A Digital Hadron Calorimeter With Resistive Plate Chamber - US Effort

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LCWS Paris 2004

Collaborators

- Argonne National Laboratory
  (Member of CALICE)
- Boston University
- University of Chicago
- Fermilab

- UTA
  (Member of Calice)

Developing GEMs for DHCAL
Collaborating on Electronics

Grand Plan:
1 m^3 RPC DHCAL

- 1 m^3 needed to contain most of Hadronic Shower

  40 layers of 1 m^2 RPCs

  1 cm x 1 cm pads → 400,000 readout channels

  Steel Absorber (20 mm)

- Readout Electronics : The Real Challenge

- To be tested in a particle beam

1 m^3 Prototype DHCAL Section

Valid on its own (independent of LCD design)
Necessary for LCD optimization

Motivation

Validate technology of active medium (RPCs, GEMs, Scintillator)
Test concept of electronic readout (400,000 channels is a challenge)
Measure hadronic showers with unprecedented spatial resolution
Compare results with AHCAL
Compare results of DHCAL with scintillator and gaseous detector
Validate MC simulation of hadronic showers

Time scales

2004: complete R&D on both RPCs and electronic readout
2005: construct prototype section
2006: test in particle beams

Resistive Plate Chamber (RPC):

- Advantage of RPCs
  - Very simple and low cost detector, easy to build
    - Resistive plate: float glass
    - Resistive ink layer: graphite spray / resistive paint, applied by spray / brush / silk screen printing
    - Gas volume spacer: nylon fishing line
  - Robust detector: no ageing effect has ever been observed for glass RPCs
  - Large enough signal, high efficiency, low noise rate
- Rate capability might be a concern in some cases, but not for linear collider
- Ideal for digital calorimeter!

RPCs built at Argonne

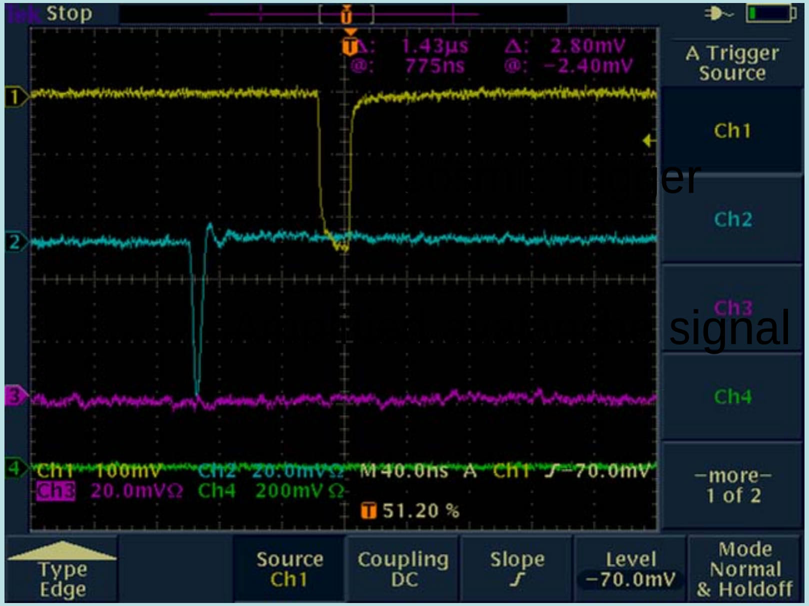
Name of chamber	AIR0	AIR1	AIR2	AIR3	AIR4
Date of construction	11/2002	1/2003	1/2003	11/2003	1/2004
Active area	20x20 cm^2	20x20 cm^2	20x20 cm^2	20x20 cm^2	20x20 cm^2
Number of gas gaps	2	2	2	1	1
Glass thickness	0.85 mm	1.1 mm	1.1 mm	1.1mm	1.1 mm
Thickness of gas gap	0.64 mm	0.64 mm	0.64 mm	1.2mm	1.2 mm
Resistive layer /applying technology	Graphite /spray	Ink /brush	Ink /brush	Ink /silk screen	Ink /silk screen
Surface resistivity	~0.3 MΩ/□	~0.2 MΩ/□	~1.2 MΩ/□	~1MΩ/□	~1MΩ/□ ~50MΩ/□
Streamer signal starting point (Freon/Argon /IsoButane = 62:30:8)	7.5 kV	6.7 kV	6.6 kV	--	--
Streamer signal starting point (Freon/IsoButane /SF6 = 94.5:5:0.5)	--	--	8.7 kV	7.5kV	7.5 kV
Pedestal width	~15 fC	~8 fC	~8 fC	~40 fC	~90 fC

