Application of GEANT4 toolkit in dd-γ experiment in Dubna

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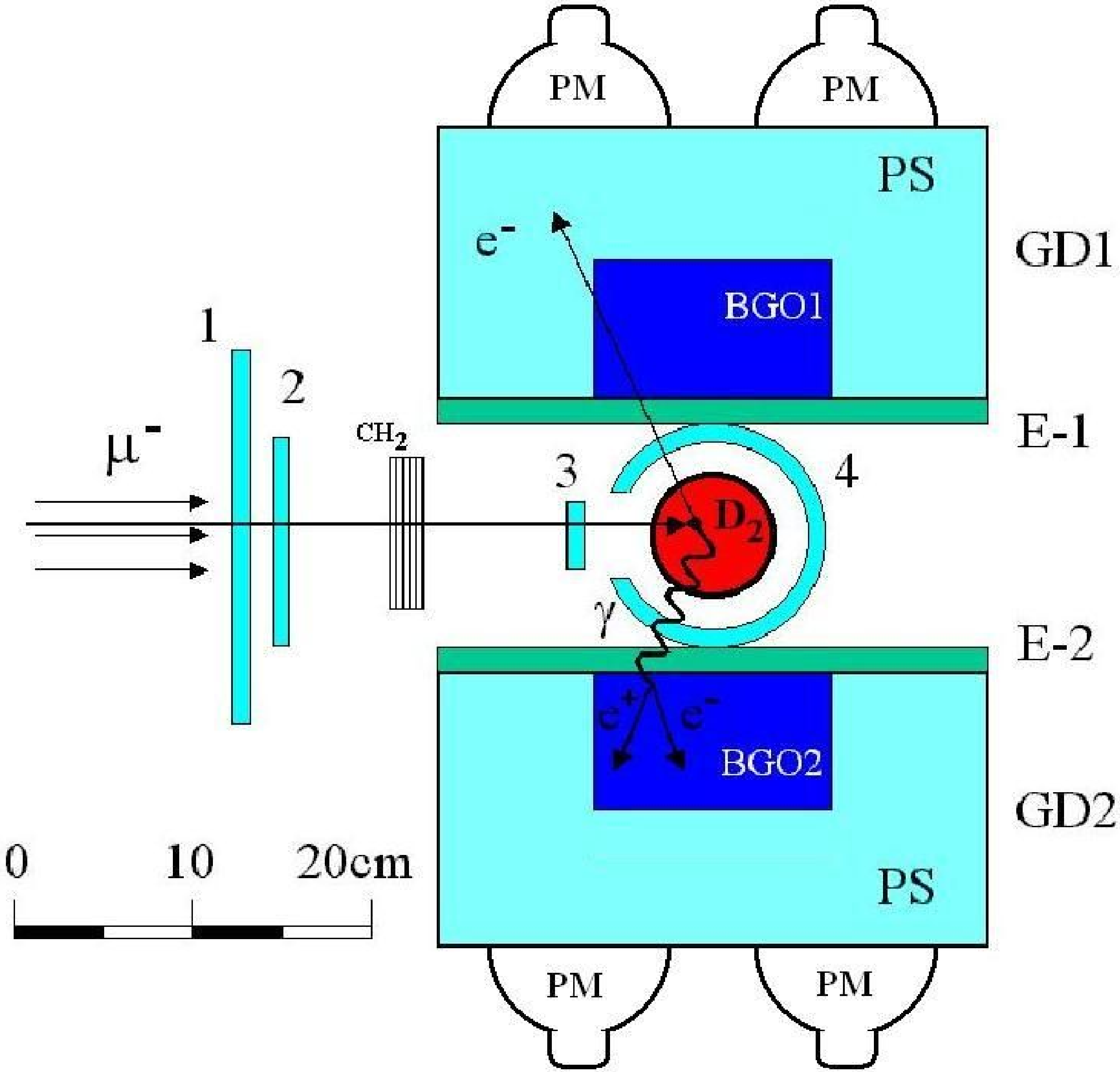
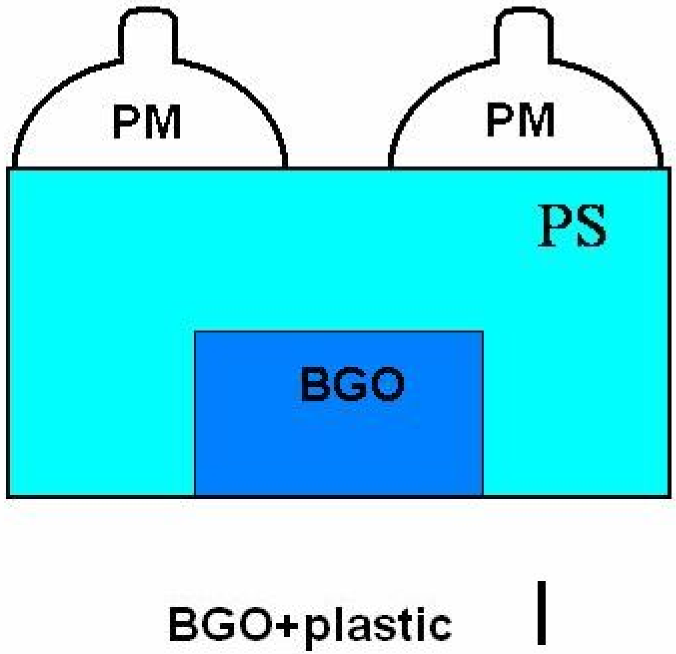
An experience of simulation of physical processes using GEANT4 software is presented. It is applied for investigation of the radiative capture reactions stimulated by the muon catalysis using gamma-detectors. The experiment is carried out in DLNP JINR.

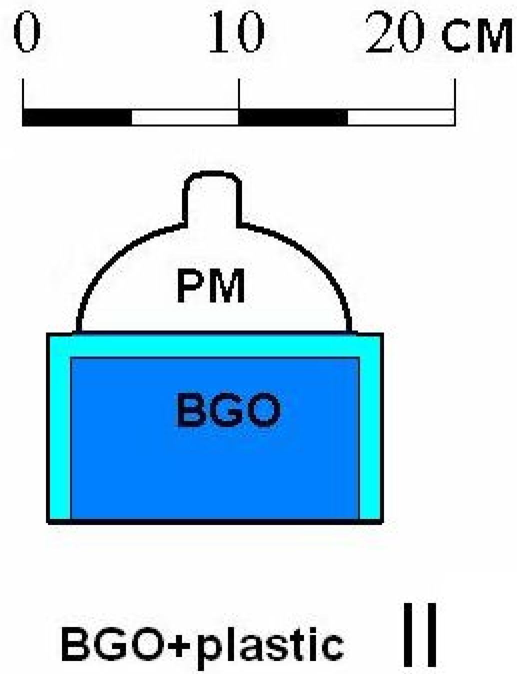
The studied problem is a rare process of the radiative capture of deuterons in muonic molecule $dd\mu$:

$$d + d = {}^4He + \gamma .$$



Muon-catalyzed detector (Dubna, Russia)





There are two variants of the gamma-detector applied in the research.

