Optical Transition and Diffraction Radiation for transverse beam size diagnostics

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INTRODUCTION

- **OTR monitor**
- **ODR beam size measurement technique**
- **Future plans on integration of the ODR/OTR technique into the LW beam profile monitor**

Optical Transition Radiation (OTR) monitor

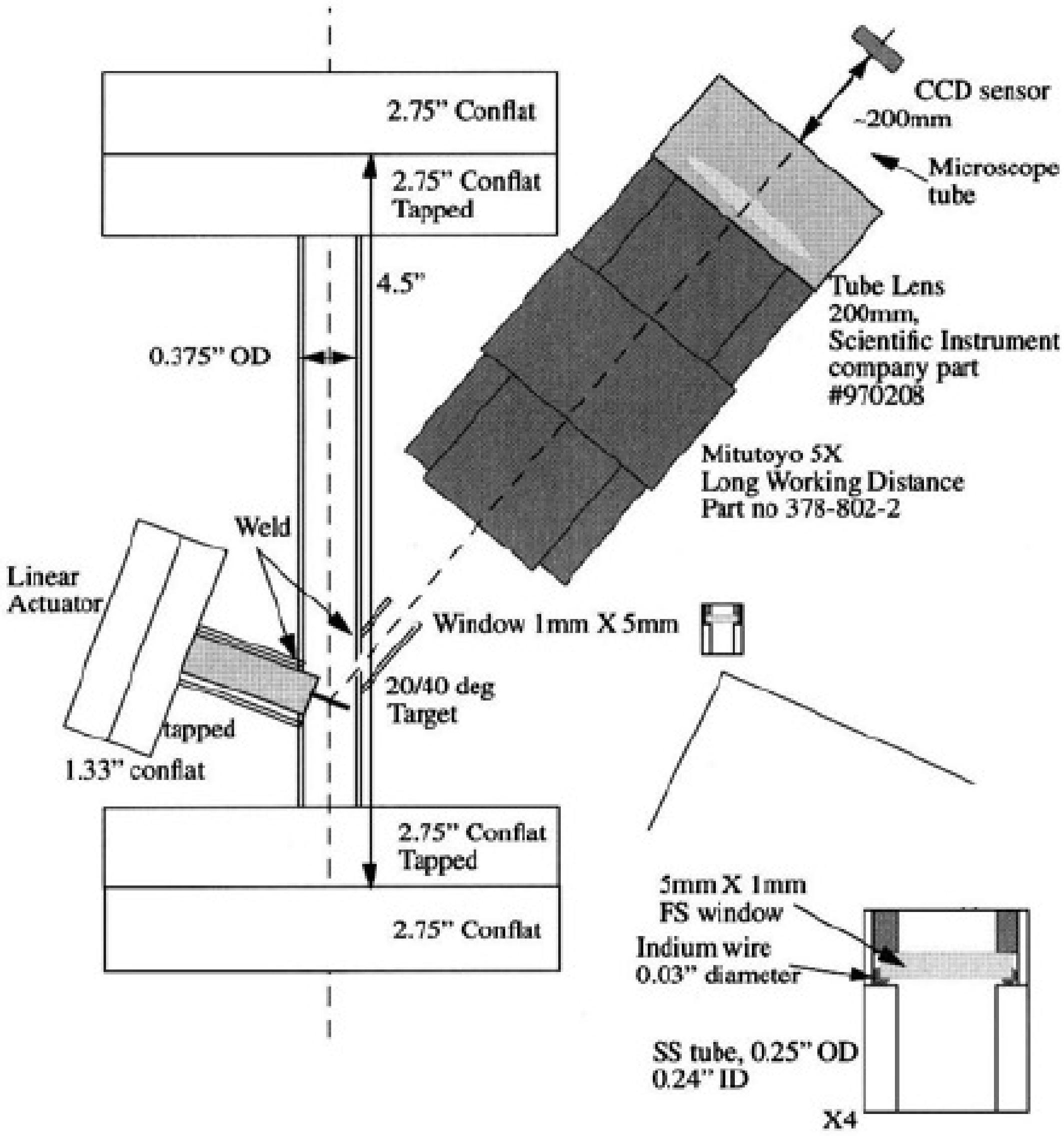
Transition radiation (TR) appears when a charged particle crosses a boundary between two materials with different dielectric properties. The most common geometry of the TR production is when the charged particle crosses a vacuum metal interface.

The single particle effective source dimension is just a few wavelengths wide. It gives an opportunity to use Optical TR (OTR) for monitoring the transverse beam profile with a few micrometer resolution.

A few more advantages:

- **large emission angles;**
- **high resolution;**
- **single shot measurements.**

OTR beam size monitor at KEK-ATF



Estimated resolution was ~2µm; rms beam size as small as 5µm was imaged.

