A Hadron Calorimeter with Resistive Plate Chambers

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CALOR 2006, Chicago, June 5 – 9, 2006

Within the paradigm of PFAs

- Role of calorimeter is to measure energy of neutrals (γ's, neutrons and K_L^0)
- Major challenge is to disentangle energy from charged and neutral particles in a jet
- Keeping the 'confusion' under control is more important than optimization for single particle resolution

Requirements for the Hadron Calorimeter

1) **Extremely fine segmentation of the readout**

→ O(1 x 1 cm^2 laterally, layer – by – layer longitudinally)
→ Large number of channels → requires multiplexing early on → reliable electronics located inside calorimeter

2) **Located inside high – field coil**

→ operation in high magnetic field
→ thin active element (cost of coil!)

3) **Active element with large area**

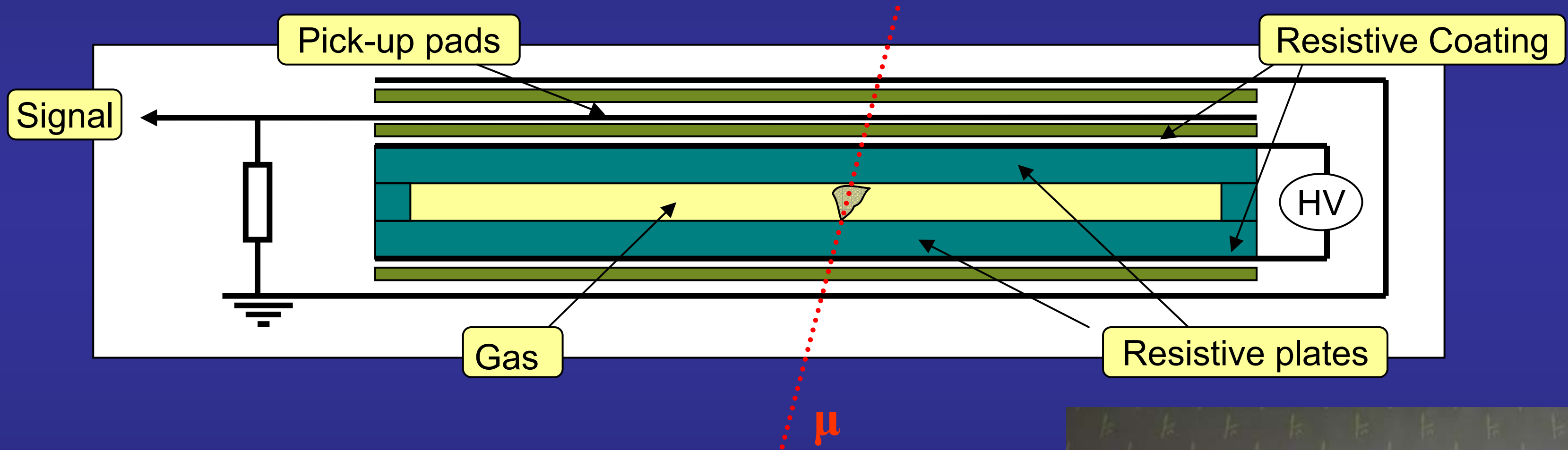
→ O(5,000 m^2)
→ affordable technique (silicon most likely not possible)

Resistive Plate Chambers

are…

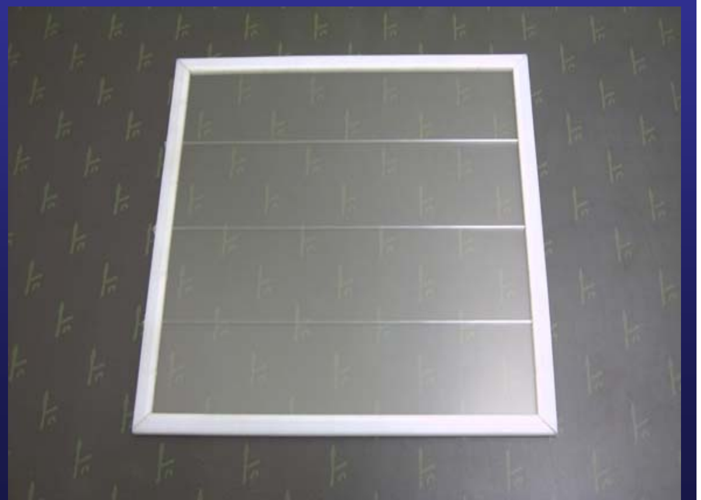
Simple, robust, cheap, quiet, well understood, reliable
Adaptable to different requirements (TOF, high efficiency, large area…)

No ageing ever observed with glass RPCs



Pick-up pads

Can be small: O(1 mm)
Can be stripes or pads



Argonne, Boston, Chicago, Fermilab, Iowa

ITEP Protvino

RPC: Design Choices for HCAL

Resistive plates

Glass with a thickness of 1.1 mm
Commercially available
Bulk resistivity $\rho \sim 4.7 \cdot 10^{12}\ \Omega$cm

Resistive paint

Surface resistivity $\sigma \sim 50\ M\Omega/\square$
Applied with silk screening techniques

