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Laser work and related research at A0, SMTF/ILC

by ––––– Jianliang Li

Outline

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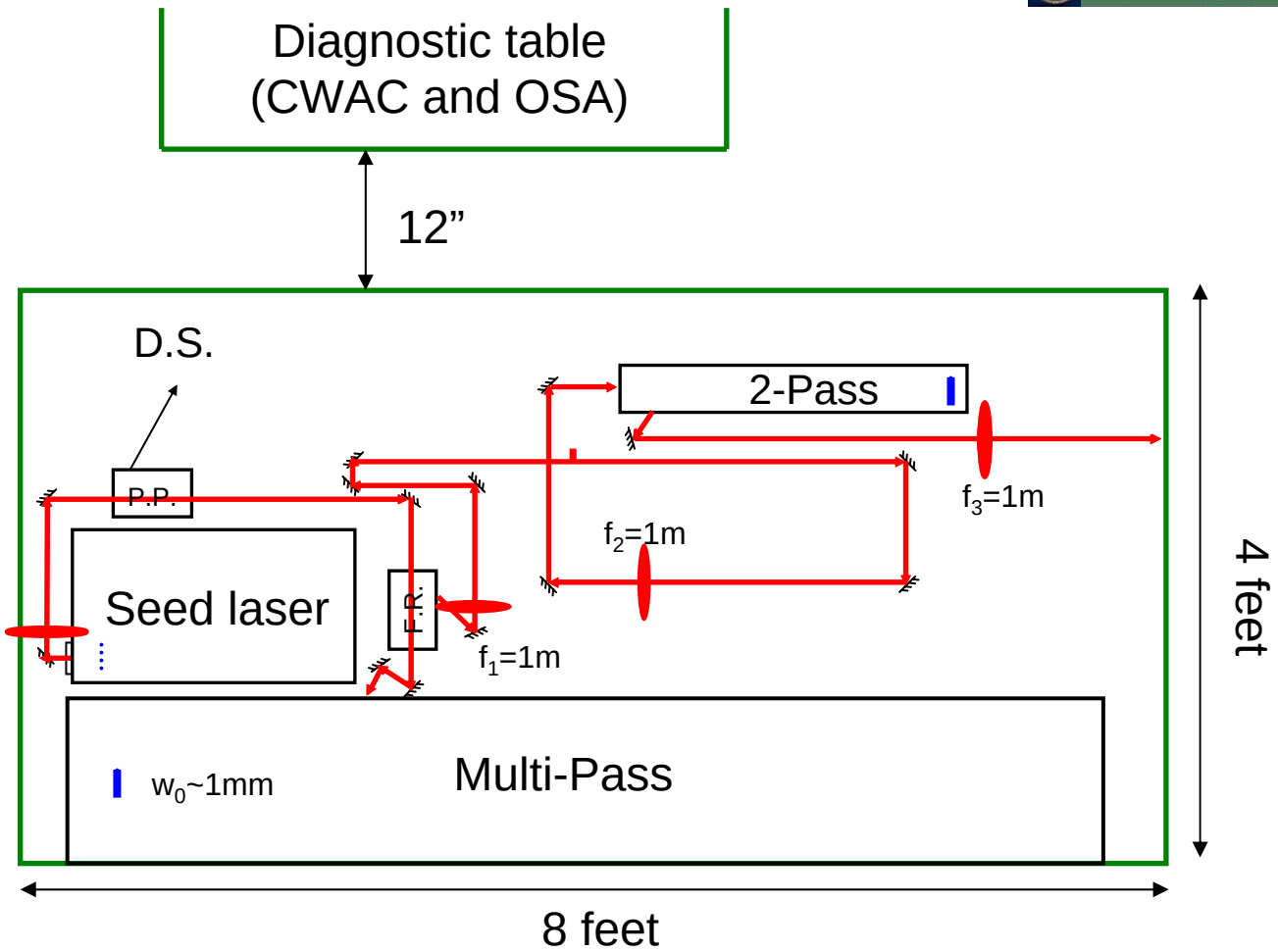
- Recent upgrade of the laser system at A0
- Future upgrade of the laser system for SMTF
- EO sampling for real time diagnostics of electron bunch
- Laser acceleration of electrons
- Laser system for polarized electron source at ILC

Recent laser work done at A0

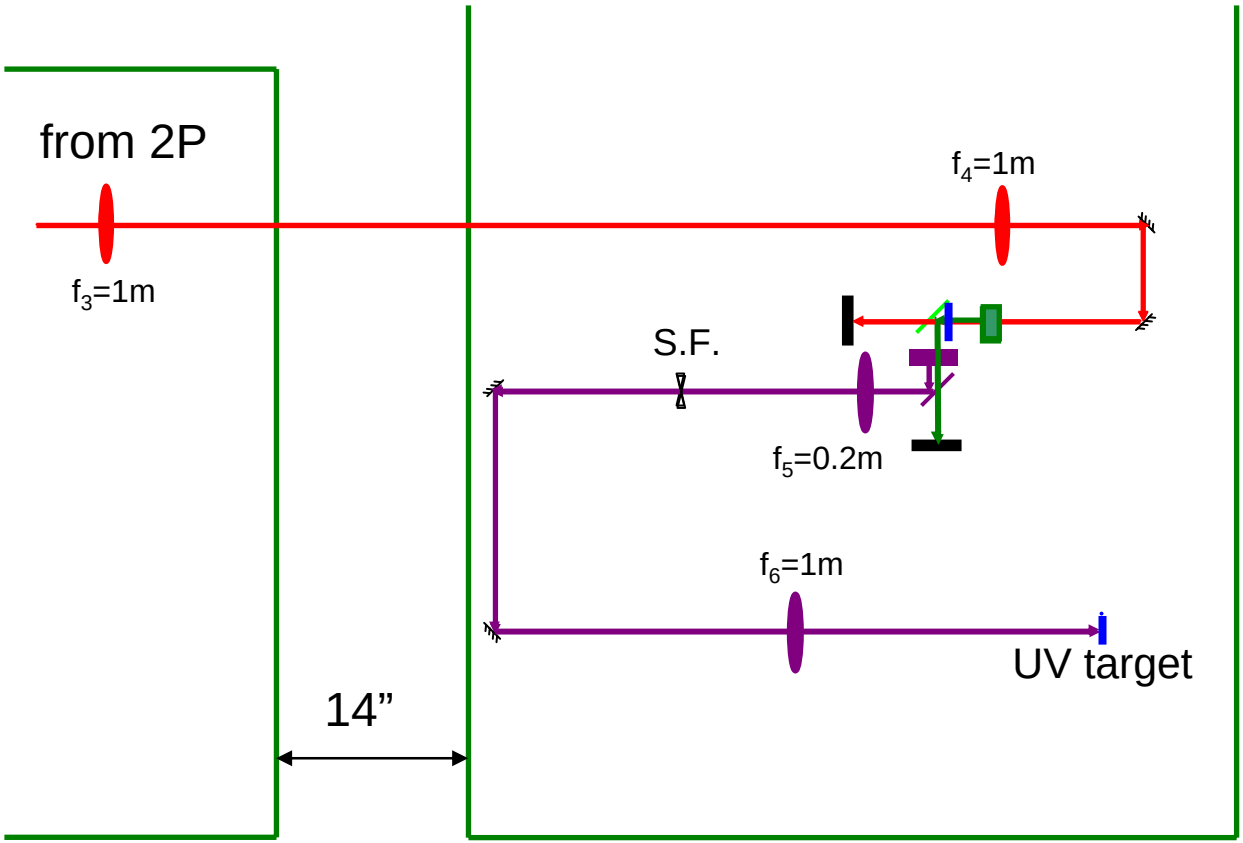
University of Rochester

- Overview and design of the new laser system
- Characterization of the seed laser and performance of the upgraded system
- Pulse stacker, single shot auto-correlator and long pulse train

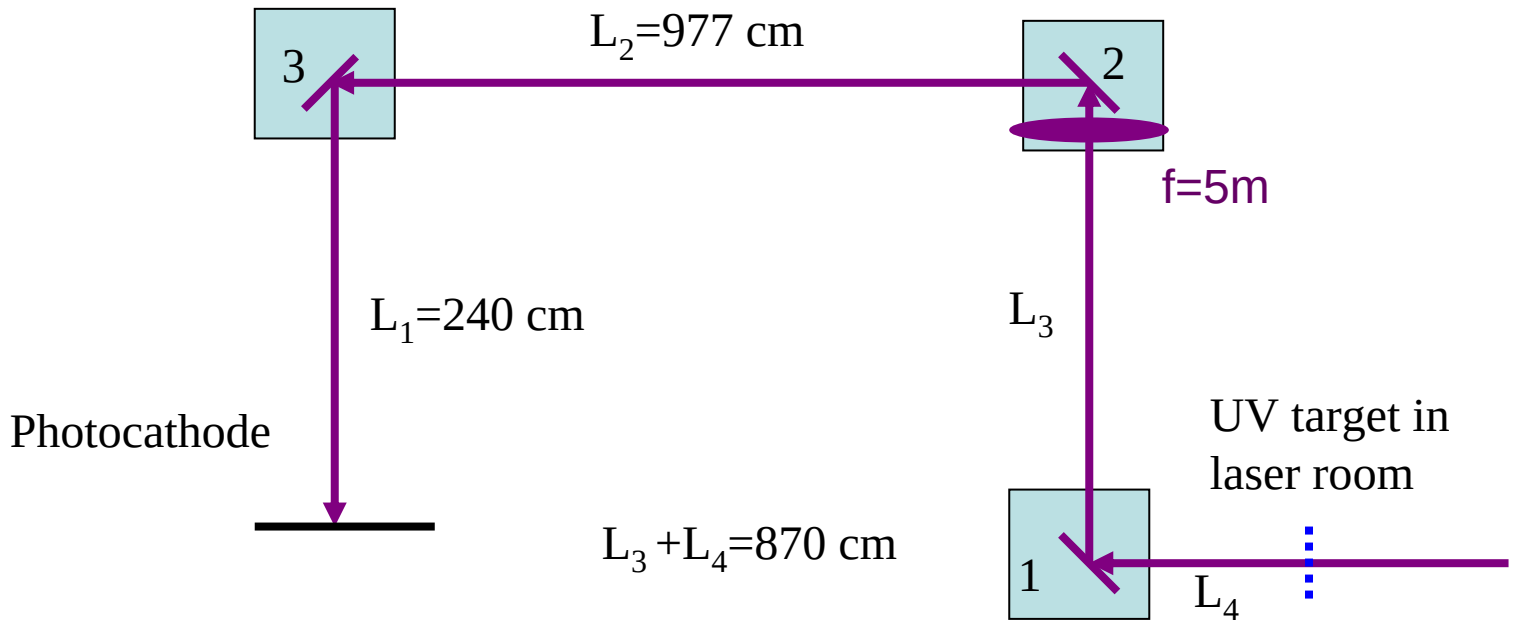
Layout of the new laser system



Crystal table



UV imaging system was designed to relay image in laser room to photocathode

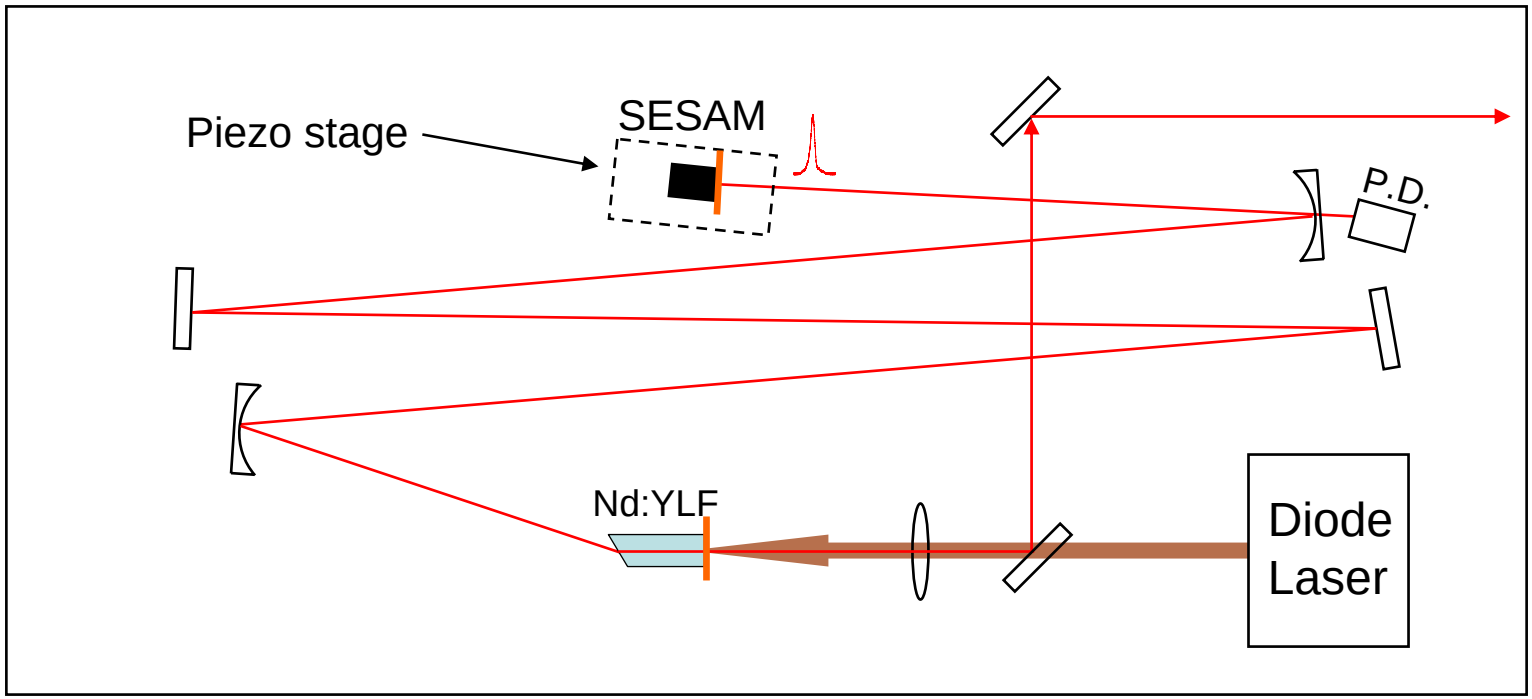


The UV transport line is in vacuum. The magnification of the lens is around 1.4. This imaging system allows us to control the UV pattern on photocathode in laser room.

New seed laser

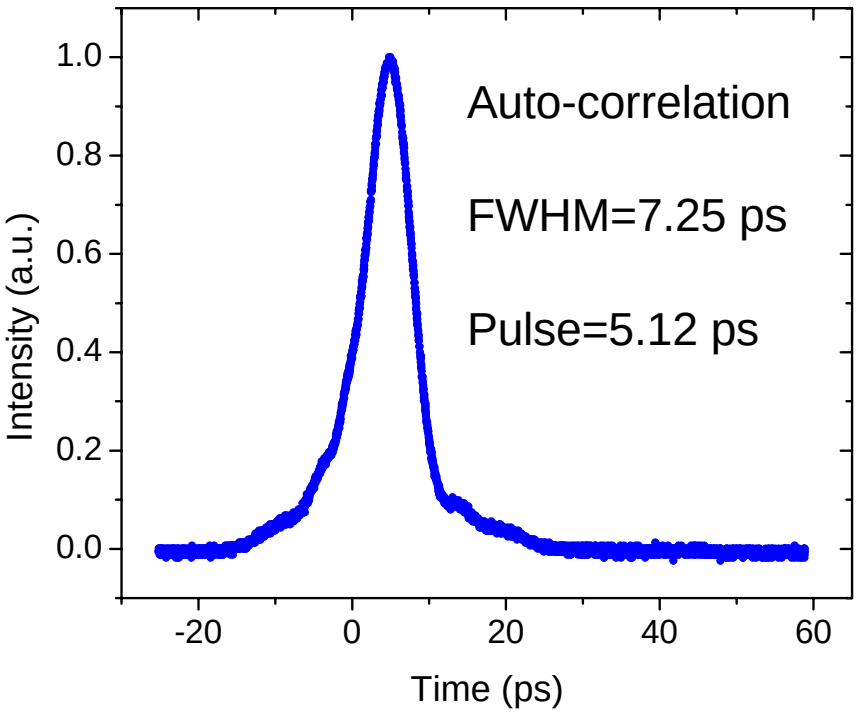
New seed laser was purchased from Time-Bandwidth by Northern Illinois University.

Principle of SESAM laser

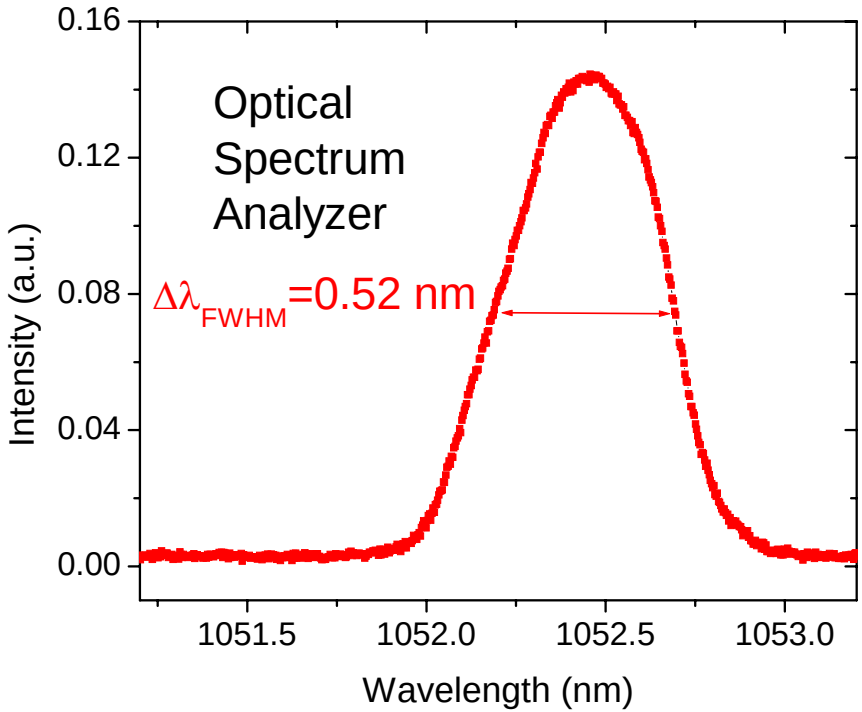


Semiconductor Saturable Absorber Mirror (SESAM) makes a passive mode-lock cavity. Nd:YLF crystal is pumped by a diode laser. P_{out}=450 mW, rep-rate=81.25 MHz, λ~1054 nm.

