Laser Description

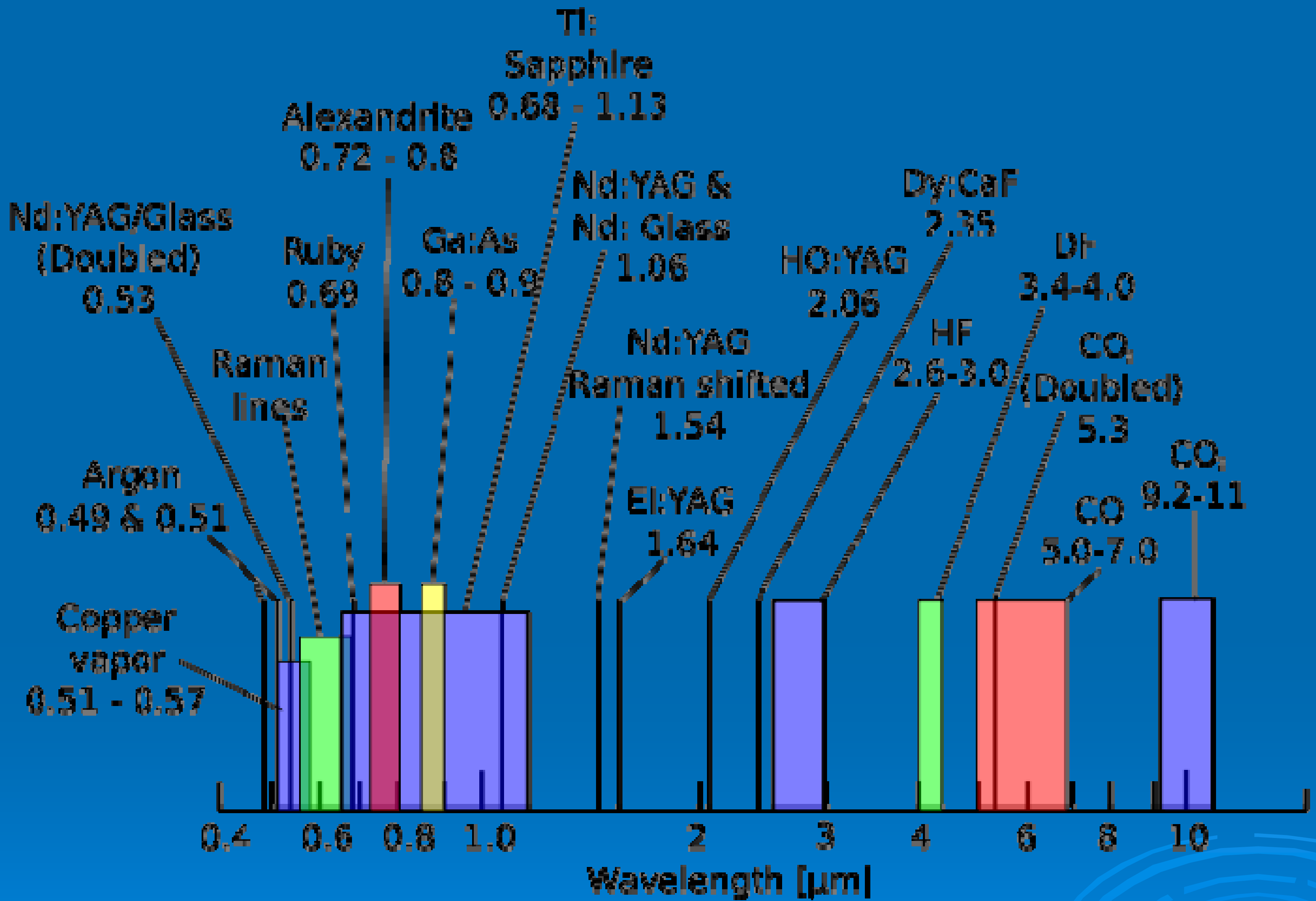
Light Amplification by Stimulated Emission of Radiation

Light Radiation:	Electromagnetic wave -10 µm-157 nm
Amplification:	Gain medium in typical laser
Stimulated emission:	Phase correlation

References:

Classical Electrodynamics by Jackson

Solid State Engineering by E. Koechner

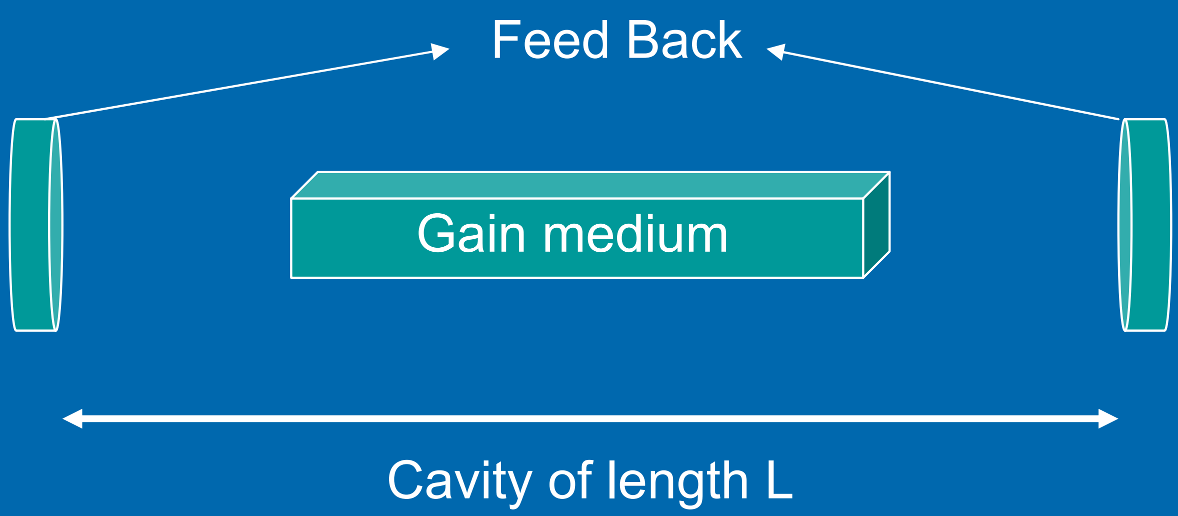


Ti:
Sapphire
0.68 - 1.13
Alexandrite
0.72 - 0.8
Nd:YAG/Glass
(Doubled)
0.53
Ruby
0.69
Ga:As
0.8 - 0.9
Nd:YAG &
Nd: Glass
1.06
Dy:CaF
2.35
HO:YAG
2.06
DF
3.4-4.0
Raman
lines
Nd:YAG
Raman shifted
1.54
HF
2.6-3.0
CO
(Doubled)
5.3
Argon
0.49 & 0.51
El:YAG
1.64
CO
5.0-7.0
CO
9.2-11
Copper
vapor
0.51 - 0.57
0.4
0.6
0.8
1.0
2
3
4
6
8
10
Wavelength [µm]

