Laser-wire Model for BDS+Linac

Grahame Blair
SLAC

10th December 2007

- Introduction
- Overview of errors
- Ongoing technical work in this area
- Linac simulations
- 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

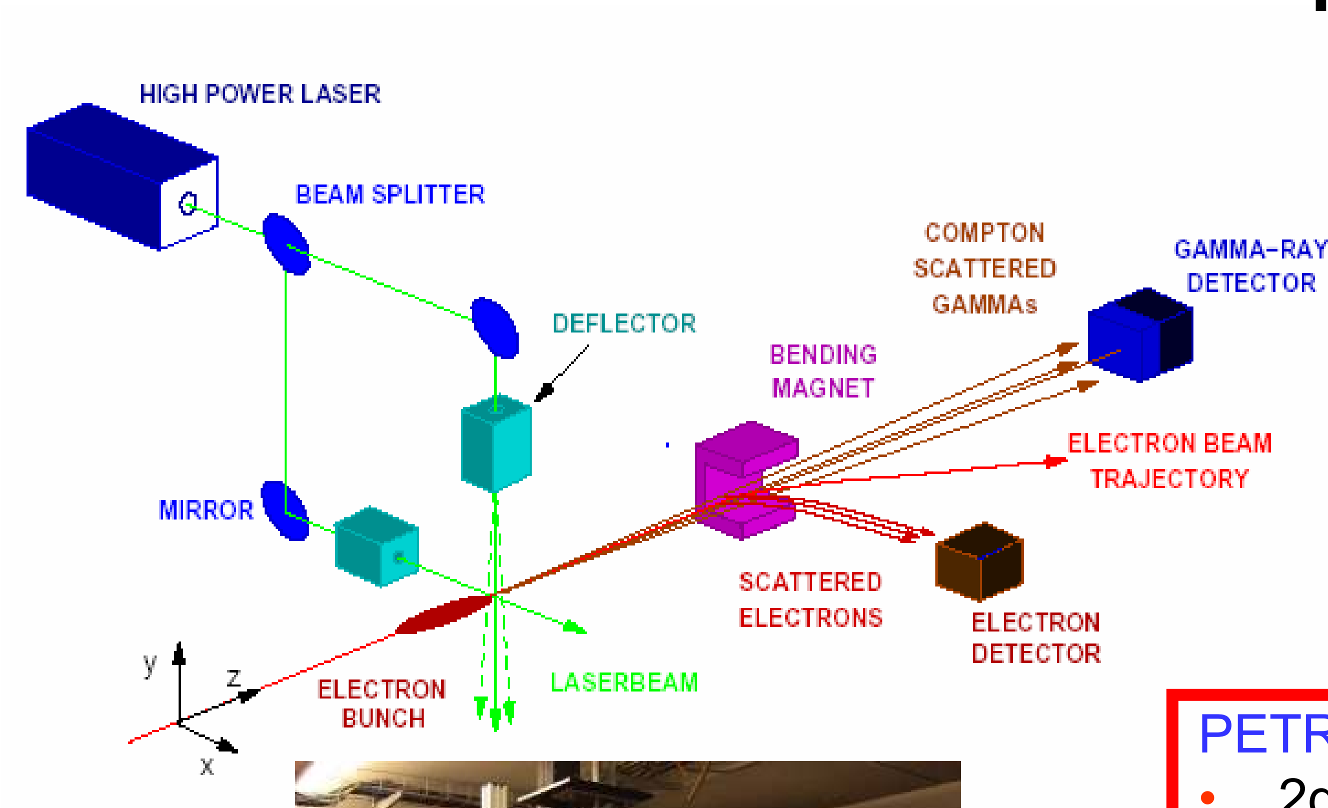
JAI@RHUL: G. Blair, S. Boogert, G. Boorman, A. Bosco, L. Deacon, P. Karataev, S. Malton , M. Price I. Agapov (now at CERN)

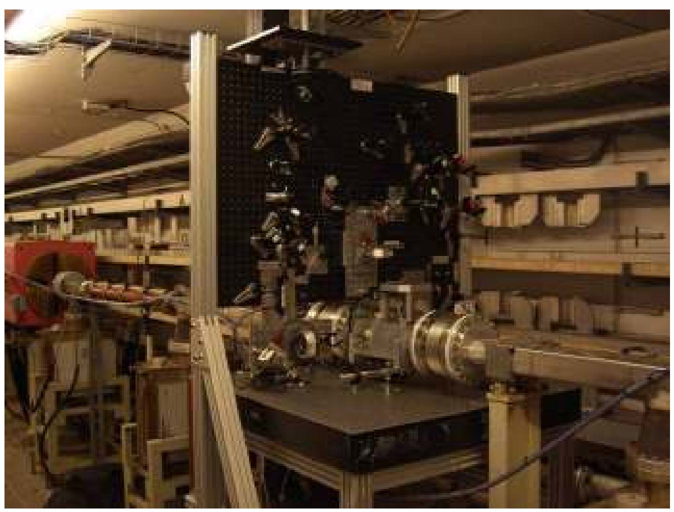
KEK: A. Aryshev, H. Hayano, K. Kubo, N. Terunuma, J. Urakawa

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

FNAL: M. Ross

Laser-wire Principle





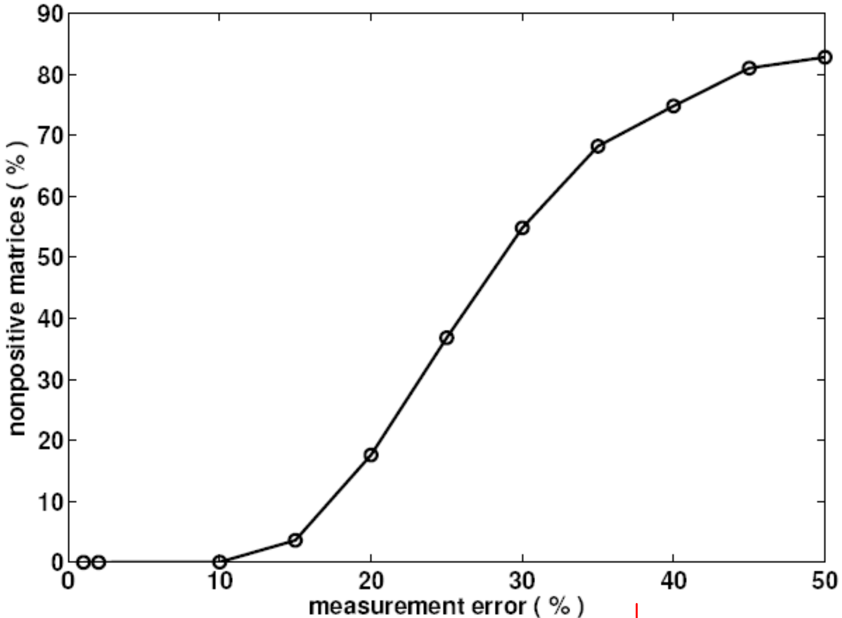
PETRAII
- 2d scanning system
- DAQ development
- Crystal calorimeter

→ PETRA III
- Ultra-fast scanning
- Diagnostic tool

Laser wire : Measurement precision

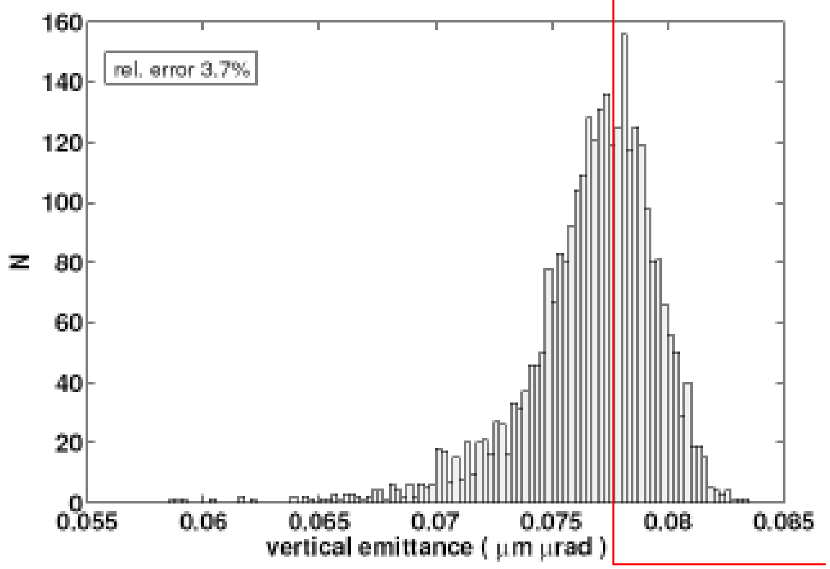
Phys. Rev. ST Accel. Beams 10, 112801 (2007)

