Hadron Calorimetry for the SiD Detector Concept - non-baseline

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SiD Hadron Calorimetry

Two approaches:

(A) Particle Flow Algorithm (baseline)

- RPC (baseline) – see Harry Weert's talk
- Micromegas
- GEM
- Scintillator/SiPM – see Felix Sefkow's talk

(B) Homogeneous Calorimetry with Dual Readout

- for details, see Adam Para's talk/Monday

Hadron Calorimetry – PFA baseline

(Alternative Homogeneous Calorimetry discussed later)

Introduction to Calorimeters (from SiD LOI)

To measure hadronic jets of particles produced in high energy collisions of electrons and positrons, with suffcient precision it is widely accepted that a new approach is necessary. The most promising method, called a Particle Flow Algorithm (PFA), utilizes both the tracking information for charged particles and the calorimeter for the measurement of the energy of neutral particles. PFAs applied to existing detectors, such as CDF and ZEUS, have resulted in significant improvements of the jet energy resolution compared to methods based entirely on calorimetric measurement alone. However, these detectors were not designed with the application of PFAs in mind. The SiD concept on the other hand accepts that a PFA is necessary and is designing the detector to optimize the PFA performance with the goal of obtaining jet energy resolutions of the order of 3% of E_{jet}.
The major challenge imposed on the calorimeter by the application of PFAs is the association of energy deposits with either charged or neutral particles impinging on the calorimeter. This results in several requirements on the calorimeter design:

. To minimize the lateral shower size of electromagnetic clusters the Moli'ere radius of the ECAL needs to be minimized This promotes efficient separation of electrons and charged hadron tracks.

. Both ECAL and HCAL have to have imaging capabilities which allow assignment of energy cluster deposits to charged or neutral particles. This implies that the readout of both calorimeters needs to be finely segmented transversely and longitudinally.

Hadron Calorimetry - PFA baseline

. HCAL needs to be inside the solenoid to be able to do particle cluster association.

. In addition, the design of the calorimeter needs to be as uniform as possible, minimizing the use of different technologies, extendable to small angles to ensure hermeticity, and to provide enough depth for the longitudinal containment of hadronic showers. The design needs to consider the cost as an additional boundary condition.

HCal Introduction – Basic Design

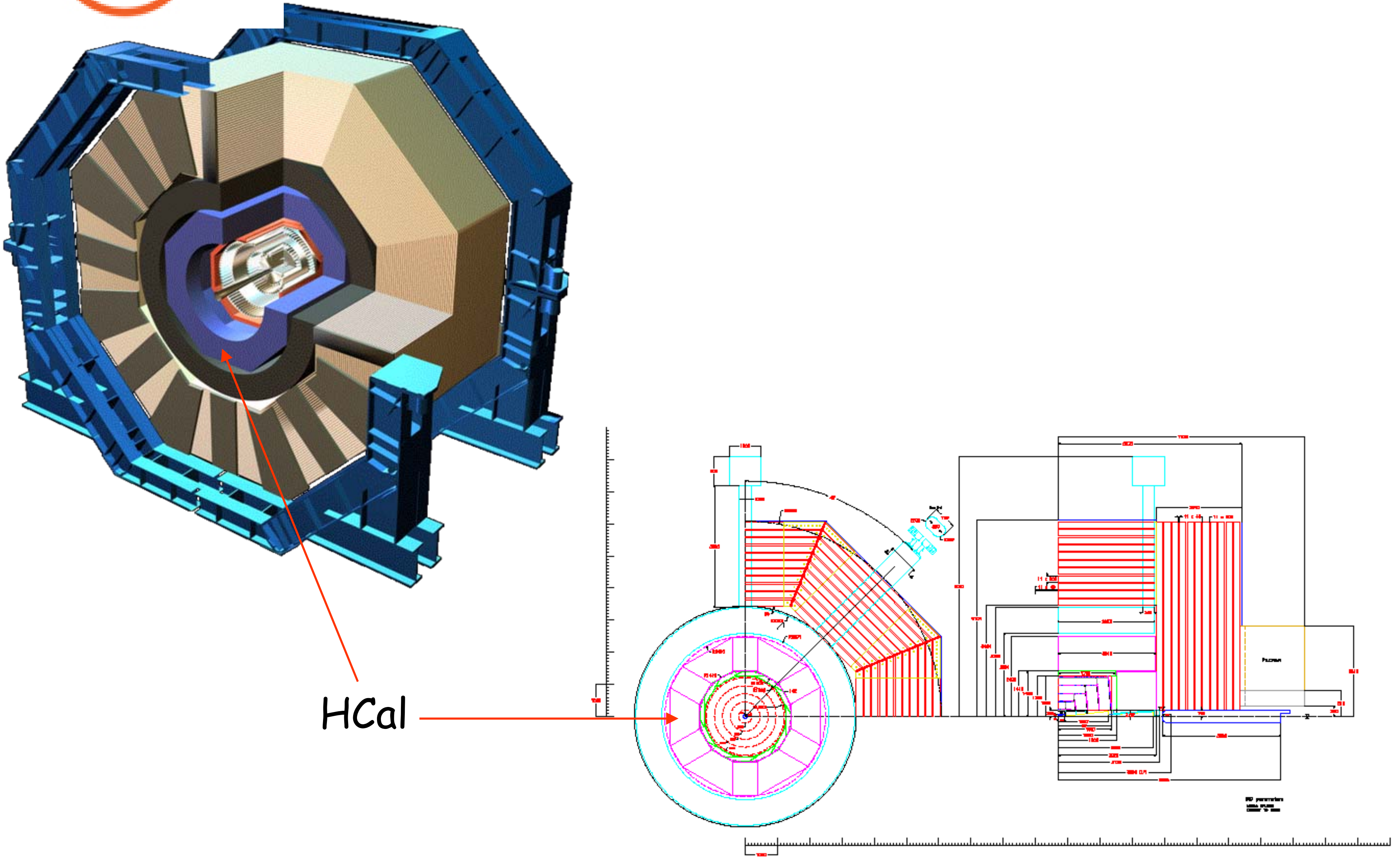
The PFA-based HCAL is a sandwich of absorber plates and instrumented gaps with active detector elements. It is located inside the magnet and surrounds the electro-magnetic calorimeter (Ecal), the latter being fixed to it. The total absorber depth amounts to 4.5 λ, made of stainless steel, divided into 40 layers, separated by 8mm gaps. Thus the HCAL internal and external radii are respectively: R_{int} =1419mm and R_{ext} =2583mm. The overall length is 6036mm long, centered on the interaction point.

The HCAL is divided into twelve azimuthal modules. In order to avoid cracks in the calorimeter, the module boundaries are not projective with respect to the interaction point. Consequently, in order to keep a symmetric shape two types of modules are used: 6 rectangles and 6 pseudo-trapezoids, as illustrated in Fig. ??.

Each module covers the whole longitudinal length. Chambers are inserted in the calorimeter along the Z-direction from both ends and can eventually be removed with out taking out the absorber structure from the magnet. Special care of the detector layout has to be taken into account to avoid a 90 degree crack.

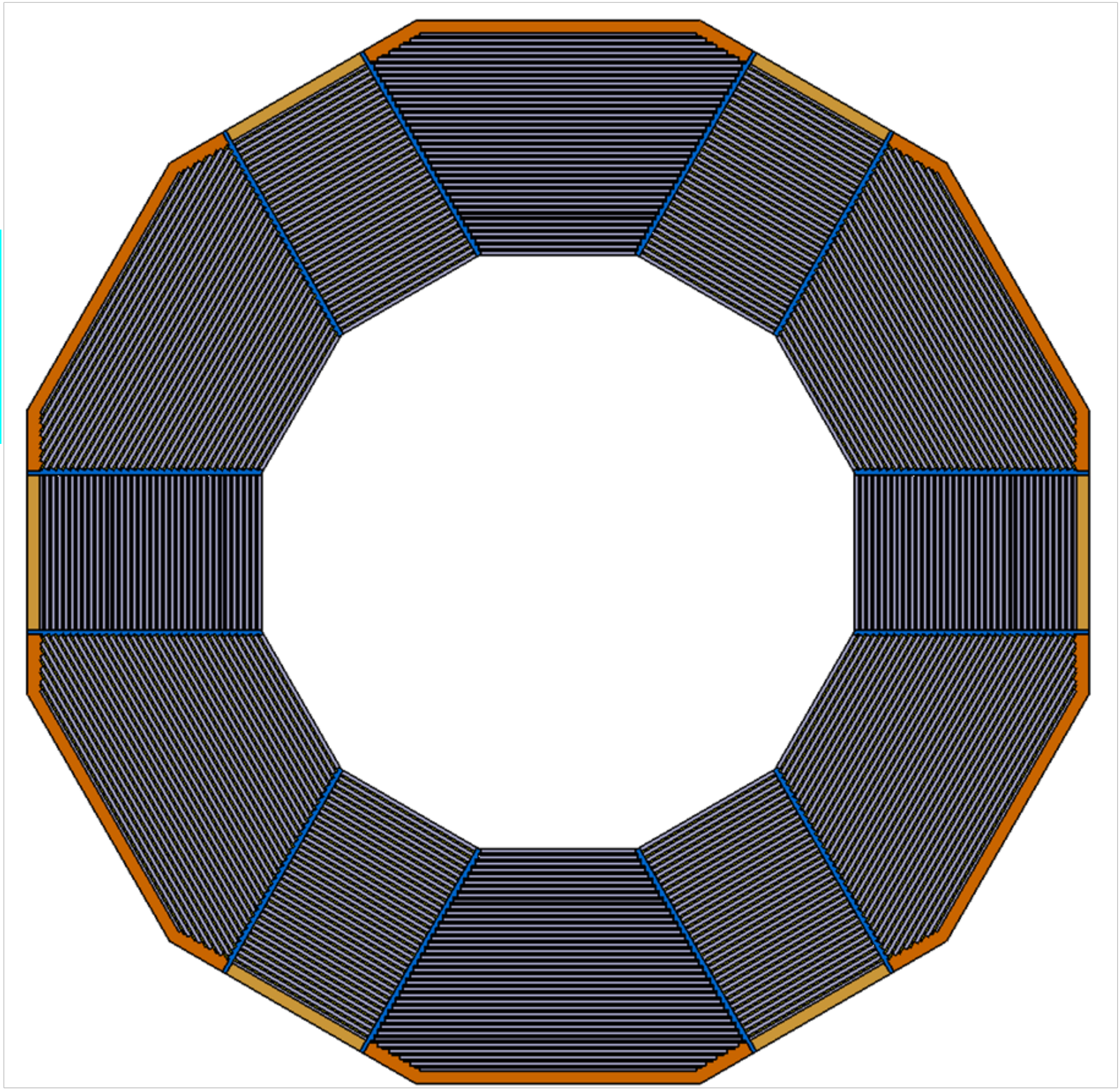
The absorber plates are supported by several stringers fixed radially on both sides of the modules. Stringers of two consecutive modules are shifted in order to maximise the active detector area. Although the space between two consecutive modules is not instrumented, it is however filled by the absorber material. The barrel will be fixed on the magnet at 3 and 9 o'clock or 5 and 7 o'clock.

The SiD Detector



HCAL Engineering Design

Cross-section of HCal Barrel

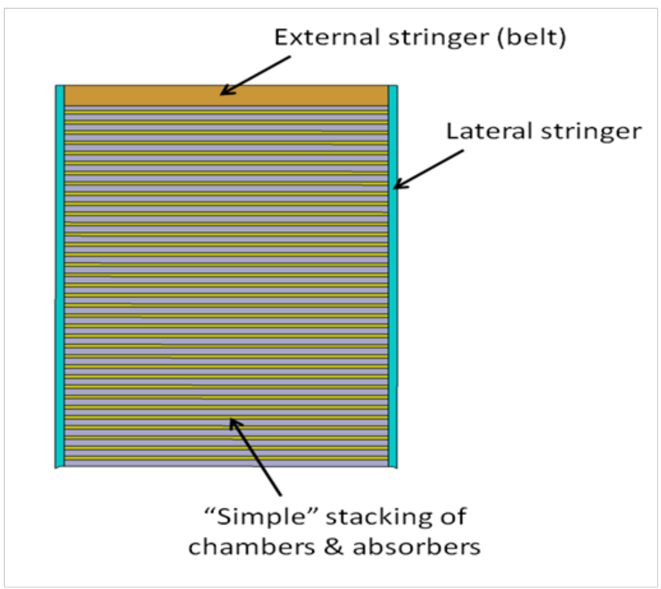


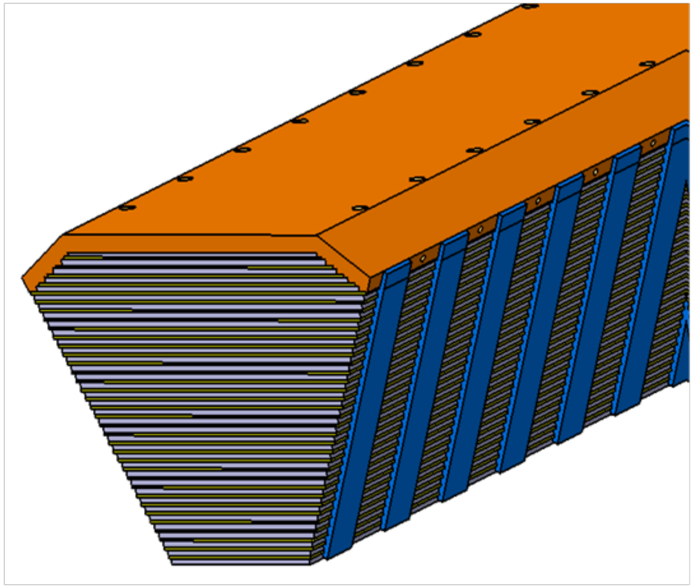
Alternating trapezoid/rectangle design with non-projective (filled) cracks

(Nicolas Geoffroy - LAPP)

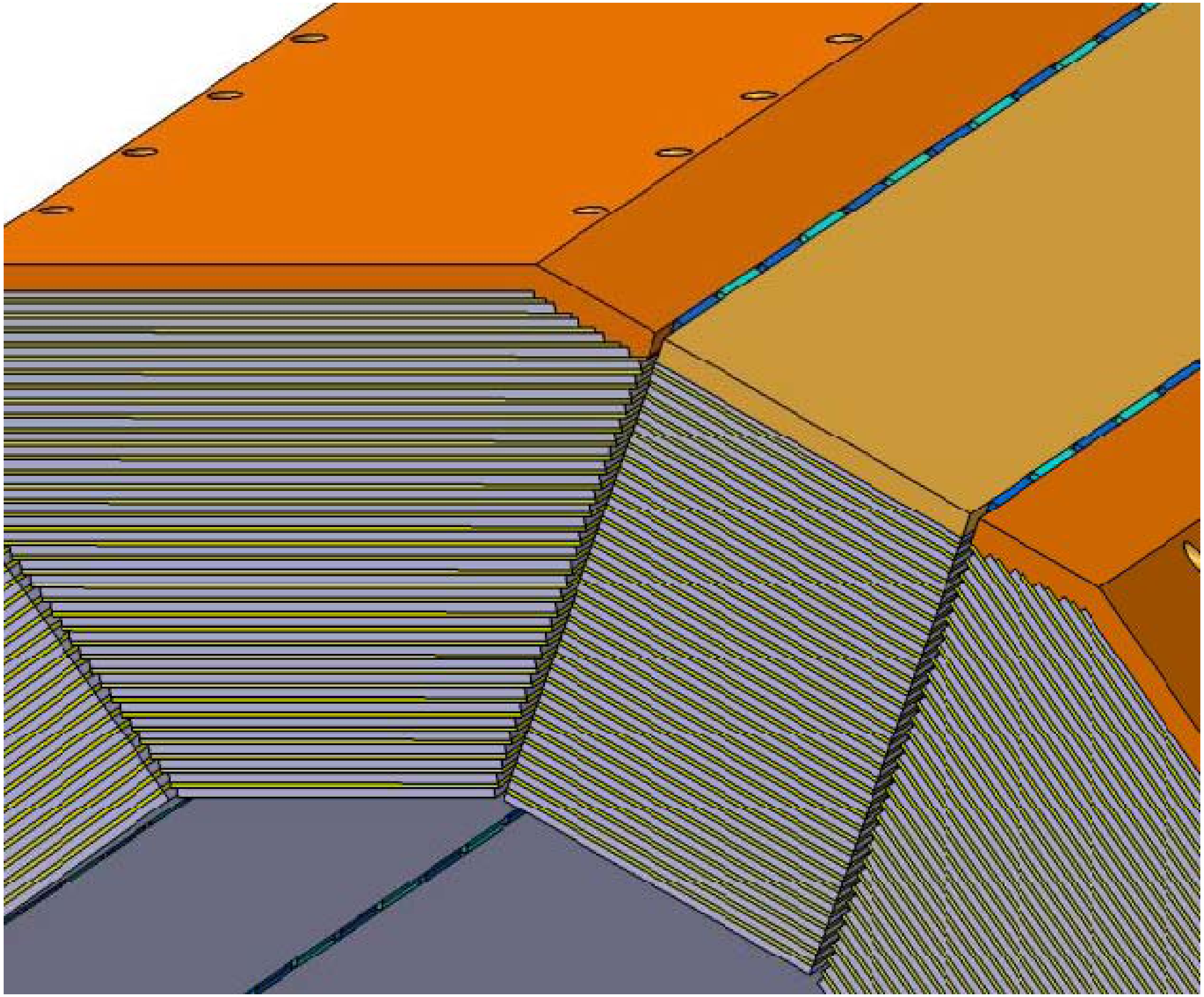
HCal Engineering Design

- **40 - 18.8mm thk. SS Plates**
- **40 - 8 mm Detector Gaps**
- **12 – Sided polygon***
- **Non-Projective Cracks***
- **Strong back Support and Support Rails***



