High Power Lasers

Catania, 17th November 2025

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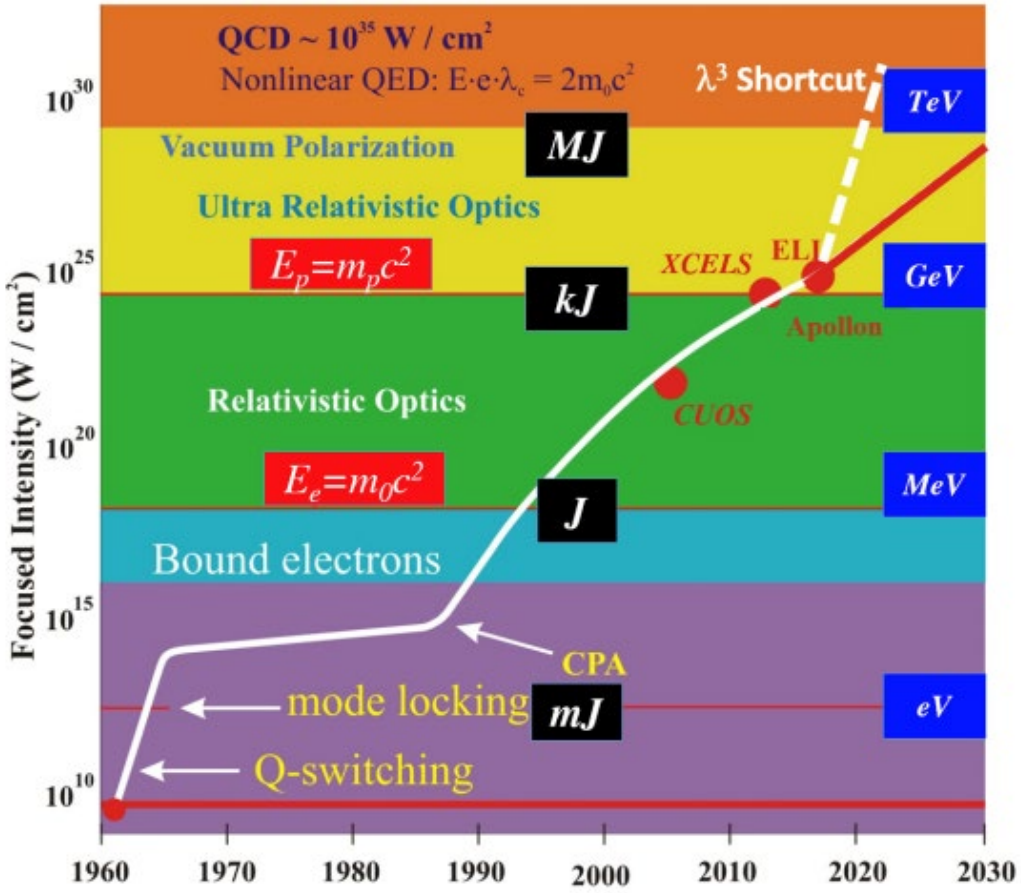
What does it mean high intensity?

$$I = \frac{P}{S} = \frac{E}{S\Delta t}$$

How small can S get to?

$$S \approx 2.44\lambda \frac{f}{D}$$

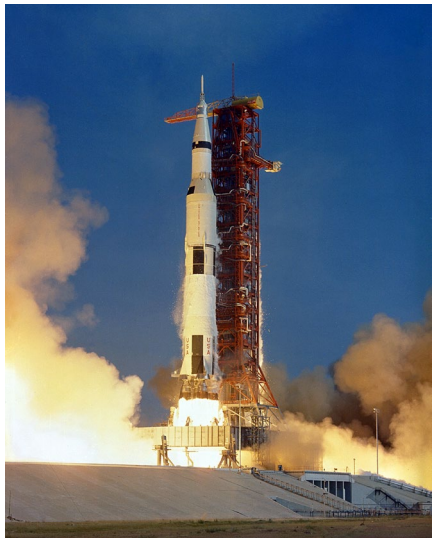
Intensità W/cm²	Fenomeno
10^{-1}	Sun Intensity on the ground
10^{12}	Ionization
10^{16}	Saturation of ionization
10^{18}	Relativistic Elettrons
10^{25}	U^{92+}
10^{29}	pair production in vacuum



Wheeler et Al. Rev. Accel. Sci. Tech. 9, 151-163 (2016)

