# Semi-Digital Hadronic CALorimeter for ILD

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# Outline

-The Semi-Digital Hadronic Calorimeter Concept

- Physics and technological prototypes

- SDHCAL for ILD :

  -Mechanical structure study

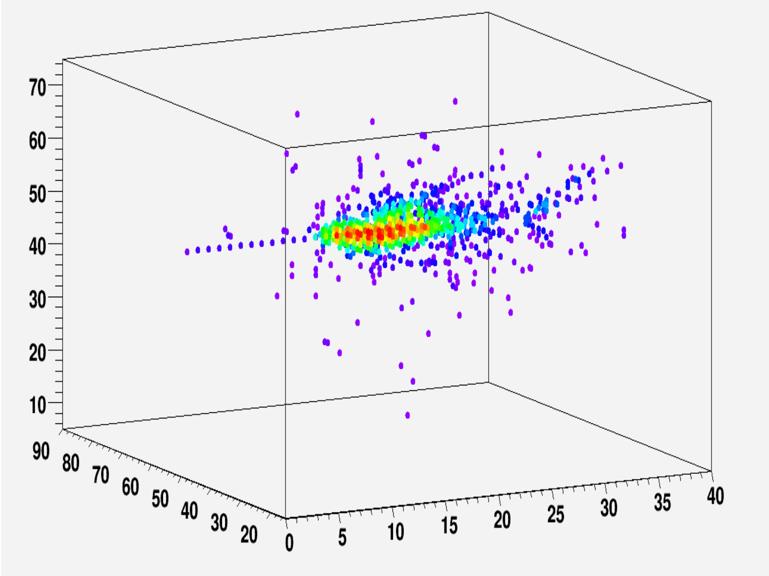
  -Services studies

  -Software

  -Expected performances

  -Conclusion

# Semi-Digital HCAL Concept




Ultra-granular HCAL can provide
a powerful tool for the PFA
leading to excellent Jet energy resolution

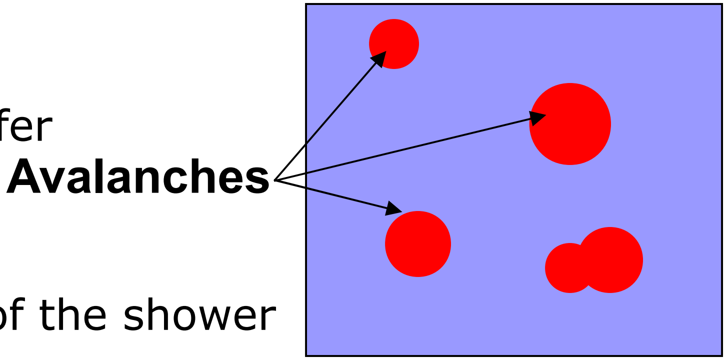
**How to obtain ultra-granularity?**

1- Gaseous Detector

Gaseous detectors like **GRPC**
are homogenous,cost-effective,
and allow high longitudinal and
transverse granularity.

2- Electronics Readout

A transverse granularity of (1cm2) with a binary readout,
leads to a very good energy resolution
However, at high energy the shower core is
very dense and the simple binary readout will suffer
saturation effect
Semi-digital readout (**2-bit**) should improve the
energy resolution by better counting the particles of the shower

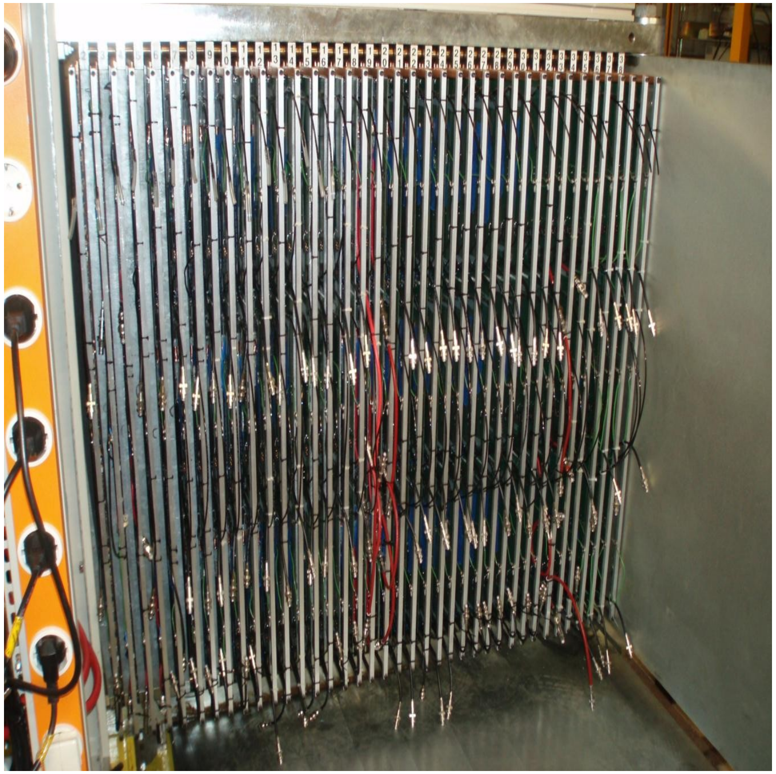


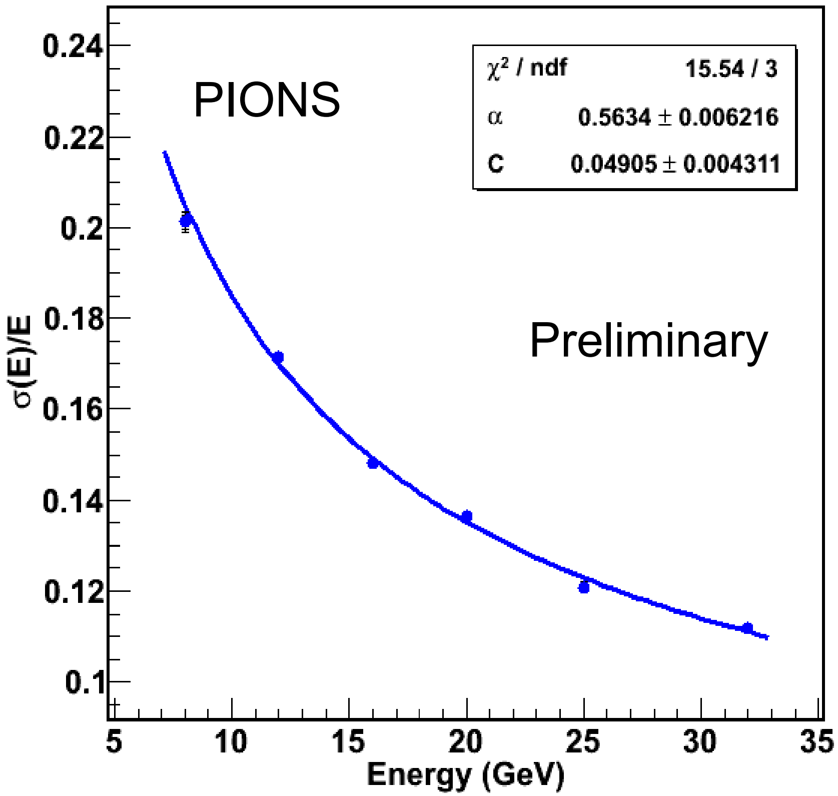

**1 $cm^2$ pad**

# Digital and Semi-Digital HCAL prototypes

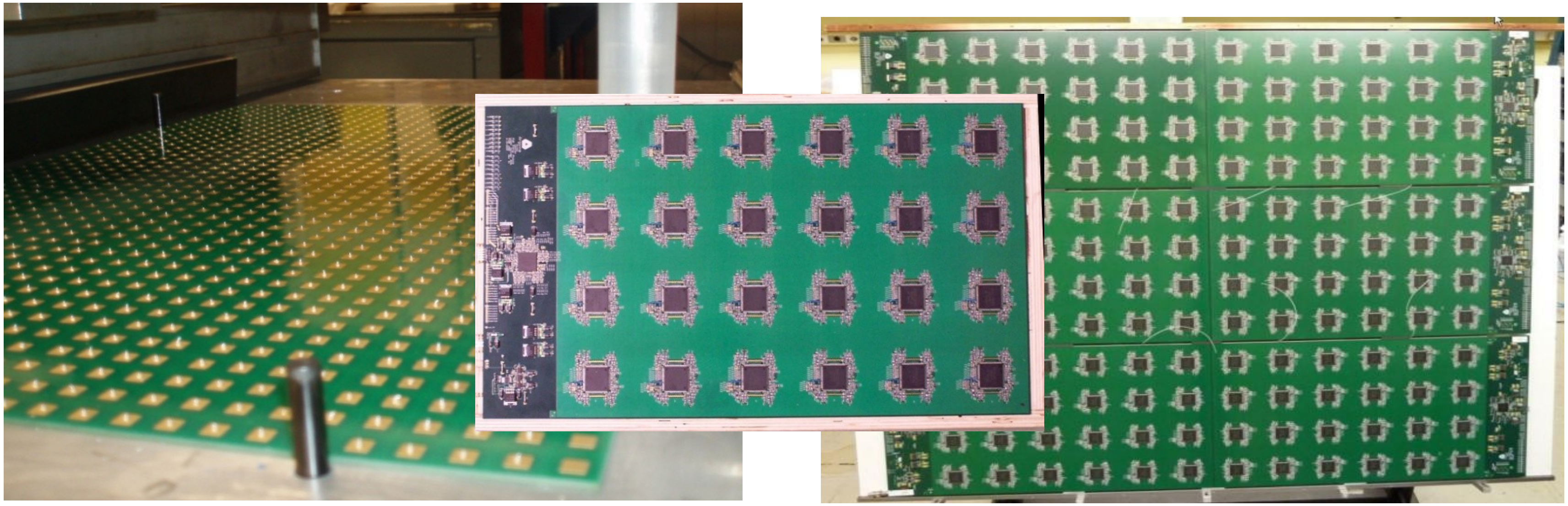
# Digital HCAL prototype

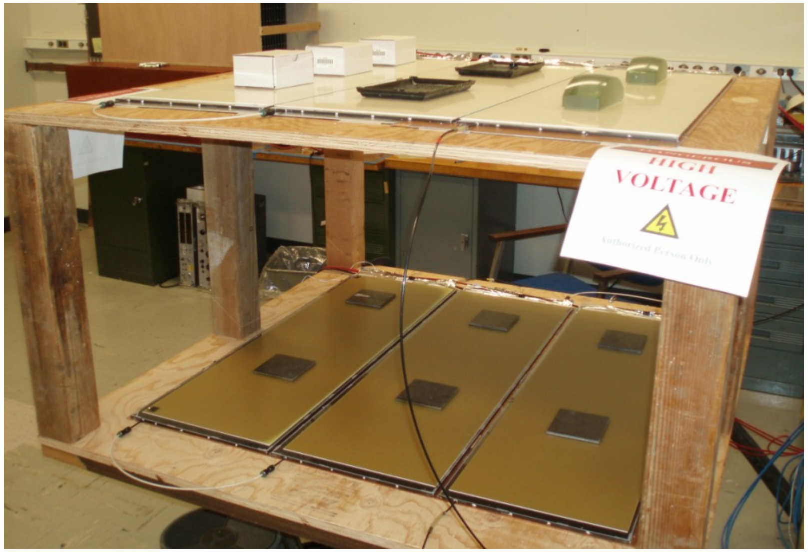
A physics prototype using GRPC with embedded binary readout electronics has been achieved recently by our American colleagues and the preliminary results Show that Digital HCAL concept is a powerful tool to achieve excellent resolution

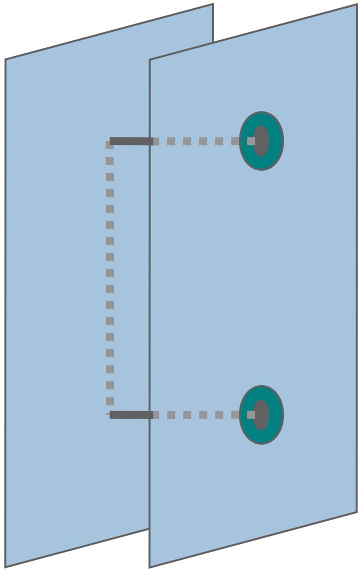




Although the DHCAL prototype is a great achievement which validates the DHCAL concept it could not be considered as a technological prototype..





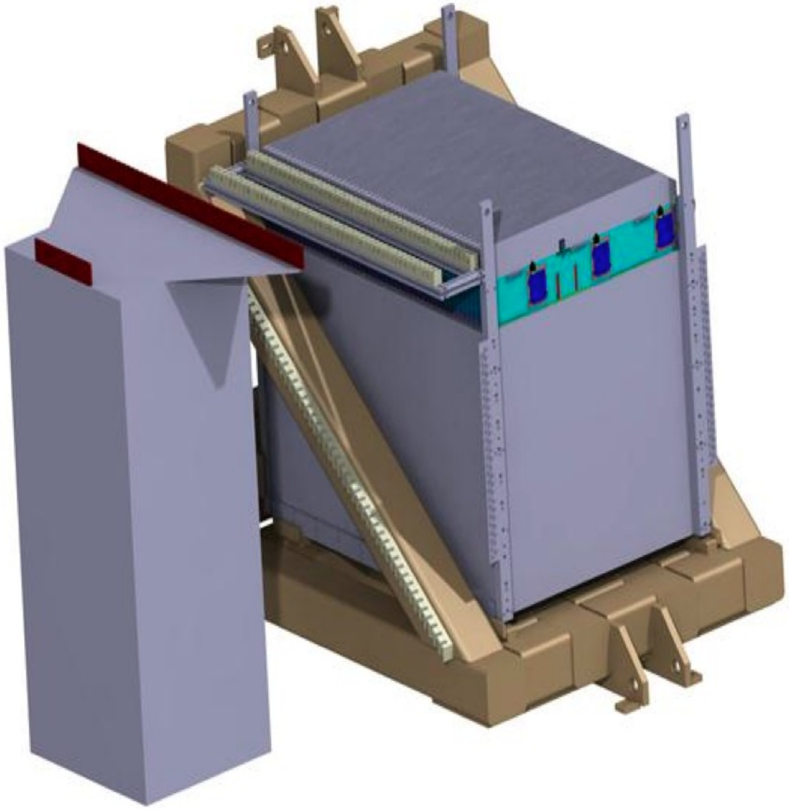
# Semi-Digital HCAL prototype

Aim : building a prototype which is
as close as possible **to the proposed SDHCAL for ILD to understand key issues of integration and operation** :Technological prototype

→ **Self-supporting mechanics**
→ **Minimized dead zone**
→ **Minimized thickness**
→ **One-side services**
→ **Power pulsed electronics**

The prototype will be made of 48 units. Each unit is made of :
**2 cm absorber**
+ **0.6 cm sensitive medium**
1 $cm^2$ transversal granularity

This is about **$6\lambda_I$**
and **442368** channels



# Challenges :

To build a **technological prototype** we need to achieve the following :

1- Large detectors with almost no dead zones :

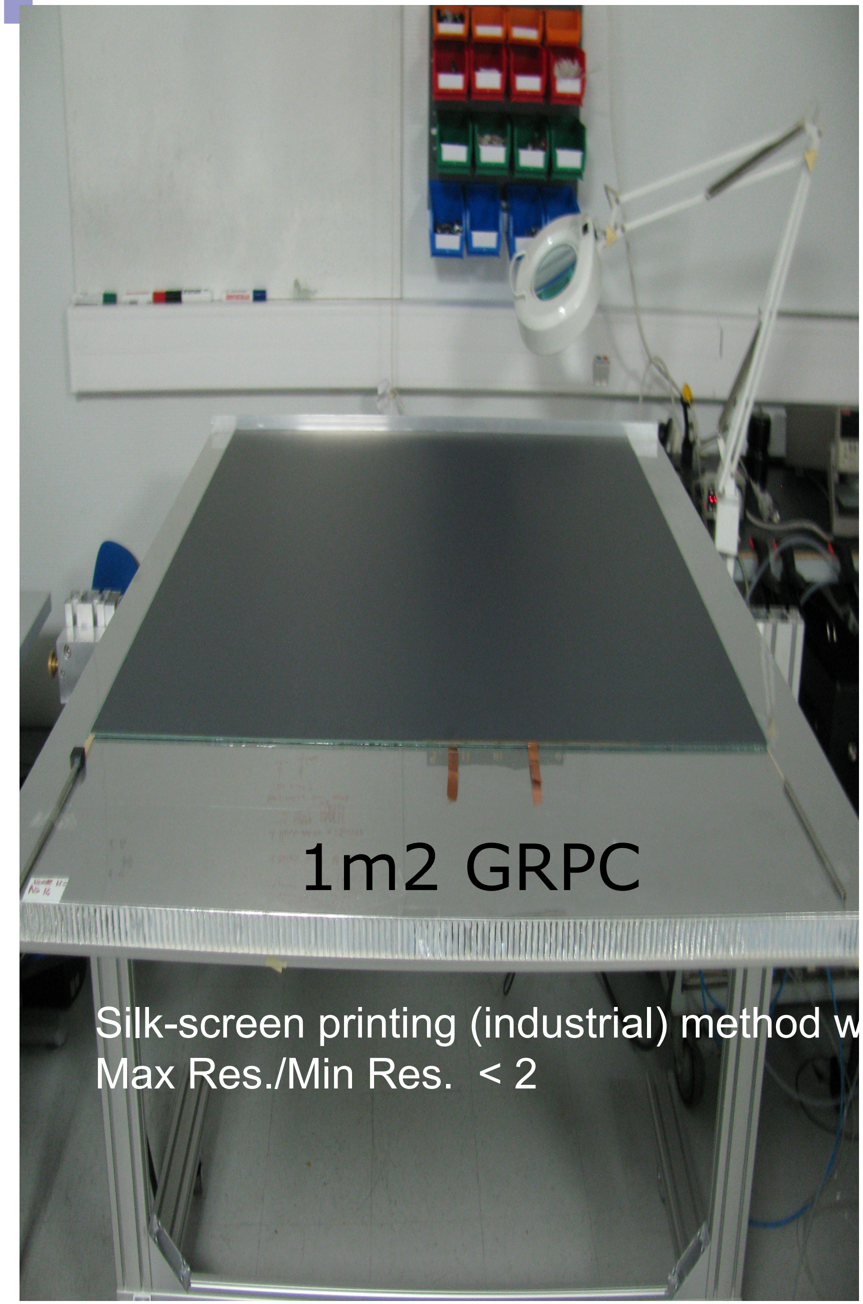
2- Large and thin embedded electronics board

4- One-side services : readout, gas outlets..

5- Self-supporting mechanical structure

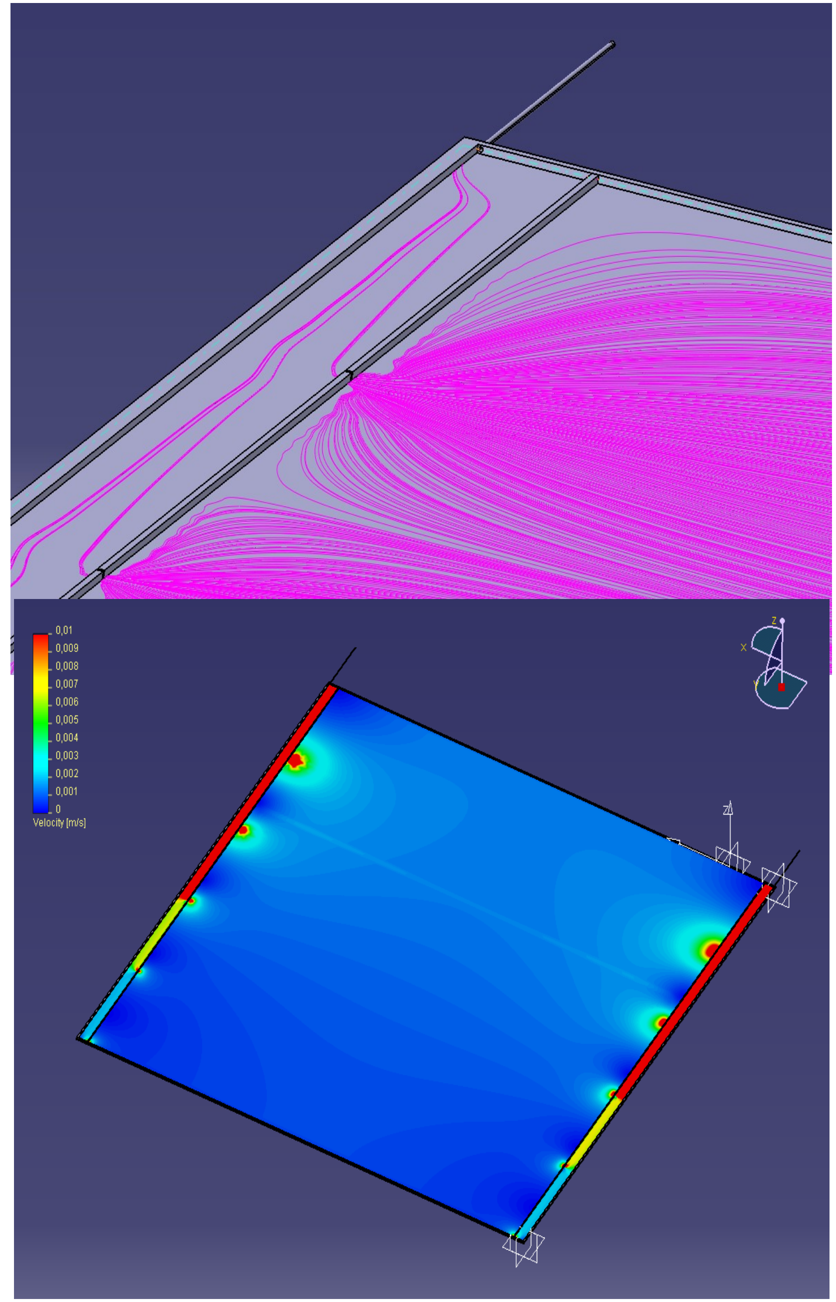
6- Power-pulsed, 2-bit electronics

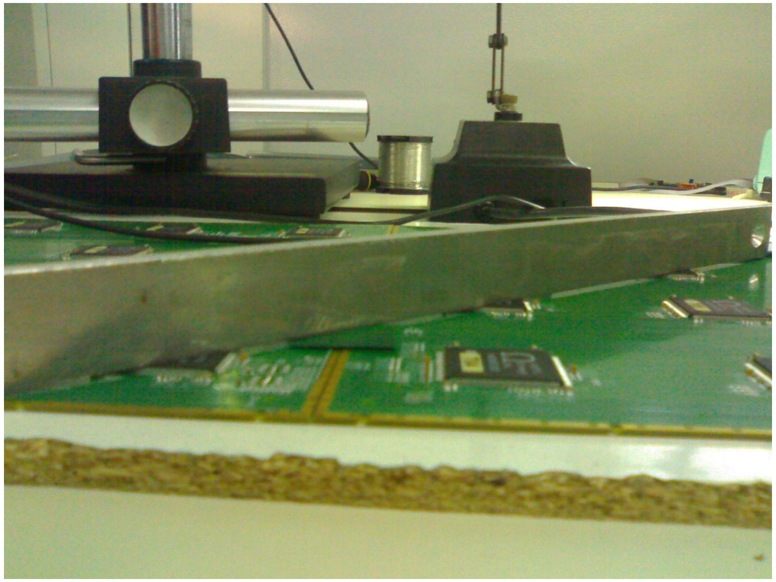
7- New generation of DAQ system capable of dealing with more than 400000 channels.

