Design and prototype tests of the RPC system for the OPERA spectrometers

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Abstract

The Inner Tracker system of the spectrometers of the OPERA experiment makes use of Resistive Plate Chambers (RPC) in a large scale application. We present here the definition of the project and the full design of the Inner Tracker. Specific performances for the OPERA-RPC in the spectrometer are also reported. Particle detection, muon identification and trigger capability are discussed, in particular. Some results from test beam (T9 and T7 lines at the CERN PS) and measurements from laboratory test (CERN, Frascati, Padova, Gran Sasso) with prototype detectors are discussed, as well as specific solutions developed for the final setup in OPERA. Full Monte Carlo simulations of the experimental setup have been also developed.

Key words: Neutrino oscillation, Muon spectrometer, Bakelite RPC, Streamer, Large detector

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1 Introduction

The OPERA experiment [1] is designed for the direct observation of ν_τ appearance from $\nu_\mu \leftrightarrow \nu_\tau$ oscillations in the CNGS long baseline beam [2] from the CERN SPS to the Gran Sasso Laboratory. OPERA aims at high sensitivity in the parameter region indicated by the deficit of atmospheric muon neutrinos and by its zenith angle dependence as observed by the Super-Kamiokande experiment (see [1] and references therein). The detector is presently under construction and is expected to be commissioned in 2005.

OPERA makes use of Resistive Plate Chamber (RPC) detectors on a large scale as Inner Trackers for the muon spectrometers [1]. RPCs own by now a long and outstanding experience as performing, cost effective and reliable detectors. However, RPCs will be exploited in a rather novel application in OPERA, so motivating a series of studies and of test measurements on prototypes. The results and the main achievements are reported in this paper.

In the next Sections a description of the different OPERA detectors is presented, to illustrate the experimental constraints and the requirements the RPC have to fullfill. Then the design of the Inner Tracker is outlined. Some of the data selection and analysis from test beam and test lab measurements are then reported. Conclusions are finally drawn.

2 The OPERA detector

OPERA exploits nuclear emulsions as very high resolution tracking devices for the direct detection of the decay of the τ produced in the charged current interaction of the ν_τ with the target. The target design is based on the so called Emulsion Cloud Chamber (ECC) concept [1], which combines in one *cell* the high precision tracking capabilities of nuclear emulsion films and the target mass given by 1 *mm* thick lead plates. By piling-up a series of cells in a sandwich-like structure one obtains a *brick*, which constitutes the detector element appropriate for the assembly of more massive planar structures (*walls*). This target is complemented by arrays of electronic trackers (Target Trackers) for the real time determination of the event position. A wall and its related electronic tracker planes constitute a *module*. A *supermodule* is made of a *target* section, which is a sequence of *modules*, and of a downstream magnetised iron *muon spectrometer* for muon identification and for the reconstruction of their charge and momentum for background rejection. The detector consists of a sequence of three supermodules. The total mass of the target is ~ 2000 *ton*.

The Target Trackers placed downstream of each emulsion brick wall are used to select the brick where the neutrino interaction took place and to guide the scanning, by defining the region of the films to be scanned. A moderate spatial resolution can be tolerated, which allows to reduce the cost of the electronic trackers covering a large surface (about 3000 m^2 for each transverse coordinate). The baseline design foresees the use of extruded plastic scintillator strips read out by wavelength-shifting fibres coupled to photodetectors at both ends. An alternative option envisages the use of RPC detectors operating in streamer mode, arranged in planes each with pickup strips with X and Y orientation. This option and the related test measurements are described in another contribution to these proceedings[3].

Each of the muon spectrometers consist of a dipolar magnet made of two iron walls interleaved by pairs of high resolution trackers. Each wall is made of 12 iron plates 5 cm thick. The iron plates are separated by 2 cm gap where RPCs have to be inserted. The iron is magnetised by a current of about 1200 A circulating in the top and bottom copper coils. The magnetic flux density in the tracking region is 1.55 T with vertical field lines of opposite directions in the two magnet walls. The transverse useful dimensions of the magnets are 8.75 m (horizontal) and 8 m (vertical) providing adequate geometrical acceptance also for muons originating in the upstream target volume. The total weight of one magnet is about 950 *ton*: 270 *ton* for the top and bottom flux return paths and 680 *ton* for the walls. The walls are self–supporting by several long bolts (36 mm in diameter) which run transversely the wall planes. More details on the magnet design can be found in [1].

