SDHCAL

I.Laktineh

IPNLyon

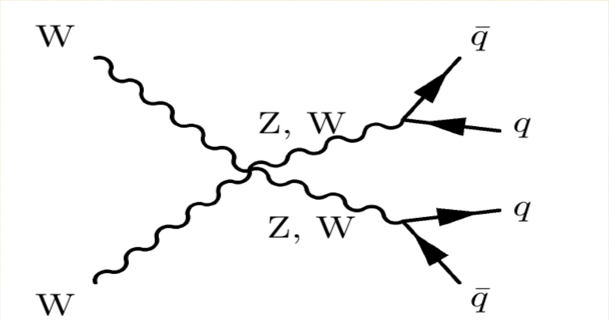
OUTLINE

- RPC-based calorimeters for leptons collider
- SDHCAL concept
- SDHCAL-GRPC prototype
- Prototype results
- Present and future development
- Conclusion

Motivations

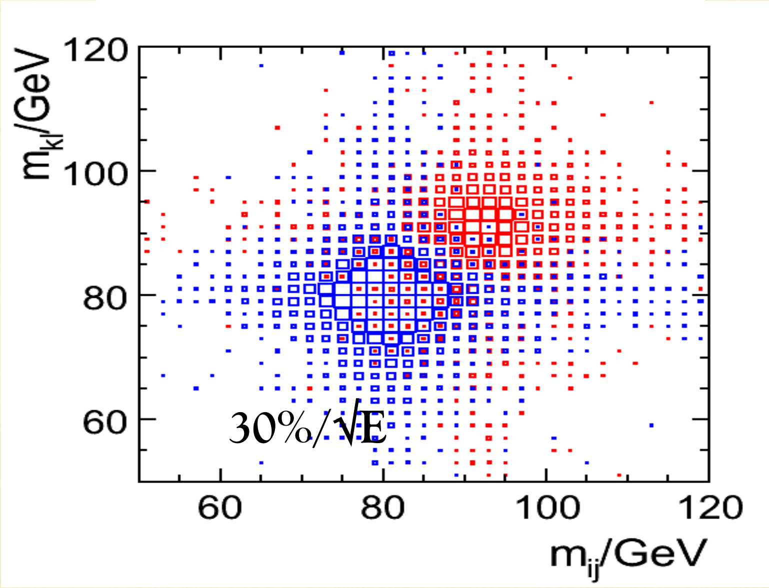
For future colliders, **jet energy resolution** will be a determinant factor of understanding high energy physics.

Exemples:
→Trilinear Higgs self coupling measurement
→WW scattering measurement



$$\frac{\sigma_E}{E} = \frac{21}{\sqrt{E}} \oplus 0.7 \oplus 0.004E \oplus 2.1 \left(\frac{E}{100}\right)^{+0.3} \%$$

Resolution | Tracking | Leakage | Confusion

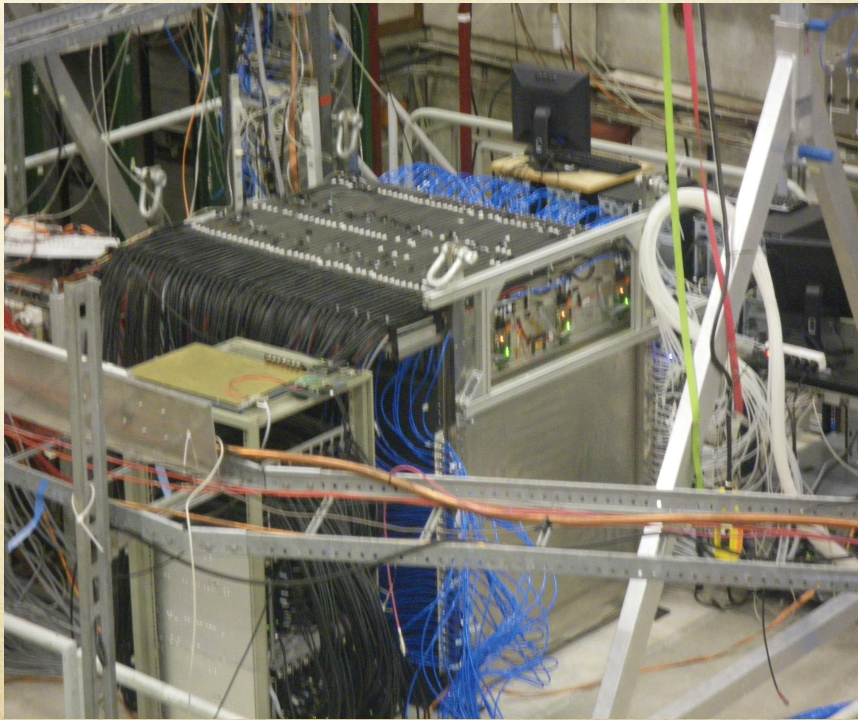


To improve on the jet energy resolution
PFA is a promising solution to reduce the confusion term.
But PFA needs **high granularity Calorimeters**

Different solutions of such calorimeters are being followed within the CALICE international collaboration. The option we are investigating is the **Digital and Semi-Digital H**adronic **CAL**orimeter using GRPC as sensitive medium

DHCAL :
First prototype with embeded electronics
(> 480k ch) by Amercian groups

SDHCAL :
First technological prototype addressing technical problems for future lepton colliders (namely ILC)

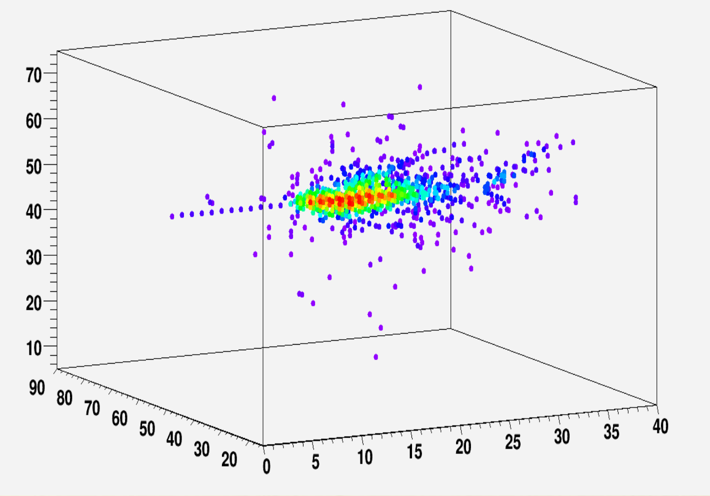


SDHCAL concept

1- Detector choice

Gaseous detectors: homogenous, cost-effective and highly transverse and longitudinal **granular.**

GRPC : is an adequate candidate for ILC and CEPC.

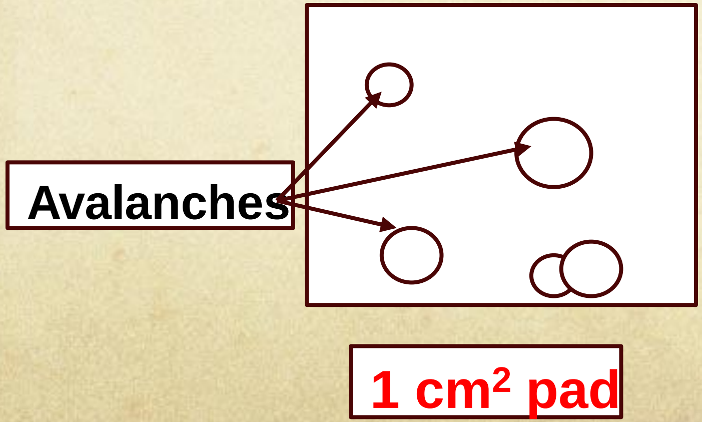


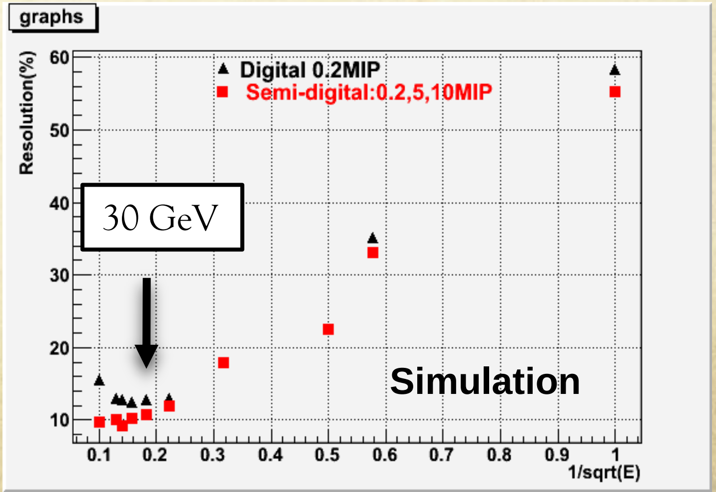
2- Electronics readout choice

At high energy the shower core is very dense

→ Simple binary readout will suffer saturation effect

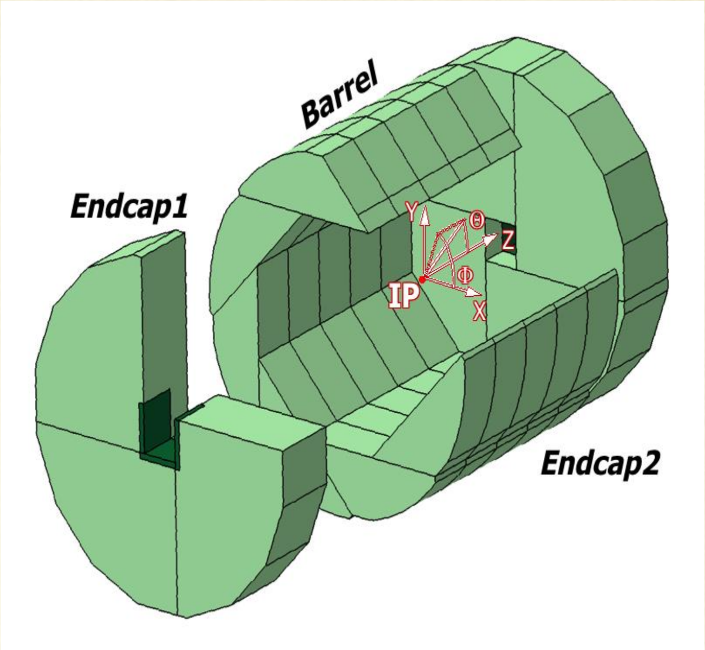
→ Semi-digital readout (2-bit) can improve the energy resolution.





SDHCAL for ILD

The SDHCAL-GRPC is one of the two HCAL options proposed in the **ILD L**etter **O**f **I**ntention (LOI). Modules are made of 48 RPC chambers ($6\lambda_I$) equipped with power-pulsing electronics readout.



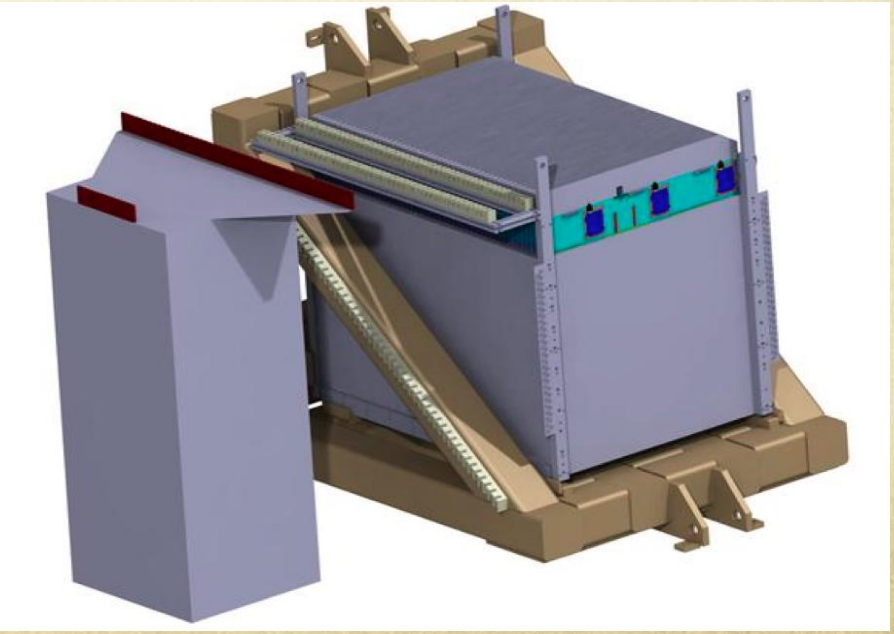
The structure proposed for the SDHCAL-ILD :

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

SDHCAL Prototype

- Come as close as possible to the ILD module and be able to study hadronic showers

-48 units (active layer + absorber) fulfilling the ILD requirements.



Challenges

-Homogeneity for large surfaces

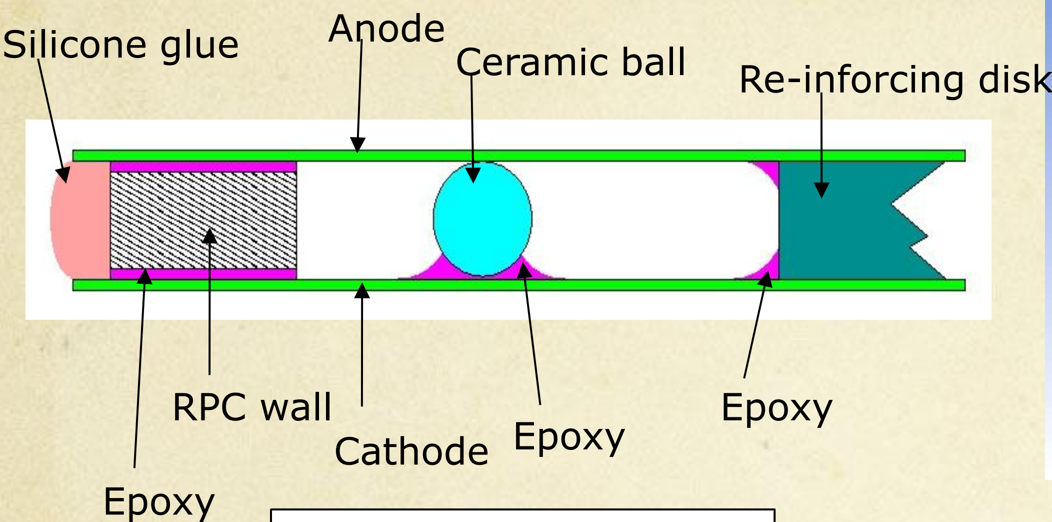
-Thickness of only few mms

-Services from one side

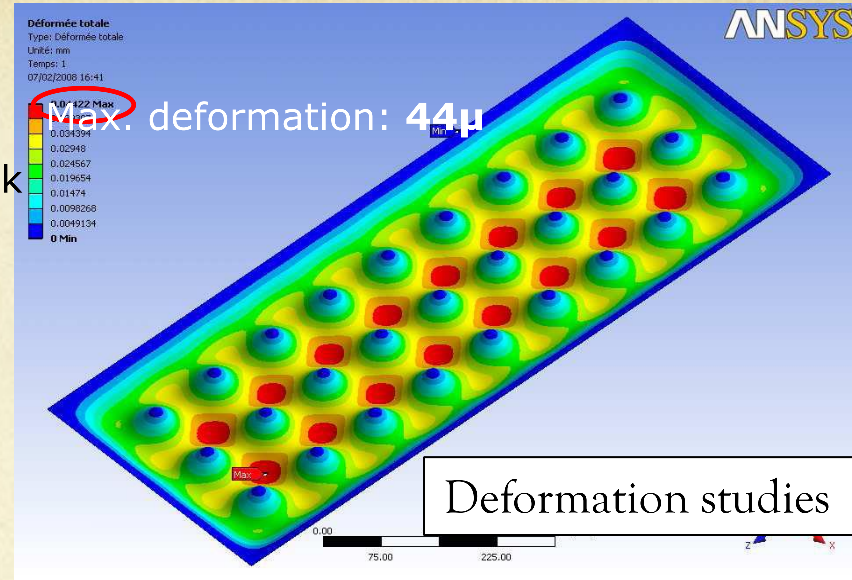
-Embedded power-cycled electronics

-Self-supporting mechanical structure

GRPC development

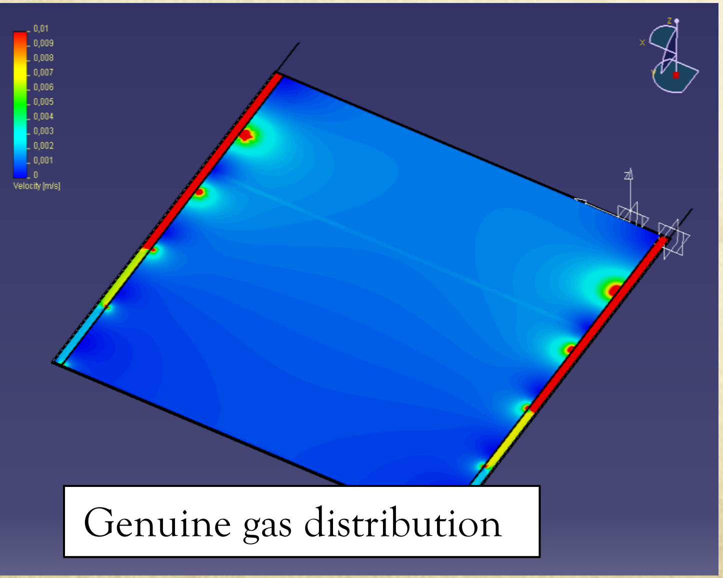


Dead zones minimized

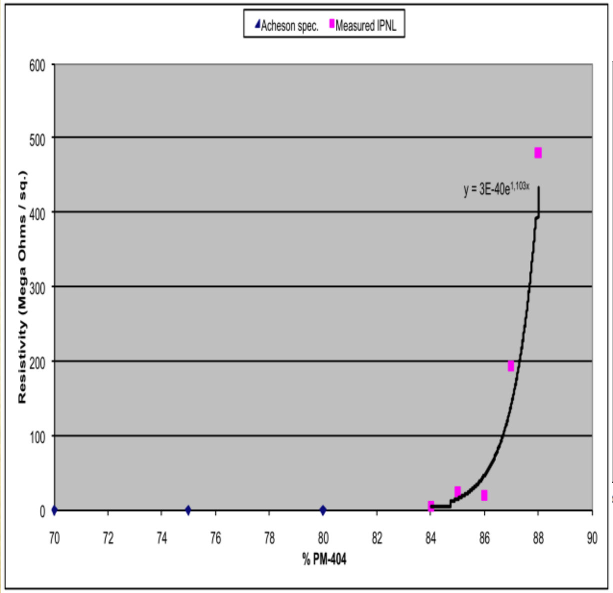


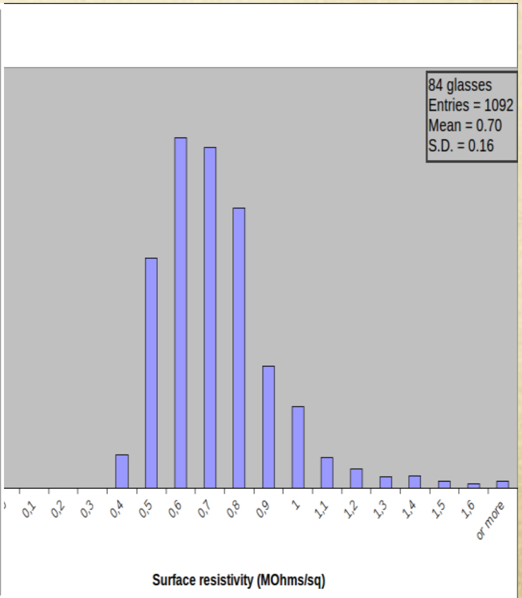
Deformation studies

New resistive painting was developed



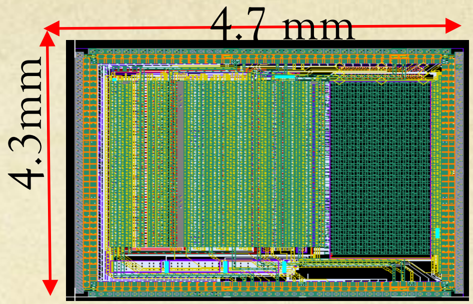
Genuine gas distribution

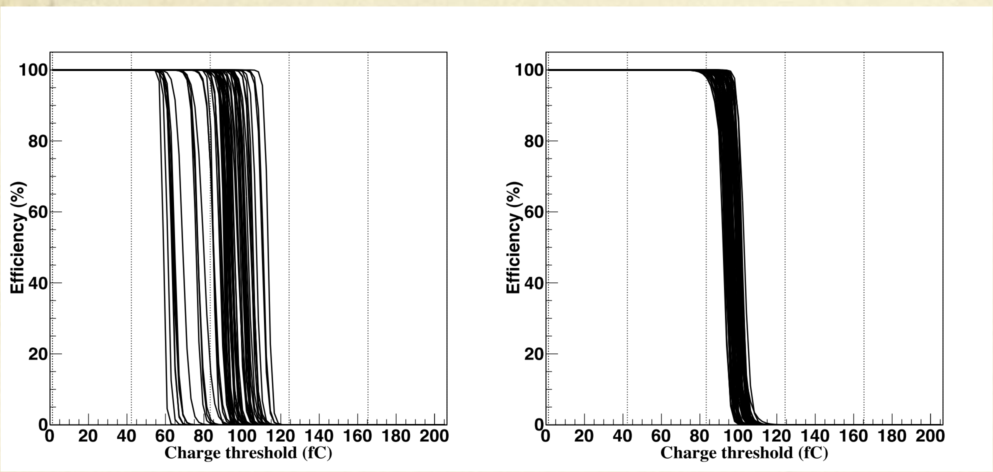


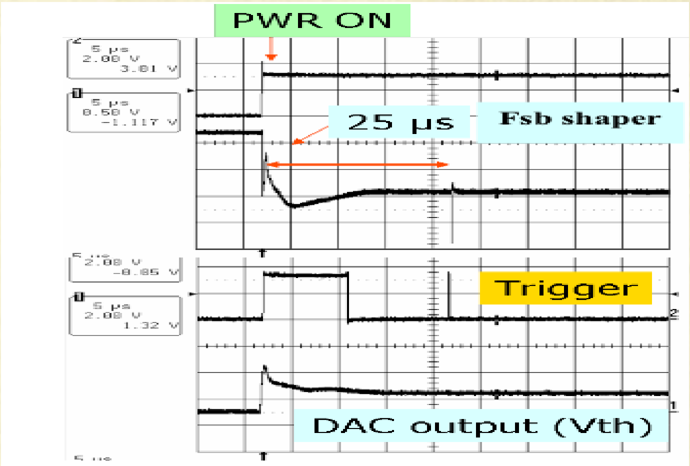


Electronics readout development

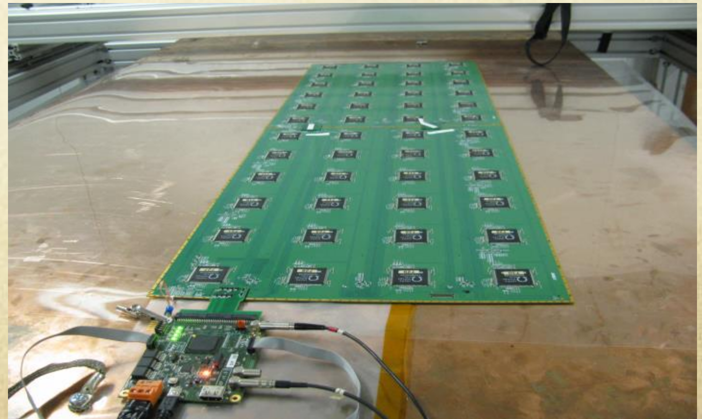
ASIC: HARDROC
64 channels, trigger less mode, memory depth: 127 events
2-bit readout : 3 thresholds
Dynamic range: 10 fC-15 pC
Gain correction → uniformity
Power-pulsed → reduced power consumption



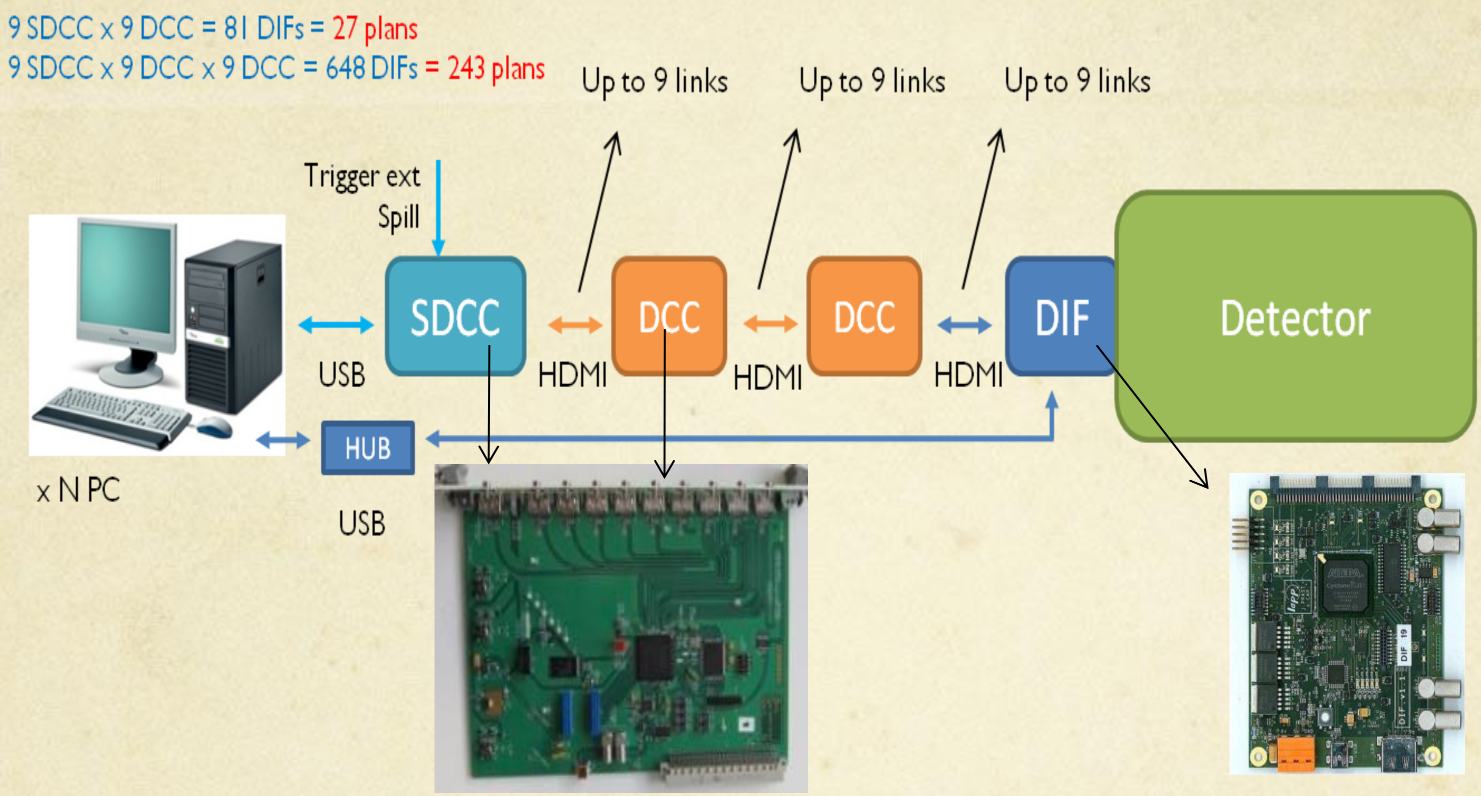




Printed Circuit Boards (PCB) were designed to reduce the x-talk with 8-layer structure and buried vias.
Tiny connectors were used to connect the PCB two by two (the 24X2 ASIC are daisy-chained).
DAQ board (DIF) was developed to transmit fast commands and data to/from ASICs.