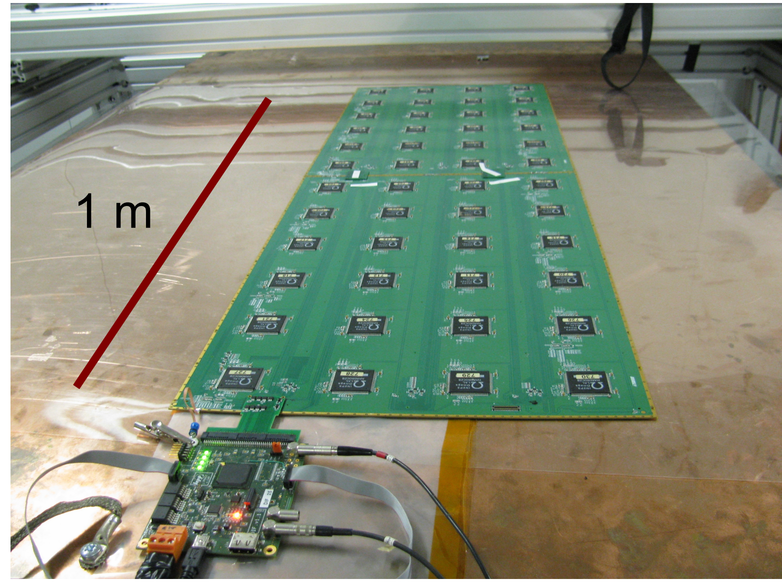


1m2 GRPC

Silk-screen printing (industrial) method w
Max Res./Min Res.  < 2







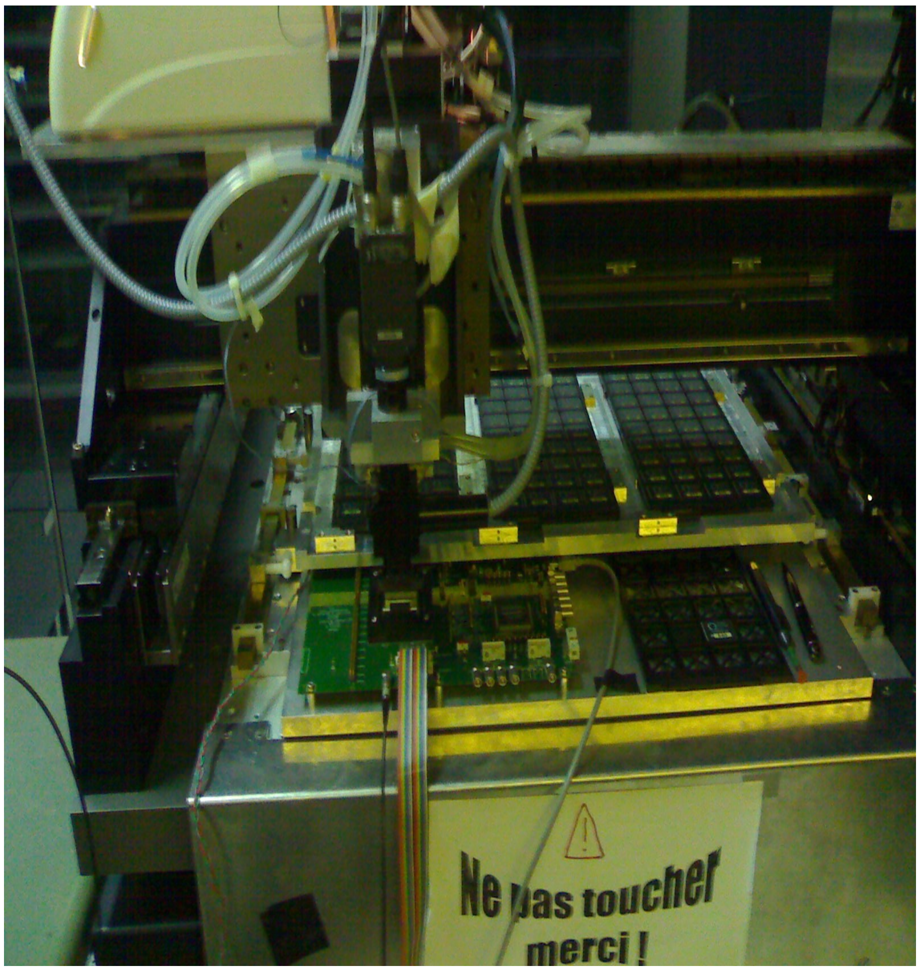

Technological issues are addressed

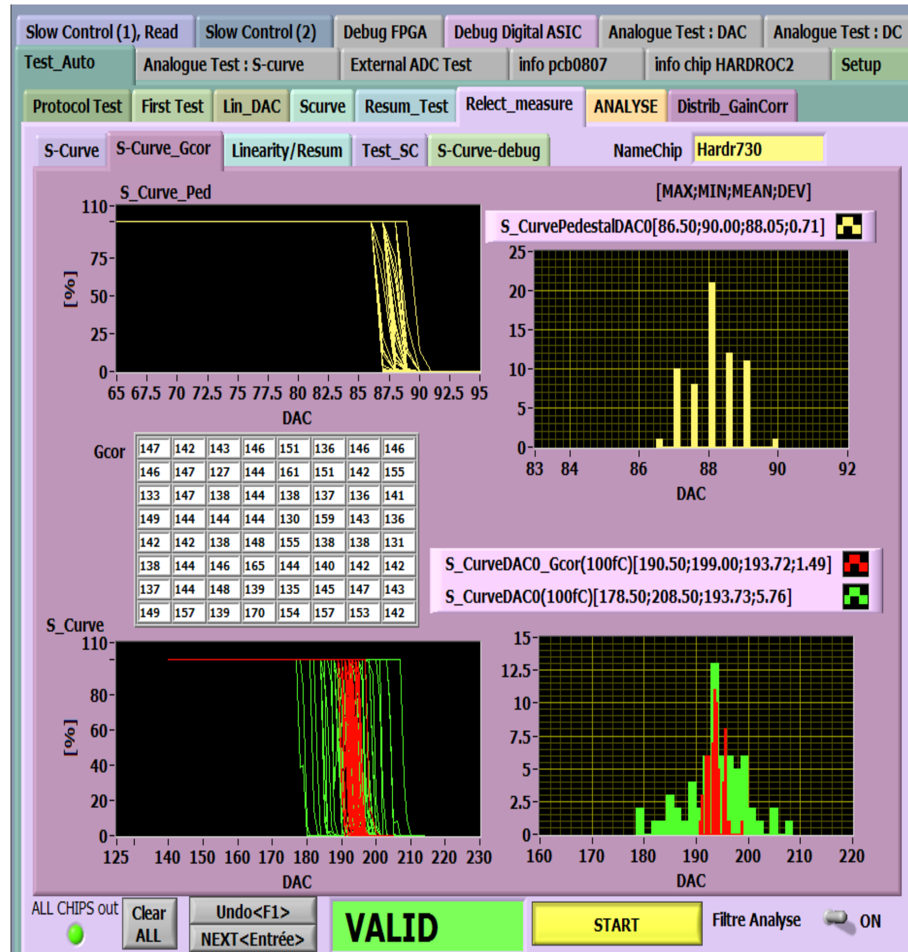

**144 ASICs= 9216 channels/1m²**


1 pad= 1cm², interpad distance = .5 mm

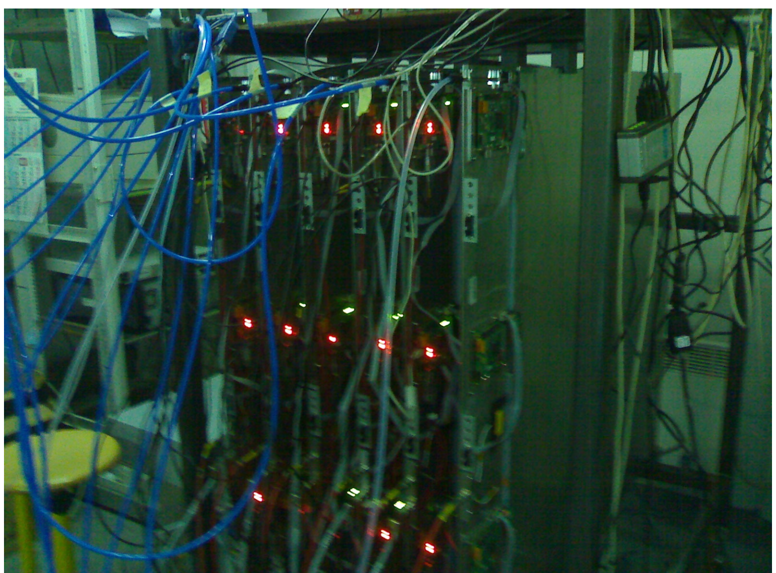
# Electronics

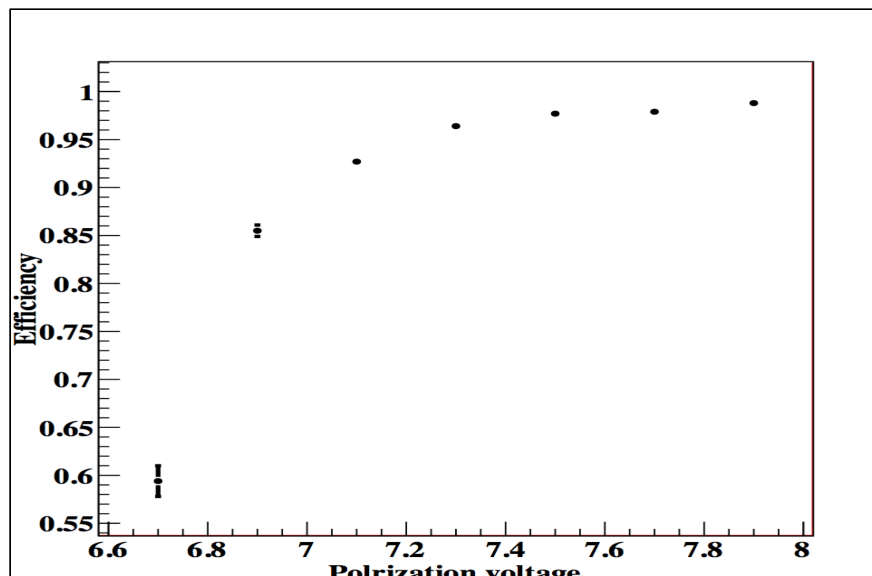
A robot was used to test the 10500 ASICs (64 ch, 3 thresholds)
The procedure allows to select the good ASICs and calibrate them
Yield 93%. Electronics boards are being produced



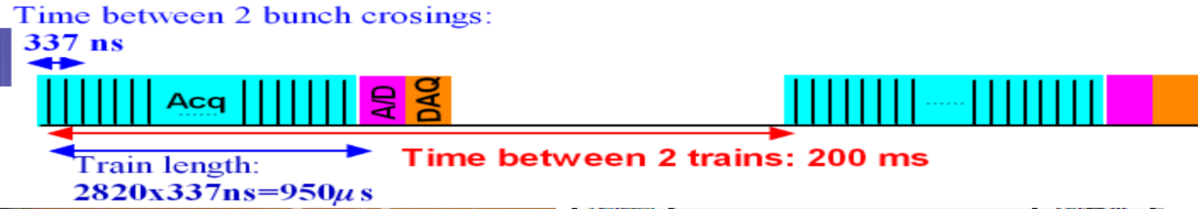
Prototype to be ready by June 2011

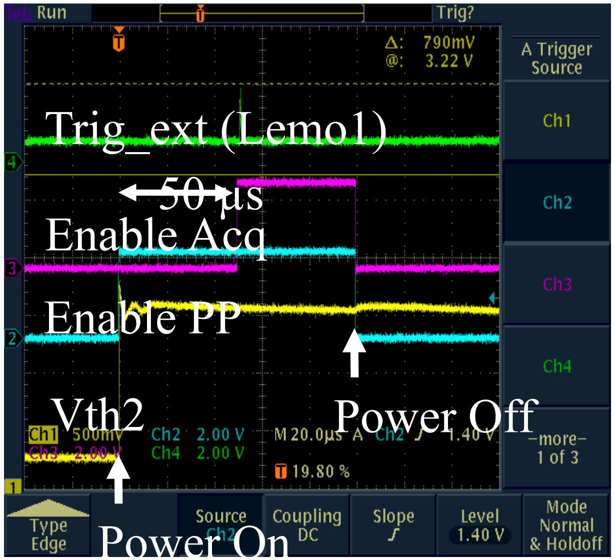


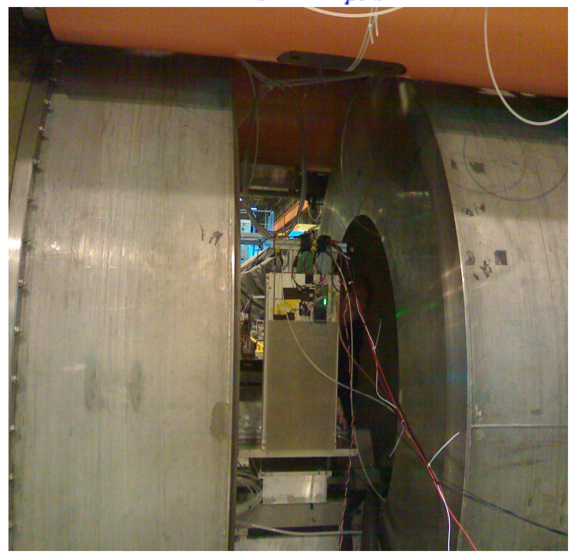


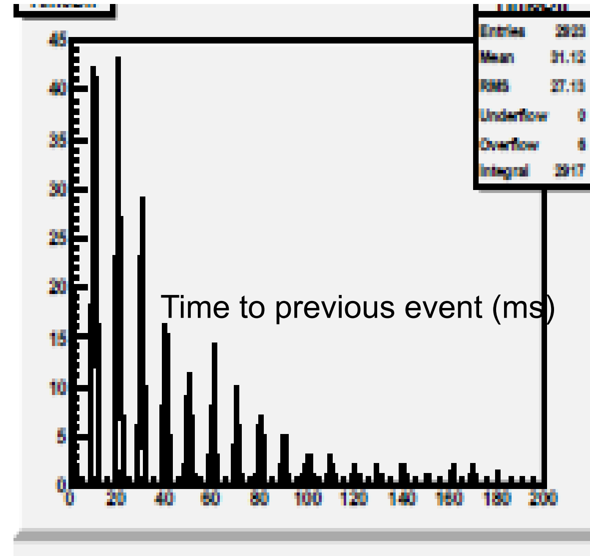

Bolts
Plates
Spacers
Planarity Verification

# Power-pulsing test

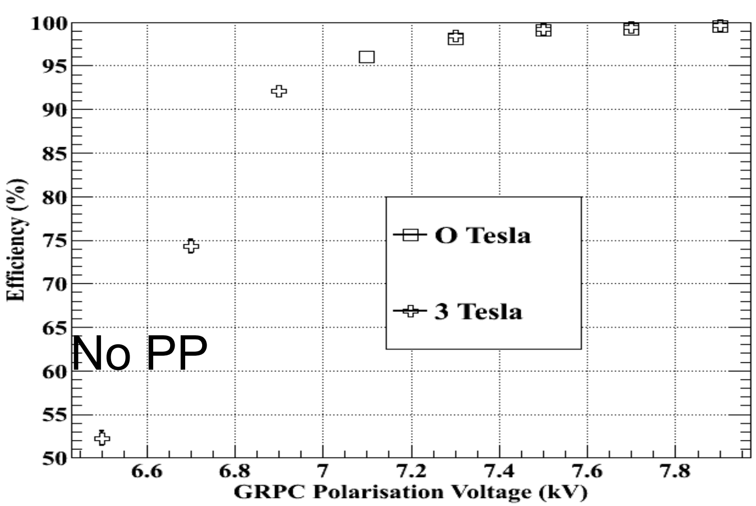


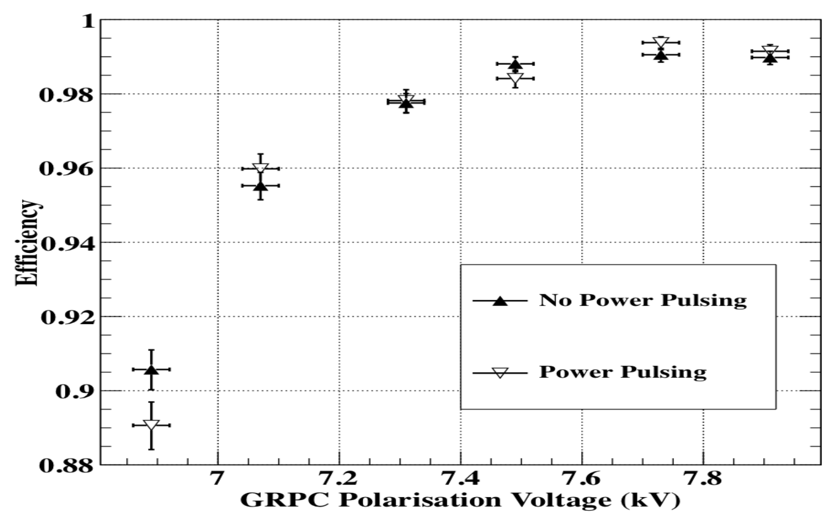






PP is on during 2 ms every 10 ms rather than every 200 ms for ILC



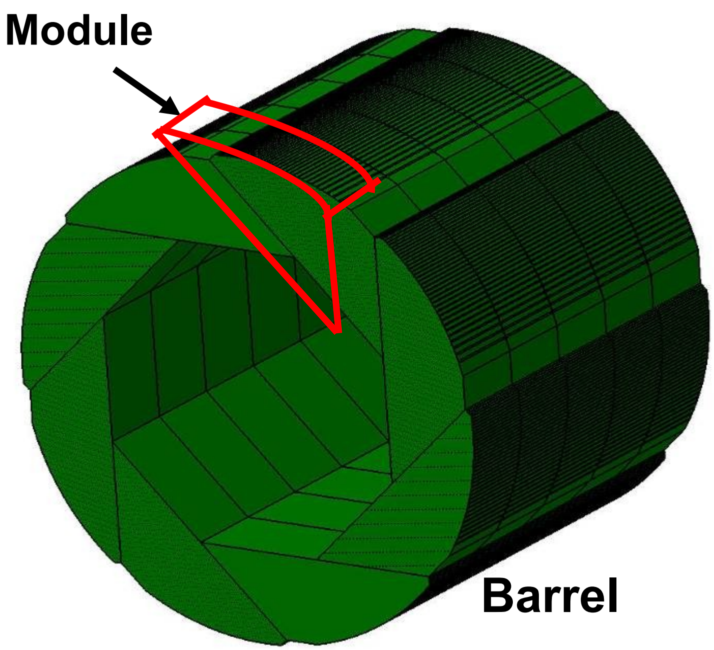



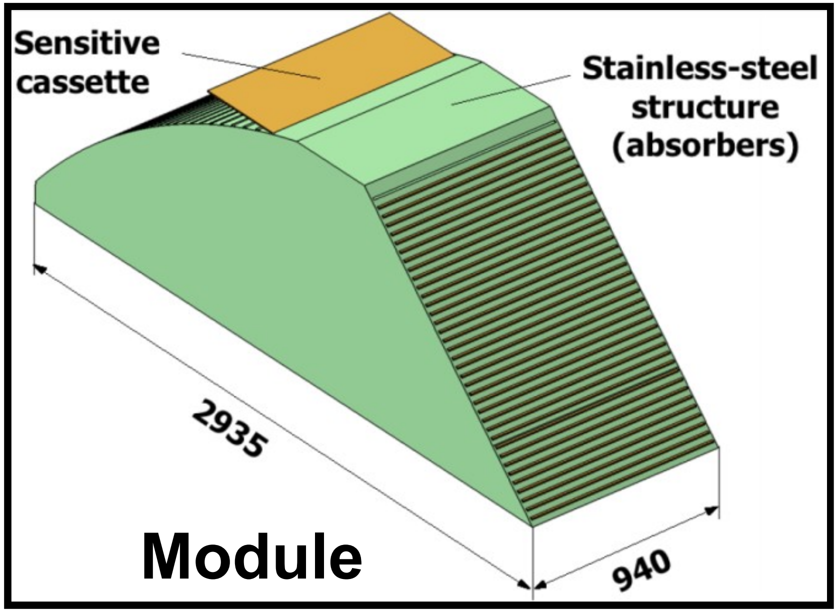
# Mechanical structure and services

# Mechanics study

Although the SDHCAL option is compatible with the two proposed mechanical structures : Tesla and Videau, we think that there are strong arguments in favor of the Videau structure:

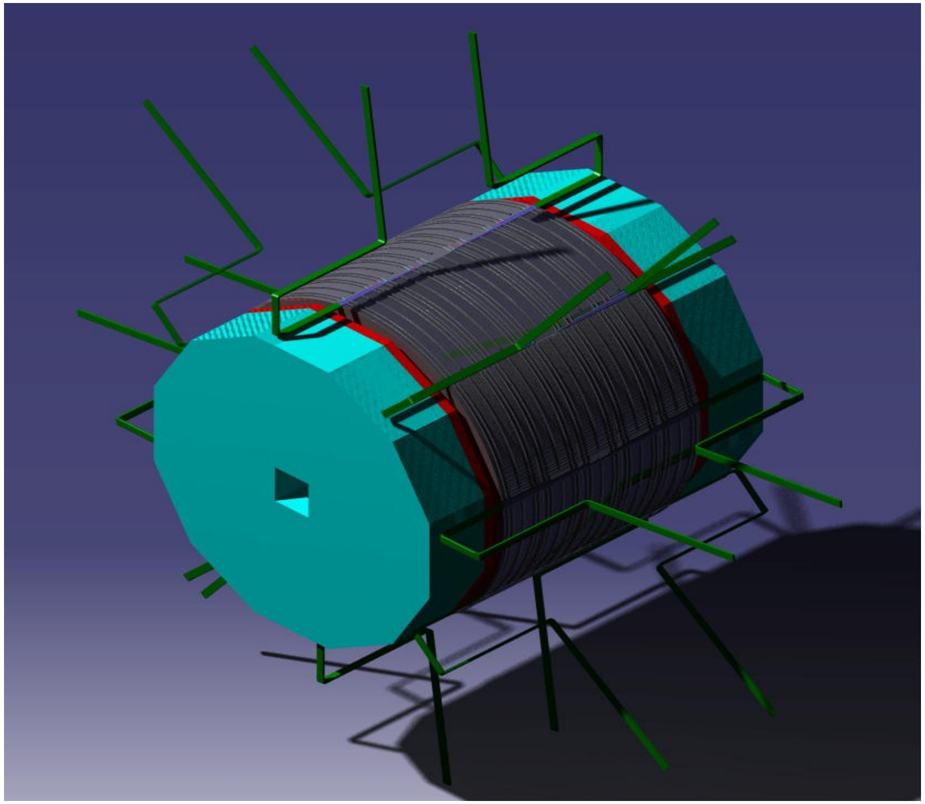
- It is self-supporting
- Has negligible dead zones
- Eliminates projective cracks
- Minimizes barrel / endcap separation (services leaving from the outer radius)



# ILD Barrel & Endcap

A mechanical model based on the Videau structure is studied.
It includes the Barrel and the Endcaps in a realistic way.
It respects the constraints imposed by the integration working group (dimensions, services...)

