XFEL Beam Dynamics

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Issues on Longitudinal Photoinjector Laser Pulse Shape

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- The TTF Laser System
- Laser Material Properties
- Conclusion?

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General Design Issues of the Laser

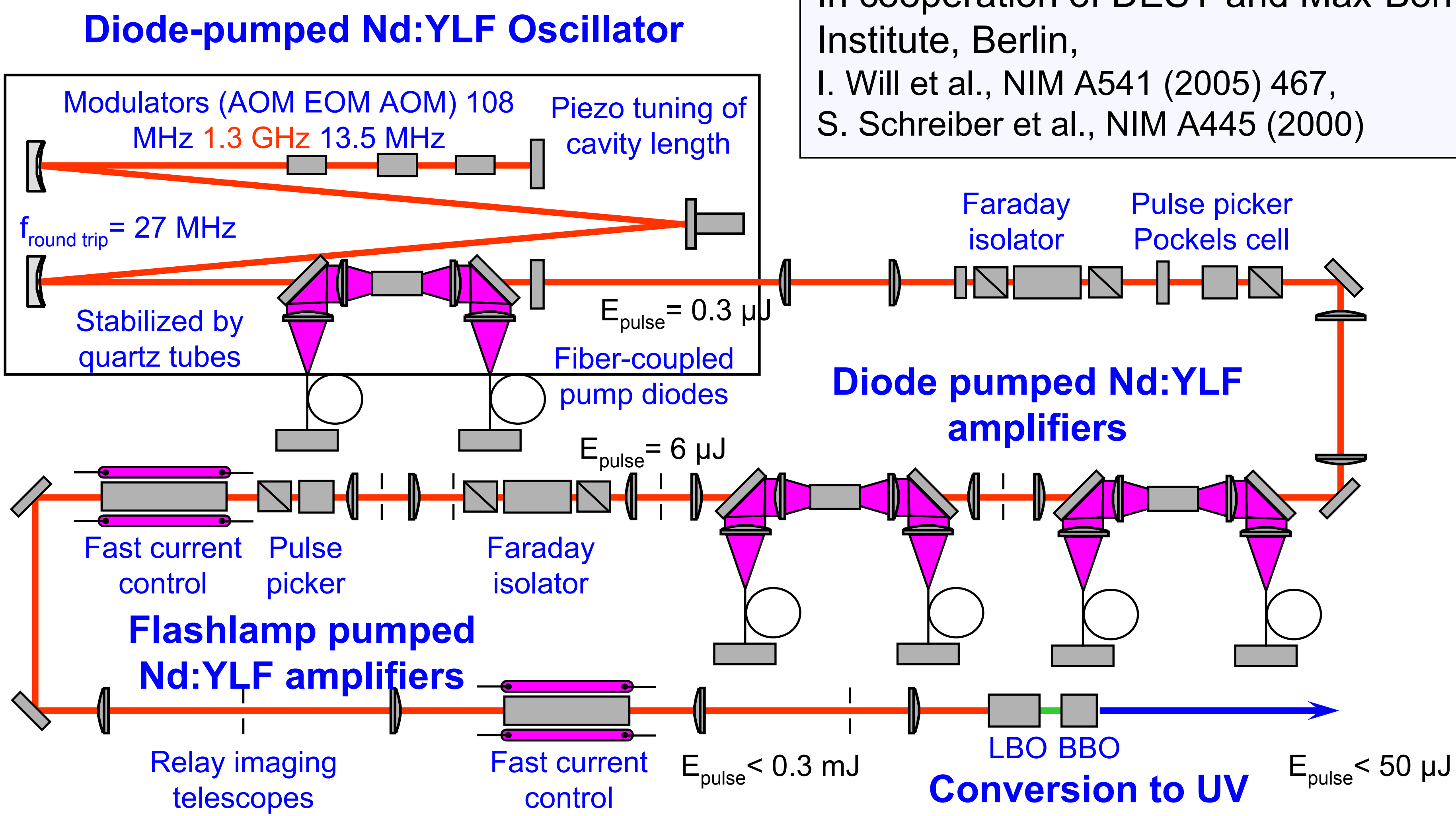
- Photocathode → the laser has to have similar transverse and longitudinal shapes as the required electron bunches
- With the given L-band RF gun, this already determines the basic properties of the laser pulses
- TTF as a sc accelerator has long bunch trains