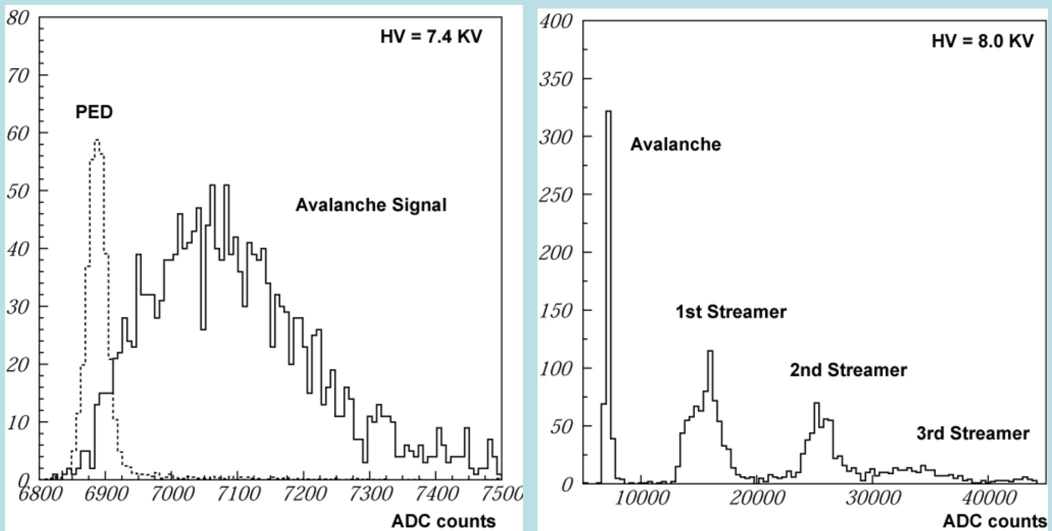
Summary of Measurements with RPCs

	Tests	Results
Mechanical	Glass deflection with gas pressure and electrostatic force	$p_{ES} > p_{Gas+}$ No need for gluing spacers
Single pad readout	Charge	Avalanche mode ~0.1 ÷ 5 pC Streamer mode 5 ÷ 100 pC
	Efficiency	Greater than 95 % Drops to zero at spacer
	Streamer fraction	Plateau of several 100 V where efficiency > 95% and streamer fraction < few percent
	1 – gas gap versus 2 – gas gap	Larger Q with 1 – gas gap Similar efficiency
	Noise rate	Small ~50 Hz
	Different gases	Best: Freon:IB:SF_6 = 94.5:5:0.5
Multi – pad readout	Radius of induced charge	Small << 1 cm
	Pad multiplicity (analog readout)	~2.6 (Threshold ~ 60 fC)
	Pad multiplicity (digital readout)	~1.4 (Derived from 1.6 Direct) (See later plots)

RPC signal: avalanche and streamer

- Large single pad to cover whole chamber
- Two types of signal
  - Avalanche signal
    - Average signal charge: 0.2 – 10+ pc
    - Lower operating voltage
    - Typical efficiency ~99%
    - Very low noise level
    - Rate capability <1kHz/cm^2
  - Streamer signal
    - Average signal charge: 10 – 100+ pc
    - Higher operating voltage
    - Typical efficiency ~90%
    - Rate capability ~10Hz/cm^2
    - Multiple Streamers