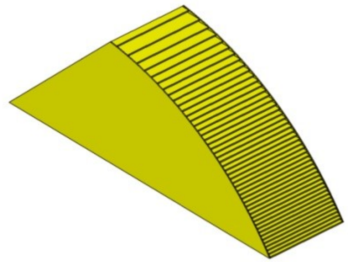


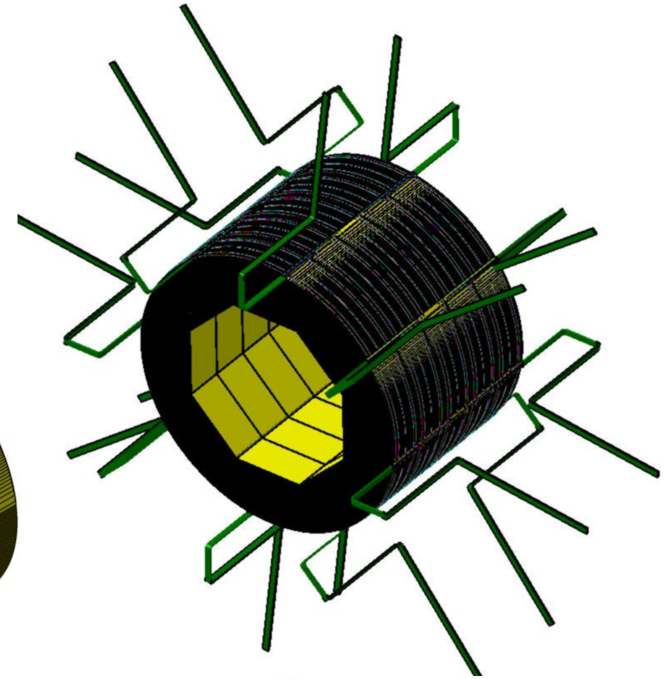
Barrel with services and Endcap+Ring

# ILD Barrel & Endcaps

## Barrel : 5 wheels

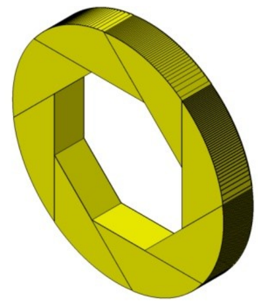
Rout : 3385 mm
Rin : 2058 mm
Z = 2350x2 =>4700 mm
47 detectors
Total weight : 624 t





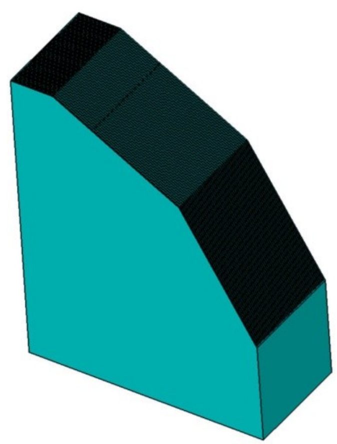
## DHcal EndCap : 4 modules

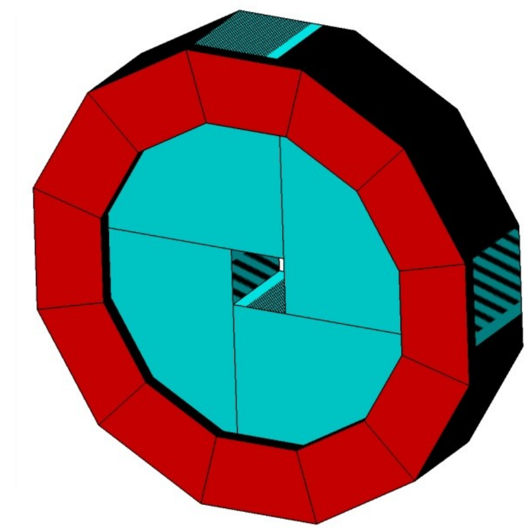
Rout : 3190 mm
Rin :  square 400 mm
Thickness : 1287 mm
48 detectors
Total weight : 262 t



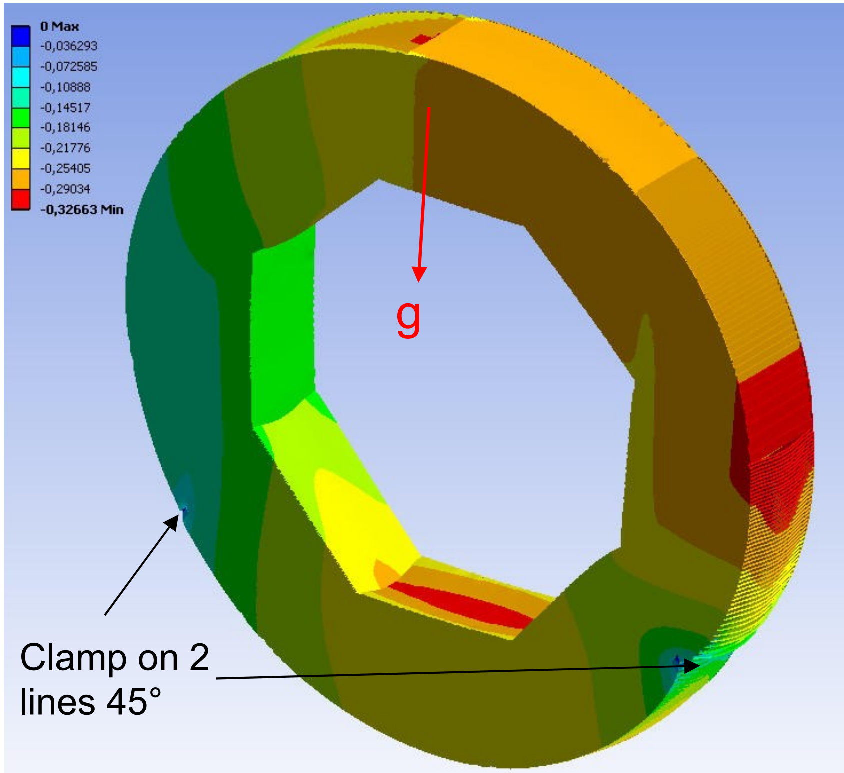
## Ring : 12 modules

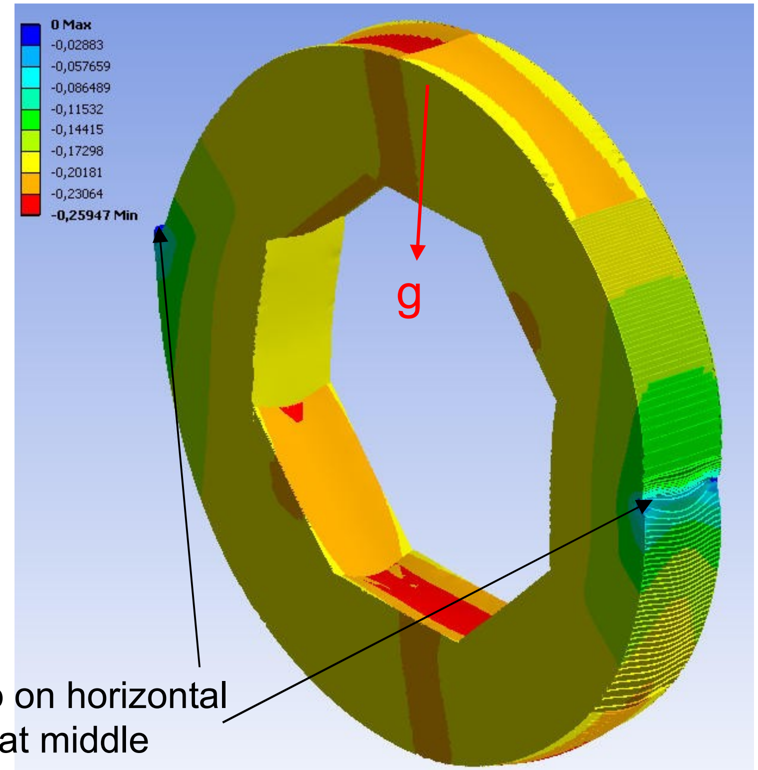
Rin : 2190  mm
Rout (see Hcal EC)
Thickness : 200 mm
7 detectors
Total weight : 20 t





- Numerical simulations : Rails position



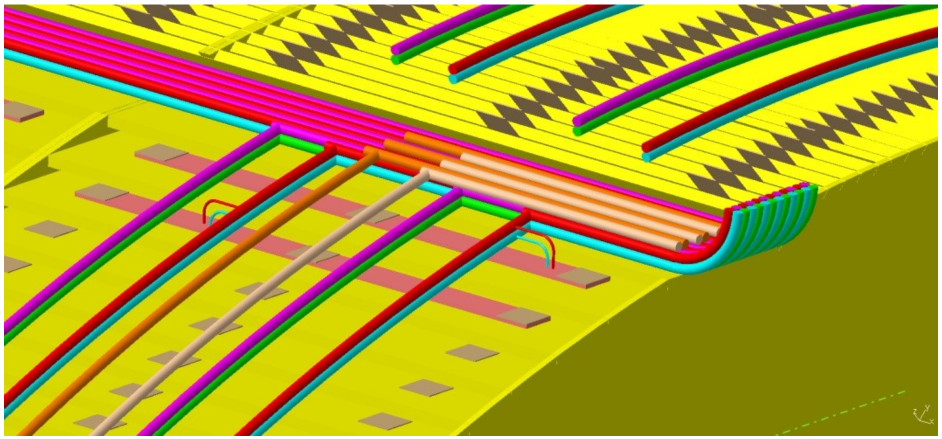

*Directionnal deformation axis Z (// gravity) (mm)*

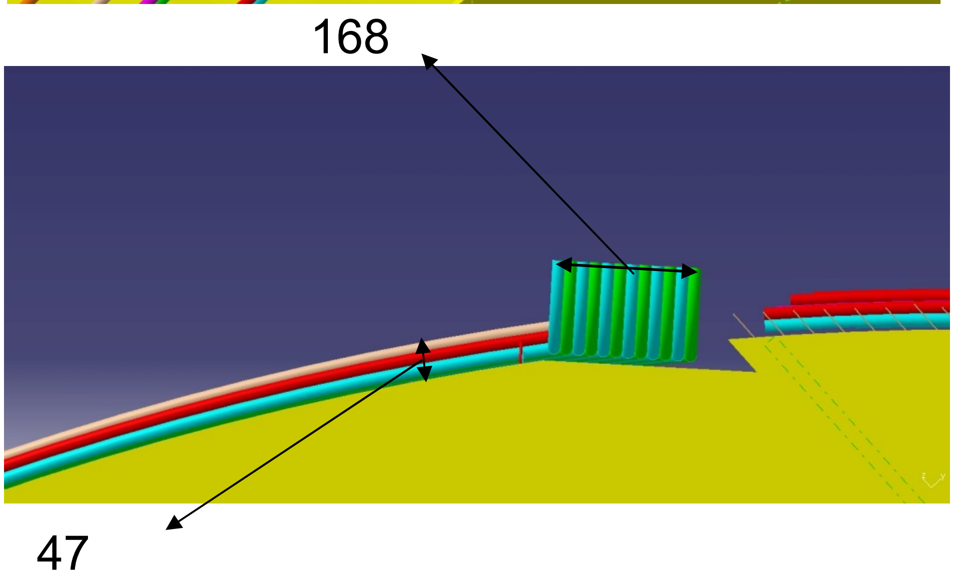
-1 wheel =8 modules

- Only gravity as load

*Max deformation : 0.32 mm for 45° position – 0.25 mm for middle plane*

## Services : Barrel






- Cooling : Blue / Red

2 loops by module
Ø14 for principal
Ø4 for distribution alternative

- Gaz For GRPC : green / pink

2 loops by module
Ø14 for principal
Ø4 for distribution alternative

- High Tension : Brown

Ø14 for supply

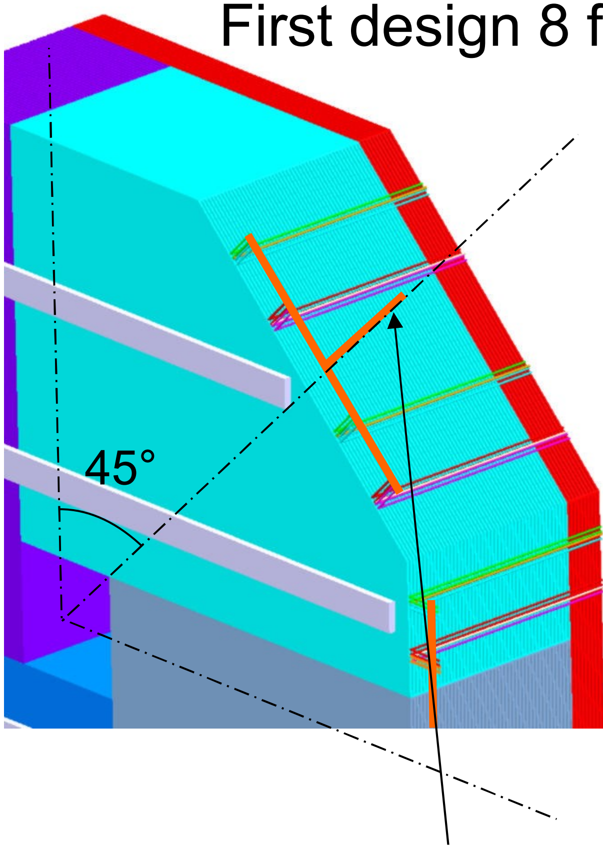
- Data acquisition : Beige

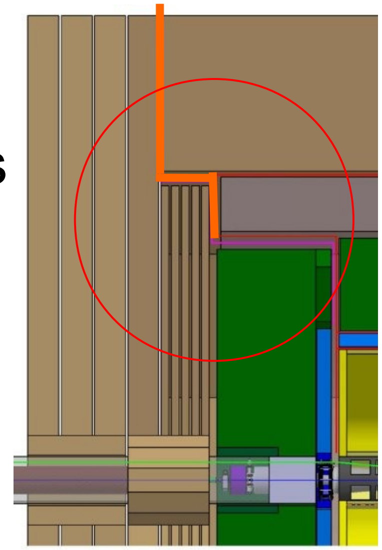
Ø14 for collecting

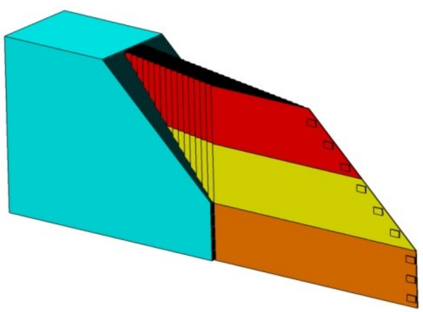
8 outings : 168 x 47

- Services : Endcap+ring

First design 8 faces





8 outing: 98 x 47 tubes

- Cooling : Blue / Red

  2 loops by GRPC
  Ø14 for principal
  Ø4 for distribution alternative

- Gaz For GRPC : green / pink

  2 loops by GRPC
  Ø14 for principal
  Ø4 for distribution alternative

- High Tension : Brown

  Ø14 for supply

- Data acquisition : Beige

  Ø14 for collecting

# Mechanics and services summary

Mechanics :

Barrel :

Design and detailed study completed

Endcap:

Design is completed and detailed study is ongoing

Services :

All services are considered and designed. They fulfill the requirement from the integration group. optimization is still ongoing

Thermal study

Done in the case of the prototype

It is ongoing in the case of the ILD.

Water cooling is the baseline but we have expertise on $CO_2$ 2-phase cooling and we will consider this option soon

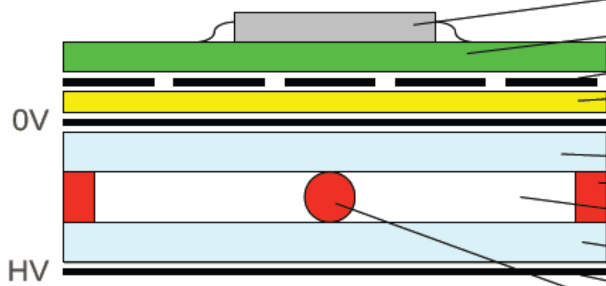
# Software

# Mokka simulation

Goal : To be as realistic as possible
1- Detailed description of material
2- Detector response controlled by data

Available in ilcsoft v01-11

Sensitive medium with detailed implementation




**Tracking of a Geantino through the RPC**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -844 | -1.9e+03 | 365 | 4e+04 | 0 | 2.11e+03 | 2.11e+03 | BarrelHcalModule | Transportation |
| 2 | -853 | -1.92e+03 | 369 | 4e+04 | 0 | 21.8 | 2.13e+03 | physiRPCFree | Transportation |
| 3 | -853 | -1.92e+03 | 369 | 4e+04 | 0 | 0.402 | 2.13e+03 | physiRPCmylarCathode | Transportation |
| 4 | -853 | -1.92e+03 | 369 | 4e+04 | 0 | 0.196 | 2.13e+03 | physiRPCGraphiteCathode | Transportation |
| 5 | -853 | -1.92e+03 | 369 | 4e+04 | 0 | 0.0544 | 2.13e+03 | physiRPCThickGlass | Transportation |
| 6 | -854 | -1.92e+03 | 369 | 4e+04 | 0 | 1.2 | 2.13e+03 | physiRPCGap | Transportation |
| 7 | -854 | -1.92e+03 | 370 | 4e+04 | 0 | 1.31 | 2.14e+03 | physiRPCThinGlass | Transportation |
| 8 | -855 | -1.92e+03 | 370 | 4e+04 | 0 | 0.761 | 2.14e+03 | physiRPCGraphiteAnode | Transportation |
| 9 | -855 | -1.92e+03 | 370 | 4e+04 | 0 | 0.0544 | 2.14e+03 | physiRPCmylar | Transportation |
| 10 | -855 | -1.92e+03 | 370 | 4e+04 | 0 | 0.0544 | 2.14e+03 | physiRPCPCB | Transportation |
| 11 | -855 | -1.92e+03 | 370 | 4e+04 | 0 | 1.31 | 2.14e+03 | physiRPCElectronics | Transportation |
| 12 | -856 | -1.93e+03 | 370 | 4e+04 | 0 | 1.74 | 2.14e+03 | BarrelHcalModule | Transportation |

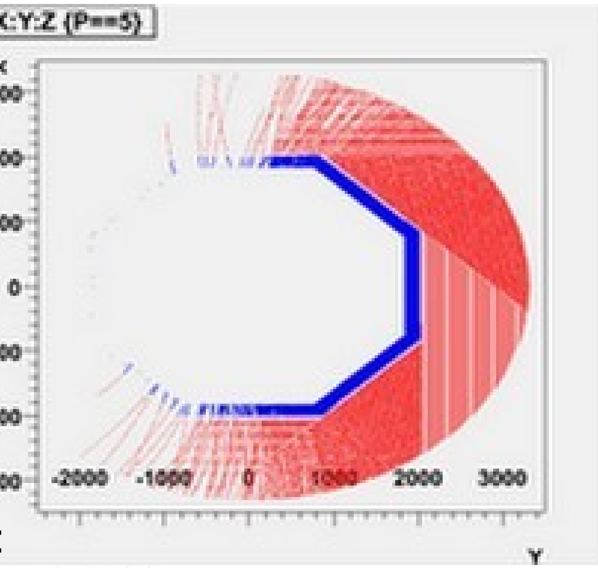
# Mokka simulation

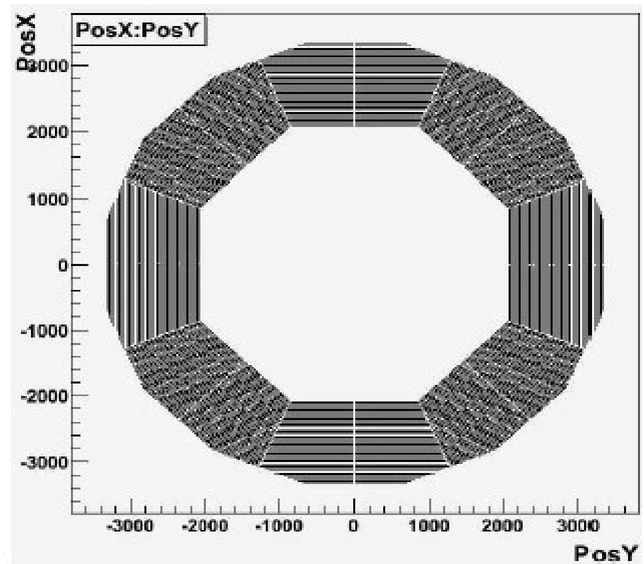
Available in ilcsoft v01-11 :

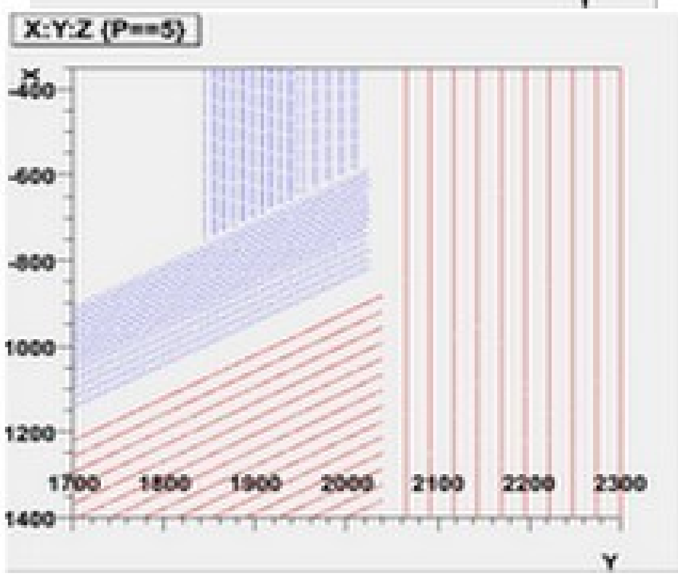
**Sensitive medium with detailed implementation**

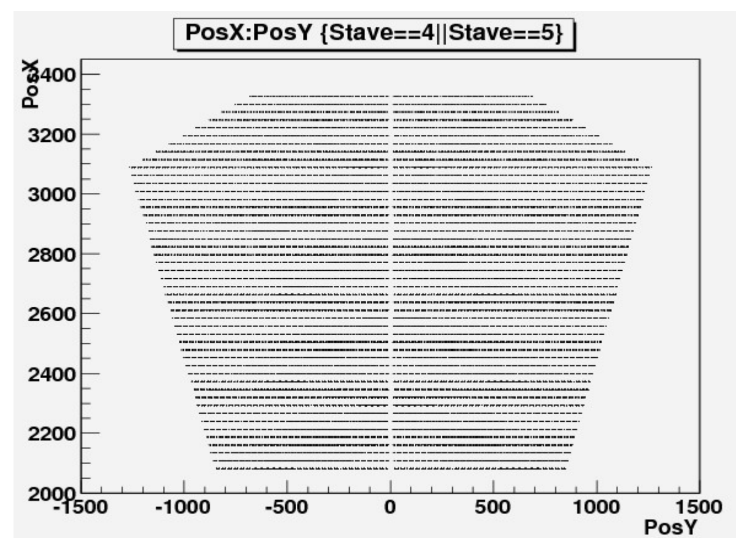
**Sensitive medium with both Videau and TESLA geometry**

Hit position
with single muon :



# Mokka simulation

Available in ilcsoft v01-11 :

**Sensitive medium with detailed implementation**
**Sensitive  medium with both Videau  and TESLA geometry**
**Easy to choose between geometries and options**

In the steering file for Mokka :

/Mokka/init/detectorModel ILD_01pre00
/Mokka/init/EditGeometry/rmSubDetector ShcalSc03
#TESLA GEOMETRY
/Mokka/init/EditGeometry/addSubDetector SHcalRpc02 110
#VIDEAU GEOMETRY
#/Mokka/init/EditGeometry/addSubDetector SHcalRpc01 110

#For TESLA GEOMETRY, CAN CHOOSE BETWEEN DETECTORS
#/Mokka/init/globalModelParameter Hcal_sensitive_model scintillator
/Mokka/init/globalModelParameter Hcal_sensitive_model  SDRPC
/Mokka/init/globalModelParameter Hcal_cells_size 10