Architectures of High Power Lasers

Peak Power

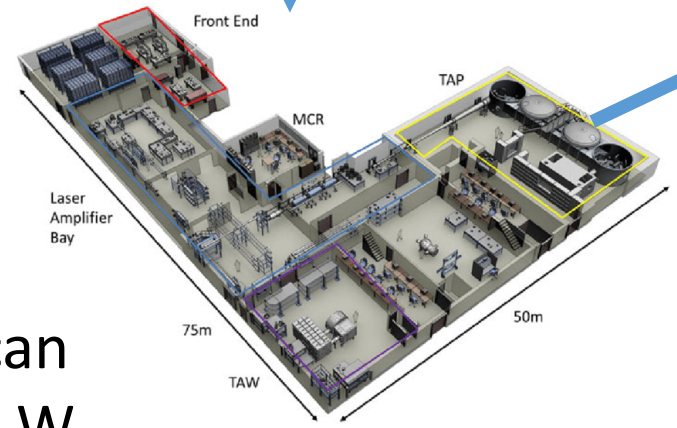


Saturn V
10^{10} W

X 100

Luli2000
10^{12} W

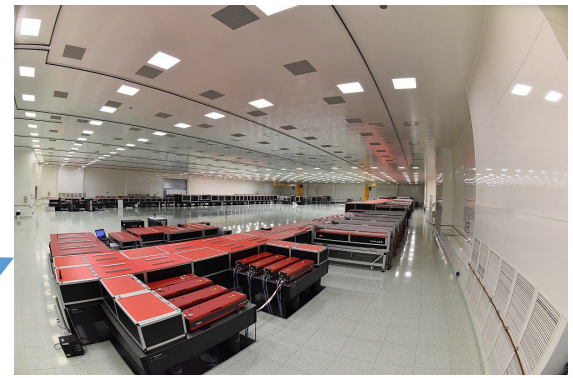
X 100



Vulcan
10^{14} W

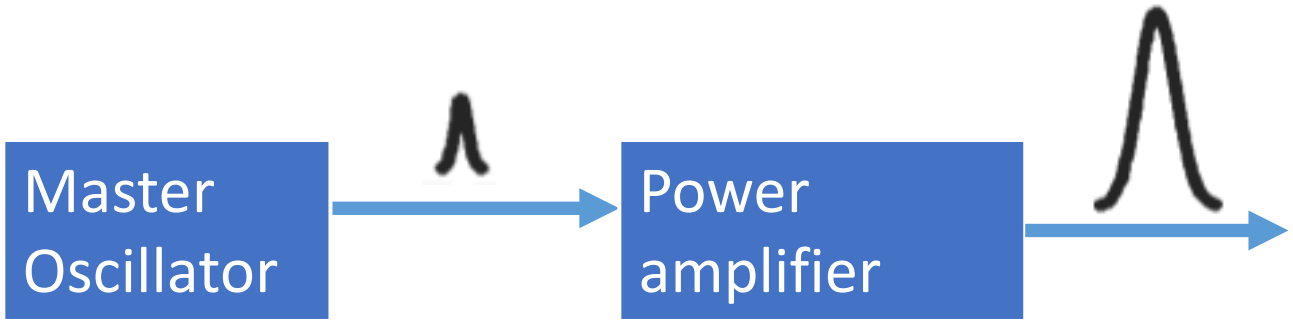
X 100

ELI-NP
10^{16} W



General Architecture

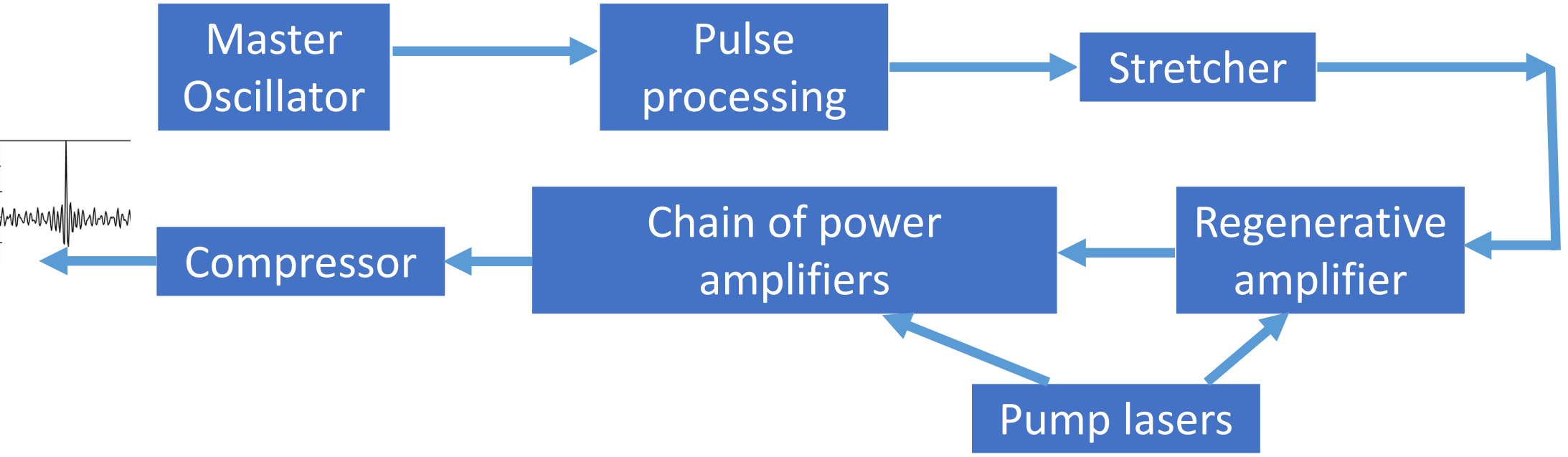
MOPA: Master Oscillator Power Amplifier



Osc= 1nJ
Amp = 1J
G = 10^9
= 90 dB

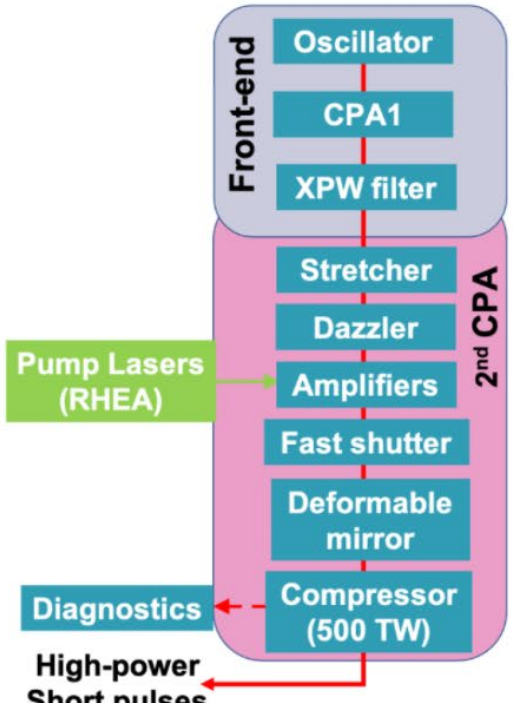
High-power Architetture

MOPA + CPA (Chirped pulse amplification)

