



JRA1 – The Demonstrator in 2008 and Telescope Outlook

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Abstract

The EUDET JRA1 demonstrator was commissioned in summer 2007 and since then heavily used by different groups. In this memo the overall status of the EUDET Telescope as of summer 2008 will be given. The experiences of the different users will be summarised. At the end of the report the option of a second telescope will be discussed and an outlook on the plans for 2009 will be given. This is a summary of the plenary talk given at the EUDET Annual Meeting in Amsterdam, October 2008.

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1 Introduction

Within EUNET JRA1 a test beam telescope was developed. It will provide a high precision of better than $3 \mu\text{m}$, even at the lower energies available at the DESY test beam facility. In addition to high precision, a high readout speed and easy handling is of importance.

The project is divided into two phases. During the first phase a first test facility with analogue readout and a low readout speed was built. This is the so-called demonstrator telescope. This gave the opportunity to check the design and to have a first telescope quickly available for the groups working on detector R&D. The use of an established pixel technology with analogue readout and no data reduction gave the possibility to have such a telescope ready on a very short time scale. The Demonstrator was ready for test beam early summer 2007 and since then used at DESY and CERN in the test beam by many different users.

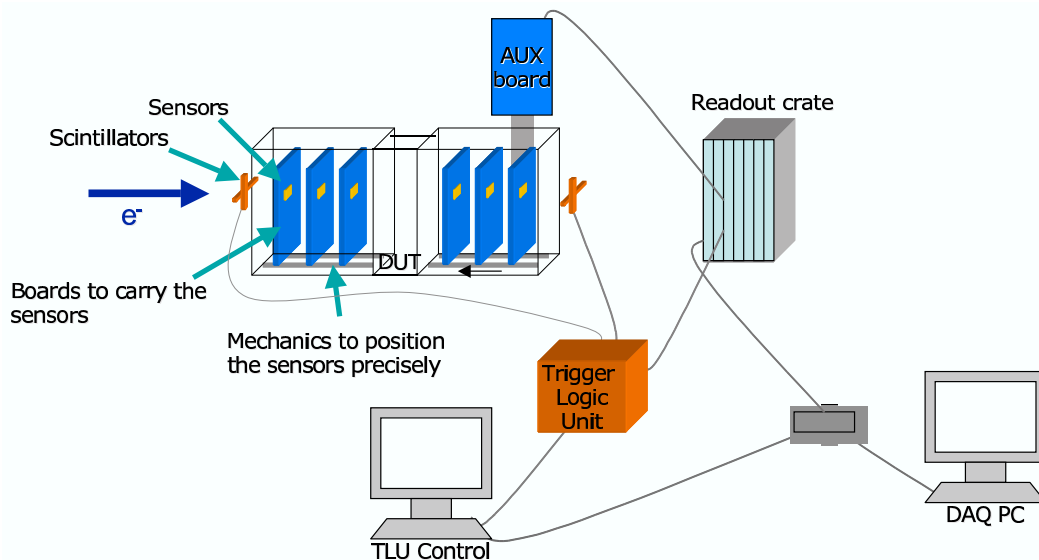


Figure 1: Overview of the ingredients needed for an analogue telescope.

In Figure 1 all "ingredients" a pixel telescope are shown. All components are available since beginning of 2007 and the telescope is running in user mode since September 2007. Following hardware elements are the main parts of the telescope:

- MimoTel Sensors with 256×256 pixels and a pitch of $30 \mu\text{m}$. These chips were developed at IPHC Strasbourg.
- Precisely worked mechanics to position the sensor boards in the particle beam.
- The EUDRB readout boards developed at INFN Ferrara.
- A MVME 6100 VME CPU.

- The Trigger Logic Unit developed at Bristol University.
- As DAQ Computer a MAC Pro with 4×1 TB raid array for data taking.

During phase 2 the analog telescope will be completed by a fully digital sensor chip and the DAQ hardware adapted to the final sensor chip.

