The Lead Tungstate Crystals Performance In The 2001 Spring Test beam Run At Protvino

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Results on Radiation Hardness of Lead Tungstate Crystals from the 2001 Spring Test beam Run in Protvino

[1] Presented by Andrei Uzunian

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Outline

- **Radiation damage in scintillating crystals**

- **Energy spectra of the particles in CMS Endcap Ecal**

- **Absorbed dose profiles in CMS Endcap Ecal**

- **Three approaches in the radiation study in Protvino:**
  - moderate dose rate irradiation
  - super-intensive dose rate irradiation
  - Cs-137 source irradiation

- **Conclusion**

Radiation damage in scintillating crystals

The experimental data, available from LHC project activity, mainly from photon, electron and neutron ($E_n < 20\,MeV$) irradiation,indicate that only the light transmission of the crystals is affected by irradiation and not the scintillation mechanism itself. Usually, the hypothesis is that the light loss due to decreased transparency has no direct dependence on the types of incident particles, but only on the absorbed dose and dose rate.

It is necessary to emphasize although photon/electron and neutron irradiation have indicated that the damage in crystals is only a function of dose rate, this cannot be considered as a proof that high-energy hadrons (with energy greater than a few hundreds MeV) could not cause some new type of damage.

Compared to photons/electrons or reactor neutrons, high-energy hadrons will be able to induce the inelastic nuclear reactions which will locally destroy the crystal lattice. In particular they can create nuclear fragments with very high linear energy transfer and lead to extended clusters of crystal lattice distortion. Thereto we will have the process of the new types of isotopes generation. This process can lead to deterioration or improvement of the crystal radiation hardness.

Therefore the radiation hardness studies of $PbWO_4$-crystals should be provided using a hadron environment which is similar to the CMS/EMcal expectations.

Energy spectra of the particles in CMS Endcap Ecal.
For comparison the same at IHEP irradiation zone.

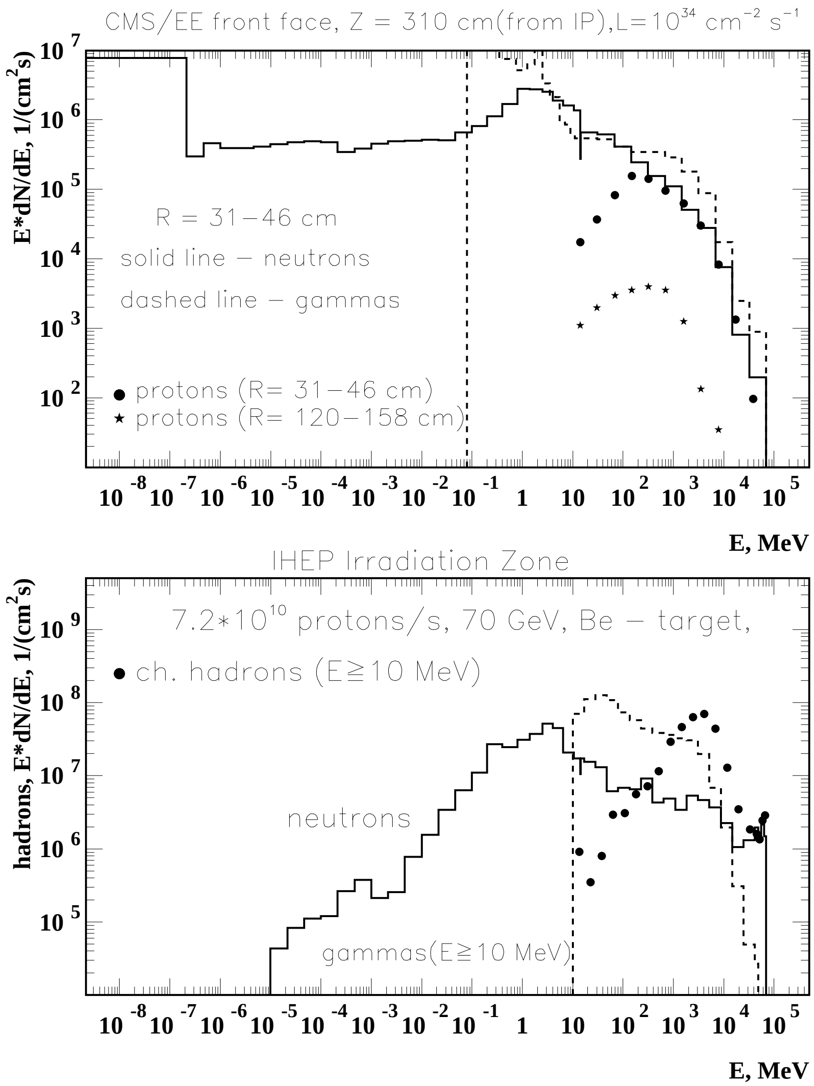

Figure 1:

Absorbed dose profiles in CMS Ecal

Position, eta(η)	Dose rate, rad/h
0	18
1.1	28
1.48	29
2.6	650
3.0	1500

Table 1: Predicted dose rates in rad/h at various places of the CMS Ecal. The values are obtained at shower maximum.(CMS TDR 4).

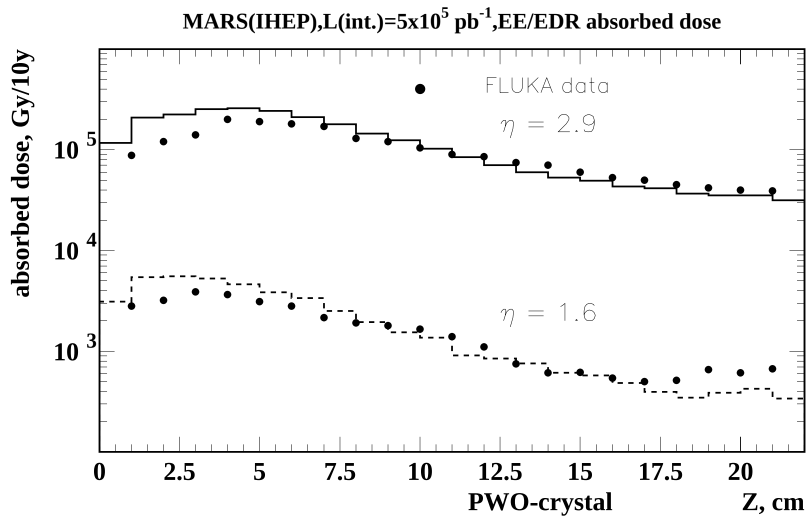

Figure 2: Absorbed dose profiles of the CMS ECaL crystals

Three approaches in the radiation study

1. Moderate dose rate irradiation

- From 0.1 up to 60 rad/hour
- 40 GeV π^- for 10 days in a row
- Integral doses up to 2-3 krad in a few crystals

