

Micron Beam Profile Measurement

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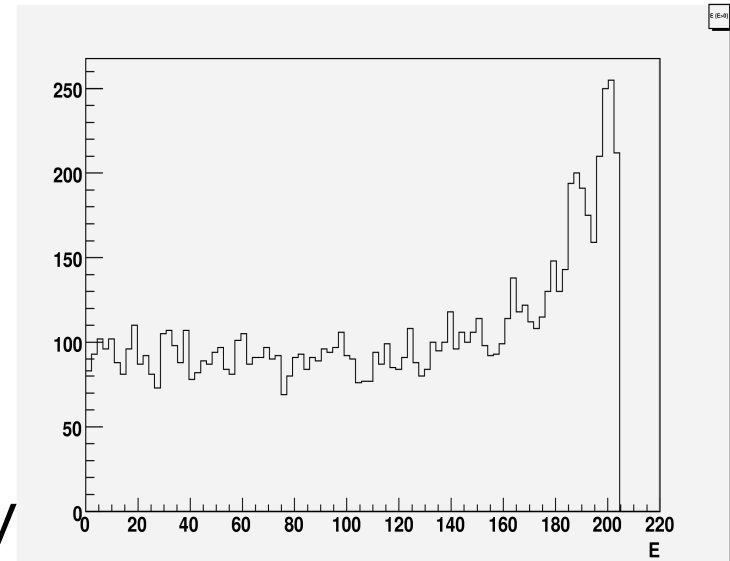
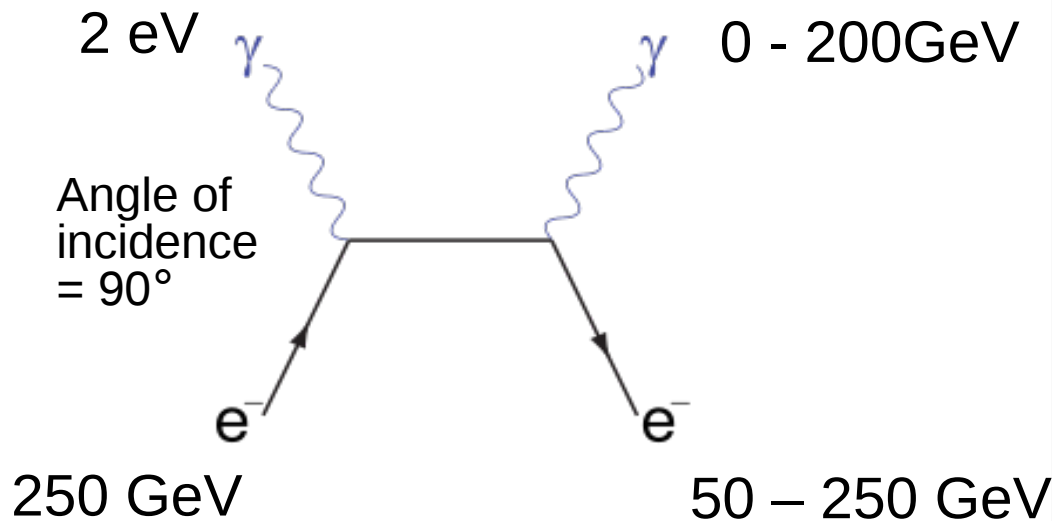


Outline

- Introduction to LW
- Outline of ATF extraction line laser wire system
- Laser system/lens measurements
- Electron beam optics
- Collision measurements
- Conclusions

Introduction

- A means of measuring transverse **beam sizes essential** for future high luminosity linear collider.
- Typical beam sizes to be measured \sim few μm , worst case μm , to within \sim few % in order to measure beam **emittance**.
- **Aim:** to develop a system which **cannon-invasively** measure **1 μm beam sizes**
- **Method:** use a finely focused pulsed laser beam and measuring rate of **inverse Compton scattering** as a function of relative **displacement**.

