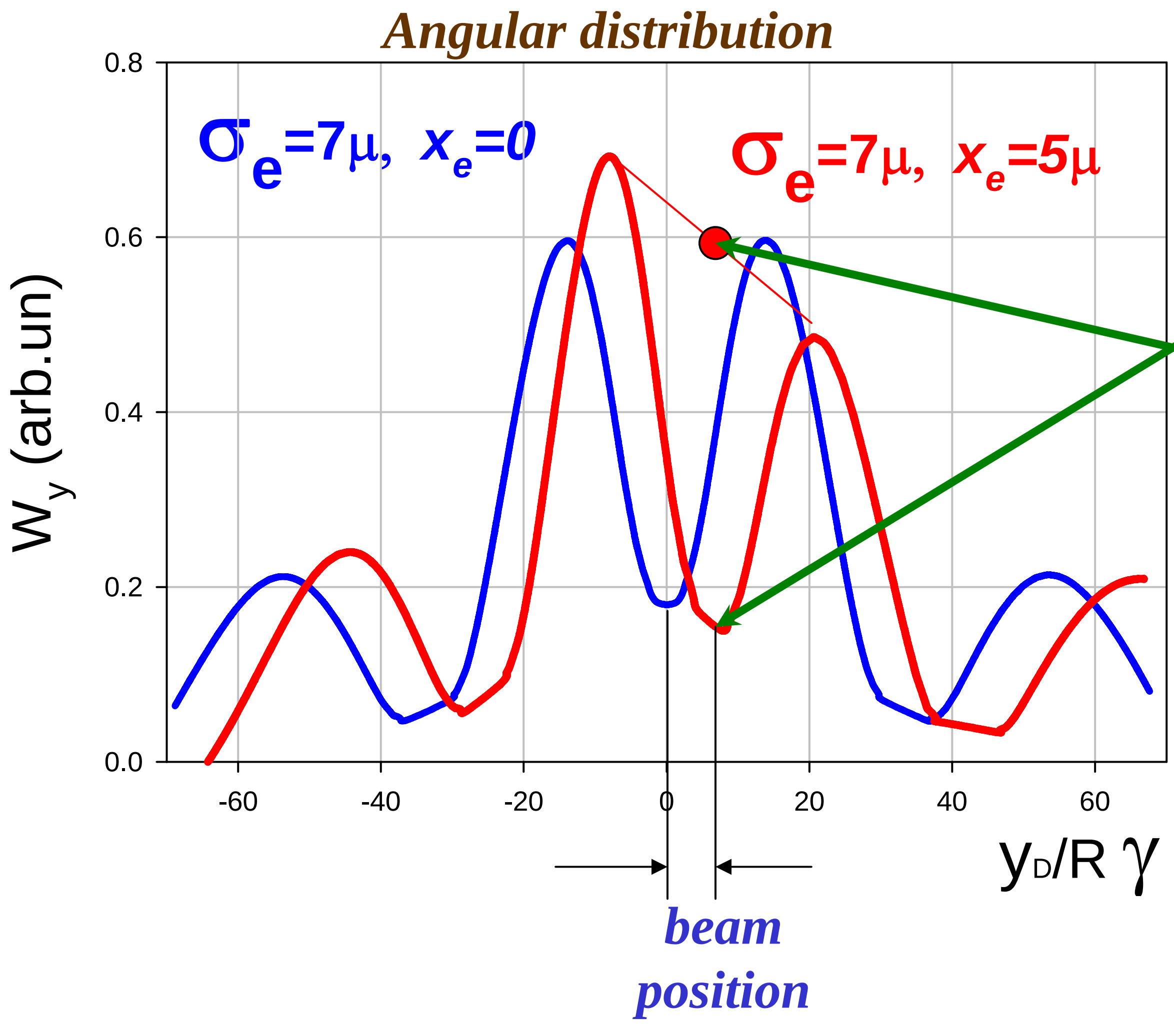


$$W_y = \left|E_y^+(x_D, y_D) + E_y^-(x_D, y_D)\right|^2$$

$$\frac{W_y^{\min}}{W_y^{\max}} = f\left(\frac{\sigma_e}{\lambda}\alpha\right)$$

Beam size measurement is possible

Beam size + beam position



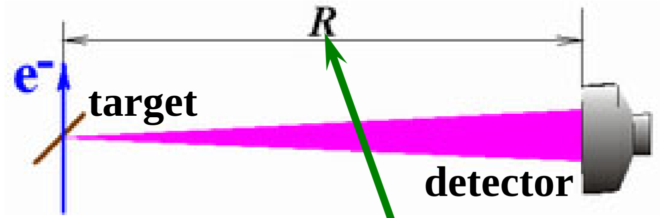
Beam size

$$\frac{W_y^{\min}}{W_y^{\max}} = f\left(\frac{\sigma_e}{\lambda}\alpha\right)$$

Single bunch measurement using CCD camera is possible

Near field zone effect

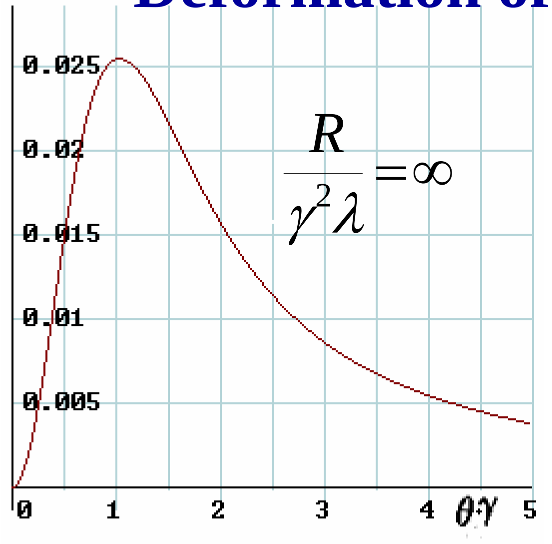
V.A. Verzilov, Phys. Let. A 273 (2000) 135-140