2. Super-intensive beam irradiation

- Composition: hadrons, gamma, electrons
- Comparable high energy spectra as in CMS Endcap Ecal
- Integral doses up to 2.5 Mrad in a few steps
- Dose rate $\sim$ 100 krad/h

3. Cs-137 source irradiation

- Integral doses up to 2 krad in a few steps
- Dose rate is equal to 630 rad/h

Absorbed dose rate profiles in CMS Endcap Ecal (upper plot) and in PWO crystals at IHEP test beam (bottom plot)

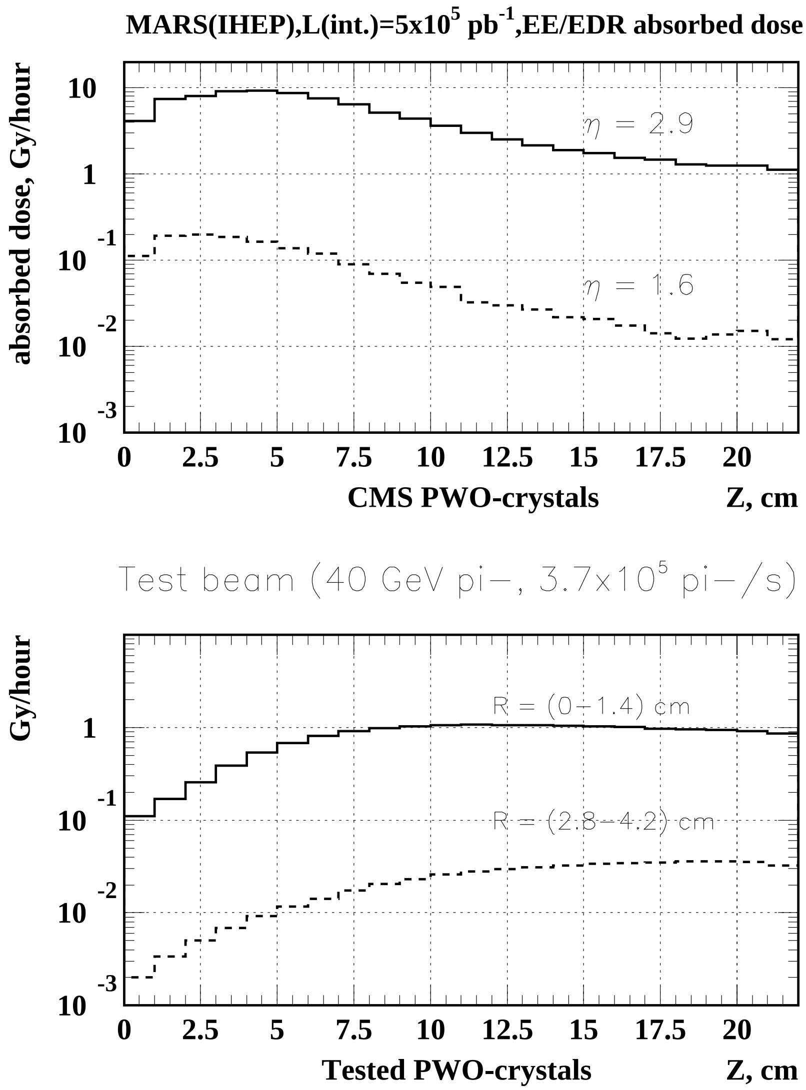

Figure 3:

Measurement of radiation damage in the crystals at moderate dose rates

- Radiate crystals by 40 GeV π^-. Size (10% -level) of the beam was 8 cm(X) x 6 cm(Y). 6 crystals were irradiated with dose rate from 1 to 60 rad/hour. Other crystals got 0.01 to 12 rad/h on the wings of the beam. Usually it took us ~6 hours in a row. The beam intensity was (1-8)x10^6pion/sec. The beam was present in 1 second of the full accelerator cycle of 9 sec.

- Lower the intensity so that we can see the MIP peak(to avoid pile-up). Monitor crystal light output signal by MIP - 1-2 hours at the beam. The intensity was $3 \cdot 10^4$/sec.

- Take again high intensity beam for the next 6 hours.

- Take low intensity MIP run. Sometimes switch to 27 GeV electrons to monitor light output additionally to MIP.

- ... the same procedure 10 days in a row ...

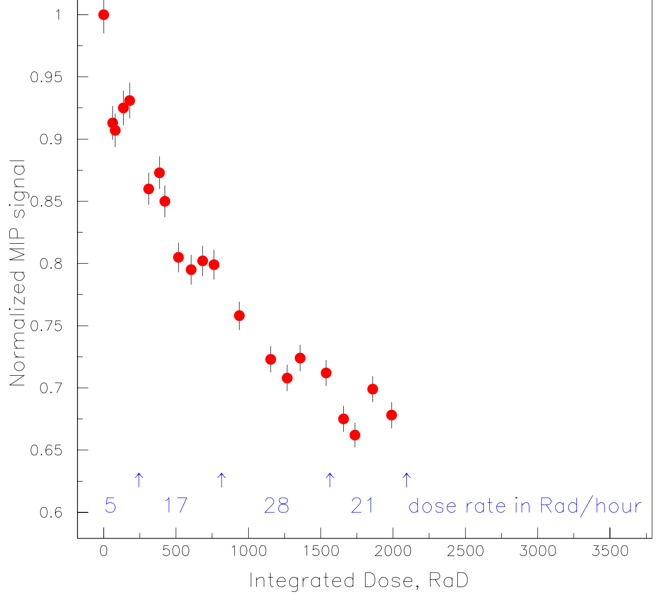

Figure 4: Dependence of a normalized MIP signal on an integrated dose for the Bogoroditsk crystal 1,2