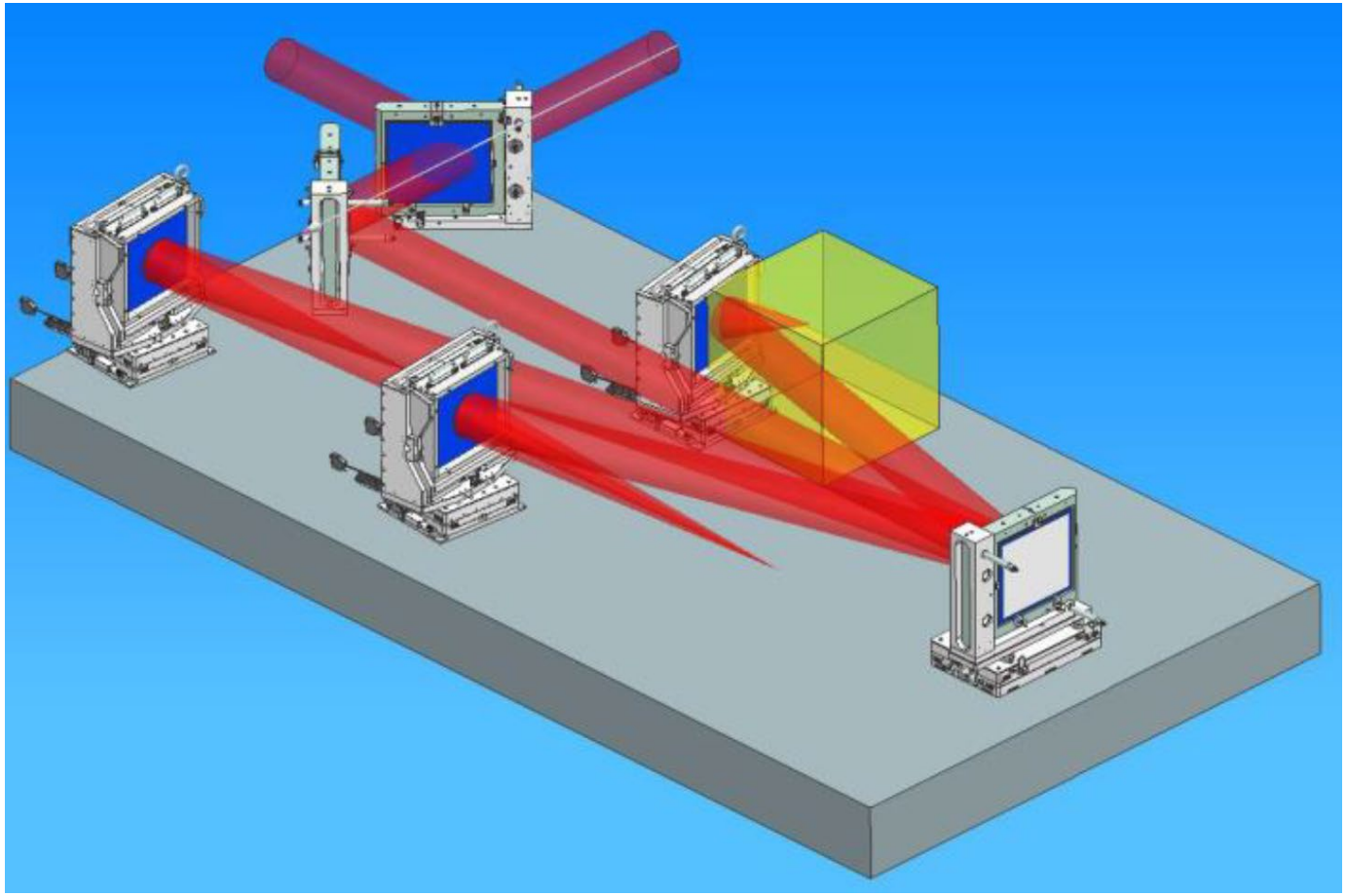


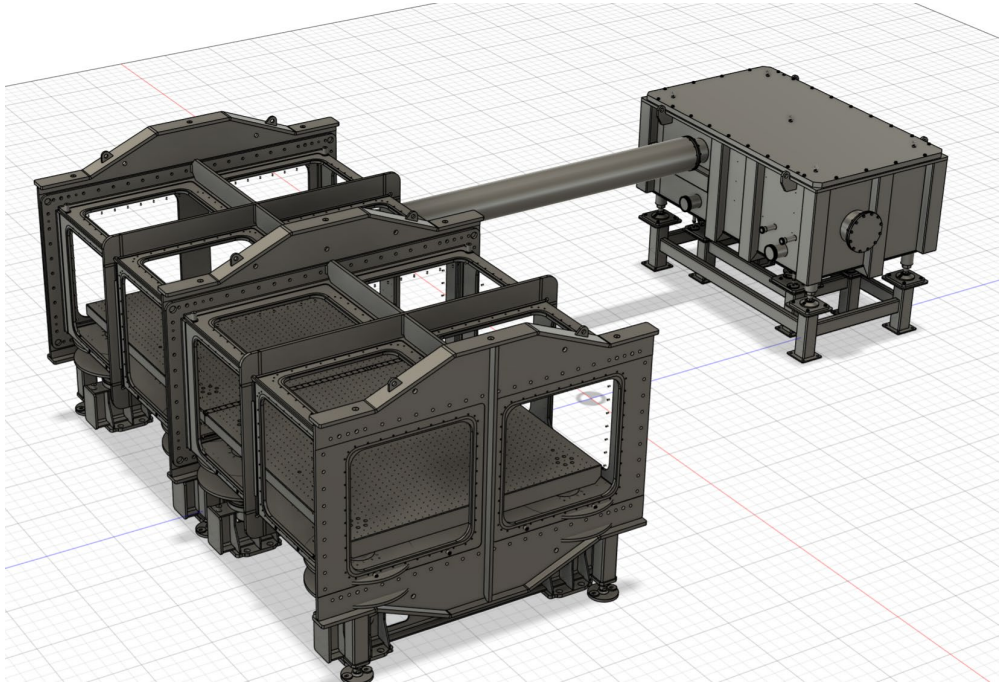
Our future laser at INFN-LNS

Thales Quark System 350 TW

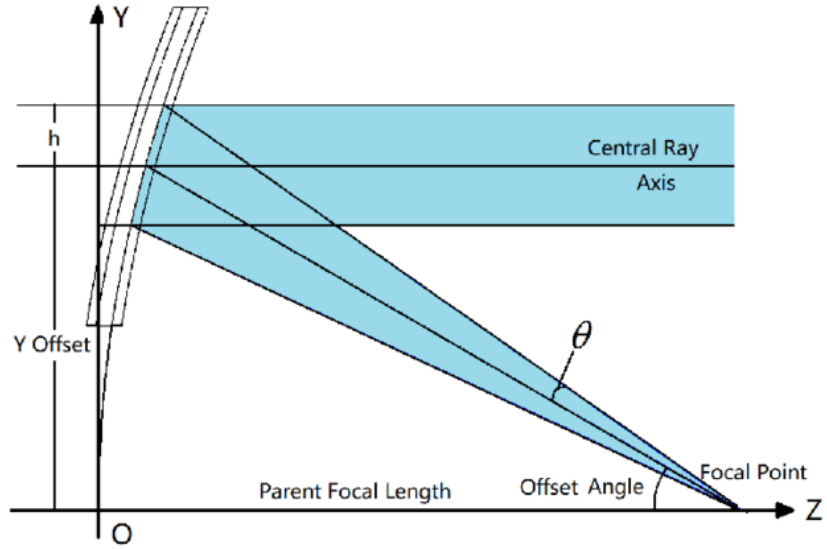


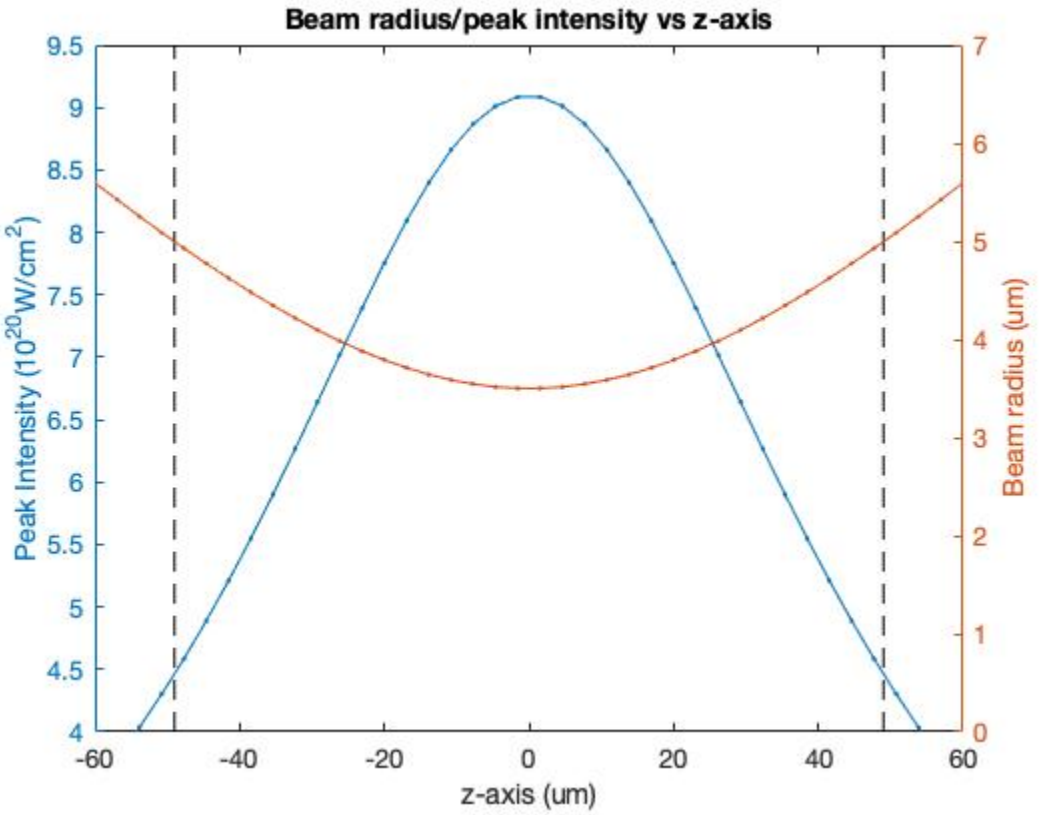
Optical path to target

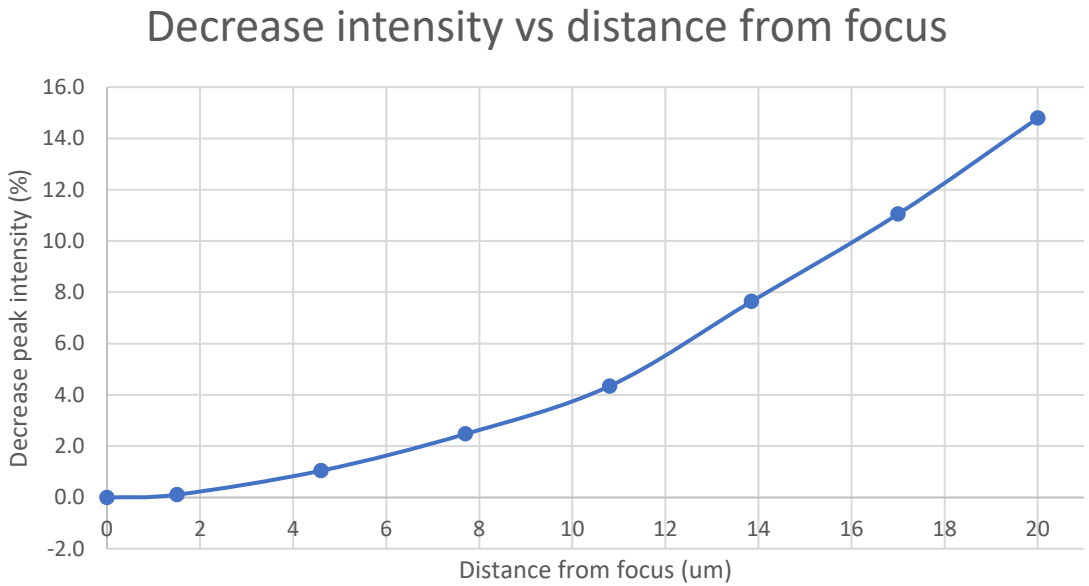