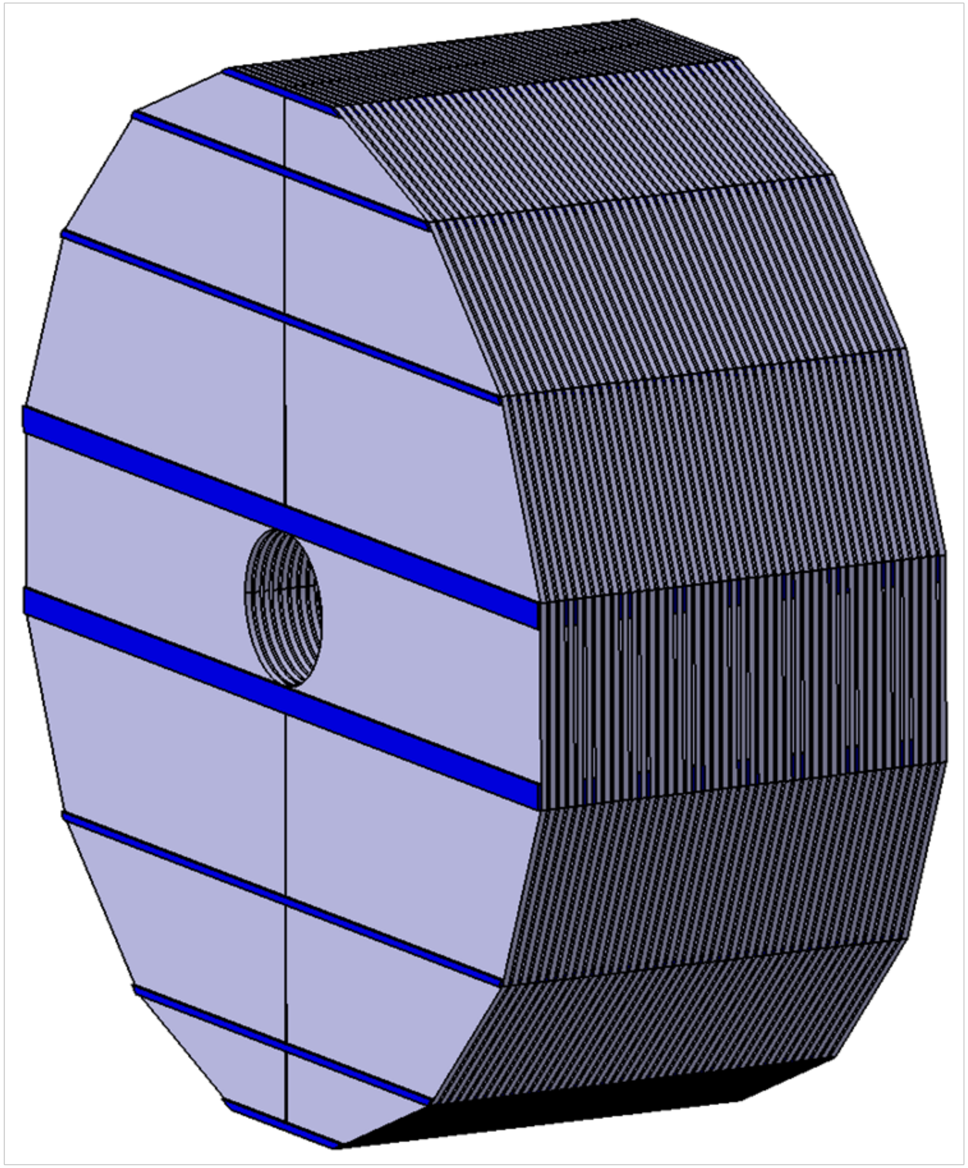


Hcal-Nonprojective Geometry



HCal Engineering Design

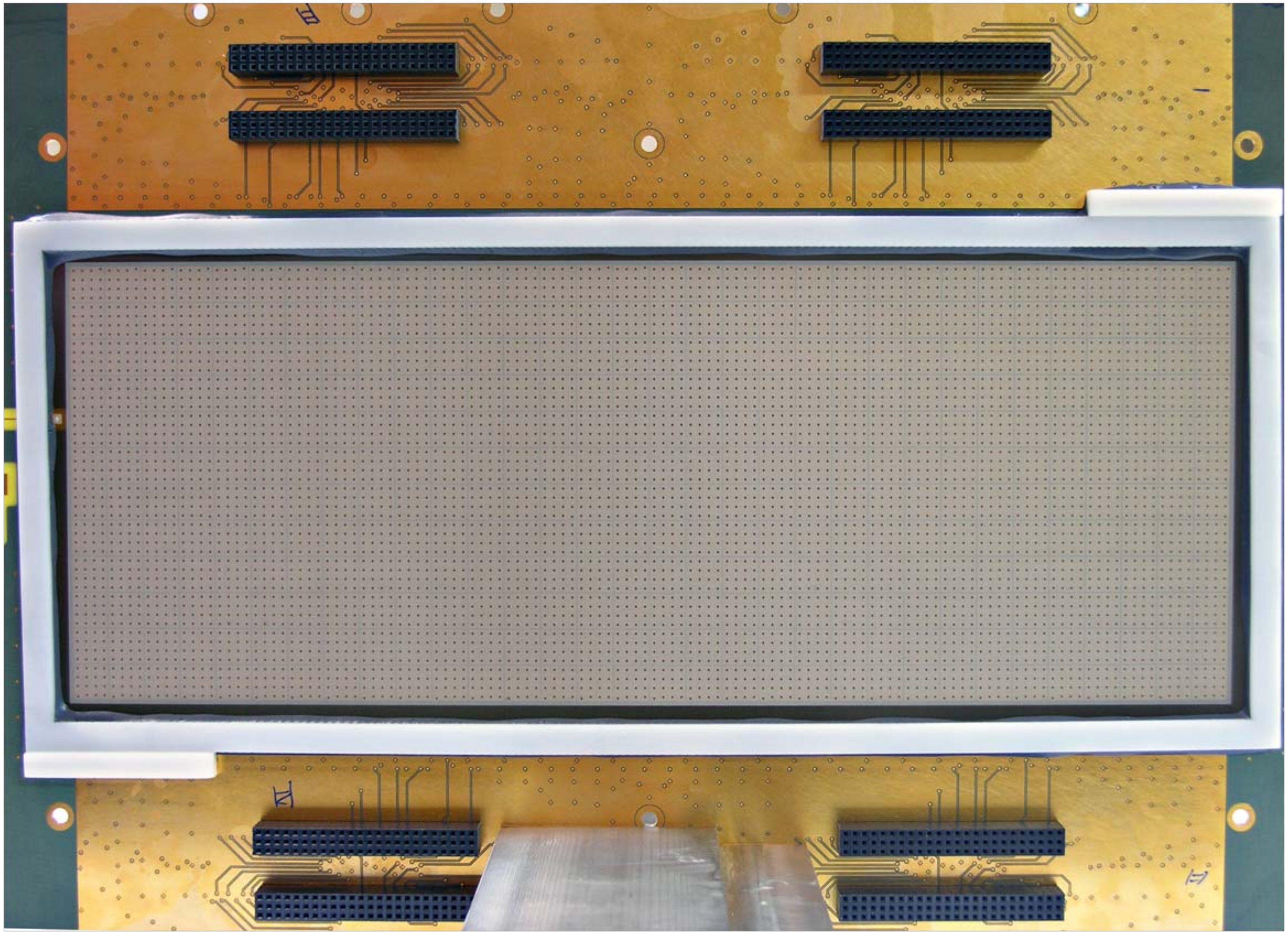
Cross-section of HCal Endcap



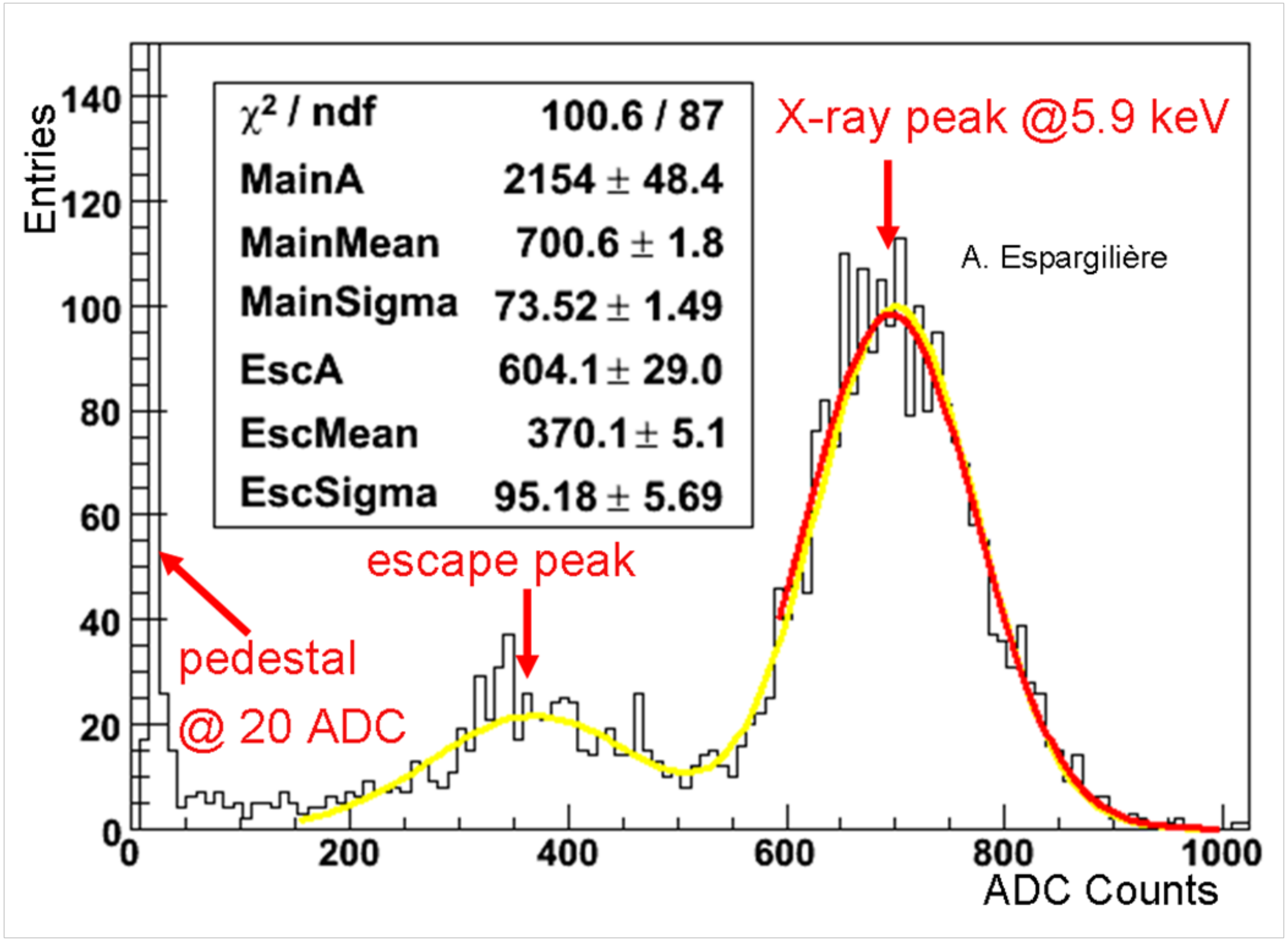
(1) Micromegas technology (LAPP)

- First prototypes 6cm x 96cm (3 chambers) and 12cm x 32cm (one chamber)
- Two chips: HARDROC (baseline for European 1m^3 DHCAL), DIRAC (longer term)
- Gain measurement from ^{55}Fe source
- Summer 2008 – 4 prototype “stack” at SPS/200GeV μ’s
  - -> chamber mappings, efficiencies, noise
- DIRAC prototype with PCB/embedded chip in beam
- 1m^2 prototype -> eventual 1m^3 stack.

12cm x 32cm first protoype micromegas chamber analog readout



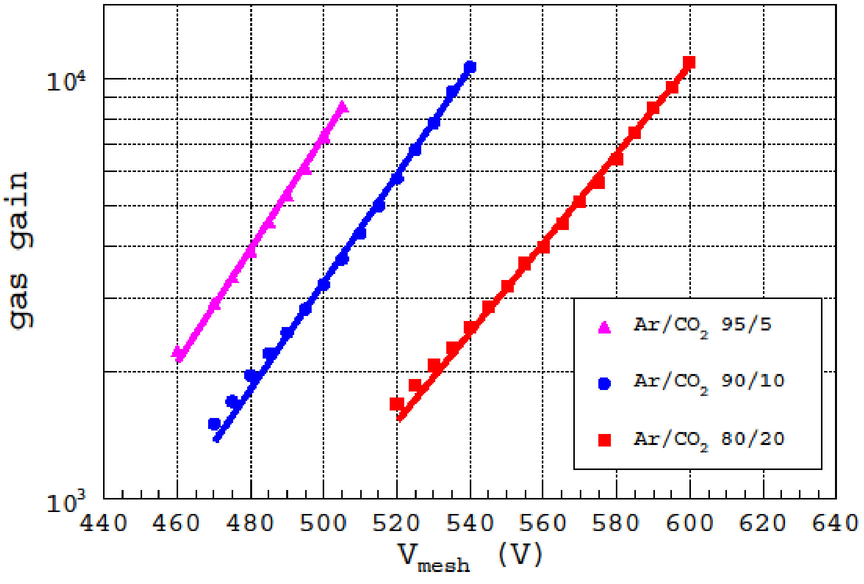
Micromegas analog response to ^{55}Fe source

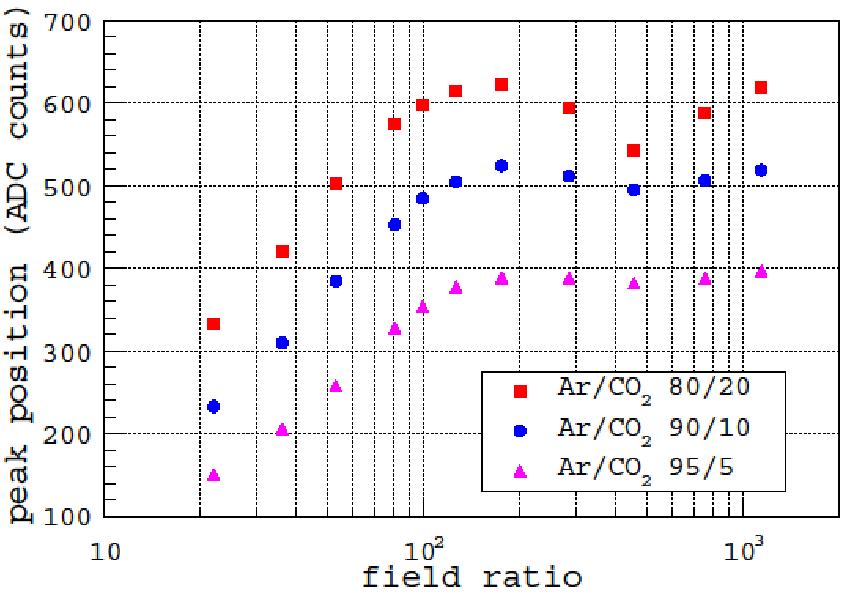


-> Gain measured to be 7600

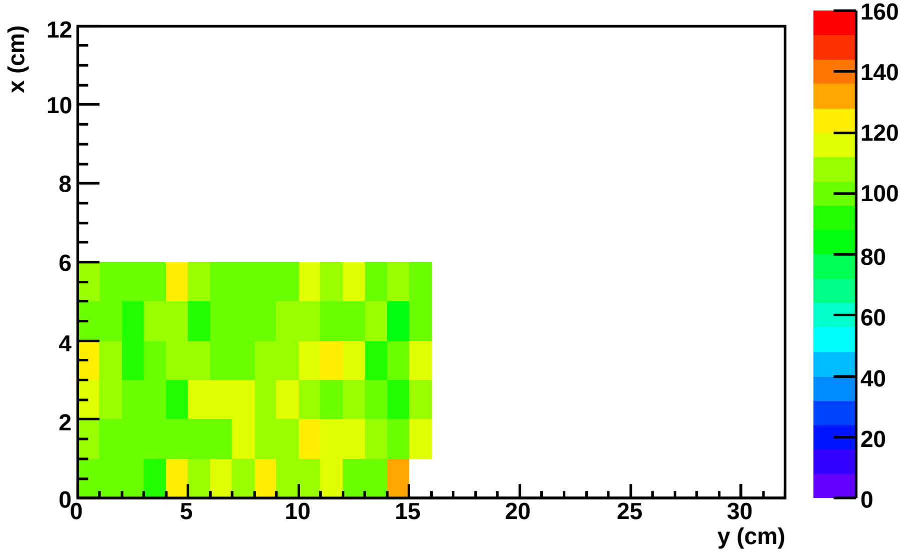
in Argon/Isobutane 95/5

MICROMEGAS in Ar/CO_2

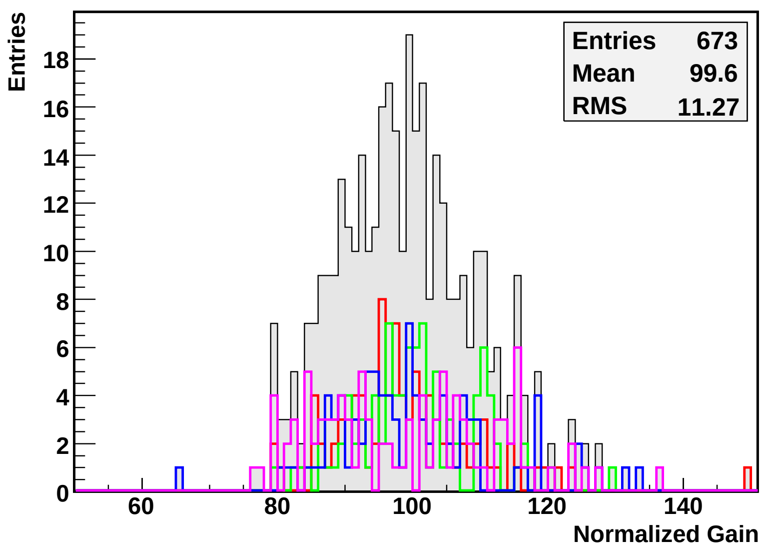




Micromegas chamber mapping, and MPV, with analog readout from CERN test beam



Example of prototype mapping with 200 GeV muons.

