Laser-wire at ATF2 and PETRA

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CERN,

18th October 2007

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

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

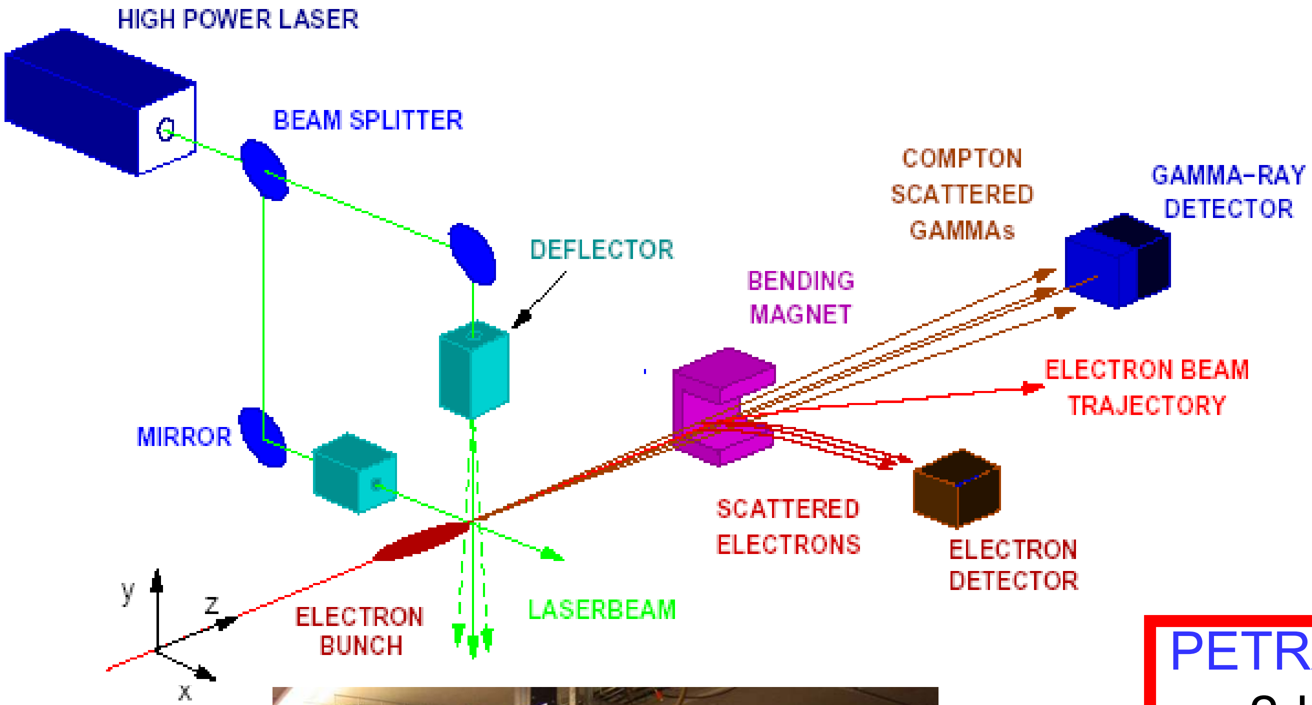
JAI@RHUL: G. Blair, S. Boogert, G. Boorman, A. Bosco, L. Deacon, P. Karataev, S. Malton , M. Price I. Agapov (now at CERN)

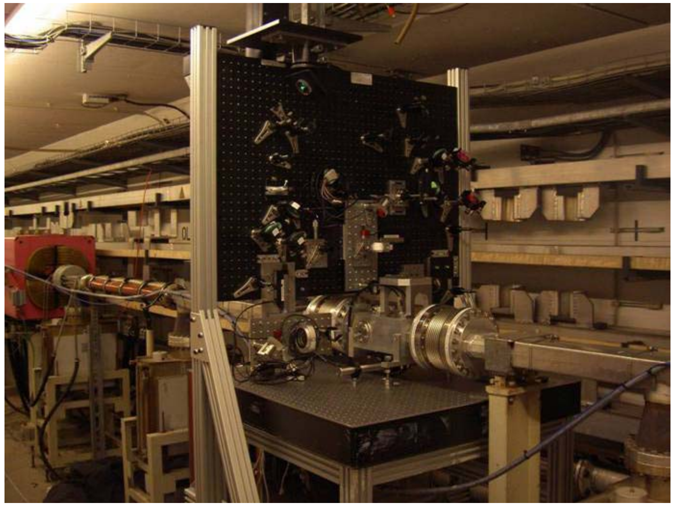
KEK: A. Aryshev, H. Hayano, K. Kubo, N. Terunuma, J. Urakawa

