EUDET-Memo-2010-19

TPC Task: the Past and the Present

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January 6, 2011

Abstract

A Large Prototype of a TPC has been setup at DESY at the end of 2008. It is serving since then as a testing bed for novel amplification structures which might become the readout structure for a TPC at the ILC. The LP is a worldwide effort and is also to a large extent provided as EUDET projects. A description of the setup and its evolution as well as the status of the present project and further plans will be given.

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1 Introduction

A TPC based on Micro Pattern Gas Detectors (MPGD) is described in the ILC Reference Design Report [1] and will be the central tracking device for the ILD detector whose Letter of Intent [2] has been submitted in 2009 and has been validated by the International Linear Collider Steering Committee (ILCSC). It will have dimensions of $\approx 3.6\ m$ in diameter and $\approx\ 4.7\ m$ in length. The TPC is expected to provide ≈ 200 space points with pad readout, along a particle track with the Rϕ spatial resolution of $100\ \mu m$ per row or better. The momentum resolution of $\delta(1/pt) \leq 0.5 \times 10^{-4}(GeV/c)^{-1}$ is envisaged in the magnetic field of $3.5\ T$.
The Large Prototype (LP) project partly came out of the EUDET project. EUDET is a project supported by the European Union in the 6^{th} Framework Program structuring the European Research Area. The project comprised 31 European partner institutes from 12 different countries working in the field of High Energy Physics. In addition, 29 associated institutes were contributing to and exploiting the EUDET research infrastructure with the aim to support the detector R&D in Europe for the next large particle physics project, the International Linear Collider. EUDET was subdivided in several scientific activities, among which were several so called Joint Research Activities (JRA). Three JRAs existed, JRA1/2/3. JRA2 wanted to integrate the efforts of European institutions working on tracking detectors for the ILC. This included the improvement of existing infrastructures for tracking detectors, the developments of common prototypes, and the development of novel techniques for Si based tracking detectors. For the TPC-task this meant to set up an infrastructure for Time Projection Chamber Research and Development around the LP activities.

2 The Large TPC Prototype

Several relevant topics towards the ILC detector will be pursued with a Large Prototype (LP) of a TPC [3] which have been studied at small and medium sized TPC prototypes and will be extended by a large scale prototype of a TPC: large prototype (LP). Presently a rather complete setup has been established at DESY and provides an infrastructure for this world-wide effort. The items are projects within the EUDET framework as well as from non-EUDET projects, which are:

- Large scale ($\varnothing \approx 1\ m$), low mass field cage
- Modular end plate system for large surface GEM and MicroMegas systems
- Development of prototype readout electronics
- MPGD Detector Modules
- Infrastructure: Test beam, magnet, and supporting devices.
- Silicon Envelope

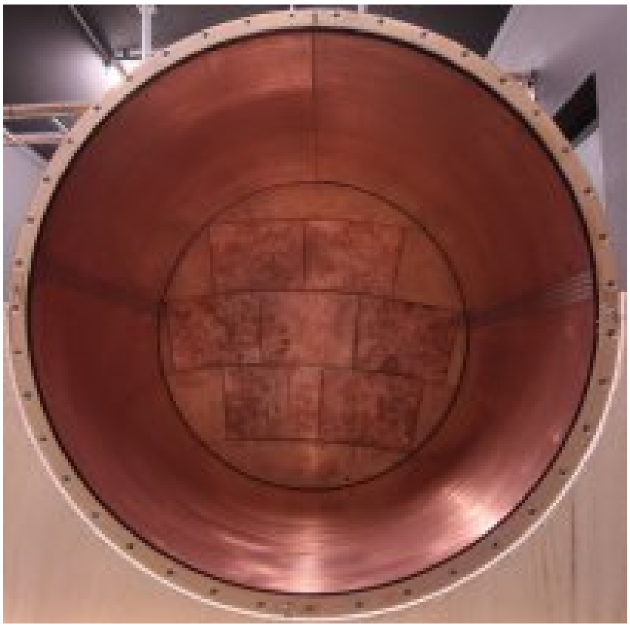

Figure 1: The LP field cage. On the back side one can see the inner part of the anode end plate equipped with seven dummy modules.

