Current Status of Semi-DHCAL R&D in European

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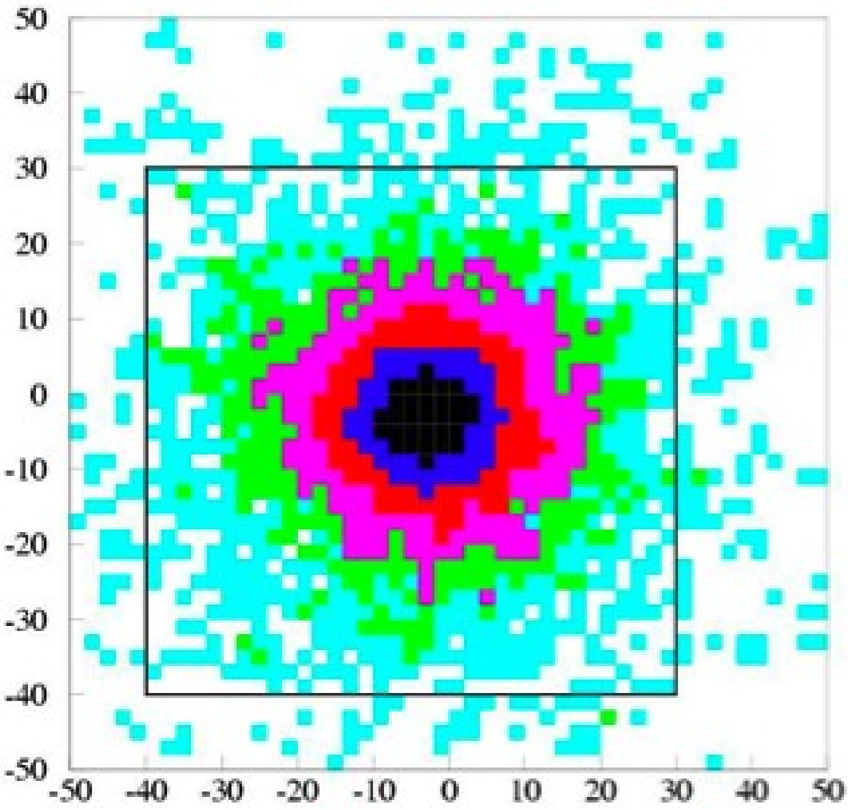
on behalf of the SDHCAL CALICE group
(CIEMAT, Ghent, IPNL, LLR, Louvain, Tsinghua, Tunis)

Case for a Semi Digital HAdronic CALorimeter

- 1 or 2 bits of information per cell
  - Finer granularity → 1×1 cm^2 × 48 planes
    - Ideal for a **PFA** approach
  - Cheaper, simpler, more robust detectors
    - GRPC, MGRPC, μMEGAS, GEM's
- Gaseous detectors
  - insensitivity to neutrons
    - narrower showers (99% of hits in 70×70 cm^2 for 100 GeV π)
    - suppression of big fluctuations
- Reconstruction of energy:
  - Counting: 3 thresholds
  - Topology: clustering

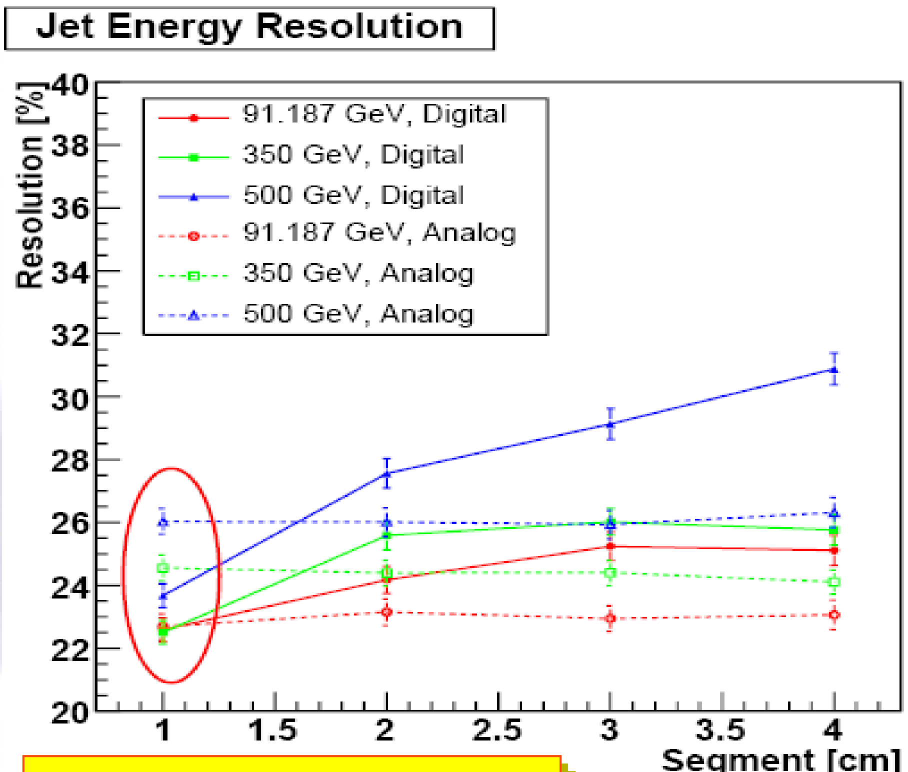


See note LC-DET-2004-029

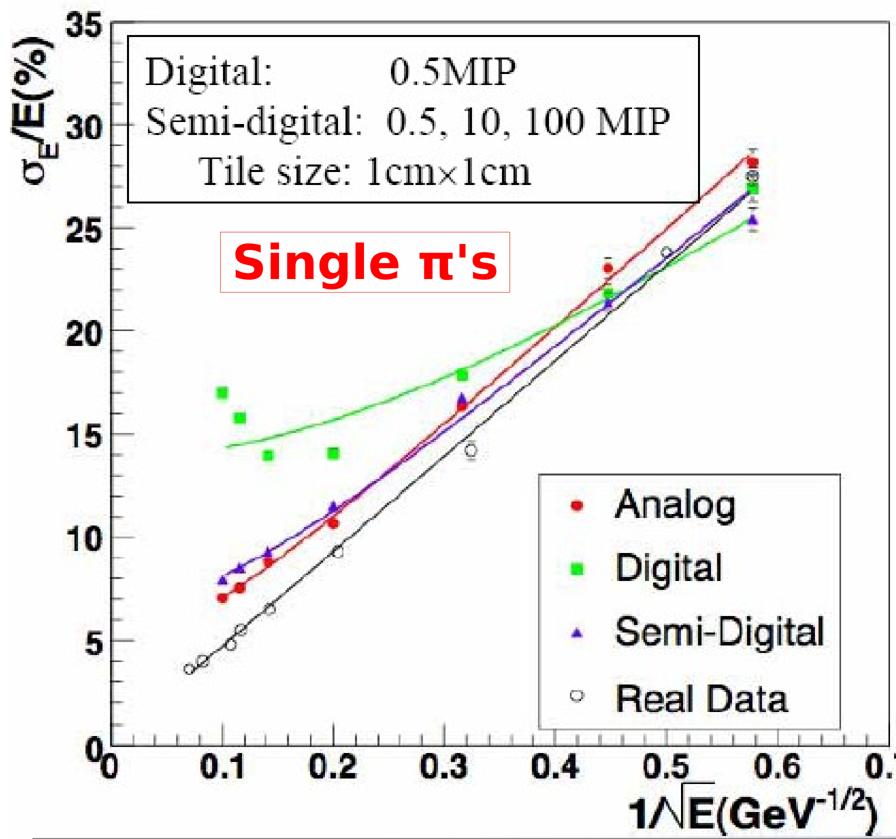
Resolution studies

GLD Scint HCAL study by KEK Group

- 3 thresholds (0.5, 10, 100 MIP's)
- 1×1 cm² **scintillator tiles**

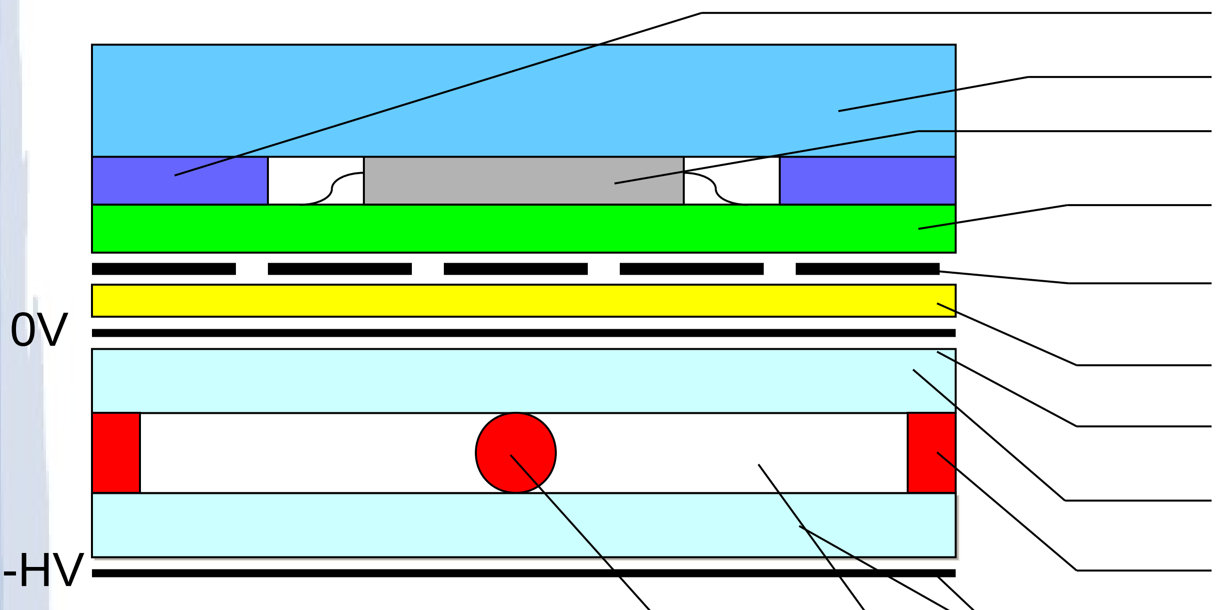


H MATSUNAGA
Pramana J. Phys., Vol. 69, No. 6, December 2007



- $e^+e^- \rightarrow qq$ (uds)
  - $\sqrt{s}$ = 91, 350, 500 GeV
- Assuming Perfect PFA
  - ▸ Improved jet resolution

GRPC in a DHCAL

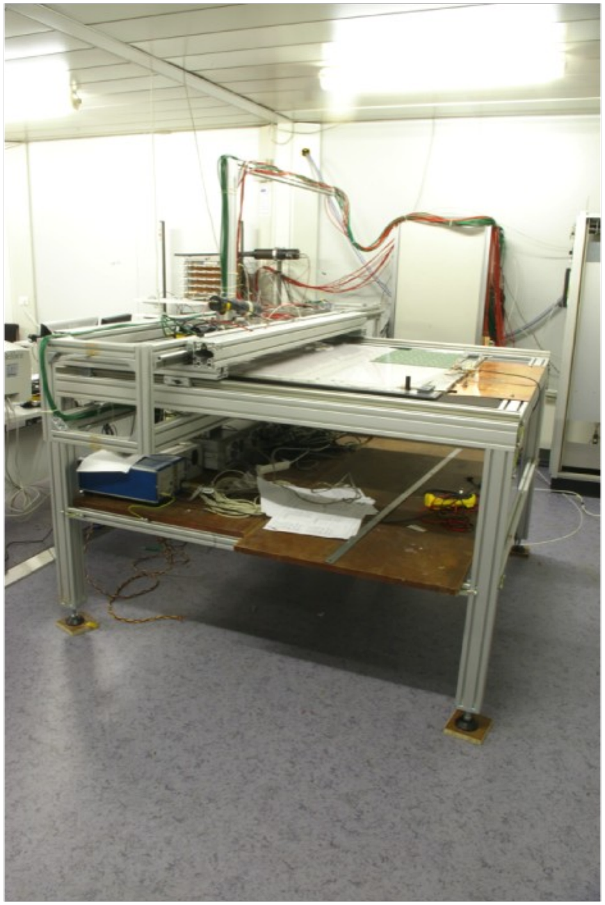


Constraints :

- Large area detectors (up to 3m x 1m)
- Thin (RPC + electronics = 6 mm)
- Low cost
- Industrialized easily

Semi-conductive paint (1)

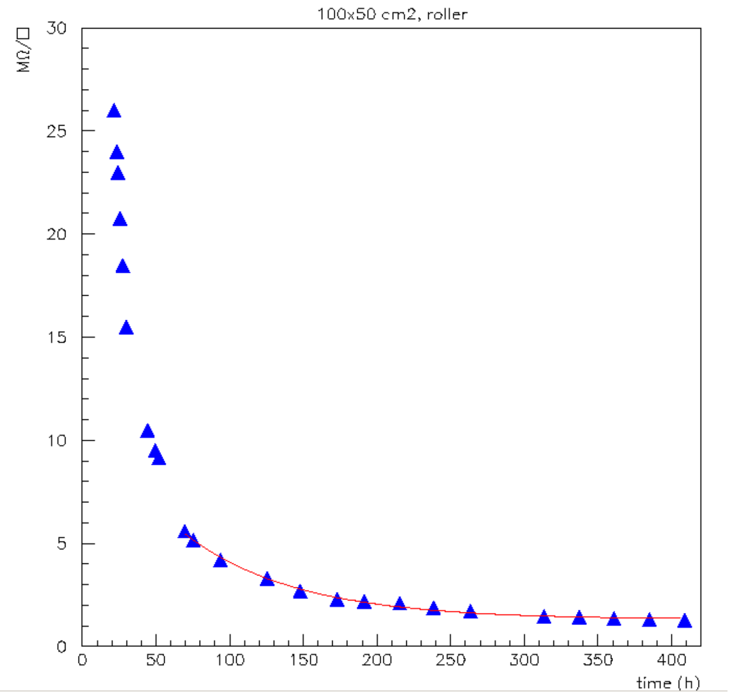
- Many chambers successfully built using Statguard product
- Applied to large areas using paint brush up to now
- Recently established industrial contacts to investigate option of silk screen printing
- Covered several m^2 using this method → now build chambers



