EUDET-Memo-2009-017

Test Beam with Silicon Detectors around the Large TPC Prototype

S. Hänsel[1,3], T. Bergauer[1], M. Dragicevic[1], M. Krammer[1],

A. Dierlamm[2], T. Barvich[2], F. Hartmann[2], Th. Müller[2]

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Abstract

In November 2009 a first test beam including both, the Large TPC Prototype (LP) and two double layers of silicon strip detector modules was performed at DESY, Hamburg. The data was recorded using an electron beam with a momentum of 5.6 GeV/c. The LP was readout using Micromesh Gas detectors (Micromegas) with electronics based on the AFTER-chip (ASIC For TPC Electronic Readout), as developed for the T2K experiment. During the test beam period a total of 80,000 triggered events were collected and the data analysis started.

In this report, the emphasis is on the silicon envelope, its final tests before and its performance during the test beam. This is the follow-up memo from EUDET-Memo-2008-16 [1].

[1]Institute of High Energy Physics of the Austrian Academy of Sciences (HEPHY), Nikolsdorfergasse 18, 1050 Vienna - Austria

[2]Institut für Experimentelle Kernphysik (IEKP) at the Karlsruhe Institute of Technology (KIT), Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen - Germany

[3]corresponding author - shaensel@hephy.oeaw.ac.at

1 Introduction

The silicon detectors are arranged in two double layers around the Large TPC Prototype, which form a first prototype for the Silicon External Tracker (SET) for the International Large Detector (ILD) concept [2]. The ILD is one of the proposed detector concepts for a future International Linear Collider [3]. In the ILD concept the tracking system, surrounding the vertex detector, is foreseen as a combination of a TPC and three layers of silicon strip detectors (Fig. 1 left). In the barrel region, between the vertex detector and the TPC, the inner part of the silicon tracking system, the Silicon Internal Tracker (SIT), is composed of two double layers of single sided silicon strip sensors. The SIT improves the linking efficiency of the vertex detector and the TPC and enables the reconstruction of charged particles with low momentum. Between TPC and Electromagnetic Calorimeter (ECAL) the Silicon External Tracker (SET) consists of one double layer of silicon strip sensors. The SET delivers a precise entry point to the ECAL and enables the monitoring of tracking systematics in the TPC. Simulations have shown that the inclusion of the three very precise measured track points provided by the SIT and the SET drastically improve the momentum resolution of charged particles in the ILD detector (Fig. 1 right). In the forward region the silicon tracking system is completed with the End-cap Tracking Detector (ETD), which will help to reduce the material effect of the TPC End Plates ($\approx 0.15X_0$) and the Forward Tracking Detector (FTD) which covers the very forward region.

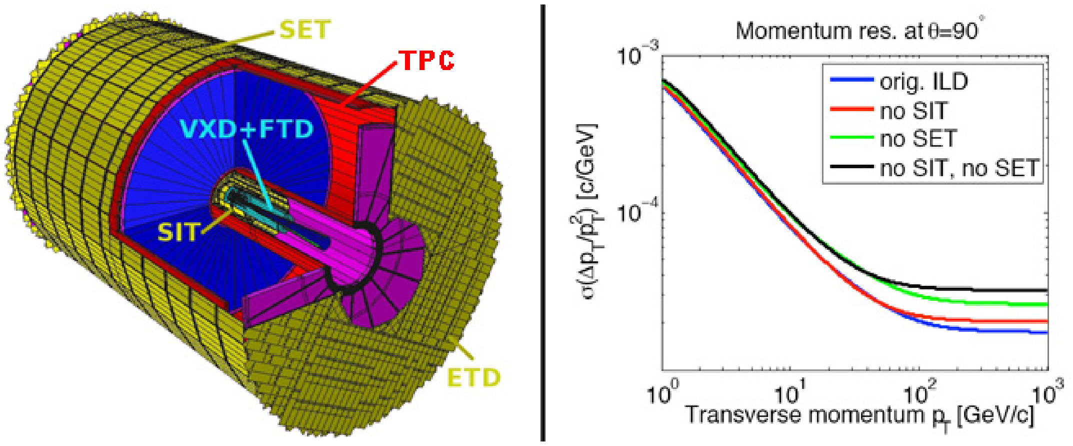


Figure 1: left: tracking system of the ILD detector; right: resolution of the transverse momentum as function of the transverse momentum in the barrel region with and without the components of the silicon tracking system [2]