2 Reference Plane Sensors: MimoTel

As sensors for the reference planes the MimoTel prototype is used. This is a chip processed in the AMS 0.35 OPTO process with 14 and 20 μm epitaxial layer. It is subdivided into four sub-arrays of 64×256 pixels. The pixel pitch is $30 \times 30 \mu\text{m}^2$ resulting in an active area of $7.7 \times 7.7 \text{ mm}^2$. The layout of the reticle is shown in Figure 2. For detailed information on this chip please refer to [?].

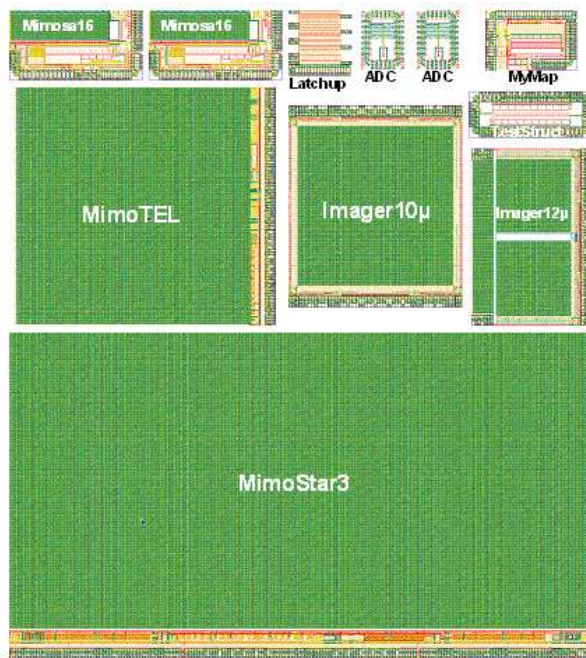


Figure 2: Layout of the reticle of the engineering run AMS-035 OPTO 07/2006 on 14 μm (standard) and 20 μm epi substrate

In the CERN test beam 2008 for the first time six sensor planes were running simultaneously. Before the sixth plane was also available, but not read out due to a problem in the VME crate.

3 Data Acquisition

The main challenge of this telescope is the integration of the different DAQs. The typical telescope users will bring their own DAQ and should not need to invest time in rewriting code or reconfiguring the hardware. A “plug-and-play” system would be desirable. Therefore we offer two different ways to integrate the user’s DAQ:

- the easy solution at the trigger level
- the full integration at DAQ level

The first option the synchronisation is done with the Trigger, Busy and Reset signals distributed by the Trigger Logic Unit (TLU). The readout software, DAQ and data storage for the DUT is provided by the DUT user. The events are then combined offline.

The second option is the by JRA1 preferred option as the data is directly in one stream and tools as the RootMonitor [?] can be used to check the correlation of the two different systems. It also eases the offline analysis with the EU Telescope software. This option was already chosen by two users in summer 2008.

The additional hardware in order to combine DUT and telescope is the trigger logic unit (TLU) which receives the trigger and passes it into the telescope and DUT. It vetoes further triggers and records the timestamp. The TLU was developed and tested and is available for the integration.

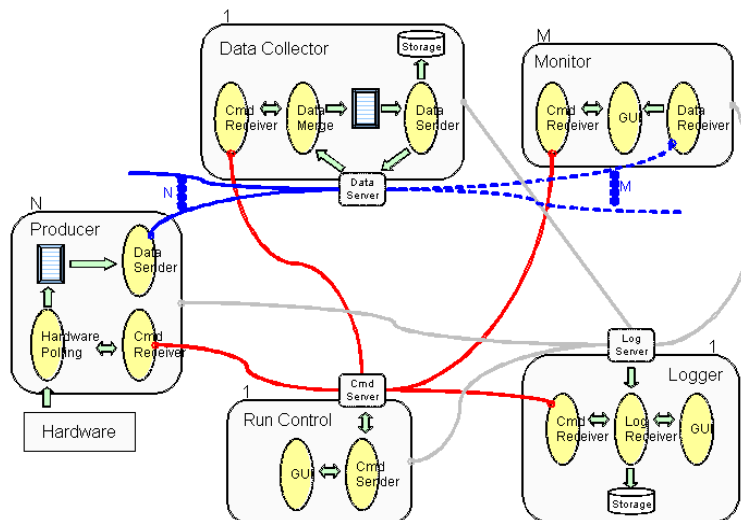


Figure 3: Organigram of the DAQ software.

