MODERN PROBLEMS OF LASER PHYSICS

10-13 October 2006

High peak power Ti:sapphire lasers

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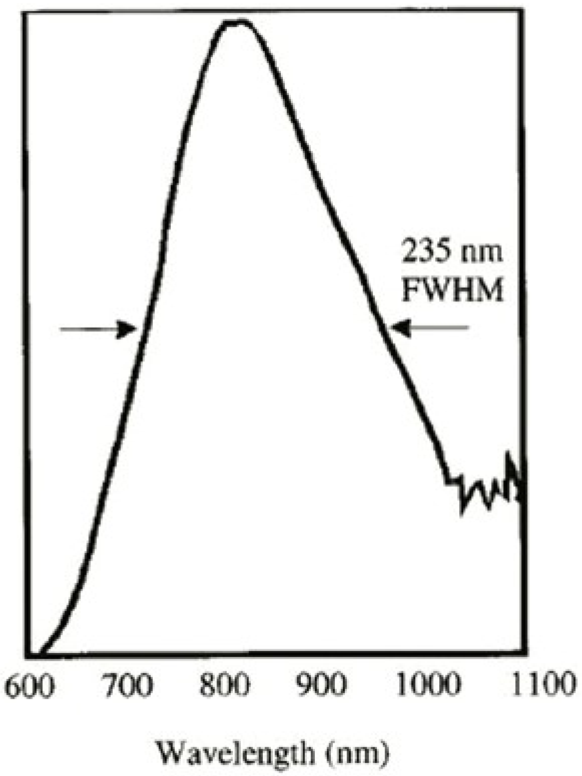
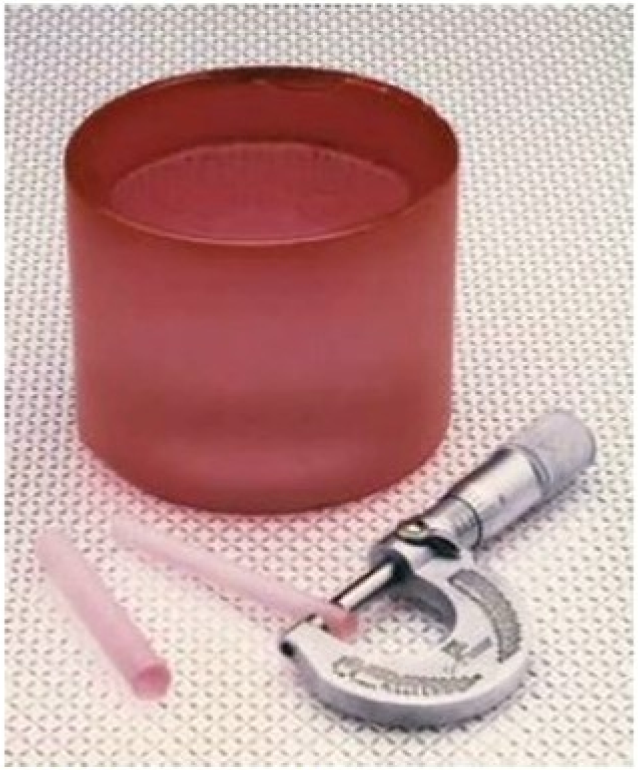
Properties of Ti:Sapphire



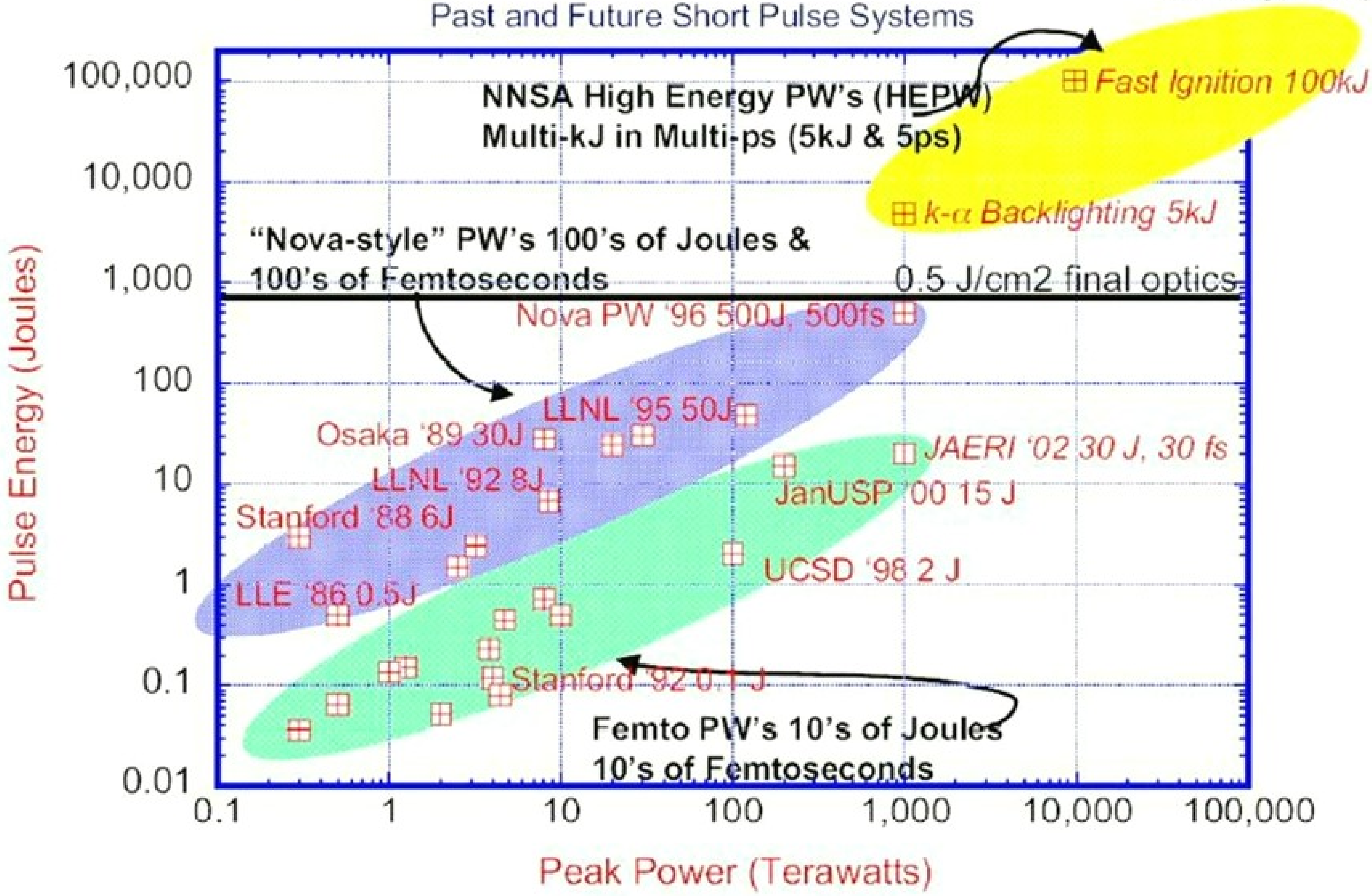
- very high damage threshold (8–10 J/cm^2)
- high saturation fluence ~0.9 J/cm^2
- high thermal conductivity
- suitable peak gain cross section of σ=2.7 10^{-19} cm^2



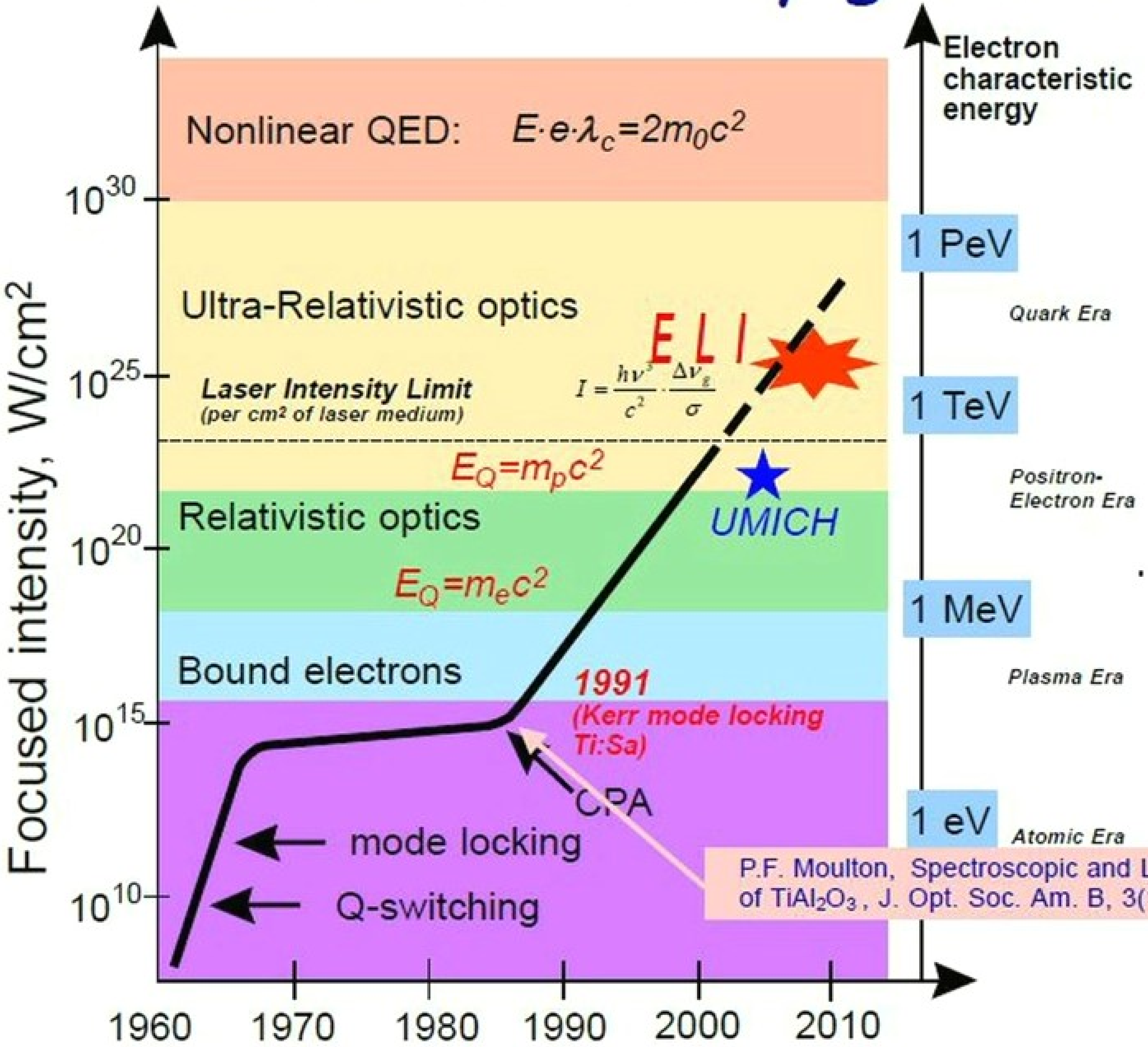
Maximum absorption at ~ 500 nm, thus pumped by 2ω of YAG lasers at $\lambda \approx 532$ nm

Three Classes of Petawatt Lasers

The National Ignition Facility

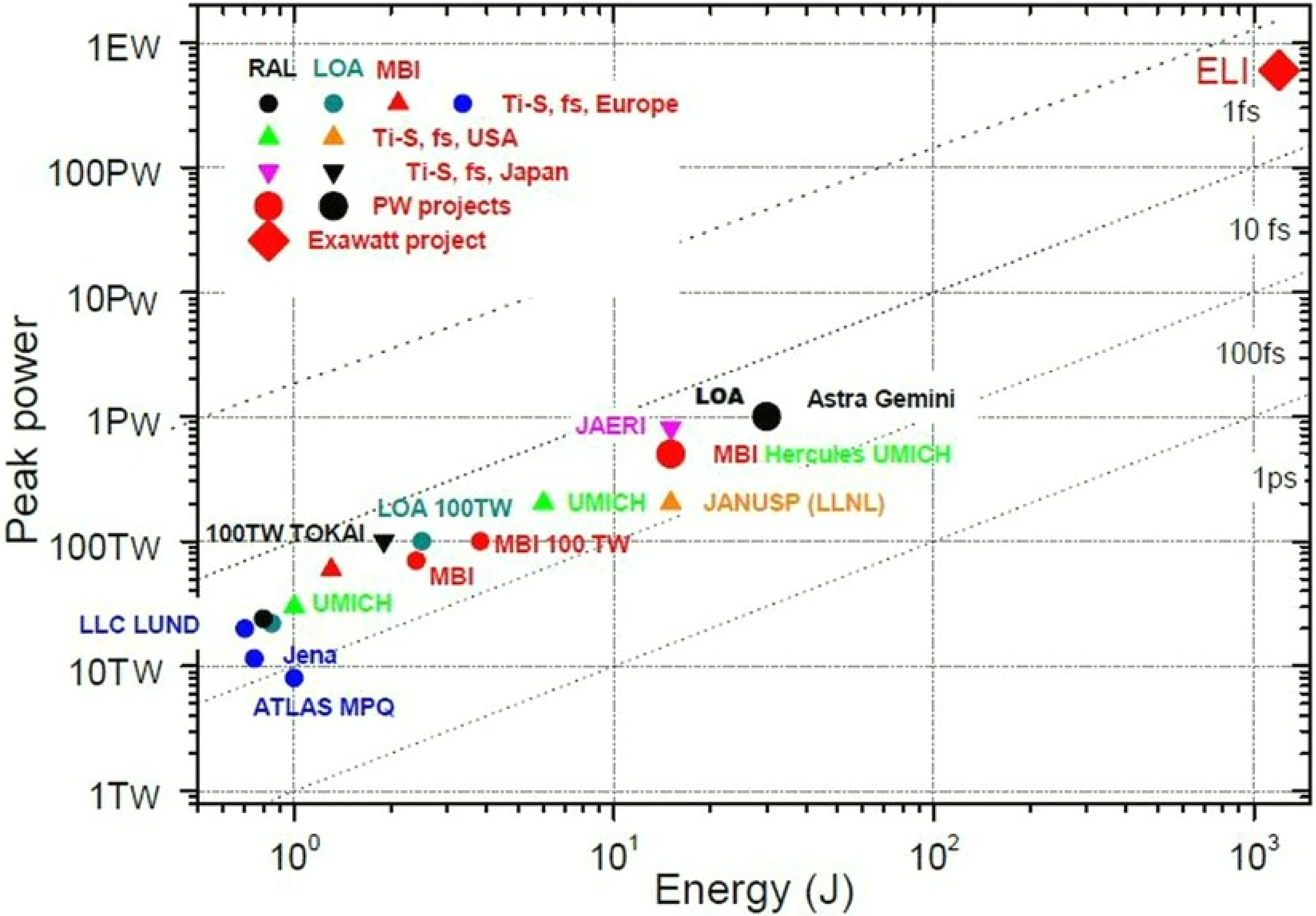


Laser Intensity growth



P.F. Moulton, Spectroscopic and Laser Characteristics of $TiAl_2O_3$, J. Opt. Soc. Am. B, 3(1), 125 133 (1986).

World Ti:sapphire high power lasers



Chirped pulse amplification

Efficiency of amplification

Saturated amplification: $J > 2 \div 3 * J_{sat} = h\nu/\sigma$

$$I_{focus} = \frac{E_{laser}}{S_{focus}\tau_{pulse}}$$

$I_{max} = J_{sat}/\Delta t_{min}$

Shortest pulse duration

Bandwidth-limited Duration: $\Delta t_{min} > 1/(0.5\ \Delta\nu_{fluorescence})$

$J_{las} = 1.8\ \mathrm{J/cm^2}$, $\Delta t_{min} = 6\ \mathrm{fs}$

$I_{max} = 6\ 10^{14}\ \mathrm{W/cm^2}$

Damage !

$I \ll I_{damage}$ $\sim 10^{10}\ \mathrm{J/cm^2}$

Longer pulse duration.
For Ti:sapphire:
$\Delta t > 1.8\ 10^{-10}$ sec

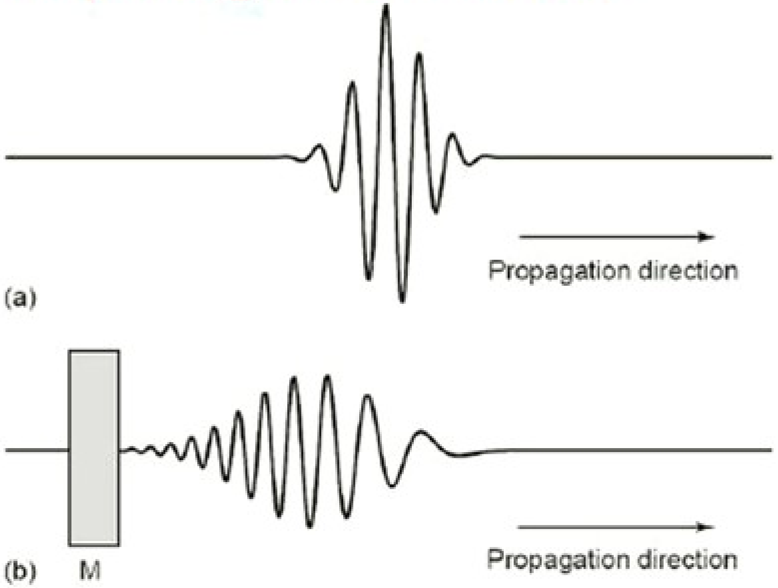
Chirped Pulse Amplification

Pulse chirping

Passing through dispersive medium the pulse gets stretched:

Undispersed Gaussian pulse

after traveling through a positively dispersing medium, M



$$\tilde{E}(\omega) = \sqrt{S(\omega)}\exp\left[-i\varphi(\omega)\right]$$

Spectrum   Spectral phase

The instantaneous frequency:

$$\omega(t) = \omega_0 - d\phi / dt$$

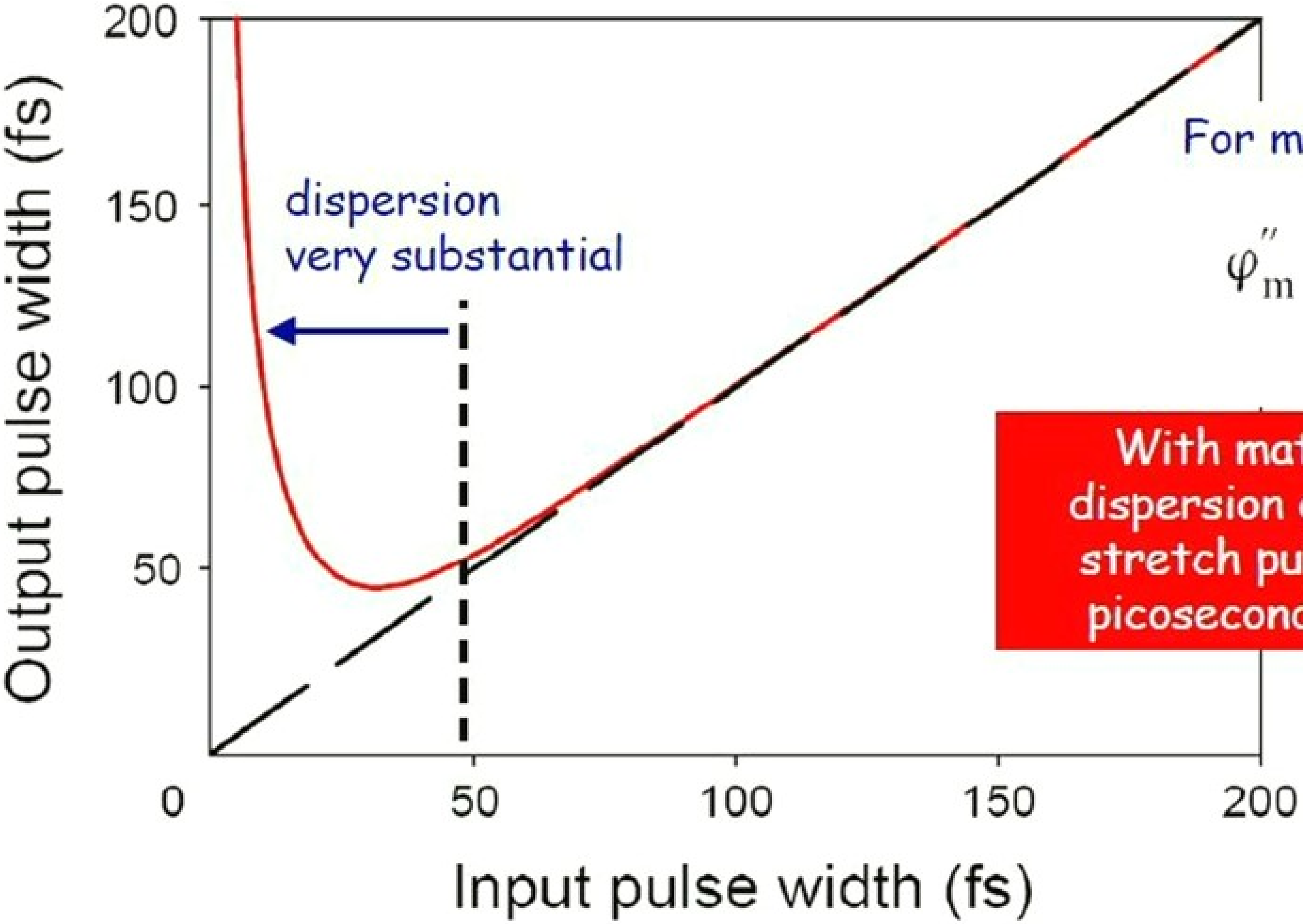
$$\varphi(w) = \varphi(w_0) + (w - w_0)\varphi'(w_0) + \tfrac{1}{2}(w - w_0)^2\varphi''(w_0) + \tfrac{1}{6}(w - w_0)^3\varphi'''(w_0) + \tfrac{1}{24}(w - w_0)^4\varphi''''(w_0) + \cdots$$

$\varphi'(\omega_0)$ is the group delay, $\varphi''(\omega_0)$ the group velocity dispersion (GVD)

$\varphi'''(\omega_0)$ and $\varphi''''(\omega_0)$ - are TOD and FOD

$$\boxed{\frac{\tau_{\text{out}}}{\tau_{\text{in}}} = 1 + \frac{\varphi''^2}{\tau_{\text{in}}^4} 16(\ln 2)^2}$$

Dispersion of 10 mm BK7



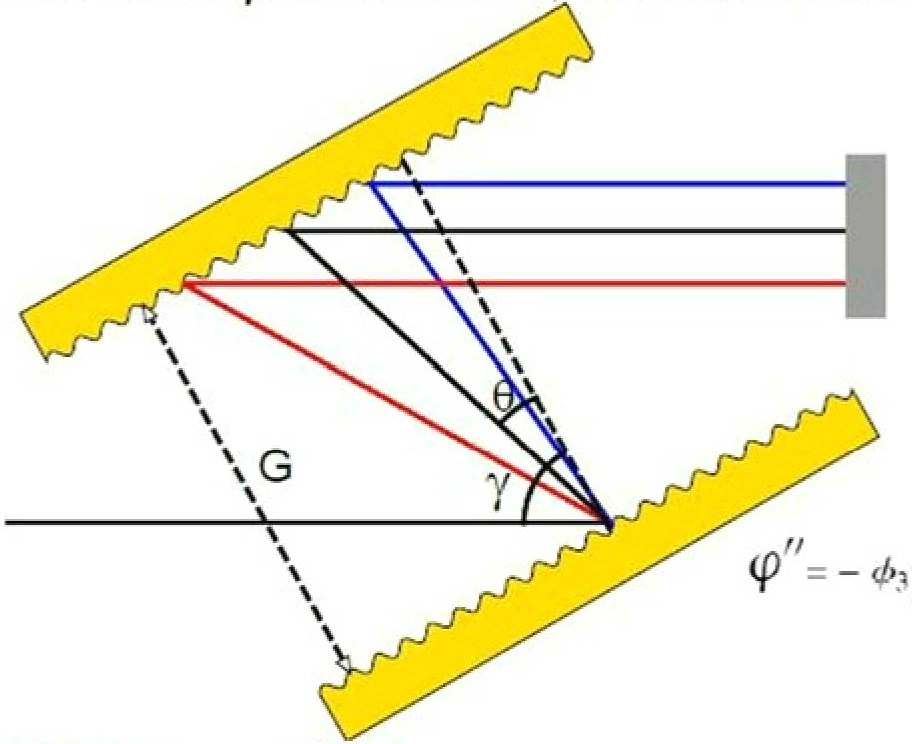
For material dispersion:

$$\varphi_{\mathrm{m}}'' = \frac{\lambda_0^3 l_{\mathrm{m}}}{2\pi c^2} \frac{\mathrm{d}^2 n(\lambda)}{\mathrm{d}\lambda^2}$$

With material dispersion one can stretch pulses to picoseconds only

Pulse stretching (diffraction gratings)

E. B. Treacy, IEEE J. Quantum Electron. **QE-5**, 454 (1969)



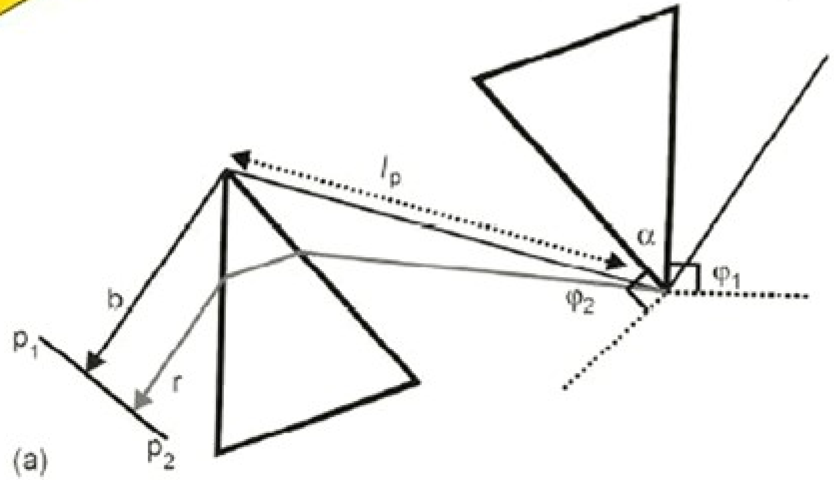
Diffraction gratings compressor

$$\varphi' = -\frac{m^2\lambda^3}{2\pi c^2 d^2 \cos^2\theta} b, \qquad b = -\frac{G}{\cos\theta(\lambda_0)}.$$

$$\varphi'' = -\phi_2 \frac{\lambda}{2\pi c}\left[1 + \frac{m\lambda}{d}\frac{\sin\theta}{\cos^2\theta}\right]$$

