Detection of the Čerenkov light from a TeO_2 crystal

Nicola Casali, Università degli studi dell'Aquila, INFN Laboratori Nazionali del Gran Sasso

F. Bellini, N. Casali, I. Dafinei, M. Marafini, S. Morganti, F. Orio, D. Pinci, M. Vignati, C. Voena

Why searching Čerenkov radiation in TeO_2 crystal?

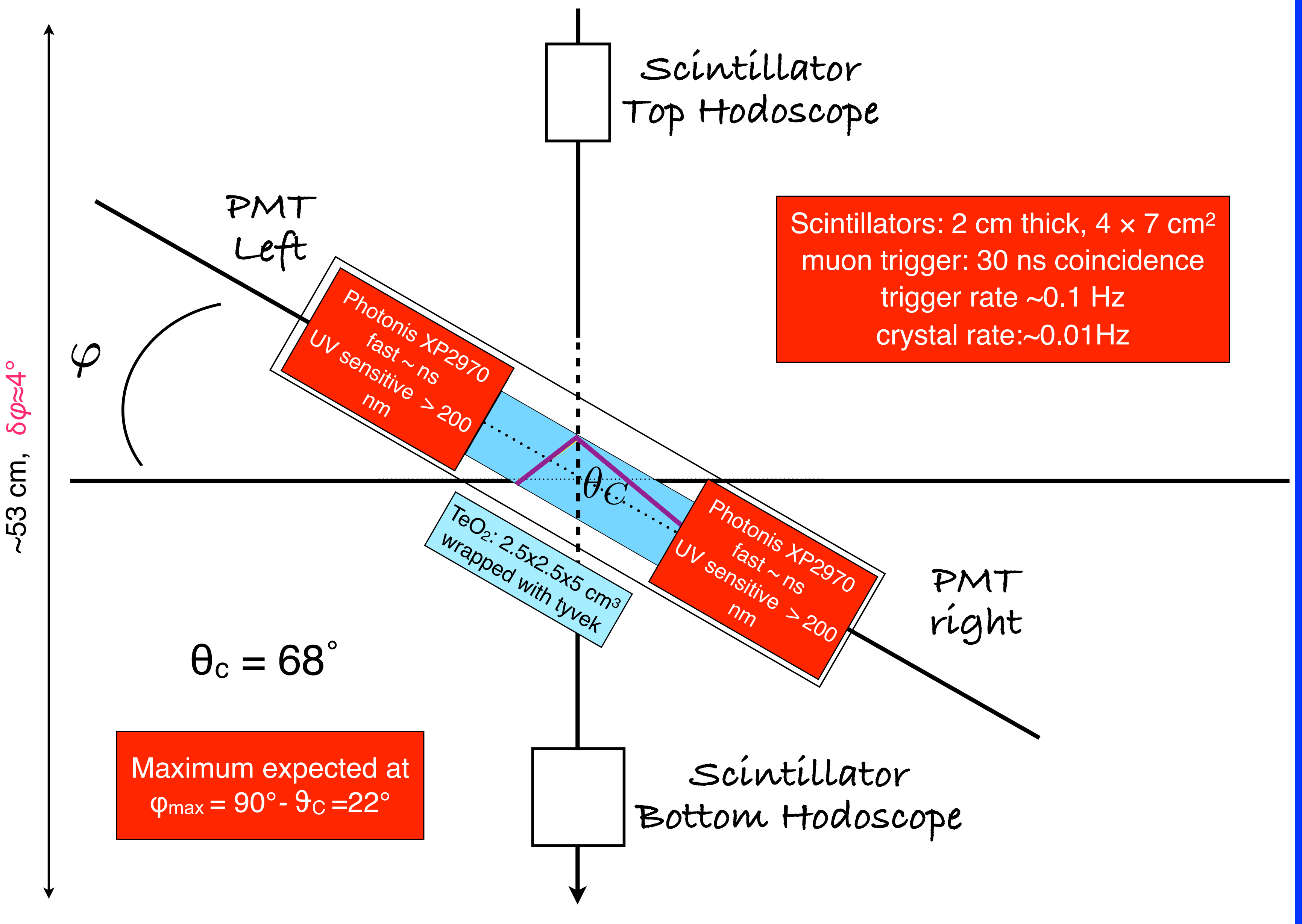
TeO_2 crystals are currently used as bolometers in experiments searching for rare processes like double beta decay or Dark Matter interaction. The natural radioactivity represents for these experiments the main background source. The background component produced by α particles can be separated by the β particles detecting the Čerenkov light emitted at low energies (50 keV ÷ 400 MeV) only by electrons.

