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DRIFT CHAMBERS FOR A LARGE-AREA, HIGH-PRECISION MUON SPECTROMETER

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ABSTRACT

We have tested two prototypes of high-precision drift chambers for a magnetic muon spectrometer. Results of the tests are presented, with special emphasis on their efficiency and spatial resolution as a function of particle rate.

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1. INTRODUCTION

To fully exploit the physics potentiality of the high-energy colliders, the new generation of experimental apparatuses must ensure precise measurements of particle momenta up to very high energy and over a wide angular range.

For forward muon detection, this reflects in the necessity of having large-area, high-precision systems of drift chambers. The design of such huge systems is the result of many compromises, both technical and financial. To better understand the various parameters which enter into this optimization, we have built and tested two prototypes of drift chambers. In this paper, we will report the results of these tests, focusing in particular on the behaviour of spatial resolution and efficiency as a function of particle rate. The best values for the parameters of the chambers will have to be chosen according to the foreseen running conditions. To begin with, we have chosen reasonable values for all parameters, one of the purposes of this test being to try to optimize them.

We have decided in favour of a vectorial chamber, i.e. one with at least three sense wires per cell in order to simplify track reconstruction and improve momentum resolution. The left-right ambiguity can be solved by staggering the wires; however if a wire is slightly inefficient it will be impossible to solve the ambiguity for a fraction of the events. It is for this reason that we have tested one prototype with three sense wires and one with four, in the same ionization space. Our previous experience has shown that a cell containing insulating material is too prone to static charge pick-up, with loss of efficiency and resolution: therefore we decided on an all-metal cell. The drift space should not be too long in order to avoid deterioration of the resolution due to diffusion: 3.5 cm has been our initial choice, although this may not be the optimal one at high particle flux. Decreasing the cell size, on the other hand, will increase the number of wires, the electronic channels, the cost, and the chances of breakdowns. Given the number of sense wires, the cell height determines the electron statistics and will influence both resolution and efficiency. The thickness of the chamber, however, is limited by the space available in the spectrometer. If we choose to have self-supporting, reasonably light chambers, one of the best materials for the outer walls is phenolic paper honeycomb, two sheets of which use about 6 cm of space; this is sufficiently stiff even for the final length of the chambers (~ 2 m).

It is worth underlining that we have preferred, for the prototypes, to have the sense wires at ground potential, rather than at high voltage. This choice makes the prototypes simpler so that the high-voltage decoupling resistors cannot limit the high-rate response of the wire. The sense wires are thus not protected. However, taking the chance of breaking a wire during a test run has seemed preferable to limiting the performance of the chamber: an adequate method of wire protection can be chosen afterwards, once the maximum rate the chamber can stand is known [1].

2. DESIGN OF THE CELL

Figure 1 shows the cross-sections of a cell. There is an outer rectangular metal box. Three or four sense wires are interleaved with field wires. The uppermost and lowermost field wires are, in fact, part of a set of horizontal field-grading wires.

The design of this configuration has stemmed from the following considerations. The cell limiting walls must be at high voltage, in order to directly couple the sense wires to the amplifiers. The upper and lower surfaces of the cell must be either at ground or at high voltage. The first option would be unacceptable since most electrons, especially from tracks near the walls, would not reach the sense wires, ending up on the ground planes. Monte Carlo simulations show that a high-voltage box with more than one sense wire in the middle will not work, since the electrons generated by tracks at the limit of the drift space will all be focused on the central sense wire. To straighten up the equipotentials, we need field-grading wires. With this cell design, we will have two voltages to adjust: V_D (voltage on the walls) and V_F (voltage on the field wires). In the final configuration we intend to apply high voltage even to the sense wires. Figure 2 shows the equipotentials and the shape of the drift lines for one set of running conditions. The quantities of actual interest are the field on the surface of the sense wires, E_w , and the essentially constant drift field, E_D , in the middle of the gap. E_w determines the gain and E_D the parameters of the transport equation: drift velocity and diffusion. If the wires are to have the same gain, the values of V_D and V_F must be chosen carefully. Figure 3 shows the linear correlation between these two quantities in order to have an equalized gain on the sense wires: naturally along this line both the gain and the drift field will change. We must remark,

however, that the correlation shown in fig. 3 is computed and small errors in the calculation will generate relatively large errors in the gains since these are very sensitive to the value of E_w .

