Fast technique based on transient optical absorption exploited to qualify LYSO:Ce crystals for CMS Barrel Timing Layer

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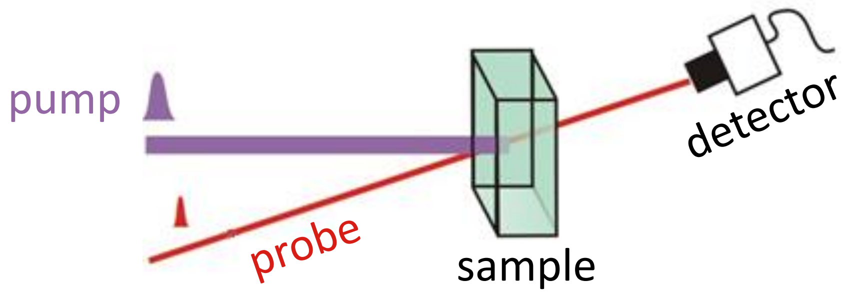
Introduction

The current upgrade of CMS Barrel Timing Layer puts forward a demand for a fast screening of materials to test the prospective scintillators, select the best crystal providers, and monitor the quality of the provided crystals in view of their timing properties. The upgraded CMS BTL MTD detector will consist of over 16500 scintillator crystal bars and testing even of a small part of them is a challenge.

We report on a novel contactless method based on the transient optical absorption monitored in subpicosecond domain in pump and probe configuration. The method is tested by comparing the results with the results obtained in the coincidence time resolution measurements, which are currently conventional but require sample mounting on photodetectors and advanced readout electronics making the measurements time-consuming and difficult to compare.

We propose the transient absorption technique as a method to expand in a complementary way the extensive qualification procedure of LYSO:Ce crystals that will be performed for the production of the CMS BTL detector, as the time required to characterize a sample by this technique is less than 0.5 hour and repeatability of the results is high.

Transient absorption technique

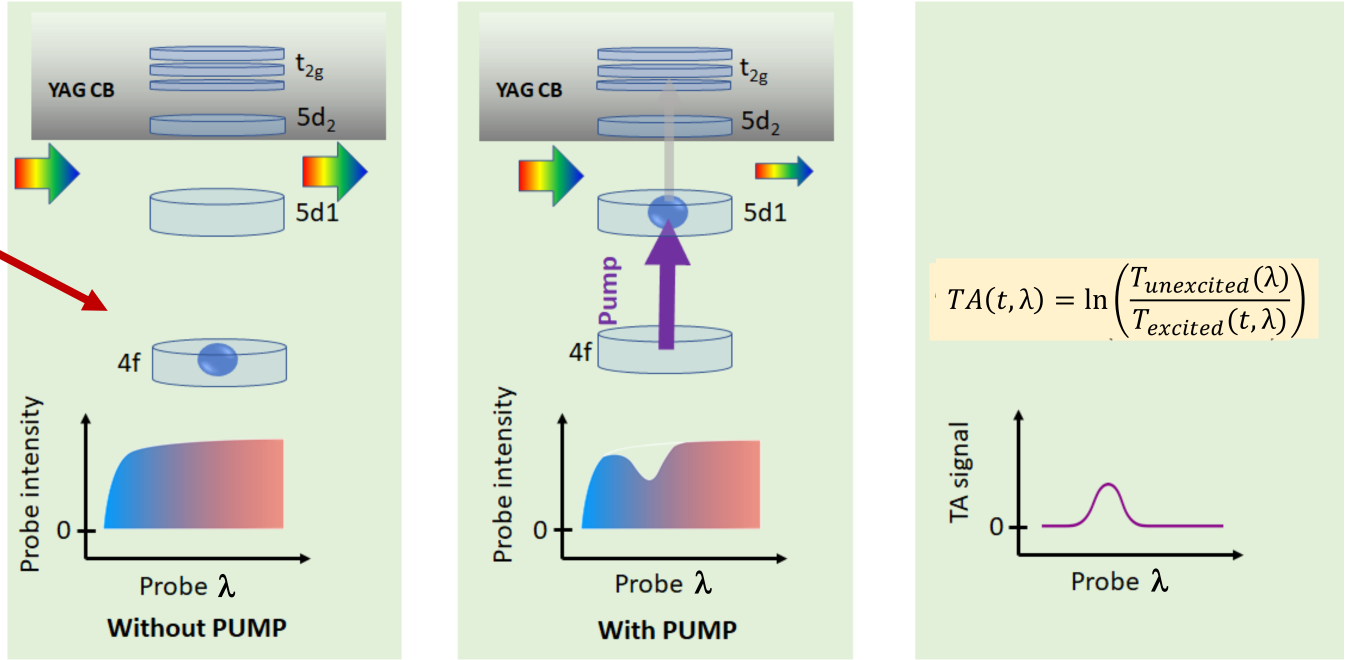


Pump-probe experiment:

