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The RPC system of the OPERA experiment

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ABSTRACT

The OPERA experiment is designed to study the $\nu_\mu \to \nu_\tau$ oscillation observing the ν_τ appearance in a pure ν_μ beam over a base line of 732 km from CERN to Gran Sasso Laboratory. The apparatus consists of a lead/emulsion-film target complemented by electronic detectors and muon spectrometers for muon charge and momentum measurements. The tracking inside the magnets is provide by Bakelite RPC chambers in a large scale application. The commissioning of the RPC system ended in August 2006. The paper present the layout of the RPC system and its performances.

1. Introduction

The OPERA experiment [1] is designed to provide direct evidence of $\nu_\mu \to \nu_\tau$ oscillations observing the appearance of ν_τ in a pure ν_μ beam produced at a distance of 732 km at the CERN SPS. The detector is located in the underground Gran Sasso Laboratory, Italy, under 2.7 km w.e. It consist of two super module each of them composed of a target section followed by a muon spectrometer. The basic constituent of the target is the ECC (Emultion Cluod Chamber [2]) which is a 56-layer stack of lead plates and nuclear emulsions providing the high precision tracking needed for τ detection. The targets are composed of 155 000 ECCs for a total of 1.35 kton. The ECCs bricks are arranged in 29 walls separated by two orthogonal planes of plastic scintillator strips (680 cm $\times$ 2.6 cm $\times$ 1 cm) to allow the event location and to drive the scanning of the emulsions. Each target is followed by a spectrometer to identify and measure muon tracks' parameters. This information will be used to locate the ECC in which a ν_μ charged current interaction occurred and, especially by means of charge measurement, to reject the charm production background. The OPERA detector is completed with a double layer of glass RPC veto [3] placed upstream the first target to reject neutrino interaction occurring in the upstream material.

2. OPERA RPC system

The OPERA muon spectrometer is composed of a dipolar magnet made of two vertical walls of rectangular cross-section ($8.75 \times 8.2\,m^2$) and a top and bottom flux return path. The walls are build lining 12 5 cm thick iron layers interleaved with 2 cm of air gap instrumented with bakelite RPC detectors (Inner Tracker). Six vertical drift tubes planes located in front, behind and between the two magnet walls measure, with a spatial resolution of 300 μm, the bending of the muon tracks. Two additional RPC planes with the readout strips inclined of $\pm 42.6^\circ$ with respect to the horizon and called XPC are placed upstream the magnet. They are used to resolve ambiguities in high track density events.

The main task of the OPERA RPC system is to reconstruct tracks inside the magnet (Inner Tracker), in particular for stopping muons for which the momentum can be reconstructed from their range. The RPCs provide also, with the XPC, the trigger and stop signal for the readout electronics and TDC of the drift tubes.

The RPC planes of the inner tracker are composed of 21 RPC of $2.91 \times 1.13\,m^2$ arranged in seven rows and three columns for a total of 462 RPC chambers per magnet. In order to fit the large bolts that hold together the magnet, 18 RPCs of each plane have grooves of semicircular shape with radius $R = 4.3$ cm along one of the two long side of the RPC. With this particular geometry the RPCs plane acceptance is 96%. The RPC signal read-out is performed by means of 2.6 cm pitch and 8 m long vertical strips, and 3.5 cm pitch and 8.7 m long horizontal strips. The adherence

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of the strips to the RPCs is granted by a layer of polyester fiber used to fill the residual 2 cm gap between the iron slab.

Each RPC row is flushed independently at the rate of five refills per day with the gas mixture $Ar/C_2H_2F_4/i{-}C_4H_{10}/SF_6 = 75.4/20.0/4.0/0.6$. The RPCs are operated in streamer mode with a potential difference of 5.8 kV at the typical temperature and pressure of 17 °C and 900 mbar.

The signals from the strips of the RPC and XPC are collected by means of ~15 m long twisted pair cables and carried to the top of the magnet where the read-out electronics is located. The readout is digital and makes use of LVDS receivers as comparators. Those devices, because of their differential inputs and high common mode rejection ratios allow for a good matching of the signals transmitted through twisted cables. Fig. 1 show one LVDS-discriminator channel with the resistive network that provide the threshold bias and the capacitors to reject the DC component. The RPC Front-End Boards (FEB) [4] consist of 64 channels discriminators, each individually maskable and with input polarity and threshold that can be set in groups of 32 channels. The FEBs are self-triggerable through a 32 channels Fast-OR which is used to form the RPC plane trigger and start the readout chain.

