Laser-wire + Transverse emittance

Grahame Blair

28th November 2007

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

Laser-wire People

BESSY: T. Kamps

CERN: I. Agapov

DESY : E. Elsen, V. Gharibyan, 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, R. Senanayake, R. Walczak

JAI@RHUL: A. Aryshev, G. Blair, S. Boogert, G. Boorman, A. Bosco, L. Deacon, P. Karataev, S. Malton , M. Price,

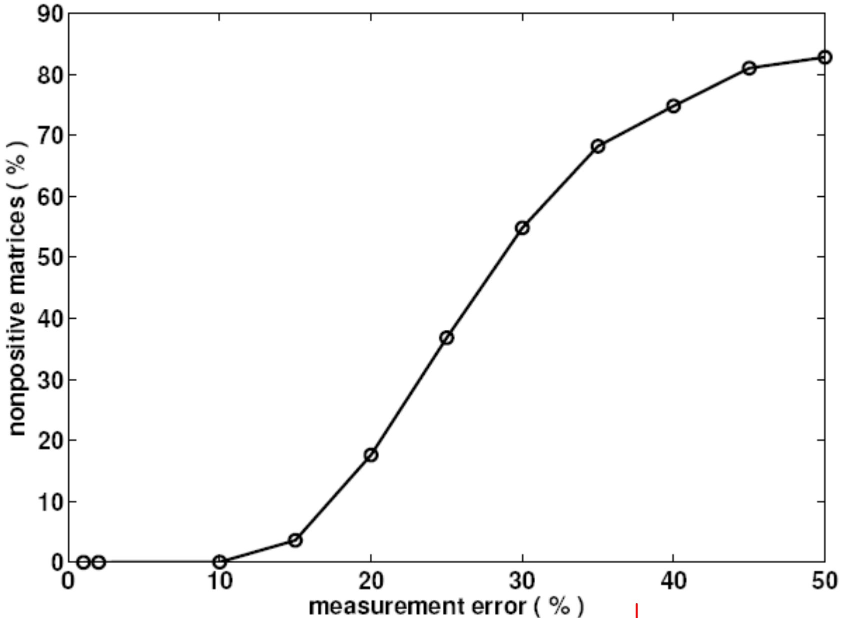
KEK:, H. Hayano, K. Kubo, N. Terunuma, J. Urakawa