Gas gap

Defined fishing lines → 1.2 mm

Operation in

Avalanche mode

Gas mixture

95:5:0.5 = R134A:Isobutane:SF_6

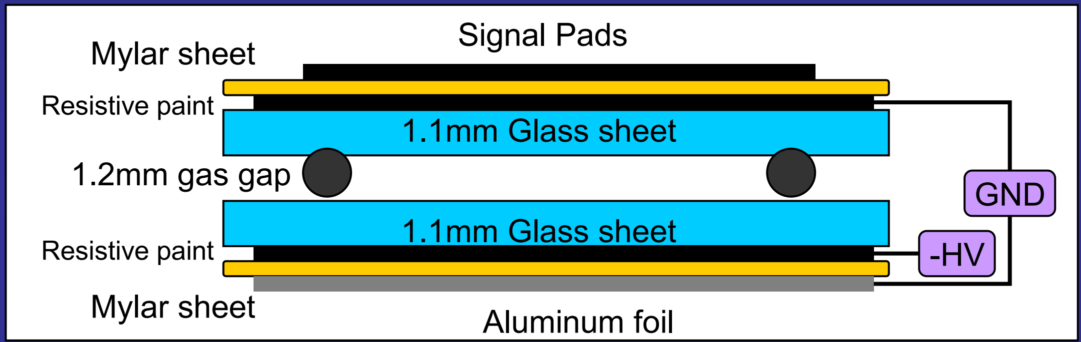
Readout pads

Squares with an area of 1 x 1 cm^2

Explored 2 different designs

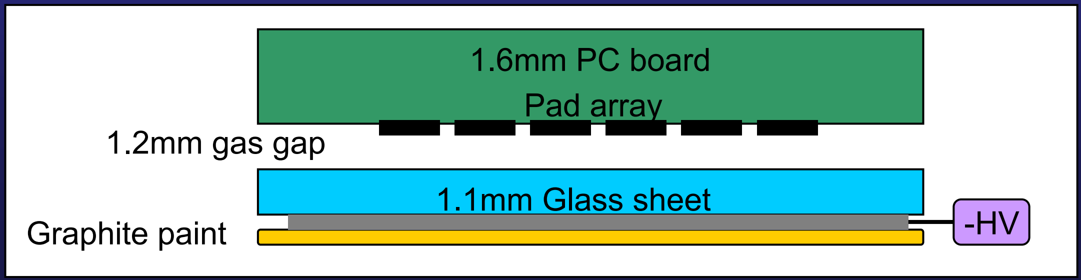
A) Standard Design: AIR5

2 glass plates: cathode and anode



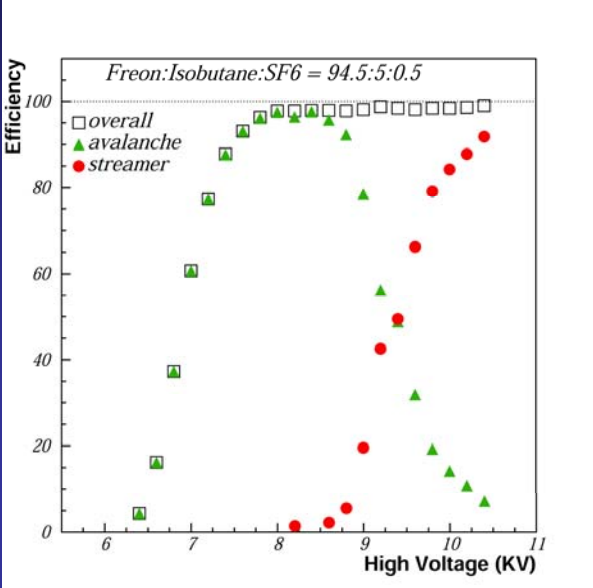
B) 'Exotic' Design: AIR9

1 glass plate: cathode
Readout pads serve as anode

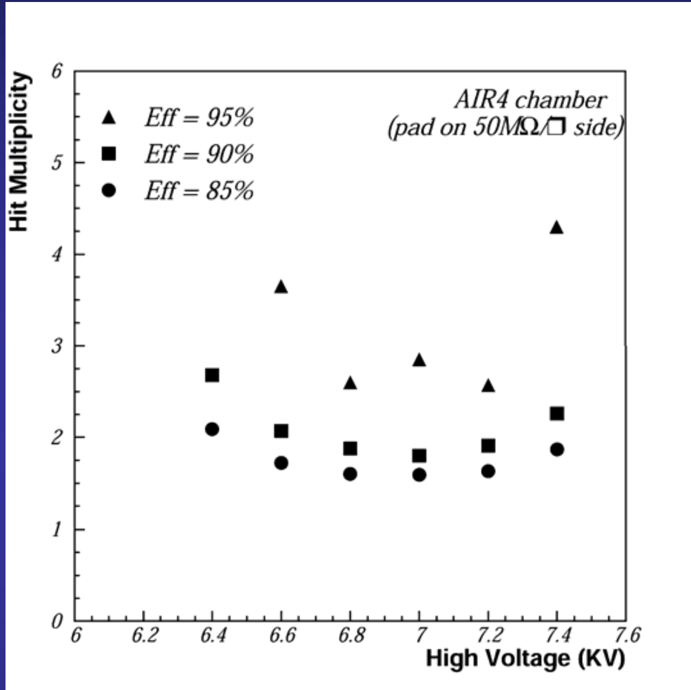


