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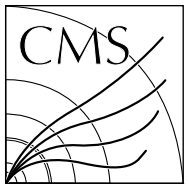
CMS DP -2024/077



The Compact Muon Solenoid Experiment

CMS Performance Note

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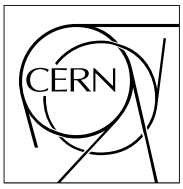


04 September 2024

Barrel Timing Layer crystals quality control plots

CMS Collaboration

Abstract

The note presents the latest results on the LYSO crystal quality controls, as uniformity of the light output and decay time, planarity of the crystal arrays and additionally, light transmittance and absorbance towards the production of the Barrel Timing Layer sensors.

Barrel Timing Layer crystals quality control plots

CMS Collaboration

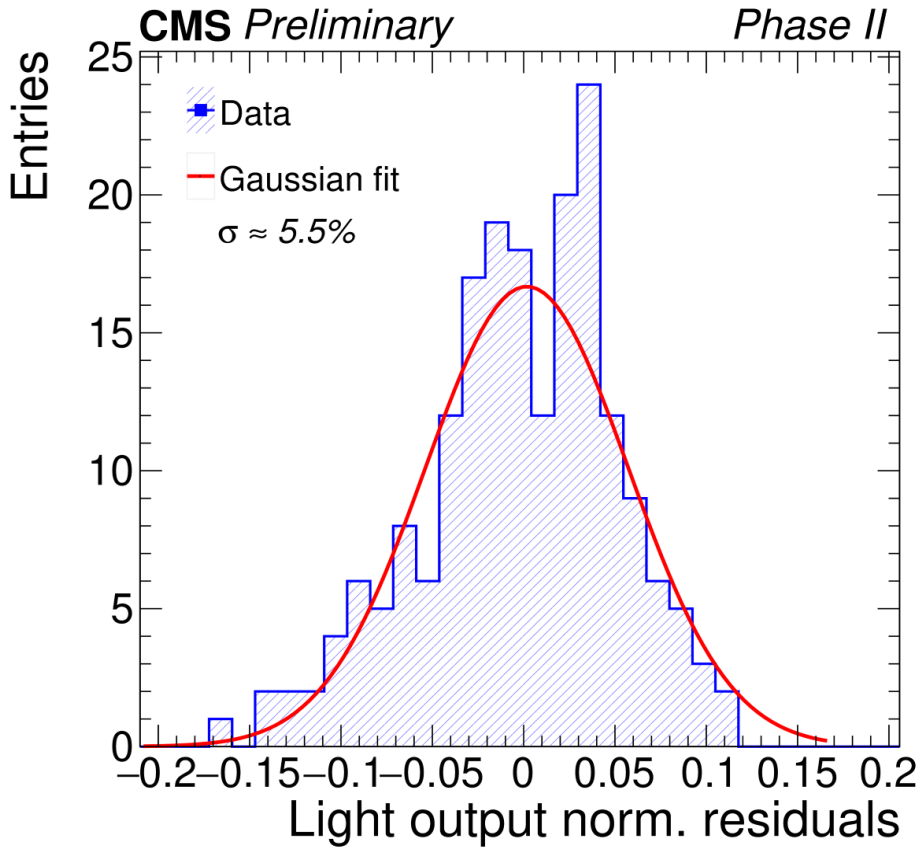
cms-dpg-conveners-mtd@cern.ch

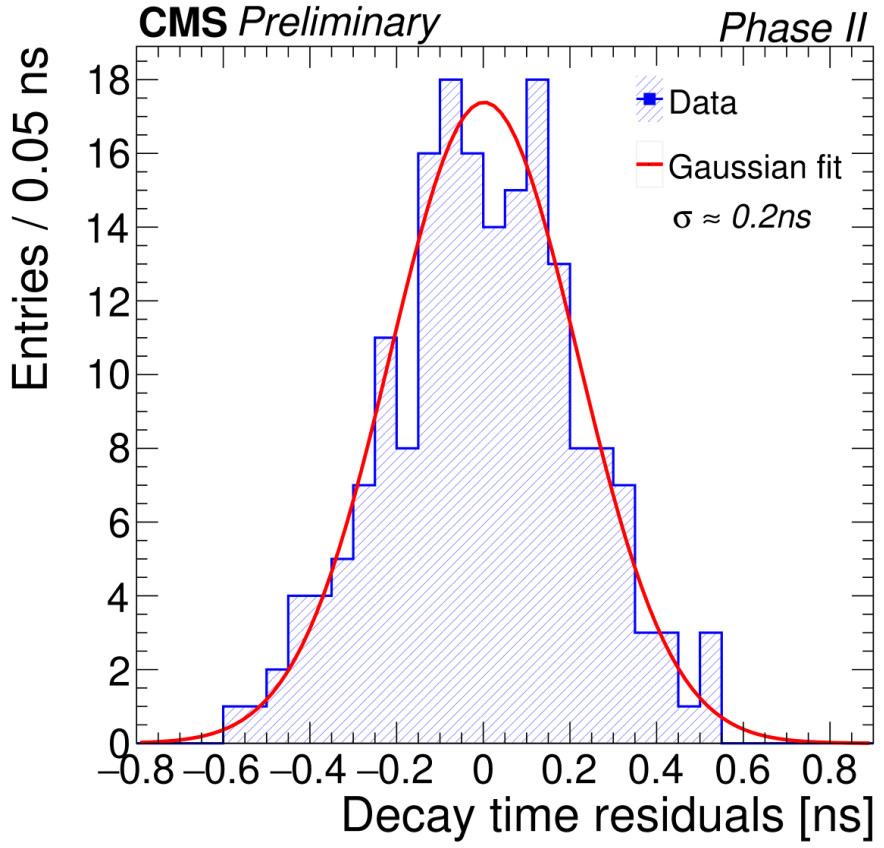
From “Barrel Timing Layer crystals quality control plots”

Ingot quality measurements reproducibility

- 4 crystals are used as reference and measured at the begin and end of each measurement session
- Residuals with respect to the average measurement of each reference crystal are shown for the absolute light output measurement and the decay time
- Reproducibility of 5.5% and 0.22ns are established from gaussian fits to the distributions

Light output normalized residuals of 4 reference crystals with respect to crystal-averaged values.