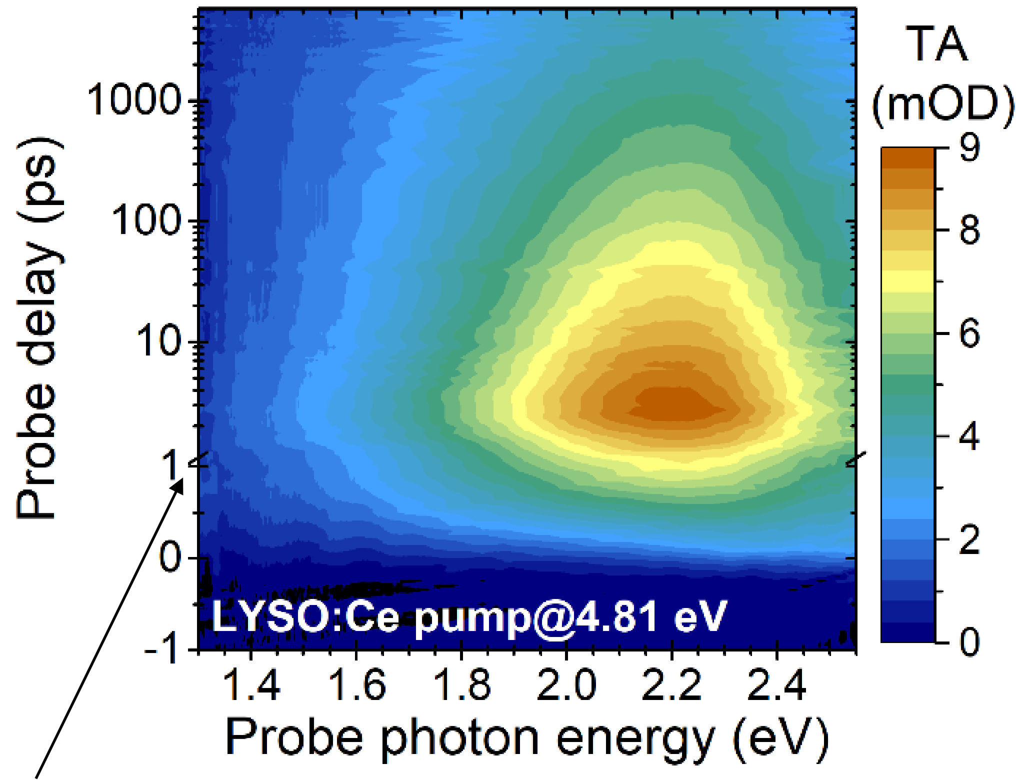
- First short laser pulse (pump) temporarily modifies material optical properties
- Second laser pulse (white light continuum probe) probes this modification by detecting the altered transmittivity (absorption)
- By varying the time delay between the pump and probe pulses, the modification evolution in time can be traced

$$TA\ signal(t,\lambda) = \ln\left(\frac{T_{unexcited}(\lambda)}{T_{excited}(t,\lambda)}\right)$$

