17TH ADVANCED BEAM DYNAMICS WORKSHOP ON
FUTURE LIGHT SOURCES

Laser and Transition Radiation-Based Electron Beam Diagnostics at High Energies

W. Leemans, LBNL

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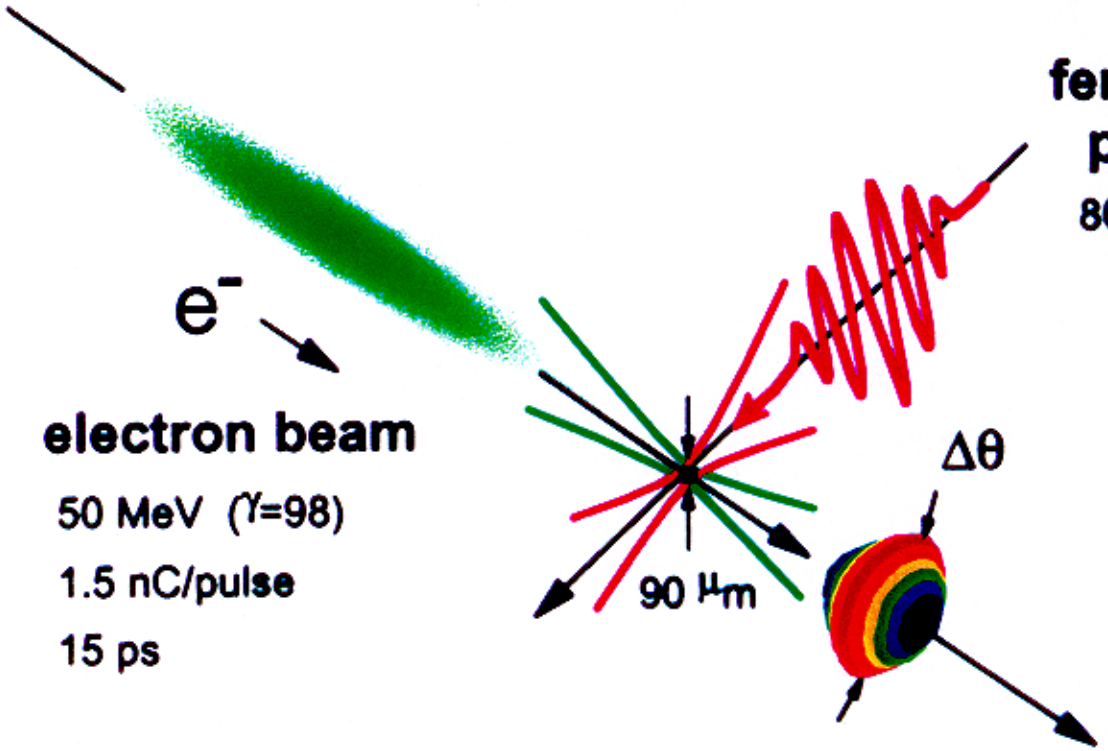
ARGONNE NATIONAL LABORATORY, ARGONNE, IL U.S.A.

90° Thomson Scattering



femtosecond laser pulse undulator

800 nm, 50 fs, 100 mJ

electron beam

50 MeV (γ=98)

1.5 nC/pulse

15 ps

$$\lambda_x = \frac{\lambda_L}{2\gamma^2}$$

femtosecond x-ray pulses

300 fs

0.4 Å (30 keV)

