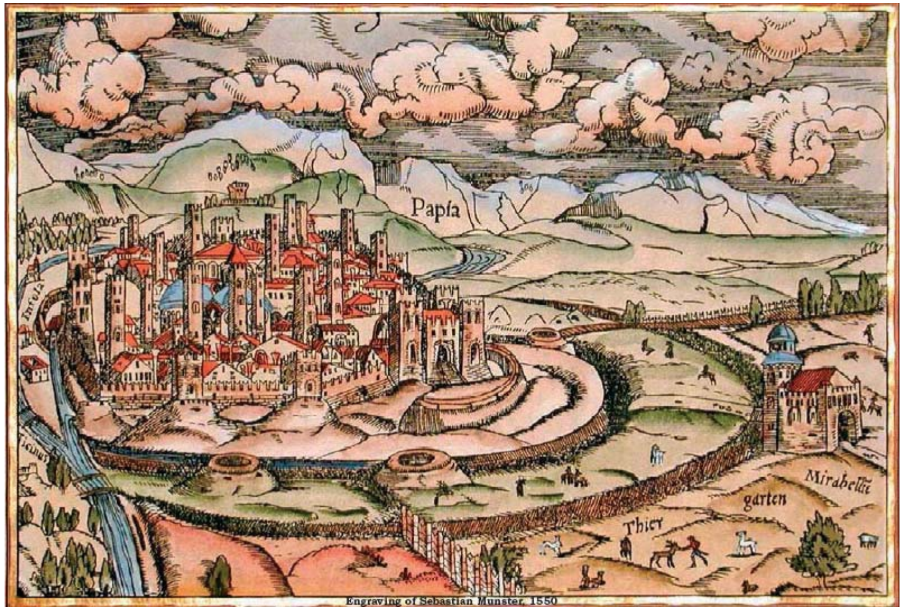
A Digital Hadron Calorimeter with Resistive Plate Chambers



José Repond

Argonne NATIONAL LABORATORY

CALICE
Calorimeter for ILC

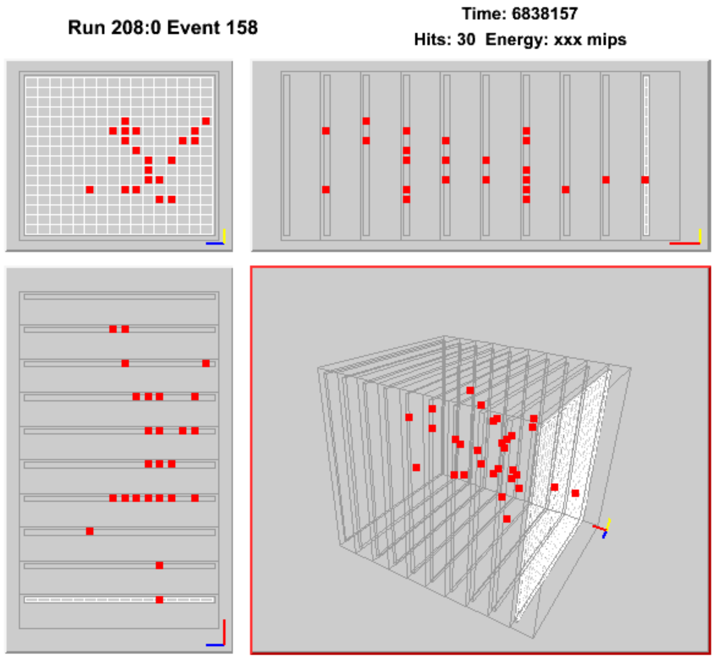
CALOR 2008
May 26 – 30, 2008
Pavia, Italy

Concept of a Digital Hadron Calorimeter

Optimized for the application of Particle Flow Algorithms

Trades resolution on a small number of cells (towers) in traditional calorimeters with low (one-bit) resolution on a large number (~10^7 – 10^8) of cells

Novel concept which needs to be validated



Active Element and readout

Resistive Plate Chambers (RPCs)

1 x 1 cm^2 readout pads

Collaboration of

Argonne National Laboratory

Boston University

Fermi National Accelerator Laboratory

University of Iowa

In the framework of

CALICE

Calorimeter for ILC

Staged Approach

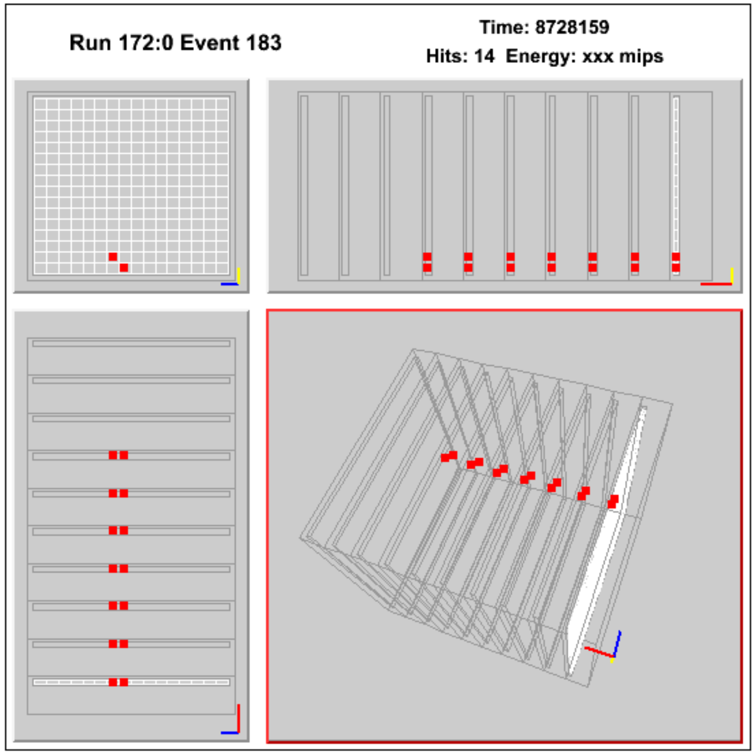
I Investigation of Resistive Plate Chambers as active elements

