Basic principles of the stimulated recovery of the radiation induced damage in PWO scintillator

V. Dormenev[1], M.Korjik[2], O.Missevitch[2], R.W.Novotny[1]

1-Justus-Liebig-University, 2nd Physics Institute, Giessen, Germany

2-Institute for Nuclear Problems, Minsk Belarus

PANDA Week/09.09.2009

Motivation of research

- **Low temperature operating PWO based PANDA electromagnetic calorimeter possible degradation under γ- irradiation**

Can we create absolutely perfect synthetic scintillation material and keep it as it is in an irradiation environment?

***A priori* existing defects**

- Thermodynamics requires a certain concentration of the defects in the crystal which is grown at high temperature and then cooled down.
- Doping of crystal with appropriate impurity can improve situation but not completely. It is just a partial substitution of one type defects by others.

Created defects under ionizing radiation

- At the irradiation environment having highly ionizing particles like hadrons an additional damage of the crystal structure occurs so a continuous rise of the defects concentration takes place.

NO, but we can control charge recharge processes of point structure defects!

Acceleration of the radiation damage recovery

Thermodynamics shows us a way to control at least charge recharge processes!

- **Fortunately, damage-recovery process is a thermo dynamical process in an open system, which can be further accelerated by injection of energy in appropriate form.**
- **At certain conditions which are:**
  - **Low probability of the carriers re-trapping**
  - **Limited amount of the sorts of the defects**

the relaxation process of the color center of sort *i* can be described by:

$$n_i = n_0 \exp(-w_T^i - \sum_j b_j I_j)t$$

where

n_0, *ni* - initial and current concentrations of the color center of type *i* ,

$$w_T^i = A_i \exp(-E_{TA}/kT)$$ **-spontaneous relaxation probability,**

E_{TA} -thermo-activation energy of the color center, *k*-Boltzmann constant, *T* - temperature,

I_j -specific energy flux, **b_i describes the interaction of the color center with a flux of specific energy.**

Specific energy fluxes

- **Heating the crystal accounting the exponential dependence of the spontaneous recovery on temperature.**
  - **Heating in between experimental phases of an entire experimental setup comprising up to thousands of crystals would require an enormous amount of energy.**
- **Treatment of the crystal with hypersonic to achieve declining of the color centers by multi- phonon absorption.**
  - **In most of the cases it is practically excluded by the specific detector assembly.**
- **Energy can be delivered to a crystal via photons of selected wavelengths but requiring high *bj* factors.**
- **Two actual processes are initiated by photons in color centers:**

1) – ionization of color centers (sometimes is called 'optical bleaching')

2) – transport of the captured electron from ground state of the color centre to a radiating excited level which we call 'stimulated recovery' .

'Stimulated recovery' is an intra-center resonant transition that can be initiated by photons with an energy even as low as *Ef* ~E_{TA} , possibly in the infrared region.

Stimulated recovery

The stimulation of the recovery becomes effective when two conditions are fulfilled:

1 – there is at least one energy level in the center located slightly above the radiating state providing fast recombination;

2 – re-trapping processes within the crystal should be strongly suppressed. The latter is achieved by minimization of the number of the color centers of type *j* (ideally *j*=1).

All types of PWO scintillators: **PWO of CMS ECAL**

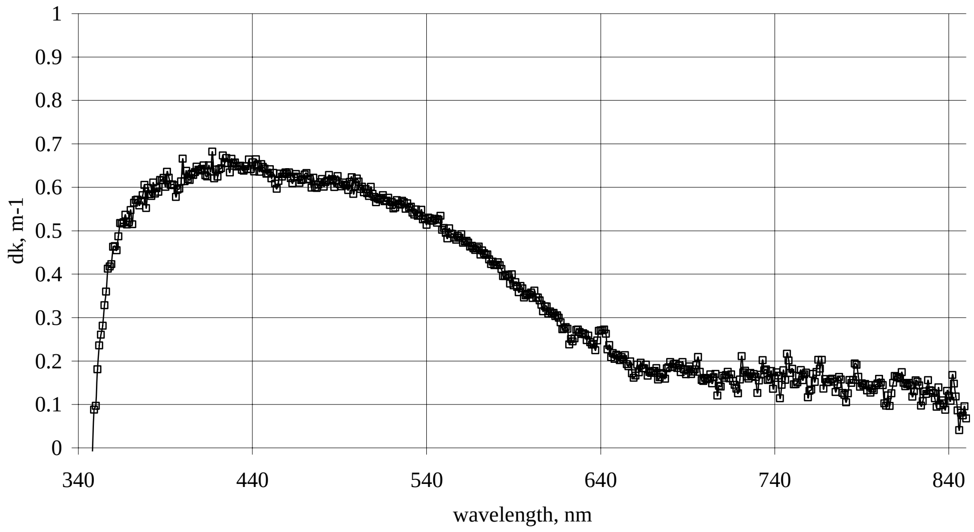
PWO-II and

PWMO

meet these requirements!

Frenkel type defects $(FTD)_O$ based on oxygen vacancy dominate in PWO of CMS ECAL type as well as PWO-II crystals. Others are suppressed by dopings.

Typical γ-radiation induced absorption spectra in PWO of CMS ECAL and PWO-II Crystals measured at room temperature