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



The Goal: Beam Matrix Reconstruction

NOTE: Rapid improvement with better σ_y resolution

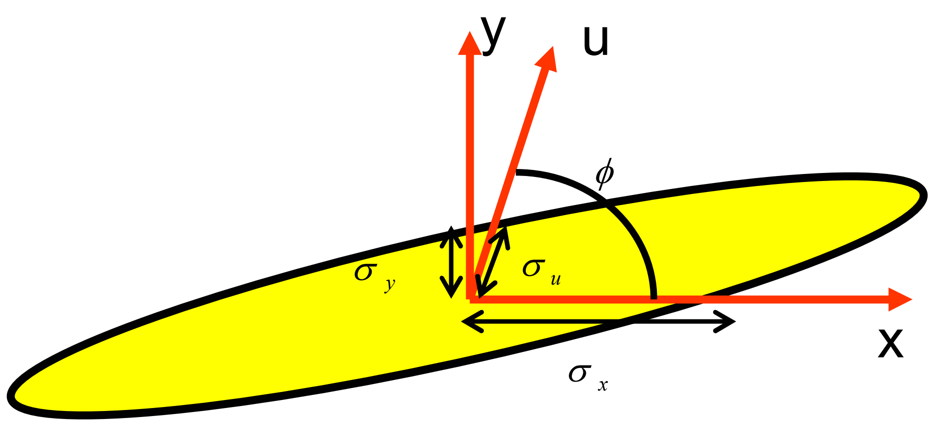


Reconstructed emittance of <u>one ILC train</u> using 5% error on σ_y

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

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

Bunch Jitter

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

BPM resolution of 20 nm may be required

Dispersion

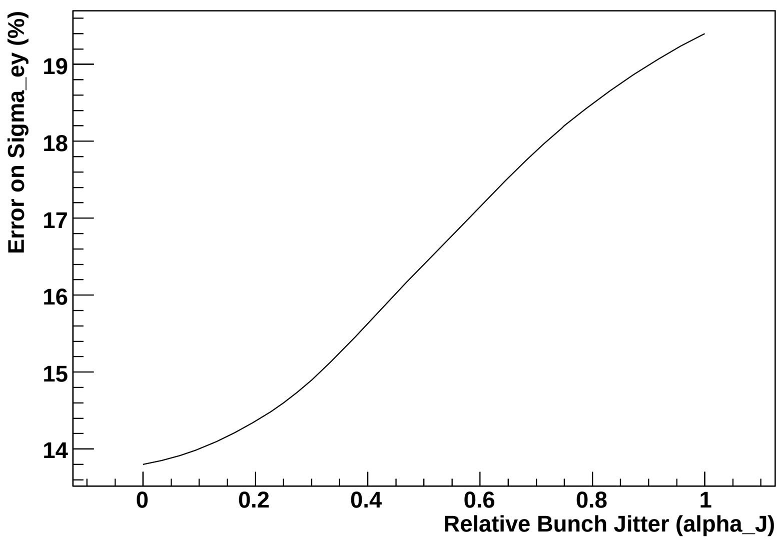
$$\boxed{\frac{\delta\sigma_e}{\sigma_e} \approx 2.3[\eta / \mathrm{mm}]^2\left(\frac{\langle\delta\eta\rangle}{\eta}\right)}$$

