Hadronic Calorimeters Using RPC detectors

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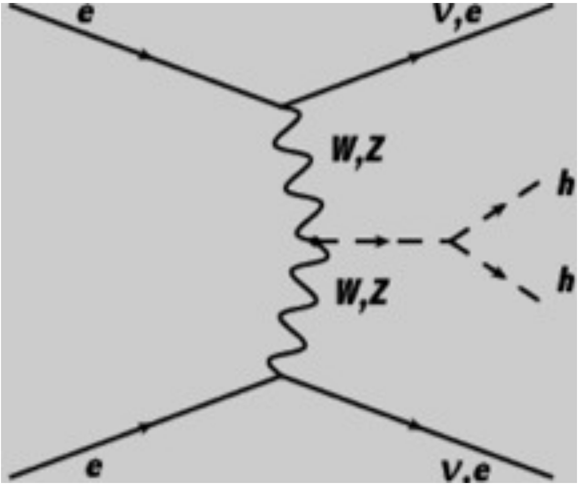
outline

- Highly granular hadronic calorimeters
- The SDHCAL concept
- Technological prototype construction
- Test Beam Results
- Perspectives

Highly granular HCAL Concept

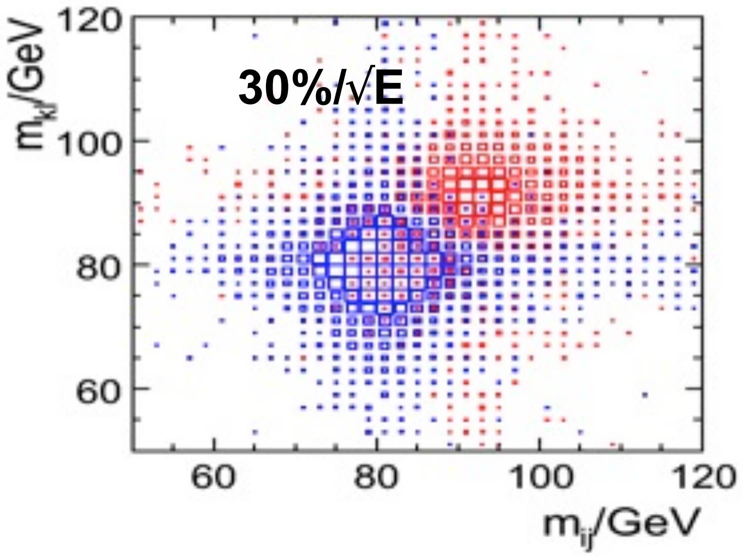
For future colliders, jet energy resolution will be a determinant factor of understanding high energy physics.



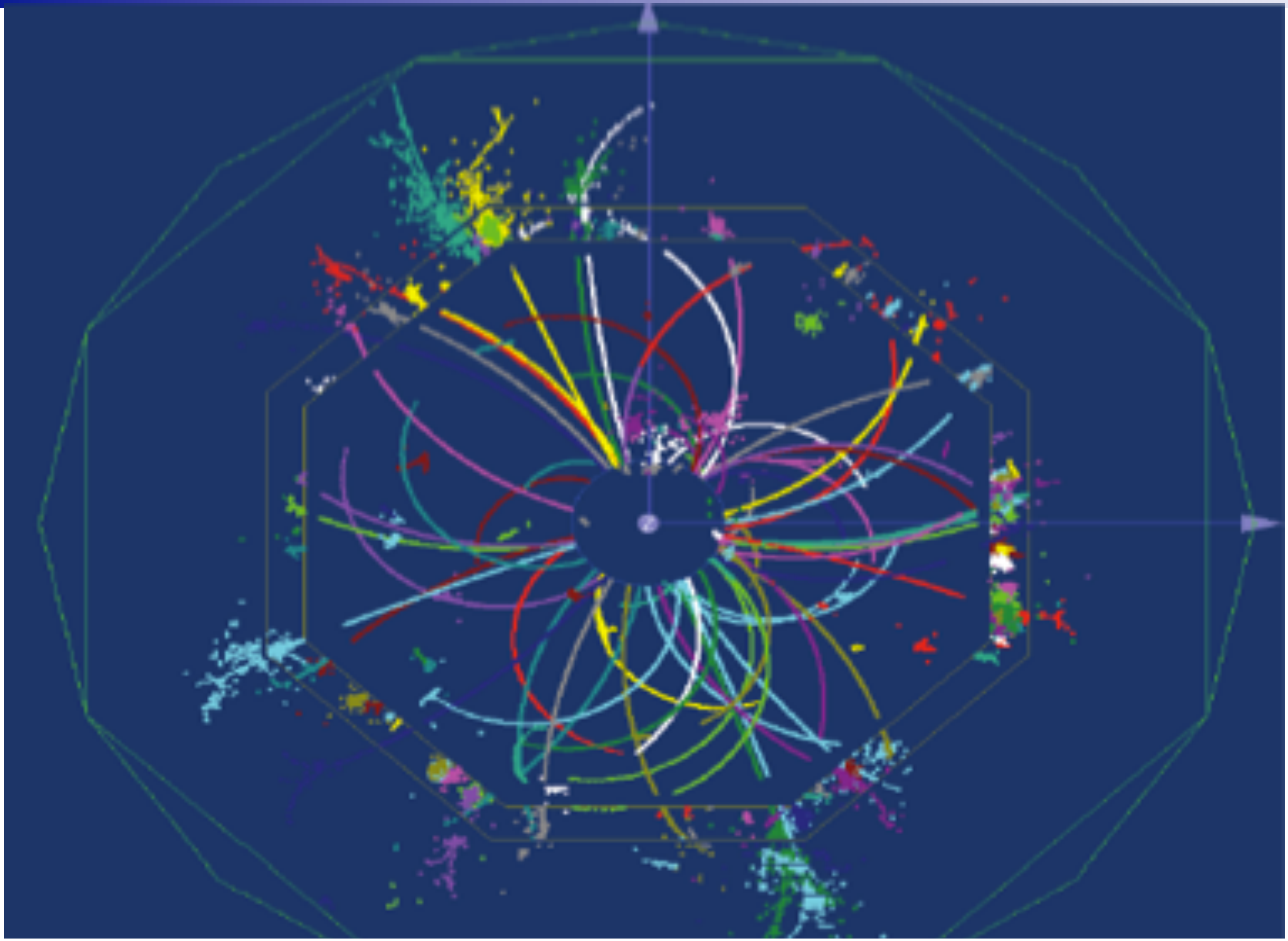
Exemples:
→Higgs coupling studies
→ Trilinear Higgs self coupling measurement

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

Resolution | Tracking | Leakage | Confusion

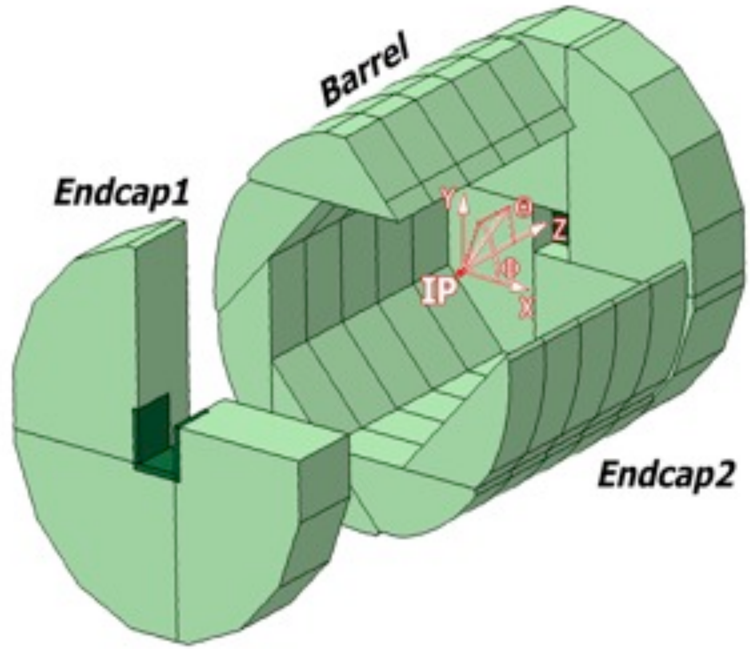


To improve on the jet energy resolution
PFA is a promising solution to reduce the confusion term → high granularity Calorimeters



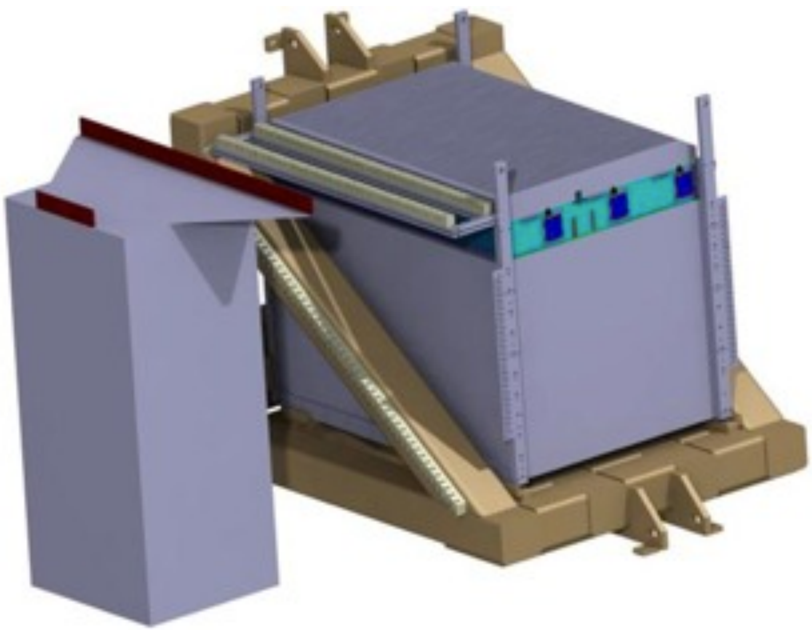
Hadronic calorimeters of high granularity (1 cm^2 lateral segmentation) and 2 cm (longitudinal segmentation) using GRPC are proposed for the two ILC, CLIC projects SiD and ILD. Two options : DHCAL and SDHCAL are being developed.

SDHCAL technological prototype



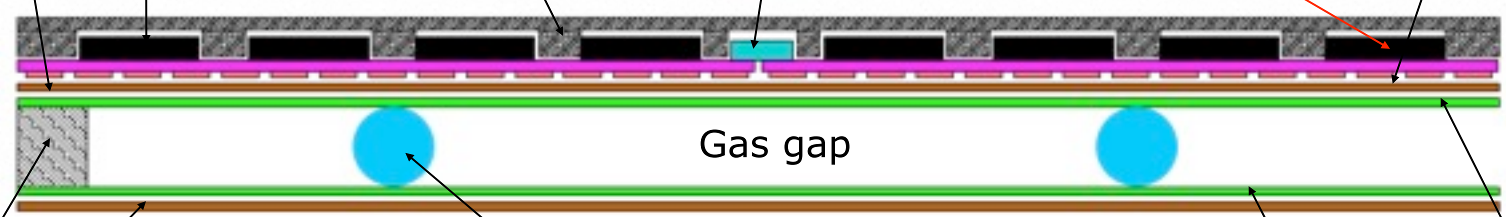
SDHCAL is one of the two HCAL options of the ILD project.
It was proposed with a genuine mechanical structure with no projective cracks and no dead zone between the Barrel and the Endcaps since services are on the periphery

Challenges
-homogeneity for large surfaces
-Thickness of only few mms
-Services from one side
-Embedded power-cycled electronics
-Self-supporting mechanical structure



Technological prototype
A prototype with 48 GRPC of 1m2 and stainless steel absorber corresponding to 6 λ_I was conceived as a demonstrator

Cross-section of Lyon 1m² glass RPCs

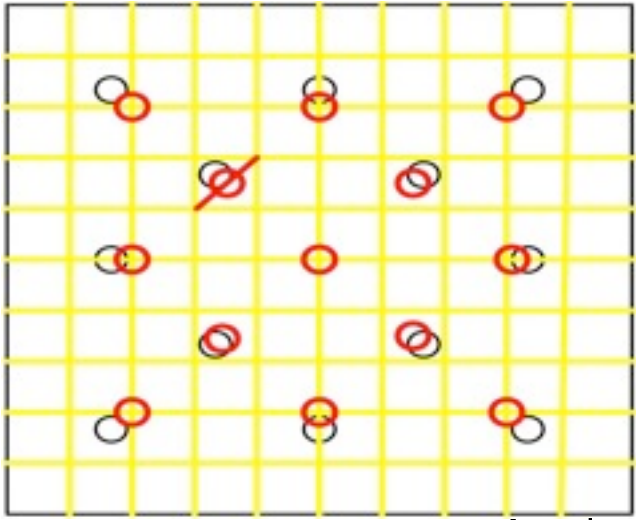


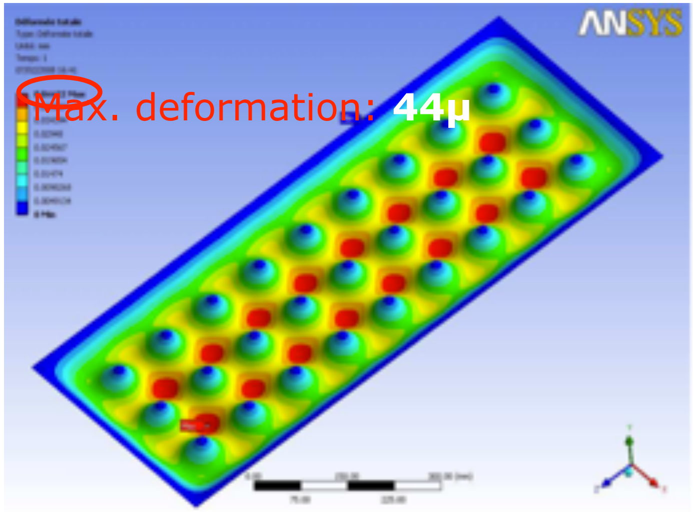
Total thickness: 6.0mm

The choice of ceramic balls rather than fishing lines aims at reducing both dead zones and noise.

Homogeneity study

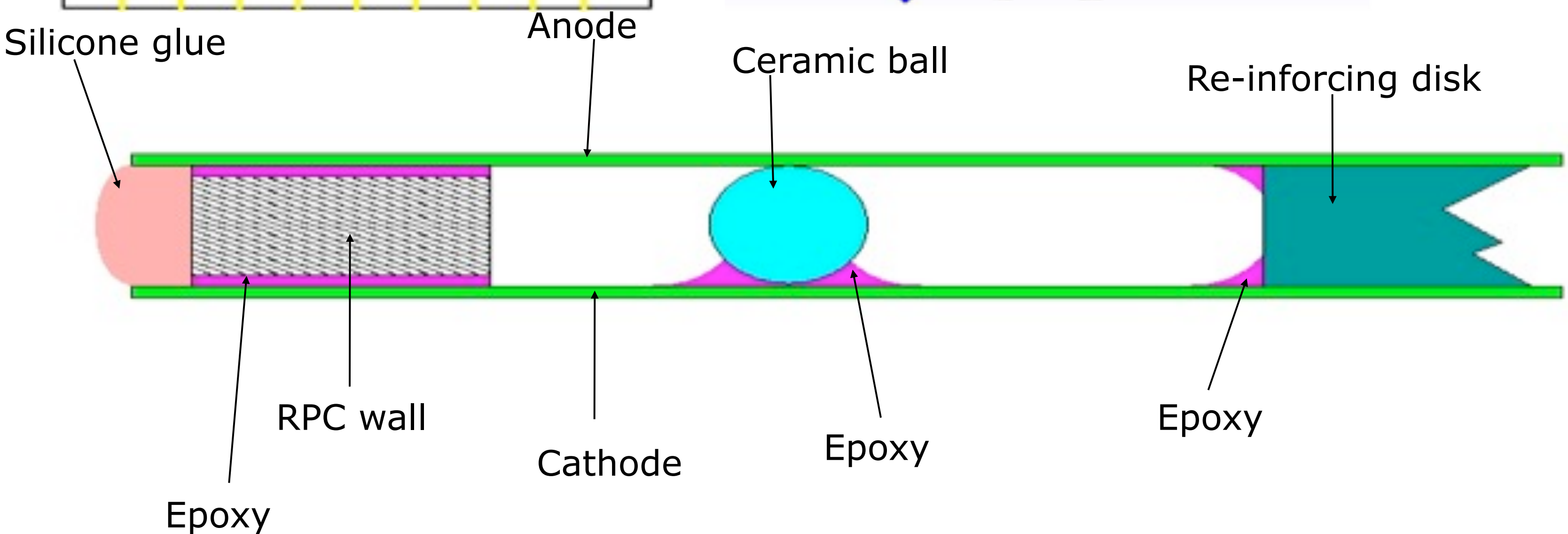
To maintain the same distance between the two glass plates, spacer are used every 10 cm : 68 ceramic balls+ 13 fiber glass disks.





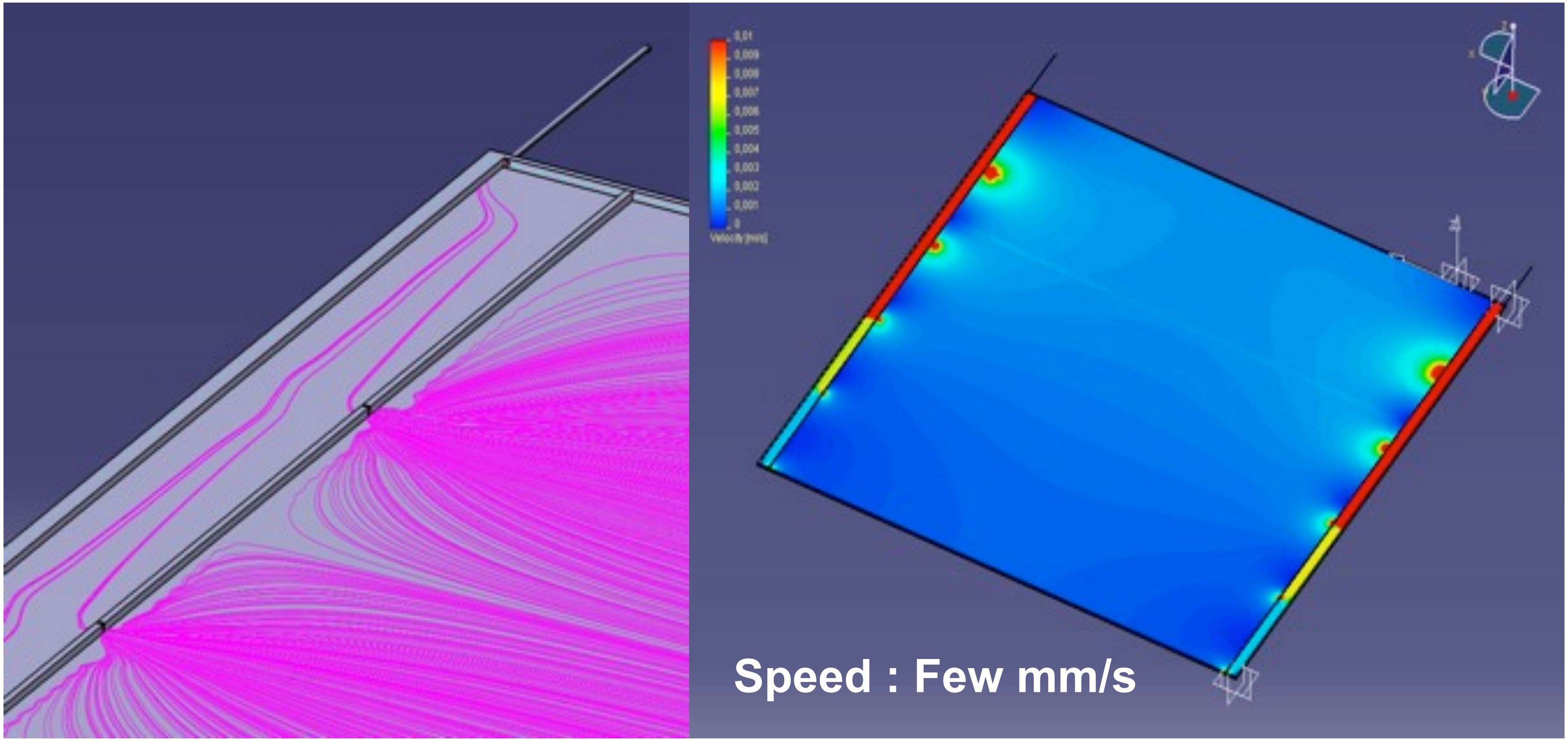
Included
- glass weight
- electrostatic force

Not included
- Gas pressure



Gas distribution system

The services being on one side of the detector, a new gas distribution design is used. It allows to distribute the gas uniformly in the large chamber.



