The MSGC-GEM Inner Tracker for HERA-B

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Abstract

The HERA-B Inner Tracker system, which is build by groups from the universities of Heidelberg, Siegen and Zürich consists of 184 detectors. The detectors are composed of Microstrip Gas Chambers (MSGC) with a pre-amplifying device in the gas volume, the Gas Electron Multiplier (GEM). The complete system of 140k analog and 10k trigger channels will be installed in HERA-B during this year.

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1 Introduction

HERA-B is a new experiment at the HERA storage ring (DESY) dedicated to measure CP violation in the neutral B system [1]. It is now in its commissioning phase. The primary goal of this experiment is to measure $\sin(2\beta)$ in the decay $B^0 \rightarrow J/\Psi K_s^0$. Using an internal wire target in the HERA proton ring $B\overline{B}$ pairs are produced by collisions of the protons (920GeV) with the target wires. The cross-section per nucleon for $b\overline{b}$ production in comparison to normal inelastic scattering is in the order of 10^{-6}. Due to small branching ratios in the golden channel and losses due to trigger and reconstruction efficiencies the overall ratio of signal to background is of the order of 10^{-12}. To acquire about 1000 signal decays per year HERA-B has to operate with an extremely high interaction rate of 40MHz, leading to 4-5 superimposed events per bunch crossing (96ns) and a large number of charged tracks (O(100)) in the detector.

Due to the strongly forward oriented kinematics the detector is build as a forward magnet spectrometer covering polar angles varying from 10 to 200mrad (see Fig. 1).

One of the challenging components of this spectrometer is the tracking system. It has to be able to cope with the extremely high particle fluxes and high radiation doses which are comparable to LHC conditions. Because of a strong radial dependence of the particle flux on the distance to the beam pipe, different granularities for the tracking detectors had to be chosen to keep occupancies at a reasonable level. The different granularities were achieved by choosing different technologies for the inner and outer tracking region. MSGC-GEM detectors will be used in the inner region (Inner Tracker) to cover the distance between 6cm and 30cm (10mrad$\leq$R$\leq$100mrad) around the beam pipe. The outer region is covered by honeycomb drift chambers. The Outer Tracking system is described in detail elsewhere in these proceedings [2].

1.1 The Inner Tracking System

The Inner Tracking system consists of 184 detectors with about 140000 analog readout channels and is distributed to ten detector stations along the beam pipe. Each station consists of several detector layers with four independent L-shaped detectors per layer which overlap in the sensitive regions in order to cover the full area (see Fig. 2). Some of the detector stations are located in a magnetic field ($B_{max} \approx 0.85$T).

The requirements for the Inner tracking detectors are

- a spatial resolution better than 100 μm in the bending plane (x), and better than 1mm in the vertical direction (y),
- a single layer efficiency better than 95 % resulting in a trigger efficiency of >99 % for a double layer,
- a rate capability of 10^4 minimum ionizing particles per mm$^2 s^1$,
- an occupancy $\leq 5\%$, with a bunch crossing of 96ns,
- to survive a maximum radiation dose of 1Mrad/year.

Tracking is performed by using three stereo orientations: vertical strips (0 degree) and strips with ± 5 degree orientation. The Inner Tracker will be used in the first level trigger. All trigger chambers are build of double layers with the same anode orientation. One trigger channel consists of the hard wired 'OR' of four neighboring analog channels. The Inner Tracker has a total of 9984 trigger channels.

The Inner Tracker and especially the used detectors will be presented in this paper. Starting with a brief history of the MSGC development for HERA-B, the present design of MSGC+GEM detectors which are currently installed will be presented. Special emphasis will be put on the performance of this device and possible problems related to high radiation doses and particle fluxes.

2 MSGC, MSGC-GEM

Not the whole R&D activities can be repeated here in all details (for further information see [3,4,5,6,10]).

At the beginning of the development for HERA-B all investigations were concentrated on a MSGC solution which had shown excellent rate capabilities and survived high doses in X-ray tests. All results gained during extensive X-ray studies with smaller sized prototype detectors showed that a MSGC with electronically conducting surface coating ($R_s \approx 10^{14}$-$10^{15} \frac{\Omega}{\Box}$) has a stable gain up to rates above 10^5 particles per mm^{2}s^1. No gas ageing was observed up to several Mrad accumulated dose comparable to several years of HERA-B operation. The preferred solution for HERA-B based on these investigations was an alkali-free glass plate coated with an amorphous carbon coating ('diamond like coating', a-Si-C:H:N) and a gold strip pattern.

In 1996 we learned that these standard MSGCs are quickly destroyed in hadronic environments. In the presence of highly ionizing particles (hips) discharge limits are drastically reduced. At normal operation voltages which are not dangerous in X-rays, in the presence of hips discharges occur between anodes and cathodes which destroy the electrode structure on the MSGC. Our investigations show that the use of standard MSGCs in the HERA-B environment is excluded.

The solution to the sparking problems was the introduction of a second amplifying element in the MSGC, the gas electron multiplier (GEM) foil [7]. This foil is introduced in the driftspace providing a first amplification step, to allow a reduction of the gas amplification at the MSGC stage, so that the MSGC can be operated in a safe regime at the same overall gain of the coupled device.

