



Beam Size Monitor Model



Grahame Blair
FNAL,
23rd October 2007

- Introduction
- Overview of errors
- Ongoing technical work in this area
- Plans for the future.

Beam Size Monitor Model

Requirements:

- Simple to use system as input to machine tracking codes
- Complex system for full LW simulations
- Possibly combine the two approaches with flags/defaults.

Inputs:

- Laser parameters
- LW laser-optics performance
- Detector locations and efficiencies (non trivial in ILC BDS)
- Required use: bunch-by-bunch or train-by-train; or other?

Laser-wire People

BESSY: T. Kamps

DESY : E. Elsen, H. C. Lewin, F. Poirier, S. Schreiber, K. Wittenburg, K. Balewski

JAI@Oxford: B. Foster, N. Delerue, L. Corner, D. Howell, L. Nevay, M. Newman, A. Reichold, R. Senanayake, R. Walczak

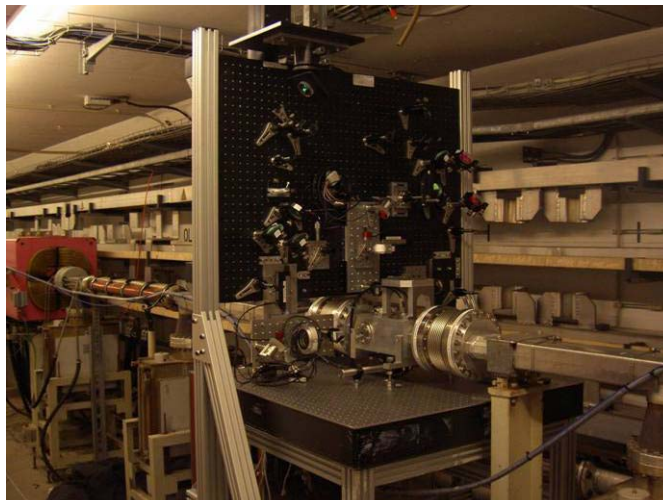
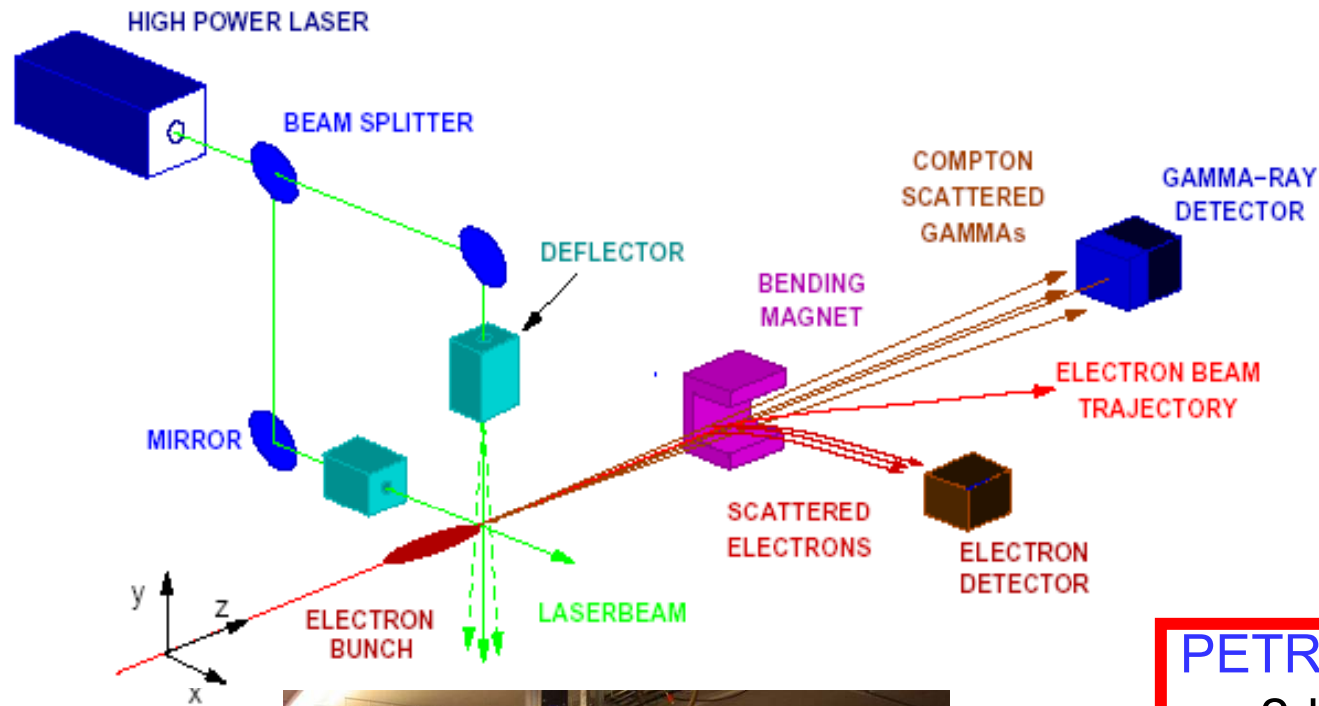
JAI@RHUL: G. Blair, S. Boogert, G. Boorman, A. Bosco, L. Deacon, P. Karataev, S. Malton , M. Price I. Agapov (now at CERN)

