Development of non-invasive micron beam size diagnostics using optical diffraction radiation

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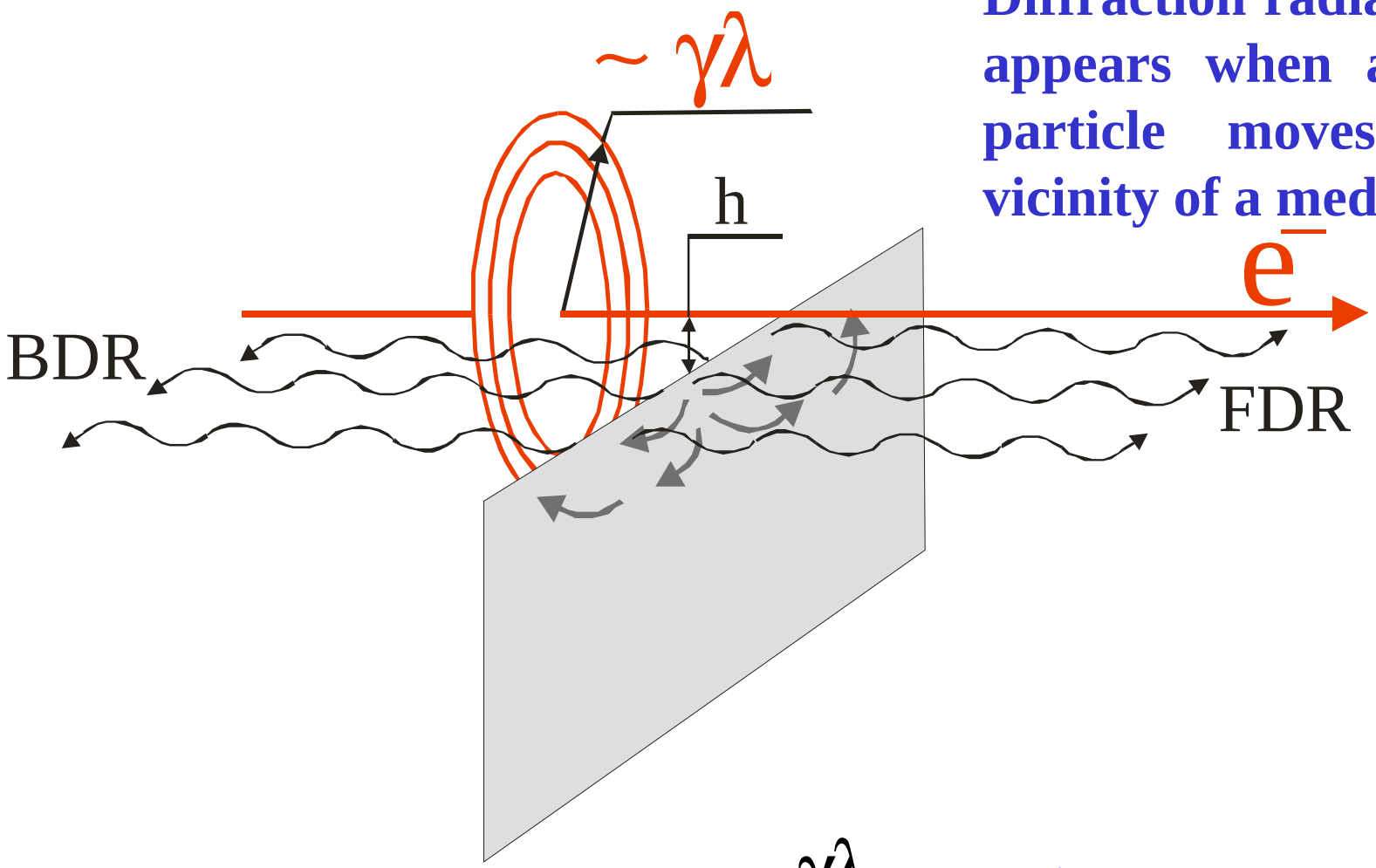
- **Introduction**
- **Experimental setup**
- **Beam size measurement with ODR from a flat slit**
- **ODR interference for micron beam size measurements**
- **Summary**

Diffraction Radiation production

Diffraction radiation (DR) appears when a charged particle moves in the vicinity of a medium



Impact parameter, h, – the shortest distance between the target and the particle trajectory

$$h \le \frac{\gamma\lambda}{2\pi}$$

λ - observation wavelength

g - particle Lorentz-factor

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Advantages of ODR technique

- **Non-invasive method**

  (no beam perturbation or target destruction)

- **Instantaneous emission**

  (quick measurements)

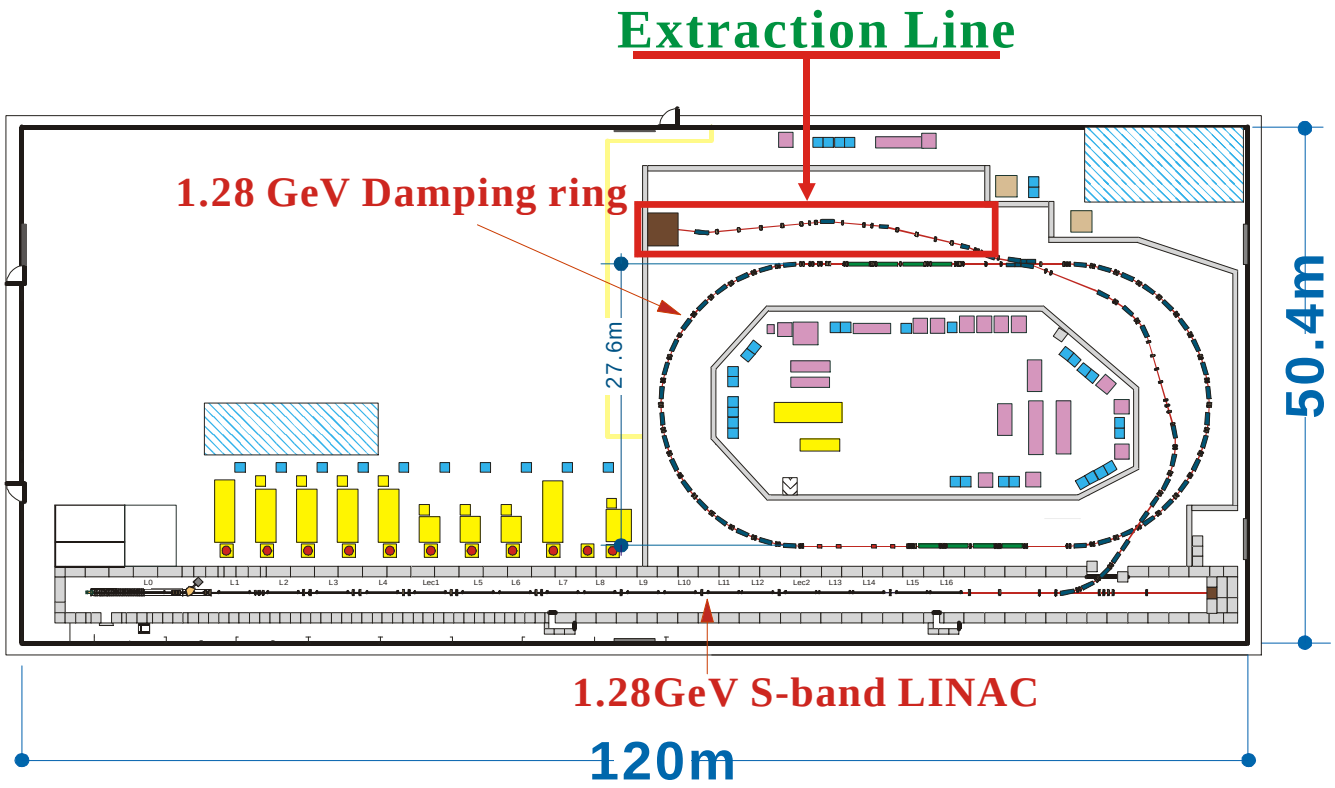
- **Single shot acquisition**

  (no additional error from shot-by-shot instabilities)

- **~1-2μm resolution is achievable**

  (Linear collider goal – 10μm beam size with 1μm resolution)

KEK – Accelerator Test Facility



Electron beam parameters

Maximum energy		**1.28 GeV (g = 2500)**
Beam emittance	**Vertical**	**(1.5 ± 0.25) ´ 10^{-11} m rad**
	Horisontal	**(1.4 ± 0.3) ´ 10^{-9} m rad**
Vertical beam size (near the ODR target)		s_y < 10m
Horizontal beam size (near the ODR target)		s_x < 100m
Bunch length		**~ 8 mm**
Single-bunch population		**1.2 ´ 10^{10}**
Energy spread		**0.08%**