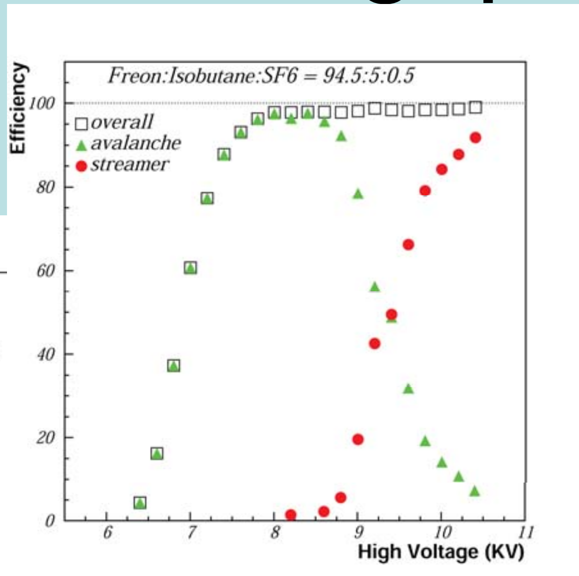


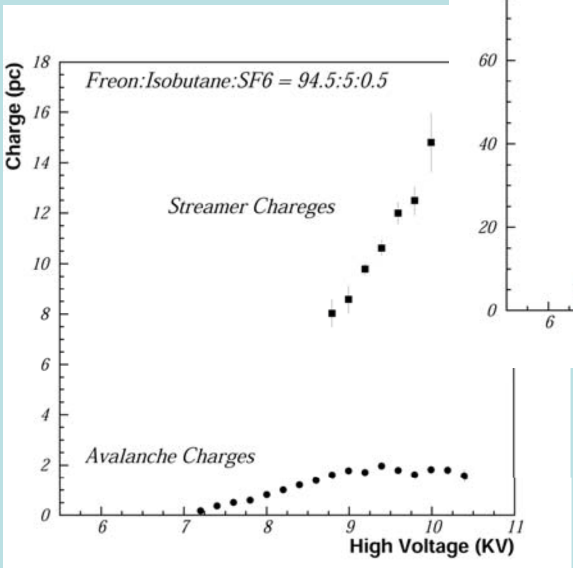


Signal charge distribution

RPC: 1-gap v.s. 2-gap

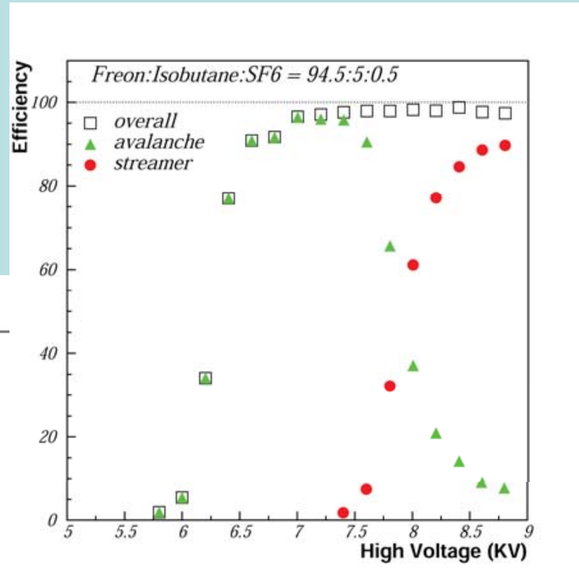
2-gap chamber

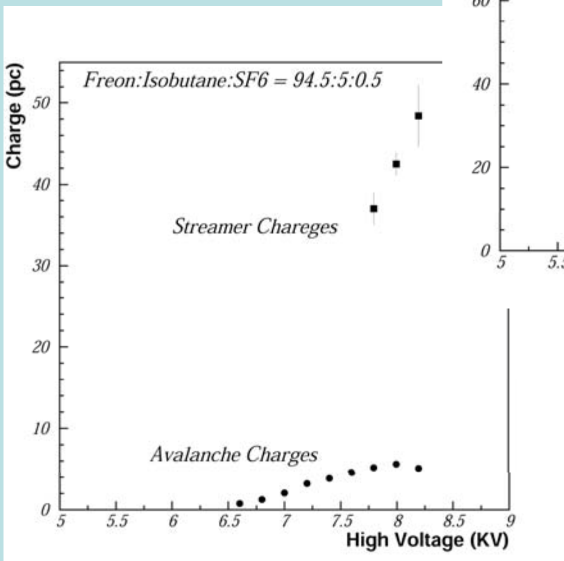




- Higher operating voltage
- Smaller avalanche signal (<2pc)
- Larger avalanche plateau range (~1kV)