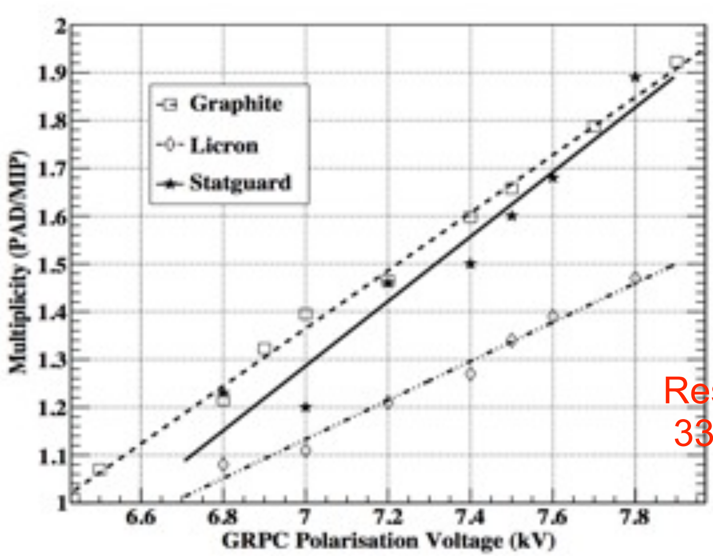
When diffusion is included→ Homogeneity is expected to be even better

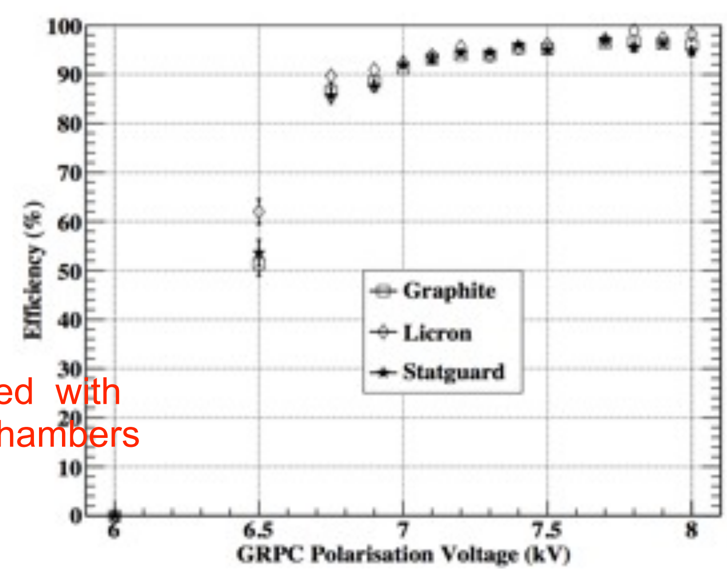
A test using Kr83m radioactive gas is scheduled to monitor online the gas distribution

Resistive coating study

The resistive coating is needed to apply the HV on the two glass plates (electrodes). The resistivity value of this coating plays an important rôle of the pad multiplicity. The higher the resistivity the lower the multiplicity
Three kinds of coatings were tested :

	Licron	Statguard	Colloidal Graphite type I	Colloidal Graphite type II
Surface resistivity (MΩ/□)	~20	1-10	~0.5	Depends on mix ratio; choose ~0.7
Best application method	Spray	Brush	Silk screen printing	Silk screen printing





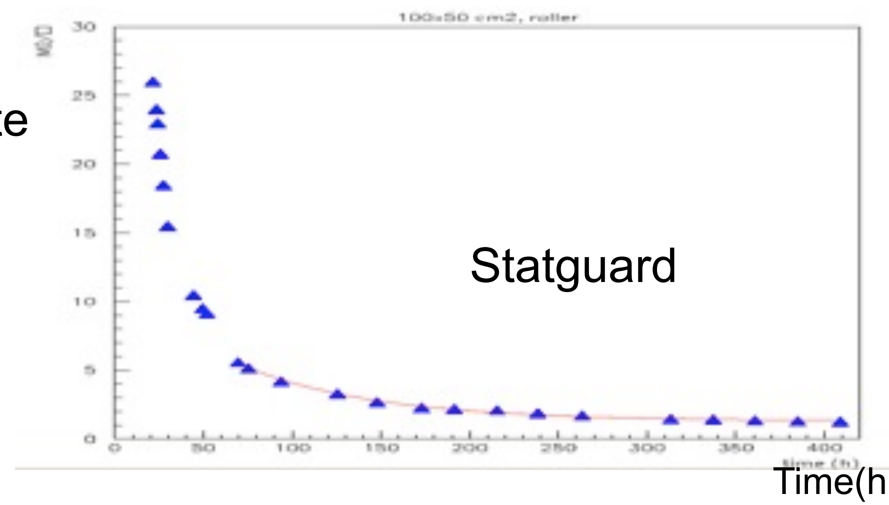
Results obtained with 33X8.3 cm2 chambers

Resistive coating study

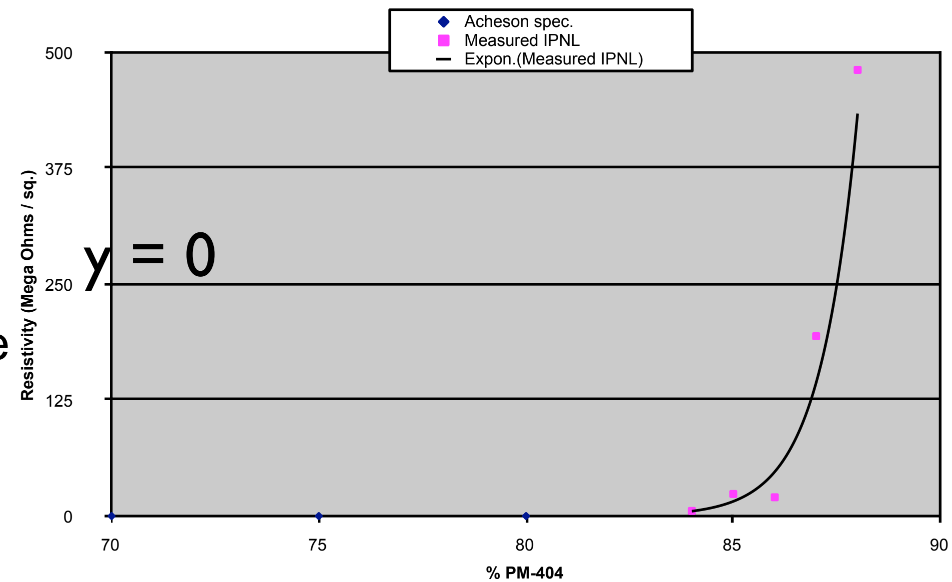
Licron and Statguard are more appropriate for low pad multiplicity. However :

Licron : Loss of HV connection over time (1-2 months)

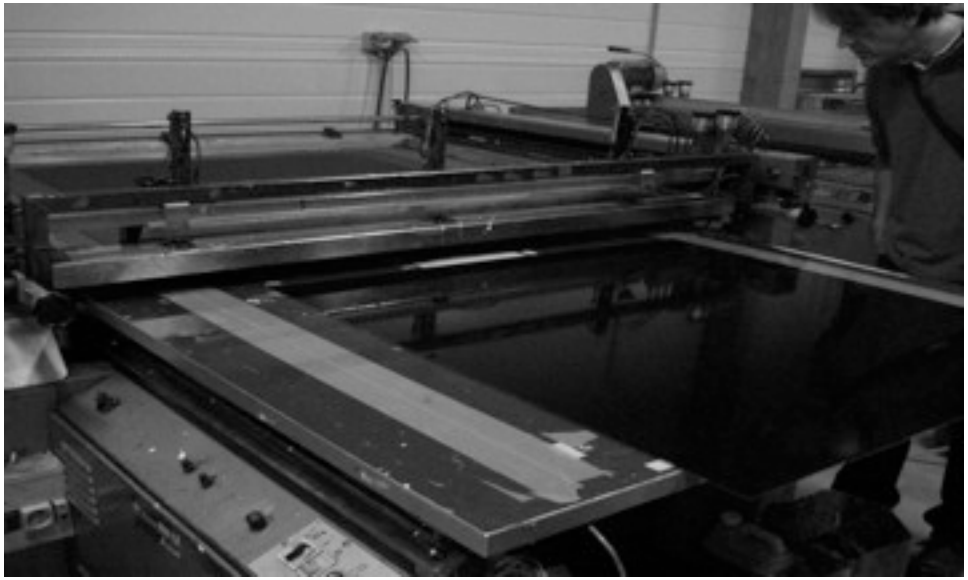
Statguard : long time constant for stable resistivity (2 weeks), poor homogeneity



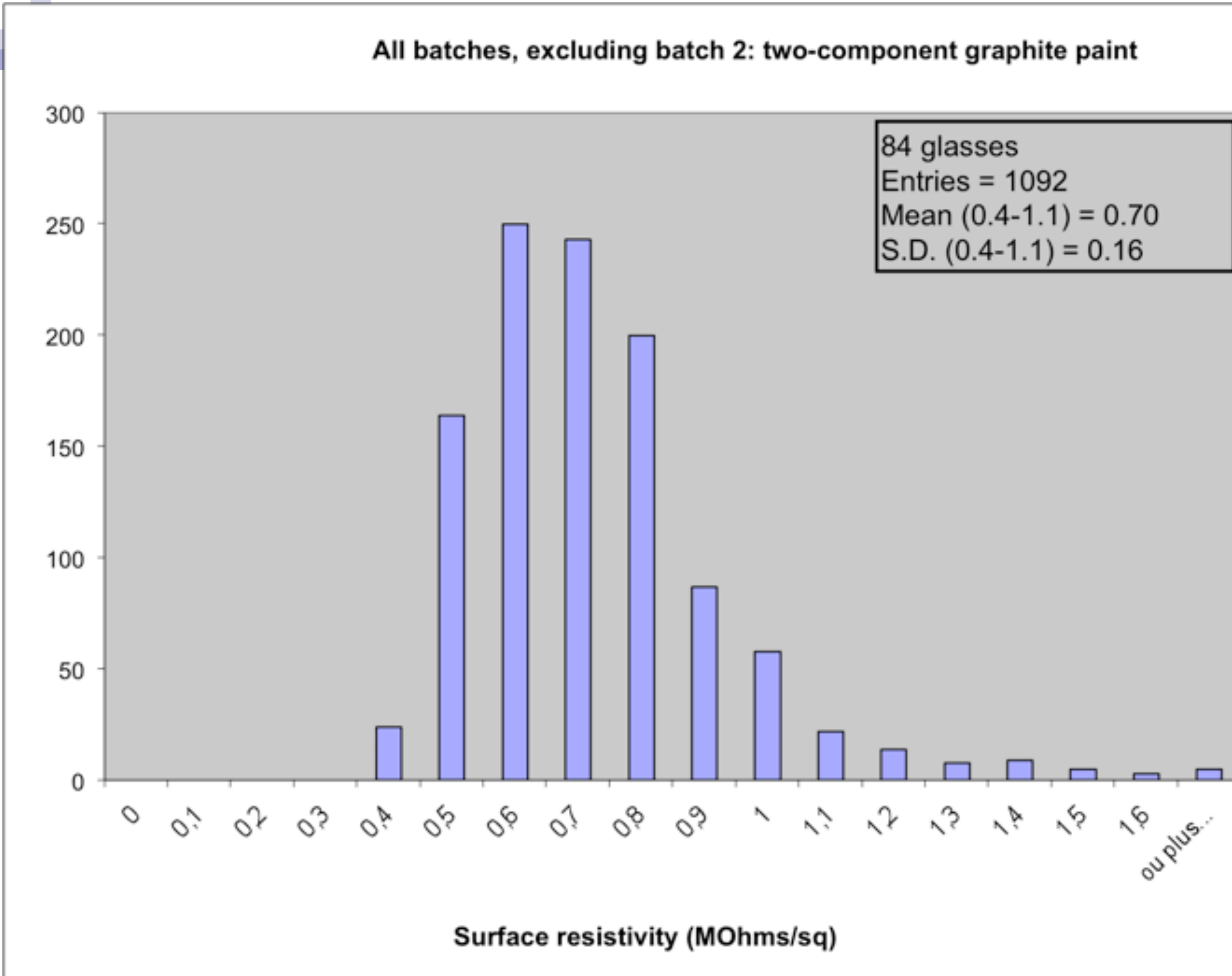
The colloidal graphite of type II is less expensive and allows to choose the needed resistivity even if this is a delicate operation



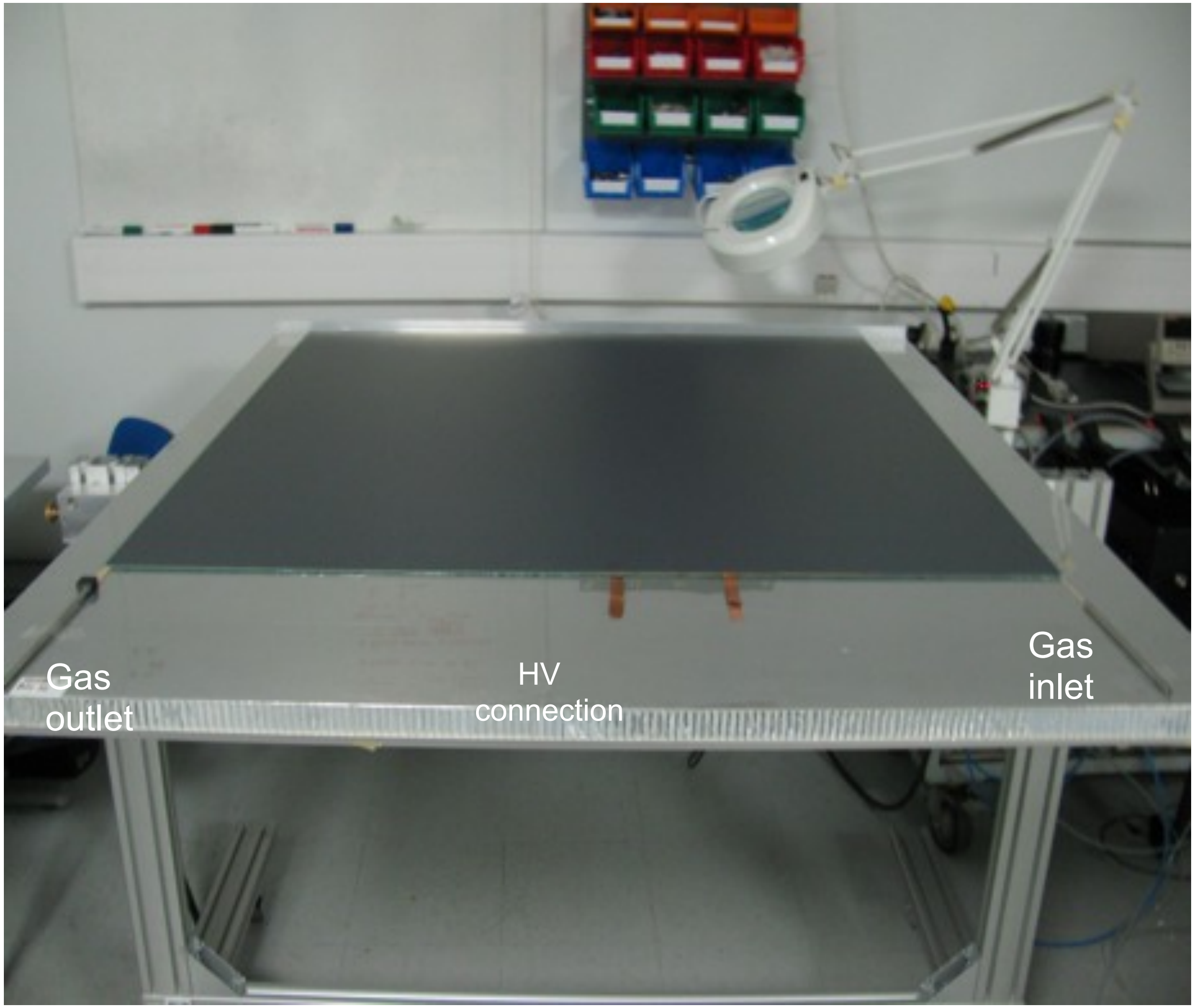
Measured resistivity as a function of the mix ratio



Silk-screen print method provides very good uniformity

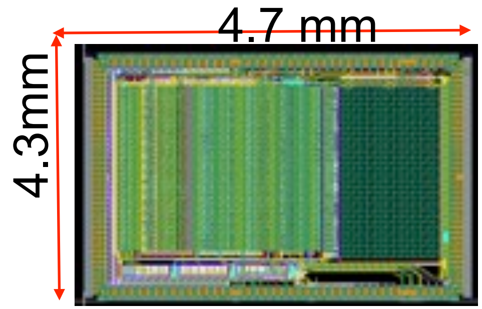


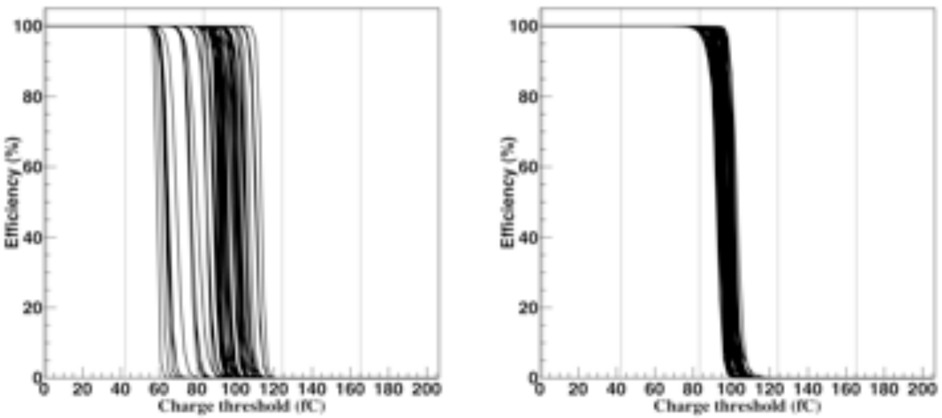
All batches, excluding batch 2: two-component graphite paint
84 glasses
Entries = 1092
Mean (0.4-1.1) = 0.70
S.D. (0.4-1.1) = 0.16
300
250
200
150
100
50
0
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1
1,1
1,2
1,3
1,4
1,5
1,6
ou plus...
Surface resistivity (MOhms/sq)

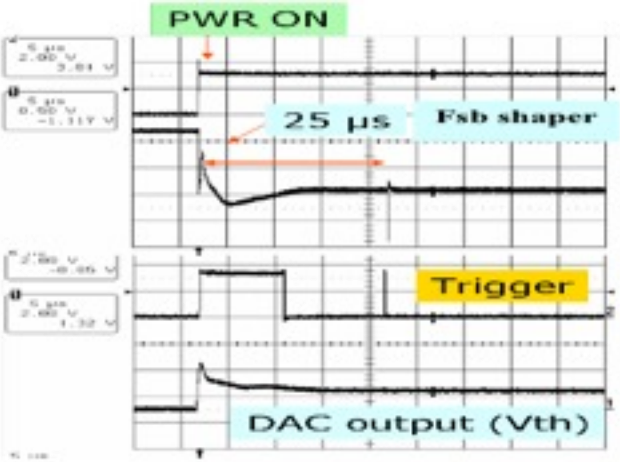

Gas
outlet
HV
connection
Gas
inlet

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





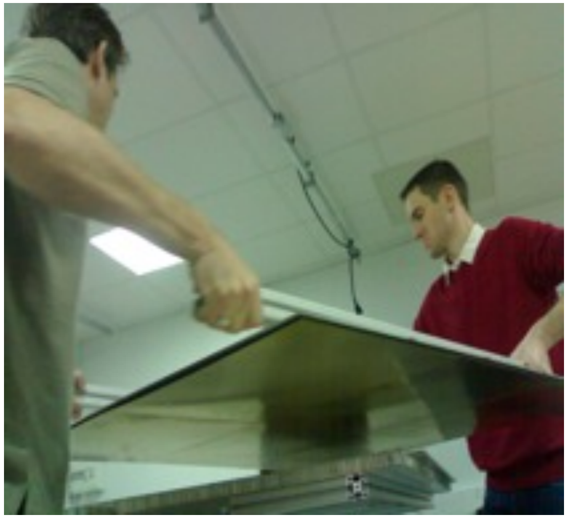


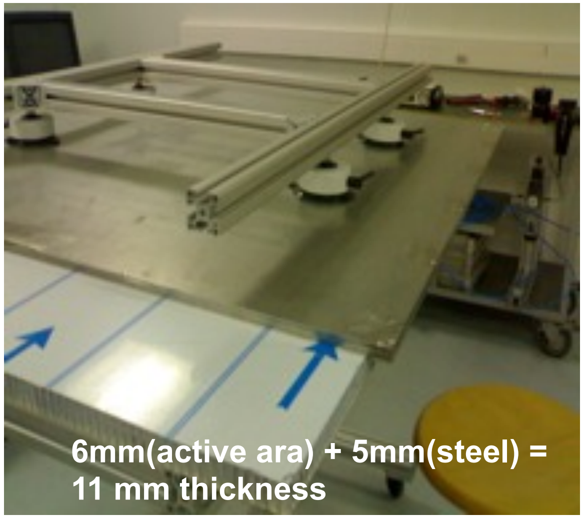
Printed Circuit Boards (PCB) were designed to reduce the x-talk with 8-layer structure and buried vias.
Tiny connectors were used to connect the PCB two by two (the 24X2 ASIC are daisy-chained).
DAQ board (DIF) was developed to transmit fast commands and data to/from ASICs.

