Development of a Digital Hadron Calorimeter with Resistive Plate Chambers

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Calorimetry at the Linear Collider

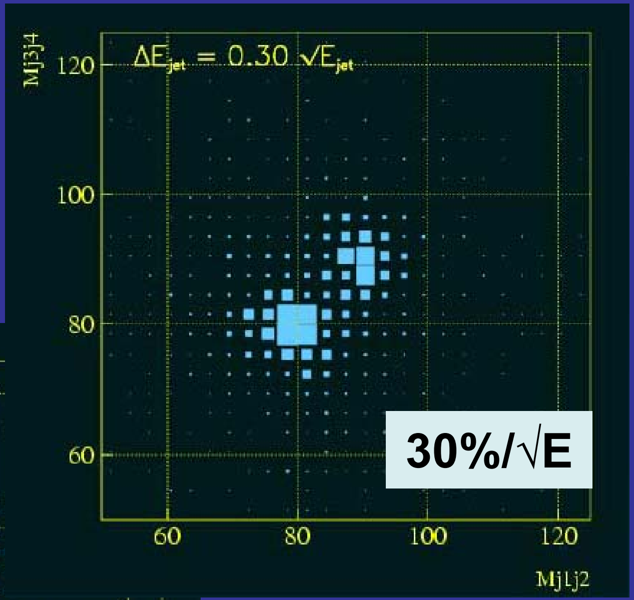
Many ‘interesting’ final states involve 2-10 jets
Benchmark process: $e^+e^- \rightarrow$ VVνν
Separation of WW and ZZ → 4 jets

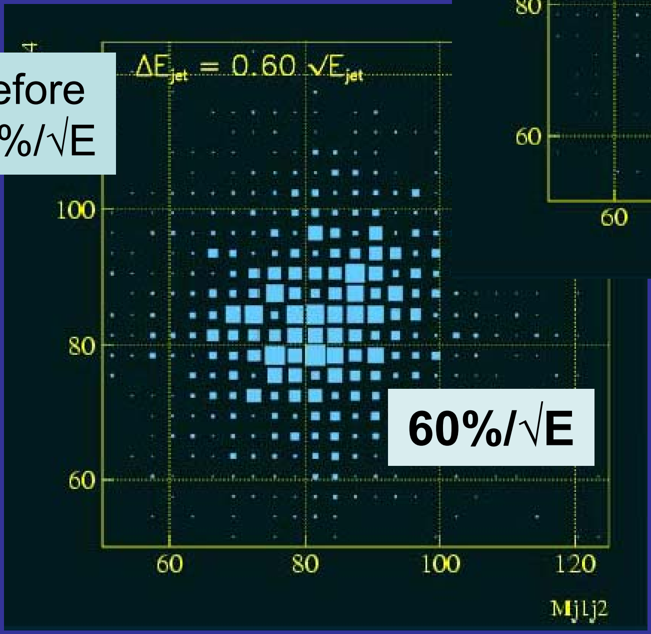
Requires excellent resolution: *O*(30%/√E)

→ Has never been achieved before
→ Best so far: ZEUS with ~ 50%/√E

New approach:
Energy flow algorithms

From H.Videau





Why a Digital Hadron Calorimeter?

Segmentation

EFA rely on separation of the different components of hadronic jets

Very fine segmentation needed ~ $1 cm^2$

Active area of LCD HCAL: $5000\ m^2$

Leads to $50\cdot10^6$ channels

→ **'Difficult' to read out analog**

Components of Jets	Fraction of Energy in %	Detector
Charged particles	60	Tracker
Photons	20	EM calorimeter
Neutral Hadrons (K^0_L,n)	10	EM and HAD calorimeter
Neutrinos	10	Lost

Counting tracks

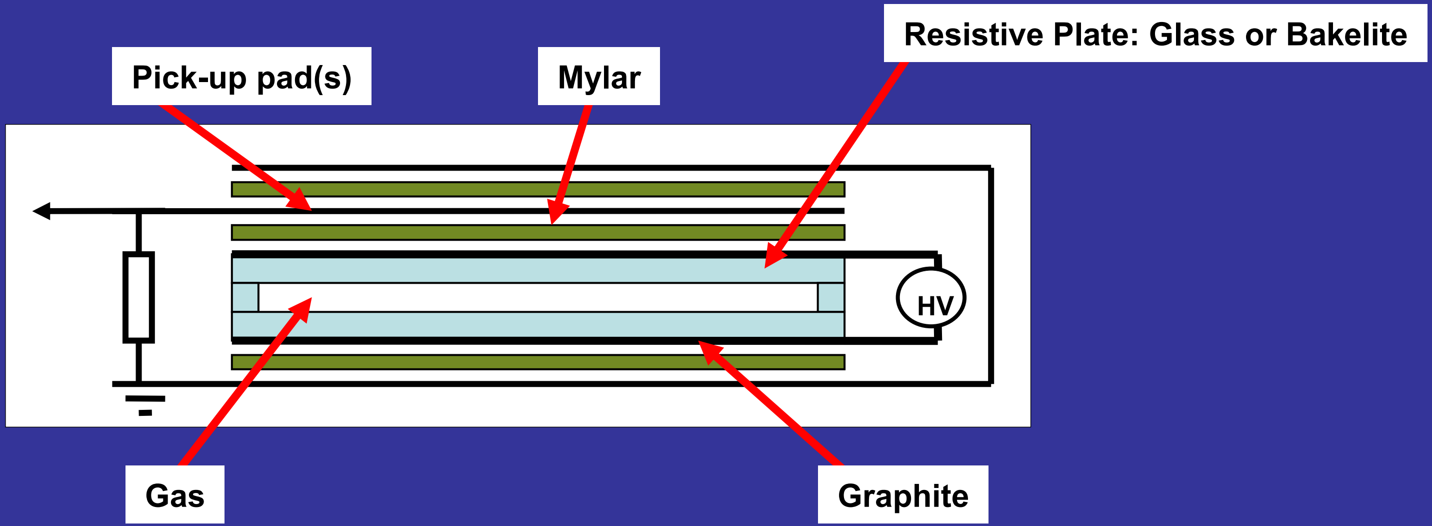
Sandwich calorimeters count tracks crossing active layer $E \propto N_{trk}$

Analog readout: sums ΔE in active layer
subject to Landau fluctuations
Digital readout: counts track independent of ΔE

→ $\sigma_E^{digital}/E \leq \sigma_E^{analog}/E$

Why Resistive Plate Chambers?

Conceptual design



Simple, cheap, robust, low noise
Many parameters to be adjusted to specific application

- Material, thickness, resistivity of resistive plates
- Thickness of gas gap, choice of gas
- Number of gas gaps
- Resistivity of graphite layer
- Distance of pads to ground layer
- ….

