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The SDHCAL prototype
Present and future

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(On behalf of CALICE Collaboration)

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Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

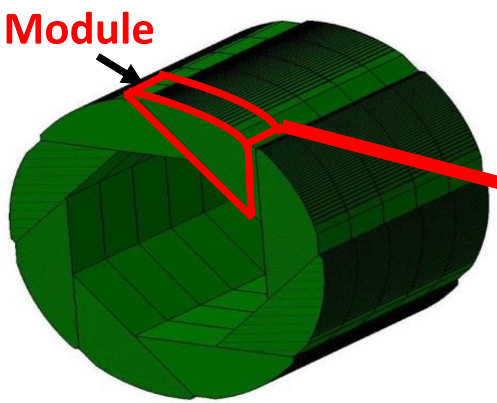
EXCELENCIA MARÍA DE MAEZTU

cfp CIEMAT física de partículas

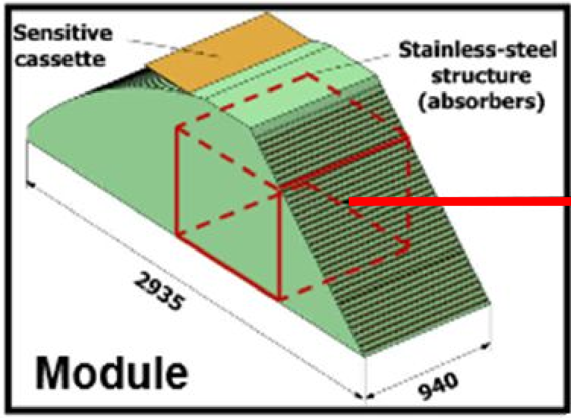
Semi-Digital Hadronic Calorimeter (SDHCAL) -ILD prototypes

The SDHCAL-GRPC is one of the two HCAL options based on PFA and proposed for **ILD of ILC**.
Modules are made of **GRPC** (**G**lass **R**esistive **P**late **C**hambers) equipped with **semi-digital, power-pulsed electronics** readout and placed in **self-supporting mechanical** structure to serve as absorber as well.

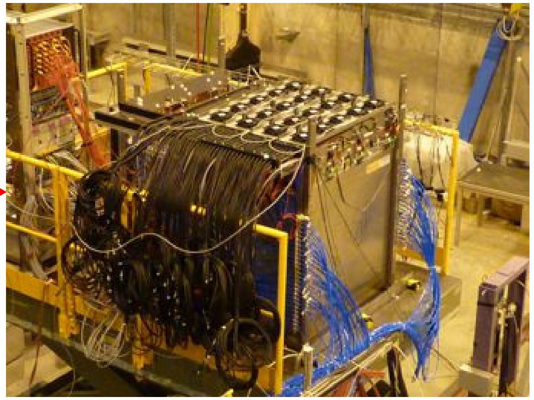
SDHCAL ILD barrel



SDHCAL ILD module



SDHCAL 1.3m^3 prototype



Absorber: Stainless Steel
Active Medium: GRPC
SemiDigital readout. **1cm^2 pads**

Electronics embeded in the detector

ILD SDHCAL
Plates & GRPCs:
up to **~3x1 m^2**
Absorber assembly
Welding?

~1.3m3 SDHCAL prototype
Plates & GRPCs :
~1x1 m^2
Absorber assembly:
Bolted

HIGH GRANULARITY CALORIMETER

SDHCAL – Main characteristics

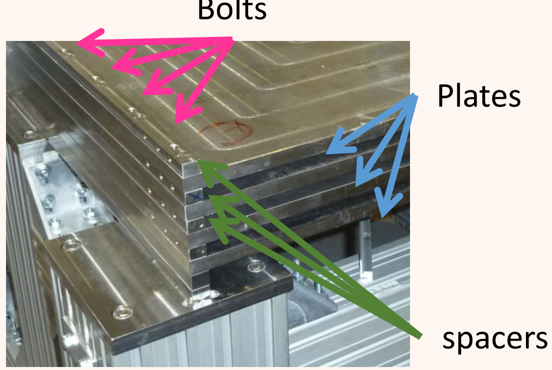
Absorber: **Steel** (**20 mm thick**).

Absorber **plates up to ~3x1 m^2** .

Surface **planarity < 1mm** ,

Thickness tolerance **50µm**

Plates assemble together by using an intermediate **spacer** insuring the place for introducing the detectors



Detail after assembly the **first 4 absorber plates of the 1.3m^3 prototype (plates ~1x1m^2)**

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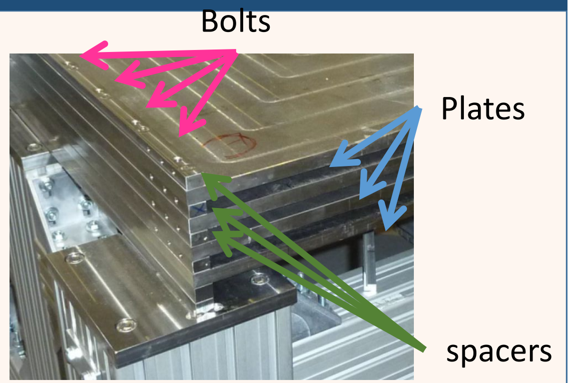


Detail after assembly the **first 4 absorber plates of the 1.3m^3 prototype (plates ~1x1m^2)**

Detector: **GRPC (Glass Resistive Plate Chambers)** operating in **avalanche mode**

1x1 cm^2 pads. Semi-Digital Readout, 2bits **- 3 thresholds**

➔ It counts **how many** and **which pads** have a **signal larger than one of the 3 thresholds**

Embedded electronics:

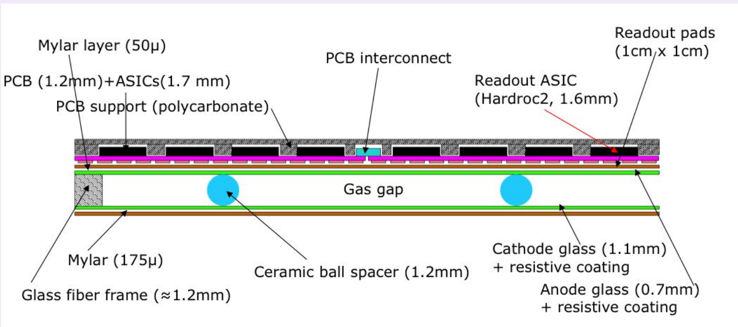
PCB separated from the GRPC by a mylar layer (50µm).