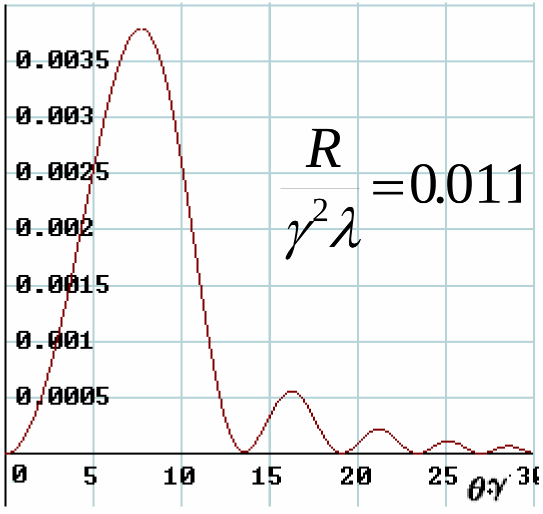


Effect is peculiar to radiation angular distribution.
It shows itself for ODR as well as for OTR.

$$\frac{R}{\gamma^2\lambda} < 1$$

Deformation of OTR angular distribution



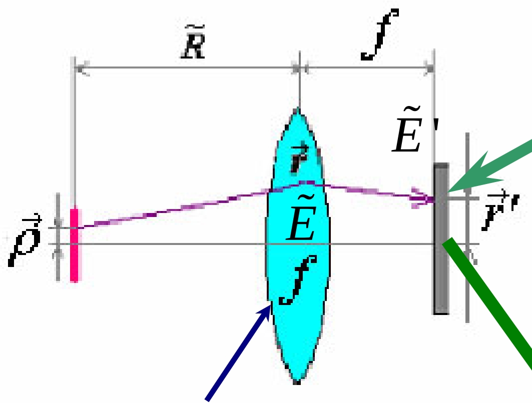


For E_0=30 GeV, $\lambda \approx 0.5\mu$

$$\gamma^2\lambda \approx 1800m$$

Near field zone effect resolution

Pis'ma w JETPh, 84 3 (2006) 136



Example for OTR

Angular distribution image

$$\tilde{E}' = \int_0^b \tilde{E}(r)\cdot r\cdot J_1\left(-2\pi\cdot R\cdot r\cdot r'\right)dr,$$