The LP has a diameter of 770 mm and a length of 610 mm. This prototype fits into a superconducting magnet (permanent current magnet, PCMAG), installed in a test beam area at DESY in Hamburg. PCMAG can be excited to a magnetic field up to 1.25 T. The test beam consists of electrons with a momentum of up to 6 GeV/c and will allow to measure tracks with the LP of up to 125 space points with pad readout. The aim of these tests is not only to enhance the results obtained with smaller size TPC prototypes to a system on a large scale, but also to understand the issues which become visible when constructing such a large TPC.

2.1 The Field-Cage

A detailed design study for the field-cage (FC) started in 2006, at the beginning of the EUDET program and is described in [4]. The outcome of the study is summarized in the following. Part of the LP is a field-cage (Fig. 1), which is made out of composite materials (Fig. 2). The materials were chosen such that they guarantee a maximum of stability, though providing a minimum of material for the traversing particles. The homogeneous electrical drift for the ion and electron clouds in the TPC volume will be provided through a series of field strips, which have to be arranged such that the relative distortions of the field are below 10^{-4} within the drift volume. This can be achieved with mirror strips that lie on an intermediate potential. The FC has been built after an extensive set of tests of its components. The tests comprised beside electrical and mechanical issues also compatibility issues with respect to the end plate which has been designed and constructed at Cornell University [5].
The field cage has been surveyed after production and delivery to DESY in the second

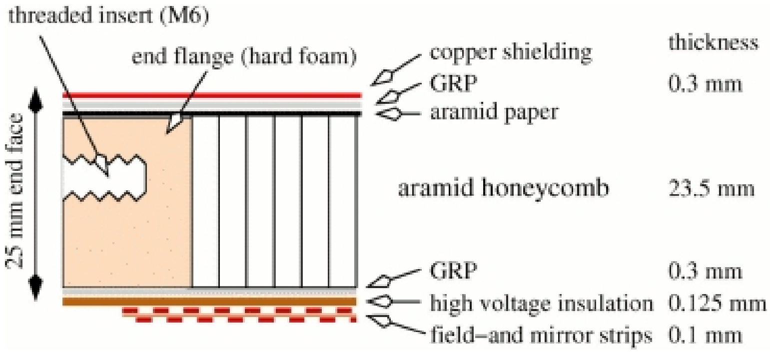

Figure 2: Sandwiched structure for the field-cage.

half of 2008. In order to achieve an electric field homogeneity of $\Delta E/E \simeq 10^{-4}$ certain requirements have to be fulfilled. From the mechanical aspect the barrel's axis should not be off its nominal direction, i.e. parallel to the field cage's wall by more than 100 μm. Another requirement is the parallelism of the anode with respect to the cathode. Here the distances should not exceed $\delta l \simeq 100$ μm at the edges from the anode/cathode.
In turned out that the axis requirement was not fulfilled and the deviation was found to be ≈ 500 μm. Calculations show that this will degrade the field homogeneity such that $10^{-3} \gtrsim \Delta E/E \gtrsim 10^{-4}$.

2.2 Anode End plate

End plates were designed such that amplification modules can be mounted in a pattern that is a circular subsection of a possible TPC for the ILC (Fig. 3). The end plates allow to position the modules to an accuracy of better than 50 μm. Several areas have been cut out in order to implement further devices for usage with the TPC, e.g. laser insertion holes.

2.3 Amplification Modules

The TPC has been equipped with MPGD readout instead of the Multiwire Proportional Chamber (MWPC). The MPGD under consideration are Gas Electron Multiplier (GEM) [6] and Micromesh Gas detector (MicroMegas) [7] (Fig. 4) with standard signal pads as well as with CMOS pixel (TimePix) readout [8] (Fig. 5). For the MicroMegas option the resistive bulk technology [9] has been used. Modules in the next future will also be equipped with gating devices in order to reduce the ion back flow into the sensitive volume.