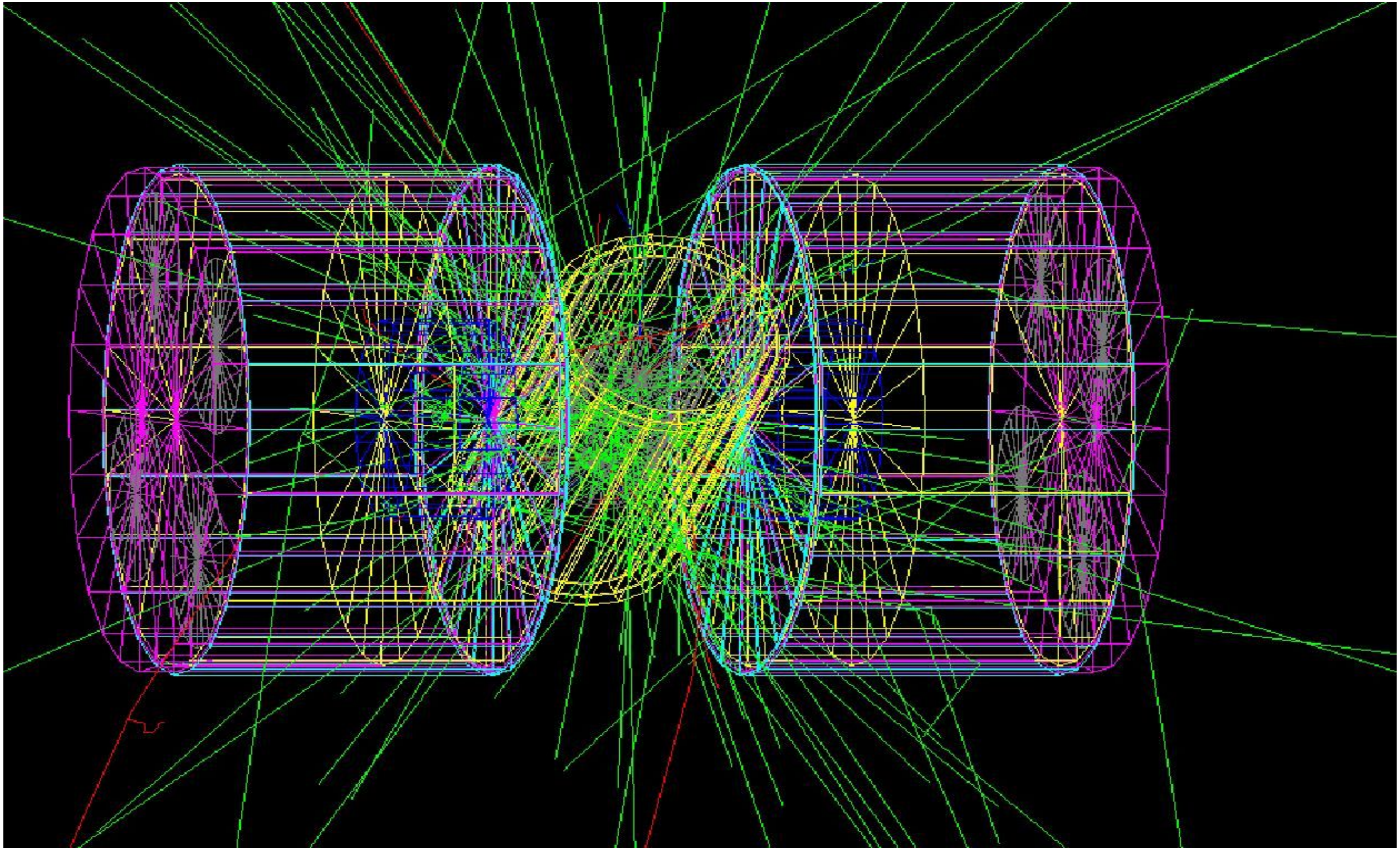
First with 4 PMTs and second with one PMT.

- Incoming muons are detected by scintillation counters 1,2,3,4 and stopped in the deuterium gaseous target. Gammas from the deuterium reaction are detected by two full-absorption crystal BGO detectors BGO1 and BGO2 . Signals from BGO crystals in turn are detected by four or one Photomultiplier (PMT).
- Collection and analysis signals entering on PMTs were primary task of modeling program.

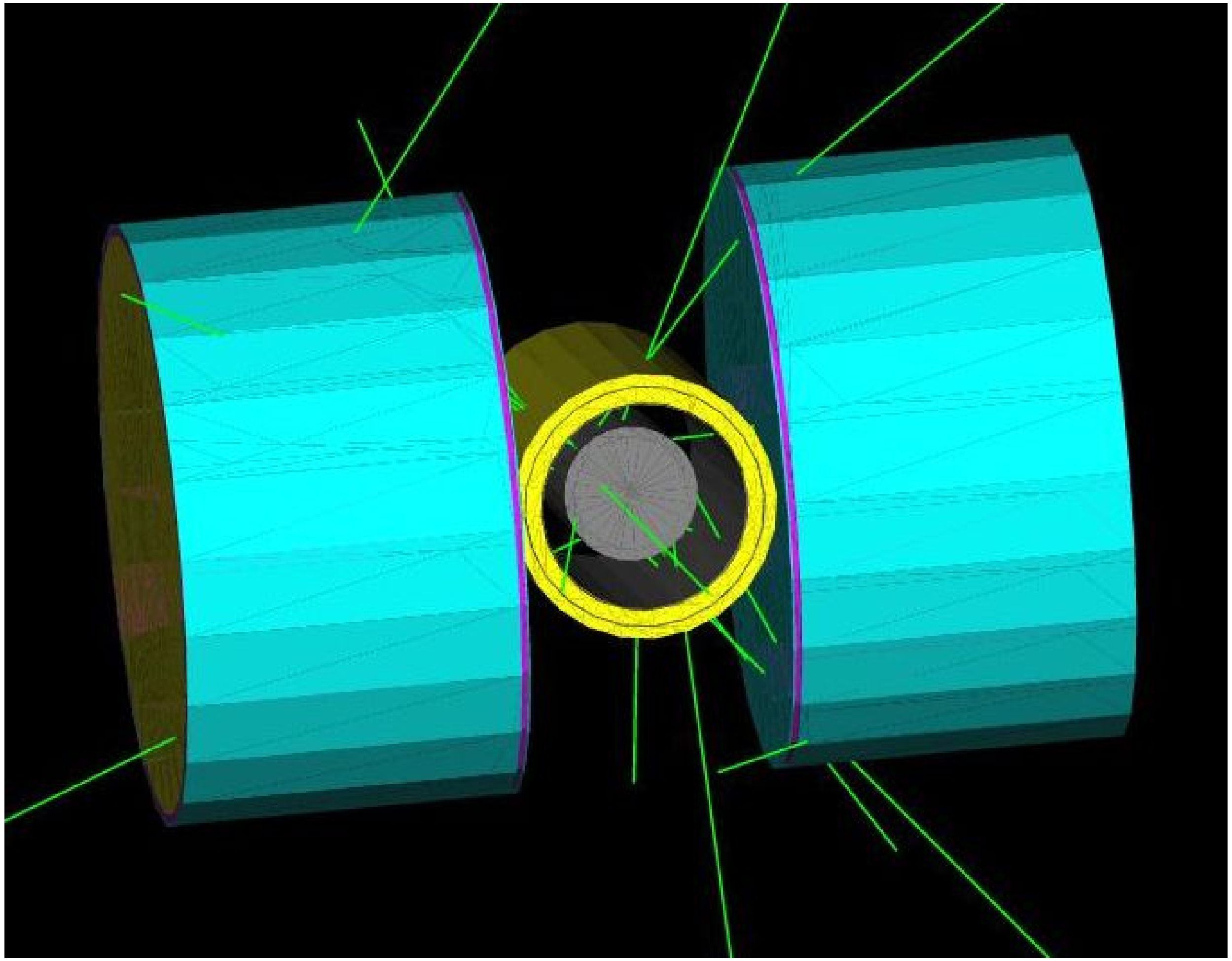
In the current task by means of muon catalysis Dubna group addresses the phenomena in dd fusion, which have not been previously investigated and are at the frontier of nuclear few-body physics. An experiment to study the muon-catalyzed radiative deuteron capture from muonic deuterium molecules

$$dd\mu \rightarrow {}^{4}He\mu + \gamma + 23.8\ \text{MeV}.$$

The relative yield of this rare reaction will be measured from the p-wave state of deuterons in a muonic deuterium molecule with sensitivity of $\mathbf{10^{-7}}$ with respect to main fusion channels.