Semi-conductive paint (2)

- Statguard: disadvantages
  - Not produced specifically for silk screen printing
  - Hard to clean silk screens
  - Long time constant for stable resistivity

- Investigating new product: colloidal graphite
  - Very stable resistivity
  - Specifically produced for silk-screen printing
  - BUT needs large oven or UV curing facilities



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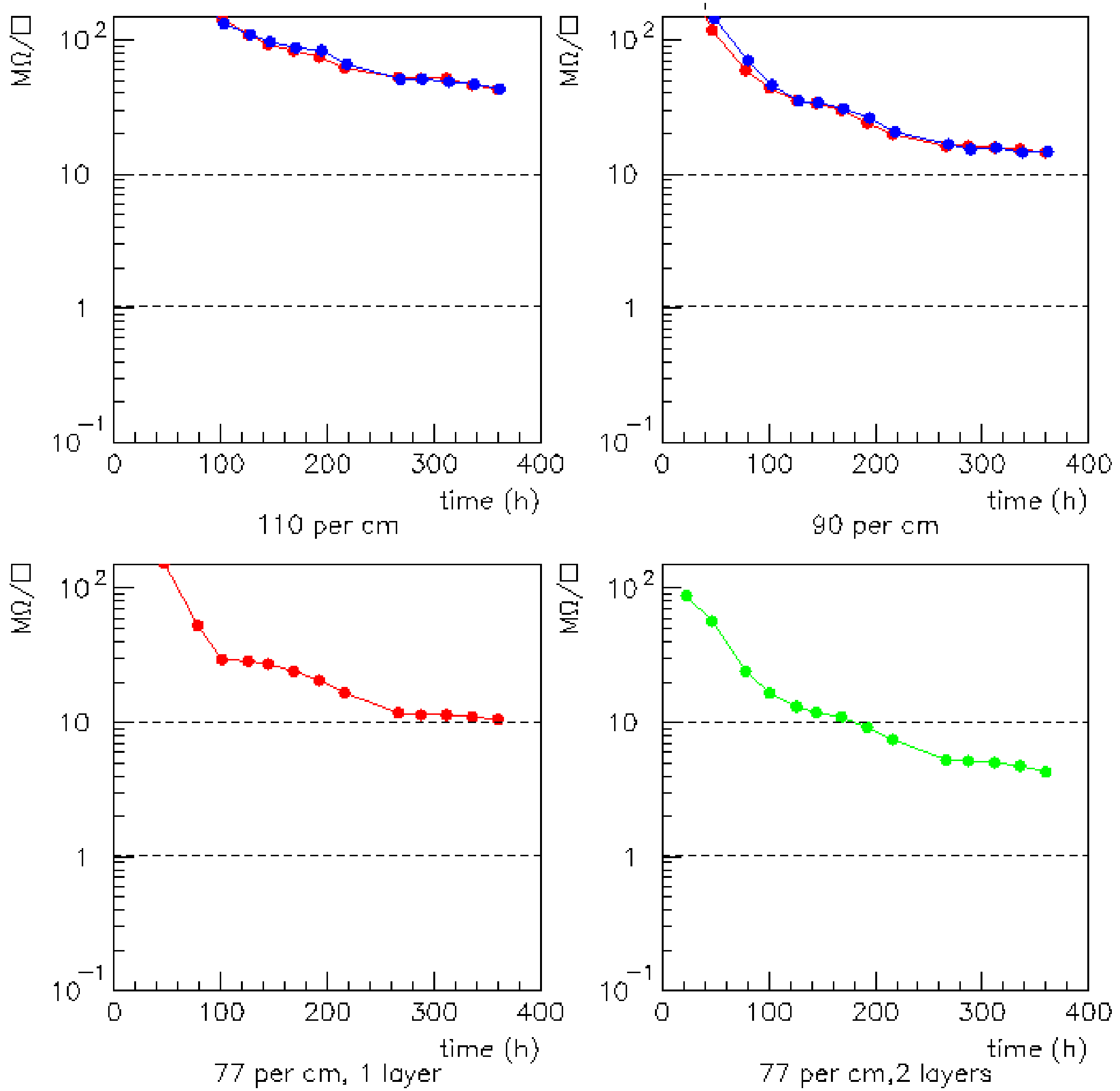
6

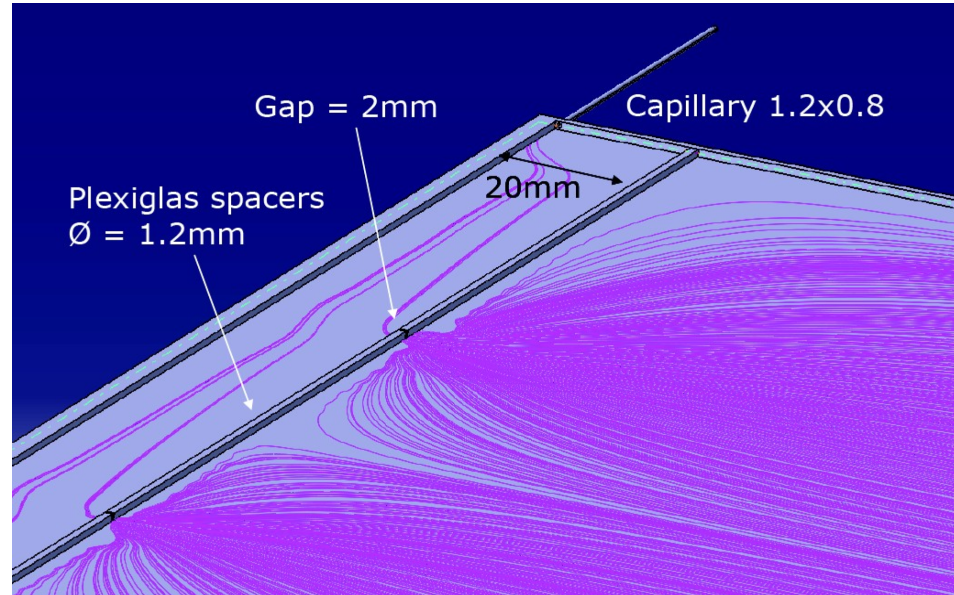
Statguard time stability - different layer thicknesses

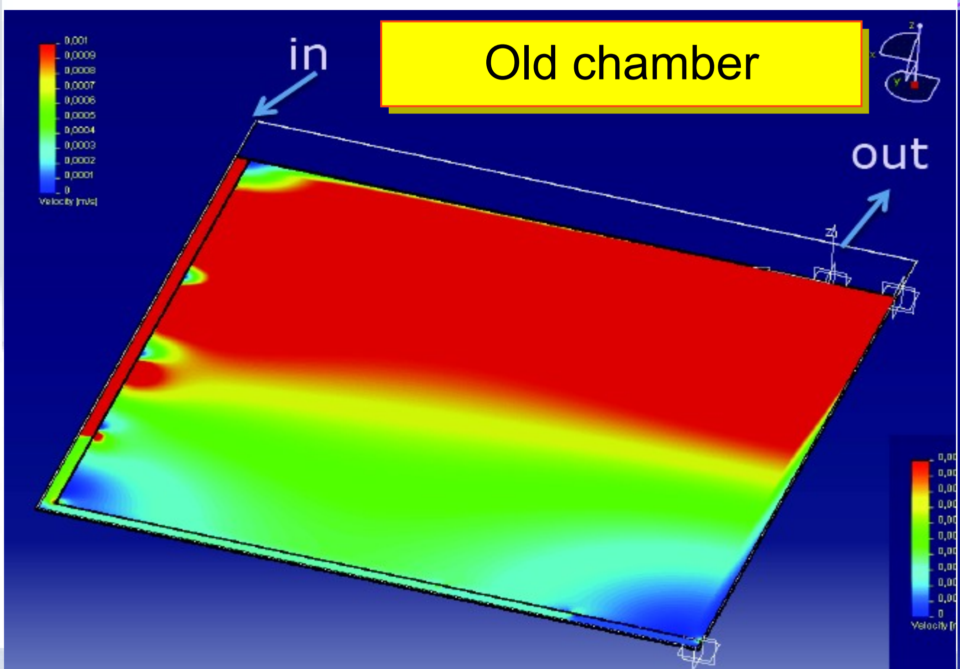


Gas circulation study

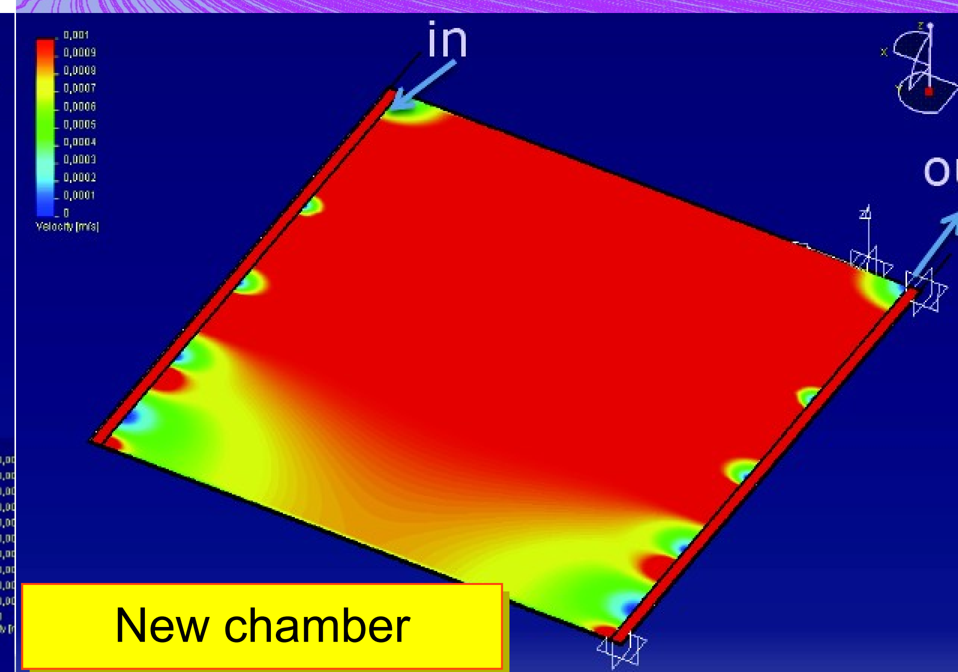
improve on gas distribution system in new chamber design

