EUDET: Detector R&D Towards the International Linear Collider[1]

I.M. Gregor, J. Mnich[2]

December 03, 2008

Abstract

EUDET is an initiative supported by the European Union to improve infrastructures for detector R&D, in particular for the International Linear Collider (ILC). The project is focused on providing support for larger scale prototype experiments as well as on facilitating collaborative efforts. It encompasses developments for vertex detectors, gaseous and silicon tracking, and highly granular electromagnetic and hadron calorimeters. In total 32 European institutes participate in the project. 27 other institutes in Europe and abroad are associated members and linked to the progress and later exploitation of the infrastructures. EUDET is closely linked to the international R&D collaborations for a future ILC detector. The R&D infrastructure programme is described and some results of the R&D efforts are presented

[1] Presentation at the IEEE 2008 Nuclear Science Symposium and Medical Imaging Conference, Dresden, October 2008

[2] DESY, Hamburg, Germany

1 Introduction

Over the past years the detector several candidate technologies for vertex and tracking detectors and calorimetry were identified which meet the challenging demands for the physics at the ILC. Currently, the R&D effort enters into a phase where these technologies have to be extended to larger prototype detectors in order to verify their feasibility and to optimize the overall detector performance. The EUDET project [1] with support from the European Union provides a framework for the development and construction of larger prototypes for ILC detector technologies. The project started in January 2006 and encompasses the design and construction of infrastructures for vertex and tracking detectors as well as electromagnetic, hadronic and forward calorimeters. It runs over a duration of four years. Most of these infrastructures will initially be commissioned at DESY but they are designed to be movable such that they can later be exploited at other laboratories across Europe and abroad. In order to have more time for the exploitation of these infrastructures an application for an extension of the project was recently submitted to the EU. The contract amendment is still pending.

Even though EU funding can only be allocated to European groups, the project is open to world-wide collaboration. Several non-European institutes are associated and contribute to the design and construction of the infrastructures anticipating their subsequent exploitation.

2 Project Overview

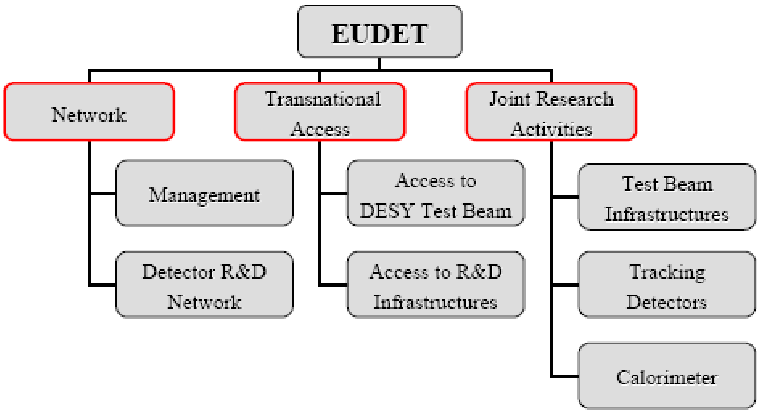

Fig 1: Layout of the EUDET project.

EUDET is an Integrated Infrastructure Initiative in the sixth framework programme (FP6) of the European Union [2]. The project started beginning of 2006 and runs over a period of four years. The total budget amounts to 21.5 million € out of which 7 million are contributed by the European Commission. It assembles 28 contractual partners from 32 European universities and laboratories working on detector R&D for a linear collider experiment. In addition 27 associated institutes worldwide participate in the design and construction of the infrastructures as well as their subsequent exploitation. The organisation of the project is shown in Fig. 1. It is based on three activities, Network, Transnational Access and Joint Research Activities. Networking between the partner institutes is particularly important. It addresses research topics of a broad interest. The joint research activities (JRA) specifically focus on the design and construction of the infrastructures. Transnational access activities support European groups in the scientific use of the infrastructures. The three activities are organised in several work packages or tasks. Examples of these tasks, their status and plans, are discussed below.

