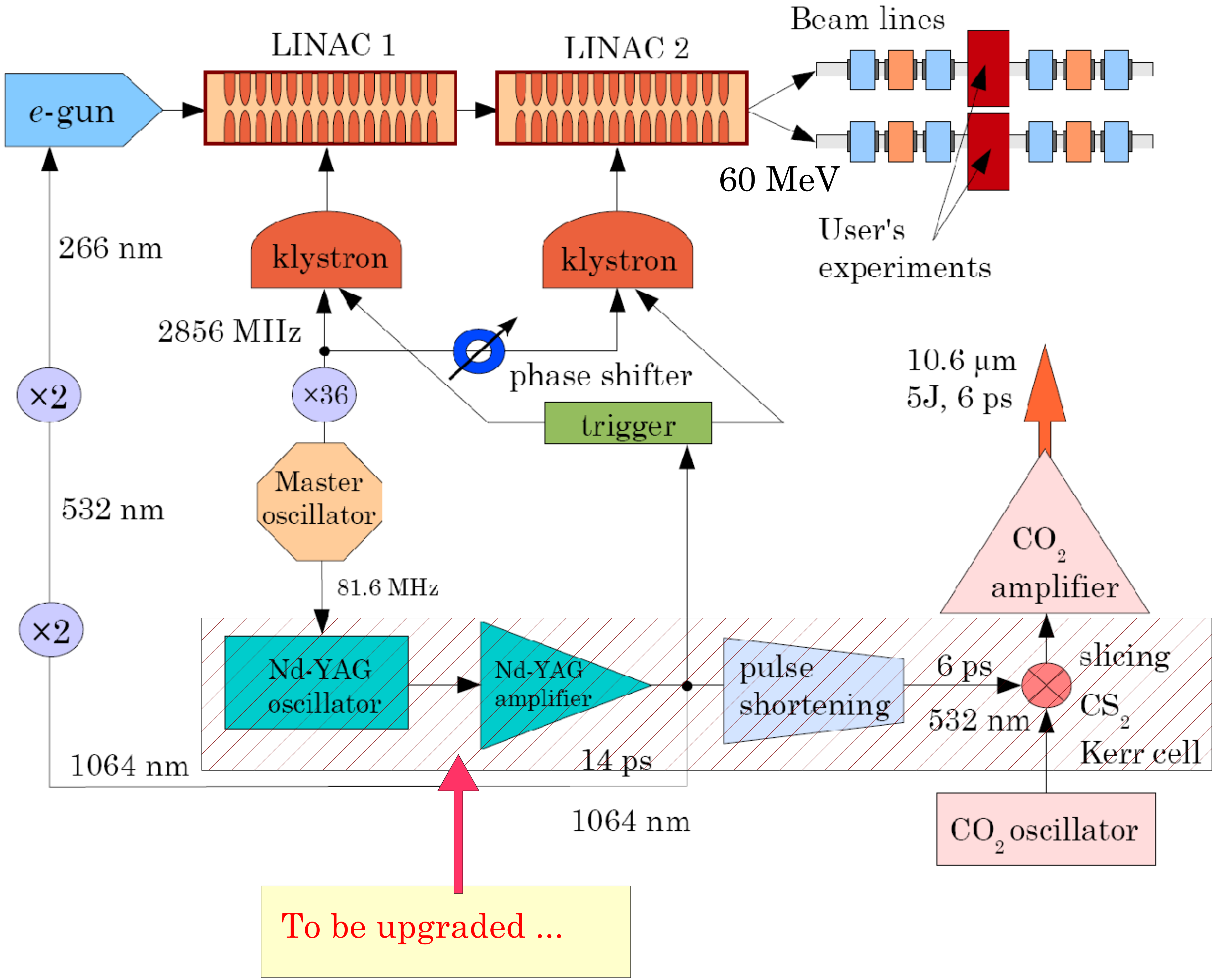
Development of the Solid-State Laser System for the Accelerator Test Facility

Daniil Stolyarov,
Accelerator Test Facility User's Meeting
April 3, 2009

Outline

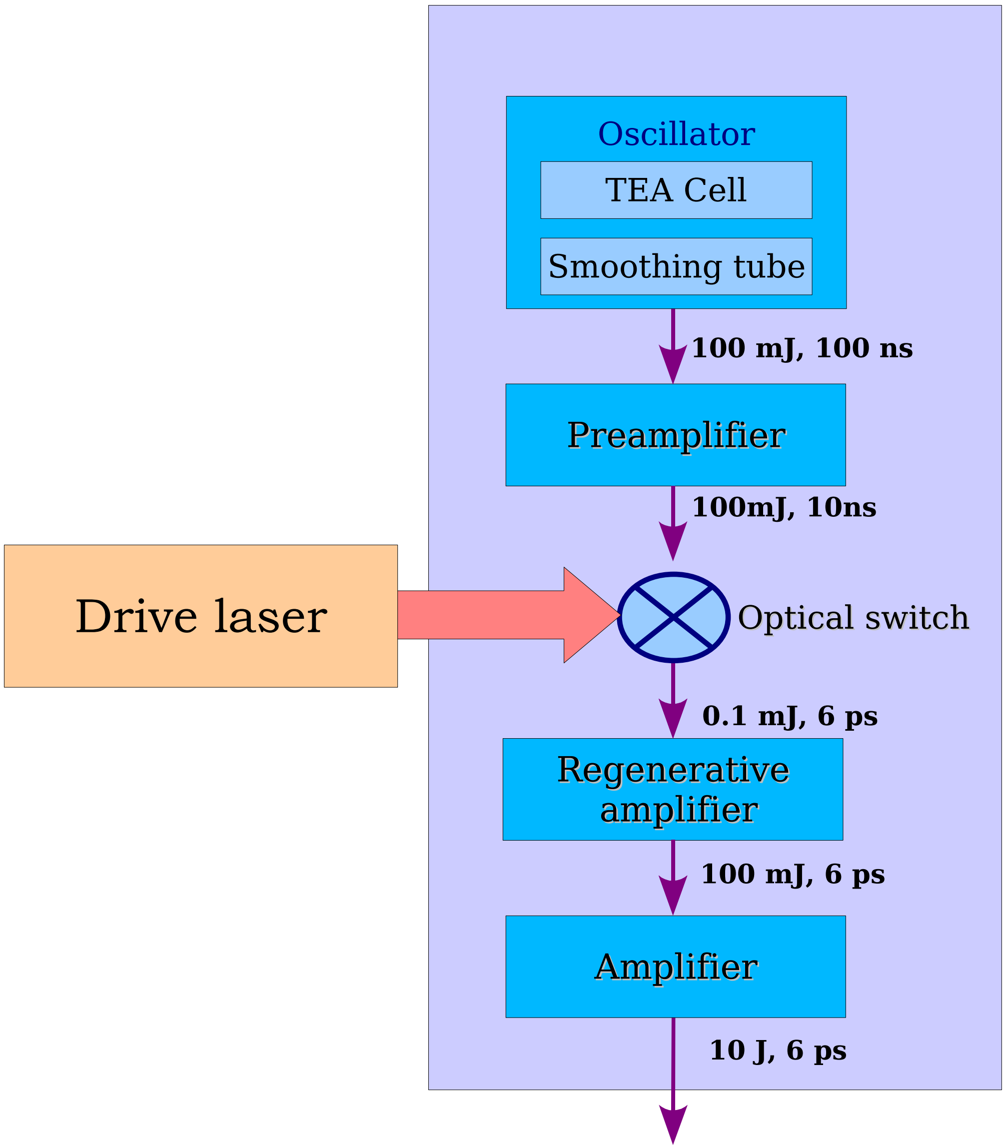
- Motivation for the upgrade of the solid state laser system
- Type II SHG pulse compressor (currently employed)
- Optical switch / CO_2 laser slicing.
- 2-stage fiber amplifier
- Regenerative amplifier

