Recent developments in gas tracking detectors for high luminosities

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Abstract: With the high luminosities of upcoming colliders, the frontiers of present generation gas tracking detectors have been pushed, resulting in a large number of innovations in their design, technology and readout systems of which I will discuss some examples. The ATLAS muon spectrometer despite comprising ‘simple’ proportional tubes, has been extensively studied to better understand and optimize its performance inclusive of the front-end electronics. The MicroStrip Gas Chambers have come long way since their introduction, their spin-offs being Micro-Gap Chambers and the MICRODOT chambers which are described. The introduction of a novel device called the Gas Electron Multiplier GEM, seems promising, and is being considered by HERA-B for improved reliability.

1 Introduction

The demanding challenges of LHC and high luminosity B-factories, have brought about impressive new developments in tracking detectors. In this paper, some of the progress will be reviewed. The Monitored Drift Tube (MDT) system of the muon spectrometer of the ATLAS detector consists of a large number ($\sim 7.10^4$) of proportional counters which have been exhaustively investigated for detector performance and large system aspects. The developments on MicroStrip gas chambers (MSGCs) in preparation of the CMS tracker for example, will be described. The MICRO-Mesh Gaseous Structure (MICROMEAS) has the advantages of being a robust, highly granular and a highly rate detector. Recent developments of the novel Gas Electron Multiplier GEM, which can improve detector reliability for operation in a high rate environment when coupled with a readout element either the MSGC, or simply a printed circuit, are discussed. Detectors for UV-photons, imaging and RICH applications have been developed as MICRO-DOT detectors on silicon wafers, and some recent results will be described.

2 Muon Detection

For the ATLAS Muon spectrometer, aluminum proportional tubes with 3 cm diameter, and lengths ranging from 70 cm to 630 cm, have been designed to operate at high rates with acceptable ageing properties. Assembly includes several layers with measurement accuracies commensurate with the physics requirements giving momentum resolutions $\partial p/p \sim 10^{-4}$ p/GeV. Details of large system aspects may be found in refs. [1, 2]. The operating gas mixture has been optimized for a linear space-time relation, and a large effort has been invested in understanding the detector physics and response of the front-end electronics. Large progress has also been made in the field of simulating detector performance. For the resolution and full chain studies, some of the following software packages have been used.

MAGBOLTZ [3, 4] is a program optimized to compute gas transport parameters, and has been incorporated into GARFIELD [5], which is by now a popular drift chamber simulation program including HEED [6] for energy loss, gas gain and gain variation with a Polya distribution for cylindrical geometry. The limitation here is the simulation of odd shaped electrodes with wires, and no possibility to include insulators, which as shown in the next section, are necessary for several applications. This is made feasible by commercial programs like MAXWELL [7] and MAFIA [8]. The front end electronics may be simulated with PSPICE [9].

Fig. 1 shows the linear space-time correlation of the drift tube, the maximum drift time is 500 ns, the gas mixture being (Ar/N₂/CH₄ 91:4:5). The positive ions have a drift time of 4 to 5 μ s which

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constrains the operation at high rates in some regions [2]. Pulse-shapes recorded with a digital scope were compared to GARFIELD+SPICE simulated signals. The simulation of resolution was corroborated by test-beam results. After getting confidence in the measurements, a scan over front-end parameters like preamplifier peaking time, filter constants and threshold settings was performed in order to optimize resolution, hit rate, trailing edge resolution and dead time. Resolution improvement by performing a time slewing correction with a double threshold discriminator or a leading edge charge measurement was studied. Fig. 2 from [10] shows the resolution, measured and simulated, as a function of drift distance for a single threshold, leading edge charge corrected and a double threshold corrected signal with a peaking time of 15 ns. Resolution is good for low threshold, but threshold is limited by noise; one could increase the gain but that is a sensitive parameter leading to ageing. Resolution has also been found to be better for fast (peaking times of 10 ns) preamps, which dictates the choice of CMOS technology [1].