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

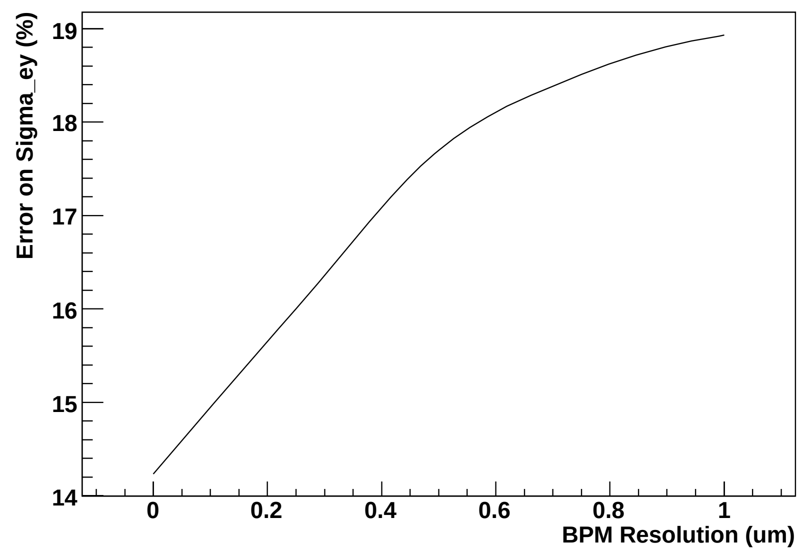
Alternative Scan Mode

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

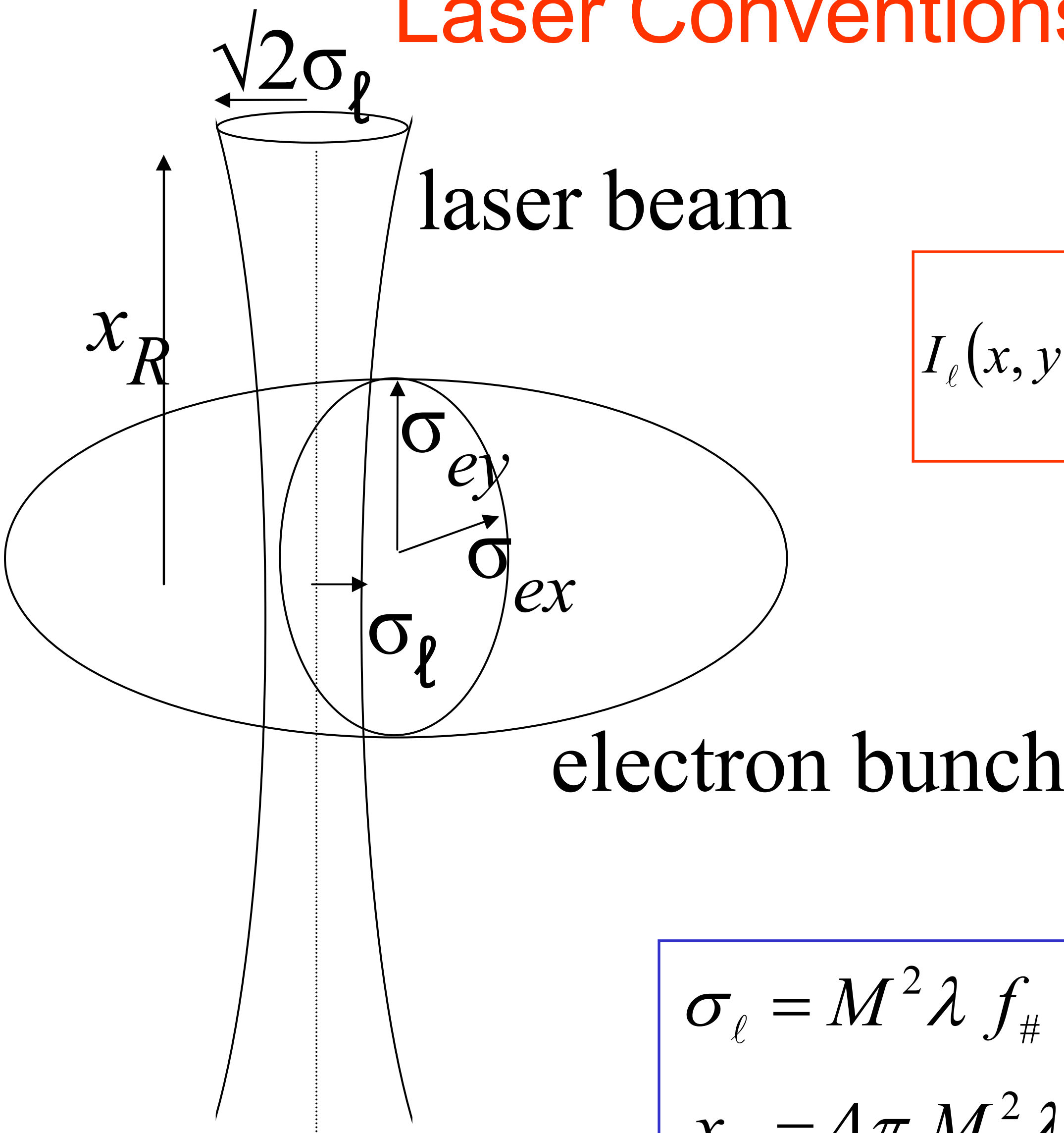


Beam jitter fixed at 0.25σ



BPM resolution fixed at 100 nm

Laser Conventions



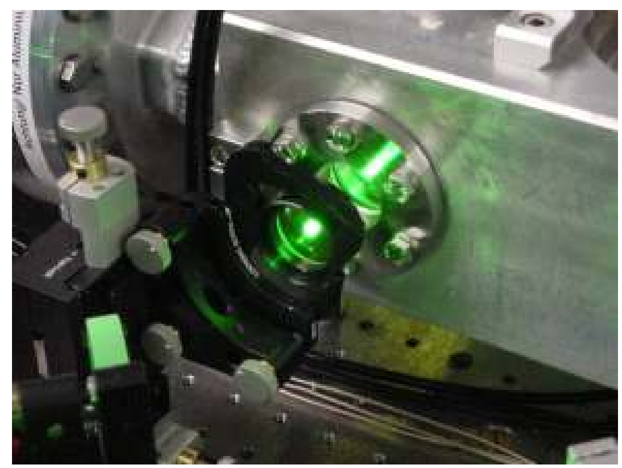
For TM_{00} laser mode:

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

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

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

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



Compton Statistics

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

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

Where :

Compton xsec factor

e-bunch occupancy

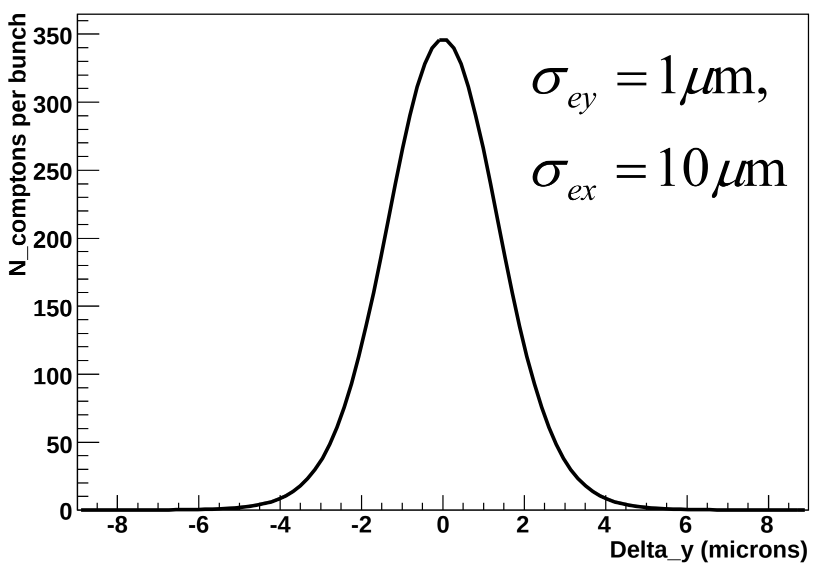
$$\xi = \left(\frac{\eta_{\text{det}}}{0.05}\right)\left(\frac{P_\ell}{10\text{ MW}}\right)\left(\frac{N_e}{2\times10^{10}}\right)\left(\frac{\lambda}{532\text{ nm}}\right)\left(\frac{f(\omega)}{0.2}\right)\mu\text{m}$$

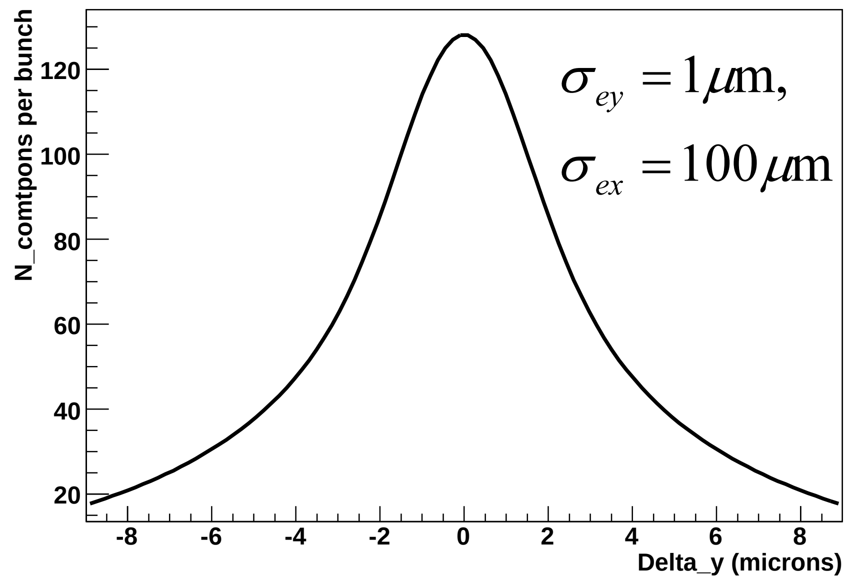
Laser wavelength

Laser peak power

Detector efficiency
(assume Cherenkov system)

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

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

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

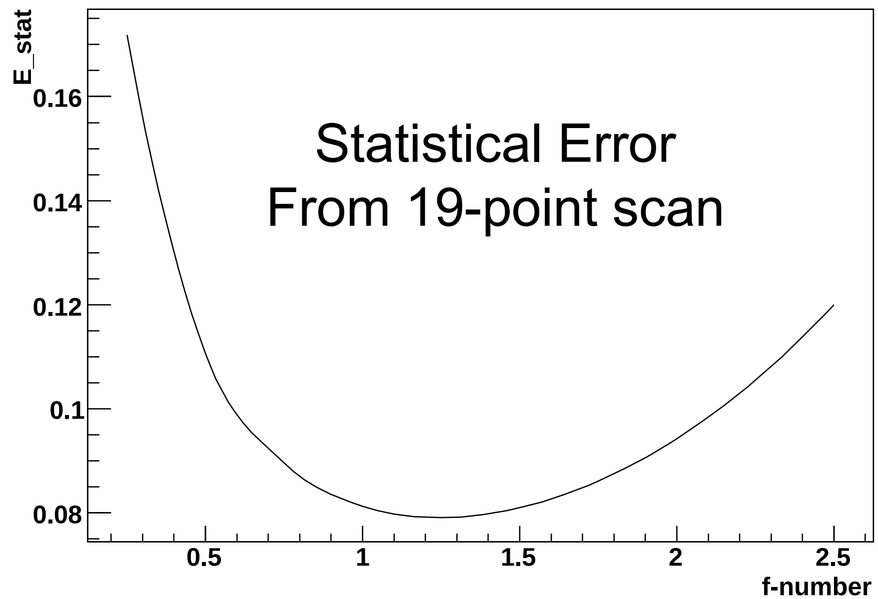
Laser Requirements

Wavelength	$\leq$ 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

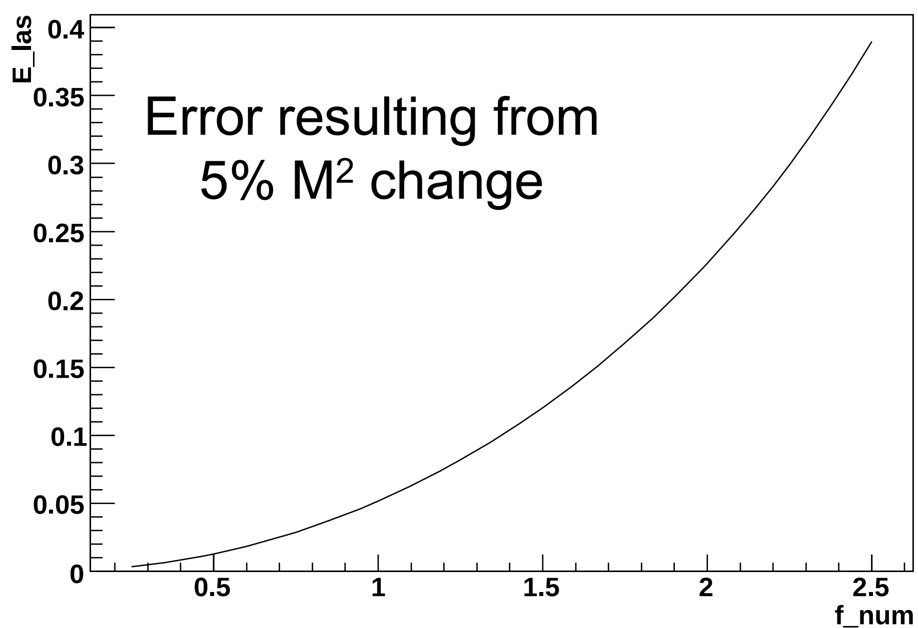
ILC-spec laser is being developed at JAI@Oxford
based on fiber amplification. L. Corner et al