2.4 Readout Electronics

The LP is being operated with a large number of channels that will read out the signals on either pads or CMOS pixels. The pad readout system is based on readout electronics that was developed for the ALICE experiment at the LHC: ALICE TPC Read Out

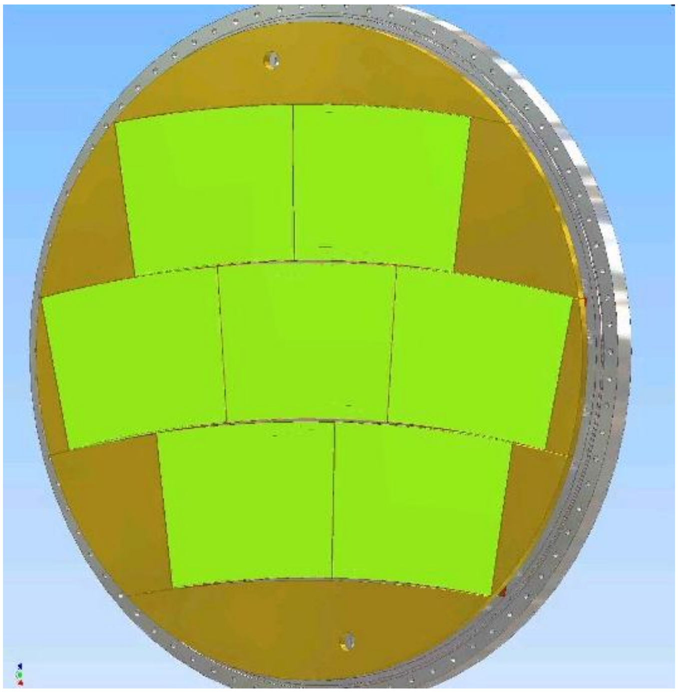

Figure 3: Schematics of the anode end plate with amplification modules and termination plates.

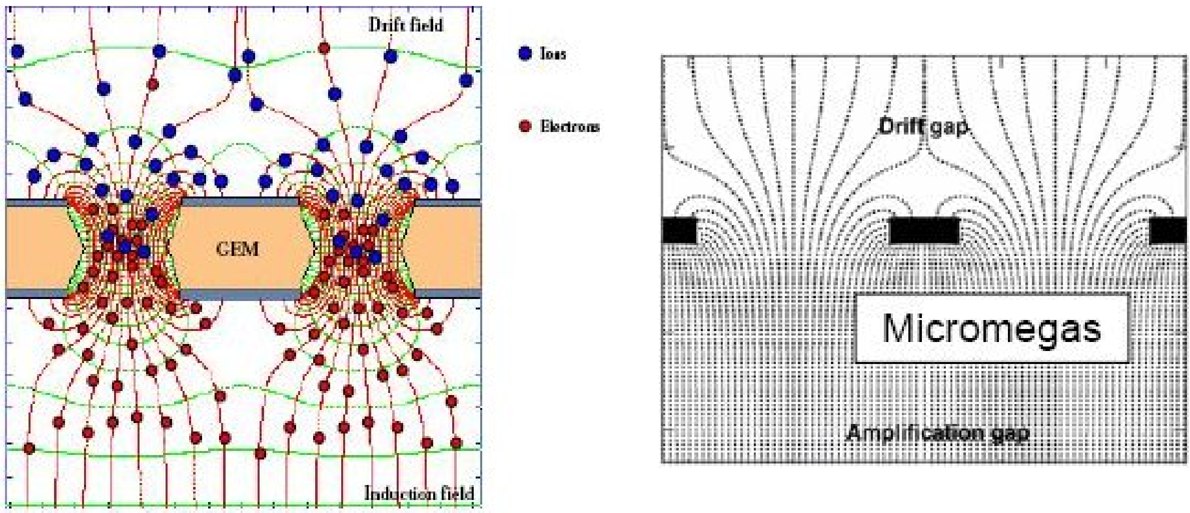

Figure 4: MPGD techniques. Left: GEM, right: MicroMegas.

[10] (ALTRO, Fig. 6). Starting with 125 ALTRO chips, which corresponds to 2000 channels, the chip will digitize the TPC signals with a sampling frequency of 40 MHz. The readout system will be extended by 1600 chips with 25 MHz sampling rate. In order to adopt this chip to the specifics of a MPGD based TPC, a new charge sensitive preamplifier has been developed (PCA16). Furthermore, a TPC readout electronics is under development in order to be tested. Here the time of arrival and charge of the

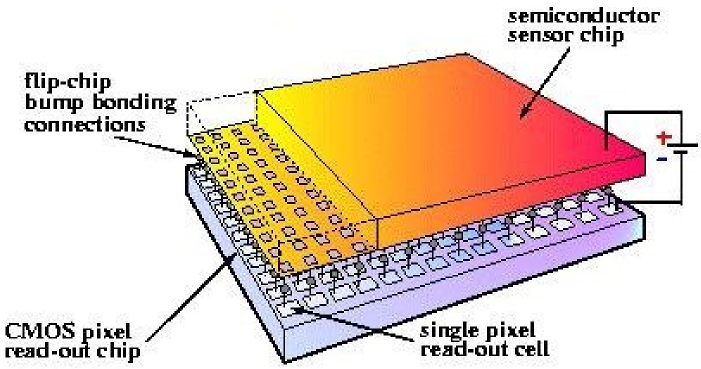

Figure 5: TimePix readout technique.

