EUDET-Memo-2006-06

The large prototype TPC *

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1.12.2006

Abstract

A status report is given on the preparations of a protoype TPC, which contains all the necessary infrastucture to study the required performance of a full scale TPC for an experiment at the International Linear Collider.

*Plenary talk given at the EUDET Annual Meeting, Munich, Germany, October 18-20, 2006

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1 Introduction

Within the framework of the EUDET project a detector concept for the future International Linear electron-positron Collider (ILC) is being extracted. A large TPC with Micro Pattern Gas Detectors (MPGD) as provided by the GEM technique (Gas Electron Multiplier) [1] or Micromegas [2] offers a promising possibility for precise tracking. In order to determine the performance, required for a full scale TPC, a large prototype is under construction with sufficient flexibility and modularity to investigate the different options concerning read-out systems, end-plate designs, pad sizes and geometries, gas properties and gas tightness, HV distribution etc.

2 The field cage

The cylindrical field cage will be placed in a solenoid magnet, which provides a nominal field of 1.2 Tesla [3]. The magnet will be mounted on a support structure such that the test beam will enter the TPC through the side wall. The support structure will allow movements vertically and horizontally in a plane perpendicular to the incoming test beam, which enabkes to explore the full detector volume with the test beam. A rotation in the horisontal plane will also be possible in order to study inclined tracks. The dimensions of the field cage are restricted by the size of the magnet. A diameter of 80 cm leaves some space between the coil and the chamber for external detectors to determine the impact and exit positions of the beam particles. The length of the chamber will be 60 cm, determined by the distance over which the magnetic field does not vary by more than 1 %. In order to investigate influence of larger field variations within the drift field, it will be possible to shift the field cage along its axis inside the magnet.

The cylindrical wall will be constructed from a composite material for stability and in order to keep the weight low. The end-plate will be exchangable to allow tests of different designs.

A homogenous drift field will be generated by distributing the high voltage over equidistant field strips on a 75-100 μm kapton layer glued to the inside of the cylindrical chamber wall. Simulations have shown that a very homogeneous field over the full drift volume is obtained with 2.3 mm wide strips at 2.8 mm pitch on both the inner and outer side of the kapton foil. The outer strips are called 'mirror strips' and are staggered by half a pitch distance compared to the inner ones. The mirror strips are at intermedate potentials with respect to the neighbouring inner strips. For details on the field cage see the talk by P. Schade at this meeting.

3 The end plate

The end-plate will contain a number of 'windows' into which pad panels will fit. The pad panels will be fixed to the end-plate from the inside via screws through the end-plate such that the pad panel extends beyond the limits of the window and thereby minimizes

the dead material between panels. O-rings will guarantee the gas tightness. With such a system different panels with different pad sizes and/or different pad geometries can be tested without breaking the gas system. The pad signals have to be distributed to a high densiy connector on the outer face of the end-plate. The connector constitutes the mechanical interface between the TPC end-plate and the read-out electronics.
It has been discussed whether the same end-plate can accomodate both GEM-based and Micromegas-based read-out systems. A solution, which has been proposed, is to use spacers between the end-plate and the pad panel in order to position the read-out system in the correct place with respect to the field strip closest to the end-plate, which defines the end of the drift volume. Such a system requires two HV-supplies where one is essentially responsible for the voltage distributed over the field strips and the other providing the correct voltages to the read-out system, which are different for GEM:s and Micromegas and it also depends on whether a gating grid is needed or not. A schematic drawing of how this may be realized is shown in Fig. 1.

4 Pads and connectors

The minimum pad size considered has an area of 1x4 mm^2, which should be small enough to meet the physics requirement to reconstruct the Higgs particle from a measurement of the recoil mass in the Higgs strahlung process. According to simulations a momentum resolution of $\Delta p_T/p_T^2 \sim 5 \cdot 10^{-5} (GeV/c)^{-1}$ would be required. We assume the separation between the pads to be 0.1 mm. The connector should be mounted directly onto the back side of the pad plane and thus has to be a high-density connector in order to fit the area given by the 1x4 mm^2 pad. Japan Aviation Electronics offers a connector, which fulfilles the requirements. It is a 40 pin connector with 0.5 mm pitch and outer dimensions 13.9 x 4.7 mm^2. If 32 pins are used for signal read-out, it leaves 8 pins for grounding, which should be sufficient. Subdividing the pad plane in units of 32 channels offers high modularity such that the pad area equipped with electronics can be varied to cover different geometries. This is a necessary condition since only a fraction of the total number of pads can be equipped with electronics. The starting point is that we need at least 2000 electronics channes. This small number should still be acceptable for the test TPC, since the incoming particles can be directed into that specific detector volume, which is covered with read-out instrumention. It is, however, investigated whether additional read-out electronics can be financed within the collaboration. With a limited number of electronics channels it must be possible to disconnect the electronics from one pad panel and move it to another one or even to install it on a different end-plate.
The connector receptacles are offered in both straight and right angle connectors, making them a good choice for vertical plug-in modules. It also offers the possibility to have connections either via short cables between the pad plane and the electronics or direct mounting onto the end-plate surface. The trace routing from the pads on one side of the end-plate board to the connector on the other side has been studied. Since the pads are small, the input capacitance will be very small, which is an advantage from a noise point of view. In order to conserve the low input capacitance and keep the cross talk