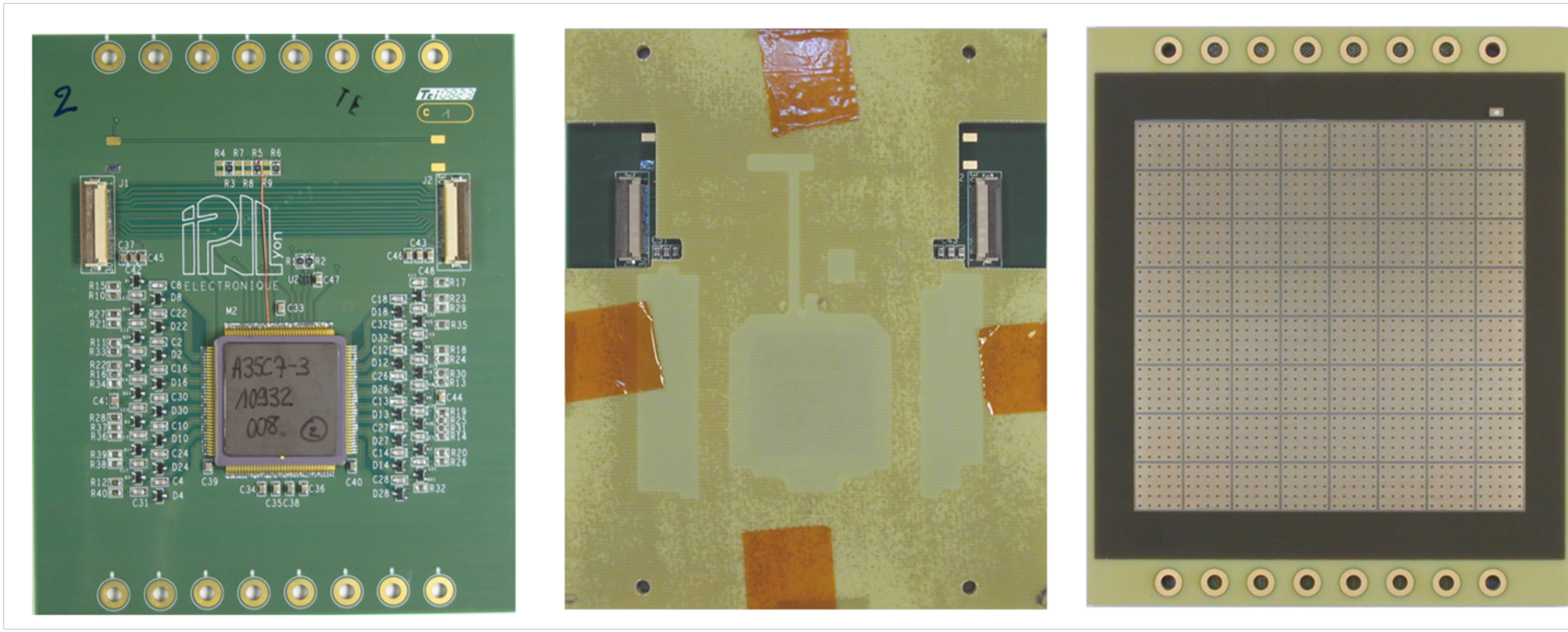


Dispersion of MPV of Landau distribution on pads for 4 prototypes

Average MPV -> ~45fC

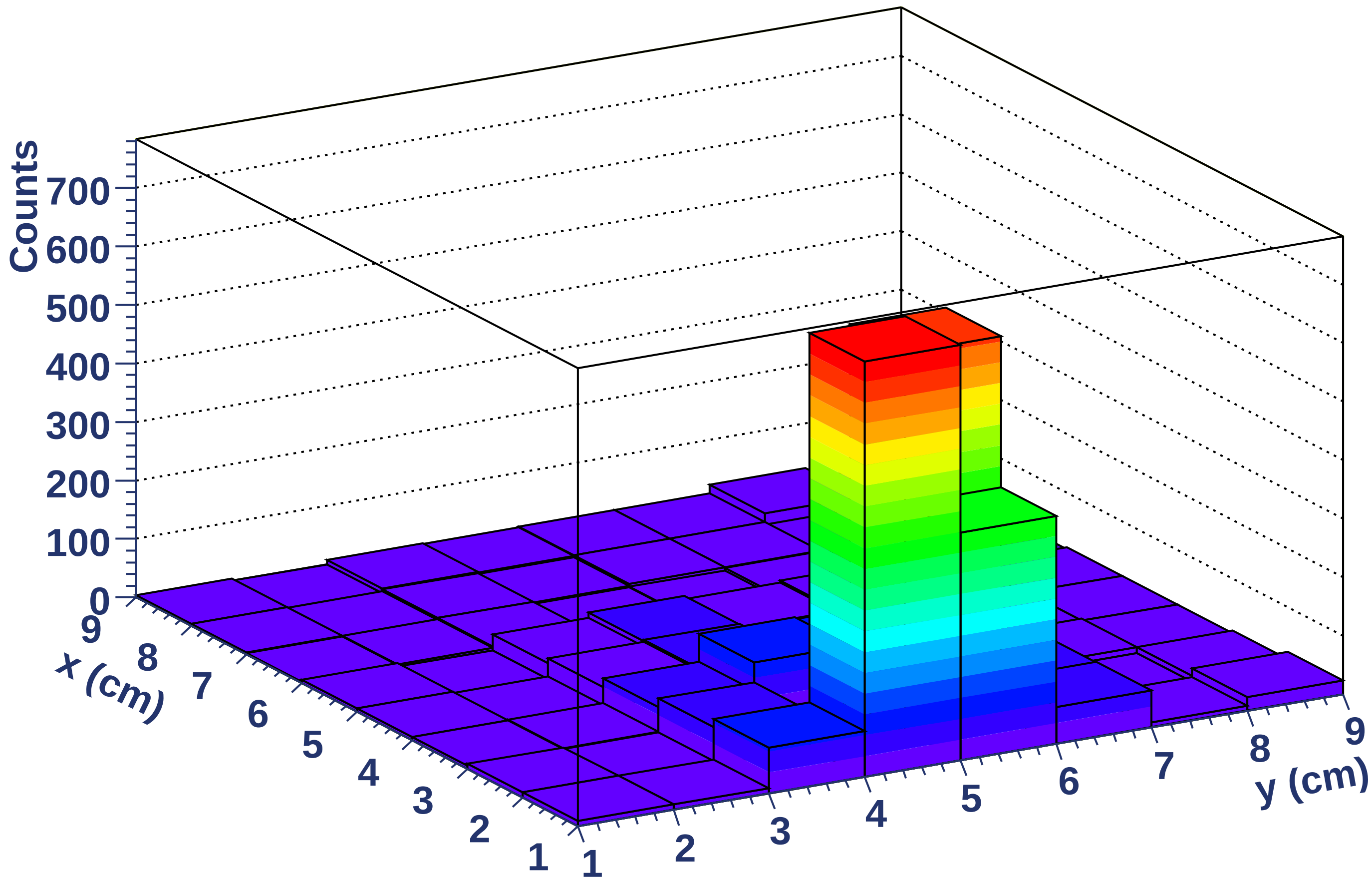
Prototype micromegas with DIRAC digital readout

8 x 8 cm^2



ASIC side, ASIC side with mask for bulk laying and pad side with bulk

Mapping of micromegas/DIRAC in 200 GeV pion beam, CERN Summer 2008



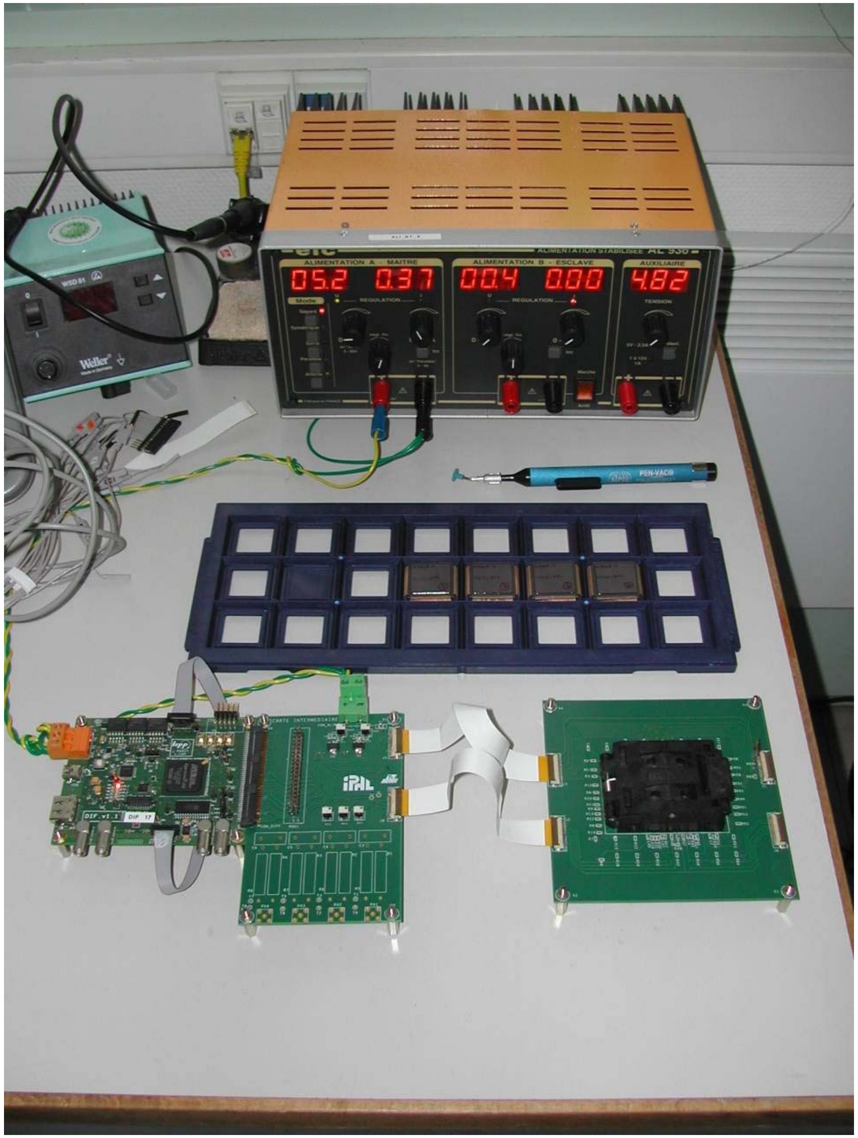
Progress on DIRAC2

DIRAC2 status

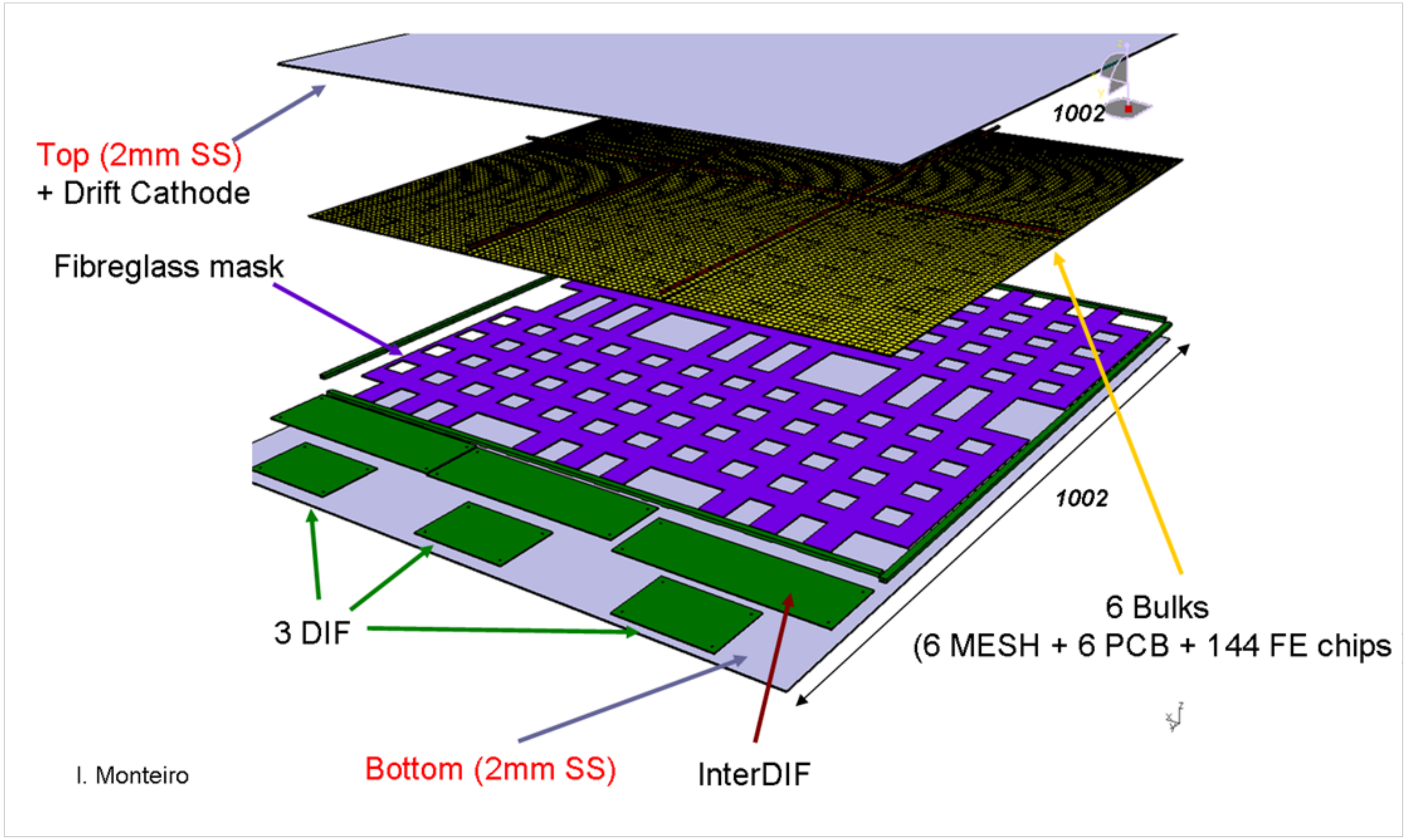
- DIRAC2 ASICs and IPNL test board have been produced and are now available to be tested.

