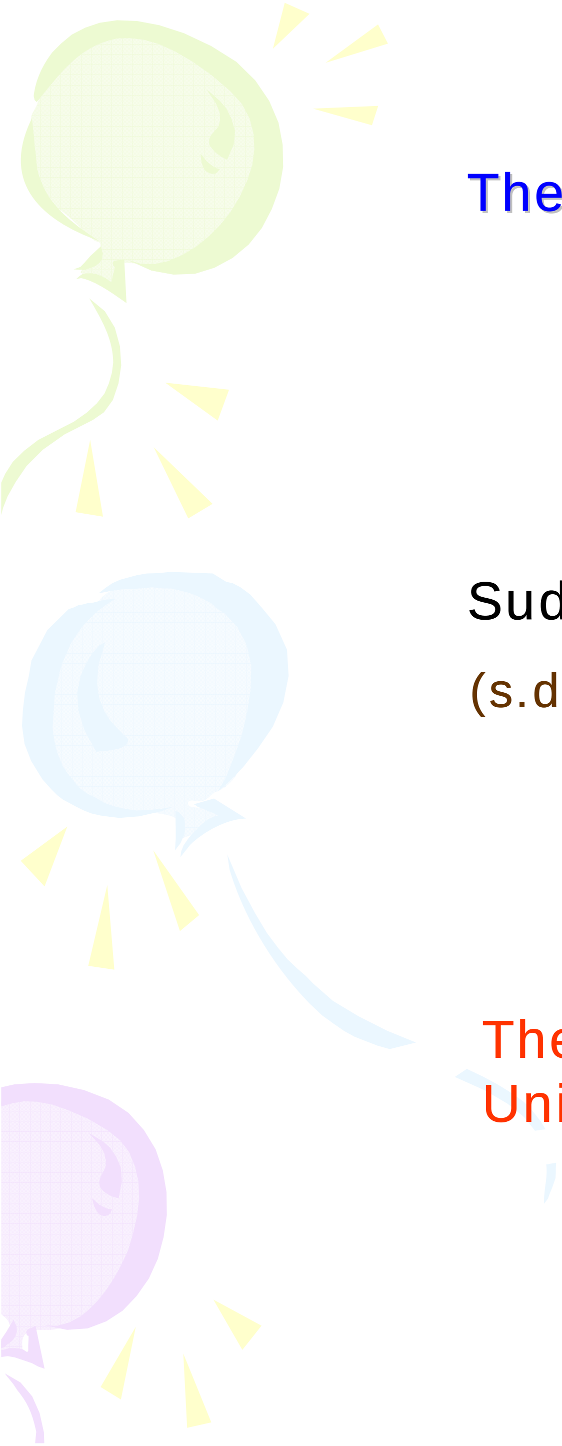

The ILC Laser-wire system

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The Laser-wire

A tool to measure e^-/e^+ beam sizes/profiles all along accelerator complex (DR, Linac, BDS, IP)