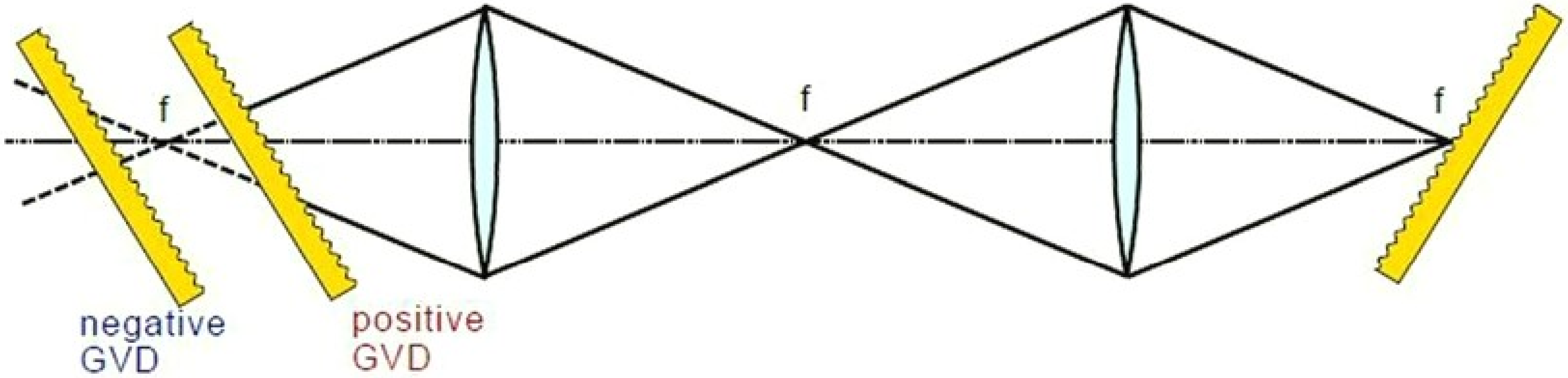
$$\varphi'' = -\phi_3 \frac{3\lambda^2}{4\pi^2 c^2}\left\{4 + 8\frac{m\lambda}{d}\frac{\sin\theta}{\cos^2\theta} + \frac{\lambda^2}{d^2}[1 + \tan^2\theta(6 + 5\tan^2\theta)]\right\}$$

Efficiency ~ 74% possible



stretcher

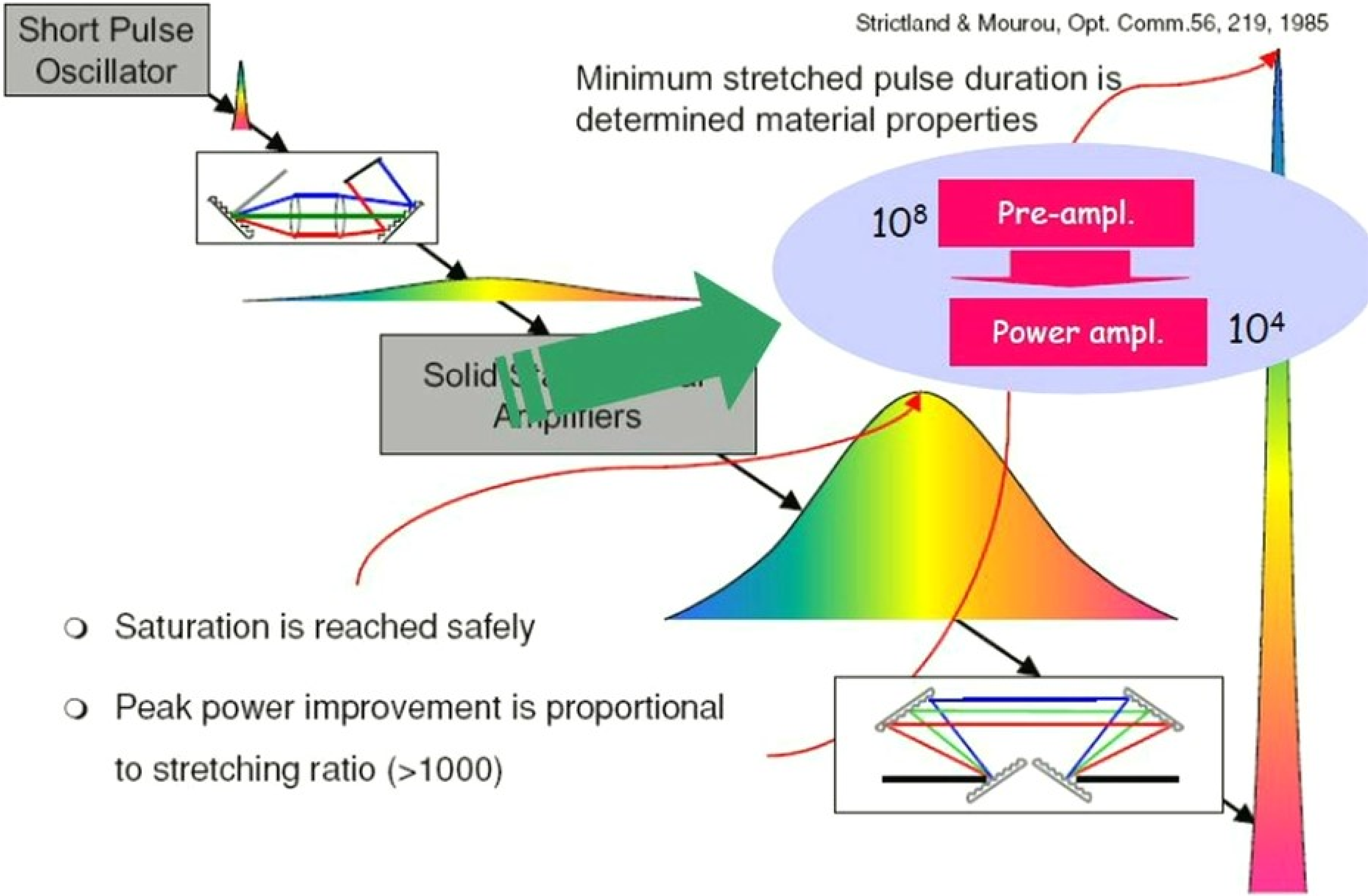
O. E. Martinez, J. Opt. Soc. Am. B **3**, 929 (1986)



Matching between the Martinez and Treacy grating pair arrangements. The input grating is imaged by a telescope of magnification 1, to form a "virtual" grating parallel to the second grating. The distance *b* between the two gratings, real and virtual, can be continuously adjusted from positive to negative

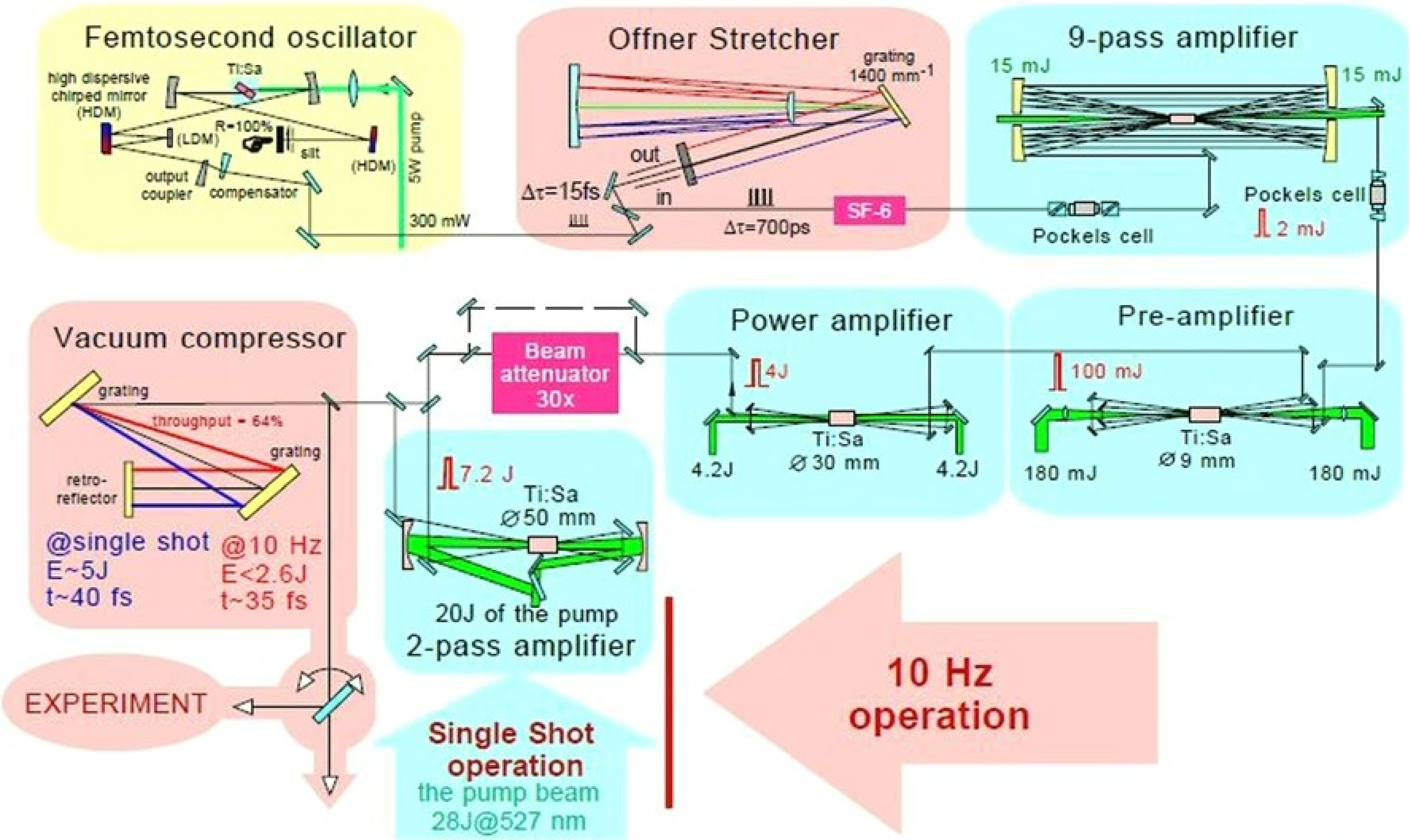
Chirped Pulse Amplification

Strictland & Mourou, Opt. Comm.56, 219, 1985



- Saturation is reached safely
- Peak power improvement is proportional to stretching ratio (>1000)

100 TW MBI Ti:Sa laser



MBI 100TWTi:sapphire laser

Temporal domain:
Pulse duration

Errors of recompression

To reach short recompressed pulses one needs to compensate for the specrtal phase:

$$\phi_{\mathrm{str}}(\omega) + \phi_{\mathrm{comp}}(\omega) + \phi_{\mathrm{med}}(\omega) = 0$$

Typically in Ti:sapphire lasers the stretching starts from 10÷15 fs and the stretching factor reaches the value of

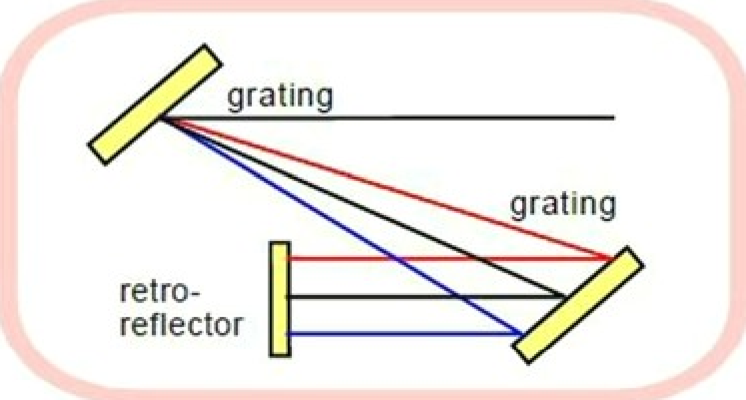
$$\tau_{str}/\tau_{tl} = 5.10^4$$

In this case:

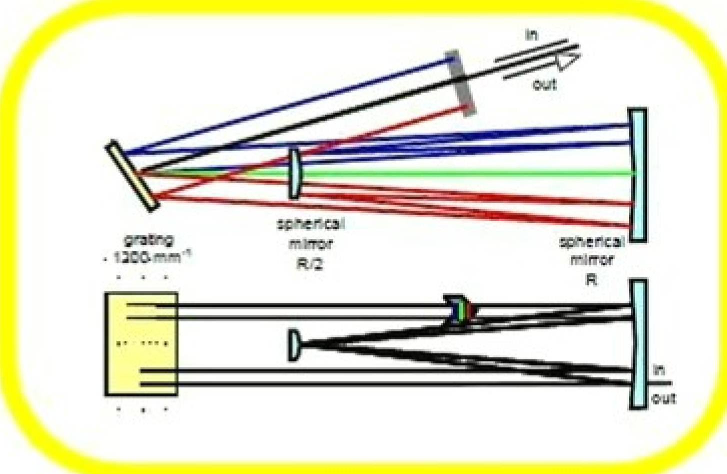
- one needs to consider spectral phase including 4th order of dispersion
- diffraction gratings have only 3 variable parameters:
  - angle of incidence
  - grating constant
  - spacing between the gratings
- different materials need to be taken into account

Compressor and stretchers

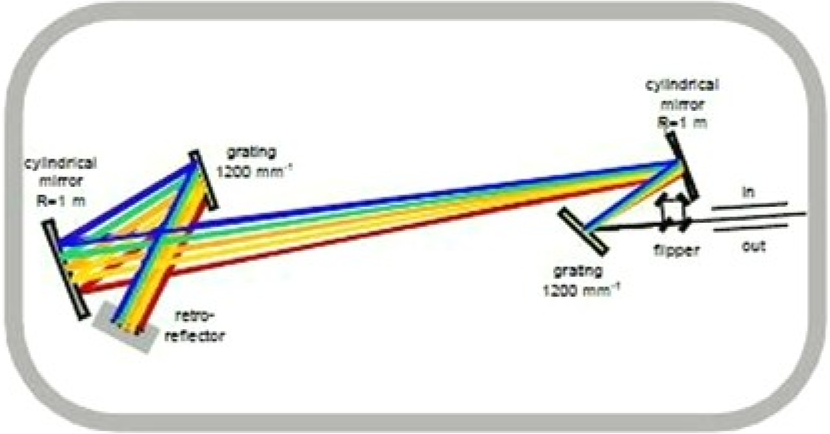
Compressor



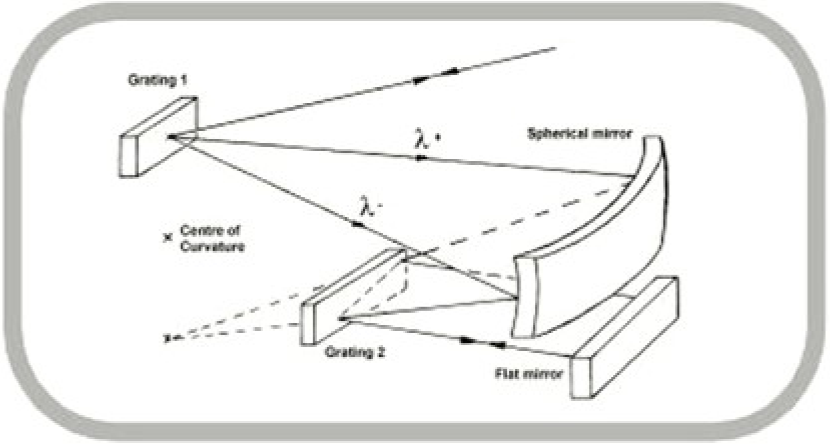
Öffner



Aberrational



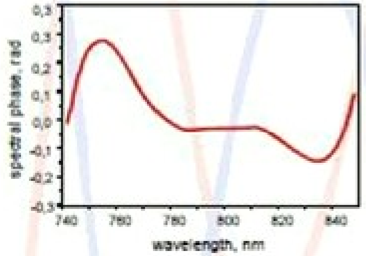
RAL



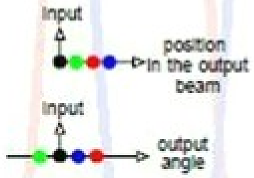
Errors of recompression

Most important errors of the stretcher and compressor:

- variation of group delay over beam aperture and spatially varying dispersion

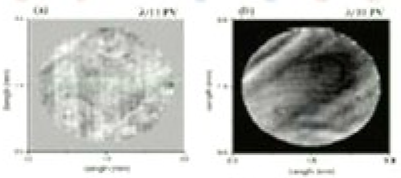


- residual spectral phase



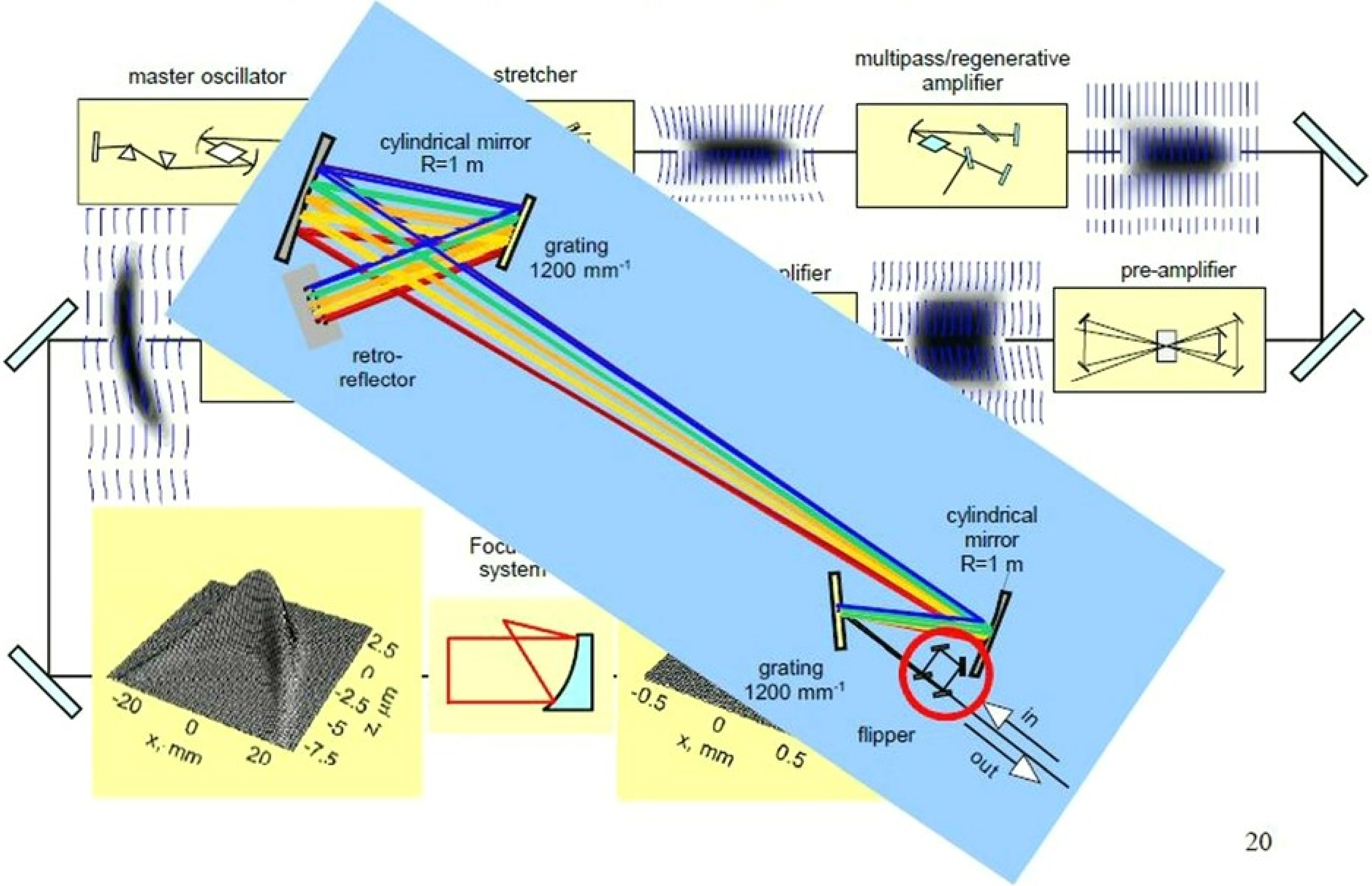
- spatial and angular chirp

- spectral clipping



- spectral phase 'noise'

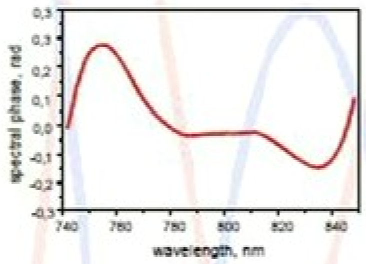
Spatially varying dispersion



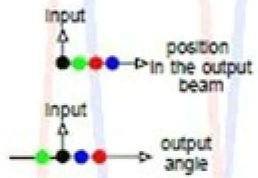
Errors of recompression

Most important errors of the stretcher and compressor:

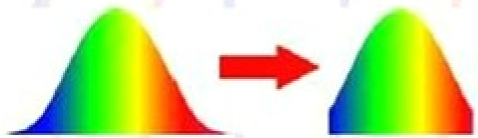
- group delay over beam aperture and spatially varying dispersion
- residual spectral phase



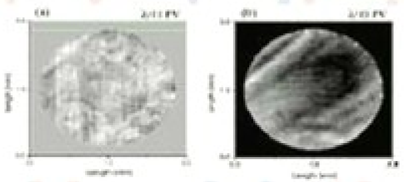
- spatial and angular chirp



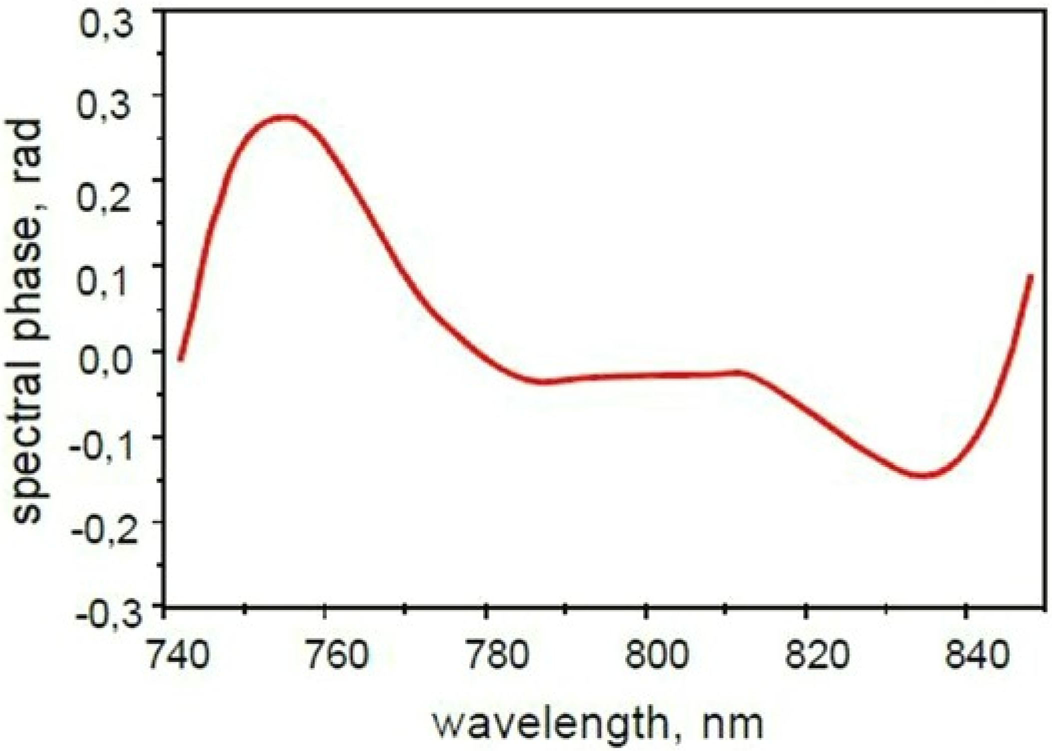
- spectral clipping



- spectral phase 'noise'



Residual phase

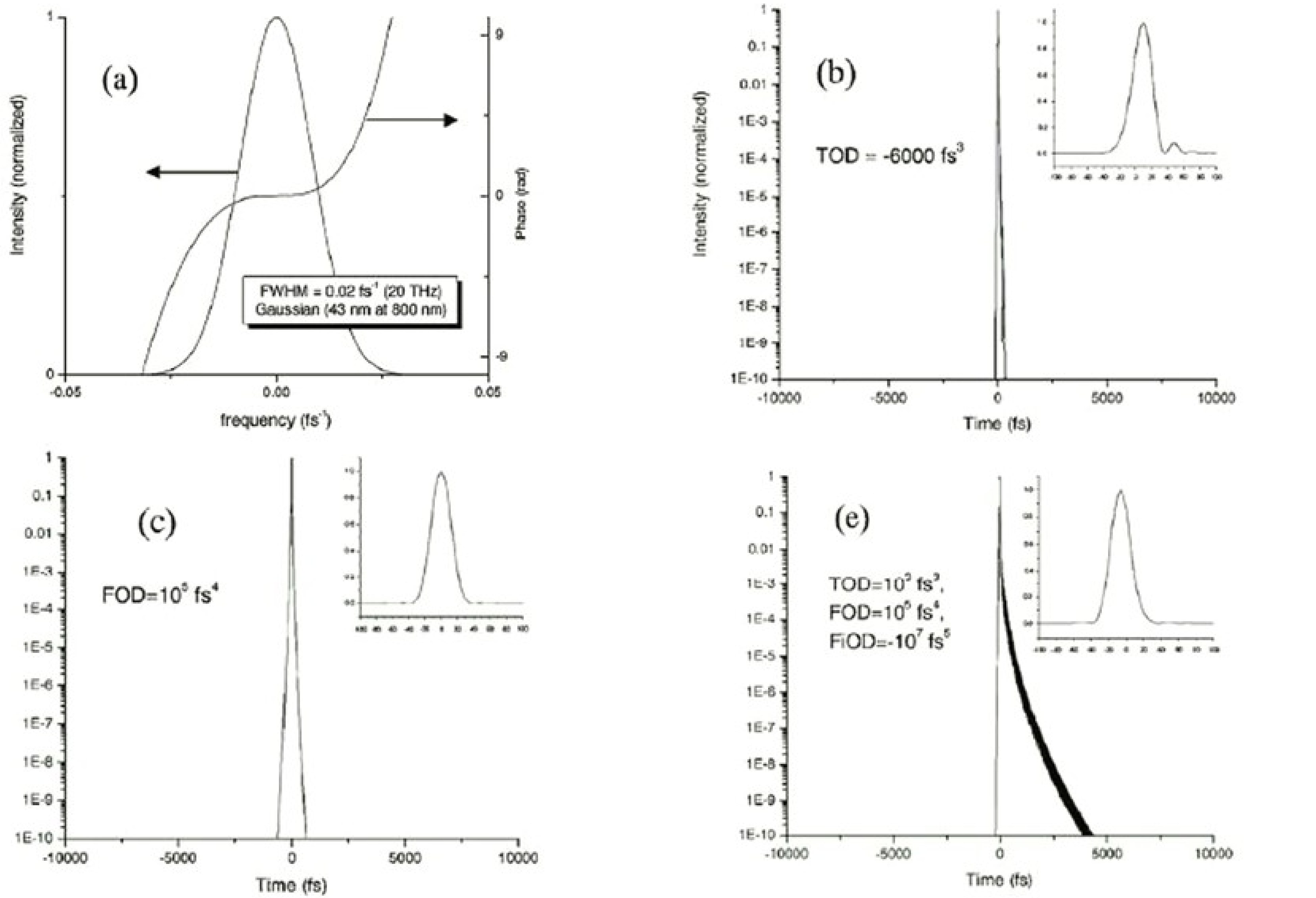


Reshaping of the pulse

High orders of dispersion (FOD) and higher are usually compensated by:

- using diffraction gratings with different constants in the stretcher and compressor
- adding materials
- stretcher geometry

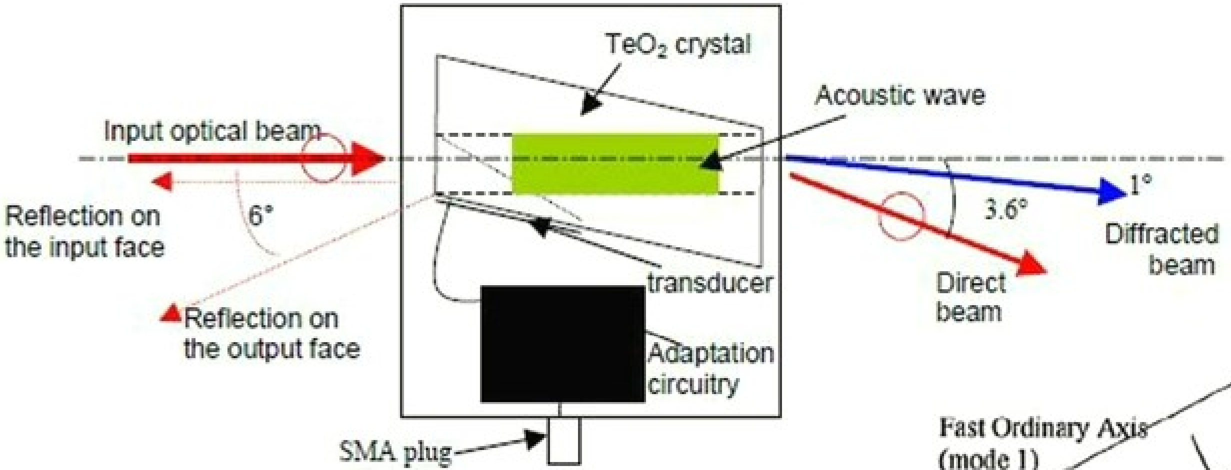
Influence of spectral phase



K.-H. HONG, B. HOU, J.A. NEES, E. POWER, G.A. MOUROU, Generation and measurement of >10^8 intensity contrast ratio in a relativistic kHz chirped-pulse amplified laser, Appl. Phys. B 81, 447-457 (2005)

Dazzler

acousto-optic programmable dispersive filter (AOPDF)



April 15, 2000 / Vol. 25, No. 8 / OPTICS LETTERS 575

Amplitude and phase control of ultrashort pulses by use of an acousto-optic programmable dispersive filter: pulse compression and shaping

F. Verluise and V. Laude

Laboratoire Central de Recherches, Thomson-CSF, Domaine de Corbeville, F-91404 Orsay Cedex, France, and Laboratoire pour l'Utilisation des Lasers Intenses, Ecole Polytechnique, 91128 Palaiseau Cedex, France

Z. Cheng and Ch. Spielmann

Photonics Institute, Vienna University of Technology, Gusshausstrasse 27-29/387, A-1040 Vienna, Austria

P. Tournois

Fastlite, Xtec, Ecole Polytechnique, 91128 Palaiseau Cedex, France

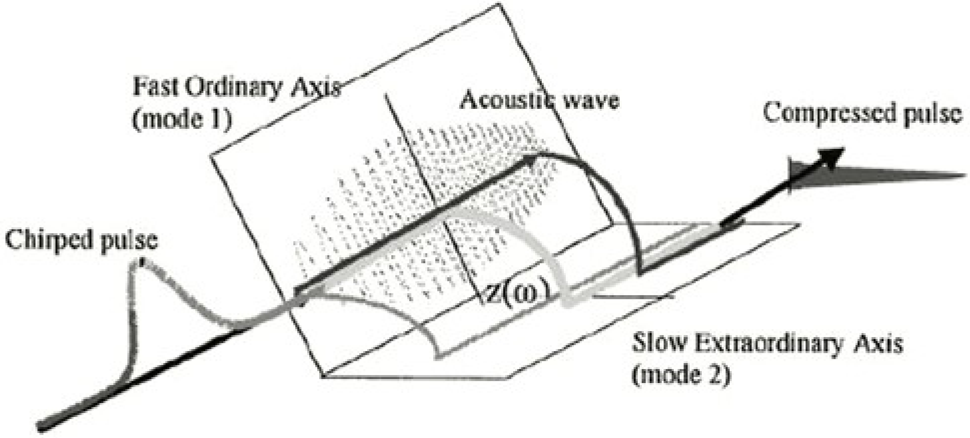
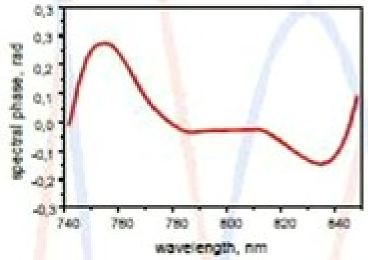


Fig. 1. Schematic of the AOPDF.

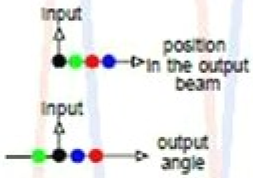
Errors of recompression

Most important errors of the stretcher and compressor:

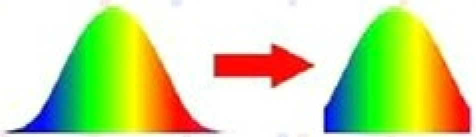
- group delay over beam aperture and
  spatially varying dispersion



- residual spectral phase



- spatial and angular chirp
- spectral clipping



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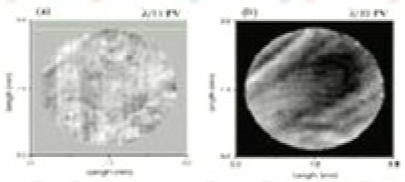
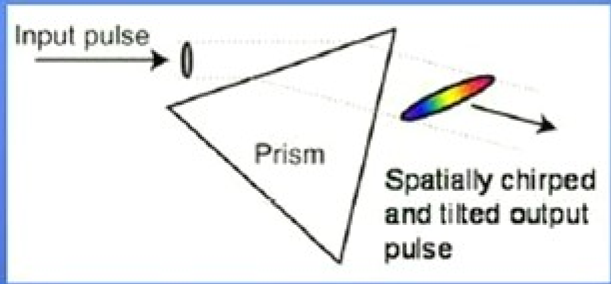


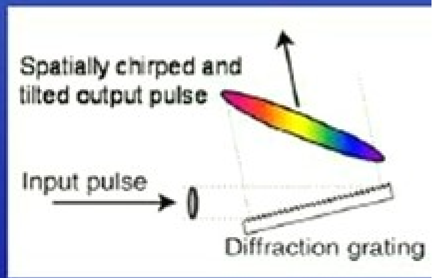
What causes angular dispersion in a CPA laser?

Prism pair in the oscillator
- Slightly different apex angle
- Non-parallel refractive surfaces



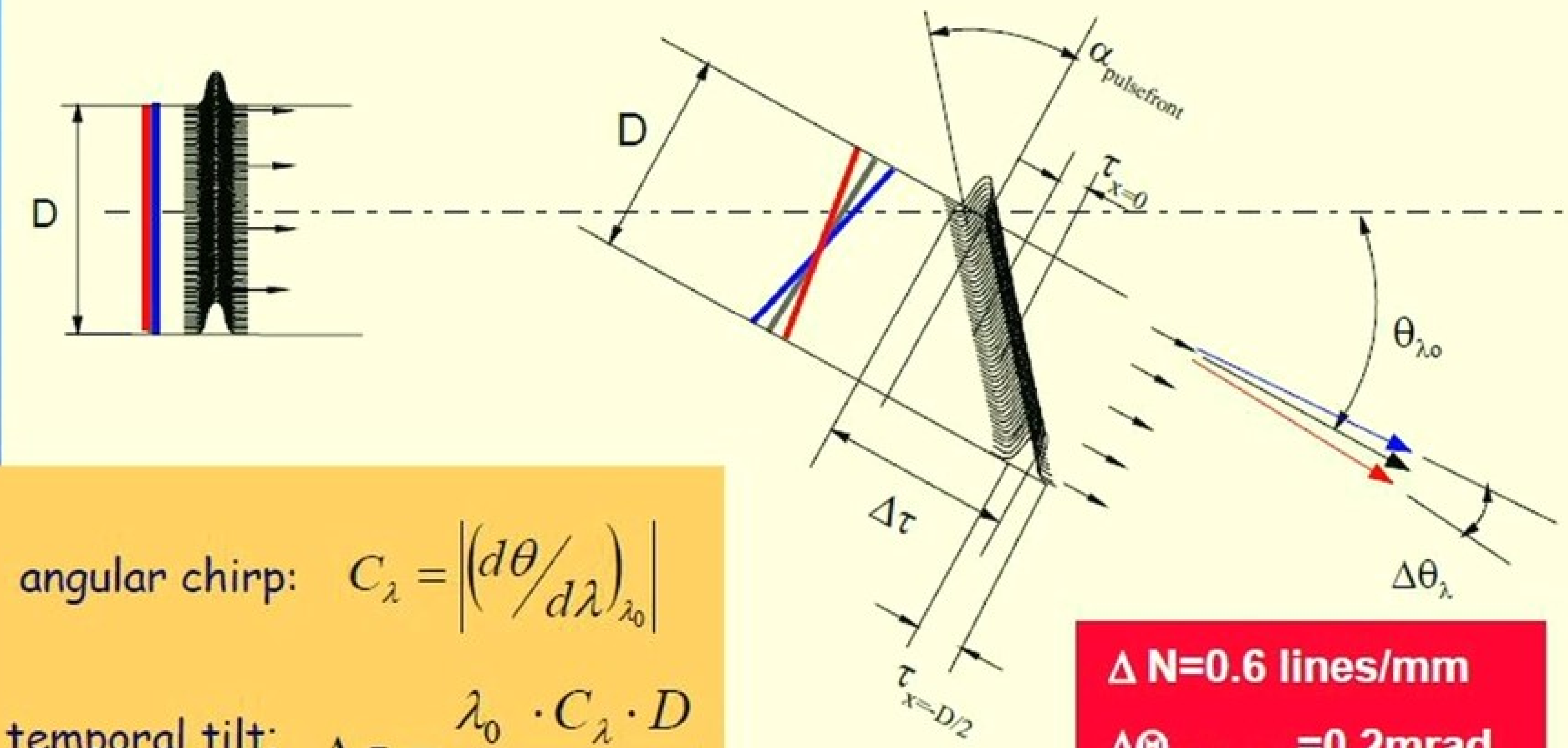
Slightly wedged optical components
- Non-precise set-up of the output coupler (osc.)
- Surfaces of the Ti:S crystals (osc., ampl.)

Grating nonparallelism in the stretcher/compressor



Diffraction gratings with slightly different constant

Tilt of the recompressed pulse front coming from the angular chirp



angular chirp: $C_\lambda = \left| \left(d\theta / d\lambda \right)_{\lambda_0} \right|$

temporal tilt: $\Delta\tau = \dfrac{\lambda_0 \cdot C_\lambda \cdot D}{c}$

Δ N=0.6 lines/mm

$\Delta\Theta_{\lambda 780-840}$ =0.2mrad

$\Theta_{\lambda o}$=2.76 mrad

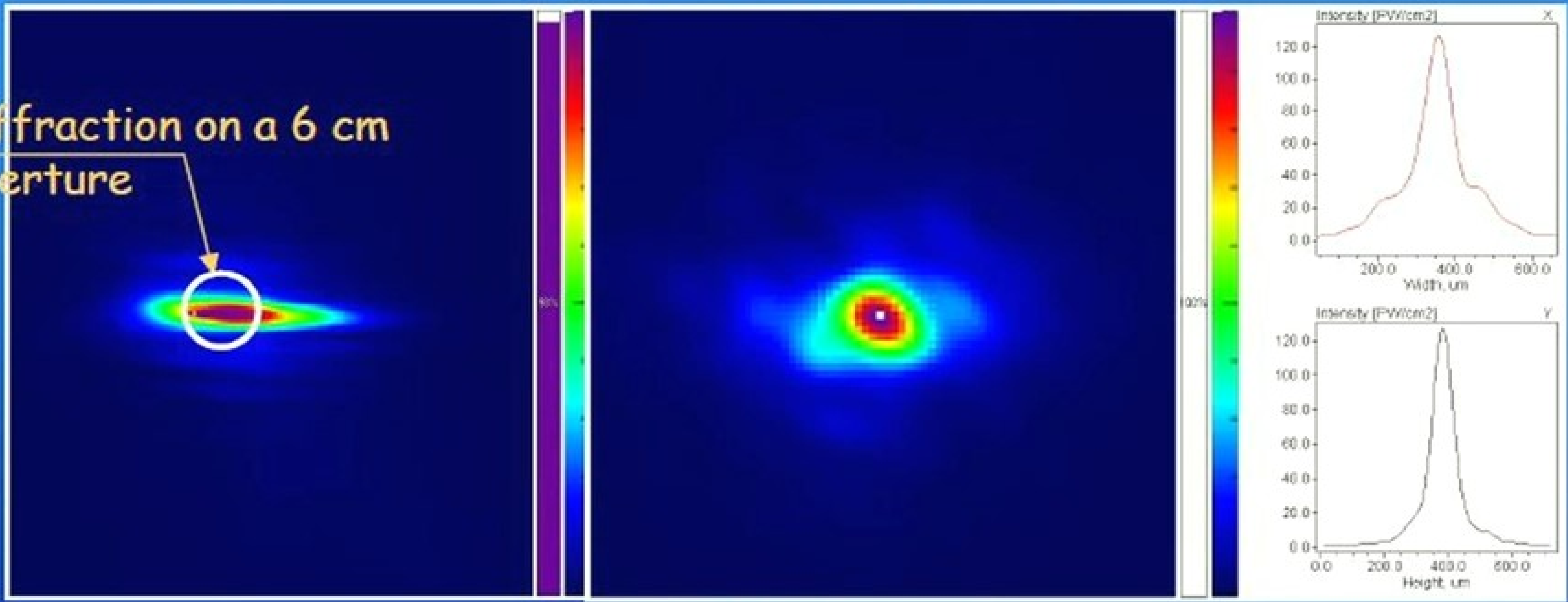
$\Delta\tau$ =530 fs

OECD

Far-field distribution

The diffraction gratings have different constants (ΔN = 0.6 lines/mm).

before　　　　　after correction



dispersion direction

Diffraction gratings are not parallel to each other

Measurement of angular dispersion

2034 OPTICS LETTERS / Vol. 27, No. 22 / November 15, 2002

Angular dispersion of femtosecond pulses in a Gaussian beam

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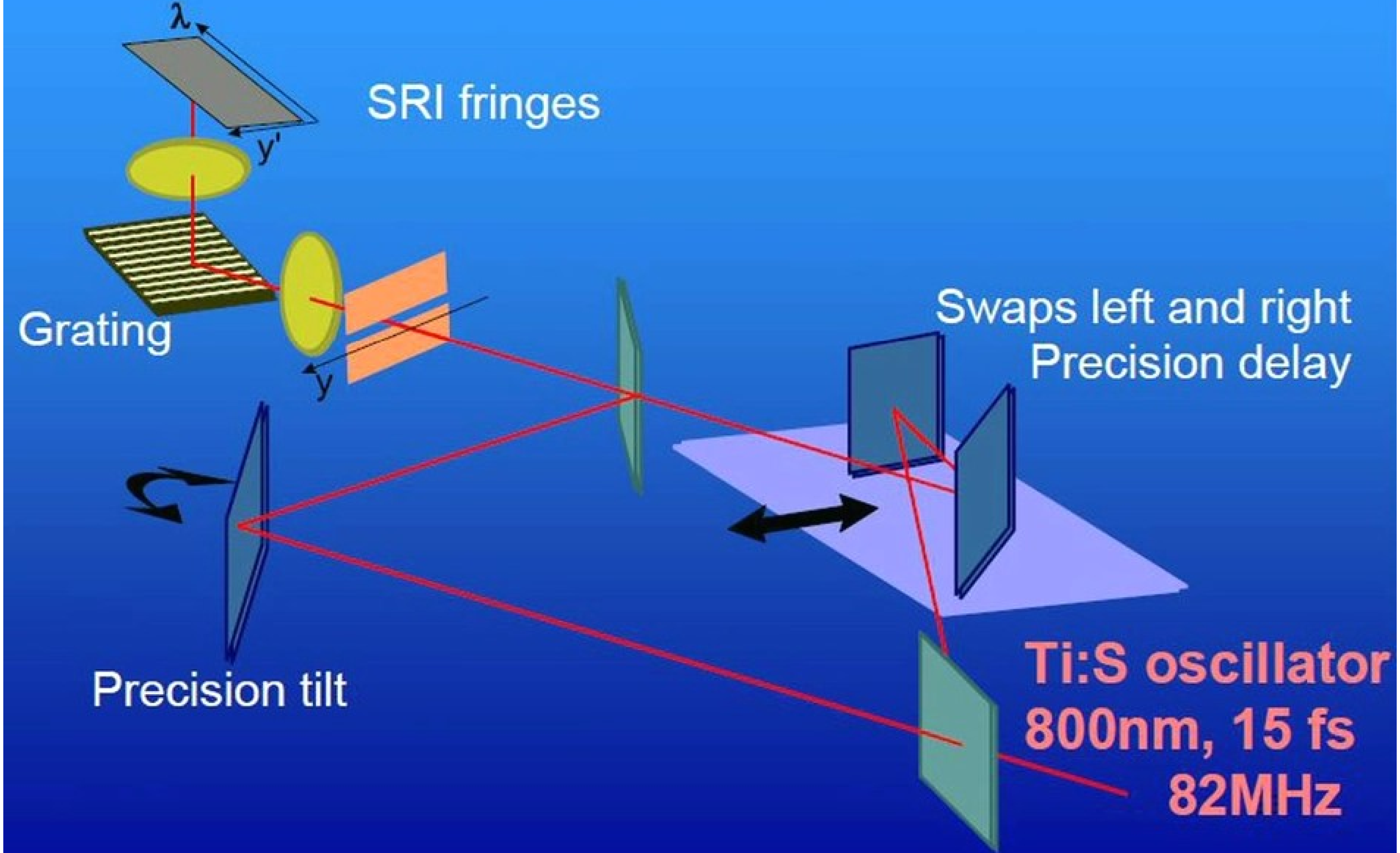
G. Kurdi

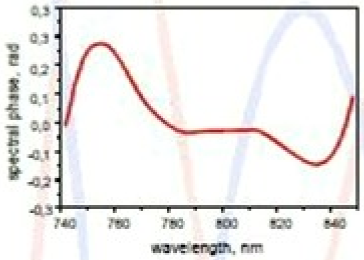
HAS Research Group on Laser Physics, University of Szeged, Dóm tér 9, Szeged 6720, Hungary

Experimental setup: Mach-Zender interferometer

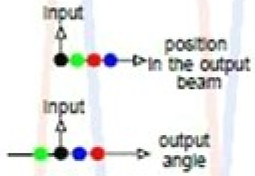


Errors of recompression

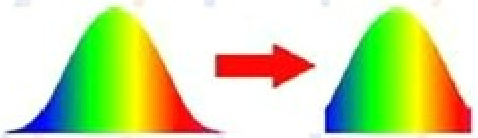
- group delay over beam aperture and spatially varying dispersion



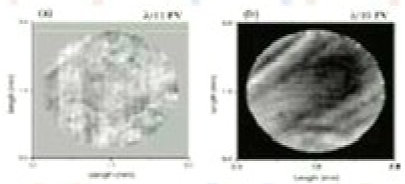
- residual spectral phase



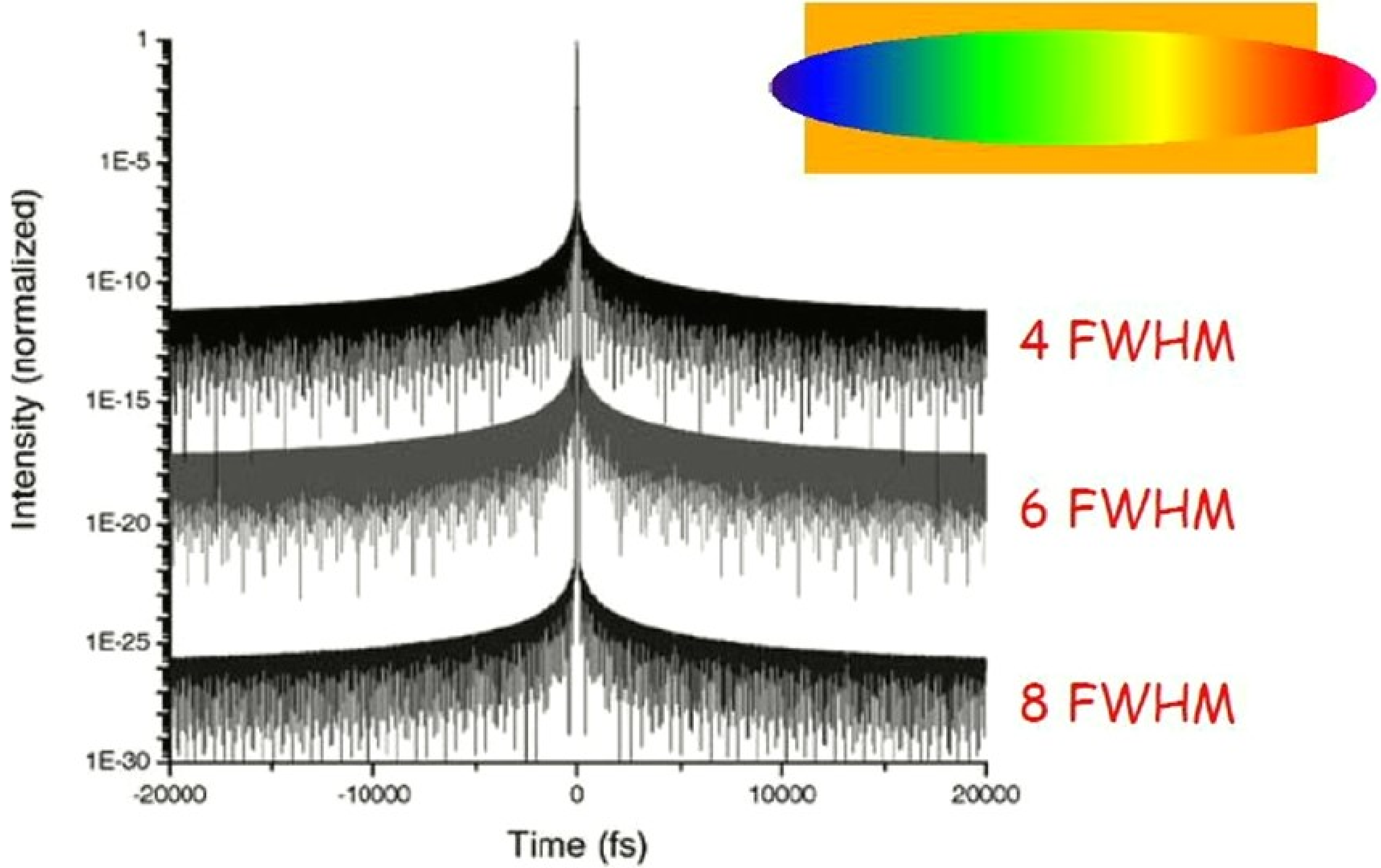
- spatial and angular chirp
- spectral clipping



- spectral phase 'noise'

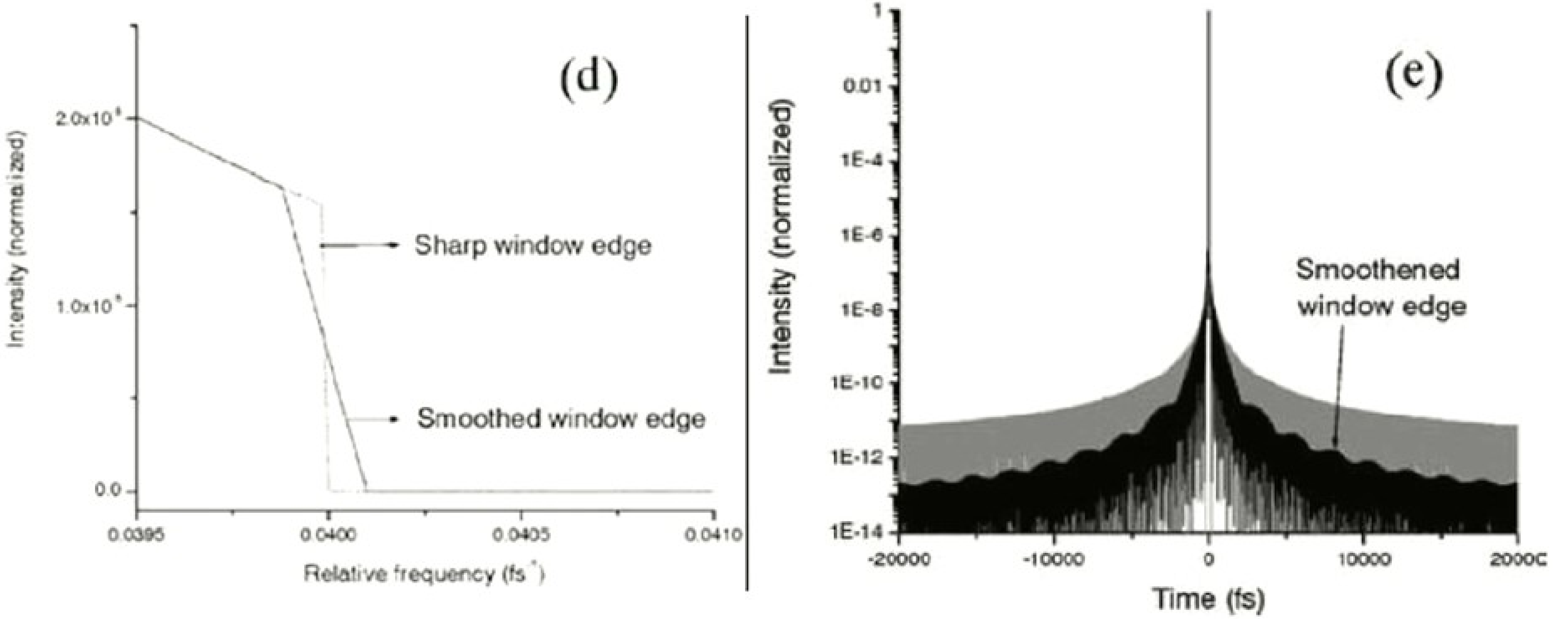


Spectral clipping



K.-H. HONG, B. HOU, J.A. NEES, E. POWER, G.A. MOUROU, Generation and measurement of >10^8 intensity contrast ratio in a relativistic kHz chirped-pulse amplified laser, Appl. Phys. B 81, 447-457 (2005)