Goal of the measurement

Assessment and measurement of the Čerenkov component in the light output of a TeO_2 crystal at room temperature and disentanglement from a possible scintillation component:

Process	Emission	Rise Time	Decay Time	Spectrum	Polarization
Scintillation	isotropic	prompt	exponential $\tau > 10 \div 15$ ns	visible peak?	no
Čerenkov	$\cos\theta_C = (\beta n)^{-1}$	prompt	prompt	UV ~ $1/\lambda^2$	yes

Experimental setup



Scintillators: 2 cm thick, 4 × 7 cm^2
muon trigger: 30 ns coincidence
trigger rate ~0.1 Hz
crystal rate:~0.01Hz

$\theta_c = 68^\circ$

Maximum expected at
$\varphi_{max} = 90° - \vartheta_C = 22°$

Analog signals acquired by CAEN V1731 8-bit 1 Vpp, 1 GS/s sampling rate, BW = 250MHz; sensitivity ~ 4 mV, rise time = 2.2/(2πBW) = 1.4 ns.

Expected Signal

The crystal light output can be divided in two components:

- A: independent from the angle between the muon and crystal → Scintillation or diffused Čerenkov light
- B: dependent from the angle between the muon and crystal → Mainly Čerenkov light

$$\begin{aligned}\bar{L}(\varphi) &= \frac{\alpha}{\cos\varphi}\left(A_L + B_L(\varphi)\right) \\ \bar{R}(\varphi) &= \frac{\beta}{\cos\varphi}\left(A_R + B_R(\varphi)\right)\end{aligned}$$