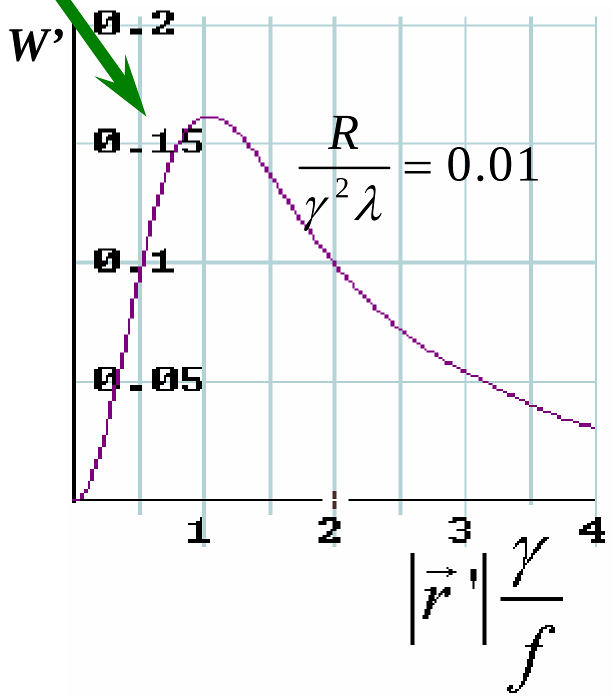
Bessel function

here

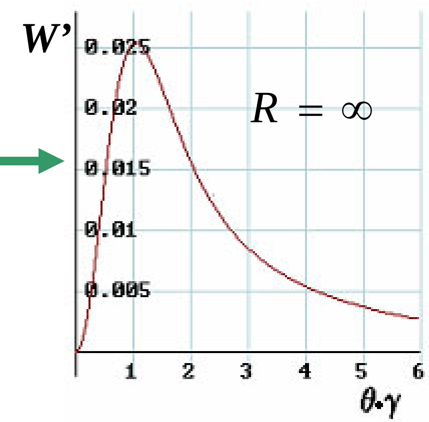
$$r' = \frac{\gamma\cdot\left|\vec{r}\,'\right|}{f}$$