Seed laser is characterized in both time and frequency domains

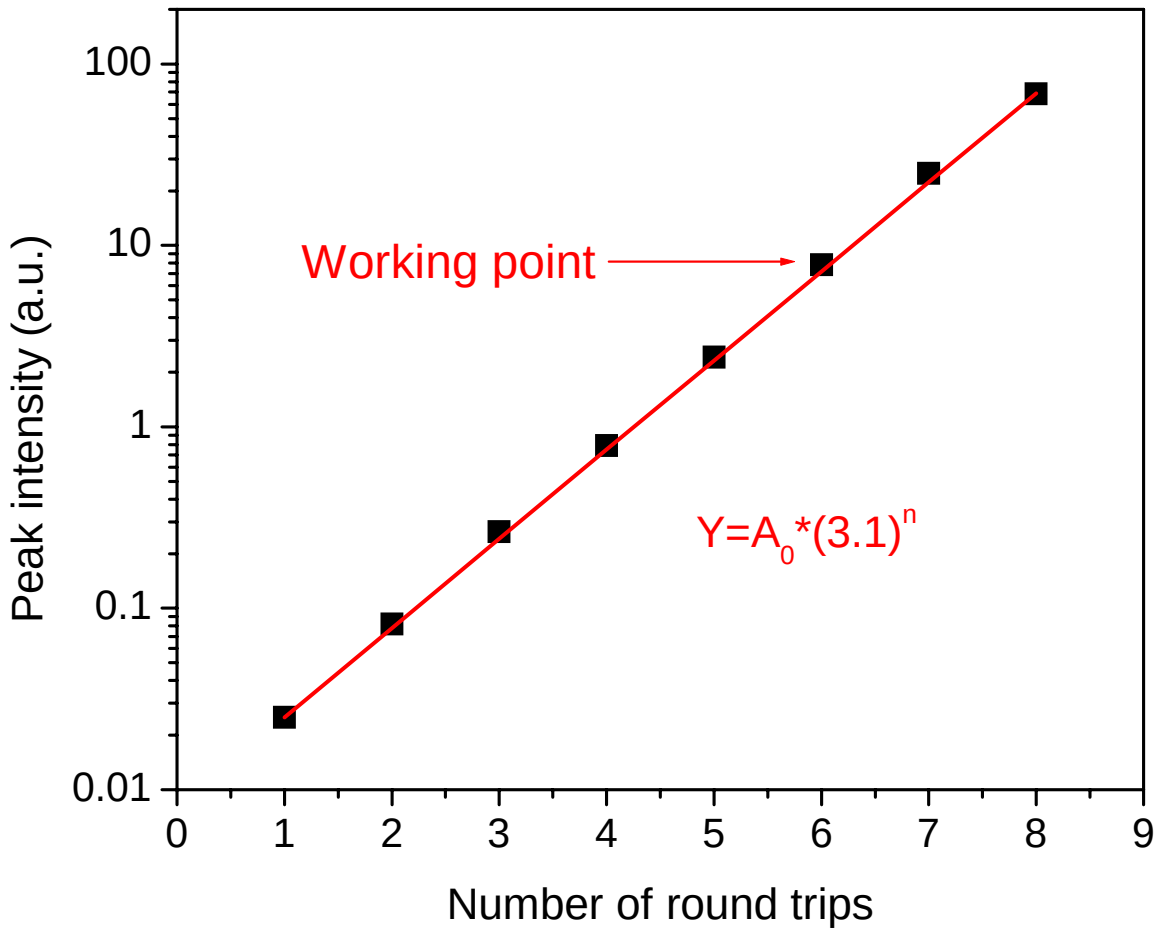


Time domain



Frequency domain

Performance of MP amplifier shows a good exponential behavior



Amplitude fluctuations after M.P. are caused by the power supply

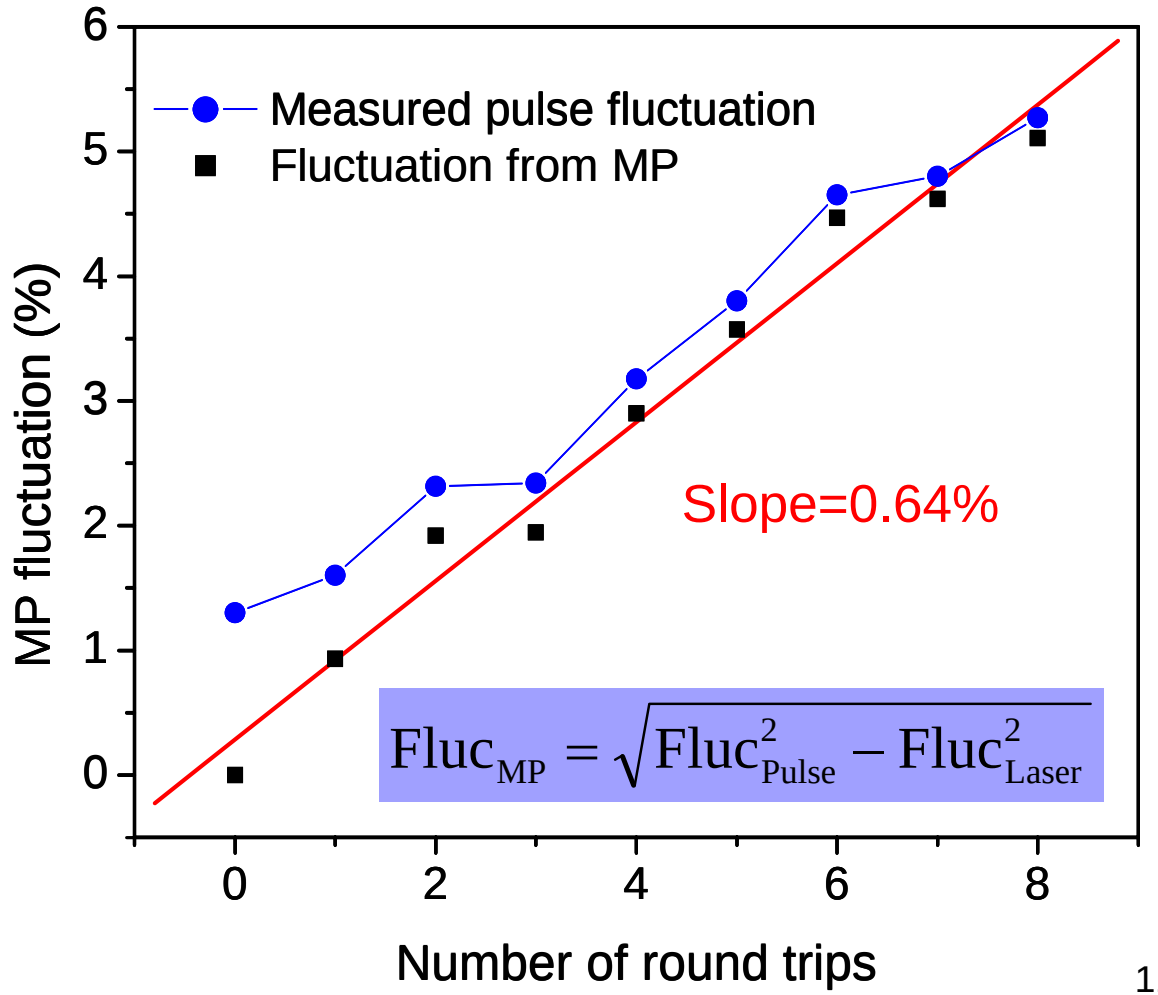
The voltage instability of the power supply of M.P. is < 0.2%

➔

Power fluctuation is < 0.4%

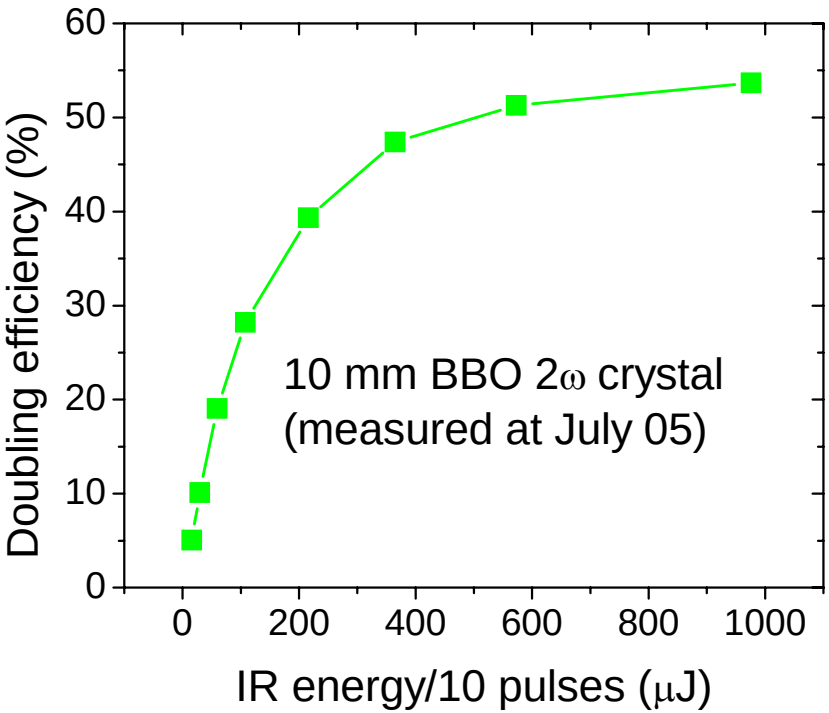
➔

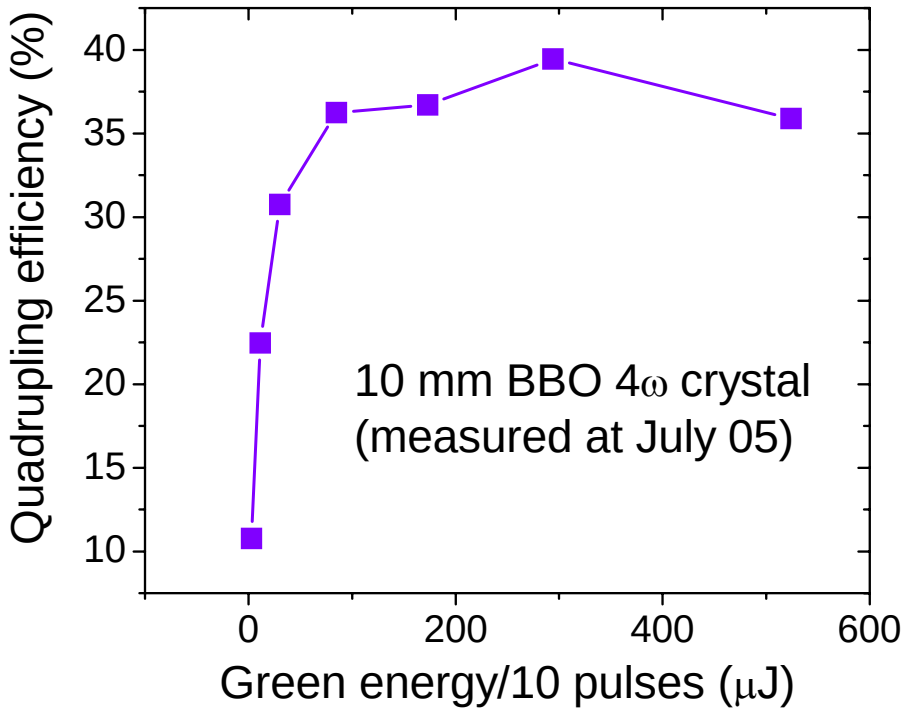
noise for each round trip < 0.8%.



$$\mathrm{Fluc}_{\mathrm{MP}} = \sqrt{\mathrm{Fluc}_{\mathrm{Pulse}}^2 - \mathrm{Fluc}_{\mathrm{Laser}}^2}$$

Green and UV conversion efficiencies

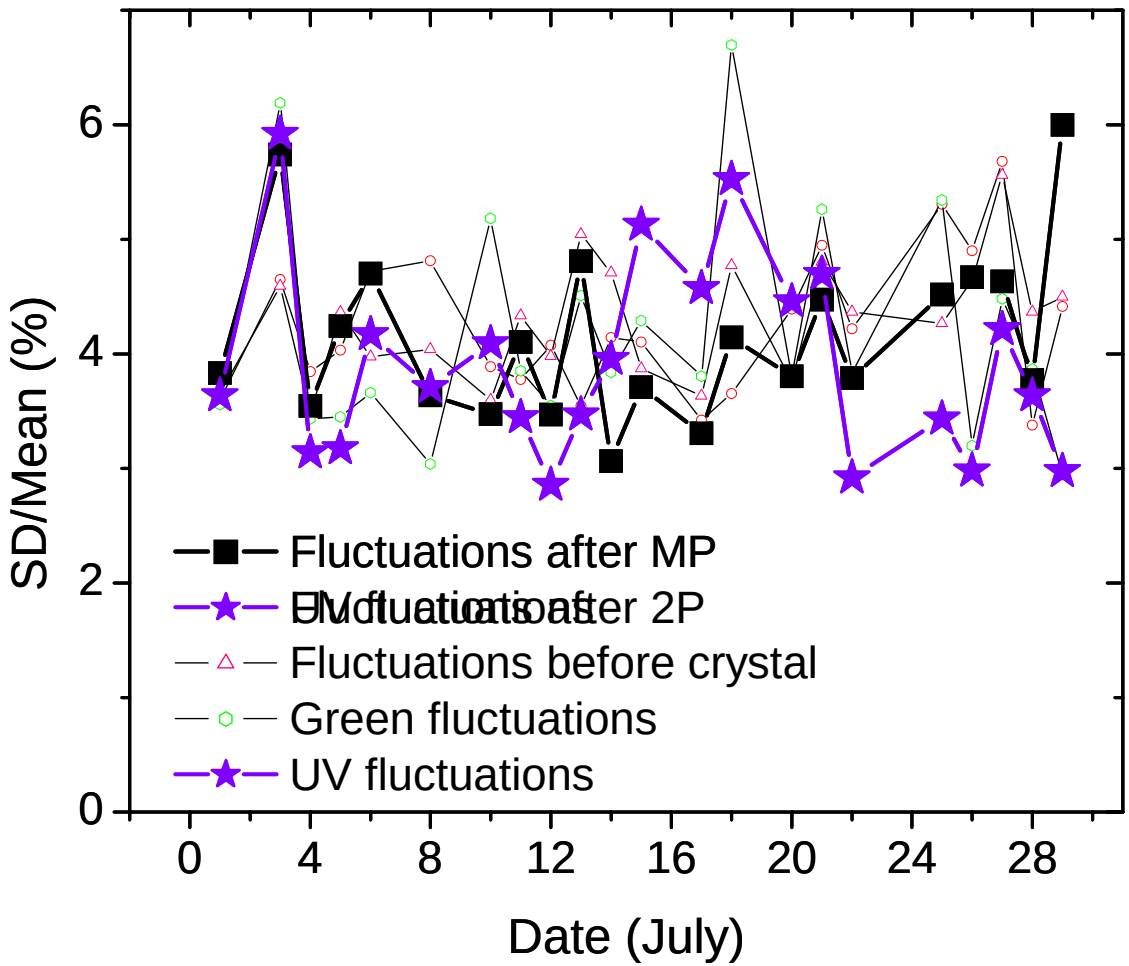




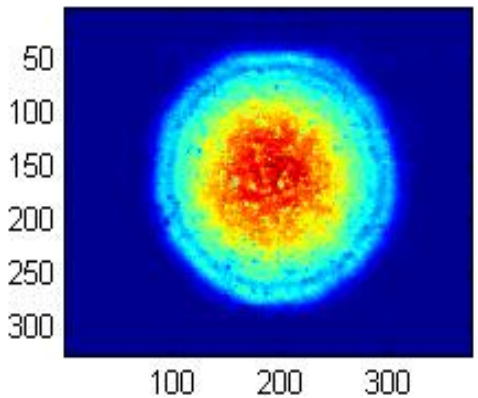
More than 50% doubling efficiency is achieved. The saturation helps reduce Green fluctuation.

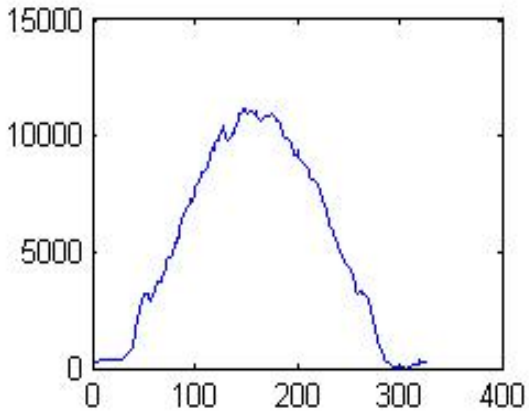
About 40% quadrupling efficiency is achieved! The saturation helps reduce UV fluctuation.

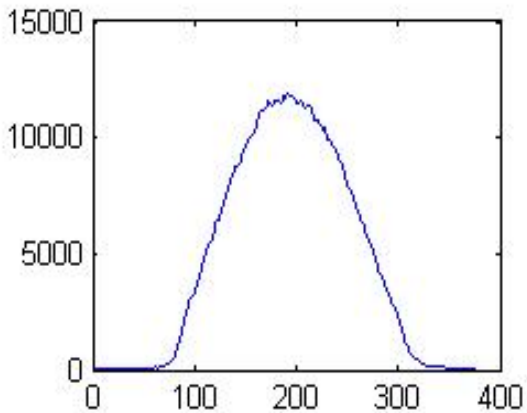
UV fluctuations are determined by M.P.



Transverse profile of UV beam



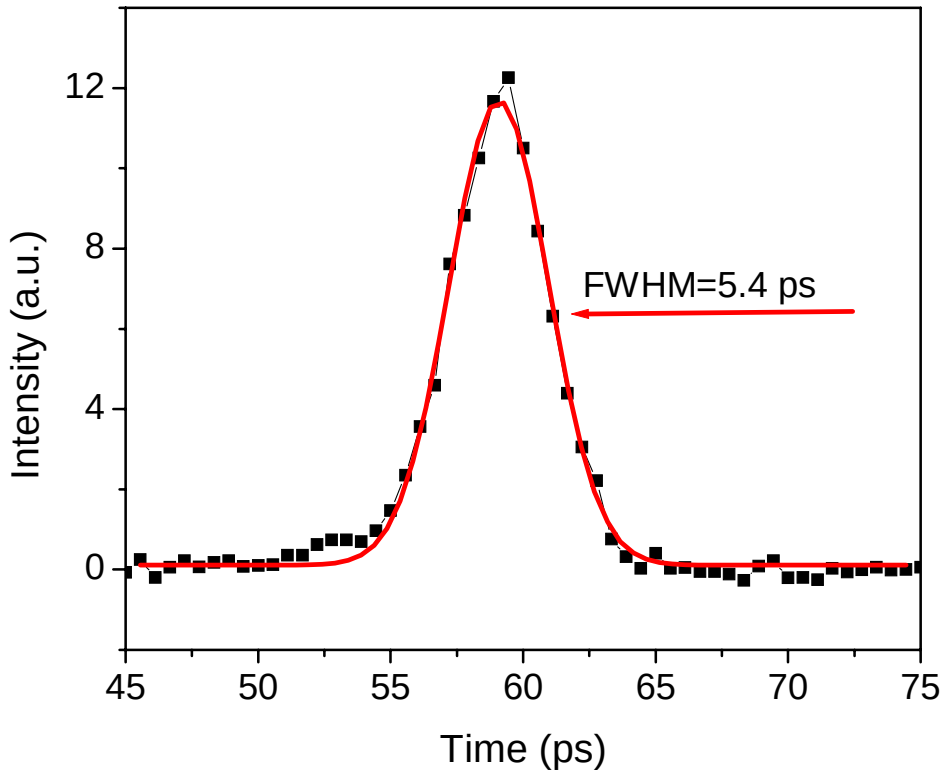




A 50 μm spatial filter is inserted to improve the UV transverse profile. The beam size is about 4.3 mm of FWHM.