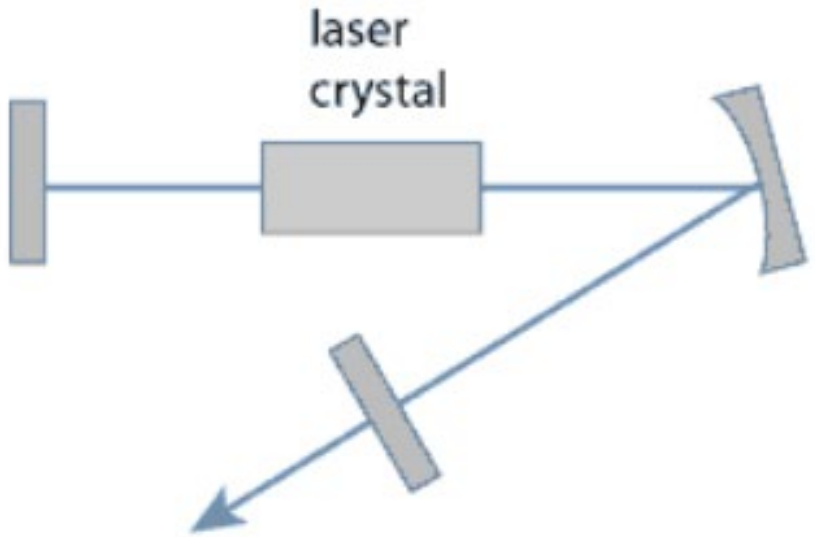
Focusing: Off-axis Parabolic Mirrors and Rayleigh range

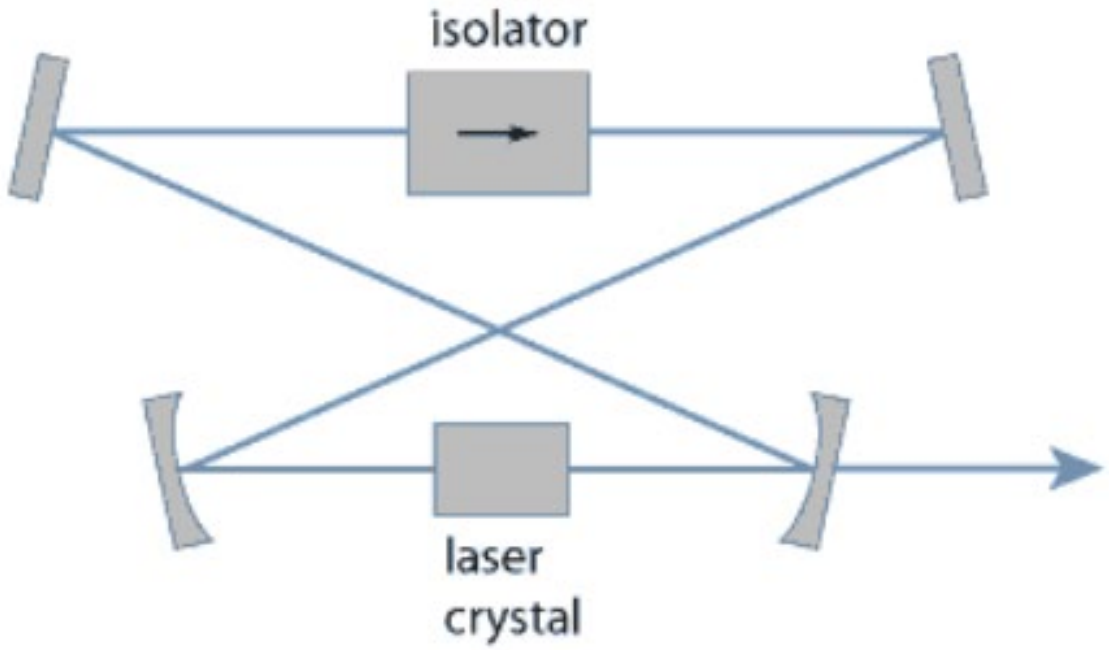






What are laser resonators (cavities)





https://www.rp-photonics.com/laser_resonators.html

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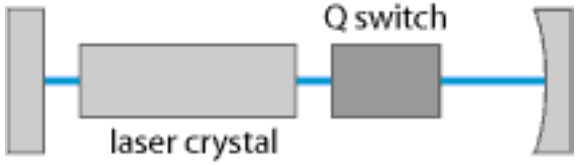