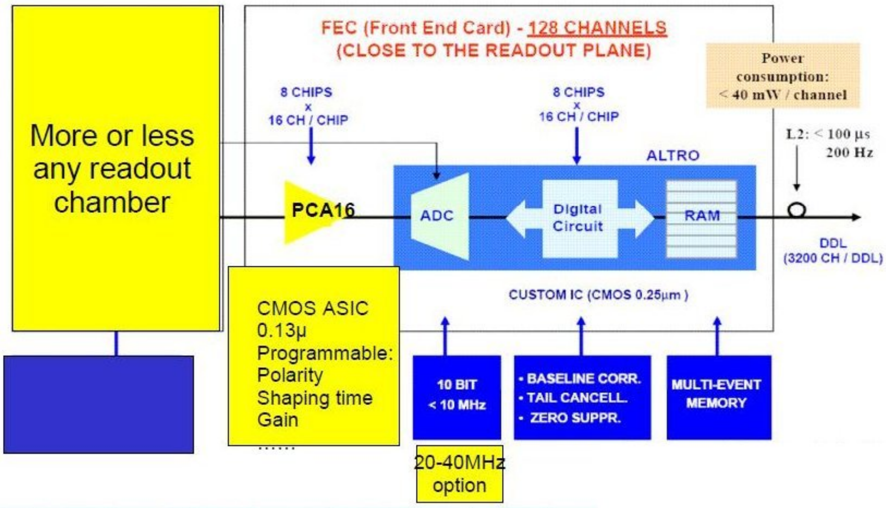

Figure 6: Schematics of the ALTRO electronics. The PASA chip has been replaced by the PCA16 chip. The AFTER electronics which will be used for the MicroMegas modules have a similar setup.

signals on the pads are measured with the help of a TDC [11] (Fig. 7). The charge is measured indirectly, with the help of a charge-to-time converter. For the MicroMegas option the AFTER-based TPC electronics [12] has been used, from T2K which has been successfully commissioned.

2.5 First Beam Test 2008

The first modular end plate was delivered from Cornell University shortly after the field cage was completed. The field cage and the the end plate was assembled and underwent a series of tests regarding compatibility and gas tightness. As the first readout a module equipped with MicroMegas/resistive anode and AFTER electronics was mounted onto the end plate.
This module was the first which was immersed to the particle beam entering DESY's

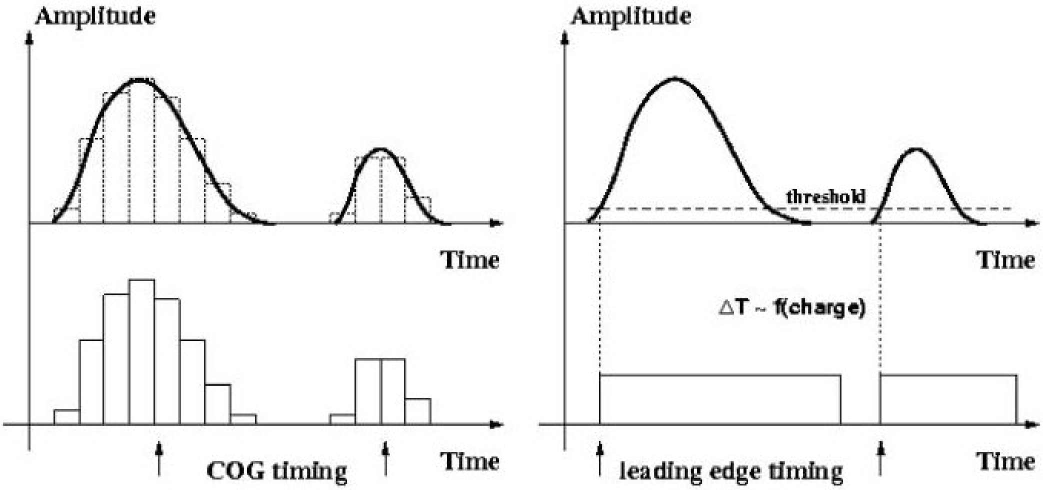

Figure 7: Principle of TDC based electronics. In contrast to the ADC based readout (left) the charge of the input signal is encoded into the width of the pulse (right).