- Tests
  → test of Firmware and Software
  → test of DIRAC2 features
  → Characterization of DIRAC2
  → …

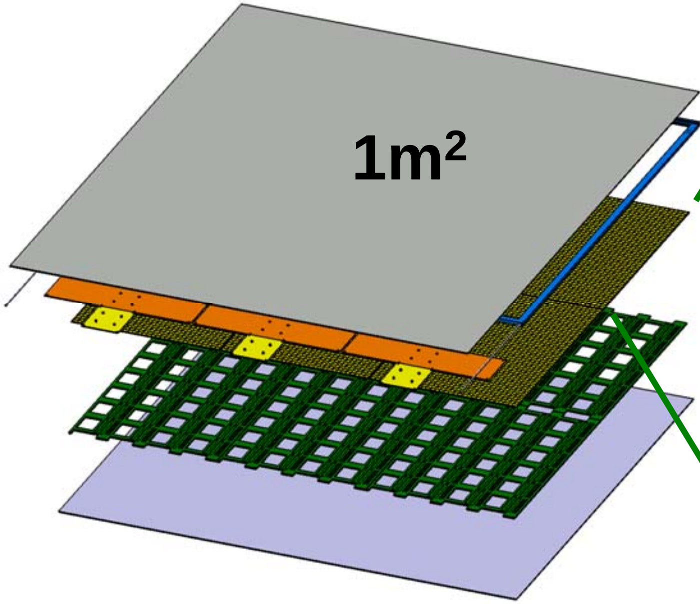
- If everything is ok, next step : 24 DIRAC2 32x48 cm^2 ASU for MICROMEGAS

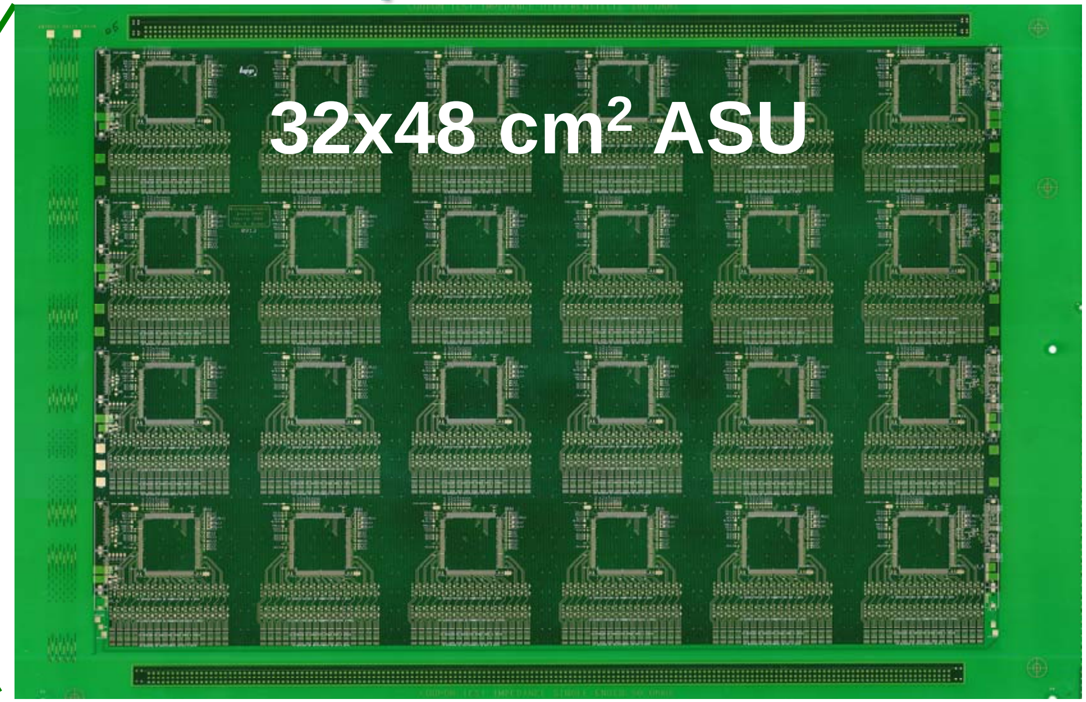


Design of 1m^2 micromegas prototype

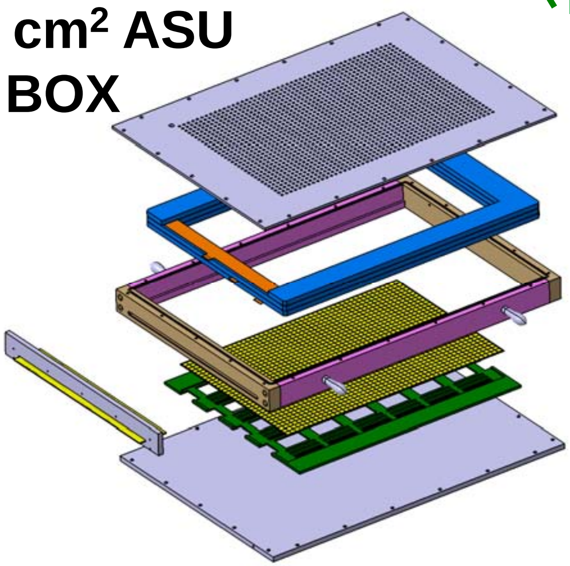


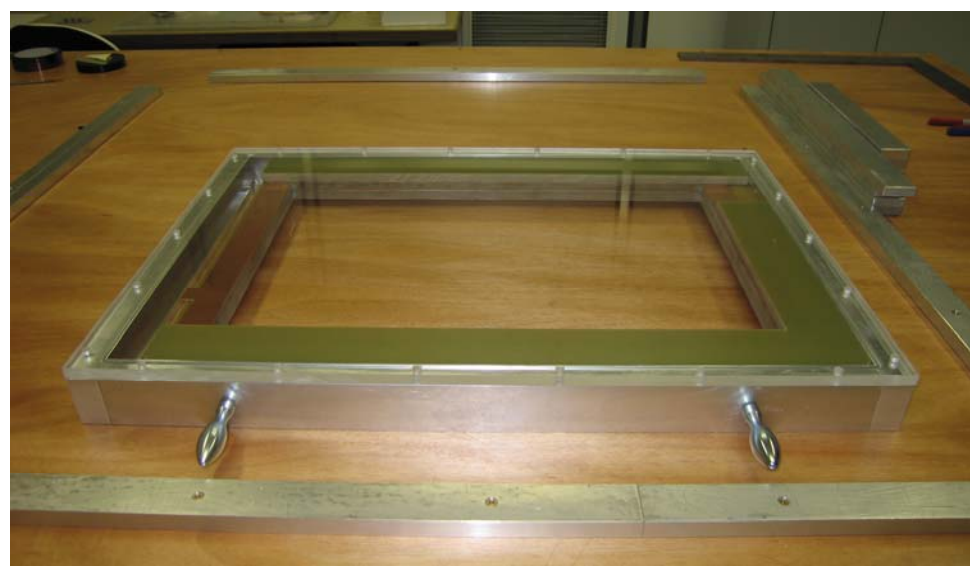
MICROMEGAS Square meter





The $32x48\ cm^2$ ASU TEST BOX



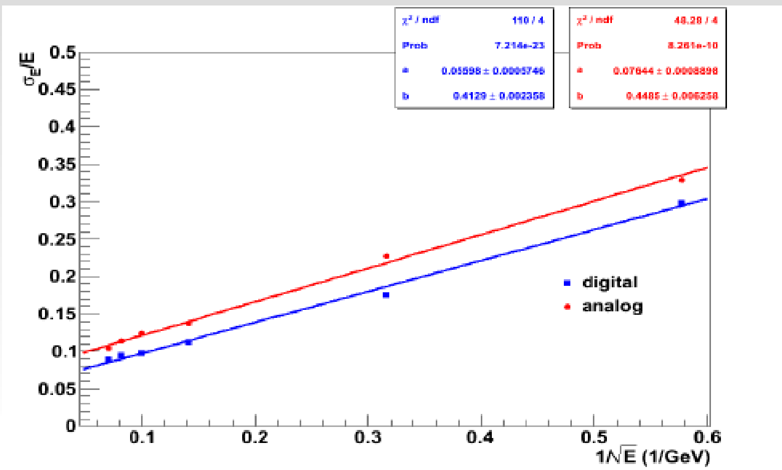


MICROMEGAS HCAL SIMULATION

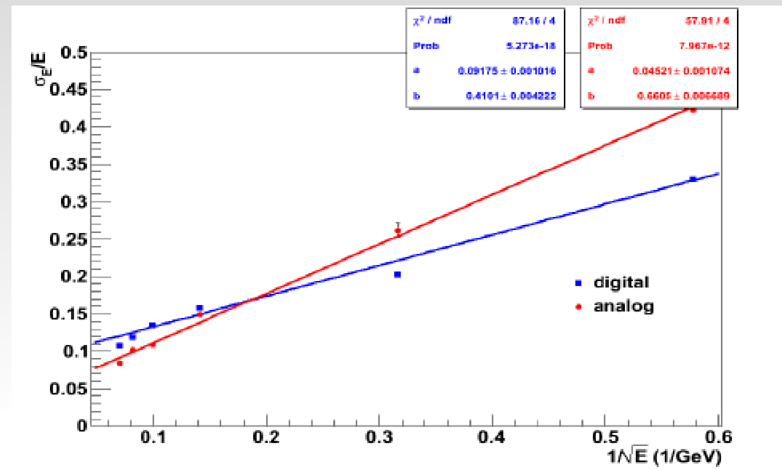
Energy resolution vs pion energy

1 cm^2 cells

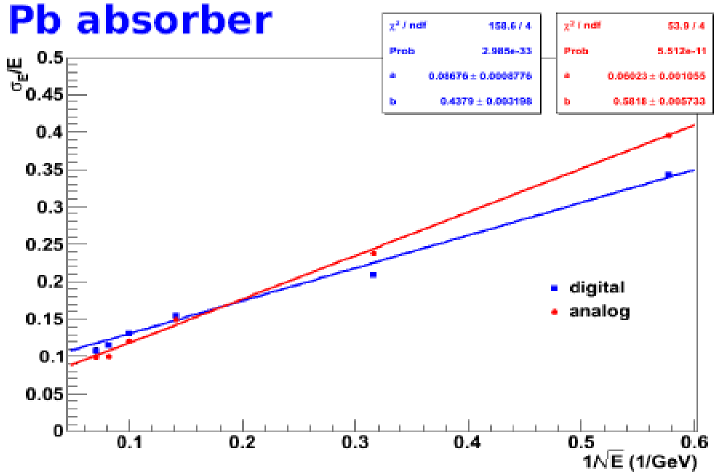
Fe absorber



absorber



Pb absorber

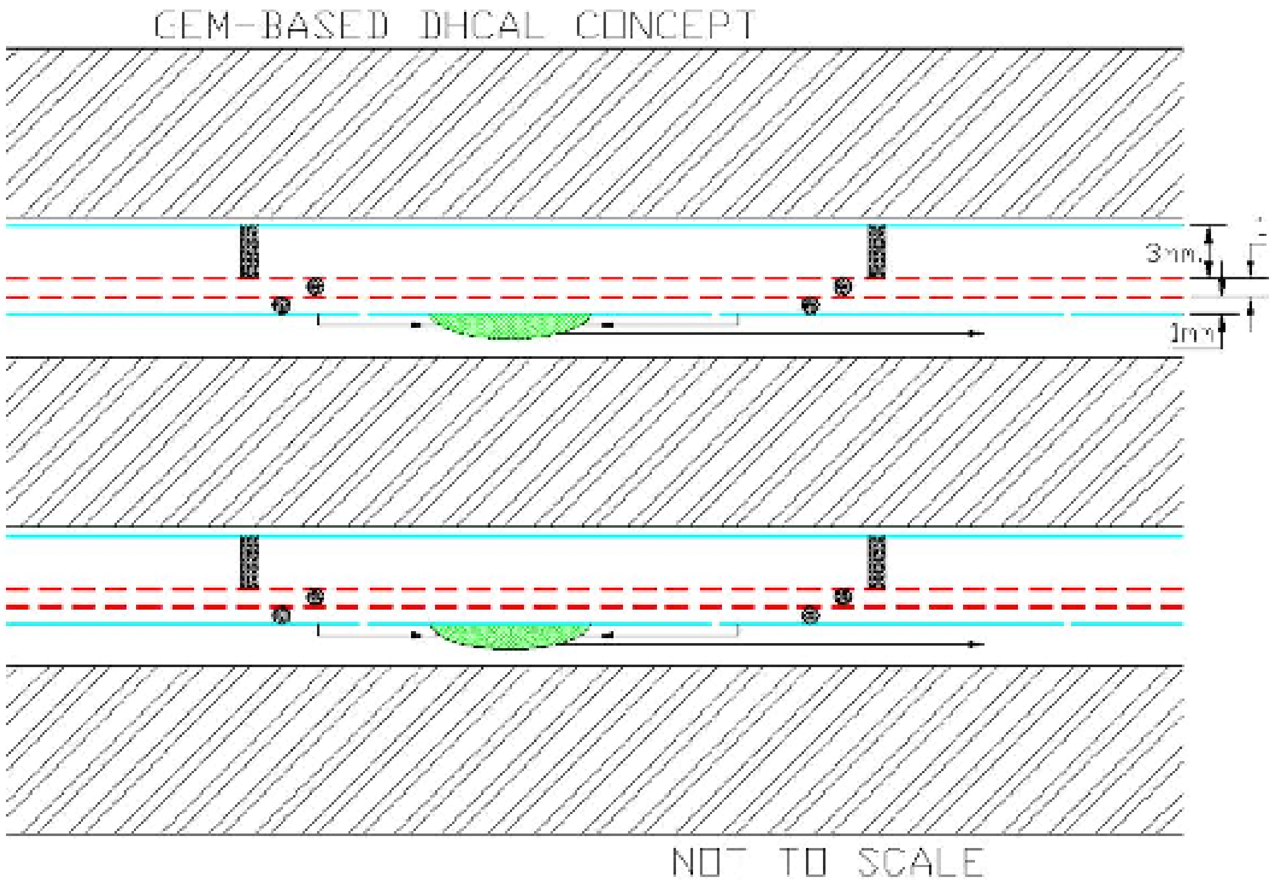


Abs	Readout	Constant (%)	Stochastic (%)
Fe	Digital	5.60 ± 0.06	41.29 ± 0.24
	Analog	7.64 ± 0.09	44.85 ± 0.63
W	Digital	9.18 ± 0.10	41.01 ± 0.42
	Analog	4.52 ± 0.12	66.05 ± 0.68
Pb	Digital	8.68 ± 0.09	43.79 ± 0.32
	Analog	6.02 ± 0.11	58.18 ± 0.58

(2) GEM/DHCAL technology (UTA)

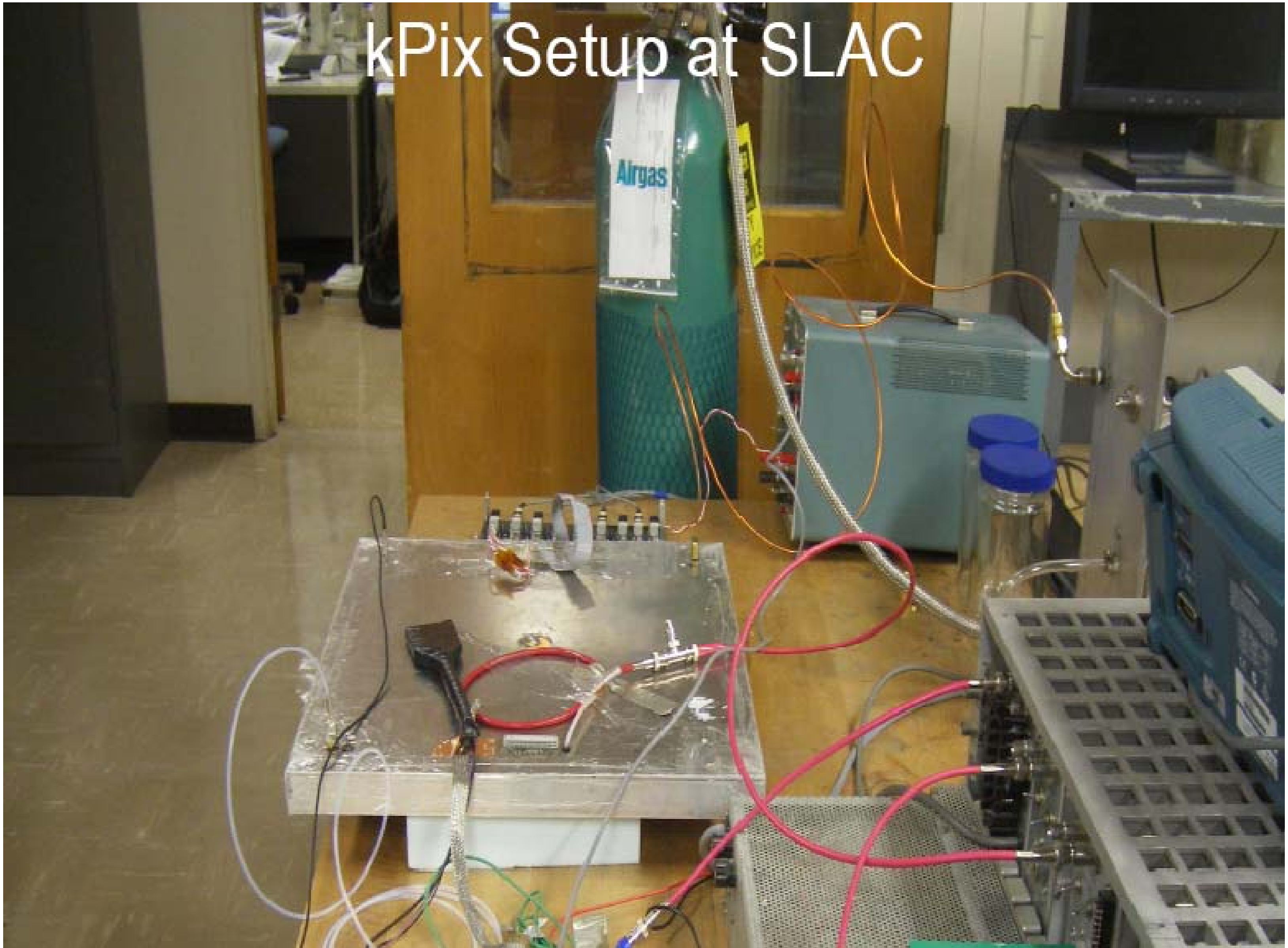
- GEM/DHCAL schematic
- Initial prototype tests, foil development
- Beam tests with 30cm x 30cm chamber(s)
- Working with the KPiX chip
- Towards 1m x 33cm chambers and 1m x 1m planes
- Thick-GEM alternative