# Mokka simulation

Available in ilcsoft v01-11 :

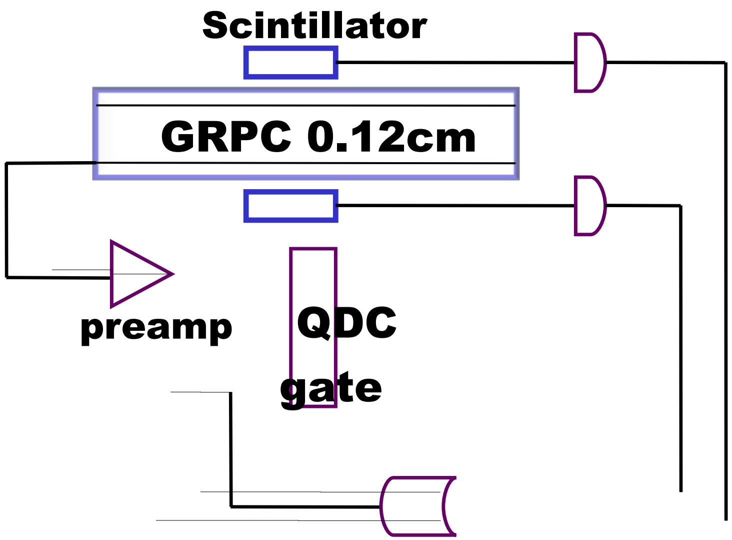
**Sensitive medium with detailed implementation**
**Sensitive medium with both Videau and TESLA geometry**
**Easy to choose between geometries and options**

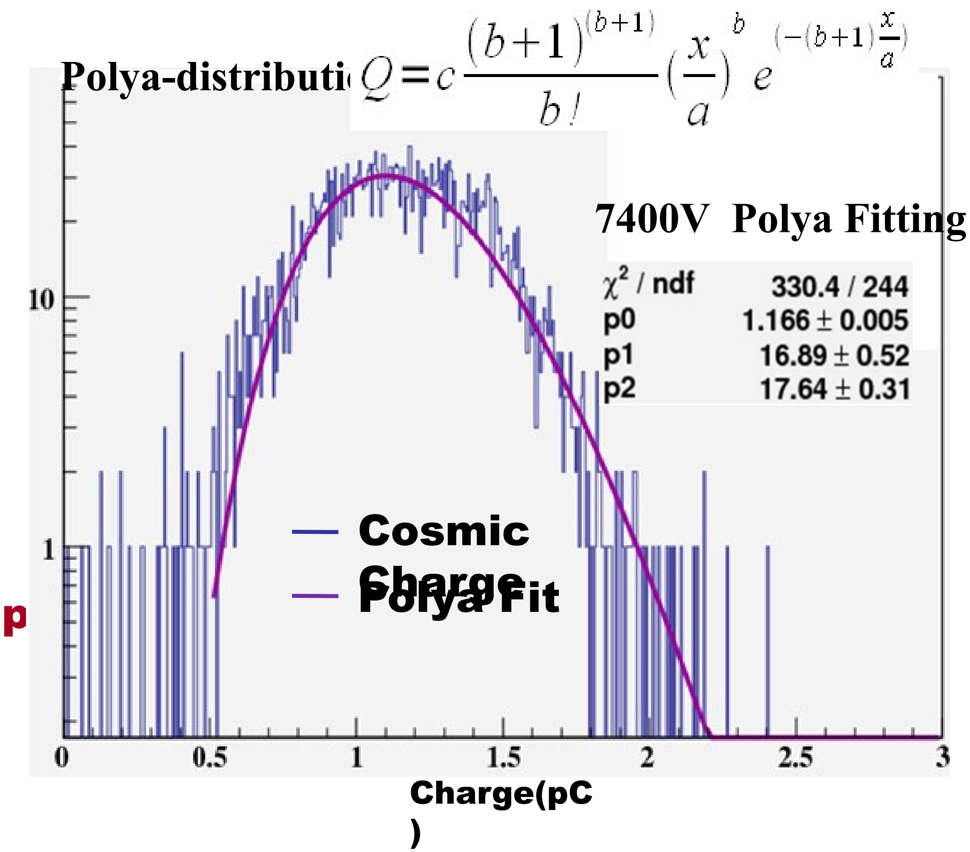
Missing items :
Endcaps and Endcap Rings still with scintillators in the Tesla case.
Work started to put GRPC there too.
Code written locally
Not yet debugged
No cables nor services in simulation (almost no effect in the case of Videau geometry) but we will implement it soon

# Digitisation

-Transform GEANT4 deposited energy into induced charge.

Measure GRPC analog signal with cosmic muon




**Charge Spectrum Cosmic Test Set Up**

64 Channels, trigger area < Channel area

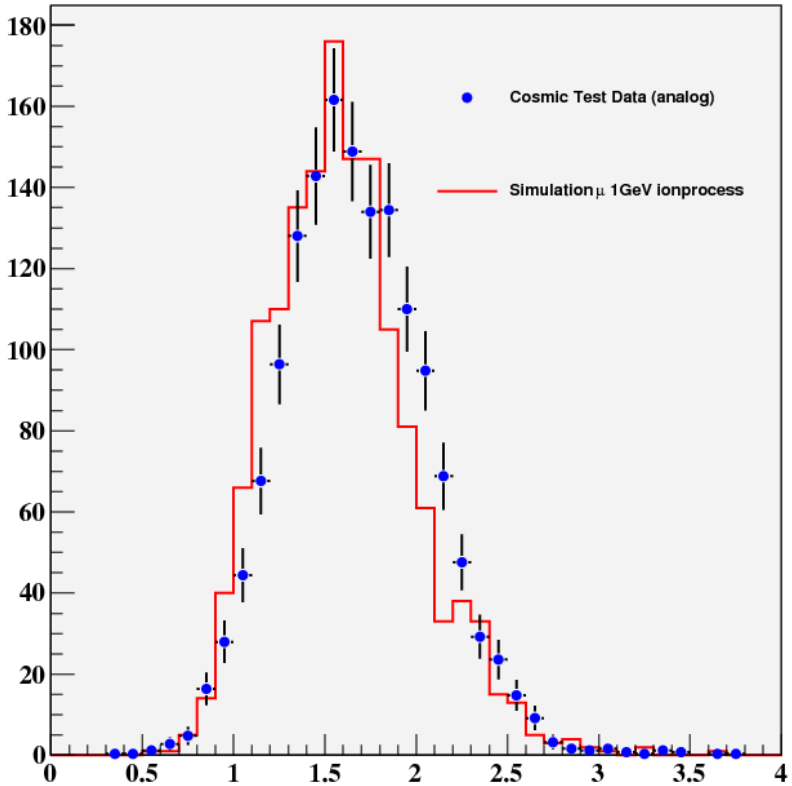
Analog readout

$$Q = c\,\frac{(b+1)^{(b+1)}}{b!}\left(\frac{x}{a}\right)^{b} e^{\left(-(b+1)\frac{x}{a}\right)}$$

# Digitisation

Transform GEANT4 deposited energy to induced charge.

- Measure GRPC Analog signal with cosmic muon
- **Simulate it in Marlin Processor and compare with data**

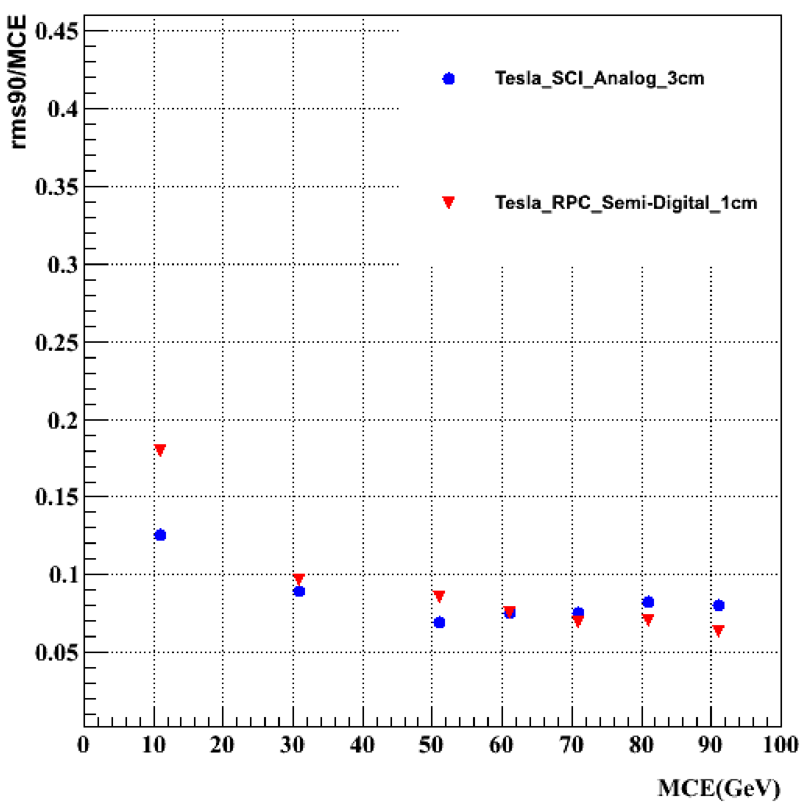


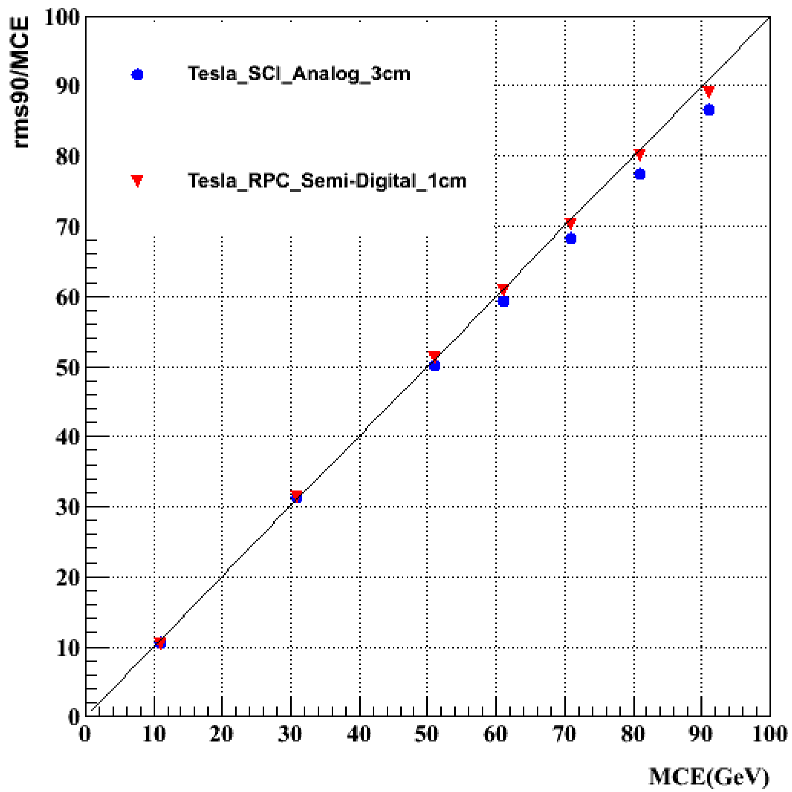

$$Q = c\,\frac{(b+1)^{(b+1)}}{b!}\left(\frac{x}{a}\right)^{b} e^{\left(-(b+1)\frac{x}{a}\right)}$$

# Digitisation

Transform GEANT4 deposited energy to induced charge.

- Measure GRPC Analog signal with cosmic muon
- Simulate it in Marlin Processor and compare with data
- **The Marlin Processor can also simulate the 3 thresholds.**
- **Calibrate the 3 Thresholds with single $K^0_L$ and Pandora.**
- **Pandora made compatible with Videau geometry.**

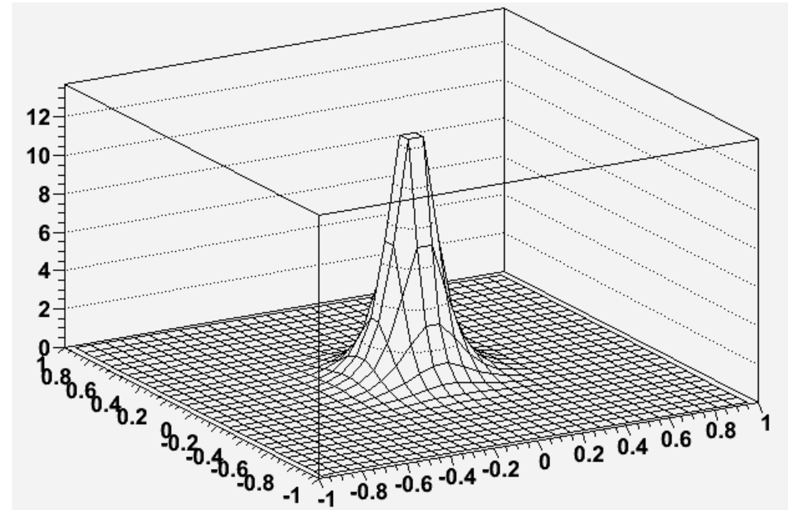


# Multiplicity

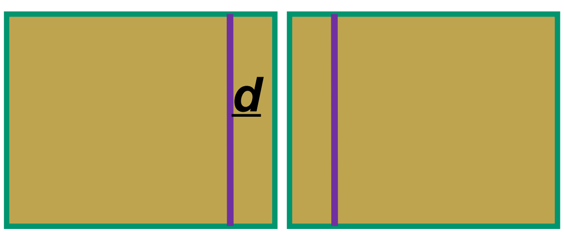
**Spread of the induced charge**

$$\sigma(x,y)=c\frac{-q}{2a}\frac{1}{\cosh\left(\pi\frac{\sqrt{(x-x_0)^2+(y-y_0)^2}}{a}\right)}$$




At low order, equivalent to a 2D gaussian with width $\frac{\sqrt{2}a}{\pi}$

**1.0cm**




Dispatching induced charge on more than one cell for tracks on the cell border.

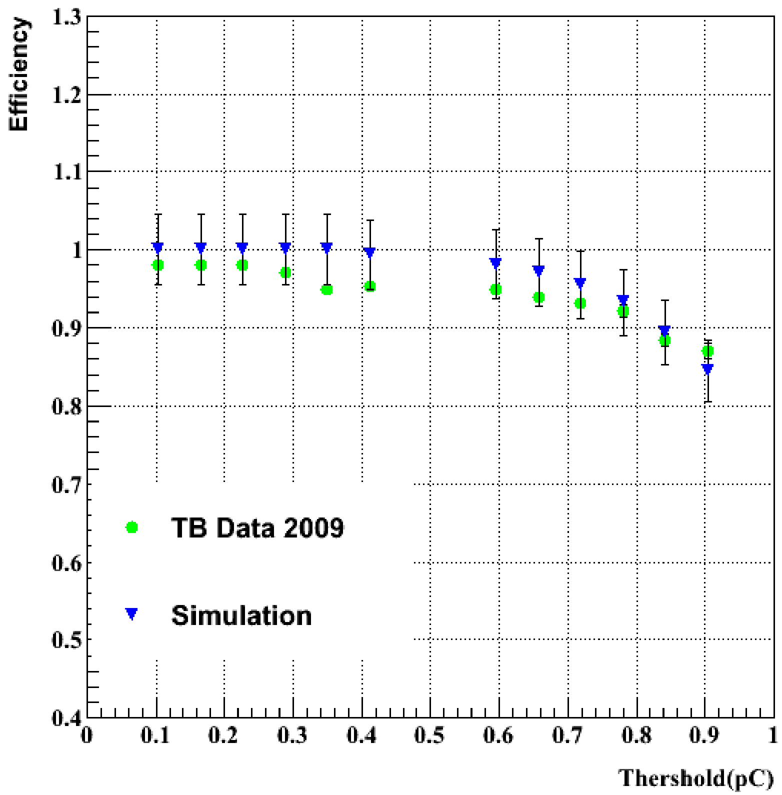
Parameter a tuned to data

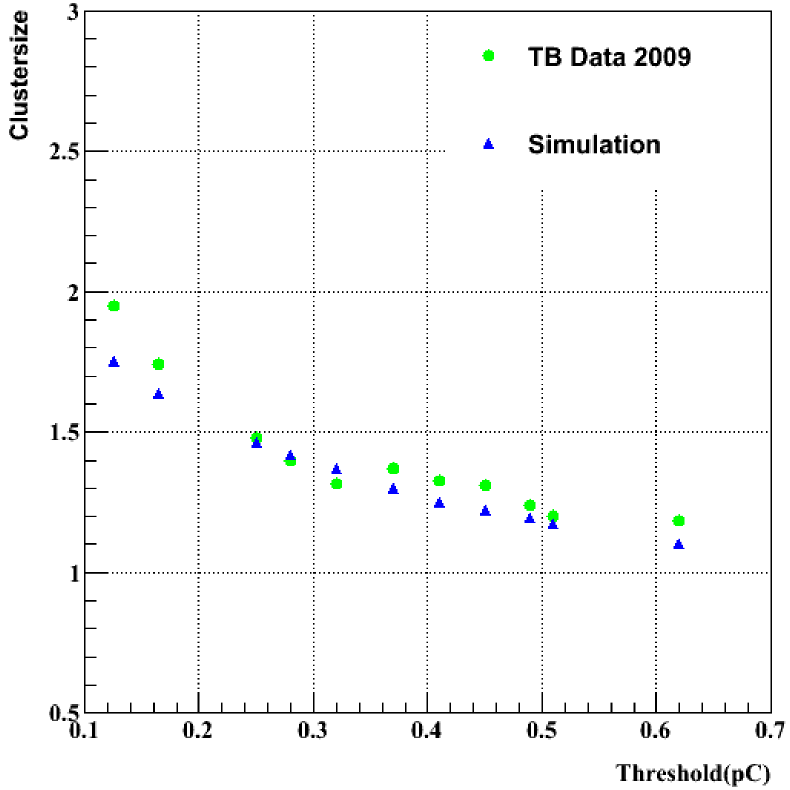
# Multiplicity

Spread of the induced charge

**Dispatching of induced charge in more than one cell**

Comparison between standalone GEANT4 program (not Mokka) and data : it works




(note : standalone GEANT4 protoype simulation produces LCIO files)

# Multiplicity

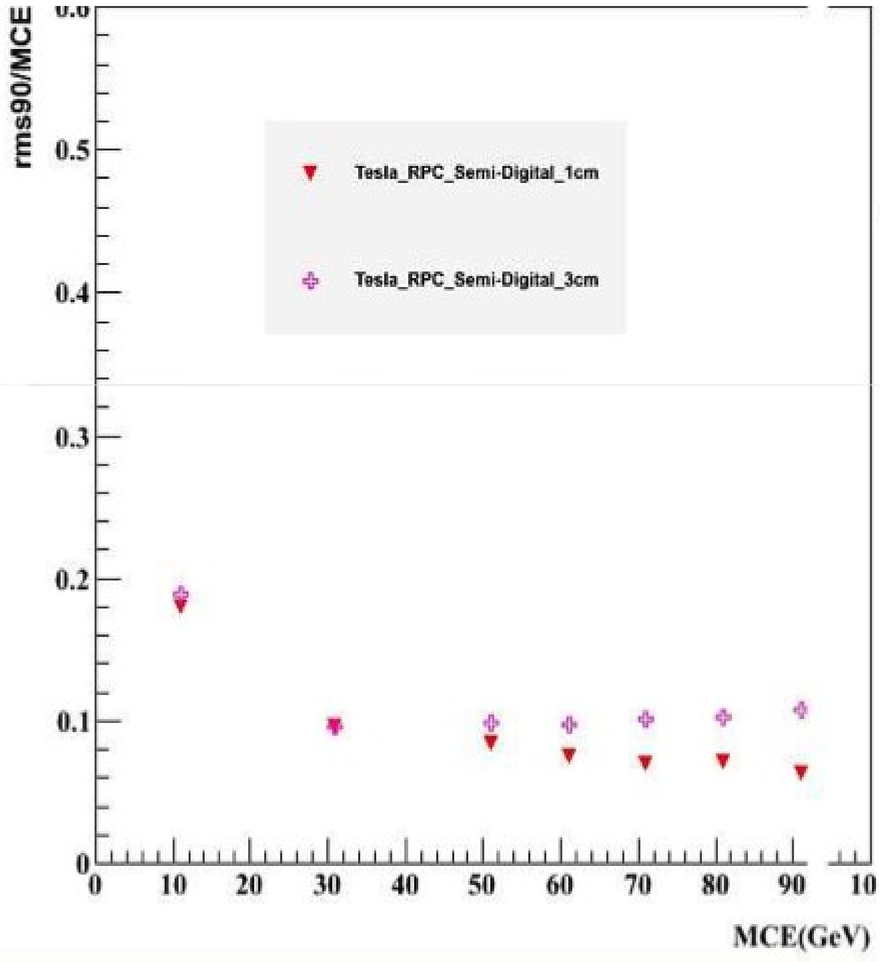
**Implementation in Marlin, need track position inside the cell :**

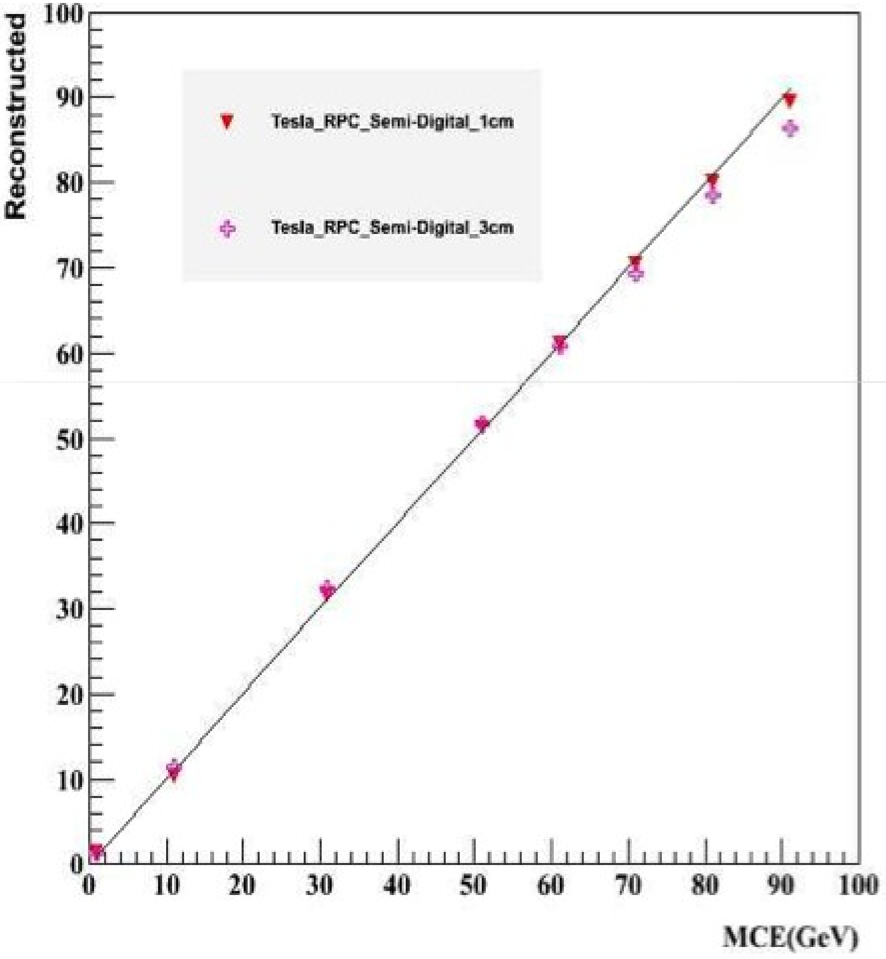
The multiplicity was introduced in the prototype standalone gean4 simulation
We need to include it in Marlin in adequate way.