3 Detector R&D Network

The establishment of a detector R&D network identifies the collaboration of the respective research group in Europe. For example, all infrastructures are designed in international collaborations with appropriate communication and management structures. The development of a common simulation and analysis framework is also part of this activity. This includes the analysis of the data of upcoming test beam campaigns of individual detectors as well as combined experiments, but also contributions to the simulation work required for the design of the ILC detectors. A successful project within this activity is the common analysis software ANALYS: it is a software framework for the analysis of the data recorded at EUDET test beam experiments. ANALYS is tightly integrated with the overall ILC detector R&D software framework that is being used in the optimization of the global ILC detector concept. This approach provides important synergies for both communities. For example EUTelescope is a package within ANALYS targeted at the reconstruction and analysis of the data from the pixel telescope (see section 4). It provides functionality for calibration, alignment and data reduction as well as for pattern recognition and determination of the resolution of the pixel telescope itself. However, it is also used by other collaborations for the analyses of their test beam data [3].

The network is complemented by work on the improved simulation of hadronic showers incorporating test beam results from highly granular calorimeters and by access to state–of–the–art deep-submicron technology for chip development as required for almost all modern particle detectors. An easy-to-use, customized design kit has been developed. Training courses are also organized within the project. This engineers and technicians from smaller laboratories can participate more easily in the development of modern deep-submicron electronics.

4 Test Beam Infrastructure

The joint research activity (JRA) on test beam infrastructure consists of a large bore super conduction magnet and a high-precision beam telescope. The magnet supplied by the associated partner KEK (Japan) provides a field of about 1 Tesla in a bore of 85 cm diameter. It possesses a light coil and a stand-alone Helium supply thus making it ideally suited for experimentation in a test beam. The cooling and control infrastructure was constructed using EUDET funds. It has been set up at DESY in close collaboration with KEK. The magnet is available for experiments in the test beam area since summer 2007.

The scientific exploitation of the magnet, for instance for tests of a high precision TPC, requires the knowledge of the magnetic field inside the magnet with a precision of 10^{-4}. Measurements of the magnetic field were done in summer 2007 and the data analysis was finalized recently. Fig.2 shows a photograph of the magnet during the field mapping measurement campaign. The field map, shown in Fig.3, is known to a few Gauss depending on the region of the magnet. The final field model is a composition of two components: The coil model with a minimum set of parameters using the coil geometry and the Fourier Bessel series with a total of 234 parameters. The field map will be available within the MarlinTPC software framework. Within this framework the field map can be provided an analytical description using the models and parameters obtained from the analysis or as a 3 dimensional grid using interpolation.

Fig 2: EUDET magnet at the DESY test beam line with field measuring

A multilayer pixel telescope with CMOS sensors is under construction with the potential of a space resolution of about 1 µm. The telescope itself consists of six layers of MAPS pixel detectors as well as a versatile DAQ system with well defined interfaces easily adaptable to the needs of other detectors which are installed inside the telescope for reference measurements (see section VII). A first version of this telescope as shown in Fig. 4, is available since summer 2007 and was tested successfully in test beams at DESY and CERN. In summer 2008 the device was intensively used by five different groups at the CERN SPS test beam. 50 million tracks were taken during that period. Its performance and first results are described in more detail in reference [4]. Currently, a fully digital device with increased readout speed is under construction. It will to be available beginning 2009.

