The Semi-Digital Hadronic Calorimeter for Future Leptonic Collider experiments

I. Laktineh

On behalf of the the
CALICE Collaboration

Outline

SDHCAL technological prototype

- ✓ Description
- ✓ Test Beam results
- ✓ Hadronic shower studies

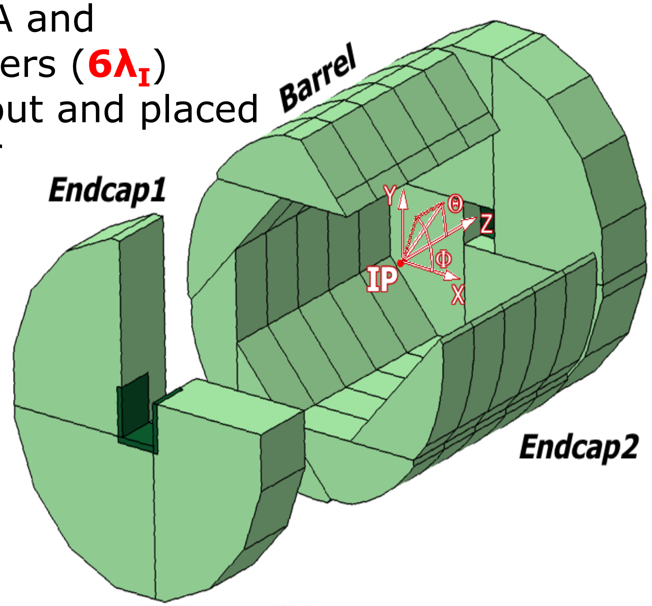
R&D for large SDHCAL modules

- ✓ Detectors
- ✓ Electronics
- ✓ DAQ
- ✓ New challenges

Conclusion

SDHCAL-ILD

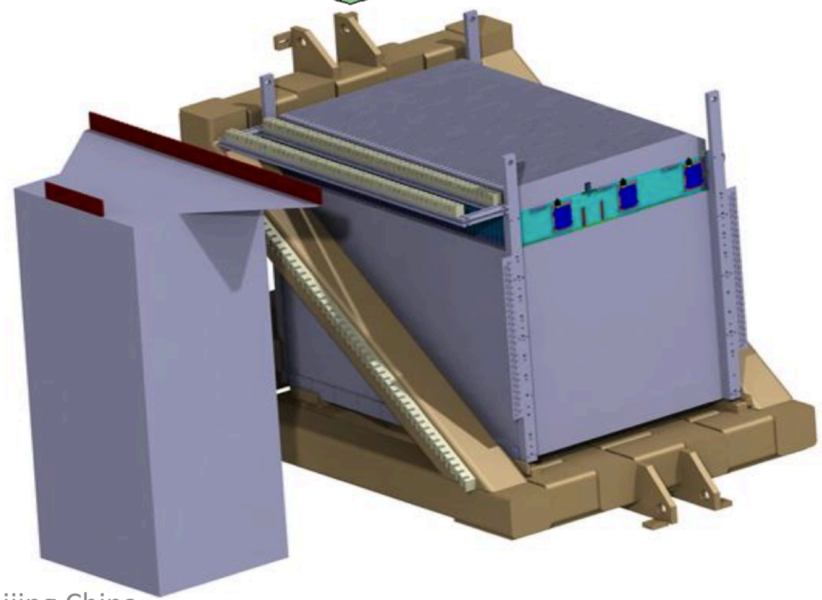
The SDHCAL-GRPC is one of the two HCAL options based on PFA and Proposed for **ILD of ILC**. Modules are made of 48 RPC chambers (**$6\lambda_I$**) equipped with **semi-digital, power-pulsed electronics** readout and placed in **self-supporting mechanical** structure to serve as absorber as well.



The structure proposed for the SDHCAL-ILD :

- very **compact** with negligible dead zones
- Eliminates projective cracks
- Minimizes barrel / endcap separation (services leaving from the outer radius)

SDHCAL Technological Prototype should be as much as possible similar to the ILD module and able to study **hadronic showers**



Challenges

-Homogeneity for large surfaces
-Thickness of only few mms
-Lateral segmentation of 1 cm X 1 cm
-Services from one side
-Embedded power-cycled electronics
-Self-supporting mechanical structure

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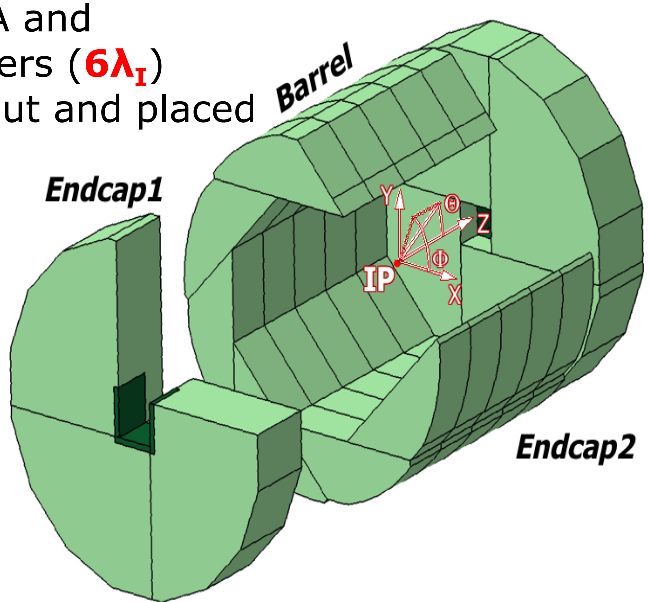

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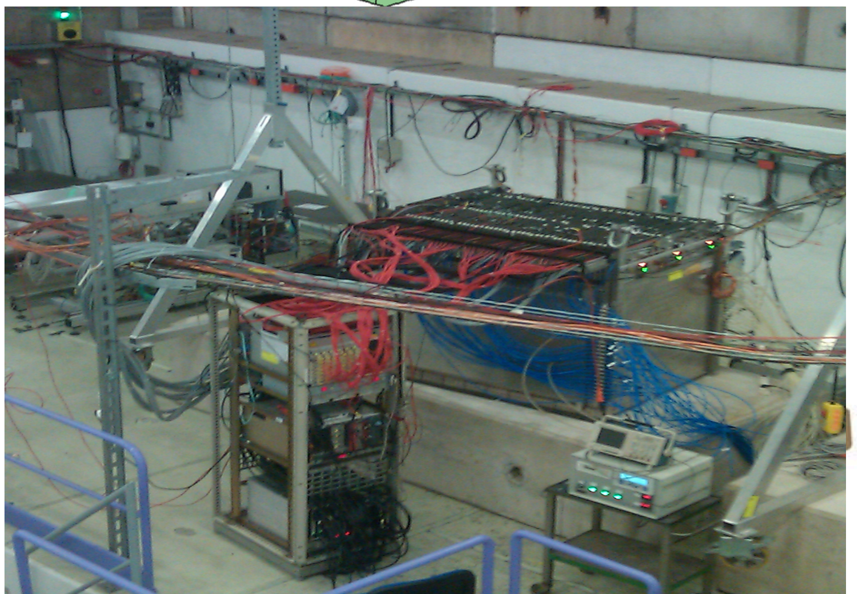

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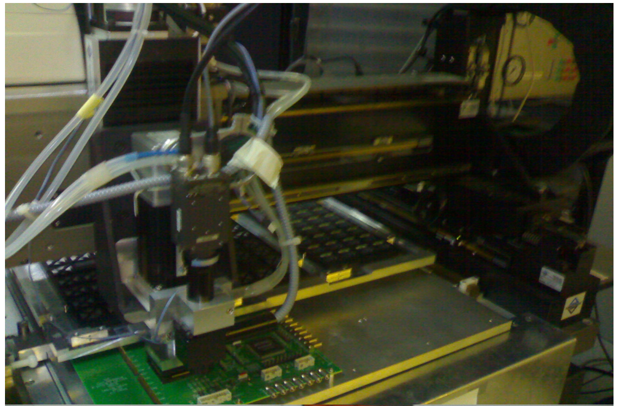
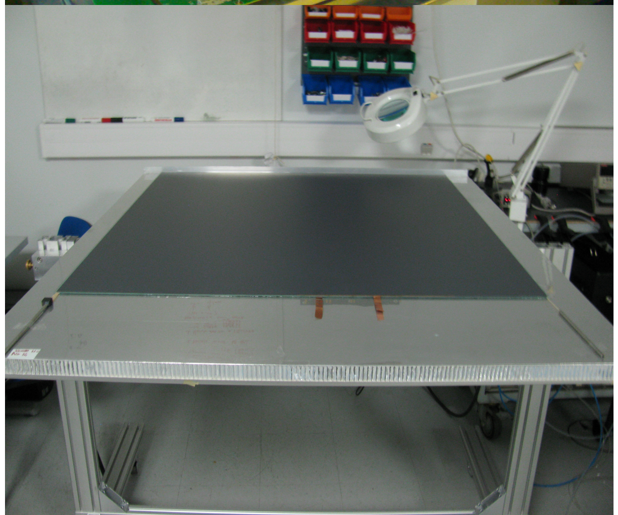
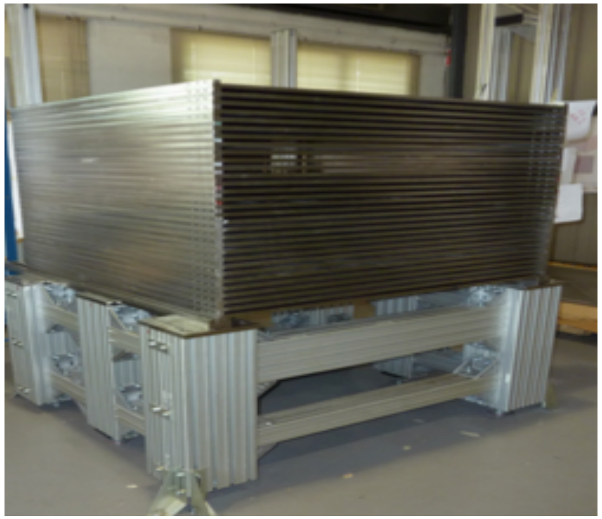
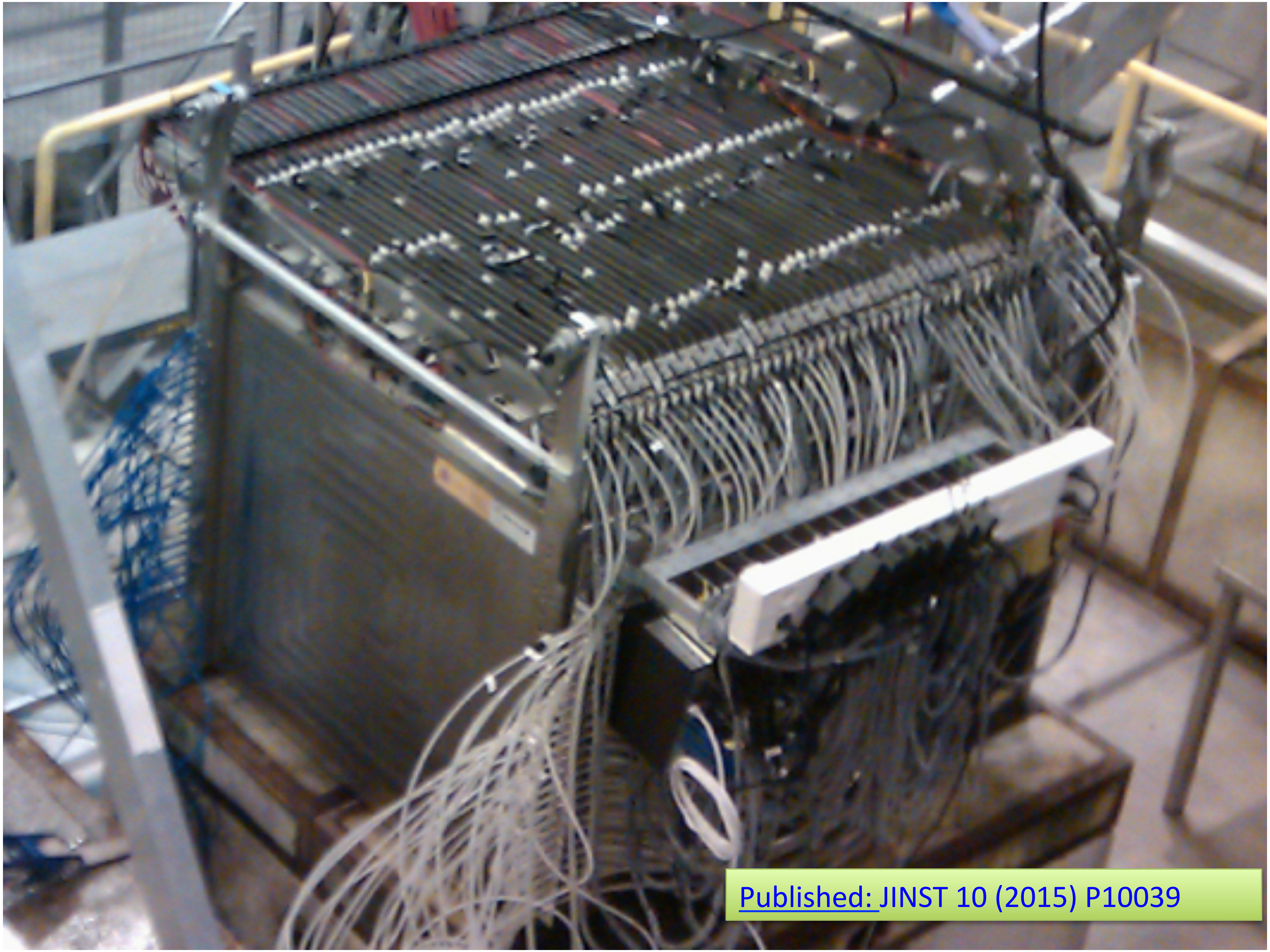
SDHCAL prototype construction

- ✓ 10500 64-ch ASIC were tested and calibrated using a dedicated (ASICs layout : 93%).
- ✓ 310 PCBs were produced, cabled and tested. They were assembled by sets of six to make 1m^2 ASUs
- ✓ 170 DIF, 20 DCC were built and tested.
- ✓ 50 detectors were built and assembled with their electronics into cassettes.
- ✓ Self-supporting mechanical structure.
- ✓DAQ system using both USB and HTML protocol was developed and used.
- ✓ Full assembly took place at CERN.