Typical laser oscillator consists of

•A lasing medium that determines the operating parameters, such as the wavelength and spectral bandwidth of the laser
•A pump that inverts the electron population in the lasing medium, storing energy in the upper lasing level.
•Atleast two mirrors that form the cavity. These mirrors provide the feed back to the cavity and output from the cavity. When the gain in the lasing medium compensates for the loss due to these mirrors as well as other losses in the cavity, the system starts to oscillate

The mirrors, the lasing medium and any other optics in the cavity form the resonator and maintain an electromagnetic field configuration for which the loss is matched by the gain. This cavity then has specific preferred spatial and temporal mode structures that define the directional, spectral and spatial characteristics of the laser radiation



Cavity supports transverse (spatial profile) and longitudinal (frequency spectrum) modes

The electric field E is given by

$$\vec{E}(r,z,t) = \vec{E}(r,t)e^{i(k\vec{n}\bullet\vec{r}-\omega t)}$$

Time averaged Energy flux S is given by

$$S = \frac{c}{8\pi}\sqrt{\frac{\varepsilon}{\mu}}\left|E\right|^2 \vec{n}$$

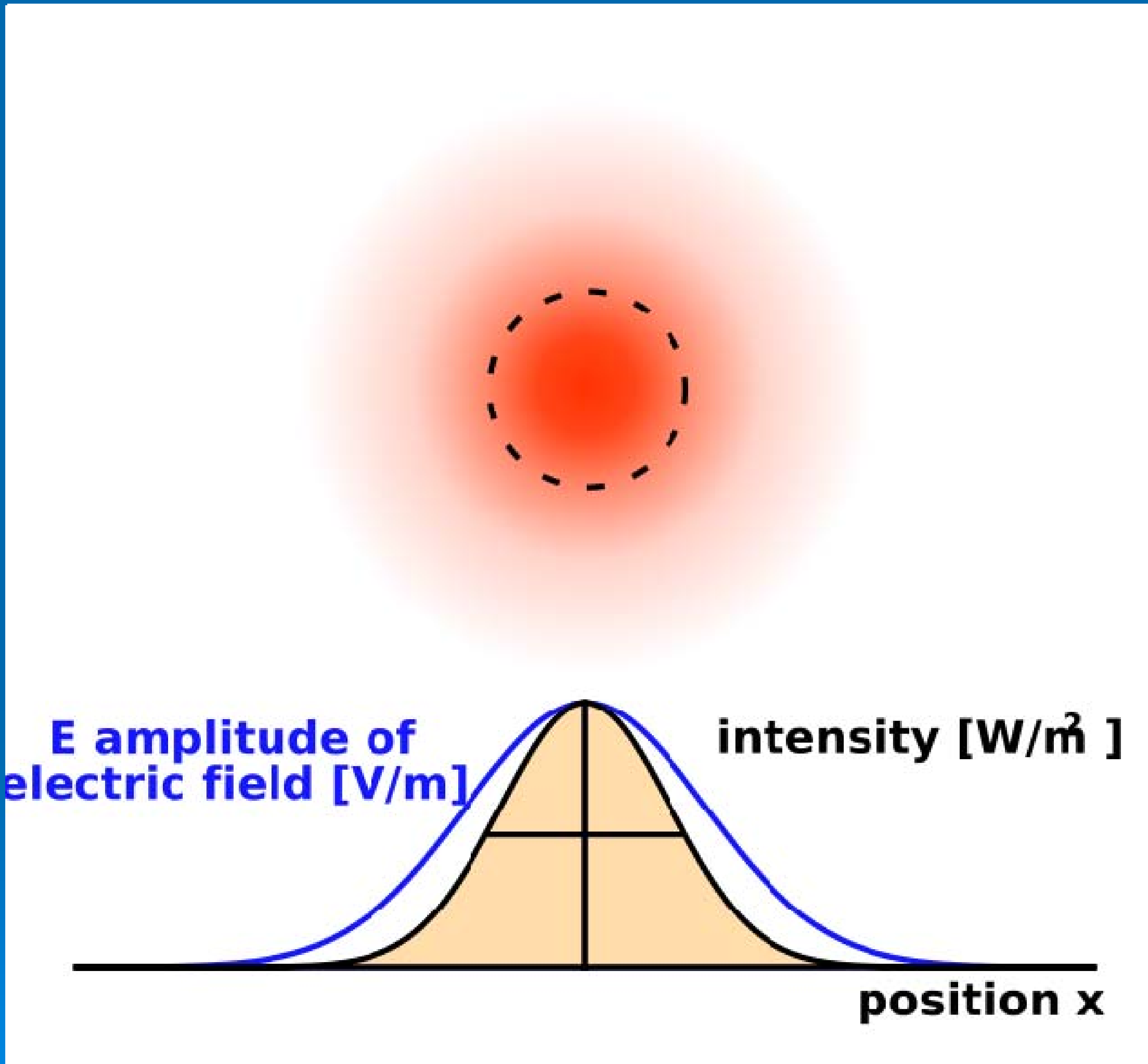
Transverse Profile E(r)

Limiting to lowest order mode,

$$E(r) = E_0 e^{-(\frac{r}{w})^2}$$

$$I(r) = I_0 e^{-(\frac{2r^2}{w^2})}$$

Gaussian Intensity profile.


E amplitude of
electric field [V/m]
intensity [W/m2]
position x

Important Parameters/Equations of Gaussian Beam

- The parameter w is called the beam radius within which 86.5% of the total power of the Gaussian beam is contained.
- The spot size at any axial distance z from beam waist w_0 can be calculated using