Resistive Plate Chambers in HEP

Experiment	Status	Subsystem	Resistive Plates	Gaps
L3	Completed	μ Spectrometer	Bakelite	2
HARP	Completed	TOF	Glass	4
BaBar	Operational	K_L/μ	Bakelite	1
Belle	Operational	K_L/μ	Glass	2x1
MONOLITH	Not approved	Calorimeter	Glass	1
ALICE	Being built	TOF	Glass	5
ATLAS	Being built	μ Spectrometer	Bakelite	1
CMS	Being built	μ Spectrometer	Bakelite	2
LHCb	Being built	μ Spectrometer	Bakelite	2x1

In general reliable…

Our Collaboration

Argonne National Laboratory

I Ambats, G Drake, V Guarino, J Repond, D Underwood, B Wicklund, L Xia

Boston University

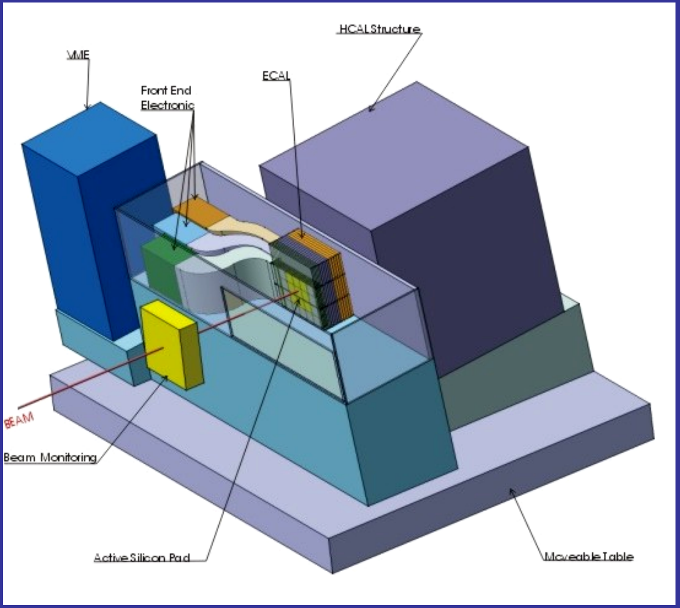
J Butler, M Narain

Fermilab

(M Albrow), C Nelson, R Yarema, (A Para, V Makeeva)

University of Chicago

K Anderson, E Blucher, J Pilcher, M Oreglia, H Sanders, F Tang



Our Goals

Develop the technologies

Chambers and readout

Build 1 m^3 DHCAL prototype section

Design considerations

Avalanche mode → **smaller signals**

⇒ **improved longevity**
reduced cross-talk
no multiple streamers
better rate capability

No evidence of aging effects

Multi-gap → **smaller signals**
less streamers

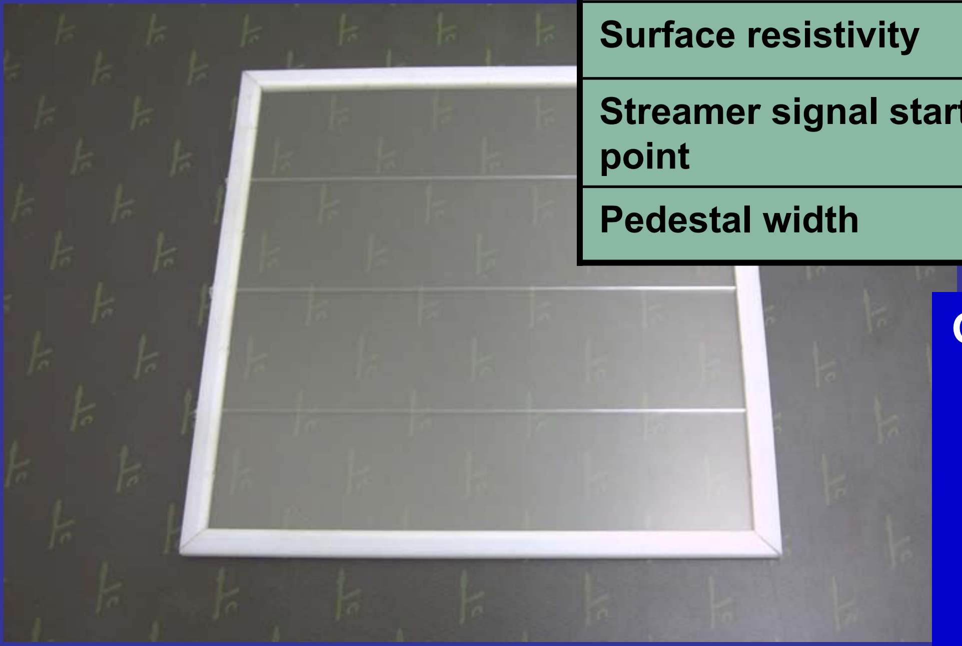
⇒ **improved longevity**
reduced cross-talk
better rate capability

High-resistive graphite layer

⇒ **reduced cross-talk**

Test chamber design and construction

Name of chamber	AIR0	AIR1	AIR2
Date of construction	11/2002	1/2003	1/2003
Active area	20x20 cm^2	20x20 cm^2	20x20 cm^2
Number of gas gaps	2	2	2
Glass thickness	0.85 mm	1.1 mm	1.1 mm
Thickness of gas gap	0.64 mm	0.64 mm	0.64 mm
Resistive layer	Graphite	Ink	Ink
Surface resistivity	~300 kΩ/□	~200 kΩ/□	~1200 kΩ/□
Streamer signal starting point	7.5 kV	6.7 kV	6.6 kV
Pedestal width	~15 fC	~8 fC	~8 fC



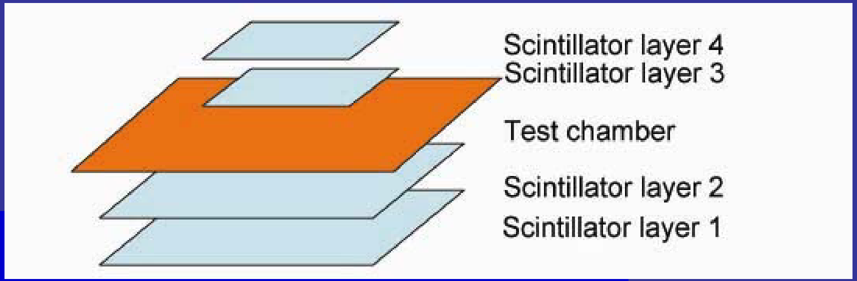
Gas mixture

Freon/Argon/IsoButane = 62:30:8

In future

Freon/IsoButane/SulfurHexafluoride = 92:5:3

Cosmic Ray test set-up



Trigger

Cosmic ray telescope with 4 layers of scintillator
Rate ~1Hz

Data acquisition

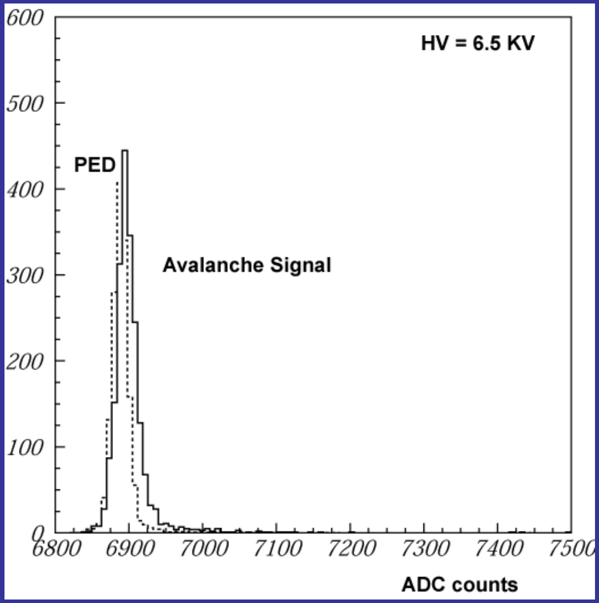
Charge integration
Gate between 700 ns and 20μs
Readout up to ~40 channels