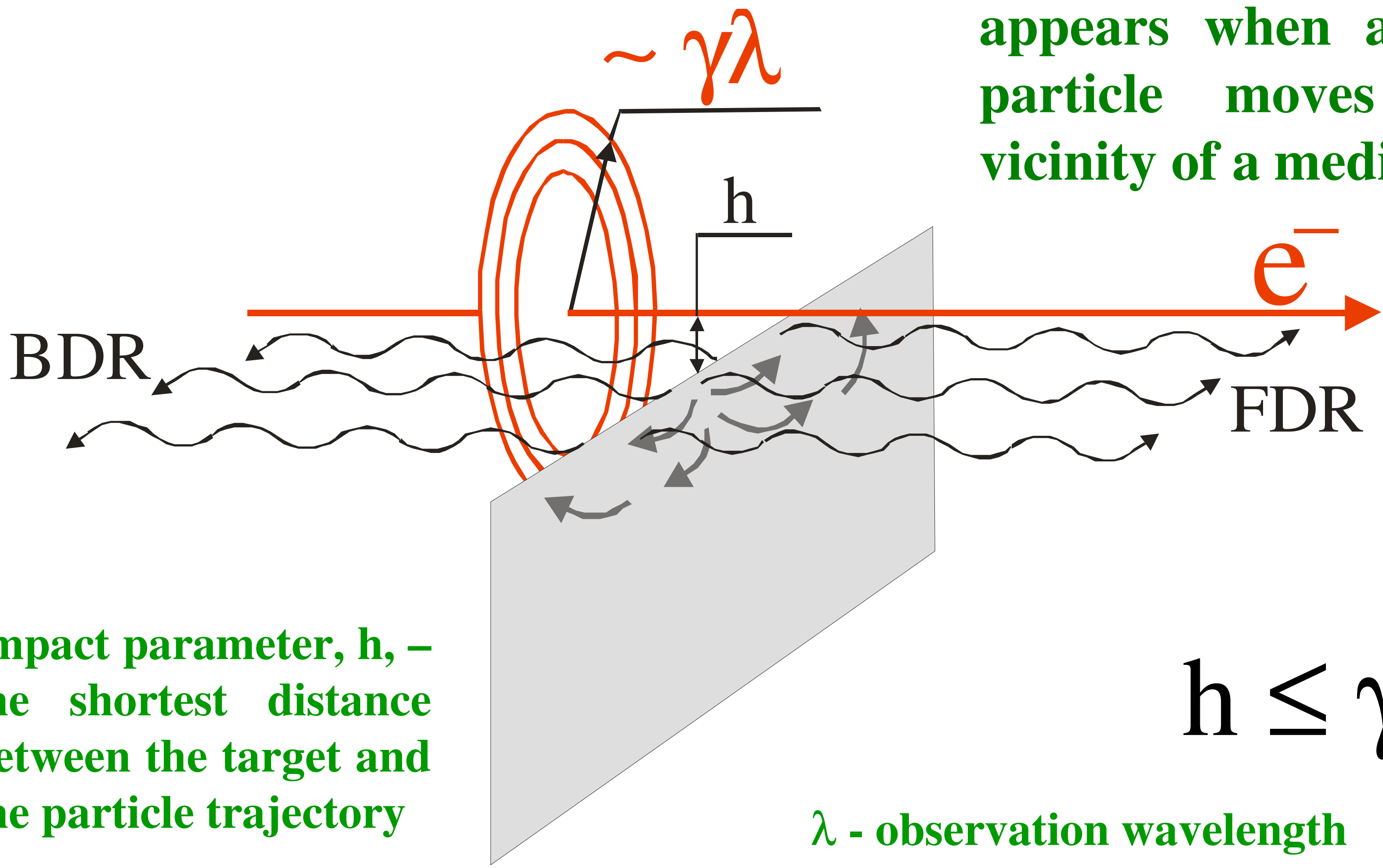
Main aspects:

- **easy to measure as the measurement system is away from the beam line and the light density is high enough to ignore synchrotron radiation contribution;**
- **field depth is important because the target is not parallel to observation plane.**
- **target damage is a problem but large beams or low intensity beams can still be measured.**

M. Ross, et al., 10th Beam Instrumentation Workshop, Upton, New York, 5/6/2002 - 5/9/2002

Diffraction Radiation

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

$$h \leq \gamma\lambda$$

λ - observation wavelength

$\gamma = E/mc^2$ – Lorentz - factor

Advantages of the ODR technique

- **Non-invasive method**

  (no beam perturbation or target destruction)

- **Instantaneous emission**

  (quick measurements)

- **Single shot measurements**

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

- **Large emission angles (0 ~ 180^0)**

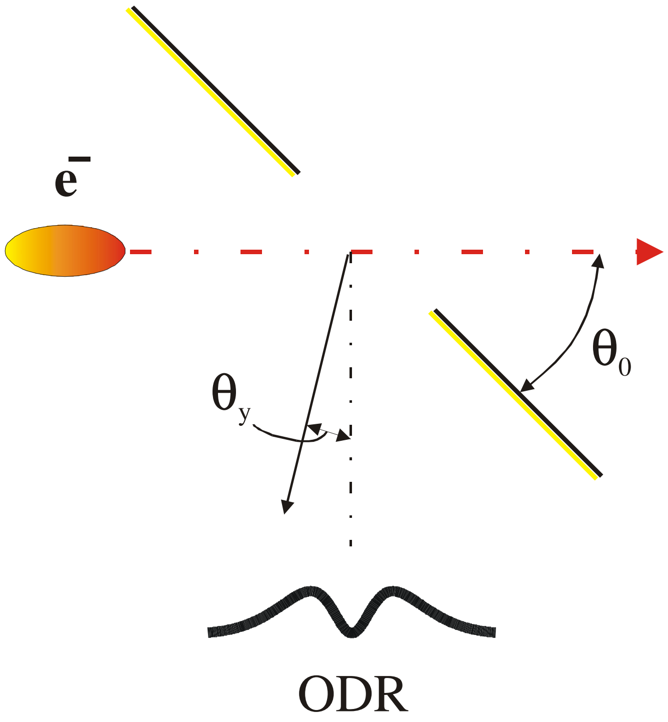
  (good background conditions)

- **~1-2μ resolution is achievable**

  (fits the ILC requirement)

Theoretical approach

(only vertical polarization component is sensitive to the vertical beam size)