1- Wait for LCIO v2
2- Randomly draw track position inside the Cell (Marlin Processor written)
3- Mokka simulation with 1mm$^2$ cells and rebuild 1cm$^2$ cells in Marlin (Marlin processor written)

Discussion with the ILD software team will allow us to choose the most convenient solution

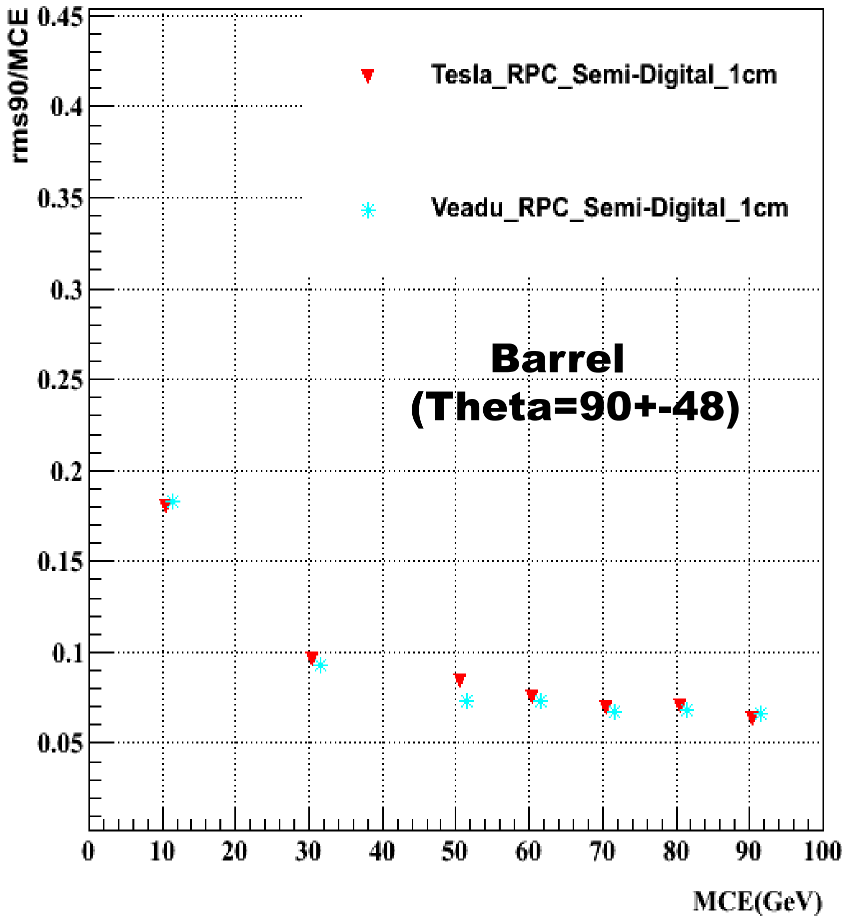
# K0_Long



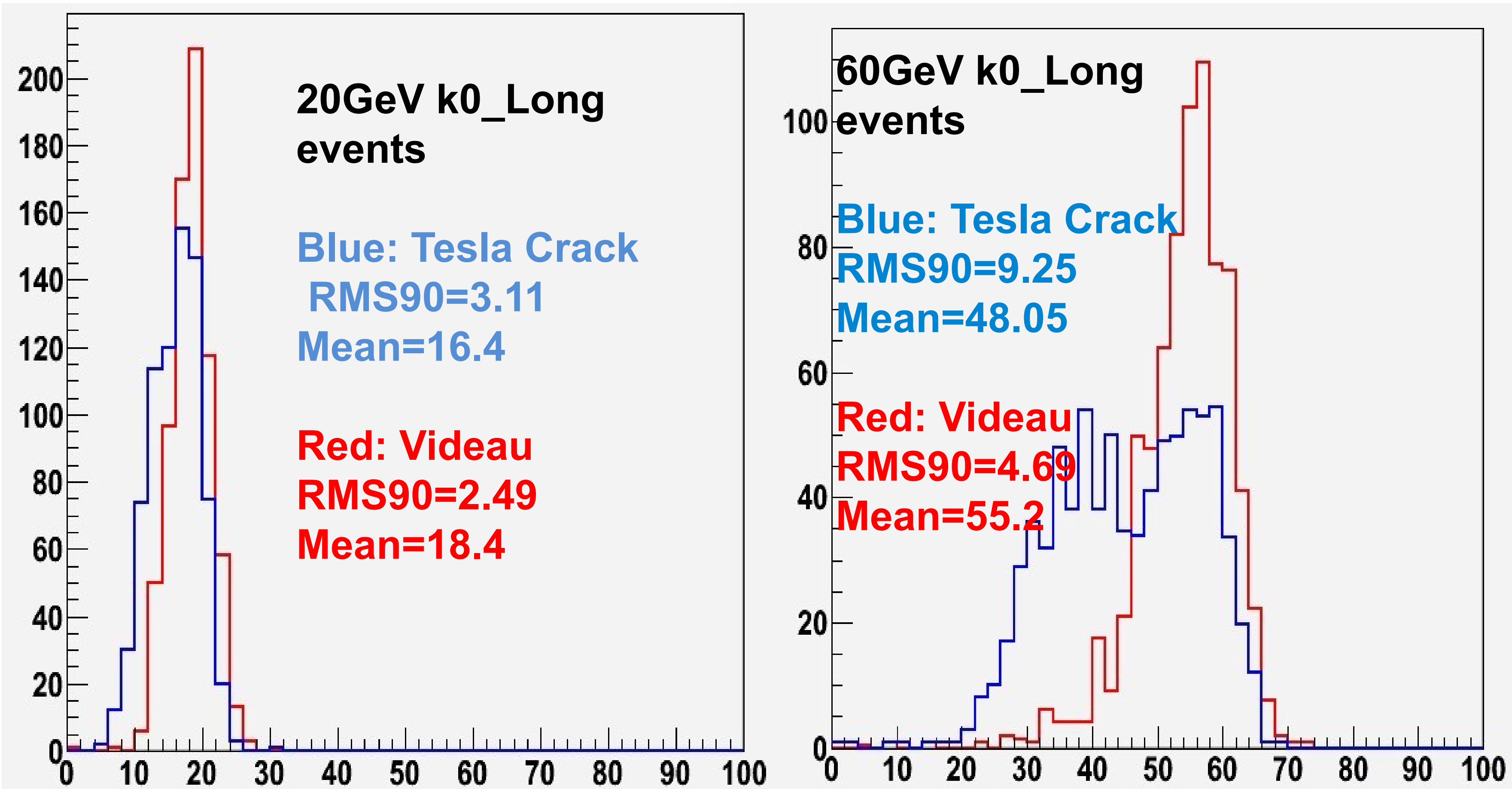

**1cm2 vs 9 cm2 granularity**

# K0_Long




**Tesla vs Videau model**

# K0_Long




**Tesla vs Videau model**

# Analysis tools

**Marlin processors written :**

**Use of PandoraPFANew**

Code have been updated to deal with Videau geometry

Some other minor stuff to implement (gap between modules)

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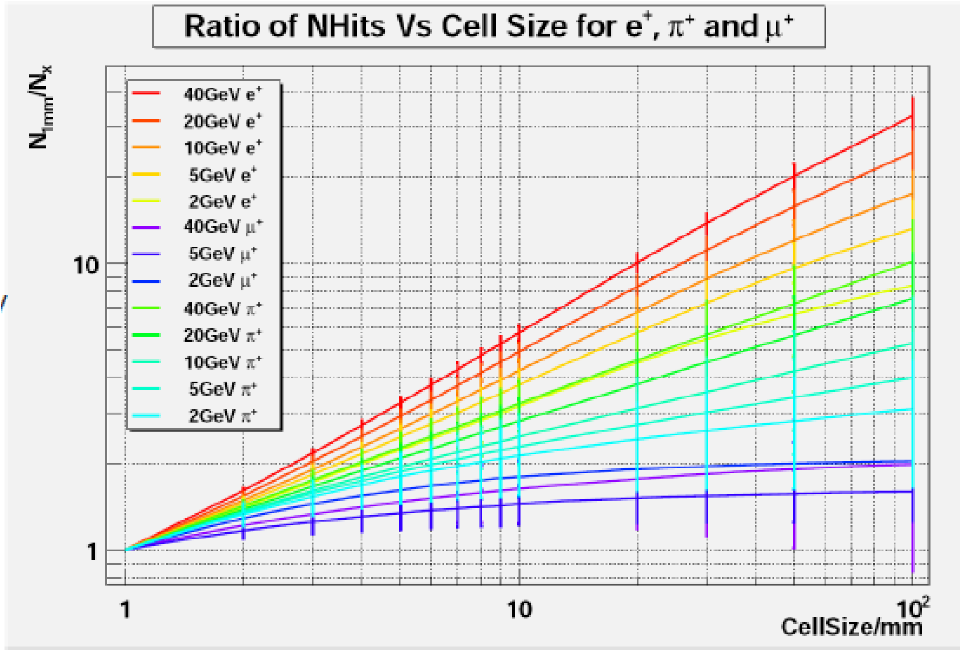
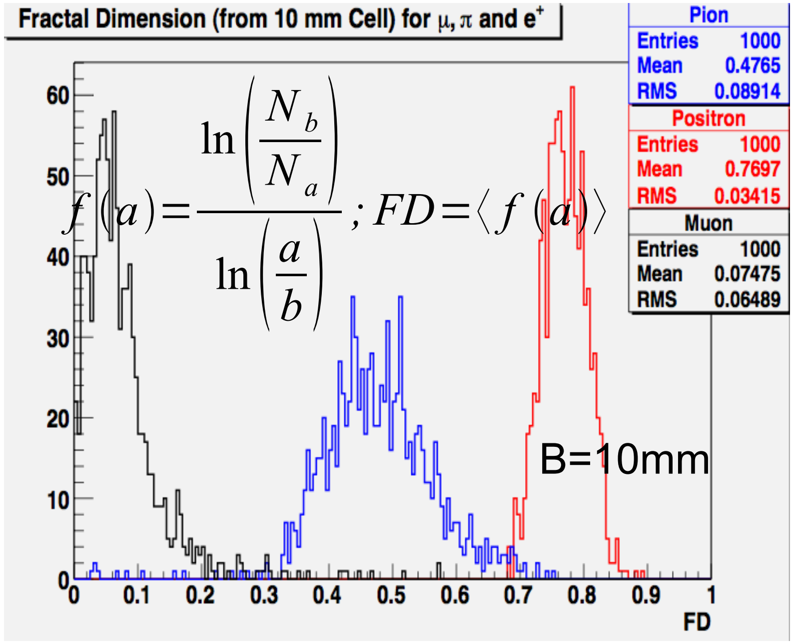
Minimum Spanning Tree

**Fractal Dimension**

**For PID and Energy Estimation**




$$f(a) = \frac{\ln\left(\frac{N_b}{N_a}\right)}{\ln\left(\frac{a}{b}\right)} ; FD = \langle f(a) \rangle$$

$N_a$ number of hits for cell surface = a

PID performance :

b=1mm

| 1mm | e+ | u | h |
|---|---|---|---|
| e+ | 998 | 0 | 2 |
| u | 1 | 994 | 5 |
| h | 15 | 14 | 971 |

b=10mm

| 10mm | e+ | u | h |
|---|---|---|---|
| e+ | 1000 | 0 | 0 |
| u | 0 | 995 | 5 |
| h | 17 | 14 | 969 |

# Analysis tools

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Some other minor stuff to implement (gap between modules)

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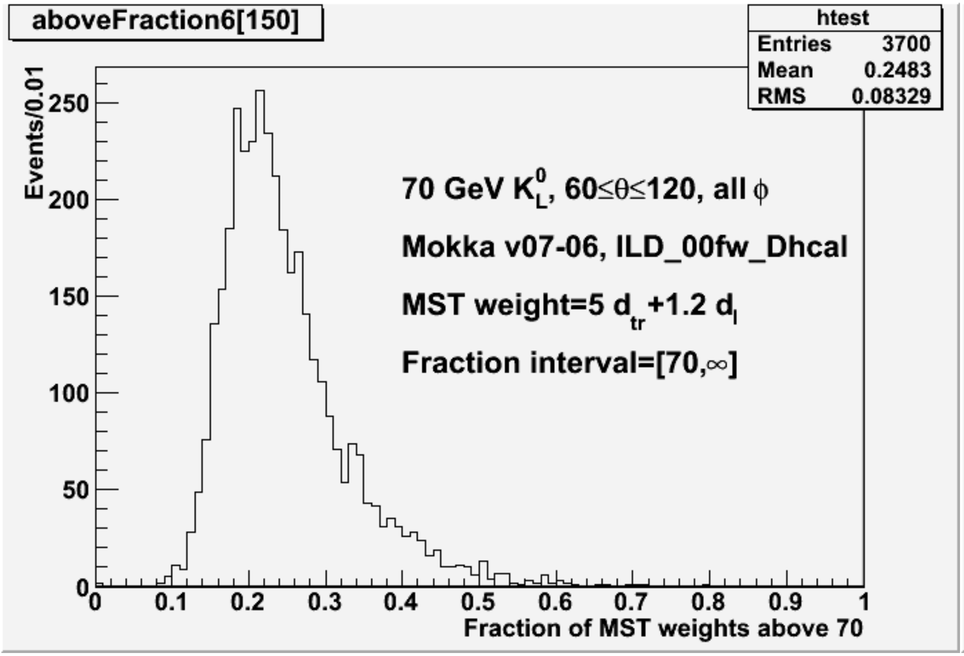
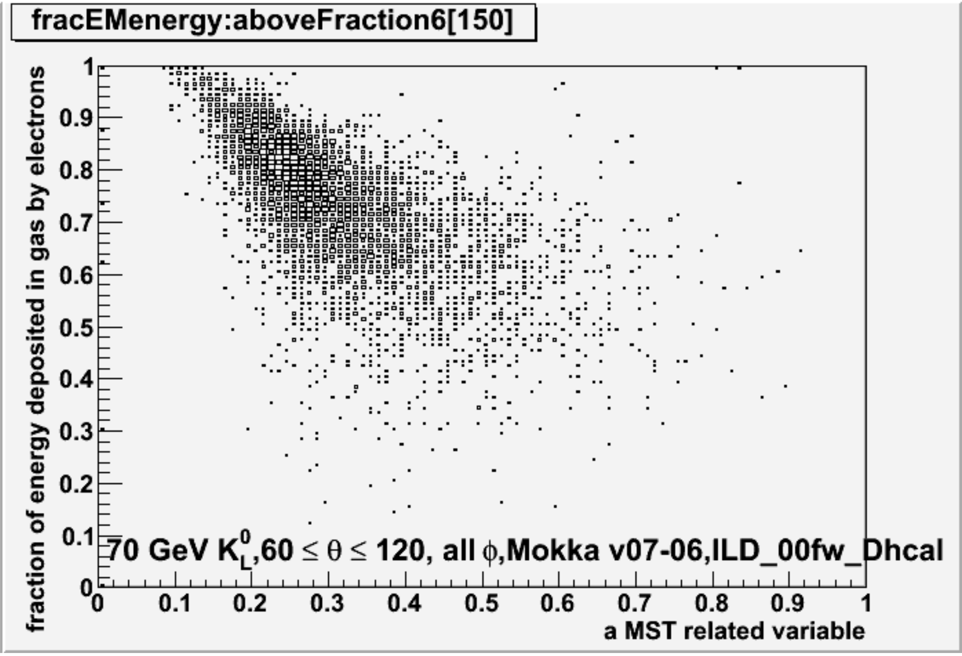
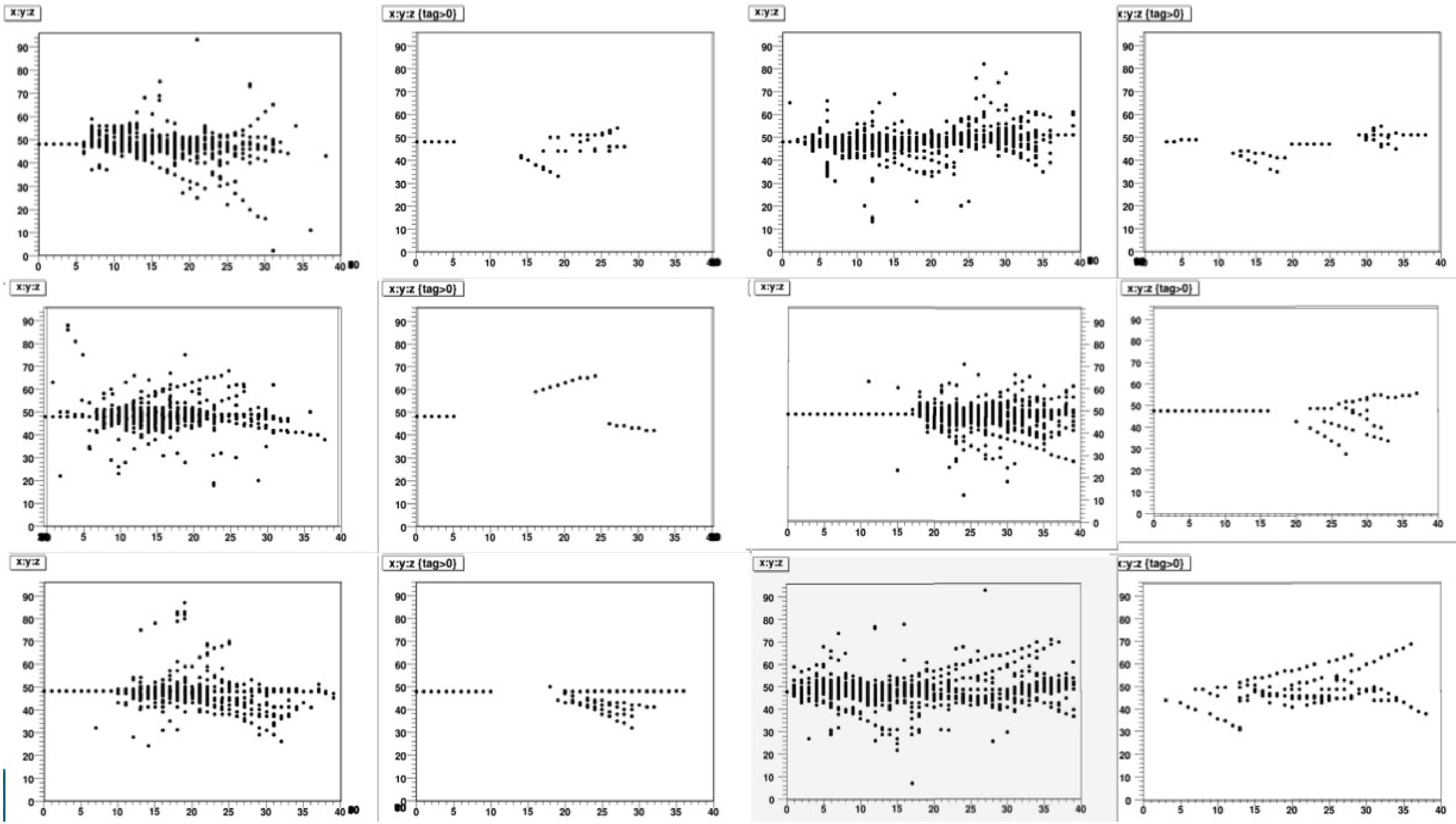
**For PID and Energy Estimation**



# Hough Transform (HT)




This allows to use mips inside the hadronic shower as a tool of
In-situ calibration, alignment and efficiency control.

# Software and analysis summary

Geometry simulation :

Barrel simulation ready, in Mokka and debugged

Endcap simulation : debug GRPC as sensitive detector.

Simulation of induced charge and threshold effects :

Ready

Debugged

Tested against data

Multiplicity simulation :

Physics understood

Tested against data

Technical solution to choose.

Reconstruction :

Update of Pandora started.

Some advanced tools using SDHCAL fine granularity already developed.

Strong collaboration with the Pandora team in the very near future will allow to better optimize the SDHCAL performance and to include new tracking tools (MTS,FD,Hough Transform...)

# Conclusion

- The concept has been and continues to be checked in prototypes
- A mechanical model exists for ILD in the standard CAD maquette
- It fulfills the integration constraints, hanging from the coil cryostat supporting the ECAL and TPC with a very small deformation providing the space for services
- A software model exists, a detailed simulation in agreement with the mechanical model
- A digitization module exists in Marlin with the right specifications.
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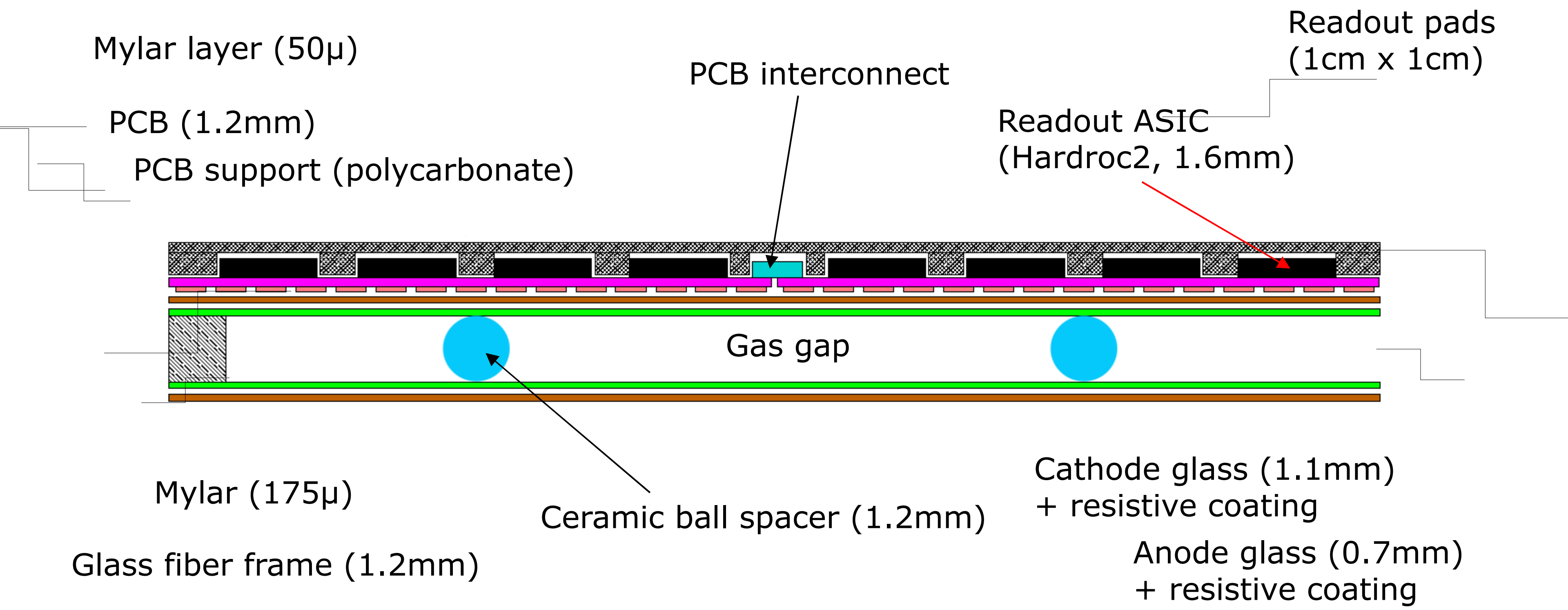
At the time of the LoI, extensive productions have been done with AHCAL. It is time to validate on a large scale set of reactions the use of sDHCAL

The productions being considered for high energy (1 TeV), the fine granularity of the SDHCAL is expected to provide better separation, the leading contribution in jet resolution.