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

FNAL: M. Ross

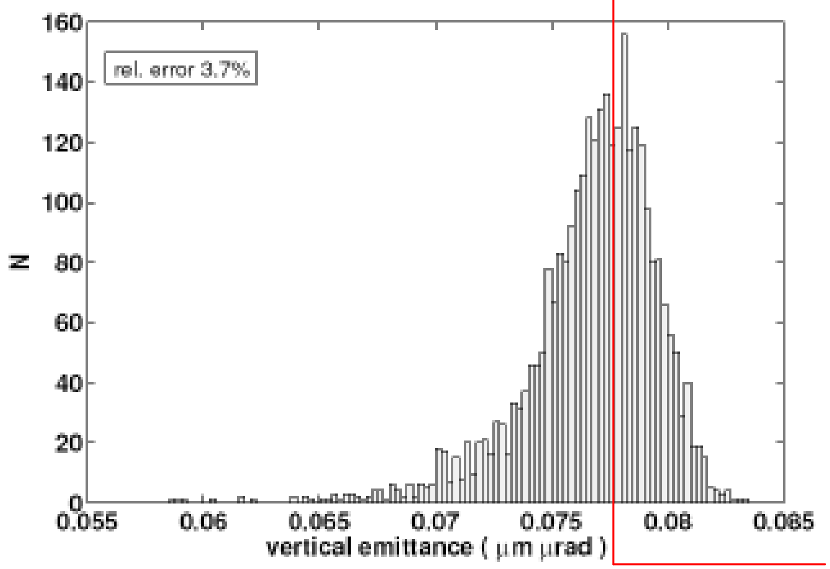
Laser wire : Measurement precision

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



Goal: Beam Matrix Reconstruction

NOTE: Rapid improvement with better σ_y resolution

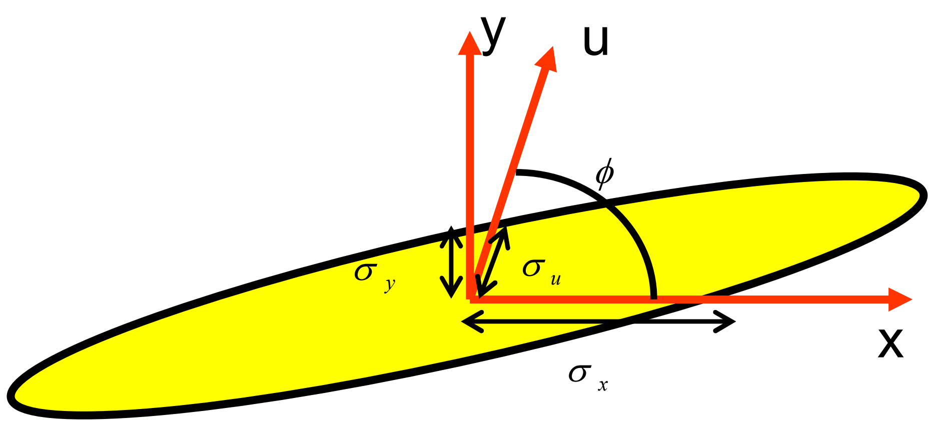


Reconstructed emittance of one ILC train using 5% error on σ_y

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

The true emittance is 0.079 µm µrad

Skew Correction



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

$$\approx 68° - 88° \text{ at ILC}$$

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

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

$$\frac{\delta\sigma_e}{\sigma_e} \approx 5\times10^{-2}\left(\frac{\alpha_J}{0.5}\right)^2\left(\frac{\sigma_{\text{BPM}}}{100\text{nm}}\right)$$

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 < ~ 1mm

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 :

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

Detector efficiency (assume Cherenkov system)

Laser peak power

e-bunch occupancy

Laser wavelength

Compton xsec factor

Smaller Wavelength brings its additional challenges

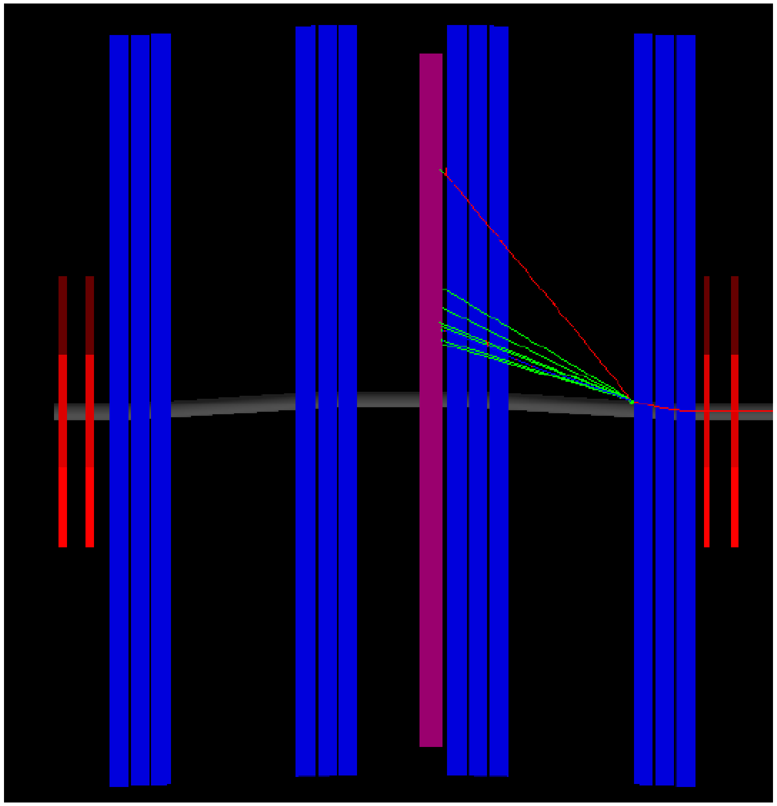
TABLE III. Values of $f(\omega)$ for various laser wavelengths λ and ILC beam energies.