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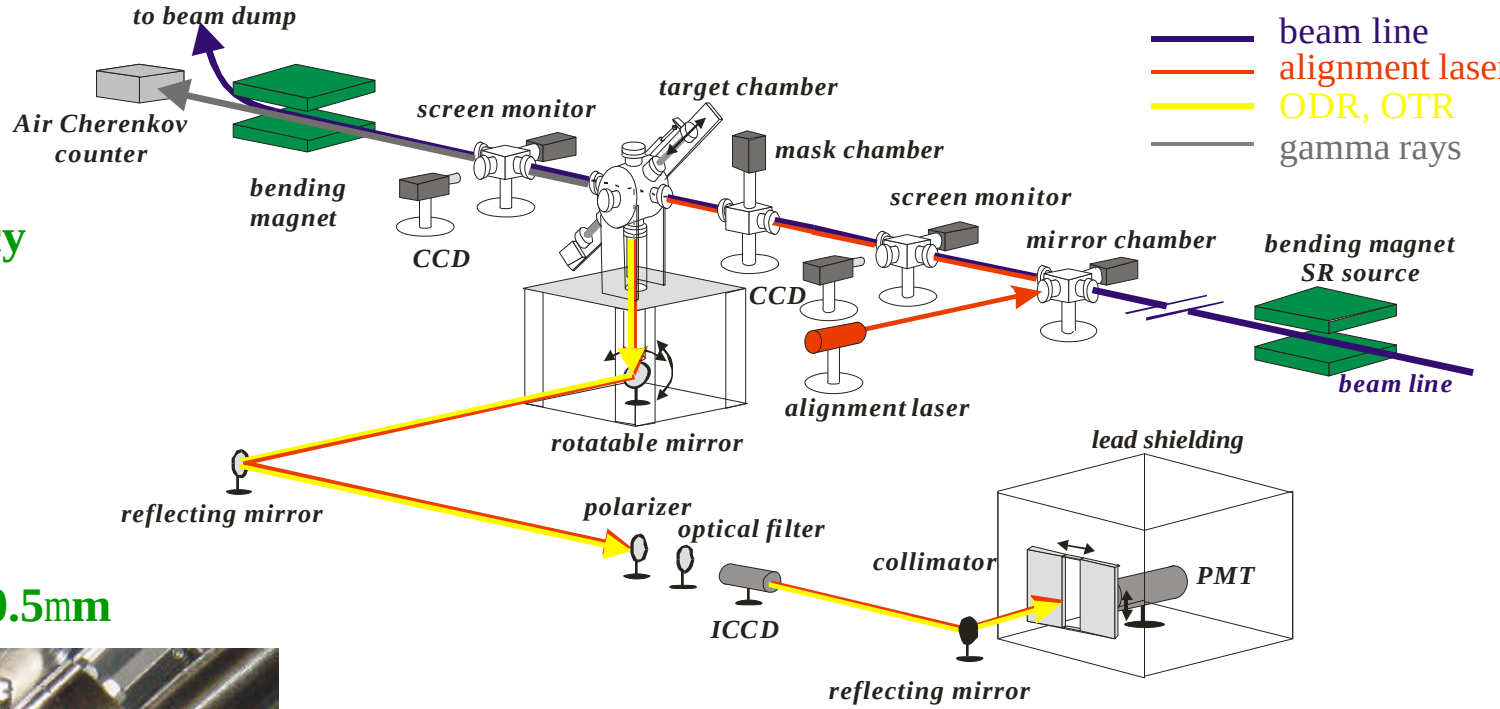
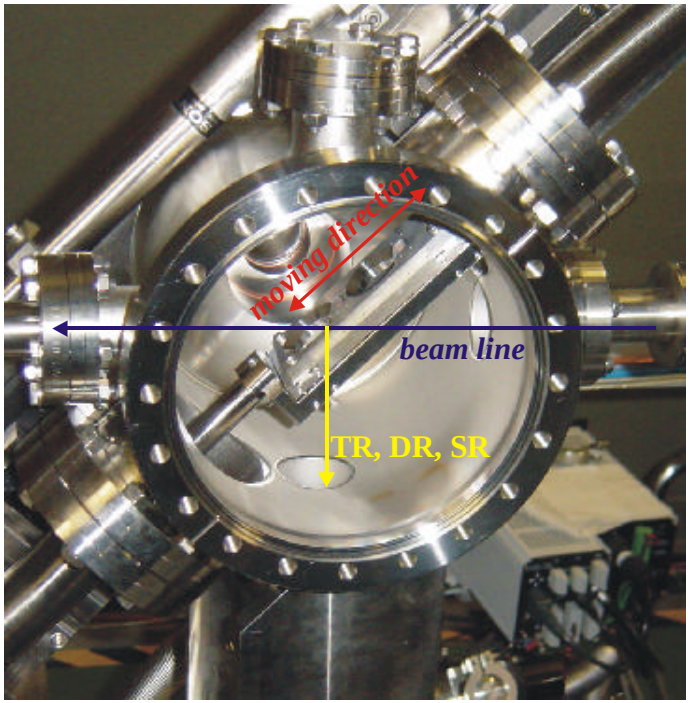
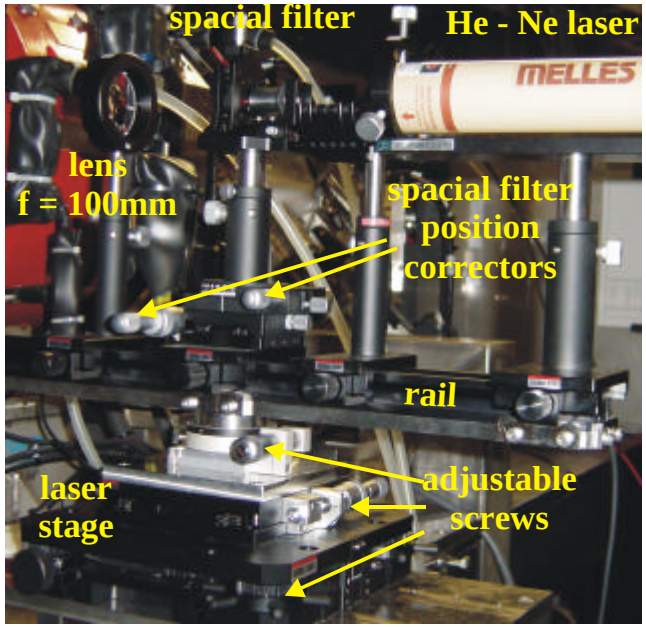
Experimental layout



Alignment accuracy
$< \gamma^{-1} = 0.4$mrad

Linear gauge < 0.5mm





PMT (Hamamatsu H1161)
spectral response range
~300 – 650nm

CCD (JAI corp. CV-M10)

I.I. (Hamamatrsu C4078-01)

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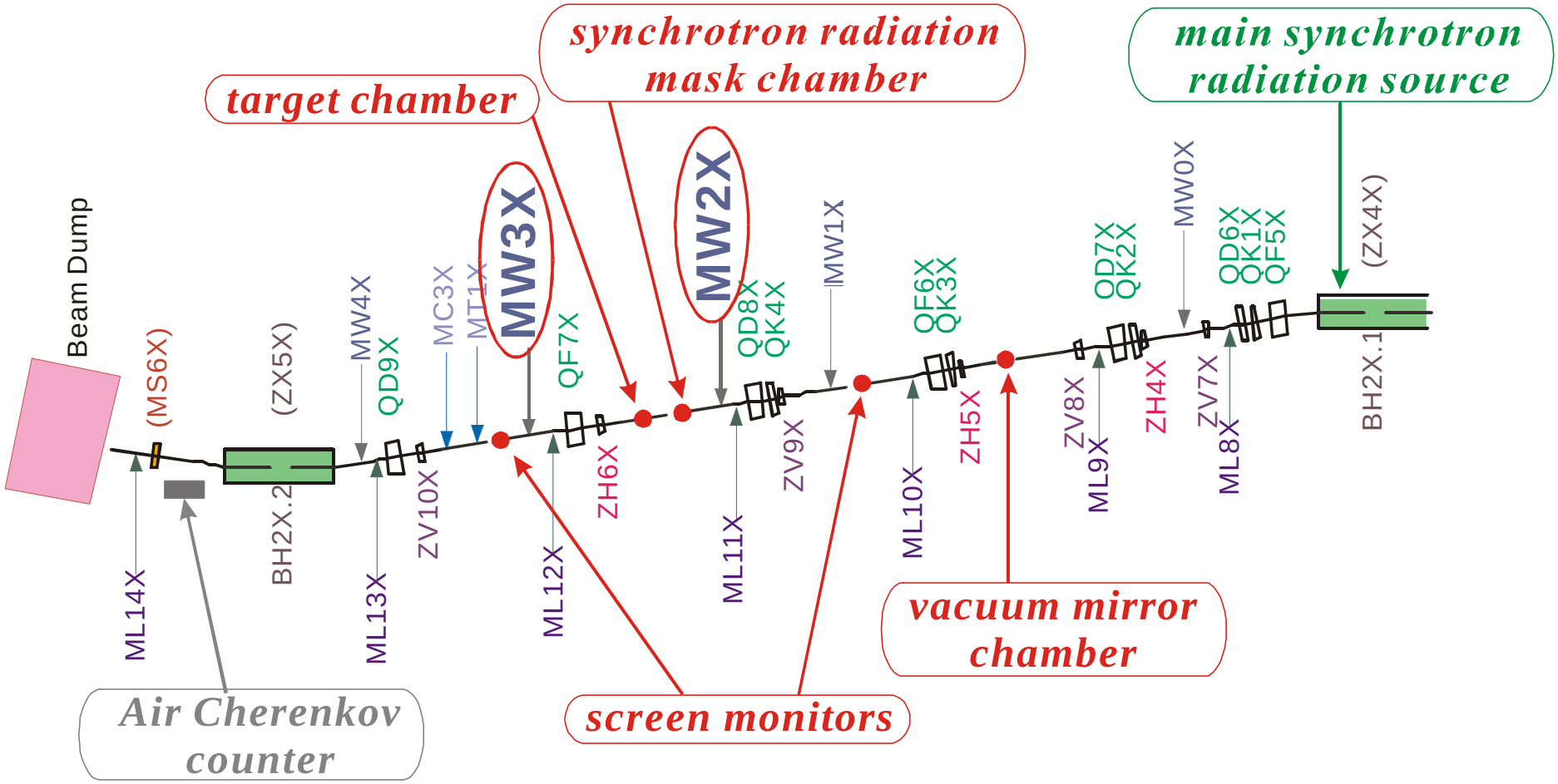
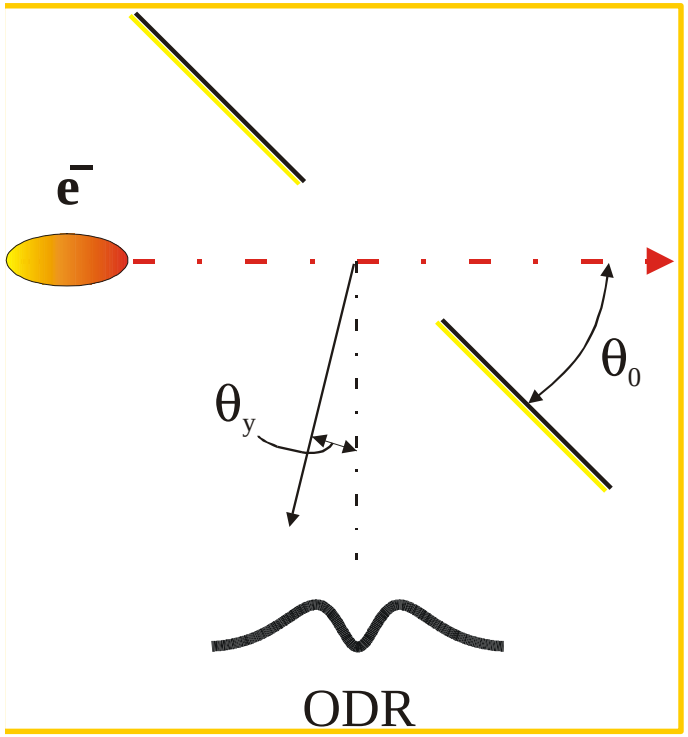
Extraction line layout