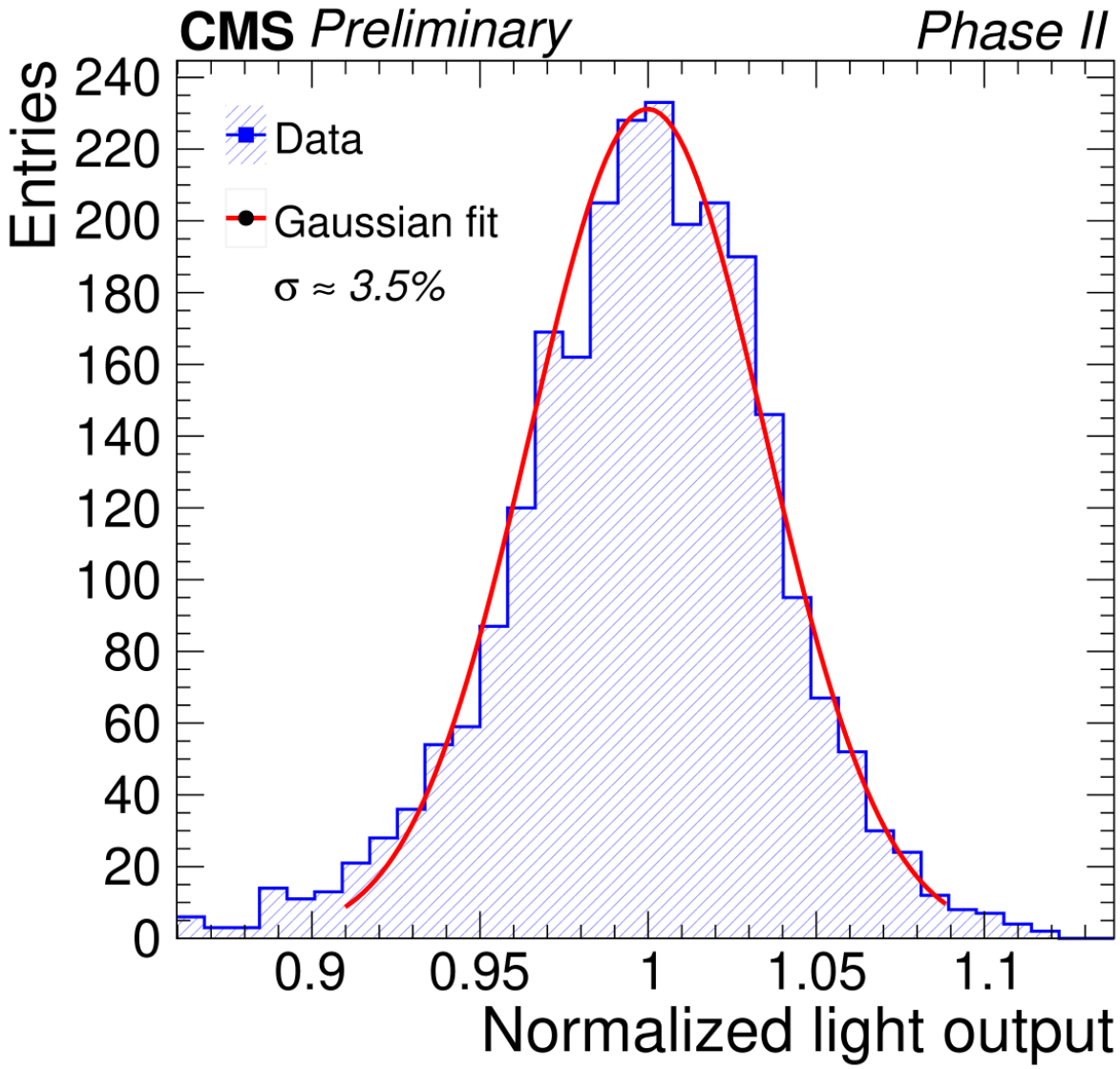




Decay time residuals of 4 reference crystals with respect to crystal-averaged values.

From “Barrel Timing Layer crystals quality control plots”