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

FNAL: M. Ross

Laser-wire Principle



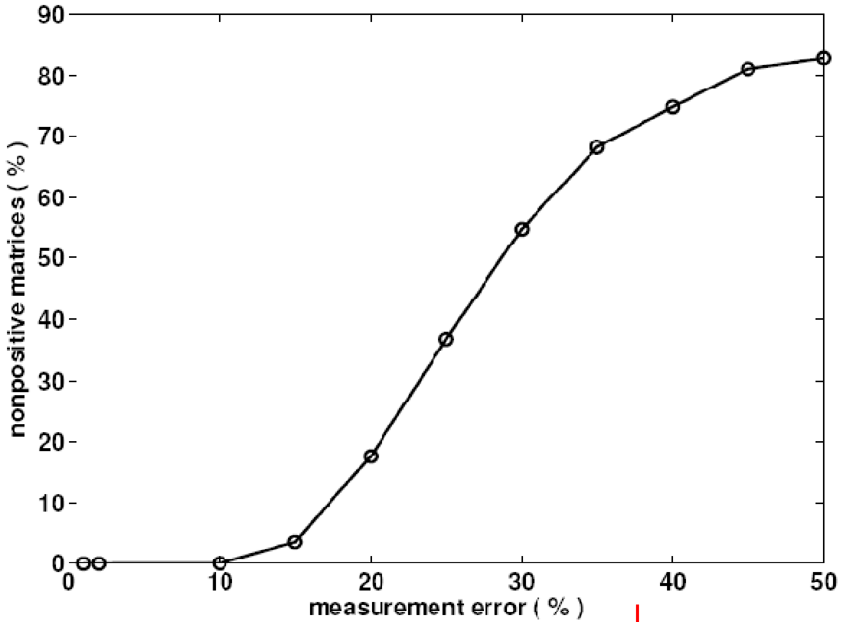


PETRAII
- 2d scanning system
- DAQ development
- Crystal calorimeter

→ PETRA III
- Ultra-fast scanning
- Diagnostic tool

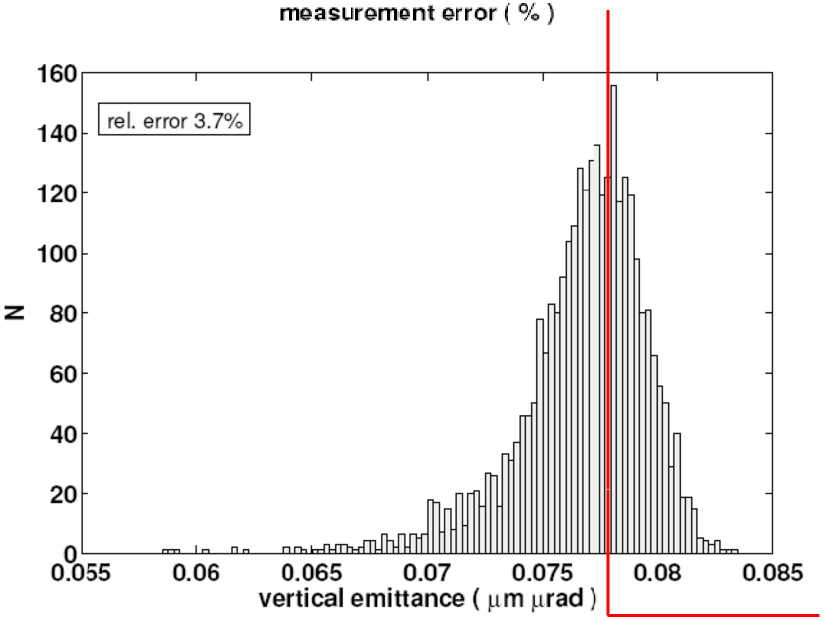
Laser wire : Measurement precision

I. Agapov



Goal: Beam Matrix Reconstruction

NOTE: Rapid improvement with better σ_y resolution

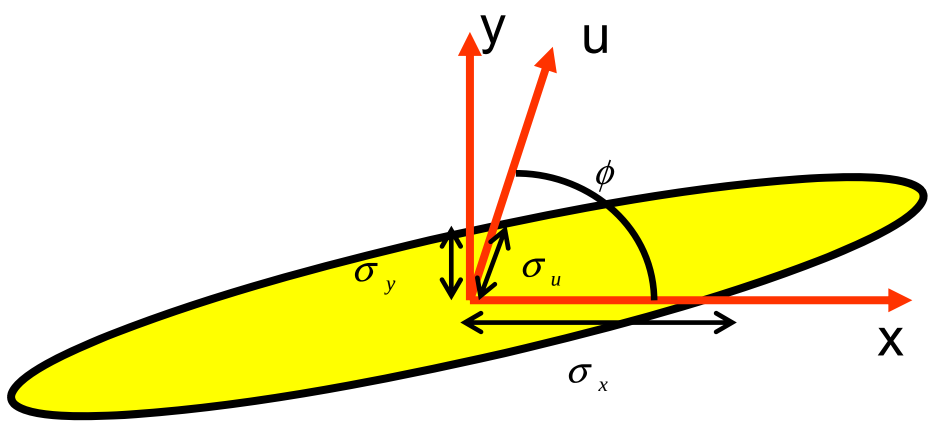


Reconstructed emittance of one ILC train using 5% error on σ_y

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

The true emittance is 0.079 μm μrad

Skew Correction



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

$$\approx 68^\circ - 88^\circ \text{ at ILC}$$

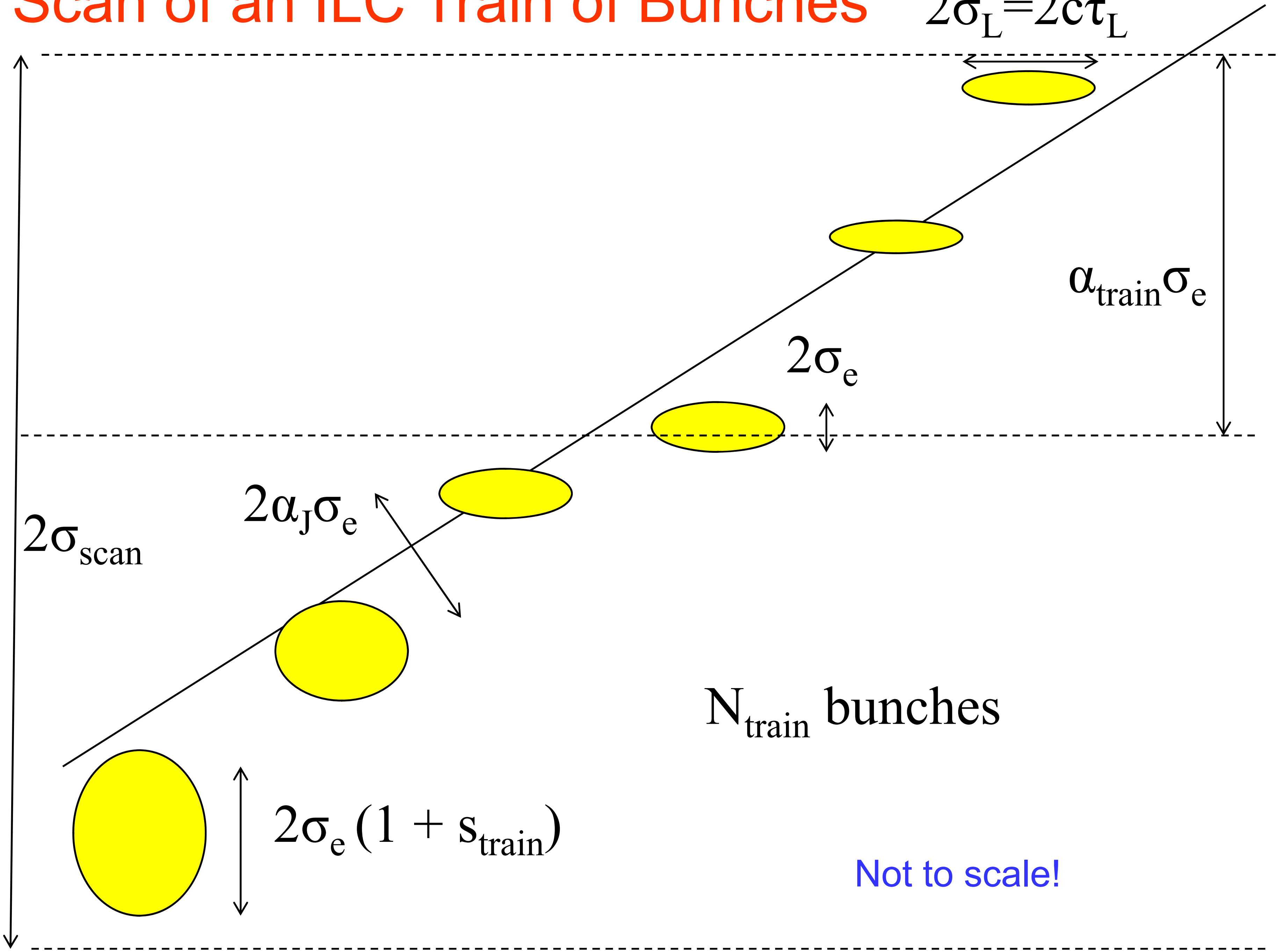
Error on coupling term:

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

ILC LW Locations E_b = 250 GeV

σ_x(μm)	σ_y (μm)	ϕ_{opt}(°)	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

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

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

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

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

$$\frac{\delta\sigma_e}{\sigma_e} = 1.9\times10^{-3}\left(\frac{\sigma_{\text{BPM}}}{100\ \text{nm}}\right)\alpha_{\text{train}}$$

