ILC Laser-wires

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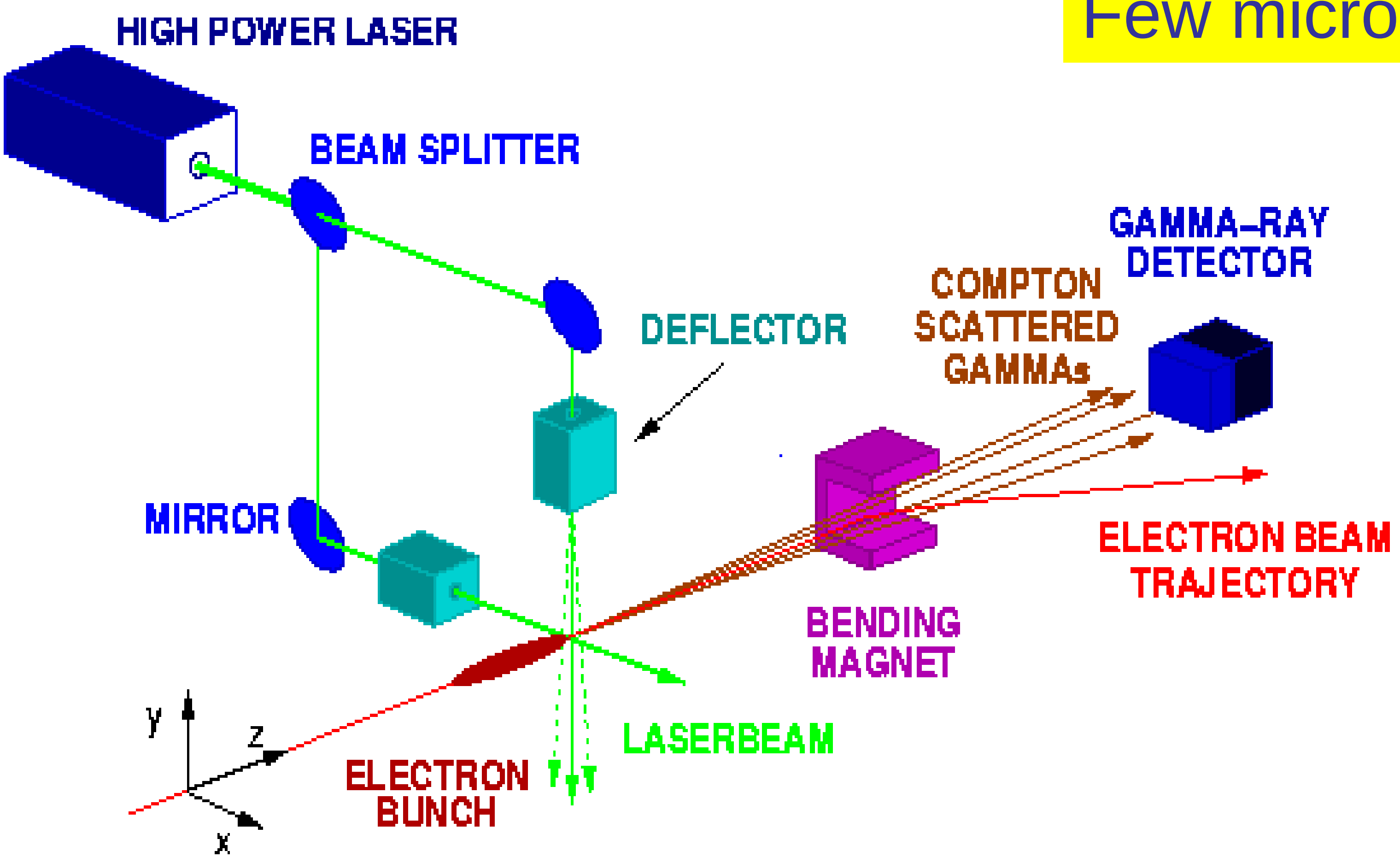
Snowmass

17th August 2005

- Introduction
- Energy regimes
- Signal Extraction
- Scanning techniques
- Laser requirements
- Light delivery
- Summary