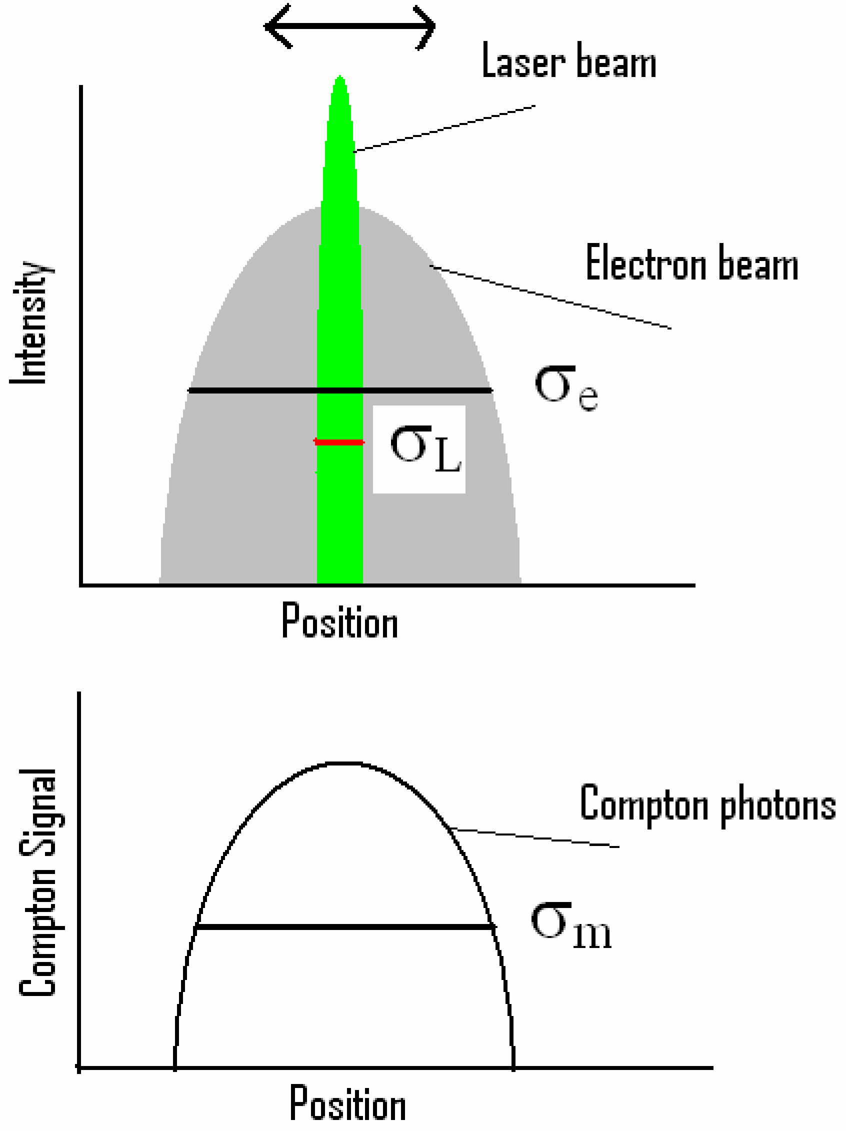
↓

Thereby Estimation & Optimization of e-/e+ beam Emittance/Luminosity

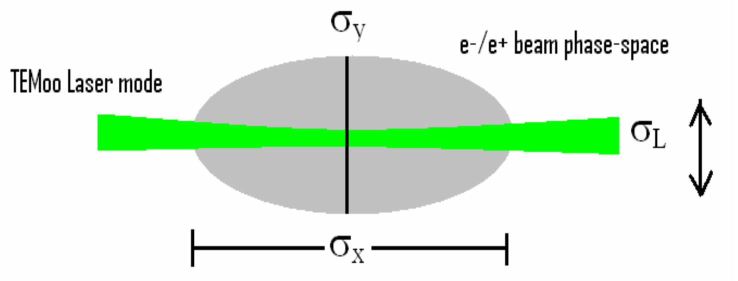
Features

- Sub-micron resolution
- Truly non-invasive
- Probably the only viable diagnostic tool for high density ILC beams