test beam area T24/1, under an angle of $\approx 8°$ with respect to the module's central radial axis. In addition PCMAG's field was excited and bended tracks were recorded.

2.6 Beam Test in 2009

2.6.1 GEM Modules

In March 2009 three GEM modules were installed in the LP. The GEMs were produced by SciEnergy Co Ltd.[1]. In contrast to standard CERN GEMs polyimide the substrate is a liquid crystal polymer (LCP) with a thin layer of copper on its both sides which allows to laser etching the holes rather than performing a chemical etching treatment. The thickness of the LCP-GEMs is 100 μm and the hole's diameter/pitch are essentially the same as of CERN-GEMs (70/140 μm).
The modules were commissioned and test beam data were recorded for about two weeks. Another test beam campaign was performed in July 2009 with only one module mounted onto the LP.

2.6.2 MicroMegas Modules

In May 2009 a MicroMegas module with a new resistive anode was tested in the LP. In parallel the laser calibration system was setup. In August 2009 another beam test campaign has been performed where the laser setup has been tested and data have been taken. The cathode consists of Aluminum and was covered with a thin layer of copper (20 μm). A hole pattern was drilled through that layer such that the holes precisely had the projected positions of defined corners on the other side of the drift volume of the

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module's read out pads. Laser light was introduced into the LP and traveled towards the cathode. There it kicked off electrons by means of the photoelectric effect, however, only the work function of Al is low enough to release such electrons. Thus, well position defined electrons are released from the cathode's surface and travel due to the applied electric field towards the anode. In case there are no distortions the readout module will record a well defined projection of the cathode's pattern. For the case there are distortions, these distortions can be estimated and corrected for.
In November 2009 two MicroMegas modules have been installed in the LP and a test beam campaign in conjunction with two modules of silicon strip detectors (Sec. 2.8) has been started. The exercise was mainly intended to test for alignment issues.
In December 2009 two further MicroMegas modules with different resistive layers were tested.

2.6.3 GEM Modules with TimePix Readout

In June 2009 a simplified CERN-GEM module was installed in the LP and test beam data were taken with the largest number of readout channels ever. The module was equipped with a centrally mounted triple-CERN-GEM stack with an area of $10 \times 10\ cm^2$. The readout has been performed with single pixel readout cells rather than metallic pads. These pixels consist of CMOS pixel readout chips which have flip-chip bump bonded connections to the readout pixels. The pixel size is $55 \times 55\ \mu m^2$. The system used in the test beam setup comprised two quad boards with four TimePix chips each and counts a total of about 500,000 readout pixels.

2.6.4 GEM Modules with TDC Readout

In June 2009 one module comprising the LCP-GEM setup was installed in the center of the LP and was connected to about 600 channels read out with TDC. The test has been performed in order to test the compatibility of the module with different readout techniques.

2.6.5 GEM Module with ALTRO Electronics

In September 2009 a simplified GEM module with a triple-CERN-GEM stack ($10 \times 10\ cm^2$) has been connected to about 640 channels with ALTRO-electronics. Data have been taken for about two weeks.

2.7 Beam Test in 2010

2.7.1 MicroMegas Modules

In March 2010 a two week continuation of the beam tests which were lastly performed in 2009 has been performed.

2.7.2 GEM Modules

Subsequently to the MicroMegas test beam campaign a setup comprising three LCP-GEM modules was installed to a 10,000 ALTRO readout system and underwent tests for about two weeks. These tests were continued with the same setup for another two weeks in September 2010.

2.7.3 InGrid Modules

A so called InGrid (integrated grid) which is made out of a TimePix chip with Micromegas structure in wafer post processing production (photo lithography) allows for alignment of the grid. A flat surface, regular structure, and the possibility to vary grid parameters in post processing are the advantages of such a structure. A test beam campaign with a module equipped with eight TimePix chips, similar to the GEM module as described in Sec. 2.6.3 has been performed in December 2010. Data were taken for about one week.