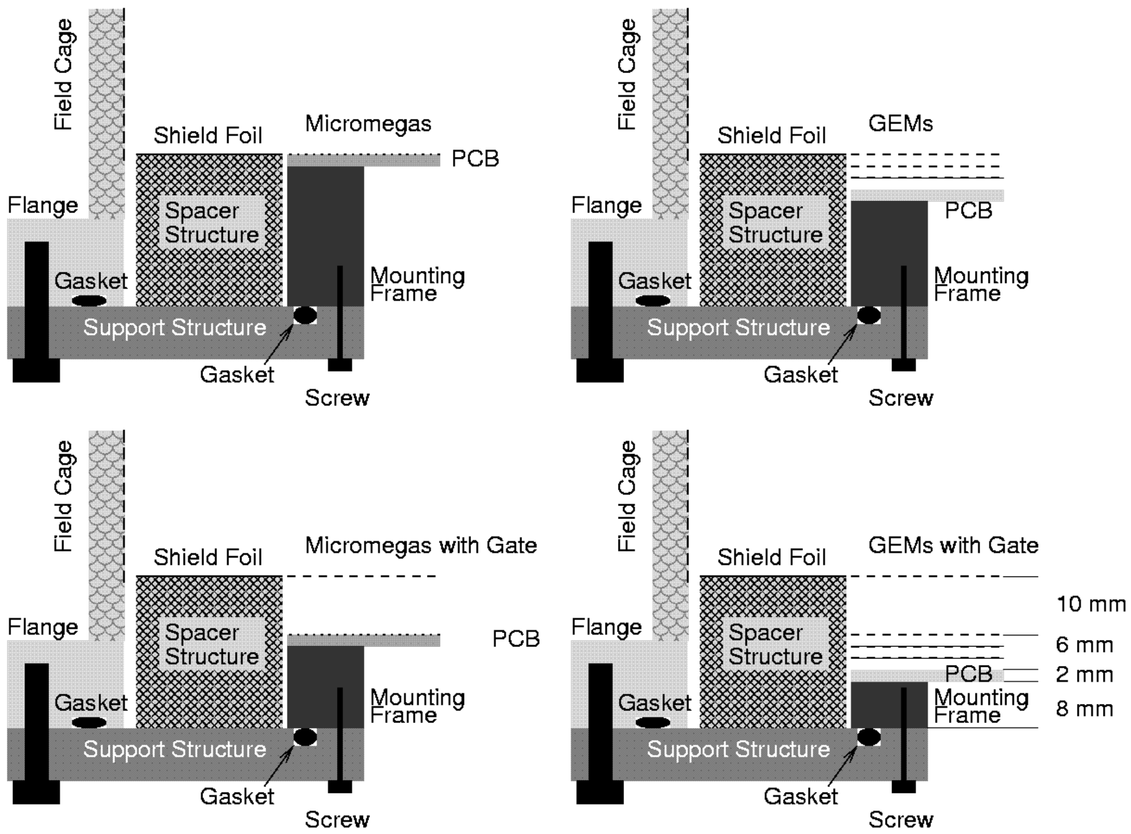

Figure 1: *Schematic drawing on the mechanical support for positioning the gas amplification system correctly with respect to the last field strip in the case of Micromegas and a GEM system, with and without a gating grid, respectively.*

to a minimum, the trace length to the premplifier input has to be as short as possible. This requirement is consistent with the design goal to have the footprint and traces to a connector fully contained inside the pad area that the connector serves. Fig. 2 shows the pad plane and the connector plane overlaid in the case of 1x4 mm^2 pad size. Although the trace routing seems feasible on one layer we foresee a multilayer board to satisfy the need for grounding and blind vias to avoid gas leakage.

