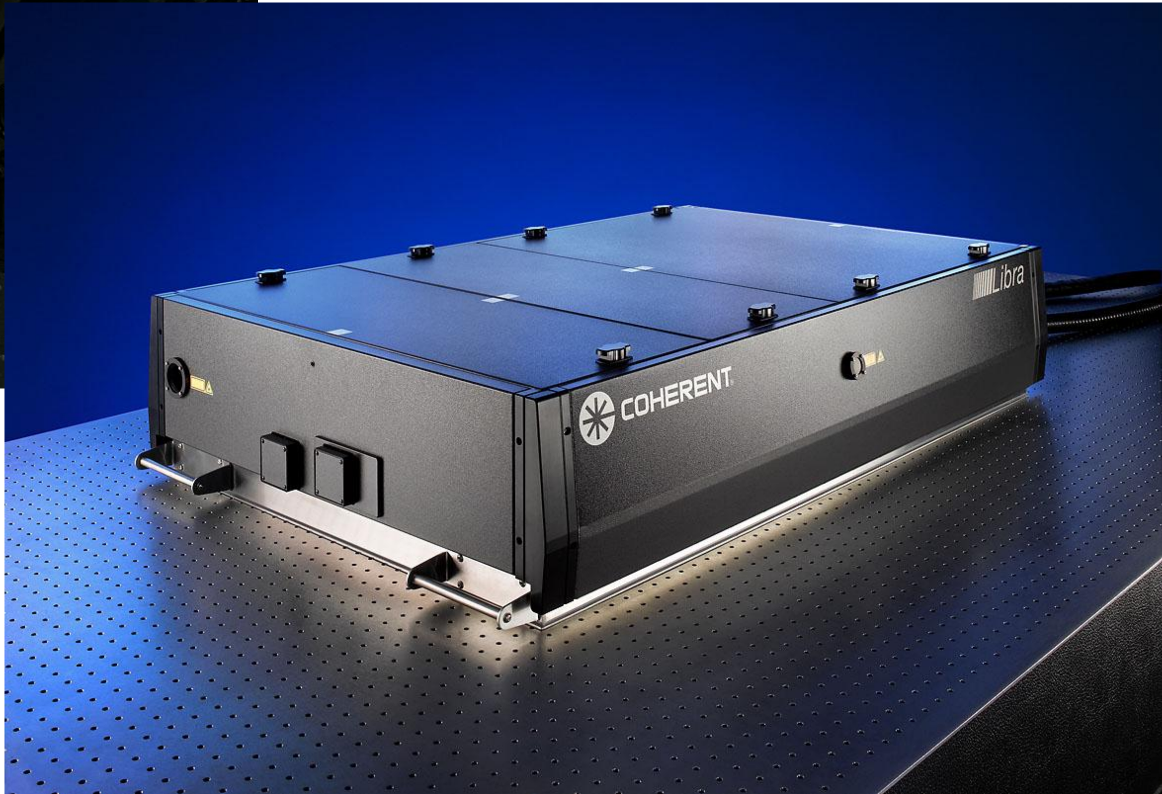
Ti:Sapphire Lasers
: Oscillator, Amplifier



Soft Matter Optical Spectroscopy

Seoncheol Cha

2012.3.24.Sat.

History of Ultrafast Lasers

1953 Maser (Microwave Amplification by Stimulated Emission of Radiation) – C. H. Townes

1960 Laser (Light Amplification by Stimulated Emission of Radiation) – T. H. Maiman

1961 Q-switching (Make ns pulses by attenuator)

1964 Mode-locking (ps pulses from HeNe laser) – L.E.Hargrove

1974 first femtosecond laser (DYE)

1986 Ti:Sapphire laser – P.F.Moulton

1991 Femtosecond Ti:Sapphire laser by Kerr-lens mode-locking (60 fs)– D.E.Spence

1994 TW Ti:Sapphire laser by Chirped Pulse Amplification

1995 kHz, mJ Ti:Sapphire laser

Novel Prize in Ultrafast Lasers

1999 Nobel Prize in Chemistry A.H.Zewail

"for his studies of the transition states of chemical reactions using femtosecond spectroscopy"

2005 Nobel Prize in Physics J.L.Hall, T.W.Hansch

"for their contributions to the development of laser-based precision spectroscopy, including the optical frequency comb technique".

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Requirement for the lasing medium for making short pulse

Requirement

Broad Gain Bandwidth (HeNe : Bandwidth ~ 0.002 nm)

Short Fluorescence Lifetime (Less than round-trip time in cavity)

-> **Fluorescent organic dye molecules**

Disadvantage of dye molecules

Unstable (fluidic vibration, etc)

Hard to maintenance – dye change, dye is harmful …

Ti:Sapphire as a lasing medium

1986 Moulton – Suggest Ti:Sapphire lasing medium

Broad Gain Bandwidth (~ 300 nm)

Broad Absorption Spectrum (allow Diode laser pumping)

Good Thermal conductivity

High 3rd order Nonlinear Optical Coefficient KLM

Spectroscopic and laser characteristics of $Ti:Al_2O_3$

P. F. Moulton

Schwartz Electro-Optics, Inc., 45 Winthrop Street, Concord, Massachusetts 01742

Received July 15, 1985; accepted October 4, 1985

Spectroscopic measurements and laser performance of $Ti:Al_2O_3$ are discussed in detail. Data on absorption and fluorescence spectra and fluorescence lifetime as a function of temperature are presented. Laser characteristics observed with pulsed-dye-laser, frequency-doubled Nd:YAG-laser, and argon-ion-laser pumping are covered and show that nearly quantum-limited conversion of pump radiation can be achieved, along with tuning over the wavelength range 660–986 nm.

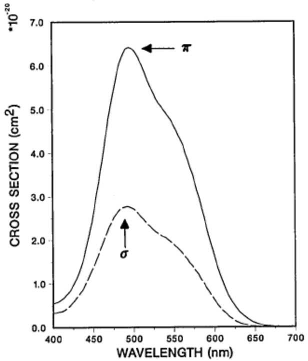


Fig. 1. Polarized absorption cross sections for the $^2T_2 \rightarrow {}^2E$ transition in $Ti:Al_2O_3$. Baseline was arbitrarily set to zero for both polarizations at 700 nm.

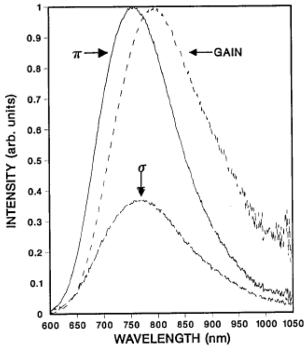
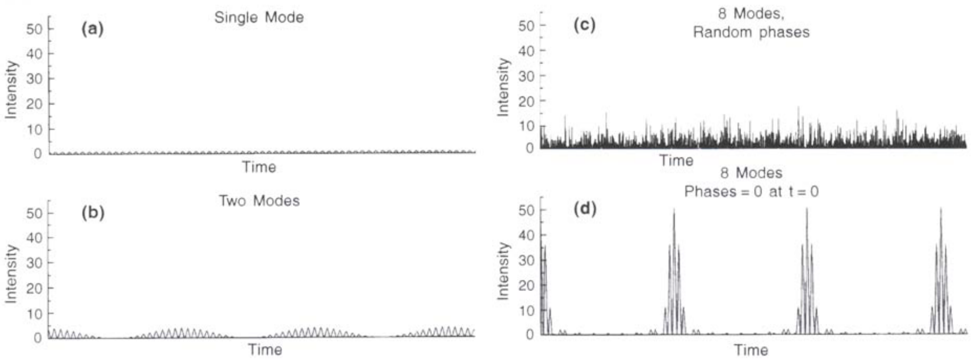


Fig. 2. Polarized fluorescence spectra and calculated gain line shape for $Ti:Al_2O_3$.