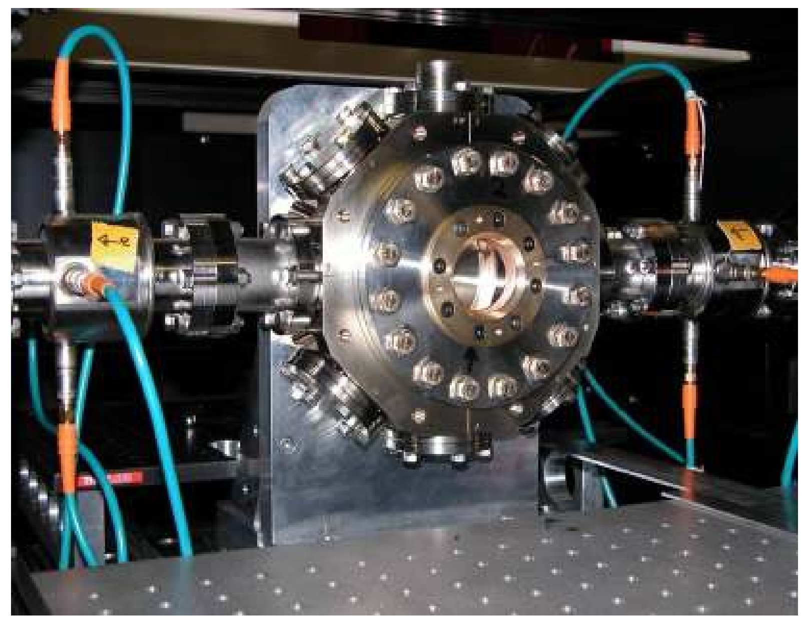
TM_{00} mode

- Optimal f-num≈1-1.5 for λ= 532nm
- Then improve M^2 determination
- f-2 lens about to be installed at ATF



Relative Errors





ATF2 LW; aiming initially at f_2; eventually f_1?

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

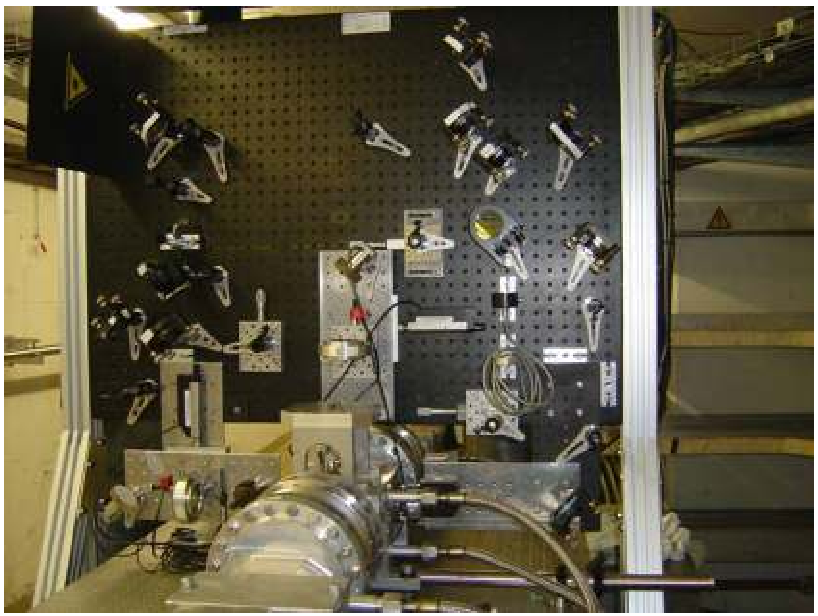
Goals/assumptions

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}

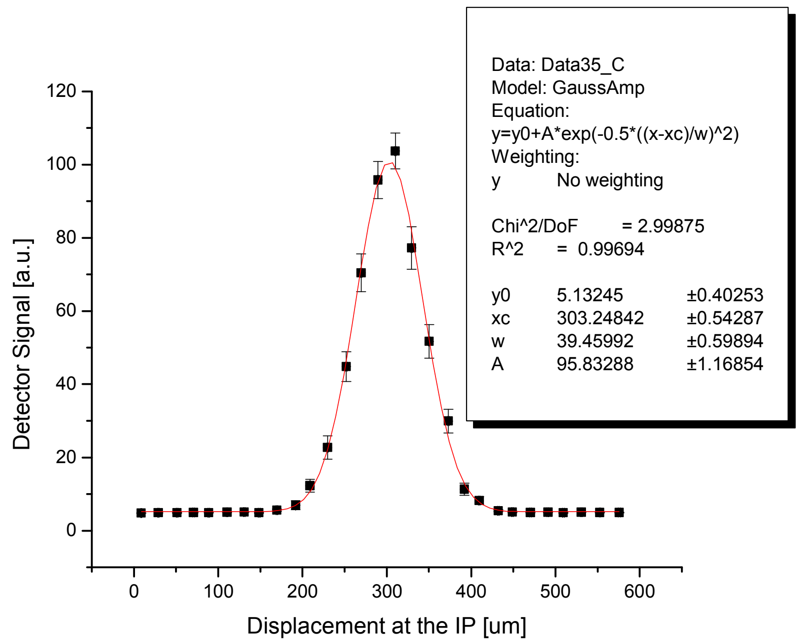
Could be used for η measurement $\rightarrow E_\eta$

