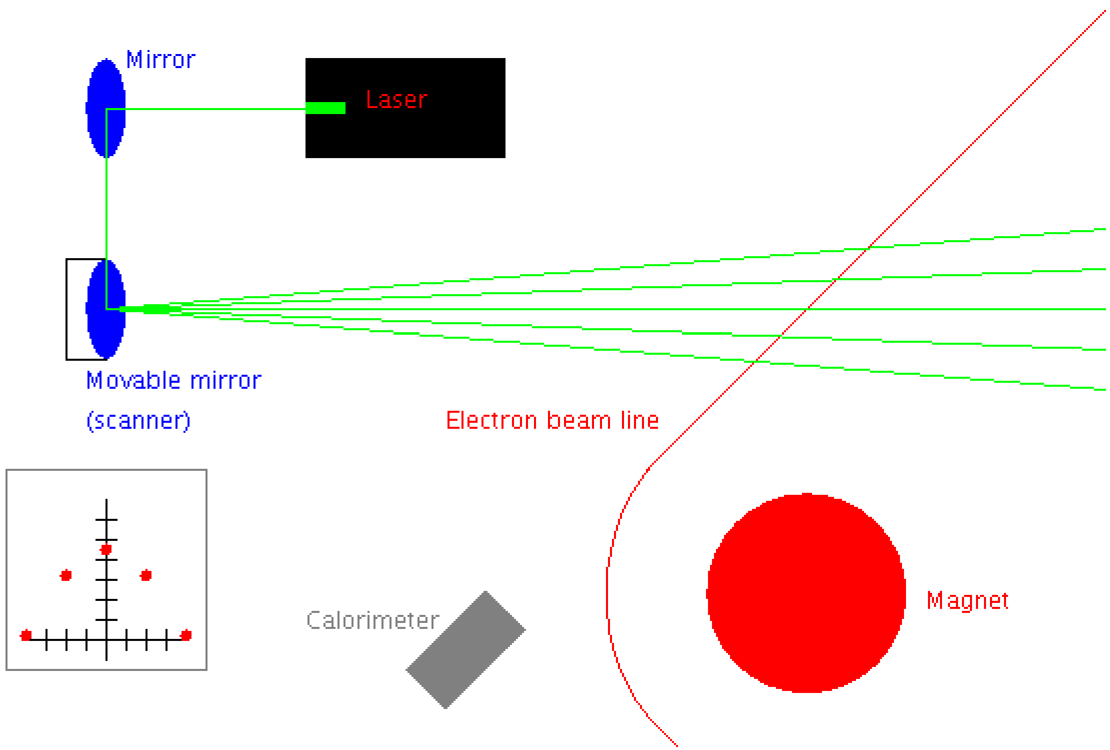
A fiber laser for laser-wire measurements

