UV/X-ray Diffraction Radiation for Non-Intercepting Micron-Scale Beam Size Measurement

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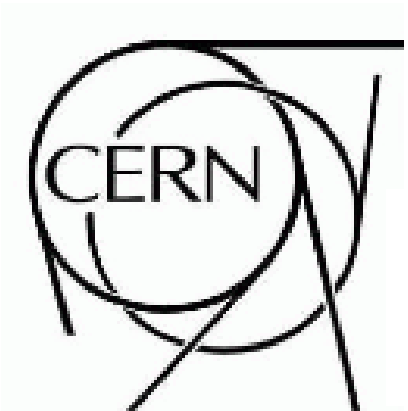

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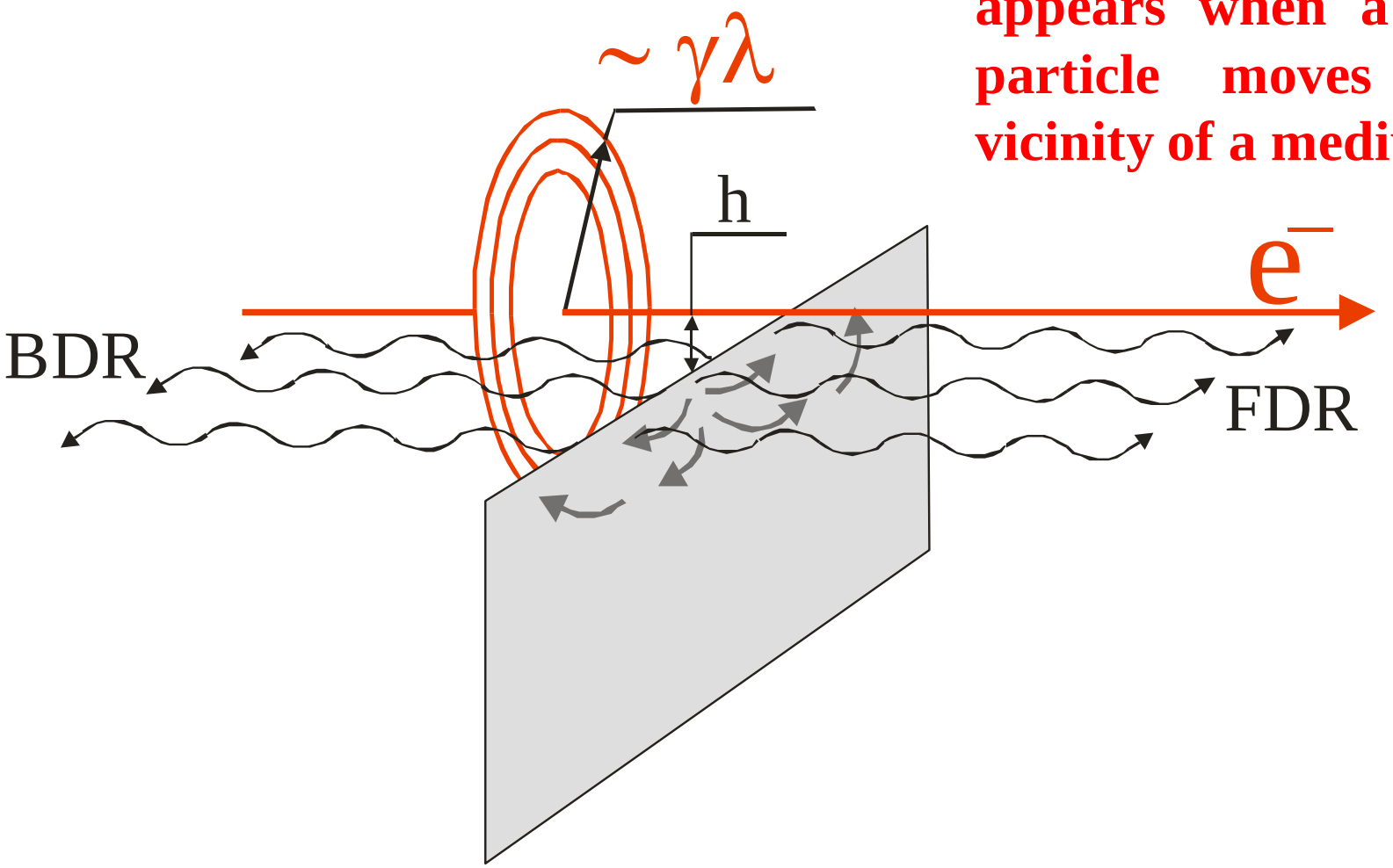
What is diffraction radiation?