For <0.5% effect, α_{train}<2.6; otherwise, higher precision BPMs required

Machine Contributions to the Errors

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

Bunch Jitter

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

BPM resolution of 20 nm may be required

Dispersion

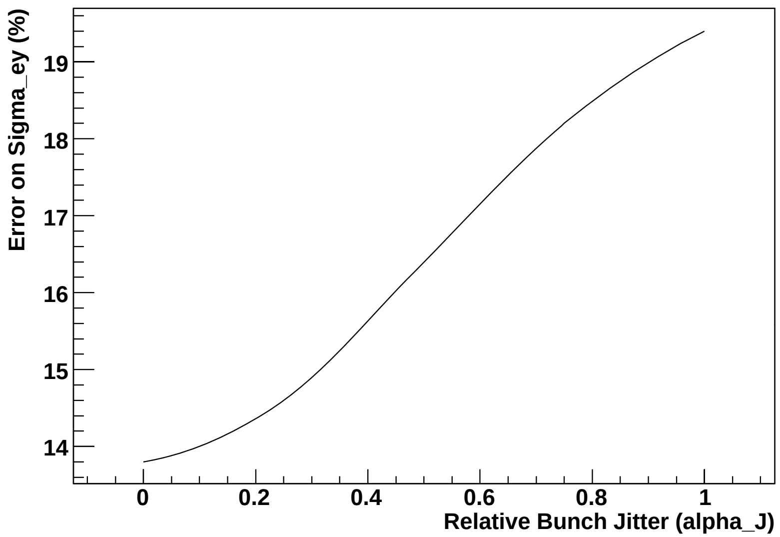
$$\frac{\delta\sigma_e}{\sigma_e} \approx 2.3\left[\eta / {\rm mm}\right]^2 \left(\frac{\langle\delta\eta\rangle}{\eta}\right)$$

Assuming η can be measured to 0.1%,
then η must be kept < ~ 1mm

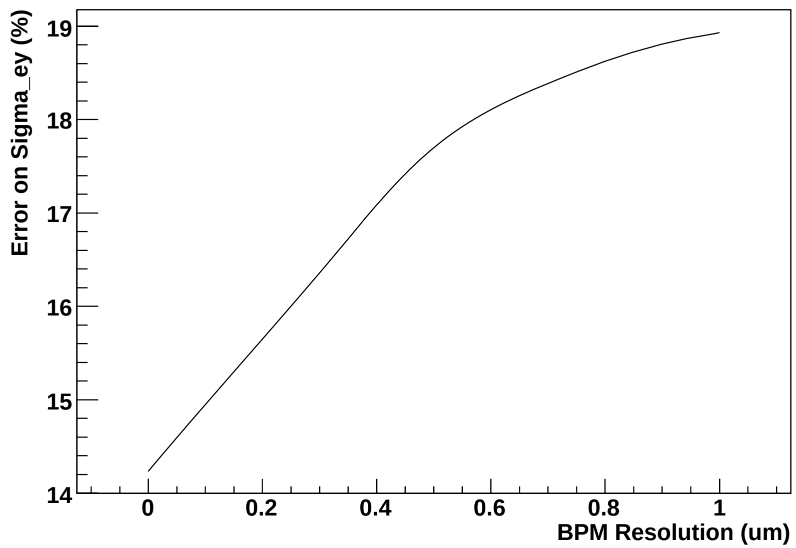
Alternative Scan Mode

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

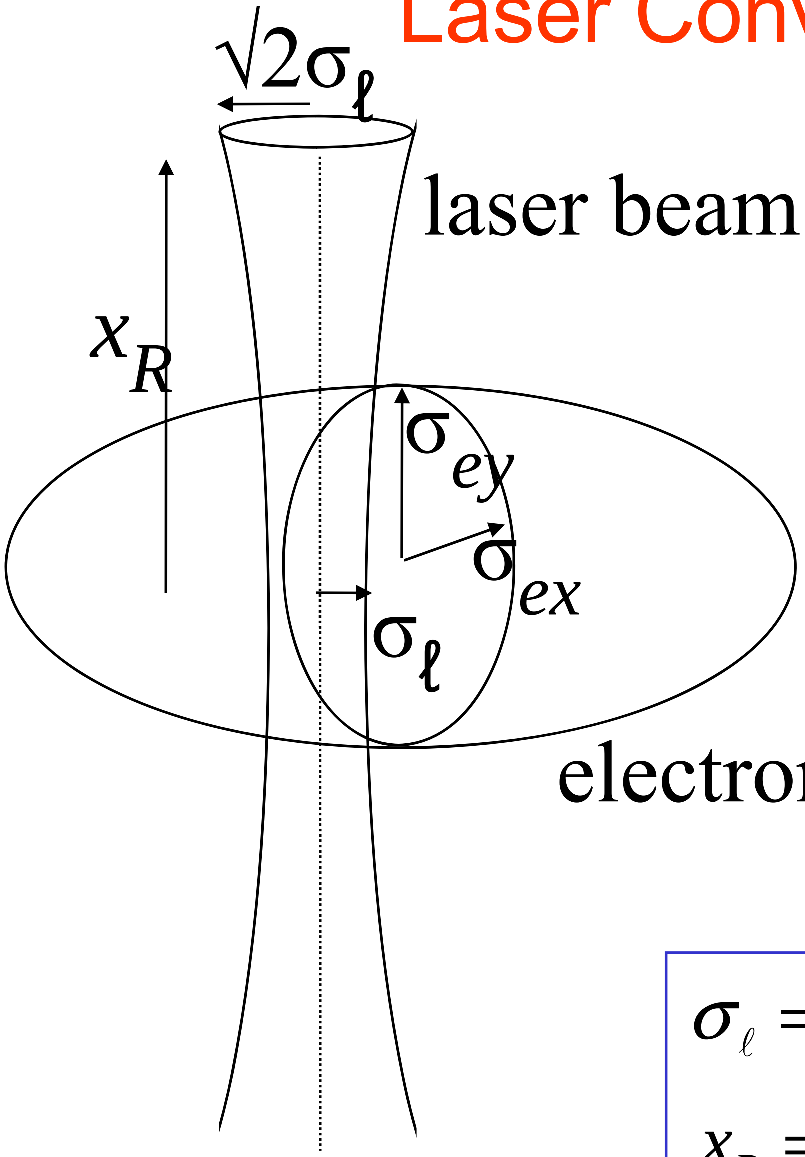


Beam jitter fixed at 0.25σ



BPM resolution fixed at 100 nm

Laser Conventions



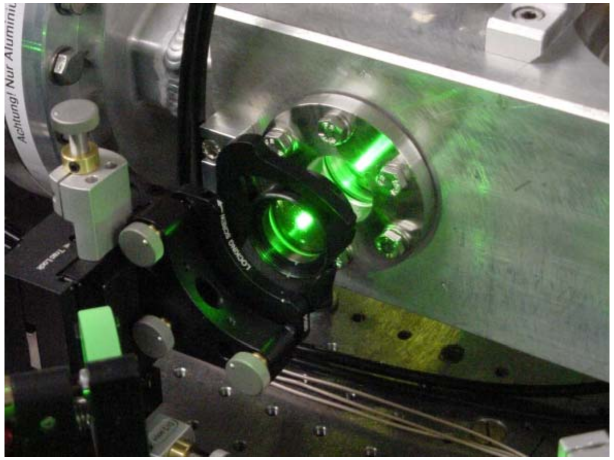
For TM_{00} laser mode:

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

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

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

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



Compton Statistics

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

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

Where :

$$\xi = \left(\frac{\eta_{\det}}{0.05}\right)\left(\frac{P_\ell}{10\ \text{MW}}\right)\left(\frac{N_e}{2\times10^{10}}\right)\left(\frac{\lambda}{532\ \text{nm}}\right)\left(\frac{f(\omega)}{0.2}\right)\mu\text{m}$$

