Scintillating crystals irradiation studies at ENEA-Casaccia Calliope photon irradiation facility

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Background radiation in SuperB

- SuperB Electromagnetic Calorimeter will be exposed to radiation doses higher than those collected up to now at B-factories
- End-cap regions will be particularly affected by the radiation coming from machine background, expected ≥ 0.5 rad/h
- This could lead to radiation-induced Light Yield (LY) variation in scintillating crystals
- **Most critical: “fast” LY variations following machine background due to collider Luminosity variations , τ(LY) ~ τ(beam)**
- Either short-term radiation-hard scintillators, or *pre-conditioned* ones, could be used in order to minimize this fast LY variations

Radiation damage in scintillating crystals

- Light Yield reduction mostly due to *radiation-induced absorption bands caused by color centre formation*. *This* ***reduces crystal's Light Attenuation Length*** *and hence the light output.*

Scintillation light is still produced but its transport efficiency is reduced

- Other minor effects come from reduced intrinsic scintillation LY and change in Light response uniformity (only some kind of scintillators)
- The radiation damage may be recovered at room temperature by thermal annealing. Thus a *slow recovery is preferred for crystals to be used in collider experiments*.
- BGO usually recovers with $\tau \in$ [hours,weeks] , while LYSO and undoped-CsI should have "high resistance - high damage persistence"

(R.-Y. Zhu, NIMA413(1998)297)

Our goal

High radiation doses with high dose-rate (Mrad , Mrad/h) could *condition* the crystals by inducing a severe damage, and consequently making them insensitive to further low radiation doses.

Goals of our tests:

- measure the radiation damage of BGO with dose (rates) close to what expected in SuperB + safety factor
- Investigate the high-dose conditioning for BGO
- Possibly include measurements on LYSO and undoped-CsI
- Set up a test stand and establish protocol for further measurements

SuperB background expectations (EndCap):

0.5 rad/h - 10 rad/d - 3 krad/y - 30 krad total

Experimental setup

Crystals samples:

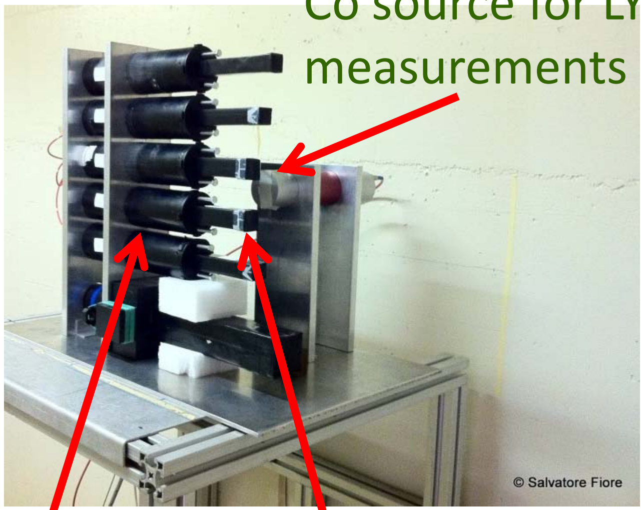
- 2 BGO from L3 experiment (2.2x2.2x18 cm^3)
- 2 BGO from SICCAS (brand new) (2.5x2.5x16 cm^3)
- 1 LYSO (2x2x20 cm^3)
- 1 large undoped CsI (5x5x30 cm^3)

- Standard VME ADC + TDC DAQ

The radiation source: Calliope facility at Casaccia ENEA centre:

- ^{60}Co radioactive sources array, 1.1-1.3 MeV γ
- 6x7 m^2 irradiation cell, different irradiation positions
- dose rate from few rad/h to Mrad/h

Experimental setup (1)



Co source for LY measurements

PMTs

crystals

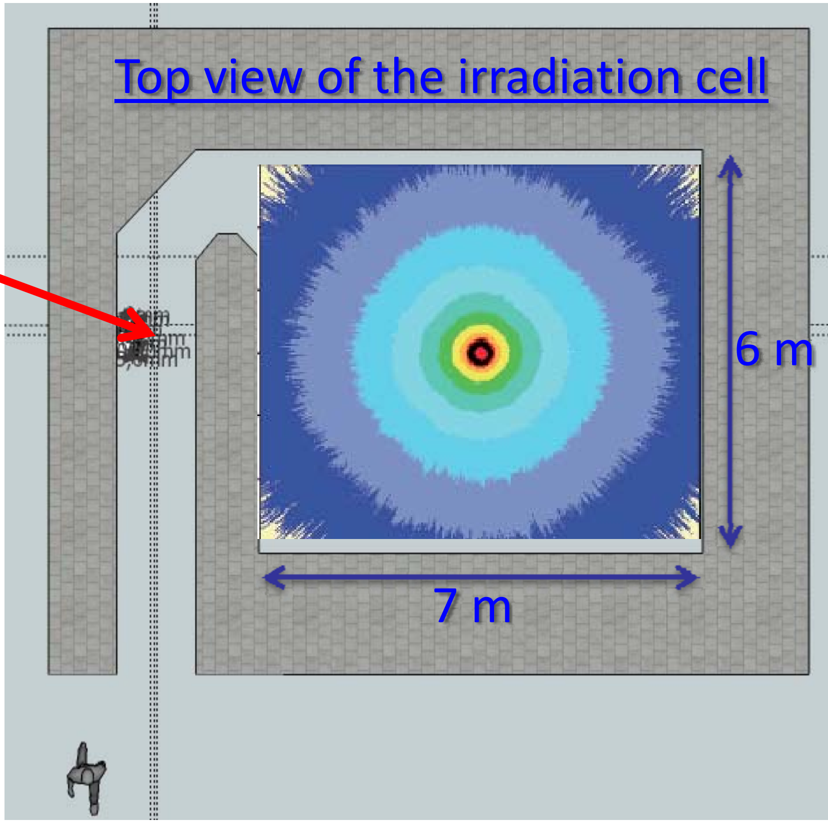
First measurement setup:

crystals on PMTs during irradiation

HV ON during fast measurements between irradiations

HV standby during irradiation

In the gangway: ~5 rad/h dose rate

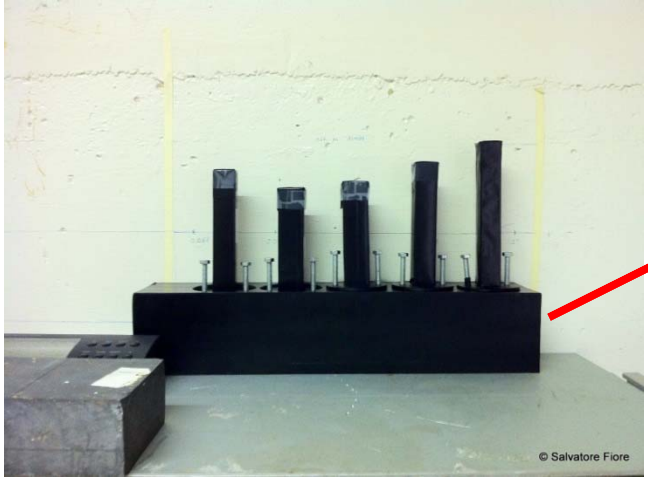


Top view of the irradiation cell

Experimental setup (2)

Second measurement setup:
specific gain drift for our PMTs requires a long gain stabilization time, thus we decided to irradiate the crystals without PMTs and place PMTs with HV ON outside irradiation zone.