Cassette R&D

Cassettes were conceived

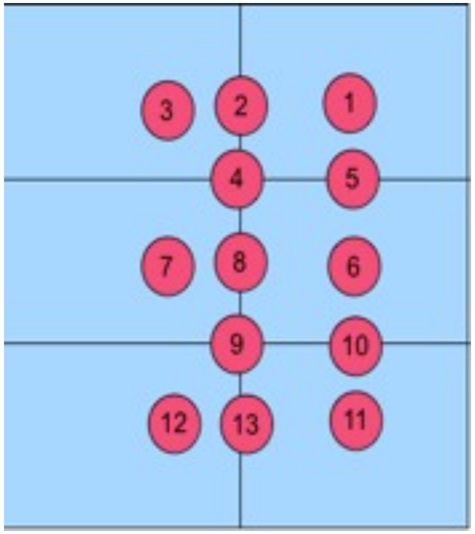
- ✓ To provide a robust structure.
- ✓ To maintain good contact between the readout electronics and the GRPC.
- ✓ To be part of the absorber.
- ✓ It allows to replace detectors and electronics boards easily.



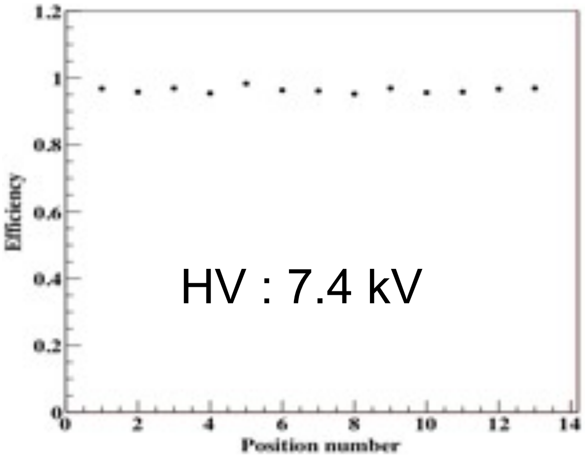


The cassettes are built of no-magnetic stainless steel walls 2.5 mm thick each
→ Total cassette thickness = 6mm (active layer)+5 mm (steel) = 11 mm

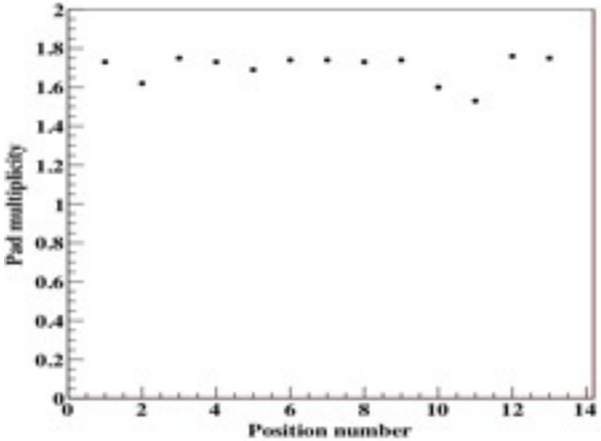
The homogeneity of the detector and its readout electronics were studied



Beam spot position



Efficiency

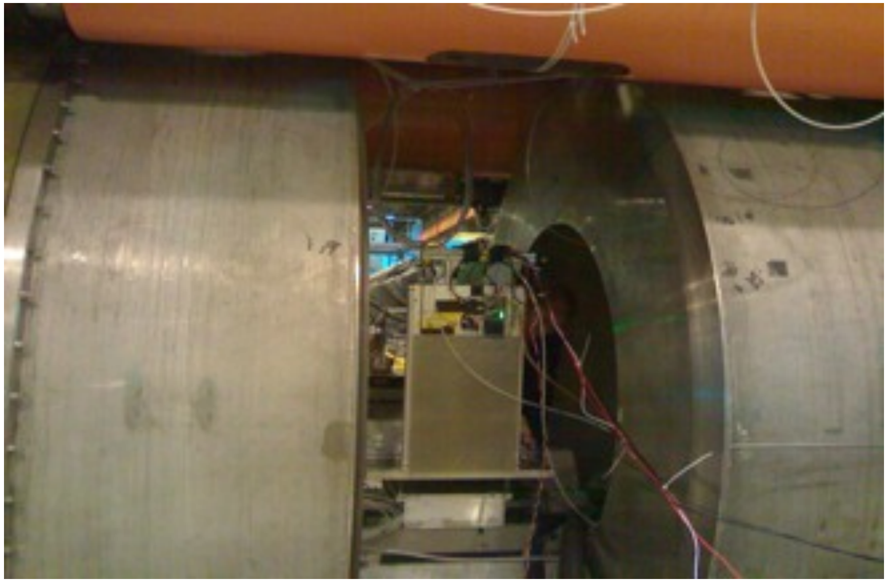


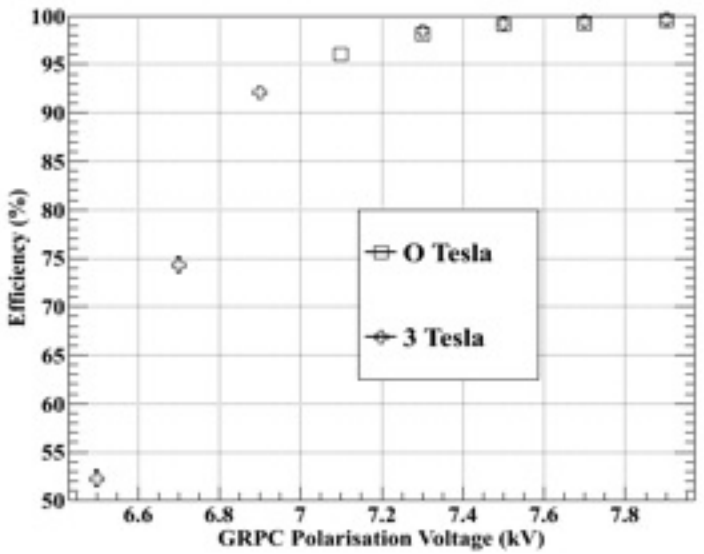
Multiplicity

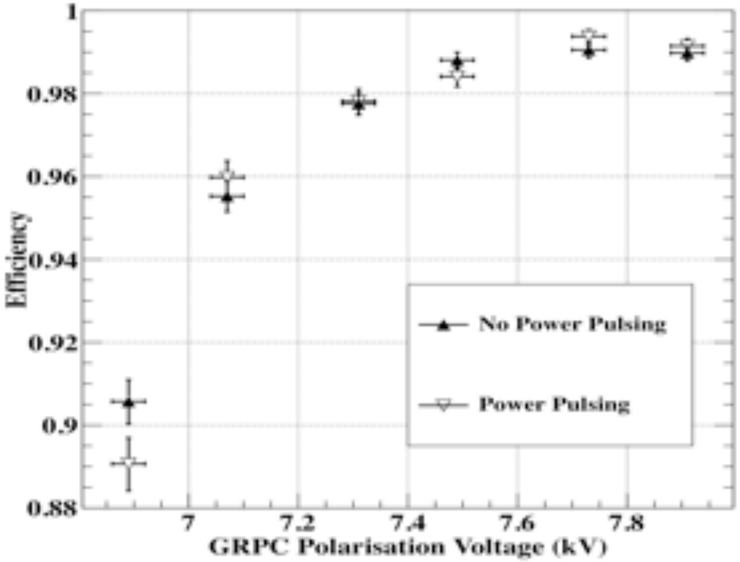
Power-Pulsing mode was tested in a magnetic field of 3 Tesla

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

ILC duty cycle :
1ms (BC) every 200 ms



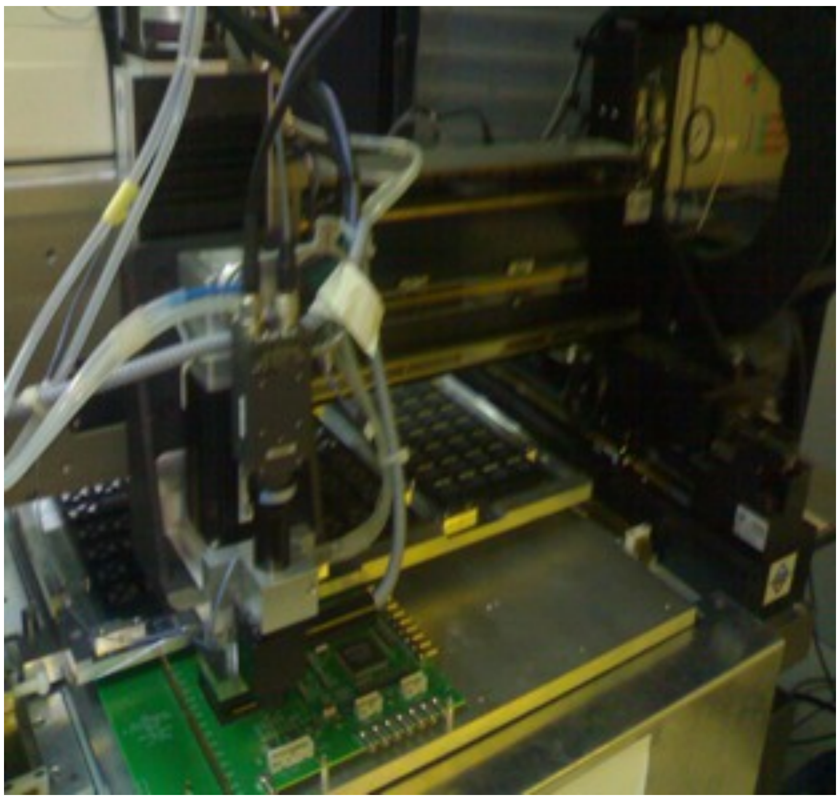


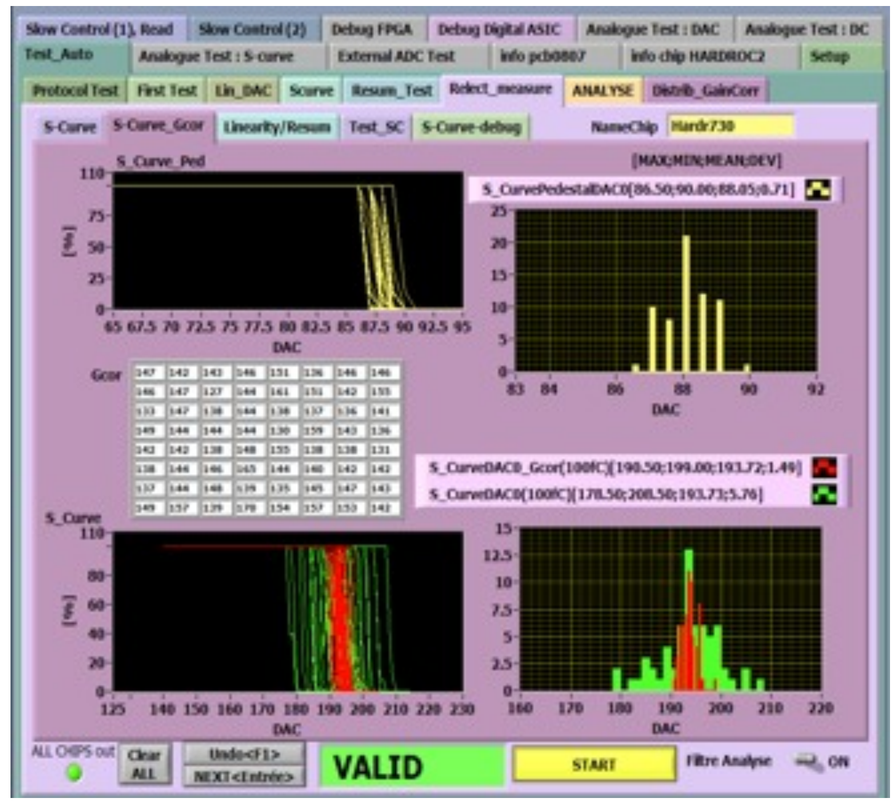


SDHCAL prototype construction

✓ 10500 ASIC were tested and calibrated using a dedicated robot(93% layout)

✓ 310 PCBs were produced, cabled and tested according to strict quality control rules



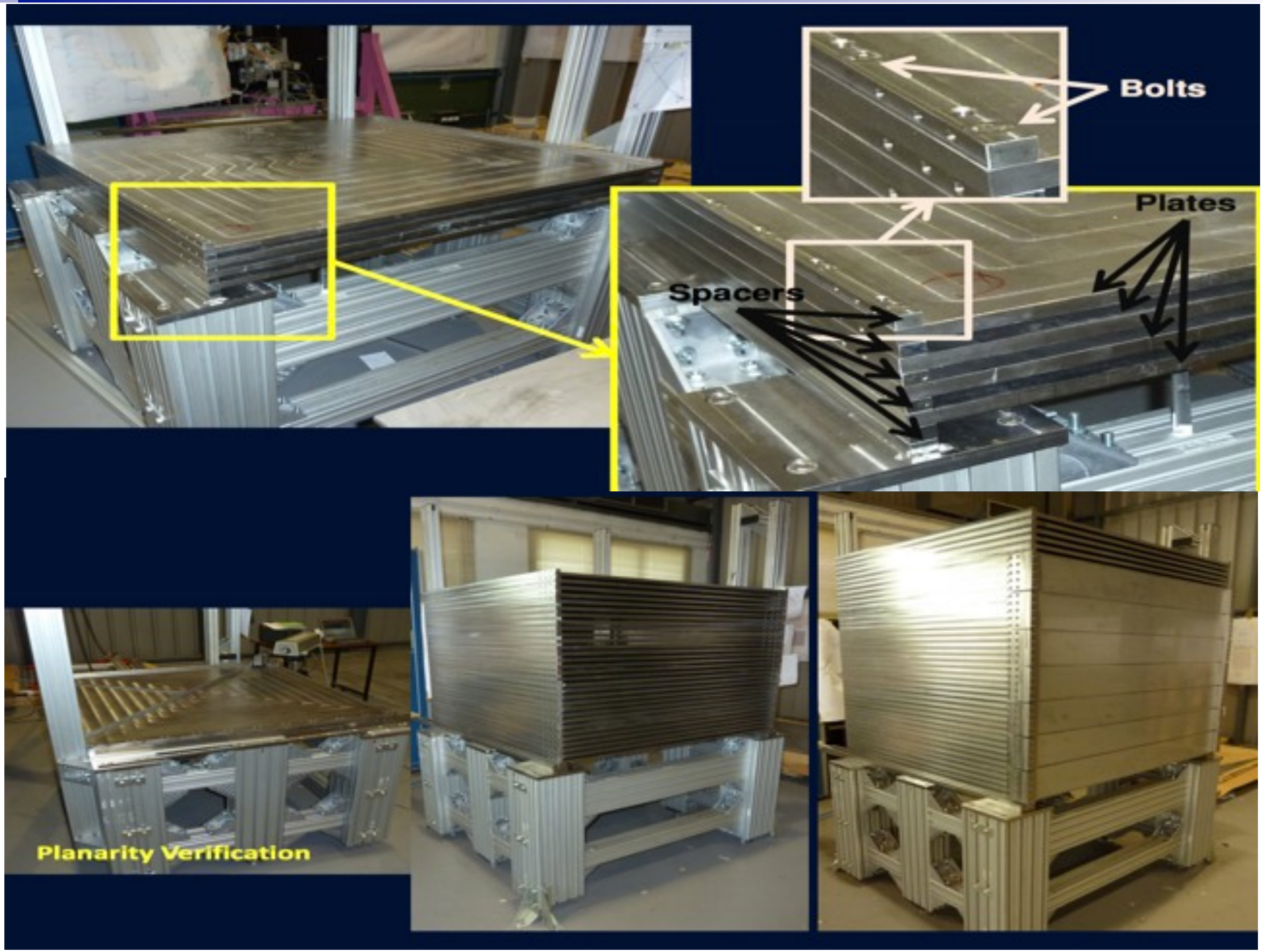


SDHCAL prototype construction

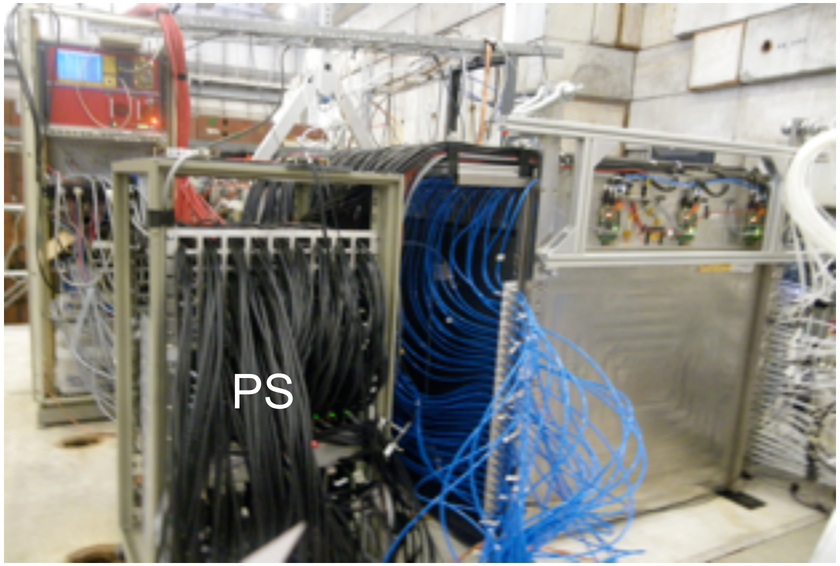
- ✓ Self-supporting mechanical structure structure was conceived and built.

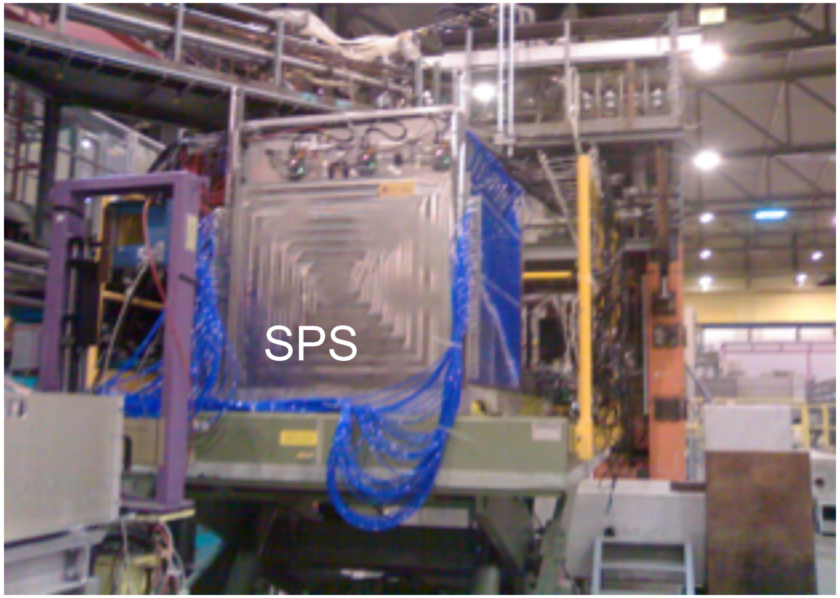
- ✓ 51 stainless steel 15mm thick plates with planarity <250 μm were machined and tested using an interferometer

- ✓ The plates are assembled on three edges thanks to spacers fixed to the plates using bolts.


