



The DESY GEM Module for the ILD TPC: Developments and tests




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RD51 8th collaboration meeting
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I'd like to update you about the work I'm doing at desy to develop a GEM readout module as a prototype for the ILD TPC readout system

It's some time since I presented anything in the RD-51 collaboration, thus I will go in some details about the development of the project

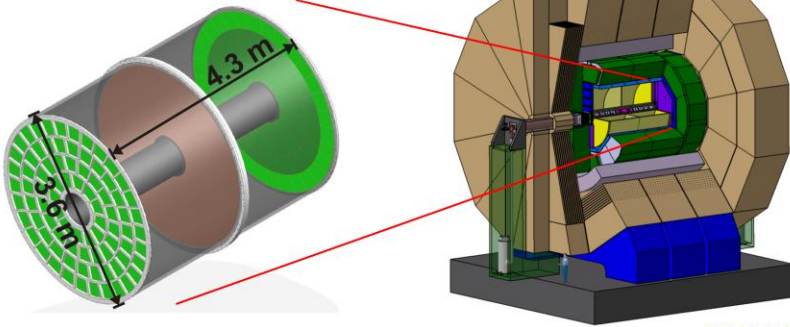




INTERNATIONAL LARGE DETECTOR

Omnipurpose detector for ILC experiments

TPC as main tracker



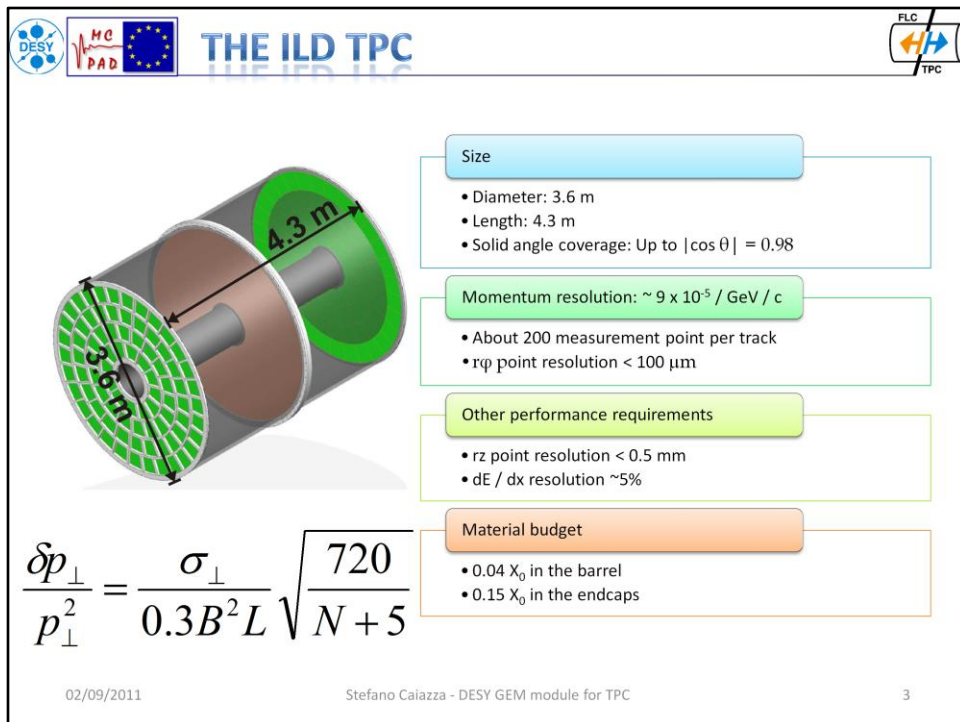
FLC-TPC develops the TPC tracker (in the LC-TPC collaboration)

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Let's start from the framework of my project: the ILD, which is the International Large Detector, an omnipurpose detector for experiments at the ILC which has at his core, as a tracker, a TPC, which the LCTPC collaboration and the FLC-TPC group at desy develops






As we said then the main tracker for our experiment is the TPC



While the size is comparable to other “big TPCs” there are other features which are particularly challenging

The momentum resolution is the major requirements driver. We need a Momentum resolution of ... and to achieve it we need 200 sample points with a point resolution better than 100 μm

Moreover we would like to have also a good point resolution in the z coordinate to achieve a good double track separation and also to achieve a good dE/dx resolution. All this must be achieved with a material budget limited to ...

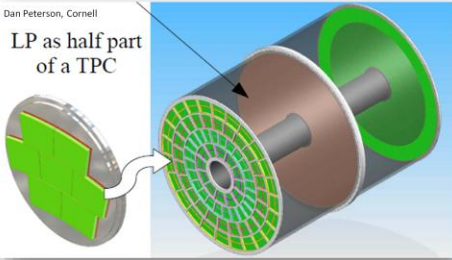
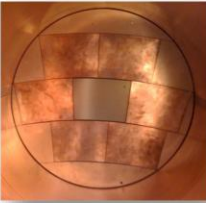




LARGE PROTOTYPE TPC

Dan Peterson, Cornell

LP as half part of a TPC

Goal

- To design and test the technologies for an ILD TPC
- First time MPGD used in a big TPC
- High channel density: $\sim 30/\text{cm}^2$ (pad readout)
- Mechanics
- ...

