Investigation of Chernekov radiation component in LYSO(Ce) crystals

A.Yu. Barnyakov, G.S. Chizhik, V.A.Kladov, I.V. Ovtin*

Budker Institute of Nuclear Physics, Novosibirsk, Russia
Novosibirsk State University, Novosibirsk, Russia

Outline:

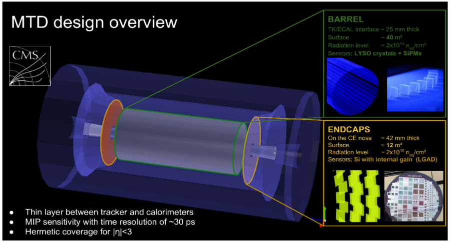
1. **Introduction**
2. **Simulation**
3. **Test beam and experiment**
4. **Conclusion**

12 September, DeSyT-2019

Introduction

- The fast scintillation crystals such as pure CsI or LYSO(Ce) today are considered for precision timing measurements in future colliding beam experiments;
- The aim of such counters is to determine time of particles arrival with accuracy σ_t <100 ps;
- LYSO(Ce) crystals fast (60 ps rise, 40 ns decay) and bright (40000 ph/MeV). Proven to be enough radiation hard.

Barrel part MIP Timing Detector (MTD) CMS will be based on LYSO(Ce)+SiPM (σ_t<30 ps)

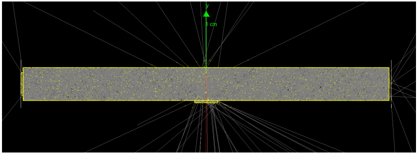


https://arxiv.org/pdf/1810.00350v1.pdf

Motivation:

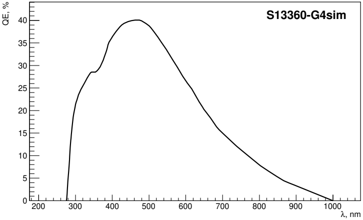
- Cherenkov photons could be a reason of an additional jitter or systematic shift of signal arriving time from different ends of the bar;
- Estimate the effect of Cherenkov radiation in LYSO crystals on its timing properties with simulation and beam test experiment.

G4 simulation: Detector construction

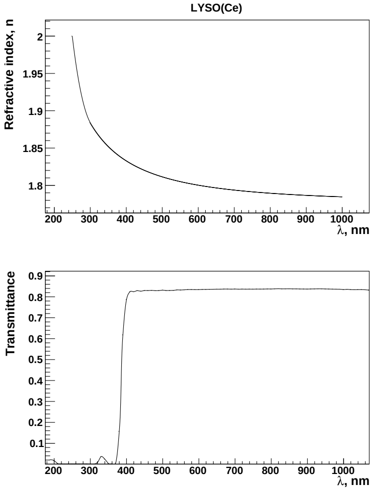


- LYSO bar 4.5×4.5×50 mm;
- 2 SiPMs with sensitive area – 3×3 mm; They are coupled to crystal through optical grease (n=1.56);

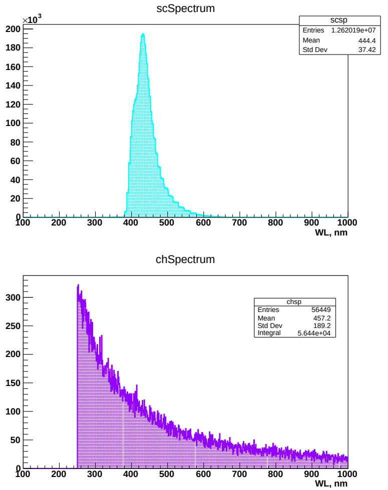
All presented results are obtained with maximal PDE of SiPM.



Data for G4 simulation

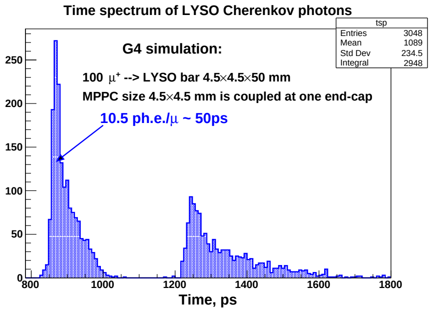


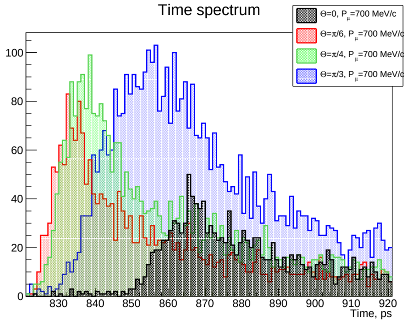
LYSO(Ce) refractive index and transmittance



LYSO emission spectra: Scintillation (top), Cherenkov (bottom).