Laser-wire

Few microns

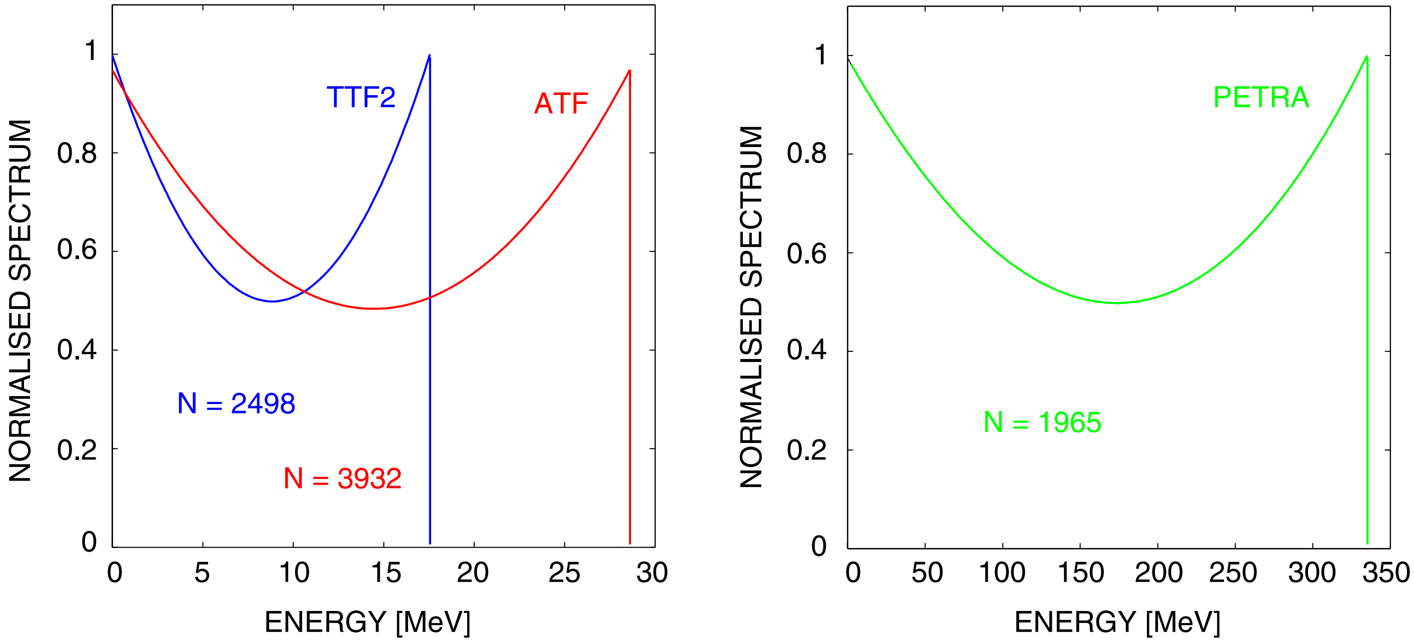


LW at damping ring

Compton photon spectrum for TTF2, ATF, and PETRA

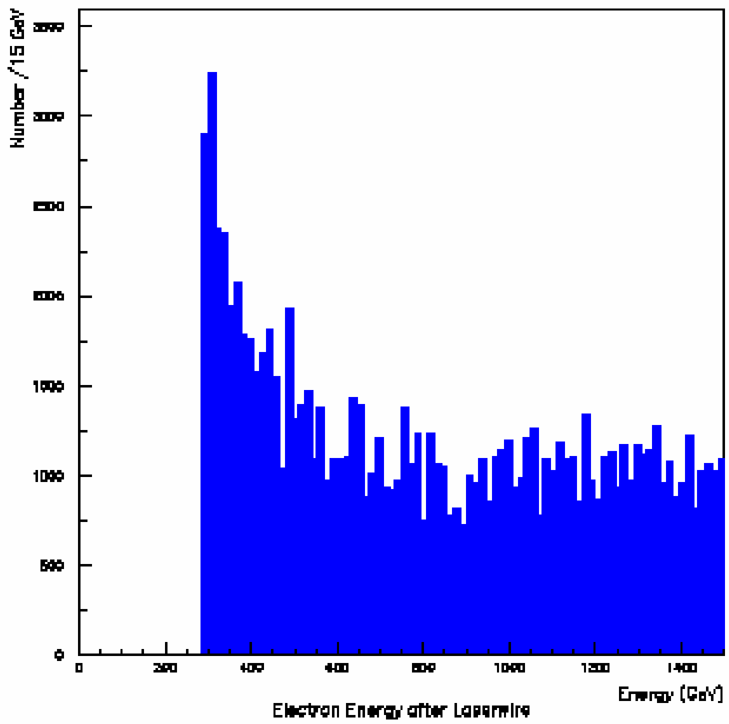
TTF2 (10 μm, 1 GeV), ATF (5 μm, 1.25 GeV), and PETRA (10 μm, 4.5 GeV)
Beam (electron beam size, beam energy)

Laser: wavelength 532 nm, 20 MW peak power, and 5 μm spotsize at IP

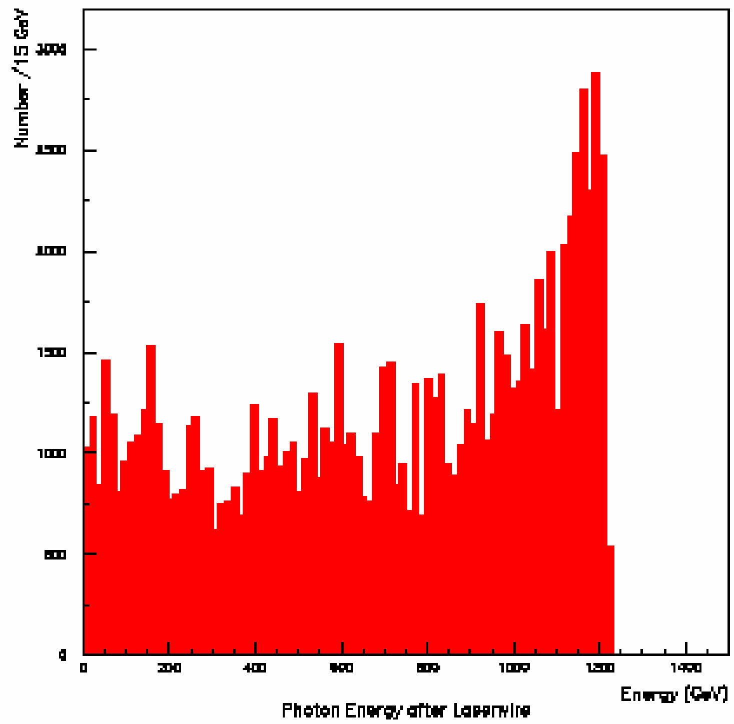


Compton photon energies

LW after LINAC (CLIC Energies here)

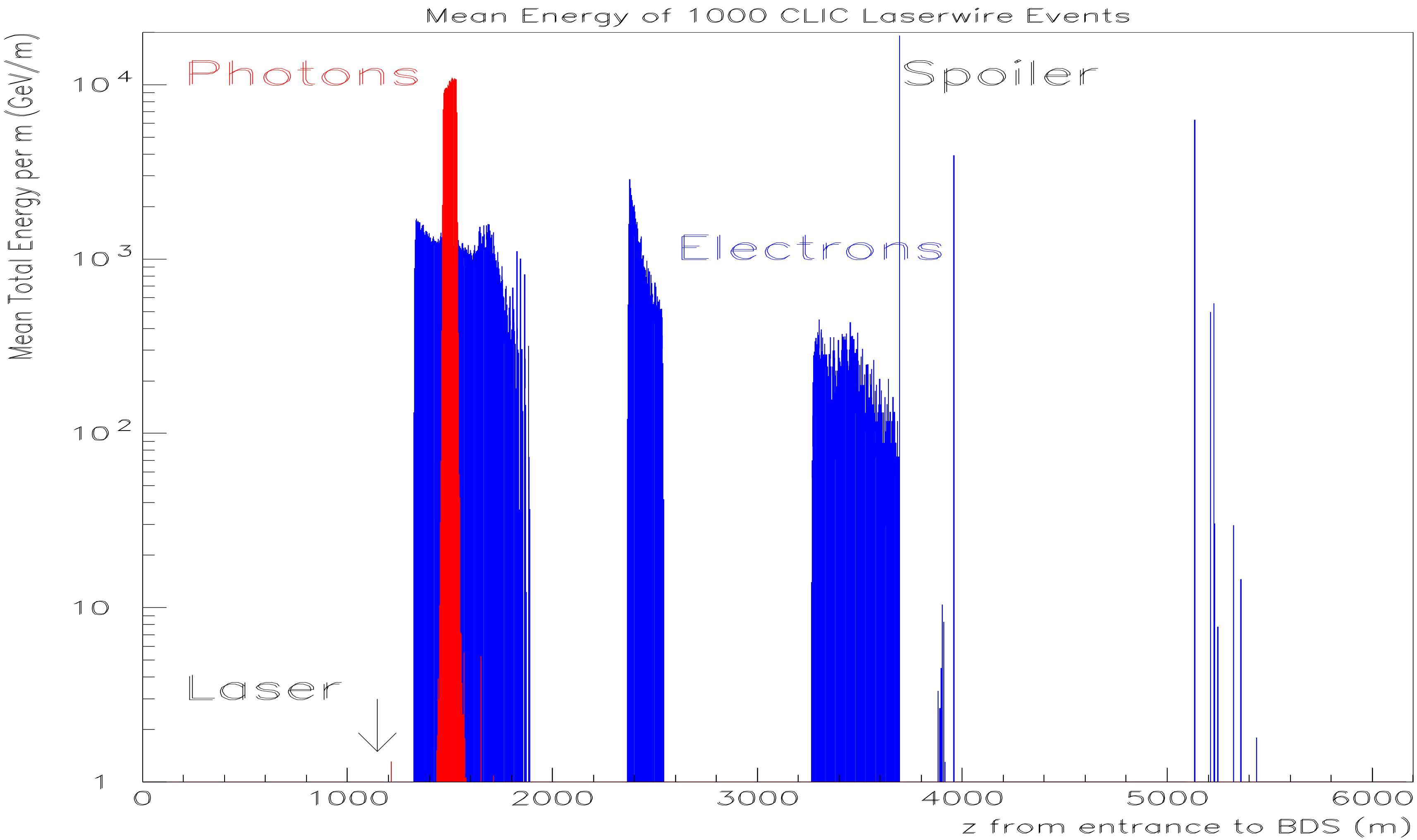


Compton Electrons



Compton Photons

Laserwire Simulation (CLIC)



Damping Ring

- Could use ATF-style CW laser-wire or a pulsed system.
- Curvature of ring makes extraction of photons easier.
- If a dog-bone solution – signal extraction in the straight sections would be problematic
- Lower energy photons – some problems with background are likely (cf ATF)