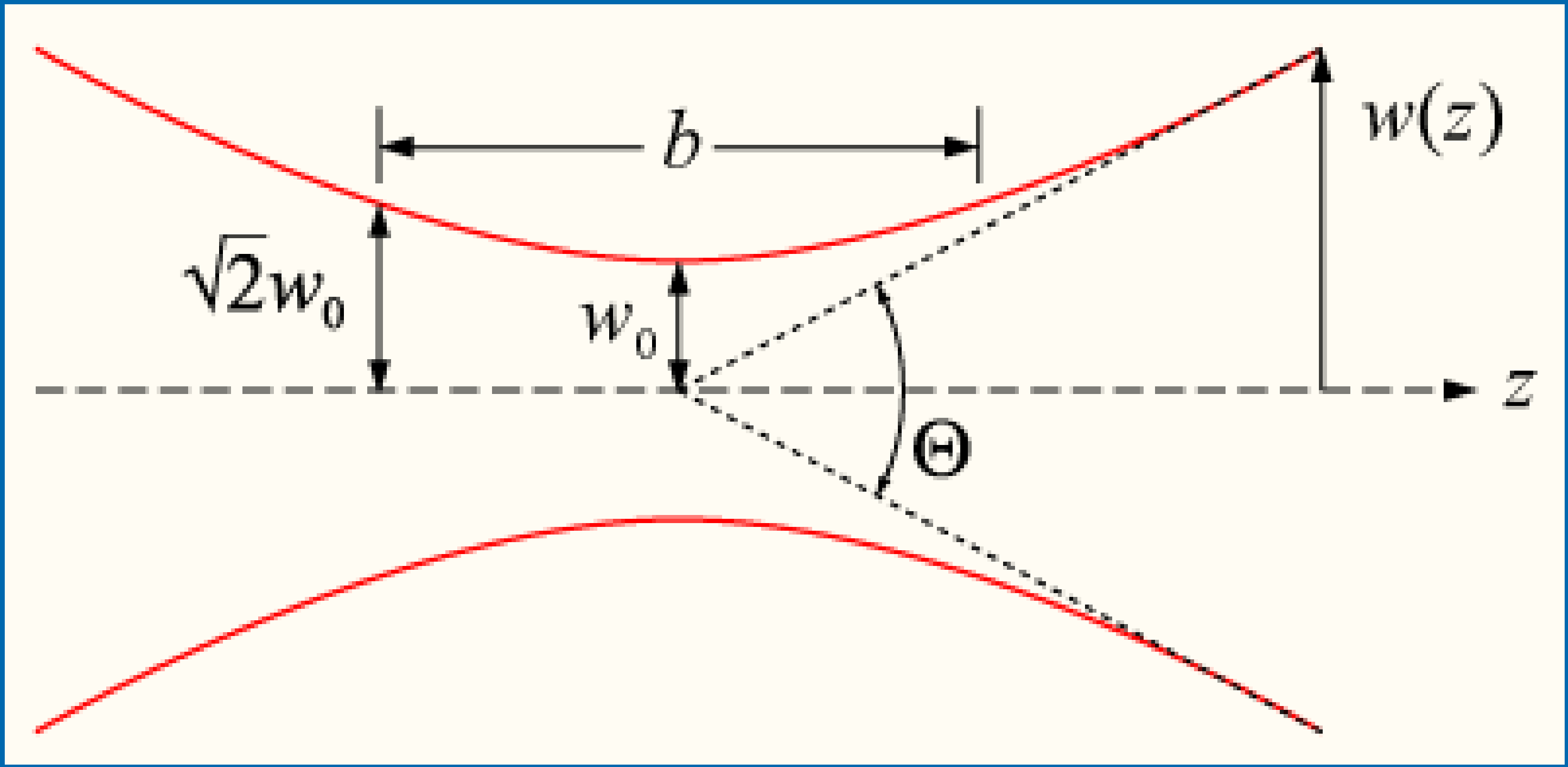
$$w(z) = w_0\left\{1+\left(\frac{\lambda z}{\pi w_0}\right)^2\right\}^{\frac{1}{2}}$$

- The full divergence angle θ is given by

$$\theta = 1.27\,\frac{\lambda}{(2w_0)}$$

- The confocal parameter b, the distance between points on either side of the beam waist for which the spot size $w(z)=\sqrt{2}w_0$ and the region over which the phase front is nearly planar, is given by

$$b=\frac{2\pi w_0^2}{\lambda}$$

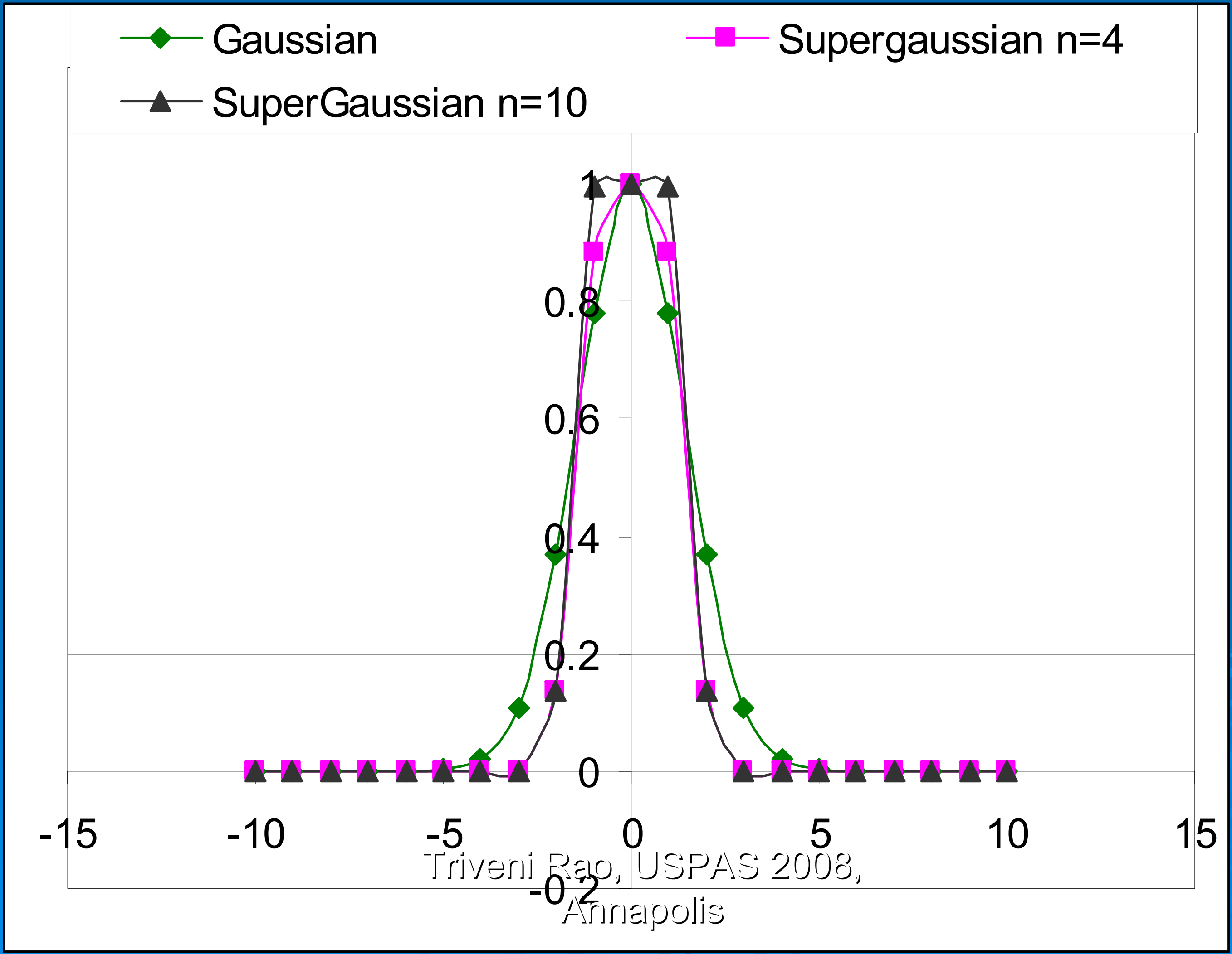


Typical commercial lasers have outputs that are nearly Gaussian, but not exactly. The extent to which they approach Gaussian is given by the *m* parameter

