# Subpicosecond phenomena in scintillators for fast timing in future CERN experiments and medical applications

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# COLLABORATION

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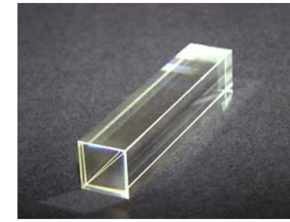
COST – EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

FAST

CRYSTAL CLEAR COLLABORATION **RD 18**

AIDA 2020

# BACKGROUND

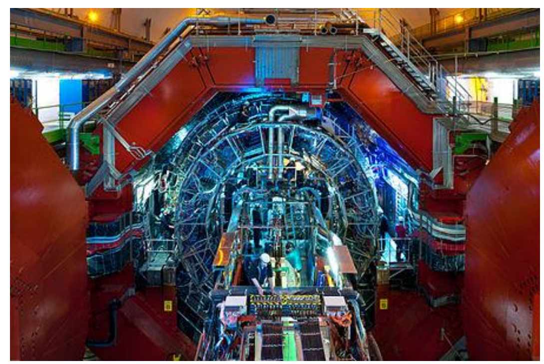


## Study of scintillation crystals

With Dr. Stanislav Burachas

Positron emission tomograph

BGO ($Bi_4Ge_3O_{12}$)



ALICE experiment

PWO ($PbWO_4$)