# BACKUP

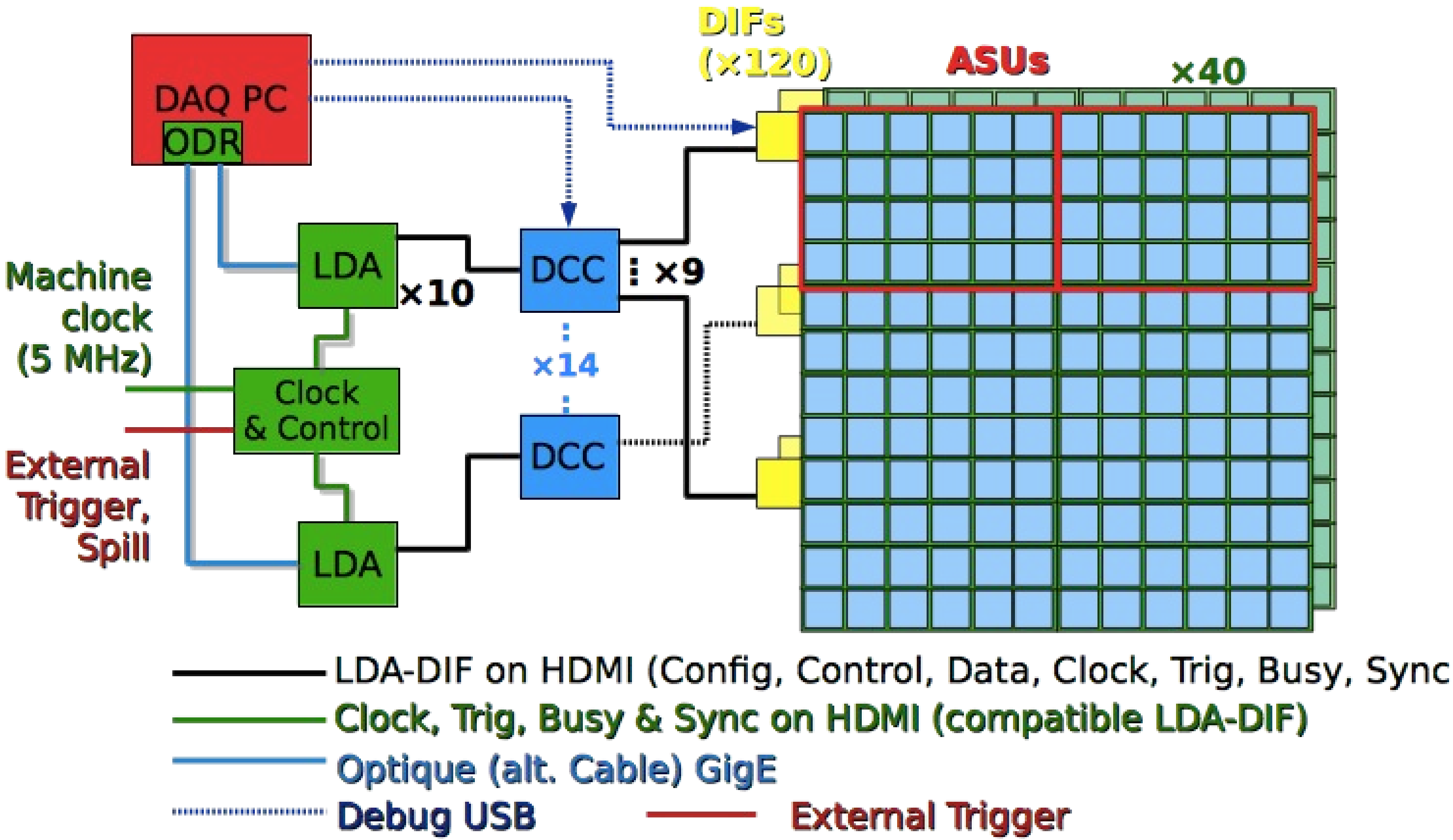
# Cross-section of 1m² glass RPCs



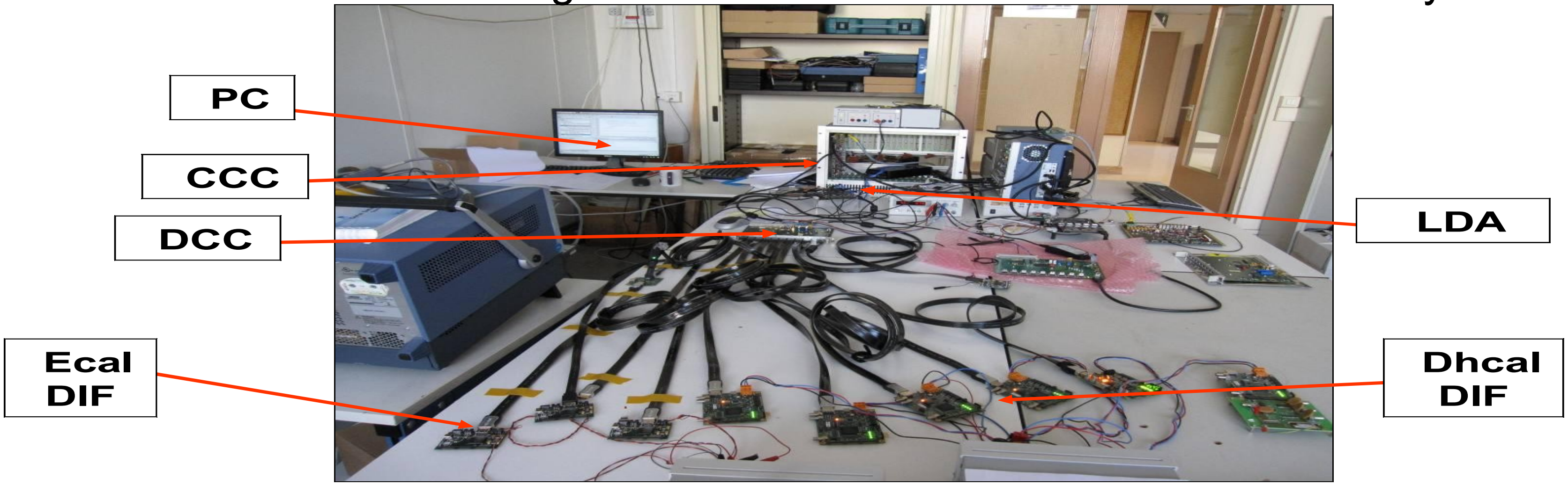

Total thickness: 6.025mm

# Acquisition system

An acquisition system developed within CALICE collaboration will be used



The full chain of the new generation of CALICE DAQ was successfully tested

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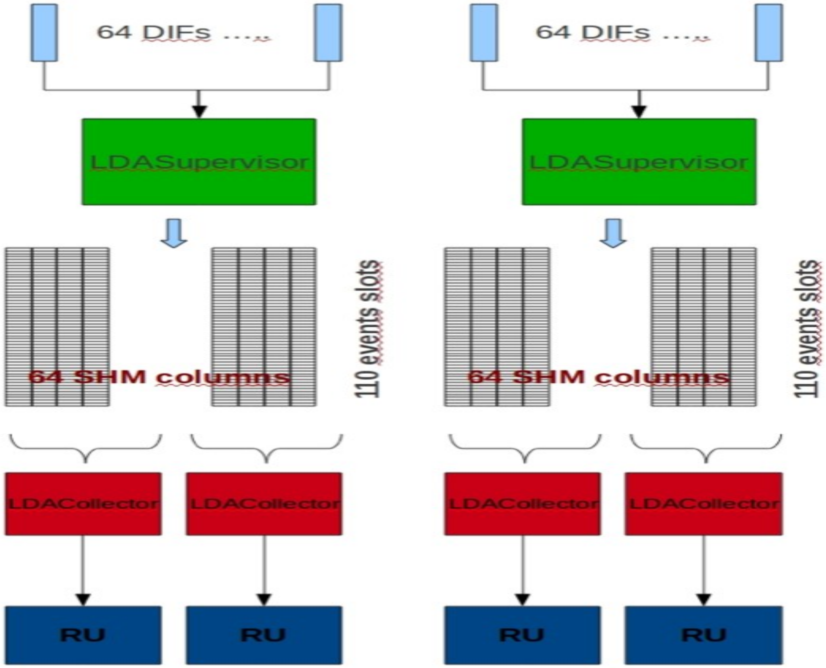
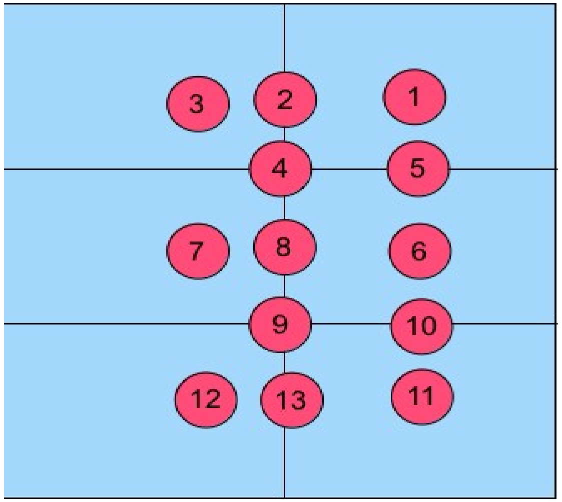
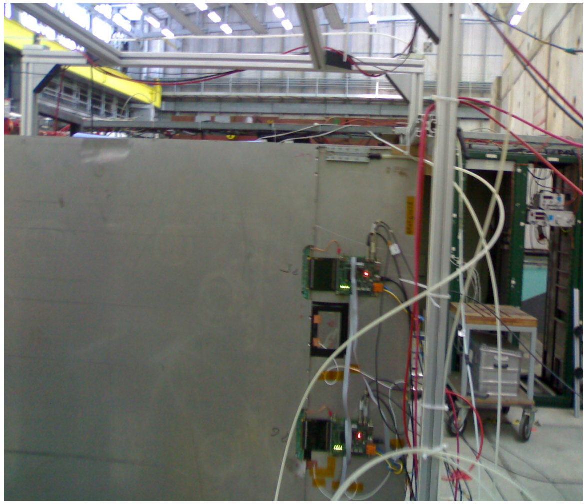
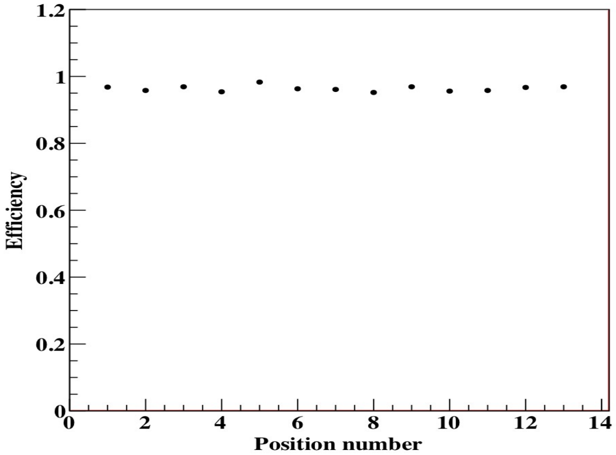


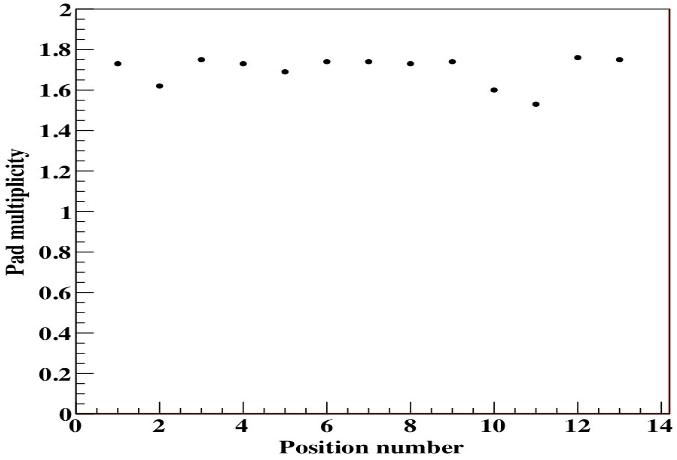
# TestBeam Validation

A full cassette was successfully tested at T9-PS May 2010 and H4-SPS in September 2010





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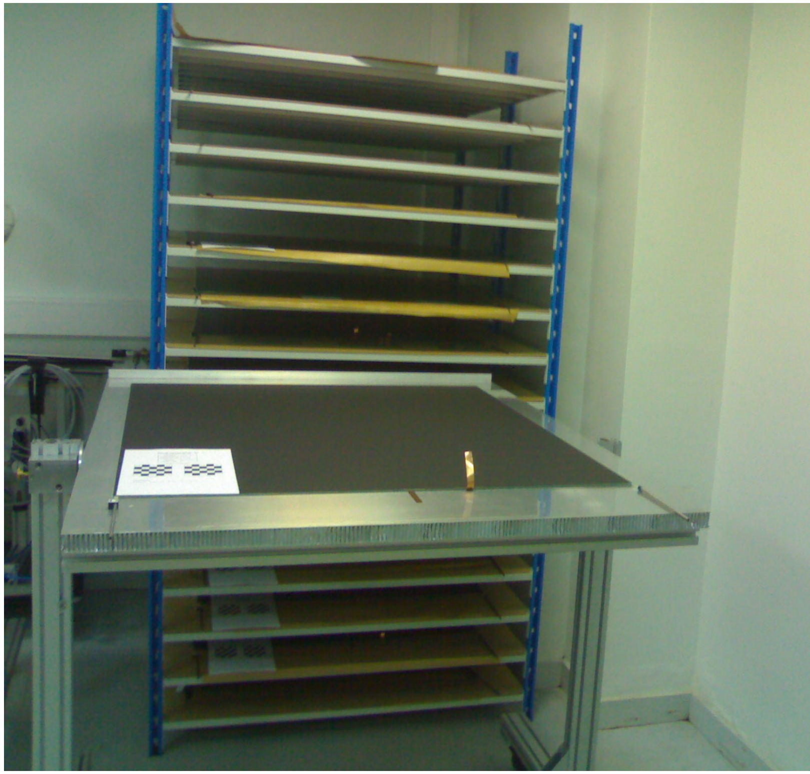

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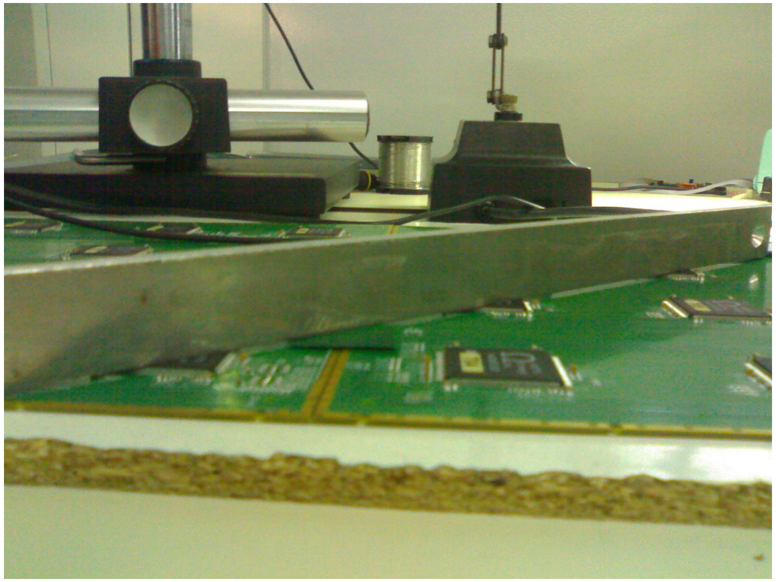

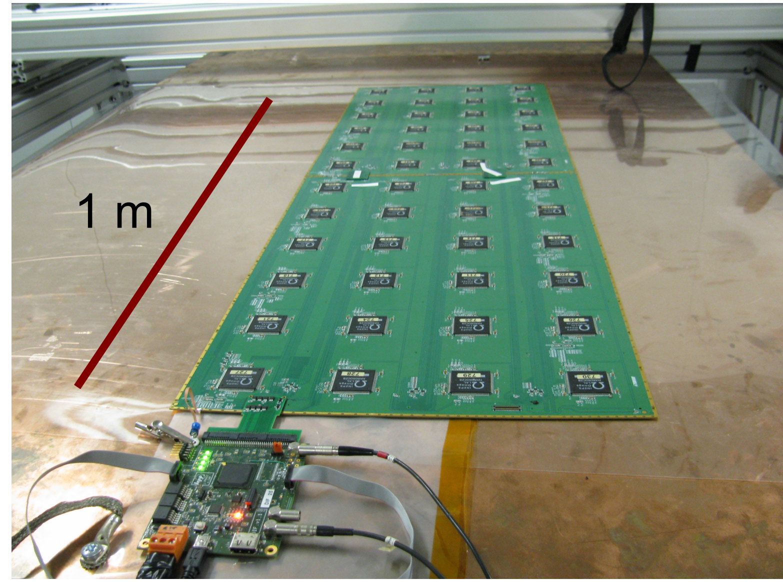


**Technological issues are addressed**

**144 ASICs= 9216 channels/1m²**

1 pad= 1cm², interpad distance = .5 mm

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  - **Testbeam DAQ produces LCIO files.**

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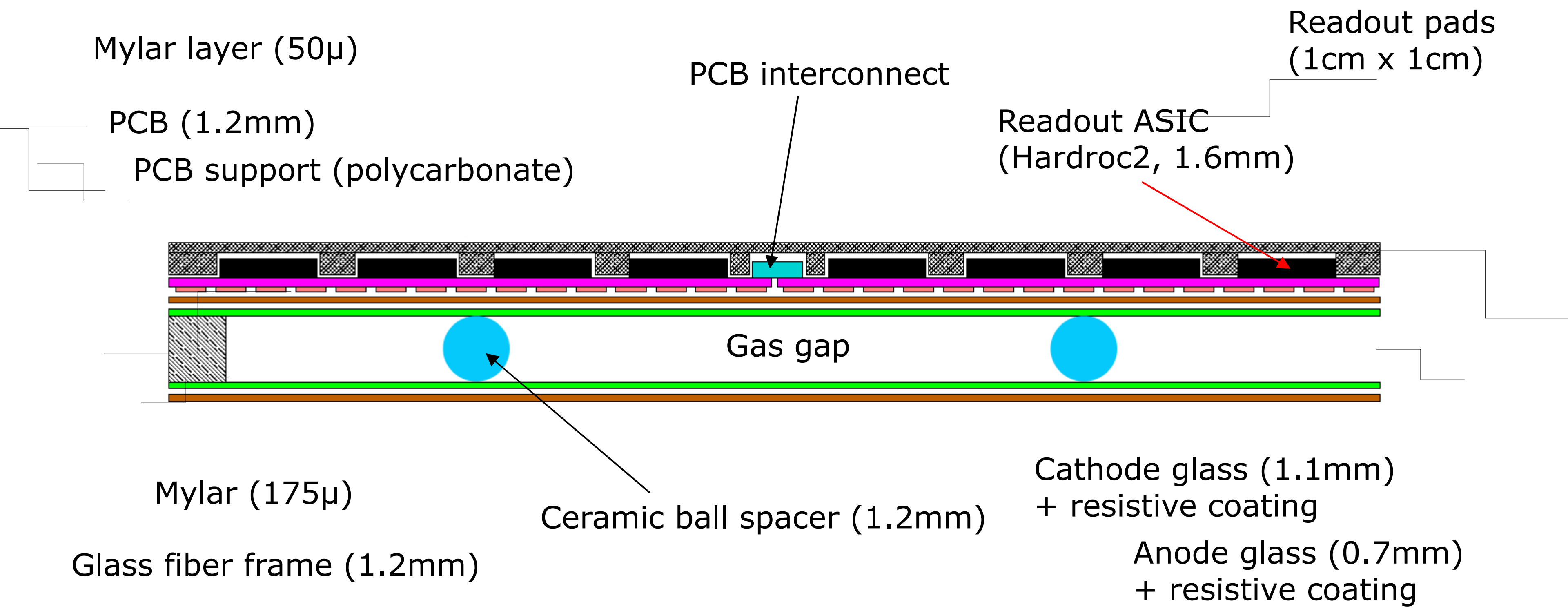


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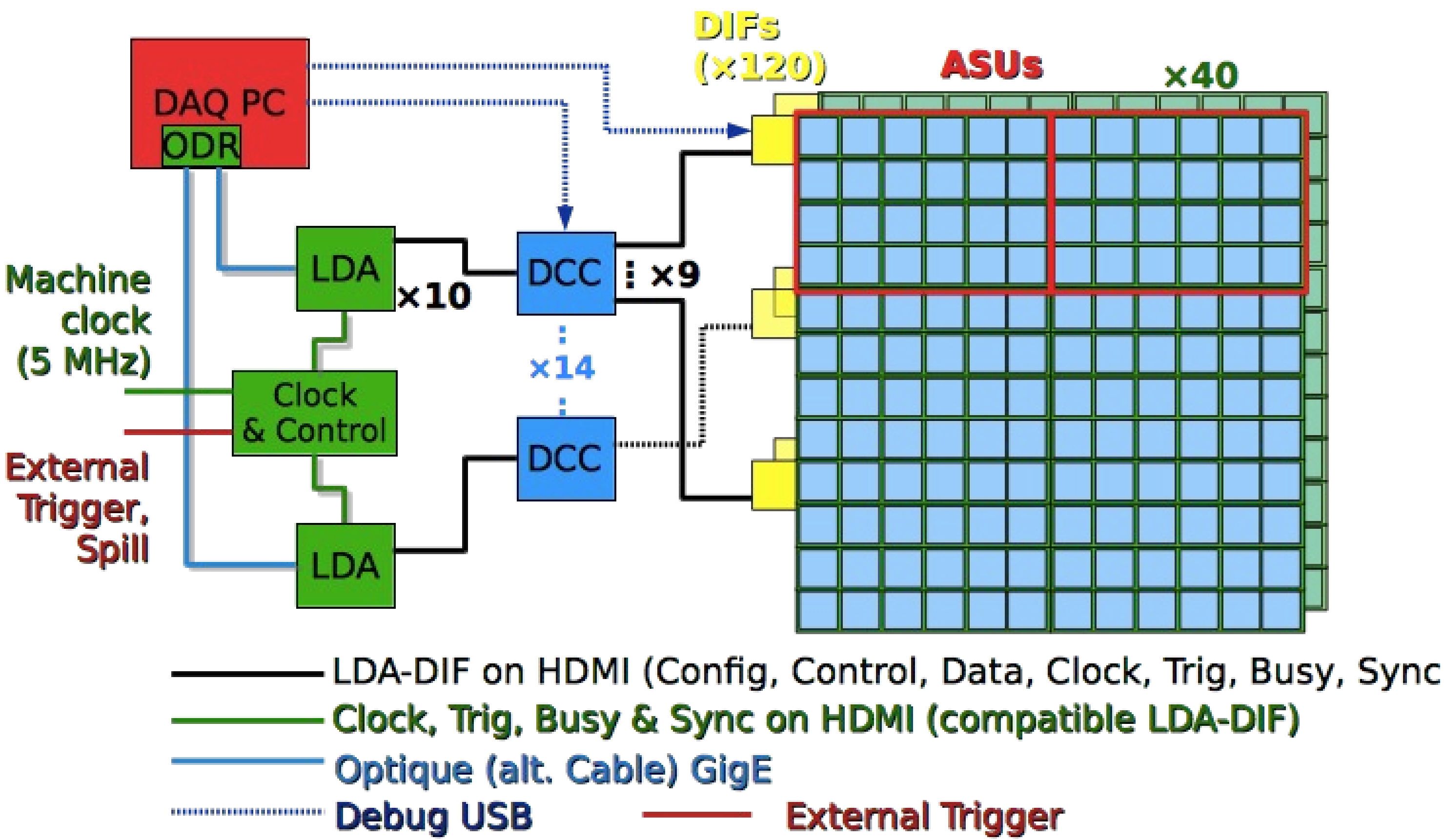