The basic idea for the DAQ software was to create a simple and easy to use DAQ system for the beam telescope and distributed across multiple computers. The software framework was inspired by the DAQ software written by the DEPFET group in Mannheim and Bonn.

The custom DAQ is platform independant (MacOSX, Linux, Windows), object oriented, distributed and multithreaded. The system is highly modular, but light-weight. The main Run Control GUI was implemented using Qt, and the Online Monitor uses Root. The organisation of the DAQ software is shown in figure 3. It is highly modular, allowing DUTs to be easily integrated into the framework. One main Run Control controls the DAQ:

- Controls all the other applications

Producers:

- Communicate with hardware and send data to Data Collector

Data Collector:

- Collects and merges data from all Producers

Monitor:

- Receives data from Data Collector for display/statistics

Logger:

- Collects logging messages from all other applications

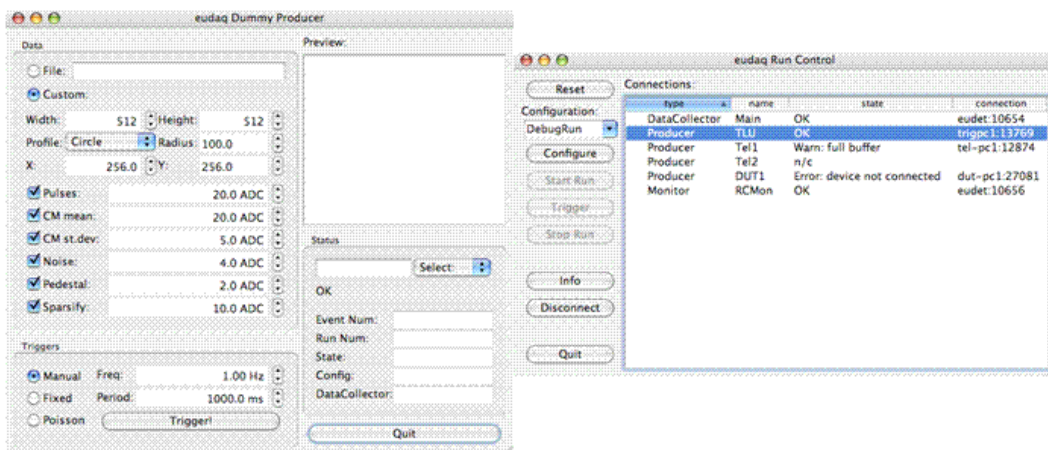


Figure 4: Screen shot of the DAQ software for the DESY test beam.

It was decided to use LCIO/Marlin for data storage and processing. Currently data is transferred internally and stored on a local RAID array in a custom binary format. It is then manually copied to the GRID for conversion to LCIO, and then clustering and tracking is performed. The option to write directly in LCIO was also implemented and tested, but for the time being we continue to use our native data format in order to store some additional information. In figure 4 screen shots of the DAQ software are shown.

Recent improvements:

So far the readout speed of EUDAQ was rather slow (<50Hz during spill). The reason for this lack of speed was identified in the switching process between the different VME slots. Each switching used 2ms for remapping of the VME address space. This was due to the VME driver which was not optimised for many switches between slots. By redefining the address space the problem was solved. An improved readout rate of 400Hz for the full demonstrator telescope expected is expected but needs to be confirmed.