$\frac{1}{\cos\varphi}$ = path length

α and β = different PMT gains

if the setup is symmetric

$$A_L = A_R = A \qquad B_L(\varphi) = B_R(-\varphi) = B(\varphi)$$

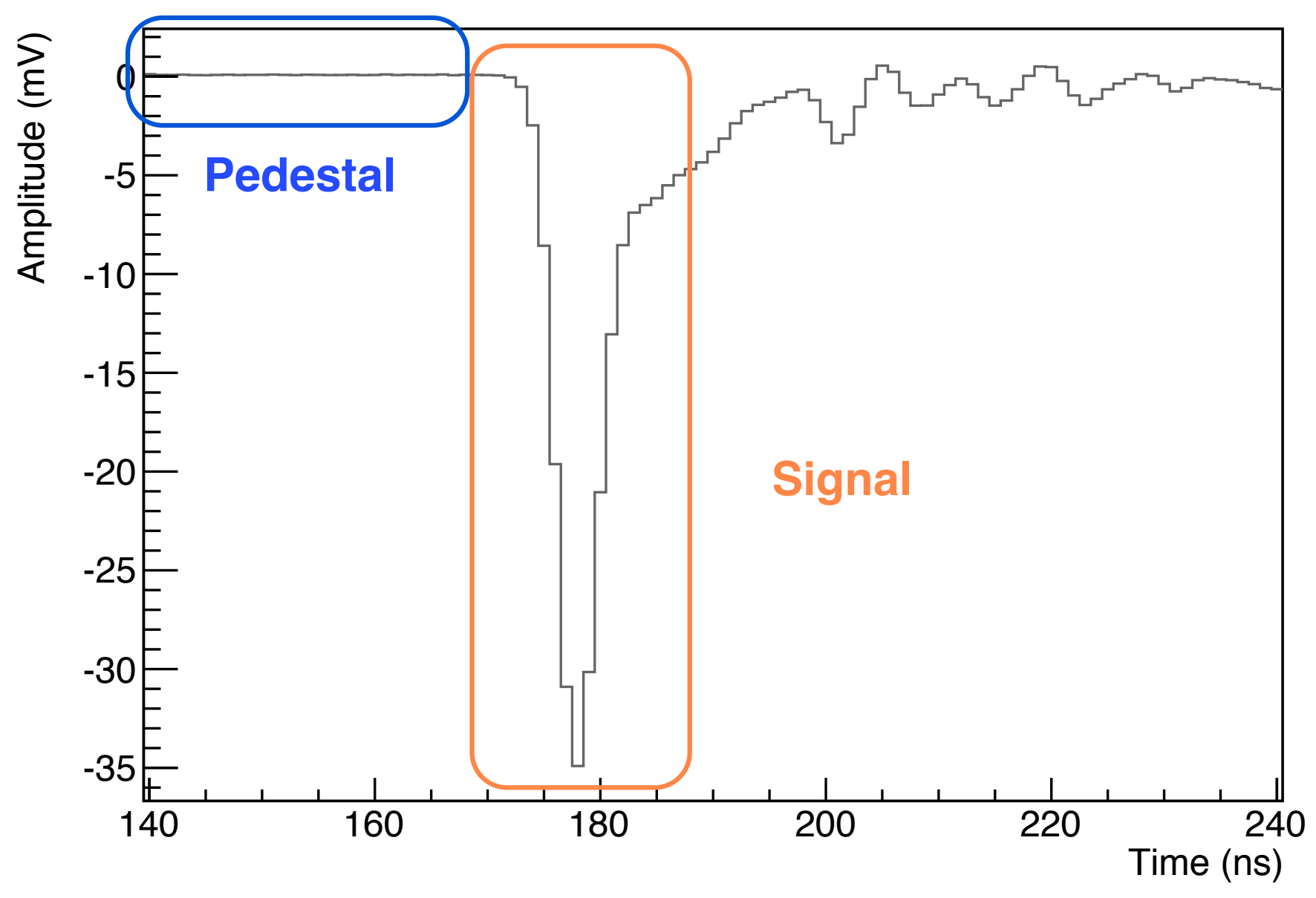
we can define the following variables

$$\bar{L}(0) = \alpha\left(A + B(0)\right) = \alpha k$$
$$\bar{R}(0) = \beta\left(A + B(0)\right) = \beta k$$

$$\begin{aligned}L(\varphi) &= \frac{\bar{L}(\varphi)}{\bar{L}(0)} = \frac{1}{k\cos\varphi}\left(A + B(\varphi)\right) \\ R(\varphi) &= \frac{\bar{R}(\varphi)}{\bar{R}(0)} = \frac{1}{k\cos\varphi}\left(A + B(-\varphi)\right).\end{aligned}$$