In order to not spoil the good time resolution of the RPC by the long flat cables witch connect the RPC strips to the FEB the stop signal for the drift tubes TDC is generated by a dedicated electronics [5] mounted directly to the horizontal strips of 9 RPC planes of each spectrometer.

The OPERA RPC Inner Tracker is fully operational since August 2006 and has collect data during the CNGS runs. The first run held in August 2006 [6] with only the electronic detector installed. The run last 12 days with a total beam intensity of 0.76×10^{17} p.o.t and was manly dedicated to the commissioning of the data acquisition system and to the fine tuning of the time synchronization between CERN and Gran Sasso.

In October 2007 OPERA perform the first physics run with 40% of the target mass installed. The CNGS run last only 4 days with a total beam intensity of 0.79×10^{17} p.o.t.. The beam operation was interrupted due to loss of ventilation control in the CNGS area caused by the radiation damage of the CNGS standard electronics. Despite the very short run it was possible to prove the principle of OPERA detection technique identifying 38 neutrino interactions in the bricks of the target.

In the following section it will be summarize the performances of the OPERA RPC system during the 2007 CNGS run.

3. Performance of the OPERA RPC Inner Tracker

During the 2007 CNGS run the OPERA RPC system has been operated continuously and in stable conditions for 22 days. The lifetime of the RPC detectors was almost 99%. Data have been collected with a simple trigger condition of at least 3 RPC planes out of 22 and a minimum amount of hit in OPERA detector to be greater than 10. With these requirements the RPC trigger rate was below 0.1 Hz and dominated by random coincidences. With additional requirement of at least 5 RPC planes to reconstruct a track in the Inner Tracker the event rate drop to 0.024 Hz dominated by cosmic ray muons. The total amount of recorded events was almost 45 000 out of which almost 400 correlated in time with the CNGS beam. Fig. 2 shows a typical beam ν_μ charged current interaction in the target with the muon which cross both spectrometers. Fig. 3 shows a multi-muon cosmic event.

Using the cosmic muon tracks we measure the efficiency of the RPC chambers in a fiducial area 10 cm away from the RPC border. The mean RPC efficiency averaged over the entries run was 97%. The maximal RPC efficiency difference inside each RPC row is plotted in Fig. 4. In most of the RPC rows the difference is small indicating a good gas flow inside the RPC rows.

Fig. 5 shows the zenith angle distribution of the tracks reconstructed by the RPC inner tracker. The data are compared to cosmic ray Monte Carlo normalized to the data. The shape of the distribution is the convolution of the cosmic ray zenith angle distribution in the LNGS underground laboratory with the acceptance of the OPERA spectrometers which is maximal around the horizon. The peak at 3.4° is due to CNGS beam related events and is compatible with the expected angular distribution of muons produced by the interaction of neutrinos originating from CERN and traveling under the earth surface to LNGS.

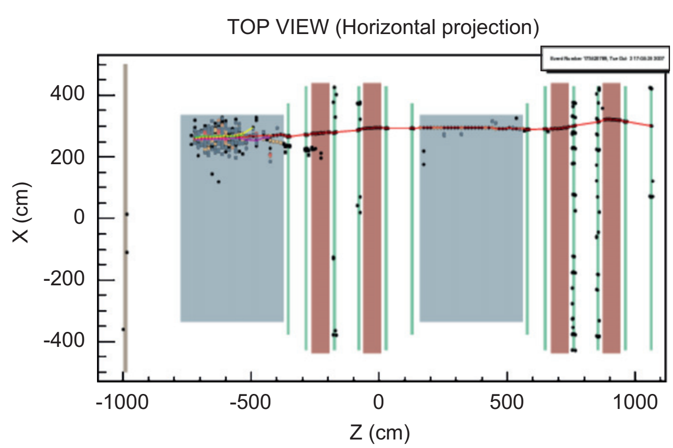

Fig. 2. A typical beam ν_μ charged current interaction in the target. The figure shows the horizontal plane projection.

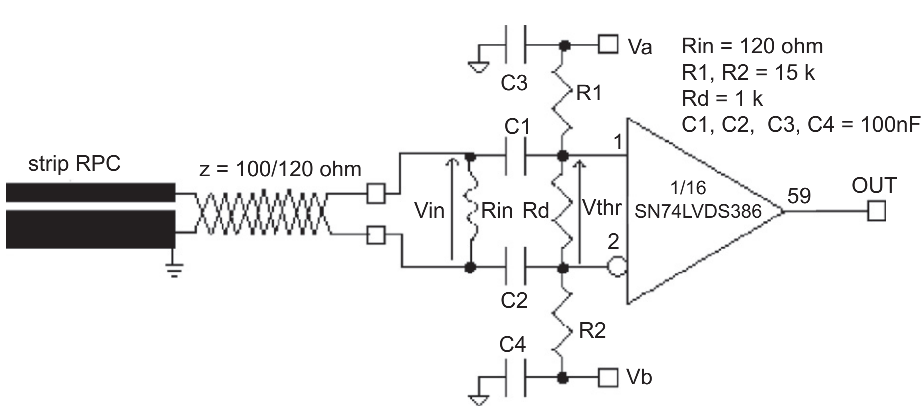

Fig. 1. The schematic of one LVDS-discriminator channel with the resistive network that provide the threshold bias and the capacitors to reject the DC component.