Further improvements for the next couple of months:

- DAQ stability
- Easier integration of users (generic RawDataEvent)
- Compatibility with 64-bit Linux
- Support for new TLU
- Automated copying to GRID and data production

4 Mechanics

Based on detailed analytical calculations [1], and also for redundancy and flexibility, it was decided to provide six telescope planes. The telescope will be subdivided into two arms of 3 sensors each, to allow more flexibility without limiting the size of the DUT. The DUT will be located between the two arms. For large DUTs mechanical actuation is foreseen in order to move the device through the active area of the telescope. The volumens containing the reference planes is cooled, DUT cooling needs to be provided by the DUT user. During the CERN testbeam in 2008 a close to final version of the mechanics was used for the first time. The main problem was the cooling of the sensors, as the thermal resistivity between the cooling and the sensor is too high. An improved version of the mechanics is under way. In Figure 5 the telescope is shown as set up at the CERN SPS beam line H6B in summer 2008.

The overall mechanics is now not as small as planned at the beginning of the project. But by using the modular mechanics a great flexibility was gained which allows not only the incorporation of small DUTs but also rather large devices as for example CALICE.

5 EU Telescope Offline Analysis Software

For the offline reconstruction of track positions in the DUT the software package EU-Telescope has been developed which is implemented as a set of Marlin processors [?]. This design allows to integrate the DUT data at different steps of the analysis chain. Figure 6 summarises the structure of the offline analysis package. Each step in the analysis procedure is implemented in a separate Marlin processor. It is possible to run each processor separately or to execute the whole analysis chain by a single command. In