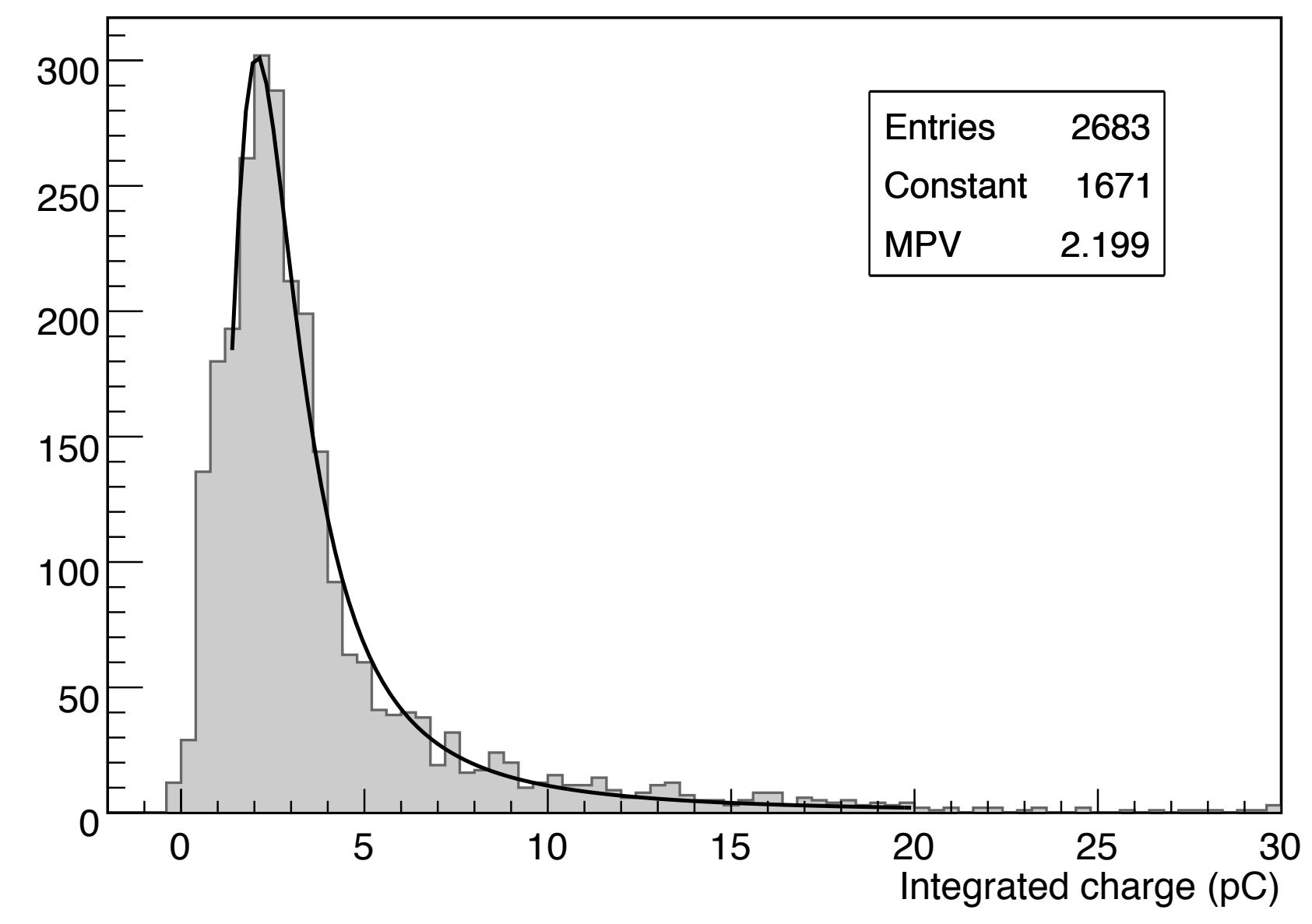
$$L(\varphi) = R(-\varphi).$$

Signal read out



Average waveform for 1000 muons