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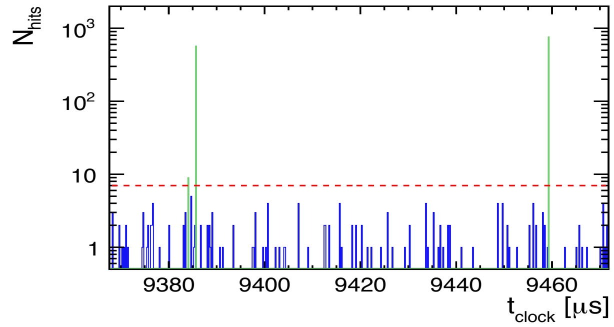
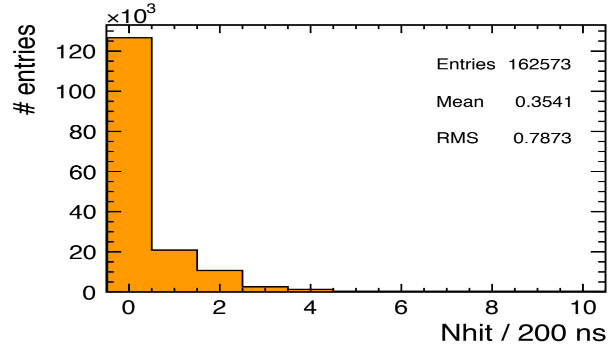
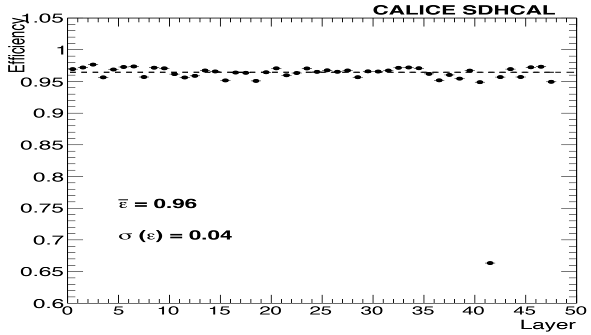
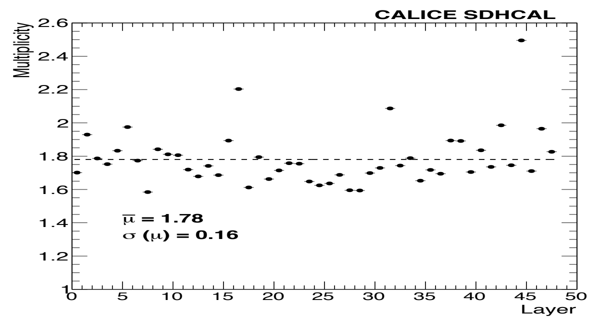
SDHCAL performance

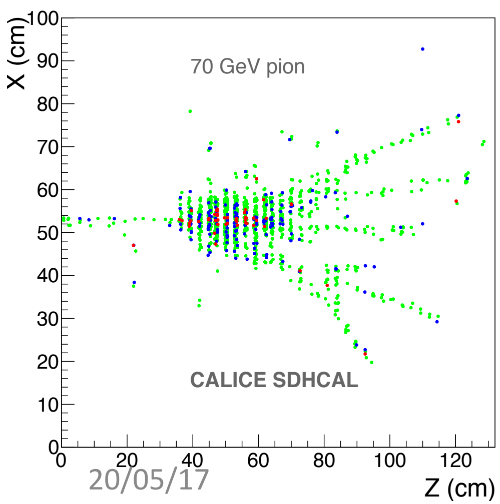
- ❑ The SDHCAL prototype was exposed to hadron, muon and electron beams in 2012, 2015 and 2016 on PS, H6 and H6 and these days H8-SPS lines.
- ❑ **Power-pulsing** using the SPS spill structure was used to reduce the power consumption.
- ❑ **Self-triggering** mode is used but external trigger mode is possible
- ❑ The threshold information helps to improve on the energy rec. by better accounting for the number of tracks crossing one pad
- ❑ New data were taken in 2015 with an improved DAQ system

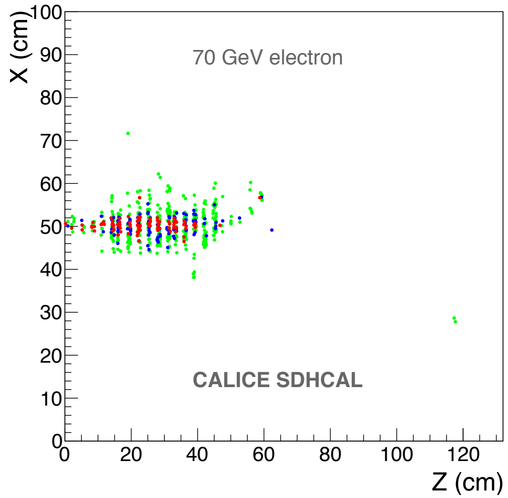








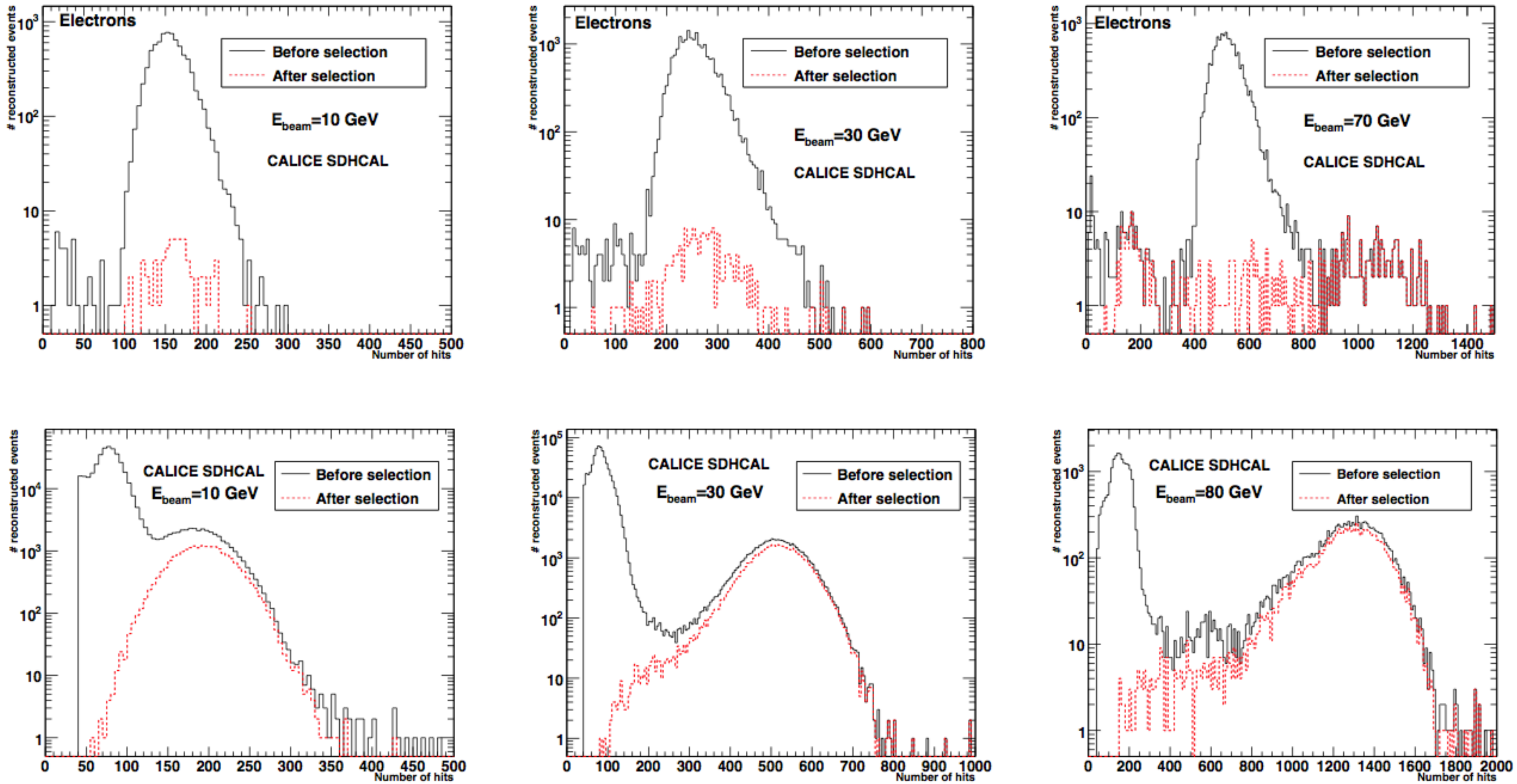




Event selection

Electron rejection	Shower start ≥ 5 or $N_{layer} \geq 30$
Muon rejection	$\frac{N_{hit}}{N_{layer}} > 2.2$
Radiative muon rejection	$\frac{N_{layer} \setminus RMS > 5cm}{N_{layer}} > 20\%$
Neutral rejection	$N_{hit \in First\ 5\ layers} \geq 4$

- No containment selection.
- No Cerenkov detector



Energy estimation

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

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

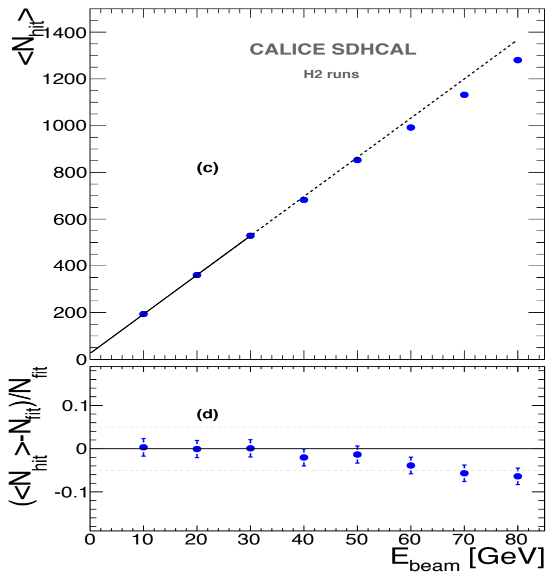
$E_{rec} = \alpha(N_{tot})\, N_1 + \beta(N_{tot})\, N_2 + \gamma(N_{tot})\, N_3$

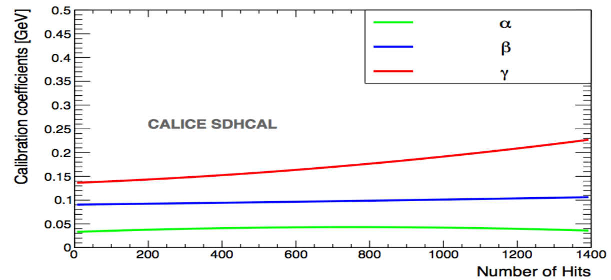
N_1,N_2 and N_3 : exclusive number of hits associated to first, second and third threshold.

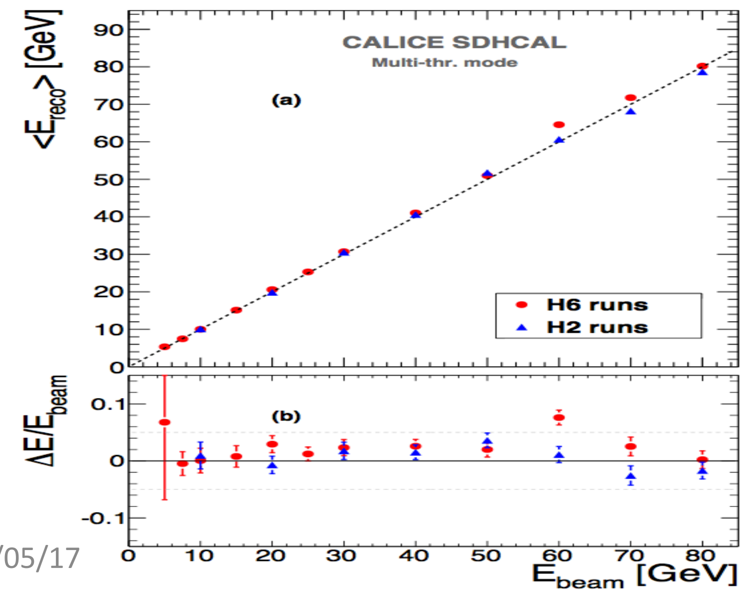
α, β, γ are quadratic functions of the total number of hits (N_{tot})

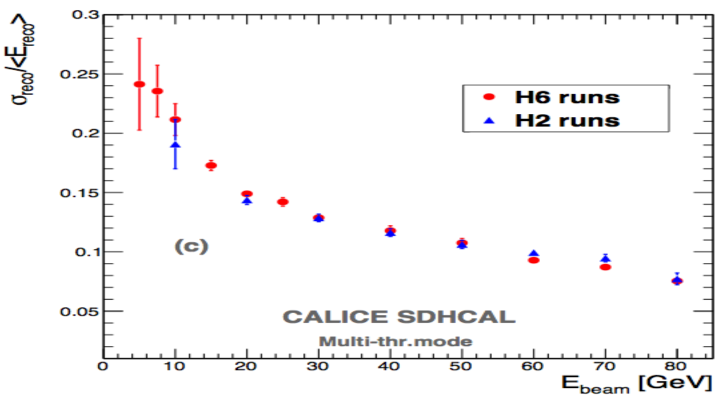
Events of H2 runs corresponding to energies : **5, 10, 30 , 60** and **80** GeV were used to fit the 9 parameters.