Same overall gap size



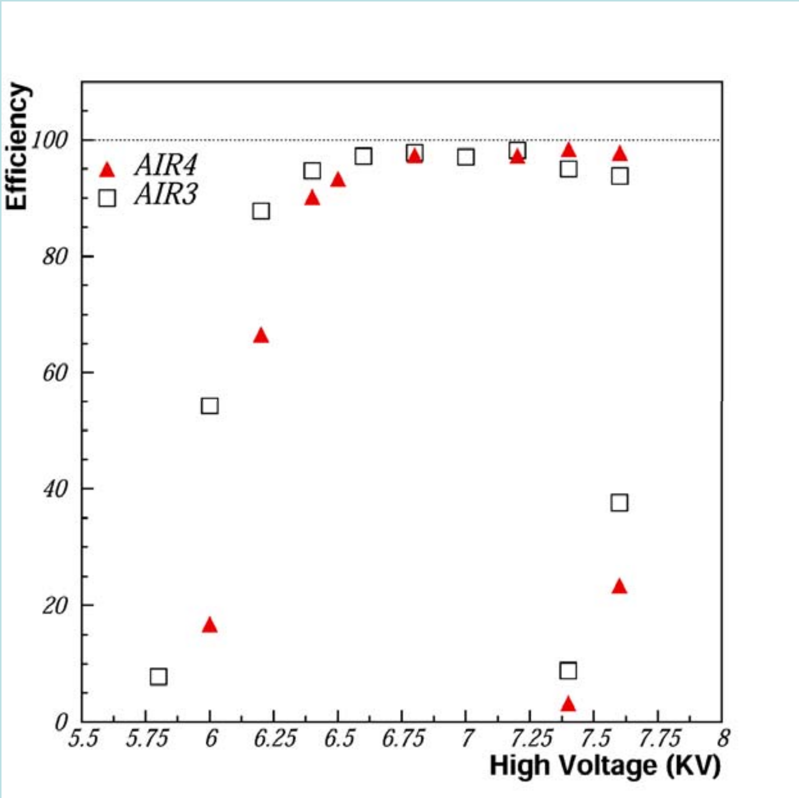


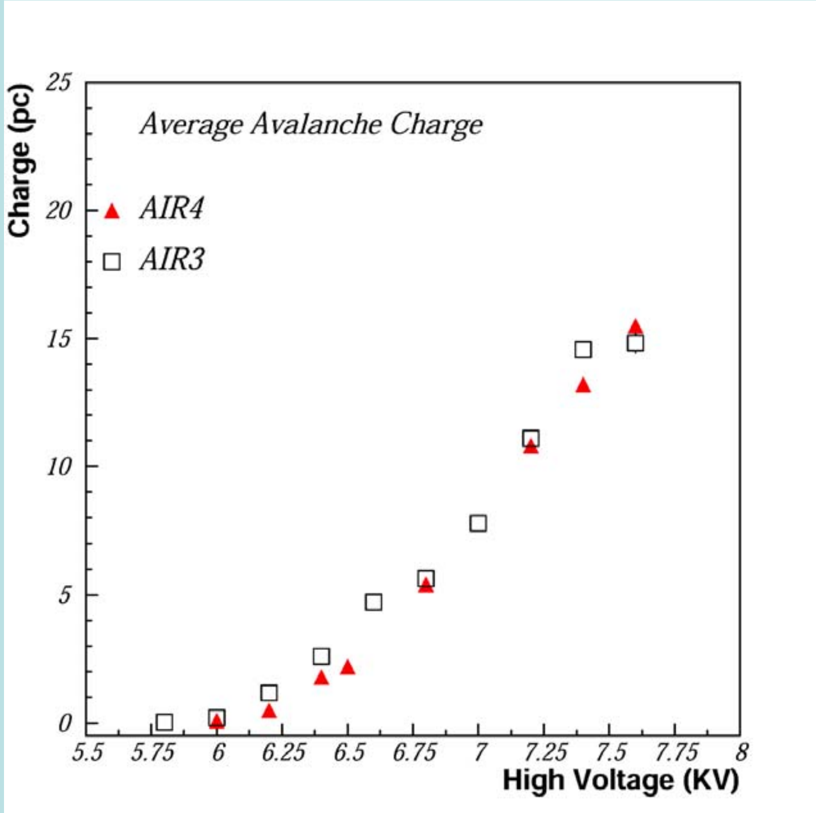
- Lower operating voltage
- Larger avalanche signal (<5pc)
- Smaller avalanch plateau range (>0.5kV)

1-gap chamber

Comparison of AIR4 and AIR3 (both single gap)