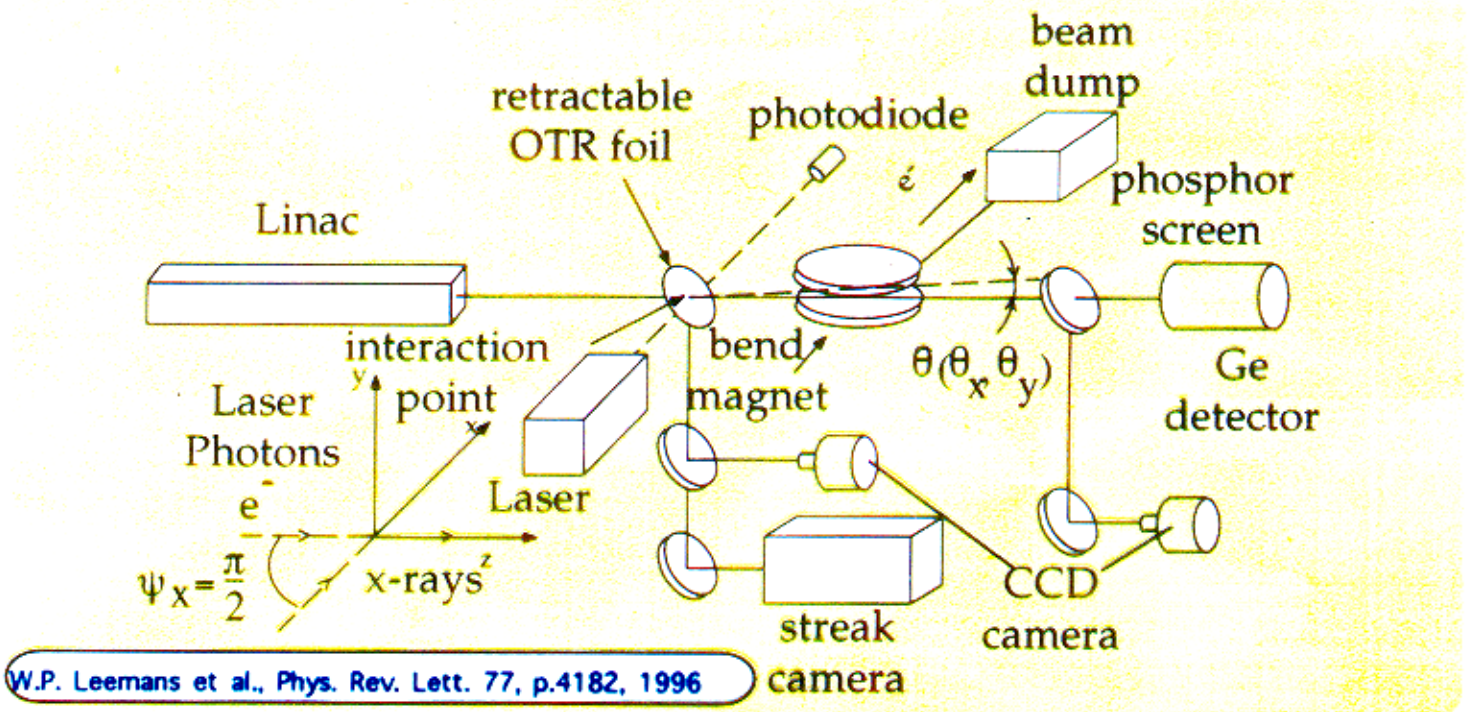
3×10^3 ph/sec/0.1% BW

(10^5 ph/pulse)

$\Delta\theta$ ~10 mrad

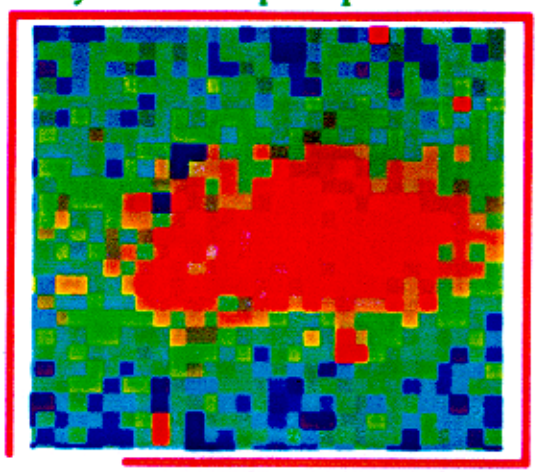
R.W. Schoenlein et al., Science, '96
W.P. Leemans et al., PRL '96, JQE '97

Thomson Scattering Phase-Space Diagnostic at the Beam Test Facility



W.P. Leemans et al., Phys. Rev. Lett. 77, p.4182, 1996

x-ray beam on phosphor screen



- X-rays detected with Gd2OS:Tb screen imaged onto 16 bit CCD camera
- Phosphor screen response calibrated with I^{129}, Am^{241}
- Phosphor used to collect beam image and measure total x-ray yield

Beam divergence from x-ray spectra

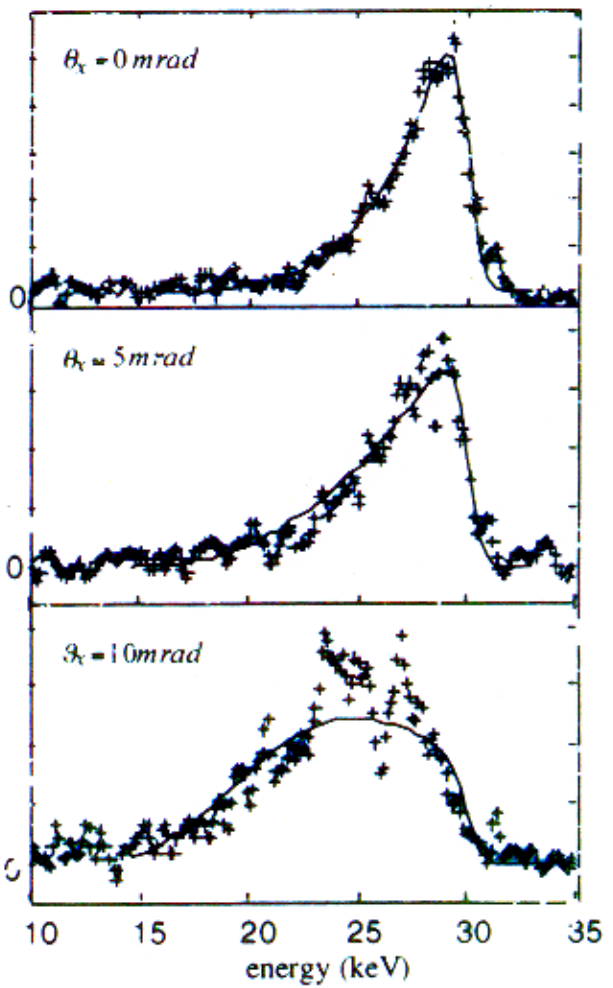
detection sensitivity

$$\frac{dn}{d\theta_x d\theta_y d\kappa} \propto \int_0^{2\pi} d\phi \left[1 - 4\kappa(1-\kappa)\cos^2\phi\right] F(\kappa) \times$$

