Optical Bleaching and Thermal Annealing in PWO Crystals

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EM Dose Induced Damage

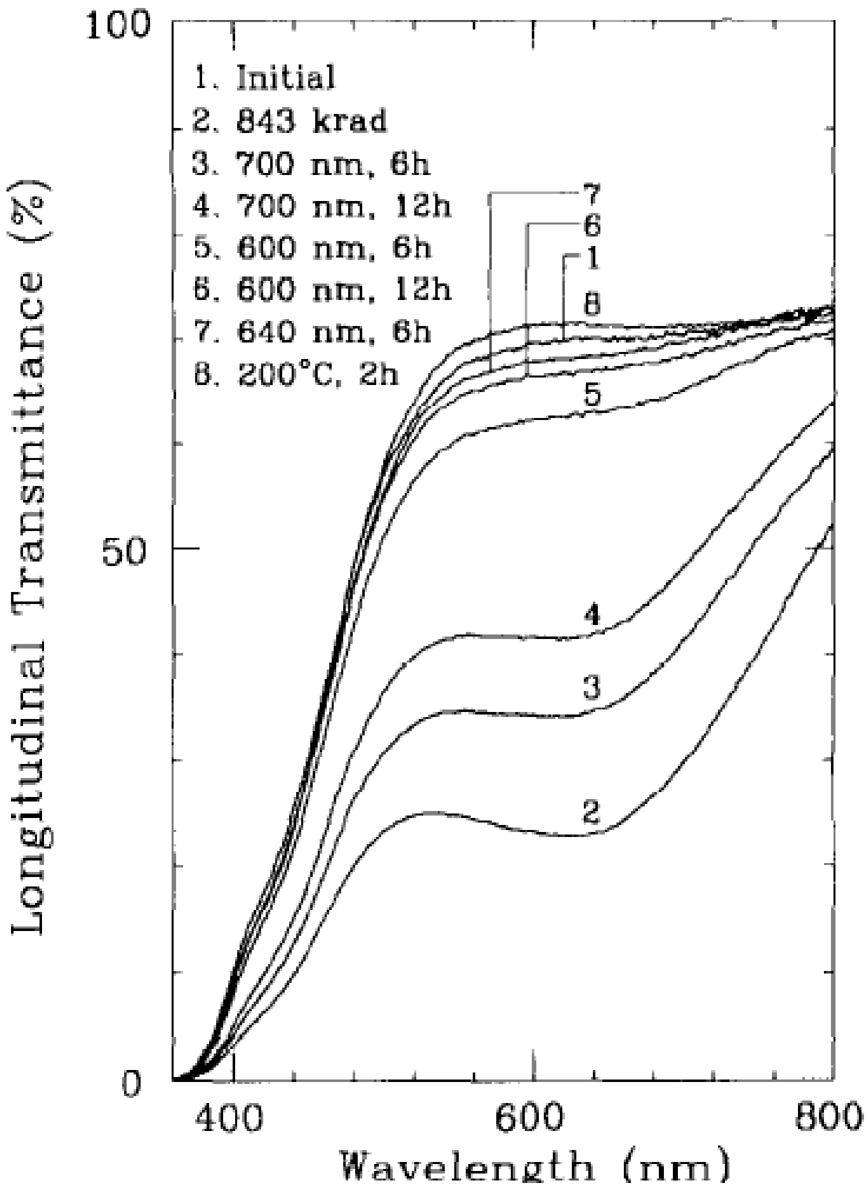
NIM A413 (1998) 297-311

Radiation damage effect in crystal scintillators

Crystal	CsI(Tl)	CsI	BaF_2	BGO	$PbWO_4$
Color centers	Yes	Yes	Yes	Yes	Yes
Phosphorescence	Yes	Yes	Yes	Yes	Yes
Scintillation	No	No	No	No	No
Recovery at room temperature	Slow	Slow	No	Yes	Yes
Dose rate dependence	No	No	No	Yes	Yes
Thermal annealing	No	No	Yes	Yes	Yes
Optical bleaching	No	No	Yes	Yes	Yes

