Technological Semi-Digital Hadronic Calorimeter (SDHCAL) prototypes for future Lepton colliders

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On behalf of the SDHCAL CALICE group

Why a SDHCAL? - General characteristics

To achieve the required excellent jet resolution Particle Flow Algorithms can be used.
This imposes the use of high granular calorimeters

Requirements

- ✓ Highly granular calorimeter ➔ True and efficient separation and association of closely spaced energy clusters with the correct tracks.
- ✓ Shower reconstruction is important
- ✓ Many longitudinal sampling ➔ To avoid jet energy resolution degradation via the sampling term
- ✓ Need excellent linkage to tracker

➔ **The calorimeters become a tracking device**

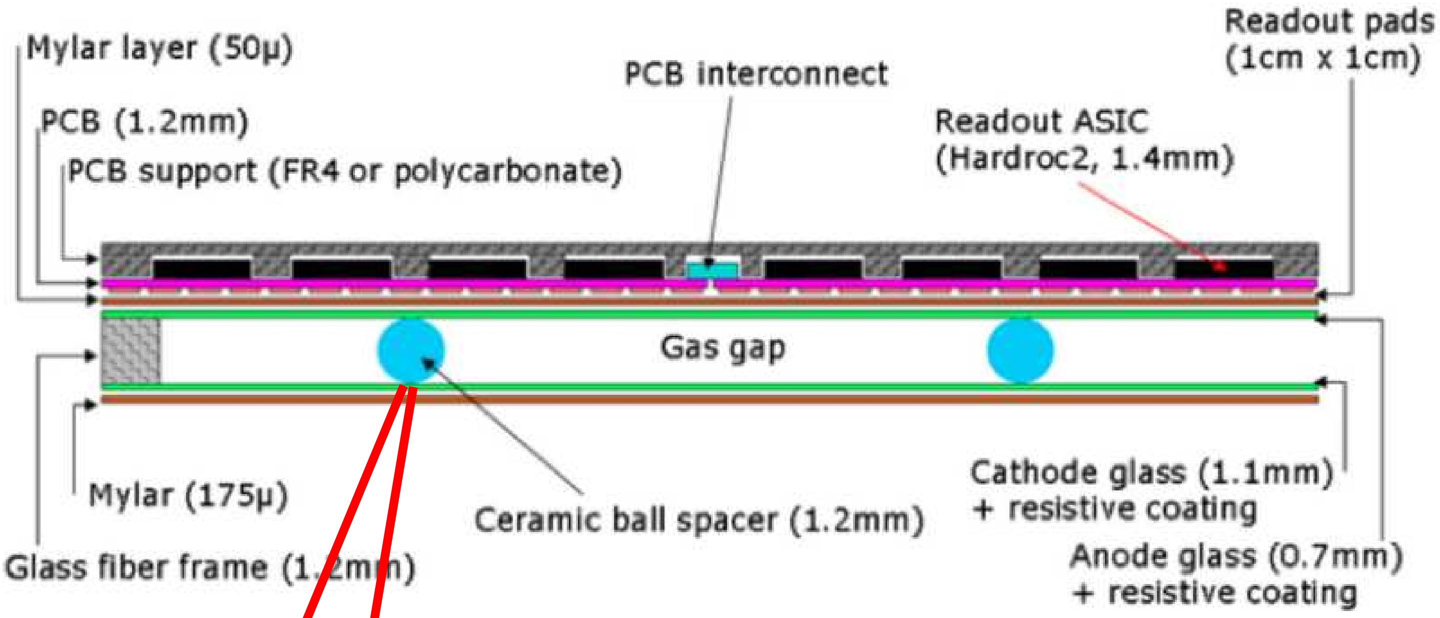
The **SDHCAL** is a **sampling calorimeter** made of
Glass Resistive Plate Chambers (GRPC) and **stainless steel**

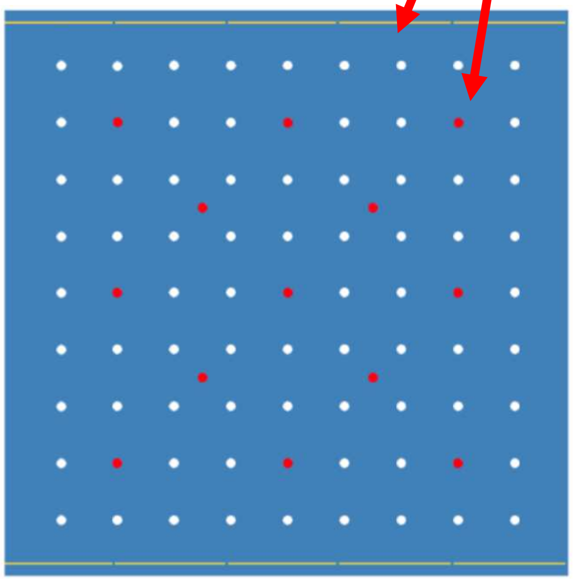
The **GRPCs** are **robust and cheap** gas detectors and their **readout can be easily segmented**
For the SDHCAL the readout is done by **1x1 cm2 pads**, longitudinally the absorber is 2cm thick
➔ **Very high granularity**

The readout is done in **semi-digital mode**: It uses the **number of hits instead of deposited energy** (**how many & which paths over a threshold**). ➔ **Simpler electronics**

GRPCs

GRPC sketch





$1x1m^2$

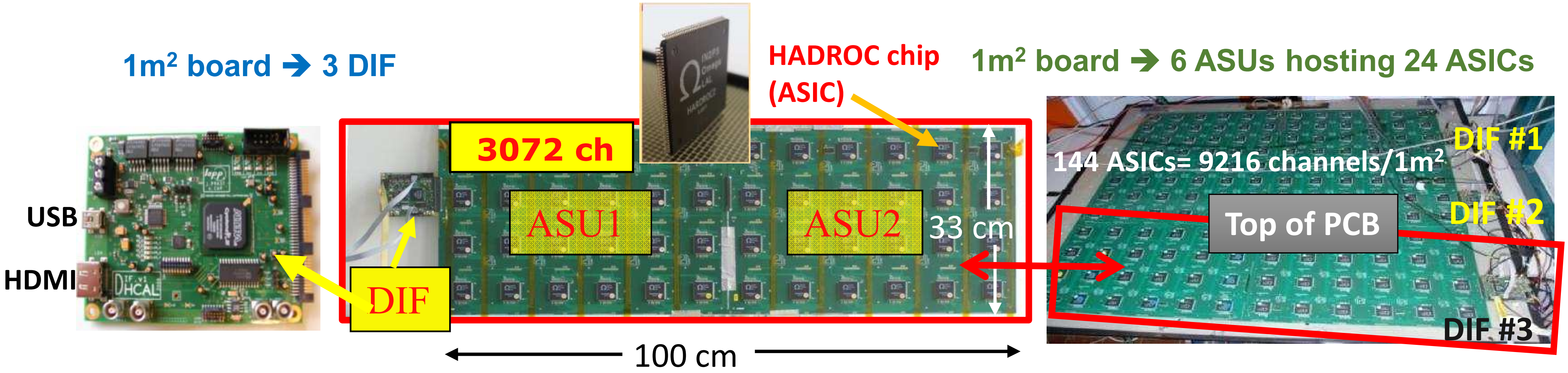
Avalanche Mode

2 – 10+ mV,
0.2 – 10+ pC
Very high efficiency (>95%)
Low noise
Lateral size (average <2 pads)
Rate capability (~100Hz/cm²)

GRPCs electronics

Readout 1m2 GRPC prototypes (Electronics embedded in the detector)

The HARDROC ASICs are hosted in a Printed Circuit Board (PCB).
PCB provides the connection between adjacent chips and link the first to the readout system



