Hadron Calorimeter Status
(Design, Engineering, R&D, Issues)

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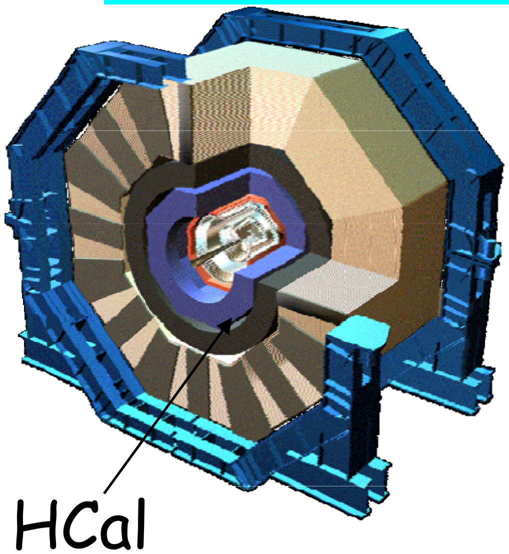
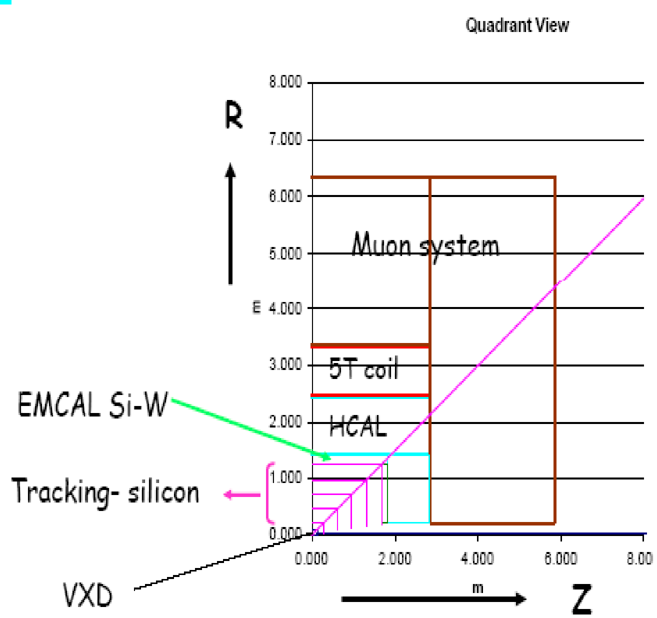
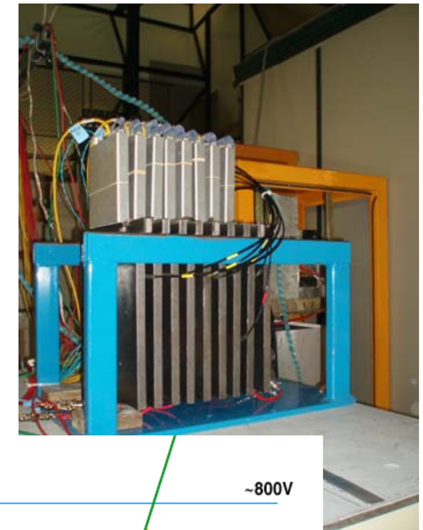
SiD-Paris

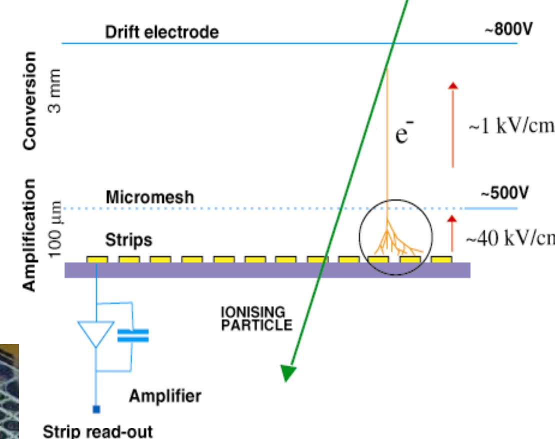
February 11, 2008

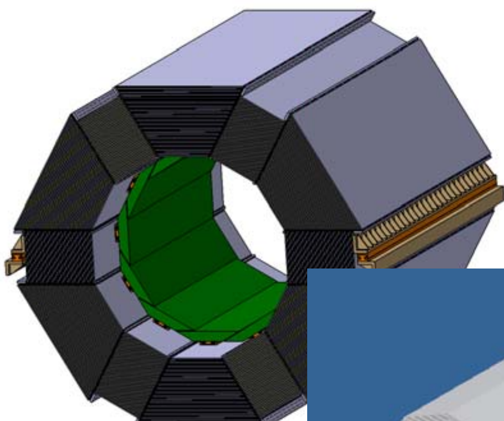
SiD HCal

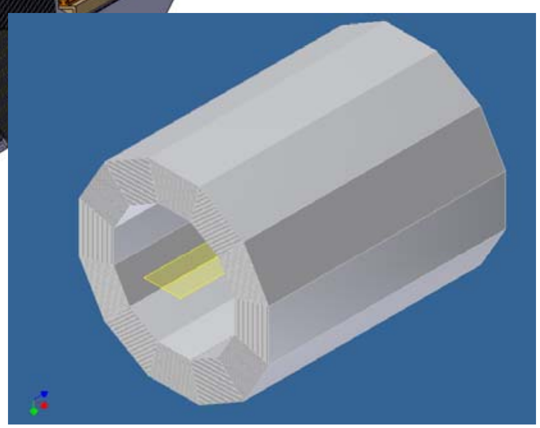

HCal

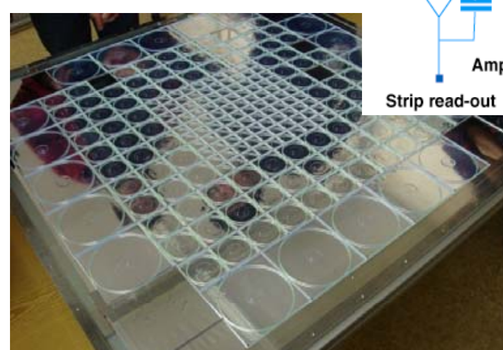

Quadrant View
R
8.000
7.000
6.000
5.000
4.000
3.000
2.000
1.000
0.000
m
Muon system
5T coil
HCAL
EMCAL Si-W
Tracking- silicon
VXD
0.000
2.000
4.000
6.000
8.00
m
Z

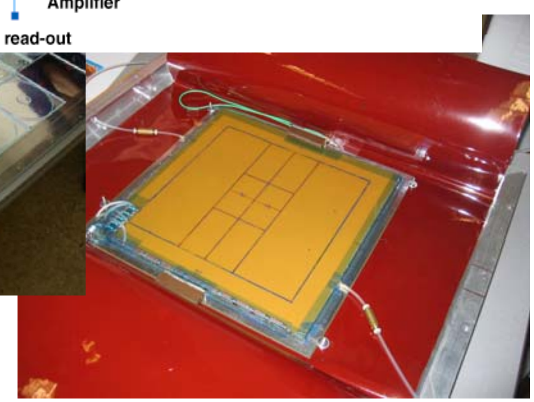



Drift electrode
~800V
Conversion
3 mm
e^-
~1 kV/cm
Micromesh
~500V
Amplification
100 µm
Strips
~40 kV/cm
IONISING PARTICLE
Amplifier
Strip read-out







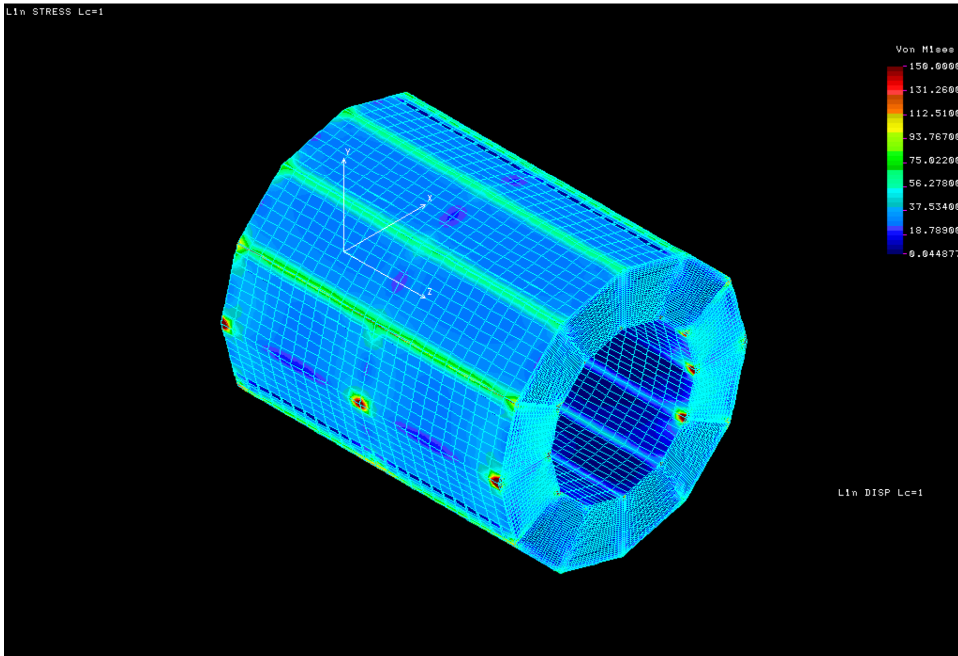


HCal Design Requirements

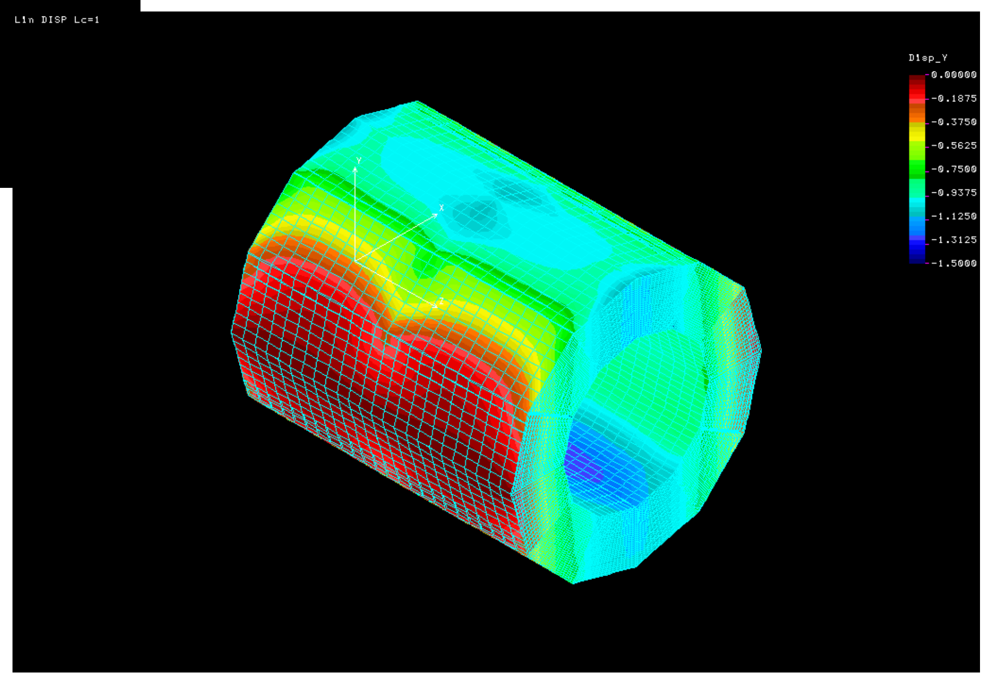
- It must efficiently allow tracking of charged particles through its volume.
- It must have sufficient depth such that any energy loss in the coil, and/or energy measured with degraded resolution (relative to the HCal) in the outer detectors (such as a TCMT) does not significantly impact jet energy resolutions at all jet energies.
- It must have a sufficiently small cell size to allow true separation and association of closely spaced energy clusters with the correct tracks – at a level that does not significantly degrade the jet energy resolution.
- It must have a sufficient sampling so as not to significantly degrade the jet energy resolution via the sampling term.
- Its outer radius must limit the cost of the solenoid and muon system to reasonable levels – requiring the radial size of each active layer to be as small as possible.
- It must have sufficient rate capability so as not to lose information, particularly in the forward directions – using a change of technology, if necessary.

From SiD HCal Design document, March 2007

SiD HCal Engineering Design



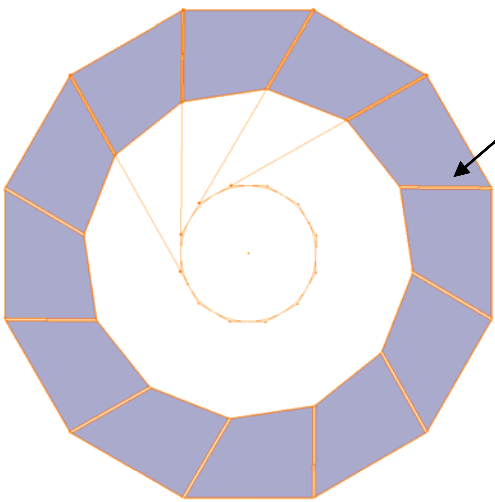
Vic Guarino ANL



Engineering - Kurt Krempetz

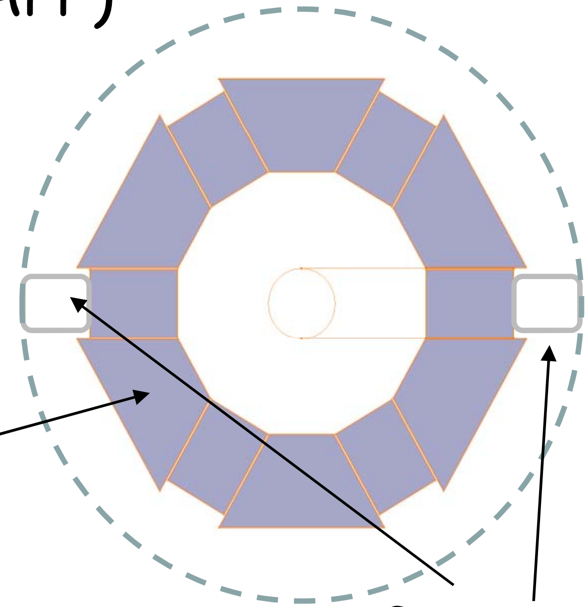
SiD HCal Engineering Design

Design work by Nicolas Geffroy (LAPP)



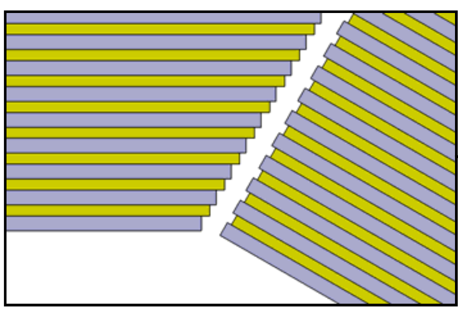
Non-projective cracks

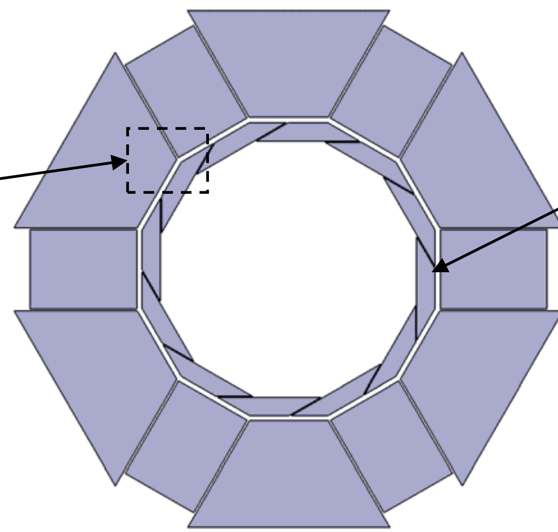
OR



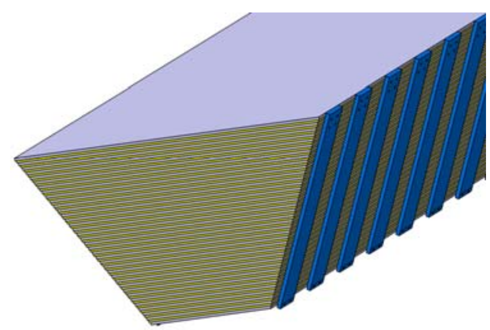
Rectangles/trapezoids

Supports





Easy ECal integration



Next: FEA on structure(s)