RPC tests

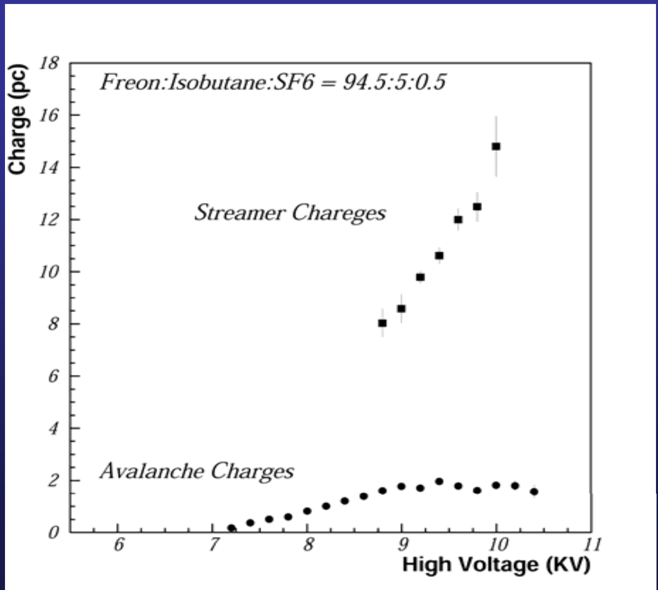
cosmic rays and
analog (=multi-bit) **readout**



Measurement of MIP detection efficiency and streamer fraction



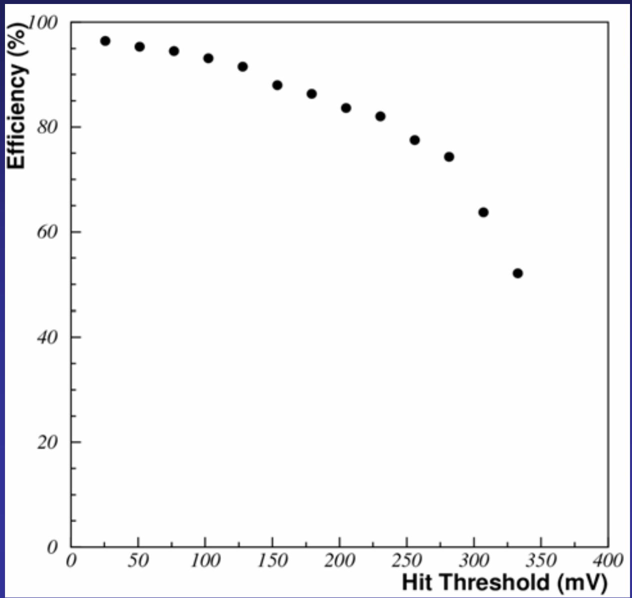
Measurement of pad multiplicity for different MIP detection efficiencies (adjustment of threshold)



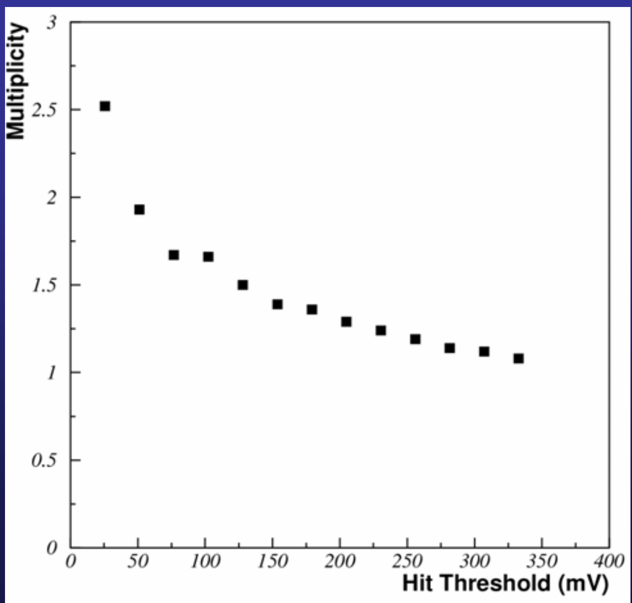
Measurement of signal charges in avalanche and streamer mode

RPC tests

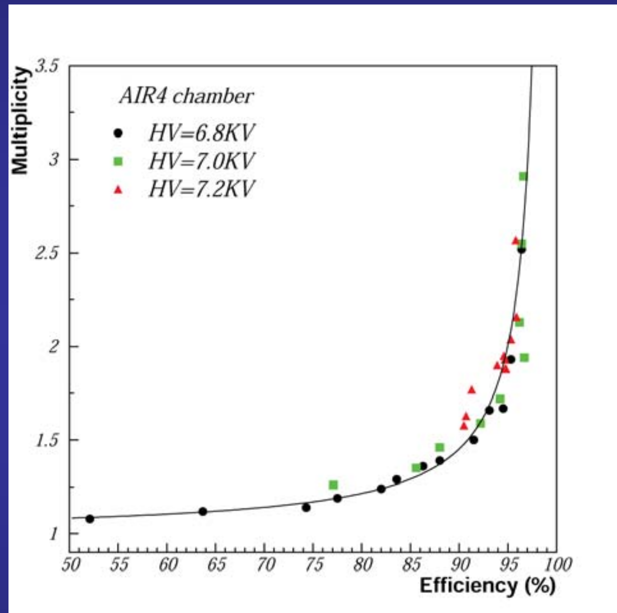
cosmic rays and digital (=single-bit) readout