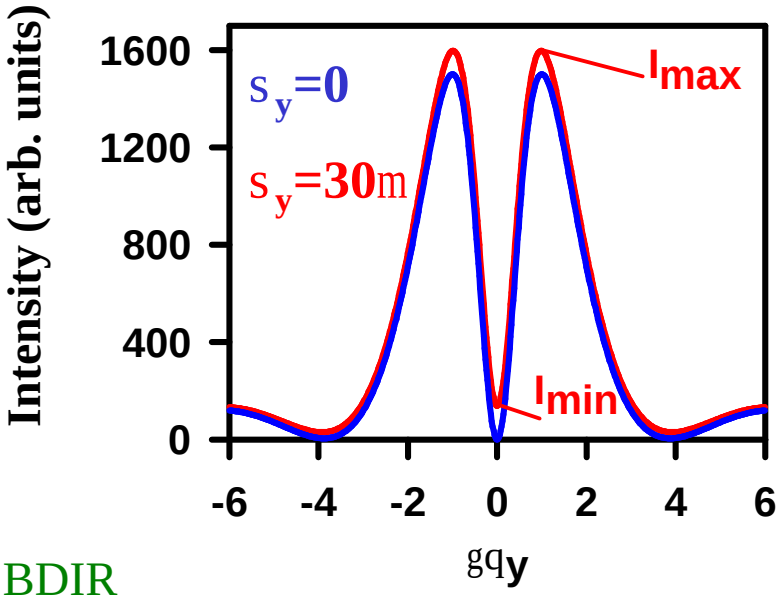
Beam size measurement using ODR from a flat slit

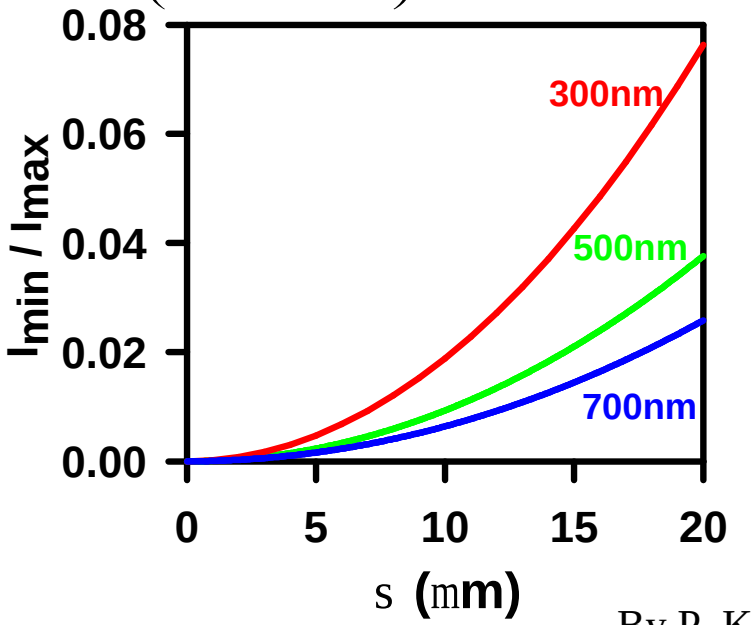


$$\frac{d^2W_y^{slit}}{d\omega d\Omega} = \frac{\alpha\left|R_y\right|^2}{4\pi^2}\frac{\exp\left(-\frac{2\pi a_{in}\sin\theta_0}{\lambda}\sqrt{\gamma^{-2}+\theta_x^2}\right)}{\gamma^{-2}+\theta_x^2+\theta_y^2}\times$$

$$\left\{\exp\left[\frac{8\pi^2\sigma_y^2}{\lambda^2}\left(\gamma^{-2}+\theta_x^2\right)\right]-\cos\left[\frac{2\pi a\sin\theta_0}{\lambda}\theta_y+2\psi\right]\right\}$$

$$\psi = \arctan\left(\frac{\theta_y}{\sqrt{\gamma^{-2}+\theta_x^2}}\right)$$





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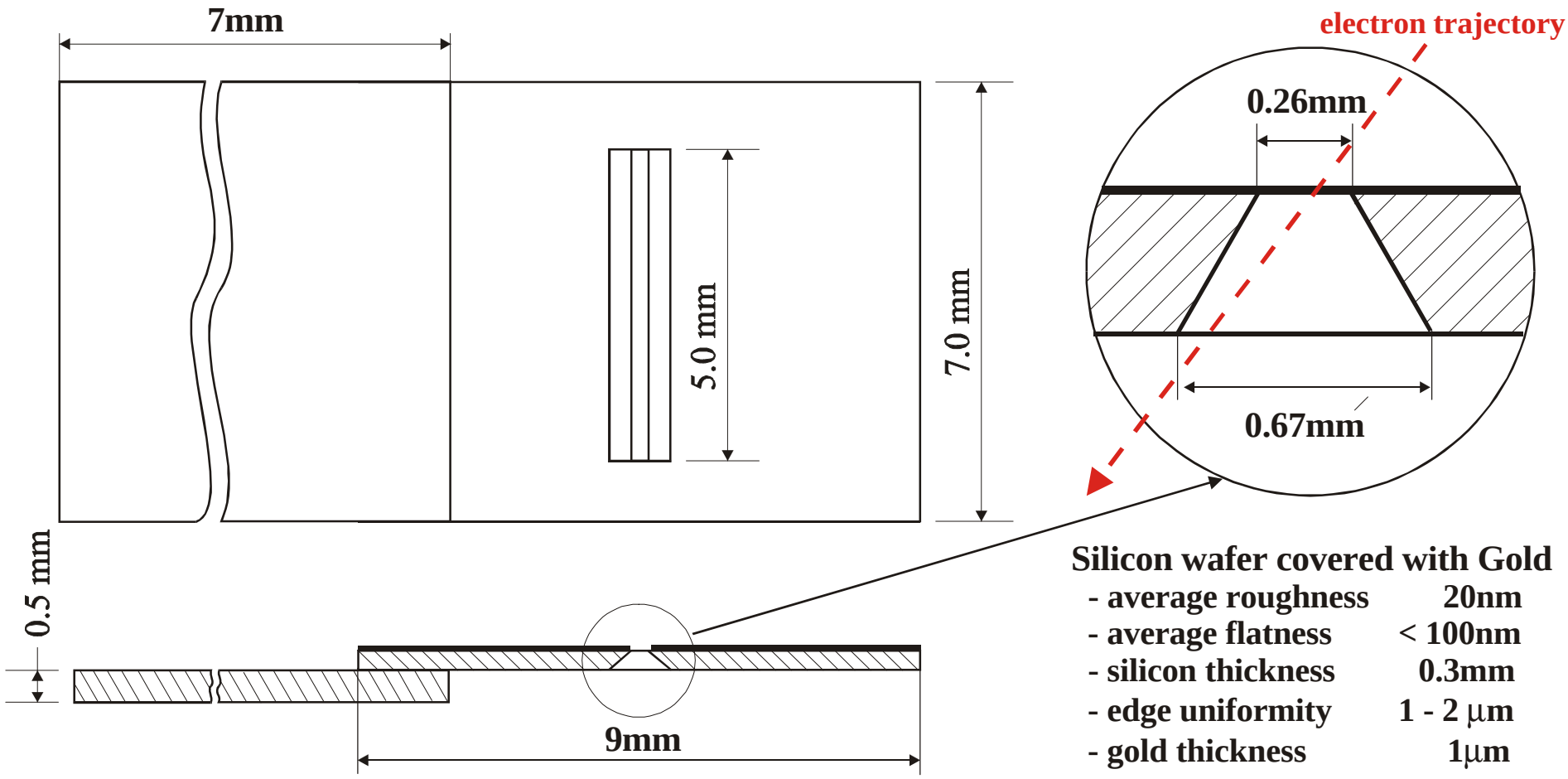
Target – silicon wafer covered with gold



