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Abstract.

We present the performance of a hodoscope made of Resistive Plate Chambers (RPC) installed in the RD5 experiment at CERN and exposed to beams of high energy muons and pions. The efficiency as a function of the particle flux is studied for different resistivities. A substantial improvement is obtained with plates of lower resistivity. Tracking muons through the RPC and using the bending power of a 2.7 Tm iron toroid, a simple trigger algorithm is used to select large momentum muons.

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1. Introduction.

Experiments at future high energy hadron colliders, LHC and SSC, will need performant triggers on large transverse momentum leptons to study signatures of rare processes. The LHC is proposed to operate with a luminosity of $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ and a bunch crossing frequency of 67 MHz. Thus the trigger should provide a very fast response and a high selective power over a large solid angle. To achieve this goal there is need for detectors with fine segmentation and good time resolution.

Detection of muons offers an advantage over electrons since the trigger will be done behind a calorimeter where the particle flux is lower. Large transverse momentum muons can be selected as charged particles pointing to the interaction region after penetrating several interaction lengths. The programme of the RD5 experiment [1] at the CERN SPS is to make a detailed study of muon momentum measurements and trigger schemes that operate in the presence of a large background of hadron showers.

Resistive Plate Chambers [2], RPC, were proposed as a suitable solution to build a first level muon trigger [3] because of their fast response and good time resolution, flexibility in segmentation, robustness and the relatively low cost of production. However, given the long recovery time, their efficiency is degraded when exposed to large particle fluxes and more progress is needed for a safe operation at high luminosity colliders. We describe the RPC hodoscope installed in the RD5 experiment, its tracking performance and present new results on the dependence of the efficiency as a function of the particle flux.

2. The RD5 experiment.

The lay-out of the RD5 experiment is shown in Fig.1. It consists of two magnets: the superconducting magnet of the EHS experiment producing a 3 T field followed by an iron torus producing a 1.5 T field. The magnetic fields have opposite directions and the field integrals are 5 Tm and 2.7 Tm respectively. This configuration can simulate a solenoidal detector with its return yoke or an iron toroidal spectrometer. In front of the EHS magnet there is a tracker made of silicon microstrips and multiwire proportional chambers and a beam defining scintillator hodoscope. A tracking calorimeter [4], TRACAL, of 10 interaction lengths made of stainless steel plates alternated with proportional gas tubes (honeycomb chambers) is installed inside the EHS magnet. The honeycomb chamber planes provide a two dimensional read-out: charge induced on cathode strips in the direction of the magnetic field and drift time in the other direction.

In front and behind the first half of the iron magnet there are two muon measurement stations with large area drift chambers [5] and RPC. A third muon station is placed behind the torus, but in 1991 was not equipped with RPC. RPC are also inserted

in two thin gaps in the first half of the torus. Fig.2 shows a perspective view of the drift chambers and of the RPC installed in Station 1.

The results presented here refer to data taken with muon and pion beams of momenta between 20 and 300 GeV/c in 1991. During this period the EHS magnet was not powered.

3. The Resistive Plate Chamber hodoscope.

The RPC hodoscope consists of 16 planes of chambers. Each plane has dimensions $2 \times 2 \text{ m}^2$ and is equipped with 64 read-out strips of 31 mm pitch. The planes are coupled in pairs providing one measurement in the horizontal projection, z , and one in the vertical projection, y . Station 1 has four pairs with two y - z measurements before and after the drift chambers. There is one y - z pair in each of the two gaps in the iron toroid. Station 2 has two y - z pairs with one measurement on either side of the drift chambers.

Each plane is made of two RPC of dimensions $1 \times 2 \text{ m}^2$ assembled as shown in Fig.3. The RPC are built with two parallel plates of phenolic polymer, bakelite, of $1 \times 2 \text{ m}^2$ surface and 2 mm thickness. The plates have a resistivity ρ of the order of $10^{11} \Omega \cdot \text{cm}$ and a permittivity $\epsilon_r \approx 4$. The sensitive gas volume is a 2 mm gap between the two plates. In order to separate the plates by a fixed distance over the whole surface, disks of polyvinyl chloride, PVC, are glued on the plates. These disks are 12 mm in diameter and there are 200 disks at a distance of 100 mm from one another producing a dead area in the detector of about 1%. The gas gap is closed at the edges with a PVC frame to insure gas tightness; small pipes let the gas in and out close to the four corners.