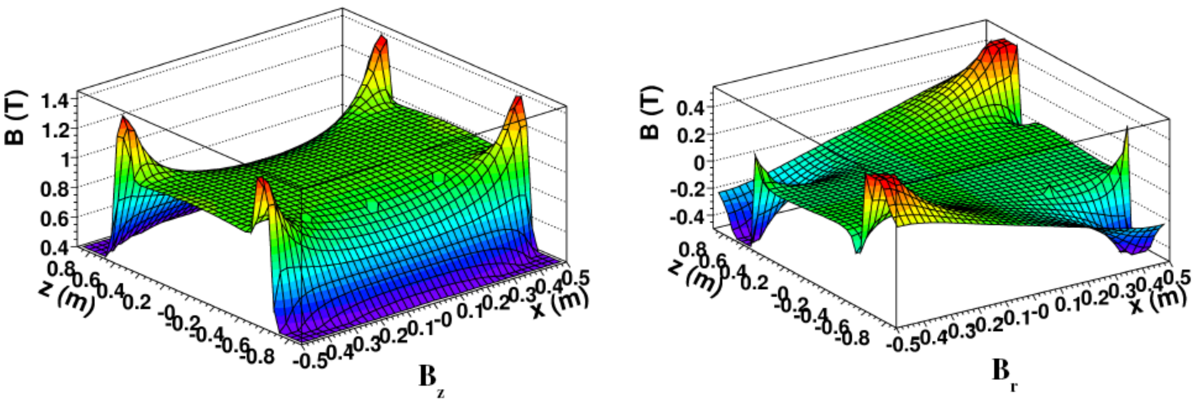

Fig 3: Final field map of the superconducting magnet PCMAG

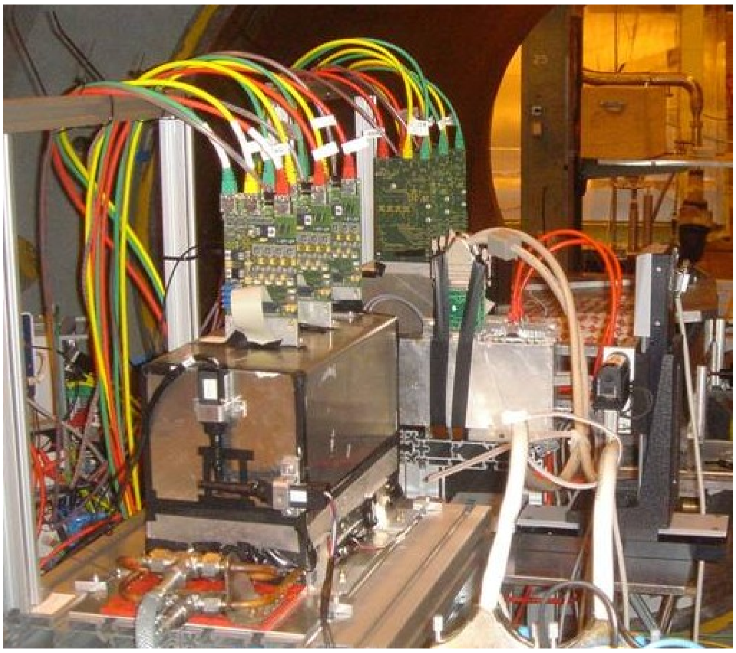

Fig 4: The EUDET beam telescope during measurements at the CERN test beam.

5 Tracking Detectors

The two main technology options for the main tracker of the ILC detector, Time Projection Chambers (TPC) and silicon strip detectors, are part of the EUDET programme. A large TPC field cage is under construction to be equipped with GEM or MicroMegas-based readout structures which have demonstrated their potential to achieve single point space resolutions of 100 μm or below in small prototypes. To this aim the field cage will be equipped with a modular endplate to receive large surface area gas amplification structures. The large prototype field cage was designed, constructed, and delivered to DESY a few weeks ago. Fig. 5 shows the field cage shortly after delivery at DESY. The development of modern readout electronics adapted for micro pattern gas detectors is also part of the TPC project. The readout system for the large prototype is based on the readout electronics developed for the ALICE experiment at the LHC. The main part of this system is a fast analog-to-digital converter. This ALTRO chip will digitizes the TPC signals with a sampling frequency of 25 MHz. In order to adopt this chip to the specifics of the TPC readout with micro-pattern gas detectors, a new charge sensitive pre-amplifier has been developed. The so-called PCA16 chip is a programmable charge sensitive device, which integrates 16 channels into one package. It has a programmable peaking time between 30 and 120 ns, and a programmable gain in four steps between 12 and 27 mV/fC. Enough chips are available to equip the large prototype. The TPC infrastructure has been fully designed and will become available in spring 2009. Thus test beam experiments with large surface GEM and MicroMegas amplification structures in a high field magnet will be possible. Details of the development of the large prototype can be found in [5].

Fig 5: Large prototype field cage at DESY

The TPC developments are complemented by the development of a silicon pixel based readout using the TimePix chip. It combines the ultimate resolution of a pixel device with a drift time measurement resulting in three-dimensional tracking capabilities. The goal is to develop and construct a TPC diagnostic module with DAQ system providing the best possible imaging of tracks, thus improving the understanding of gaseous tracking related issues.