Bolts
Plates
Spacers
Planarity Verification

Prototype integration





Prototype data acquisition

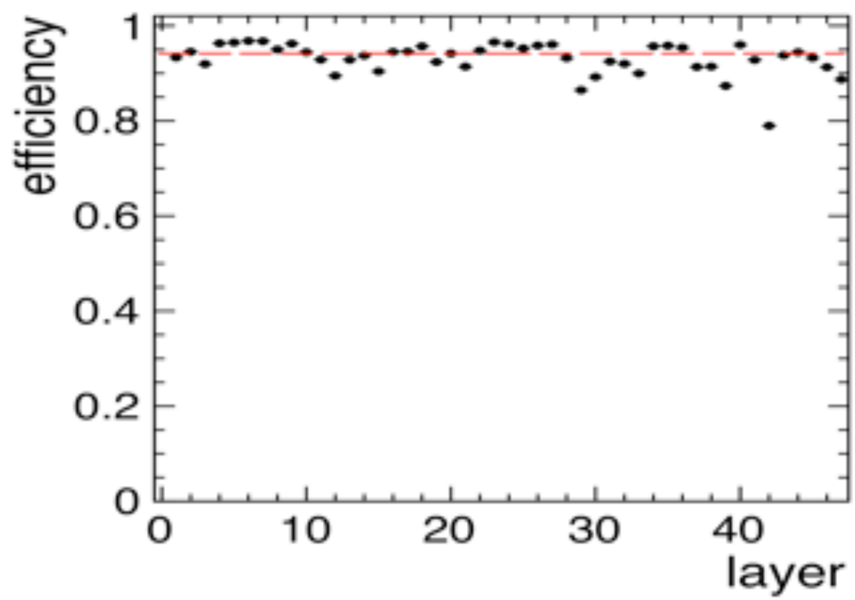
Running conditions
HV : 6.9 kV
Gas flow : 2 l/h
Gas mixture:
93% R134A, 5% CO_2, 2% SF_6

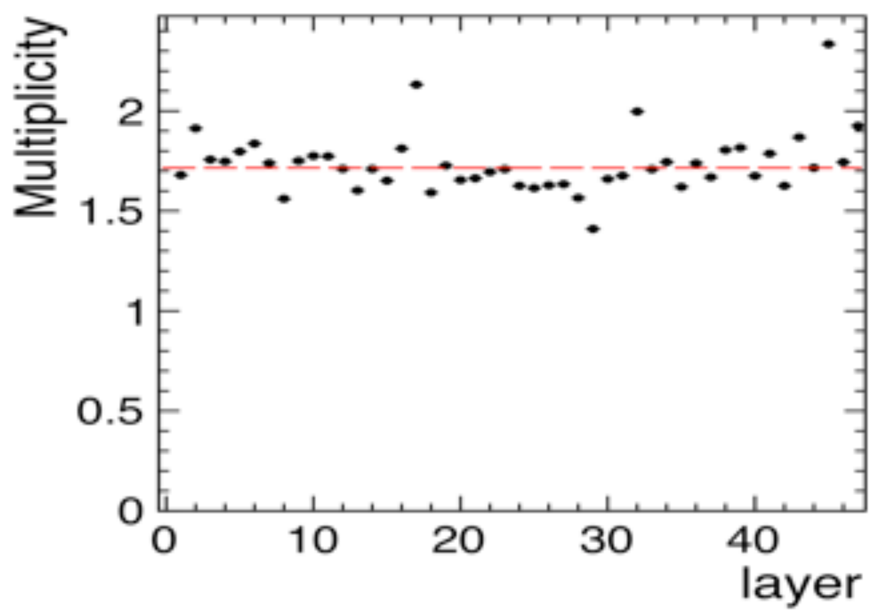
Muon beams are used to study the GRPCs behaviour during the TB.

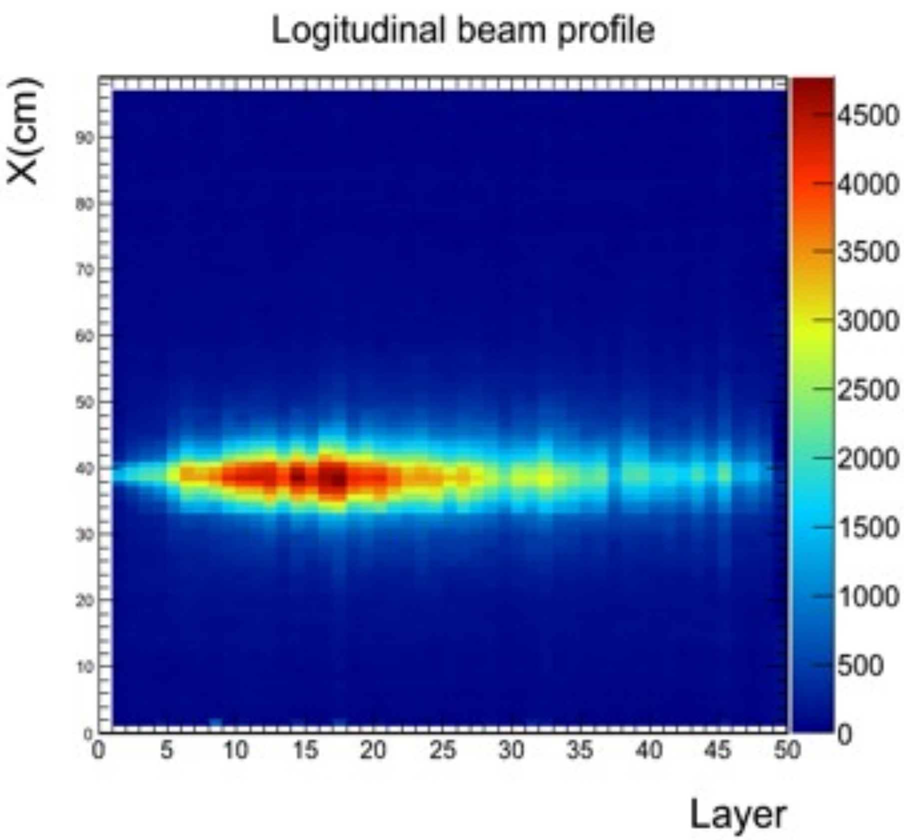
The tracks are reconstructed from hits of the other layers.

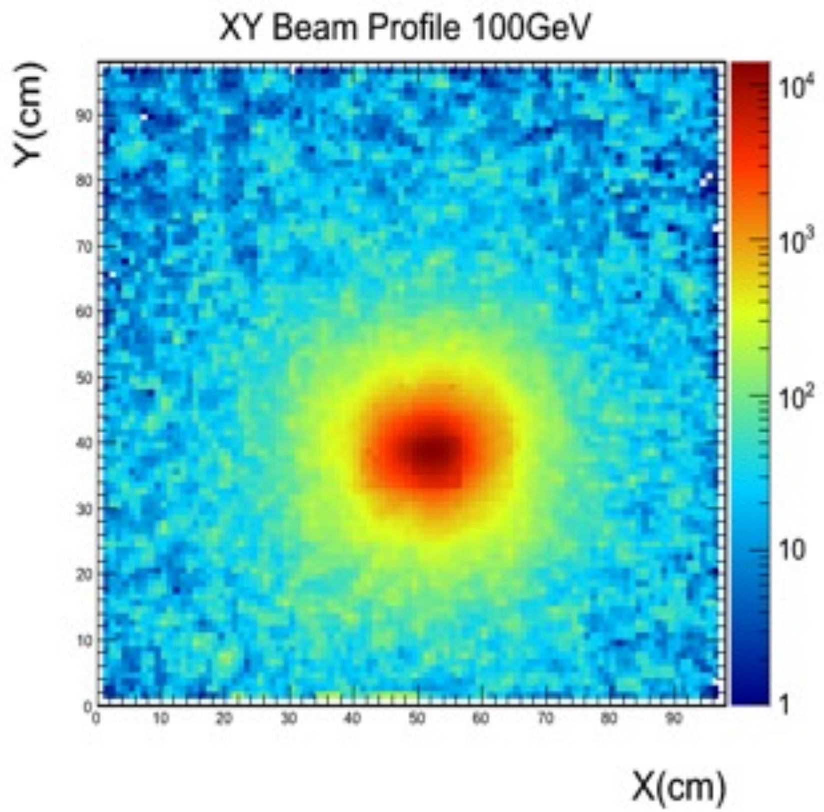
Hits are grouped in clusters if sharing an edge

Tracks reconstructed if remaining N_{layers} > 7, with at least 1 layer on each side of investigated one (except 1st and last layer)



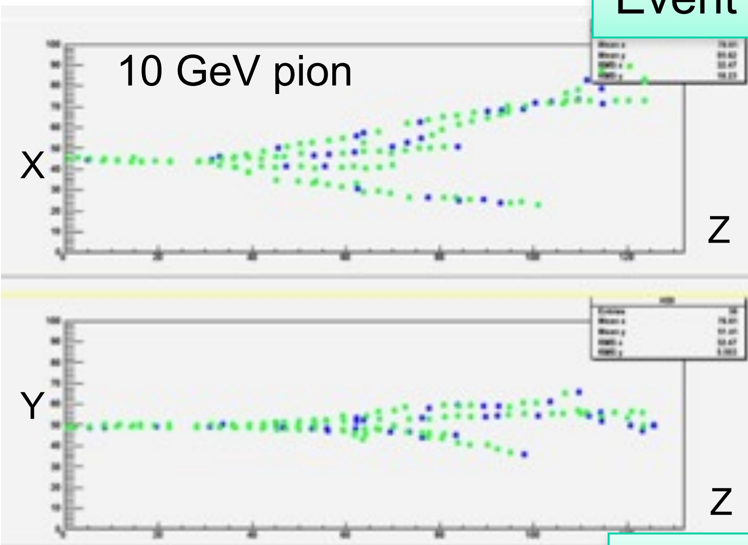


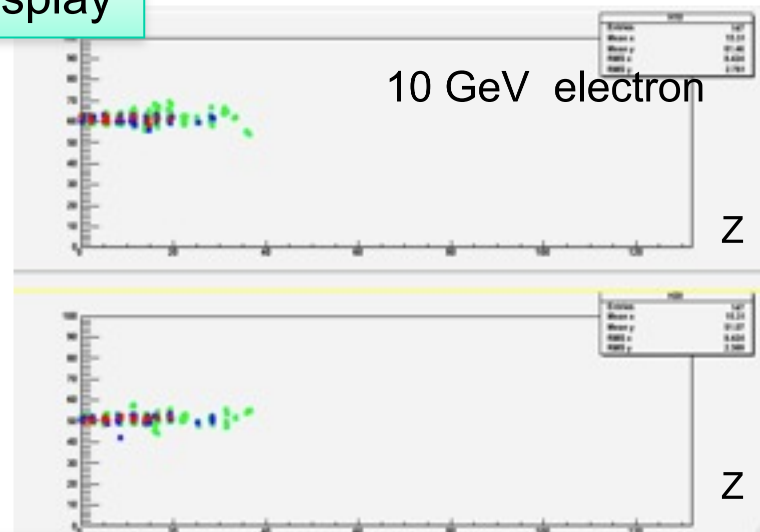




100 GeV pions

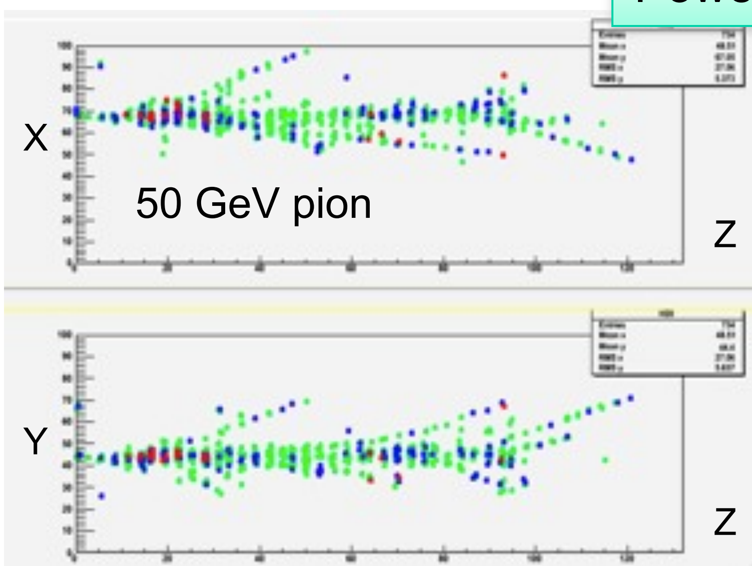
Event display

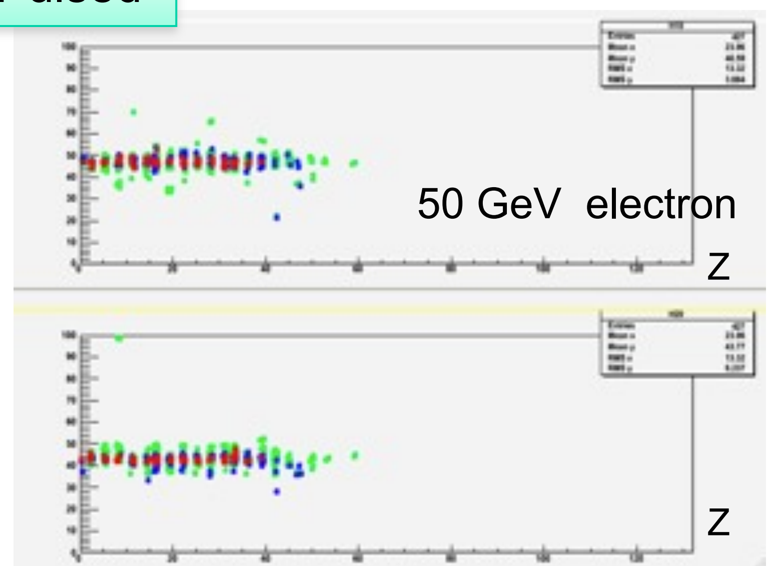




Power-Pulsed

units in cm





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

Raw data, no treatment except time hit clustering

Results

Energy : SDHCAL readout (2 bits)

$E_{rec} = \alpha\ N1 + ß\ N2 + \gamma\ N3.$

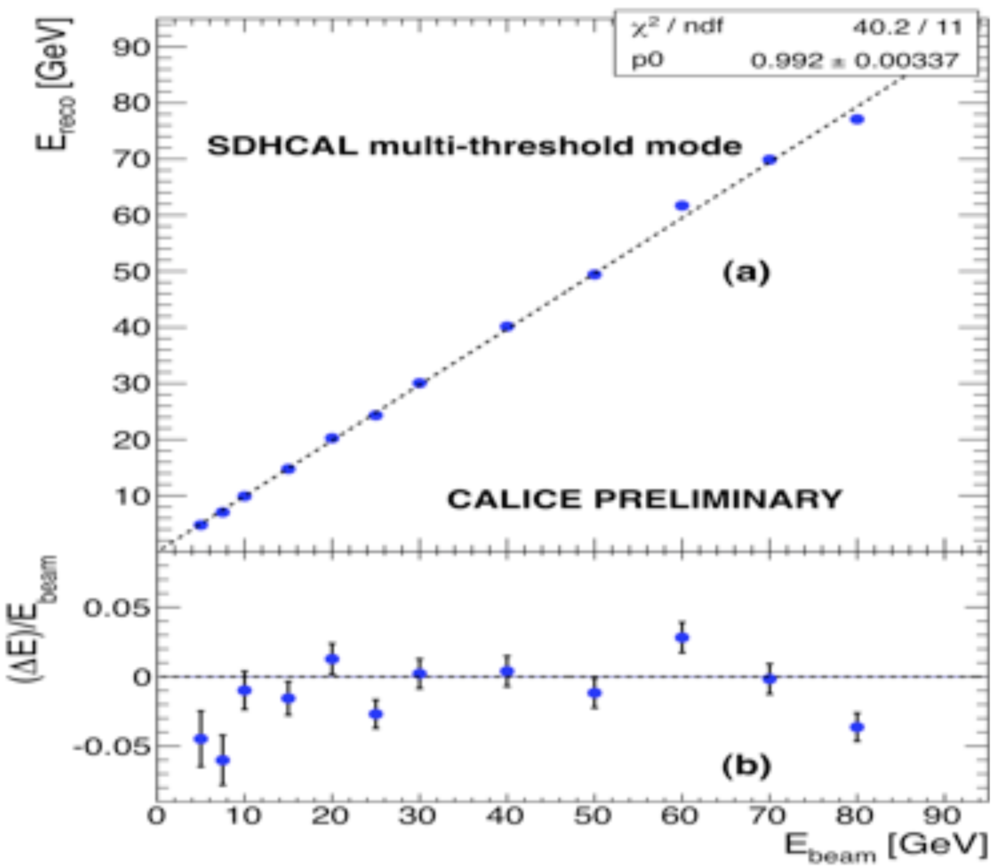
$\alpha, ß, \gamma = f(Nhit)$

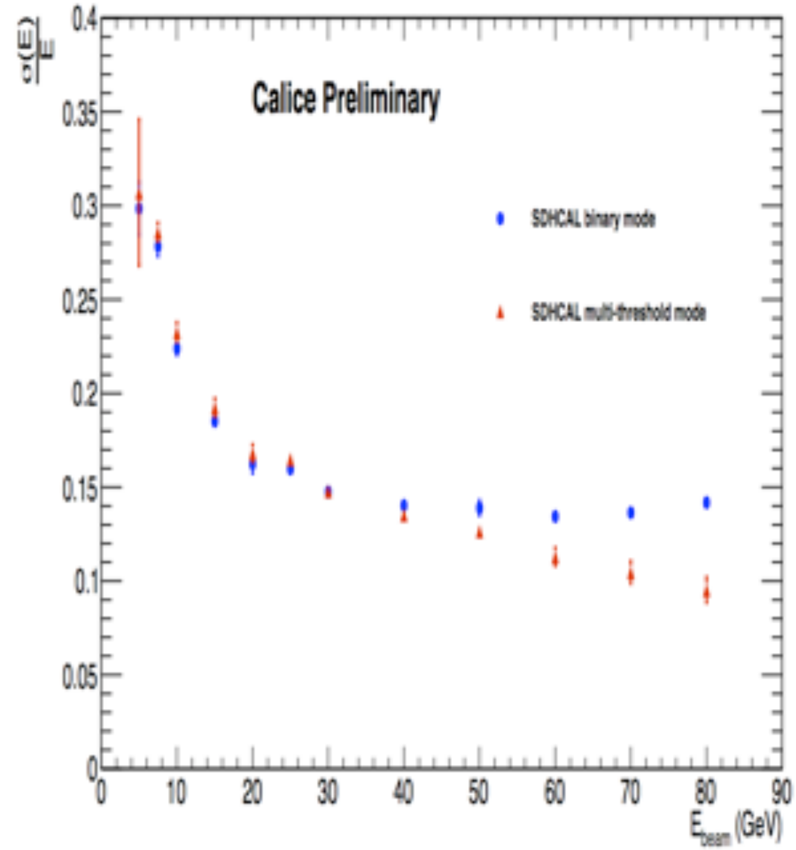
N1 = # of Hits ≥ thr1, <thr2

N2 = # hits ≥ thr 2, <thr3

N3 = # hits ≥ thr3

Nhit = N1+N2+N3





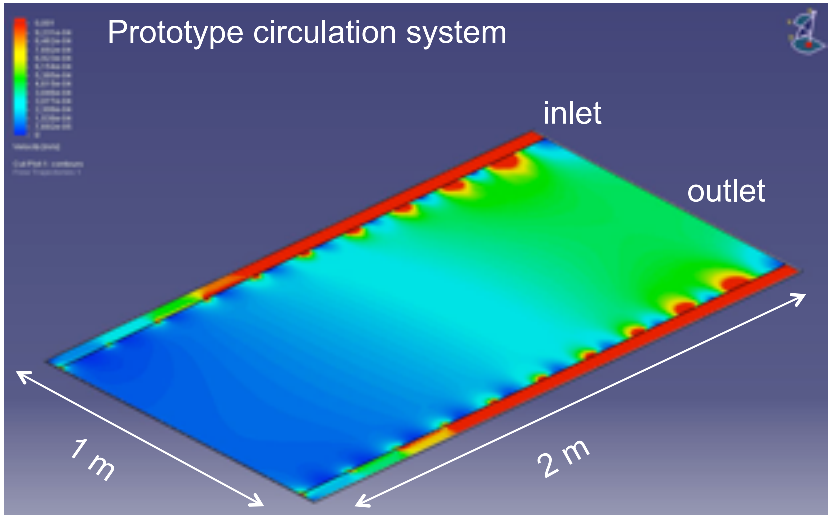
Current R&D

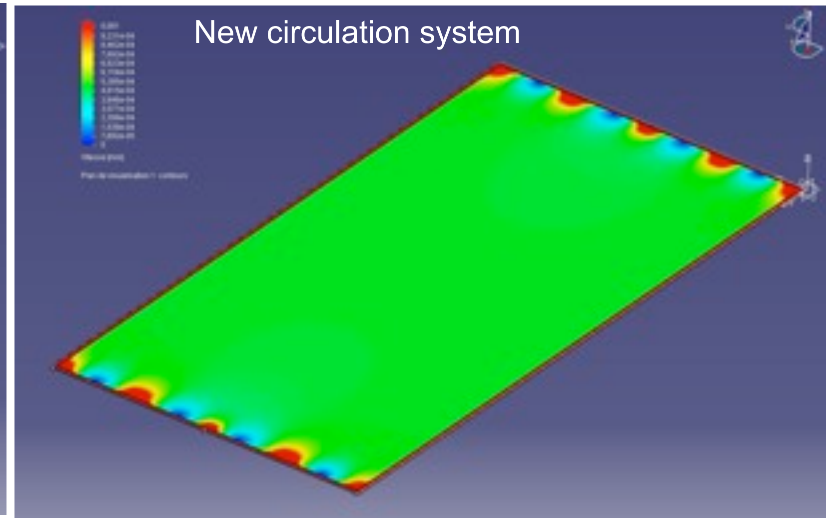
→ Larger GRPC to validate completely the SDHCAL option