3 Detector description

As described before, the microstrip gas detector consists of a glass plate coated by a chemical vapor deposition method[2] with an amorphous carbon coating ('diamond like coating', a-Si-C:H:N). The surface resistivity of this coating is in the range of 10^{14}-$10^{15}\frac{\Omega}{\Box}$ and it has a thickness of 60nm. On this coated glass plate a strip pattern is produced by a lift-off technique[3]. This structure consists of 10μm wide anodes and 170μm wide cathode strips with a gap of 60μm in between, resulting in a pitch of 300μm. The MSGC is combined with the Gas Electron Multiplier foil which is located between the microstrip structure and the drift electrode, 2.8mm above the MSGC and 3.0 mm below the drift electrode (see Fig. 3). The distances between the MSGC, the GEM and the drift electrode are defined by hollow G10 frames which are also used for the gas distribution. The GEM itself consists of a kapton foil (thickness 50μm) which is copper glad on both sides (thickness 7μm). It has a regular hole pattern (round holes with a diameter of 90μm in

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the copper and 50-60μm in the kapton with a pitch of 140μm). In its active area the detector represents a total radiation length of $7.8 \cdot 10^{-3}$.

Readout electronics is based on the HELIX chip [8], a 128 channel preamplifier chip which consists of a charge integrating preamplifier followed by a shaping stage. The chip includes trigger outputs and a 141 stage analog pipeline. The readout chip is connected to the anodes via a fanin which also includes a serial overcurrent protection resistor of 600Ω.

The HV is connected to cathode groups of 16 cathode strips through a common protection and decoupling resistor of 1MΩ.

4 Performance of MSGC-GEM Detectors for HERA-B

The GEM development for HERA-B was done in coorporation with F. Sauli and the CERN workshop. The proper design of these large size GEM foils including hole shape and size, copper thickness has been improved during the development. The performance of coupled GEM+MSGC detectors has been measured extensively in laboratory tests, at PSI and at HERA.

These measurements have shown the usability of MSGC-GEM detectors in the HERA-B environment, i.e. operation of MSGC-GEM in magnetic fields up to 1 Tesla, single detector layer efficiencies >98%. These results have been summarized in detail in previous papers [5,9].

The introduction of the GEM also influences the choice of the operation gas. For MSGCs, Ar-DME is a good choice because of its high sparking thresholds and its high radiation hardness. For a combined MSGC+GEM detector Ar-DME is less favorable. The reason is that DME reacts with the GEM foil leading to a loss of the foil tension and thus producing inhomogeneous distances between GEM and drift electrode and MSGC structure which result in gain inhomogeneities. A variation in the distance between GEM and MSGC of only 5% ($150 \mu m$) results in a gain variation of $\approx$13%. Furthermore we have observed gas ageing using Ar-DME in our MSGC-GEM detectors.

We have chosen a mixture with Ar and CO_2 in the ratio of 70-30% which has slightly reduced sparking thresholds but does not react with the GEM. Ageing tests with Ar-CO_2 showed its capability to survive more than 2 Mrad equal two years HERA-B.

4.1 GEM induced discharges

In addition to discharges on the MSGC structure in the presence of highly ionizing particles which can be avoided by reducing the MSGC voltages and which has led to the introduction of the GEM foil we observed a new sparking problem in 1998. Operating a MSGC-GEM detector at settings with high drift- and transfer fields in a test beam at PSI we observed from time to time (typically every few hours) discharges through the GEM foil which sometimes lead to strong damages on the MSGC structure.

Extensive laboratory measurements were performed to understand this phenomenon. Figure 4 shows an oscilloscope shot of a discharge in the GEM and following induced discharges in the whole detector.

After the first spark in the GEM foil several discharges on the MSGC structure can be observed. A few microseconds later a further discharge occurs through the gas gaps. These induced discharges started by the initial GEM discharge result in extreme deteriorations on the MSGC structure.

Discharges in the GEM foil cannot be avoided completely, also with decreased GEM voltages discharges are observed from time to time. Thus the primary goal is to avoid secondary effects. Therefore we tried to reduce the large GEM capacitance (O(30nF)) by dividing the GEM into segments. We also investigated the influence of the field configuration on the spark behavior.

The GEM segmentation did not solve the discharge problem. Also a segmented GEM with six segments showed a similar sparking behavior. Furthermore at the interface between these segments sparking was enhanced. This effect may be cured by an improved production mechanism. For our tests the segmentation was done with already produced GEMs. Finally we abandoned the segmentation because tests with small sized GEMs had shown that a capacity of a few nF is sufficient to produce induced discharges.

Measurements of the influence of the electric field configuration on the spark rate are shown in figure 5. The spark rate depends on the transfer field. Below a transfer field (field between GEM and MSGC) of 6 kV/cm no induced discharges are observed. Above this threshold there is an increasing probability for induced discharges with increasing MSGC cathode voltage. No influence from the drift field was observed. Choosing an operating point below this threshold prevents induced discharges. The reduction of the transfer field has tolerable drawbacks on the detector performance. The drift velocity is slightly reduced, the Lorentz angle increases and the diffusion is enhanced. But these effects are acceptable in contrast to large deteriorations produced by induced discharges.

Detectors have been operated with these setting in X-rays and in a high intensive hadronic beam at PSI up to accumulated doses of a few HERA-B years and showed no induced detector sparks.