is proportional to the population of the emitting level



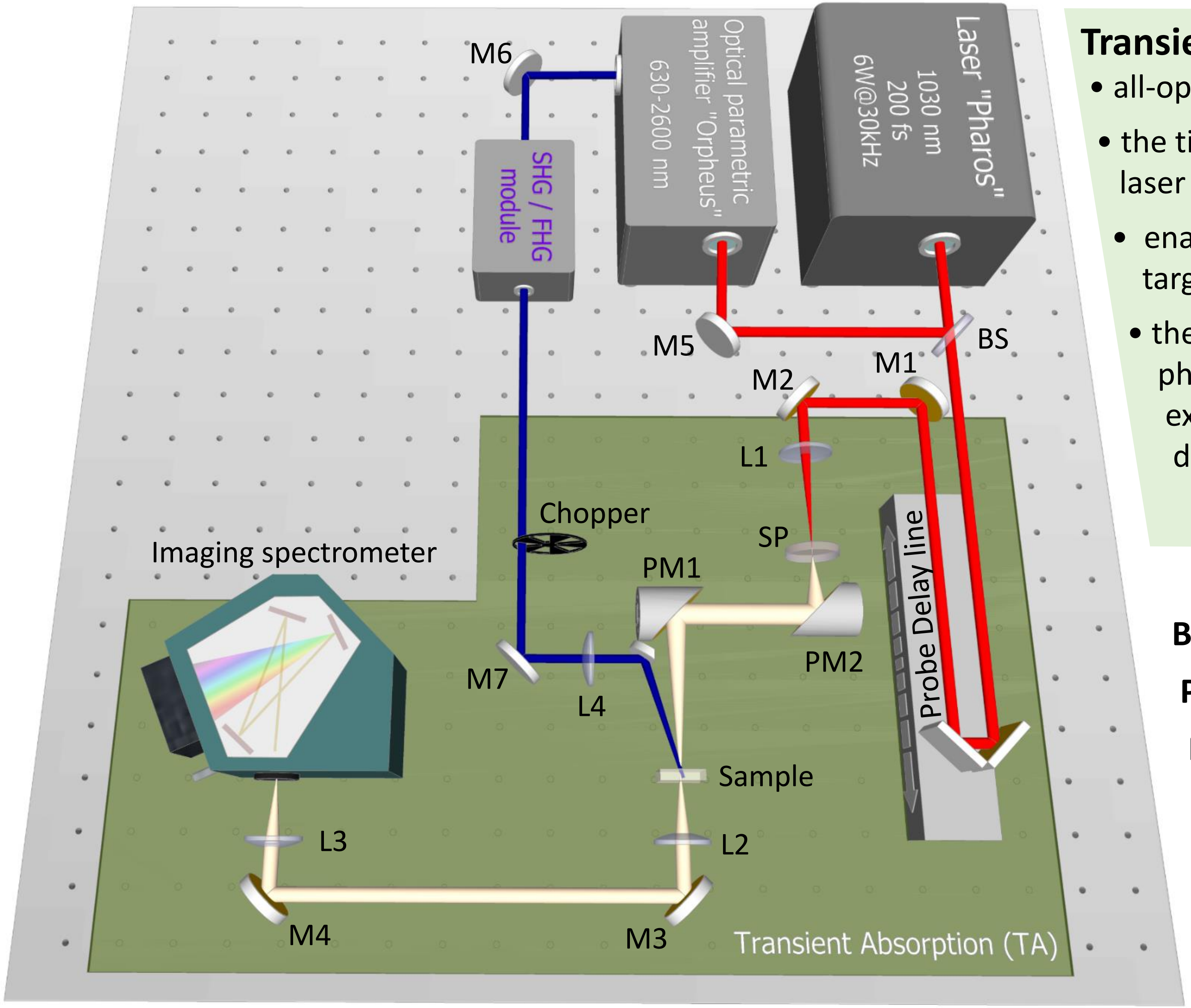
Transient absorption technique



Probe delay axis is split into linear and log parts to equivalently represent fast and slow relaxation processes

- The result of the TA measurement is recording the time evolution of the spectrum of nonlinear optical absorption induced by photoexcitation by pump pulse.
- Typically, the results are presented as a data carpet showing the TA signal as a function of the probe photon energy and the delay between pump and probe pulses.
- The cross section of the data carpet probe photon energy and probe delay axes provides nonlinear absorption spectrum at fixed delay and the kinetics of the nonlinear absorption at certain photon energy, respectively.

Transient absorption experimental setup



Transient absorption technique

- all-optical contactless signal readout
- the time resolution of the measurements is limited just by the laser pulse duration
- enables selective excitation via specific optical transitions targeted in the crystal
- the dependences of pump-induced transient absorption on probe photon energy and time, which are simultaneously obtained in the experiment, facilitate the discrimination of contributions of different kinds of non-equilibrium carriers