2 Summary of EUDET-Memo-2008-16

The large TPC prototype with its support structure and the silicon layers with their support structures are mounted inside the persistent current, superconducting magnet

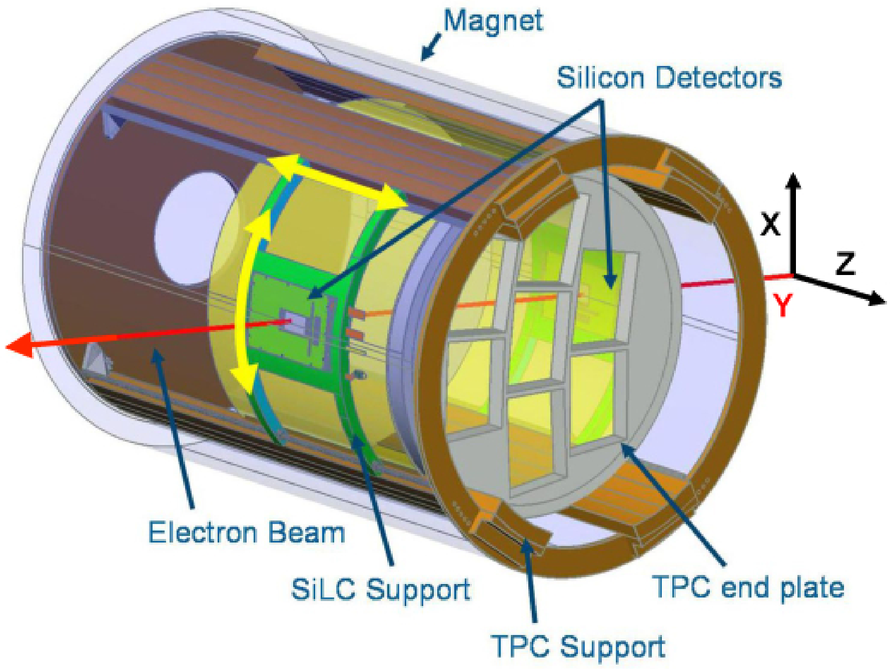


Figure 2: Large TPC Prototype Setup at DESY

in test beam area T24 at DESY, Hamburg. There an electron beam with an adjustable momentum of 1 to 6 GeV/c is available. The magnet can provide a magnetic field of up to 1.25 Tesla. The TPC end plate has seven geometrically identical cut-outs, where readout modules can be mounted, and represents a circular subsection of a TPC with a diameter of 3.6 m, as included in the ILD letter of intent. Due to the limited space of 35 mm between the field cage of the TPC and the surrounding magnet, only one double layer of silicon strip modules on both sides of the TPC could be installed in the large TPC prototype setup (Fig. 2). Each double layer consists of two modules with single sided silicon microstrip sensors. The layers are designed in a way, that the strips of their silicon sensors are rotated by 90 degrees with respect to each other which enables the measurement of both coordinates orthogonal to the beam.
The silicon sensors for the two silicon double layers were designed by HEPHY and build by Hamamatsu Photonics, Japan. The detector modules were designed and build in Vienna and all components were extensively tested before and after their assembly, described in EUDET-Memo-2008-16 [1]. The readout pitch of the sensors is 50 μm, which results in a spatial sensor resolution of better than 10 μm, which was determined with a test beam at CERN in 2008 [4]. The integrated sensors cover an area of approximately 100×200 mm^2. Since only 768 strips of each sensor are connected to the readout electronics, the readout region of each sensor has a width of 38.4 mm.
The support of each silicon layer has to compensate all movements of the magnet in order to keep the sensitive silicon area inside the beam spot. A huge xyz-table enables movements of the magnet which makes a scanning of the TPC with the electron beam possible. In addition it is possible to change the drift distance inside the TPC by moving

the TPC in and out of the magnet, which is of interest, because the magnetic field of the magnet is most homogeneous in its centre.
The data acquisition system used for the data taking with the silicon layers was initially designed for functionality tests during the production of so-called petals for the CMS tracker end caps. For the data analysis the AC1Analysis software [5] developed by R. Brauer is used.