$$\exp\left[-\frac{(\theta_x - \gamma^{-1}\sqrt{\frac{1}{\kappa}-1}\sin\phi)^2}{2\sigma_{\theta x}^2}\right] \times \exp\left[-\frac{(\theta_y - \gamma^{-1}\sqrt{\frac{1}{\kappa}-1}\cos\phi)^2}{2\sigma_{\theta y}^2}\right]$$

$$\kappa = U/U_{max} = (1+\gamma^2\theta^2)^{-1} \qquad U_{max} = 2\gamma^2\hbar\omega$$

angle of observation

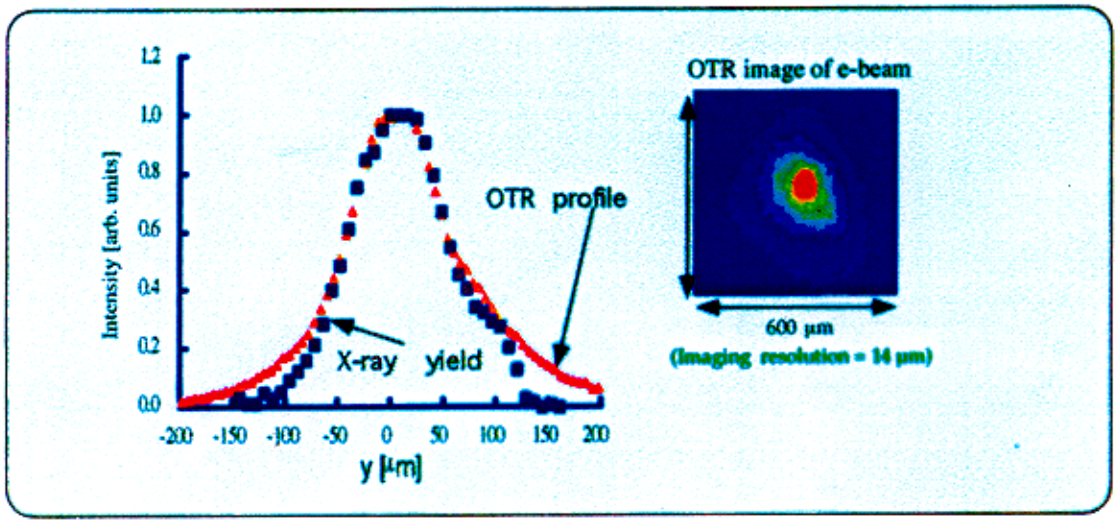


- Spectrum is acquired over 10,000 shots
- Data corrected for
  - window transmissivity
  - Ge efficiency
- Finite laser bandwidth included in modeling
- Spectral resolution ≃240eV (0.8%)
- Sensitivity calibrated with I^{129}, Am^{241}

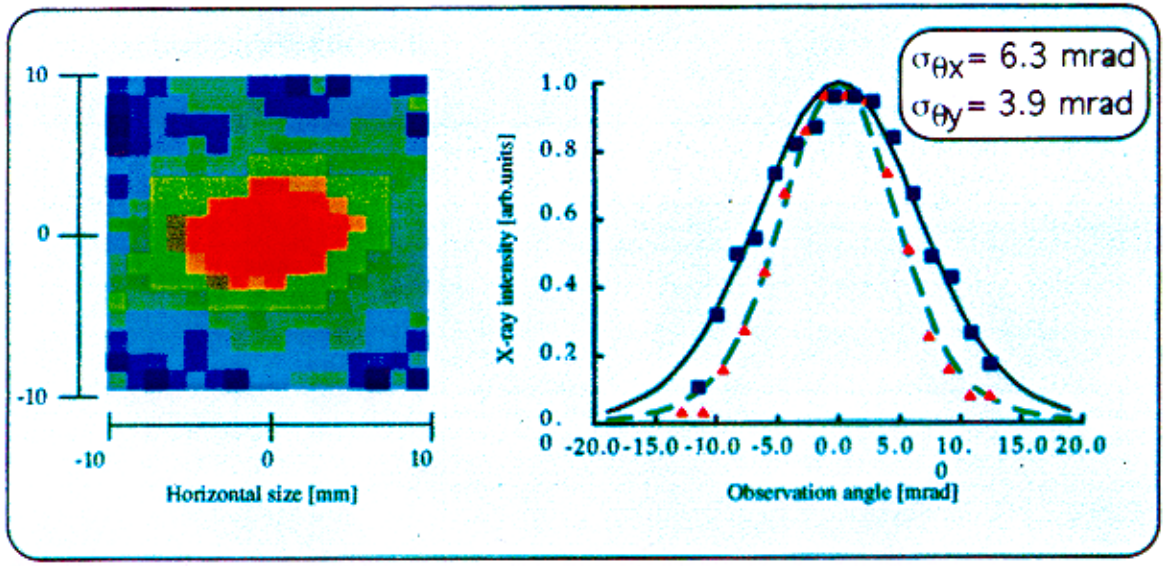
- Electron beam divergence = 3.5 - 4.0 mrad

Transverse phase space information is obtained from 90° Thomson scattering

⇒ Vertical beam size is obtained by scanning laser vertically across electron beam



⇒ Beam divergence of a single 200 fs slice is obtained from the far field x-ray profile