$$W' = \left|\tilde{E}'\right|^2$$

Near field zone



Far field zone without lens



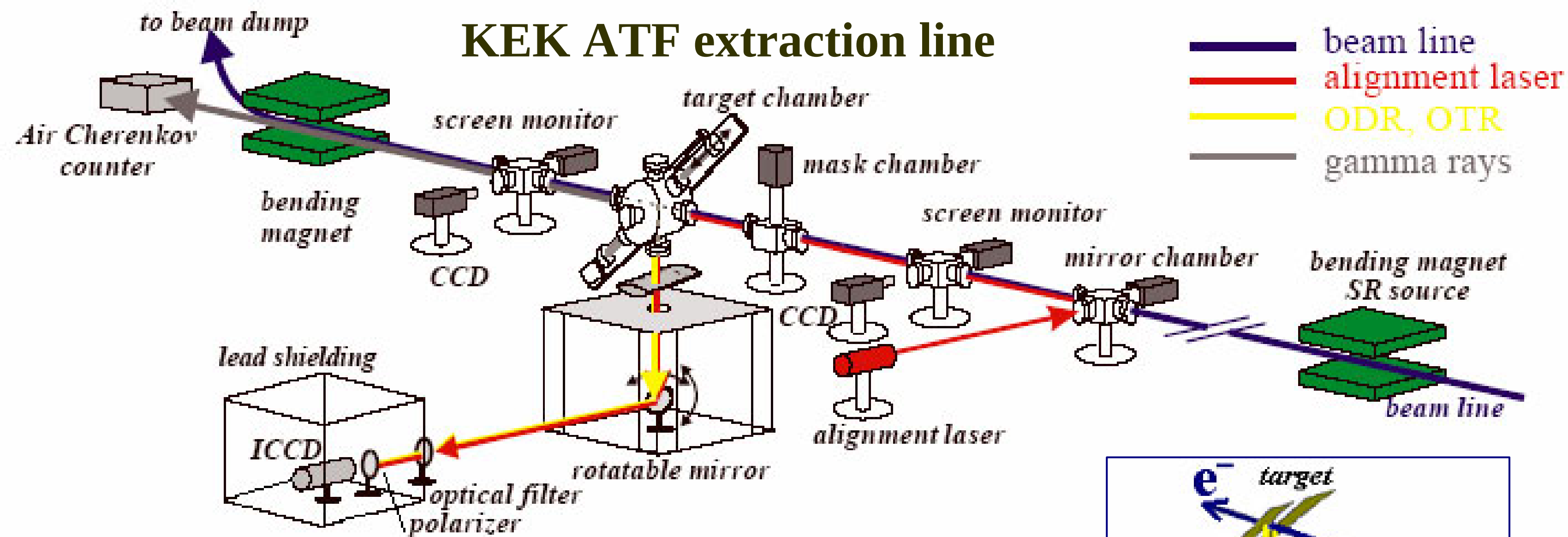
Conclusion

- ***Beam size ODR effect of this method is of the first order in contrast to the effect of the second order for the method based on a flat slit target. A radiation intensity beam size effect comprises 20~60% of OTR intensity. Single bunch measurement using CCD is possible near well as OTR measurement.***

- ***The problem of radiation beams together bringing may be resolved using a special Frenel bi-prism.***

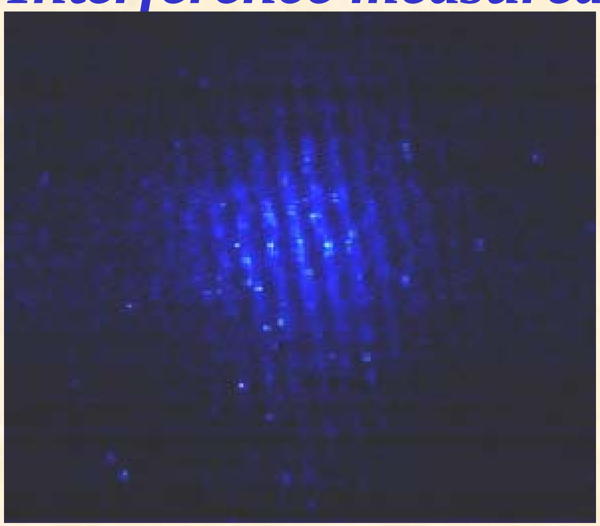
- ***The near field effect problem may be resolved using optical system.***

Test of ODR interference from the crossed target



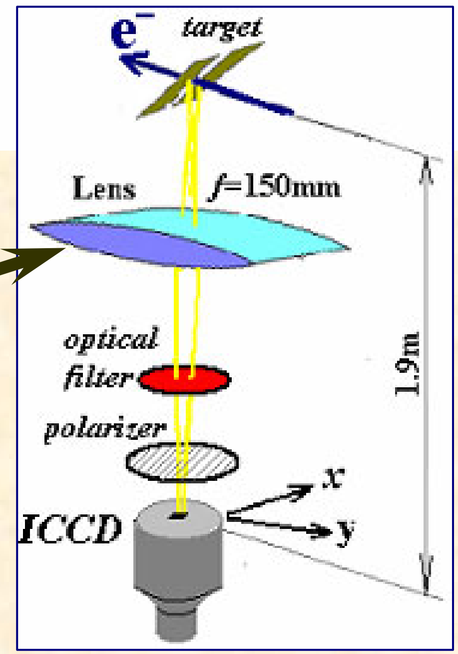
Target parameters: α = 6.2mrad, a = 420μm

Interference measured



Only for interference test.

Not usable for beam size measurement



Scheme

Thank you