**The results obtained form 1995 to 2009 are published in 20 papers in journals like *J. Cryst. Growth, NIMA, etc.***

# CURRENT MOTIVATION

# FAST TIMING

CRYSTAL CLEAR COLLABORATION

**TARGET**


**STATE OF THE ART**

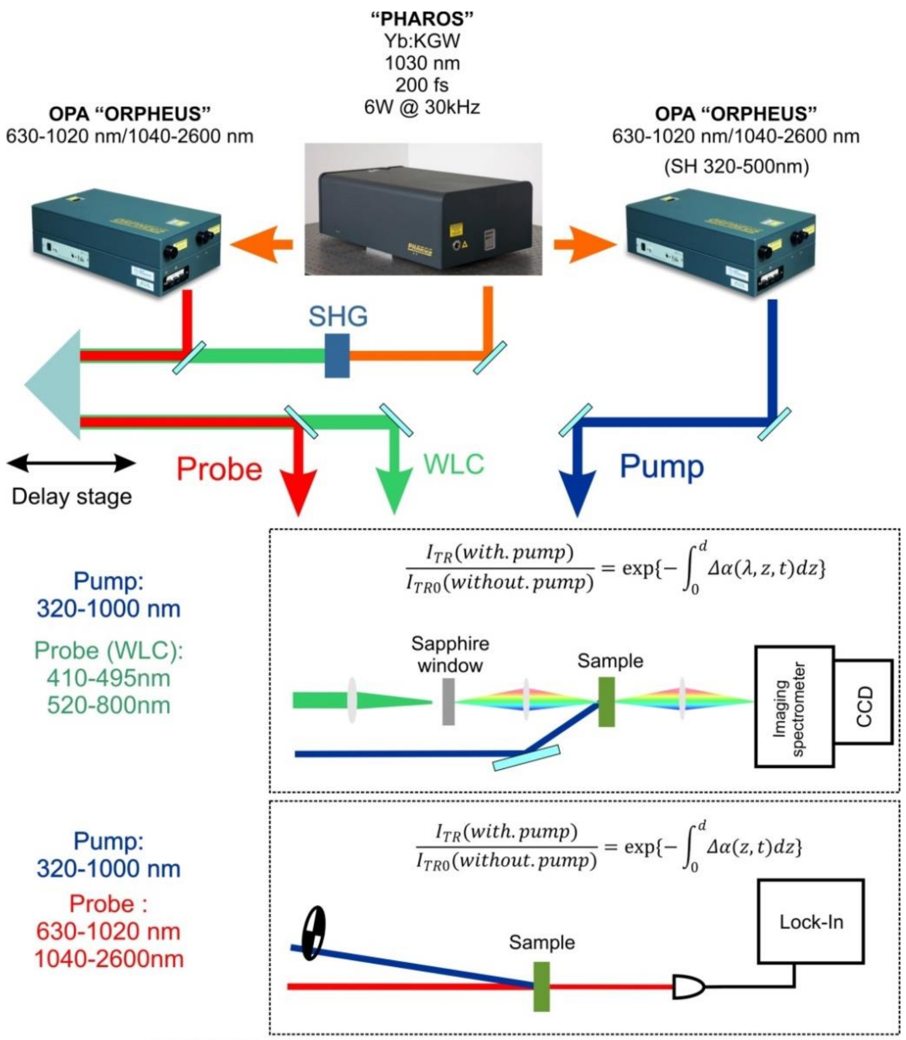
100 ps

# TWO ROADS TO 10 ps RESOLUTION

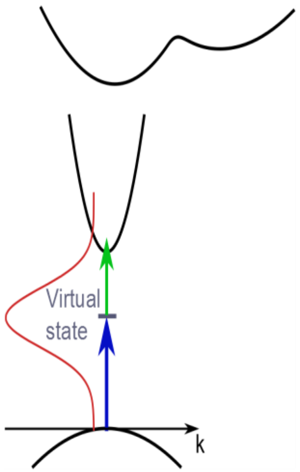

**Exploitation of faster luminescence response**

**Exploitation of novel fast phenomena**

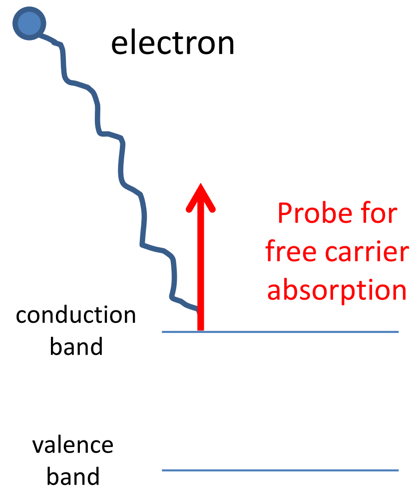
# THE ROADS ARE PAVED BY EXPERIMENTAL TECHNIQUES




## Two-photon absorption




## Free carrier absorption



# THE ROADS ARE PAVED BY EXPERIMENTAL TECHNIQUES

## Time-resolved photoluminescence spectroscopy

**EXCITATION:**

Yb:KGW oscillator (*Light Conversion Ltd.*)
emitting at 1030 nm.
**80 fs** pulses at 76 MHz repetition rate

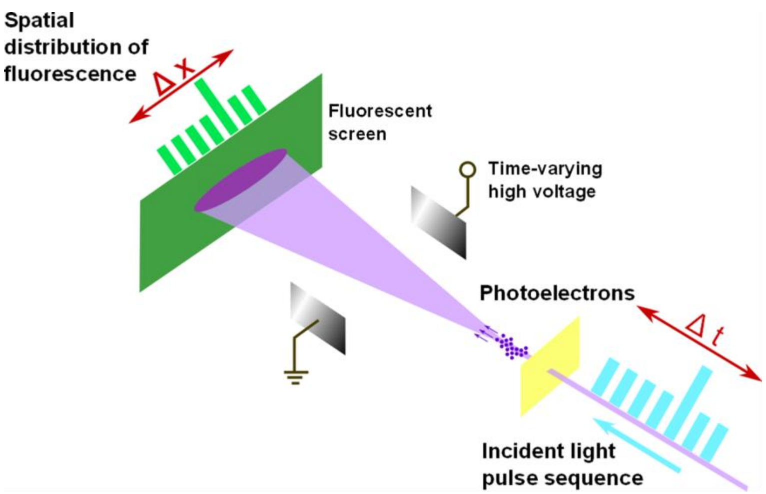

Harmonics generator
(HIRO, *Light Conversion Ltd.*);
the third **343 nm (3.64 eV)** and fourth
**254 nm (4.9 eV)** harmonics