4.2 MSGC Coating deteriorations

Another effect with MSGC-GEM detectors was observed during a beam test at PSI. The gain increased while at the same time the dark current between anodes and cathodes decreased. According to the increasing gain we observed that the energy resolution deteriorated. This behavior could be fully attributed to the coating on the microstrip structure. An investigation of the coating with an electron microprobe technique showed that the coating thickness after an accumulated dose comparable to three HERA-B years is drastically reduced (see Fig. 6)

In a region of 20μm around the anodes the coating had disappeared. In the remaining part of the gap the coating thickness is reduced by a factor of two. This effect obviously changes the detector performance. Further investigations showed that the effect is similar for Ar-DME and Ar-CO_2 but it is enhanced in other gases, for instance Ar-CO_2-CF_4. It only happens if there is gas amplification in the detector. Presumably it is due to a chemical etching process by ions produced in the avalanche.

Figure 7 shows the influence of this coating deteriorations on the detector performance. In the first phase the detector operates in a normal way as expected for a coated MSGC. In phase two we observe an increasing gain combined with a decreasing energy resolution. Since the deterioration of the coating is not homogenous we expect large variations of the amplifying electric field and consequently worse energy resolution. On the other hand the gain increases because the electric field near the anodes increases. In phase three when a high resistivity region around the anodes has been established we have better energy resolution again at higher gains. But one drawback in this phase is that the gain shows a moderate rate dependence of a factor 2-3.

All measurements show that the detector can be operated in all three phases. The performance in phase two is not favorable but tolerable. An attempt to harden the MSGC coating by an additional tempering step does not substantially improve their behavior.

5 Conclusion, Outlook

The challenging requirements for the Inner Tracking System of the HERA-B experiment are comparable to LHC. We developed a solution consisting of a MSGC coupled with a GEM. This device produces the gas gain in a cascade of two amplification steps and allows to reach sufficiently high gains while operating both devices in safe regions.

We have shown that induced discharges in the whole detector can be avoided by reducing the electric field in the transfer region. During operation we observe an abrasion of the MSGC coating which results in performance changes. These performance changes are tolerable.

Extensive tests with X-rays and at the PSI beam indicate that the detector is operational at least for three years of HERA-B.

Two problems have not been completely solved: 1) The MSGC structure is very sensitive to discharges which can produce a short between anodes and cathodes which leads then to an inefficient region of 16 anodes (2% of the detector). 2) In the GEM foil the occurrence of discharges between the two electrodes cannot be completely avoided. By keeping the voltage difference at a reasonable level the probability is very low. Because of the large GEM capacity a GEM discharge can produce in rare cases a short which is by far more severe than a MSGC short because in this case the whole detector becomes inefficient. However the shorts can usually be removed by applying a short current pulse. To avoid this kind of problems all our chambers are tested extensively before being installed in the HERA-B experiment and all our HV settings are chosen such as to minimize the risk of discharges in the MSGC and GEM.

The commissioning of the Inner Tracking system started in June 1999 and will be finalized by end of this year. Figure 8 shows one of the installed half superlayers.

References

[1] T.Lohse et al., An experiment to study CP Violation in the B System Using an Internal Target at the HERA Proton Ring, Proposal, DESY-PRC 94/02, 1994

[2] M. Capeans, Status of the Outer Tracker for the HERA-B experiment, these proceedings

[3] T.Zeuner, Development of a 150000 channel MSGC tracking system for the experiment HERA-B, Nucl. Instr. and Meth. A 392 (1997) 105

[4] T.Hott, Entwicklung und Test großflächiger Mikro-Streifen-Gas-Kammern für das innere Spurkammersystem von HERA-B, Dissertation, Universität Heidelberg, 1997

[5] B.Schmidt, MSGC Development for HERA-B, Proc. Erice Workshop, 1997

[6] T.Zeuner, Entwicklung eines Spurdetektors für das Experiment HERA-B, Dissertation, Universität Siegen, 1998

[7] F.Sauli, GEM, a new concept for electron amplification in gas detectors, Nucl. Instr. and Meth. A 386 (1997) 531

[8] W.Fallot-Burghardt et al., Helix128-x User Manual V2.1, Asic Labor Heidelberg, 1999

[9] T. Hott, MSGC development for the Inner Tracker of HERA-B, Nucl. Instr. and Meth. A 408 (1998) 258

[10] H.B.Dreis et al., Operation of a large GEM-MSGC detector in a high intensity hadronic test beam using fully pipelined readout electronics, HERA-B internal note 98-149, 1998

FIGURE CAPTIONS

Fig. 1 : The HERA-B detector.

Fig. 2 : Four MSGC-GEM detectors form one Inner Tracker layer (stereo layers are shown in the background).

Fig. 3 : Sketch of a MSGC-GEM detector.