KEK: A. Aryshev, H. Hayano, K. Kubo, N. Terunuma, J. Urakawa

SLAC: A. Brachmann, J. Frisch, M. Woodley

FNAL: M. Ross

Laser-wire Principle



PETRA II

- 2d scanning system
- DAQ development
- Crystal calorimeter

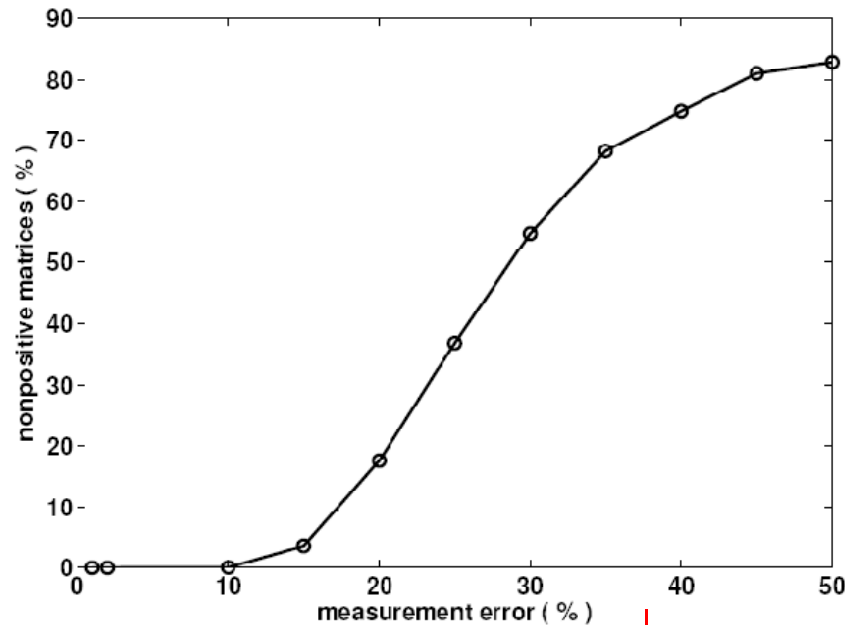
→ PETRA III

- Ultra-fast scanning
- Diagnostic tool

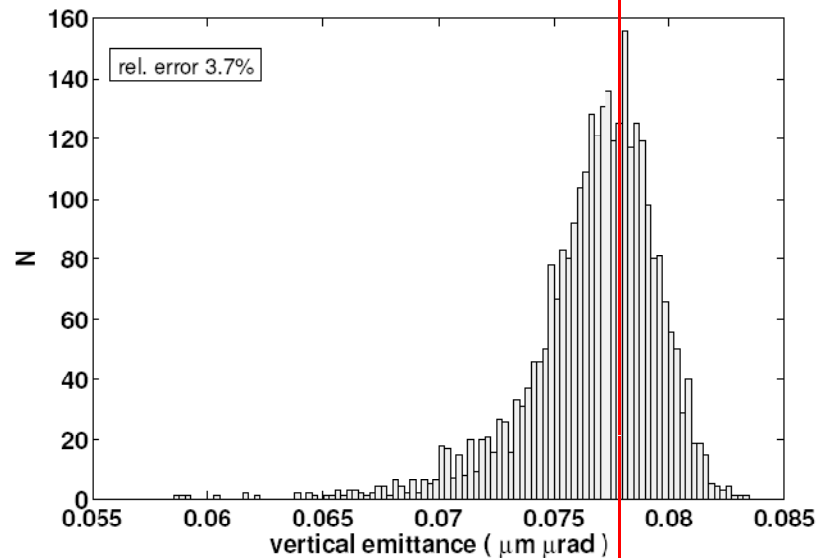
Laser wire : Measurement precision

I. Agapov, G. B., M. Woodley

Goal: Beam Matrix Reconstruction



NOTE: Rapid improvement with better σ_y resolution

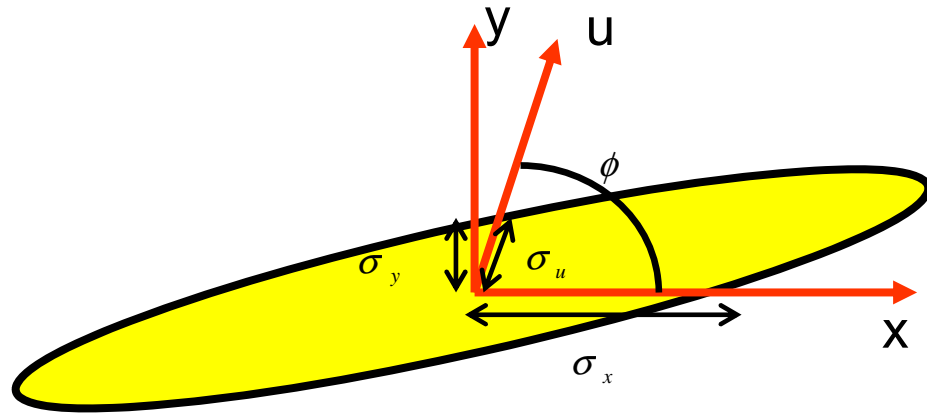


Reconstructed emittance of one ILC train using 5% error on σ_y

Assumes a 4d diagnostics section
With 50% random mismatch of initial optical functions

The true emittance is 0.079 $\mu\text{m } \mu\text{rad}$

Skew Correction



$$\phi_{\text{optimal}} = \tan^{-1} \left(\frac{\sigma_x}{\sigma_y} \right)$$

$\approx 68^\circ - 88^\circ$ at ILC

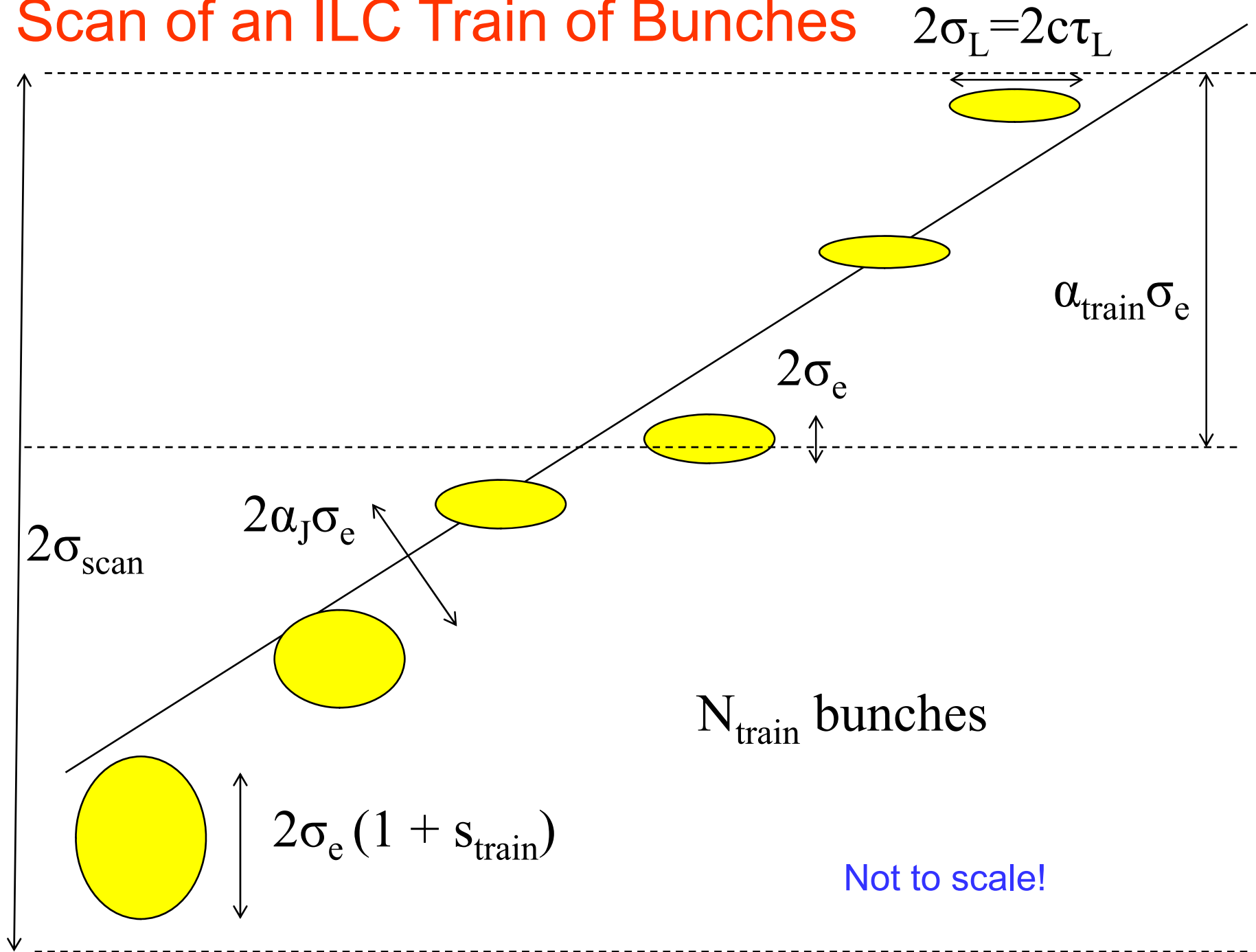
Error on coupling term:

$$\delta \langle xy \rangle = \sigma_x \sigma_y \left[4 \left(\frac{\delta \sigma_u}{\sigma_u} \right)^2 + \left(\frac{\delta \sigma_x}{\sigma_x} \right)^2 + \left(\frac{\delta \sigma_y}{\sigma_y} \right)^2 \right]^{\frac{1}{2}}$$

ILC LW Locations $E_b = 250$ GeV

σ_x (μm)	σ_y (μm)	$\phi_{\text{opt}} (^\circ)$	σ_u (μm)
39.9	2.83	86	3.99
17.0	1.66	84	2.34
17.0	2.83	81	3.95
39.2	1.69	88	2.39
7.90	3.14	68	4.13
44.7	2.87	86	4.05

Scan of an ILC Train of Bunches



Need for Intra-Train Scanning

$$L = \frac{N_{\text{train}} N_e^2 f_{\text{rep}}}{4\pi\sigma_x\sigma_y} H_D$$

$$\left\langle \frac{1}{\sigma} \right\rangle = \frac{1}{\langle \sigma \rangle} \left(1 + \frac{1}{3} s_{\text{train}}^2 \right)$$

For <0.5% effect, $s_{\text{train}} < 0.12$; otherwise, the effect must be subtracted

For $1\mu\text{m}$ bunches, the error after subtracting for any systematic shift (assumed linear $\pm\alpha_{\text{train}}$ along the train) is:

$$\frac{\delta\sigma_e}{\sigma_e} = 1.9 \times 10^{-3} \left(\frac{\sigma_{\text{BPM}}}{100 \text{ nm}} \right) \alpha_{\text{train}}$$

For <0.5% effect, $\alpha_{\text{train}} < 2.6$; otherwise, higher precision BPMs required

Machine Contributions to the Errors

$$\sigma_e = \left[\sigma_{\text{scan}}^2 - (\alpha_J \sigma_e)^2 - (\eta \delta_E)^2 \right]^{\frac{1}{2}}$$