OB and TA are Effective for PWO

NIM A376 (1996) 319-334

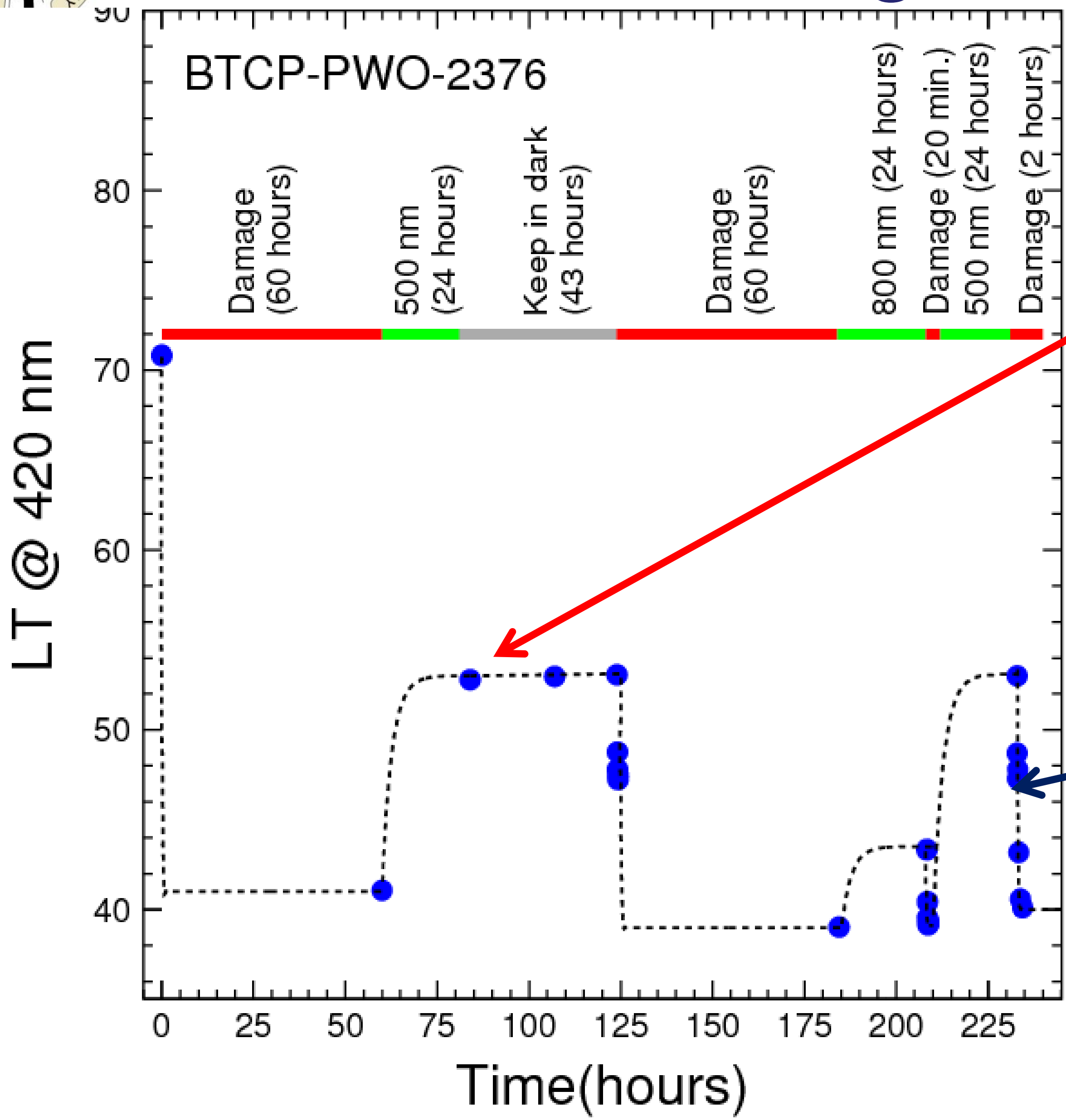


The radiation induced absorption can also be reduced by either optical bleaching or thermal annealing. It is known that the color centers in crystals can often be entirely eliminated by heating the crystal to a high temperature, a process know as thermal annealing [6]. By injecting light into the crystal, the color centers can also be eliminated by the process of color center annihilation [20], and the effectiveness of this optical bleaching is known to be wavelength dependent.

Optical bleaching and thermal annealing for sample 768

Operation	Duration [h]	@486 nm T [%]	@486 nm LAL [cm]	@510 nm T [%]	@510 nm LAL [cm]
Initial	–	51.2	58	60.0	98
After 840 krad	–	21.0	17	24.0	19
700 nm bleaching	6	27.5	21	32.4	26
700 nm bleaching	12	32.7	26	38.5	33
600 nm bleaching	6	45.6	44	54.1	67
600 nm bleaching	12	49.0	52	58.1	86
500 nm bleaching	6	44.6	42	53.6	65
Recovery @ RT	24	45.6	44	54.5	68
640 nm bleaching	6	49.2	52	59.1	92
200° thermal annealing	2	52.9	63	62.5	120
660 nm bleaching	6	51.5	59	61.5	110