Influence of the spectral edge sharpness



The spectral window edges with different sharpness and resulting temporal structures

K.-H. HONG, B. HOU, J.A. NEES, E. POWER, G.A. MOUROU, Generation and measurement of >10^8 intensity contrast ratio in a relativistic kHz chirped-pulse amplified laser, Appl. Phys. B 81, 447-457 (2005)

Errors of recompression

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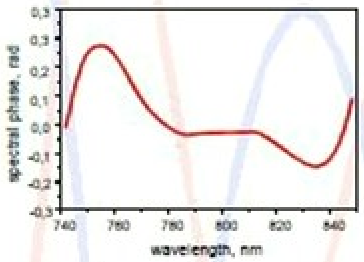
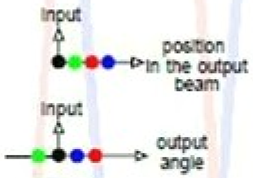


- residual spectral phase



- spatial and angular chirp

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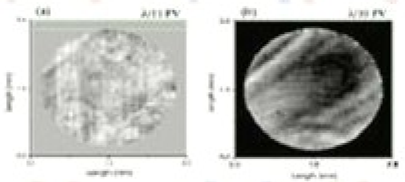
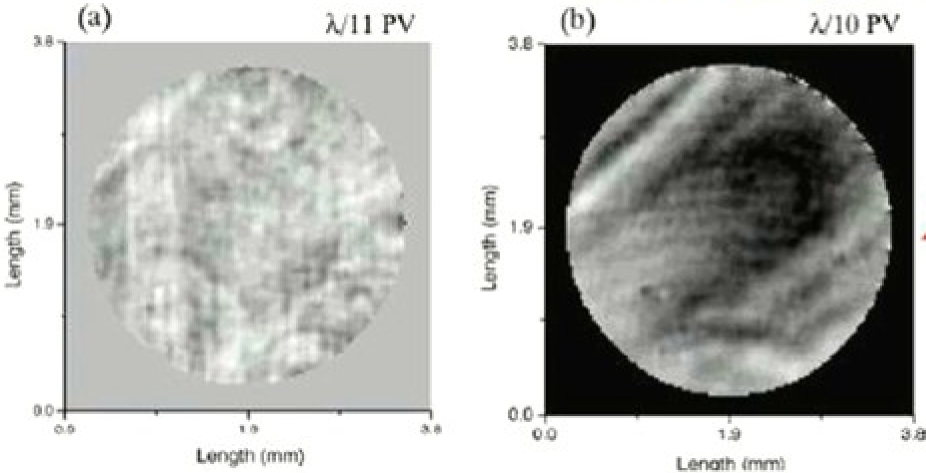
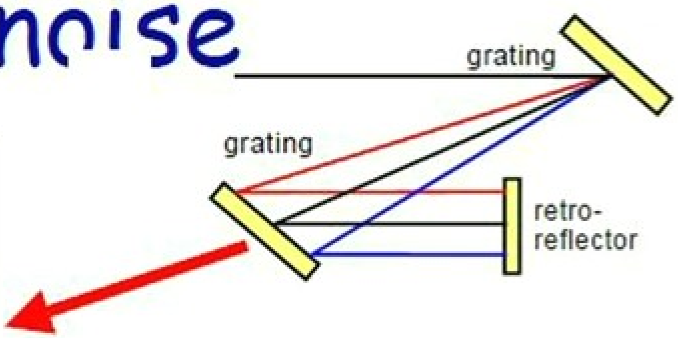
- spectral phase 'noise'



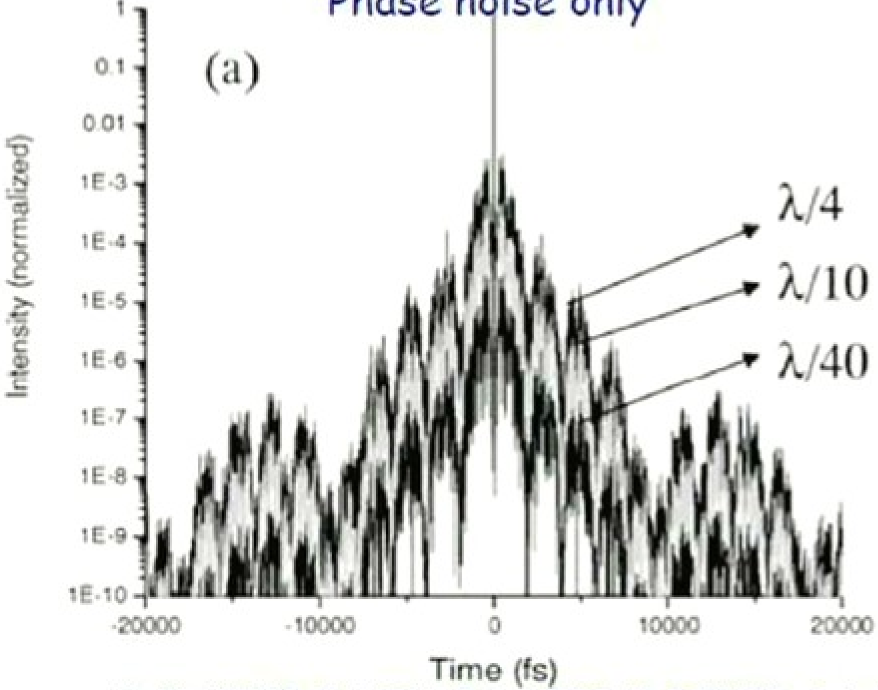
Phase noise



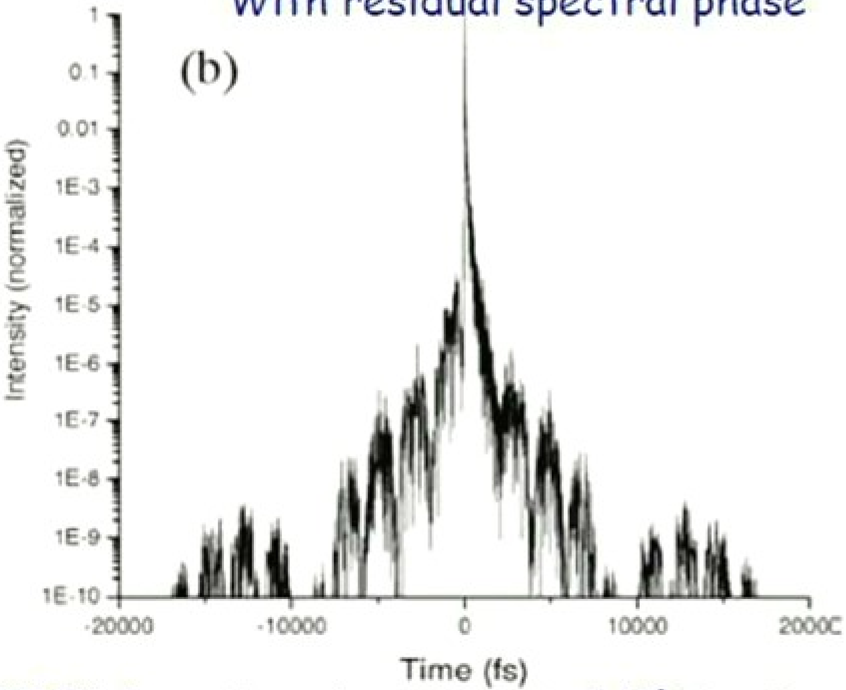


Optical elements in the compressor, stretcher, diffraction gratings

Phase noise only



With residual spectral phase



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Specific for CPA

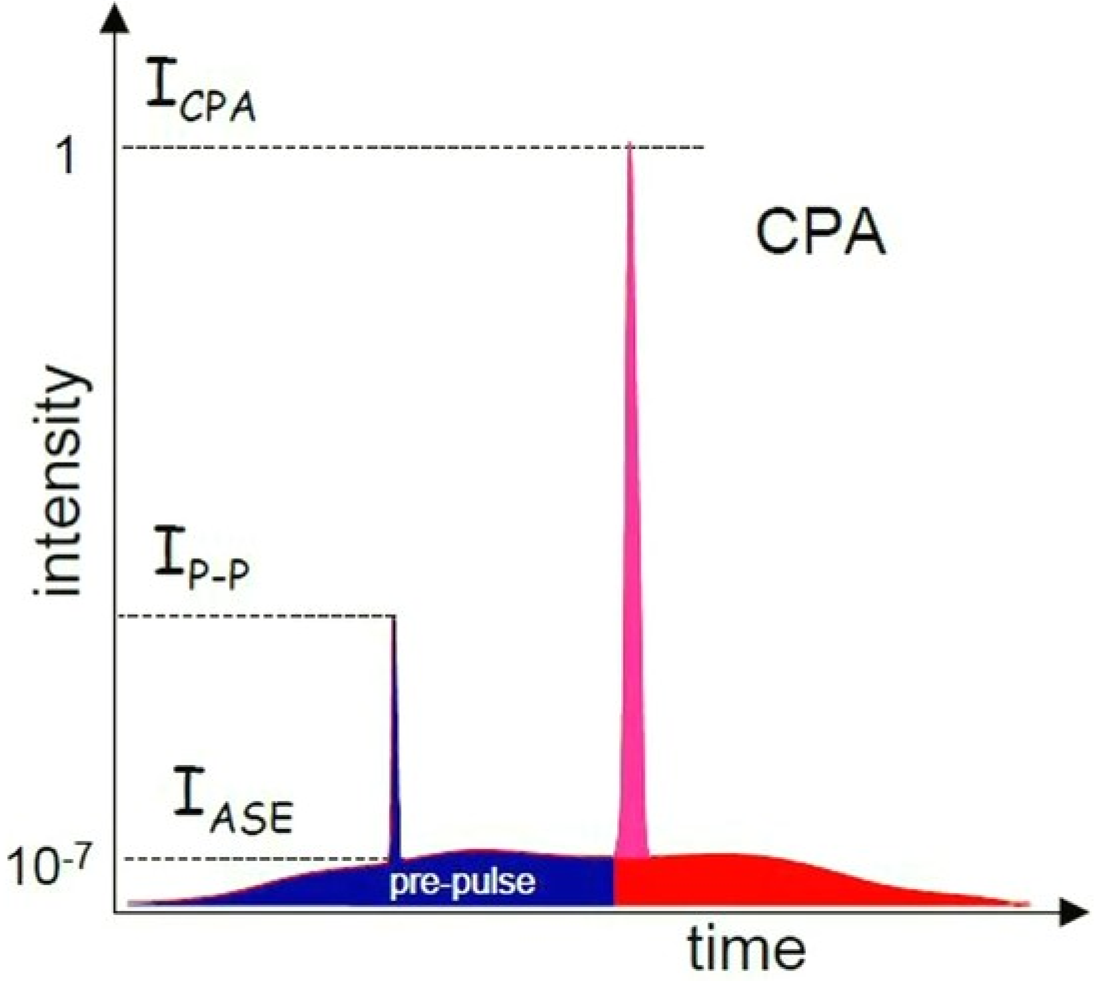
Energy contrast:

$K_E = \int I_{CPA} dt / \int I_{ASE} dt$

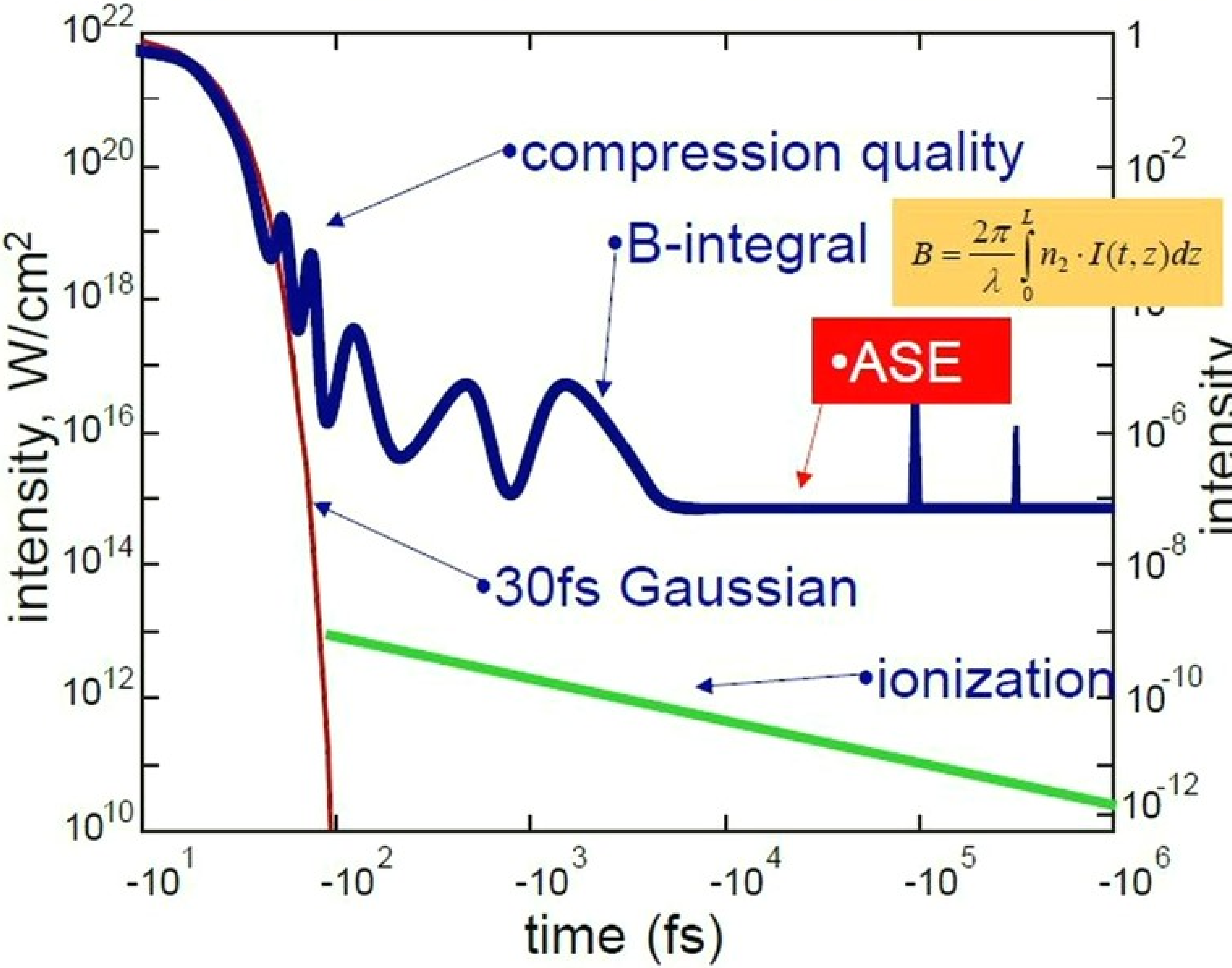
Intensity contrast:

$K_I = I_{CPA} / I_{ASE}$

At a fixed ASE-level shortening of the pulse not only increases the laser power, but leads also to higher contrast.

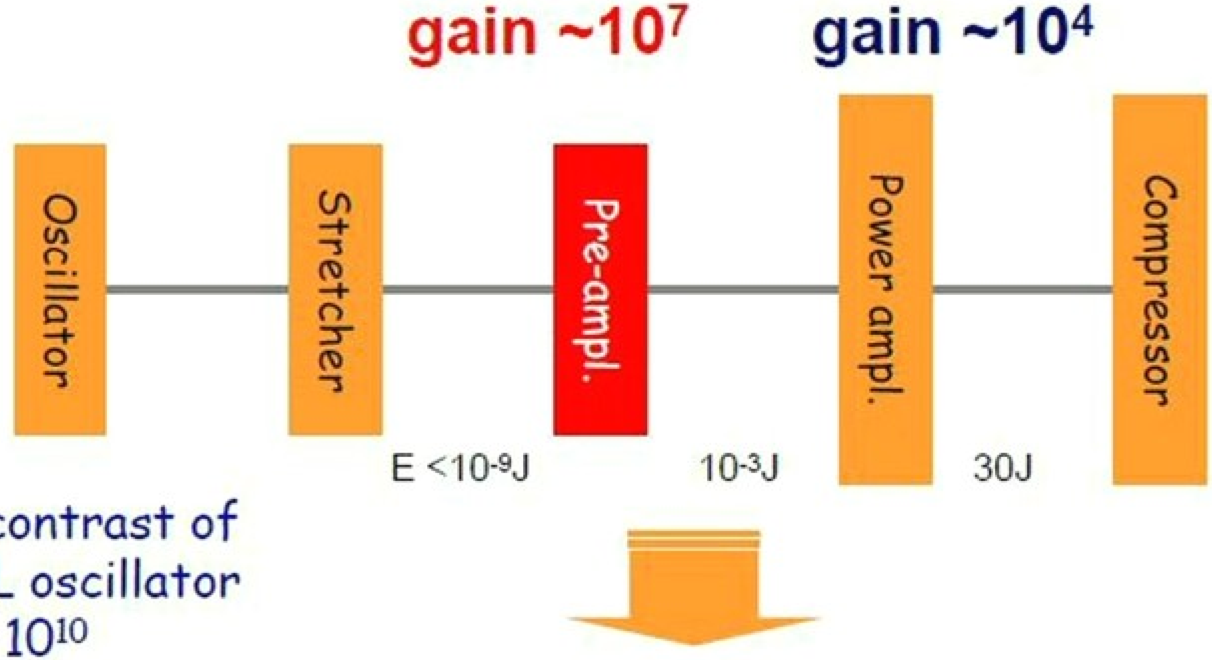


Time domain of laser - solid target interaction



Typical CPA Ti:sapphire laser architecture

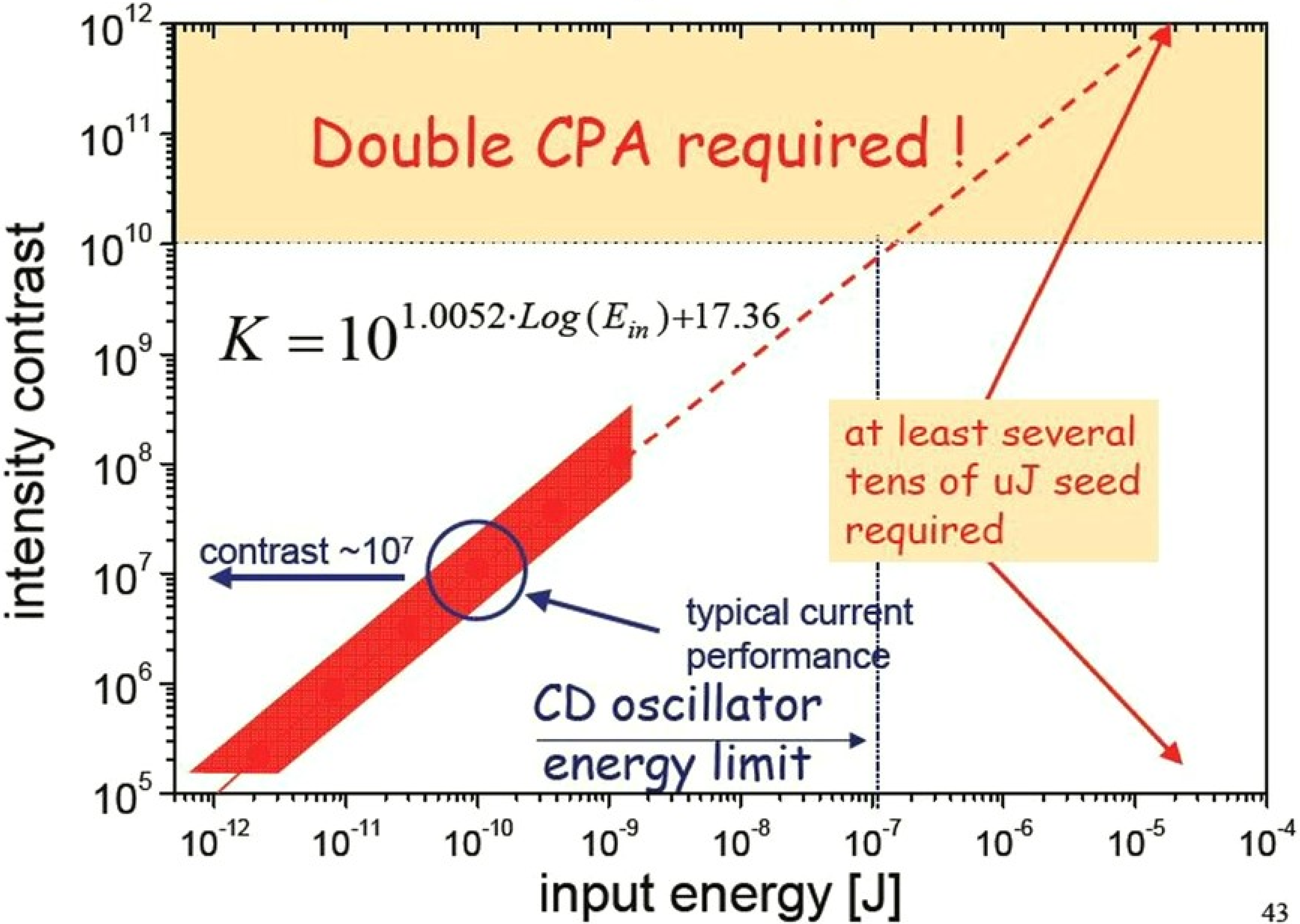
The ASE brightness is given by: $$B_{ASE} = \frac{F_{SAT}\Delta\nu}{4\pi\tau_{FL}\Delta\nu_{FL}}.(G_{ASE}-1)$$



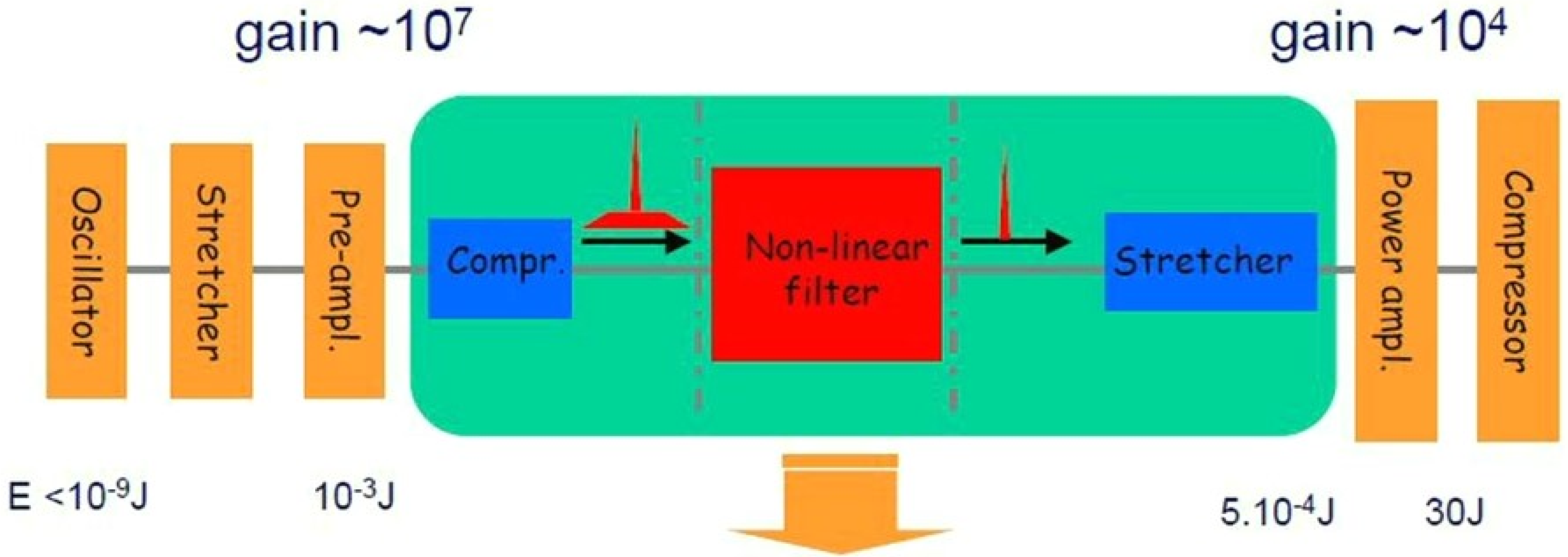
Temporal contrast of a good KML oscillator is ~ 10^{10}

The contrast is almost fully determined by the laser front end.