			TTF specs
synchronized	~1 dg of RF cycle	~2 ps @1.3 GHz	< 1 ps rms
longitudinal and transverse size	~5 dg == ~ 10 ps	field uniformity ~ some mm	length 20 ps, Ø = 3 mm
charge of ~1 nC per bunch required	Cs_2Te cathode QE ~ 1…10% (UV)	~1 µJ/pulse@UV	factor of ~10 overhead
long trains of pulses with low rep rate	trains 800 µs long with up to 7200 pulses (9 MHz) @ 10 Hz		

- Suitable type of laser → mode-locked solid-state system (synchronized oscillator + amplifiers + frequency converter to UV)

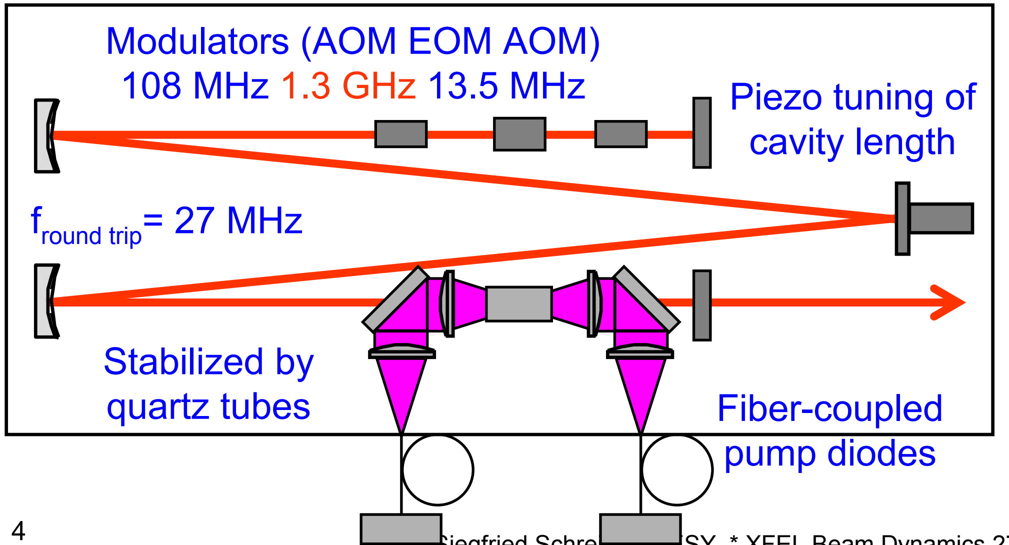
Laser System Overview

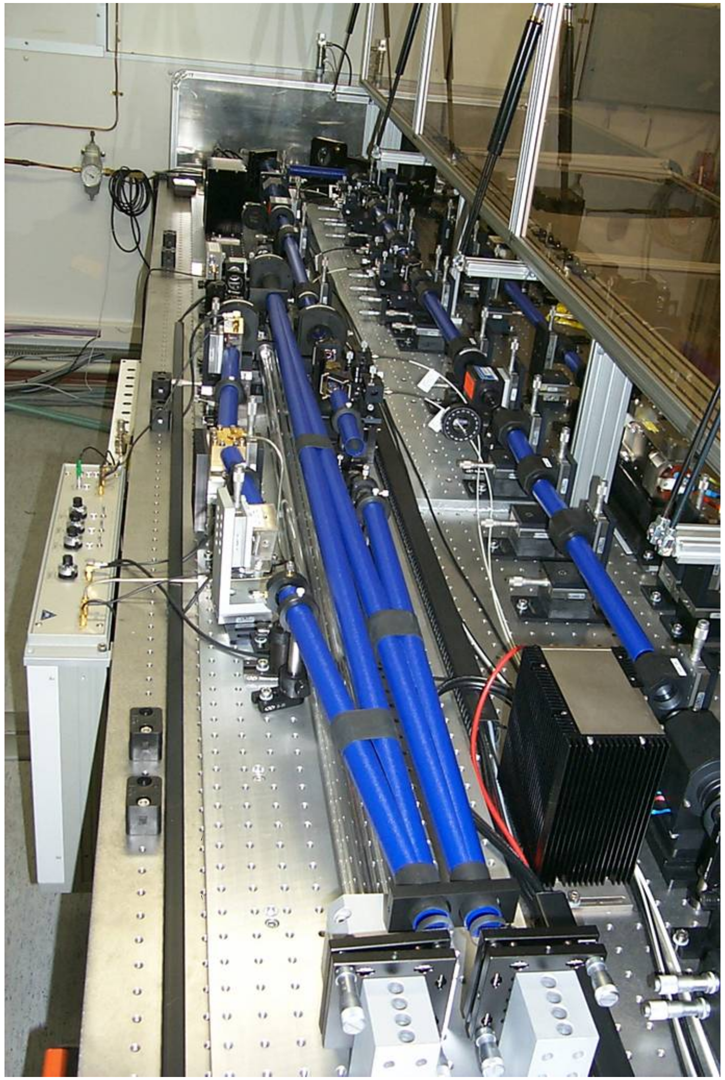
In cooperation of DESY and Max-Born-Institute, Berlin,
I. Will et al., NIM A541 (2005) 467,
S. Schreiber et al., NIM A445 (2000)