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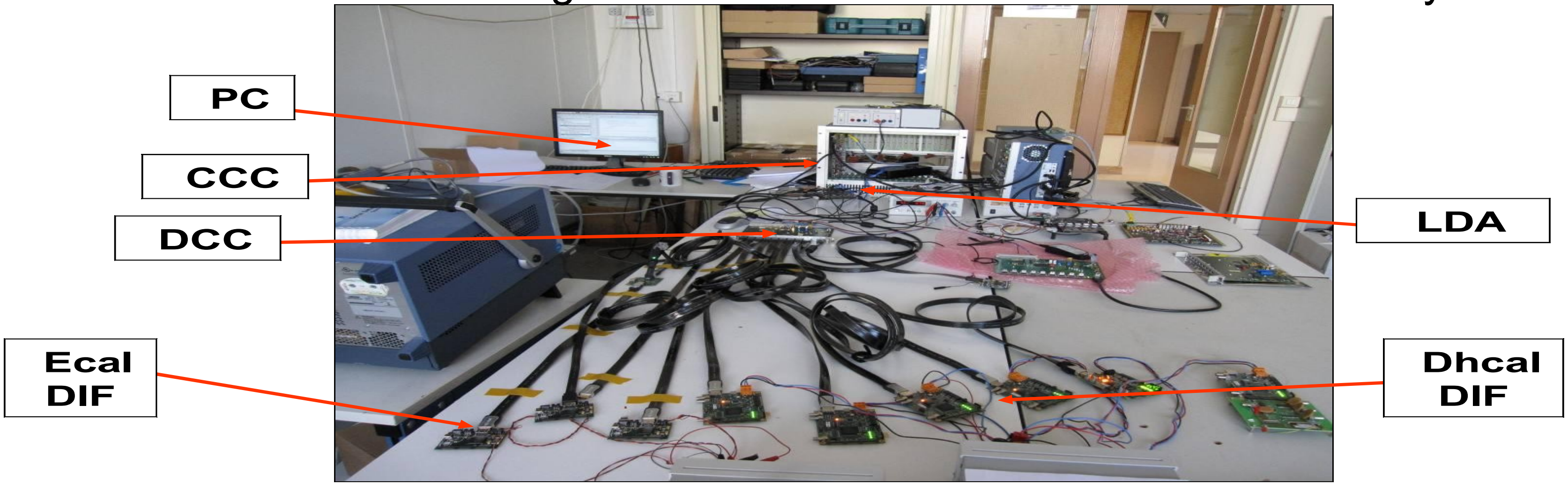


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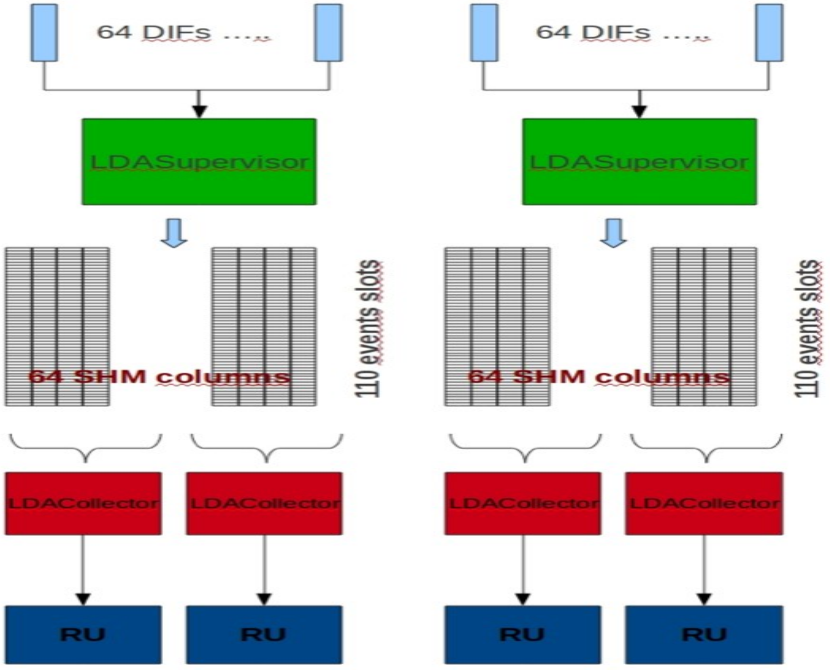

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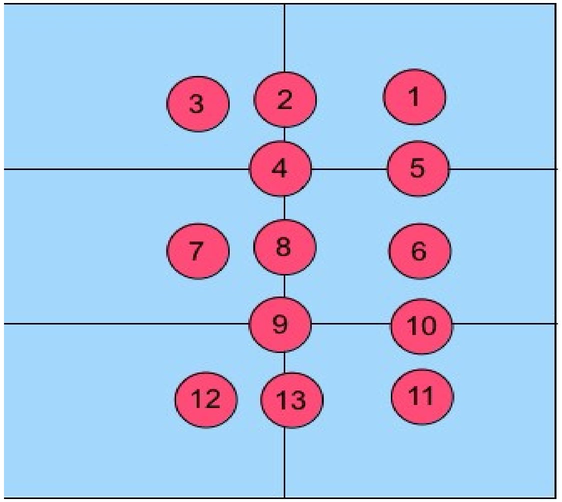


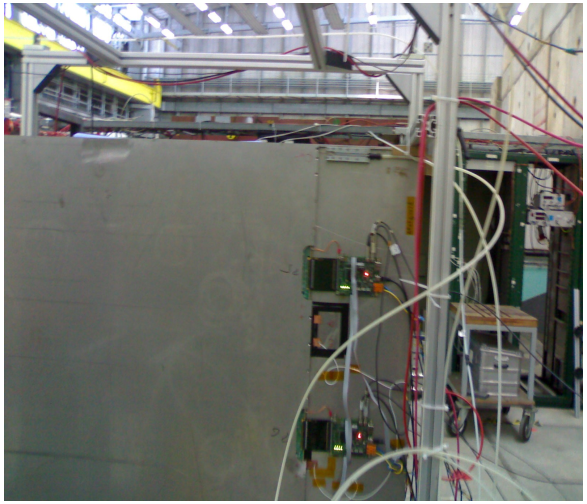

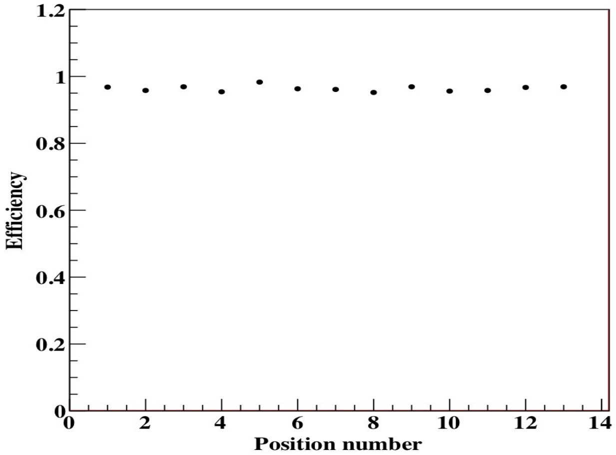


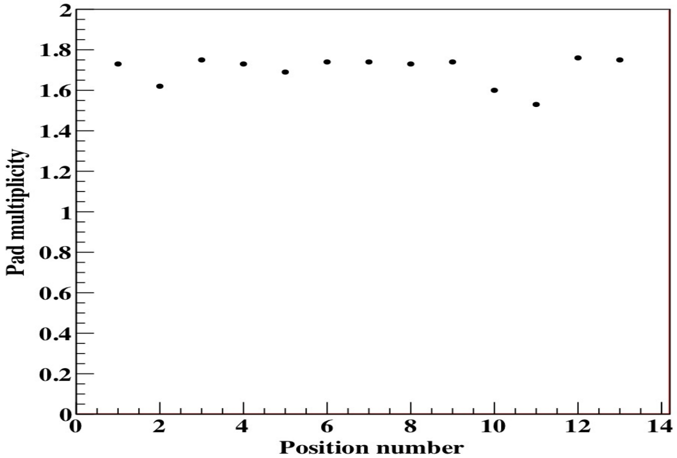

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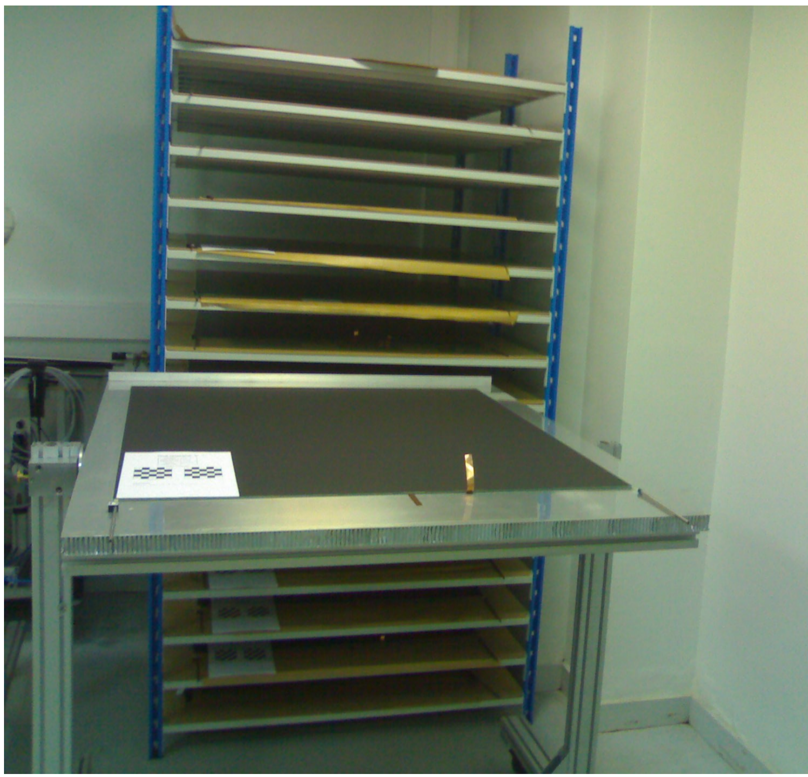
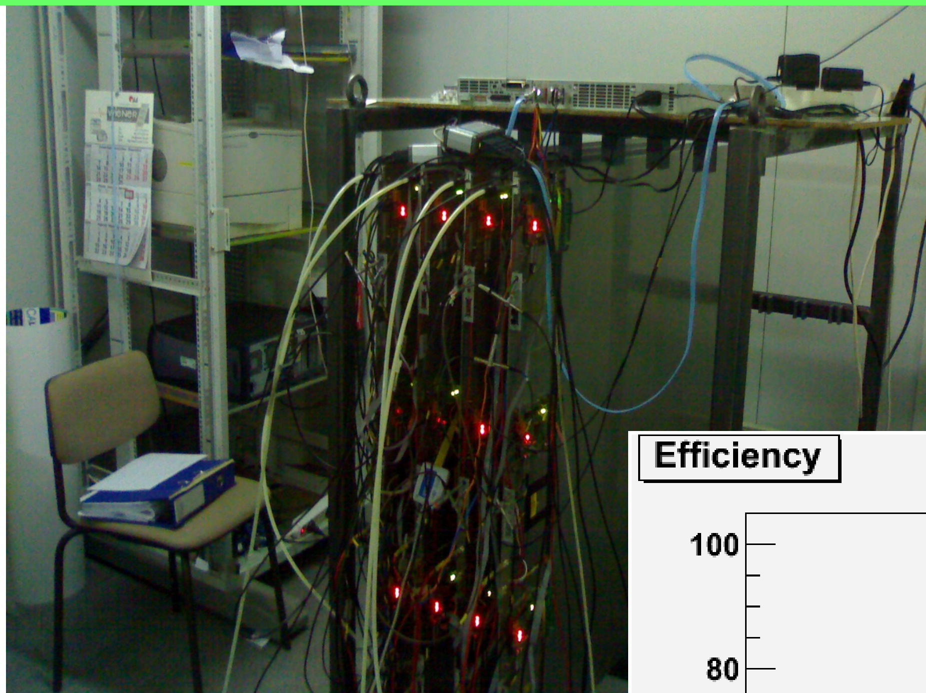


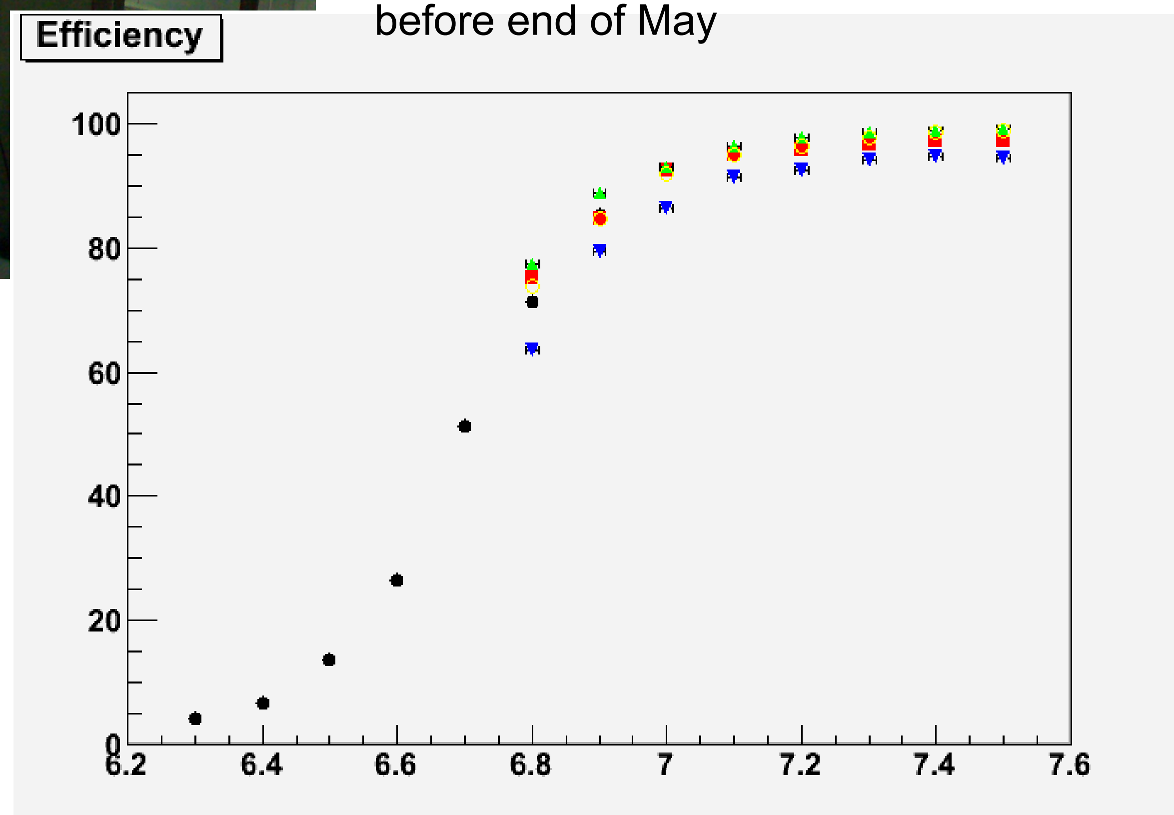
Cassette and GRPCs ard assembled

# Prototype construction: Acquisition



6 fully equipped 1m2 GRPC were produced up to now. They were used to validate the whole system and more particularly the DAQ.
3 of them are currently used for the TOMUVOL project (volcanic muons)

The remaining part will be produced before end of May

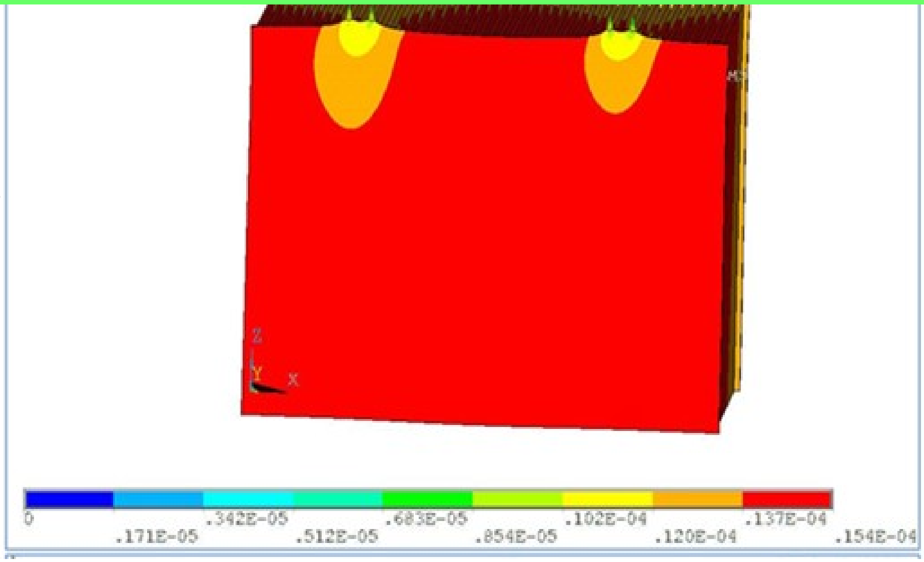


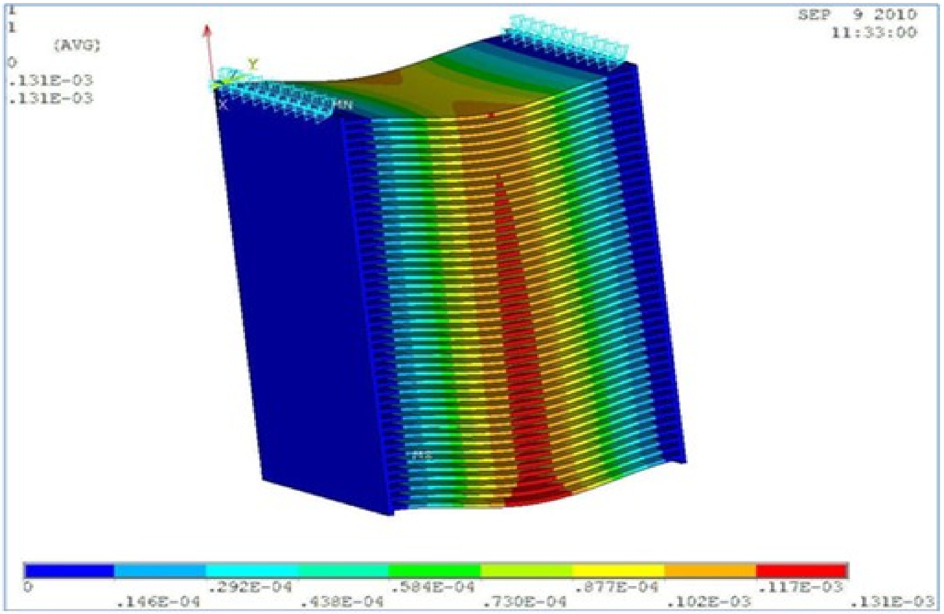

The GRPCs are being tested in vertical position using cosmic rays

# Prototype construction: Mechanical structure

The self-supporting mechanical structure was conceived to be modular. Spacers with bolts used to assemble the absorbers

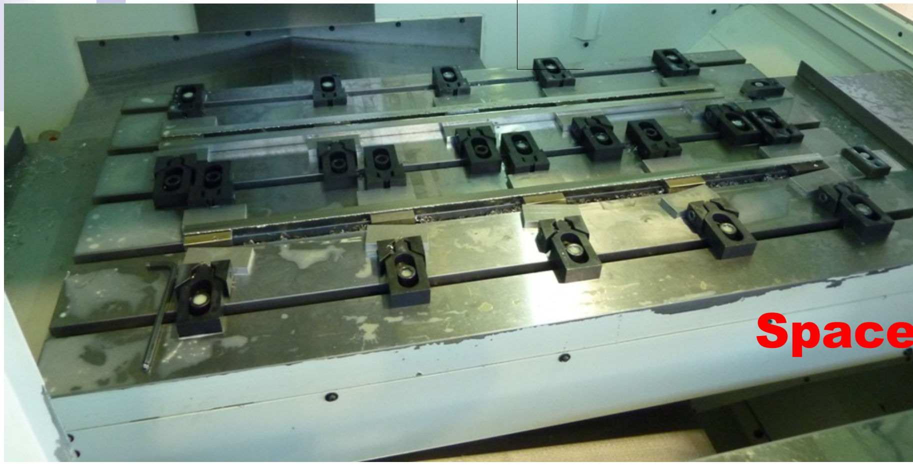
Detailed mechanical deformation study was performed in different configurations of the prototype.



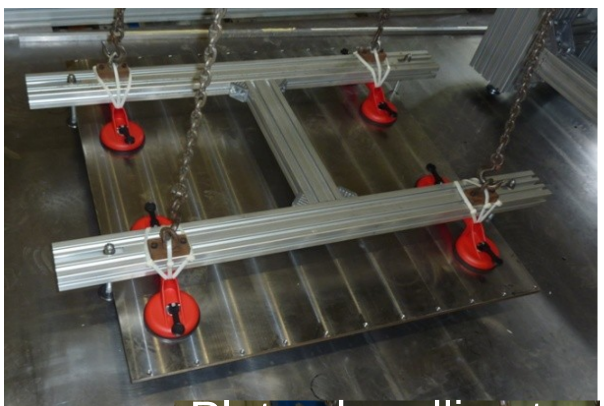

Maximum deformation was found To occur during manipulation (rotation, transport) but still with no effect on the cassettes.
A rotation tool will allow to use the prototype to study cosmic rays... tests will be conducted during assembling to check this possibility.