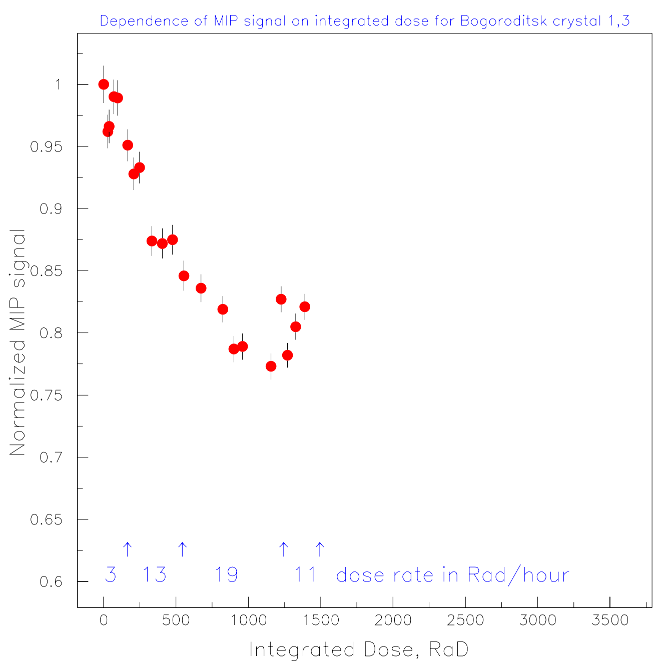

Figure 5: Dependence of a normalized MIP signal on an integrated dose for the Bogoro ditsk crystal 1,3

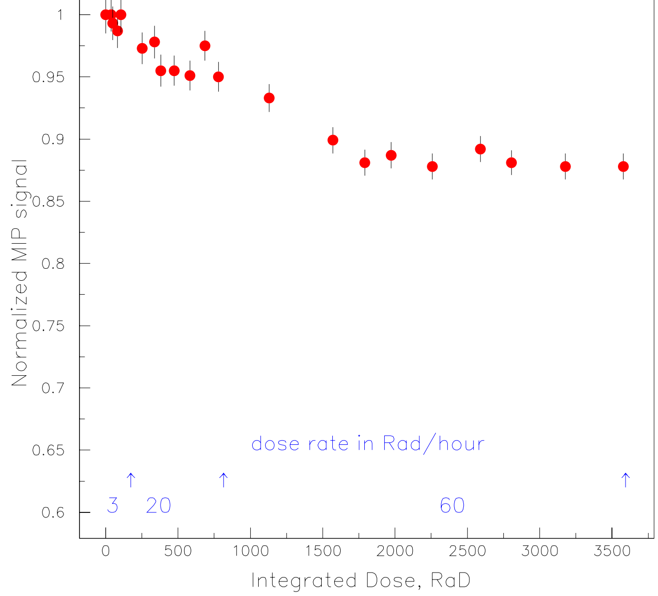

Figure 6: Dependence of a normalized MIP signal on an integrated dose for the Sh anghai crystal 2,2

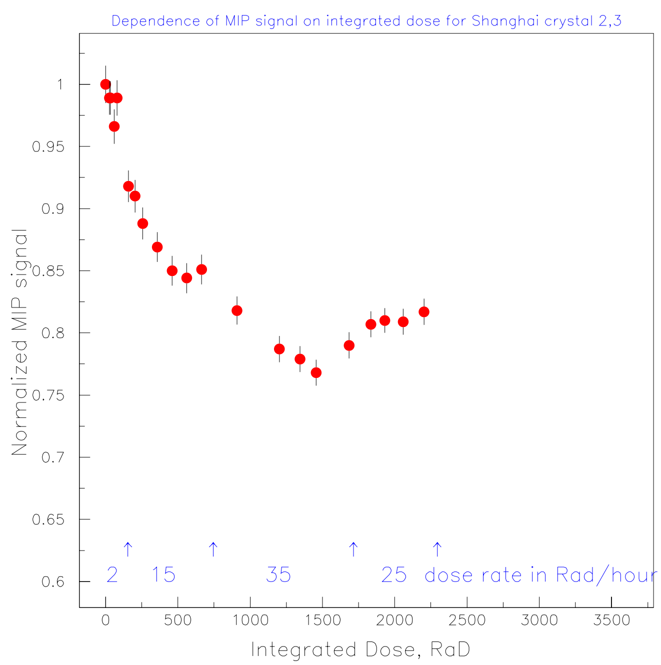

Figure 7: Dependence of a normalized MIP signal on an integrated dose for the Sh anghai crystal 2,3

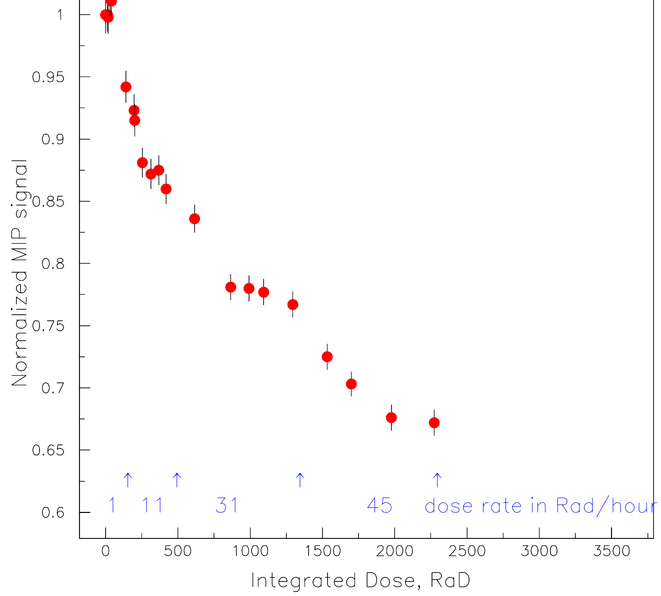

Figure 8: Dependence of a normalized MIP signal on an integrated dose for the Sh anghai crystal 3,2

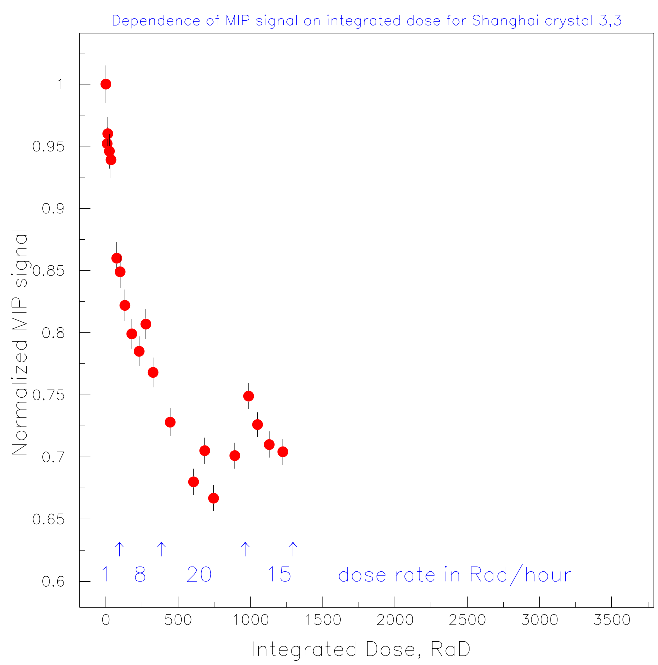

Figure 9: Dependence of a normalized MIP signal on an integrated dose for the Sh anghai crystal 3,3