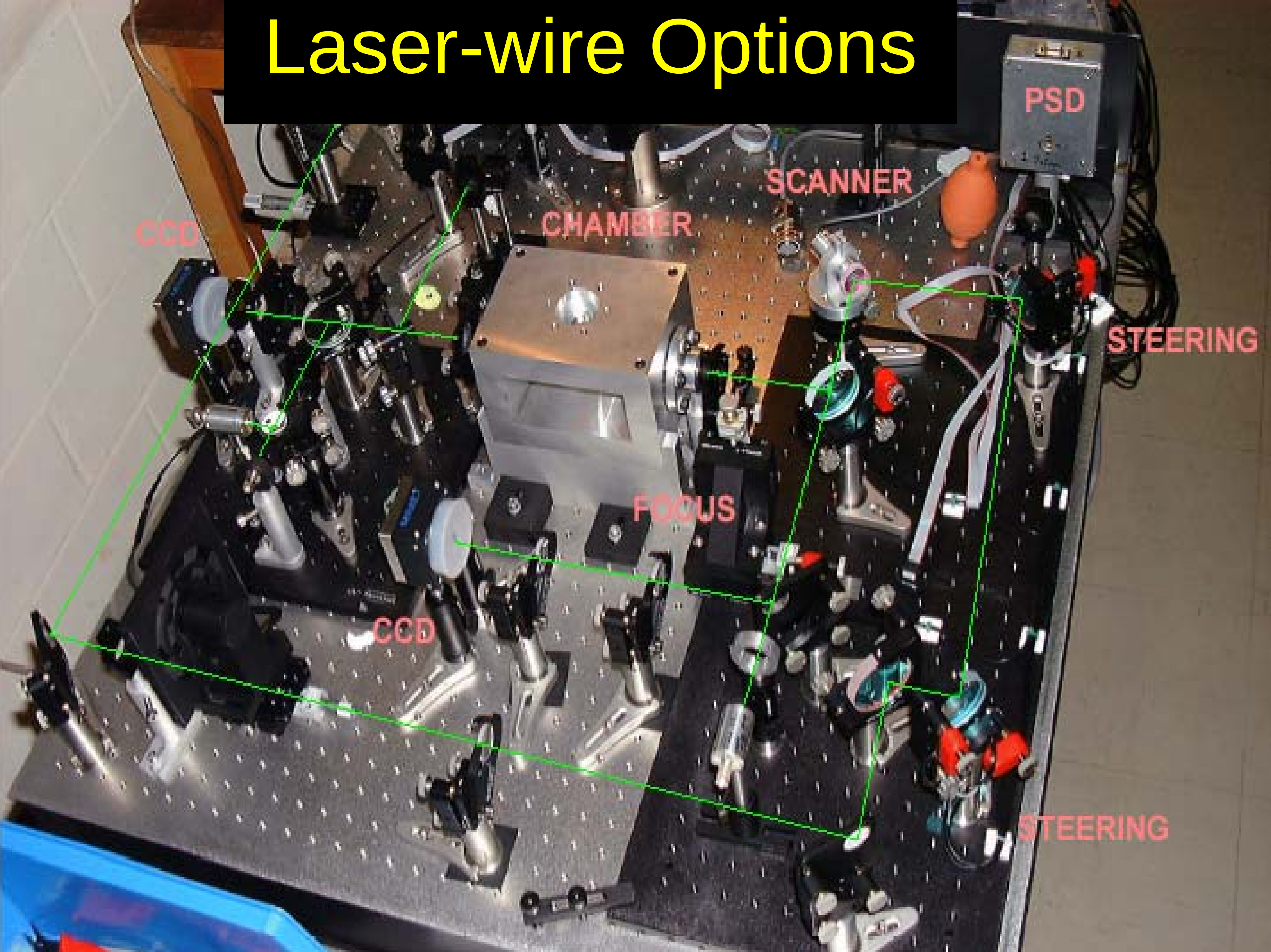
Linac

- Would need a pulsed system
- Probably don’t want extra chicanes (?)
- Could use degraded Compton electron signal – not optimal for accuracy.
- Also confusion as to which location gives rise to the signal. This would limit the number of lw stations in the linac.

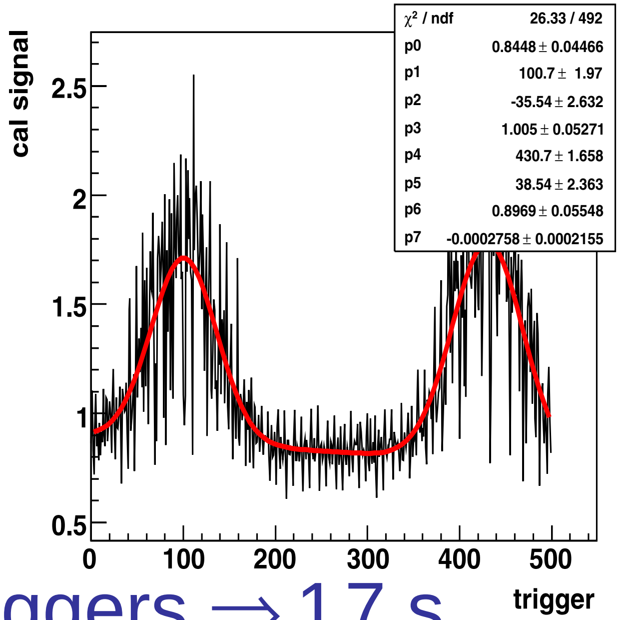
BDS

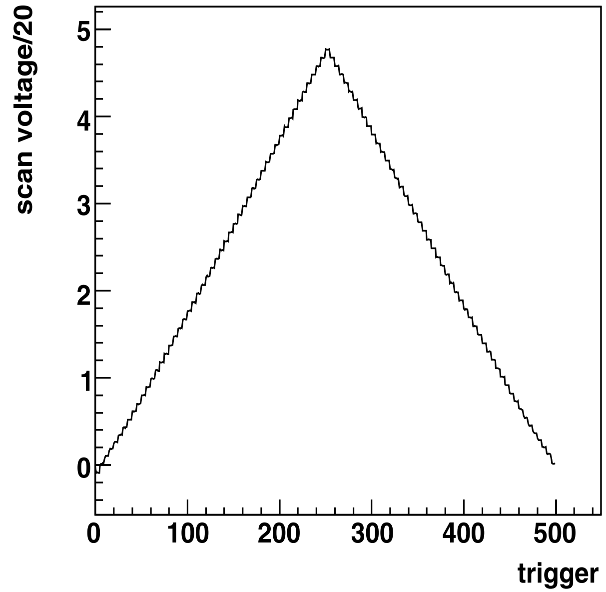
- Would need a mode-locked pulsed system
- Will need a chicane for signal extraction
- Best to use Compton photons for signal
- Intra-train emittance measurement is a goal.
- Best to avoid the collimation region because backgrounds are high there; a dedicated diagnostics section is required.