In this configuration the radiation dose was precisely known.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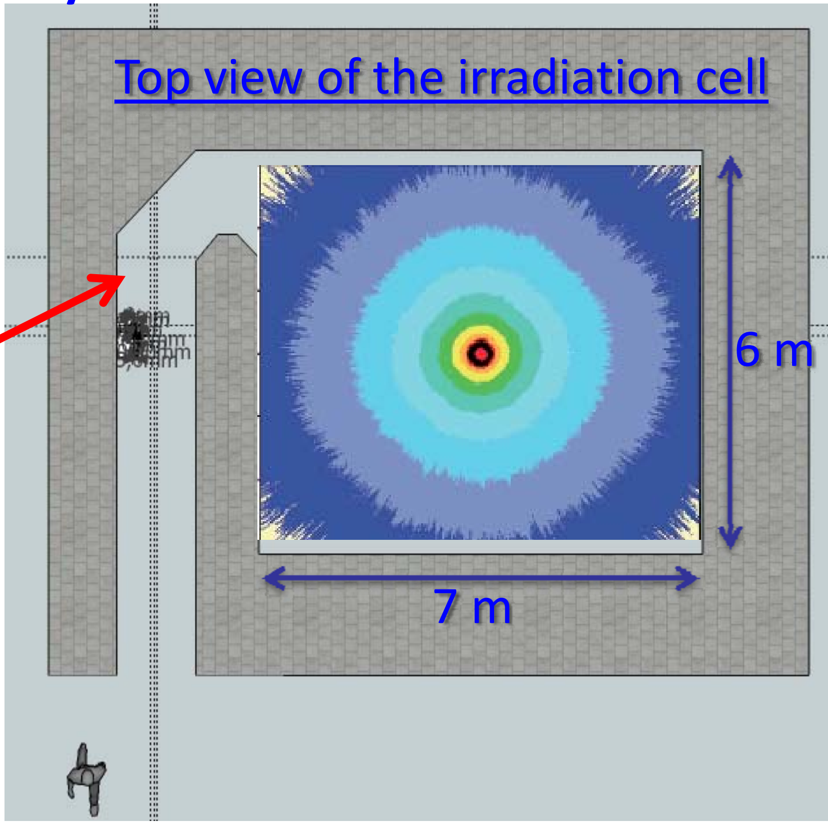
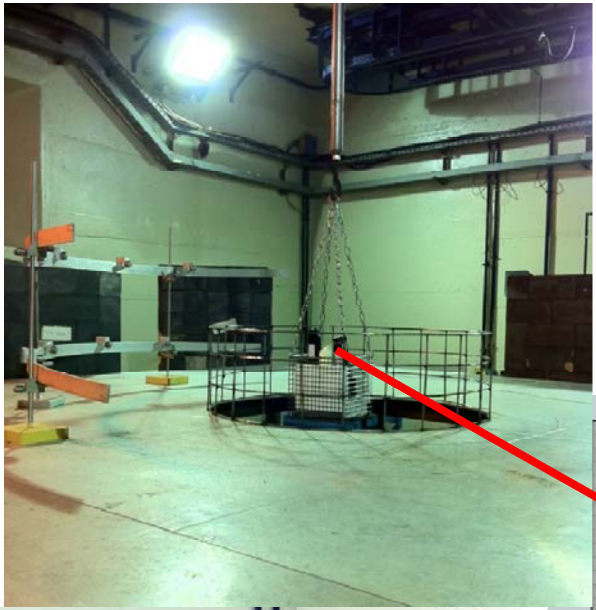
On the gangway side: 10 rad/h dose rate

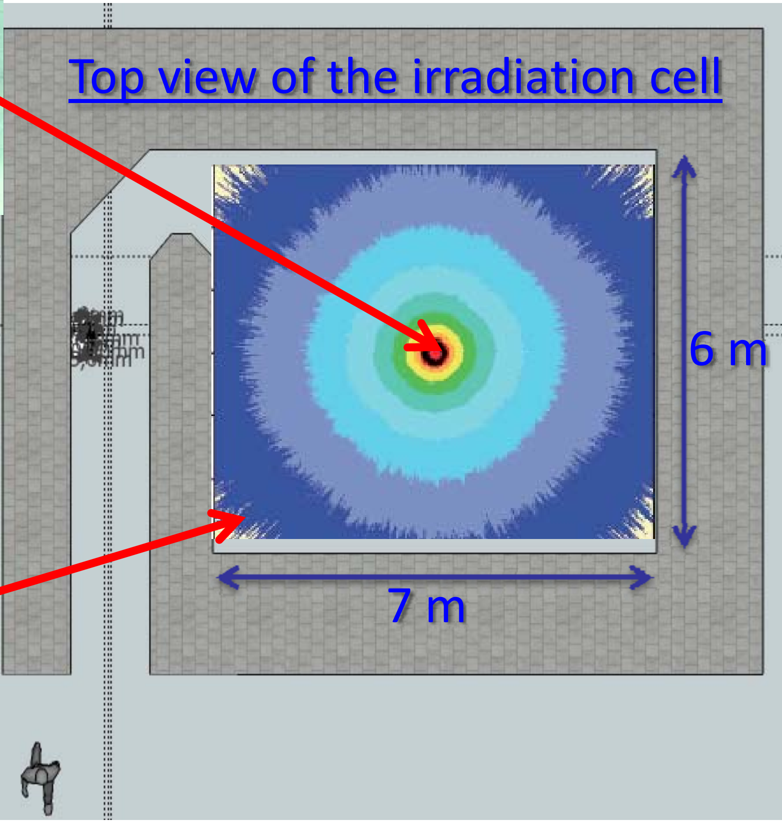

Top view of the irradiation cell

Experimental setup (3)

Other irradiation positions:



Source centre:
230 krad/h dose rate



Top view of the irradiation cell

In a lead box inside the cell: 1,5 rad/h dose rate

Irradiation profiles

★ = 2.5h irradiation @ ~8rad/h

Recovery #1

★ = 2.4h irradiation @ ~8rad/h

Recovery #2

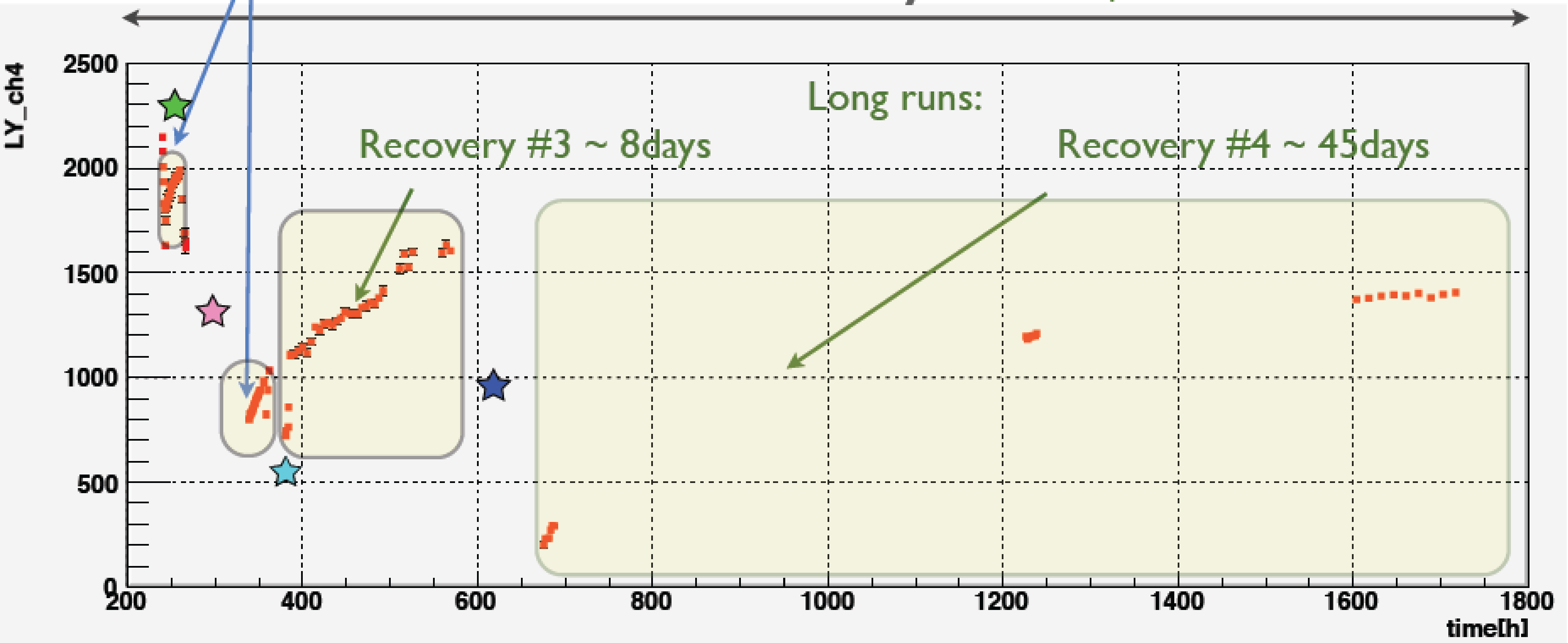
★ = 1day irradiation @ 10rad/h

Recovery #3

★ = 3days irradiation @ Mrad/h

Recovery #4

Each crystal has a complex irradiation history: this is BGO L3 #1



Short runs:
Recovery #1,2 ~ 15h

~60 days

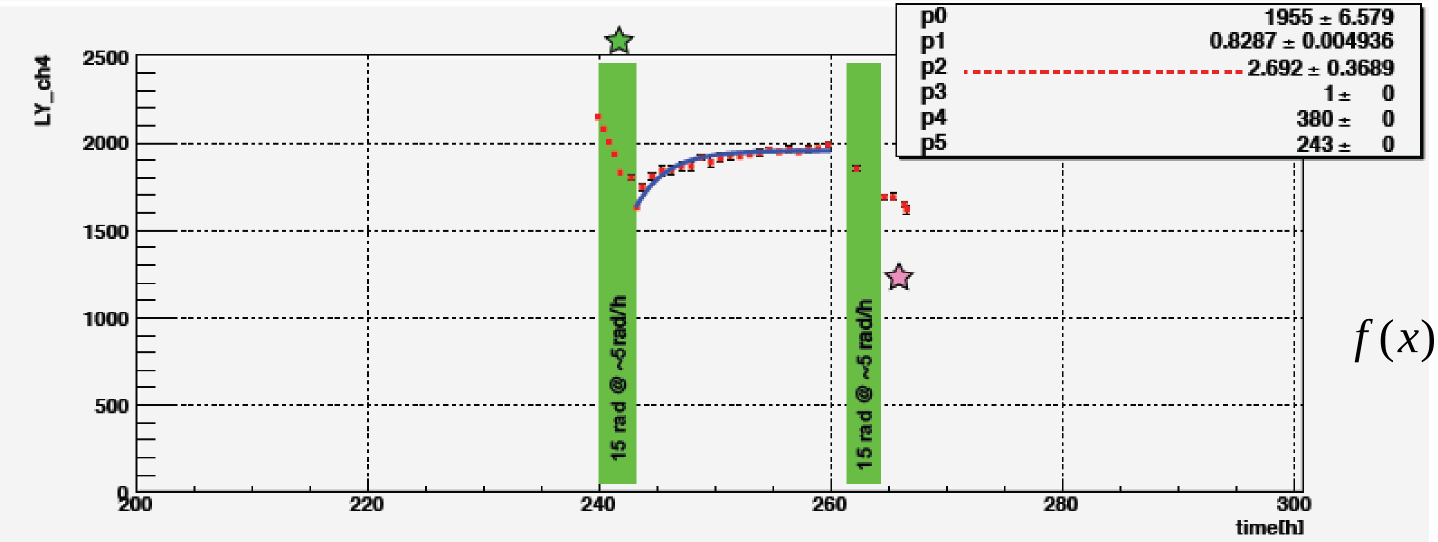
Long runs:

Recovery #3 ~ 8days

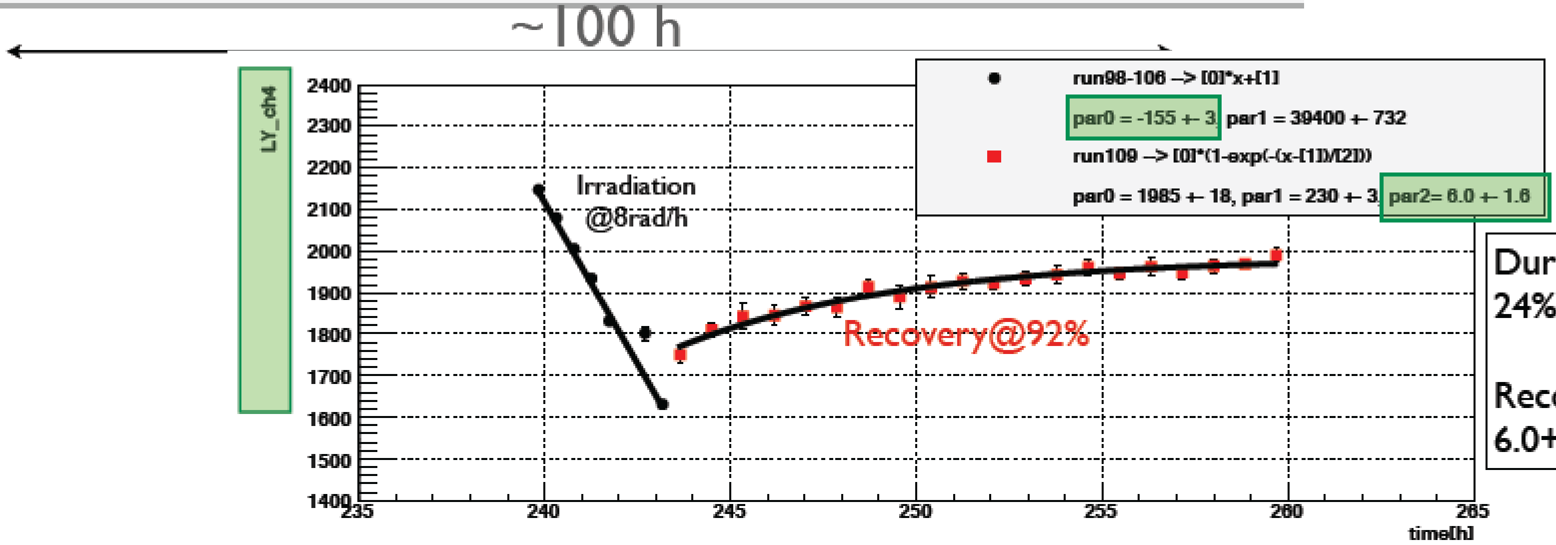
Recovery #4 ~ 45days

Total recovery after few rad

- Few rad at ~5 rad/h induce a damage which is quickly and almost completely recovered (single-exponential function) τ_{fast}=2.7 h



$$f(x)=P_0\left(1-(P_3-P_1)e^{-\frac{x-x_0}{P_2}}\right)$$



During irradiation: 24%drop

Recovery time 6.0+- 1.6 h

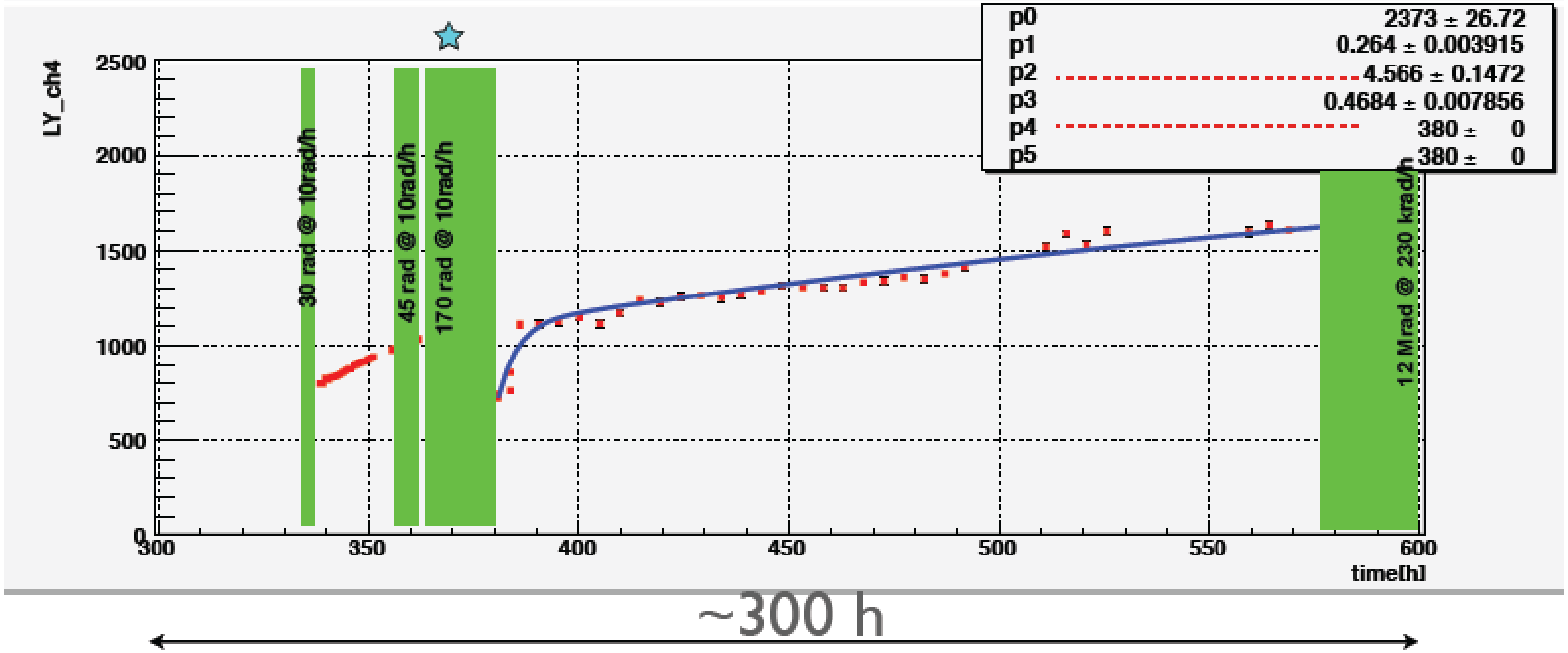
Two-component recovery profile for 10^2 rad

- Hundreds of rad at 10 rad/h induce a damage which is partly quickly recovered (fast component of a double-exponential function) leaving a persistent LY attenuation (slow component)
- τ_{fast}=4.5 h

Two Components Fit Function:

☆ = irradiation @ 10rad/h

$$F(x) = P0^{*}(1 - (P3-P1)\exp(-(x-xin)/P2) - (1-P3)\exp(-(x-xin)/P4))$$



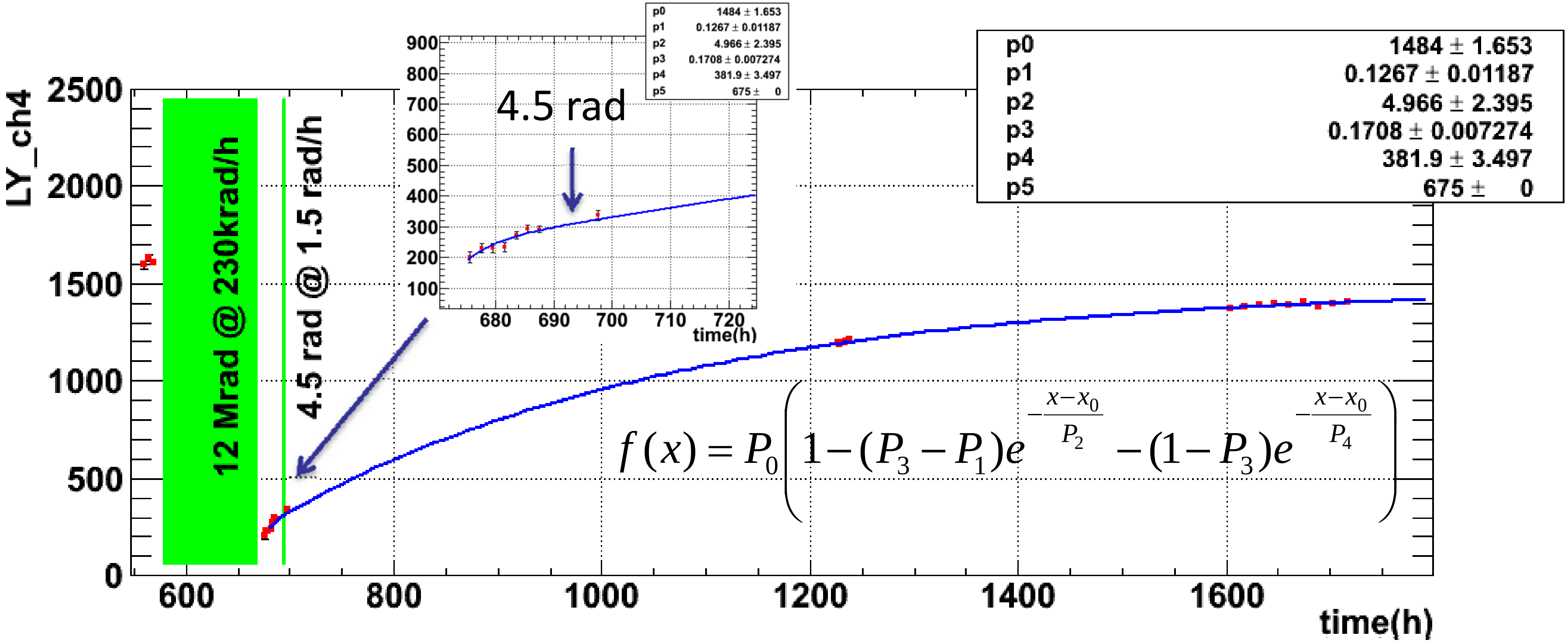
Summary for BGO L3#1

Irradiation	Drop wrt LY0	τ1 = P2[h]	τ2 = P4[h]
15 rad @ ~5rad/h	25%	2,7±0,4	/
15 rad @ ~5rad/h	64%		
170 rad @ 10rad/h	67%	4,5±0,2	380,3 fixed
12 Mrad @ 230 krad/h	90%	4,2±2,2	380,3±3,3

In the following I will focus on the effects of long (days) irradiations at low (10 rad/h) and high (0.2 Mrad/h) dose rates, and the related conditioning effect on BGO crystals

BGO L3 #1

- This sample shows large LY attenuation (1/5 of the pre-irradiation value) after 12 Mrad irradiation at 230 krad/h
- <u>Two-component LY recover</u>
- No visible effect from subsequent short low-rate irradiation

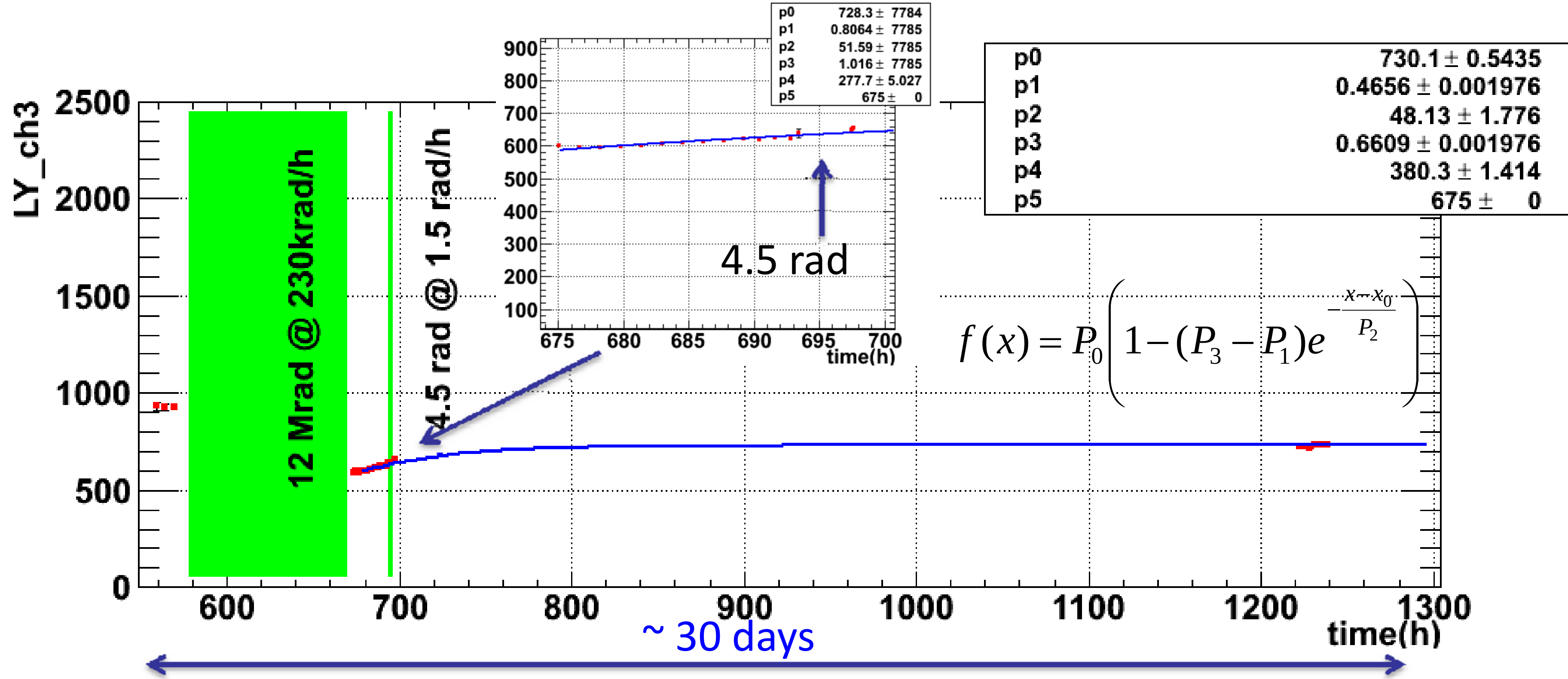


$$f(x) = P_0\left(1-(P_3-P_1)e^{-\frac{x-x_0}{P_2}}-(1-P_3)e^{-\frac{x-x_0}{P_4}}\right)$$

~ 50 days

BGO SIC #2

- This sample shows smaller LY attenuation (2/3 of the pre-irradiation value) after 12 Mrad irradiation at 230 krad/h
- Single-component LY recover
- No visible effect from subsequent short low-rate irradiation