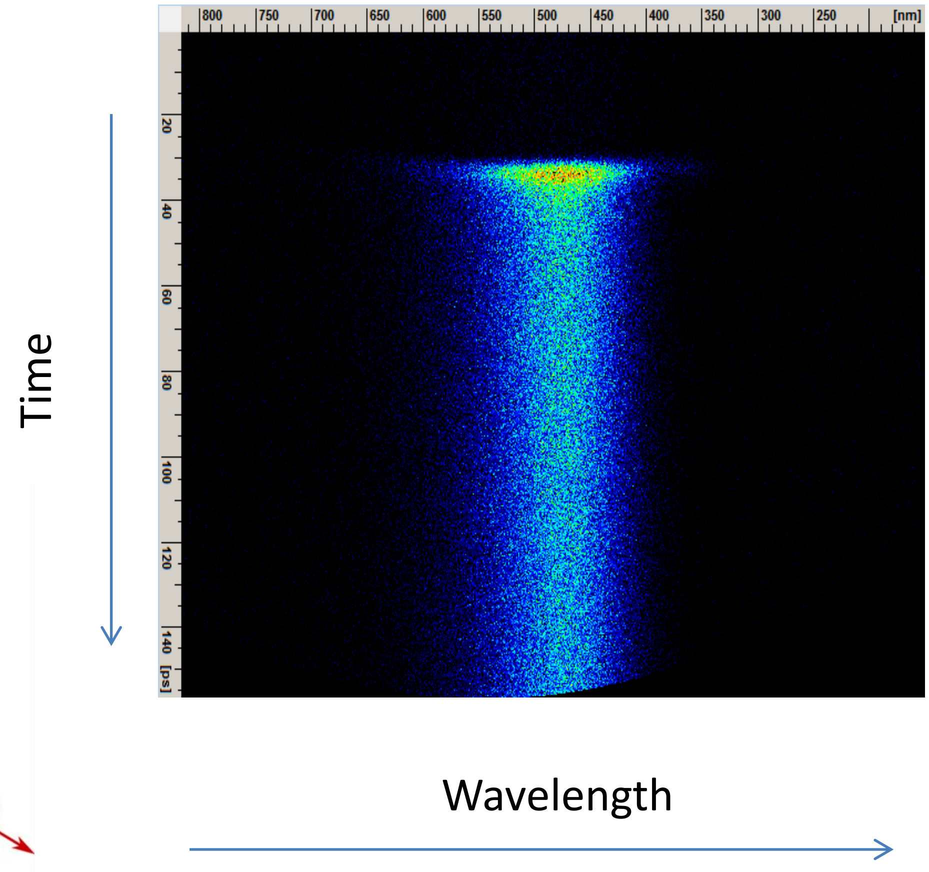
# THE ROADS ARE PAVED BY EXPERIMENTAL TECHNIQUES

## Time-resolved photoluminescence spectroscopy

**DETECTION:**

*Hamamats*u streak camera.
FWHM of the instrumental response function : 2.95 ps



# SCINTILLATORS UNDER CURRENT STUDY

**Self-activated**

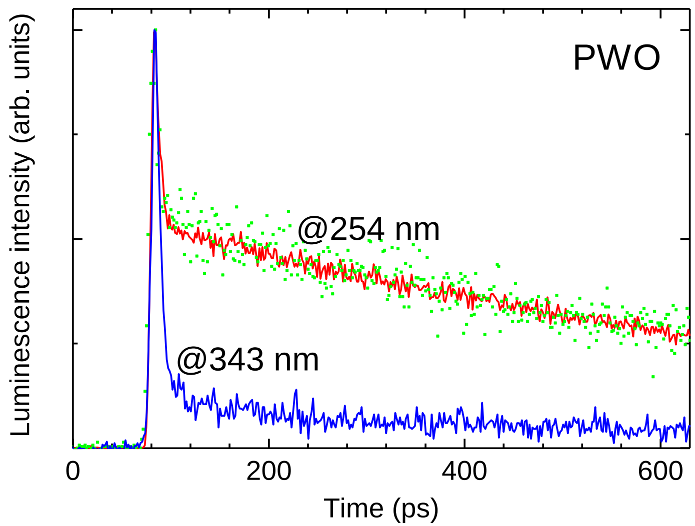
PWO ($PbWO_4$)

**Ce-doped**

gadolinium aluminum gallium garnet

(GAGG, $Gd_3Al_2Ga_3O_{12}$)

# Results on TRPL, PWO

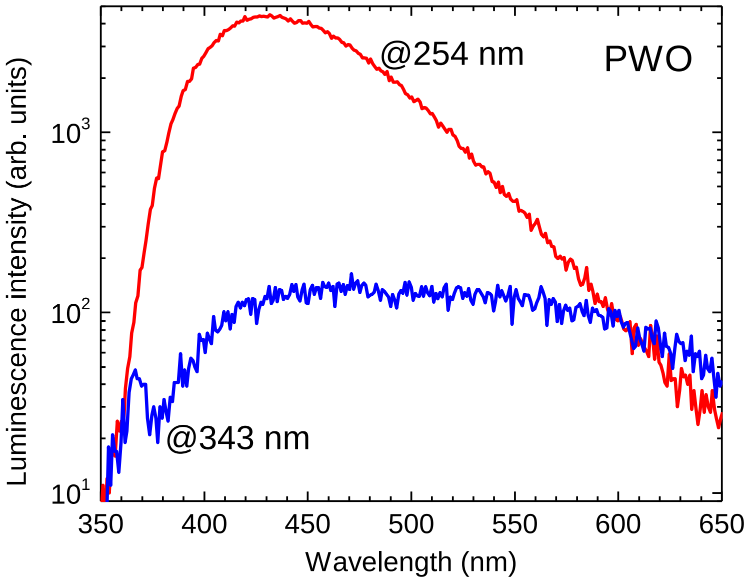



Decay times:

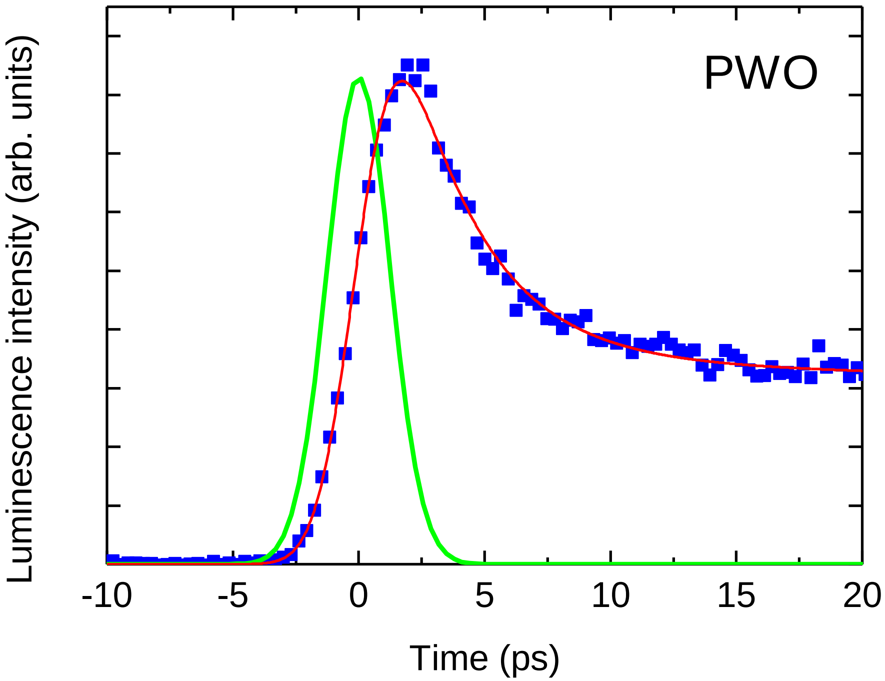
$\tau_1$ = 3.8 ps and $\tau_2$ = 683 ps @ 343 nm exc.

$\tau_1$ = 5.9 ps and $\tau_2$ = 824 ps @ 254 nm exc.

Both at 343 nm and 254 nm excitation, the kinetics of luminescence within 400-500 nm and 500-600 nm are identical



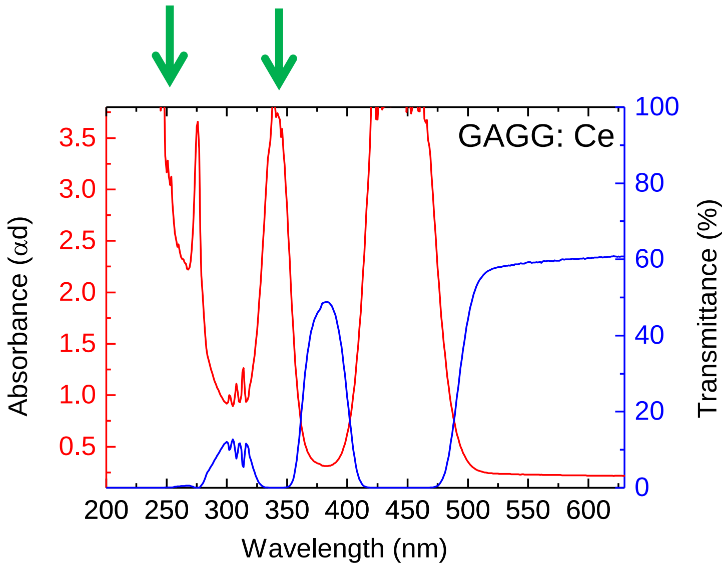
# Results on TRPL, PWO

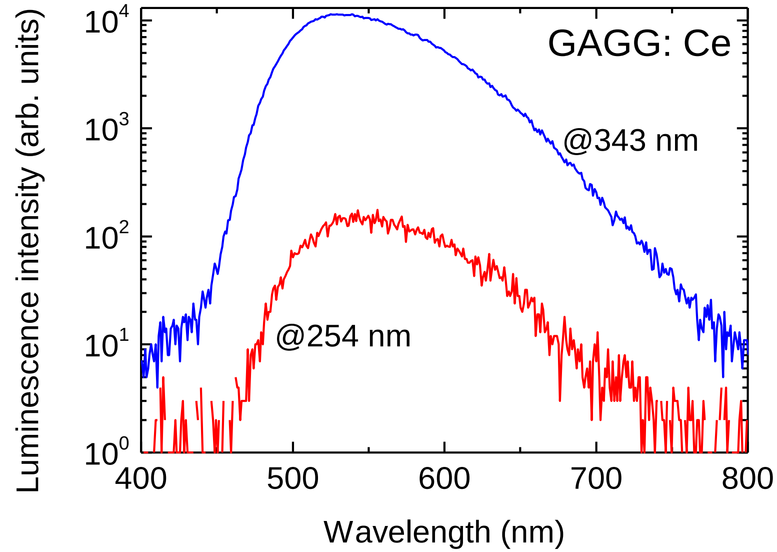



Initial stage of spectrally integrated photoluminescence kinetics (dots),
the instrumental response function (green line), and
the best fit obtained using a bi-exponential decay function (red solid line)