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

SiD HCal – Technology Options

(A) Gas-based

- RPC digital
- GEM digital or analog
- MicroMegas

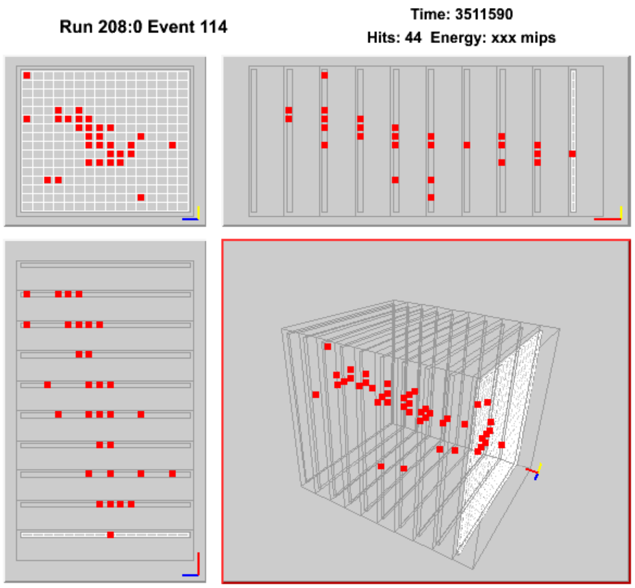
(B) Scintillator

- Analog or semi-digital

(C) Dual readout (see Adam Para's talk at SiD/SLAC January Workshop)

HCal Technology - RPC

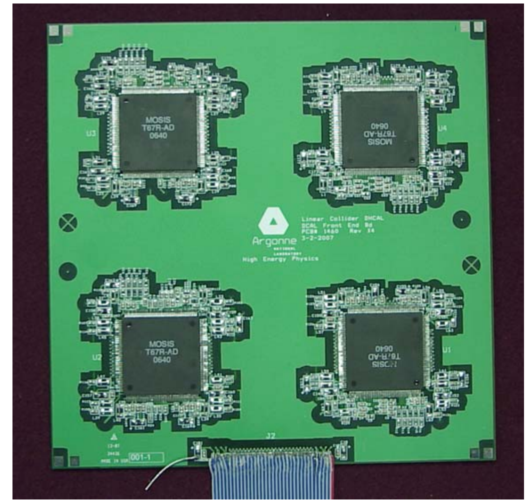
Status and Plans of the RPC-DHCAL Project



José Repond
Argonne National Laboratory

SLAC SiD Meeting, SLAC, January 28 – 30, 2008

Quick overview of the project



Active medium

Resistive Plate Chambers operated in avalanche mode

Electronic readout

Based on DCAL chip (64 channel, digital readout)

Complete readout chain contains
- **Pad- and Front-end boards**
- **Data concentrators**
- **Data collectors**
- **Timing and trigger modules**

Prototypes

Assembled 9 – layer calorimeter with 2304 readout channel
Plan to build 1 m^3 physics prototype with 400,000 channels

Measurements

Cosmic Rays
Particle beams at FNAL → Vertical Slice Test
Noise rates
Charge injection
Long-term studies

Recent activities II: R&D in preparation of construction

- **Development of simplified pad- and front-end boards**

  Previous boards

  4 and 8 layer boards with blind vias
  ~$1000/board

  New boards

  2/4 and 8 layer boards without blind vias
  ~$100/board
  Boards in hand

If successful might incorporate Data Concentrator on Front-end board

Final design needs final DCAI chips

- **Larger RPCs for prototype section**

  Previous chambers

  Used in Vertical Slice Test
  20 x 20 cm^2

  Production chambers

  32 x 96 cm^2
  Glass samples in hand
  Channels to be delivered in 2 weeks

Absolute last developments before construction

Recent activities III: Analysis of Muon Data

Two independent analyses

a) Track segment based

Can be applied to hadronic showers

b) Track reconstruction based

→ Results from both very consistent

Data sample

- Two different RPC designs

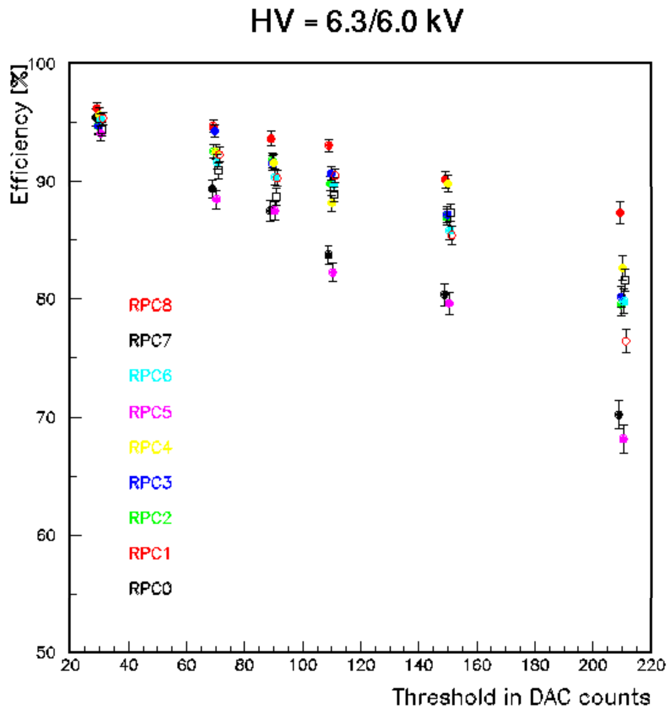
Default (2-glass)
Exotic (1-glass)

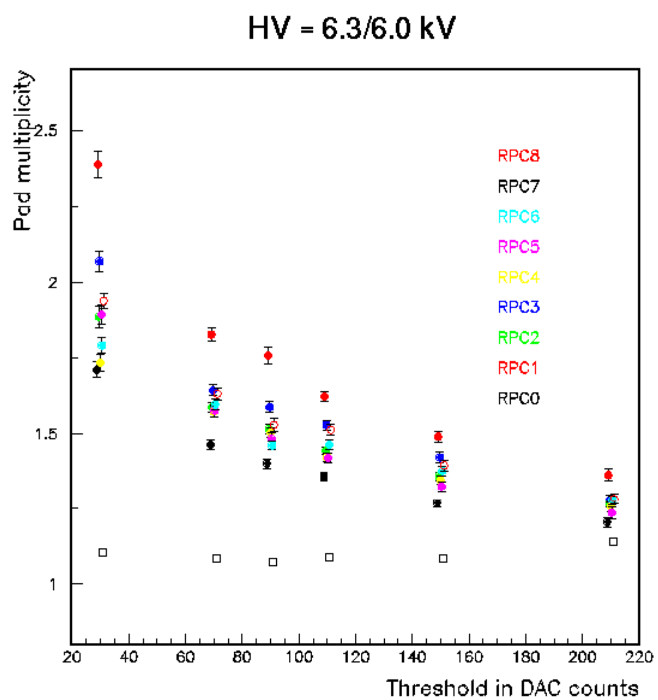
- Various High Voltage settings
- Various Threshold settings

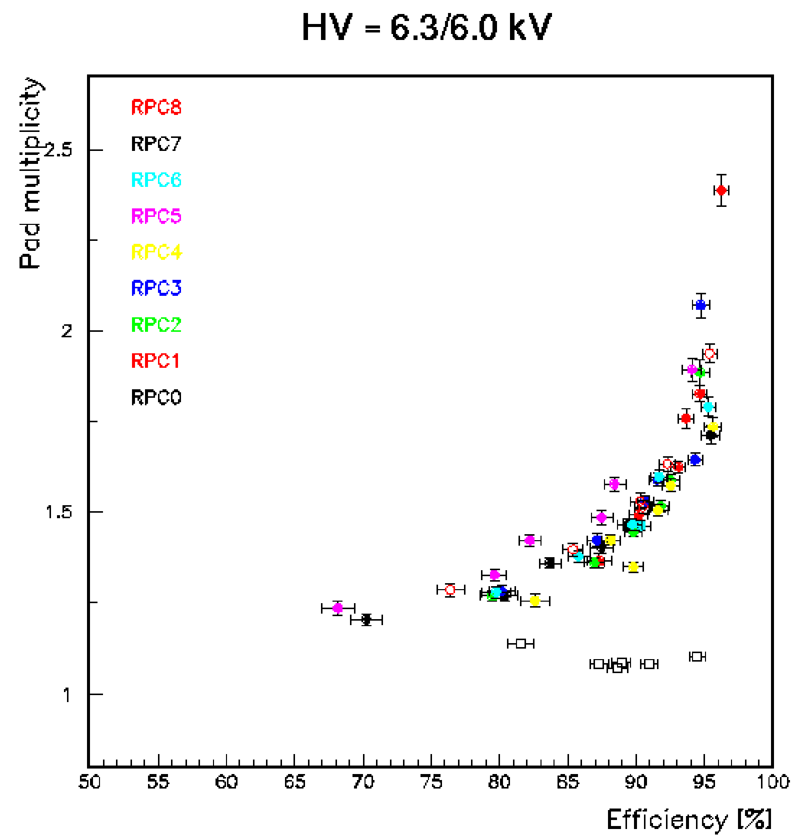
→ About 5,000 – 10,000 events/setting

Number of chambers in the stack	**High Voltage in kV**	**Threshold in DAC counts**
8	6.2/5.9	30
		50
		70
9	6.3/6.0	30
		70
		110
		150
		210
7	6.4/5.8	30
		50
		70
		110
		150
		190
		210
8	6.5/6/2	30
		120
		210

Example – Results at 6.3/6.0 kV







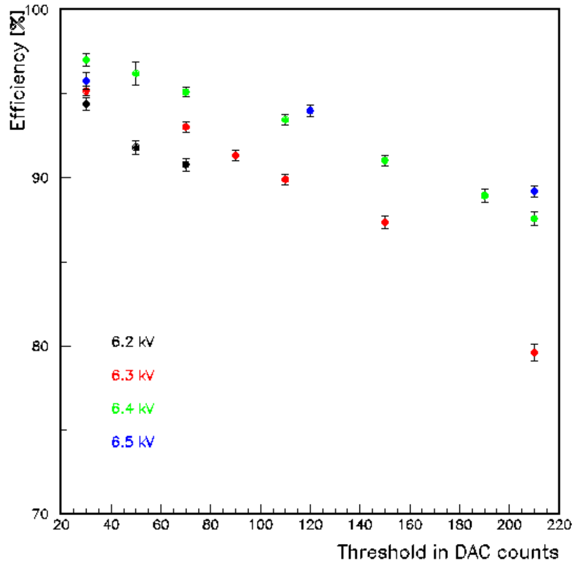
RPC5 – Has lower efficiency (← grounding problem)
RPC1 – Needs lower HV
RPC0 – Needs higher HV
RPC7 – Exotic design

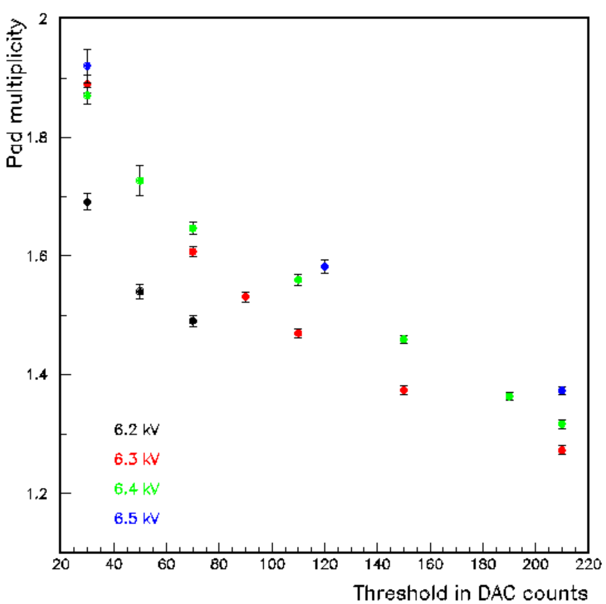
Combined results

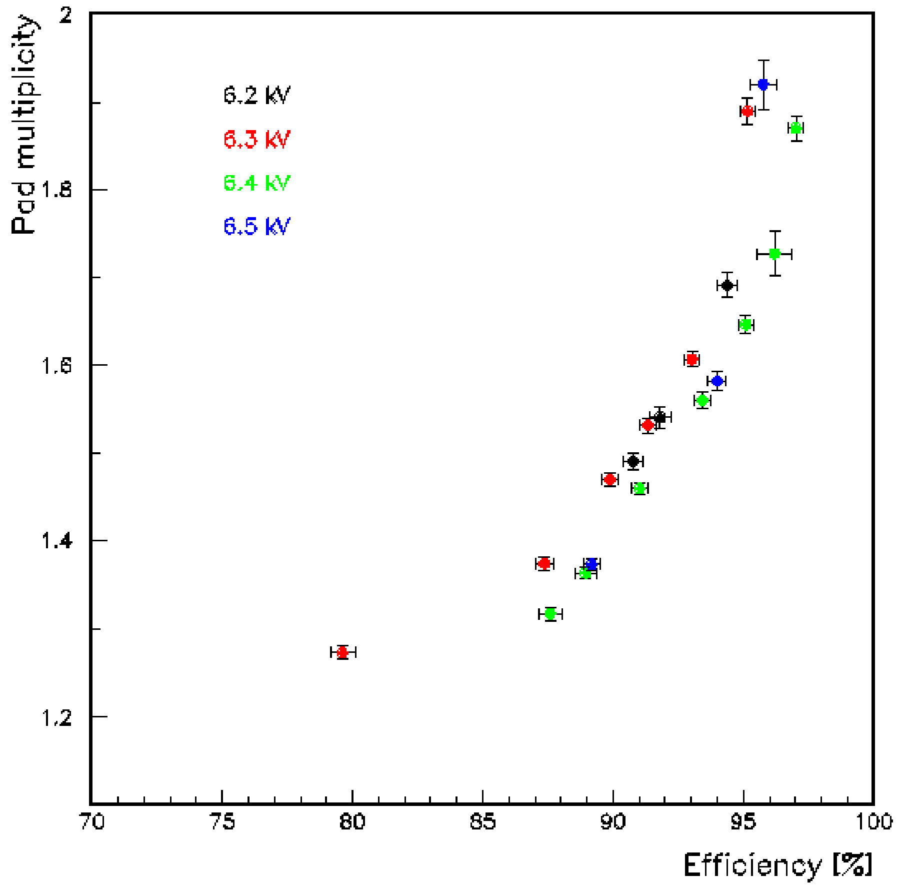
Excluded RPC0 – Not working properly
RPC1 – Needs lower HV
RPC5 – Has lower efficiency
RPC6 – Needs higher HV
RPC7 – Not working properly