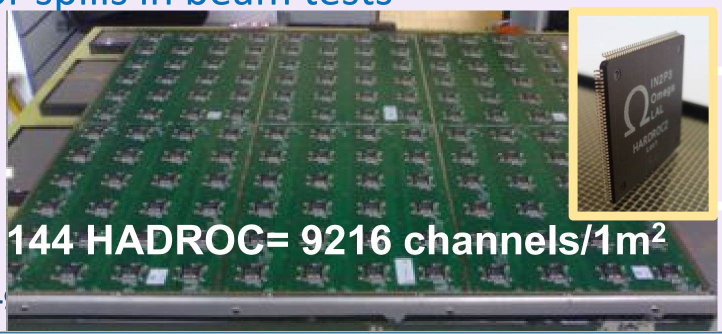
➔ Bottom: **1x1cm2 pads**

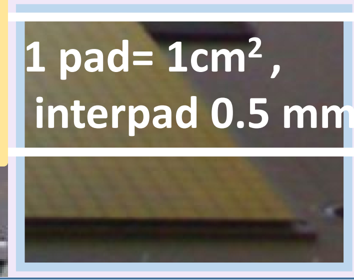
➔ Top: **HADROC** (**HA**dronic **R**pc **R**ead**O**ut **C**hip) & related connections

Power-pulsed electronics: In **stand-by during dead time** in between ILC Collisions or spills in beam tests

GRPC Sketch

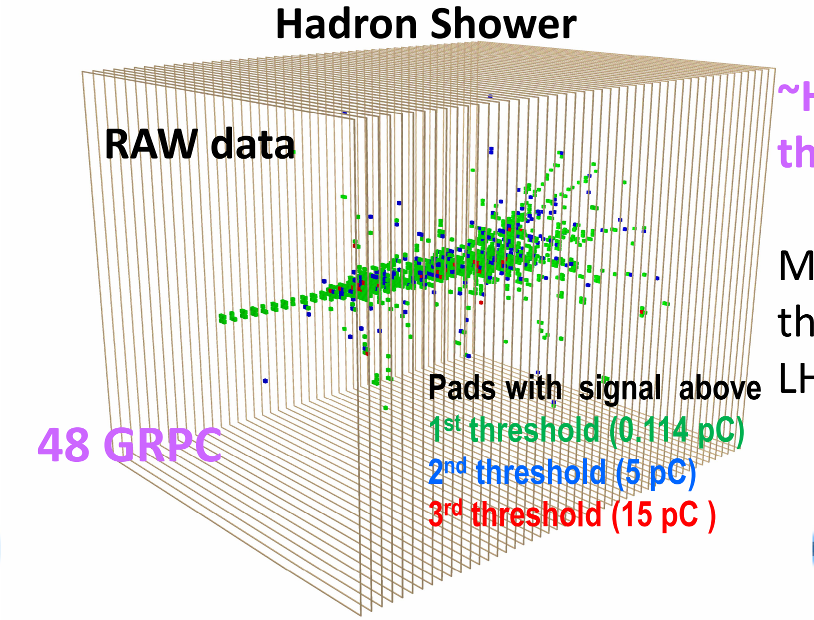






Performance of the SDHCAL 1.3m^3 prototype – (I)

N_1= Nb. of pads with **first threshold <signal < second threshold**
N_2 = Nb. of pads with **second threshold <signal < third threshold**
N_3 = Nb. of pads with **signal> third threshold**



~Half million of channels in the prototype

More readout channels than in the full calorimeter systems of LHC detectors

Performance of the SDHCAL 1.3m³ prototype – (I)

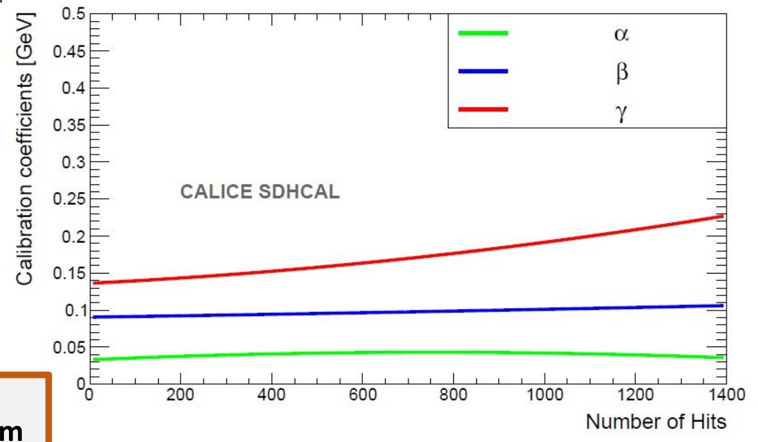
Energy Reconstruction – SemiDigital Readout

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

$N_{tot} = N_1 + N_2 + N_3$

α , β , γ are **quadratic functions** of N_{tot}

They are computing by minimizing $\chi^2 = (E_{beam} - E_{rec})^2 / E_{beam}$

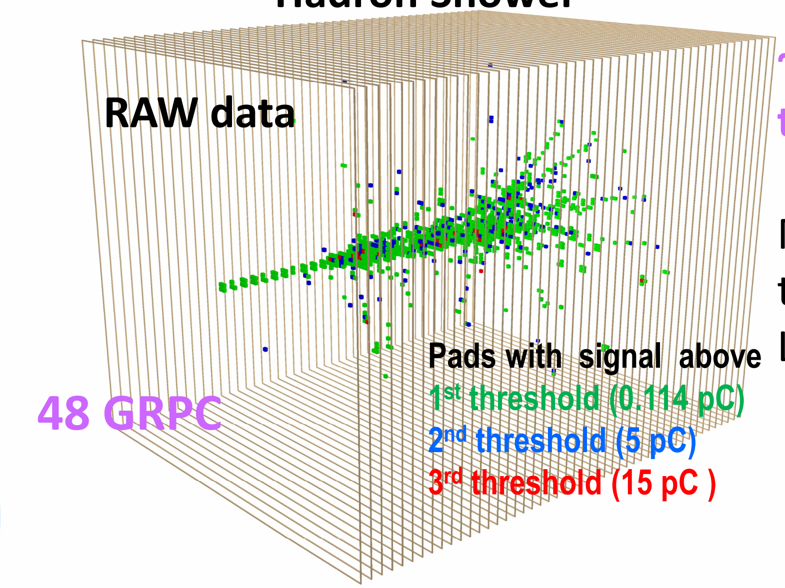


N_1 = Nb. of pads with **first threshold <signal < second threshold**

N_2 = Nb. of pads with **second threshold <signal < third threshold**

N_3 = Nb. of pads with **signal> third threshold**

Hadron Shower



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More readout channels than in the full calorimeter systems of LHC detectors

Performance of the SDHCAL 1.3m^3 prototype – (I)

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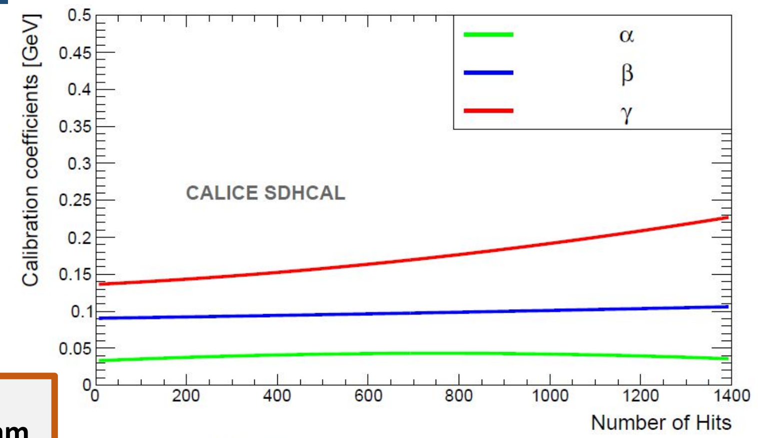
$$N_{tot} = N_1 + N_2 + N_3$$



α, β, γ are quadratic functions of N_{tot}
They are computing by minimizing $\chi^2 = (E_{beam} - E_{rec})^2 / E_{beam}$