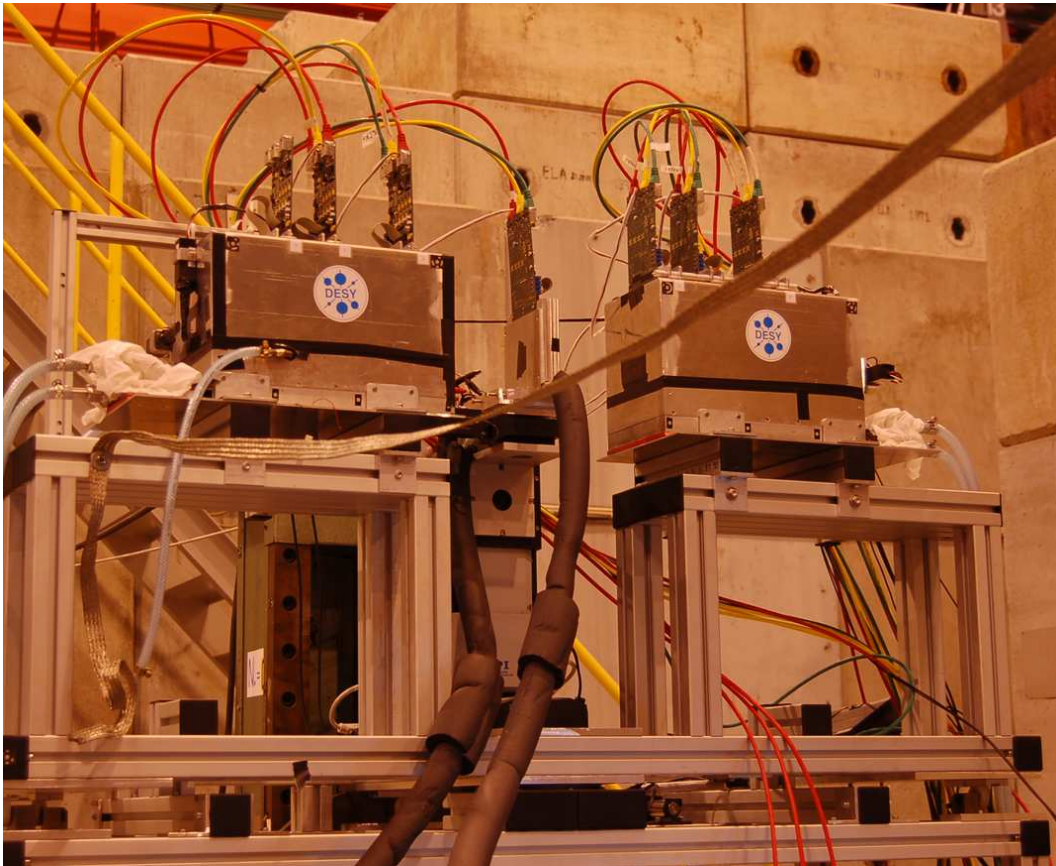


Figure 5: Photo of the EUDET telescope as set up at the H6B beam line at CERN in summer 2008.

the first step the data is converted from a native format used by the EUDAQ software to the LCIO format. Afterwards a pedestal correction is applied and clusters are searched for. It is possible to improve the reconstructed cluster positions using the η algorithm. Clusters are accordingly transformed into hits in the telescope frame of reference. The alignment procedure is based on the Millepede II package and uses full tracks in a simultaneous fit to derive the alignment parameters. Finally, tracks are fitted using the hits after the alignment constants have been applied. The result of the track fit can be saved in a ROOT file if needed by the user of the telescope.

5.0.1 Latest Improvements

One important point to mention is that an increased number of detector R&D groups is adopting the EU Telescope package. The DEPFET and the Strasbourg group started to use this software now. This is showing, that the package seems to be reliable, but also helps to debug the system when different sets of data are analysed.

Several issues have been addressed to ease the installation and usage of EU Telescope:

- Installation procedure

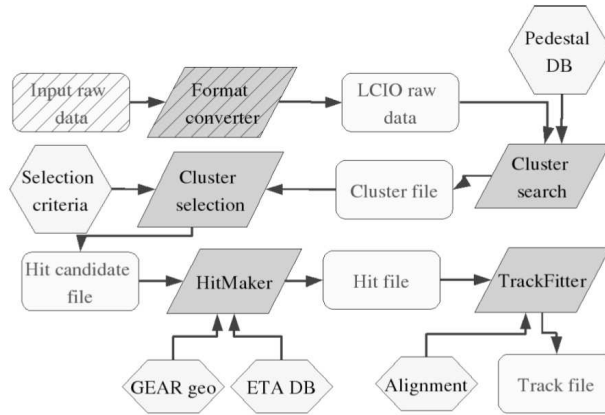


Figure 6: Schematic overview of the offline analysis package EUTelescope.

- Keep documentation updated
- A tutorial was held in May 2008 (available on the JRA1 webpage)

The new features (since Paris meeting) include the Universal Reader which is a very general data reading and conversion processor. The Correlator is a display correlation of hits and clusters in different telescope planes. Also the alignment was improved by including the Millipede II package. The Improved Event Viewer with tracks (before and after alignment) is completing the package.

6 All-inclusive Package for the Telescope User

After more than one year of user implementation for the telescope we have a complete package to offer to the users:

- The two arm telescope with different geometries with the possibility to add one extra high resolution sensor plane. The telescope comes with all the mechanics and the cooling system for the reference sensors.
- Operating support: mainly remote but also local in some circumstances.
- The DAQ system, both hardware and software. The user can connect the DUT to the EUDET TLU, or (better) help is provided to integrate the DUT R/O in the DAQ software.
- The analysis and reconstruction software EUTelescope. As for the DAQ, the user can rely on the output track file, or integrate the DUT data in the main analysis stream.

7 Test Beam Campaign 2008

Table 1: Data collected with EUDET telescope at CERN in summer 2008.

Date	Beam	Scope
05/08	CERN SPS	User: SiLC
07/08	CERN PS	User: CALICE
07/08	CERN PS	User: DEPFET
08/08	CERN SPS	User: MimoRoma
08/08	CERN SPS	User: DEPFET
08/08	CERN SPS	User: ISIS
09/08	CERN SPS	EUDET

In table 1 the different periods at the CERN test beam and the users of the telescope are listed.