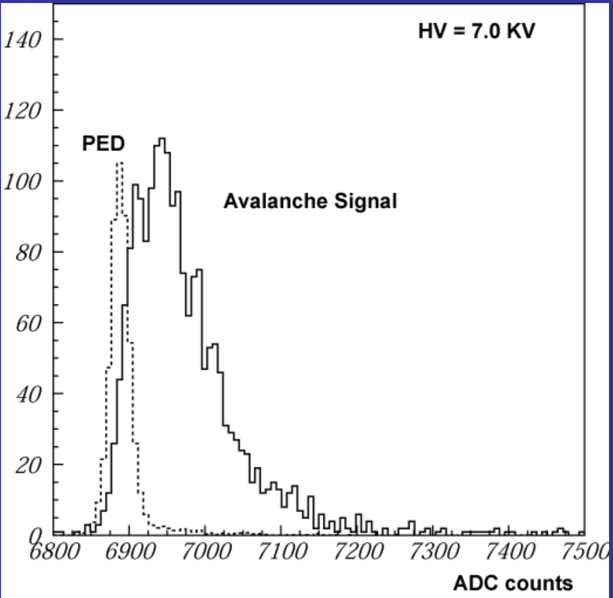
Alternative tests

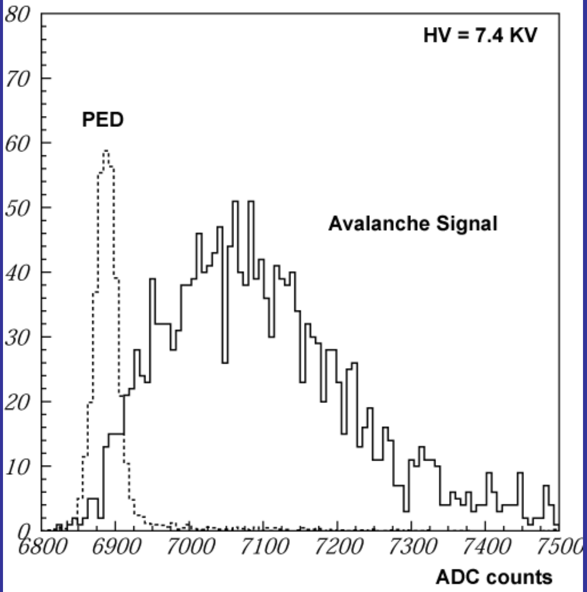
Amplifier, shaper, discriminator

Tests with single pads

Avalanche mode



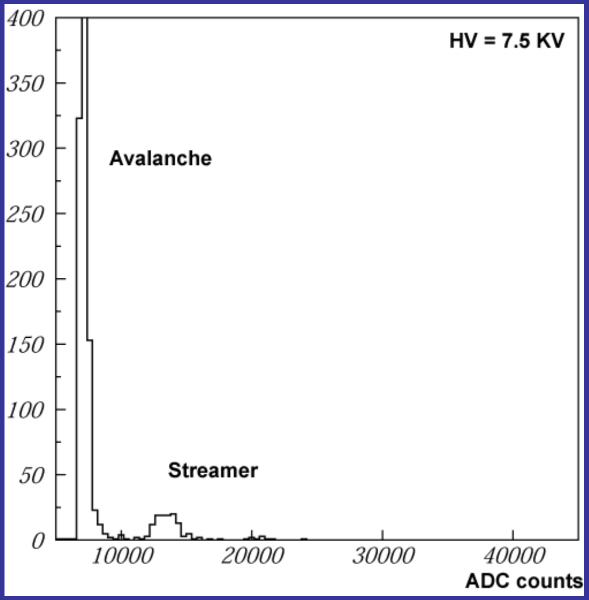


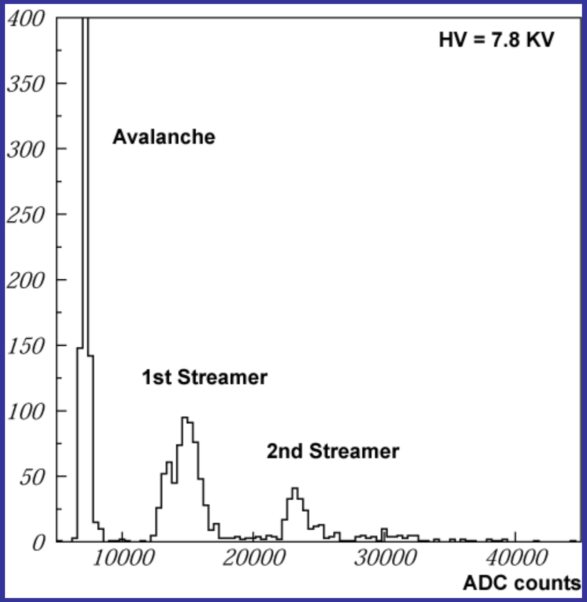


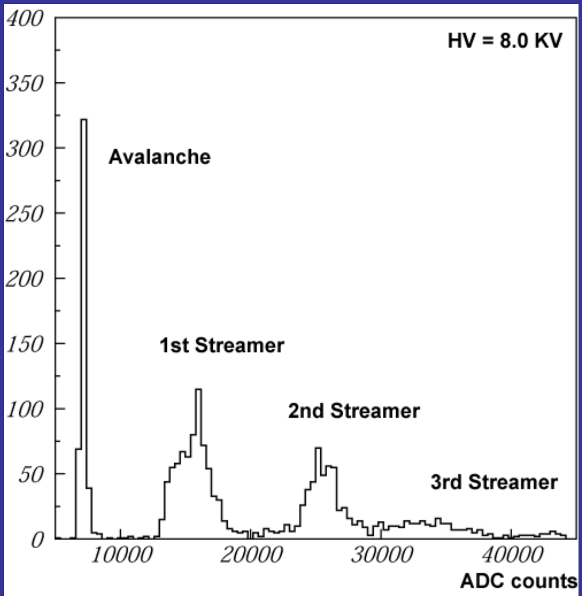
Total charge of signal increases with HV