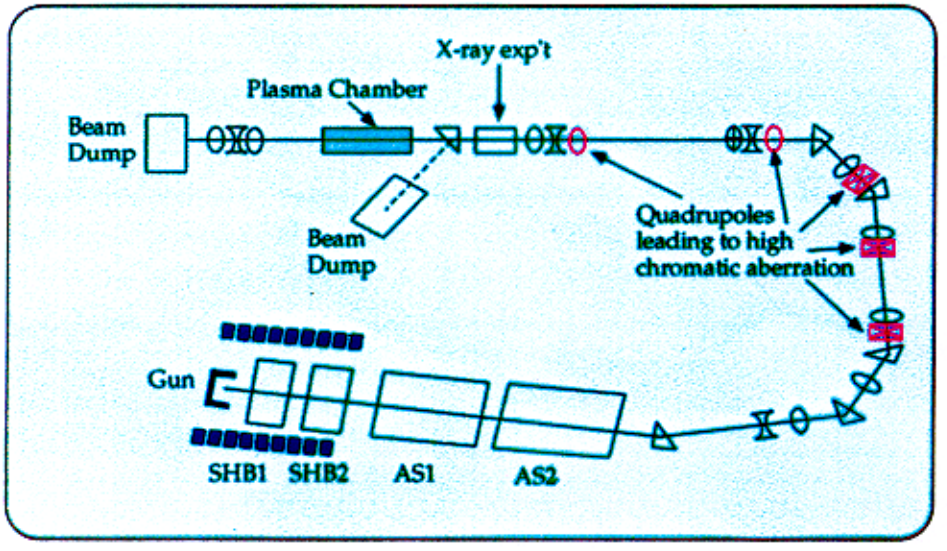
$$\frac{dP}{d\theta_x d\theta_y} \propto \int_0^{2\pi} d\phi \int_0^1 d\kappa\, F(\kappa)\kappa\left[1 - 4\kappa(1-\kappa)\cos^2\phi\right]$$

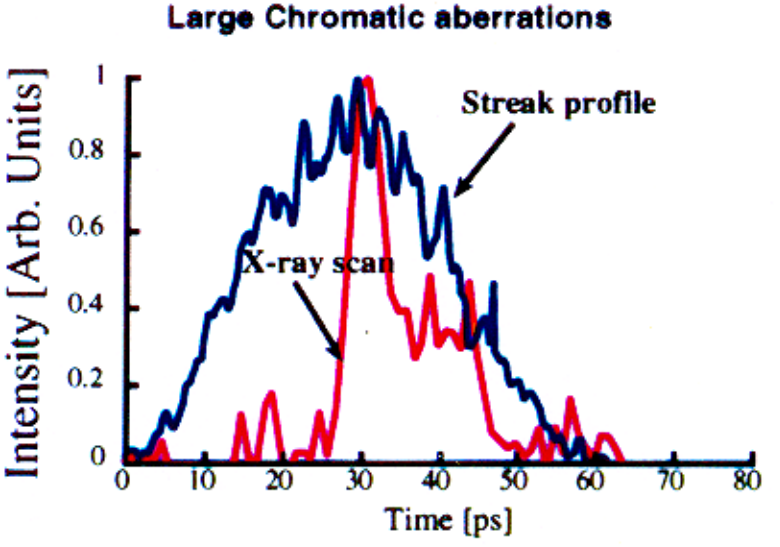
$$\times \exp\left[-\frac{(\theta_x - \gamma^{-1}\sqrt{\frac{1}{\kappa} - 1}\,\cos\phi)^2}{2\sigma_{\theta x}^2}\right]$$

$$\exp\left[-\frac{(\theta_y + \gamma^{-1}\sqrt{\frac{1}{\kappa} - 1}\,\sin\phi)^2}{2\sigma_{\theta y}^2}\right]$$

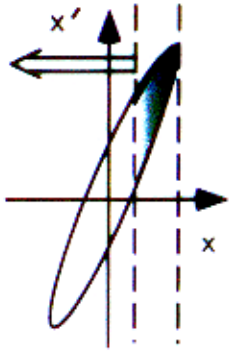
Chromatic aberrations in lattice were detected with laser probe, not with OTR