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

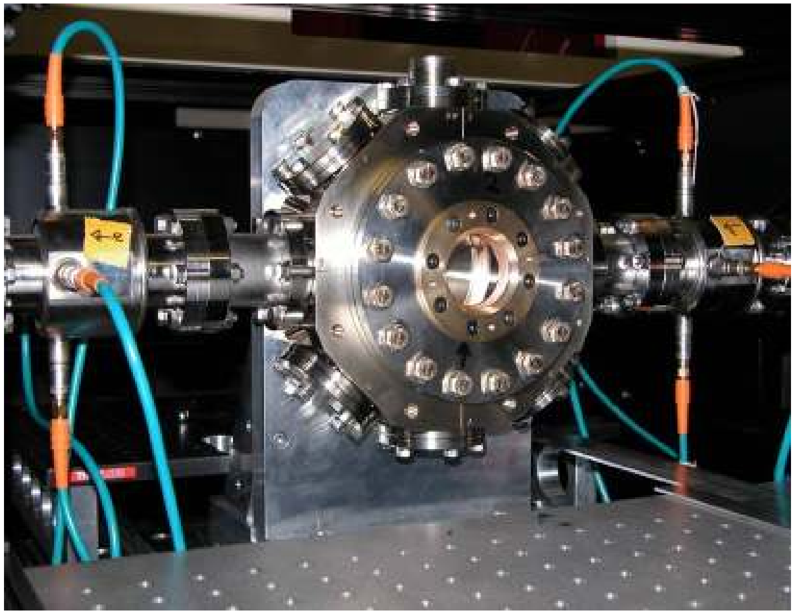


PETRA II



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

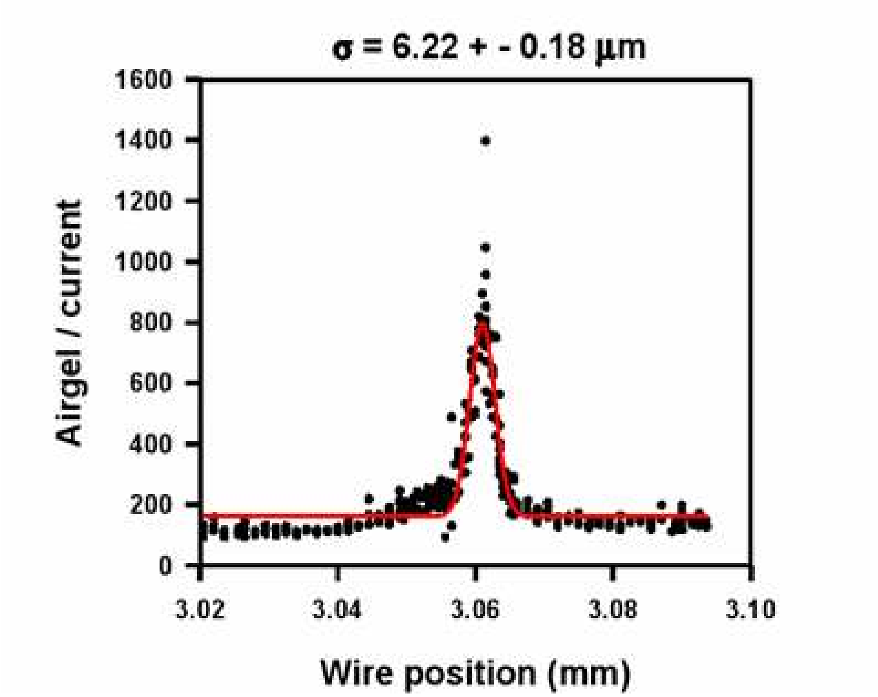
ATF LW



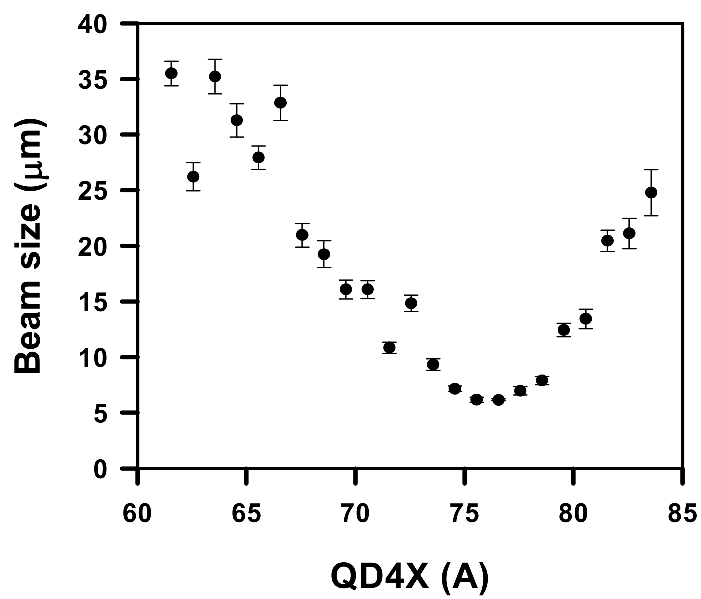
Tests of f_2 lens system currently underway at Oxford

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.