SDHCAL acquisition system



→ Acquisition software was developed to deal with the output of large number of electronics channels (> 460 000).

→ Oracle database used for ASIC configurations and slow control.

→ CMS Xdaq used to provide the DAQ framework.

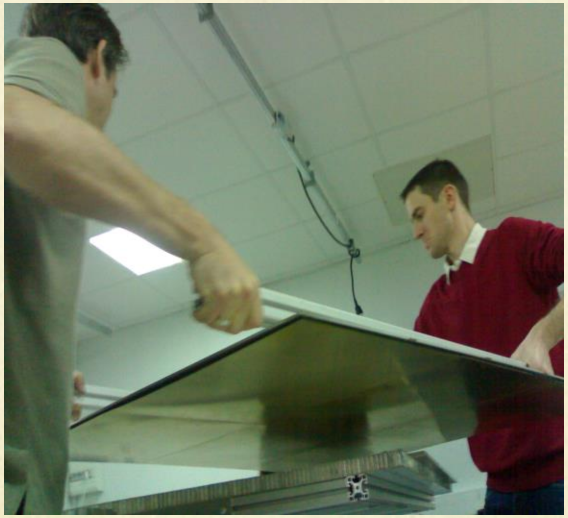
Cassette development

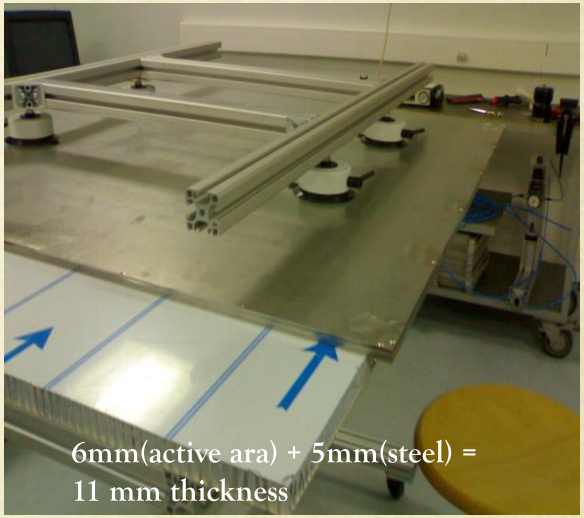
→ To provide a robust structure.

→ To maintain good contact between the readout electronics and the GRPC.

→ To be part of the absorber.

→ It allows to replace detectors and electronics boards easily.

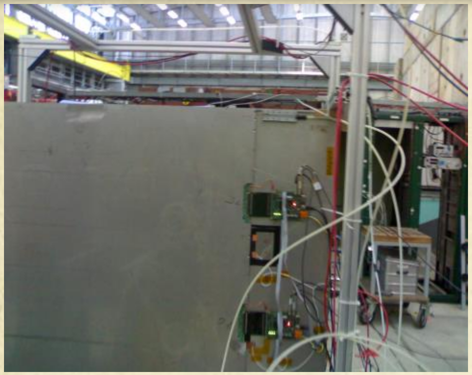


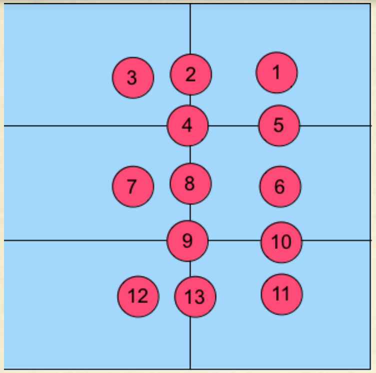


The cassettes are built of no-magnetic stainless steel walls 2.5 mm thick each → Total cassette thickness = 6mm (active layer)+5 mm (steel) = 11 mm

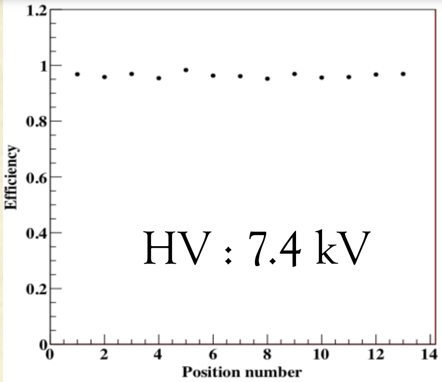
Test Beam validation

The homogeneity of the detector and its readout electronics were studied

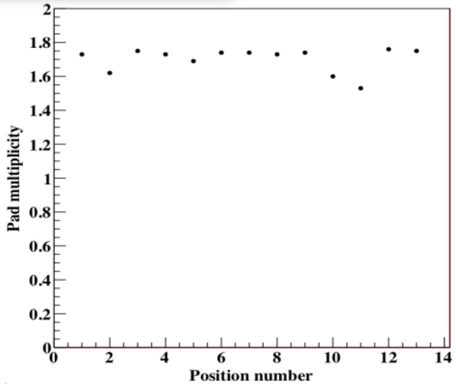




Beam spot position



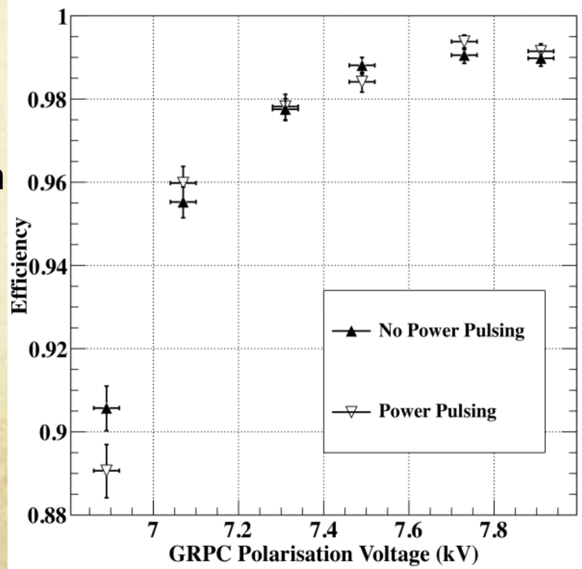
Efficiency



Multiplicity

Power-Pulsing mode was tested in **a magnetic** field of **3 Tesla**

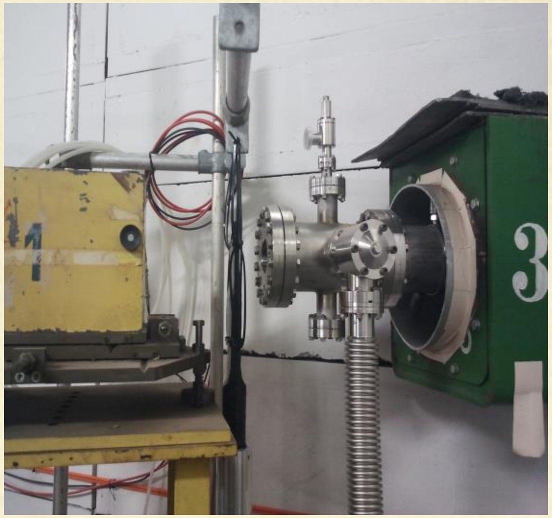
The Power-Pulsing mode was applied on a GRPC in a 3 Tesla field at H2-CERN
(2 ms every 10 ms)
No effect on the detector performance



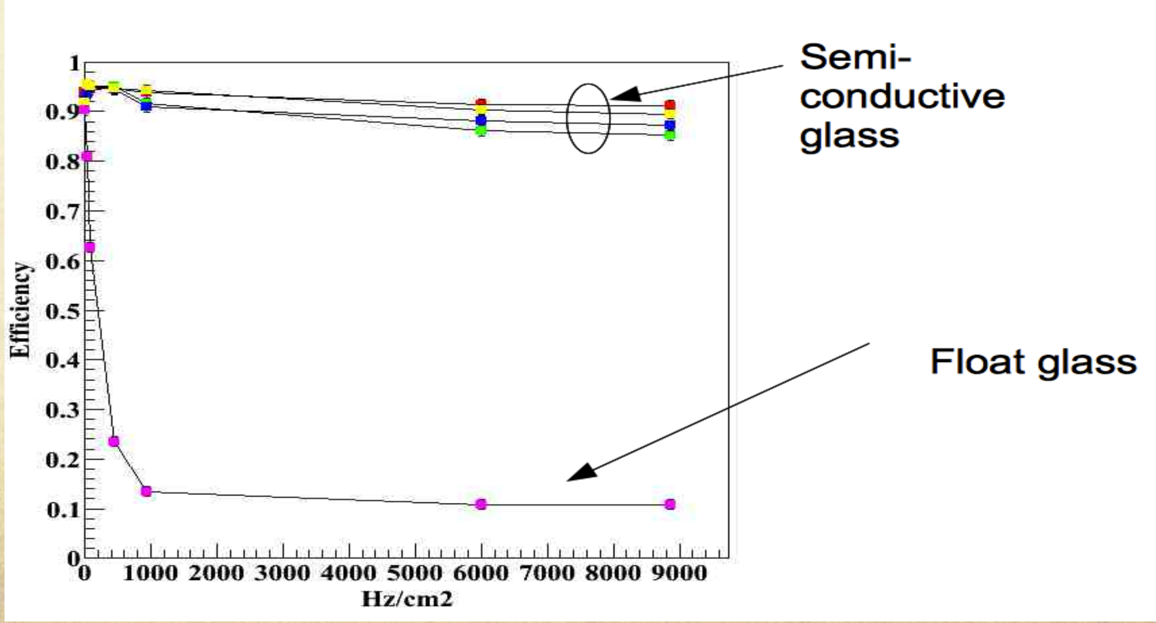
High-Rate GRPC

High-Rate GRPC may be needed in the very forward region

✓Semi-conductive glass (10^{10} Ω.cm) produced by our collaborators from Tsinghua University was used to build few chambers.
✓4 chambers were tested at DESY as well as standard GRPC (float glass)

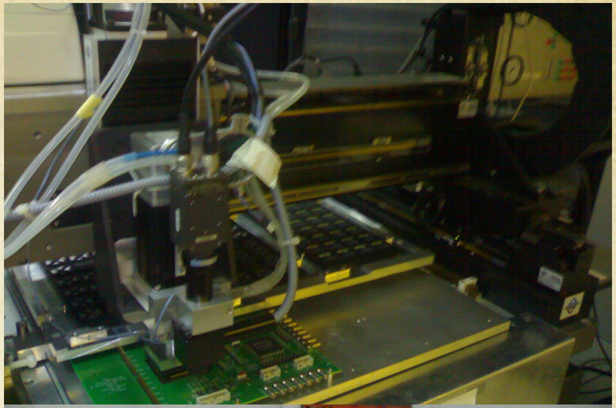


Performance is found to be excellent at high rate for GRPCs with the semi-conductive glass and can be used in the very forward of ILD region if the rate exceeds 100 Hz/cm^2 in future ILD upgrades



SDHCAL prototype construction

- ✓ 10500 ASIC were tested and calibrated using a dedicated robot that was used by CMS (IPNL, OMEGA) (ASICs layout : 93%).
- ✓ 310 PCBs were produced, cabled and tested (IPNL). They were assembled by sets of six to make 1m^2 ASUs
- ✓ 170 DIF(LAPP), 20 DCC(LLR) were built and tested.
- ✓ 50 detectors were built and assembled with their electronics into cassettes. Cassettes were tested by sets of 6 using a cosmic test bench (IPNL).
- ✓ The mechanical structure was built in CIEMAT.
- ✓ HV, cooling services were built by UCL, Gent.
- ✓ Full assembly took place at CERN.



Prototype @TB

3 periods of TB in 2012 (5 weeks)

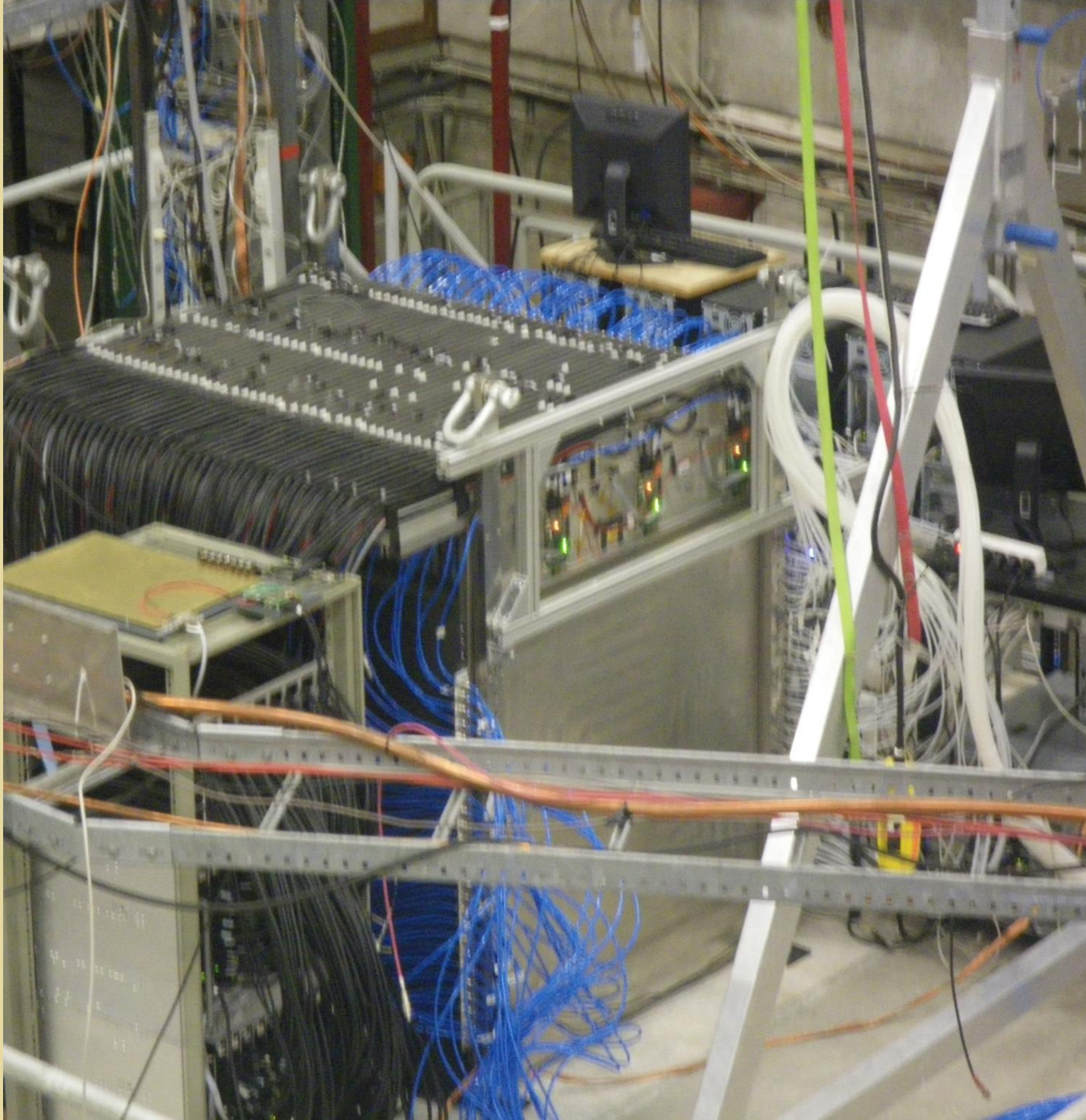
→ SDHCAL Commissioning with TrigerLess, Power-Pulsing modes;

→ Thresholds choice optimization;

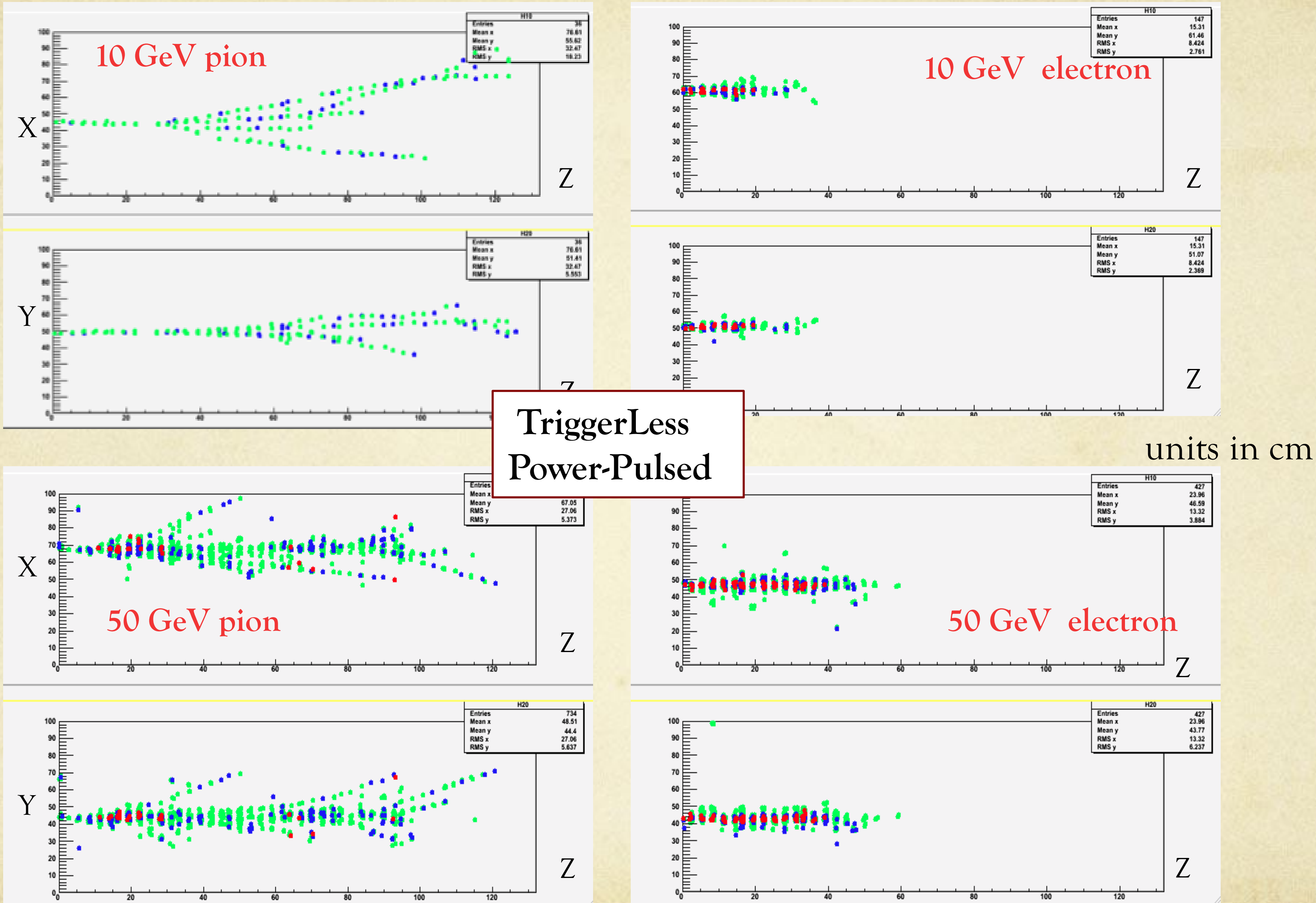
→Muons run calibration;

→ Pion, electron runs to study EM and hadronic showers;

→No particle identification detector was used.

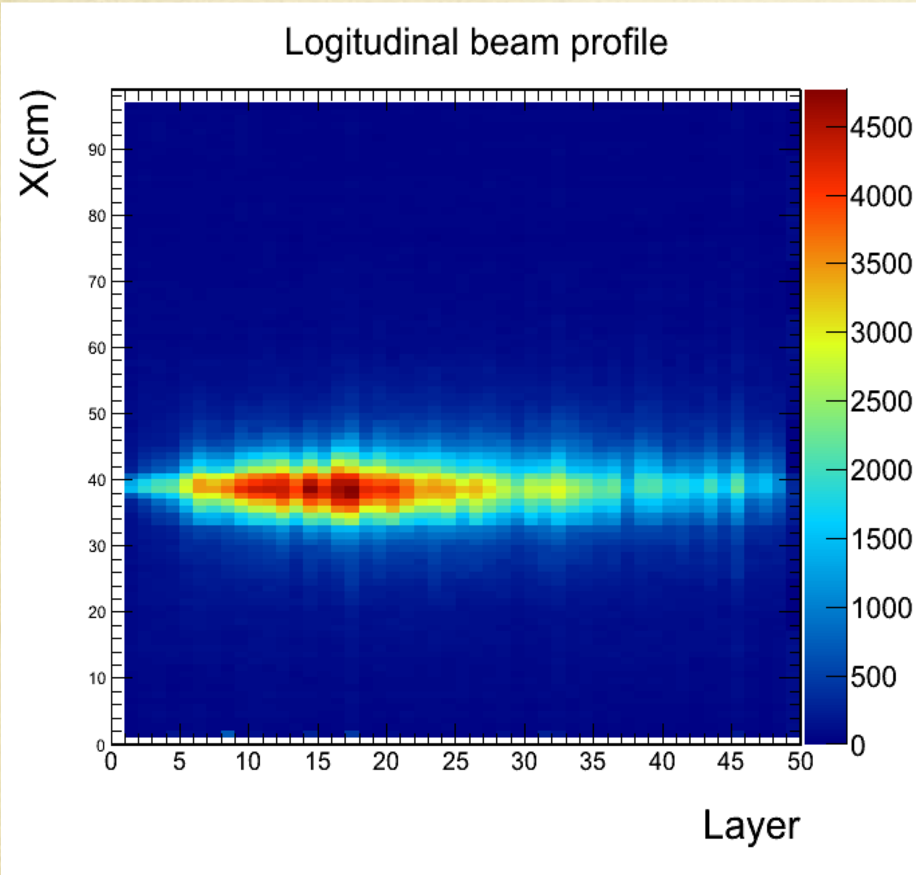


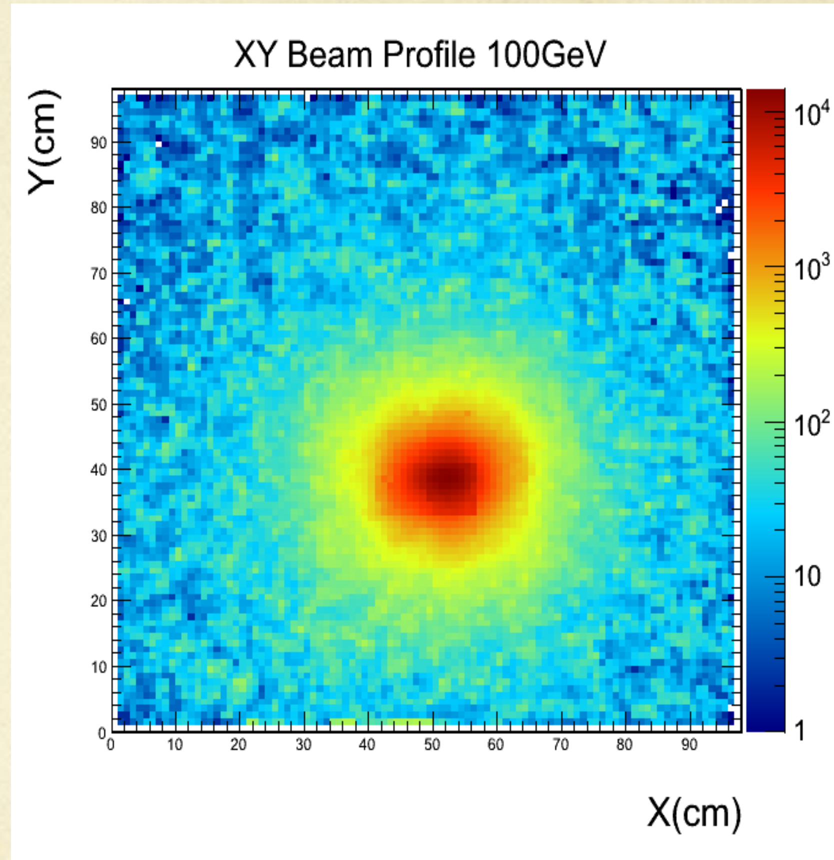
Event display



Colours correspond to the three thresholds: Green (100 fC), Blue (5 pC), Red (15 pC)

Raw data, no treatment except time hit clustering

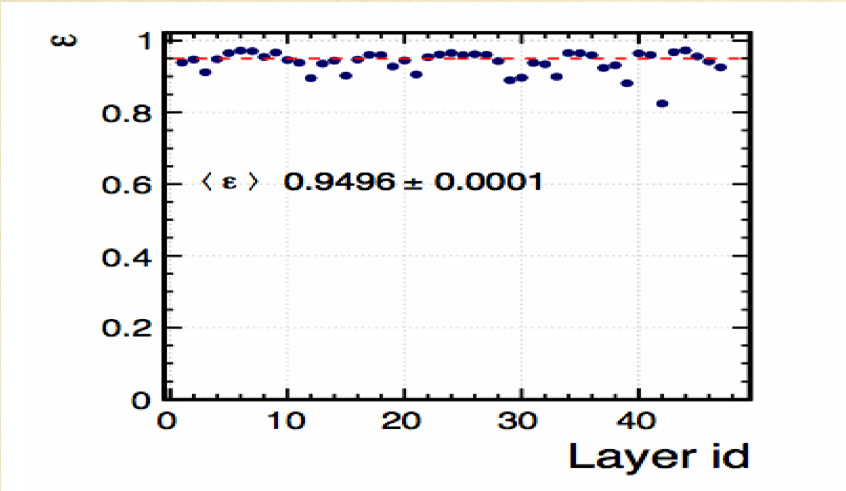




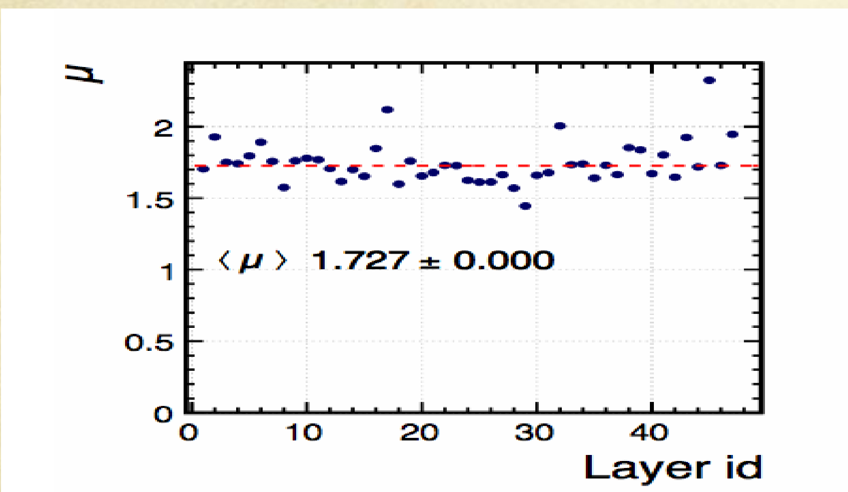
100 GeV pions

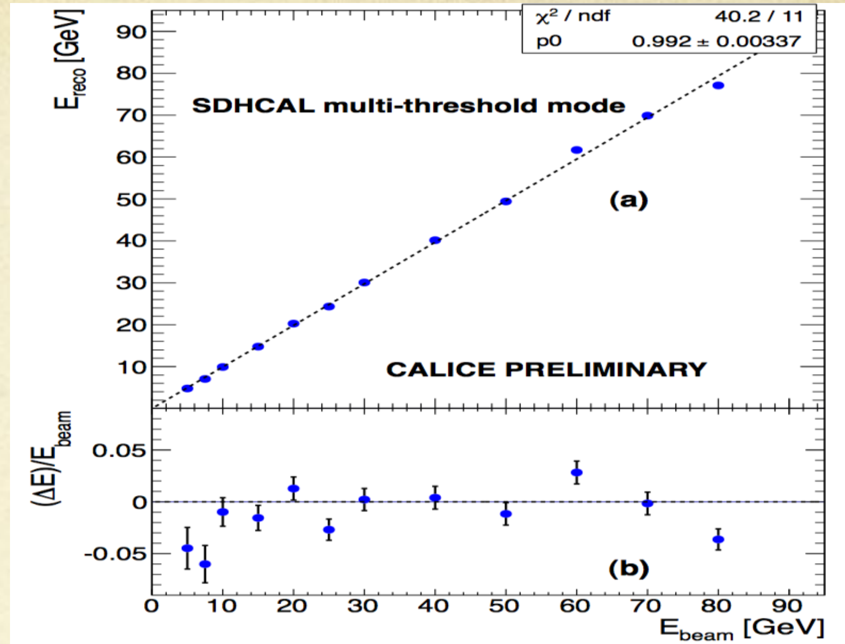
First results on linearity and energy resolution
with no calibration and with no gain correction.