The outer surface of the resistive plates is coated with a graphite solution with a surface resistivity of $\approx 0.1 \text{ M}\Omega/\square$. The two graphite electrodes, transparent to the fast component of the discharge pulse, are connected to the high voltage power supply to produce the electric field. A $300 \mu\text{m}$ foil of PVC is glued on the graphite surface to provide isolation of the high voltage electrodes. The inner surface of the resistive plates is coated with linseed oil to insure a smooth surface and prevent local disuniformities of the electric field that would produce noise or discharges.

The read-out electrode is made of plastic foils of 1 m width on which are deposited thin aluminum strips of 29 mm width and 2 mm spacing. The strip plane is separated from the outer ground shield with a foam plate 10 mm thick. Each strip-line is terminated on 50Ω , close to the value of its characteristic impedance, on either end and one side is connected to the front-end electronics. The propagation time of the transmission line is about 5 ns/m and there is no attenuation of the pulse from the induction point to the end. The whole detector is electrically shielded in a Faraday cage made of a thin aluminum foil that is connected to the ground of the high voltage power supply and of the front-end electronics. A section of the chamber is shown in Fig.4a.

Particular care was devoted to the ground connections to prevent any induction of the RPC, that operate in a discharge mode producing large pulses, on the other detectors. In fact no influence was observed on any detector during the measurements.

The scheme of the front-end electronics is shown in Fig.4b. Each plane provides a fast trigger signal made with the wired OR from the discriminator outputs of the 64 strips. The signals from the individual strips are formed 100 ns in time. Line drivers with differential TTL outputs are connected with twisted pair cables to VME registers [6] that are strobed by the scintillator hodoscope trigger.

4. Performance of the Resistive Plate Chambers.

Chambers with two different resistivities of the electrode plates have been tested. The resistivity of the electrodes is an important parameter that defines the recovery time of the electric field after a local discharge and thus influences the efficiency of the chamber as function of the particle flux. Bakelite plates were ordered with different specifications and then selected in two groups according to their resistivity. A variation of about 50% was observed within each group. During the assembly of the chambers care was taken to couple plates with the same value of resistivity. Low resistivity chambers, $\rho \approx 4 \cdot 10^{10} \Omega \cdot \text{cm}$, were placed in Station 1 where a larger flux of particles is expected from leakage of hadron showers in the tracking calorimeter. The chambers in the gaps of the iron magnet and in Station 2 have a resistivity 5 times higher.

Most of the data were taken with the chambers filled with a gas mixture of 58% argon, 38% n-butane and 3.8% of freon. The supply voltage was 7.0 kV and 7.2 kV for the low and high resistivity chambers respectively. A second gas mixture of 57% argon, 37% n-butane and 5.8% of freon was also used during part of the tests with an operation voltage of 200–300 V higher. The rate of the fast-OR signal was, on average, 10 kHz (2 kHz) per plane for the low (high) resistivity chambers. The probability of accidental hits in coincidence with the experiment trigger was between 10^{-4} and 10^{-3} per plane. Fig.5 shows the behaviour of the power supply current and of the fast-OR rate as a function of the high voltage, for two extreme cases of chambers that differ in resistivity of the electrode planes. The efficiency, averaged over the whole surface of the chambers, was measured using the fast-OR signals with muons of the beam halo. Fig.6 shows the efficiency as a function of the high voltage for the two gas mixtures used.