3 Simulations

3.1 Resolution Study

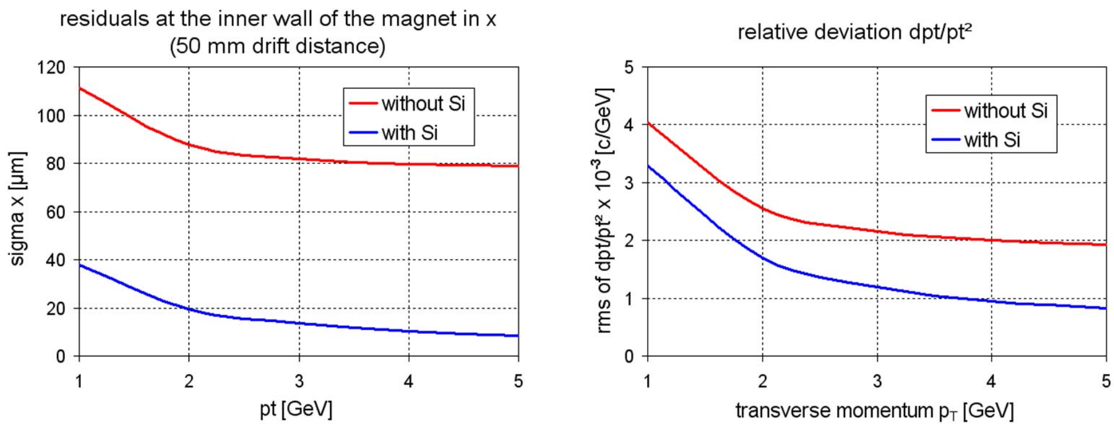


Figure 3: simulation for the large TPC prototype setup - left: simulation of the resolution in x, right: rms of dp_t/p_t^2 - with and without the silicon layers

The simulations were performed with the Vienna Fast Simulation Tool for Charged Tracks [6]. This tool has been developed for detector design studies for the purpose of comparing and optimising different detector setups. It investigates the resolution of reconstructed track parameters with a simplified simulation of the detector measurements, based on a helix track model, followed by full single track reconstruction using the Kalman filter. Multiple scattering is taken into account.
Fig. 3 shows a simulation for the Large TPC Prototype setup, comparing the spatial resolution in x-direction, indicated in Fig. 2, and the rms of dp_t/p_t^2 with and without the information of the silicon layers. For these simulations it was assumed that the TPC is read out with 3 double Gas Electron Multiplier (GEM) modules simultaneously (Fig. 4 right) and that the magnet provides a magnetic field of 1 Tesla. Each GEM module measures 28 points of the track with a pitch of 1.2 mm and a spatial resolution in x of 100 μm. These numbers were taken from a talk of K. Dehmelt at the 2009 Europhysics Conference on High Energy Physics [9]. It is also assumed that the TPC and the silicon sensors are fully aligned and that the silicon sensors have a resolution of 10 μm. The simulation clearly shows the improvement of resolution with the inclusion of the silicon layers.

3.2 Alignment Study

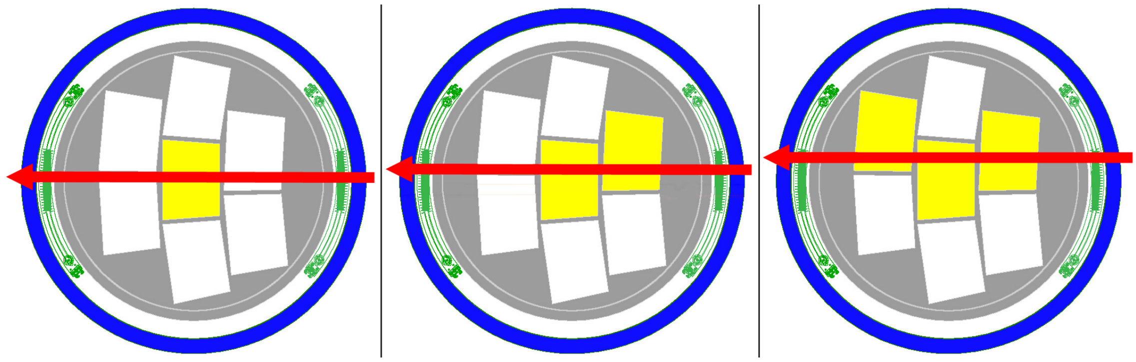


Figure 4: Three different setups of the large TPC prototype readout - the red lines indicate the beam and the blue circle the magnet. The silicon envelope is coloured green and the TPC endplate grey, with yellow read out panels and white dummy modules.