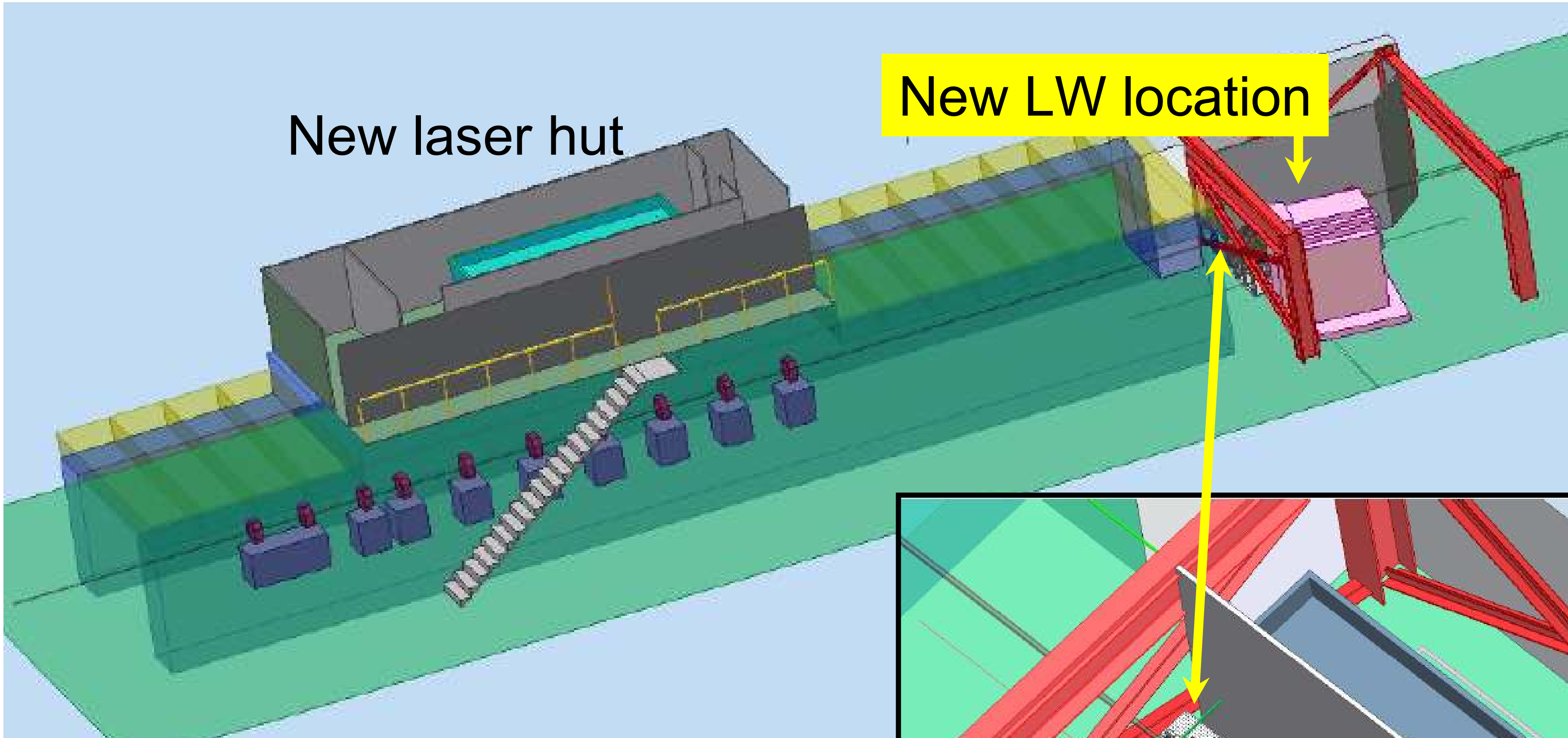


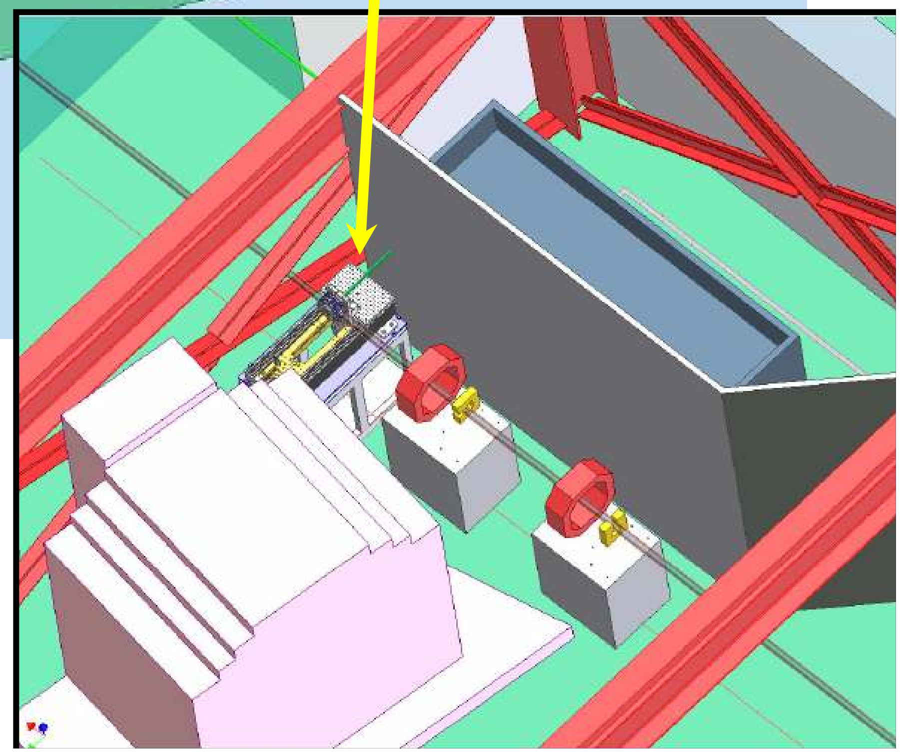
single LW scan



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

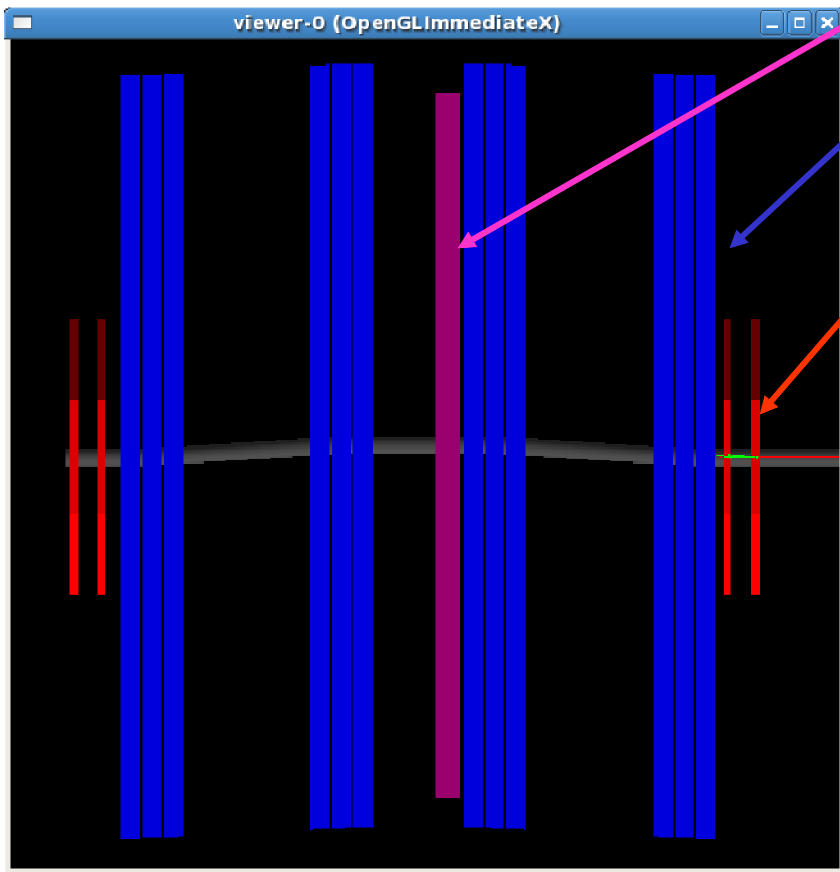
P. Karataev

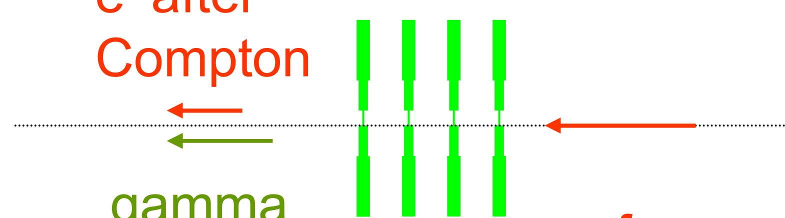
LW-IP (1)	LW-IP (2)
$\sigma_x = 20.43\ \mu m$	$\sigma_x = 20\ \mu m$
$\sigma_y = 0.9\ \mu m$	$\sigma_y = 1.14\ \mu m$

