MazePi Experiment: Searches for Correlations of Extensive Air Showers with Gamma Ray Bursts

K. Jędrzejczak*, M. Kasztelan*, L. Mankiewicz†, K. Nawrocki‡, M. Sokolowski‡, B. Szabelska*, J. Szabelski*, T. Wibig*§ and G. Wrochna†

*A. Sołtan Institute for Nuclear Studies,Cosmic Ray Laboratory, Łódź, Poland

*Center for Theoretical Physics PAS, Al. Lotników 32/46, 00-668 Warsaw, Poland

‡A. Sołtan Institute for Nuclear Studies, Hoża 69, 00-681 Warsaw, Poland

§University of Łódź, Poland.

***Abstract*— The aim of the project is to study Gamma Ray Bursts (GRB) simultaneously by observations of high energy photons (of energies above TeV) and photons in the optical range. We plan to register high energy photons via secondary cosmic ray particles in the Roland Maze Project detectors. Optical range observations are to be performed by the project *Pi of the Sky* apparatus.**

I. Introduction

To find the nature of GRB the systematic studies are needed in all available electromagnetic radiation wave lengths (searches in the neutrino sector are also underway). The optical investigations are, however, of particular importance. The angular resolution available here gives possibility for unique identification of the GRB source object and the galaxy which it belongs to. The visible spectrum can thus lead to the red-shift measurement and to the distance to the GRB source estimation. Observations of photons of energies in GeV and TeV regions are particularly interesting from the point of view of elementary particle physics. Gammas of such high energies appear in non-thermic processes. The extremely high energy densities are highly probable there, so the valuable information on the elementary forces in such, laboratory unavailable matter states is, in principle, to be found. The understanding of the mechanism of the creation of very high energy photons correlated with GRB could be helpful to understand the creation of cosmic rays as a whole. Additionally, short duration time and long distance traversed by the photons gives unique chance to look for quantum gravity effects, like, e.g., ”vacuum dispersion”, or even experimental studies of the problem of additional dimensions appearing in some of contemporary theories of the grand unification.

II. The MazePi Experiment

The MazePi is a ”multiwavelength” project to study GRB. The ’optical wavelenghts’ part will be covered by the *Pi of the Sky* experiment [1] and the network of cosmic ray detectors of the Roland Maze Project [2], under construction at present, will be used to search for TeV photon emission.

A. The Roland Maze Project

The Maze detection points would be placed on the roofs of Lodz high schools over the area of $\sim$ 100 km^2. Each

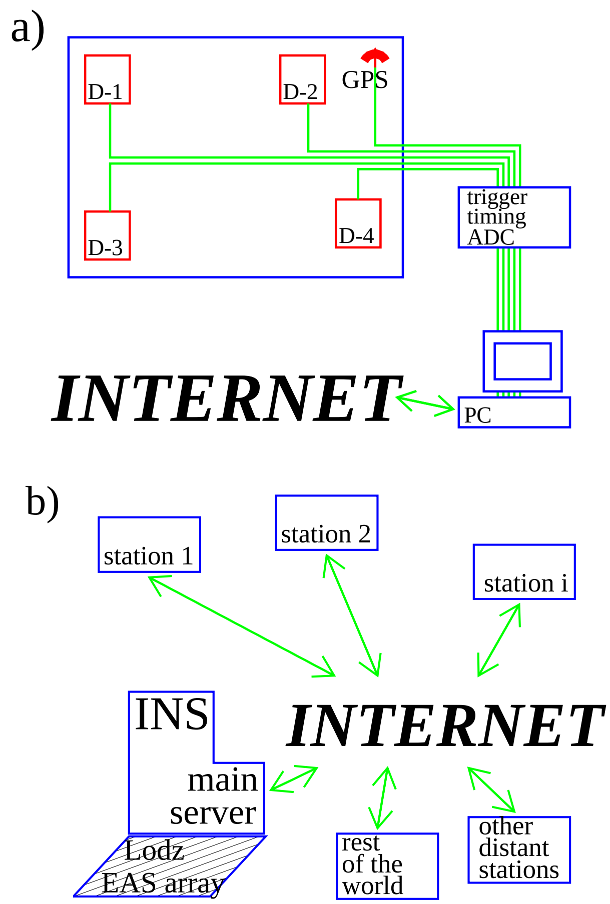

Fig. 1. Schematic view of a single station (a) and the idea of the whole Maze network (b).