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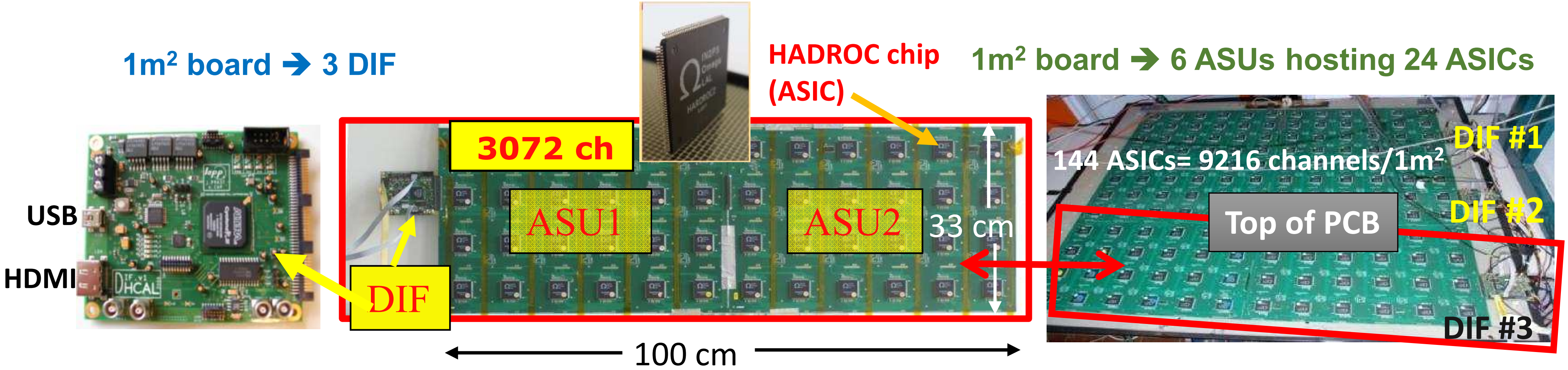

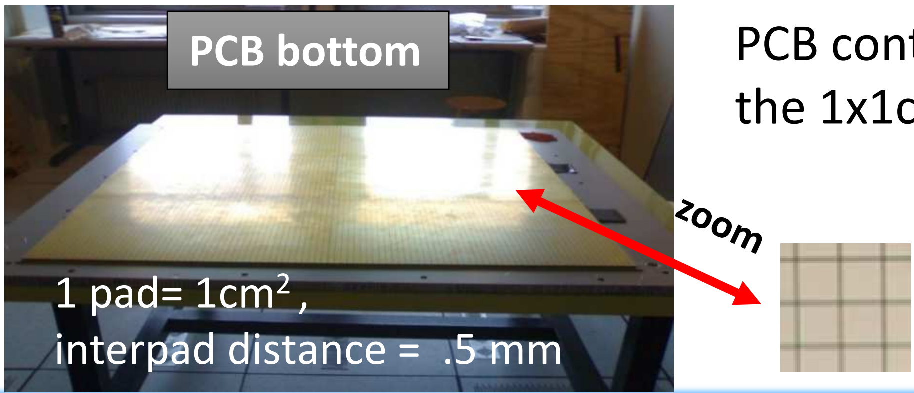

PCB contains in the opposite face
the 1x1cm2 copper pads

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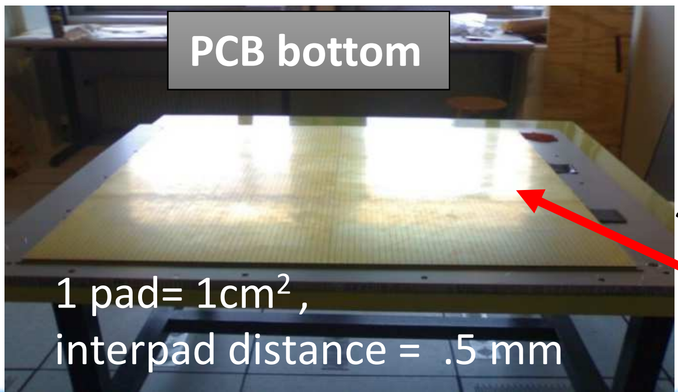
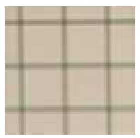
$1m^2$ board ➔ 3 DIF

$1m^2$ board ➔ 6 ASUs hosting 24 ASICs



zoom

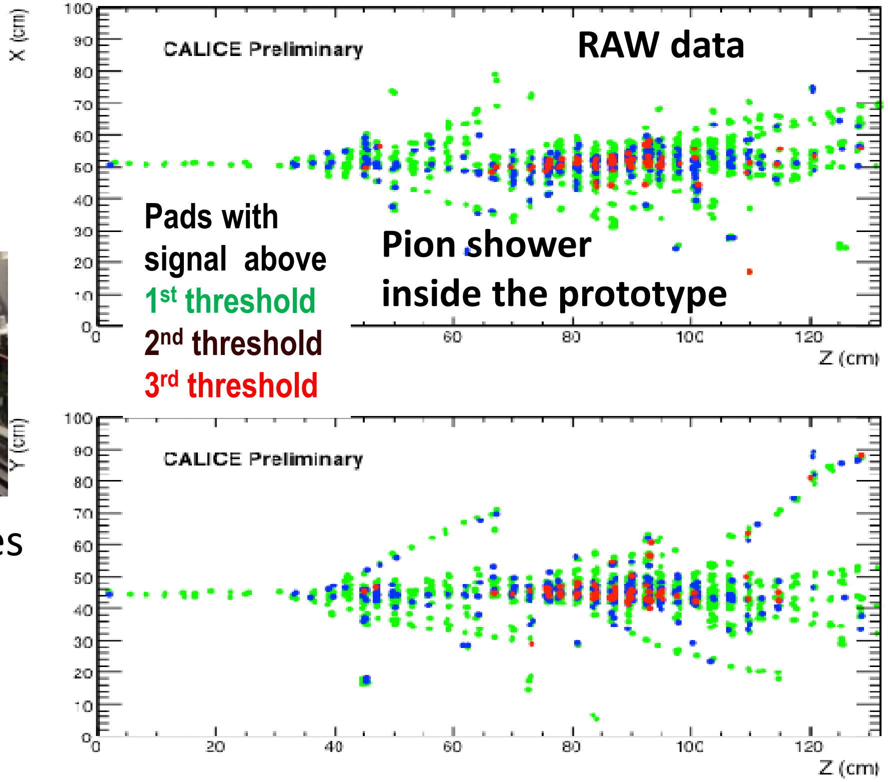


PCB contains in the opposite face
the 1x1cm2 copper pads

GRPC + electronics are hosted in a stainless steel box (cassette)

~1.3 m³ SDHCAL prototype

G. Baulieu *et al* 2015 *JINST* 10 P10039



50 Large **(1x1 m²) GRPC detectors** with almost not dead zones

Readout : **pads 1x1cm², semi-digital 3 thresholds**

→3 thresholds vs only 1 improve the energy resolution for higher energy particles (>40 GeV)

Electronics : **HARDROC ASIC chip**, **embedded**

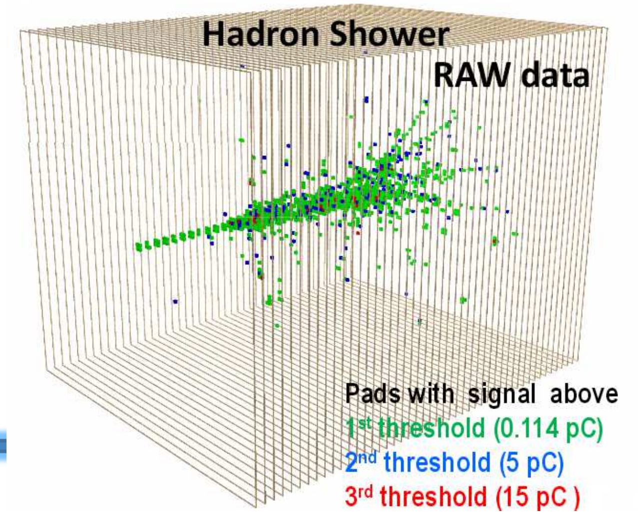
GRPC + electronics located in a cassette

(stainless steel, part of the absorber, 2x2.5mm thickness)

First detector using successfully power pulsed electronics the full prototype all the time

Self-supporting mechanical structure:

51 Stainless steel absorber plates (each 15 mm thickness)



Energy calibration

Triggerless acquisition mode → **Time Clustering for event building**

It includes also cosmics. **Particle identification** (muons, electrons, pions) is applied