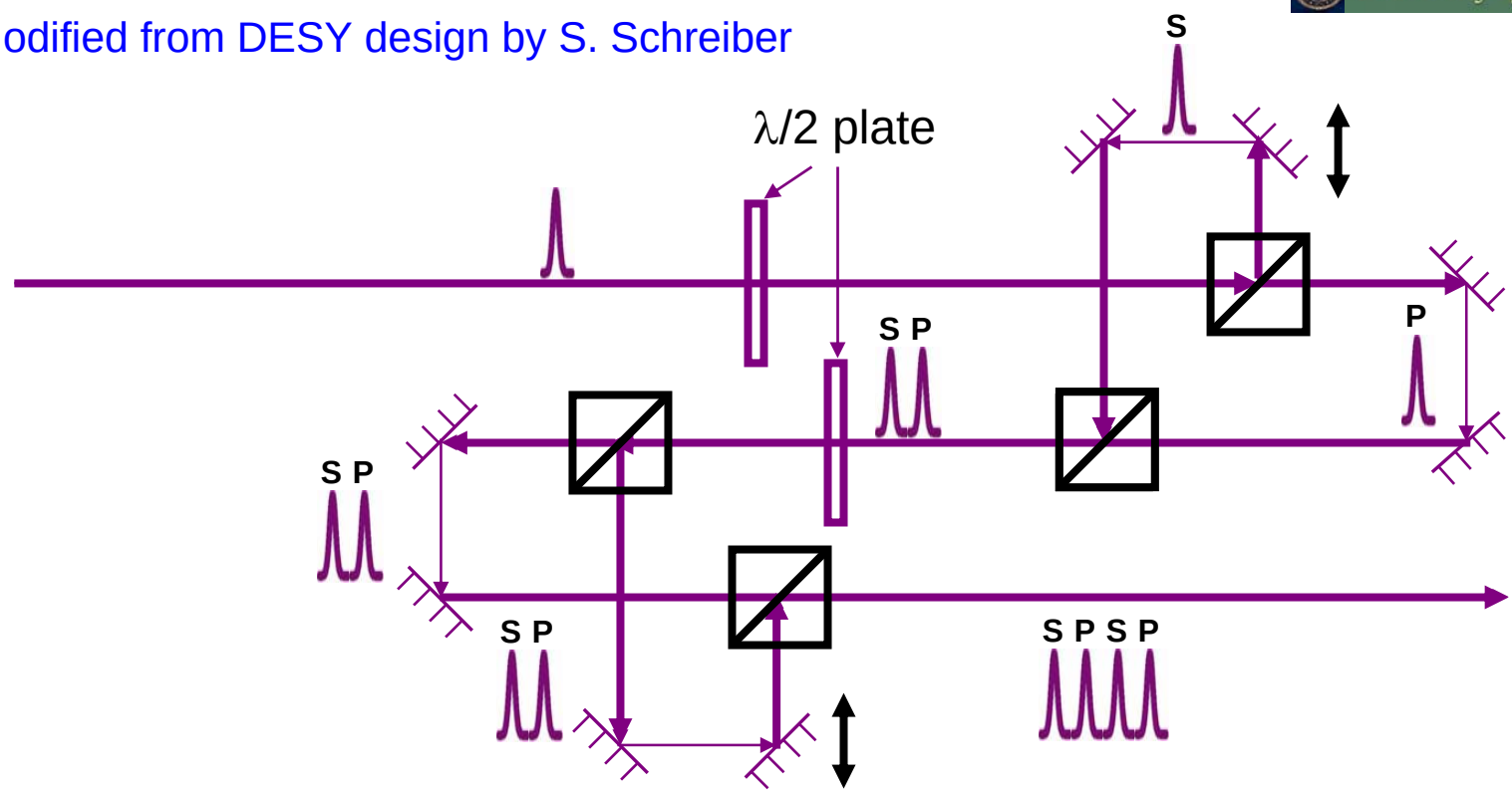
Longitudinal profile of UV pulse

Streak camera measurement



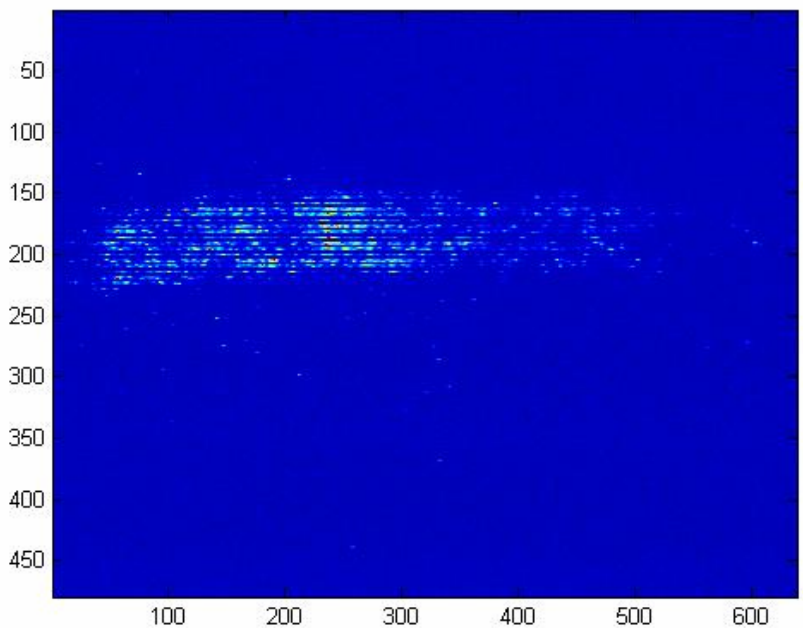
UV pulse stacker

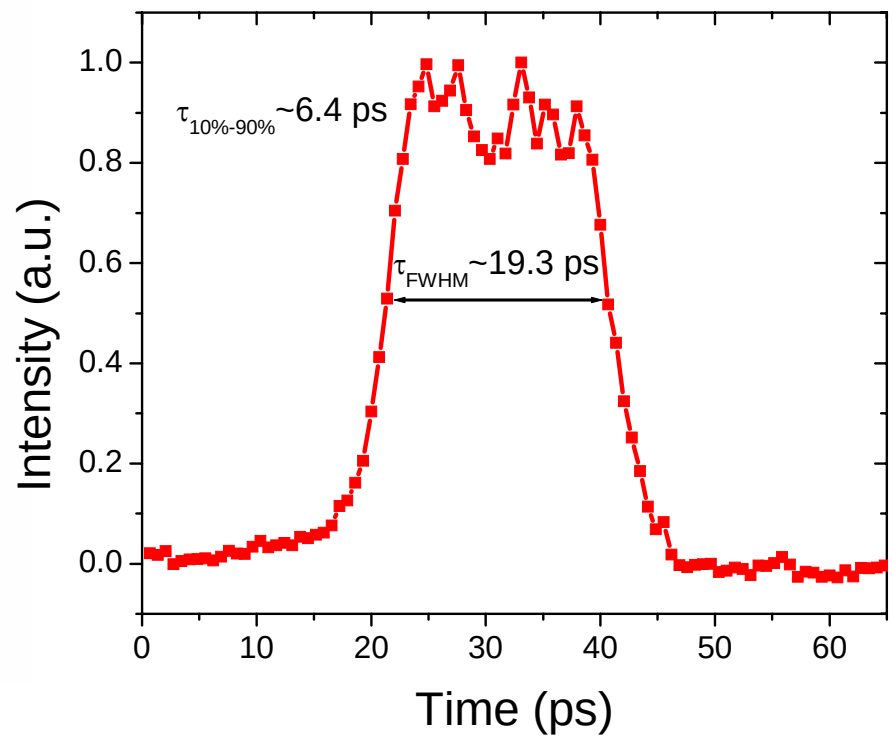
Modified from DESY design by S. Schreiber



Final output has four pulses stacked with adjustable delays and the neighbors have orthogonal polarizations, which eliminates the interference of the pulses both transversely and longitudinally.

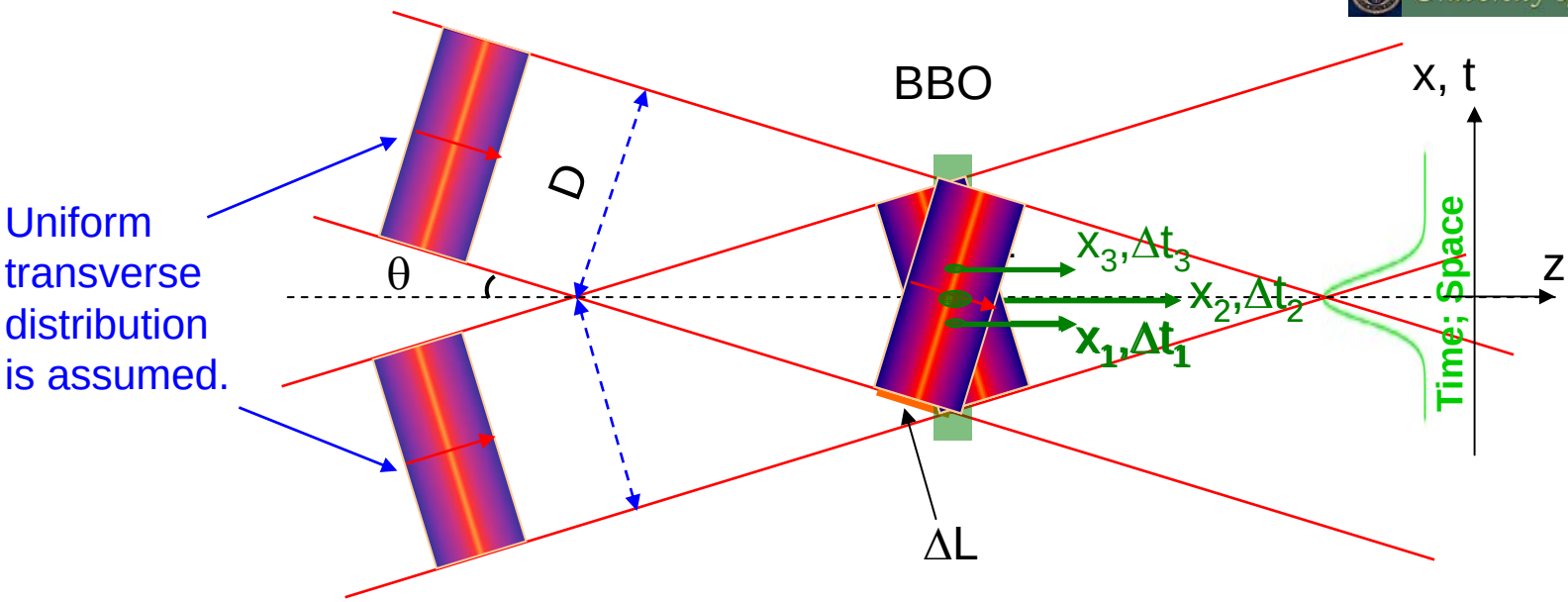
Flat top with four stacked pulses was achieved





Combination of four stacked pulses gives relative flat top. This will suppress the space charge induced emittance growth.

Principle of single shot auto-correlator

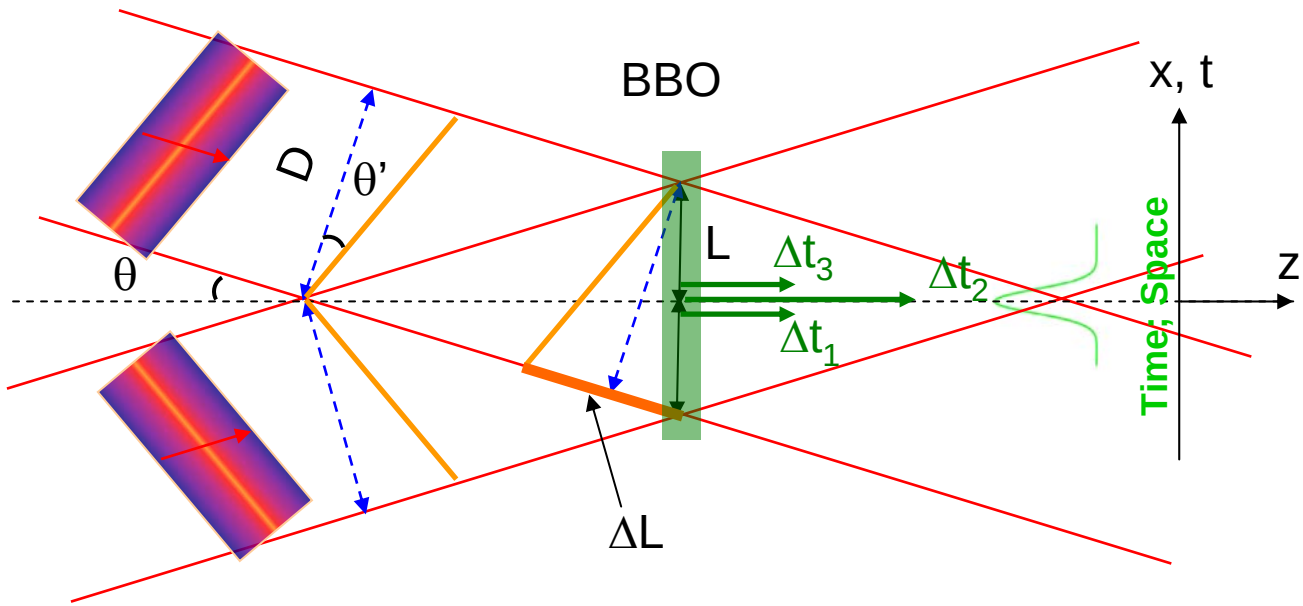


The time window is determined by the maximum delay of the two beams,

$$\Delta T_{\text{time\_window}} = \frac{\Delta L}{c} = \frac{20}{3} \bullet L \bullet \sin(\theta) = \frac{10}{3} \bullet D \bullet \tan(\theta)$$

where ΔT is in ps, x and D mm. Usually θ is a small angle ~ 5°, implying a time window of 2 ps or so. It is not enough for our pulse length of 5 ps.

Tilted wavefront increases time window

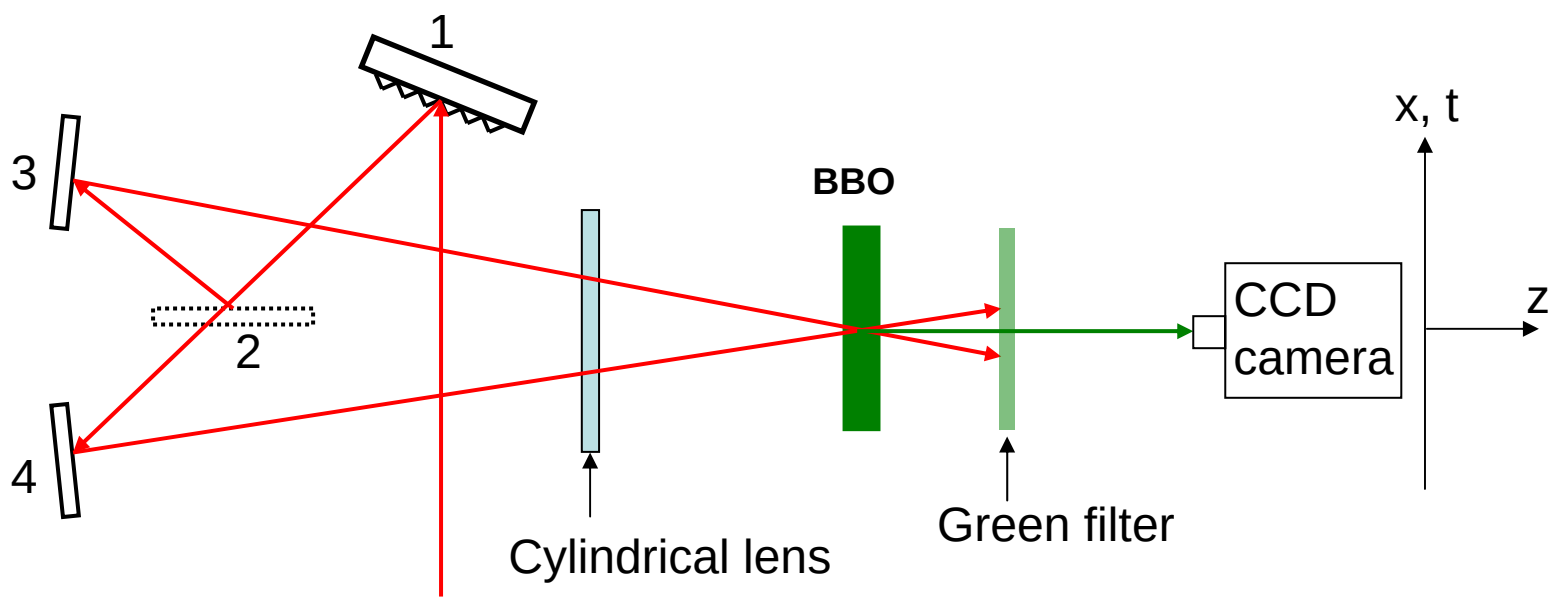


A grating can be used to tilt the wavefront so that

$$\Delta T_{time\_window} = \frac{20}{3} \bullet L \bullet [\sin(\theta) + \sin(\theta')] = \frac{10}{3} \bullet D \bullet [\tan(\theta) + \sin(\theta')/\cos(\theta)]$$

If it is tilted by 45°. The time window becomes 12 ps about enough for the 5 ps pulse.

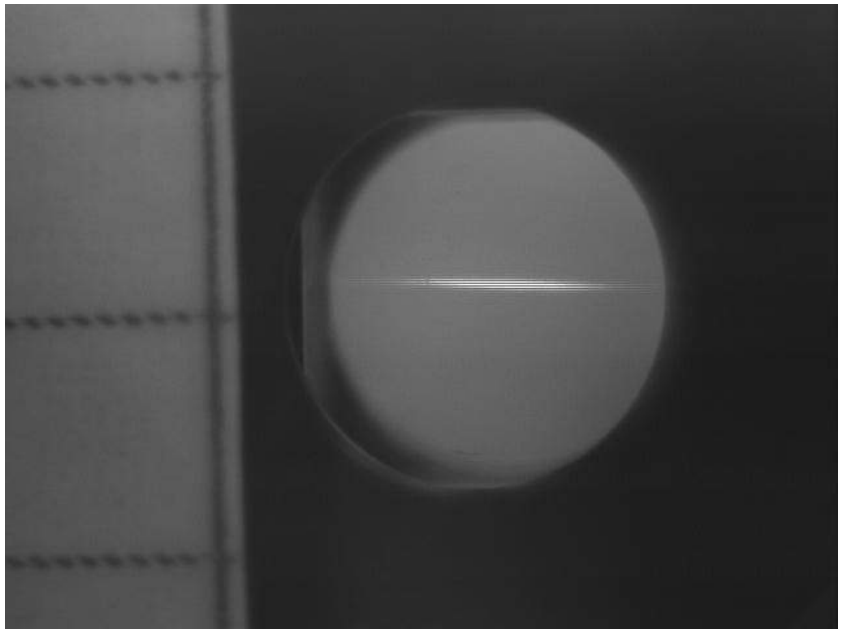
Setup of single shot auto-correlator

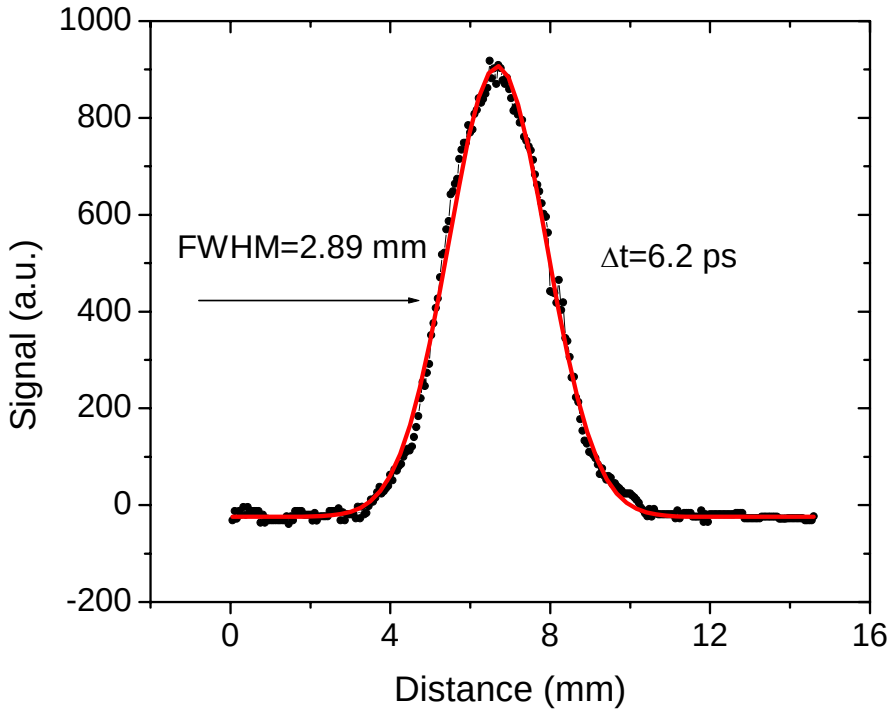


1, grating to tilt the wavefront of the laser beam; 2, 50% beam splitter; 3 and 4, mirrors coated for IR beams.

From technical report of Minioptic Technology Inc.