Practically, the chamber is built using two Al-covered sheets of honeycomb with one printed circuit (PC) board at each end holding the grading wires. On the same PC boards hybrid resistor chains will grade the voltages to the wires. Two side members, glued to these sheets, will form a flat box in which the sense wires are inserted using a jig, i.e. a flat Al bar holding two pillars with holes and crimp tubes through which the wire is threaded. The jig is inserted horizontally in the cell and turned 90 degrees; the two pillars are fastened to the front and rear of the box by dowel pins. The jig is then detached from the pillars and withdrawn leaving the wires in place. We plan to use the capacitive coupling of the sense wires to the flat Al bar to measure the resonance frequency of the wire, and therefore its mechanical tension, before inserting the jig in the box [2]. Tests have started on this point.

3. ELECTRONICS

A long PC board holds the preamplifiers on top of the chamber. Our preamplifiers have a gain of 20 mV/ μ A and are capable of driving at least 40 m of shielded twisted-pair cable. The outputs have been sent to a discriminator followed by a time-to-digital converter (TDC) (LRS 2228) and an analog-to-digital converter (ADC) (LRS 4248W).

In future, there will be two possible locations for the discriminators: either we put them directly on or very near the chambers, or we put them in the counting room. The first solution has the advantage of less electromagnetic noise pick-up and no deterioration of the pulse rise-time due to the limited bandwidth of the twisted-pair cable. On the other hand, the solution with the discriminator in the counting room has, at least for now, been preferred because it allows one to look at the analogic signals (from the linear output), and also permits replacement of broken channels and adjustment of thresholds or signal widths in a much simpler way. Anyway, the results reported here show that 40 m of twisted-pair cable do not seriously affect the performance of the system.

4. GAS

A standard admixture of 50% Ar and 50% ethane has been used in these tests. No attempt has been made to optimize the ratio of the two gases. The mixing has been done with a standard CERN mixing rack. A test of the amount of O₂ in the chamber has been made as a function of the flow rate: two complete changes of gas a day are enough to keep the oxygen down to a comfortable level of 0.015%. A preliminary ageing test done with a tube and a source of ⁶⁰Co has shown only some Si deposits.

5. TESTS

We have measured the plateau of the chambers, by changing the voltages so as to take into account the gain equalization condition. In this way, we changed the field on the sense wires; field that can easily be transformed into gain, once we measure the charge with the ADC, take into account the gain of the preamplifier, and know the number of ion pairs per centimetre produced by the track [3].

We have used a 3.5 GeV/c negative pion beam and a system of three scintillation counters in order to measure the efficiency and the resolution of the chamber. The first counter has the same size as the cell and is made to overlap with it as accurately as possible; the second is a vertical (orthogonal to the wire) 2 cm wide finger, to take data only on a short piece of the wire; the third was used only to reduce the accidentals to a negligible level. A coincidence of the three counters (trigger) gives a start to the TDC and opens a 1 μ s gate to the ADC. The spatial resolution is obtained using the method described in [4]. We report results on track efficiency only, i.e. the fraction of triggers in which at least three wires gave a signal, and the track could be reconstructed with no points having a distance greater than 1 mm from the best fit.