The description of geometry and materials, utilized in the physical experiment, presents basic difficulty with writing of simulation programs.



On the figure are shown muon-catalyzed frame with 10 gamma generated.

Green tracks presents moving of gamma particles.

The main design elements of muon-catalyzed detector are deuterium target with Special steel's walls, 2 polystyrene scintillator cases around the target.

There also are aluminum, polystyrene and teflon heads and flanks with two BGO crystals inside them.

GEANT4 implementation

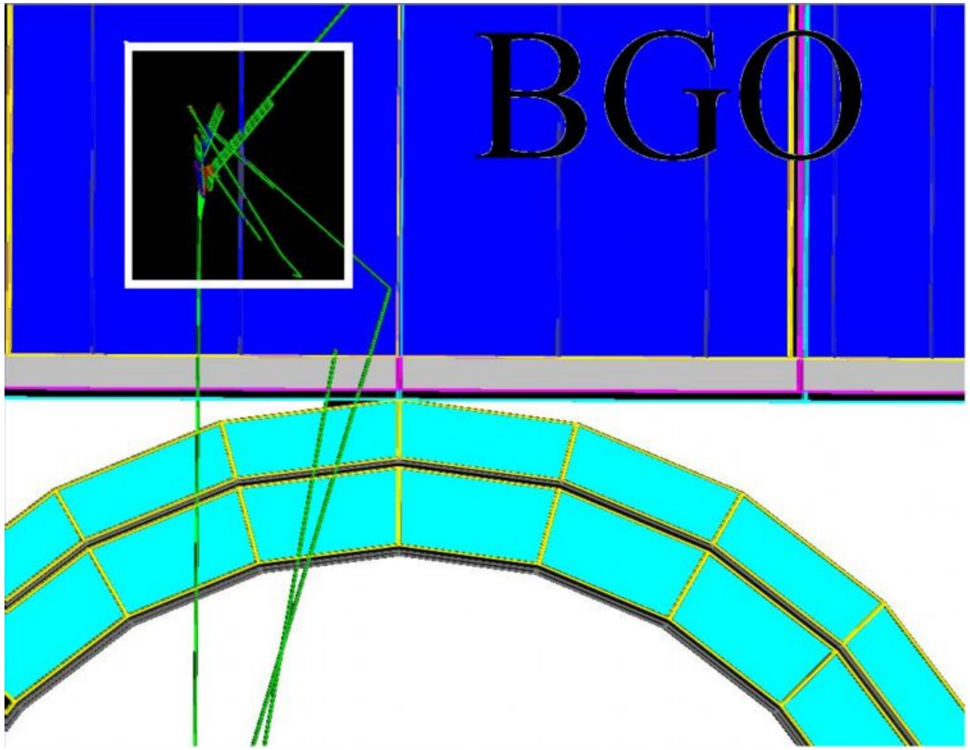
- **At the beginning of modeling program is generated the unified distribution in the target and having unified distribution in the direction of moving.**
- **All the secondary particles, born in the course of gamma moving, are traced by program in the course of their tracking in the detectors.**
- **For writing Ntuples in forms of ROOT files were used OpenScientist AIDA implementation**

(http://openscientist.lal.in2p3.fr/).

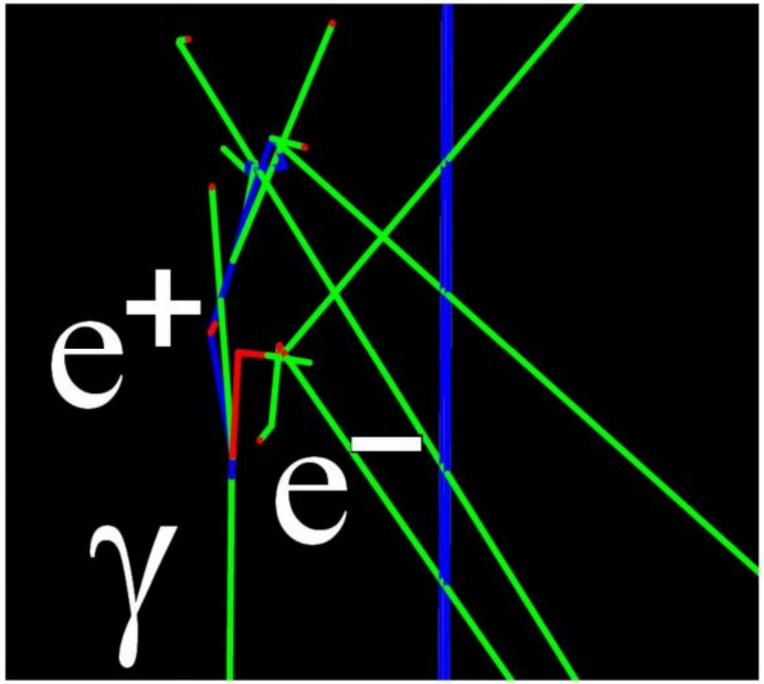
Energy losses, appearing in the course of moving the particles in the detector, are written down in the manner of Ntuple's records. They are subsequently used by program for building analyzing histograms.

Physics list subprogram with electromagnetic and **optical** physics facilities has special importance, describing behavior of the particles in various situations. In particular in case of the different conditions appearing on the optical surfaces between different optical media (BGO crystals and plastic scintillator, teflon, PMTs). The order of the value in the number of photons amounts to **100 000 photons** born in one experimental event (registration of single 23.8 MeV gamma).

The GEANT4 program was written with the implementation of optical processes (scintillation, rayleighscattering, absorption, boundary processes).