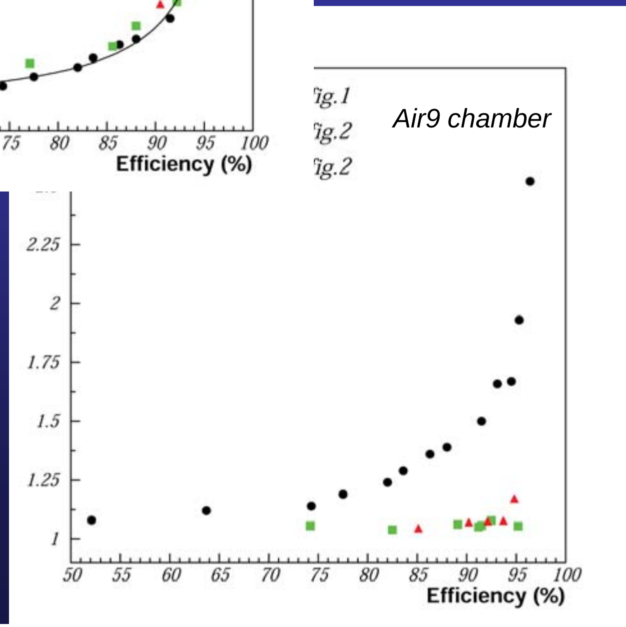
MIP detection efficiency versus threshold



Pad multiplicity versus threshold

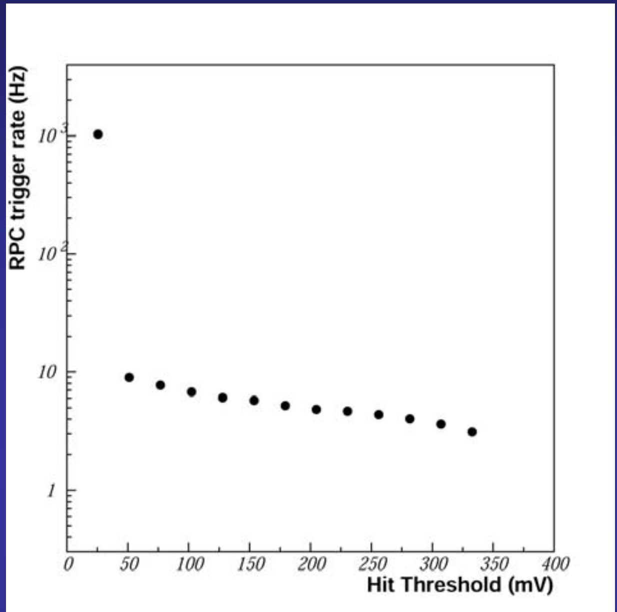


Comparison with exotic chamber

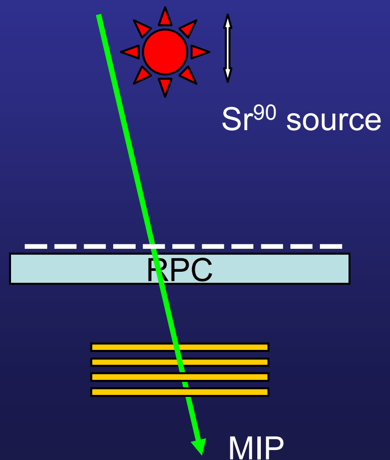


RPC tests

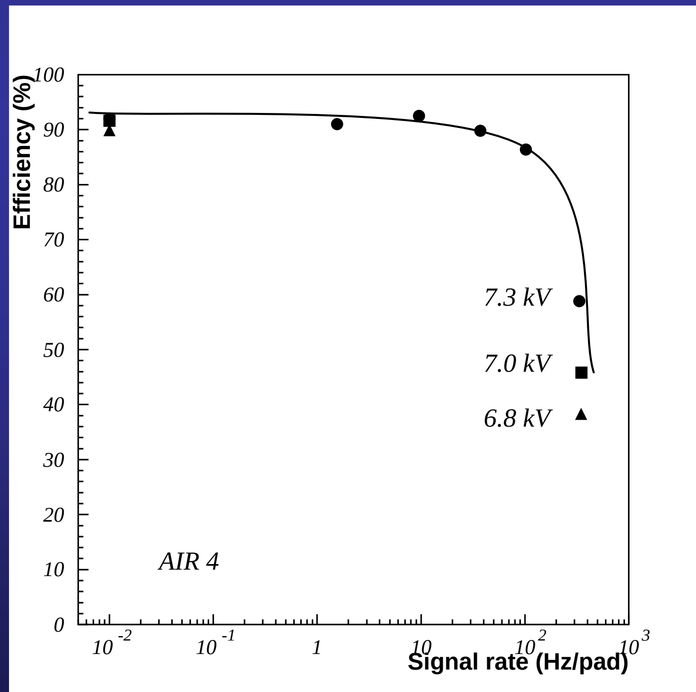
cosmic rays and digital (=single-bit) readout