- Laser-wire
- Laser requirements
- Laser tender
- Laser strategy

A laser to produce Compton photons at the ILC

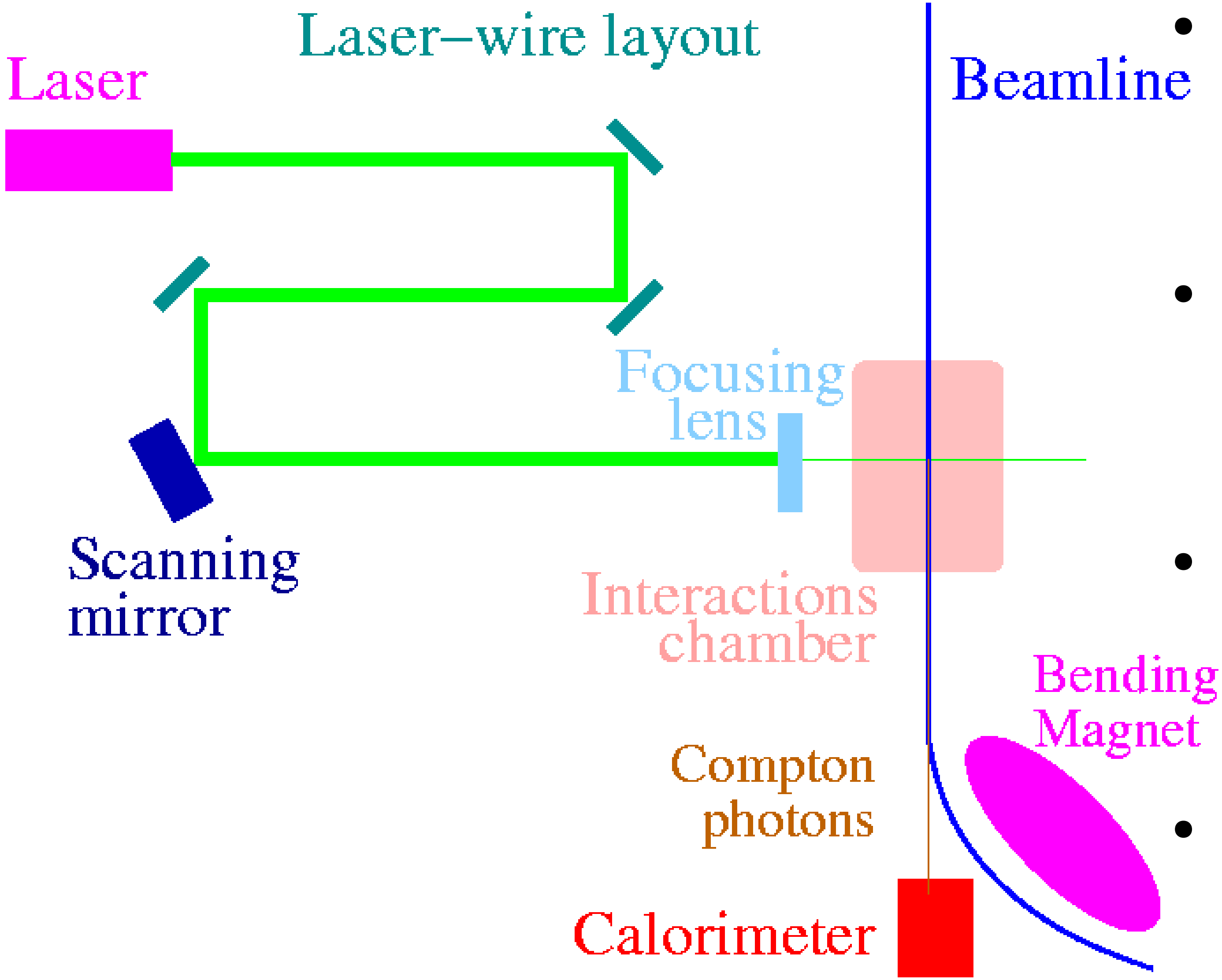
- Like in polarised positron production, Laser-wire measurements require a high power laser to produce Compton photons
- During the past year we looked at what exists on the market and what could be done to get the best possible laser for an ILC laser-wire.

What is a laser-wire?



- A laser-wire scans a laser beam across an electron beam (at 90°) to produce Compton photons...
- This provides a profile of the electron beam and allow to measure its emittance.
- More than 70 laser-wires are foreseen at the ILC (depends on our R&D results)

Components needed to build a laser-wire



- Laser "wire" quality depends on laser quality
- Strong Focusing lens => Monochromatic (very low bandwidth)
- Particle accelerator => need good synchronisation
- Need a very good laser...