Built and operated at DESY

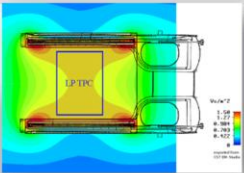
- 60 cm drift length, 72 cm inner diameter
- Field quality: $10^{-4} < \Delta E / E < 10^{-3}$
- Operational since the end of 2008

The Magnet - PCMAG

- 1.2 T magnet provided by KEK
- Operated at 1 T
- Same L/B ratio of LP-TPC and ILD-TPC
- Same transversal diffusion

Endplate

- 7 slots where to mount different modules
- Modules developed by various institutions to test different technologies
- Saclay, KEK, Bonn, DESY, NIKHEF






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To test the technologies needed for the development of the ILC TPC we have the Large Prototype TPC designed to model a section of the final detector. We built it and operate it at DESY since 2009



The TPC is installed in a magnet, called PC-MAG operated at 1T so that the ration between the length of the TPC and the magnetic field is the same for the LP and the ILD TPC so that the transversal diffusion compared to the relative drift time of the electrons will be roughly the same in both cases simplifying the extrapolation of the results.

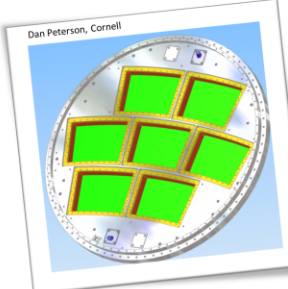
The LPTPC has an endplate where is possible to mount up to 7 independent readout modules to test new technologies.

All of this module are developed also by members of this collaboration like... so you already know some details about those

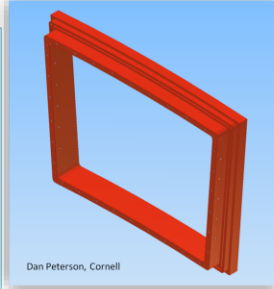
MODULES FOR THE LP-TPC



Common Features

- Fixed allotted space
- Cornerstone shape
 - 20-24 cm wide
 - 17 cm high
- Common mounting system






DESY Module Specific features

- 3 GEM stack with an optional gating module
- Ceramic mounting structure developed at DESY
- Pad readout system
- Minimal amount of dead space
- Modular system (great for prototyping) and simplified assembly


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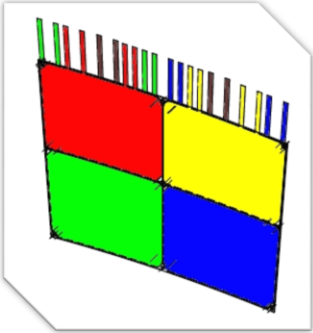
All of these modules have some common feature, or common constraint if you wish which is the space available and the mounting structure to use that is everything must fit in these holes in the endplate and be mounted through a backframe similar to the one sketched

The specific features of our module are... with the goal to minimize the dead space and build a modular system, especially useful in the prototyping phase with a simplified assembly procedure that will be used in the industrialization phase

GEM FEATURES





Basic Features

- Standard hole size, 70 μm . and pitch, 140 μm
- 50 μm kapton foil
- Produced at CERN

Shape and Segmentation

- Shape constrained by the module size
- 4-fold segmentation on one side
- Each section $\sim 94 \text{ cm}^2$, like a standard CERN GEM
- Gap size matching ceramic width