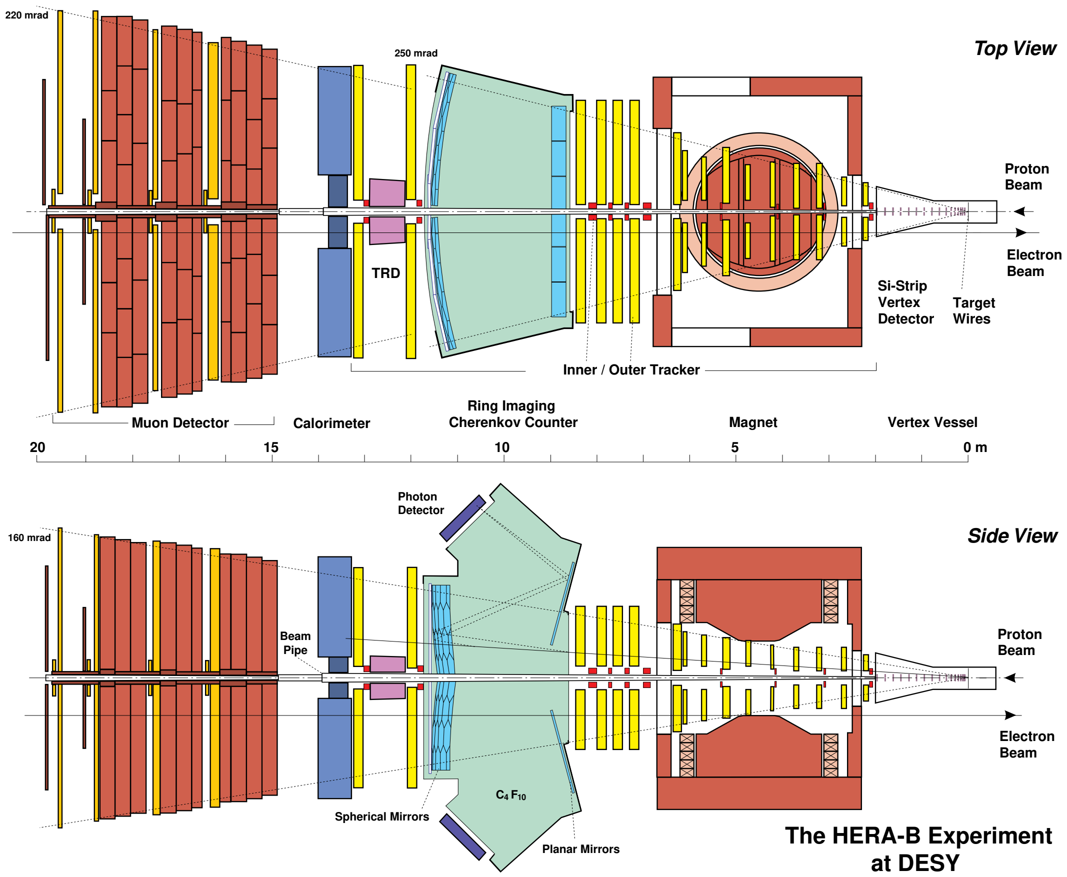
Fig. 4 : Oscilloscope shot of an initial GEM discharge and induced detector sparks (capacitive voltage divider 100:1).

Fig. 5 : Number of secondary sparks per 100 GEM sparks as a function of the transfer voltage and MSGC cathode voltage.

Fig. 6 : Thickness profile of the carbon coating between cathode and anode strips. The coating thickness of a non irradiated MSGC is 60nm.

Fig. 7 : Pulseheight versus irradiation time in years of HERA-B operation. X-ray irradiation with Cu-K_α and 20 times HERA-B rate.

Fig. 8 : Picture of a half superlayer installed at HERA-B. The MSGC-GEM detectors were mechanically mounted onto carbon fibre honneycomb plates. The shown half superlayer consists of 16 detectors distributed to 8 half layers (see Fig. 2).



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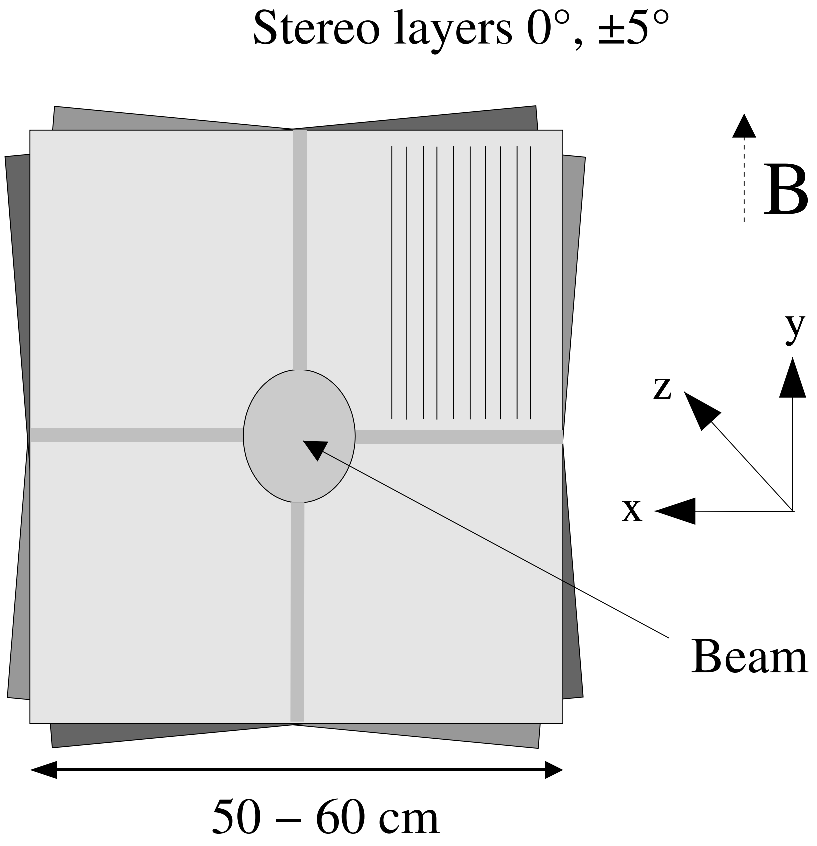


Figure 2: Four MSGC-GEM detectors form one Inner Tracker layer (stereo layers are shown in the background).