→ left with RPC 2,3,4,8

All problems later traced back to unfortunate grounding scheme



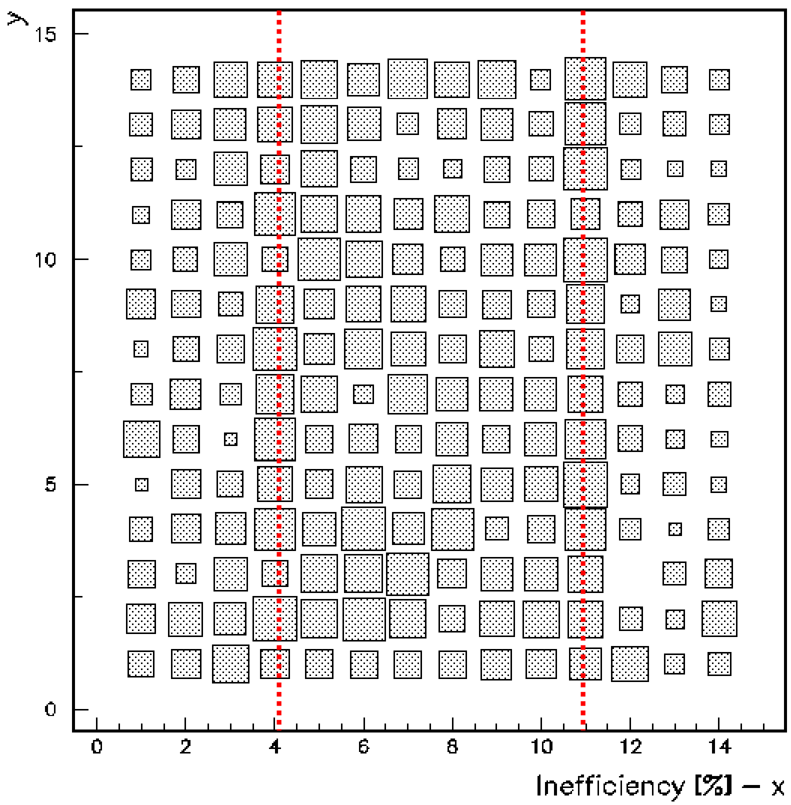


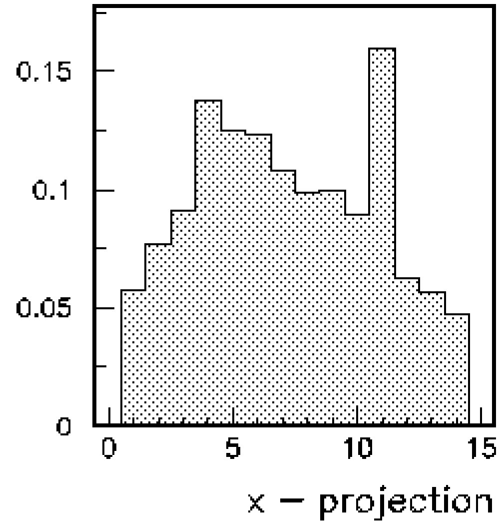


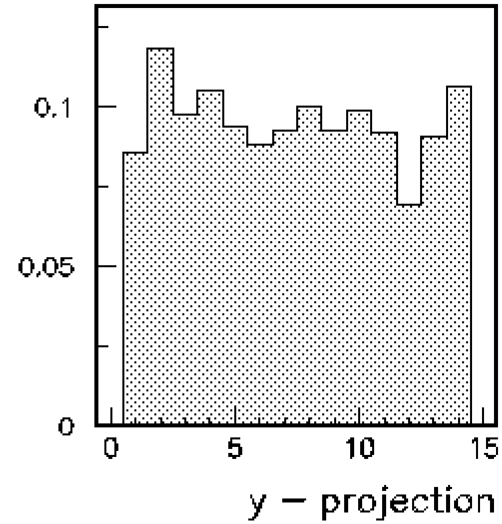
Inefficiency

$\not\varepsilon = N(M=0)/N_{Total}$

All clean Chambers







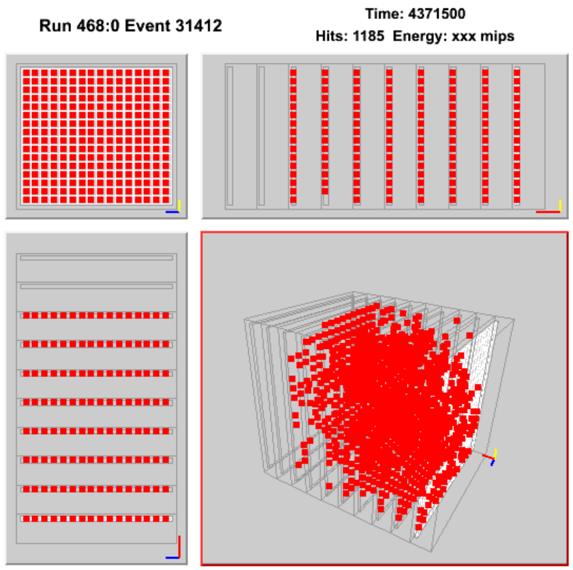
Clear evidence for loss of efficiency around fishing lines

Draft paper written for Muon Calibration

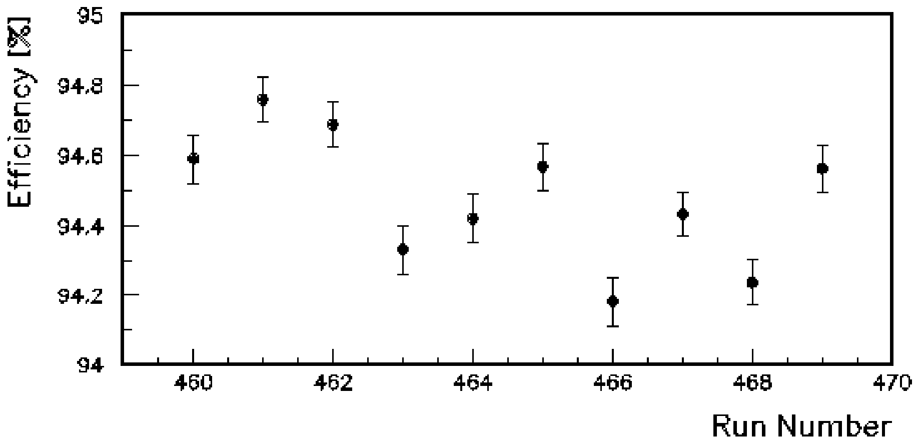
-> submission in 2 weeks!

Recent activities IV: Cosmic Ray Data

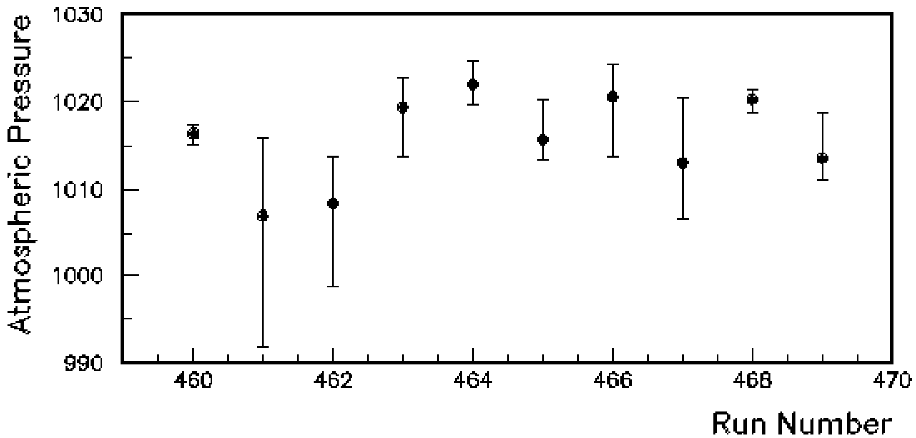
Run Number	# of events	Empty events	Out of time	More than 1000 hits	Dead cells
460	32539	2939	49	1	12
461	39633	3787	208	0	11
462	37602	3338	13	0	11
463	34473	3191	21	0	11
464	34365	3059	52	0	11
465	35398	3192	54	0	11
466	31253	2885	56	0	11
467	38744	3426	32	0	11
468	35495	3190	21	1	11
469	35731	3172	12	0	11
Total	**355233**	**32179**	**518**	**2**	**11**



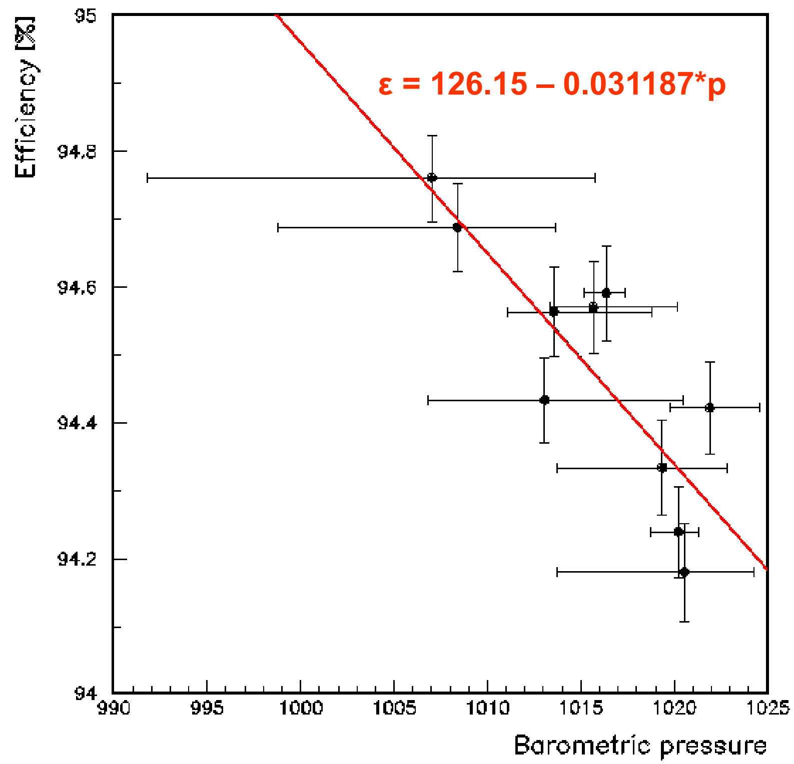
Average over all non-exotic chambers



Higher pressure → lower efficiency



Error bars on pressure show range



$\Delta\varepsilon/\varepsilon = -0.34\ \Delta p/p$

Error bars on pressure set to 0 for fit

Recent activities V: Analysis of Positron Data

Two independent analyses

a) Study of energy response
b) Study of longitudinal development

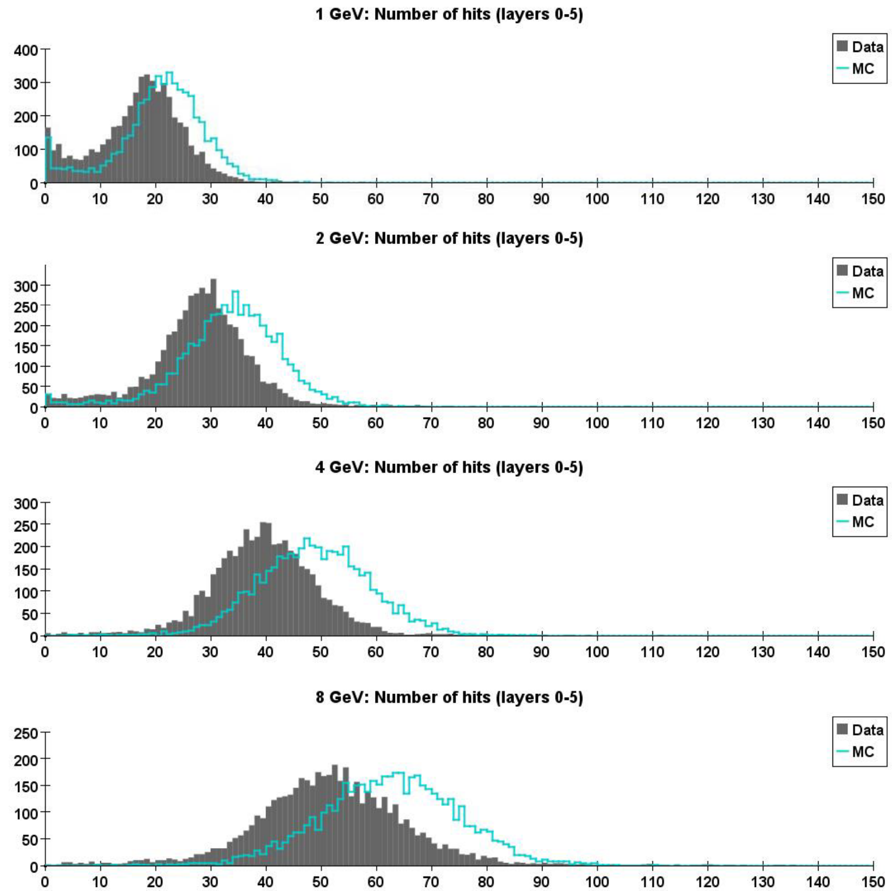
→ Results still very preliminary

Data sample

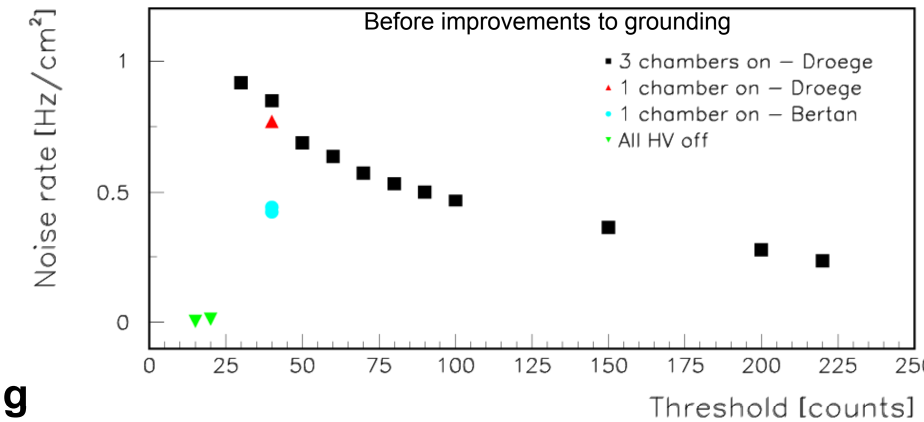
- Data at 1, 2, 4, 8, and 16 GeV

Monte Carlo simulation

- Needs calibration constants from μ-runs
- Needs careful implementation of pad multiplcities
- Current comparison based on assumptions and ignoring details



Recent activities VI: Measurement of Noise Rates



Uses self-triggered mode of DCAL chip

Correction of x2 for data loss

Noise rate very low! With new grounding

Typically 20 – 30 Hz/chamber at a threshold of 30 (default is 110)
Two chambers somewhat noisy (100, 500 Hz/chamber)

→ Probability of a noise hit in 1 m^3 stack P ~ 10^{-2}/event

Environmental impact

Noise rate depends on gas flow (accident!)
Noise rate (might) depend(s) on p,T,H
→ Needs detailed studies, will acquire weather station