Then the energy of hadronic events in both H2(only pions) and H6 (presence of protons)







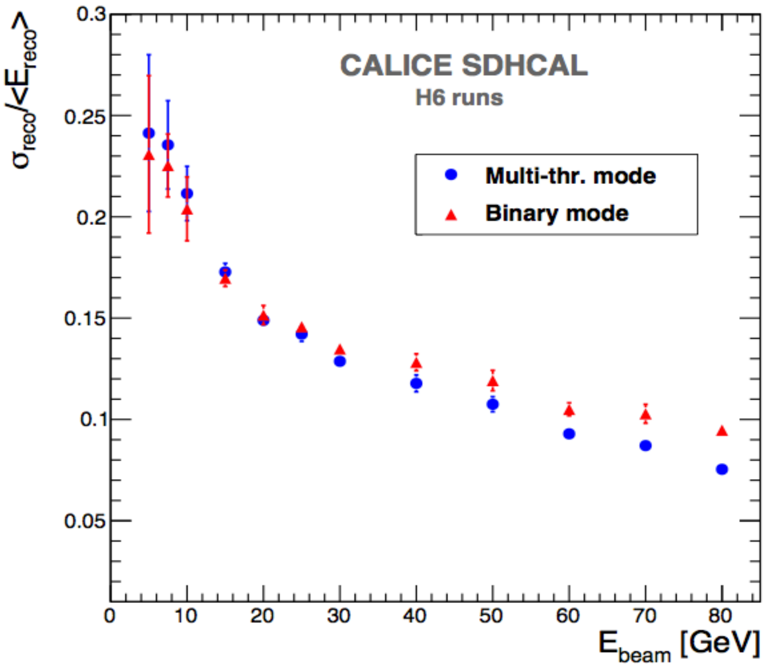


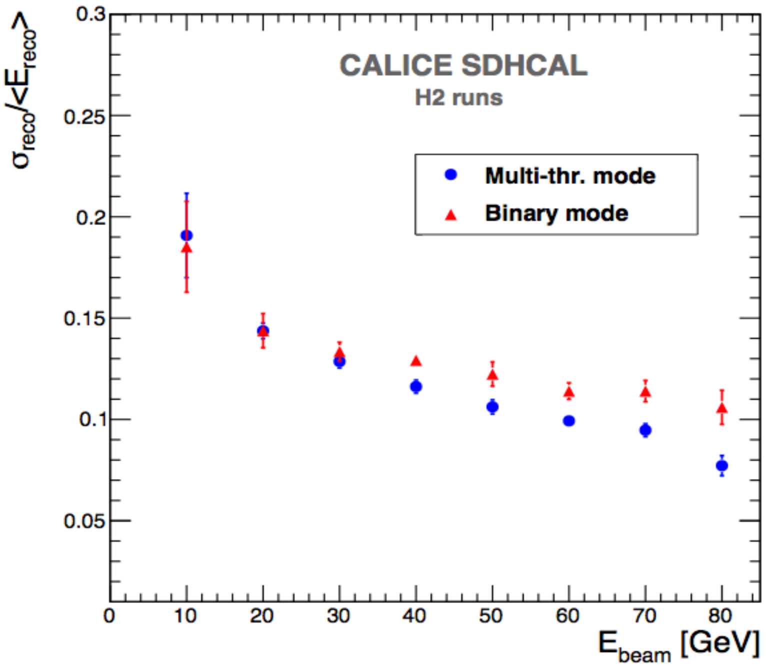
Energy estimation

Comparison semi-digital versus binary readout

E_{rec} (binary) = $C\,N_{tot} + D\,N^2_{tot} + F\,N^3_{tot}$

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





Substantial improvement a energy > 30 GeV

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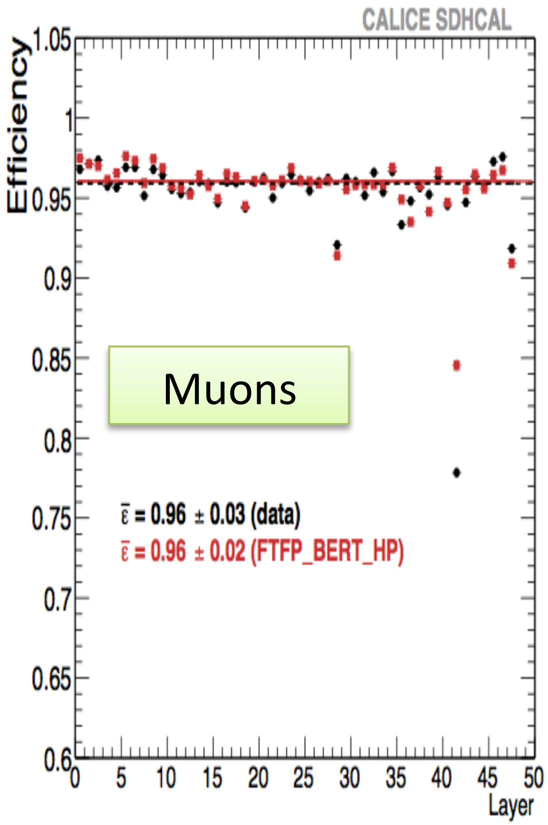
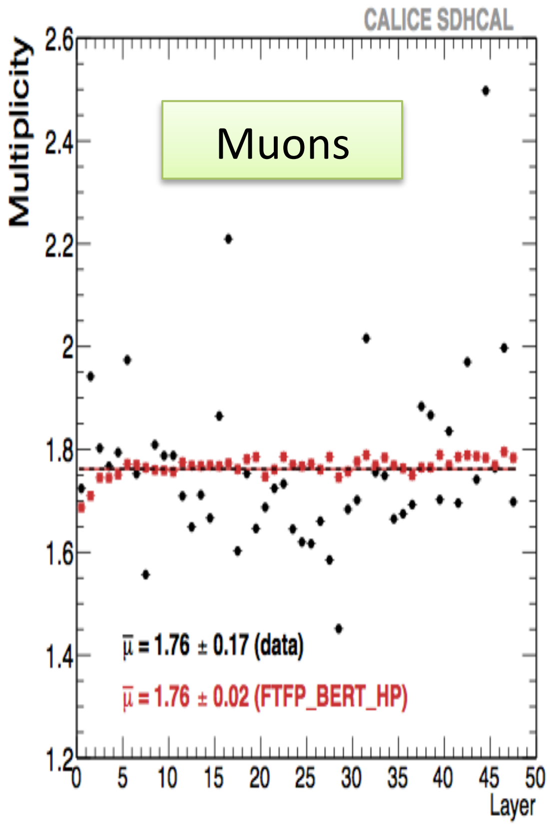
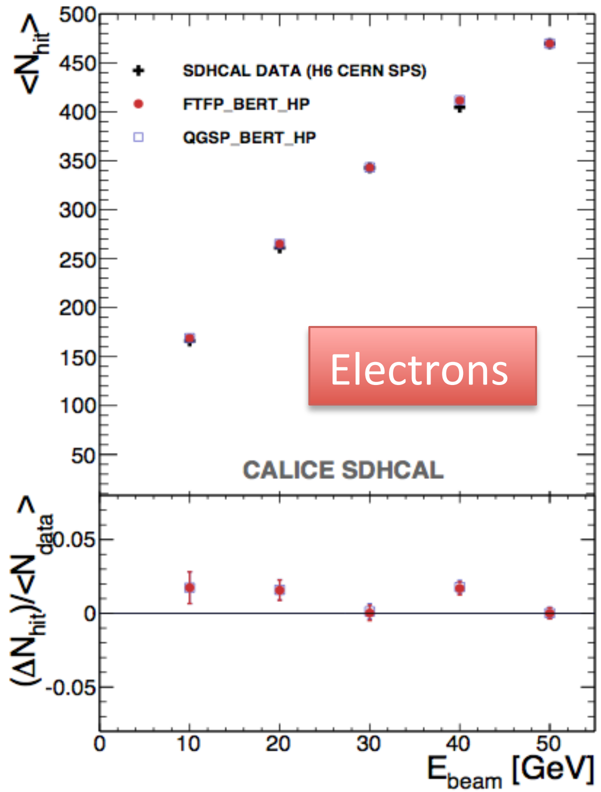
SDHCAL Simulation

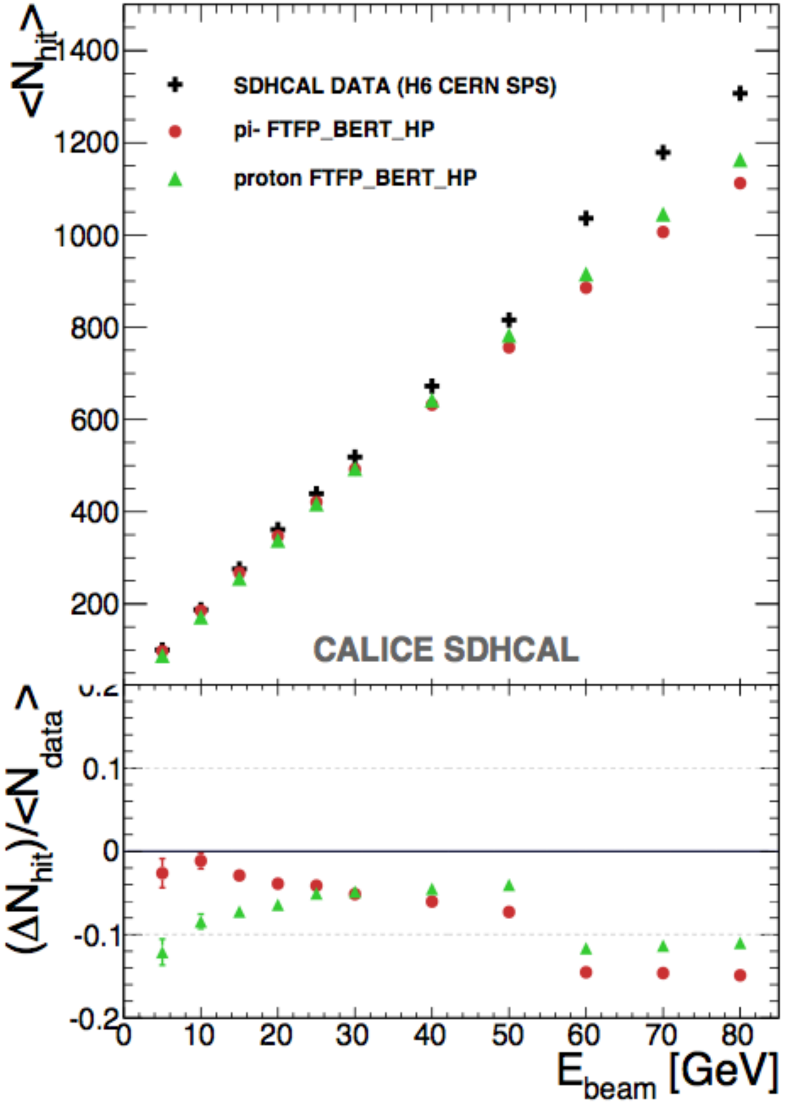
A **digitizer** to describe the RPC response was developed. Parameters tuned using muons and electrons. Detector inefficiencies (dead channels) are included.

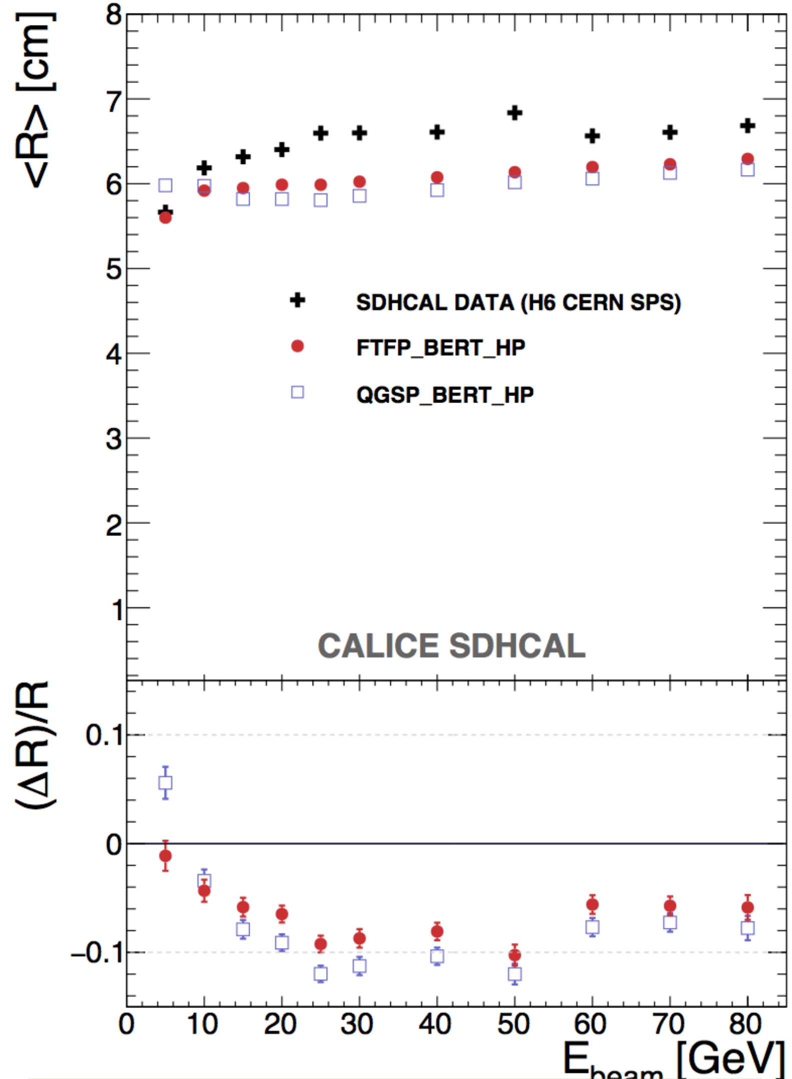






Comparison data/simulation





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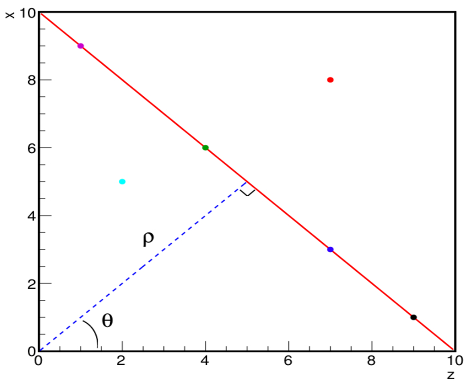
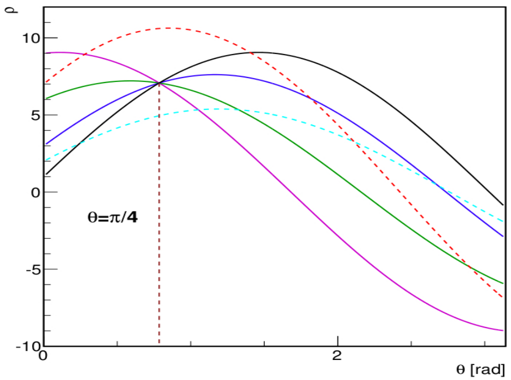
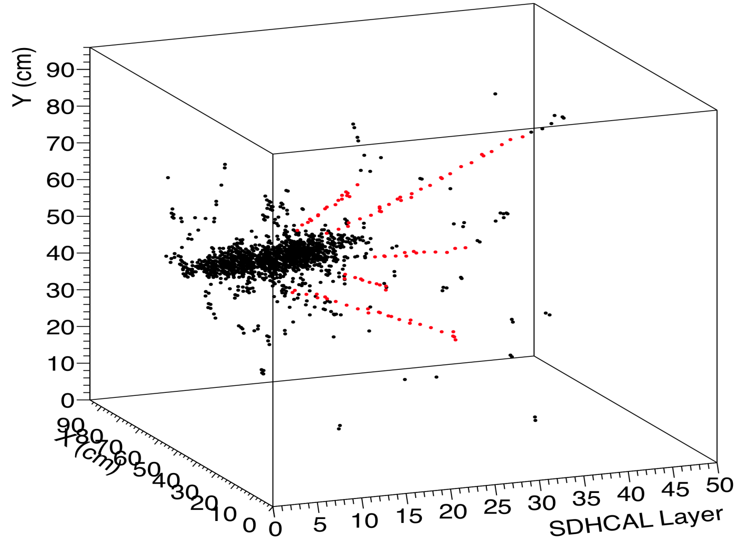
SDHCAL High-granularity impact