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Energy Reconstruction – Binary mode

$N_{tot} = N1 + N2 + N3$ Number of pads with signal

$E_{reco} = (C + D\, N_{tot})\, N_{tot}$

N1 = Nhits crossing only the first (lower) threshold
N2 = Nhits crossing the 2nd threshold but not the 3rd
N3 = Nhits crossing the 3rd (higher) threshold

Allows restoring linearity

$C = 0.0543$, $D = 0.09 \times 10^{-4}$ Determined from data (Ebeam vs Nhit)

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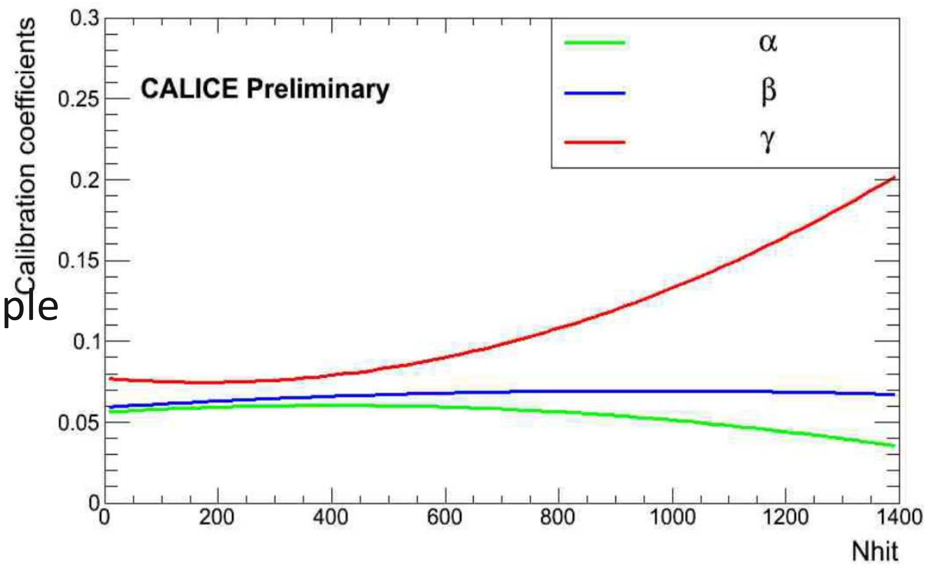
Energy Reconstruction – Multithreshold mode

$E_{reco} = \alpha\,N1 + \beta\,N2 + \gamma\,N3$

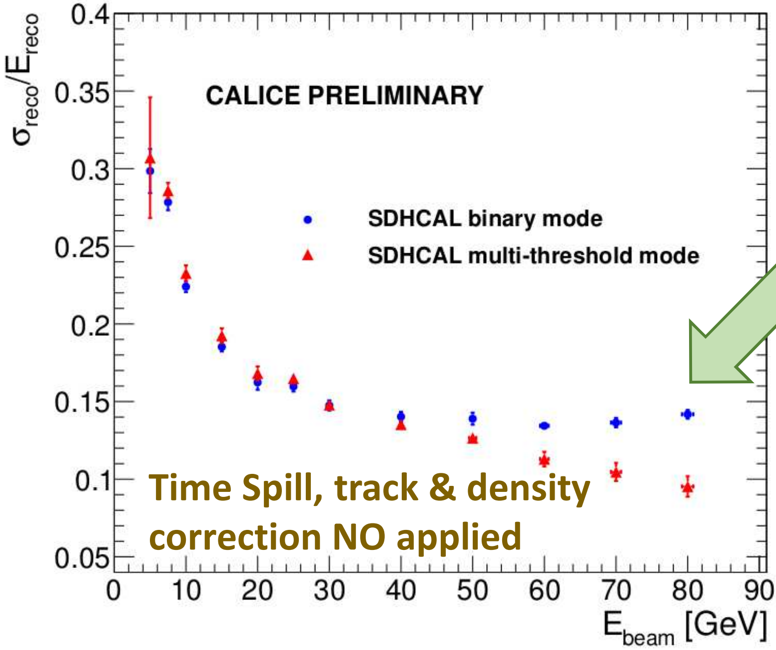
$\alpha, \beta, \gamma = f(N_{tot})$ (Quadratic function)

α, β, γ are obtained by minimizing from a data subsample

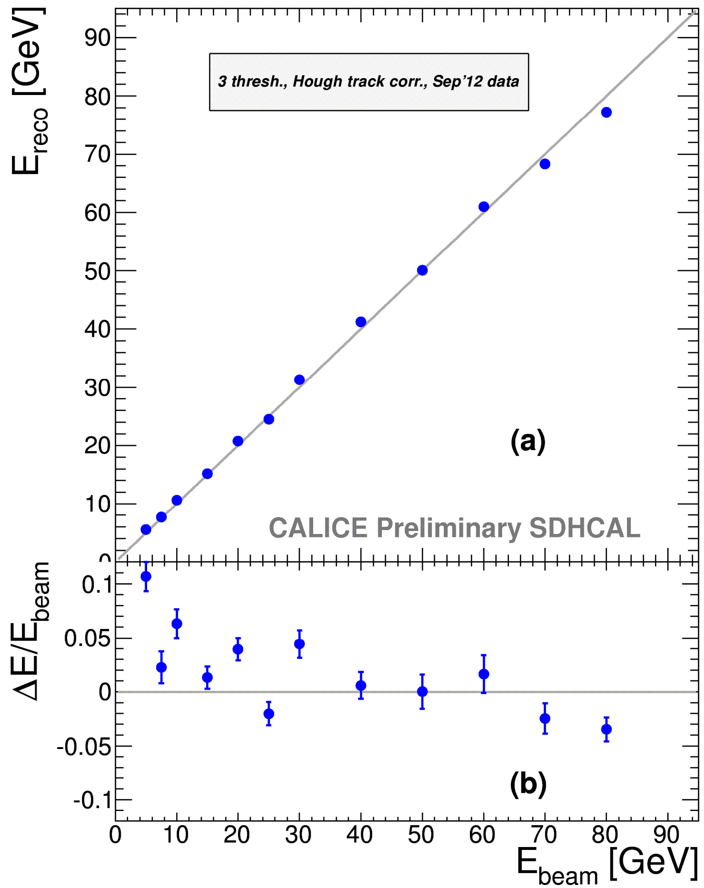
$$\chi^2 = \sum_{i=1}^{N} \frac{\left(E^i_{beam} - E^i_{reco}\right)^2}{E^i_{beam}}$$

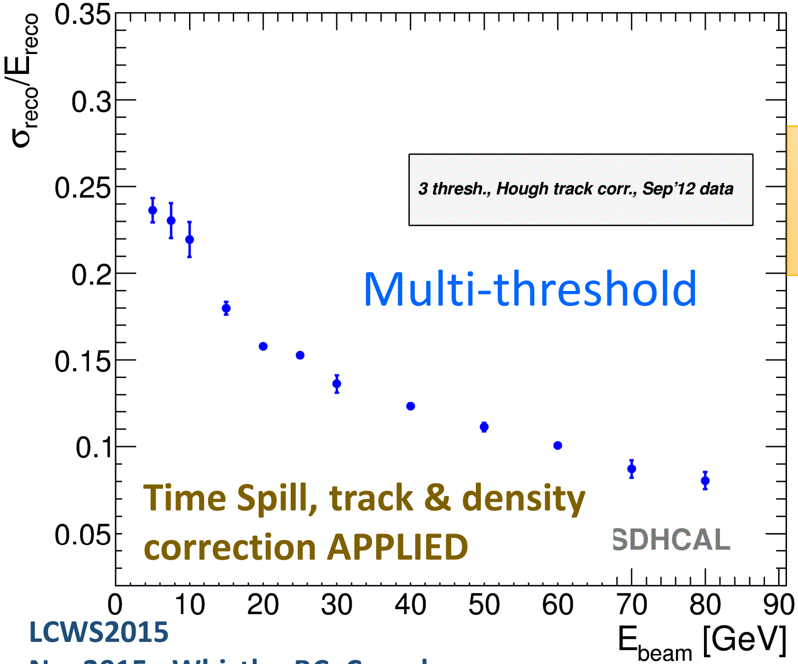


~1.3m³ SDHCAL Prototype Performance



Multi-threshold mitigate the saturation effects at higher energies and improve the resolution respect to binary.