RPCs are very quiet

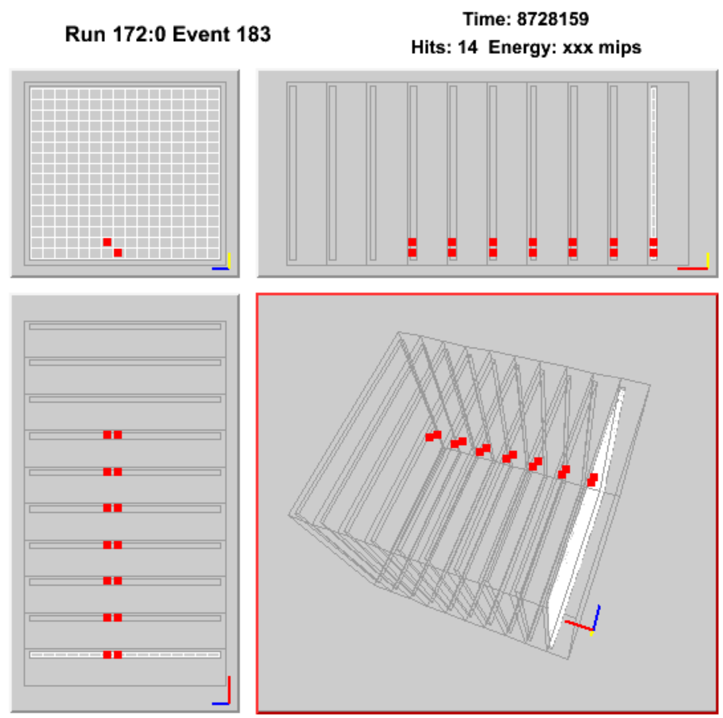
Summary of status

Vertical Slice Test

Was very successful
Proves concept of DHCAL with RPCs
Validates entire electronic readout chain
Several publications in the next few months

Further developments since VST

New Pad- and Front-end board designs
Study of error modes (almost complete)
Detailed long-term studies (ongoing)



Two μ's separated by 1.4 cm

We are ready for the construction of the 1 m^3 physics prototype

Plans

Under all circumstances

Will complete ongoing studies
Will publish results from Vertical Slice Test

Assuming availability of funds

Will complete changes to DCAL chip and will produce chips
Will start assembly of large chambers
Will complete design of integrated Front-end boards and Data Concentrators
Will produce entire readout system

→ ready for test beams in early 2009

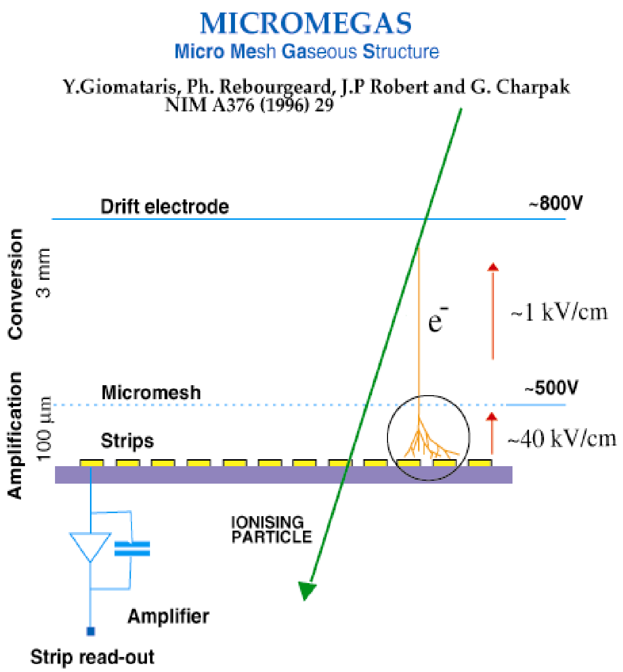
Assuming some funds are available

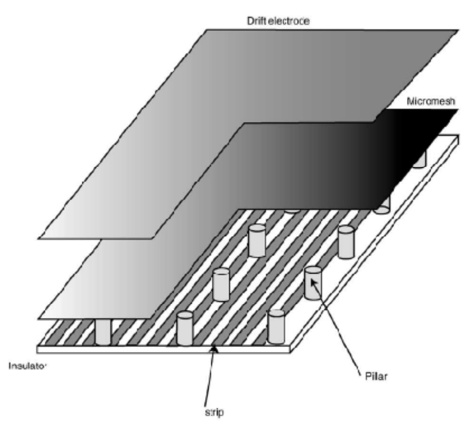
Will consider additional iteration of DCAL chip (larger range of Q_{inj})
Will complete design around new DCAL chip and perform all necesssary tests

Assuming no funds available

Will consider returning to FNAL test beam with ‘perfect’ system
Will look for other things to do…

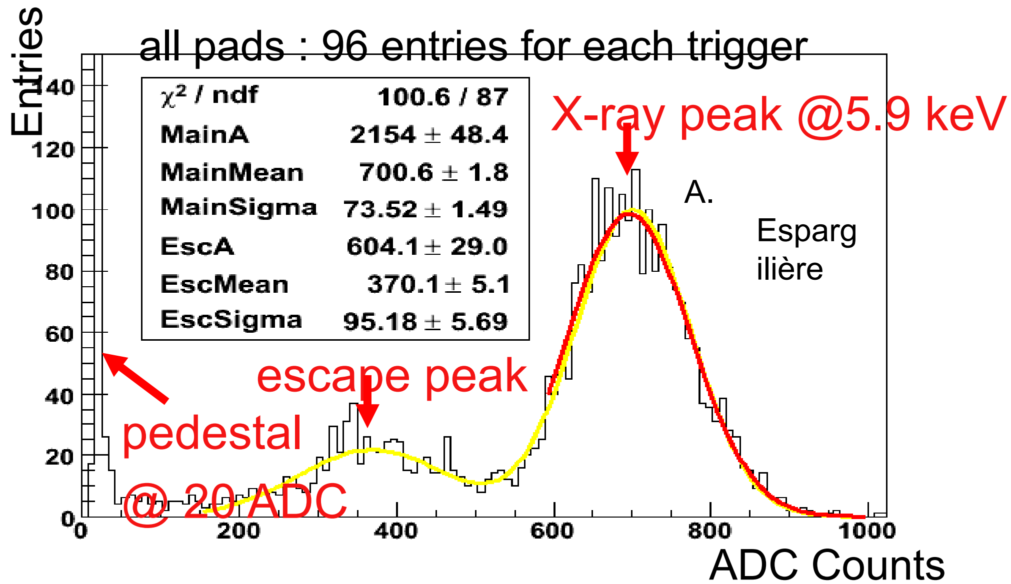
HCal Technology R&D - MicroMegas





- The chamber
  - **95% Argon, 5% Isobutane**
  - **conversion volume (3mm)**
  - **a top in Stainless Steel with a cathode drift**
- The Readout
  - **Gassiplex card : 6 gassiplex chips -96 channels**
    Electronics card built for CAST by DAPNIA (P. Colas, Philippe Abbon)
  - **VME sequencer and ADC from CAEN**
  - **CENTAURE acquisition (SUBATECH, Nantes, D.Roy)**
- PCB and bulk from CERN (*Rui de Oliveira*)
  - **325 LPI mesh**
  - **spacers : 120 µm height**
    300 µm diameter

HCal Technology R&D - MicroMegas



Gassiplex Readout :

Peak = 680 ADC cnts

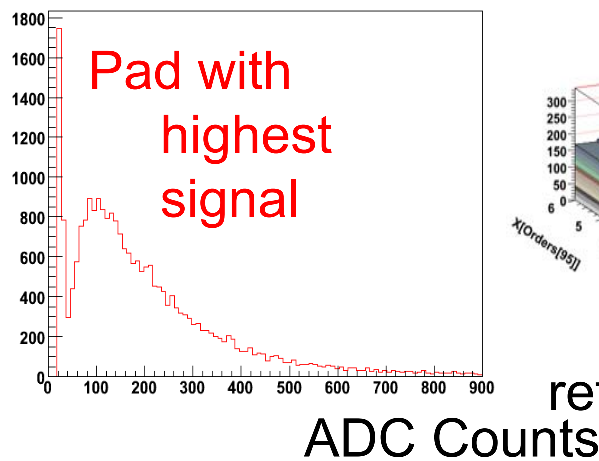
= 996 mV

≈ 277 fC

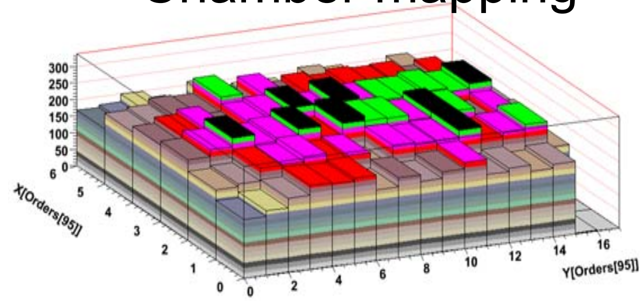
⇒ Gain ≈7600

FWHM = 25.5%

Cosmics



Chamber mapping



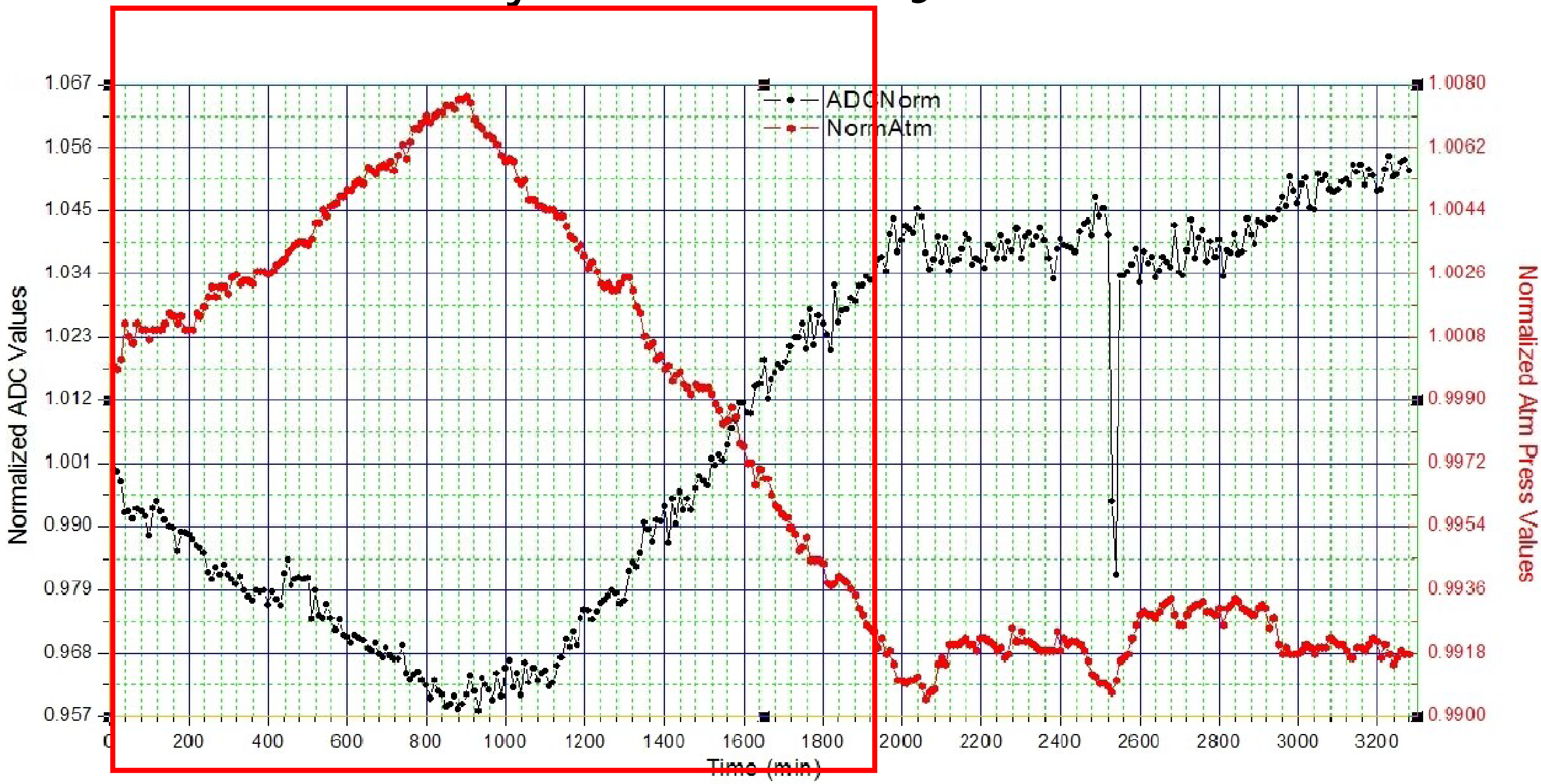
reflects scintillators geometry?