II Development of the electronic readout system

III Vertical Slice Test with 10-layer prototype calorimeter

IV Construction of a 1 m^3 prototype section

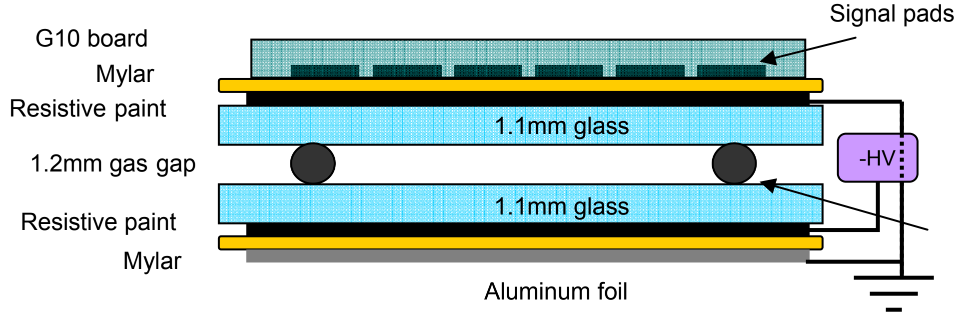
V Further developments



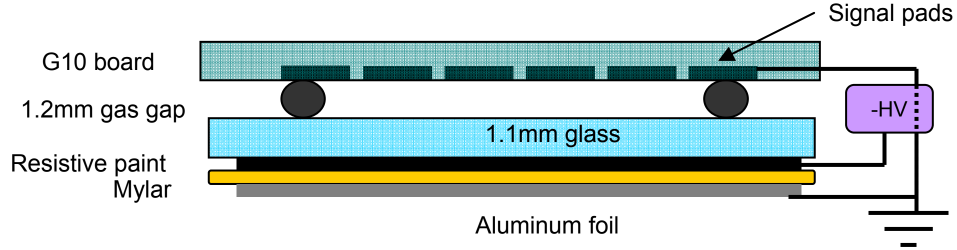
I Resistive Plate Chambers

Pursued two design options

Two-glass design

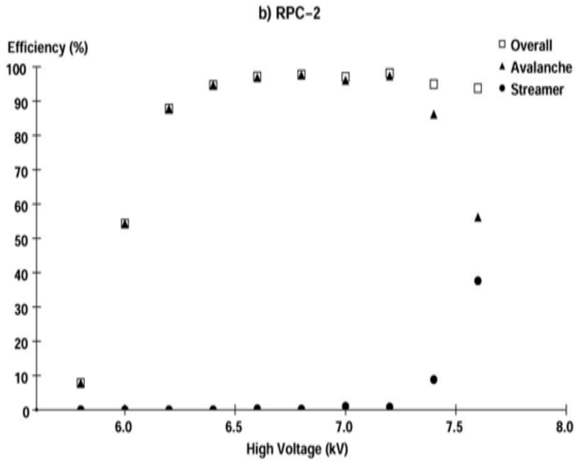


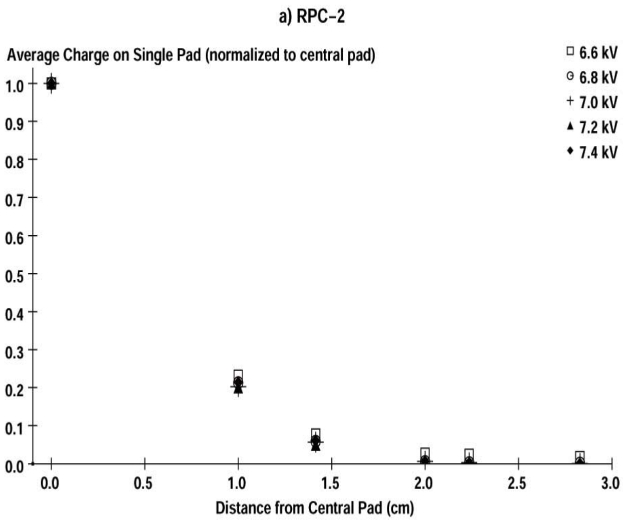
One-glass design

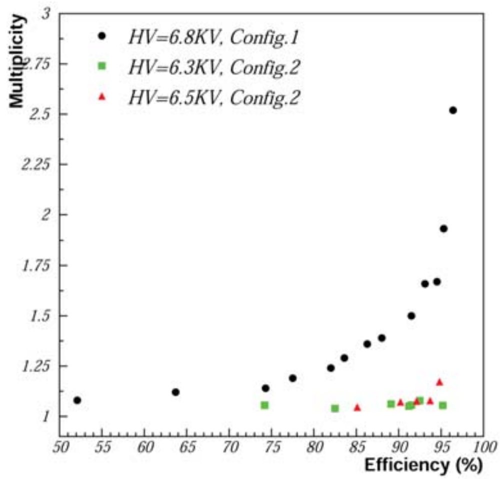


Extensive tests with single readout pads, multiple pads, analog and digital readout

G.Drake et al., Nucl. Instr. Meth. A578, 88 (2007)

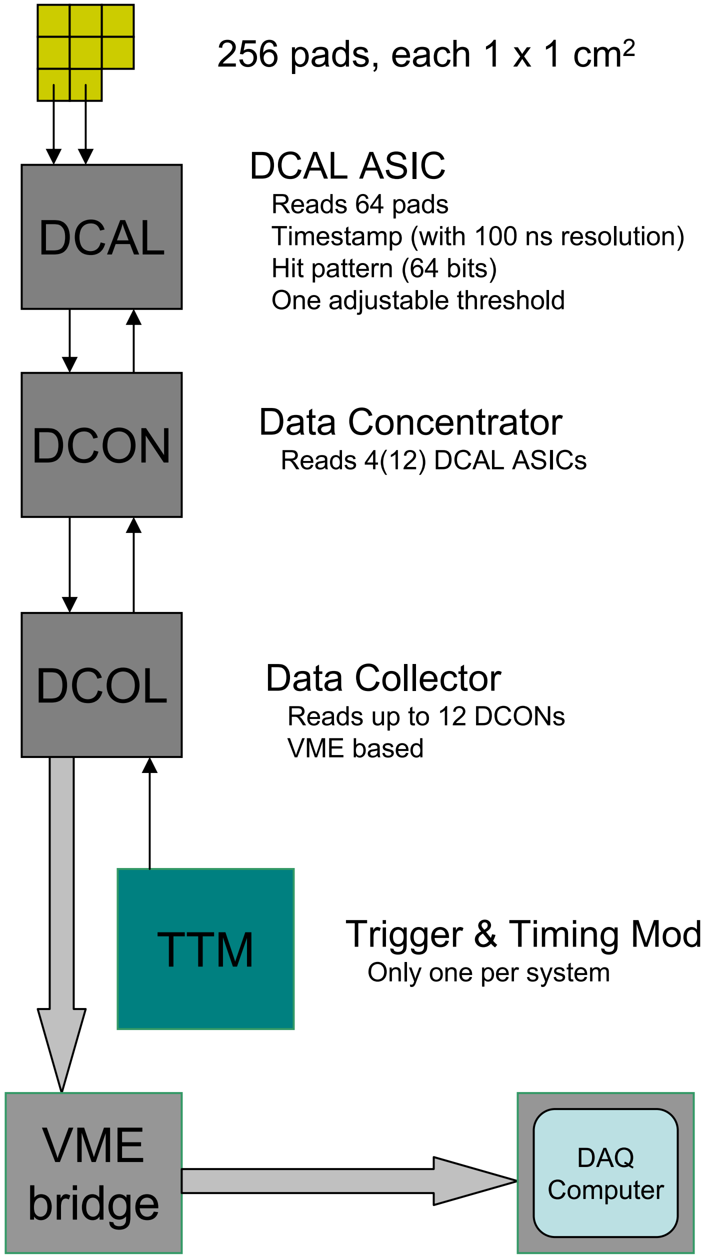






Studies completed: RPCs excellent choice for Digital Hadron Calorimetry

II The Electronic Readout System



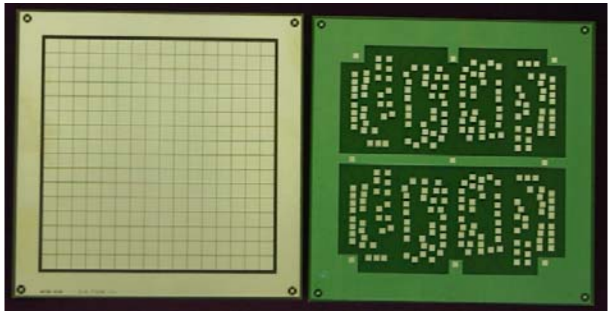
256 pads, each 1 x 1 cm^2

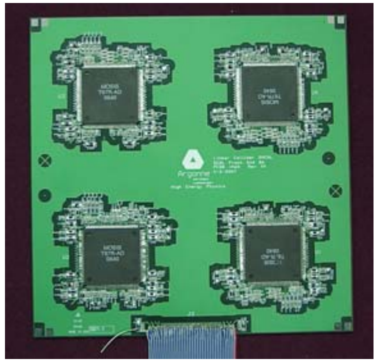
DCAL ASIC
- Reads 64 pads
- Timestamp (with 100 ns resolution)
- Hit pattern (64 bits)
- One adjustable threshold