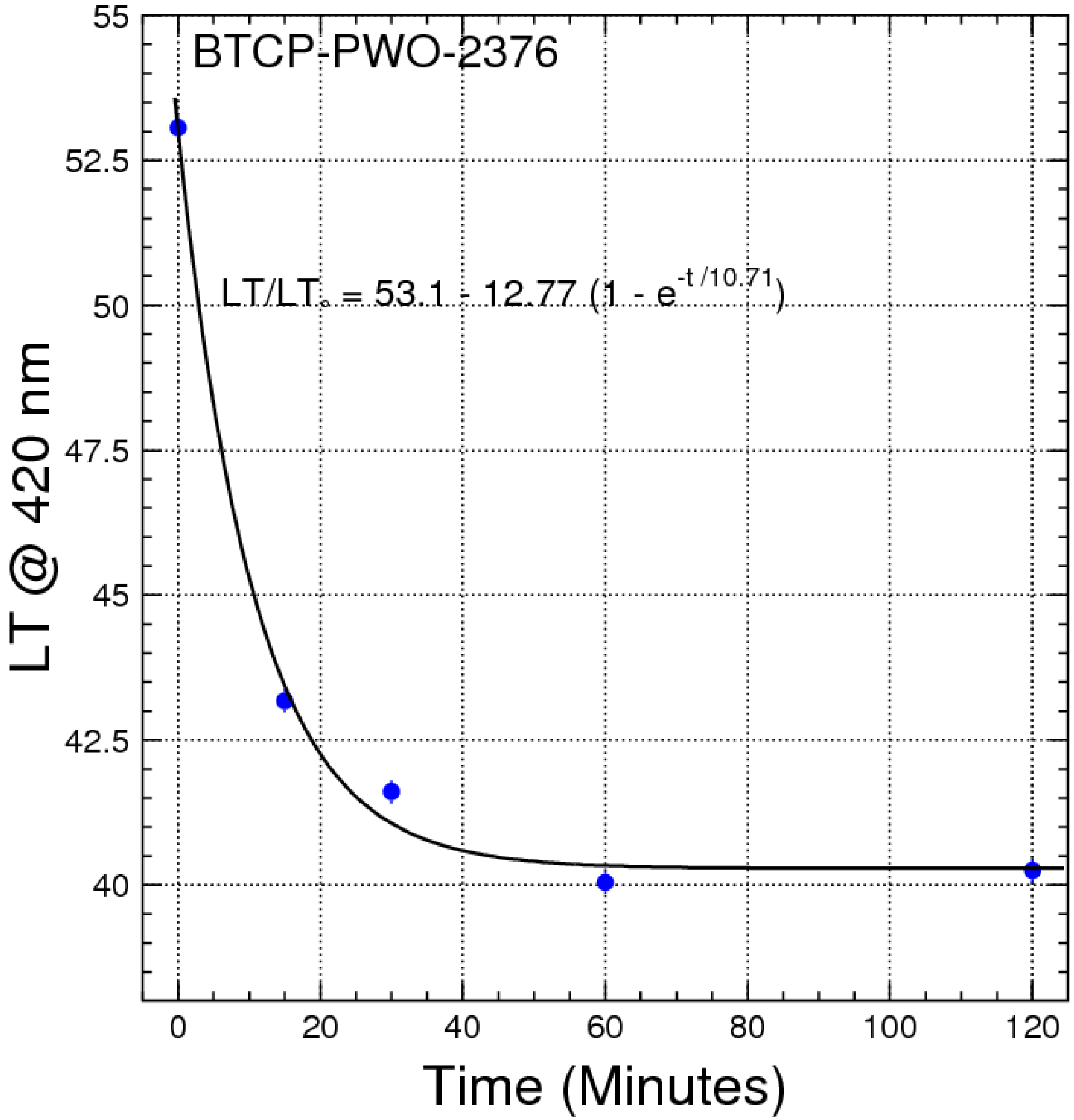
BTCP-2376: Damage/OB/Recovery



After 500 nm bleaching for 24 h no natural recovery was observed at room temperature

The time constant for damage @7,000 rad/h is very short

BTCP 2376: Damage Speed @ 7k rad/h

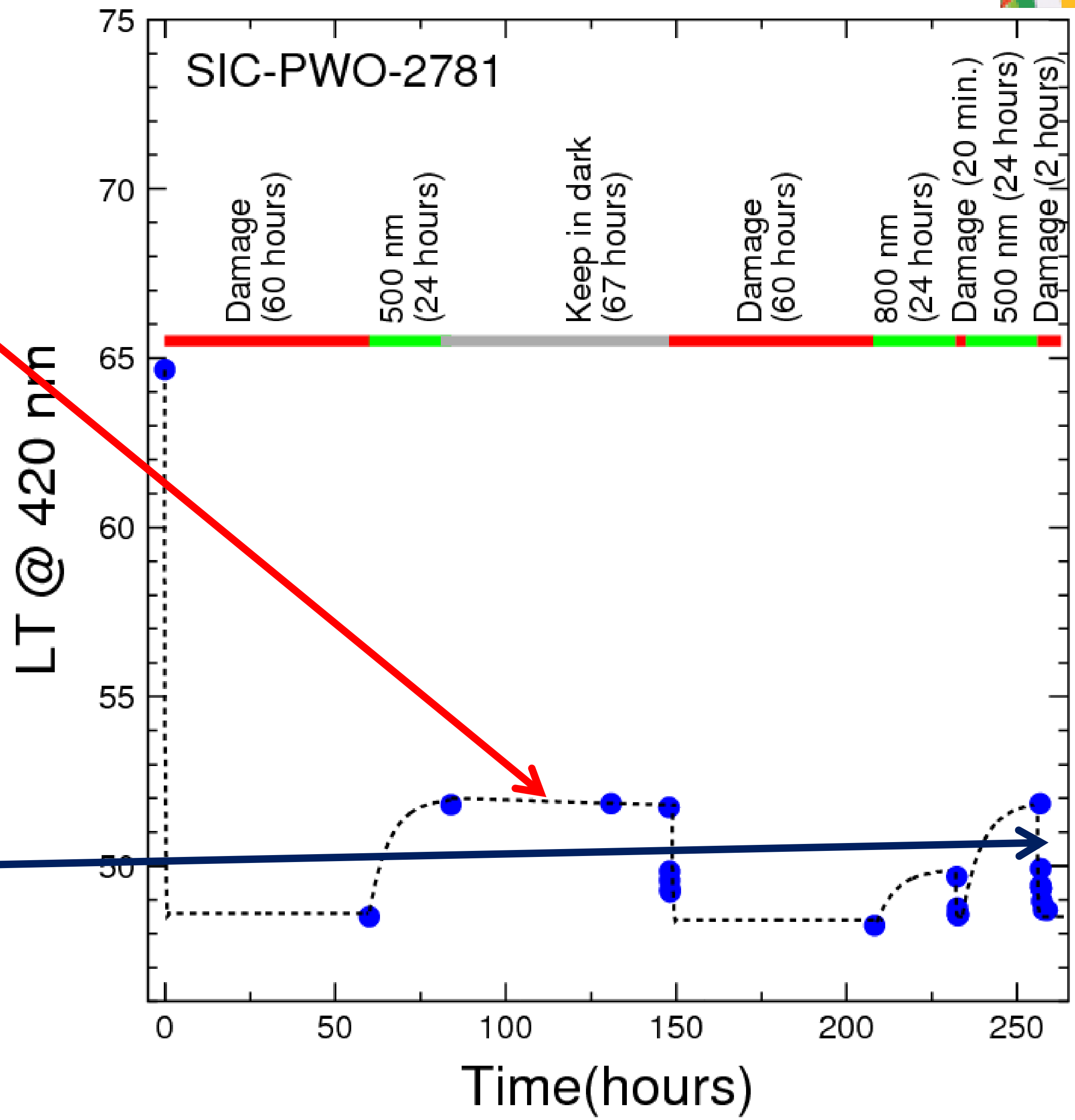


The time constant for the damage process @7,000 rad/h is about 10 minutes

The transmittance @420 nm changes more than 20% in half hour, indicating difficult for monitoring to follow.