Efficiency
Streamer fraction
Average charge





Consistent Results

as expected…

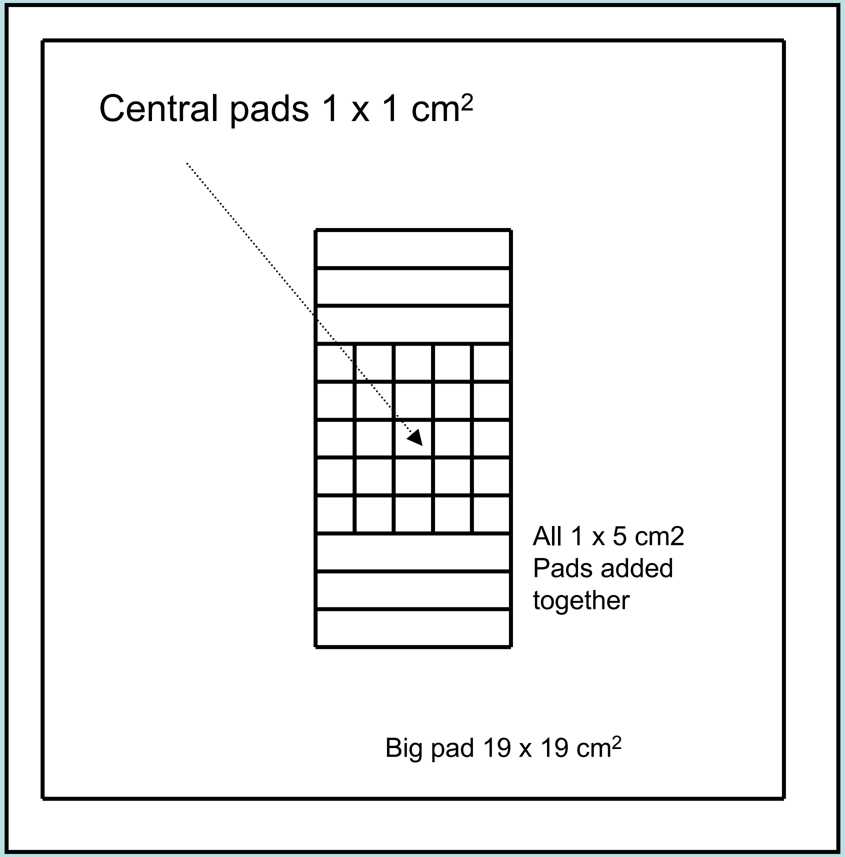
RPC: gas mixture for operation

Component		Ar:Freon:IB 30:62:8	Ar:IB:SF6 Bal:8:(2-40)	Freon:IB:SF6 94.5:5:0.5
Avalanche	Operating voltage	6-7KV /0.6mm gap x 2	4-6KV /0.6mm gap x 2	8KV/0.6mm gap x 2 7KV/1.2mm gap
	Plateau	0.2-0.3 KV /0.6mm gap x 2	--	1.0KV/0.6mm x 2 0.5KV/1.2mm gap
	Efficiency	> 90% /0.6mm gap x 2	50 – 70 % /0.6mm gap x 2	~ 98%
	Signal charge (pad on one side)	0.2-0.3 pc /0.6mm gap x 2	~0.1 pc /0.6mm gap x 2	1-2pc/0.6mm x 2 1-5pc/1.2mm gap
Streamer	Starting voltage	~7.4KV /0.6mm gap x 2	4-6KV /0.6mm gap x 2	8.8KV/0.6mm x 2 7.5KV/1.2mm gap
	Efficiency	> 90% /0.6mm gap x 2	70 – 90% /0.6mm gap x 2	> 90%
	Signal charge	~10pc /0.6mm gap x 2	~10pc /0.6mm gap x 2	~10pc/0.6mm x 2 ~40pc/1.2mm gap

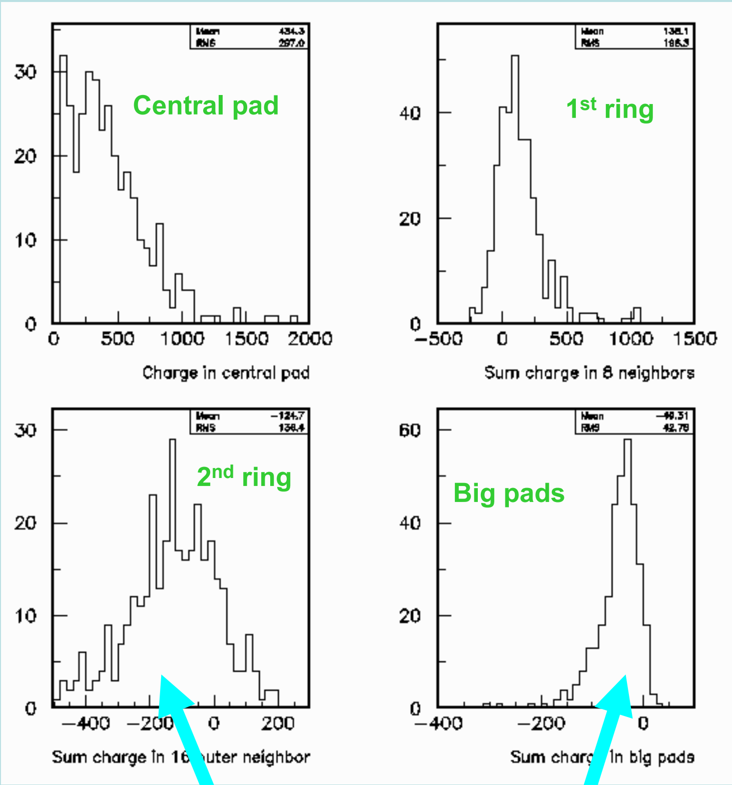
^PREFERED^

Hit multiplicity with avalanche signal: analog readout

- Pads used in this study: 5x5+2:
  - 5x5 array of $1x1cm^2$ pads
  - 6 $1x5cm^2$ strips on the sides of the 5x5 array, they are connected to form a bigger pad
  - The rest area on this $19x19cm^2$ board forms another big pad
- Use RABBIT readout system, to measure charge collected on each pad when a cosmic ray passes through the chamber (1 fC/tic)
- A pad is counted in an event if the signal charge collected on the pad exceeds given threshold
- A typical cosmic ray signal has a few ‘central pads’ collecting most of the signal charge
- Pad-of-hit is the pad that collects the largest amount of charge in an event
- Hit multiplicity is measured with pad-of-hit among central 3x3 pads