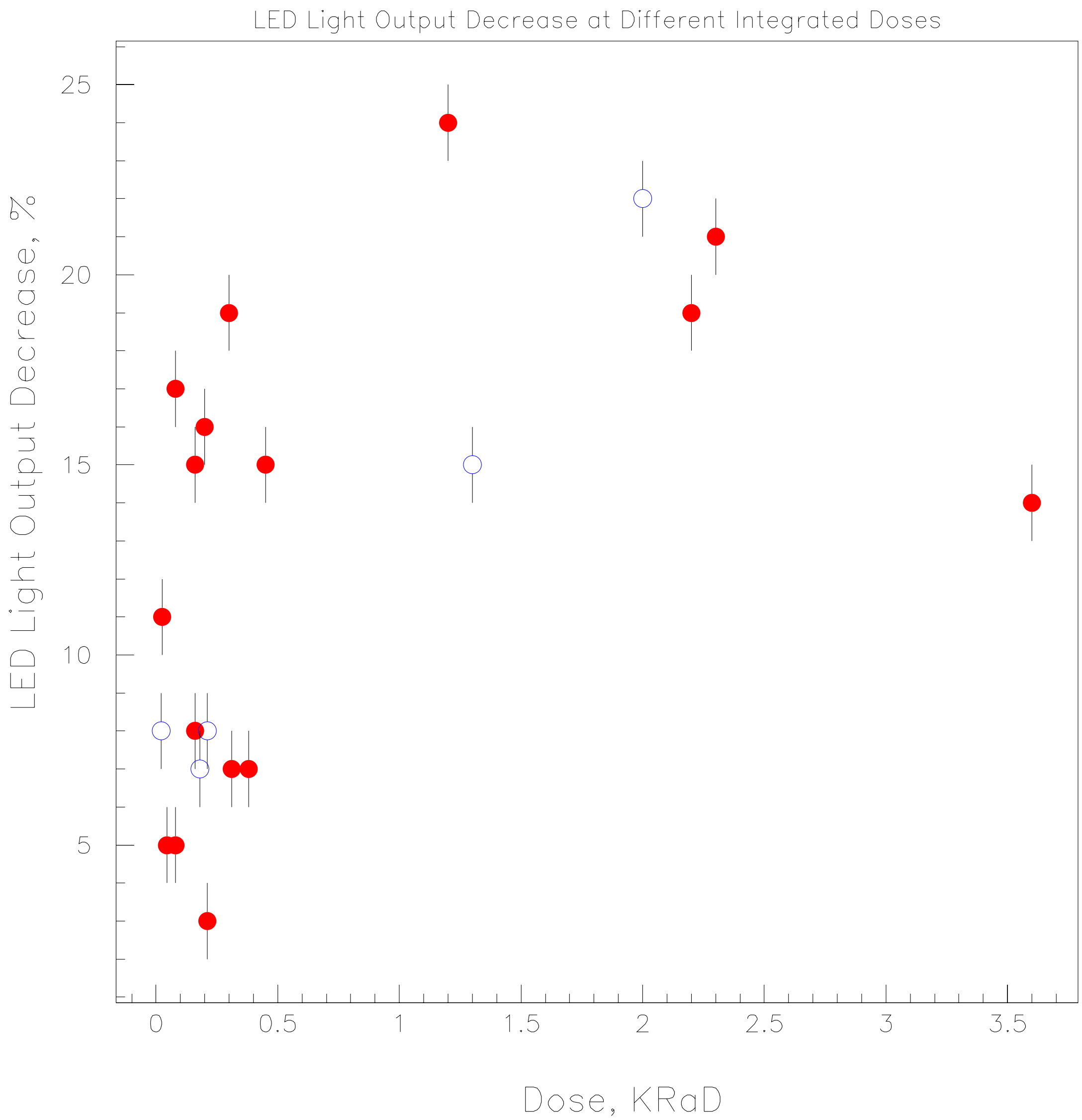

Figure 10:

Maximal LED(470 nm) signal decrease for each out of 21 crystals (5 from Bogoroditsk - open points, 16 from Shanghai - closed points)

What can we learn from these last six Figures?

We could see an indication on a saturation of the normalized MIP signal at 5, 17 and 28 rad/hour for the crystal 1,2. The same effect could be seen for the crystal 1,3 at 13 rad/hour. When we decreased the dose rate from 19 down to 11 rad/hour for the crystal 1,3, the crystal recovery started and MIP signal started to rise up. These two crystals lost 35% of the signal at 2 krad and more than 20% at 1 krad.

The crystal 2,2 is the best one out of the six irradiated. It lost slightly more than 10% of the signal at 1.5 krad and stayed unchanged up to 3.5 krad integrated dose. Clearly a saturation effect is seen in this wide region (from 1.5 up to 3.5 krad). A recovery effect can be seen in the behavior of the crystal 2,3 when the dose rate is decreased from 35 down to 25 rad/hour. This crystal lost about 25% of the signal at 1.5 krad. The crystal 3,2 lost about 35% of the signal at 2 krad but at higher dose rate as 45 rad/hour. We can see that the crystal 3,3 is the worst one out of the six crystals irradiated - it lost 35% of the signal already at 700 rad with a pretty moderate dose rate of 20 rad/hour.

We can see that all six crystals are different in their behavior under irradiation.