Corrections improve the resolution

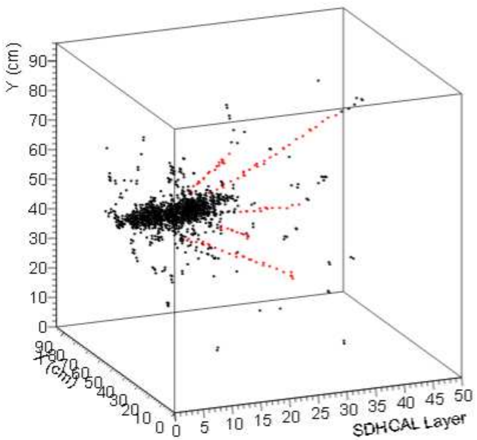
Use of Arbor for the first time in SDHCAL

See Rémi Eté's talk

More work is going on with new test beam data and on simulation optimization

SDHCAL – Single Track reconstruction

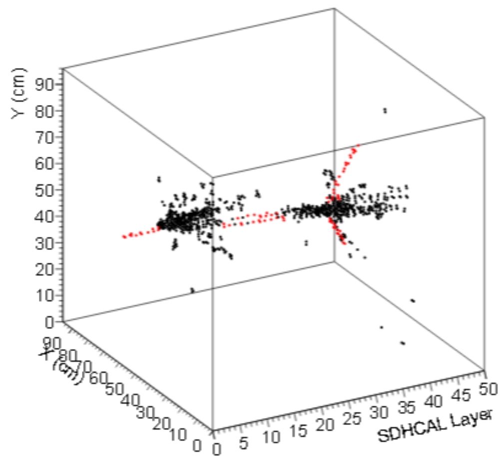
The excellent tracking capabilities allow to **distinguish single tracks** inside the shower
The analysis use the **Hough Transform Technique** (CaliceAnalysisNote CAN-047)



The tracks extracted from showers can be used for calibration, using them (requiring good tracks with good χ^2) to check the **efficiency** and **multiplicity** of the individual GRPCs

The values obtained are compatibles with the ones obtained using muons

This can be **very helpful in the PFA studies** as well to **disentangle the close-by hadronic showers** by **connecting clusters produced by hadronic interaction of secondary charged particles to the main one**

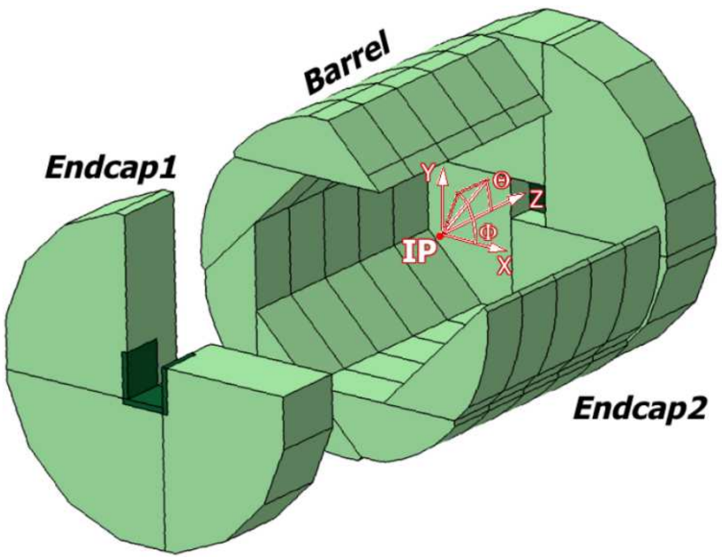


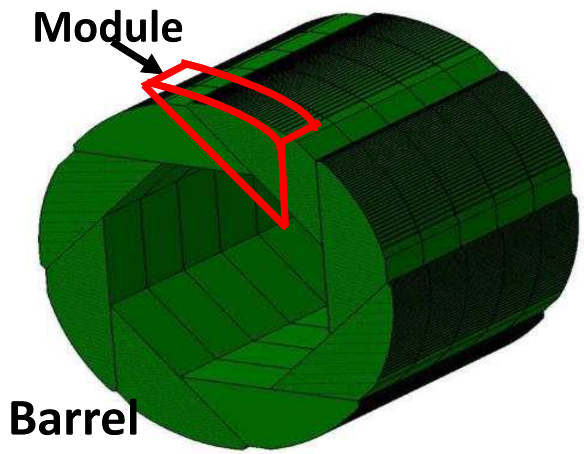
New prototype for validating the SDHCAL for ILD

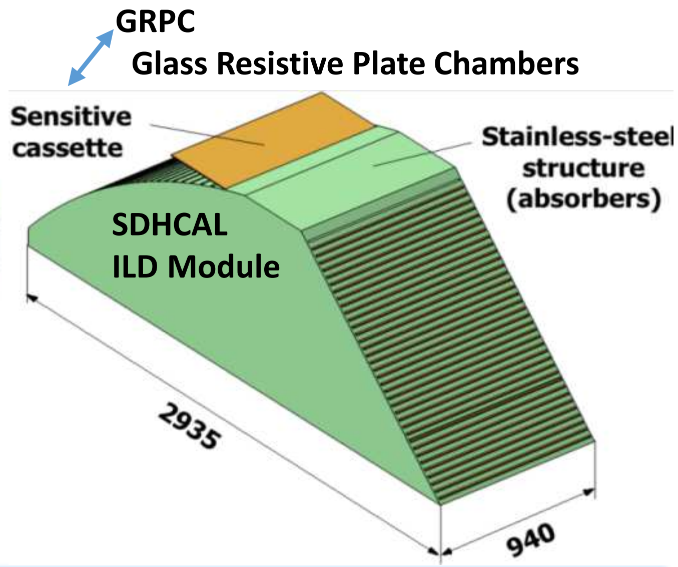
NEW PROTOTYPE MAIN GOALS

- Build a **few large GRPC** with the final dimensions foreseen for ILD
- Equip the GRPCs with a **new version of the electronics being developed**
- Design and build, with the same procedures as the final one, an **absorber mechanical structure** capable to host up to 4 large GRPC ($290x91m^2$)

ILD DHCAL







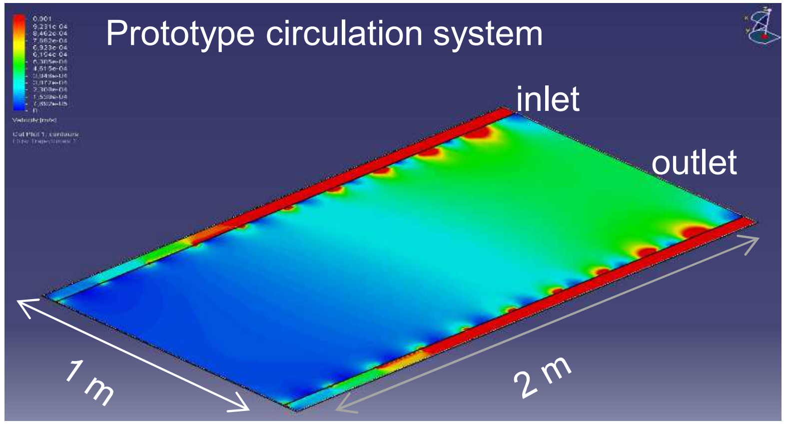
Large GRPC developments

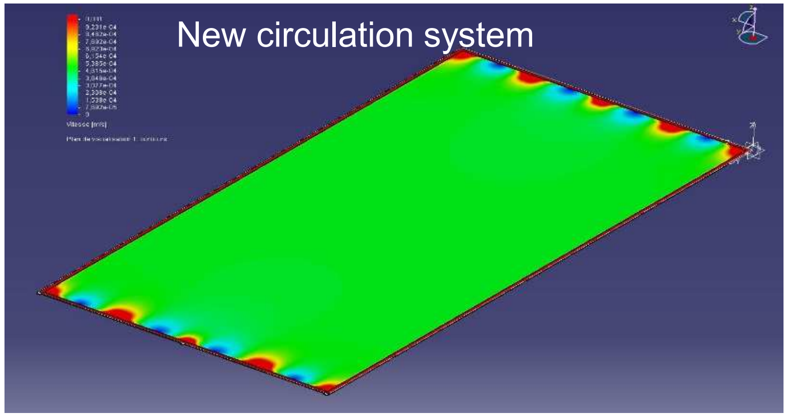
The **largest GRPC of SDHCAL is ~1x3 m²** our **next step is to build chambers ~1x2m²**

