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High resolution micro-pattern gaseous tracking detectors

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Micro-strip gas chambers have excellent localization properties, high rate capability and good granularity, and have been adopted for may experimental set-ups. Two recurrent problems hower have been reported: slow degradation under sustained irradiation, and damaging accidental discharges. New breeds of detectors aim at improving on these crucial points; CAT, micromegas, gas electron multiplier are examples. Very performing, they are more robust and reliable. Two-stage devices, making use of a gas electron multiplier as first element, permit to sustain larger gains in presence of high rates and heavily ionizing tracks.

1. MICROSTRIP GAS CHAMBER

Micro-strip gas chambers (MSGC), introduced in 1998 [1], largely improved on resolution and rate capability over devices based on multi-wire chambers. A MSGC consists of alternating thin anodes and cathode strips, engraved on an insulating support, at a pitch of a few hundred microns (Fig. 1). With suitable potentials applied, electrons released by ionization in an overlaying gas layer drift to the anodes, where avalanche multiplication and detection occur. With optimized choices of geometry, substrate materials and gas fillings, very good performances can be achieved: localization accuracy around 40 µm, two-track resolution of 500 µm, and a rate capability exceeding 10^6 mm^{-2}s^{-1} [2]. Fig. 2 shows, for a MSGC operated in typical conditions, and as a function of voltage, the proportional gain and the efficiency in the detection of minimum ionizing particles [3]. Full efficiency is attained at proportional gains above 2000.

Long-term studies have revealed however a slow degradation of performances, attributed to discharges induced by the release in the gas of large ionization trails [4]. Discharge processes have been studied in the laboratory making use of alpha-emitters, such as ^{220}Rn, added in the gas flow. The dashed curve in Fig. 2 shows the observed discharge probability as a function of voltage [5]. In these conditions, full efficiency cannot be reached before discharges set in.

Another source of degradation during long-term irradiation is the slow formation of polymers in the avalanches. MSGCs are particularly prone to aging because of the small electrode area; minute amounts (few ppm) of organic pollutants released by materials or in the gas flow strongly affect the detector lifetime. Systematic investigations of aging have been performed using plates manufactured on different substrates and in various operating conditions. With proper choice of the component materials and gas fillings, and in optimal laboratory conditions, a long-term survival up to a collected charge above 100 mC per cm of strip (corresponding to ten years of operation at LHC) has been demonstrated [6].

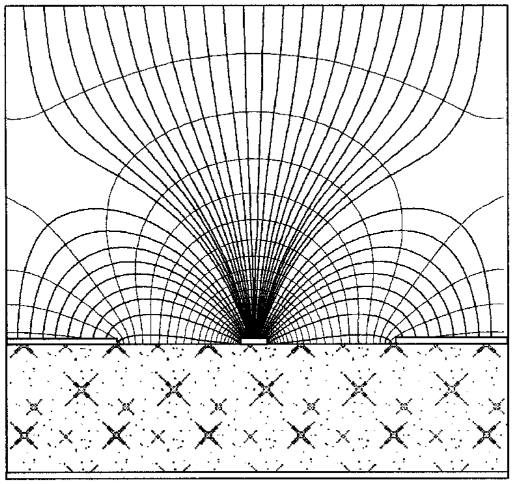

Fig. 1: Schematics and electric field in the MSGC

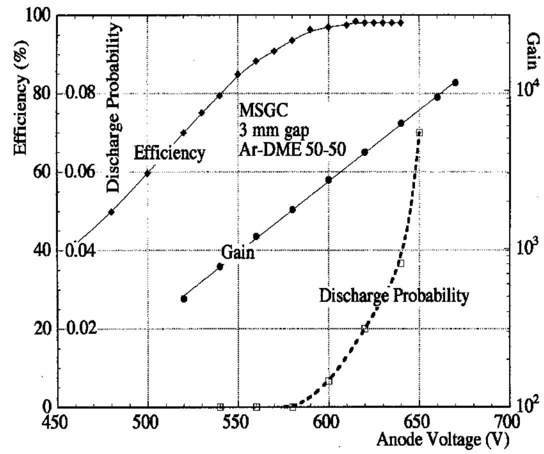

Fig. 2: Gain, efficiency for MIPs and discharge rate on alphas for the MSGC

2. ALTERNATIVE MICRO-PATTTERN DETECTORS

Innovative detector designs have been developed recently, with very promising performances and higher reliability. Micromegas, a thin-gap parallel plate counter, is shown schematically in Fig. 3 [7]. It consists of a thin metal mesh, stretched above a readout electrode, at a distance of 50 to 100 µm. Regularly spaced supports (insulating fibers or pillars) guarantee the uniformity of the gap. A high field is applied across the multiplying gap, and electrons released in the upper drift region are collected and multiplied. Operation at very high particle fluxes has been demonstrated, with good efficiency plateaus for minimum ionizing particles [8].

Another very interesting device is the so-called "Compteur à Trous" or CAT [9, 10]. It consists of a matrix of holes, drilled through a metallic foil with an anode at the bottom (Fig. 4). Proportional gains up to 10^4 and good energy resolution have been demonstrated. The detected signal has a fast electron and a slower ion component, whose length depends on the gap (several µs for one mm). Several variations of the CAT structure have been described, with multiple holes and an insulator plate between anode and cathode in order to improve the mechanical stability and easy the construction [11].