E_b (GeV)	λ (nm) 1064	532	355	266
5	0.96	0.92	0.89	0.86
50	0.72	0.59	0.51	0.45
150	0.51	0.38	0.31	0.27
250	0.41	0.30	0.24	0.20
500	0.30	0.20	0.16	0.13

- Additional stage of frequency doubling is inefficient (>factor of 2)
- Cross section is smaller
- Light transport is an issue; may need local frequency doubling near the LW-IP, which brings its own set of problems.
- Laser power is expensive; so factors of 4 or so are not insignificant

It should not be assumed that UV light can be used for the ILC LW
Without significant additional R&D

Detector Location + Simulations



L. Deacon

Currently evaluating:

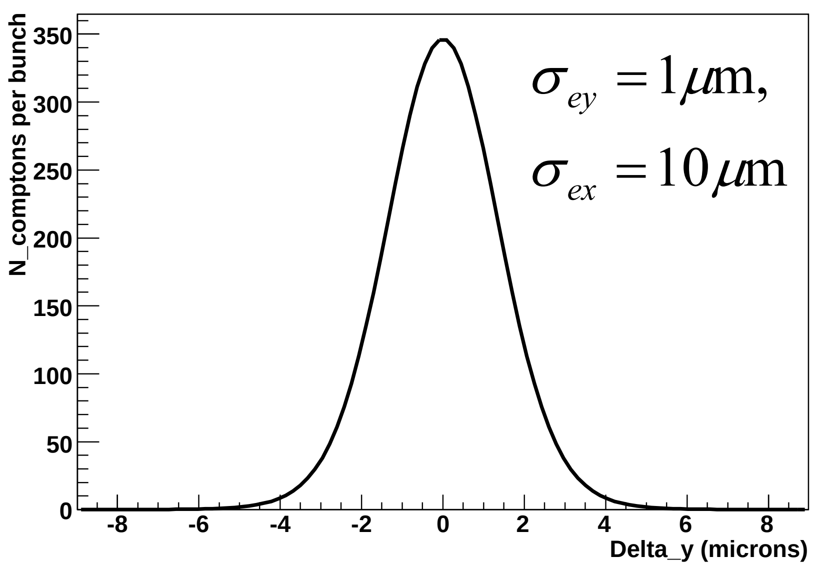
- Whether to detect electrons or photons
- Backgrounds from LW for polarimetry
- Location of vacuum windows
- mode of operation (bunch by bunch?)

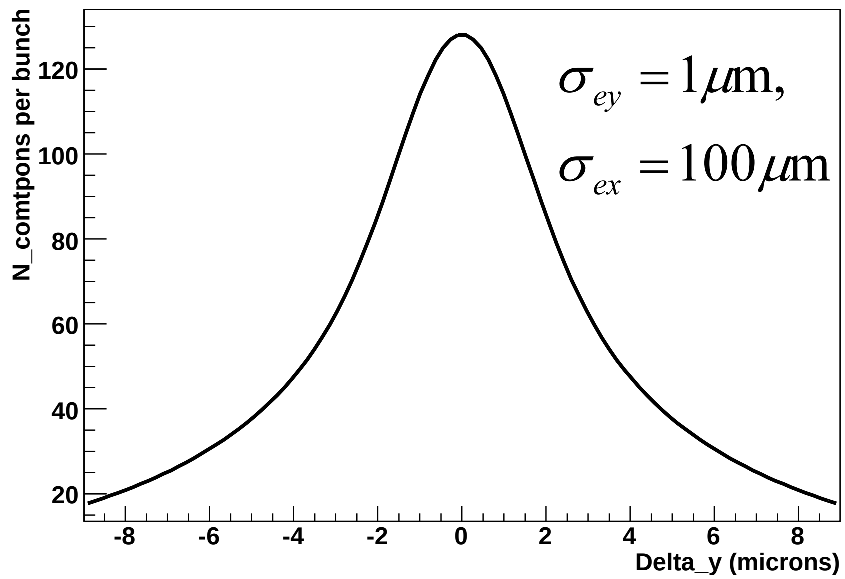
We are discussing the issues with the DESY polarimetry group

The effective value of η_{det} has implications on the needed laser power

This is a significant activity, now also in collaboration with DESY.
Had a phone meeting last week; plan a future meeting in January 07
Conclusions aimed for Zeuthen workshop next year.