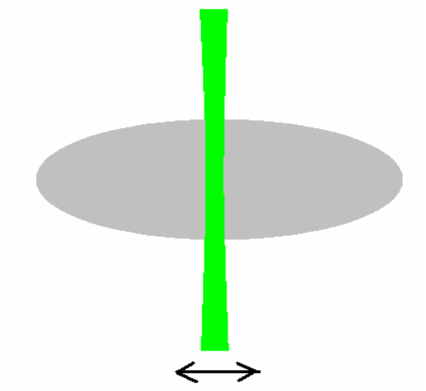
Laser-wire principle



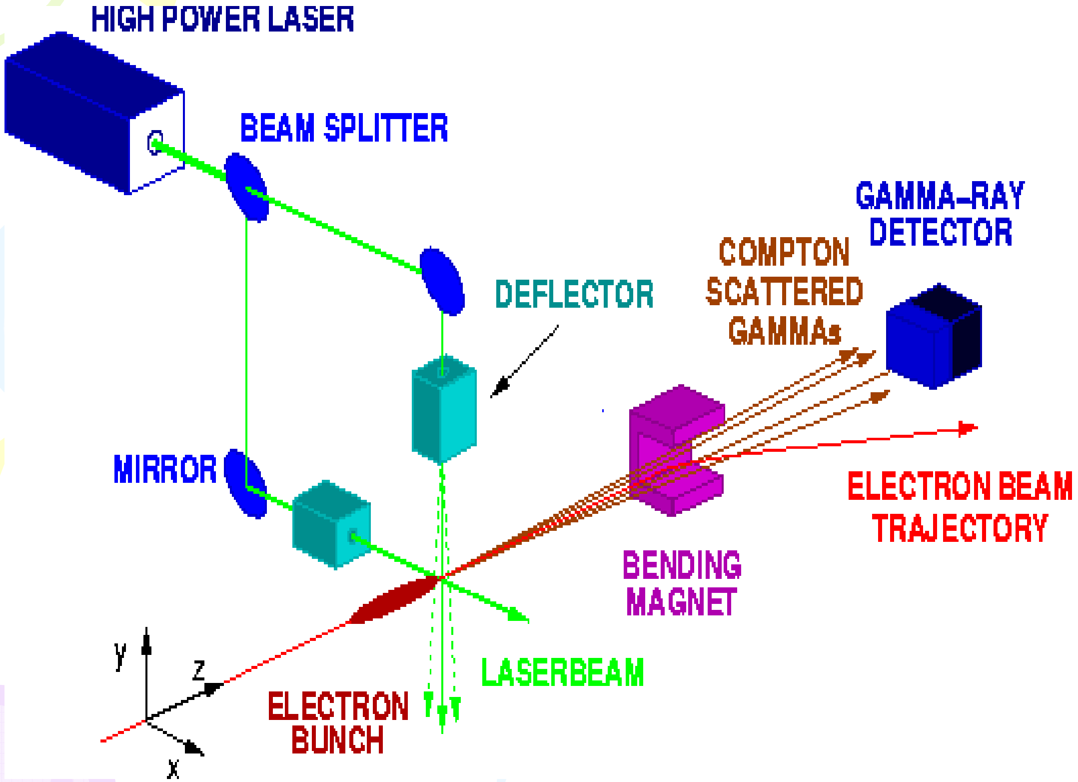
Vertical scanning: σ_y



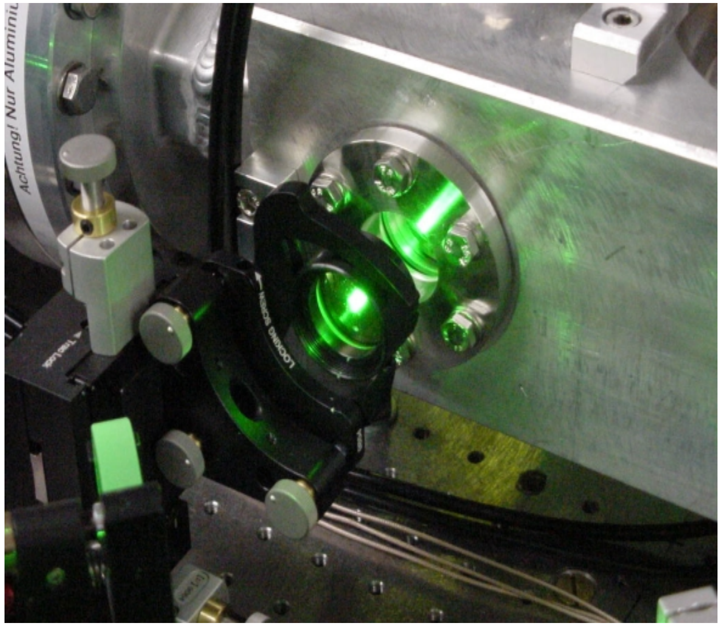
Horizontal scanning: σ_x



The Experimental LASER-WIRE



Laser-wire at PETRA



Laser-wire implementations: Our current status

- LW system in operation at PETRA storage ring at DESY

  σ_e = 68 ± 3 μm measured at 7 GeV

  Upgradation planned with newly acquired injection seeded Q-switched Nd:YAG laser (20Hz, 10 ns, 532 nm)