N_1 = Nb. of pads with **first threshold <signal < second threshold**
N_2 = Nb. of pads with **second threshold <signal < third threshold**
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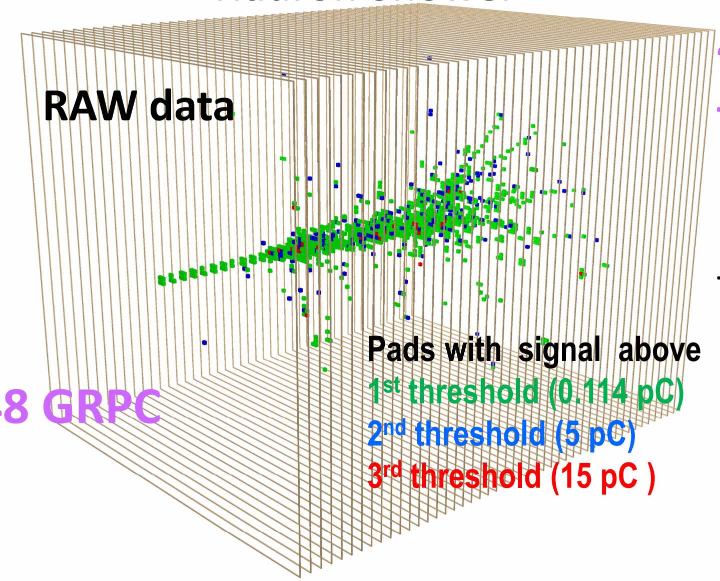
Hadron Shower



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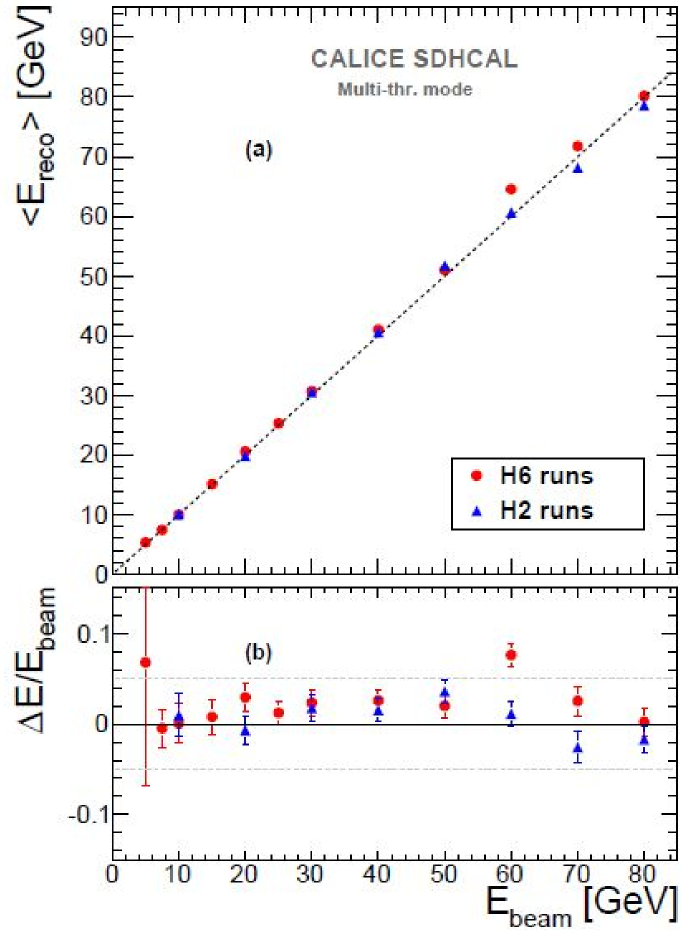
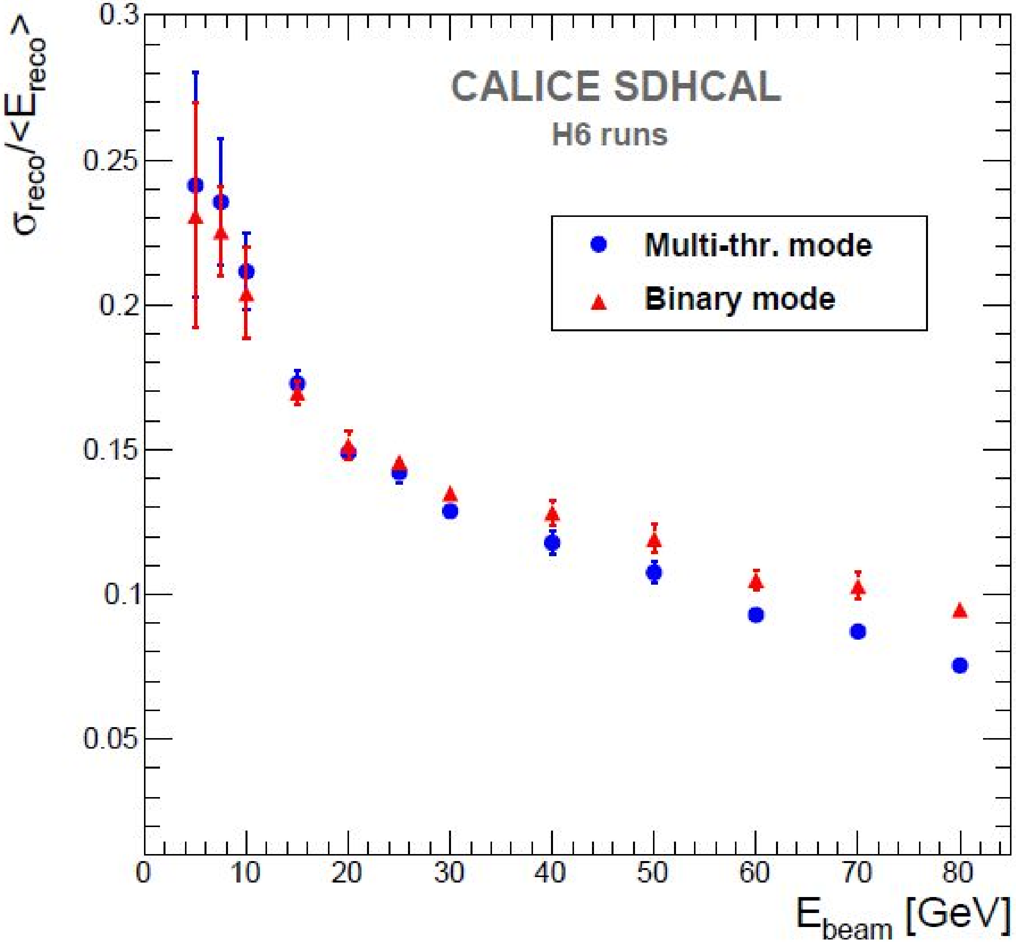
More readout channels than in the full calorimeter systems of LHC detectors



Performance of the SDHCAL 1.3m^3 prototype – (II)

Comparison semi-digital (3 thresholds) versus binary readout (1 threshold)



Substantial improvement a energy > 30 GeV

When increasing energies the binary produces **saturation** (mainly in the core of the shower). The number of particles crossing a single pad increases

Advantage vs an analogic ("standard") HCAL Is any ?

It allows a **higher granularity at lower costs**. **Granularity is crucial to improve the jet energy resolution using Particle Flow Algorithms.**

Jet energy resolution is needed to be a factor 2 better at ILC compared to LHC to achieve the high precision required for the ILC physics goals.