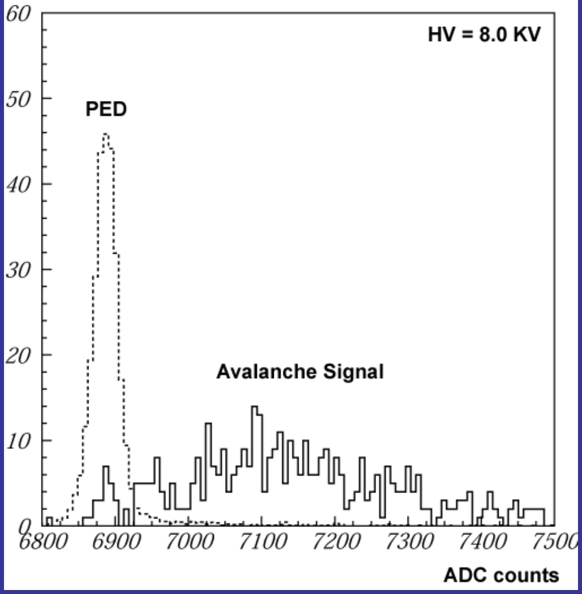
At 7.4 kV Signal ~ 0.2 pC

…and streamer mode









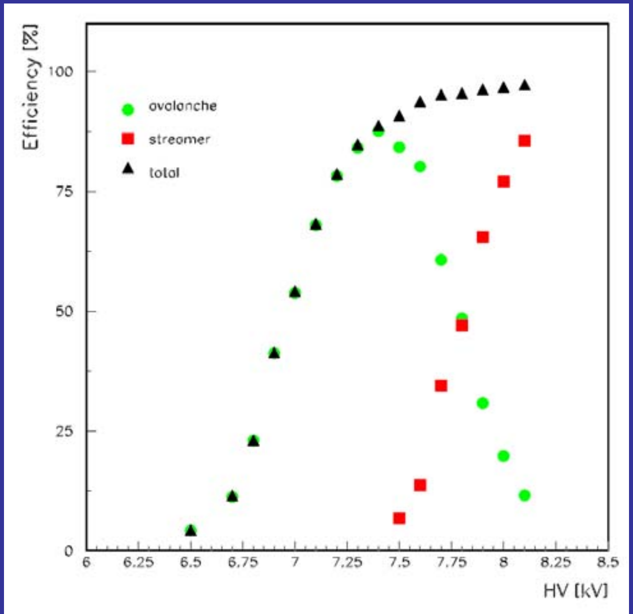
Total charge of signal increases with HV

⇒ **At 8.0 kV Signal ~ 10 pC**

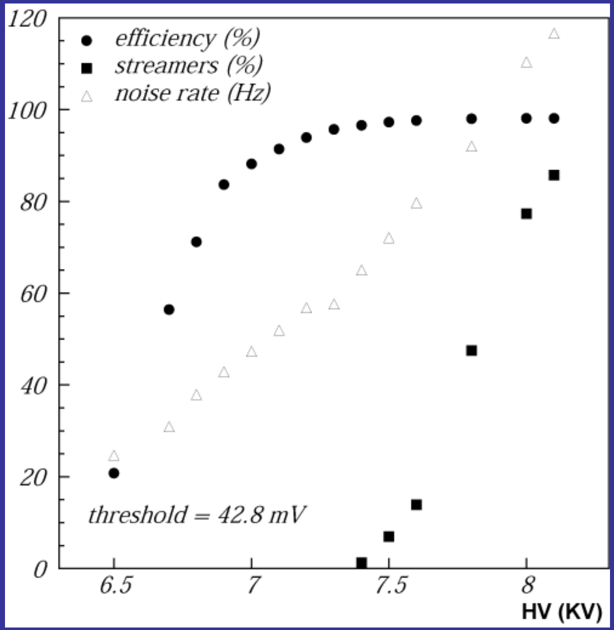
Significant amount of multi-streamers and of avalanches

Measurements of efficiencies

Counting charges above Q_0



Counting events above V_0



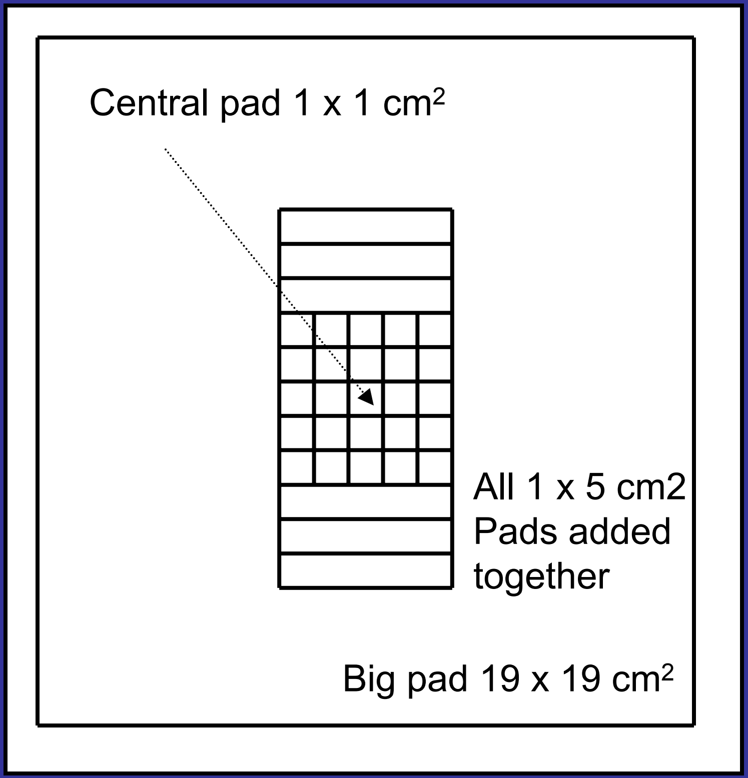
Efficiency greater than 90%
in avalanche mode (plateau ~200V)
Small fraction of streamers

Efficiency greater than 90%
in avalanche mode (plateau ~300V)
Small fraction of streamers
Noise rate ~50Hz for avalanche mode

This is low!