Power supply

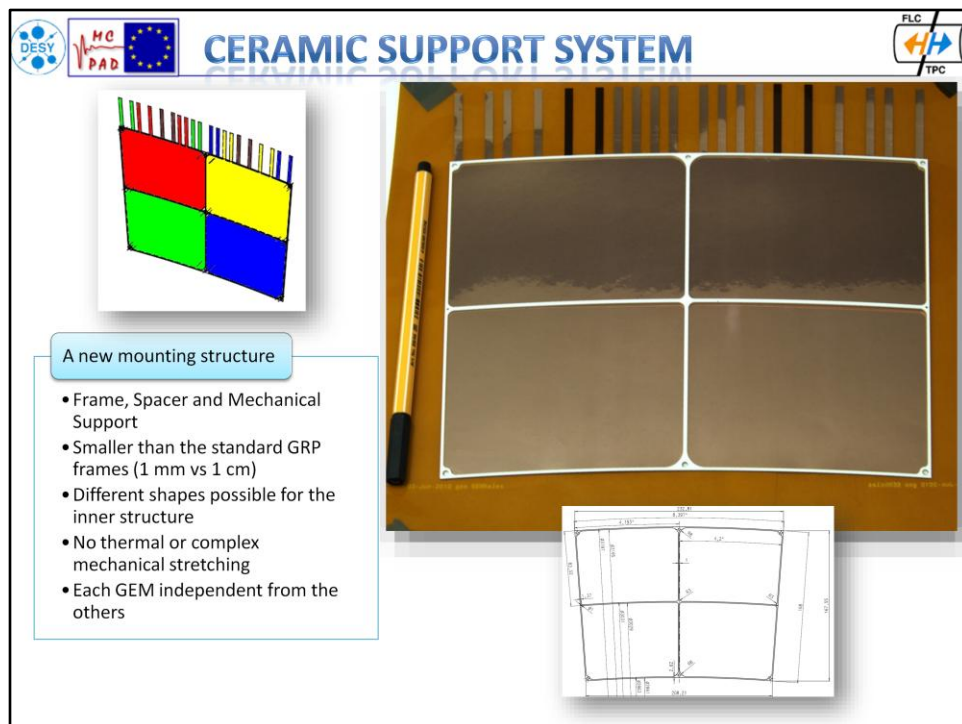
- Supplied through the readout PCB
- Each GEM need 5 independent power lines
- Each sector has 4 electrodes to pile up 4 GEMs
- 20 total electrodes per GEM foil at production

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The GEM basic features are pretty standard issue.

The size of the GEM itself is constrained by our mounting structure and the segmentation in 4 independent areas is constrained by the total area of the active surface.

To supply each of these GEM one needs 5 independent power lines. If we want to pileup up to 4 GEMs we need each GEM to be powered from a different position on the PCB. To avoid designing 4 different type of GEMs for each GEM position each GEM has a total of 20 electrode, 15 of which are cut away during the assembly phase



The most innovative part of the design is probably the mounting system where we decided to move from the standard GRP frames to a ceramic support system that integrates the function of framing and spacing minimizing the dead spaces required by the support system. You can appreciate this noticing how the outer frame in our case is only 1 mm wide compare to the cm of the standard GRP frames.

Some may remember that we tested this system on the standard 10x10 GEMs and we now want to use the same principle on larger area GEMs

The inner supporting structure, can have different shapes. This simple cross like shape is produced so that we can test the effects of vertical and horizontal elements on the signals.

Moreover the frame is completely glued to the GEM which allows the GEM foil to be as flat as GEM mounted with the standard system without using complicated thermal stretching or complicated mechanical system.

Each GEM can have the grid on one side only or on both side and usually the GEMs are handled independently and not glued together

AUTOMATED GLUING

VOLUNTARY GLUING

Small width of the elements to glue (1.4 mm)

Active area close to the grid elements (<500 μ m)

Total gluing length (> 1 m)

Complex gluing path

Gluing Jigs

Robotized table with glue dispenser and microscope monitoring

Labview steering program

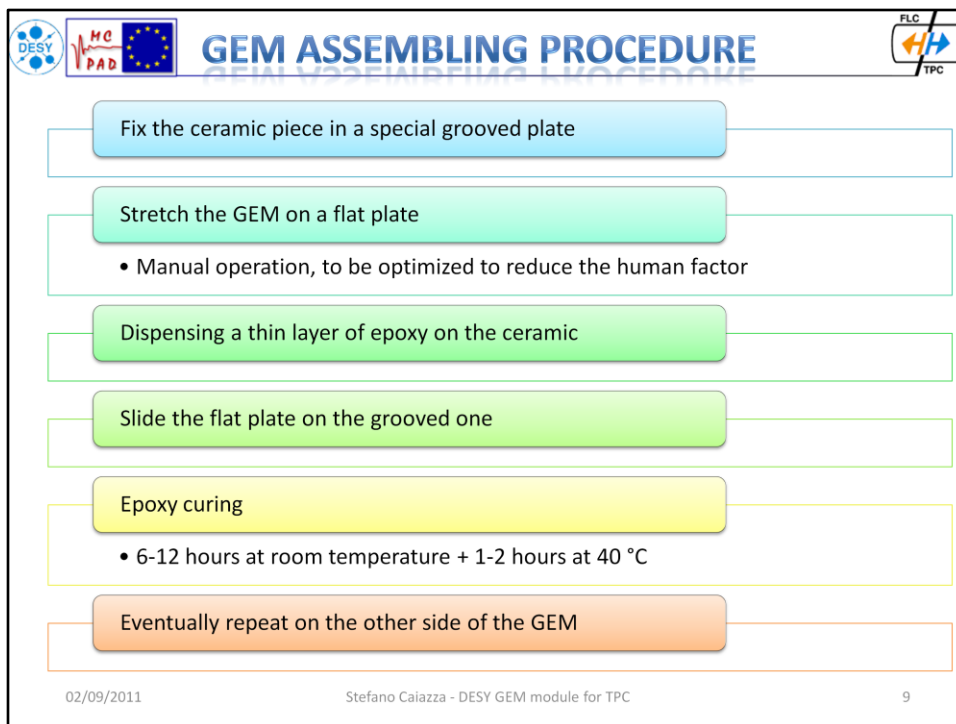
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Gluing the grid to the GEM is a delicate procedure due to the small width of the ceramic element to glue (1.4 mm), the closeness of the active area to the grid elements < 500 μ m and the fact the gluing path is long and complex. To perform this operation I developed a semi automatic method involving a couple of gluing plates a robotized table with glue dispenser and microscope monitoring all steered through a labview program.

and I just want to illustrate the procedure I use.