Allows to reach nanosecond width pulses

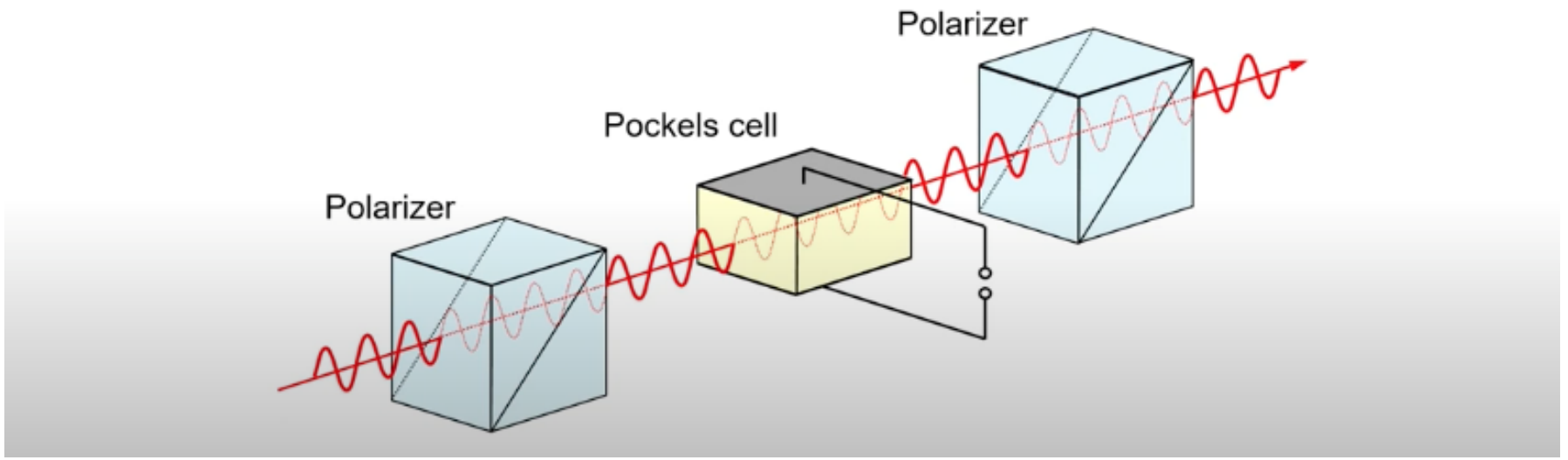
https://www.rp-photonics.com/q_switched_lasers.html

Q-switching

Q-switching: Electro-optic modulator (EOM)

Pockels effect

- Index of refraction of certain crystals is proportional to an external electric field: $\Delta n \propto E$.
- In these crystals birefringence can be produced by means of high voltages (typically several kV).
- Such a crystal can consequently act as a controllable wave plate and be used to change the polarization of light.



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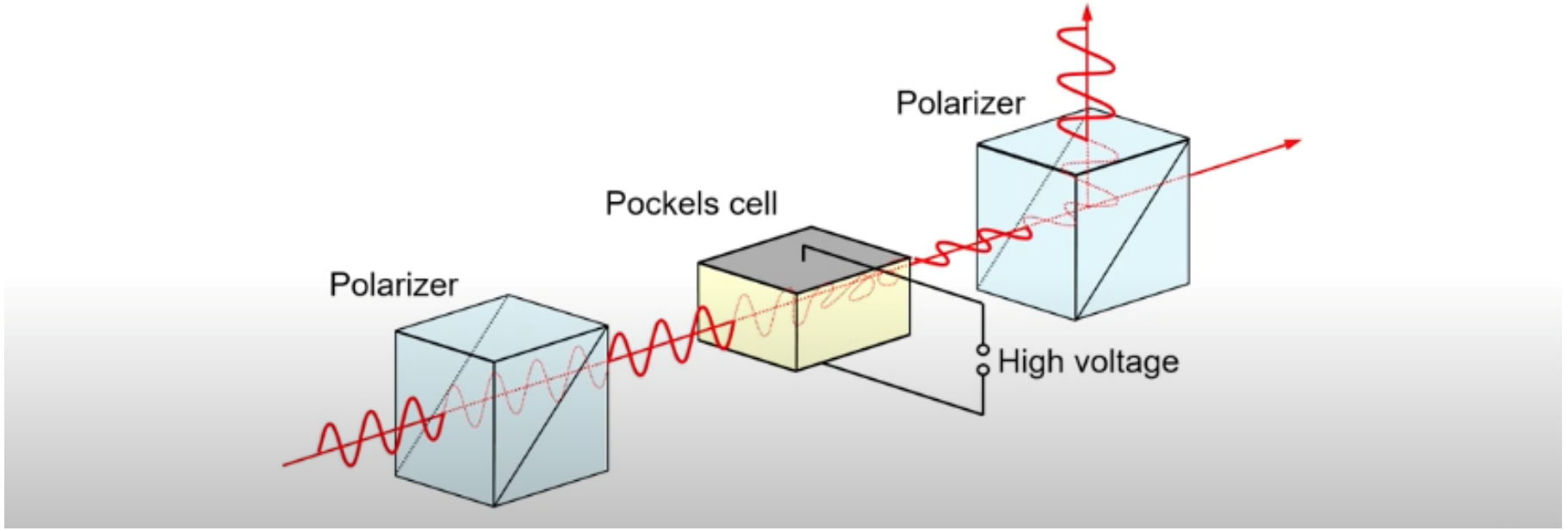
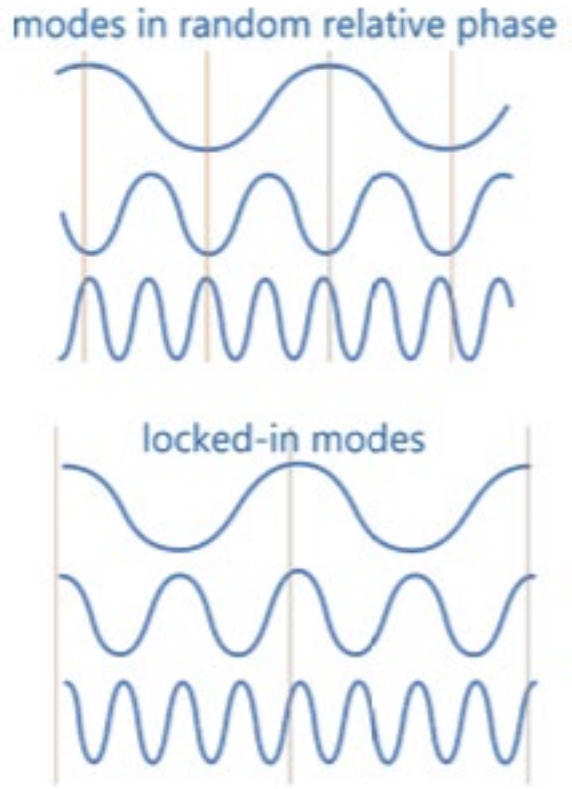
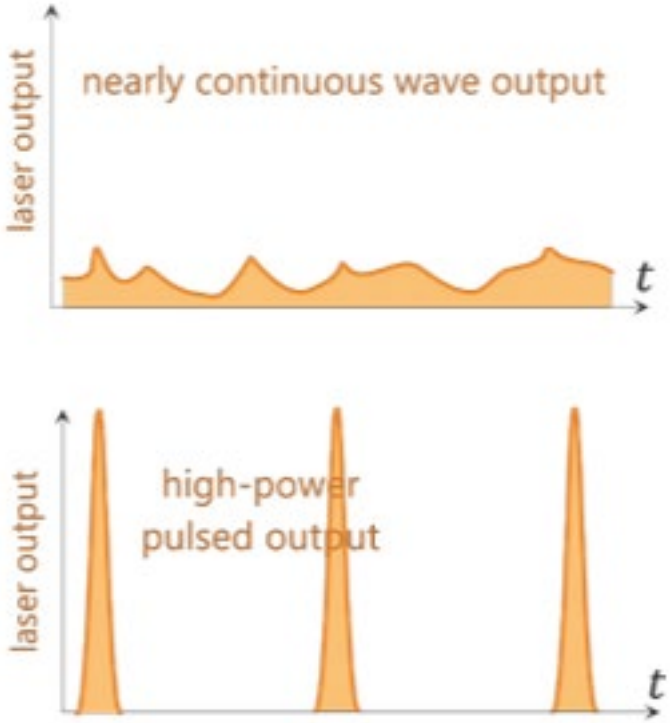