BTF lattice

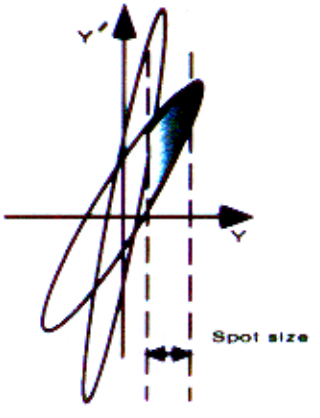


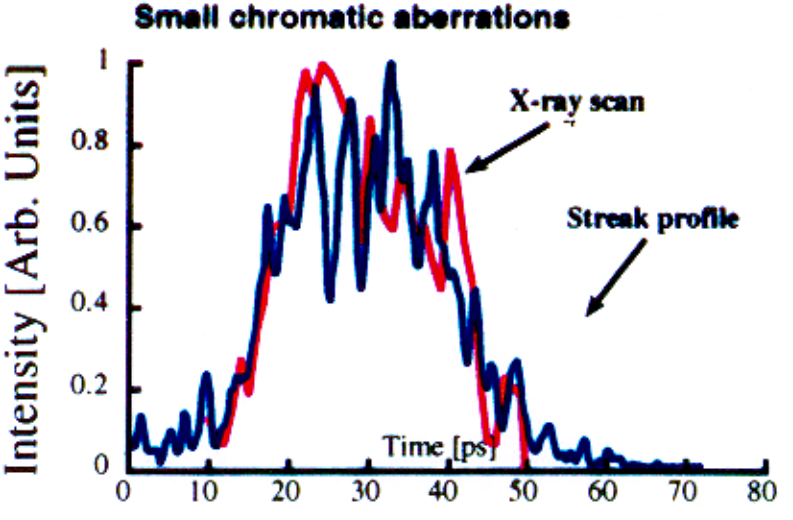


Horizontal phase space

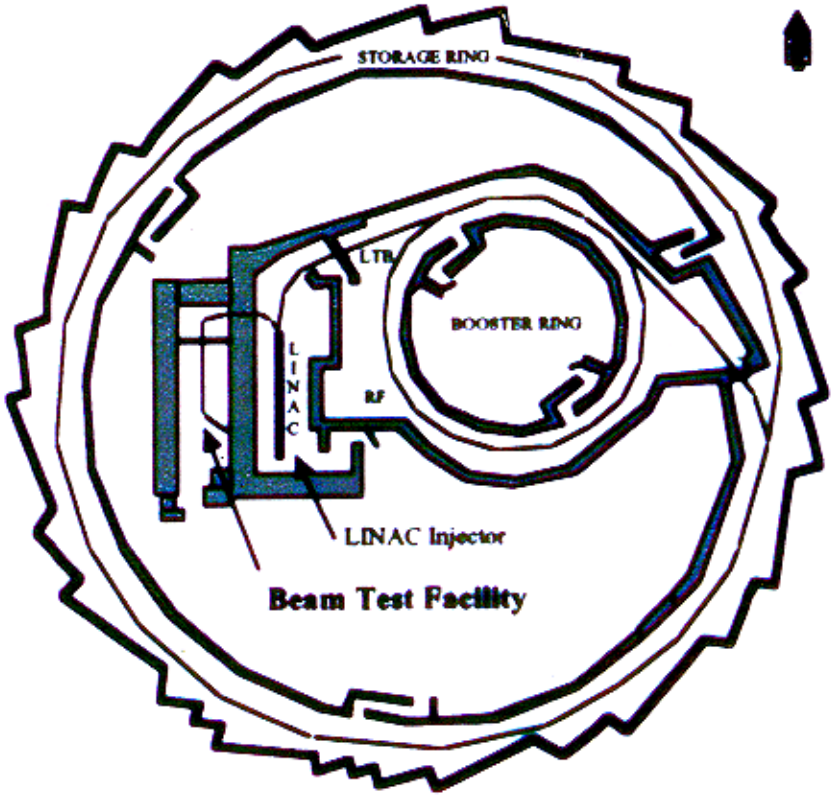


Vertical phase space

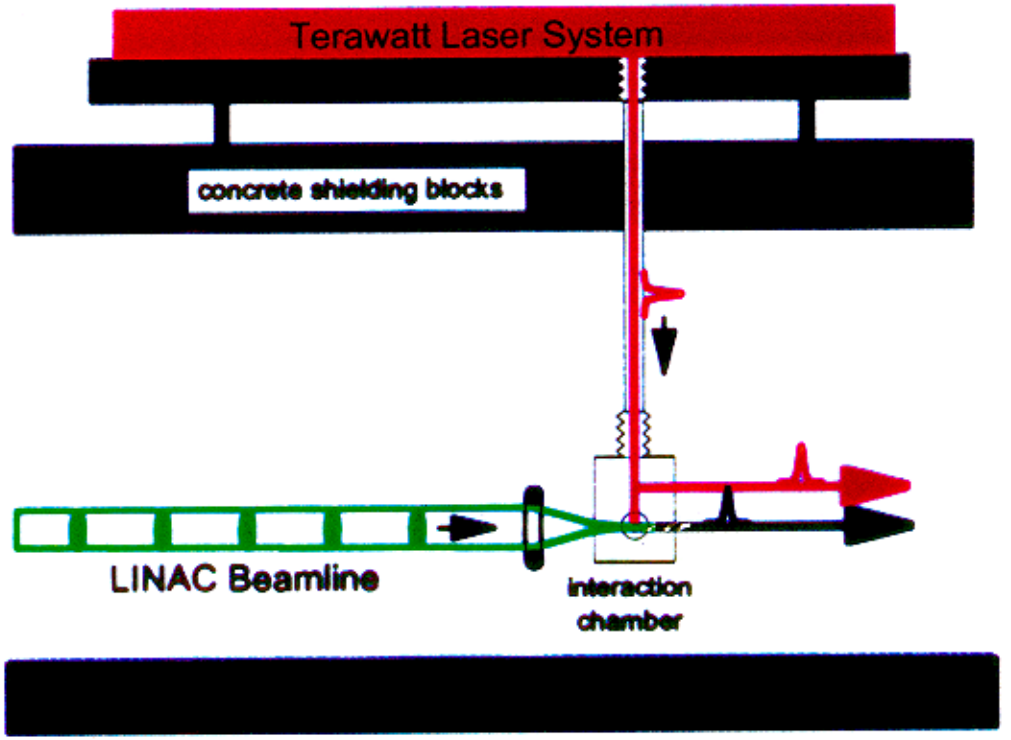




Thomson Source Layout at the Beam Test Facility*



Advanced Light Source