Bunch Jitter

$$\frac{\delta \sigma_e}{\sigma_e} \approx 5 \times 10^{-2} \left(\frac{\alpha_J}{0.5} \right)^2 \left(\frac{\sigma_{\text{BPM}}}{100 \text{nm}} \right)$$

BPM resolution of 20 nm may be required

Dispersion

$$\frac{\delta \sigma_e}{\sigma_e} \approx 2.3 [\eta / \text{mm}]^2 \left(\frac{\langle \delta \eta \rangle}{\eta} \right)$$

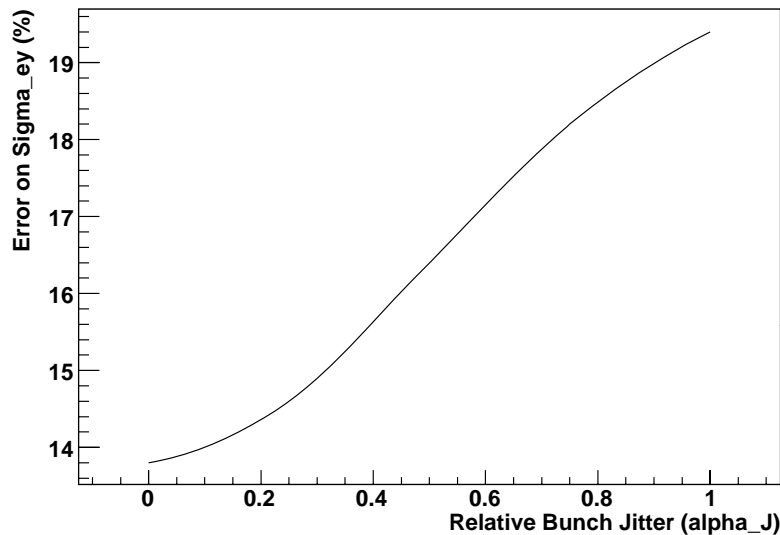
Assuming η can be measured to 0.1%,
then η must be kept $< \sim 1 \text{mm}$

Alternative Scan Mode

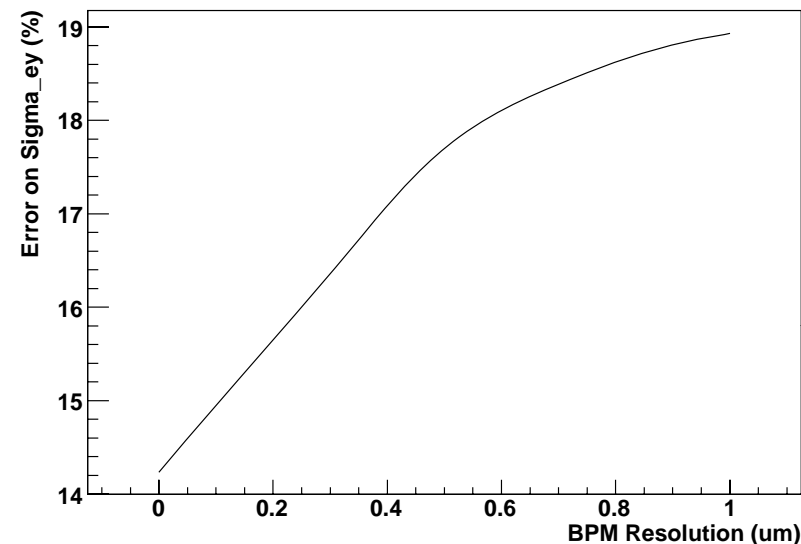
- R&D currently investigating ultra-fast scanning (~100 kHz) using Electro-optic techniques
- Alternative: Keep laser beam fixed and use natural beam jitter plus accurate BPM measurements bunch-by-bunch.
Needs the assumption that bunches are pure-gaussian
- For one train, a statistical resolution of order 0.3% may be possible

Single-bunch fit errors for

$$\sigma_{ey} = 1\mu\text{m}, \sigma_{ex} = 10\mu\text{m}$$

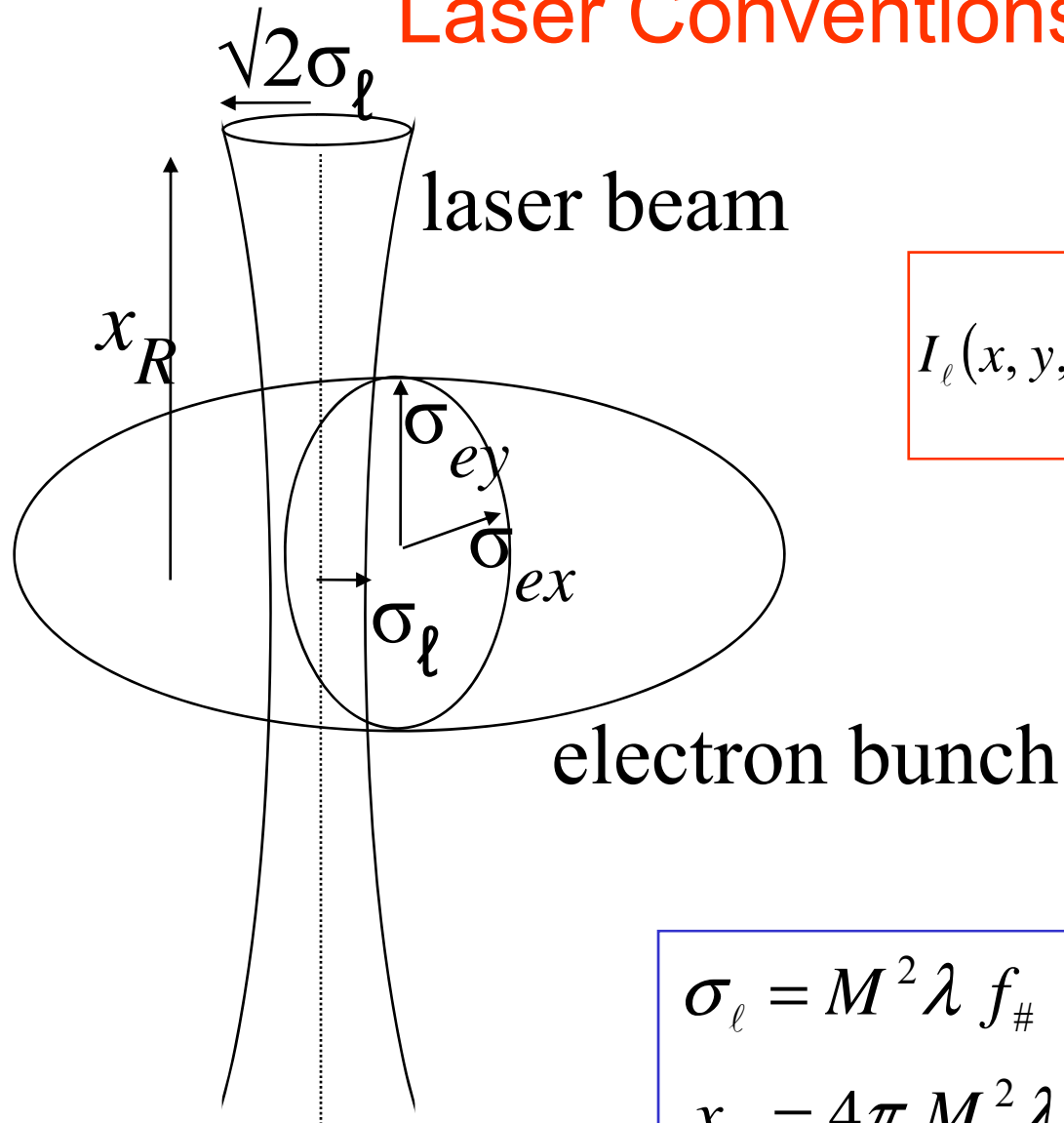


Beam jitter fixed at 0.25σ



BPM resolution fixed at 100 nm

Laser Conventions



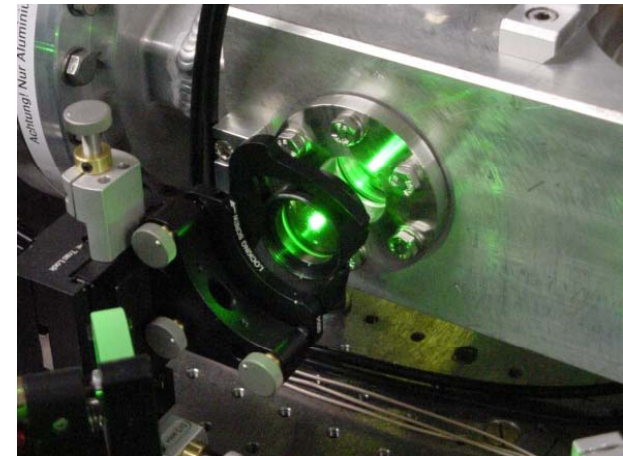
For TM_{00} laser mode:

$$I_\ell(x, y, z) = \frac{I_0}{2\pi\sigma_\ell^2} \frac{1}{f_R(x)} \exp\left[-\frac{y^2 + z^2}{2\sigma_\ell^2 f_R(x)}\right]$$

$$f_R(x) = 1 + \left(\frac{x}{x_R}\right)^2$$

$$\sigma_\ell = M^2 \lambda f_\#$$

$$x_R = 4\pi M^2 \lambda f_\#^2$$



Compton Statistics

$$N_{\text{Detected}} = 1212 \xi \frac{1}{\sqrt{2\pi\sigma_m}} \exp\left(-\frac{1}{2} \left[\frac{\Delta_y}{\sigma_m}\right]^2\right)$$

Approximate – should use full overlap integral (as done below...)