Laser-wire Options



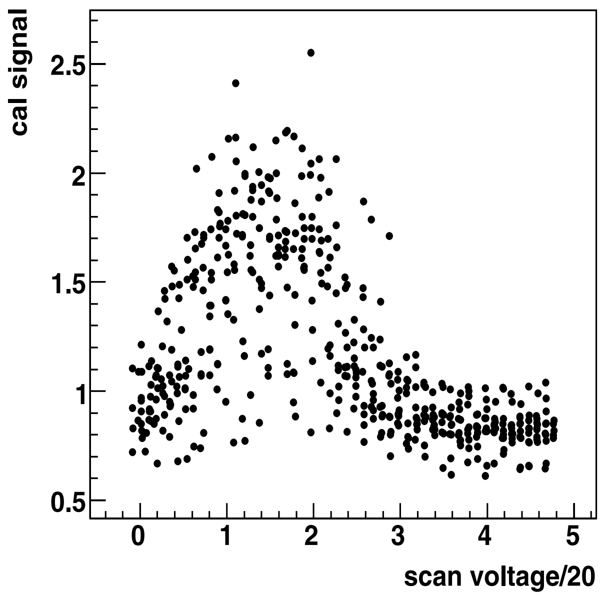
Raw cal. signal

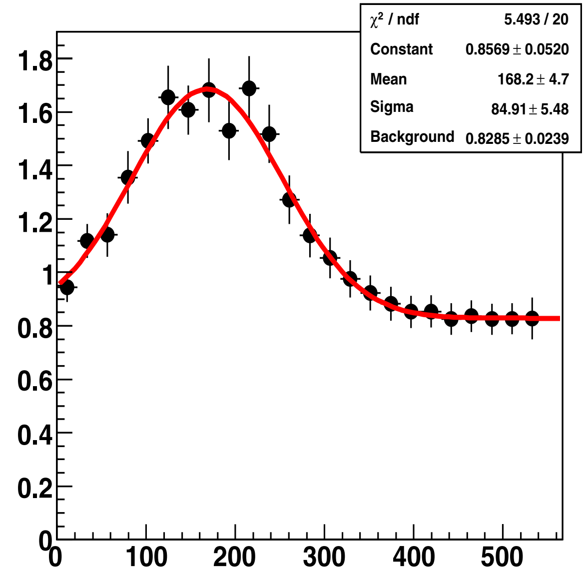




Piezo voltage (angle)

500 triggers ⇒ 17 s





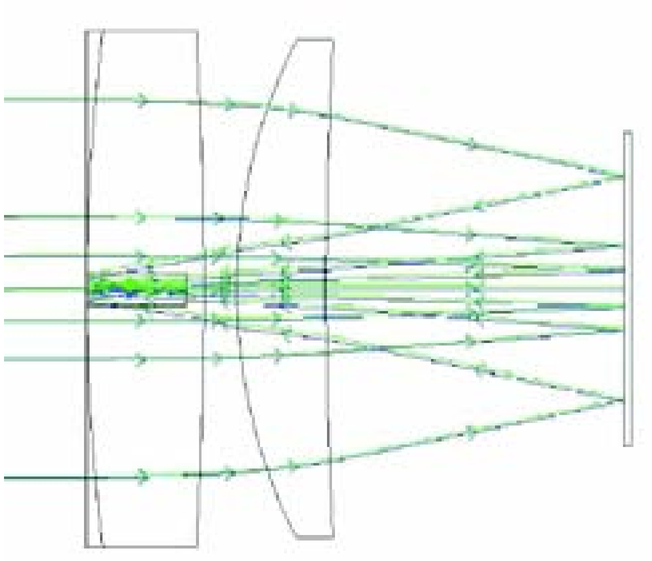
$\mu=168.2 \pm 4.7$
$\sigma=84.9 \pm 5.5$

Will improve with injection seeding

S. Malton

Pulsed: Practical Considerations

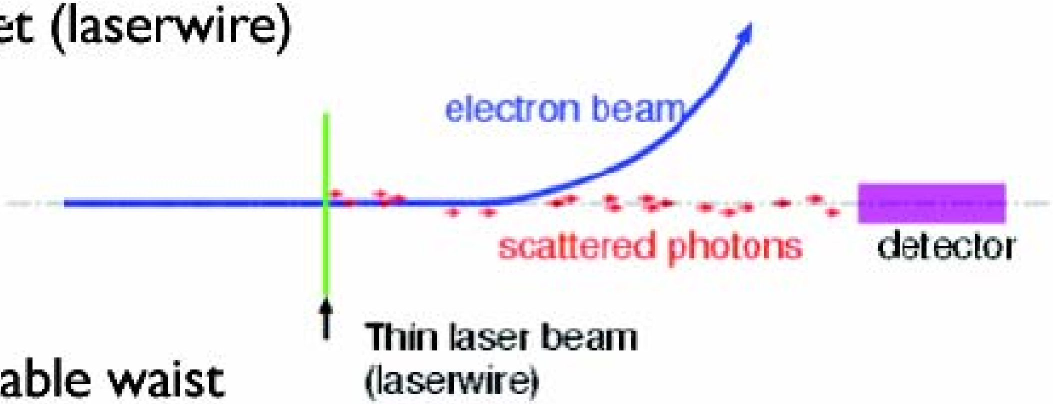
f1 geometry is challenging
- Limitations from power
- Limitations from angle
- Surface optical quality
- Alignment tolerance

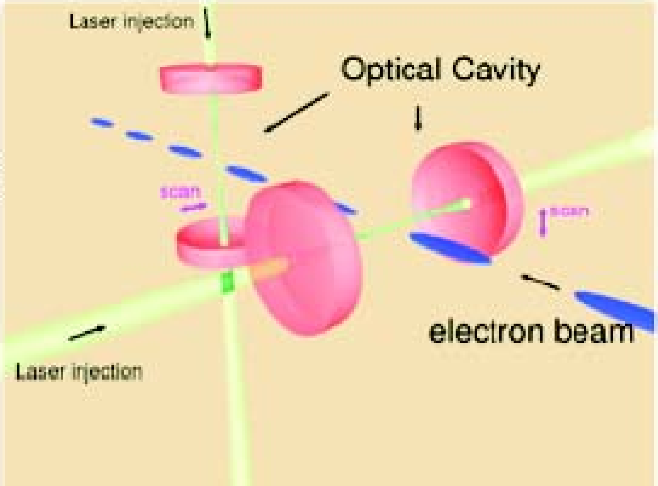


f1 Lens design is challenging
- Limitations from power
- Limitations from ghost images
- Alignment tolerance

Laserwire with an external optical cavity

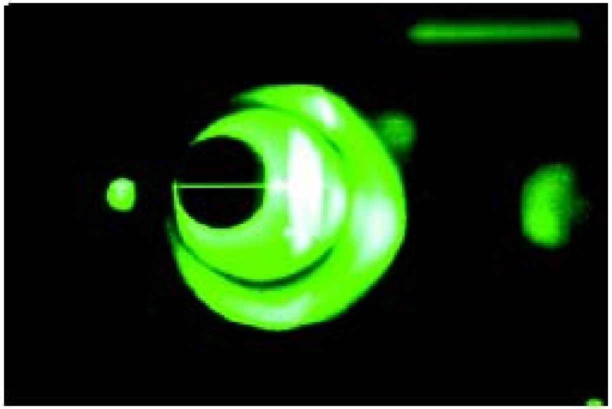
- Requirements for laser target (laserwire)
  - Intensity
  - small width (w0)
- Optical cavity
  - Power build-up
  - Accurately measurable/stable waist
  -
- CW cavity
  - no need to find the right timing
  - bunch separation by signal detection timing
- Pulse cavity
  - efficient collision
  - bunch length



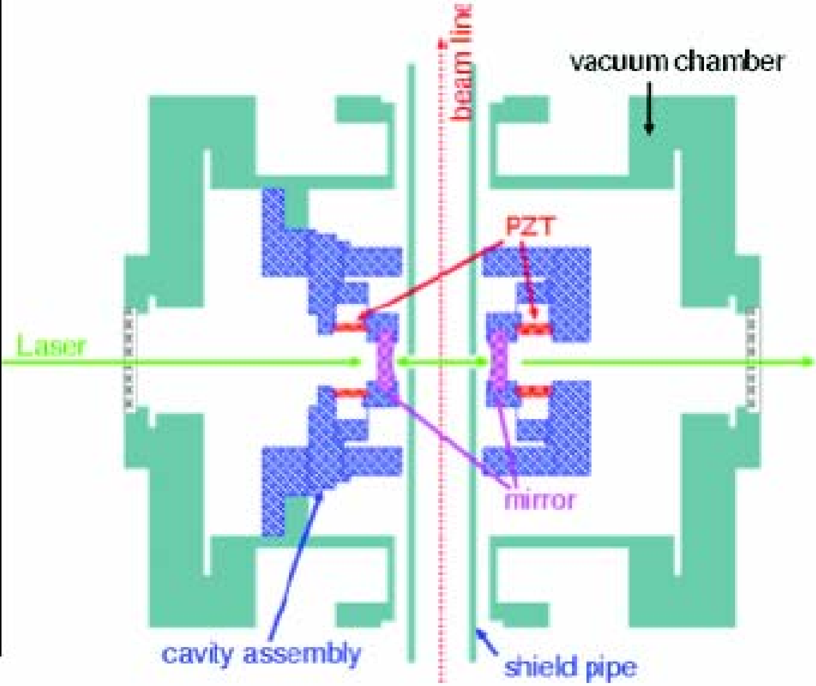


Cavity and the chamber

- Cavity is in the vacuum.
- Position of the cavity mirrors are finely controlled by PZTs.