# Results on TRPL, GAGG:Ce

**Luminescence spectra at two excitation wavelengths**

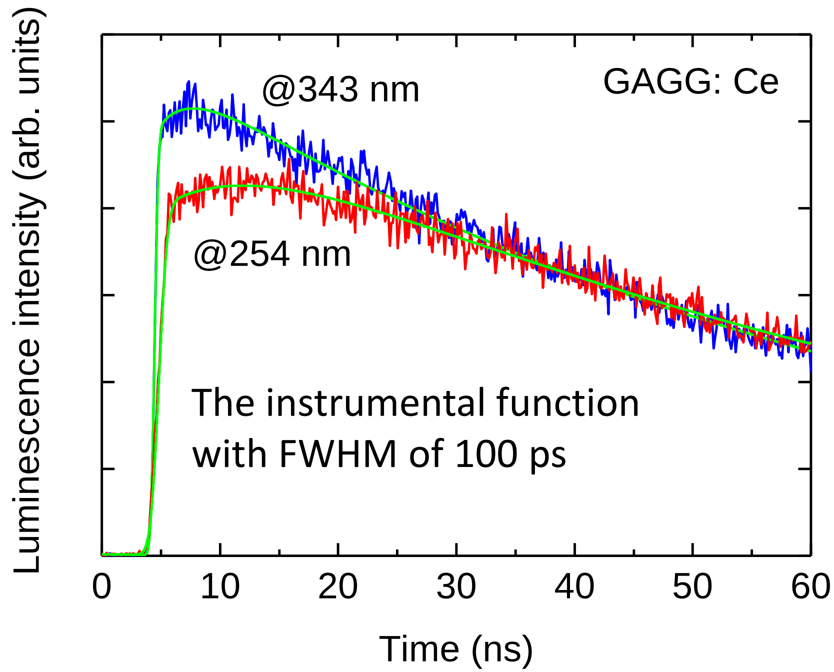



At the same excitation pulse energy and absorption coefficient ,
PL intensity is considerably lower after predominant excitation of $Gd^{3+}$ ions $\Rightarrow$ nonradiative recombination during the excitation transfer to radiative recombination centers is important

# Results on TRPL, GAGG:Ce

## Luminescence kinetics at two excitation wavelengths

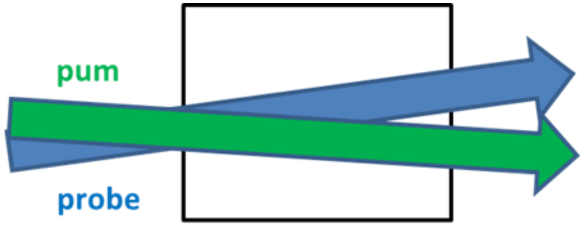


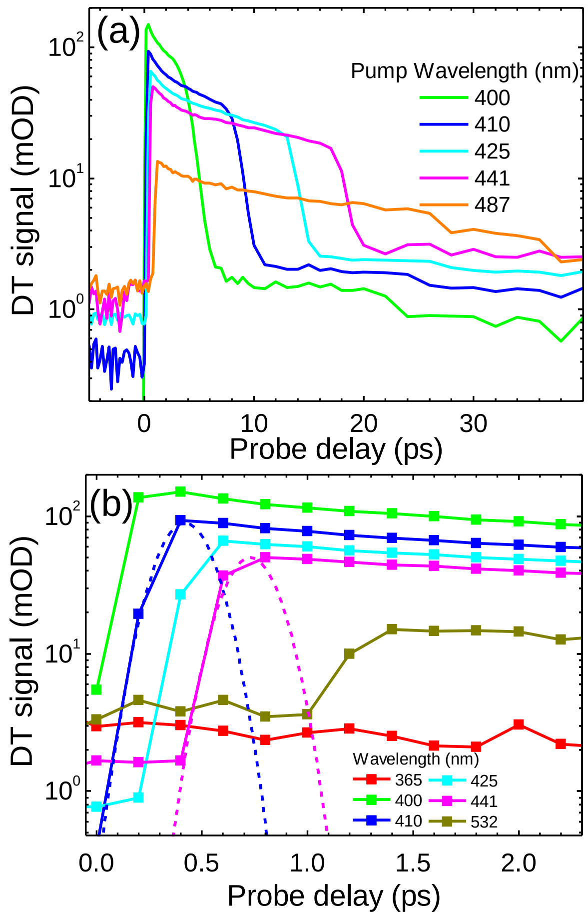

The major part of the luminescence follows the leading edge of the instrumental function.
We observe a rise component with the rise time of
8 ns @ 254 nm exc.
2.5 ns @ 343 nm exc.

This is in consistence with the 2 ns rise time observed in GAGG:Ce under gamma irradiation [M.T. Lucchini et al., NIMA, **816,** 176 (2016)].