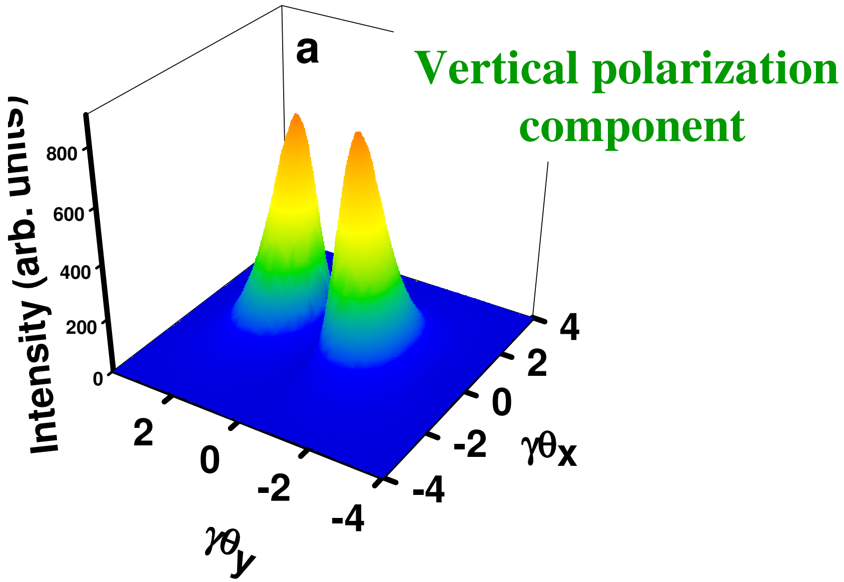


$$\frac{d^2W_y^{slit}}{d\omega d\Omega} = \frac{\alpha|R_y|^2}{4\pi^2}\frac{\exp\left(-\frac{2\pi a\sin\theta_0}{\lambda}\sqrt{\gamma^{-2}+\theta_x^2}\right)}{\gamma^{-2}+\theta_x^2+\theta_y^2}\times$$
$$\left\{\exp\left[\frac{8\pi^2\sigma_y^2}{\lambda^2}\left(\gamma^{-2}+\theta_x^2\right)\right]\cosh\left[\frac{4\pi a_s}{\lambda}\sqrt{\gamma^{-2}+\theta_x^2}\right]-\cos\left[\frac{2\pi a\sin\theta_0}{\lambda}\theta_y+2\psi\right]\right\}$$

$|R_y|^2$ is the Fresnel reflection coefficients;
α is the fine structure constant;
γ is the charged particle Lorentz-factor;
λ is the radiation wavelength;
θ_y and θ_x are the observation angles measured from the mirror reflection direction;
θ_0 is the target tilt angle;
σ_y is the rms Gaussian beam size;
a_s is the offset of the electron beam wrt to the slit centre.

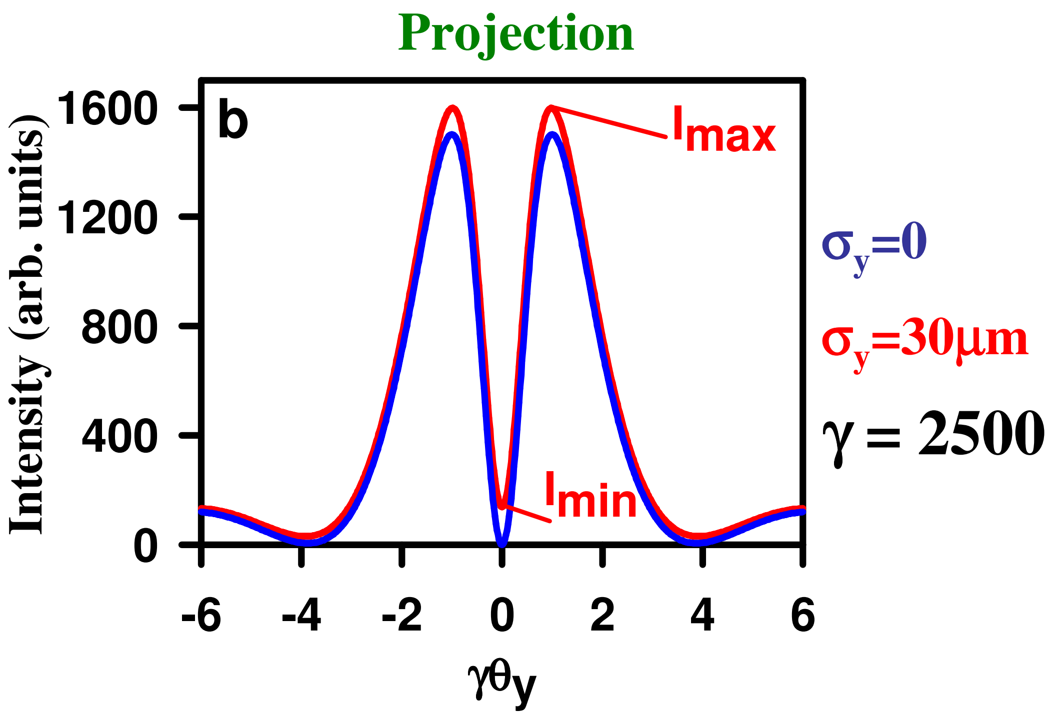
- **ODR intensity decreases exponentially as a function of the ODR photon energy or as a function of the slit size.**
- **Dependence on the size of the electron beam is similar to the dependence on the beam offset wrt to the slit center.**