BS – beam splitter

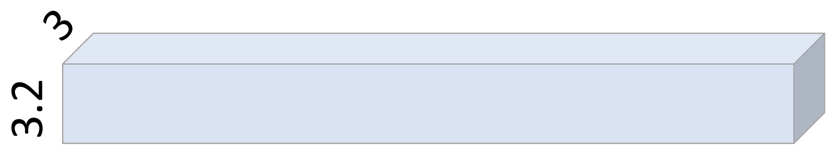
PM1-2 – parabolic metallic mirrors

M1-7 - mirrors

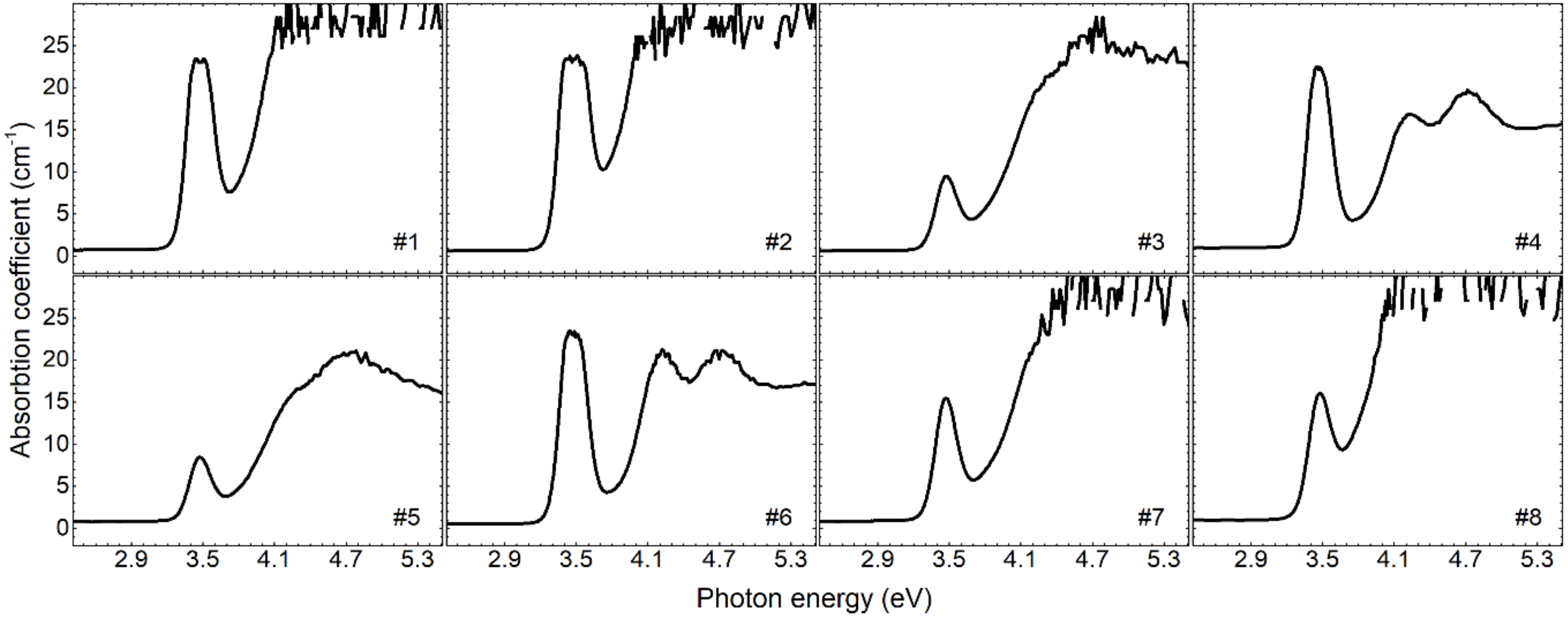
L1-4 – lenses

SP – sapphire plate for white-light supercontinuum generation

Samples



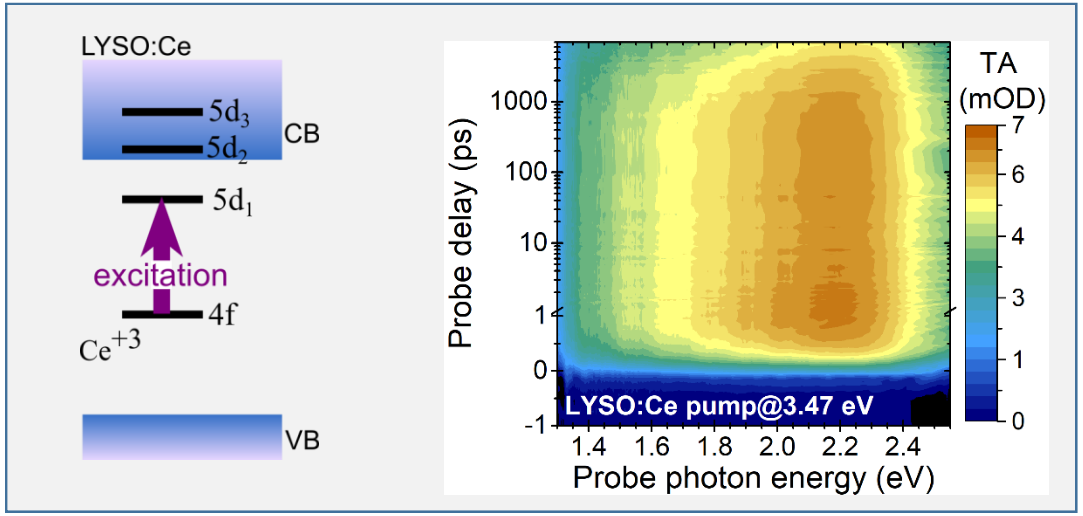
The study on eight LYSO:Ce bars is presented.