configuration	extrapolated resolution at silicon [μm]	number of measurements needed to reach a precision of 2 μm	1 μm
one TPC panel in the centre (Fig. 4 left)			
JGEM (B=0T)	2,307	1,300,000	5,300,000
JGEM (B=1T)	1,867	900,000	3,500,000
two TPC panels (Fig. 4 centre)			
JGEM (B=0T)	676	110,000	450,000
JGEM (B=1T)	225	13,000	50,000
three TPC panels (Fig. 4 right)			
JGEM (B=0T)	284	20,000	80,000
JGEM (B=1T)	103	3,000	10,000

Table 1: alignment study in x-direction, not taking systematic errors into account

A proper alignment of different systems has to be better than one fifth, ideally one tenth, of the resolution of the measurements. Since the demanded resolution of the silicon sensors is less than 10 μm, the alignment should have a precision in the order of 2 μm or better. With the available setup it is not possible to make an alignment of the two silicon layers and the TPC with the needed accuracy. It would be possible to make an optical position measurement with a laser alignment, but only with the help of the survey team of DESY. Unfortunately this would be a major effort and the alignment would be gone after movements of the setup. In addition it would be necessary to use special mirrors, embedded into steel spheres, mounted on the sledges of the silicon support which would have an influence on the magnetic field. The only realistic possibility is a track based alignment where each single track of the TPC is extrapolated to the silicon layers and compared to the positions measured with the silicon sensors. Simulations show that, with enough tracks, such an alignment should be possible when the TPC is equipped with at least two readout modules, Micromegas or GEM. As starting point for the simulation, measurements of the spatial resolution in x-direction of one GEM module at magnetic fields of 0 T and 1 T were used [9]. Unfortunately no values for the resolution in drift direction were found. The Vienna Fast Simulation Tool for Charged Tracks [6] was used to simulate track-measurements of the TPC and to extrapolate the "measured" tracks to the planes of the silicon sensors. Table 1 shows the extrapolated resolution at the centre of one silicon layer and the approximate number of tracks needed to reach a precision of 2 μm and 1 μm respectively for the three different configurations, shown in Fig. 4.

4 Final Test at Karlsruhe

In May 2009 the two silicon double layers were brought to the Institut für Experimentelle Kernphysik (IEKP) at the KIT in Karlsruhe and assembled onto the silicon support (Fig. 6 left). The moveable support structure was build by IEKP with the assistance of HEPHY.

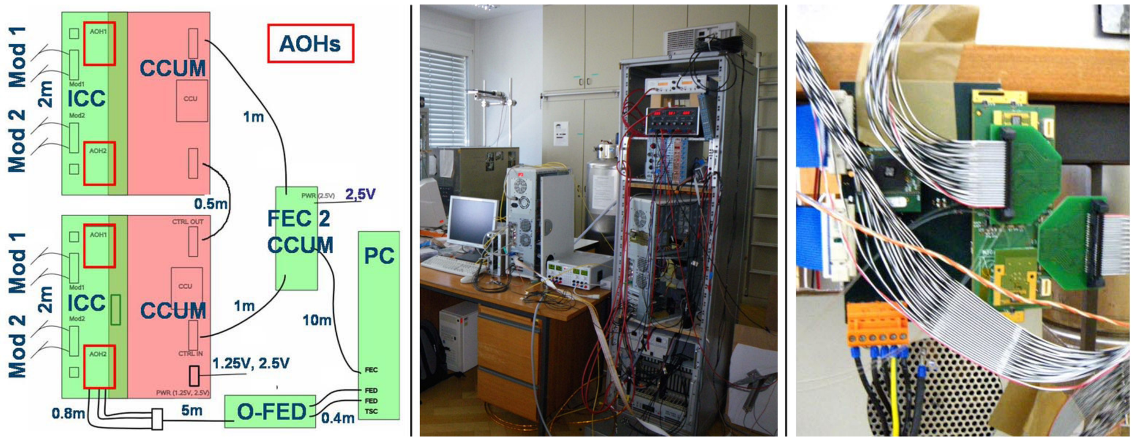


Figure 5: left: schematic of the silicon DAQ system; centre: PC with readout cards, low voltage and high voltage power supplies; right: the twisted pair cables coming from the silicon layers are connected to the ICC sitting on the CCUM-card

The schematic of the silicon data acquisition system, provided by IEKP, is divided into a readout chain and a control sequence (Fig. 5 left):

- The front end hybrids on the silicon layers transfer the signals from the silicon sensors via four 2 m long twisted pair cables to specially for this setup designed Inter Connect Cards (ICC) (Fig. 5 right). There the electrical signals get converted to analogue optical signals in the Analogue Opto Hybrids (AOHs). These signals are transferred via 15 meter long optical links to the Optical Front End Driver (O-FED) where they get re-converted to electrical signals and delivered to the FED card in the PC (Fig. 5 centre).