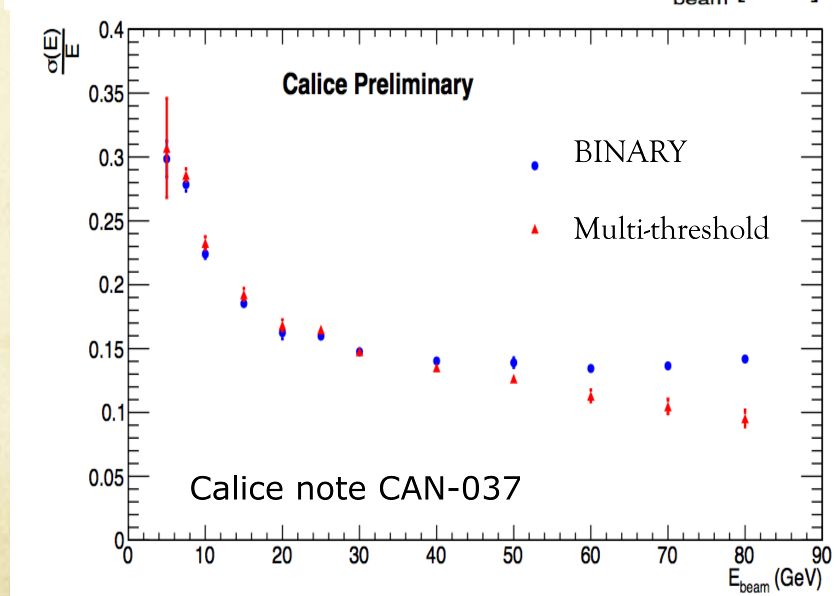
Efficiency



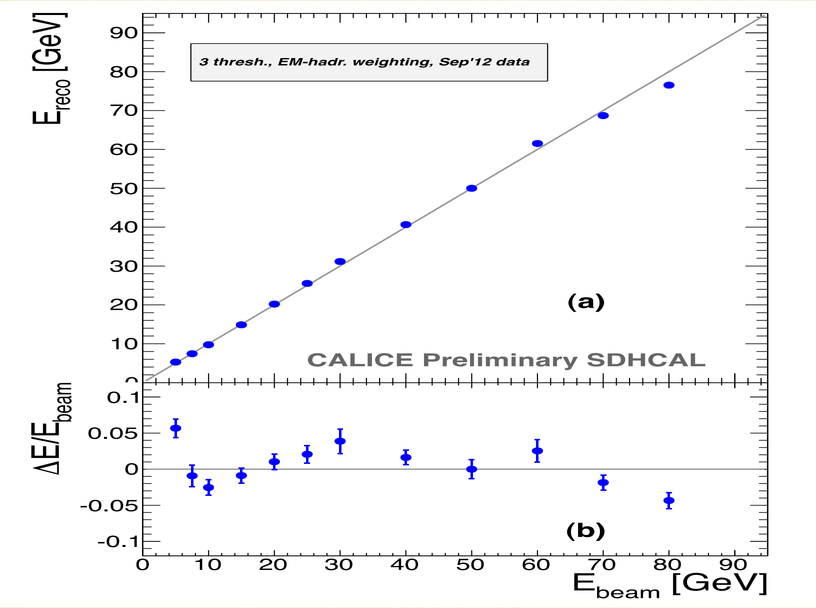
Pad multiplicity

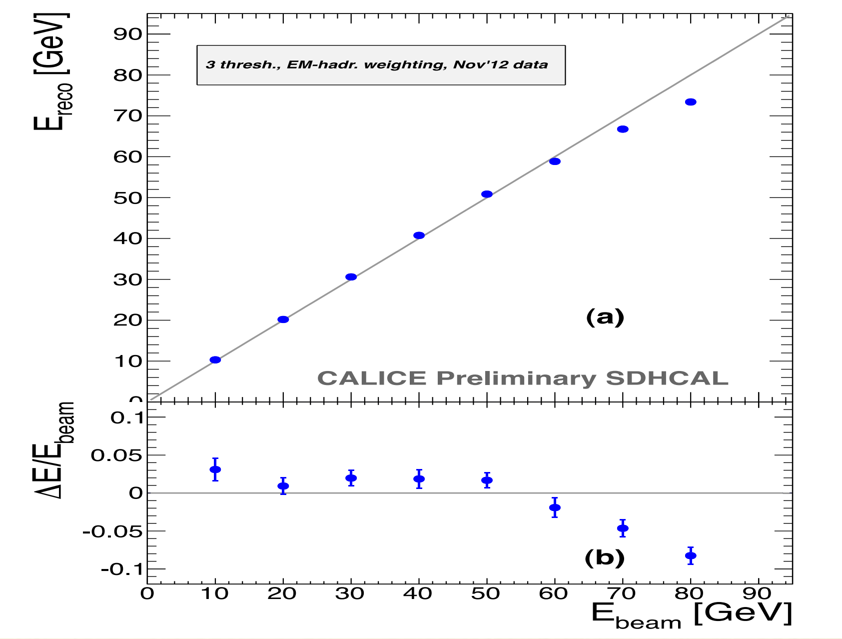


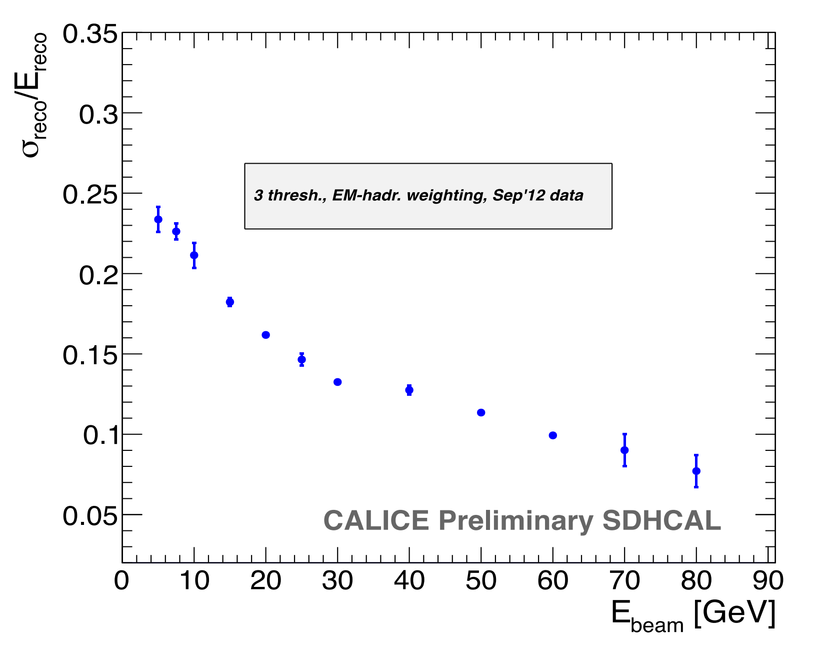


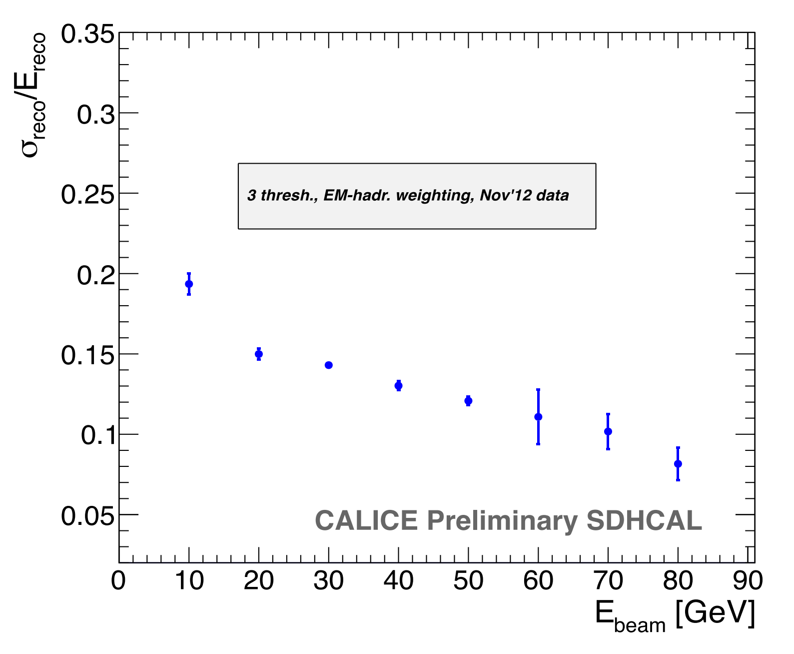


Semi-digital improvement with respect to digital version.

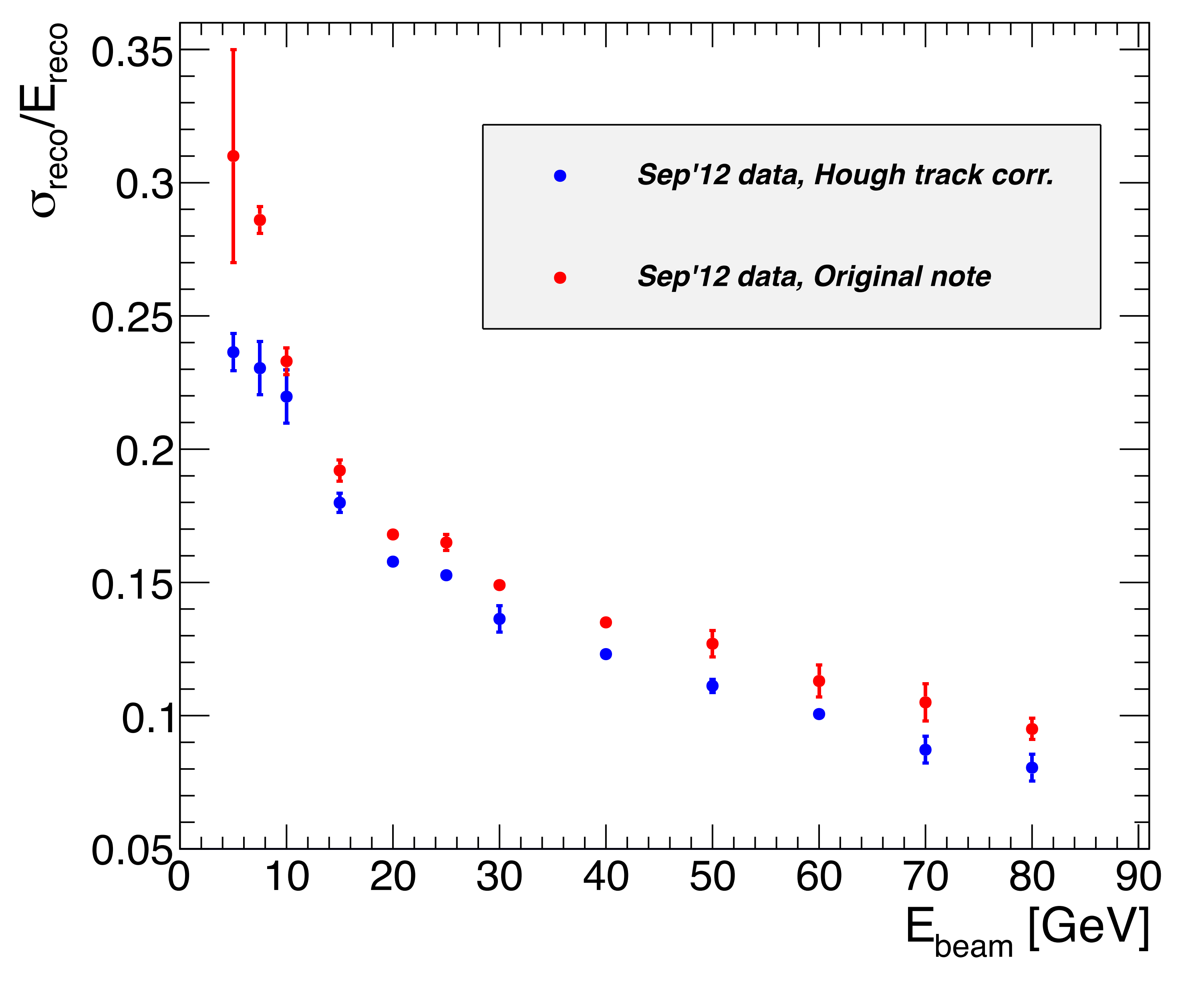

3 thresh., EM-hadr. weighting, Sep'12 data
(a)
(b)
CALICE Preliminary SDHCAL
E_{reco} [GeV]
$\Delta E/E_{beam}$
E_{beam} [GeV]


3 thresh., EM-hadr. weighting, Nov'12 data
(a)
(b)
CALICE Preliminary SDHCAL
E_{reco} [GeV]
$\Delta E/E_{beam}$
E_{beam} [GeV]


3 thresh., EM-hadr. weighting, Sep'12 data
CALICE Preliminary SDHCAL
σ_{reco}/E_{reco}
E_{beam} [GeV]


3 thresh., EM-hadr. weighting, Nov'12 data
CALICE Preliminary SDHCAL
σ_{reco}/E_{reco}
E_{beam} [GeV]

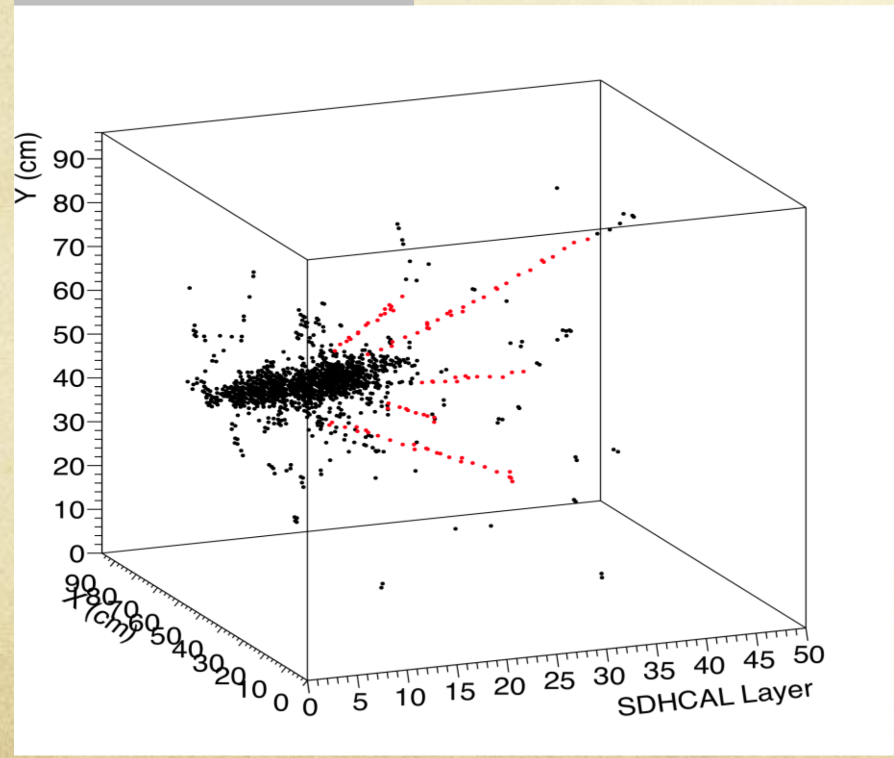
Improvement of energy resolution



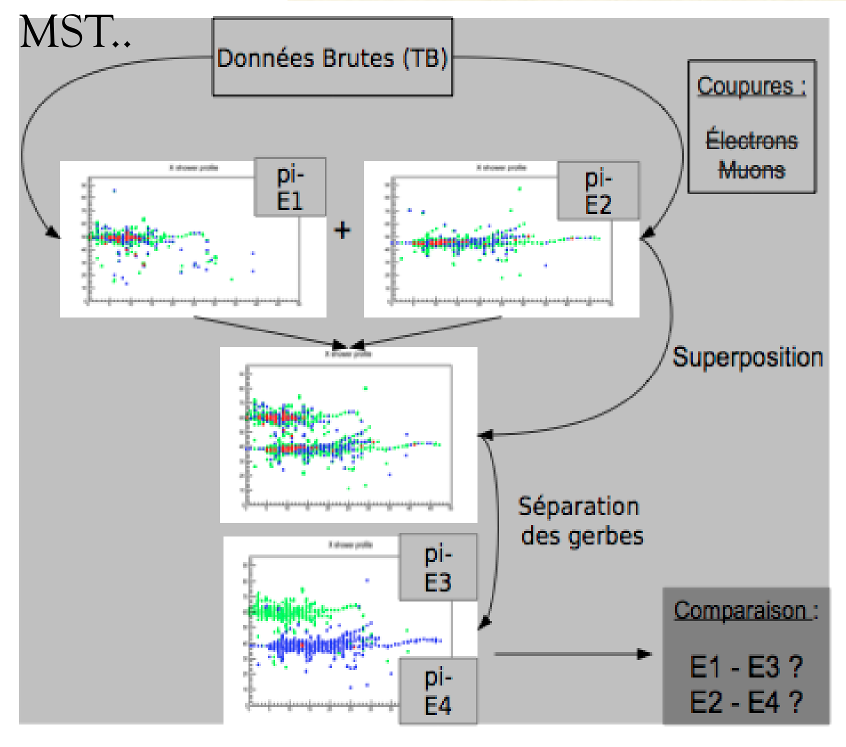
Ongoing analyses

→ Calibration study;
→Electron-Pion separation;
→ Energy resolution improvement by taking into account hadronic shower structure and calibration correction: *an improvement of 7-15% already achieved with respect to the preliminary ones obtained immediately after TB;*
→ Imaging algorithm developments (HT, Arbor, MST) → PFA

Hough Transform

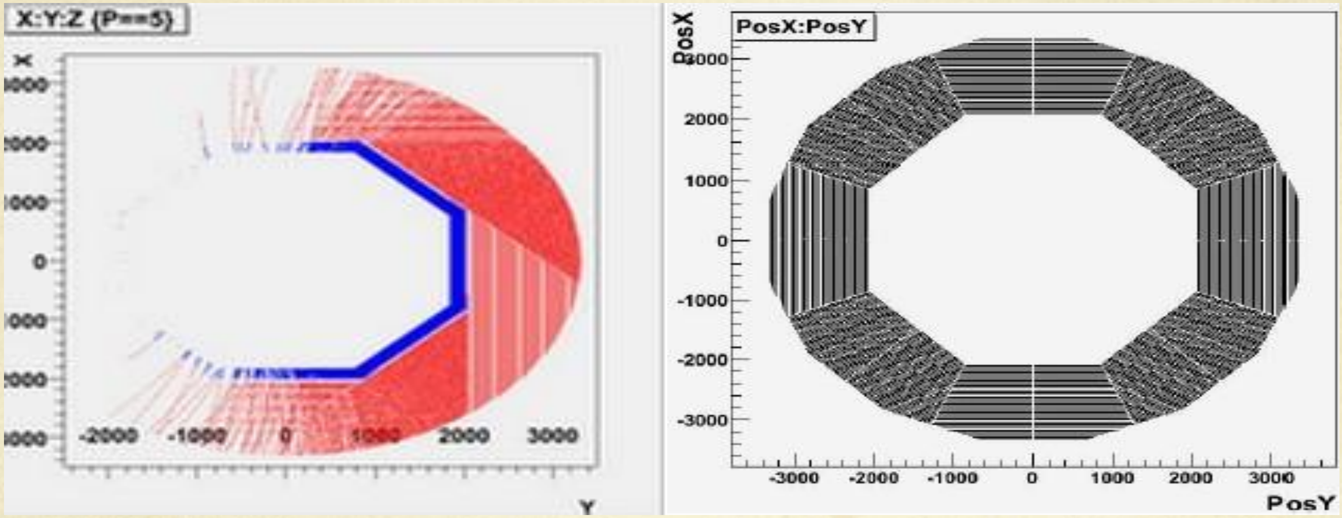


Arbor, MST..

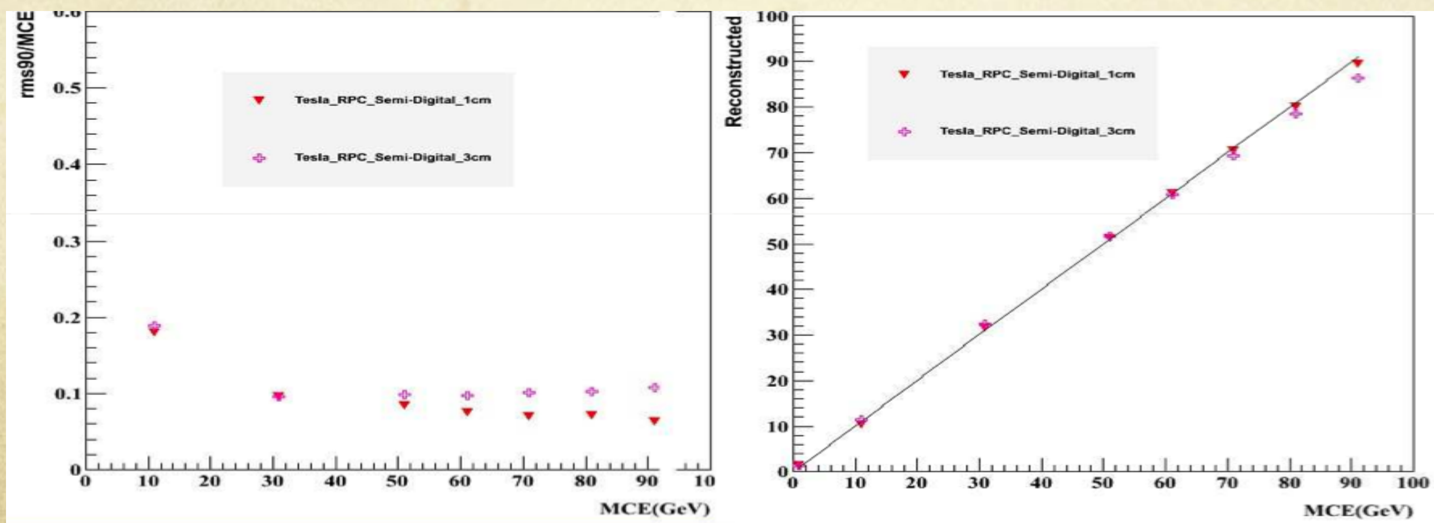


Simulation and optimization studies

SDHCAL was simulated with two mechanical structures for ILD (V and Tesla)



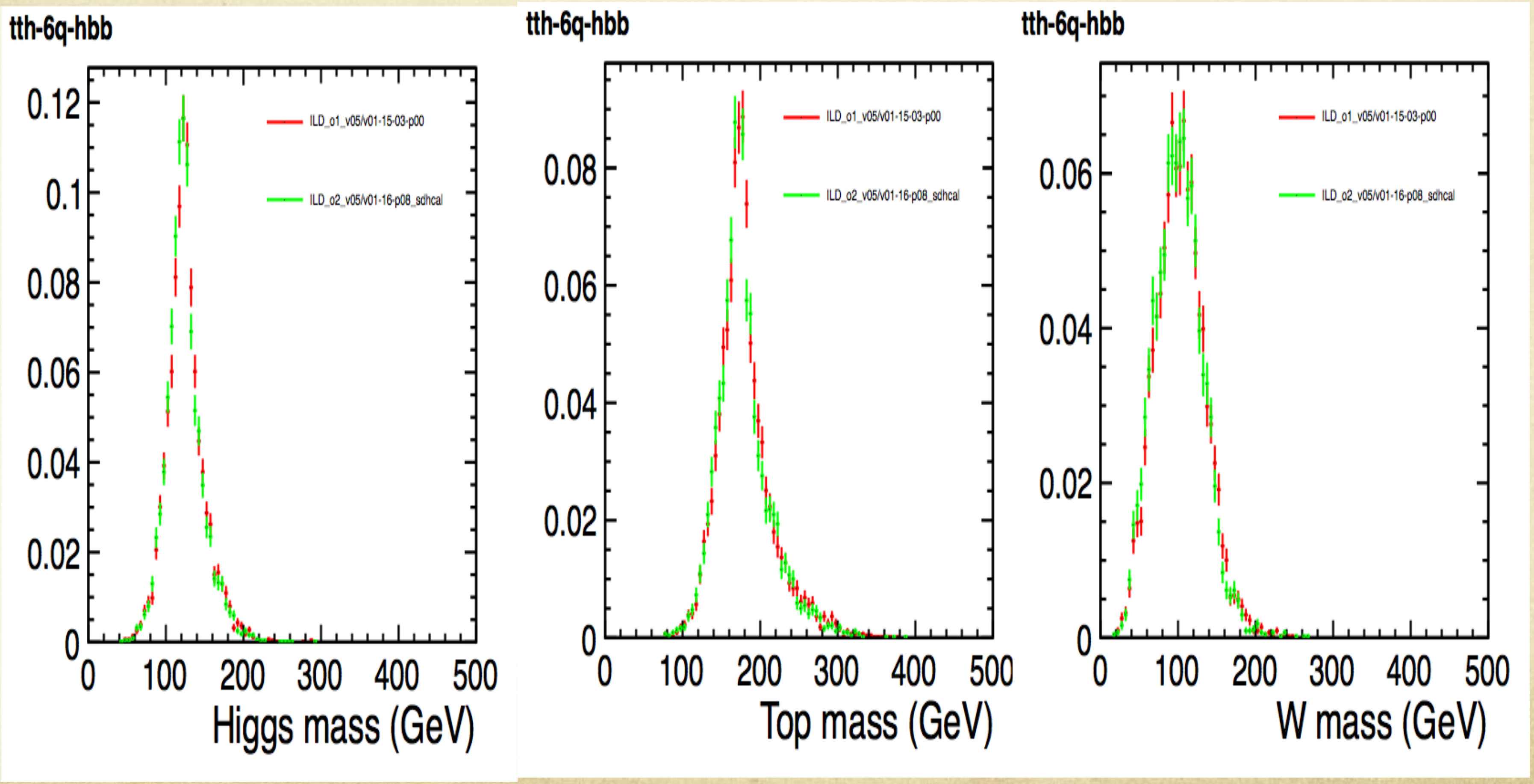
Studies on granularity and readout (binary vs semi-digital and also granularity of $1x1\ cm^2$ vs $3x3\ cm^2$) were conducted. They allowed to confirm the SDHCAL choice before to start building the prototype



Simulation and optimization studies

The SDHCAL simulation was re-performed taking into account the constraints and the results of the prototype. The new version was used for the DBD studies, showing that same performance are obtained as for the AHCAL (albeit the PFA optimization was done for the AHCAL topology)

Higgs, top and W in the tth 8jet mode (1000 GeV).