Pulse Train Oscillator (PTO)

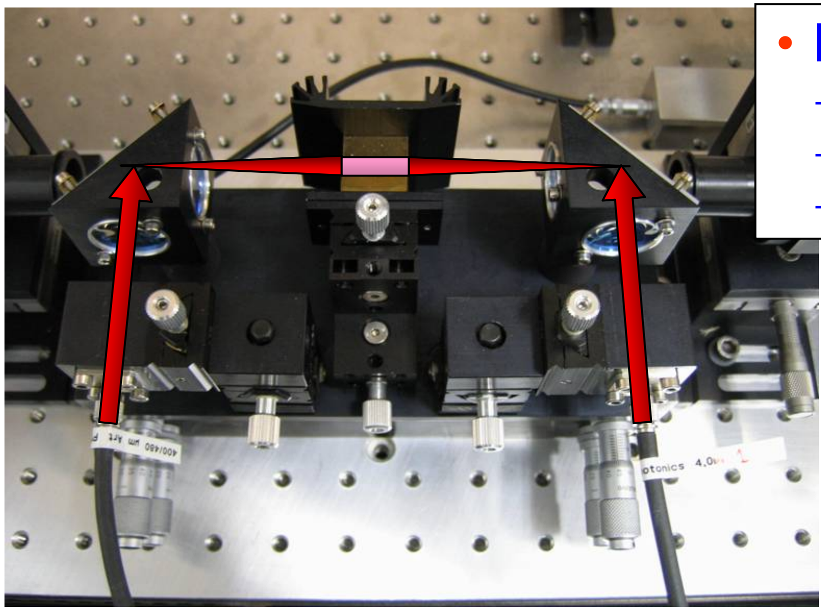
- Mode-locked pulsed oscillator
  → diode pumped (32 W)
- Synchronized to 1.3 GHz from the master oscillator, stabilized with quartz rods
  → 1.3 GHz EO modulator with two AOM
  → phase stability 0.2 ps rms
  → pulse length 12 ps fwhh
- 27 MHz pulse train
  → length 2.5 ms, pulsed power 7 W
  → pulse picker up to 3 MHz