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

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

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

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

Towards a 1 μm LW

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

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 $\rightarrow E_\eta$

Error Summary

TABLE XI. Error terms for σ_{ey} for an electron bunch whose transverse dimensions are $\sigma_{ey} = 1\ \mu$m and $\sigma_{ex} = 10\ \mu$m, giving $\sigma_u = 1.41\ \mu$m and $\sigma_v = 9.95\ \mu$m. The values were obtained assuming the performance goals of Table X, laser $\delta_{M^2} = 0.01$, $\sigma_{BPM} = 20$ nm, $\alpha_J = 0.25$, The electron-bunch charge and laser power are assumed each to be known to 1% and the pointing jitter to 10%. The measurement statistical errors are for a full train (i.e. $N_{scan} \simeq 140$). No subtraction of residual dispersion has been made for these measurements; instead they are input into the global fit to extract the emittance and dispersion terms together.

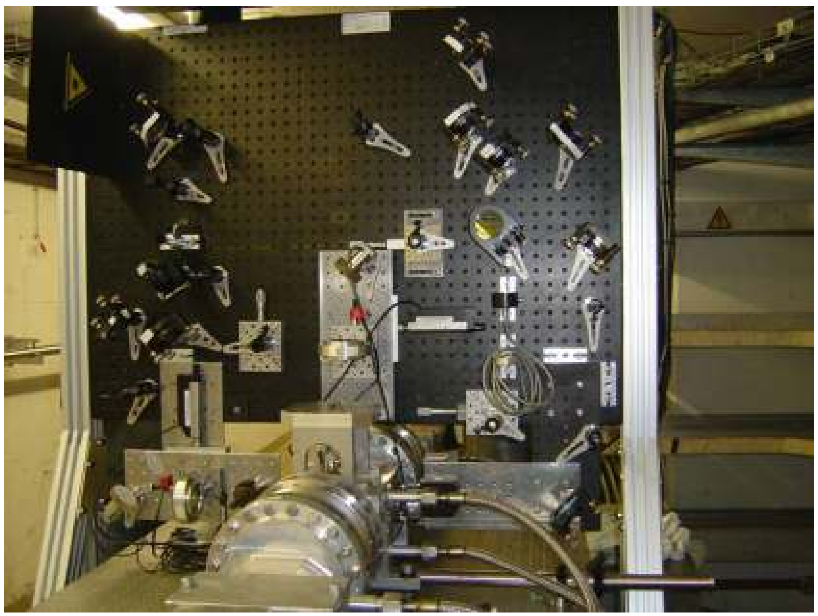
	Symbol	σ_y	σ_u	σ_x
Value (μm)	σ_e	1	1.41	10
Laser wavelength (nm)	λ	532 (266)	532 (266)	532
Optics f-number	$f_\#$	1.5	1.5	1.5
Optics focal length (mm)	F	15	15	70
Pointing stability ($\times 10^{-3}$)	E_{point}	2.2	1.1	0.5
Beam jitter ($\times 10^{-3}$)	E_{jitter}	5.0	3.5	0.5
Fit statistics ($\times 10^{-3}$)	E_{stat}	4.3 (4.5)	3.4 (4.2)	4.8
Laser spot size ($\times 10^{-3}$)	E_{M^2}	10.9 (2.7)	5.4 (1.4)	0.1
Normalization ($\times 10^{-3}$)	E_ξ	0.9 (0.6)	0.7 (0.5)	0.4
Total error ($\times 10^{-3}$)	$\delta\sigma/\sigma$	13.0 (7.6)	7.5 (5.8)	4.9