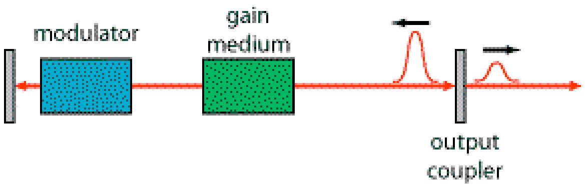
Mode-locking Technique

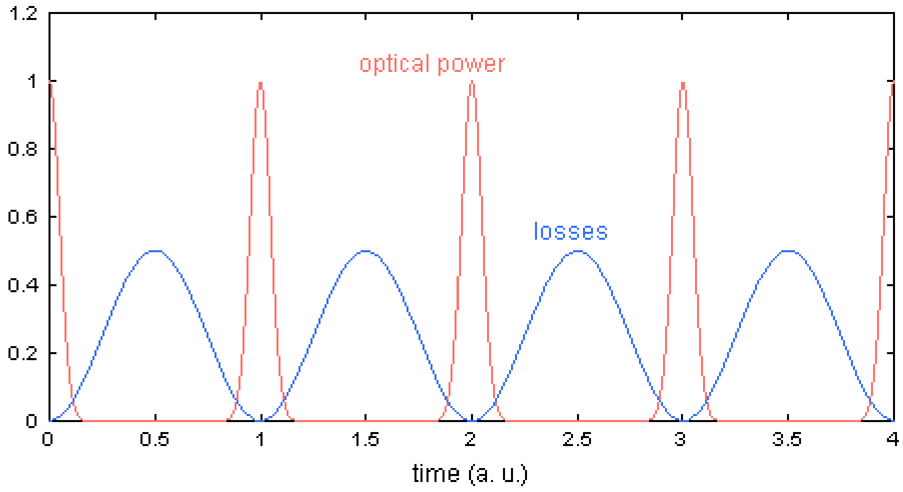
The purpose of mode-locking is to organize the modes so that the relative phases are constant, which is equivalent through Fourier transformation to the output intensity of the laser consisting of a periodic series of pulses that are the result of a wave packet oscillating back and forth in the cavity.



Mode-locking Technique

Active mode-locking is a technique for generating ultra short pulses by modulating the cavity losses or modulating the round-trip phase change.



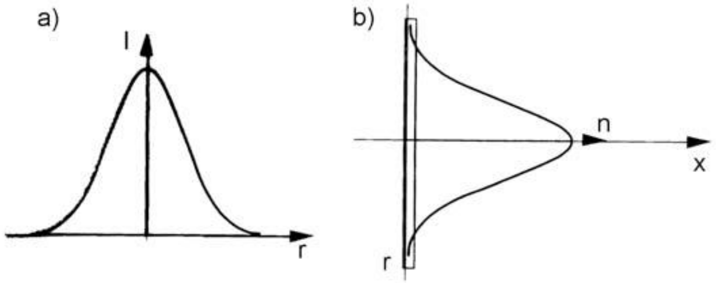


Kerr Lens Mode-Locking in Ti:Sapphire laser

1991 Moulton – first KLM Ti:S laser

Optical Kerr Effect

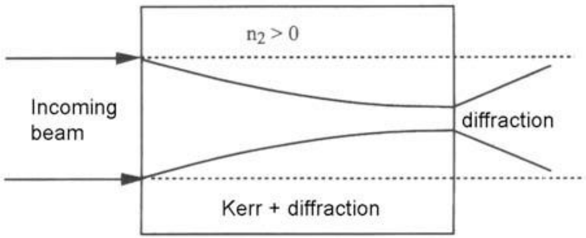
$n(r) = n_0 + 1/2 n_2 I(r)$

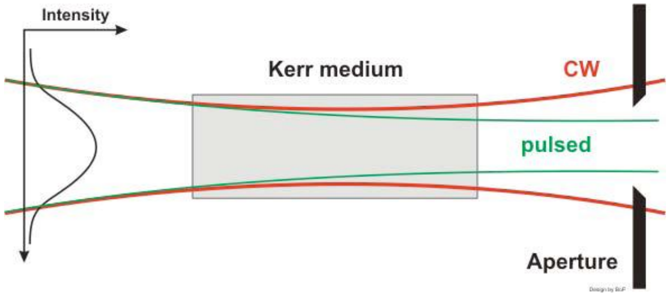


Intensity distribution of Gaussian Beam

Index of refraction variation under (b) for $n_2>0$

-> behave like Lens



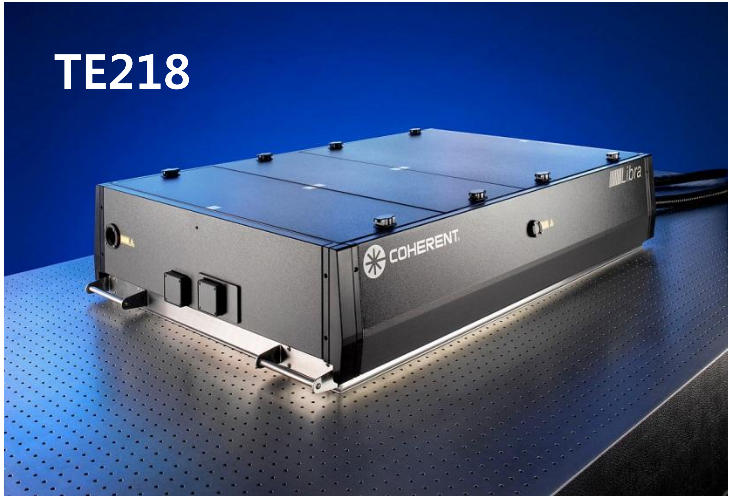


Ti:Sapphire Oscillator

Spectra Physics Tsunami
80MHz
12nJ / pulse

We need more energy !

Ti:Sapphire Regenerative Amplifier



3.5 mJ / pulse !!

Very good for nonlinear optics …

3.5 mJ / 50 fs (~TW) is too high power to gain medium

Gain medium will be damaged

How solve?