Gas velocity maximal ~ 1mm/s





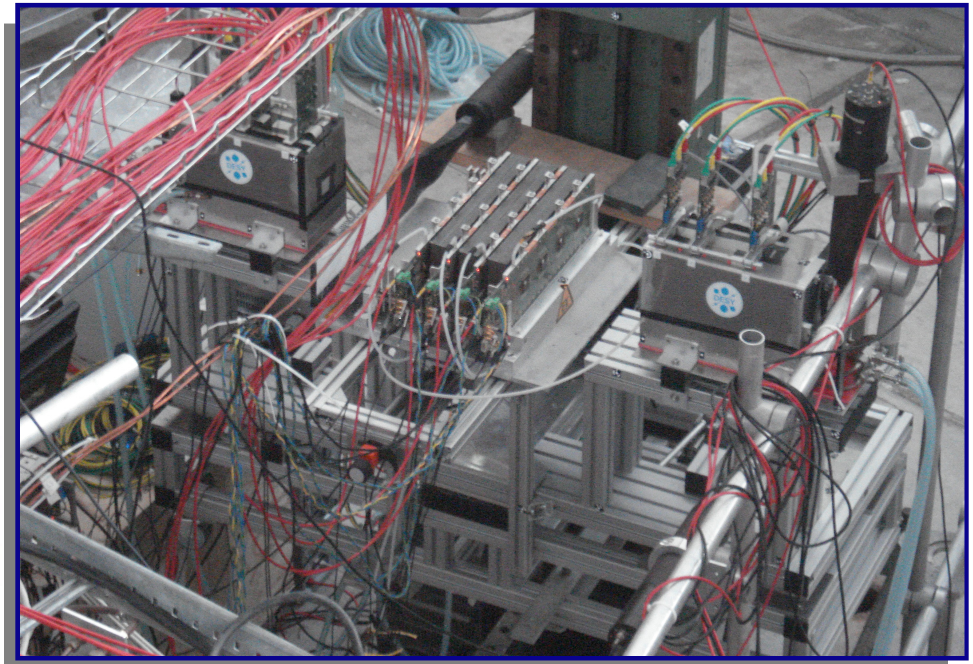
Old chamber

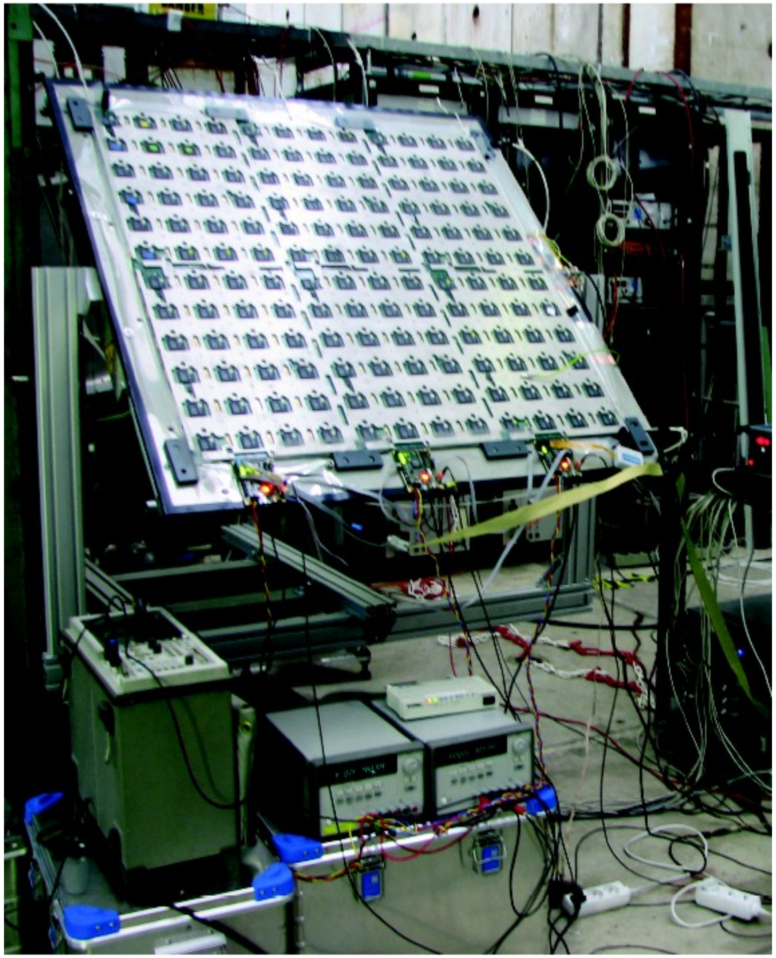


New chamber

Prototypes: Mini DHCAL and 1 m^2

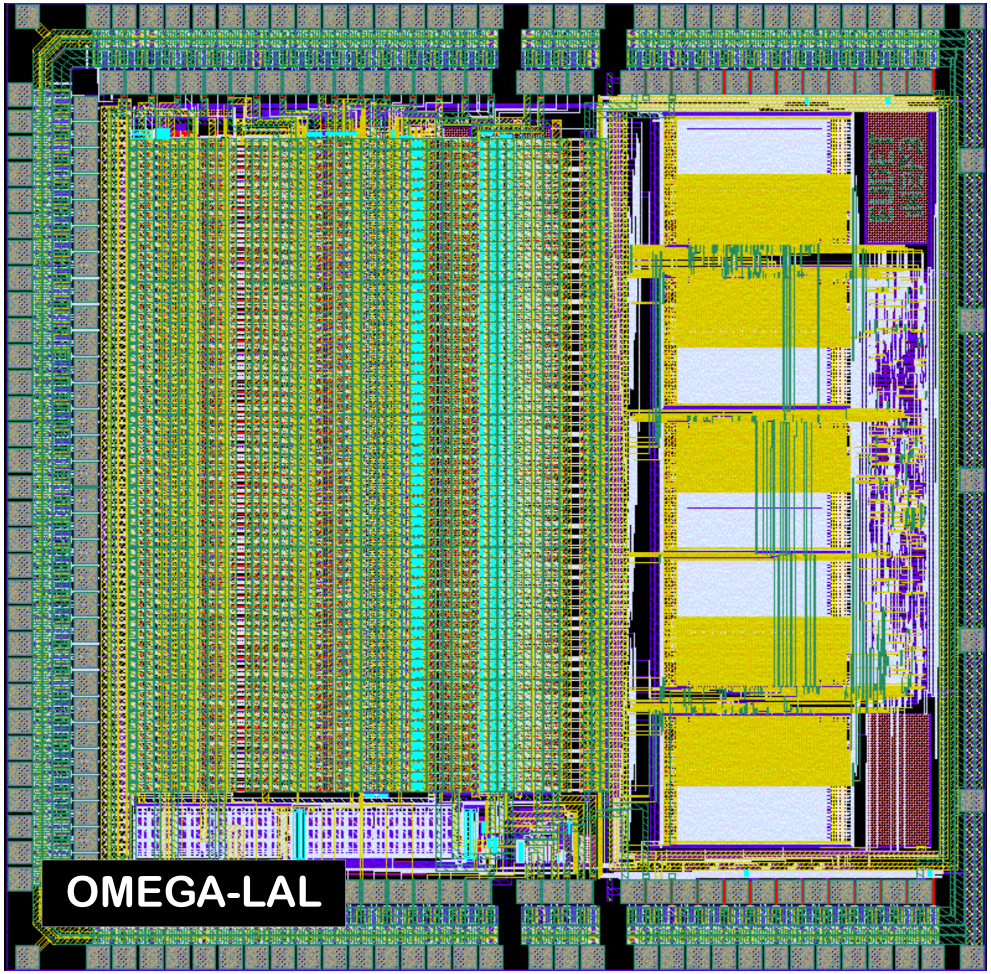
- GRPC:
  - 8×8, 32×8, 50×32, 100×32, 100×100 with 1 cm²-pad : already produced (with different option) and tested.
- MGRPC
  - 32×8, 100x100, produced & tested





Electronics: HarDROC (Hadronic Rpc Detector Read Out Chip)

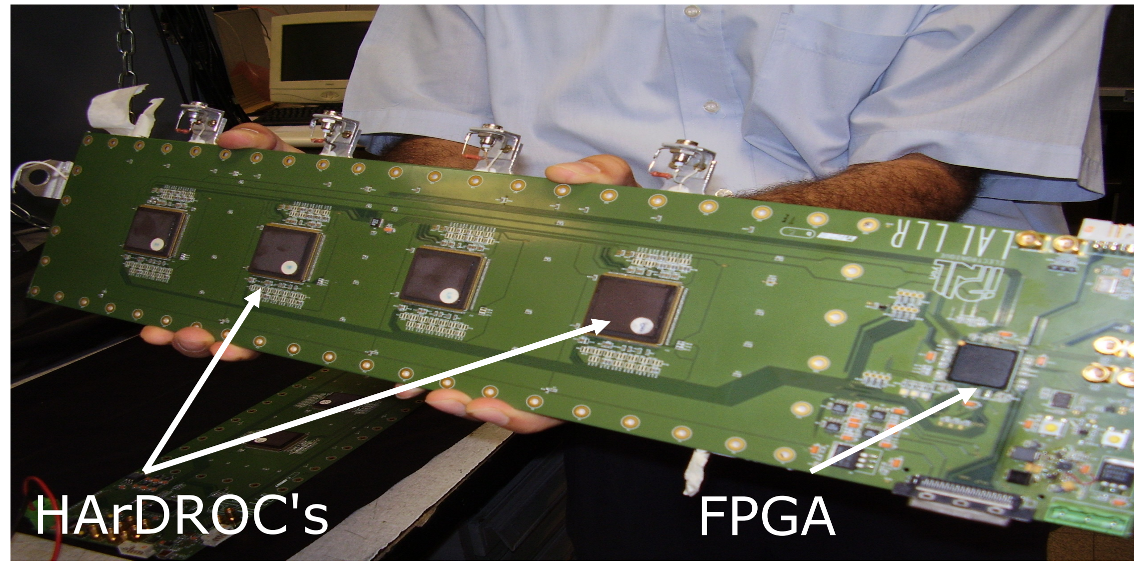
- AMS SiGe 0.35µm, 16 mm^2
- 64 channels
- Digital/analogue output
- 2 independent thresholds
- low consumption
  - < 10 µW/ch
  - Power pulsing
- Digital memory
  - 128 events
  - ASIC ID (8b), BC ID (24b), hits
- Large gain range (6bits)
  - Channel wise
- X-talks < 2%
- Threshold > 10 fC



*** DIRAC: Another ASIC developed in IPNL/LAPP aims at a threshold of 3 fC**

Mini DHCAL

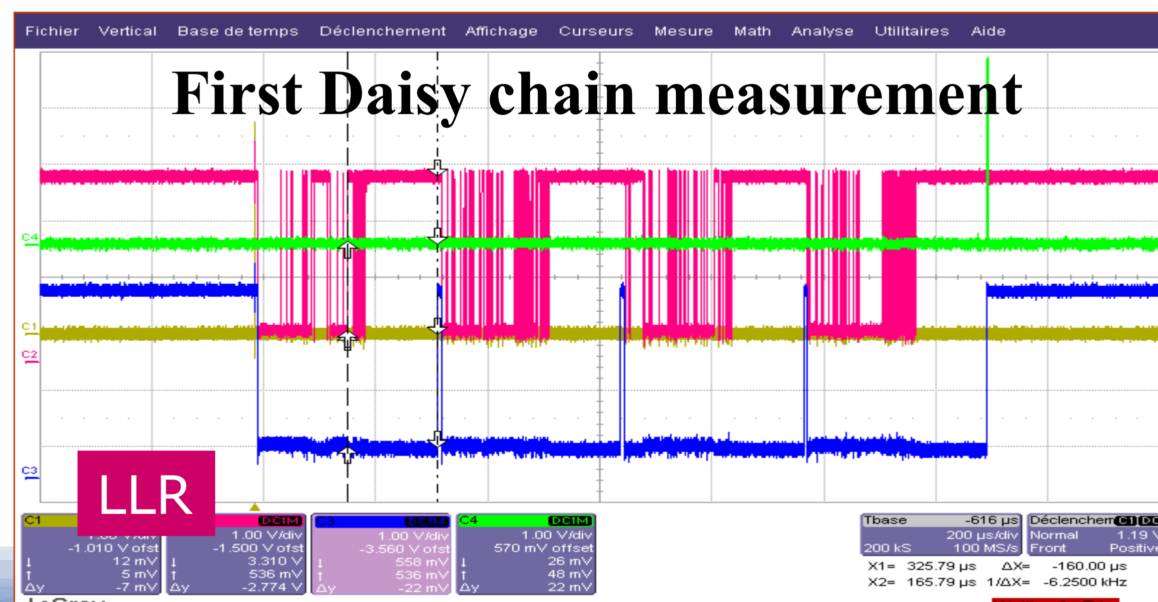
- **8-layer**, **800 μ** thick PCB
  buried and blind vias
  x-talk <0.3 %
- 4 hardroc chips
- Readout **FPGA** → USB
- **8×32** pads detector



Acquisition modes : different modes are allowed:

a) Train (ILC mode)

b) External trigger :
cosmic rays & test beam

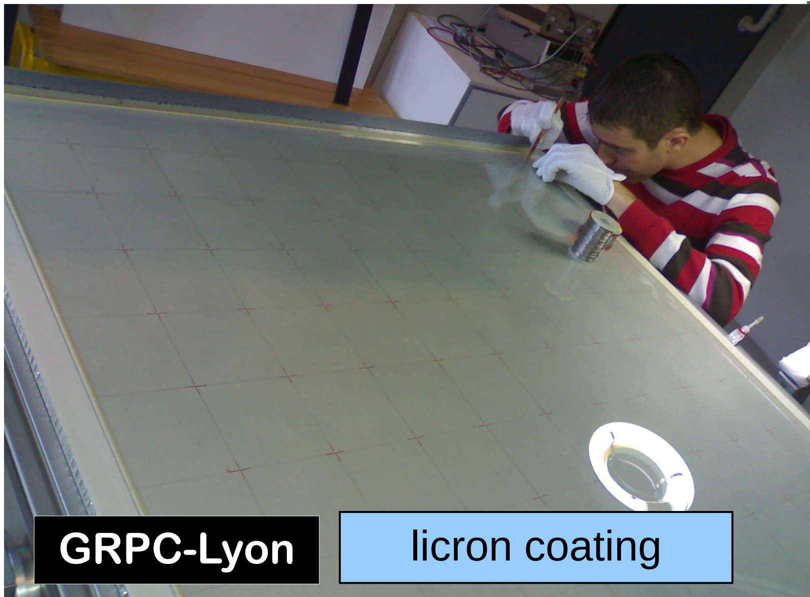


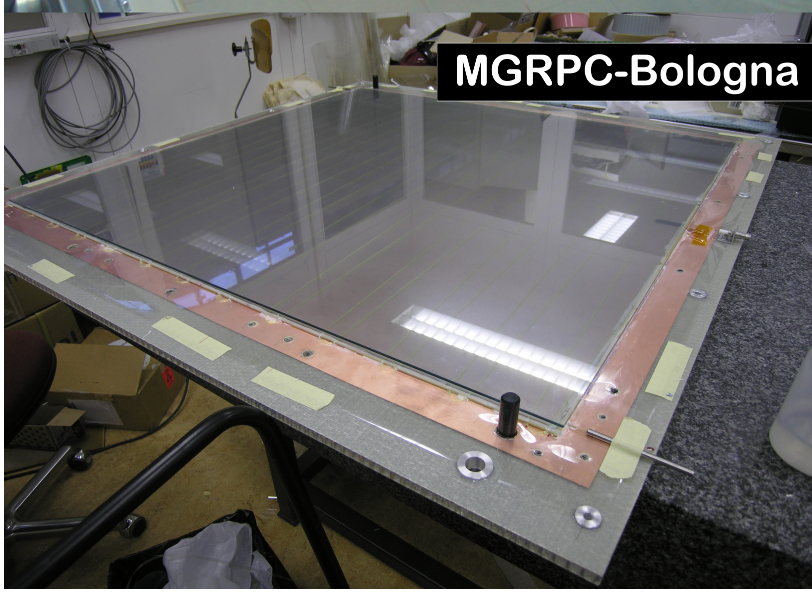
Data output:
digital and analogue

LLR

The 1 m^2 project

Calorimeter for ILC





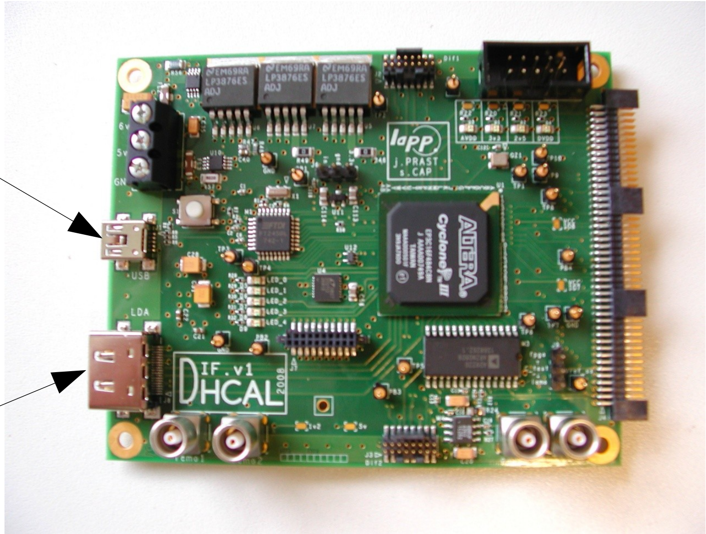
1 m^2 GRPCs were built with **different options**