Silicon wafer covered with Gold

- average roughness 20nm
- average flatness < 100nm
- silicon thickness 0.3mm
- edge uniformity 1 - 2 μm
- gold thickness 1μm

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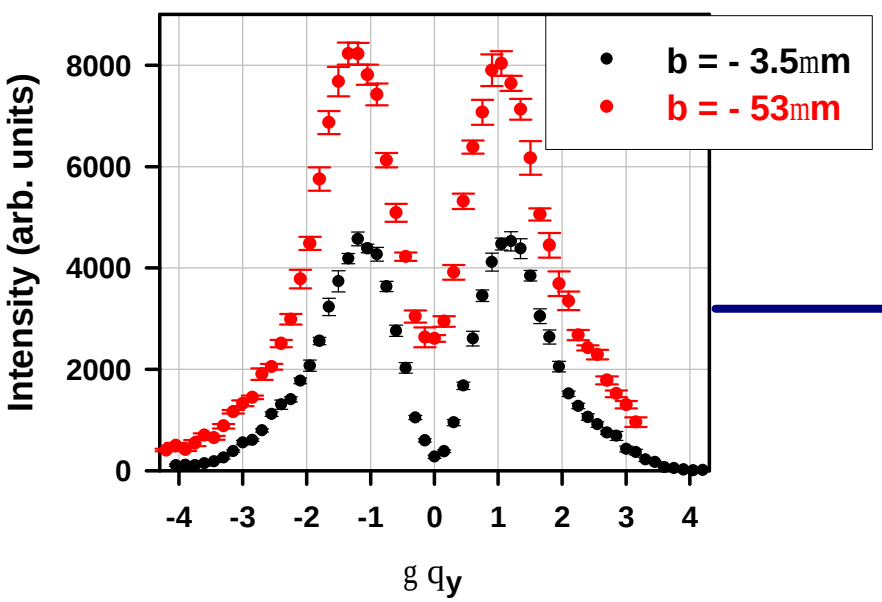
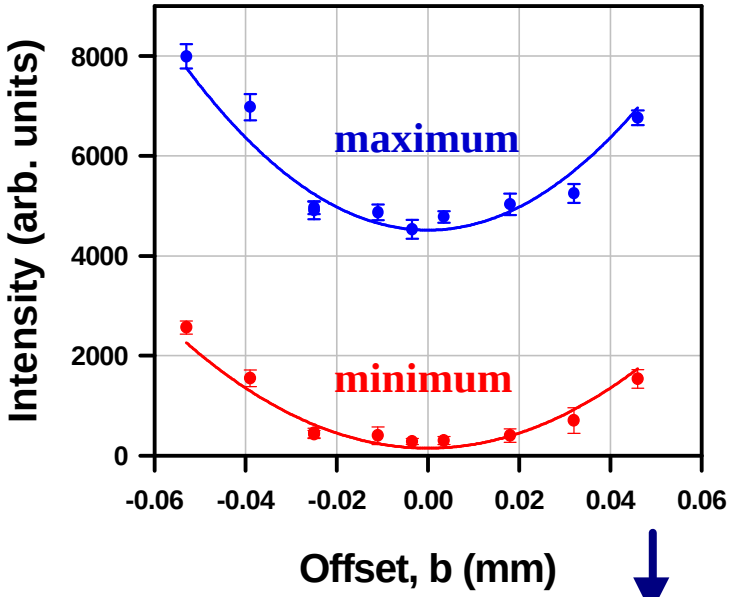
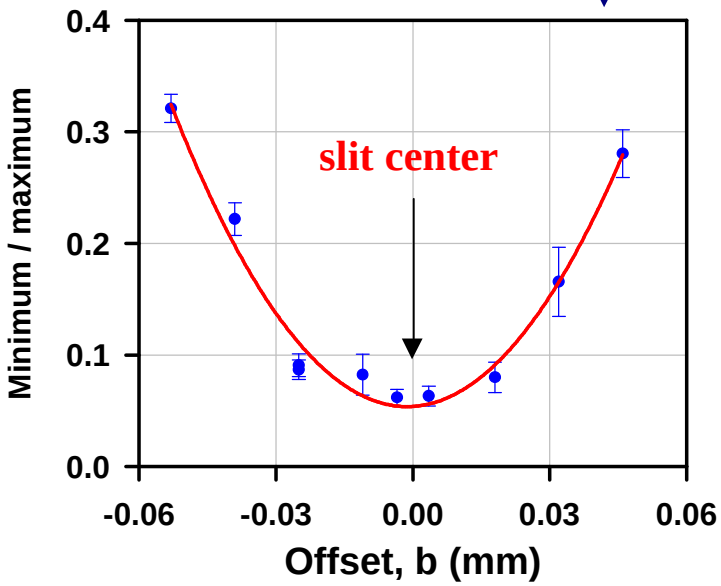
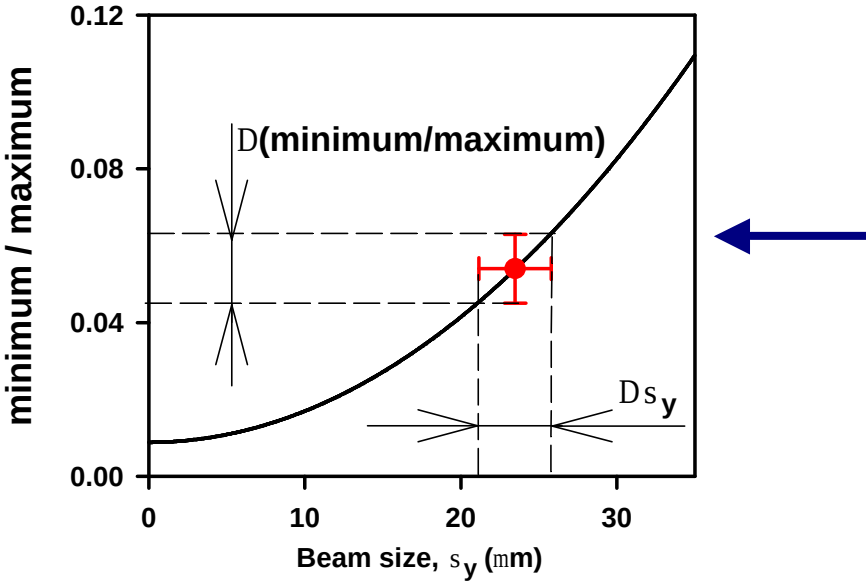
Method for the beam size measurement