6. RESULTS

In fig. 4, we have plotted the efficiency as a function of the measured gain. The 3-wire chamber reaches a plateau at higher gain than the 4-wire one. The efficiency is at least 97%. The 3% inefficiency is mostly geometrical or due to the reconstruction algorithm. Interesting also is the

behaviour of this plateau, as a function of the particle rates on the cell. Figure 5 shows this behaviour for the two prototypes. It appears that the 4-wire chamber holds the rate better. For instance, with $E_w = 319$ kV/cm, the efficiency curve is flat up to 2×10^5 Hz/m; at $E_w = 325$ kV/cm, we can reach a rate of 5×10^5 Hz/m. Should these values of the rate be considered too small then the size of the drift gap will have to be shortened [5]. In fig. 6 we show the correlation between the gain and the rate for different values of E_w .

In fig. 7, we report, for the indicated conditions of rate and E_w , the intrinsic spatial resolution σ as a function of the drift distance y . These curves show, probably more dramatically than the efficiency, the effect of the rate: while at low rate the curve of σ as a function of y rises mostly because of diffusion, at higher rates the resolution grows faster, to unacceptable values. For a good intrinsic resolution of ~ 100 μ m, the rate will have to be limited to $\sim 2 \times 10^5$ Hz/m. The monotonic worsening of the resolution, at small y , as a function of the rate is easily attributable to the gain reduction as the rate increases. The increase of the slope at higher rates seems to be the effect of the diffused positive charge [6].

In fig. 8, we show the behaviour of the average resolution as a function of the rate.

7. CONCLUSIONS

To summarize, the purpose of this test was to compare the two prototypes for efficiency, resolution, and their behaviour with particle rate, in addition to trying to optimize the design of the cell. From the plots presented, we can conclude that the 4-wire chamber has a better efficiency at high particle rate. If we add to this fact the advantage of a greater reliability, we feel that the 4-wire chamber is preferable. The increase in the number of channels with this choice is only moderate (25%). It appears, on the other hand, that the resolutions of the two chambers are equal.

In conclusion, the width of the cell seems adequate, unless we want to further extend the particle rate for which the chamber is efficient [5], and the initial choice of parameter values seems suitable for a muon magnetic spectrometer.

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Figure captions

- Fig. 1 : a) Cell geometry, showing the two sheets of honeycomb, with the Al lining, both inside and outside, forming a double Faraday cage. The partitions separating the cells are made of 1 mm thick fibre glass covered with 25 μm of Cu. The inside Al lining, together with the Cu of the walls, forms the metal box mentioned in the text. Each chamber has nine identical cells.
b) This view shows more clearly the PC boards supporting the grading wires and the hybrid resistor chain. The length of the wire is 60 cm.
- Fig. 2 : a) Equipotentials at $V_D = 4.8 \text{ kV}$ and $V_F = 2.15 \text{ kV}$.
b) Drift lines of electrons produced by a track passing near the end of the cell. The figure shows that some differences in primary electron statistics will exist between different wires. The sense wires are numbered 1 to 4, starting from the top of the cell.
- Fig. 3 : The relation between V_D and V_F in order to have equal electric fields on the sense wires; owing to slightly different collection efficiencies and to the sensitivity of the gain to the E_w , it is actually very difficult to equalize the pulse heights of the different sense wires. At some points, we have reported the value of E_w and E_D . The drift field is such that the diffusion is at its minimum. a) The curve refers to the 3-wire chamber; b) the curve refers to the 4-wire chamber.
- Fig. 4 : Track efficiency as a function of gain. A plateau is clearly visible for both chambers.
- Fig. 5 : Efficiency as a function of rate at fixed wire field a) for the 3-wire chamber, b) for the 4-wire chamber.
- Fig. 6 : Chamber gain as a function of particle rate, for different values of the wire field: a) for the 3-wire chamber, b) for the the 4-wire chamber.
- Fig. 7 : a) Spatial resolution as a function of drift distance y for the 3-wire chamber. Rate is the variable parameter. Two effects are clear: the monotonic increase of the low- y point with the particle rate and the equally monotonic increase of the slope of the curve. b) Same as (a), for the 4-wire chamber. Clearly, the worsening of the resolution becomes enormous at high rate.
- Fig. 8 : Average spatial resolution as a function of particle rate for both chambers.

Fig. 1a

Fig. 1b

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8