The high resolution trackers, denoted as Precision Trackers, consist of vertical drift tube planes with an intrinsic resolution of 0.3 mm in the bending direction. The two tracker planes housed between the two magnet walls provide an angular measurement of the track with a 100 cm lever arm. The lever arm for the external trackers is 50 cm. This design leads to a momentum resolution better than 30% in the relevant kinematical domain. RPCs with inclined strips, called XPC, are combined with the Precision Trackers to provide unambiguous track reconstruction in space.

The so-called Inner Trackers are inserted between the magnet iron plates. They are made of planes of RPC detectors operating in streamer mode. On each face of the chambers, the induced pulses are collected by 2.6 cm wide pickup copper strips in the horizontal and vertical directions. The Inner Trackers allow a coarse tracking inside the magnet to identify muons and ease track matching between the Precision Trackers. They also provide a measurement of the tail of the hadronic energy leaking from the target and of the range of muons which stop in the iron.

3 The RPC Inner Tracker system in OPERA

RPC detectors are an optimal choice for the instrumentation of large surfaces as in the application for OPERA, given their high intrinsic and geometrical efficiency, the low cost, the robustness and the ease of segmentation with the desired shape. We plan to adopt the technology developed by R. Santonico *et al.* [4,5], which is used in various accelerator experiments [6], in cosmic rays physics [7] and which is foreseen for the first-level muon trigger systems of the ATLAS and CMS experiments [8]. The knowledge gathered in several years of R&D has been transferred to industry and the production capabilities are well-matched to the large detector area required for the OPERA Inner Tracker, nearly 4600 m^2 for the three spectrometers.

In the L3 experiment [6] where RPC detectors were extensively used, the streamer mode operated with a gas mixture of Argon (58%), Isobutane (39%) and $CBrF_3$ (3%). This mixture is flammable and contains the freon component $CBrF_3$ which is no longer recommended due to its ozone destroying property. These constraints were considered by the BABAR Collaboration which adopted an ecologically acceptable and inflammable mixture of Argon (48%), Isobutane (4%) and $C_2H_2F_4$ (48%), with rather good performance [9].

The percentage of the quenching components (Isobutane and TetraFluoroEthane) does not seem to play an important role, as reported recently by the Argo Collaboration [10]. In the test beam we pursued an extensive study of the RPC performance as a function of Isobutane percentages, below the flammability limit (6%). With the present choice of the gas mixture the operating voltage of the RPCs is about 8 kV. The current drawn has been measured to be 2 $\mu A/m^2$.

The transverse dimensions of the instrumented area of the spectrometer magnet are 8 m in height and 8.7 m in width. Therefore, the three spectrometers with 22 gaps each, cover a total detector area of $\sim$ 4600 m^2. With 26 mm pickup strips, the total number of readout channels is $\sim$ 44350. The present industrial technology permits the building of RPCs with maximum chamber size of about 1.3 $m \times 3.2$ m. Within these limits, RPC elements can be built in practically any dimension. In the design we adopted a complete plane can be covered by 7 RPCs and the width by 3. In total we have 21 elements for each gap and only two different elements types (all of them have dimensions of 1.14 $m \times 2.91$ m). The total number of RPC elements for three spectrometers is 1386. The iron plates also constitute the support onto which RPCs are fixed.

The design of a RPC plane is shown in Fig. 1. An important feature of the RPCs for the OPERA spectrometers is represented by their gondola–like shape design, which is needed to take into account the presence of the bolts of the dipole structure. The bolt position corresponds to the top edges of almost all the chambers. The 'holes' in the RPC surface are half circles of 8 *cm* diameter.

A simple and reliable system for mixing the different gas components and circulating the mixture serially through the chambers has been designed for the OPERA spectrometers. To ensure the long term reliability of the RPC performance, it is presently foreseen not to recirculate the gas in close circuit but to recuperate it with a balloon system and send it back to the gas company. Each plane of RPC is serially fed by 7 parallel lines, each line serving the 3 horizontal chambers in order to have a uniform impedance.