Cherenkov photons time distribution

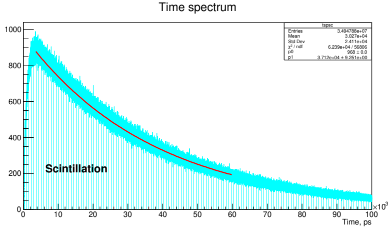


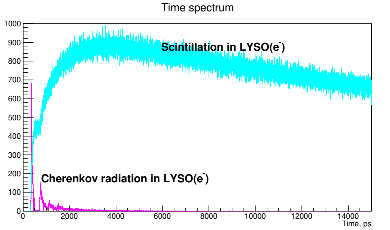


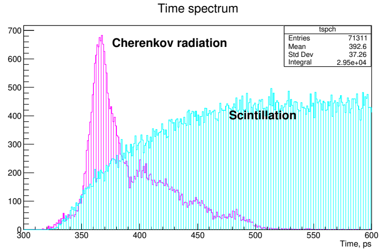
The Cherenkov photons arrival time is shifted up to 30 ps for different angles between particle track and crystal

Optical photons time spectra

Time distribution of photoelectrons produced in MPPC S13330 by 5000 e^- (2.5 GeV)



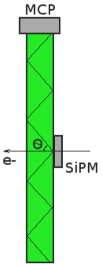




~6 Cherenkov photons will be detected in first 100 ps.

Optical photons time spectra

Idea for beam test experiment

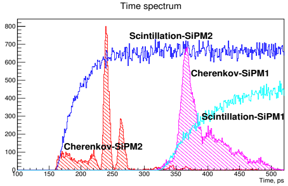


Cherenkov angle: $cos(\theta_{ch}) = \frac{1}{\beta n}$,
where $\beta = \frac{\vartheta}{c}$ $\approx$1 and LYSO(Ce) refractive index n=1.82 (λ=445 nm)

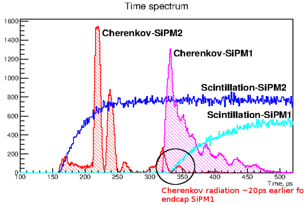
- 0° to beam line – θ_{ch} $\sim 57^\circ$ and Cherenkov radiation captured in total internal reflection ($n * sin\theta_{ch} > 1$) and go to both endcaps;
- -30° to beam line – Cherenkov radiation go to down endcap;
- $+30^\circ$ to beam line – Cherenkov radiation go to top endcap.

Expected results

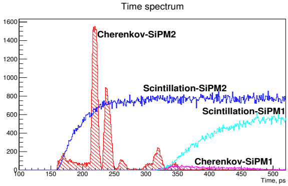
0° to beam line



$+30^\circ$ to beam line



-30° to beam line



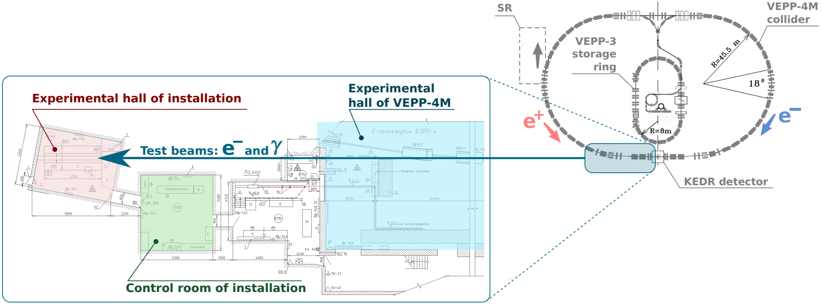
Need was to check the simulation results on test beam!

Beam test facilities at BINP

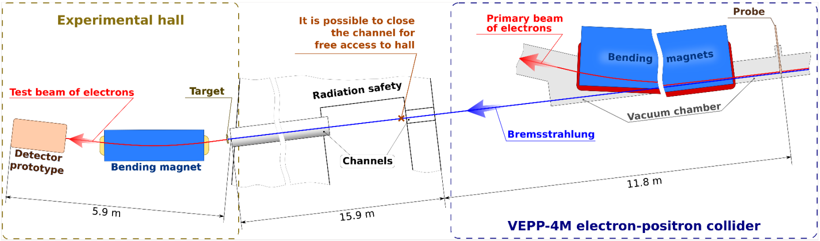
VEPP–4M electron–positron collider is used to provide γ- and electron- beams.

VEPP–4M main parameters:

- Perimeter 366 m;
- Beam energy 1÷5.5 GeV;
- Number of bunches 2×2;
- Luminosity 10^{30} $\text{cm}^{-2} \cdot \text{s}^{-1}$ for E_{beam}=1.5 GeV.



Beam test facilities at BINP



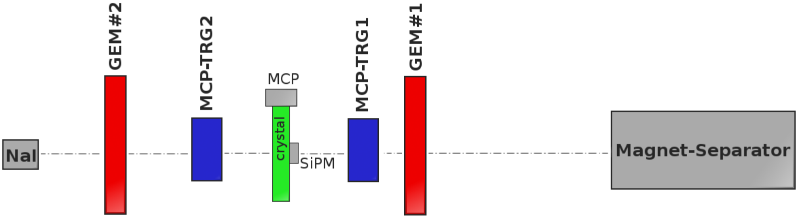
- A special probe is moved into the halo of a primary electron beam of the VEPP–4M collider for generation of Bremsstrahlung gammas.
- These gammas are converted to electron – positron pairs on a lead target at the entrance to the experimental hall.
- Electrons with a certain momentum are selected using a bending magnet.