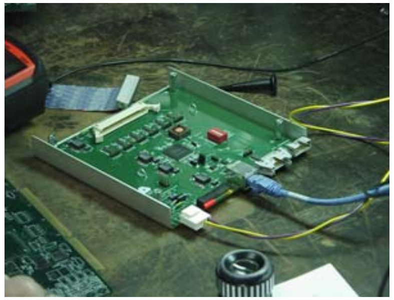
Data Concentrator
- Reads 4(12) DCAL ASICs

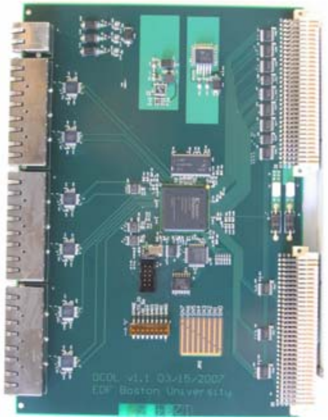
Data Collector
- Reads up to 12 DCONs
- VME based

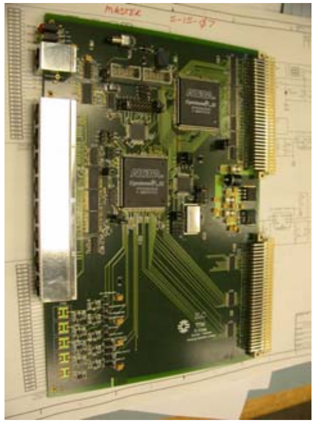
Trigger & Timing Module
- Only one per system











J.Butler et al., IEEE transactions (2007)

Performance of the Electronic Readout System

Operation in

Triggered (Cosmic rays, test beam) or
Triggerless (Noise measurements) mode

Data push

Dead time free up to ~1 kHz

Gain choices

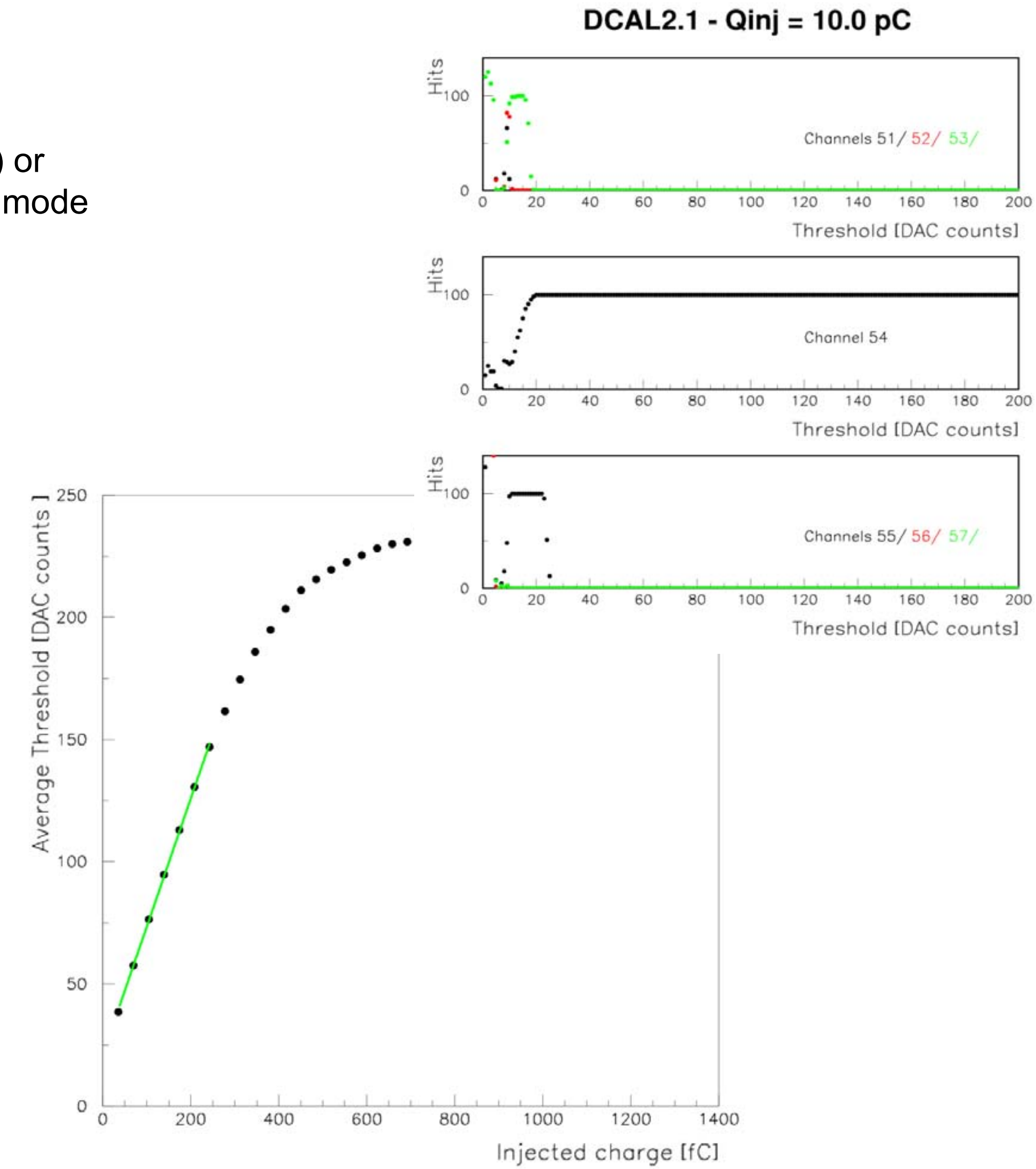
High gain (GEMs) }
Low gain (RPCs) } x 5

Noise

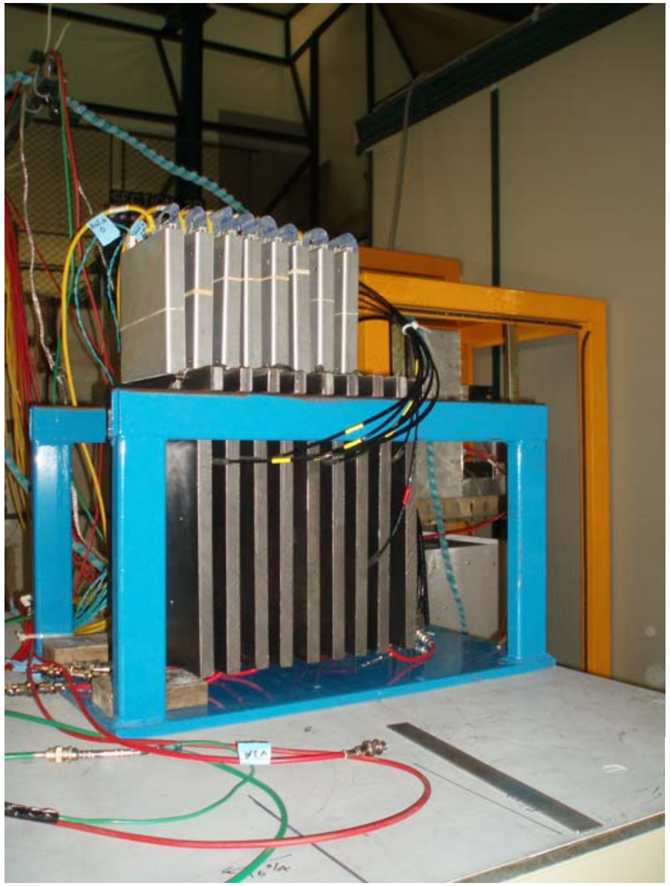
Without detector < 4 10^{-5} Hz/cm^2

Cross talk

At the 0.3% level



III Vertical Slice Test



Test of whole system with

Up to 10 RPCs, each 20 x 20 cm^2
(Up to 2560 channels)