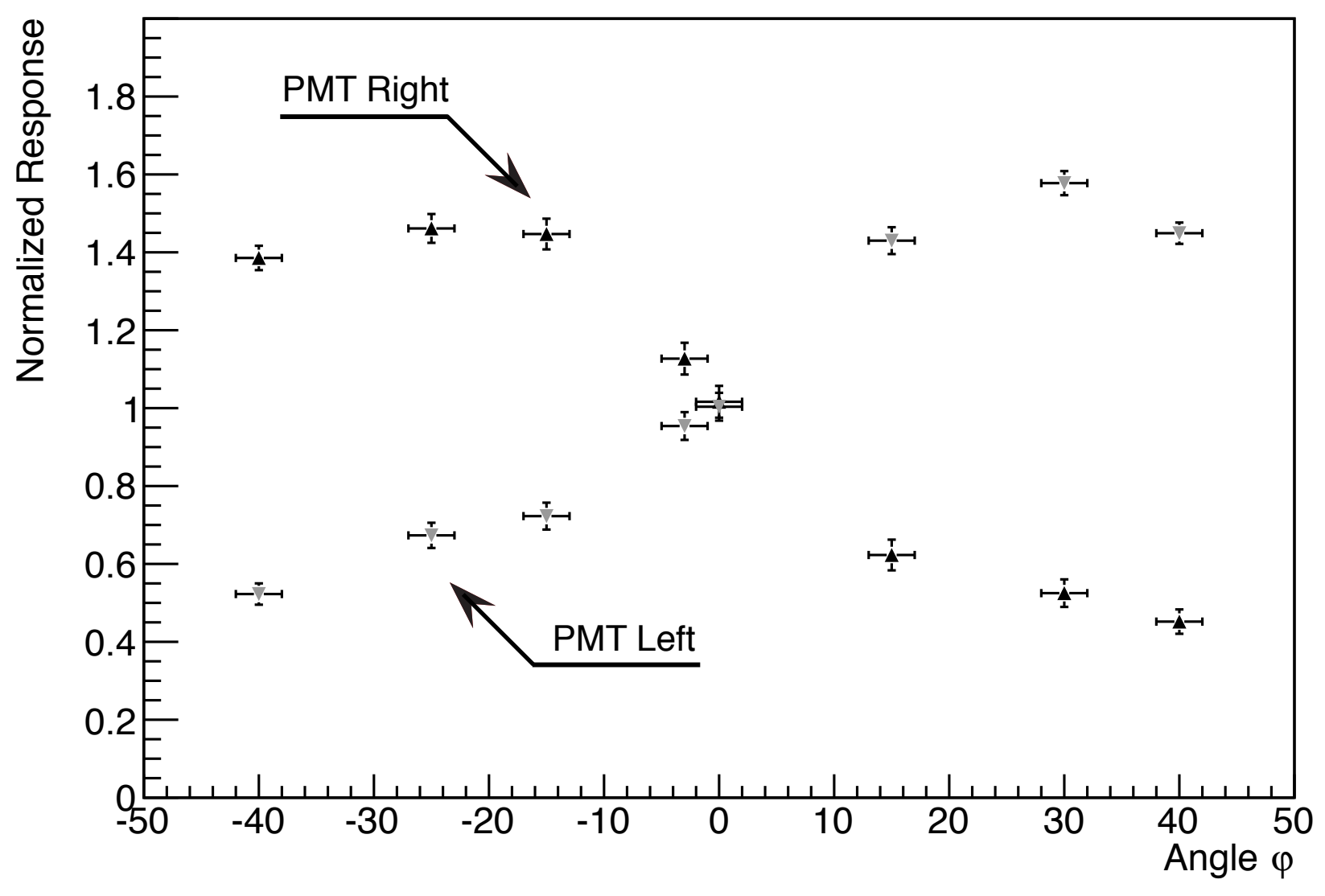
- Fast signal: rise and decay time of the order of few ns