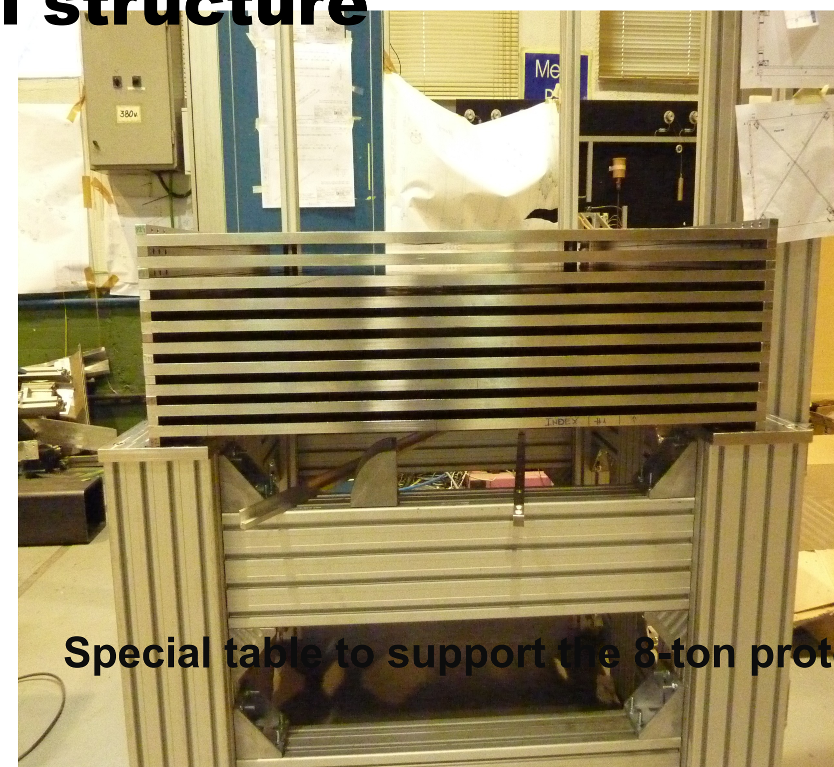
# Assembling the mechanical structure



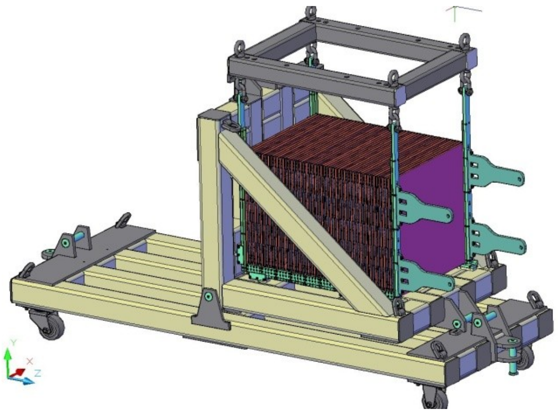


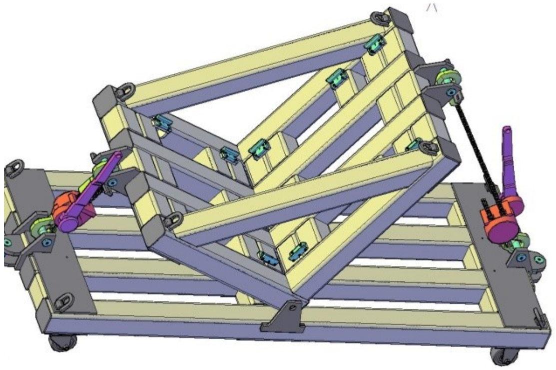
**Absorbers assembled together using lateral spacers fixed to the absorbers through bolts.**

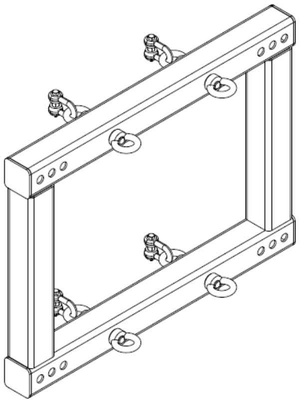


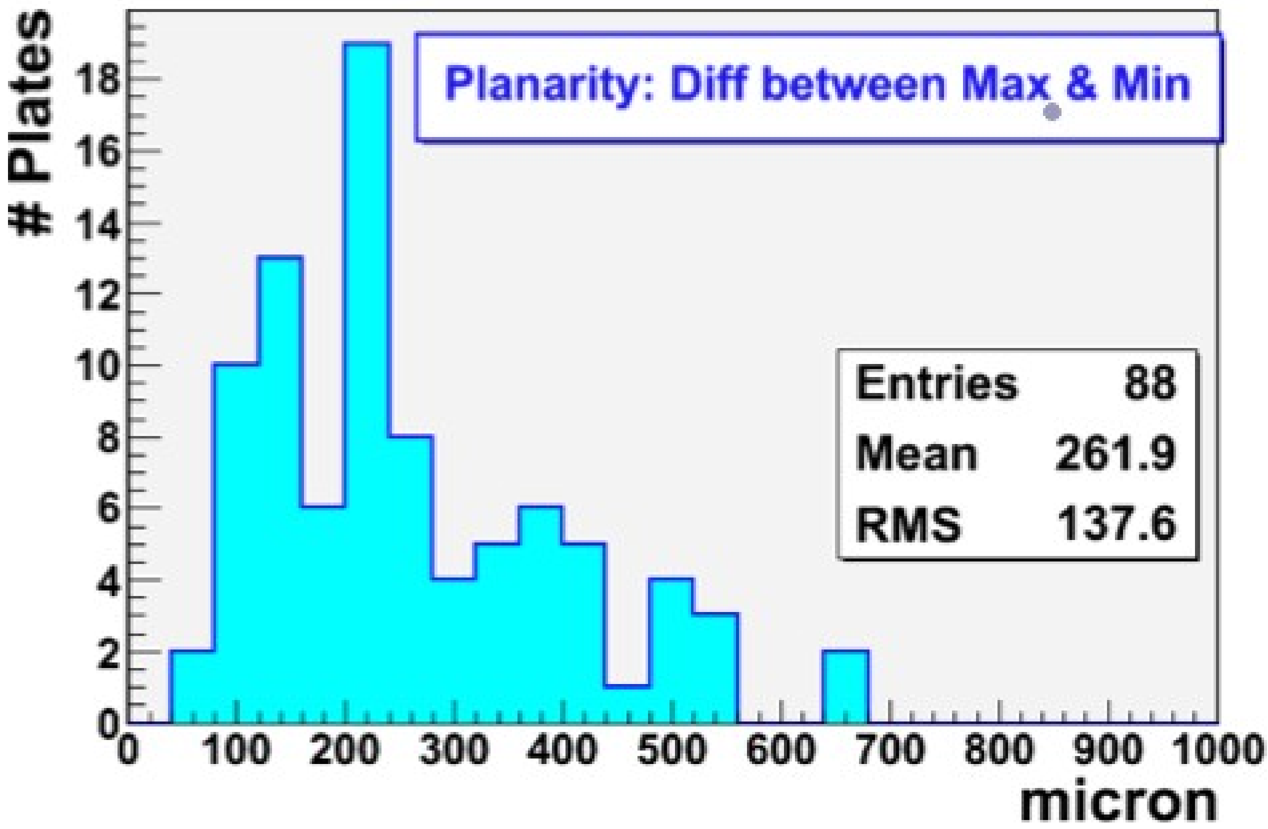



# Rotation tool





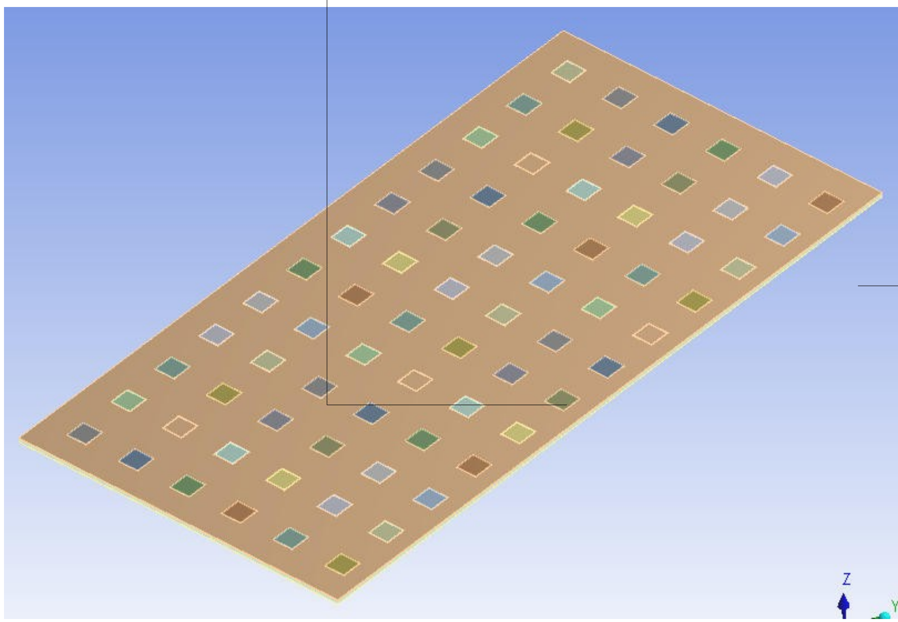


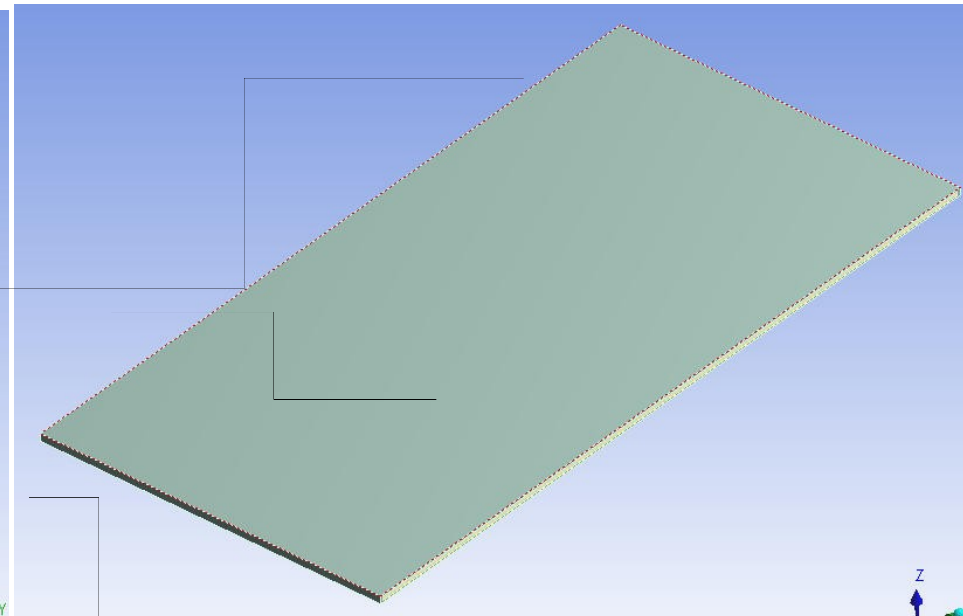



Planarity of the stainless steel plates used for the SDHCAL prototype

# Thermal studies on SDHCAL prototype

12 x 6 chipsets modelisation = 1/2 detector





2 absorbers steel stainless 2.5 mm
72 chipsets 1.4 mm
1 pcb plate 1.4 mm
1 spacer polycarbonate 1.4 mm
1 glass 0.7 mm
1 frame pcb 1.2 mm
1 glass 1.1 mm

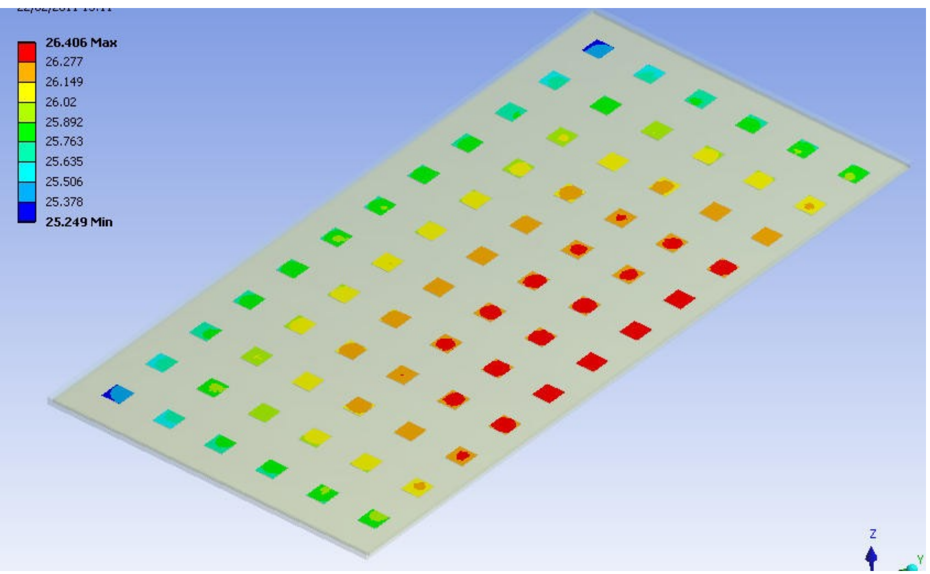
**Heat exchange with air ambient 22°C on 2 faces and 3 sides**

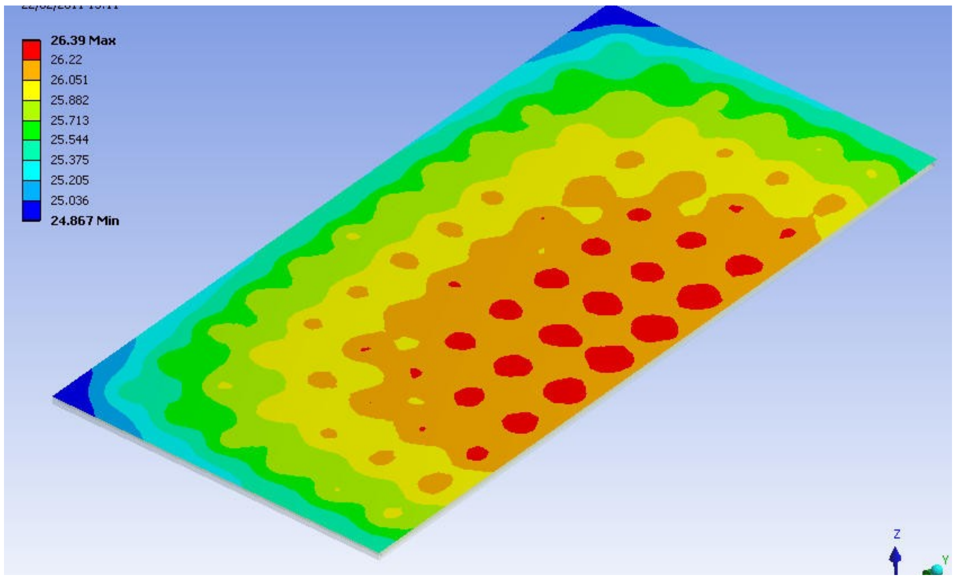
Heat flux on chipset = 0.133 W x 72 = 9.6 W

Laminar flow in gap of 2 mm between GRPC and absorbers

# Thermal studies on GRPC

**Tmax = 26.4°C**

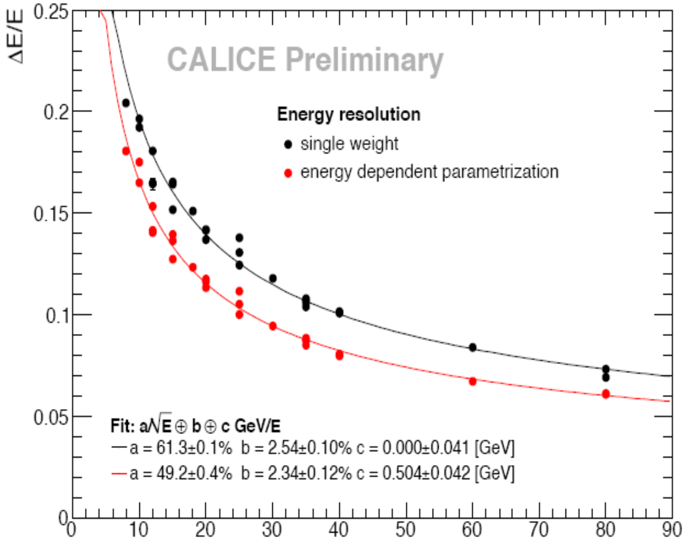


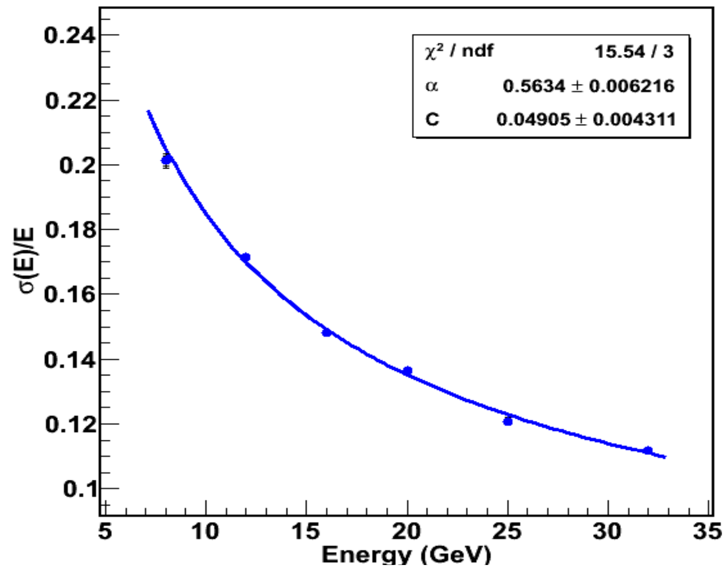



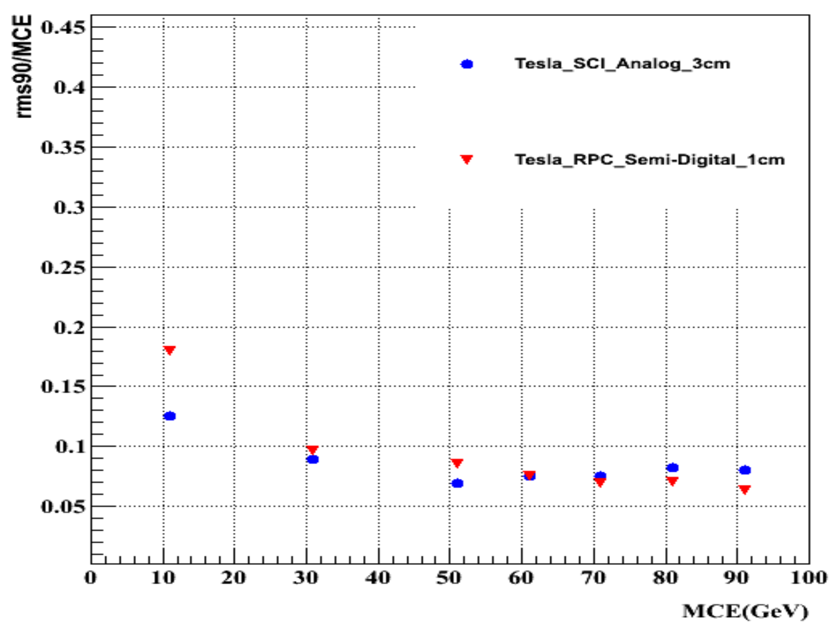

Chipset

Absorber in contact with chipset

Heat extraction on 1 side absorbers for one detector = 9.6 w
Air ambient is OK for ILC M3
Water cooling is needed for ILD Barrel – 0 W transmission

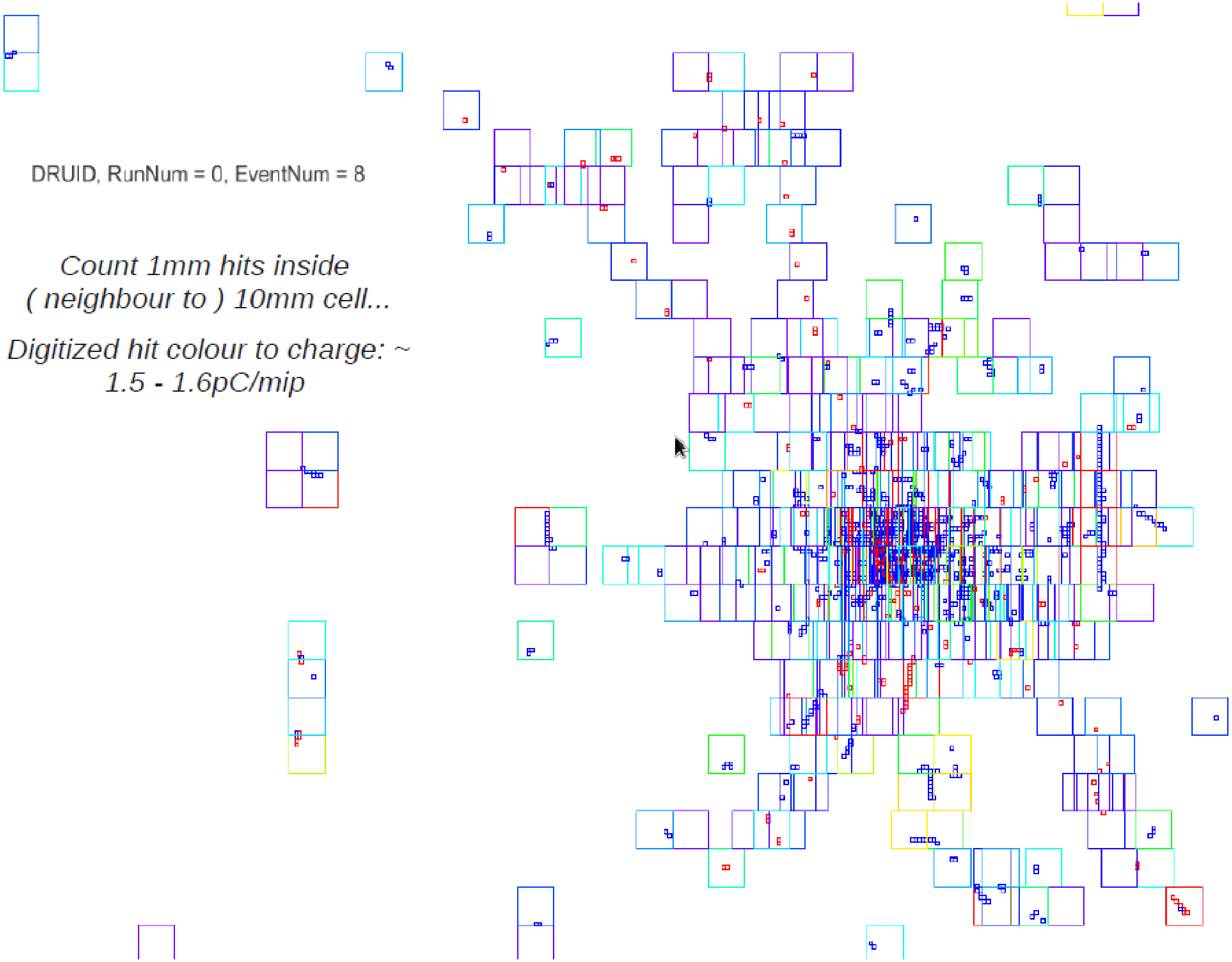

ΔE/E
CALICE Preliminary
Energy resolution
single weight
energy dependent parametrization
Fit: a/√E ⊕ b ⊕ c GeV/E
a = 61.3±0.1% b = 2.54±0.10% c = 0.000±0.041 [GeV]
a = 49.2±0.4% b = 2.34±0.12% c = 0.504±0.042 [GeV]


χ² / ndf 15.54 / 3
α 0.5634 ± 0.006216
C 0.04905 ± 0.004311
σ(E)/E
Energy (GeV)


rms90/MCE
Tesla_SCI_Analog_3cm
Tesla_RPC_Semi-Digital_1cm
MCE(GeV)

# Multiplicity

- Dispatching of induced charge in more than one cell
  - **Implementation in Marlin, need track position inside the cell :**
    - **Mokka simulation with 1mm² cells and rebuild 1cm² cells in Marlin (Marlin processor written)**



# Multiplicity

- Dispatching of induced charge in more than one cell for tracks on the cell border

| Options | | pros | cons |
|---|---|---|---|
| Marlin processor | Wait for LCIO v2 | •Flexible,<br>•Realistic,<br>•Tested against data. | •Not written<br>•Size of Mokka output (detailed shower+position) |
| | Random draw of track position | •Marlin processor exists | •Not exactly right.<br>•Not yet tested against data<br>•Size of Mokka output (detailed shower) |
| | $1mm^2$ simulation | •Marlin processor exists<br>•Size of Mokka output kept low<br>•Tuned to reproduce mean data multiplicity and mean hit efficiency.<br>•Can be used for GEM,μ MEGAS,... | •Not yet fully tested against data.<br>•Change of geometry while running Marlin (GEAR?) |
| Mokka | Perform it in simulation | •Tested against data for many thresholds.<br>•Size of Mokka output low<br>•Can simulate with the right cell size | •Energy to induced charge should also be put there.<br>•No flexibility to retune parameters.<br>•Code not yet ported to Mokka. |