Radiation hardness study of CsI(Tl) crystals for Belle II calorimeter

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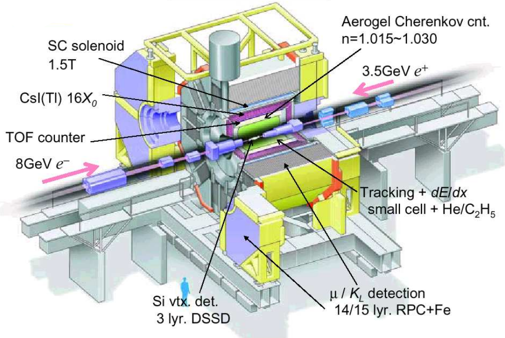
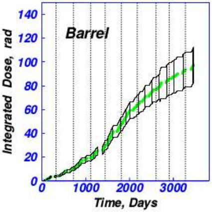
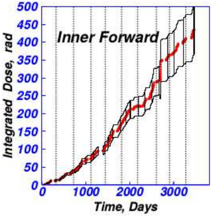
Belle detector

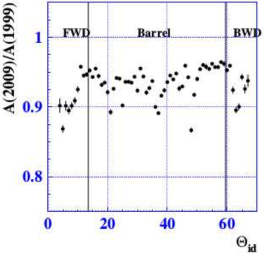


- Belle detector — universal magnetic detector with several sub-detectors
- High resolution electromagnetic calorimeter based on CsI(Tl) crystals (16 X_0)
  - Detection of photons from 20 MeV to 4 GeV, $\sigma_E/E = 1.7\%$, for $e^+e^- \to \gamma\gamma$
  - Determination of photon coordinates, $\sigma_\phi = 0.2°$
  - Separation of electrons and hadrons
  - Formation of a signal for a neutral trigger
  - Luminosity measurement

Absorbed dose for Belle calorimeter

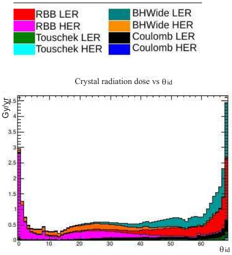




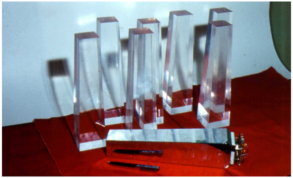


- Integrated dose (for luminosity $\sim$ 1000 fb^{-1})— 100 rad for the barrel crystals and 400 rad for the highest-dose endcap
- Light-output loss — 7% in the barrel and up to 13% in the endcap
- Good agreement with previous measurements of crystal radiation hardness (30% light-output loss for 3.6 krad),
  D. Beylin *et al.*, NIM Phys. Res. A **541**, 501 (2005)

CsI(Tl) with higher luminosity (Belle II and $c-\tau$)



- SuperKEKB luminosity of up to 8×10^{35}/cm^2/s $\Longrightarrow$ Expected integrated dose (after 10 years of operation) of about 5 - 10 krad
- Super $c-\tau$ factory luminosity $\sim 10^{35}$/cm^2/s $\Longrightarrow$ Expected integrated dose (after 5 years of operation) of about 1 krad

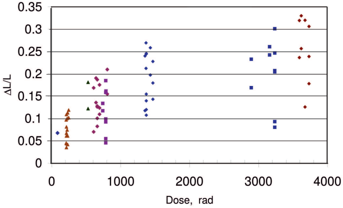


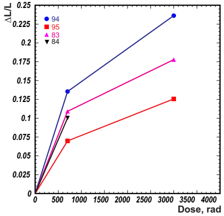
- Additional measurement of the CsI(Tl) radiation hardness $\Longrightarrow$ four CsI(Tl) Belle typical crystals for our study (selected from crystals produced for Belle calorimeter)
- Four tested CsI(Tl) crystals $\Longrightarrow$ shape of truncated pyramids (height of 30 cm $=16.2X_0$) with slightly different sizes $\Longrightarrow$ polished, wrapped in 200 μm porous teflon and covered 20 μm aluminized mylar
- Previous radiation hardness study (D. Beylin *et al.*) $\Longrightarrow$ known characteristics of tested crystals for 3.6 krad dose

Previous radiation hardness study

Our study is a logical continuation of previous study for large set of crystals (NIM, Phys. Res. A **541**, 501 (2005))

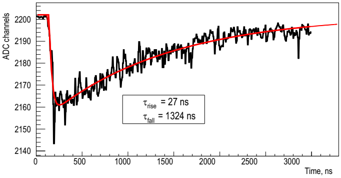
- Light-output drops faster at small irradiation doses than at higher doses.
- Wide spread of light-output degradation is observed for crystals produced within one technology and cut from different ingots.
- Increase of the light absorption in large crystals is the main radiation induced effect.
- All crystals have enough radiation hardness for Belle experiment.

