Laser Wire: :LBPM

G A Blair

EUROTeV Scientific Workshop,
Uppsala
27th August 2008

- Introduction
- Emittance extraction
- Experimental programme
- Laser R&D
- Summary

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

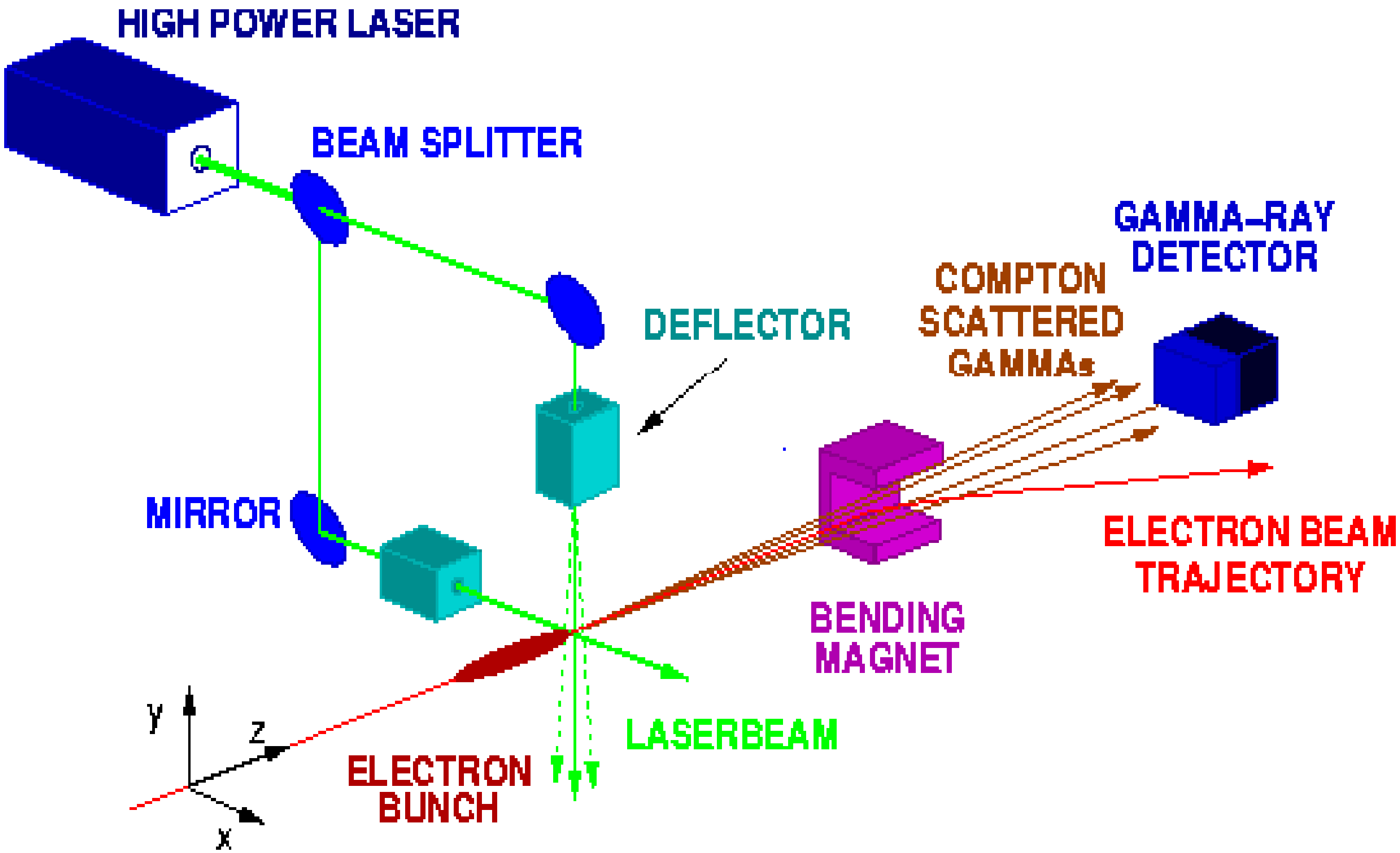
JAI@RHUL: A. Aryshev, G. Blair, S. Boogert, G. Boorman, A. Bosco, L. Deacon, P. Karataev, S. Malton , M. Price,

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

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

FNAL: M. Ross

Laserwire


HIGH POWER LASER
BEAM SPLITTER
GAMMA-RAY
DETECTOR
COMPTON
SCATTERED
GAMMAs
DEFLECTOR
MIRROR
ELECTRON BEAM
TRAJECTORY
BENDING
MAGNET
y
z
x
LASERBEAM
ELECTRON
BUNCH

Linac

ILC

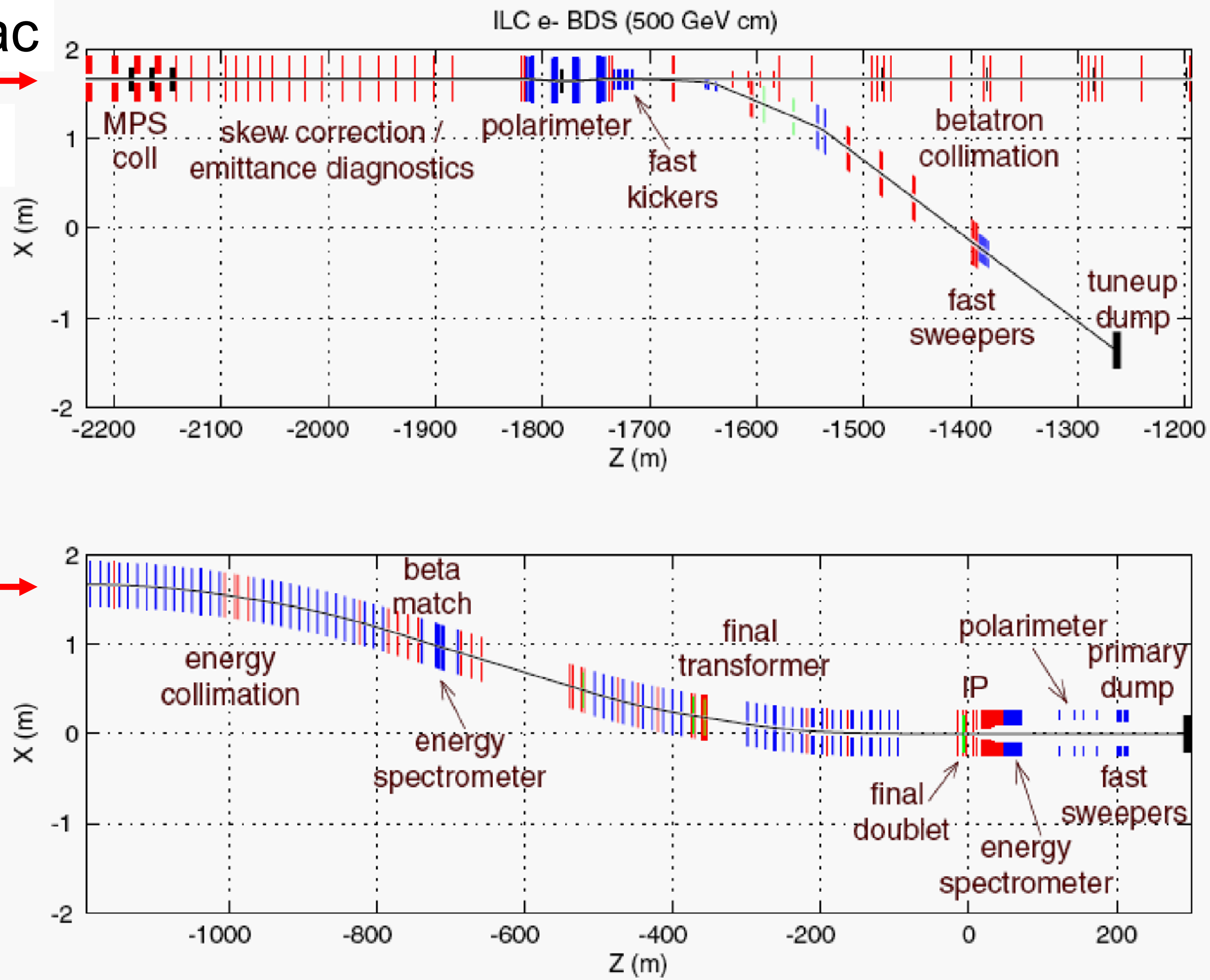
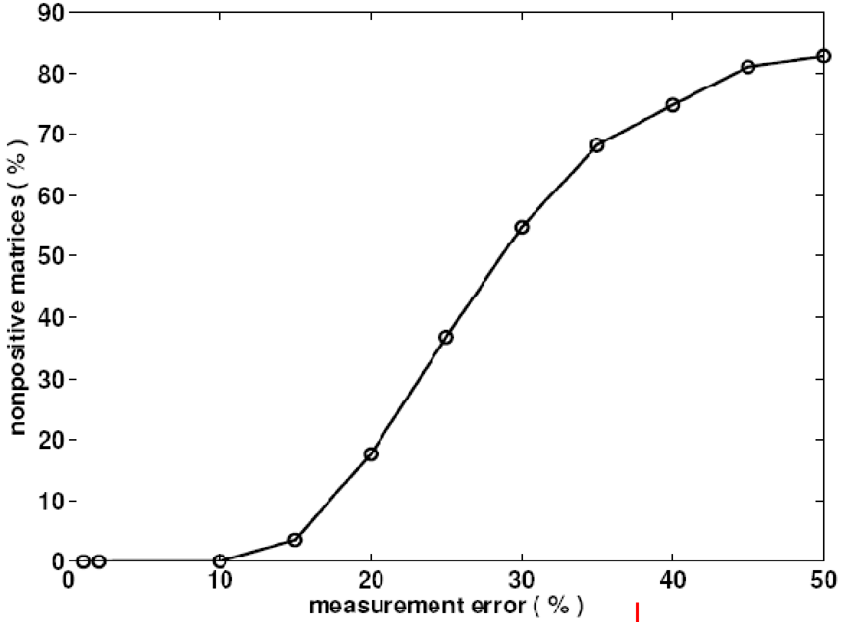


FIGURE 2.7-2. BDS layout showing functional subsystems, starting from the linac exit; X – horizontal position of elements, Z – distance measured from the IP.