GEM/DHCAL schematic



30cm x 30cm foil developed with 3M

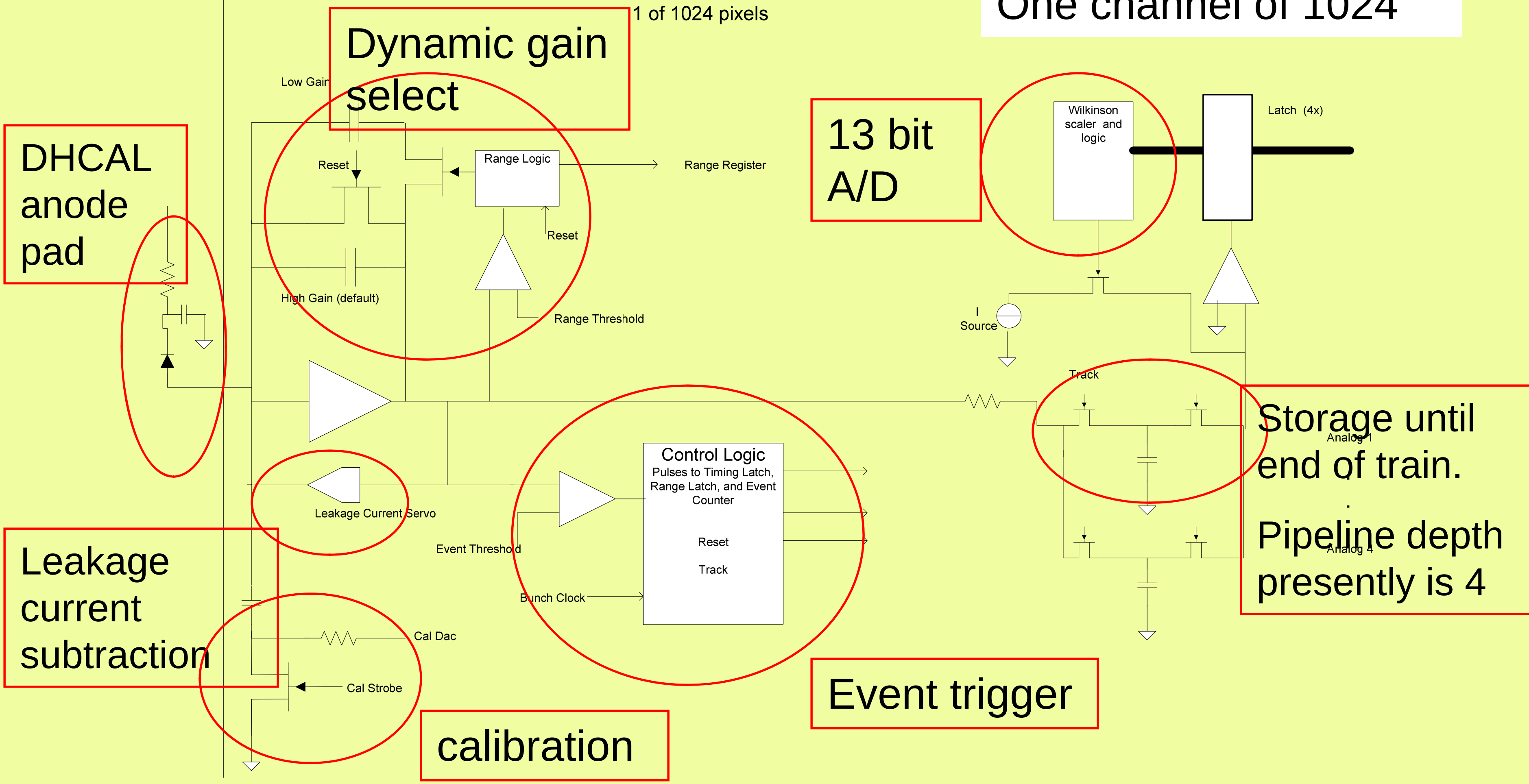
GEM chamber with KPiX v4



KPiX/GEM/DHCAL

KPiX chip

One channel of 1024

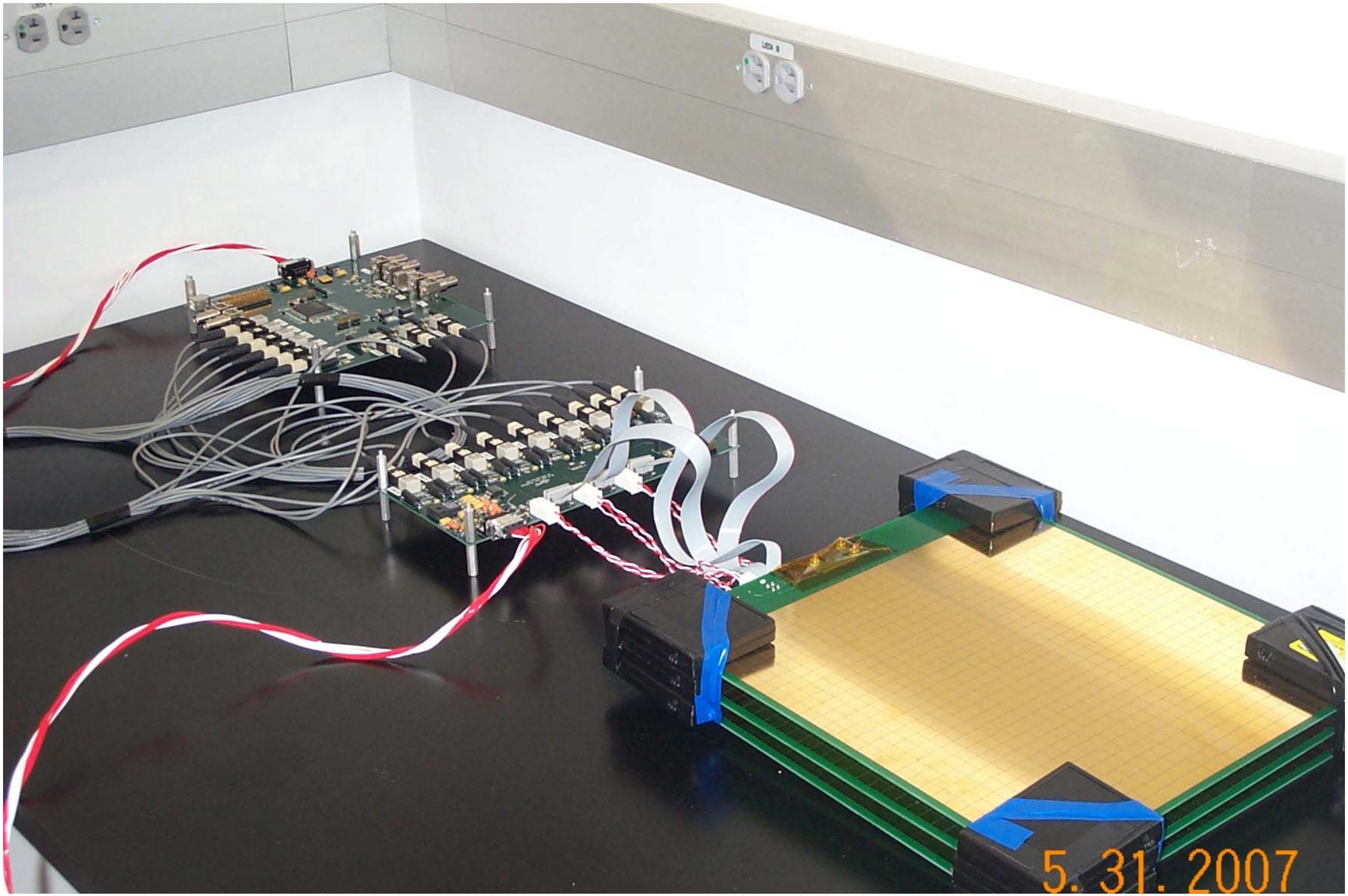


Simplified Timing:

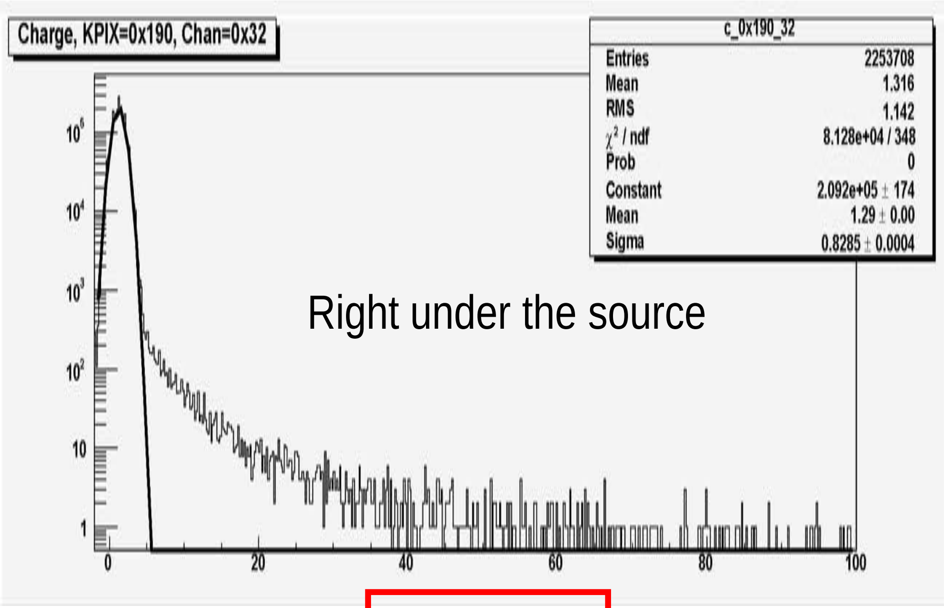
There are ~ 3000 bunches separated by ~300 ns in a train, and trains are separated by ~200 ms.

Say a signal above event threshold happens at bunch n and time T0.
The Event discriminator triggers in ~100 ns and removes resets and strobes the Timing Latch (12 bit), range latch (1 bit) and Event Counter (5 bits).
The Range discriminator triggers in ~100 ns if the signal exceeds the Range Threshold.
When the glitch from the Range switch has had time to settle, Track connects the sample capacitor to the amplifier output. (~150 ns)
The Track signal opens the switch isolating the sample capacitor at T0 + 1 micro s. At this time, the amplitude of the signal at T0 is held on the Sample Capacitor .
Reset is asserted (synched to the bunch clock) . Note that the second capacitor is reset at startup and following an event, while the high gain (small) capacitor is reset each bunch crossing (except while processing an event)
The system is ready for another signal in ~1.2 microsec.
After the bunch train, the capacitor charge is measured by a Wilkinson converter.

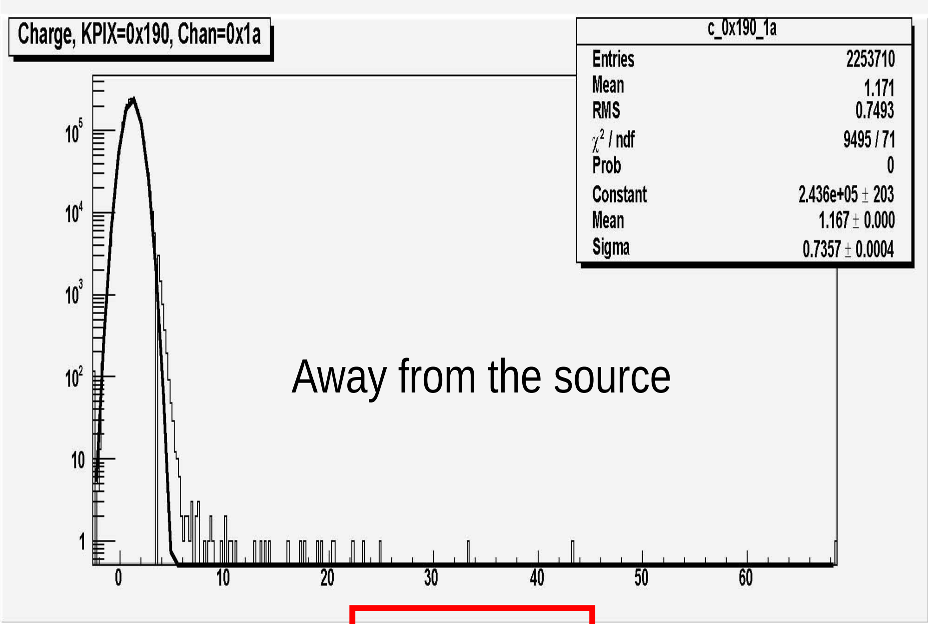
GEM-DHCAL/KPiX boards with Interface and FPGA boards