Recent measurements show that both structures, similarly to the MSGC, exhibit a fast increasing discharge rate with voltage when subjected to to high rates or highly ionizing alpha particles [5]. They have therefore a similar limitation in gain, although the sturdier construction prevents permanent damages to the electrodes under repeated discharges.

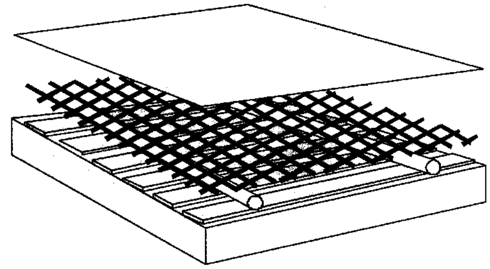

Fig. 3: Schematics of the micromegas

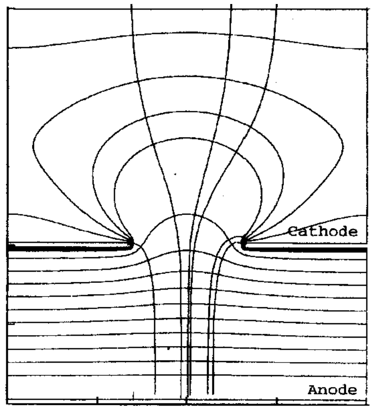

Fig. 4: Electric field in the CAT detector

3. THE GAS ELECTRON MULTIPLIER

The Gas Electron Multiplier (GEM) is a thin insulating foil, metal-clad on both sides and perforated by a regular matrix of holes (50 to 100 mm^{-2}) [12]. Upon application of a difference of potential, a high dipole field develops in the holes and multiplies electrons released by ionization in the gas and drifting in the high field through the open channels (Fig. 5). Mounted in front of a MSGC, the device pre-amplifies ionization electrons, thus permitting to obtainin higher overall gains. Alternatively, given the total gain, the voltage on the MSGC can be considerably reduced improving its reliability. This solution has been adopted for the tracker in the HERA-B experiment, originally making use of large area MSGCs and confronted with serious discharge problems [13]. The detectors operate satisfactorily in a wide range of gases, including convenient, non-flammable mixtures of argon and carbon dioxide. Systematic studies of amplification as a function of geometry show that gains above 10^4 can be attained with a single GEM, and above 10^5 in a double GEM device. A simple printed circuit board can be used for detection; bi-dimensional localization can be achieved using a double-sided circuit as read-out element [14].

Sharing the gain between two elements results in a large improvement of the tolerance of the detector to high ionization losses. Exposed to heavily ionizing alphas, a double GEM detector can be operated at gains above 10^4 without discharges, an order of magnitude higher that single devices, see Fig. 6 [5].

The simplicity, and ruggedness of the GEM detectors make them attractive for large experiments and as X-ray position sensitive devices. The controlled electrical transparency, with a reduced optical transparency, together with the observation of high gain in pure noble gases [15], suggests the possibility of using one or more GEM meshes in cascade for the detection of electrons produced on solid photocathodes, for example CsI as used for Cherenkov ring imaging.

The possibility of using a reverse photocathode geometry, with the photosensitive material deposited directly on one of the GEM electrodes, is also being investigated [16]. Another interesting prospect, presently under study in several groups, is to deploy a set of GEM modules as read-out elements for time projection chambers. Advantages in this case are the large intrinsic ion feedback supppression, a much improved two-track resolution and a higher rate capability.

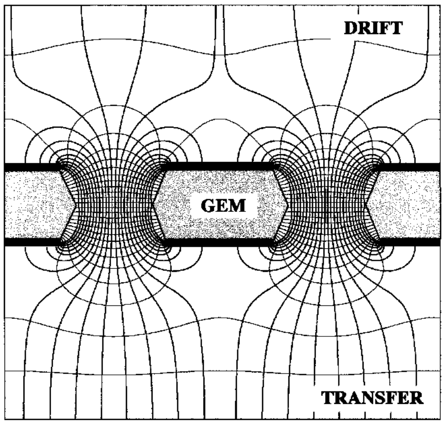

Fig. 5: Structure and fields in the gas electron multiplier

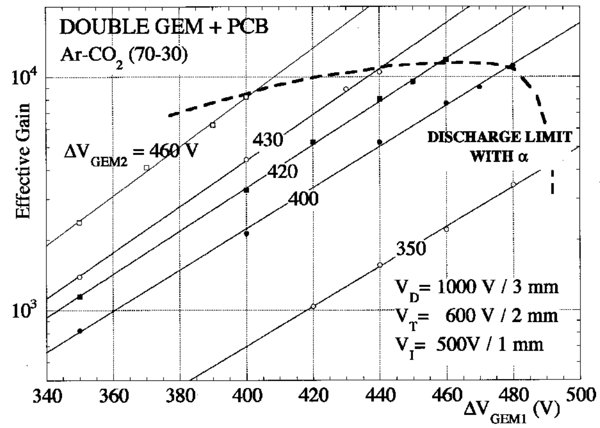

Fig. 6: Alpha discharge limit in the double GEM

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