LYSO Production uniformity

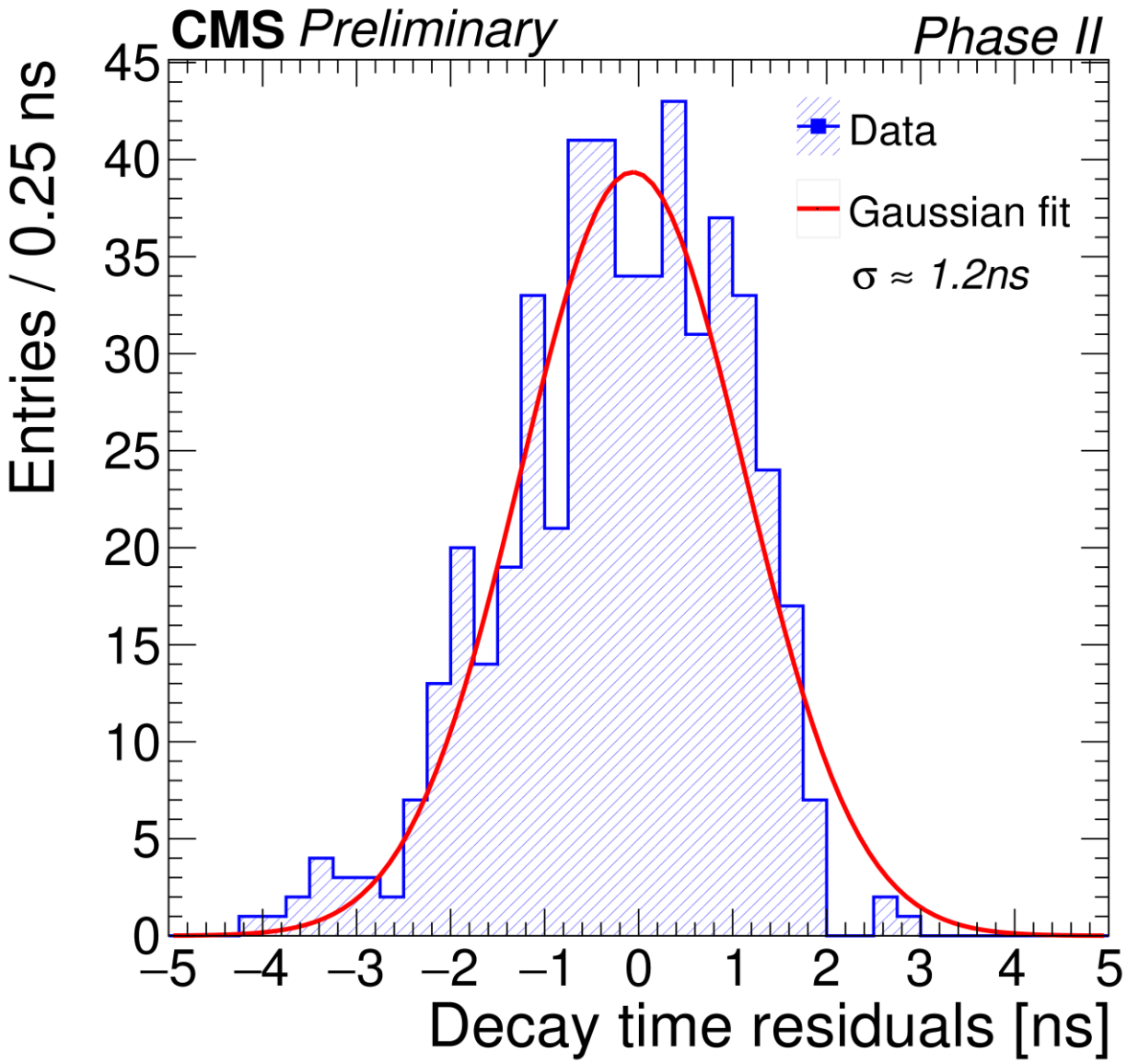


- About 1/3 of the total production has been delivered and measured so far (total production is divided in 9 monthly batches)
- The normalized distributions of light output for all crystals inside arrays is shown
- Standard deviation of 3.5% is found after gaussian fit to the distribution

Normalized light output of crystals inside arrays

From “Barrel Timing Layer crystals quality control plots”

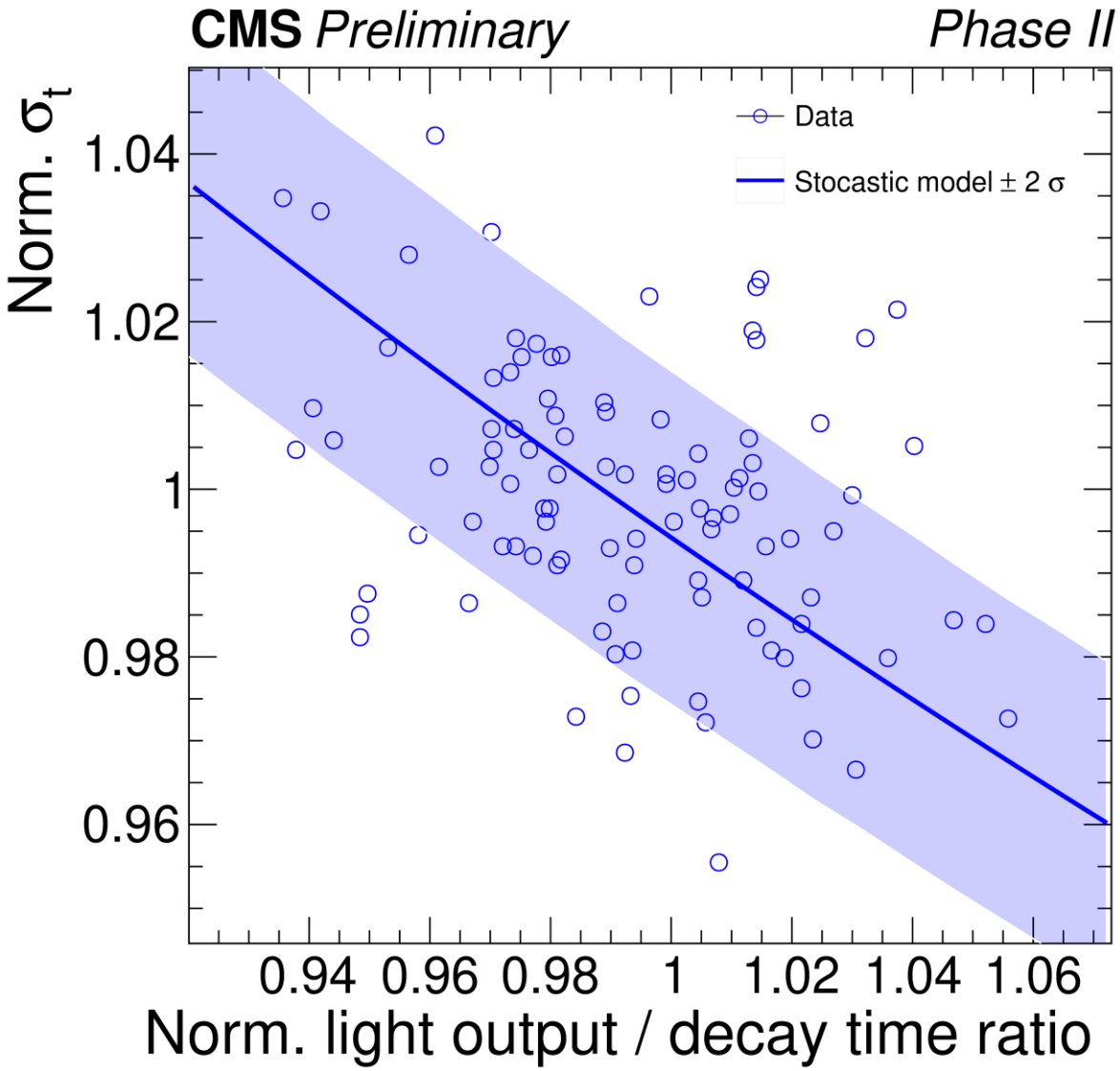
Decay time uniformity



- About 1/3 of the total production has been delivered and measured so far (total production is divided in 9 monthly batches)
- A standard deviation of 1.2 ns on the decay distribution is found after a gaussian fit

Decay time distribution of about 1/3 of the crystals produced so far and tested for quality control

Time resolution correlation with the light output/decay time figure of merit



From "Barrel Timing Layer crystals quality control plots"