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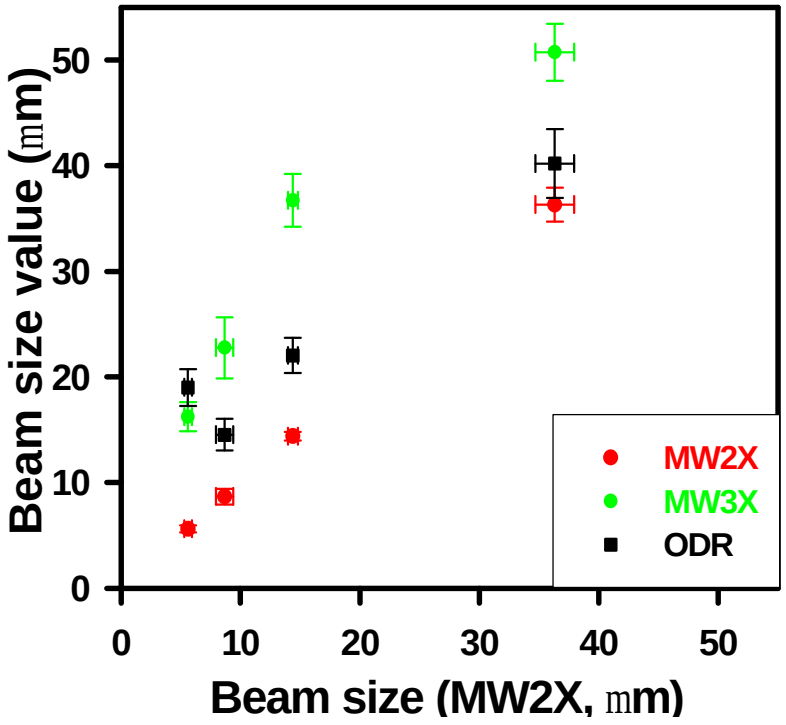
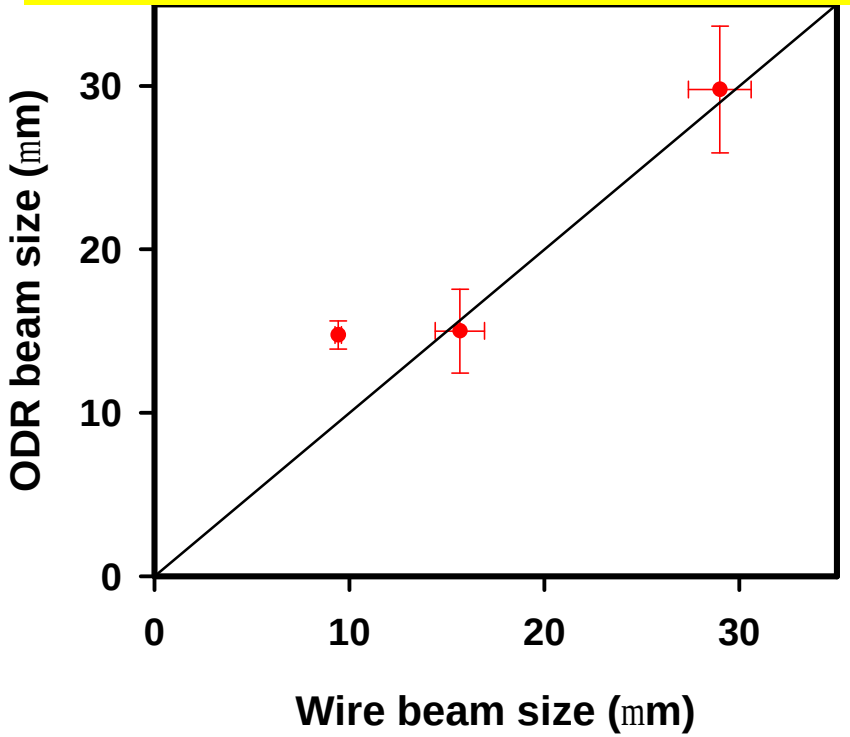
Beam size measurement

Correlation between the ODR (black points) and two wire scanners installed upstream (red points) and downstream (green points) the target.



Correlation between the the ODR and the beam size measured with 10mm tungsten wire installed in the target chamber at the same position as the target. The black line represents a 45 degree line.



$$z = \frac{2\pi a_{in}}{\gamma\lambda} \geq 1; \quad 1 >> \frac{\sigma}{a_{in}} > 0.01$$

Limitation

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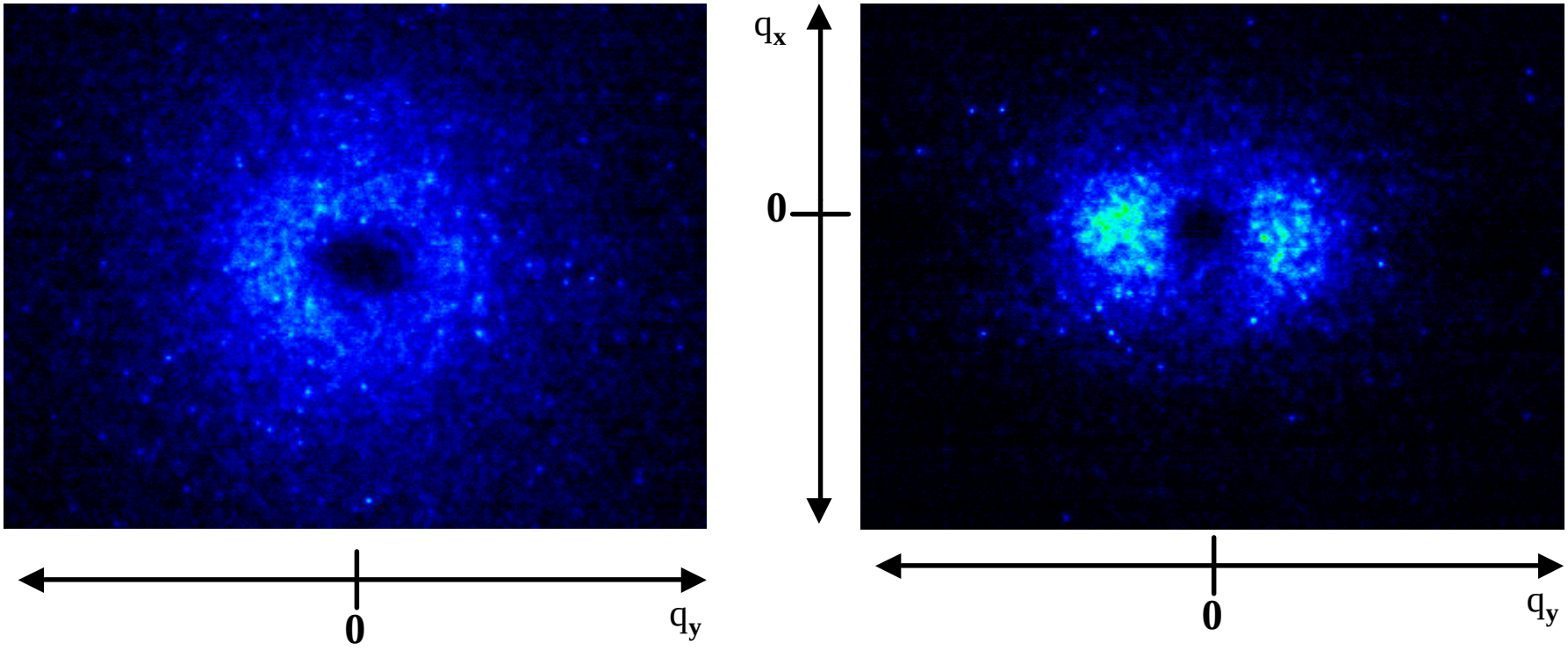
Single shot OTR and ODR measurement without the polarizer

OTR **ODR**



Optical filter $\lambda = 550 \pm 20$nm

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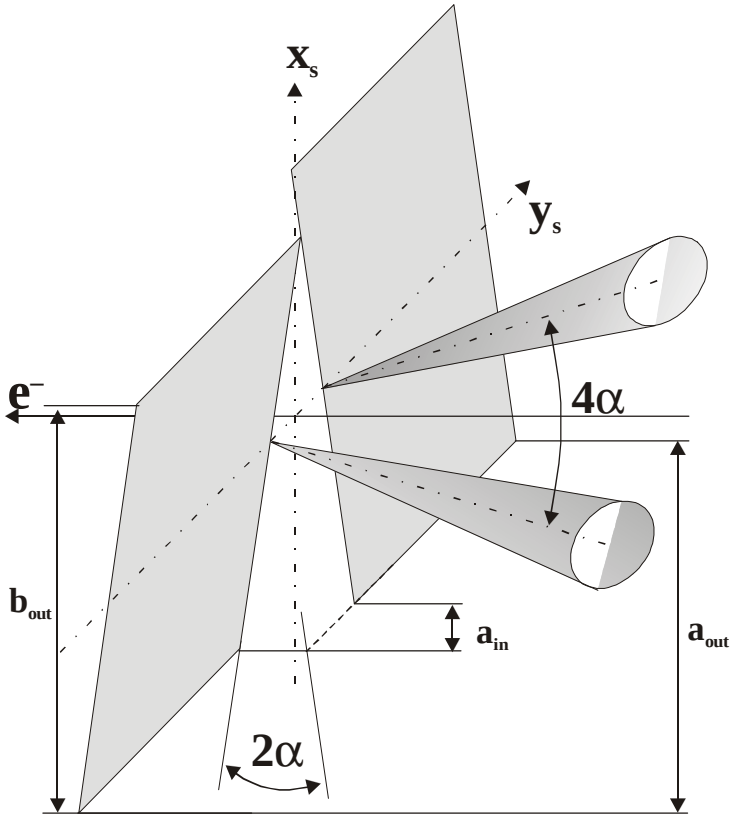
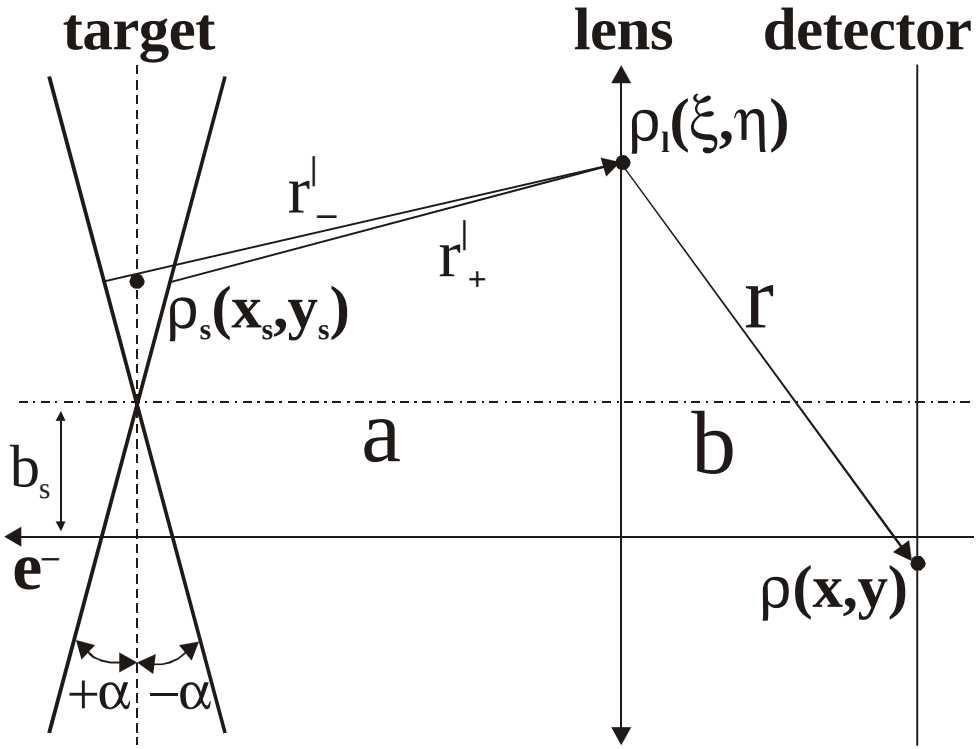
ODR Interference for micron beam size diagnostics