Accelerator Test Facility



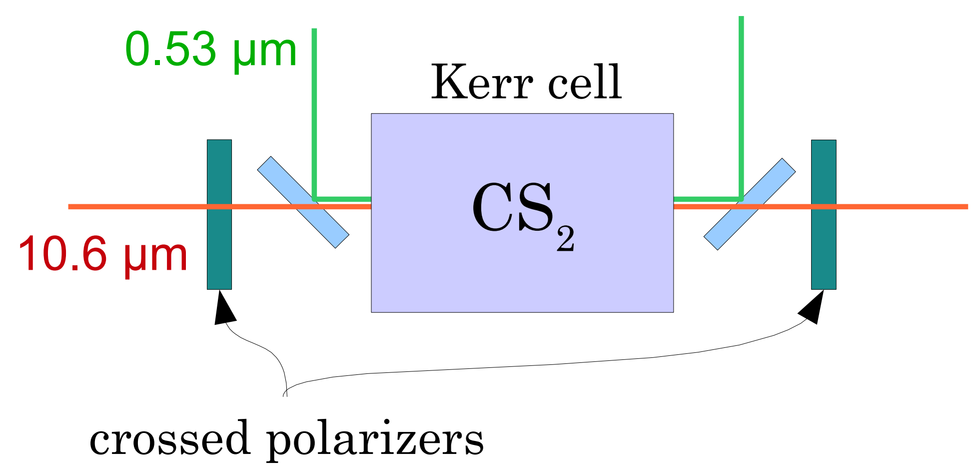
Slicing of the CO_2 laser pulse

ATF CO_2 laser diagram



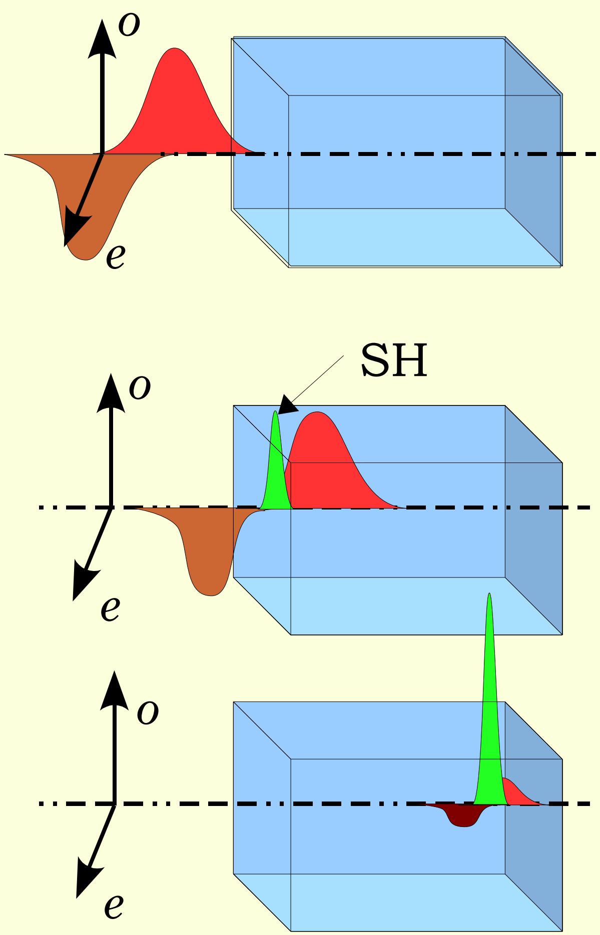
- The slicing makes the duration of the CO_2 laser pulse approximately equal to the duration of the drive laser pulse
- If output energy of the pulse stays the same – the peak intensity grows

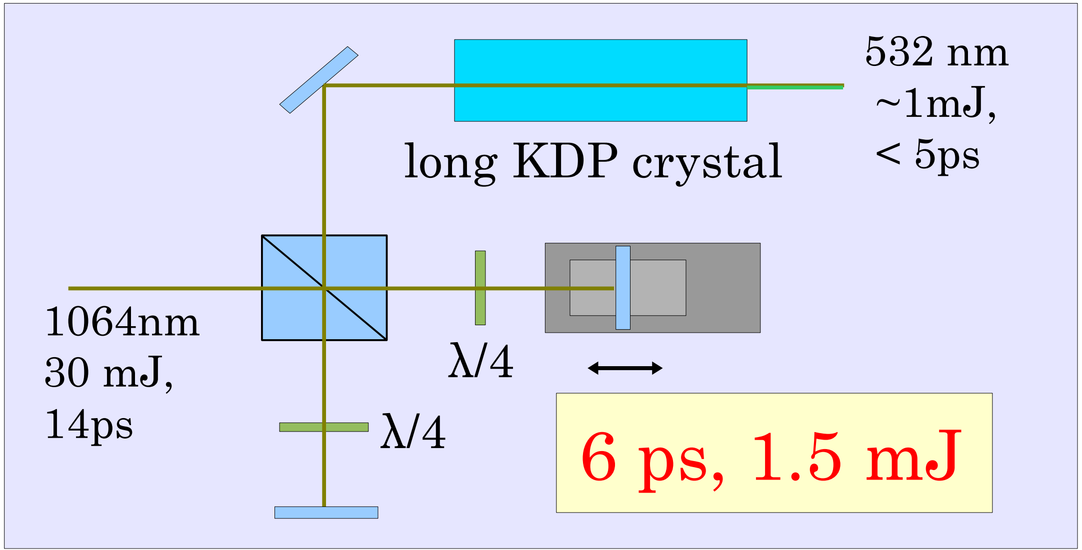
Optical switch

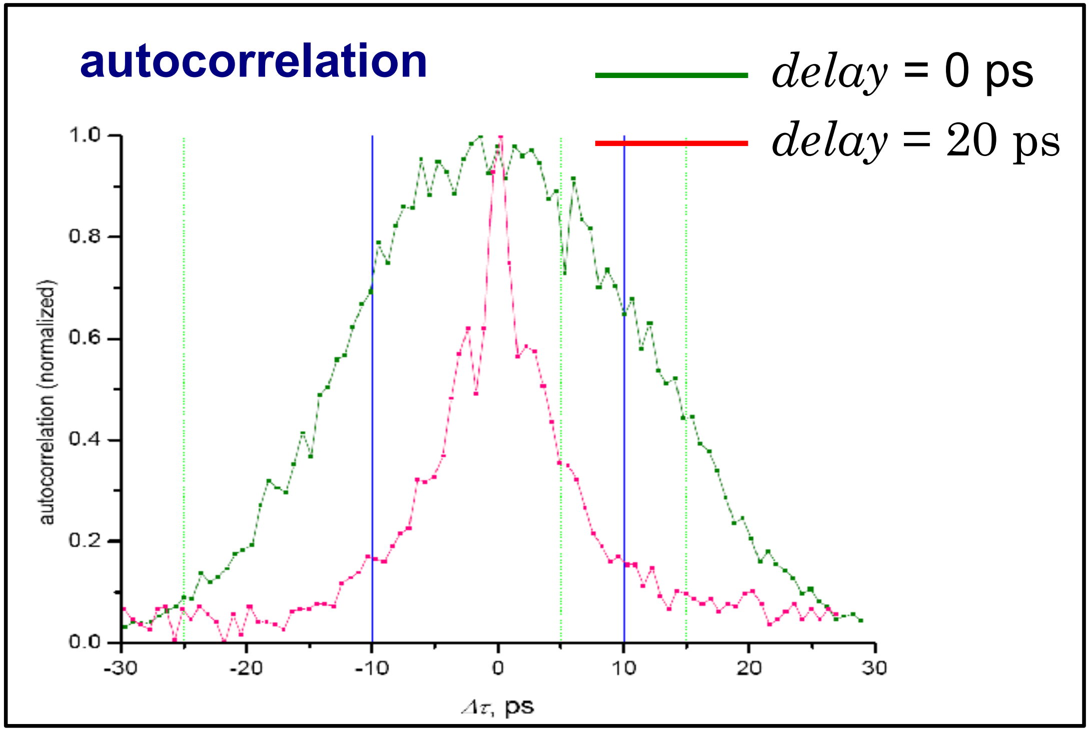


Pulse compression in a long Type II SHG crystal

Pulse compression scheme:

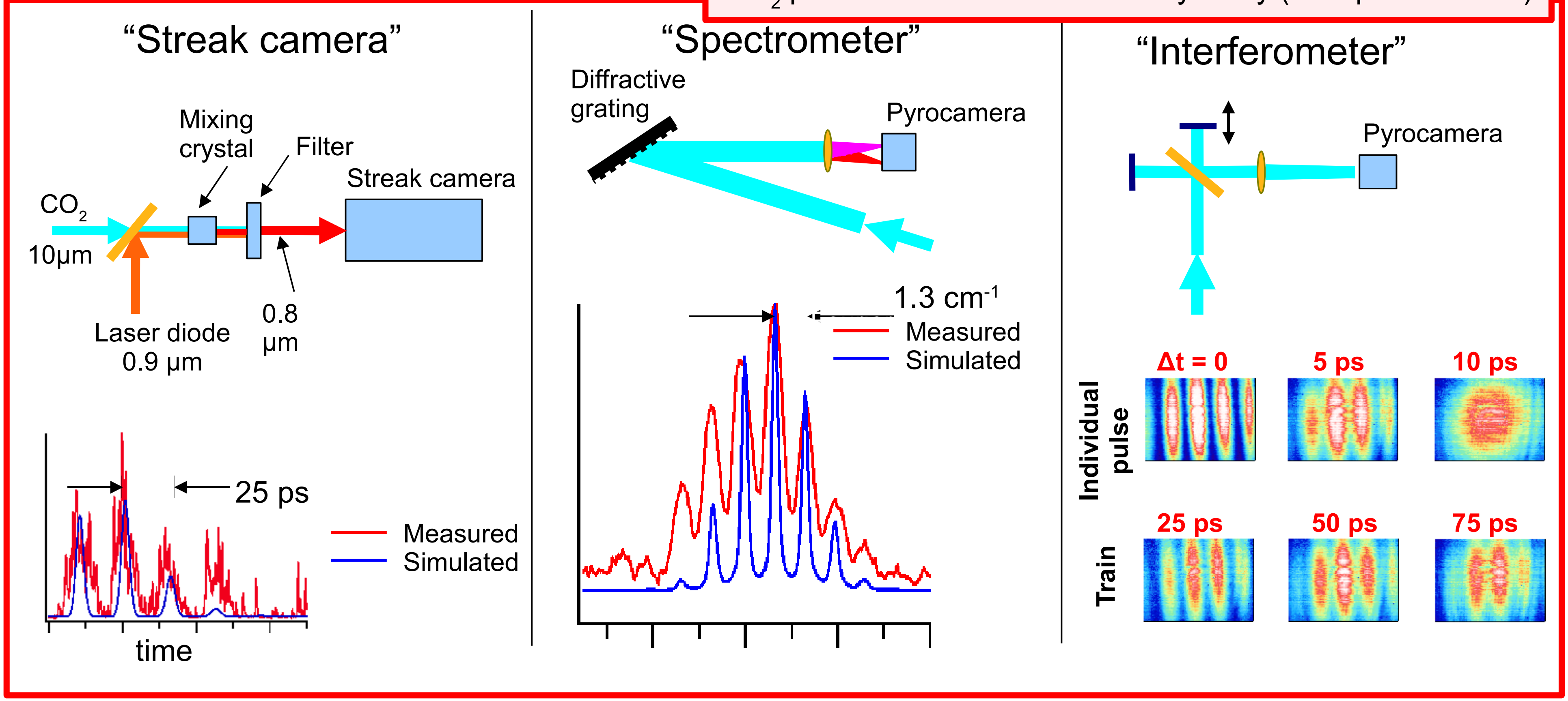






CO_2 pulse shortening

"CO_2 pulse measurements" M. Polyansky (next presentation)



- Our measurements show that the CO_2 laser pulse consists of a train of individual pulses
- Duration of each individual pulse is ~ 6 ps
- These results are in agreement with the simulation for the given gas mixture

Motivation

Normalized vector potential: $a_0 = \frac{eE}{mc\omega}$ ($a_o \geq 1$ – relativistic regime)

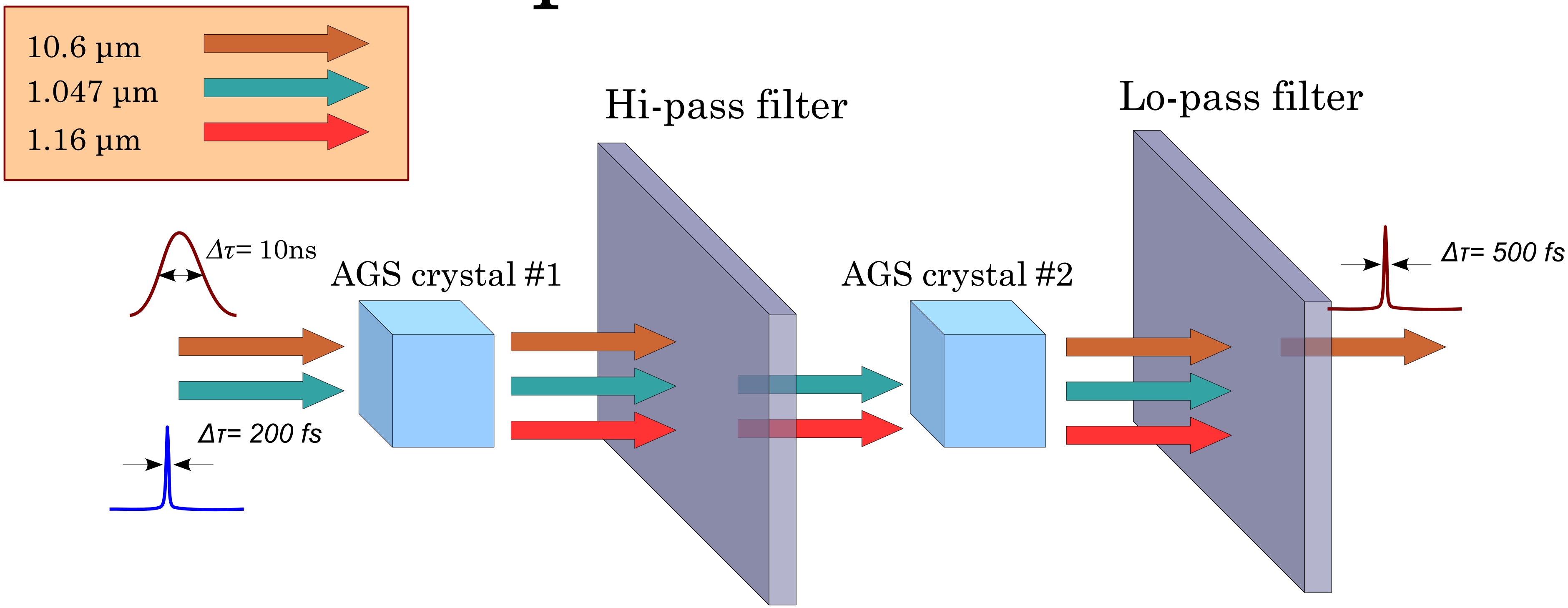
Yb-doped glass system → Nd YAG laser system

pair of nonlinear crystals → CS_2 Kerr cell

improvement of ATF CO_2 laser parameters:

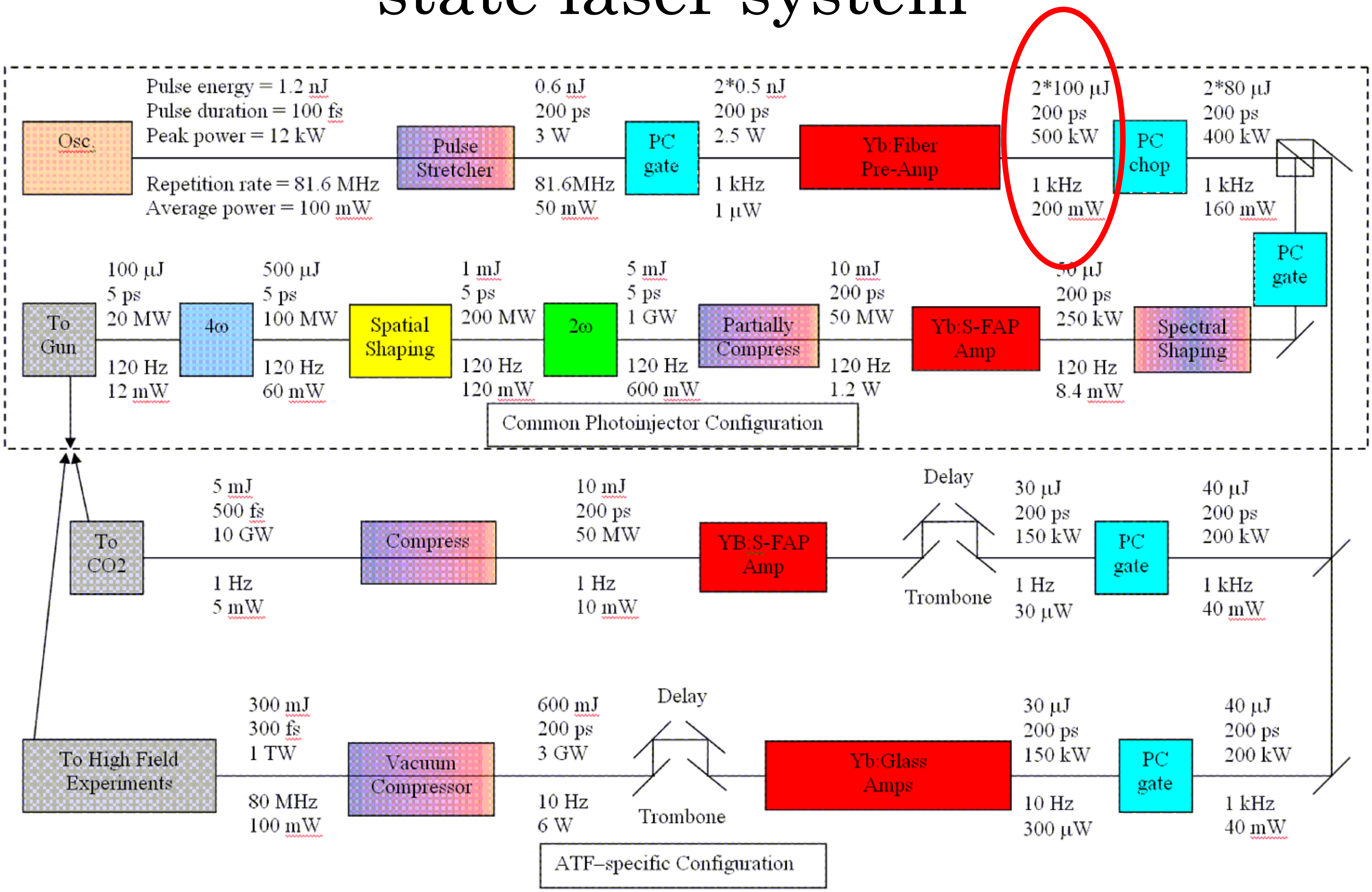
Currently	After upgrade
λ = 10.6 μm	λ = 10.6 μm
τ = 6 ps	τ < *1* ps
E_{pulse} = 5 J	E_{pulse} = 5 J
w_o = 65 μm	w_o = 65 μm
$I_o = 1.25 \times 10^{16}$ W/cm^2	$I_o > 7.5 \times 10^{16}$ W/cm^2
$a_o \approx 1$	$a_o > 2.5$

Optical switch



1.05 μm (E = 40 μJ) + 10.6 μm (E = 2 mJ) → 1.16 μm (E = 20 μJ) + 1.05 μm (E = 20 μJ) → 10.6 μm (E = 2 μJ)

Plans for improvement of the ATF solid-state laser system



Self-Phase Modulation (SPM) and Spectrum Broadening in a Yb-doped Fiber

Pulse evolution is governed by the Nonlinear Schrödinger equation:

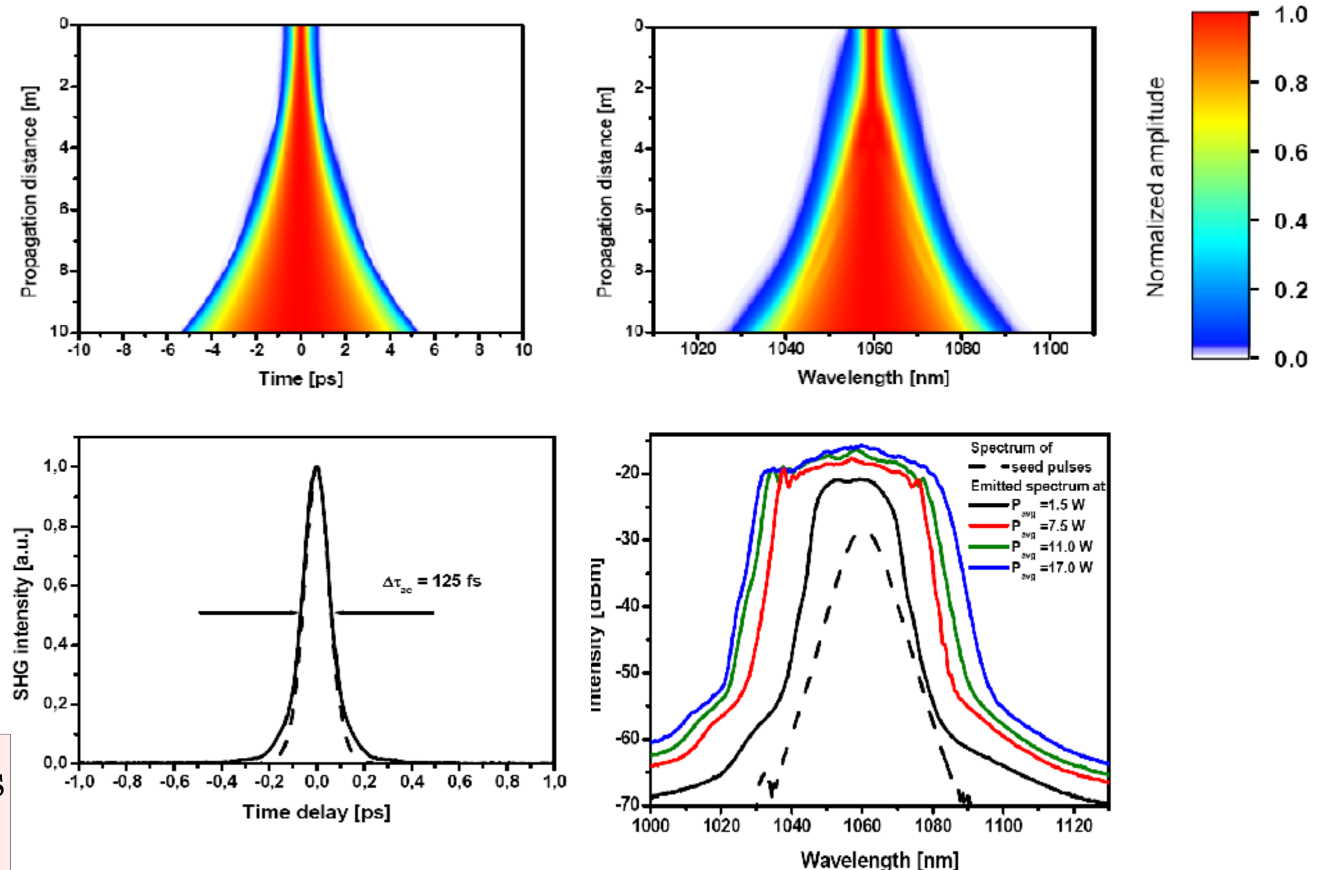
$$i\frac{\partial A}{\partial z} = \frac{1}{2}\beta_2 \frac{\partial^2 A}{\partial T^2} - \gamma |A|^2 A + i\frac{g}{2}A$$