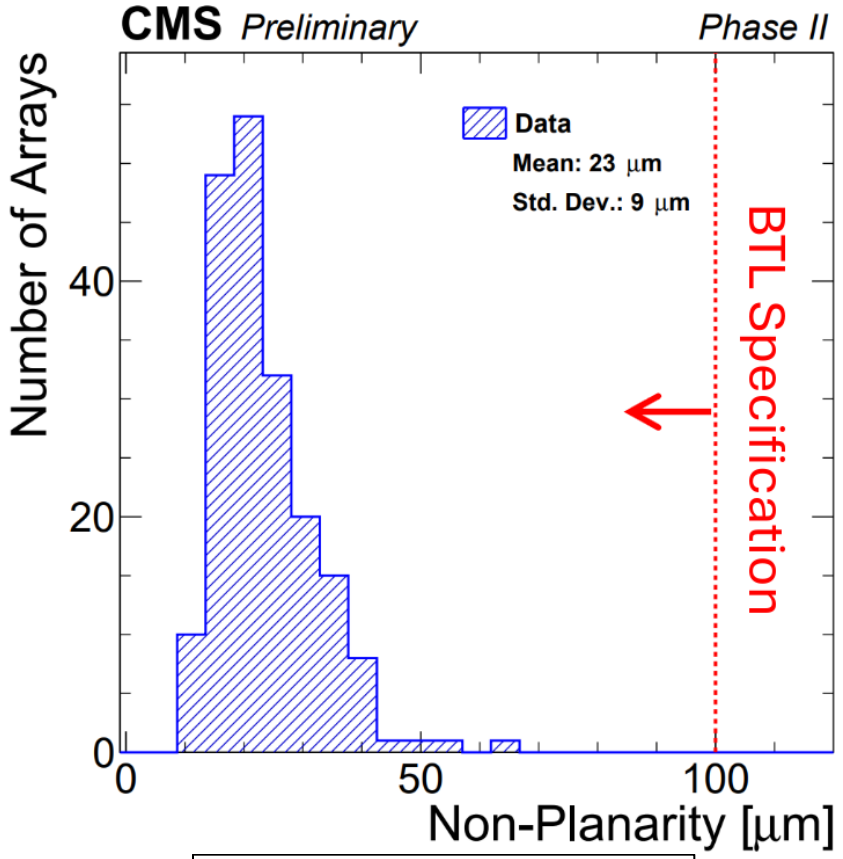
- The plot represents the correlation between the normalised LYSO figure of merit (light output/decay time) and the normalised time resolution
- Each point is averaged over the measurements performed on each ingot: light output and time resolution is extracted from each bar inside the LYSO arrays, decay time is obtained from the sample crystals measured on each ingot
- A line is super-imposed, corresponding to the expected dependence as a photostatistics model (inverse square root). The confidence intervals are at 2 sigmas, considering the measurements reproducibility as error.

Normalized time resolution vs. normalized light output / decay time ratio, averaged per each ingot

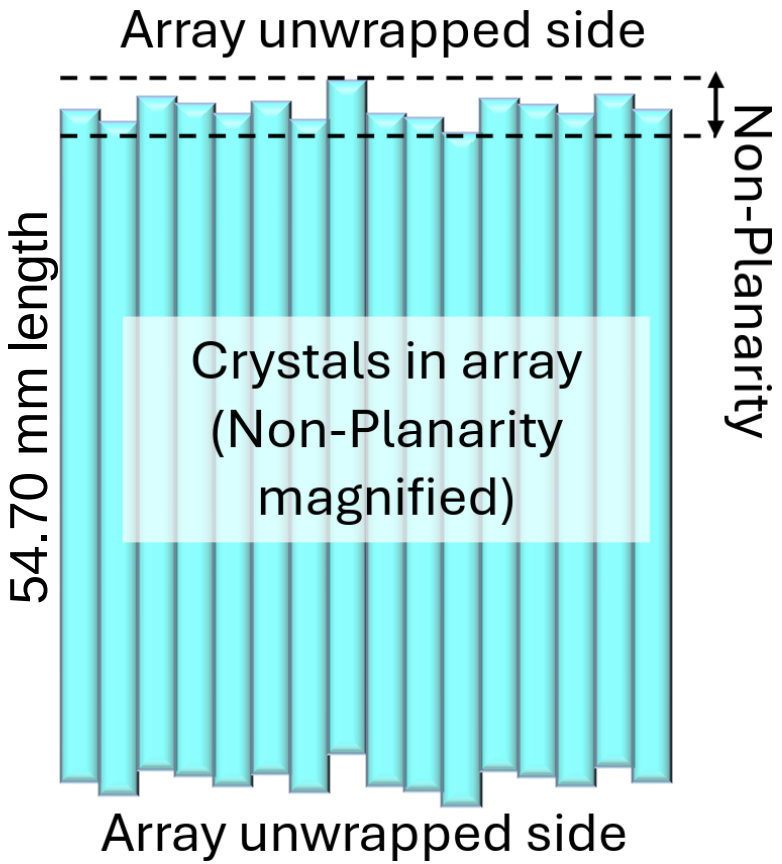
From “Barrel Timing Layer crystals quality control plots”

Array planarity checks

- The position of the face of each crystal on the unwrapped side of the array is measured with a Coordinate Measuring Machine with a precision of few μm. The difference between the position of the crystal that protrudes the most and the one that protrudes the least is taken as the measurement of the Non-Planarity of the array