$$I_y = \left|E_y^+\right|^2 + \left|E_y^-\right|^2 + 2\left|E_y^+\right|\left|E_y^-\right|\cos\left(\psi_+ - \psi_- + 4k\alpha\left(b_s - \frac{x}{m}\right)\right)D$$

$$\begin{Bmatrix} E_y^{(R)\pm} \\ E_y^{(I)\pm} \end{Bmatrix} = \left|E_y^{\pm}\right| \cdot \begin{Bmatrix} \cos(\psi_\pm) \\ \sin(\psi_\pm) \end{Bmatrix}, \quad \text{where} \quad \psi_\pm = \tan^{-1}\left[\frac{E_y^{(I)\pm}}{E_y^{(R)\pm}}\right]$$

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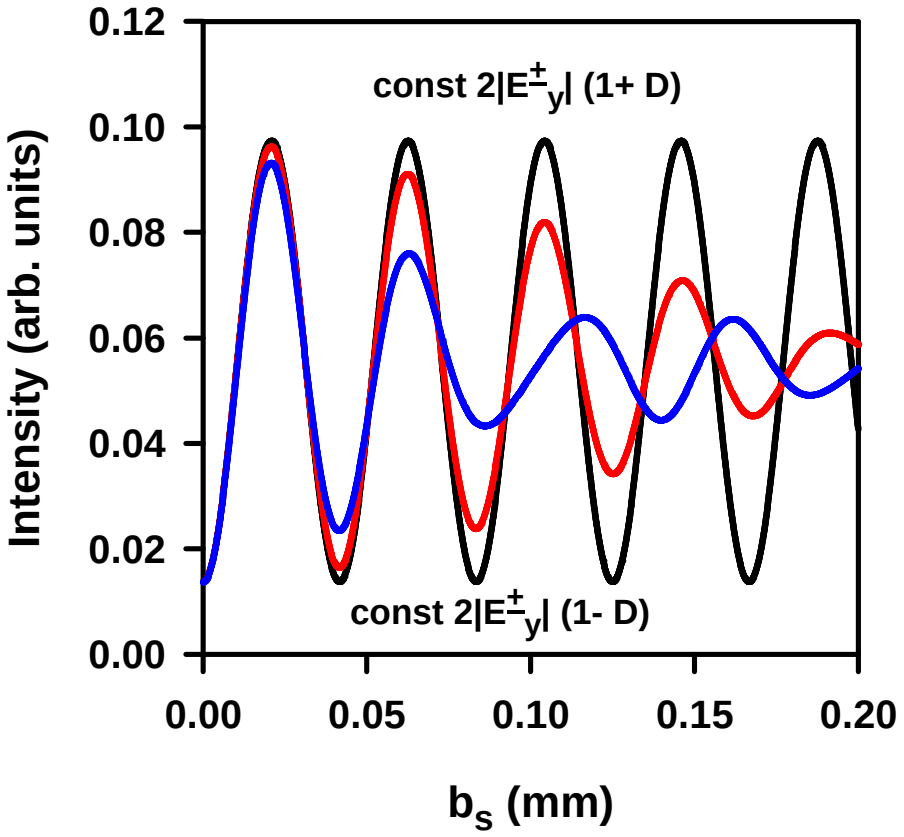
Dependence of the ODR intensity vs. target position



$$D = \int_{-\infty}^{\infty} \mathrm{Gauss}(\sigma_x, \Delta b_s) e^{i4k\alpha\Delta b_s} d\Delta b_s$$

$$= \exp\left[-8k^2\alpha^2\sigma_x^2\right]$$

Visibility

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

Black line – differential intensity

Red line - Dl = 20%

Blue line - Dl = 40%

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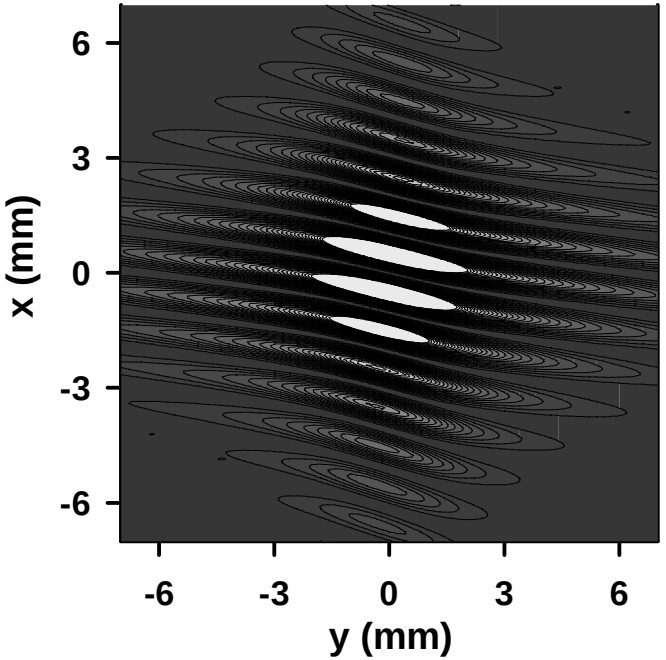
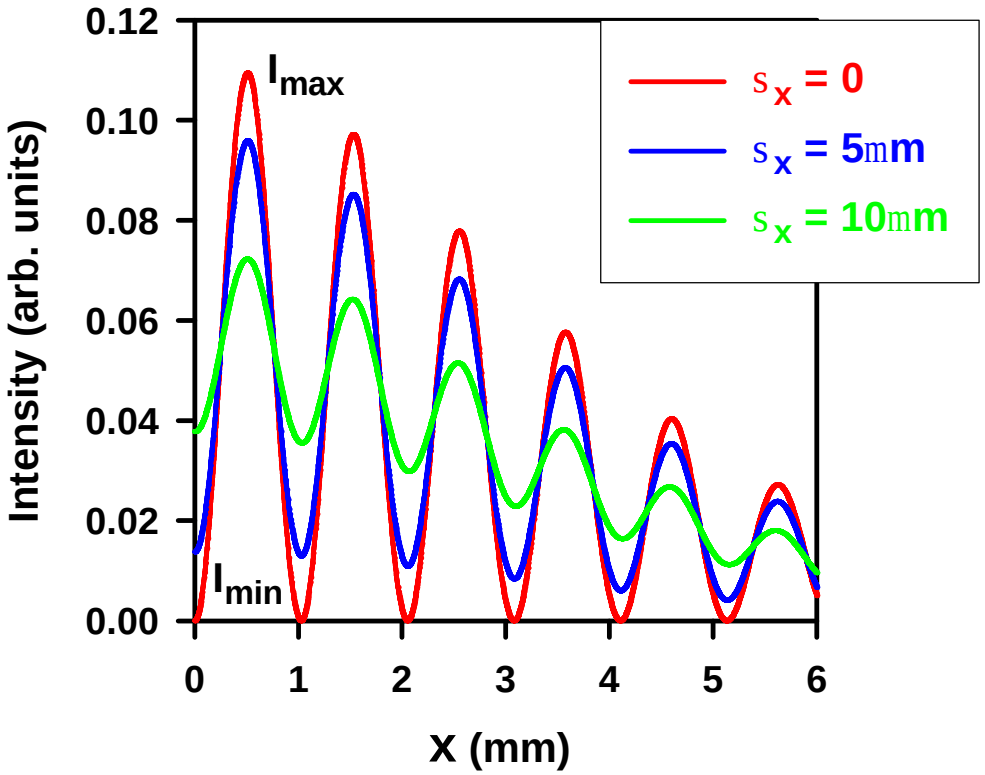
A method for the beam size measurement