Example of results from tests of GEM with KPiX

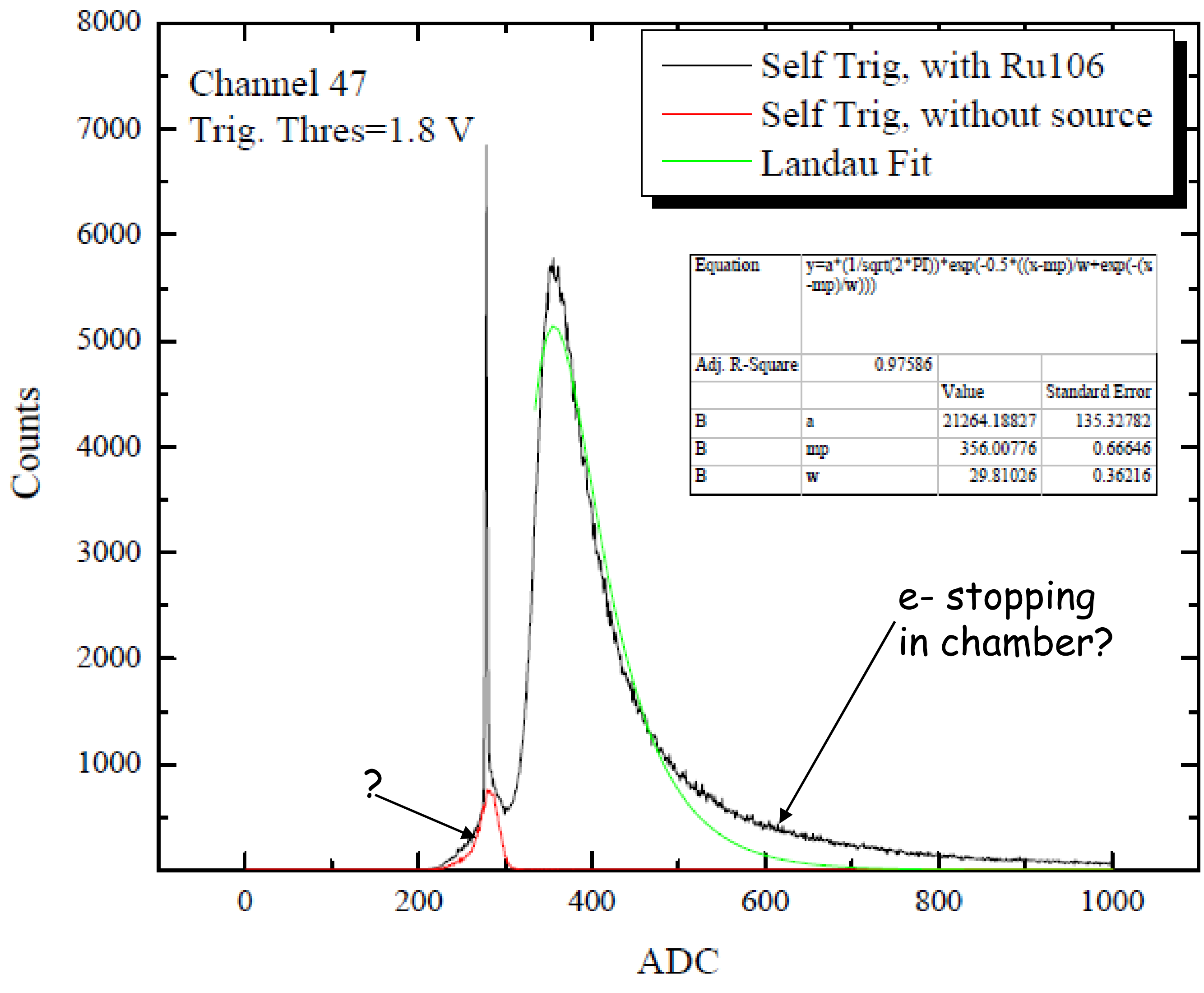


fC scale



fC scale

Example of results from tests of GEM with KPiX v.7



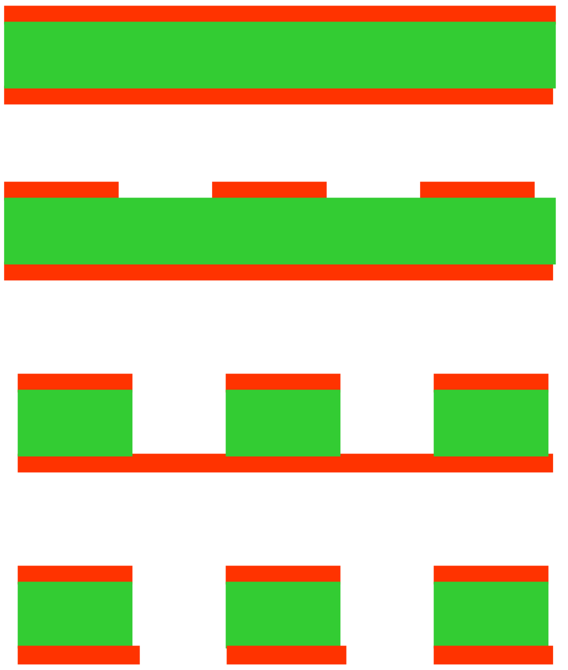
Electrochemical conical single mask

Raw material

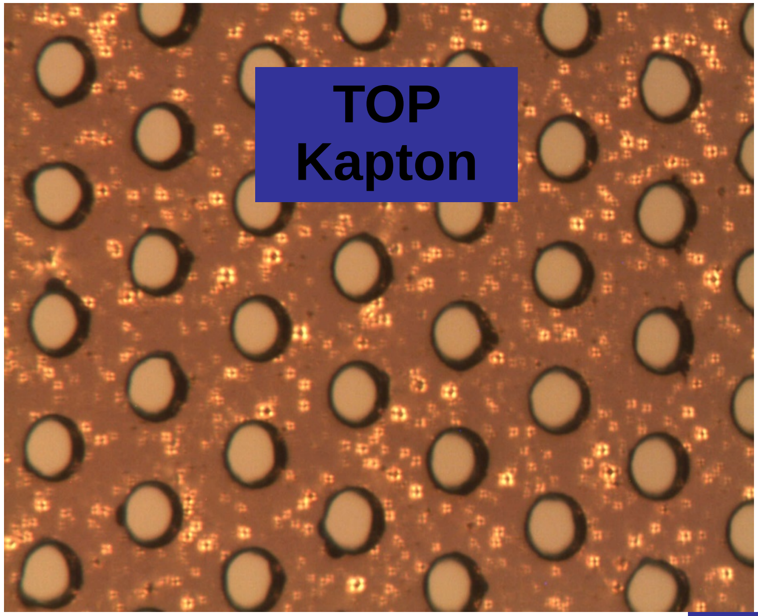
Top patterning

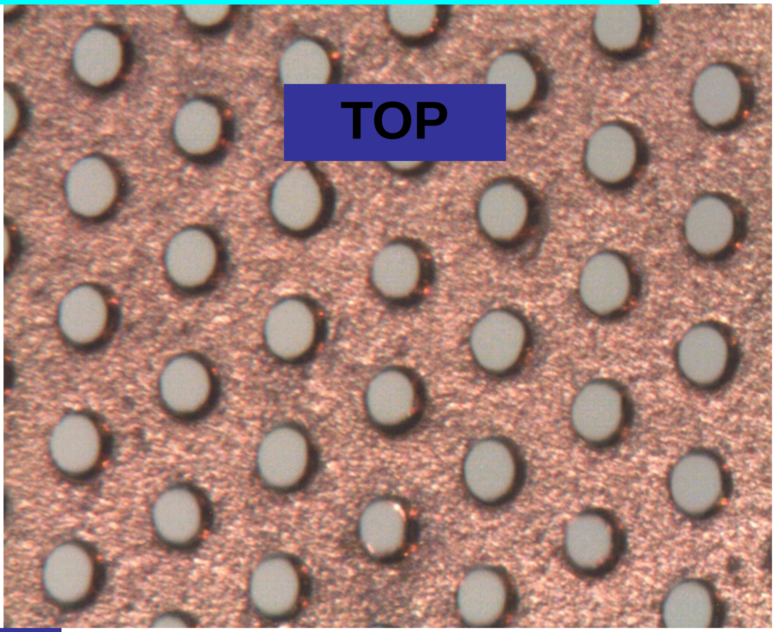
Polyimide etching

Electrochemical etch

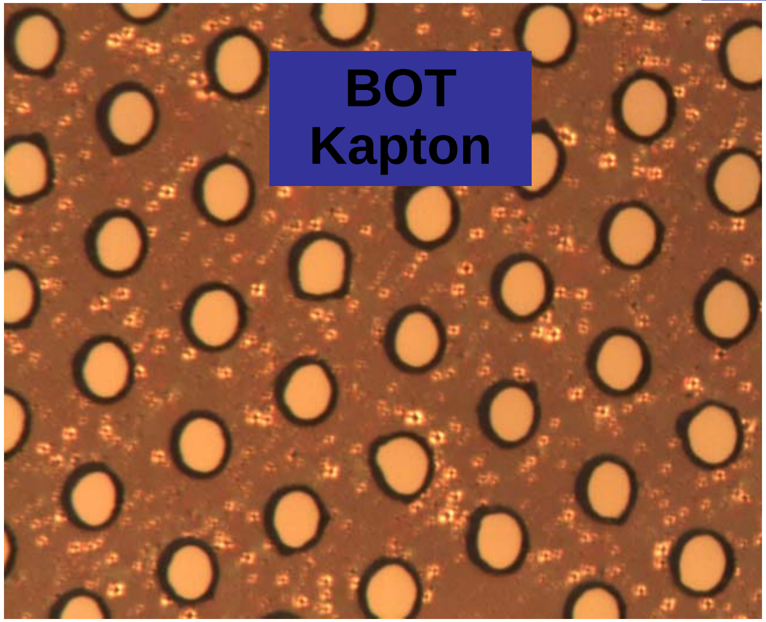


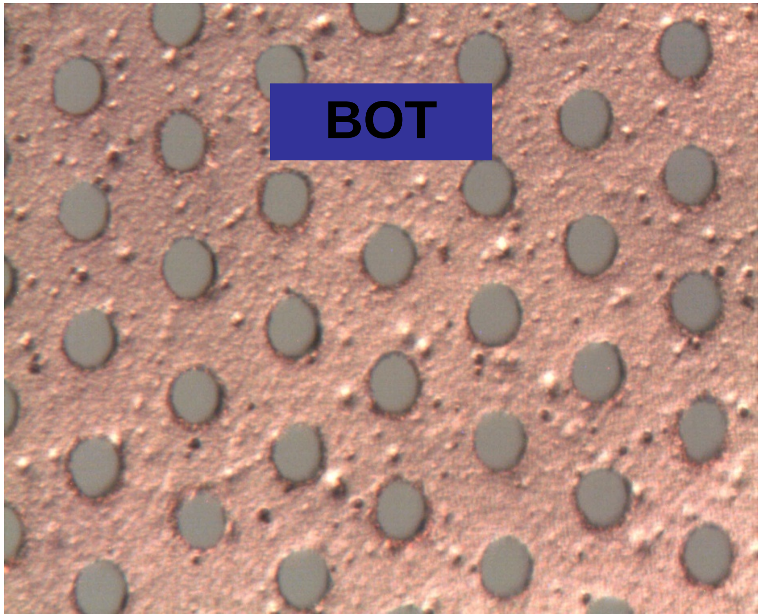
Rui de Oliveira – CERN





700 V in air





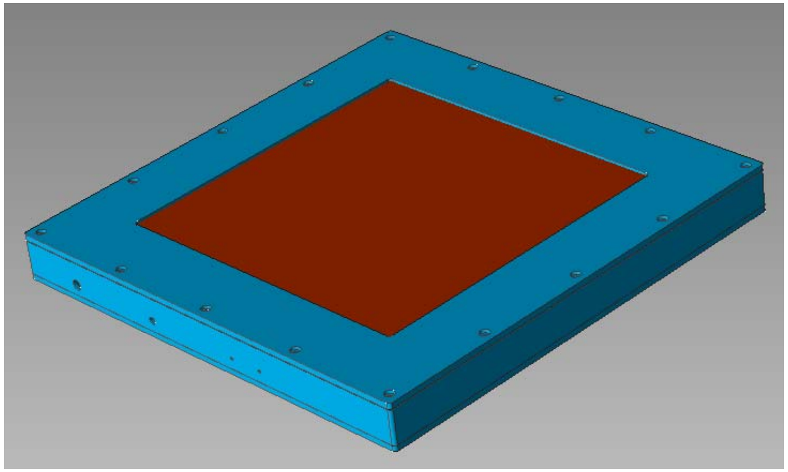
Rui de Oliveira - CERN

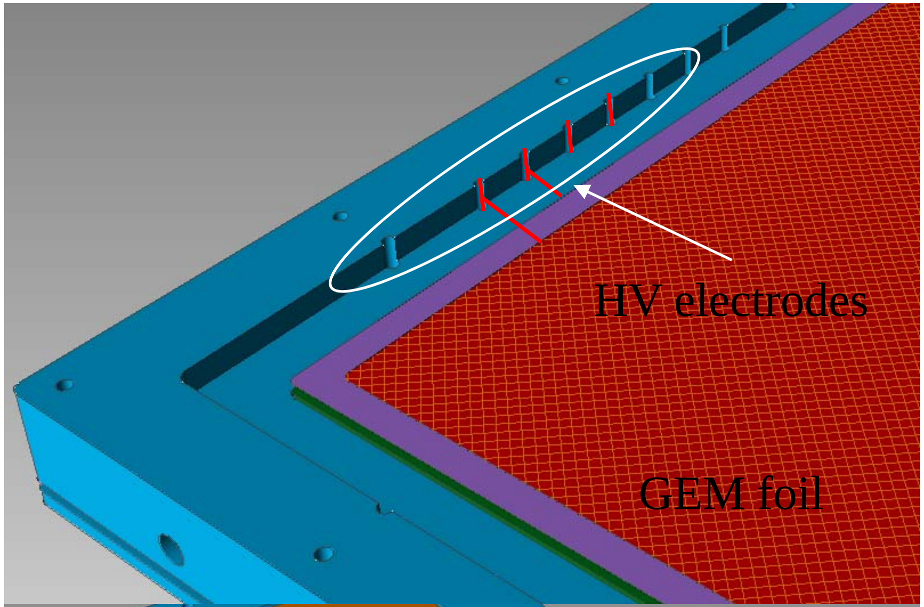
- **Production of 10 to 15 pieces in March**
  - **Check uniformity and operating process windows**

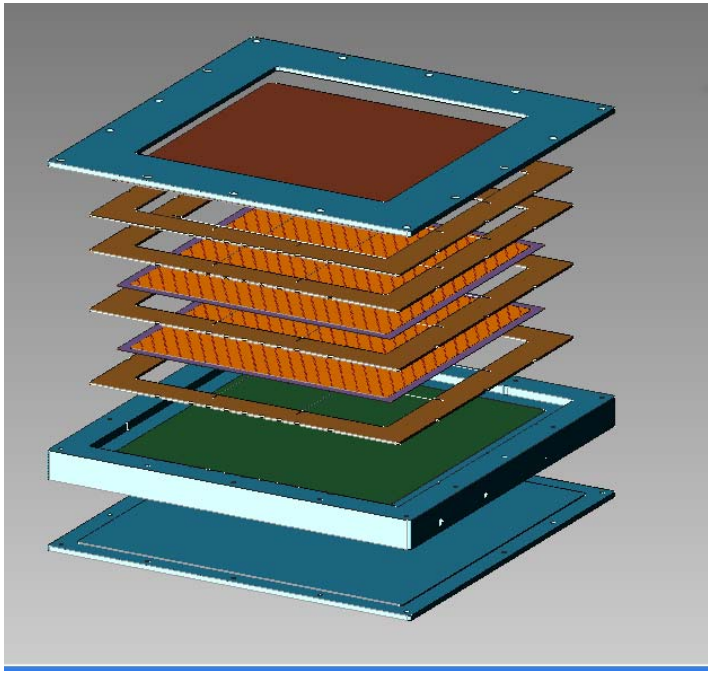
↓

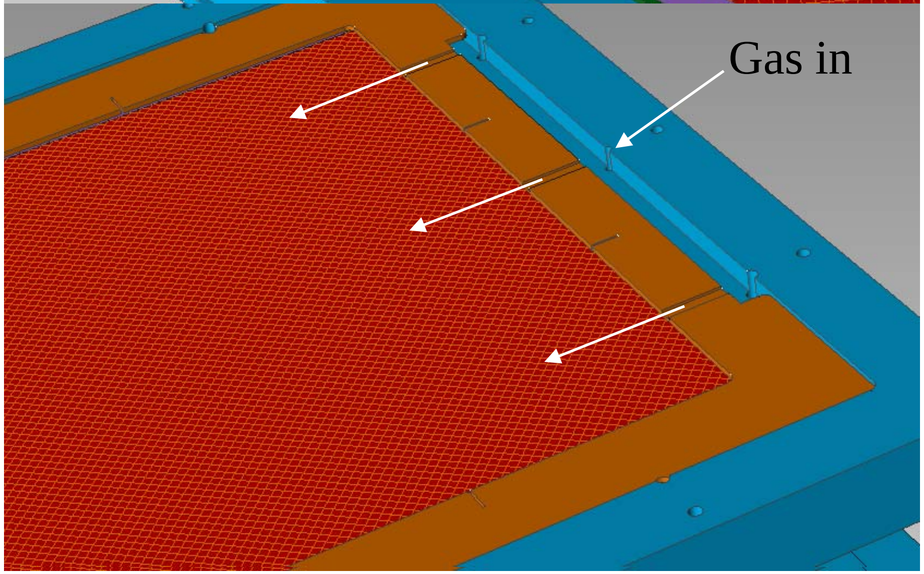
- **Production of first 1 meter GEM in April**

GEM prototype design









GEM/DHCAL – next steps

Current year goals:

– complete new 30cm x 30cm prototype + KPiX readout characterization (many features of KPiX understood)

- construct 1m x 33cm chamber using foils developed with CERN/RD51-MPGD.

- complete design/start assembly of 1m x 1m planes.

- planning inclusion/testing of multiple 1m x 1m layers in $1m^3$ stack

(3) Scintillator/SiPM technology (NIU)