Towards a ~1x3m^2 long SDHCAL prototype

Different studies have shown that the SDHCAL technology fulfill the requirements for a ILD HCAL from the point of view of physics, but… is it feasibly a large scale calorimeter as the one for the ILD? Which will be the more robust way to construct it? How are the costs?

The largest plates & GRPC of ILD are as large as ~1mx3m. This imposes more difficulties than a 1mx1m design

R&D under development for a new prototype
- → **Chambers**
- → **Electronics**
- → **Mechanical Structure**

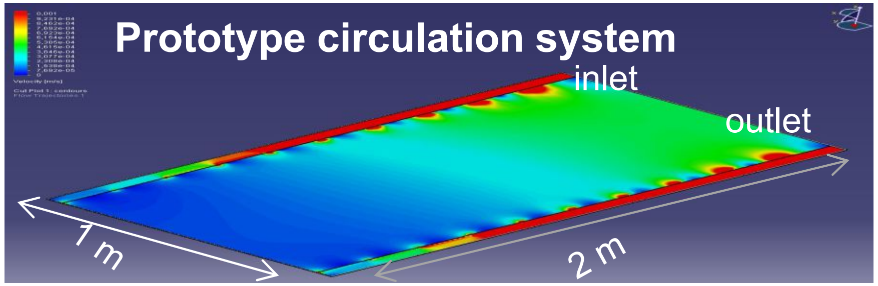
GOAL:
To build a prototype with a mechanical structure of 4-5 plates of ~1x3m^2 (assembly with similar procedures to the final one) where inserting large RPCs equipped with a new improved electronics.

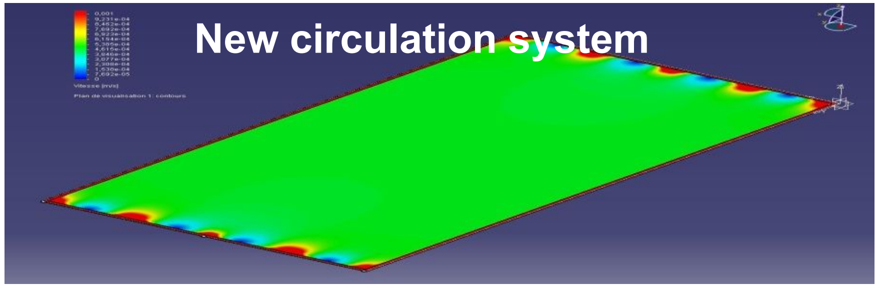
Larger GRPCs

GRPCs up to ~3x1m2 needed (1x1m2 in the 1.3m3 SDHCAL prototype)

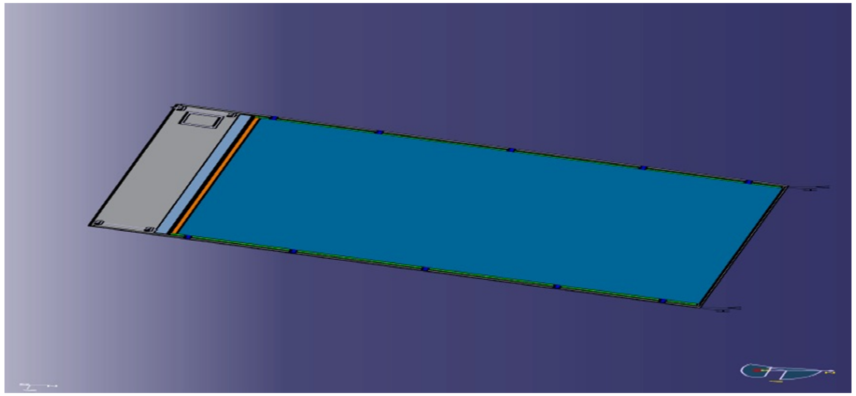
Some improvements are needed.

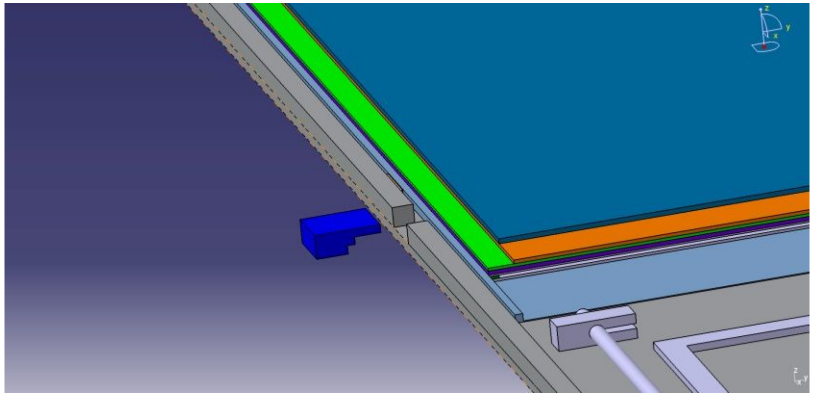
- New scheme for the **gas distribution** is proposed





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



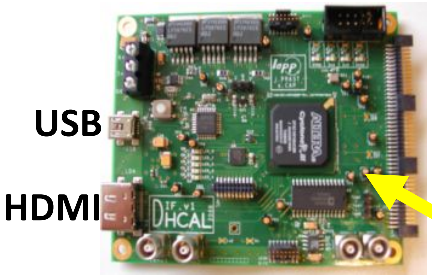


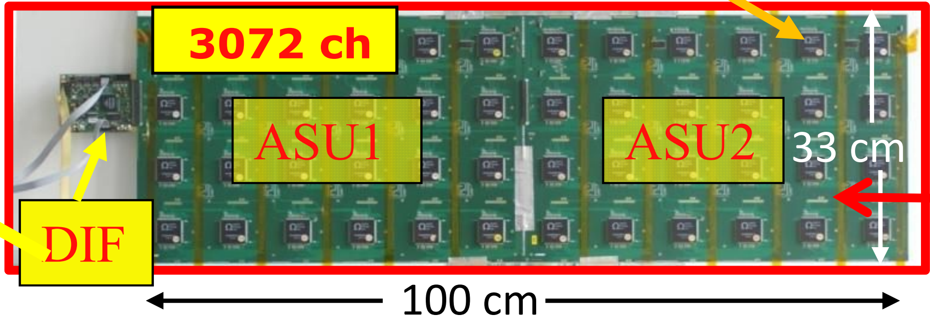
New electronics: ASIC,PCB,DIF

Electronics readout for the 1m³ prototype

HADROC chip

1m² board → 6 ASUs hosting 24 ASICs





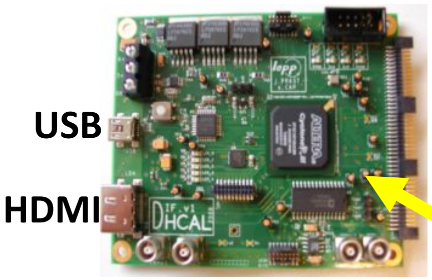
1 DIF for 2 ASU (Active Sensor Unit.- PCB+ASICs) → **3 DIFs for ONE 1m2 GRPC detector**