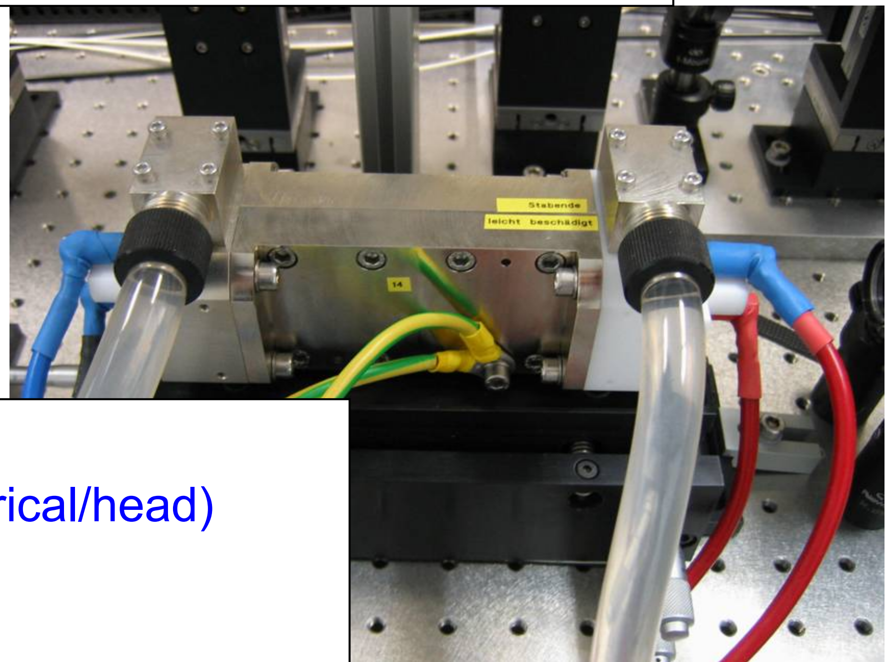


Chain of Linear Amplifiers

- 2 diode pumped and 2 flashlamp pumped single pass amplifiers
- Fully diode pumped version is being tested now at PITZ, DESY Zeuthen



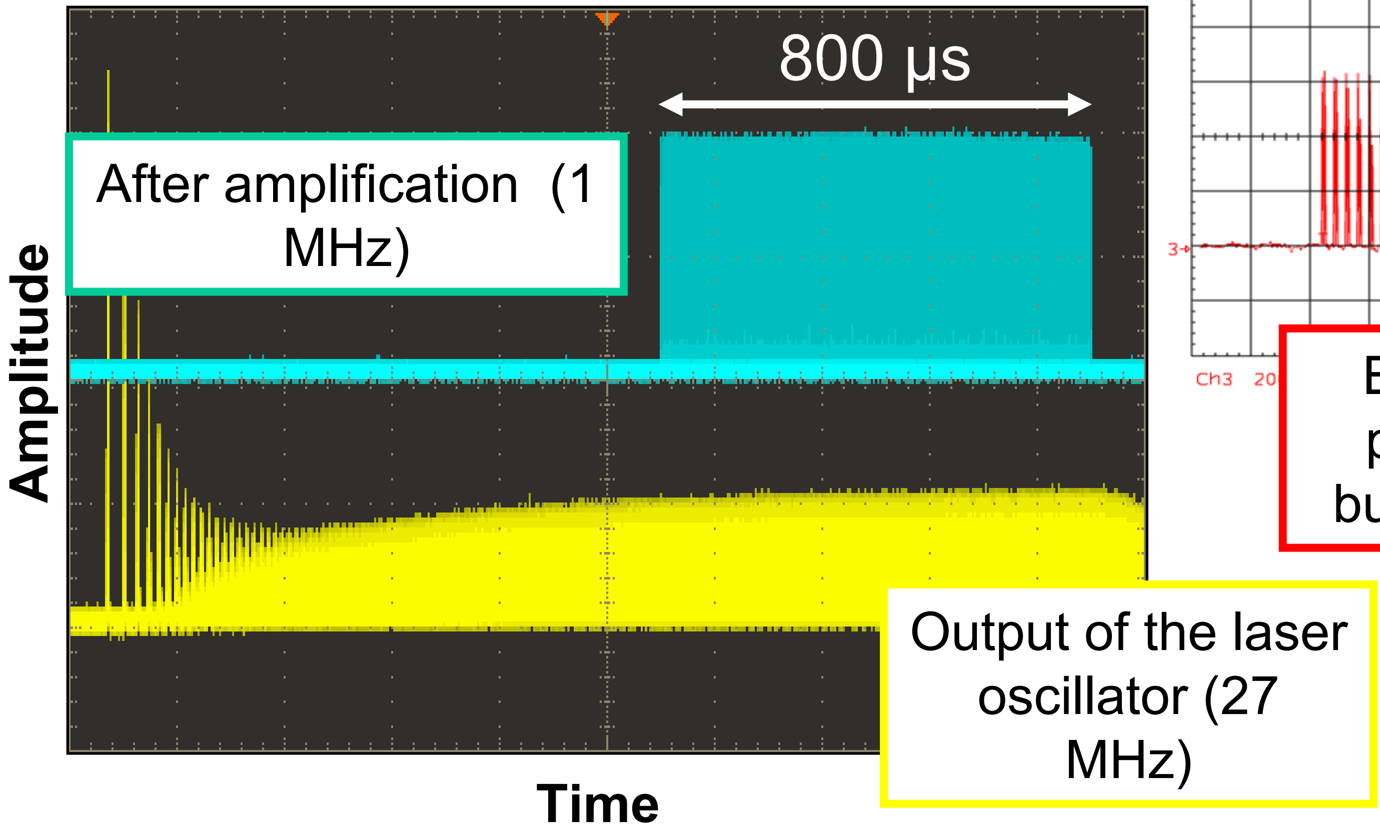
- Laser diodes:
  → 32 W pulsed, 805 nm
  → end pumped through fibers
  → energy from 0.3 µJ to 6 µJ/pulse

