A Beam Profile Monitor for a Future Linear Collider

Steve Malton, UCL

1st Year Transfer Report
11th June 2004

Overview

- Future Linear Collider
- Petra Laserwire
  - Expected Signal
  - Scan Results Dec ’03
- Laser Imaging
  - Current
  - Future?
- CCD Resolution
- Future Plans

Future Linear Collider

- Next generation physics machine
- ~ 10^{10} particles per bunch
- 0.5 – 1.5 TeV
- Luminosity ~ 10^{34} cm^{-2} s^{-1}
- Beam profile monitor
  - Wire scanners destroyed!

	CLIC	NLC/JLC	TESLA
BDS $\sigma_x(\mu m)$	3.4 to 15	7 to 50	20 to 150
$\sigma_y(\mu m)$	0.35 to 2.6	1 to 5	1 to 25
IP $\sigma_x^*(\mu m)$	196	355	535
$\sigma_y^*(\mu m)$	4.5	4.5	5

Laserwire

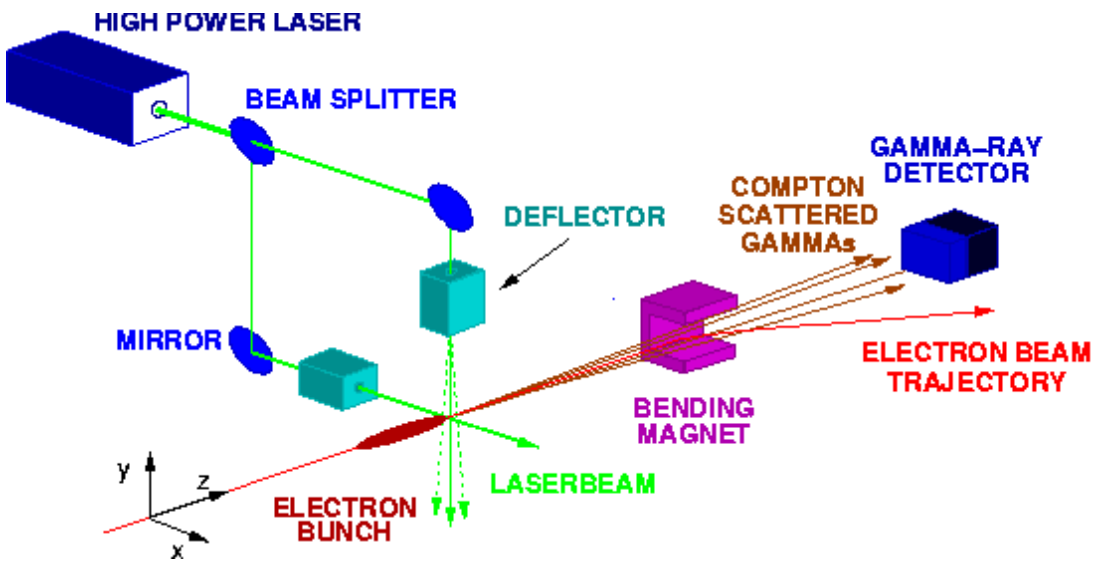
- Compton scattering

$$e^- + \gamma \rightarrow e^- + \gamma$$

- High energy – small angular spread

$$\alpha_c \sim 1 / \gamma$$

- Non-invasive
- Indestructible



$$N_C = N_b \frac{P_L \sigma_C \lambda}{c^2 h} \frac{1}{\sqrt{2\pi}\sigma_s} \exp\left(\frac{-y^2}{2\sigma_s^2}\right)$$

Signal - Simple

- Assumes particle density functions of the electron and laser beams to be gaussian about the beams' axes and constant in beam direction

P = 2 MW

σ_x/σ_y [μm]	Beam Energy [GeV] 4.5	7	12
500/50	115/689	257/664	685/619
300/30	185/1111	416/1070	1056/998
100/10	415/2485	930/2393	2362/2231

E_{tot}[GeV]/N_γ

- Number of Compton photons is a gaussian function of the beam separation, with width σ_s

$$\sigma_s^2 = \sigma_e^2 + \sigma_g^2$$

Laser Propagation

- Divergent
  - Light spreads as it propagates

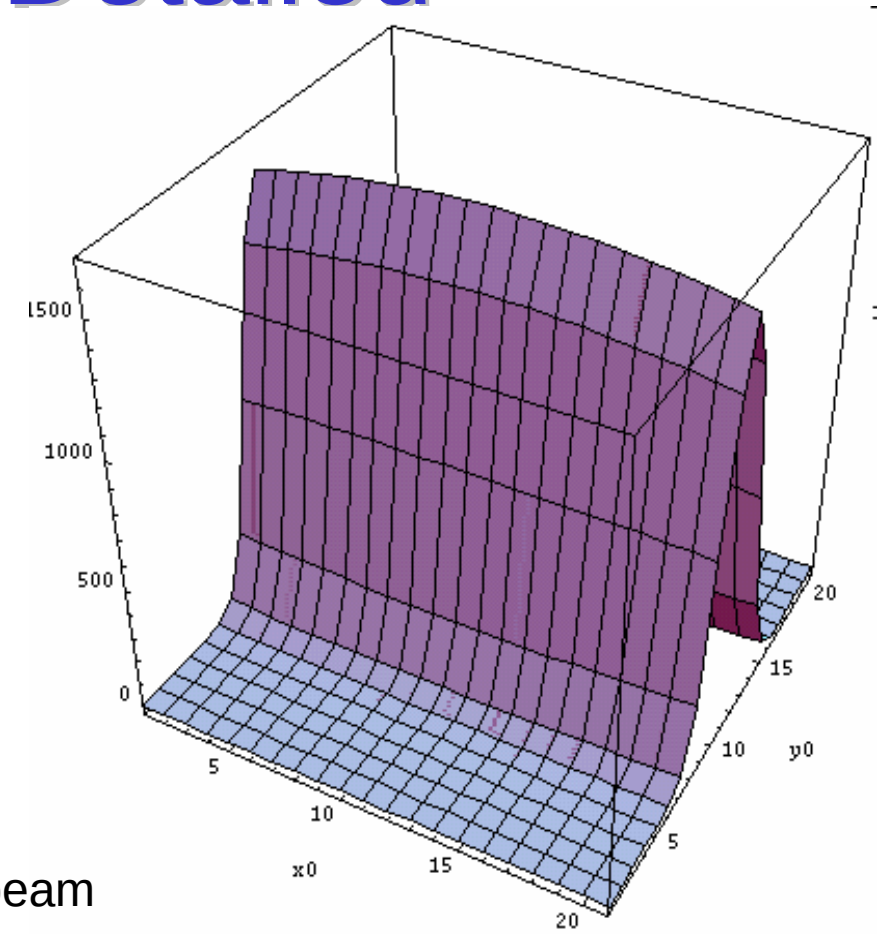
$$w^2 = w_0^2\left[1+\left(\frac{M^2 l z}{p w_0^2}\right)^2\right]$$