Mode-locking to reach ultrashort pulses





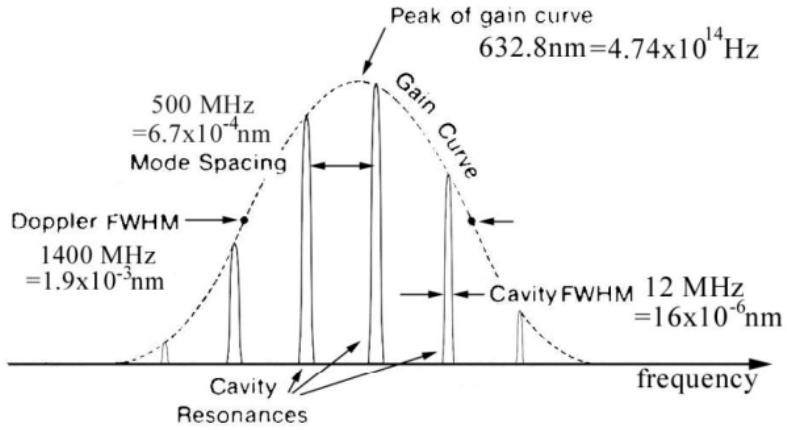
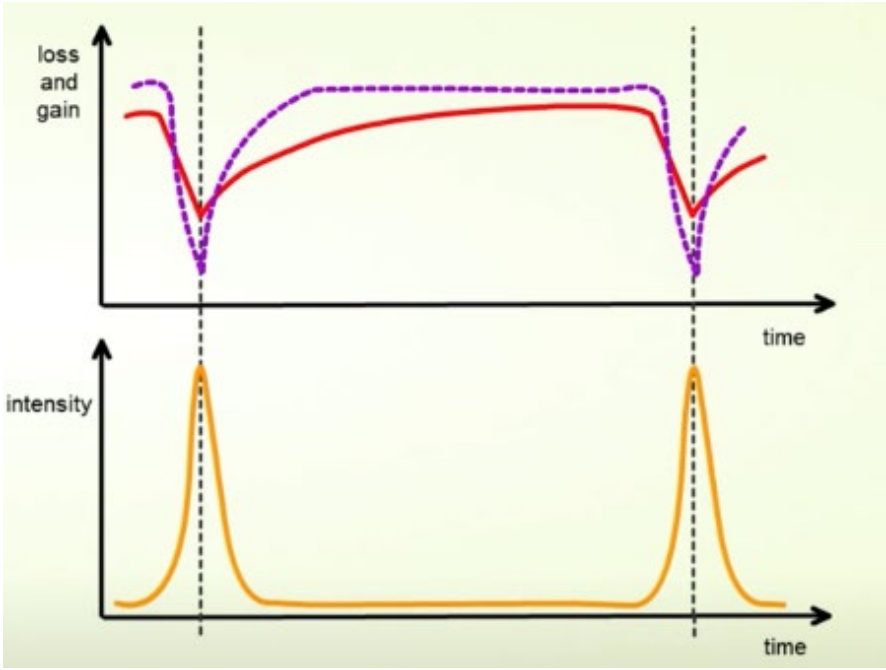


Figure 1. Longitudinal Modes in a laser.

Mode-locking: Saturable absorber

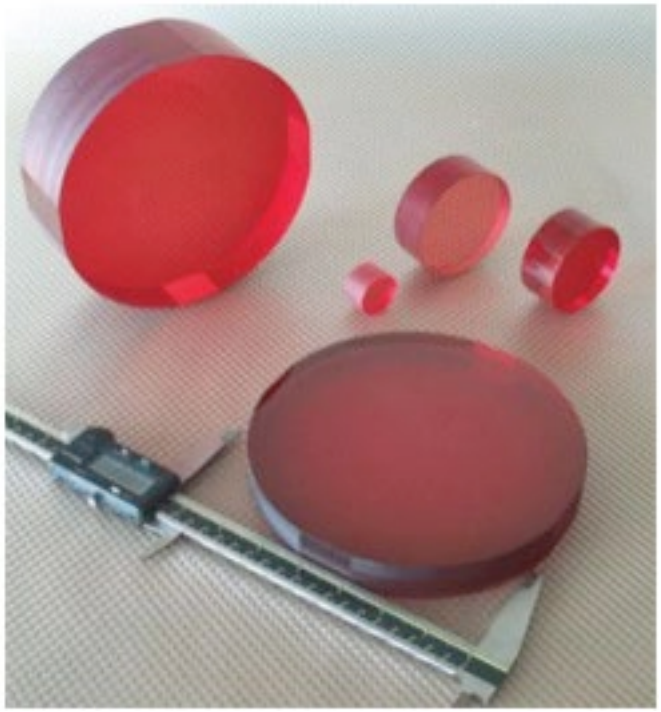
Figure 1: Schematic setup of a laser which is passively mode-locked with a saturable absorber mirror, e.g. a **SESAM**.

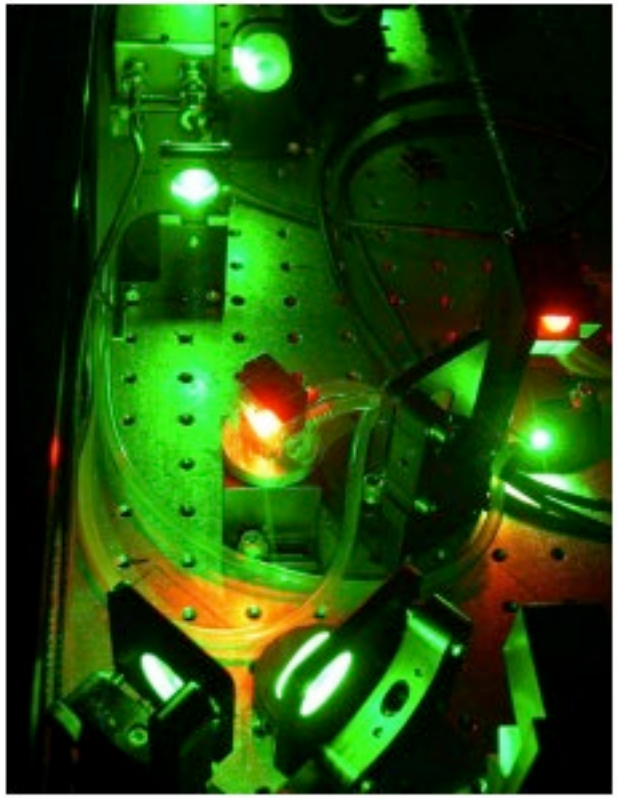


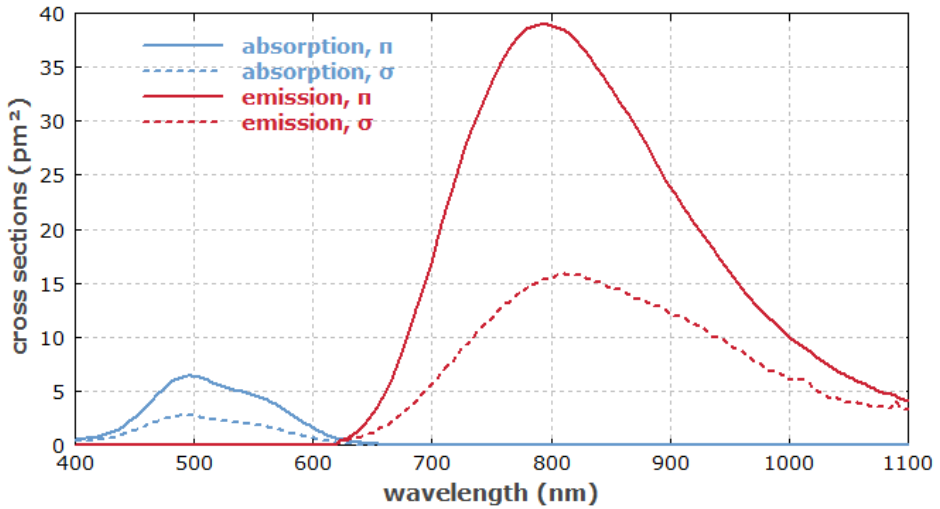
From picosecond to femtosecond pulses

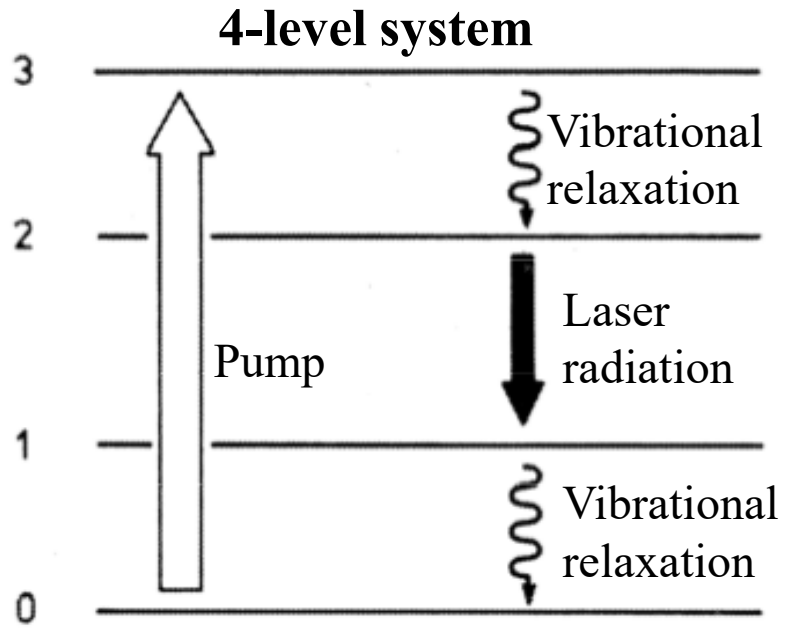
https://www.rp-photonics.com/passive_mode_locking.html