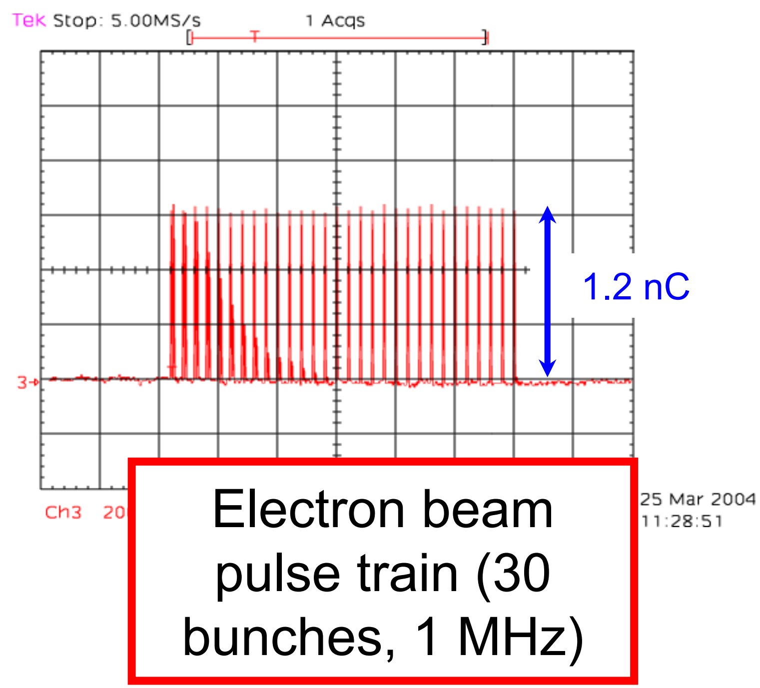


- Flashlamps:
  → cheap, powerful (pulsed, 50 kW electrical/head)
  → current control with IGPT switches
  → allows flat pulse trains
  → energy up to 300 µJ (1 MHz), 140 µJ (3 MHz)

Pulse Trains

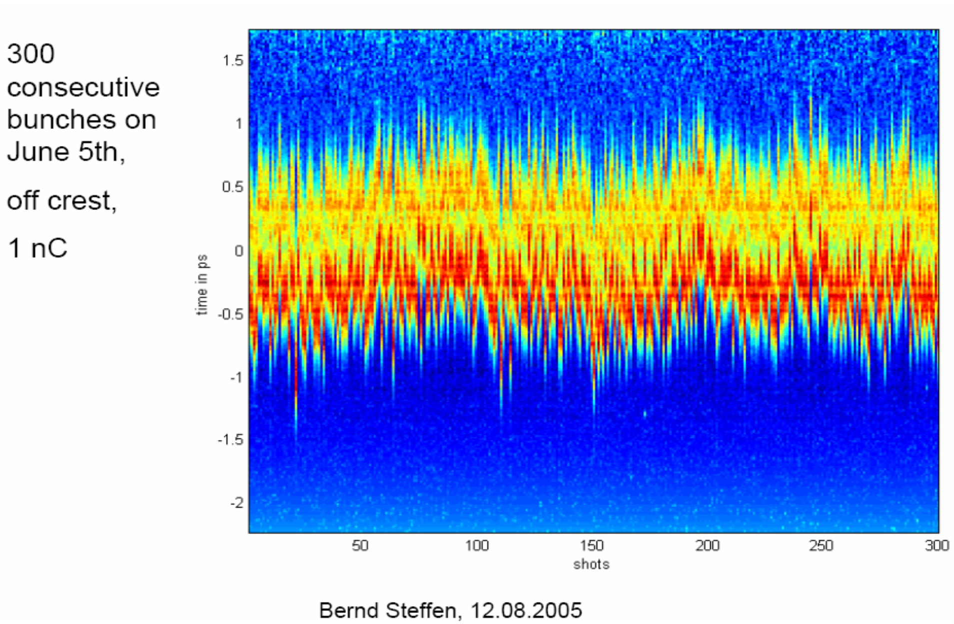
- Amplified laser pulse train - up to now 3 MHz possible, 9 MHz in preparation