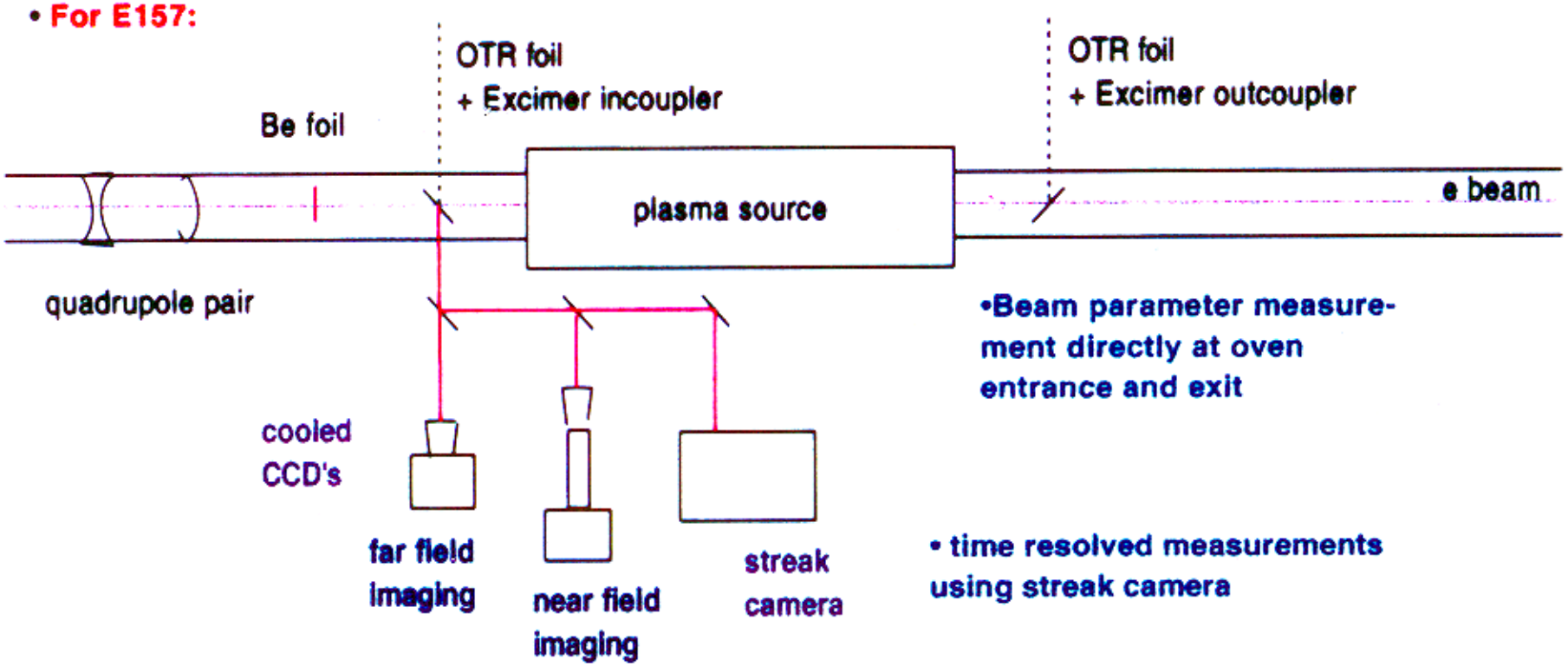
W.P. Leemans et al., PAC93

OTR at 30 GeV - Motivation

- **In general:**

-optical radiation-based diagnosis at multi-GeV energies

- **For E157:**



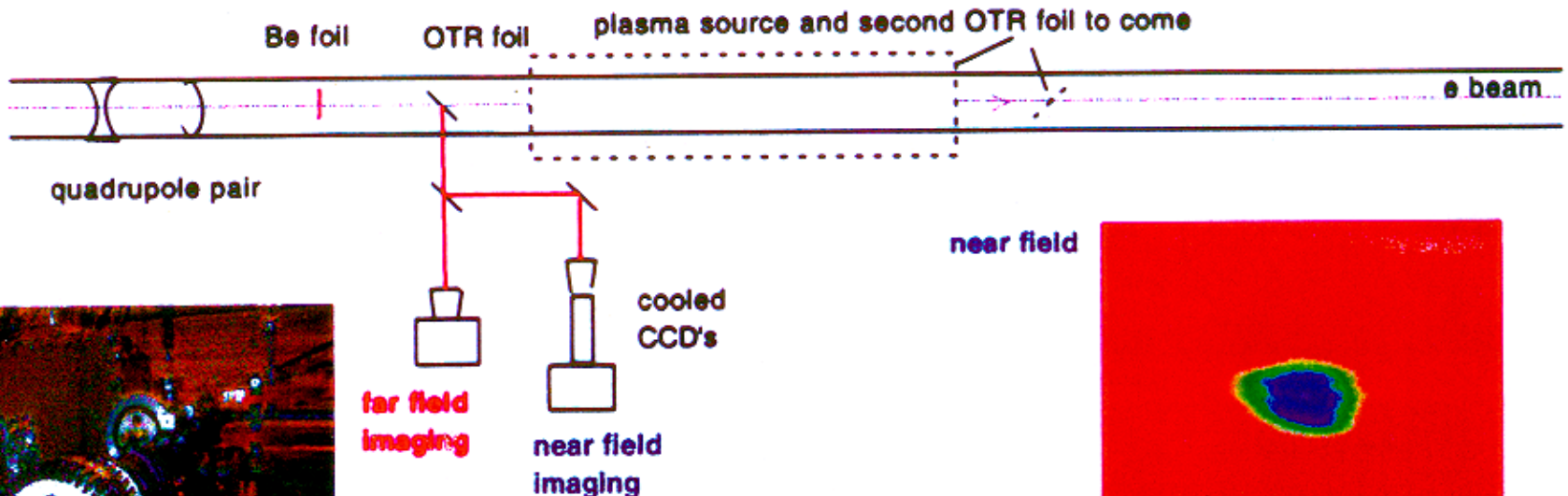
•Beam parameter measurement directly at oven entrance and exit