Charge ≈ 80(1500mV)/1024/3.6(mV/fC) = 32 fC

HCal Technology R&D - MicroMegas

X-ray Results

- Time Stability

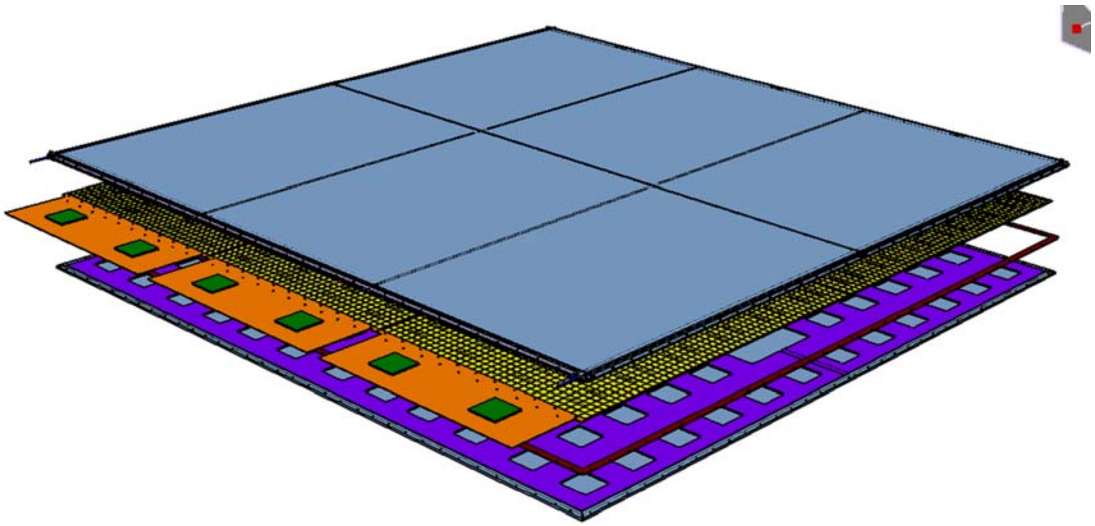


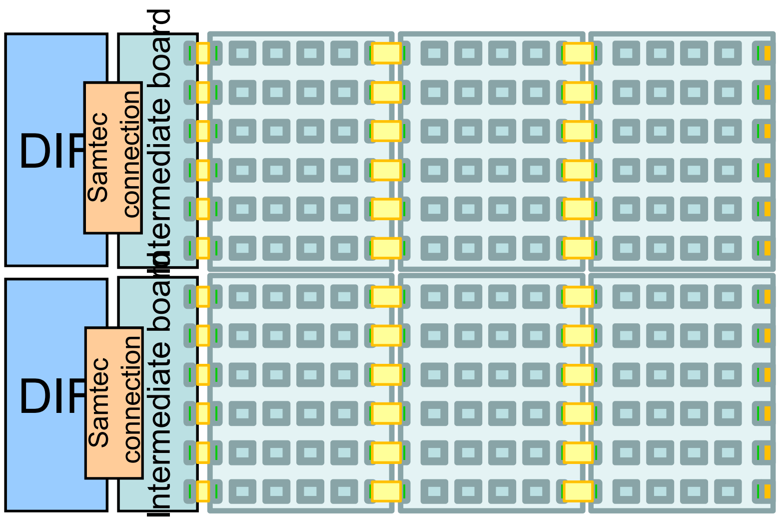
K. Karakostas

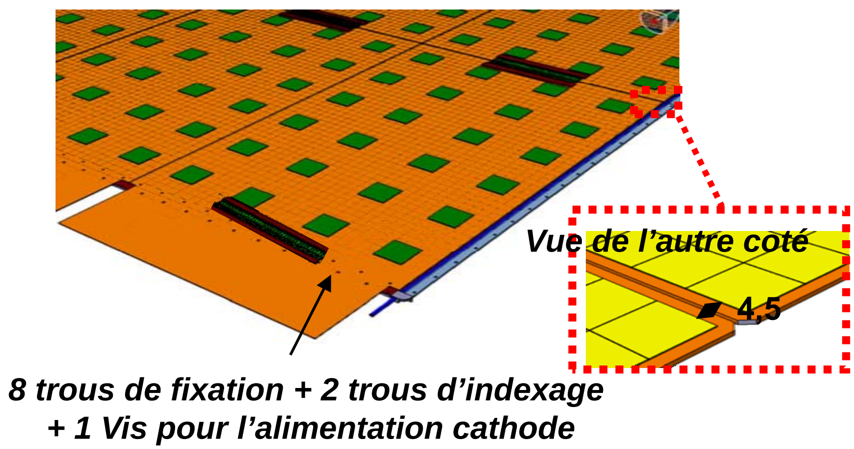
Gain ↘ when Atmospheric Pressure ↗

HCal Technology R&D - MicroMegas

Designs for a 1m² prototype







HCal Technology R&D – GEM's

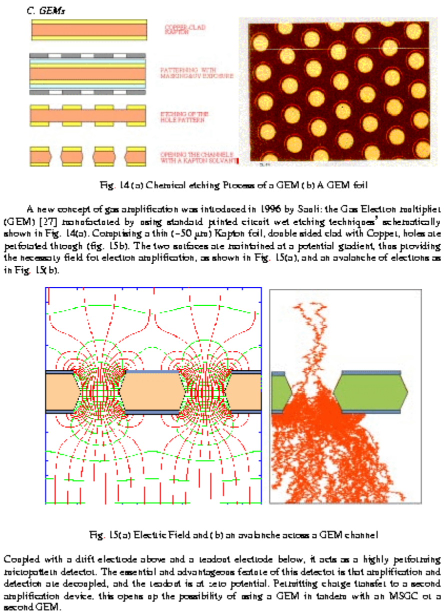
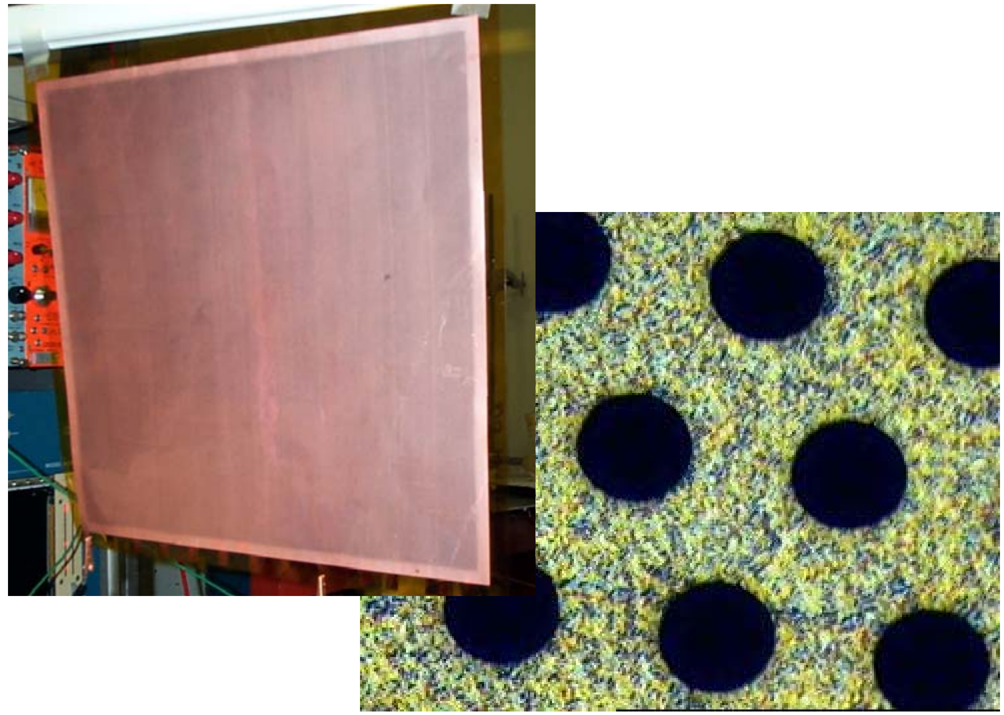

C. GEMs

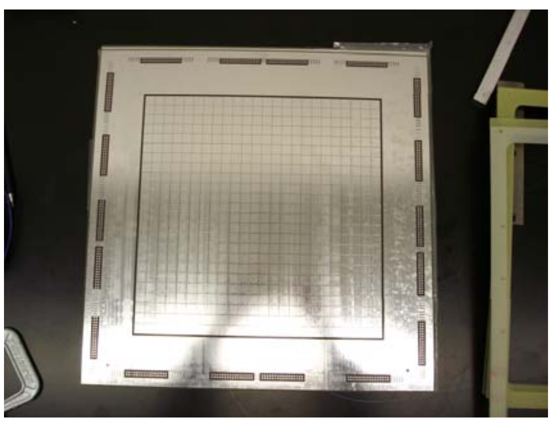
Fig. 14 (a) Chemical etching Process of a GEM (b) A GEM foil

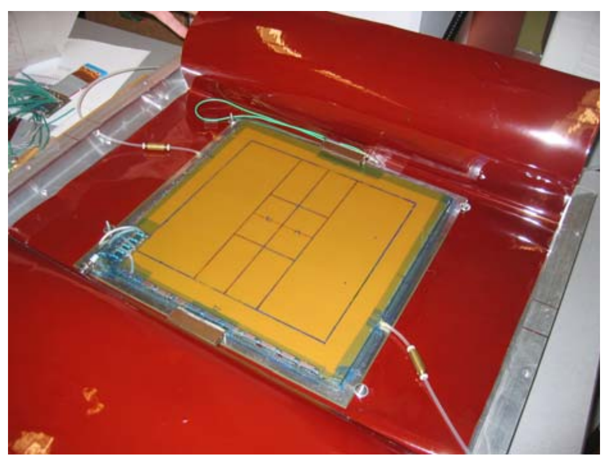
A new concept of gas amplification was introduced in 1996 by Sauli: the Gas Electron multiplier (GEM) [27] manufactured by using standard printed circuit wet etching techniques' schematically shown in Fig. 14(a). Comprising a thin (~50 μm) Kapton foil, double sided clad with Copper, holes are perforated through (fig. 15b). The two surfaces are maintained at a potential gradient, thus providing the necessary field for electron amplification, as shown in Fig. 15(a), and an avalanche of electrons as in Fig. 15(b).

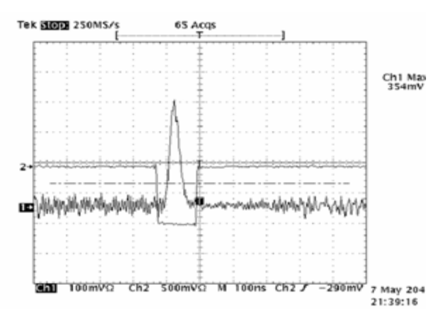
Fig. 15(a) Electric Field and (b) an avalanche across a GEM channel

Coupled with a drift electrode above and a readout electrode below, it acts as a highly performing micropattern detector. The essential and advantageous feature of this detector is that amplification and detection are decoupled, and the readout is at zero potential. Permitting charge transfer to a second amplification device, this opens up the possibility of using a GEM in tandem with an MSGC or a second GEM.