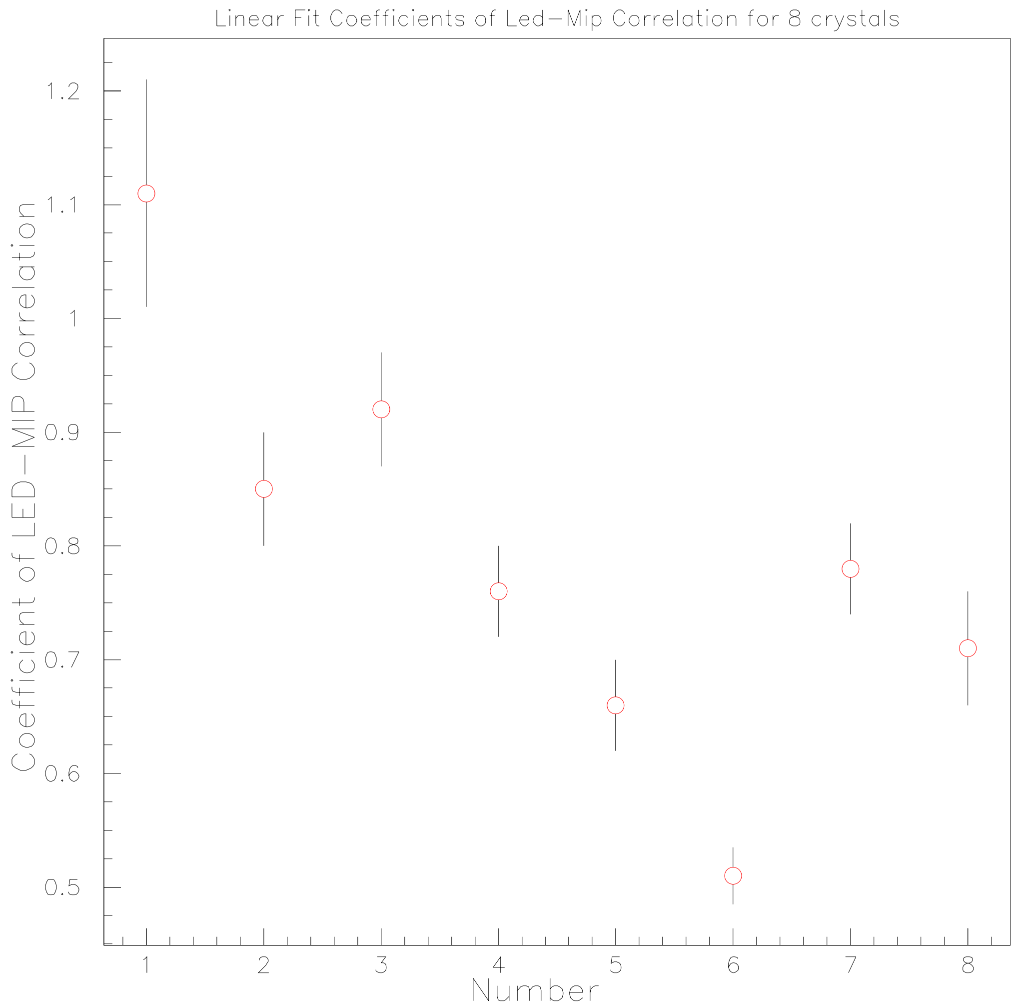

Figure 11:

Constants of proportionality between the change observed by the LED monitoring system and the change in the beam (MIP) signal. Shanhai crystals - first 5 points and 3 Bogoroditsk crystals (points 6-8). Points 5 (Shanhai) and 6 (Bogoroditsk) stand for superintensive dose rate

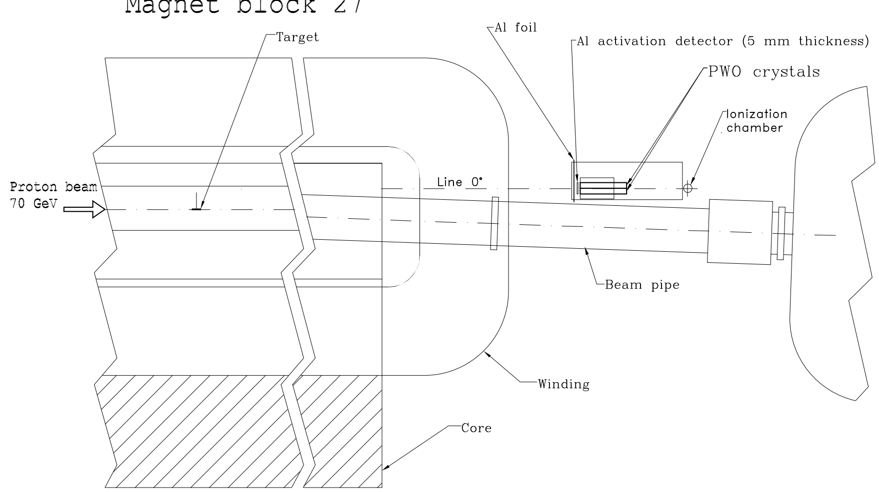

Figure 12:

Scheme of the superintensive irradiation zone.

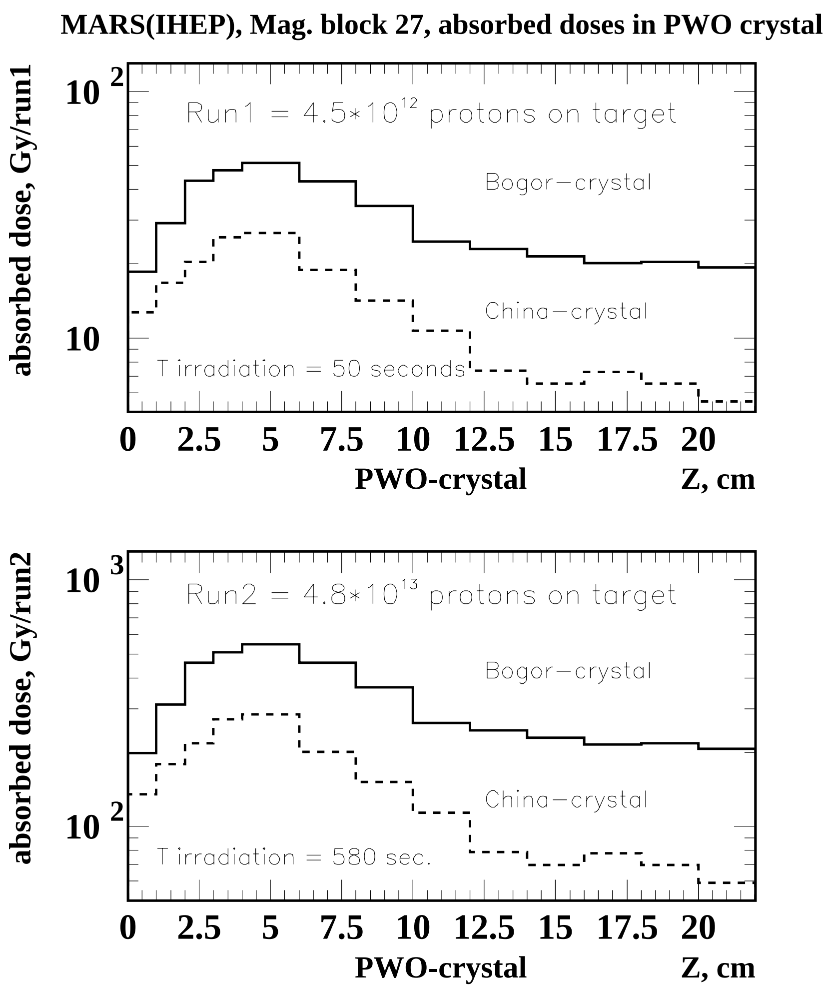

Figure 13:

Absorbed dose profiles in crystals (super-intensive zone).