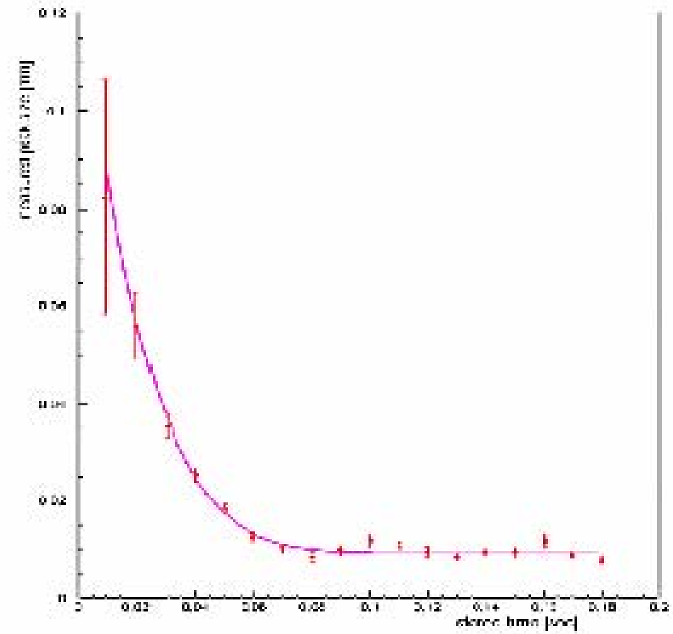
	horizontal-wire	vertical-wire
reflectance (front)	99.1 %	99.8 %
reflectance (rear)	99.9 %	99.9 %
curvature	20 mm	20 mm
finesse	620	1700
enhancement	660	1300
effective power	79 W	156 W
w0	11.3 ±0.16 µm	29.4 ±0.5 µm
Rayleigh length	760 µm	5100 µm
wave length	532 nm	
laser line width	10 kHz (single line)	
laser power	300 mW (cw)	

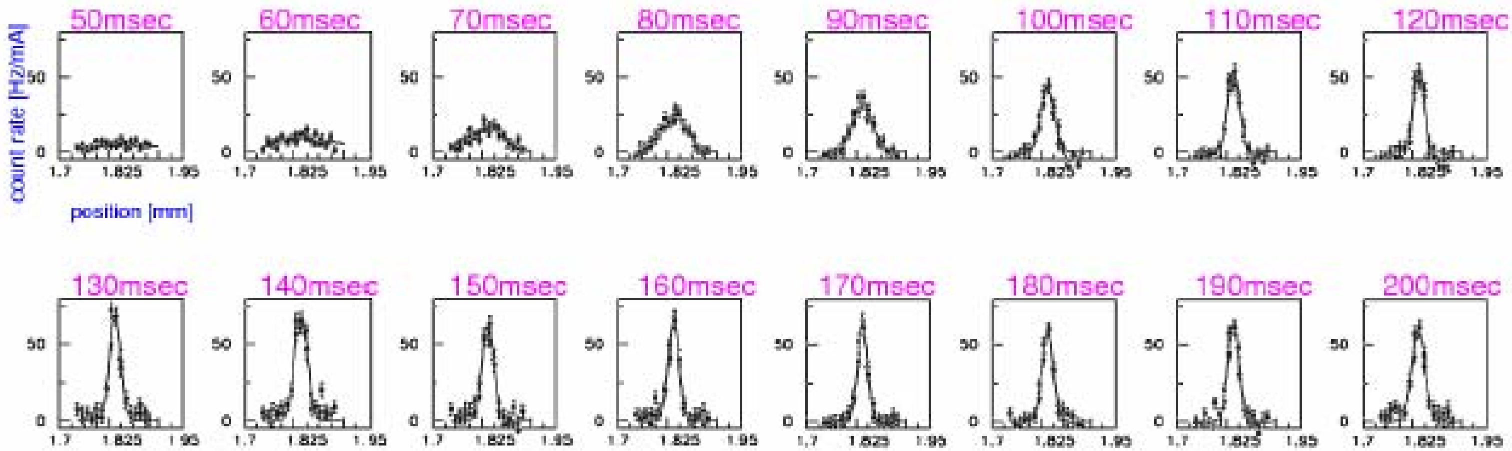


Measurement of the emittance damping

- Repeat beam injection to the DR.
- Separately count up the signal according to the time after the injection.

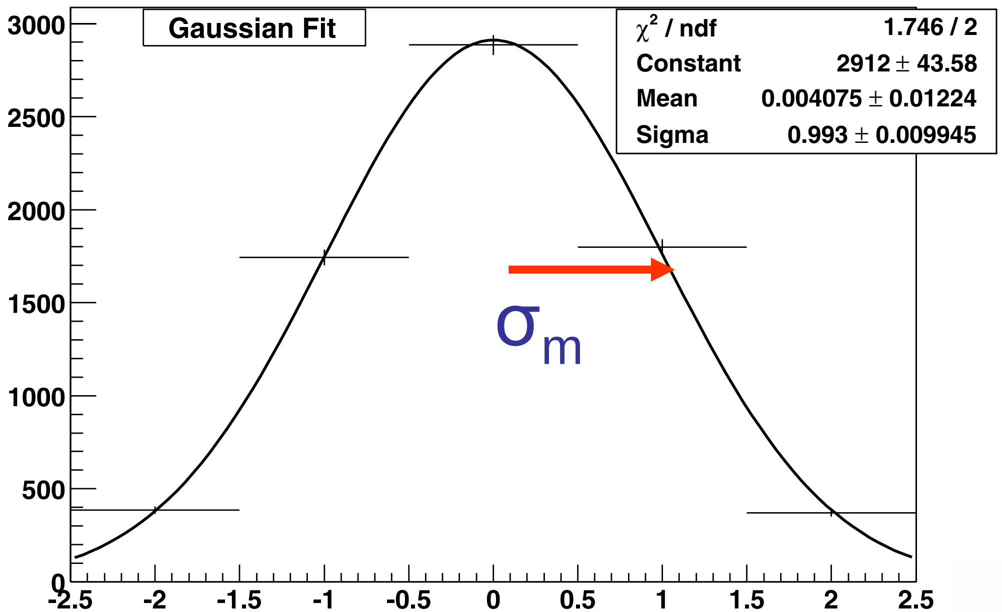
1 scan in ~ 6 mins





Y. Honda

Accuracy



A 5-point Gaussian
1% σ_m measurement
⇒~2900 events at peak

(assumes 100% efficiency
so this is too optimistic)

$$\sigma_m^2 = \sigma_l^2 + \sigma_e^2$$

$$\frac{\delta\sigma_y^e}{\sigma_y^e} = \left[1 + \left(\frac{\sigma_\ell}{\sigma_e}\right)^2\right]\frac{\delta\sigma_m}{\sigma_m}$$