- Diffraction Limited
  - Does not focus to a point

$$w \propto \frac{M^2 l f}{w_0}$$

Signal - Detailed

- Allow for laser beam radius to vary
  - Integral is not analytical
  - Solve numerically



Energy deposited in calorimeter

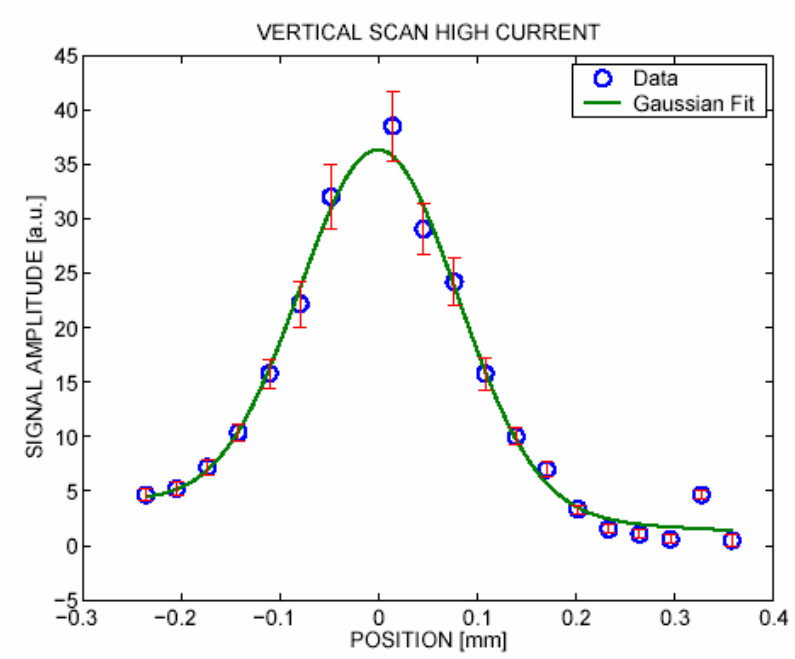
x0 : Offset of laser waist from IP

y0 : Offset of laser axis from electron beam

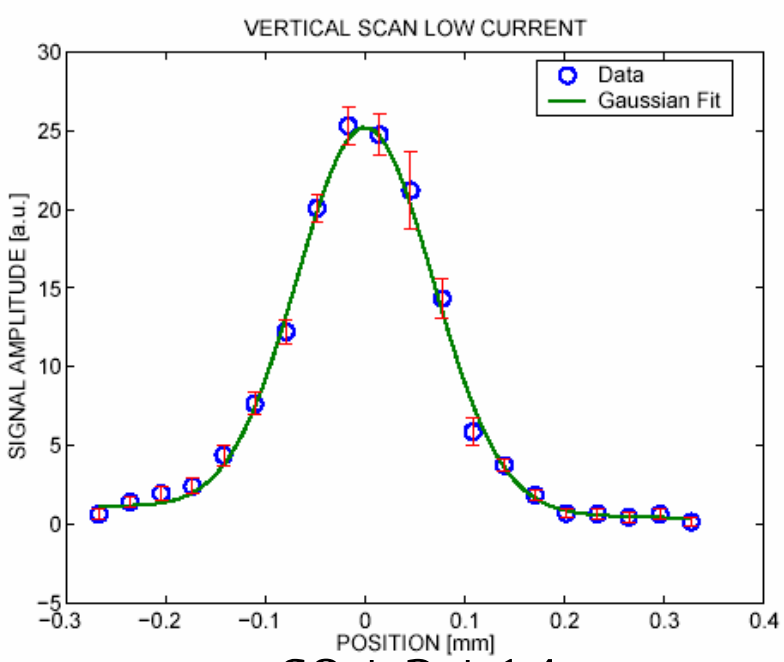
λ	M^2	σ_e	σ_{ez}	σ_γ	E_b	N_e	P_L
532 nm	3.62	20μm	12.75mm	10μm	6 GeV	$8\ 10^{10}$	10 MW

December ’03

- High current scan
  - Beam current 40.5mA
  - First bunch 22.3nC
- Low current scan
  - Beam current 7.1mA
  - First bunch 3.9nC