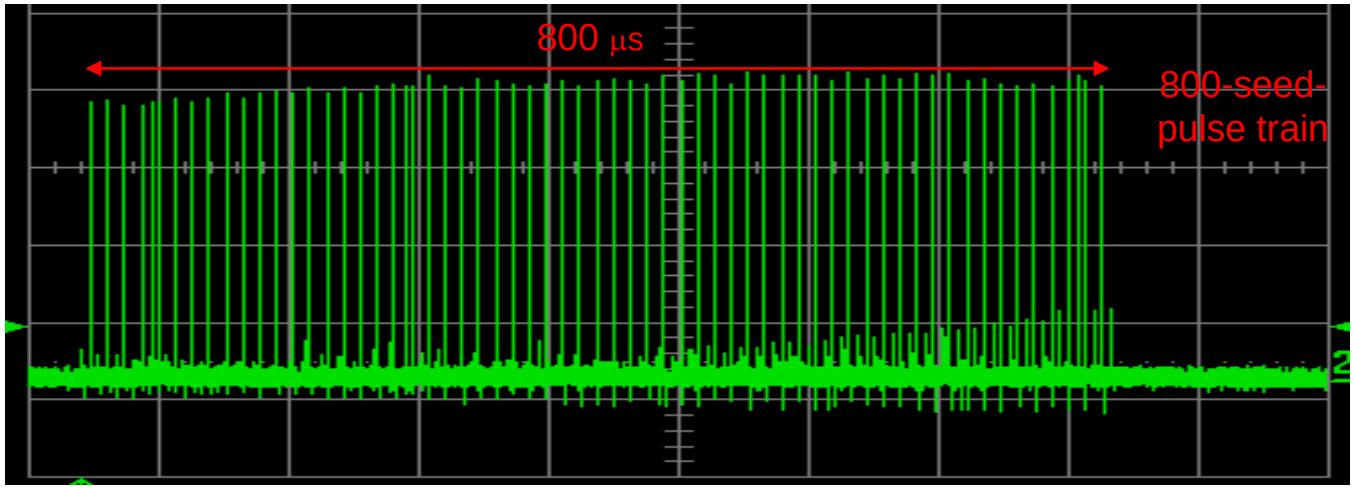
Result of Single Shot AC

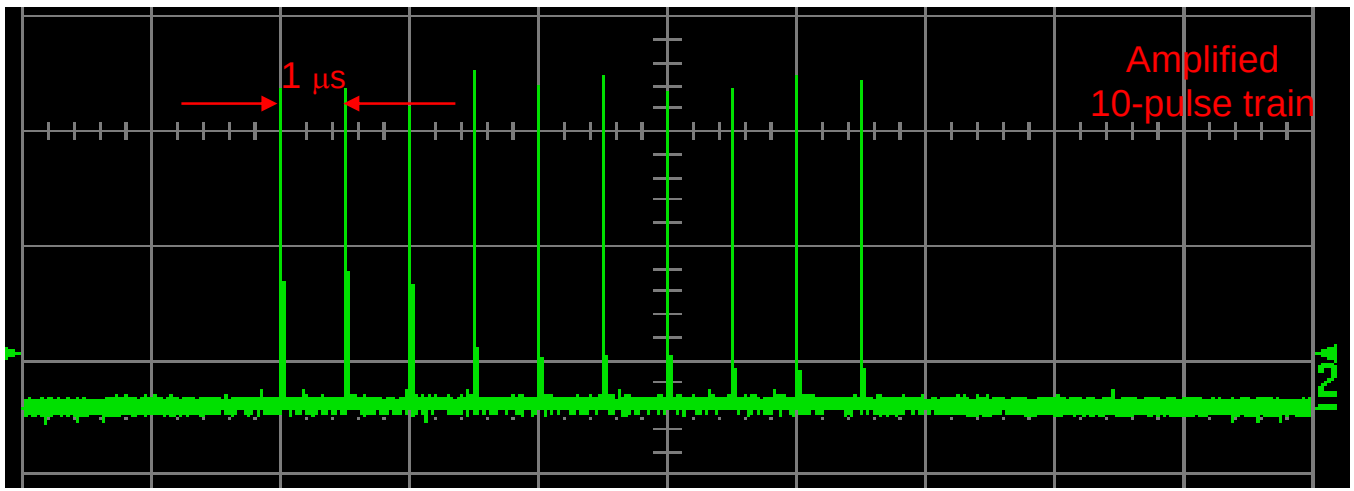




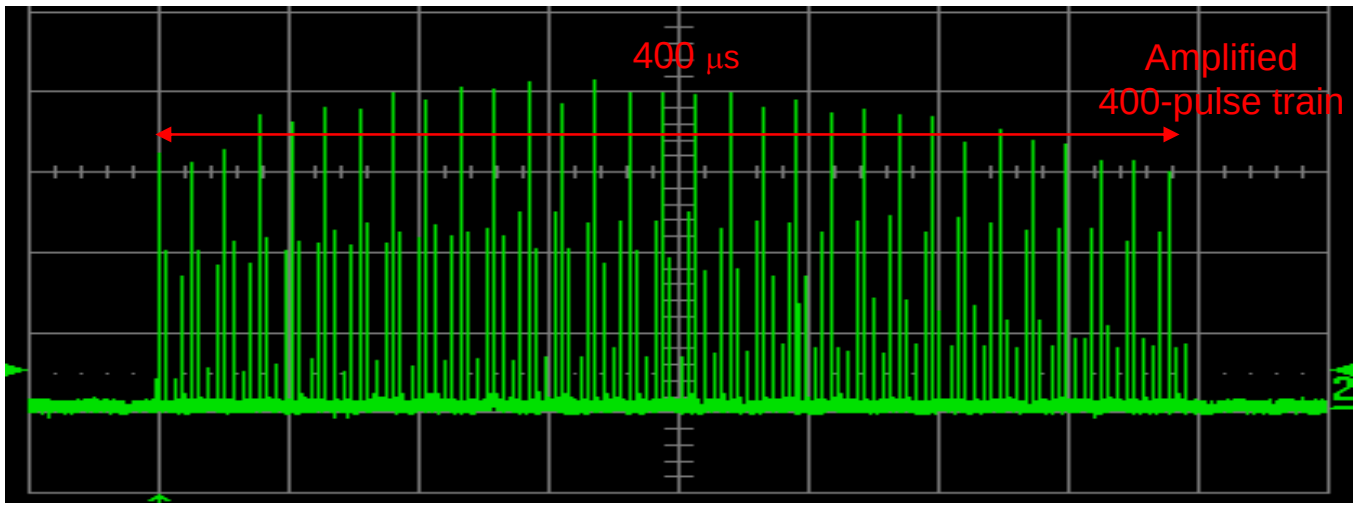
The FWHM was determined to be ~6.2 ps, which corresponds to 4.4 ps for single pulse. This is a little shorter than 5.4 ps UV pulse measured by streak camera. The discrepancy is caused by the non-uniform transverse profile of the input beam.

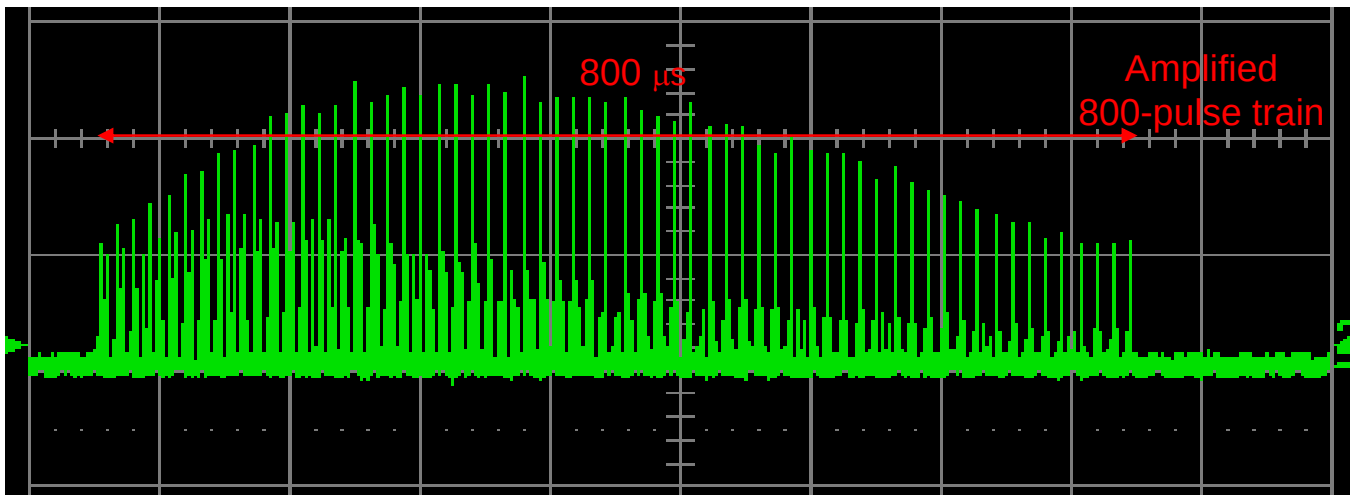
Long pulse train I





Long pulse train II





Future upgrade of the laser system for SMTF

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- Laser requirements of SMTF
- Further upgrade of the laser system
- Construction of transverse flattop beam
- Filling 4 successive RF accelerating buckets

Laser requirements of SMTF

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Parameters	A0	SMTF
Beam pulse length	~0.8 ms	1 ms
Bunch charge	>4 nC	3.2 nC
Charge stability	5%	5%
Micro bunch distance	1000 ns	337 ns
Number of bunches	~800	up to 2820
Pulse rep-rate	1 Hz	up to 5 Hz

We need to increase the number of bunches in each pulse train and the duty cycle and reduce the distance between bunches.

Long pulse train with high rep-rate

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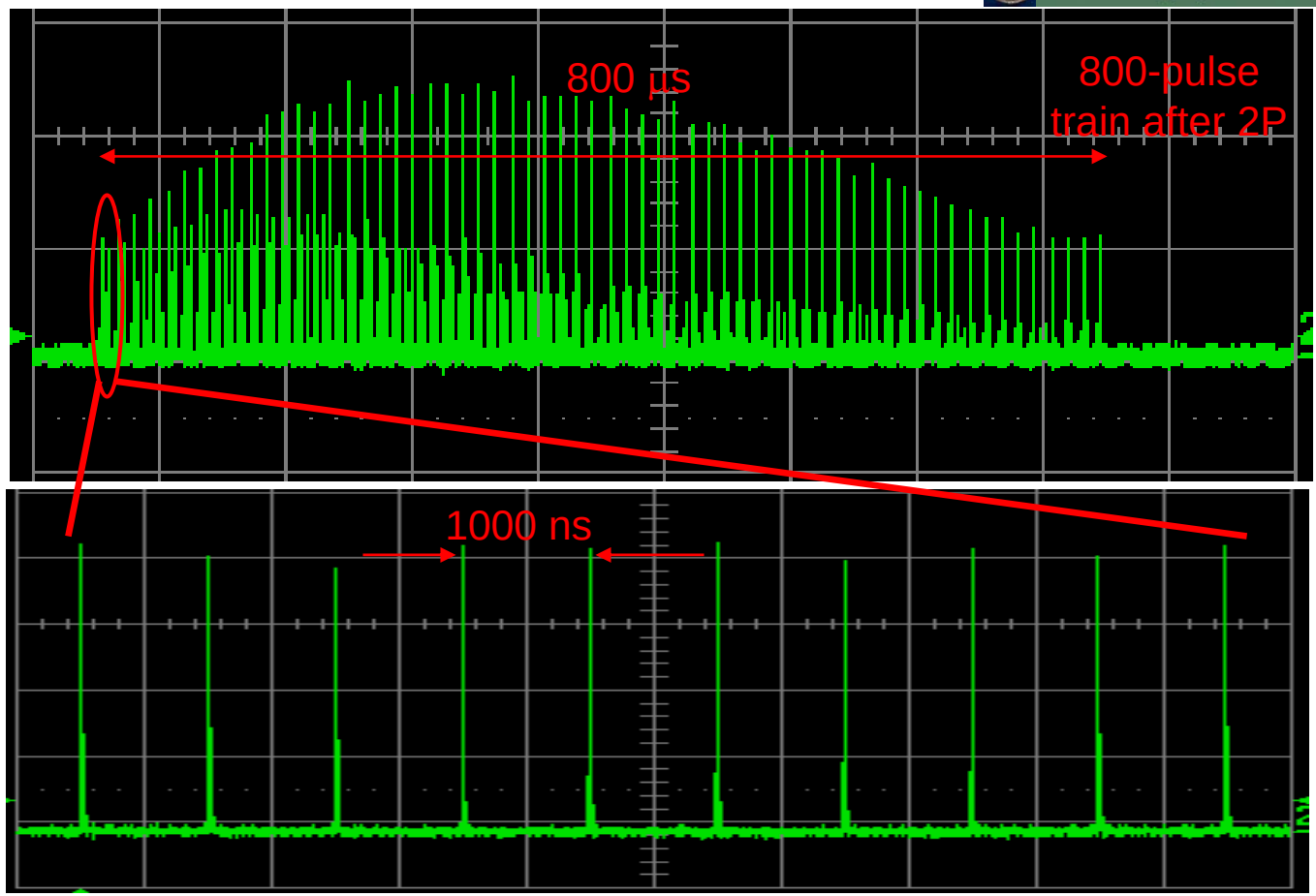
Increase pulse length from 800 μs to 1 ms.

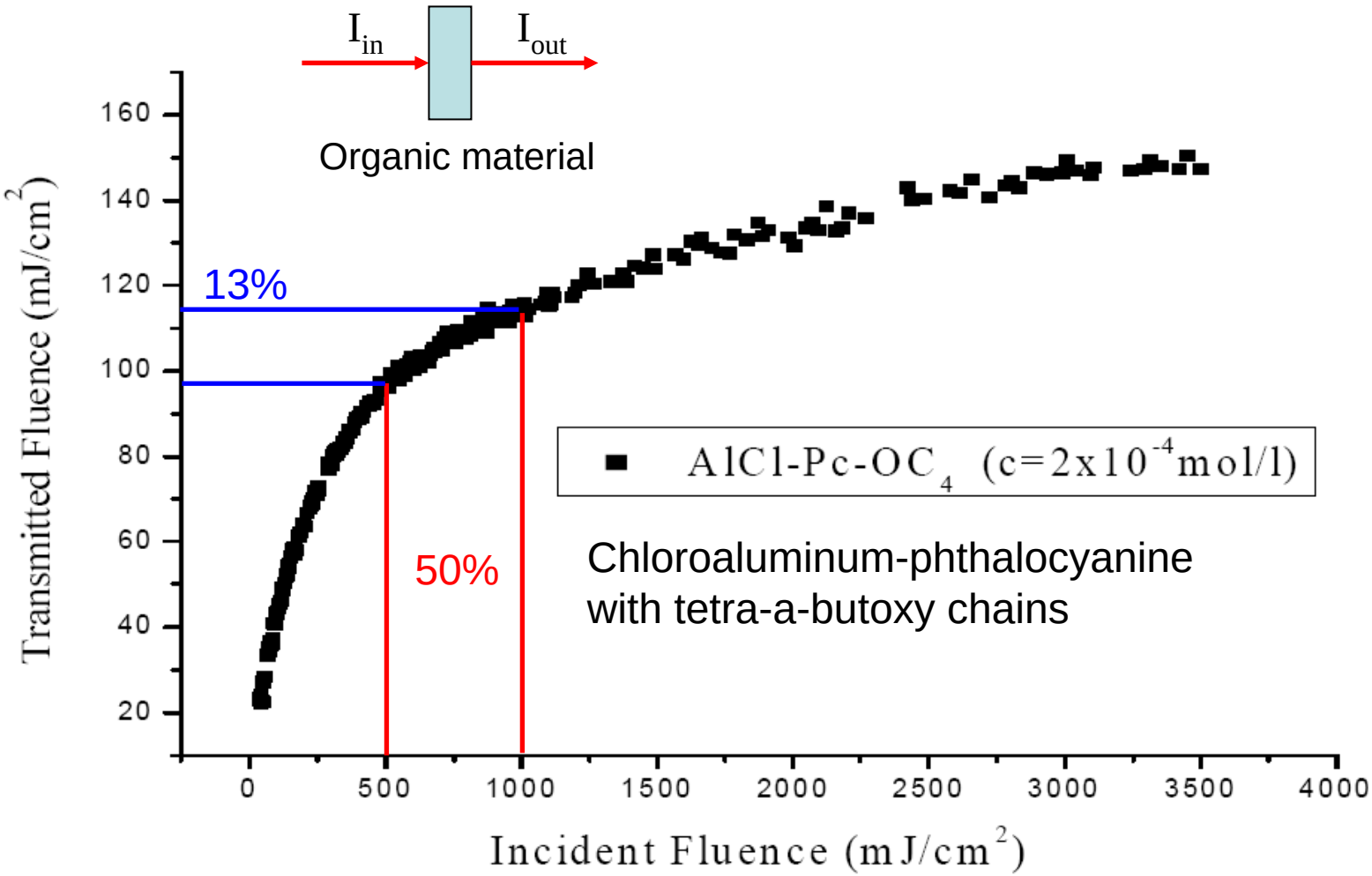
Decrease the bunch spacing from 1 μs to 337 ns.



Make it happen five times per second (Nd:YLF has five times larger thermal conductivity than Nd:glass).

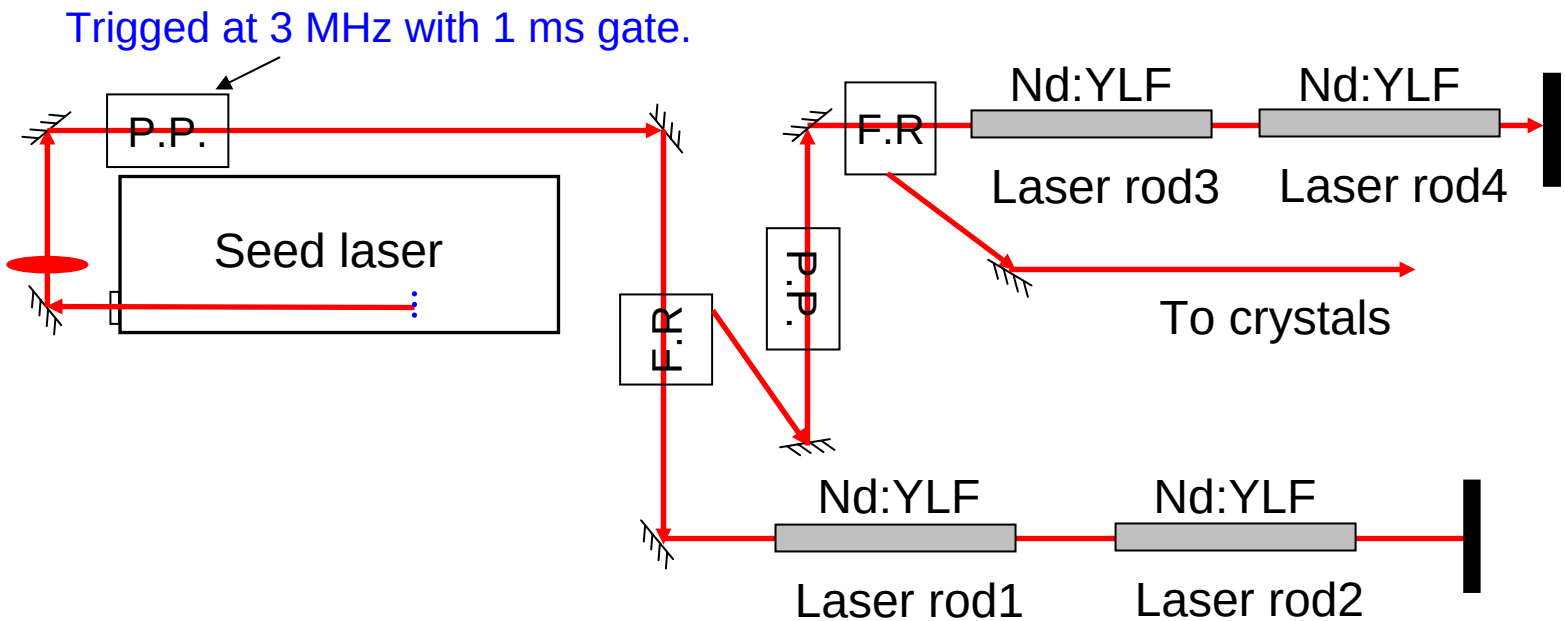
Make the long train flat (pre-shaping and Optical Limiting).