The 1 m^2 project

CALICE Calorimeter for ILC

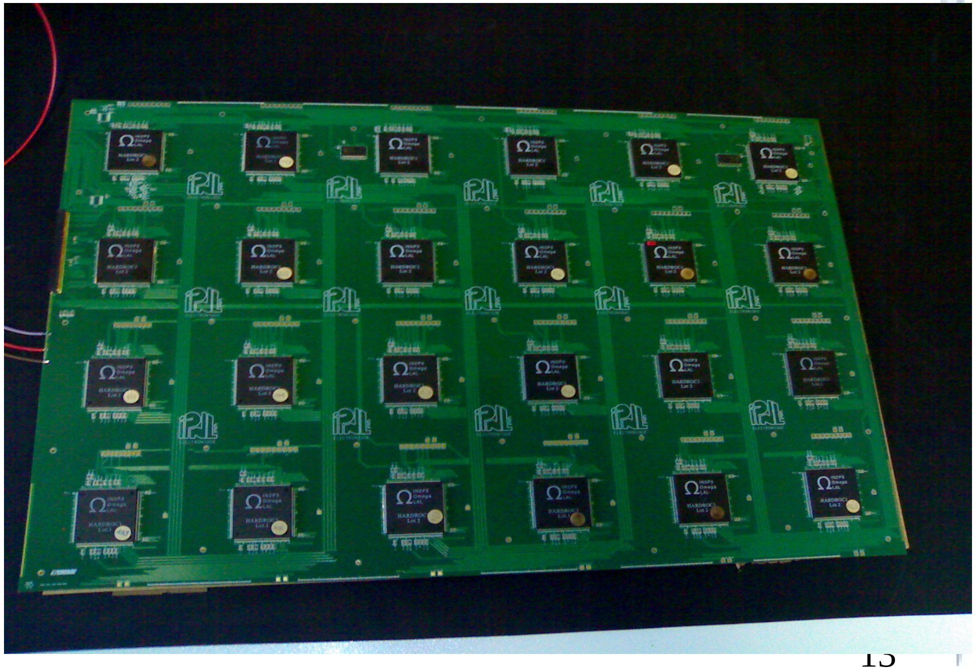
DIF

- 10-layer board (6 for signals) designed and prototype produced
- FirmWare & SoftWare operationnal and tested in beam (with 4 HR μMegas card)



ASU

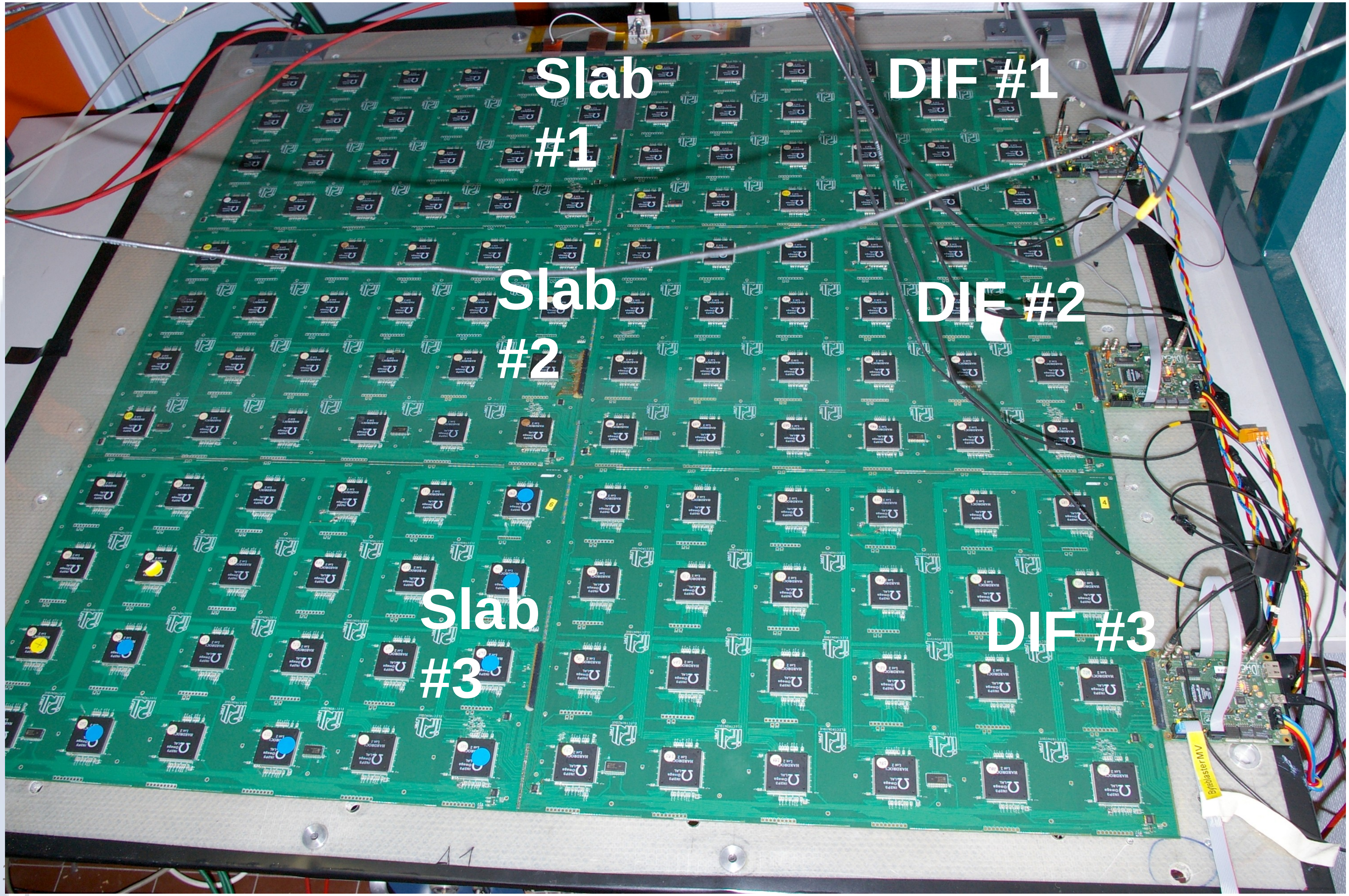
- 8-layer board designed and produced
- $500\times33.3\times1.2$ mm^3
- Connections between adjacent PCB foreseen
- ASICs were tested and plugged



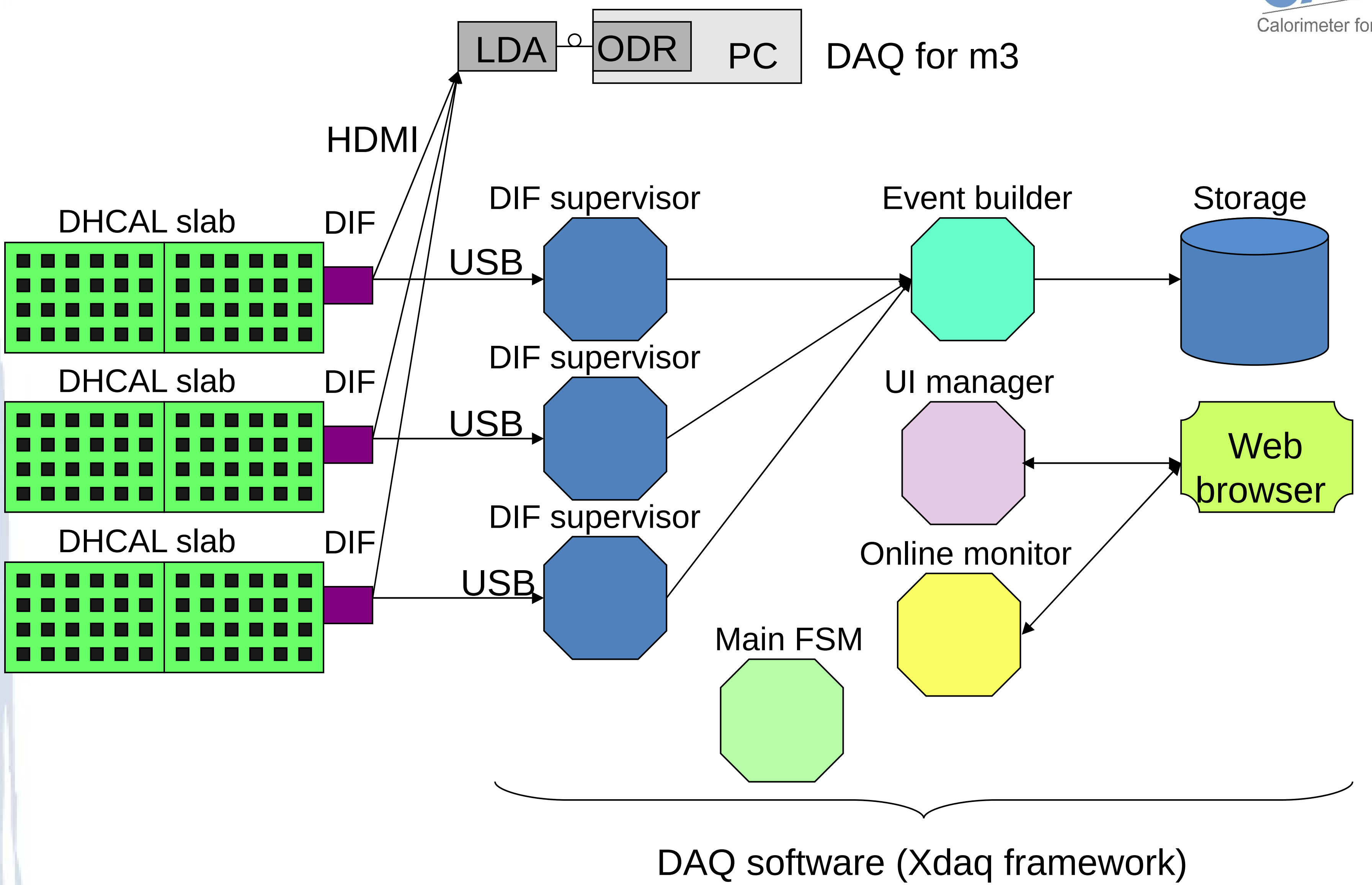
Software

Acquisition software based on US/XDAQ developed

1 m² of equipped detector



DAQ Schematic view



DAQ capabilities

3 modes to operate the DAQ :

- *Manual mode* : all functions, commands and registers of one or several DIF(s) are accessible one by one (mainly used for debug purpose)
- *Semi Automated mode* : More complex functions of one or several DIF(s) can be performed, ie send slow control, start acquisition
- *Automated mode* : All behavior is driven by main finite state machine

2 trigger modes :

- *Standard mode* :
  - Hardrocs store data on the external trigger
  - Data are sent to the DAQ PCs when RAM is full
- *Beamtest Mode* :
  - Hardrocs store all valid data (internally autotrigged)
  - Hardrocs stop storing on external trigger (i.e. common stop) and send data to DAQ PCs

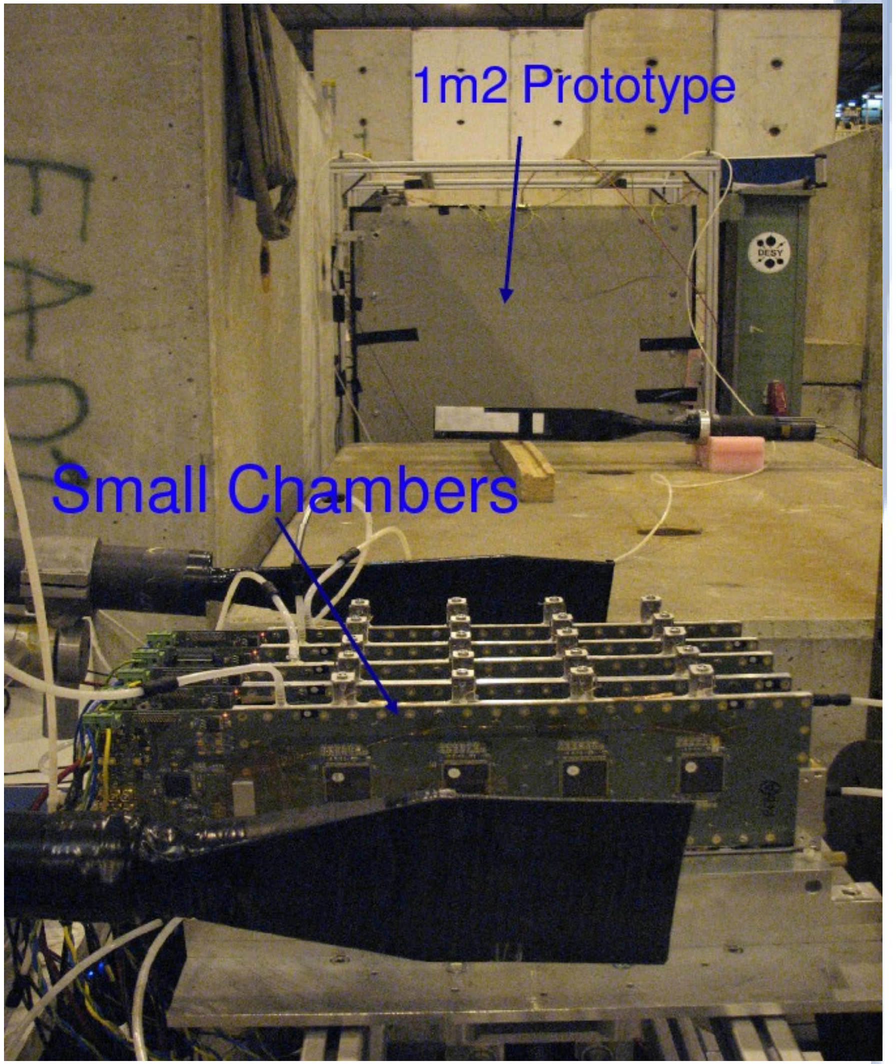
LCIO format for reconstructed DHCAL Calorimeter hits (proposal v0.01)

back of envelop discussion
V. Boudry, G. Grenier, R. Kieffer

```
EVENT::RawCalorimeterHit
{
    int  _cellID0;          // Chan (64 ==> 6b)
                               // + Asic (max 420 ==> 9-10b)
                               // + Dif_Id (48-144 ==> 7-8b)
                               // + Module_Id (40 Barrel + 24 Endcap ==> 6b)
                               // == 28-30b
    int  _cellID1;          // Time2Previous in BC ==> 24b (remain 8b) (CHBIT_ID1 must be set)
    int  _amplitude;        // 3 Thr ==> 2b (remains 30)
    int  _timeStamp;        // Rec Time on 32b wrt (Spill start or Trigger)
}

EVENT::CalorimeterHit
// Reconstructed Hits
{
    int  _cellID0;          // Idem RAW
    int  _cellID1;          // Idem RAW (CHBIT_ID1 must be set)
    float    _energy;      // Rec Energy
    float    _time;        // time from ref (in ns).(LCIO::RCHBIT_TIME must be set)
    (float   _position [3]);   // Position (unit not fixed) (LCIO.CHBIT_LONG must be set)
    int  _type;             // Deposit type (mip, EM, noise, ...)
    EVENT::LCObject *  _rawHit; // Link to RAW hit
}

One also needs the mapping functions:    int[3] GetIJK(cellID);
                                         float[3] GetXYZ(cellID);

Error on Energy => to be recalculated, or integrated to energy.
```