# Results on two-photon absorption

# Results on two-photon absorption, PWO



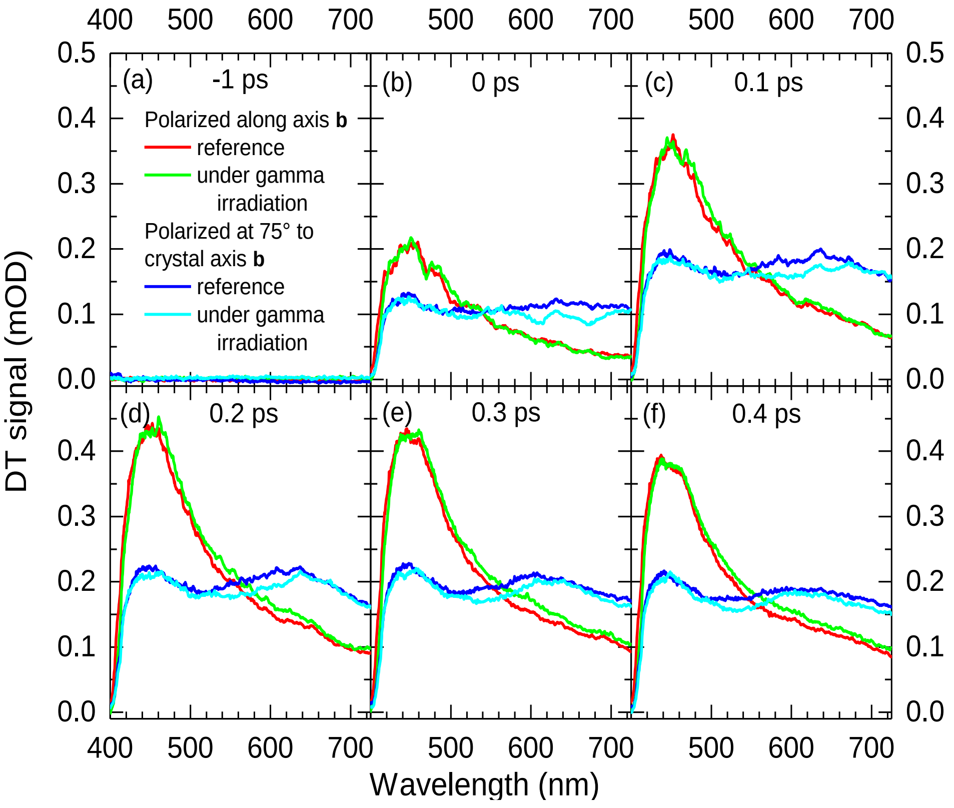




**Differential transmittance**

**Inittial part of differential transmittance**

# Results on two-photon absorption, PWO

## Influence of gamma irradiation




**Spectra of differential optical transmittance induced by 500 mJ/cm$^2$ pump at 395 nm**

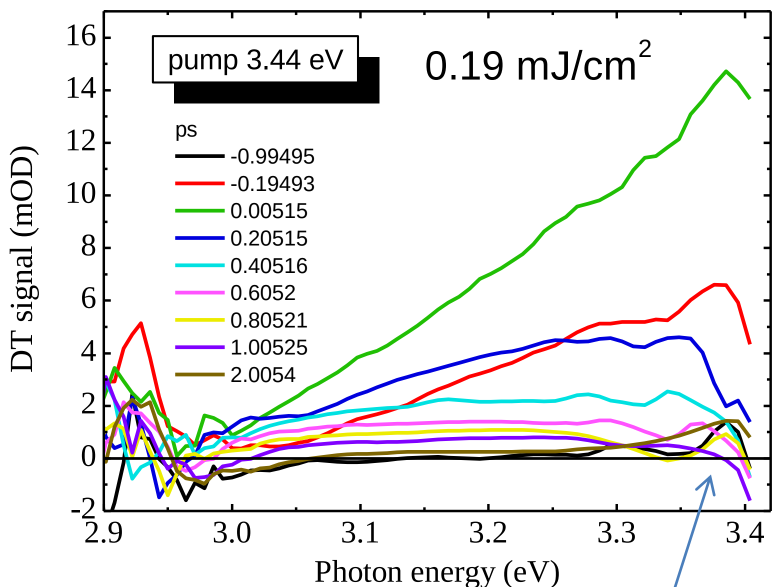
Polarization: along and at 75˚ to the crystal axis **b**