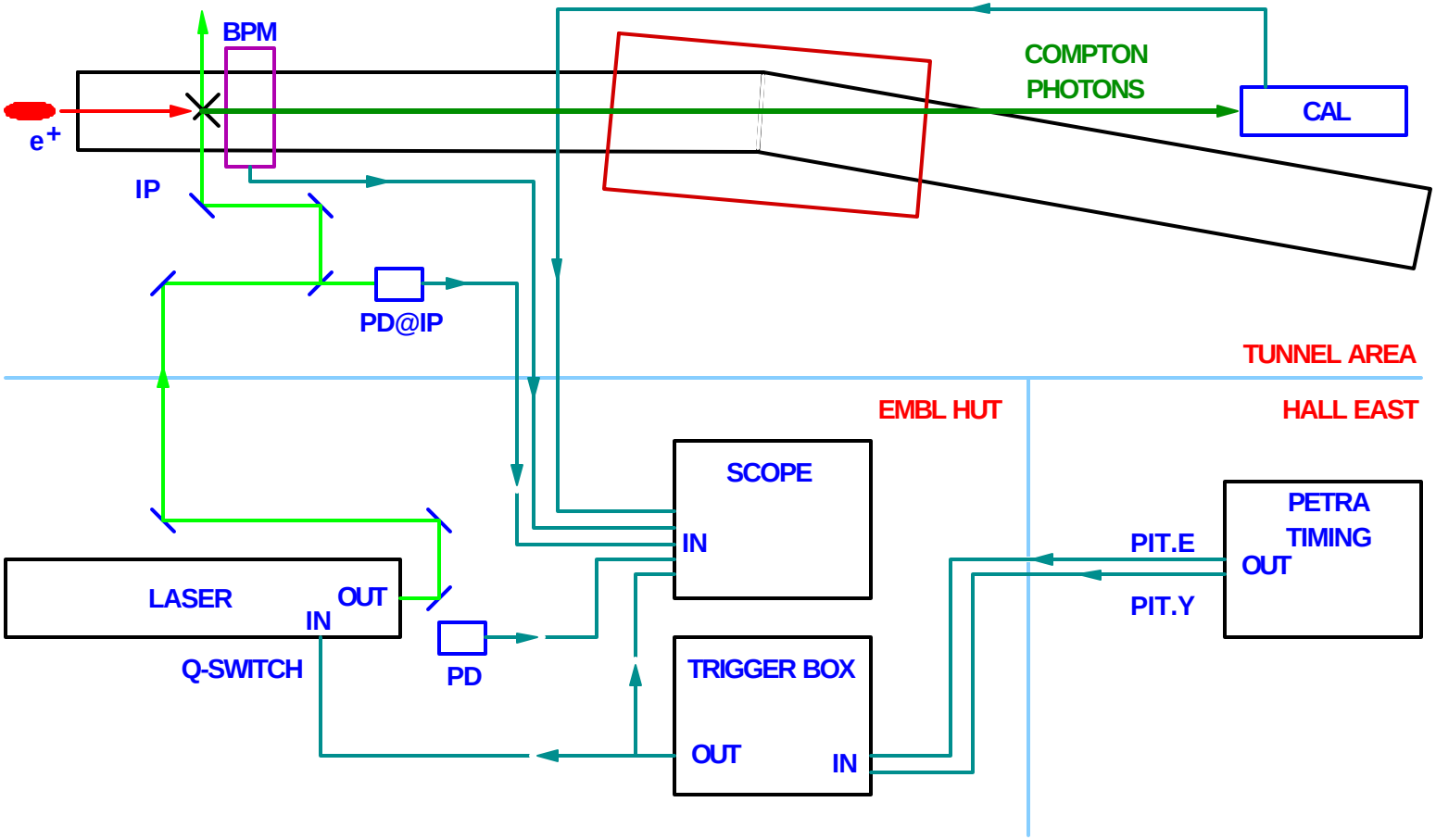


$$s_y = 80 \pm 6 \pm 16 mm$$



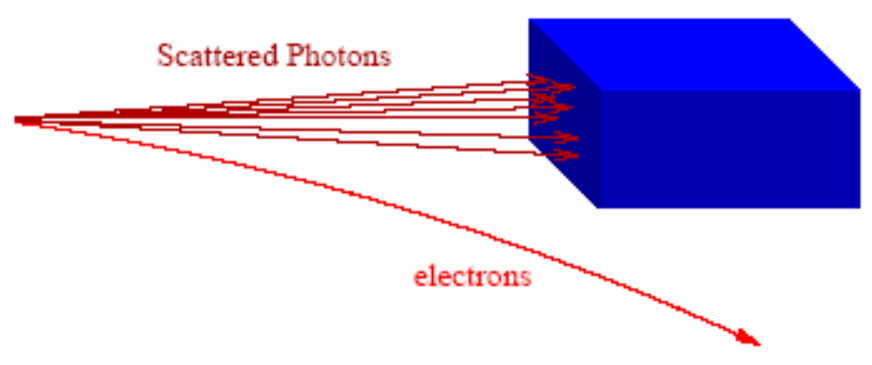
$$s_y = 68 \pm 2 \pm 14 mm$$

Setup at PETRA



Detector

- $PbWO_4$ crystals
  - 18 x 18 x 150 mm
  - 3 x 3 matrix
    - Contains 90% shower energy at 350 GeV
- Single PMT

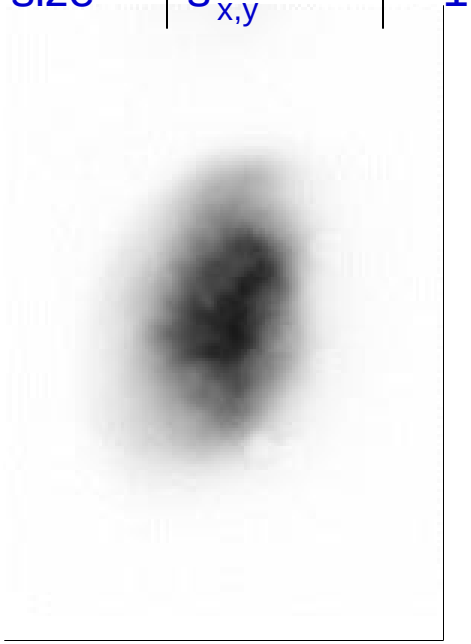


Radiation length	[mm]	8.90
Molière Radius	[mm]	22
Density	[g/cm^3]	8.28
Avg. #Photoelectrons/MeV		16
Decay time	[ns]	5–15