We have a aluminum jig with a groove that has the same shape of the ceramic grid to glue and a flat one where we stretch the GEM. At the moment the stretching of the GEM is performed manually with the help of a bit of scotch tape. This part of the procedure is yet to be optimized, to possibly reduce the importance of the human factor. After we dispense a thin layer of glue on the grid the two plates are aligned, slide over one another and pressed to ensure a good adhesion. After about 6-12 hours curing at room temperature the top plate is removed bringing with it the gem and grid, and they are put in the oven at 40° for 1-2 more hours to ensure a perfect curing.

For the gluing itself you need 30-45 minutes with about half a day devoted to curing. The final product after the gluing is this one.



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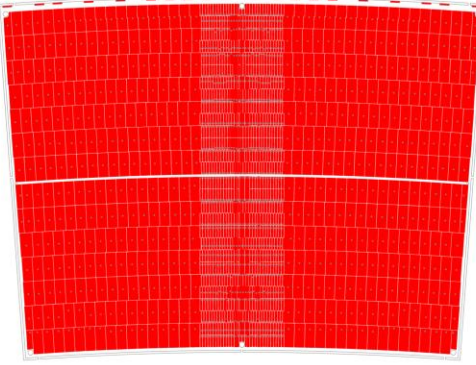
PAD READOUT BOARD

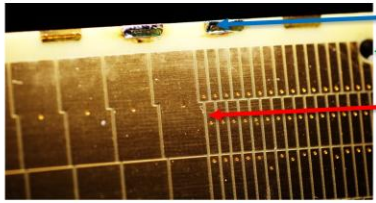
Design Goals

- 1.25 x 5.86 mm² pads
- Almost 5000 pads
- GEM HV supply from the board
- Minimal dead space
- Ceramic grid shields HV

Iteration 1

- 1000 channels
- Central track (32 pads) at full resolution
- Bigger pads elsewhere
- 3 boards produced





HV Slots

Alignment Hole

Readout pads

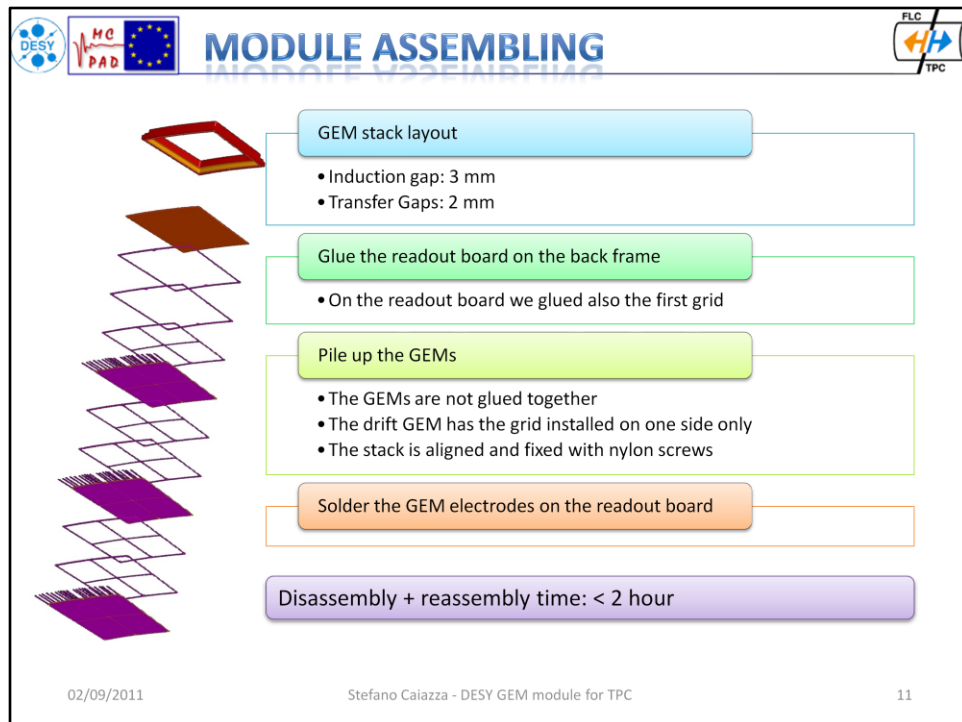
Designed at Bonn by Jochen Kaminsky

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The readout system of our module is based on pads.