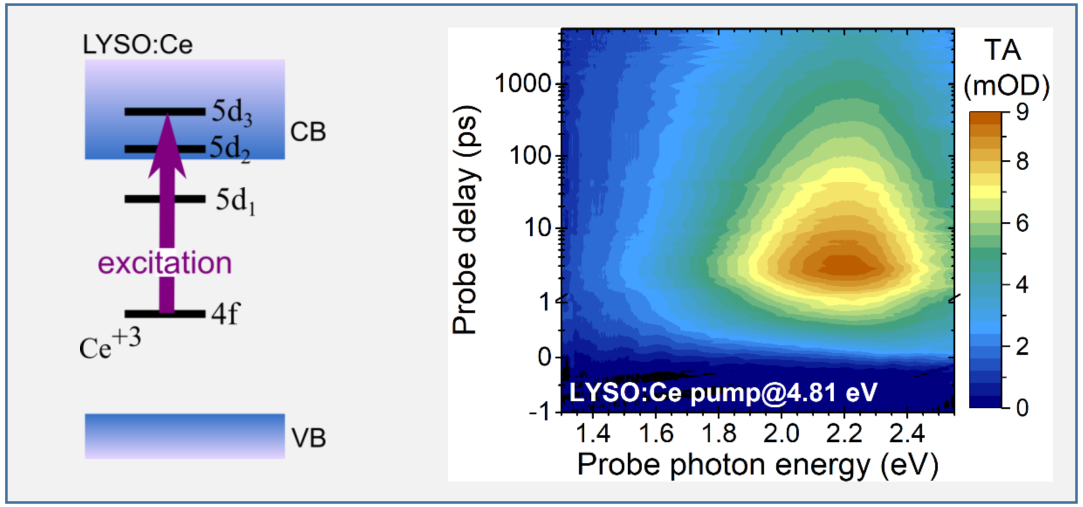


Linear optical absorption measurements shows that LYSO bars differs both by Ce and codopant content.

Results

Two excitation conditions, corresponding to the excitation to $5d_1$ or $5d_3$ levels of Ce^{3+} was used.

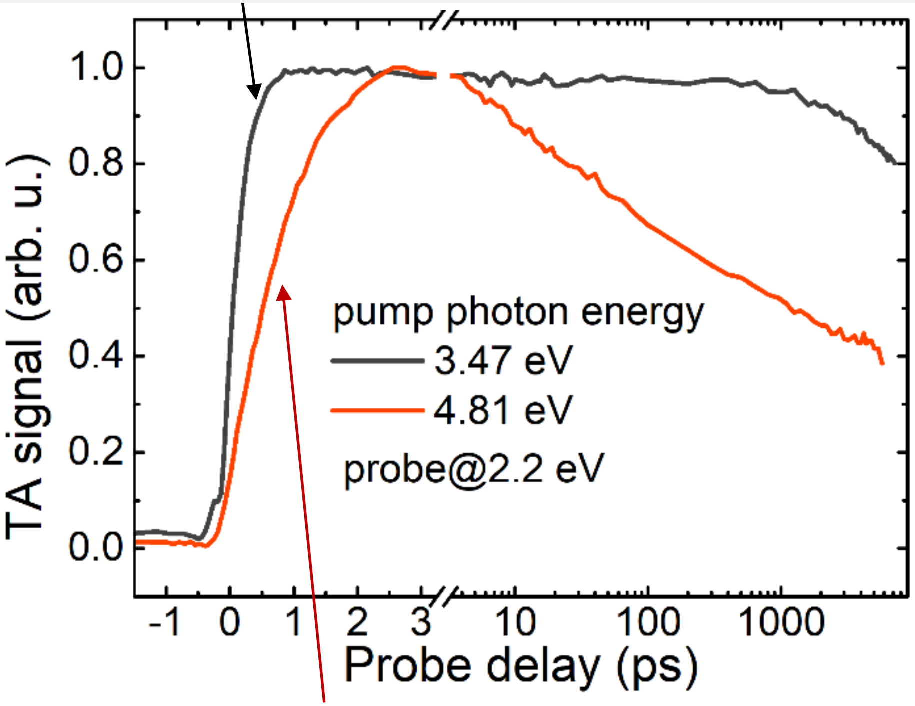




Excitation conditions

Typical TA data carpets after excitation of Ce ions to $5d_1$ and $5d_3$ levels.

TA signal appears instantly after photoexcitation of electrons via transition 4f - $5d_1$. The leading edge of the TA signal follows the temporal profile of the excitation pulse.