$$m = w_{laser}/w_{gaussian}$$

Supergaussian (Flat Top) Intensity Profile

- $$I(r) = I_0 e^{-2\left(\frac{r}{w}\right)^n}$$ **n>2**



Measurement Techniques for Transverse Profile

Technique	Advantage	Disadvant.	Application
CCD	Direct Ease of measurements w/algorithms Good resolution	Dynamic range Long/short wavelength sensitivity	On line beam diagnostics
Slit scan	Inexpensive	Poor resolution Multi-shot Data analysis	Low cost beam diagnostics
Video camera	Multiple displays Inexpensive	Poor resolution Data analysis	Monitoring, aligning

Examples of commercial products

CCD:

http://www.dataray.com/

http://www.spiricon.de/selectionguide/scientific_technology/cameras/telecomircameras.shtml

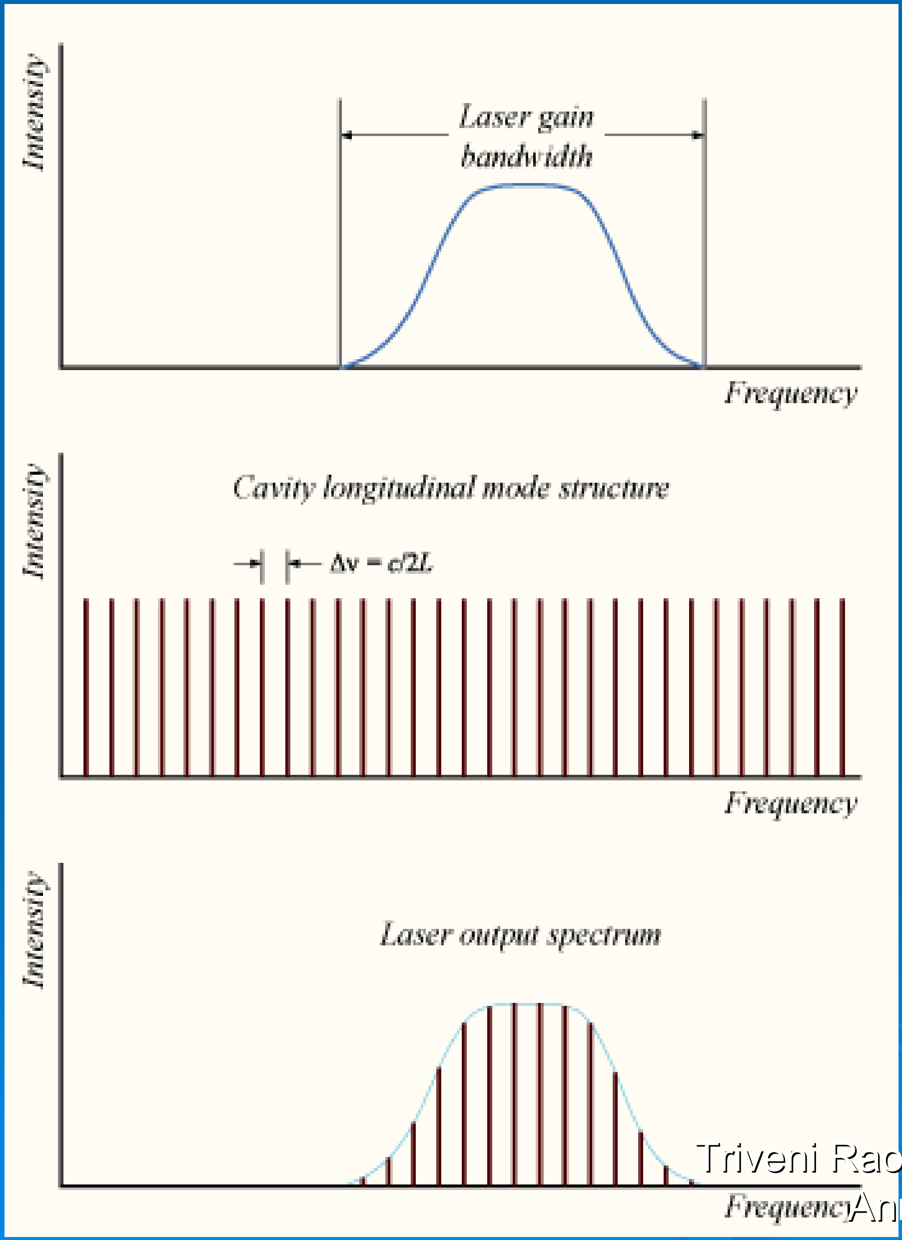
Slit scan:

http://www.thorlabs.com/NewGroupPage9.cfm?ObjectGroup_ID=804

Wave front sensor:

http://www.thorlabs.com/NewGroupPage9.cfm?ObjectGroup_ID=2946

Longitudinal modes-Spectral Content, Pulse Duration



The pulse duration of the laser beam is dictated by a number of factors

- Storage time (upper state life time) of the lasing medium
- Bandwidth of the lasing line
- Pump duration
- Design of the cavity elements, their linear and nonlinear dispersion

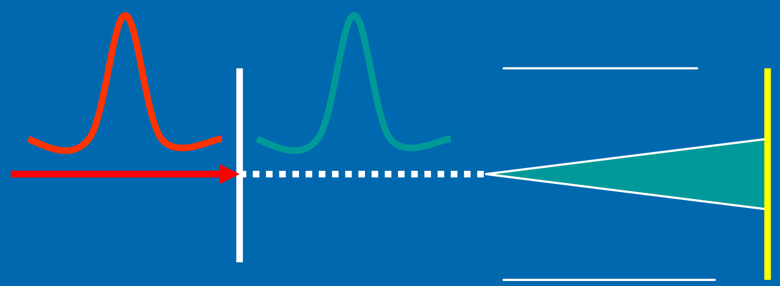
Minimum Pulse duration for Gaussian profile is

$$\Delta t = \frac{0.44}{N \Delta \nu}.$$

Measurement Techniques for Longitudinal (temporal) profile

Technique	Advantage	Disadvant.	Application
Photodiode, phototube	Direct Inexpensive Sensitive Linear simple	Bandwidth limited	ns, subns pulses
Streak camera	Direct Vis-UV	Expensive Complicated	Few ps
Auto/cross correlator Single, multi shot	Moderately inexpensive	Indirect Insensitive to assymmetry	ps, fs