GVD SPM gain

- SPM can cause wavebreaking making pulse incompressible
- SPM broadens the spectrum of the pulse

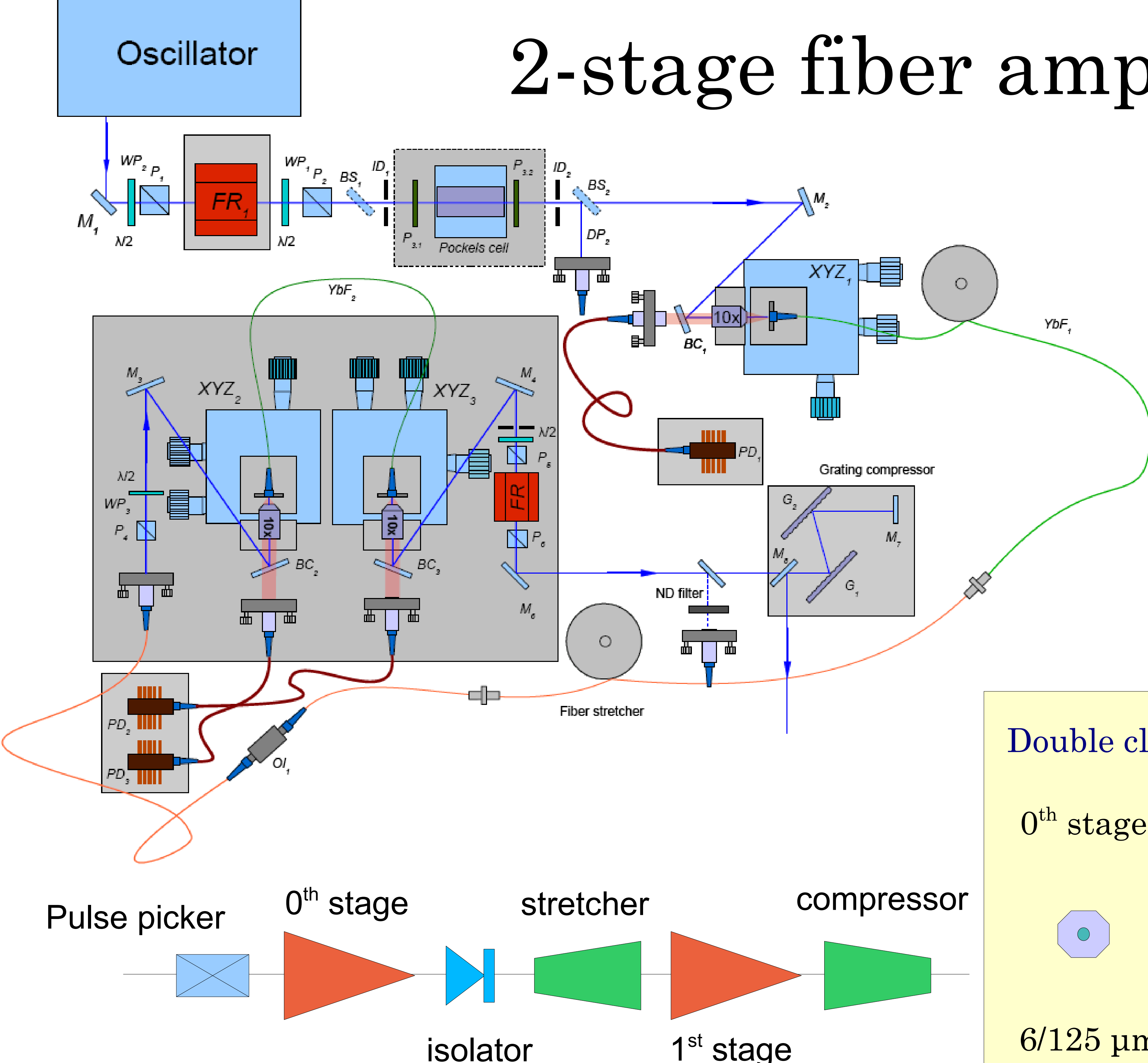
With the certain set of parameters β_2, γ, and g, the propagating short pulse attains the parabolic shape resisting the wavebreaking.

Propagation of parabolic pulse



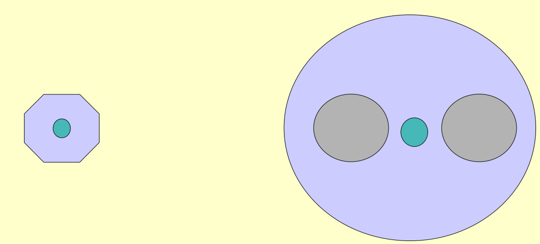
J. Limpert et.al Vol. 10, No. 14 / OPTICS EXPRESS 628

2-stage fiber amplifier



Double clad Yb-doped fibers:

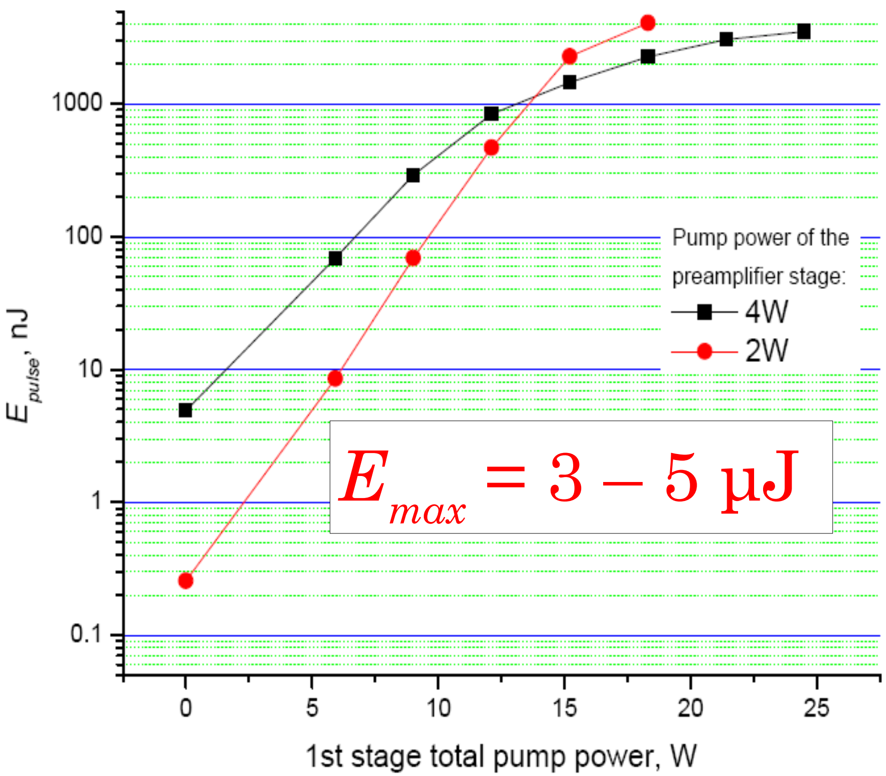
0th stage — 1st stage (PM)



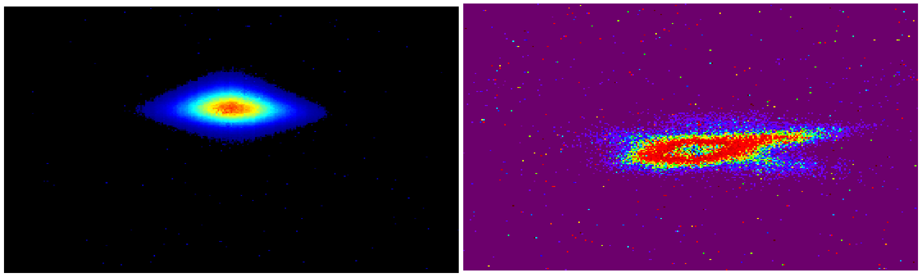
6/125 μm — 30/400 μm

Performance of the 2-stage fiber amplifier

Output pulse energy:

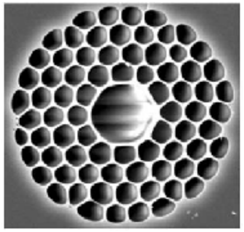


The temporal profile of the compressed pulse



- pulse duration of the output after compression is close to the duration of the oscillator pulse
- pulse is distorted due to nonlinearity

3rd stage (Photonic crystal fiber)

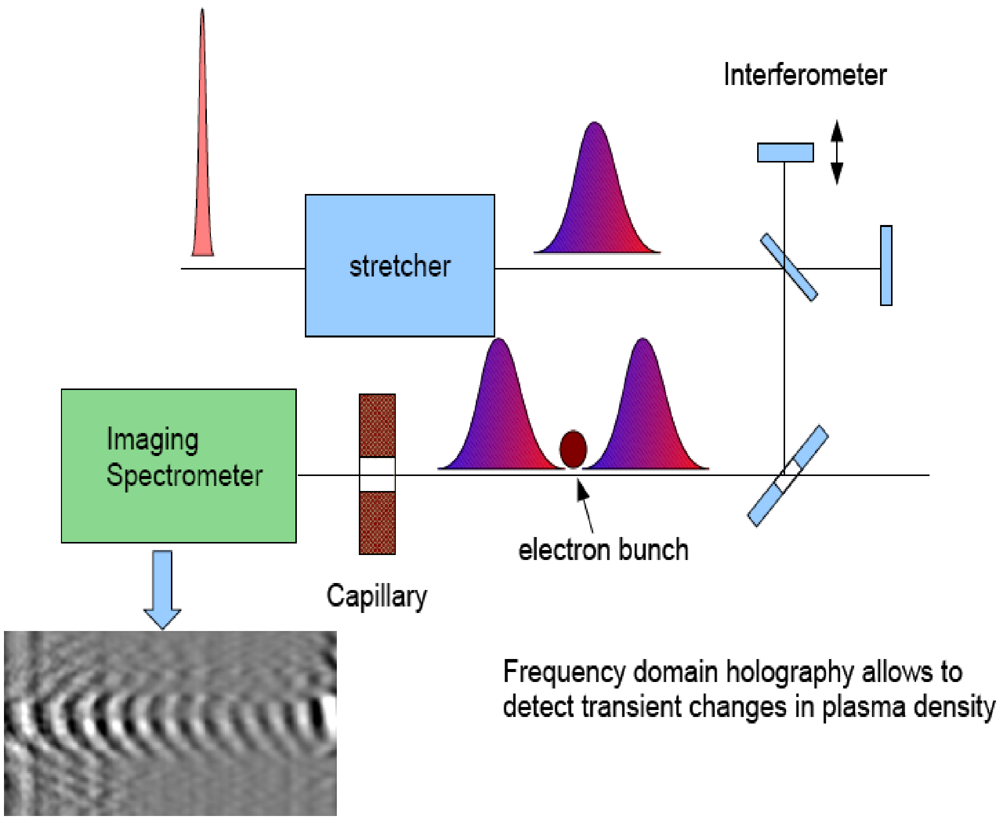


Photonic crystal fiber would allow reaching 100 μJ of the output power.

BUT

Nonlinear distortion making the pulse incompressible.

Wakefield imaging (Frequency Domain Holography)

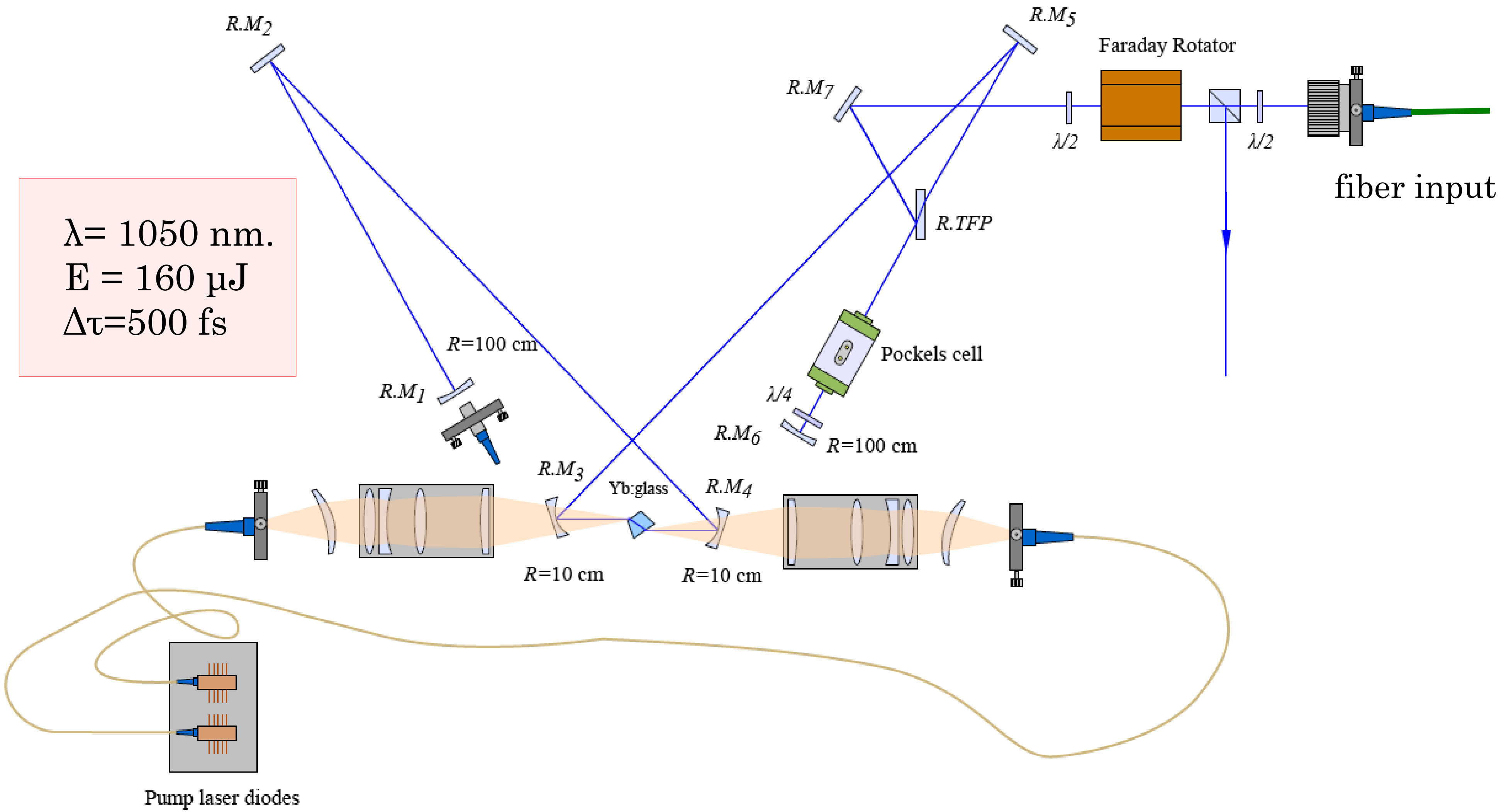


(N. H Maltis et. al. Proceedings AAC06)

- A short laser pulse is stretched in a fiber stretcher and attains a frequency chirp
- The chirped pulse is split into two pulses (reference and probe)
- Sequence: reference pulse – electron beam – probe pulse is sent through the plasma.
- Wakefield causes phase modulation in the probe pulse
- The probe and the reference pulses interfere in a spectrometer revealing the wakefield structure

Regenerative amplifier (layout)