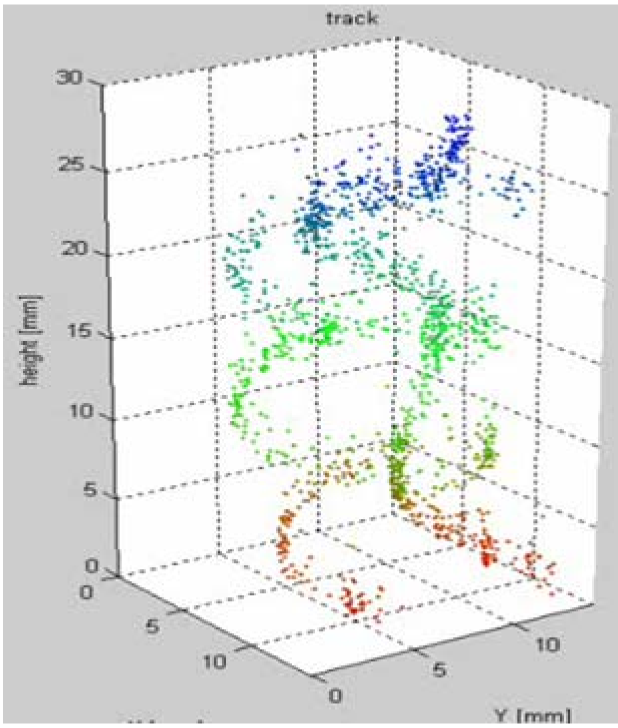

Fig 6: Timepix SR90 signal in magnetic field

First TimePix prototypes are operational since the end of 2006. They show excellent performance [5]. A TimePix chip, protected with a thin layer of aSi:H and combined with an integrated gas multiplication grid has proven to be a viable candidate for readout of a TPC. Detailed studies were initiated on a large variety of geometries for the integrated grid structures (gap, hole dimensions and shapes) in order to optimize the single electron detection performance and at the same time limit the ion backflow. Fig. 6 the output from a TimePix in a magnetic field from a Sr^{90} signal is shown.

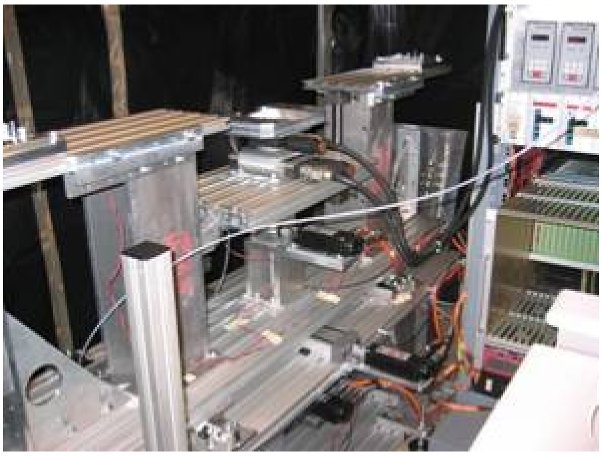

Fig 7: 3D motorized table for silicon module tests

The development of a large silicon strip tracking detector is also supported within this activity. In the framework of EUDET large and light mechanical structures for the silicon strip detectors are developed. This includes prototypes for cooling and alignment systems as well. A 3D motorized table was built (Fig. 7) for use at laboratory test benches and at test beams for small size Silicon tracking prototypes. It allows very fine step movements (20 µm) in three spatial directions. A LabView-based programme allows piloting the movements as part of the data taking. In addition, the design of multiplexed deep-submicron front-end electronics is supported. Also significant progress has been achieved since the start of the project in this area.

6 Calorimeter Infrastructure

The anticipated physics at the ILC requires calorimeters with unprecedented energy resolution, in particular for jets. Particle-flow algorithms based on highly granular electromagnetic and hadronic calorimeters are considered to be promising candidates to achieve these goals. In EUDET scalable prototypes for these main calorimeters are developed and constructed, together with developments of silicon sensors and calibration systems.