Detector efficiency (assume Cherenkov system)

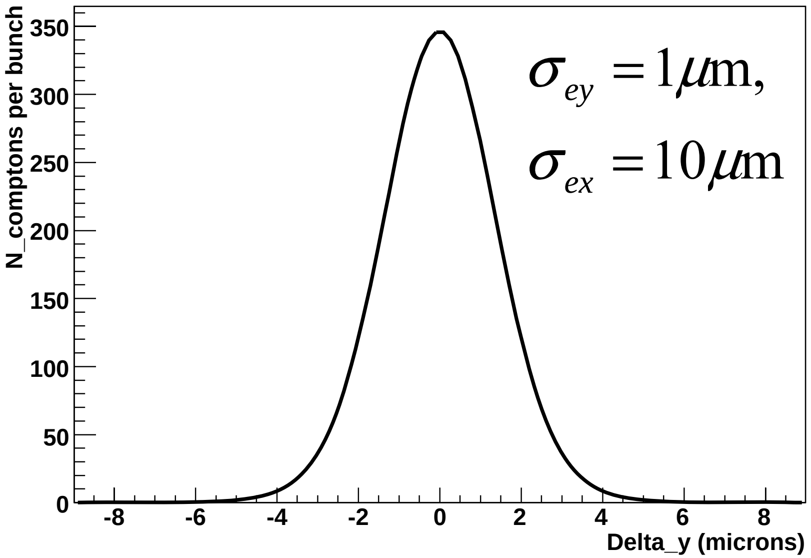
Laser peak power

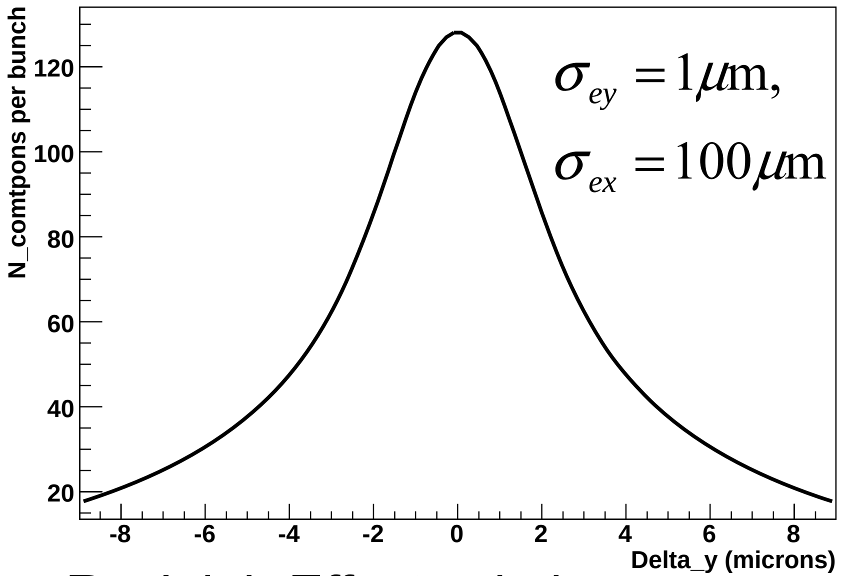
e-bunch occupancy

Laser wavelength

Compton xsec factor

TM_{00} Mode Overlap Integrals





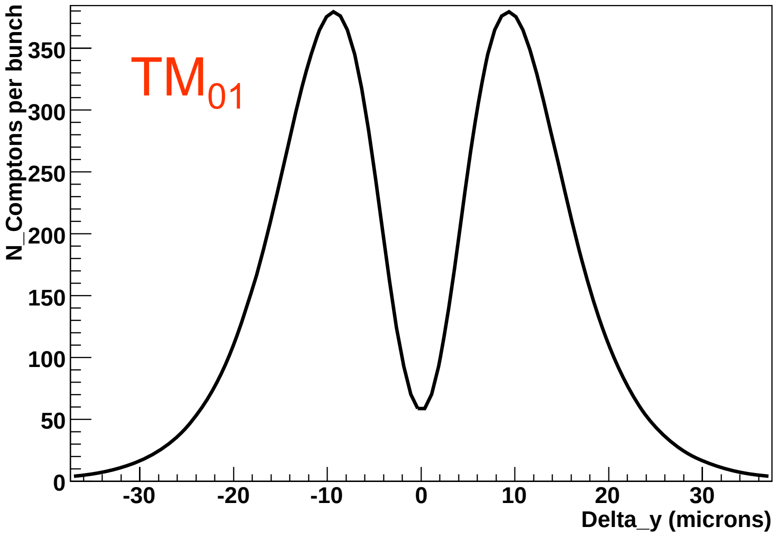
Rayleigh Effects obvious

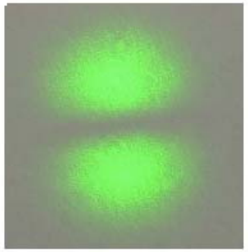
Main Errors:

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

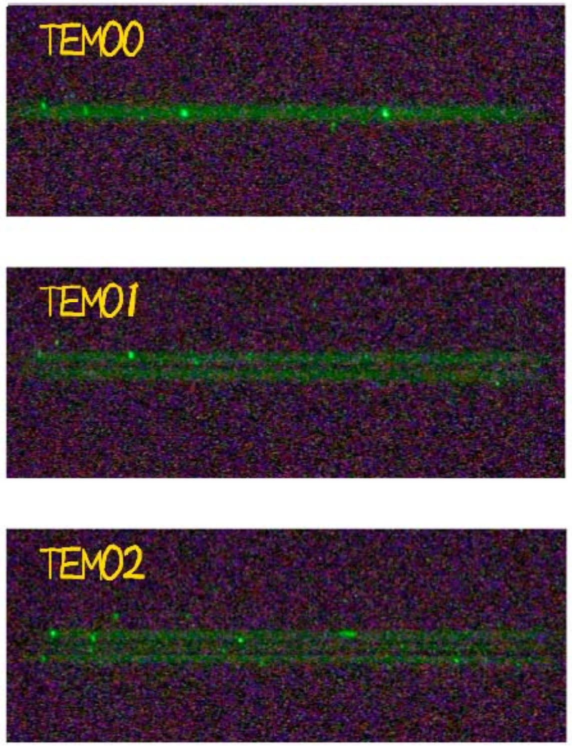
$$\frac{\delta\sigma_e}{\sigma_e} \approx 2.2\times10^{-3}\left(\frac{\psi}{10\mu\text{rad}}\right)^2\left(\frac{\delta\psi}{\psi}/10\%\right)$$