The RPC front end electronics is rather simple since the signal pulses in streamer mode are large (100 mV) and no preamplification is needed. The excellent timing properties of the RPC allow also to form a clock signal for the Precision Trackers. Such an electronic card is already used in the BABAR experiment to readout RPCs in digital mode. A draft of the spectrometer RPC data acquisition system foresees that a whole Inner Tracker plane is read out with $8+9$ 32-channel front end cards linked on an acquisition card in a daisy chain mode. For each trigger (provided by a fast OR of the plane's signals, in coincidence with the adjacent planes) the acquisition card performs a simple formatting of the data and adds the time stamp of the event, given by a 10 MHz free counter running on the acquisition card and synchronise with the Global Position System (GPS) clock through a Pulse Per Second (PPS) signal distributed to each acquisition cards. The interface of the acquisition card can be either a serial link, a direct Ethernet connection or a VME bus. Connection of the strips to the boards makes use of twisted and flat cables.

4 Test setup, measurements and performances

The RPC prototype chambers for OPERA have been extensively tested in a full test–beam setup with high statistics by muon, pion and electron beams. Data were collected in the T9 and T7 beam lines at the CERN PS, by using an analog readout. The achieved final resolution is of the order of one millimeter as exhaustively reported in [3]. The obtained results have been used for the correct modeling of the digital signal obtained by the RPC of the Inner Tracker System (see Fig. 2), via a full GEANT3 simulation.

An interesting use of the RPC in association with more precise detectors is provided by the combination of XPC and the OPERA precision trackers. To this respect some simple tests have been performed in our laboratories, via a standard cosmic telescope made of a RPC (60 x 70cm), read by 3 cm strips connected to a LeCroy discriminator card through 15 m of flat twisted cable, and 3 scintillator as trigger. As an example, the measurement of the time resolution easily provides a 2 ns result (Fig. 3).

The mounting schema constitutes a challenging point due to the extremely short time schedule (installation of each spectrometer in only 6 months). The adopted solution makes use of a special frame which hosts 3 RPC chambers with already gas and HV services on. The frame is then placed parallel to the iron wall and with adequate movements the 3 RPCs are mounted at once on the wall (see Fig. 4).

5 Conclusions

The Inner Tracker system of the spectrometers of the OPERA experiment makes use of Resistive Plate Chambers (RPC) in a large scale application. About 4600 m^2 of RPC surface is needed for the three spectrometers which compose the OPERA detector. We described the design of the Inner Tracker and presented some results from test measurements with prototype detectors. The overall results and the foreseen solutions for the final setup confirm the optimal choice of the RPC for our experiment.

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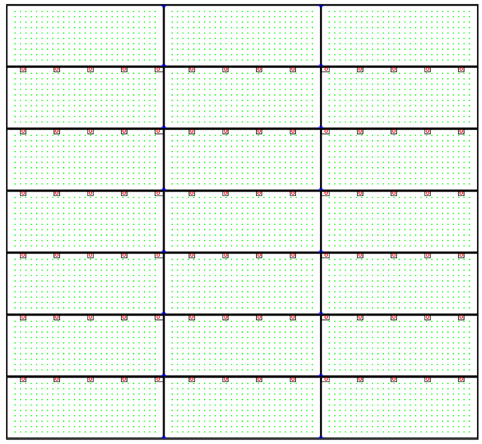