The most important issue is the gas circulation design to provide a good gas distribution to insure a homogeneous behavior (efficiency & multiplicity) over the full chamber

Simulation shows the **old distribution** used for the 1x1m² GRPC is **rather less efficient** for the 2m long chambers

A new distribution has been proposed





Electronics : ASIC – HADROC3

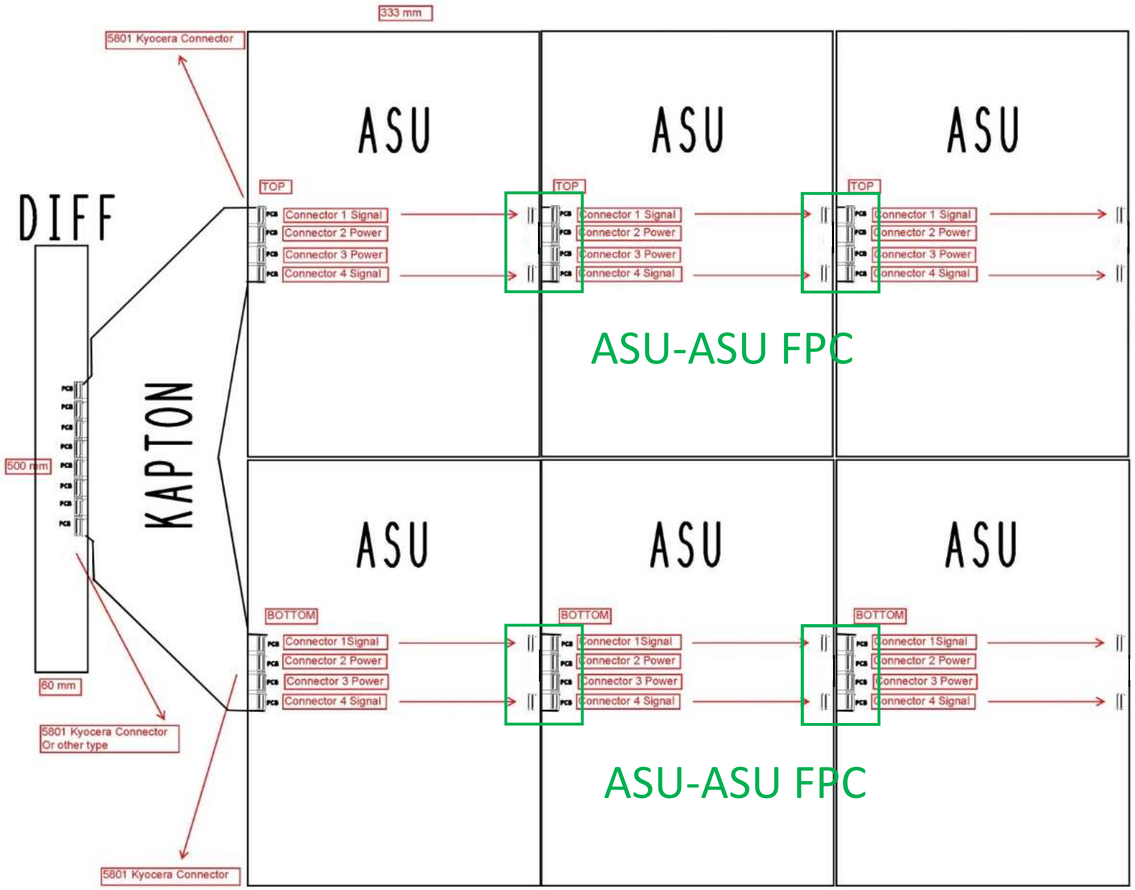
New ASIC version: HADROC3 (HR3)

Some new features as:

Independent channels (=zero suppression)
New slow control using I2C
New PLL capable to generate fast clock internally
Input frequency 2.5MHz
→ Output frequency 10, 20, 40 and 80 MHz
Need to distribute only slow clock to ASUs

Preliminary results confirm that all functionalities are ok.
Test of the 600 HARDROC3 is under preparation at IPNL.

Electronics: PCB (ASU)



Only 1DIF per GRPC

Single PCB 50x33.3 cm2

Design scalable up to 3m long chambers

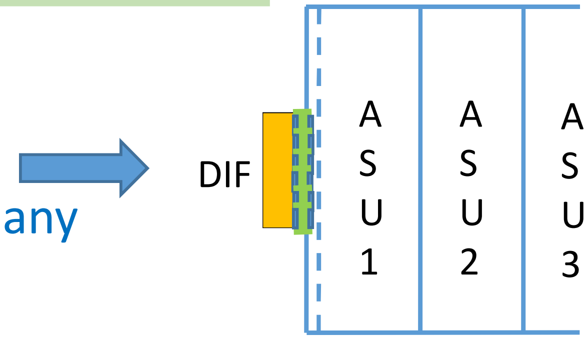
- 6 lines of 4HR3 per ASU
- 12 HR3/Line for 1 m long ASU
- 36 HR3/Line for 3 m long ASU

All buffers on DIF side :

- ✓ save power on ASU side
- ✓ easier to cool

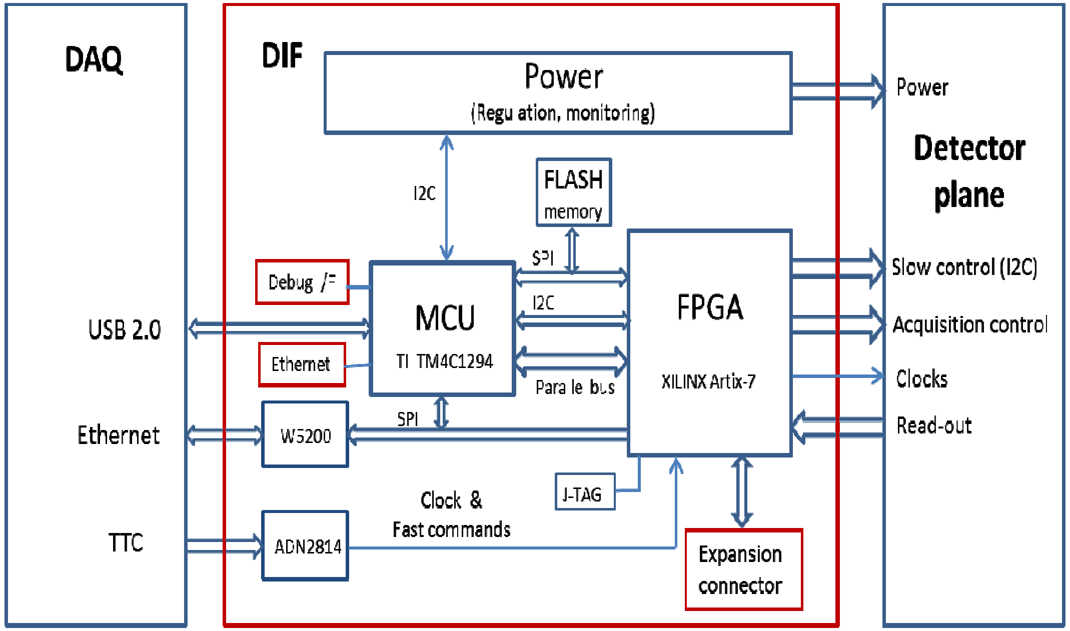
Rooting is being finalized

Investigating also the possibility of 100x33.3cm2 PCB in a Chinese company



Electronics: DIF

DIF: Detector InterFace
It sends DAQ commands (config,clock,trigger) to ASICs and transfers their signal data to DAQ