Noise rate versus threshold



MIP detection efficiency versus rate



RPC tests

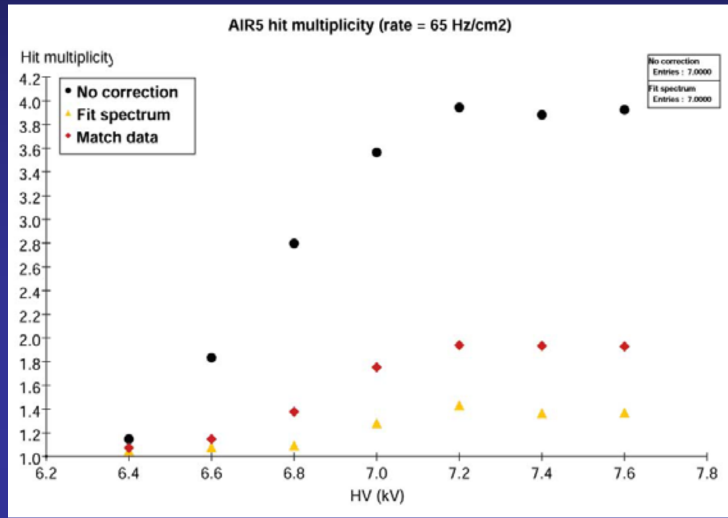
particle beams and digital (=single-bit) readout

Tests at MTBF (FNAL)

120 GeV/c protons

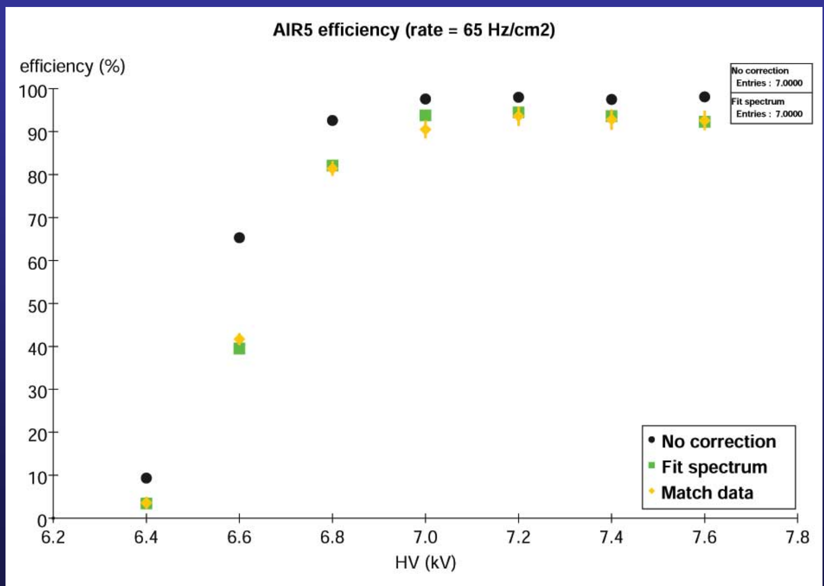
Set-up off beam axis → high particle multiplicity

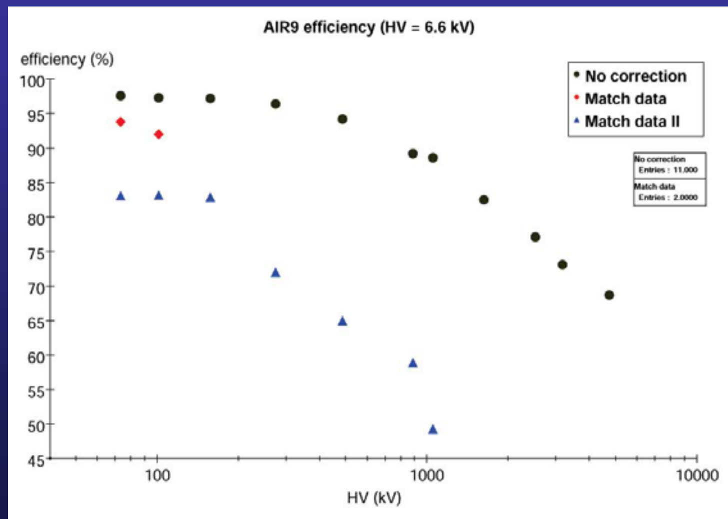
Unintentional!
Trigger selects events from upstream showers
Complicated correction procedure applied to
determine efficiency and pad multiplicity



Pad multiplicity

MIP detection efficiency





MIP detection efficiency versus trigger rate

Conclusions from RPC tests

Large signals in avalanche mode

Q in the range 100 fC ↔ 2 pC

MIP detection efficiency very high

ε_{MIP} close to 100%

Pad multiplicity

Lower with single-bit readout (short integration time)
Standard design ~1.6 for an ε_{MIP} = 95%
Exotic design ~ 1.1 for any ε_{MIP}

Noise rate very low

N_{noise} < 1 Hz/cm^2

Rate capability limited

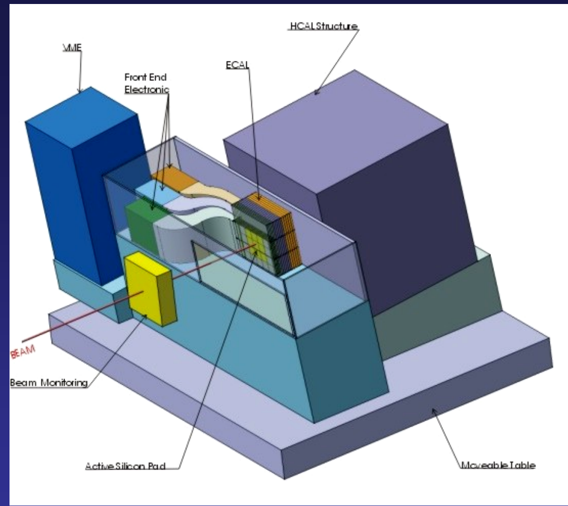
ε_{MIP} drops for dN/dt > 50 Hz/cm^2
Probably an underestimation