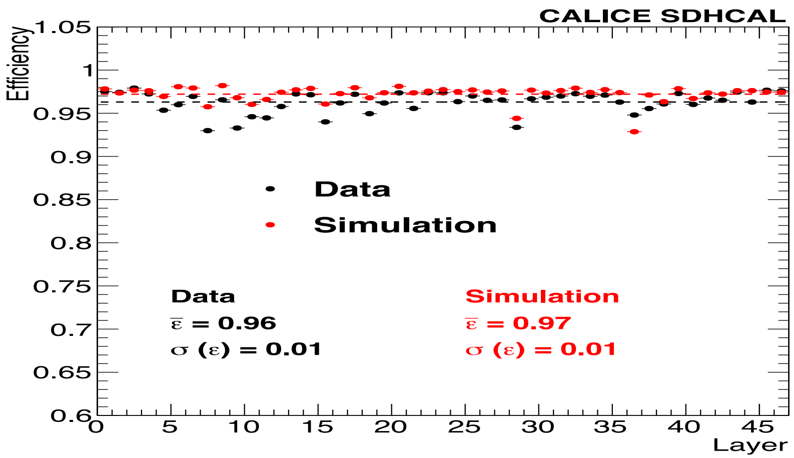
Hough Transform is an example to extract tracks within hadronic showers and to use them to control the calorimeter in situ

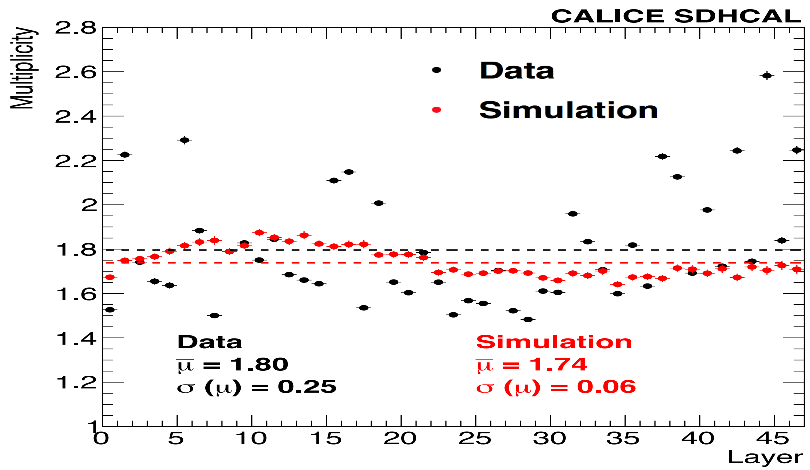






$\rho_{xz} = z \sin(\theta) + x \cos(\theta)$



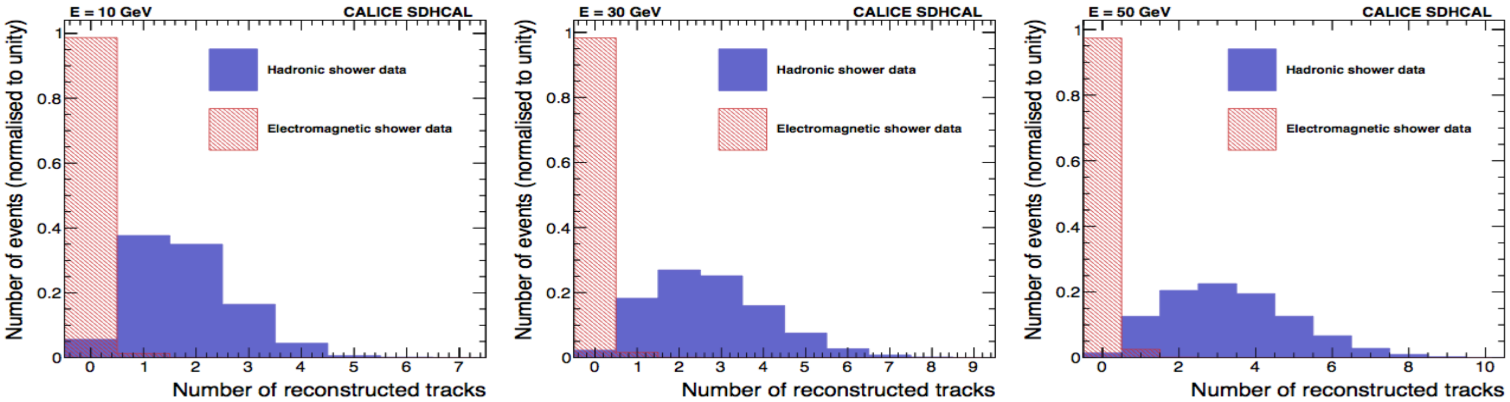


Excellent agreement with results obtained with cosmic and beam-muons.

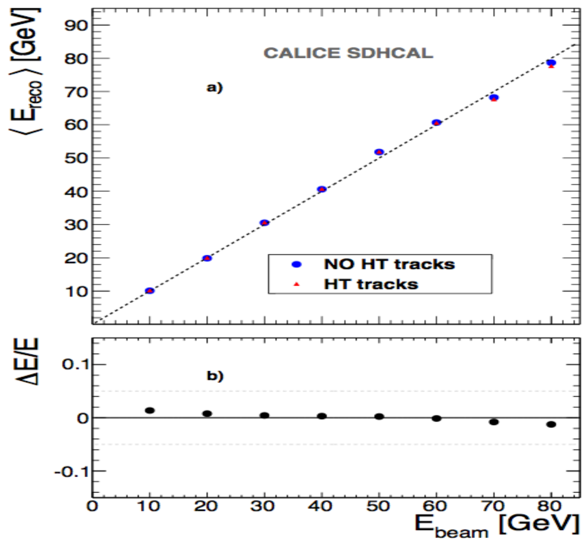
Excellent agreement data/MC

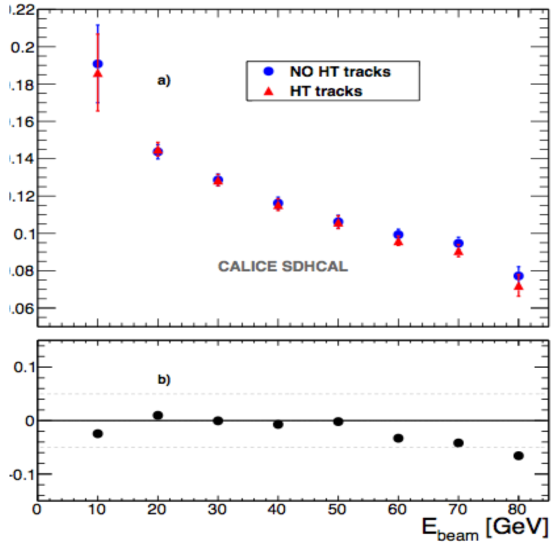
SDHCAL High-granularity impact

Good tool to discriminate **electron/hadron**



It improves on the **energy reconstruction** by dealing with the hits belonging to the track segments independently of their threshold





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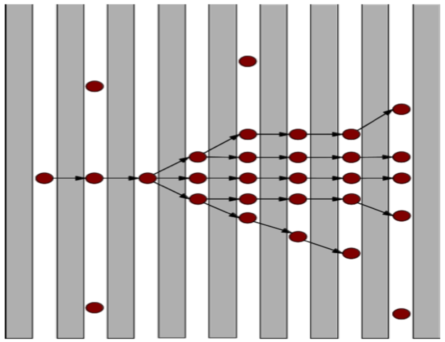
The technique could be extended to hadronic showers in the presence of magnetic field.

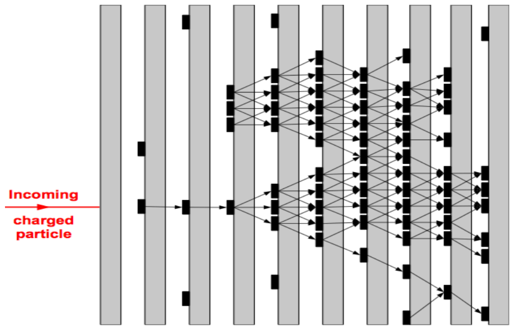
SDHCAL high granularity is good

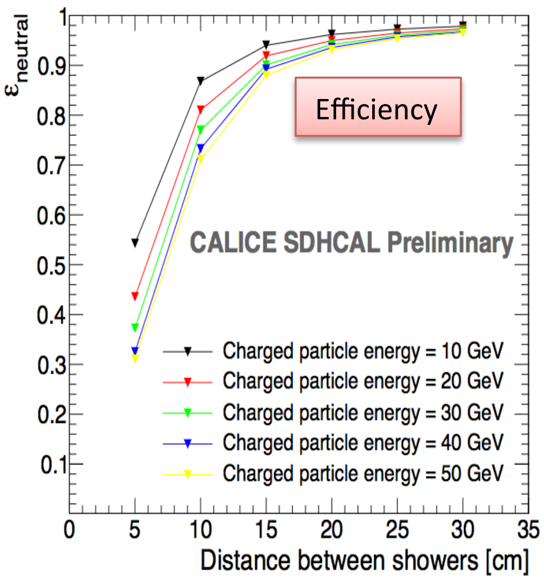
It helps to optimize the connection of hits belonging to the same shower by using first the topology and then the energy information

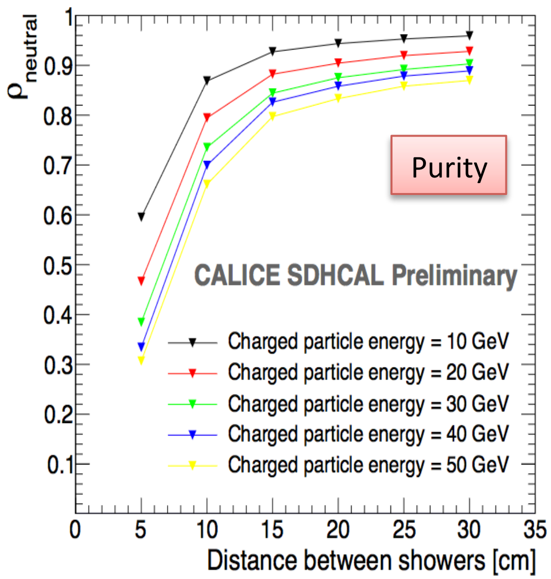
ArborPFA algorithm*:

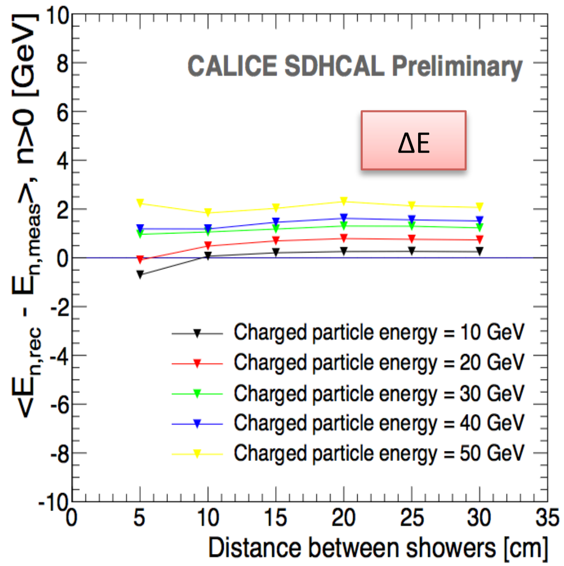
It connect first hits and then their clusters using distance and orientation information
Then correct using tracker information









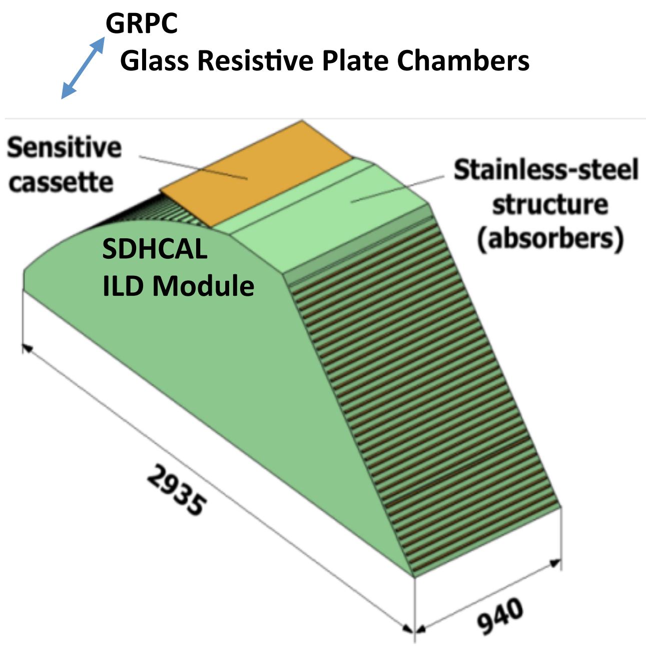


CALICE note CAN054

** Algorithm idea was first developed by ALEPH collaboration*

SDHCAL for future experiments

- Detectors as large as 3m X 1m need to be built
- Electronic readout should be the most robust with minimal intervention during operation.
- DAQ system should be robust and efficient
- Mechanical structure to be similar to the final one
- Envisage new features such timing, etc..

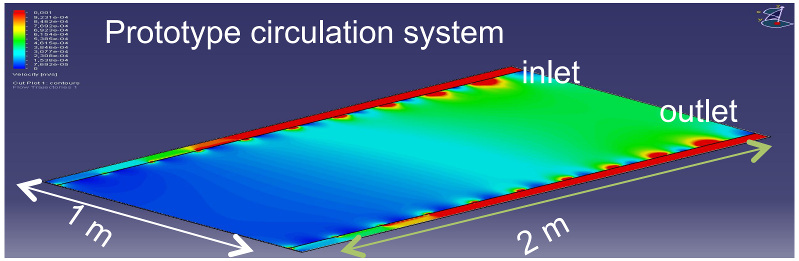


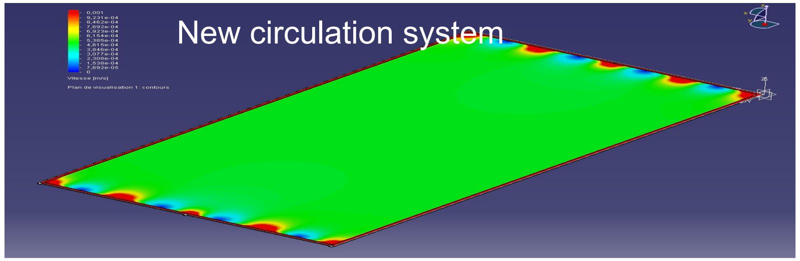
Goal: to build new prototype with few but large GRPC with the new components

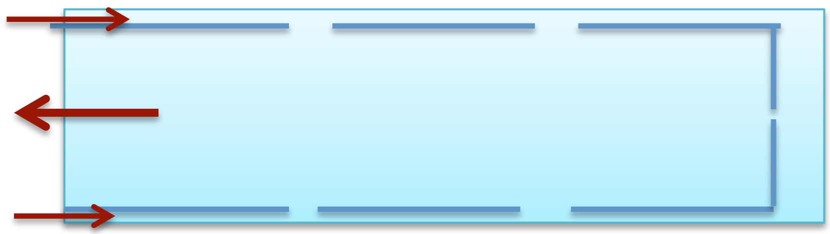
Detector conception

Construction and operation of large GRPC necessitate some improvements with respect to the present scenario.