Laser wire : Measurement precision

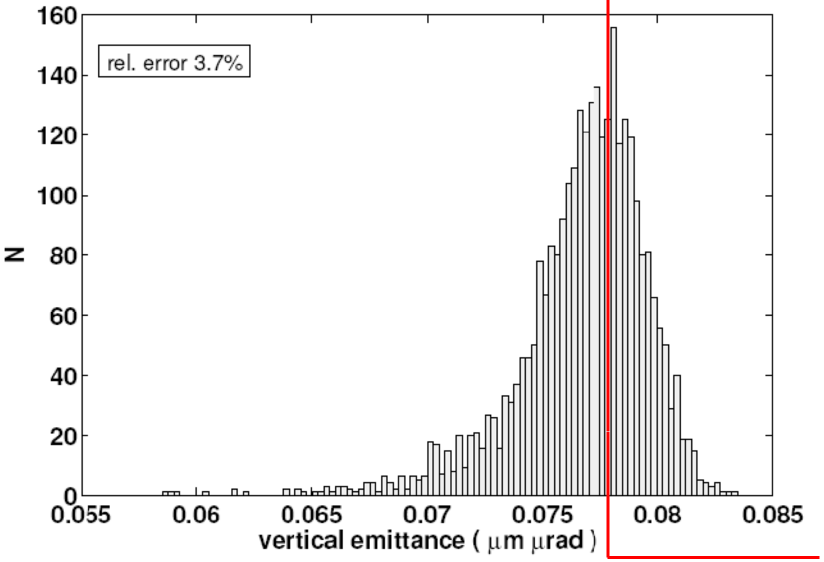
Phys. Rev. ST Accel. Beams 10, 112801 (2007)

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



The 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

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): η_{det}
- Laser peak power: P_ℓ
- e-bunch occupancy: N_e
- Laser wavelength: λ
- Compton xsec factor: $f(\omega)$

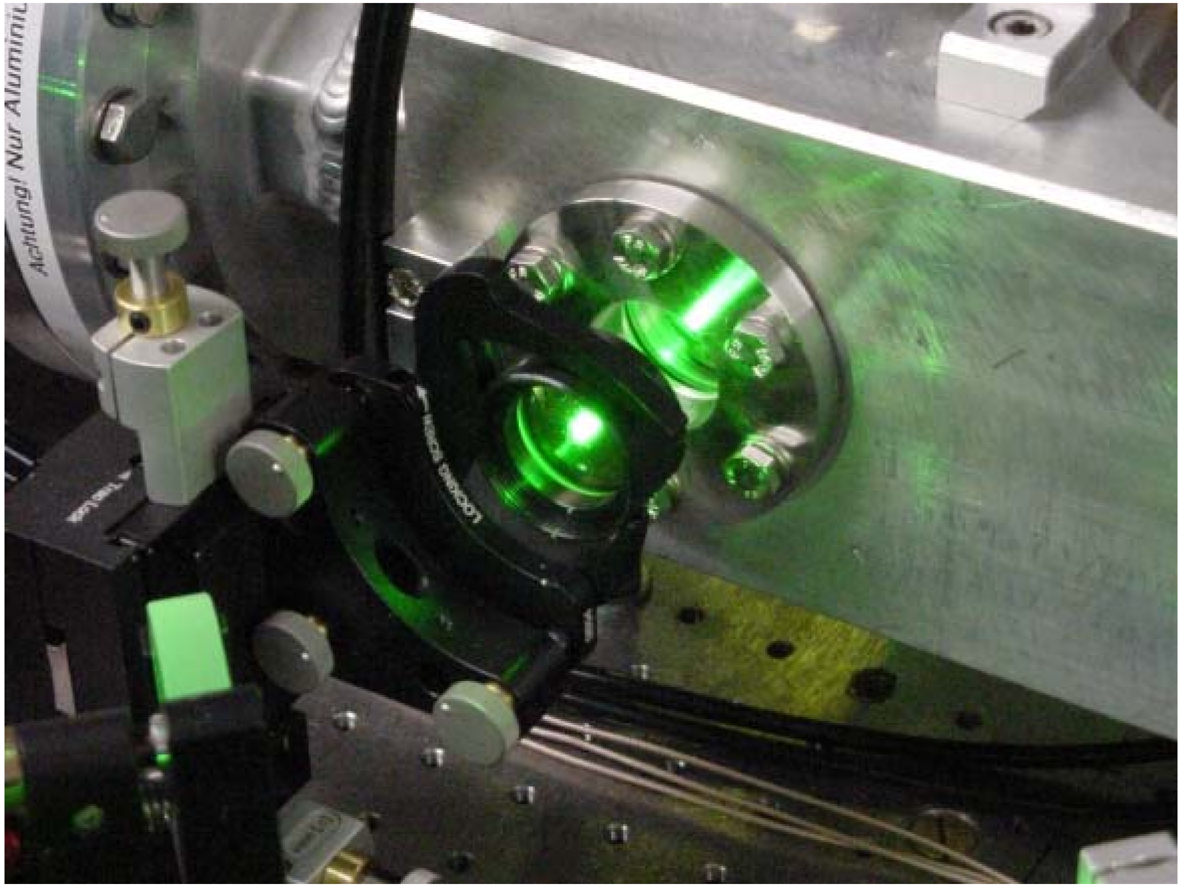
Eurotev report 2008-027

LW Experimental Programme:

PETRAII

ATF2

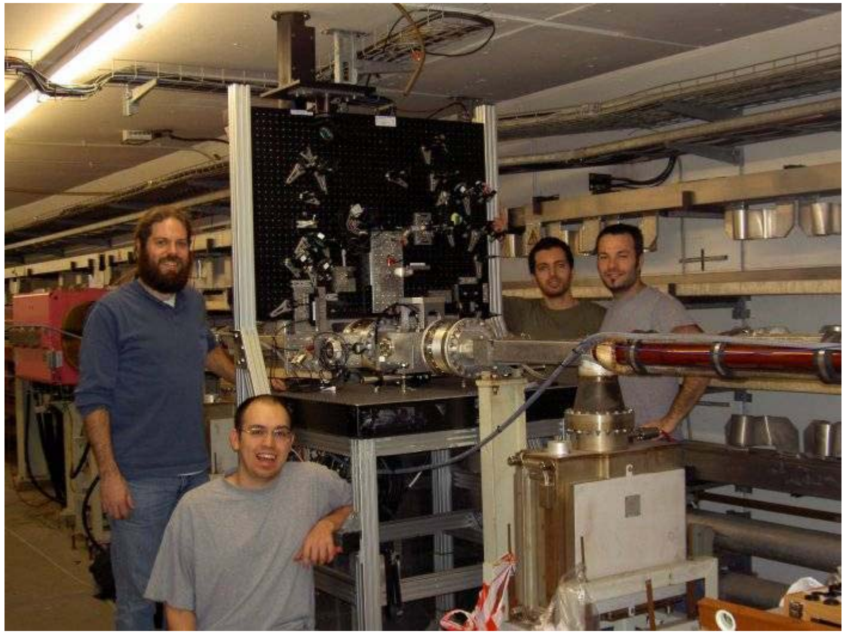
PETRAIII

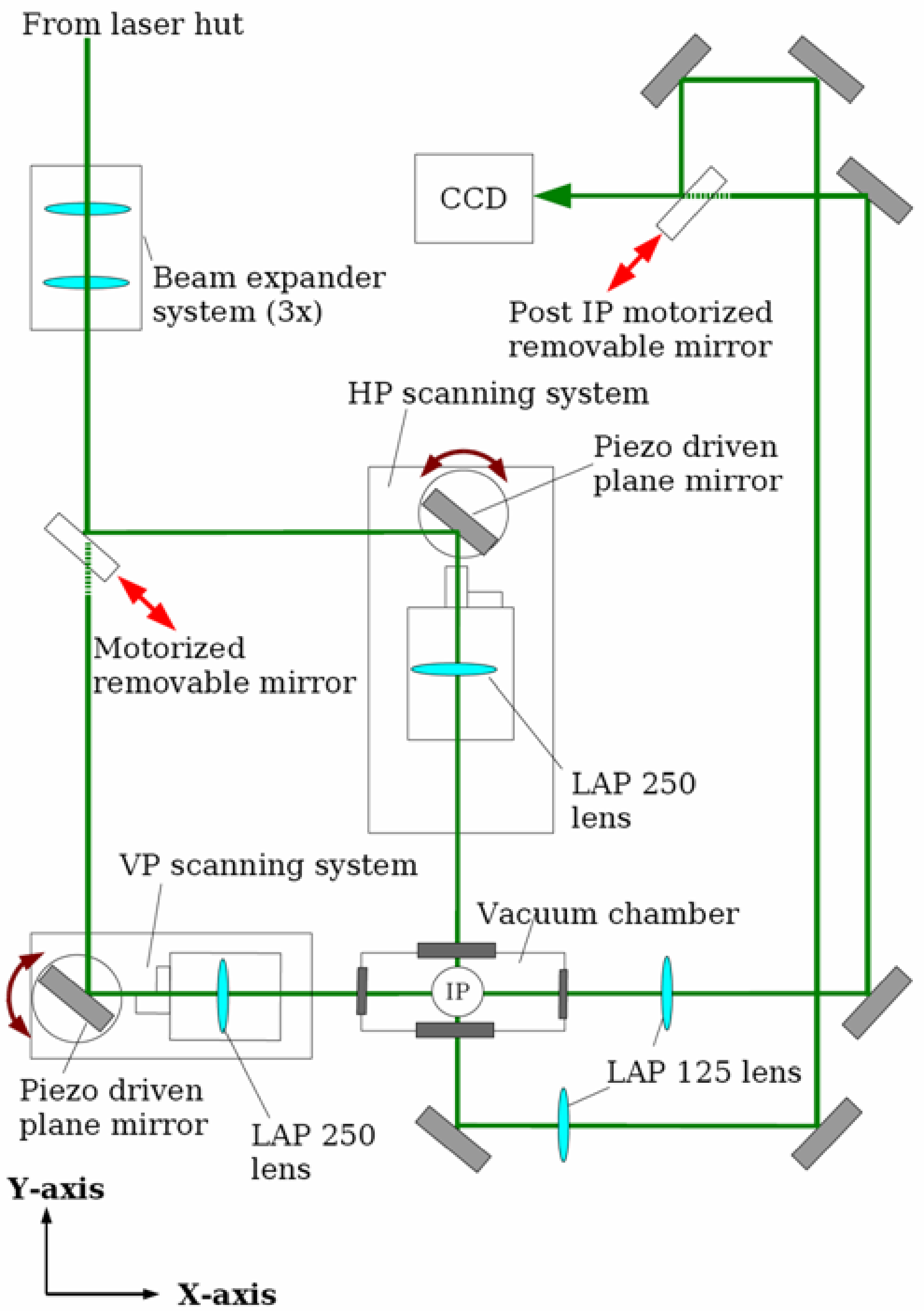


PETRA LW

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

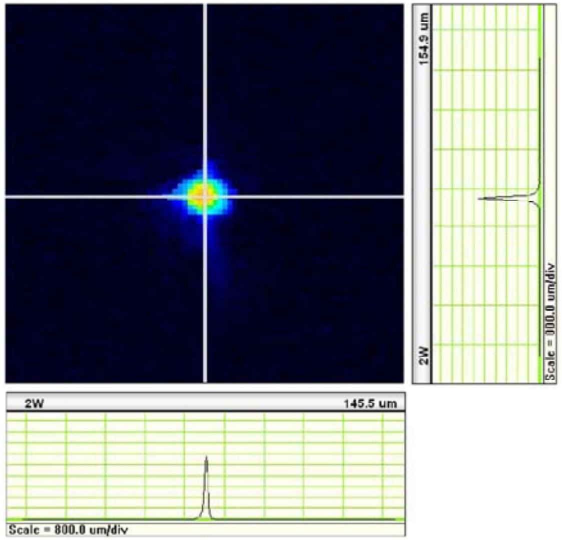
Vertical bread-board design; 2D scanning:

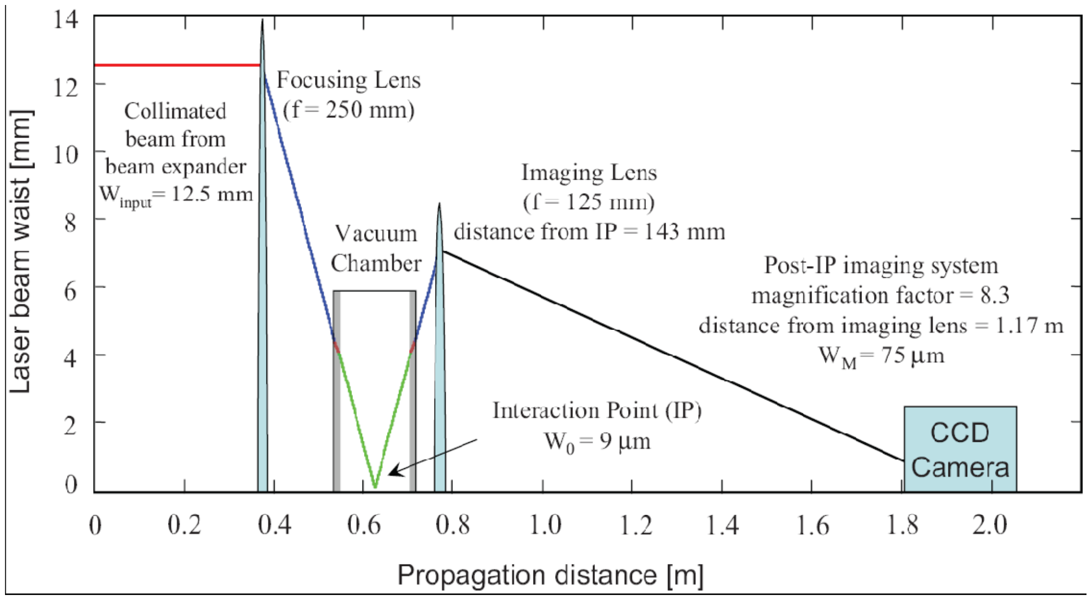




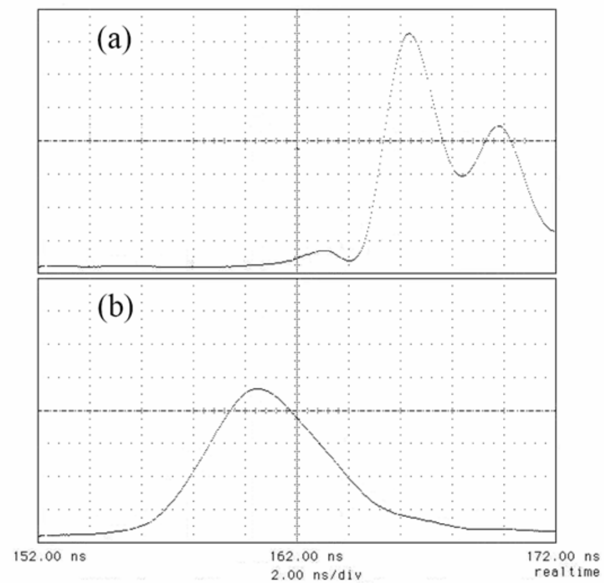
Laser Profile

Transverse:





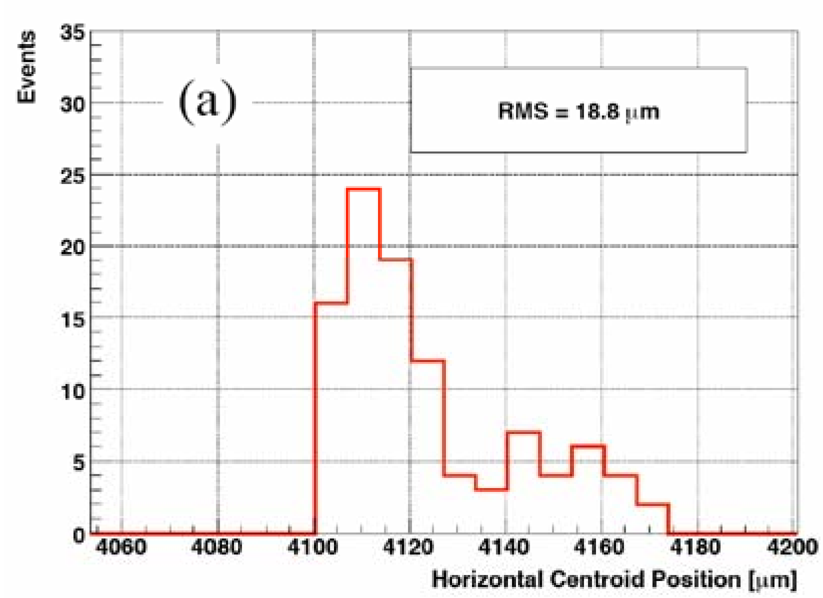
Temporal:

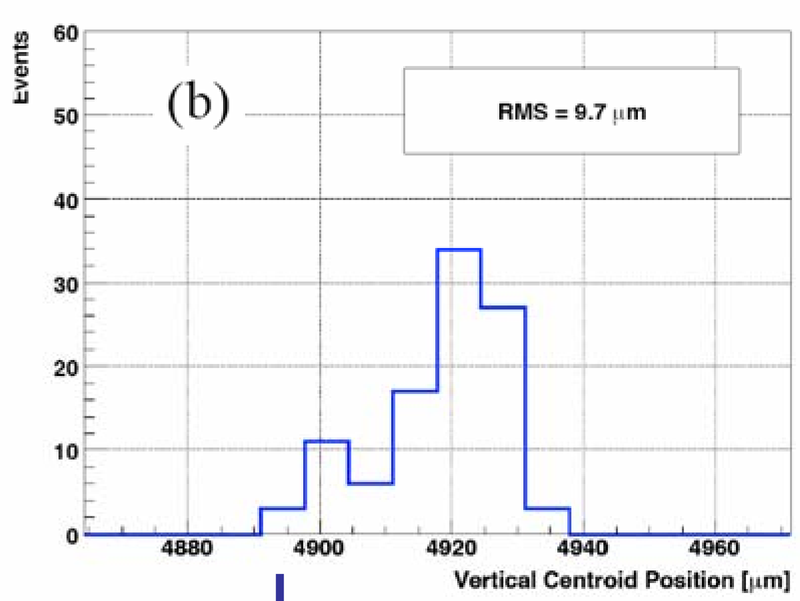


Unseeded

Seeded

Laser Pointing Jitter



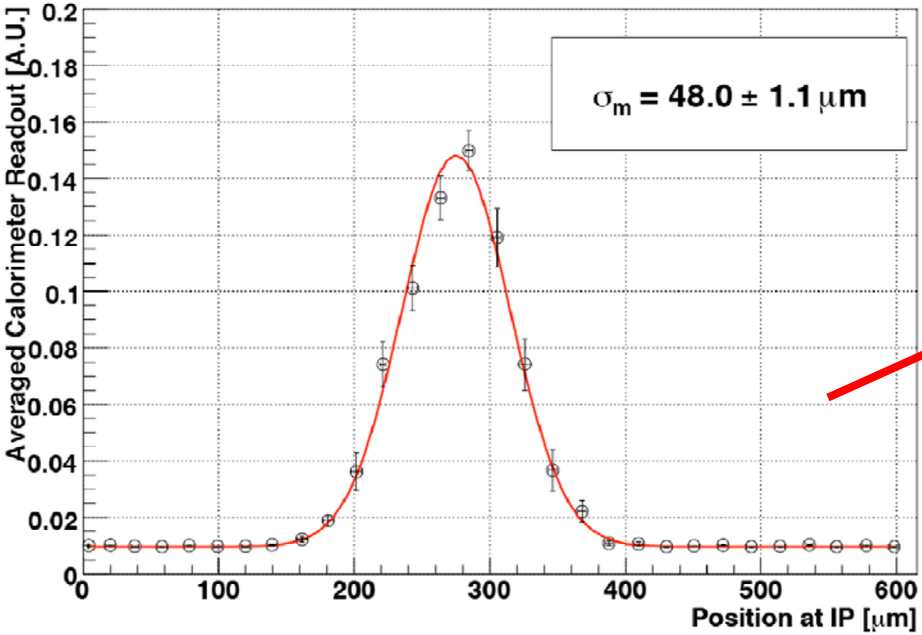


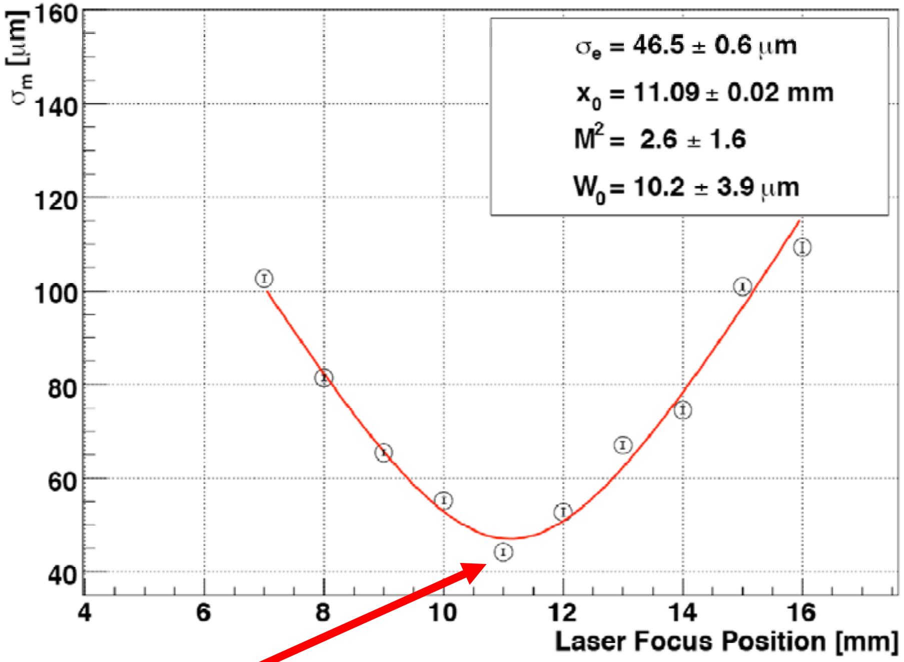
Translates to longitudinal so not relevant

Translates into a 1.6 μm jitter at the LW IP for Both horizontal and vertical scans

PETRAII Results: Vertical

Convoluted profile
(takes<50s)