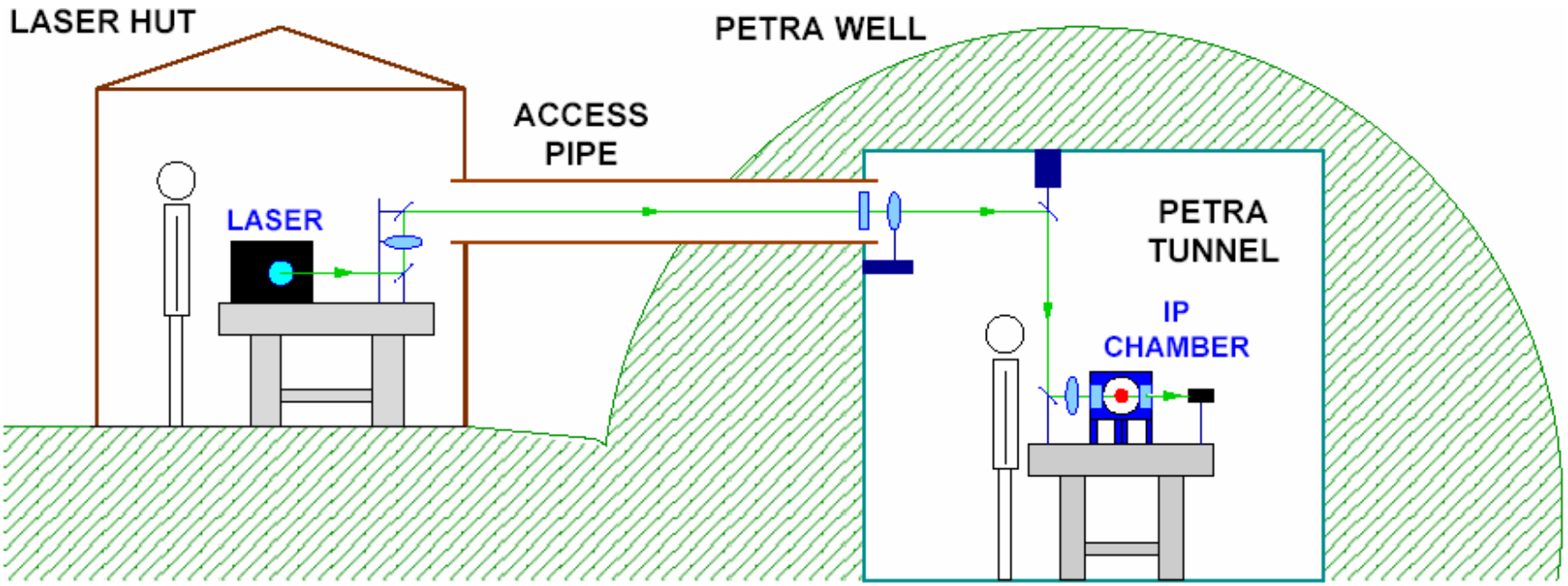
Laser

- Q-switched Nd:YAG with second harmonic generator
- Transverse mode quality poor
- Imaged on CCDs
  - Basler A302fs
  - 8.3μm pixel size
  - 780 x 582

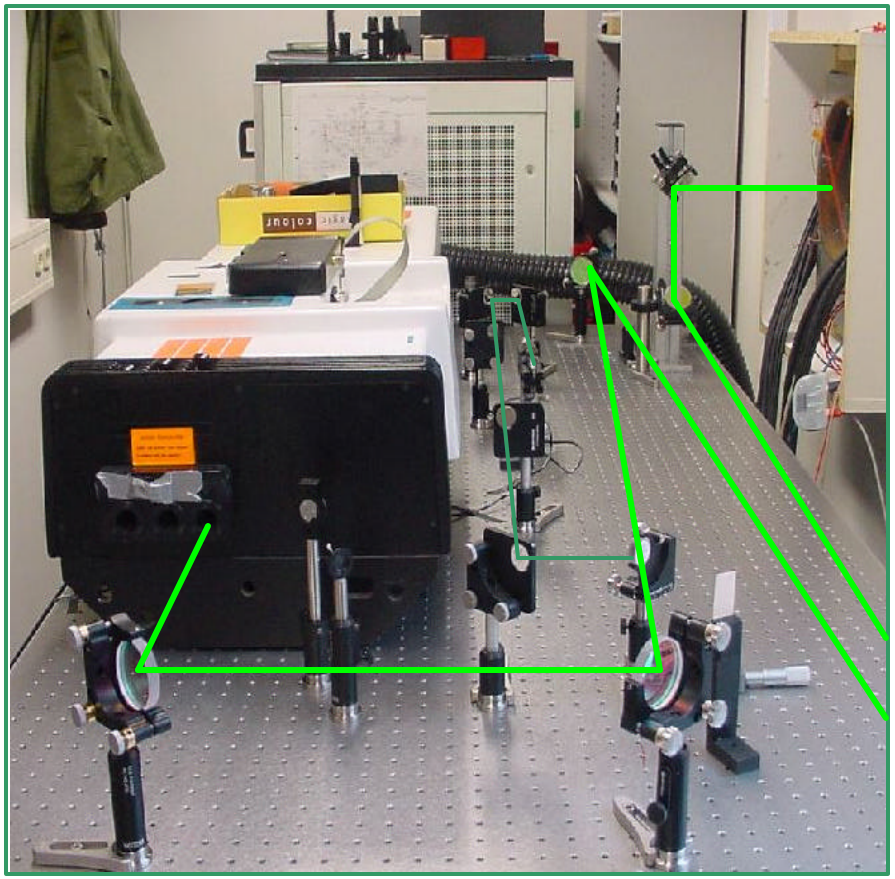
Wavelength	?/nm	1064/532
Energy	E/mJ	250/90
Pulse length	dt/ns	10
Rep rate	f_{rep}/Hz	up to 30
Beam size	$s_{x,y}$	= 1 mm

