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Results from the first use of Microstrip Gas Chambers in a High-Energy Physics experiment

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Abstract

The first use of Microstrip Gas Chambers in a High-Energy Physics experiment is described. The forward magnetic spectrometer of NA12 (GAMS) experiment at CERN-SPS has been equipped with 8 planes of microstrip gas chambers for a total of 1100 low-noise analog channels. The detectors have been exposed for 100 days to a high flux proton beam. A 0.2% momentum resolution at 450 GeV/c, a rate capability higher than 5×10^5 /s-mm² and a 9 ns time resolution have been measured.

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1 Introduction

Since its introduction (1,2), the Microstrip Gas Chamber has been considered one of the most promising detector for the instrumentation of the next generation of experiments at high luminosity machines. This is due to very good detector performance, now very close to those of solid state microstrip detector, as well as to simplicity, low-cost and radiation resistance that should be intrinsic to a flushed detector with internal gas amplification. Obviously, prior to any consideration for possible use at the SSC-LHC, all these qualities, together with reliability and long-term survivability, have to be demonstrated not only in the somewhat artificial laboratory environment, but also in the real, hard-life environment of a modern high-energy physics experiment. The aim of this paper is to report on the performance of a medium-scale system of microstrip gas chambers installed in the fixed target experiment NA12 (GAMS), which upgrades the magnetic spectrometer that measures the momentum of the forward scattered beam particles.

2 The microstrip gas chamber

2.1 The technology

The Microstrip Gas Chamber is a gas proportional detector made with microelectronics technology. It can be thought of as a ultra-miniaturized Multiwire Proportional Chamber working at a moderate gas gain ($G \approx 10^4$). The main technological ingredients we have utilized to build it are those typical of silicon processing, i.e., 1) e-beam and U.V. lithography, 2) thin-film deposition and 3) ion implantation. The fabrication of the detector is made of several steps: 1) a 500 μm thick quartz substrate is ion implanted with a dose of 5×10^{16} Boron ions/ cm^2 to reduce the surface resistivity and therefore avoid any charge accumulation on the substrate itself, 2) a 2 μm thick aluminum layer is deposited with a sputtering technique onto the implanted surface, 3) a mask with a suitable pattern of anode and cathode strips is prepared using e-beam lithography, 4) according to the mask pattern, 9 and 70 μm wide anode and cathode strips are engraved, at a pitch of 200 μm , onto the aluminum layer using U.V. lithography and plasma etching. Fig. 1 shows a cross section of the detector. The application of the appropriate potentials on anodes and cathodes creates a proportional gas multiplication field (see Fig.2).

Peculiar to our design are the use of e-beam lithography which is the lithographic technique with the highest accuracy (0.1 μm), the use of an ion implanted quartz substrate which gives the best results in terms of long term stability of gas gain and the use of plasma (dry) etching instead of the more common chemical (wet) etching. The dry technique avoids the under-cut problem and shows a much better uniformity of the strip width (see Fig.3).

The performance of the microstrip gas chambers has been described in detail elsewhere (3,4) and can be summarized as follows: 1) 30 μm (rms) single track resolution, 2) 250 μm two-track

resolution, 3) 11% (fwhm) energy resolution at 6 KeV and, 4) 10^6 particles/s-mm² rate capability.