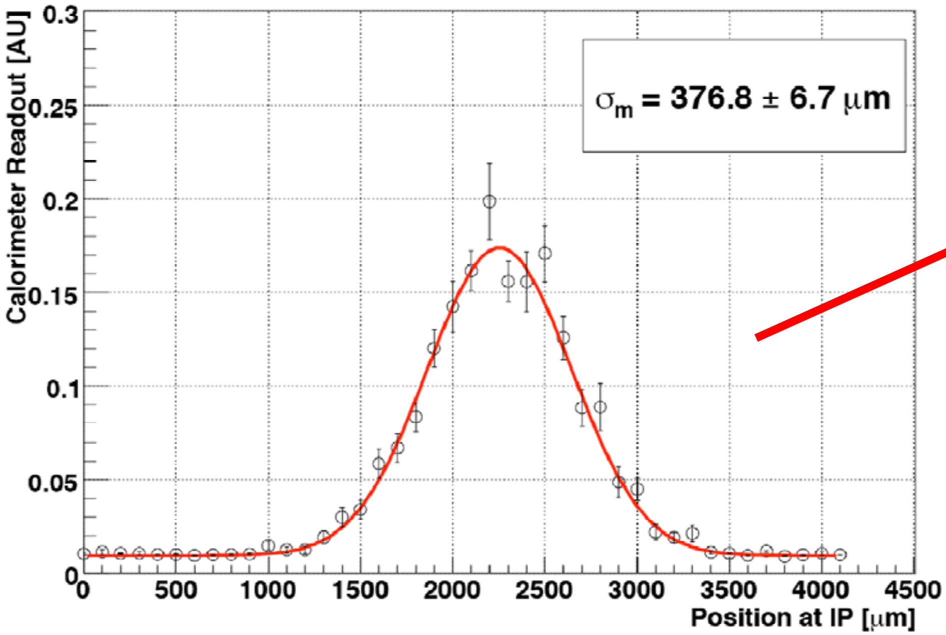


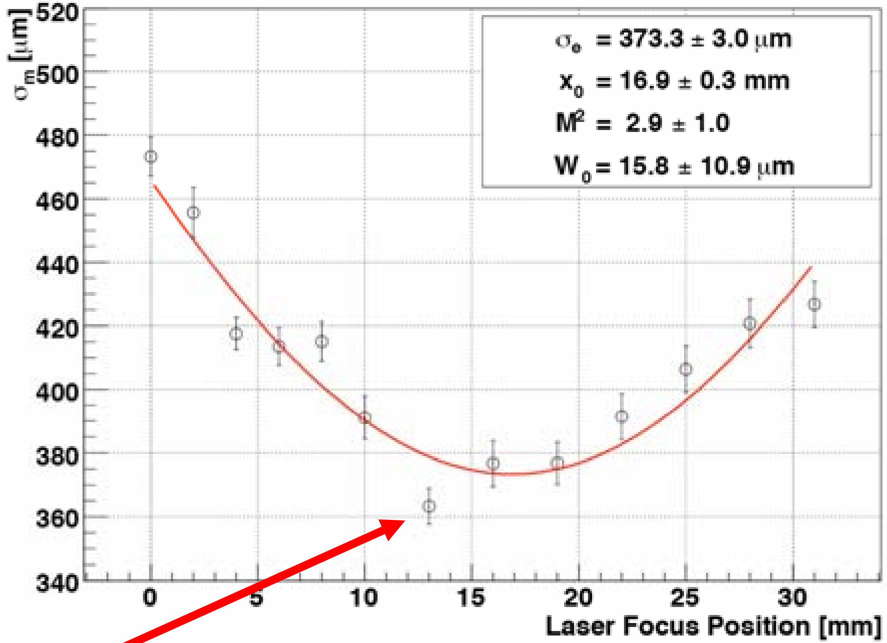


Fit to Rayleigh formula

PETRAII Results: Horizontal

Convoluted profile



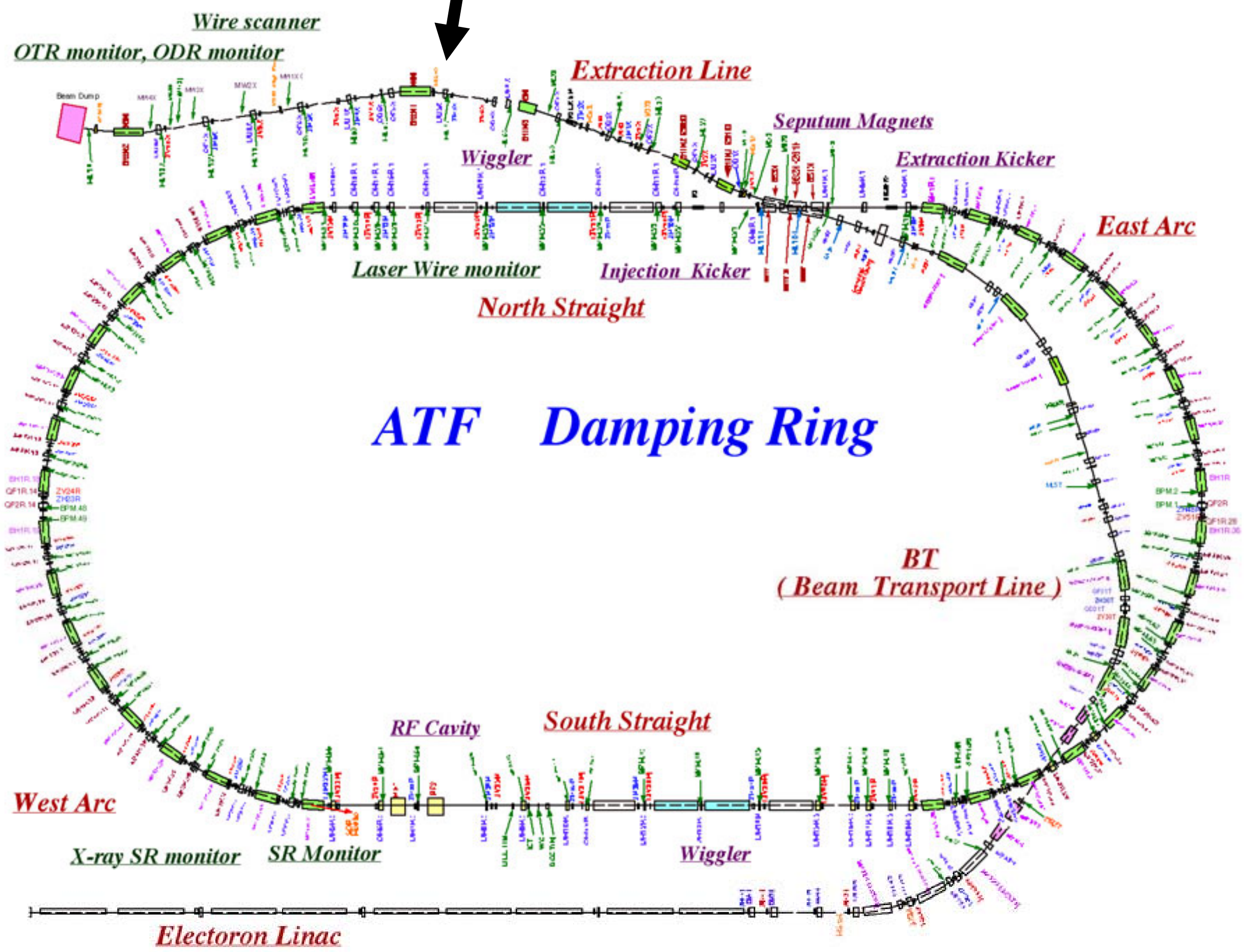


Fit to Rayleigh formula

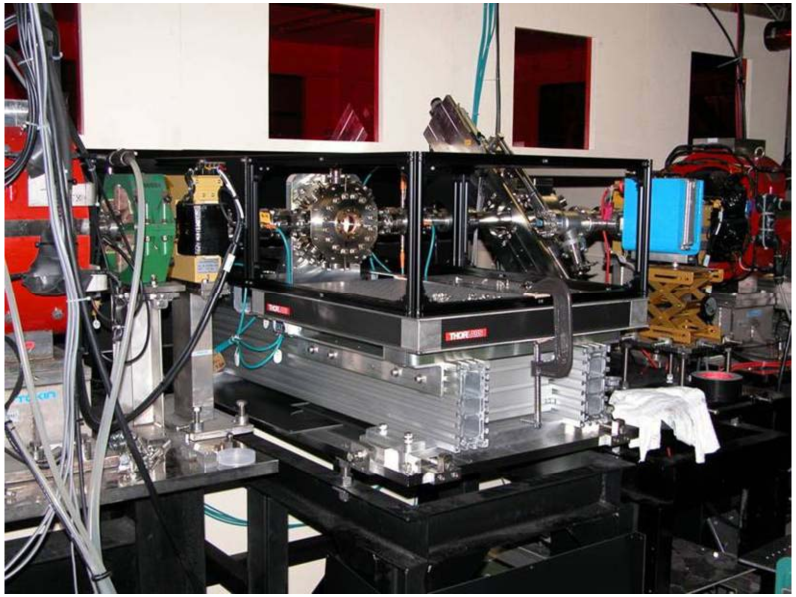
NIM A 592 (2008) 162–170

LW in the ATF Extraction Line

pulsed laser-wire location



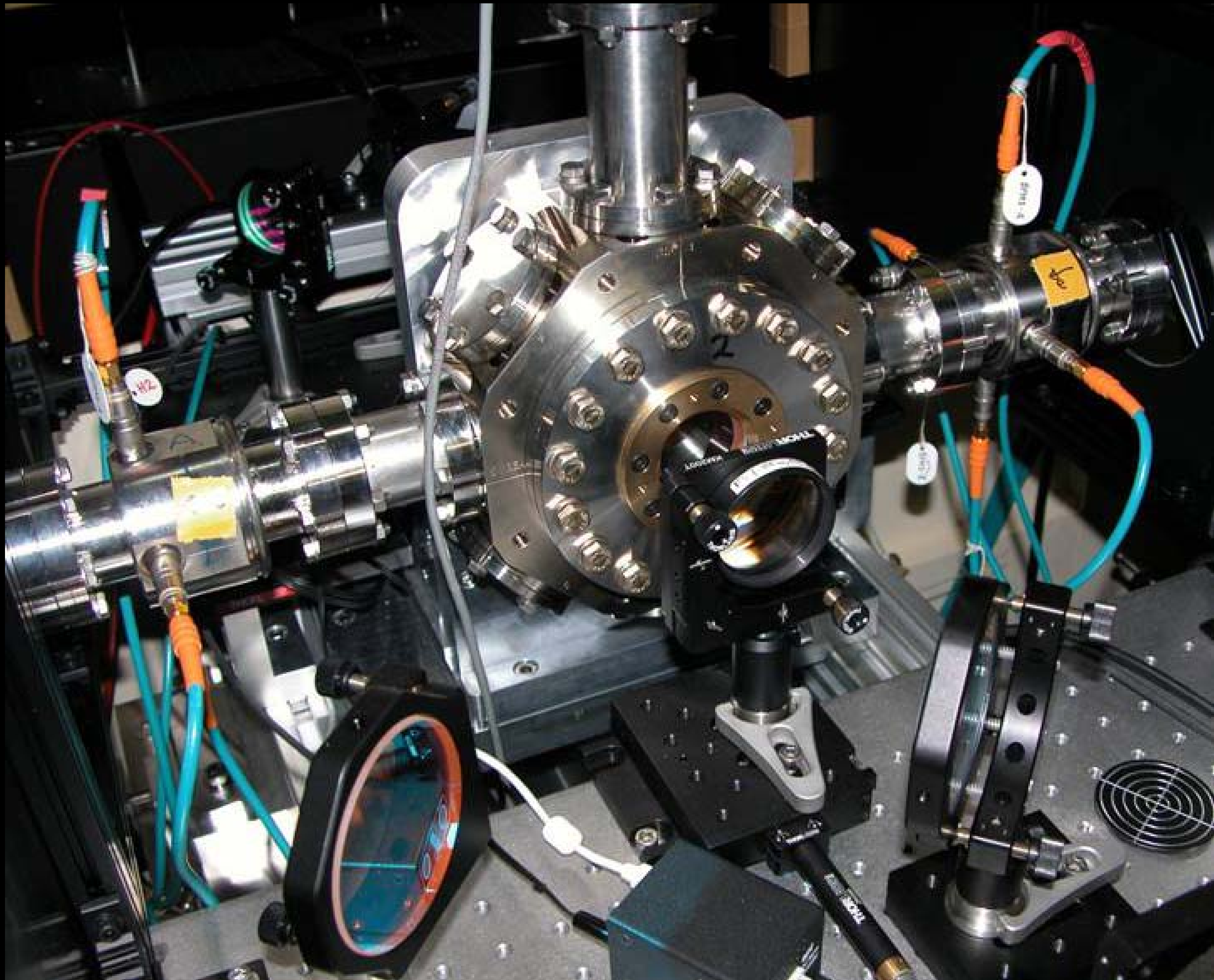
ATF Parameters



Beam energy :	1.28 GeV
Beam intensity single bunch operation :	1.0×10^{10} electrons/bunch
multi bunch operation :	0.7×10^{10} electrons/bunch x 20 bunch
Beam reputation :	0.7 - 6.4 Hz
X emittance (extrapolated to 0 intensity) :	1.0×10^{-9}rad.m (at 1.28GeV)
Y emittance (extrapolated to 0 intensity) :	1.0×10^{-11} rad.m (at 1.28GeV)
Typical beam size :	70μm x 7μm (rms horizontal x rms vertical)