Test stands

Horizontal for cosmic rays
Vertical for testbeam

RPCs

Up to 9 2-glass designs
1 1-glass design
Thickness = 3.7 mm (chamber) + 4.6 mm (readout) = 8.3 mm

Absorber

For cosmic rays, muon, pions, electrons: Steel (16 mm) + Copper (4 mm)
Rate capability measurement (120 GeV protons): 16 mm PVC with whole cut out in center

Data acquisition

Not fully debugged in the test beam (July 2007)
Now 100.000 % error free!

Digital Hadron Calorimeter: Calibration Procedure

Convert number of hits into the energy of particle

Data

$$E_{hadron} = \alpha_{samp}(\Sigma_i H_i) \cdot \Sigma_i(H_i - B_i) \cdot (\varepsilon_0^{MIP}/\varepsilon_i^{MIP}) \cdot (\mu_0^{MIP}/\mu_i^{MIP})$$

i …index running over layers
H_i … number of hits in layer i
ε_0^{MIP}… average MIP efficiency
μ_0^{MIP} … average pad multiplicity

Number of pads firing for one MIP in layer i

From testbeam

Efficiency for having at least one pad firing in layer i

Average noise rate in layer i

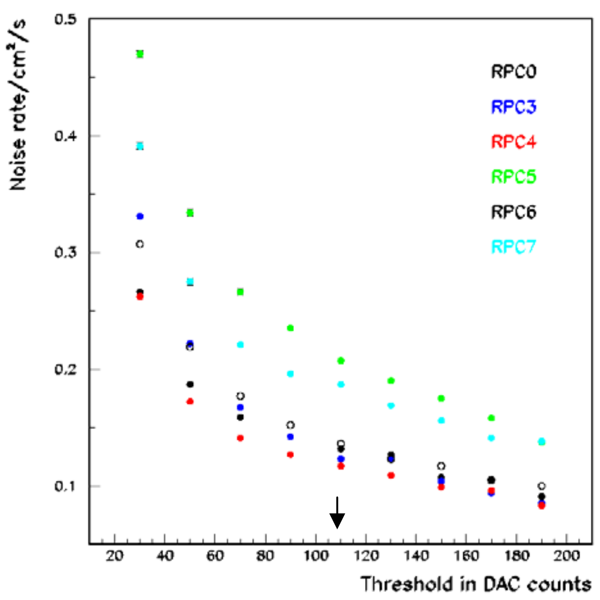
From measurement with MIPs

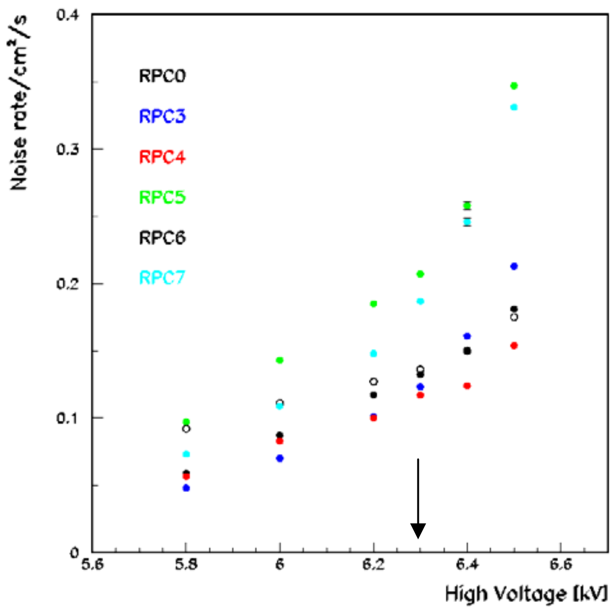
Monte Carlo

Generate events using ε_0^{MIP} and μ_0^{MIP} → see later
Allows for direct comparison with data (at the hit level)

Measurement of Noise Rates

B.Bilki et al., 2008 JINST 3 P05001





At the default setting the rate measures

~ 0.1 Hz/cm²

For a $5 \cdot 10^7$ channel calorimeter this rate corresponds to 1 hit in a 200 ns gate

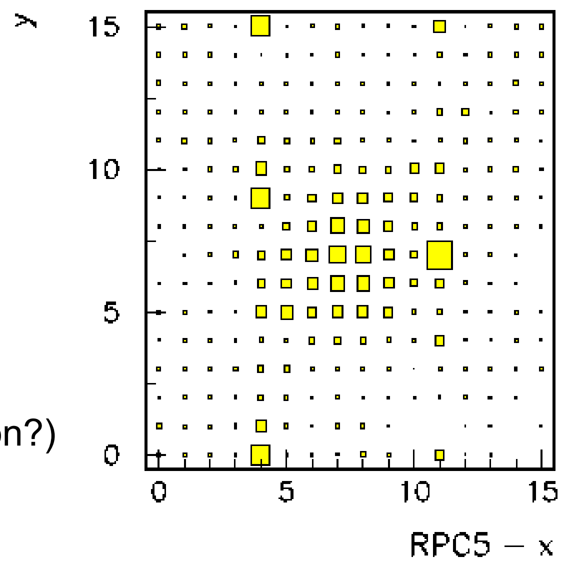
Noise rates

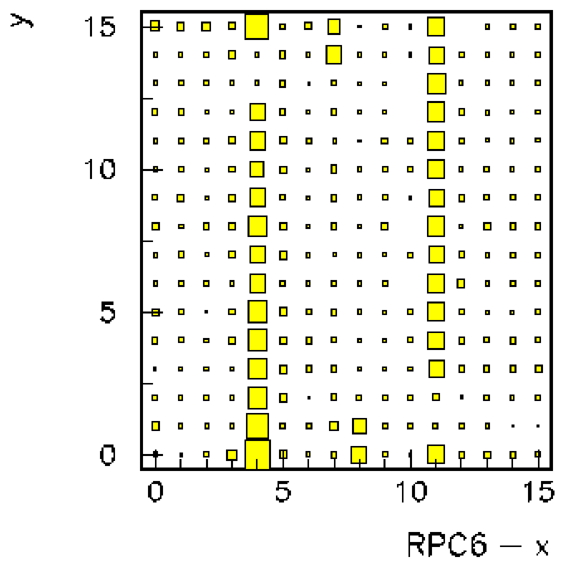
Decrease with increasing threshold
Increase with increasing high voltage

x – y map

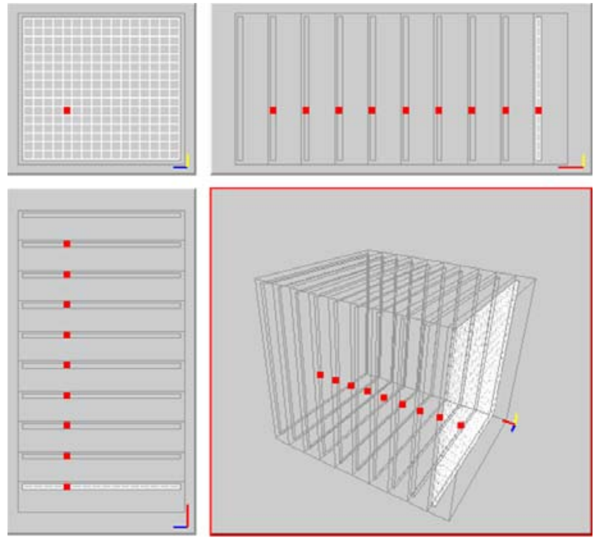
Noise rates higher around location of spacers (fishing lines)