Analysis of Multi-pad Data

Pad structure



Readout system and analysis

RABBIT system
Records charges
Calibration: 1.1fC/ADC count
Pedestal subtracted

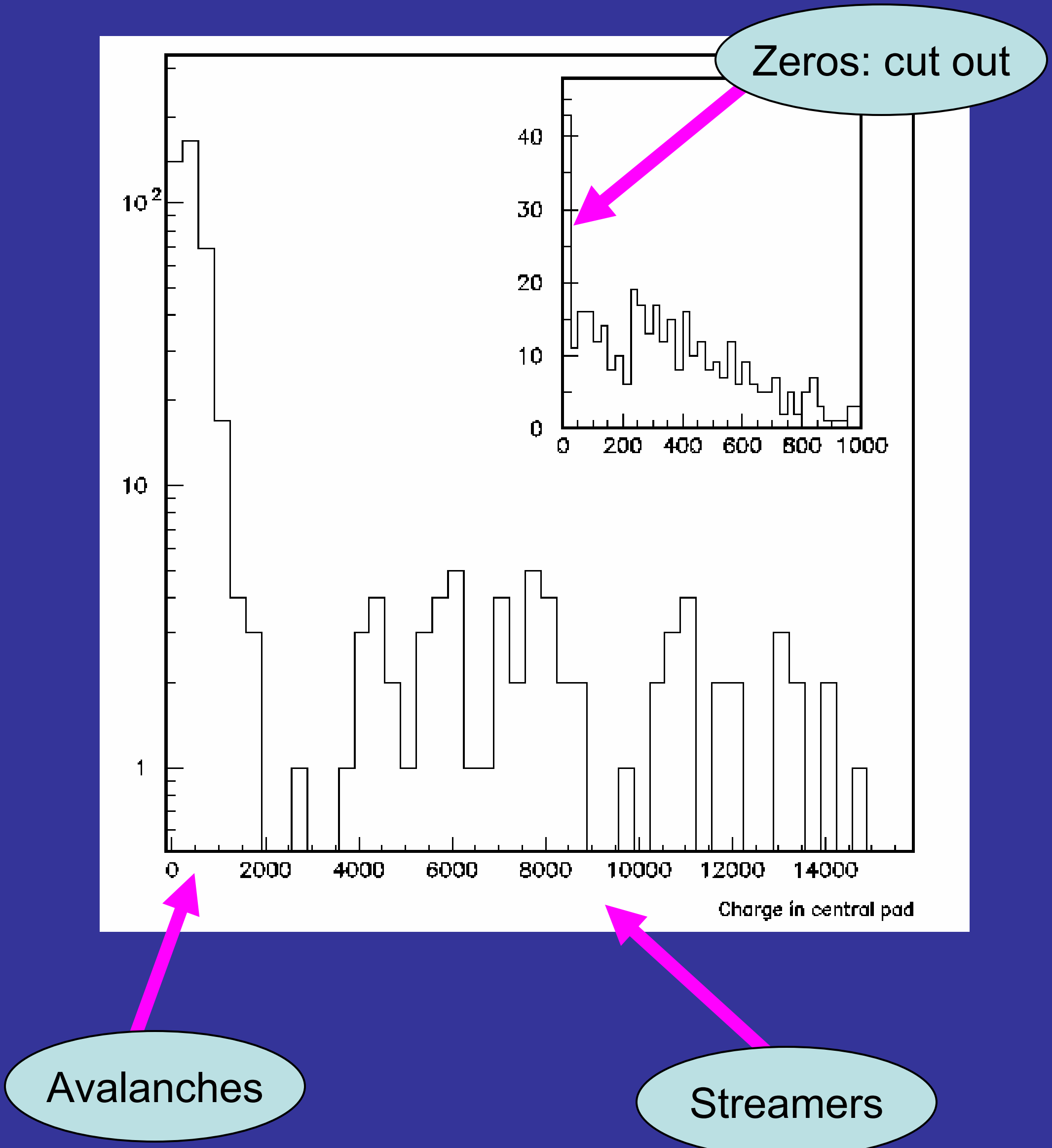
Data sets

- **AIR2** 38 kEvents
  2 gaps of 0.64 mm
  glass of 1.1 mm
  $R_\square$ ~ 1.2 MΩ

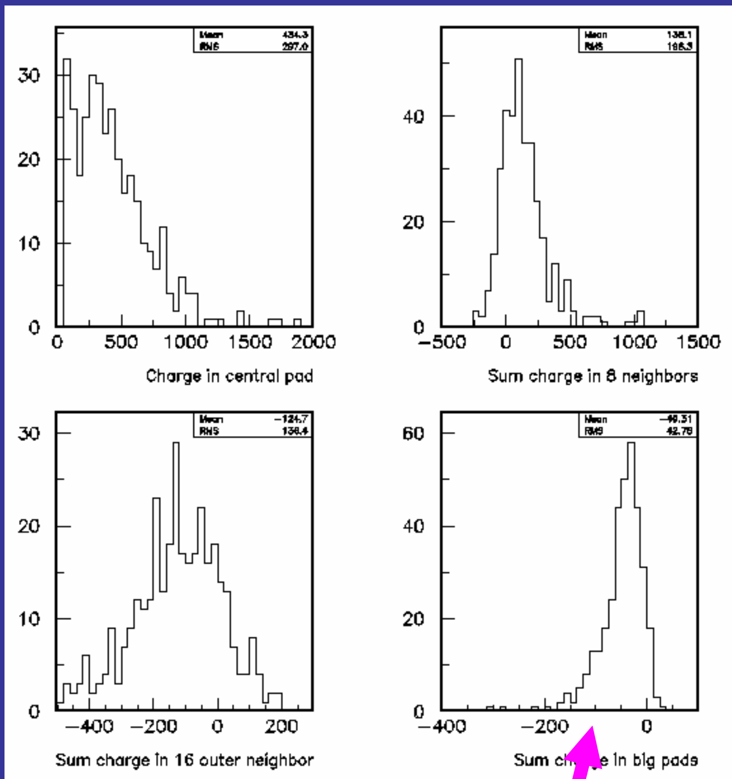
Default

- **AIR1** 24 kEvents
  same as above
  $R_\square$ ~ 200kΩ

Central pad with maximum charge



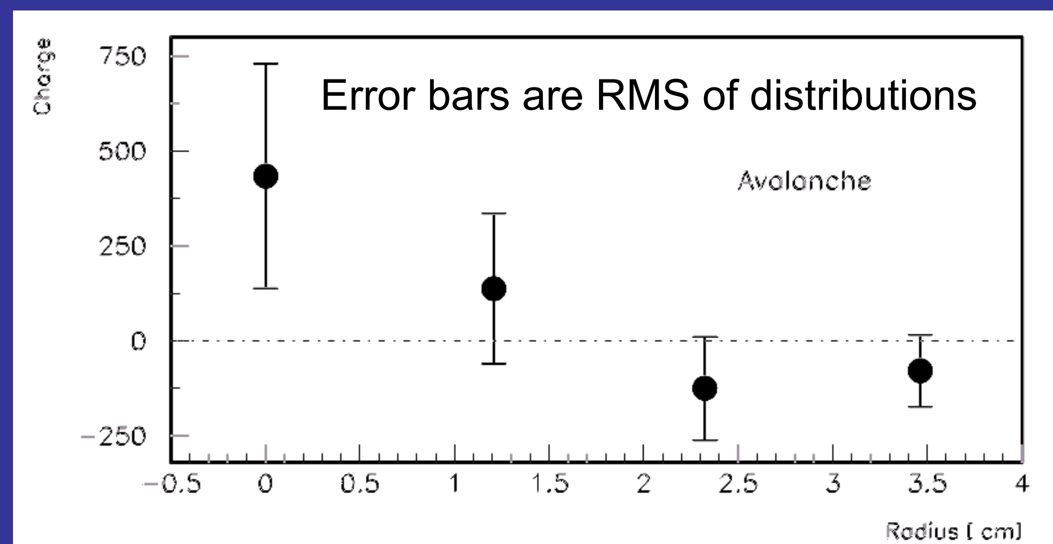
Central pad with maximum charge: select avalanches