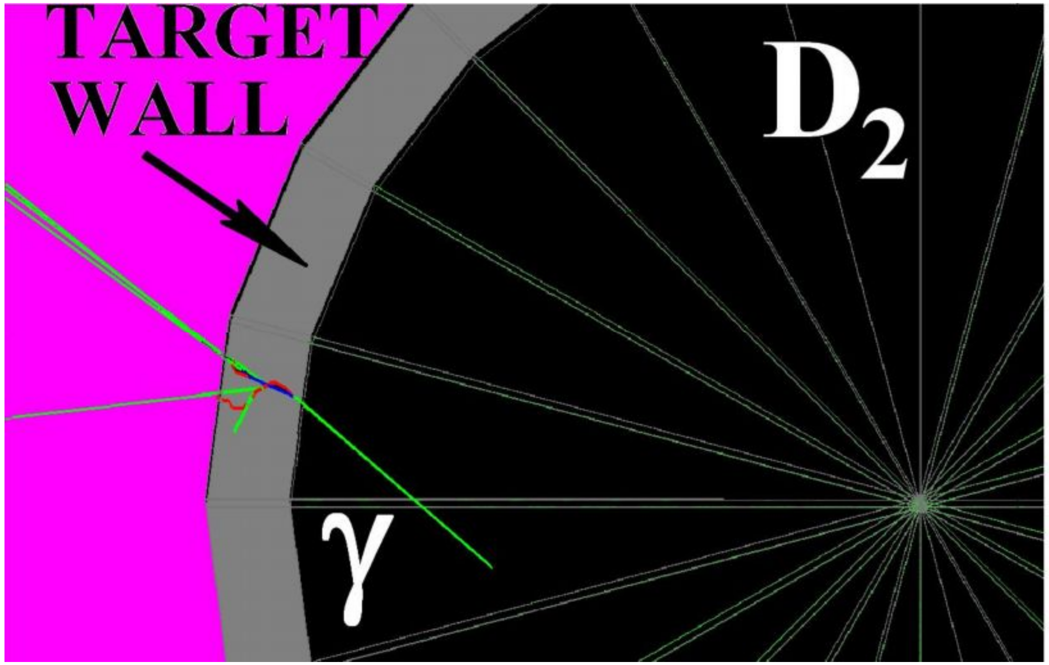


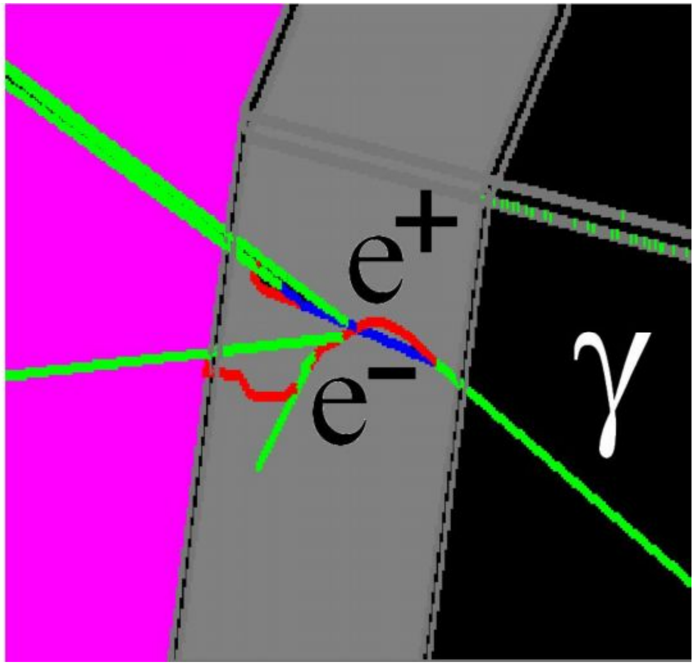
GEANT4 VIEW OF CONVERSION PROCESS INSIDE BGO



ENLARGED FRAGMENT

Conversion of 23.8Mev gamma inside BGO crystal

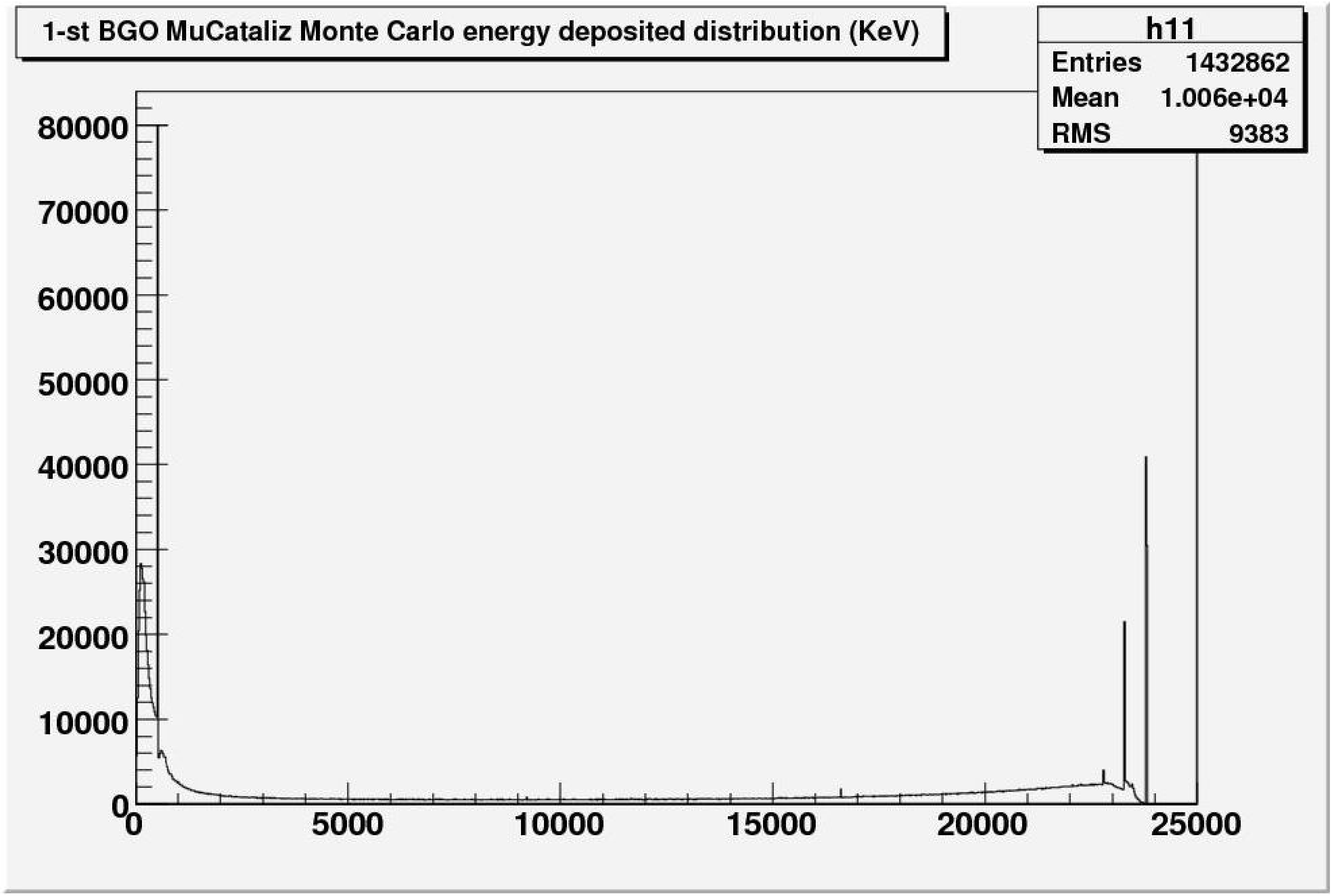