SIC-2781: Damage/OB/Recovery

After 500 nm bleaching no natural recovery was observed at room temperature

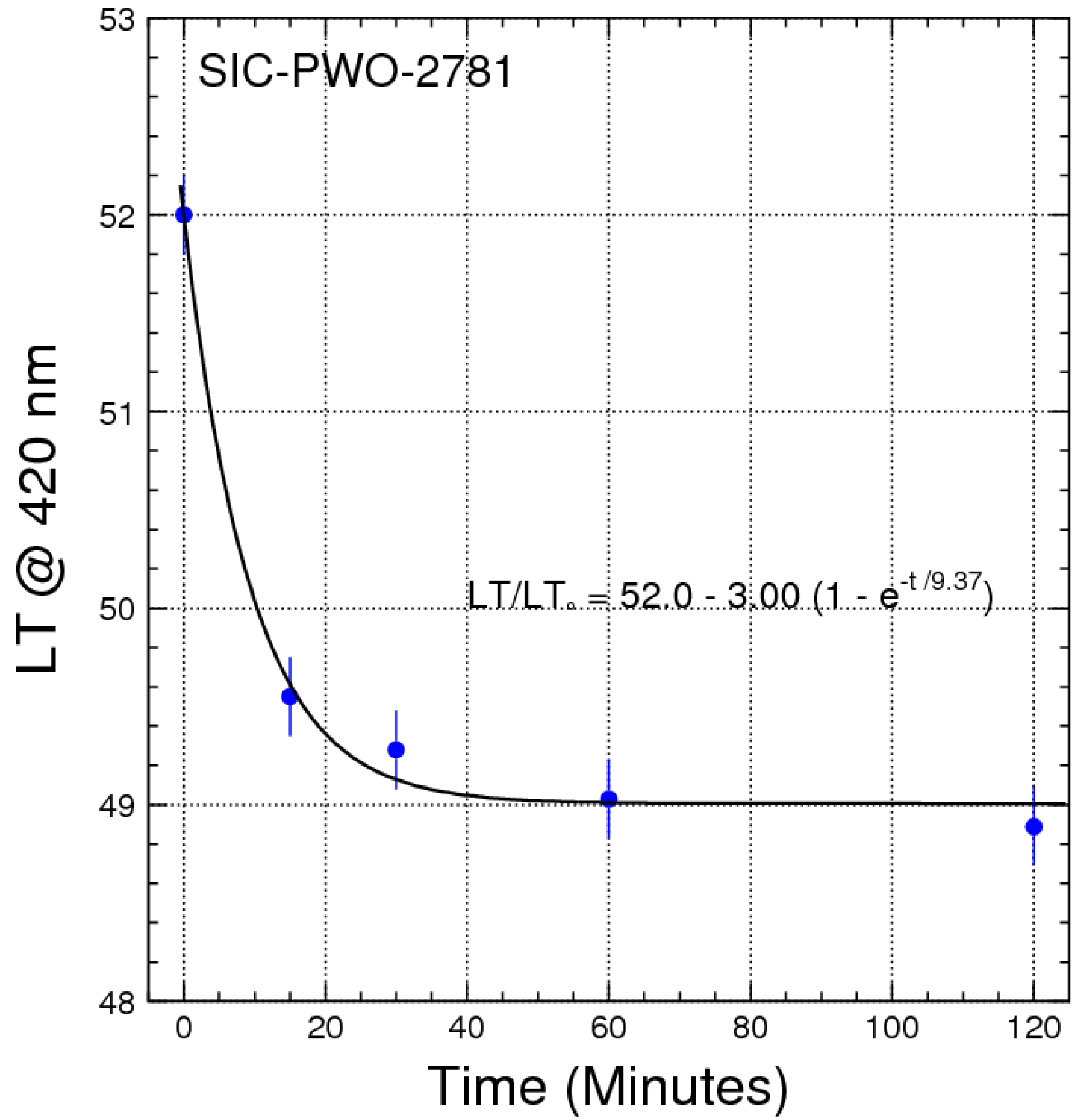


The time constant for damage @7,000 rad/h is very short

SIC-2376 Damage Speed @ 7 krad/h

The time constant for the damage process @7,000 rad/h is about 10 minutes

The transmittance @420 nm changes 6% in half hour, indicating difficult for monitoring to follow.



Color Center Kinetics in PWO

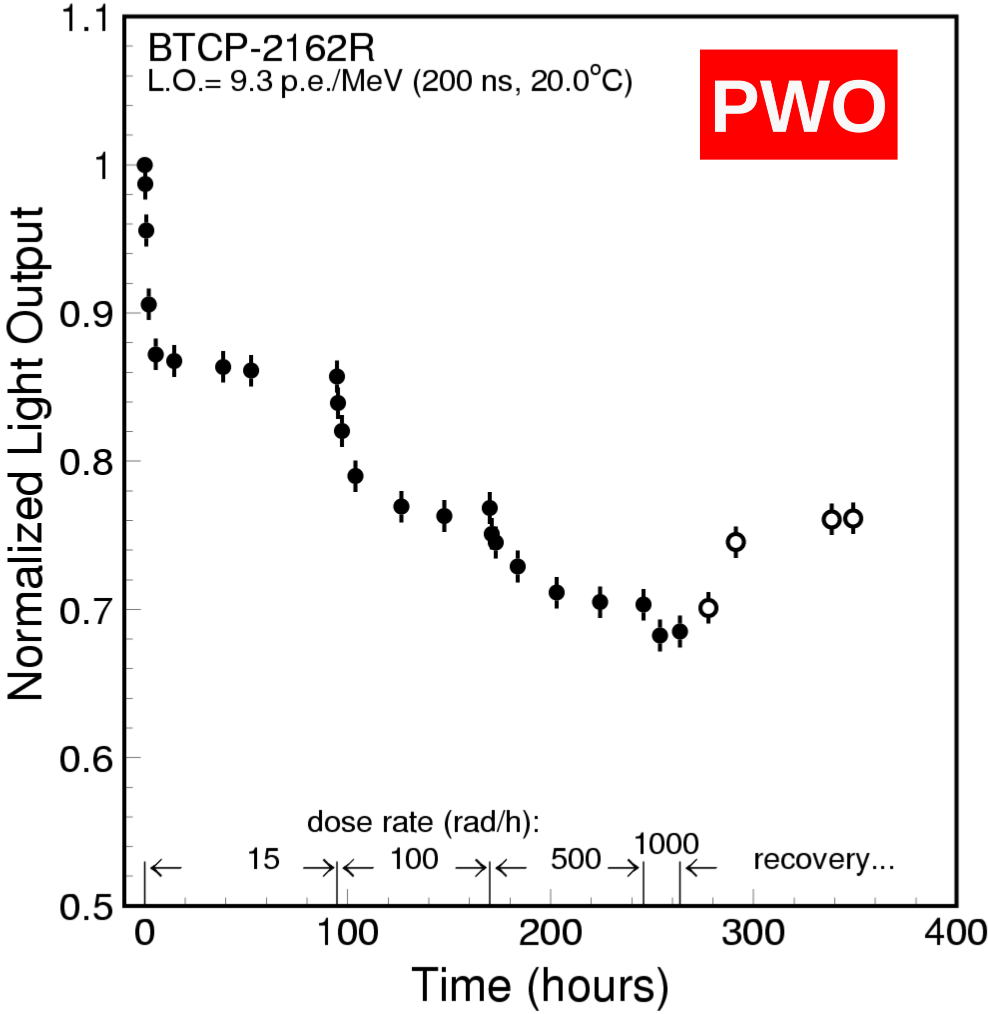
IEEE Trans. Nucl. Sci., Vol. 44 (1997) 468-476