Results from cosmic rays and test beams are consistent

Chambers perform as required for the active element of a hadron calorimeter

Chambers technology in hand to proceed to the construction of a prototype calorimeter

HCAL R&D Goal



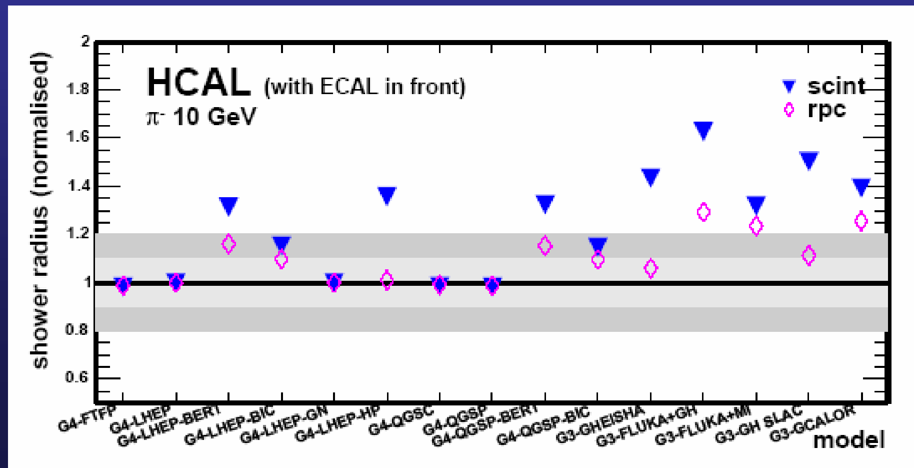
Prototype section (PS)

1 m^3 (to contain most of hadronic showers)
40 layers with 20 mm steel plates as absorber
Lateral readout segmentation: 1 cm^2
Longitudinal readout segmentation: layer-by-layer
Instrumented with Resistive Plate Chambers (RPCs) and Gas Electron Multipliers (GEMs)

Motivation for construction of PS and beam tests

Validate RPC and GEM approach (technique and physics)
Validate concept of the electronic readout
Measure hadronic showers with unprecedented resolution
Validate MC simulation of hadronic showers
Compare with results from Scintillator HCAL