Where :

$$\xi = \left(\frac{\eta_{\text{det}}}{0.05}\right) \left(\frac{P_\ell}{10 \text{ MW}}\right) \left(\frac{N_e}{2 \times 10^{10}}\right) \left(\frac{\lambda}{532 \text{ nm}}\right) \left(\frac{f(\omega)}{0.2}\right) \mu\text{m}$$

e-bunch occupancy
Compton xsec factor

↓
↓

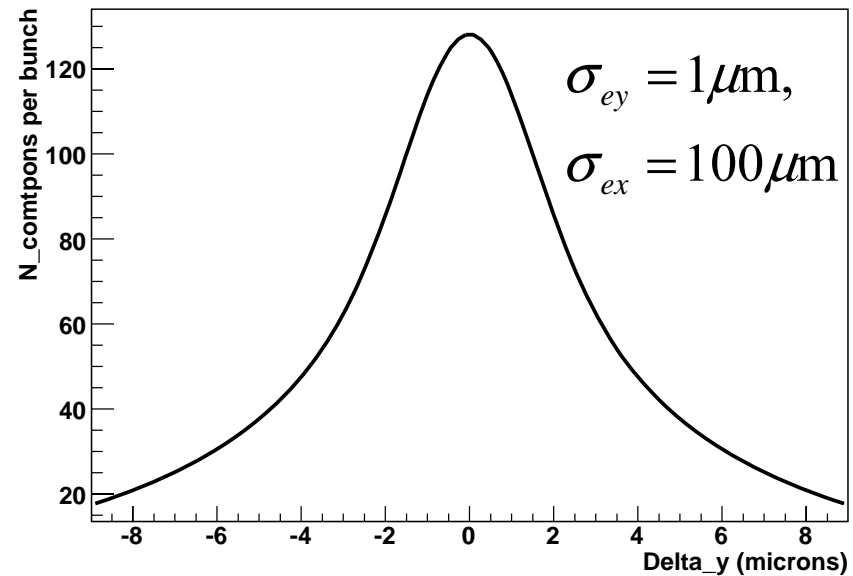
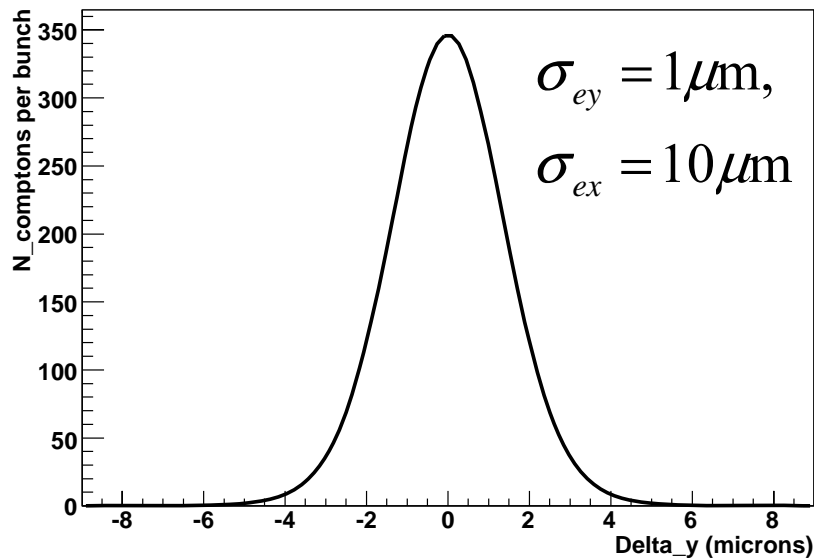
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Laser peak power
Laser wavelength

↑

Detector efficiency
(assume Cherenkov system)

TM₀₀ Mode Overlap Integrals



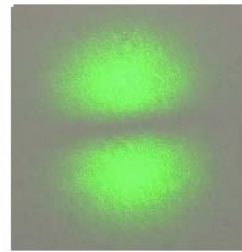
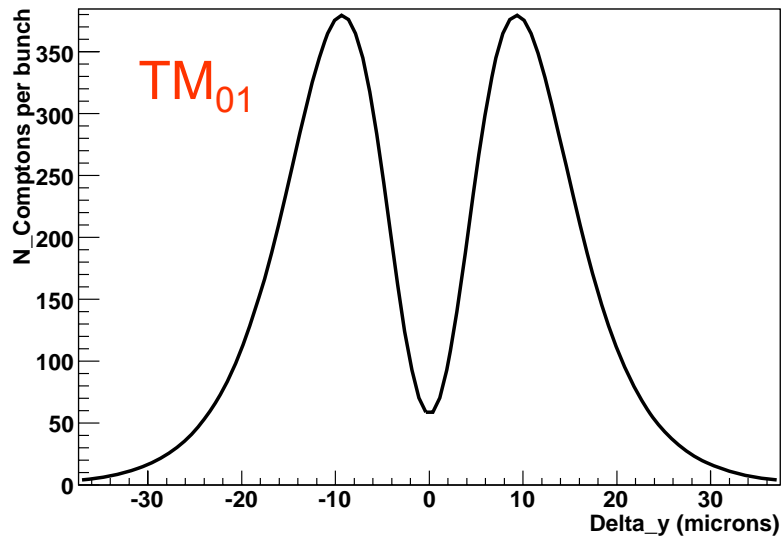
Rayleigh Effects obvious

Main Errors:

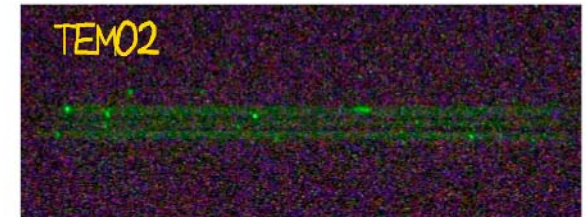
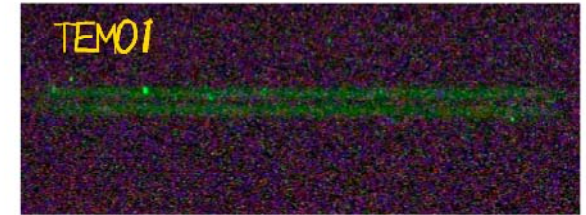
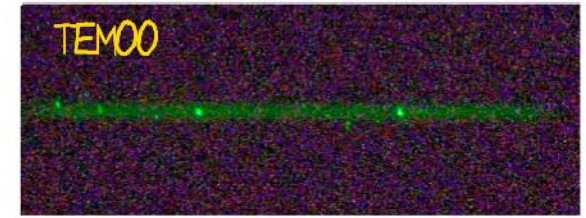
- Statistical error from fit $\sim \xi^{-1/2}$
- Normalisation error (instantaneous value of ξ) – assume $\sim 1\%$ for now.
- Fluctuations of laser M^2 – assume M^2 known to $\sim 1\%$
- Laser pointing jitter ψ

$$\frac{\delta\sigma_e}{\sigma_e} \approx 2.2 \times 10^{-3} \left(\frac{\psi}{10\mu\text{rad}} \right)^2 \left(\frac{\delta\psi}{\psi} / 10\% \right)$$