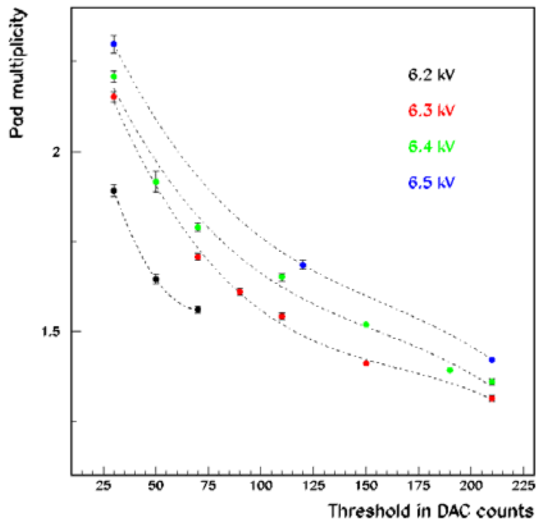
Somewhat higher in center (beam activation?)





Calibration with Muons

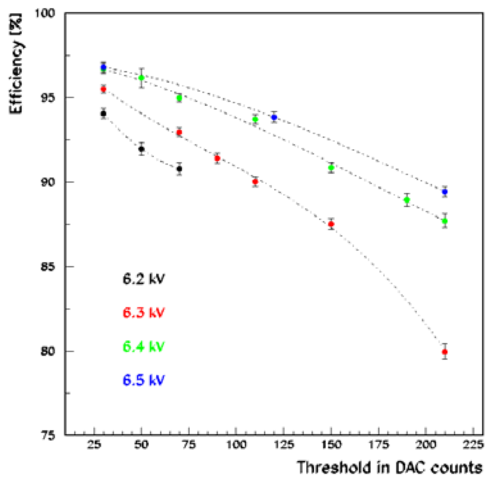




Explored operating space

Dependence on threshold & HV

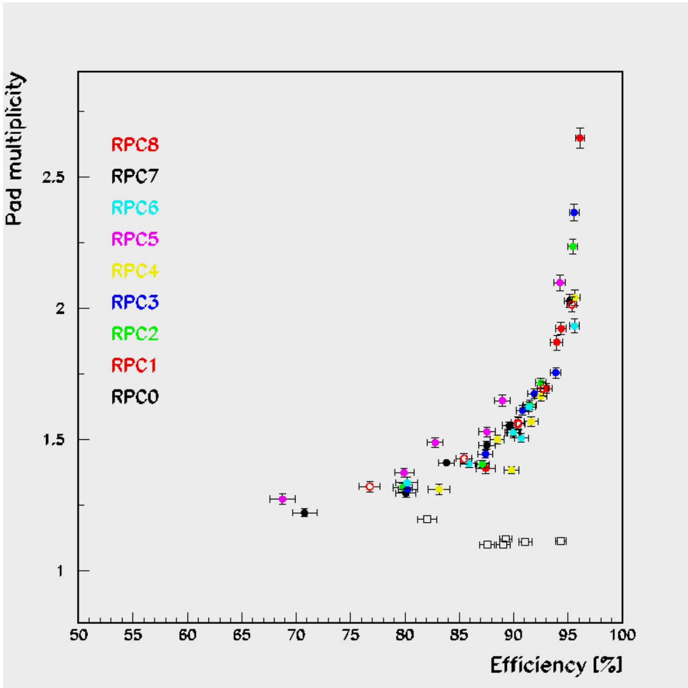
Results confirmed earlier studies



Efficiency vs. pad multiplicity

2-glass RPCs: results on common curve

1-glass RPC: constant $\mu^{MIP} \sim 1.1$



Chose as default operating point

HV = 6.3 kV, THR = 110

$\varepsilon^{MIP} \sim 90\%$

$\mu^{MIP} \sim 1.5$

B.Bilki et al., 2008 JINST 3 P05001

Monte Carlo Simulation

<u>Simulate avalanches and hit distributions</u>

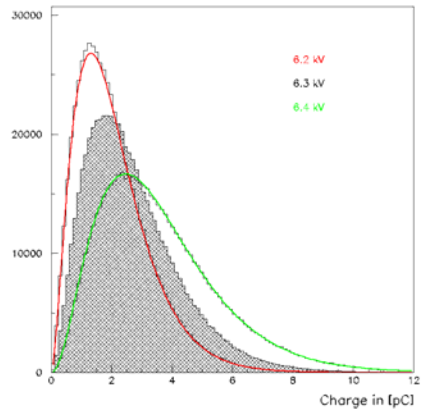
- Generate **muons** (at some energy) with GEANT4
- Get x,y,z of each energy deposit (point) in the active gaps
- Generate measured charge distribution for each point

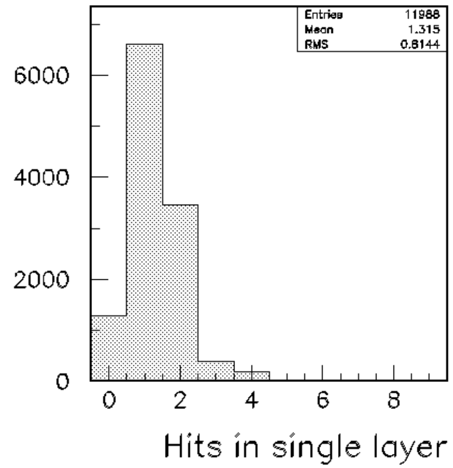
  (according to our own measurements)
- Noise hits can be safely ignored

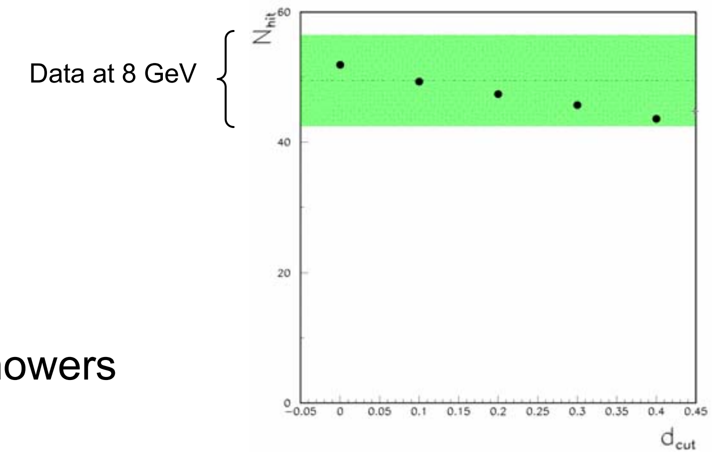
- Distribute charge according to exponential distribution with slope **a**
- Apply threshold **T** to flag pads above threshold (hits)
- Adjust **a** and **T** to reproduce measured hit distributions