- LW system hardware in place at ATF extraction line at KEK

  σ_e down to a few microns is to be measured

  Mode locked laser system (357 MHz, 200 ps, 532 nm) is used

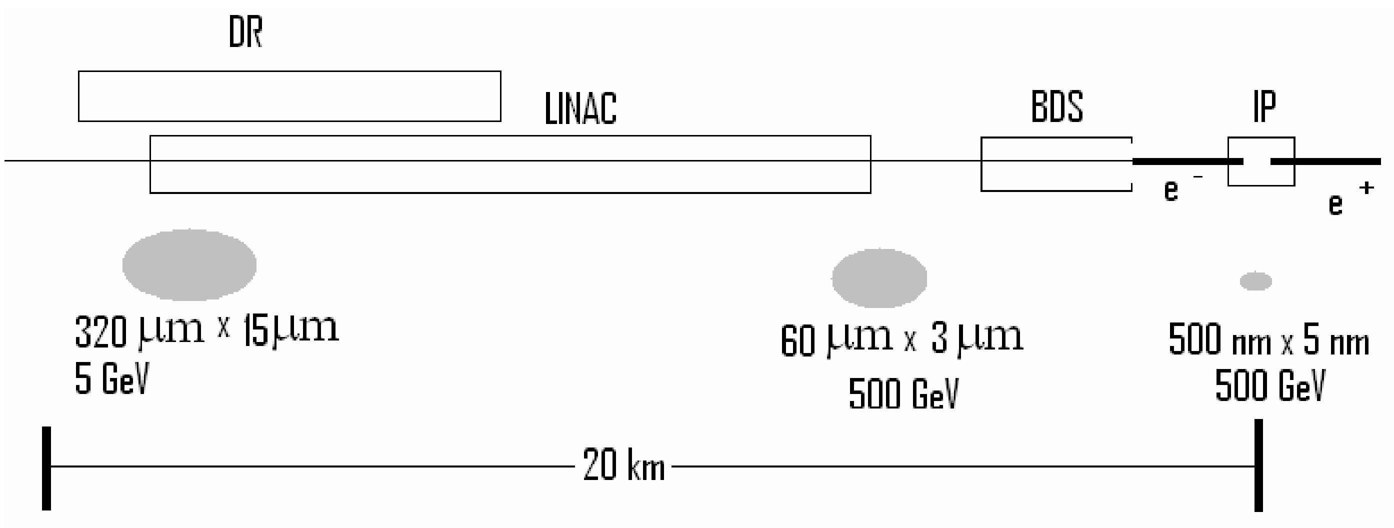
  First Compton signal observed on 14th April

- ILC Laser-wire system being planned at Oxford

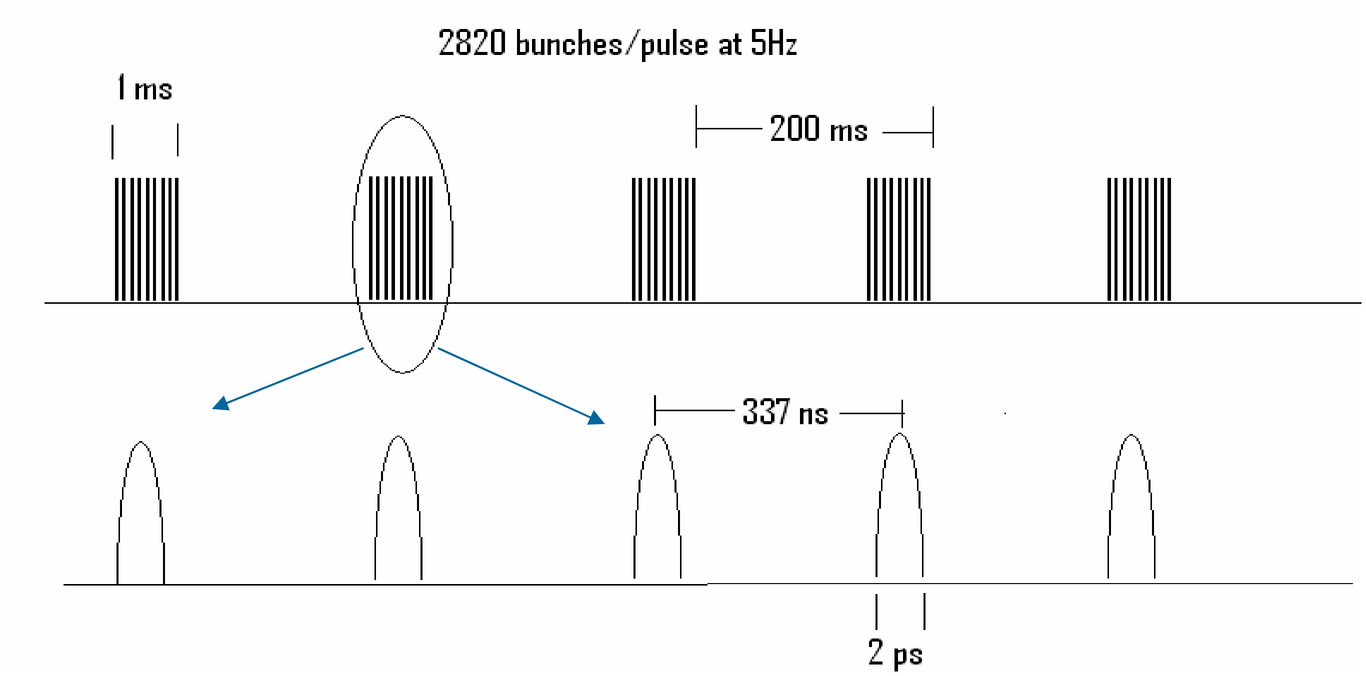
  Time resolved measurement within an ILC pulse (870 μs) is aimed