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 ($0 \sim 180^0$)**

  (good background conditions)

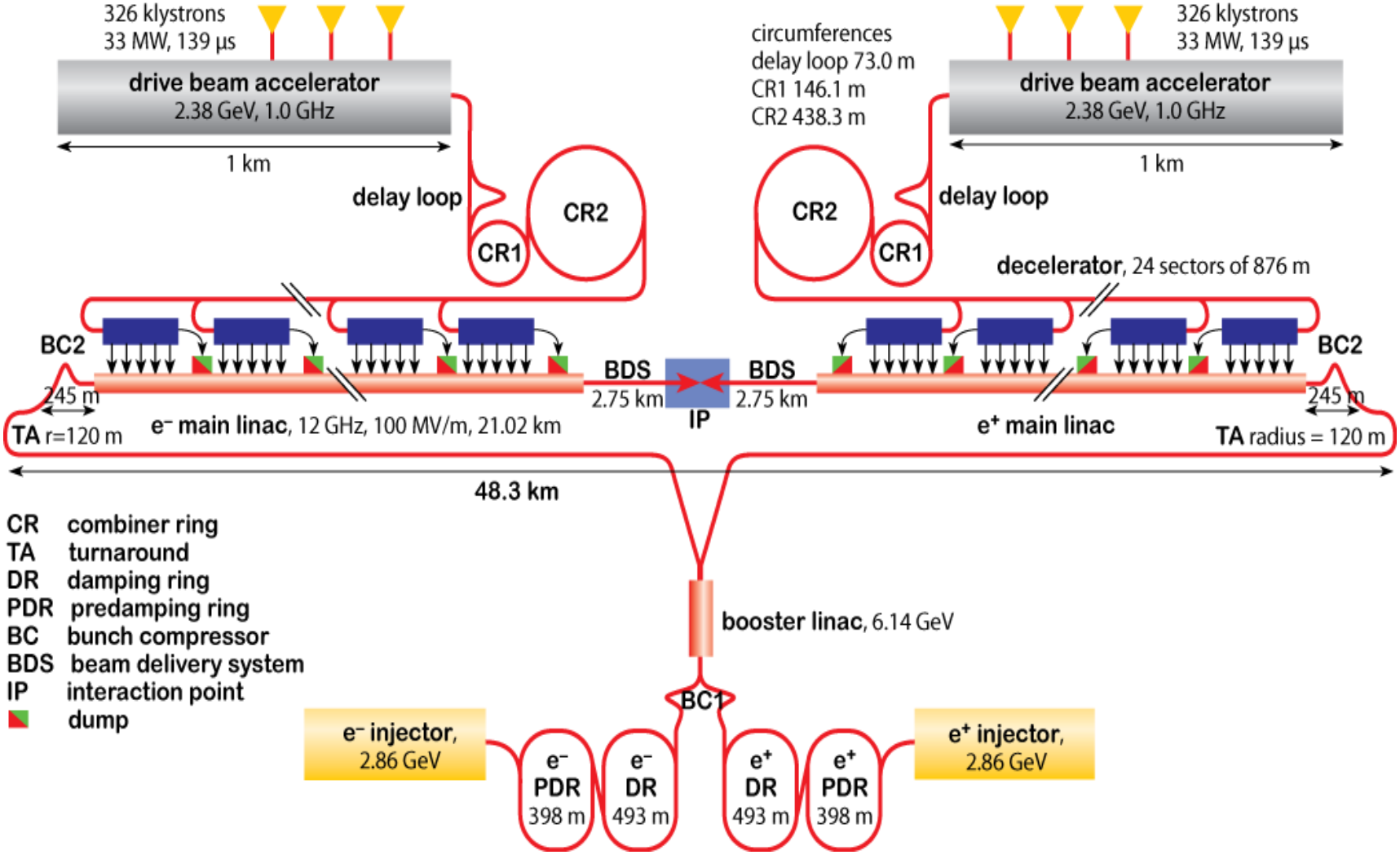
ODR developments

- A. Lumpkin, et al., Near-field imaging of optical diffraction radiation generated by a 7-GeV electron beam, at Advanced Photon Source, Physical Review ST – AB 10 (2007) 022802
- A. Cianchi et al., Non-Intercepting Diagnostics for High Brightness Electron Beam Using Optical Diffraction Radiation Interference, at FLASH (DESY), RREPS'11 (next talk)
- P. Karataev, et al., Beam-Size Measurement with Optical Diffraction Radiation at KEK Accelerator Test Facility, Physical Review Letters 93 (2004) 244802

The State-of-the-Art

- There are a few experiments in Optical Diffraction Radiation finished or still ongoing
- Sensitivity to the beam size as small as 14 μm was achieved at KEK
- The resolution was limited by
  - Diffraction limit
  - Residual synchrotron radiation background
  - Non-optimal measurement system