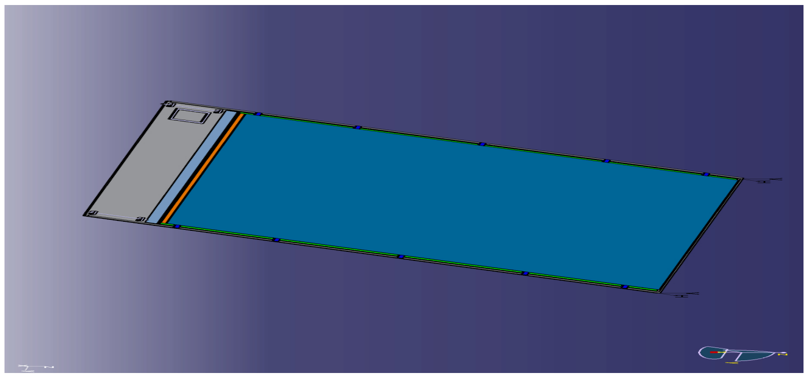
Gas distribution : new scheme is proposed

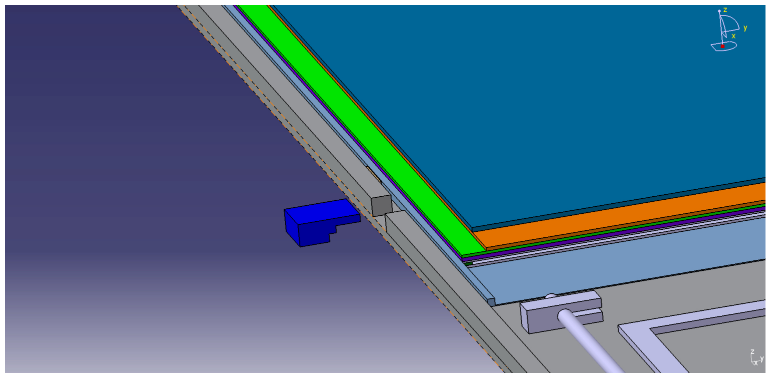






Cassette conception to ensure good contact between the detector and electronics is to be improved





New electronics

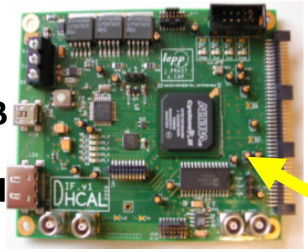
Electronics readout for the 1m³ prototipo

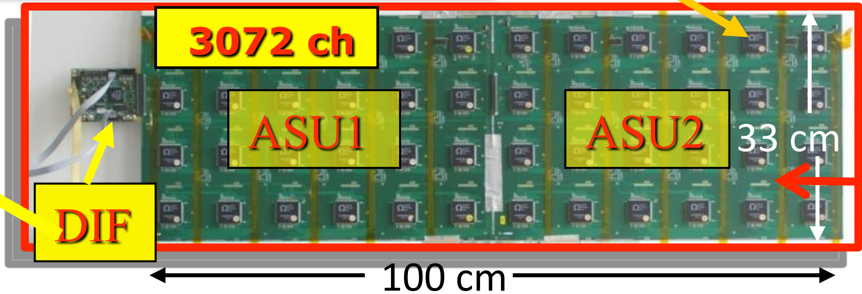
HADROC chip (ASIC)

1m² board ➔ 6 ASUs hosting 24 ASICs

USB

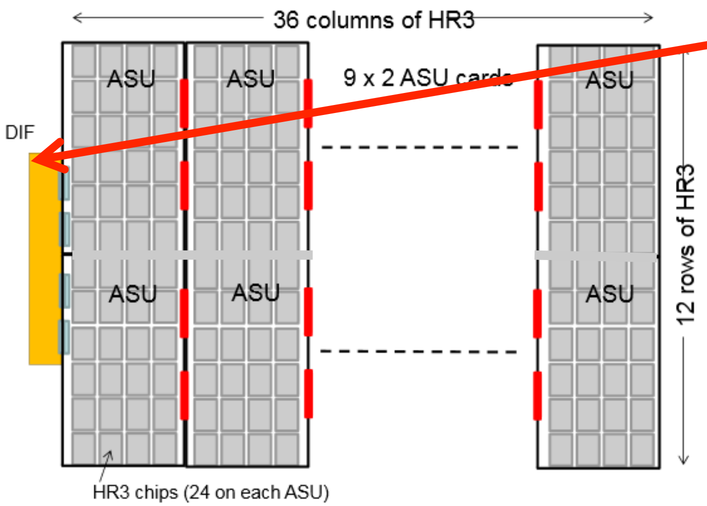
HDMI





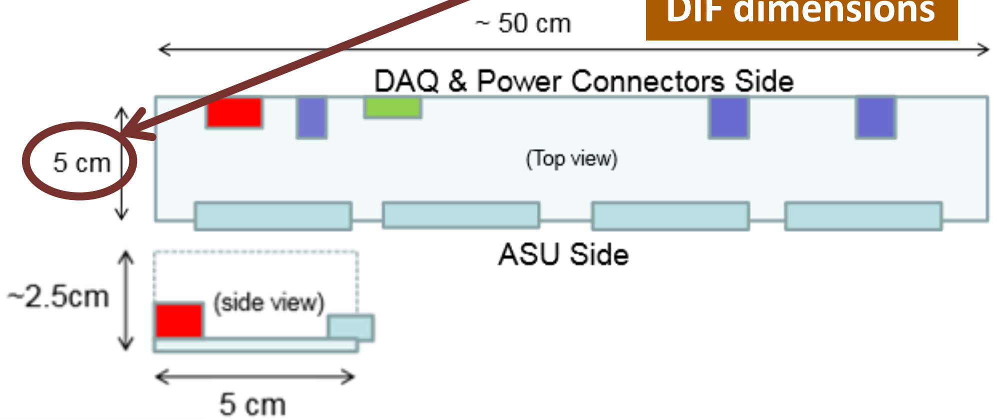
1 DIF (detector InterFace) for 2 ASU (Active Sensor Unit.- PCB+ASICs) ➔ **3 DIFs for ONE 1m2 GRPC detector**

Electronics readout for the final detector



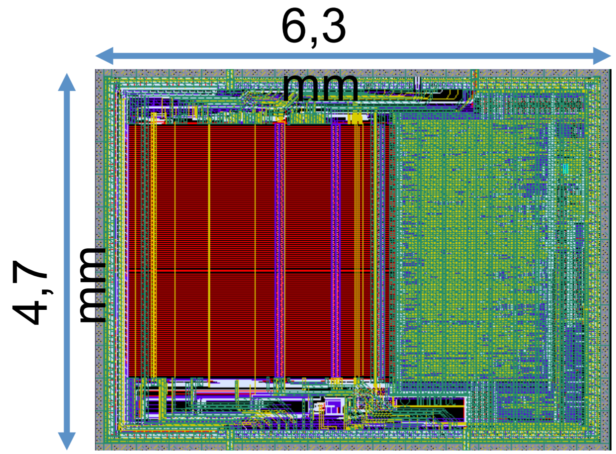
Only **1 DIF per GRPC (any size)** with small dimensions to fit in the **small** space available at the ILD detector

DIF dimensions



ASUs of 1000 mmx333 mm are being produced

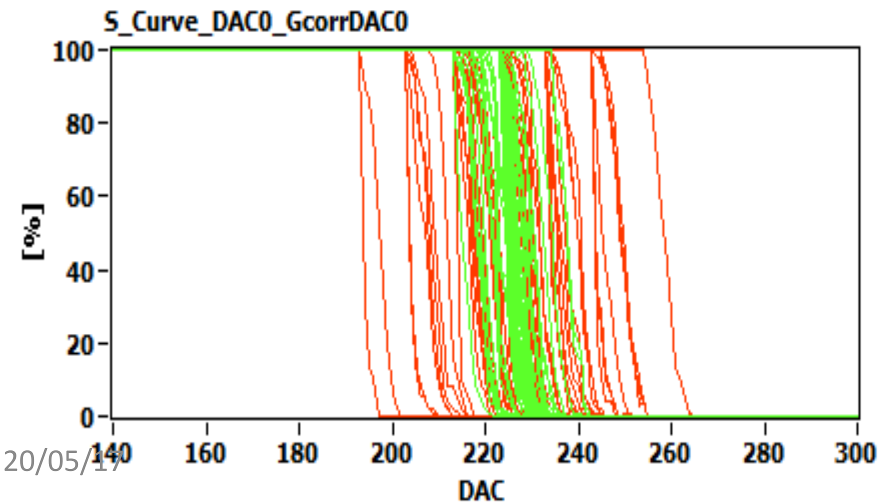
New electronics: ASIC

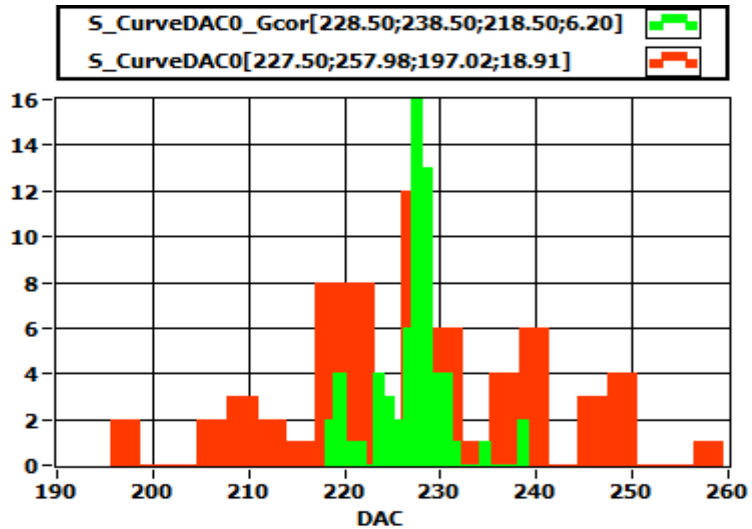


HARDROCR3 main features:

– Independent channels
– Zero suppress
– Extended dynamic range (up to 50 pC)
– I2C link with triple voting for slow control parameters
– packaging in QFP208, die size ~30 mm^2
– Consumption increase (internal PLL, I2C)

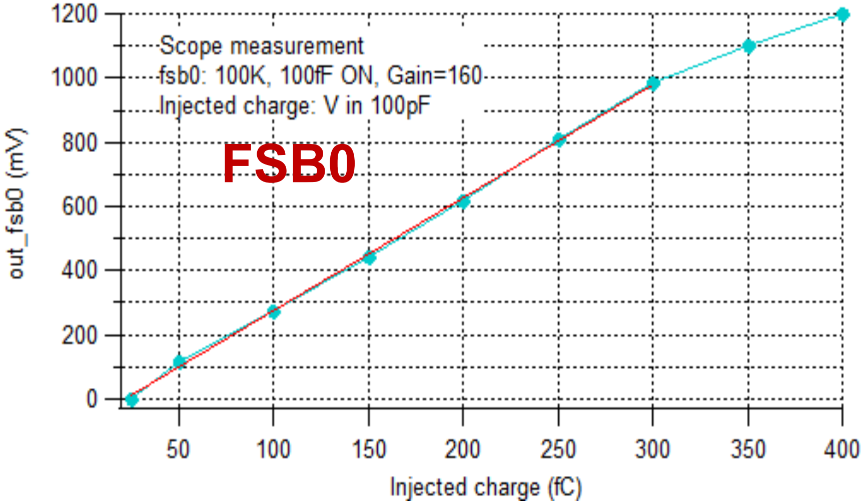
H3B TESTED : 786, Yield : 83.3 %

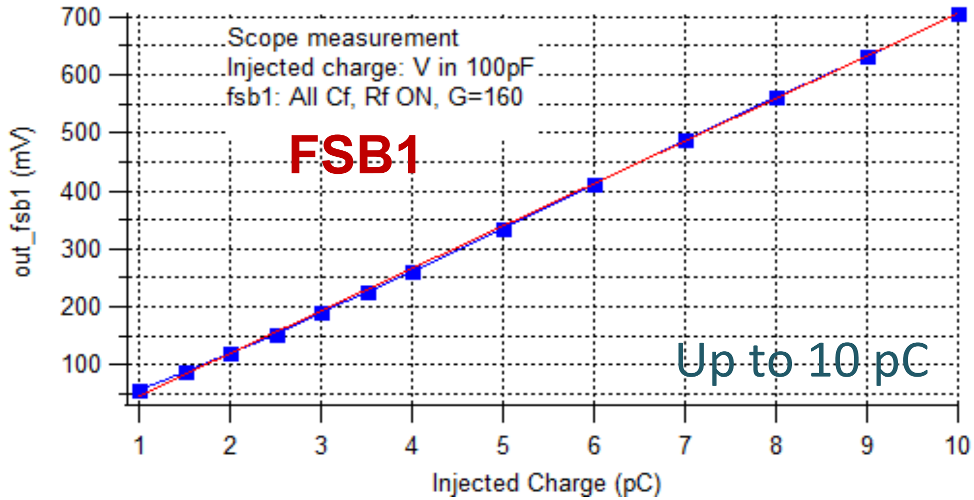


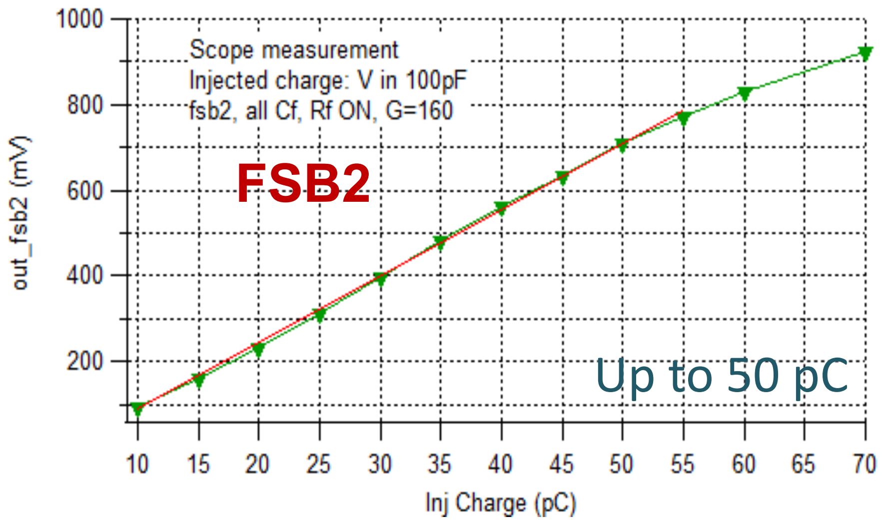


HARDROC3: Analog linearity

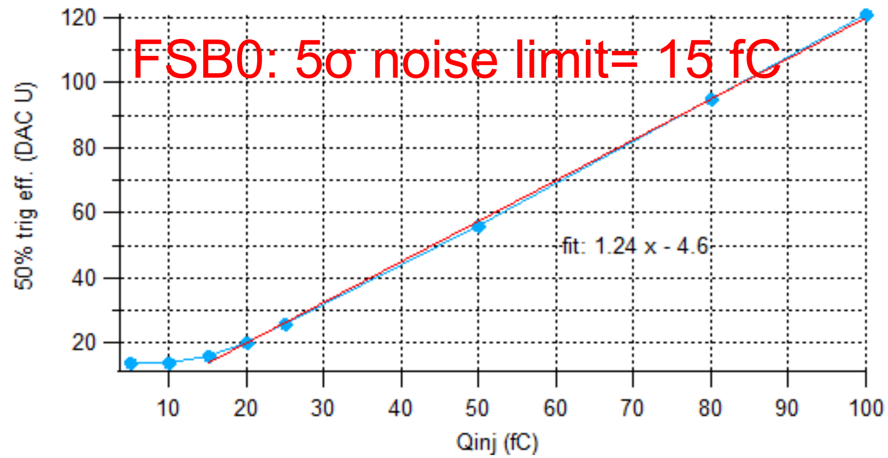
Fast shaper outputs (mV) vs Qinj (fC)