  Proof of principle will be tested at ATF-2 at KEK on ILC like pulses

ILC beam sizes



ILC e-/e+ pulse structure



Guidelines on the choice of Laser for the ILC LASER-WIRE

1. Laser repetition rate, f_{laser}	$f_{laser} = f_{emicrobunch}$ (3 MHz, timing accuracy < 1 ps, Mode locked laser)
2. Laser pulse duration, t_{micro} and t_{macro}	$T_{micro} = e^{-}$ bunch length (0.5 mm) = 2 ps (But may be relaxed to 10 ps) T_{macro} = 870 μs (Long pulse ML Laser)
3. Laser spot size, σ_L $\sigma_L \approx M^2 \lambda f^{\#}$	$\sigma_m^2 = \sigma_e^2 + \sigma_L^2 + \sigma_{L\ jitter}^2 + \sigma_{e\ jitter}^2 + ...$ We require, $\sigma_{jitter} < \sigma_L < \sigma_e$ [$\sigma_L \cong 1\ \mu m$] Gaussian profiles in space and time, TEMoo mode spatial coherence ($M^2 \cong 1$) Focussing lens $f^{\#} = 1.5\text{-}2$
4. No. of Comptons (N_C) & Laser peak power (P)	$N_C = P\ N_e \lambda \sigma_C\ h^{-1}\ c^{-2}\ \pi^{-1/2}\ \sigma_m^{-1/2} \exp[-\ 0.5\ (\Delta/\sigma_m)^2]$ For good accuracy, $N_C > 2000$ and good energy stability. This requires $P \cong 10MW$ (100 μJ/10ps)
5. Laser wavelength, λ_L & Rayleigh Range, R_L	We want, $R_L = 4\pi \sigma_L^2/\lambda = \sigma_x$ and $\sigma_L < \sigma_Y$ Also we know, σ_C reduces as λ_L is reduced The net choice λ_L = 250 nm – 500 nm

Laser design ($\lambda \cong 1\ \mu m$) for P = 50 MW@ f $\cong$ 3MHz

Option 1: 500 μJ@10 ps@3 MHz; Pulse train power = 1.5 kW

Option 2: 50 μJ@1 ps@3 MHz; Pulse train power = 150 W

A laser master oscillator - power amplifier/s (MOPA) system is needed

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An attractive futuristic choice (option 2)

A mode-locked fiber laser oscillator- preamplifier (1047/1053/1064 nm) system followed by high power DPSSL, Nd: YAG or Nd:YLF amplifier/s

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An alternative choice, already employed over the years (option 1)

A diode/flashlamp pumped mode-locked Nd:YLF/Nd:YAG MOPA

Choice on 2nd/4th harmonic crystal : LBO/BBO (250 nm – 500 nm)