Fig.1

Fig. 2

3 CENTRAL TRACKING DETECTORS

MicroStrip gas chambers have been introduced in 1988 by Oed [11], comprising glass or plastic substrates few hundred μm thick with metal anode and cathode strips patterned on its surface using micro-photolithography. A drift plane placed a few mm away from this surface defines the active area and delimits the gas volume. By applying appropriate potentials on the electrodes this detector has been demonstrated to be capable of high rates ($\sim 10^6 \text{ Hz/mm}^2$), with position resolutions of $< 40 \mu\text{m}$ and fully efficient for minimum ionizing particles [12, 13]. Long term stable operation has been demonstrated in clean conditions by several groups [14-17] while severe ageing was observed in other cases with different metalizations and operating conditions [18]. In view of the sizes required for the tracking volumes, large areas (27cm x25 cm) have been manufactured [19]. Performances in magnetic fields up to 2.3 T have been verified with good spatial accuracies [20, 21].

Due to the deposition of ions from the avalanche on the substrate between the anodes and the cathodes, a rate dependent gain drop was observed. This was overcome by using either an electron-conducting substrate [22-26] or a resistive over- or under-coat on the substrate [27, 28]. The diamond-like coating [29] completely eliminates the gain loss at high rates as shown in fig. 3 from ref. [28]. Several other kinds of coatings have also been investigated [30, 31], the electron-conducting glass being difficult to produce technologically. Fig. 4 shows a comparison of the behaviour of MSGCs with some such coatings with surface resistivities of the order of $10^{14} - 10^{15} \Omega/\square$ from ref. [30]. Comparing the electric field in the case of an insulating substrate and a substrate with a thin resistive coating, it was seen that this field is higher along the surface of the insulator in the latter case. Another observation from studying the electric field is that avalanches originating from the region close to the edges of the cathodes have a gain ten times higher than those coming from the rest of the active volume [32, 33]. This has led to the hypothesis that in the presence of a heavily ionizing particle (few 100 keV of

Fig. 3

Fig. 4

energy loss compared to few keV of minimum ionizing particles) avalanches that originate close to the edges of cathodes transform into streamers, which due to the higher field along the surface lead to gliding discharges between anodes and cathodes [34] damaging their edges, resulting in yet higher field and thus larger gains from neighboring channels. A large effort has also gone in the understanding of these effects [25, 34-36] and several techniques have been proposed to overcome this problem; some authors [37] have proposed to passivate the edges of the cathode strips by an insulating polyimide, which would prevent the onset of Malter effect at the cathode edges. This concept has been extended in ref. [38, 39] and [40] passivating all along the edges of the cathodes in the inter-electrode space. This technique permits the increase of the efficient working potentials on the MSGC, and reduces the probability of discharges as reported in [41, 42].

A novel technique for operation at high rates is afforded by the MICROMEAS detector [43]. It consists of a fine mesh kept at $\sim 100 \mu\text{m}$ from the read-out plane by polyimide spacer pillars and separated from the drift (conversion) plane by a few mm; held at a high potential, it provides a high multiplication field. With a large ratio of amplification to conversion field this mesh is fully transparent and the detector operates with large gains $\sim 10^4$. Long term stable operation, good spatial resolutions and operation in magnetic field have still to be demonstrated.

The novel self supporting Gas Electron Multiplier (GEM) was proposed in ref. [44]; this detector element has the specific feature that it subdivides the gain of a critically operating detector into several sub-critical parts, thus easing the operation [45]. It consists of a polyimide (Kapton) foil metallized on both sides, with through holes of $80\text{-}100 \mu\text{m}$ in diameter and $140\text{-}200 \mu\text{m}$ pitch. With the drift plane a few mm away and appropriate voltages applied, coupled with an MSGC as shown in fig. 5 [45], the GEM provides pre-amplification (PA) factors upto ~ 100 . Operating the GEM say at a PA factor of 30, and the MSGC at a gain of 100 (see fig. 6), implies a total gain of 3000, and the operation of the MSGC at a much lower voltage, thus eliminating the problem of discharges [46]. The combined detector works at full efficiency for minimum ionizing particles with a much longer plateau. Spatial resolution has been measured in a cosmic ray hodoscope as shown by fig. 7 [47] to be better than $30 \mu\text{m}$. In another test with minimum ionizing particles full efficiency, timing, and spatial resolution have been measured with a GEM and an MSGC [48]. Higher PA factors are demonstrated with thicker GEMs and operation in a magnetic field of $\sim 1 \text{ T}$ has been demonstrated without any effect on the gain. Several large sizes of GEMs ($27 \times 25 \text{ cm}^2$) are built for the high rate HERA-B tracker and are operational at PA factors of ~ 30 [49].