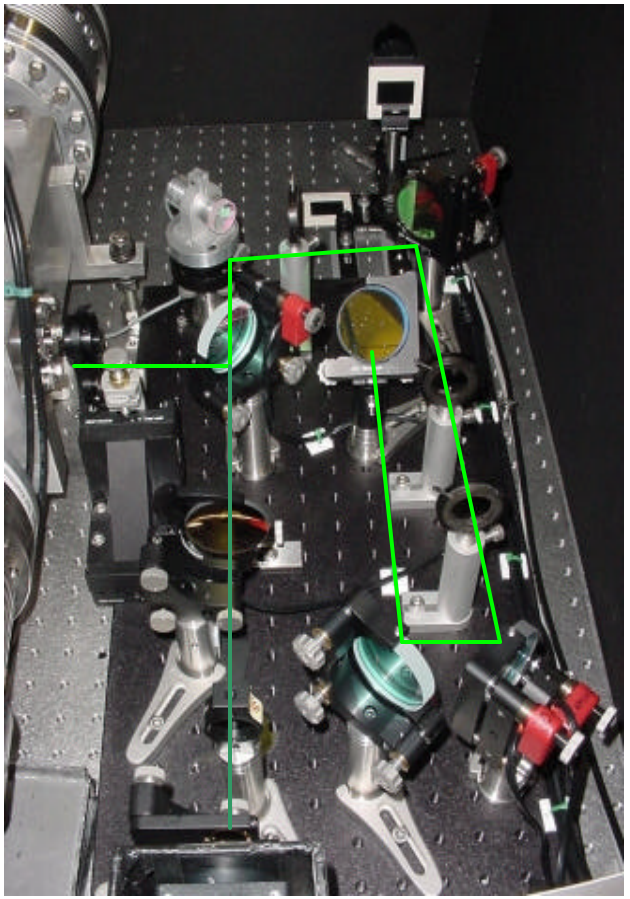


Optical Transport

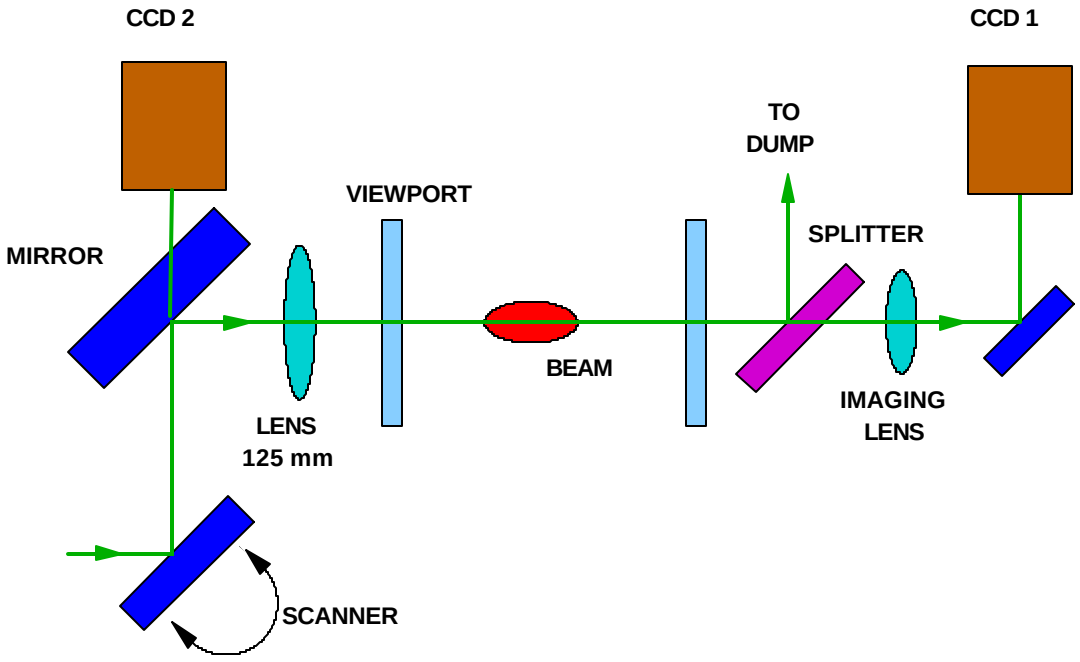


Optical Transport



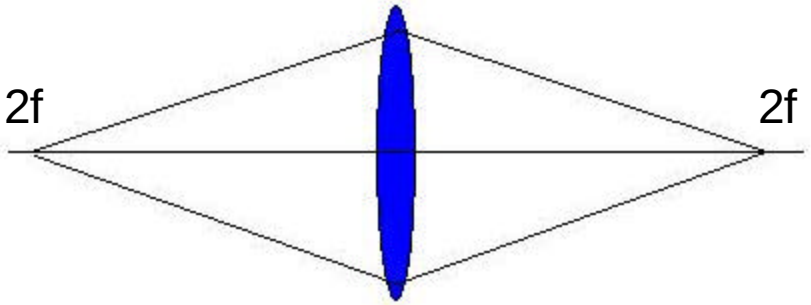


Beam Scanning

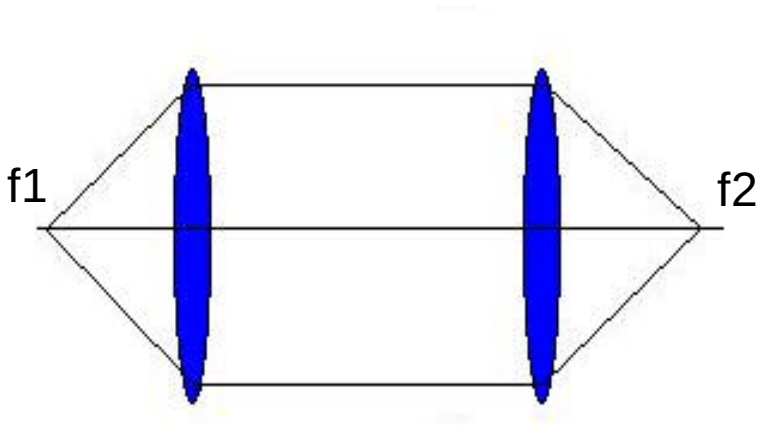


- Mirror on piezo-electric stack
- Apply 0 – 10V, amplified x10
- Angular range 5mrad
- ~kHz scan rate

Imaging Optics



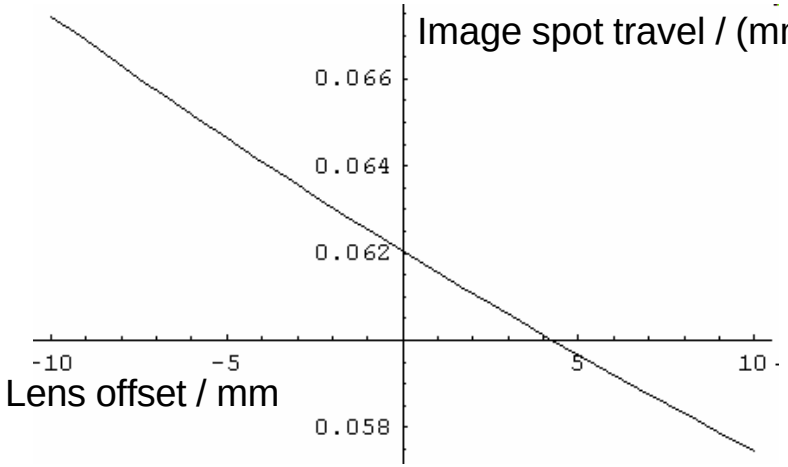
- 4f relay
  - Single lens : PAC076
    - 125mm EFL
  - 1:1 imaging
  - Place by hand ± 10mm?