Number of Comptons

$$n_i = N_0 \epsilon_i$$

$$\epsilon_i = \frac{1}{\sqrt{2\pi}\sigma_m} \exp - \frac{(\Delta_y^i)^2}{2\sigma_m^2}$$

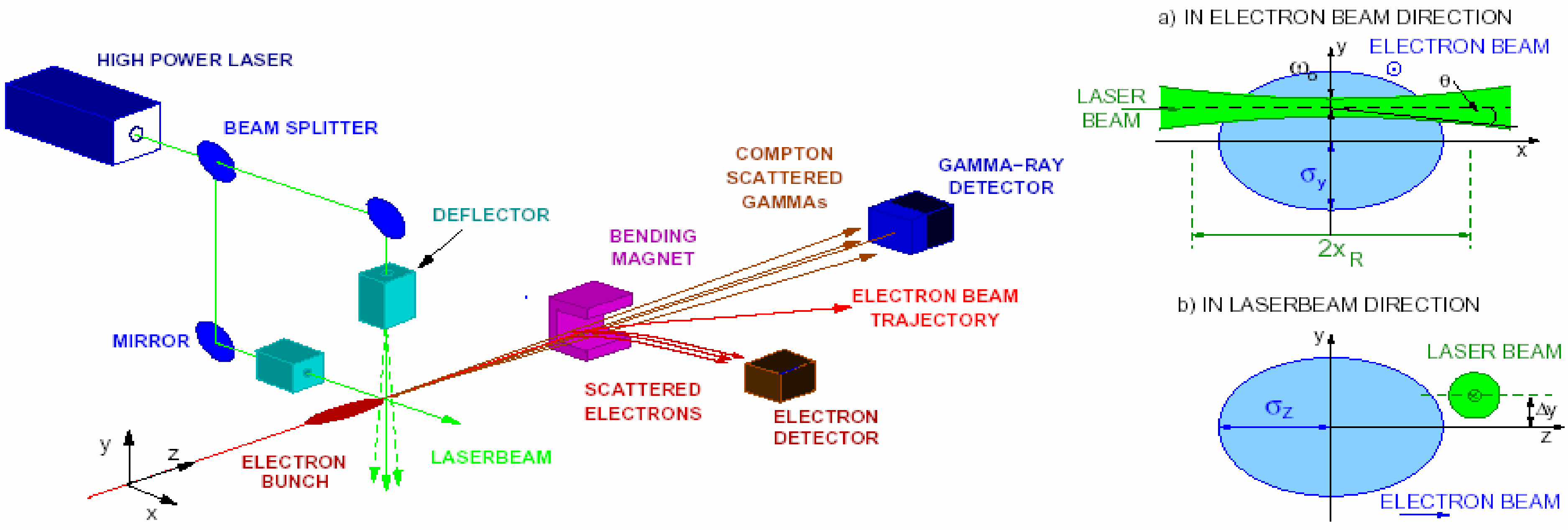
$$N_0 = \frac{P N_e \lambda \sigma_T}{hc^2}$$

Requiring a 1% σ_e : Instantaneous laser-power

$$P = 1.23\sigma_m / N_e \left[1 + \left(\frac{\sigma_\ell}{\sigma_e} \right)^2 \right]$$

N_e ($\times 10^{10}$)
σ_m (μm)
P (MW)

Rayleigh-Range

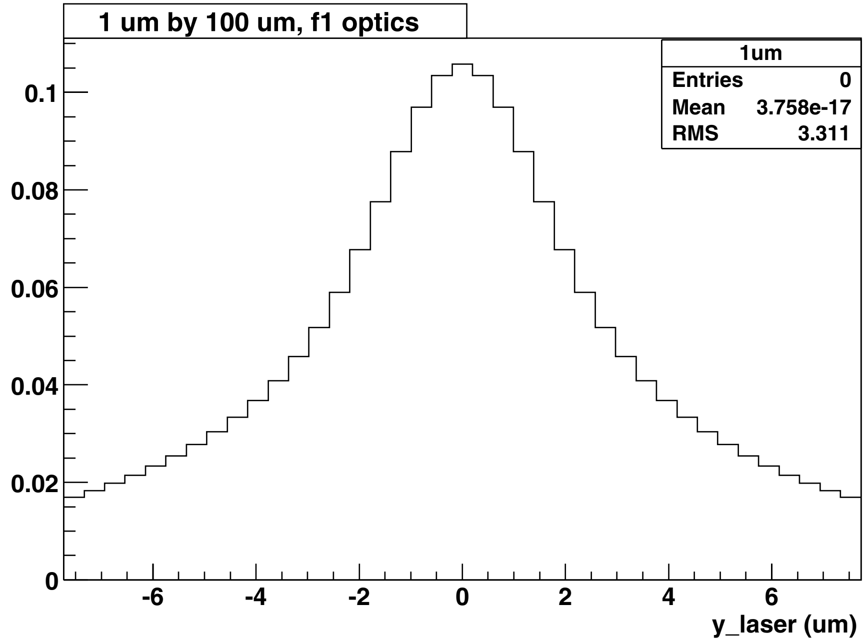


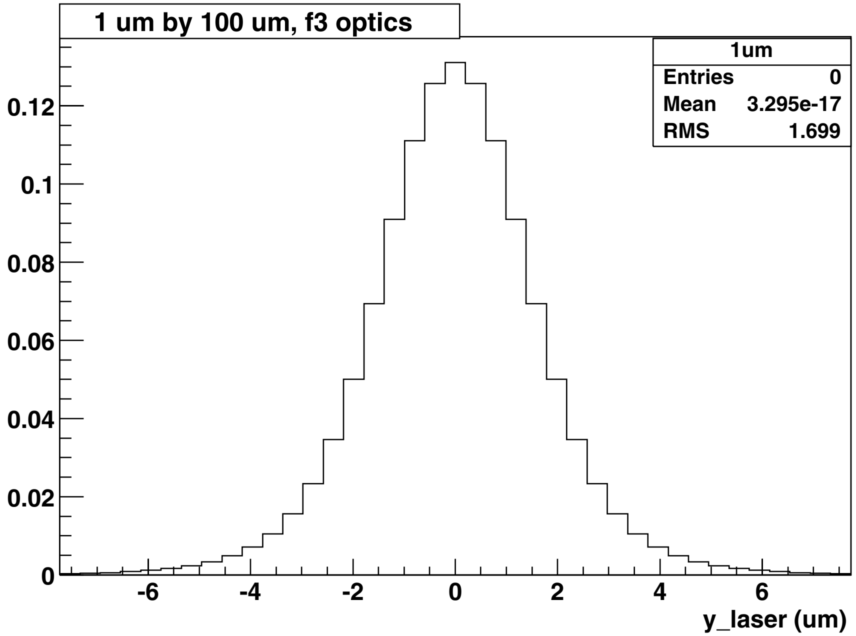
$$\theta = \frac{\lambda}{\pi\sigma} = \frac{1}{f_{\#}}$$

$$x_R = M^2 \frac{4\pi\sigma_0^2}{\lambda}$$

Full Overlap Integral

$$\epsilon(\Delta_x, \Delta_y) = \int \frac{dxdy\ I_\ell I_e}{(2\pi)^{\frac{3}{2}} A\sigma_e^2 \sigma_\ell \sqrt{f_R(x-\Delta_x)}} exp\left[-\frac{x^2}{2A^2\sigma_e^2} - \frac{y^2}{2\sigma_e^2} - \frac{(y-\Delta_y)^2}{2\sigma_\ell^2 f_R(x-\Delta_x)}\right]$$