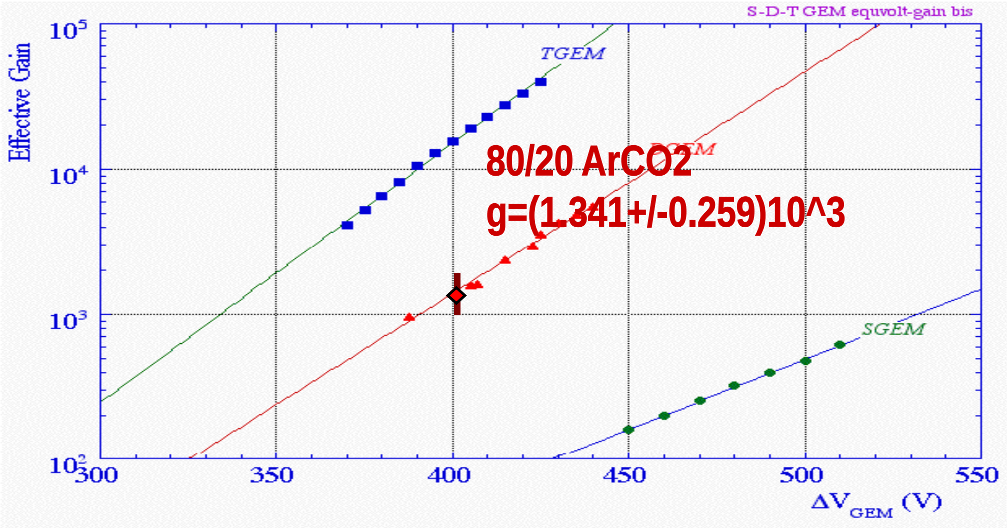


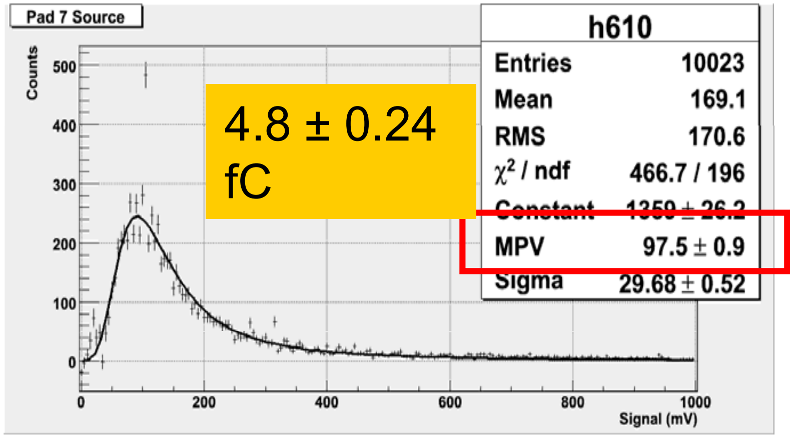


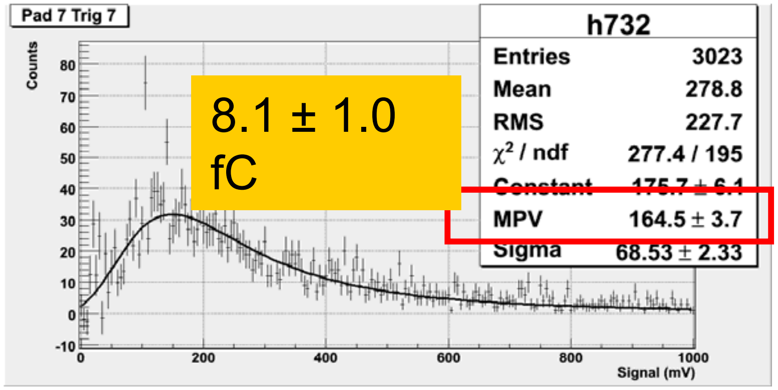
HCal R&D/GEM's - Test beam

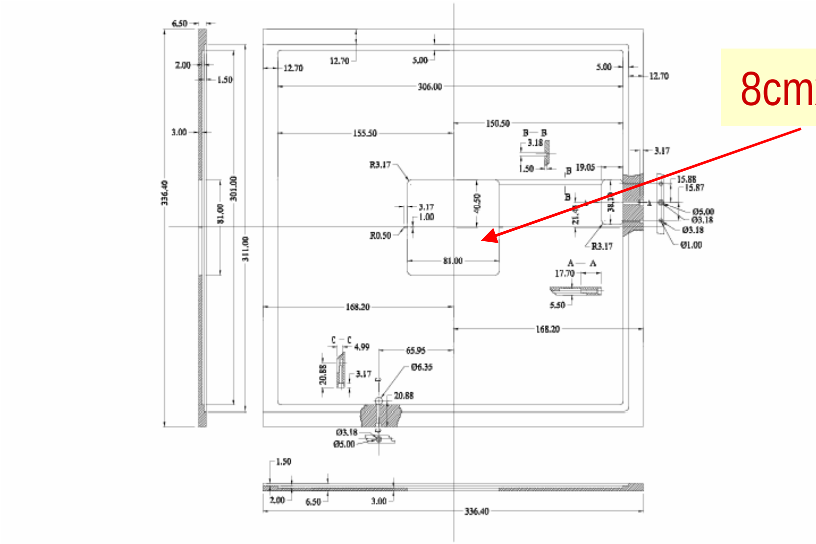
Beam tests at FNAL MTBF

Spring 2007

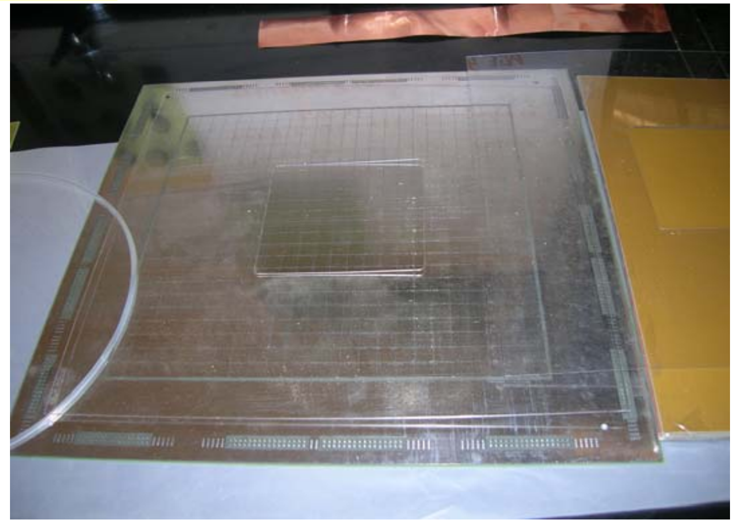






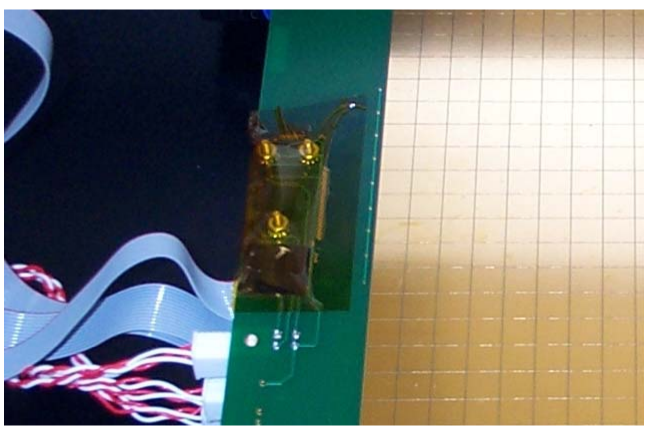


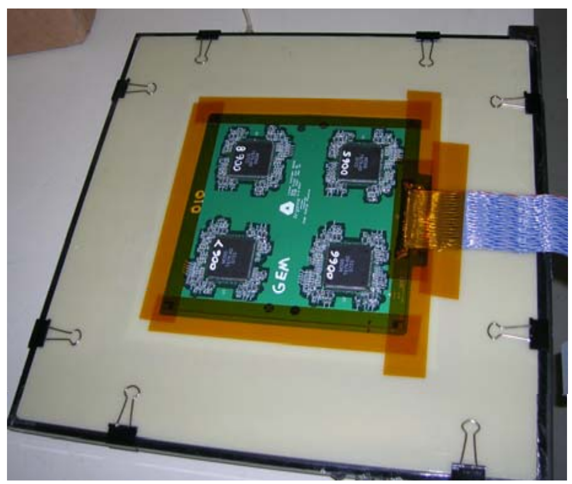
8cmx8cm active area



GEM-DHCAL/KPiX/DCAL chamber design

FNAL TB 2007





HCal Technology R&D – GEM's

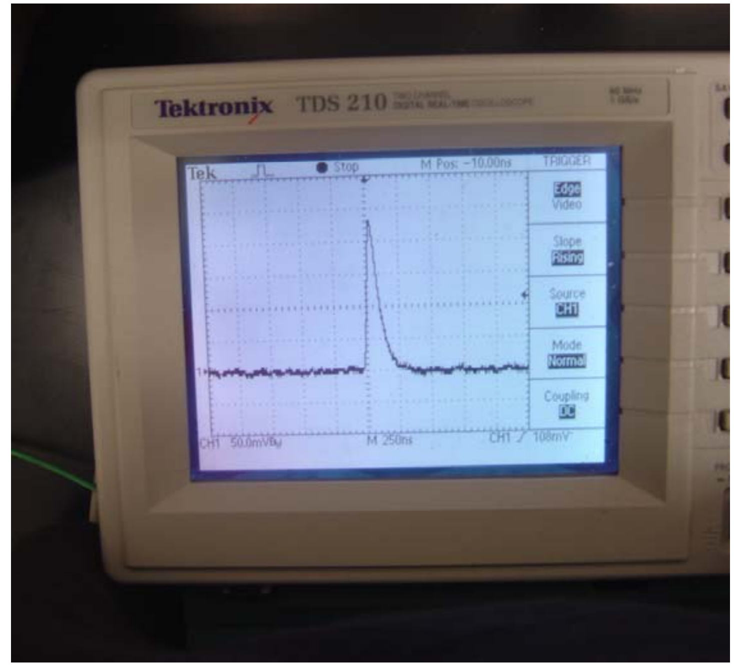
Problems with GEM/KPiX and GEM/DCAL chambers operated in 2007 with test beam/cosmics.

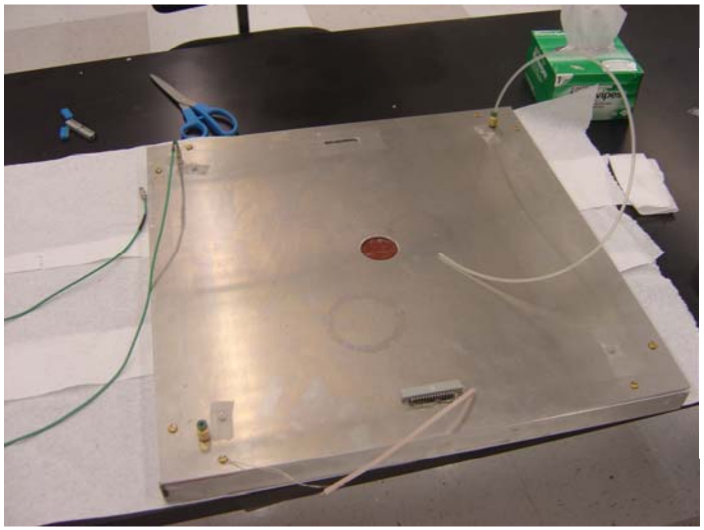
Source of problem most likely the Delrin spacers used between layers.

New chamber built with "fishing line spacers". Works well, but a new problem when operating with the KPiX -> discharges killing the chip.

Discharges associated with anode board – discharge between pads? Chamber operates well with anode board/or with single pad -> discharges not occurring across the GEM foils. Problem of floating pads discharging through pads tied to ground via KPiX FE??

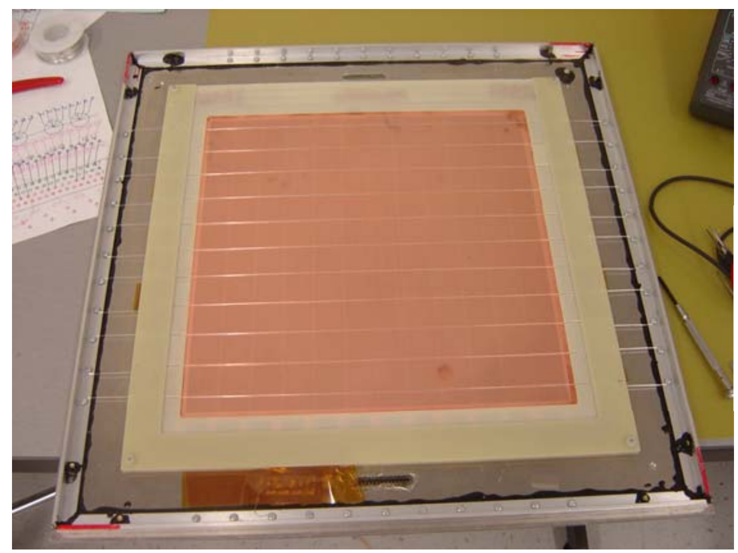
Rebuild KPiX chamber with fishing line spacers



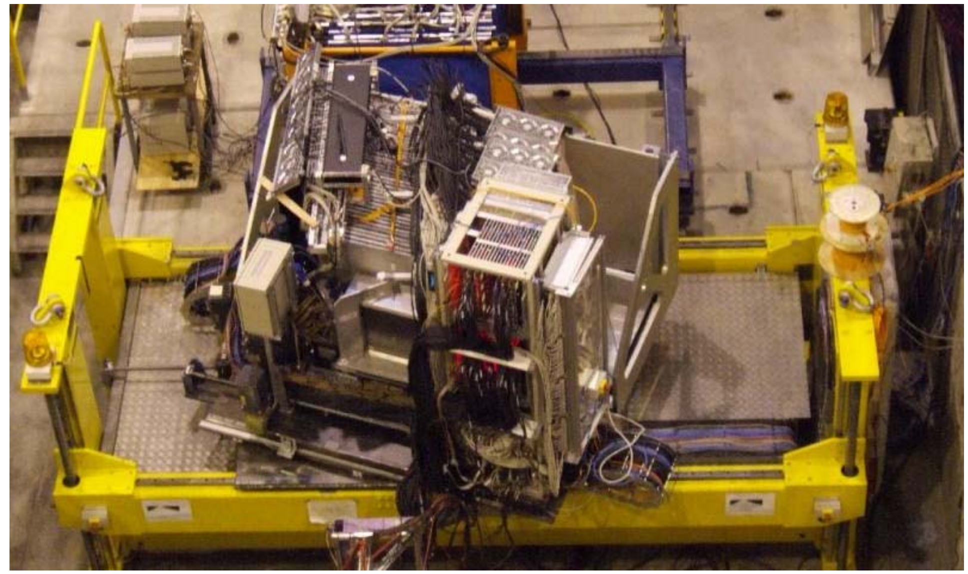


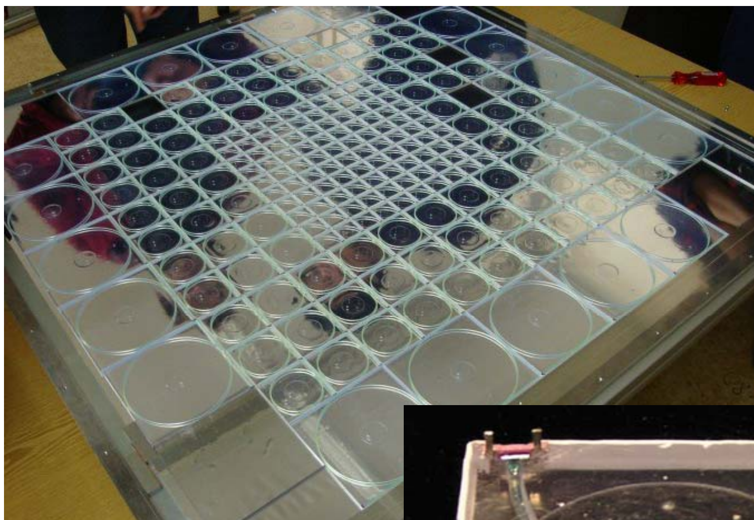
Next: tests at SLAC/discharges,

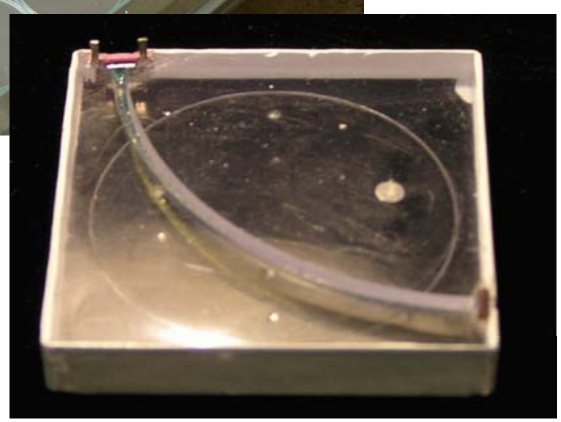
then back to FNAL test beam for KPiX and DCAL chamber tests.



HCal Technology - Scintillator







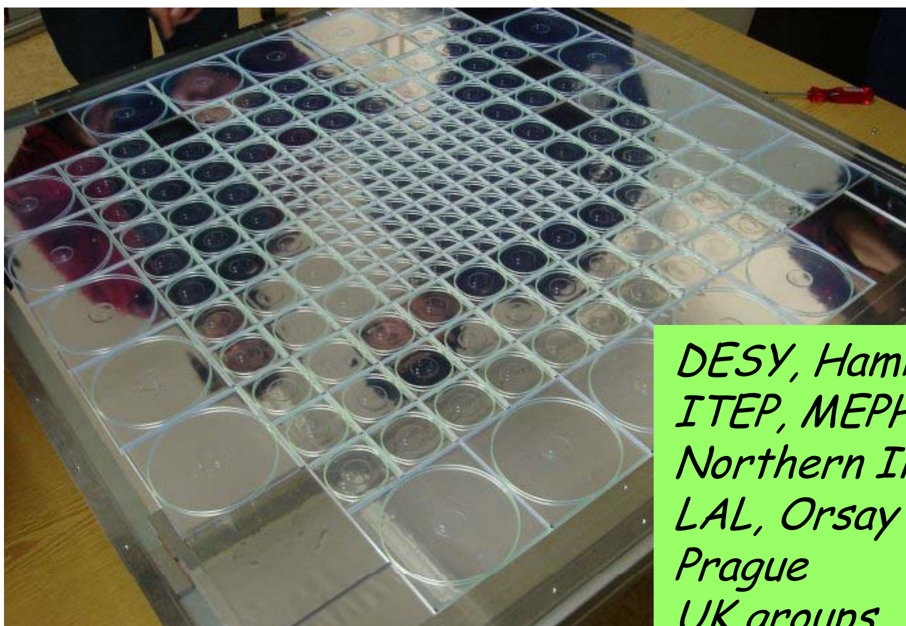
CERN test beam 2007, moving to FNAL in 2008.

Results from full depth HCal stack as shown at ALCPG07

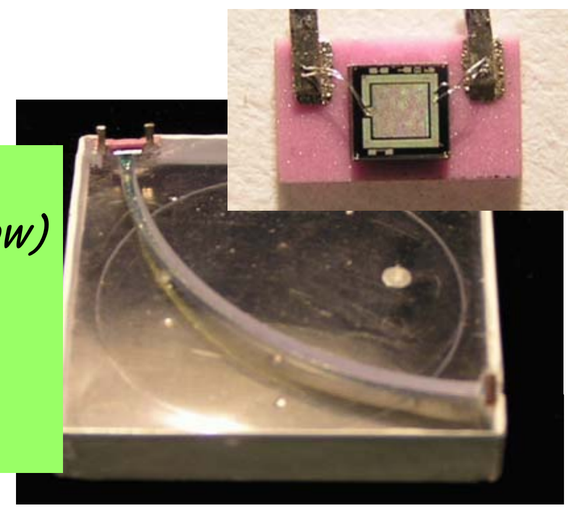
HCal Technology - Scintillator

- 1 cubic metre
- 38 layers, 2cm steel plates
- 7608 tiles with SiPMs
- CALICE electronics and DAQ
- Versatile LED calibration system

- SiPM (MPEPHI/PUSAR)
  - Gain ~10^6, Eff (green) ~ 15%, quenching R ~ 1 – 10 MΩ
- SiPM tile fibre system (ITEP)
  - 3x3x0.5 cm^3 tiles from UNIPLAST, Russia
  - WLS fibre Kuraray Y11(300) 1mm
  - 2% light xtalk per edge
  - Faces covered with 3M mirror foil



DESY, Hamburg U,
ITEP, MEPHI, LPI (Moscow)
Northern Illinois
LAL, Orsay
Prague
UK groups