Charges go negative

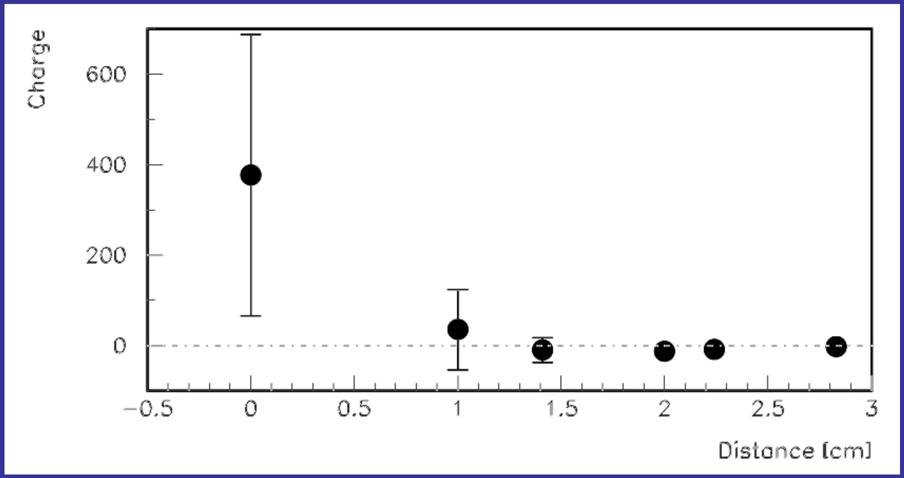
All pads at a given distance added up

Similar results for streamers



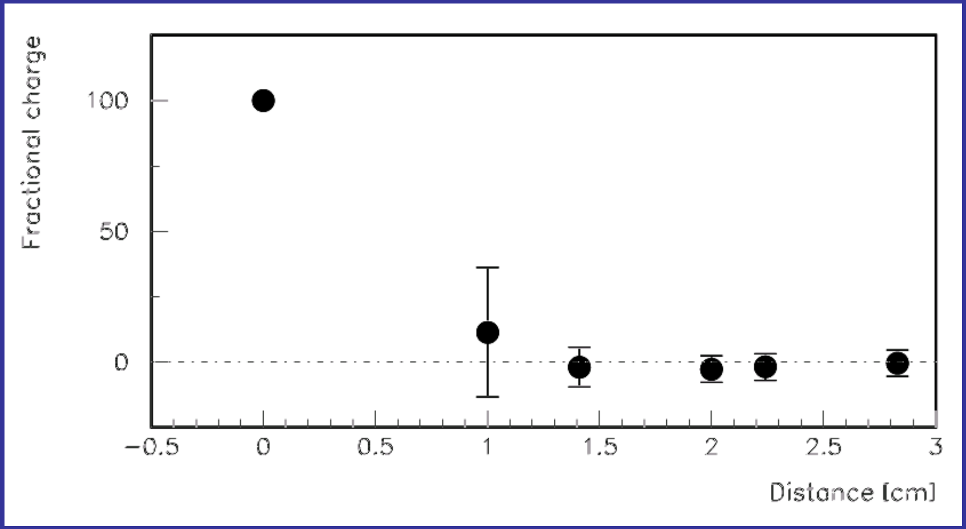
Charge contained in A ~ 12 cm^2

Central pad with maximum charge: select avalanches

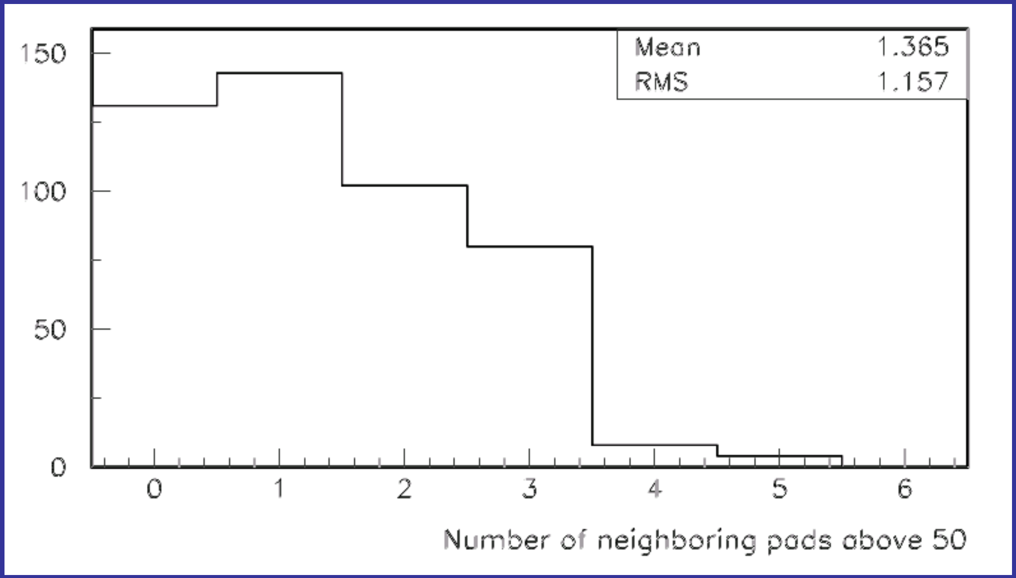


Looking at individual pads

Charge on neighboring pads small!



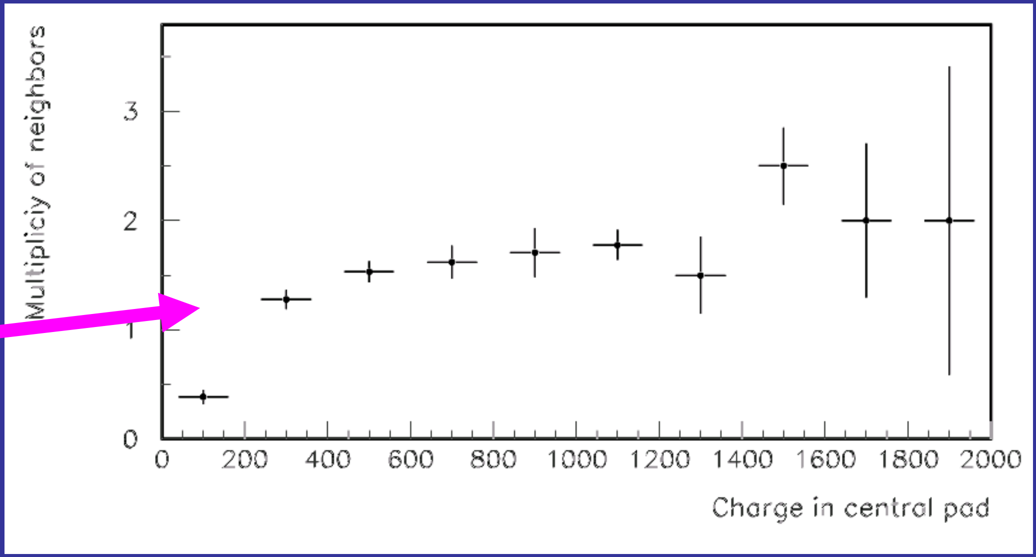
Central pad with maximum charge: select avalanches



Mostly direct neighbors

No counts in second ring

<Multiplicity high>
Probably ok for 2x2 cm^2 pads
Will look better with discriminators
Important to suppress streamers