school will be equipped with 4 scintillation counters of area of 1 m^2 separated by about 10 m distance. The electronic system should enable measurement of relative times and measurement of signal amplitudes from all the detectors (Fig. 1a).

Basic detector of the Maze Project is built of scintillator plates of 10cm$\times$12cm$\times$0.5cm with 6 grooves of 1.2 mm along the 10 cm dimension. Plates are combined by two one on top of the other. Thus we have 1cm thick scintillator. In the rows the re-emitting optical fibers BCF-91A Bicron are placed guiding the light to photomultipliers Photonis XP 1912. 160 plates make the area of about 1 m^2. Signals coming from the whole detector are collected to one photomultiplier. To achieve the assumed dynamic range we use anode signal and the signal from 8th dynode (about 30 times weaker) converted by 10 bits converter. Signals from anode and dynode are amplified about 100 times in the preamplifier. This analogue signal is sent by constant fixed length from all detectors to amplitude-digital converters.

Each array station is equipped by the GPS receiver (Motorola M12+ Timing Oncore) with the special antenna (Motorola Oncore Timing2000 Antenna) which gives the 1 Hz second signals (PPS) with the accuracy of 25 ns (RMS $\sim$2 ns) with respect to the universal time (UT). Each station has also its own clock. Its status could be registered and stored to the memory together with the other event data. The PPS signals gives the possibility to accurate calibration of the array clock. Each observation of the detector signal over single muon threshold also leads to the registration of its amplitude with the actual time stamp.

The system of converters and master elaboration would be connected to a PC-class computer, on which preliminary data analysis and storing would be performed. Occasionally data will be sent via internet to the central server (Fig. 1b). For the purposes of GRB searches the system is equipped with the buffer able to store $\sim$8 hours of detail information about each detector count.

The main scientific goal of the project are studies of extensive air showers of energies above 10^{18} eV. The detection system of one station will constitute autonomous air shower array capable also to register events at energy $\sim 10^{15}$ eV.

Single detector counting rate (i.e. registrations of muon flux) is related to cosmic rays in GeV energy range, thus, e.g., with the activity of the Sun and geomagnetic events, the state of atmosphere, and atmospheric effects. The same data are to be used to look for GRB related signals of photons of TeV energies.

B. *Pi of the Sky* Project

The *Pi of the Sky* project [1] is conducted by The Soltan Institute for Nuclear Studies in collaboration with The Center of Theoretical Physics, Warsaw University and Warsaw University of Technology. Its main goal is the continuous observation and real-time analysis of the sky in a search for optical flashes, which are connected with GRB.

Because systematic search for phenomena responsible for GRB with classic astronomical equipment are rather difficult, we have designed a system [3], which consists of two sets of CCD cameras installed in two locations separated by about 100 km and working in coincidence. Each set contains 16 cameras covering a large fraction of the visible sky. A prototype system has been already built and it operated since June 2004 at Las Campanas Observatory in Chile. It consists of two cameras installed on a movable mount. A single camera is equipped with lenses of focal length f=50mm and aperture $d = f/1.4$. It covers a $33^\circ \times 33^\circ$ field. Exposure time of 10 s gives a limiting magnitude about 11m. The cameras are based on CCD442A sensor by Fairchild Imaging with 2032$\times$2032 sensitive pixels. The pixels are 15μm$\times$15 μm. The pixel size gives the scale of 1 arcmin/pixel. The cameras are cooled with a stack of Peltier modules. Control electronic and shutter were designed for 10s exposures all night for several years.