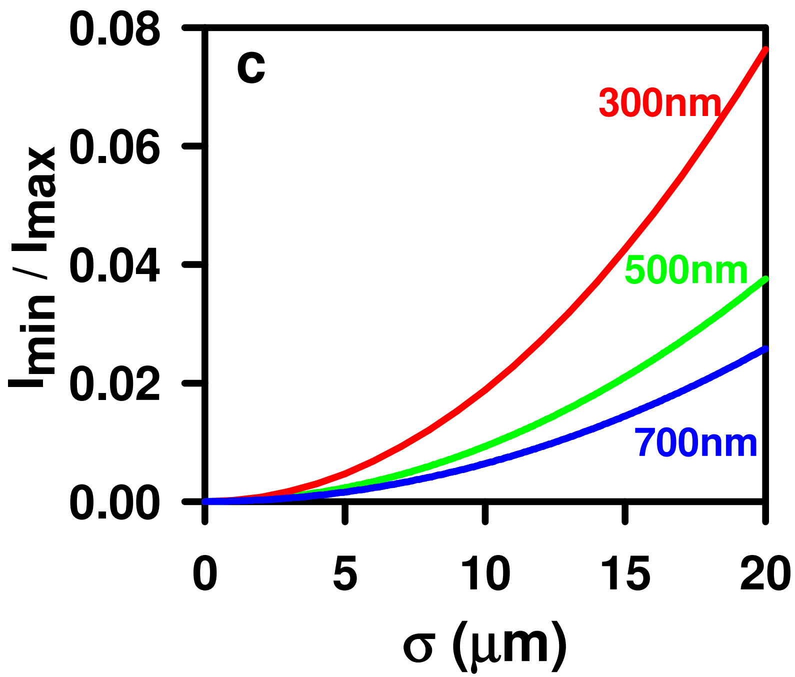
Beam size effect



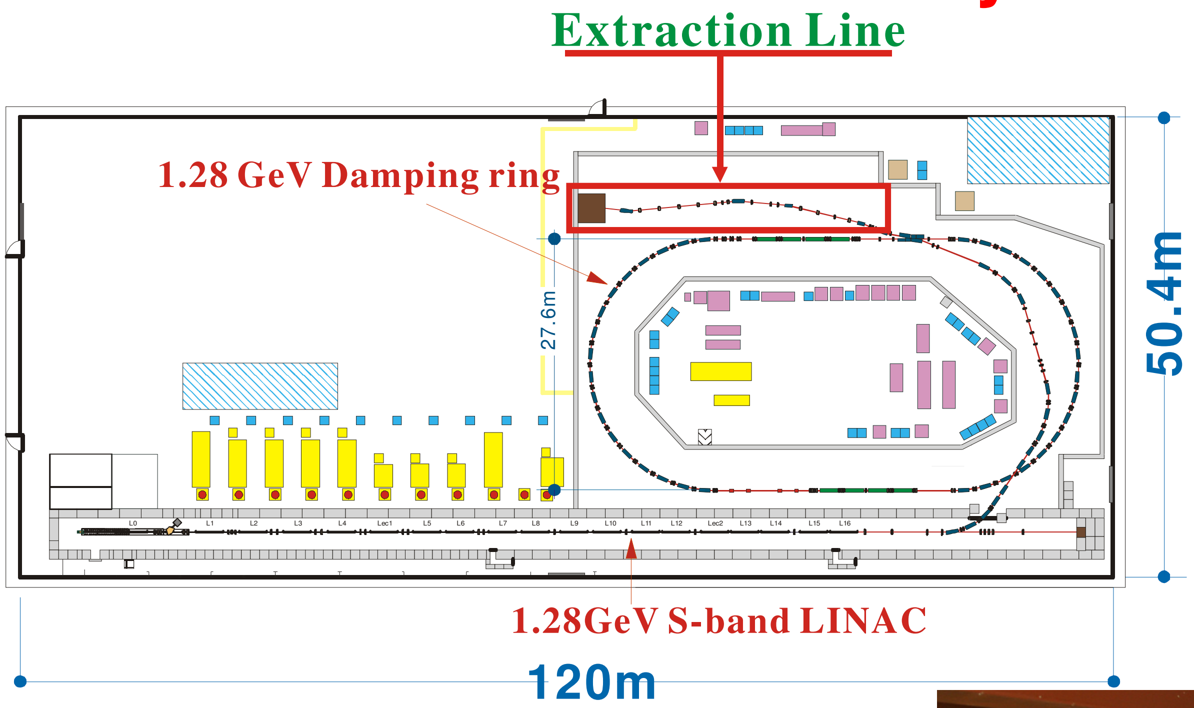
Mostly the radiation in the minimum between two peaks depends on the electron beam size; therefore, it is natural to collect all photons between those peaks and increase the signal-to-noise ratio.

One may see that the sensitivity to the beam size is better at shorter wavelengths (lower right picture). However, due to the intensity decrease some optimization of the experimental conditions is required.