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

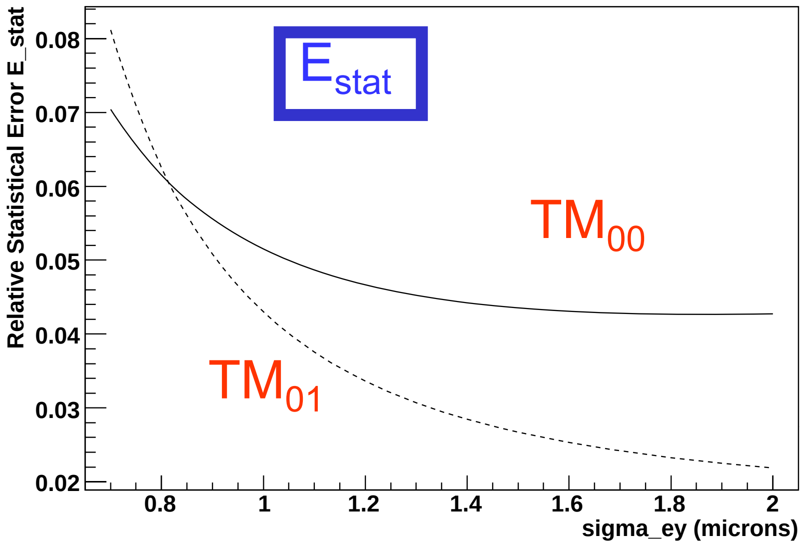


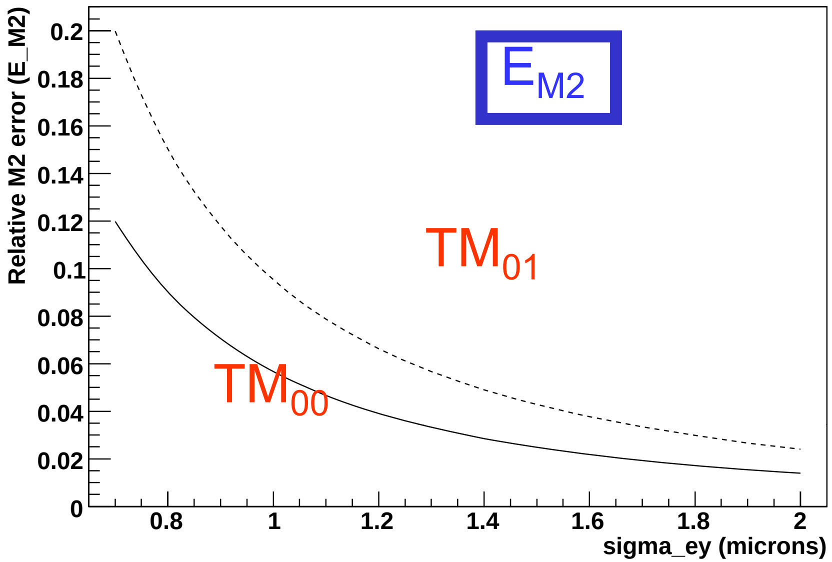


Y. Honda et al



TM01 gives some advantage for larger spot-sizes



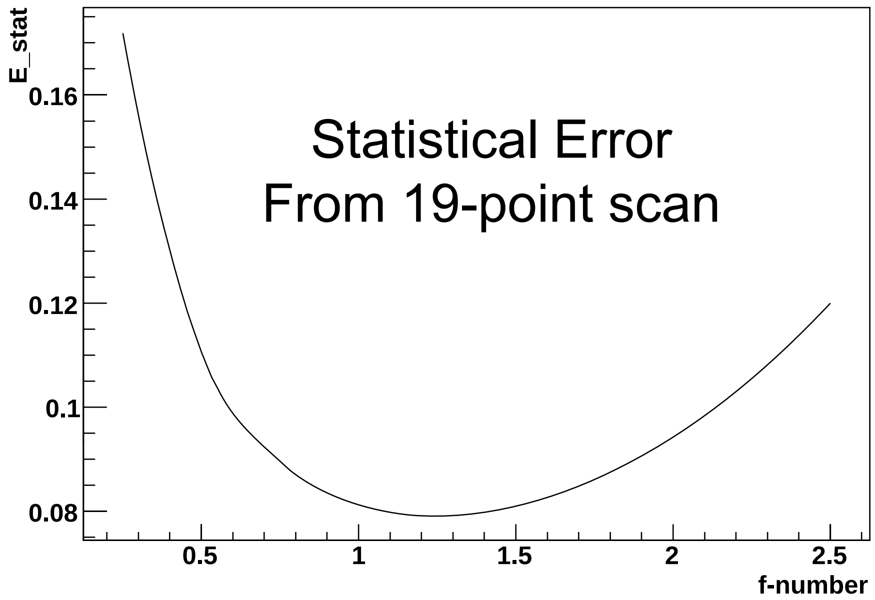


Laser Requirements

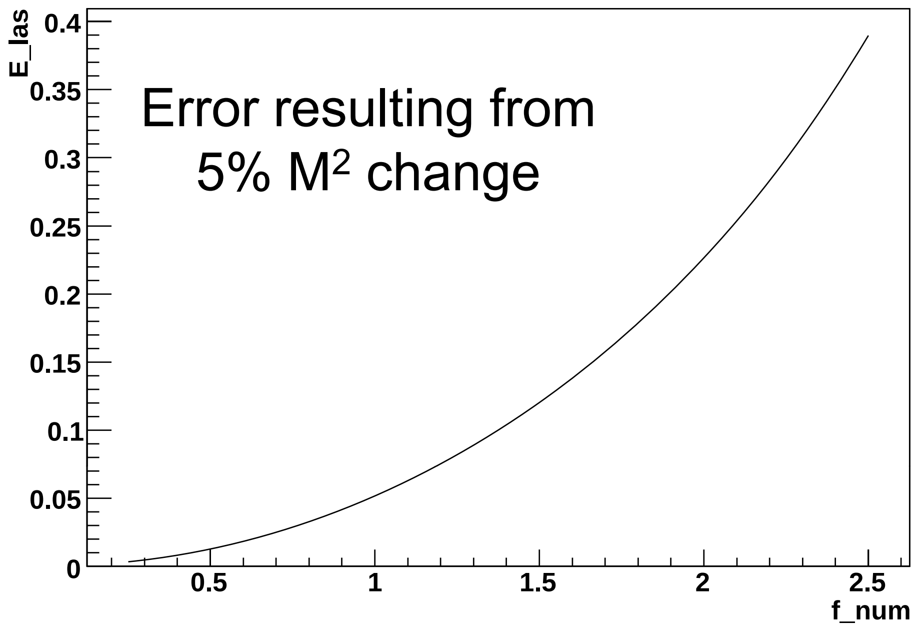
Wavelength	≤ 532 nm
Mode Quality	≤ 1.3
Peak Power	≥ 20 MW
Average power	≥ 0.6 W
Pulse length	≥ 2 ps
Synchronisation	≤ 0.3 ps
Pointing stability	≤ 10 μ rad

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

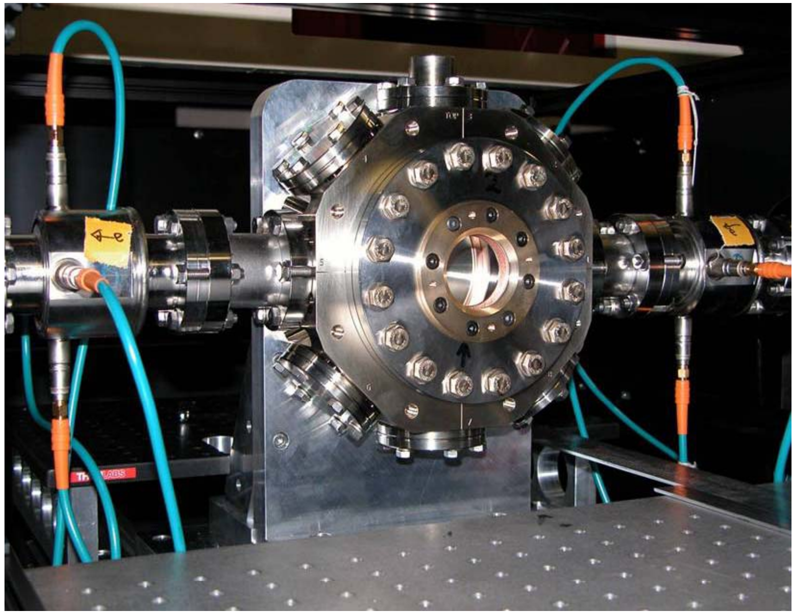
TM_{00} mode



Relative Errors



- Optimal f-num≈1-1.5 for λ= 532nm
- 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