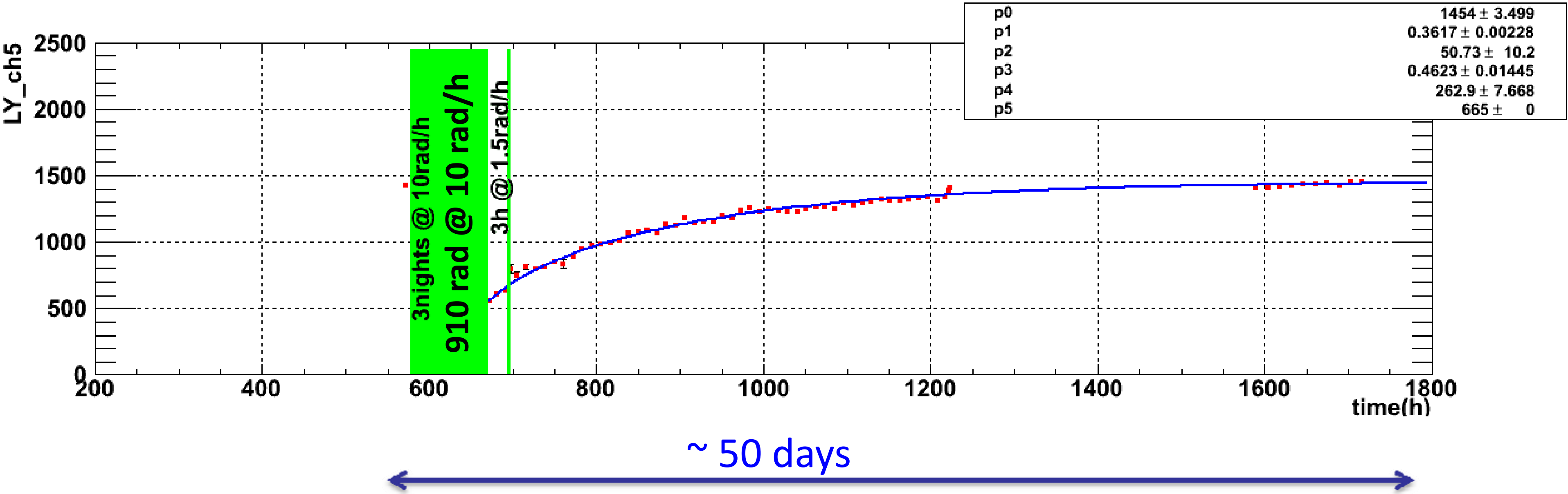


$$f(x) = P_0\left(1-(P_3-P_1)e^{-\frac{x-x_0}{P_2}}\right)$$

BGO L3 #2

This sample was exposed to a **lower dose w.r.t. the previous**:

- ~1 krad at 10 rad/h, drops at ½ the pre-irradiation LY
- Two-component LY recover
- No visible effect from subsequent short low-rate irradiation, although the dose is 10^{-4} the one given to L3#1 and SIC#2

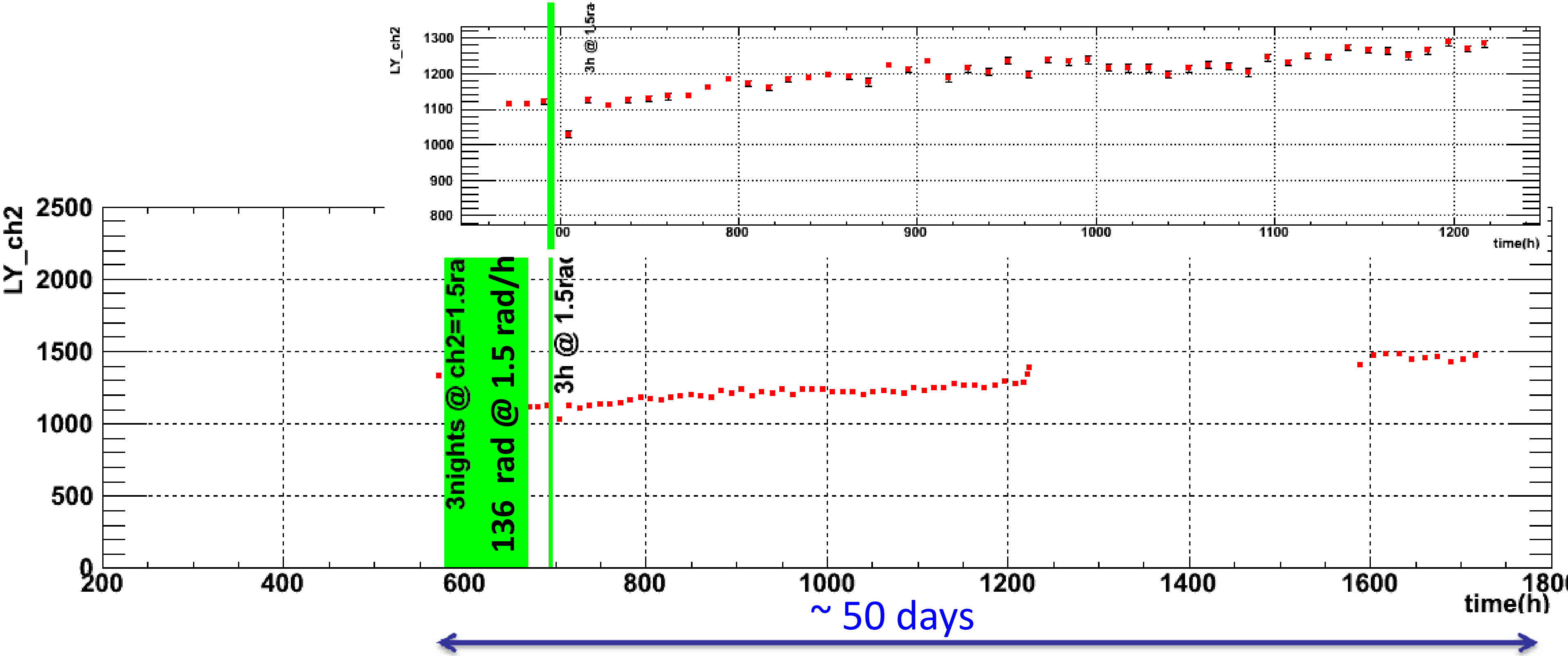


~ 50 days

BGO SIC #1

This sample was exposed to a **very low dose** and rate w.r.t. the previous:

- 136 rad at 1.5 rad/h, looses only 20% of the pre-irradiation LY
- In this case a further short irradiation, at the same dose rate, further reduces the LY: no conditioning

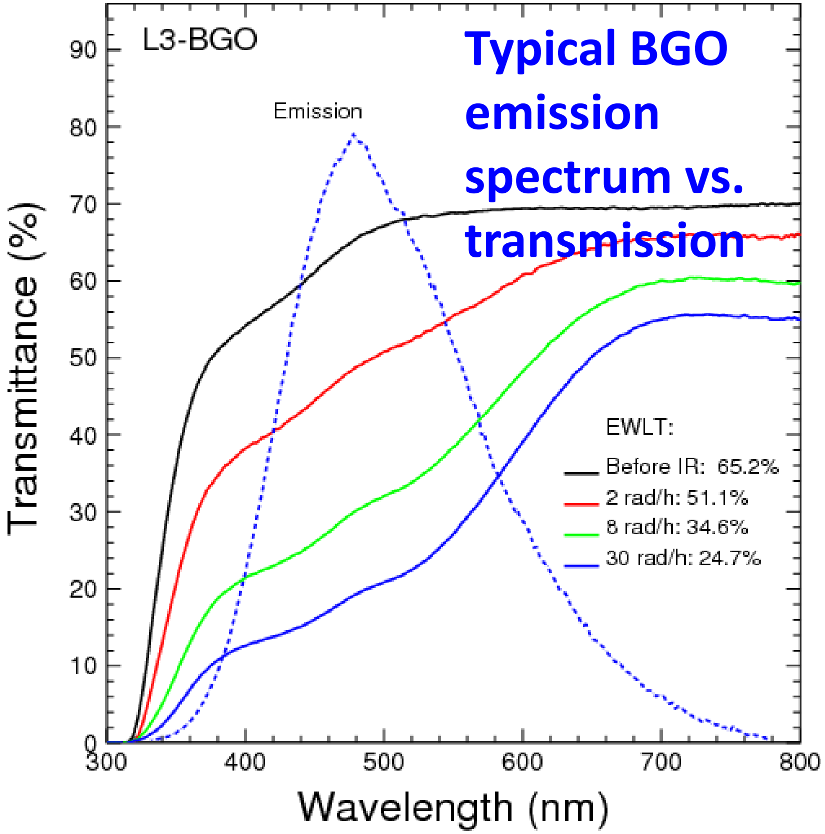


Light Trasmission measurements

- An independent method to evaluate radiation damage is the measurement of Light Transmission through the crystals
- In this way **we can measure the change in light attenuation due to radiation-induced color centre formation**
- A spectrophotometer sends a monochromatic light beam through the crystal and measures the transmitted intensity with respect to light wavelength