The final design goal would be to have a board equipped with about 5000 pads of 1.25x5.86 mm². The board must also provide the HV power supply necessary for the GEMs minimizing the dead space. To reduce at a minimum the distance between the HV lines and the readout pads the system is design in such a way that the ceramic grid will just fit in the gap between the two elements shielding them from one another.

As a first iteration, to verify the functionalities of the system, we produced a simplified version of the board where only a central track about 4 cm wide is equipped with the small pads where the rest of the board is filled with bigger pads. On the top row of the board you can see the HV slots. These are deep cuts in the PCB where you can fix and solder the GEM electrodes





When all the elements are ready we proceeded to assemble the whole system. We decided for a GEM stack with 3 mm induction gap and 2 mm transfer gaps. The first step was to glue the pad board to the aluminum back frame, on top of the readout board we also glued the first grid. The GEMs are simply piled up on top of each other and fixed with nylon screws.

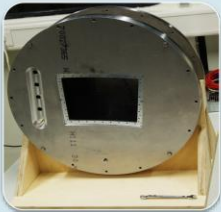
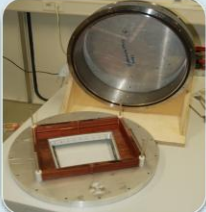
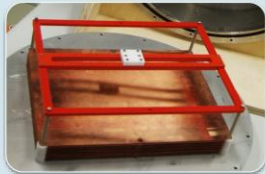
When everything is firmly in place the GEM electrodes are soldered on the board. One nice feature of all this procedure is that you can disassemble and reassemble the whole module, in case for example a GEM broke down, in less than a couple of hours.

COMMISSIONING TEST BOX

To commission the module before going to the test beam




| | | |
|---|--|--|
|  |  |  |
| <p>Gas tight container</p> <ul style="list-style-type: none"> • Hosts one LP Module • Support structure for the other elements | <p>Field rings stack</p> <ul style="list-style-type: none"> • Variable drift distance up to about 10 cm • Variable ring number and gap • Independent and versatile voltage divider | <p>Radioactive source support</p> <ul style="list-style-type: none"> • Piled up over the cathode • Can host more than one radioactive source at the same time |

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Another thing we were doing this last year, was the development of the test box for the module commissioning. The idea was to use this device to test the module before going for a test beam. The testbox features 3 main elements:

A gas tight box which contains the field rings stack where you can also pile the radioactive source container. This container hosts one LP module

The field ring stack is built on top of one of the endcap of the container and can host a variable number (up to 25 including termination plate and cathode) of field rings with a variable

GEM AND MODULE TESTING

Single GEM testing

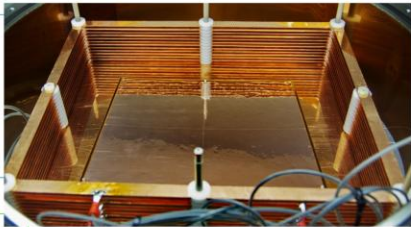
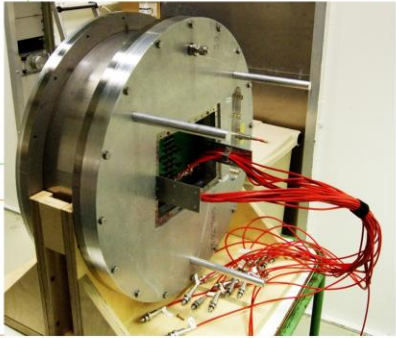
- Absence of shorts
- 300 V in counting gas for one night
- 350 V for a few seconds
- Before and after mounting the ceramic grids

Board testing

- Each HV channel powered up to 3KV before mounting the GEMs
- Only the first grid is glued
- Test to be introduced for the next module we assemble

Module testing

- Performed in the test box
- Each GEM retested after mounting
- The module is brought to nominal voltages







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

Before and after the framing each GEM received a basic HV testing.

At the arrival each test is connected to the HV and powered up in air or nitrogen to verify that there are no evident problems. Then our test chamber is flushed with a counting gas and slowly powered up to 350 V to perform the initial training. I consider the GEM to be acceptable if it stand about 350 V for a few seconds and 300 V for an entire night.

After the framing the same test is repeated to verify that no damage was produced on the GEM

TEST BEAM JUNE-JULY 2011

To be performed at the DESY T24 test beam

- Initial plan: First 2 weeks of June

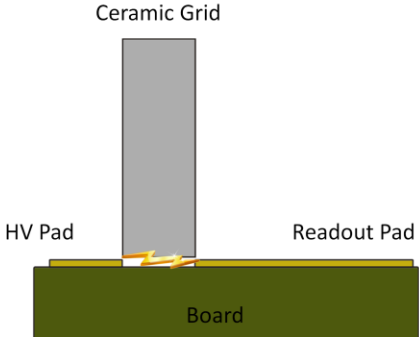
Problems with powering up the module

- Sparks between the HV slots and the readout pads
- The first grid was not glued to the board

1 month lost

- Understanding the problem
- Repairing the module
- Optimizing the gluing




Test beam shifted to the end of June





The diagram illustrates the physical components of the module: a dark green rectangular 'Board' at the base, with a yellow 'HV Pad' and a grey 'Readout Pad' on its surface. A grey 'Ceramic Grid' stands vertically between them. A yellow lightning bolt symbol is positioned at the junction of the HV Pad and Readout Pad, indicating an electrical spark.