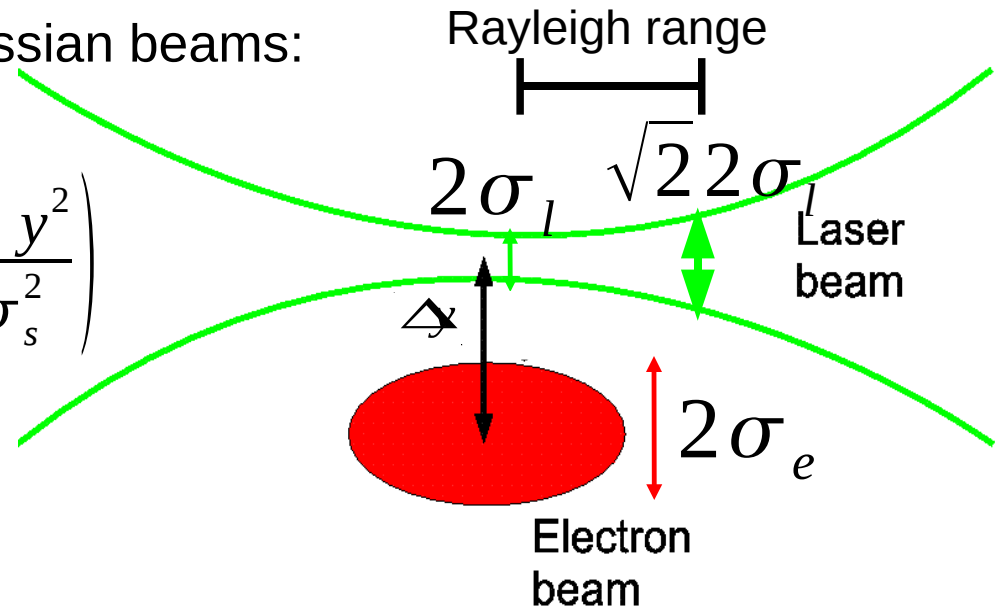


Compton Scattering Rate

- Compton scattering rate for Gaussian beams:

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

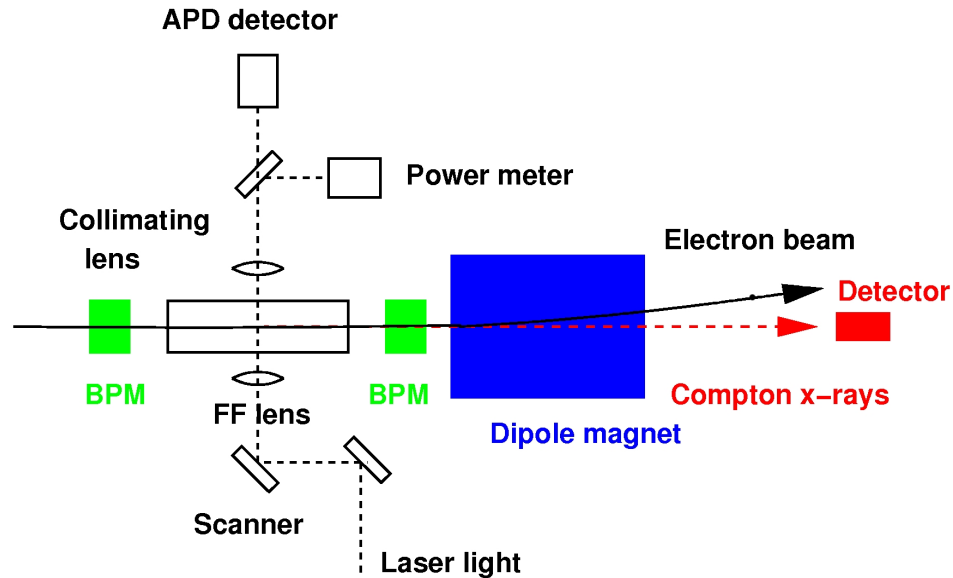
$$\sigma_s^2 = \sigma_e^2 + \sigma_l^2$$



- By measuring Compton rate (N_y) as a function of relative displacement (Δy), the quadrature sum of the beam sizes (σ_s) can be determined
- If laser beam size is known then the electron beam size can be determined

System

- FF lens mounted directly on vacuum chamber. Chamber has a 3 axis translation system