Tomohiko Tanabe

Road map in the 2-3 coming years

-Improve on the energy reconstruction using new techniques;

-Improve on simulation (digitizer) and compare hadronic shower models to data;

-Develop PFA techniques to be used to separate close-by hadronic showers;

-Complete TB (ECAL+SDHCAL+…);

--------- ---- ----------

-Build few very large GRPC detectors (2-3 m2) : gas circulation system, thickness…;

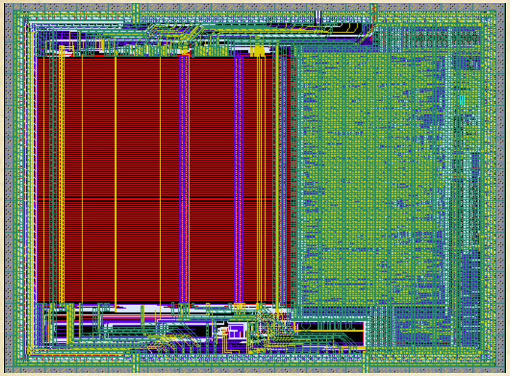
-Test the new version of electronics (I2C, roll mode..) ;

-Design a new ASU capable to read the large GRPC (up to 3 m^2);

-Develop a new DIF (low consumption, reduced size, new functionalities);

-Build a small mechanical prototype to host the few large chambers and test it.

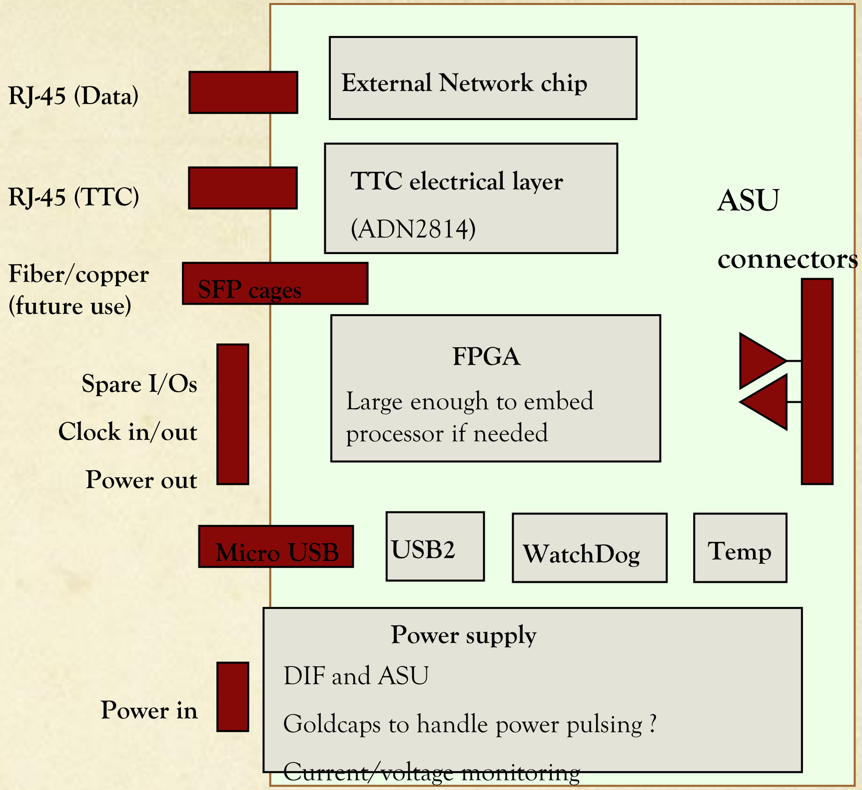
New version of the readout electronics



The new version brings improvements on the previous one:
→Independent channels and zero suppression
→Independent ASICs (I2C)
→Better dynamic range (up to 50 pC).
→ successfully tested;
→
This activity is funded essentially by **AIDA**

New ASU design for large detectors under study

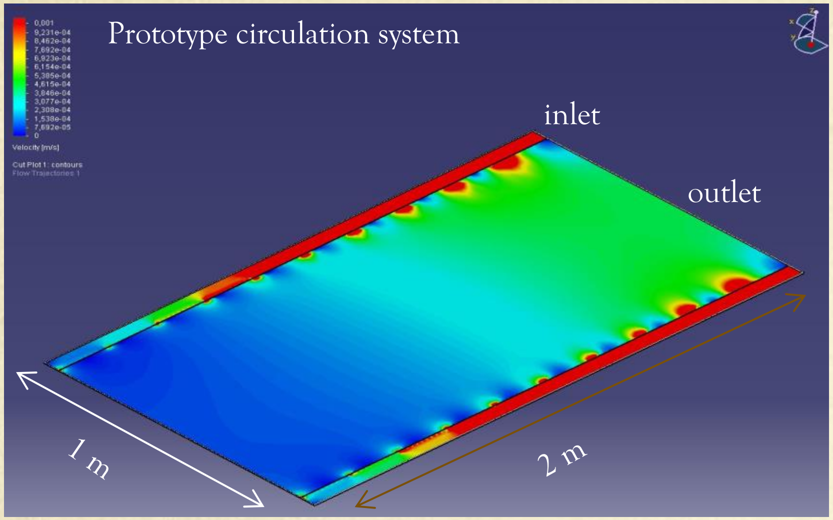
New features in the DAQ boards

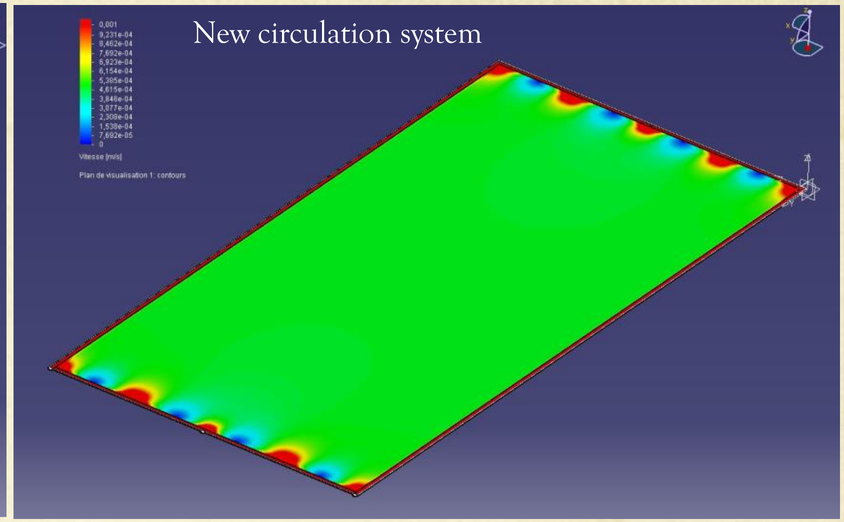


→ Only one DIF per plane. For the maximum length plane (1x3m) the DIF will handle 432 HR3 chips;
→ Slow control through the new HR3 I2C bus;
→ Data transmission to DAQ by Ethernet using commercial switches for concentration;
→ Clock and synchronization by TTC;

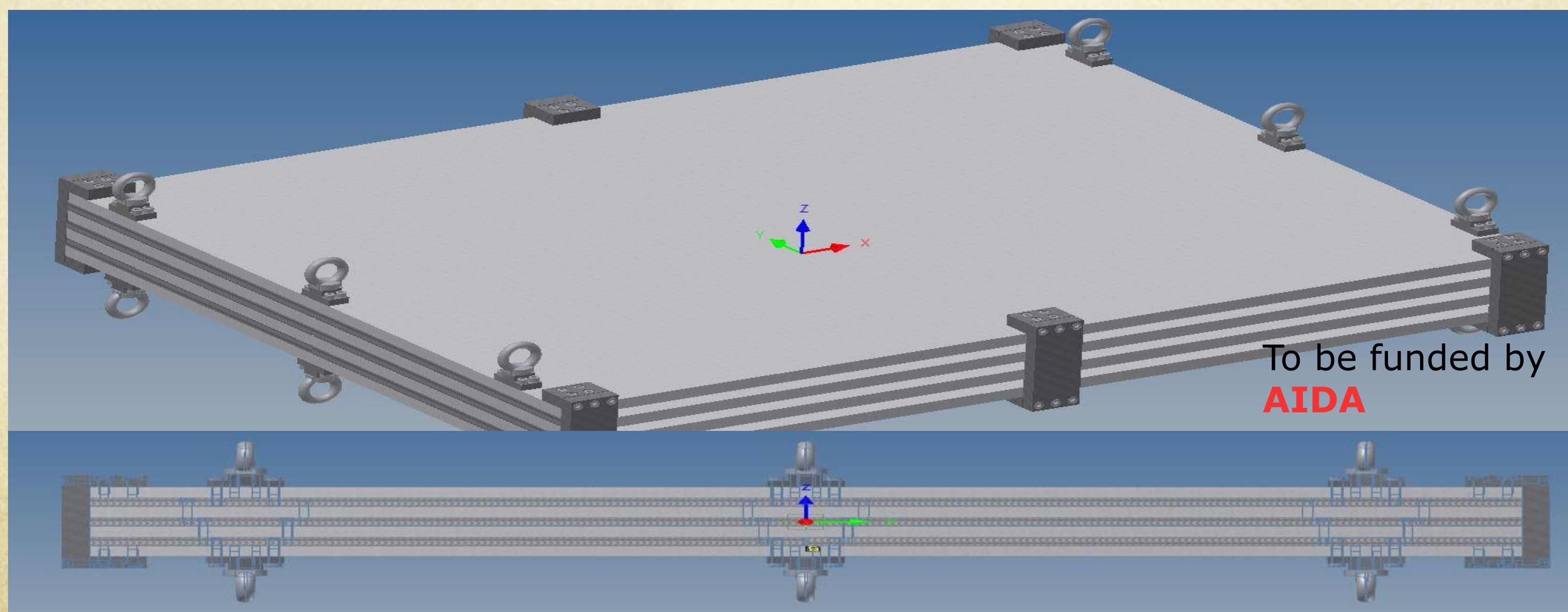
Synergy with R&D on fast links R&D of LHC (GBT)
Funded essentially by CIEMAT

Detector improvement : to achieve same performances with very large GRPCs





Mechanical structure : to be built with EBW techniques and to host few large detectors GRPCs



Conclusion and prospects

-The SDHCAL prototype is the first and up-to-now unique **technological** calorimeter prototype. Its success proves that SDHCAL is an excellent option for ILD;

-SDHCAL with its fine granularity is an excellent tool to develop and exploit PFA algorithms;

-The expertise accumulated during the conception, construction and commissioning is very precious for physicists and technical staff in our labs;

-The project has led to several spin-offs (TOMUVOL, CMS,..);

- Work on complete validation of the SDHCAL concept is ongoing.

Backup slides

Articles

Published :

-Performance of Glass Resistive Plate Chambers for a high granularity semi-digital calorimeter, Bedjidian et al, 2011_JINST_6_P02001.

-Construction of technological semi-digital hadronic prototype using GRPC, Laktineh I., Journal of Physics Conference Series, volume 293, A.N. 012077, 2011.

-First test of a power-pulsed electronics system on a GRPC detector in a 3-Tesla magnetic field, Caponetto et al, 2012_JINST_7_P04009.

In preparation :

-Large GRPC detector for the future ILC SDHCAL hadronic calorimeter.

-

-Construction and commissioning of the SDHCAL technological hadronic calorimeter.

Calice notes :

-First results of the SDHCAL technological prototype and its addendum (CAN-037).

-Tracking within Hadronic Showers in the SDHCAL prototype using Hough Transform Technique (CAN-047).

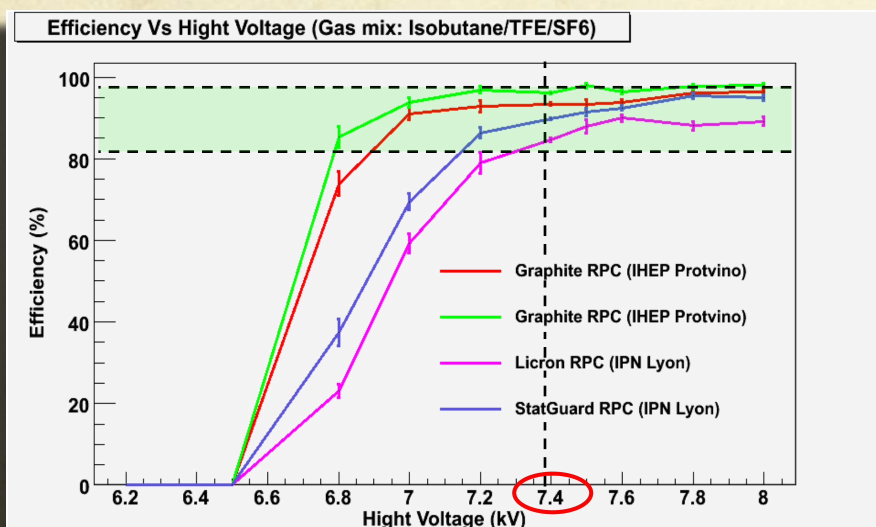
Detector

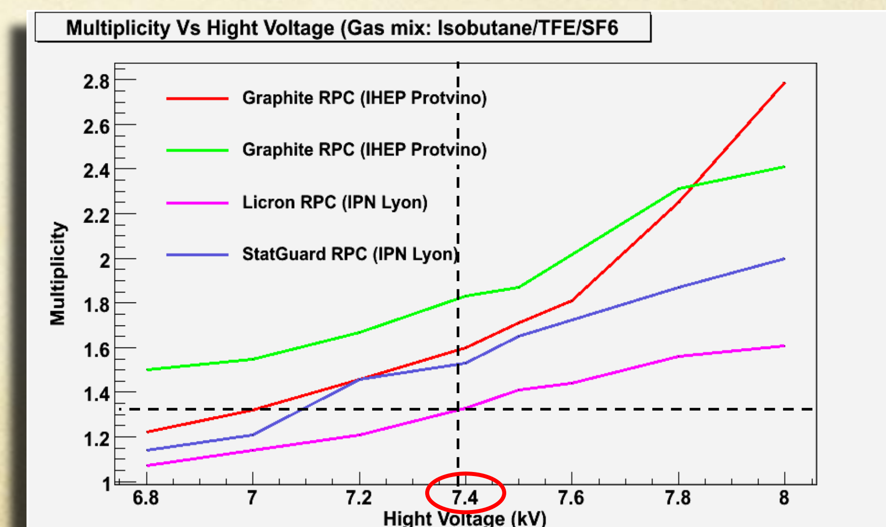
Resistive coatings :

Following detailed study on the effect of resistive coating on pads multiplicity realized using small GRPC in TestBeam conditions it appeared that the higher the resistivity of the coating the lower the pads multiplicity (see figure). This is of big importance to improve on tracking capability.

Many kinds of coatings were tested on large GRPC and different painting techniques were tried in order to ensure the best homogeneity

Some paintings like the Licron® were dropped due to long term stability of high voltage connection.





Detector

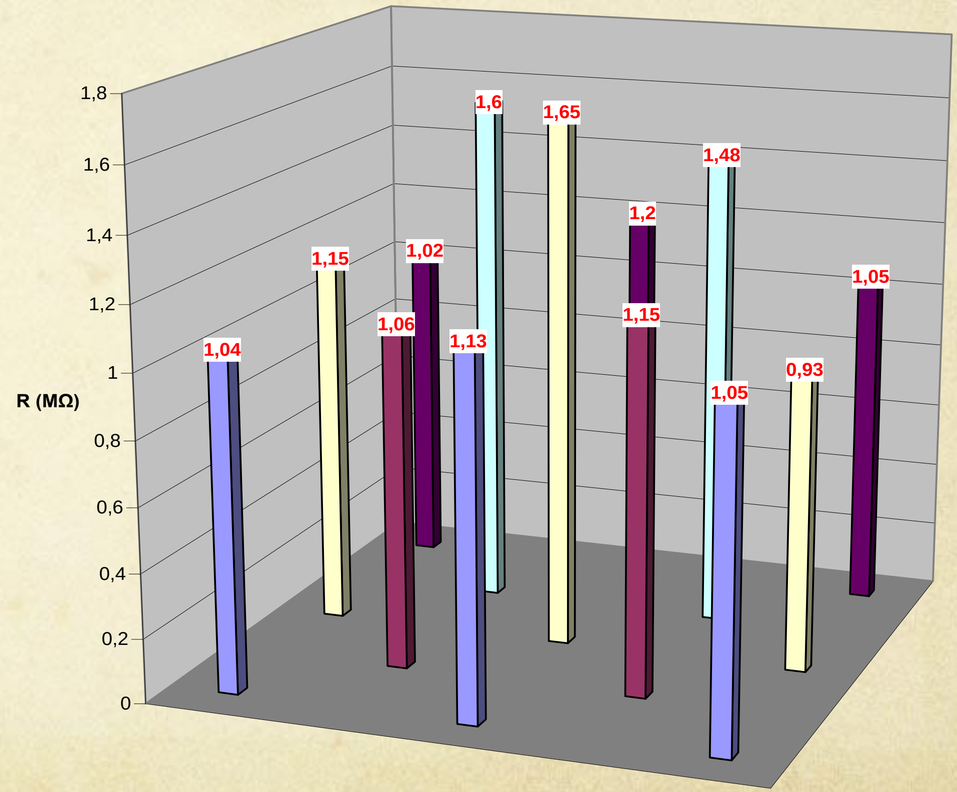
Painting technique

Different techniques were tested and finally the silk screen print one is adopted. It provides **homogenous** and well controlled coating. Simple tools are needed. First tests were done manually.
Painting of 20 large glass plates was then performed successfully in a semi-automatic way.

Detector

Painting techniques

The measured resistivity on the 20 plates using semi-automatic Silk screen print machine show very nice homogeneity.



$R_{MAX}/R_{MIN} < 2$
over 1 m^2 surface

Readout Electronics : ASIC : HR2

64-Channel

Dynamic range

- Gain correct.: **8 bits**
  G=0 to 255 (analog G=0 to 2)
- **3 shapers, different Rf,Cf and gains:**
  Fsb1, G= ½,**1/4**,1/8,1/16
  Fsb2, G= 1/8,**1/16**,1/32,1/64
- **3 thresholds** (=> 3 DACs):
  100fC, 1pC, 10pC (GRPC)

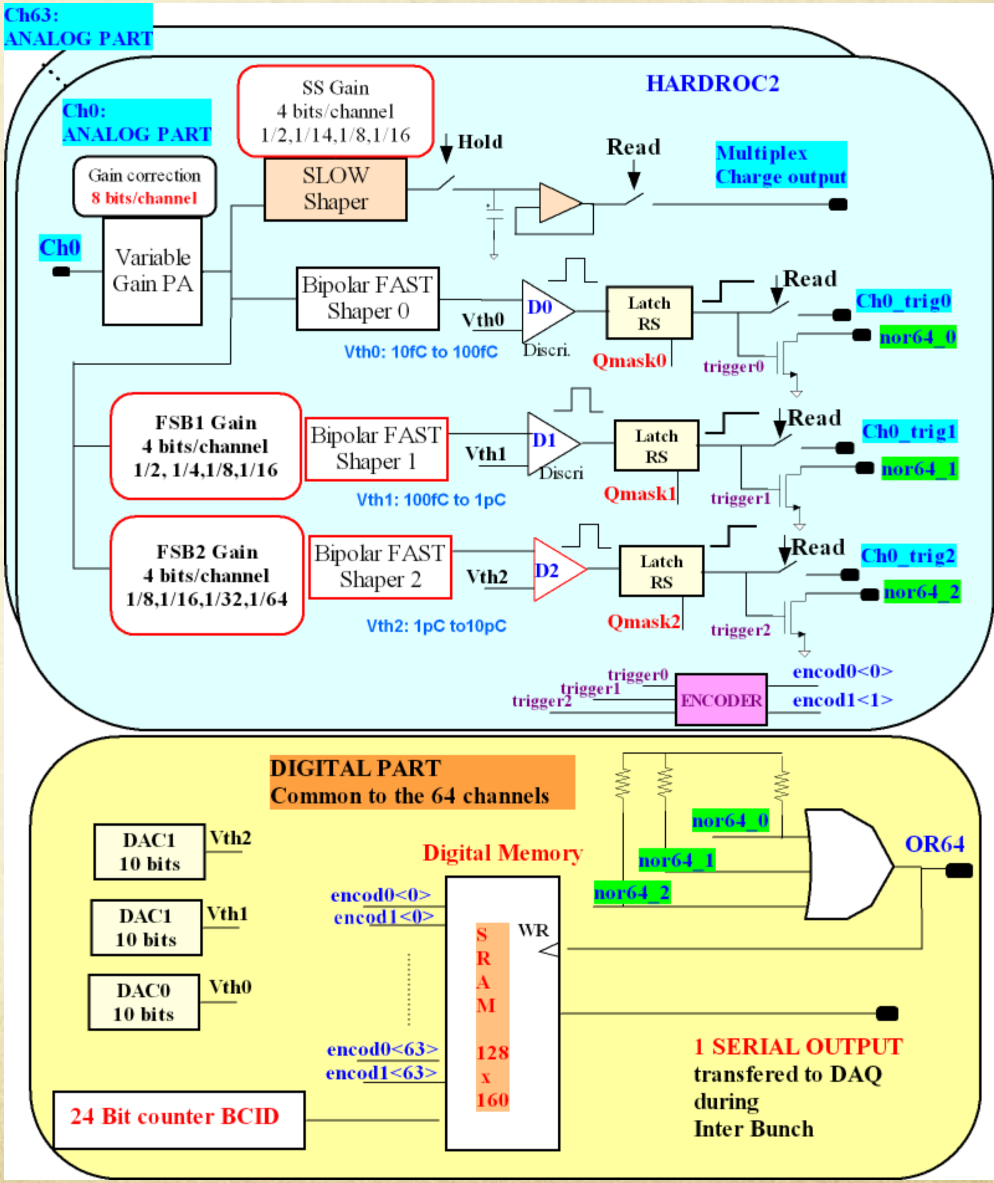
128 memory depth

Mask

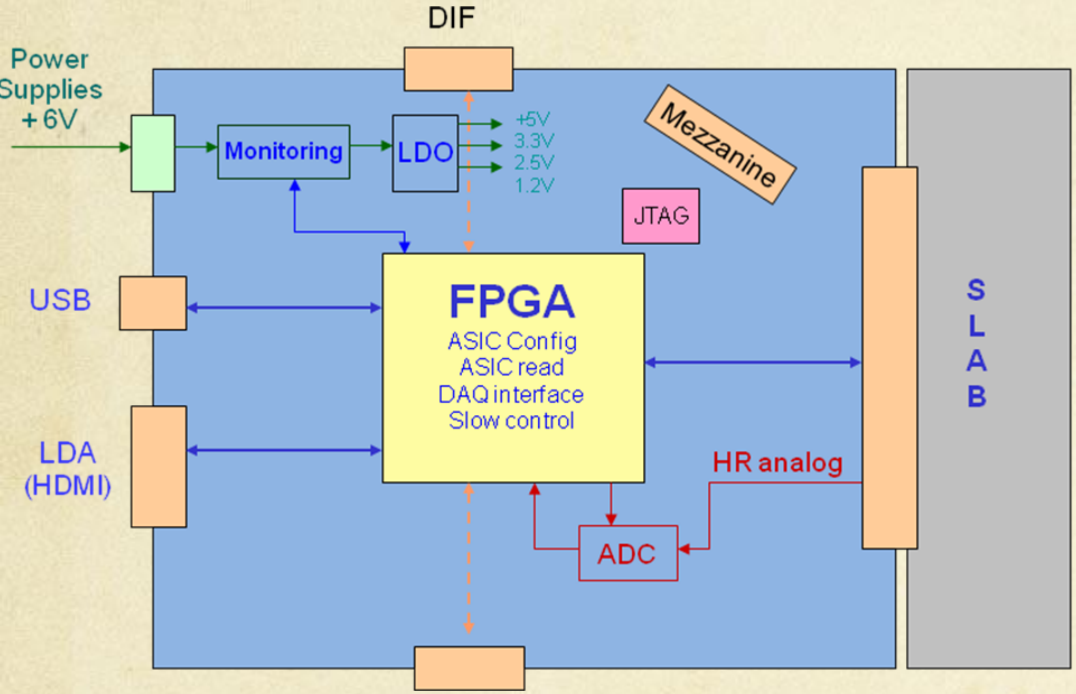
872 SC registers, default config

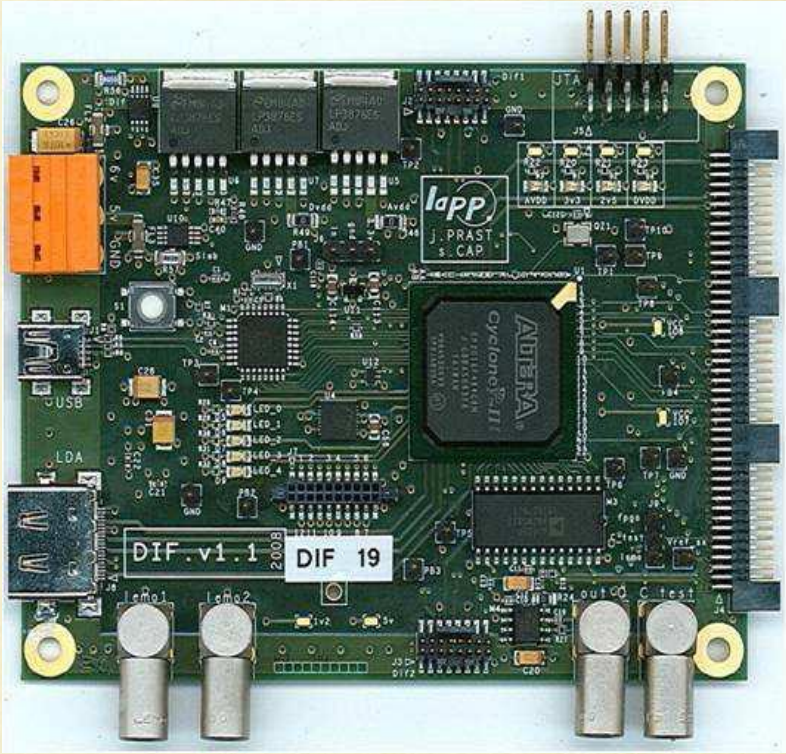
Power pulsing:

- Bandgap +ref Voltages + master I: power pulsed
- POD module (power budget)



Readout Electronics : DIF

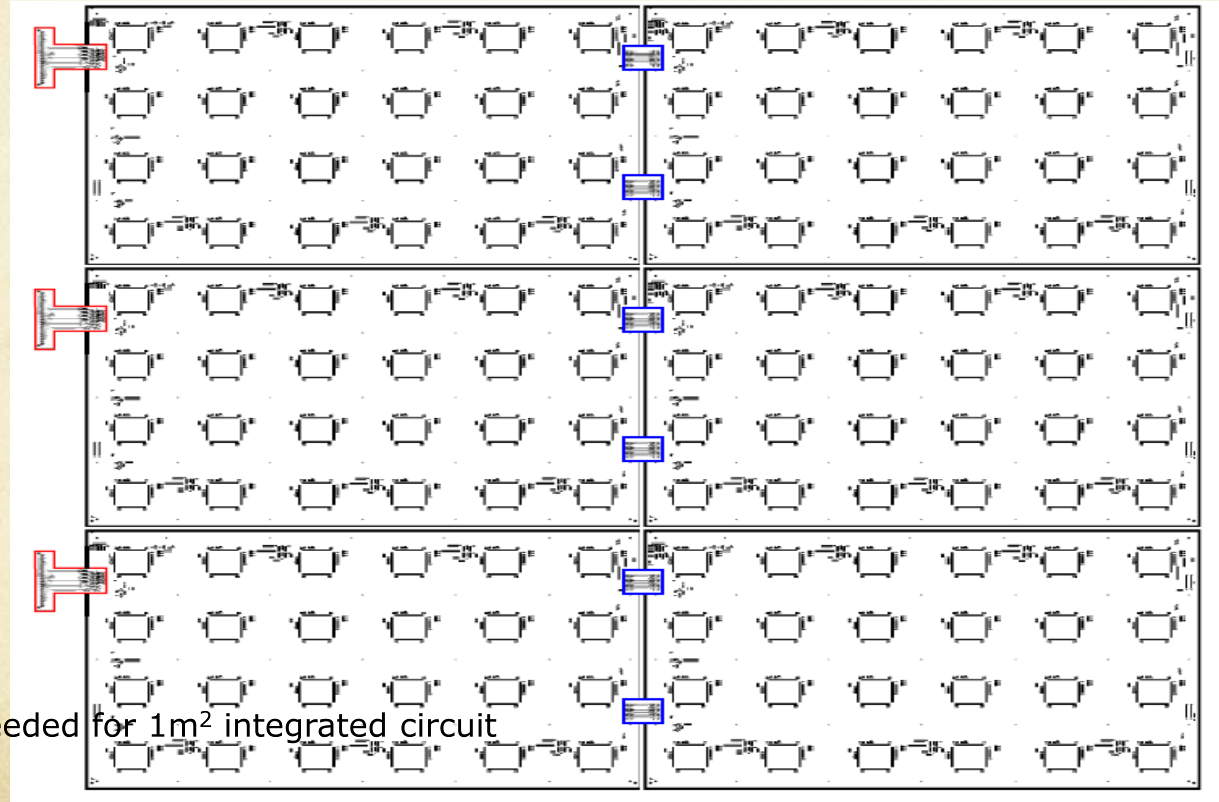




Readout Electronics : ASU

The Active Sensor Unit (ASU) board hosts the front-end electronics.