Motivation to Continue



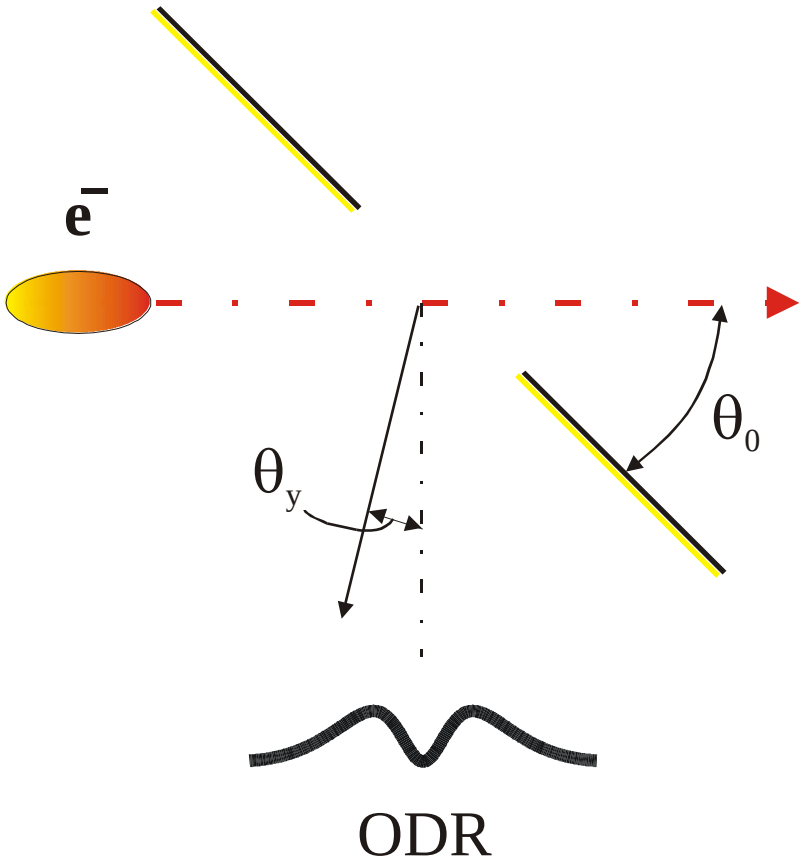
Motivation to Continue

- **The state-of-the-art in transverse beam diagnostics for linear colliders is Laser-Wire**
  - ✓ **nearly a 1000 beam profile monitors is required!**
  - ✓ **nearly 130 with extremely high resolution 1 - 10um**
  - ✓ **one Laser-Wire emittance measurement system including laser, multi-IP transport system, and IPs costs £1m,**
  - ✓ **Requires a team of people for maintenance.**

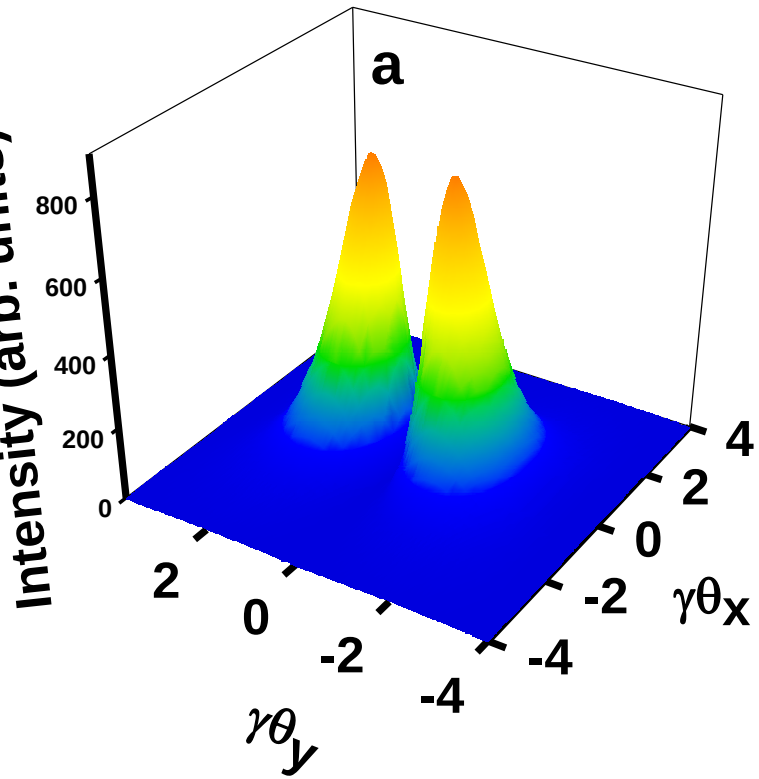
- **An alternative simple (but may be not that precise) solution is required**