Besides pre-shaping, optical limiting effect can reduce the intra-train fluctuation



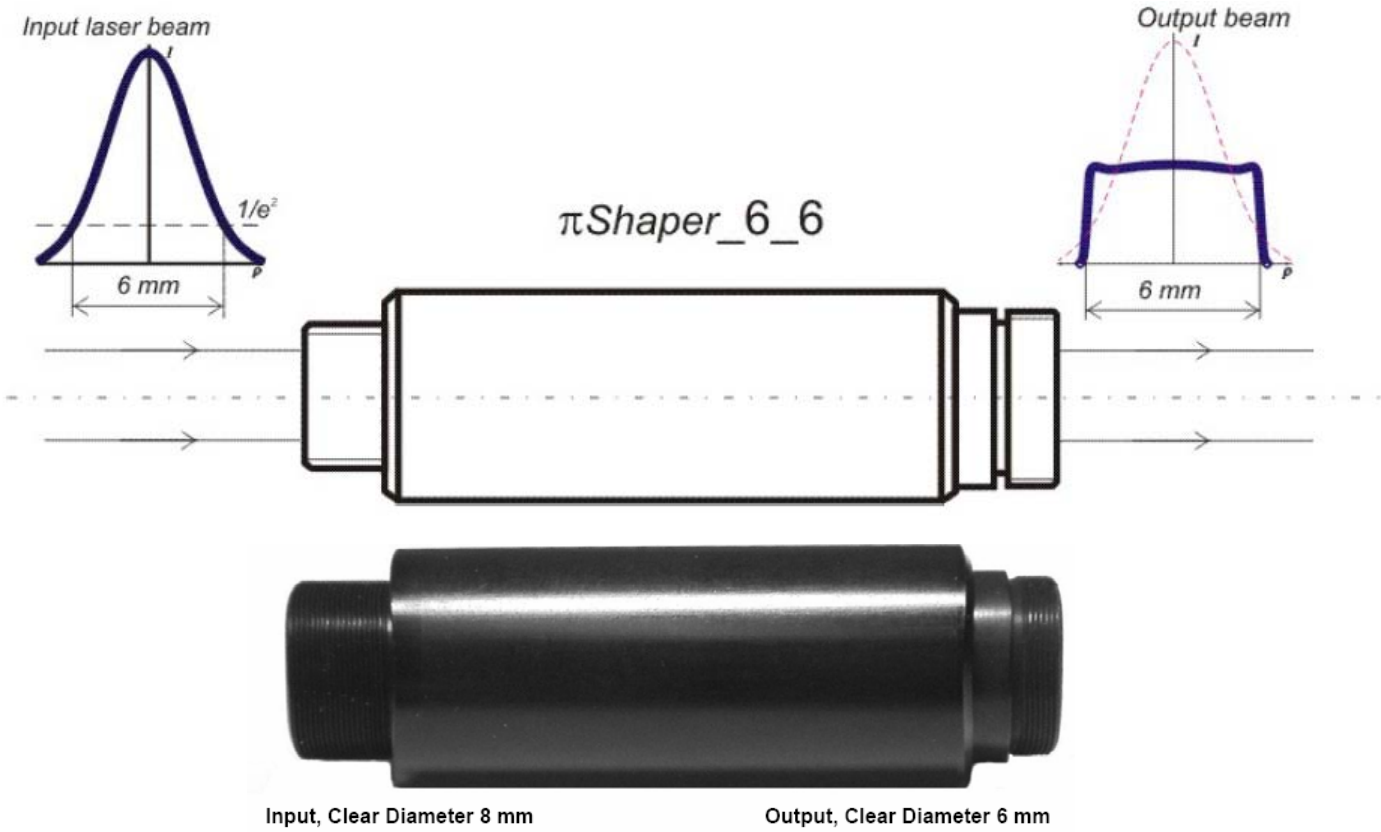
From Quan Gan et al., Optics Express, Vol. 13, No. 14, 5424(2005)

New schematic design for future upgrade of the laser system



1. All the optics should be installed on one optical table.
2. Flash pumped Nd:glass M.P. should be replaced by diode pumped Nd:YLF.
3. The pulse picker must be trigged at 3 MHz with 1 ms gate and 5 Hz rep-rate.
4. Coupling of seed laser to amplifiers must be redesigned.
5. Another P.P. is needed to increase extinguish ratio and reduce beam loading.

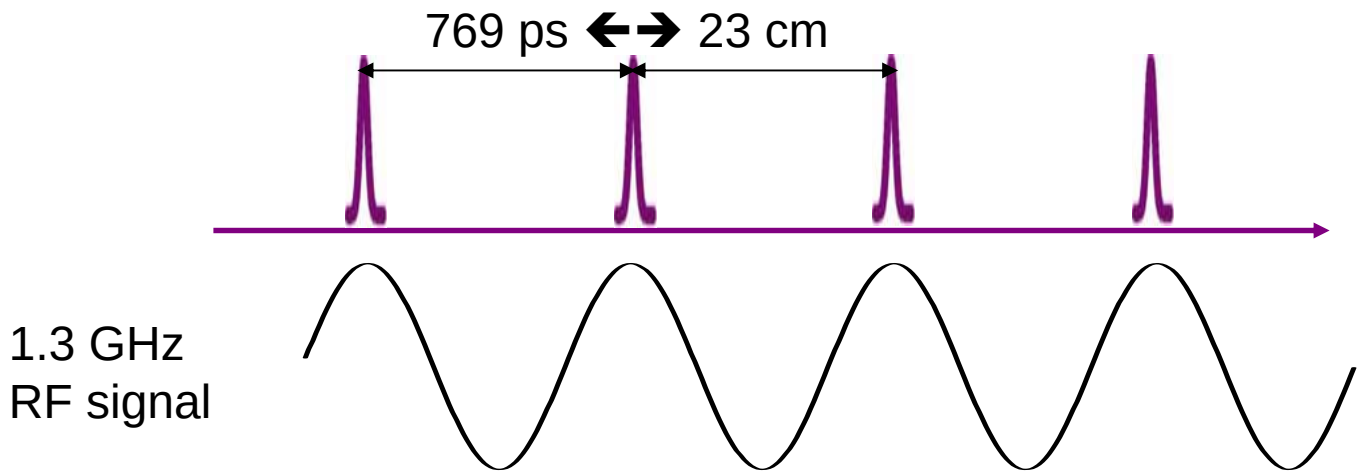
π Shaper converts Gaussian beam to flattop



Input size is fixed and not good for long distance transport (> 20 m).

From http://www.mt-berlin.com/frames_home/shaper_descr.htm

Modified pulse stacker can fill 4 successive RF accelerating buckets



Delaying each pulse by 769 ps, we can fill 4 successive RF accelerating buckets. It is very doable in laser room to separate the pulses by 23 cm, but more thoughts are needed to design experiments that can take this advantage.

Single shot EO sampling for real time diagnostics of electron bunch length

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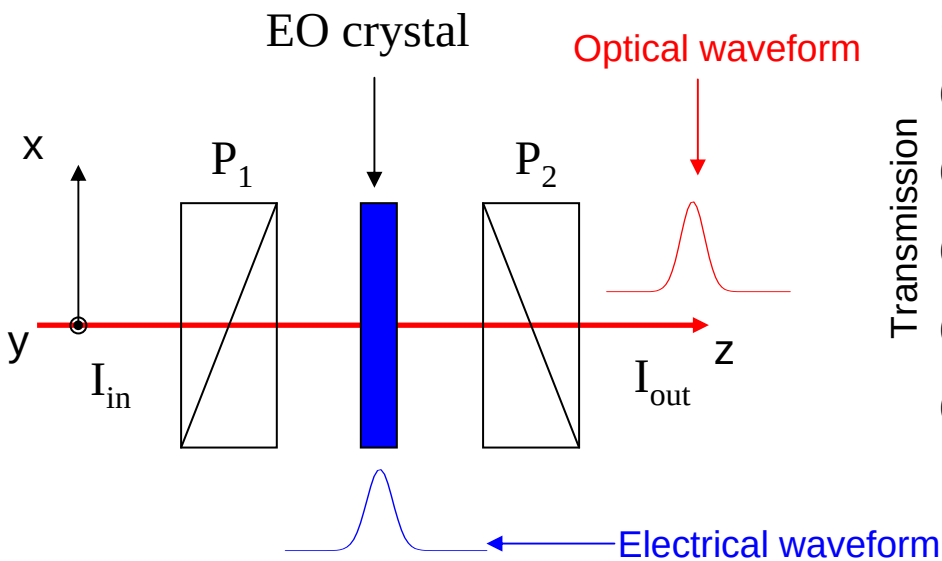
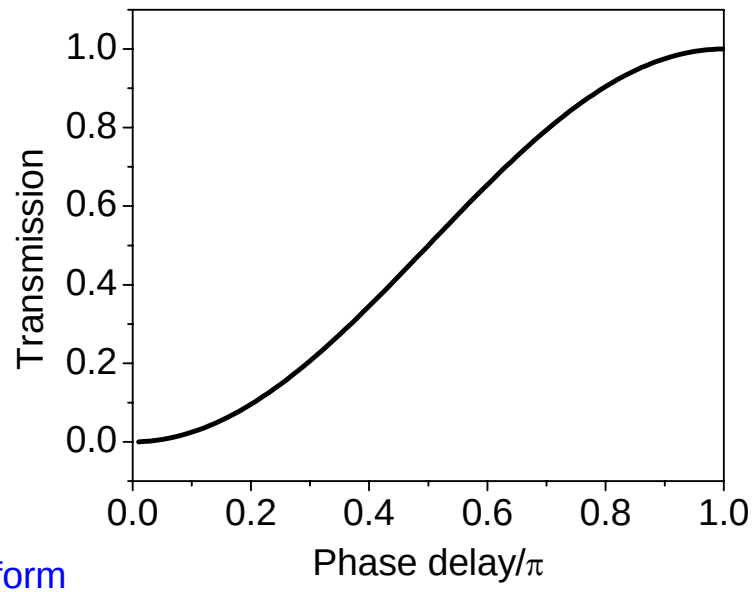
- Principle of EO sampling
- EO sampling with spectral decoding
- EO sampling with temporal decoding
- EO sampling with spatial decoding
- BPM with sub-picosecond time resolution

Principle of EO sampling

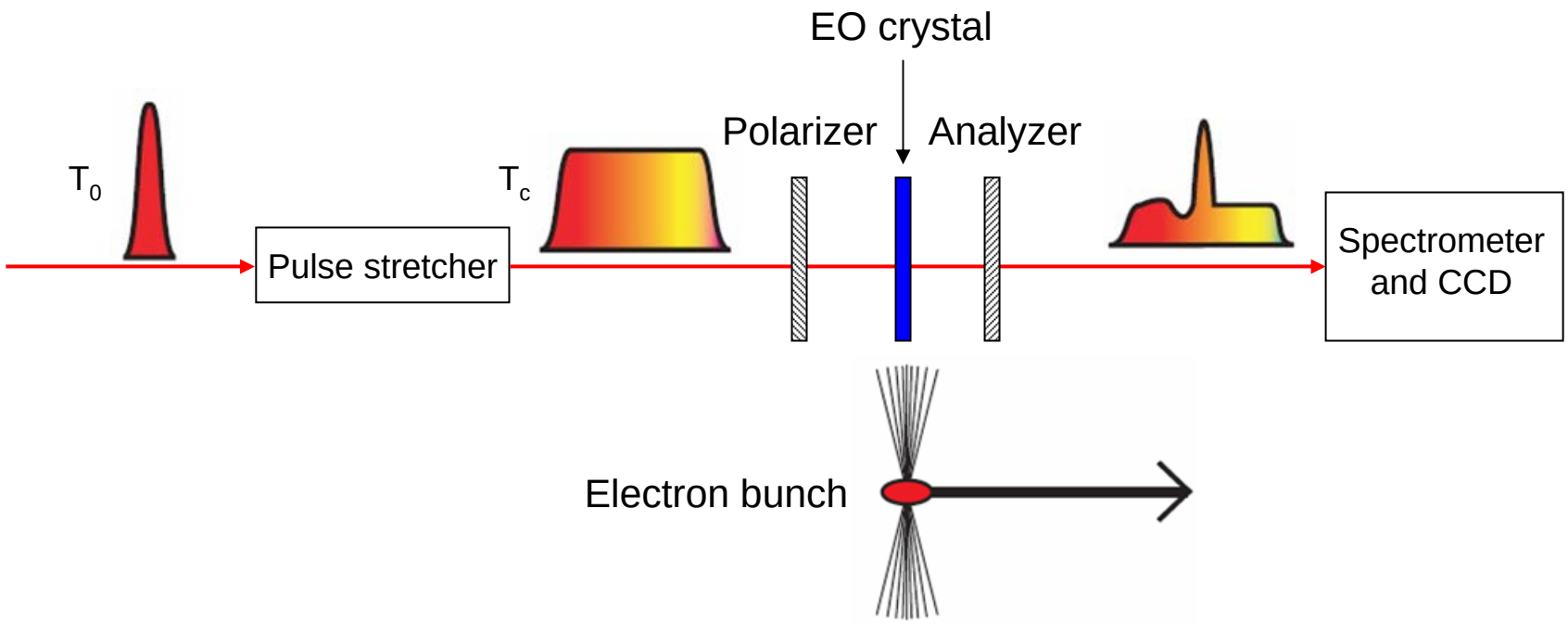




No external electric field,
no EO effect,
no output ➔ $T=I_{out}/I_{in}=0$.

Under external electric field, EO effect introduces phase delay between two polarizations of the laser beam. The phase delay can be determined by the measured T.

Single shot EO sampling with spectral decoding



From I. Wilke et al., Phys. Rev. Lett., Vol. 88, No. 12, 124801(2002)

Limitations of spectral decoding

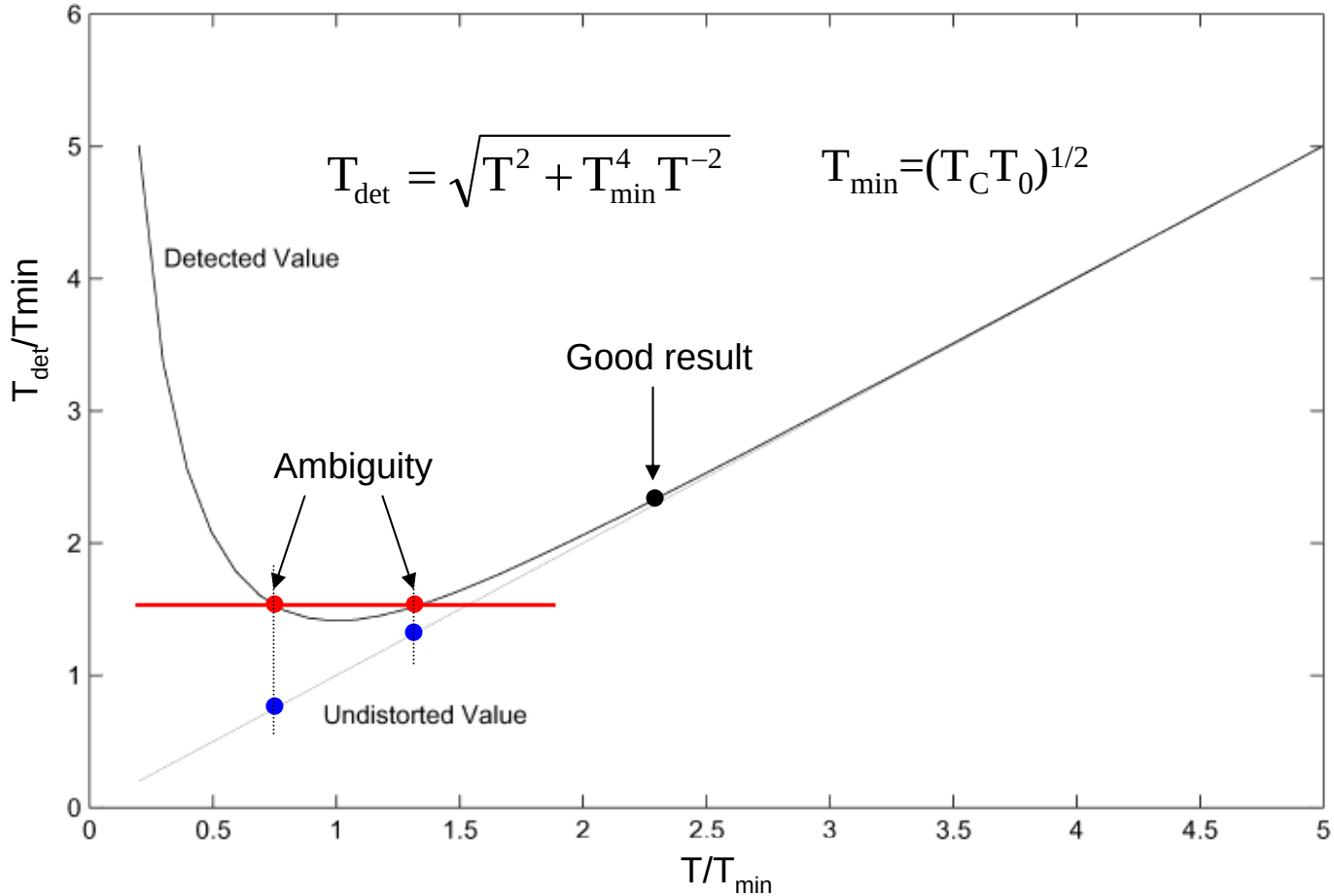
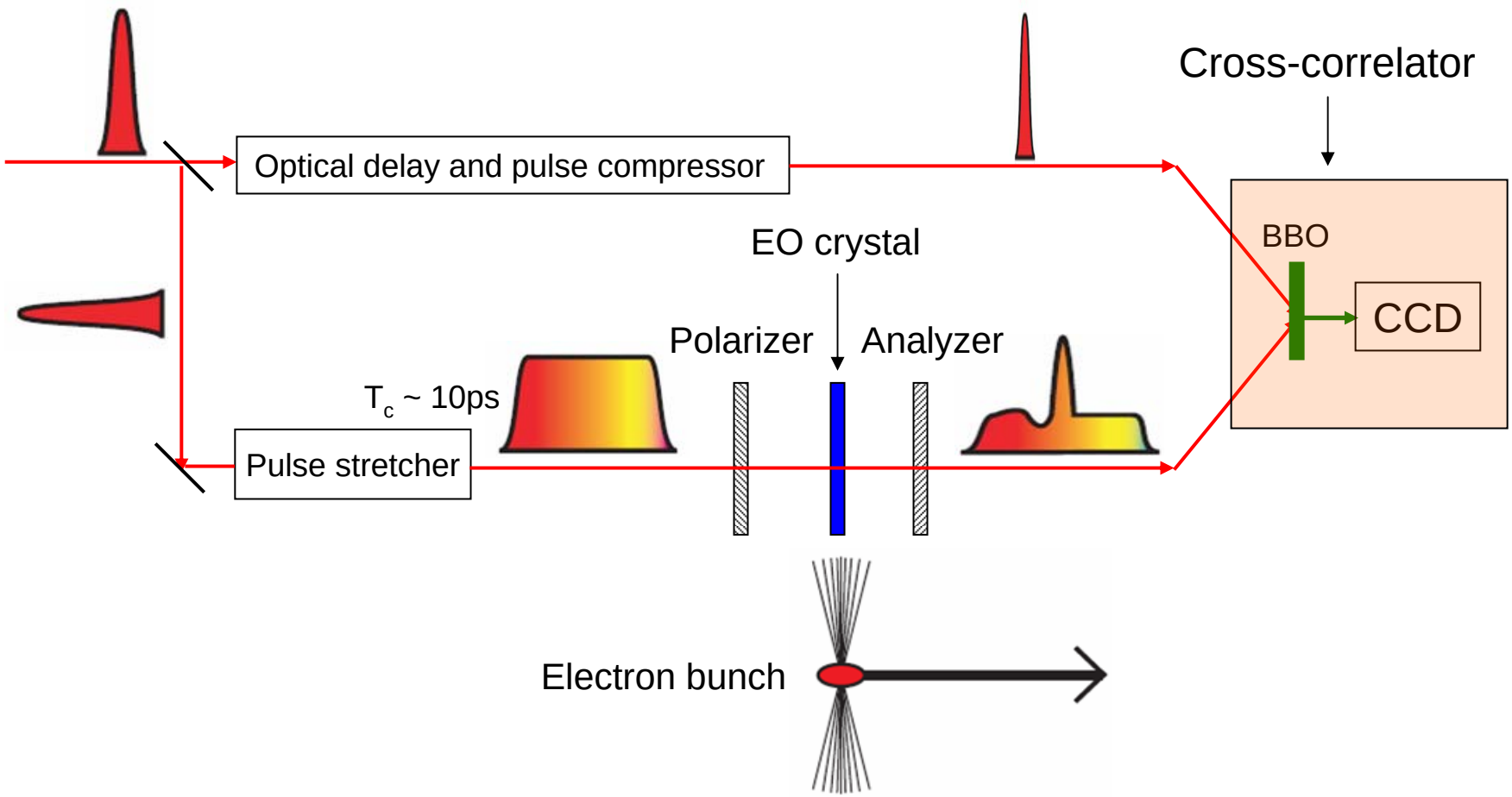


Fig. 1. Variation of detected pulse length versus input pulse length for strong signals.