Scaling to a PW power (10^{22} W/cm^2)



Concept of the Double-CPA laser



- transmits the short pulse for further amplification
- stops the ASE background and satellite pulses

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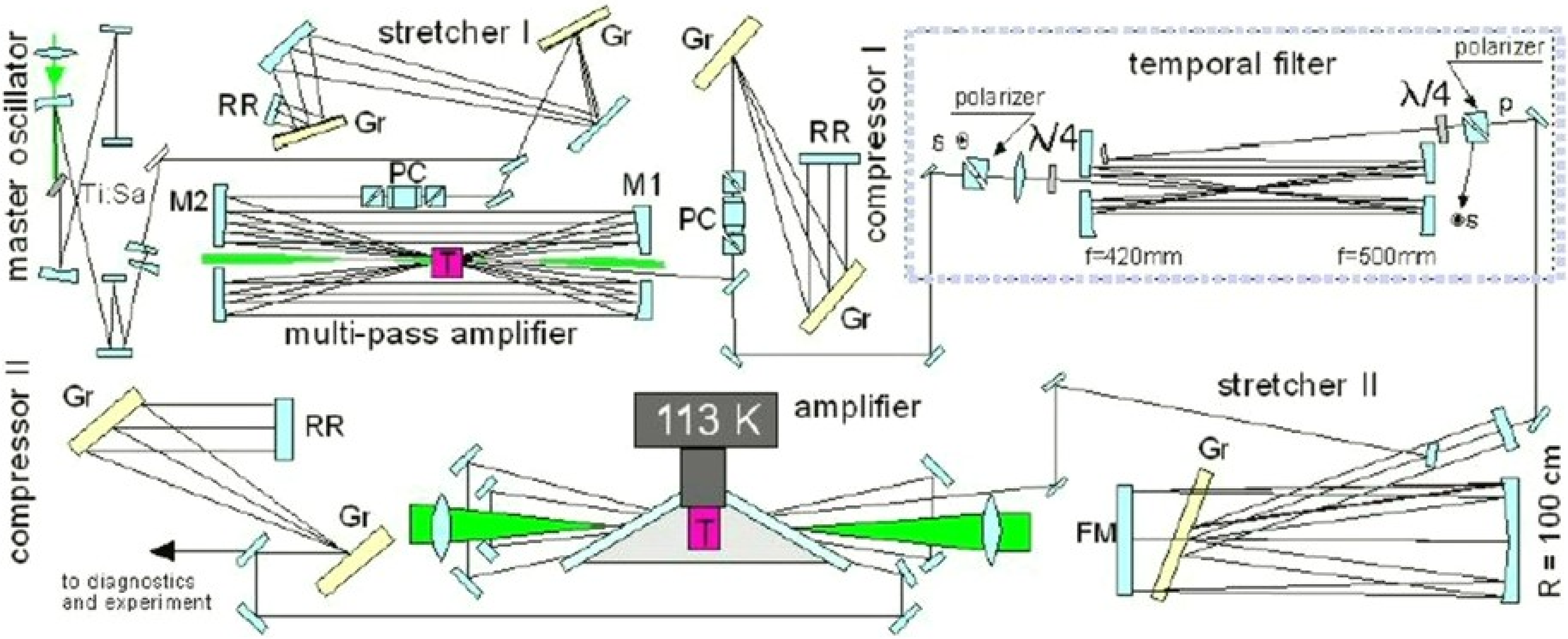
Scheme of the DCPA laser



M. P. Kalashnikov, E. Risse, H. Schönnagel, and W. Sandner, Opt. Lett. **30** (2005), 923-925.

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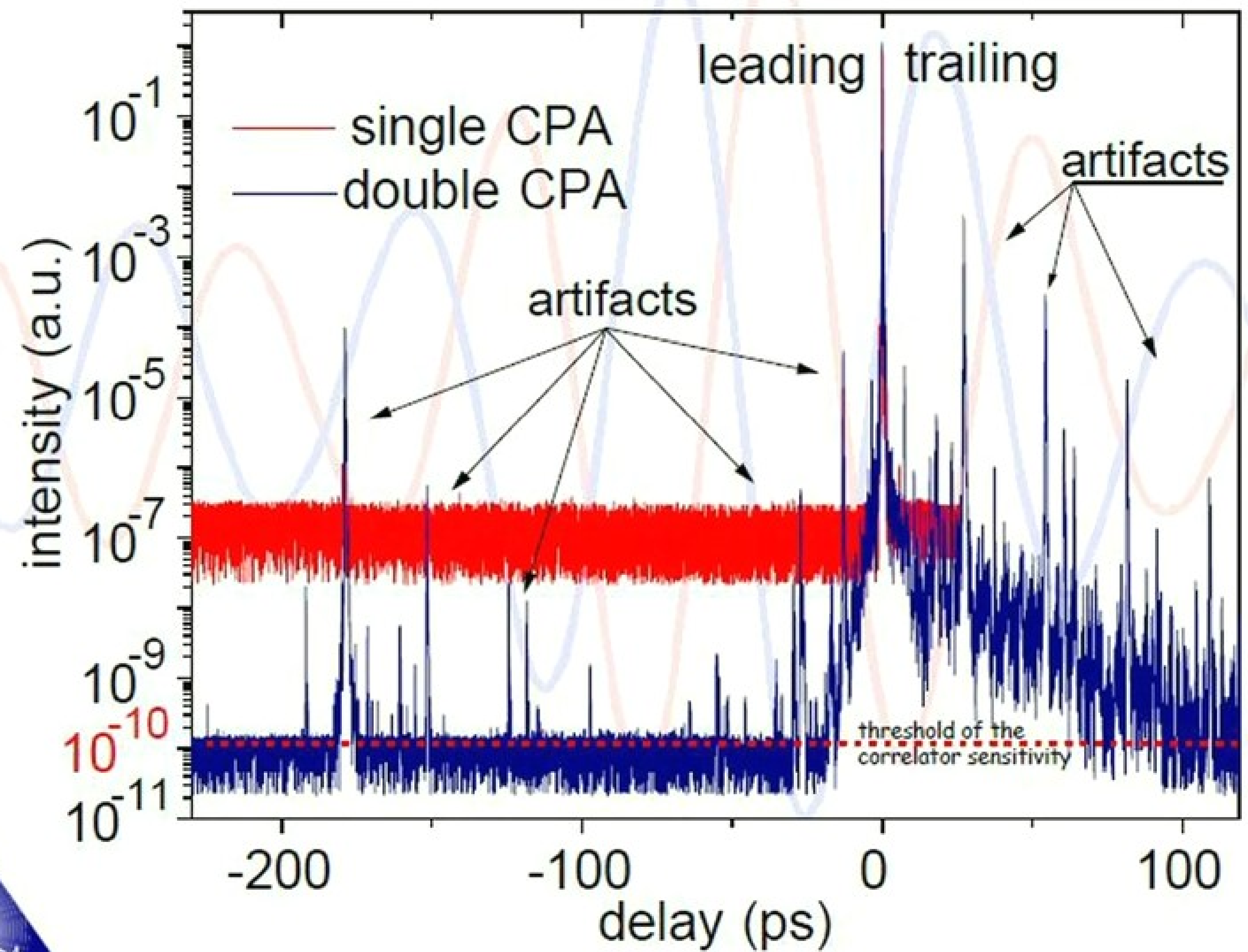
Contrast of the Double-CPA laser



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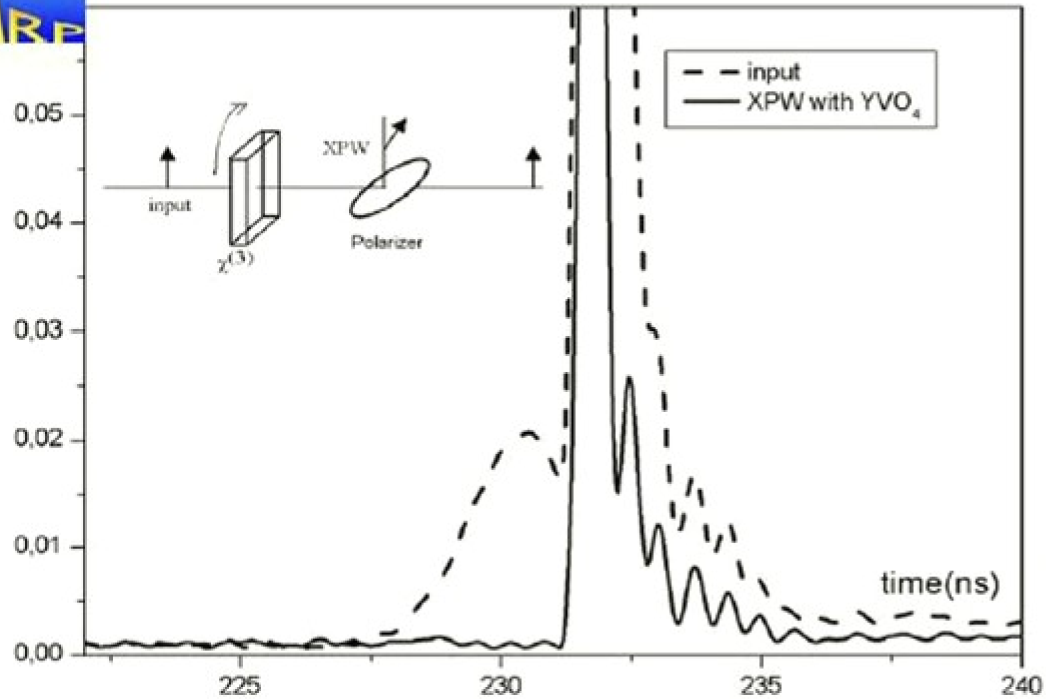
M. P. Kalashnikov, E. Risse, H. Schönnagel, and W. Sandner, Opt. Lett. **30** (2005), 923-925.

XPW : generation of an orthogonal polarized



Principle :
Generation of an orthogonally polarized wave with the same λ.
Non linear effect governed by $Re(\chi^3)$ anisotropy

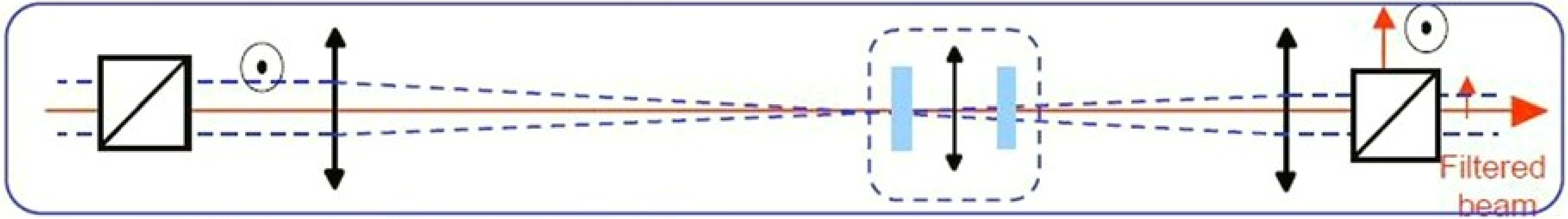
$I_{XPW} \propto I_0^3 \Rightarrow$ interesting for pulse temporal contrast enhancement

BaF_2 crystal :
- **Low SPM**
- **High χ^3 anisotropy $\Rightarrow$ correct efficiency**
- **Adaptable on various laser wavelengths**
  $\Rightarrow$ Demonstrated at λ=620nm, λ=800nm, λ=1.06µm

Opt. Lett. 26 (2001) 335, JOSA B 21 (2004)1659, Opt. Lett., 30

An experimental technique to ensure stability and reliability of the setup with high transmission

- Experiments with two crystals in the far-field :



- several crystals successively "imaged"
- 1^{st} crystal $\Rightarrow E_{XPW1}$
- 2^{nd} crystal $\Rightarrow E_{XPW2}$ with the same spatial and temporal properties
- E_{XPW1} and E_{XPW2} can constructively or destructively interfere

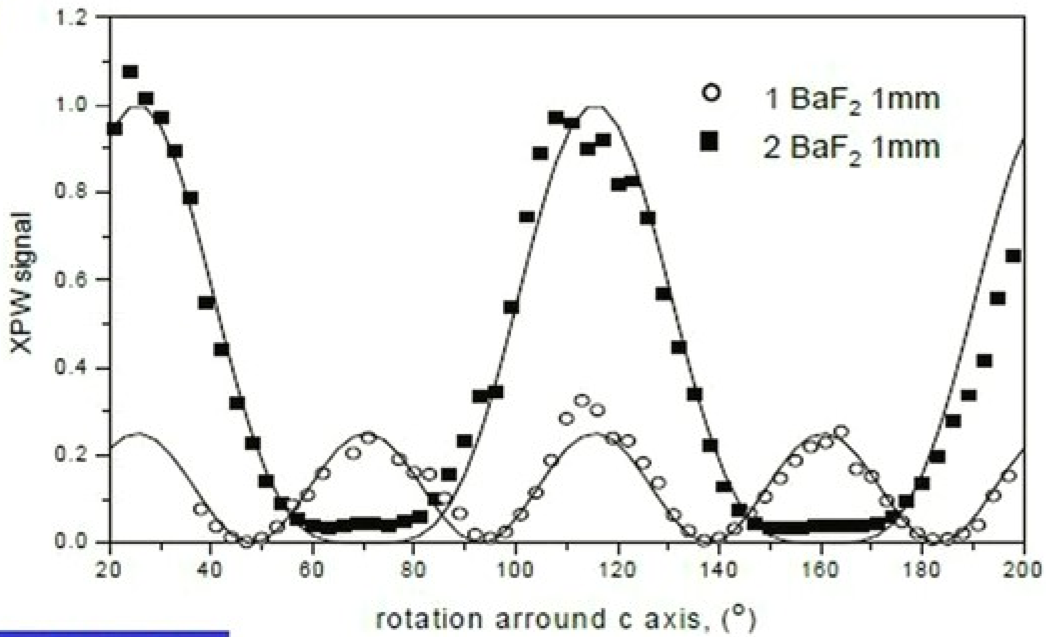
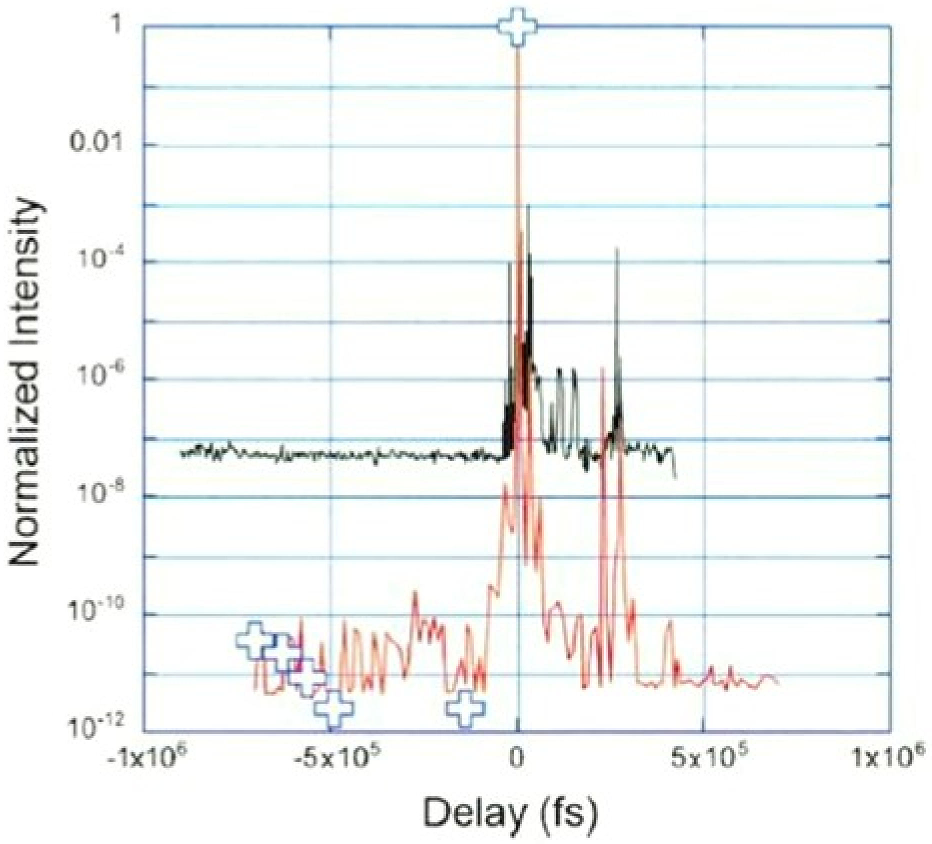


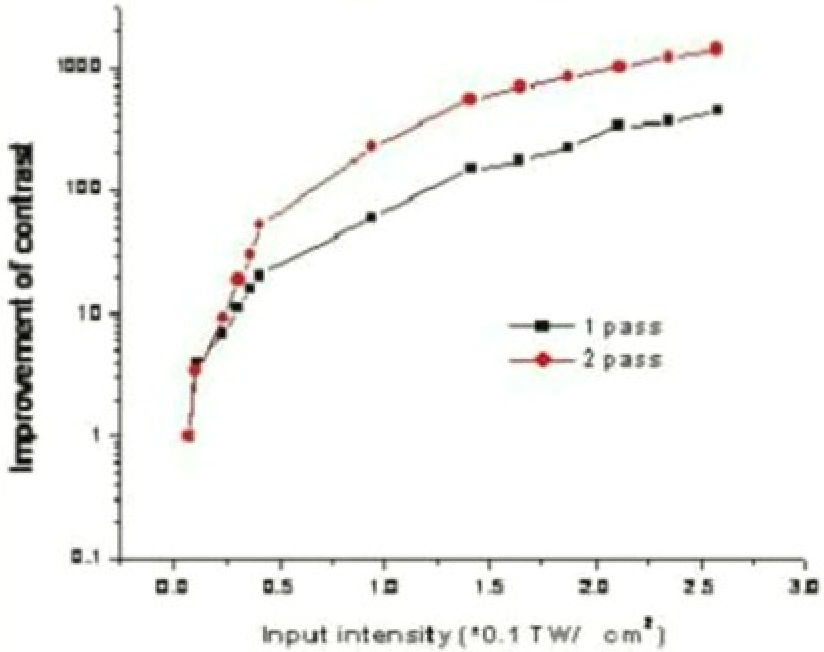
Fig. 1

⇒ *LOA - THALES LASER Patent FR 04-12964*

Record contrast of 10^{11} demonstrated at 50 TW



- XPW BaF_2 crystal
- Filtering at a μJ level



V. Chvykov, P. Rousseau, S. Reed, G. Kalinchenko, V. Yanovsky, Generation of 10^{11} contrast 50 TW laser pulses, Opt. Lett, **31**, 1456-1458 (2006).

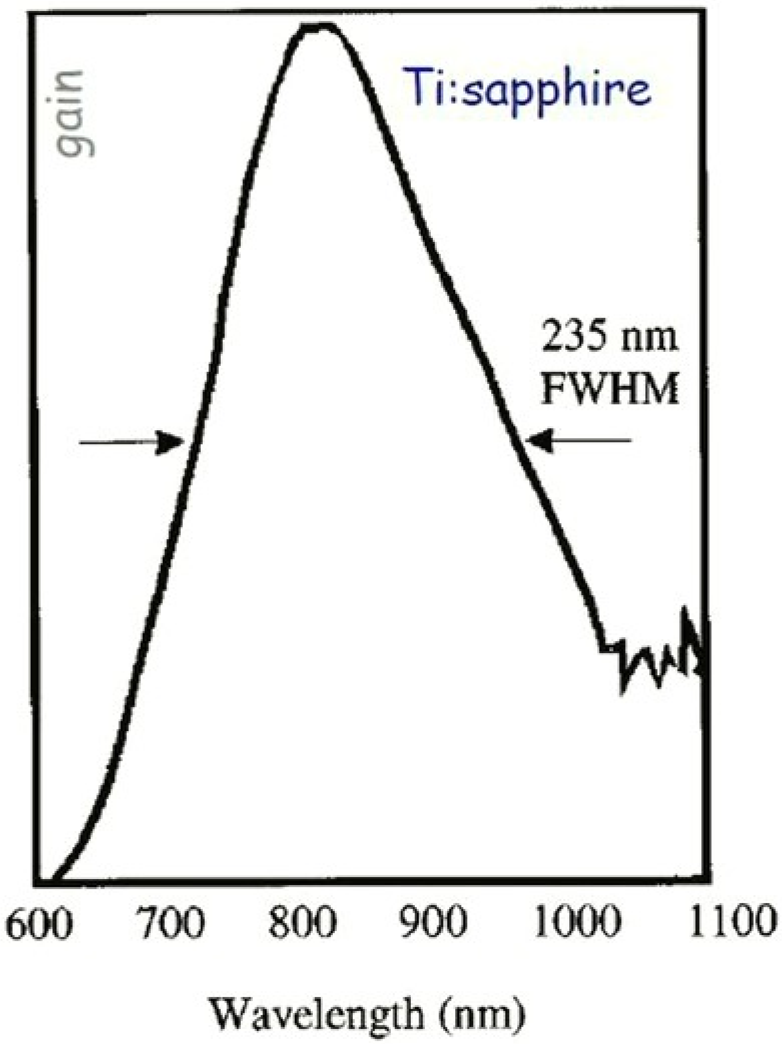
Gain narrowing

M.P. KALASHNIKOV
K. OSVAY *
I.M. LACHKO
H. SCHÖNNAGEL
W. SANDNER

Suppression of gain narrowing in multi-TW lasers with negatively and positively chirped pulse amplification

Max-Born-Institut für Nichtlineare Optik und Kurzzeitspektroskopie,
Max-Born-Straße 2a, 12489 Berlin, Germany

Factors limiting pulse duration



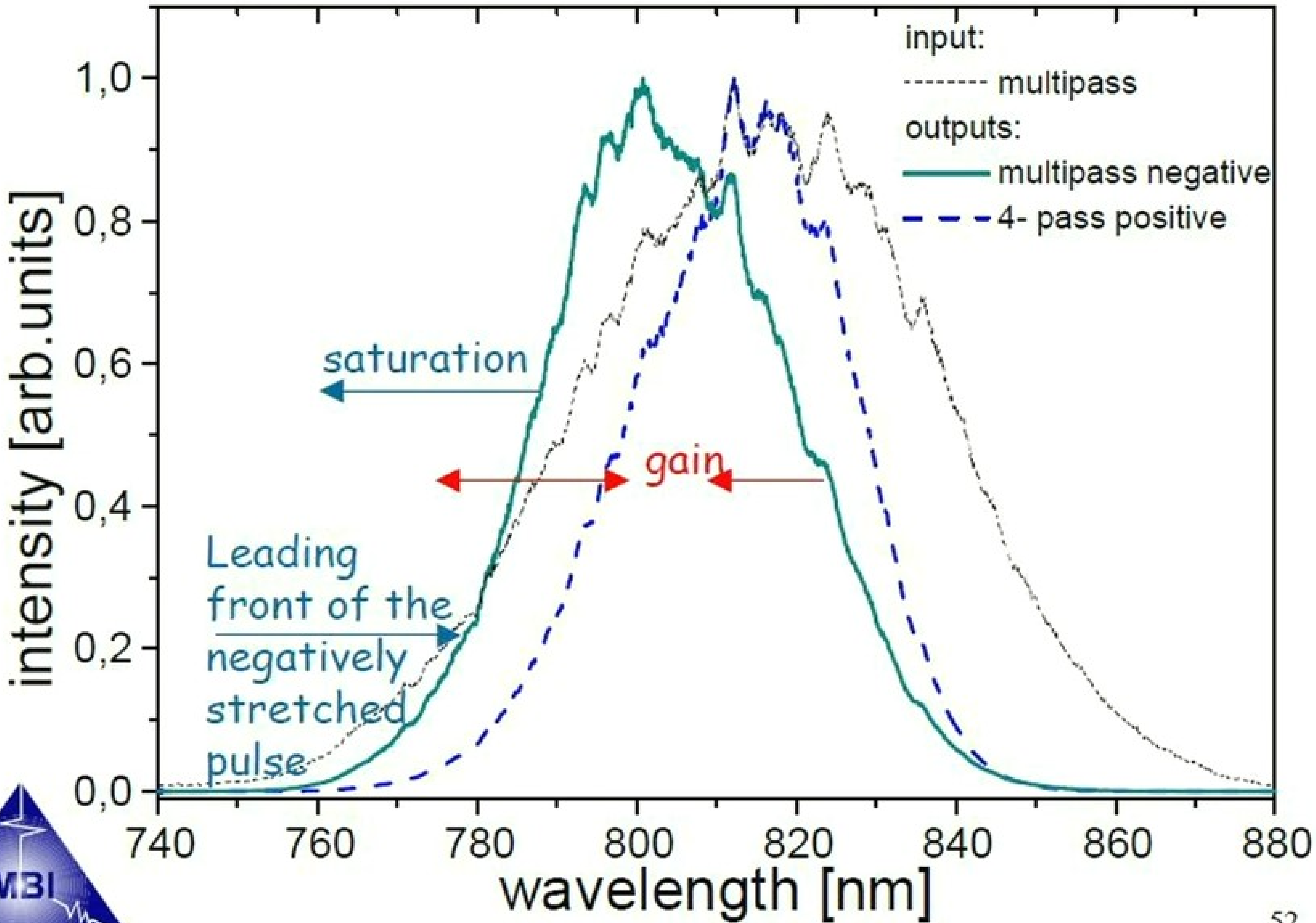
- Gain narrowing – frequency dependence of the gain.

Bandwidth of a nanojoule seed pulse (60-80 nm) amplified to a petawatt is reduced to < 30 nm.

- Saturation of amplification

Similar to the temporal contrast, the spectrum is almost fully determined by the laser front end: half bandwidth of a good oscillator

Negatively-positively chirped



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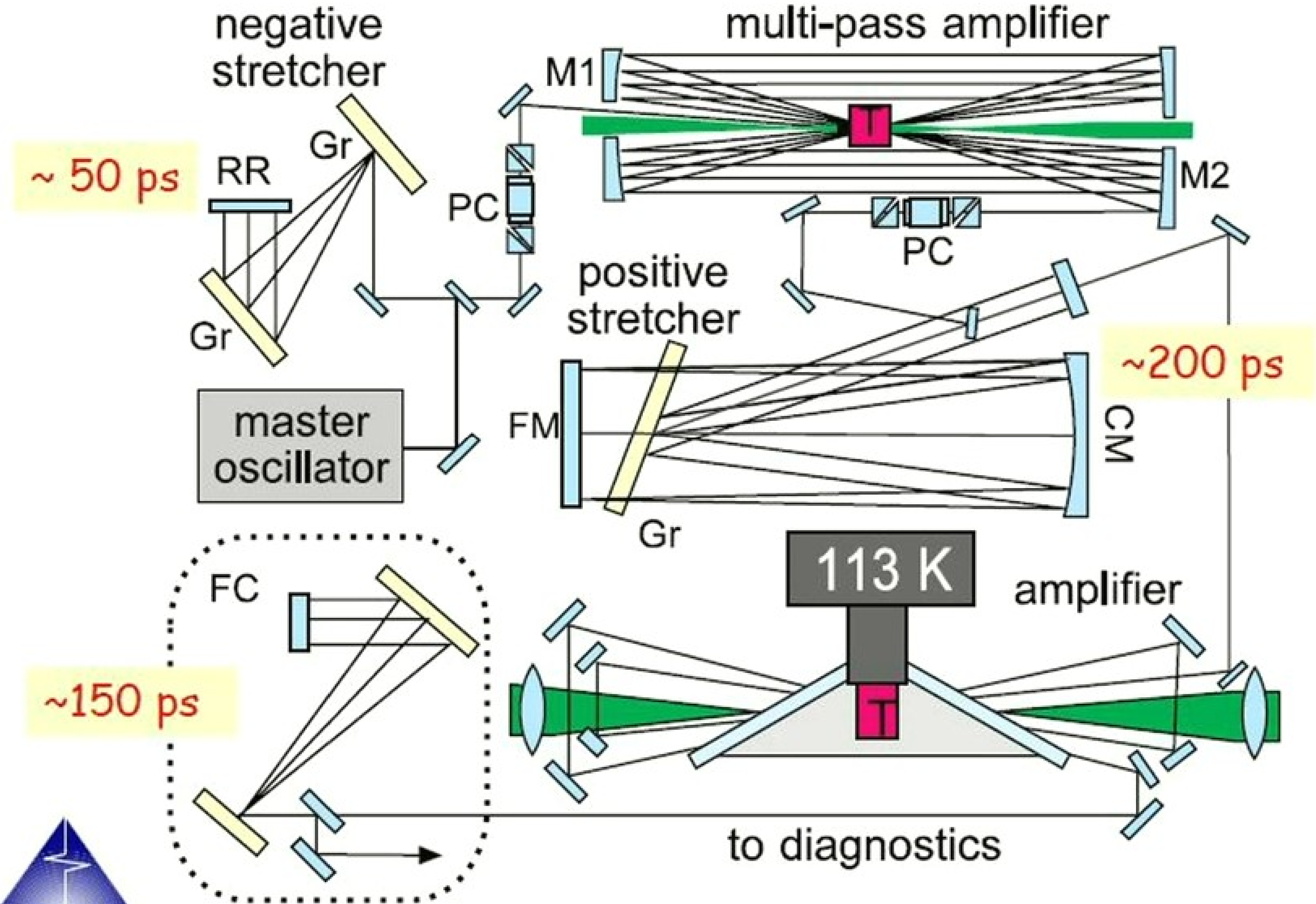
Negative- Positive CPA laser (NPCPA)