ATF Laser-Wire

Aiming at micron-scale vertical scans



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

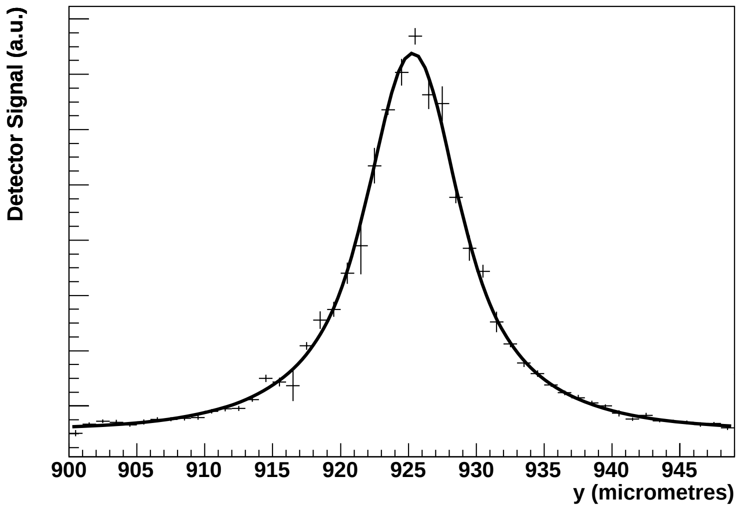
P. Karataev

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

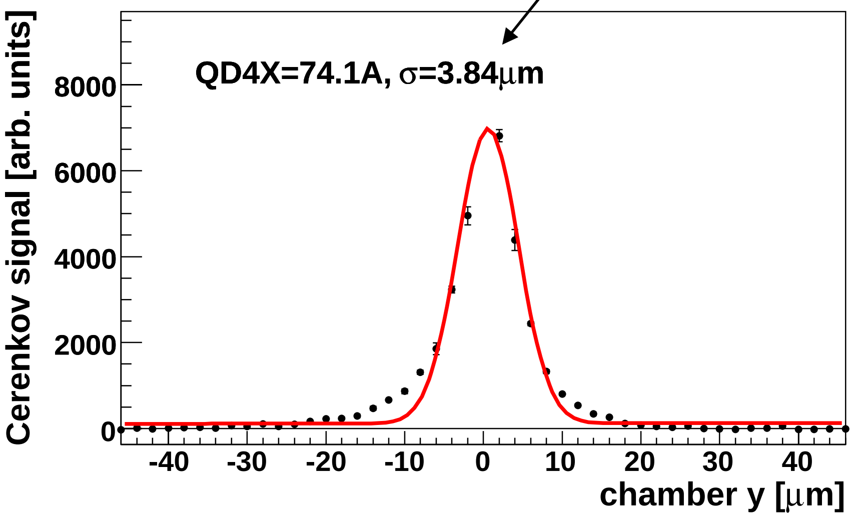
⇒ Ideal testing ground for ILC BDS Laser-wire system

ATF2 Detector

Prelminary ATF LW Results



Convoluted value



Laser M^2 not yet optimised
Laser astigmatism not yet corrected
Rayleigh Range effects well described by fit to full overlap integal

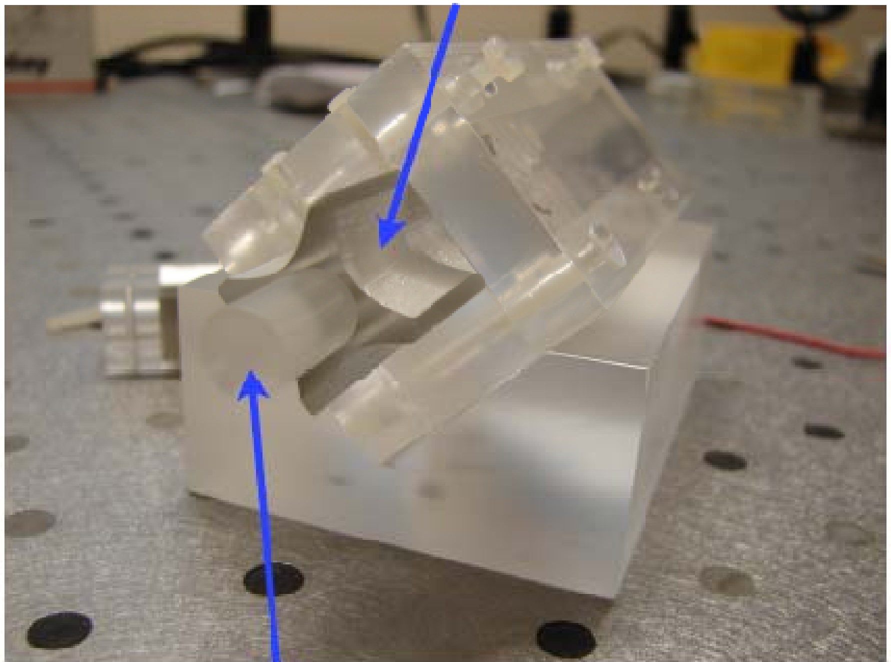
Simple Gaussian fit
(at the minimum of a quad scan)

S. Boogert et al

Prototype scanner

- First stage of high power scanner prototype
  - Simple EO crystal geometry
- Currently using
  - Lithium Niobate
  - Diameter 8.5 mm
  - Length 45 mm
- Different crystals
  - Damage thresholds
  - Electro-optic coefficient