2.7.4 GEM Modules

In December 2010 a triple-CERN-GEM stack module has been installed in the LP. This new system comprises a fully active area over the module surface and is supported by a new type of ceramic grid The grid is expected to support the three GEM layers with a minimum amount of material such that it will only cost a minimum of dead space but providing a high mechanical stability.
A first test beam campaign with such a module attached to about 1000 channels of ALTRO electronics has been performed over about one week.

2.8 Silicon Envelope

In order to have precise external reference points w.r.t. the tracks within a TPC, a set of highly accurate Si-strip modules have been deployed on the surface of the TPC (Fig. 8). They will offer a position accuracy of $\sim 15\ \mu m$ in $R\phi$ as well as along the TPC-axis.
First beam tests have been performed and the analysis for alignment procedures are ongoing.

3 Infrastructure

3.1 Test beam Area

The DESY II accelerator is providing electrons/positrons with energies up to 6 (7) GeV and an intensity of $\sim 10^3\ Hz/cm^2$ [13]. The particles in the test beam areas emerge from converted Bremsstrahlung beams due to 7 μm carbon targets in the DESY II beam pipe and subsequent collisions with targets on the way to the test beam areas. The produced electrons/positrons experience a dipole magnet, which controls the energy and spreads

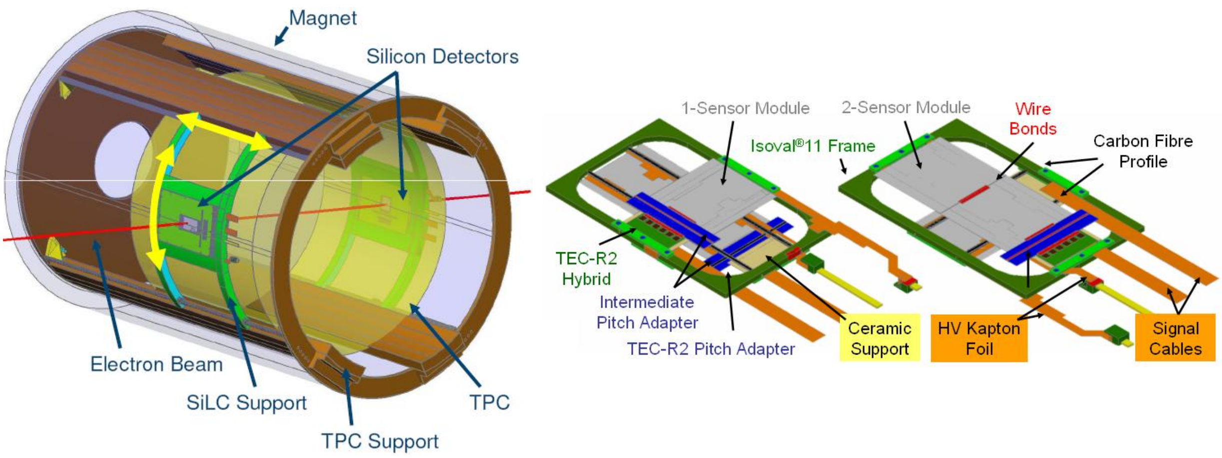

Figure 8: Silicon detectors which are mounted on a support structure around the LP (left) and a zoom in of the Si-modules (right).

the beam out into a horizontal fan. Eventually a set of collimators form the beam for usage in the test areas.
The electrons in the test beam area are minimum ionizing particles (MIP), their energy distribution is nearly flat and the Bremsstrahlung spectrum has an $1/E$ dependence. Typical particle rates in the test beam area can be seen in Table 1.

Energy / GeV	Rate (3mm Cu) /Hz	Rate (1mm Cu) /Hz
1	330	220
2	500	330
3	1000	660
5	500	330
6	250	160

Table 1: Estimated particle rates from DESY II.