Note: this performance will require significant additional R&D

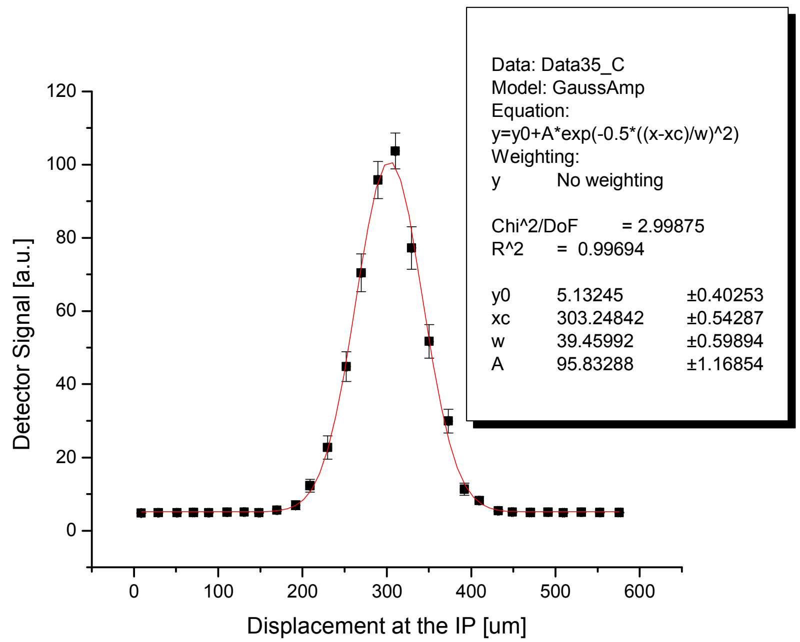
I. Agapov, GB, M. Woodley

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



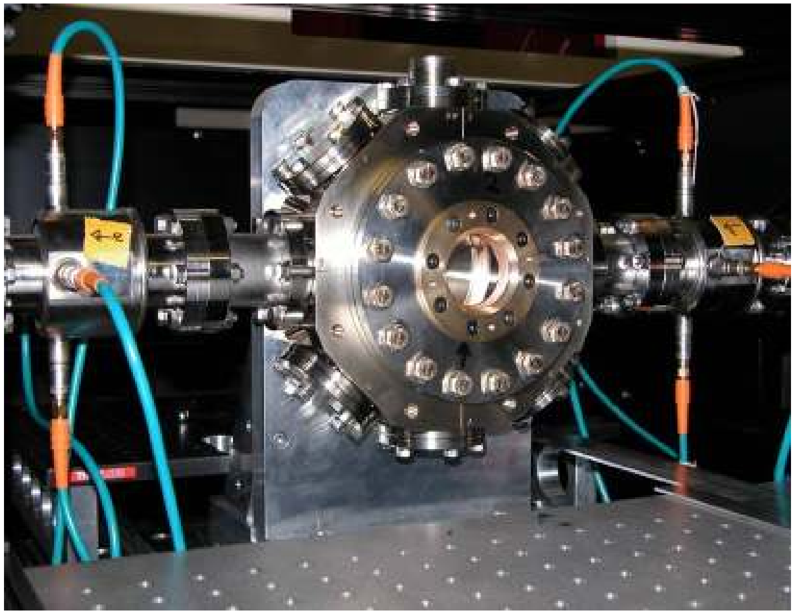
1000 laser shots= 50s.
beam: 6 GeV, 0.5 mA.