The *Pi of the Sky* apparatus is controlled by a PC located inside the dome. The system is fully autonomous, but also fully controllable via Internet. Every night the system runs autonomously according to a pre-programmed schedule. To make the schedule programming easy and flexible a dedicated script language was developed, with commands to control the mount and the cameras.

For most of the time, the cameras follow a field of view (FOV) of the HETE satellite. Its position is read out from the Internet in regular intervals and mount position is automatically corrected accordingly. If the HETE FOV is not visible, another location in the sky (for example part of FOV of INTEGRAL satellite) is programmed. The system is also listening to the Gamma ray burst Coordinates Network (GCN) alerts received directly and through a backup server in Warsaw. Should an alert located outside the current FOV arrive, the mount automatically moves towards the target and exposures are taken for 30 minutes.

In addition to using GCN alerts, custom flash detection algorithms have been developed [3], which are being used as internal triggers for the apparatus. Moreover, twice a night a scan of the whole visible celestial hemisphere is performed. 16 fields are visited and three images are taken by both cameras. A single scan lasts about 20 minutes.

For data acquisition and analysis the MazePi system is being prepared. It consist of PostgreSQL Databases (it could be easily changed into another system like IBM DB2 or Oracle), object-oriented database API, SOAP web services and clients, and Trigger Broadcast System.

III. Coordination of the Roland Maze Project and *Pi of the Sky* experiments

Almost all existing at present experiments for study GRBs use as a trigger signal from satellite gamma ray detectors distributed via GCN network. System MazePi will have such ability too. However, the satellites capable to measure burst directions covers only very limited part of the sky. Thus there is a great importance of using independent, own triggering system. This solution opens also the possibility of interesting new findings not related to the GRBs.

The availability of Project Maze detector data during GRB events will be realized by introduction to the common software of Maze station the specialized programs to take action in ”unusual situations”: programs to be started remotely in short time after optical and/or x-ray and/or gamma registration of GRB will analyze the data stored on-line on station computer hard disk and look for data close in time to GRB event to be stored for the further and more detailed analysis, and programs which will start automatically, when the standard analysis of the registrations gives the signal of enhancement of Maze detector counting rates. The data around this period will be stored as above for further analysis.

In both cases the data to be transmitted to the Maze central server will be as detailed as possible. Analysis of the selected periods and comparison of the data from different stations will have a high priority. The enhancements of the background secondary cosmic rays flux, small and bigger shower rates will be the subject of the searches. Information of interesting finding will be distributed to the participants of the project.

IV. Registration of high energy particles in GRB by the MazePi setup

The EGRET experiment during its lifetime observed few photons of energies above 10 GeV from the GRB direction. Ground based observations in two cases have shown the significant excess of events correlated with GRB:

- Milagrito (the prototype of the Milagro experiment) saw excess during the GRB970417a. 18 events were observed during 18 sec, while the expected background was 3.46 ± 0.11. The photon energy threshold was estimated as 650 GeV. [4]
- HEGRA-AIROBICC, air shower Cerenkov experiment found significant excess during GRB020925c. Within 4 minutes (9° from the direction reported by WATCH) 11 events were registered with the background estimated to 0.93. The energy of photons was in all these cases greater than 16 TeV. [5]

These experiment data record searches didn't give any other positive result for tens of GRB registered in their fields of view.

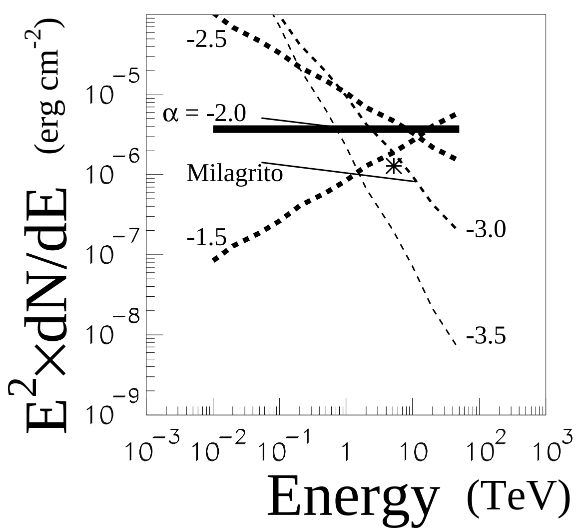

Fig. 2. Maze network short GRB registration limits shown for different indexes of GRB spectrum α. Thin lines and the star represents three possibilities of gamma flux responsible for the observation of GRB970417a by the Milagrito experiment.