Condition1-**OK**

$^1A_1 \rightarrow {}^1T_1$

$^1T_1$ fast relaxation to $^3T_1$

$^3T_1$ fast recombination to $^1A_1$

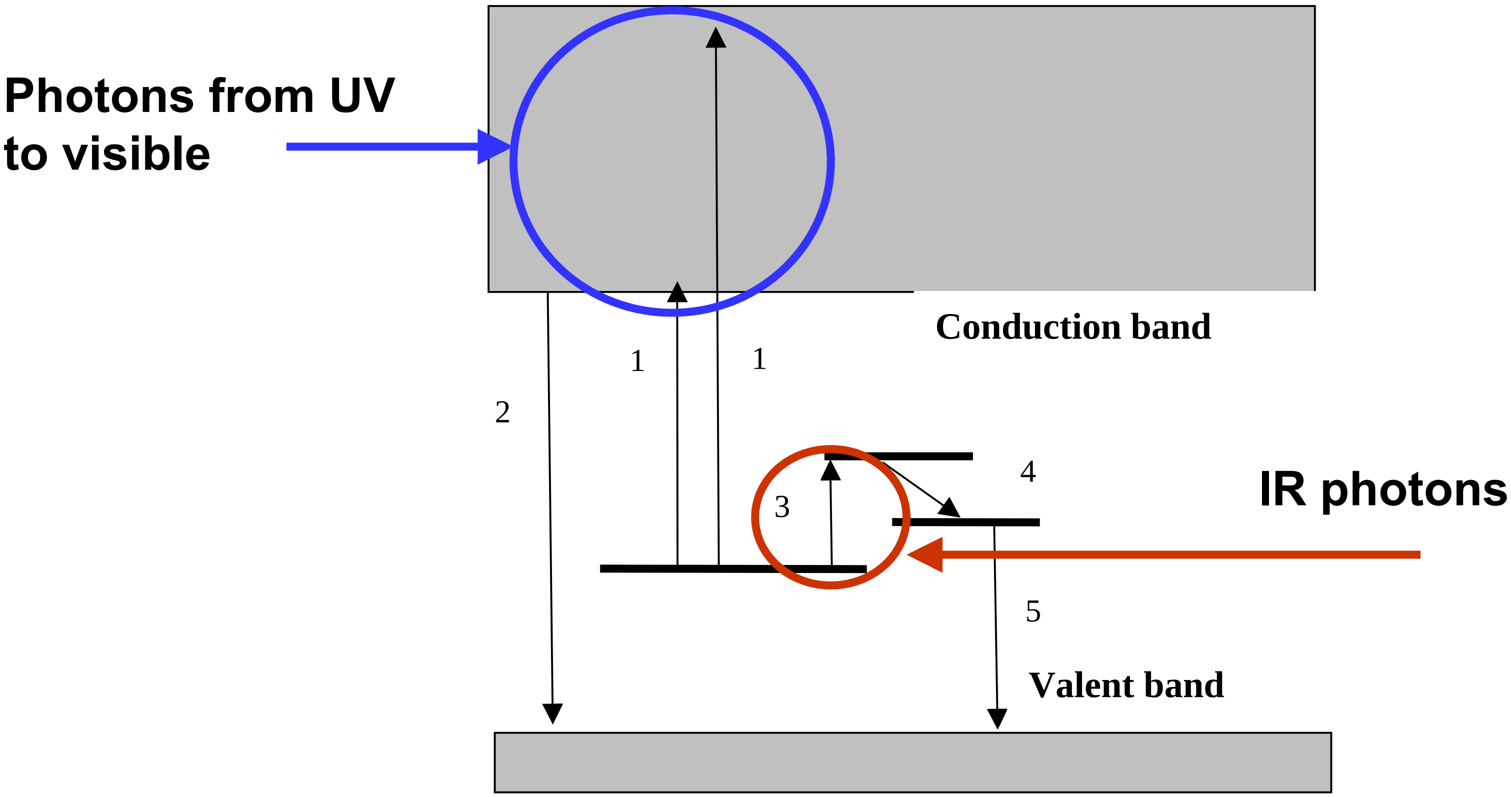
Condition2-**OK**

FTD in a regular structure

FTD in the super structure

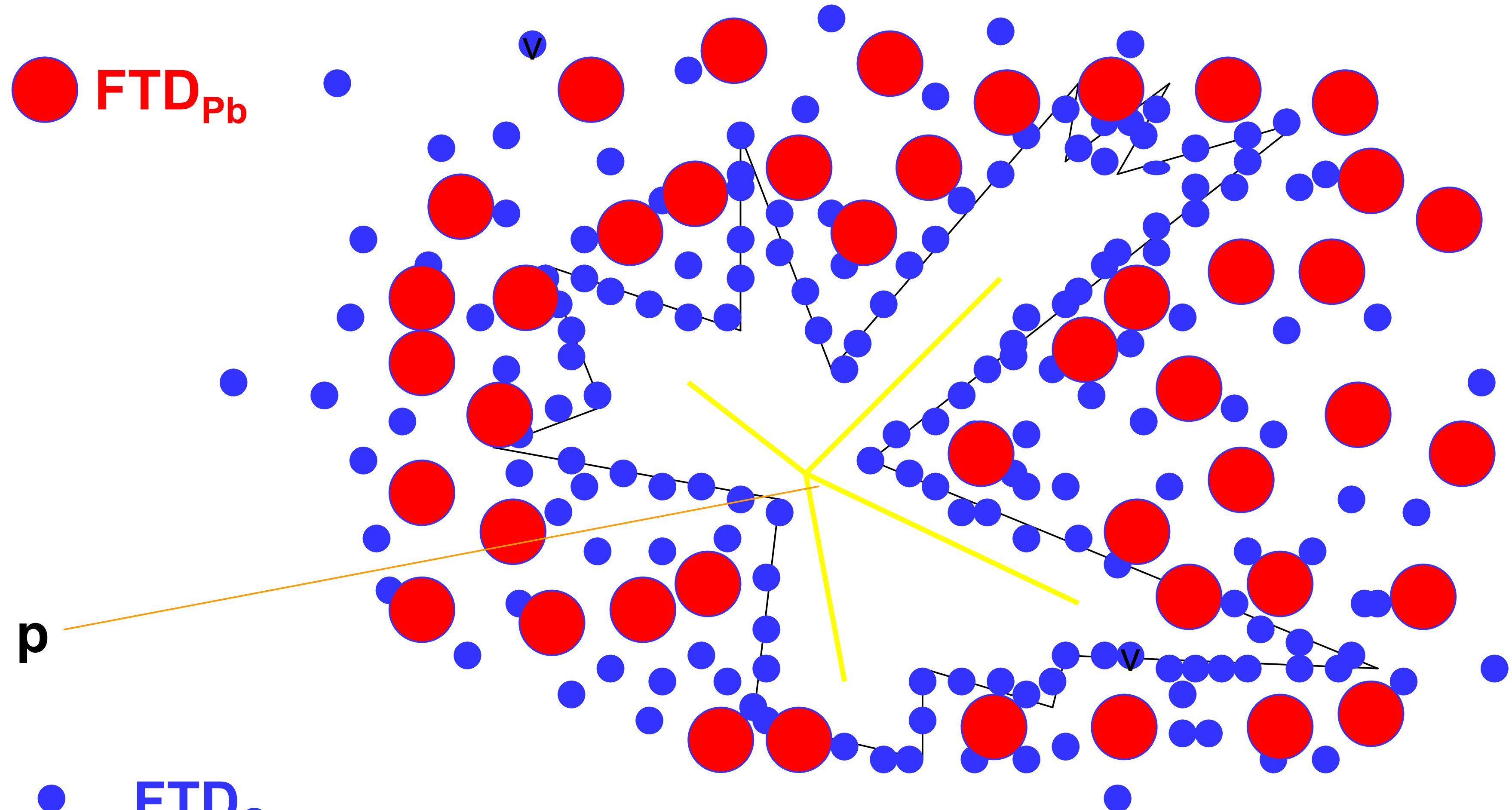
γ – radiation causes recharging of the existing point structure defect only !

Ionization and stimulation processes in PWO



1-ionization of FTD_o, 2-radiative/non-radiative recombination, 3-intracenter absorption in FTD_o, 4-nonradiative relaxation, 5- radiative/non-radiative recombination of FTD_o.

From the crystal chemistry point of view two Frenkel type defects based on oxygen $(FTD)_O$ and led $(FTD)_{Pb}$ vacancy are created in the vicinity of stars under hadrons .



Hadrons creates new point structure defects !

Energy diagram of $(FTD)_O$ and $(FTD)_{Pb}$ Frenkel type centers in PWO.

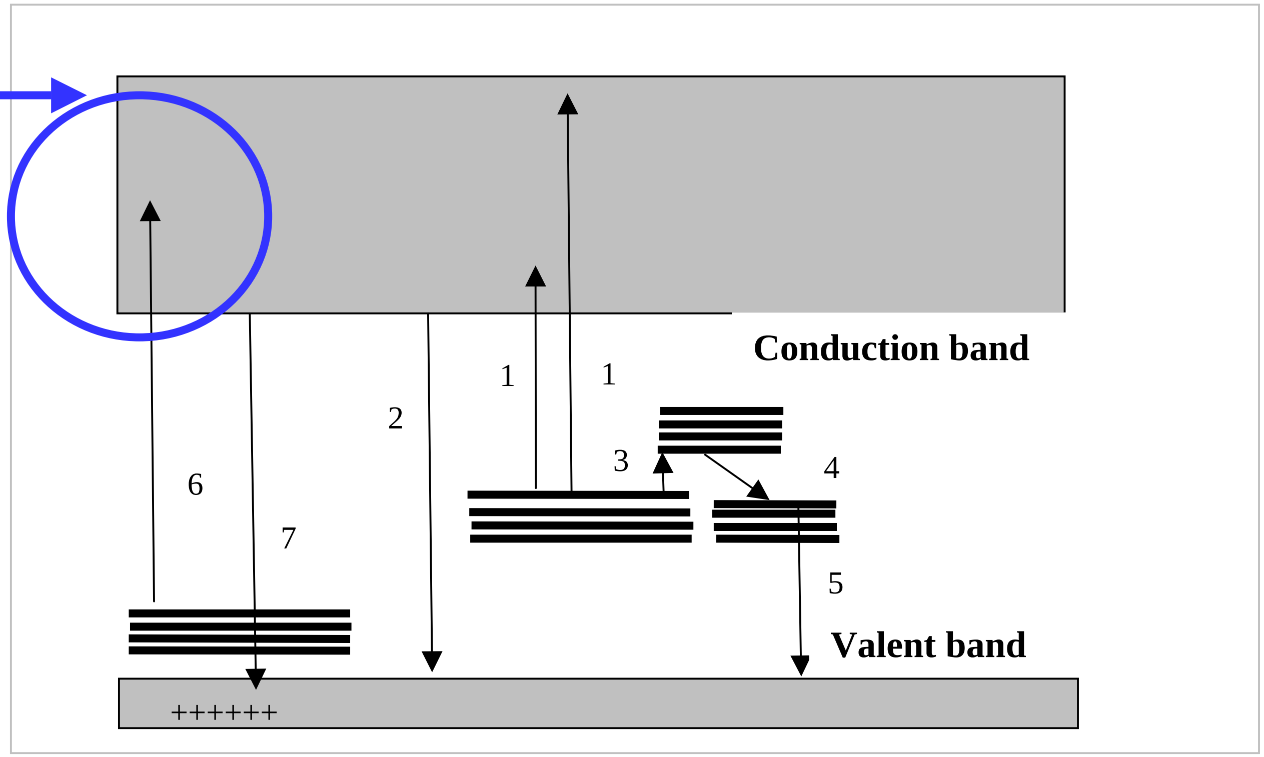
UV and visible light

Significant difference is:

$(FTD)_O$-electron capturing center;

but

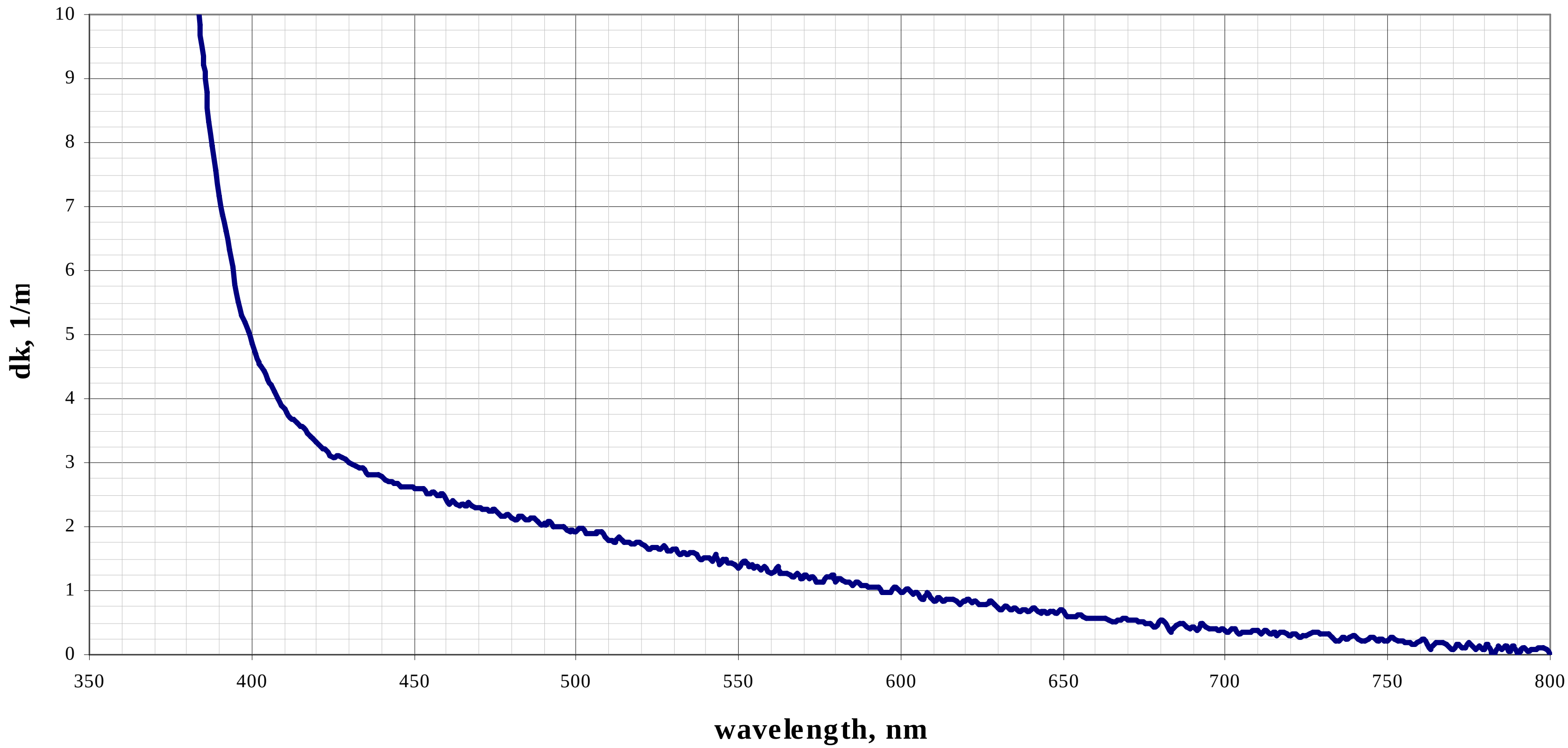
$(FTD)_{Pb}$-hole capturing center.



1-ionization of FTD_o, 2-radiative/non-radiative recombination,
3-intracenter absorption in FTD_o, 4-nonradiative relaxation, 5- radiative/non-radiative recombination of FTD_o, 6-ionization of FTD_{Pb}, 7-holes recombination.

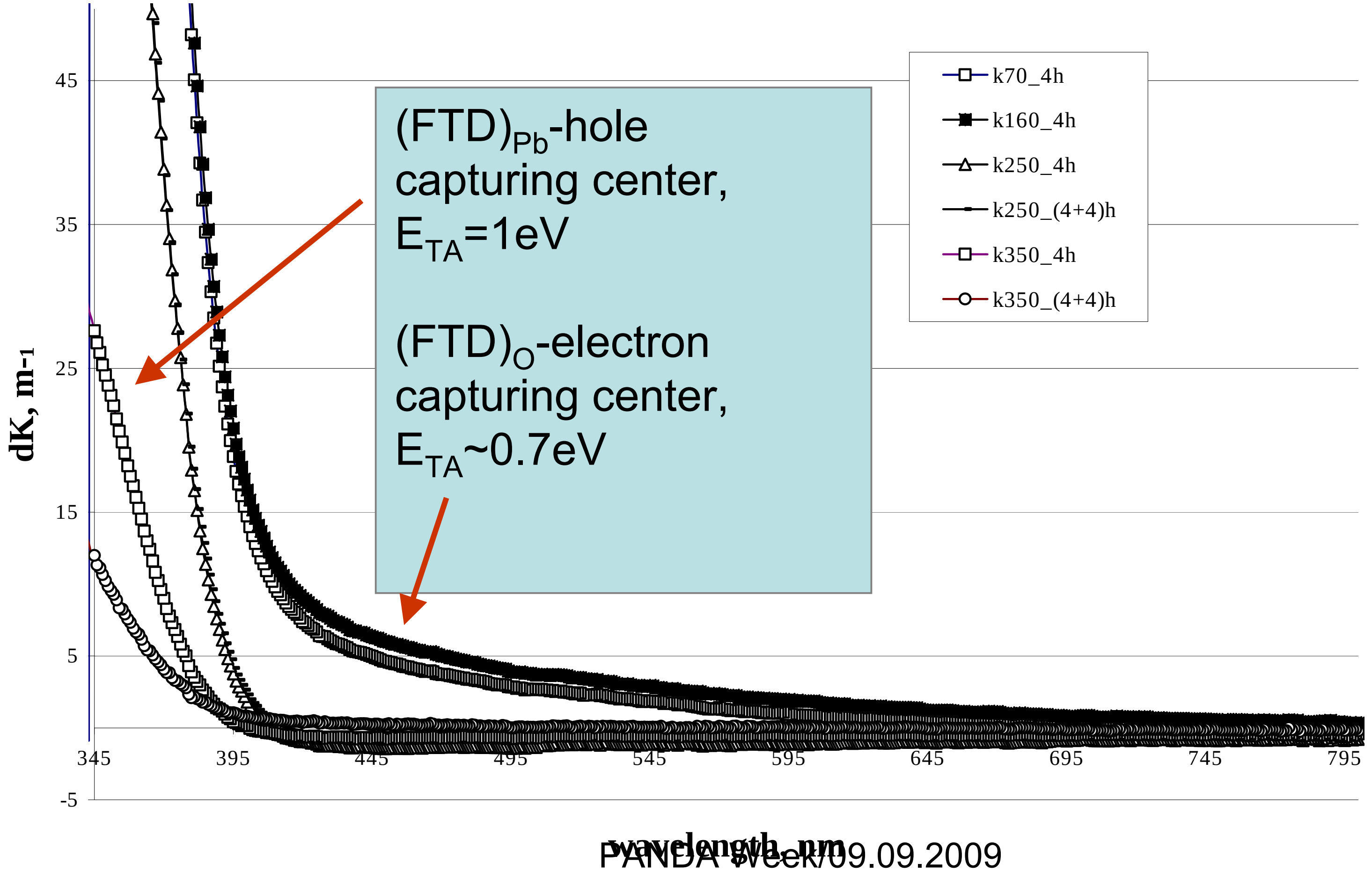
Typical p-radiation induced absorption spectra in PWO of CMS ECAL type. Fluence 10^{13} p. 2 cm long crystal measured at room temperature 14 days after irradiation.

(Measurements have been performed at ETH, Zurich radiation damage research facilities)



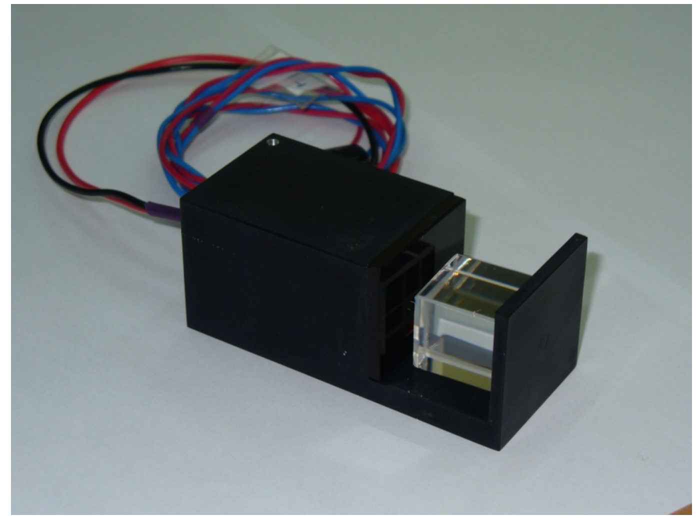
Created by hadrons color centers of FTD type can be annealed in PWO crystals!