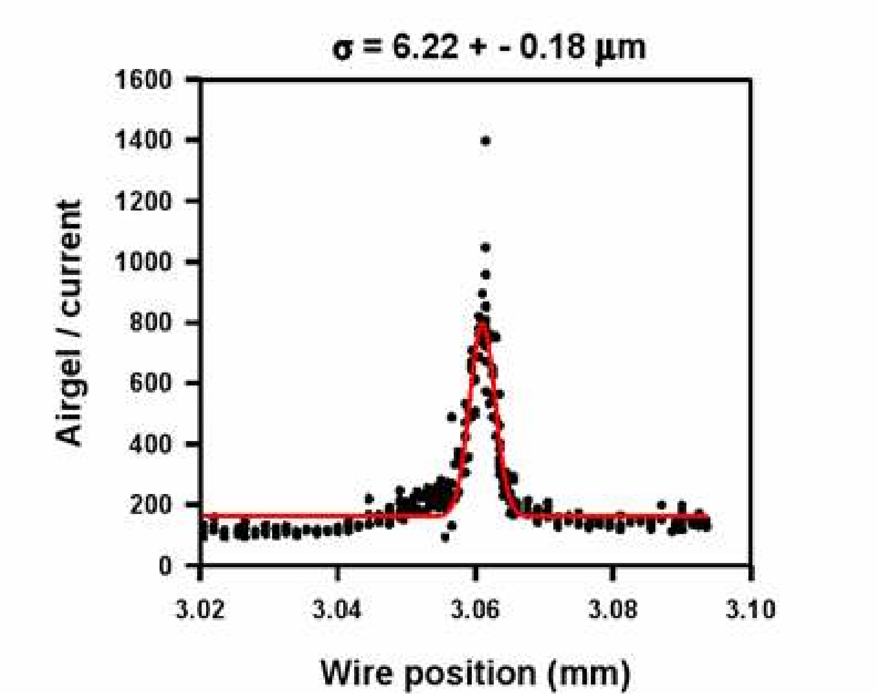
ATF LW

Tests of f_2 lens system currently underway at Oxford

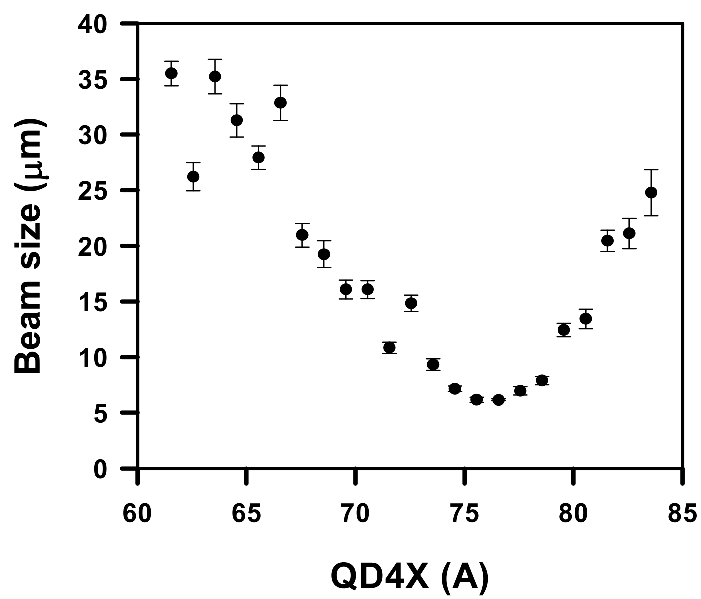
We have improved mode quality
Of ATF laser at KEK in October 2007.