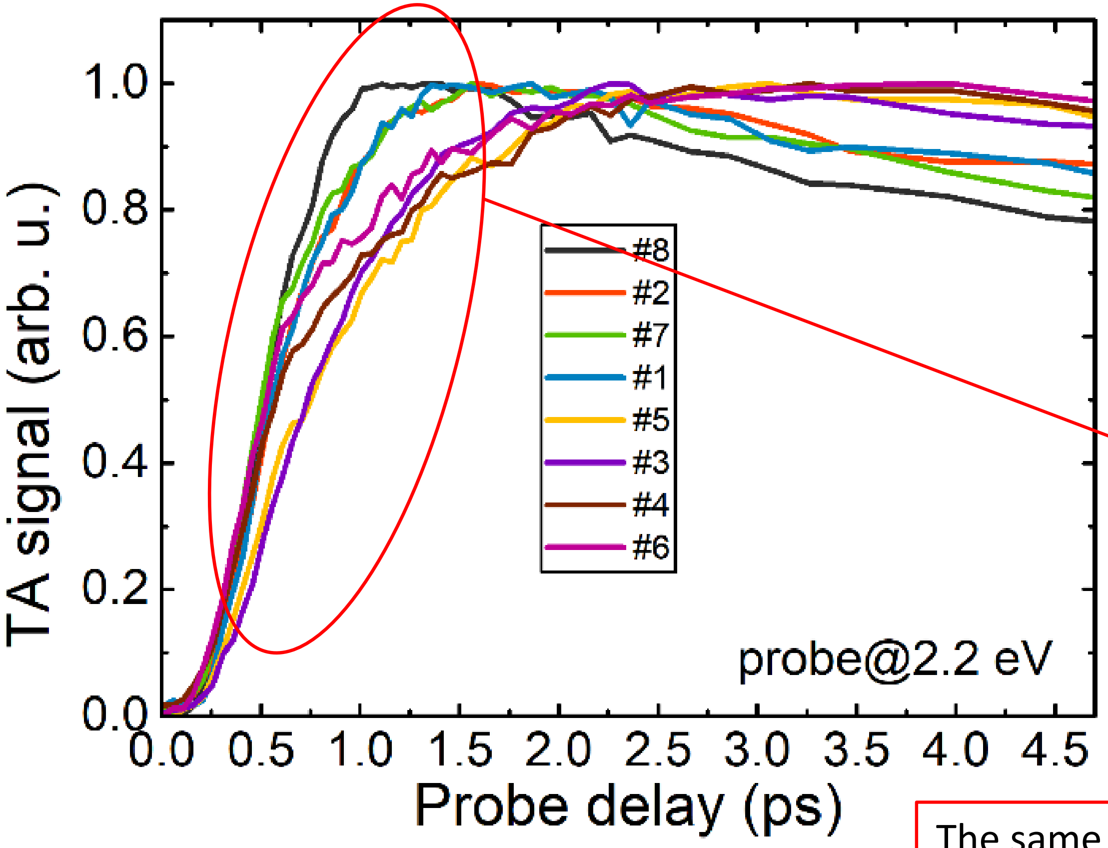


A noticeable delay is observed in the rise of the TA signal after photoexcitation of electrons to level $5d_3$. The delay is caused by slower electron relaxation to $5d_1$ through the states in the conduction band of LYSO.

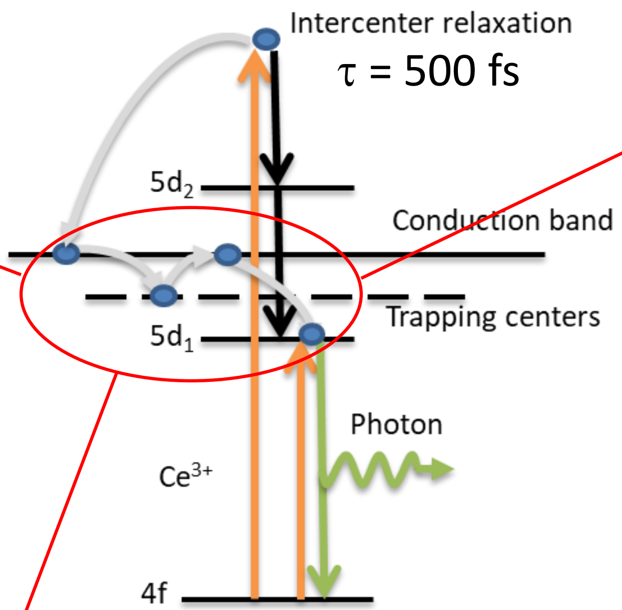
Excitation by 4.81 eV photons was selected for the comparison of LYSO:Ce bars.

Comparison of TA kinetics

Initial part of transient absorption kinetics after excitation with 200 fs pulse in LYSO:Ce bars.



- The leading edge of the TA kinetics is substantially different in the different LYSO:Ce bars.