(Raw data of the annealing of p-damaged crystals are a courtesy of ETH, Zurich Group)



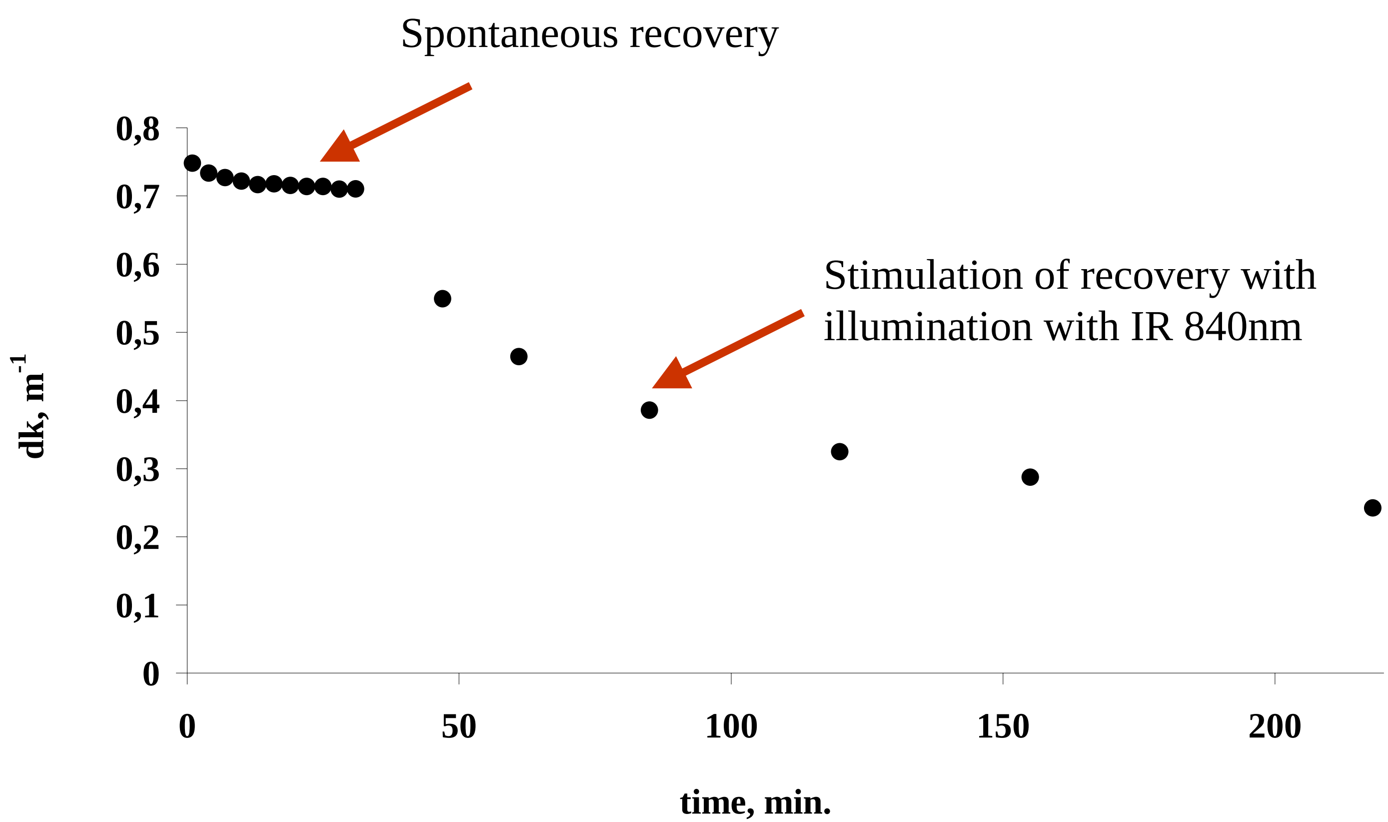
Modes of measurements

1. Stimulated recovery of γ- and p- induced absorption in 2x2x2cm^3 naked crystals at room temperature.

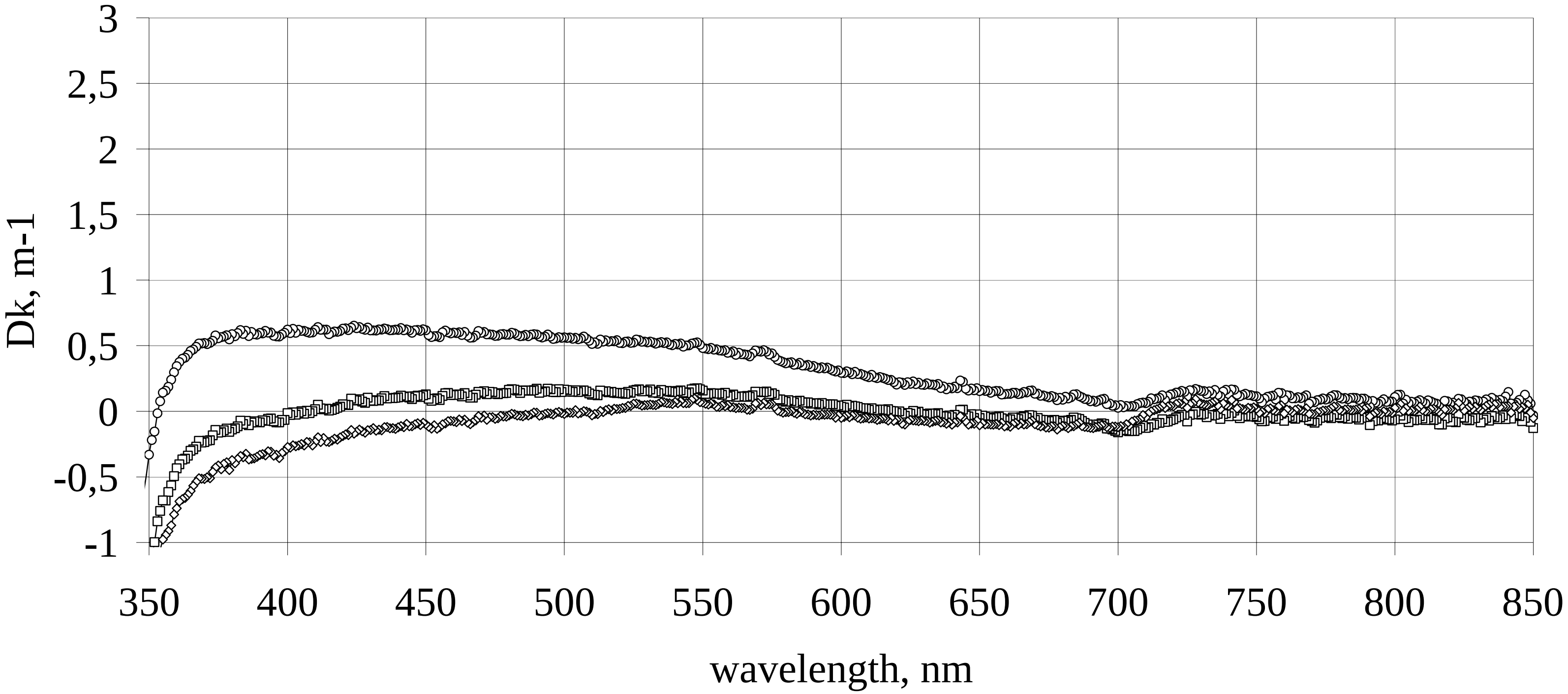


2. Stimulated recovery of γ- induced absorption in full size wrapped crystals

420 nm radiation induced absorption coefficient change due to spontaneous and stimulated recovery with IR(840nm), $2\cdot10^{16}$ ph/(s·cm^2), T=293K. 2x2x2 cm^3 naked crystal.



Change of the γ-irradiation induced absorption spectra of PWO crystal under stimulation with IR (940nm) at room temperature.