Superintensive dose rate (∼100 krad/h)

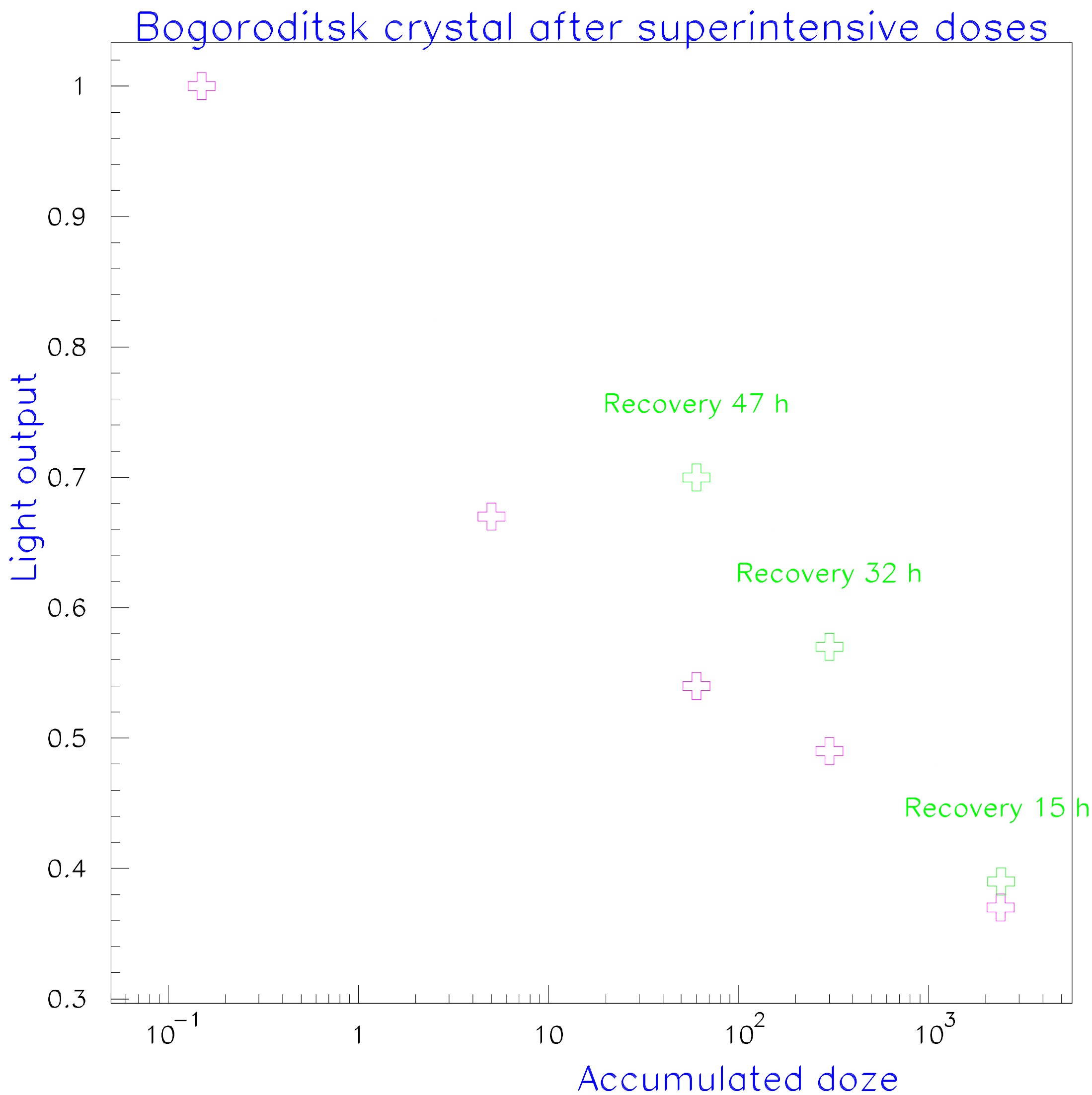

Figure 14:

Light output (at the 27 GeV electron beam) of the Bogoroditsk crystal versus accumulated dose in krad after different steps of irradiation procedure . Red points stand for light output just after the irradiation. Green points stands for light output after some recovery time

Superintensive dose rate (∼100 krad/h)