Charge distribution for a PMT

- For each angle the signal is fitted with a Landau distribution

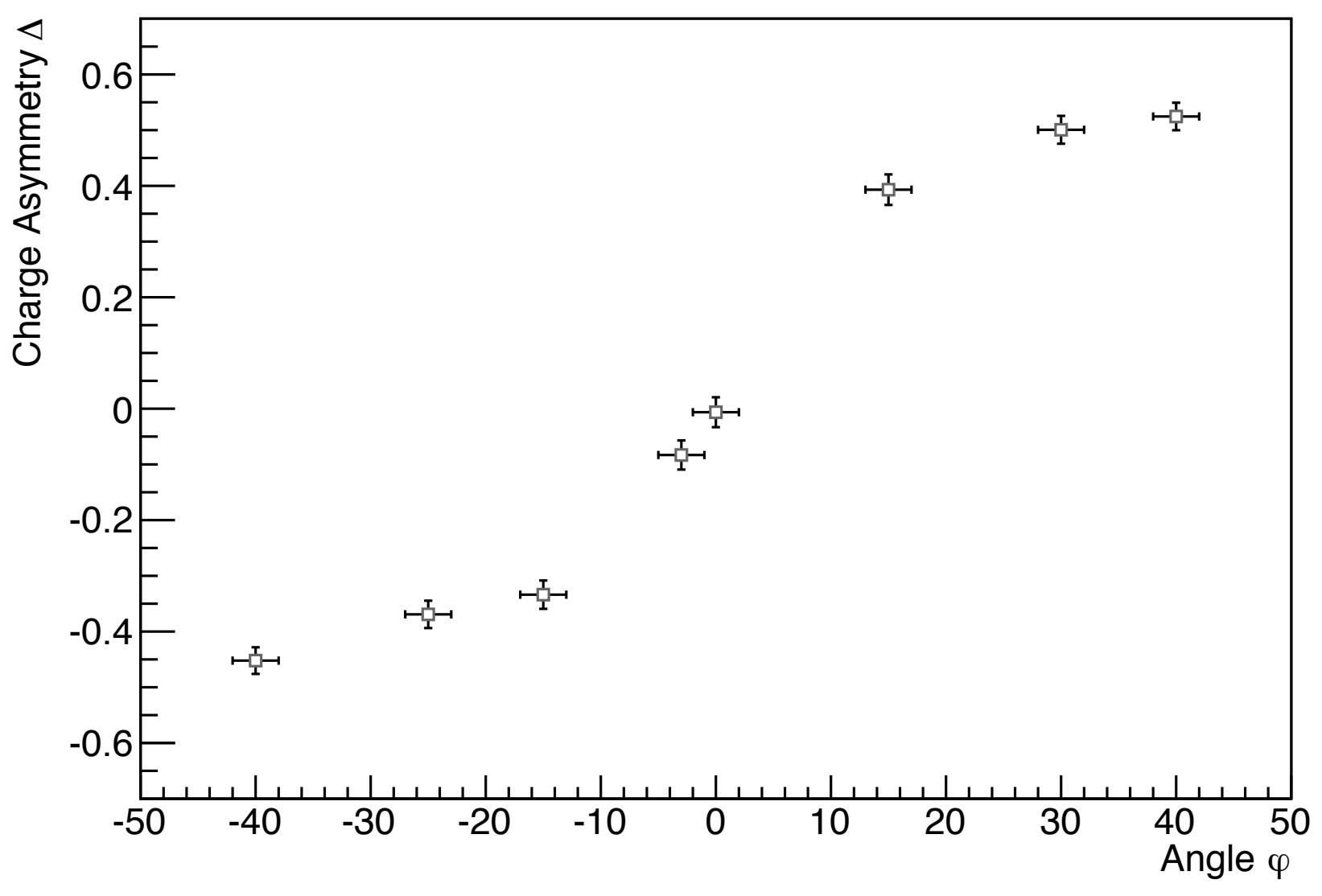
Results



Response corrected for the muon path length and PMT gain equalize;

The angle dependence is clearly visible and similar on the two sides
Flat component ~ 0.6
Directional component ~ 1.5