Goals/assumptions

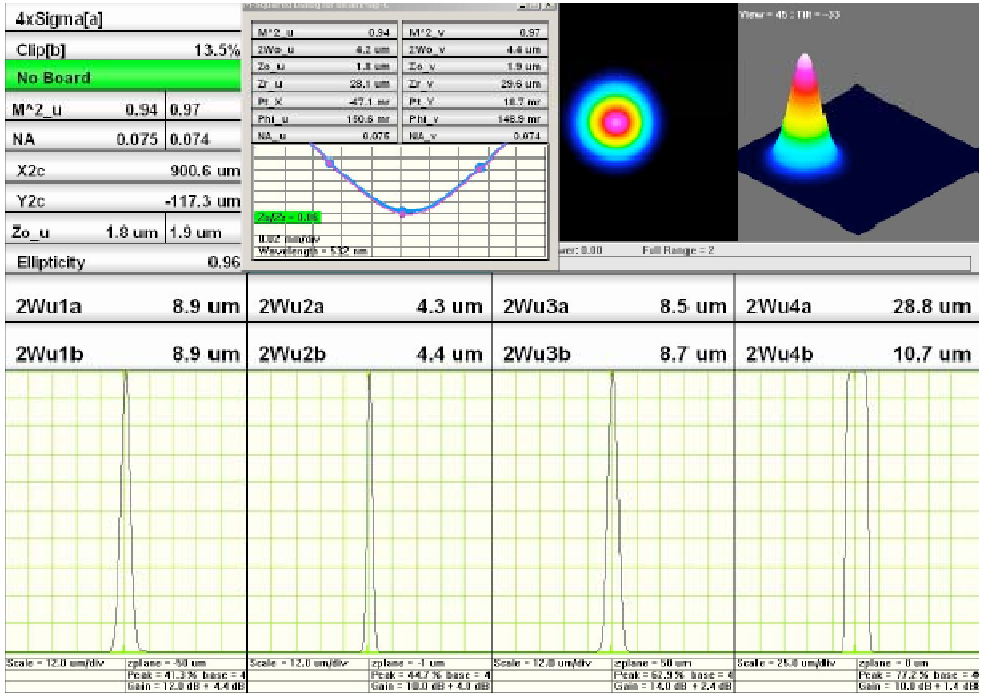
Wavelength	266 nm
Mode Quality	1.3
Peak Power	20 MW
FF f-number	1.5
Pointing stability	10 μrad
M^2 resolution	1%
Normalisation (ξ)	2%
Beam Jitter	0.25σ
BPM Resolution	20 nm
Energy spec. res	10^{-4}

Could be used for η measurement → E_η

preliminary Resultant errors/10^{-3}

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

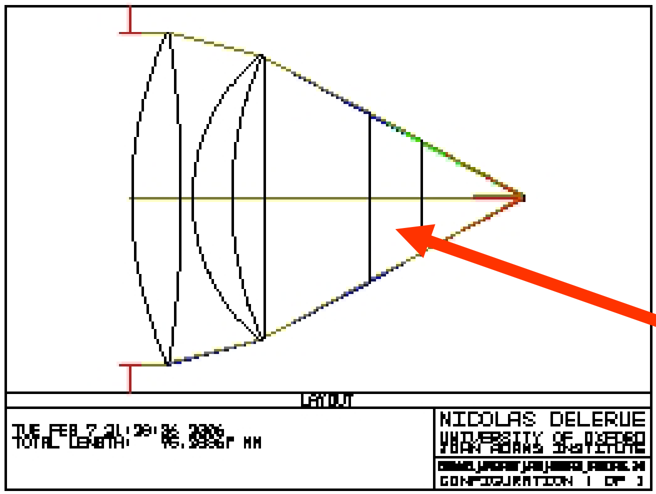


Lens Design + Tests

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

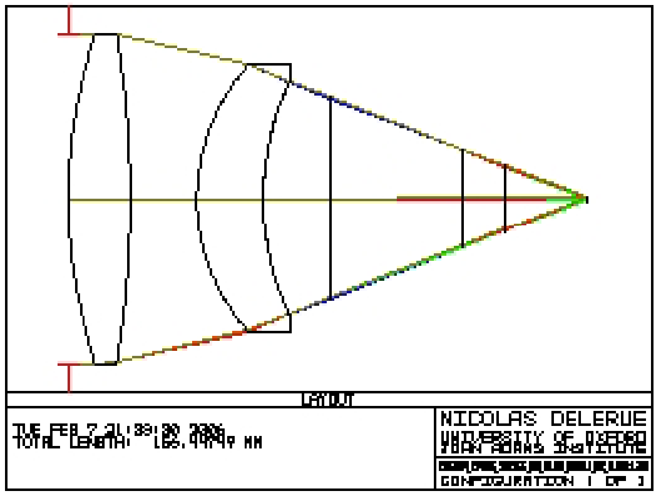
M. Newman, D. Howell et al.

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



Aspheric doublet

Vacuum window



N. Delerue et al.

BDS Laser-wire

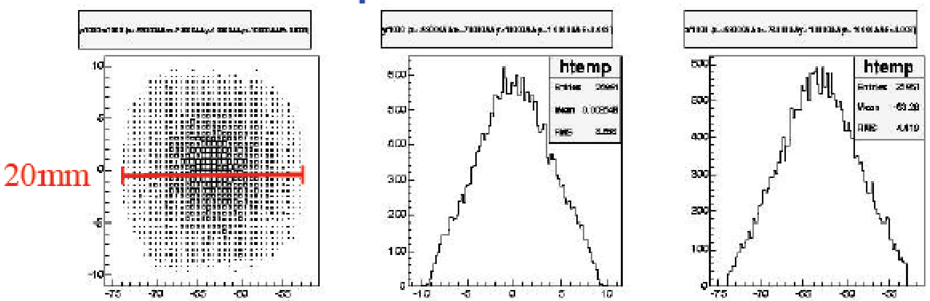
- PETRA – 2d scans, multi-shot.
- ATF – micron, single shot
- Laser R&D
- Fast Scanning R&D
- Simulation

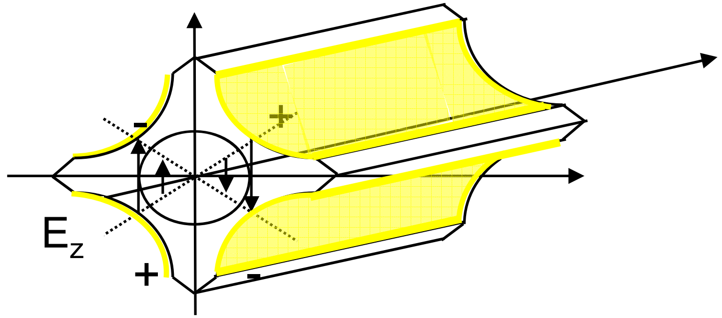
All initial goals have been achieved.