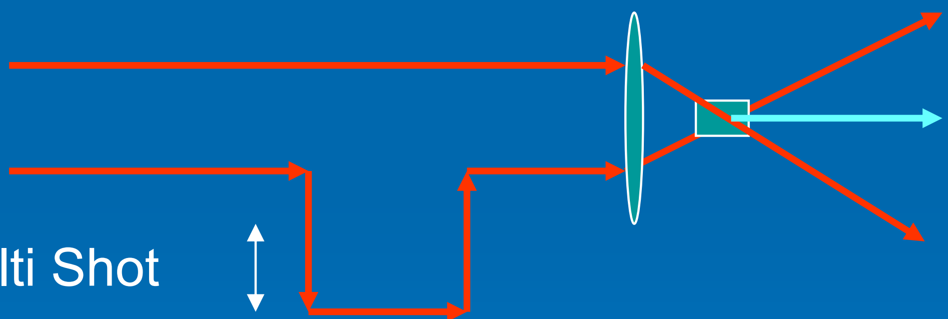
Streak Camera Principle



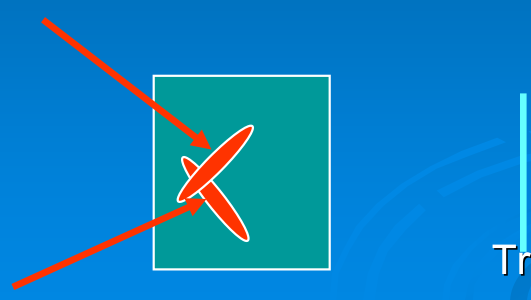
Laser spot size, intensity: Space charge Vs s/n

Synchronization

Autocorrelator Principle

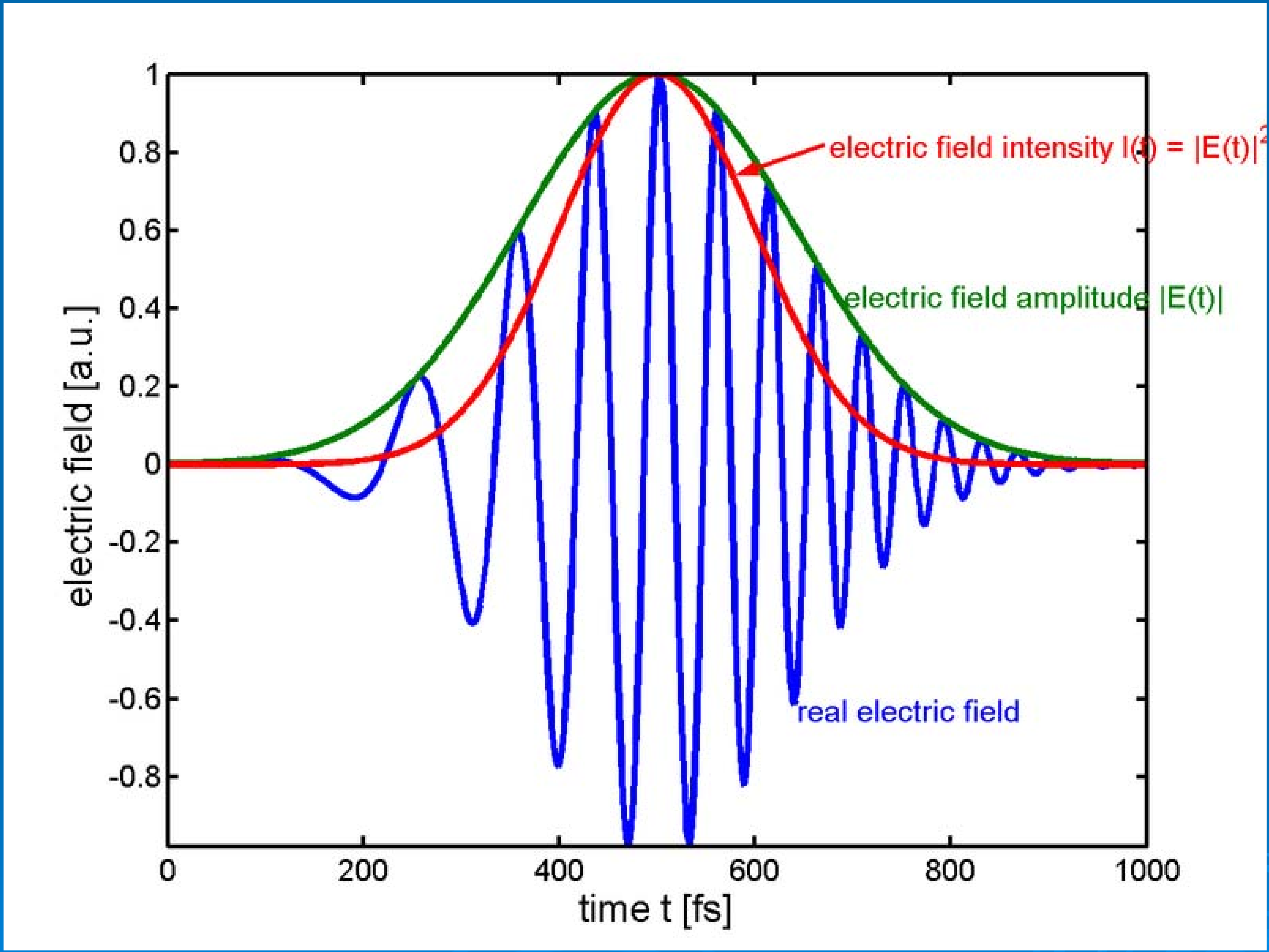


Multi Shot



Single shot

Ultra short pulses may not be transform limited: Need to measure amplitude and phase simultaneously