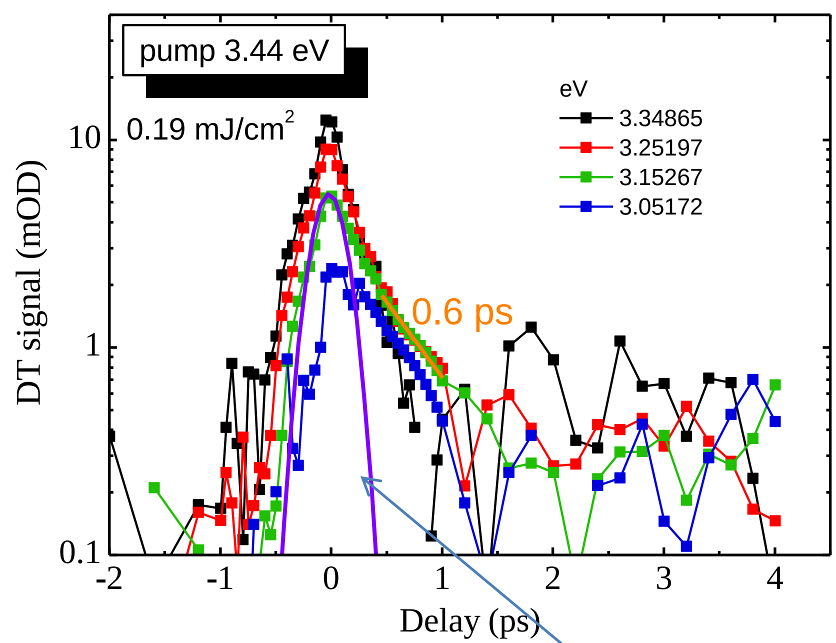
**Under** and **without gamma irradiation** ($^{57}$Co source of ionizing radiation (122 keV, 2 mCi) mounted at a distance of 1 cm from the plate surface)

# Results on two-photon absorption, GAGG:Ce

**Two-photon absorption in GAGG:Ce**

Pump at 3.44 eV (360 nm)



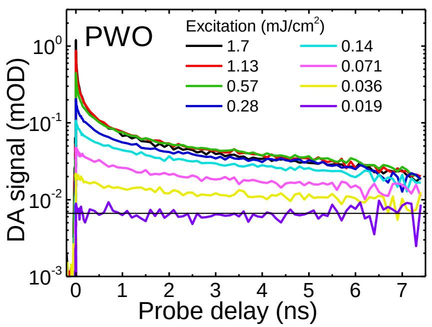




Distortion caused by scattered laser beam

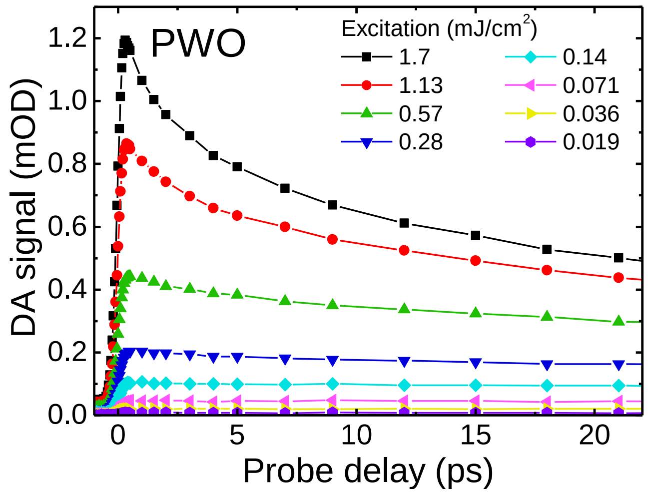
Laser ~150 fs

# Results on free carrier absorption

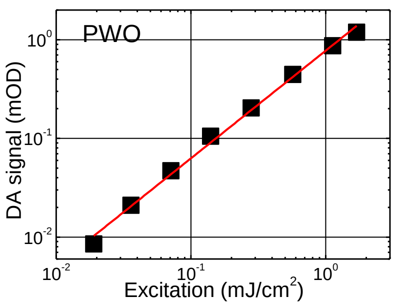
# Results on free carrier absorption, PWO




Kinetics of optical density induced by short pulse excitation of PWO crystal at 254 nm, probed at 1030 nm, for different excitation pulse energy densities (indicated)