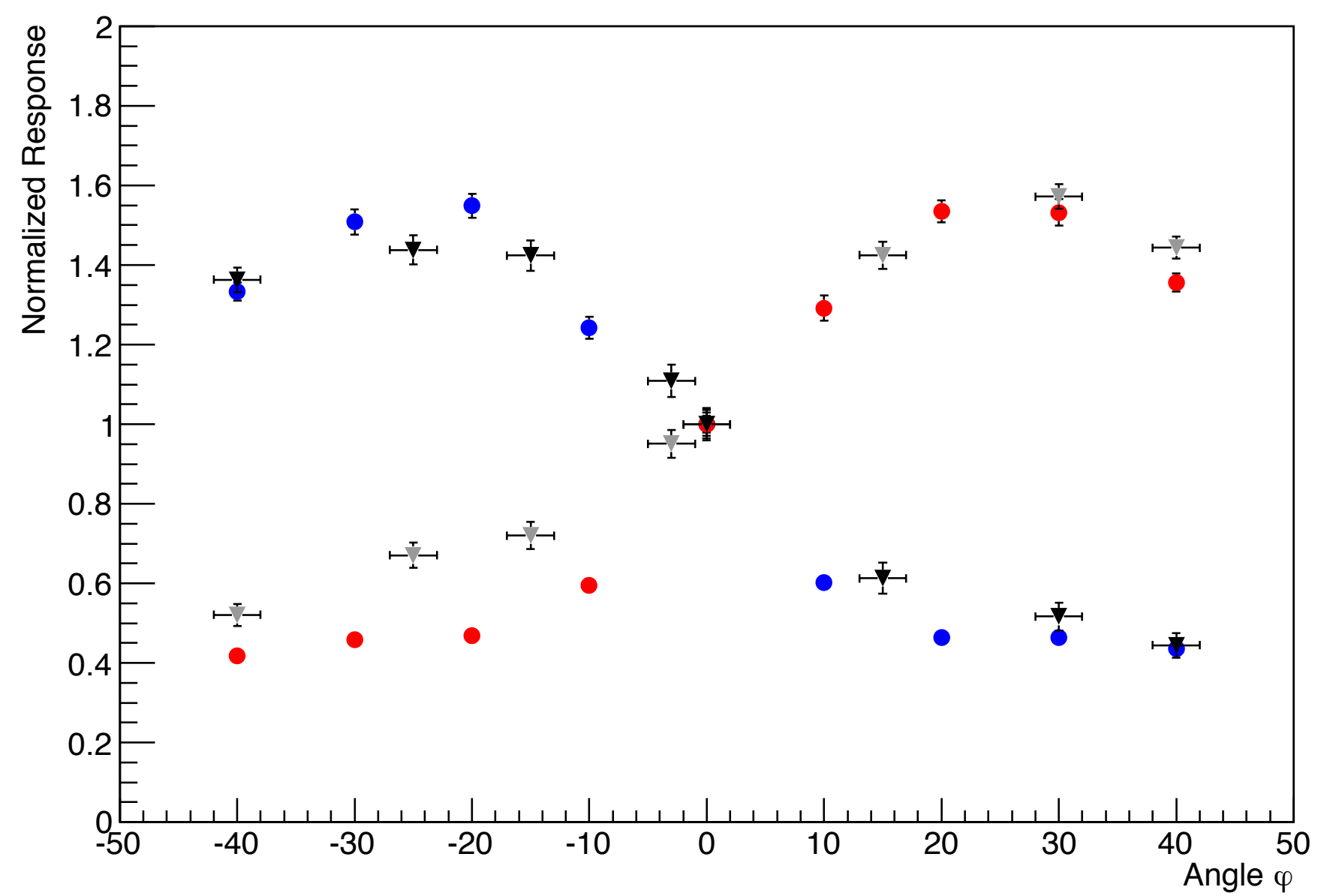
$$\Delta(\varphi) = \frac{L(\varphi) - R(\varphi)}{L(\varphi) + R(\varphi)} = \frac{-B(-\varphi) + B(\varphi)}{2A + B(\varphi) + B(-\varphi)}$$