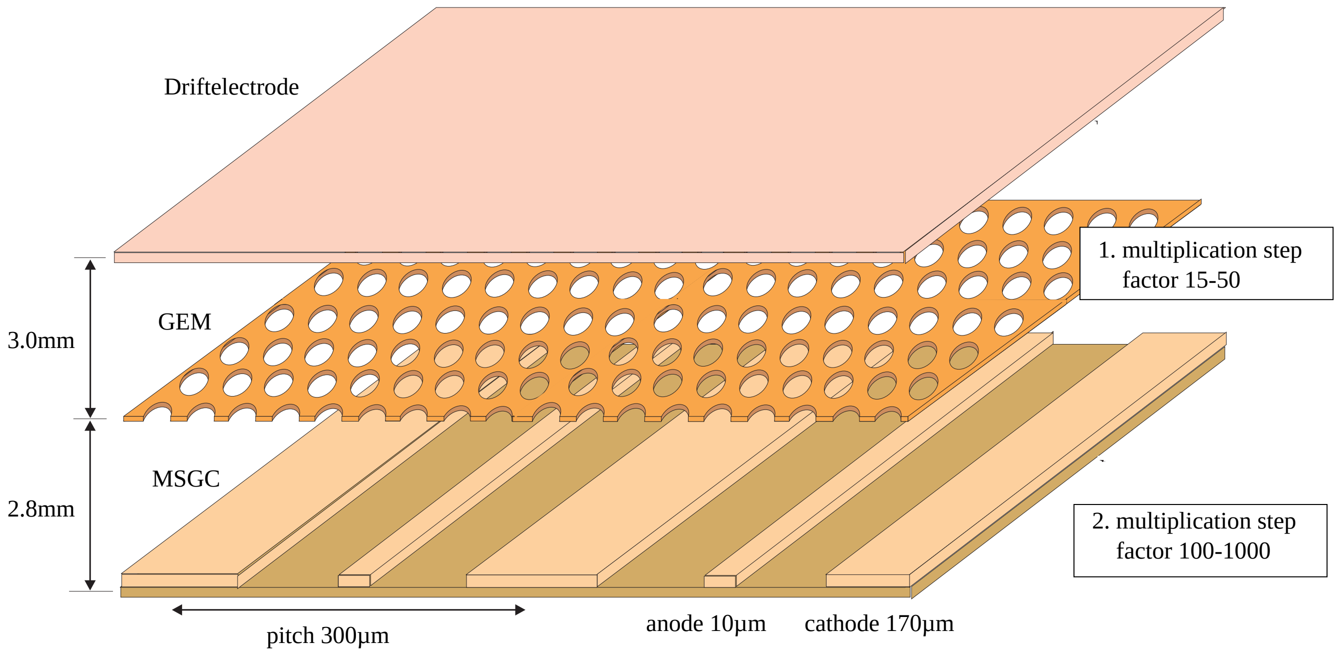
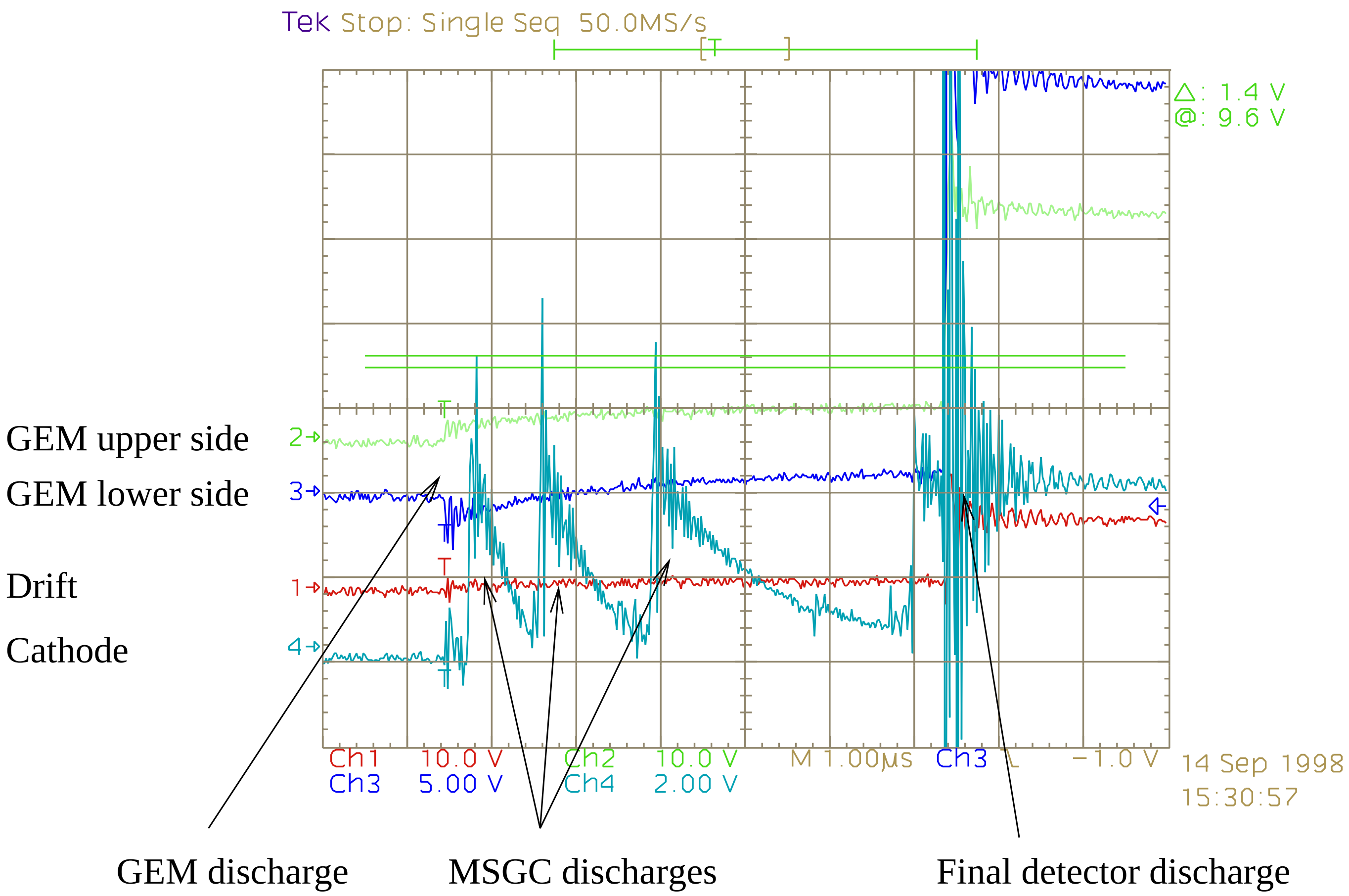