DIF design almost finished (being integrated with the final ASU requirements)

Most relevant changes

- 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
- USB 2.0 for debugging
- Synergy with R&D on fast links R&D of LHC(GBT)

Mechanics

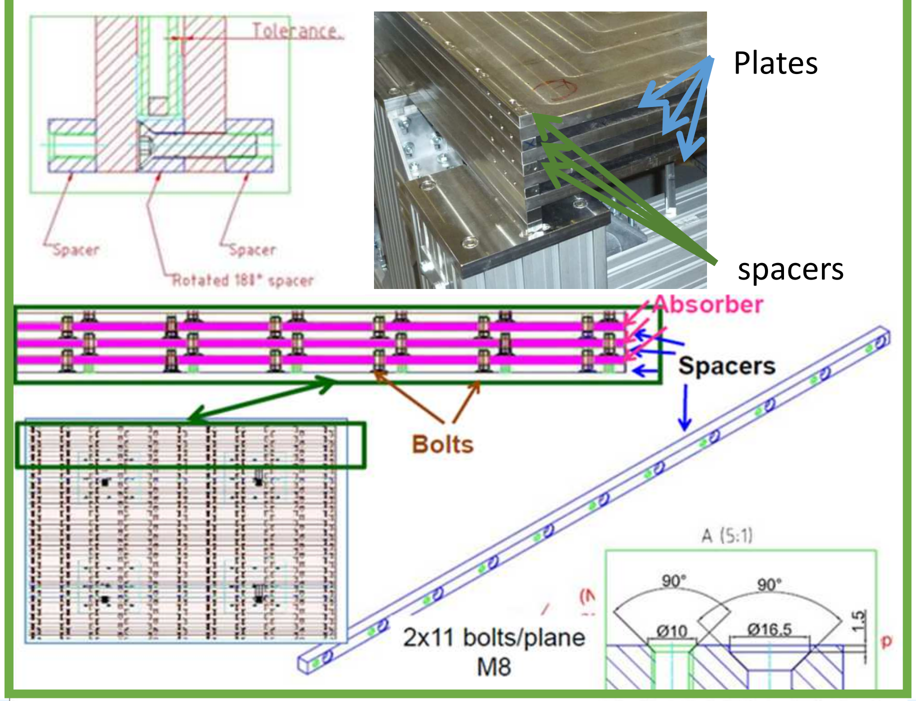
Final objective :

To design and build a mechanical absorber SHDCAL structure with ~4 long (3m) plates using beam welding capable to accommodate the largest ILD GRPC chambers .

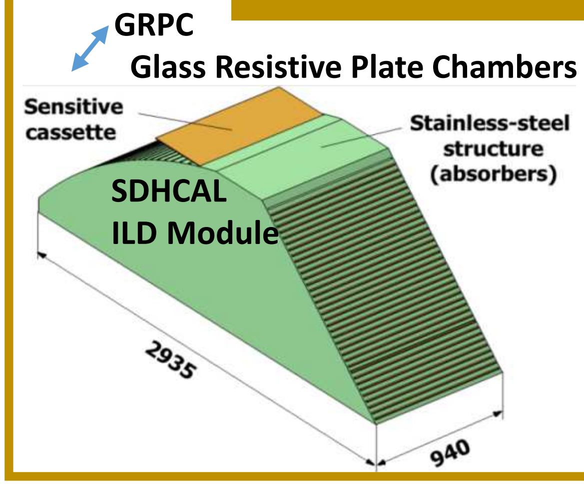
1m3 prototype mechanics concept

~1m2 stainless still plates 15mm thick,
<0.5mm planarity

Assembled together with lateral spacers fixed to the absorber **using staggered bolts**



ILD SDHCAL Barrel Module Design



Stainless still plates
up to ~3x1m2
15mm thick,
<1 mm planarity

Assembled together with lateral spacers by **welding**

Main Differences

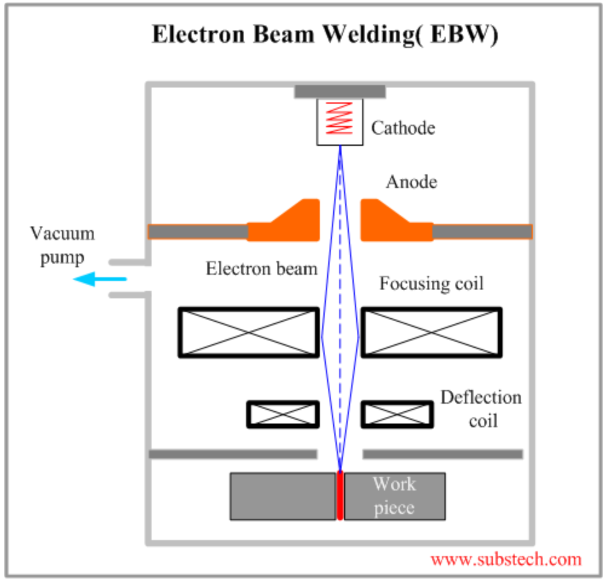
1m3 prototype	New Prototype
~1x1m2 plates	~3x1m2 plates
51 plates	4 plates
Bolts	***Welding***

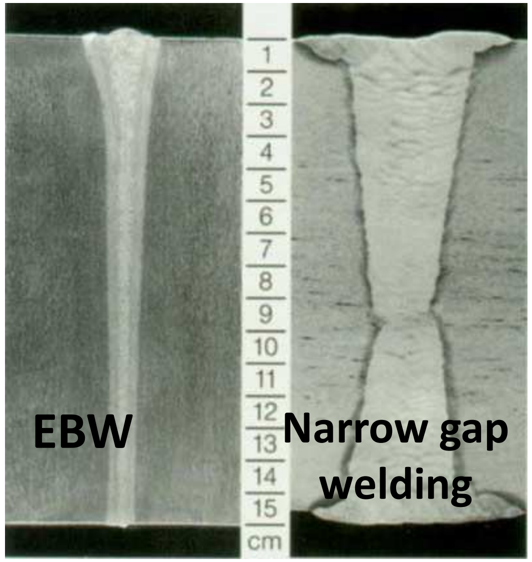
Electron beam welding machine @ CERN

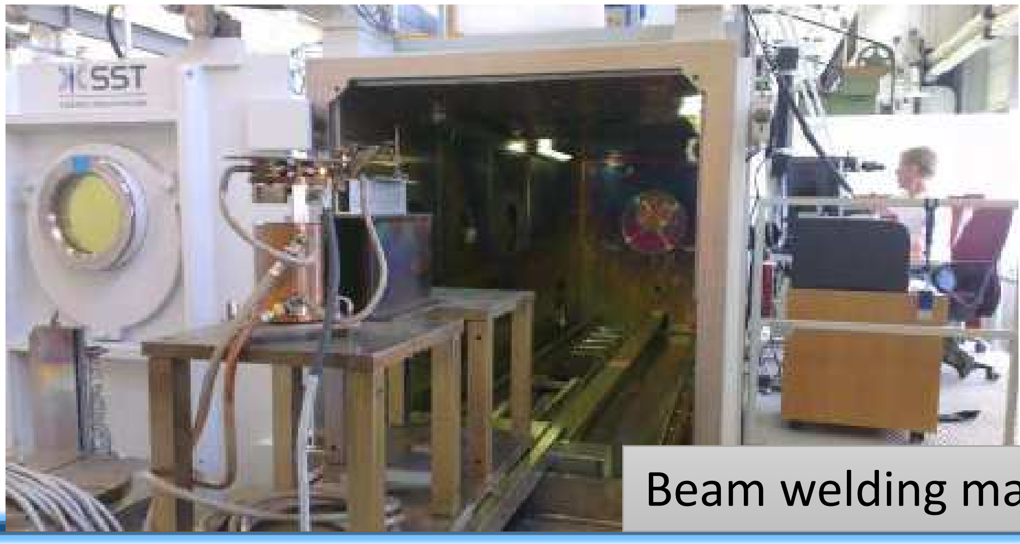
"Standard" welding can introduce deformations