Array non-planarity

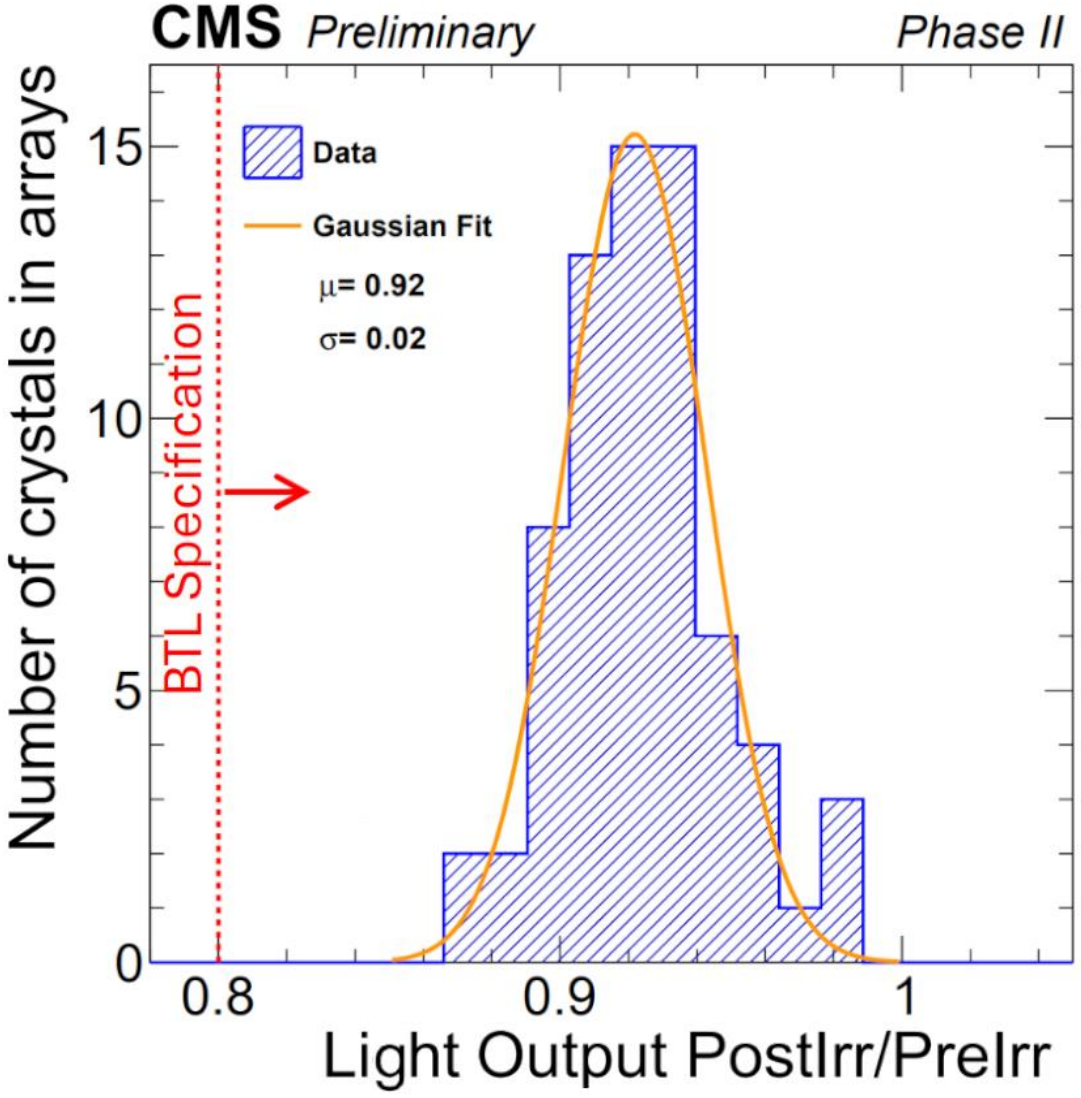


51.38 mm width

- LYSO Array planarity is crucial to ensure a good coupling with the strip of photosensors (SiPM) that is attached to both unwrapped sides of the array. Non-Planarity is well below the expected thickness of the layer of glue that will couple LYSO crystals with SiPMs, which is about 100 μm.

From “Barrel Timing Layer crystals quality control plots”

Array light output loss after irradiation

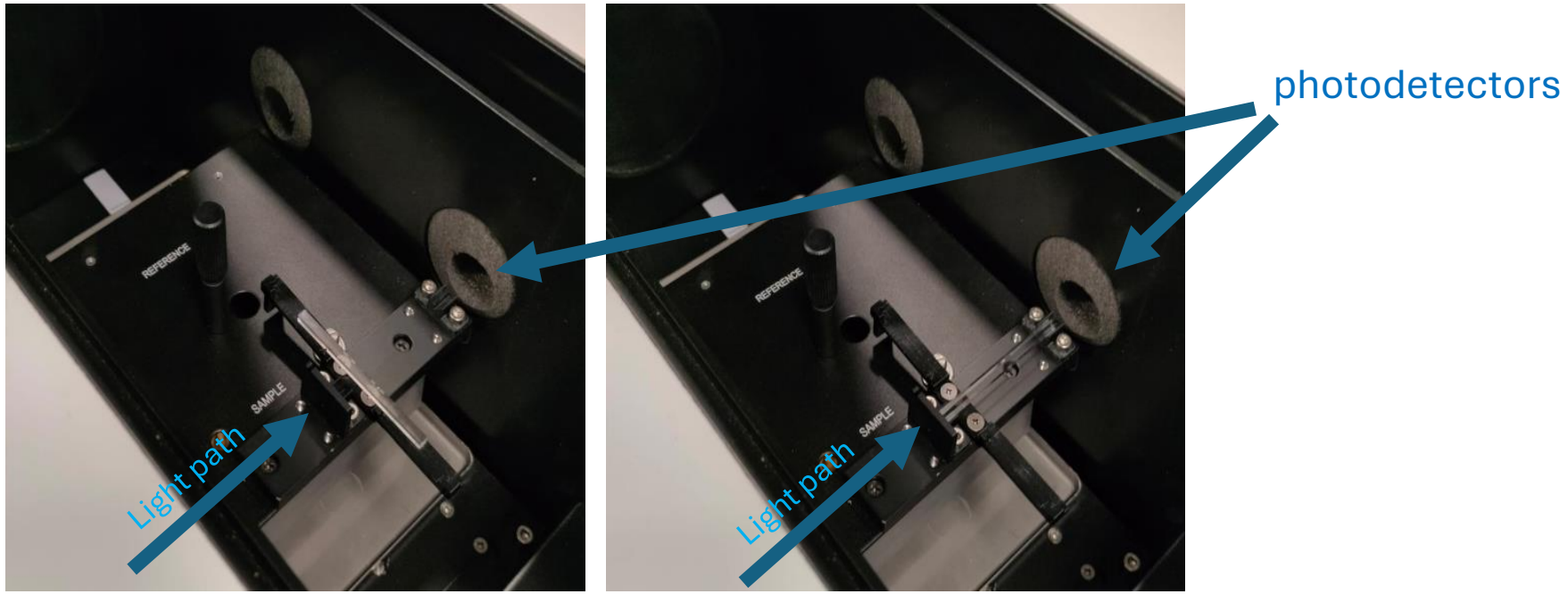


Array light output loss after irradiation

- The Light Output (LO) of LYSO crystals inside array is measured using photons from an Na22 radioactive source, coupling LYSO crystals with SiPMs, as in final BTL design.
- The measurement of LO has been done before (PreIrr) and after (PostIrr) irradiating the crystals with 50 kGy of photons from a Co60 source.
- A gaussian fit (orange line) shows a reduction of 8% on average, caused by the crystal transparency loss, with σ = 2%
- The LO PostIrr is above the tender specification for BTL (vertical red line), which is set at 80% of LO PreIrr.