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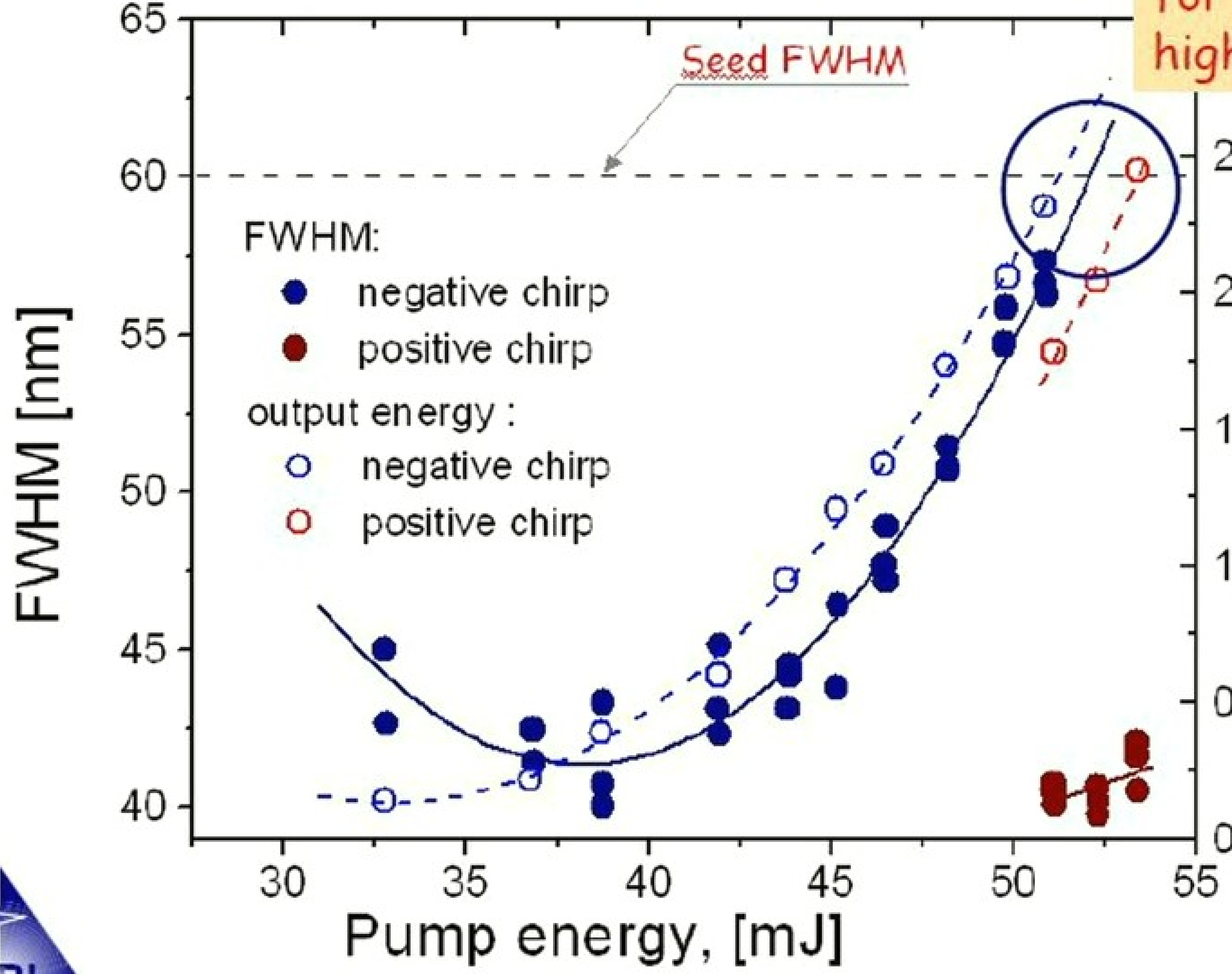
Reshaping of the pulse spectrum

multipass amplifier (9 passes)

less pump energy
for NPCPA->
higher contrast



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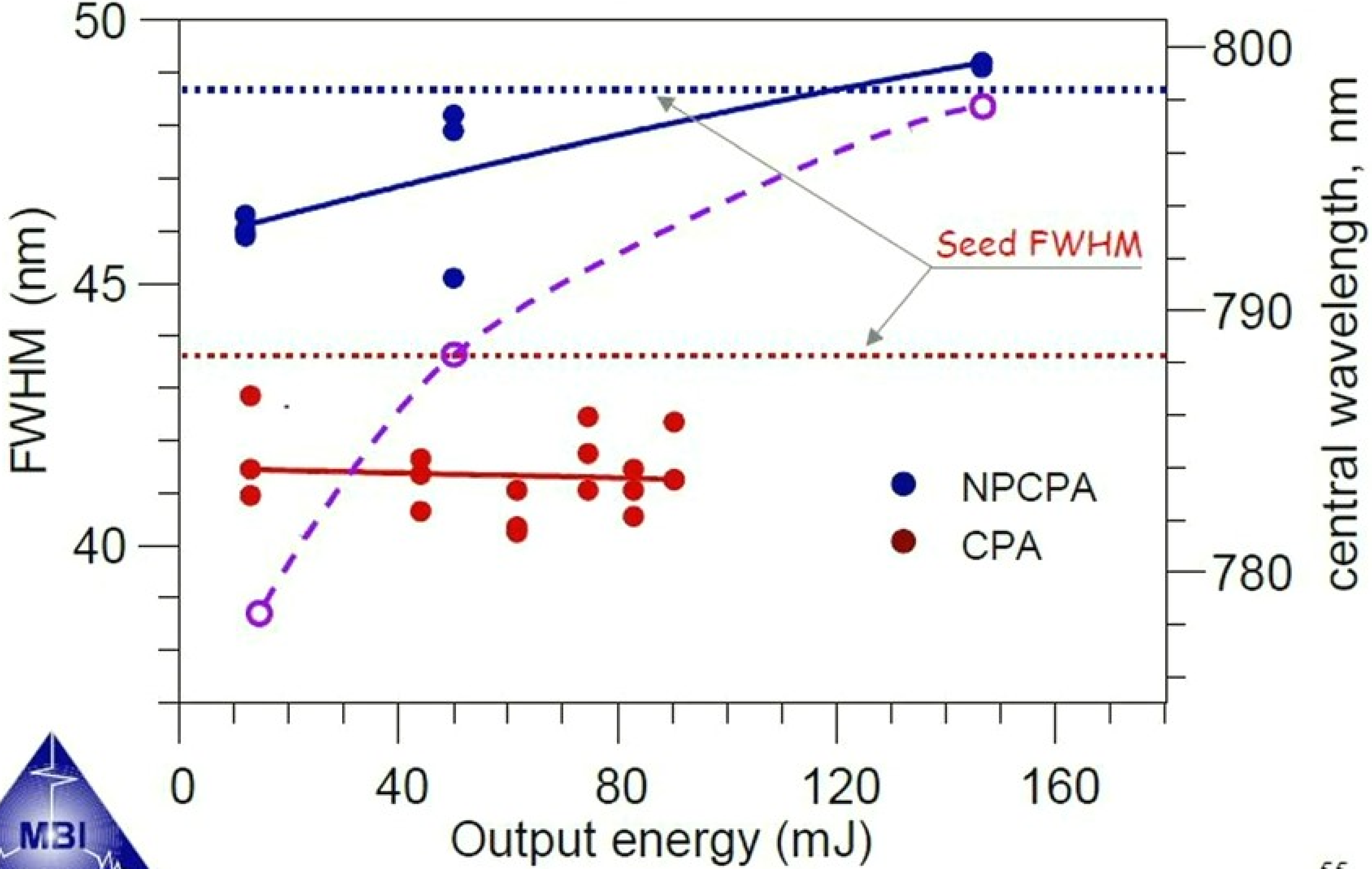
Reshaping the pulse spectrum

power amplifier (4 passes)



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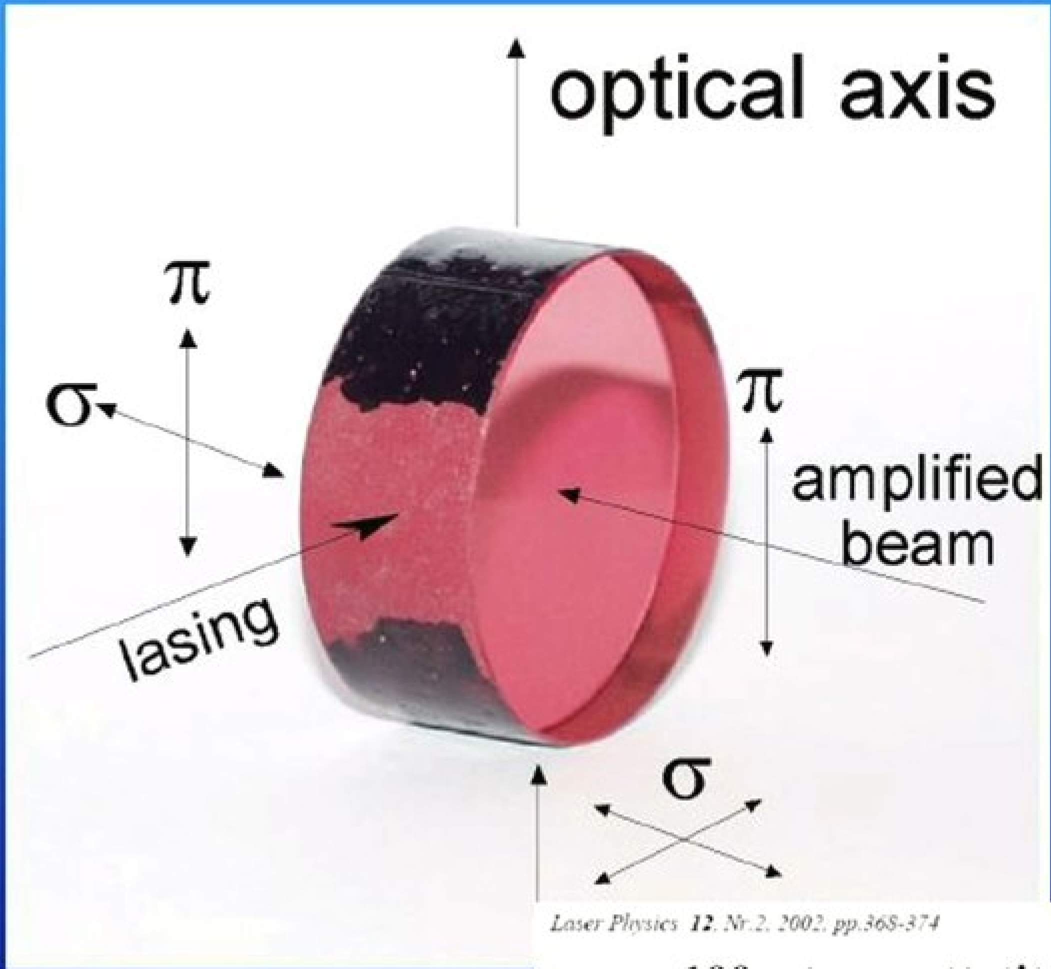
Parasitic lasing in a high aperture Ti:sapphire crystal



Diameter 35 mm

Thickness 15 mm

Coated by a usual black paint, n~1.5

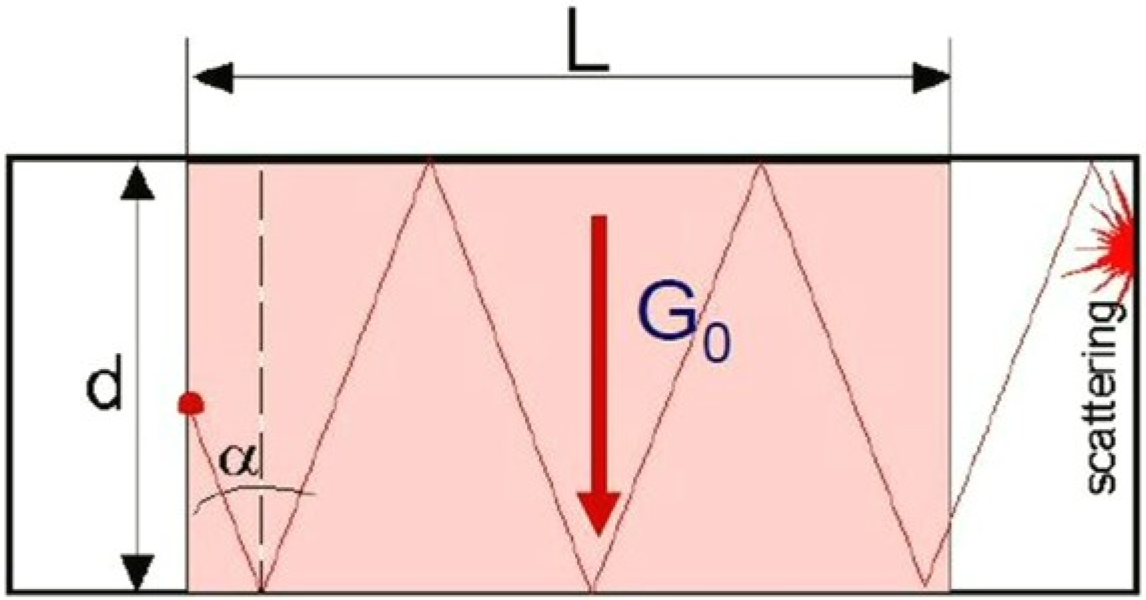
Laser Physics **12**, Nr.2, 2002, pp.368-374

100 – terawatt titanium-sapphire laser system

M.P.Kalachnikov, V.Karpov, H.Schönnagel, W.Sandner

Max-Born-Institut für Nichtlineare Optik und Kurzzeitspektroskopie, Max-Born-Strasse, 2a, D-12489 Berlin, Germany
Tel. +4930 63921321, Fax: +4930 63921329, E-mail kalashni@mbi-berlin.de

Parasitic lasing in a high aperture Ti:sapphire crystal



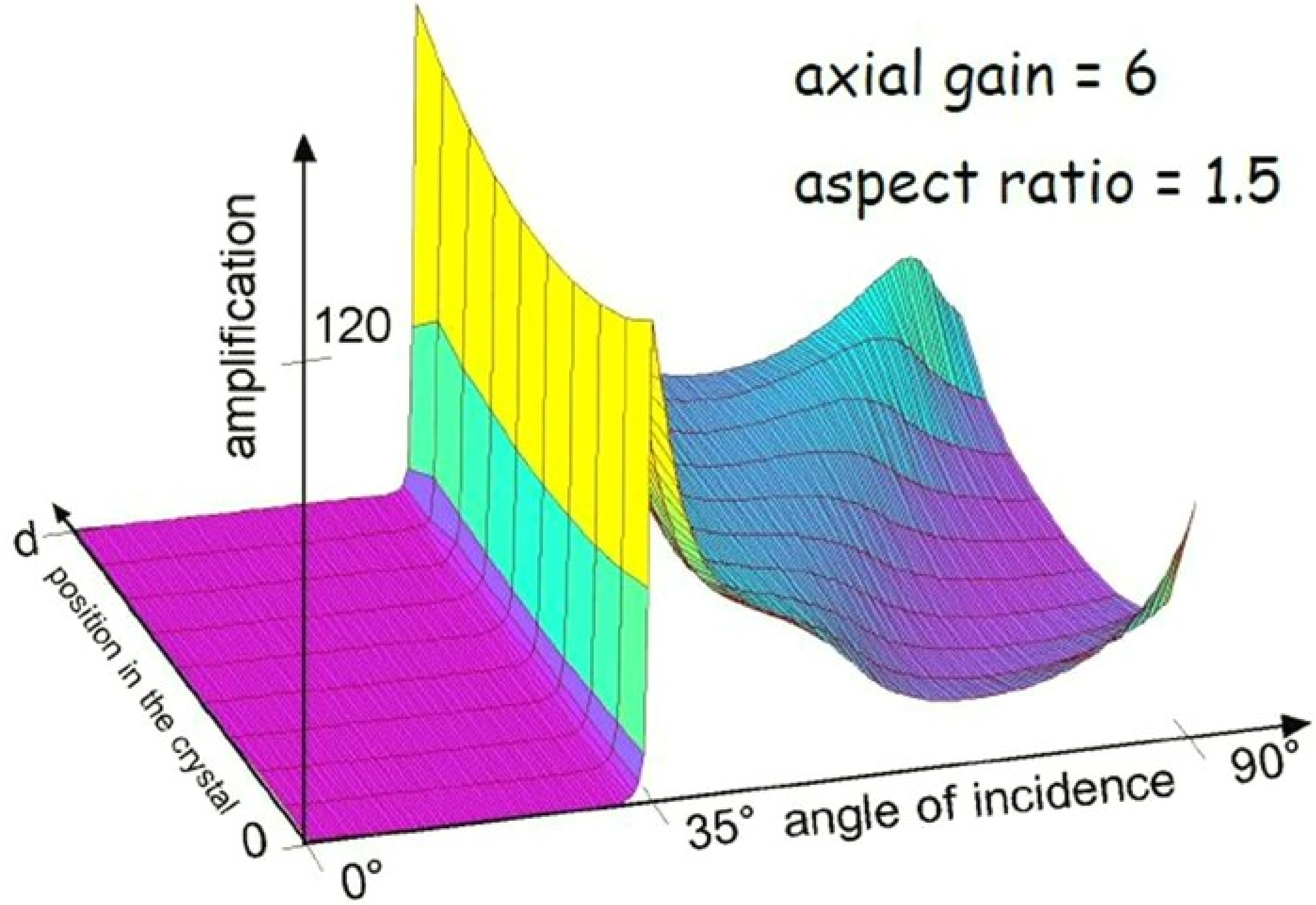
$G_\pi = R_s^N \exp(A_s \ln G_o / \sin\alpha)$

$G_\sigma = R_p^N \exp(A_s \ln \sqrt{G_o} / \sin\alpha)$

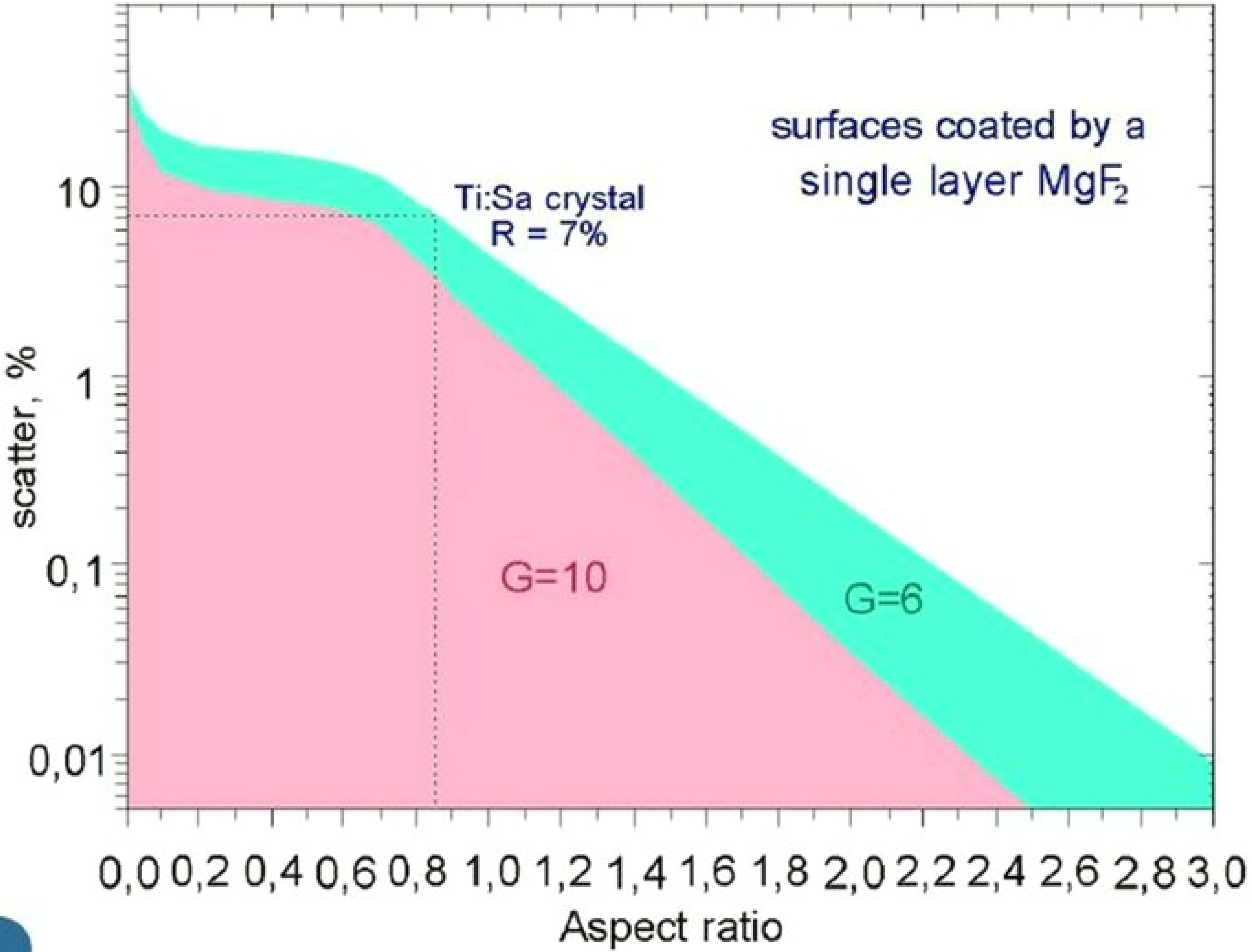
A_S =L/d - aspect ratio
N - number of reflections
a - angle of incidence
G - axial amplification

Free lasing in a Ti:Sa rod

(non-uniform pump).



Threshold for parasitic lasing in a Ti:Sa rod

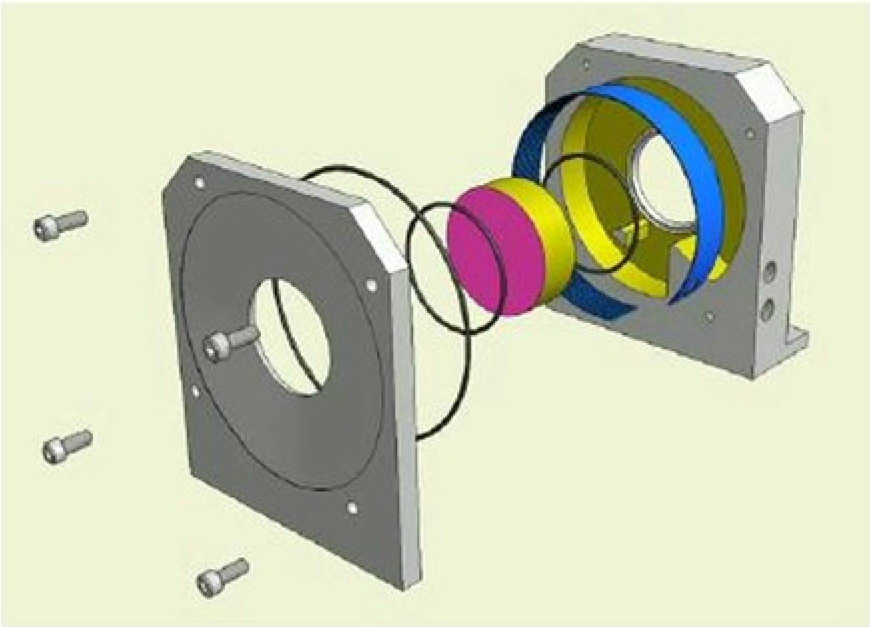


Suppression of Parasitics

1. Transverse parasitics:

Caused by feedback from cylinder surface into gain region

Use an index-matching material at the cylinder surface



Schematic of Ti:sapphire mount

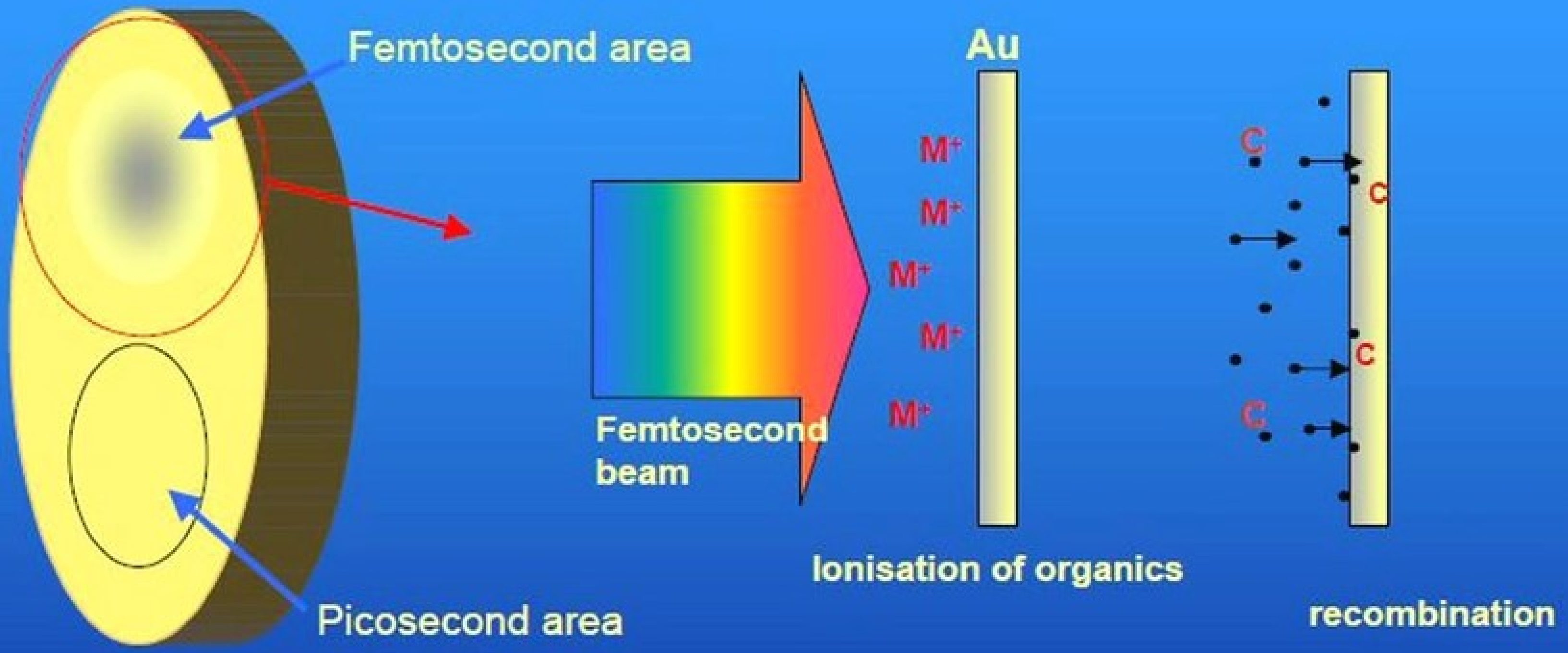
- Index-match liquid has n_{800}=1.7547
- Fresnel reflection is only 2 x 10^{-6}
- Absorber dissolved in liquid **OR** absorbing insert in cell
- Can circulate liquid for cooling if necessary

Consequences of high intensity laser and high repetability on gratings

When running at 10 Hz
Total diffraction efficiency decreases from 70 % to 50 % in few days

Diffraction gratings are very expensive:
A set for a 100 TW laser system costs ~ 90 k€

Decontamination of optical elements



Intensity of a recompressed pulse exceeds the value of 10^{12} W/cm^2. High laser intensity leads to dissociation or/and ionization of organic molecules followed by contamination of the gratings and other optical elements (dielectric mirrors) with carbon.