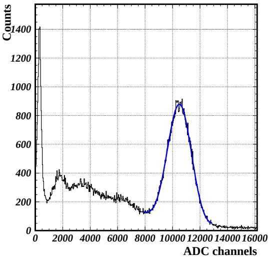


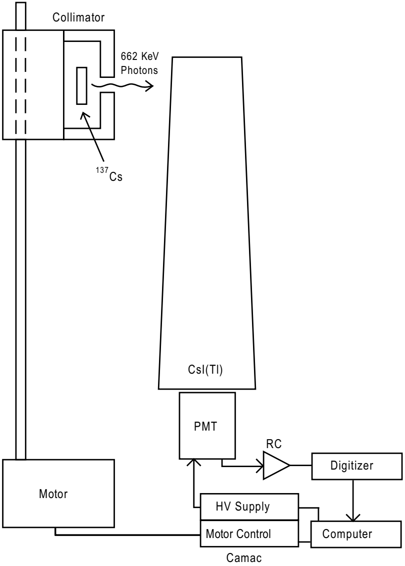


Studied crystals have been irradiated before

Light-output measurement setup



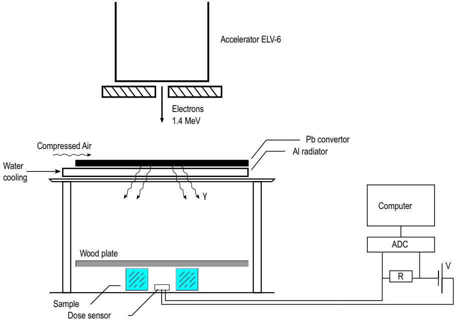


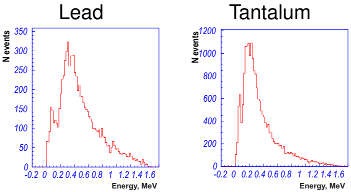


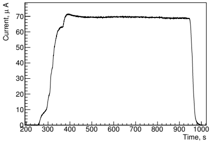
- $\bar{L} = (L_1 + \ldots + L_9)/9$, $L_i = A_i/A_0 \times 100\%$ — average light-output
- $G = (L_{max} - L_{min})/\bar{L}$ — non-uniformity

Reference

Irradiation of crystals

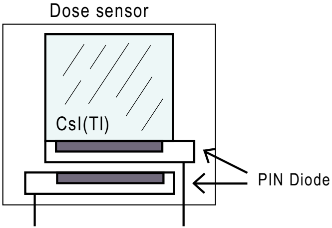


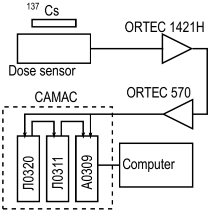




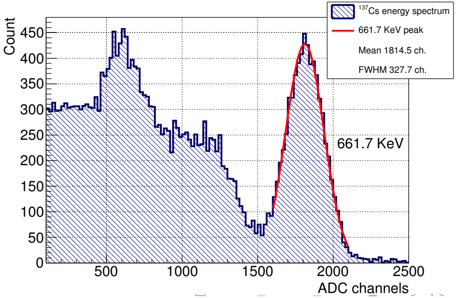
- Accelerator ELV-6 (BINP) provides electron beam with $E = 1.4$ MeV and bremsstrahlung photons are created in the converter (lead or tantalum). The resulting photons have wide energy spectrum with average value around 0.6 MeV.
- Special dose sensor has been made. The dose sensor current is proportional to the dose rate.
- The non-uniformity of dose absorbed in the crystal volume is compensated with equal doses from opposite sides.

Dose sensor calibration

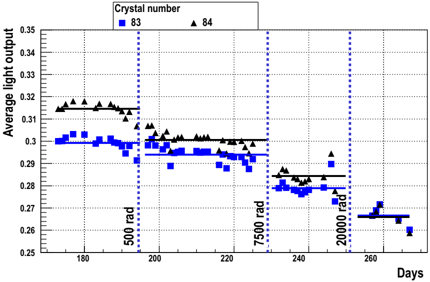


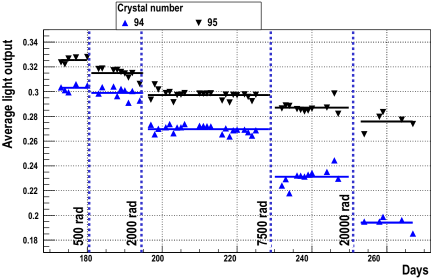


- The dose sensor consists of CsI(Tl) crystal of sizes of $1 \times 2 \times 2$ cm^3 and two PIN diodes (Hamamatsu).
- The dose rate $Q = kI = \bar{E}\nu/M$, I — dose sensor current, $\bar{E}$ – average energy deposition, ν — counting rate and M — crystal mass. $k = \bar{E}\nu/M/I$.
- The source ^{137}Cs with $I \sim 10^5$ Bq is used to determine the average energy deposition per photon.
- The source ^{137}Cs with $I \sim 10^8$ Bq is used to measure the dose sensor current.