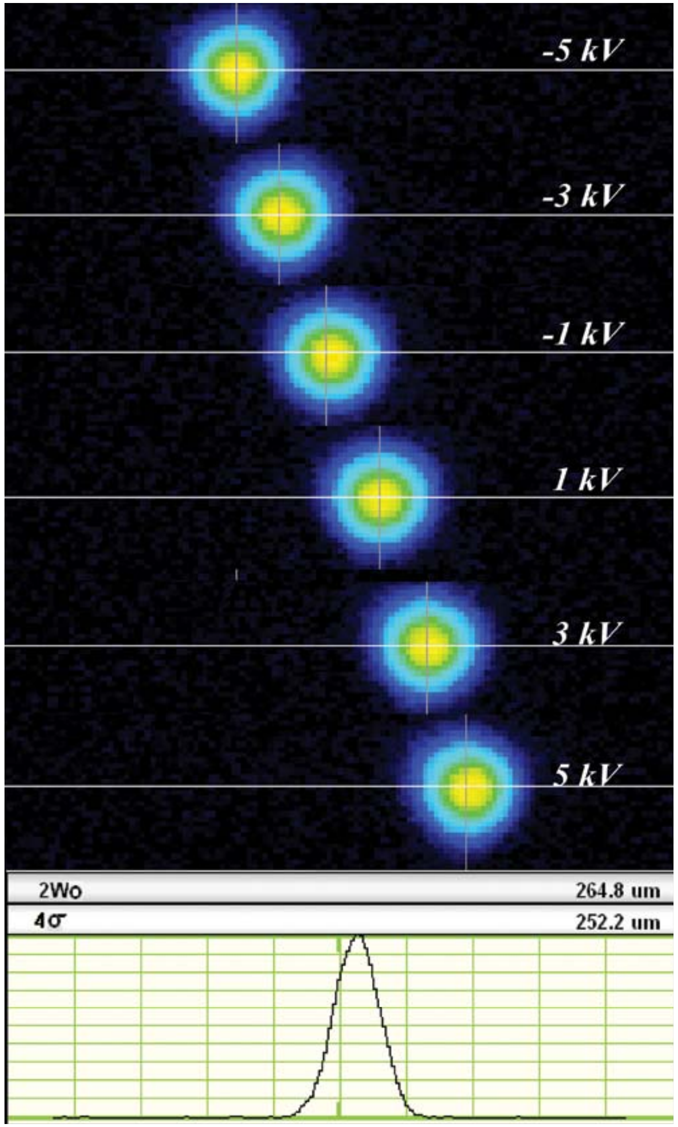
Quadrupole electrodes on outer surface



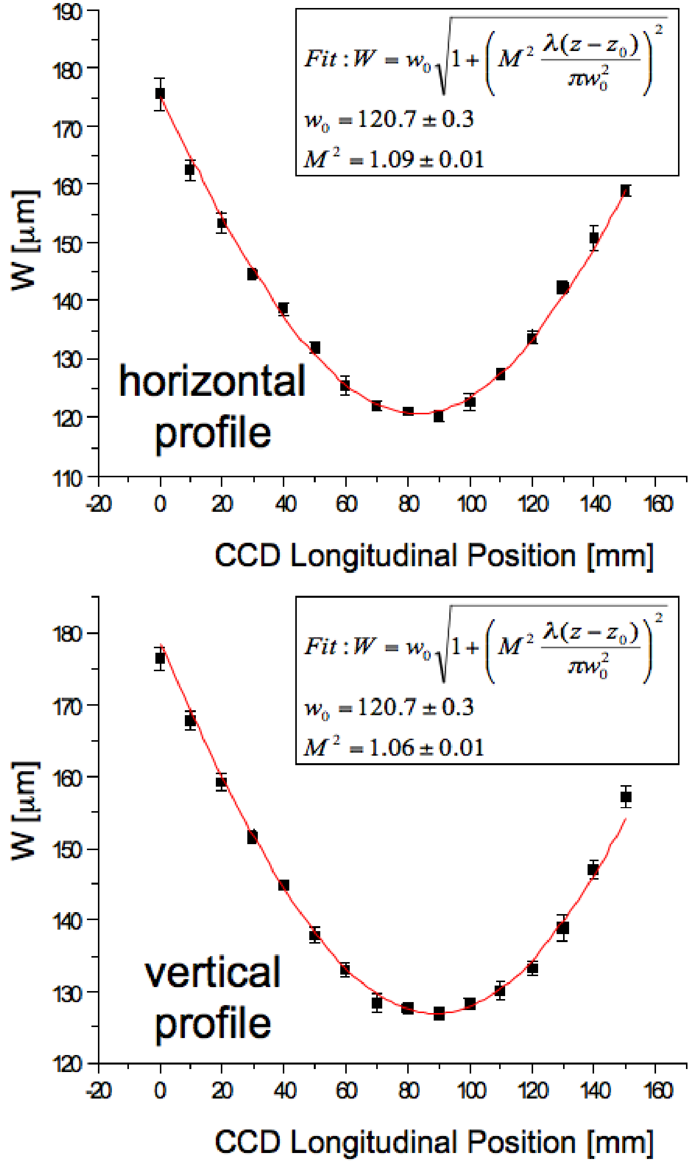
Cylindrical crystal hole

A. Bosco et al.

Beam images and profiles during scan



M² measurements with 5 kV applied



Laser R&D

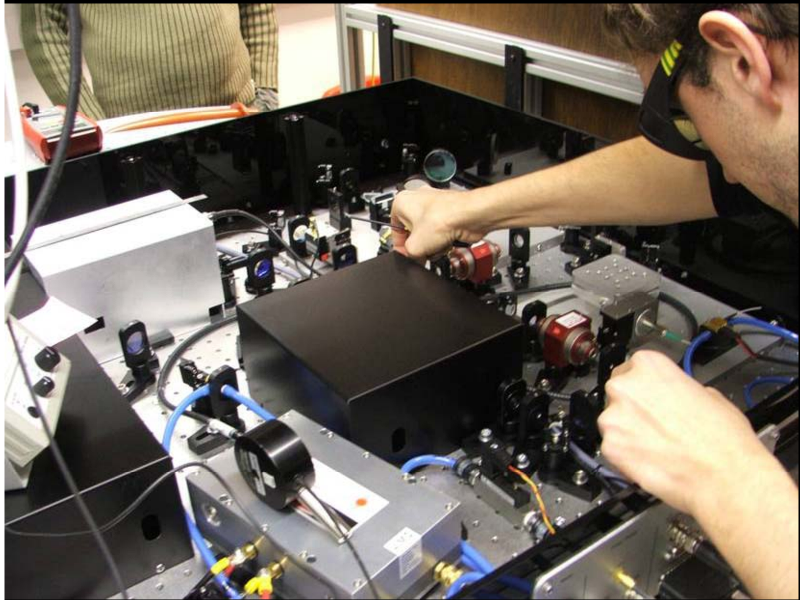
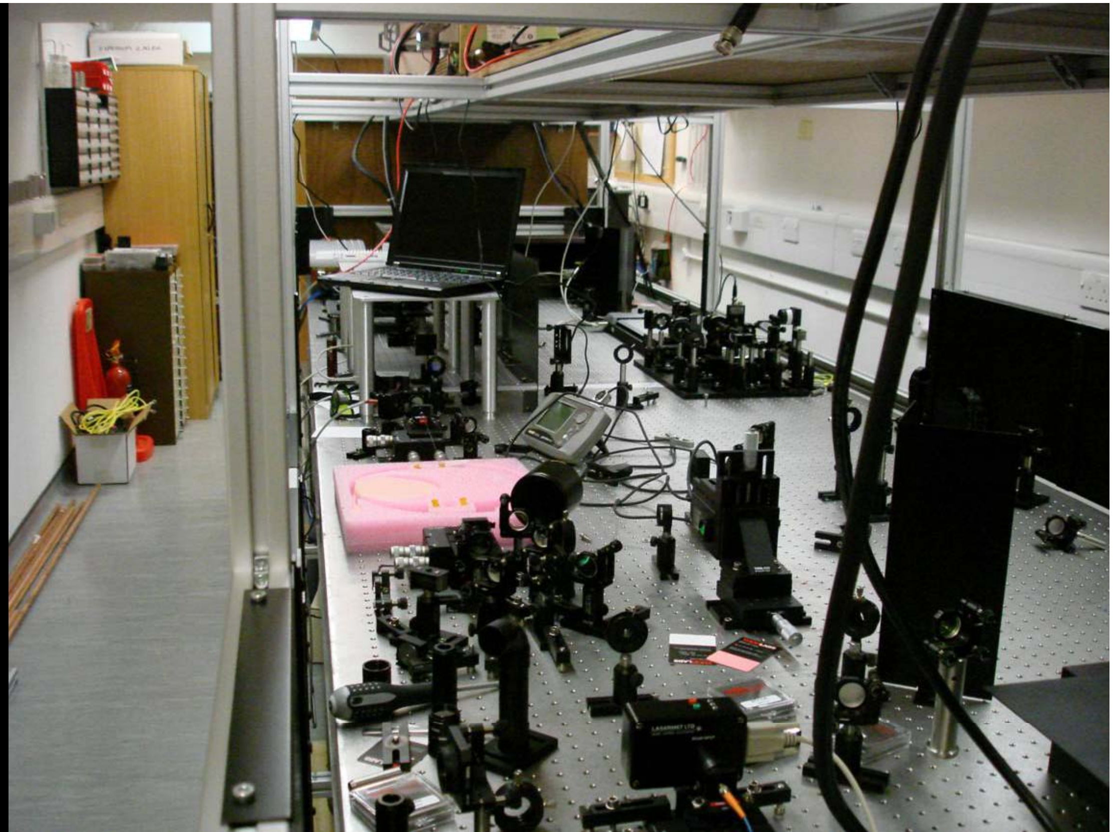
ILC goals

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

Oxford fibre laser progress:

- Test system laser amplifier slope efficiency 88%.
- AS seed laser installed & working in internally triggered burst envelope mode.
- M^2 measurements taken showing no change in beam quality with pumping.
- High power (400W) pump diode tested to specification in cw and pulsed mode.
- Test photonic crystal fibre arrived in Oxford.
- First investigations of pulsed pumping using test system and double clad normal Yb doped fibre – triggering/relative timing of seed and pump pulses.