Design work on the electronic readout

System overview

I RPC ASIC

located on the chambers

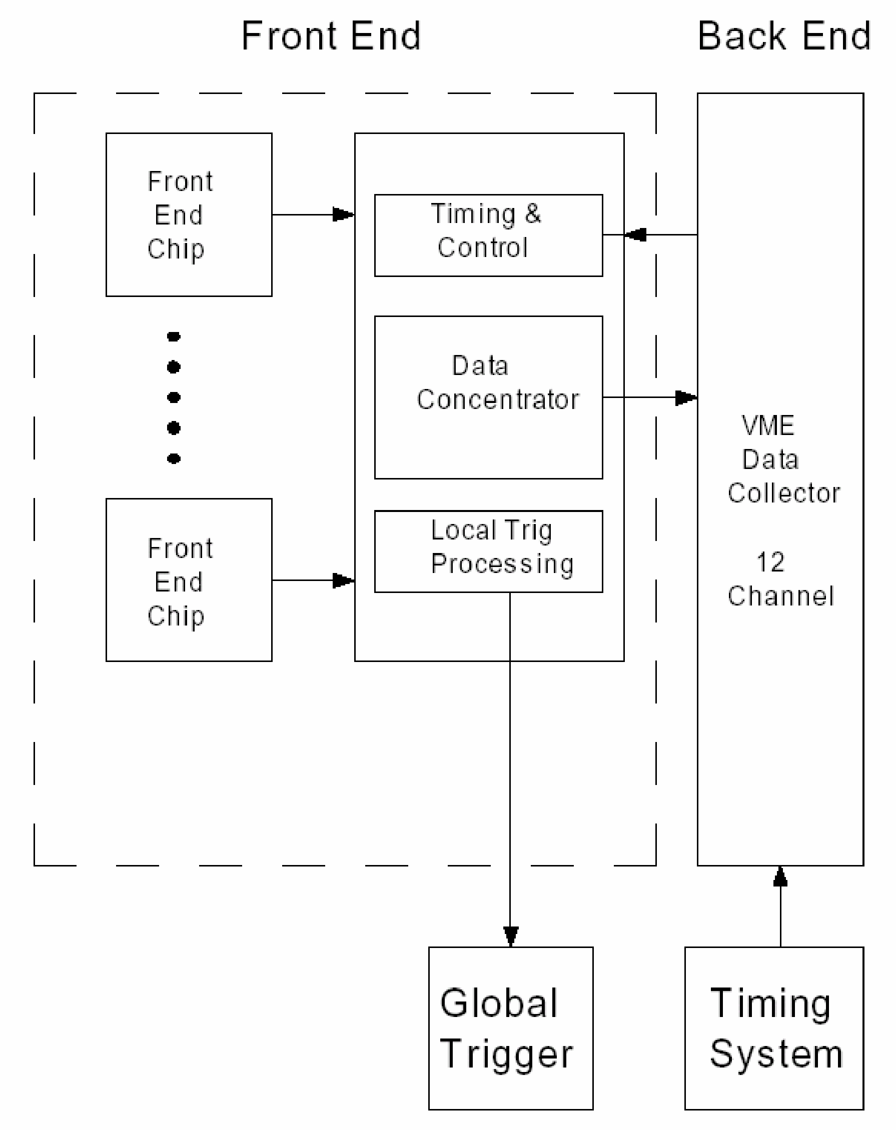
II Data concentrators

funnels data from several FE chips

III VME data collector

funnels data from several data concentrators

IV External timing and trigger system



Conceptual design of readout pad

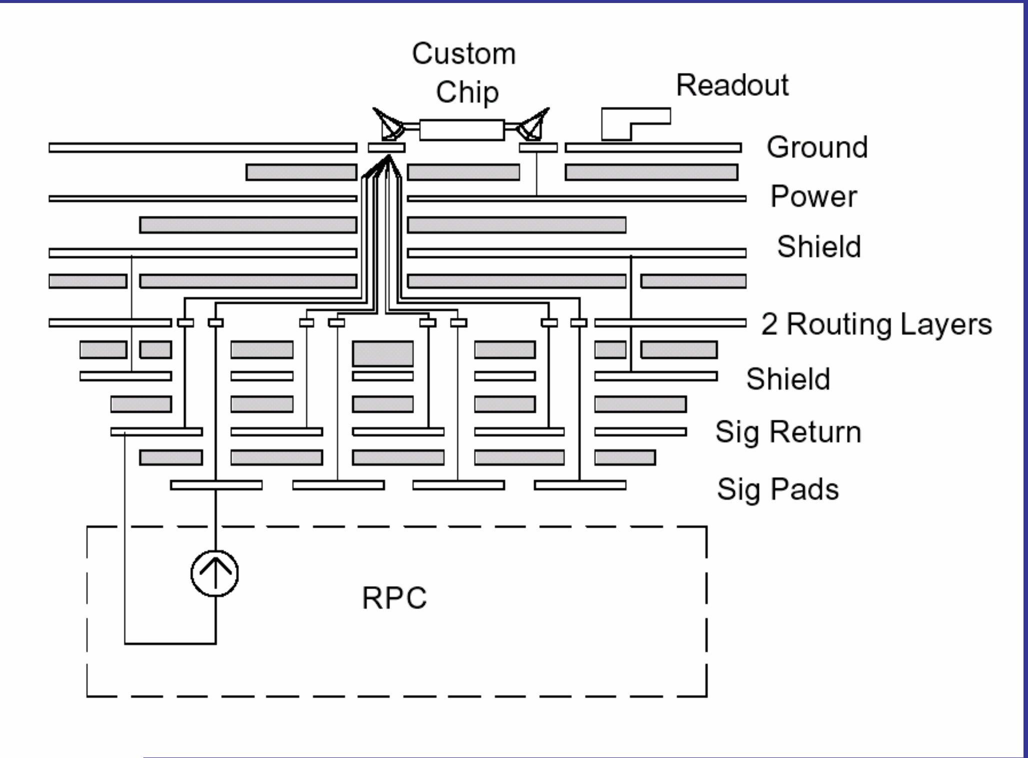
Attempt to minimize cross-talk

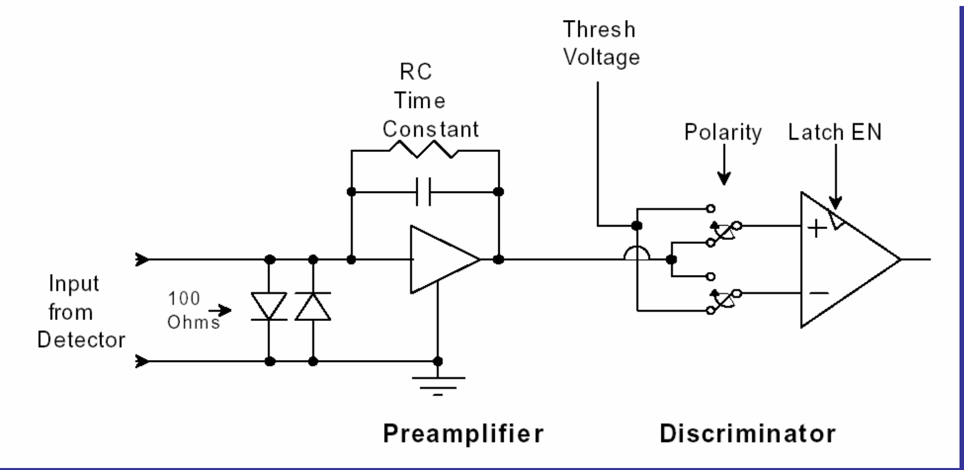
Overall thickness 2 - 3 mm

One ASIC for
64 (or 128) channels

Will need 6250 (3125) ASICs
for 1 m^3 prototype

First version of boards being
laid out



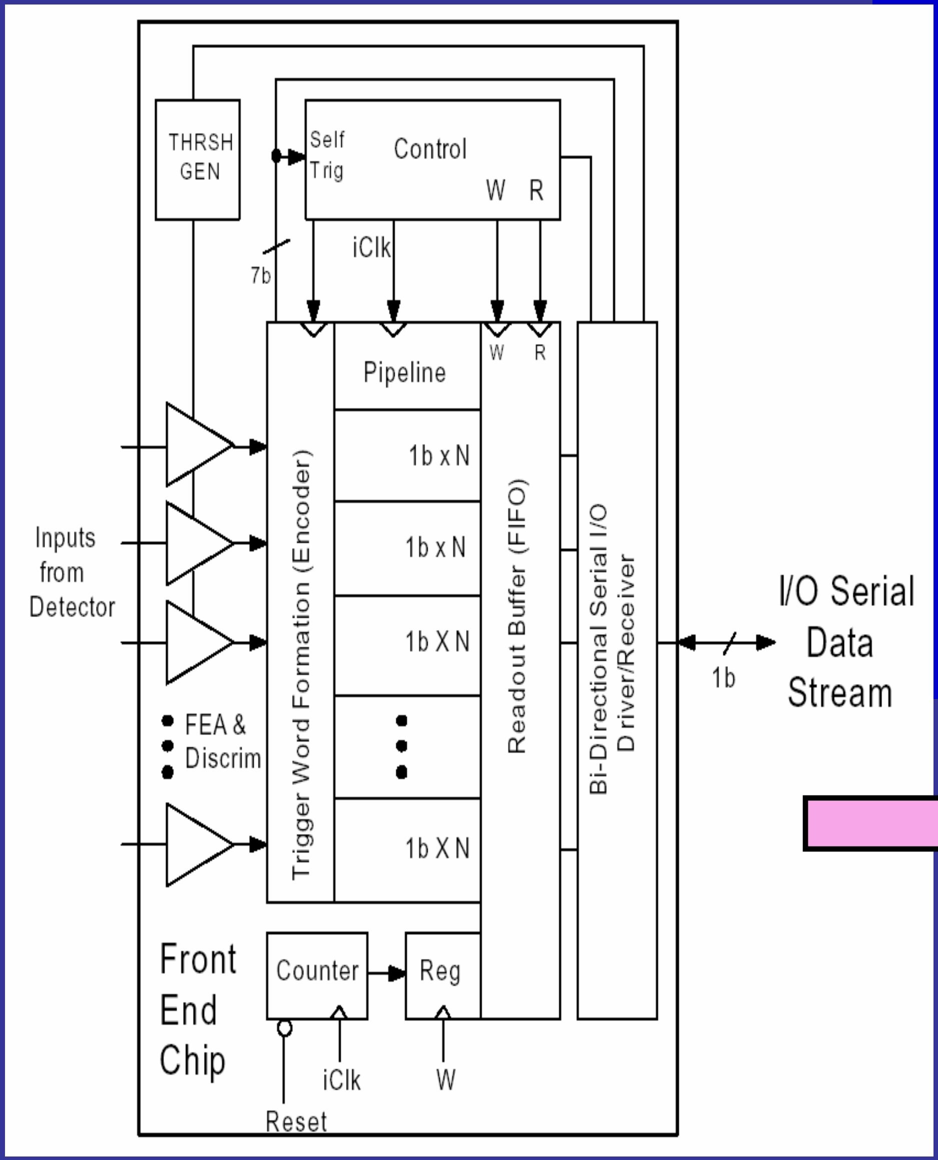


ASIC: Analog signal processing

Each channel has a preamplifier

- **Needed for avalanche mode**
- **Can be bypassed (in streamer mode)**
- **Provides pulse shaping**
- **Provides polarity inversion**

Design of ASIC: Digital Processing Functions



Modes of operation

I Trigger-less operation

Timestamp counter running inside chip
(with external reset)
Store timestamp and channel number when hit

II Triggered operation

Provide pipeline for temporary data storage
Provide trigger input to capture data of interest
(Provide trigger output: 1 bit)
Timestamp to identify event

Attempt to implement features possibly useful for other detectors

Significant overlap with what is needed for Off-axis detector

Performance specifications being defined now…

Plans for the next few months

I. Resistive paint

Investigated over 50 paints and mixtures
→ many mixtures not stable over time
Found 2-3 (acrylic) with over 1 MΩ/□
Developing methods to control thickness

II. Effect of distance to ground plane and capacitance

Multipad boards with two different thicknesses on hand

III. Repeat measurements with different gas

Mixture available