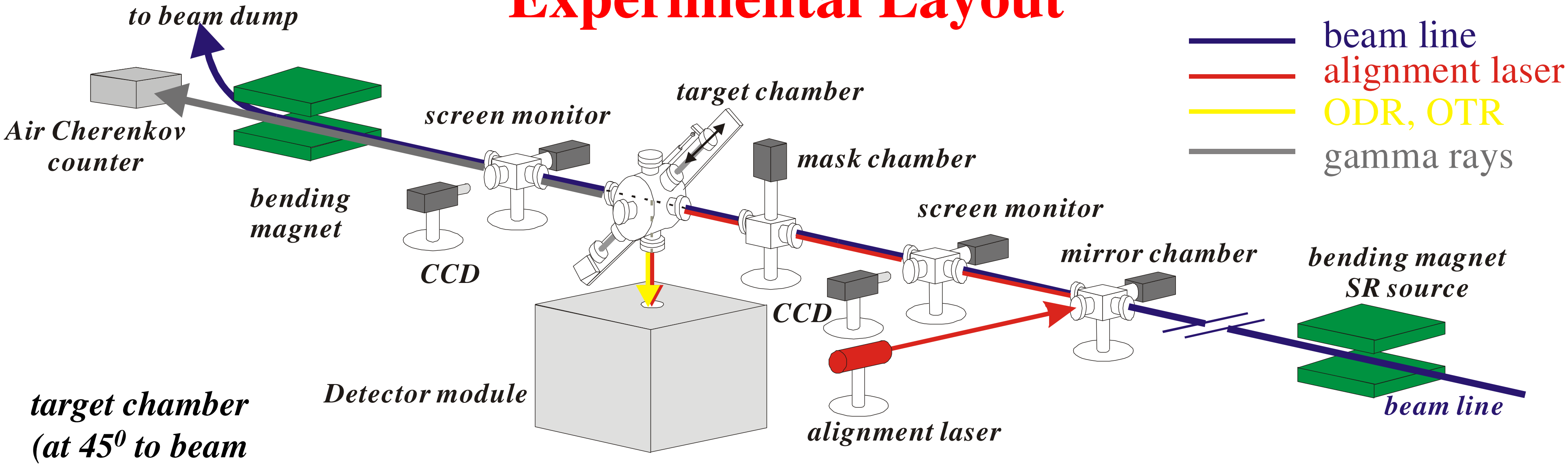
Accelerator Test Facility at KEK



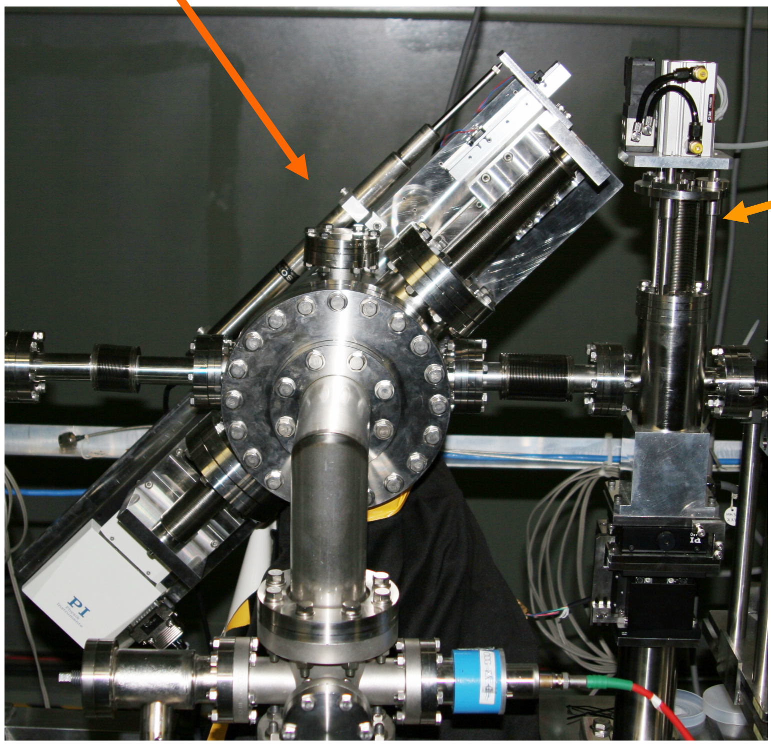
Electron beam parameters

Maximum energy		1.28 GeV ($\gamma = 2500$)
Beam emittance	Vertical	$(1.5 \pm 0.25) \times 10^{-11}$ m rad
	Horisontal	$(1.4 \pm 0.3) \times 10^{-9}$ m rad
Vertical beam size (near the ODR target)		$\sigma_y < 10\mu$
Horizontal beam size (near the ODR target)		$\sigma_x < 100\mu$
Bunch length		~ 8 mm
Single-bunch population (max)		2×10^{10}
Energy spread		0.08%