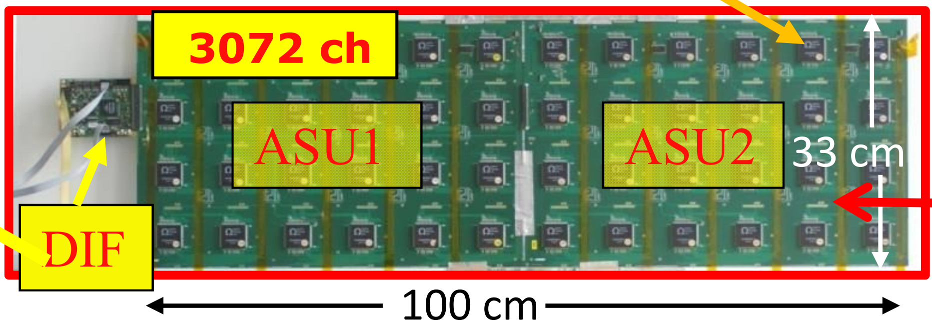
New electronics: ASIC,PCB,DIF

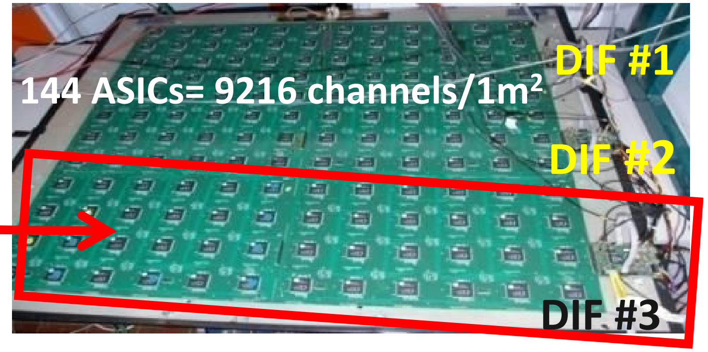
Electronics readout for the 1m^3 prototype

HADROC chip

1m^2 board ➔ 6 ASUs hosting 24 ASICs





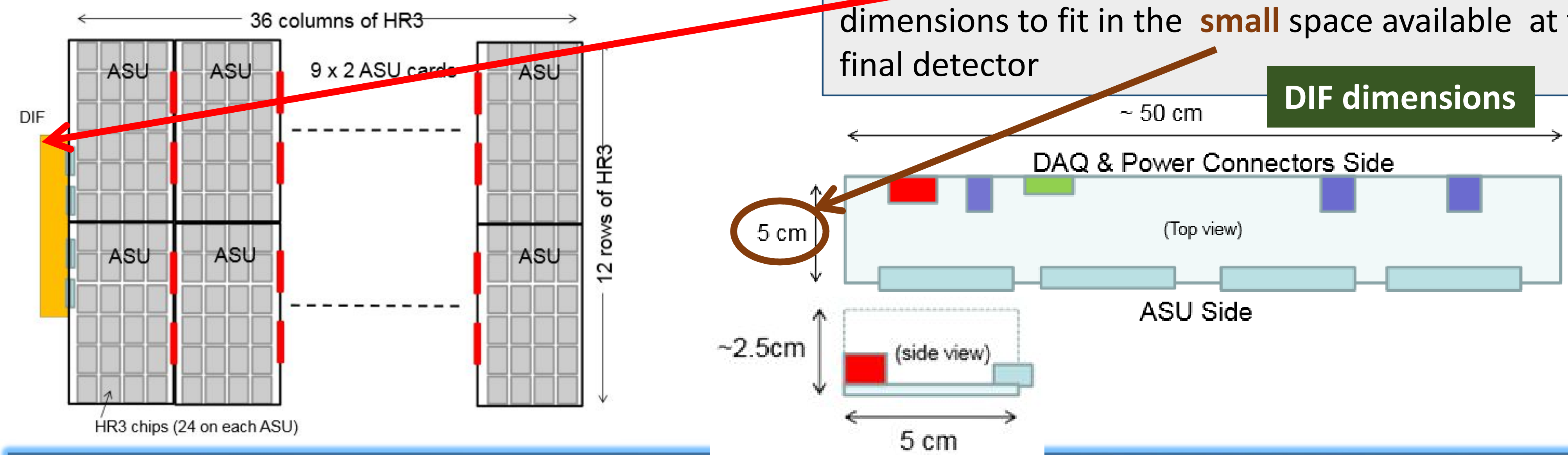


1 DIF for 2 ASU (Active Sensor Unit.- PCB+ASICs) ➔ **3 DIFs for ONE 1m2 GRPC detector**

Electronics readout for the final detector

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

DIF dimensions



New electronics: ASIC,PCB,DIF

New ASIC — HADROC3 (HR3)

Zero suppress
Extended dynamic range (up to 50 pC)
I2C link with triple voting for slow control parameters
packaging in QFP208, die size ~30 mm2

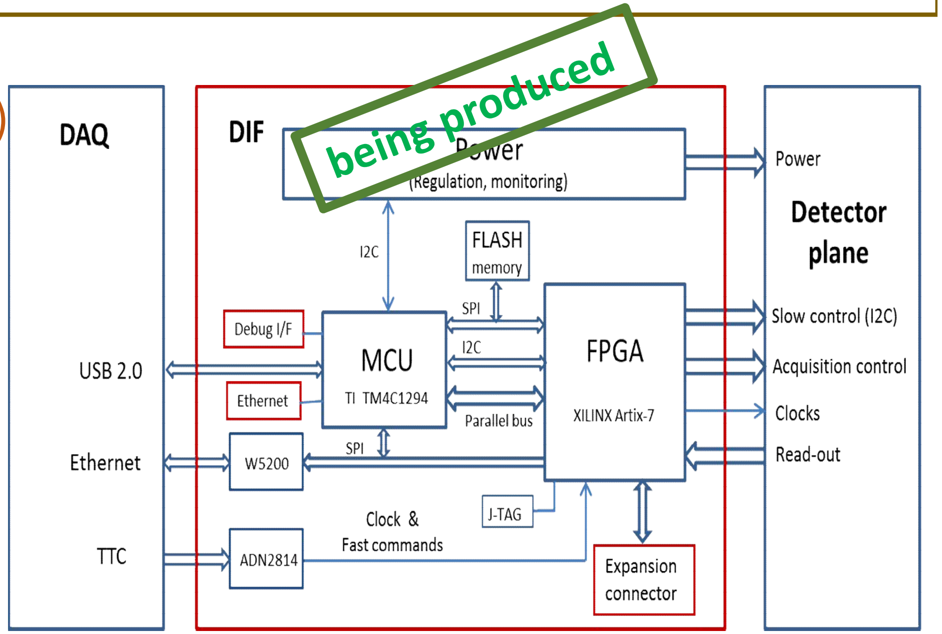
Chips already available

New ASU — The **ASU** (**A**ctive **S**ensor **U**nit) hosts the ASICs and connect them to the rest of electronics

1m X 0.33 m2, **12 layers ASU** with **new rooting design** was conceived — being produced

New DIF & DAQ — **DIF** (**D**etector **I**nter**F**ace) sends DAQ commands (config, clock, trigger) to front-end and transfer their signal data to DAQ. It controls also the ASIC power pulsing