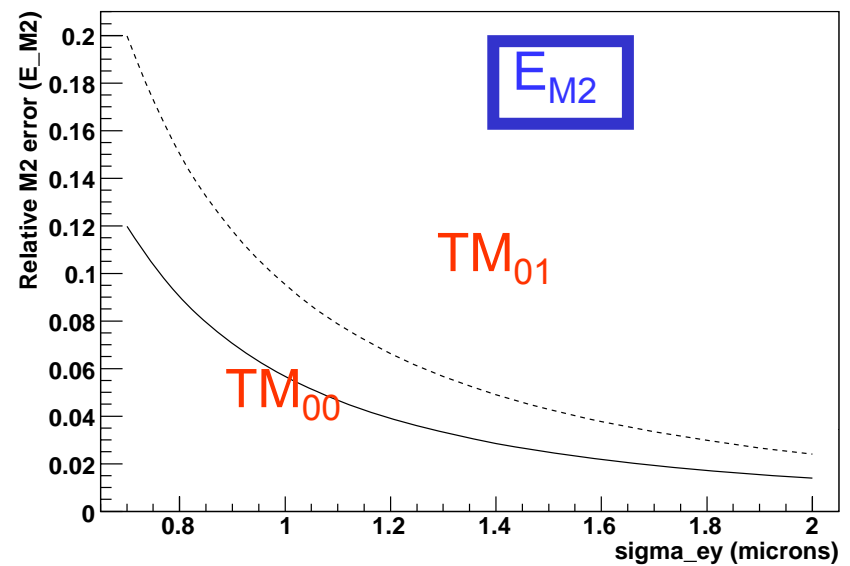
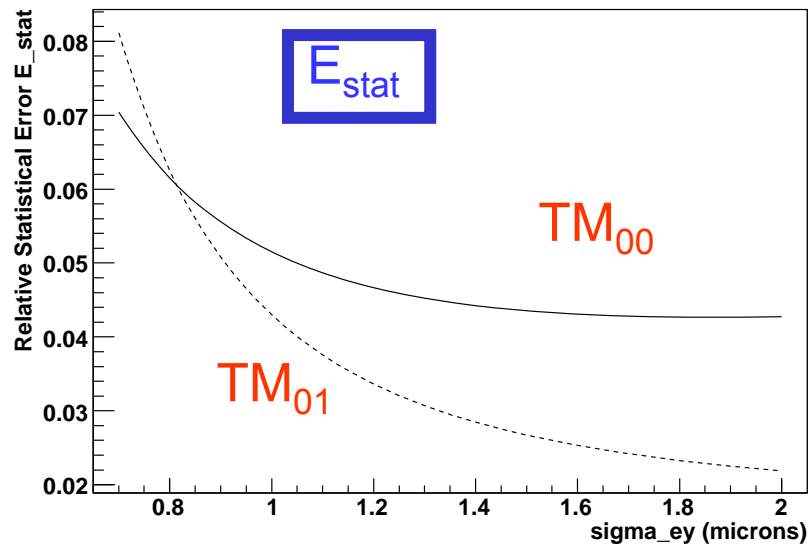
$$\frac{\delta\sigma_e}{\sigma_e} \approx \left(\frac{\lambda f_{\#}}{\sigma_e} \right)^2 M^2 \left(\frac{\delta M^2}{M^2} \right)$$



Y. Honda et al



TM₀₁ gives some advantage for larger spot-sizes

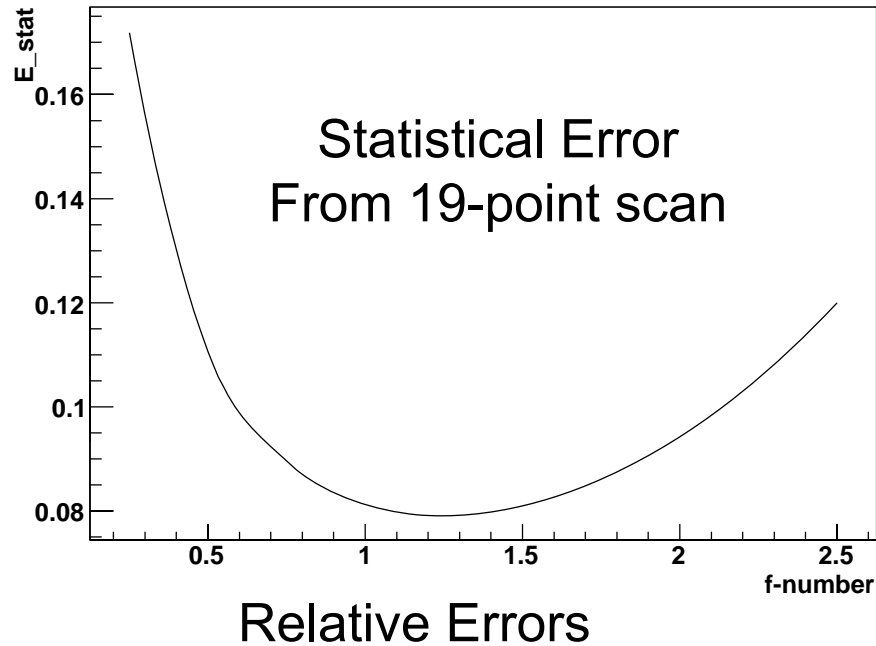


Laser Requirements

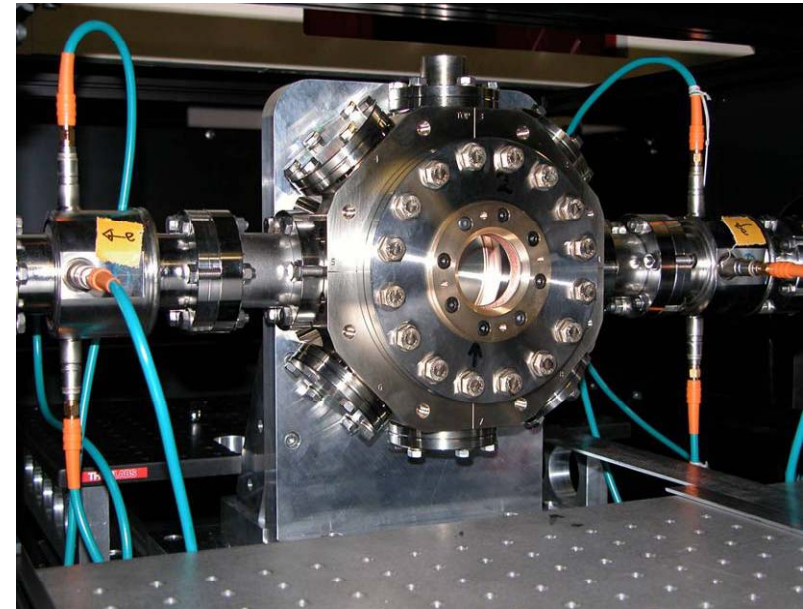
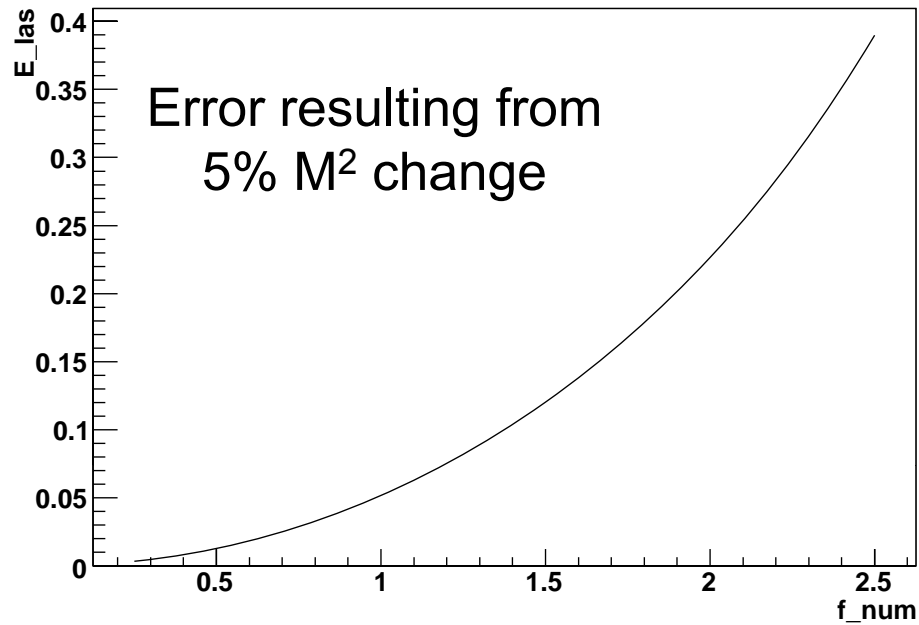
Wavelength	≤ 532 nm
Mode Quality	≤ 1.3
Peak Power	≥ 20 MW
Average power	≥ 0.6 W
Pulse length	≥ 2 ps
Synchronisation	≤ 0.3 ps
Pointing stability	≤ 10 μ rad

ILC-spec laser is being developed at JAI@Oxford based on fiber amplification. L. Corner et al

TM₀₀ mode



- Optimal f-num \approx 1-1.5 for $\lambda = 532\text{nm}$
- Then improve M^2 determination
- f-2 lens about to be installed at ATF



ATF2 LW; aiming initially
at f_2 ; eventually f_1 ?