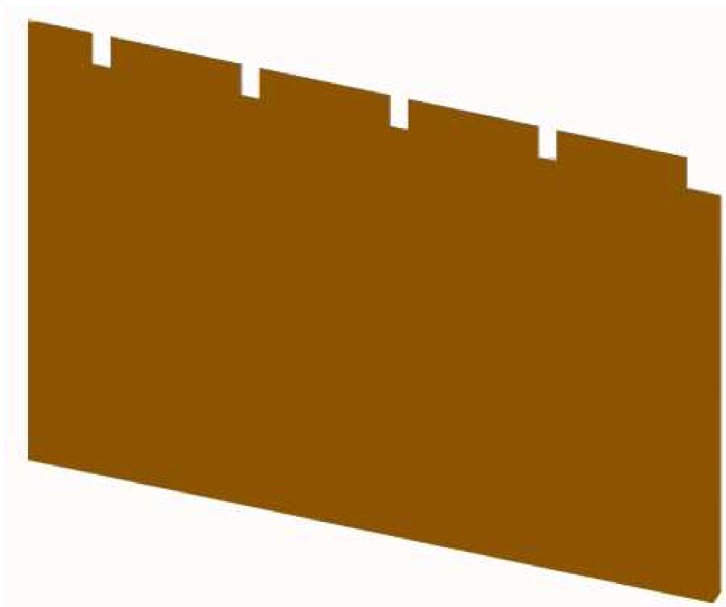

Fig. 1. Layout of an Inner Tracker RPC plane. The wall is 8.7 m in width and 8.0 m in height. 21 RPC chambers, each 291x114 cm^2, recover the wall. Note the gondola-like RPC shape around the magnet bolts.

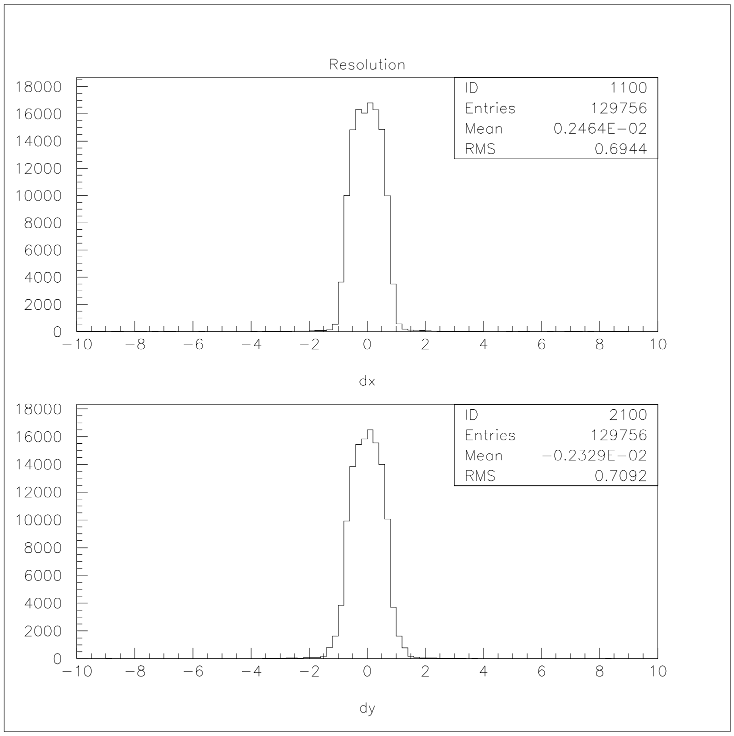

Fig. 2. The distribution of residuals (in cm) for 2.6 cm pitch of the digital signal from the strips of the Inner Tracker System. The response of the RPC signal has been modeled by using the results obtained from the test beam and the laboratory tests.