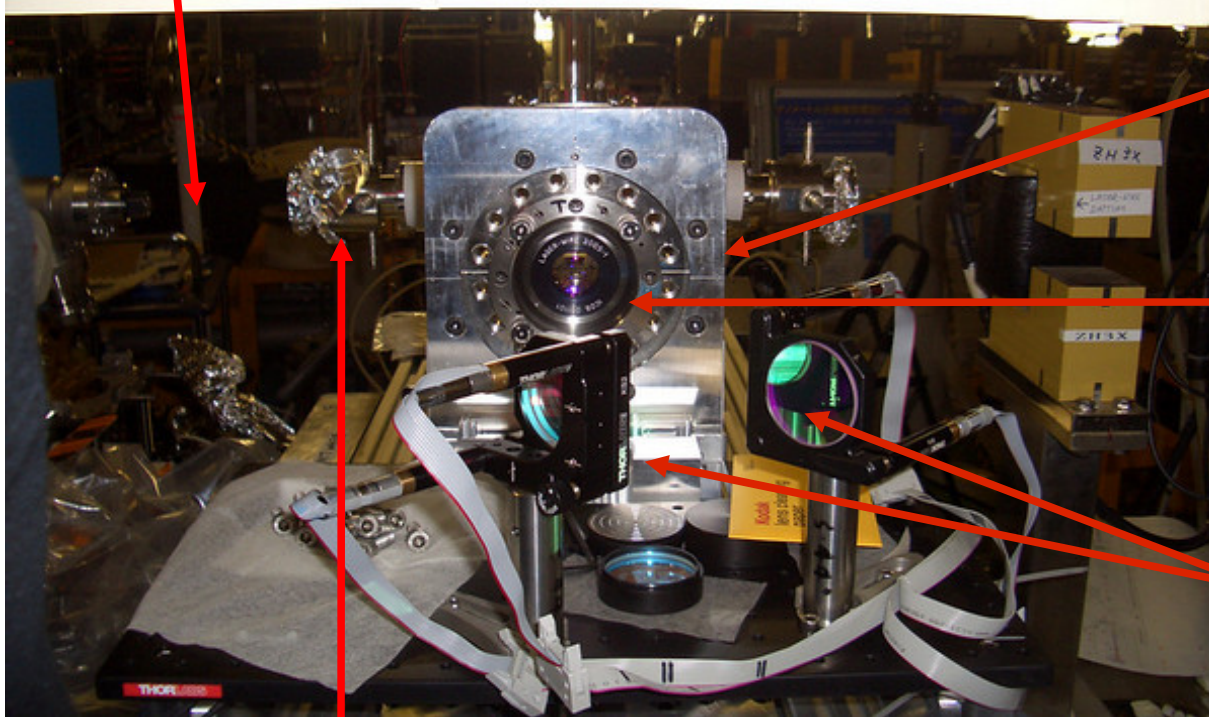


- Light steered onto final focus (FF) lens using 2 mirrors

Interaction Chamber

Beam line

Chamber can be moved along 2 axes transverse to electron beam

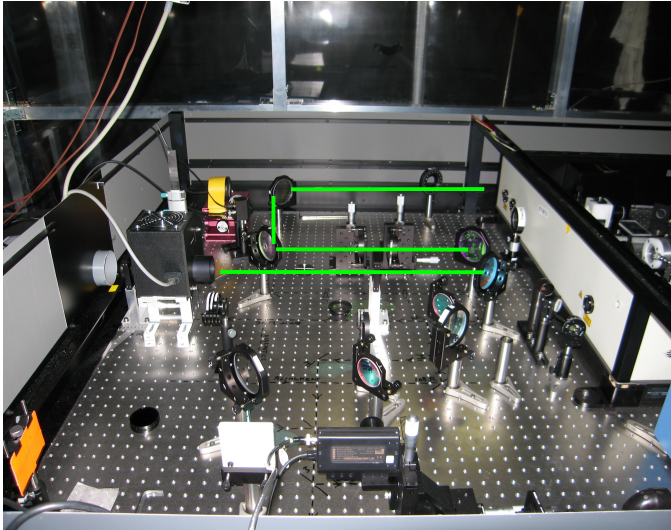


Custom $f=56\text{mm}$ lens fixed to chamber

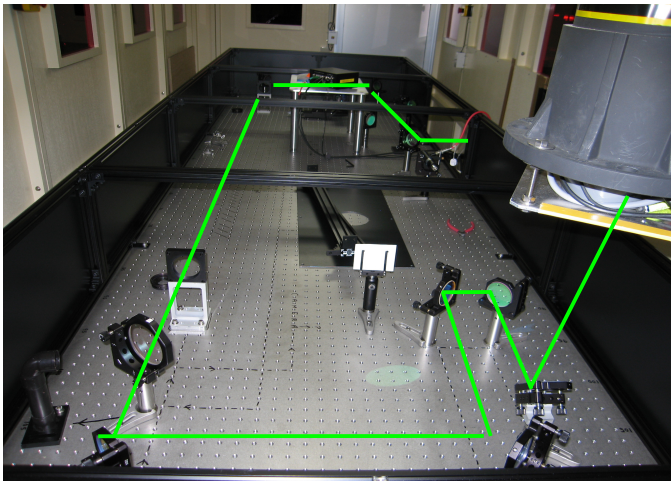
Two scanning mirrors

Strip line beam position monitors fixed to chamber

Laser



- High energy green ($\lambda=532\text{nm}$) laser pulses
- Amplify a single pulse from passively mode-locked seed laser
- Frequency locked to ATF RF distribution system at 357MHz
- Pulse duration $\sim 150\text{ps}$
- Pulse energy $\sim 30\text{mJ}$
- Laser light is transported collimated to extraction line by series of mirrors and aligned using irises