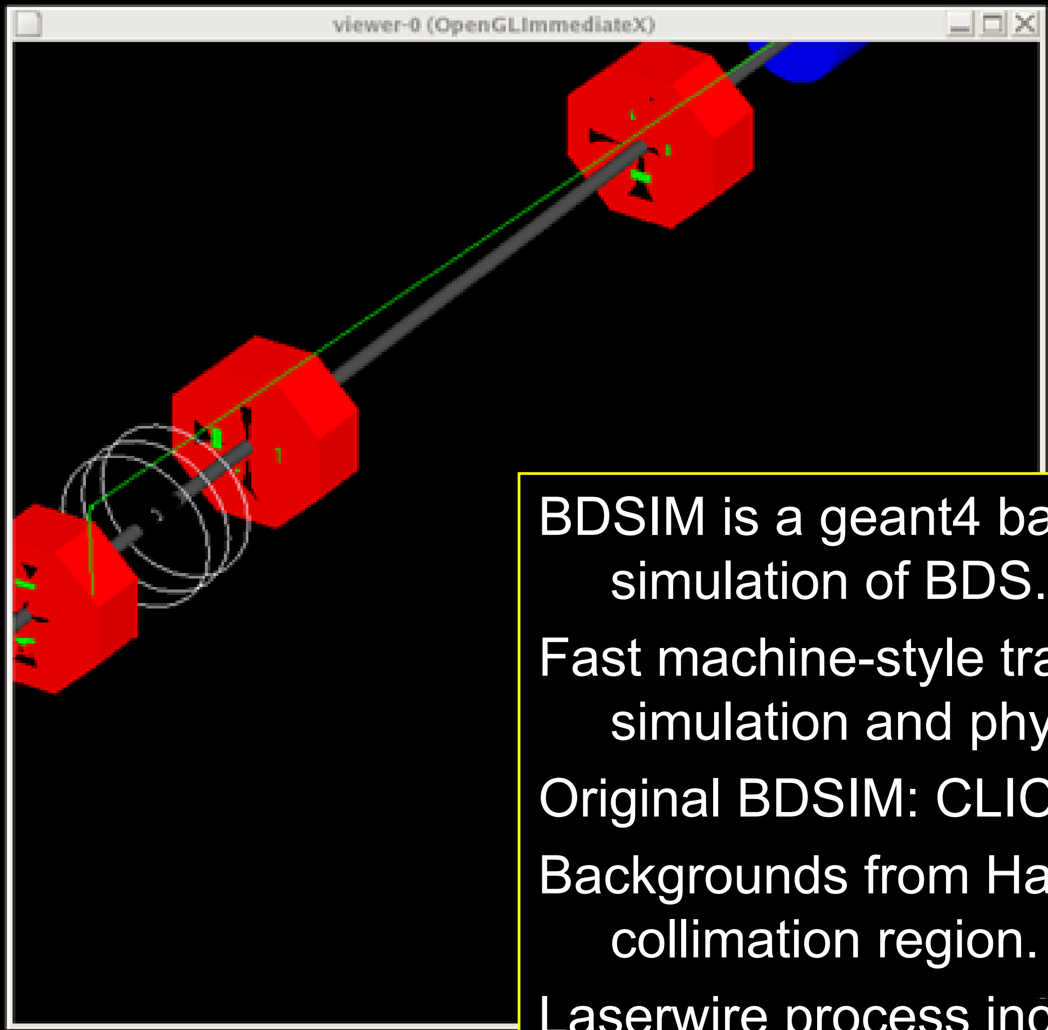
ILC-spec laser is being developed at JAI@Oxford based on fiber amplification. L. Corner et al

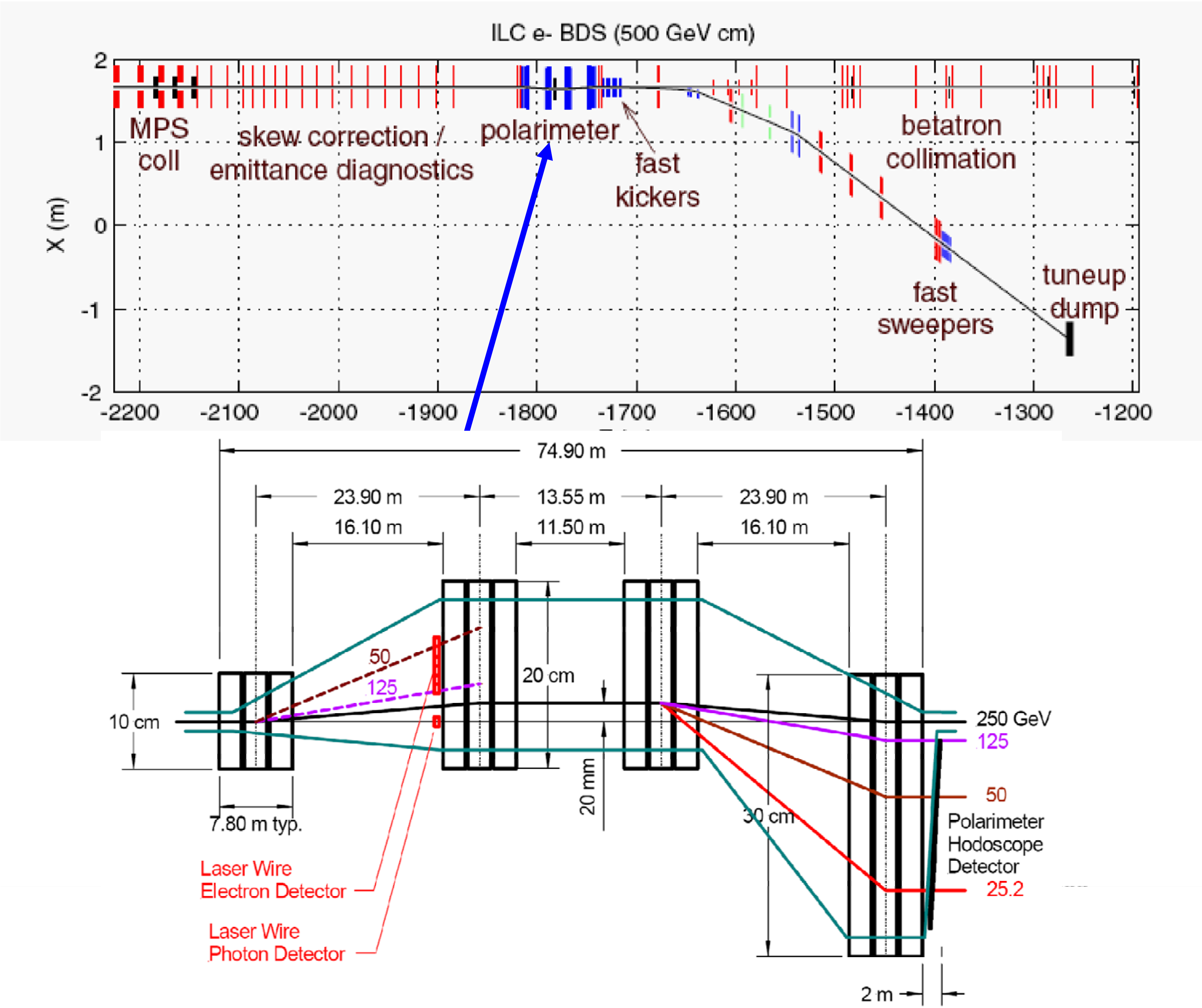
Current research:

- Optimal timing conditions for efficient extraction of pump energy in pulsed conditions.
- Externally triggering seed laser _after_ pump pulse.
- Coupling of seed and pump into crystal fibre.
- Operation of crystal fibre as cw amplifier at low power levels, pulsed at low power and up to highest powers.
- Investigation of frequency doubling efficiency

BDSIM:Geant4 Simulation of Beamlines



- BDSIM is a geant4 based programme for detailed simulation of BDS.
- Fast machine-style tracking combined with full shower simulation and physics processes.
- Original BDSIM: CLIC-Note-509 (2002)
- Backgrounds from Halo loss along BDS, especially in collimation region.
- Laserwire process included
- https://twiki.pp.rhul.ac.uk/twiki/bin/view/JAI/Simulation



ILC e- BDS (500 GeV cm)
X (m)
MPS coll
skew correction / emittance diagnostics
polarimeter
fast kickers
betatron collimation
fast sweepers
tuneup dump
2
1
0
-1
-2
-2200
-2100
-2000
-1900
-1800
-1700
-1600
-1500
-1400
-1300
-1200
74.90 m
23.90 m
13.55 m
23.90 m
16.10 m
11.50 m
16.10 m
50
125
20 cm
10 cm
250 GeV
125
50
20 mm
30 cm
7.80 m typ.
Polarimeter Hodoscope Detector
25.2
Laser Wire Electron Detector
Laser Wire Photon Detector
2 m

Assuming pressure $P = 10$ nTorr, temperature $T = 2$ K, and $N_e = 2 \cdot 10^{10}$ electrons per bunch, the number of background events per bunch is $DPN_e\sigma_B/k_BT$ where k_B is Boltzmann's constant, which gives about 160 bremsstrahlung photons per bunch. This is a few % of a typical peak LW signal for a vertical LW scan (the signal is $\sim 10000\ \gamma_C$ for $\sigma_m \simeq 2\ \mu$m) and about 10% for a horizontal scan (with $\sigma_m \simeq 20\ \mu$m).

Simulation results for hits due to SR in γ_C detector. H_d is the number of detector hits due to SR with the Cherenkov detector placed just after the next dipole, where "hits" is defined as the number of electrons and positrons above the Cherenkov threshold energy (9.25 MeV) hitting the detector plane. σ_{H_d} is the statistical error in the simulation.

k	H_d/bunch	$\sigma_{H_d/\text{bunch}}$	95% upper c.l.
20	$2.92 \cdot 10^{-5}$	$1.16 \cdot 10^{-5}$	$4.834 \cdot 10^{-5}$
10	6.35	3.17	11.7
4.5	3.23	3.23	8.82

Hits from the LW and polarimeter in the polarimeter detector as a fraction of Compton events for both LW and polarimeter with no MPS collimator in the chicane. "Hits" are defined as electrons or positrons with energy greater than 9.25 MeV entering the detector plane. "H" means hits and the subscript denotes the origin of the hits. $e^-_{C,pol}$ means Compton scattered electrons from the polarimeter.

$H_{e^-_C}$	H_{γ_C}	$H_{e^-_{C,pol}}$
(3.7 ± 0.6) %	(3.2 ± 0.3) %	(60 ± 0.3) %

L. Deacon et al.
Eurotev report 2008-018

Summary

- Very active + international programme in laser-based diagnostics:
  - 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
- Full simulations of Signal extraction
- Full analysis of emittance determination