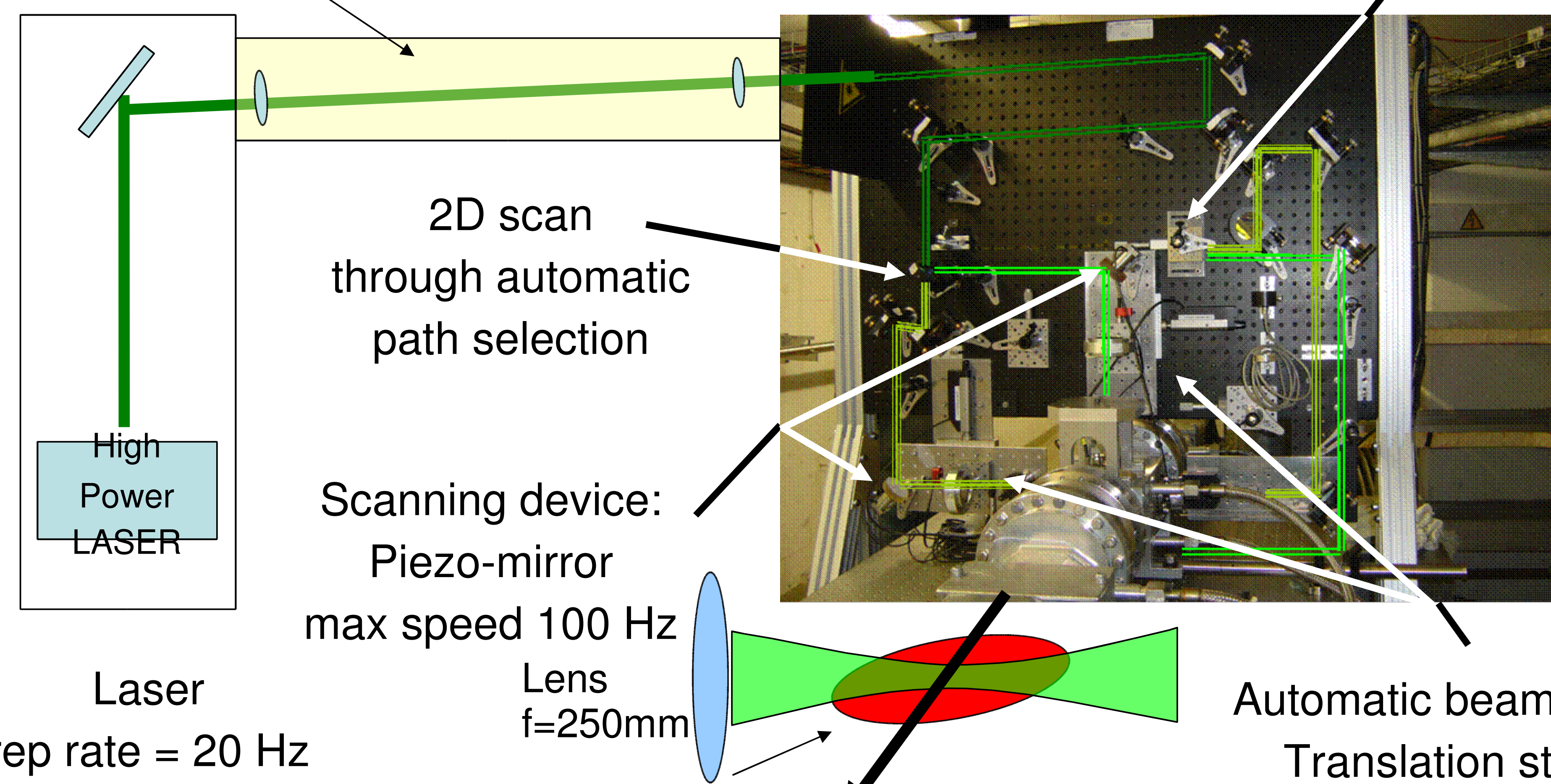
Laser-wire prototypes

The UK groups have developed 2 prototypes:

- A prototype at PETRA to study fast scanning and 2D scanning
- A prototype at the KEK ATF extraction line to demonstrate that micometre resolution can be achieved.

The experience gained from these prototypes will be used to provide emittance measurements at PETRA III, at the ATF2 and at the ILC.