$$dD = \sum_{i=1}^{n} \{-a_i D_i dt + (D_i^{all} - D_i)\, b_i R dt\}$$

$$D = \sum_{i=1}^{n} \{\frac{b_i R D_i^{all}}{a_i + b_i R}\, [1 - e^{-(a_i + b_i R)t}] + D_i^0 e^{-(a_i+b_i R)t}\}$$

- D_i: color center density in units of m^{-1};
- D_i^0: initial color center density;
- D_i^{all} is the total density of trap related to the color center in the crystal;
- a_i: recovery costant in units of hr^{-1};
- b_i: damage contant in units of kRad^{-1};
- R: the radiation dose rate in units of kRad/hr.

$$D_{eq} = \sum_{i=1}^{n} \frac{b_i R D_i^{all}}{a_i + b_i R}$$

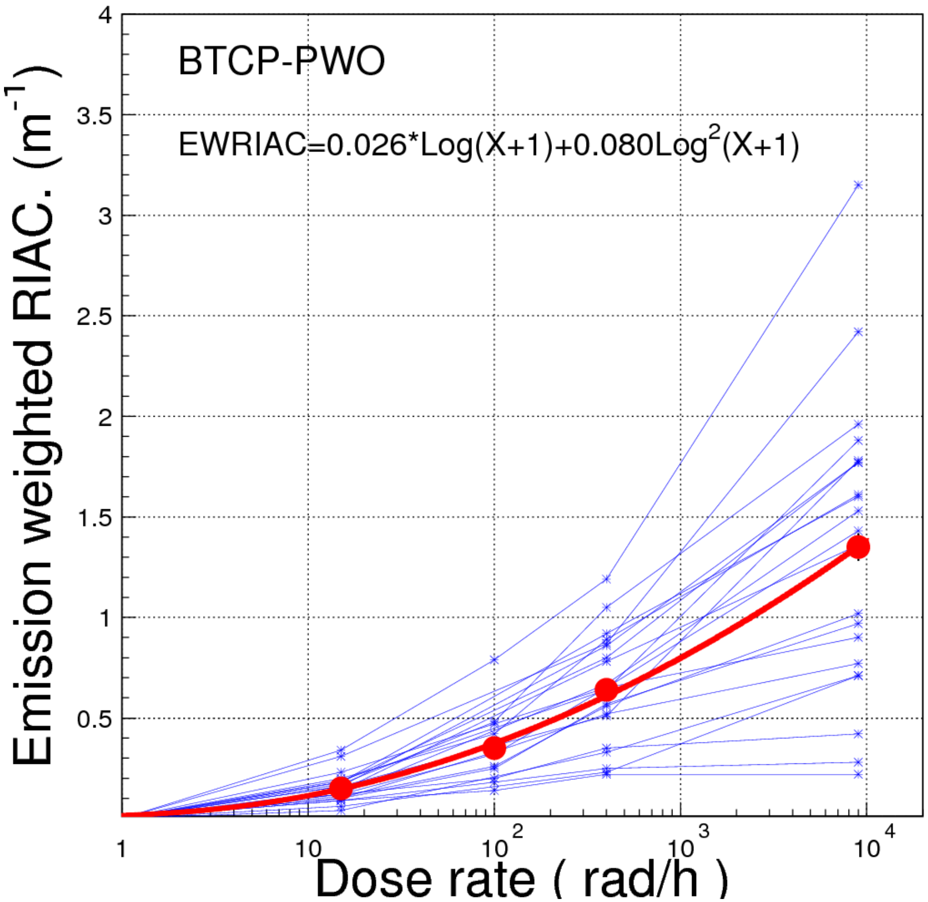


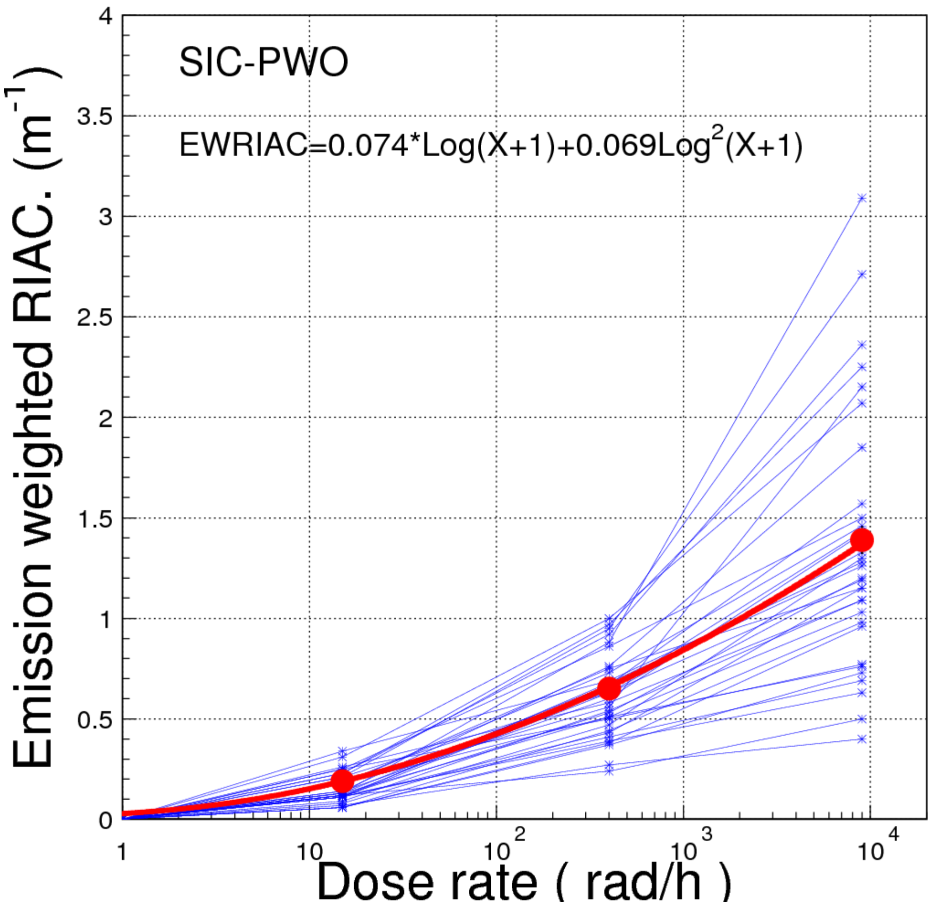
RIAC of Mass Produced Crystals

Average RIAC fits to 2nd order polynomials of log dose rate

Large spread of RIAC under high dose rate is noticed

R.H.~Mao et al., *Quality of Mass-Produced Lead Tungstate Crystals*}, IEEE Trans. Nucl. Sci. NS-51 1777 (2004)