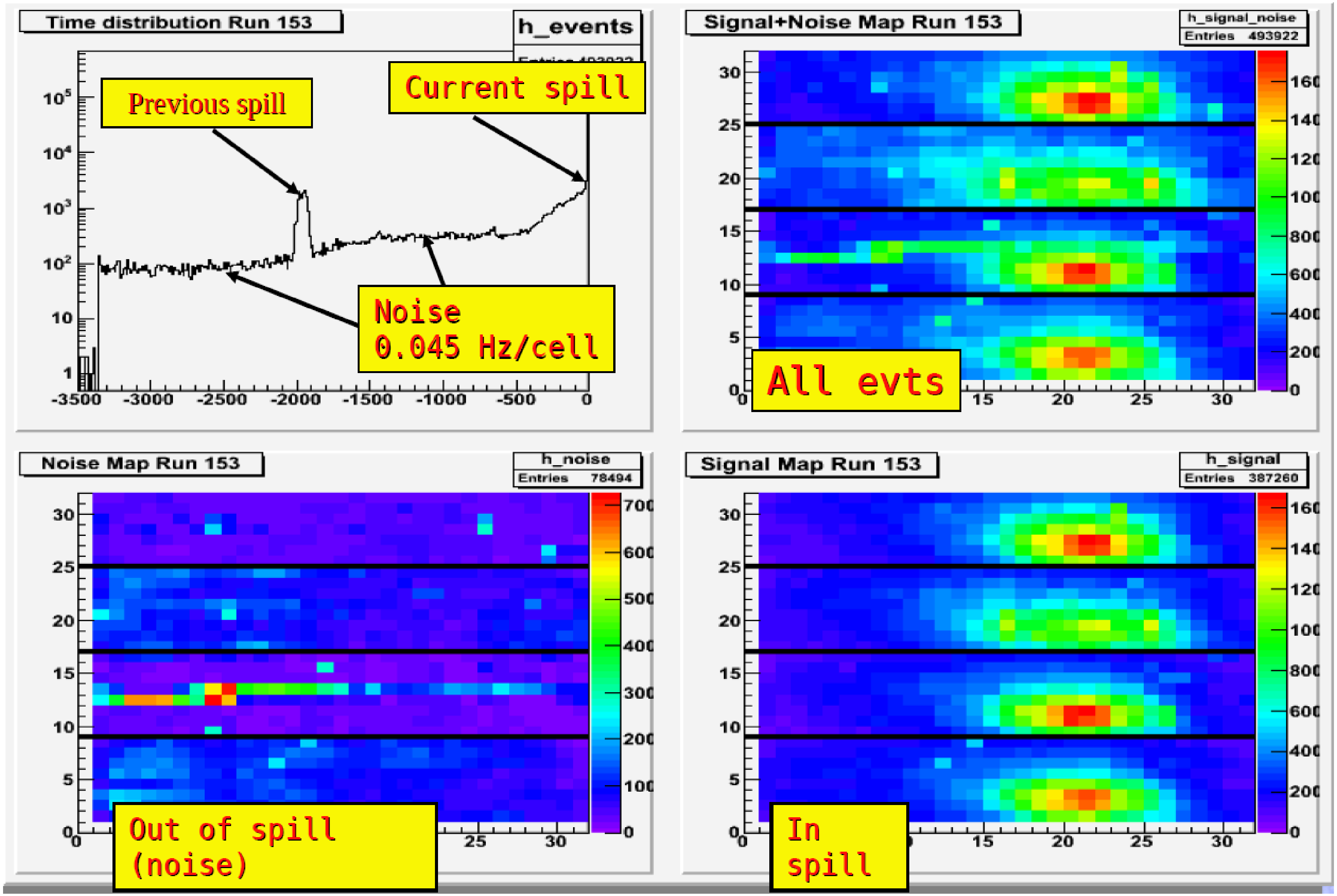
TB Performances:

	Time	Statistic	Detector
PS T10	17-24 July, 2008	260k	Mini DHCAL
PS T9	28 Jul - 4 Aug, 2008	80k	Mini DHCAL
PS T9	7-12 Nov, 2008	65k	Mini DHCAL + 1m2
PS T9	18 Jun - 8 Jul, 2009		Mini DHCAL + 1m2
SPS H4	31 Jul - 8 Aug, 2009		Mini DHCAL + 1m2

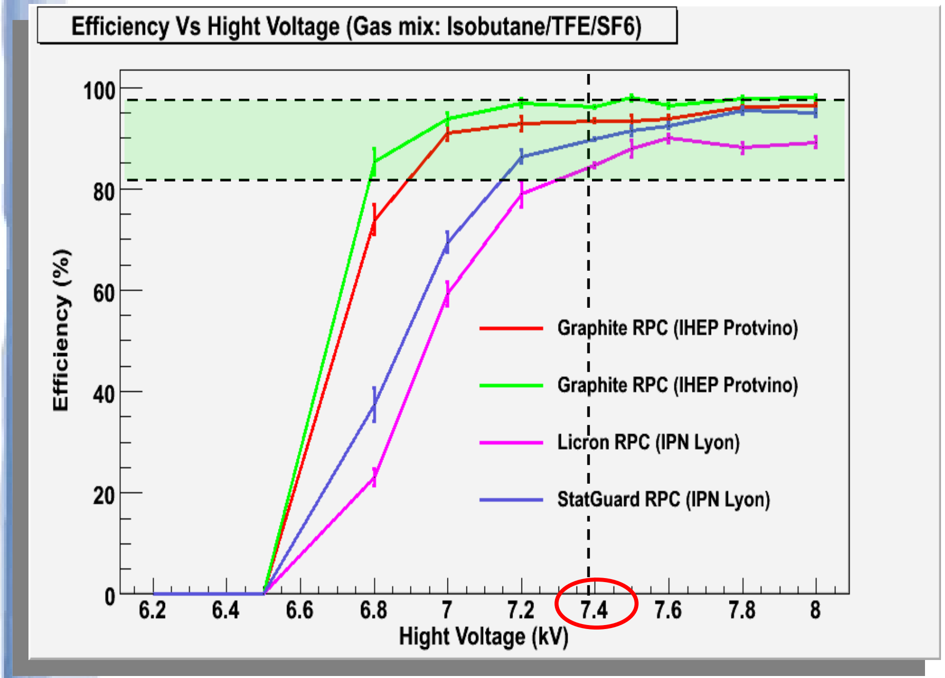


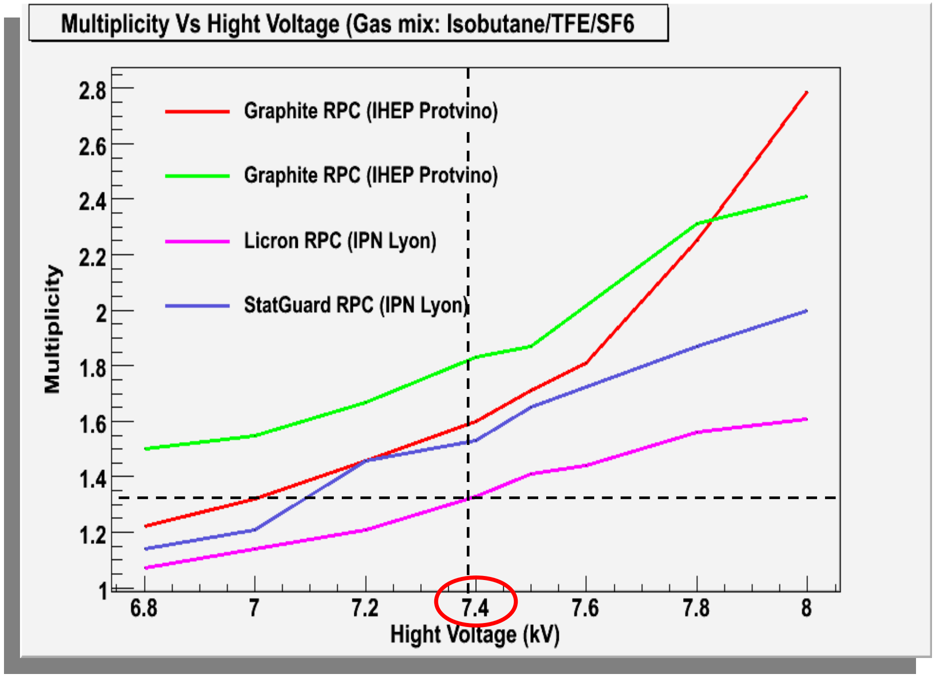
2009 SPS CERN TB Setting

Mini DHCAL: Event Selection



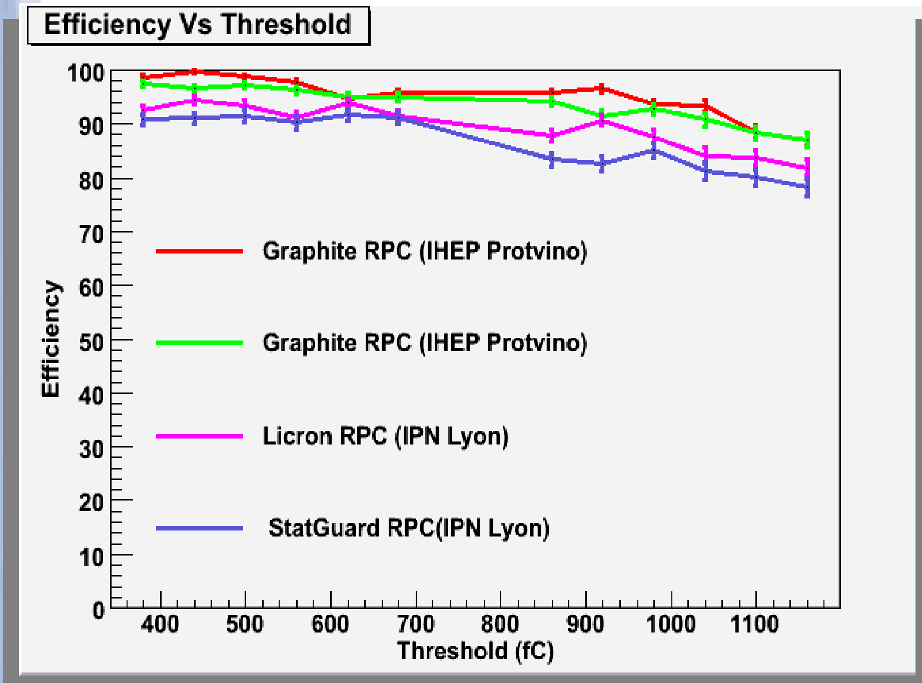
Mini DHCAL: HV Scan

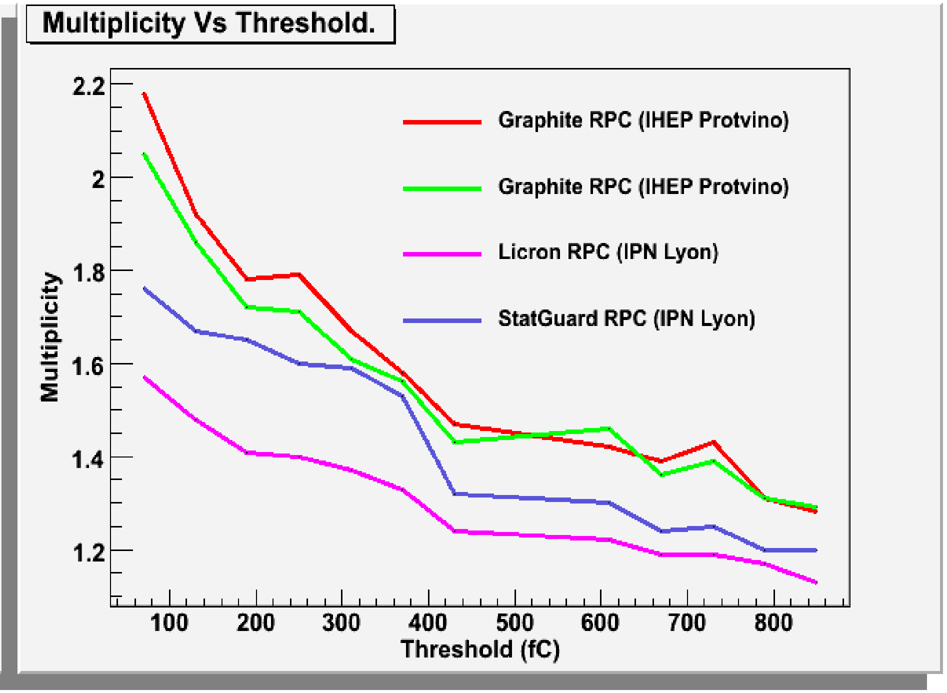




- DAC's **Thresholds**: lower 120 fC / higher 450fC
- **Plateau:** 7.2 to 8 kV
  -> Efficiency between 80 and 98%
- Lower multiplicity is preferred.
  -> Best ratio multiplicity/efficiency: around 7.4 kV
- Until now the licron coated detector seems to be **the best candidate**:
  -> it has the **lowest multiplicity** and shows **very good efficiency** performance.