Towards a 1 μm LW

preliminary Resultant errors/ 10^{-3}

Goals/assumptions

Wavelength	266 nm
Mode Quality	1.3
Peak Power	20 MW
FF f-number	1.5
Pointing stability	10 μrad
M^2 resolution	1%
Normalisation (ξ)	2%
Beam Jitter	0.25 σ
BPM Resolution	20 nm
Energy spec. res	10^{-4}

E_ξ	2.5
E_{point}	2.2
E_{jitter}	5.0
E_{stat}	4.5
E_{M^2}	2.8
Total Error	8.0

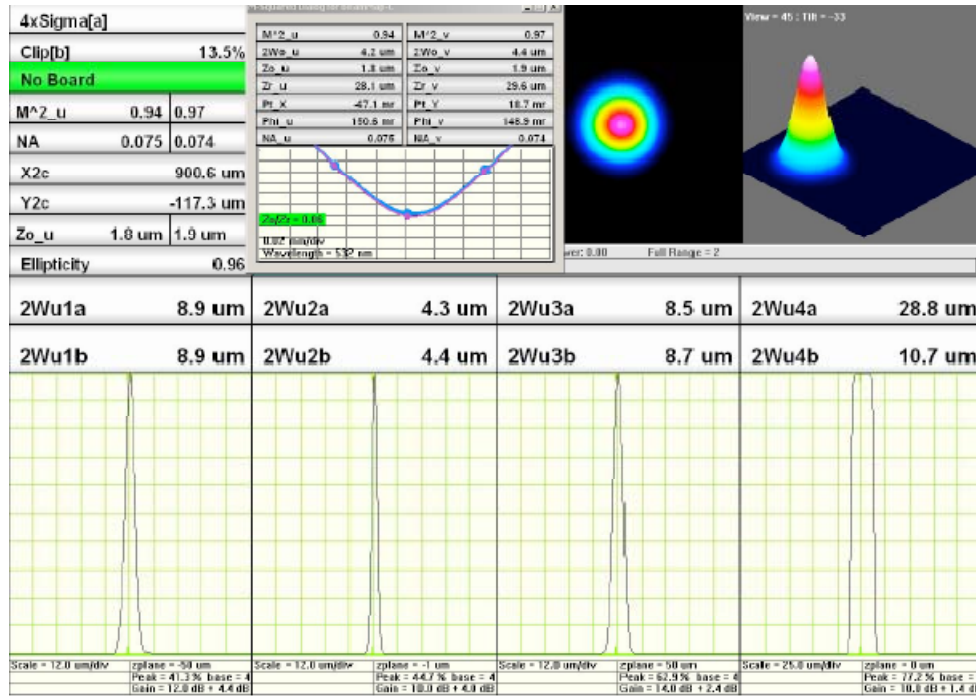
Final fit, including dispersion

} Could be used for η measurement
 $\rightarrow E_\eta$

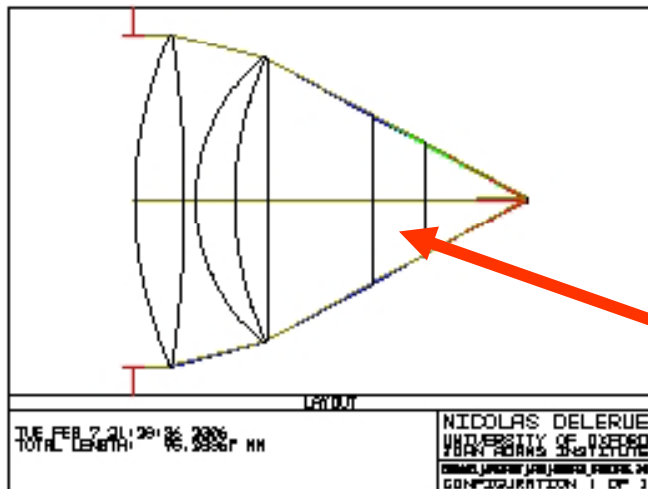
Lens Design + Tests

- f-2 lens has been built and is currently under test.
- Installation at ATF planned for this year

M. Newman, D. Howell et al.

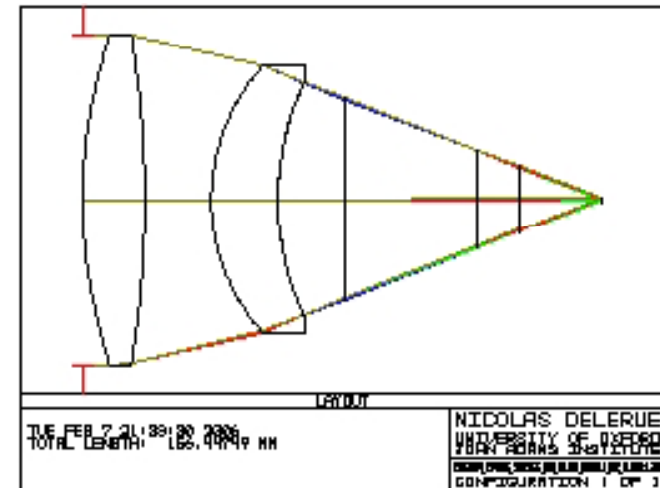


Designs for f-1 optics are currently being studied, including:



Aspheric doublet

Vacuum window



N. Delerue et al.

BDS Laser-wire

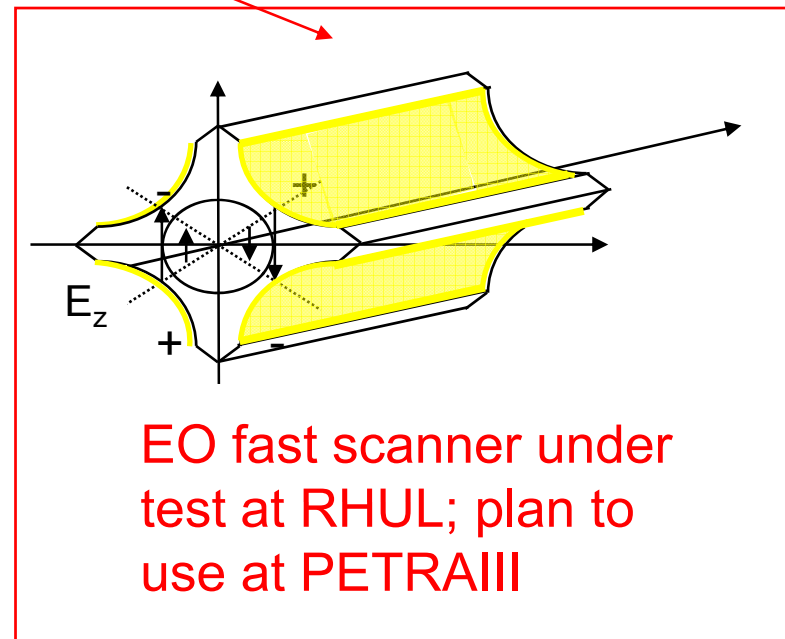
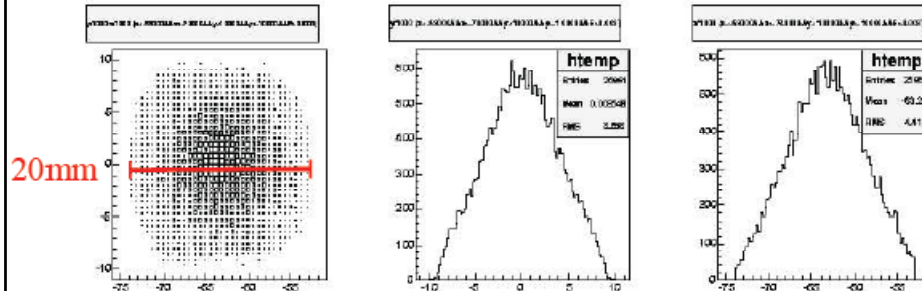
- PETRA – 2d scans, multi-shot.
- ATF – micron, single shot
- Laser R&D
- Fast Scanning R&D
- Simulation

All initial goals have been achieved.