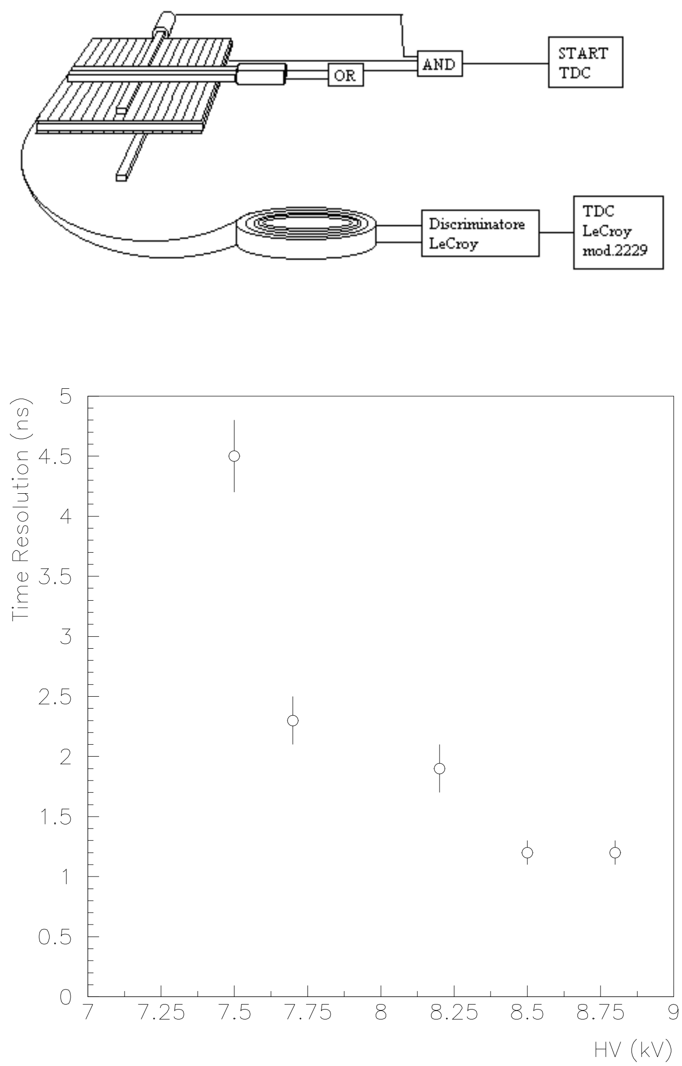

Fig. 3. The system test stand and the result of the measurement of the achieved temporal resolution as a function of the HV.

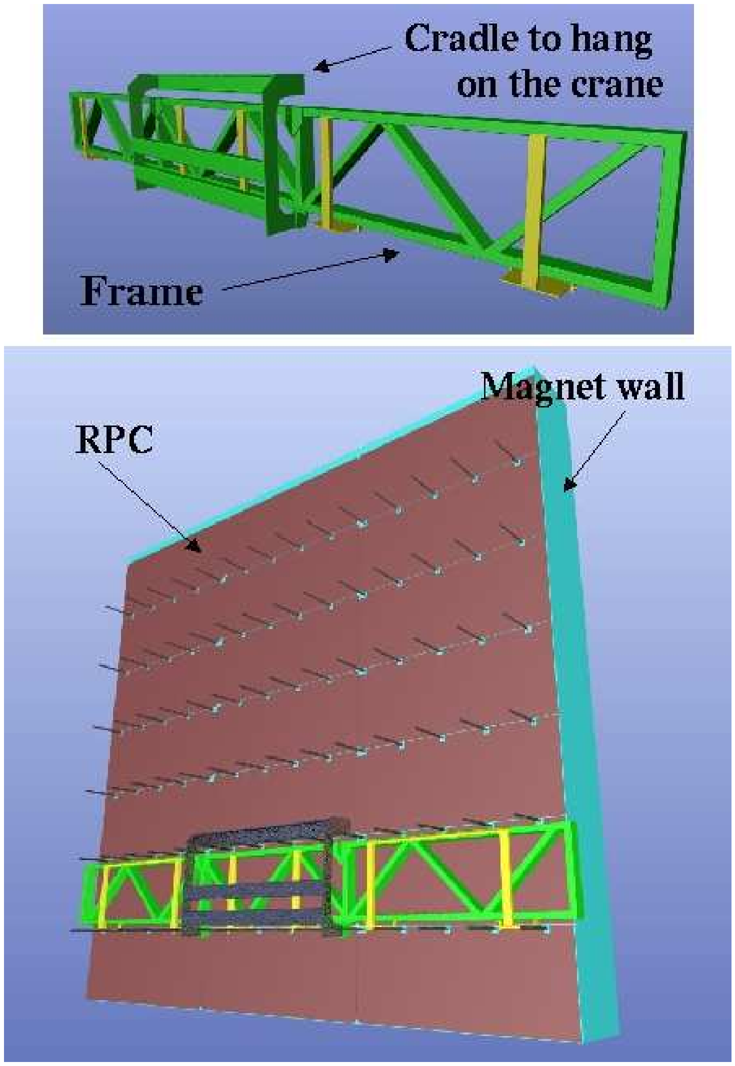

Fig. 4. The procedure of mounting 3 RPC chambers at once in a row by using a special frame and cradle.