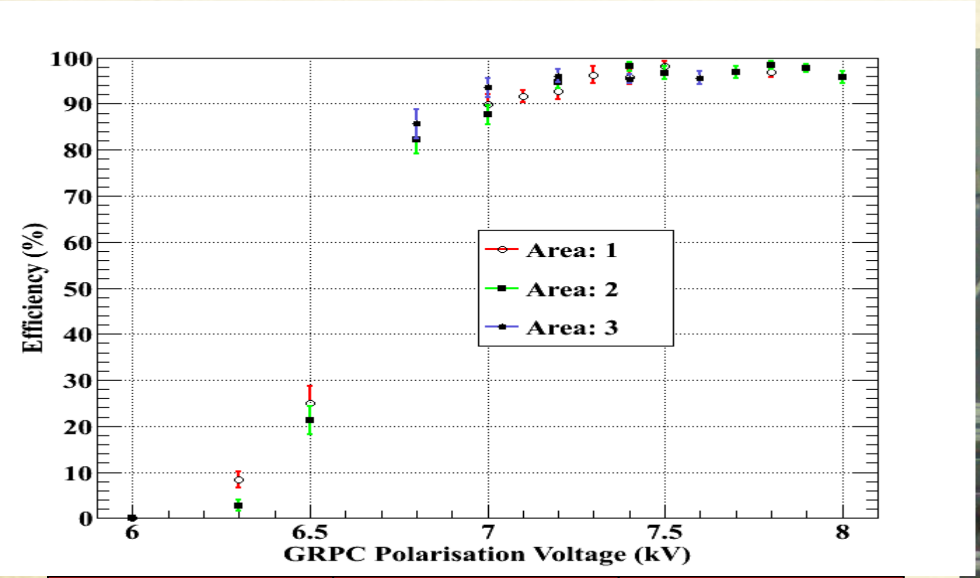
To circumvent the fabrication difficulties of the square meter integrated circuit, the approach of assembling 6 smaller boards has been taken.

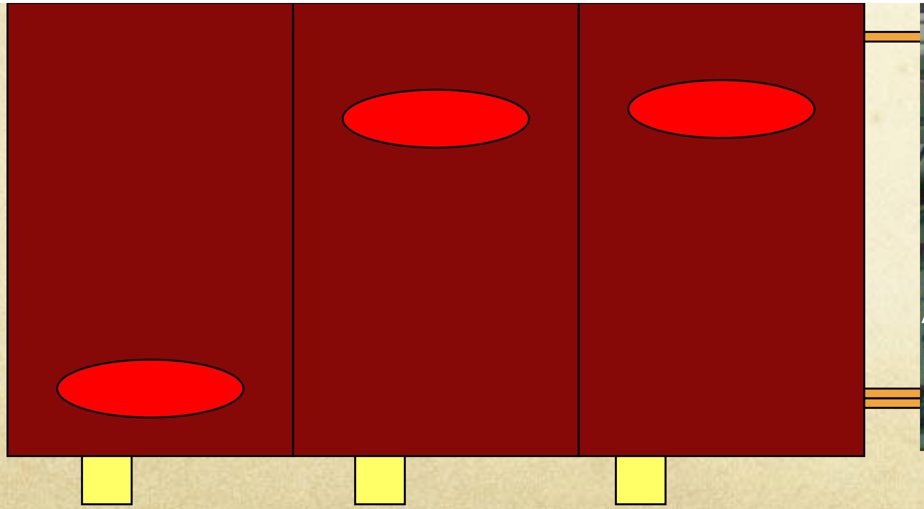


2 ASUs are connected two by two using an inter-connect to form a slab. A slab is connected to a DIF using an Interconnect board 3 DIFs are needed for $1m^2$ integrated circuit

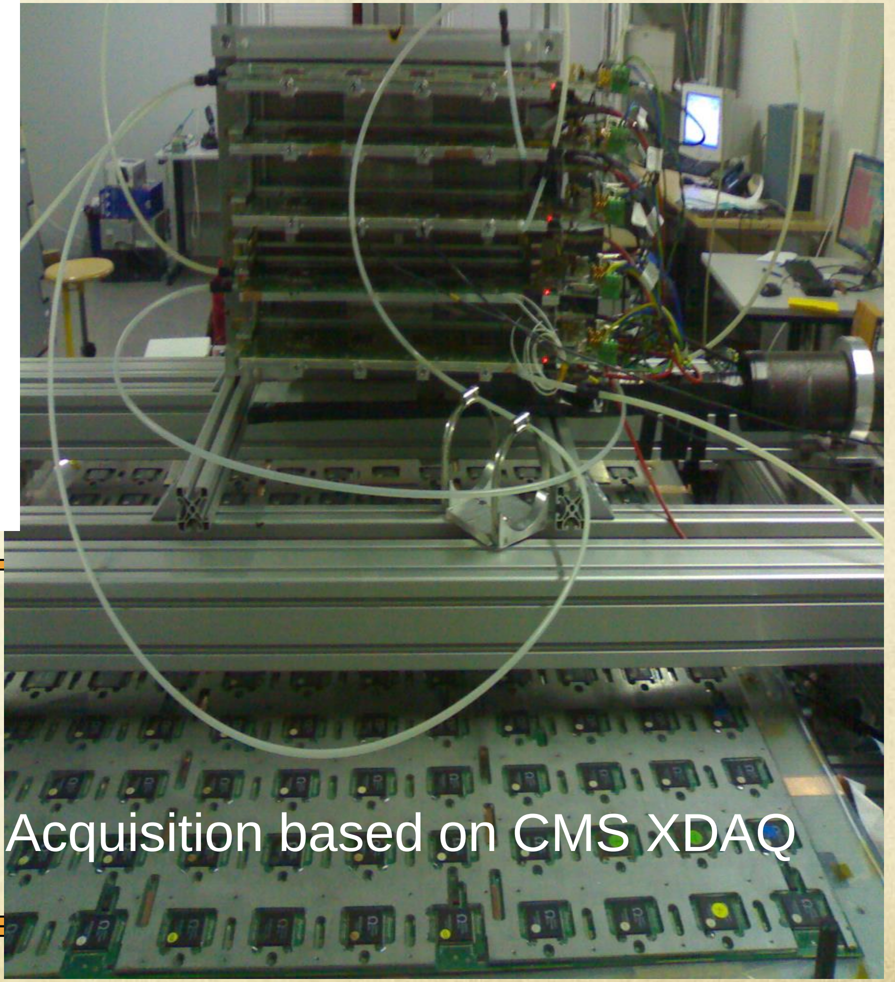
Detector

Homogeneity validation





DIF6 DIF9 DIF10

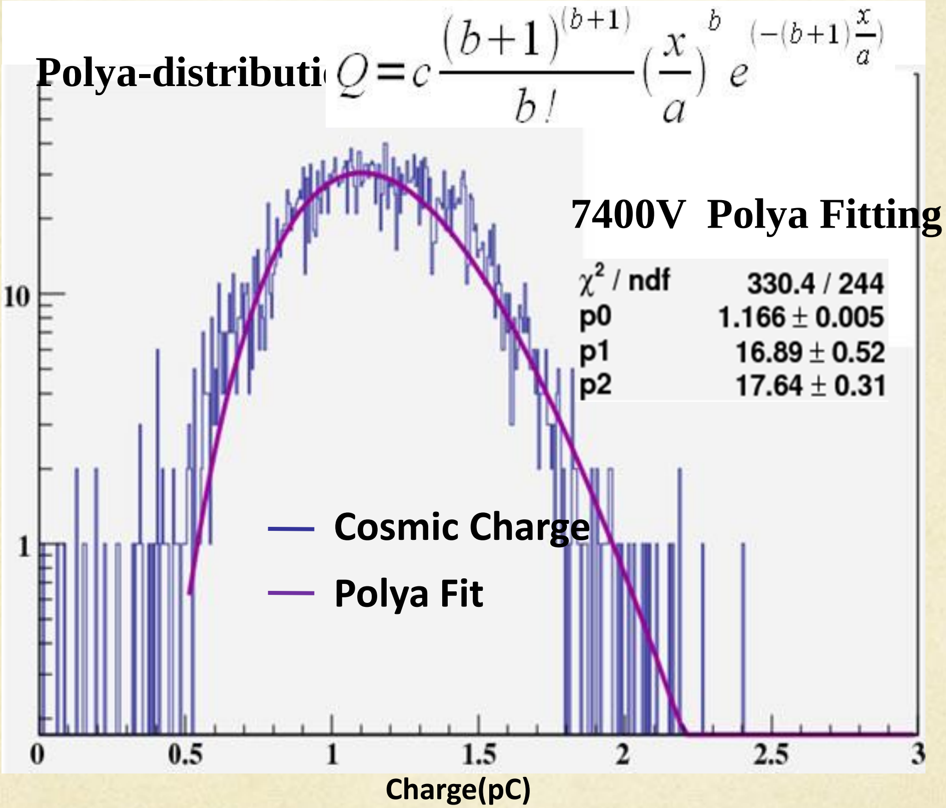


Acquisition based on CMS XDAQ

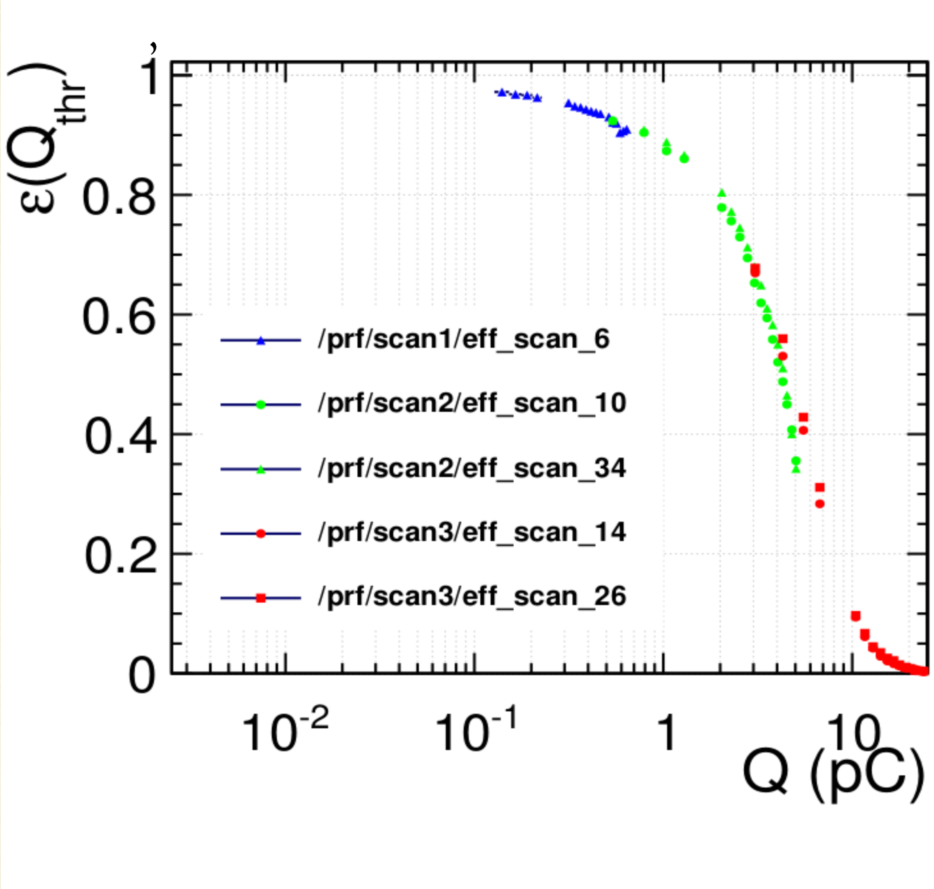
Digitisation

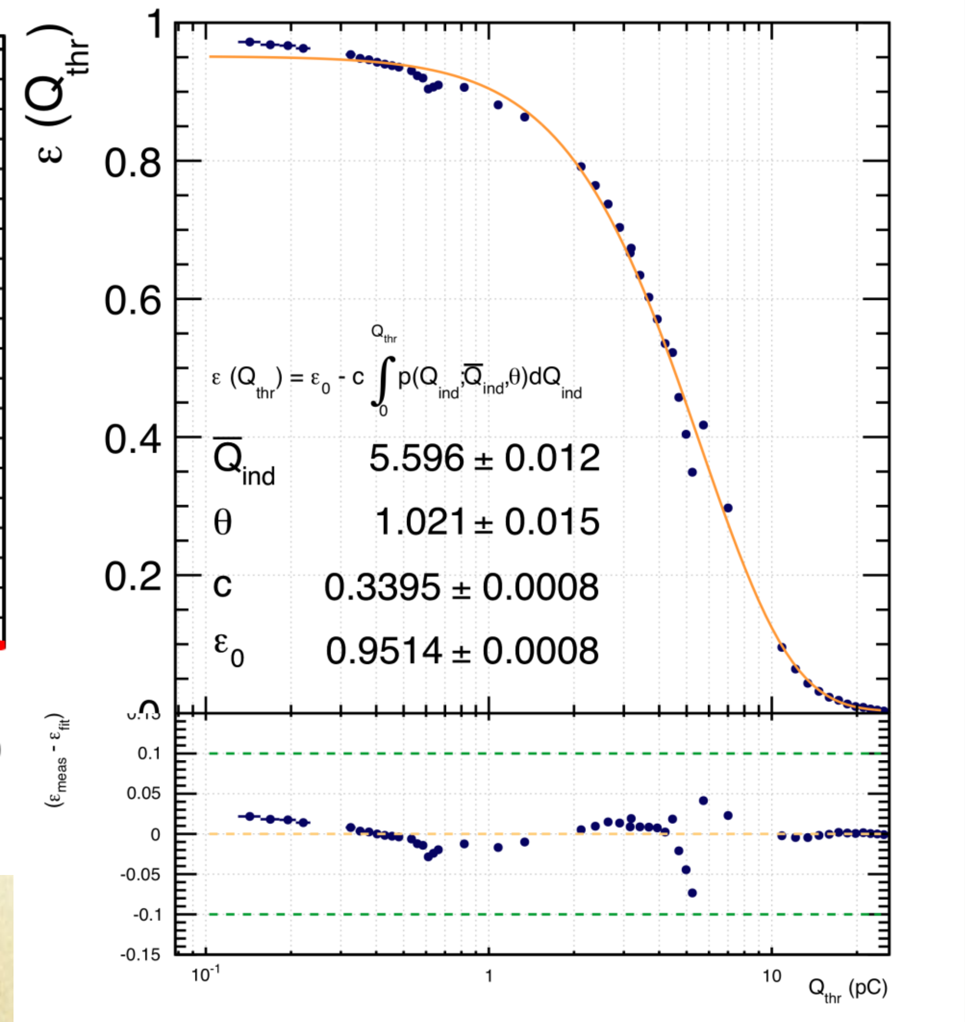
First step:

Measure GRPC analog signal with cosmic muon



Simulation:
A partir des données expérimentales on peut remonter au spectre de la charge associée au passage des mips dans les GRPC. On peut donc simuler l'effet des seuils et le nombre de hits laissés par une gerbe hadronique.
:

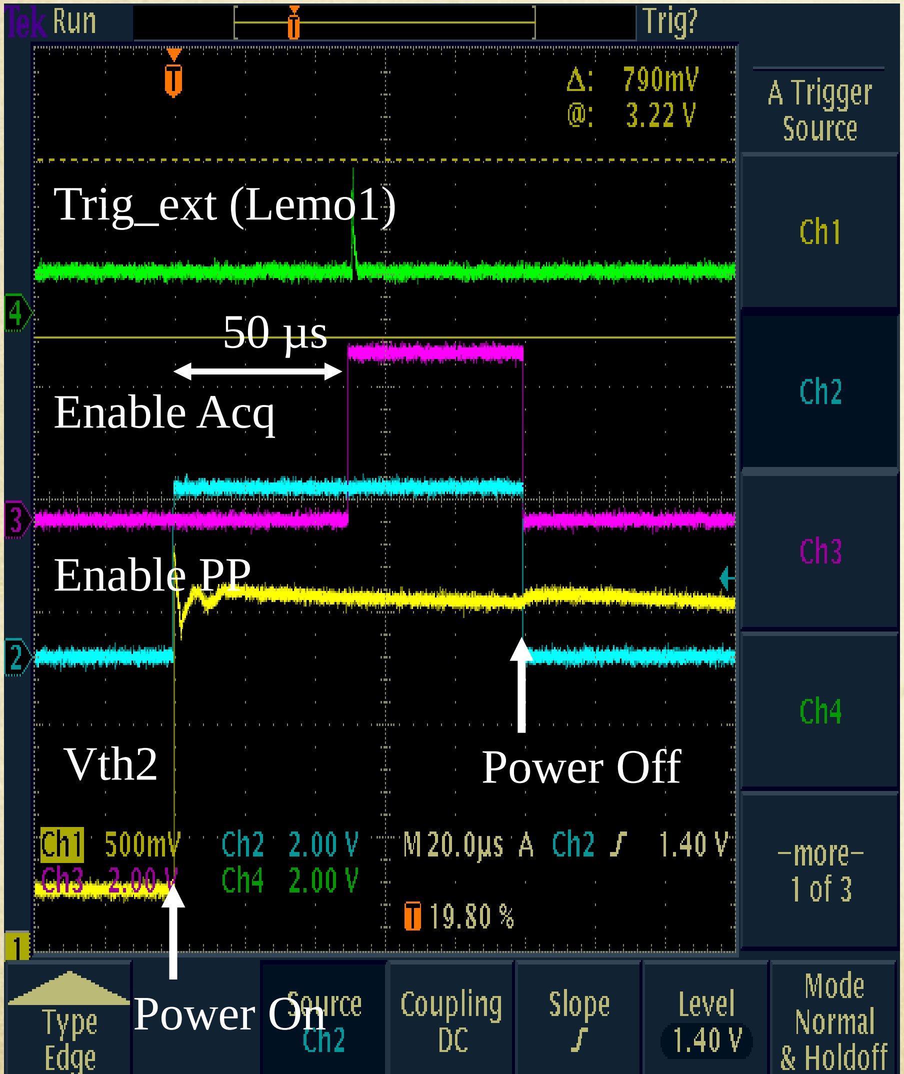




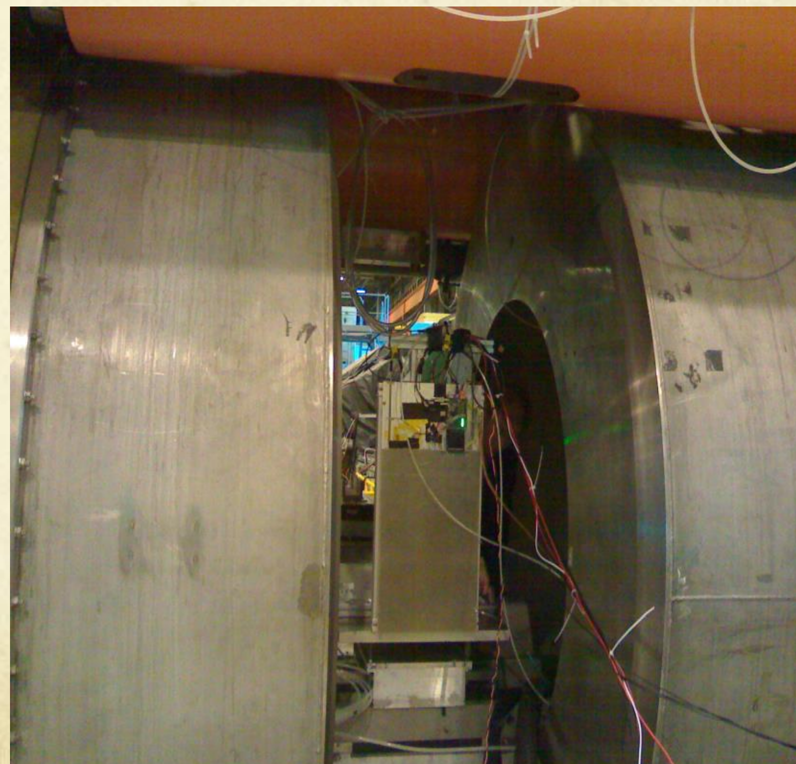
Plusieurs modèles de gerbes hadroniques sont ensuite simulées dans le SDHCAL et comparées aux données

Y.Haddad

Readout Electronics : Power-Pulsing



Power pulsing was successfully tested on a 24-ASIC electronic board. The board associated to a GRPC was also successfully tested in a 3-Tesla B field in June (SPS-H2)

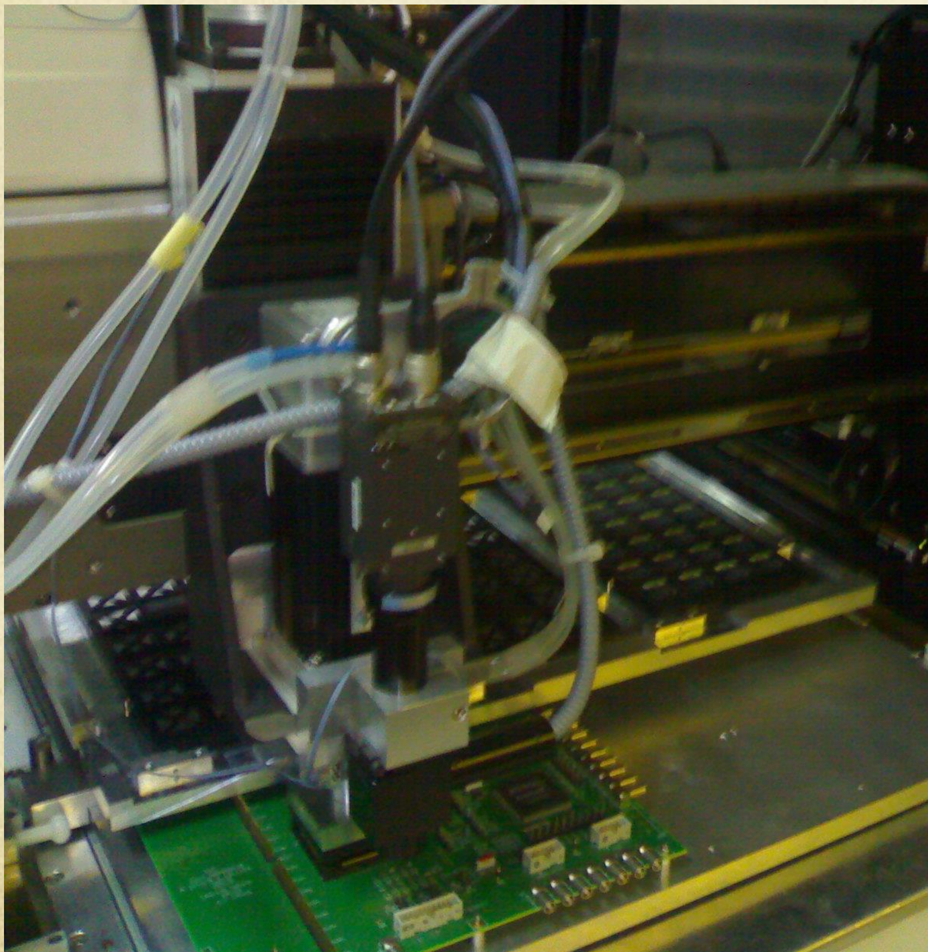


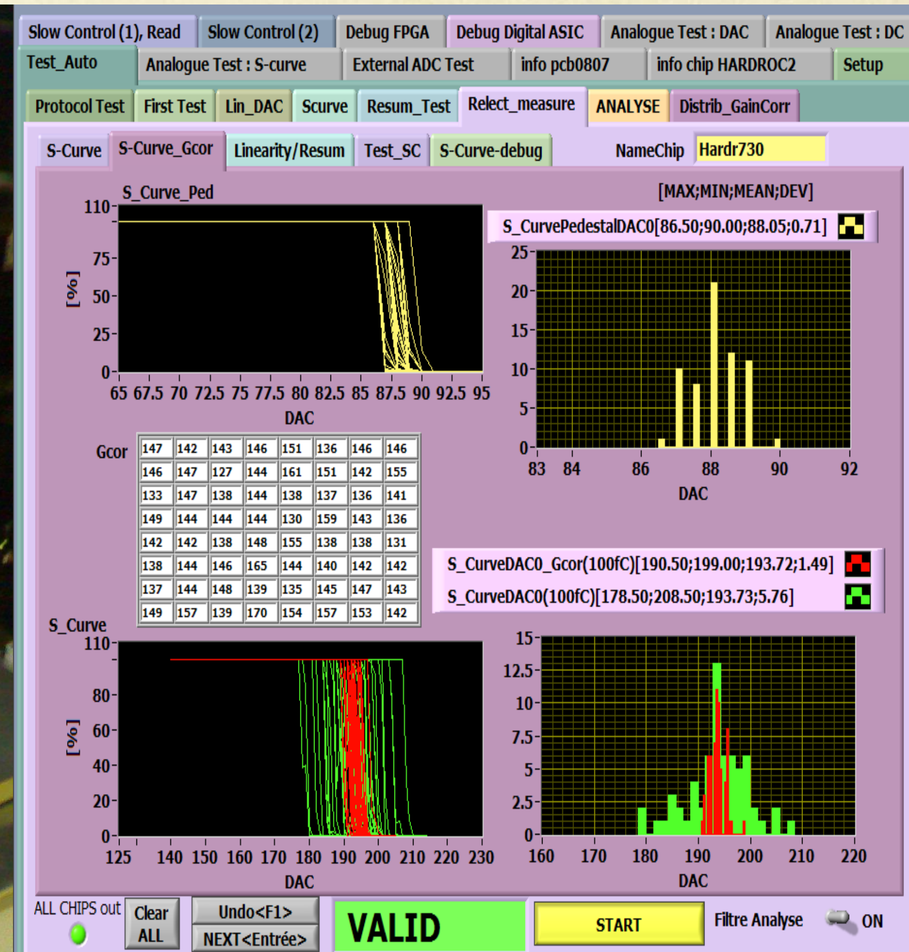
Electonics: ASICs stand test

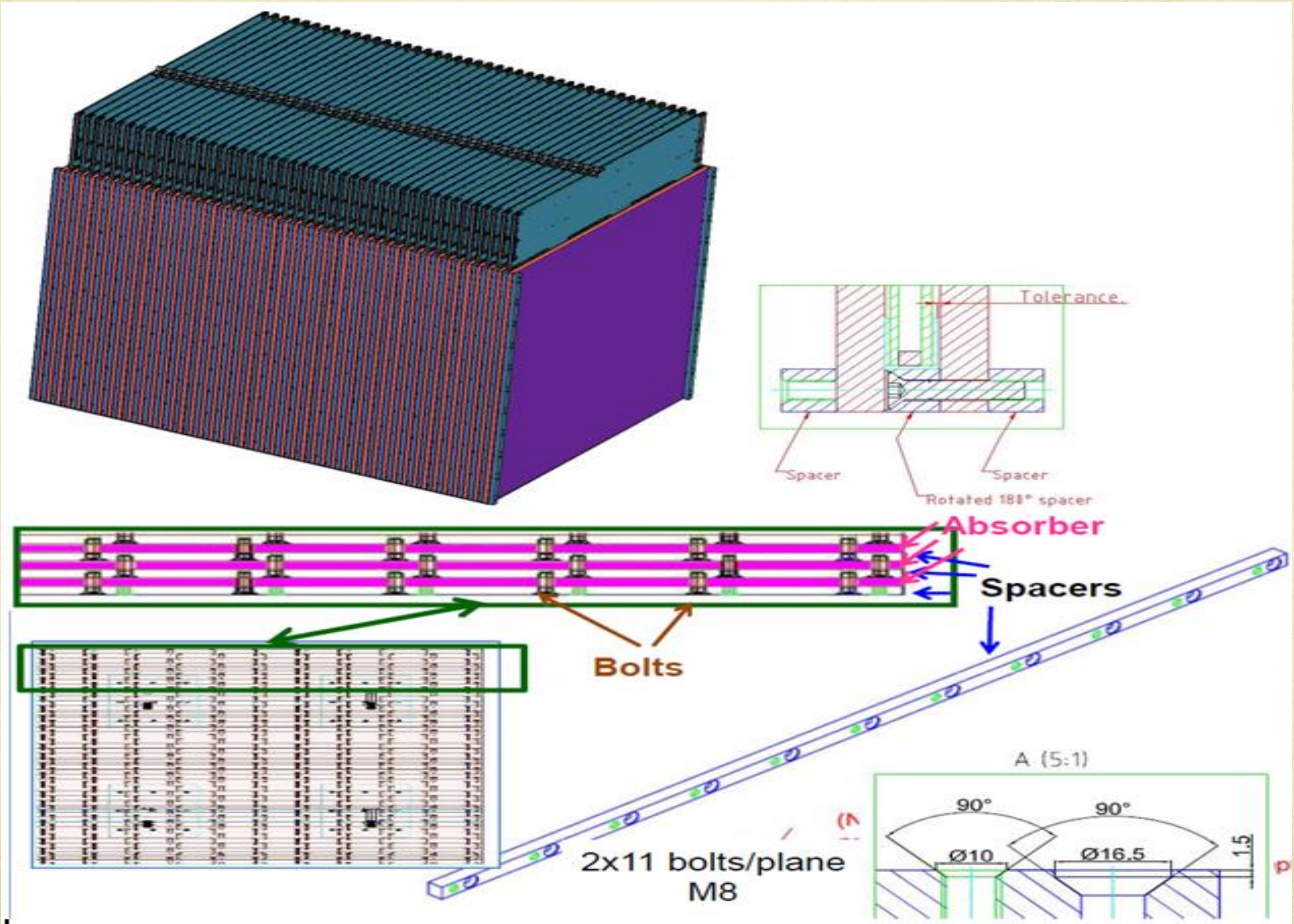
A robot was used to test the 10500 ASICs