- Generate **positrons** at 8 GeV with GEANT4
- Filter hits if closer than $\mathbf{d_{cut}}$ (pick one hit randomly)

  (RPCs do not generate close-by avalanches)
- Adjust $\mathbf{d_{cut}}$ to reproduce the hit distribution
- Generate predictions for other beam energies
- Generate **pions** at any beam energy







<u>Final parameters</u>

a = 0.13 cm

T = 0.60 pC

$\mathbf{d_{cut}}$ = 0.1 cm ← only needed for electromagnetic showers

(expected to be of the order of the gap size)

Response to Positrons

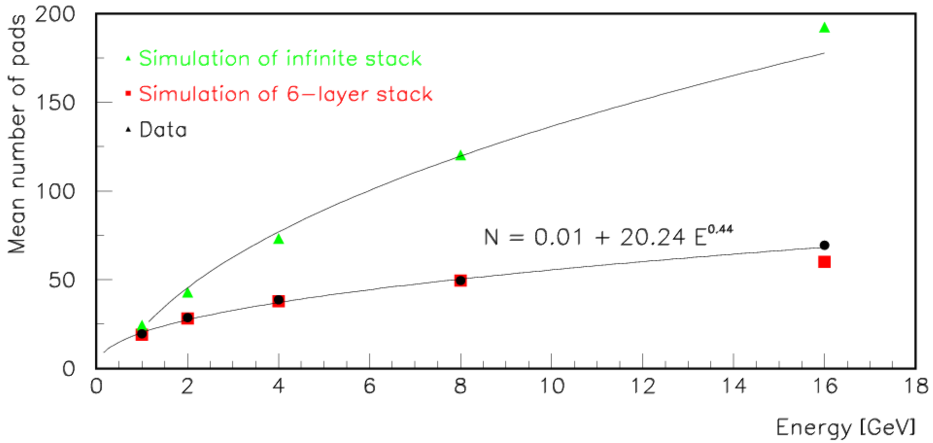
Preliminary: To be published soon

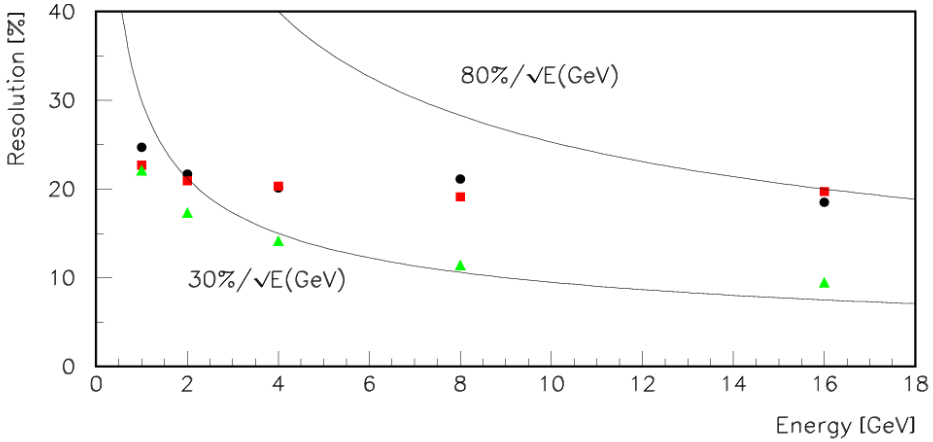
Data at

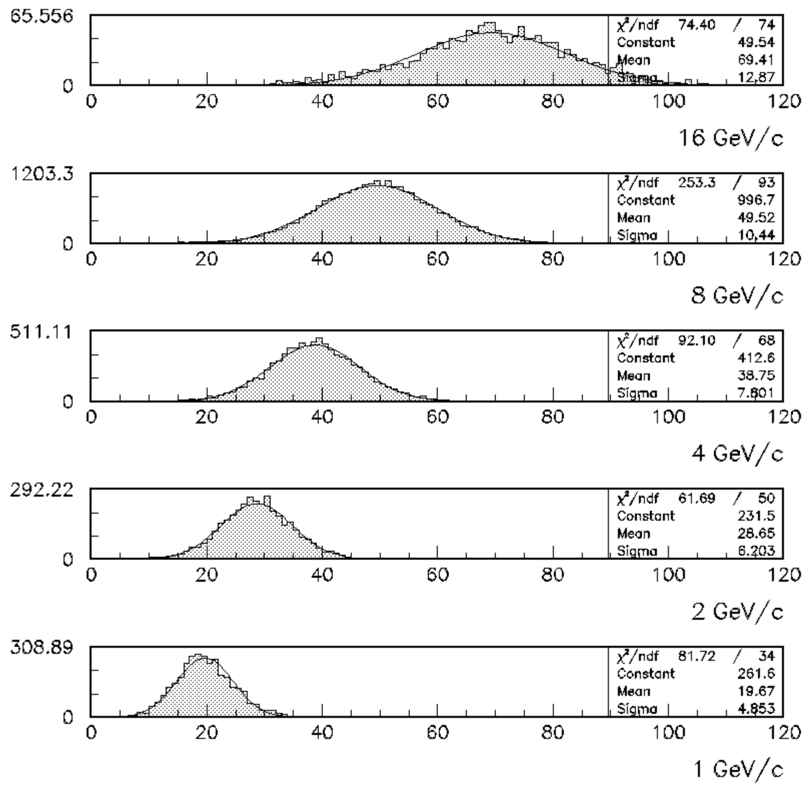
1, 2, 4, 8, 16 GeV (electrons selected by Čerenkov)

Response well fit by Gaussian

Accident!







Monte Carlo simulation

Both mean and sigma well reproduced

Large non-linearity

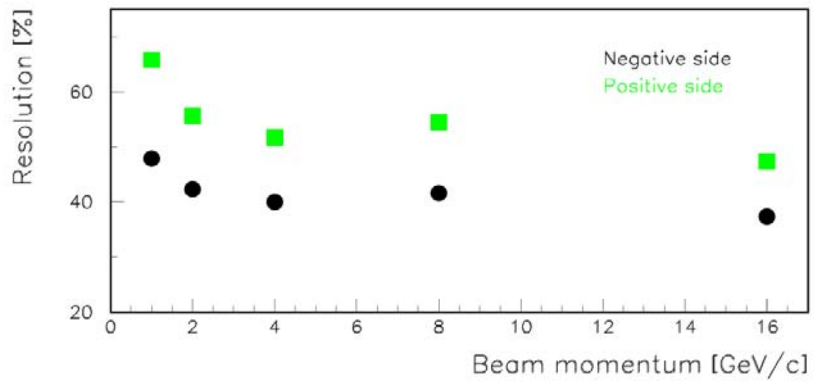
Dominated by leakage out the back (only 6.8 X_0)
Infinite stack – non-linearity due to overlaps in pads