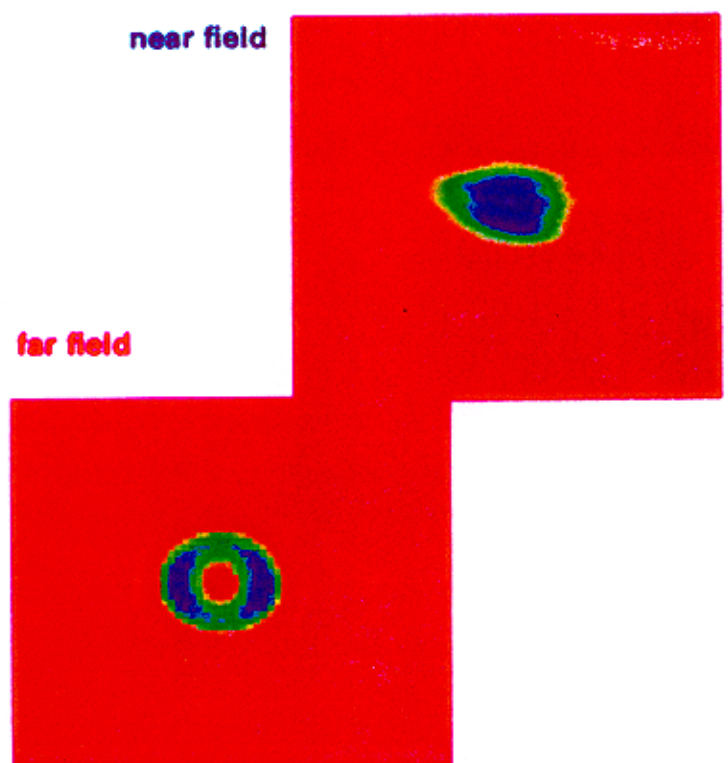
• time resolved measurements using streak camera

- spot size and divergence using spatial profile (present)
- bunchlength/spot size using fluctuations (future)

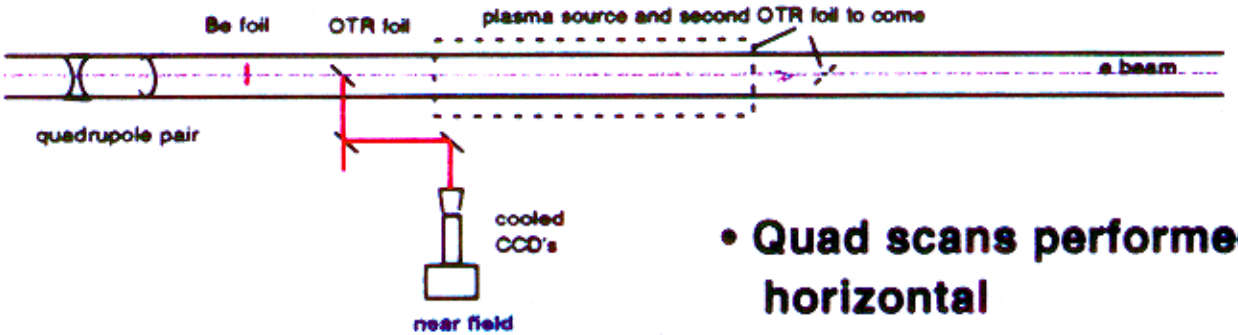
OTR at 30 GeV - Experimental Setup

- **Near and far field simultaneously imaged**
- **Two-foil interference observed in far field**