ODR interference pattern that could be observed with a CCD





$$\sigma_x = \frac{\lambda}{4\pi\alpha}\sqrt{\frac{\ln\left(V^{-1}\right)}{2}}$$

l = 558nm- observation wavelength;
2a = 6.2mrad - angle between two target plates

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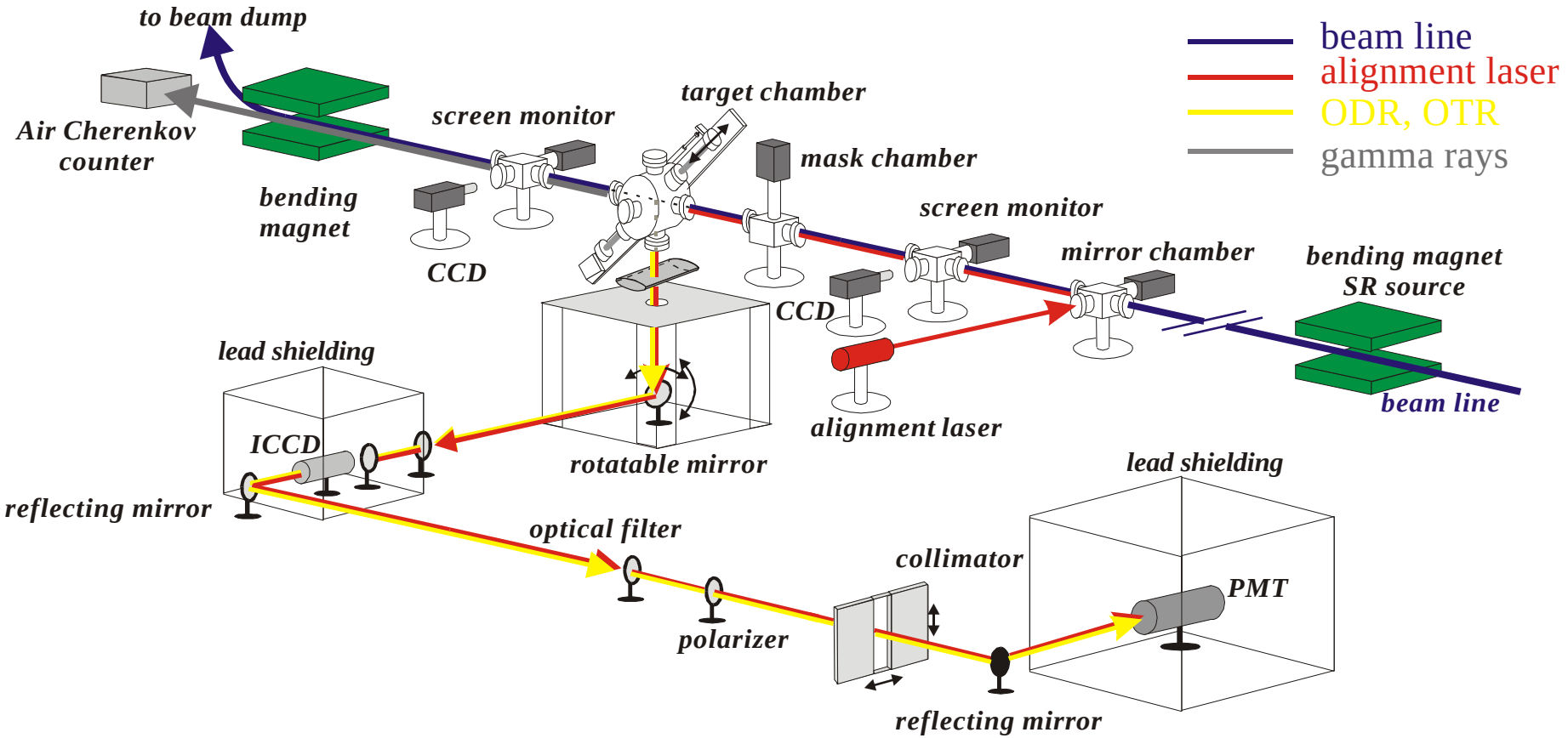
Modified experimental layout



Target to ICCD distance = 1.9m
Lens f = 150mm

Target parameters: $2\alpha = 6.2\text{mrad}$

$a_{in} = 420\mu\text{m}$

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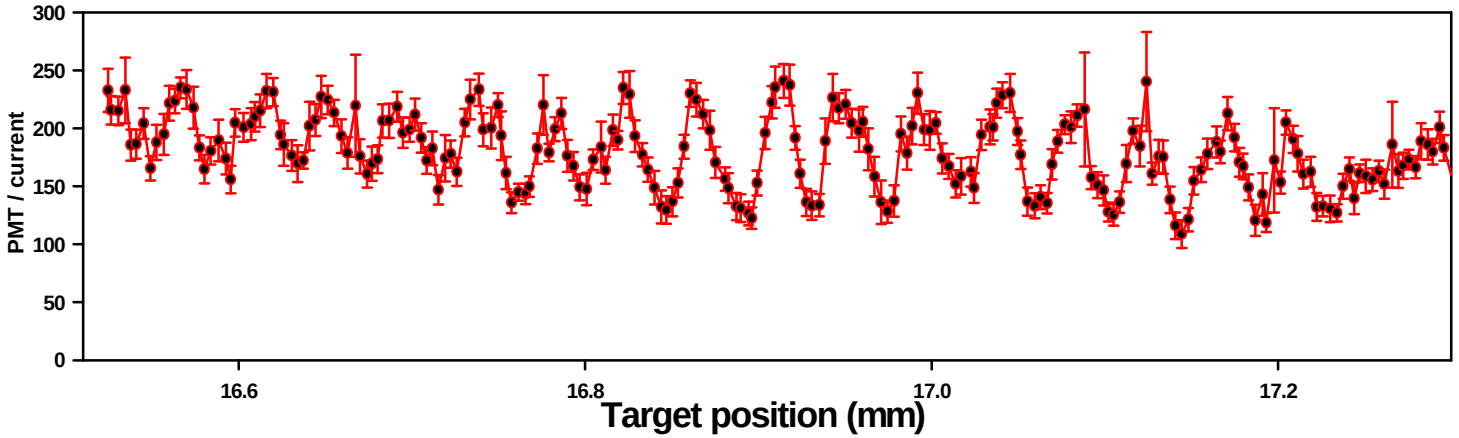
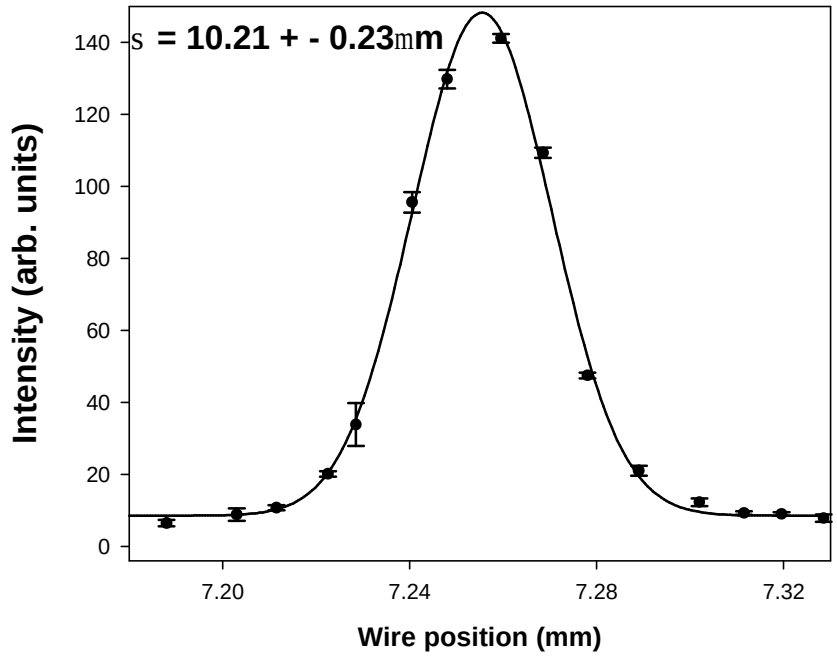
Measurements with photomultiplier



$$\text{Period} = \frac{\lambda}{2\alpha} = 45\mu\text{m}$$



Estimated beam size:

$$\sigma = \frac{\lambda}{4\pi\alpha}\sqrt{\frac{\ln\left(V^{-1}\right)}{2}} = 11.4 \pm 1.2\mu\text{m}$$