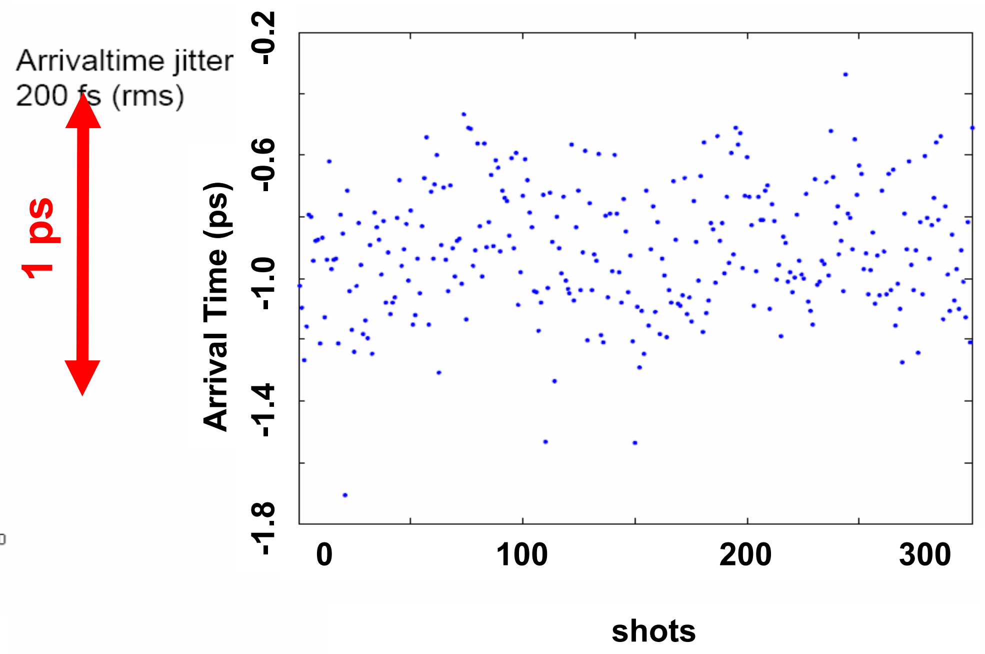




Beam Arrival or Phase Stability

- Phase stability measured with electro-optic decoding technique: arrival time fluctuations 200 fs rms
  - After acceleration to 450 MeV, dominant contributions: jitter of beam energy (magnetic chicane bunch compressors) and phase of laser in respect to linac rf