-> Chirped Pulse Amplification

Chirped Pulse Amplification

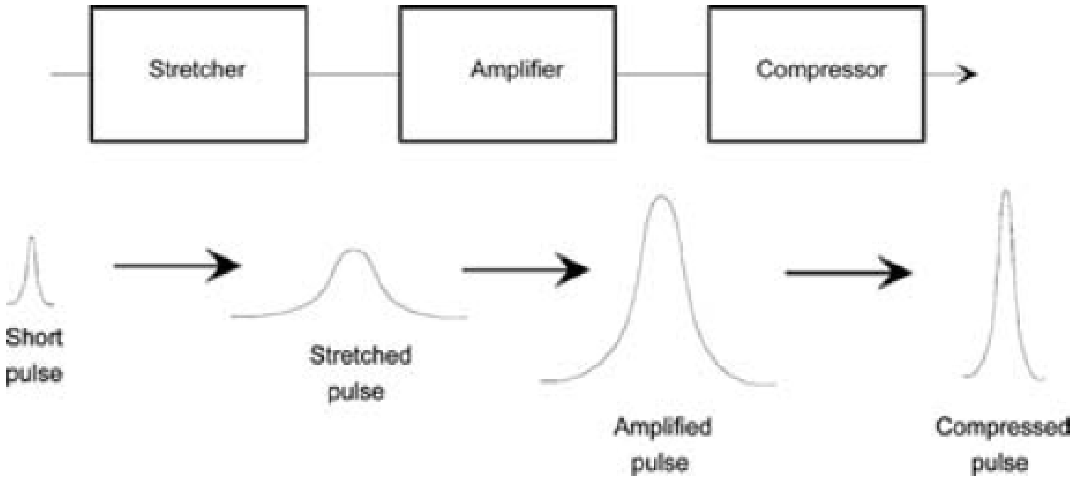


Figure 8-1. Principle of Chirped Pulse Amplification

Chirped Pulse Amplification

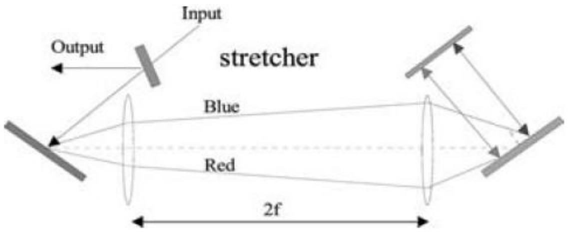


Figure 8-2. Principle of Pulse Stretching

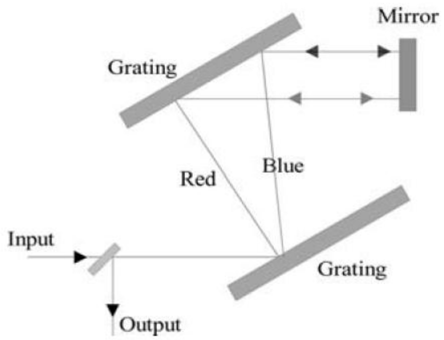


Figure 8-3. Principle of Pulse Compression

$D_{BLUE} > D_{RED}$
: Positive GVD
"Positively chirped"

$D_{BLUE} < D_{RED}$
: negative GVD
"negatively chirped"

Chirped Pulse Amplification - Stretcher

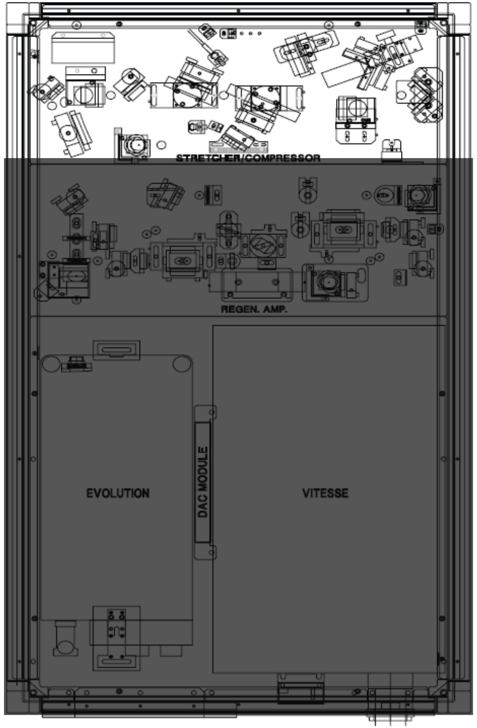
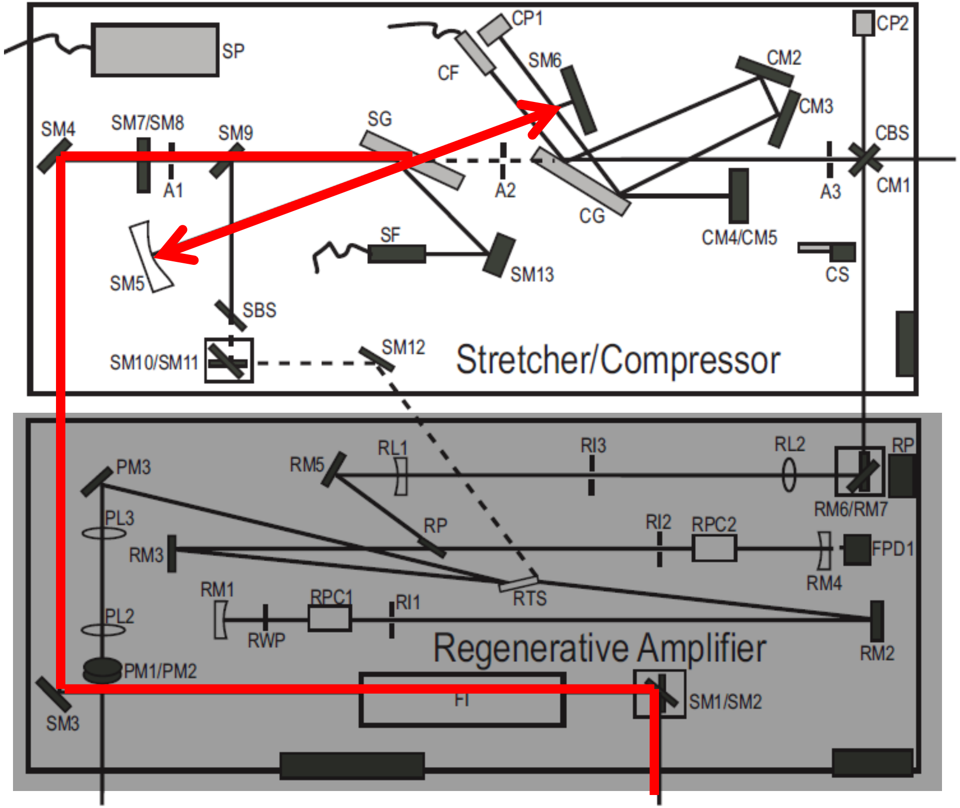
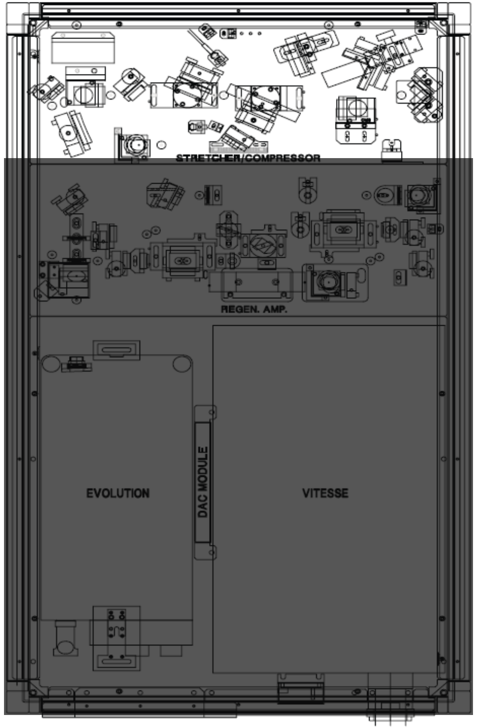