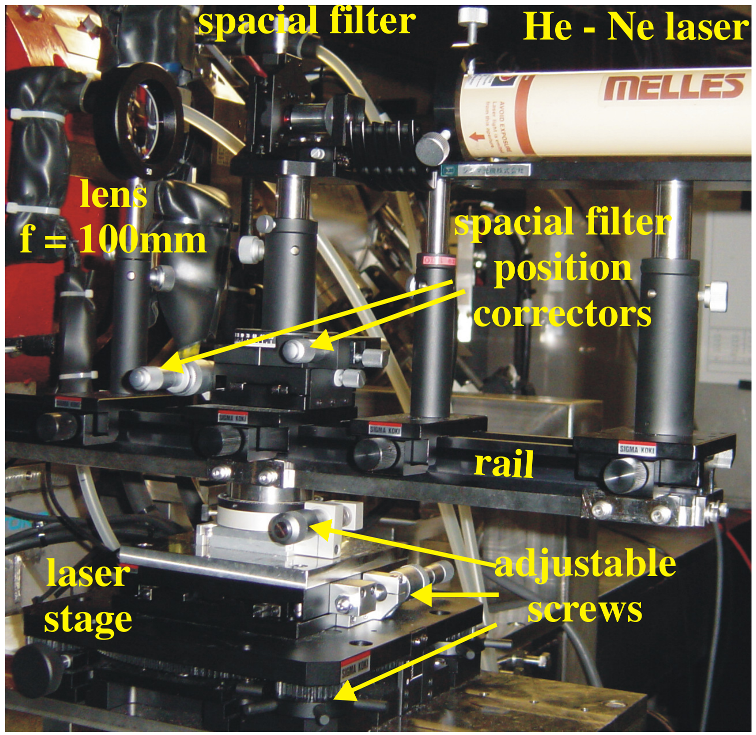
Experimental Layout



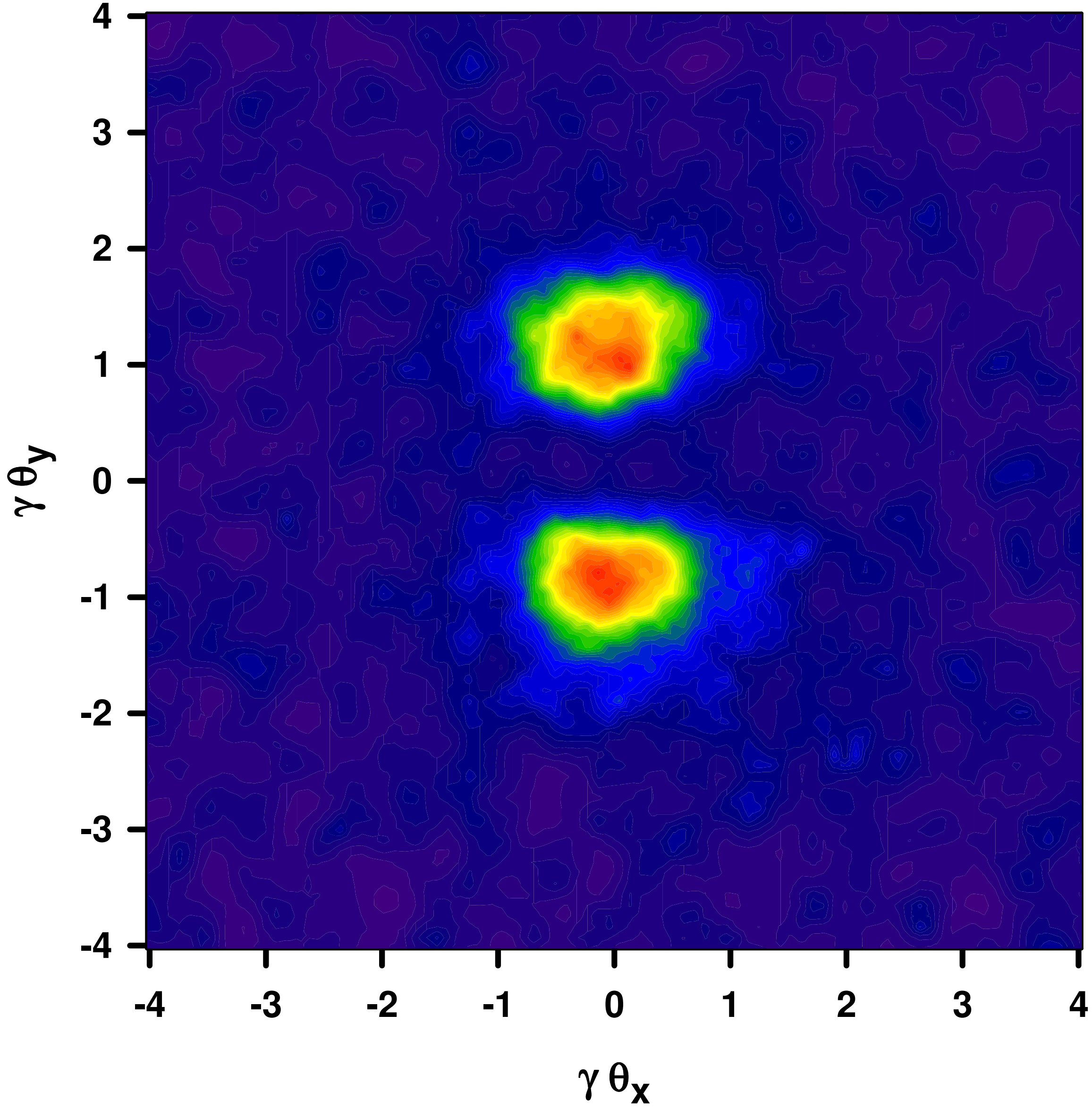
target chamber (at 45^0 to beam trajectory)



SR mask cuts off the dominant part of the synchrotron radiation

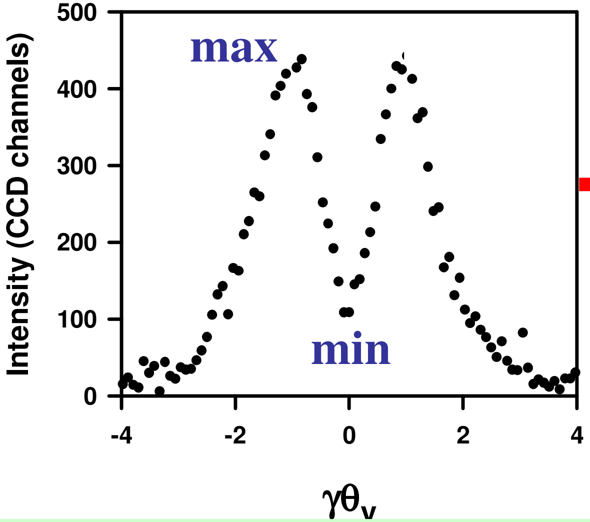


Typical CCD image measured in the back focal plane of the lens

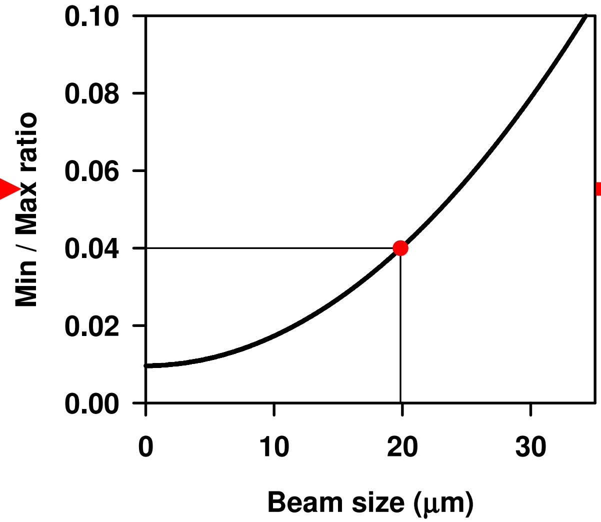


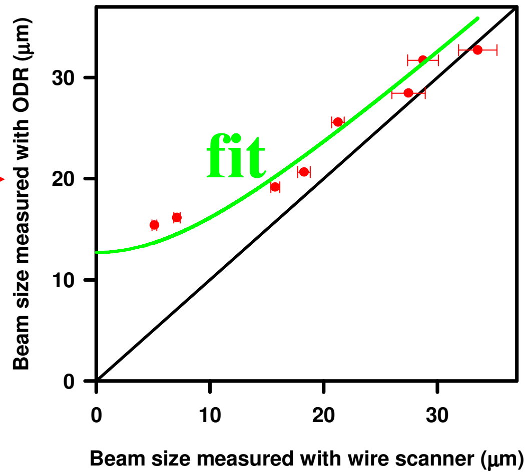
Visibility of the ODR vertical Polarization component depends on the electron beam size