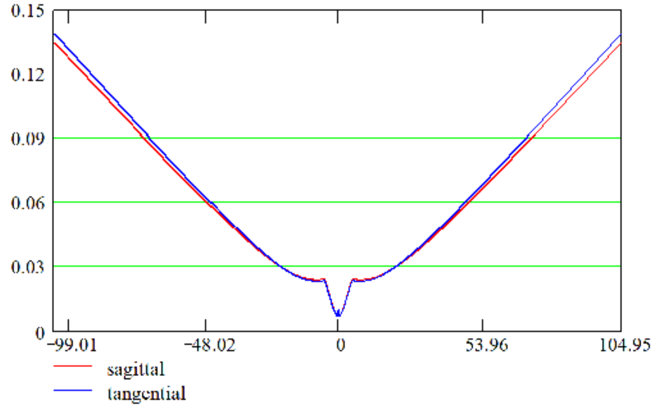
λ= 1050 nm.
E = 160 μJ
Δτ=500 fs



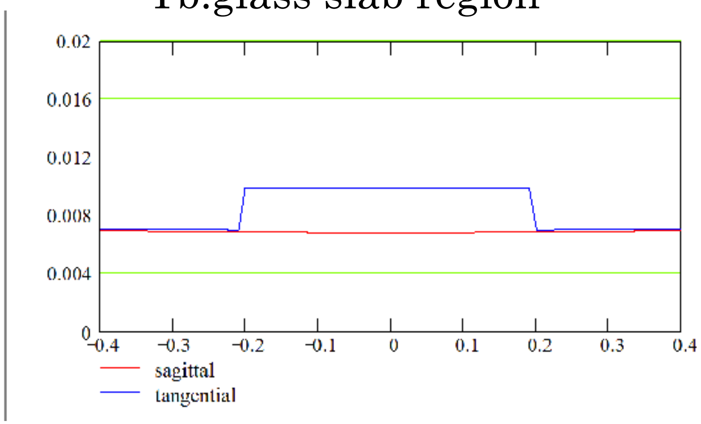
Regenerative amplifier simulations

Beam propagation:

Entire cavity

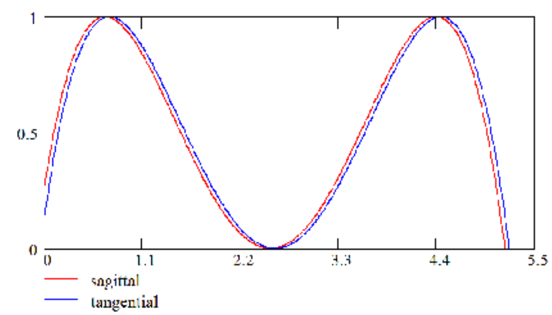


Yb:glass slab region

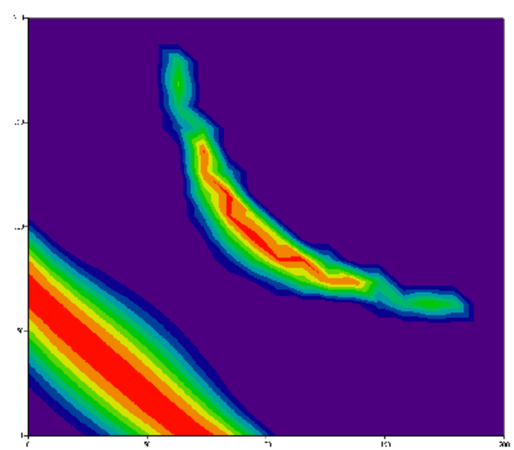


Cavity stability

Stability vs. distance between folding mirrors

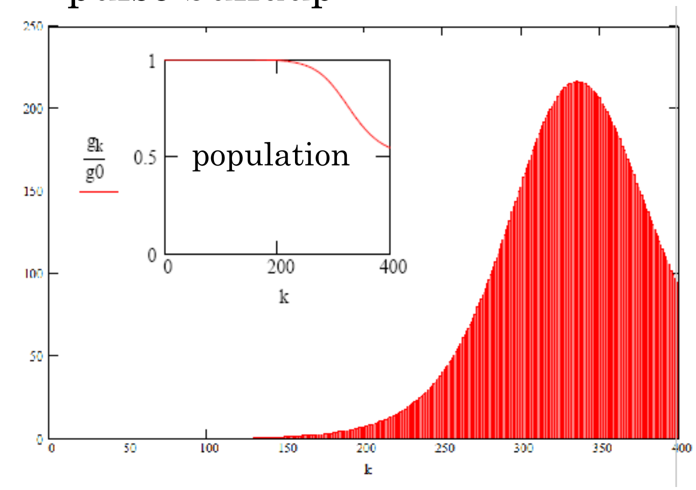


Stability vs. position of end mirrors



Laser Kinetics:

pulse buildup



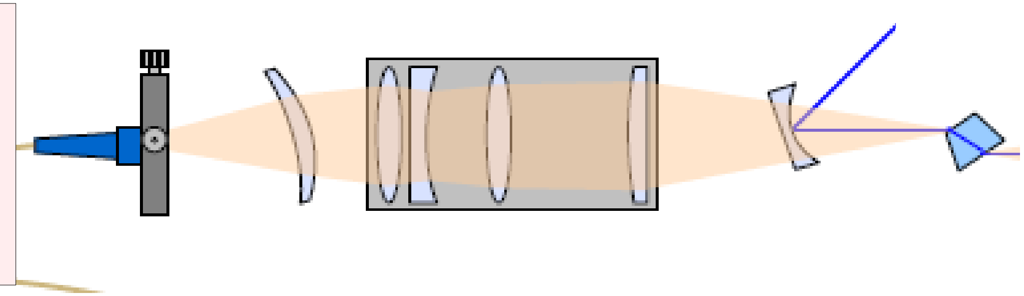
$$gf := \begin{array}{|l} g_0 \leftarrow g0 \\ f_0 \leftarrow \dfrac{E0}{EsatL} \\ \text{for } k \in 1..Kpass \\ \quad \begin{array}{|l} f_k \leftarrow T \cdot \ln\left[\exp(g_{k-1}) \cdot (\exp(f_{k-1}) - 1) + 1\right] \\ g_k \leftarrow g_{k-1} - p \cdot \left(\dfrac{f_k}{T} - f_{k-1}\right) \end{array} \\ \text{augment}(g, f) \end{array}$$

$$k := 0..Kpass$$

Design of the pump coupling units

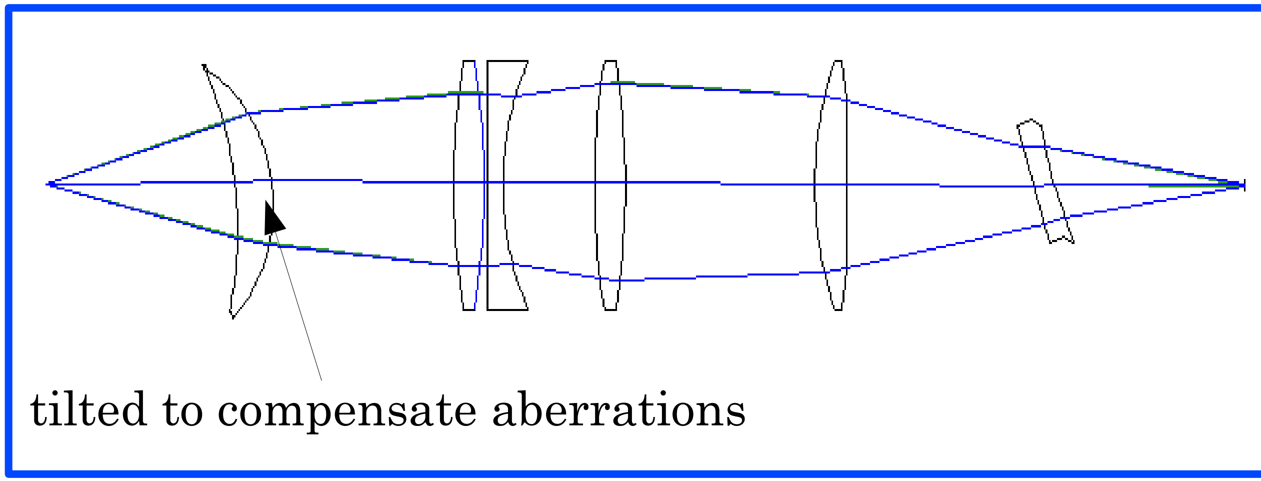
Goal: to couple the 100 μm fiber output to the Yb:glass slab through the cavity folding mirror