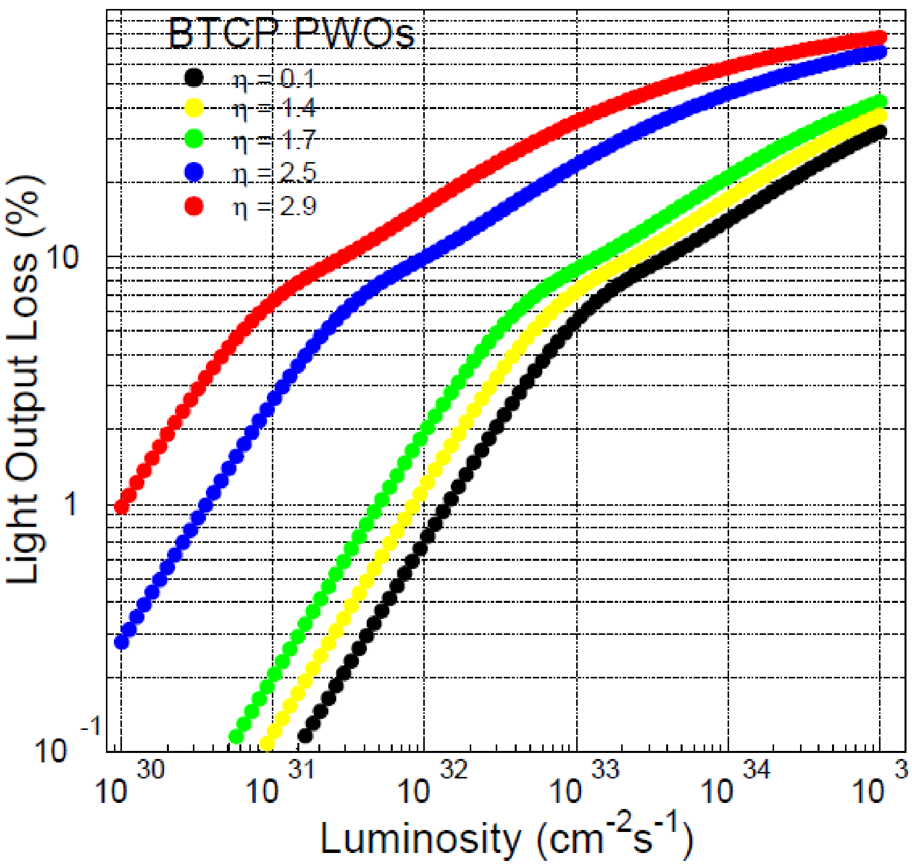
EM Dose Rate Used in Estimation

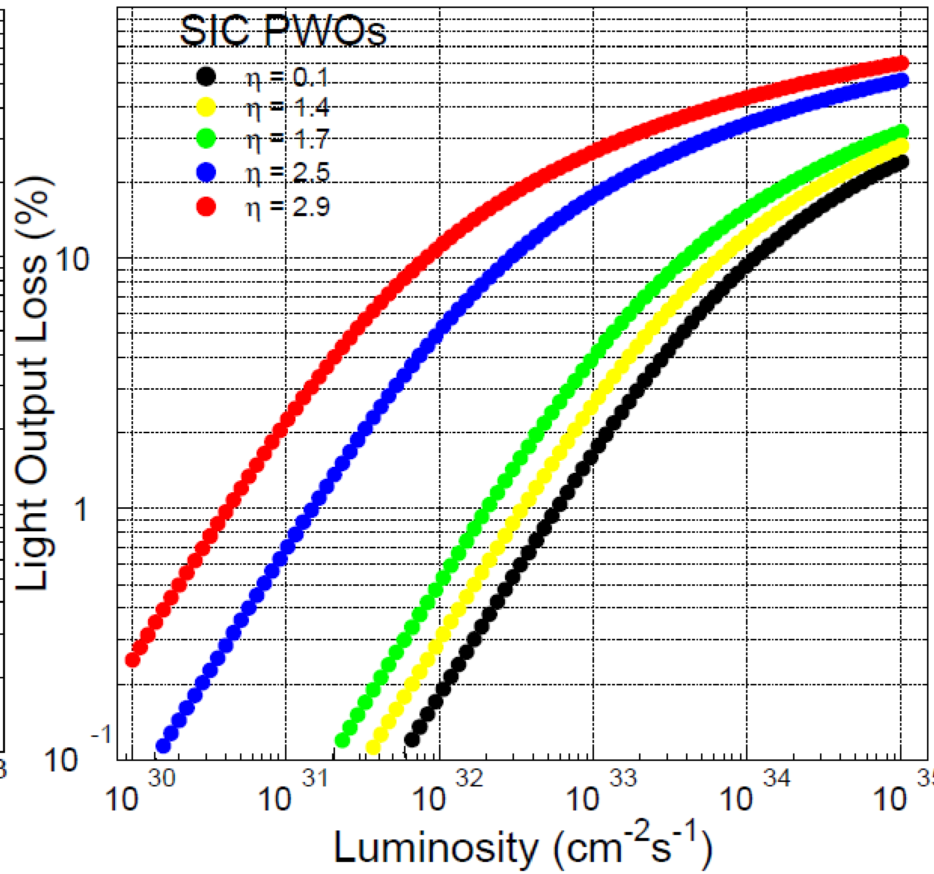
Data from CMS ECAL TDR (1996) for LHC of 14 TeV

Pseudo rapidity (η)		0.1	0.8	1.4	1.7	2.1	2.5	2.9
LHC (rad/h)	Ave	6	7	10	17	70	234	826
	Peak	17	19	25	41	160	478	1193
SLHC (rad/h)	Ave	60	70	100	170	700	2340	8260
	Peak	170	190	250	410	1600	4780	11930

Expected Light Loss in PWO

Several and a few tens percent are expected in the barrel and endcaps respectively at a few x 10^{33}