→ Upgraded electronics based on zero suppression and I2C protocol
(funded essentially by **AIDA)**

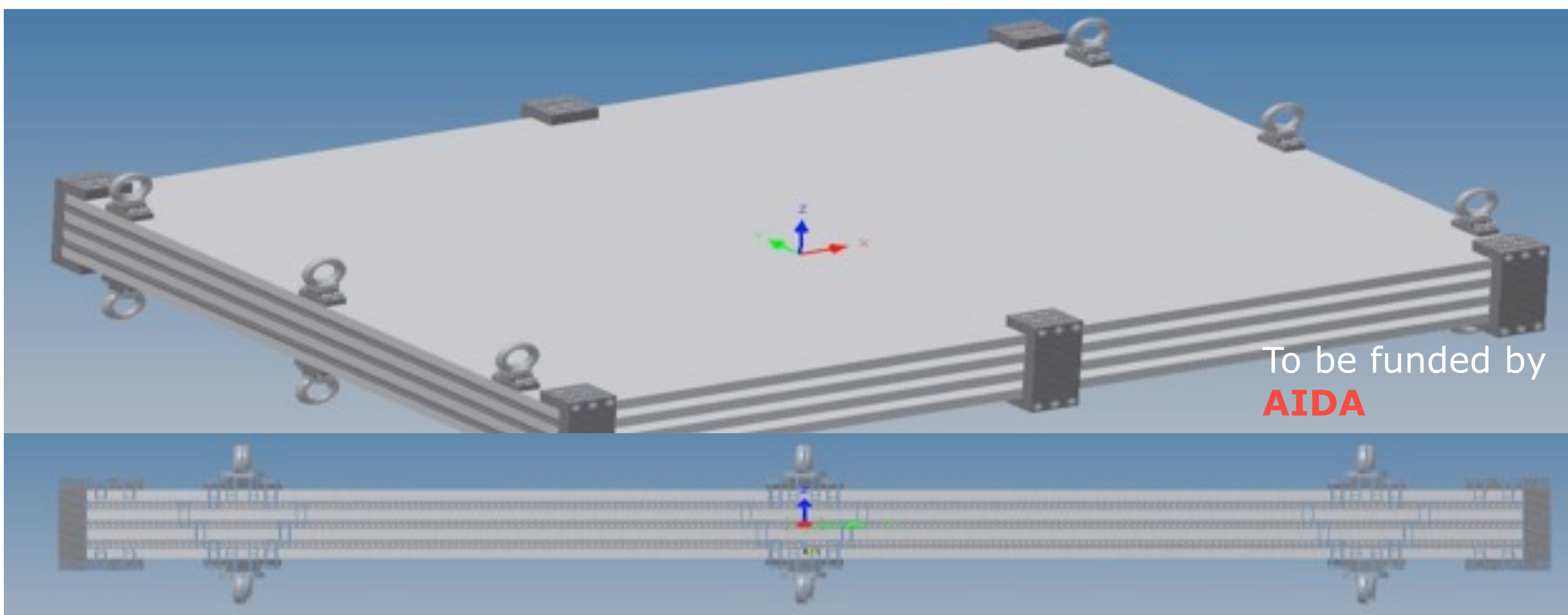
→ Mechanical structure using new welding technique

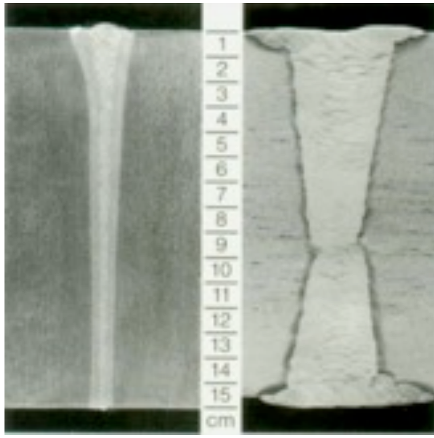
Detector improvement : to achieve same performances with very large GRPCs

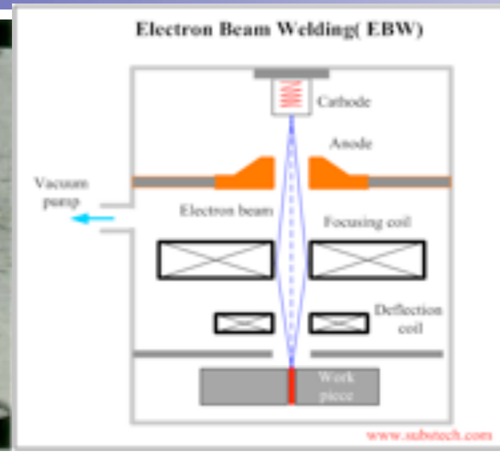


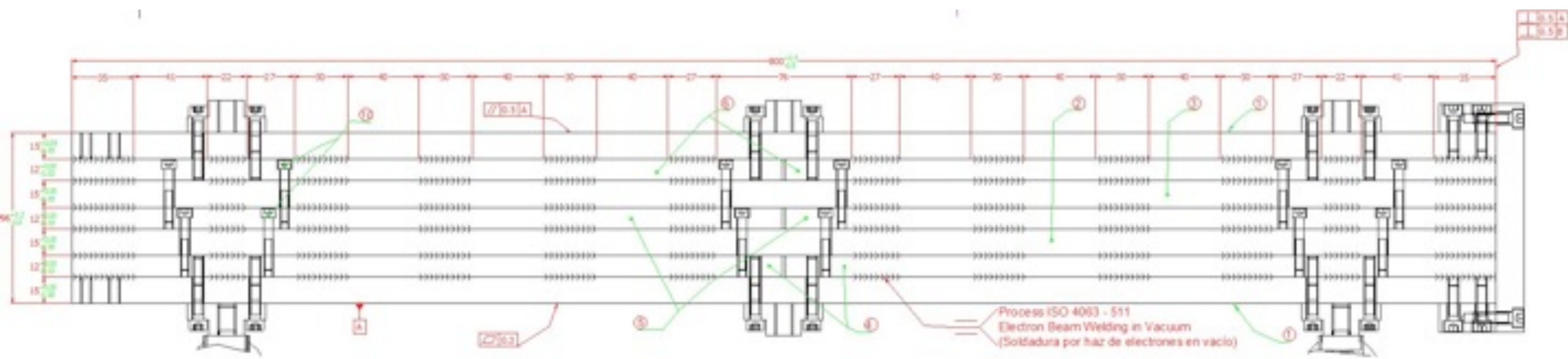


Mechanical structure : to be built with EBW techniques and to host few large detectors GRPCs







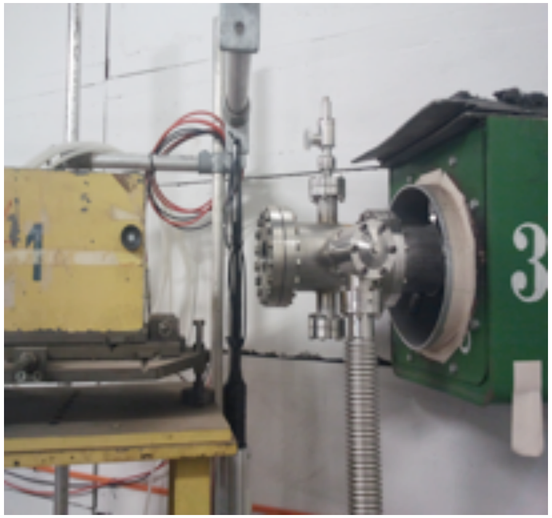


Made by Electron Beam Welding proccess in Vacuum.
Welding deep of 5 mm.

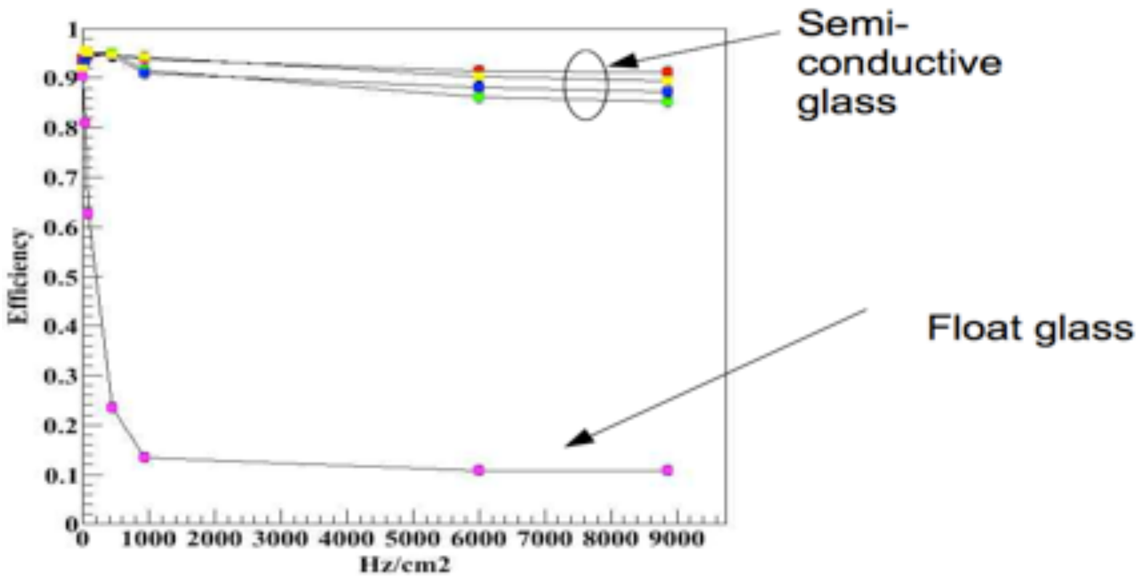
High-Rate GRPC

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 region if the rate > 100 Hz/cm^2



Conclusion

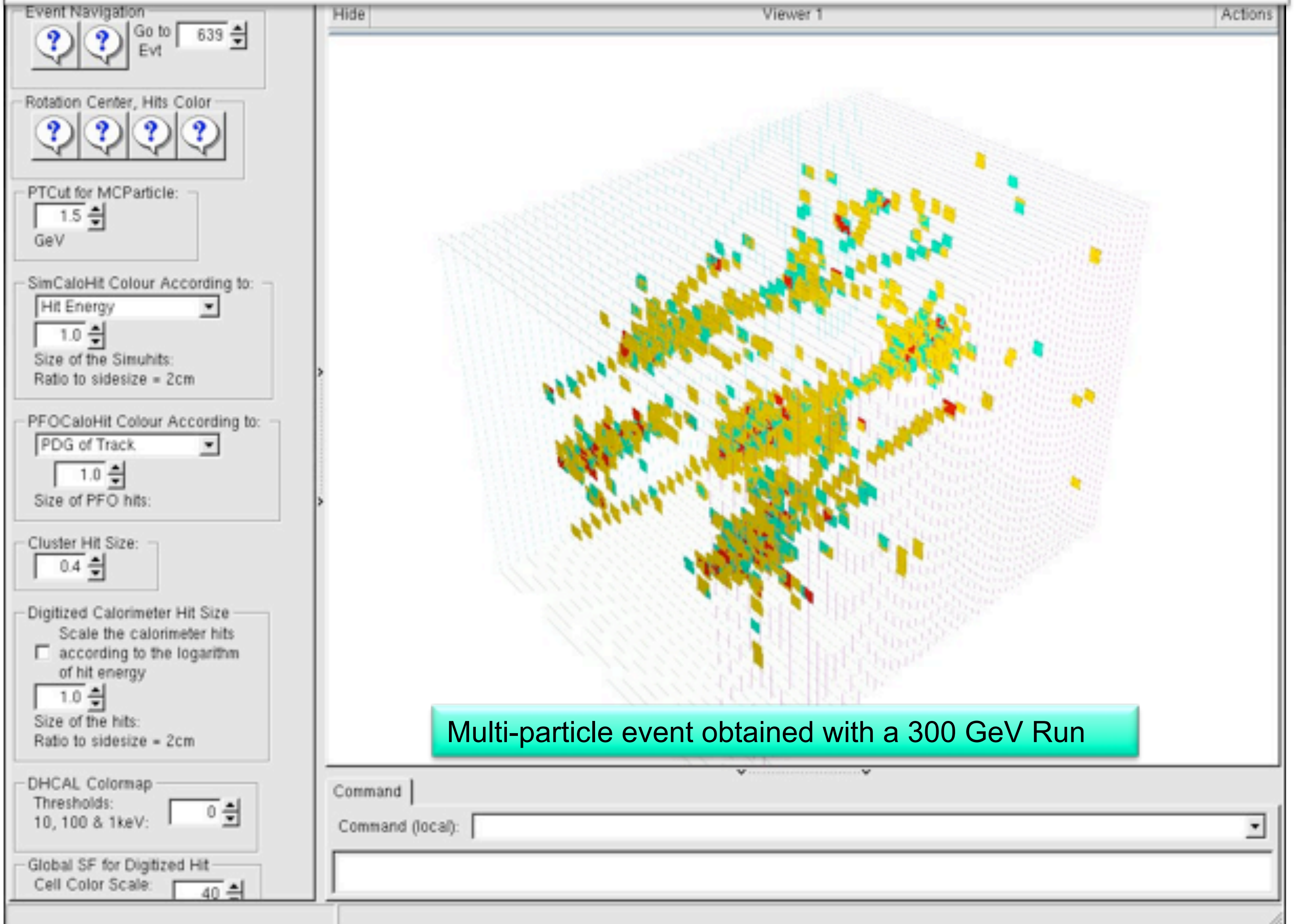
RPC is an excellent detector which could be used as an active medium for hadronic calorimeters at low cost.

Realization of a large prototype validated the SDHCAL concept.

R&D is still ongoing to validate completely the option of SDHCAL for the ILD project

Strong collaboration with industrial companies was behind the technological prototype success. This will be a must for the construction of the SDHCAL.

Conclusion



Multi-particle event obtained with a 300 GeV Run

SDHCAL Concept

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

It is based on two points:

1- Gaseous Detector

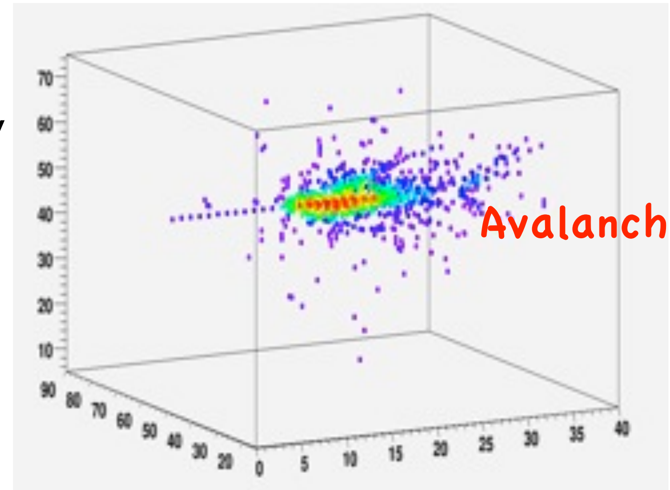
Gaseous detectors like **GRPC** are homogenous, cost-effective, and allow high longitudinal and transverse segmentation.