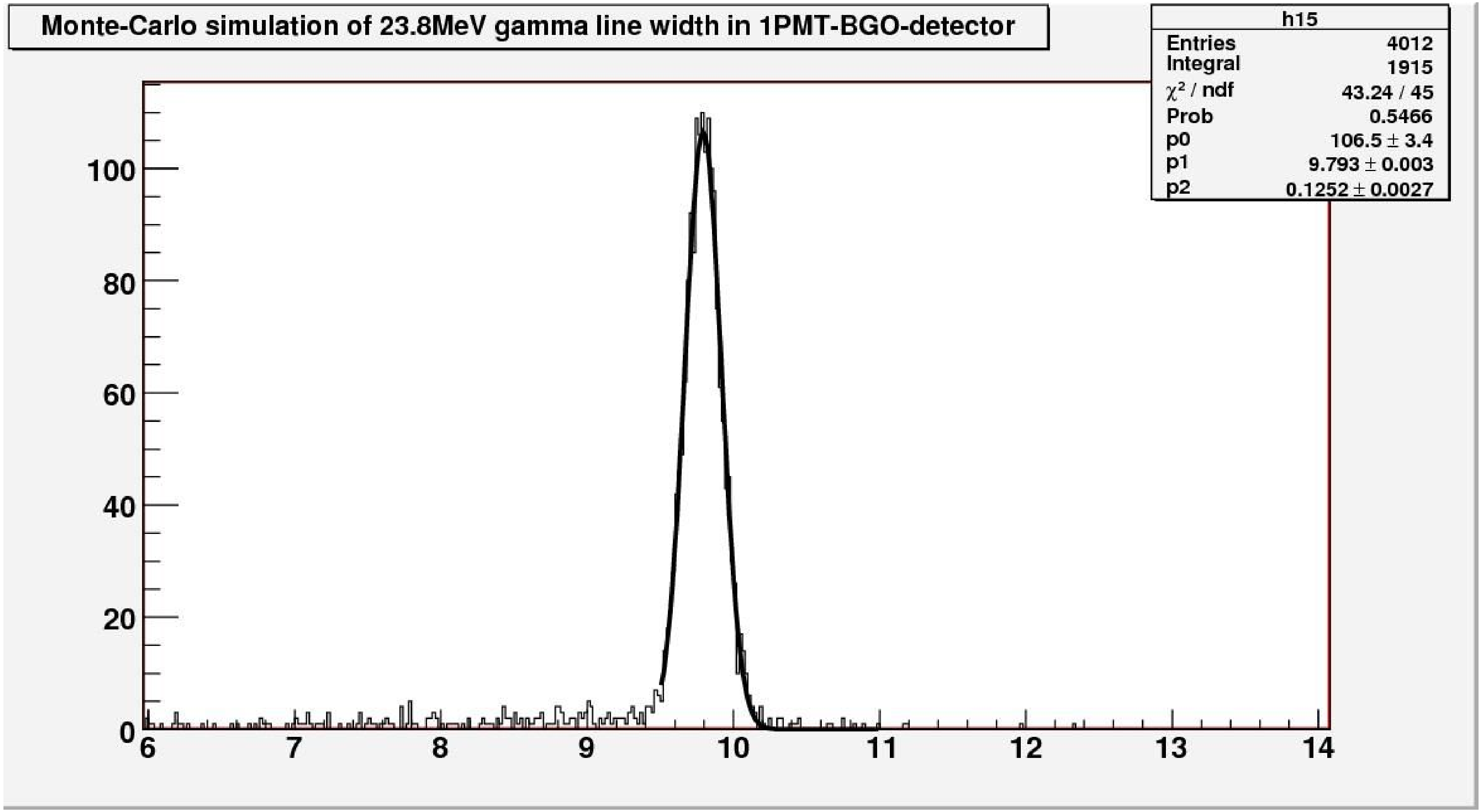
GEANT4 VIEW OF CONVERSION PROCESS INSIDE TARGET WALL

ENLARGED FRAGMENT

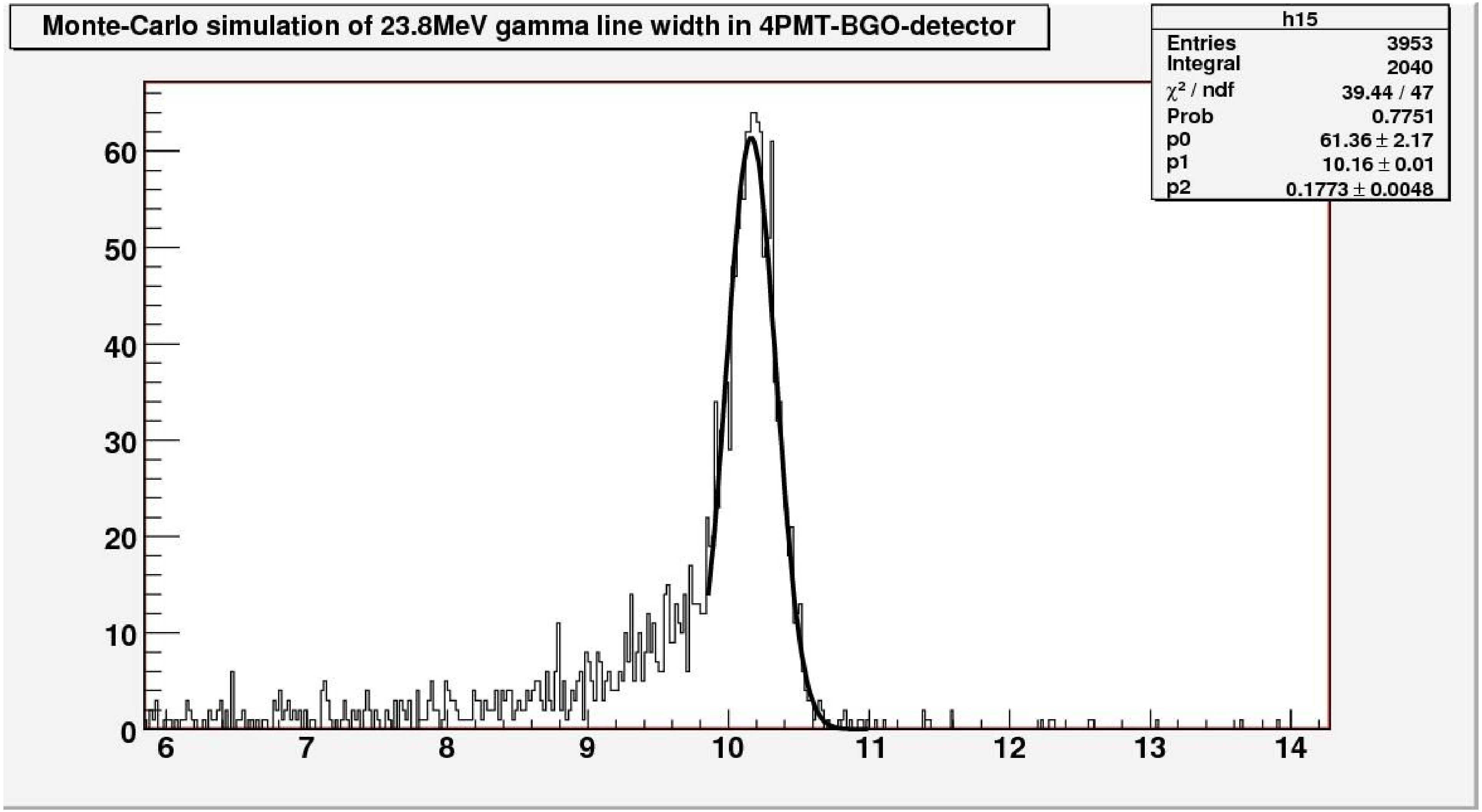
Conversion of 23.8Mev gamma inside target wall