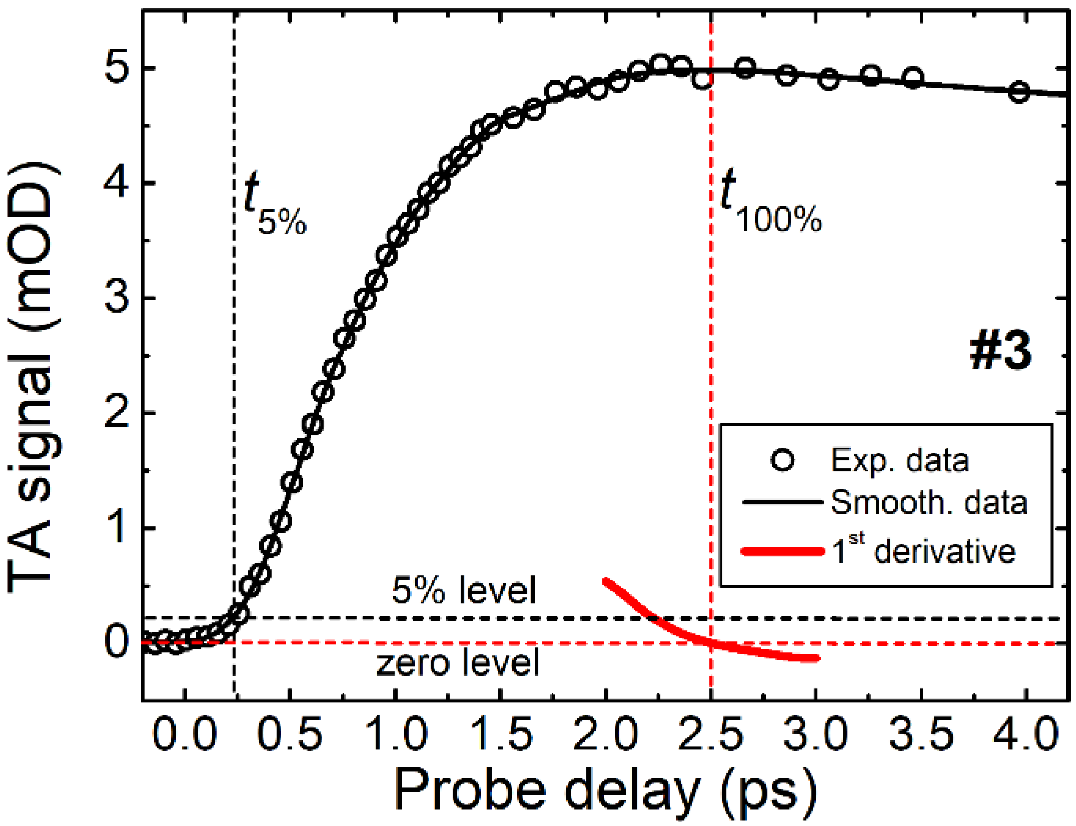


- The rise time of the TA response is predominantly defined by the transfer of the relaxed electrons to the emitting level $5d_1$ of Ce^{3+}.

The same processes govern the excitation transfer to activator ions after excitation by ionizing radiation

- The rise time is appropriate for the characterization of the timing properties of LYSO:Ce crystals.

TA rise time definition



Initial part of the transient absorption kinetics of one sample before (points) and after smoothing (black solid line) and the first derivative of the curve in the vicinity of its peak (red solid line).

The TA rise time is defined as the time interval between the peak point in the TA response and the initial point of the response defined as 5% level from the peak value.

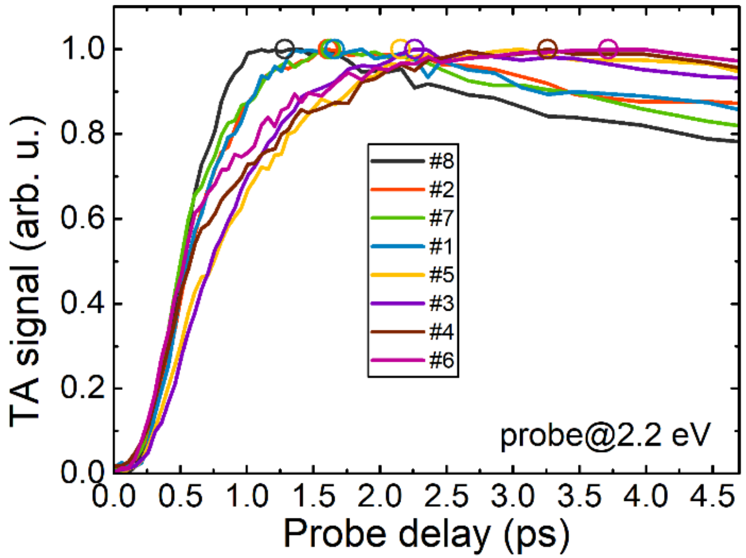
Algorithm:

Step 1. The experimental data is smoothed using second-order Savitzky-Golay filter with a 10-points window.