Laser M squared Measurement

- The formula for the focus spot size is

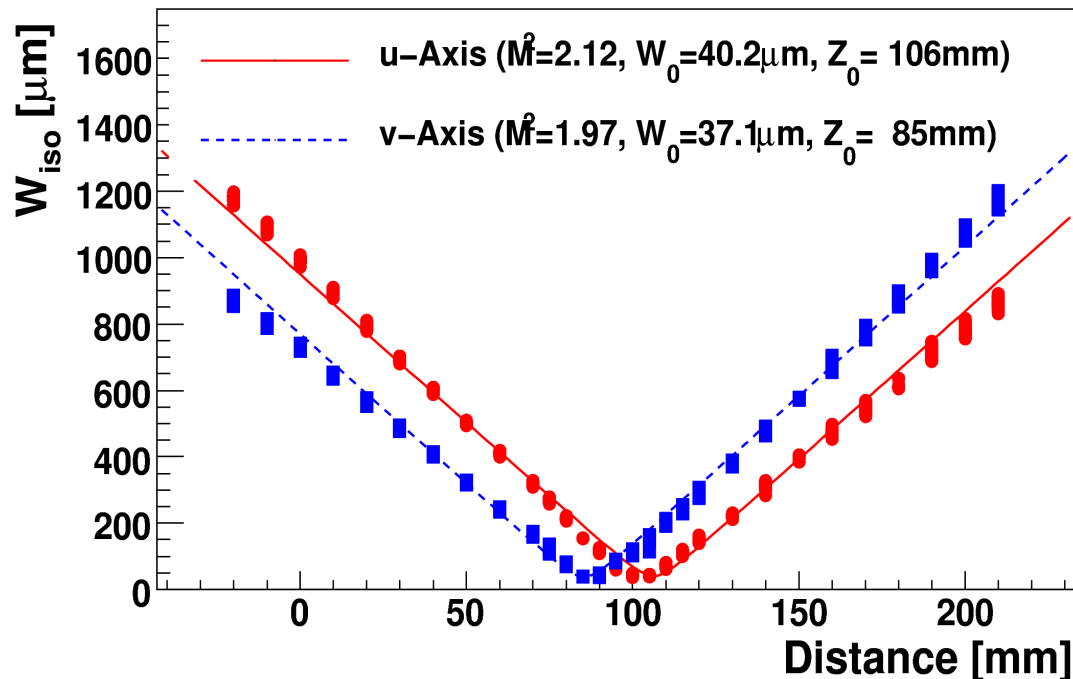
$$W_0 = \frac{M^2 \lambda f}{W_i \pi}$$

- M^2 = laser quality factor. $M^2 > 1$. For a laser with a perfect Gaussian profile $M^2=1$.
- Lambda = wavelength.
- The focal length of the lens is f.
- W_i = input beam size. ($W=2\sigma$)
- We measured the M^2 of our laser in the following way...

Laser M squared Measurement

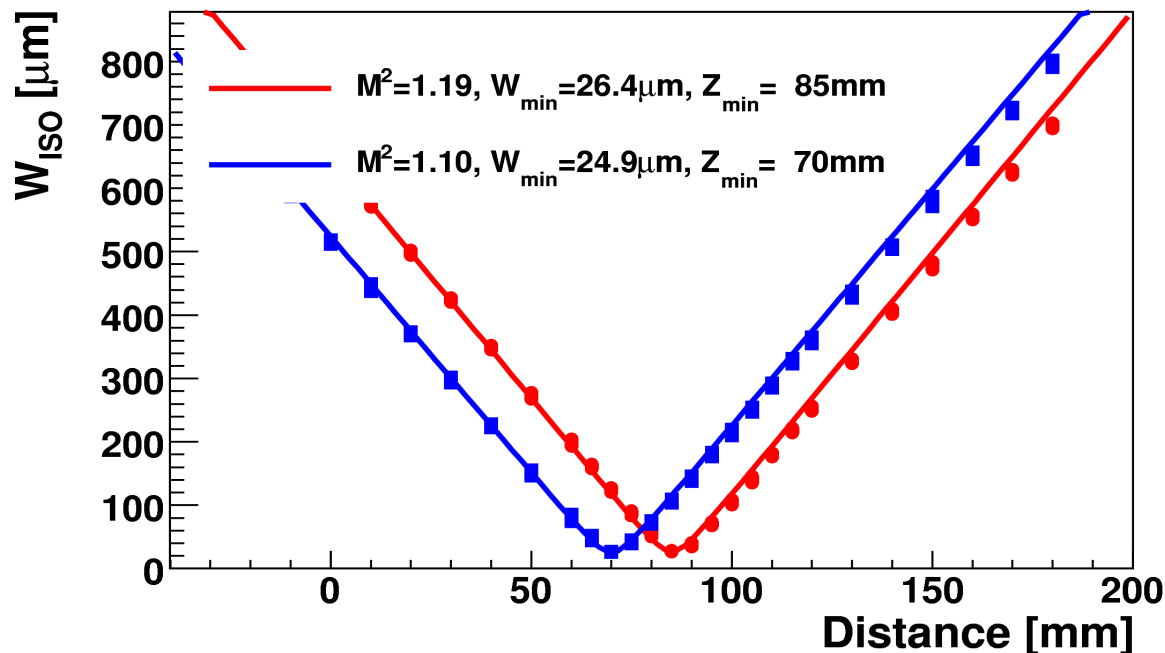
- W was measured at different positions, z , along the propagation axis, after a 1m focal length lens
- The data were fit to the laser propagation formula; $M^2 \sim 2$

$$W(z) = W_0 \left[1 + \left(\frac{M^2 \lambda}{\pi W_0^2} z \right)^2 \right]^{1/2}$$



Laser M squared Measurement

- As a cross check, the same procedure was carried out with a low power CW laser
- In this case, $M^2 \sim 1.15$