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



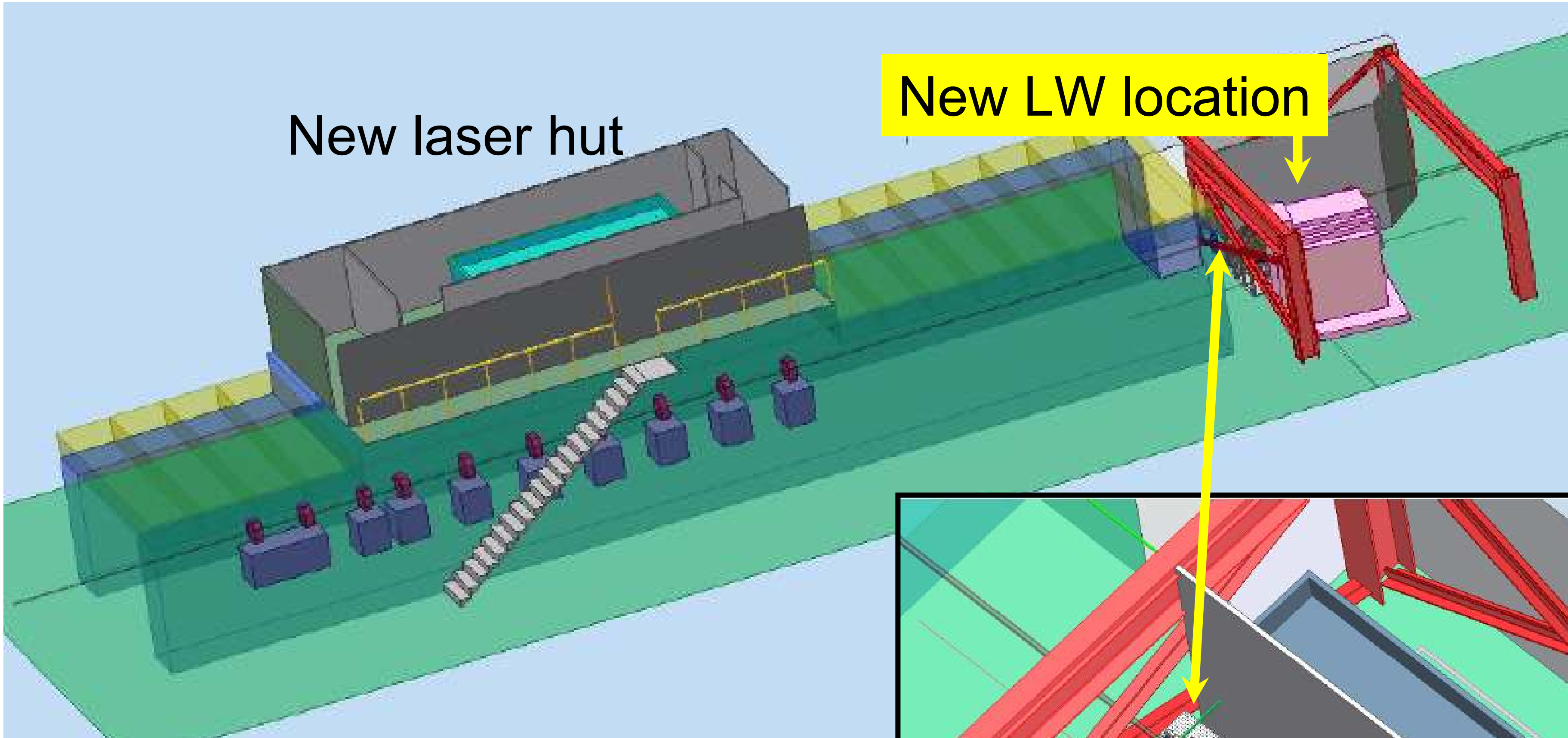


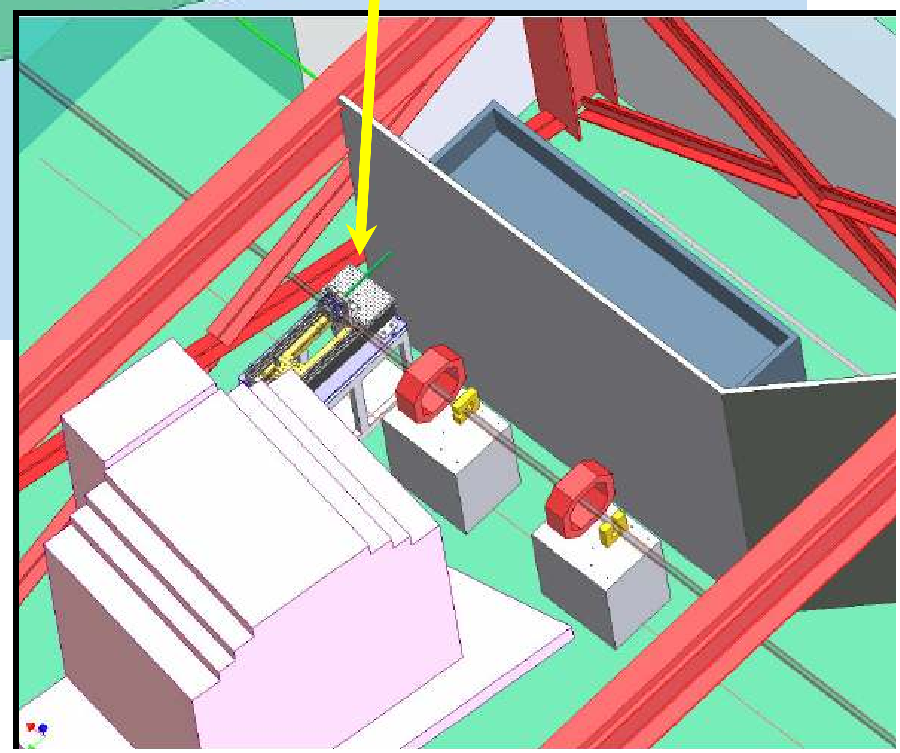
single LW scan



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)
$\sigma_x = 38.92\ \mu m$	$\sigma_x = 142.77\ \mu m$
$\sigma_y = 7.74\ \mu m$	$\sigma_y = 7.94\ \mu m$

ATF2 LW-test optics

P. Karataev

LW-IP (1)	LW-IP (2)
$\sigma_x = 20.43\ \mu m$	$\sigma_x = 20\ \mu m$
$\sigma_y = 0.9\ \mu m$	$\sigma_y = 1.14\ \mu m$

$\Rightarrow$ Ideal testing ground for ILC BDS Laser-wire system

Schedule + Milestones

- Aim to achieve micron-scale scans early 2008 at ATF
- Relocate to new position in ATF2 over the summer of 2008
- Should be able to use existing system at ATF2 from startup
- Meanwhile develop ATF2 system in UK, including skew scan. A location for this new system has already been discussed; we will further discuss at ATF2 meeting in December.
- Next generation of final focus laser optics will be developed

- Aim to develop fast (up to10kHz) scanning using electro-optic techniques.
- Laser plus HV driver are at RHUL; new lab almost complete.
- Aim to (re-)install laser-wire system at PETRAIII middle of 2008.
- Test fast scanning in accelerator environment there.

- Developing ILC-spec laser using fibre-based technology.
- Driver laser will be delivered to Oxford in December.