8 SiLC

The main goal of the test beam was to record data that allows us to estimate the resolution for different detector geometries with the help of the EUDET Telescope. Unfortunately the Telescope's sensitive area, which is $7 \times 7 \text{ mm}^2$ didn't cover the full sensor width of the DUT, so it was necessary to split each measurement into three runs. Each of this resolution runs had 105 events. The different areas on the sensor, covered during the runs, can be seen in the picture on the left. The SiLC group collected about 1.5M events in several configurations with the EUDET telescope. At the time of the annual report the analysis of this data just started. A more advanced report can be found here [?].

8.1 CALICE

The CALICE collaboration used the EUDET telescope to validate a new concept of a digital hadronic calorimeter for ILC. The sampling calorimeter is constructed as a sequence of stainless steel absorbed plates and planes of gaseous detectors with high granularity and digital readout. As gaseous detectors GRPC and μ MEGAs were installed. The electronic readout was based on the hardroc chip. A study of the efficiency and cross-talk in different beam conditions was done. Different gas mixtures and different high voltage values to optimise the detector response were tested.

8.2 DEPFET

The DEPFET collaboration used the EUDET telescope at two different beams at CERN in summ 2008, PS and SPS. At PS they efficiently worked on all little details for the

user integration. This was done in the framework of the evaluation of the telescope. At SPS the main goal of the DEPFET group was the measurement of efficiency, purity and intrinsic resolution. The DEPFET was included on DAQ level as described in section ??, meaning that they had their own producer within EUDAQ and only one data stream. One million events were taken while DEPFET was the EUDET DUT. A detailed report on this work can be found here [?].

8.3 ISIS

The charge collection efficiency, charge sharing, hit-efficiency as function of position Standard and the "p-well variant" of ISIS was tested. The analysis of the data is still ongoing.

9 EUDET

The last period in September 2008 was a dedicated EUDET test beam period for detailed tests of the telescope performance. For this tests one of the MimoTel sensors was placed in a separate DUT box (so-called Maser box) between the two sensor boxes. This Maser box has a more direct cooling and the temperature control is more efficient. An Energy scan at energies from 20 to 120 GeV at a stable temperature was done, the performance of the telescope at different temperatures ($T = 8, 12, 16$ In order to build a high resolution silicon strip sensors the strip geometry is of crucial importance. The geometry influences the strip capacity and the charge sharing ability of the strips, both basic properties that contribute to the spatial resolution. Therefore the aim of the project was to evaluate the best strip geometry of silicon strip sensors with 50 microns pitch to achieve the highest possible spatial resolution. For this purpose a custom multi geometry sensor was designed by the SiLC collaboration. Over the 16 zones of this sensor we varied the strip width from 5 to 25 microns. The number of intermediate strips varied between zero and two.

10 What did we learn this summer?

The EUDET telescope was 16 weeks at CERN, 13 weeks of which for taking data. During that time more than 10 million events were taking which are about 50 million tracks. 887 Gbyte of data were written to the GRID. In table 2 the number of runs, the number of events and the data size for each user are summarised. We learned that making the telescope an easy to use infrastructure with full support is moke difficult than one would think at the beginning.

Below a list of items we have to keep in mind for next user test beam campaign, especially if the telescope is transported to a different facility such as CERN:

- Certify EUDRB firmware (at DESY test beam)

Table 2: Data collected with EUDET telescope at CERN in summer 2008.

User	TB	#Runs	#Events	Data Size [Gbyte]
Cadarache	SPS	64	5438957	2
SILC	SPS	230	1458173	157
Calice	PS	212	318437	9
Tapi	SPS	123	97598	149
Mimoroma	SPS	17	23985	20
ISIS	SPS	427	637866	27
DEPFET	SPS	355	2333133	346
EUTEL	SPS	148	342708	167
			10691178	887

- When moving to different location (e.g. CERN) allocate some time with standalone data taking before users arrive (3 days)
- Even better documentation for user integration; users mostly have problems with the integration of the TLU signals in their system.
- Created to-do list to optimize the start up.