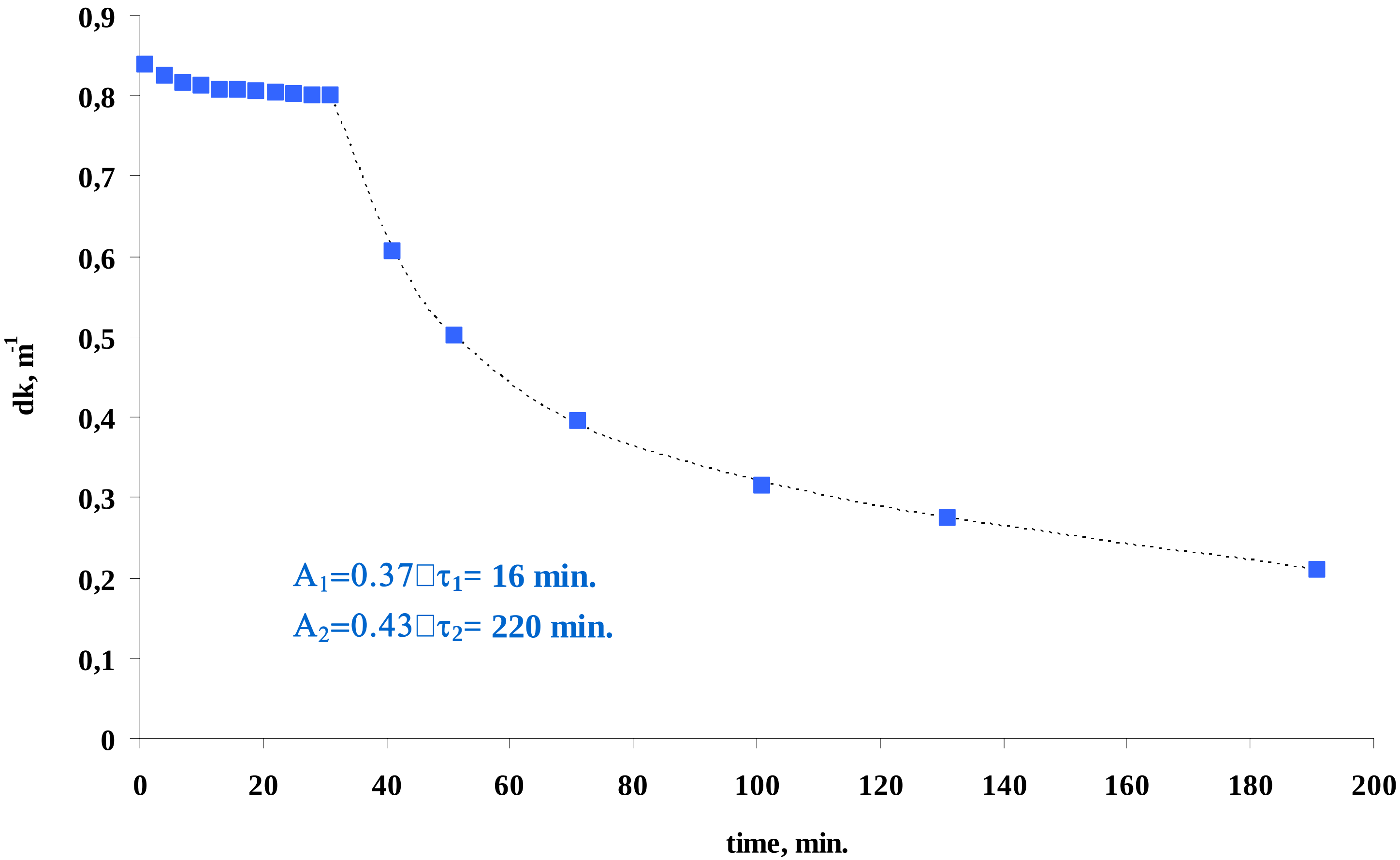


○-10 min. after irradiation with 60Co source, accumulated dose 2 kGy,

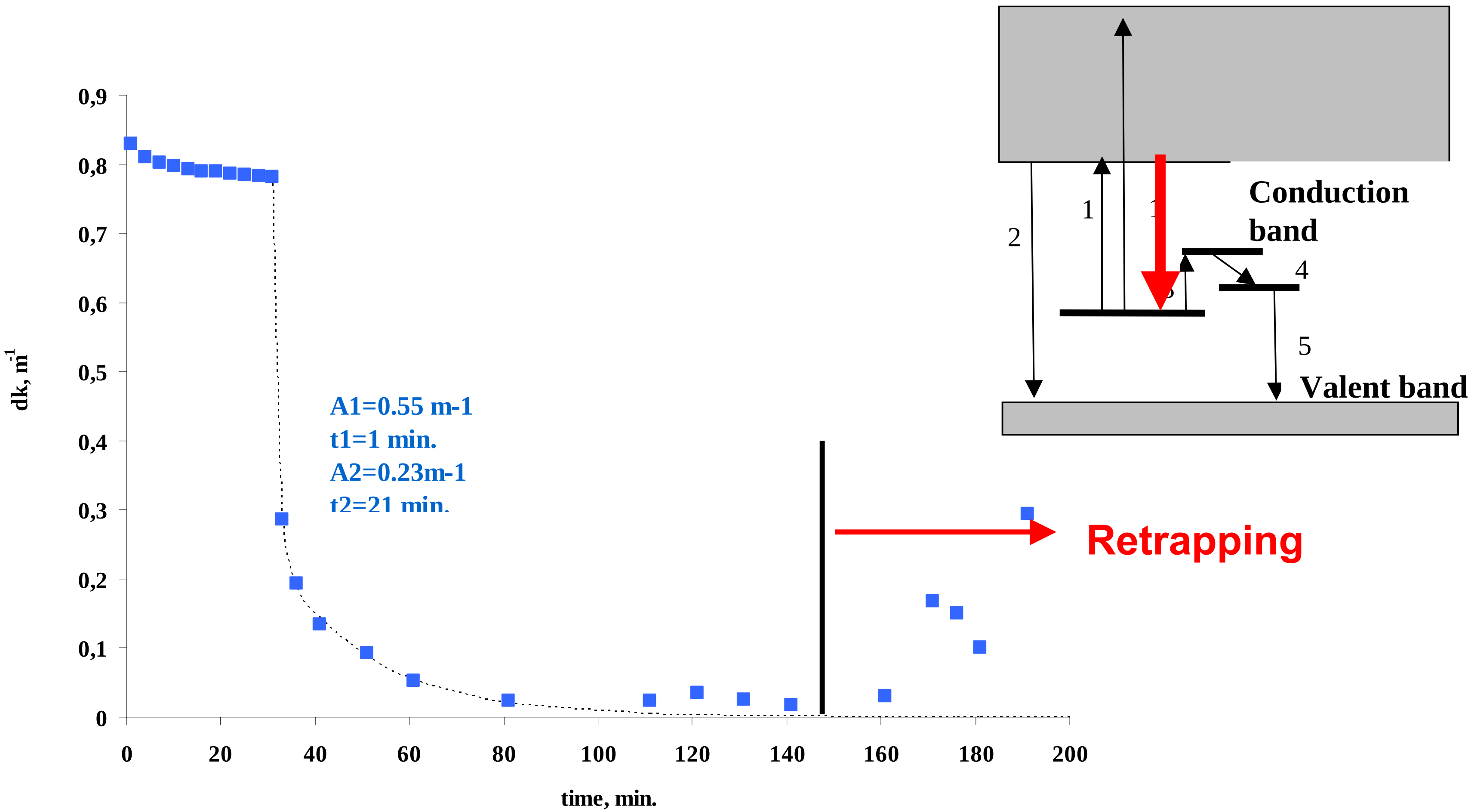
□- after 10 min. of recovery stimulation with IR source,

◊- after 30 min. of recovery stimulation with IR source.

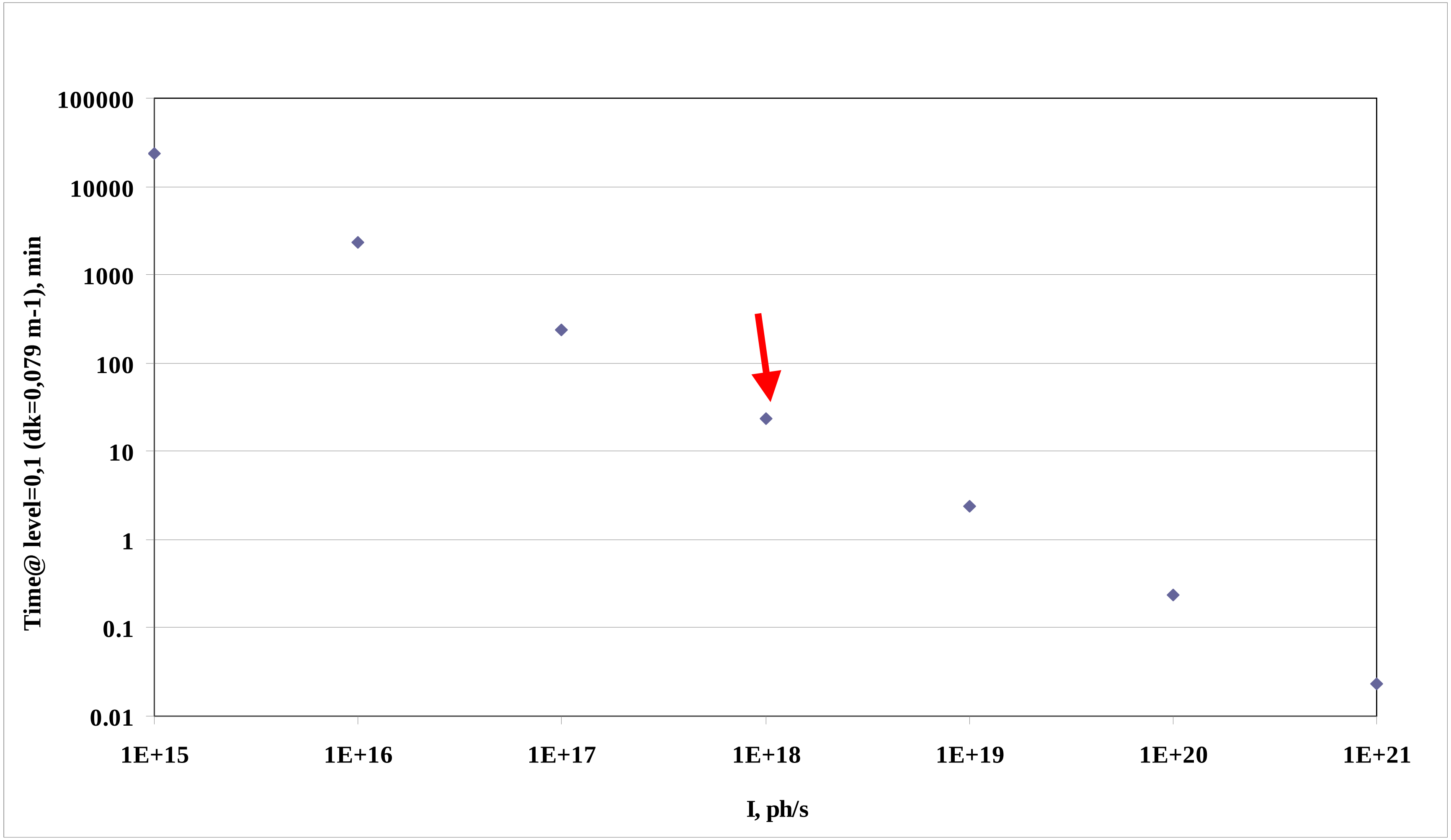
420 nm radiation induced absorption coefficient change due to spontaneous and stimulated recovery with IR(940nm), 2,4·10^{17} ph/(s·cm2), T=293K, 20cm long wrapped crystal.