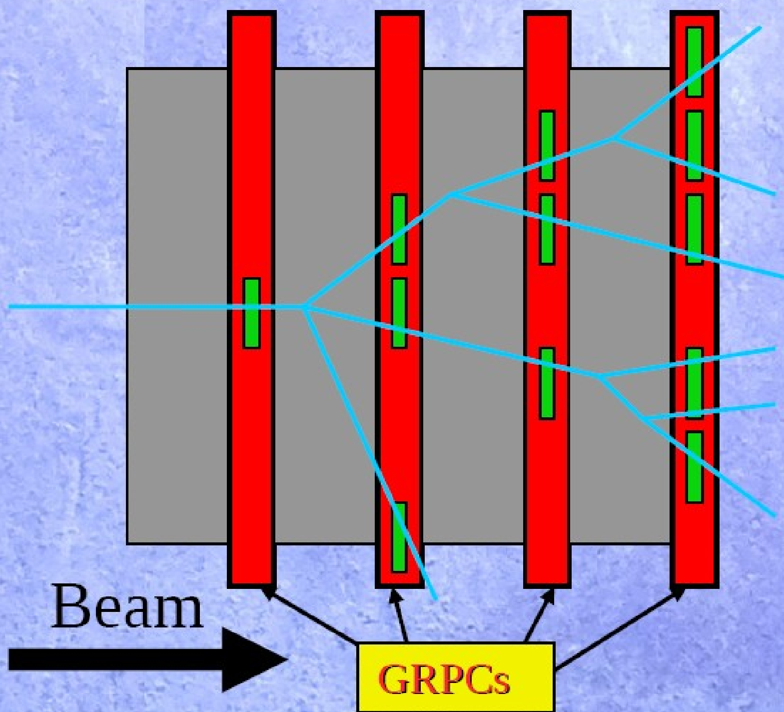
Mini DHCAL: Threshold Scan

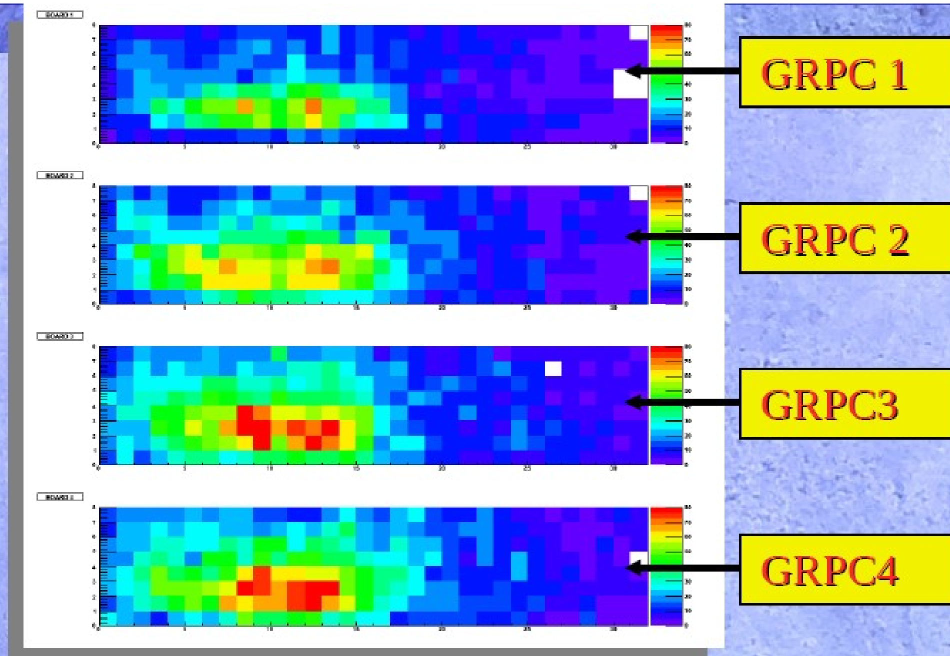


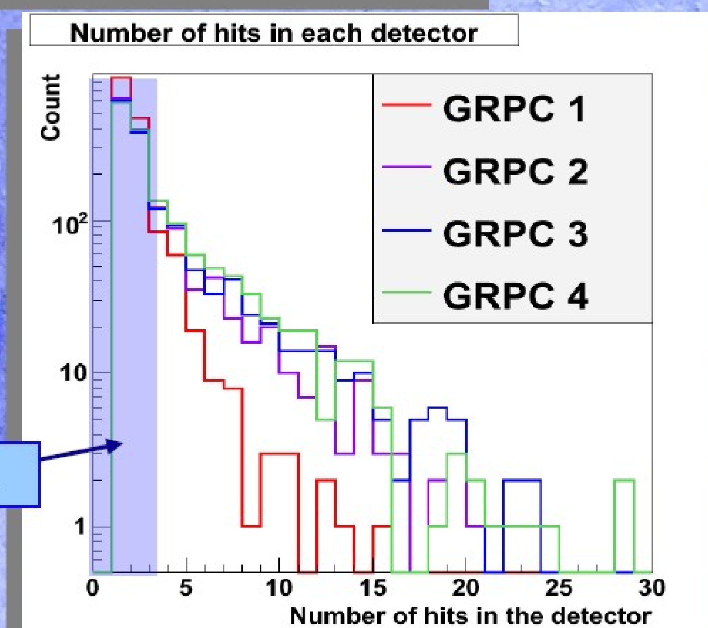


- Multiplicity moving as expected => **lowering as threshold increases**.
- Efficiency **decreasing** down to 80% at 1.1 pC threshold.

Mini DHCAL: Hadronic shower





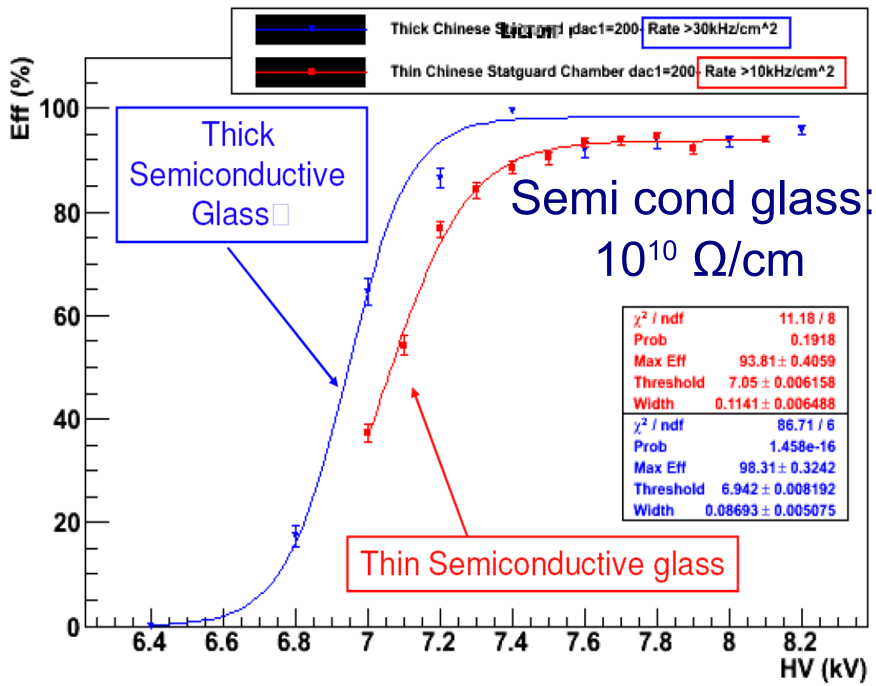


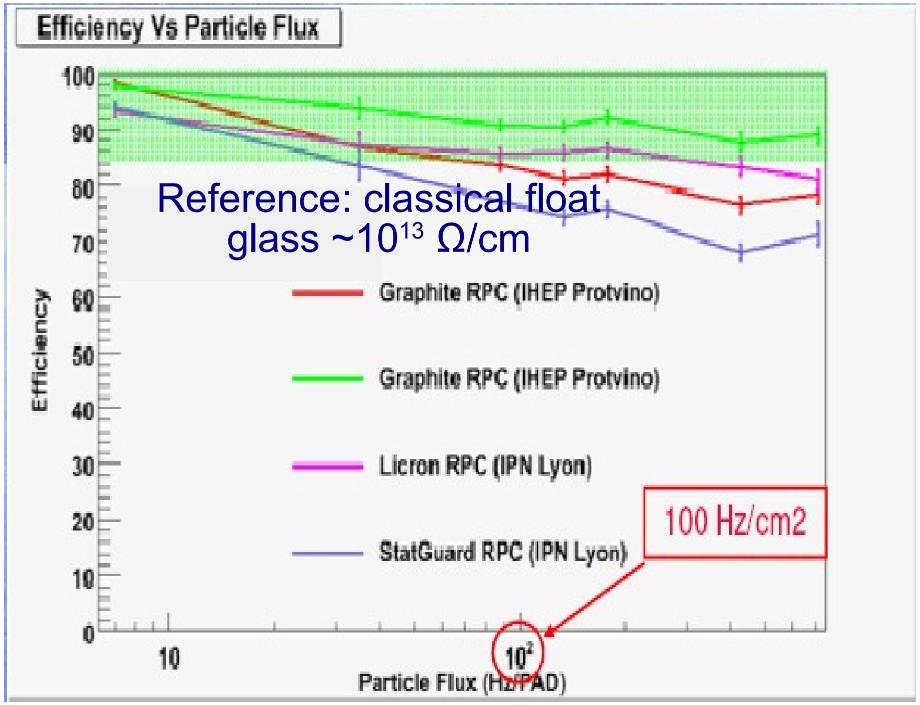
Muon contamination area

Hadronic showers are mostly uncontained in Mini DHCAL but these profiles give a first idea of shower development, and energy deposition.

Mini DHCAL: with Semi conductive glass

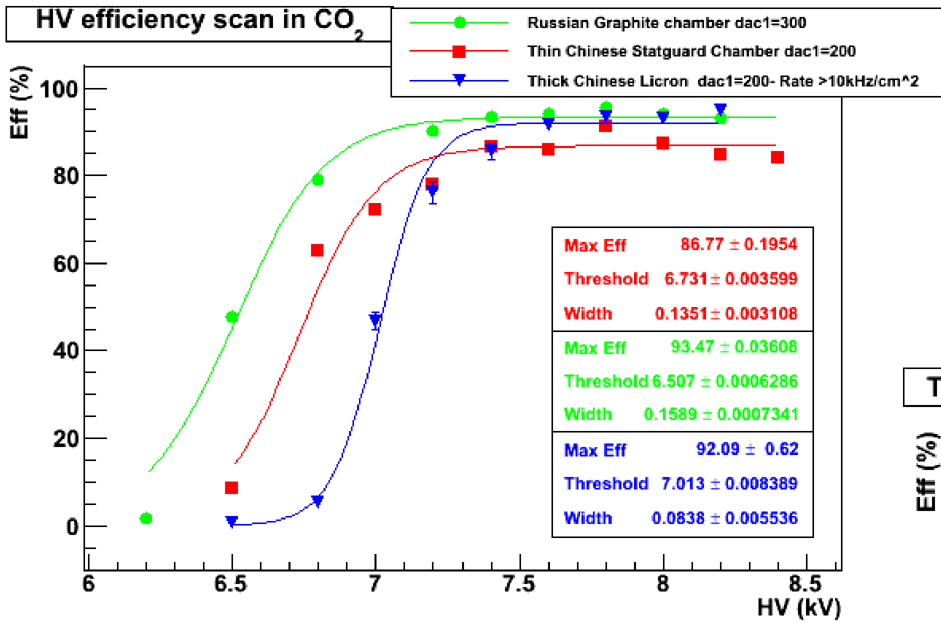
Calorimeter for ILC



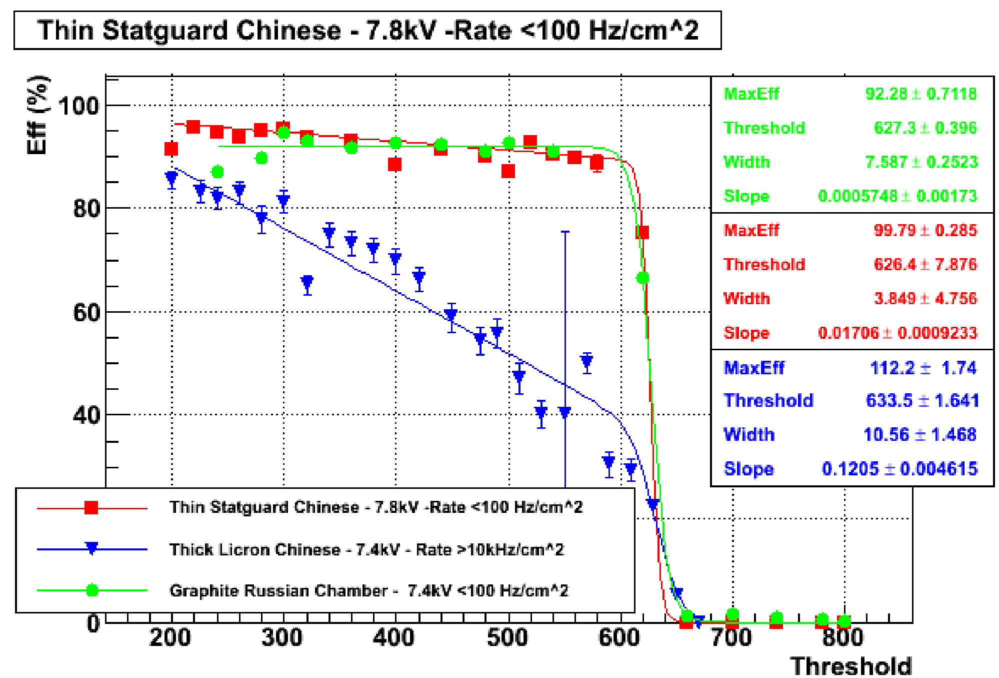


- Cooperation with Tsinghua University:
  Provide us with semi-conductivity glass 10^{10} Ω/cm;
- 2 chambers with 32*8 pads: **thin:** *1.1 mm at both side + licron coating &*
  thick: *1.1mm on cathode + 0.83 mm at readout + statguard coating*
- Semi conductivity glass has good efficiency at high event rate (>10kHz/cm²), while classical glass has significant efficiency drop when event rate exceed 100Hz/cm^2