Fig. 5

Fig. 6

Employing two GEMs in cascade coupled with a Micro-Gap Chamber [50] Seguinot and Ypsilantis have shown a high pressure operation with detector gains $\sim 10^5$, suited for single photoelectron detection; see fig. 8 [51]. On the other hand Breskin et al [52] have demonstrated (see fig. 9) the high gain operation of the GEM at low pressure with sensitive photocathodes for UV and visible light detection. The photocathodes are protected since ions no longer recede towards it, due to the special GEM geometry, thus increasing their longevity.

Fig. 7

Fig. 8

4 Gas Pixel Detectors

As a spin off from the MSGC design and technology, the Micro-Dot Gas Avalanche Detector introduced by Biagi [53] consists of anode dots surrounded by cathode rings on a silicon wafer on which a layer of oxide has been deposited to maintain a 'safe' distance from the cathodes. With a gas delimiting drift plane and appropriate voltages applied, this detector is conceptually a true pixel device. Small sizes have been operational. A floating cathode 'ring' was introduced in order to defocus the electric field from the buried anode bus. Large gains $\sim 10^4$ have been reported [54] while charging up and ageing studies are still in progress. Coating the drift electrode with a photosensitive layer, one can operate this device both in a parallel plate mode or a gas avalanche mode with preamplification in the drift region and multiplication at the MICRODOT [55] giving very high gains $10^5 - 10^7$ as shown in fig. 11 at low pressure. Very fast single electron pulses are obtained with rise times of ~ 3 ns with propane as filling gas at low pressure. One can avoid the floating rings by coating the surface with a low resistance overlayer as shown in a variation called the MICRO SQUARE detector [56]. The advantage of the MICRO-DOT detectors is that

the field close to the cathodes is not as high as encountered in MSGCs; if one 'dot' discharges the effective working area lost is one pixel. Nevertheless large areas and single pixel read-out are still difficult to be obtained by this technology.

Fig. 9

Fig. 10

5 SUMMARY AND OUTLOOK

For the ATLAS Muon detectors, the MDTs are well understood in terms of space-time relationship, efficiency and simulations of resolution corroborated by measurements. The choice of gas mixture is pending for ongoing studies on ageing, since larger gain and hence better signal/noise work in the opposite direction. The problems relating to the performance of MSGCs in high rate environments in the presence of highly ionizing particles have led to several new developments namely the MICROMEAS and the GEM detectors. Stable operation, large areas, full efficiencies, high rate capabilities, operation in magnetic field without gain loss and good spatial resolutions have been reported for the GEM. Long term operation is still an open issue. In conjunction with UV and visible photocathodes MICRODOT detectors have been shown to operate stably with high gains at low pressure, with very fast signals. Addition of the GEM protects the sensitive photocathodes from ion/photon feedback increasing their lifetime. Despite impressive progress, this exciting field has still some work to be done for successful charged particle detection at high luminosities.

References

- [1] ATLAS MUON Collaboration, CERN/LHCC 97-22 (1977)
- [2] Y. Hasegawa, Proc. International Conference on High Energy Physics, Jerusalem, Israel (1997)
- [3] S.F. Biagi, Nucl. Instrum. Methods **A 283** (1989) 716
- [4] S.F. Biagi, *MAGBOLTZ*, 1994
- [5] R.Veenhof, *GARFIELD*, 1996, CERN, also <http://wwwcn.cern.ch/writeup/gas/examples/trans2000.html>
- [6] I. Smirnov, <http://wwwcn.cern.ch/writeup/heed>
- [7] Simulation Program, *MAXWELL 2D and 3D Parameter Extractor*, 1994, Ansoft Corporation: Pittsburgh, PA
- [8] Simulation Program, *MAFIA*, CST GmbH, Darmstadt, Germany
- [9] Simulation Program, *PSICE*, MicroSim Corporation
- [10] W. Riegler, CERN-ATLAS MUON-NO137 and 173 (1997)
- [11] A. Oed, Nucl. Instrum. Methods **A263** (1988) 351
- [12] Proc. International Workshop on Micro-Strip Gas Chambers, Legnaro, Italy, (1994)
- [13] Proc. Int. Workshop on Micro-Strip Gas Chambers, Lyon (1995)