3.2 Superconducting Magnet PCMAG

The LP is placed in a superconducting magnet PCMAG, which is provided by KEK. PCMAG is a rather lightweight magnet: a low mass coil and no return yoke make its weight to be 460 kg. It has a usable diameter of about 85 cm and the usable length is about 130 cm. Its 3342 windings with an operating current of 480 A provide a magnetic field density of up 1.25 T in the center region of the magnet. The field is homogeneous within 3% in the region of ± 30 cm of the center, whereas larger deviations are expected in the remaining region (Fig. 9). This, however, allows for establishing correction tests during operation.
The magnet is operable and was tested twice within the DESY II T24/1 test beam area. A field measurement was performed in July 2007 and the proper determination of the

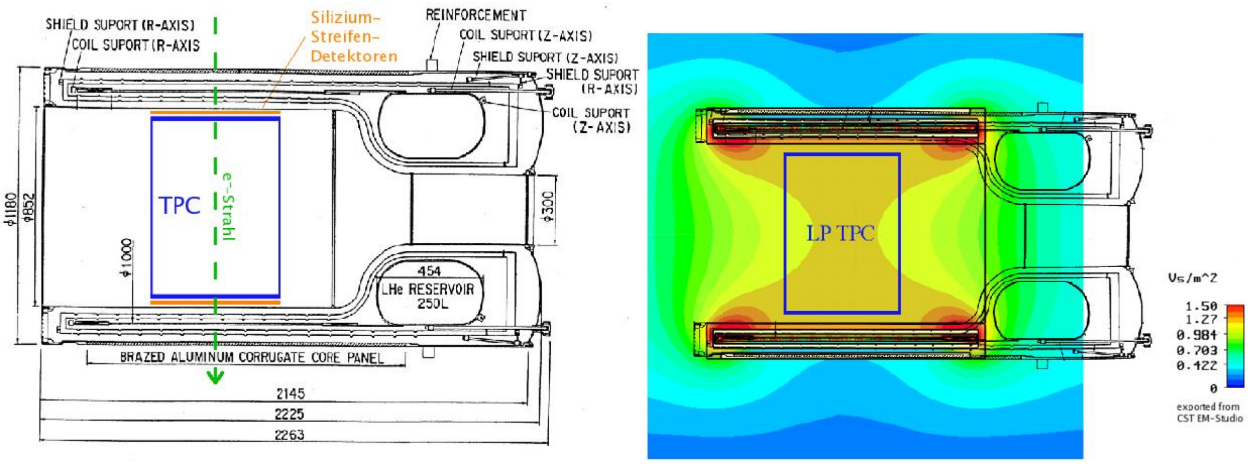

Figure 9: Schematic drawing of PCMAG and its field density distribution.

field map has been performed [14].
In the middle of 2011 the magnet will be shipped to Japan to undergo a modification with respect to its liquid Helium supply which is expected to last about 6 months. It is foreseen to upgrade the system such that there will be no more need to refill the magnet after short periods with liquid Helium. The upgrade will consist of the installation of cryo-coolers and attached Helium gas compressors. A water chiller will be installed in order to cool the compressors.
The advantage of the system will be that once the magnet has a filling of liquid Helium the evaporating Helium will be liquefied again by the cryo-coolers and a non-interruptive operation can be established.

3.3 Supporting Devices

A set of supporting devices has been installed in order to obtain flexibility in the test beam setup. The TPC itself has to be inserted into the bore of PCMAG. There it needs to be moved in order to make "use" of the magnetic field in-/homogeneity. Since the inner wall structure of PCMAG is rather thin (1 mm), the TPC has to be supported independently. This has been achieved by a rail system which is implemented in a cylinder. The cylinder is attached to the frame of PCMAG.
Since the beam is fixed in space one needs to move the TPC in order to make use of its full drift volume. Therefore the magnet has been installed on a movable stage that allows lifting, sliding, and rotating the whole system, PCMAG and TPC (Fig. 10). The movement is controlled by a set of motors and the position is measured by linear glass scales.
This stage has been finalized and installed in 2009 such that test beam campaigns from then could be conveniently performed.