Input beam size vs focus size

- The formula indicates that spot size at the focus is inversely proportional to spot size at the lens input

$$W_0 = \frac{M^2 \lambda f}{W_i \pi}$$

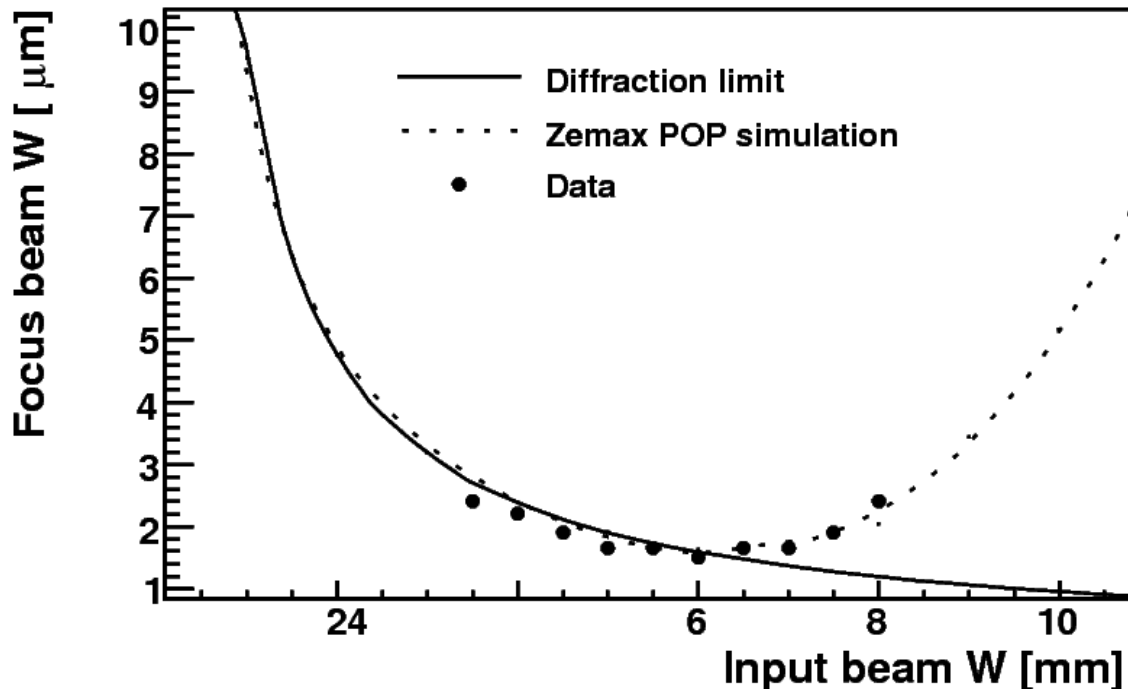
- However, this equation is modified in the presence of spherical aberrations by adding a “lens M^2 ” term to M^2 in quadrature

$$M^2 = [(M_{r0}^2)^2 + (M_{rq}^2)^2]^{1/2}$$

- Simulations and measurements were carried out and to determine M_{rq}^2 as a function of input beam size...