The main documentation and help for the users is located on a specific users webpage on the EUDET webpages [?]. Information from how to restart the DAQ system to telephone numbers of the JRA1 support crew are included.

11 Towards the Final Telescope

In Figure 7 the timeline of the project is shown up to the point when the final telescope is ready at the end of month 39. The coming milestones/deliveries are the Mimosa26, the final readout, the test report on the demonstrator telescope and the tracking software. The DAQ software and the tracking software are in a very good shape and the milestones can be kept easily. For the DAQ hardware and the sensor chip a short description can be found below.

11.1 Mimosa26

In autumn 2008 the fabrication of MIMOSA-26, which is the final sensor for the telescope, is planned. It is the Mimosa-22 (binary outputs) complemented with zero-suppression (SUZE-01). For this chip the best performing (rad. tol.) pixel architecture of MIMOSA-22 will be selected. It will have an active surface: 1152 columns of 576 pixels ($21.2 \times 10.6 \text{ mm}^2$) and a pixel pitch of $18.4 \mu\text{m}$. This results in 0.7 million pixels. A single point resolution σ_{sp} of better than $3.5 \mu\text{m}$ is expected which would give a pointing resolution of $2 \mu\text{m}$ on the DUT surface. The integration time of the chip is about $110 \mu\text{s}$ which results

in 104 frames per second. The overall chip dimensions is about 21×12 mm². The data throughput will be 80 Mbits/s for one output or 2 outputs at 40 Mbits/s. A more detailed description can be found in [?].

11.2 Upgrade the EUDRB for Mimosa26

During the JRA1 parallel session two options for the upgrade of the EUDRB for the Mimosa26 were discussed.

11.2.1 Hardware Plan A - Old daughter card approach

- No need to build new daughter card
- Use the present J5 connector on current daughter card which provides 4 spare LVDS inputs (needs to be tested)
- Cost: 3kEUR

11.2.2 Hardware Plan B - New daughter card approach

- Additional FPGA for de-serializing and data transfer
- Up to three Mimosa26 could be read by one board !
- Cost: 9kEUR

During the discussion the JRA1 group decided to follow hardware plan A to have DAQ hardware ready by end of year (milestones) and not to endanger our delivery at the end of month 39 (final telescope ready).

12 Two Telescopes?

In the recent months the JRA1 group was contacted a couple of times and asked if copies of the telescope are possible and how much this would cost. This is also a question for the EUDET group as it might be desirable to have the demonstrator telescope still available after the final telescope is completed. In table 3 the costs of the full telescope are listed.

A full copy of the EUDET telescope would cost in the order of 100kEUR. Keeping the demonstrator and building a more simple second telescope (using existing cooling, VME crate, power supplies etc.) might relax the price to 40kEUR. But this would only be the option for a EUDET copy. An outsider group would have to invest 100kEUR. In the discussion during JRA1 meeting it was clear that it would be feasible to have two telescopes in the end. But the final telescope was given priority. If we still have manpower and money after the final telescope was delivered the option of a second telescope will be discussed again.

Table 3: Cost estimate for a full copy of the EUDET telescope.

Item	Full Copy [kEUR]
Chips (Mimosa26)	20
Sensor Boards	5
Readout Boards	20
Mechanics (simple)	10
VME CPU	3
VME crate 64bit	5
XY table	15
Cooling	5
Power Supplies	5
TOTAL	88

13 Conclusion and Outlook

This memo summarises the status of the JRA1 Demonstrator at the time of the annual meeting 2007 in Paris. This analog telescope was ready for data taking in summer 2007 and extensively tested at test beams at DESY and CERN. All ingredients necessary for successful data taking are tested and available. Remaining issues to be solved are the optimisation of sensor board supports (L-pieces). Also the readout speed needs improving, mainly in the VME library. And last but not least the software needs improved documentation.