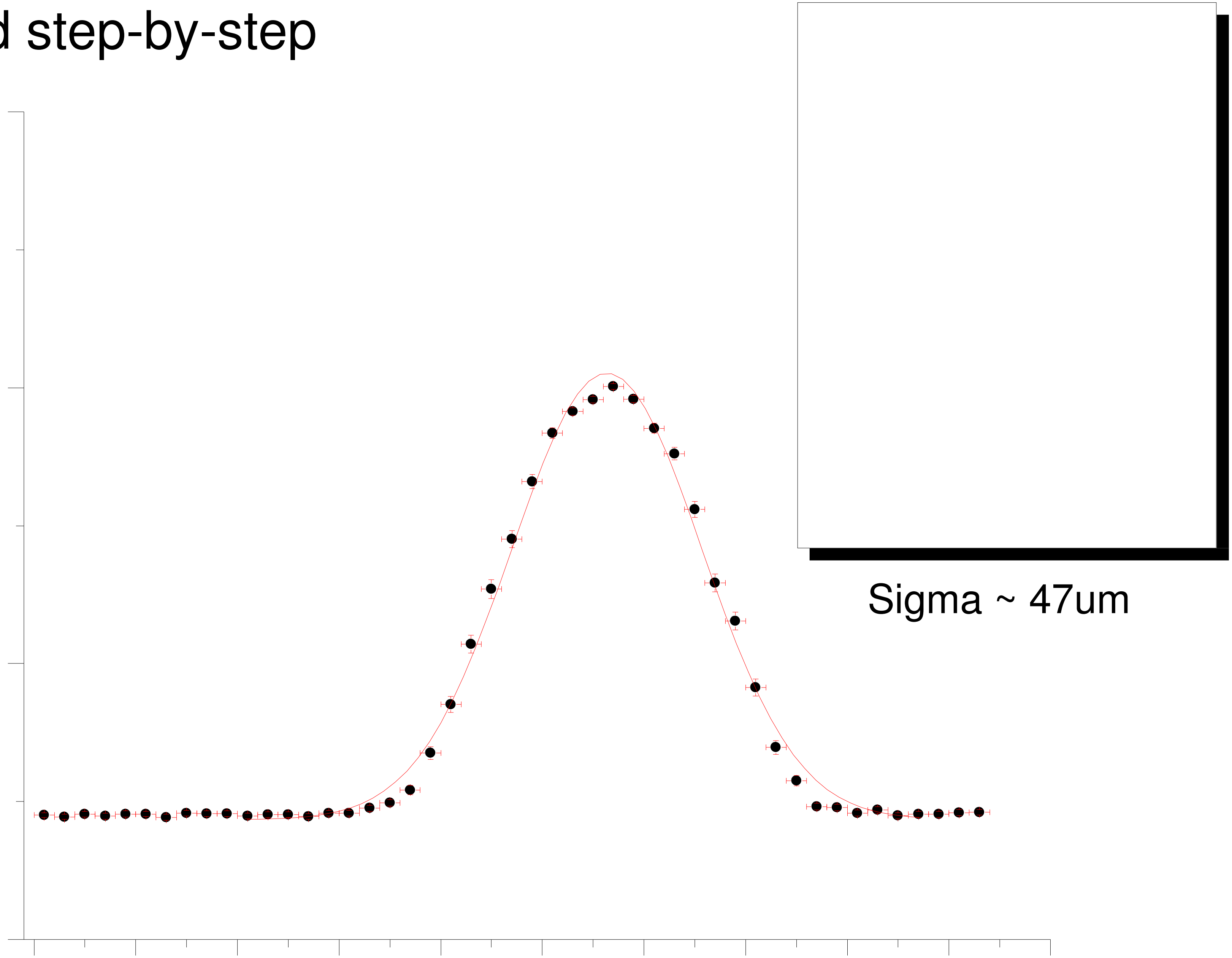
2D LW scanner at PETRA



Slide by M. Price, A Bosco et al

Seeded (100 steps, 100 points per step) 10,000/20Hz = 500sec

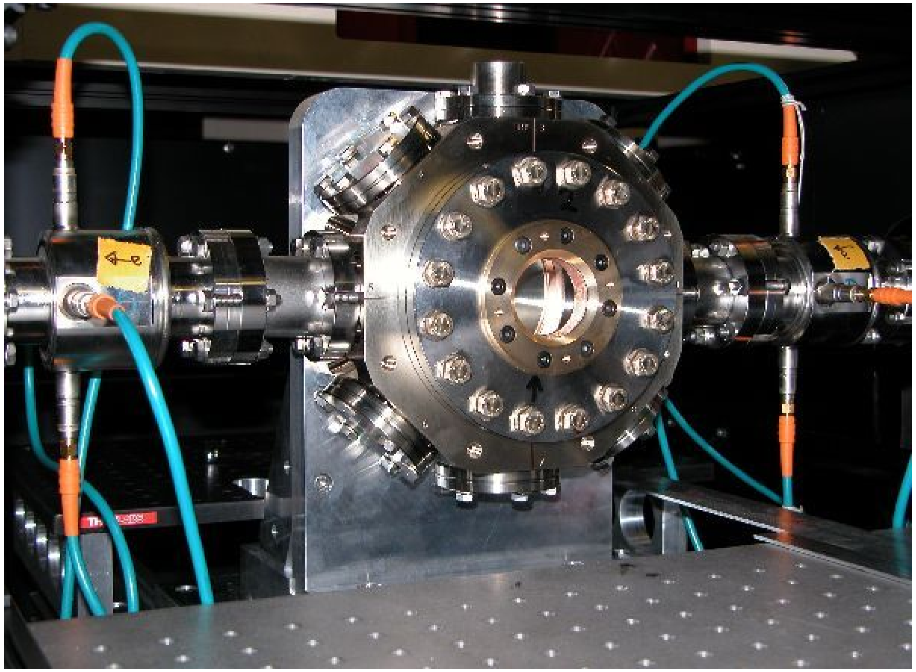
Averaged step-by-step



Sigma ~ 47um

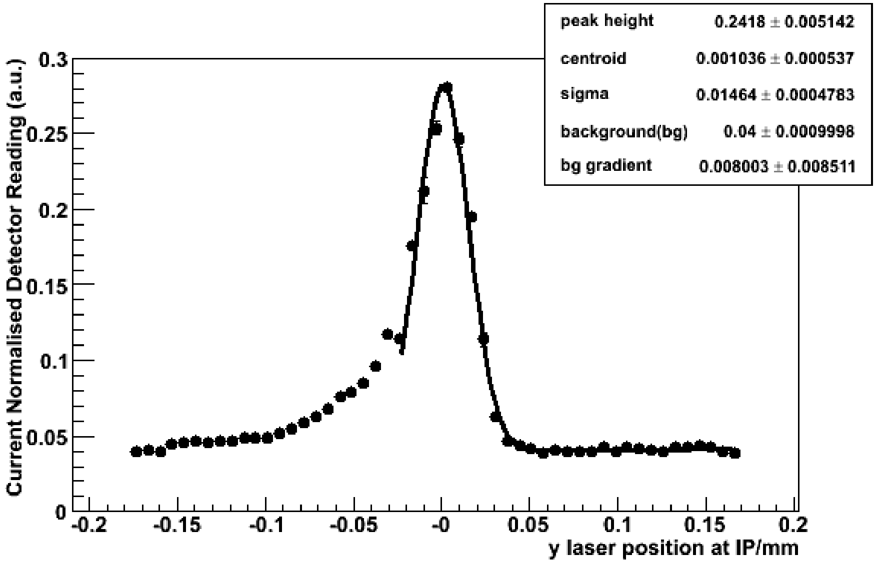
M. Price, A Bosco et al

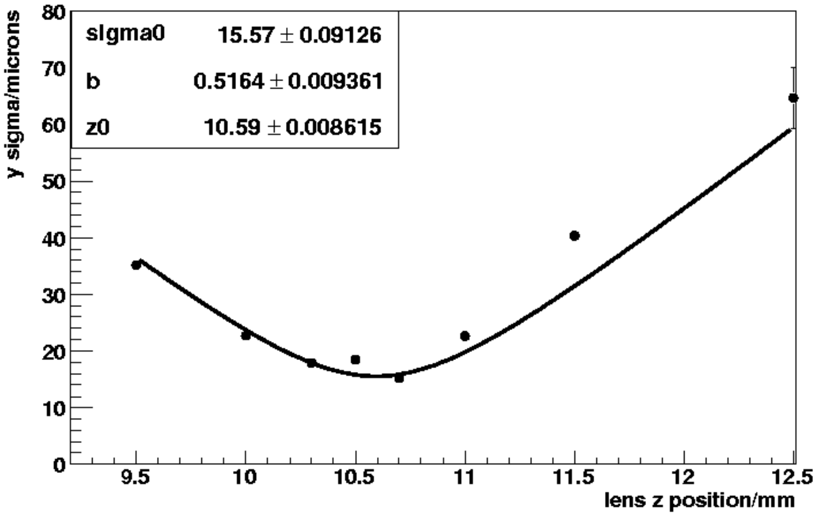
ATF Extraction line laser-wire



- Installed in the extraction line of the Accelerator Test Facility at KEK
- Goal: demonstrate um-scale resolution in a single pass system
- System successfully installed and tested last year.
- Strong focusing lens will be installed this year to reach micrometre-resolution.