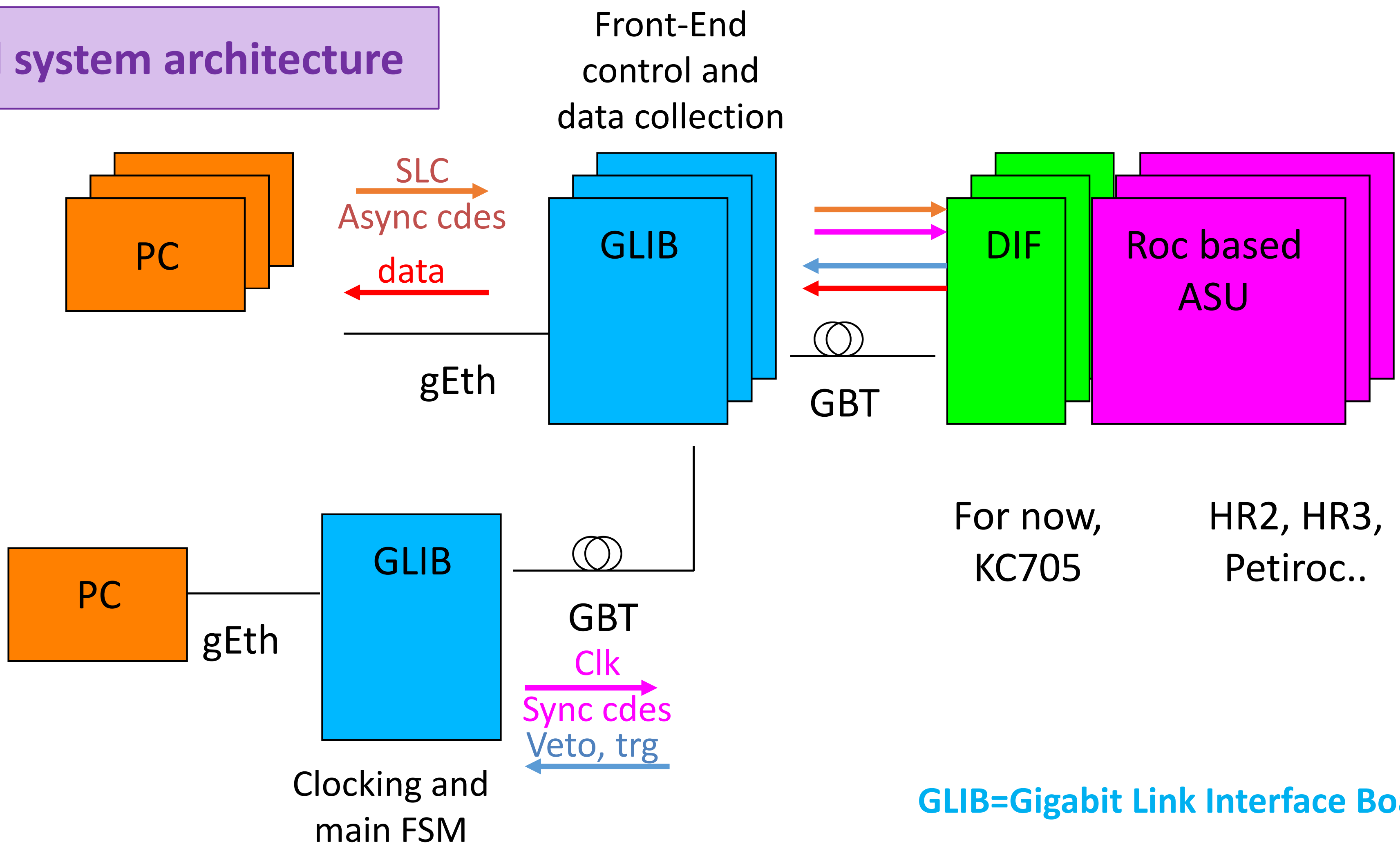
- Only **one DIF per plane** (instead of **three**)
- DIF handle up to **432 HR3 chips** (vs **48 HR2** in previous DIF)
- HR3 **slow control** through **I2C bus (12 IC2 buses).** Keeps also **2 of the old slow control buses as backup & redundancy**.
- **Data transmission to/from DAQ** by **Ethernet**
- **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**



DAQ

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

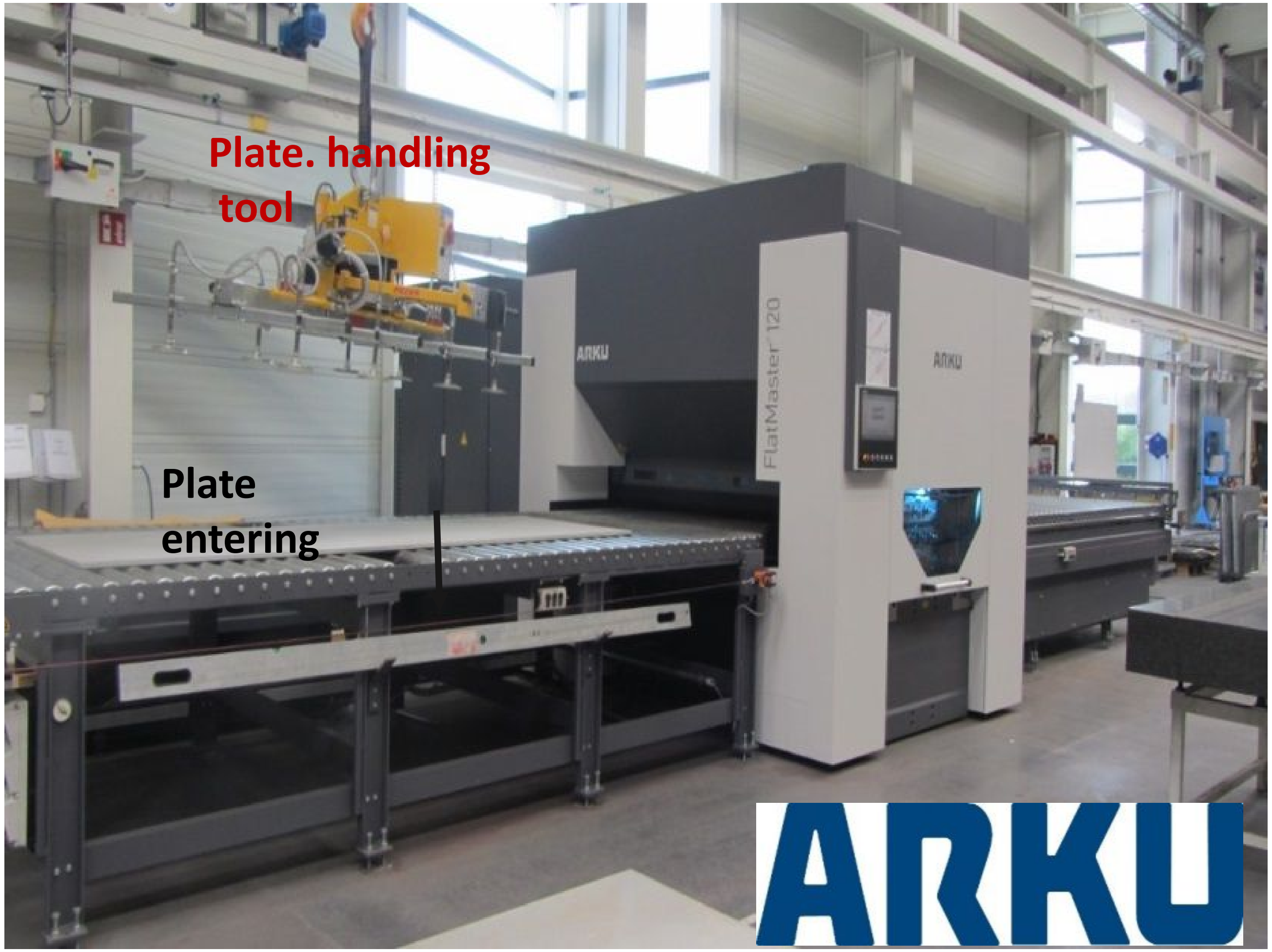


GLIB=Gigabit Link Interface Board

Mechanical Structure: Plates

Industrial production of large absorber plates (~3 m X 1 m) by **roller leveling** process with very good **flatness** (< 1mm)