New fibre-laser programme at Oxford now under-way in collaboration with EU industry

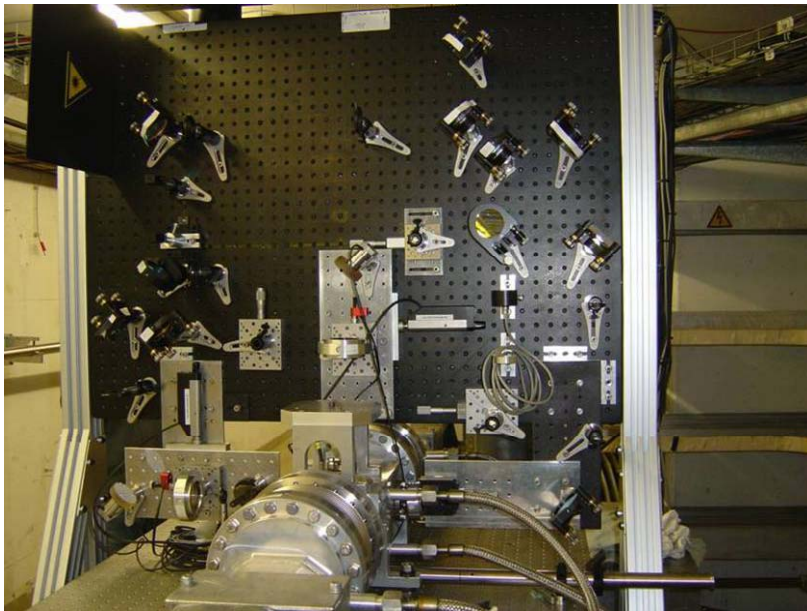
BDSIM plots.
At ATF2:

IPBPM in new location – 43% photons lost

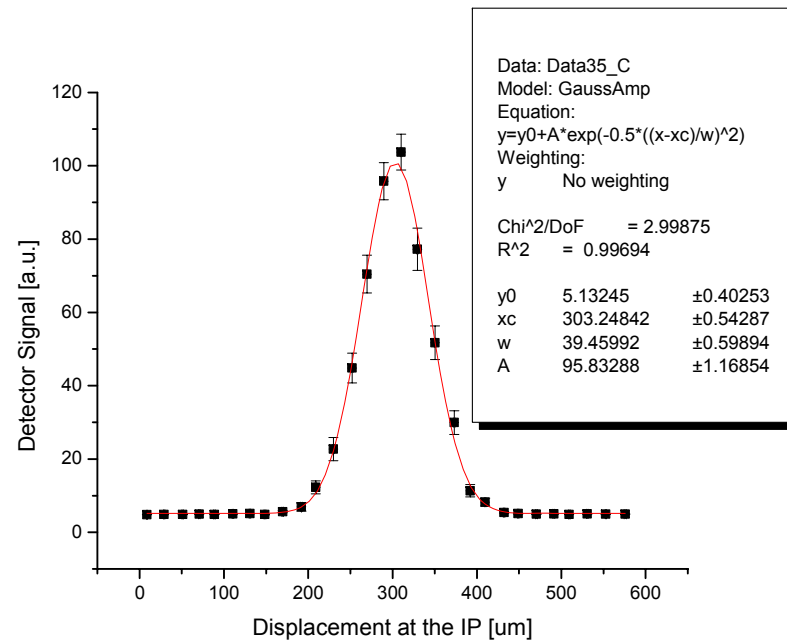


PETRA LW

Routine scans of two-dimensions were achieved
PETRAII programme now finished; preparing for PETRAIII
Fast scanning system with 130kHz laser at RHUL planned
Collaborating with DESY on fast DAQ
Look forward to installation in new location for **PETRAIII next year**



PETRA II



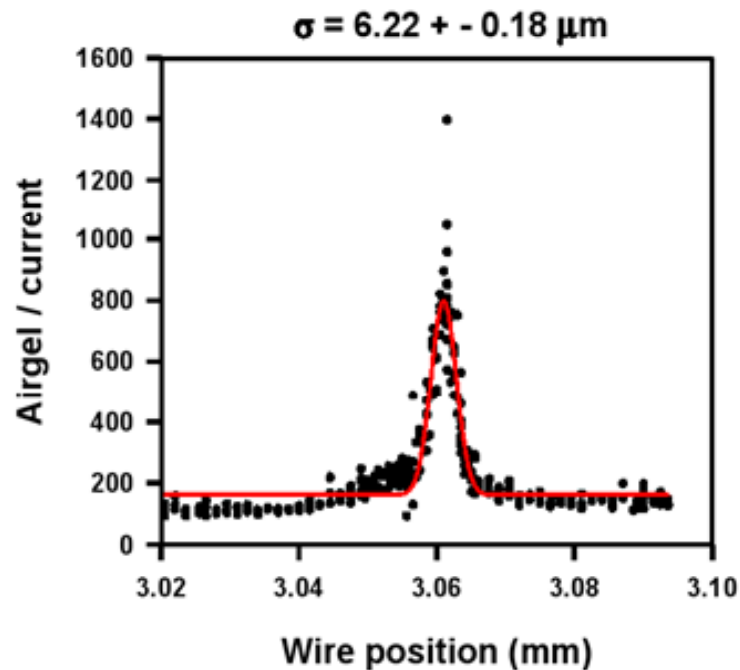
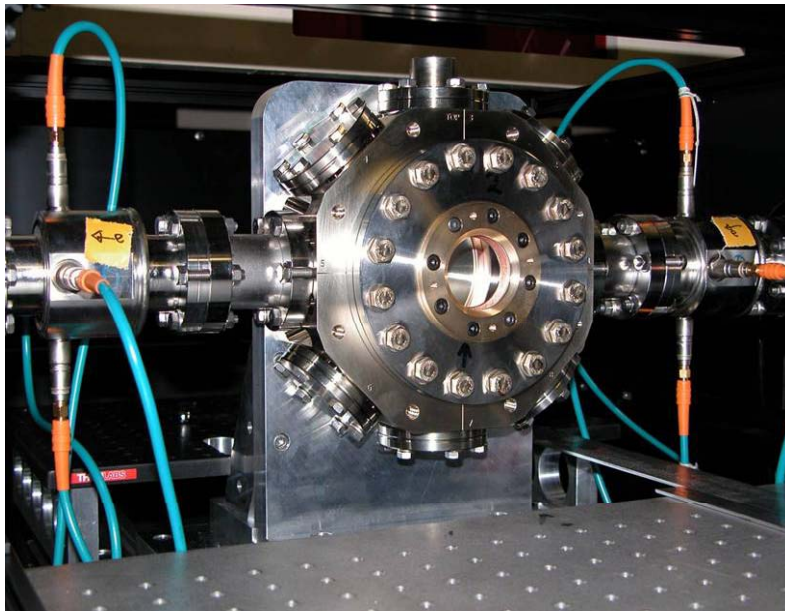
1000 laser shots= 50s.
beam: 6 GeV, 0.5 mA.