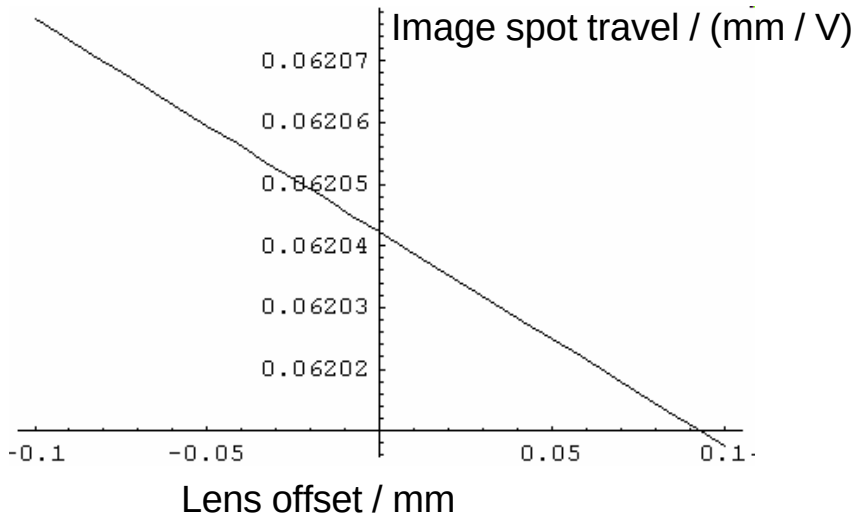


- 2 lenses
  - Collimate beam
    - Can test! ± 0.1mm
  - 2nd lens location irrelevant
  - f_1 ? f_2 → magnification

Scan Travel Range

Image spot translation at CCD (mm) vs. Lens offset from ideal position (mm)

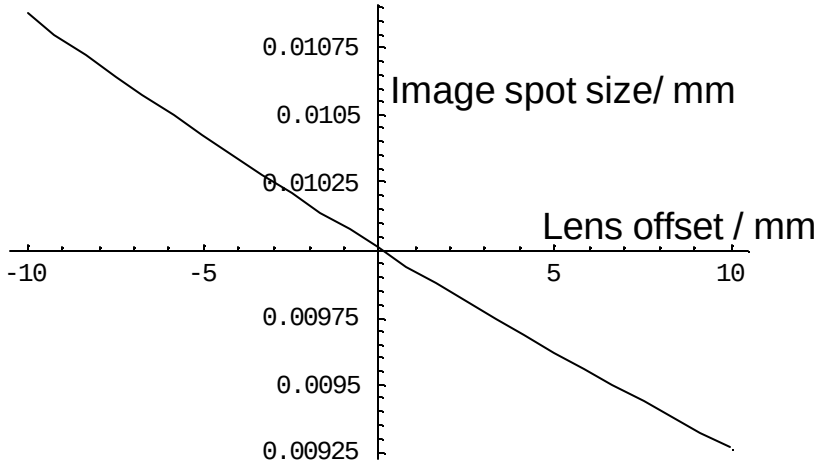


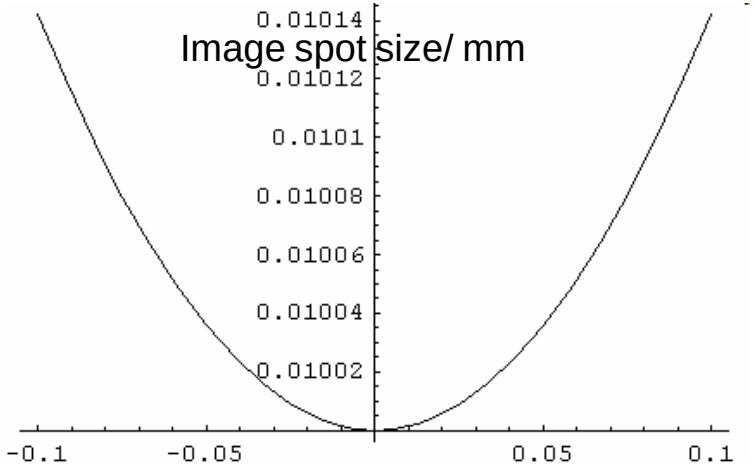


- 4f relay
  - ±10mm → ± 8%
- 2 lens system
  - ± 0.1mm → ± < 0.1%

Beam Spot Size

Image beam spot size vs. Lens offset (mm)