5 The front end electronics

The test infrastructure read-out electronics for the large prototype should offer a performance that is better than that of the final TPC, so that the compromises that may become necessary for the multimillion channel final system can be studied and opti-

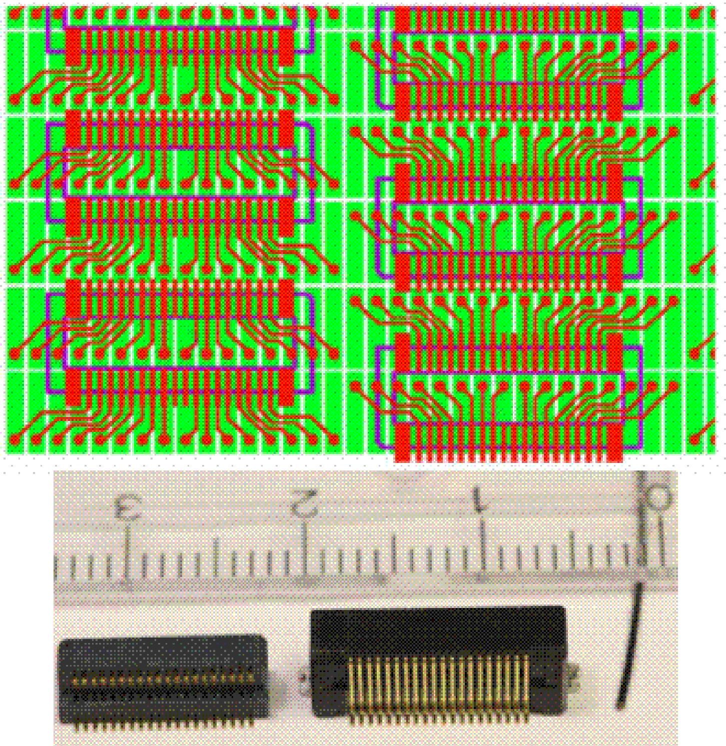

Figure 2: *Pad plane with 1x4 mm^2 pads and connector boundaries overlaid. The trace routings between the connector pins and the pads are shown. Below is a photo of the connectors (male and female) together with a piece of coax cable compatible with the 0.5 mm pitch of the connector pins.*

mized. In order to meet these requirements the front end electronics will be based on a programmable preamplifier-shaper ASIC, presently under development, and digitisation at 40 MHz sampling rate by a modified ALTRO chip [4] , as developed for the ALICE experiment.

The existing front end card (FEC), available from the ALICE experiment, contains 128 channels and have the physical dimensions 19 cm high and 17 cm deep. The height of the card is thus not compatible with the 128 mm, which corresponds to 128 pads of 1 mm width. In addition the connectors of this board are 6 mm thick which exceeds the 4 mm length of the pads. It is thus clear that the use of these boards will need connection via cables, which should be as short as possible in order not to increase the noise level significantly. The alternative would be to make a redesign of the board to match the available area and thereby allow mounting directly onto the pad connectors. This may become necessary due to space reasons if we will be able to extend the number of electronics channels significantly. On the other hand a new borad would need extensive development work and testing.

5.1 The preamlifier-shaper

The very small sensor pads and short input traces give very low input capacitance ($\approx$ few pF). Thus the external conditions for excellent noise performance both for random noise as well as for coherent pick-up noise are very good for direct mounting of the electronics and as long as cables can be kept short.
The characteristics of the new shaping amplifier are planned to be programmable in situ via a serial interface, making it an ideal solution for a versatile test set-up. The programmability will allow sensitivity to charges greater than a few hundred electrons and an input capacitance of 0.1 pF to 10 pF. The peaking time can be defined within the range $\sim$20 ns - $\sim$140 ns. The number of channels will be 32 or 64. A first prototype of the preamlifier-shaper chip, containing 12 channels with a fixed rise time of 100 ns, has been produced in 130 nm CMOS technology. It has recently been tested and the test results are summarized in Table 1.

Parameter	Specification	Simulation	MPR Samples
Noise	$<$ 500e	300e (10 pF)	270e (10 pF)
Conversion gain	10 mV/fC	10 mV/fC	9.5 mV/fC
Peaking time (default)	100 ns	100 ns	100 ns
Non linearity	$<$ 1%	$<$ 0.35 %	$<$ 0.3 %
Cross talk	$<$ 0.3 %	0.4 %	$<$ 0.3 %
Dynamic range	$>$ 2000	3300	4600
Power consumtion / channel	$<$ 20 mW	10 mW	10 mW

Table 1: *Comparison between specifications and results from simulations and tests of the preamplifier-shaper prototype.*

As can be seen from the table the performance of the chip is up to the specifications or better. Especially one may notice that noise is much below the specifications and the dynamic range is significanly wider. The next prototype with 16 channels will be programmable and the submission is planned for the beginning of 2007.