- First fiber amplification already achieved in the lab.
- Collaboration with EU industry on use of photonic crystal fibres.
- Longer term: aim to ship to KEK for tests at ATF2.

Wider Issues

- Collaboration with CERN on use of laser-wires as a LINAC diagnostic
  First results will be reported at LET meeting in December.
- Extensive simulation programme, not reported here.
- RTML laser-wires
- LINAC laser-wires

At present all the LW effort has been submitted within the EOI to the ILC BDS group.

This may need to be re-distributed in the light of how the WBS evolves.

UK accelerator programme is currently under review so
all numbers are preliminary.

Effort and M&S

FTE	2007/8	2008/9	2009/10
	9.3	9.3	9.3
Equipment + travel	2008	2009	2010
	£450k	£260k	£175k
Source of funds	STFC/ EUROTeV	STFC	STFC fp7??

Note: Only 2007/8 funds are in place
Extension of accelerator programme is under review

Summary

- Very active + international programme:
  - Hardware
  - Optics design
  - Advanced lasers
  - Emittance extraction techniques
  - Data taking + analysis
  - Simulation
- Important effects:
  - Laser pointing
  - M^2 monitoring
  - Low-f optics
  - Fast scanning
  - High precision BPMs
- A good team is now in place
  - Major contribution to PETRAIII/ATF2
  - Additional studies to include Linac and RTML.
  - All statements subject to an ongoing review process