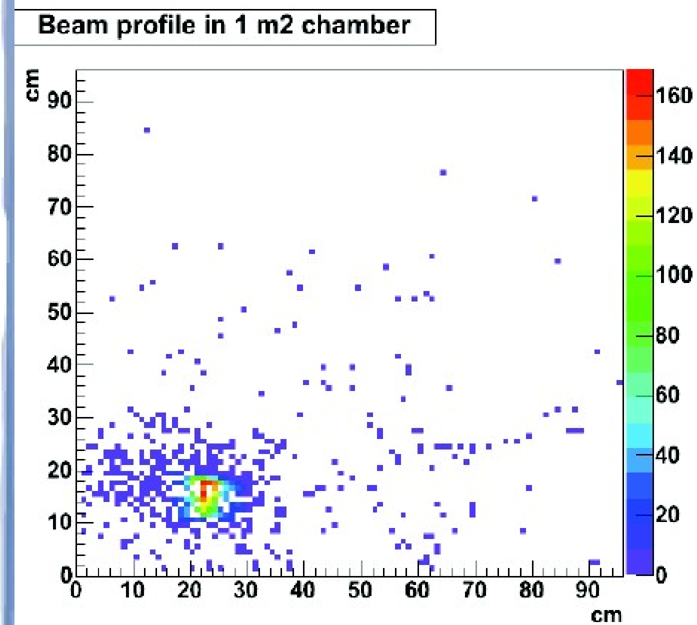
Mini DHCAL: with CO_2 gas

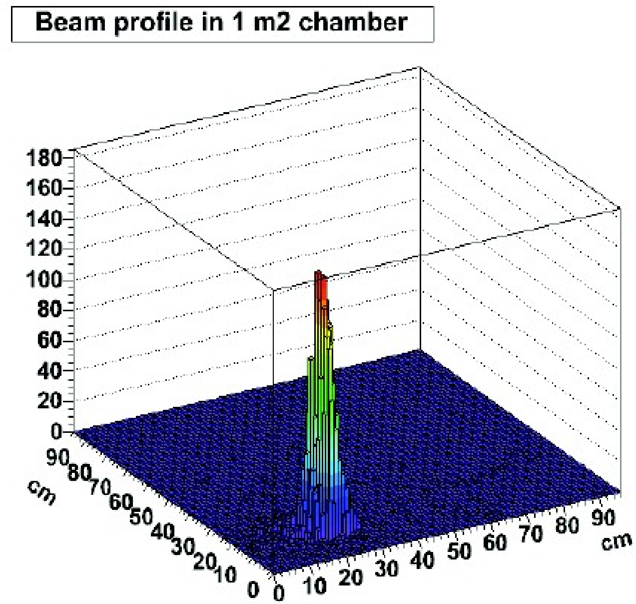


- Shallower raise as with Isobutane
- wrt to standard GRPC wider distribution from the thick semiconductive glass

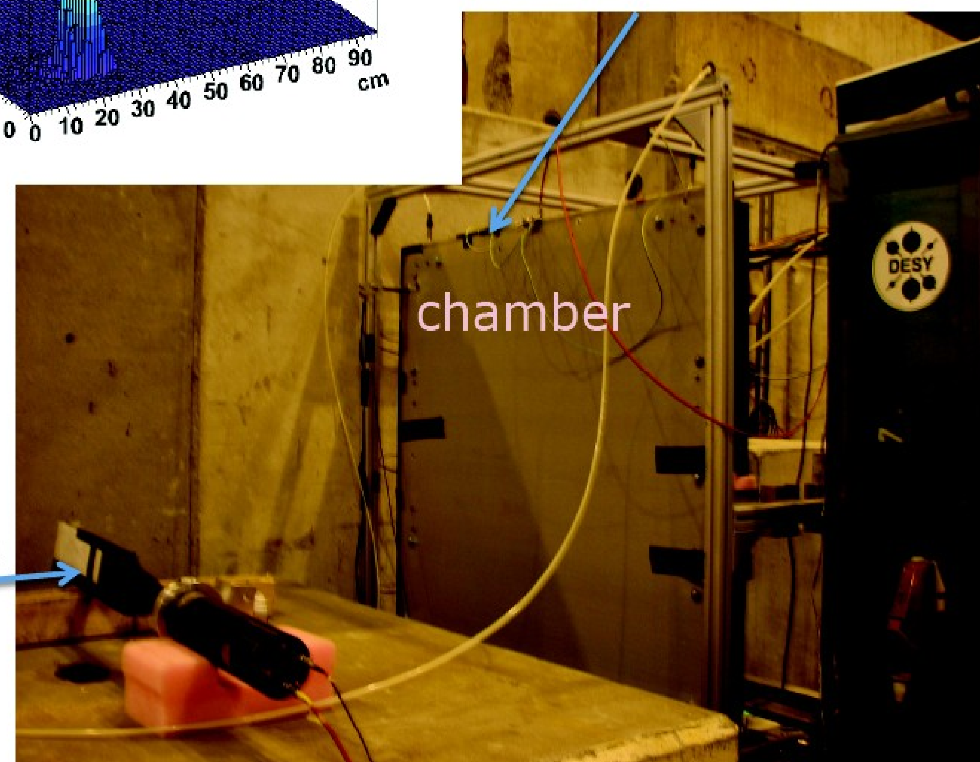


1 m^2 : beam profile





HV connection



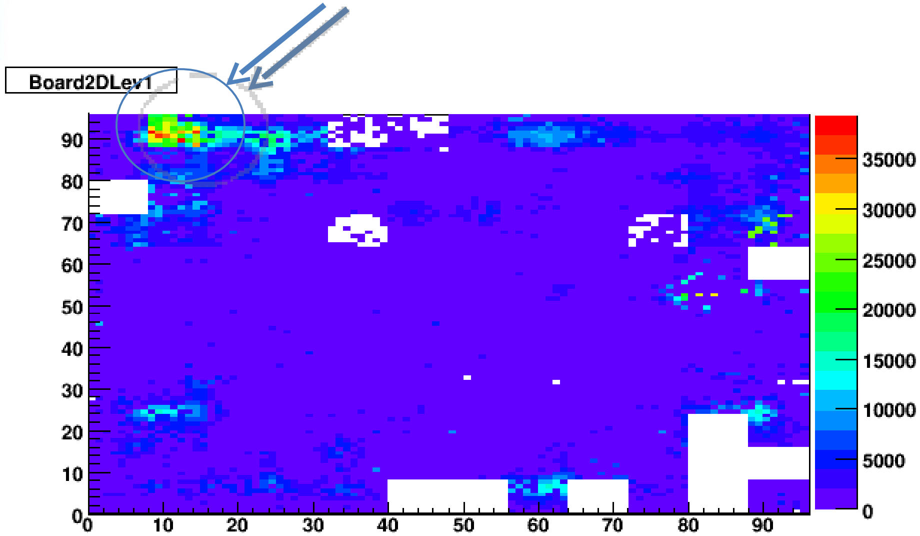
Pads over (low) threshold

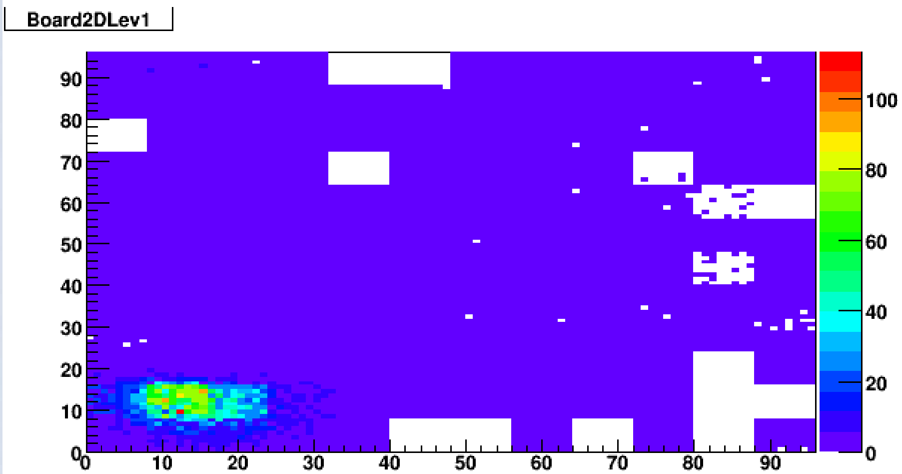
DAQ successful in testbeam mode
With 3 DIFs synchronised
Up to 93% efficiency

pion /muon beam

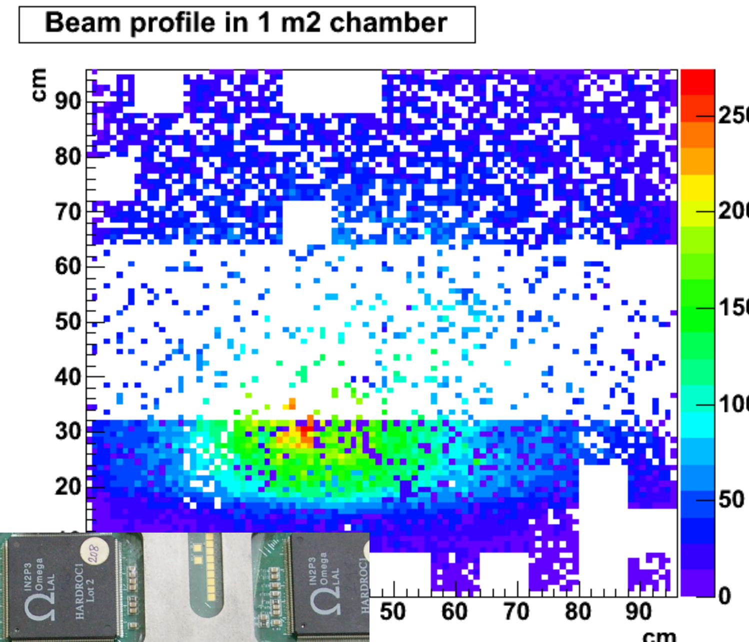
Some issues under investigation

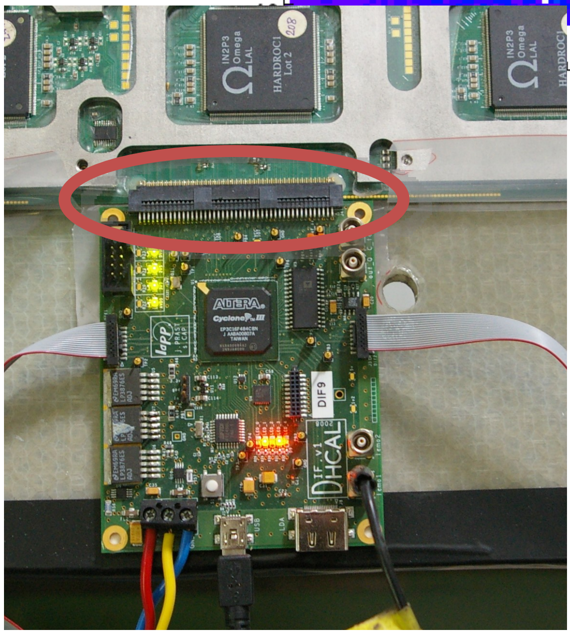
Some noise in the HV connector region





Electric connections



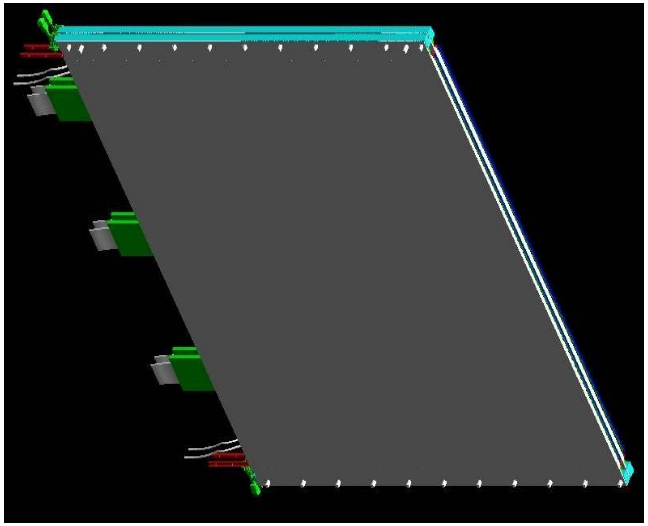


Flat kapton cable under development for next prototype

L. Thomas

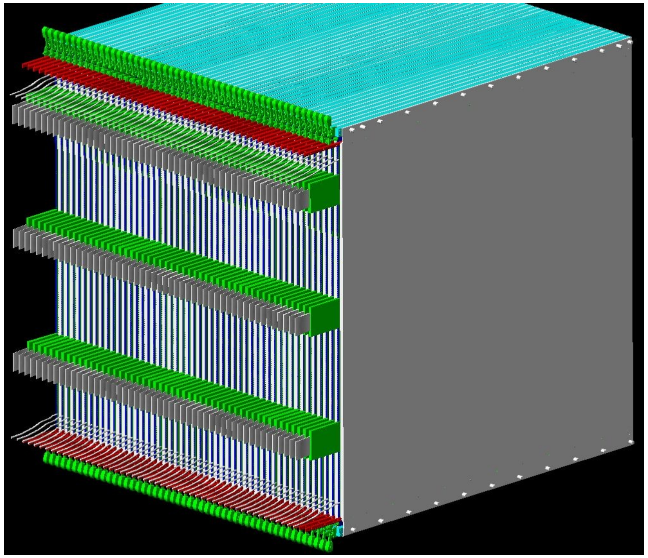
Next step:
1 m^3 prototype

The aim is to build a realistic prototype, validating the technological solution we propose for the ILD concept.



Technological prototype is made with:

- 40 planes of 1m^2
- One plane composed by:
  20 mm s.steel absorber + 6 mm GRPC/PCB
- A mechanical structure supporting the planes.
- A parallel gas distribution system.