$$E(t) = \sqrt{I(t)} e^{i\omega_0 t} e^{i\psi(t)}$$

$$E(\omega) = \mathcal{F}(E(t))$$

$$E(\omega) = \sqrt{S(\omega)} e^{i\phi(\omega)}$$

Triveni Rao, USPAS 2008, Annapolis

Ψ(t): Phase function

Φ(ω): spectral phase

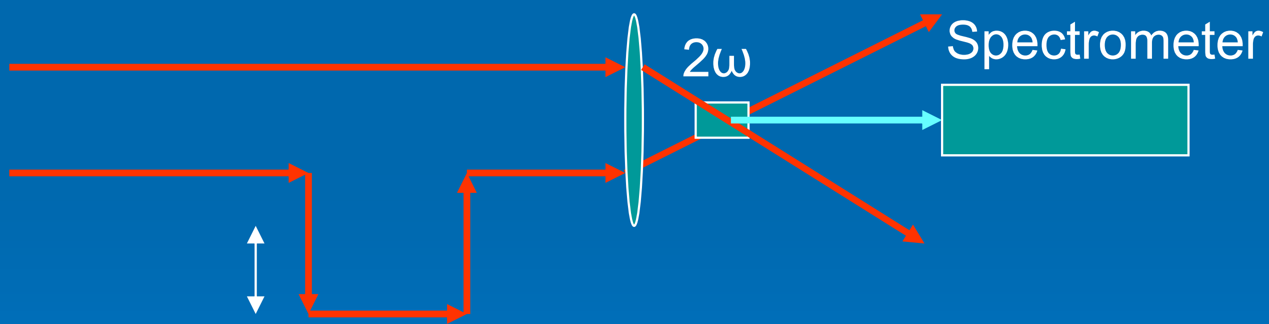
Characterizing fs pulses

$$E(t) = \sqrt{I(t)e^{i\omega_0 t}e^{i\psi(t)}}$$

$$E(\omega) = \sqrt{S(\omega)e^{i\phi(\omega)}}$$

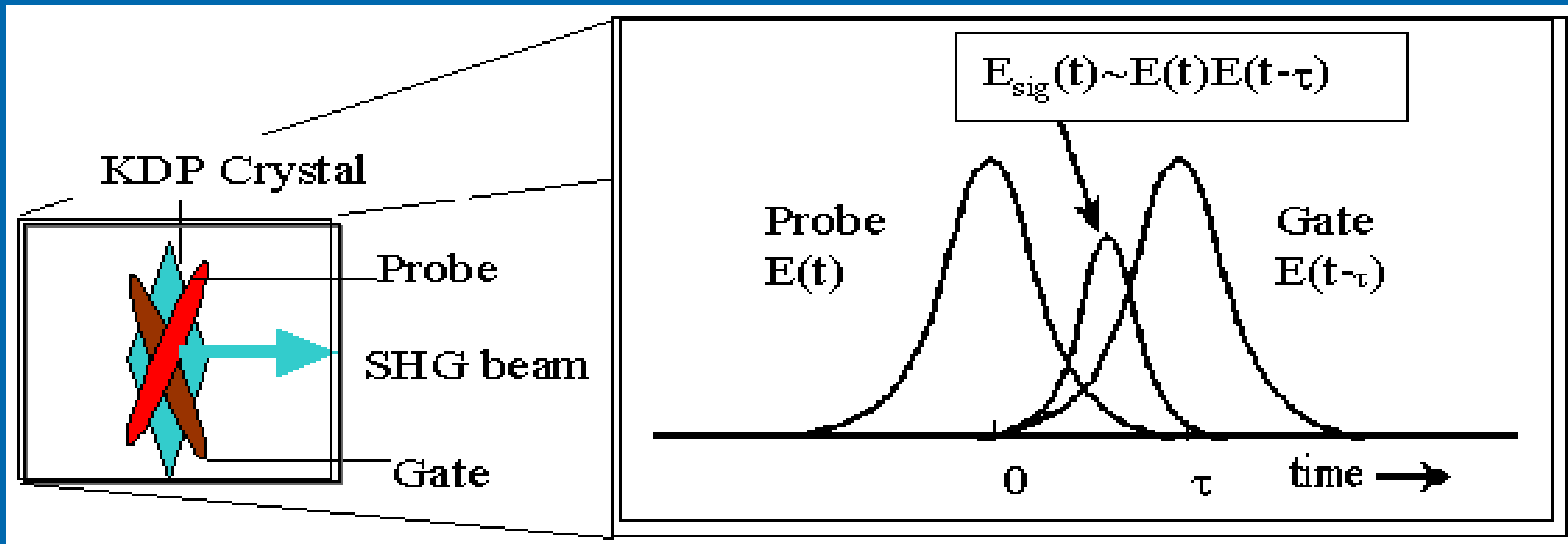
Need to measure both spectrum and spectral phase simultaneously