- The readout is controlled from the PC via a Front End Control (FEC) card which steers, via a ten meter long electrical cable and the FEC-2-CCUM card, the Central Control Units (CCU) sitting on the Central Control Unit Modules (CCUM) (Fig. 5 right). Via the ICCs the CCUs provide I^2C control sequence and clock for the APV readout and controls. The FECs receive clock and trigger signals from the Trigger Sequencer Card, which gets external trigger signals from the Distributor Box (DB) [8], which in turn receives its information from the Trigger Logic Unit (TLU) [7].

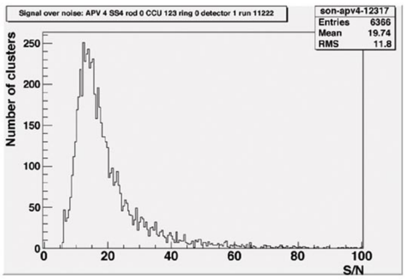


Figure 6: left: one half of the silicon support carrying a silicon double layer; right: signal over noise measured with cosmic muons at IEKP

The left picture in Fig. 6 shows one half of the moveable support structure for the silicon layers. For the final test at IEKP wooden plates were used to hold the bars and as dummy for the gap between the TPC and the magnet. The silicon double layer is mounted on a curved sledge, in a way that it is moveable along the curvature, which can be moved along two bars. After movements of the magnet, with the exact geometrical information of the silicon layers, the active area of the silicon sensors can easily be positioned in the beam line. In May first data was recorded at IEKP, using scintillators to trigger on cosmic muons. With the DAQ software pedestal subtraction, common mode correction and cluster search leading to the hit positions were performed. The plot on the right of Fig. 6 shows a first signal over noise plot of one of the silicon sensors. Due to the use of two glass pitch adapters in the silicon modules, the length of the cables and the noise in the setup, the signal over noise ratio of the silicon sensors is reduced to about 19.

5 Installing the silicon envelope at DESY

In June the silicon envelope was brought from IEKP to the test beam area T24 at DESY, Hamburg. To integrate the bars of the silicon support into the support of the TPC it was necessary to move the magnet out of the test beam area and the TPC support out of the magnet (Fig. 7 left). After the supports were assembled together and the functionality was verified, the combined support was mounted into the magnet and everything was moved back to the test beam area (Fig. 7 right).
Everything fitted perfectly, only one small problem occurred: the TPC end plate is not mounted centrically on the TPC field cage and therefore slightly touched the silicon sledges during rotations of the TPC. The problem was solved by grinding some small parts of the silicon sledges away.

Figure 7: left: on their rails the silicon sledges can easily be moved along the TPC field cage; right: with a special pole the sledges can be positioned inside the gap between magnet and TPC

6 Test Beam

In November 2009 the first combined test beam of the silicon double layers and the TPC was performed. The TPC was readout with Micromesh Gas detectors (Micromegas) equipped with electronics based on the AFTER-chip (ASIC For TPC Electronic Readout) designed for the T2K experiment. The beam intensity was reduced to minimise the average number of recorded tracks per event inside the TPC by setting the momentum of the electron beam to 5.6 GeV/c. With this beam setting about 28% of the recorded events have exactly one cluster in all four silicon layers. This low amount is mainly caused by multiple scattering in the magnet wall in front of the first silicon layer.
In a first run we collected about 20,000 triggered events with one Micromegas panel in the centre position of the TPC end plate (Fig. 8 centre) surrounded by six dummy modules. Due to the large distance between TPC readout and silicon sensors it is not possible to