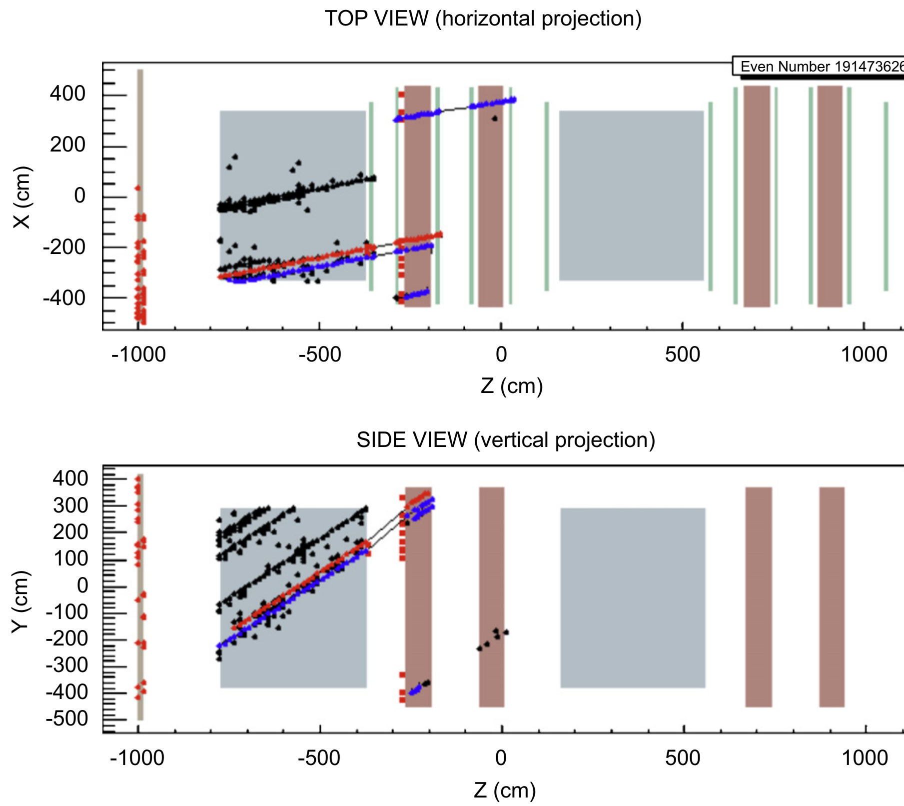

Fig. 3. A multi-muon cosmic ray event crossing the first OPERA super module.

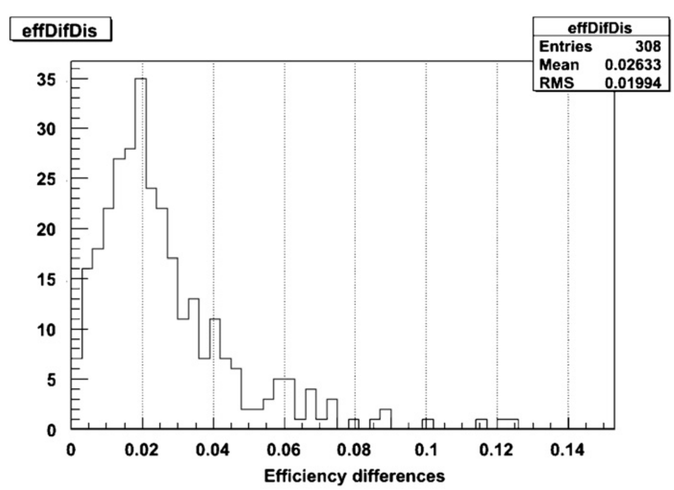

Fig. 4. Maximal RPC efficiency difference between RPCs of the same row. The RPC efficiency is mediated over the 22 days of data acquisition.