2.2 The NA12 requirements

NA12 is a fixed target experiment looking for "glueballs" and other exotics within the spectrum of the light neutral mesons which are centrally produced in the exclusive reaction $p+p = p+p+M_0$. M_0 is a neutral particle decaying into a multiphoton final state. The kinematics of this reaction are completely reconstructed using the experiment set-up shown in fig.4. A time of flight system (TOF) measures the momentum of the slow proton recoiling from the liquid hydrogen target, a forward magnetic spectrometer (MWPC_{1,2,3,4}) measures the momentum of the fast leading proton and a cellular electromagnetic calorimeter (GAMS-4000) measures the momentum and energy of the neutral particle produced in the reaction. The bending power of the NA12 spectrometer is 10 Tesla-meter, deflecting 450 GeV/c particles by 7 mr. Because the cross sections for the production of these exotics are rather small, a high intensity proton beam of 450 GeV/c momentum is used. However, with the previous set-up the maximum rate was limited to 10^4 particles/s-mm² by space-charge problems occurring in the standard, 2mm pitch, Multiwire Proportional Chambers of the magnetic spectrometer. As for all spectroscopy experiments, NA12 needs also a good overall energy resolution to study the details of the crowded spectrum of light mesons. A good energy resolution is especially needed when looking for the centrally (i.e. at rest in the C.M. reference system) produced states. In this case, the laboratory energy of the neutral particle and the corresponding energy loss of the fast proton is 10-20 GeV only. With the previous set-up, the energy resolution was limited to 10 GeV with roughly equal contributions from the electromagnetic calorimeter and the magnetic spectrometer. It should be noted that the global electromagnetic calorimeter resolution will substantially improve if the magnetic spectrometer resolution is improved because it is then possible to optimize it using powerful multiparameter, kinematically constrained, fitting procedures for exclusive reactions.

The NA12 collaboration has decided to upgrade the magnetic spectrometer with the goal of improving both the experiment rate capability and the energy resolution for the 1991-1992 runs. The addition to the standard MWPCs of a set of 4 x,y planes of Microstrip Gas Chambers (MicroC_{1,2,3,4}), which have much higher rate capability and much better position resolution and which cover the region of high intensity and low momentum loss, i.e. the region of the beam and its immediate surroundings, fulfills both requirements.

2.3 The NA12 detector

The goals of the detector specifically designed for the NA12 magnetic spectrometer were the operation at high flux and at high momentum (position) resolution together with a first level

triggering capability on charged particle multiplicity and minimum momentum loss. A further constraint was the need to reduce as much as possible the amount of material traversed by the beam to avoid the spoiling of position resolution by multiple scattering.

The active area of the detector was chosen to be 25.6 mm x 25.6 mm, corresponding to 128 anode strips at 200 μm pitch. This area covers the kinematic region of momentum loss between 0 and 90 GeV/c, which is the most important for central production. At higher momentum loss the relative resolution provided by the standard MWPCs is, indeed, more than adequate. Each detector of 128 channels is subdivided into 8 independent subdetectors. This was obtained by grouping together 16 cathode strips (see fig.5). The resulting 8 cathode ORs have a pitch of 3.2 mm and are connected to HV through an individual 1 M Ω resistor. While the anode strips in the group are individually read-out to get the position information, the cathode OR of 16 provides, through a 23 pF decoupling capacitor, a prompt signal to be used for triggering purposes. In case of sparking, the subdivision of the detector also provides much better protection of the thin, fragile, aluminum strips, substantially reducing the overall detector capacity and, therefore, the spark energy.

The detectors were etched on a 4 inch quartz wafer, each containing 4 identical detectors . The individual detector was cut with high precision ($-0+20\ \mu\text{m}$) and placed on a window that has been previously opened on a thin (300 μm) ceramic substrate. The opening window was obtained by cutting the ceramic plate with a high precision laser saw ($\pm 20\ \mu\text{m}$ tolerance). The detector is then microbonded to a gold fan-out printed on the ceramic board. A flexible Kapton printed circuit, glued on the sides of the ceramic board, allows an easy assembling and disassembling of the detector on the read-out board (see fig.6). The overall procedure of alignment of the detector on the ceramic board and of the 8 ceramic boards on the 8 read-out boards should have an accuracy of $\pm 30\ \mu\text{m}$. The read-out boards are mounted in pairs at 90 degrees (x,y) onto a mechanical assembly of three micrometric stages providing a fine adjustment of x,y and angle (see fig. 7).

The detectors we have built for this application are very thin (3 mm overall gas thickness) because they must work in a high flux environment. To avoid pile-up problems the pulse duration has to be less than 100 ns. While the fall-time is set by the electronics shaping time, the pulse rise-time is set, at very short shaping times, by the electron collection time and therefore by the length of the drift space. The gas drift volume is defined by a spacer made of machinable glass ceramic (Macor) and by an entrance cathode window made with a very thin (300 μm) ceramic plate whose internal surface was coated with a gold film. The full detector assembly is thus made with very clean materials (glass,ceramics,gold). The overall amount of material added by the 8 detector planes is 7% of a radiation length. This should be compared with 11% provided by 30 meters of air and by 5% provided by the beam counters. The multiple scattering from all this material contributes with 7 μr to the system angular resolution, setting a lower limit of 0.1% to the momentum resolution .