420 nm radiation induced absorption coefficient change due to spontaneous recovery and ionization with blue light 464 nm, $4{,}4 \cdot 10^{17}$ ph/(s·cm^2), T=293K, 20 cm long wrapped crystal.

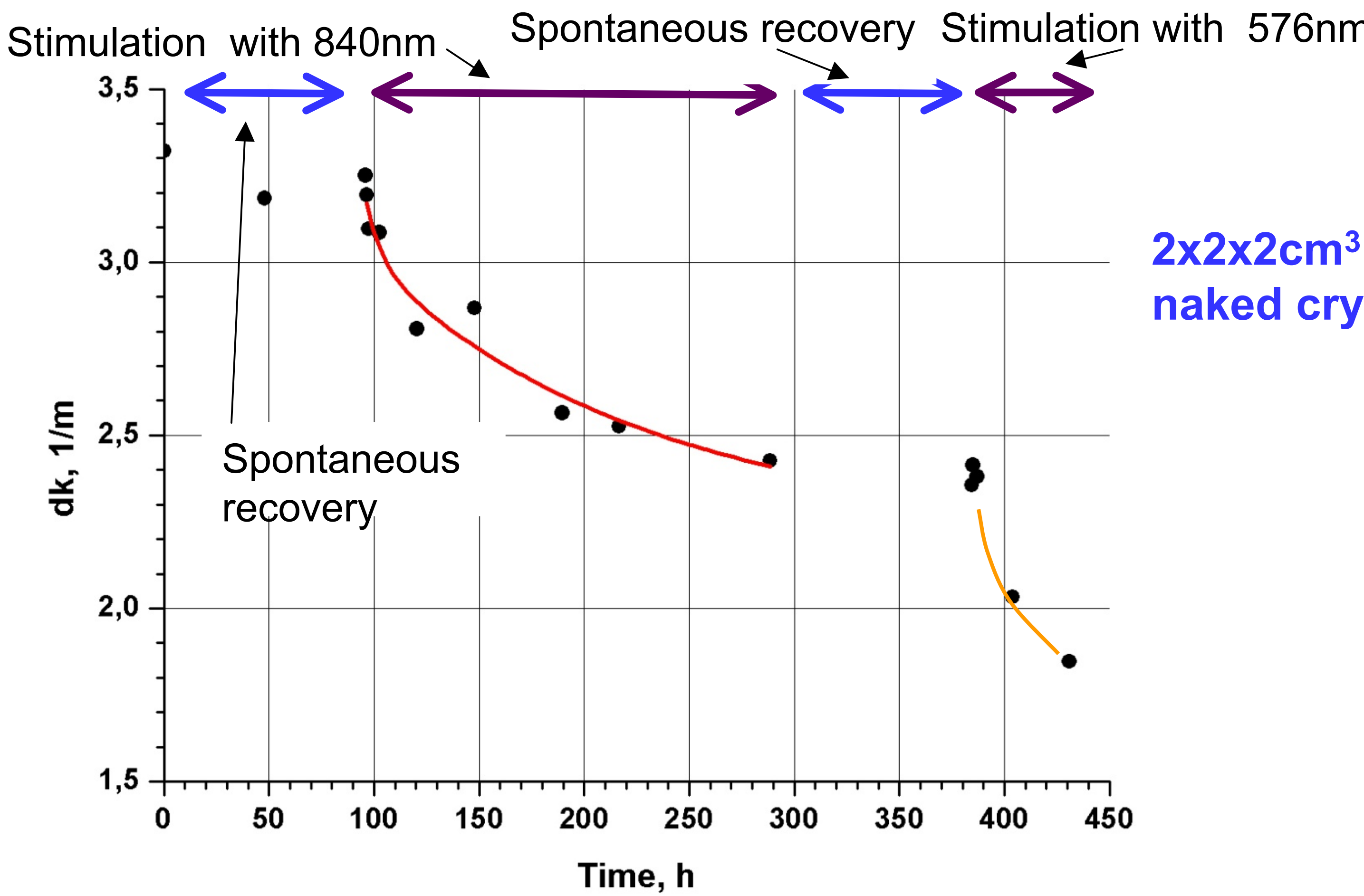


Time of IR (940 nm) stimulation needed to achieve 0.1 level of damage after γ- irradiation versus photons intensity (wrapped 20 cm long crystal).



Spontaneous and stimulated recovery of PWO crystal irradiated with protons ($1\cdot10^{13}$ p) and illuminated with IR ($5\cdot10^{16}$ ph/(s·cm^2))and visible light ($2\cdot10^{17}$ ph/(s·cm^2)).

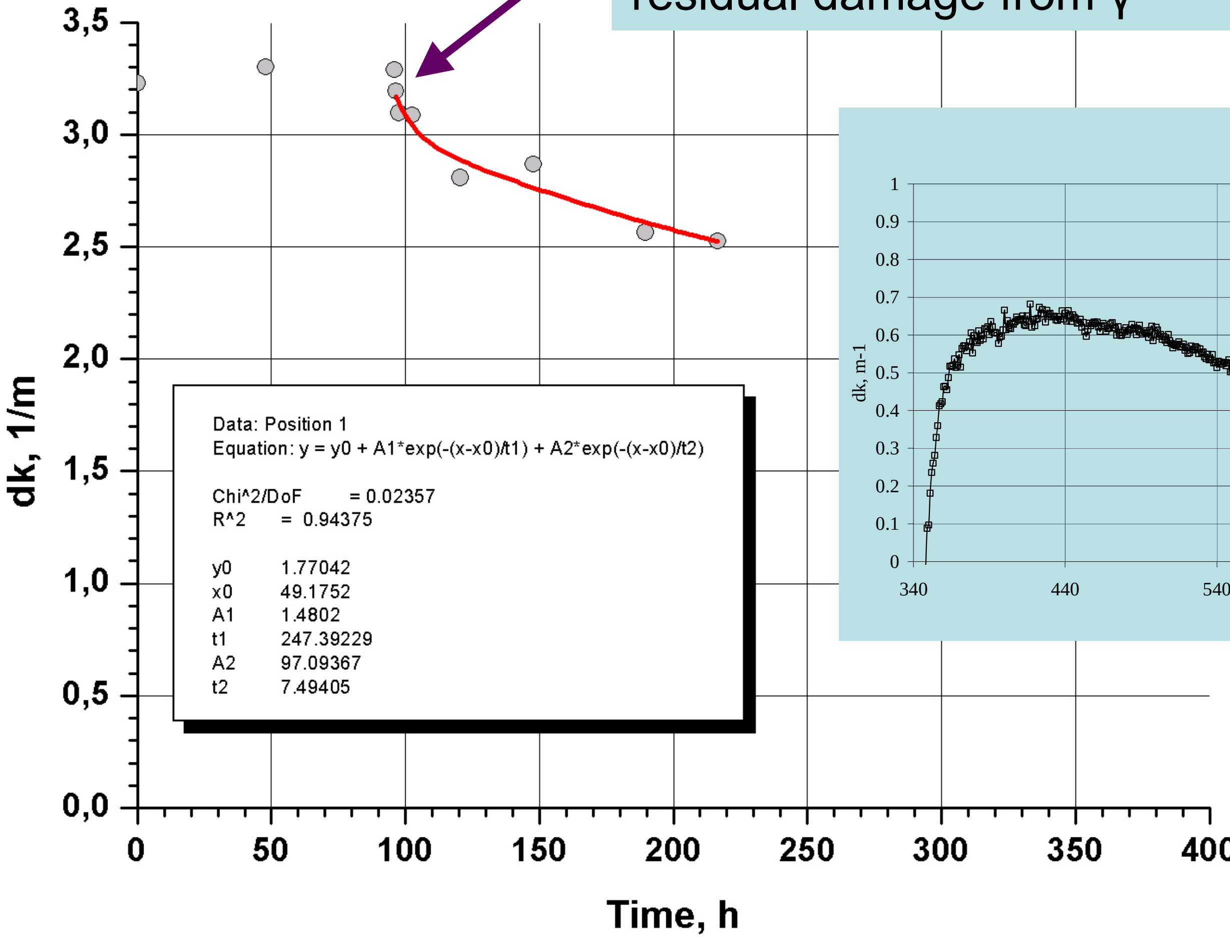
(Measurements have been performed at ETH, Zurich radiation damage research facilities)