The performance of the chambers was studied by tracking high momentum muons, 100-300 GeV/c, through the different planes. Signals from adjacent strips were grouped in clusters, then tracks were defined with a least square fit to a straight line. Fig.7 shows the distribution of the residuals from the track fitted in the non-bending projection: the r.m.s. space resolution is 8 mm. Fig.8 shows the distribution of the number of strips per cluster for different muon momenta: the average size of clusters is 1.3 strips. A

significant broadening of the cluster size with increasing muon momentum is observed. The effect is different in the first RPC in Station 1, that are placed after 70 cm of free space with no magnetic field behind the calorimeter, and those placed immediately after the iron absorber. This broadening of the size of clusters is interpreted as due to the contribution of electromagnetic showers accompanying high energy muons and it is confirmed by a simulation of muons penetrating through the iron absorbers.

The efficiency of each plane was measured requiring that a hit is found in three strips centred on the line fitted requiring the presence of at least three other planes. At low beam intensity, for muon fluxes smaller than 10 Hz/cm^2 , the efficiency for the different chambers varies between 94% and 99%. Fig.9 shows the efficiency as a function of the muon flux in different chambers. The spread in the behaviour of the efficiency reflects the variations in the resistivity of the bakelite plates. For this measurement the beam was defined by two scintillators of dimensions $10 \times 15 \text{ cm}^2$ and $15 \times 15 \text{ cm}^2$ respectively and the particle flux was measured by the rate of the $10 \times 15 \text{ cm}^2$ scintillator and of a smaller scintillator of dimensions $4 \times 4 \text{ cm}^2$ centred on the beam line. The particle flux was conservatively estimated as that measured on a $10 \times 15 \text{ cm}^2$ surface with a $4 \times 4 \text{ cm}^2$ hole in the centre. The scintillators rate was uniform over the 2.6 s of the extraction cycle of the beam: thus the data shown in Fig.9 represent the average efficiency over this time interval. A significant degradation in efficiency is observed in the RPC with high resistivity electrodes for particle fluxes larger than 10 Hz/cm^2 . The efficiency of low resistivity RPC degrades at fluxes larger than 50 Hz/cm^2 . From the different behaviour of high and low resistivity chambers, we can extract the ratio between the values of the relaxation time and thus of the resistivity. We obtain a ratio $r = 4.7 \pm 0.7$ that is consistent with the value measured before assembling the chambers.

In experiments at the LHC, a charged particle flux of $(0.1-1) \text{ Hz/cm}^2$ is expected in the barrel region, $|\eta| < 1.2$, behind a calorimeter of 10–12 nuclear interaction lengths [7]. This flux is mainly due to decays in flight, $\pi \rightarrow \mu\nu$, $K \rightarrow \mu\nu$, in the central tracking volume and to punchthrough of hadron showers in the calorimeter. The flux is expected to be much higher in the end cap region: about 100 Hz/cm^2 at $|\eta| = 2$. Moreover a much larger flux of low energy neutrons, of about $(10^4-10^5) \text{ Hz/cm}^2$ almost uniform over the surface of the muon detectors, has been recently reported [8]. The average efficiency of the RPC to these neutrons is of the order of 10^{-3} [9]. Thus for a safe operation at LHC experiments, a trigger hodoscope made of RPC should provide good performance with a constant particle flux of about 100 Hz/cm^2 .

In order to estimate the behaviour of the chambers when exposed to a constant flux, we have measured the efficiency as a function of time during the extraction cycle of the beam. The extraction cycle was subdivided in time intervals of $\approx 80 \text{ ms}$ and the efficiency was computed for each interval. The results are shown in Fig.10 for fluxes of 6, 64 and

208 Hz/cm². It is evident that the asymptotic value of the efficiency of high resistivity chambers is lower than the average value at all fluxes. On the other hand, low resistivity chambers show better performance and we do not expect any significant degradation of their efficiency when operated at a constant particle flux of 20 Hz/cm².

The efficiency of similar chambers built with high resistivity plates has been previously measured [10,11] with different particle fluxes at a beam of the CERN PS extracted in 300 ms. It should be noted that in those measurements the voltage on the chambers was increased with the flux, while in the measurements presented here it was kept constant. Since the drop in efficiency is due to the lower electric field in the gas gap, our data are much affected at large particle fluxes. The values of the efficiency measured over the first 300 ms of the beam spill are compared in Fig.11 with those measured in ref. [10] and [11]. Though the measurements have been done in slightly different conditions, the dependence upon the particle flux of the efficiency of high resistivity chambers is similar to that measured previously. Measurements of the efficiency of high resistivity chambers with a continuous flux of photons from a nuclear reactor have been also reported [12]. The results show that the dependence of the efficiency upon the flux is more marked than for time intervals of 0.3 s and 2.6 s.