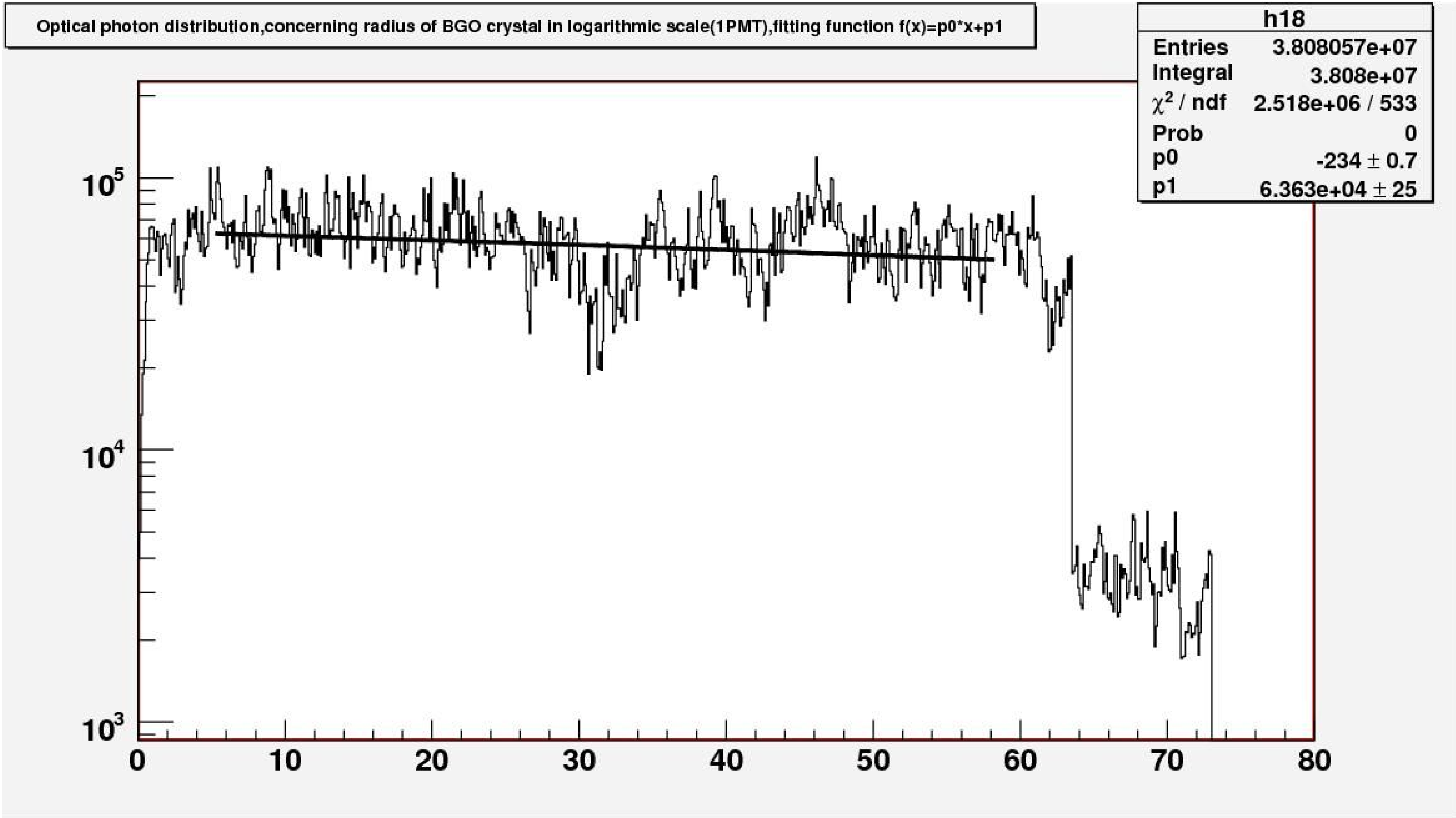
After finishing of Muon-catalyzed simulation program one Ntuple is generated with data displaying energy deposited in two BGO crystals (for example, after 10 million initial gamma generated inside target).



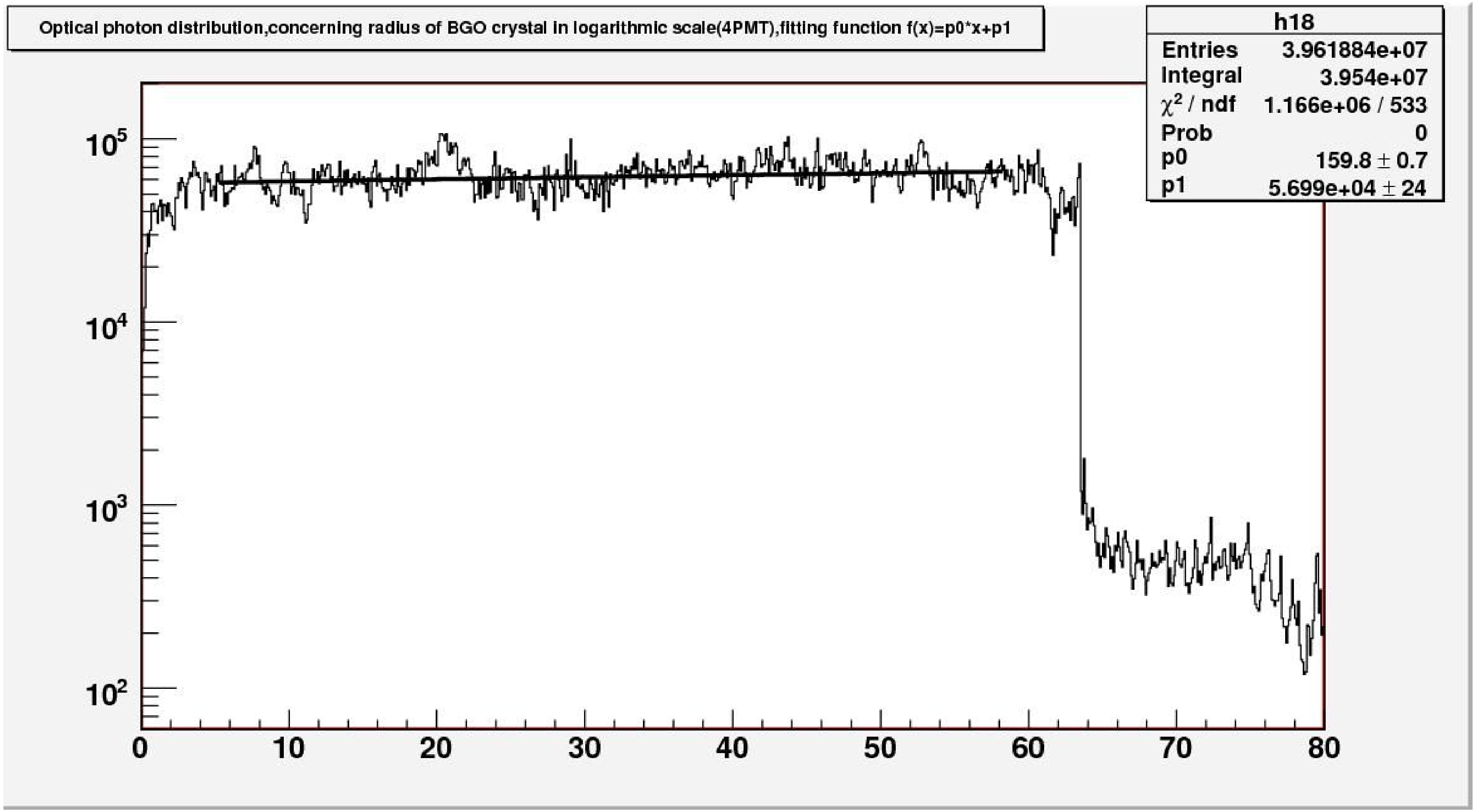
Monte-Carlo simulation of gamma-branch with the pulse-shape analysis performed (for 1PMT detector variant)