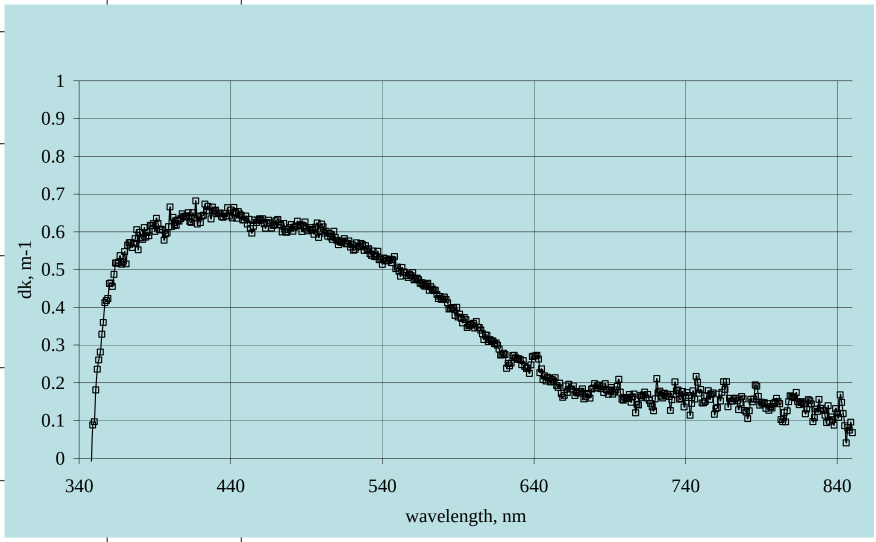


$2x2x2cm^3$ naked crystal.

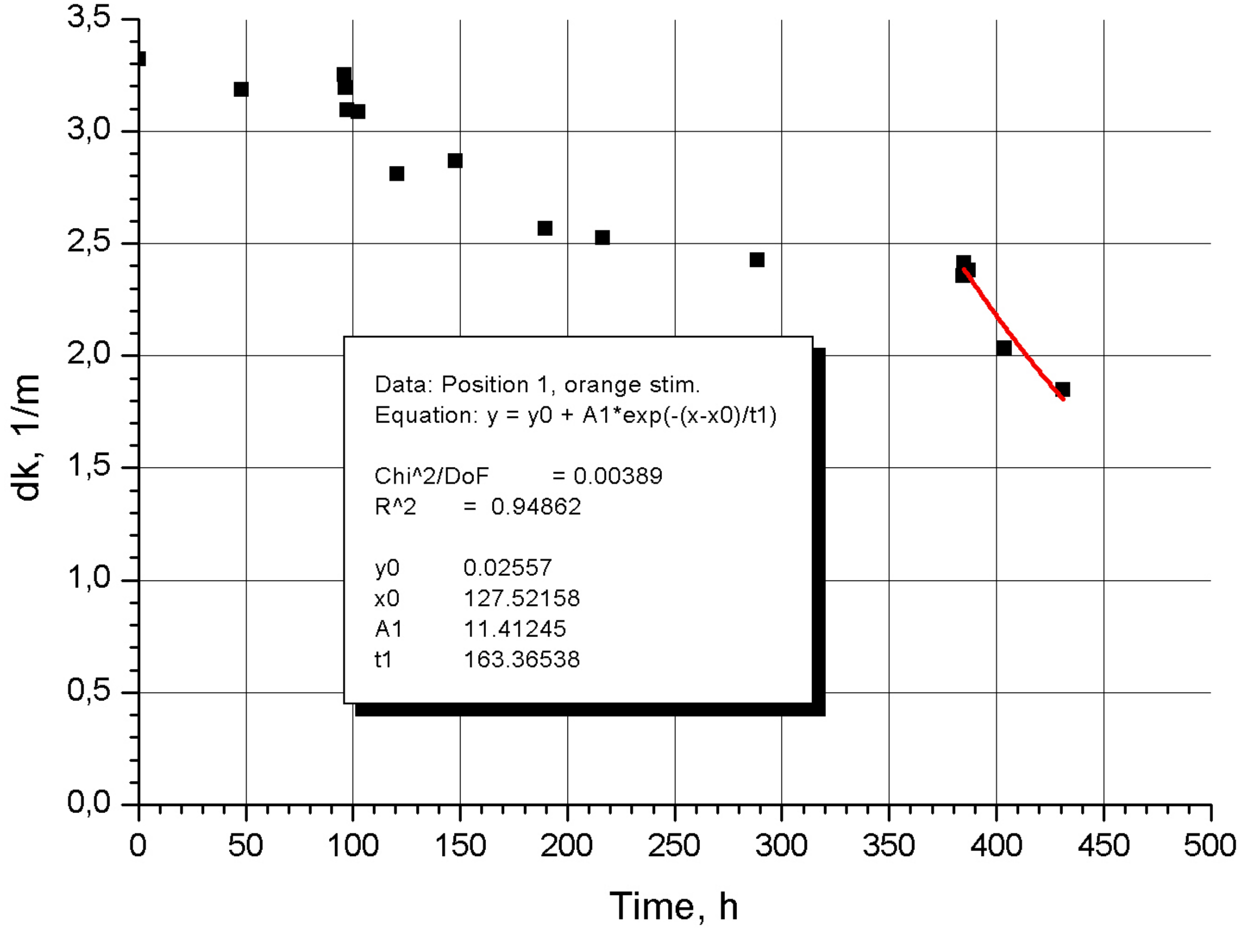
Spontaneous and stimulated recovery in PWO crystal irradiated with protons and illuminated with IR, 2x2x2cm^3 naked crystal