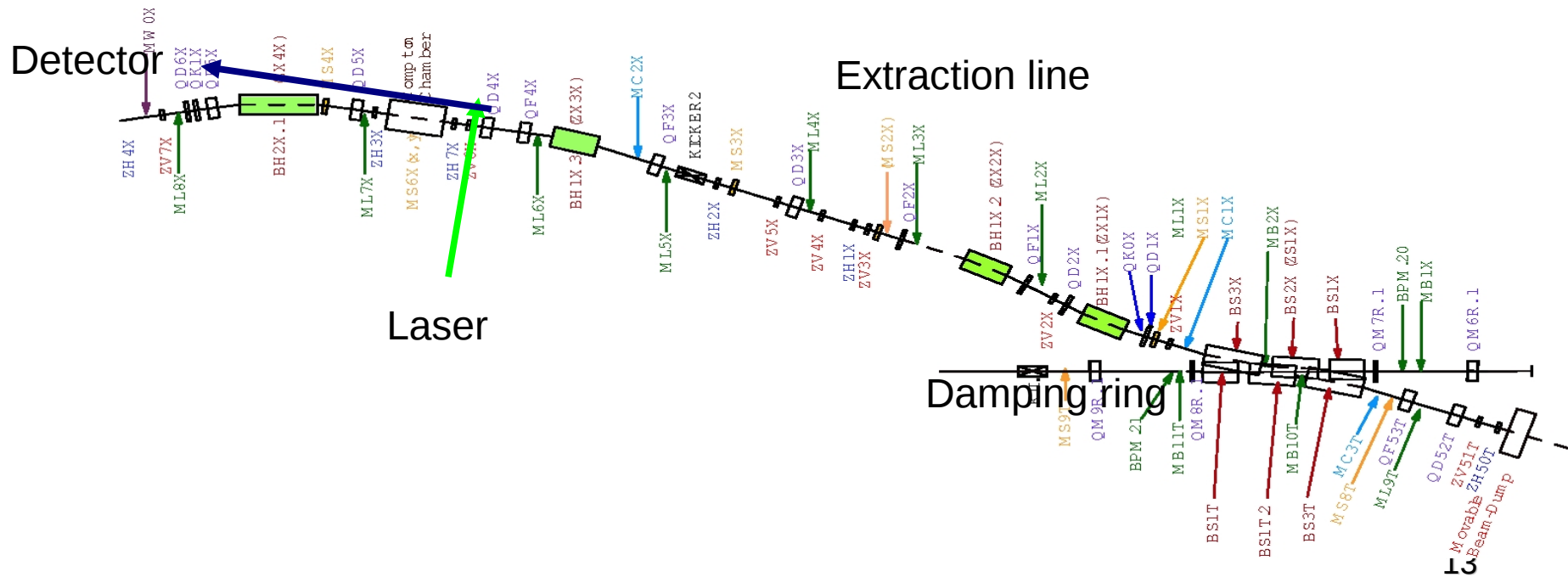
Input beam size vs focus size

- The results show that the optimum input beam size is ~6mm. With a $M^2=2$ laser gives a sigma ~1 mum focus size
- Our input beam size was ~8mm, which with a $M^2=2$ laser would result in sigma~2.2 mum focus size



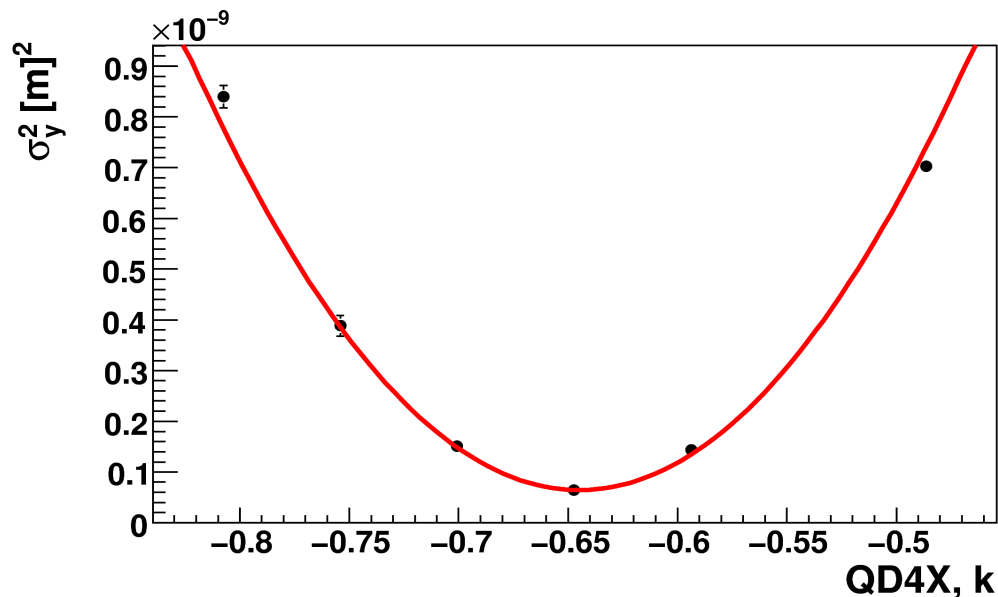
ATF Electron Beam Optics

- Modified so that it is possible to produce electron beam sizes from $\sim 50 \mu\text{m}$ down to the ILC like $20 \mu\text{m} \times 1 \mu\text{m}$



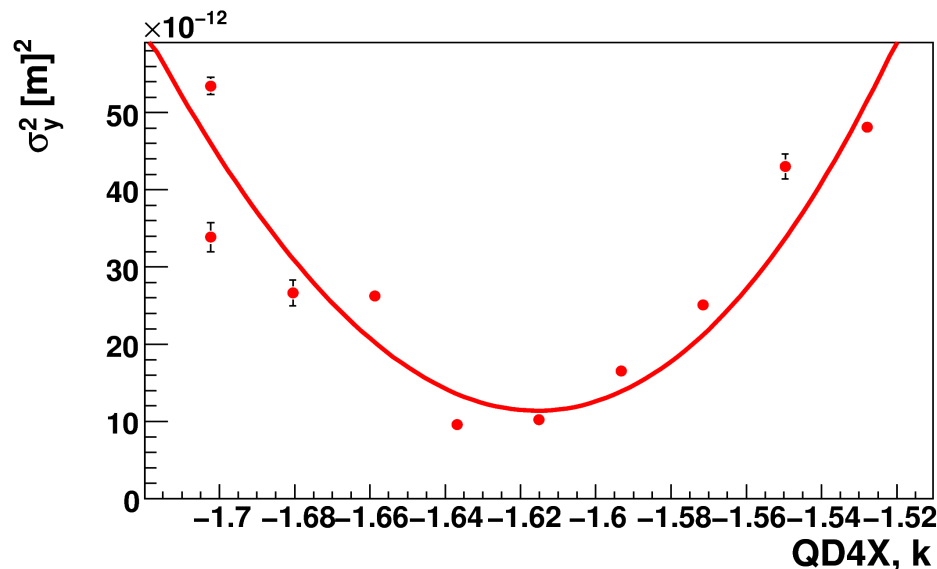
Emittance Measurement

- To probe a 1 micron laser spot an equivalent size electron beam is required
- This depends on the emittance and the dispersion
- The emittance was measured by performing a quad scan using a wire scanner
- Result: emittance = 207 ± 2 pm, so e beam size at LWIP expected to be ~ 3 micron, without dispersion