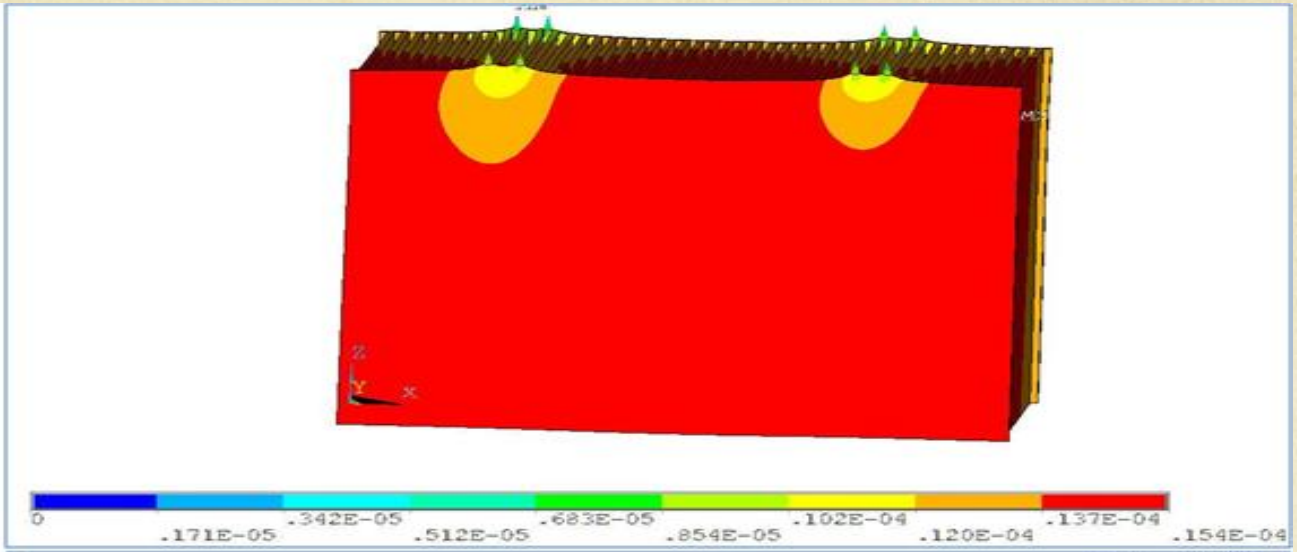
The procedure allows to select the good ASICs and calibrate them

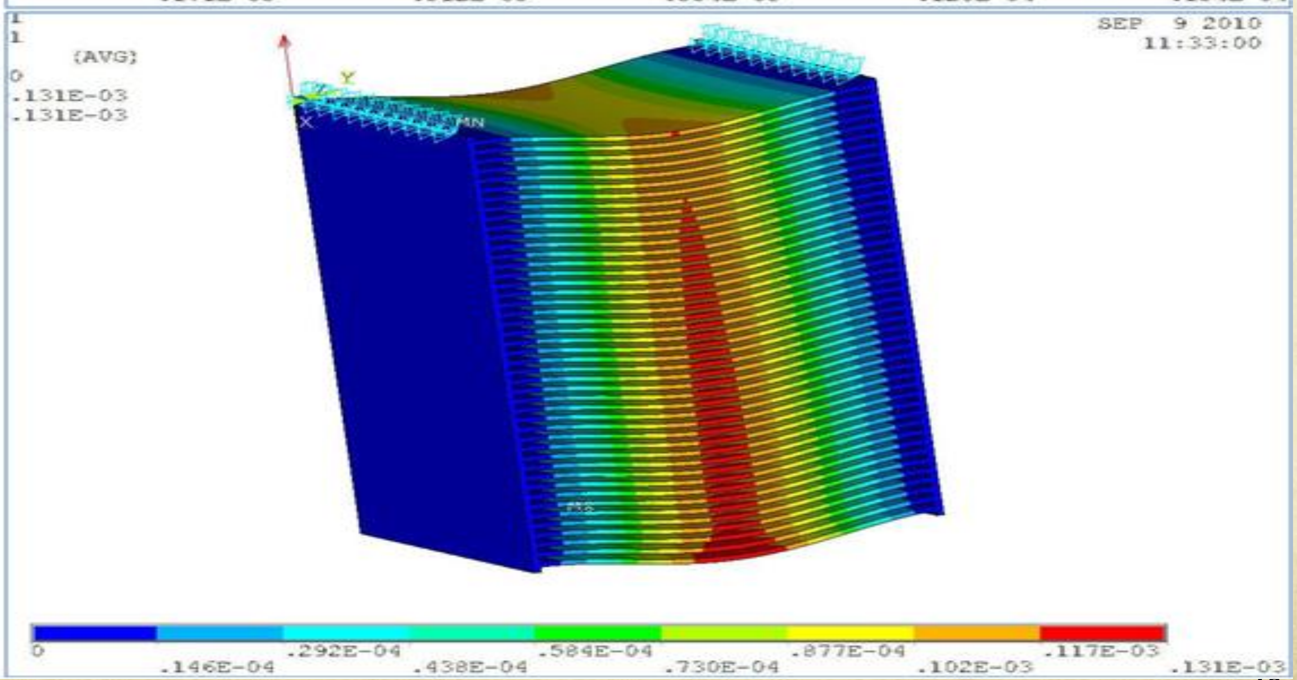
Yield 93%

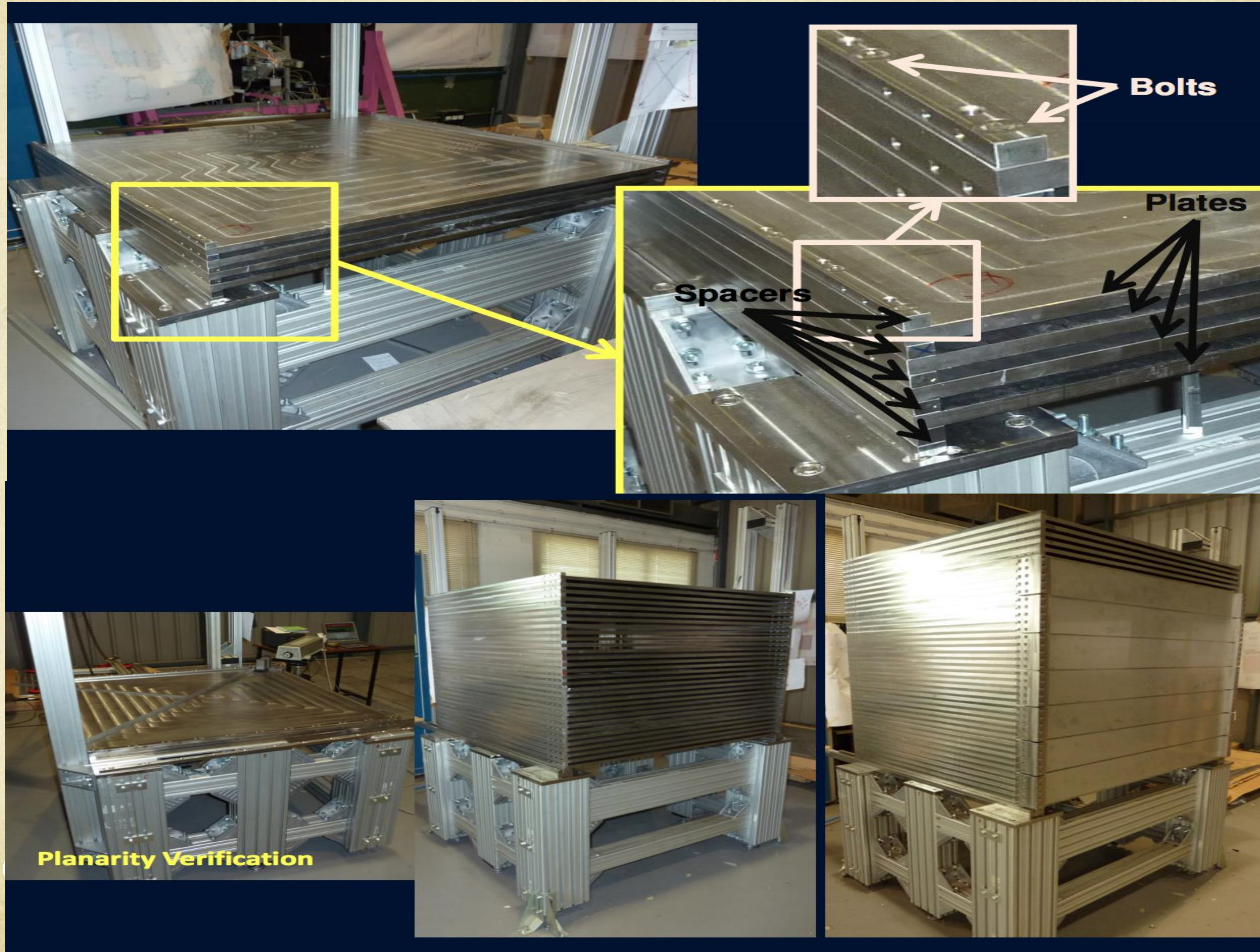





Tolerance.
Spacer
Spacer
Rotated 180° spacer
Absorber
Spacers
Bolts
2x11 bolts/plane
M8
A (5:1)
90°
90°
Ø10
Ø16,5
1,5


Z
Y
X
0
.171E-05
.342E-05
.512E-05
.683E-05
.854E-05
.102E-04
.120E-04
.137E-04
.154E-04


1
1
(AVG)
0
.131E-03
.131E-03
SEP 9 2010
11:33:00
Y
X
MN
0
.146E-04
.292E-04
.438E-04
.584E-04
.730E-04
.877E-04
.102E-03
.117E-03
.131E-03



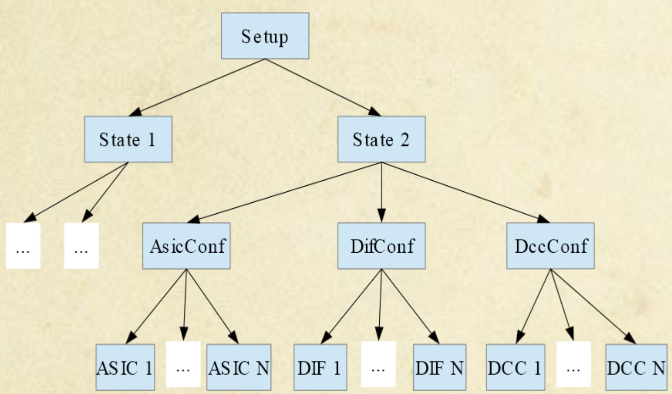
Cl

SDHCAL acquisition system

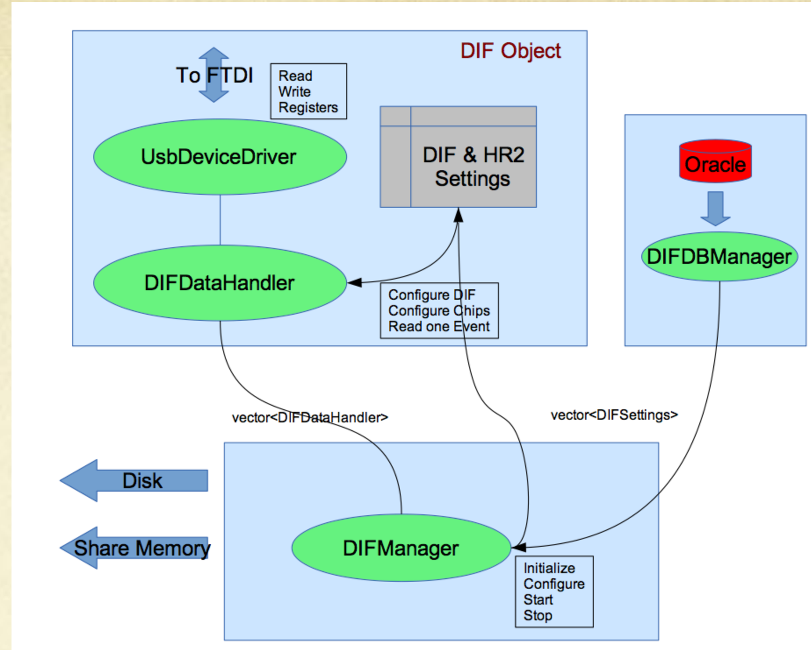
→ Low level hardware access

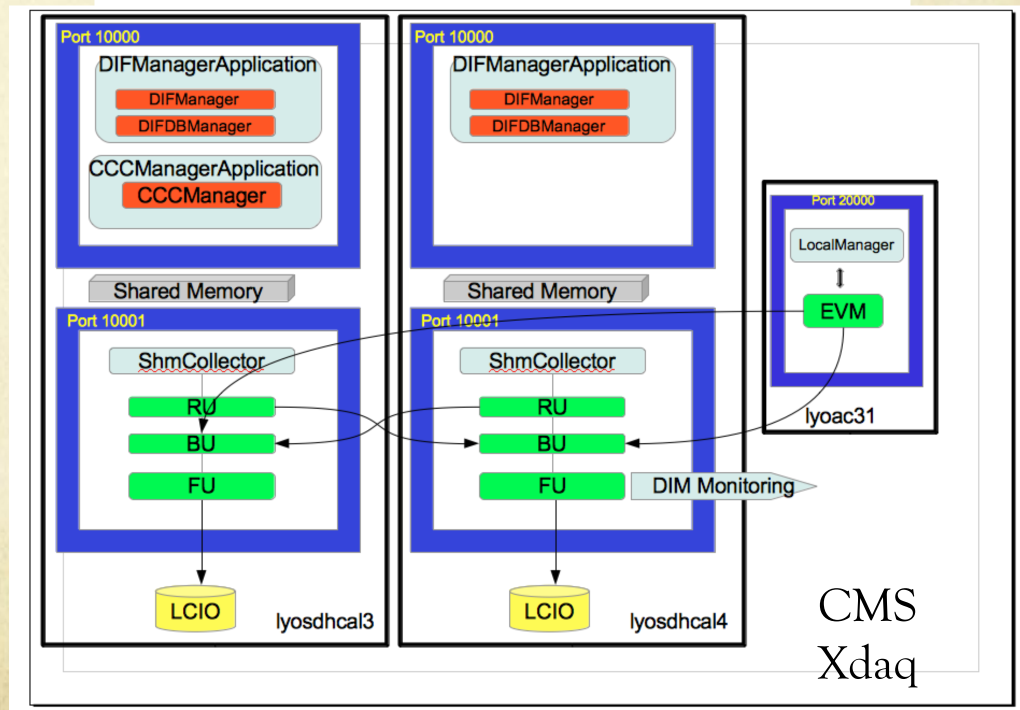
→ Configuration data base software handling devices description and settings

→ Data collection and the monitoring



Setup configuration structure



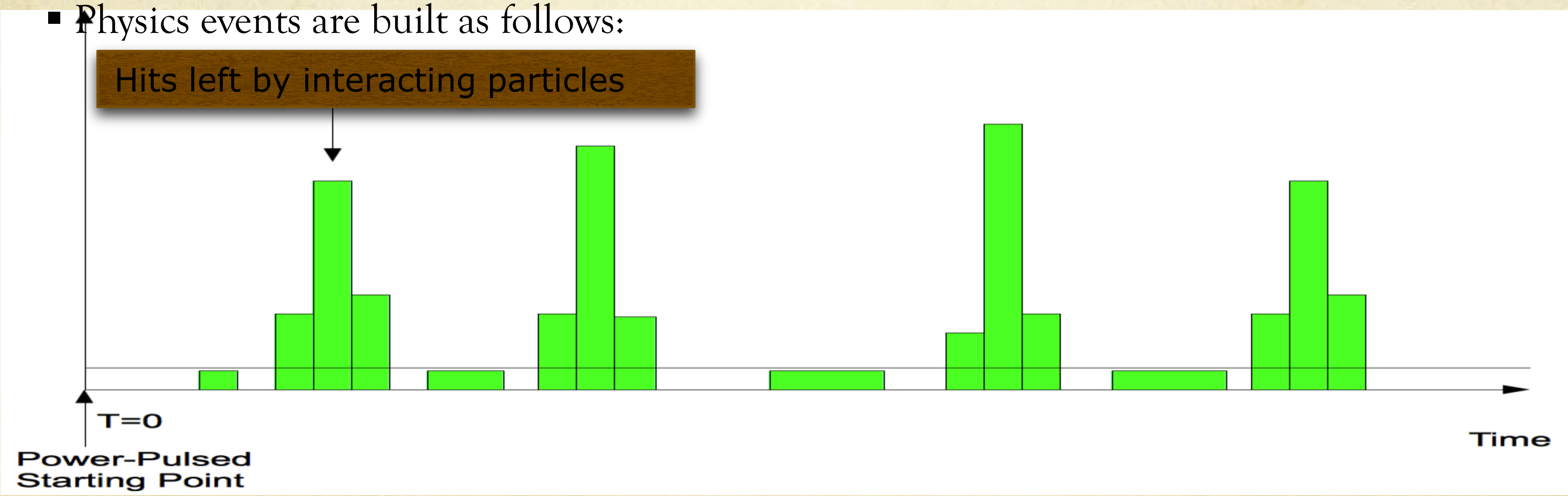


IPNL

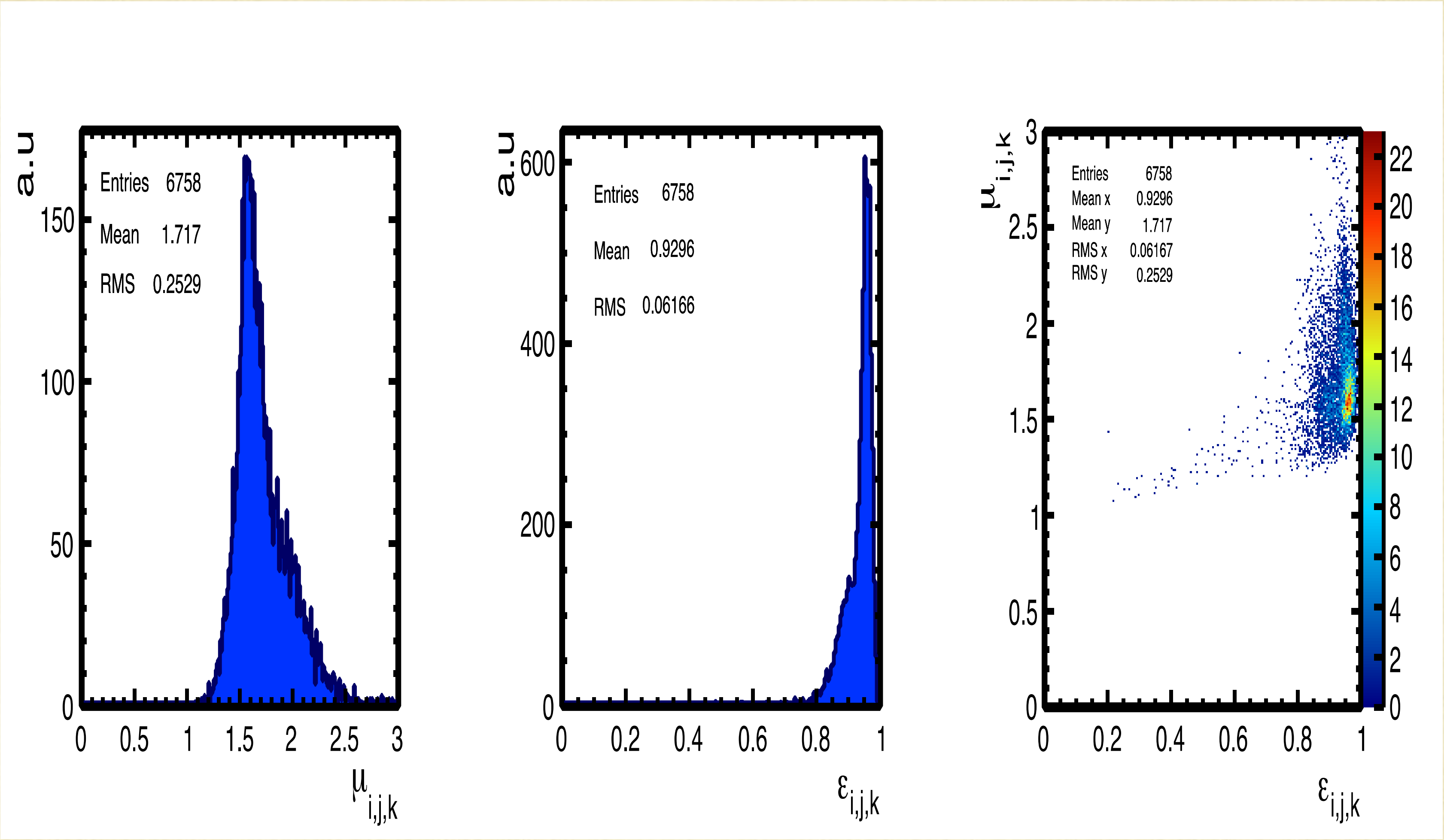
Prototype data acquisition

- Trigger less mode : Recording events until memory is full, then data transfer and restart.
- Power-Pulsed mode : ASIC is idle between two spills. According to the time spill structure (NX400 ms (PS)*, 10 s(SPS) every 45 s)

- No gain correction applied for this TB.
- Physics events are built as follows:



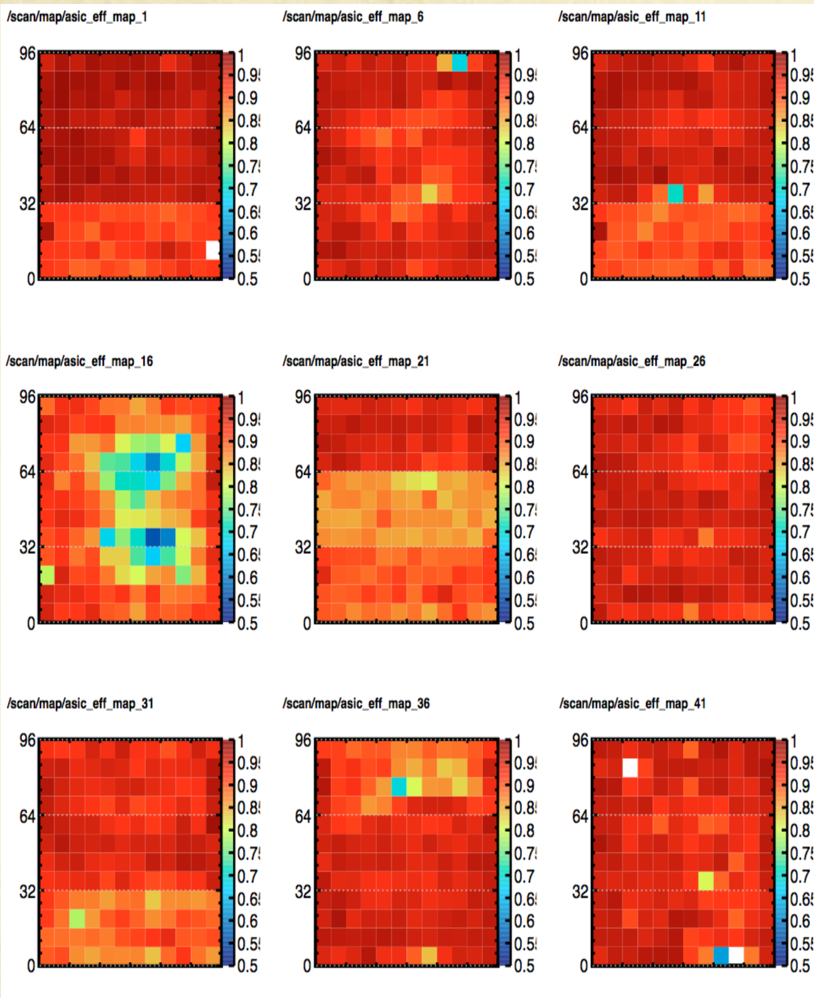
* N is often 1 and sometimes 2-3 spills/cycle

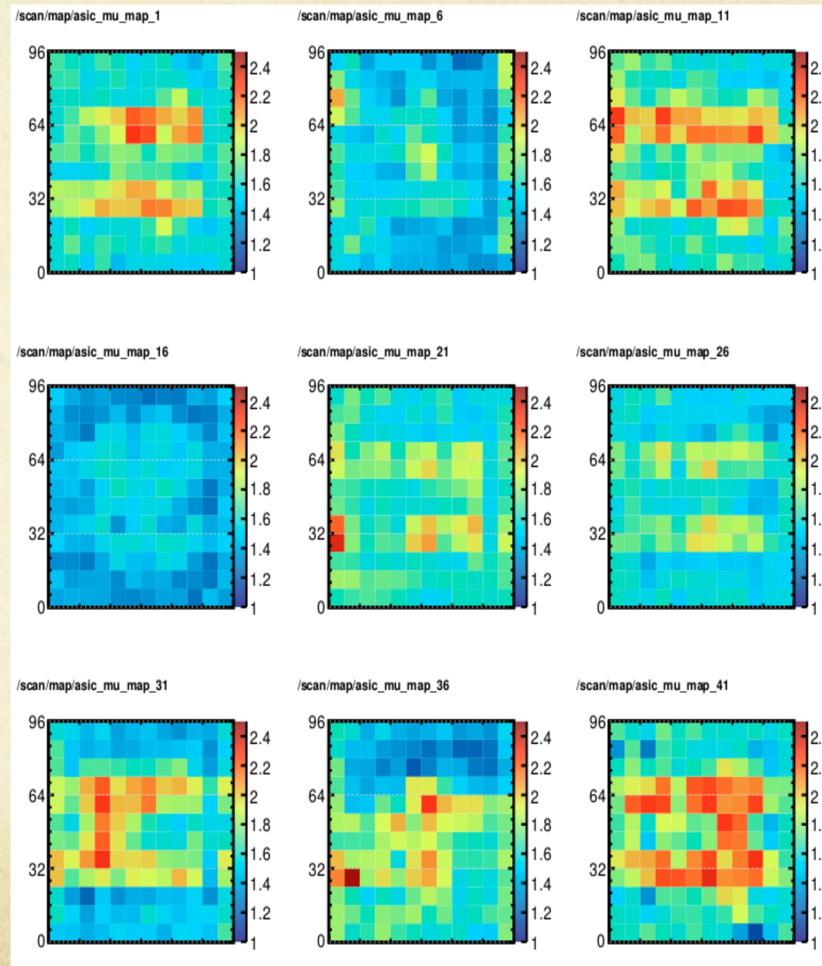

a.u
Entries 6758
Mean 1.717
RMS 0.2529
μ i,j,k
a.u
Entries 6758
Mean 0.9296
RMS 0.06166
ε i,j,k
μ i,j,k
Entries 6758
Mean x 0.9296
Mean y 1.717
RMS x 0.06167
RMS y 0.2529
ε i,j,k

Y.Haddad

Calibration :

Etude de la calibration de SDHCAL est en cours afin d'améliorer la résolution de l'énergie. Cela inclut l'étude de l'efficacité et la multiplicité des chambres localement à l'aide des muons et des cosmiques. La dépendance de la performance en temps (effet température…) peut aussi analysée d'une manière indirecte.