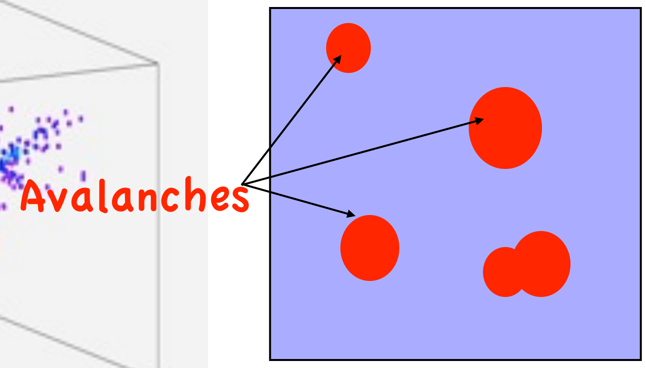
2- Embedded electronics Readout

A simple binary readout leads to a very good energy resolution

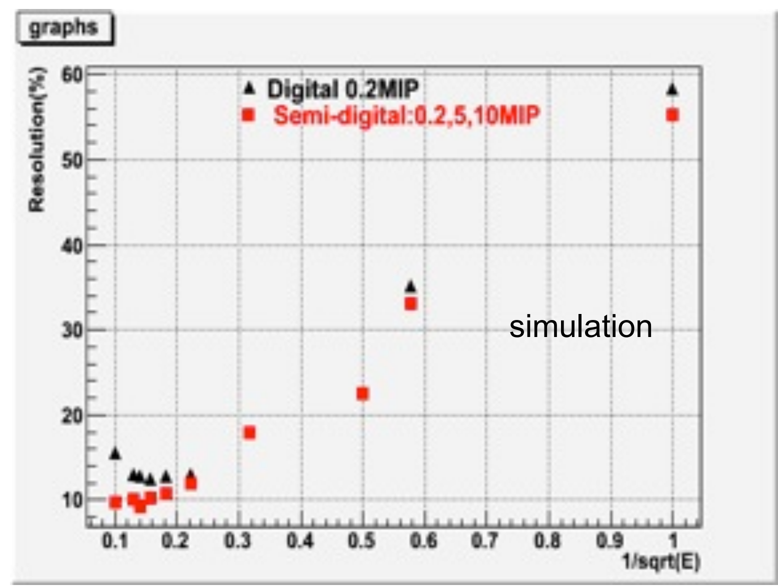
However, at high energy the shower core is very dense and saturation shows up

→ 2-bit readout improves on energy resolution at energies> 30 GeV

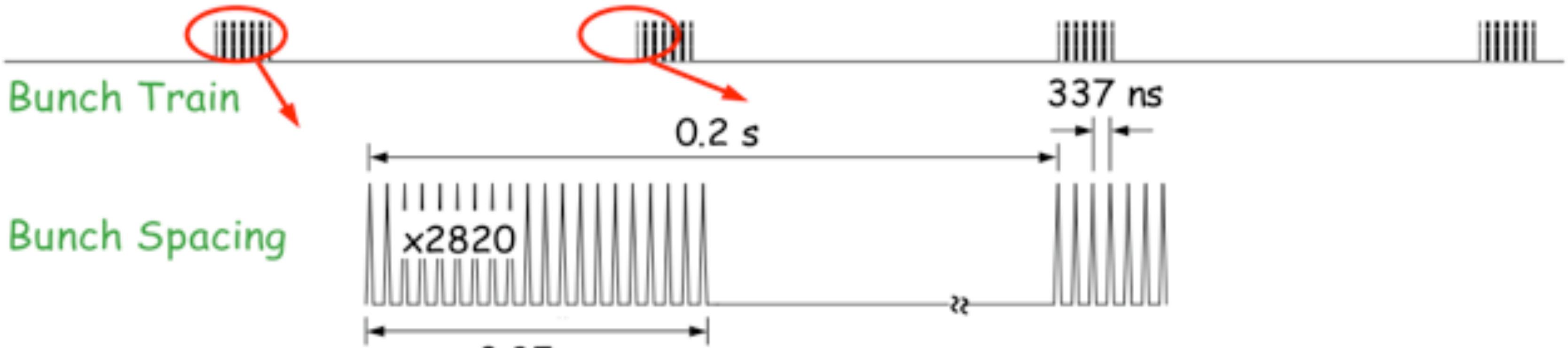




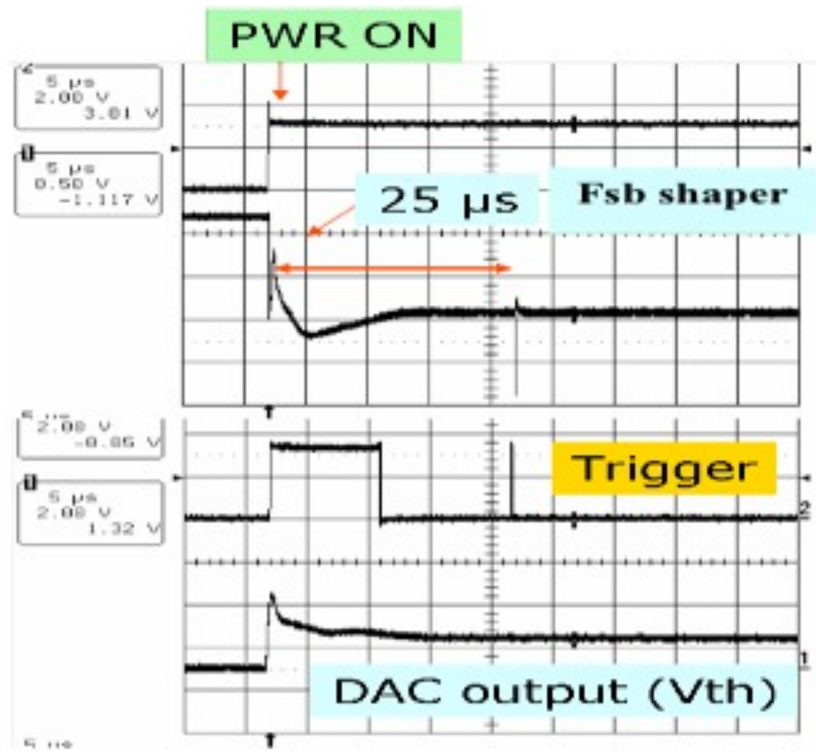
1 cm^2 pad



Electronics readout system R&D: Power-Pulsing

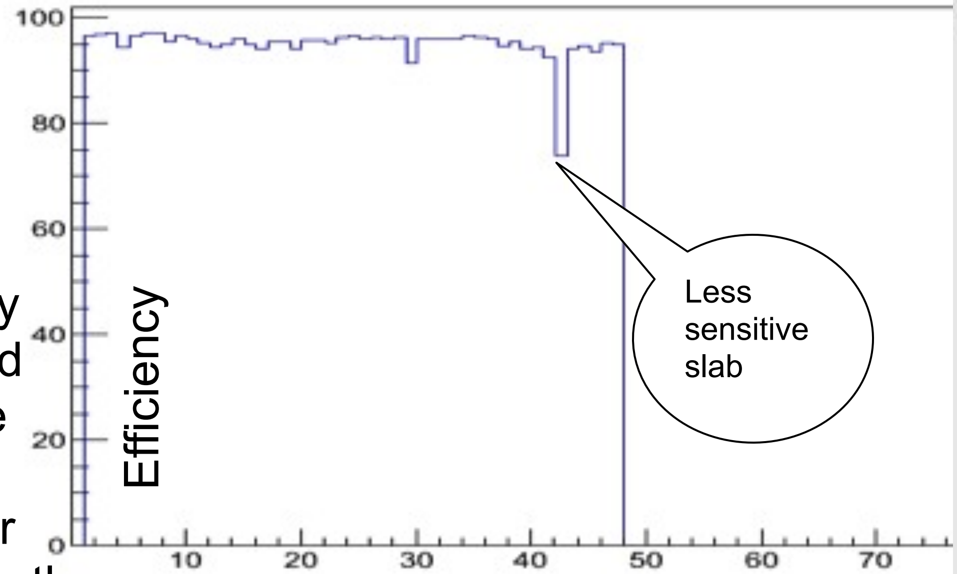


Switch on the electronics just before the BX and switch it after.
→
(7.5 μW in case of ILC duty cycle)



Prototype data acquisition

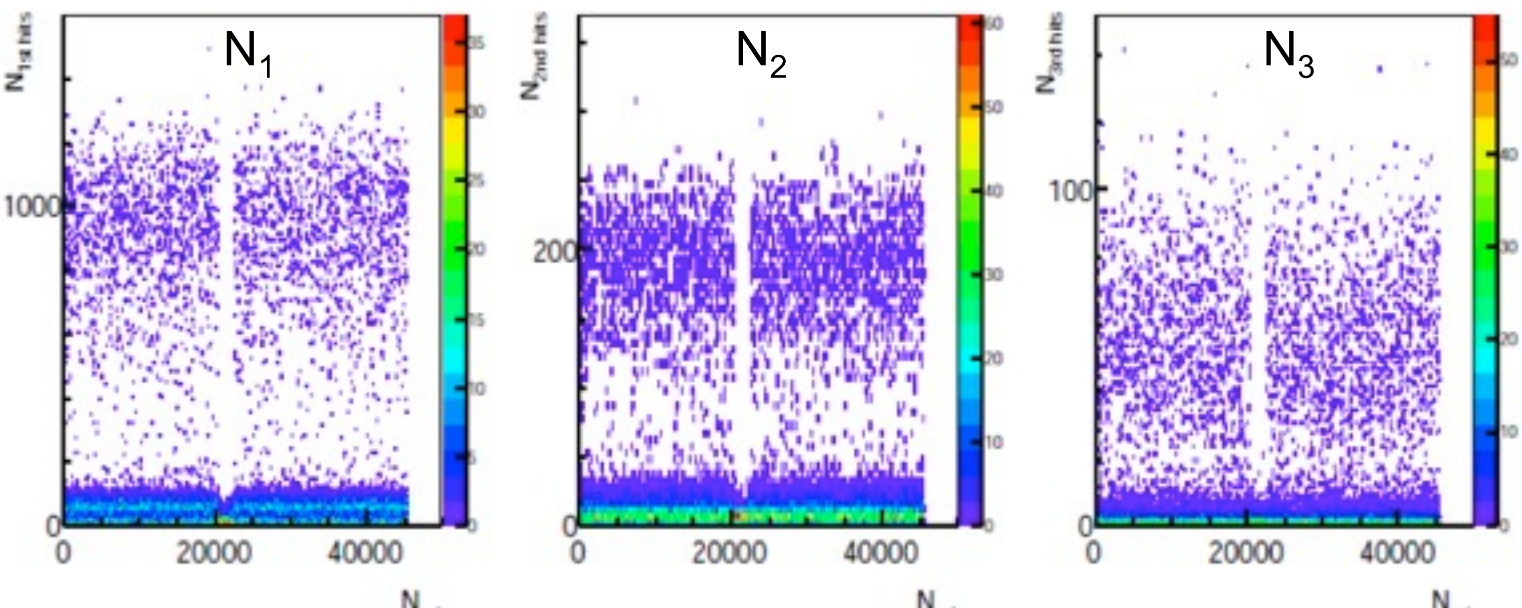
During data taking, efficiency and multiplicity are estimated ever now and then using the muon beam, cosmics. This allows to control the detector quality and its stability during the run.



Efficiencies for 43138

1	298770	288178	96.
2	299923	289999	96.
3	300587	291836	97.
4	302290	285384	94.
5	303182	292831	96.
6	304359	295212	96.
7	303836	295208	97.
8	303234	289097	95.
9	301413	290684	96.
10	299341	287161	95
11	296713	282710	95
12	295025	278118	94
13	292102	277133	94
14	289232	277629	95
15	287725	273191	94
16	285409	268881	94
17	283921	271082	95
18	281189	268578	95
19	279243	262735	94
20	276900	265080	95
21	274932	263257	95
22	273358	260185	95
23	271427	261003	96
24	269284	260190	96
25	267388	256939	96
26	265796	255818	96
27	264488	253723	95
28	262853	253066	96
29	260714	238445	91
30	258935	248365	95
31	257347	247229	96
32	256354	246290	96
33	255078	244701	95
34	253576	244776	96
35	252403	243090	96
36	251564	241647	96
37	250462	237246	94
38	249468	237927	95
39	248213	233770	94
40	252447	238044	94
41	251368	232604	92
42	249871	184524	73
43	247550	232840	94
44	245550	232342	94
45	243090	227223	93
46	240189	228552	95
47	237527	225465	94

Stability of the three thresholds is also controlled by the hits distribution hadronic showers



Study of hadronic shower

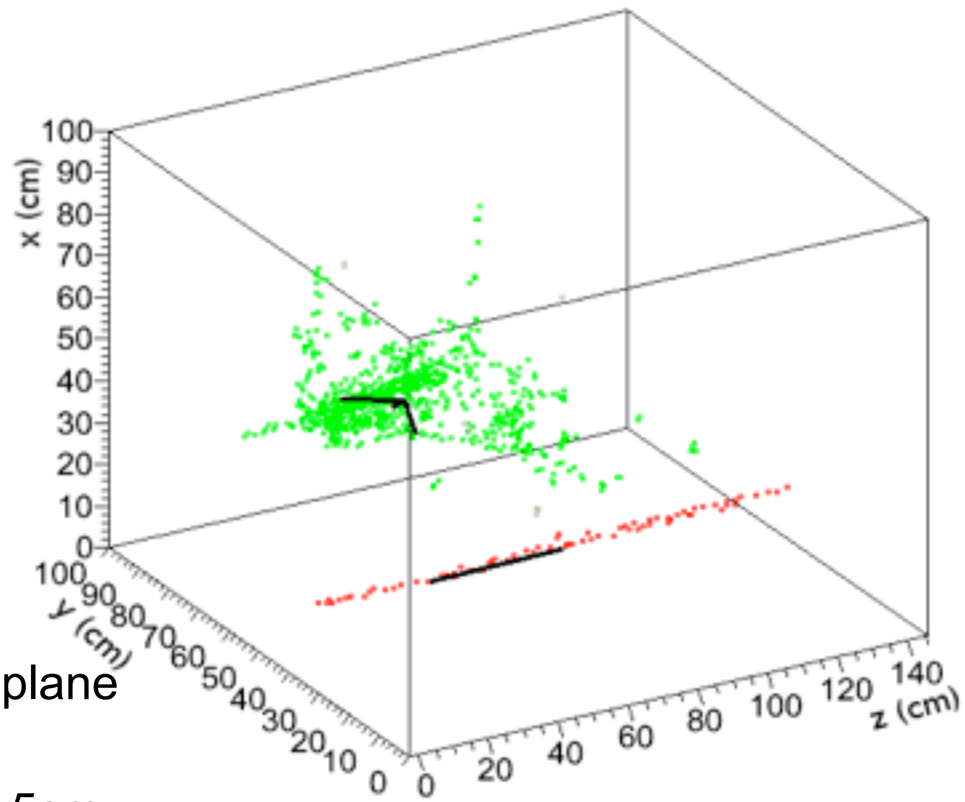
Beams of pions, electrons and muons at CERN

2 weeks in May 2012 @ SPS H2
π^+: 20, 30, 40, 50, 60, 70, 80 GeV
e^- :10, 20, 30, 40, 50, 60 GeV
μ dedicated runs...

2 weeks in August (& September) 2012 @ SPS H6 and 1 week in November
π^+: 5, 7.5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, 90, 100 GeV
+ few μ dedicated runs
Beam composition:
All π runs contain μ , e^- and cosmics (no Cerenkov detector used)
π's runs filtered by 4mm Pb to remove e^- (efficient esp. for $E \geq 20$ GeV)
proton component in HE π runs (@ $E \geq 20$ GeV)
$\delta E_{beam}/E \sim 1$ %
Large beam profile :
low rates (ε ↘ at $f \geq 100$ Hz)
Rate monitored online by μ tracks and π tracks segments
Only run with $f \leq 1000$ part/spill ⇔ $\varphi \leq 100$ Hz/cm

Selection

✓ Topological:
Principal Component Analysis (PCA) on all hits or clusters
3 main ⊥ axis eigenvalues
$\lambda_i \equiv \sigma$ (hits) on axis
λ_3 = longitudinal comp.
Transverse Ratio TR = $(\lambda_1 \oplus \lambda_2) / \lambda_3$
→ muons vs e, π



✓ Shower start
$\lambda_{1p}, \lambda_{2p}$ idem to λ_1, λ_2 restricted to 1 plane

Interaction plane *(FIP)* ≡ $\lambda_{1p} \oplus \lambda_{2p} > 1.5cm$
$N_{hit}^{plane} > 5$

Selection

✓ Density

V_1 = ($\sum_{layers} N_{25}^{layer}$) / N_{hits}

N_{25}^{layer} = N_{hits} in 5×5 around barycenterin 1 layer

V_2 = FD_{3D} / ln(N_{hits})

Fractal dimension:

$$\mathrm{FD}_{3\mathrm{D}} = \frac{1}{|I|}\sum_{n\in I}\frac{\ln(N_{\mathrm{hit}}/N_{\mathrm{cube}}(n))}{\ln(n)}$$

$N_{cube}(n)$ ≡ number of cube in I={2,3,4,6,8,12,16}

✓ Shower clustering

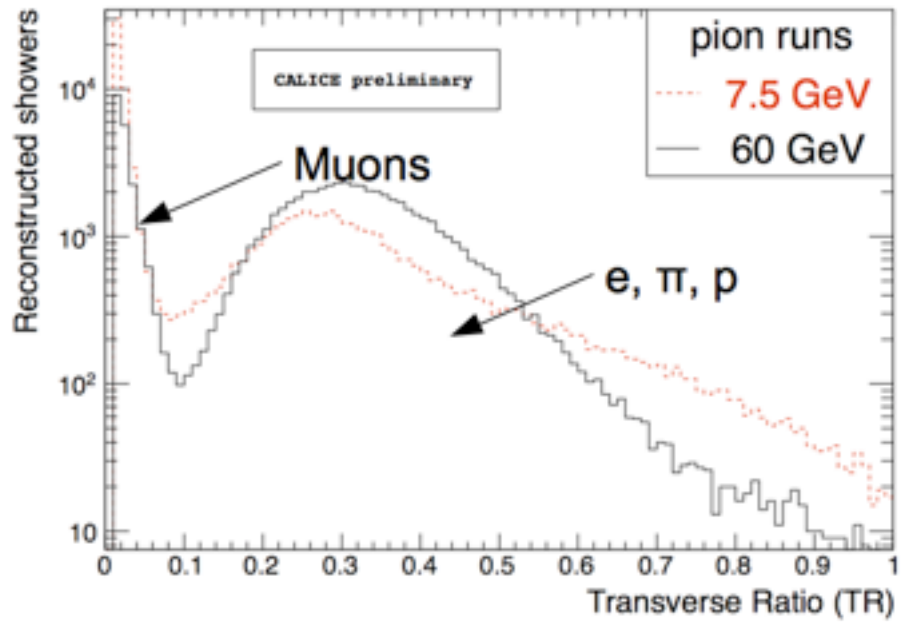
Removal of isolated hits and tagging of overlapping events

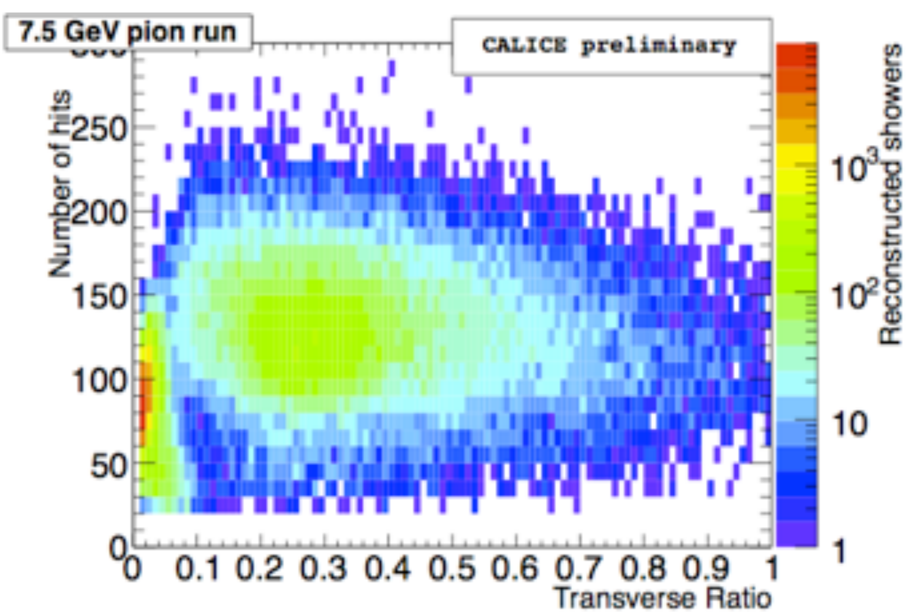
MST à la charm-II using a distance definition:

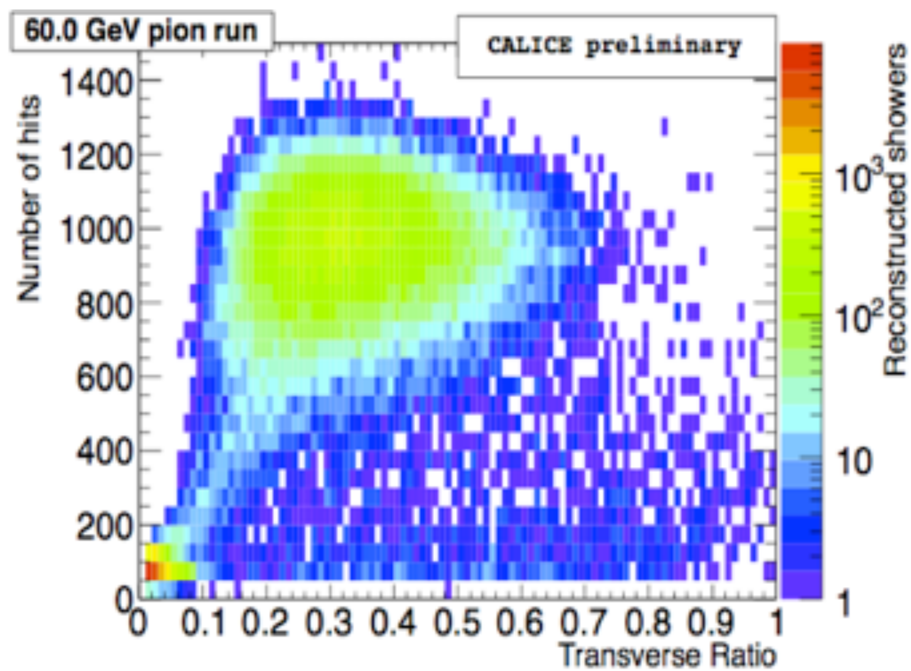
$$D_{\alpha,\beta} = \left|\mathrm{plane}_\alpha - \mathrm{plane}_\beta\right| + 2\times(\left|I_\alpha - I_\beta\right| + \left|J_\alpha - J_\beta\right|)$$