Figure 8-4. Libra Ti:Sapphire Regenerative Amplifier System



Chirped Pulse Amplification - Stretcher



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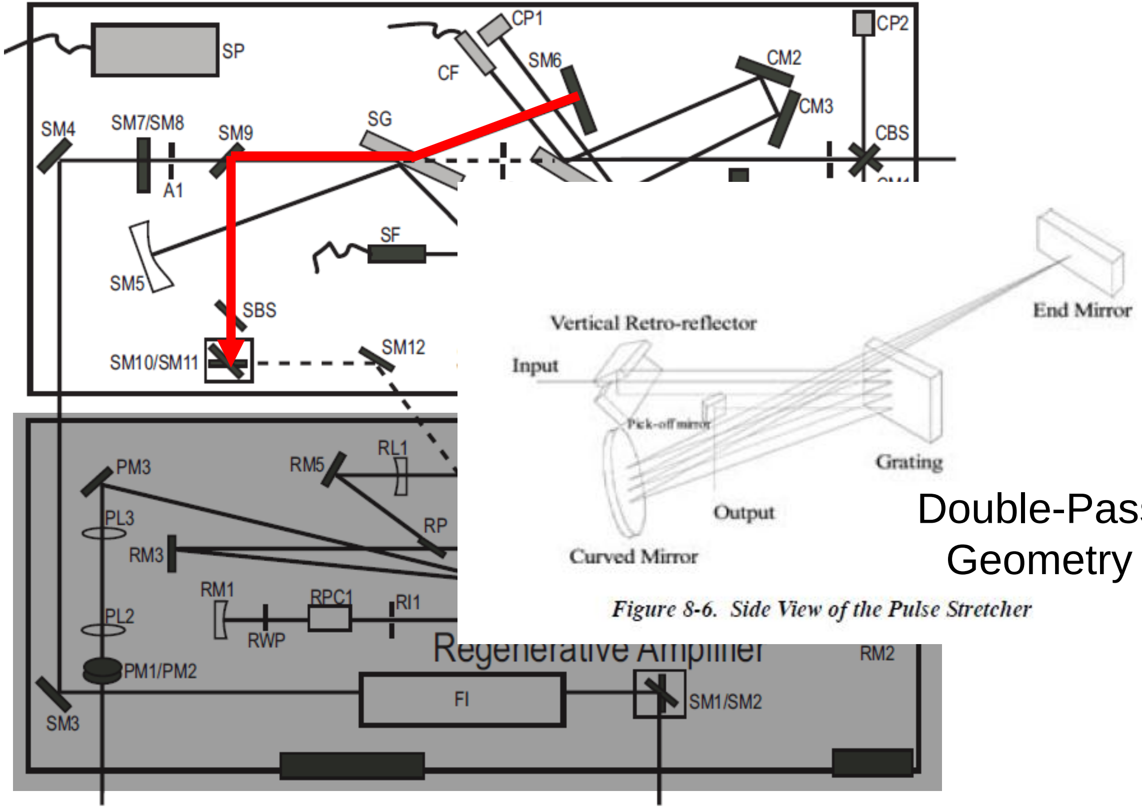
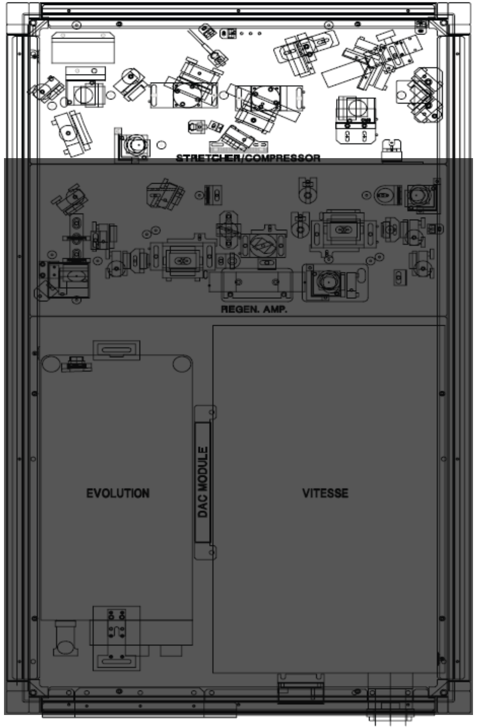


Double-Pass Geometry

Figure 8-6. Side View of the Pulse Stretcher

Chirped Pulse Amplification - Stretcher



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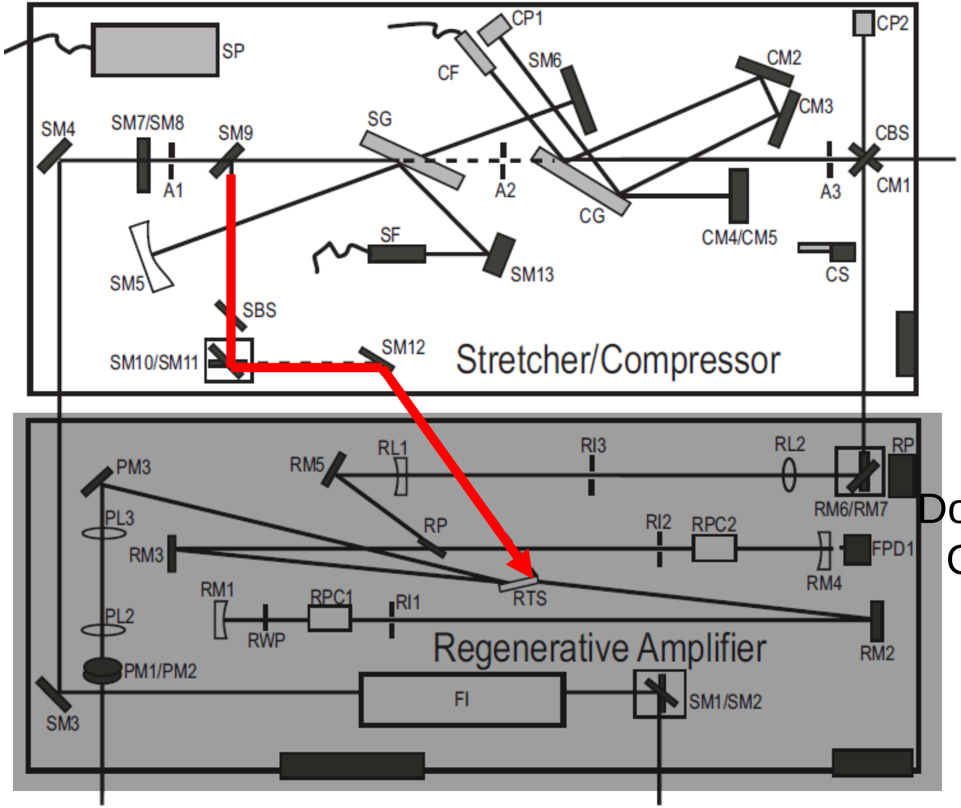


Double-Pass Geometry

Chirped Pulse Amplification

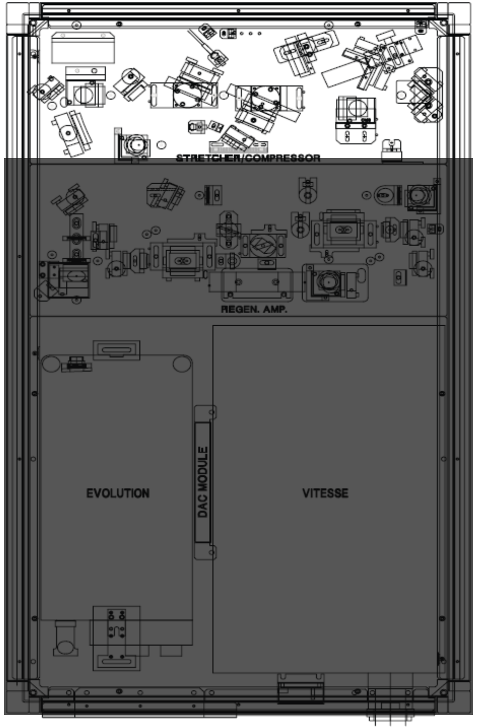
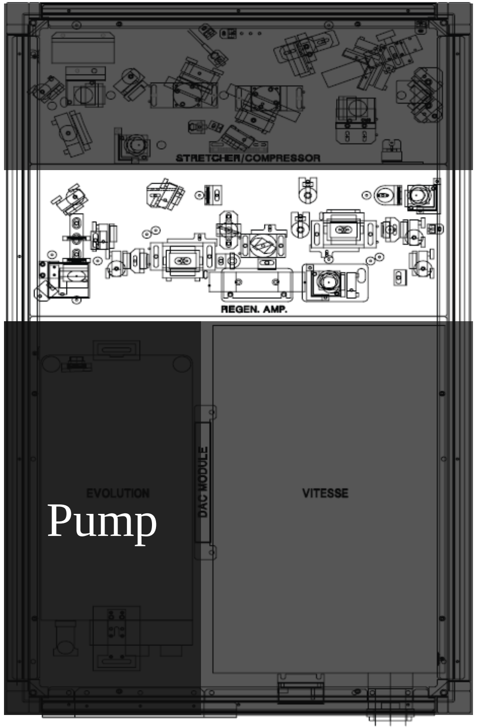