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

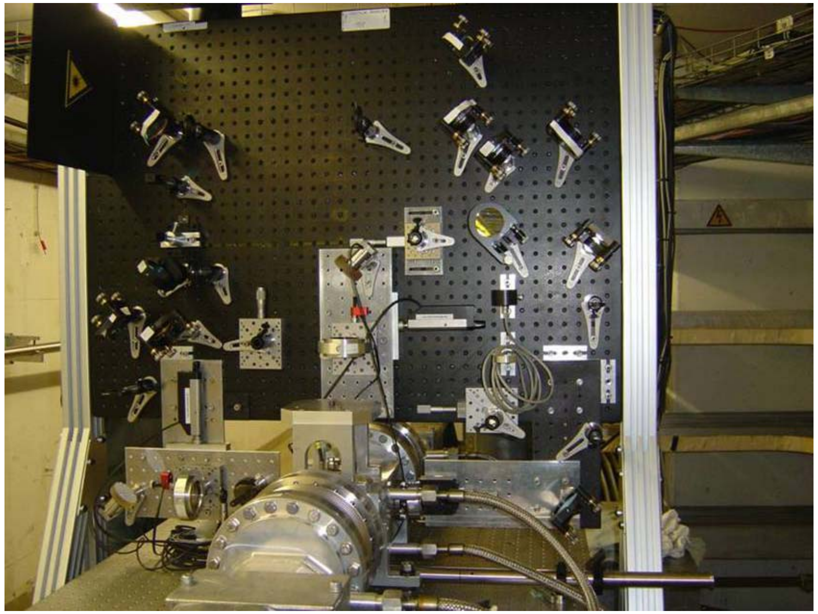




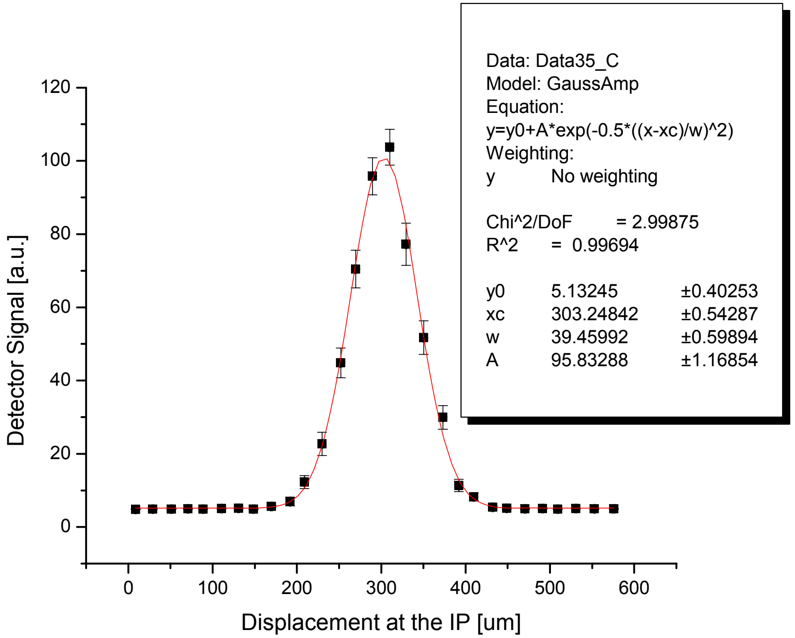
EO fast scanner under test at RHUL; plan to use at PETRAIII

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

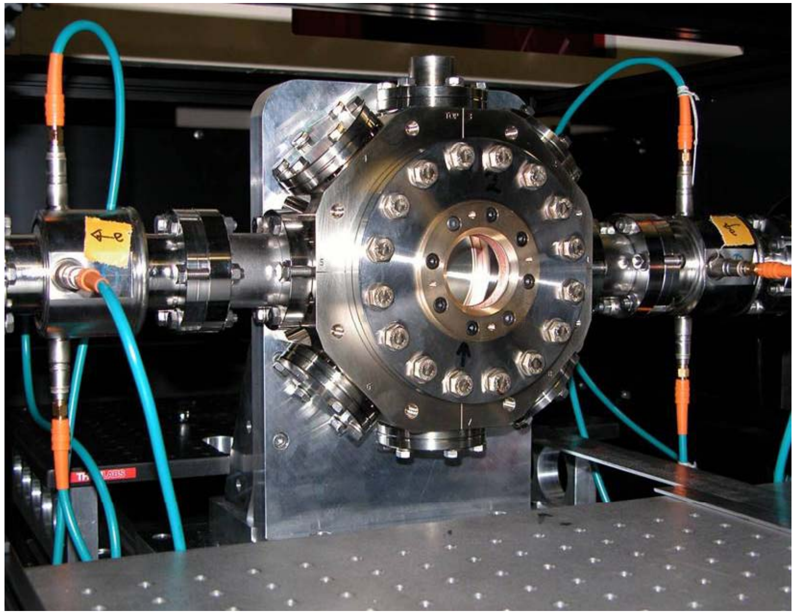


PETRA II



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

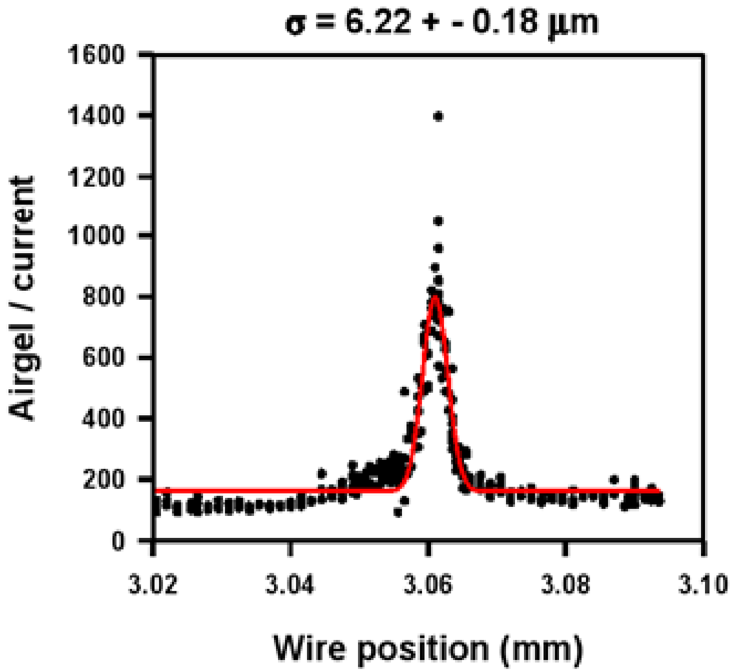
ATF LW



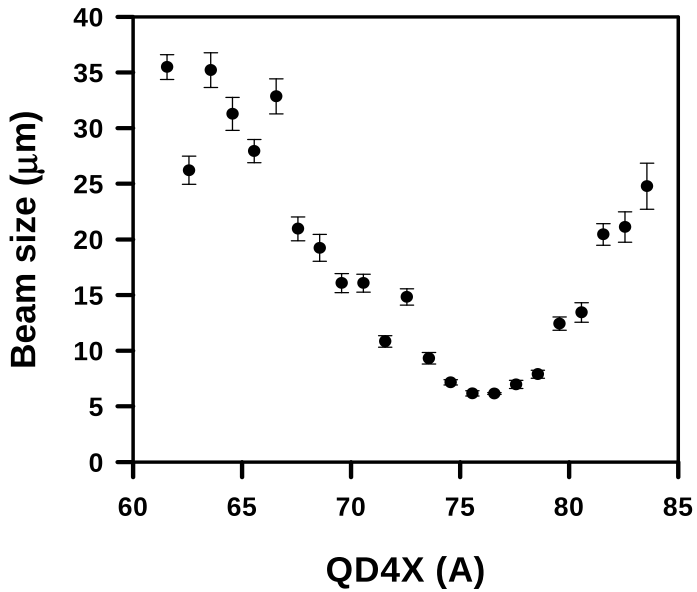
Tests of f_2 lens system currently underway at Oxford

We will improve ATF laser at KEK in October 2007

Look forward to running with f2 optics in Nov 07 and in 2008.