- [14] F. Angelini *et al.*, Nucl. Instr. and Meth. **A 382** (1996) 461-469
- [15] R. Bouclier *et al.*, Proc. Int. Conf. on Micro-Strip Gas Chambers (Legnaro, 1994), 48
- [16] R. Bouclier *et al.*, Proc. Int. Workshop on Micro-Strip Gas Chambers (Lyon, 1995)
- [17] R. Bouclier *et al.*, CERN- CMS Note CMS-TN 96-018 (1996)
- [18] NIKHEF/HERMES, 1996
- [19] *At Heidelberg for the HERA-B experiment at DESY*, 1996
- [20] F. Angelini *et al.*, Nucl. Instrum. Methods **A343** (1994) 441
- [21] F. Angelini *et al.*, CERN-CMS TN 94-136 (1994)
- [22] G.D. Minakov *et al.*, Nucl. Instrum. Methods **A326** (1993) 566
- [23] N. Lumb *et al.*, Proc. Int. Workshop on Micro-Strip Gas Chambers (Lyon, 1996) 291
- [24] V. Grishkevich *et al.*, ATLAS Int. Note INDET-NO-064 (1994)
- [25] J.P. Duerdoth *et al.*, Proc. Int. Workshop on Micro-Strip Gas Chambers (Lyon, 1995)
- [26] L. Alunni *et al.*, Nucl. Instrum. Methods **A348** (1994) 344
- [27] R. Bouclier *et al.*, Nucl. Instrum. Methods **367** (1995) 168
- [28] R. Bouclier *et al.*, Nucl. Instrum. Methods **A 369** (1995) 328
- [29] *Diamond-like coating done by SURMET Corp.* Burlington MA, USA
- [30] Private Com. J.M. Brom *et al.* (1997)
- [31] S. Brons *et al.*, Nucl. Instrum. Methods **A342** (1994) 411
- [32] J.J. Florent *et al.*, Nucl. Instrum. Methods **A329** (1993) 125
- [33] R. Bouclier *et al.*, Nucl. Instrum. Methods **A367** (1995) 163
- [34] V. Peskov *et al.*, (Proceedings, Manchester, 1996)
- [35] B. Boimska *et al.*, CERN-PPE/96-201, see also Proceedings of the 5th International Conference on Advanced Technology and Particle Physics, Villa Olmo, Como (1996)
- [36] M.R. Bishai *et al.*, Proc. Int. Conf. on Micro-Strip Gas Chambers, Legnaro, (1994)
- [37] T. Tanimori, Nucl. Instr. and Meth. **A381** (1992) 280
- [38] V. Hlinka *et al.*, Comenius Univ. Preprint (1993)
- [39] Hlinka, Nucl. Instr. and Meth. **A365** (1995) 54-58
- [40] R. Bellazzini, CMS Document 1996-146 (1996)
- [41] G. Davies, Proc. EPS-HEP 97 (Jerusalem, 1997)
- [42] A. Caner, Proc. Frontier Detectors for Frontier Physics, Isola d'Elba, May 25-31, 1997
- [43] Y. Giomataris, DSM DAPNIA/SED 95-04, CERN/LHC/96-04 May 1996
- [44] F. Sauli, Nucl. Instr. and Meth. **A 386** (1996) 531-534
- [45] R. Bouclier, CERN-PPE 97-32, 97-73 (1997)
- [46] F. Sauli, Proc. Frontier Detectors for Frontier Physics (Isola d'Elba, 1997)
- [47] W.V. Doninck *et al.*, *GEM and MSGC, Results obtained in the cosmic hodoscope* (1997), Private Com.
- [48] F. Sauli, *Beam Tests with GEMs*, Private Com. Aug-1997
- [49] F. Sauli and B. Schmidt for HERA-B Collaboration at DESY Private Com., July 1997
- [50] F. Angelini *et al.*, Nucl. Instrum. Methods **A335** (1993) 69
- [51] J. Seguinot and T. Ypsilantis, Nucl. Instr. and Meth. To Appear (1997)
- [52] A. Breskin, *Low Pressure Operation of GEM*, 1997, Private Com.
- [53] S.F. Biagi *et al.*, Nucl. Instrum. Methods **A361** (1995) 72
- [54] S.F. Biagi, (Manchester, 1996)
- [55] A. Breskin, WIS-96/45/Nov.-PH (1996)
- [56] W.S. Hong, Proc. IEEE-96 (1996).