Talk by Felix in this session

- CALICE 1m^3 prototype stack in 2-180 GeV/c test beams at CERN in 2006-8

  -> large samples of e- ,e+, π, p, μ events recorded

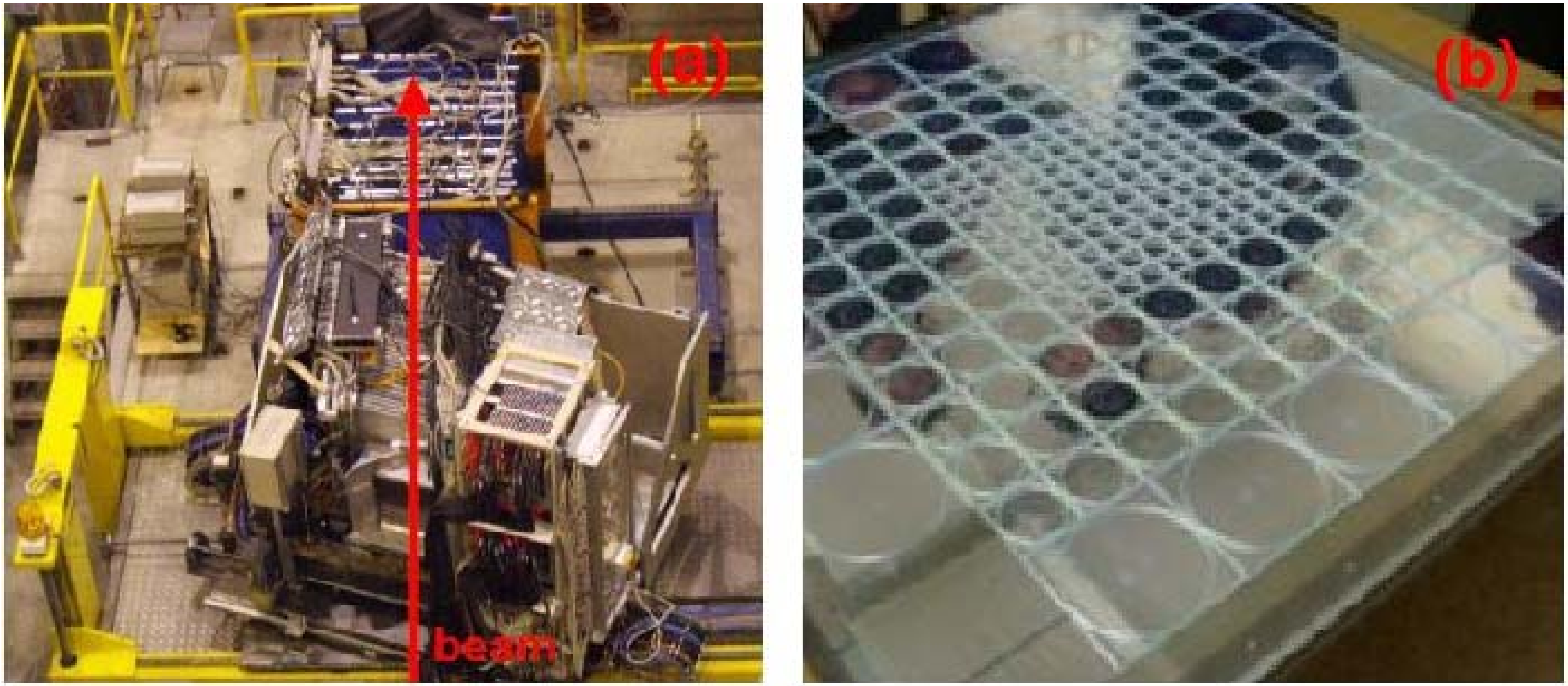
  -> analyses ongoing

- Development of integrated readout layer

- Direct coupling (SiPM/tile) studies

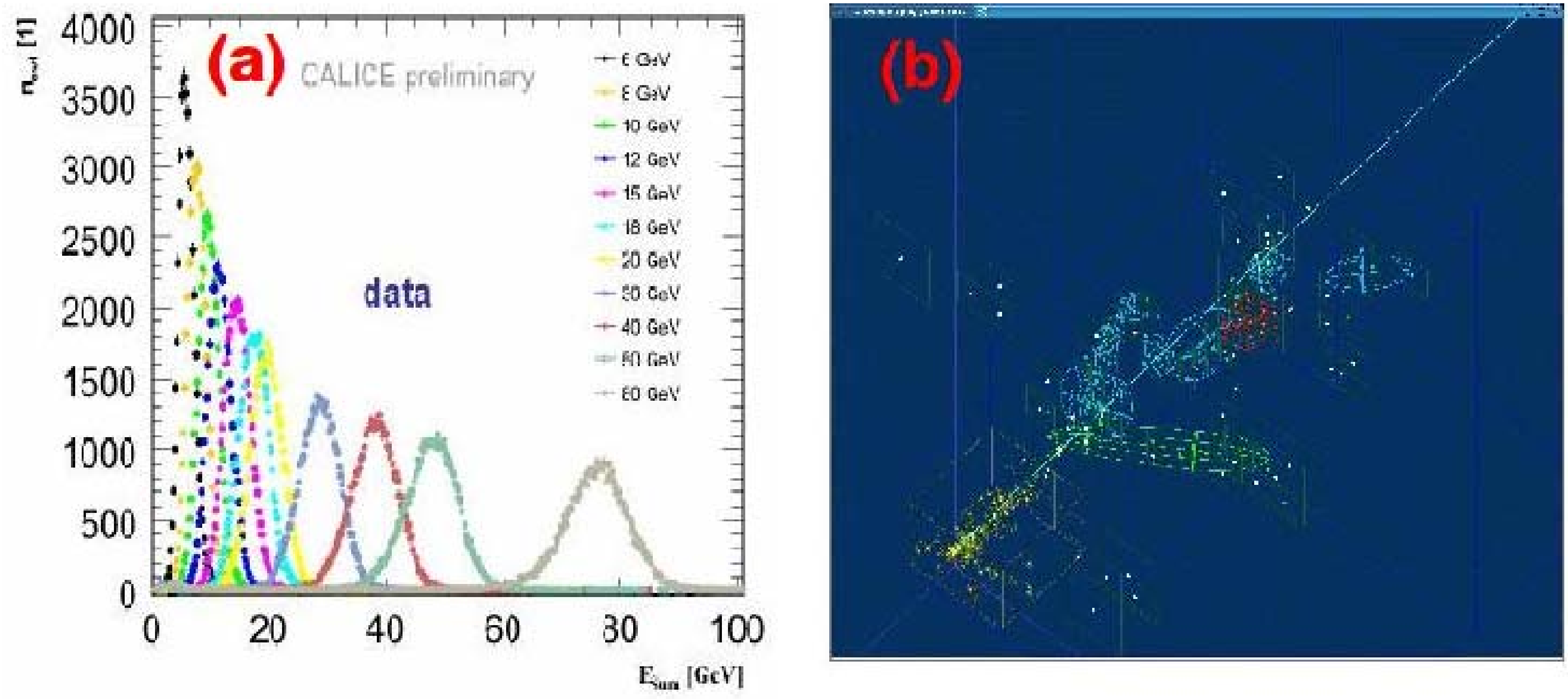
- EUDET/CALICE "technological" prototype – 2010 ->

CALICE testbeam setup at CERN + active layer

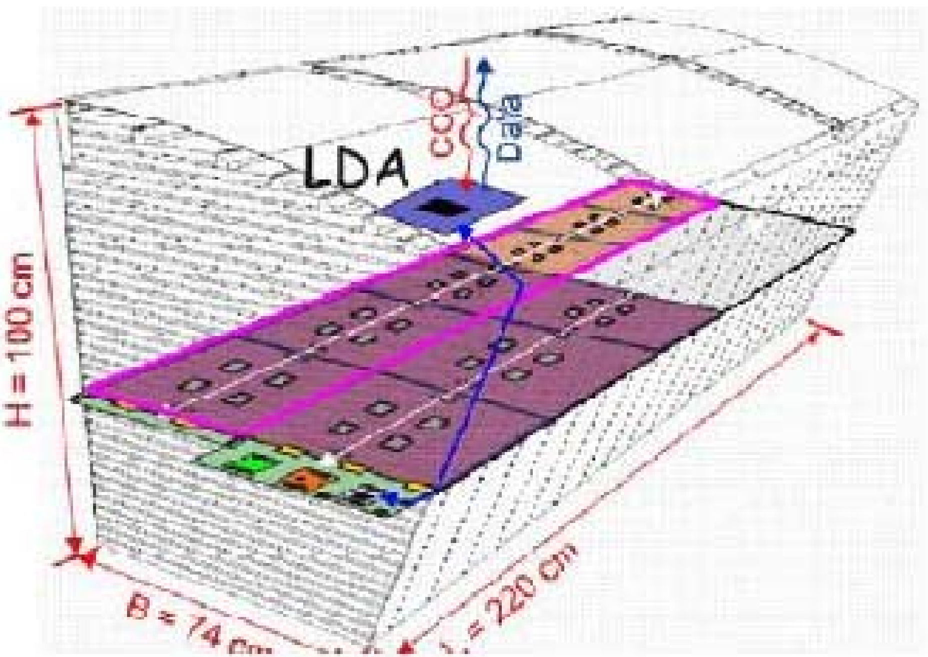


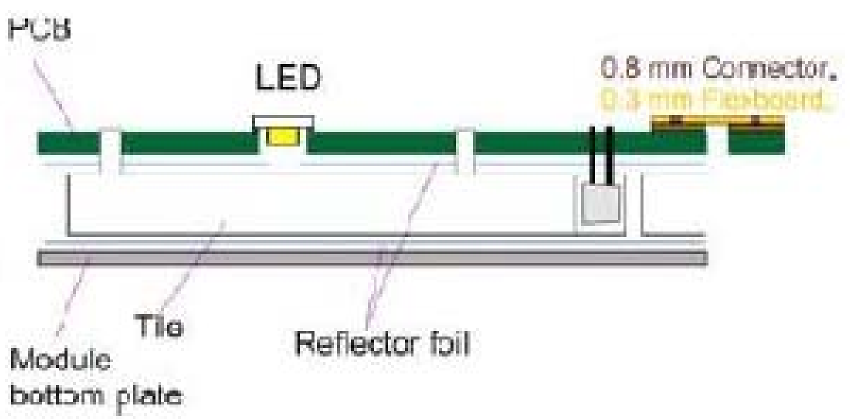
CALICE Calorimeter for ILC

Response of 1m^3 stack to charged pions and view of stack imaging abilities.

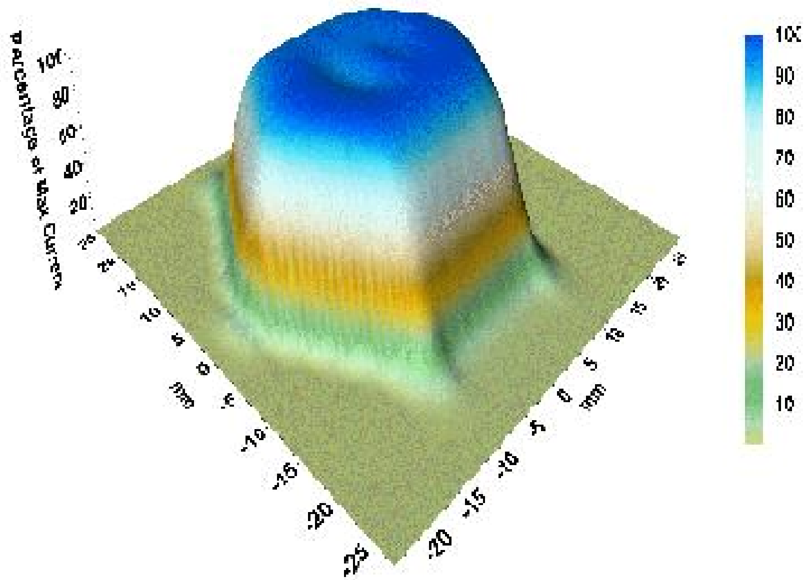


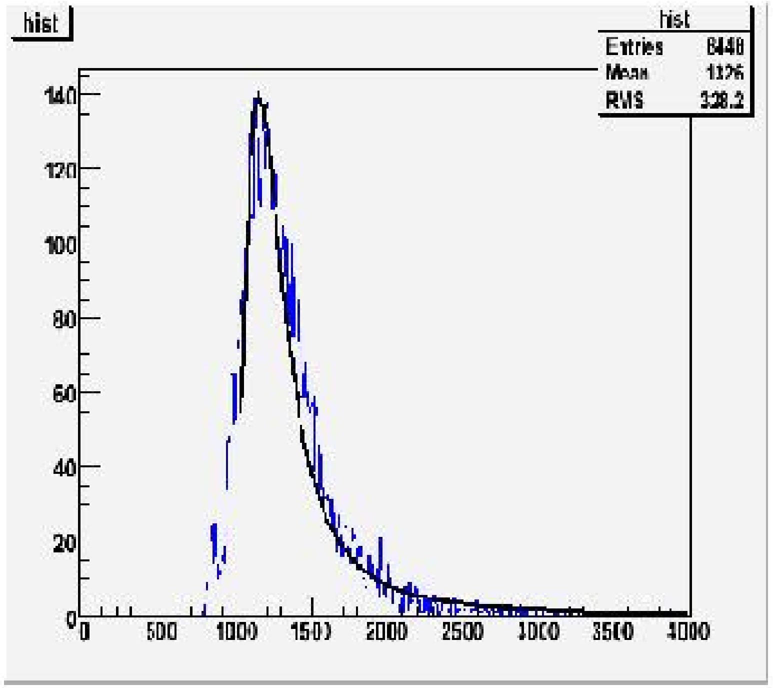
Schematic of barrel wedge with integrated readout





Response uniformity and muon response





(4) Homogeneous/Dual-readout technology

Talk by Adam Para tomorrow - via Webex

- Introduction – limitations on hadron energy resolution
- Elimination of limitations, use of correlation function
- Results of use of correlation function
- Enabling technologies (crystals and APD/SiPM)
- Conceptual design of HRC (High Resolution Calorimeter)
- Required R&D tasks

-> May offer a solution to obtaining good jet energy resolution at very high Ejet – where PFA can have problems.

Limitations of sampling calorimetry

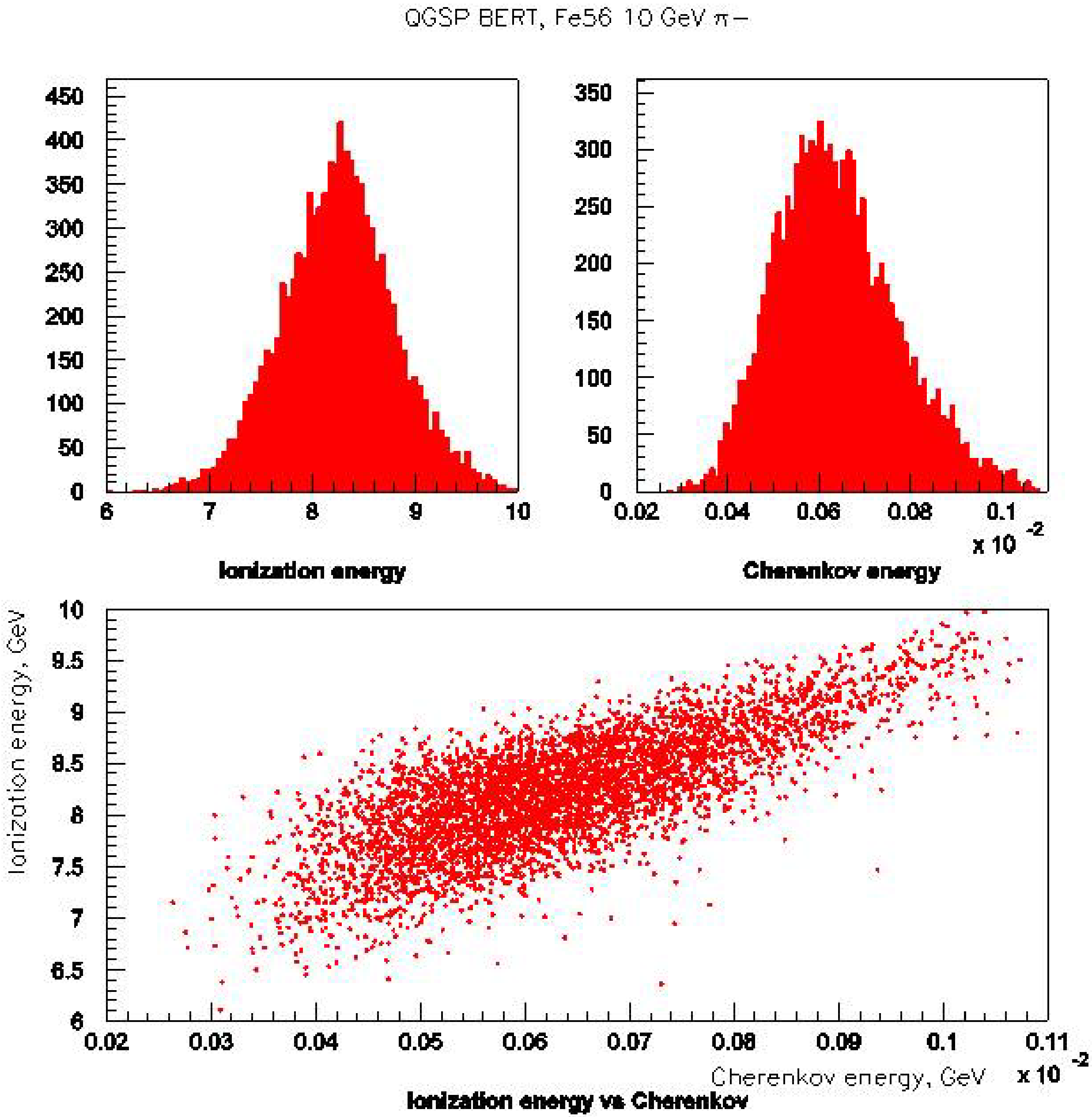
- Sampling fluctuations

- Nuclear binding energy losses
-> significant non-linearity of the response of the detector
-> difference of the response to neutral and charged pions

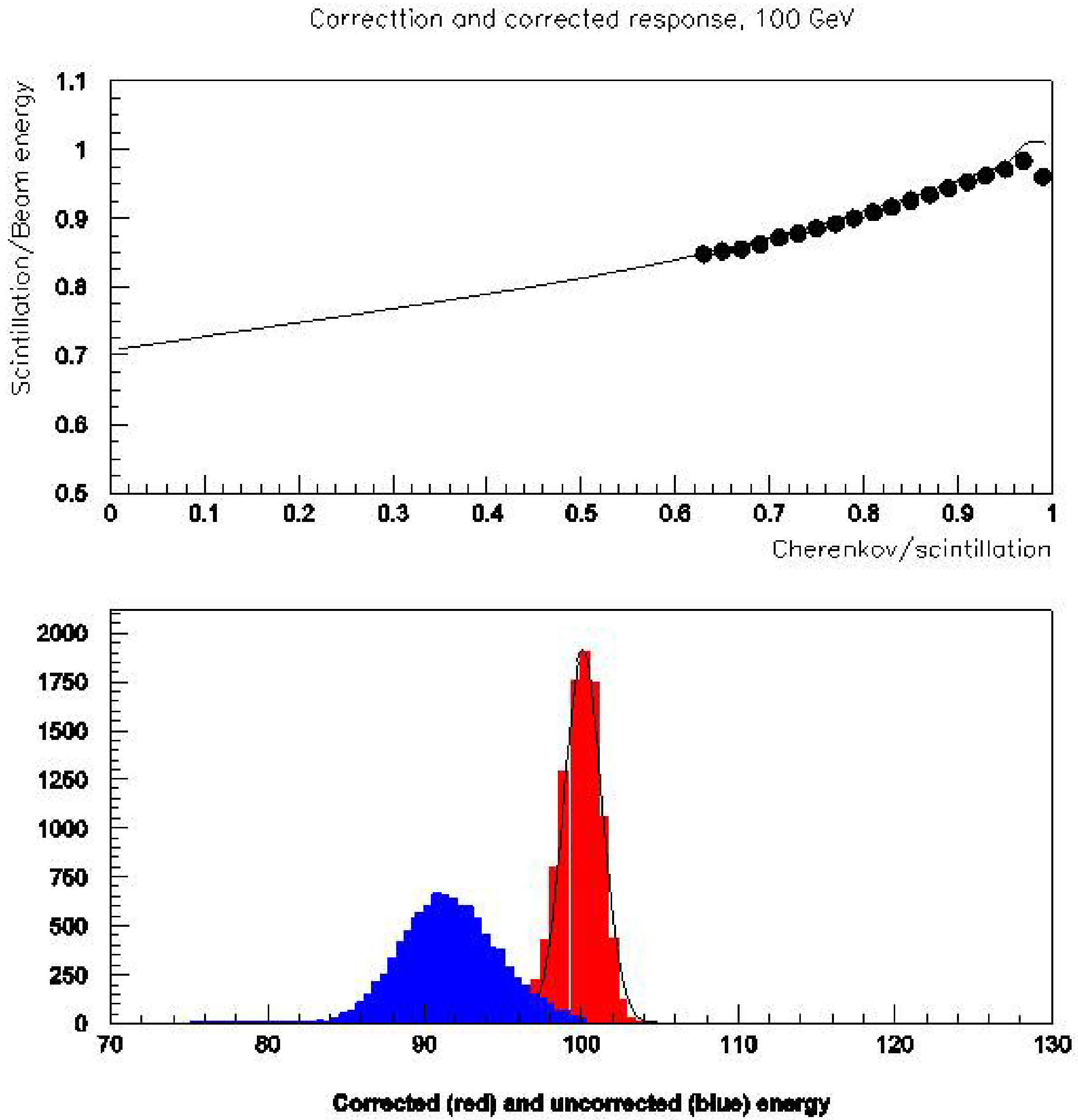
These are responsible for the dominant contribution to jet energy resolution, as the result of the fluctuations in the jet fragmentation.