The gas mixture we have used is Xe (60) -DME (40), flushed at very low rate (1 bubble per plane every 4 s). The overall Xenon consumption is less than 1 l/hour. This gas mixture was chosen for its high primary ionization density, needed to provide full efficiency for a thin detector, and for its sufficiently high drift velocity when the detector is operated with a high drift field (8 kV/cm). Another important feature of this gas mixture is its immunity from aging when used in conjunction with clean materials (5).

3 The read-out electronics

The position information is obtained from the measurement of the centroid of the anode charge distribution. The signal read-out chain is a fast, low-noise, hybrid preamplifier mounted on the detector board, followed by a remote shaping amplifier and 12 bit ADC for each individual channel (see fig.8). The overall system counts 1088 analog channels (1024 anode strips+64 cathode OR).

Because the individual channel is designed to work in the MHz range, the detector signal has to be fast shaped (see fig.9). The delta current response of the analog chain shows 10 ns rise-time and 30 ns width. The response to the detector current after a charged particle crossing has 30 ns rise-time, completely determined by the electron collection time. The equivalent noise charge of the preamplifier has been measured to be $1500\ e^-$ for 10 pF input capacity.

4 The spectrometer performance

During the 1991 run, NA12 has usually taken data with a beam intensity of 2.5×10^6 protons/burst. This beam has a size of 8mm x 8 mm (fwhm). For test purposes a high intensity (5×10^6 protons/burst) narrow beam of 2mm x 2mm size has also been used. These latter conditions will be adopted during the 1992 run. Fig.10 and fig.11 show the profiles of these two beams as reconstructed by the Microstrip Gas Chambers and by the MWPCs. It should be noticed that the whole narrow beam was essentially collected by only one wire of the MWPCs and that their detection efficiency dropped to less than 50%, while the Microstrip Gas Chambers retained full efficiency as it is clearly demonstrated by the shape of the Landau energy-loss distribution (see fig.12). Fig.13 shows the distribution of the difference between the coordinate measured by the Microstrip Gas Chamber and that measured by the MWPC immediately behind it. It is the difference between events belonging to a narrow gaussian distribution and to a wide rectangular distribution, respectively. The result is the fully rectangular distribution typical of the digital response of the MWPC, clearly indicating the difference of scale between the resolutions of the two systems. A residual modulation with a 200 μ m pitch is due to the 40% of events in the Microstrip Chambers which have only one anode strip hit. With the present set-up it is not possible to measure directly the position resolution because we do not have an independent, high

resolution, position measuring system. Nevertheless, the position and angular (momentum) resolution can be indirectly evaluated measuring the distribution XINT of the distance between the intersections of the incoming and outgoing straight lines with the magnet middle plane. Indeed, it is possible, using simple formulas from the error propagation theory, to derive, for our geometry, the relation $\sigma_{\text{xint}} = 2.7 \times \sigma_{\text{point}}$. Fig.14 shows the two XINT distributions measured with the Microstrips and with the MWPCs. From these data we evaluate the single point resolution as $50 \mu\text{m}$ and the overall angular resolution as $14 \mu\text{r}$ (0.2%) , with a significant contribution coming from multiple scattering and alignment precision. Fig.15 shows the distribution of the momenta of non interacting particles (i.e. of the beam) as measured by the Microstrip Gas Chambers (top) and by the MWPCs (bottom) .The RMS resolution , including beam dispersion, field non-homogeneity, etc., improves from 7 GeV to 1.16 GeV. This improvement is fully compatible with the angular resolution (i.e. position resolution and lever arm) of the two systems. The asymmetric shape of the momentum distribution measured with the MWPCs is due to their discrete, not interpolating, position response function. A significant resolution gain is visible also in the spectrum of the sum of the energy of the centrally produced neutral particle and of the forward proton, as reconstructed by the electromagnetic calorimeter and by the magnetic spectrometer, respectively, (see fig.16). The line width depends now only on the electromagnetic calorimeter resolution for which the kinematically constrained fitting procedure was not applied yet. The improvement of the energy resolution translates in a more effective background rejection and, finally, in a mass resolution improvement. Fig.17 shows the resolution of the reconstructed mass of the π_0 meson decaying in two photons as obtained by the on-line monitoring program with the new technique (top) and with the MWPCs (bottom). All these results may be considered, in practice, as upper limits because the system has still to be calibrated and no use has been made, up to now, of the matching information from the standard chambers.