Fiber lasers for Accelerator R & D

High quality beams: Diffraction limited divergence, excellent beam profiles, very low pointing jitter

Wide range of pulse- widths: 100 fs to 10 ps

Ultra-low noise jitter: 10s of fs

Rep. rate: kHz to 10s of MHz

Pulse energies: 1 micro-joules (6 MHz, 1 ps pulses) to
1000 micro-joules (50 kHz, 200 fs pulses)

Long diode life: 10 years

Issues to be worked on more seriously:

Exact rep. rate control and synchronization to external RF signal

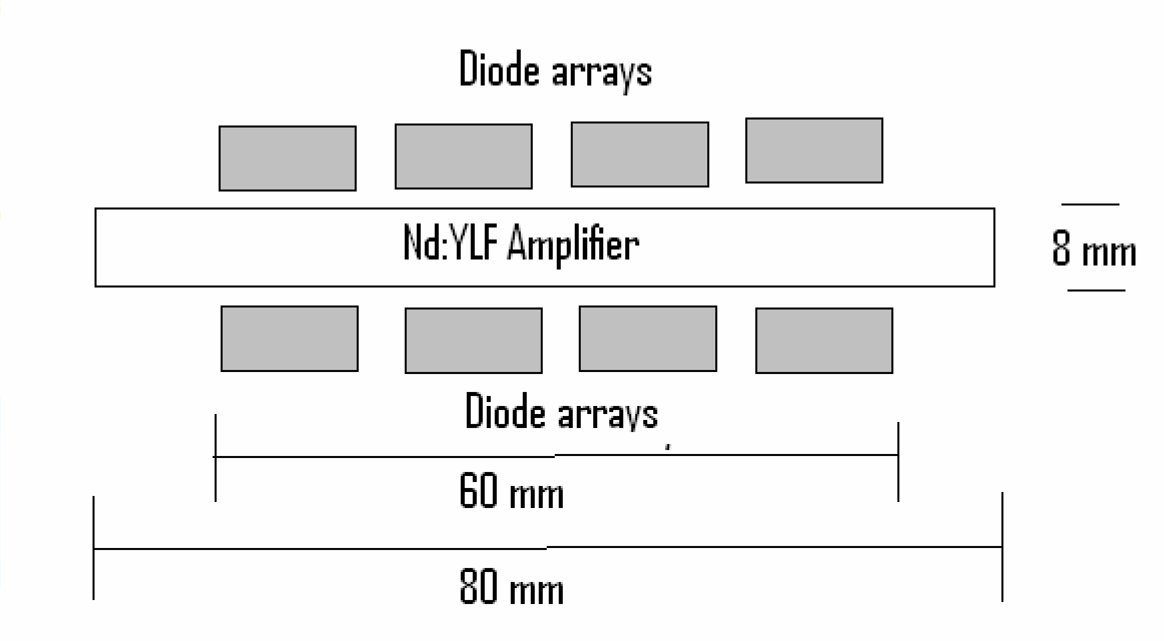
Nd:YLF vs Nd:YAG

Parameter	Pointer	Nd:YAG	Nd:YLF
Lasing Wavelength		1.06 μm	**1.053 μm (o)** **1.047 μm (e)**
Stimulated emission cross-section	Laser gain/ASE	6.5 x 10^{-19} cm^2	**1.2 x10^{-19} cm^2 (1.053 μm)** **1.8 x 10^{-19} cm2 (1.047 μm)**
Upper laser life-time	Energy storage	230 μs	**540 μs (1.053 μm)** **490 μs (1.047 μm)**
dn/dT	Thermal aberrations	7.3 x 10^{-6}/ °C	**- 2.0 x 10^{-6}/ °C (1.053 μm)** **- 4.3 x 10^{-6}/ °C** (1.047 **μm)**
Gain-bandwidth	Mode-locked pulse duration	0.45 nm	**1.4 nm**
Thermal conductivity	Heat dissipation	13 W $cm^{-1}K^{-1}$	7 W $cm^{-1}K^{-1}$
Fracture limit	Thermal fracture	80 W/cm Thermal power	**22 W/cm** Thermal power
Pump wavelength		808 nm	**800 nm**
Pump Source		Flashlamps/Diodes	Flashlamps/Diodes

Nd:YLF scores over Nd:YAG in terms of:

Higher energy storage, lower wave-front distortions, better pointing, polarized output

Nd:YLF amplifier design



Thermal fracture data

For pulse train power = 1.5 kW

And diode duty cycle = 2%

Average laser power = 30 W, i.e.