Spectrophotometer

- Measurements of transmittance as a function of wavelength of crystal bars done using a double-beam UV-Vis spectrophotometer
  - Complementary to LO, study of crystal transparency loss after irradiation
  - LYSO crystals are doped with cerium – instrument is also used in dopant concentration studies
- Sample support for two different crystal positions with respect to the incident beam – longitudinal (~ 5.5 cm) & transversal (~3 mm)
- Wavelength scans done in 300 nm to 600 nm spectral range with 5 nm steps



Transversal

Longitudinal

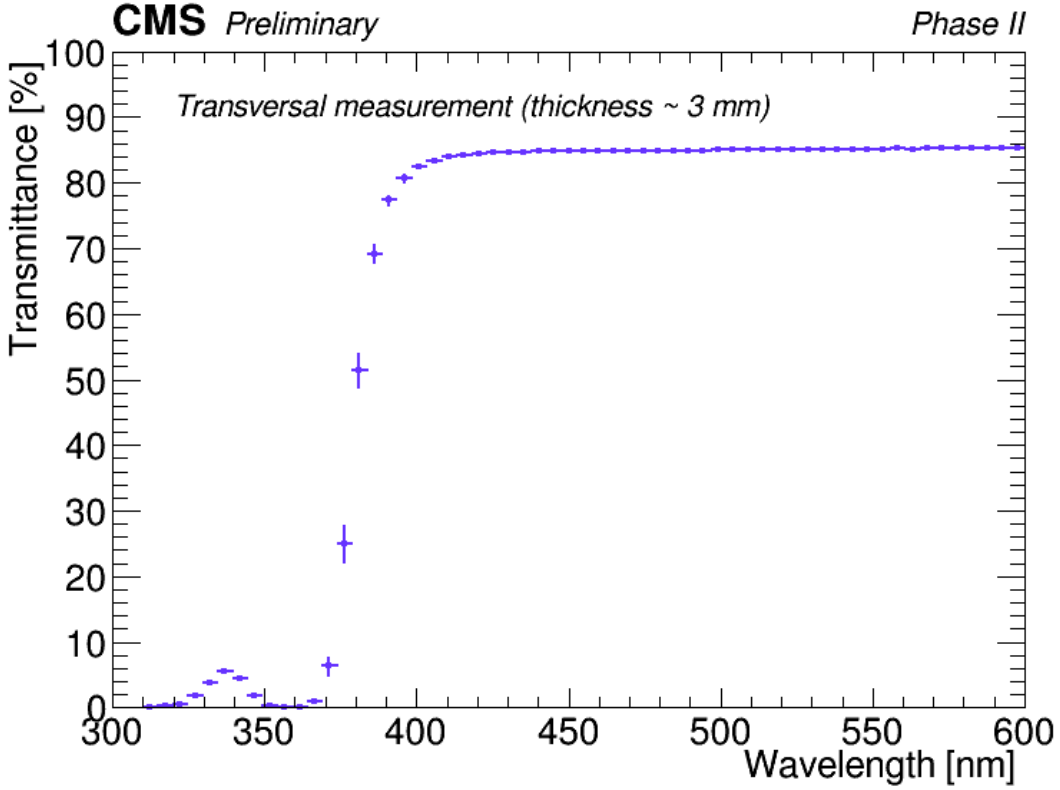
Transmittance & absorbance

- Transmittance spectrum of a crystal bar in UV-VIS range, as a function of wavelength

$$\mathrm{T} = \frac{\mathrm{I}}{\mathrm{I_0}}$$

$I_o\ (I) =$ intensity of incident (outgoing) beam

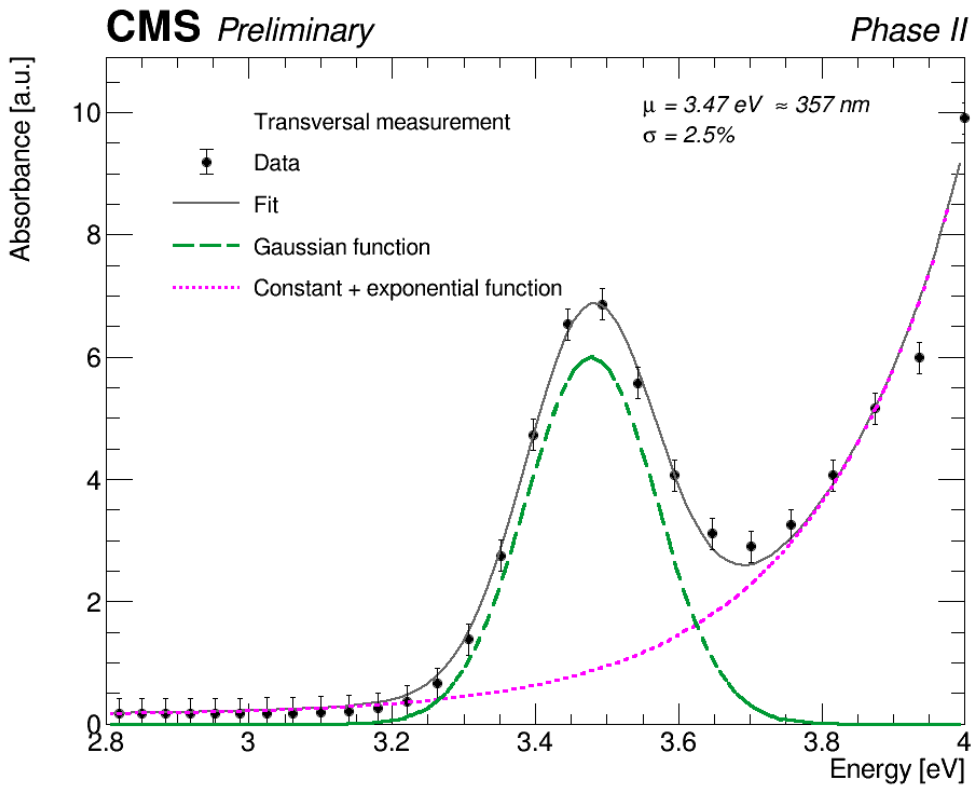
- A dip in transmittance around 360 nm occurs due to the absorption of cerium for smaller optical paths



- Corresponding absorbance for the same crystal as a function of the energy (E)