We have performed respective Monte Carlo calculations to estimate the 'discovery potential' of the MazePi experiment. We used CORSIKA program (v.6.200 (Oct. 5, 2004) [6] to check the possibility of registration of high energy GRB tails in the Maze array detectors.

The exact electromagnetic cascade development in the atmosphere was simulated and the charged particles were counted on ground level. The power-law (above 10 GeV) energy spectrum of GRB photons was assumed. The burst is assumed to be detected if in all Maze detectors single particle counting rate exceed the background on 2σ level. We are particularly interested in very short GRB which origin remains a mystery still, so the gamma emission duration of 0.1 sec was assumed.

The background was measured with the prototype Maze detector [7].

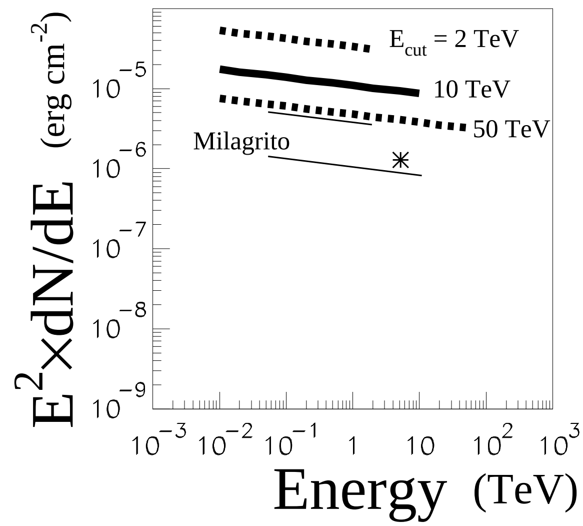

Fig. 3. Maze network short GRB registration limits for different high energy cutoffs $E_{\rm cut}$ (index $\alpha = 2.1$, the same as used in the Milagrito interpretation of GRB970417a burst - shown by thin lines for $E_{\rm cut} = 2$ and ∞).

The efficiency of the array depends strongly on the zenith angle of the GRB direction, what is obvious. But it also depends on the details of the GRB high energy photon spectrum. The index of short GRB spectra in TeV range is, of course, unknown. We present in Fig. 2 calculated observation limits for the spectra of vertical GRB for different spectral slopes.

The gamma ray flux above respective line will be seen by the MazePi experiment on the level higher than 2σ. It is seen that fluence of order of 10^{-5} erg/cm^2 will be seen by MazePi if the gammas energies extend to TeV range.

The two thin lines and the star show results of the Milagrito observation of GRB970417a [4]. The spectral index used there is -2.1.

The GRB spectra probably have an upper energy cutoff which effect the sensitivity of the experiment too. Respective results are shown in Fig. 3. Power law form of its energy spectrum (in the high energy range of $E > 10$ GeV and $E < E_{\rm cut}$) with an index of -2.1 is assumed. The calculated