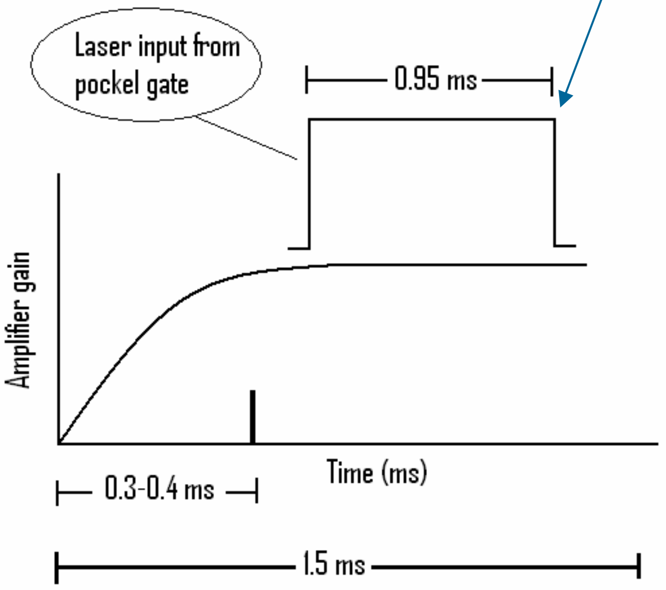
4 W/cm << Frac. limit

- The amplifier is pumped by 16/20 diode arrays distributed in 4/5 rings.
- Each ring contains symmetrically located 4 diode arrays.
- These 4/5 rings are rotated w. r. t each adjacent one suitably to maintain excellent uniformity of pumping

On pump laser diodes for ILC LW power amplifier/s

Pump diodes specifications: Modular design with relatively lower cost

- Each diode module --- Standard 1 cm linear bar/array
- Peak power of each bar --- 500 W at 5 to 10 Hz, at 800 nm
- Total input power to amplifier --- 10 kW
- Diode pulse duration --- 2 m-sec
- Duty cycle --- 2 %