ATF LW results (spring 2006)





- Obtaining Compton photons at the LW IP is a 2D problem: photons and electrons must overlap in time (within 200ps) and space (vertically, within 20um)
- First collisions observed in April 2006.
- Measured beam size compatible with our expectations.
- Scan asymmetry due to lens aberrations
- Laser M^2 ~ 2.9

Our laser experience so far...

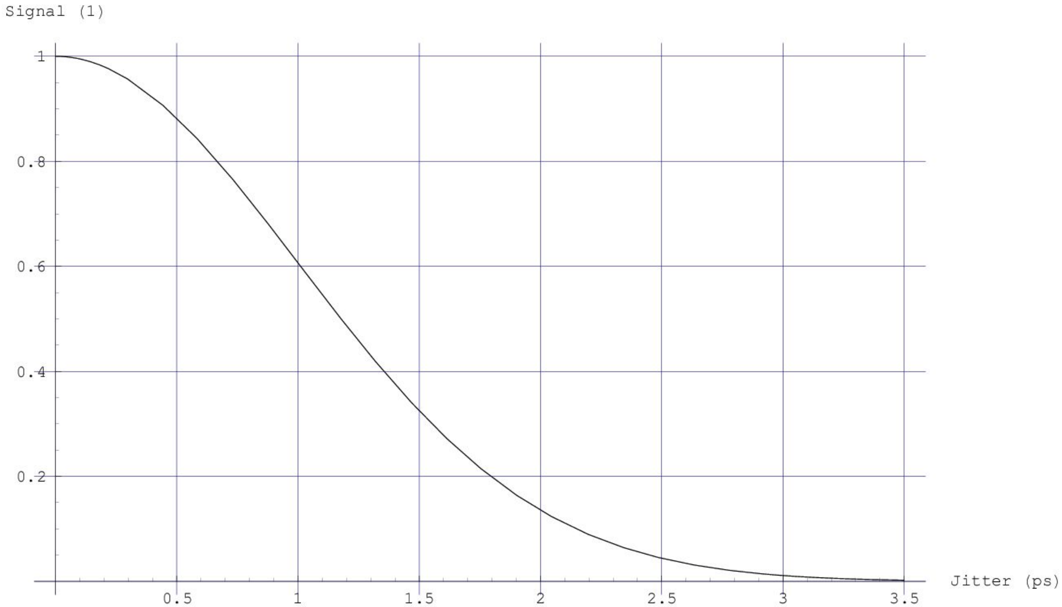
- For both prototypes the laser has been a limiting factor:
  - bad beam quality reduces the LW resolution
  - Laser breakdowns have resulted in significant down times
- For the ILC we need a laser more reliable and with a better beam quality than what is currently available on the market!

Our laser requirements

- Good beam quality: M^2 <1.2
- High Power (to create enough Compton photons):
  Need 50 MW during at least 1ps
- Stable:
  - Good pointing stability (<0.1 x Diffraction limit)
  - Pulse to pulse stability < 2% RMS
  - Long term stability: better than 5%
- Synchronisable to a particle accelerator:
  - Mode locked & synchronised to external RF source
  - Pulse timing jitter < 0.5 ps
  - Tunable repetition rate with good tuning resolution
  - "Train" pulse structure: 1ms trains of pulse @6.5MHz; trains at 5Hz
- Wavelength: 1053nm but open to other suggestions