f1 is not always optimal; depends on aspect ratio

Optimal Powers and f#

σ_ℓ μm	$A=(\sigma_x/\sigma_y)_{\rm ebeam}$	$f_\#$	ρ	σ_ℓ (μm)	x_R (μm)	P (MW)	δ_x(%)
1	1	1	0.92	0.692	8.69	1.8	1
1	10	1	0.99	0.692	8.69	1.8	3.7
1	100	3	4.3×10^{-1}	2.07	78.2	4.0	7.8
2	1	1	4.0×10^{-1}	0.69	8.69	4.2	1
2	10	1	3.46×10^{-1}	0.692	8.69	5.0	3.7
2	100	3	1.39×10^{-1}	2.07	78.2	12	9.9
3	1	1	2.0×10^{-1}	0.69	8.69	6.4	1
3	10	1.5	1.77×10^{-1}	1.04	19.6	7.6	3.7
3	100	4	7.5×10^{-2}	2.77	139	17	10
5	1	1.5	7.35×10^{-2}	1.04	19.6	24	1
5	10	1.5	6.78×10^{-2}	1.04	19.6	26	3.7
5	100	5	3.35×10^{-2}	3.46	217	50	11

Details in EUROTeV note.

Systematics

Measured profile is a complicated convolution of laser profile and electron beam profile.

$$\frac{\delta\sigma_y^e}{\sigma_y^e} = \sqrt{\delta_m^2(1+r^2)^2 + \delta_\ell^2 r^4}$$

where r = $\frac{\sigma_\ell}{\sigma_e}$

Require a 1% σ_e (?)
Assume we can measure σ_l to 10% (?)

$\Rightarrow r < 0.3$

Converging on a solution

- f1.5 optics seems "do-able" (R&D addressing this at ATF extraction line)
- Green light efficient and practical (but UV is still possible if required).
- Precision measurement of 1% on σ_y assuming e-beam aspect ratio of 10 $\Rightarrow$

  Laser pulse power ~ 8MW

  3.7% measurement of σ_x (using same laser)

  σ_y ~ 3 μm (from systematics)

  $\Rightarrow \beta$~441m at 1 TeV ($\gamma\varepsilon_y = 4.10^{-8}$ m-rad)

Q: Is 1% needed?

Q: Is 441m OK for the β -fn? or maybe ∃ optics tricks?

Laser Parameters I

Injection-seeded Q-switched with 8MW pulses

pulse length ~ ns

5Hz repetition rate

Nd-YAG doubled (green – 532 nm)

Advantages:

- essentially no new R&D required (similar system will be tested at PETRA)
- Should be reliable
- Commercial solutions available

Disadvantages:

Only one pulse per train; “slow” system.

Laser Parameters II

Mode locked system with 8MW pulses
pulse length ~ 2ps
300 ns pulse spacing
Nd-YAG doubled (green – 532 nm)

Advantages:

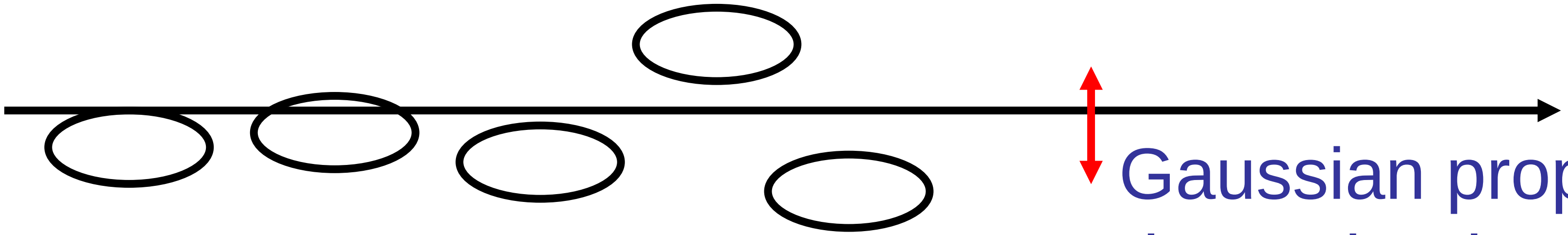
- will allow intra-train pulse properties to be measured
  - Centroid to ~ 1 % of a σ over 5 bunches
  - Value of σ to ~1%

Disadvantages:

- Expensive & may have reliability issues.
- Research project in itself (R&D will start in UK this year).

Good summary of laser-wire issues from Nanobeam2001 J Frisch:
http://icfa-nanobeam.web.cern.ch/icfa-nanobeam/slides/frisch_laserwire.pdf

Mode-locked potential



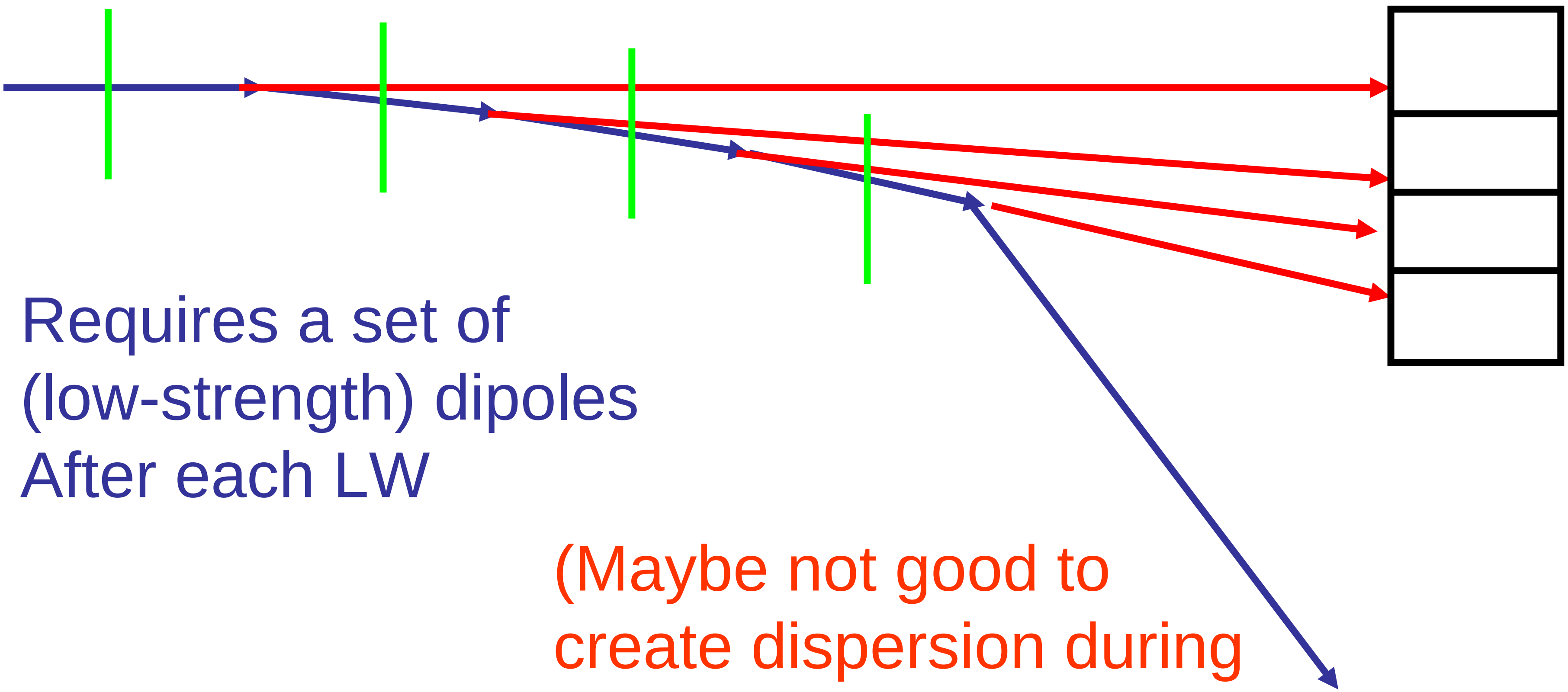
Gaussian properties determined to ~1% within a single train

So every ~ 5 bunches a Gaussian fit is returned
$\Rightarrow$ 564 separate bunch profiles within a train.