Collimate electron beam
➔ Very **narrow welding**
➔ **Less deformations**

Vacuum conditions needed





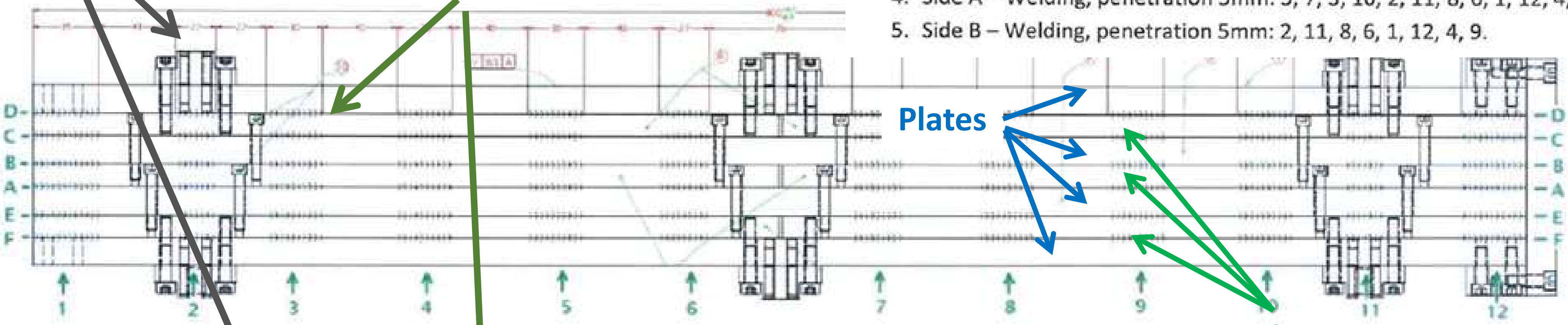


Beam welding machine @ CERN

4(1m2) plates prototype welding @ CERN

The welding sequence has been the following:

1. Side A – Tack welding, penetration 2mm: 6, 1, 12, 4, 9.
2. Side B – Tack welding, penetration 2mm: 6, 1, 12, 4, 9.
3. Side B – Welding, penetration 5mm: 5, 7, 3, 10.
4. Side A – Welding, penetration 5mm: 5, 7, 3, 10, 2, 11, 8, 6, 1, 12, 4, 9.
5. Side B – Welding, penetration 5mm: 2, 11, 8, 6, 1, 12, 4, 9.



Prototype after welding

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

New test with small prototypes foreseen to optimize the procedure before building the final large prototype

Mechanics: Plate planarity

For the 1.3m3 prototypes the required plate flatness(<1mm) has been obtained by machining the plates but this process is very time consuming and expensive for the final production.
Roller leveling could be the solution

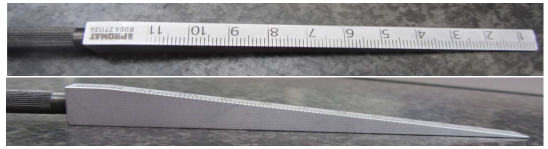
Tests performed in ARKU (Baden-Baden, Germany) with

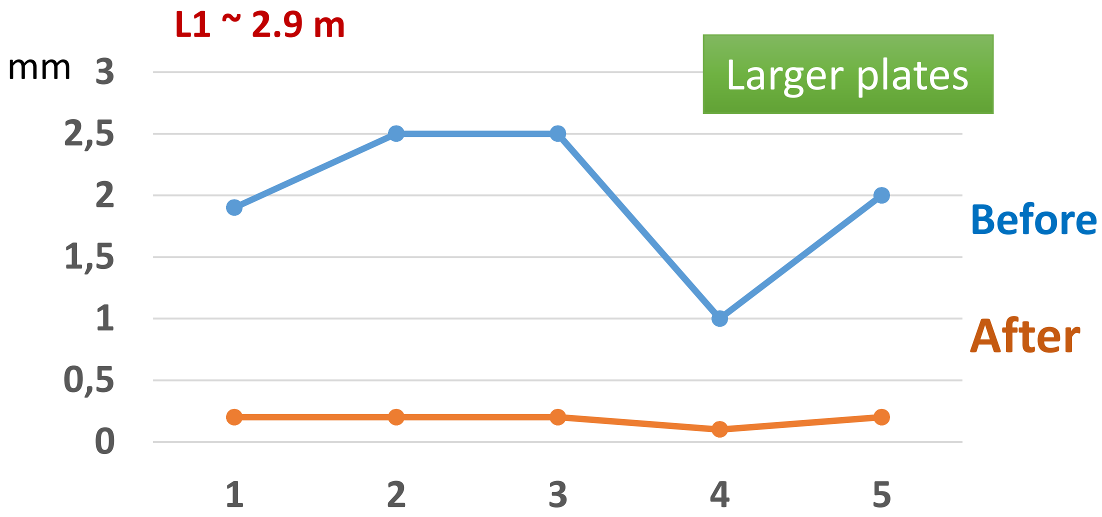
- 8 small plates (~1000x400 mm2) for 2 small prototypes
- 5 plates (~2900 x 1010 mm2) for the final prototype

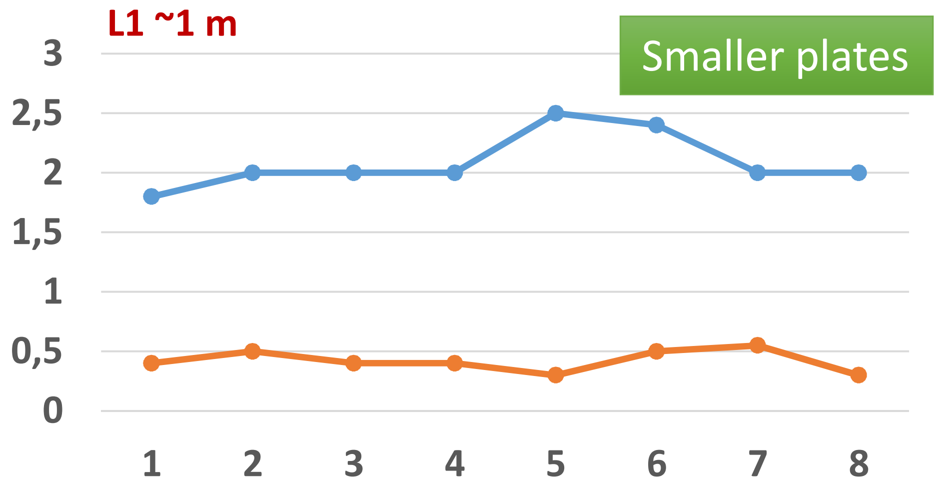
Preliminary results for all plates

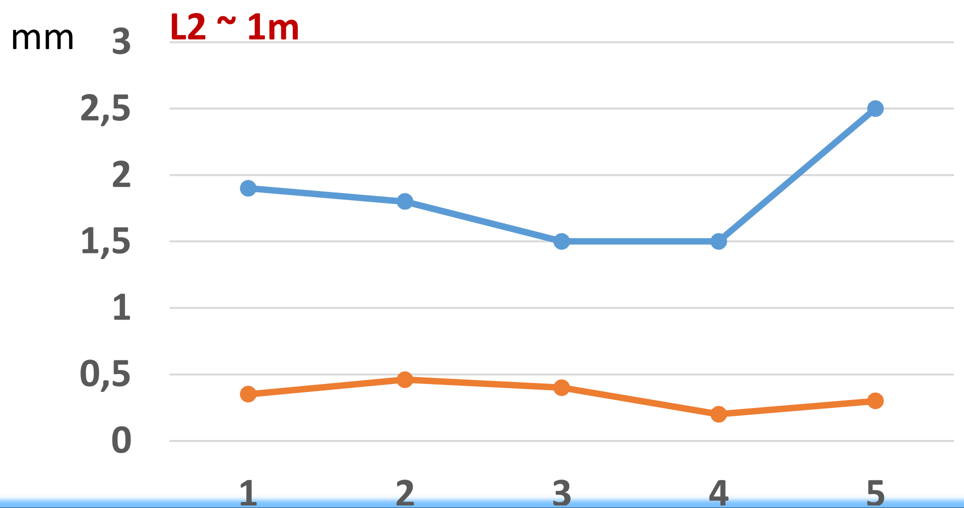
A fast quality control has been performed during the tests at ARKU using feeler gauges