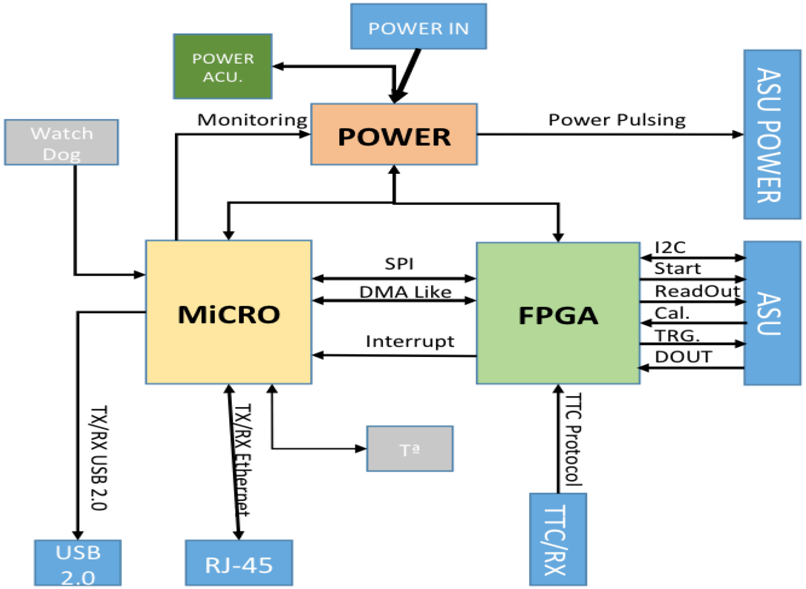
50% trig. Eff. (DAC units) vs Qinj (fC)



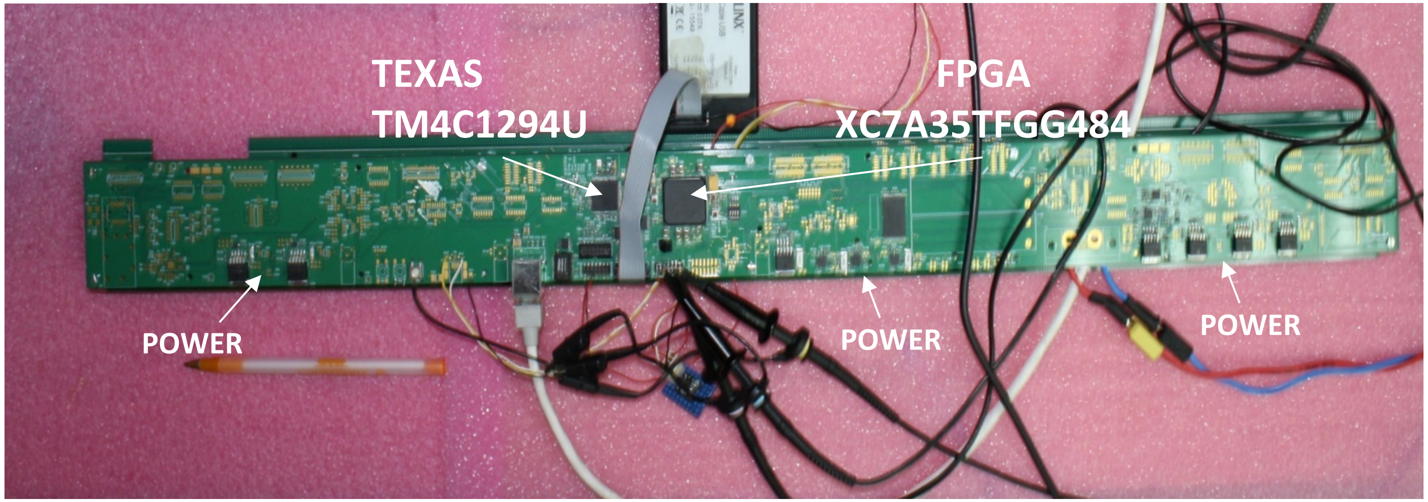
Dynamic range: 15fC - 50 pC

New electronics : DIF

DIF sends DAQ commands (config, clock, trigger) to front-end and transfer their signal data to DAQ. It controls also the ASIC power pulsing

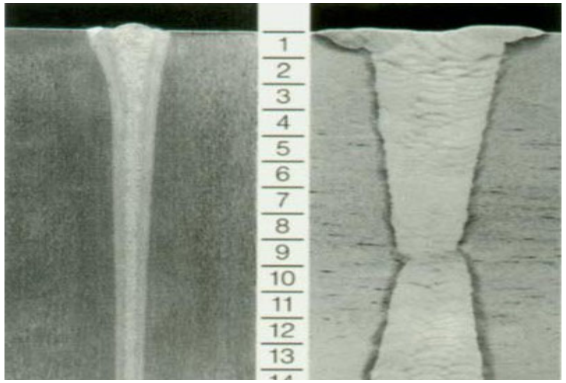


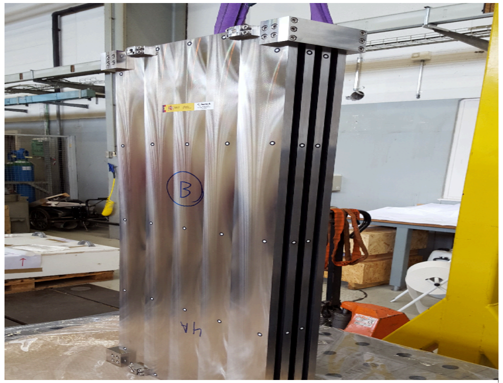
- Only **one DIF per plane** (instead of **three**)
- DIF handle up to **432 HR3 chips** (vs **48 HR2** in previous DIF)
- HR3 **slow control** through **I2C bus (12 IC2 buses).**
  Keeps also **2 of the old slow control buses as backup & redundancy**.
- **Data transmission to/from DAQ** by **Ethernet**
- **Clock and synchronization** by **TTC** (already used in LHC)
- **93W Peak power supply** with super-capacitors
  (vs **8.6 W** in previous DIF)
- Spare I/O connectors to the FPGA (i.e. for GBT links)
- Upgrade **USB 1.1** to **USB 2.0**



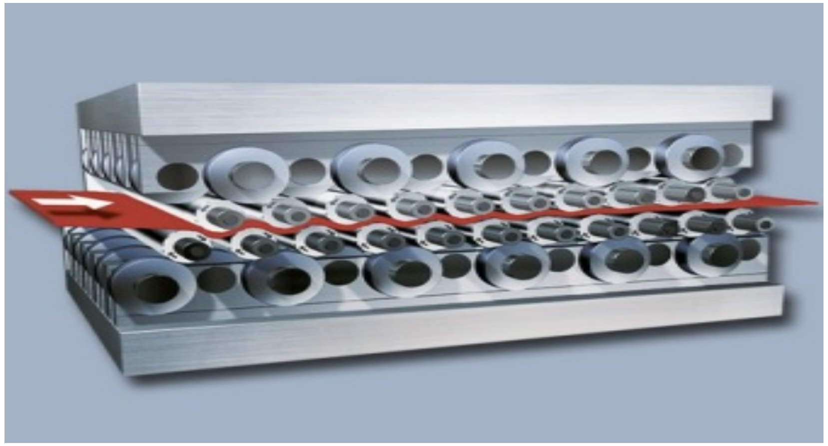
Mechanical Structure

Improvement on the present system is being made by using **Electron Beam Welding** rather than bolts to reduce the deformation and the spacers thickness.



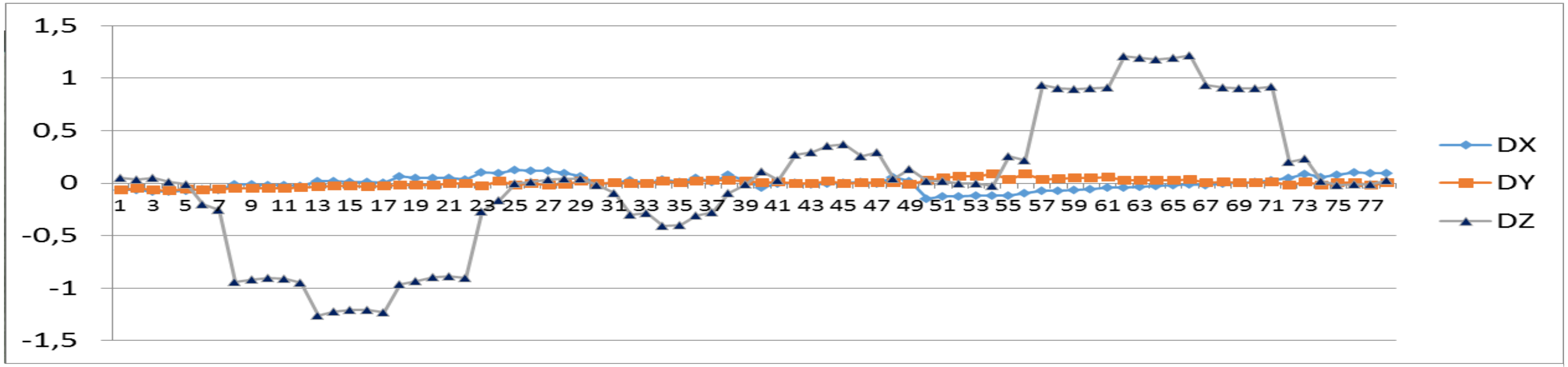


Industrial production of **flat** large absorber plates (3 m X 1 m) by **roller leveling** process