Comparison of hadron shower simulation codes by G Mavromanolakis



Electronic Readout System for Prototype Section

40 layers à 1 m^2 $\rightarrow$ 400,000 readout channels

More than all of DØ in Run I

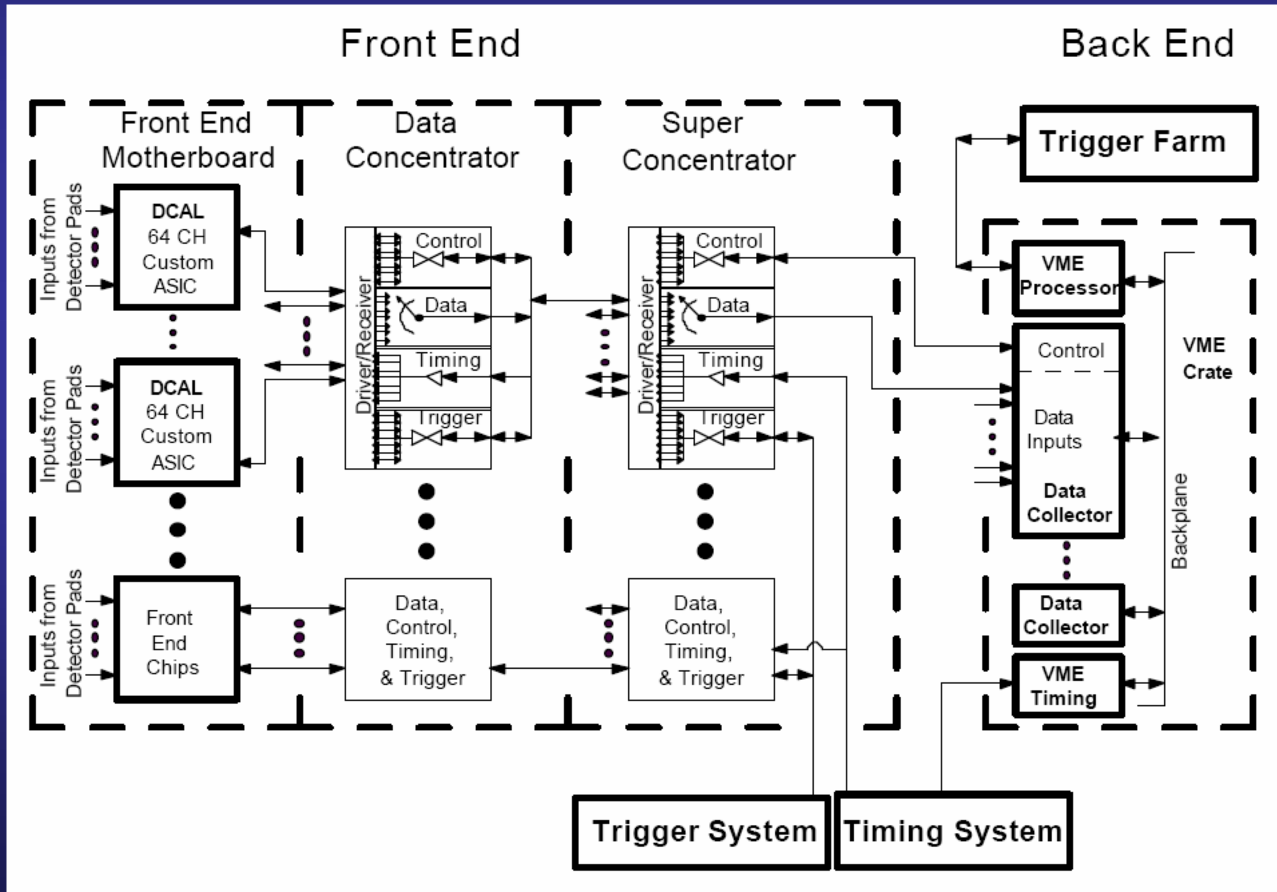
I Front-end ASIC and motherboard

II Data concentrator

III Super Concentrator

IV VME data collection

V Trigger and timing system



The DCAL chip

Specifications

Developed to readout digital (hadron) calorimeters

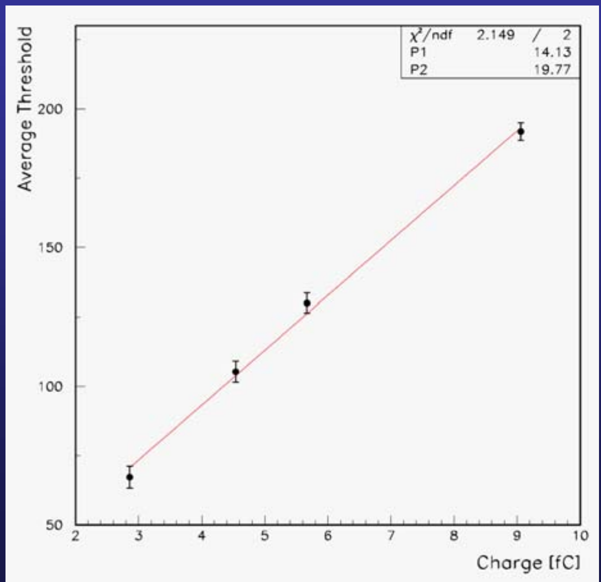
64 inputs with choice of input gains

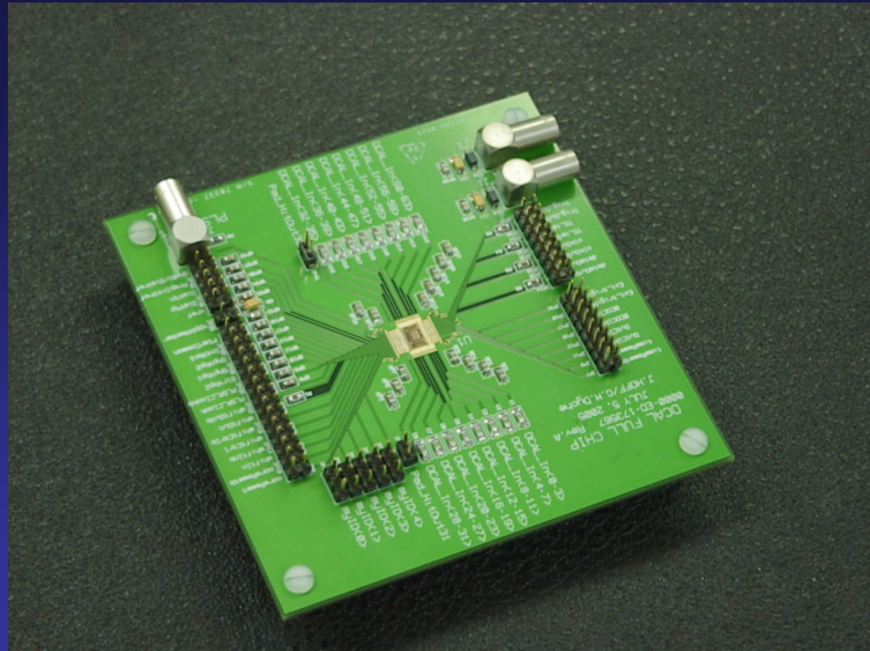
→ RPCs (streamer and avalanche), GEMs…

Triggerless or triggered operation

100 ns clock cycle

Output: hit pattern and time stamp





History of development

Designed by FNAL

Prototype run submitted on March 18th 2005

→ 40 unpackaged chips

2 chips mounted on test boards (wire bonded)