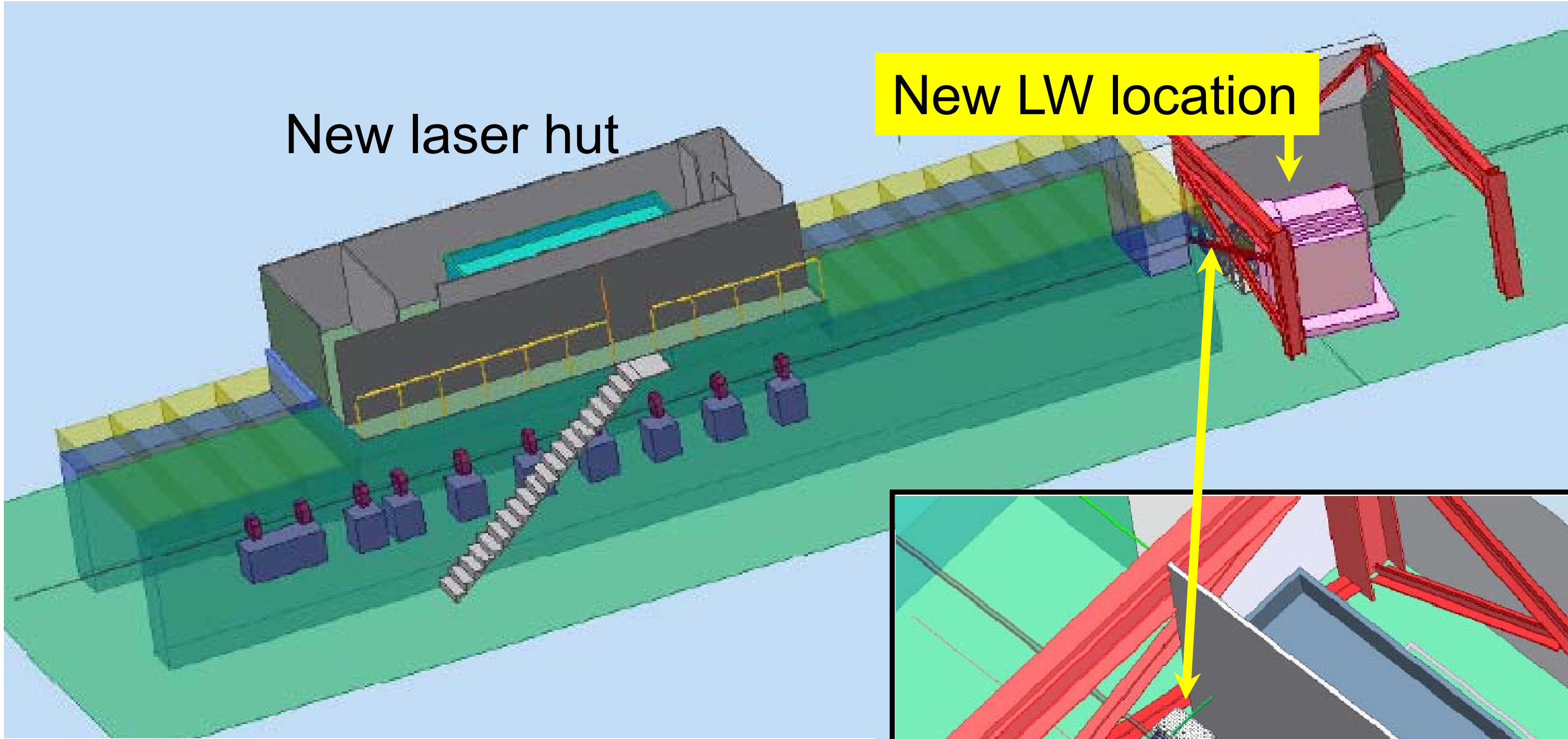


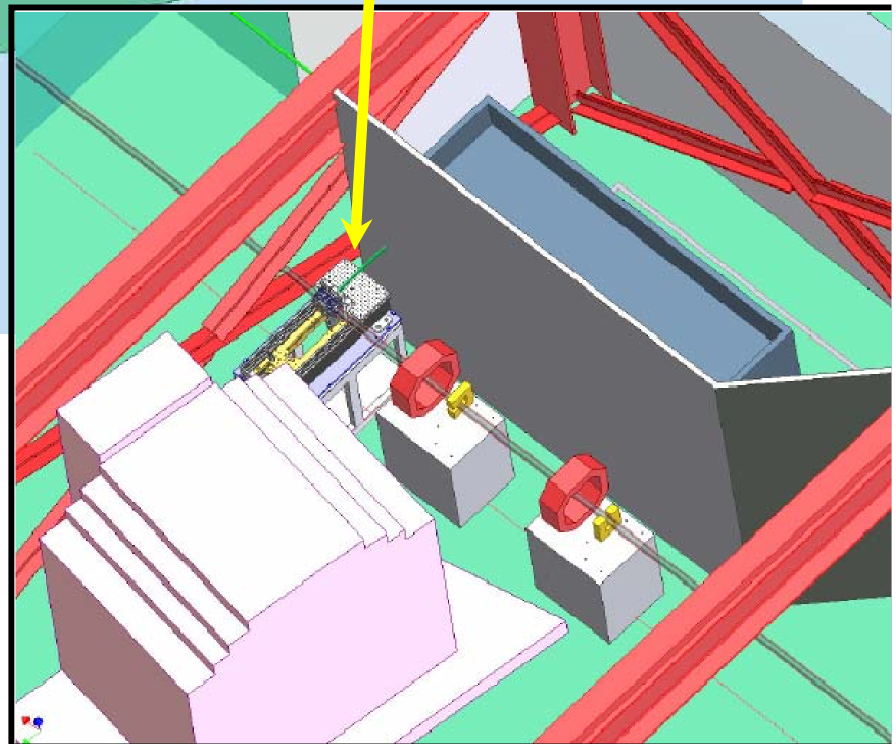
single LW scan



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)
σ_x = 38.92 μm	σ_x = 142.77 μm
σ_y = 7.74 μm	σ_y = 7.94 μm

ATF2 LW-test optics

P. Karataev

LW-IP (1)	LW-IP (2)
σ_x = 20.43 μm	σ_x = 20 μm
σ_y = 0.9 μm	σ_y = 1.14 μm

⇒ 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
- All elements require R&D
  - Laser pointing
  - M^2 monitoring
  - Low-f optics
  - Fast scanning
  - High precision BPMs
- Look forward to LW studies at PETRA and ATF
- ATF2 ideally suited to ILC-relevant LW studies.
- CLIC Laser-wire parameters will also be studied