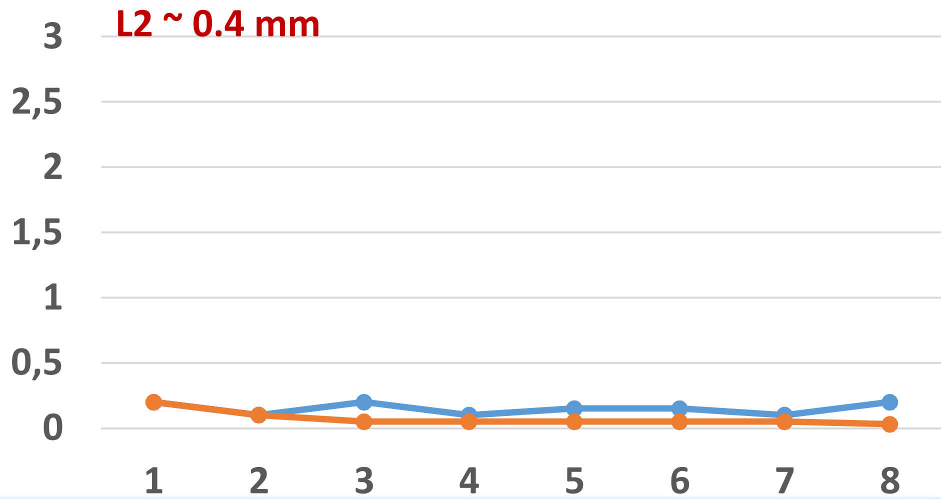
➔ **More precise tests will be done at CIEMAT (setup still to be prepared)**











Summary

The 1.3 m^3 prototype have proven the **technology is valid** for lepton collider experiments in terms of **resolution and track reconstruction**

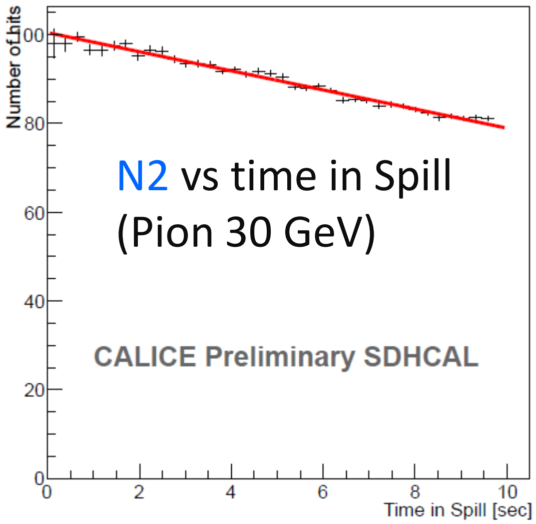
A **new prototype** with **less planes but bigger chambers** will be build.
The prototype should be **closer to the ILD final design**

The **electronics design** is **ongoing** and should be **finalized by 2016**
R&D on **mechanics** is **ongoing** to **define the procedures to minimize the deformations of the single plates and the final structure**

Results are promising, but **still some more optimization needed**

Back-up

SHDCAL Energy Calibration



Time Spill correction

GRPC efficiency decreases at high rate. Efficiency decrease with time in spill due to charge accumulative effects. This can be corrected

$$N_{TOTcor} = N1 - Slope1 \times Time + N2 - Slope2 \times Time$$

Track reconstruction in the shower

SHDCAL Energy Calibration

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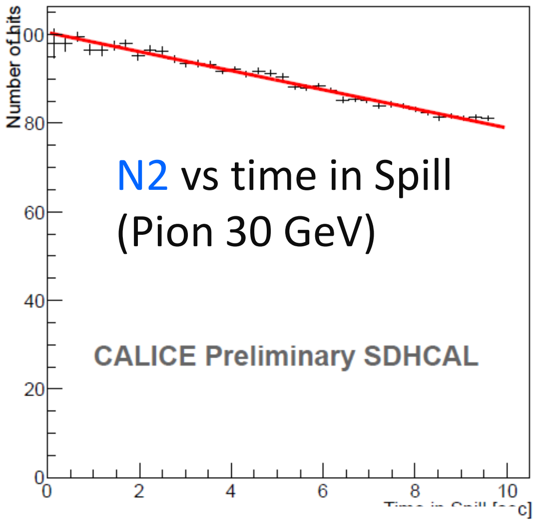
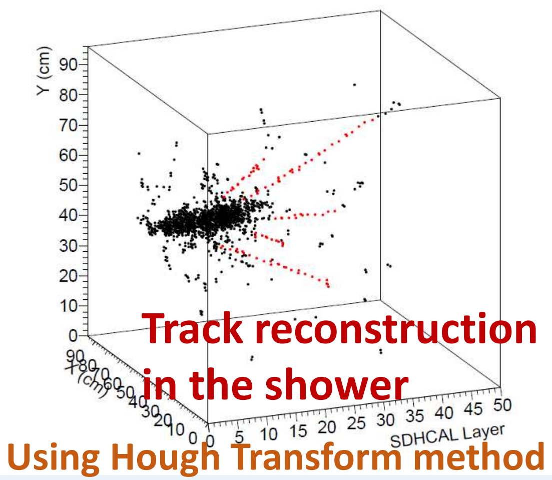


Track hits correction.

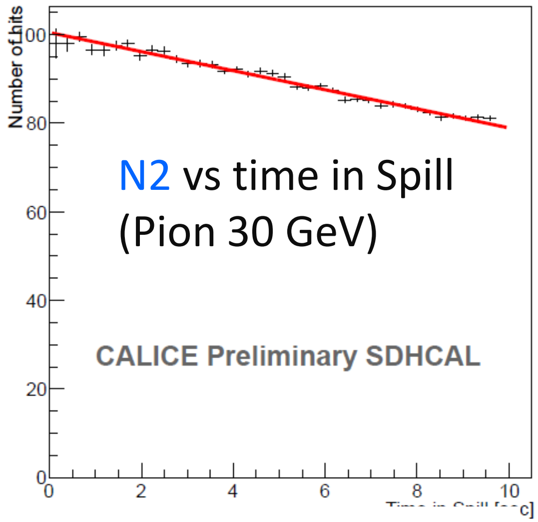
Single tracks can produce a signal bigger than 2nd or 3rd threshold and can bias the measurement

Identifying those tracks, removing the hits belonging to them from N1,N2,N3 and giving them the same weight can improve the results

$$E_{reco} = \alpha\, N1' + \beta\, N2' + \gamma\, N3' + c\, N_T$$



SHDCAL Energy Calibration



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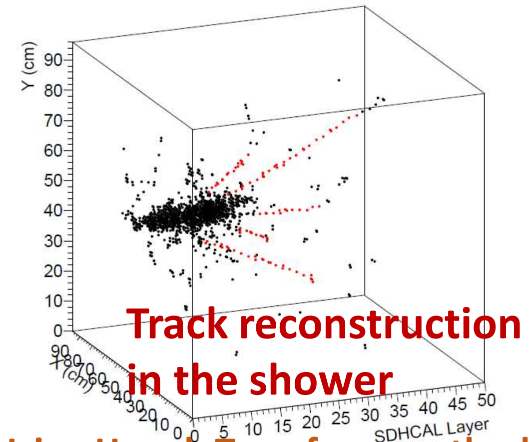

Using Hough Transform method

Density weighting

Separate the hits in **high-density** (e.m) and **low-density** (had) and give different weights

Density computed in a volume 1.5(x) x 1.5 (y) x 3.1 cm^3 **>9 → High density**

	High density part	Low density part	Track
$E_{reco} =$	$\alpha_h\, N1_h + \beta_h\, N2_h + \gamma_h\, N3_h$	$+ \alpha_l\, N1_l + \beta_l\, N2_l + \gamma_l\, N3_l$	$+ c\, N_T$