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

BDS
Laser Wire Electrons

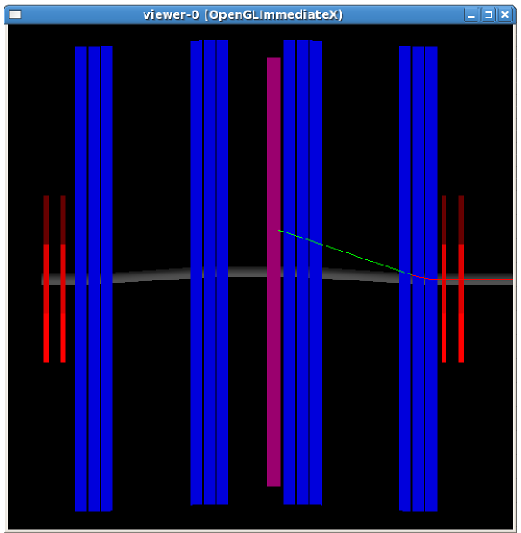
Simulated using BDSIM

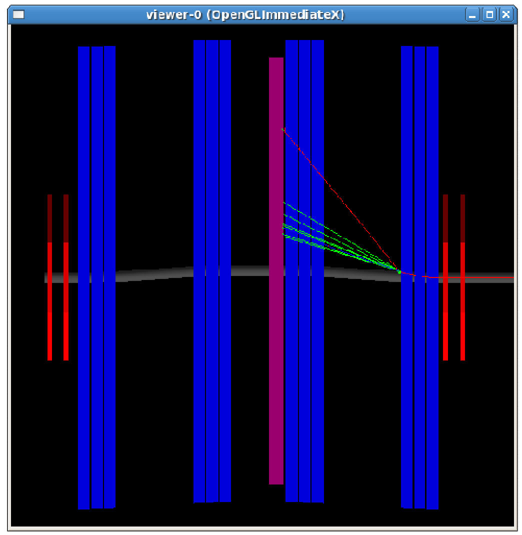


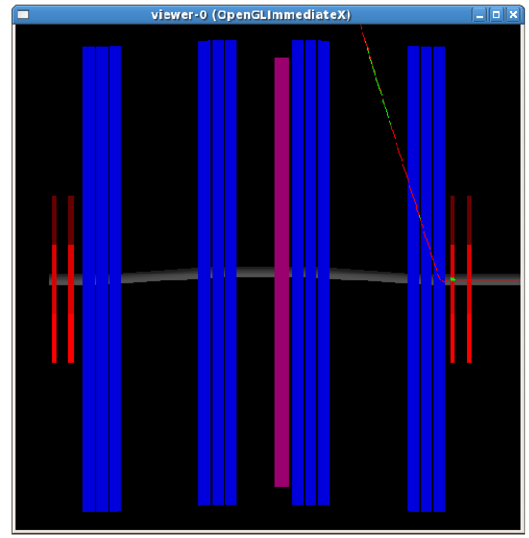


L. Deacon

Laser Wire Electrons
no vacuum window



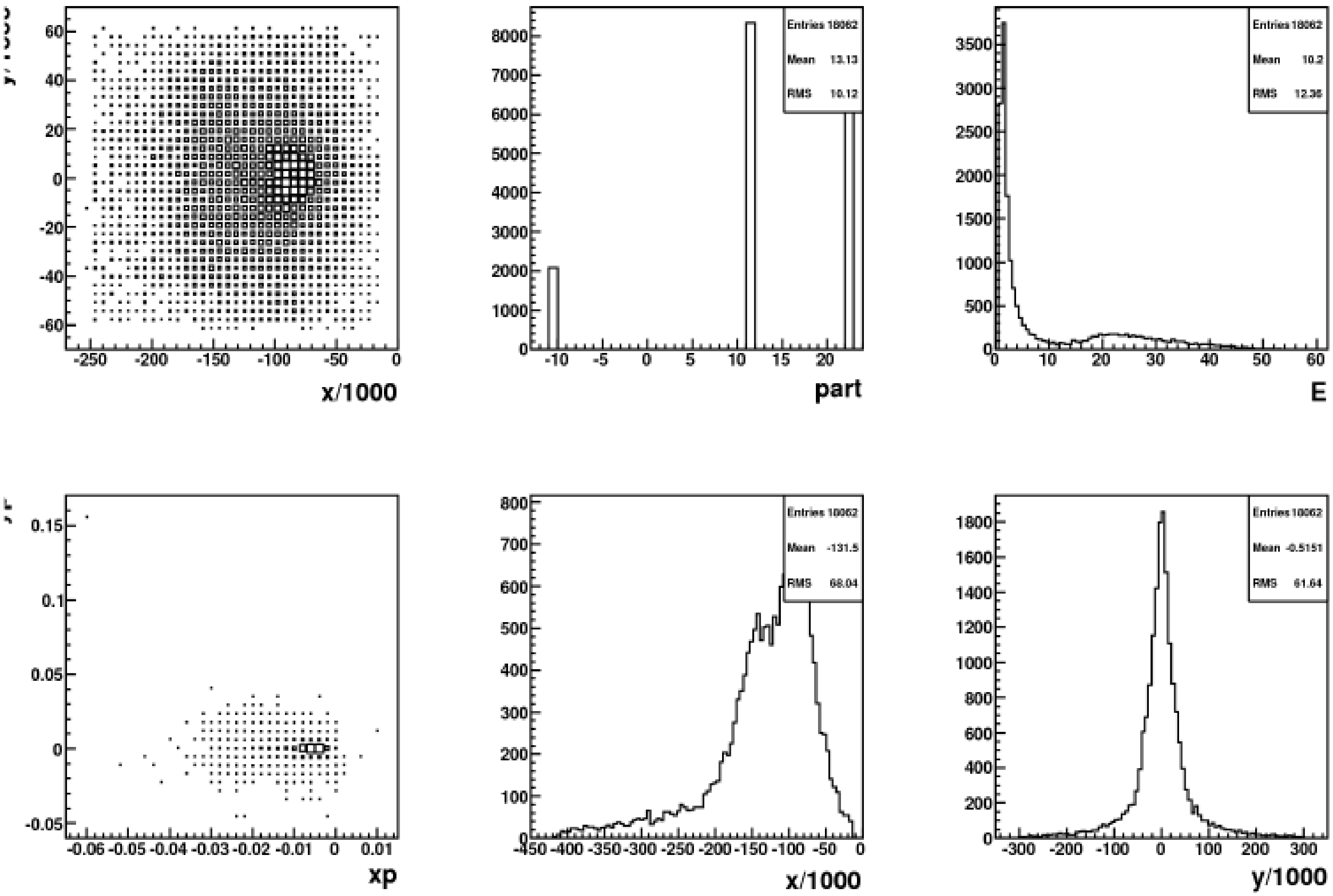




Showering in beampipe seriously degrades the signal
A vacuum window, similar to that foreseen for polarimeter will be included in future simulations
Such a window is clearly needed

L. Deacon

Laser Wire Electrons
no vacuum window



L. Deacon

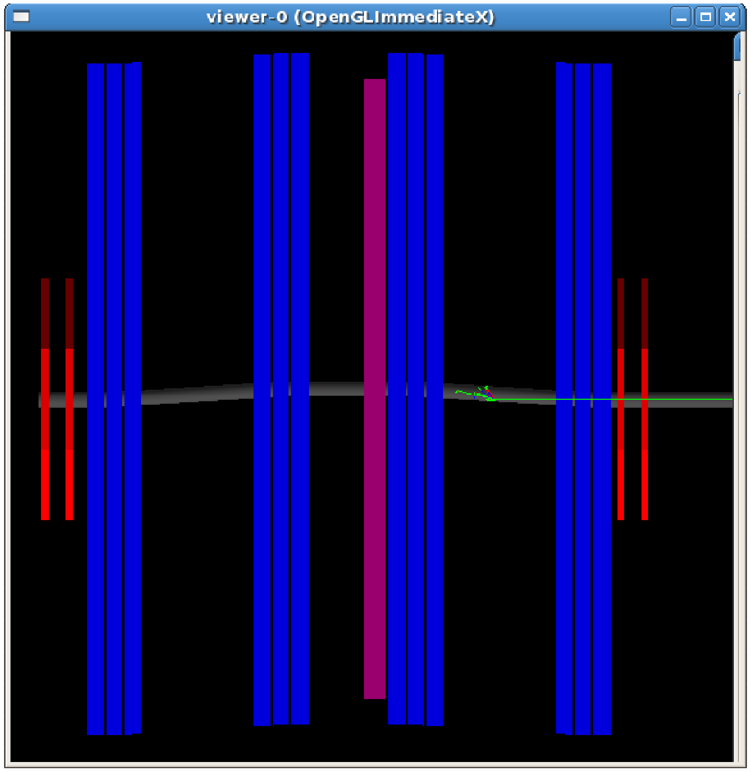
Laser Wire Electrons
no vacuum window

- 10 trials, 1000 compton events per trial. Results:
- Mean energy = 1830 GeV
- Mean number of particles = 554
- RMS energy = 566= 30%
- RMS number of particles = 168 = 30%

L. Deacon

Laser Wire Photons
no vacuum window

- Particles have to go through beam pipe at small angle so they have to pass through a lot of material
- Illustration: particles shower inside beam pipe

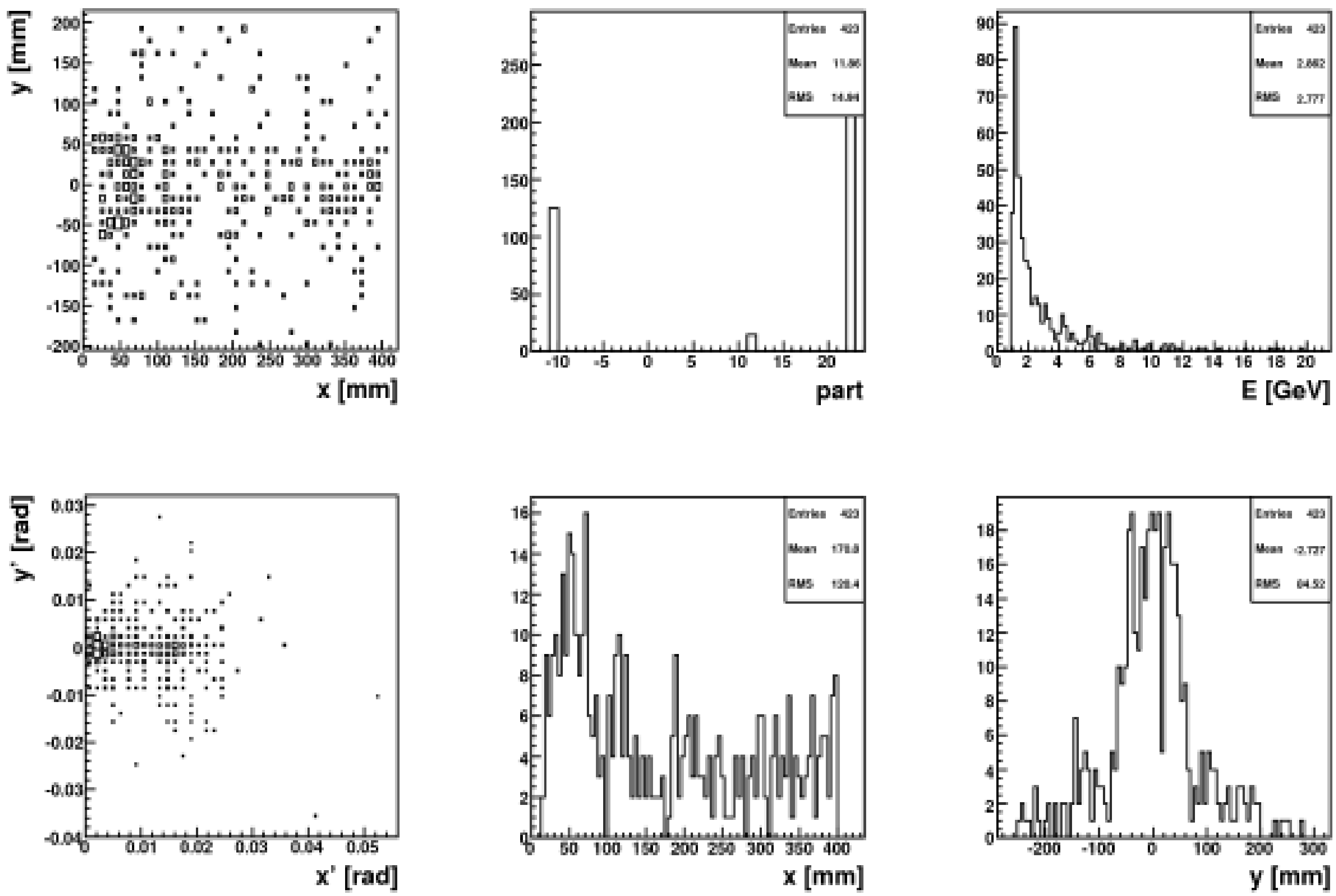


A vacuum window is also required – but space is very tight in this region: only a mm or two of clearance between Compton photons and beampipe

L. Deacon

Laser Wire Photons

no vacuum window



L. Deacon

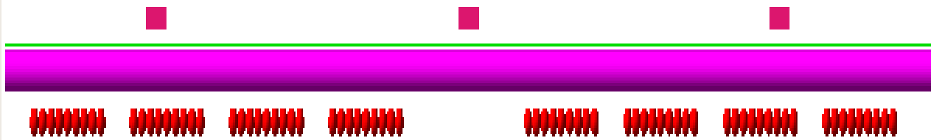
Laser Wire Photons
no vacuum window

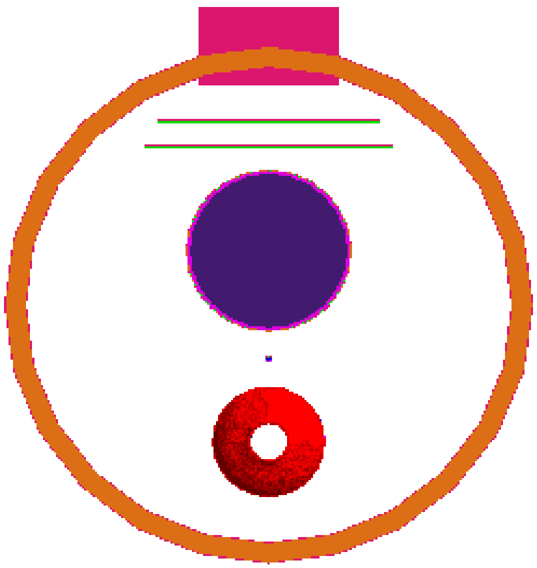
- 10 trials, 1000 compton events per trial. Results:
- Mean energy = 388 GeV
- Mean number of particles = 254
- RMS energy = 172= 44%
- RMS number of particles = 113 = 44%