Comparing Light Yield and Transmission

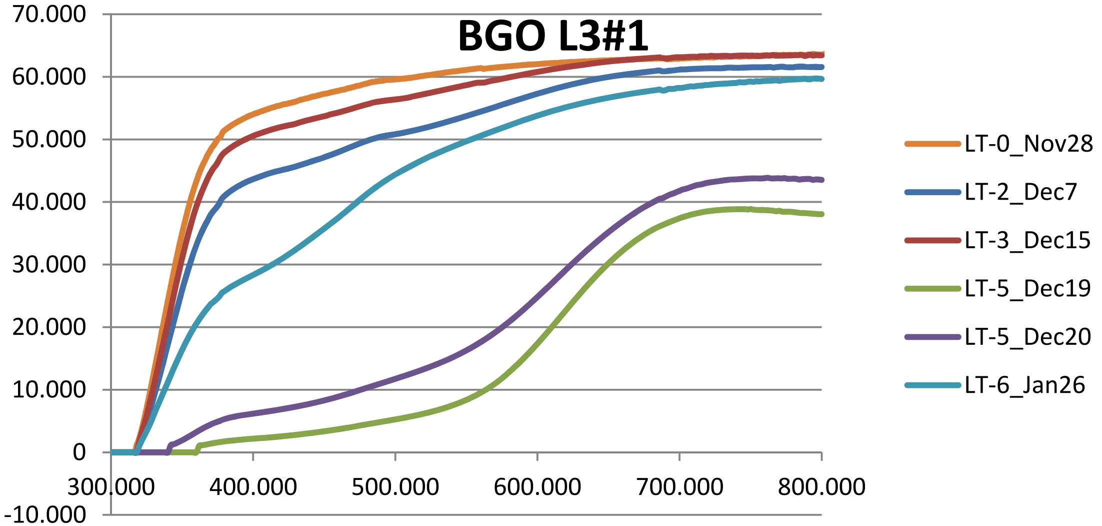
- Since the emission spectrum for BGO is peaked at 480 nm, a rough comparison between Light Yield and Transmission can be done by taking the Transmission values at 480 nm and comparing with measured LY, in the same moment of the irradiation history of one crystal

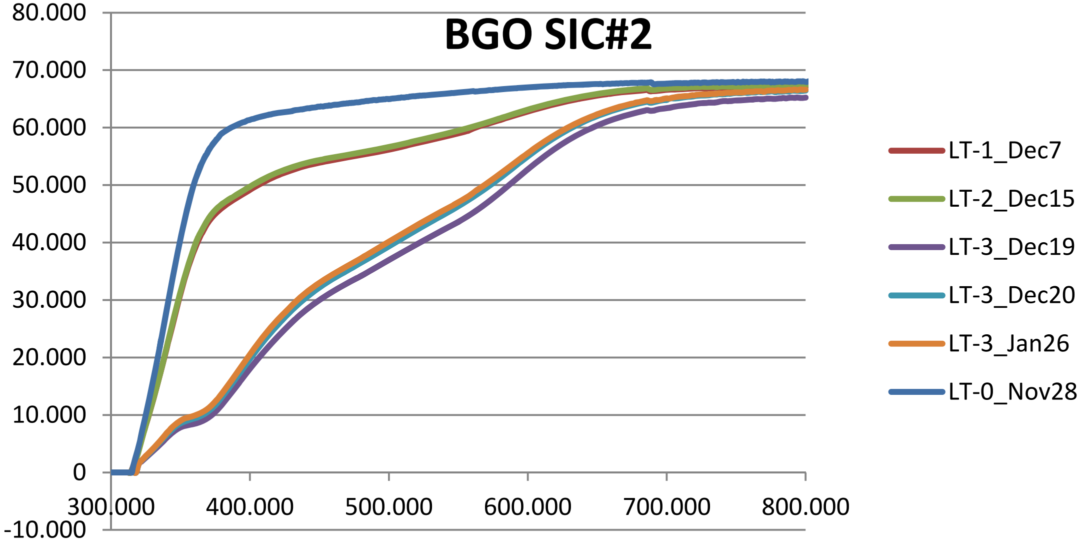


Typical BGO emission spectrum vs. transmission

Transmission spectra

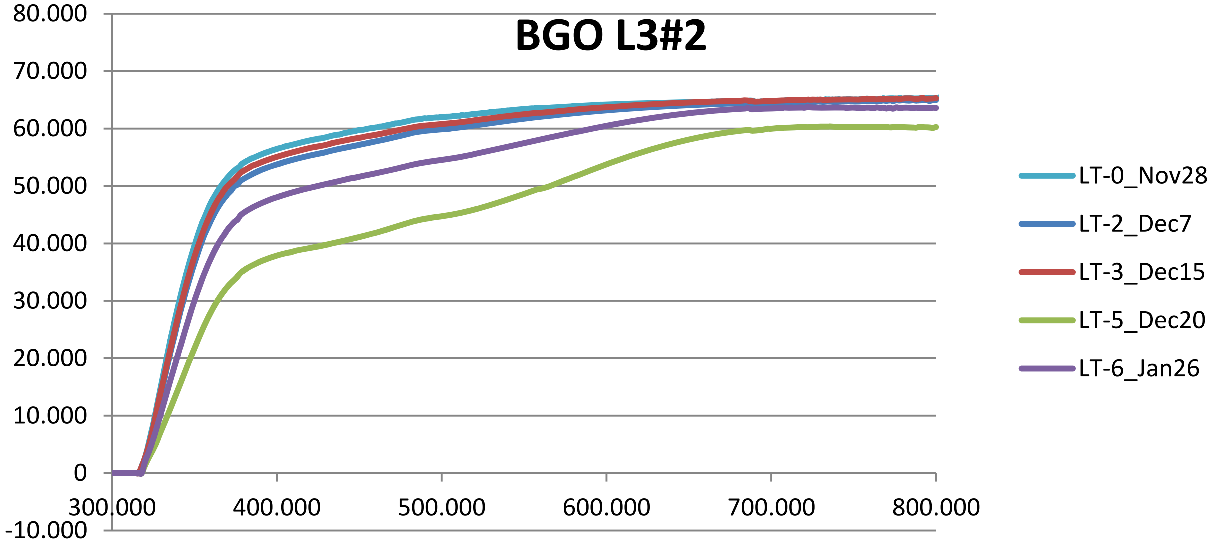
- Severe transmission reduction and distortion in the crystals which have been intensively irradiated
- Different recover is visible, confirming the LY measurements