Laser synchronisation

- Having our laser well synchronised with the particle beam is critical!
- The 2 beams interact at 90° => short temporal overlap window.
- An average jitter of 0.5ps leads to a loss of 12% of our signal.
- If the jitter becomes 1ps, we loose 40% of our signal!!!
- Goal: ~-100dBc/Hz at 100Hz from carrier



- The accelerator is a long piece of metal
  => dilates/contracts
  => Need good tunability

Wavelength choice

- The Compton process has no strong dependance on the photon's wavelength.
- Creating small laser “wire” is easier with shorter wavelength
- Shorter wavelength can be created either directly or with SHG/FHG crystals. The later is more efficient.
- To achieve a resolution of 1um (required by the ILC) with a 500nm beam, a F/1 lens is required (difficult but achievable).
- So our wavelength choice was dictated by amplifying mediums available to go to high power with good beam quality.
- Our choice was 1053nm [Nd:YLF] but we were open to other suggestions.

Laser tender

- Last spring we initiated a world-wide tender for the first stage (50kW - 1 MW) of a laser matching our requirements.
- Several companies replied with a wide array of prices and solutions.
- Offers could be divided in 2 categories:
  - Traditional bulk systems
  - Fibre systems

Bulk systems

- Bulk lasers are more established and offered by well established companies.
- Some of the systems offered were mass-produced and thus very reliable (turn key & high MTBF).
- The pulse energy was often not very high (few nJ only)
- Synchronisation of bulk oscillators is well established.
- Most offers had a wavelength of either 1064nm or around 800nm, no true 1053nm (Nd:YLF) oscillators.
  => concerns on the beam quality when amplified to 50MW.

Amplification of bulk systems

- See presentation by Sudhir Dixit at POSIPOL'06
- Nd:YLF amplification seems to be the most suitable to give a good beam quality.
- Nd:YAG suffers from higher thermal effects (especially at high powers) => lower beam quality & pointing stability issues
- Ti:Sapphire requires multiple stage pumping which may create reliability and efficiency issues.
- Pointing stability of Ti:Sapphire is also an issue.
- *None of the bulk system offers we received had a clear path toward high power with good beam quality at an affordable cost.*

Fibre systems

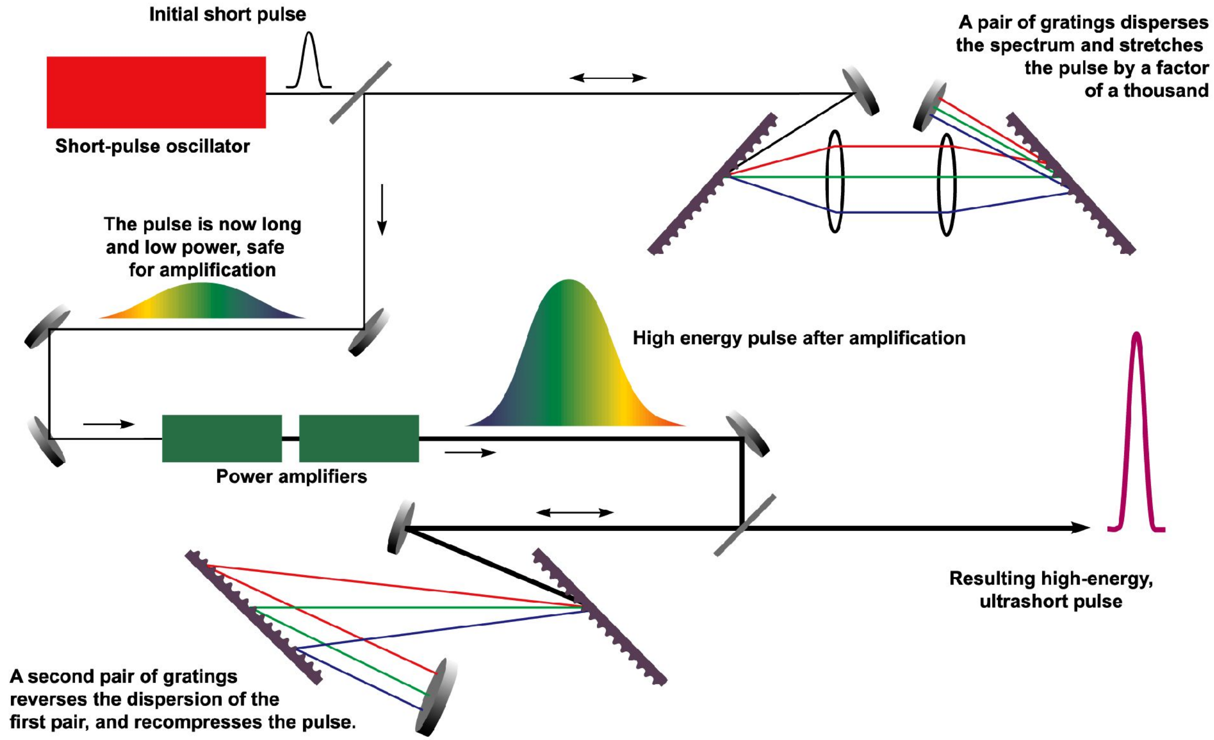
- Only smaller companies offered fibre systems
- Such systems offer a much better beam quality
- Synchronisation of fibre systems is less established (especially with Ytterbium doped fibres) but can achieve very low noise levels (few fs).
- It is also possible to build an hybrid system (bulk oscillator with a fibre pre-amplifier).
- Fibre systems are cheaper than bulk systems and require less maintenance (less alignment to do, more compact, ...).