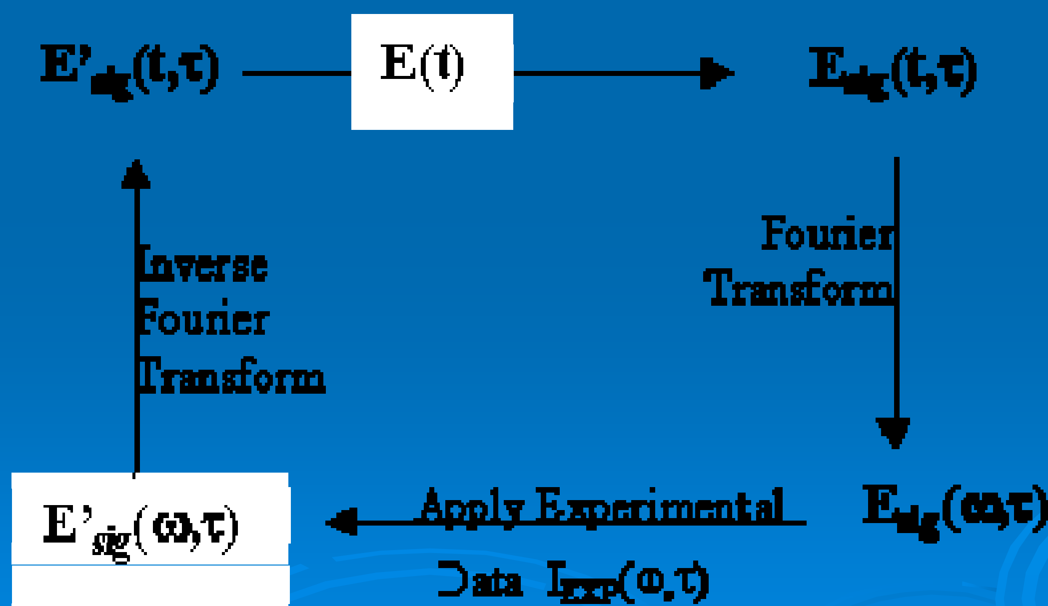
FROG: Frequency Resolved Optical Gating



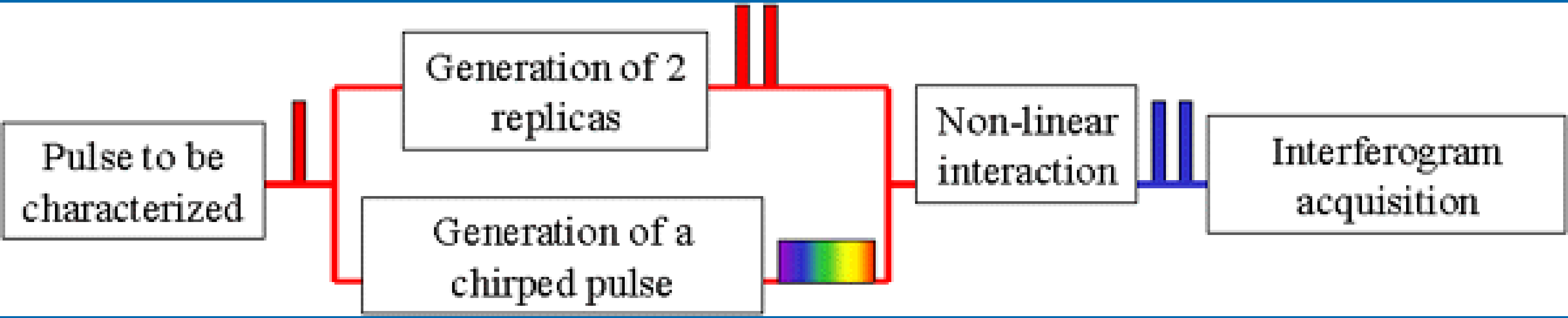
Most commonly used technique

GRENOUILLE: (Grating eliminated no-nonsense Observation of Ultrafast laser light e-fields) simplified device based on SHG FROG-Thick SHG crystal for 2ω and spectrometer, Fresnel biprism for beam splitter, delay line and beam recombination





Courtesy: http://www.phys.ufl.edu/reu/1999/reports/mei/mei.htm



The interference of the two fields is given by

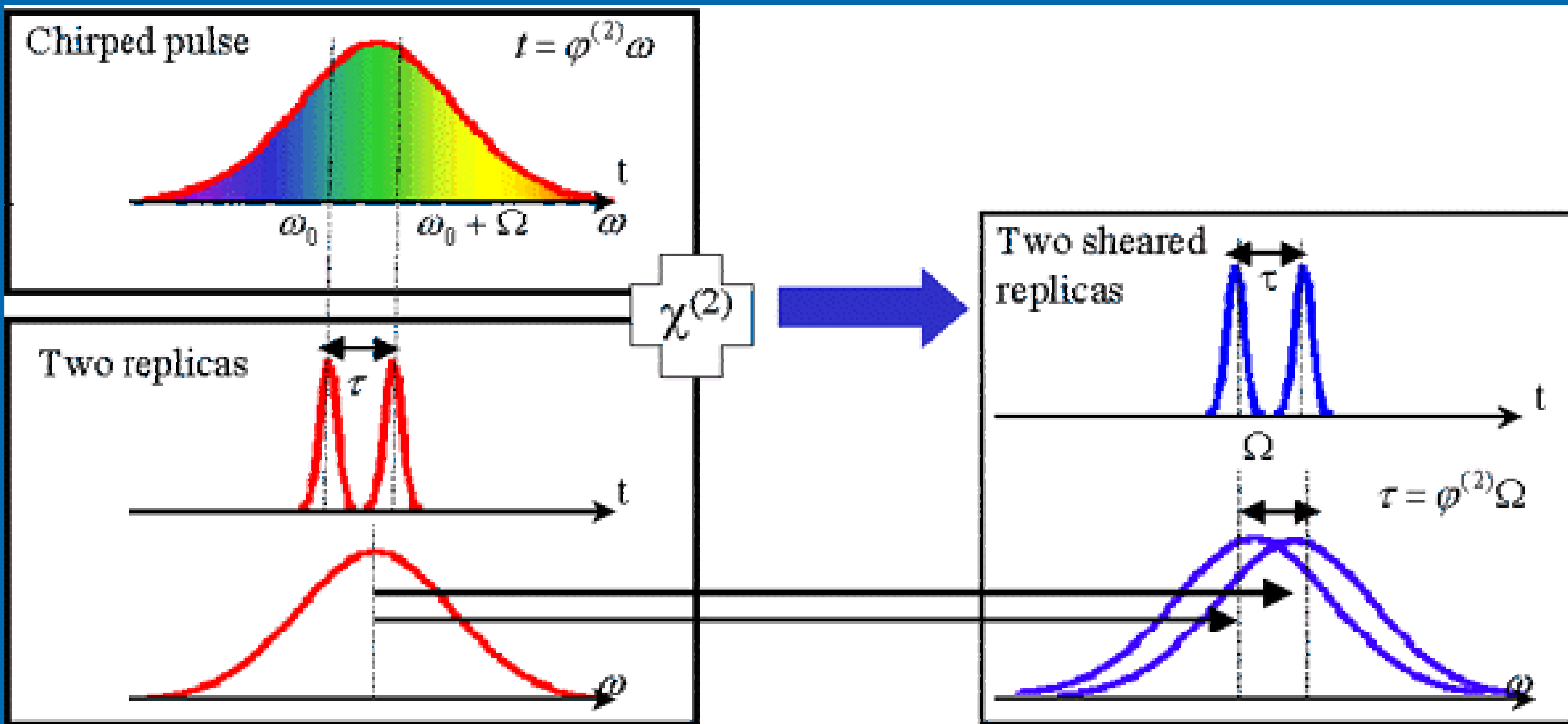
$$S(\omega) = I(\omega) + I(\omega+\Omega) + 2\sqrt{I(\omega)}\sqrt{I(\omega+\Omega)}\cos(\phi(\omega) - \phi(\omega+\Omega))$$