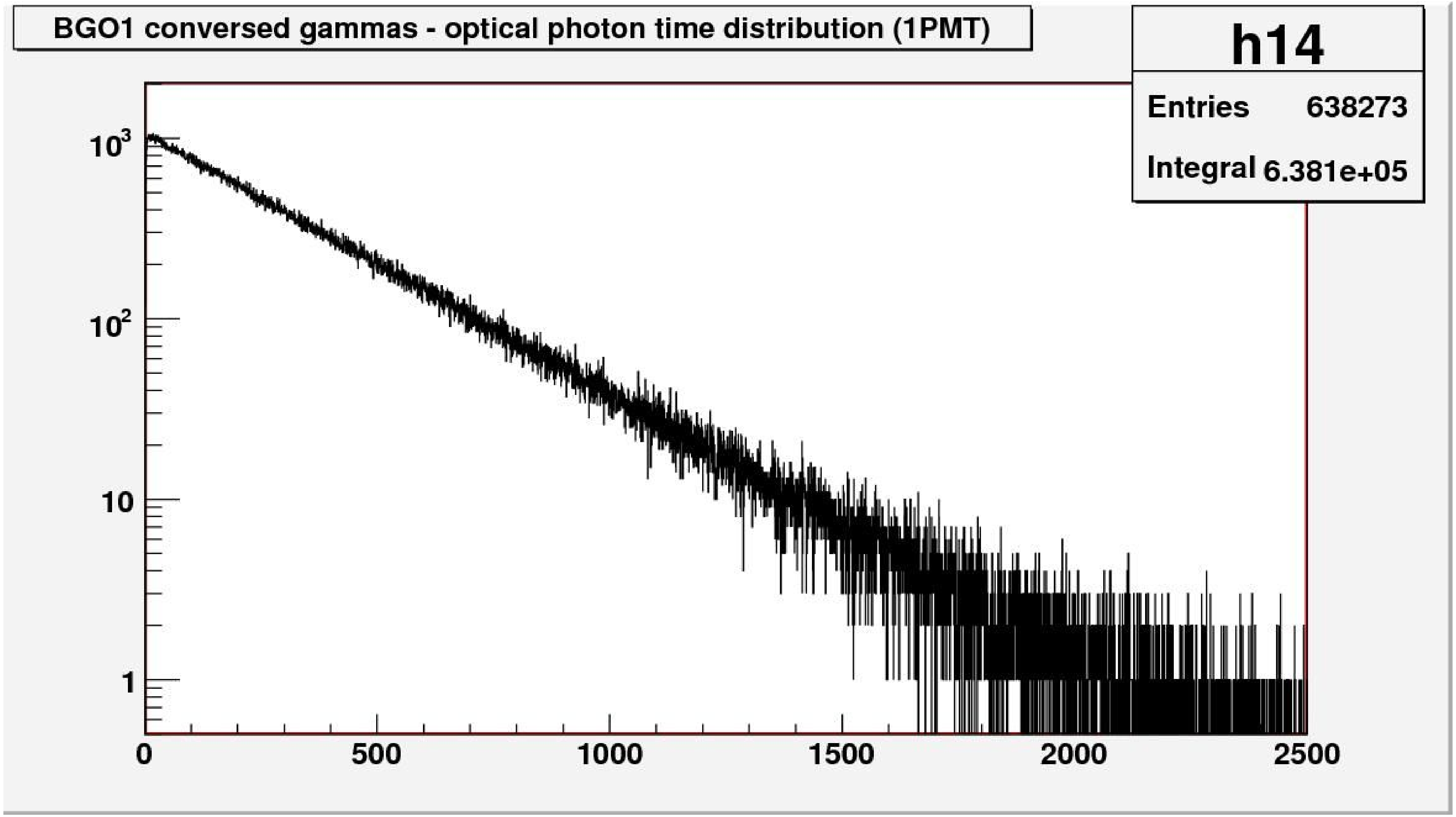
Monte-Carlo simulation of gamma-branch with the pulse-shape analysis performed (for 4PMT detector variant)



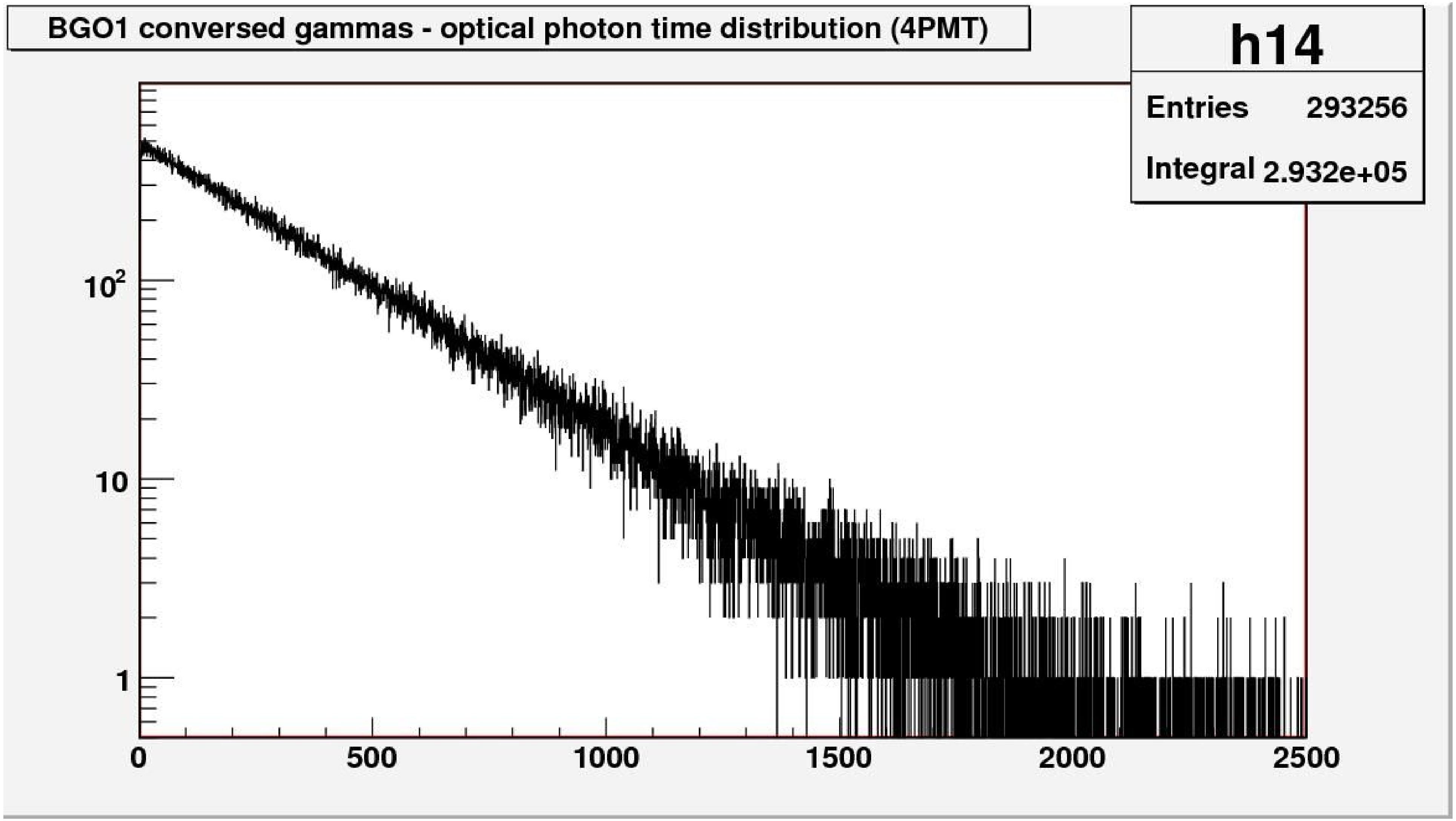
The histogram shows the uniformity of 1PMT detector response with the regard to the conversion point location inside BGO (X-axis – BGO radius) with respect to the scintillation light collected (Y-axis – energy of scintillation photons detected)