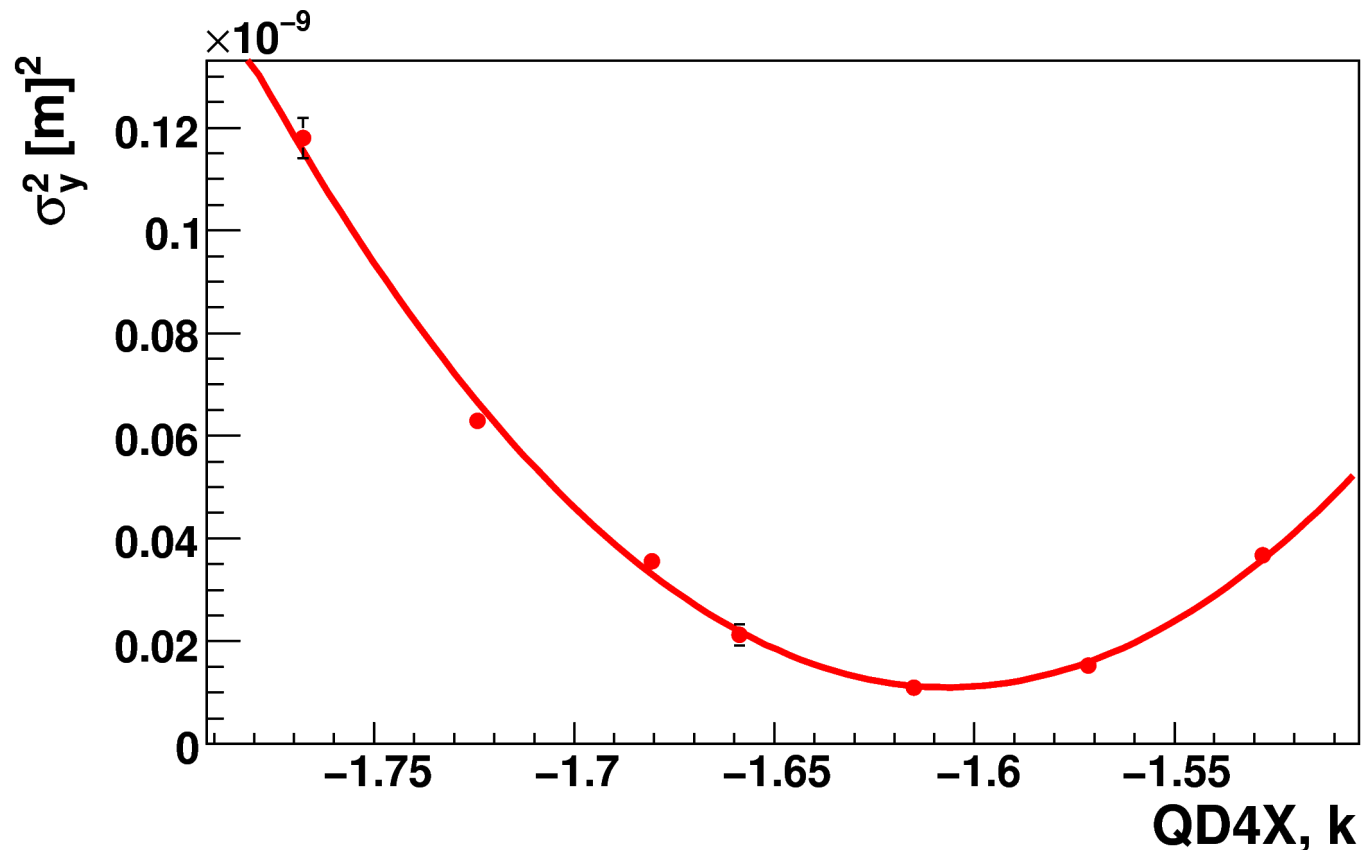
LW Emittance Measurement

- The emittance was measured using the LW by performing a quad scan
- The dispersion was measured at the LWIP using the upstream/downstream BPMs
- The beam size due to the dispersion and laser beam size as calculated from the M2, lens M2 and input beam size measurements were subtracted in quadrature from each convoluted beam profile
- Result: vertical emittance = 232^{+11}_{-32} pm – agrees with wire scan