The beam parameters:

- Energy range 0.1÷3.5 GeV;
- Intensity 50÷100 Hz;
- Energy spread 7.8% for 0.1 GeV and 2.6% for 3.0 GeV.

Scheme of the experiment

- Electron energy – 2.5 GeV;
- Tracking based on GEM detectors with $\sigma_x \sim 70\ \mu$m and $\sigma_y \sim 200\ \mu$m;
- Trigger formed from MCP-TRG1 and MCP-TRG2 coincidence, and VETO from GEMs "BUSY"-signals summarised as "OR";
- Signal MCP-TRG1,2 and from prototype are digitized by V1742 (CAEN), operated in "Fast TRG"mode;
- LYSO(Ce) bar read out from one endcap MCP PMT and with forward SiPM Hamamatsu (3×3 mm).

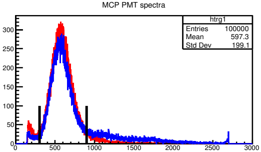


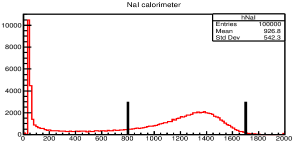
- LYSO(Ce) bar (3.5×4×50 mm, covered by PTFE) placed respect to beam line at the +30°, 0° and -30°;
- ∼100 kevents were collected for each configuration (June 2019).

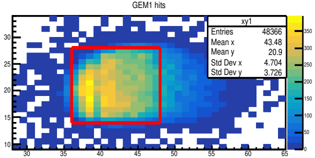
Test Beam results with LYSO(Ce) tile

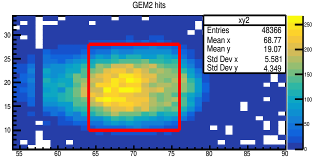
Some cuts for event selection.

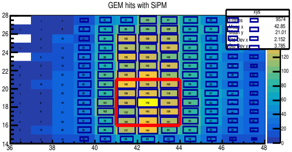
- NaI-calorimeter and MCP PMTs amplitudes cuts are applied to select single particle events with straight tracks.



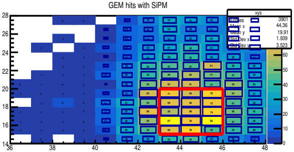




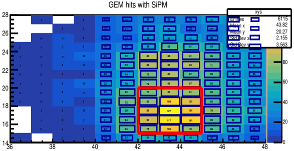




0° to beam line



-30° to beam line

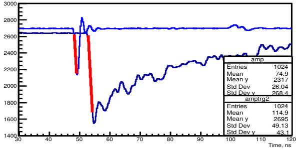


$+30^{\circ}$ to beam line

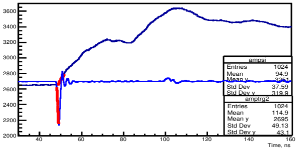
Centers of the spots are used for alignment.

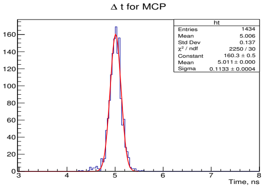
ΔT is determined at different threshold of amplitude with help of linear fit of the signal edges.

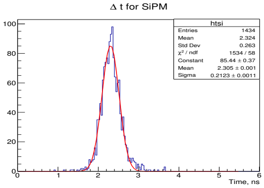
MCP TRG and MCP signals

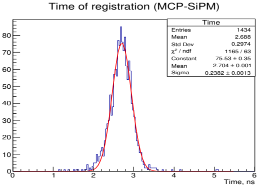


MCP TRG and SiPM signals

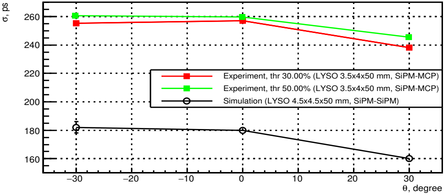


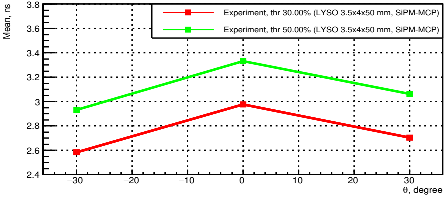






Test Beam results with LYSO(Ce) tile





The time resolution depends on the angle of rotation of the crystal to beam line (∼20 ps).

Conclusion

- G4 simulation was done and effect of Cherenkov radiation on time resolution of LYSO(Ce) crystal based counters was demonstrated;
- The first experiment to detect the effect of Cherenkov radiation in LYSO(Ce) crystal at BINP was carried out in June 2019;
- The time resolution depends on the angle of rotation of the crystal to beam line and could increased up to 20 ps;
- The time of signal arrival to the endcap of the LYSO crystal depends on the angle of rotation of the crystal to beam line and could be up to 120 ps;
- The next seria of the experiments are planned in 2019-2020 at BINP test beam facilities.