Cleaning of contaminated optics

experimental setup

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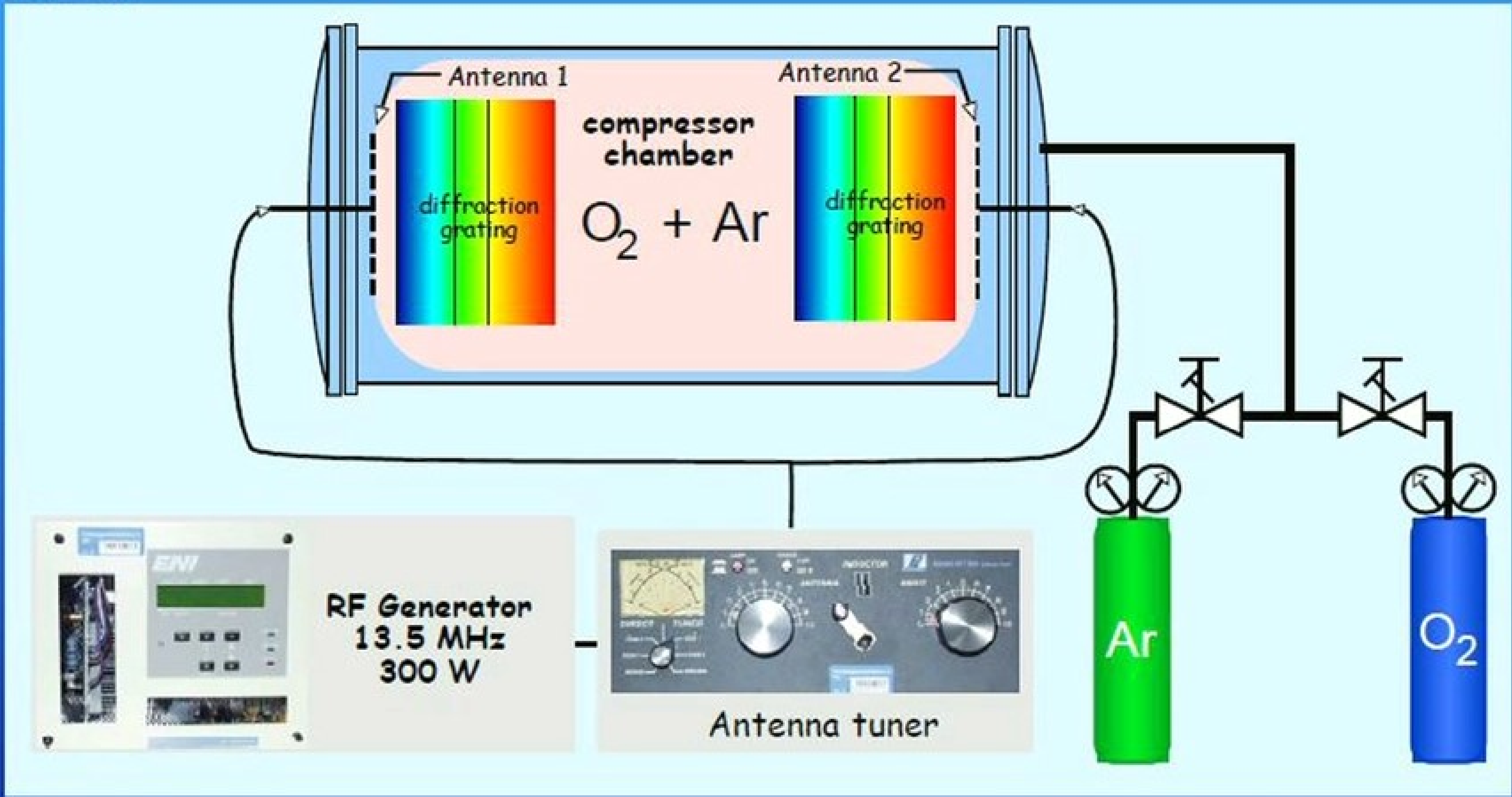


typical conditions

pressure: O_2 : 5.10^{-3} mbar, Ar : 3.10^{-3} mbar

power : 60 W

OECD

Pulse characterization

- High dynamic range (temporal contrast)
- Autocorrelation
- FROG
- SPIDER

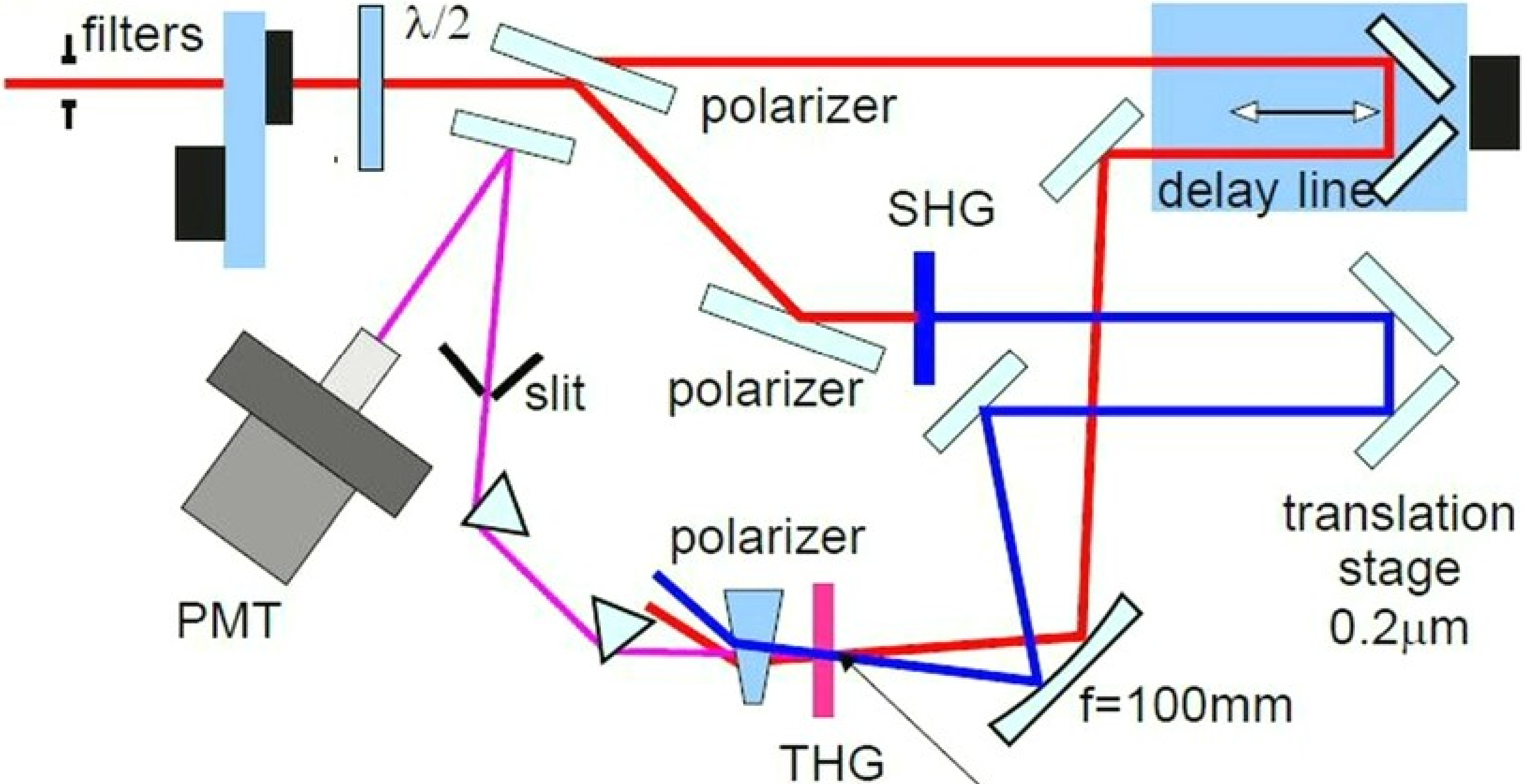
High dynamic range contrast characterization

How to measure the contrast within intensity range of 10^{10}-10^{12}?

Scanning cross-correlators:

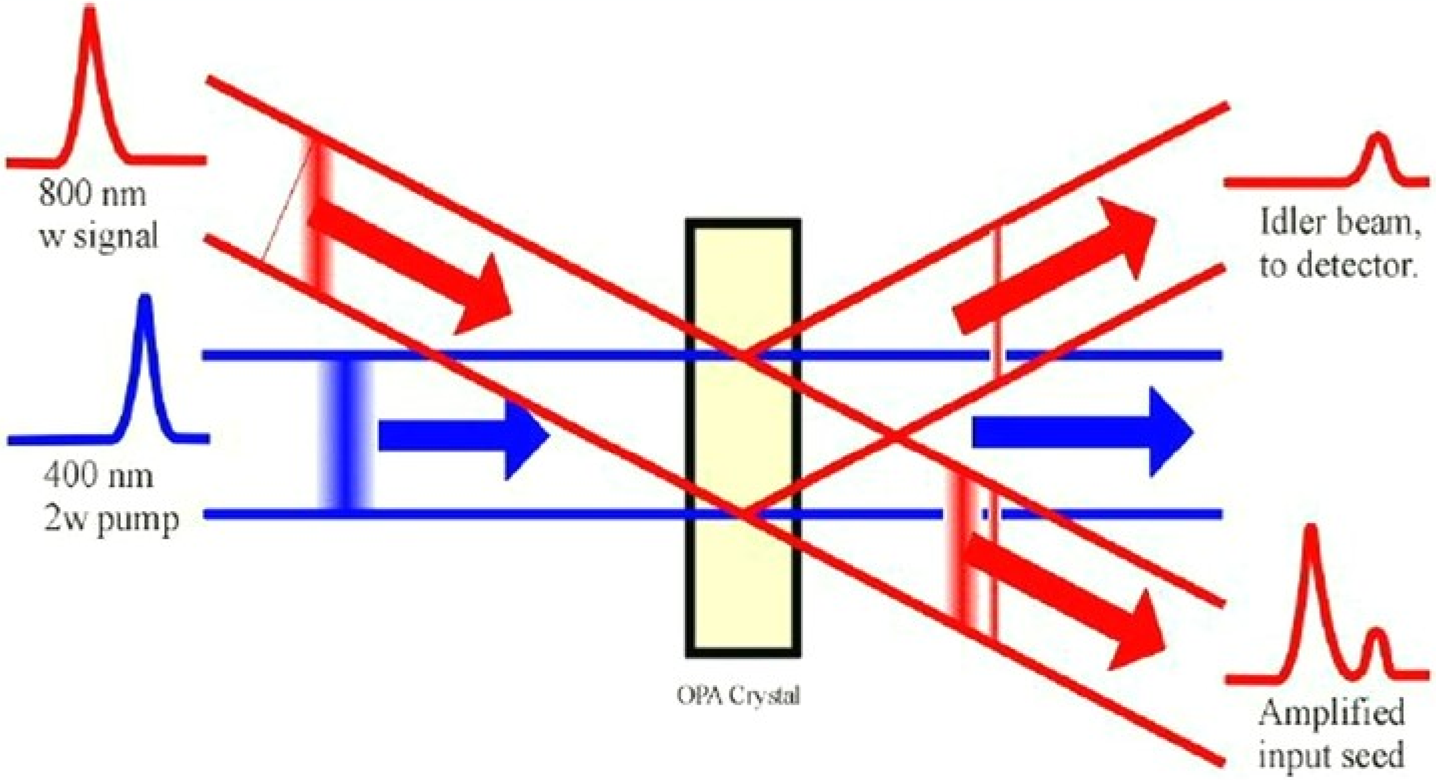
- third order (generation of $3\omega=\omega+2\omega$)
- optical parametrical (active, amplification)

High dynamic range 3-rd order cross-correlator



- non-collinear
- selection of 3ω spectrally, polarization

Concept of the OPA correlator



Pedestal is amplified, no longer limited by detector noise.
Idler measurement off axis - direct scatter reduced.

So how do you measure the pulse itself?

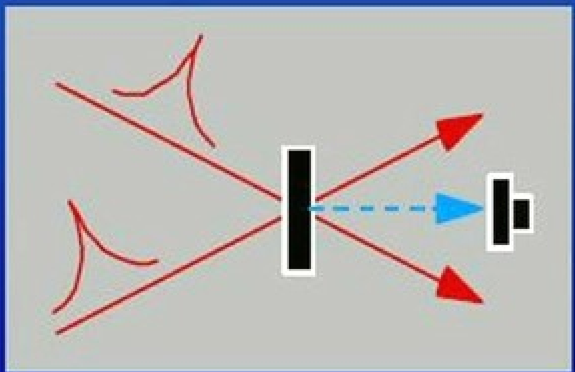
You must use the pulse to measure itself.

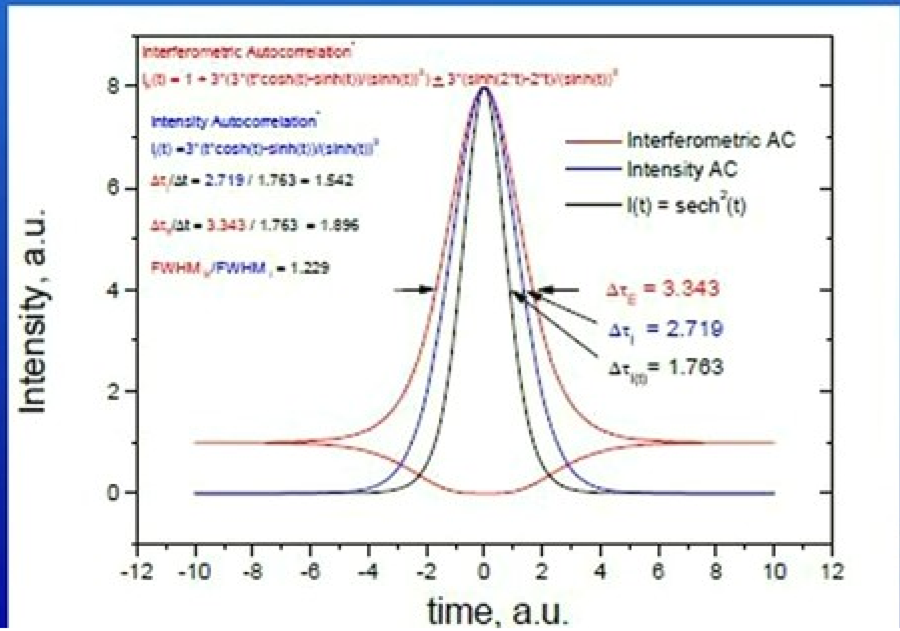
But that isn't good enough. It's only as short as the pulse.
It's not shorter.

Example: Intensity Autocorrelation

$$\int_{-\infty}^{\infty} I(t)\,I(t-\tau)\,dt$$

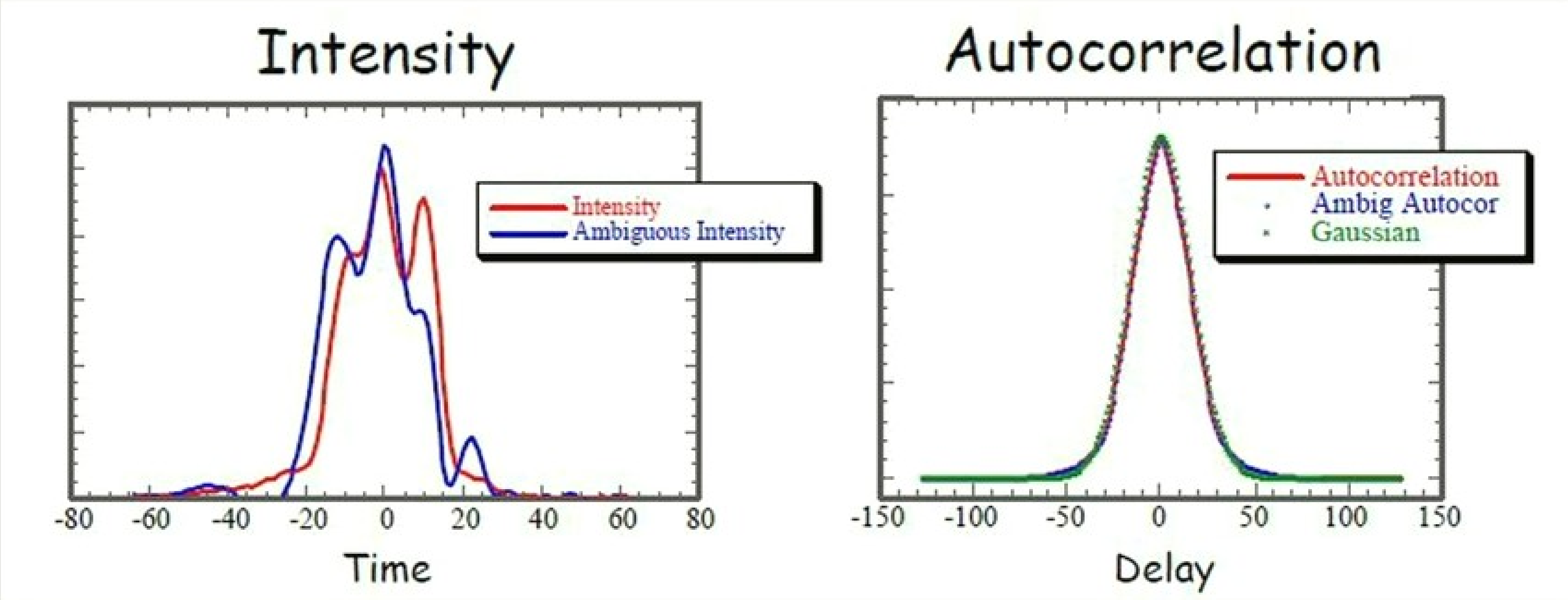
where $I(t)$ = pulse intensity





Autocorrelations have ambiguities.

These intensities have the same, nearly Gaussian, autocorrelations.



Retrieving the intensity from the autocorrelation is equivalent to the 1D Phase-Retrieval Problem, a well-known unsolvable problem.

We must measure an ultrashort laser pulse's intensity and phase vs. time or frequency.

A laser pulse has the time-domain electric field:

$$E(t) = \mathrm{Re}\left\{\sqrt{I(t)}\exp\left[i(\omega_0 t - \phi(t))\right]\right\}$$

Intensity

Phase

Equivalently, vs. frequency:

(neglecting the negative-frequency component)

$$\tilde{E}(\omega) = \sqrt{S(\omega)}\exp\left[-i\varphi(\omega)\right]$$

Spectrum

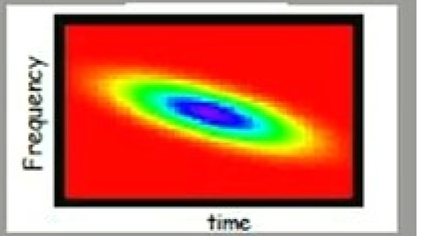
Spectral Phase

Knowledge of the intensity and phase or the spectrum and spectral phase is sufficient to determine the pulse.

Web presentation of Rick Trebino, School of Physics, Georgia Institute of Technology, Atlanta, GA 30332

A mathematically rigorous form of the musical score is the "spectrogram."

If $E(t)$ is the waveform of interest, its spectrogram is:



$$\Sigma_E(\omega,\tau) \equiv \left| \int_{-\infty}^{\infty} E(t)\, g(t-\tau)\, \exp(-i\omega t)\, dt \right|^2$$

where $g(t-\tau)$ is a variable-delay gate function and τ is the delay. Without $g(t-\tau)$, $\Sigma_E(\omega,\tau)$ would simply be the spectrum.

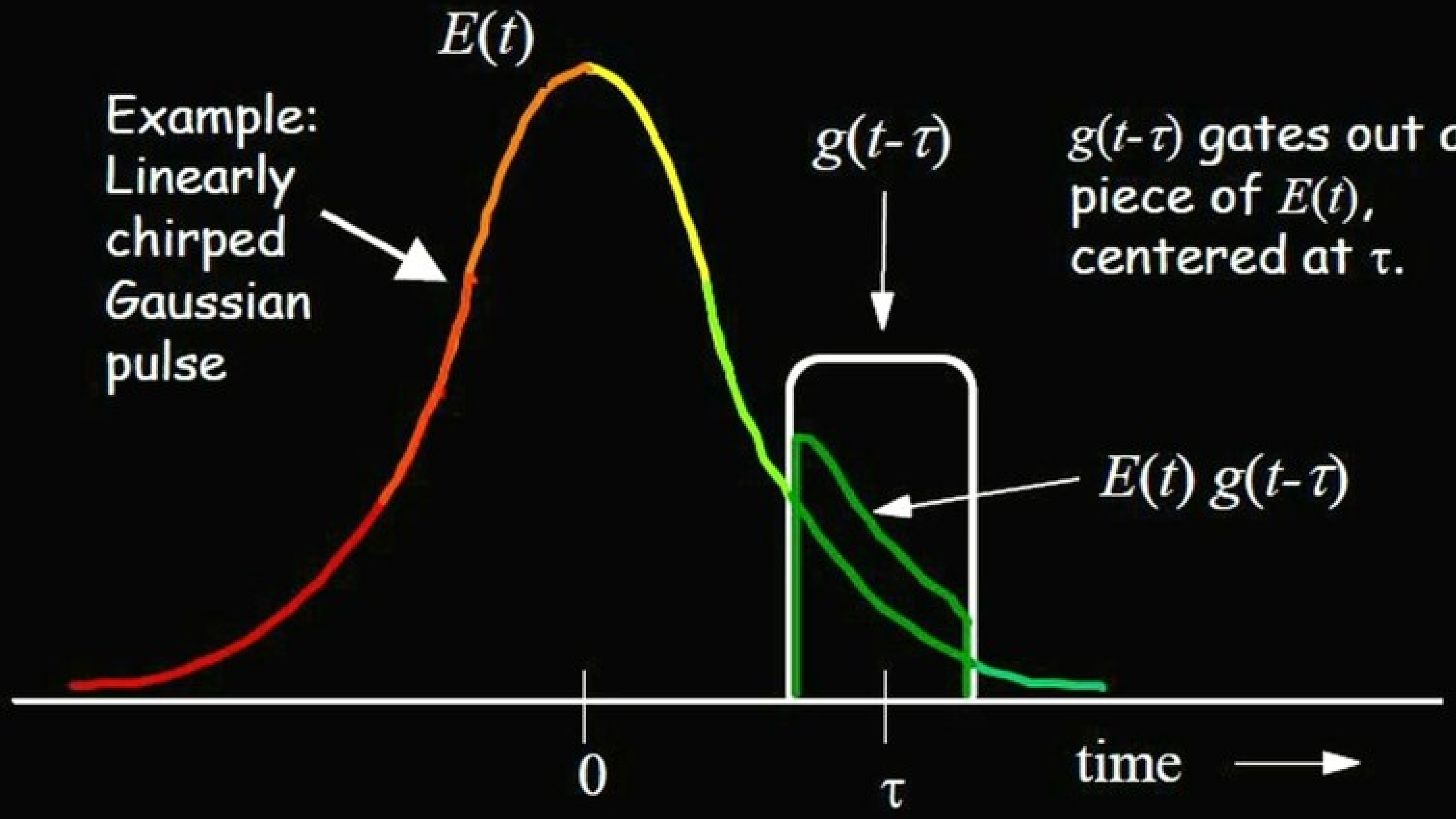
The spectrogram is a function of ω and τ.

It is the set of spectra of all temporal slices of $E(t)$.

The spectrogram is one of many time-frequency quantities, such as the Wigner Distribution and others.

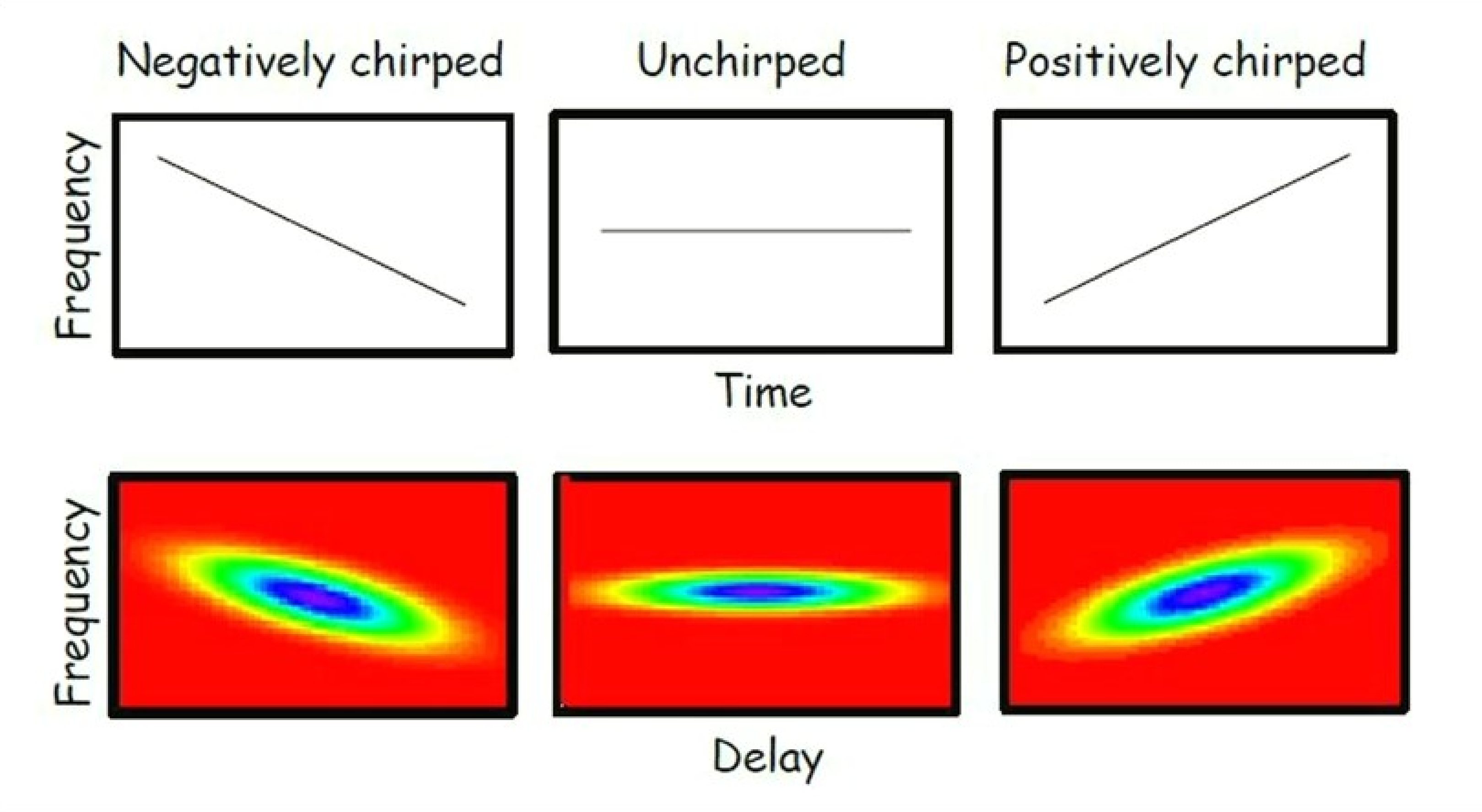
The Spectrogram of a waveform $E(t)$

We must compute the spectrum of the product: $E(t)\,g(t-\tau)$



The spectrogram tells the color and intensity of $E(t)$ at the time, τ.