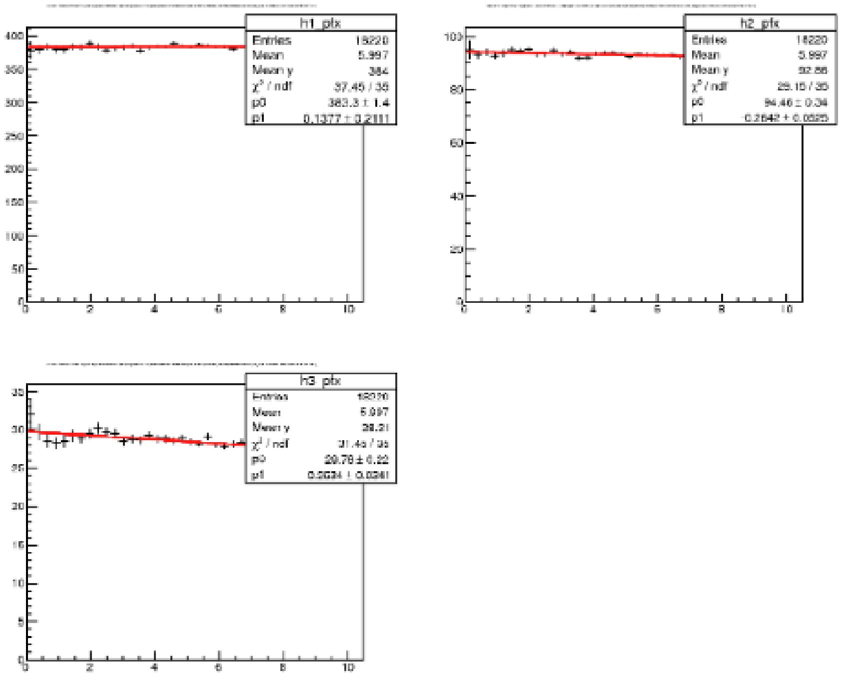




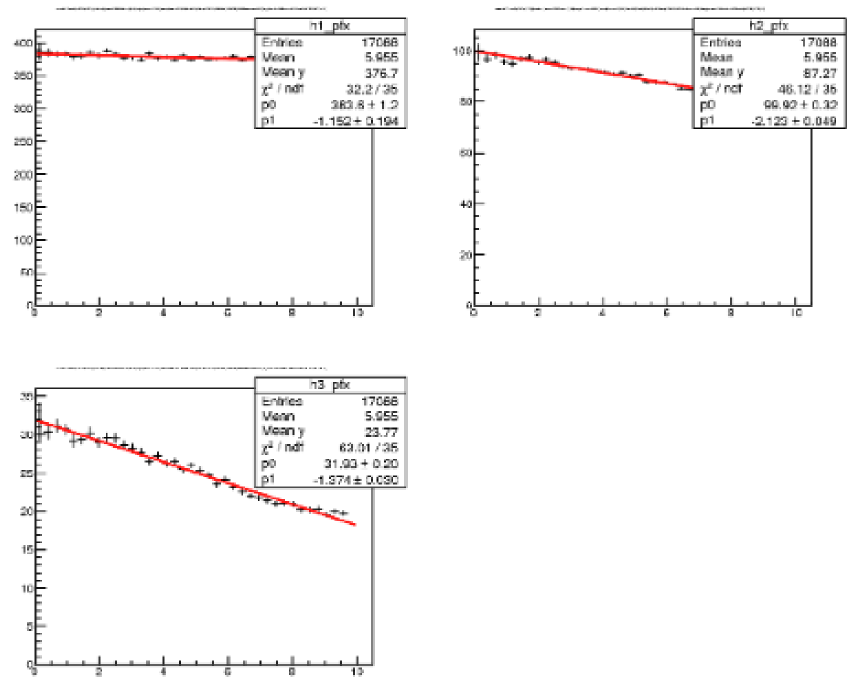
Y.Haddad

Nb of hits versus spill time depth

Run 715671 (40M)

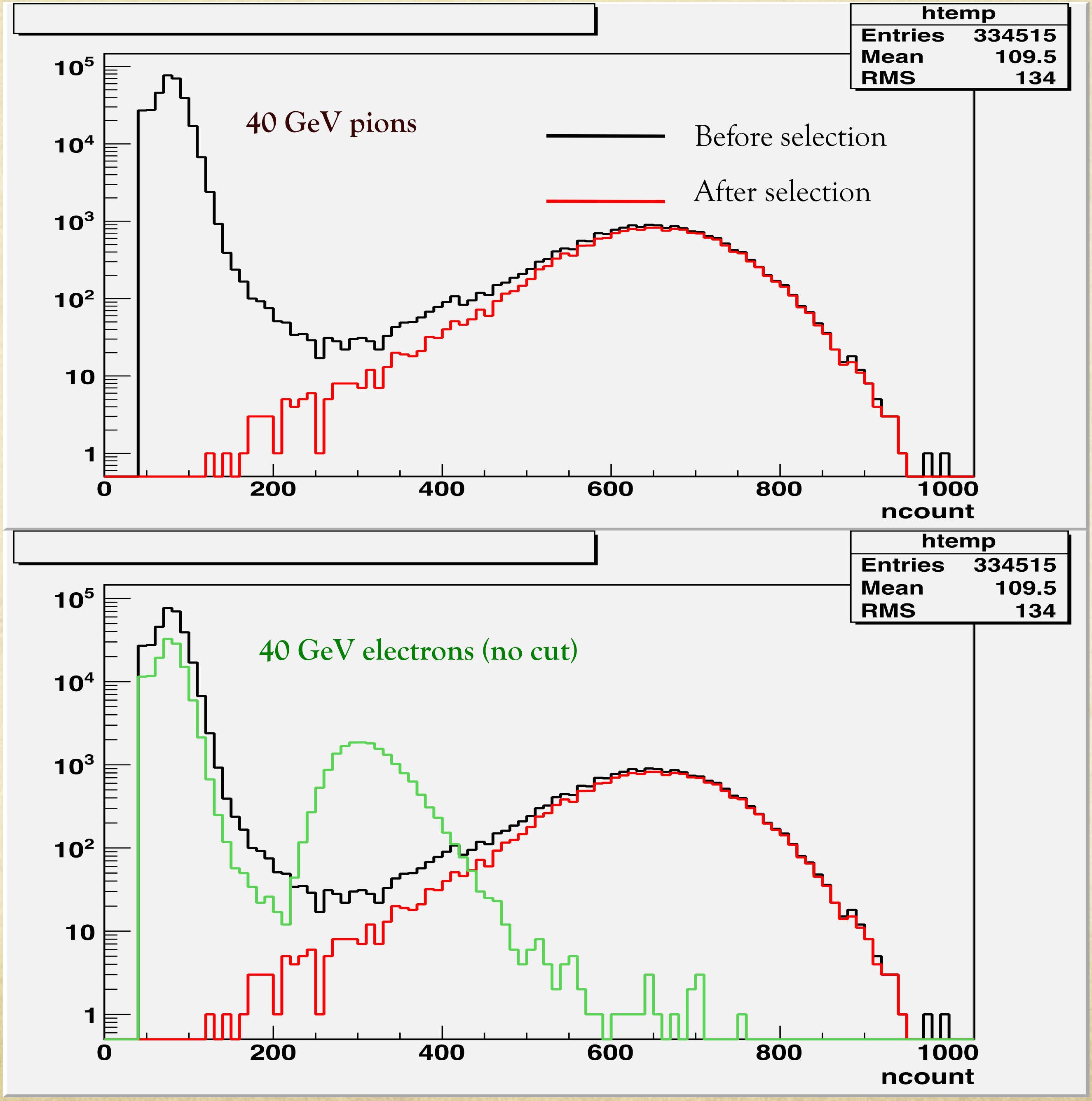


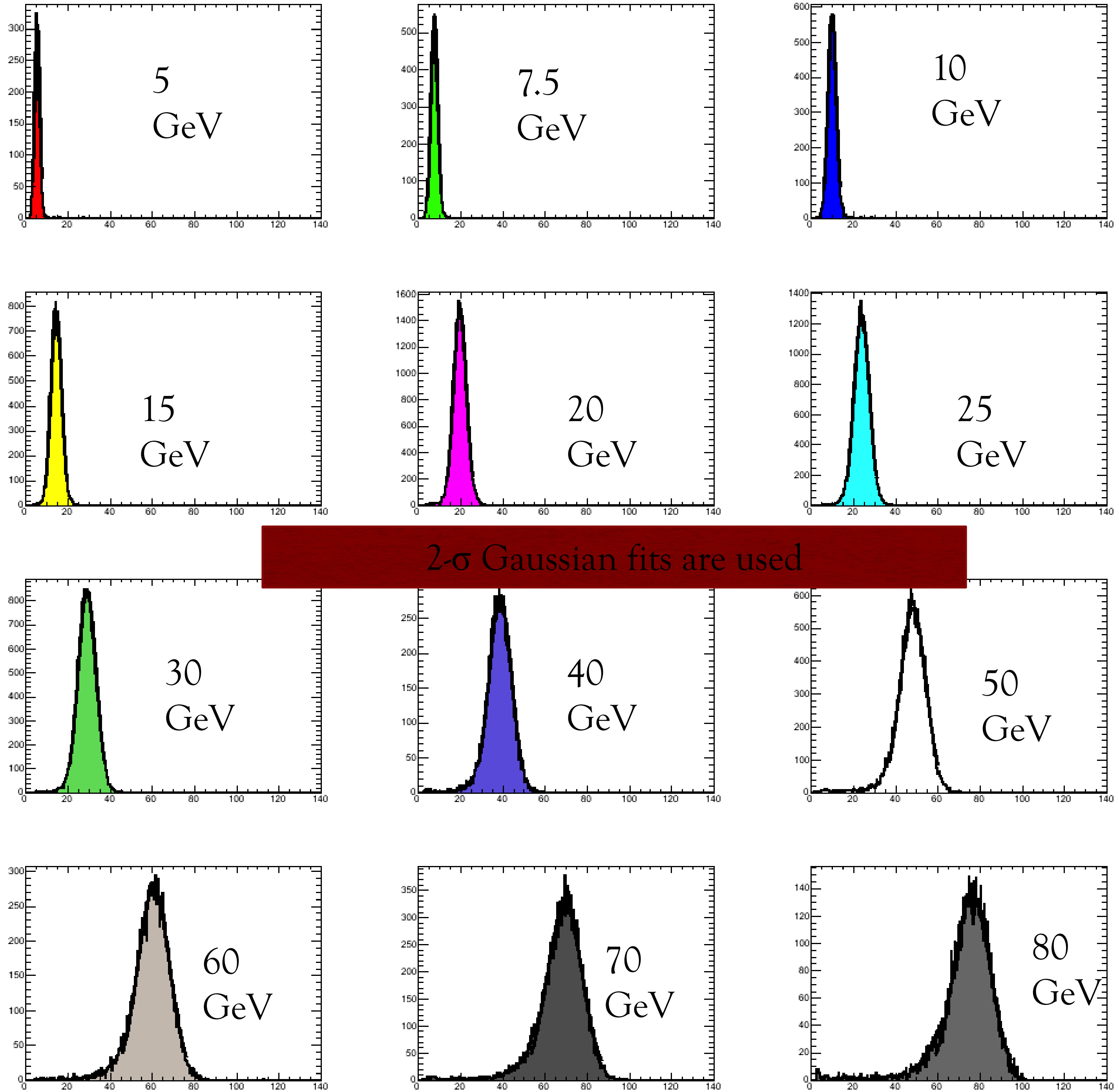
Run 715747 (16M)



Very different beam conditions, intensity

The selection should not impact the hadronic shower resolution





2-σ Gaussian fits are used

Energy estimation :

The thresholds weight evolution with the total number of hits obtained by minimizing a χ^2

$X^2 = (E_{beam} - E_{rec})^2 / E_{beam}$

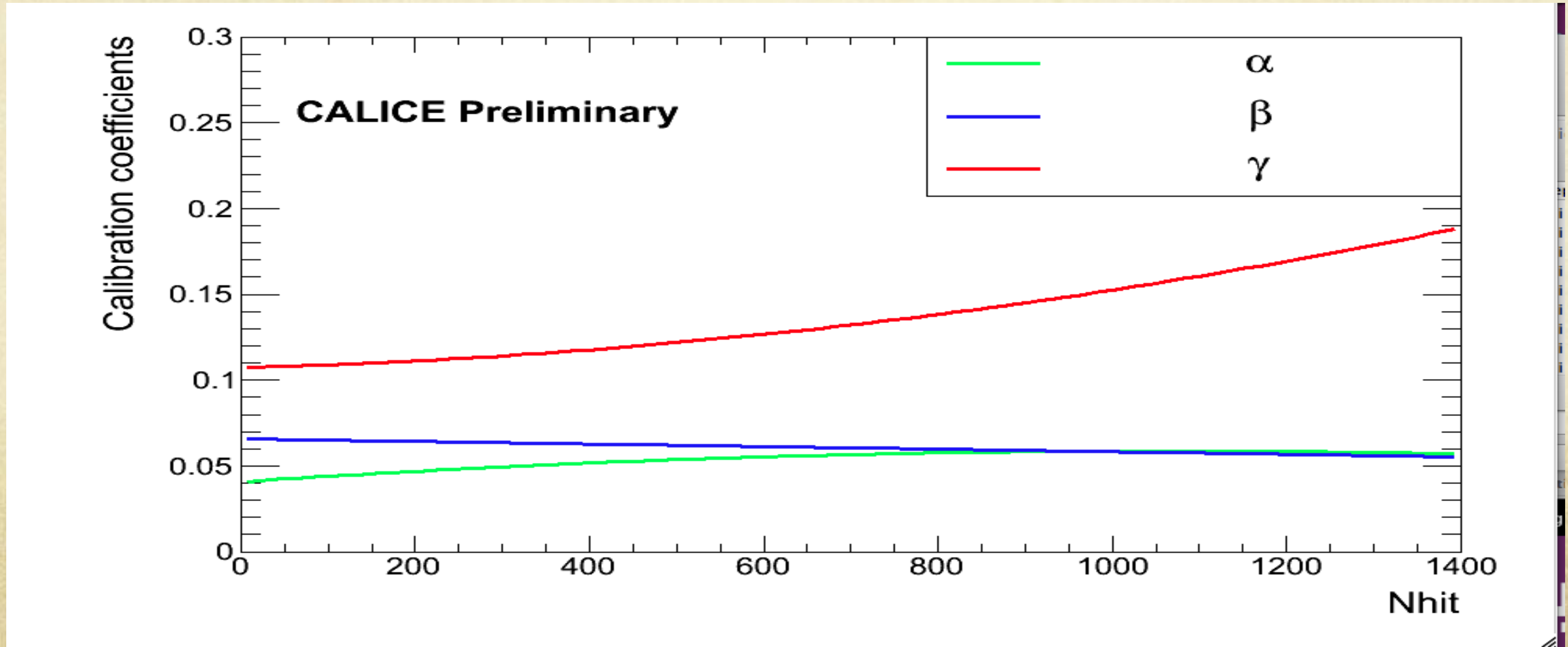
$E_{rec} = \alpha(N_{tot}) N_1 + \beta(N_{tot}) N_2 + \gamma(N_{tot}) N_3$

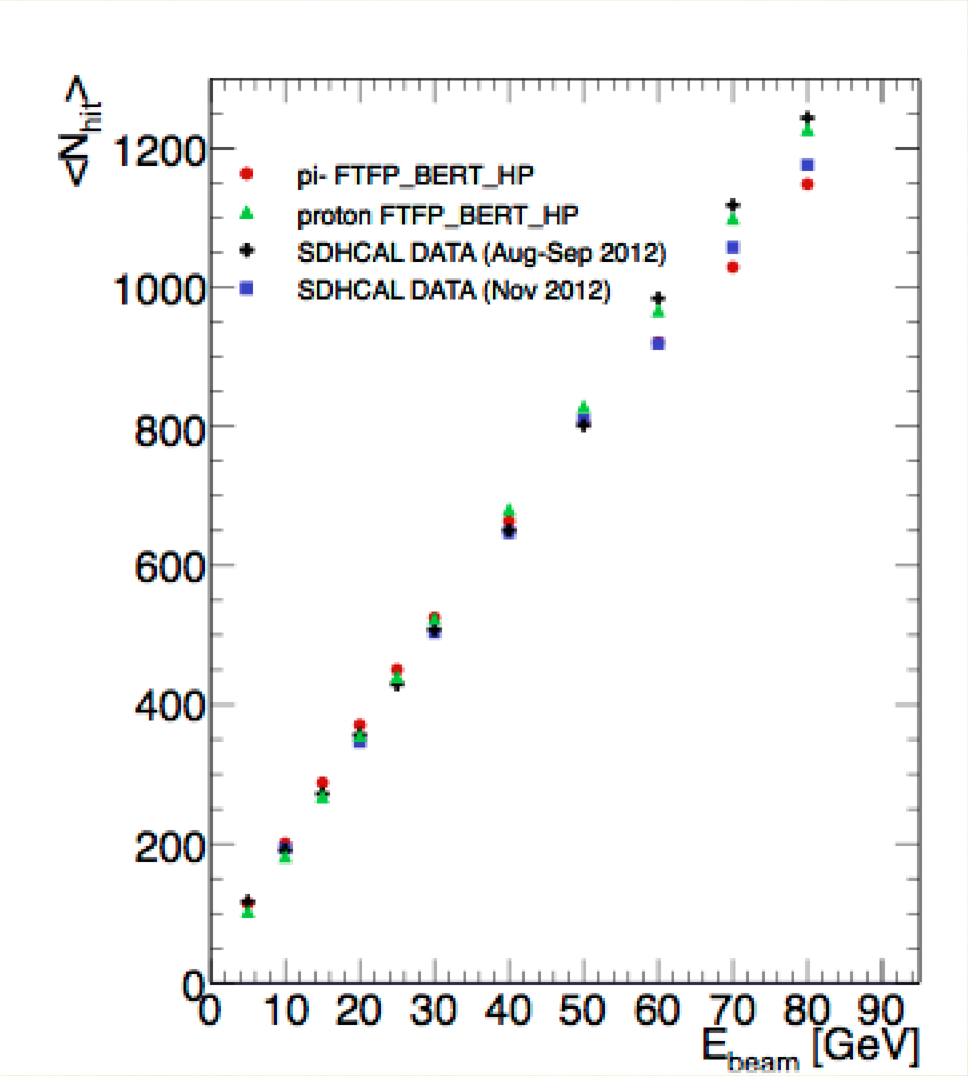
N_1, N_2 and N_3 : exclusive number of hits associated to first, second and third threshold.

α, β, γ are quadratic functions of the total number of hits (N_{tot})

For instance $\alpha = \alpha_0 + \alpha_1 N_{tot} + \alpha_2 N^2_{tot}$

Events of September runs corresponding to energies : 5, 10, 30 , 60 and 80 GeV were used to fit the 9 parameters. This represents more than 50 k events.

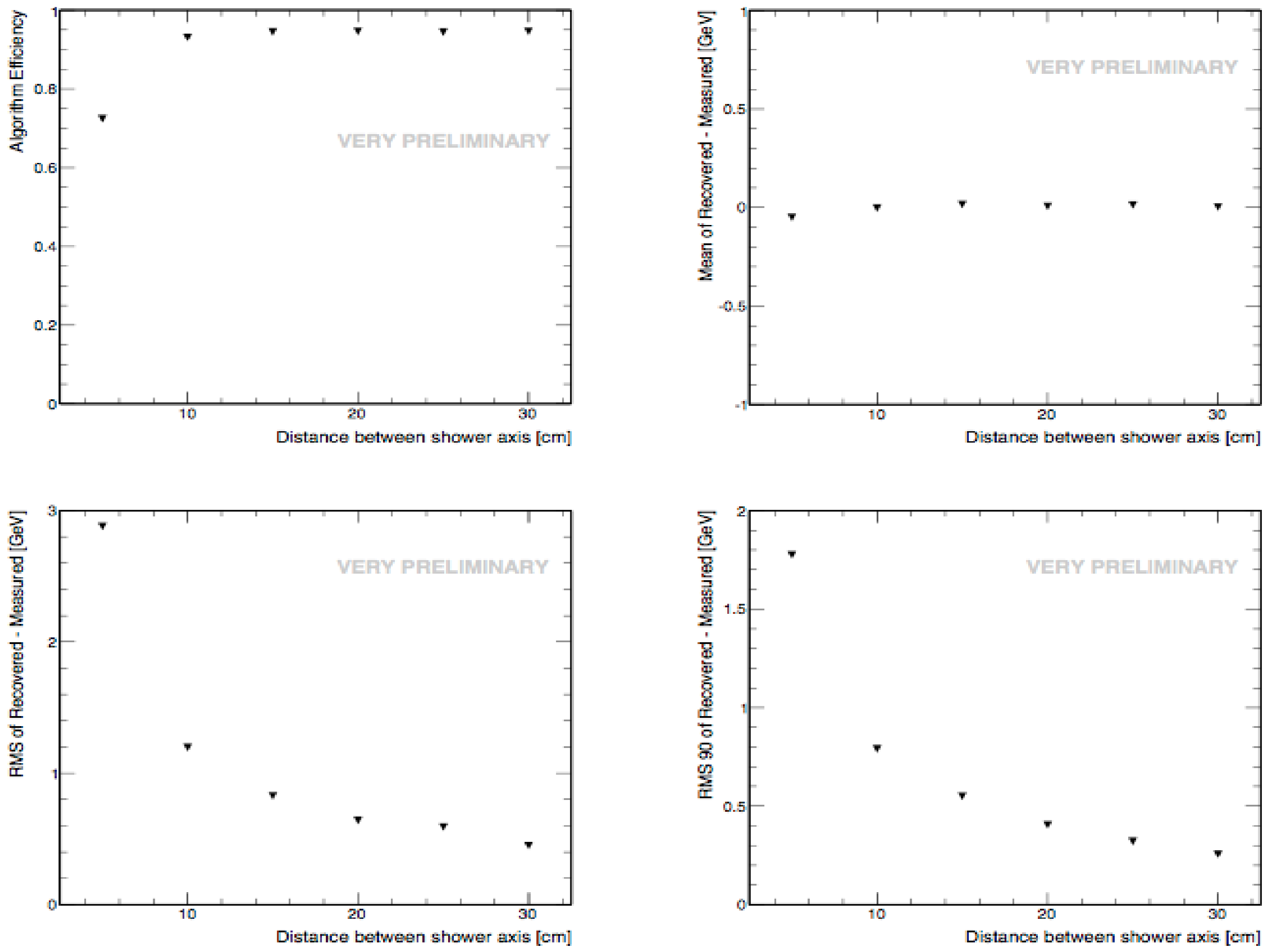




<Nhit>
1200
1000
800
600
400
200
0
pi- FTFP_BERT_HP
proton FTFP_BERT_HP
SDHCAL DATA (Aug-Sep 2012)
SDHCAL DATA (Nov 2012)
0 10 20 30 40 50 60 70 80 90
Ebeam [GeV]