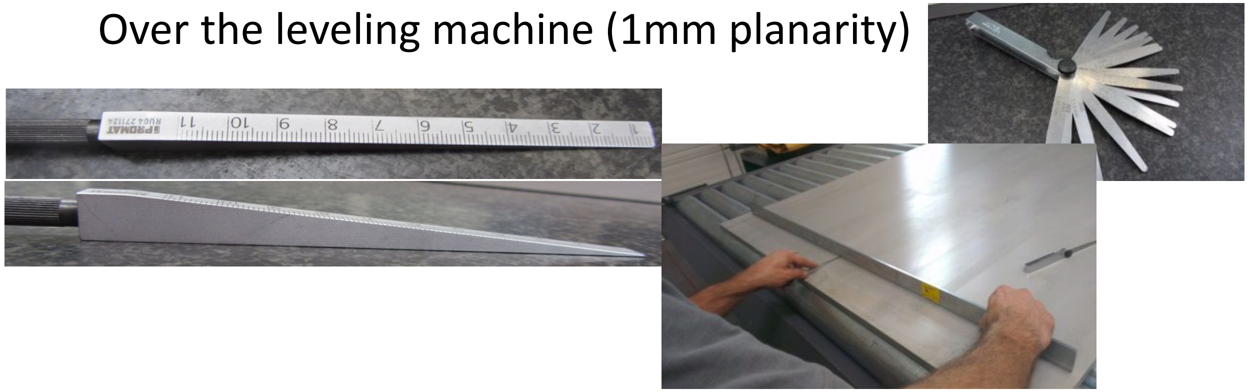
Roller leveling at **ARKU Baden-Baden (Germany)**
[*www.arku.de/*](http://www.arku.de/)

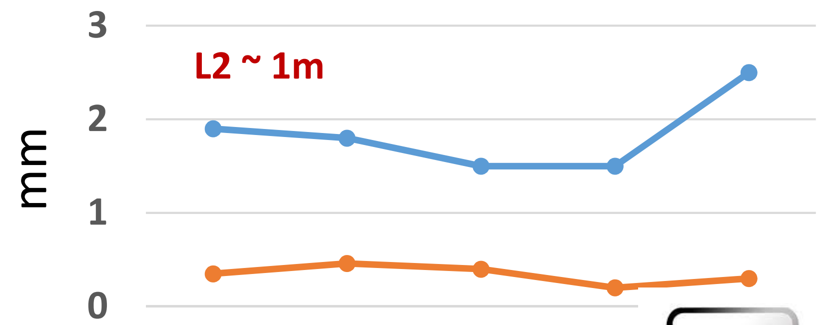


Plates (~3x1m^2) planarity & thickness

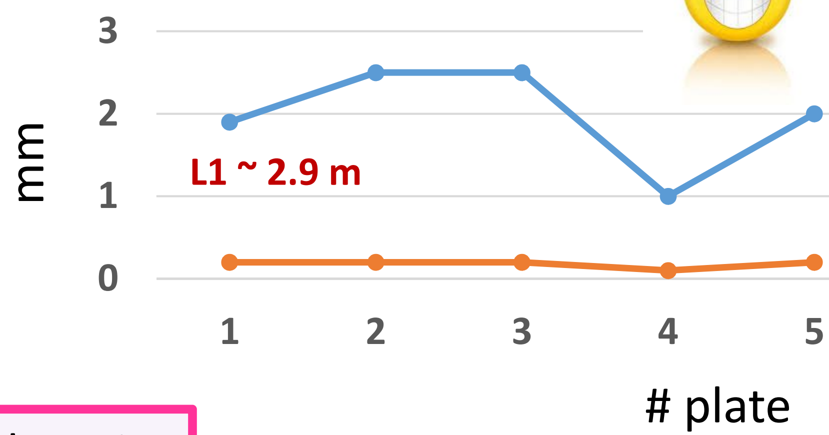
Fast quality control performed during the tests at ARKU

The measurements have been done using **feeler gauges**
Over the leveling machine (1mm planarity)





Before
After using roller levelling



More precise quality control at CIEMAT

Measurements using **laser interferometer.**
Over a flat table (0.1mm planarity)

Planarity

Plate	A	B	C	D	E
Side up (μm)	2.7	30.0	43.2	175.0	12.3
Side Down (μm)	67.3	116.4	26.0	49.8	48.6

Thickness

Plate	A	B	C	D	E
Average (mm)	15,324	15,233	15,334	15,225	15,322
max (mm)	15,324	15,292	15,348	15,270	15,325
min (mm)	15,323	15,173	15,320	15,179	15,318
Δ (mm)	0,001	0,119	0,028	0,091	0,007

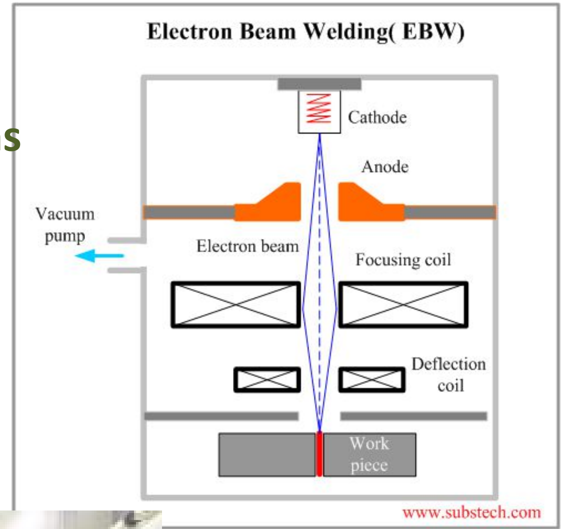
Mechanical Structure: Welding procedure

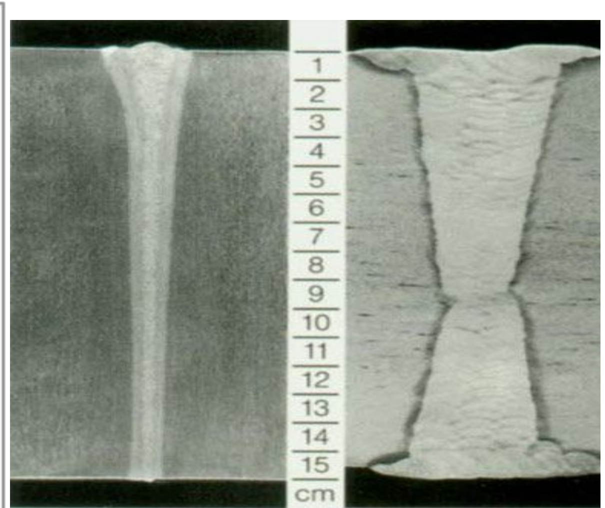
Improvement on the present system is being made by using **Electron Beam Welding (EBW)** rather tan bolts to reduce the deformation and the spacers thickness.