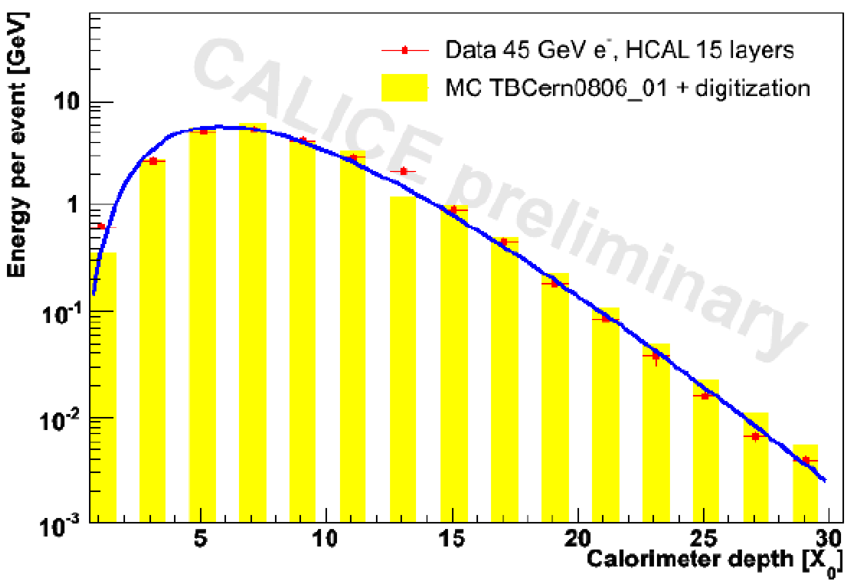


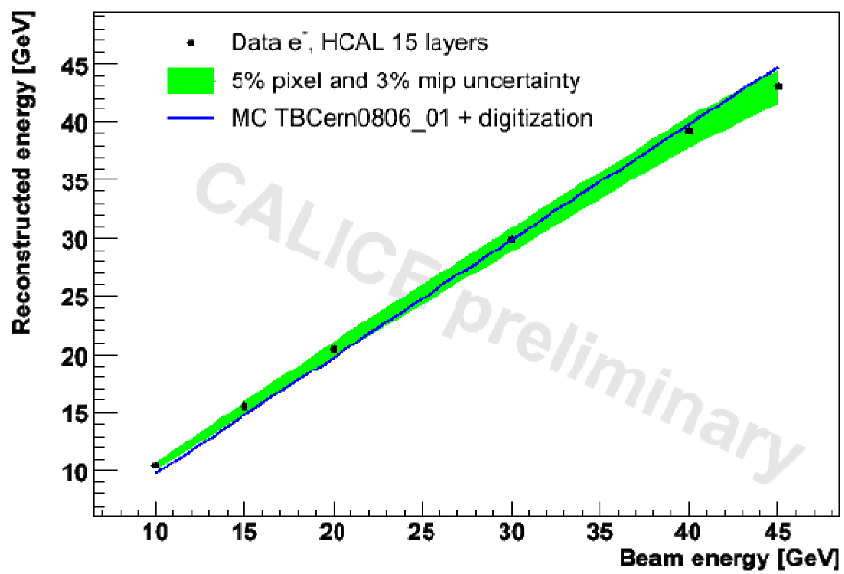
HCal Technology - Scintillator

Electron data

in HCal

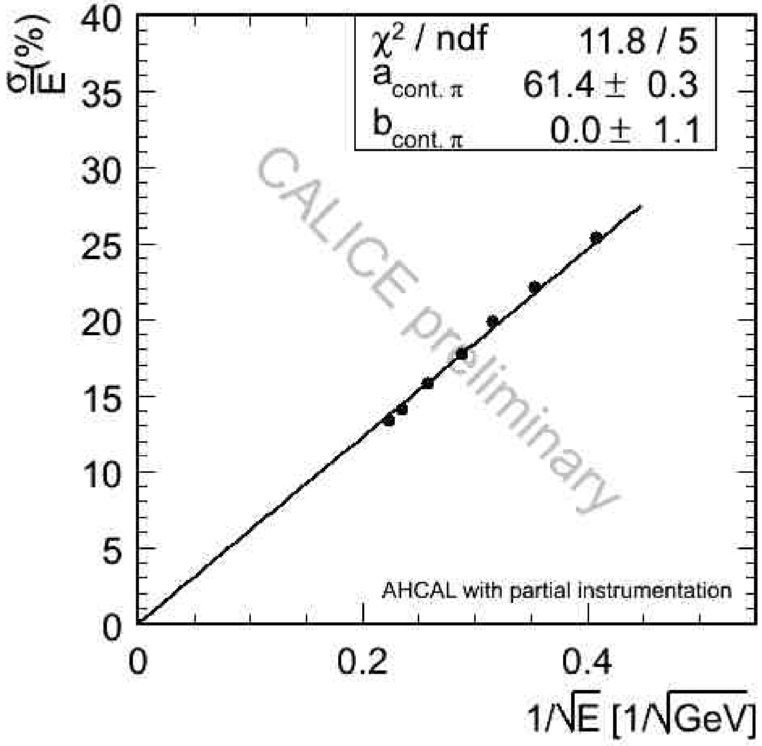
Felix Sefkow – ALCPG07

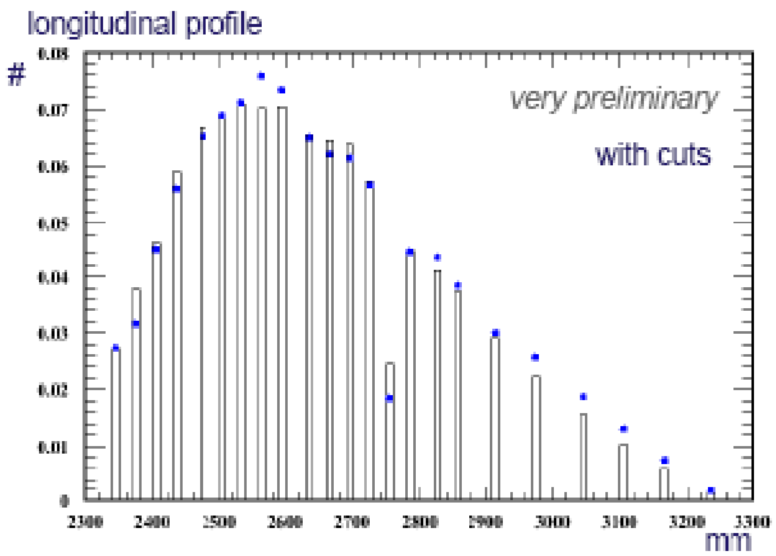




HCal Technology - Scintillator

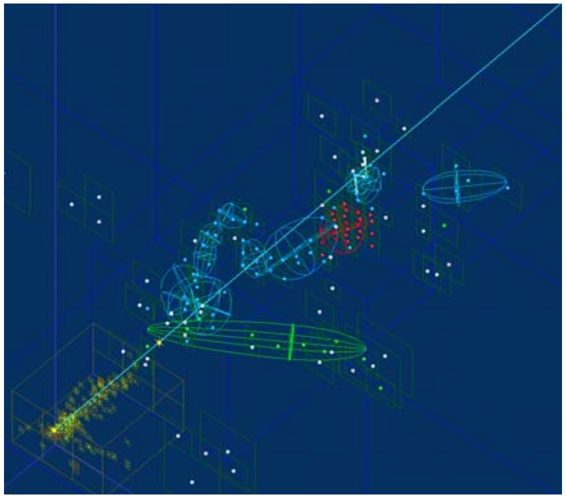
Hadron data





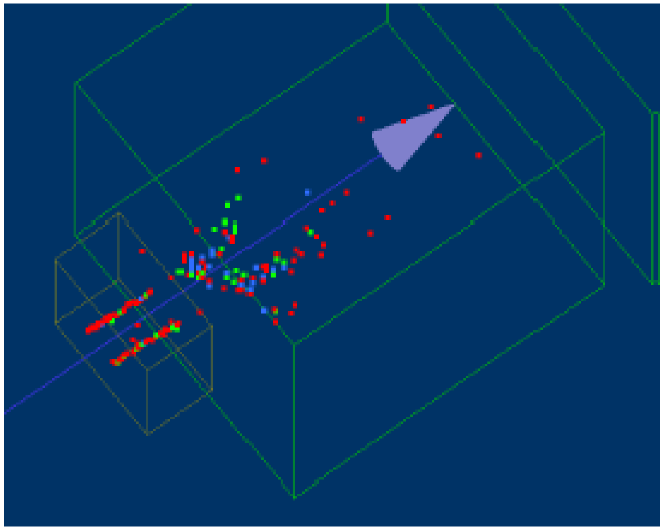
HCal Technology - Scintillator

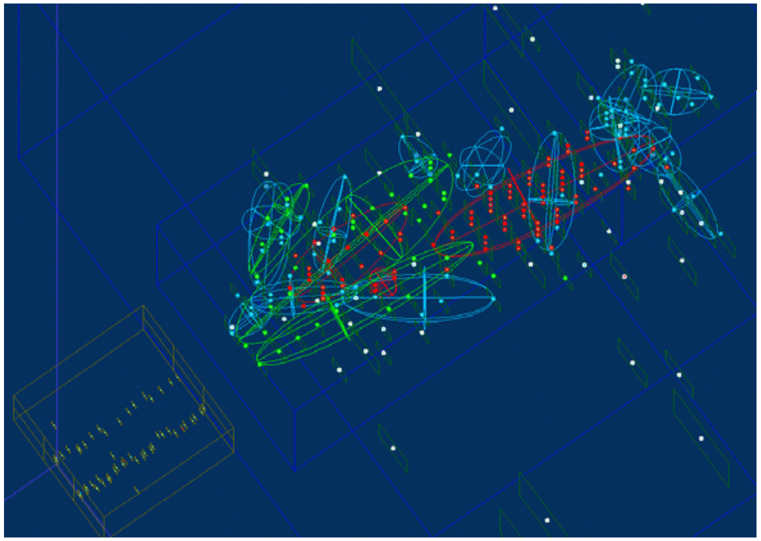
Imaging HCal – studies for weighting



>4 MIP
>1.8MIP & <4MIP
>0.5MIP & <1.8MP

Data





MC

Overlay events – study confusion

HCal Technology - Scintillator

Future activities

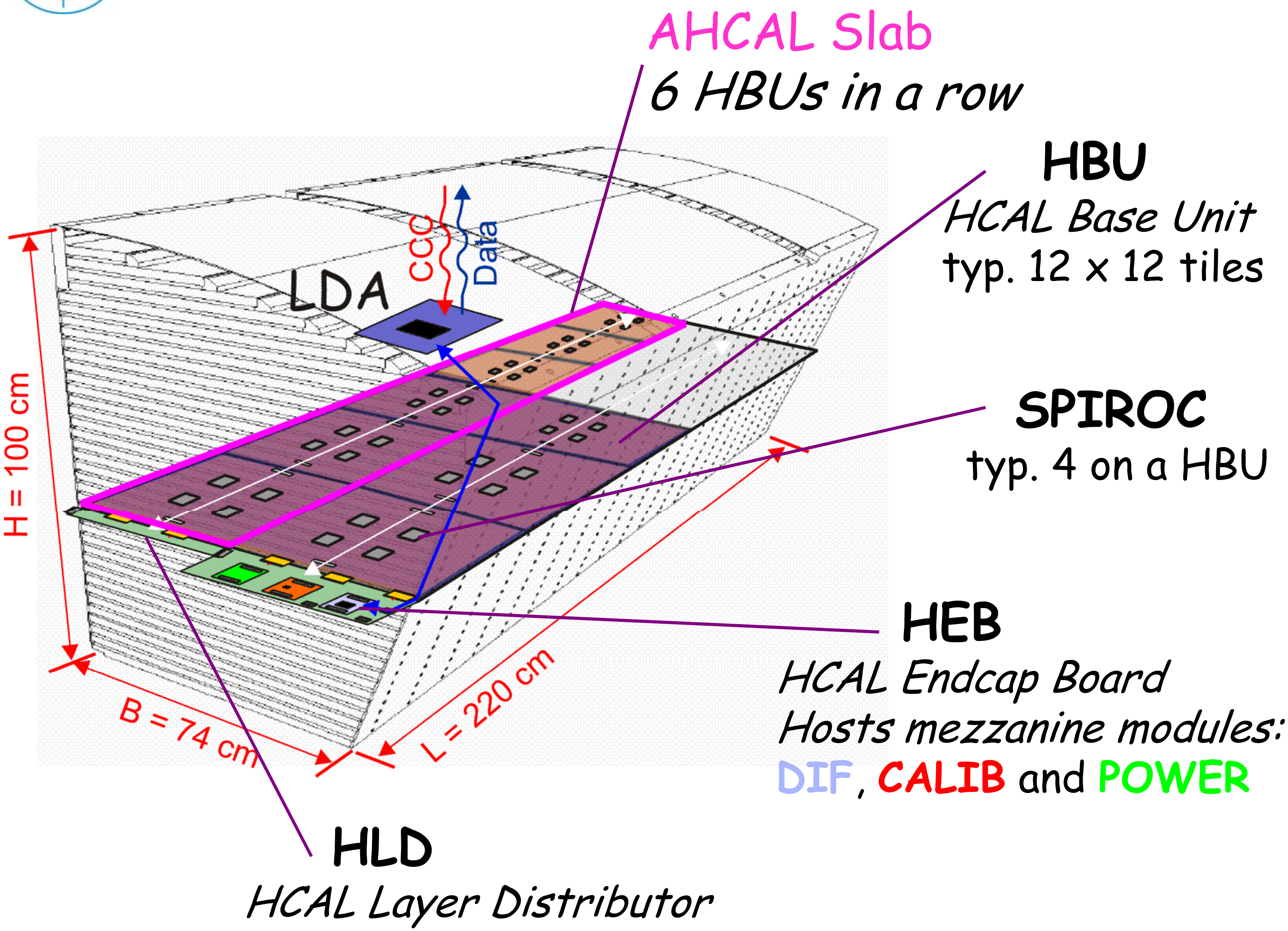
- Looking forward to FNAL test beam 2008-09
  - Low energy 1-10 GeV
  - Combined analysis with different ECALs
  - Comparison with gaseous HCAL

- Technical Prototype design

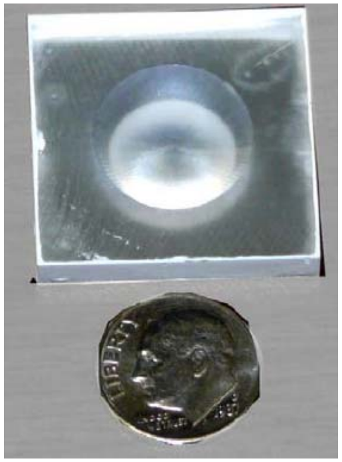
  Goal: A compact and realistic (i.e. scaleable) scintillator HCAL structure with embedded electronics

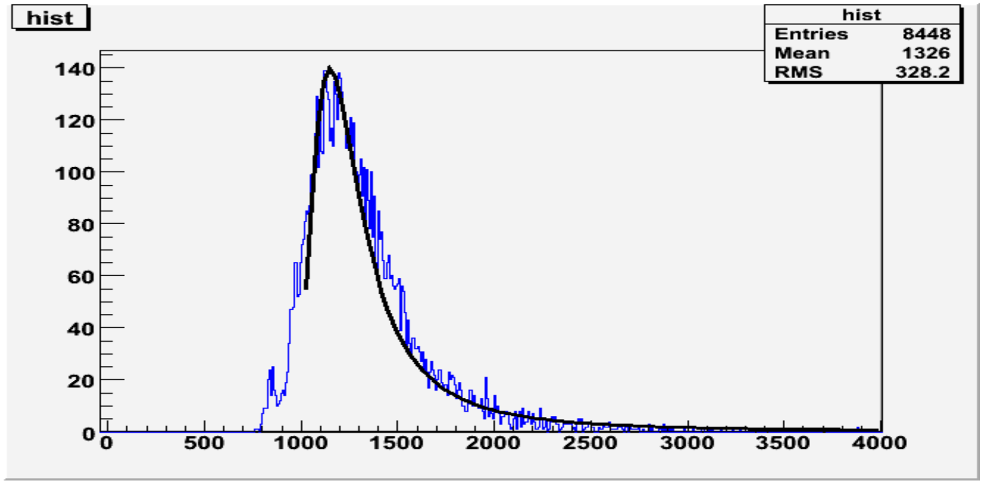
AHCAL Half Sector - Integration

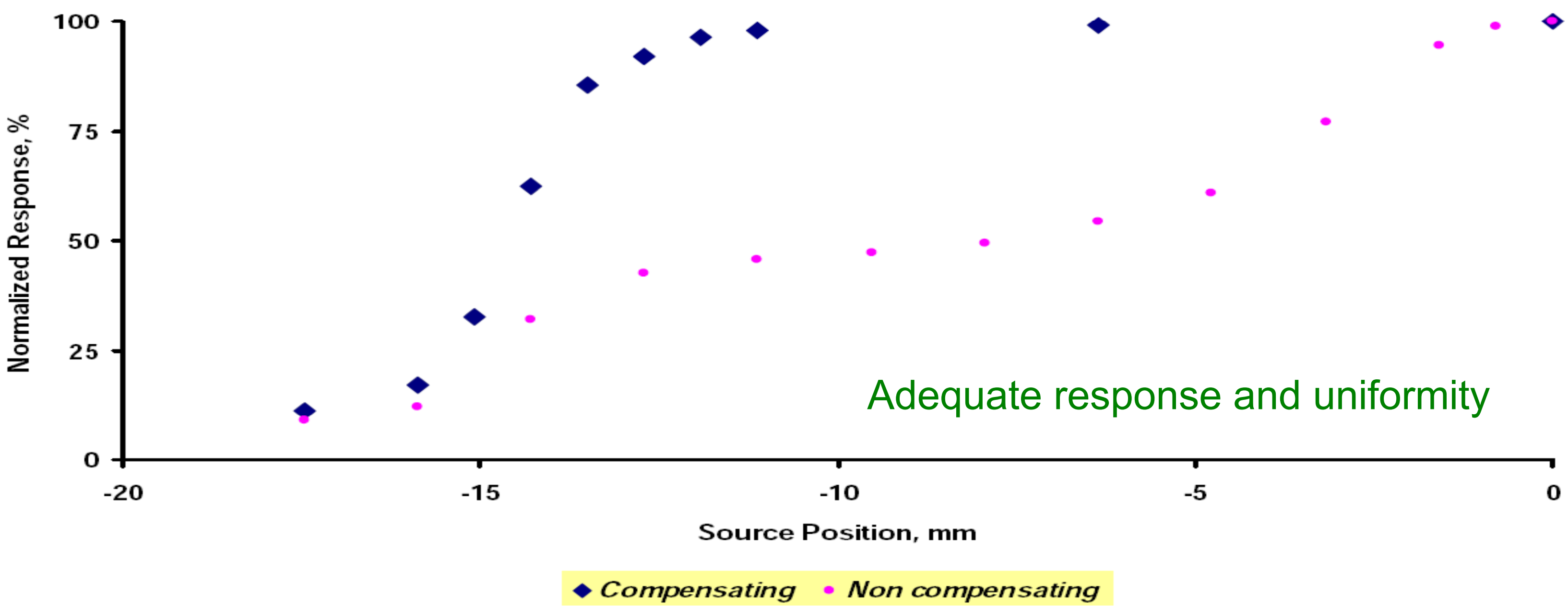
FEB



Direct SiPM-Scintillator coupling (NIU)