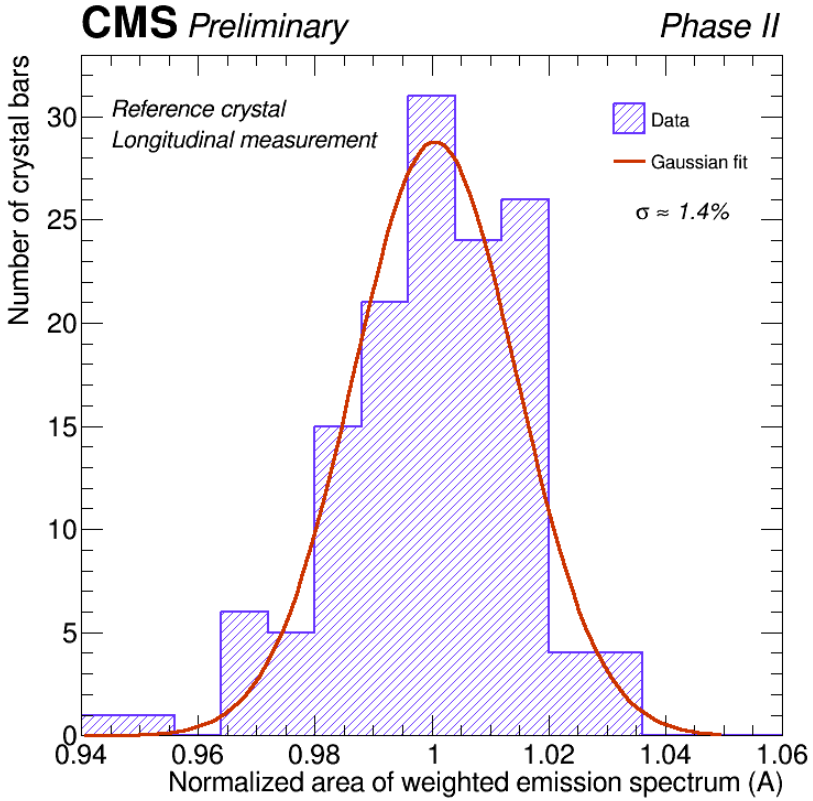
$$\mathrm{E} = \frac{\mathrm{hc}}{\lambda}, \qquad Abs = -lnT$$

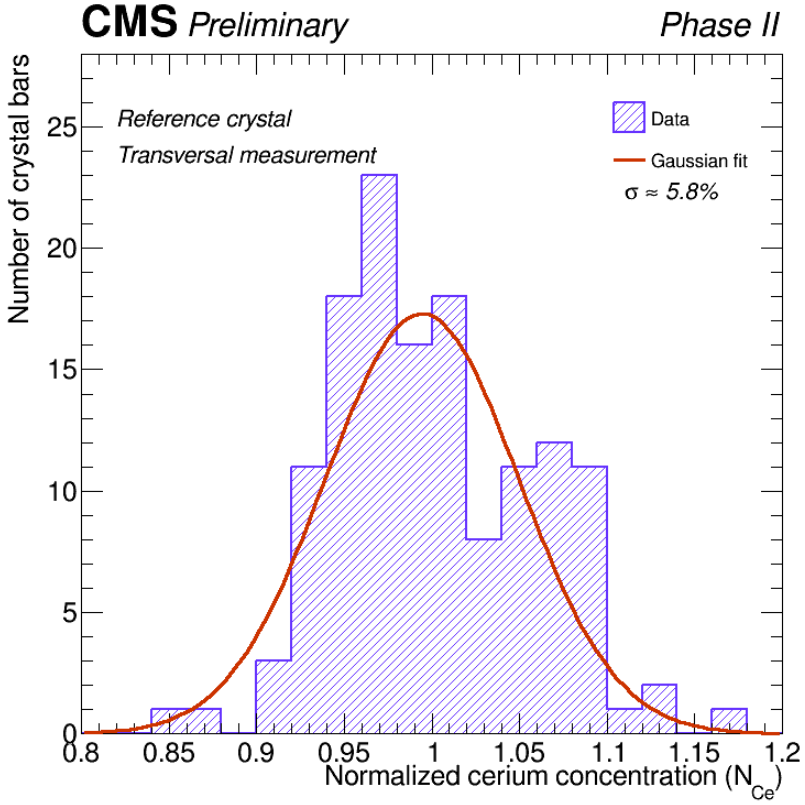
- Area of the Gaussian peak (which corresponds to cerium's absorption peak wavelength, around 360 nm) is approximately proportional to concentration of cerium dopant in LYSO crystal



Reproducibility measurement of reference crystal

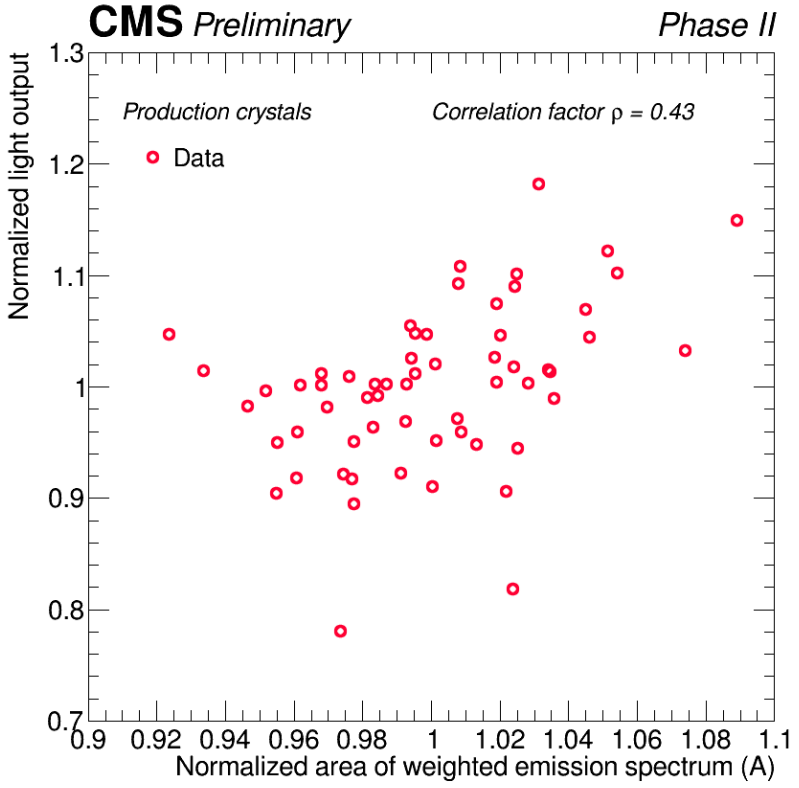
- One LYSO:Ce reference crystal has been repeatedly measured every several days for few months
  - This procedure is performed to study the reproducibility of the measurement assuming no change in the sample.
- Area of weighted emission spectrum: integral of the LYSO:Ce emission spectrum multiplied by the photo-multiplier tube (PMT) quantum efficiency and by measured longitudinal transmittance spectrum
  - Distribution normalized to its average shows measurement reproducibility of 1.4%
- Cerium concentration distribution normalized to its average from repeated measurements on a reference gives a reproducibility of 5.8%
- The measured spread reflects the reproducibility of the crystal positioning at each measurement. Small changes in the crystal position produce sizeable variations in the measured transmittance due to the relatively small size of crystal samples compared to the light beam section.