A.Steen

Separation of two close-by pions of 10 GeV each

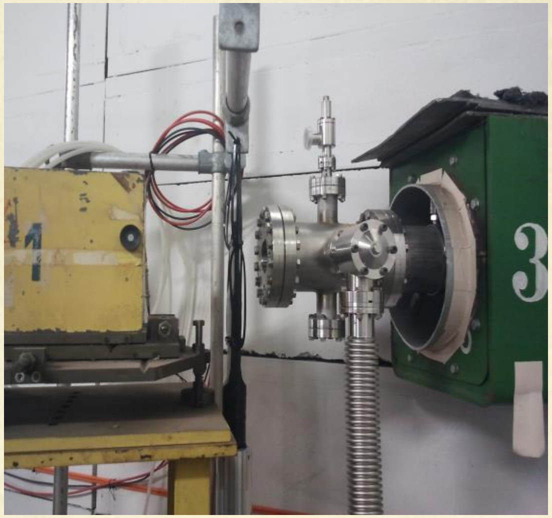


R.Eté

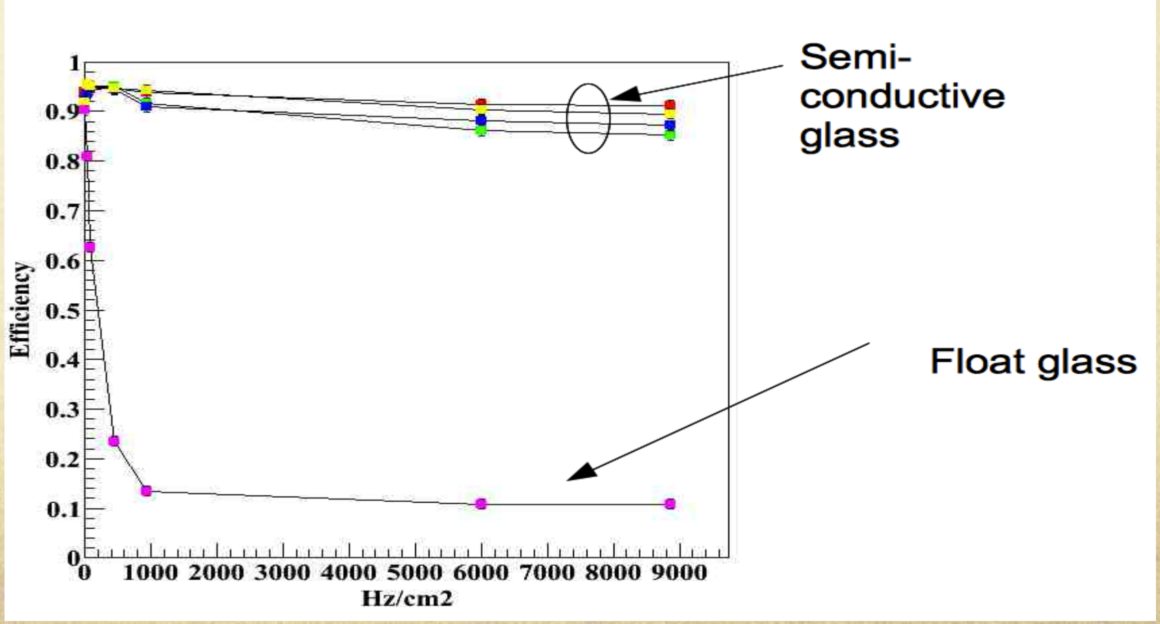
High-Rate GRPC

High-Rate GRPC may be needed in the very forward region

✓Semi-conductive glass (10^{10} Ω.cm) produced by our collaborators from Tsinghua University was used to build few chambers.
✓4 chambers were tested at DESY as well as standard GRPC (float glass)



Performance is found to be excellent at high rate for GRPCs with the semi-conductive glass and can be used in the very forward of ILD region if the rate exceeds 100 Hz/cm^2 in future ILD upgrades



HARDROC3

I2C link (@IPNL)

PLL: integrated before in a builiding block, first measurements are very good

Input frequency 2.5 MHz =>output frequency: 10, 20, 40, and 80 MHz available

Bandgap: new one with a better temperature sensitivity, tested in a building block

Roll mode

Triple voting

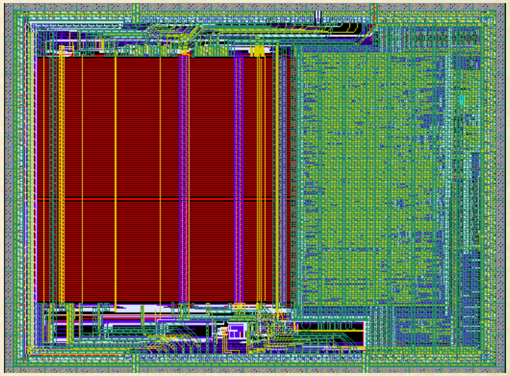
Temperature sensor: tested in a building block, slope – 6mV/°C

Die size ~30 mm2 (6.3 x 4.7 mm2)

To be packaged in a TQFP208

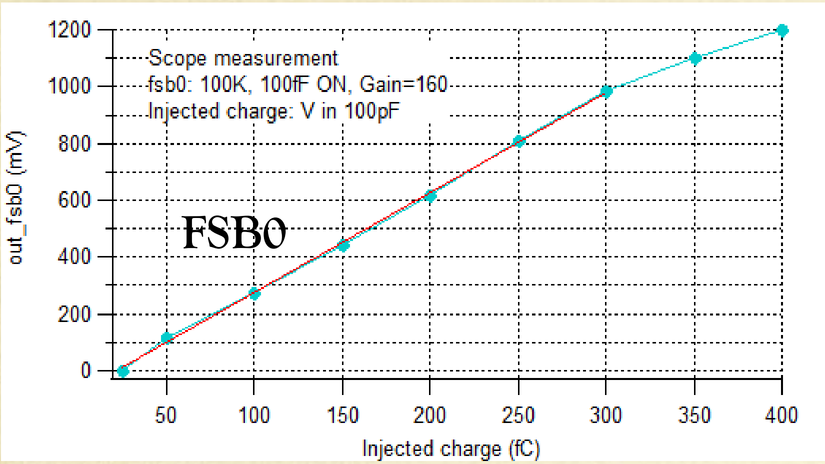
Submitted at the end of Feb 2013 (SiGe 0.35μm)

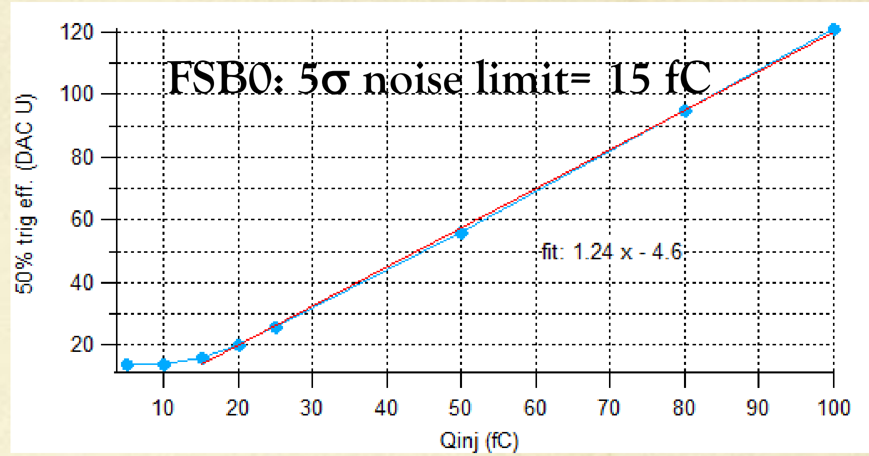
Currently tested.

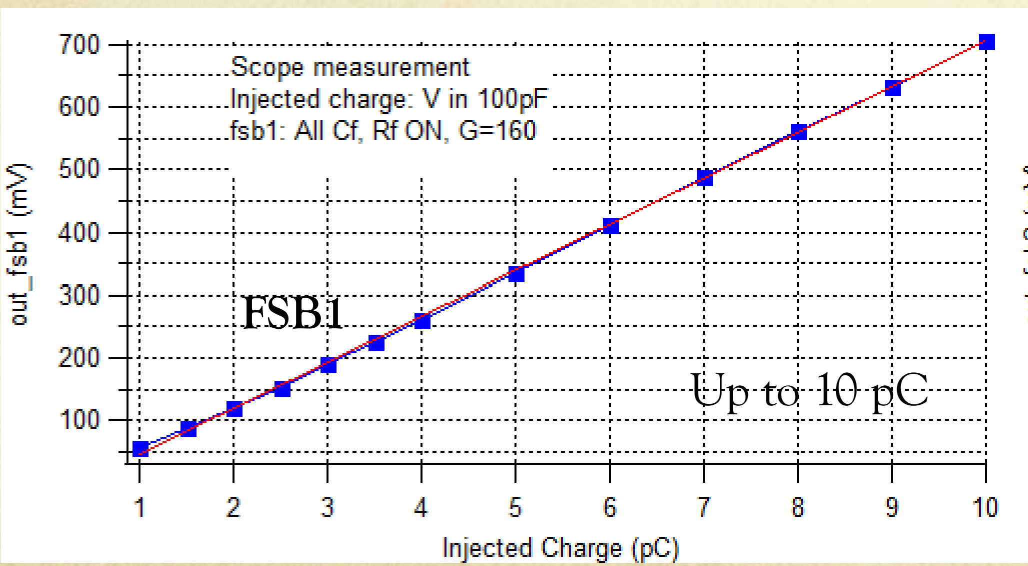


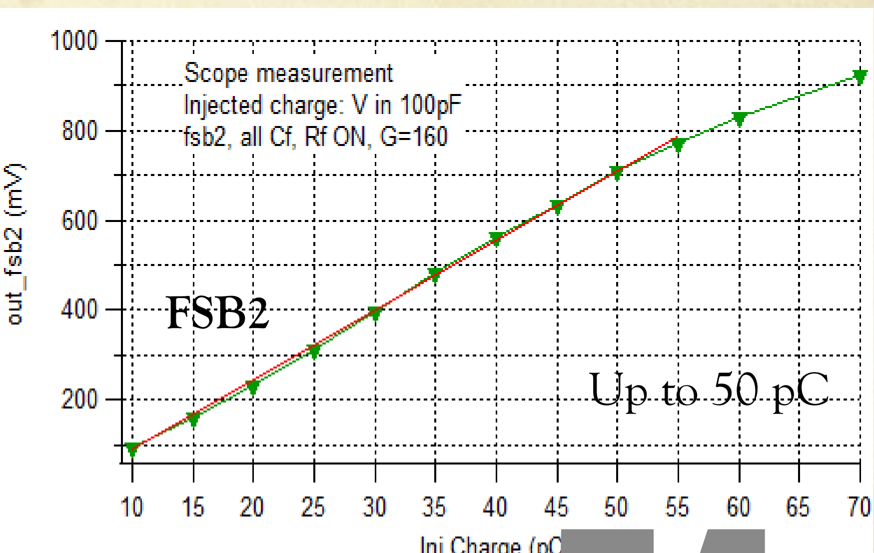
Omega-IPNL

ANALOG PART: FSB LINEARITY



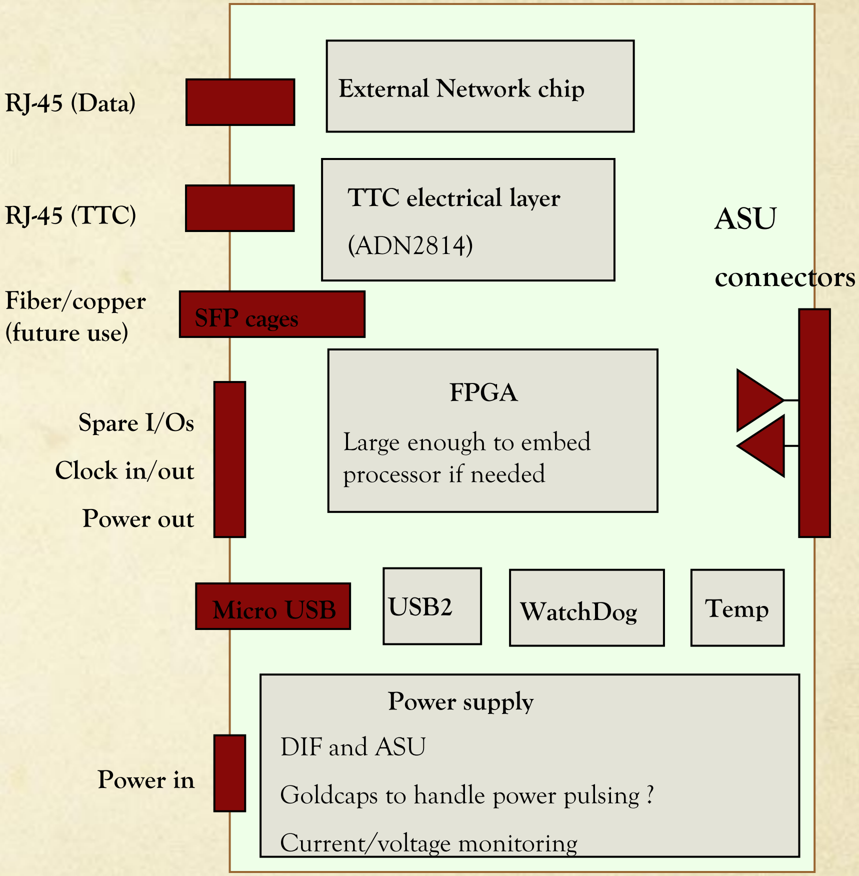






DIF: Designed for ILD SDHCAL

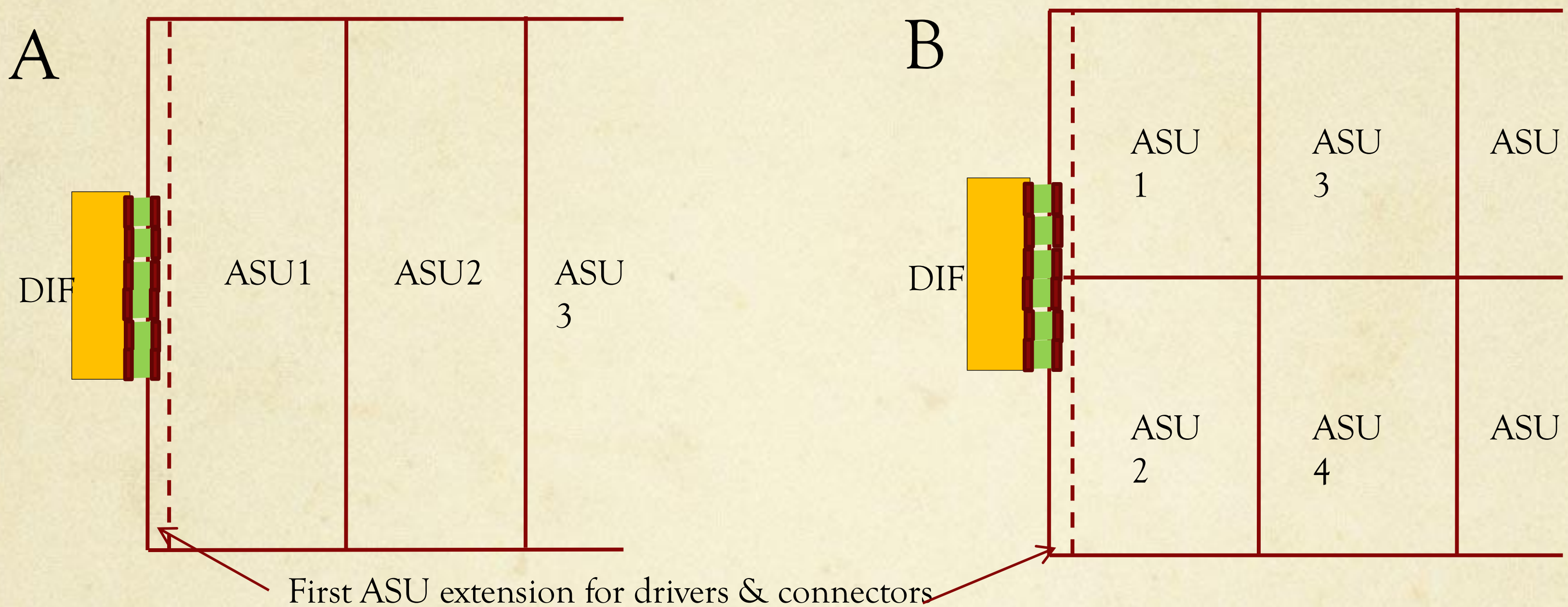
- Only one DIF per plane. For the maximun lenght plane (1x3m) the DIF will handle 432 HR3 chips
- Slow control through the new HR3 I2C bus
- Data transmision to DAQ by Ethernet using comercial switches for concentration
- Clock and syncronization by TTC
- USB 2.0 for debugging



CIEMAT-IPNL

New ASU layout options

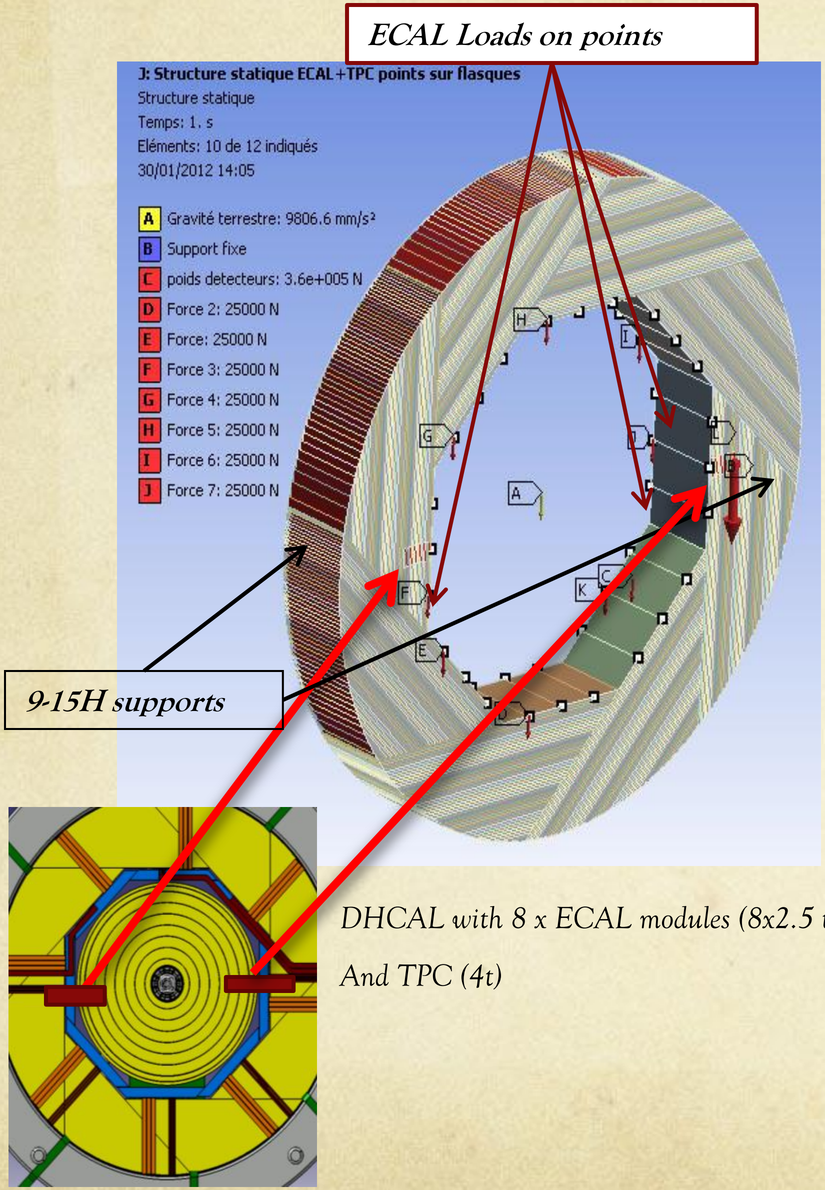
As there will be only one DIF per plane, the distribution of the ASU boards in the plane will be rearranged to reduce the number of conections between the DIF and the plane



- In option B the common signals for the plane have to be sent twice (one per slab) while in option B they can be sent only once
- But, option A looks more risky from the point of view of the feasibility of the 1m long ASU boards.

- In both options the ASUs connected to the DIF will be a bit longer to host the connectors and the buffers for driving the long lines. This extension provides more freedom for the connectors selection and moves the drivers heat disipation to the ventilation area

Mechanical, integration, service studies

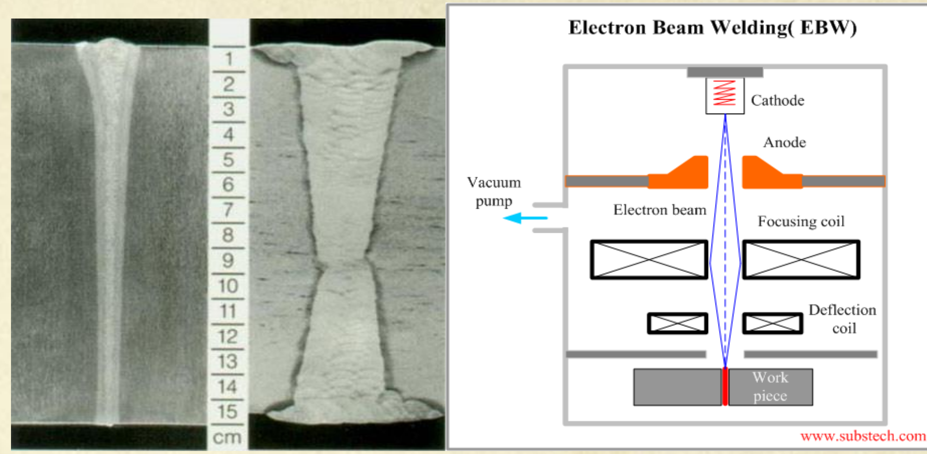


DHCAL with 8 x ECAL modules (8x2.5 t)

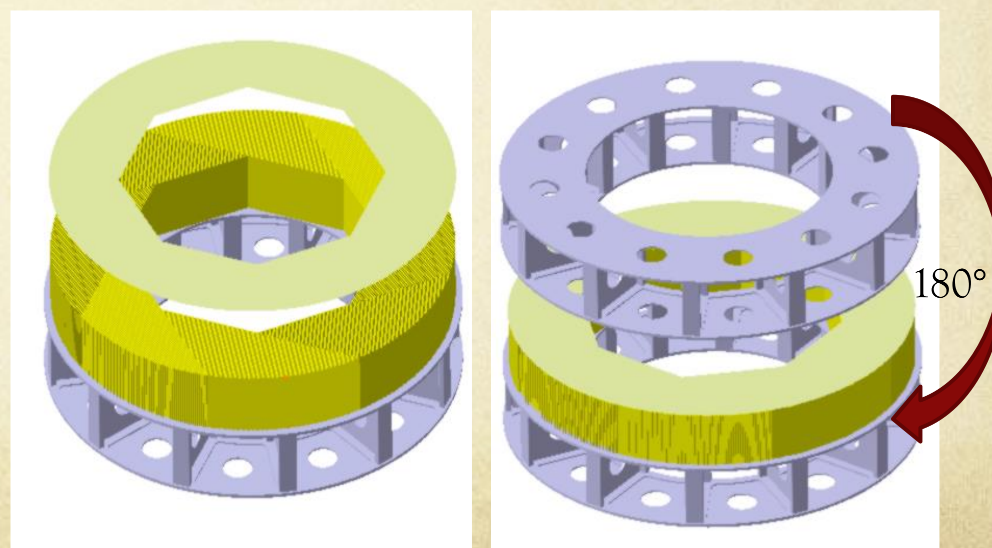
And TPC (4t)

Deformation max SDHCAL + ECAL + TPC = 0,4 mm

Welding techniques

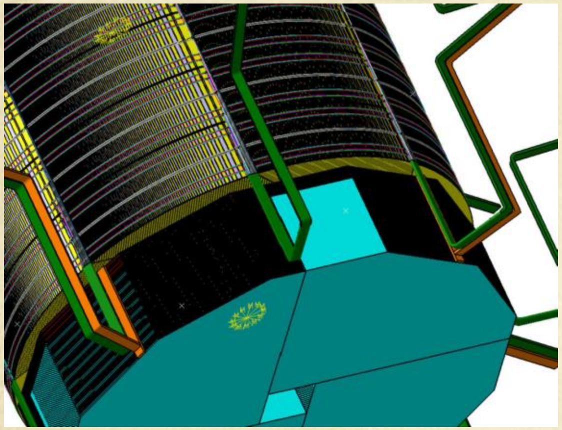


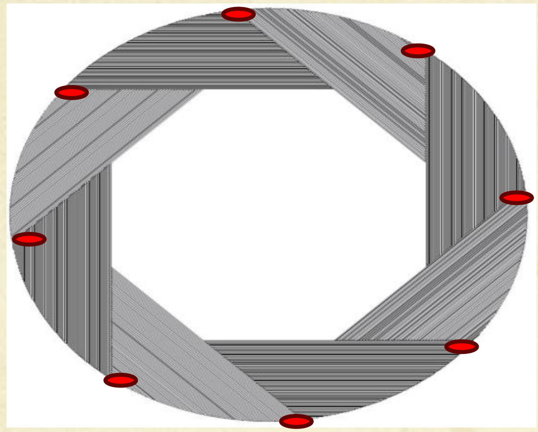
Building scenarios

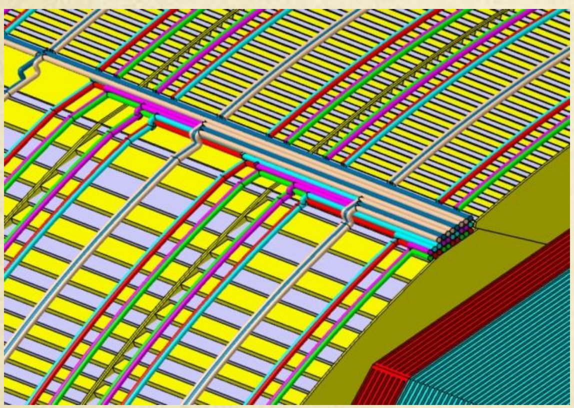


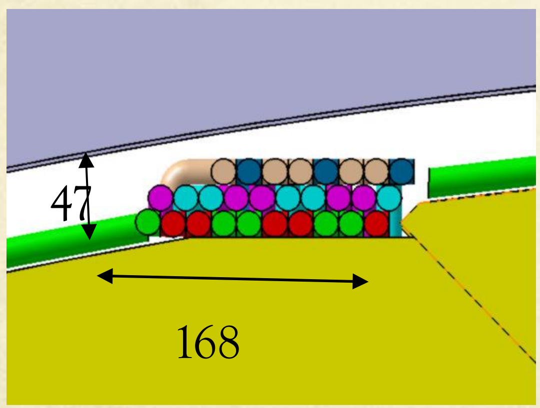
Mechanical, integration, service studies

Services were studied in detail to provide a realistic model for the ILC DBD

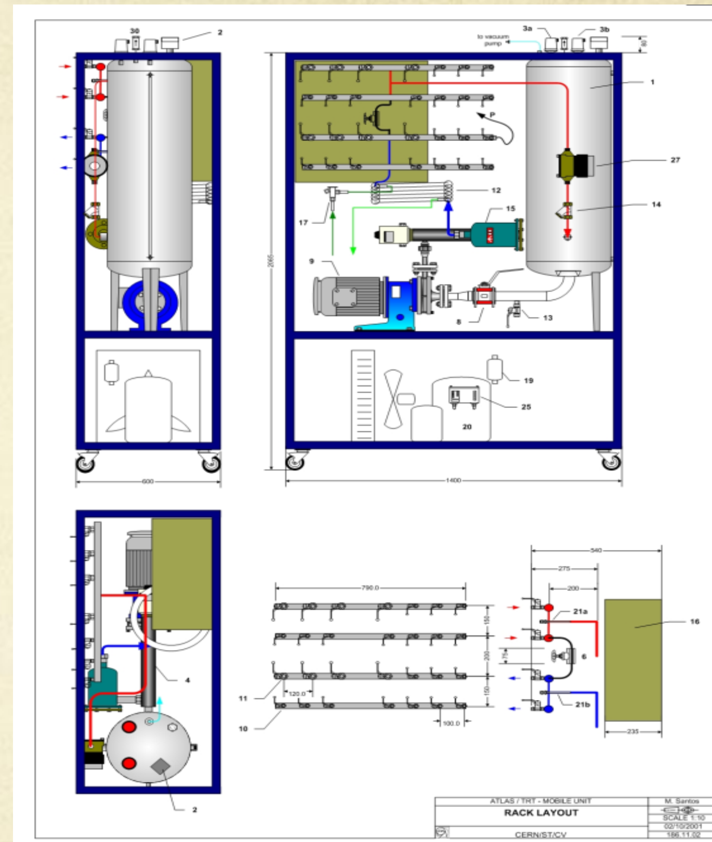








Few cooling scenarios were studied and compared with each other



Mono-phasic gas like C6F14 : limited effect in case of leak, good quality/price ratio, adapted to low heat extract, simple to use