Acknowledgement

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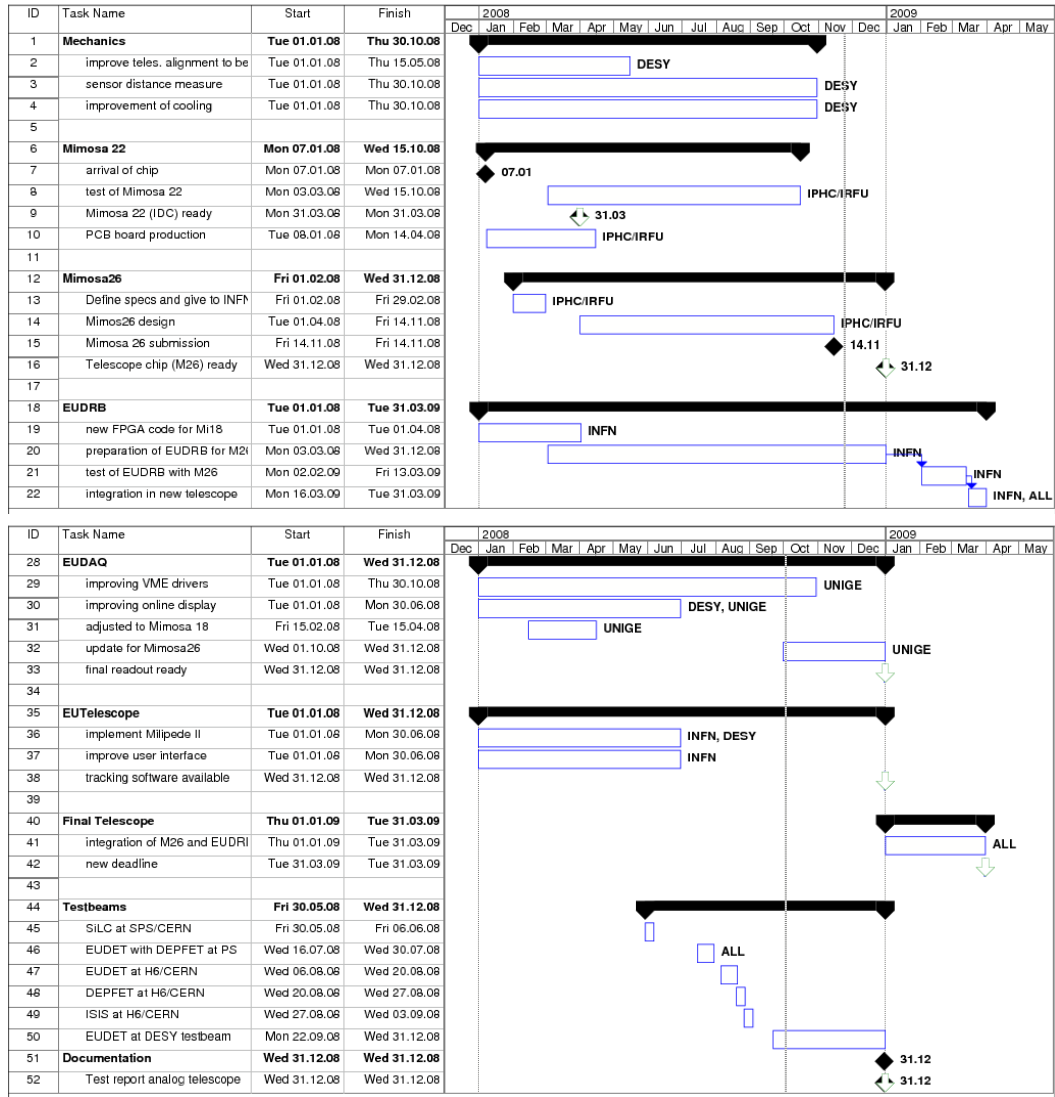


Figure 7: Timeline of the JRA1 telescope project from fall 2008 to the completion of the final telescope in end of March 2009.