Single-shot beam size measurements with Optical Diffraction Radiation



Calibration curve





Beam diagnostics procedure:

The left most figure represents the experimentally measured projection (integrated over x angular variable along the minimum) of the vertical polarization component. The visibility of the curve is sensitive to the beam size. From the experimental dependence we determine the maximum and central minimum values. Comparing the min-to-max ratio wit the one calculated for exactly the same parameters (see picture on the middle) we determine the beam size. The right most figure represents a correlation between the beam sizes measured with the ODR method and the 10μm tungsten wire mounted on the target holder. Using the following fit function we defined the resolution of our monitor.

Fit function:

$$\sigma_{ODR} = \sqrt{a_0^2 + \sigma_{WS}^2}$$

$$a_0 = 12.7 \pm 1.0$$

Plans

- the ODR technique will be integrated into Laser Wire system at ATF2 to cover the beam sizes from 20μm to 50μm;
- we shall partially re-use the existing equipment we have created during the last 7 years;
- ODR target will be upgraded to be able to measure both vertical and horizontal beam sizes [P.Karataev, et al., NIM B 227 (2005) 198];
- The project will be proposed to the ATF TB in December, 2007.
- Cavity Beam Position monitors will be used to eliminate the shot-by-shot jitter effect.

Laser Wire Beam Profile Monitor

BESSY

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DESY

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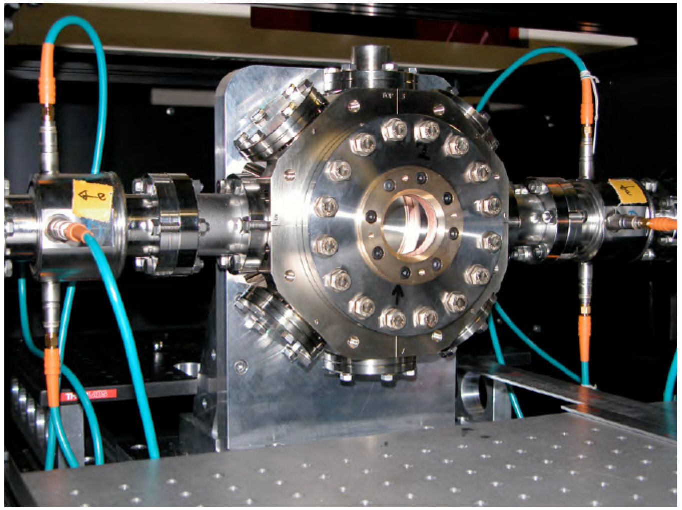
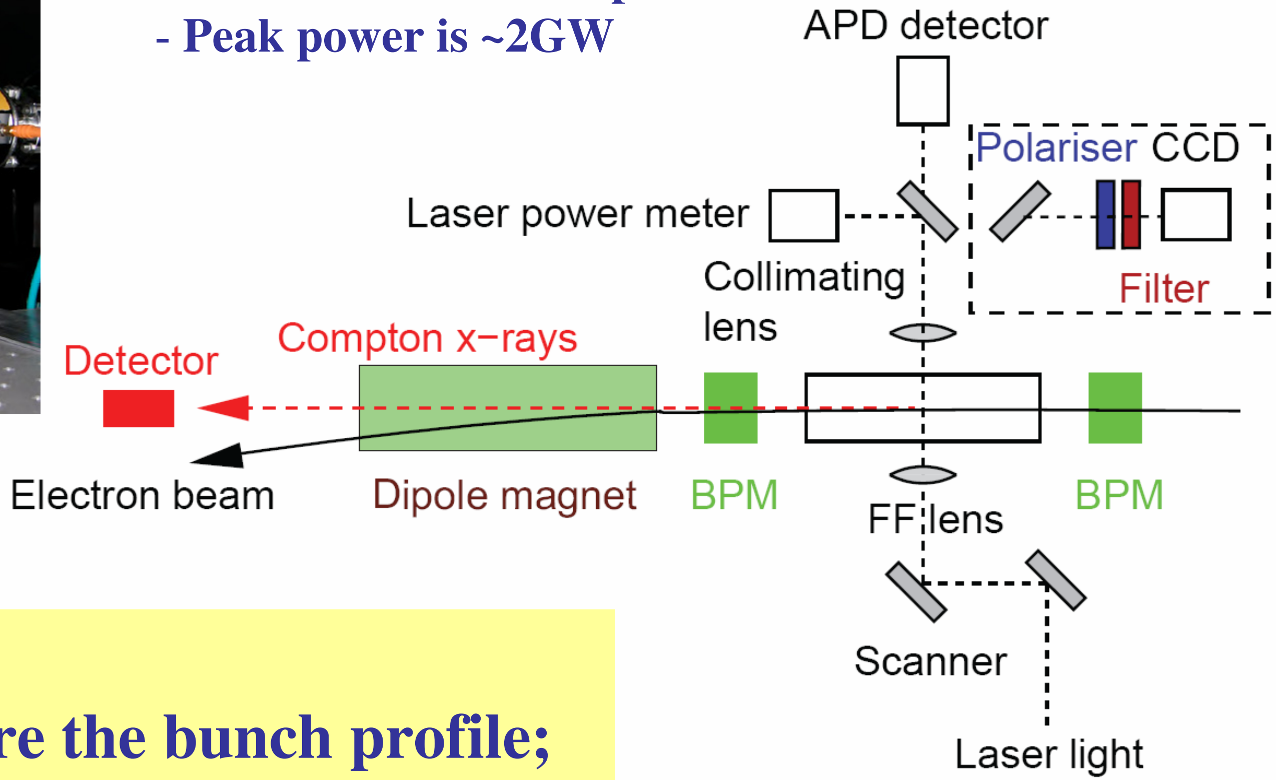
M. Ross