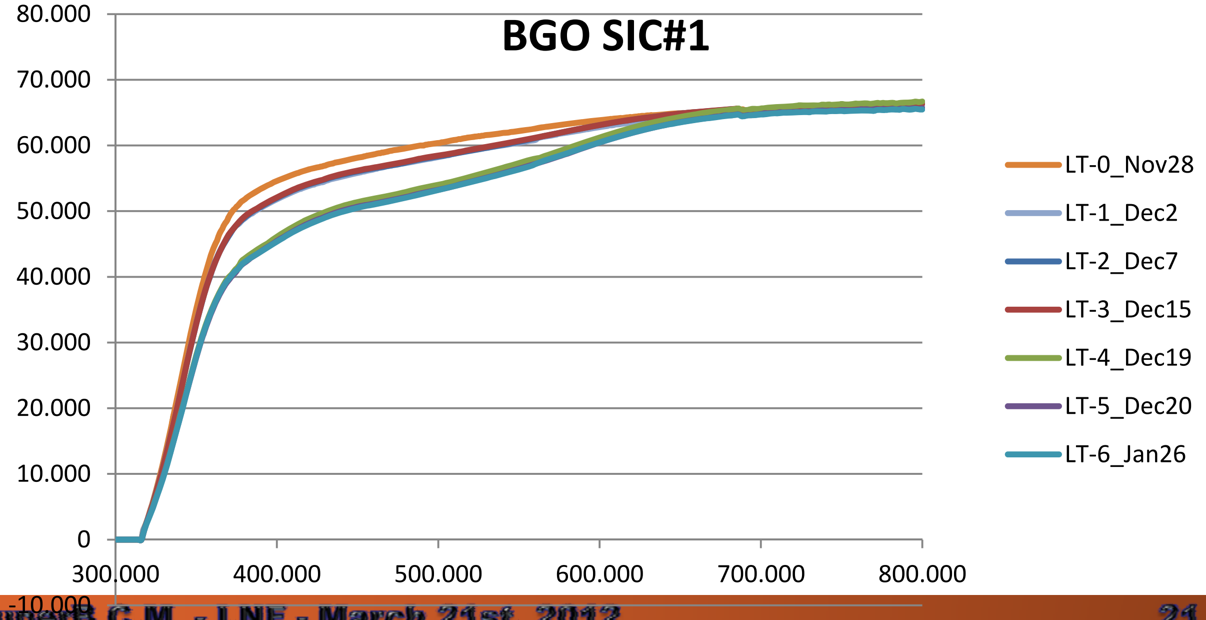




Transmission spectra

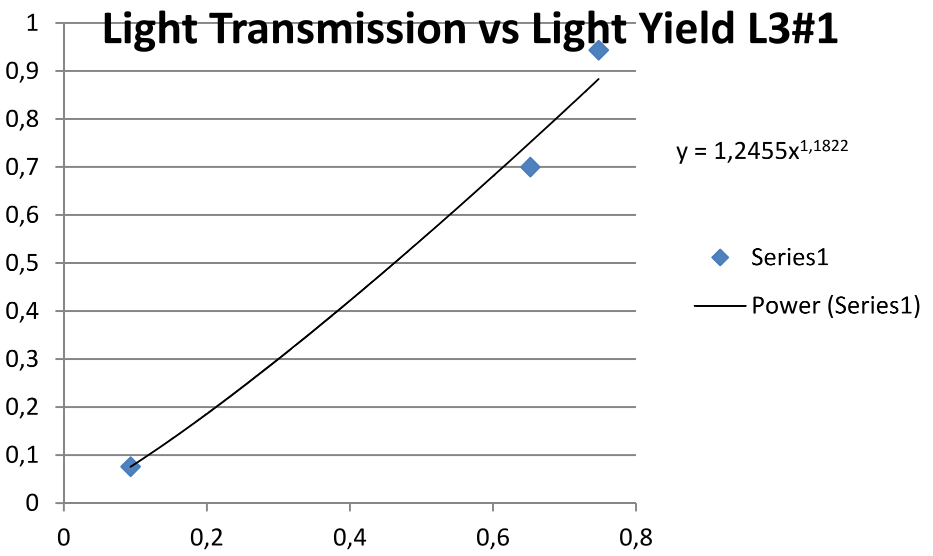
- Minor Transmission reduction due to low intensity irradiation

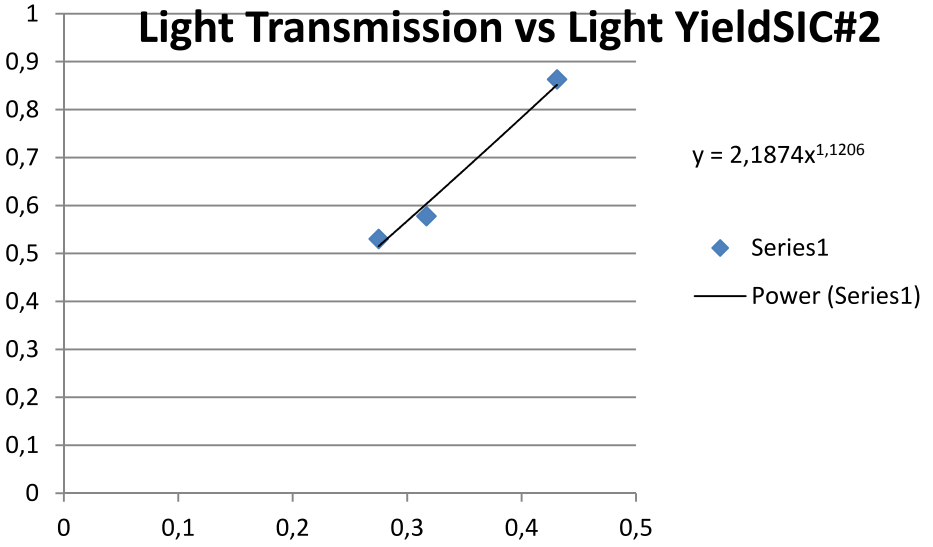




Relative Light Transmission vs Relative Light Yield

- Relative Transmission values @480 nm are compared with Relative LY values
- Measurements made in the same day
- Expected: LT/LT0$\propto$(LY/LY0)^α





Conclusions

- No visible effect from short low-rate irradiation (rad/h) after high dose, high dose-rate irradiation (≥1krad @ 10 rad/h) of BGO crystals. This should be confirmed by low-rate irradiations once the LY has reached its recovery plateau
- Light Yield and Light Transmission trends are in agreement (to be further investigated)
- Few more information from BGO to be extracted

Further investigation with new irradiation campaign would add knowledge to these effects:

- once the LY has reached its recovery plateau, further measurements after low-rate irradiations would confirm the high radiation dose conditioninig
- prolongued low-rate irradiation would allow to measure the LY drop saturation