Figure 3: Sketch of a MSGC-GEM detector.



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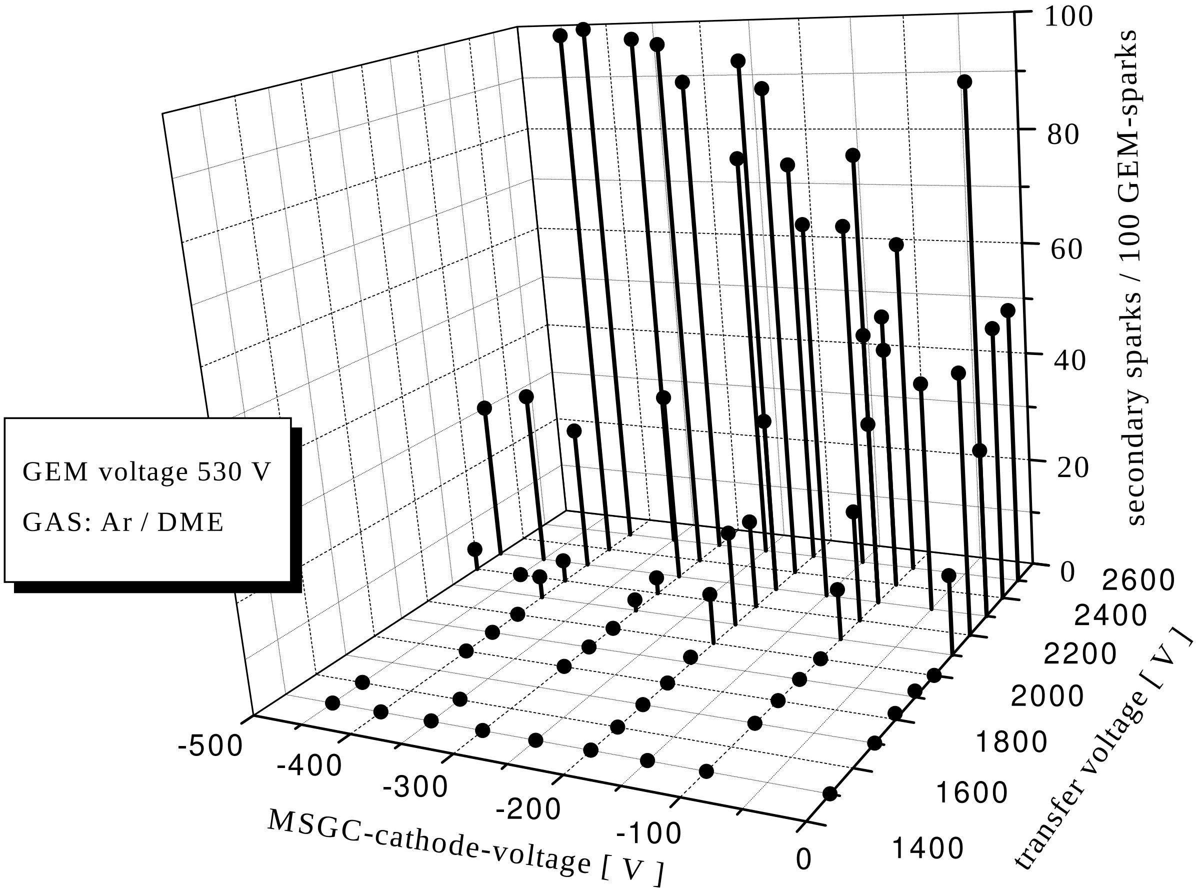