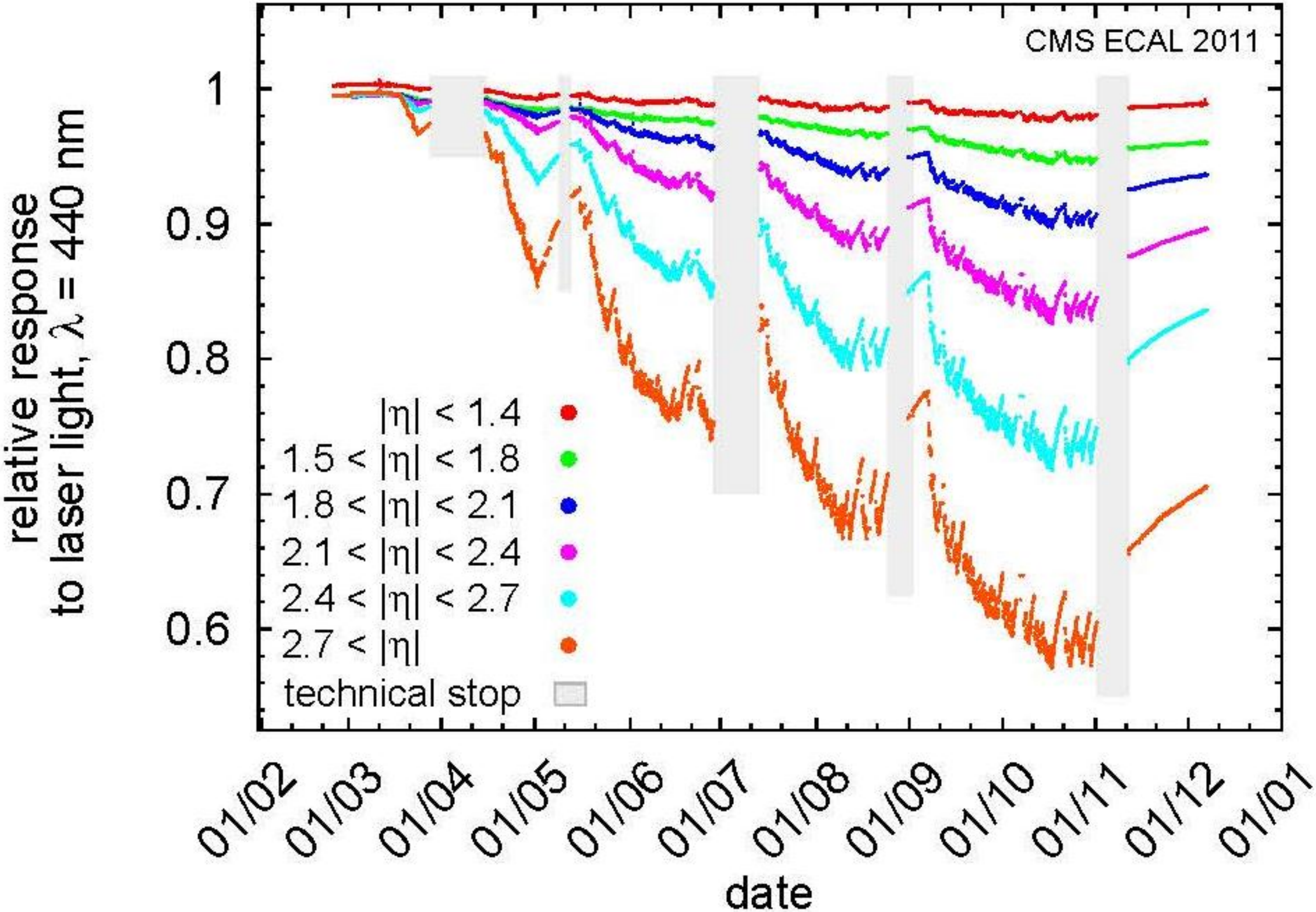




Talk in forward calorimeter taskforce meeting 12/9/2010

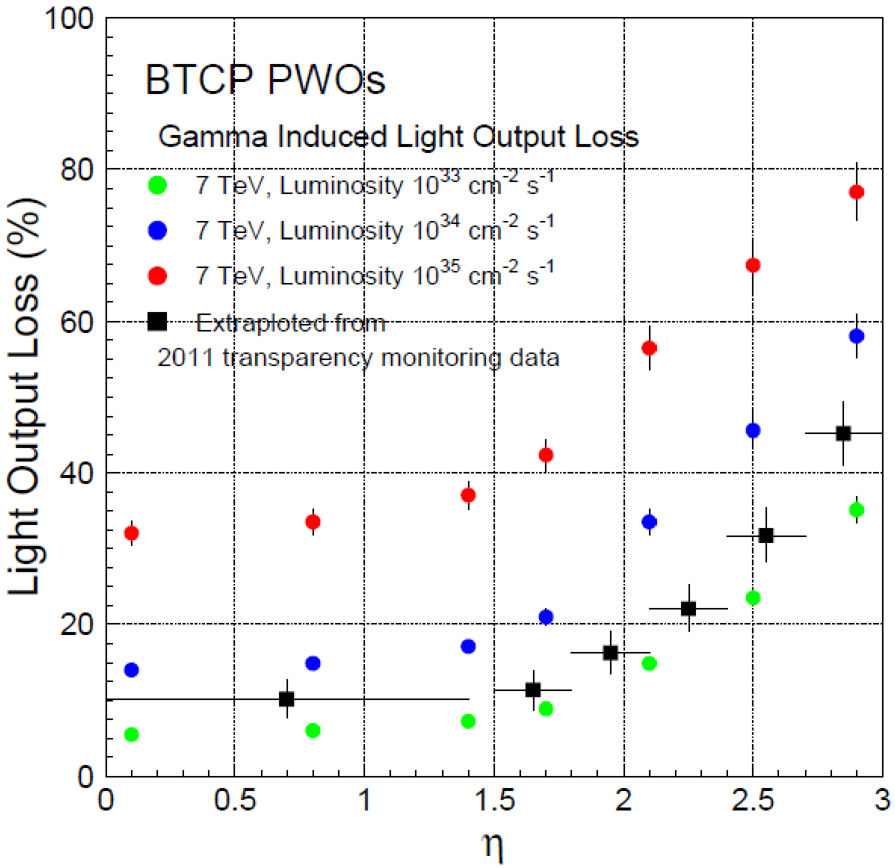
PWO Response to 440 nm Light

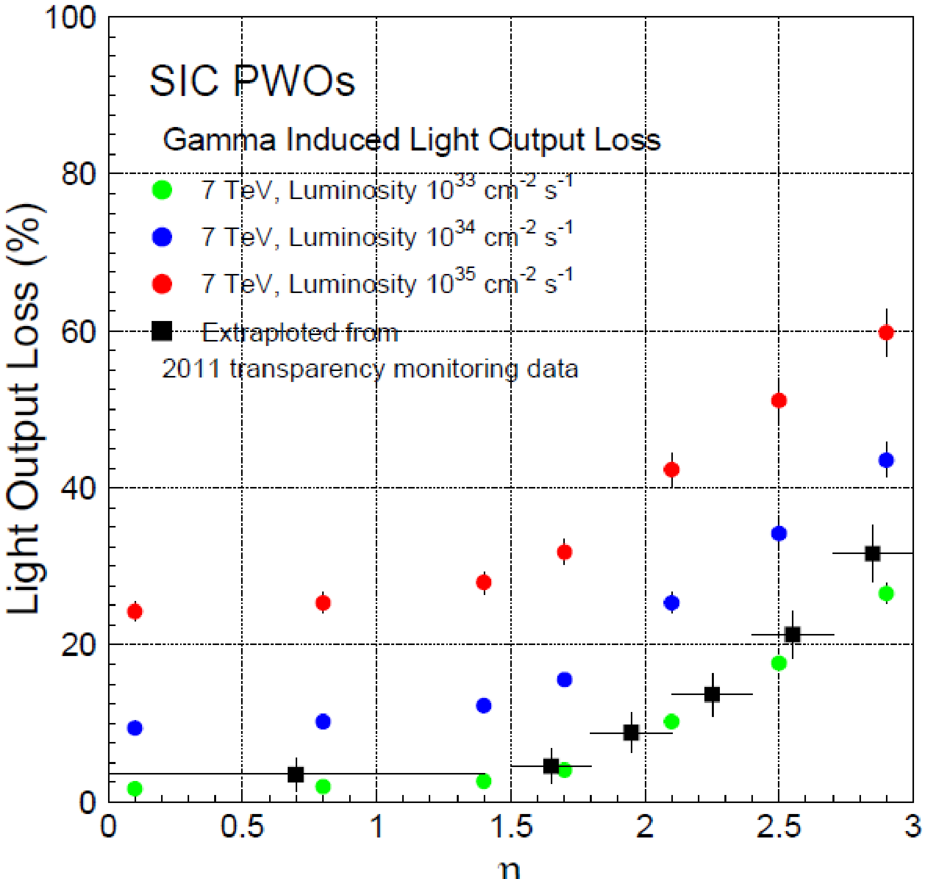
ECAL data observed in 2011 for peak luminosity of 5 x 10^{33}



Good Agreement between Data & Expected EM Damage

Are observed, indicating a good understanding of the EM damage





EM Dose Induced Damage

The defects related to color is formed during the crystal growth process, and its density is not changed by after growth manipulations, such as optical bleaching or thermal annealing.

After growth manipulations, however, may change the recovery speed "a", thus affects the color center density in the equilibrium under certain dose rate "R".

As soon as the external manipulation is removed, the damage in crystals returns to where defined by the defects density. The time constant 1/(a + bR) is short, e.g. 10 minutes @ 7,000 rad/h.

After growth manipulations thus are **useless** for the EM dose induced damage unless it is applied constantly.