where $E(\omega) = \sqrt{I(\omega)}e^{i\phi(\omega)}$

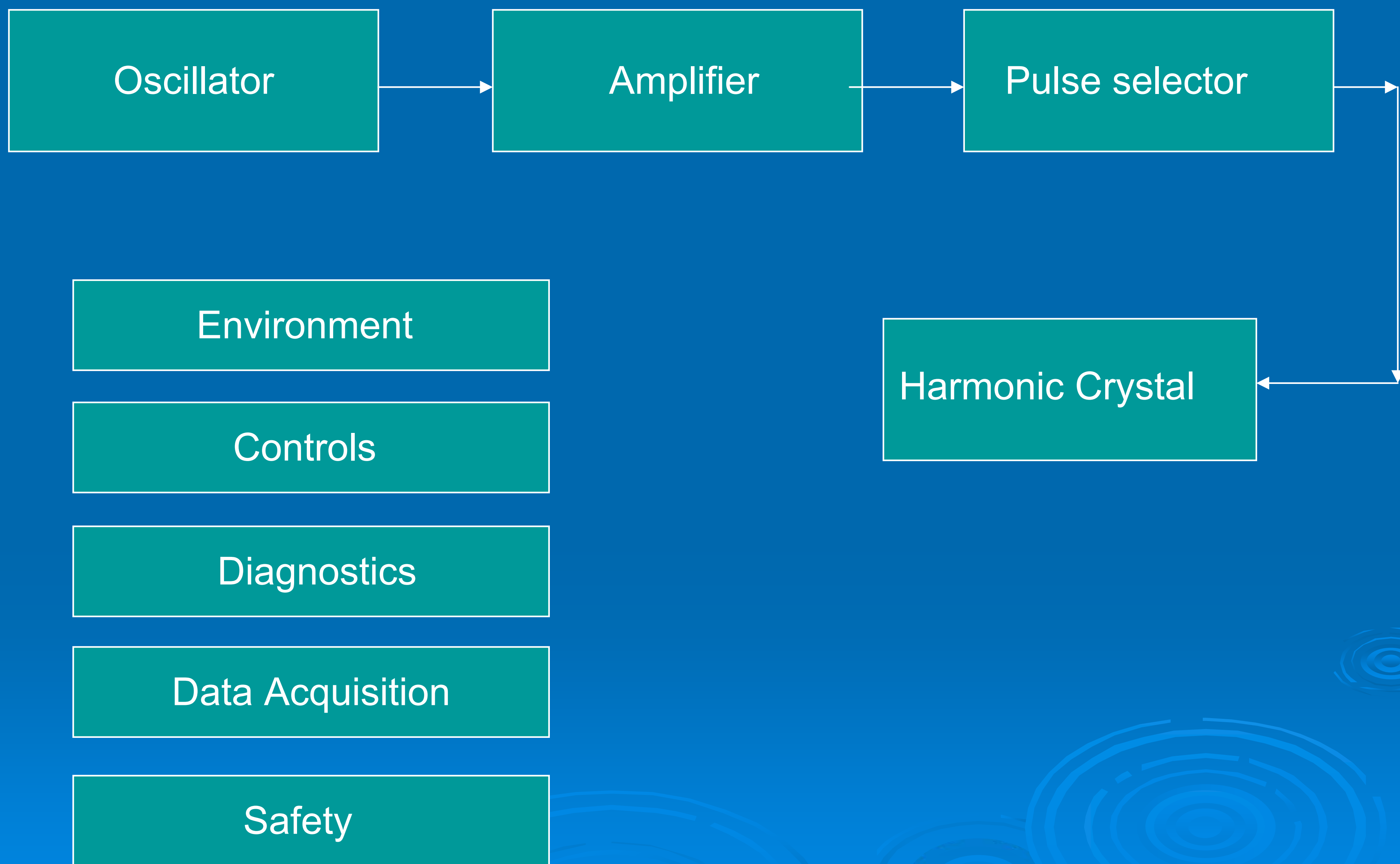
Use Algorithms to extract the phase information

http://ultrafast.physics.ox.ac.uk/spider/tech.html

SPIDER: Spectral Phase Interferometry for Direct Electric field Reconstruction



Selection/Design Considerations of Laser system



Oscillator

- Wavelength
- Gain medium
- Pump source
- Repetition Rate
- Pulse duration and shape
- Mode Locking technique
- Jitter control

Amplifier

- Type of amplifier-Regenerative, linear
- Gain medium
- Pump source
- Number of passes
- Acceptable signal to noise ratio
- Repetition rate

Pulse selector

- Type-AO/EO etc.
- Location
- Electronics requirement

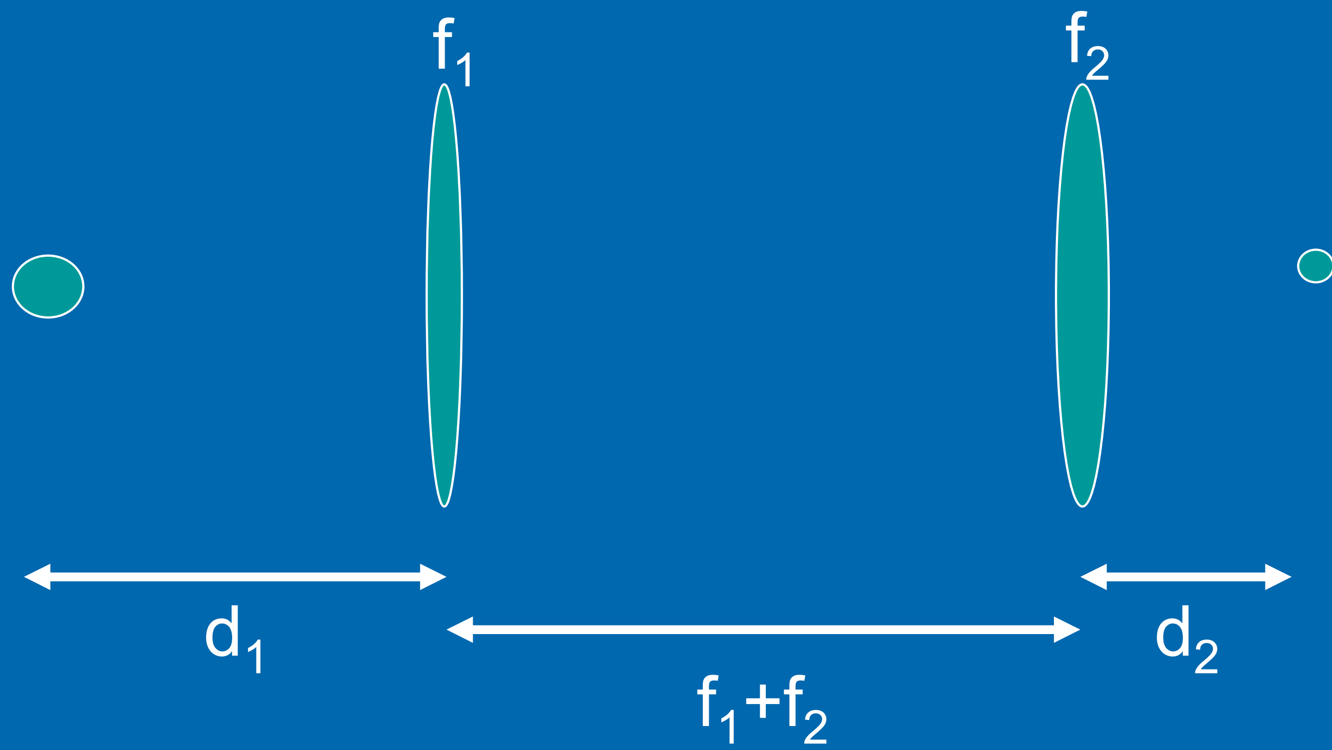
Harmonic Crystal

- Crystal type
- Location
- Conversion efficiency

Beamshaping

- Order
- Location
- Beam transport

Beam transport: Optical relay imaging



Relay Image equation

$$f_1+f_2= md_1+d_2/m; \quad m=f_2/f_1$$

Typically $d_1=f_1$ and $d_2=f_2$

Environment

- Climate requirements and control
- Positioning of utilities-air current, safety

Control

- What
- How
- Compatibility of with controls

Diagnostics

- What
- Where
- How
- Resolution & dynamic range

Data Aquisition

- What
- How
- Platform
- Resolution and Dynamic range
- Frequency
- Display mode