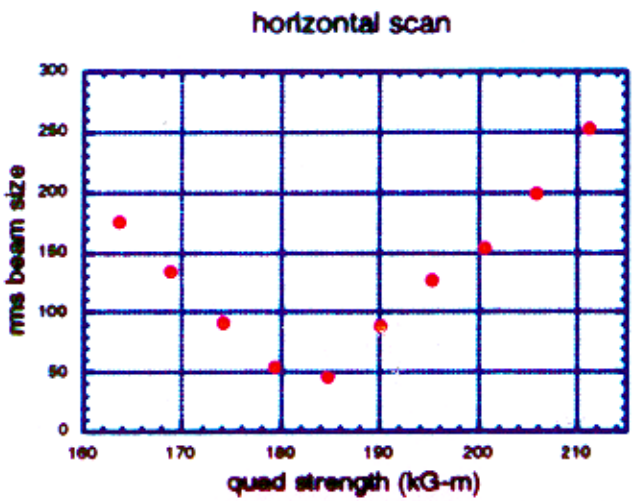


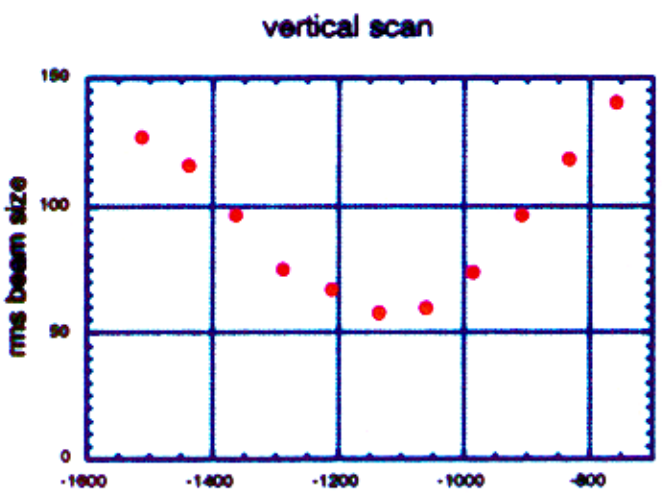


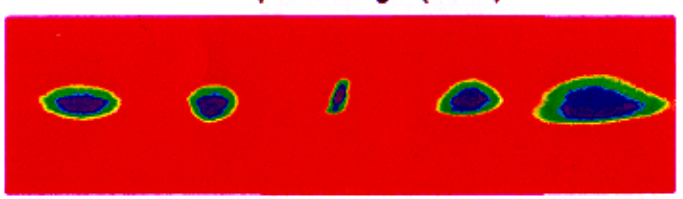
OTR at 30 GeV - Beam spot size resolution



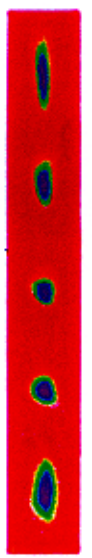
- Quad scans performed in vertical and horizontal
- 50 micron resolution achieved in both axes using visible wavelength OTR.







OTR near field images



OTR at 30 GeV - Beam divergence from 2-foil interference

Formation length (distance required to accumulate π phase shift):

$$L_f = \frac{\lambda}{\gamma^{-2} + \theta^2}$$

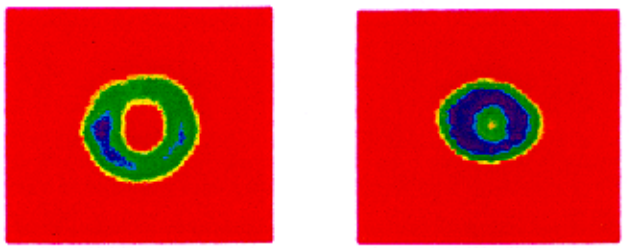
Intensity distribution:

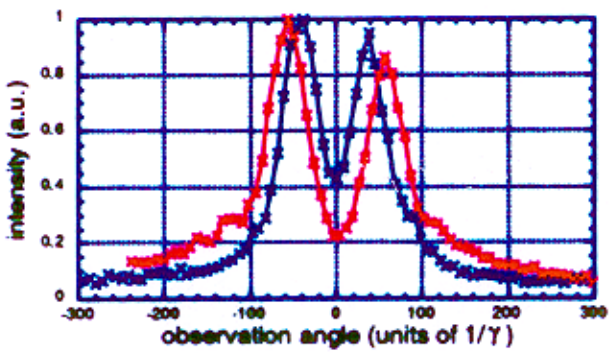
$$\frac{d^2W}{d\omega d\Omega} = \frac{\theta^2}{\left(\gamma^{-2} + \theta^2\right)^2} \sin^2\left(\frac{L}{2L_f}\right)$$

At 30 GeV λ=532 *nm*, *L*~0.6*m*, $L_f(\theta = 1/\gamma) \sim$ **0.5 *km*** but: $L_f(\theta = 30/\gamma) \sim 0.6m \sim$ *foil separation, L*

2 foil interference patterns may be observed and utilized by collecting angles >>1/γ

Wavelength dependence of measured intensity distribution and theory are in agreement.

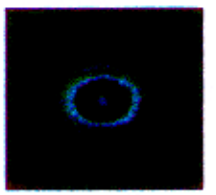


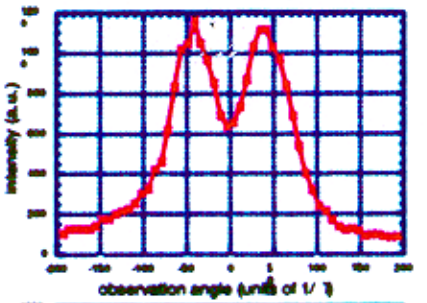


Application: beam divergence calibration

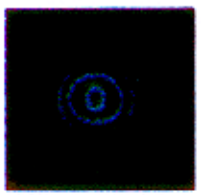
Sensitivity range adjustable via foil separation and wavelength BP.
Range of ~10-50/γ demonstrated below

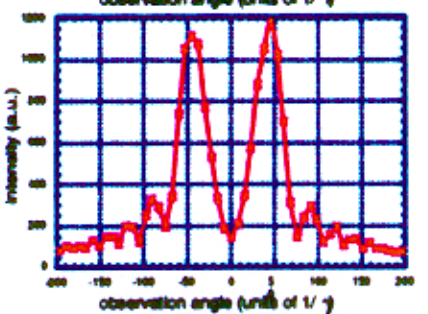
HIGH DIVERGENCE





LOW DIVERGENCE





- differing divergences in horizontal and vertical resolved;
- divergence evolution during quad scan resolved