Extensive tests began in July 2005…

Chips perform as expected

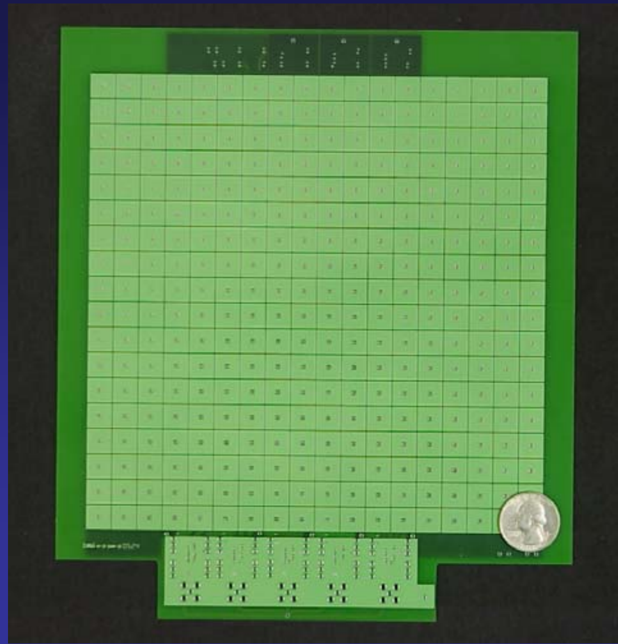
Redesign started for 2nd (and last) prototype submission

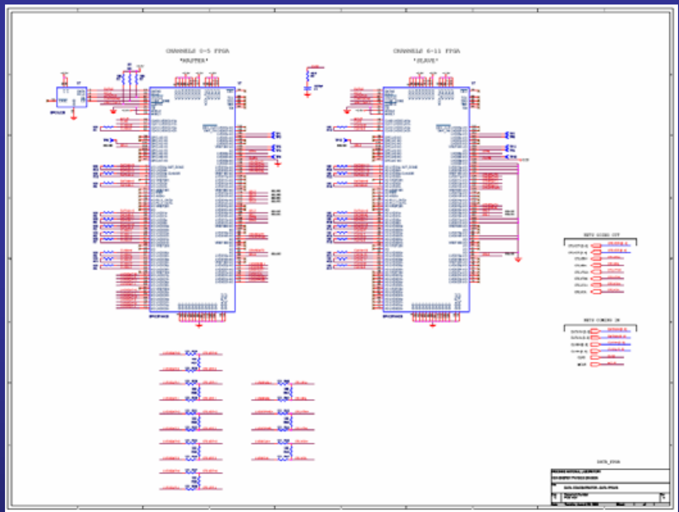
→ Decrease sensitivity of front-end

Remainder of the system

Front-end boards

Prototype boards tested
Cross talk between digital and analog lines ~ 11 fC
Better grounding schemes being investigated





Data concentrator boards

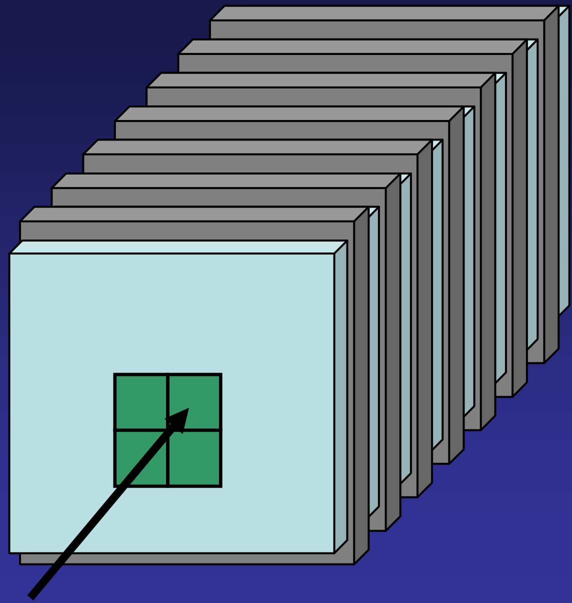
Readout 12 front-end ASICs
Provide clock, trigger etc. to front-end
Design work started

Back-end

Several options being evaluated

1) Use of CALICE Tile-cal back-end
2) Use of BTeV back-end at MTBF
3) Develop new system

Slice test



Uses the 40 DCAL ASICs from the 2nd prototype run

Equip ~8 chambers with 4 DCAL chips each

256 channels/chamber
~2000 channels total

Chambers interleaved with 20 mm steel absorber plates

Electronic readout system identical to the one of the prototype section

Tests in MTBF beam planned for January 2007

→ Measure efficiency, pad multiplicity, rate capability of individual chambers
→ Measure hadronic showers and compare to simulation

Validate RPC approach to calorimetry

Validate concept of electronic readout

Future Developments beyond the Prototype Section

Resistive plate chambers

More tests with exotic design (thinner!)

Increase sensitivity to neutrons (gadolinium?)

Long term tests (years)

Experience with prototype section will provide specific guidance

Electronic readout

Finer segmentation of readout	1 x 1 cm^2 → ?
Finer timing resolution	100 ns → ?
Thinner front-end boards	~ 3 mm → 1 mm?
Higher multiplexing at front-end	64 → ? Channels/ASIC
Higher multiplexing at back-end	Token rings?
Power pulsing of front-end	Eliminate need for cooling

Train structure of ILC beams

Nominal baseline design

2820 bunches/train
307.7 ns bunch length
5 trains per second

Collisions during 0.43% of running time

Turn power down between collisions

Power consumption negligible
No cooling needed

Conclusions

► Application of PFAs require fine grained calorimeters

► Resistive Plate Chambers provide an excellent choice for the active media of the HCAL

► R&D on the chambers is completed with tests using cosmic rays as well as test beams

► Preparation for a slice test are under way

► Assuming

a) the slice test is successful
b) funding is being provided

construction of 1 m^3 prototype section will initiate in 2007

► First results from tests in particle beams are expected by 2008

► R&D beyond the prototype section will start soon…