IV. Reading off on ground versus HV side

So far reading off HV side (risk of breakdown)
Signals reading off ground side inverted in charge
→ Study effect on cross-talk

V. Single gap versus multigap

Will build chamber with single gap with same gas volume
→ study effect on cross-talk

VI. Discriminators versus charge integration

Readout of multi-channel with discriminators started
VME boards (64 channels) being designed

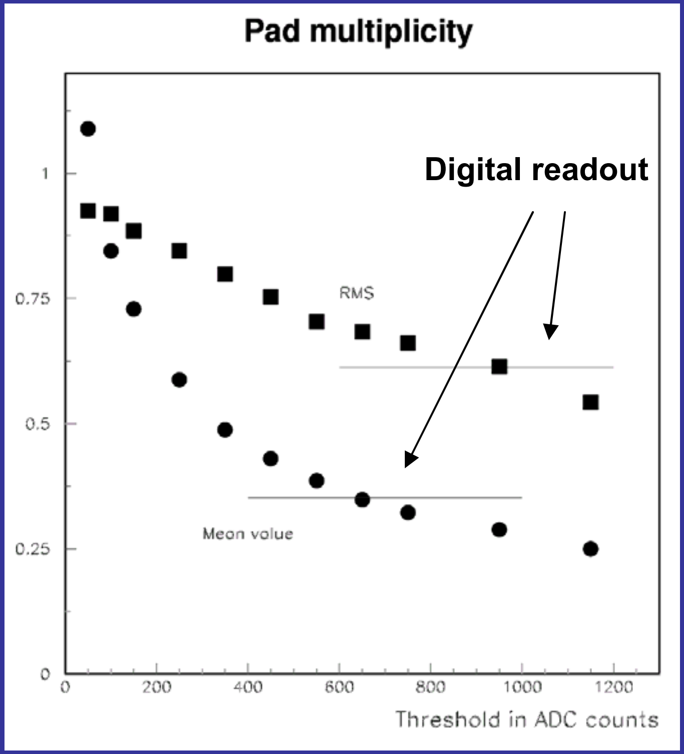
VII. Geometrical acceptance

Construction of scintillator hodoscope at ANL

Re-commissioning of Cosmic ray test stand with tracking at Chicago

VIII. Effect of temperature on

Noise rate
Efficiency



Plans for the next 15 months

Finalize chamber design by 6/03

Develop application procedure for paint by 6/03

Complete tests with prototype readout systems by 6/03

Specify characteristics of FE ASIC by 7/03

Initiate production of chambers by 10/03

Evaluate pre-production of readout boards and ASIC by 3/04

Initiate production of readout boards by 4/04

Initiate production of data collections systems by 4/04

→ Ready for test beams in Summer 2004?

Conclusions

RPCs are ideally suited for a Digital Hadron Calorimeter

- Based on simple concept, but very flexible in design
- Cheap
- Robust
- Low noise rate
- Readout can be highly segmented

RPCs are reliable

- Don't use bakelite (only needed in high rate environment)
- Successfully used in many experiments (not only HEP)
- The details matter (as usual!)

Status of project

- Have built and tested our own RPCs
- Results as expected
- Concentrating effort on designing readout system

Future

- Continued R&D for next few months
- Construction of $1m^3$ hadron calorimeter section
- Extensive tests in particle beams
  → evaluation of technology and MC simulation