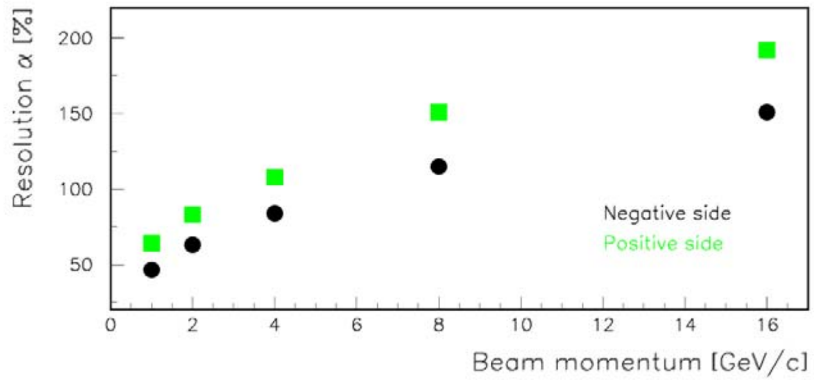
Resolution

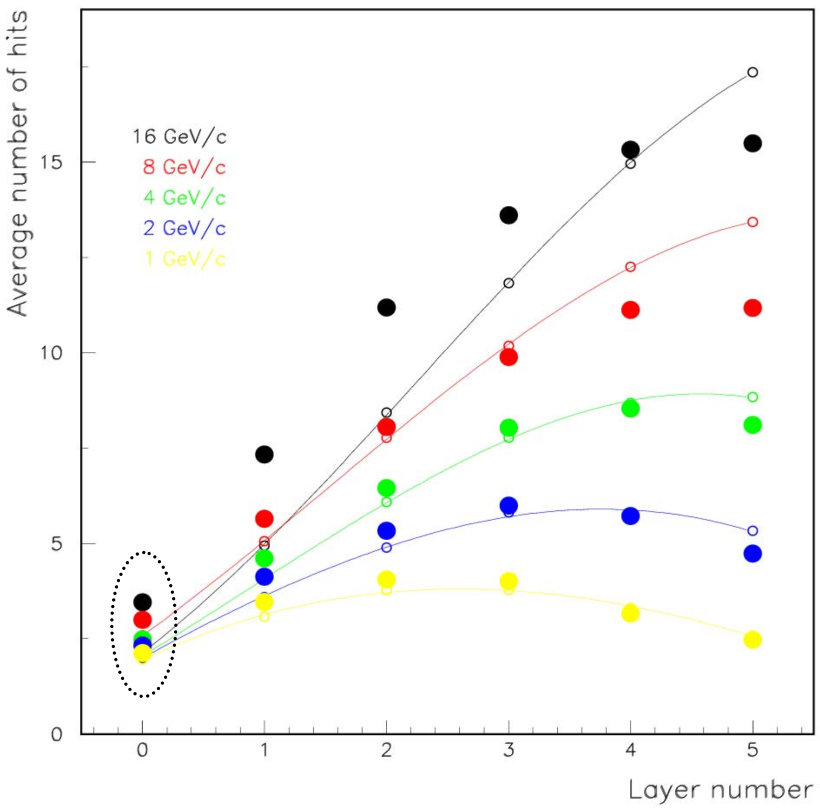
Effect of non-linearity ignored in this plot
Infinite stack – should reach 30%/√E at least

Resolution values corrected for non-linearity

Remember → Dominated by leakage
Effect of overlaps (saturation) secondary







Measurement of longitudinal shower shape

Agreement with simulation adequate (at best)
Simulation - Requires additional material in beam line

Response to Pions

Preliminary: To be published soon

Data at

1, 2, 4, 8, 16 GeV (electrons rejected by Čerenkov)

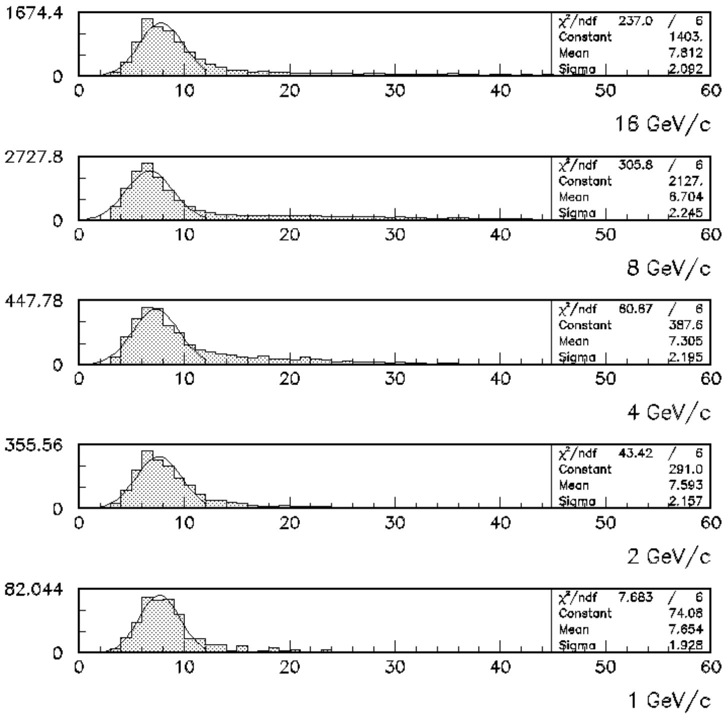
Analysis separates

- Non-interacting pions/muons
- Pions interacting in first layers
- Pions interacting later (rejected)

} { Exactly one cluster in first layer
Distance R< 5
Number of hits in **first** layer <5