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With this module we planned to perform a test beam at the beginning of June 2011. When we finally managed to solve and optimize all the assembly problems we found out that we couldn't power up the module to the nominal voltages. As it happened we discovered the problem was due to sparks between the HV slots and the readout pad due to the lack of gluing between the first grid and the board. To understand, repair the problem and optimize the procedure we lost almost 1 month so we shifted the test beam to the end of June

TEST BEAM JUNE-JULY 2011

Electronic setup

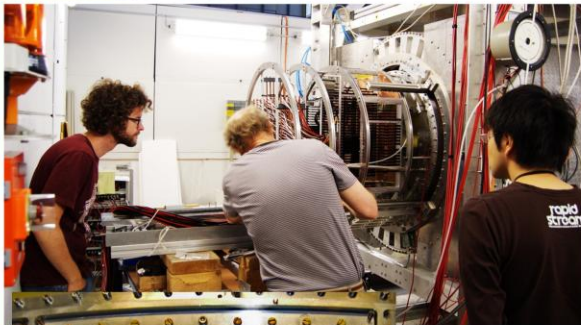

- ALTRO Electronics: 896 channels
- 20 cm kapton cables between pad board and FEC
- Pedestal subtraction and zero suppression
- Custom DAQ system designed at Lund
- Support provided by the Lund group of the LC-TPC

Catastrophic spark

- 3 Sector destroyed on 2 GEMs in one single shot

Hypothesis 1




- Unbalance in the protection resistors



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After this repair we installed finally everything in the test beam. For the electronic readout of our system we use the ALTRO electronics as provided by the LC-TPC collaboration and I would like to thank you the Lund group for the collaboration concerning the whole electronic setup and Ryo Yonamine and the whole KEK group with their help concerning the whole enterprise. We equipped 896 electronic channels, we took a couple of run then a catastrophic spark happened destroying 3 sectors of 2 GEMs in one shot.

First hypothesis: unbalance of the protection resistors

TEST BEAM JUNE-JULY 2011

First data take

- First set of run taken with damaged module
- Definition of working point for GEM and electronics
- No magnetic field

Run conditions

- GEM voltage: 260:250:240
- Pedestals: $\sim 200 \pm 0.8$ ADC counts

Module repairs

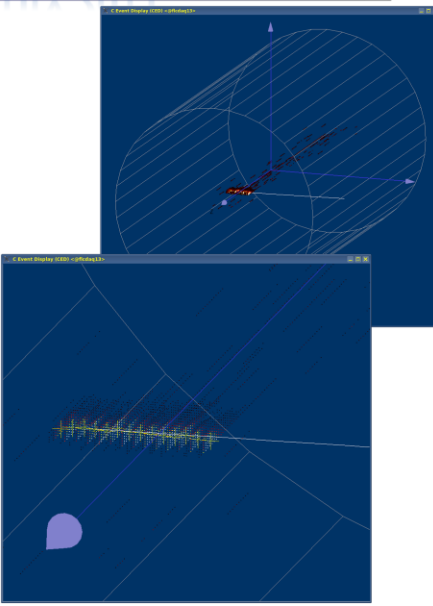
- Prepare new GEMs
- Update the resistor protection system
- Disassemble and reassemble the module

Field cage problems

- While reassembling the module in the TPC
- Due to mishandling

Magnet problems

- Clog of frozen air stopped the flow of liquid helium
- Magnet warm up necessary






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
We took some data with the damaged module while preparing new GEMs to repair it, still without magnetic field. With this run we define our working conditions. In the meantime we repaired the module, and reinstalled everything again, modifying the resistor protection scheme to solve that problem we thought caused the troubles.

While reinstalling everything we made a mistake handling the field cage which was slightly damaged in the process, luckily in such a way that didn't disturb the measurements.

When we were ready again we wanted to switch on the magnet but unfortunately there was a problem with it. A clog of frozen air formed in one of the inner pipeline and the magnet had to be warmed up and cooled down again before we could try again.