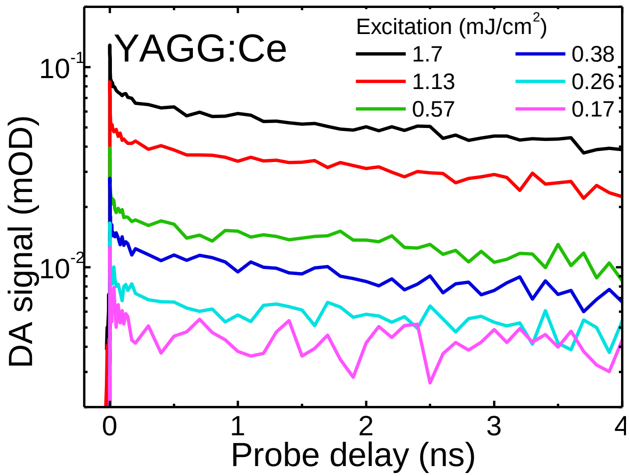



Initial part of the kinetics

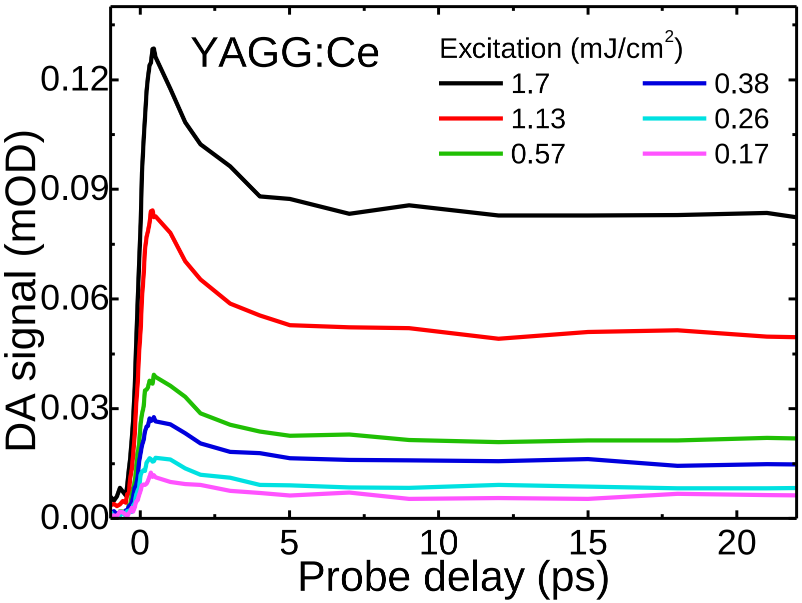



Induced optical density at 1030 nm probe wavelength at 0.3 ps delay after short pump pulse at 254 nm versus pump pulse energy density

# Results on free carrier absorption, YAGG:Ce

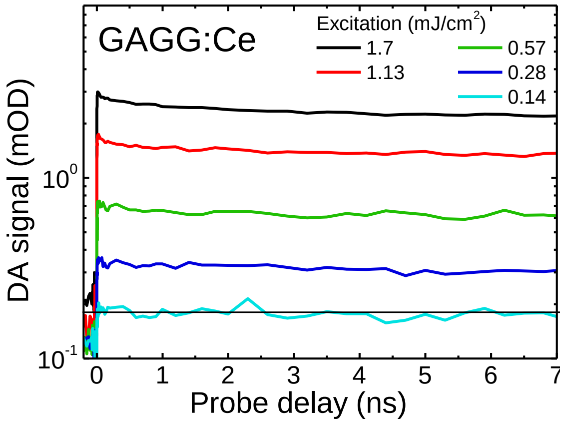



Kinetics of optical density induced by short pulse excitation of YAGG:Ce crystal at 254 nm, probed at 1030 nm, for different excitation pulse energy densities (indicated)

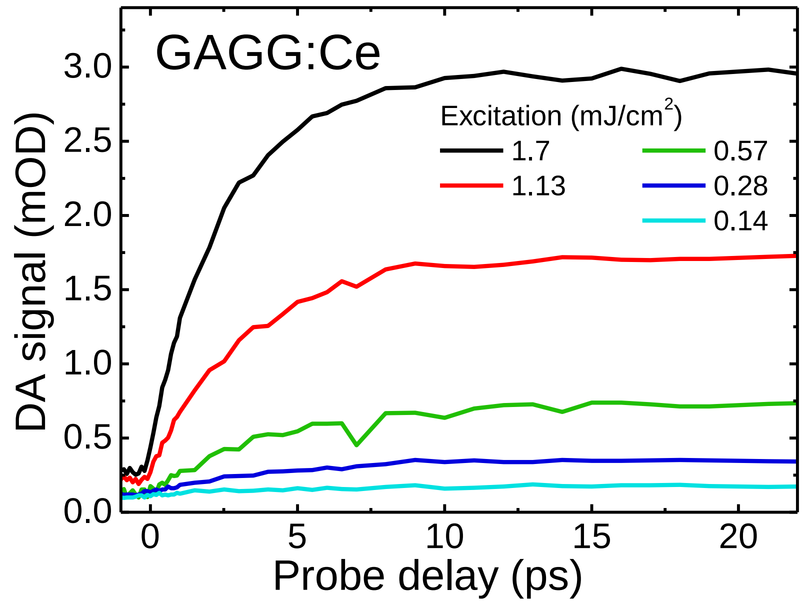



Initial part of the kinetics

# Results on free carrier absorption, GAGG:Ce




Kinetics of optical density induced by short pulse excitation of GAGG:Ce crystal at 254 nm for different excitation pulse energy densities (indicated)




Initial part of the kinetics

The rise of FCA in GAGG:Ce, takes a few picoseconds, what is caused by delocalization of holes from $Gd^{3+}$ to valence band.

This observation is consistent with the conclusion reported in [P. Dorenbos, ECS J. Solid State Sci. Technol. 2, R3001 (2013)] that the ground state of the $^8S \rightarrow {}^6D_{7/2,9/2}$ intracenter transition of $Gd^{3+}$ ions is located within the valence band.

# Thank you for your attention