UV/X-ray DR is a part of CLIC – UK Collaboration

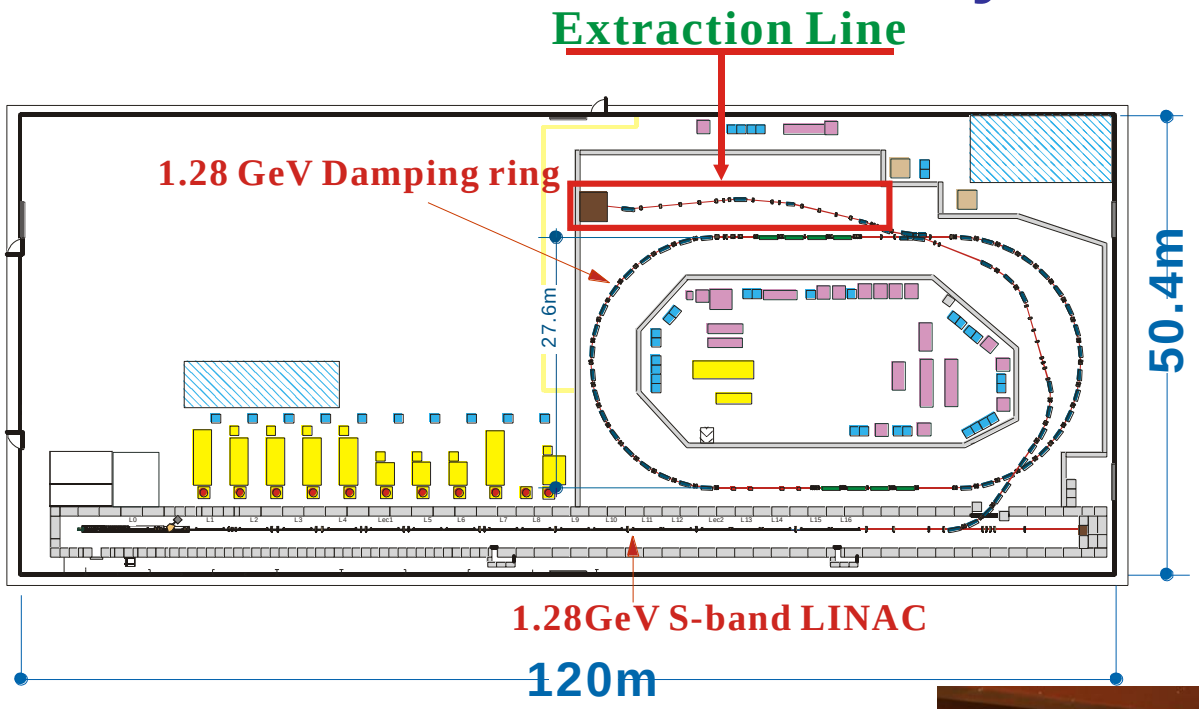
Basic Principle



Vertical Polarization component



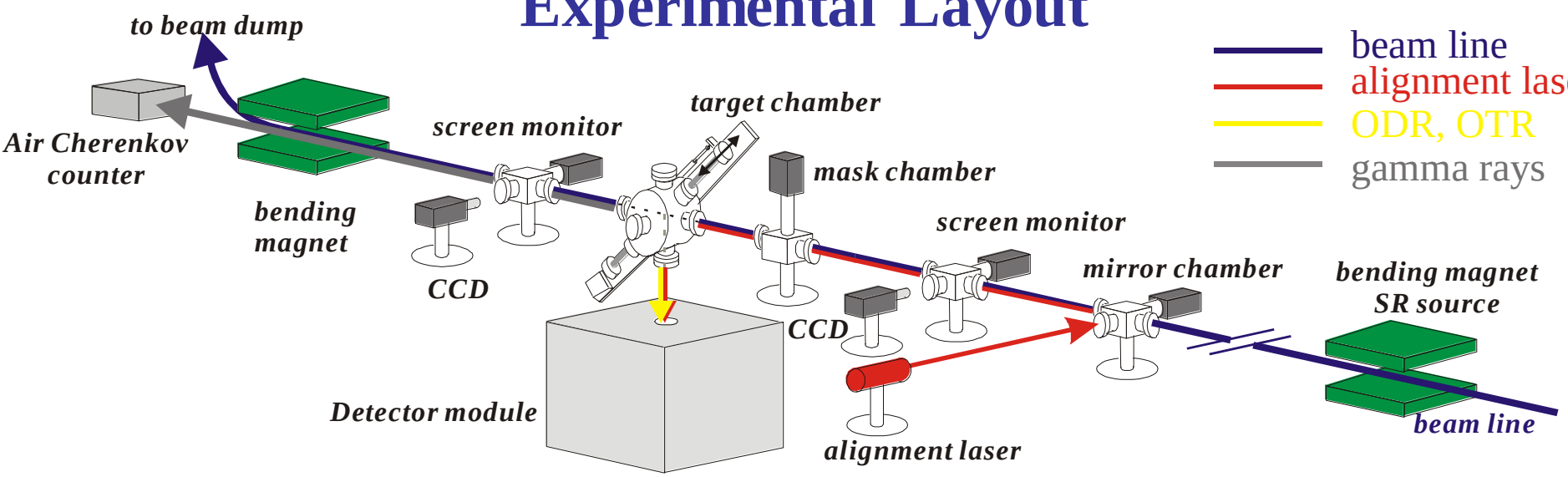
Accelerator Test Facility at KEK

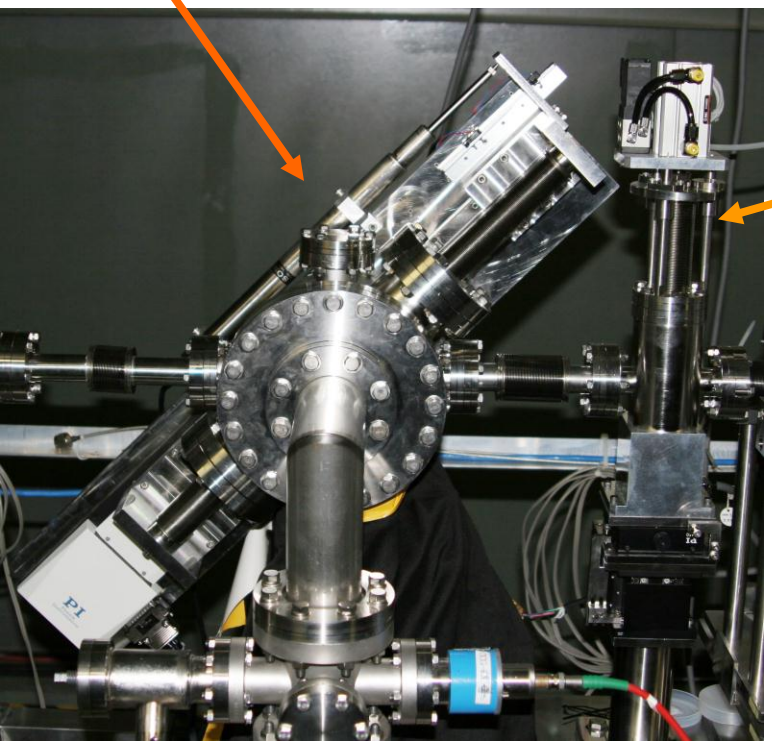


Electron beam parameters

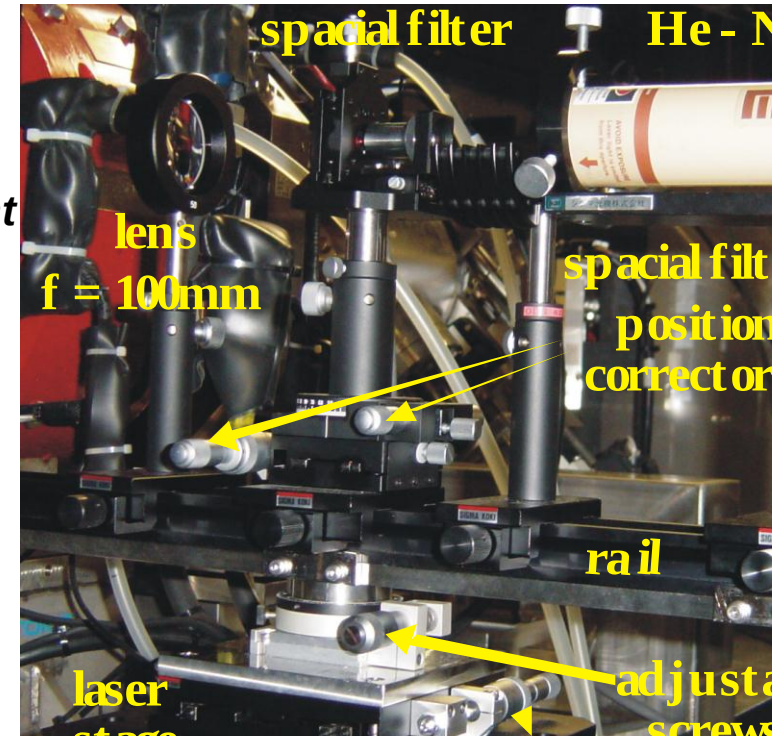
Maximum energy		1.28 GeV ($\gamma = 2500$)
Beam emittance	Vertical	$(1.5 \pm 0.25) \times 10^{-11}$ m rad
	Horisontal	$(1.4 \pm 0.3) \times 10^{-9}$ m rad
Vertical beam size (near the ODR target)		$\sigma_y < 10\mu$
Horizontal beam size (near the ODR target)		$\sigma_x < 100\mu$
Bunch length		~ 8 mm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