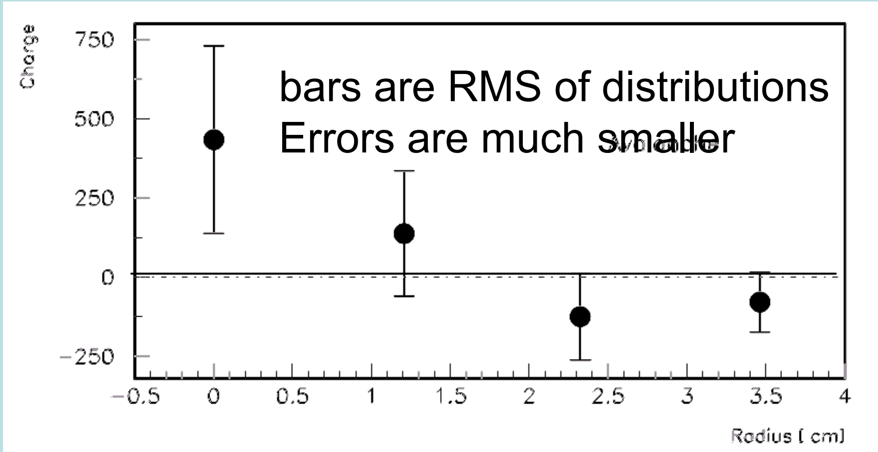
Central pad with maximum charge: select avalanches



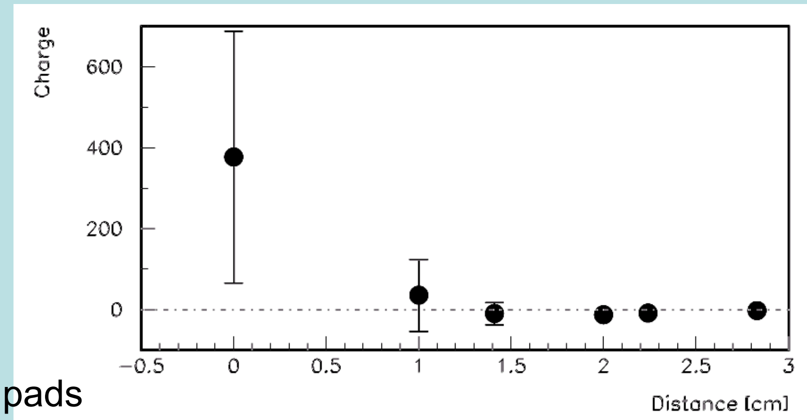
Charges go negative

All pads at a given distance from central pad added up

Similar results for streamers

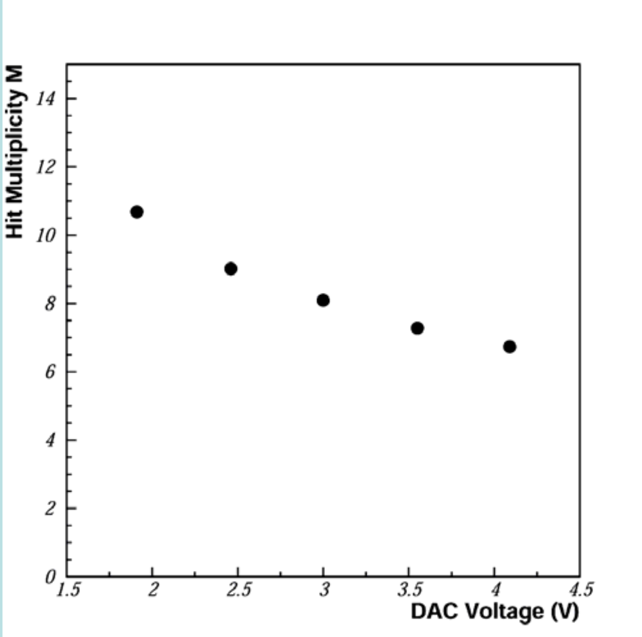


Sum over all pads at each radius from “central hit”