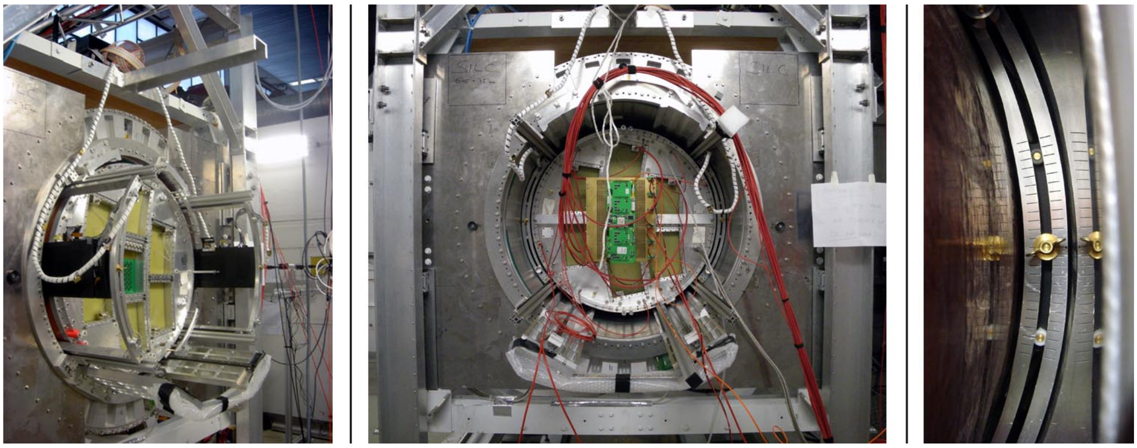


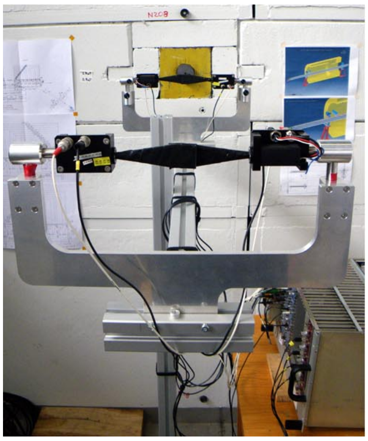
Figure 8: left: silicon sledges in front of the magnet and the TPC; centre: during data taking with one Micromegas panel in the centre position of the TPC end plate; right: silicon sledge inside the gap between TPC and magnet

make a proper TPC-track based alignment. To increase the number of measured track points inside the TPC a second run with two Micromegas panels was performed. During this run a second readout panel was mounted, with respect to the electron beam, in front of the module in the centre (Fig. 4 centre). With this second configuration we collected 60,000 triggered events.
During data taking the coincidence signal of four scintillators (Fig. 9 left) in front of the setup was used as trigger signal. This trigger signal was centrally distributed using the Trigger Logic Unit (TLU) [7] in combination with a Distributor Box (DB) [8]. The initial idea was, that both data acquisition systems include the time stamp and the trigger number, provided by the DB, into their data files to ensure a matching of the recorded events. Unfortunately this was not implemented in the DAQ system of the TPC, leading to the problem in the data analysis, that we have no common number to allocate the events of the silicon with those of the TPC. The right sketch in Fig. 9 describes the trigger logic used during the test beam:

- the Trigger Logic Unit (TLU) gets the coincidence trigger signal from four scintillators in front of the setup
- the TLU sends trigger signal, TLU timestamp and TLU trigger number to the Distributor Box (DB) which sends a busy signal back to the TLU, preventing the TLU to send another trigger
- the DB sends the trigger signal to both DAQ systems and sends TLU trigger number, the trigger number of the DB and the timestamp of the DB to the silicon DAQ system which sends a busy back to the DB, preventing it to end the busy to the TLU
- additionally, since the silicon DAQ system needs less time to record an event than

the TPC DAQ system, the DB has an intern adjustable delay which was set to 100 ms, which ensures that the TPC readout has enough time to process the events

- after the silicon DAQ system stops its busy and the DB intern delay is over, the DB ends its busy to the TLU and waits for the next trigger



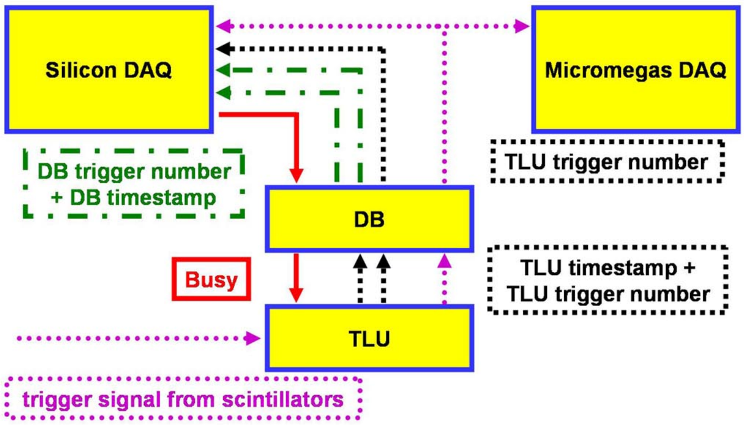


Figure 9: left: during the test beam four scintillators in front of the magnet were used for triggering; right: schematic of the used trigger logic