Figure 8-4. Libra Ti:Sapphire Regenerative Amplifier System

Regenerative Amplification



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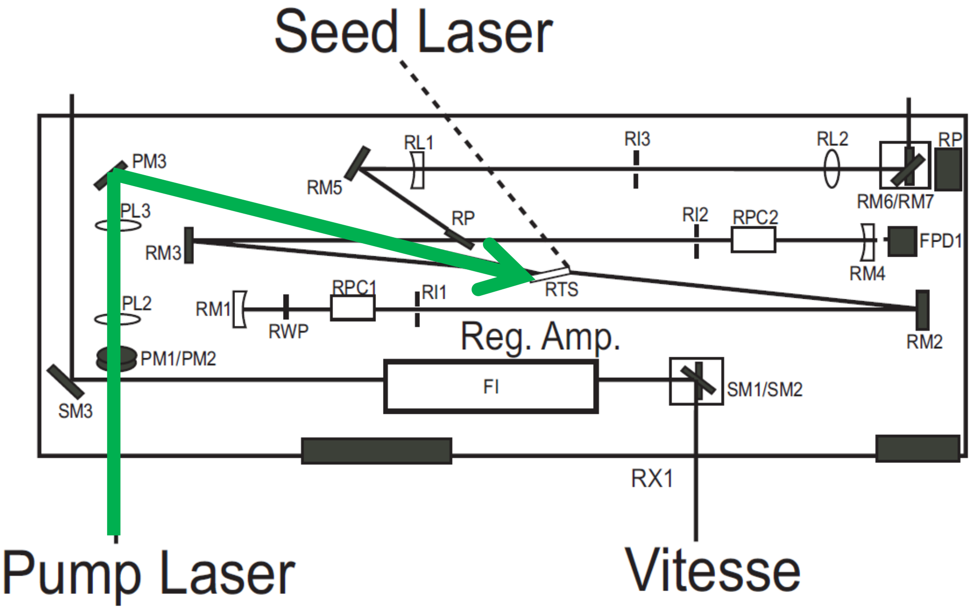
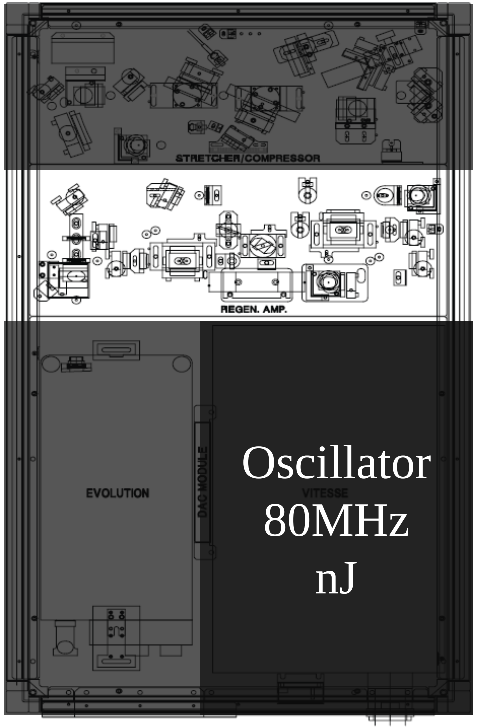


Coherent Evolution 30
1kHz, 20mJ / pulse, 527 nm
Q-switched,
Intra-Cavity Doubled ND:YLF Laser

Regenerative Amplification



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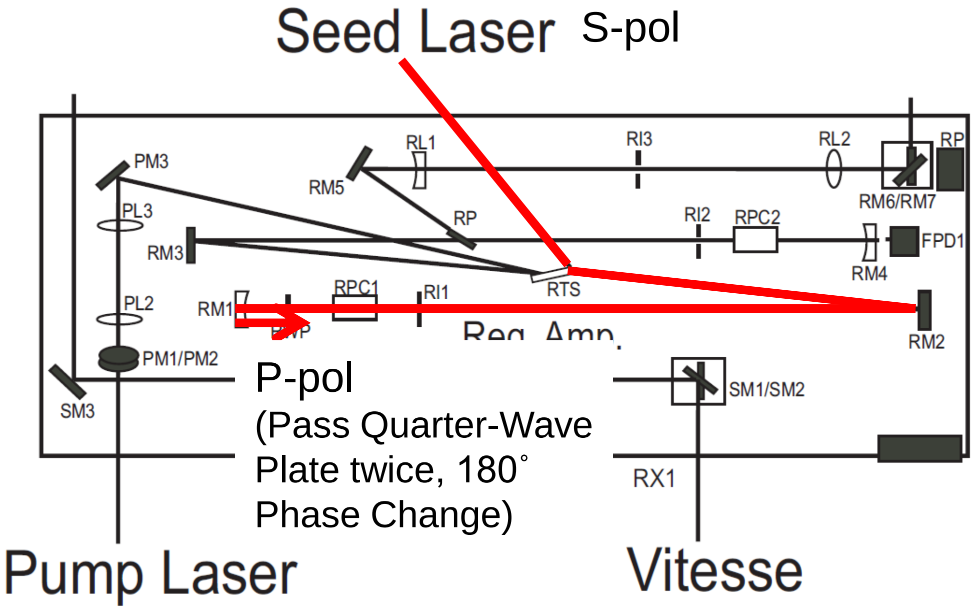


No voltage applied on
Pockels cell 1 (RPC1)