Selection

Muon rejection:
Transverse RatioTR ≥ 0.1
→ 98% of μ's







Selection

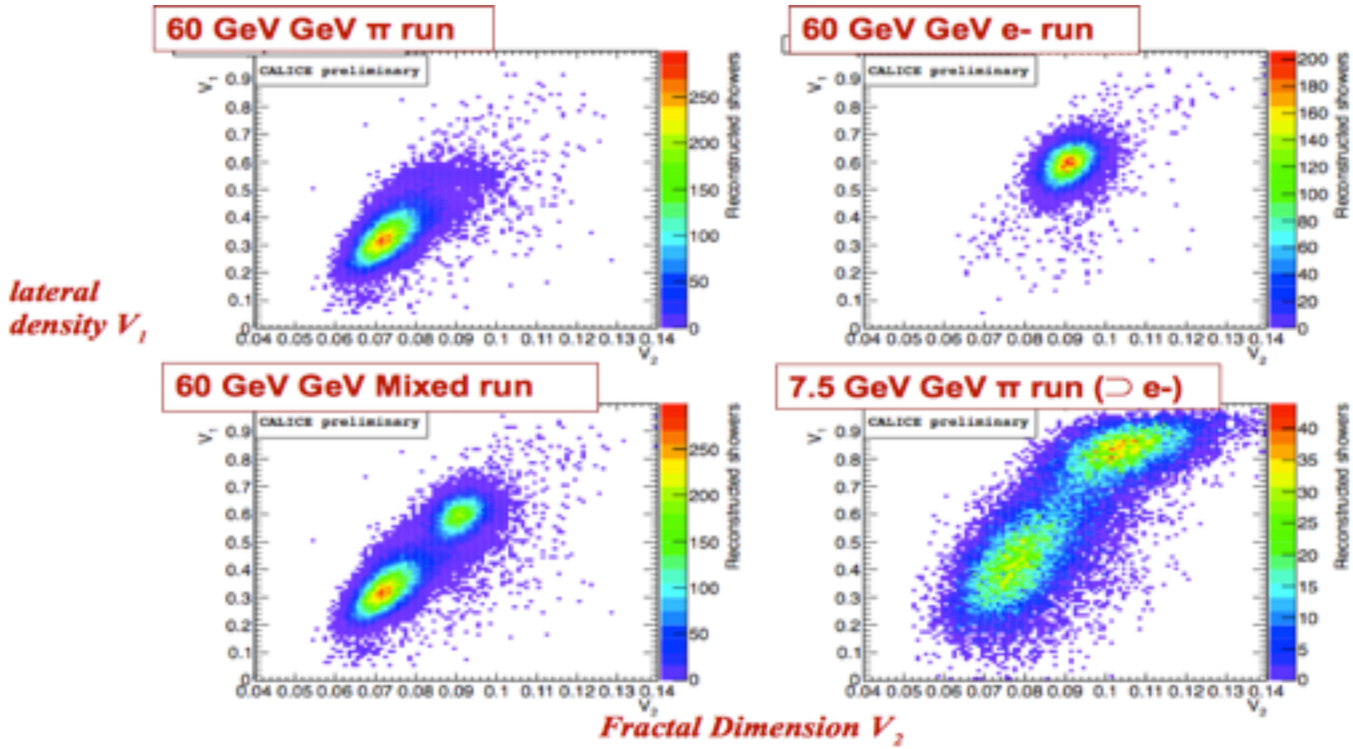
Eletron rejection :

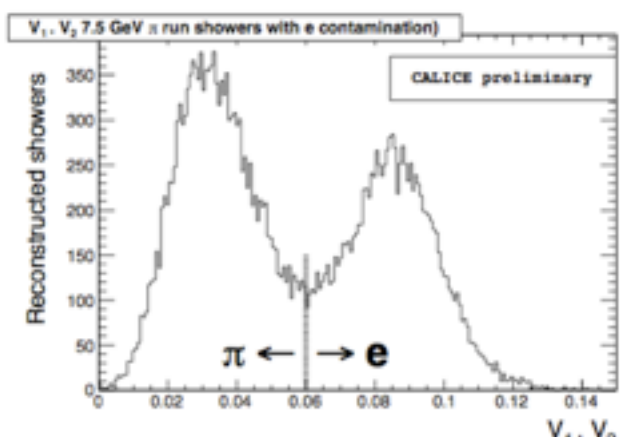
•Operation on clusters
 Negligeable loss of
 π's @ HE

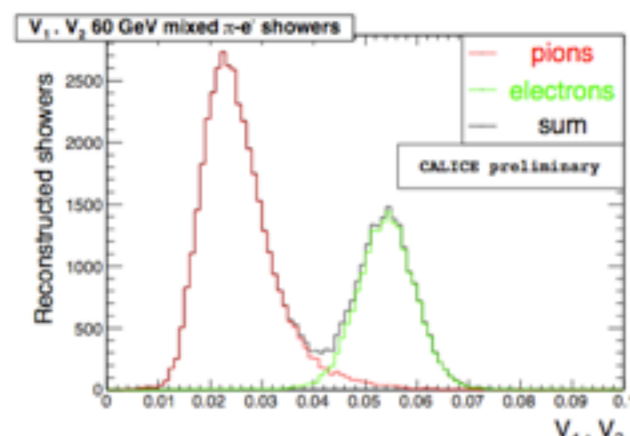
• few % e- residual contamination @ LE

about 10% variation of

⇒ Systematics





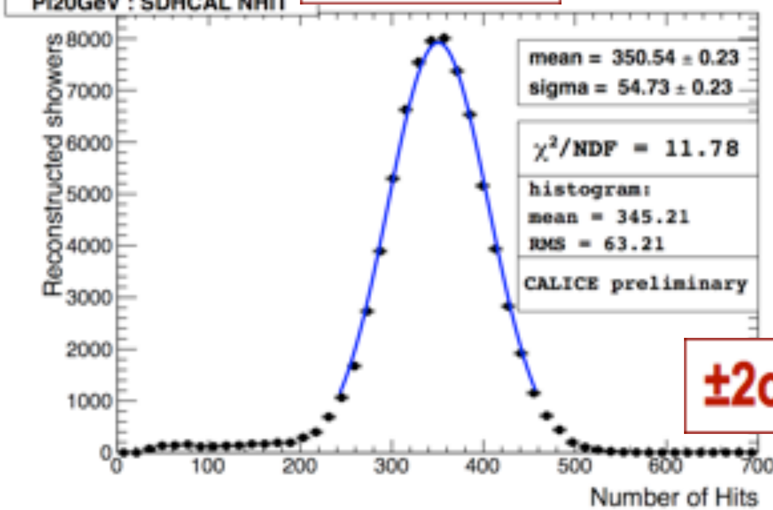


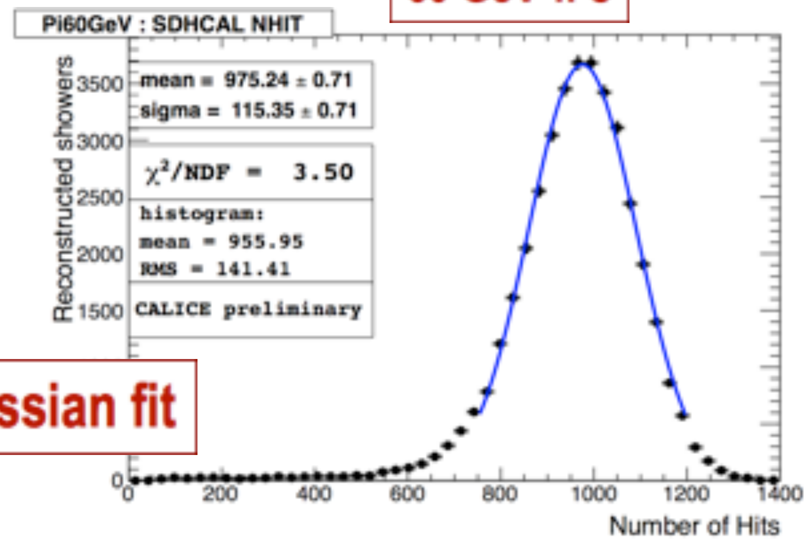
pion run energy (GeV)	5	7.5-15	20	30-40	50-60	70-80
min $V_1 \cdot V_2$ value	0.065	0.06	0.055	0.05	0.045	0.04

Results

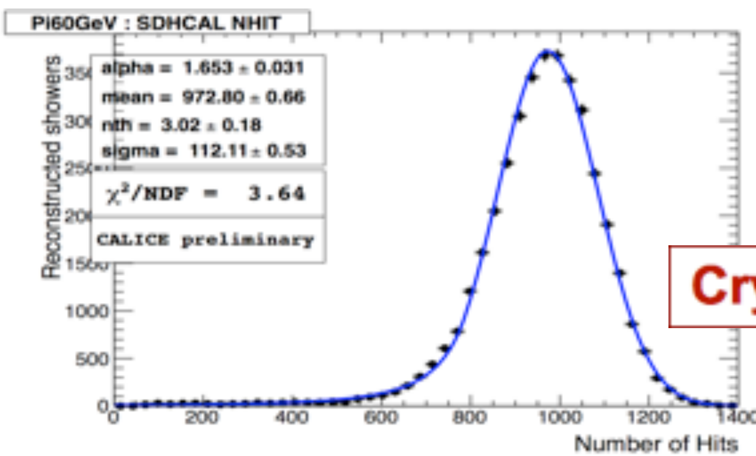
20 GeV π's

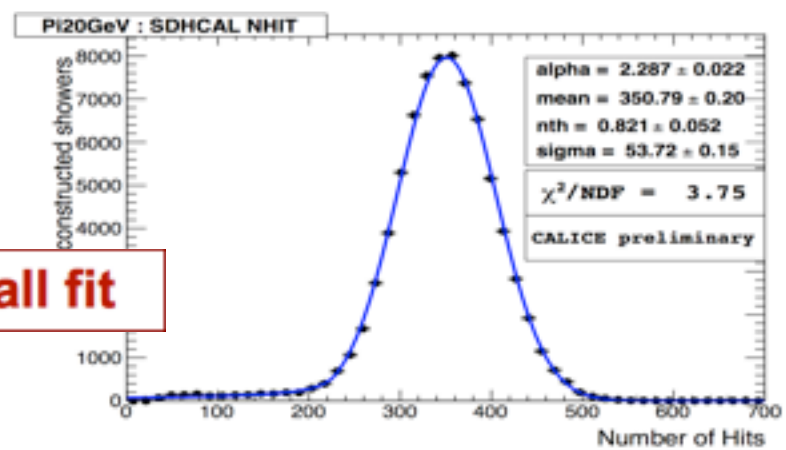
60 GeV π's





±2σ Gaussian fit

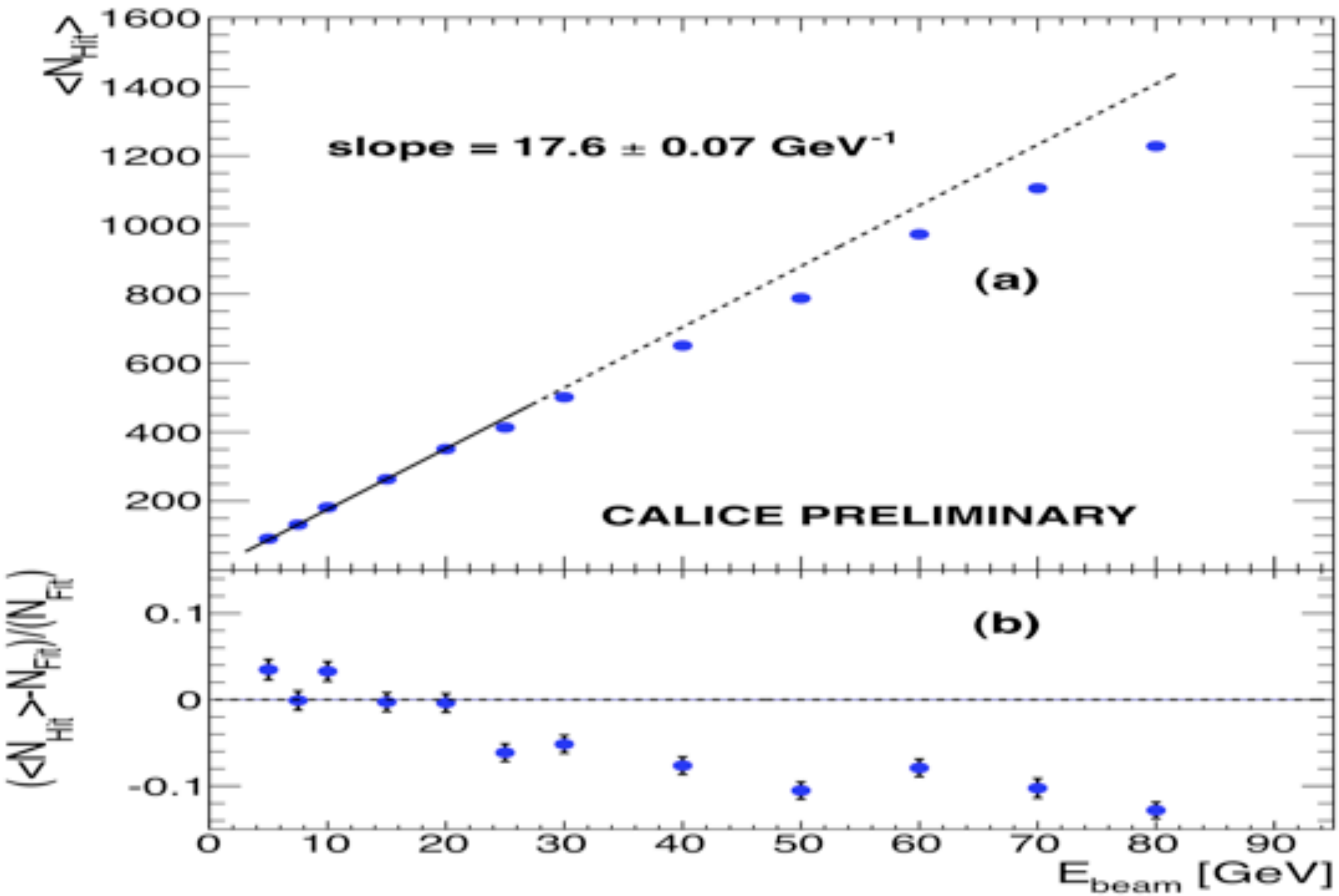




Crystal Ball fit

Results

Number of hits



- Saturation observed for $E_{beam} \geq 30$ GeV

- Offset (~4 hits) compatible with noise over 3 clock cycles

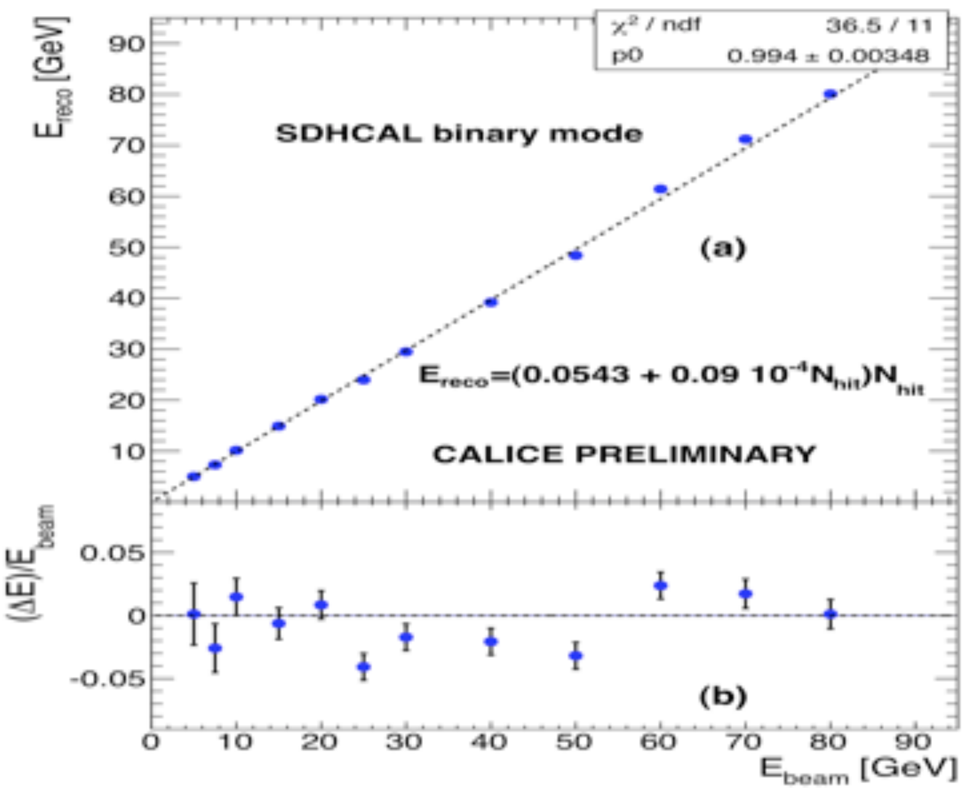
Results

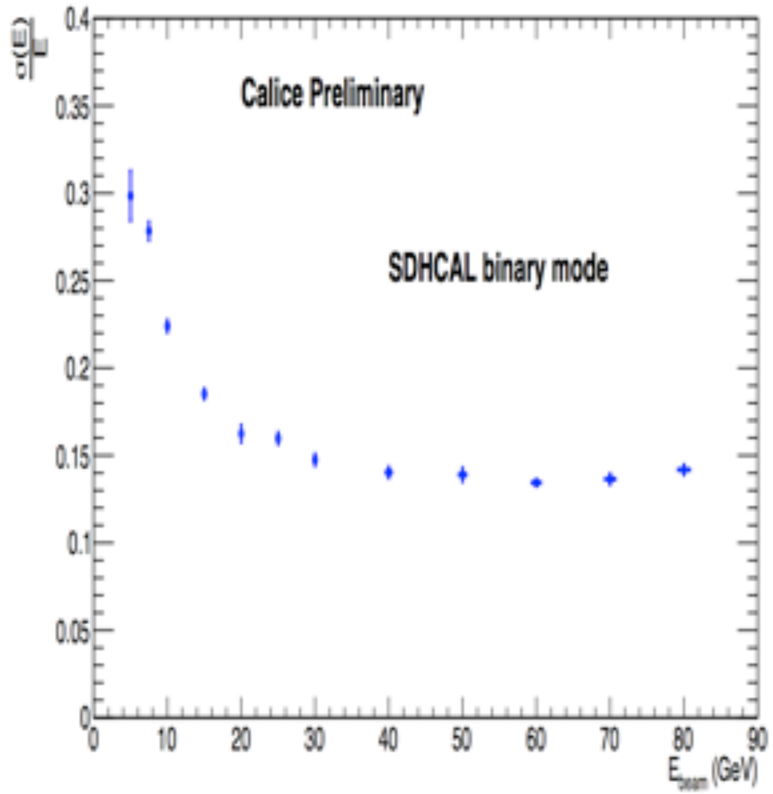
Energy : DHCAL readout (1 bit)

Fit by quadratic function:
E = (C+ D • Nhit) Nhit
yields:
C = 54.3 MeV
D = 0.09 10^{-4} MeV

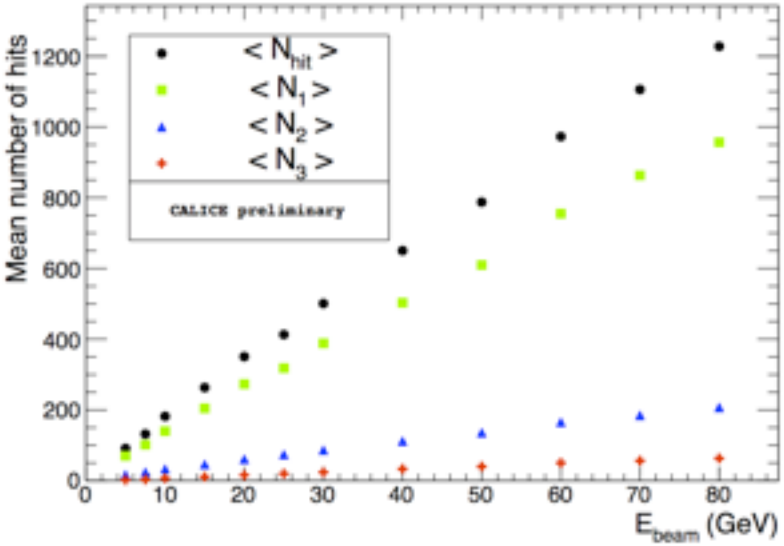
Error = Stat ⊕ δ(Gauss, CB fit)

⊕ cut var ±10%





Results Energy : SDHCAL readout (2 bits)



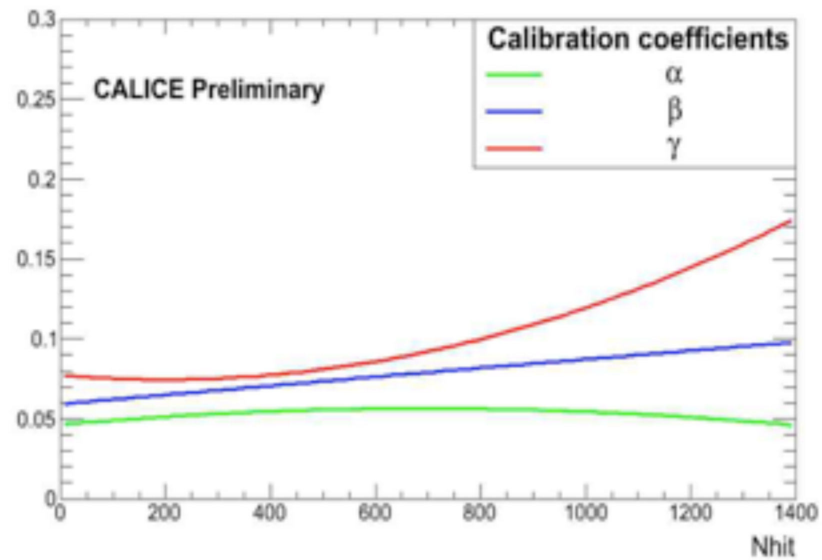
N1 = # of Hits ≥ thr1, <thr2
N2 = # hits ≥ thr 2, <thr3
N3 = # hits ≥ thr3
Nhit = N1+N2+N3

E_{rec} = α N1 + ß N2 + γ N3.