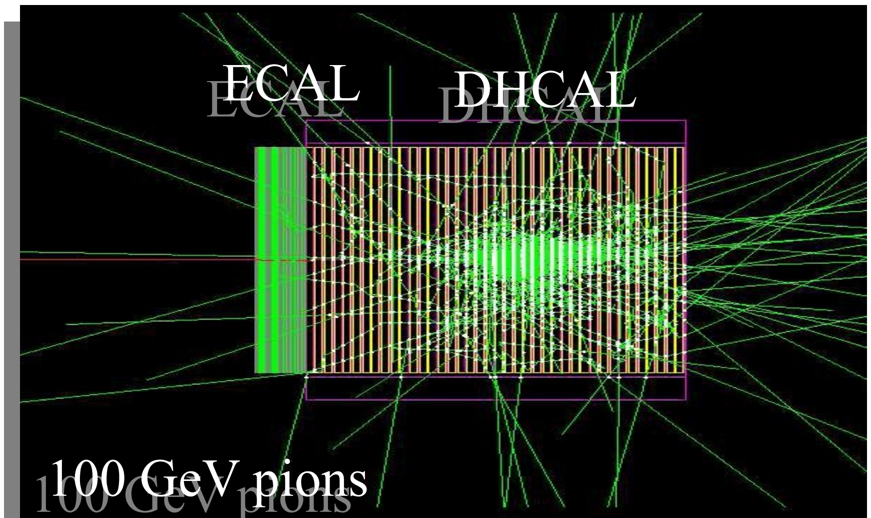


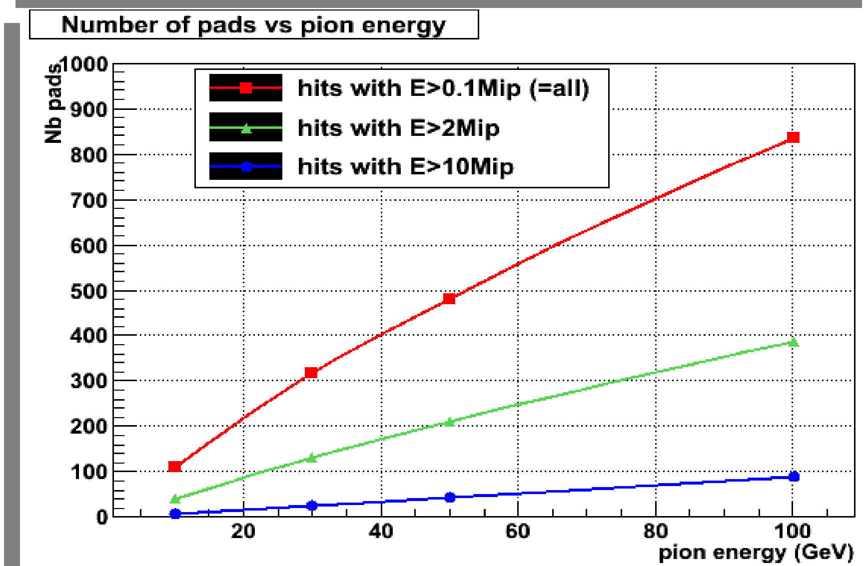
Important points:

- Mechanical structure development:
  1m^3 of (Absorber+GRPC) is about **6 ton** weight.
- Use of gas system with re-cycling option.
- Semi Digital readout of 368.640 channels **:**
  DAQ, event buiding, & data storage.

1 m³: shower containment

- With a **1m³ DHCAL**, hadronic shower could be mainly contained, even for high energy pions (about 100 GeV).
- We already try to evaluate the **energy deposition** to help the 1m³ design.
- The 40 planes of 9216 channels each, will permit us to have the complete profile of the showers, with a very high granularity.
- As the **HARDROC2** will have 3 thresholds, we try to evaluate the number of fired pads for different thresholds values, to better reconstruct the energy.

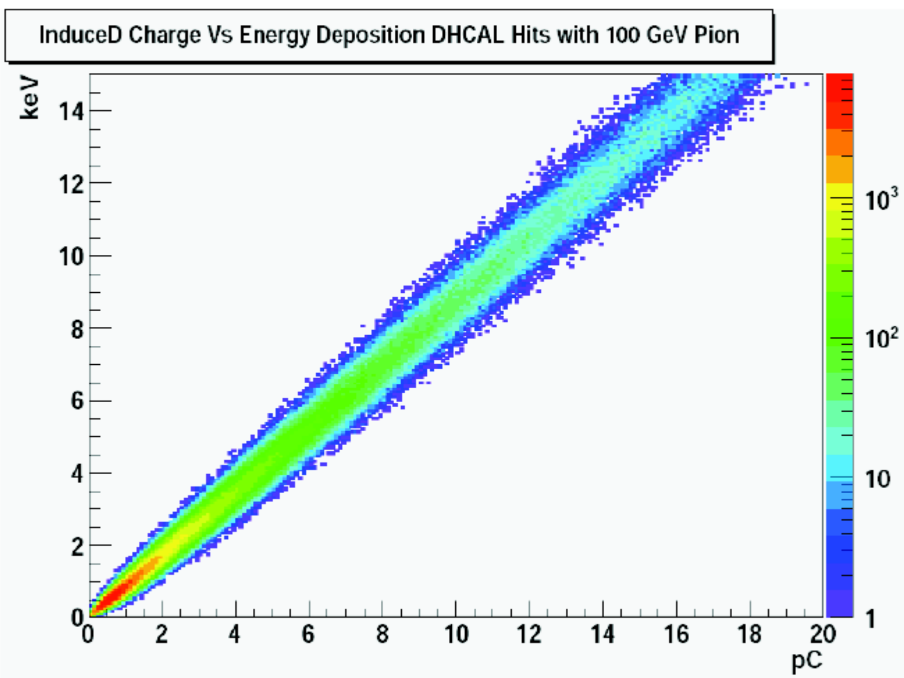


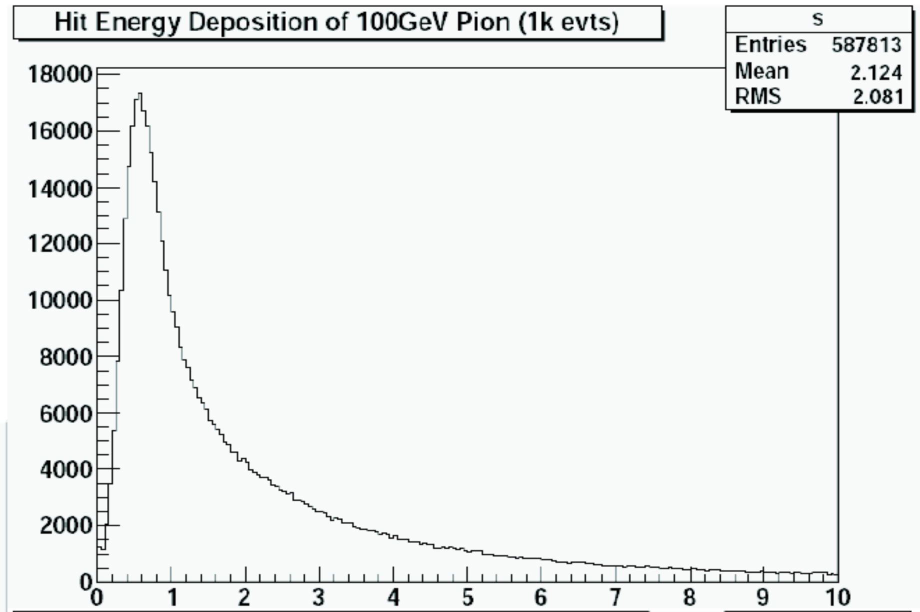


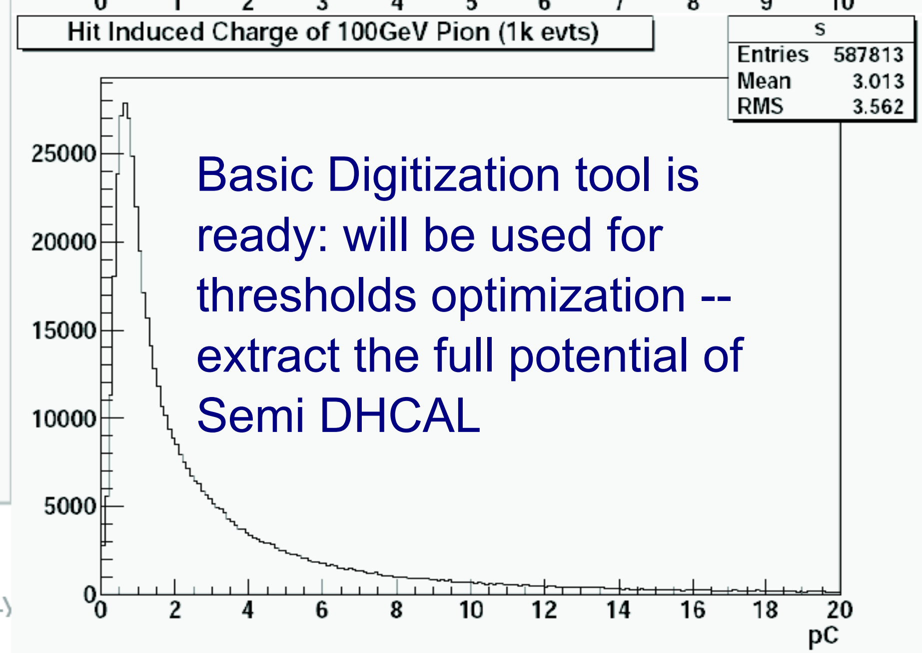
MC Digitization: Estimate the induced Charge

Calorimeter for ILC

Digitization with 100 GeV Pion





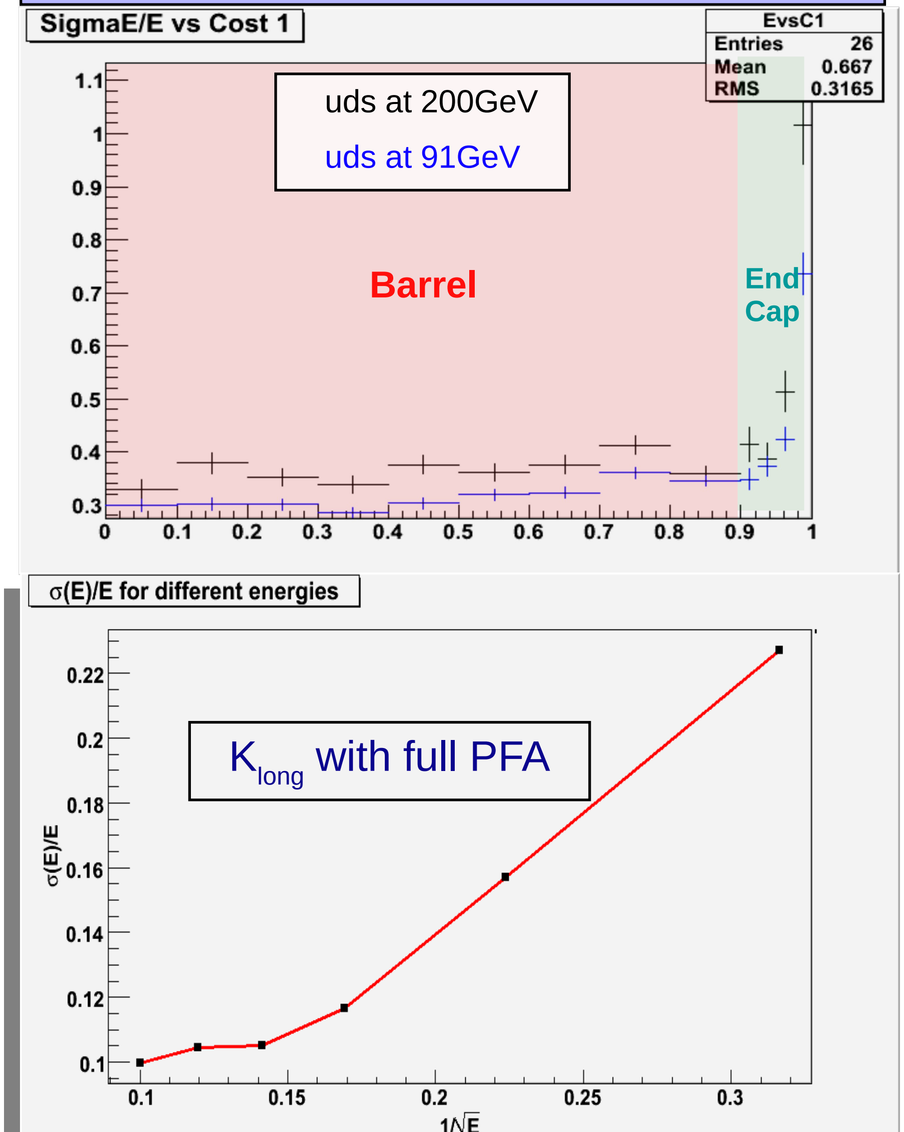


Basic Digitization tool is ready: will be used for thresholds optimization -- extract the full potential of Semi DHCAL

ILD Integration

- Simulations were done with Mokka software integrating DHCAL geometry.
- **Event produced:** single klong & uds.
- First analysis was done using Marlin with single threshold at 0.1 MIP in Mark Thomson's PFAnalysis module.
- **P**article **F**low **A**lgorithm need to be optimized to use the **full potential** of a multi threshold DHCAL.
- More work has to be done for it.

Detector's resolution Vs polar angle



SemiDigitalHCAL with PFA:

MC: Full Detector Occupancy study

	Barrel N_{hits}	Barrel N_{asic}	EndCap N_{hits}	EndCap N_{asic}	Ring N_{hits}	Ring N_{asic}
$e^+e^- \rightarrow qq$ GigaZ,30evt/s	207.6 6.2k/s 0.1/s	124.6 3.7k/s 0.05/s	117.8 3.5k/s 0.1/s	77.8 2.3k/s 0.06/s	6.7 201/s 0.036/s	4.5 135/s 0.02/s
Minimal bias GigaZ,10evt/s	0.78 7.8/s	0.64 6.4/s	20.2 202/s 0.06/s	17.0 170/s 0.05/s	0.038 0.38/s	0.033 0.33/s
Minimal bias Nominal 660evt/s	1.06 700/s	0.91 600/s	29.7 19.6k/s 4.6/s	25.1 16.6k/s 4/s	0.058 38.3/s	0.05 33/s

Black: expected N_{hits}/N_{asic} per event;

Blue: expected N_{hits}/N_{asic} per second;

Red: N_{hits}/N_{asic} per second on the hottest Asic

MC Simulation: our RPC has sufficient rate capability!

Conclusions & perspectives

- A Semi-Digital Gaz Hadronic Calorimeter with embedded readout is a very promising candidate for future linear colliders experiments
- Building ILC-like large GRPCs is now a controlled technique
  - Electronics readout for $1m^2$ is debugged and works for Hardroc 1 and Hardroc 2
  - Mechanical structure to hold GRPC+ equipped PCB has been successfully used in testbeam.
- Another equipped $1m^2$ with HR2 is under preparation
- Simulation and threshold optimization progress in parallel
- A technological prototype "1 m^3" (RPC and/or MGRPC) is funded and expected late 2010