Ti^{3+}:Sapphire Laser



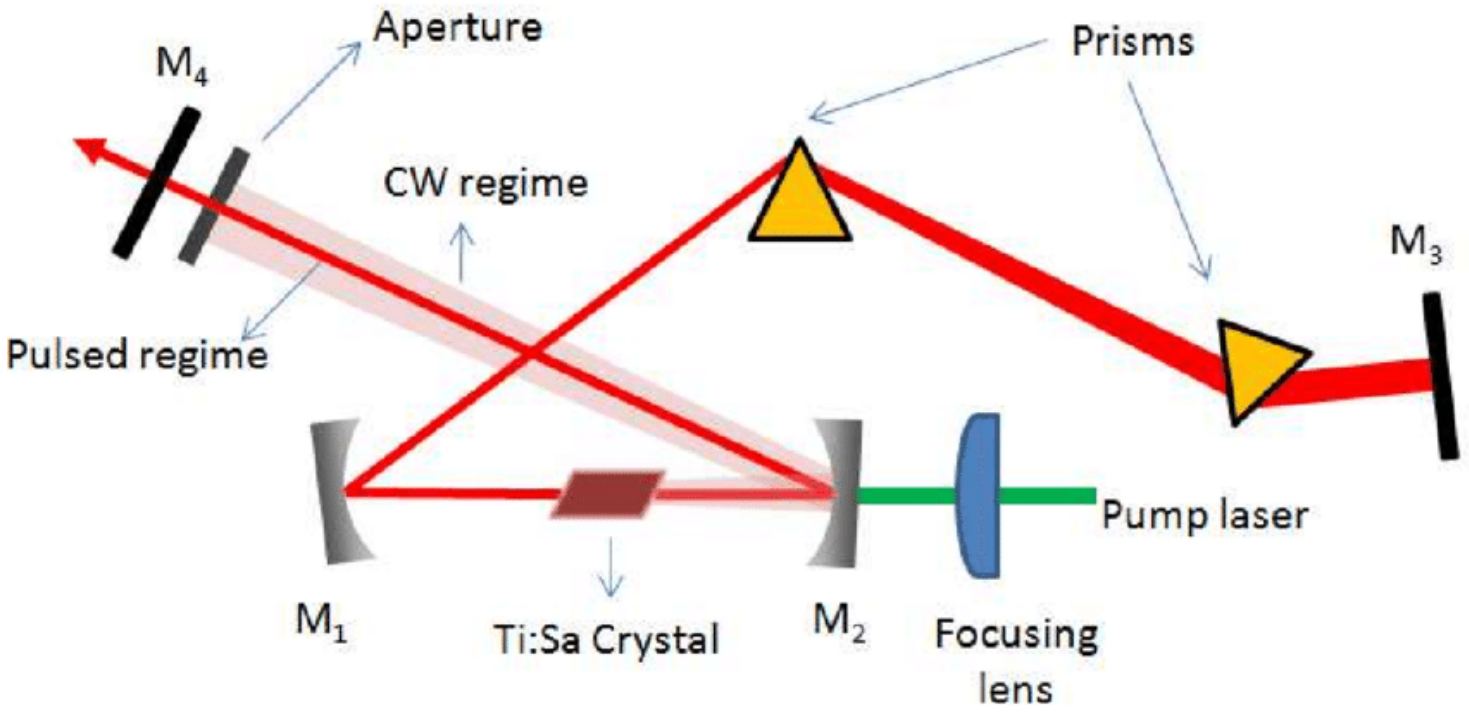




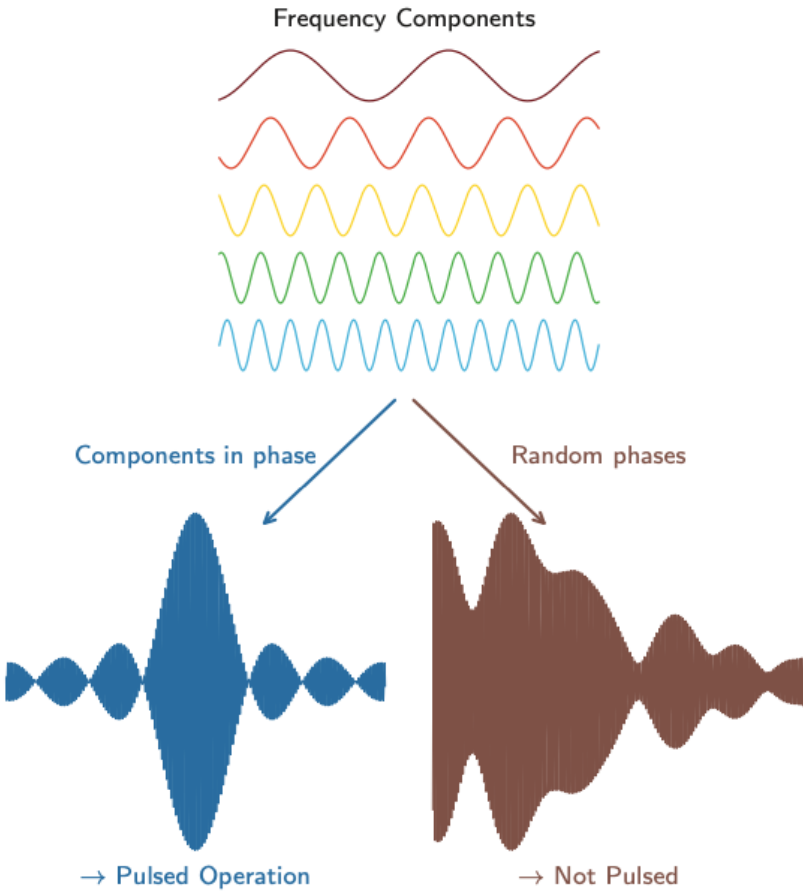


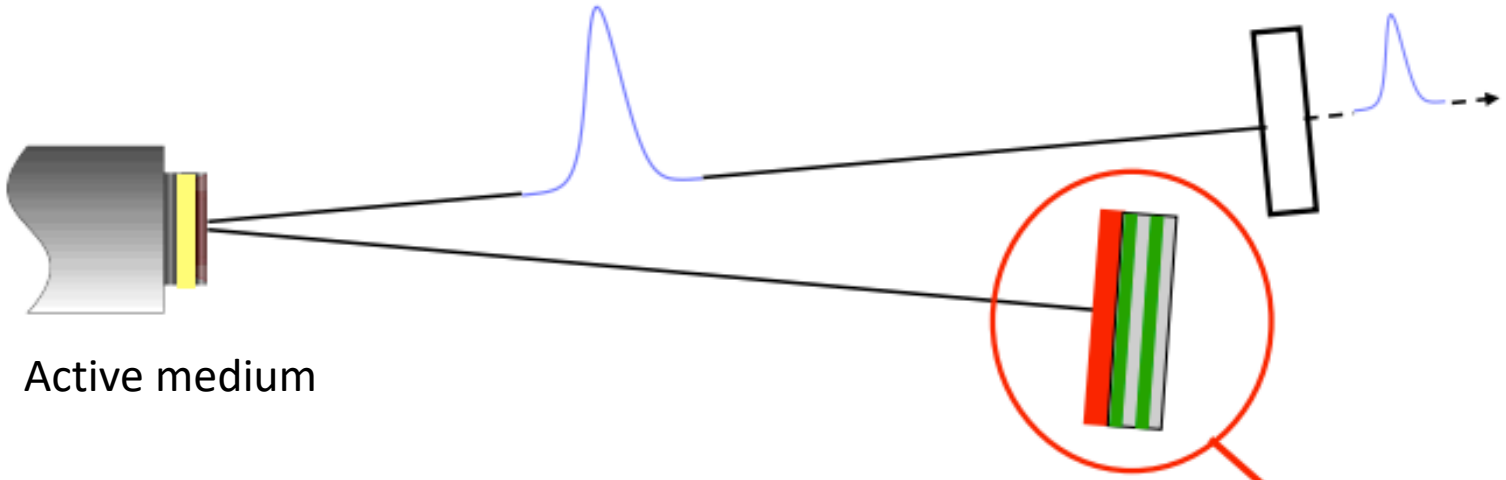
Oscillator

Gecco One from Novanta

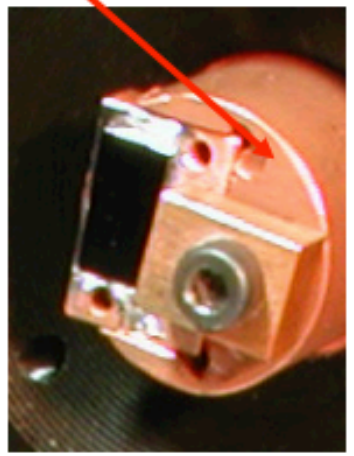


Cavity for short pulses





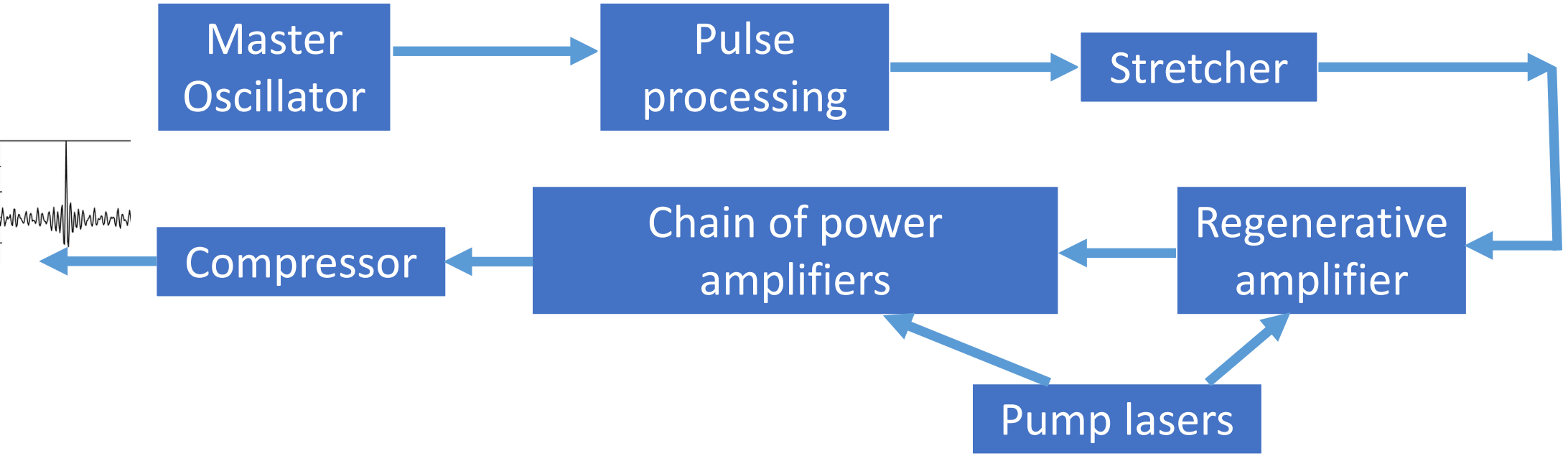
SESAM: SEmiconductor Saturable Absorber Mirror