Regenerative Amplification

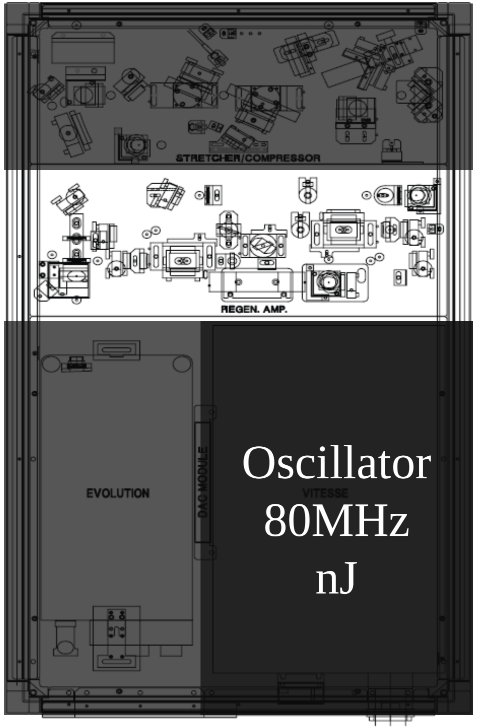
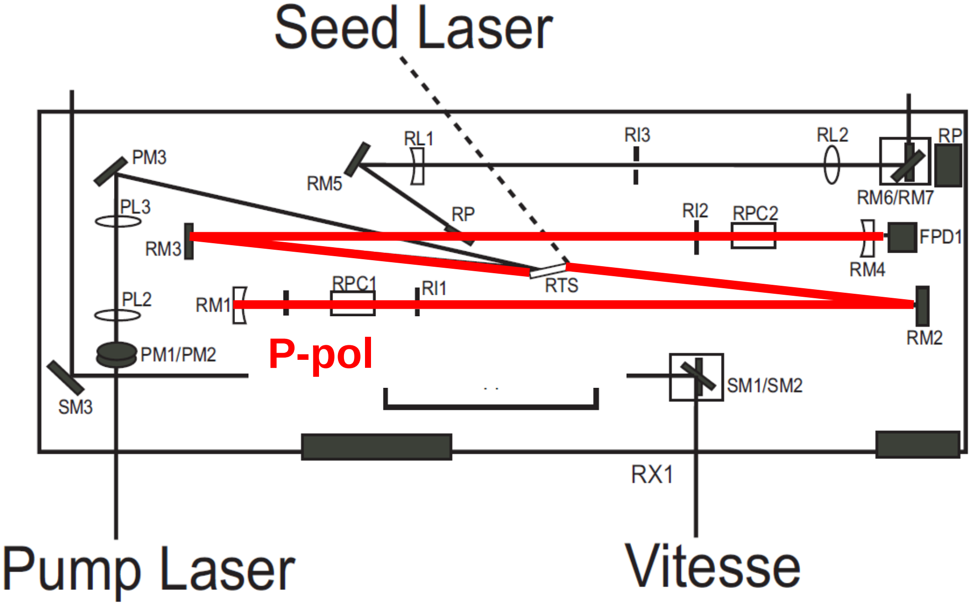


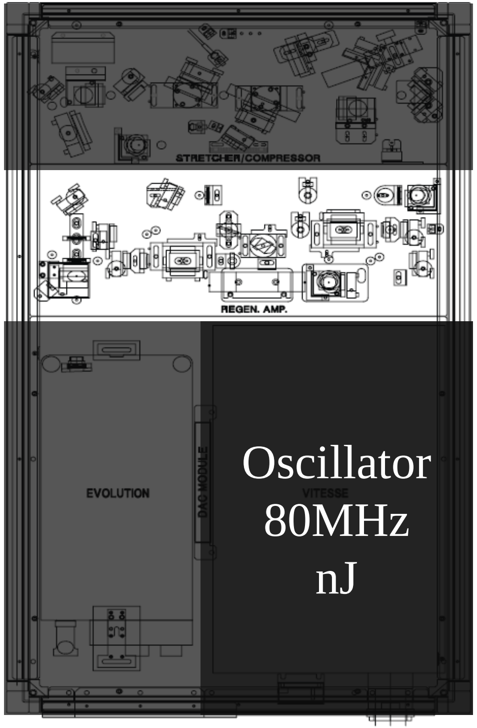
Figure 8-4. Libra Ti:Sapphire Regenerative Amplifier System

15 ~ 20 passes round trips -> $\mathbf{10^6}$ times amplification !



3.5kV voltage applied on Pockels cell 1 (RPC1) ->
QWP -> noting happens between QWP & RPC1
: beam is remained at P-pol

Regenerative Amplification



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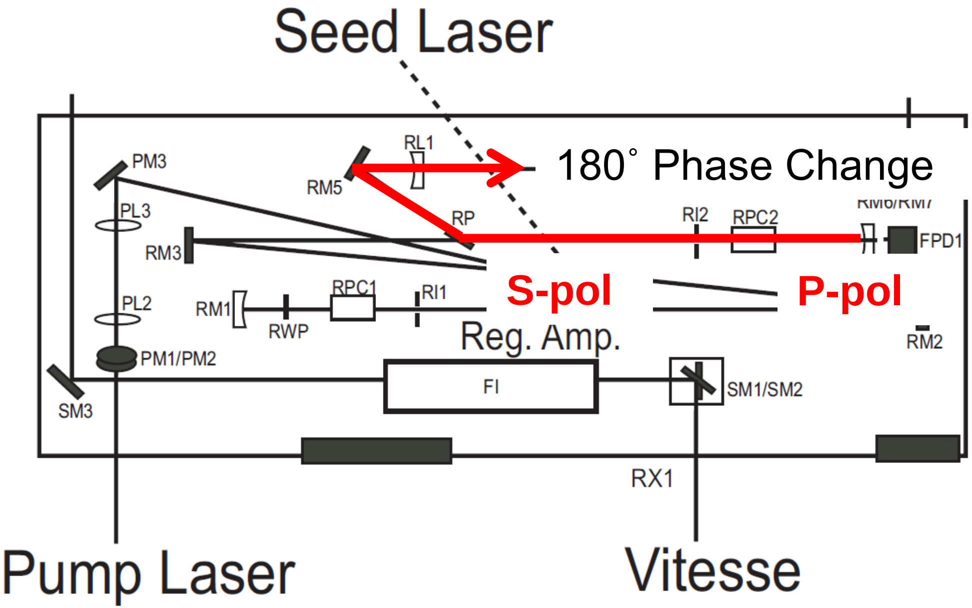
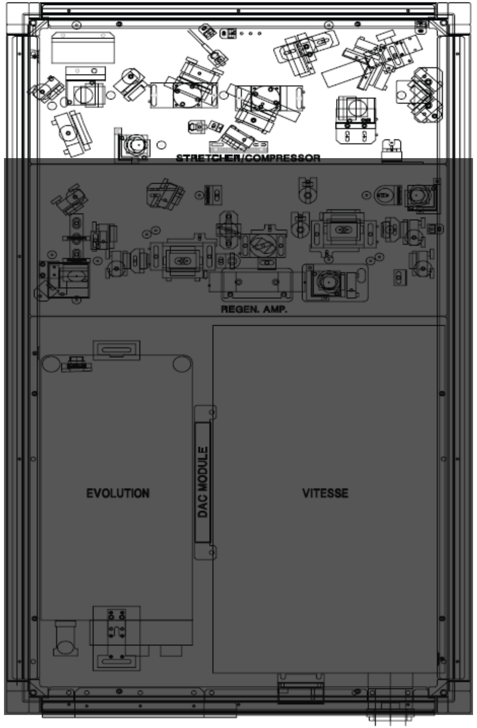


3.5kV voltage applied on Pockels cell 2 (RPC2)