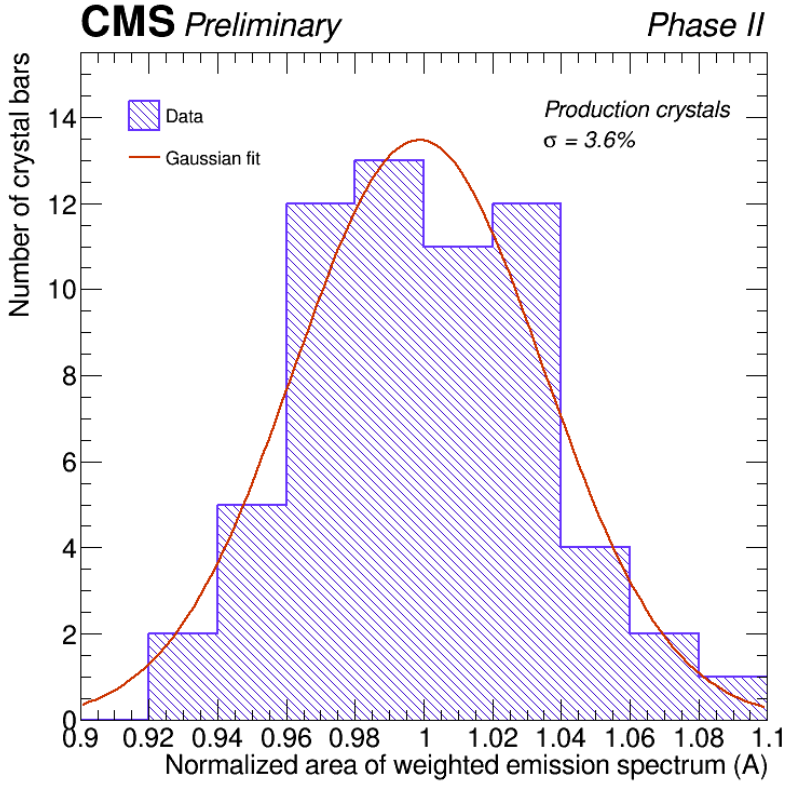




Longitudinal transmittance measurement of production crystals

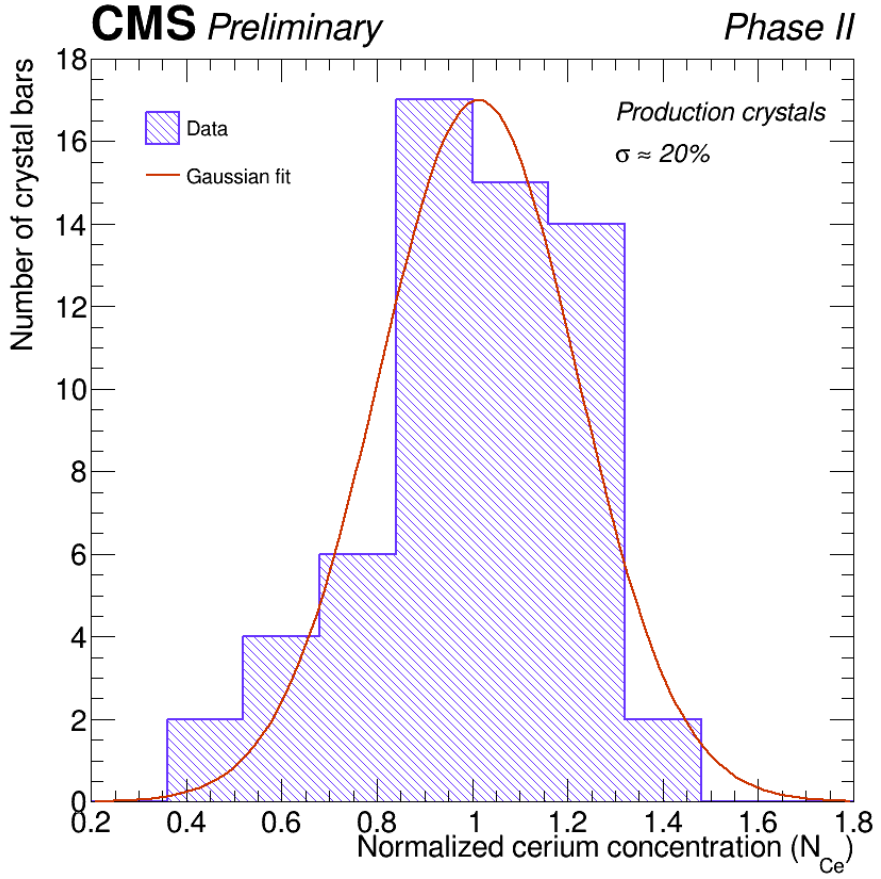
- 1/3 of total production has been delivered and measured so far (total production is divided in 9 monthly batches)
- Transmittance is measured for half of the ingots per batch
- Scatter plot of normalized light output (LO) vs the normalized area of the weighted emission spectrum (A)
  - LO is measured with photons from Na^{22} radioactive source coupling the LYSO:Ce crystal with PMT
- Normalized area of the weighted emission spectrum of the crystal fitted with a gaussian function that gives a width of 3.6%





Transversal transmittance measurement of production crystals

- 1/3 of total production has been delivered and measured so far (total production is divided in 9 monthly batches)
- Transmittance is measured for half of the ingots per batch
- Normalized cerium concentration in production crystals fitted with a gaussian function
- The fit gives a spread of 20%



Irradiation effects on production crystals - transparency

- 1/3 of total production has been delivered and measured so far (total production is divided in 9 monthly batches)
- Transmittance is measured for half of the ingots per batch
- Production crystals were irradiated with 50 kGy of photons from a Co^{60} radioactive source
- Ratio of weighted emission spectrum of production crystals before (A_{pre}) and after (A_{post}) irradiation
- From the plot, there's ~ 8% loss in transparency of the crystals
- From the fit, mean of the distribution is 0.92, with a spread of 1.7% (comparable with the reproducibility of the measurement)