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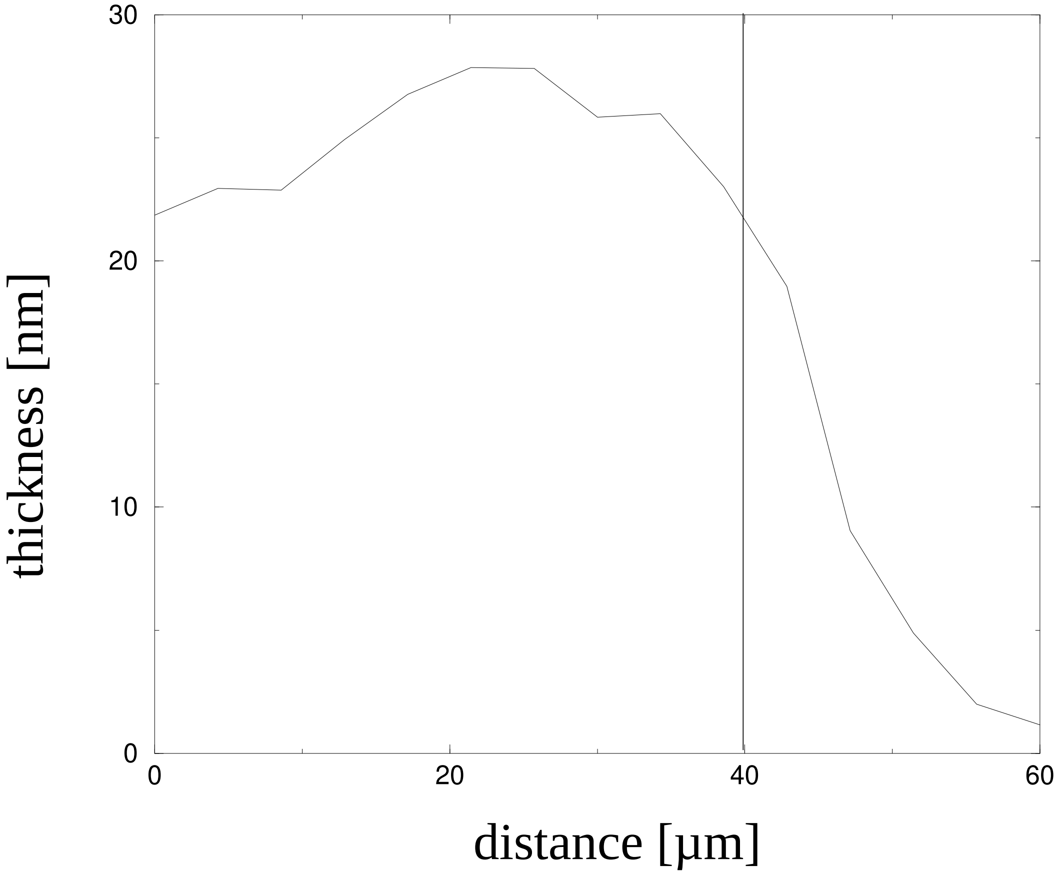

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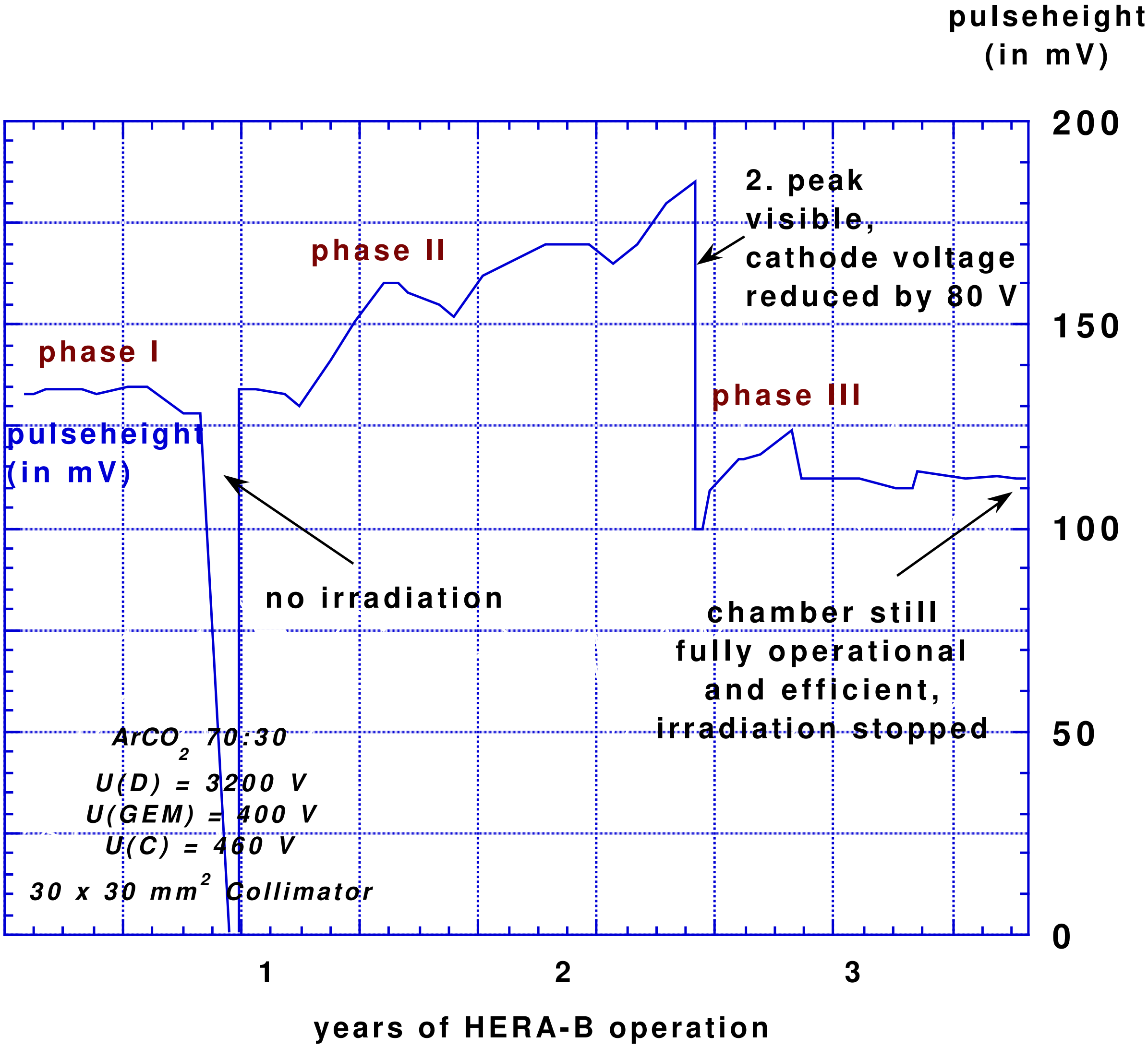