Experimental Layout

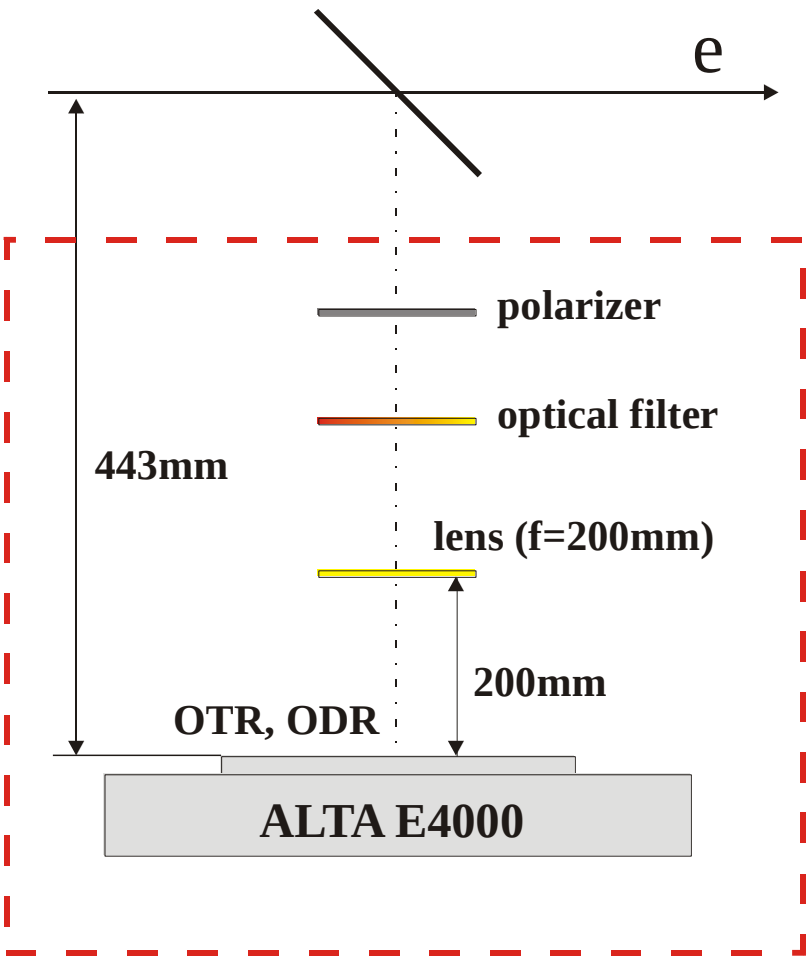




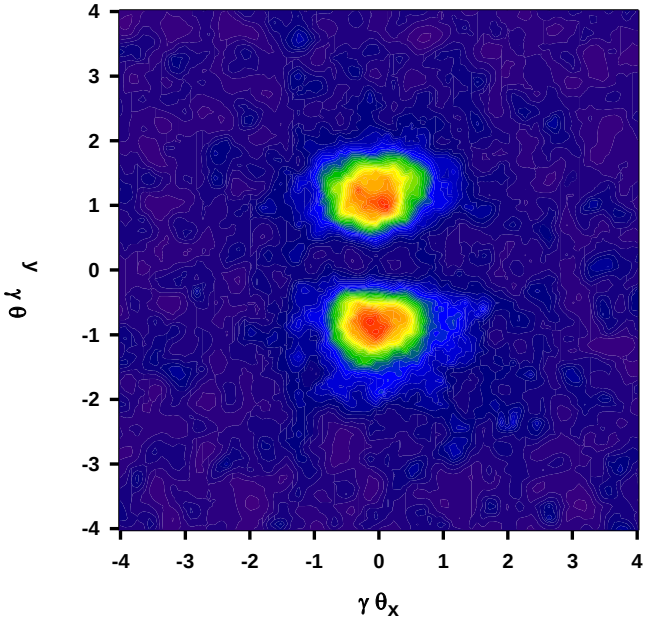
SR mask cuts off the dominant part of the synchrotron radiation