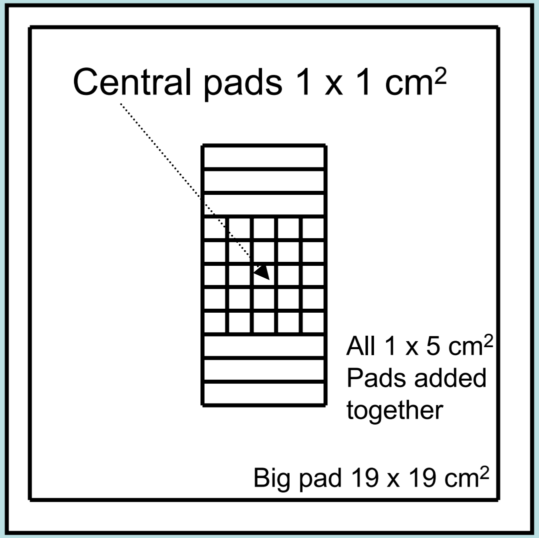
Charge in individual pads

Hit multiplicity in streamer mode - Digital Readout

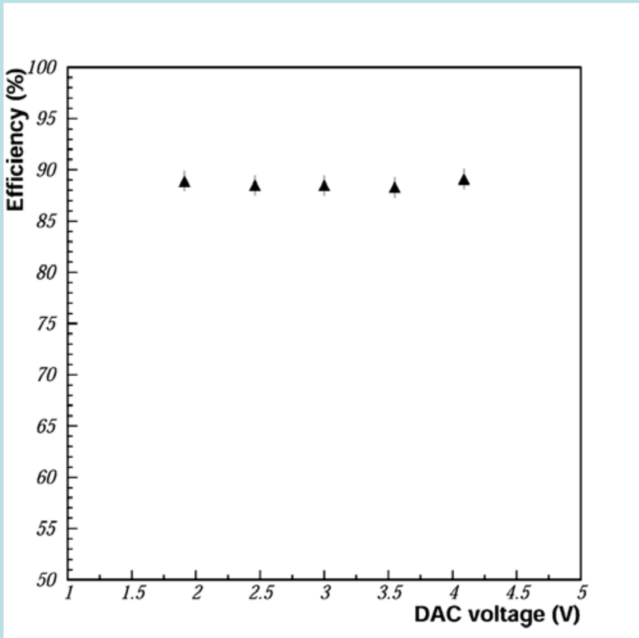


Select events where at least one hit in central array of 9 pads

(With no tagging, can't tell which pad was hit)

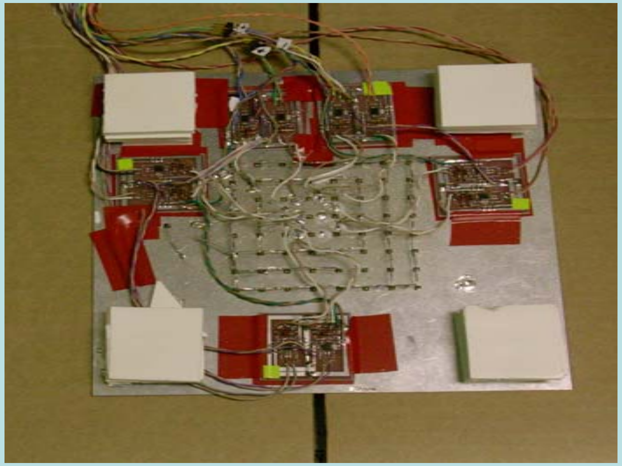


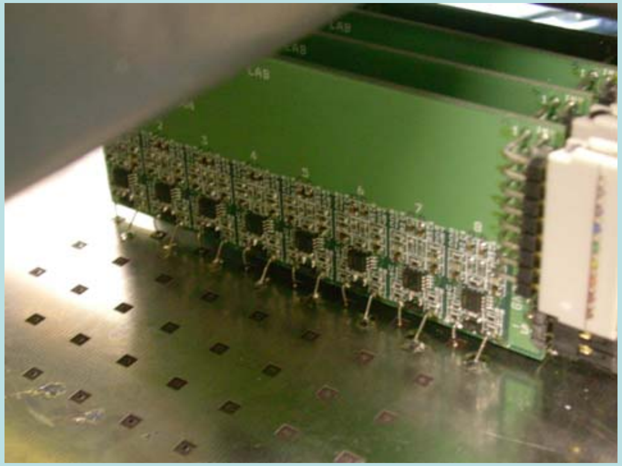
High multiplicity: 6 – 11
Decreasing with increasing threshold
Range of threshold too small: ε = constant
Threshold circuitry modified: results soon…