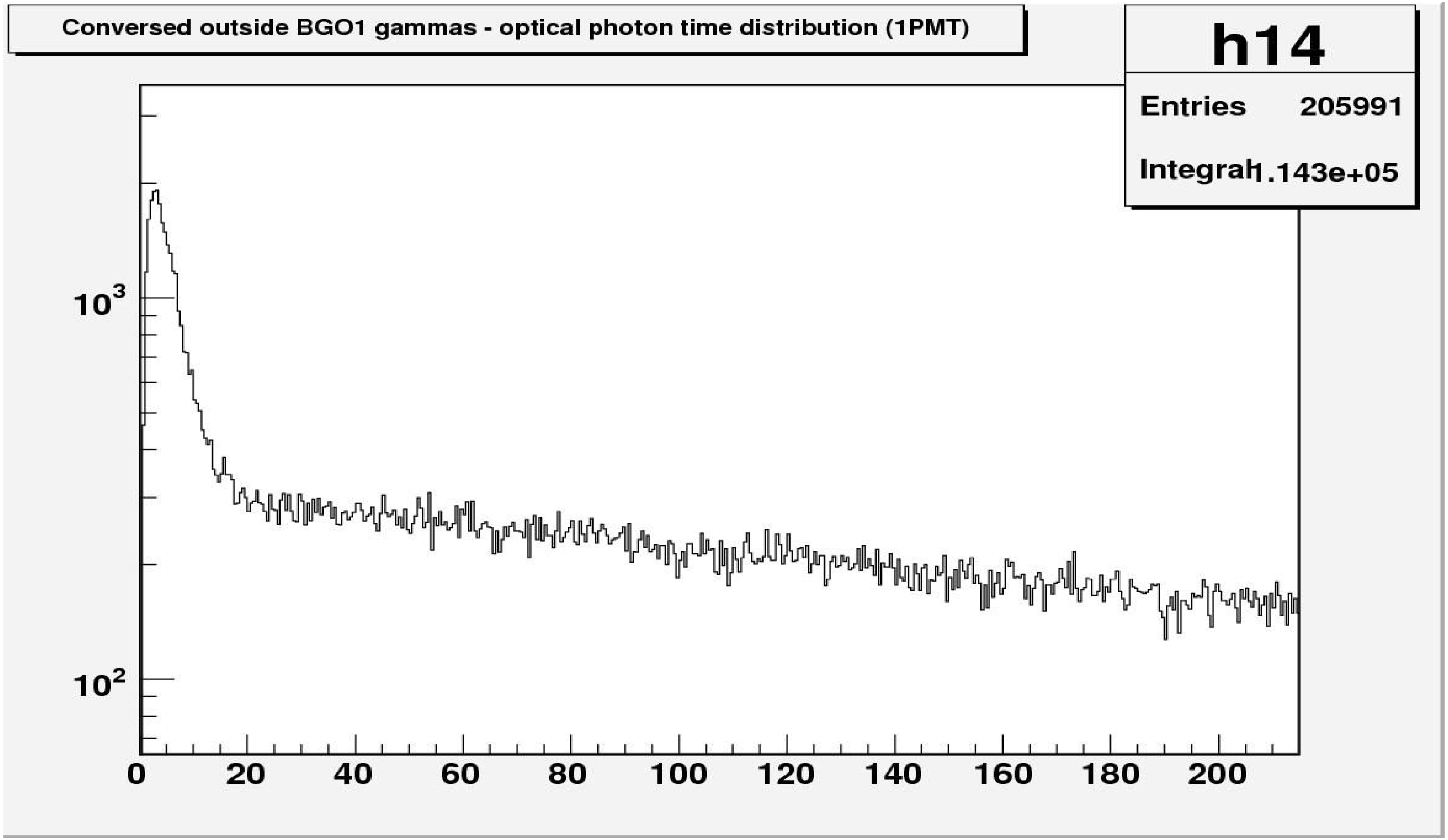
The histogram shows the uniformity of 4PMT detector response with the regard to the conversion point location inside BGO (X-axis – BGO radius) with respect to the scintillation light collected (Y-axis – energy of scintillation photons detected)



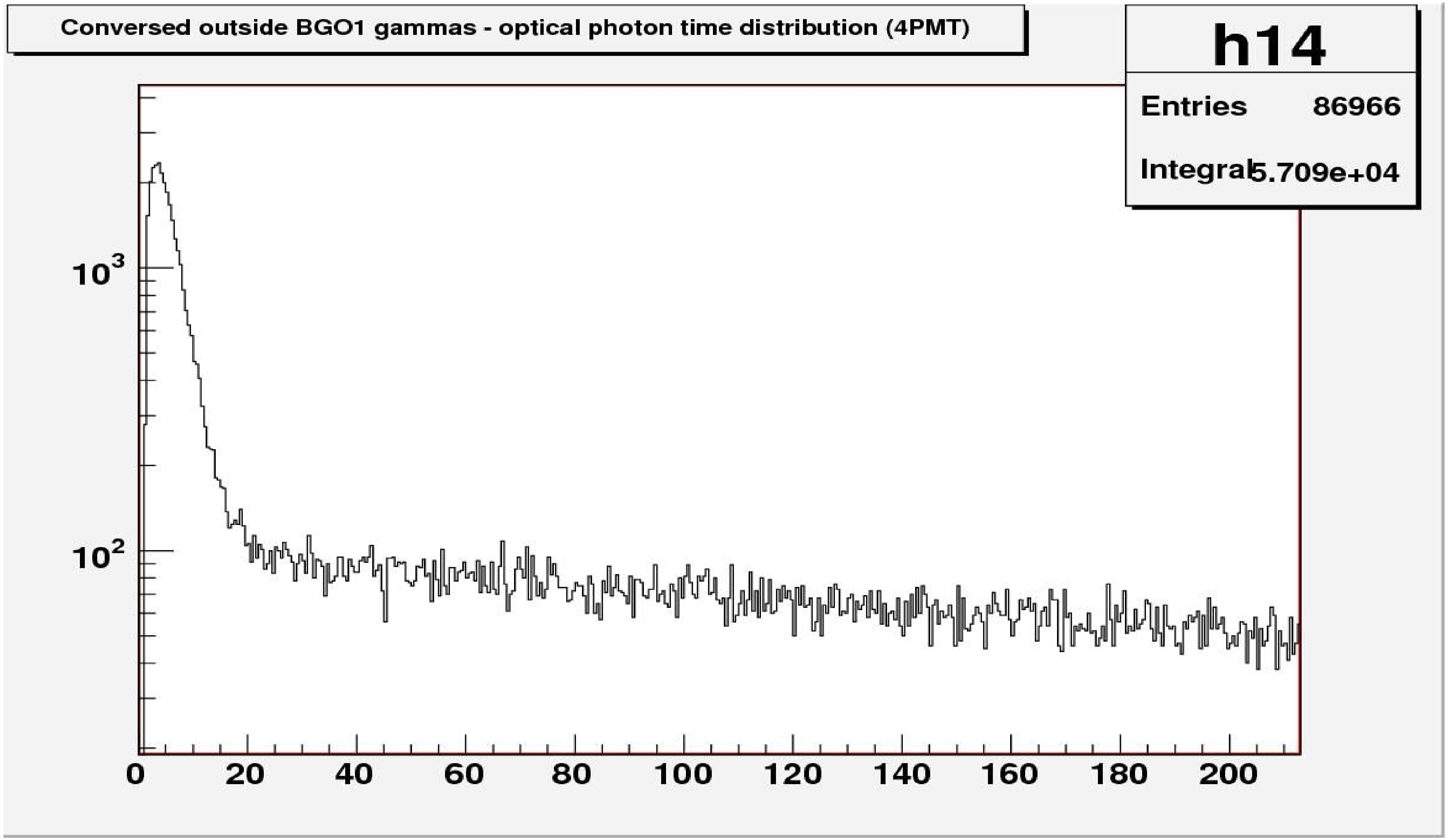
The histogram shows the timing distribution of the scintillation light collected inside BGO in 1PMT detector



The histogram shows the timing distribution of the scintillation light collected inside BGO in 4PMT detector



The histogram shows the timing distribution of the scintillation light collected inside plastic scintillator in 1PMT detector



The histogram shows the timing distribution of the scintillation light collected inside plastic scintillator in 4PMT detector

CONCLUSION

•The GEANT4 simulated **efficiency** of the gamma detector in the energy range **18-24 MeV** in the geometry of the installation considered amounts to **0.095 (9.5% of gamma-conversion inside BGO)**

•This result is confirmed by the **energy deposited** inside BGO crystal as well as by **photons** born due to gamma-conversion inside BGO.