Solution: a homogenous, totally active calorimeter with dual readout: scintillation and Cherenkov. Eliminates all contributions related to the sampling nature of the device whereas an anti-correlation between the scintillation and Cherenkov light can be used to reduce the fluctuations of the nuclear binding energy loss.

Total Ionization energy loss and Cherenkov signals and correlation



Dimensionless anti-correlation function and result of its use for 100 GeV pion in total absorption calorimeter



Plot average S/Ebeam as a function of C/S

- Fit some correction function F(C/S) (for example polynomial)
- Re-analyze the data:

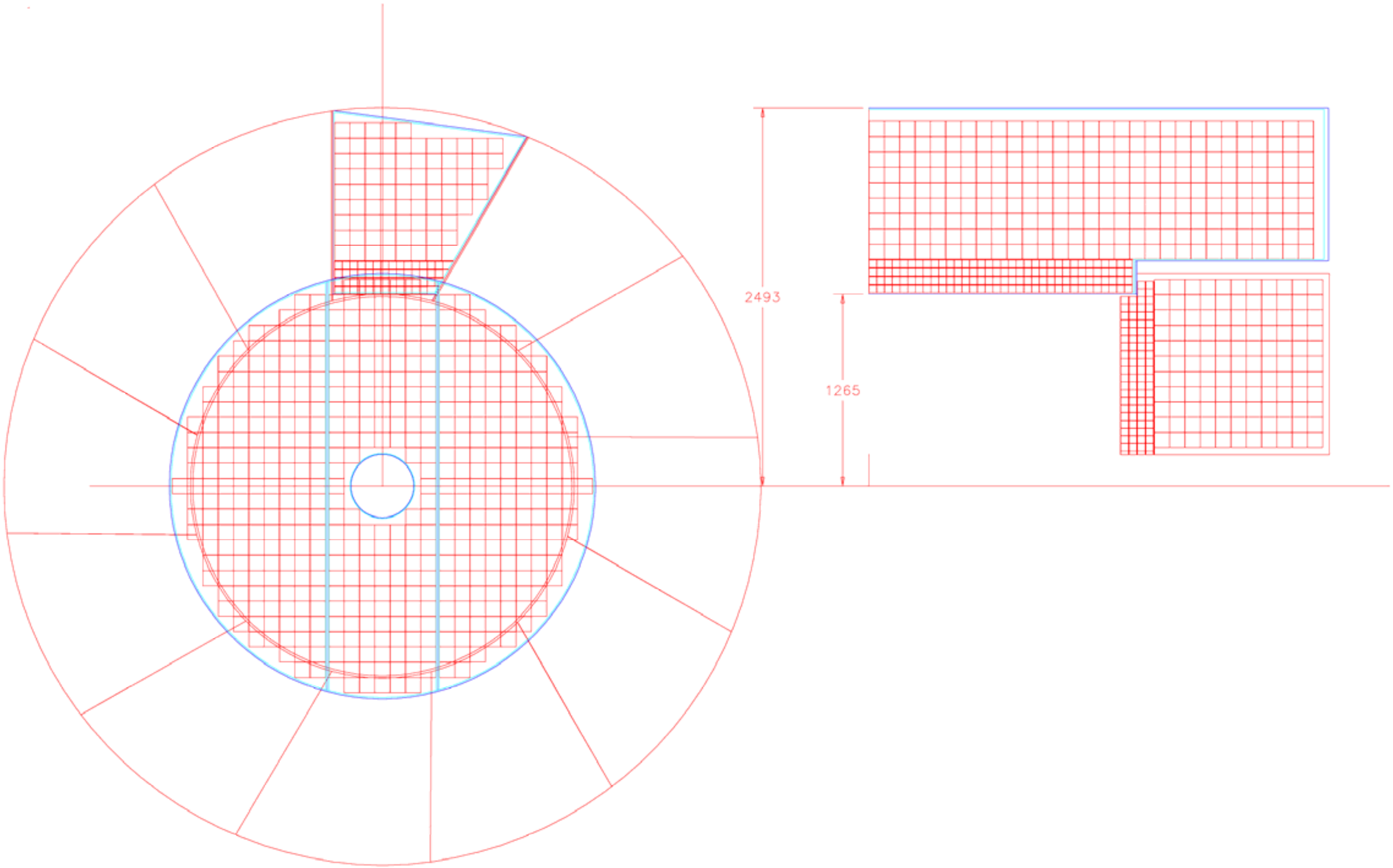
– E = Asc*S/F(C/S)

Homogenous Dual-Readout: R&D tasks

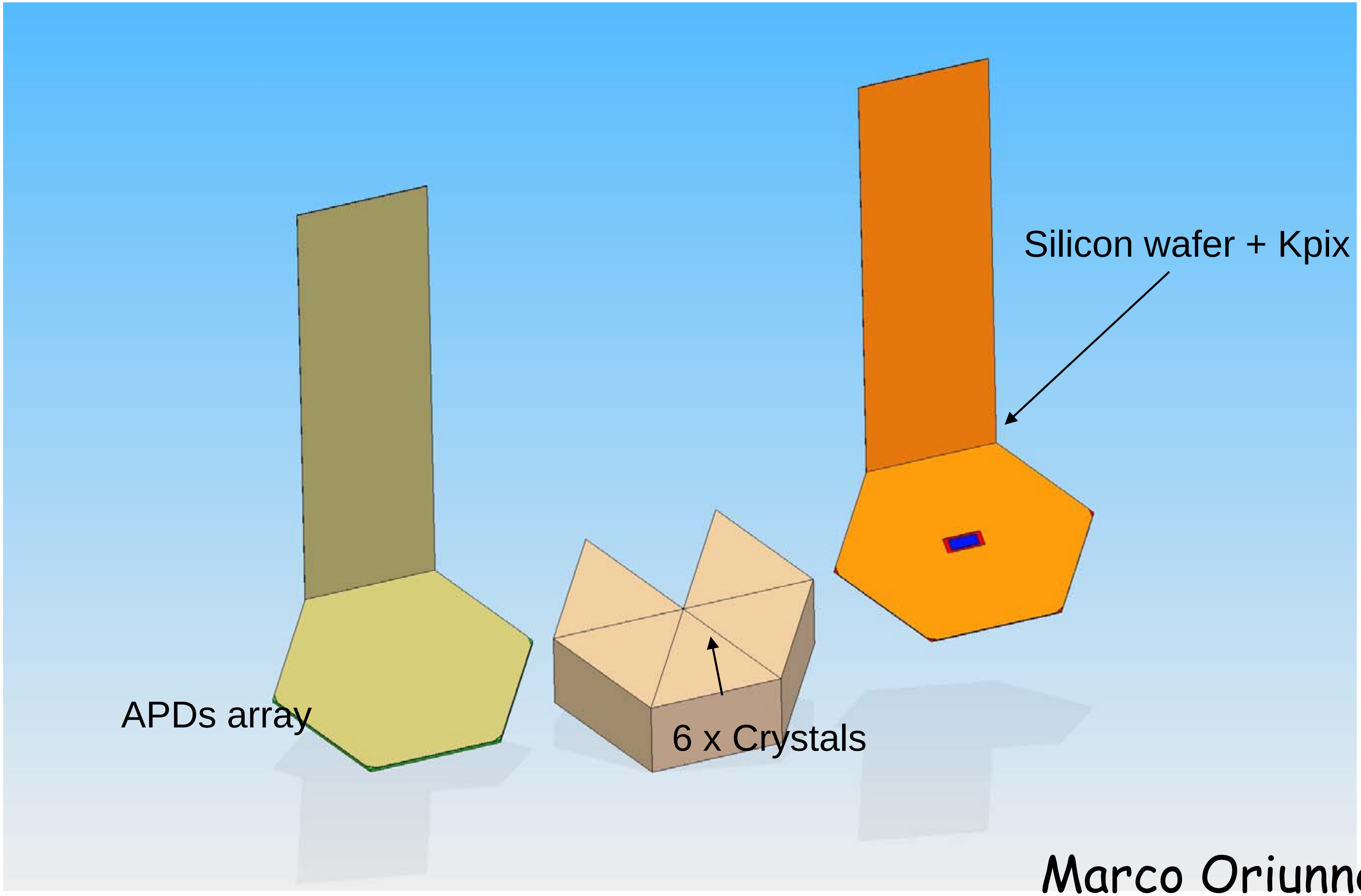
Five R&D tasks identified:

1) Demonstrate good linearity/energy resolution for hadrons in test beam
2) Optimize detector performance
3) Develop engineering design of detector/support
4) Development of novel, inexpensive optical materials
5) Development of compact photodetection system + electronics.

First draft engineering study - crystal calorimetry



Initial design ideas – dual readout



Marco Oriunno
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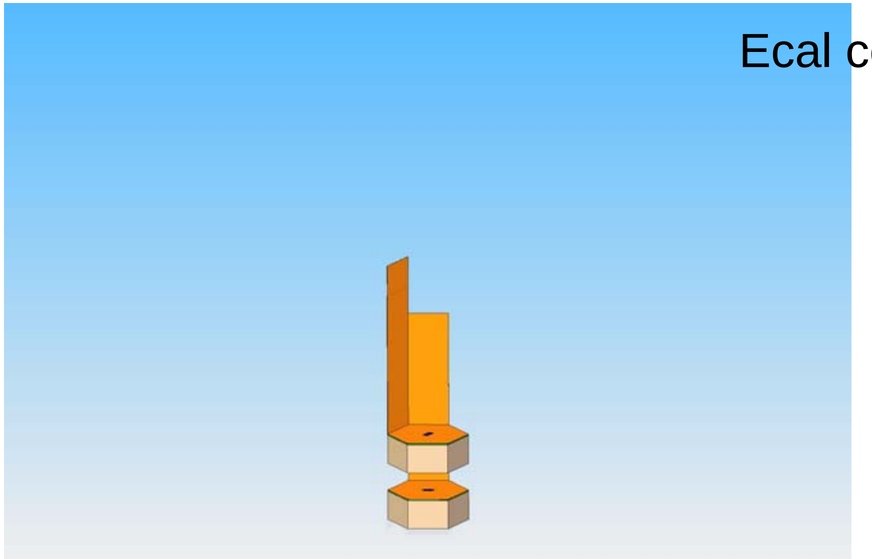
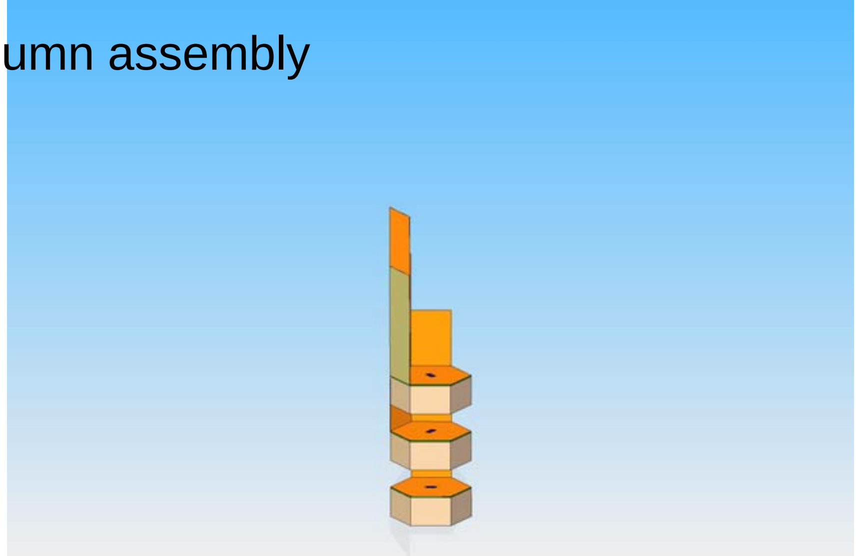
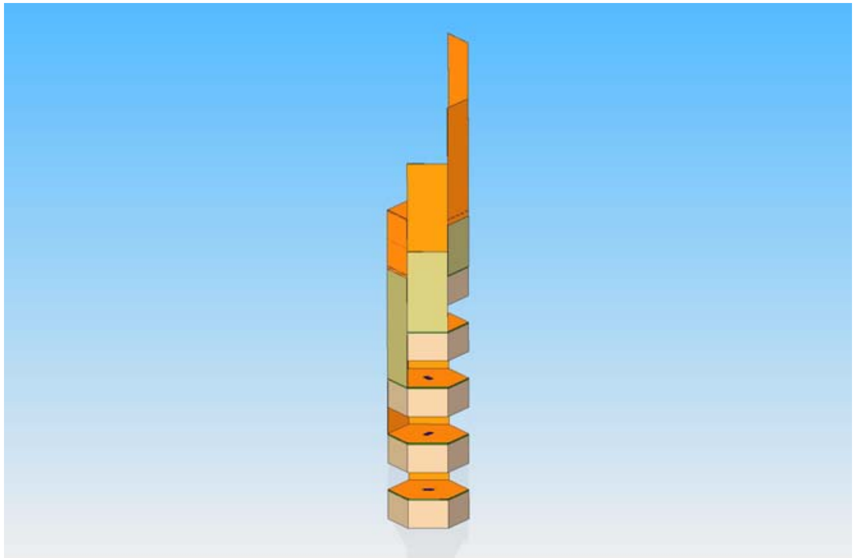
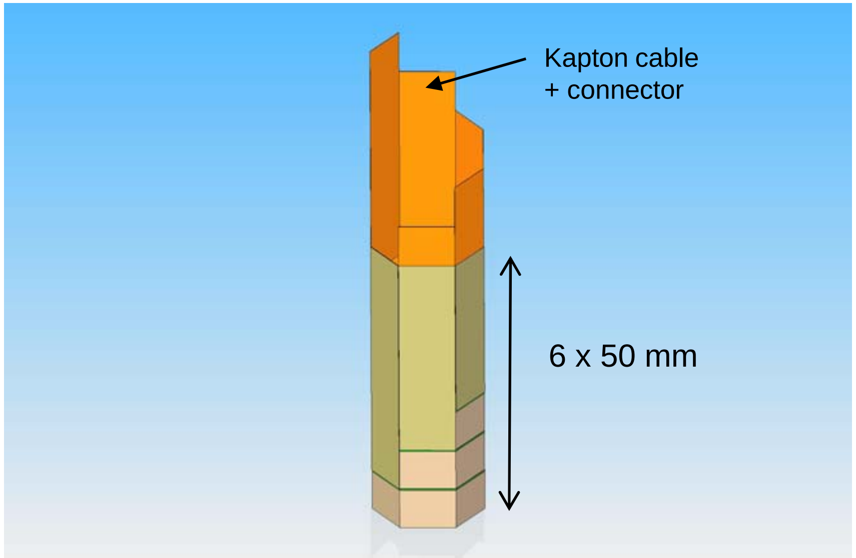
Ecal column assembly









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CONCLUSIONS

- SiD has a variety of Hadron Calorimeter options beyond the baseline RPC/PFA choice

- Several alternative ways to implement PFA-based calorimetry

- One more radical approach based on homogeneous crystal dual-readout calorimetry.

- Plenty of R&D still to be done!

- Aim for technology choice prior to TDR in 2012.

Extra slides

HCal Design Requirements

- Choice of absorber – physics benefits/engineering issues
- Tail-catcher vs. extra HCal depth
- Vary absorber thickness with depth?
- Number of modules lengthwise in barrel?
- Cracks – filled/not-filled
- B field? (Spreading out tracks/energy clusters)

HCal Technology Active Medium Selection Criteria

Performance criteria:
1) MIP Efficiency/pad
2) Hit multiplicity/MIP
3) Uniformity of response across active layers
4) Need for or ease of calibration
5) Recovery time after hit(s)
6) Recovery time after a "significant beam event"
7) Rate of discharges (gas)
8) Track-cluster separability
9) PFA jet resolution at a) Z-pole, b) 250, 500, 1000 GeV
10) Magnetic field issues – signal location offsets in barrel and endcaps (gas)
11) Response to neutrons

HCal Technology Selection Criteria

Technology issues:
1) Maturity and previous history
2) Reliability
3) Availability of components (in quantity)
4) Active layer thickness
5) Smallest readout unit size
6) Technical risk of approach
7) Ease of assembly/testing/installation/commissioning (often referred to as “scalability”).
8) Effects of aging on performance

Cost:
1) Overall HCal cost
2) Active layer cost as a percentage of total cost
3) System development costs
4) Costs for assembly and test

Linearity, energy resolution, scaled energy resolution for hadronic jets