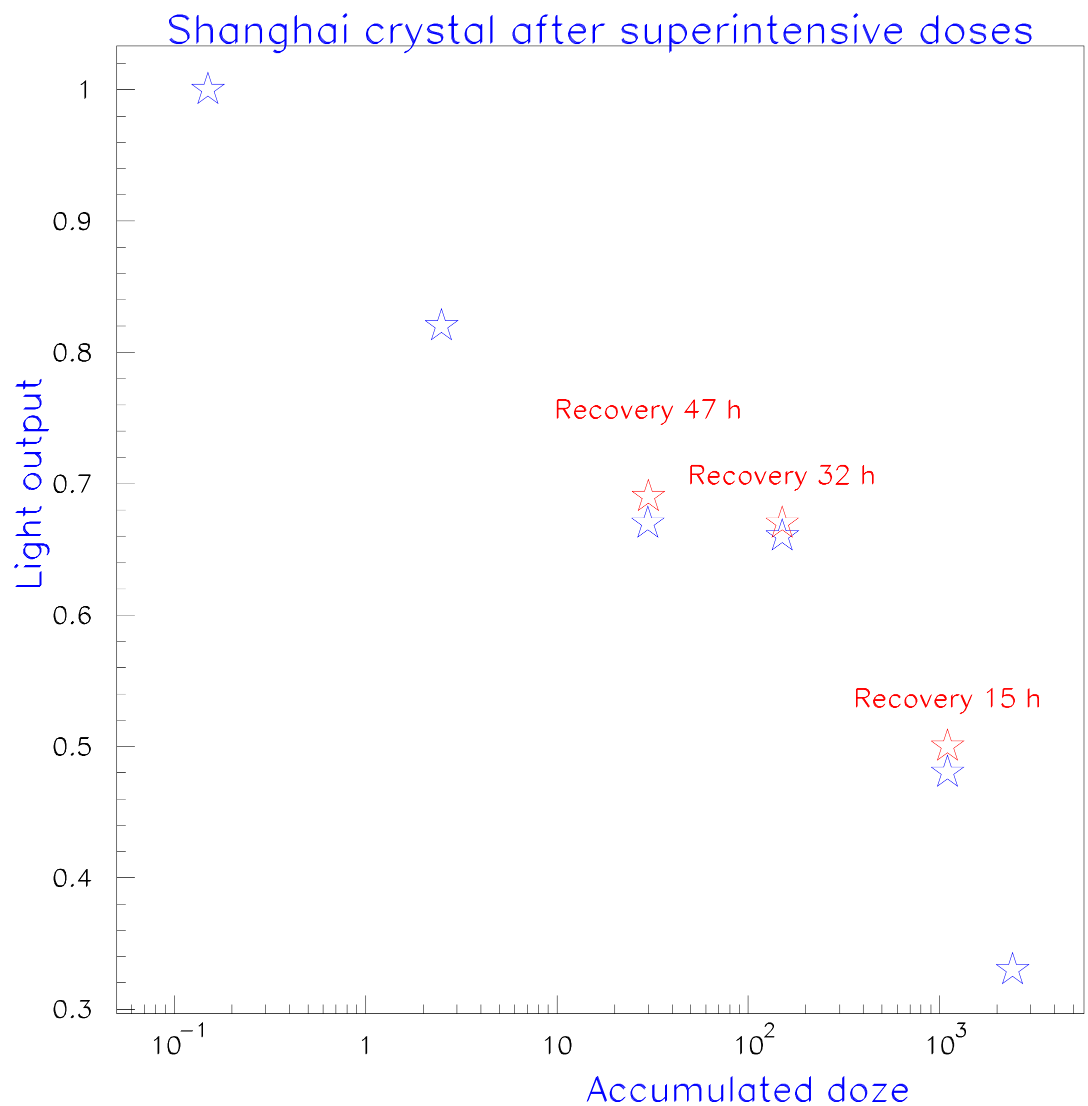

Figure 15:

Light output (at the 27 GeV electron beam) of the Shangai crystal versus accumulated dose in krad after different steps of irradiation procedure . Blue points stand for light output just after the irradiation. Red points stands for light output after some recovery time

Crystal irradiation by CS-137 0.66 MeV gamma-source

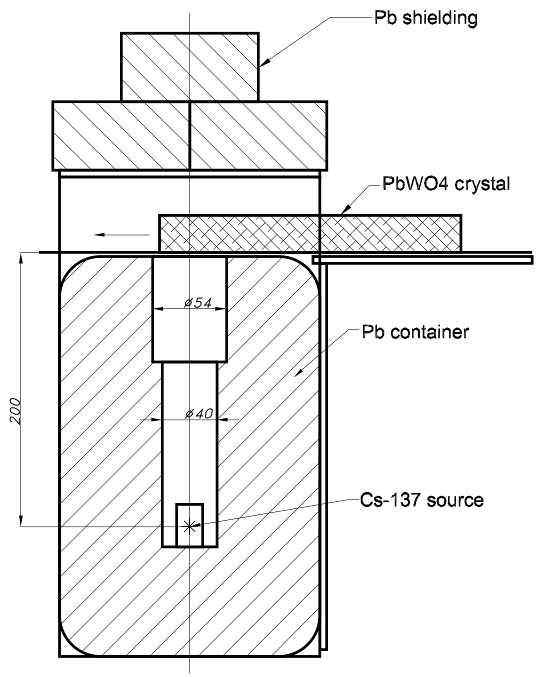

Figure 16:

Scheme of the gamma-irradiation setup.

The irradiation of the two crystals (one from Bogoroditsk and one from Shanghai) was carried out for 4 cm section of the crystal. The dose rate (in air) of the reference field in place of the irradiation was equal to 630 rad/hour.

Five expositions were made : Run 1 - 50 seconds duration, Run 2 - 250 sec, Run 3 - 1200 sec, Run 4 - 3500 sec, Run 5 - 5040 sec. Immediately after Run 5, the crystals were rotated at 180 degrees and the opposite side of the crystals (the same 4 cm!) was irradiated also for 5040 sec.