On non-linear optical frequency conversion: Generating harmonics

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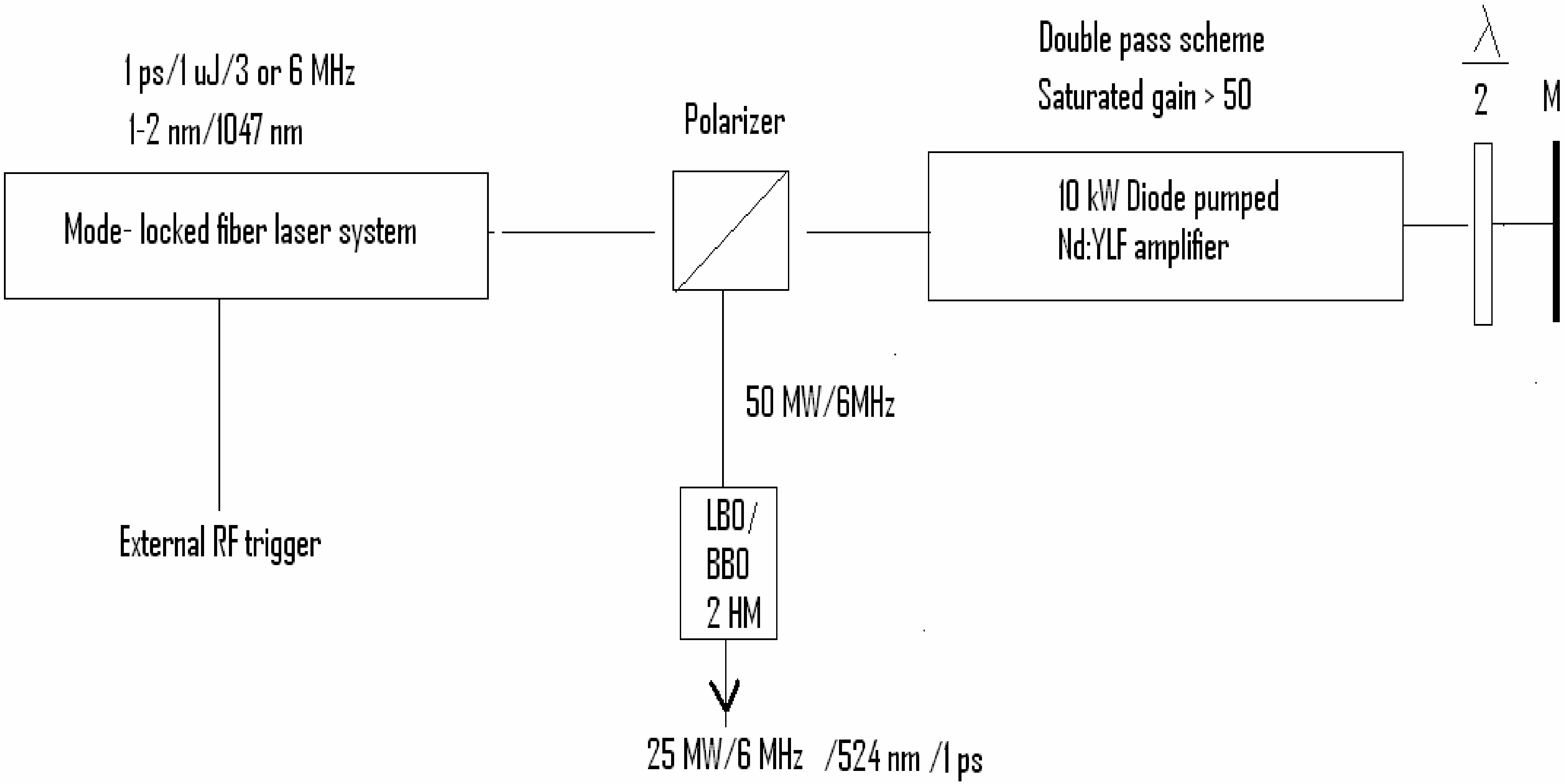
For 1047 nm to 524 nm: The best choice is Type I non-critically temperature phase matched LBO crystal

- No walk- off - Long interaction lengths, Excellent circular beam Gaussian profile with good coherence, High Conversion efficiency > 70%
- Large acceptance angle – 100 mrad
- Large temperature bandwidth – 4^0 c at 150^0 c
- Damage threshold– 20 GW/cm^2 at 1053 nm, a factor of 2 to 4 larger than all other crystals e.g. KDP, KTP, BBO

For 524 nm to 262 nm: The choice is limited to Type I critically phase matched BBO crystal

Large walk-off, Elliptical output beam (needs correction)
Conversion efficiency - 20 to 30%

Schematic of LW system we wish to build up at Oxford



1 ps/1 uJ/3 or 6 MHz

1-2 nm/1047 nm

Mode- locked fiber laser system

External RF trigger

Polarizer

Double pass scheme

Saturated gain > 50

10 kW Diode pumped
Nd:YLF amplifier

$\frac{\lambda}{2}$ M

50 MW/6MHz

LBO/
BBO
2 HM

25 MW/6 MHz /524 nm /1 ps

ILC LW Mode-locked Fiber laser system specifications: Finer details

Set repetition rate: 6.490 MHz (both for ILC & ATF-2)

Repetition rate tune-ability: ± 100 kHz

Resolution of tuning: <1 kHz

Timing jitter: < 1ps at fixed rep. rate

Pulse energy: 1 μJ

Wavelength: 1047 nm

Pulse width: 1ps

Beam M^2: < 1.1

Bandwidth: 1-2 nm

Pointing stability: < 1 μrad

Polarization: Linear

Energy stability: $< 2\%$

External trigger to RF

Instrument version

Conclusion

The laser system planned to developed at John Adams Institute, Oxford, has overlapping parameters with Laser polari-meter and photo-injector

We can all mutually benefit and think about collaborations

To the laser suppliers present here,

We have requirements on Advanced Fiber lasers, Laser amplifiers, Special diodes, Laser Optics, etc

Let us get in touch

Thank you