TEST BEAM JUNE-JULY 2011

New set of data taken

- ~ 70 runs taken with the undamaged module
- No magnetic field

New catastrophic spark

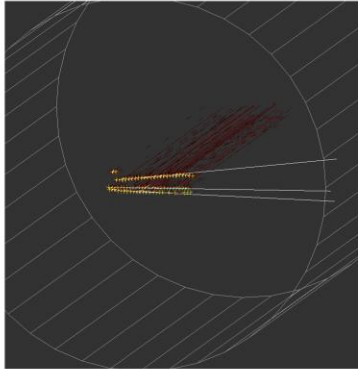
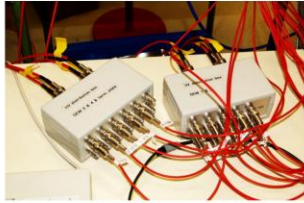
- 2 Sector destroyed on 1 GEM in a single event

Hypothesis 2

- Protection resistors too far from the GEMs
- Big charge stored on the cables

Final runs

- Magnet ON
- Using damaged module
- Until the other 2 sectors failed

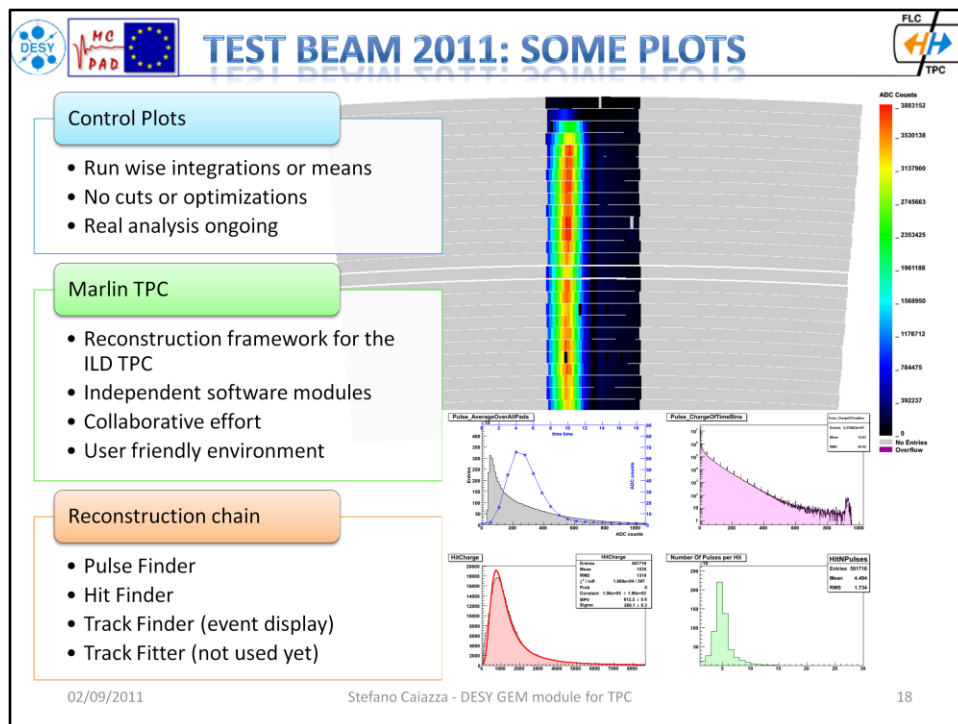



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In the meantime we took data for a couple of days with the repaired module until a new catastrophic spark damaged the module again. Once more two sector at the same time were damaged in a single event.

After some more brain storming we think the cause of all these trouble was the physical position of the protection resistors, too distant from the GEMs, in a distribution box one meter of cable away from the module. That was a problem we couldn't solve in the few days we still had at our disposal.

In the meantime we could switch on the magnet and we managed to gather some more events using the damaged module before even the other two damaged sector gave up



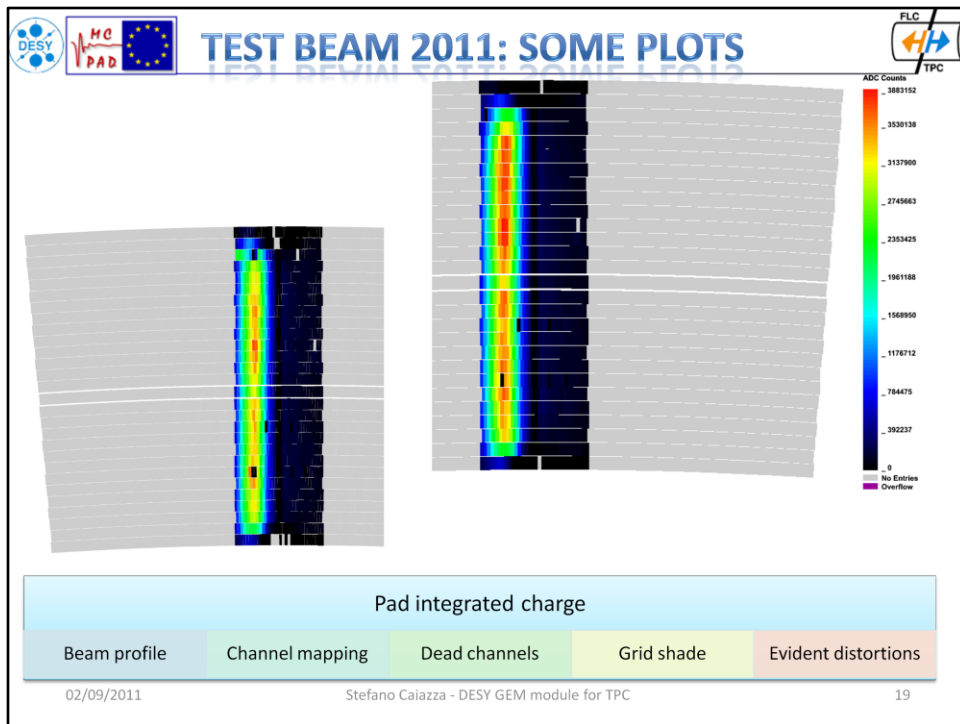
To conclude the presentation I would like to show you some plots from our data to show you the first really raw results from this module and this test beam campaign. You already saw some of our event displays.