α,ß,γ = f(Nhit)

f(Nhit) for ech coefficient is a quadratic function whose parameters are determined by minimozing a χ^2 over 10, 20, 30, 40, 50 and 60 GeV samples (1/3 of stat.)

This treatment is valid for identified single particle



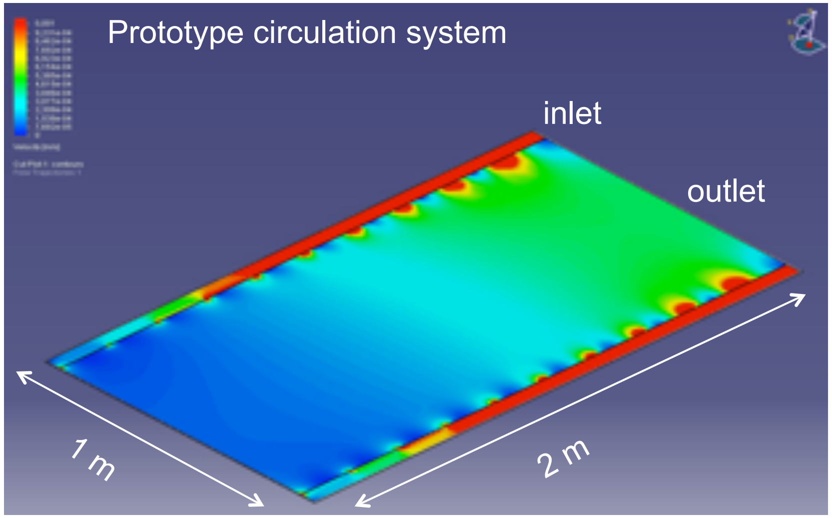
Large GRPC for ILD model:

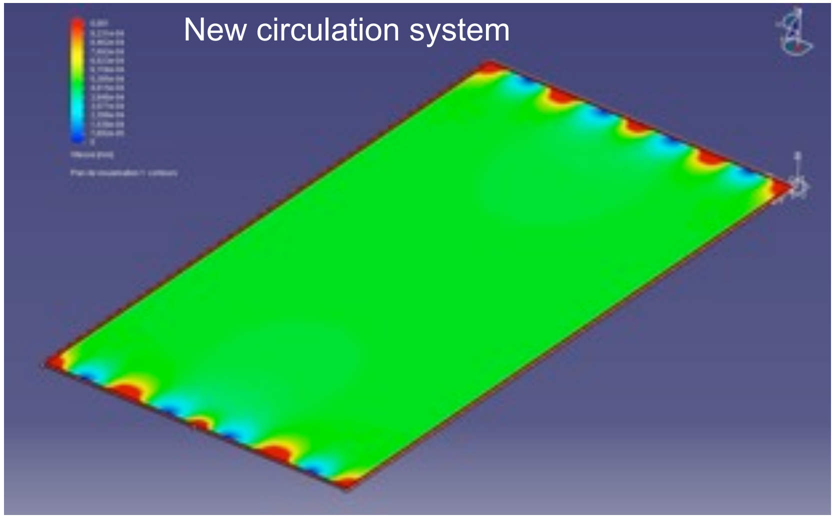
GRPC with a surface
≤ 3 m^2 are needed.

We intend to build
a $2m^2$ GRPC.

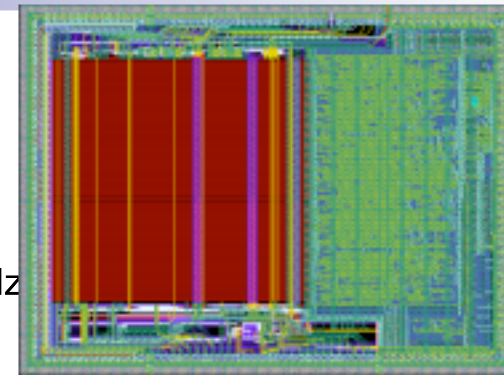
We are currently studying
the gas distribution system
to ensure a good gas
renewal.

Once the first large detector is built
the gas circulation of the new scheme
will be controlled using radioactive
^{83m}Kr





HARDROC3



This a new version of the HARDROC ASIC has:

-64 independent channels, zero suppression

-I2C link

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

Bandgap: new one with a better temperature sensitivity

Triple voting

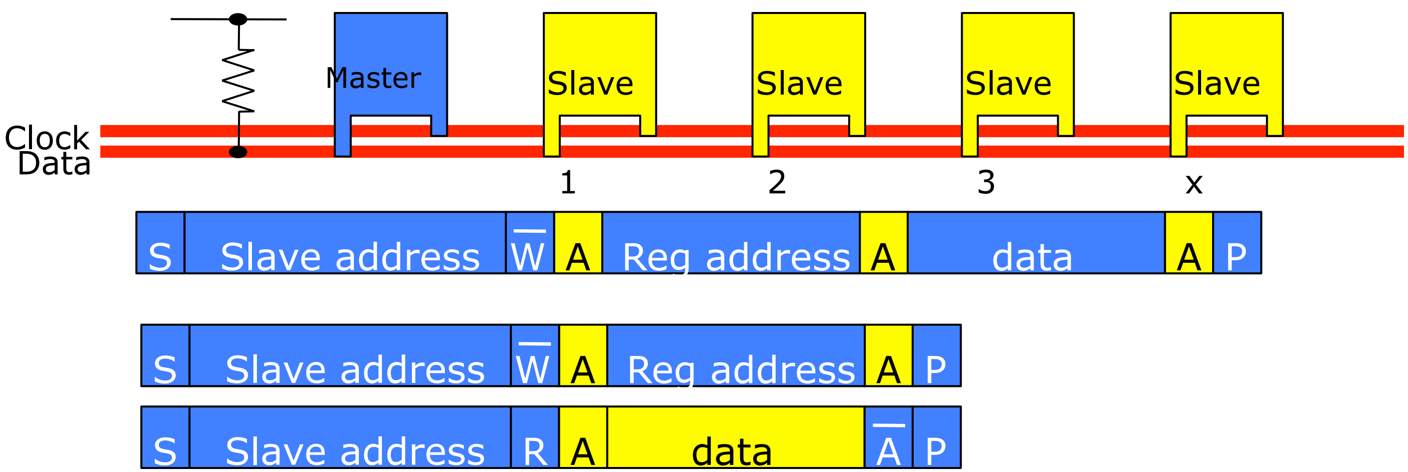
Roll mode

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

Die size ~30 mm2 (6.3 x 4.7 mm2)

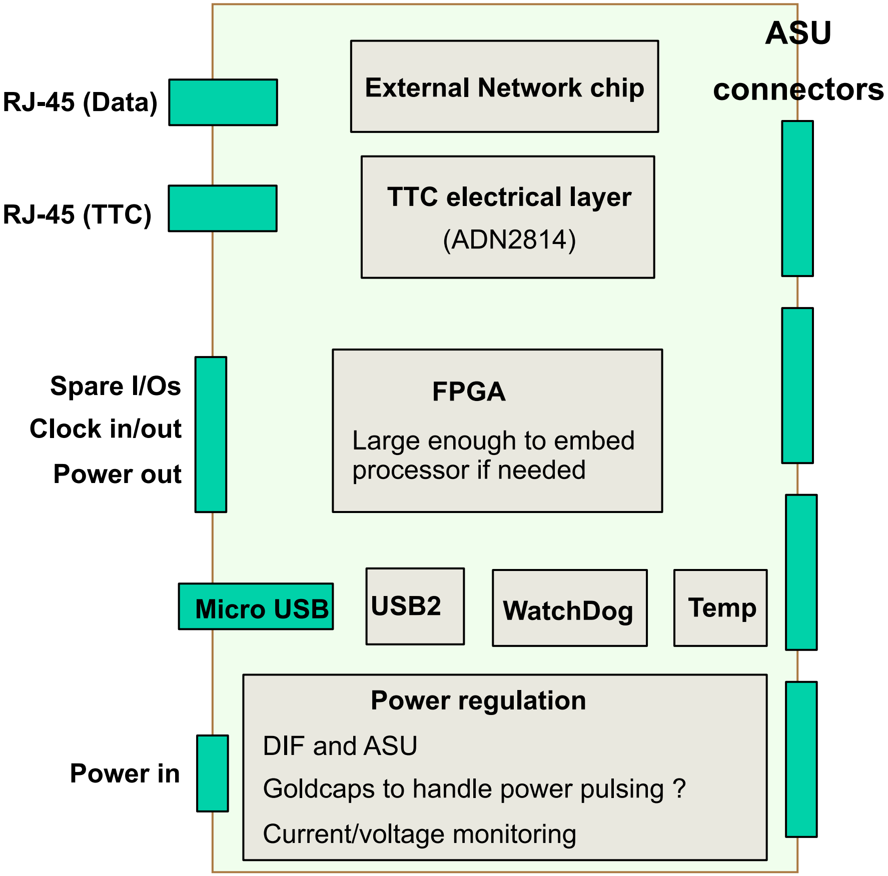
Packaged in a TQFP208

The ASIC was produced and tested. All functionalities were successfully tested.
A minor problem was found with the I2C scheme (buffer stuck to zero)
This I2C was however successfully tested after a BIF.



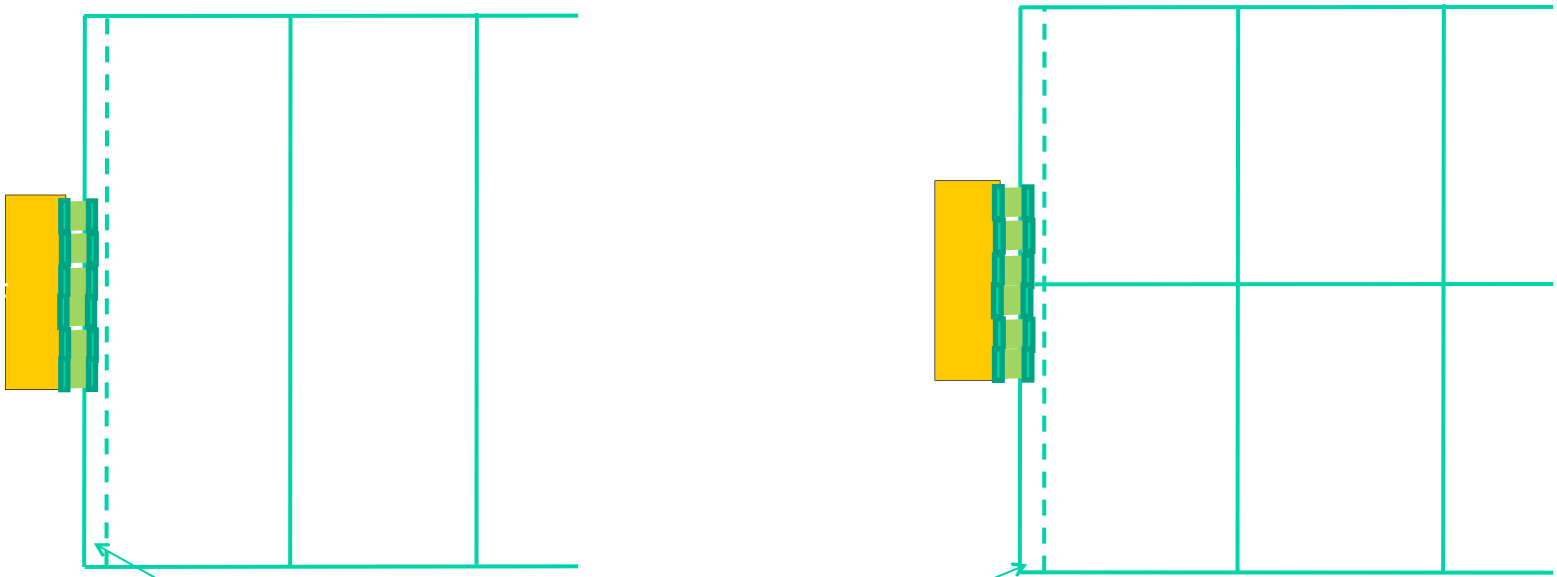
New SDHCAL DIF main features

- 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)



New ASU layout options

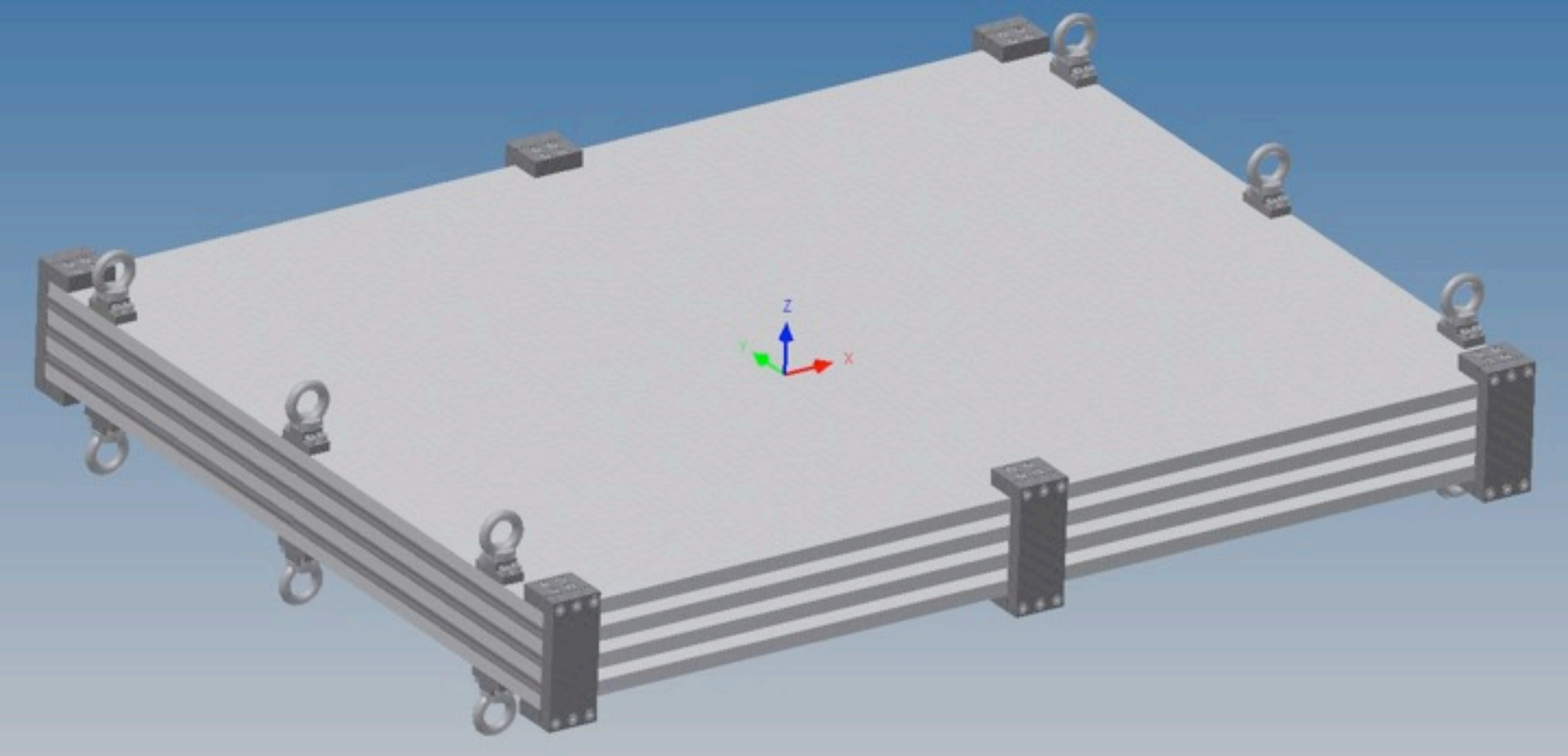
there will be only one DIF per plane, the distribution of the ASU boards in the plane will be rearranged to reduce the number of conections between the DIF and the plane

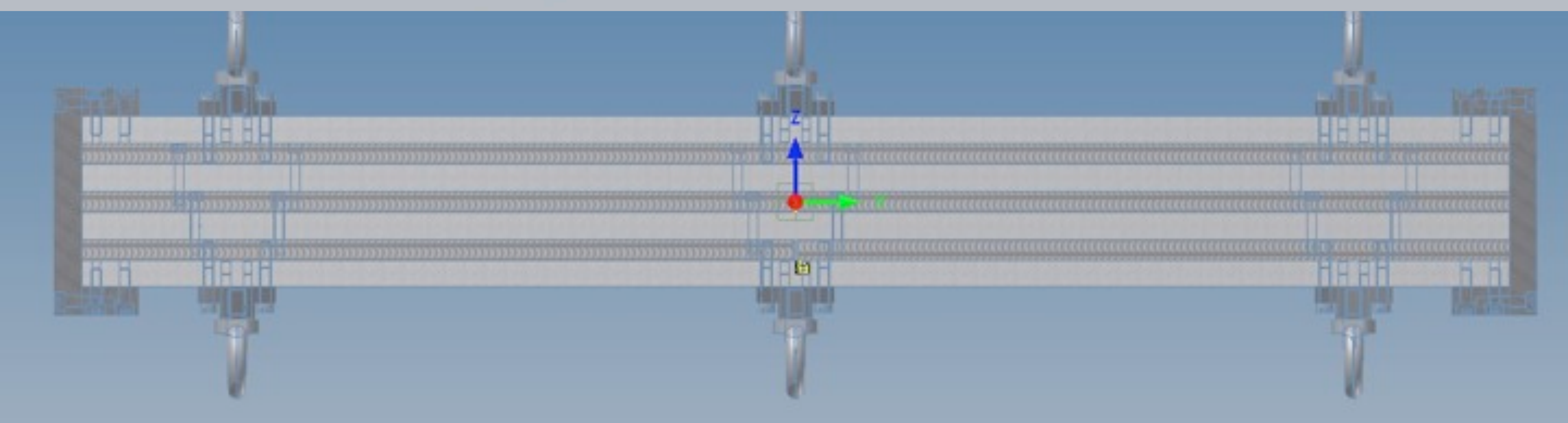


First ASU extension for drivers & connectors

- 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


Z
Y
X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Y