Fig. 8 shows the design of the tungsten absorber structure for an electromagnetic calorimeter which will partially be constructed from EUDET funds. It will be the basis for important studies towards the ILC detector calorimeter. The power dissipation of the readout electronics which is completely embedded in the detector is among the critical design issues. The low duty cycle of the ILC (0.5%) can be exploited to power-pulse the electronics avoiding cooling systems which would deteriorate the calorimeter performance. EUDET will allow for large-scale studies on these and other R&D issues. The active Silicon sensors to be placed in the gaps are matrices of 18x18 pixels of 5x5 mm^2 obtained from a 6 inches 300µm thickness wafer. 30 wafers were recently delivered and characterized with IV and CV curves. The wafers are glued on special printed circuit boards (PCBs) of 18x18 cm^2 with minimal thickness (800 µm) to also house the readout Asics. It was shown that these Silicon sensors fulfil the requirements, but further manufacturers are still under consideration [6].

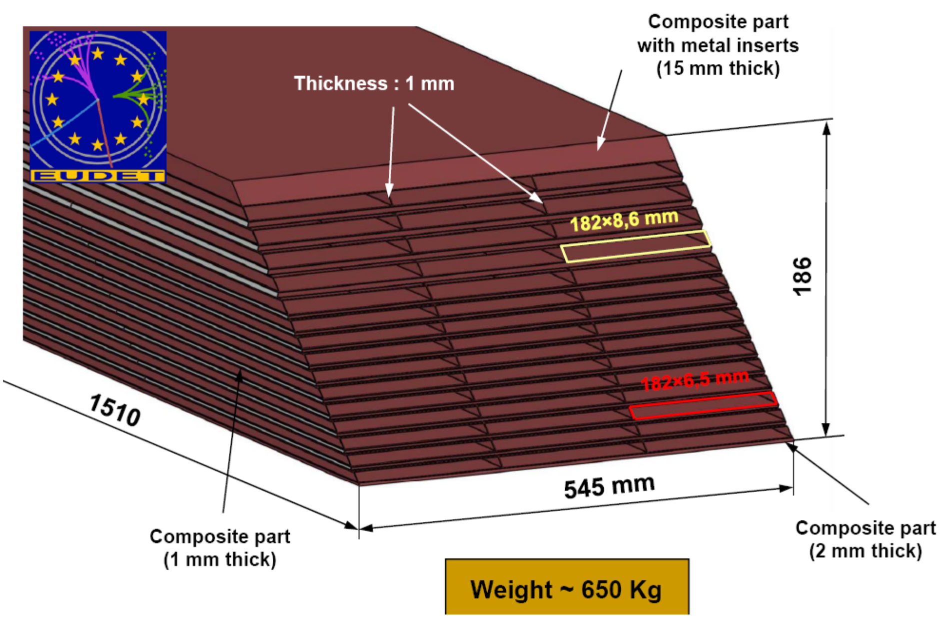

Fig 8: Design of a scalable tungsten based absorber structure for the development of an ILC electromagnetic calorimeter.

A similar detector architecture with embedded electronics is foreseen for the hadron calorimeter. It requires the development of very front end readout electronics Asics for electromagnetic and hadron calorimeters on a common platform and a unified DAQ system. The board in the volume is subdivided into "base units" of manageable size, each carrying four front-end Asics. The footprint of the SPIROC ASIC prototype, which was produced in 2007 within the EUDET project, was incorporated, and a solution for the inter-connection of the boards was found and prototyped. Control and communication electronics for data transfer, calibration steering and power distribution are designed in this modular approach as mezzanine boards located in the accessible periphery of the layer [7].

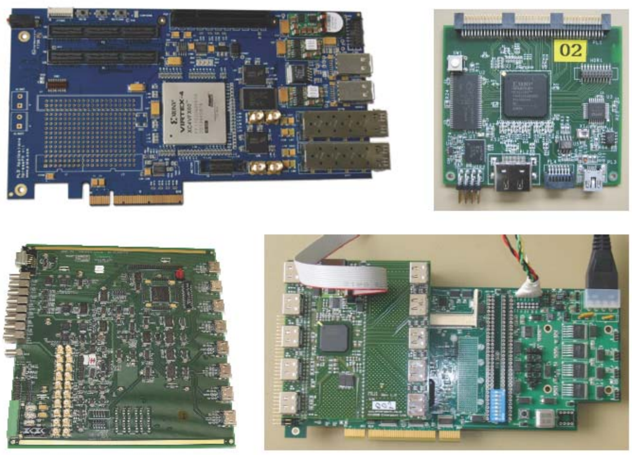

Fig. 9: Control and communication electronics as mezzanine boards.