Stimulated fast recovery of residual damage from γ

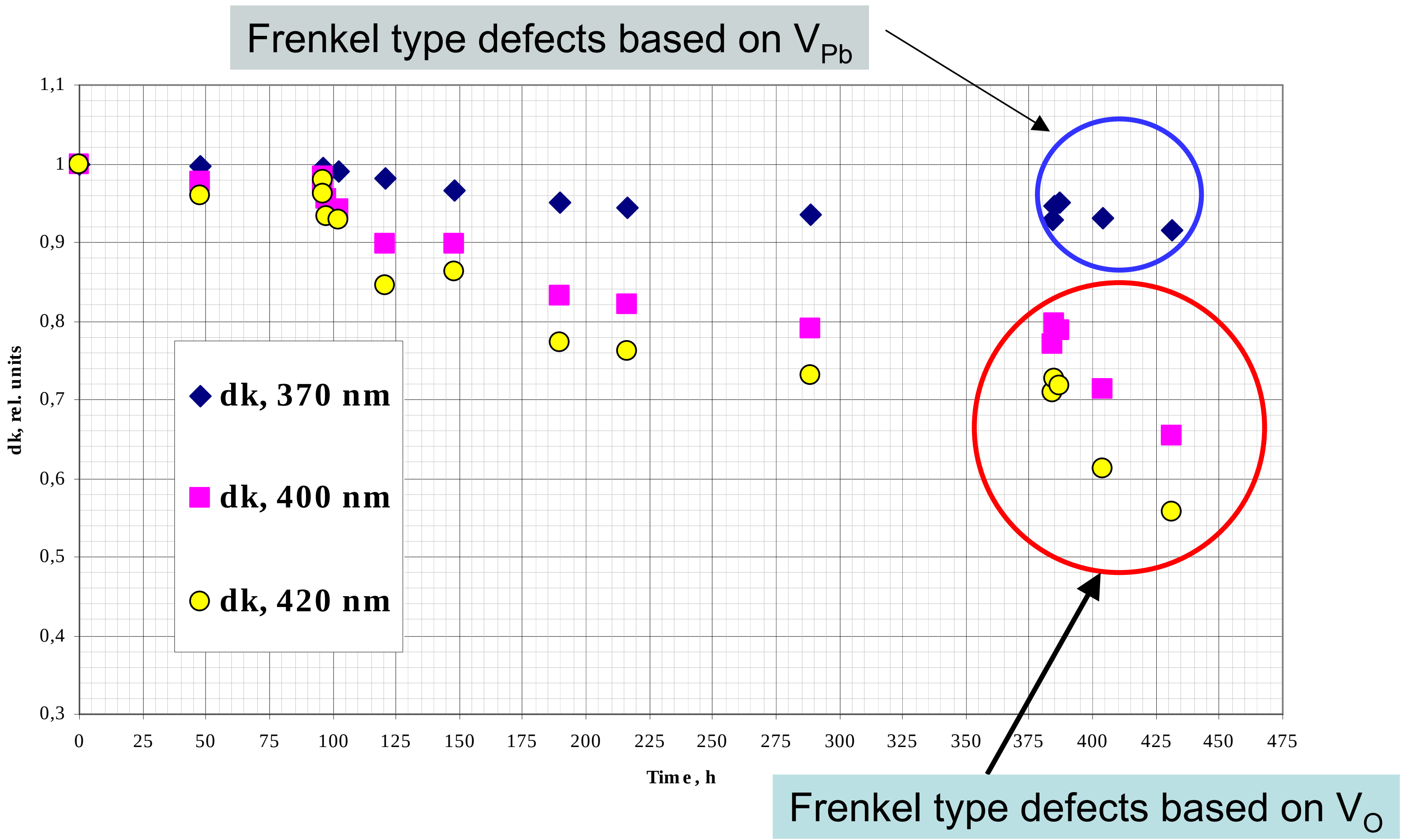




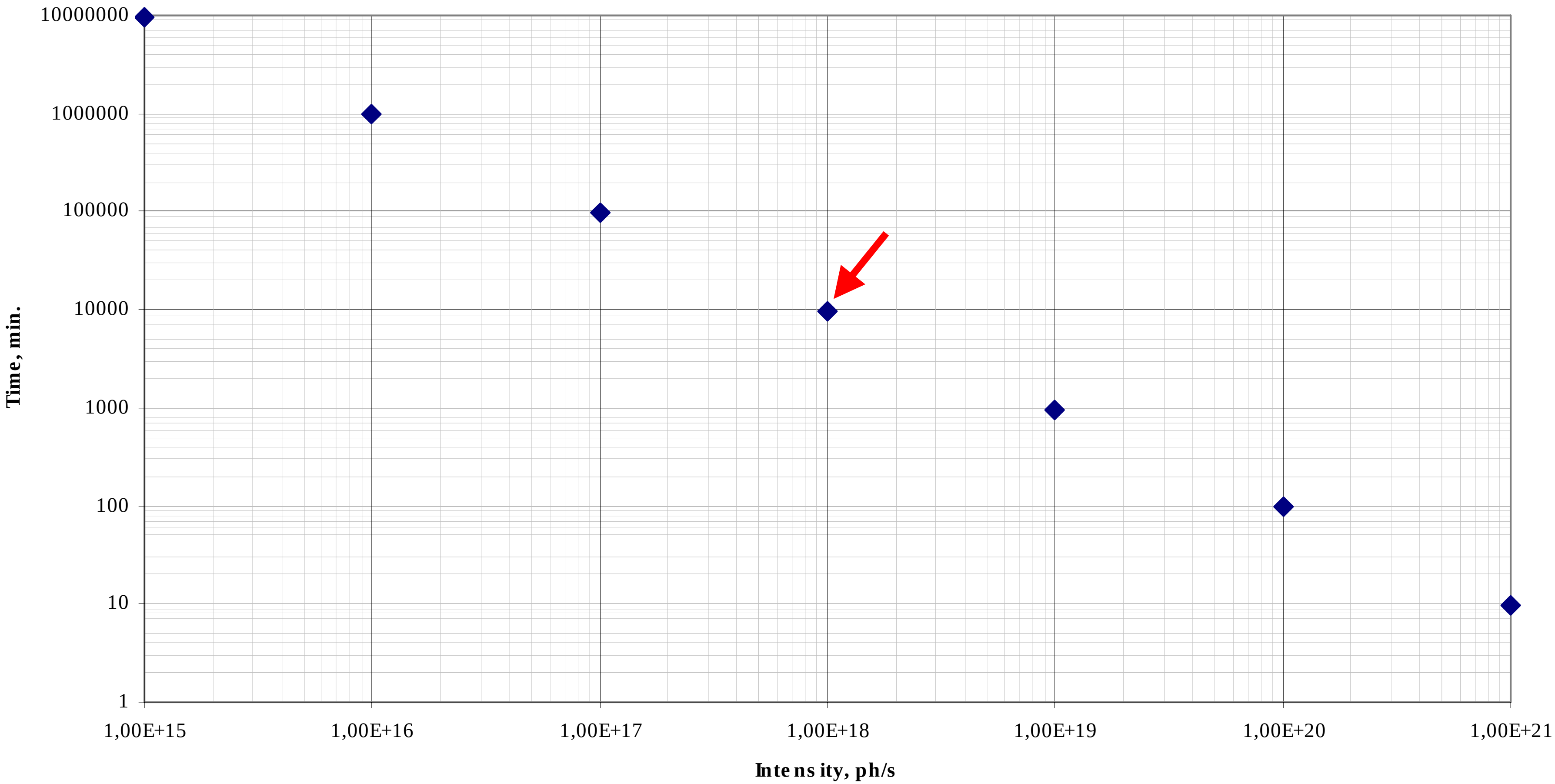
Spontaneous and stimulated recovery in PWO crystal irradiated with protons and illuminated with 576nm, 2x2x2cm^3 naked crystal.



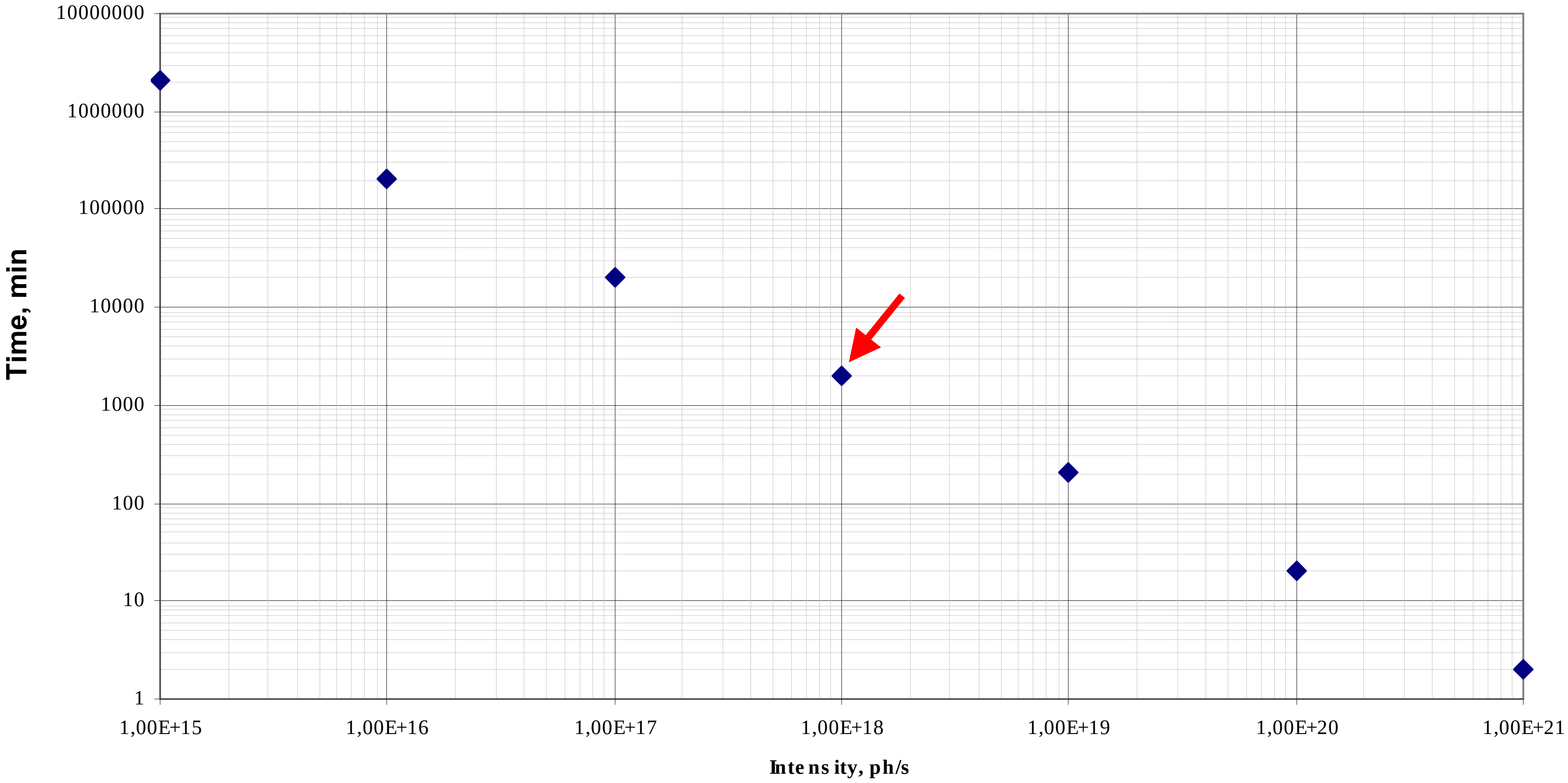
Relative change of the induced absorption coefficients at different wavelengths at stimulation.



Time of IR stimulation needed to achieve 0.1 level of damage after proton irradiation versus photons intensity, naked crystal.



Time of stimulation with visible light (576nm) needed to achieve 0.1 level of damage after proton irradiation versus photons intensity, naked crystal.



Time scale of stimulation process

- Time for crystal recovery by stimulating photon flux 10^{18} ph/s (1/3 of 1W-power limit for optical fiber):

  after gamma irradiation – 0.5 h (wrapped crystal at room temperature);

  after proton irradiation – 150 h (naked crystal at room temperature).

Conclusions

An application of the stimulated recovery method in lead tungstate scintillation crystals can change our mind how to operate PWO based Electromagnetic Calorimeters.

In-situ recuperation of the scintillation elements optical transmission by its recovery stimulation during the breaks or in parallel with data acquisition can substantially prolong life of the PANDA ECAL in an irradiation environment.

Developed approach may be important at operation of CMS and ALICE experiments at LHC and crucially important for them at Super LHC.