Magnification: -1.5



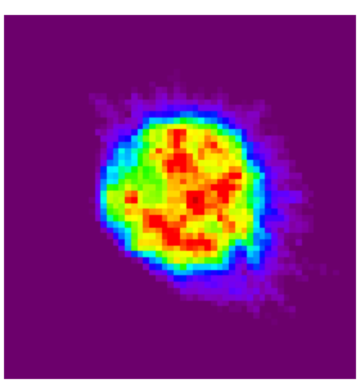
Ray tracing programs:

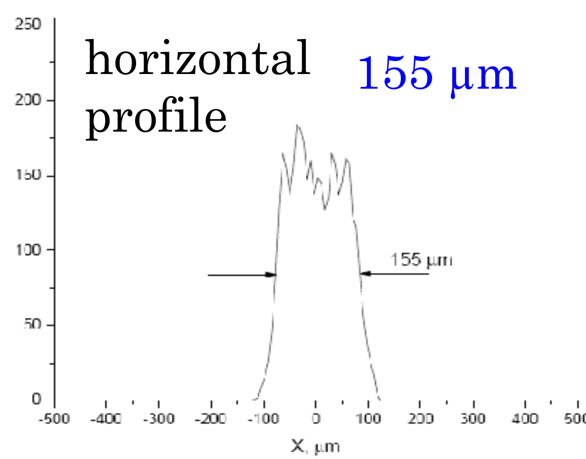
Zemax
OpTailX

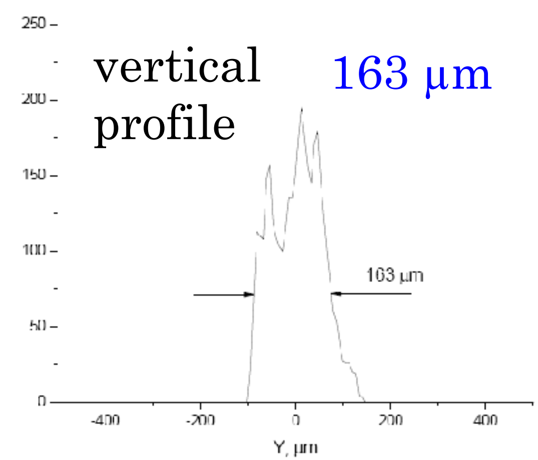


Thanks to M. Polyansky

Power throughput: >75%

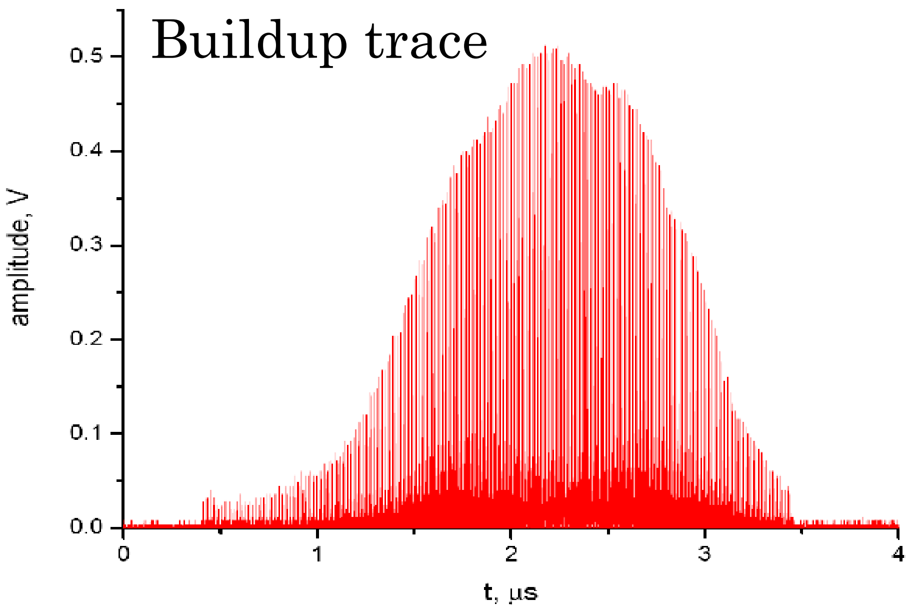




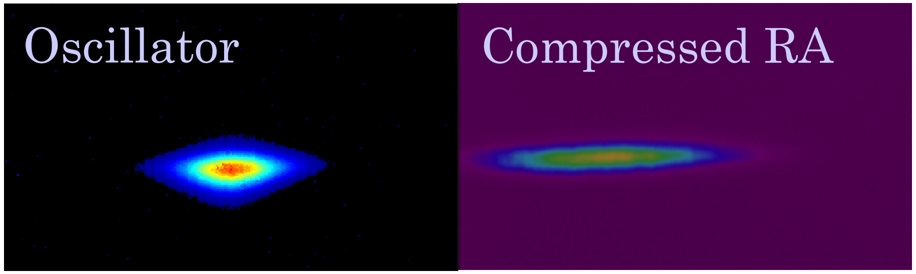


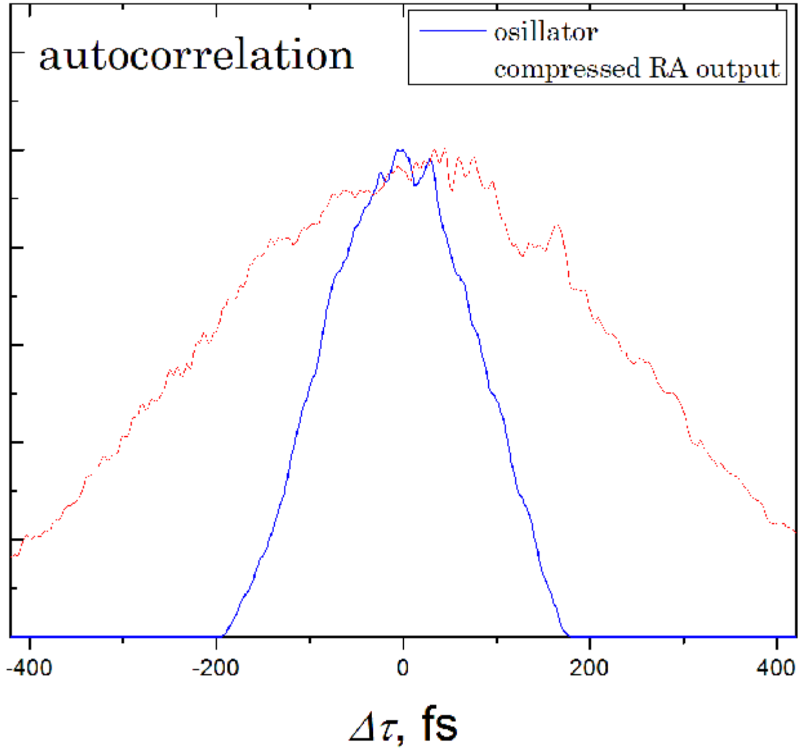
Performance of the regenerative amplifier

- The maximum output pulse energy of the regenerative amplifier is E_{max} = 180 μJ (50-60 μJ after compression)
- Duration of the compressed regenerative amplifier pulse is about 450 fs



Temporal profile measurements (FROG)





Summary

We developed so far:

- Pulse compressor based on SHG in Type II crystal:
  1.5 mJ, ~6 ps, $\lambda = 532$ nm
  (currently employed for the slicing of the ATF CO_2 laser)
- 2-stage fiber amplifier: (5 μJ, ~200 fs, $\lambda = 1047$ nm) - non-feasible for slicing
- Regenerative amplifier: 180 μJ, 400 fs, $\lambda = 1047$ nm

In progress...

- Packaging of the regenerative amplifier
- Development of the slicing setup based on the pair of non-linear crystals

Acknowledgments

ATF team:

V. Yakimenko,
I. Pogorelsky,
M. Babzien,
I. Pavlishin
M. Polyansky
K. Kusche
M. Montemagno
D. Davis
T. Corwin