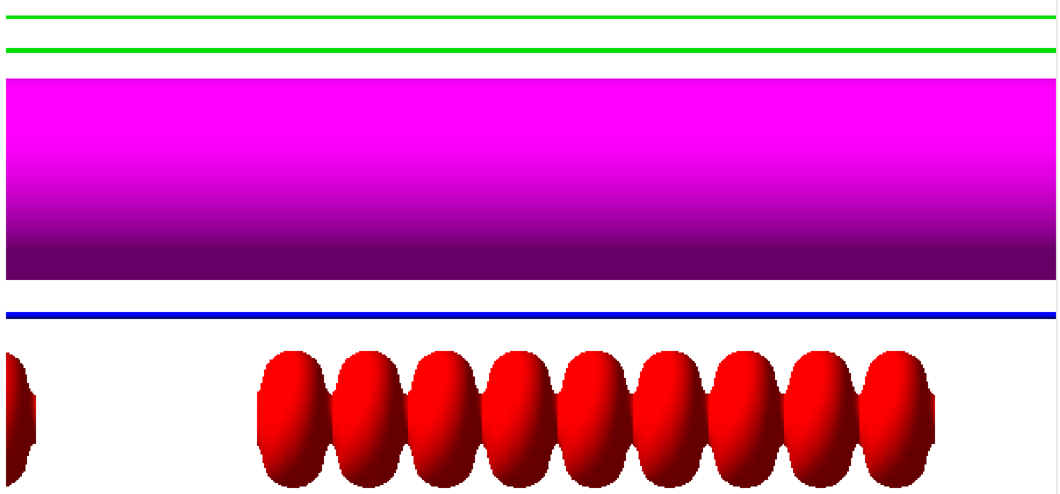
L. Deacon

Linac Module

- The ILC linac module has been modelled in BDSIM

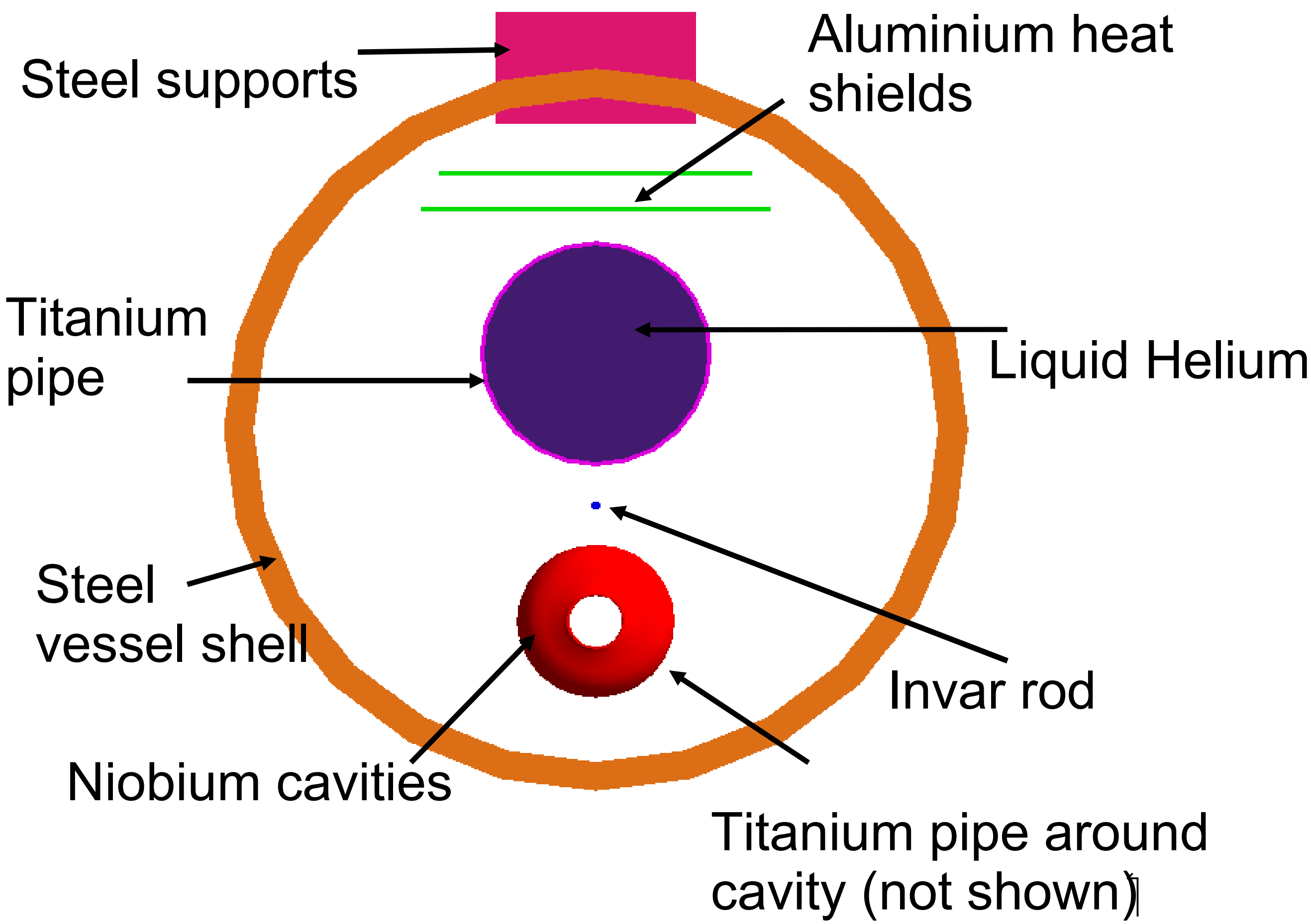




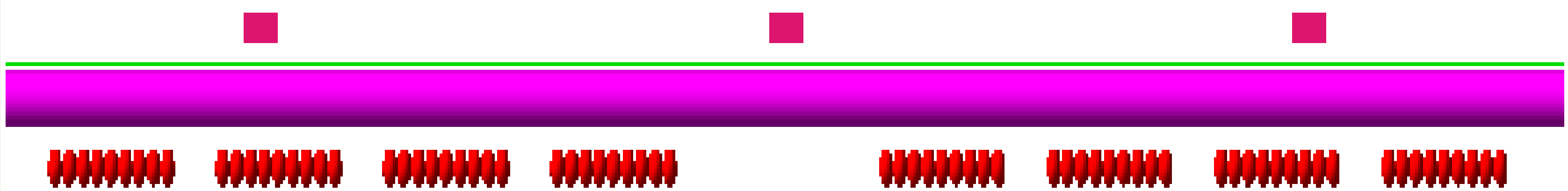


L. Deacon

Linac Module



- Length 12.5m
- 8 sets of 9 cavities

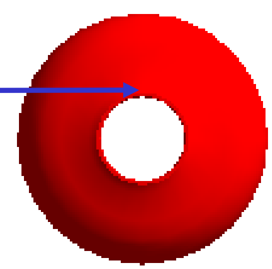


L. Deacon

Linac

- The linac comprises a string of these modules with vertical dipoles between them. Linac follows Earths curvature.
- Preliminary results for laser wire signal extraction: assuming particles can be detected once they exit the cavity (y>34mm), largest signal is obtained by placing a detector after the 51st cryomodule, z ~ 650m
- End plate of 4cm steel was set in front of detector.
- For 2×10^{10} electrons per bunch, total extracted energy per bunch is $(3.2 \pm 0.3) \times 10^{10}$ GeV
- Initial energy per bunch ~ 2.5×10^{12} GeV, so ~ 1.3 % of the signal energy is extracted

Particles detectable above this line



L. Deacon

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.
  - ILC linac studies have started; signal extraction is an issue