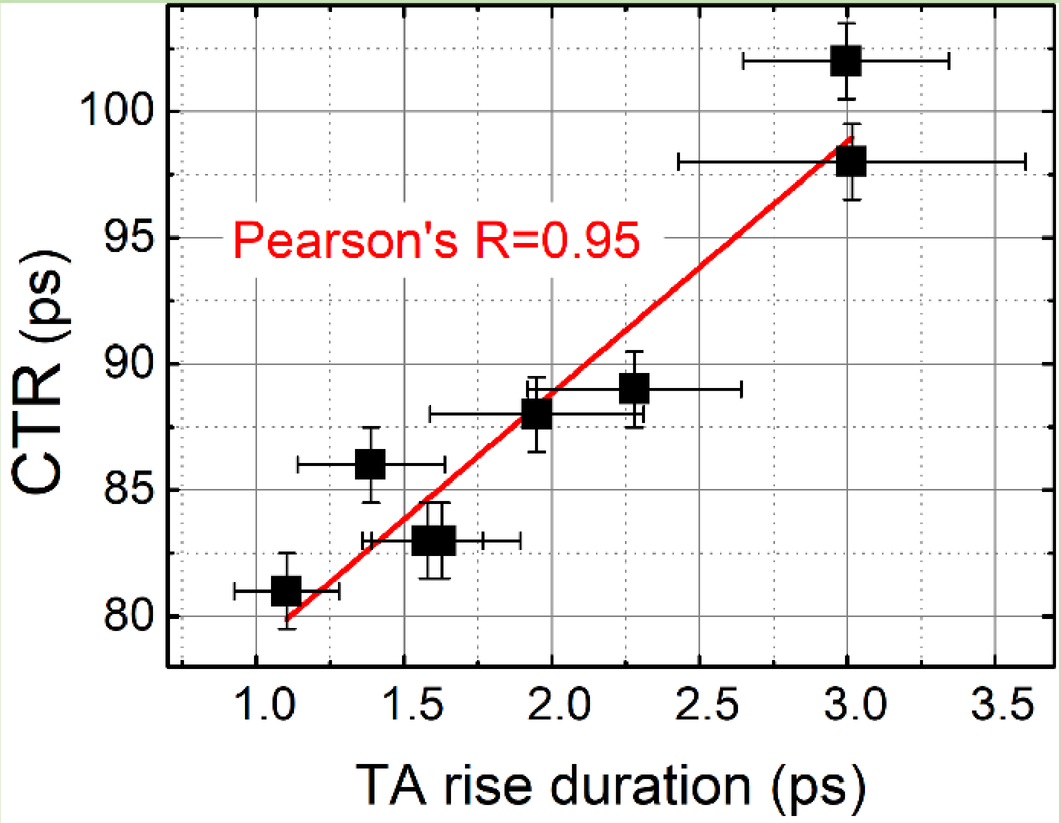
Step 2. The peak position of the TA response is obtained as the point where the first derivative of the TA signal dependence on time equals zero.

Step 3. The start point of the TA rise period is taken where the TA signal is 5% of its peak value.

Figure of merit



Initial part of transient absorption kinetics after excitation with 200 fs pulse in LYSO:Ce bars. The peak of TA response for every kinetics is indicated by a circle of corresponding color.



The correlation of the results obtained by CTR and TA techniques to measure different parameters related to the time resolution of 8 LYSO:Ce crystals. The Pearson's coefficient of 0.95, so close to its maximal value of 1, evidences an excellent correlation.

The correlation shows that the TA rise duration is a good figure of merit for the characterization of LYSO:Ce scintillation crystals.

Conclusion

The excellent correlation between CTR and the appropriately determined TA rise time shows that the TA rise duration is a good figure of merit for the characterization of LYSO:Ce scintillation crystals in view of the time resolution of radiation detectors based on these scintillators. Since the TA measurement is fast and requires no special treatment of the bars cut and polished for installation into the BTL, the technique might be applied for prompt testing of the timing properties of *en masse* produced bars selected according to a certain pattern.

In more detail:
G.Tamulaitis, S.Nargelas, A.Vaitkevicius, M.Korjik, Y.Talochka, V.Mechinsky, R.Paramatti, I.Dafinei, M.Lucchini, E.Auffray, S.Gundacker, N.Kratochwil, Transient optical absorption technique for qualification of LYSO:Ce crystals for the CMS Barrel Timing Layer, CMS Internal Note, 2020/002, 15 May, 2020

Acknowledgment

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