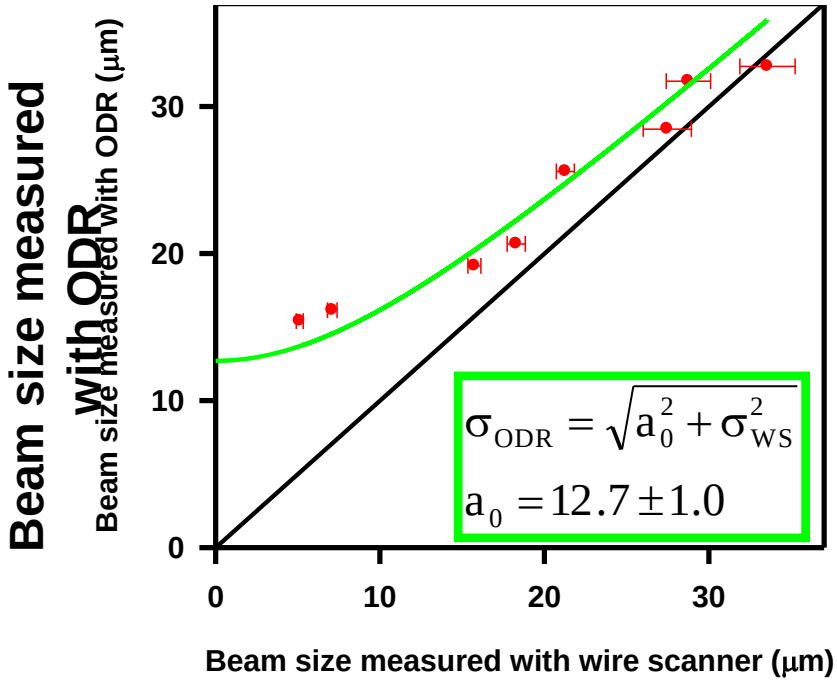
Basic Principle



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



Limitations and Sensitivity for CesrTA

$$\lambda = 500nm$$

Photon yield: $Z = \frac{\omega}{\omega_c} = \frac{2\pi a}{\gamma\lambda} < 1$

$\gamma = 4000, \quad a < 320mm$

Optimal Sensitivity: $\sigma > 0.05\frac{\gamma\lambda}{2\pi}$

$\sigma > 16\mu m$

$$\lambda = 150nm$$

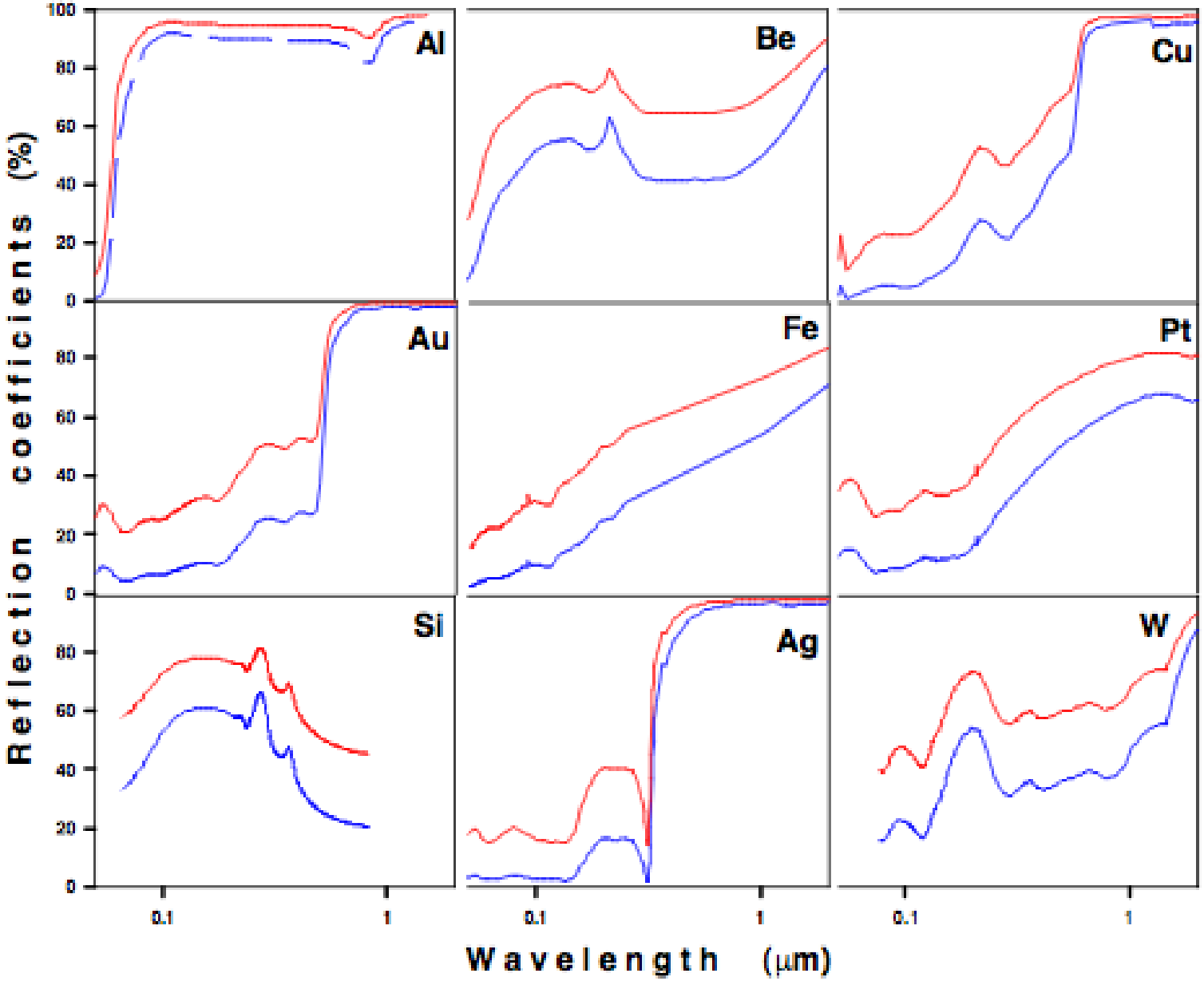
Photon yield: $Z = \frac{\omega}{\omega_c} = \frac{2\pi a}{\gamma\lambda} < 1$