Chirped Pulse Amplification - Compressor



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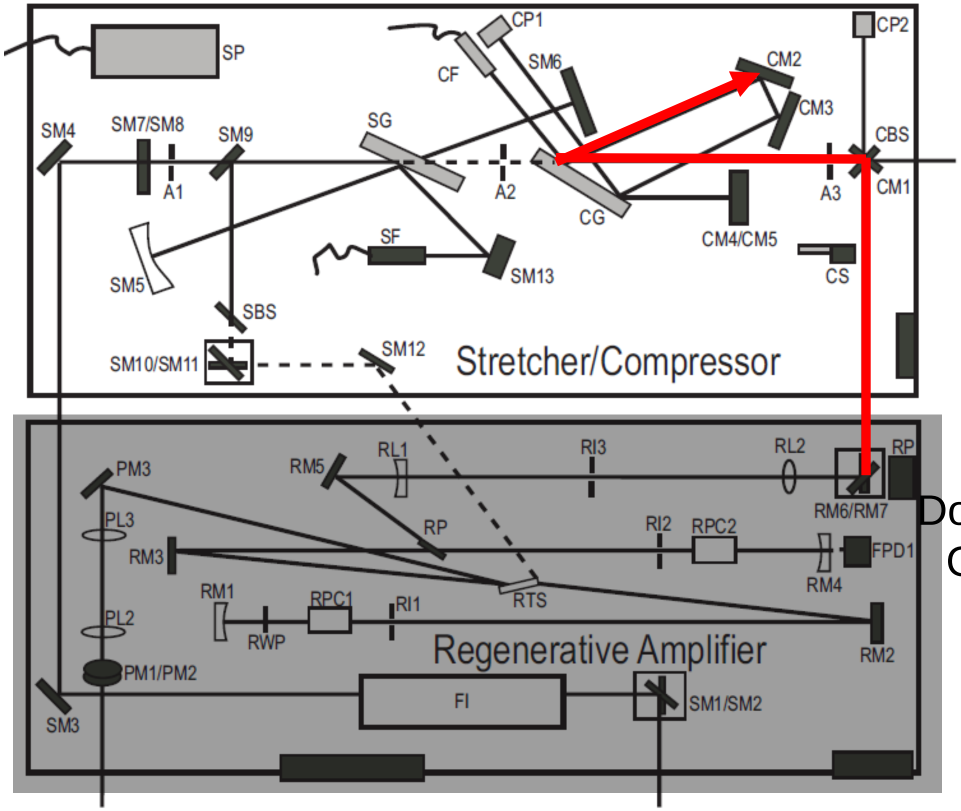
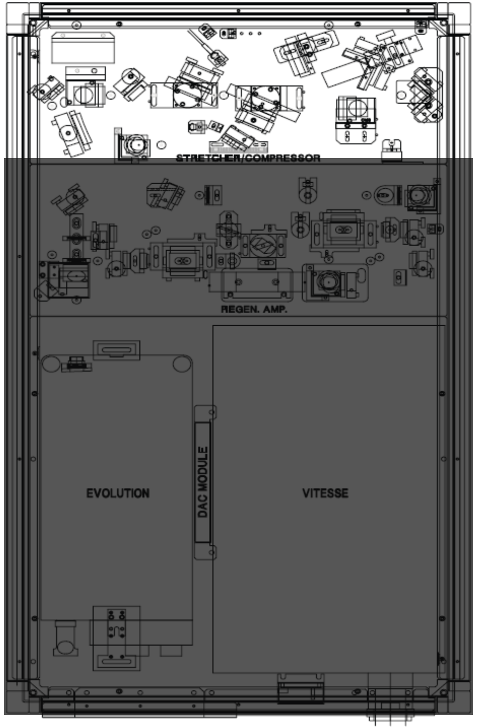


Double-Pass Geometry

Chirped Pulse Amplification - Compressor



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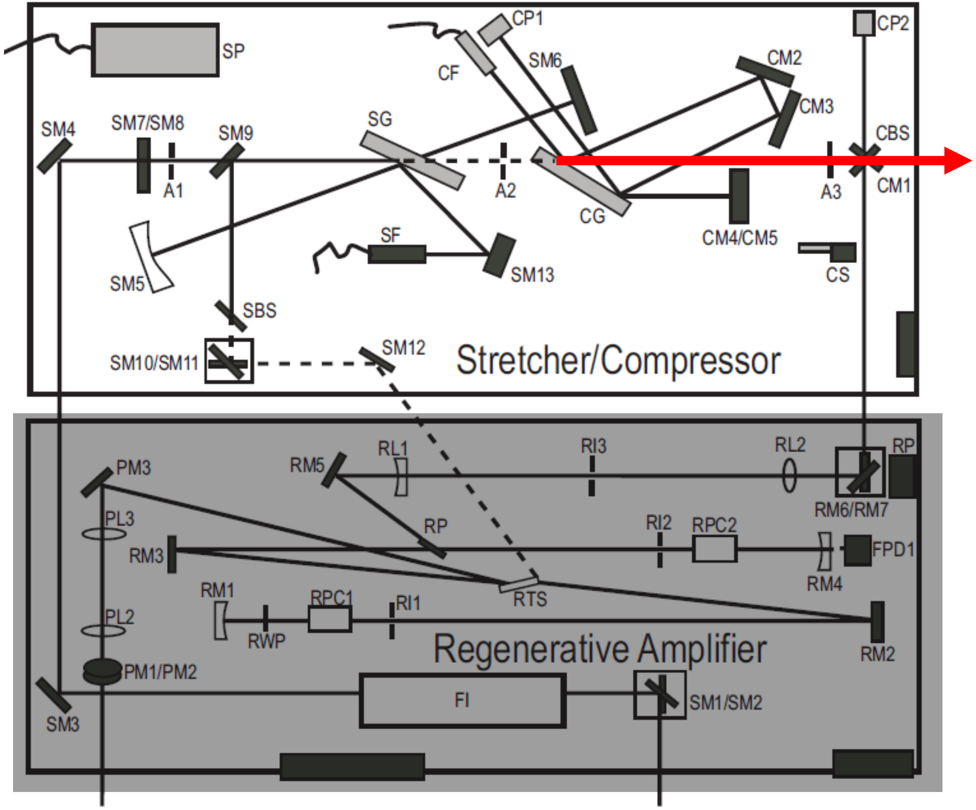
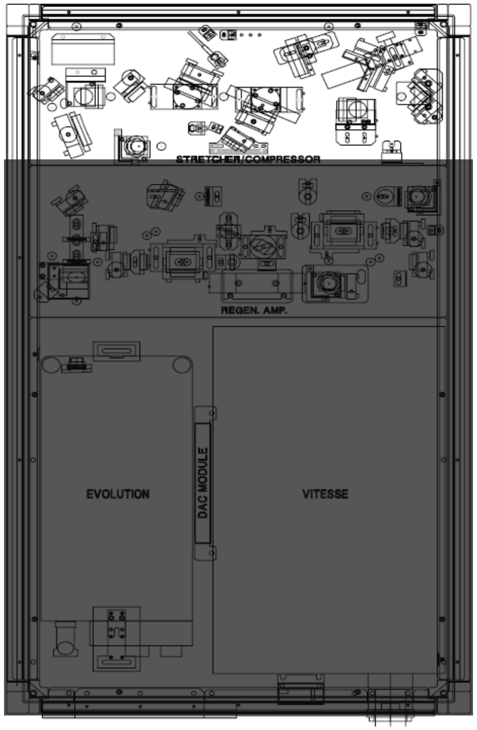


3.5 mJ
50 fs
1kHz
800 nm

Chirped Pulse Amplification - Compressor



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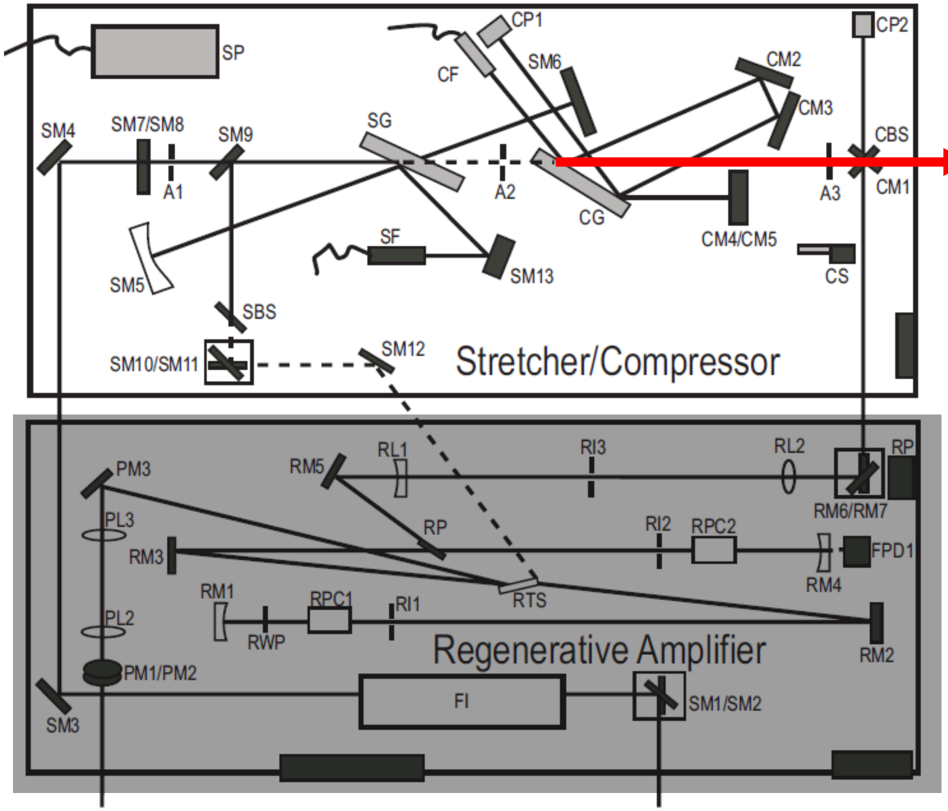