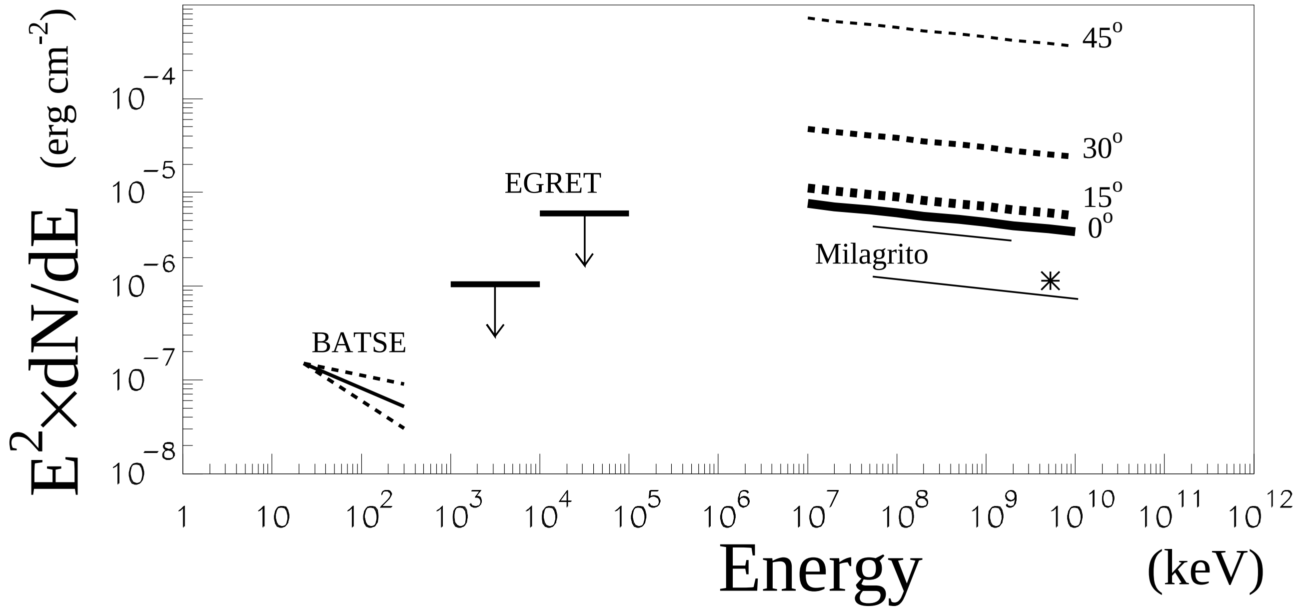

Fig. 4. Angular dependence of the registration sensitivity of Maze network (different angle value are shown by the respective lines) and the GRB 970417a registration results obtained by BATSE and Milagrito. The EGRET flux limit is also shown.

limits are compared again with the Milagrito registration. The lower thin line is for spectrum without cutoff, the upper with the cutoff at 2 TeV and the star is for the monoenergetic GRB (with the energy fixed at the "most probable" value).

The angular dependence of the short GRB registration efficiency is shown in Fig. 4. The spectral index was assumed to be equal to -2.1 and the cutoff fixed at 50 TeV. The comparison with GRB 970417a observed by BATSE and Milagrito is shown. The upper limits from the EGRET experiment are also given (after [4]).

The zenith angle acceptance of the MazePi experiment makes it a kind of a telescope looking up with the opening angle of about 30°.

V. European network of school based Cosmic Ray experiments

The Roland Maze Project is a member of European collaboration of school CR experiments EuroCosmics. The limited angular acceptance of the Maze network (shown in Fig. 4 and plotted on the northern sky map in Fig. 5) is, from other point of view, its adventage. The collaboration of a few similar experiments could obviously increased the abilities of observing high energy gammas, and could give the important crosschecks due to overlapping acceptances of different arrays.

In Fig. 5(a) the sensitivity of single MazePi experiment is shown and in (b) sensitivity of the network of five similar experiments. Portugal, Holland, Finland and Greece are taken for this example. The sky over the Europe is covered quite uniformly (with the additional array in Italy the coverage will be almost complete). The light (yellow) colour represents maximum of the acceptance (e.g., vertical events at the small black dot position) and as it gets darker the acceptance drops and at the dark (orange) edges there are shown directions from where the acceptance is 100 times less than at the maximum.