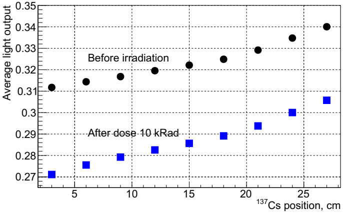
Light-output measurements

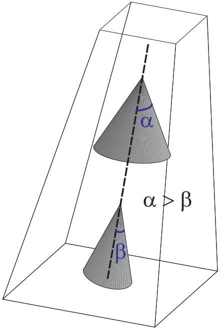


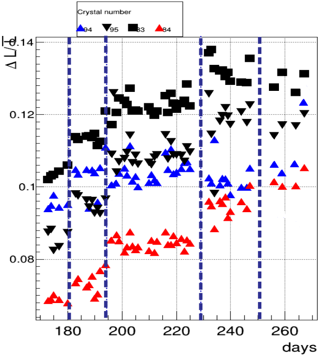


- Four expositions with total dose of 30 krad have been performed.
- Different degradations of light-output are observed. Light-output degradation for crystal No 94 is not essential after dose of 500 rad but significantly increases with higher doses (drop of 25% after dose of 10 krad and 37% after 30 krad). Other effect is observed for crystals No 83,84,95: light-output degradates of $7-10\%$ after dose of 10 krad and $16-18\%$ after 30 krad.

Light-output nonuniformity

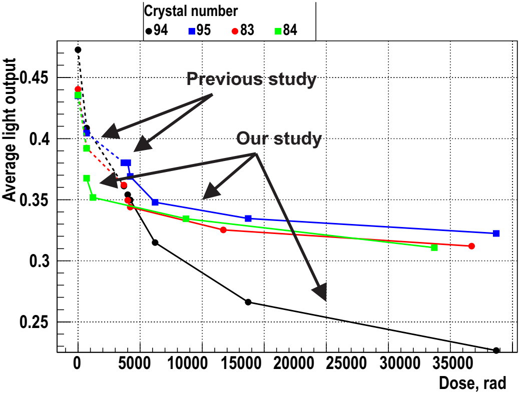






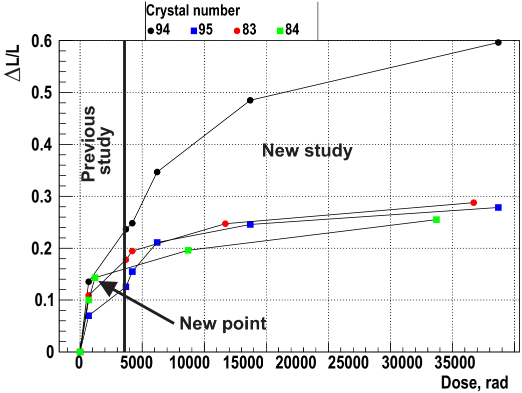
- Light-output is increased together with distance between collimator and PMT cathode. Specific shape of crystal (truncated pyramid) leads to this effect.
- Certain deterioration of light-output uniformity is observed. Final nonuniformity is less 14%.

Light-output degradation



- Absolute light-output is not measured. In that case we combine our measurements with previous ones normalising to the previous measurements for the crystal No 95. We see that this assumption is valid.
- We see that light-output drops slower after increasing the dose.

Light-output degradation



- Light-output degradation is described by similar curves for crystals No 83, 84, 95.
- Total light-output degradation after dose of about 35 krad is 30% for crystals No 83, 84, 95 and 60% for crystal No 94.
- Belle crystals have enough radiation hardness for Belle II experiment (including crystals closest to the beampipe, at least, at the initial stage of experiment).

CsI(Tl) option for Super $c-\tau$ factory

- High energy resolution for wide range of energies.
- High light-output (about 5×10^4 photons/ MeV) and emission spectrum with maximum of about 550 nm.
- Sufficient radiation hardness for conditions of e^+e^- colliders.
- Low maintenance cost.
- Big experience of working by BINP scientific group.

Conclusion

- Series of expositions for four Belle typical crystals has been performed with total dose of 30 krad.
- Results have been combined with previous measurements of radiation hardness.
- Light-output degradates faster after doses of about 1 krad and slower after higher doses.
- Total degradation is about 30% for three tested crystals and about 60% for one worst crystal after dose of about 35 krad.
- Clear degradation of uniformity is observed up to 14% after 35 krad.
- One can expect that Belle crystals have sufficient radiation hardness for Belle II experiment.
- CsI(Tl) crystals are considered as possible option for calorimeter of Super $c-\tau$ factory in Novosibirsk.