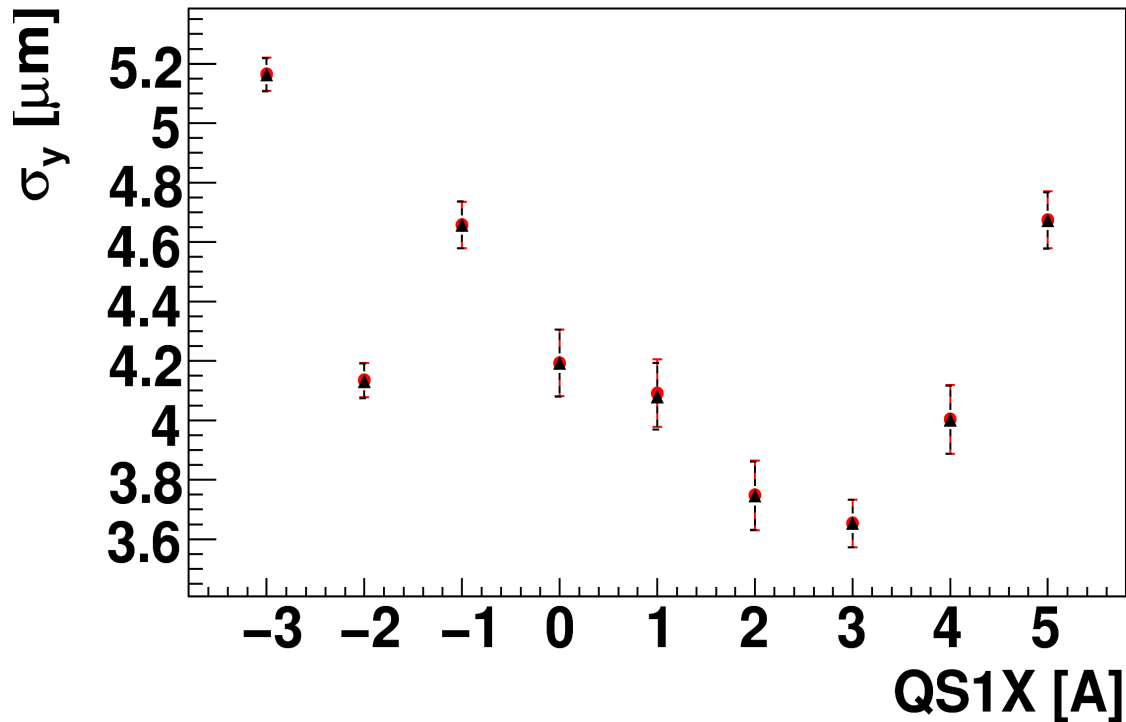
LW Emittance Measurement

- Another example of a quad scan with an emittance fit (no dispersion measurement, however).



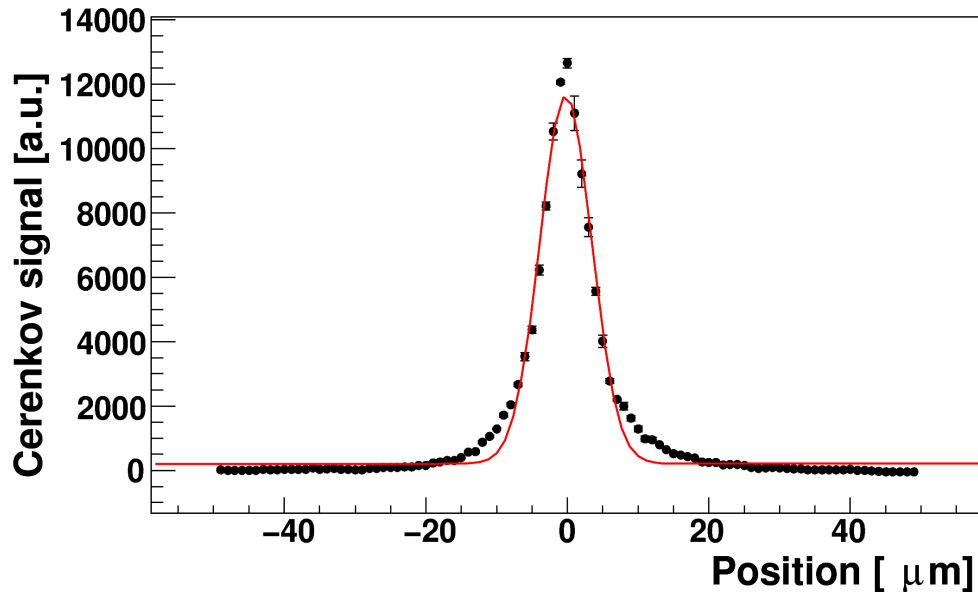
Smallest Scan

- The smallest electron/laser beam overlap was found by iterating the laser/quad foci, and then reducing the electron beam size further using a skew quadrupole



Smallest Scan

- Size of electron/laser beam overlap with Gaussian fit: $\sigma = 3.65 \pm 0.09 \mu\text{m}$
- Subtracting laser beam in quadrature gives $\sigma_{\text{e}} = 2.9 \pm 0.2 \mu\text{m}$ – this is consistent with the measured emittance
- Profiles away from e beam focus are Gaussian, therefore tails are from laser
- The tails could be due to Rayleigh range or spherical aberration effects



Summary

- Measurements were made to account for the contributions to the size of the convolution between the laser and electron beam profiles, σ_c , as measured in a laser wire scan
- Factors contributing to laser beam focus size are laser M^2 and input beam size, which determines lens M^2
- Impact of astigmatism is small
- Using an input beam size of $W_i=6\text{mm}$ will allow us to achieve a laser spot size of ~ 1 micron
- Emittance tuning and dispersion correction at ATF2 will allow us to achieve an e beam spot size of ~ 1 micron. The emittance at ATF2 is expected to be smaller and more stable.