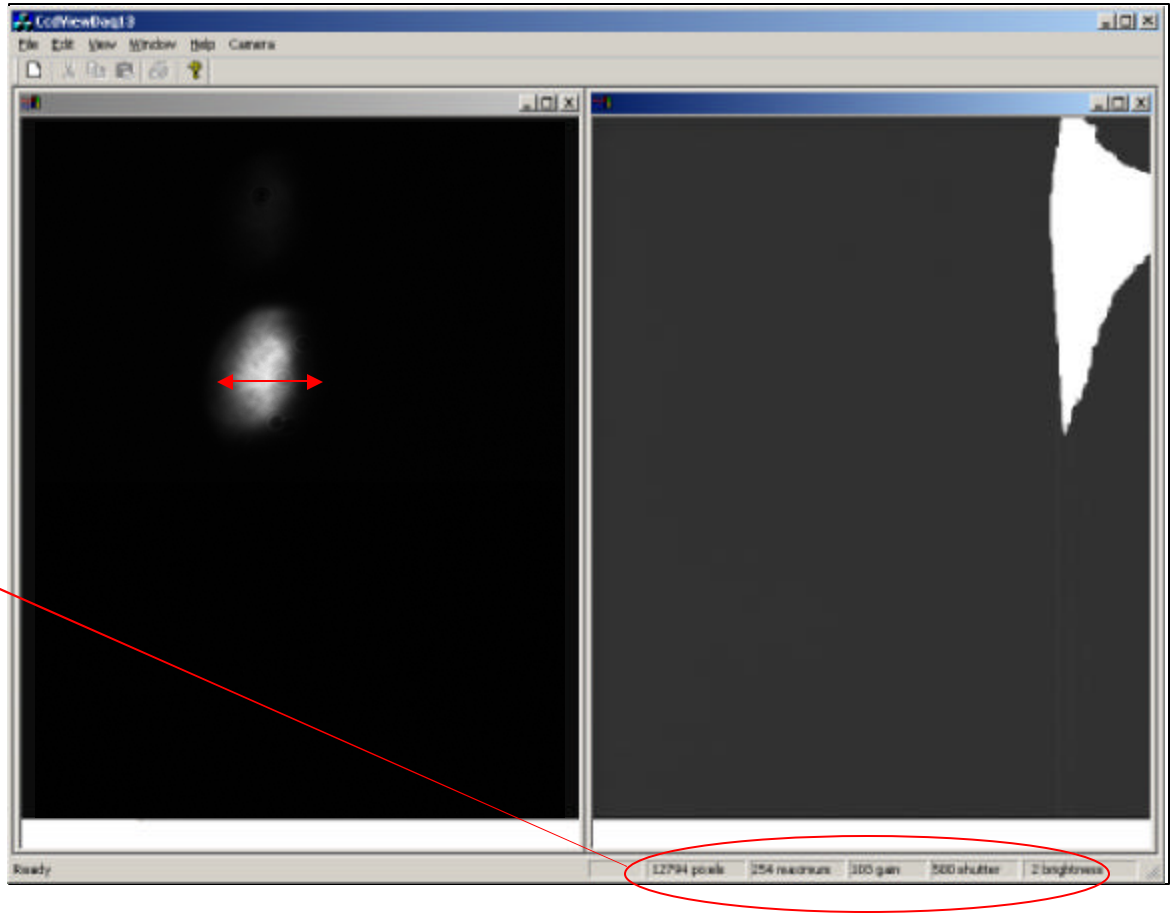




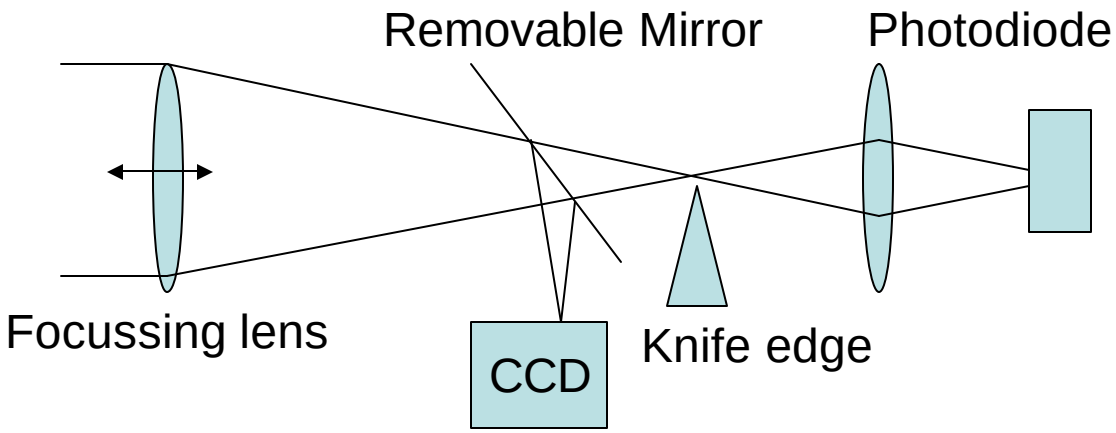
- 4f relay
  - ± 10mm → ± 8%
- 2 lens system
  - ± 0.1mm → +1.4%

CCD DAQ

- VC++ MFC
- Arbitrary number of cameras
- Statistics
  - Camera properties
- TCP/IP
  - control program

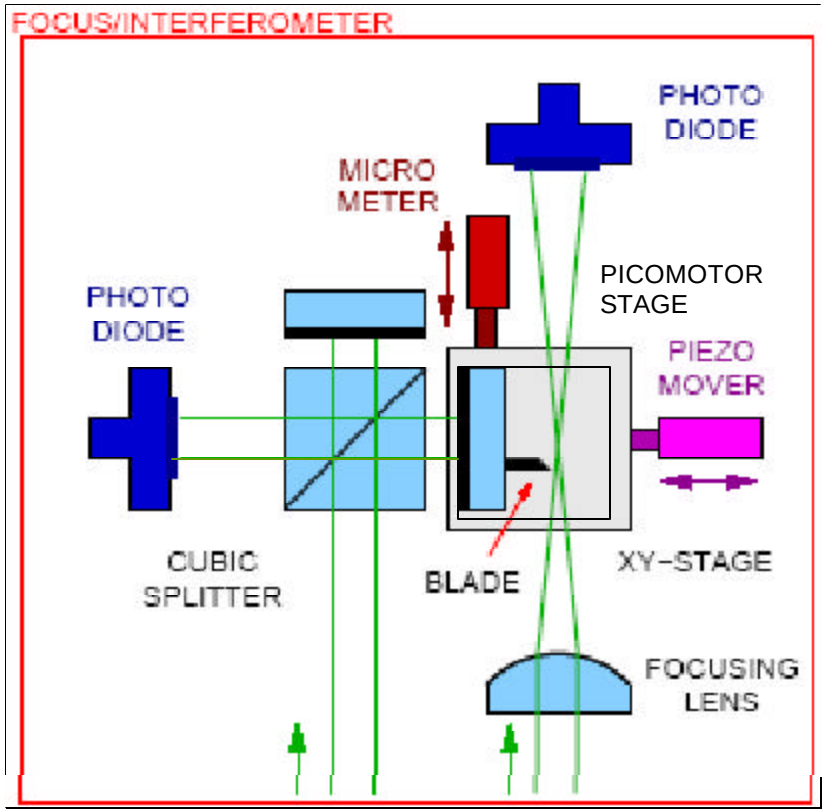


CCD Resolution



- Current setup at RHUL
- (Mirror – CCD) distance matched to (mirror – knife edge)
- Measure different beam sizes by moving focussing lens
  - Compare w_{ccd} against w_{knife}