Collimate electron beam

➔ Very **narrow welding** ➔ **Less deformations**

Vacuum conditions needed





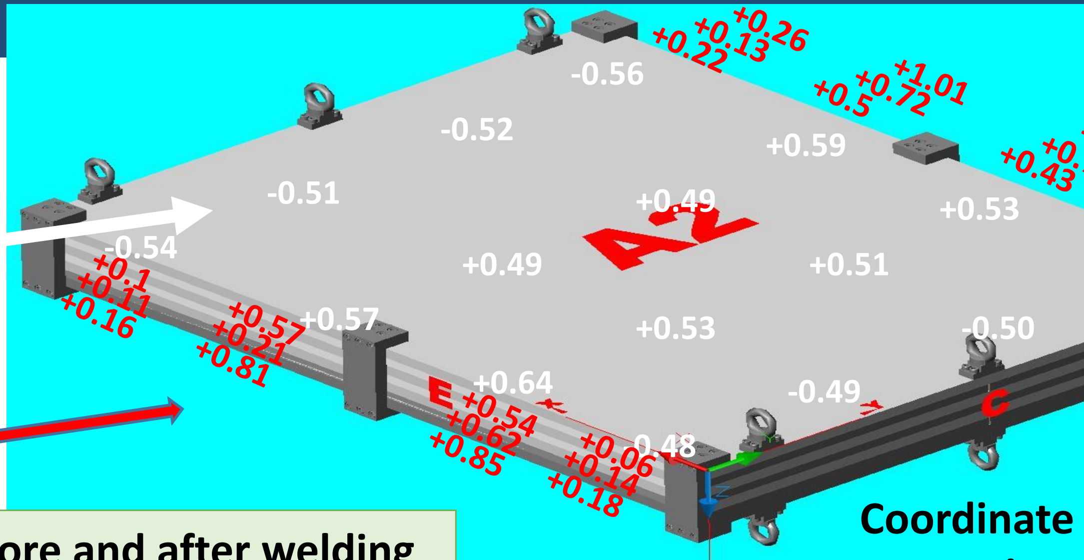
EBW Machine @ CERN

Electron beam Welding @CERN:Tests with Small prototypes

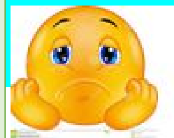
First small prototype: 4 plates 1x1 m2

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

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



Coordinate measuring machine



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

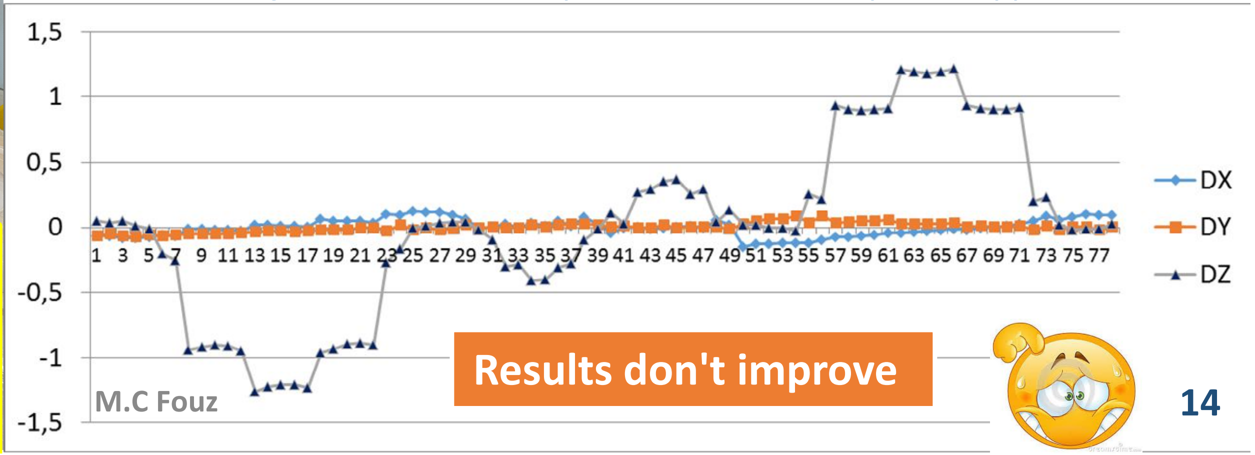
O.K in Y-axis

➔ **Probably due to the welding sequence used??**

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

Second small prototype: 4 plates 1x0.5 m2

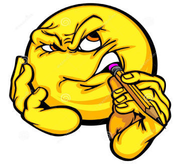
Welding performed **changing a bit the welding sequence** with respect to the first prototype



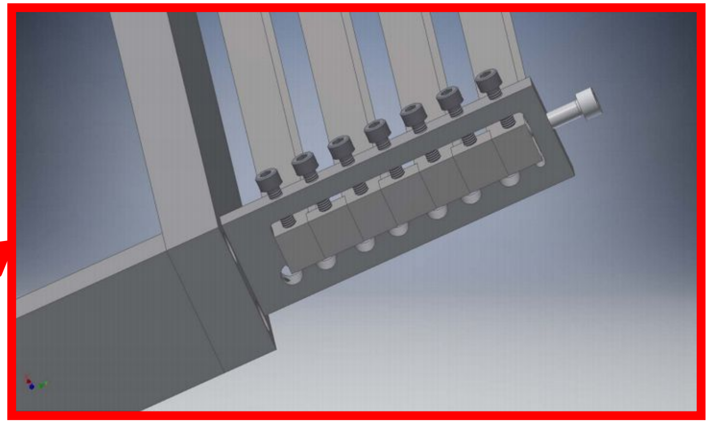
Results don't improve

Next step – Optimization with small pieces

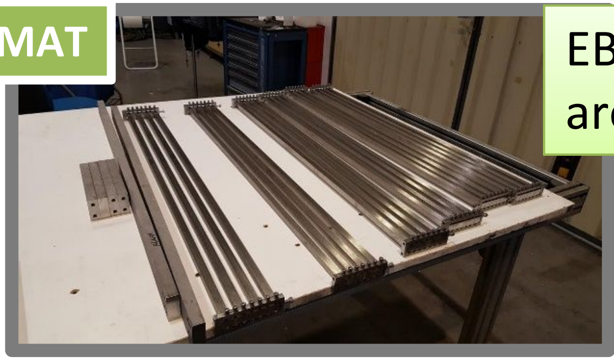
Before assembling new small prototypes some tests using **smaller pieces** are foreseen to evaluate "qualitatively" the best way for performing the welding



This should allow to make several **cheaper tests**, **changing the sequences and depth of welding** in order to find the procedure producing the **lowest deformation**.



Pieces already produced at CIEMAT



EBW tests should start around February 2017

It depends on CERN welding machine availability

➔ **The best option will be tested in a small prototype** (similar to the second one)

Once the procedure is optimized a larger prototype (plates ~3mx1m) will be built

Status Summary and pending things

➔ It has been demonstrated that the **SDHCAL technology fulfill the physics requirements as hadron calorimeter for the ILC detectors**

➔ **New developments for having big GRPCs and absorber structure together with the improved electronics & DAQ are ongoing.**

- New larger **chambers**:

  Design **ongoing**

- New **electronics** version: HADROC, ASU & DIF

  Available by ~**March 2017**

- **Mechanical Structure**
  - **Plates**

    Thickness & planarity inside requirements

    Finished

  - **Assembly procedure** using electron beam welding

    Procedure **being defined** using small prototypes and special designed pieces