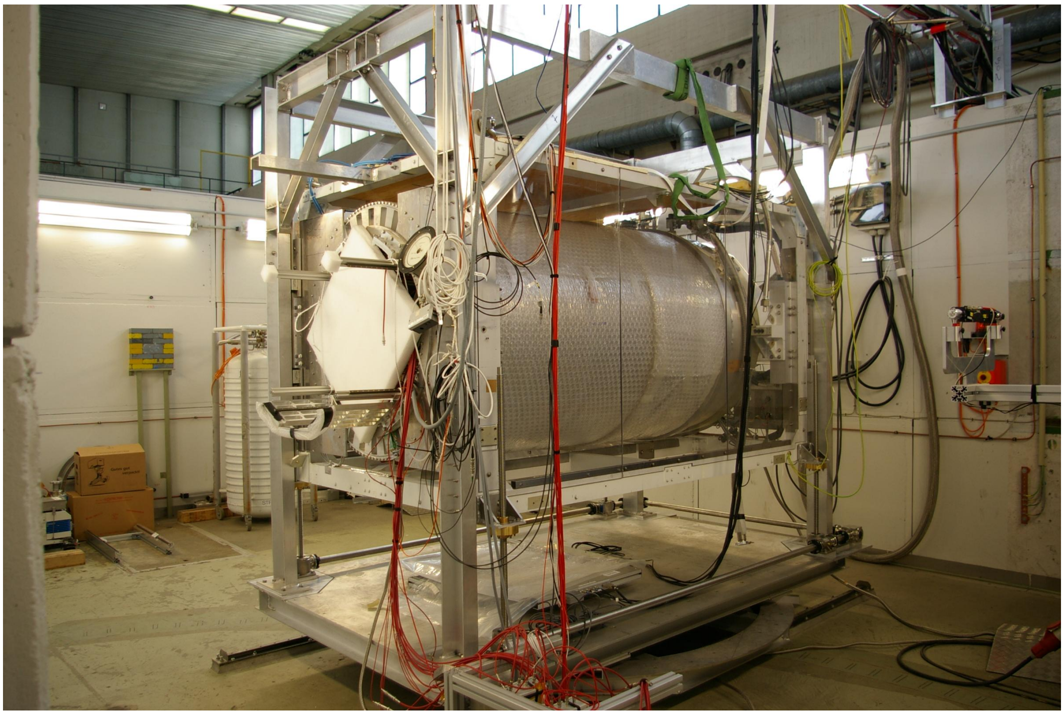

Figure 10: Movable stage around the magnet PCMAG in DESY's testbeam area T24/1.

3.4 Developments

For the electronic readout of the various MPGD modules one needs to miniaturize the existing electronics. The current scheme has a chain which consists separately of an analog front end, an ADC, and digital processing units. R&D has been started to implement all these devices in a single chip based on ALTRO electronics. The current design exists with a PCA16 connected to ADCs and afterward to a digital processing unit based on a two-channel-prototype.
Future plans are to adopt the design to a real geometry, understanding the heat production and cooling issues, as well as a power pulsing scheme. For the latter an FPGA prototype has been already developed by a Japanese group.
A so called S-ALTRO16[2] electronics prototype is being worked on so that

- the prototype pad modules will fit into the present end plate;
- the chip size is compatible with a realistic pad size;
- power pulsing can be implemented and a solution for effective cooling can be found;
- a realistic noise level can be achieved;
- the experience with S-ALTRO16 will guarantee a safe move to a final S-ALTRO64 design.

[2] 16 stands for the number of readout channels per chip.

In order to circumvent possible problems with this compact design it is proposed to use a system with multi chip modules (MCM). All items listed above can be kept, however, reducing the risks due to its more conservative approach can be achieved. Its modular structure allows re-design of the readout chain without affecting the pad board.

4 Summary

A field cage, cathode end plate, and cathodes have been delivered as EUDET projects so that a large prototype of a TPC could be constructed. Furthermore an anode end plate with MPGD modules was installed, a total of 10,000 channels of ALTRO electronics respectively 1800 channels AFTER electronics are in use. The LP is a testing bed for several readout techniques based on MPGD in connection with a test of mechanical feasibility of a large TPC. A total of 24 weeks of test beam operation has been performed so far and more tests are planned for the year 2011/12. More than 10M events have been recorded which corresponds to more than 2 TB data stored on the grid. The data is currently being analyzed.
A first alignment run with a prototype of the planned Silicon Envelope Tracker has been performed.
A sophisticated ensemble has been established in order to perform R&D whose goal is to obtain confidence that a TPC with MPGD readout will be a suitable central tracking device for an ILC detector.
R&D on S-ALTRO has been started in order to develop a compactified readout system that can be conveniently placed on the back side of each readout module.

Acknowledgment

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.

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