Time Bandwidth Limit

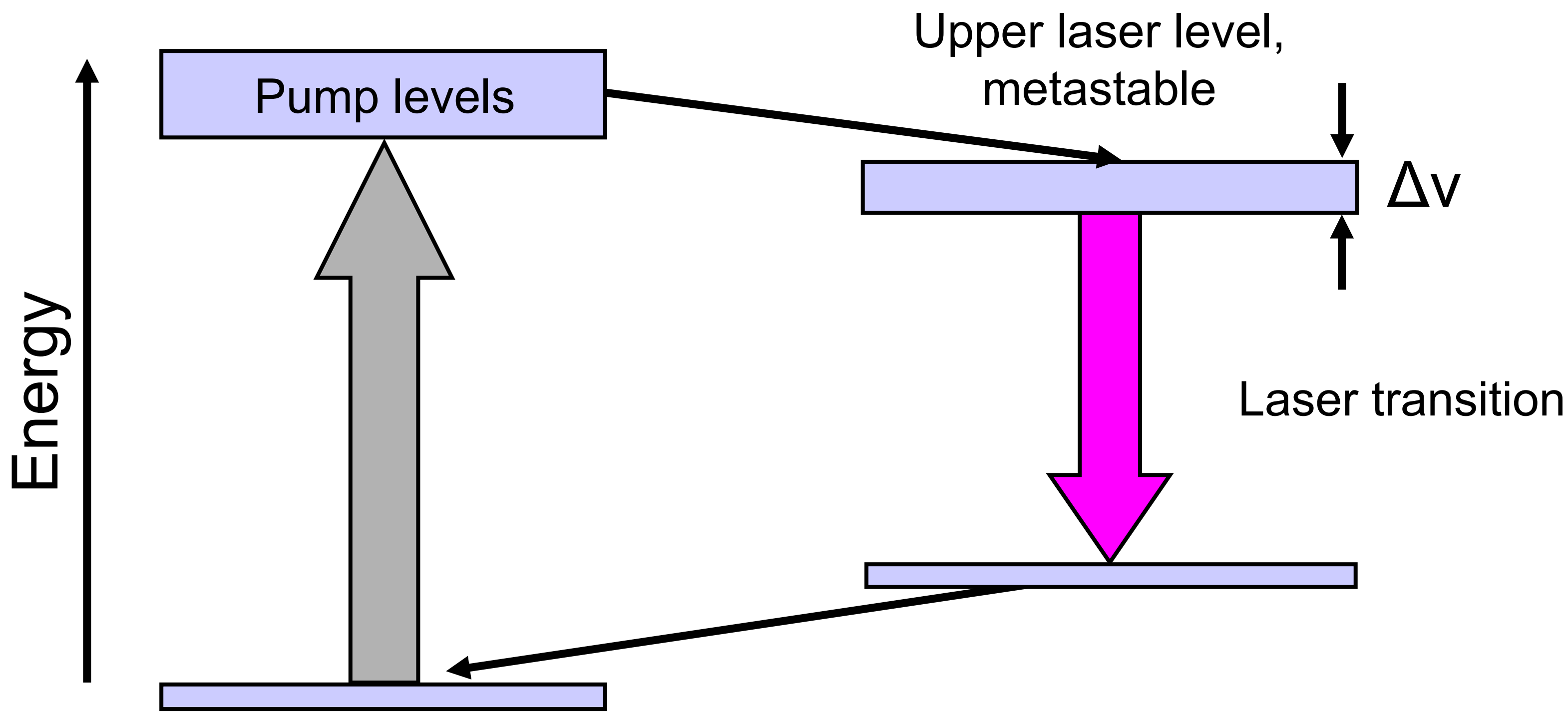
- From the uncertainty principle we have a limit in the time bandwidth product

  $\Delta t * \Delta v > K$, K in the order of 1
  (gaussian laser pulses = 0.44, cw mode-locked 0.36)

- Δt is the fwhh length of the pulse, Δv the fwhh gain bandwidth of the laserline at the frequency v
- For TTF, choice of laser crystal not only by bandwidth arguments, others like emission cross section, fluorescence lifetime, diode-pumping capability have been more important

Principle Scheme of a Laser Transition

- Example of a 4 level system, typical for high gain solid state lasers



Examples for laser materials in question

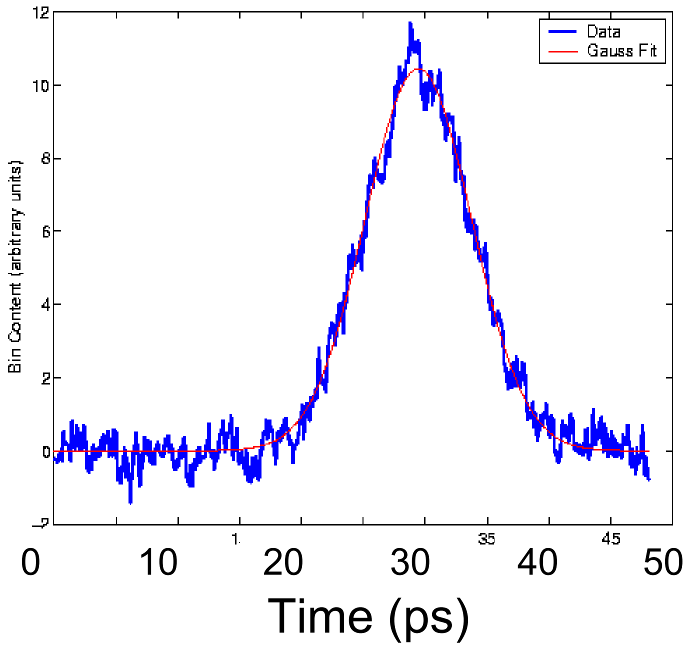
Shortest pulse length obtainable using K=0.4