5.2 The digitization

The ALTRO chip has been developed for the ALICE TPC to be operated at 10 MHz with 10 bit resolution. It offers a large flexibility and can be used as a general purpose AD-converter for a multi-channel system. A modified version with 40 MHz sampling rate has been developed, the performance of which should be more than sufficient for the linear collider TPC test set-up. The chip contains a memory of 1024 10-bit words for event storage. This corresponds to a depth of 25 μsec drift time at 40 MHz sampling rate. The maximum drift time in the 60 cm long prototype TPC is 15 μsec if we assume a drift velocity of 4 cm/sec. Thus, the 25 μsec event length foreseen for the ALTRO storage, provides sufficient margin for different gas choices. The ALTRO has a flexible

sample by sample subtraction of pedestals accompanied by a powerful suppression of zero data. Thus, it is expected that only valid data will have to be read out from the ALTRO. This will reduce the requirements on the data aquisition (DAQ) system. The ALTRO chip is read out in 40 bit wide words on a customized 40 MHz bus. Presently 125 chips of 40 MHz sampling rate are available, which corresponds to 1900 channels in total. In case it is decided to increase the number of channels significantly a new submission will be necessary.
More details concerning the read-out electronics can be found in the talk by G. Trampisch at this meeting.

6 The data aquisition system

A data aquisition (DAQ) system, which has been used during the ALICE TPC development and testing phases, is based on a U2F card (USB-to-FEC interface card). This card communicates the signals from the FEC card bus to the USB cable (Universal Serial Bus), which provides a data transfer rate of 160 Mbit/sec. One U2F card can handle maximum 16 FEC's and it can be operated in two different modes:
- reading channel by channel, which gives full control but is slow.
- reading of all channels within one USB read-out, which is fast but requires decoding of the end-of-event mark.

This system would be sufficient for a system containing 2048 channels, which corresponds to 16 FEC's, but if the number of channels would increase significantly beyond that one has to consider different solution to the DAQ task.
An alternative would be to read out every FEC with ethernet, which is fast and flexible but requires some development work.

7 Read-out using Time-to-Digital Converters

An alternative to the read-out electronics based on AD conversion might be a system with Time-to-Digital Converters (TDC), together with a Charge-to-Time Conversion (QTC) technique [5]. The basic principle is that an incoming pulse, as it exceeds a predetermined threshold, will cause the charge-to-time converter to generate a standard square pulse. The duration of the square pulse is proportional to the charge content of the incoming pulse, which means that the square pulse will always be longer than the time-over-threshold of the original pulse. Thus, the leading edge of the square pulse will provide information on the longitudinal coordinate whereas the width of the pulse contains the dE/dx information. Tests have been performed using a Nd-YAG laser beam, which entered a small TPC prototype perpendicular to the drift direction. A double GEM-structure was used for the gas amplification and the pad plane contained 8x8 quadratic pads of size 7x7 mm^2. The read-out boards contained 16 channels, each with two 8 channels charge-to-time converter (ASDQ) circuits [6], together with a commercial 128 channel multihit VME TDC (CAEN v767), based on four 32 channel

TDC chips [7]. The coordinate resolution was measured to $\Delta z = 0.4$ mm for a drift distance of 30 cm. The width of the pulse produced by the ASDQ is longer than the original pulse and therefore the two track resolution will always be worse than that of a system with AD converter read-out. The resolution of the charge measurement varied between 9% and 20%.
The next step is to construct an 'evolution board' to study the performance of the analogue (ASDQ) and digital (TDC) components on the same board. A small chamber with a few centimeters drift length and a triple GEM structure will be used for the tests. For the large prototype TPC a board will be designed, containing four 8 channel ASDQ and one 32 channel high precision TDC. This board will fit directly onto the connectors of the large TPC prototype. The talk by A. Kaukher at this meeting provides more details on this read-out system.

8 Conclusion

Acknowledgement

This work is supported by the Commission of the European Communities under the 6^{th} Framework Programme "Structuring the European Research Area", contract number RII3-026126 and by the Swedish Research Council. I would like to thank R. Settles and H.G. Moser for a well organized meeting. My colleagues in Lund, B. Lundberg, U. Mjörnmark, A. Oskarsson, E. Stenlund and L. Österman, are acknowledged for invaluable help in the preparation of my talk. I am indebted to T. Behnke, A. Kaukher, M. Killenberg, L. Musa, D. Peterson and P. Schade for providing me with material and information.

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