$\gamma = 4000, \quad a < 100mm$

Optimal Sensitivity: $\sigma > 0.05\frac{\gamma\lambda}{2\pi}$

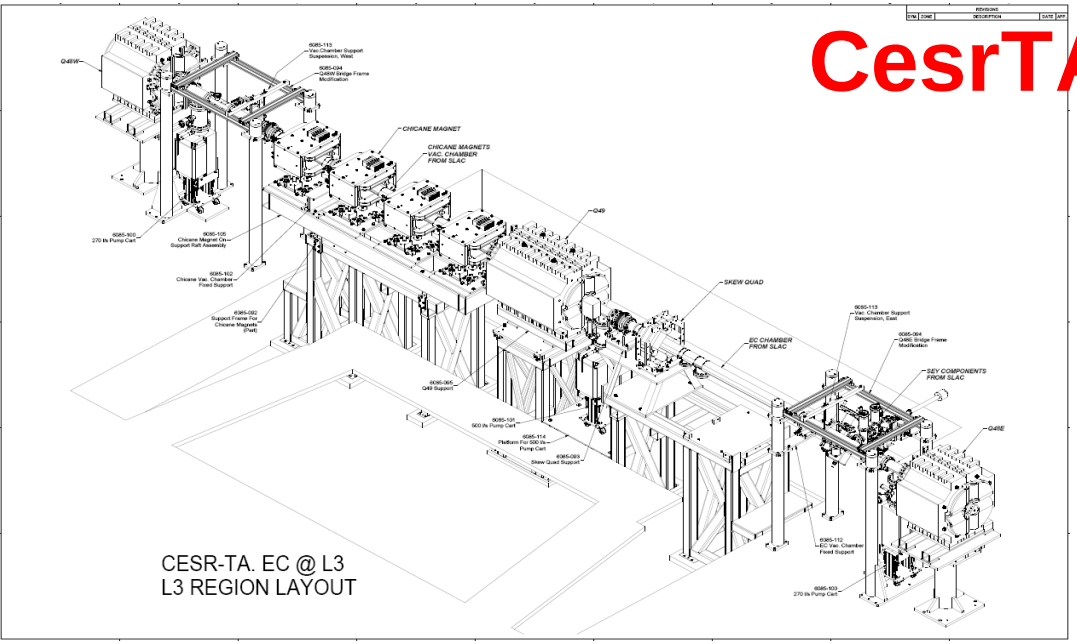
$s > 5mm$

Fresnel Reflection Coefficients



Cornell electron synchrotron radiation Test Accelerator

CesrTA



Layout of the CESRTA experimental region in the L3 straight

Parameter	Value
Energy	2 – 5 GeV
Emittance (x / y)	2.6 nm / 20 pm
Minimal beam sizes (x / y)	50 um / 1 um
Energy spread	$8.4 \bullet 10^{-4}$
Beam jitter requested (x / y)	25 um / 2.2 um
Bunch population	$3 \bullet 10^{10}$

Work plan

- DR simulations and evaluation of its sensitivity to beam size measurement
- Estimations of absorption in air and output window transmission.
- Hardware development for the beam test in CESR-TA
  - Design and Construction of the Vacuum system and detection system in UV range by Spring 2012
  - Installation in Summer 2012
  - Design of a X-ray detection system 2012
  - Installation of the X-ray detection system in 2013
- Beam test and validation of UV/X-ray DR monitoring
  - Beam test in the UV domain in 2012
  - Beam test in the X-ray domain in 2013