VI. Conclusions

We have shown that the MazePi project is able to deliver data on intense short GRB in the optical wavelenghts and symultanously in the TeV energy range. The project adjoins two originally distinct experiments the *Pi of the Sky* and the Roland Maze Project creating new interesting possibilities.

VII. Acknowledgments

This work was financed by Polish Ministry of Science in 2006-2007 as a research project. We would like to thank the Authorities of City of Lodz for the financial support.

References

[1] M. Cwiok *et al.*, Acta Phys. Pol. **37**, 919 (2006); `http://grb.fuw.edu.pl/`
[2] J. Gawin *et al.*, Acta Physica Polonica **B33**, 349 (2002); `http://maze.u.lodz.pl`.
[3] M. Biskup *et al.*, to be published in proceedings of *18^{th} IEEE-SPIE Symposium on Photonics, Electronics and Web Engineering: Electronics for Astronomy and High Energy Physics Experiments*, May 29 - June 4, 2006, Wilga, Poland; M. Molak *et al.*, "Search for cosmic rays from gamma ray bursts by 'MazePi' project", Proc. "The multi-messenger approach to high energy gamma-ray sources", July 4-7, 2006 - Barcelona, Spain; to be published in Astrophysics and Space Science.
[4] R. Atkins *et al.*, ApJ, **533** L119, (2000); ApJ, **583** 824 (2003).
[5] L. Padilla *et al.*, A&A, **337** 43-50 (1998)
[6] D. Heck *et al.*, Report FZKA 6019, Forschungszentrum Karlsruhe, Germany (1998).
[7] M. Kasztelan *et al.* "Calibration and Data Acquisition System in the Roland Maze Project", this conference.

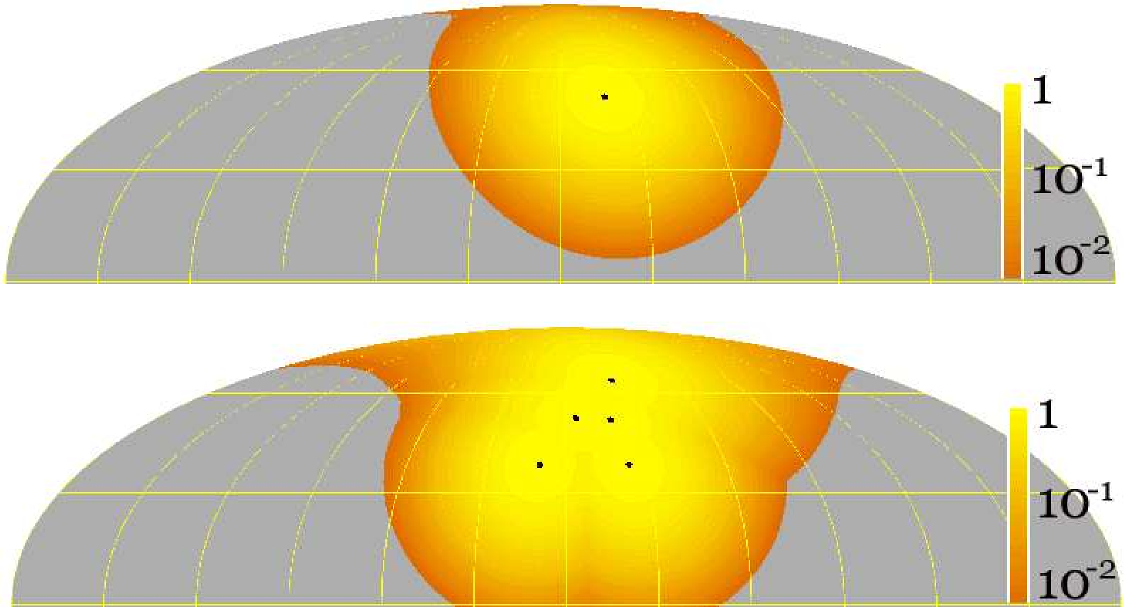

Fig. 5. The angular sensitivity of the MazePi experiment (top) and of five networks of school based cosmic ray experiments in Europe (bottom).