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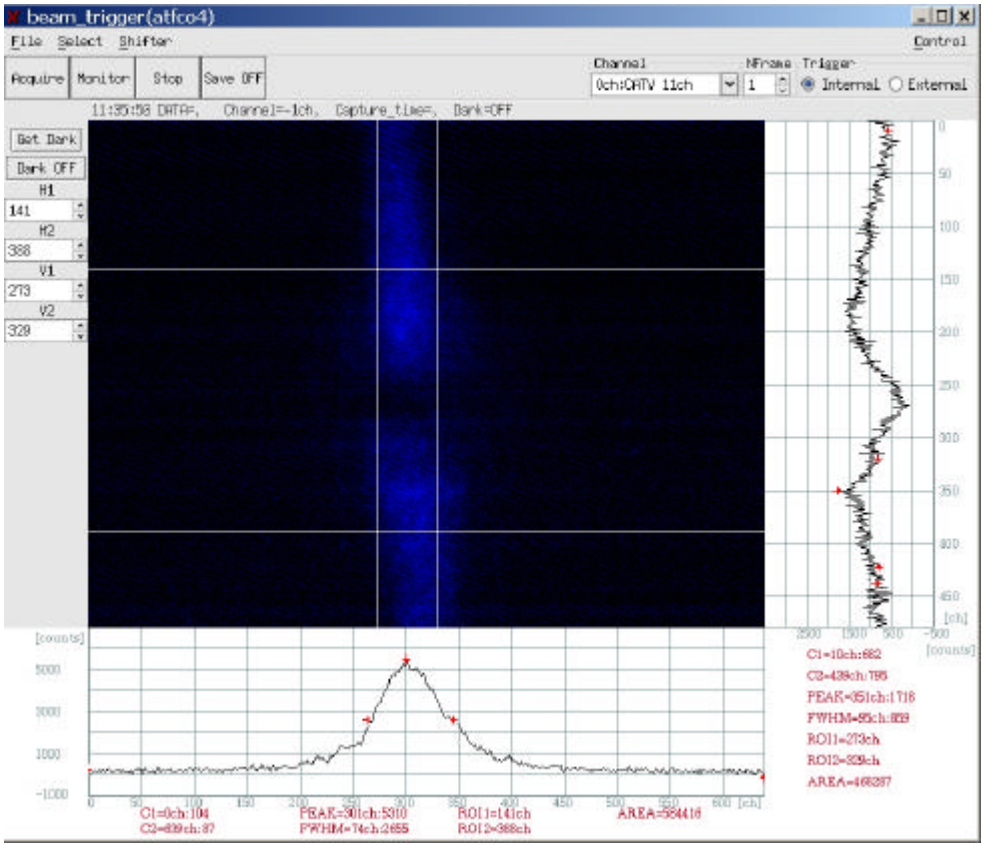
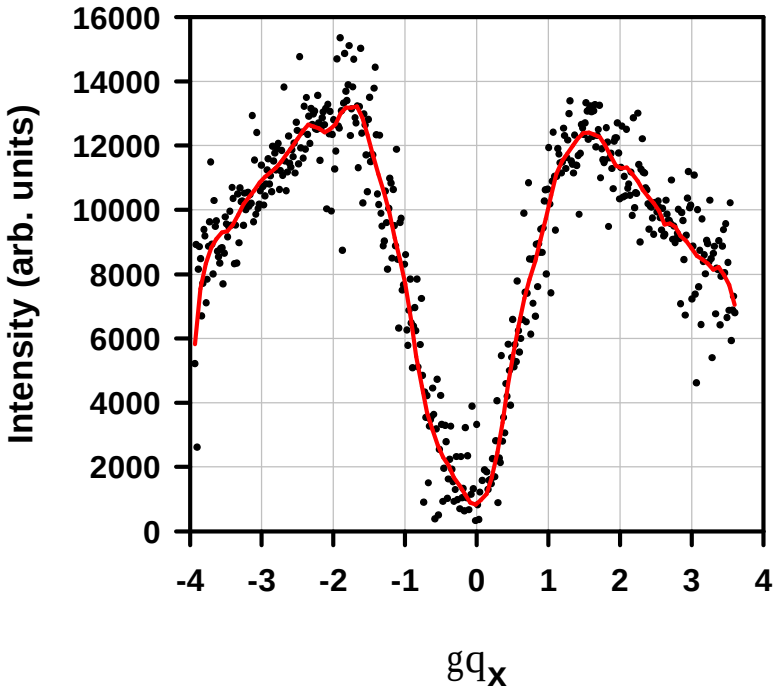
Measurements of OTR with ICCD





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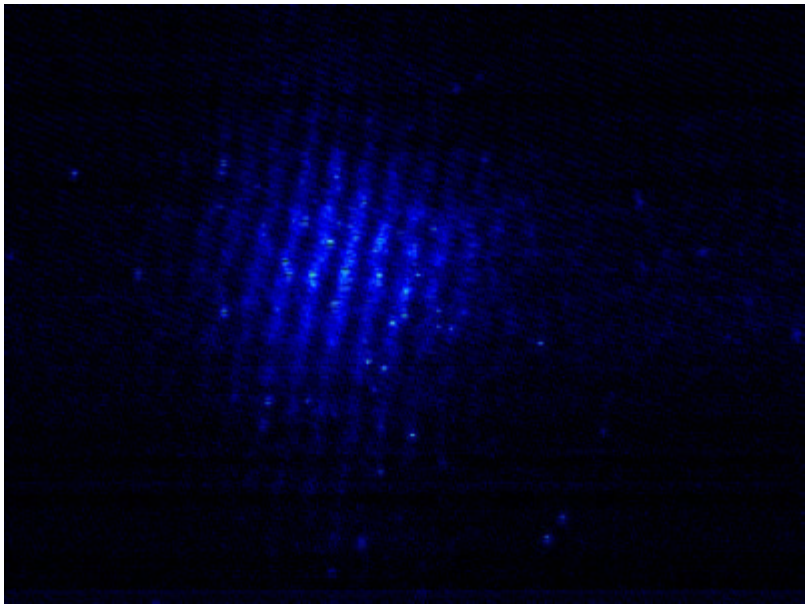
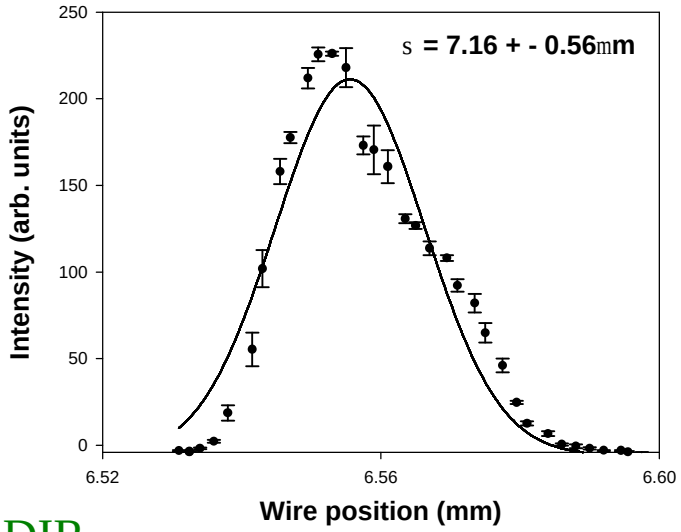
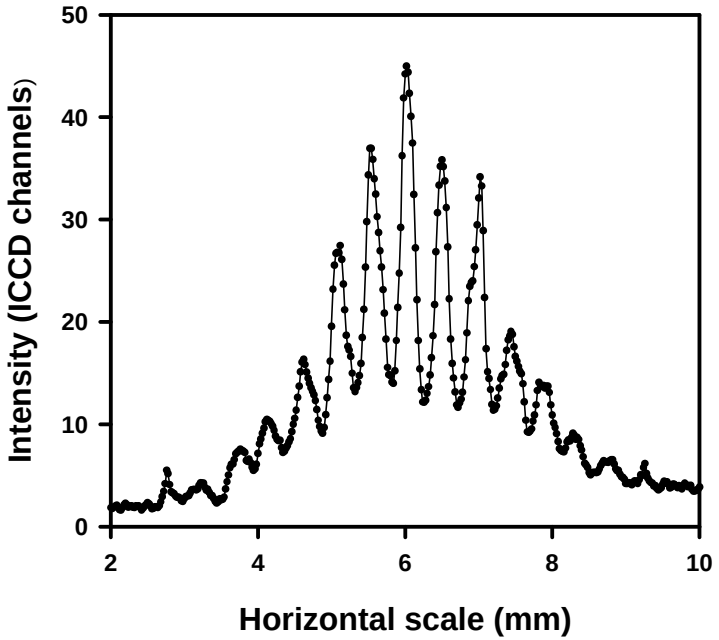
Preliminary of ODR with ICCD

The beam current was increased to 5 10^{10} e/pulse





Integrated over 100 channels of ICCD



Estimated beam size:

$$\sigma = \frac{\lambda}{4\pi\alpha}\sqrt{\frac{\ln\left(V^{-1}\right)}{2}} = 6.2\mu m$$

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Summary

- a new method for micron beam size diagnostics using interference properties of diffraction radiation was developed and tested at the ATF extraction line
- the periodic behavior of the ODR pattern as a function of the target position was confirmed
- a single shot ODR measurements with ICCD was performed
- the electron beam size was estimated and compared with the measurements with wire scanner

- the measurements require very high beam current 5 10^{10}

- it is a promising technique for extremely high energy electrons like SLAC FFTB (γ = 60000)

Non-invasive micron high energy electron beam size measurement using diffraction radiation at SLAC FFTB

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