We can conclude that RPC built with phenolic plates of resistivity lower than 10¹¹ Ω·cm show a substantial improvement and are better suited for application with a constant flux of particles in excess of 10 Hz/cm². A promising way to improve the rate capability of RPC is to use mixtures with a higher content of electronegative gas [13] and is now actively pursued. In this case the discharge is smaller and more localized and the current pulse is faster. Therefore there is need of a front-end electronics with amplification and bandwidth larger than the one used in the present chambers.

5. Muon trigger study.

Though the first magnet was not powered during the data taking, the segmentation of the hodoscope and the bending angle in the iron magnet provide sufficient analysing power to test a tracking trigger to select large momentum muons. We expect a resolution $\Delta p/p^2 \approx 10^{-2} \text{ (GeV/c)}^{-1}$.

The RPC strips were aligned with muons of 300 GeV/c momentum when the iron magnet was not powered. The bending effect of the iron magnet is shown in Fig.12 where the angular deflection of 40 GeV/c and 300 GeV/c momentum muons are compared. The two distributions are clearly separated. The bending angle is defined by the coordinates measured in the four planes of Station 1 and the two planes in Station 2: $\theta_y = 2 [\langle y_2 \rangle - \langle y_1 \rangle] / \Delta x$, where $\Delta x = 2.9 \text{ m}$ is the distance between Station 1 and Station 2.

We tested a simple trigger scheme for an iron spectrometer using only the exit angle of the muon measured by the two planes of Station 2 that are separated by 80 cm. For each strip hit on the first plane of Station 2 a window is opened on the second plane centred on the intersection of the line joining the strip hit on the first plane and the centre of the $4 \times 4 \text{ cm}^2$ trigger scintillator. The size of the source of particles and its distance from the trigger planes are comparable to those of muon spectrometers proposed for experiments at future pp colliders. A hit found in such a window selects muons with momenta larger than a threshold defined by the width of the window. The efficiency of this trigger algorithm as a function of the muon momentum is shown in Fig.13 for a window defined by three strips on the second plane.

To study the rejection power of this trigger scheme against hadron showers produced by pions, we must first remove events due to muons contaminating the pion beam. This is done by cutting on the distribution of the multiplicity of wires hit in TRACAL and, if a penetrating track is found in the RPC of Station 1, on the angle in the non-bending plane between the beam axis and the direction of the track. The selection is discussed in detail in ref. [14]. The selectivity of the trigger is shown in Fig.13 as a function of the primary pion momentum. Punchthrough pions are defined by any pair of clusters in the two y-planes of Station 2. A trigger that is fully efficient for muons of 40 GeV/c momentum provides a rejection larger than a factor 10 against hadron showers produced by 40 GeV/c pions that penetrate up to Station 2, thus reducing the level of punchthrough to less than $2 \cdot 10^{-4}$. In this configuration the punchthrough is mostly due to decay muons produced in the development of the hadron shower [14] and their contribution can be reduced only with a fine segmentation of the trigger hodoscope. Though the geometry and the bending power are different, the selectivity of this trigger scheme can be easily extrapolated to experiments that have been proposed with an iron spectrometer: ATLAS and CMS [7] at the LHC and SDC [15] at the SSC.

6. Conclusions and future developments.

A hodoscope made of 16 planes of resistive plate chambers of $2 \times 2 \text{ m}^2$ surface with the read-out electrodes segmented in 3 cm strips has been used in the RD5 experiment at the CERN SPS to track large momentum muons and to study the punchthrough of hadron showers in iron. The hodoscope has operated with good reliability for two years.

The space resolution measured tracking large momentum muons through the hodoscope is adequate for a first level muon trigger at LHC/SSC experiments. The efficiency as a function of the particle flux has been studied for different resistivities: a substantial improvement is obtained with plates of lower resistivity.