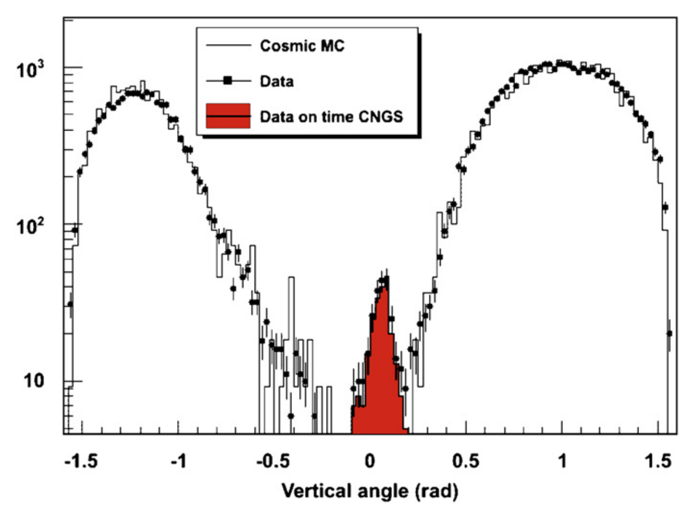

Fig. 5. Zenith angle distribution of beam-induced and cosmic-muon events reconstructed by the inner tracker RPCs. The histogram indicates the prediction from cosmic-ray simulations normalized to the data. The solid histograms are the events correlated in time with the CNGS.

The RPC tracking resolutions are shown in Fig. 6 as a function of zenith angle of the track. The resolution is higher for almost horizontal track, mostly beam events, with a better resolution for the bending (vertical strips) projection due to the lower strips pitch. The degradation of the spatial resolution at higher zenith angle is expected due to the broadening of the RPC induced signal for inclined tracks. This is due both to a geometrical effect and to the fact that the streamer charge has a logarithmic dependence on the primary ionization [7]. The intrinsic angular resolution for beam events is of the order of 0.2°. The angular resolution for cosmic ray events can be evaluated measuring the angular divergency in multi-muon cosmic events. This is the convolution of the detector angular resolution with the resolution due to the Coulomb multiple scattering in the rock. The measured angular resolution for cosmic events is of the order of 1°.

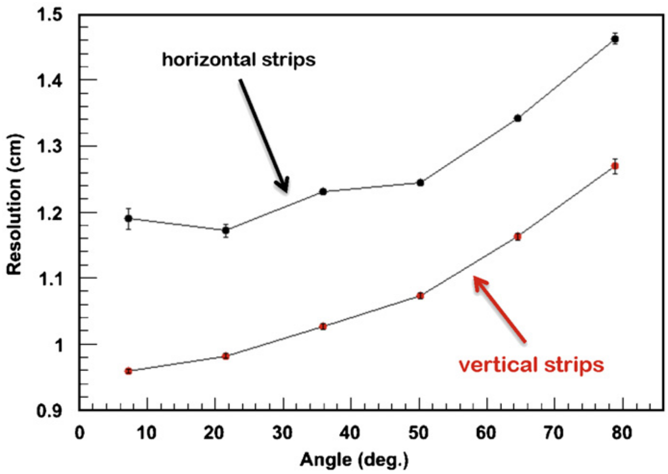

Fig. 6. Inner tracker spatial resolution as a function of the zenith angle of the track. The top and bottom curves refer to the coordinate measured by the horizontal and vertical strips, respectively.

4. Conclusions

The RPC system of OPERA detector is the largest application of RPC detectors in underground. It operated successfully during the 2006 and 2007 CNGS runs matching the required specifications.

The large data sample collected during 2007 CNGS run allowed a detailed study of the efficiency of the RPC chambers and the investigation of the impact of the gas flow on the RPC efficiency.

References

[1] M. Guler, et al., CERN/SPSC 2000-028, SPSC/P318, LNGS P25/2000.
[2] Y. Ashie, et al., Phys. Rev. D 71 (2005) 112005.
[3] A. Bergnoli, et al., Nucl. Instr. and Meth. A (2009), in press, doi:10.1016/j.nima2008.12.076.
[4] A. Bergnoli, The OPERA spectrometer Front End Electronics, Presented at 15th IEEE Real Time Conference 2007 (RT 07), Batavia, Illinois, 29 April–4 May 2007.
[5] A. Bergnoli, et al., Nucl. Instr. and Meth. A (2009), in press, doi:10.1016/j.nima.2008.12.072.
[6] R. Acquafredda, et al.OPERA Collaboration, New J. Phys. 8 (2006) 303.
[7] D. Autiero, Tests results from a prototype RPC setup for the OPERA Target Tracker, Presented at the VI Workshop on Resistive Plate Chambers and Related Detectors, Coimbra, Portugal, 26–27 November 2001 ⟨www-lip.fis.uc.pt/rpc2001/talks/autiero/index.htm⟩.