Crystal irradiation by CS-137 0.66 MeV gamma-source

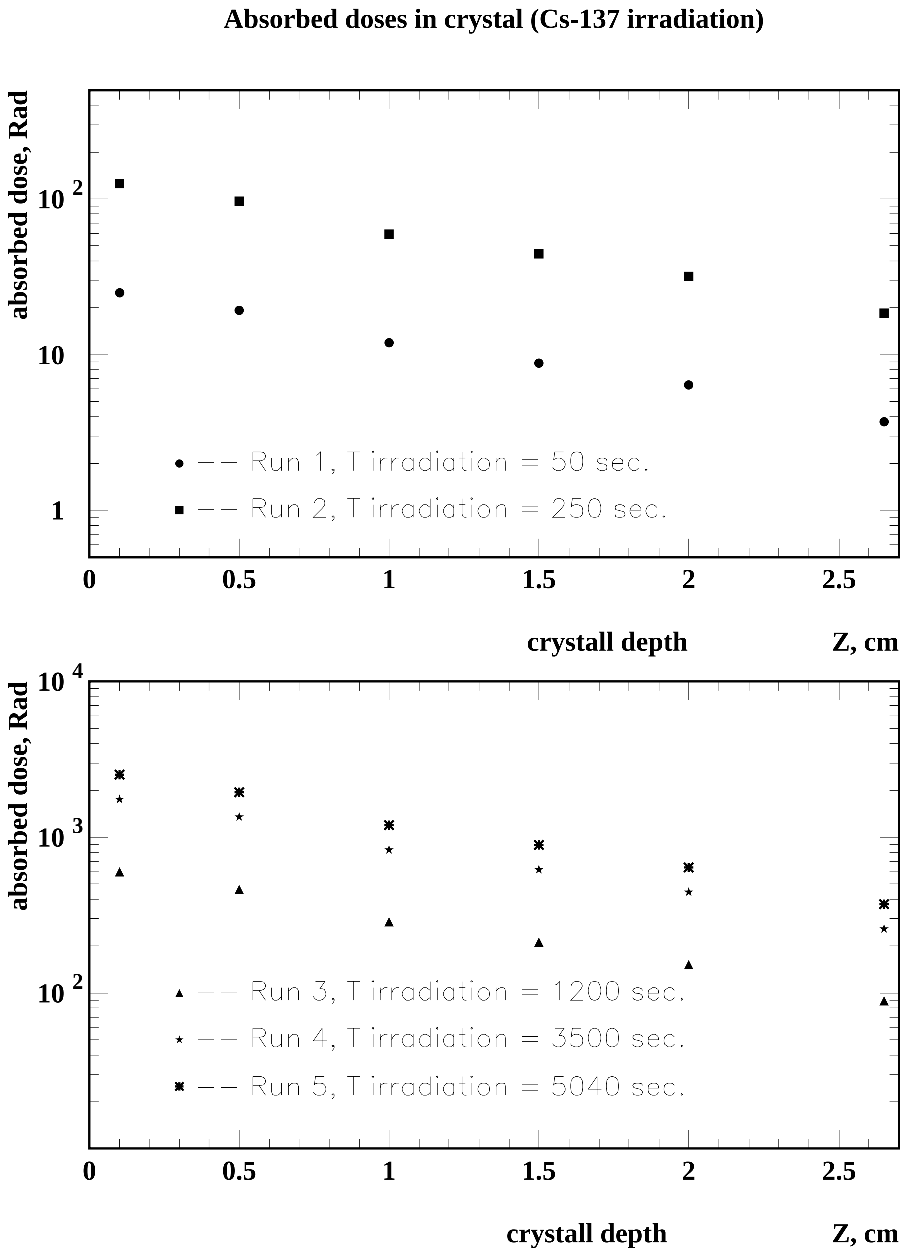

Figure 17:

Absorbed dose profiles inside the crystal after each run of irradiation.

Crystal irradiation by CS-137 0.66 MeV gamma-source

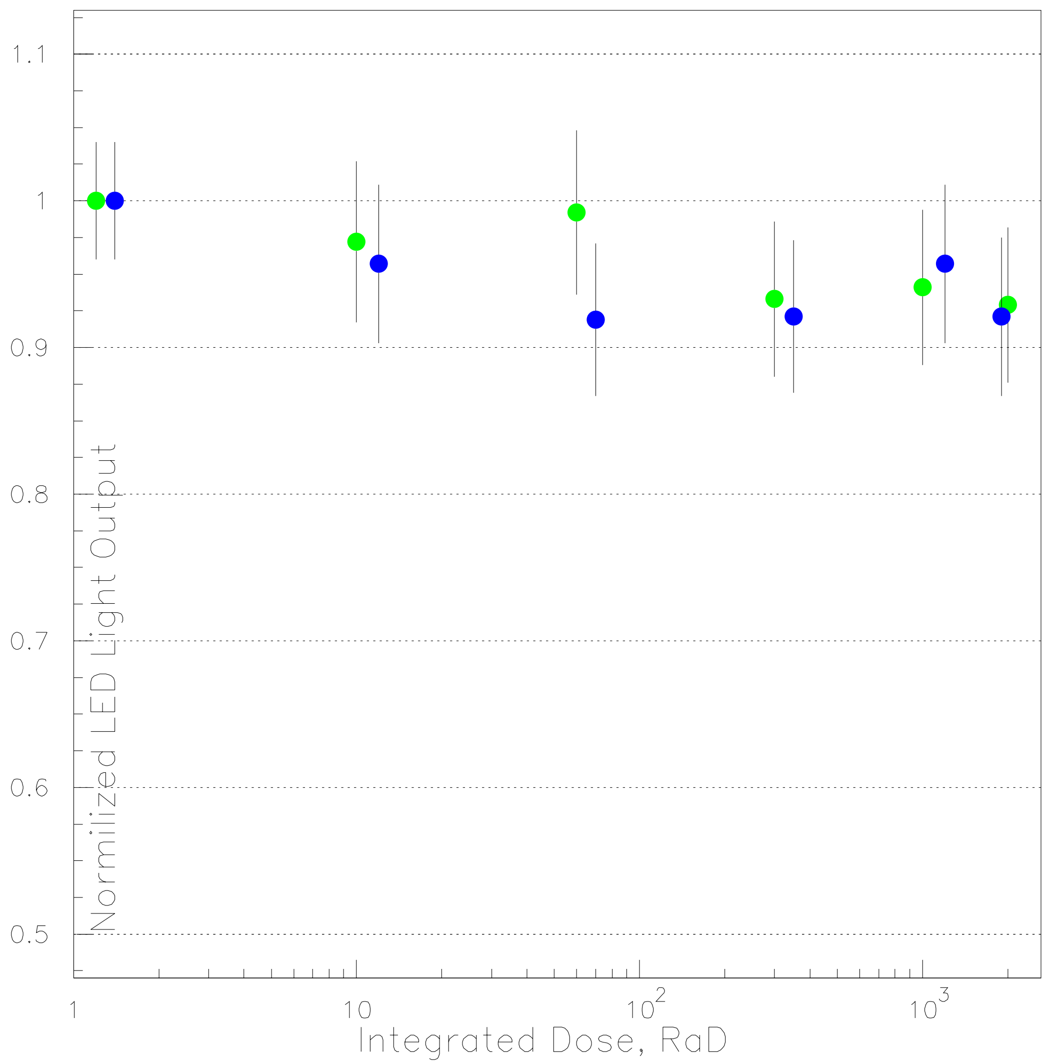

Figure 18:

Dependence of a normalized LED signal on the integrated dose after irradiation by Cs-137 source. Blue color - a Bogoroditsk crystal. Green color - a Shanghai crystal.

Conclusion

There were three approaches in radiation hardness study. Crystals were irradiated: a) by hadrons at a moderate dose rate

b) by hadrons and gammas at a superintensive dose rate

c) by a radioactive Cs-137 source.

The crystals were irradiated by 40 GeV pions during 10 days in a row. 21 irradiated crystals have accumulated different doses from 50 rad to 3.5 krad.

- No light output loss has been seen for dose rates < 0.2 rad/hour for 2 rad integrated dose.
- Light output loss was $< 5\%$ for dose rates from 0.2 to 2 rad/hour for 50-60 rad integrated doses.
- Light output loss was from 12% to 33% for different crystals for dose rates from 2 rad/h to 60 rad/h when they accumulated 1-2 krad integrated dose.
- An indication on saturation effect at different dose rates has been seen.
- Two crystals got extremely high dose rate $>$ 100,000 rad/h to accumulate 2.5 Mrad. They remained alive. Their light output loss was a factor of 3, but degradation of energy resolution was only 20%(Bogoroditsk) and 50%(Shanghai).
  This is far away from the CMS Endcap case where $\sim$1500 rad/h is a maximum dose rate.

- Irradiation of 4 cm zone in two crystals up to 2 krad by Cs-137 gamma-source has shown an indication on a few percent light loss.

A few days ago we have finished the next step of PWO crystals radiation study at IHEP test beam ...
... the data processing is in progress ...