Laser Wire Layout



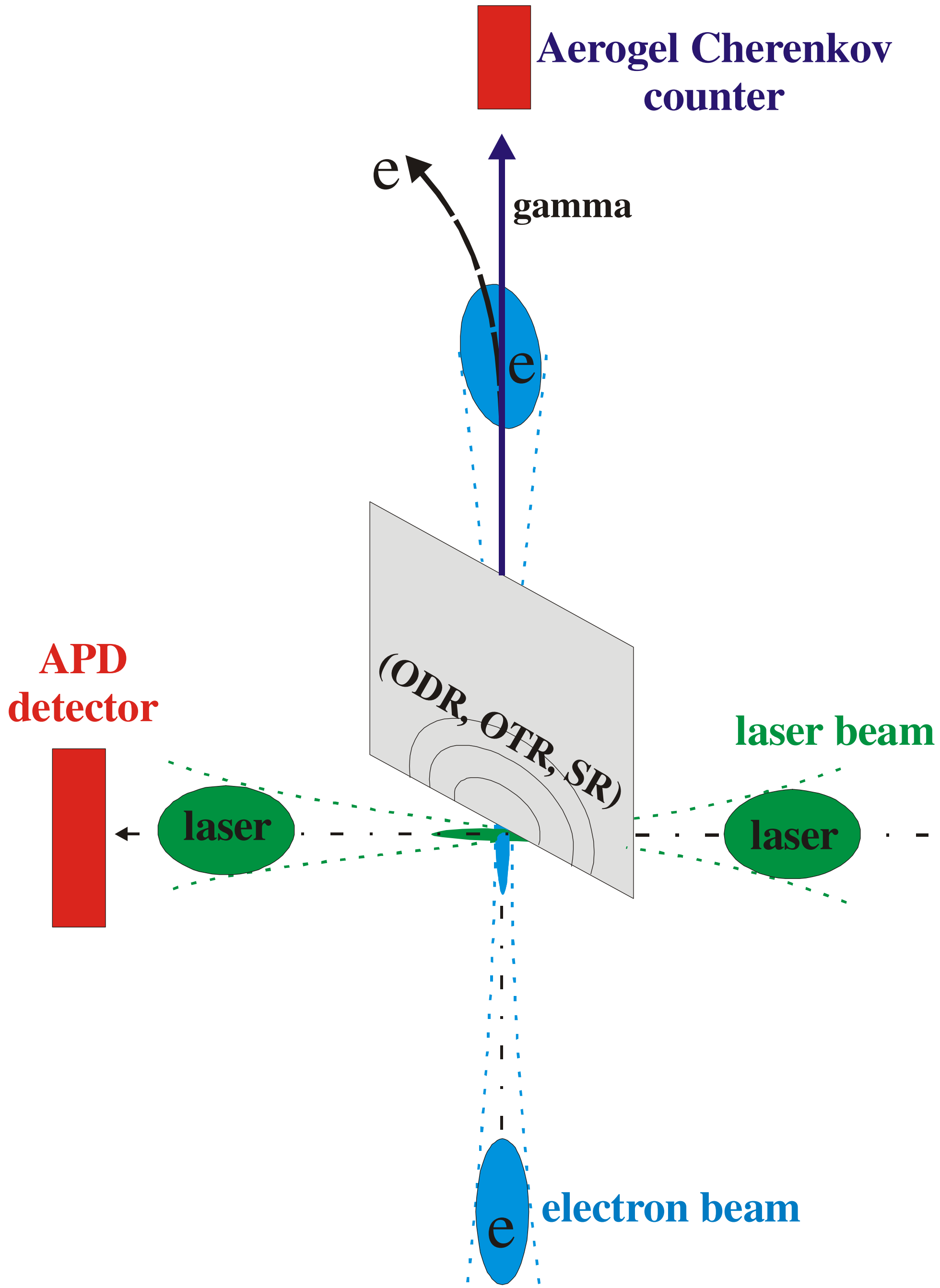
LW IP Chamber

The laser parameters:
- Pulse duration is 200ps
- Peak power is ~2GW



Problems are:
- Long time to measure the bunch profile;
- Requires a team of experts for operating the device;
- accuracy decreases when both decreasing the beam intensity
- and increasing the beam size.

Timing and position matching



The initial purposes were:

- ❑ to match the e-beam--laser arrival time;
- ❑ to match the e-beam--laser position;
- ❑ to align the laser optics;
- ❑ to measure the laser size with the knife edge.

❑ the screen is mounted on a 4D vacuum manipulator and tilted with 450 wrt to the beam trajectory;
❑ we will make a few rectangular holes in the screen for ODR;
❑ the screen will be big enough to measure the beam size with OTR.

ODR/OTR technique integration in the Laser Wire system for ATF2

- ODR technique will cover the beam sizes in the range 20 ~ 50μm;
- OTR technique will cover the beam sizes in the range >50μm (or low beam charge);

- Solid 10μm thick tungsten wire scanner will be integrated for a cross check;
- Two Cavity Beam Position Monitors (about 0.2μm resolution) will be attached from both sides of the LW IP for beam jitter control;
- At ATF2 the LW IP position is right after the coupling correction section which perfectly suits this kind of experiment