To guarantee that both systems use the same trigger for the same event, before the start of data taking a busy signal is send from the DB to the TLU and from the silicon DAQ system to the DB, preventing the DB to accept a trigger from the TLU. At the time both DAQ systems are ready for data taking the busy from the silicon DAQ system is ended, allowing the DB to end its busy to the TLU. Unfortunately there is no guarantee that triggers get lost, but with the used DAQ systems the possibility for such a failure is very small. The first thing to verify with the recorded data is that consecutive events in the two data files refer to the same triggers. This will be done by matching the frequency of events with just one track in both DAQ systems. During the test beam this was done by hand for the first couple of events and looked promising. To be absolutely sure this has to be verified for all events in each data set.

7 first look at the data

During the test beam we collected about 20,000 events with one Micromegas panel in the centre position of the TPC end plate and 60,000 events with two Micromegas panels. The plot in Fig. 10 shows a hit profile of about 40,000 recorded events. For each cluster the readout channel with the highest signal was counted up by one. The axis show the 768 readout strips of the four silicon modules. In x the sensors measuring the x coordinate and in y the sensor measuring the z coordinate are plotted. The silicon sensors in the back recorded nearly twice as many clusters as the silicon layer in the front. This shows that the secondary emission yield due to the material in the large TPC prototype setup is quite high. This comes mainly from secondary particles produced in the magnet wall in front of the first silicon layer. Since the mean variation due to multiple scattering at the front sensors is below 10 μm there the majority of the secondary particles will not be measured as a separate cluster. From the profile in the silicon layer in the front the diameter of the beam spot can be estimated to be about 5 mm, since the silicon sensors have 768 readout strips with a pitch of 50 μm.

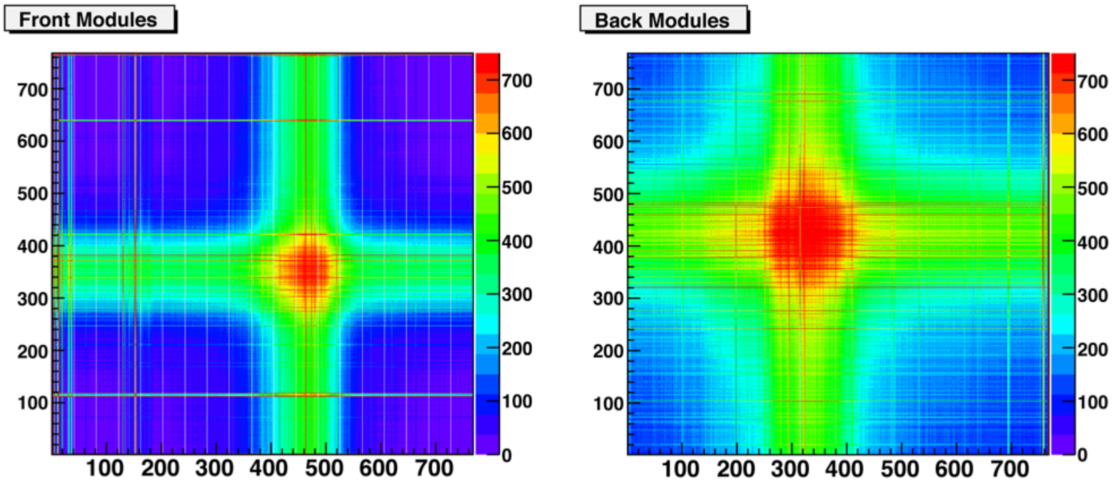


Figure 10: hit profile of the two silicon double layers, hit strips are represented by lines

8 Conclusion

The combined test beam of the silicon layers and the large TPC prototype in November 2009 was a success. 80,000 triggered events were recorded and the analysis of the data has just started. For the first half of 2010 it is foreseen to perform a test beam at DESY, Hamburg, with the TPC read out with three GEM modules simultaneously.

Acknowledgement

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