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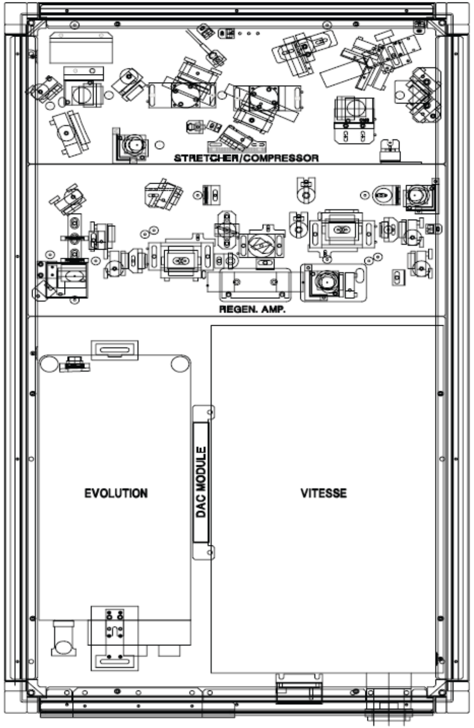
Summary



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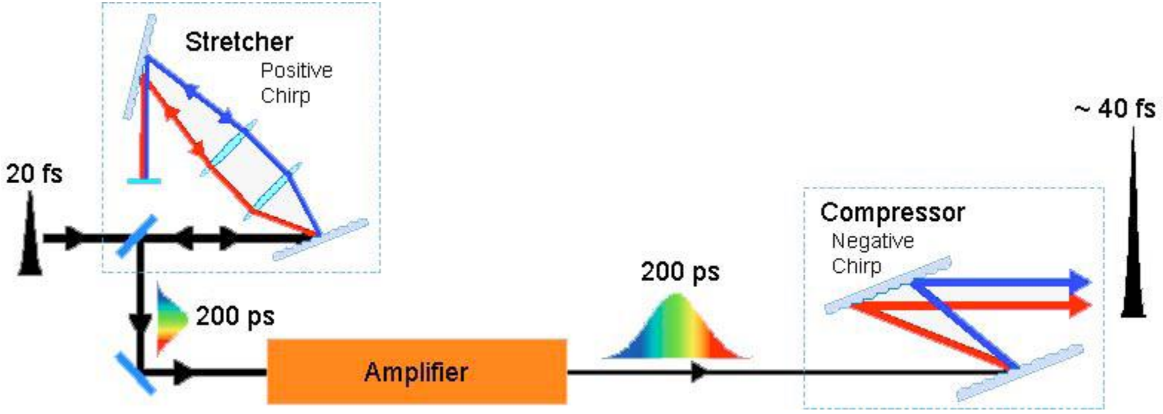
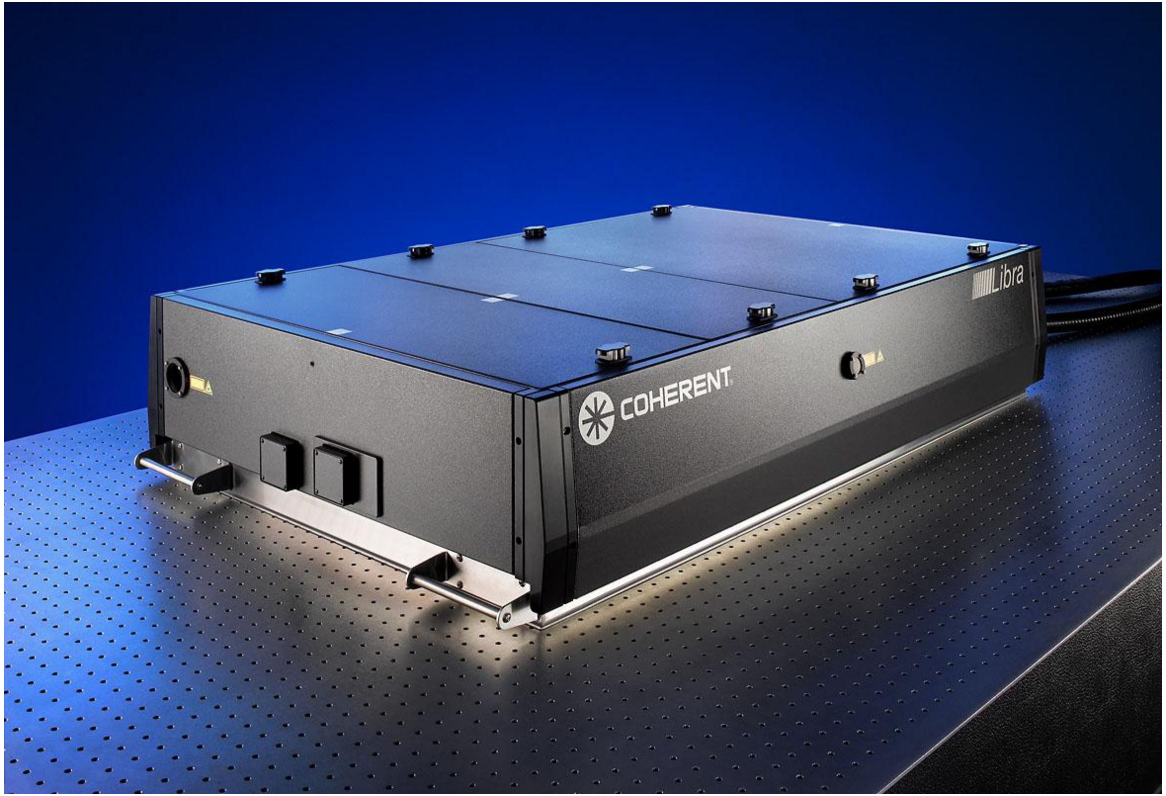


Conclusion



3.5 mJ, 50 fs, 1kHz, 800 nm

SETUP!!! (OPA, TR-SFG …)

EXPERIMENT!!!
(Nonlinear Opt, Dynamics…)

PAPER!!!

Longitudinal Modes of Laser

Suppose laser cavity having length L

$m\lambda/2 = L$, by standing wave condition (m : arbitrary integer)

$\nu\Delta = mc/2L$

$\Delta\nu = c/2L$

$\Delta\nu = c\Delta\lambda/\lambda^2$

For 30 cm cavity,

He-Ne (0.002 nm gain bandwidth) has 3 longitudinal modes

Ti:Sapphire (300 nm gain bandwidth) has 250,000 longitudinal modes