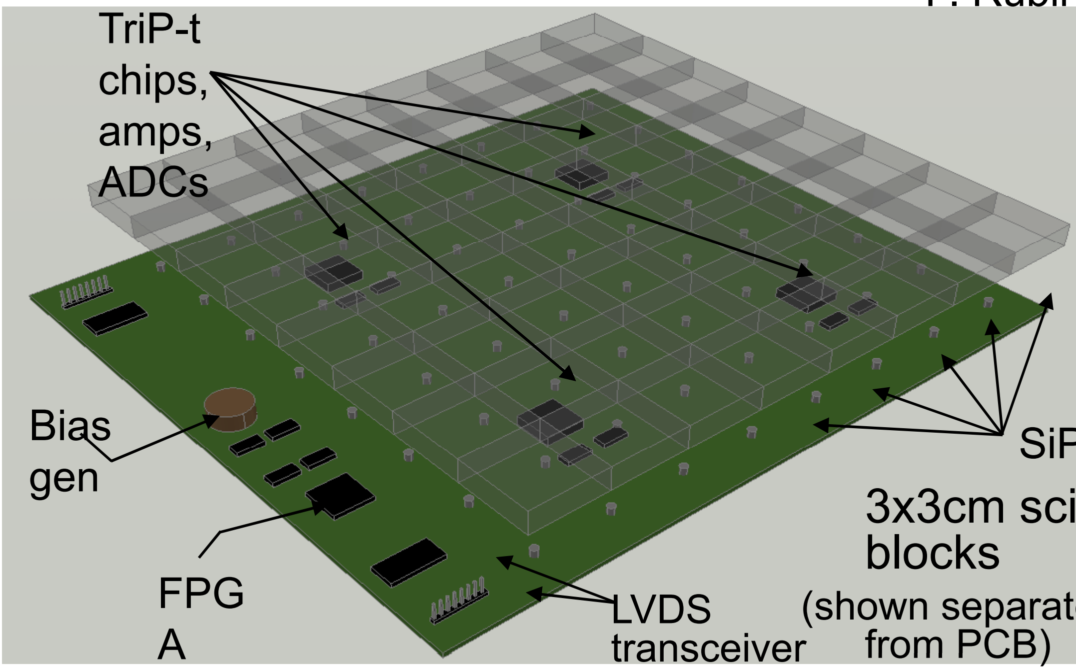




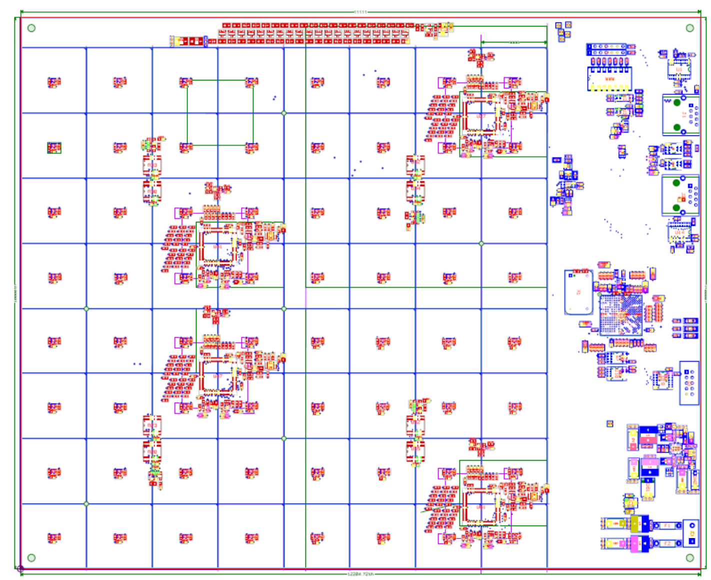


Direct SiPM-Scintillator coupling (NIU)

P. Rubinov, FNAL



On the fabricated board the electronics will be on the underside of the board



IRL – nearly completed layout

The Choice between Gas and Scintillator

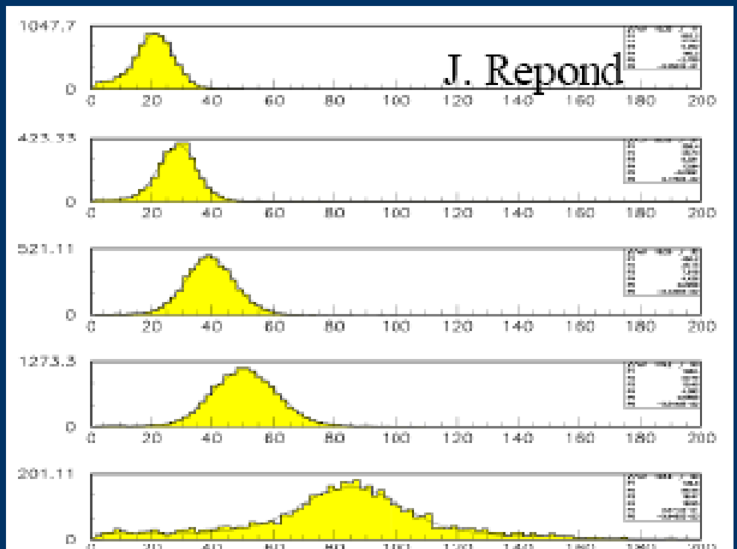
-> Accumulating R&D data for both technologies

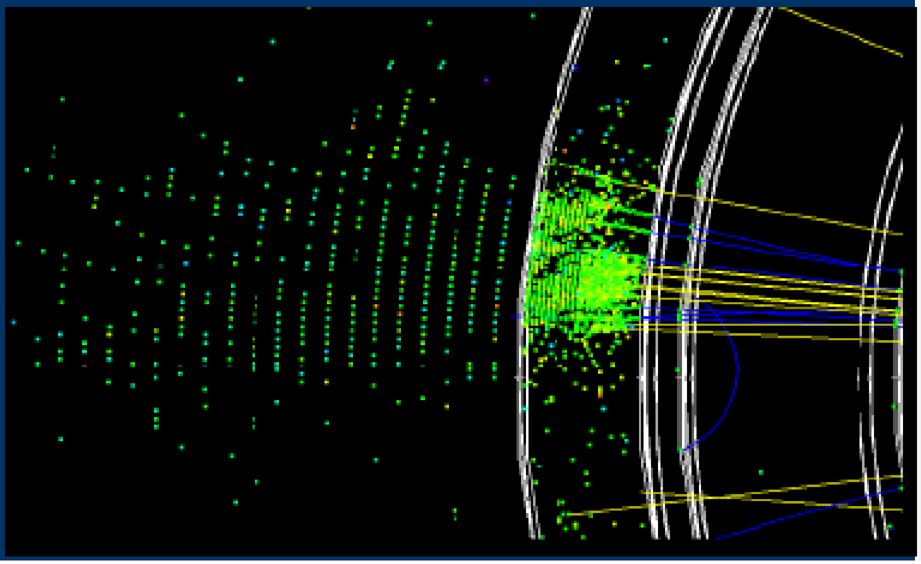
-> Redefining the HCal plan in light of extended LOI timescale.

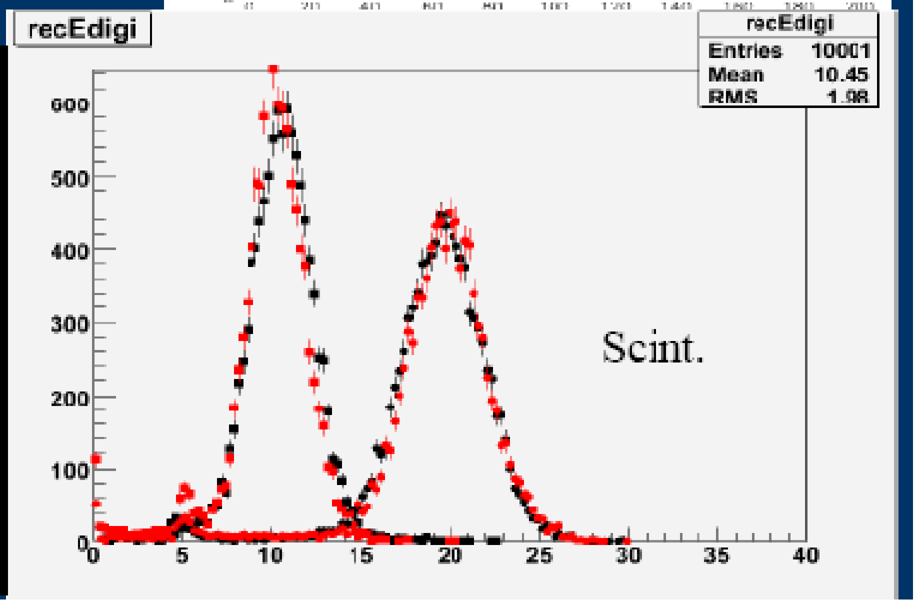
-> Many issues to consider!

Digital vs Analog

- Data seems to confirm that hit counting is a legitimate method of single hadron energy estimation.
- But does it work in full events with overlapping showers?
- Worse E/p x-check

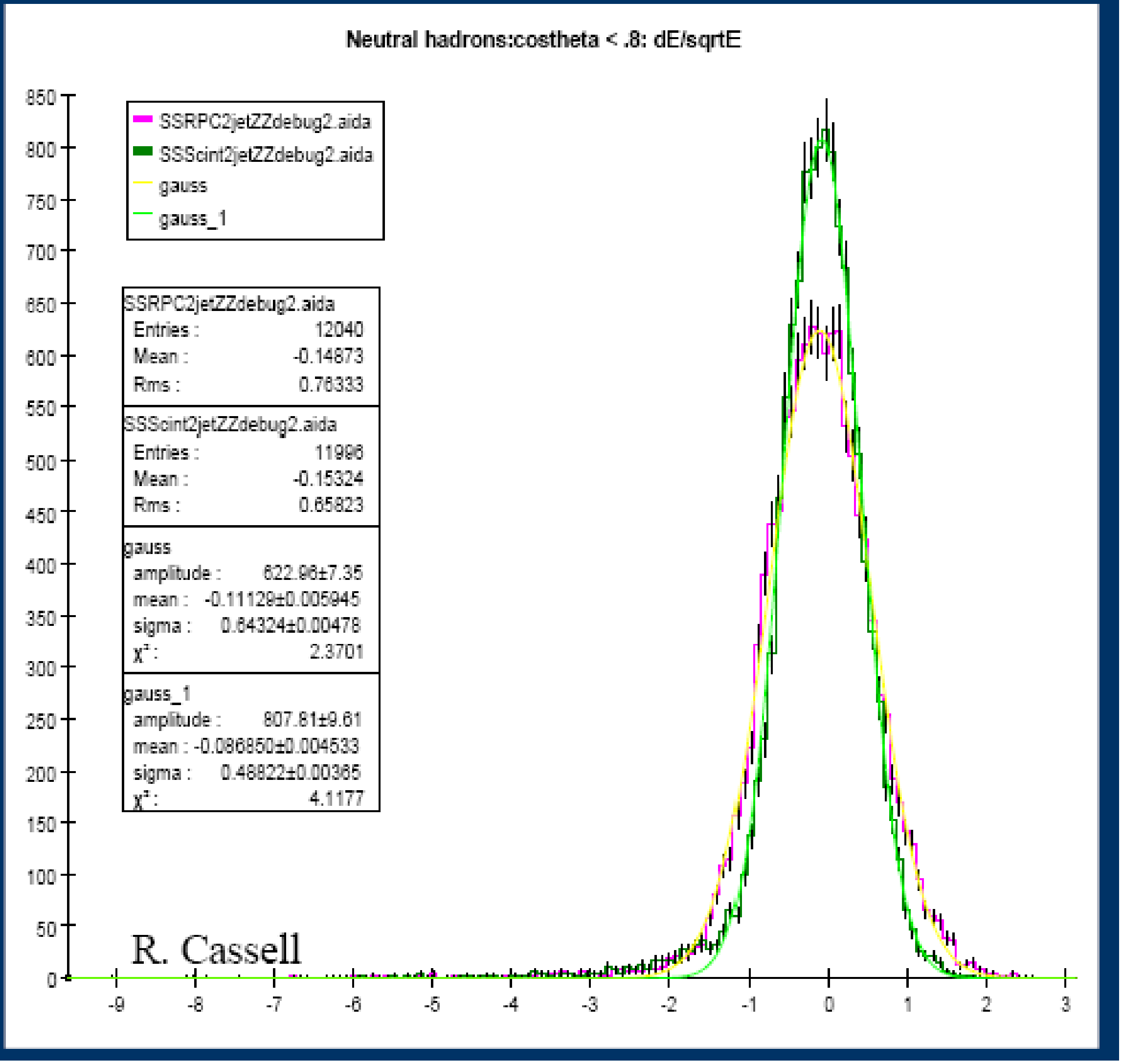






Energy Resolution

- Single hadron resolution significantly better for scint.
- However on average only 10% of energy in neutral hadron clusters.
- On the other hand you are going to have coalesced showers...



HCal Status - Summary

- Continued development of HCal overall design and technological implementations of the active media.

- HCal engineering activities in U.S. and France

- Active media – many choices, many studies!

- All the detector R&D will, with the parallel PFA studies, feed into the eventual decision for the choice of an active medium.

- We need to ensure that we accumulate all the necessary data towards this decision – your participation is very welcome!

- How much of the above do we need to settle for the (delayed) LOI?