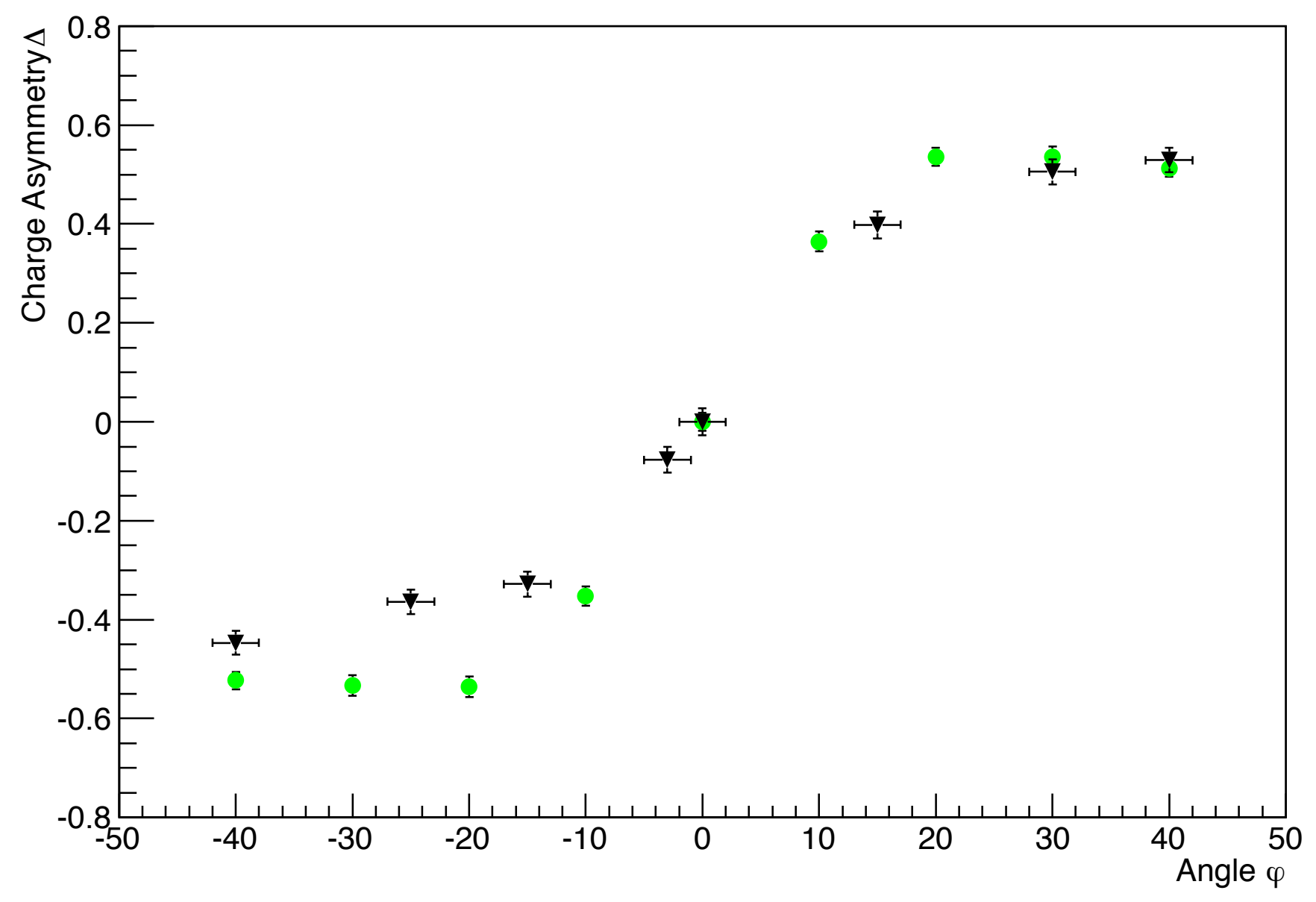
If the flat component is due to the scintillation alone, Čerenkov would be ~ 60 % of collected light.

Simulation vs Data

Simulation: Red and Blu bullets
Data: Black and Gray triangles



Simulation: Green bullets
Data: Black triangles



Is the flat component due to diffused Čerenkov light ?

Simulating only Čerenkov radiation produced by cosmic muon in our experimental setup we obtain this results;

The Čerenkov light diffused by lateral surface produces the flat component that we have measured.

Therefore the contribution of scintillation light (if exist) to the observed signal is negligible.

Conclusions

- TeO_2 crystal emits light when crossed by fast charged particles.
- The signal is very fast: rise and decay time of the order of few ns.
- There is a clear angular dependence compatible with Čerenkov emission.
- There is a flat component: the Monte Carlo simulation confirms that this component is totally explained by the Čerenkov radiation alone.
- The contribution of an hypothetical scintillation light seems to be negligible.

Ref: F Bellini *et al* 2012 *JINST* **7** P11014

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Nicola Casali