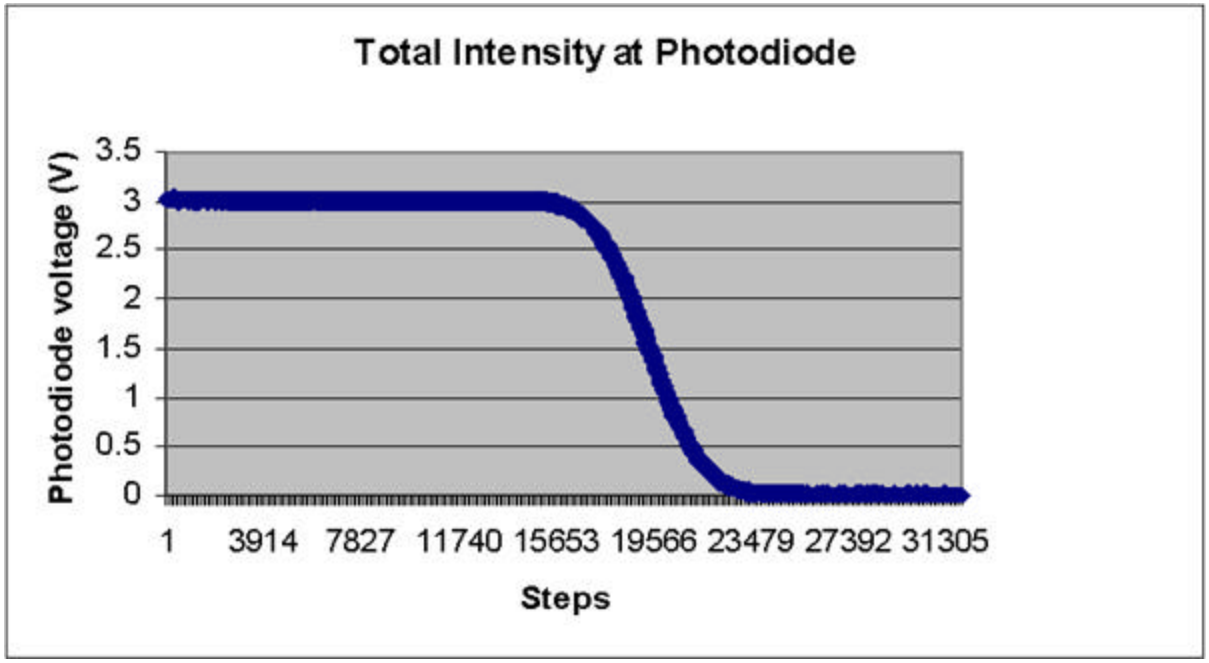
Knife-Edge Scans



- Measure total intensity at photodiode
- 3 translation stages
  - Crossed x-y stages, coarse
  - Picomotor stage, fine
- x-position
  - Picomotor steps
  - Interferometer to calibrate stage step size

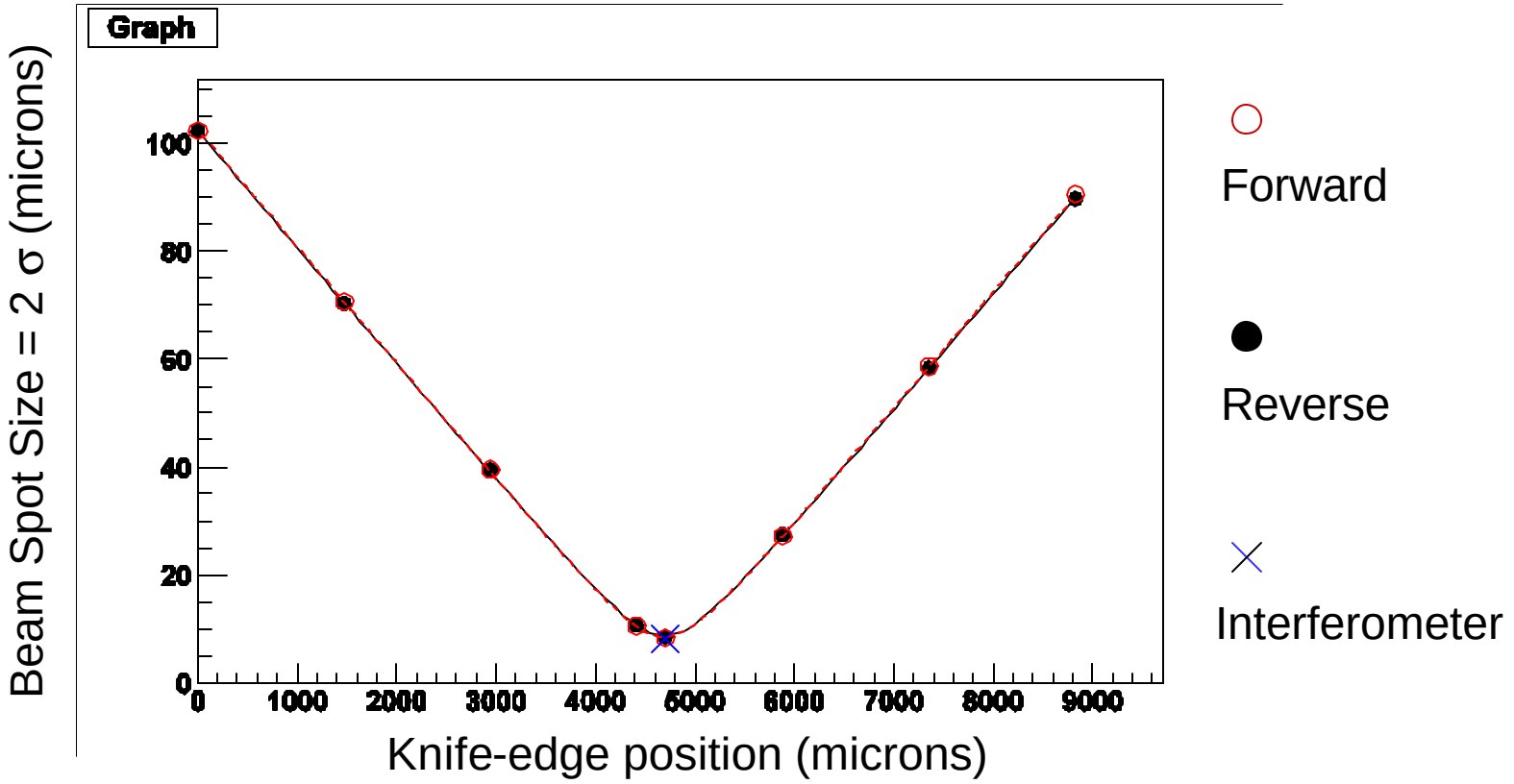
Example of knife edge

- Knife edge is stepped through the laser by the picomotor stage
- Intensity measured by photodiode
- Fit to error function for beam radius w_{beam}



Stage calibration

- Fitted w_{beam} at points along laser axis
- Measurement with interferometer calibrates stage step size



Future Plans

- Compare new imaging optics
- Compare w_{ccd} and w_{knife}
- Second axis
- Fast scanning
- Nanometre beam sizes?
  - Interferometric techniques