All these plots were control plots that we used during our data taking. All the plots are integration or averages of one entire run. There were no cuts or optimization applied to the data. The real analysis is still ongoing.

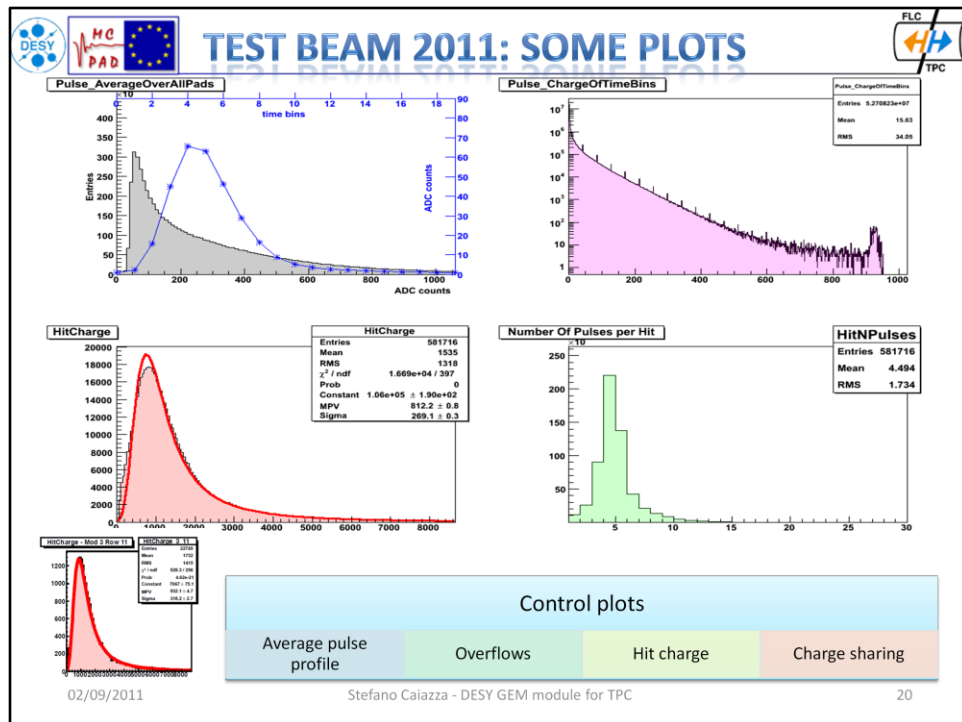
To perform this analysis we used a standard Marlin TPC reconstruction chain.

MarlinTPC is the reconstruction framework we are developing for the ILD TPC. It is a good example of collaborative effort in developing a user friendly software environment.

The reconstruction chain we used in our test beam was ...



The first interesting plot is the integrated charge on each pad. With this plot you can appreciate the beam profile, the channel mapping correctness like we noticed at one point in the top rows of the left plot, we can see the ceramic grid shade and check for evident distortions as you can notice on the top and bottom rows of the board



These are other very useful control plots where you can notice the average pulse shape, the average pulse charge to verify whether you have too many overflows, the hit charge. And the charge sharing

FINAL SUMMARY

- Module design and production**
 - First iteration completed
 - Tested successfully
 - Simulation and optimization to do
- Lot of experience**
 - How to handle the system
 - How NOT to handle the system
- Test Beam**
 - ~150 usable runs: 20k events per run
 - ~20 runs with magnetic field but damaged module
 - Analysis on going
- Thanks to Ryo, Takeshi and all the other people from KEK who were invaluable**

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To conclude we did complete the first iteration of the design of our module and we produced it and tested it. I would definitely call our test a success. Sure we had a lot of problems but as you can see from the amount of troubles we had we gathered a huge amount of experience about the operation of our system, in particular on how not to operate it, and that's what testing is all about.

In the end we managed to gather also a relevant amount of data, about 150 runs, most of them unfortunately without magnetic field, and in those cases where we had the magnetic field available the module was damaged.