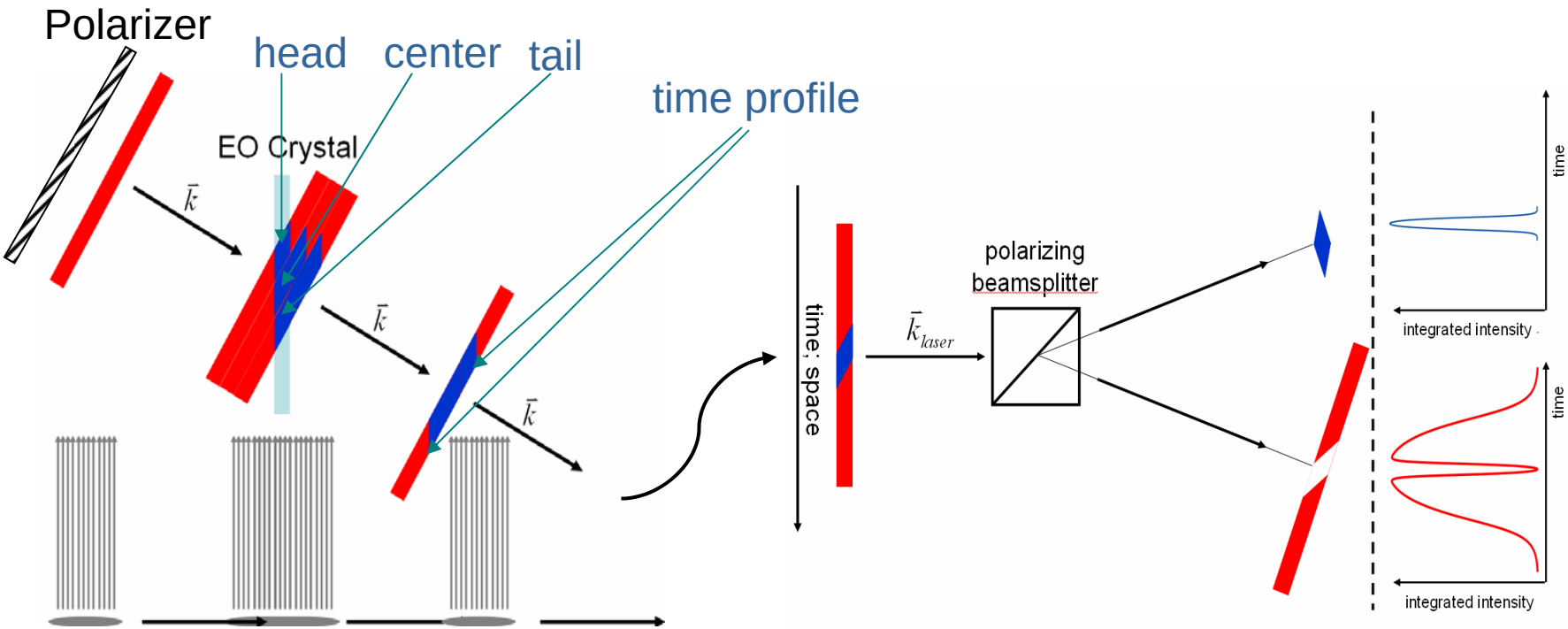
From J. R. Fletcher, Optics Express, Vol. 10, No. 24, 1425(2002)

Single shot EO sampling with temporal decoding



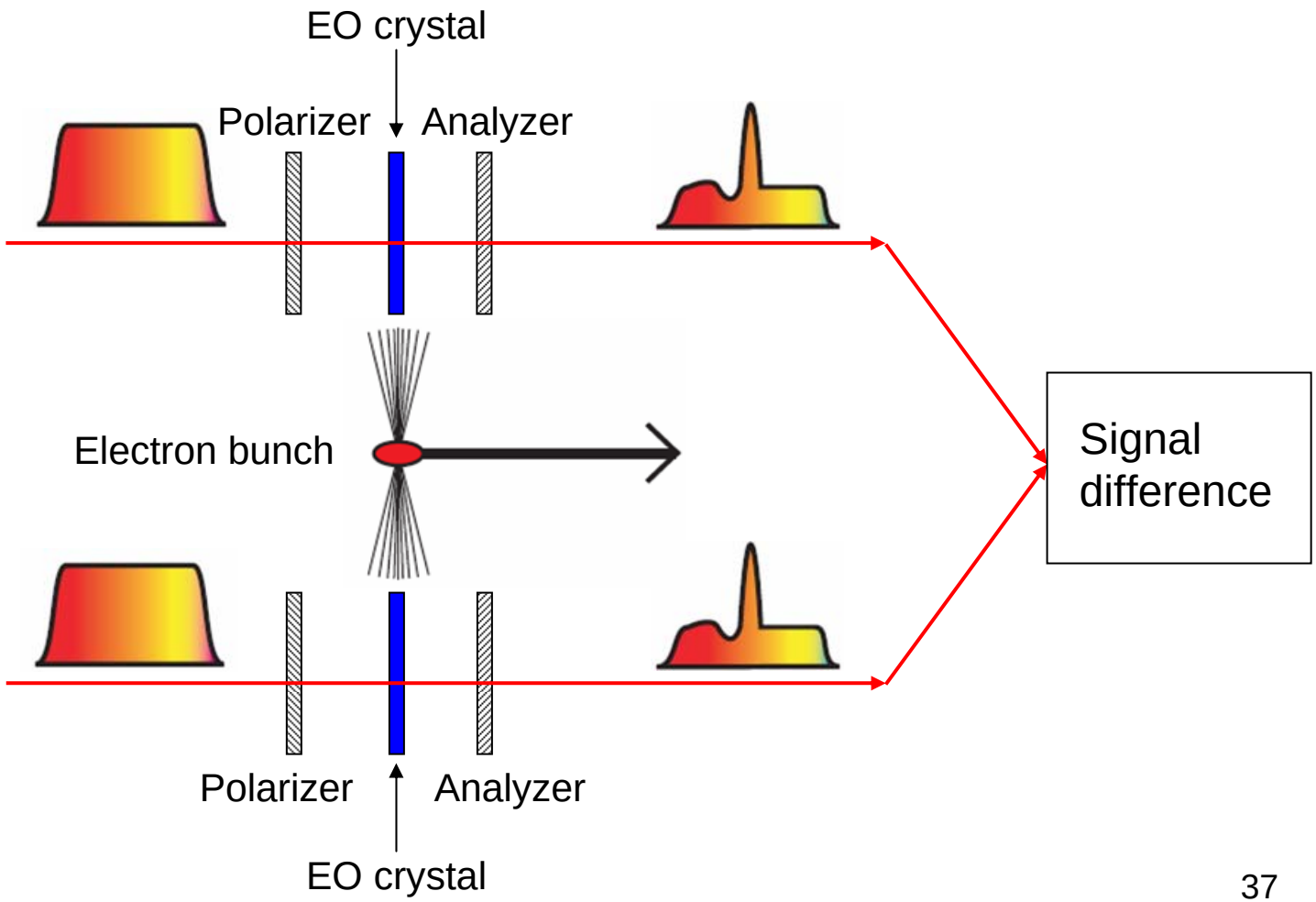
From G. Berden, et al., Phys. Rev. Lett., Vol. 93, No. 11, 114802(2004)

EO sampling with spatial decoding



From A. L. Cavalieri, et al., Phys. Rev. Lett., Vol. 94, 114801(2005)

BPM with sub-picosecond time resolution (dream on!)



Laser acceleration of electrons

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- Open iris-loaded structure
- Diagram of laser acceleration
- Generation of TE_{01}^* “donut” mode
- Theoretical simulations

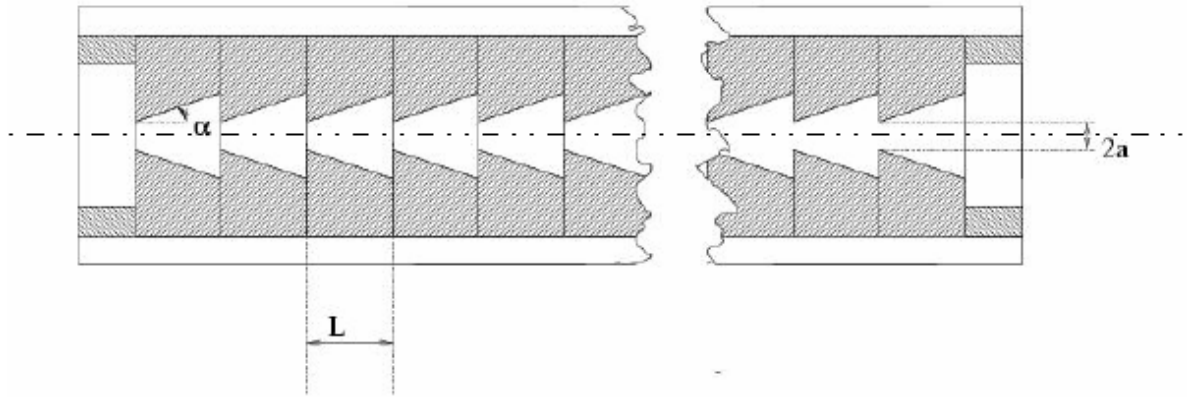
Eigenmode of open iris-loaded structure gives longitudinal filed for acceleration

R. Pantell (NIM A 393, 1(1995))

M. Xie (LBNL-40558 and PAC 97)

No side walls;
L, a >> λ;

➔ "**open**"



The fields associated with TEM mode are given by,

$$E_z(r,z,t)=\hat{E}\,J_0(k_r r)\exp(i(k_z z-\omega t))$$

$$E_r(r,z,t)=Z_{TM}H_\phi=-i\frac{k_z}{k}\hat{E}\,J_1(k_r r)\exp(i(k_z z-\omega t))$$

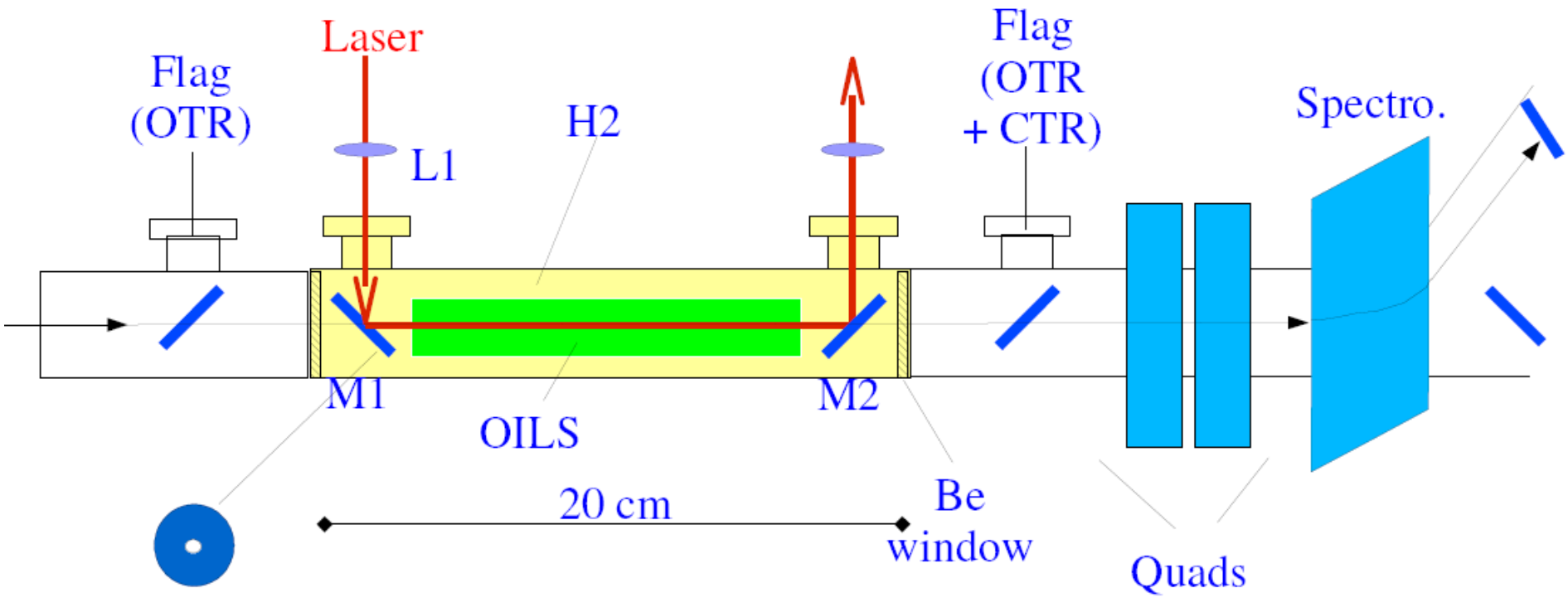
where, $\hat{E}$ is the axial peak electric field, k=nω/c.

The phase velocity of the wave is,

$$v_\phi=\frac{\omega}{\Re(k_z)}\approx\frac{c}{n}\left[1+\frac{1}{2}\left(\frac{p_{10}\lambda}{2\pi a}\right)^2\right]$$

Where λ is the wavelength, $J(p_{10})=0$, n refractive index and c speed of light.

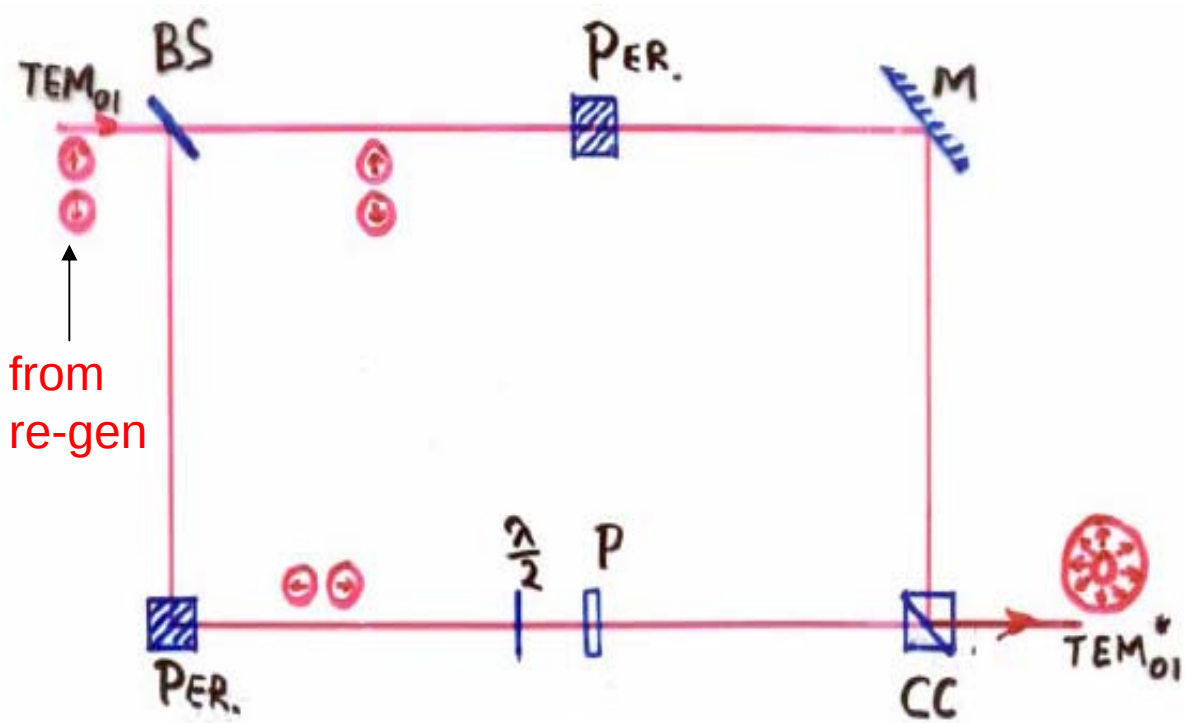
Schematic diagram of laser acceleration

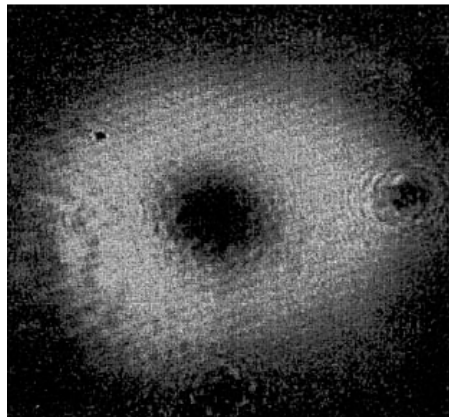


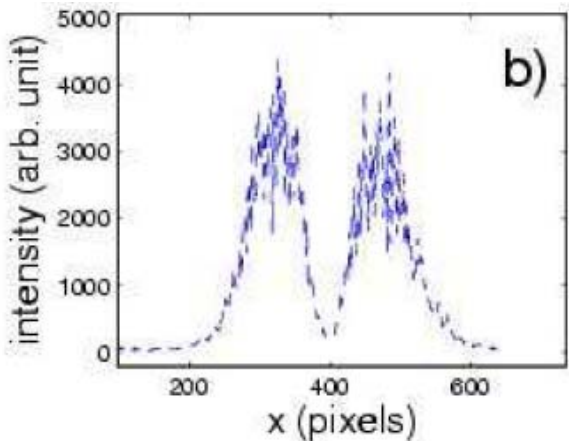
The chamber is filled with gas to compensate the phase slippage.