As a by-product, during the same run we have also measured for the first time the Microstrip Gas Chamber time resolution. The coincidence of a set of beam counters started a TDC which was stopped by a Constant Fraction discriminated signal from one of the cathode OR. For this measurement we have used two kinds of gas mixtures, the standard Xe (60)-DME (40) and the faster Xe (50)-DME (25)-CO₂ (25). Fig.18 shows the corresponding arrival time distributions . The root mean square was 11 ns and 9 ns for the slower and faster gas mixture, respectively. The resolution is, probably, limited by the OR signal-to-noise ratio which is 4 time worst than for the individual anode read-out. The intrinsic time resolution should be, therefore, substantially better. In our experimental conditions, the detector memory, i.e., the gate width requested by the two gas mixtures for full detection efficiency , can be estimated from fig.18 to be 55 and 45 ns, respectively.

4 Conclusion

The first operation of a medium-scale system of Microstrip Gas Chambers as key component of a modern High Energy Physics experiment is going well. The system worked smoothly and quietly since the beginning, providing the expected performance. After more than two months of operation in a high intensity beam no sign of deterioration has appeared. The overall number of dead channels is less than 1% of the total and is partially due to cable or electronics problems. During the 1992 run the beam flux will be increased to 10^6 particles/s·mm², which, together with the factor 5 improvement of momentum resolution, represents a major contribution to the upgrade of NA12.

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Figure captions

Fig.1) A cross section of the detector.

Fig.2) The field-line map within one detector cell.

Fig.3) The anode strip obtained with the wet etching technique (top) and with the dry etching technique (bottom). In the case of wet etching , the strip width non-uniformity is clearly visible.

Fig.4) The NA12 experimental set-up.

Fig.5) A detail of one side of the detector along the strips , showing the cathode grouping and the pads for the individual anode read-out.

Fig.6) The complete detector mounted on its ceramic board.

Fig.7) The detector couple providing x, y projections mounted on the front and back side of the electronics board (top and bottom , respectively).

Fig.8) Schematics of the read-out system.

Fig.9) The single-shot response of the analog chain to 220 e^- from ^{55}Fe X-rays (upper trace), and the amplifier noise amplitude (lower trace). The S/N ratio is 100 .

Fig.10) The narrow-beam profile as reconstructed by the Microstrip Gas Chambers (top) and by the MWPCs (bottom).

Fig.11) The same of fig.10, but for the wide-beam.

Fig.12) The Landau energy-loss distribution obtained with the Microstrip Gas Chambers when working with the narrow-beam.

Fig.13) The distribution of the difference between the coordinate measured by the Microstrip Gas Chamber and that measured by the MWPC immediately behind it.

Fig.14) The XINT distribution for the Microstrips (top) and for the MWPCs (bottom).

Fig.15) The beam momentum distribution as obtained with the Microstrip Gas Chambers (top) and with the MWPCs(bottom).

Fig.16) The spectrum of the sum of the energy seen in the electromagnetic calorimeter with the energy of the leading proton .

Fig.17) The very preliminary distribution of the π_0 mass as reconstructed with the Microstrip Gas Chambers (top) and with the MWPCs (bottom). Only a very limited data sample has been used (one raw-data tape).

Fig.18) The arrival time distributions of the signal from one cathode OR for the Xe (60) - DME (40) gas mixture (top) and for the Xe (50) - DME (25) - CO₂ (25) gas mixture (bottom). The start is provided by a coincidence of beam counters.

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Fig.4)

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Fig.7)

Fig.8)

CH1 100mVΩ A 20ns -75.0mV VERT
CH2 20mVΩ

Fig.9)

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Fig.17)

Fig.18)