Spectrograms for Linearly Chirped Pulses



Like a musical score, the spectrogram visually displays the frequency vs. time (and the intensity, too).

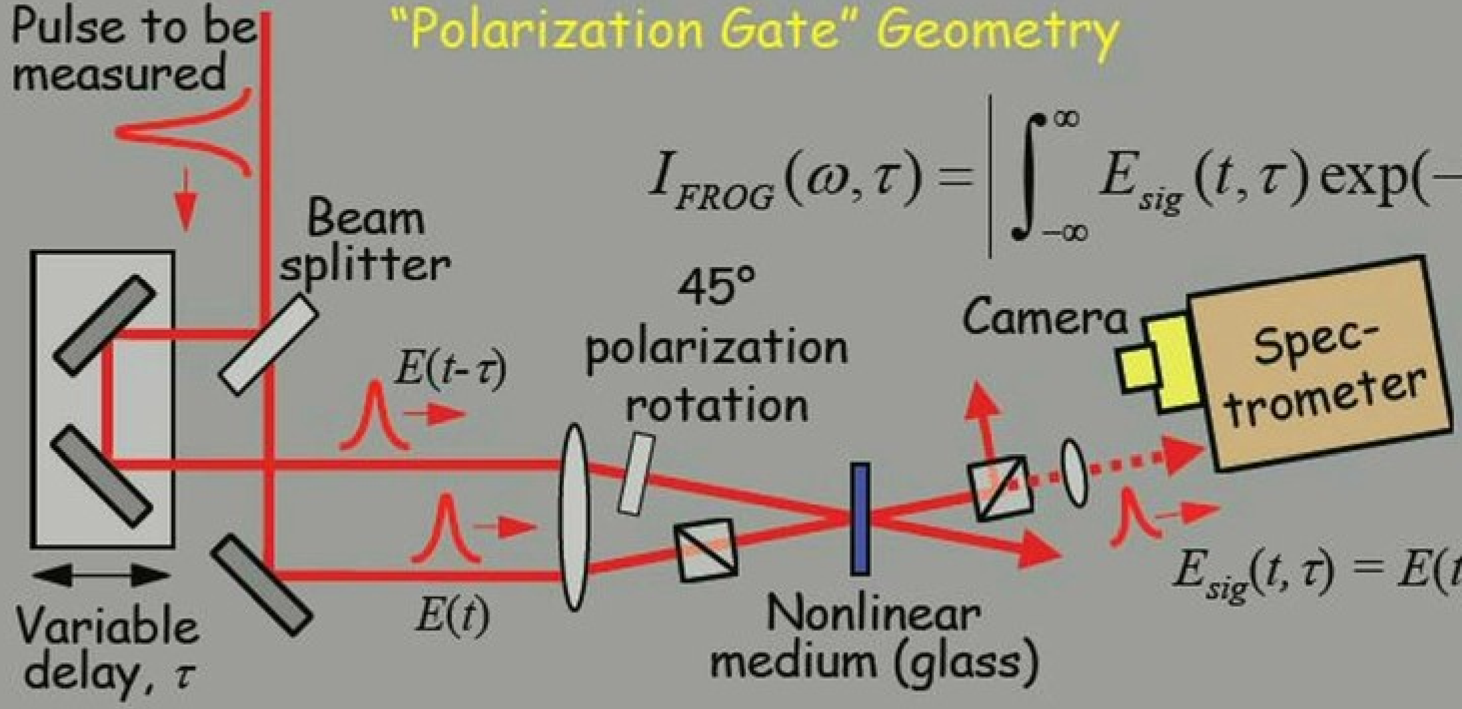
Web presentation of Rick Trebino, School of Physics, Georgia Institute of Technology, Atlanta, GA 30332

Frequency-Resolved Optical Gating (FROG)

FROG involves gating the pulse with a variably delayed replica of itself in an instantaneous nonlinear-optical medium and then spectrally resolving the gated pulse vs. delay.

Collaborator:
Dan Kane

"Polarization Gate" Geometry



$$I_{FROG}(\omega,\tau) = \left| \int_{-\infty}^{\infty} E_{sig}(t,\tau)\exp(-i\omega t)\,dt \right|^2$$

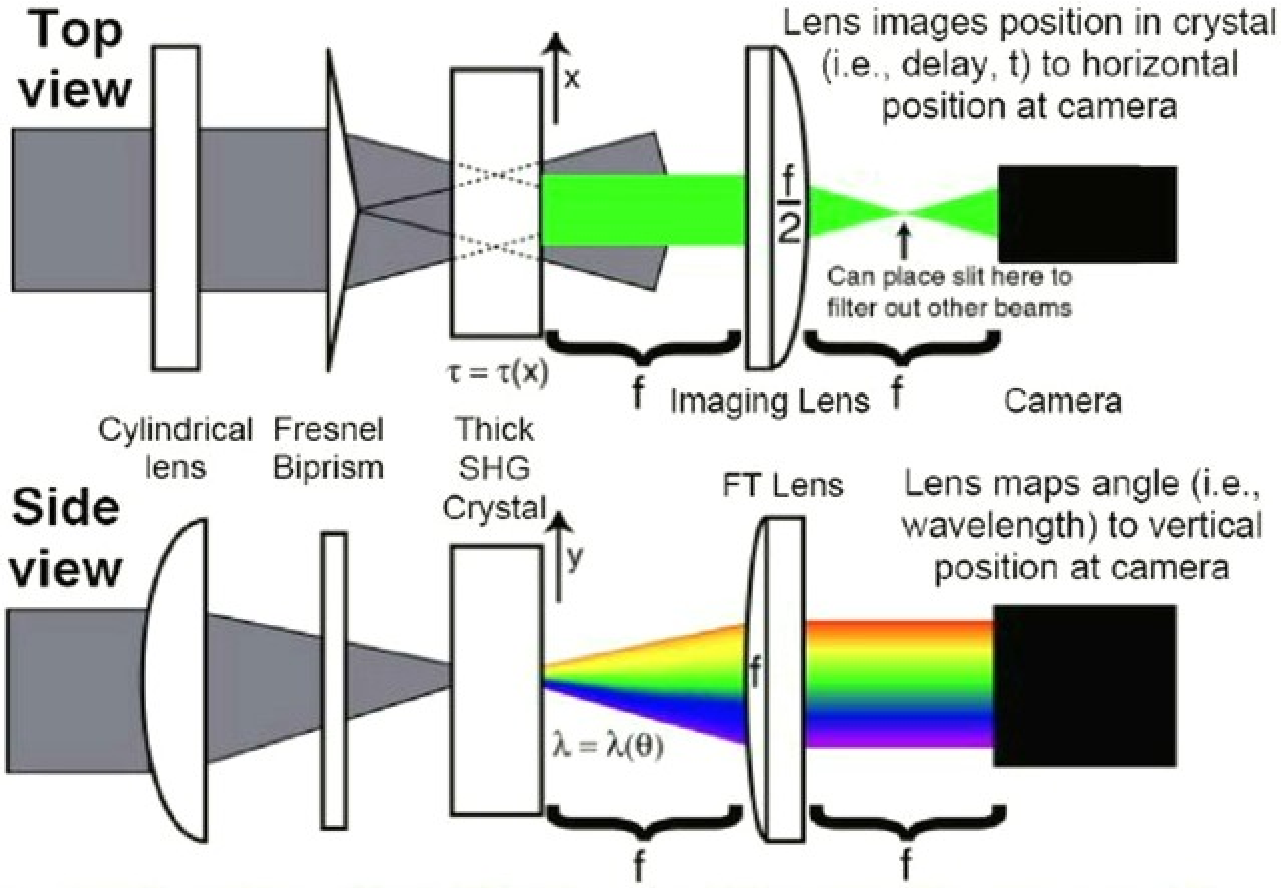
$$E_{sig}(t,\tau) = E(t)\,|E(t-\tau)|^2$$

Use any ultrafast nonlinearity: Second-harmonic generation, etc.

R. Trebino, *Frequency-Resolved Optical Gating: The Measurement of Ultrashort Laser Pulses*, Kluwer

GRENOUILLE

Grating-Eliminated No-nonsense Observation of Ultrafast Incident Laser Light E-fields (GRENOUILLE, which is the French word for "frog").

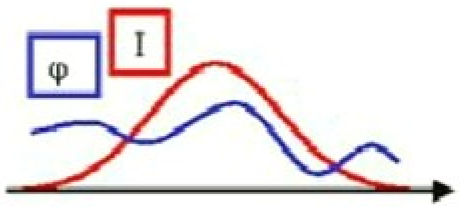


SPIDER

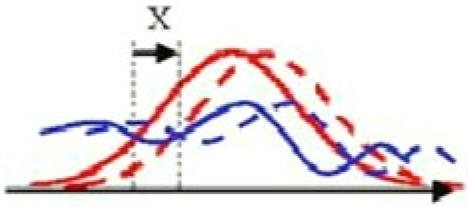
Spectral Phase Interferometry for Direct Electric-Field Reconstruction

based on shearing interferometry in the optical frequency domain

Initial wavefront



Generation of a sheared wavefront



electric field: $E(x) = \sqrt{I(x)}e^{i\phi(x)}$

shifted: $E(x+dx) = \sqrt{I(x+dx)}e^{i\phi(x+dx)}$

interference pattern as recorded by a square-law detector:

$$S(x) = I(x) + I(x+dx) + 2\sqrt{I(x)}\sqrt{I(x+dx)}\cos(\phi(x) - \phi(x+dx))$$

phase difference $\Delta\phi(x) = \phi(x) - \phi(x+dx)$ can be easily and algebraically extracted from the interference pattern using standard Fourier processing techniques

spatial phase of the field $\phi(x)$, can then be reconstructed by concatenation

SPIDER

Spectral share interferometry

electric field of the pulse in the frequency domain: $\tilde{E}(\omega) = \sqrt{\tilde{I}(\omega)}e^{i\phi(\omega)}$

shared electric field : $\tilde{E}(\omega + d\omega) = \sqrt{\tilde{I}(\omega + d\omega)}e^{i\phi(\omega + d\omega)}$

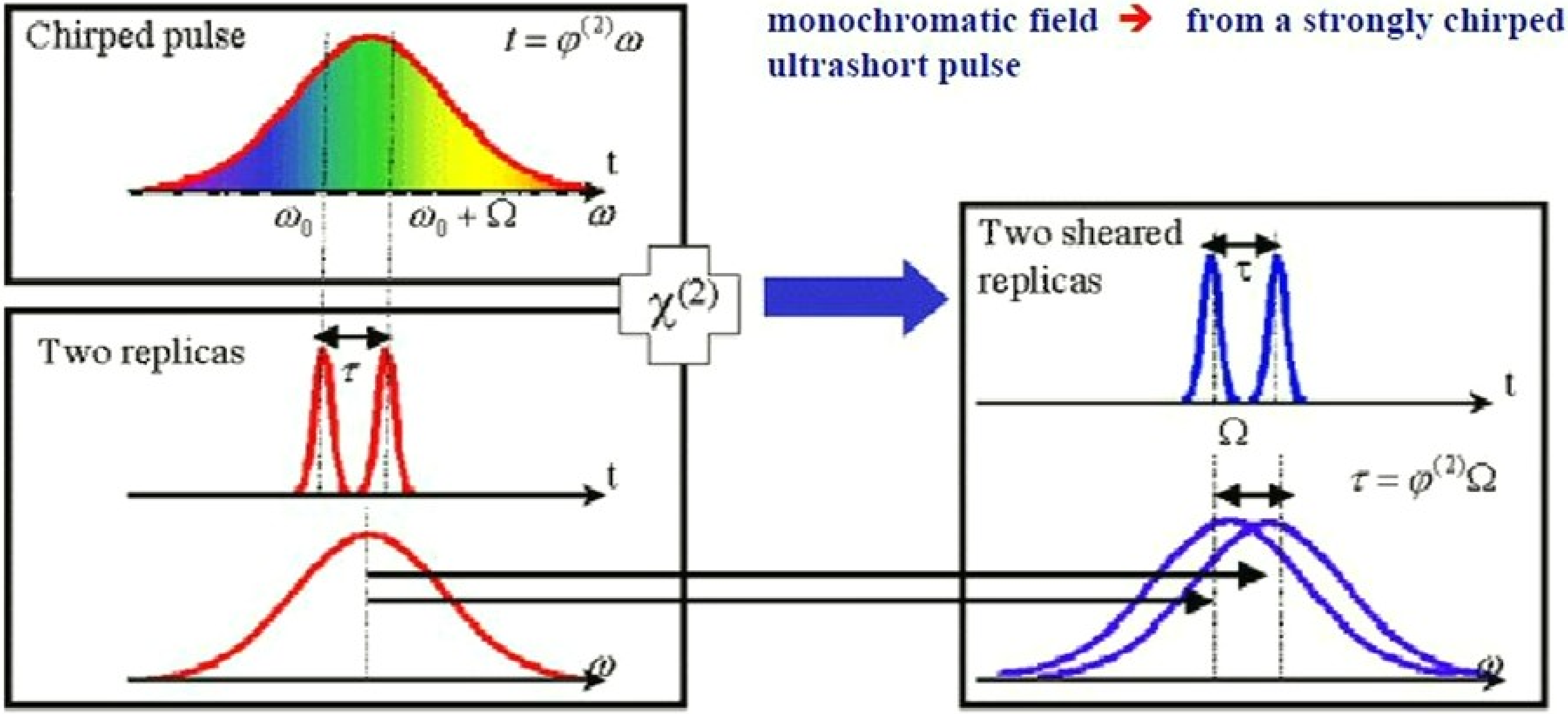
interference pattern: $\tilde{S}(\omega) = \tilde{I}(\omega) + \tilde{I}(\omega + d\omega) + 2\sqrt{\tilde{I}(\omega)}\sqrt{\tilde{I}(\omega + d\omega)}\cos(\phi(\omega) - \phi(\omega + d\omega))$

The spectral phase $\phi(\omega)$ can be extracted in the same way as in the case of spatial shearing

Shearing a complex spectral amplitude can be done by sum frequency generation between a monochromatic field of frequency ω_0, and the field you want to shear $\tilde{E}(\omega)$, resulting in a sheared field $\tilde{E}(\omega + \omega_0)$

monochromatic frequency ➔ from a strongly chirped ultrashort pulse

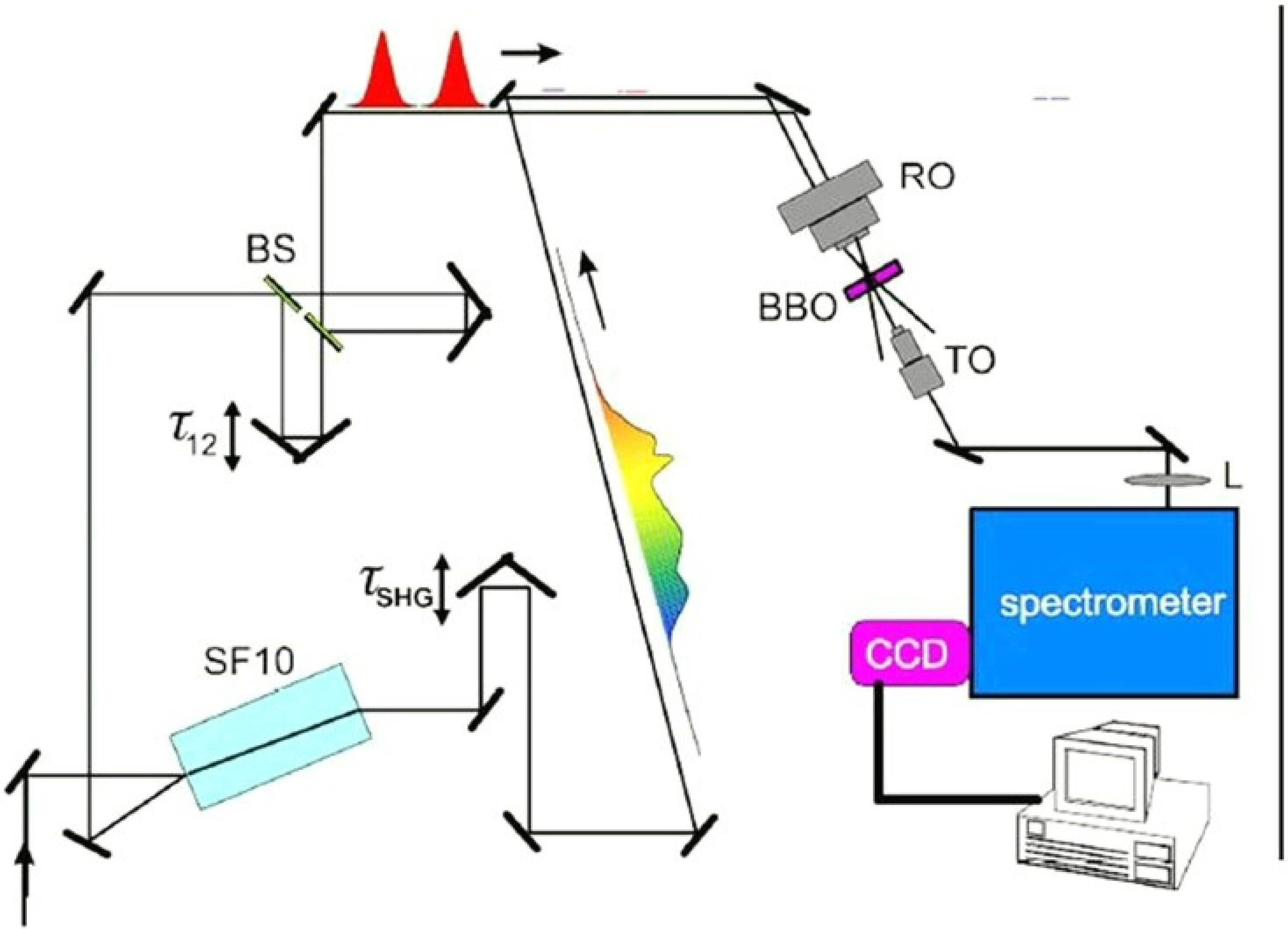
SPIDER - principal scheme



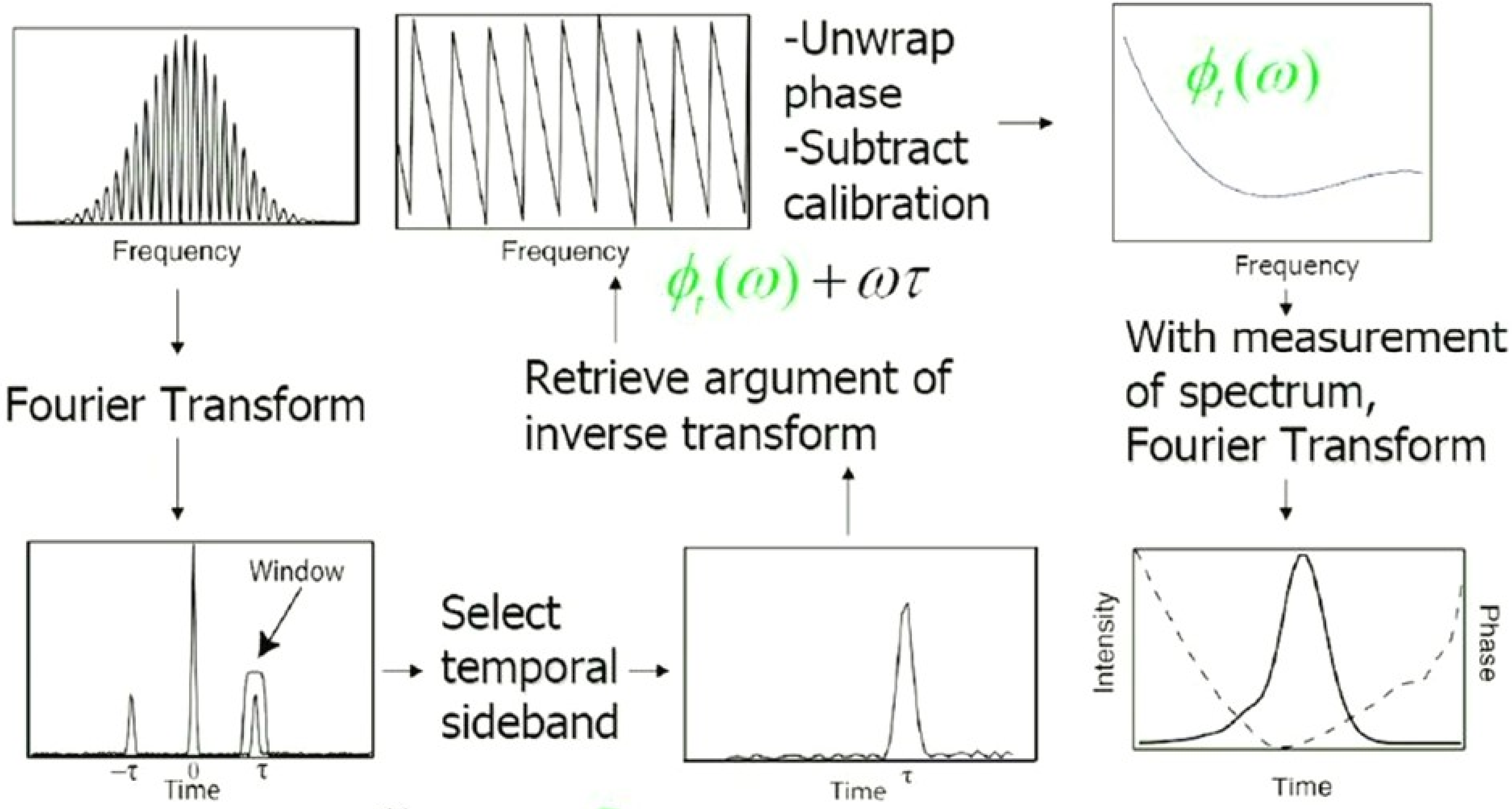
monochromatic field ➔ from a strongly chirped ultrashort pulse

$$\tilde{S}(\omega)=\tilde{I}(\omega+\omega_0)+\tilde{I}(\omega+\omega_0+\Omega)+2\sqrt{\tilde{I}(\omega+\omega_0)}\,2\sqrt{\tilde{I}(\omega+\omega_0+\Omega)}\cos(\phi(\omega+\omega_0)-\phi(\omega+\omega_0+\Omega)+\omega\tau)$$

SPIDER optical setup



Fourier Transform Spectral Interferometry (FTSI)



$$\tilde{S}'(t) = \tilde{A}_{AC}(t-\tau)$$

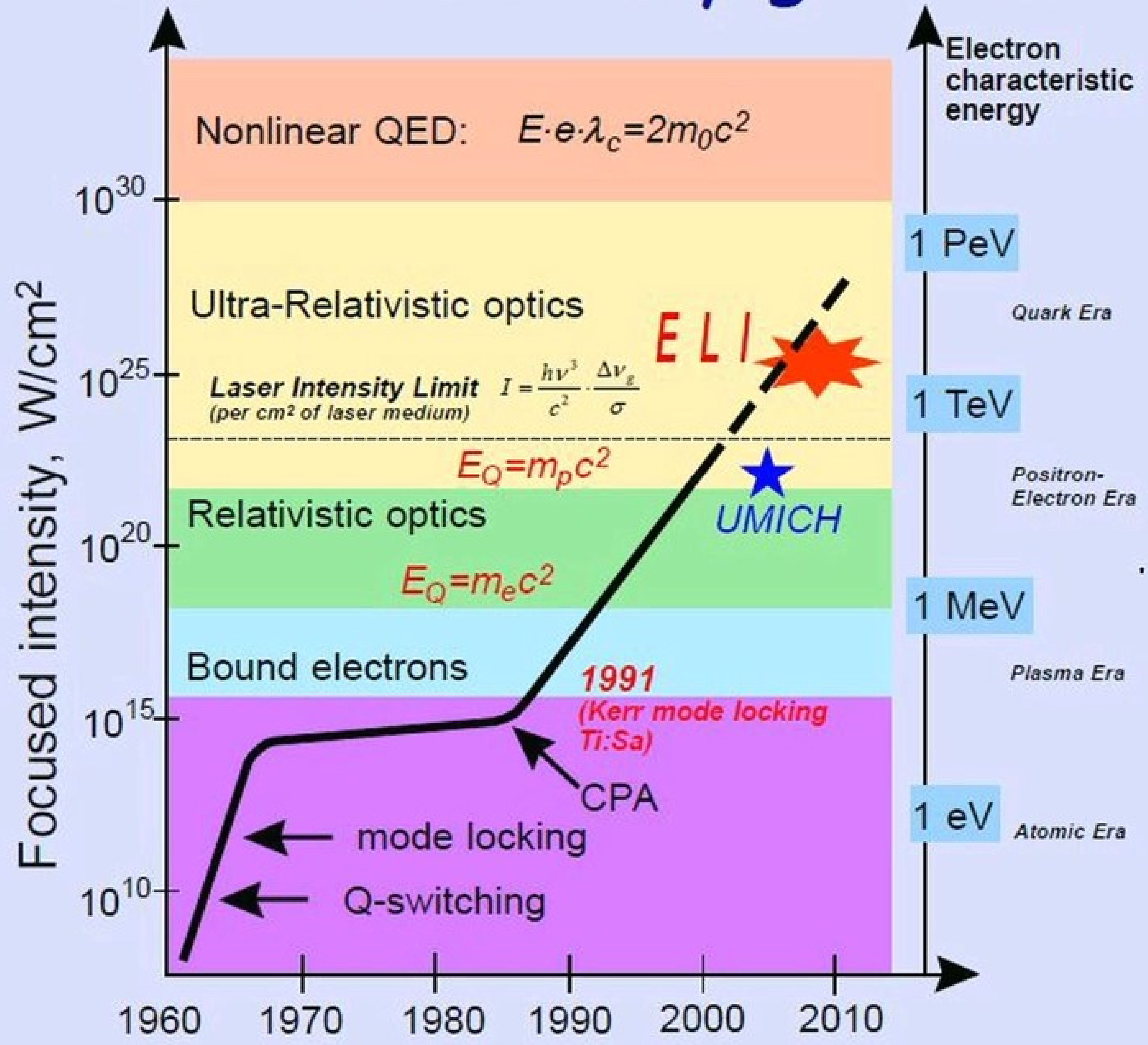
EXTREME LIGHT INFRASTRUCTURE (ELI)

Joint EU-project

Exawatt (10^{18}W) laser facility

Ultra-relativistic Laser-matter Interaction

Laser Intensity growth



Schematic picture of the exawatt system starting with a front-end producing 5-fs pulses at the joule level (PW).