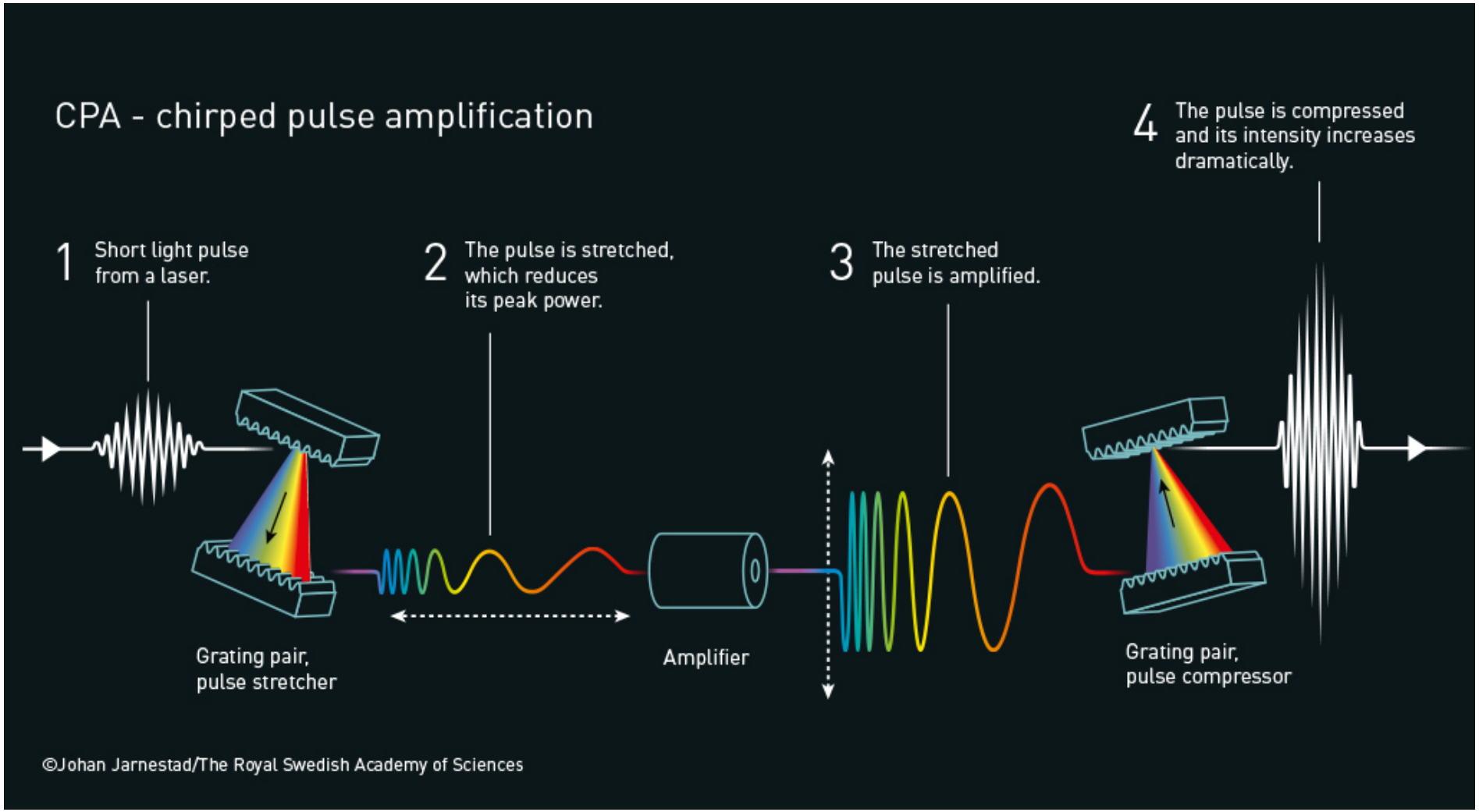
U. Keller et al. Nature 424, 831, 2003

Recalling High-power Architetture

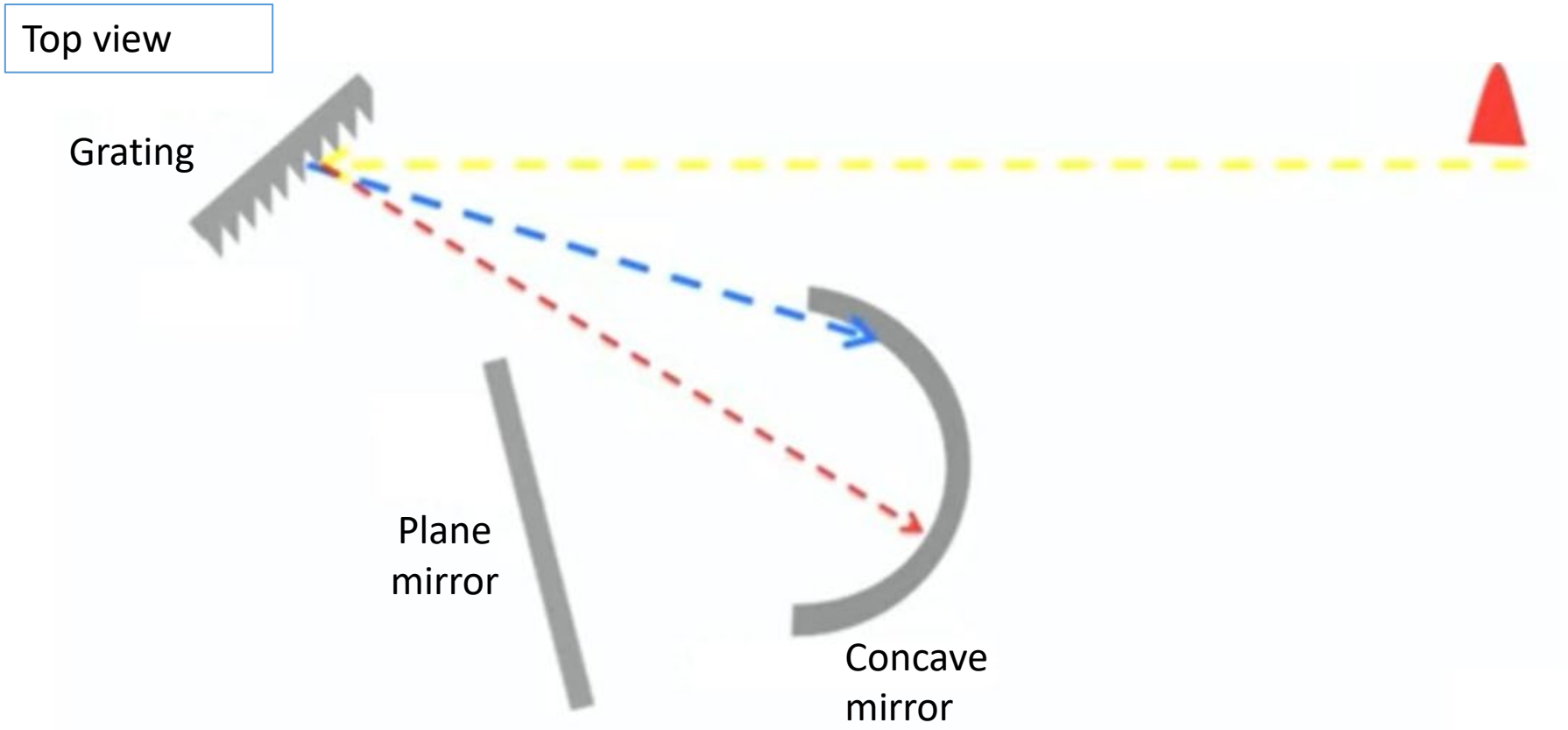
MOPA + CPA (Chirped pulse amplification)



Chirped pulse amplification



Stretcher Architecture (Simplified)



IIT Bombay Ultrafast laser spectroscopy online lectures: Week 6-Lecture 31 : Stretching and compressing ultrafast laser pulses (https://www.youtube.com/watch?v=pcUE24TOm9s)

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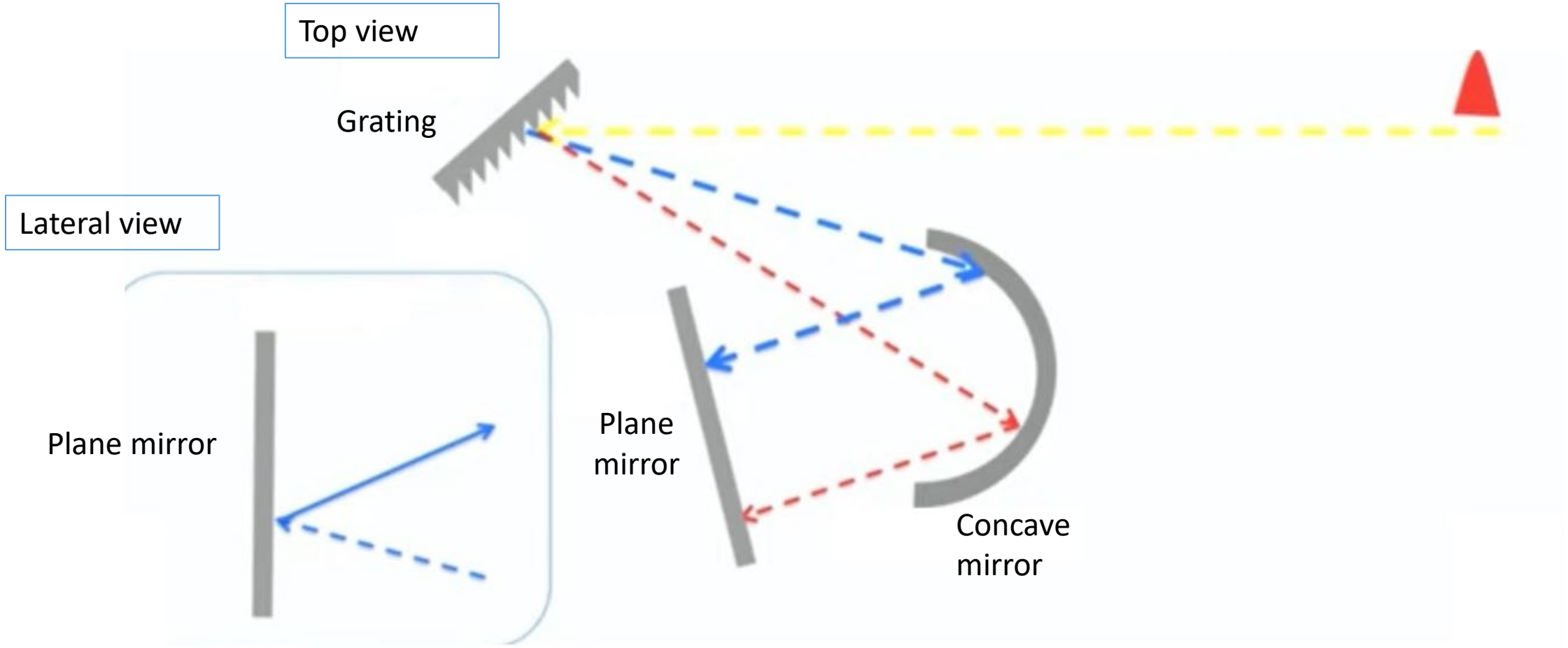

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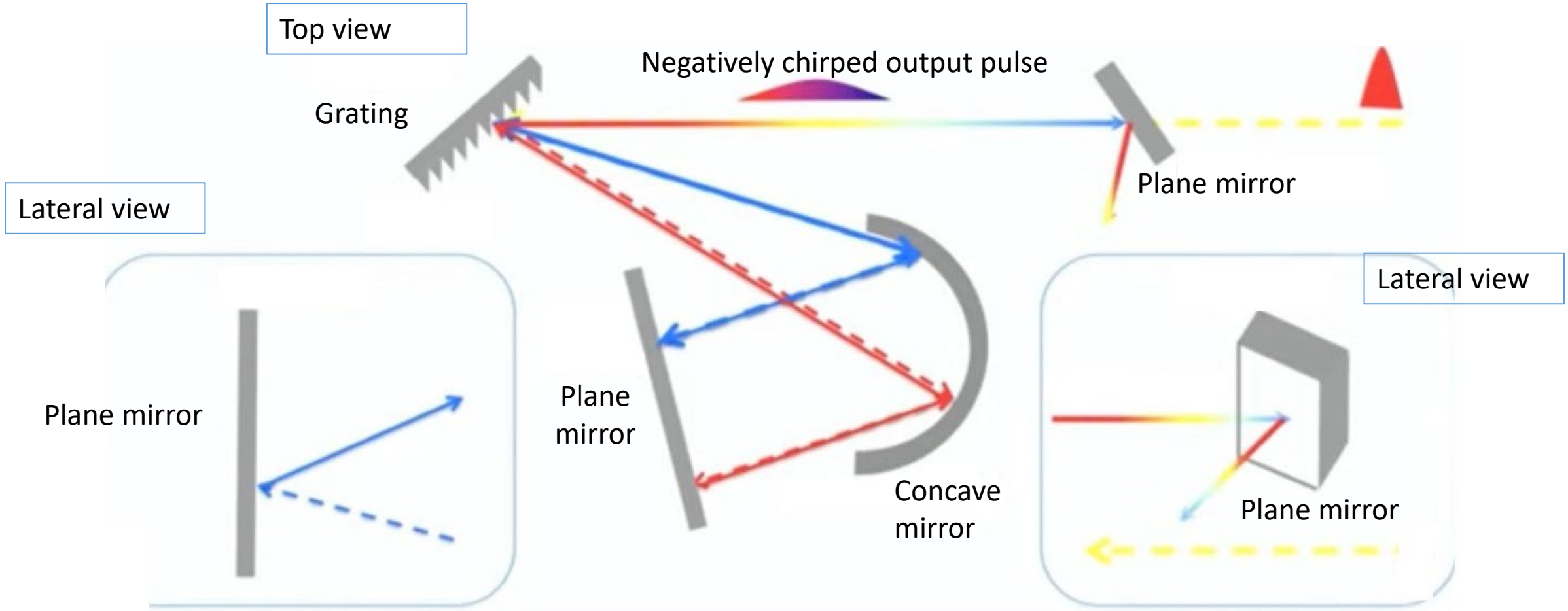

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Example of Parametric amplification and frequency conversion

Nonlinear Polarization Density

$$\mathbf{P}(t) = \varepsilon_0 \left(\chi^{(1)} \mathbf{E}(t) + \chi^{(2)} \mathbf{E}^2(t) + \chi^{(3)} \mathbf{E}^3(t) + \ldots \right)$$