ATF LW

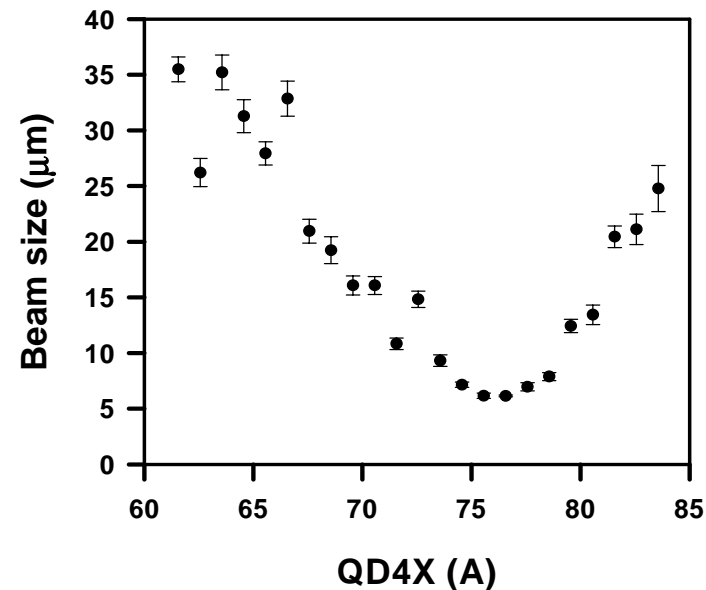
Tests of f_2 lens system currently underway at Oxford

We have improved mode quality Of ATF laser at KEK in October 2007.

Look forward to running with f_2 optics in Nov 07 and in 2008.

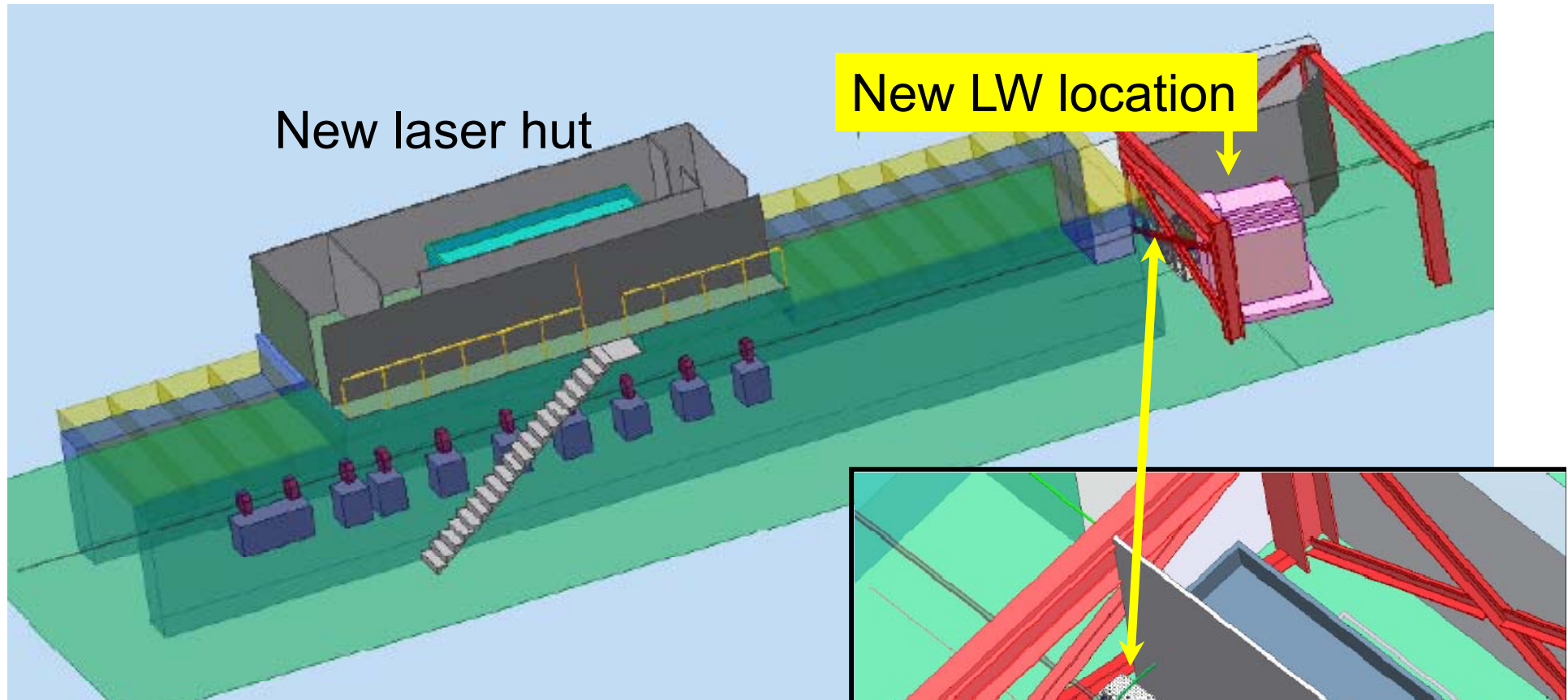


single LW scan

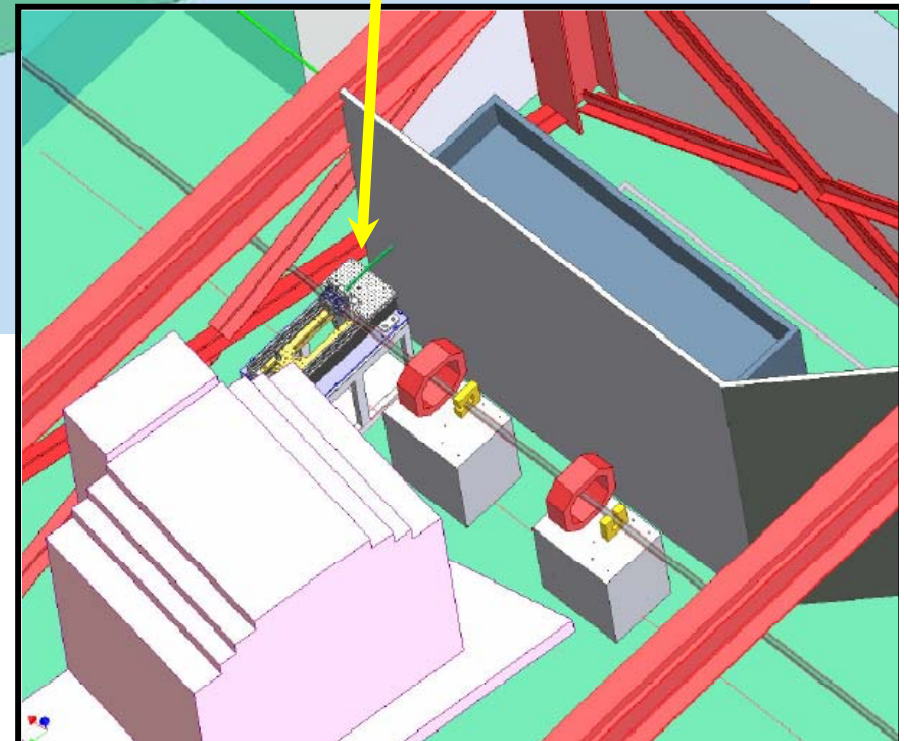


quad scan using LW scans

ATF2 Laser-wire



- Detailed design of layout, light path, laser hut are underway.
- An additional LW location has been reserved downstream for multi-axis scans → **LC-ABD-II**



ATF/ATF2 Laser-wire

- At ATF2, we will aim to measure micron-scale electron spot-sizes with green (532 nm) light.
- Two locations identified for first stage (more stages later)
 - 1) 0.75m upstream of QD18X magnet
 - 2) 1m downstream of QF19X magnet

Nominal ATF2 optics

LW-IP (1)

LW-IP (2)

$$\sigma_x = 38.92 \mu\text{m}$$

$$\sigma_x = 142.77 \mu\text{m}$$

$$\sigma_y = 7.74 \mu\text{m}$$

$$\sigma_y = 7.94 \mu\text{m}$$

ATF2 LW-test optics

LW-IP (1)

LW-IP (2)

$$\sigma_x = 20.43 \mu\text{m}$$

$$\sigma_x = 20 \mu\text{m}$$

$$\sigma_y = 0.9 \mu\text{m}$$

$$\sigma_y = 1.14 \mu\text{m}$$

P. Karataev

⇒ Ideal testing ground for ILC BDS Laser-wire system

Summary

- Very active + international programme:
 - Hardware
 - Optics design
 - Advanced lasers
 - Emittance extraction techniques
 - Data taking + analysis
 - Simulation
- A useful model will include effects:
 - Laser pointing
 - M^2 monitoring
 - Low-f optics
 - Fast scanning
 - High precision BPMs
- BDSIM already contains a simple LW generator
 - What other formats are required?
 - Additional benchmarking can be done at PETRA/ATF.
 - What about the ILC linac?