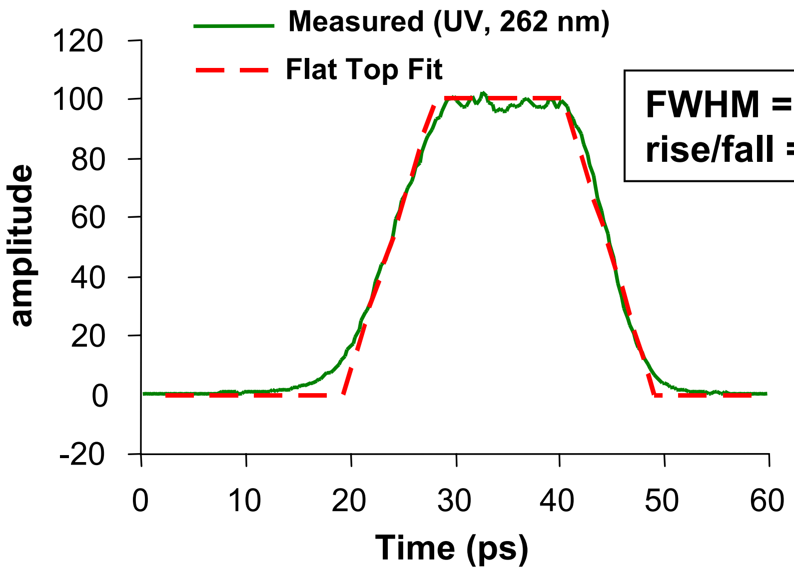
Laser material	Bandwidth (GHz)	Shortest pulse length
Nd:YAG	150	2.9 ps
Nd:YLF	350	1.3 ps
Nd:KGW	720 (2.73 nm)	0.6 ps
Ti:Sapphire	$d\lambda$=400nm	2.5 fs, 15 fs achieved

Laser Pulse Length and Shape

- VUV-FEL:
  Longitudinal shape is Gaussian
- Average over 50 gives
  $\sigma_L = 4.4 \pm 0.1$ ps (at 262 nm)

- PITZ:
  Longitudinal flat-hat shape
- Works fine in 'lab environment', not yet mature for the VUV-FEL





Example of temporal shaping

- Manipulation in the frequency domain using gratings

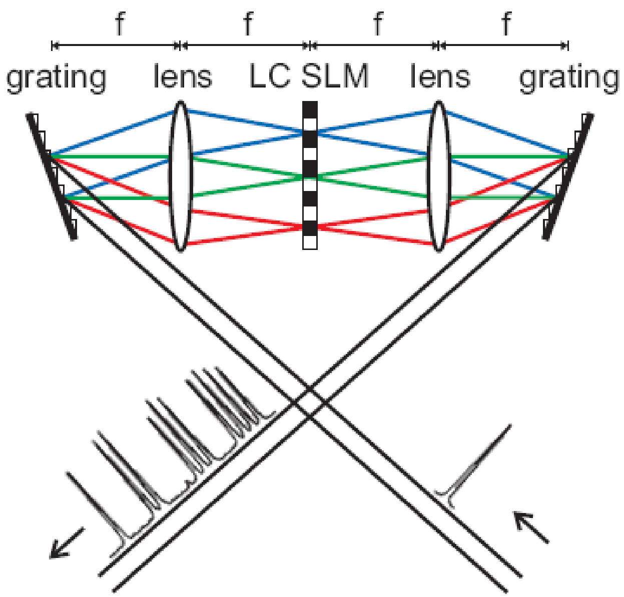


Fig. 1. Schematic illustration of experimental apparatus used for temporal-only pulse shaping and representative input and output pulse shapes.

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