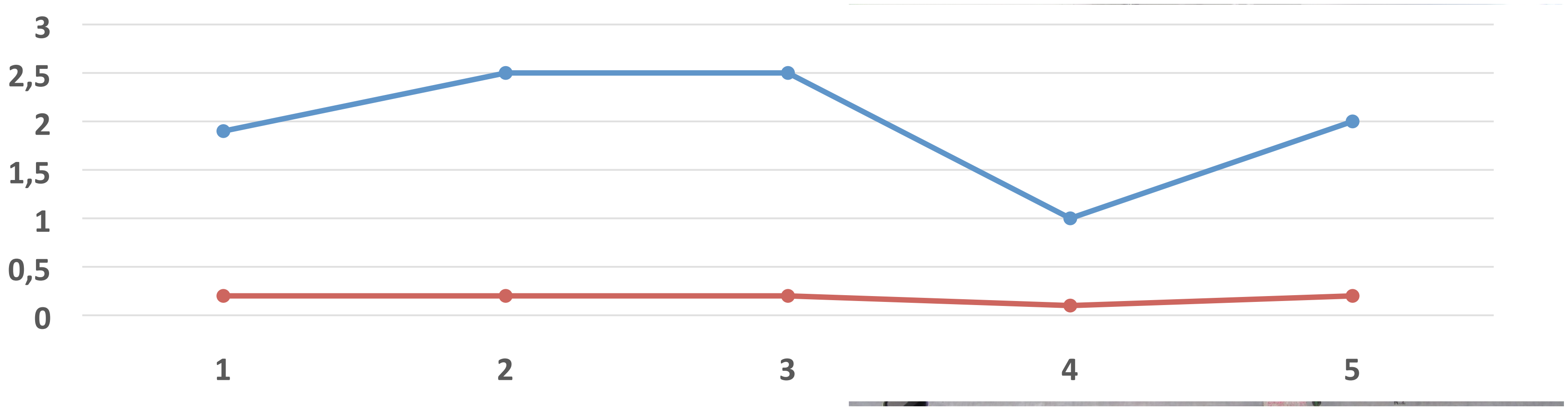


Mechanical Structure

Promising results but better performance is still needed



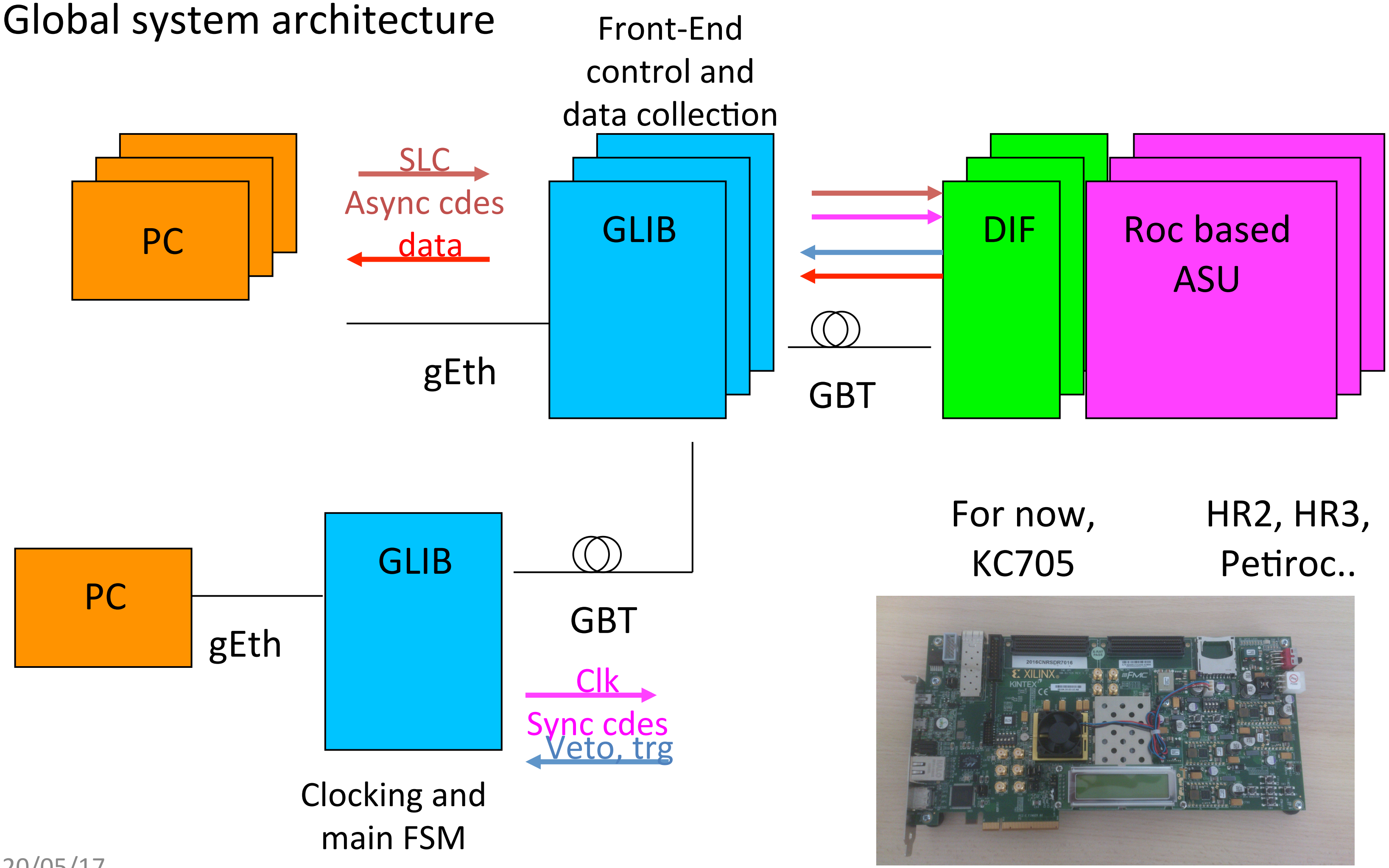
Very good flatness (< 1mm)



DAQ system

Implementation of a GBT-based communication system for ROC chips. This aims to reach higher performance using robust and well maintained system in the future

Global system architecture



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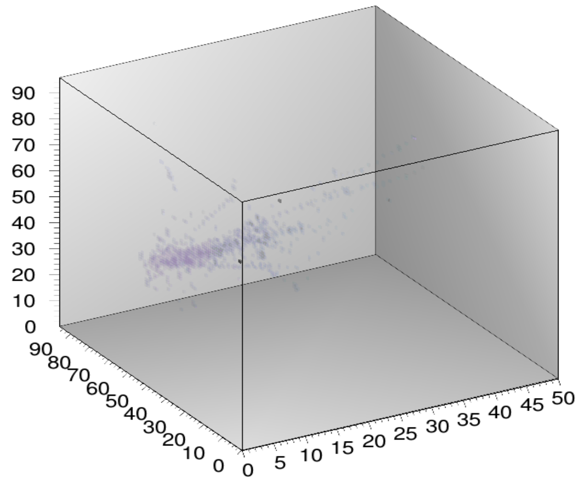
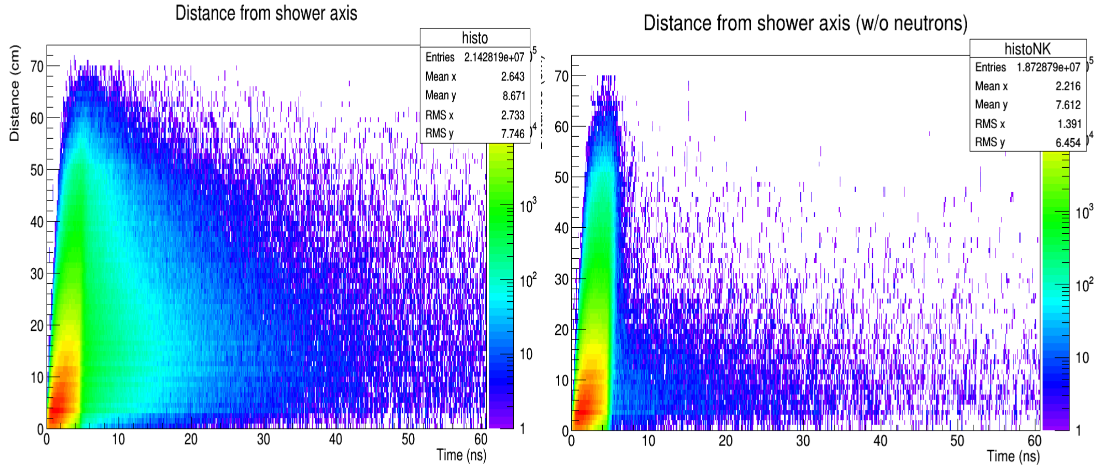
Next step : Timing

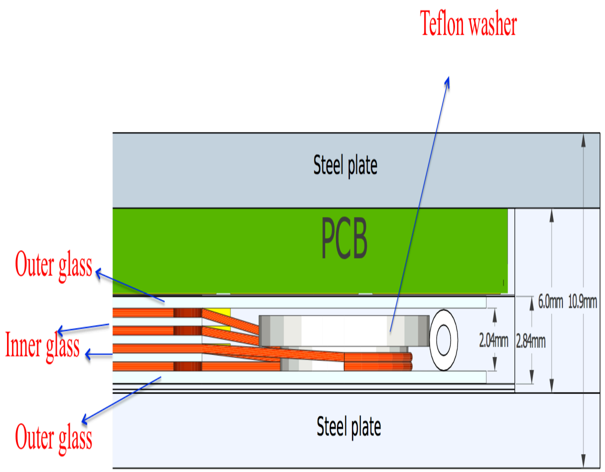
Timing could be an important factor to separate showers and better reconstruct their energy

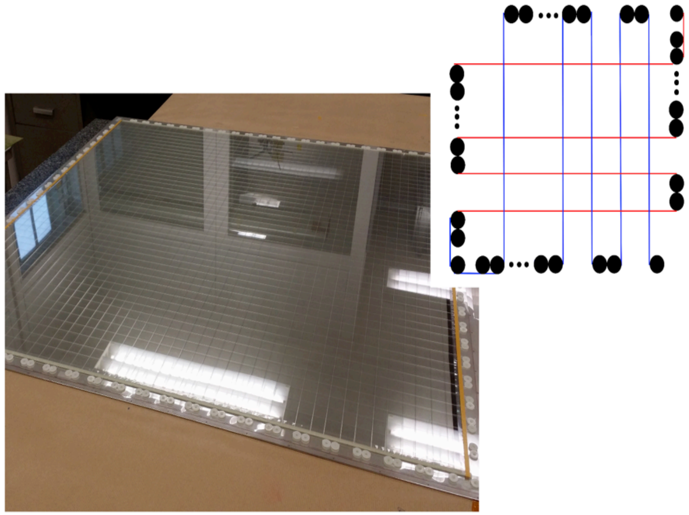


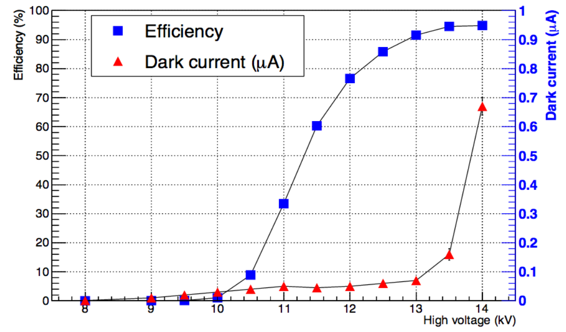


Multi-gap RPC are excellent fast timing detectors

Several were designed and built . Excellent efficiency when tested with HARDROC ASICs. **Next step use PETIROC (< 20 ps time jitters)**



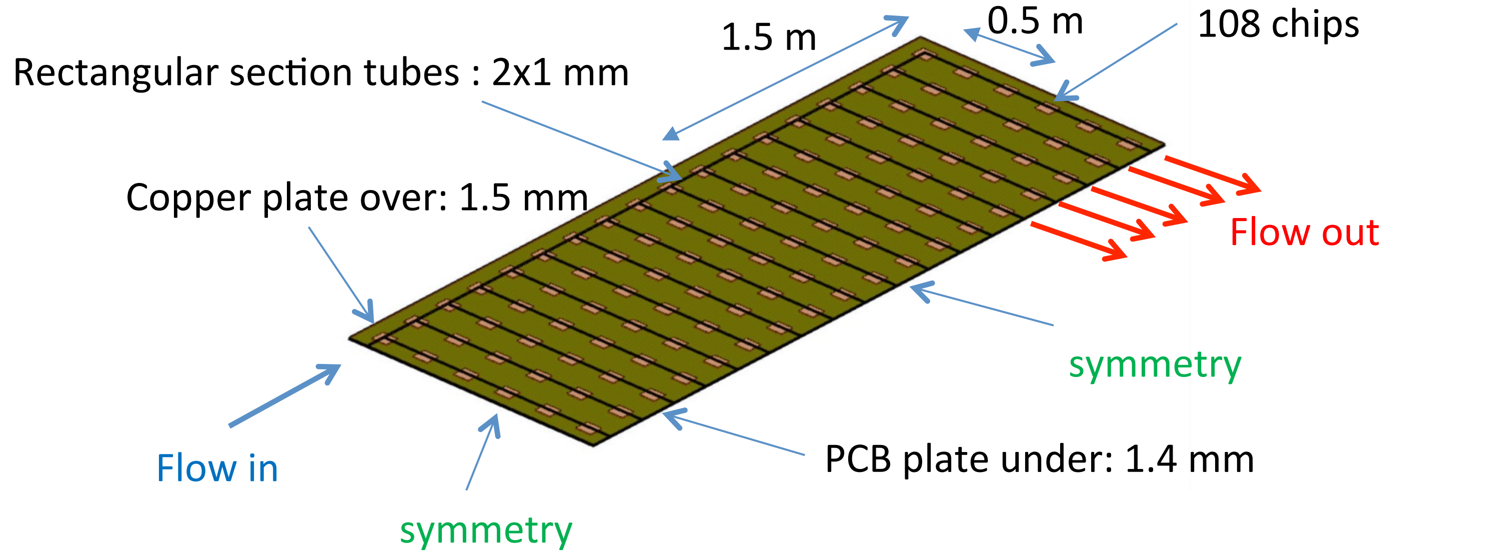




Threshold sets at 114 fC

Next step : cooling

Cooling becomes necessary if the power pulsing scheme is not possible (CEPC project)

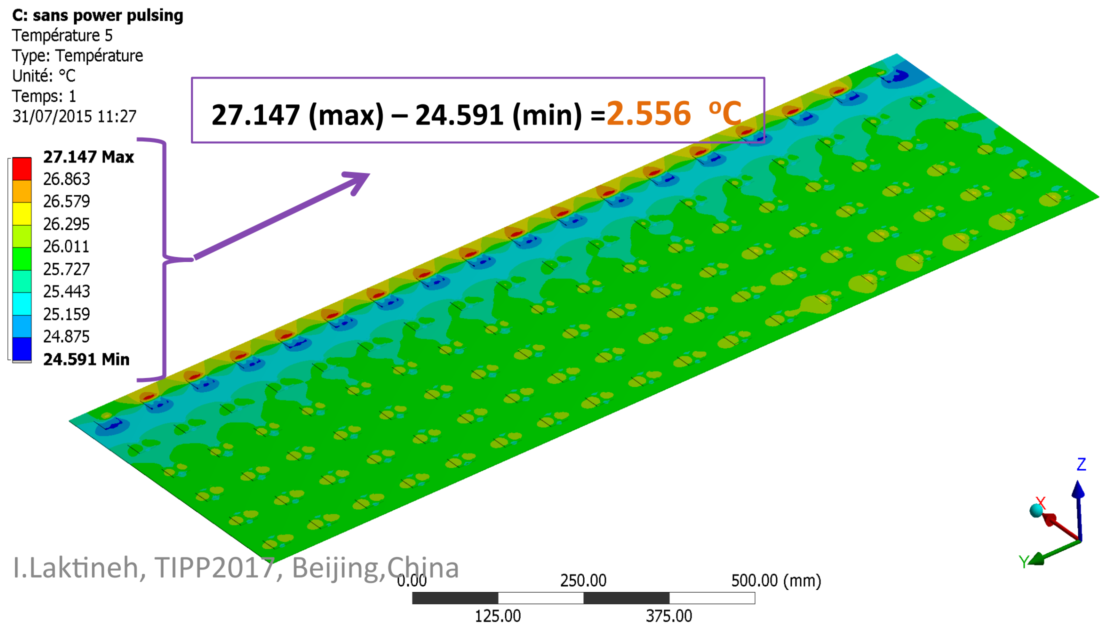


Water cooling :

h = 10000 W/m²/k

Thermal load :

80 mW/chip without power pulsing



Simulation ¼ structure pcb + chips

Conclusions and perspectives

→SDHCAL is the first technological prototype to be conceived and built for future leptonic experiments.

→Results of beam tests validate the concept

→ New prototype is on the rails and in principle could be achieved before the end of 2017.

→ New features such as timing and cooling will play important role in future R&D for future colliders.