The project also includes positioning and calibration systems for the very forward calorimeters. This is complemented by the development of a common front-end electronics and data acquisition system for all calorimeters. Several electronic chips have been developed in EUDET for the calorimeter and are now under test. The full calorimeter infrastructure is expected to be available in 2009.

Also within the calorimeter task new front end electronics adapted to different detectors was developed. The first three prototype Asics have been fabricated: HaRDROC (Hadronic RPC detector Read Out Chip) for the Digital Hadronic Calorimeter (DHCAL) which contains 64 channels and the full readout scheme, common to all EUDET calorimeters. SKIROC (Silicon Kalorimeter Integrated Read Out Chip) for the electromagnetic calorimeter (ECAL) integrates 36 channels of low noise charge preamps, bi-gain shaper, analogue memories and 16 bit Wilkinson ADC. SPIROC (Silicon Photomultiplier Integrated readout Chip) which contains 36 channels of low noise amplifiers, auto trigger, digitization over 15 bits and on chip token-ring readout scheme. More versions of this front end chips are in the design phase.

7 Transnational Access

The EUDET infrastructures are open for use by other interested international groups which perform R&D on particle detectors for the ILC, other high energy physics projects or other scientific research work. In the framework of the transnational access instrument which is part of this EU programme travel support to European groups using the installations can be provided. The goal is to encourage transnational European collaboration and to stimulate the use of research infrastructures by groups based in other European countries.

Infrastructures open to EUDET transnational access are the DESY [8] electron test beam and the infrastructures developed and constructed as part of the EUDET project: the beam telescope, the TPC prototype, the silicon TPC diagnostic endplate, silicon tracking as well as the calorimeter infrastructure. Interested users can apply for access and travel support using a web-based interface [1]. Projects are evaluated based on a short scientific proposal. It should be noted that support in the transnational access scheme is open to all scientific projects and not restricted to specific ILC-related applications.

8 Conclusions and Summary

This paper summarizes the EUDET project and discusses the significant progress achieved since its start in 2006. Examples of achievements are the TimePix chip, the commissioning of the large bore magnet and the first operational version of the beam telescope. In 2008 most of the remaining EUDET infrastructures are to be completed such that they can be fully used. The project is embedded in international ILC detector R&D collaborations such as CALICE [9], LCTPC [10] and SILC [11]. It provides additional funds for European partner institutes for ILC detector R&D and through the transnational access scheme can support other groups in their research for the ILC and beyond. Most importantly for the ongoing phase of the R&D programme which is focusing on larger detector prototypes EUDET has played an important role in establishing and fostering collaboration in Europe and has also made major contributions to the international R&D efforts. At around mid-term the project is well on track with major milestones already accomplished.

Acknowledgement

This work is supported by the Commission of the European Communities under the 6th Framework Programme "Structuring the European Research Area"; contract number RII3-CT-2006-026126.

References

[1] URL: www.eudet.org
[2] URL: cordis.europa.eu/fp6/
[3] J. Furletova, "The Integration of DEPFET into the EUDET Telescope", presentation at the IEEE 2008 Nuclear Science Symposium and Medical Imaging Conference, Dresden, these proceedings.

[4] D. Haas, “The EUDET Telescope – Towards the final digital readout”, presentation at the IEEE 2008 Nuclear Science Symposium and Medical Imaging Conference, Dresden, these proceedings.
[5] K. Dehmelt, “The Large TPC Prototype for an ILC Detector“, presentation at the IEEE 2008 Nuclear Science Symposium and Medical Imaging Conference, Dresden, these proceedings.
[6] R. Poeschl, „Response of the CALICE Si-W ECAL Prototype to Electrons“, presentation at the IEEE 2008 Nuclear Science Symposium and Medical Imaging Conference, Dresden, these proceedings.
[7] B. Hommels, “Data Acquisition Systems for Future Calorimetry at the International Linear Collider“, presentation at the IEEE 2008 Nuclear Science Symposium and Medical Imaging Conference, Dresden, these proceedings.
[8] Details on the DESY test beam facilities can be found at the URL: testbeam.desy.de
[9] URL: http://polywww.in2p3.fr/activites/physique/flc/calice.html
[10] URL: http://alephwww.mppmu.mpg.de/~settles/tpc/lp/lp.html
[11] URL: http://silc.in2p3.fr/