Studies to improve the efficiency and the time resolution at large particle fluxes using mixtures with a higher content of electronegative gas or operating the chambers at higher electric field are in progress to assess whether RPC will fulfil all requirements to build a fast tracking muon trigger at high luminosity hadron colliders.

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References

- [1] M.Della Negra et al.: "Study of muon triggers and momentum reconstruction in a strong magnetic field for a muon detector at LHC", CERN/DRDC/90-36, DRDC/P7, 1.9.1990.
- [2] R.Santonico and R.Cardarelli: Nuclear Instruments and Methods in Physics Research, A187 (1981) 377; R.Cardarelli et al.: Nuclear Instruments and Methods in Physics Research, A263 (1988) 20.
- [3] F.Ceradini et al.: "A fast tracking muon trigger for high luminosity colliders using resistive plate chambers", Proceedings of the Large Hadron Collider Workshop, CERN/90-10, ECFA/90-133, eds. G.Jarlskog and D.Rein, vol.III, page 99.
- [4] F.Bakker et al.: Nuclear Instruments and Methods in Physics Research, A330 (1993) 44.
- [5] K.Eggert et al.: Nuclear Instruments and Methods, 176 (1980) 217.
- [6] C.Bacci et al.: Nuclear Instruments and Methods in Physics Research, A324 (1993) 83.
- [7] CMS, Letter of Intent, CERN/LHCC/92-3, 1.10.1992. ATLAS, Letter of Intent, CERN/LHCC/92-4, 1.10.1992.
- [8] A.Ferrari: private communication.
- [9] I.Pless: contribution to the Workshop on Resistive Plate Chambers in Particle Physics and Astrophysics, Rome, 18-19 february 1993.
- [10] M.Bertino et al.: Nuclear Instruments and Methods in Physics Research, A283, (1989) 654.
- [11] I.Crotty et al.: Nuclear Instruments and Methods in Physics Research A329 (1993) 133.
- [12] M.Iori and F.Massa: Nuclear Instruments and Methods in Physics Research, A306, (1991) 159.
- [13] R.Cardarelli: contribution to the Workshop on Resistive Plate Chambers in Particle Physics and Astrophysics, Rome, 18-19 february 1993.
- [14] M.Aalste et al.: "Measurement of hadron shower punchthrough in iron", CERN-PPE/93-71, 22.3.1993, submitted to Zeitschrift für Physik C.
- [15] SDC, Technical Design Report, SDC-92-201, 1.4.1992.

Figure Captions

- Fig.1 The lay-out of the RD5 experiment.
- Fig.2 View of the muon measurement Station 1 with the drift chambers and the resistive plate chambers.
- Fig.3 View of one y-z plane of the resistive plate chamber hodoscope.
- Fig.4 a) Cross section of a resistive plate chamber (1: bakelite plate, 2: gas gap, 3: graphite coating, 4: PVC insulating foil, 5: aluminum strips, 6: PVC spacer, 7: read-out transmission line, 8 line termination, 9: front-end electronics).
b) Scheme of the front-end electronics.
- Fig.5 Current (a) and rate (b) per unit surface as a function of the supply voltage for two RPC that have different resistivities. The gas mixture is: 57% argon, 37% n-butane and 5.8% freon.
- Fig.6 Efficiency as a function of the supply voltage for two gas mixtures: (a) 57% argon, 37% n-butane and 5.8% freon; (b) 58% argon, 38% n-butane and 3.8% freon.
- Fig.7 Distribution of the residuals from a straight line fit to 300 GeV/c muon data.
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- Fig.9 Efficiency as a function of the particle flux averaged over the 2.6 s cycle of the beam extraction.
- Fig.10 Efficiency as a function of time during the extraction cycle of the beam.
- Fig.11 Efficiency as a function of the particle flux, averaged over 0.3 s, compared with the results of ref. [10] and [11].
- Fig.12 Bending angle measured with the PRC of Stations 1 and 2.
- Fig.13 Efficiency of the trigger algorithm using only the RPC in Station 2. Each strip of the first plane is in coincidence with three strips of the second plane.

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