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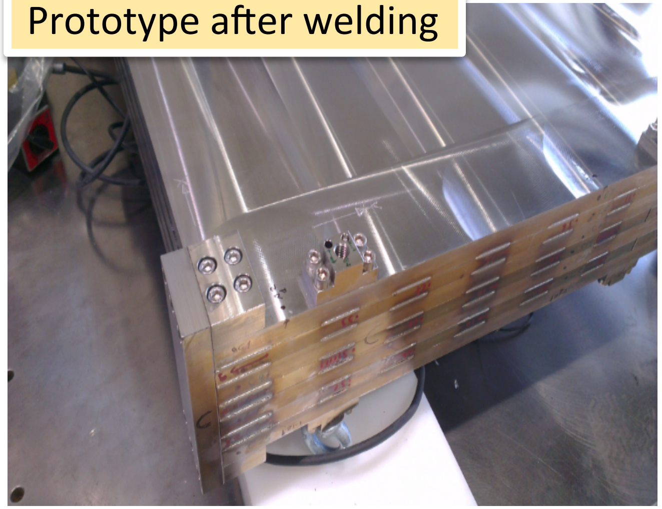
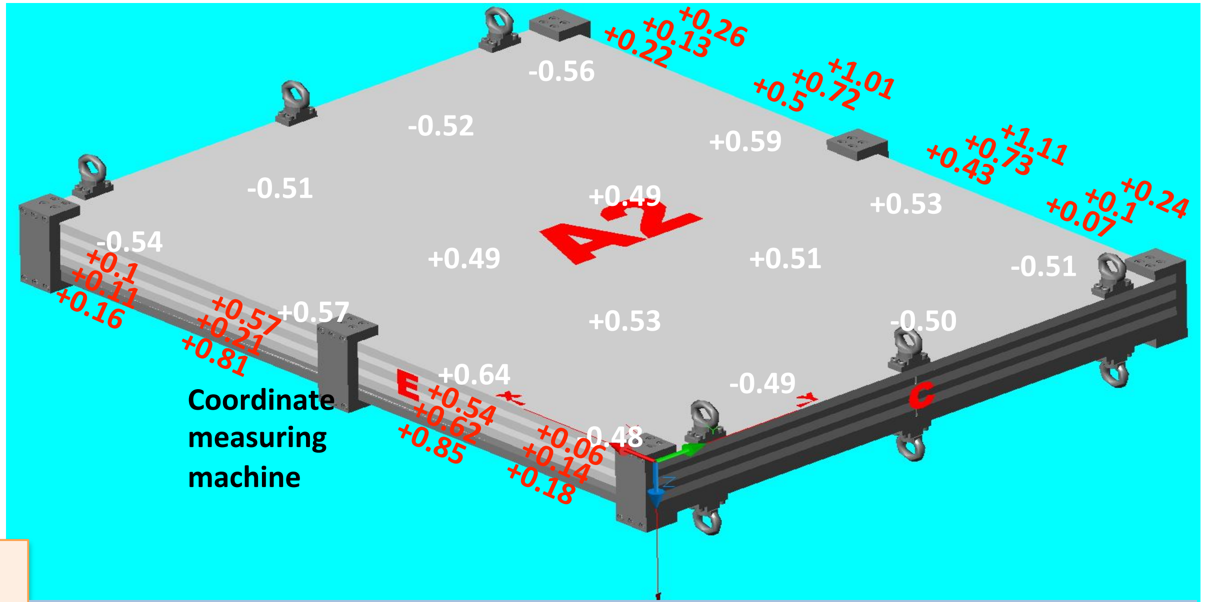
Tests of small mechanical structures prototypes

Before assembly the big prototype (~3x1m2), **welding tests with smaller prototypes are foreseen**

Prototype after welding



First small prototype: 4 plates 1x1 m2



After comparing the measurements before and after welding deformations found (~1mm) bigger than expected in X-axis. O.K in Y-axis

→ Probably due to the welding sequence used

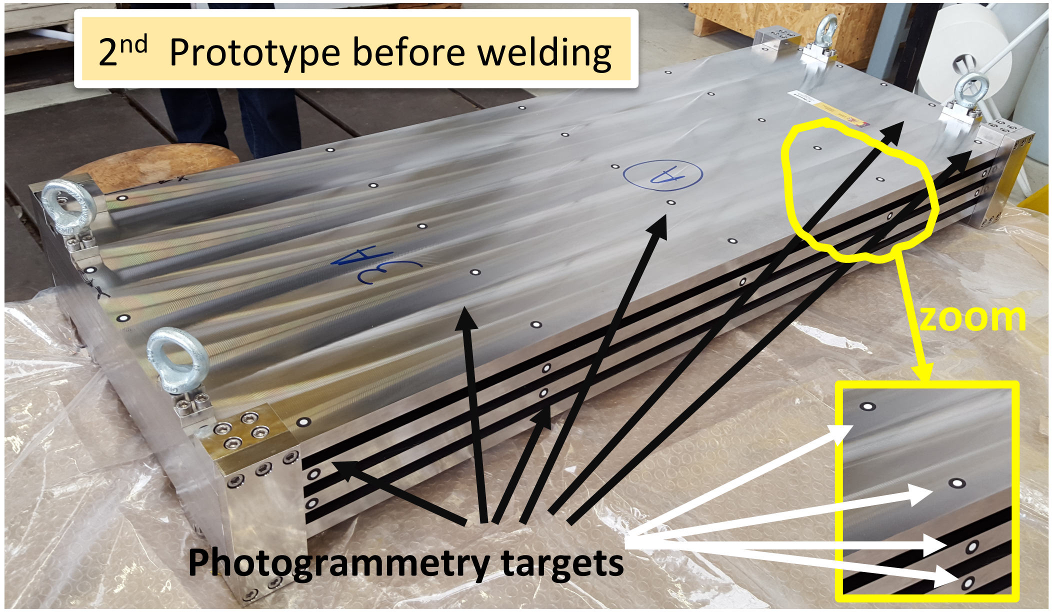
Differences with respect to the initial status of the plate in Z.

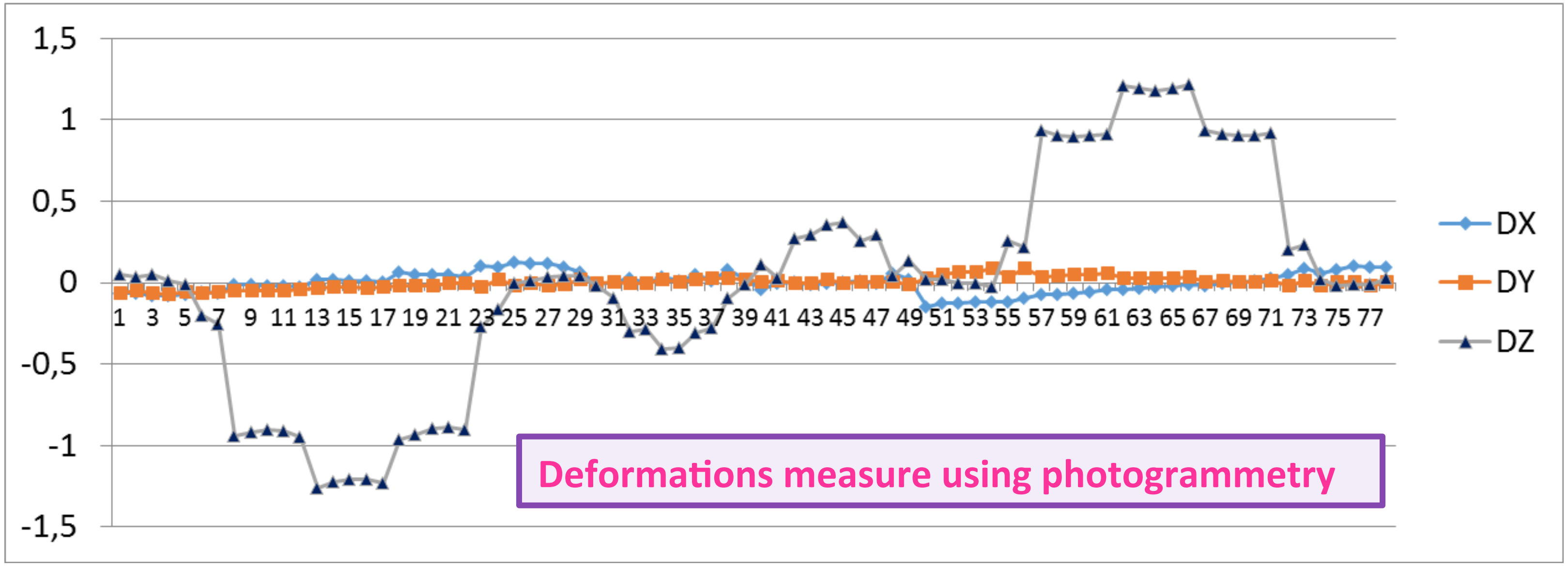
Differences with respect to the initial status of the distance between plates

Measurements have been done AFTER REMOVING the PIECES used FOR RIDIGITY (the picture includes them)

Second small prototype: 4 plates 1x0.5 m2

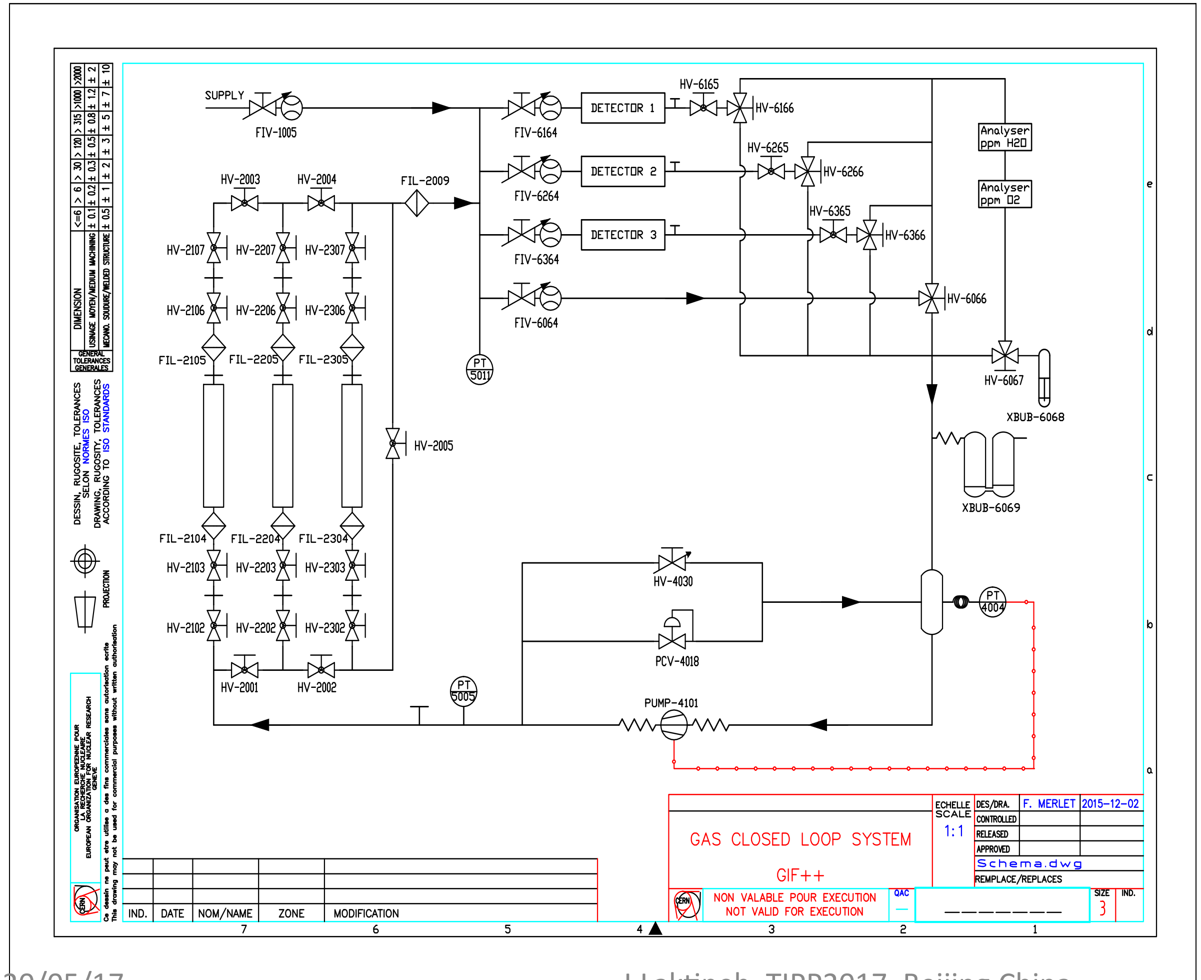
Welding performed **changing a bit the welding sequence** with respect to the first prototype





Gas purifier

-Goal: reduce the gas consumption to reduce the cost.
-Gas renewal of 5-10% rather than 100%
-Conceived by the CERN gas group



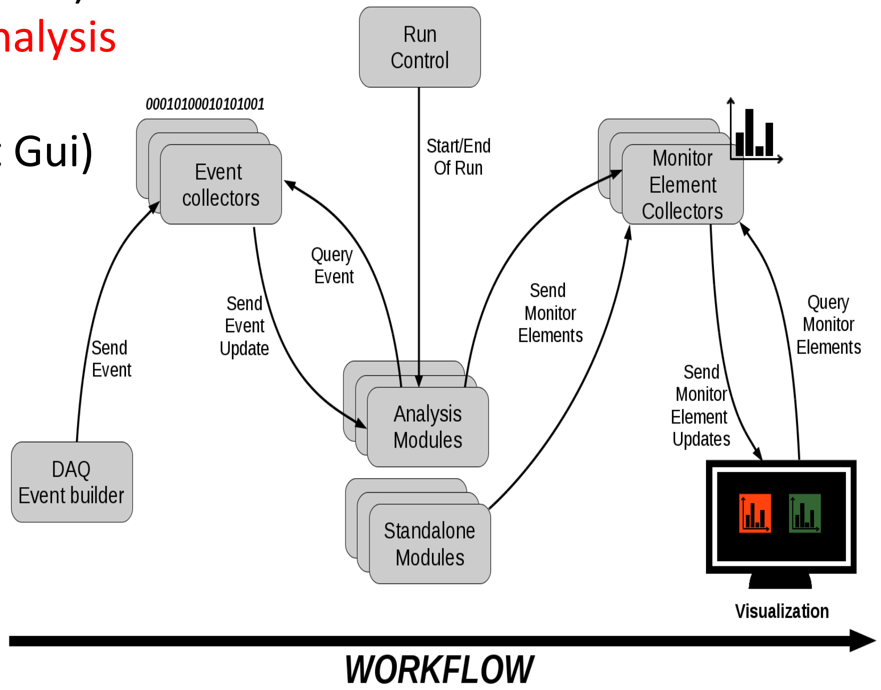
Online monitoring

DQM4HEP: Data Quality Monitoring for High Energy Physics

This is a generic C++ framework to perform online data analysis and data quality report. It deals with online application workflow, inter-process communication and memory management.

Main features :

- Event distributed system (client / server architecture)
- Set of user interfaces designed for data quality analysis
- Monitor element distributed system
- Graphical user interface for data visualisation (Qt Gui)
- Large scale remote process management
- Generic IO support for different experiments
- Designed for simple prototype monitoring up to complex systems like ILD or LHC detectors
- Logbook interface (ELog)



Example: **Hit map control**