From Ph. Piot, ACC workshop, Stony Brook (2004)

TEM_{01}^* donut mode has been generated at A0 with a Mach-Zender interferometer







R. Tikhoplav et al., Proceedings of EPAC 2002, Paris, France

Simulation with single electron

Parameters:

2a=1mm;

$\alpha > \lambda/a$;

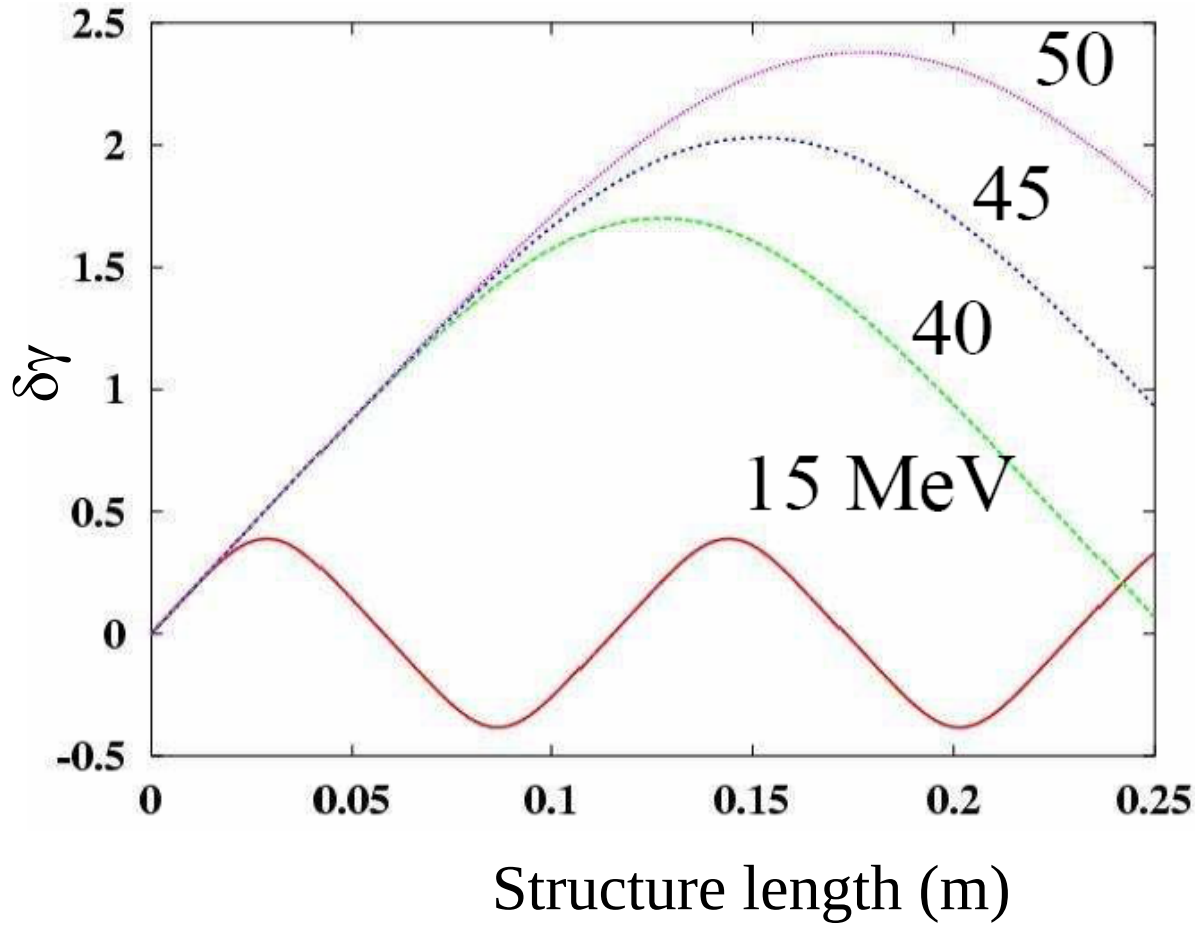
Elements #: 50

L=2mm;

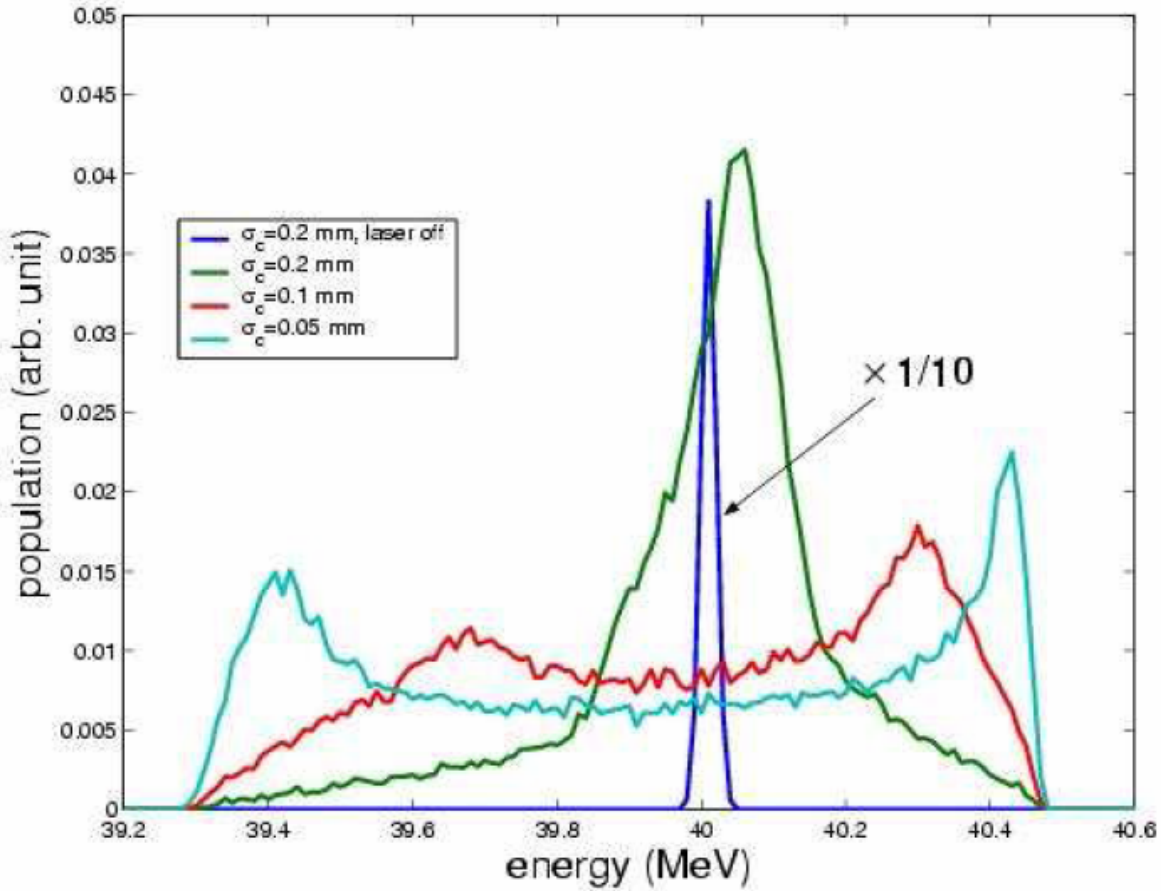
λ=1054 nm;

E_{laser}=20 mJ;

Pulse length=2ps;



Simulation with electron bunch



Evolution of the energy spectrum for electron bunch with various beam size propagating in the laser field.

Laser system for polarized electron source

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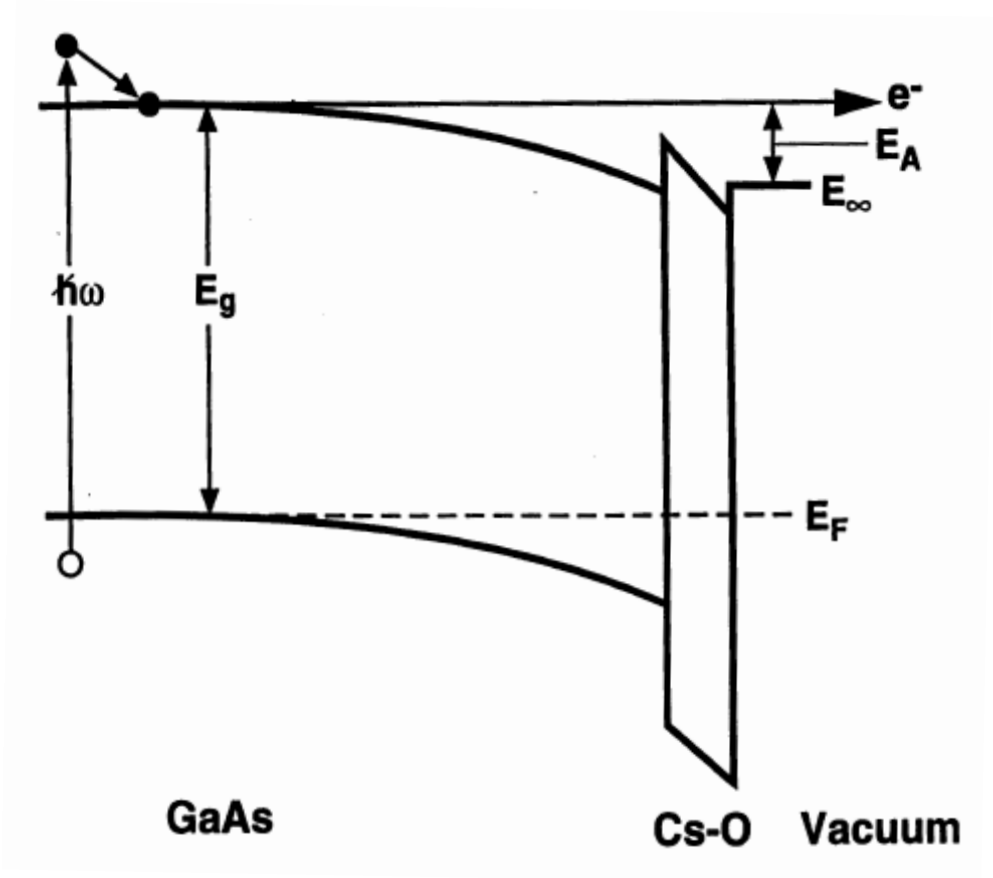
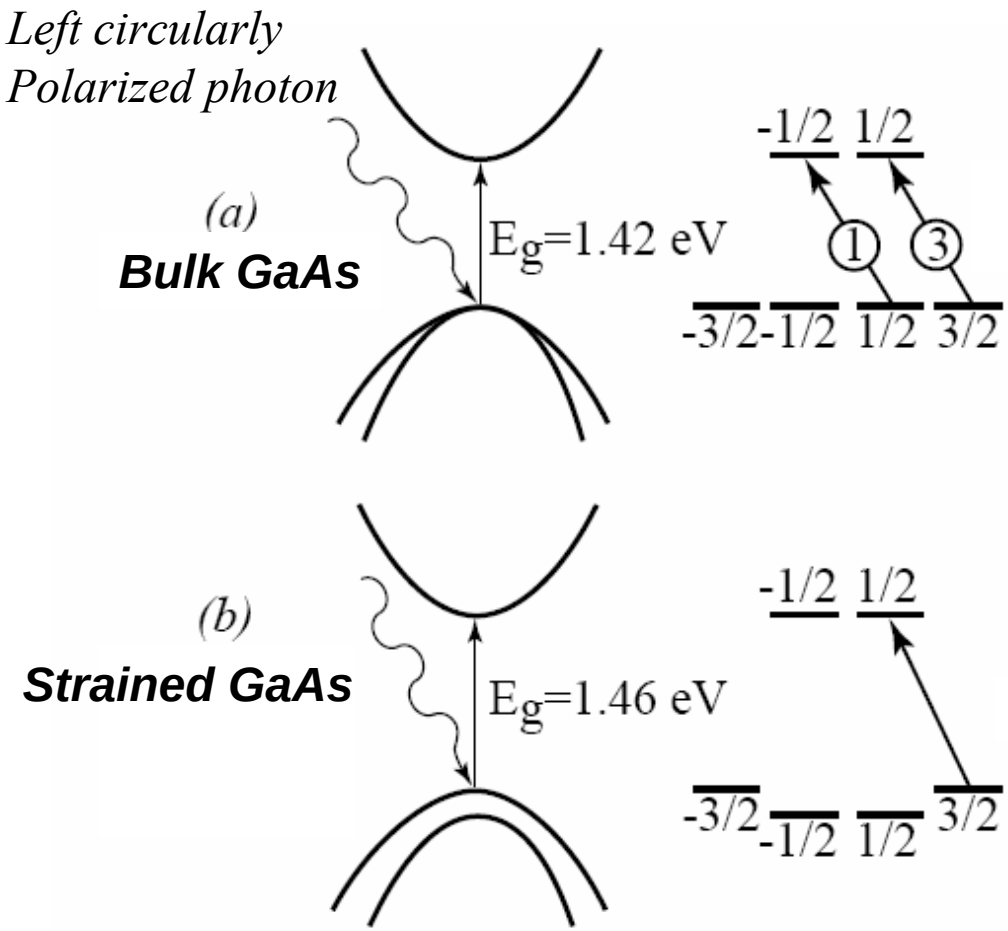
- Principle of GaAs photoemission
- Laser parameters for ILC
- Prototype laser system based on Ti:Sapphire

Negative electron affinity (NEA) in GaAs



In strained GaAs energy levels split



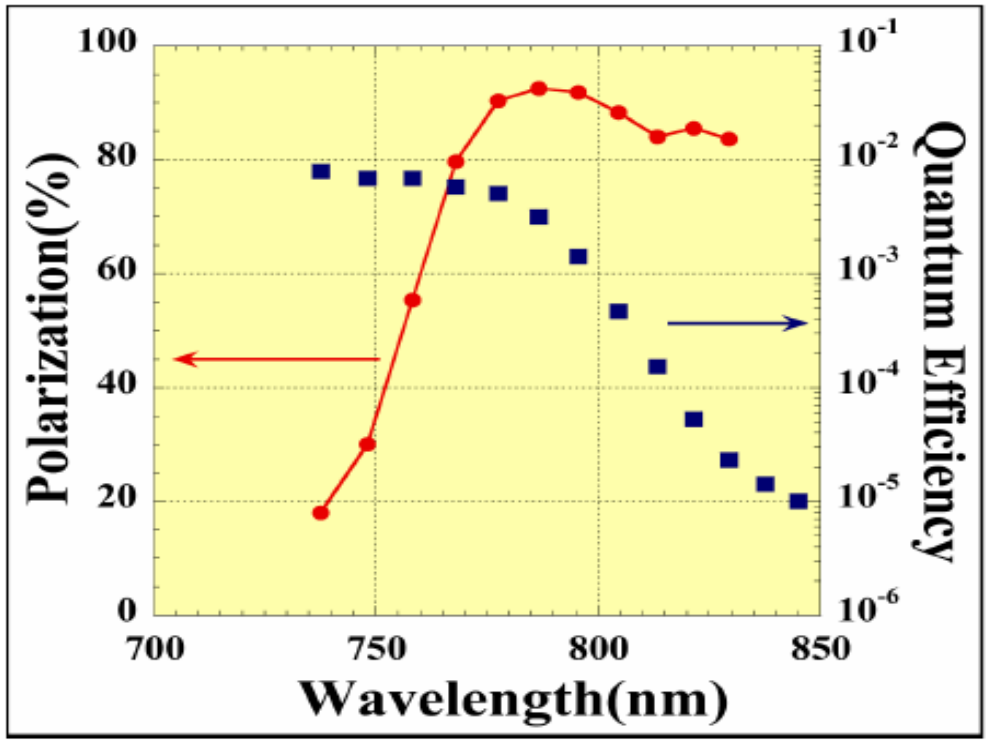
Polarization is at best 50%.

Polarization could be close to 100%.

Most recent results on polarization and quantum efficiency in strained GaAs

University of Rochester

Nagoya (MOCVD)



Polarization 85 - 90%
QE 0.5 - 1%

From Takashi Maruyama, KEK ILC workshop (2004).

Laser parameters recommended for ILC

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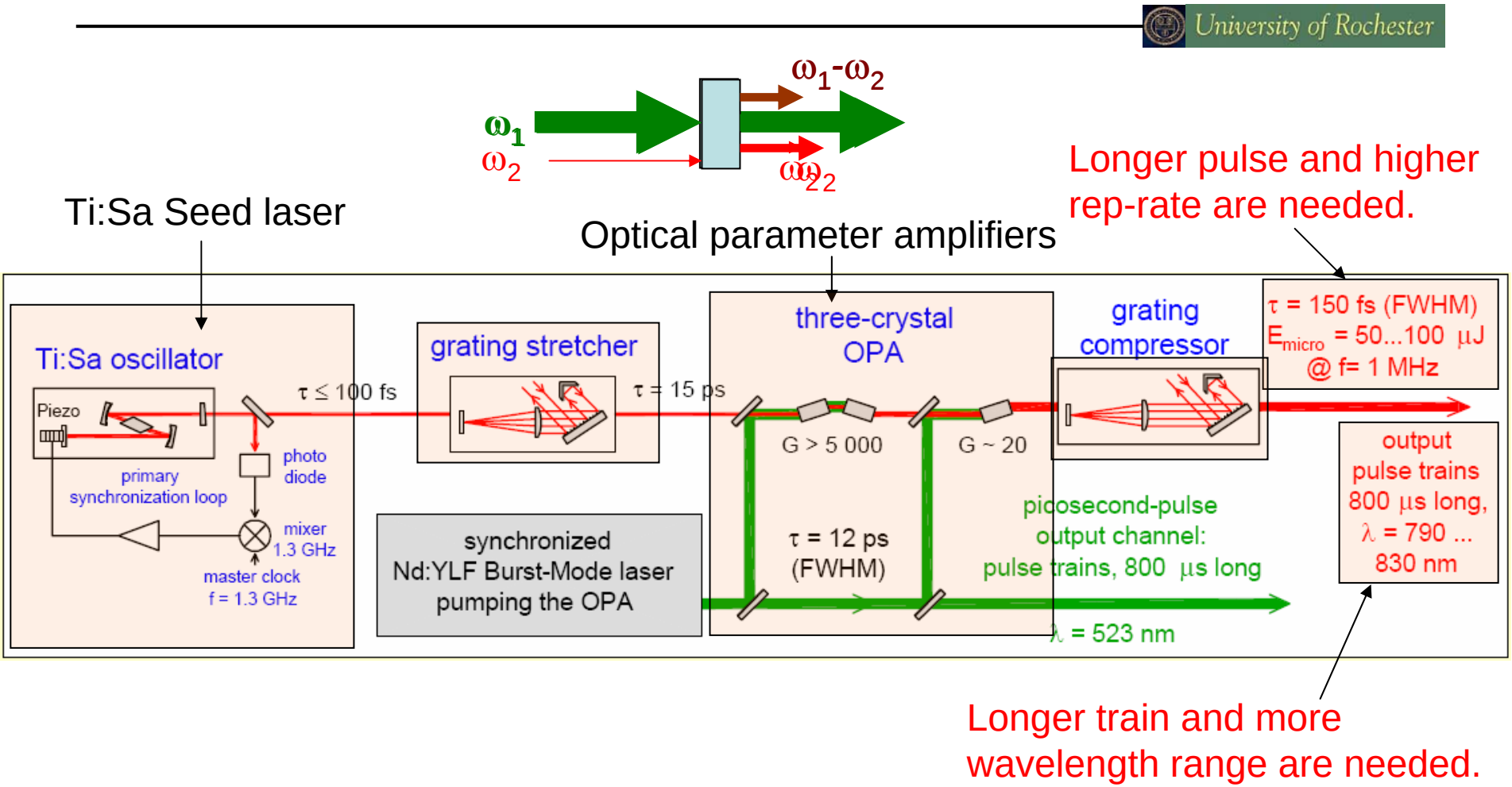
Laser parameter	Value	Unit
Micro-pulse energy at photocathode	~3 (1.5)	μJ
Micro-pulse length	~2	ns
# micro-pulse per train	2820 (5640)	Number
Intensity jitter	2	% (rms)
Micro-Pulse spacing	337 (169)	ns
Repetition rate	5	Hz
Wavelength	750-850	nm

From WG3a ILC Electron Source Recommendation

Similar laser system was built at DESY



From I. Will, et al., Status Sep. 2004

Summary

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In summary, the recent laser work done at A0 has been reviewed. A commercial seed laser purchased by NIU replaced the home-made oscillator. The performance of the new laser system is improved remarkably. Several future research fields, including drive laser system for SMTF, EO sampling for beam diagnostics, laser acceleration of electrons and drive laser for ILC, have been discussed too.