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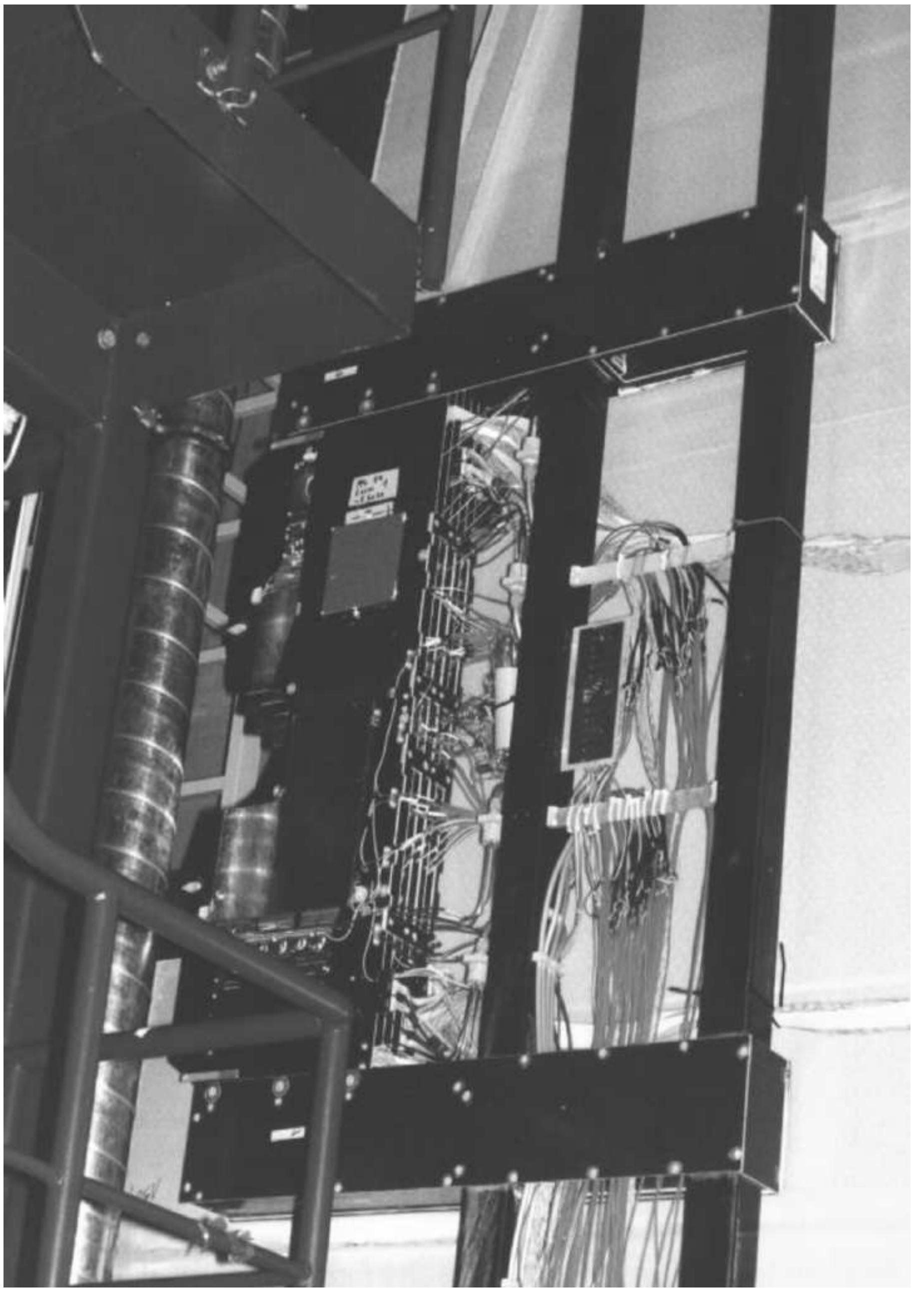

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