MIP selection

Number of hits in **second** layer < 5

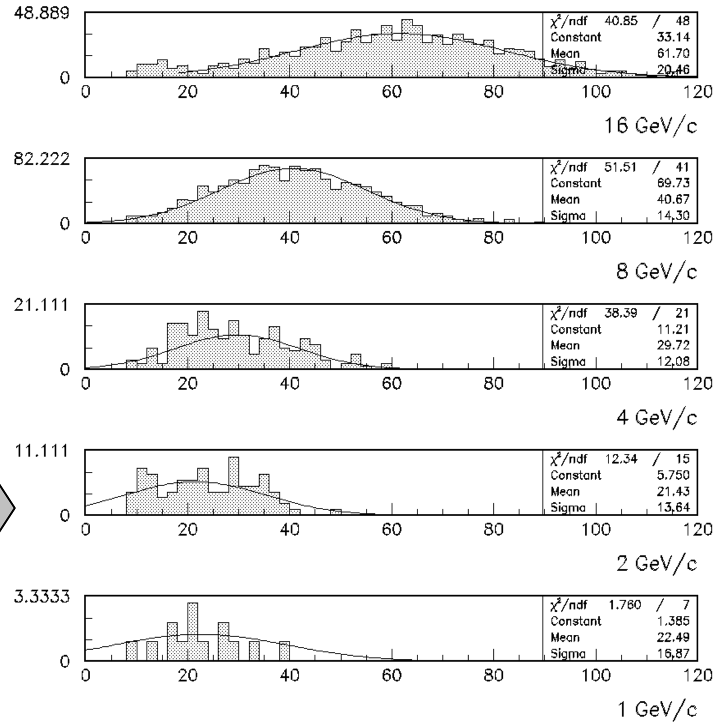


Nice MIP peaks

Gaussian distributions

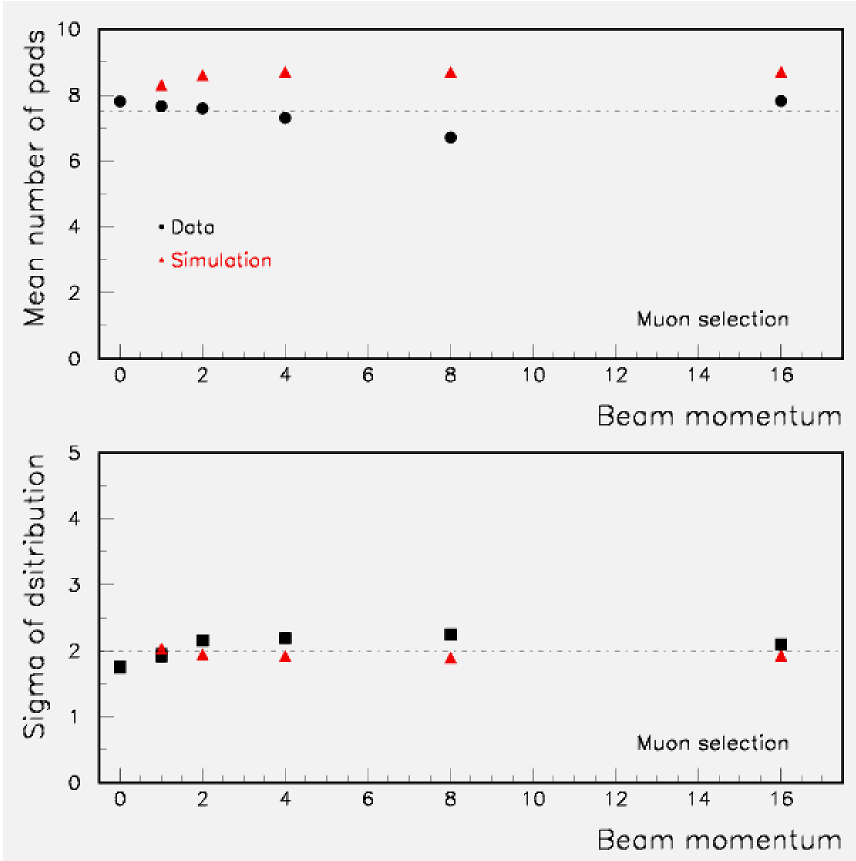
Pion selection

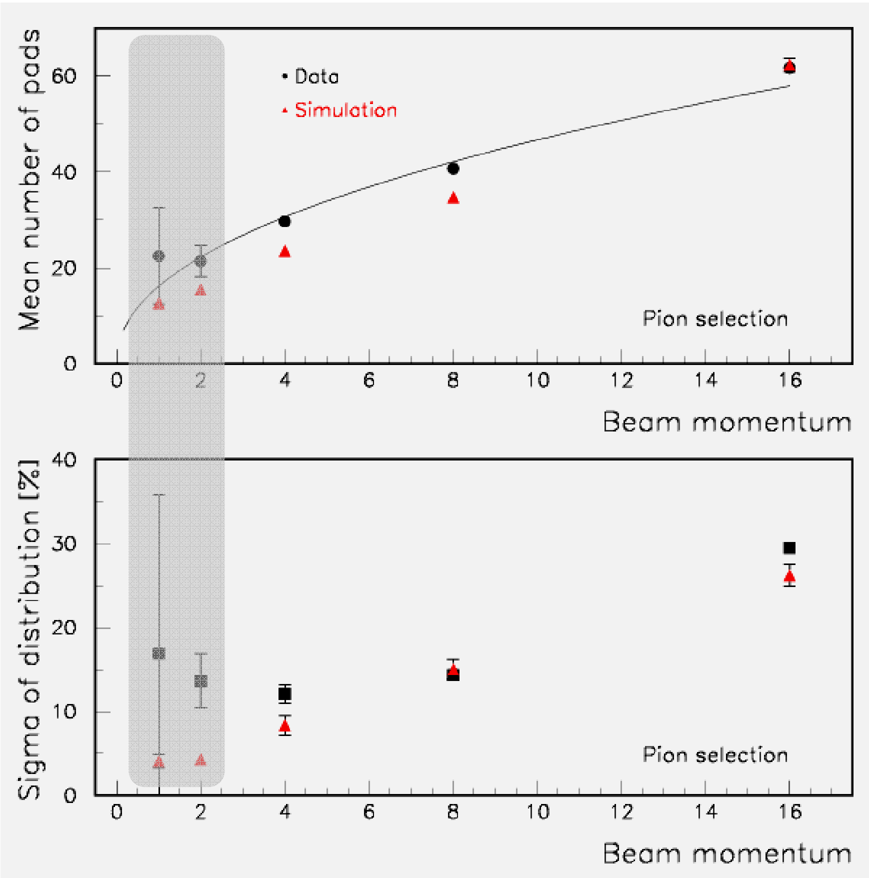
Number of hits in **second** layer ≥ 5



MIP selection

Mean and sigma ~independent of beam momentum
Mean not very well reproduced by simulation
→ Beam contains muons, simulation does not
(data are cleaner !!!)
Width of distributions adequately reproduced





Pion selection

Measurements at 16, 8 and 4GeV/c
Not sufficient statistics at 2, 1 GeV/c
Non-linearity due to leakage
Adequate agreement with simulation

IV Construction of a 1 m^3 Prototype section

Larger prototype section needed to

Measure hadronic showers in detail
Gain experience with larger system
Compare performance with scintillator approach to granulated calorimetry

Description of the prototype section

40 active layers each 1 x 1 m^2
Each layer contains 3 chambers with an area of 32 x 96 cm^2
1 x 1 cm^2 pads read out with 1 – bit resolution → 400,000 channels
Absorber structure and test beam stage from CALICE Analog HCAL

Status

Larger chambers being tested (32 x 96 cm^2)
Assembly for chamber production and test procedures being developed
Final touches to design of front-end ASIC → submission in July (engineering run → ~8,000 chips)
Redesign of pad- and front-end boards → tested successfully
Redesign of data concentrator ongoing
(Data Collector and TTM module designs final)

Plan

Construction of 10 layers by early 2009
Followed by tests in Fermilab test beam
Construction of remaining layers in 2009
Followed by tests in Fermilab test beam

V Further Developments

1 – glass RPCs

Investigation of ways to protect the front-end electronics from sparks
→ Need more than the protection diodes inside ASIC
(so far has not created problems!)

Front-end readout

Investigation of ways to **increase multiplexing**

increase number of channels for the front-end chip
token ring passing between chips
….

Investigation of ways to **reduce the thickness** of the readout boards

embedded ASICs, non-packaged ASICs…

Implementation of **power pulsing**

tuned to the timing of the ILC bunch crossings
reduced power consumption

Conclusions

Development of a Digital Hadron Calorimeter for the PFA approach

Resistive Plate Chambers as active elements
Readout pads with an area of 1 x 1 cm^2

Resistive Plate Chambers

Investigated both the traditional 2-glass and the exotic 1-glass design
Excellent performance for calorimetry
→ **G.Drake et al., Nucl. Instr. Meth. A578, 88 (2007)**

Vertical Slice Test with Small Prototype Calorimeter

Contained up to 10 RPCs
Tested entire readout chain
Very successful
- Calibration with muons → **B.Bilki et al., 2008 JINST 3 P05001**
- Response to positrons → **To be published soon**
- Response to pions → **To be published soon**
- Rate capability measurements → Data not yet analyzed

} Reasonable agreement with simulation

⇓

Validation of concept of Digital Hadron Calorimetry

1 m^3 prototype section

Preparing for construction
10 – layer stack by early 2009
Complete 40 – layer stack later in the year