Fibre systems (2)

- Telecom wavelength fibres are very cheap but not suitable for high power amplification.
- With Ytterbium doped fibres the preferred wavelength is around 1030nm.
- For Nd:YLF (bulk) amplification operating a fibre laser at 1053nm is possible but inefficient
- Got offers at 1030nm and at 1053nm.
- Amplification to High power at 1030nm seems possible with dedicated fibre amplifier.

Amplification of fibre systems

- See talk by Y. Zaouter
- Fibre can not directly amplify short pulses to high power => Chirped Pulse Amplification is needed



Fibre amplification (2)

- Not all laser pulses are suitable for amplification
  =>Spectrum must be suitable
  =>There is a limit on the stretching that can be achieved during CPA
- Travel in fibre introduces dispersion
  => Need to amplify in a short length of fibre to keep a good pulse quality.
  => "standard" fibre will not produce good beam quality at high power.
  => Need to use photonic crystal fibre

Some issues to look at with fibre lasers...

- External synchronisation is not yet supported by most companies (market is very limited) but well-synchronised fibre oscillators have very low phase noise.
- Some companies are looking for big markets (spectrometry, ...).
  Particle Physics is not seen as a big market
  => some companies are very reluctant to work on a custom system (train structure, RF synchro.)

Some issues to look at with fibre lasers... (2)

- Wide bandwidth can lead to significant loss during further amplification.
- Not all pulses are suitable for further amplification (SPM) so all oscillators delivering 1MW at the same wavelength are not equal.
- Amplification to high power is still a research topic. Most companies are afraid to go beyond a few MW. PCF is a new technology
  => some companies consider it as not yet “mature”.

Other considerations...

- Our work should focus on building an accelerator tool, not on building a new laser (not our core skills) => need help from a laser company
- There are several years from now to the ILC so it is better to choose a promising new technology as it is likely to have become more mature by the time the ILC is built.
- Good beam quality, lower maintenance, higher MTBF are very important for the ILC Laser-wire.

Our choice

- We took 6 months to review the offers we had received.
- The offer made by Amplitude Systèmes was the most suitable for us.
- It is based on a bulk oscillator pre-amplified to 1MW by a mono-mode PCF (wavelength=1030nm).
- We will work jointly with Amplitude Systèmes on a PCF-based upgrade to 50MW.

Outlook

- For the ILC Laser-wires many lasers will be required to operate reliably at remote locations in a "noisy" environment (ground motion, RF/EM noise,...).
- Fibre systems are the most suitable for such application.
- We hope that a fibre system will give us a much better beam quality at high power.
- Today, there is no such system on the market.
  R&D will be done in collaboration with Amplitude Systèmes