Backup Slides: CWAC

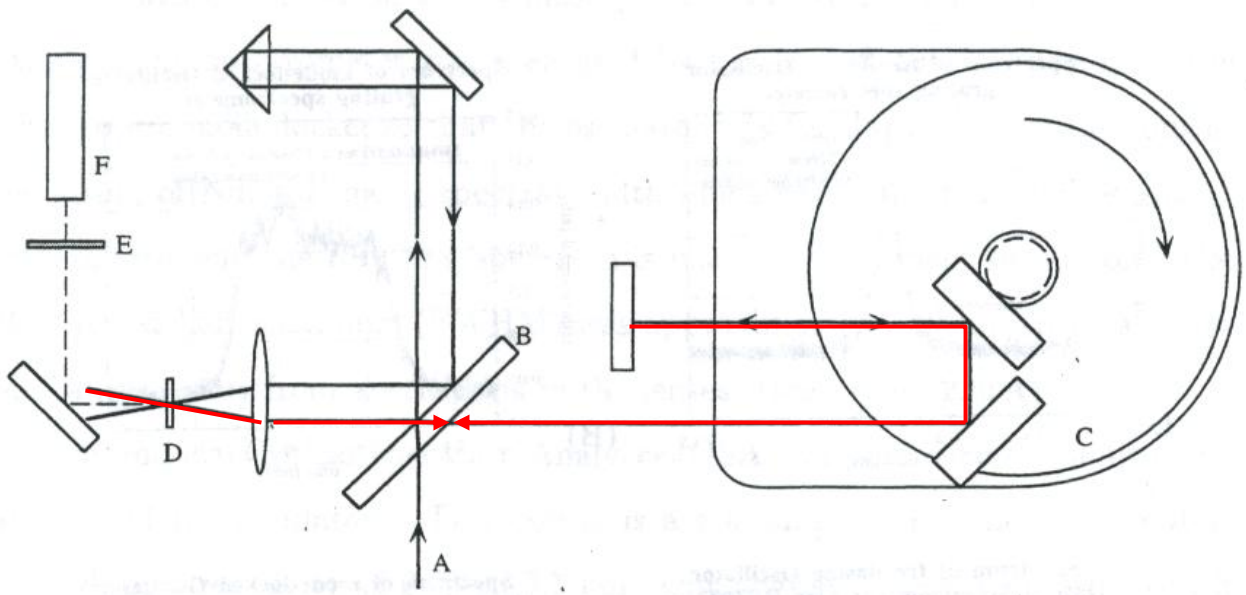
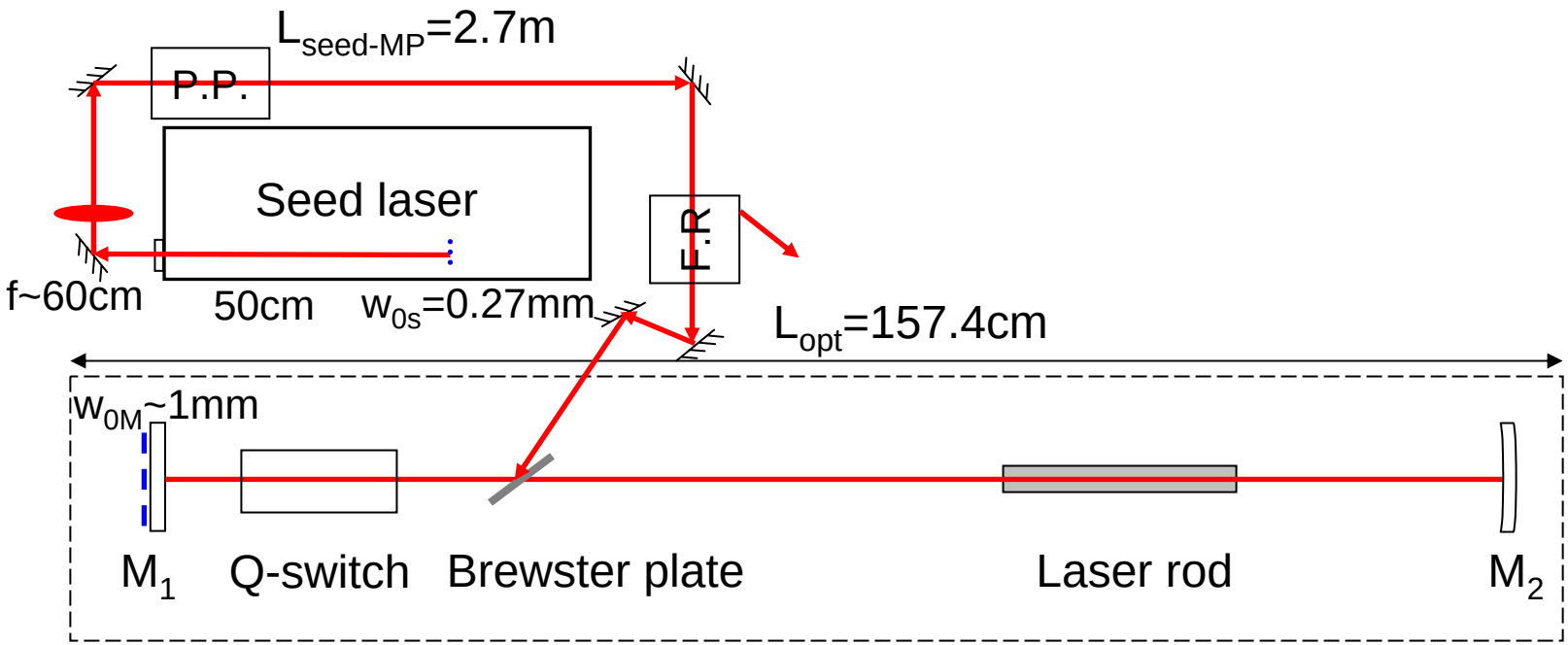


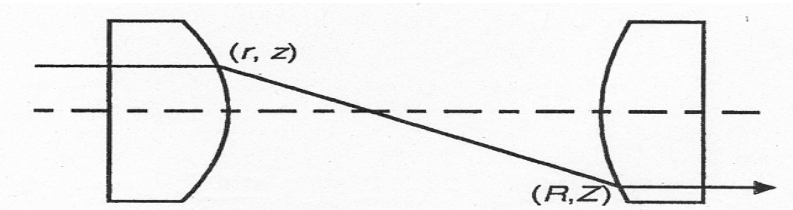
Figure 2.7: Schematic drawing of the continuous-wave autocorrelator (CWAC). The input beam (A) is divided by a beamsplitter (B) into a fixed arm and a variable delay arm on a rotating platform (C). The beams are crossed at a focus in a $LiIO_3$ crystal (D), and the green light is detected by a photomultiplier tube (F) after an infrared-blocking filter (E).

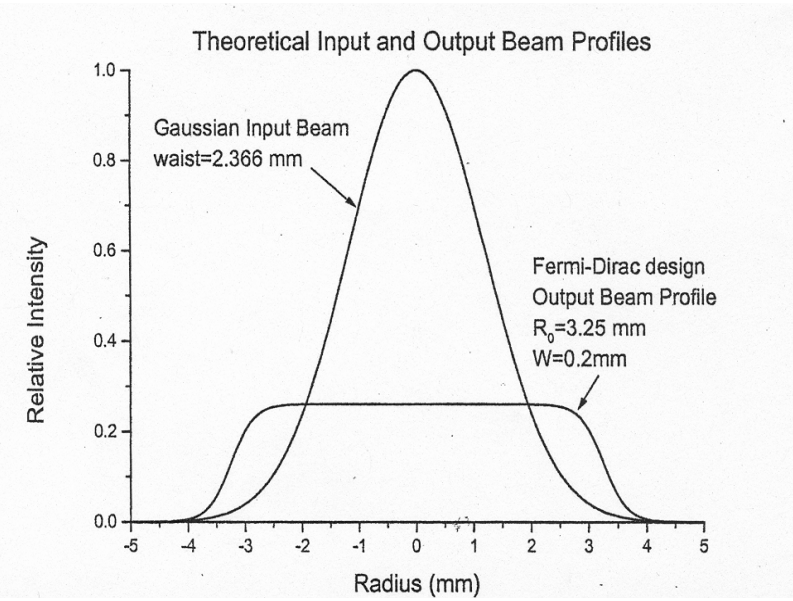
Beam match between seed laser and multi-pass cavity

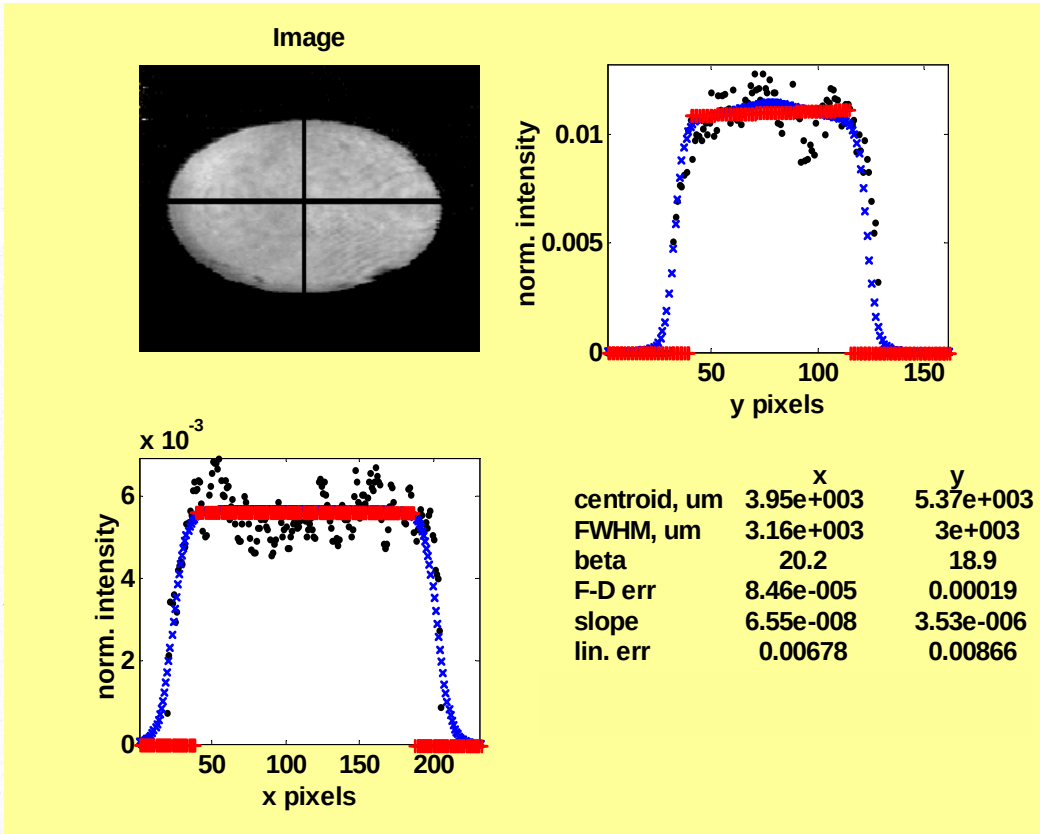


A lens with focal length of 60cm is inserted so that the seed beam is matched to the eigen mode of the multi-pass cavity.

A plano-aspheric lens pair to convert a Gaussian to a flattop beam







	x	y
centroid, um	3.95e+003	5.37e+003
FWHM, um	3.16e+003	3e+003
beta	20.2	18.9
F-D err	8.46e-005	0.00019
slope	6.55e-008	3.53e-006
lin. err	0.00678	0.00866

From Paul Bolton's talk at ANL, Feb. 18 2005.

Large gain for Nd:YLF diode pump laser

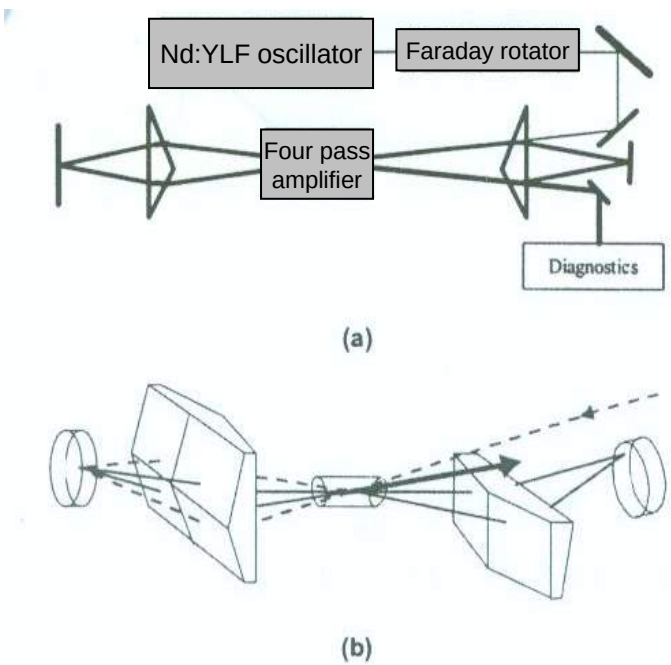


Fig. 3. (a) Experimental arrangement for the diode-pump amplifier system. (b) The four-pass amplifier geometry.

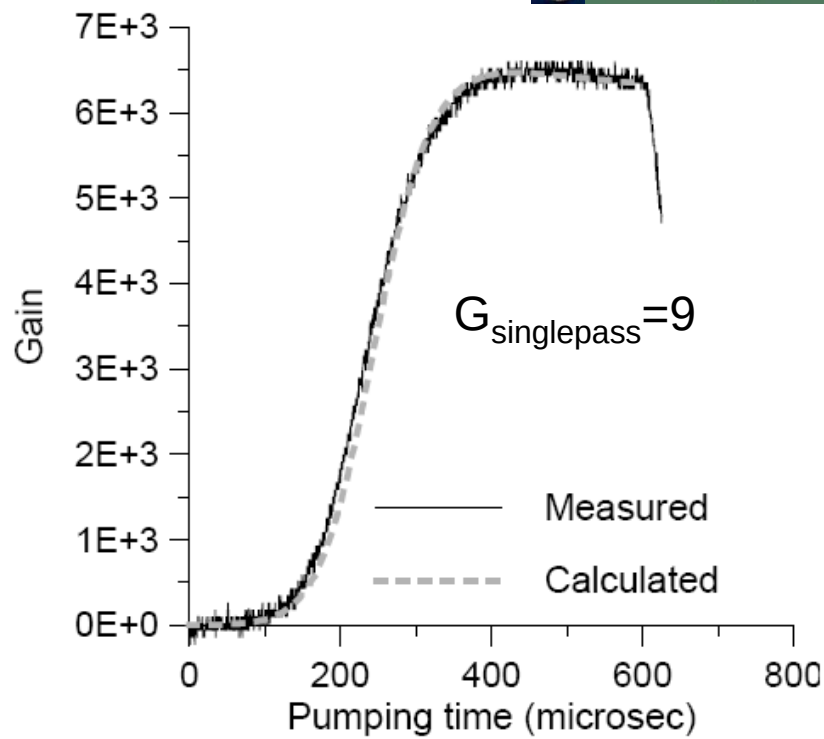
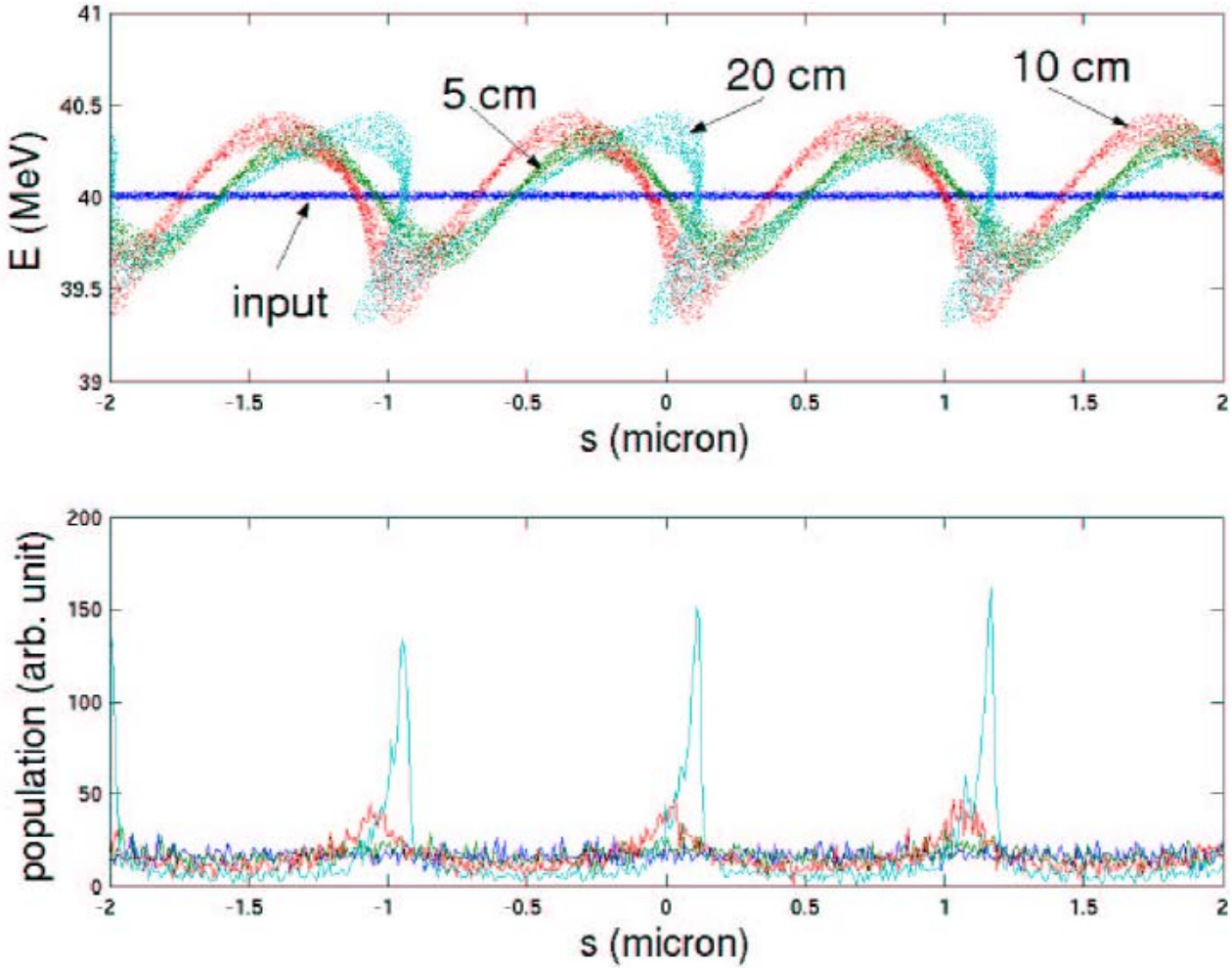


Fig. 8. Calculated and measured gain for amplifier under strong saturation.

With diode pump and Nd:YLF crytal, amplification of up to 6,000 was achieved after a 4-pass amplifier.

From Ian Ross et al., Applied Optics, Vol. 42, No. 6, 1040(2002)

Micro-bunching effect



Difficulties at A0 and future improvements

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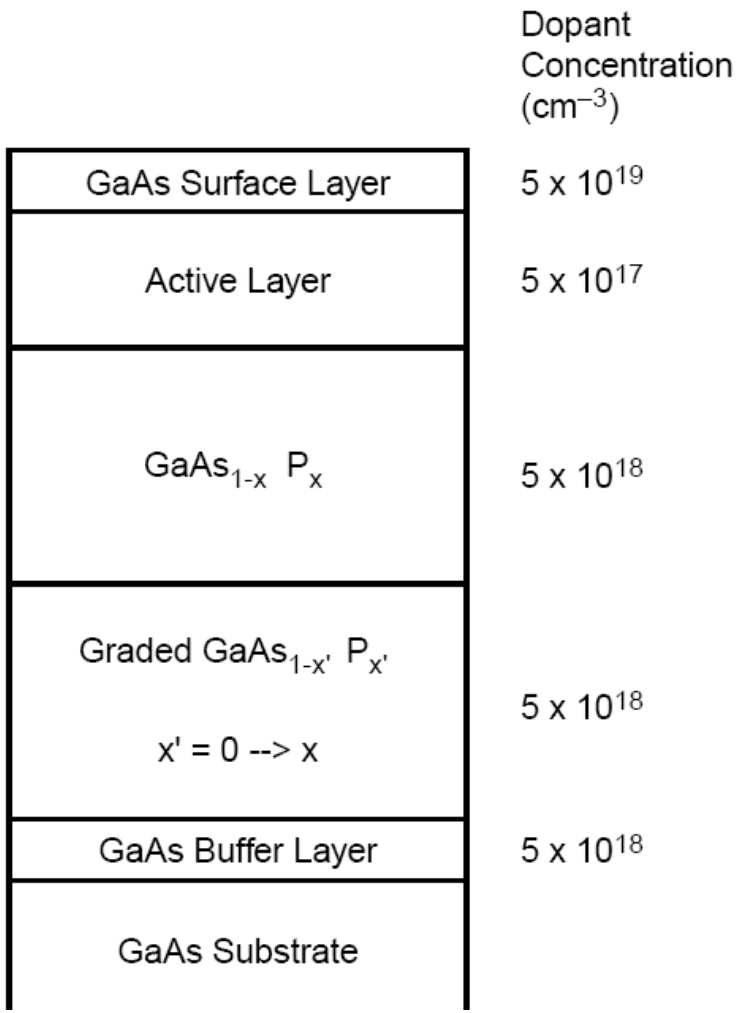
- The stability of seed laser caused the poor repeatability of TEM_{01}^* mode.
- The new seed laser should solve it (hopefully).

- The electron energy is only 15 MeV, too low for significant acceleration.
- At SMTF, the electron energy will exceed 200 MeV.

- Laser intensity is not yet 20 mJ.
- Another amplifier after re-gen is needed.

- Laser beam can not be compressed and sent to cave.
- At SMTF, another IR transport line should be installed so that the laser pulse is transported and compressed and then the TEM_{01}^* is produced.

Schematic diagram of the strained photocathode structure



From T. Maruyama, SLAC-PUB-9133 (2002)