After 5 trains, each bunch would have its own fit; both central point and sigma to about 1%.

Q: Is this required, nice-to-have, or over-kill ?

Could do even better



Requires a set of
(low-strength) dipoles
After each LW

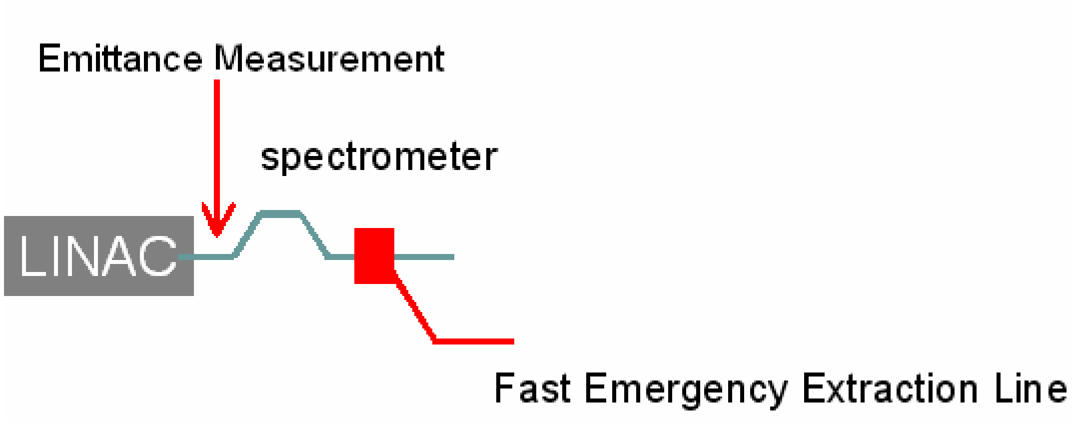
(Maybe not good to
create dispersion during
emittance measurement)

Design of Diagnostics Section

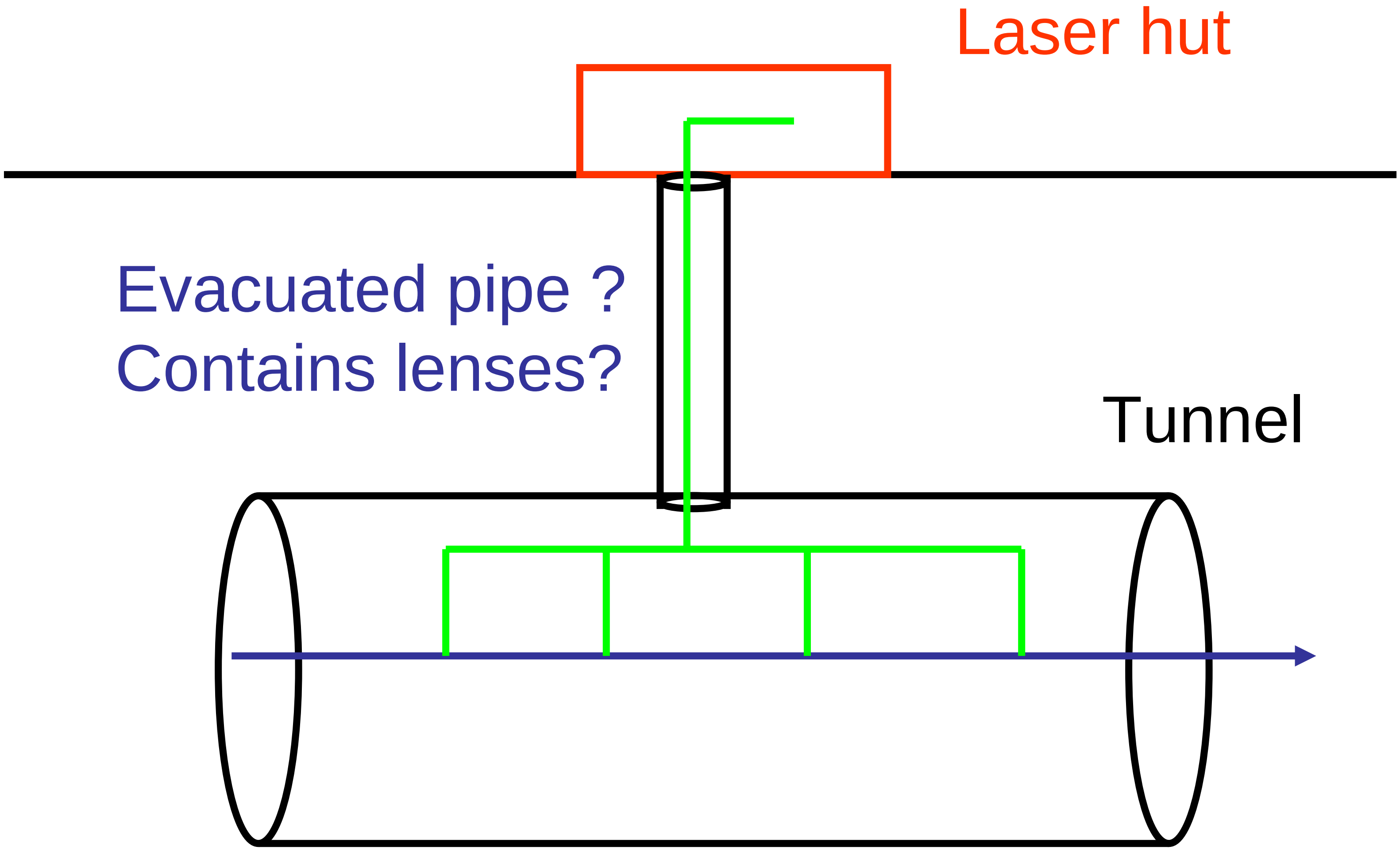
We aim to set up a task force to address the BDS Diagnostics section this and next week.

We propose a meeting early next week followed by work during the week.

A report back session towards the end of next week, within WP4.
Who?:
GB, D. Angal-Kalinin, J. Carter, I. Agapov
M. Woodley + anyone interested in joining.



Light delivery



Attempt at a Matrix
Preliminary

Sub-system	LW type	Detection	Number required	Scanning tech.
DR	CW or pulsed	Low energy Photons, Compton det.	6?	Piezo, or stepping motor
Linac	Pulsed (Mode-Locked?)	Electrons? Beam loss monitors?	??	Fast piezo? Semi-Fixed?
BDS	Pulsed Mode-locked	High energy Photons; Compton det. or cal.	8?	Fast Piezo, Or EO tech.

Cost?

Summary

- Several LW solutions are possible
- What is actually needed in each part of the machine?
- LW systems may need significant infrastructure so their location and function needs to be specified.
- Intra-train emittance measurement at the micron scale seems possible, but still needs R&D (ongoing).
- Signal extraction is an important issue and impacts on the layout of the beam-pipe and nearby elements.
- Light delivery is a significant issue too.
- A combination of systems may be necessary; BDS with a mode-locked high-power system. Q-switched systems may be adequate elsewhere (?).
- Tuning against a fixed laser-wire (D. Schulte et al.)
- We need to specify requirements in more detail now.