Hit multiplicity study: Avalanche

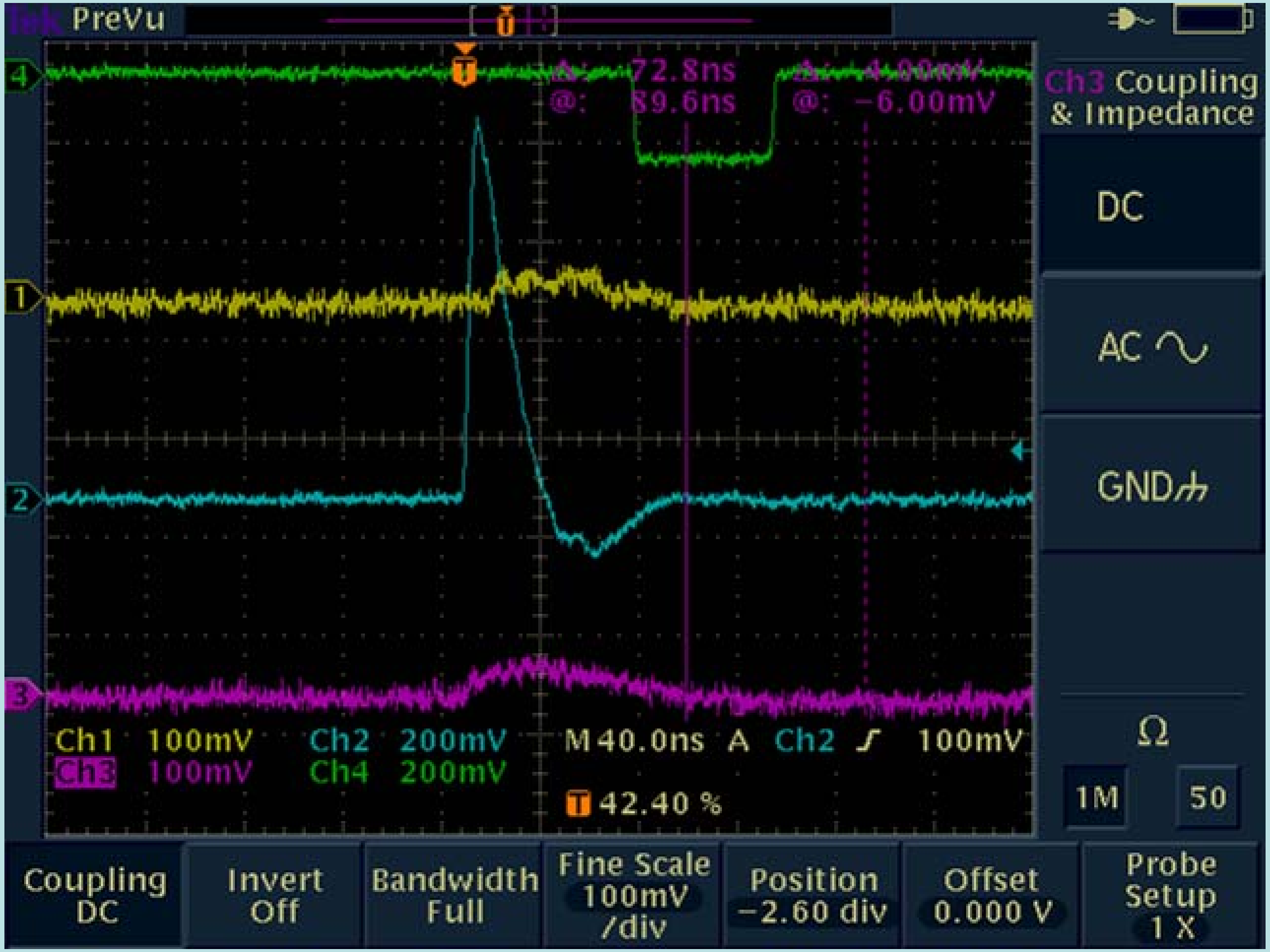
- Readout board: 3x3 array of $1x1cm^2$ pads
- Signal out of each pad is amplified by an on-chamber amplifier (gain ~80*100 Ω)
- At the moment, no cosmic ray trigger for such a small area.
- …
- NEW
- We have 32 of 64 pads instrumented with the same amplifiers





Example Signal Showing Neighboring Pads

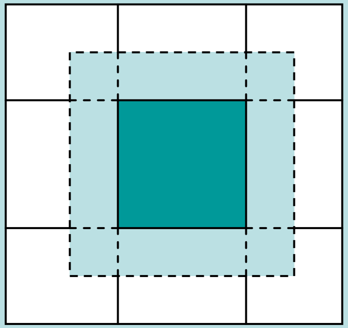
- Signal amplitude in adjacent 1 cm pads is < 10%
- Rise time of signal larger on neighboring pads ?

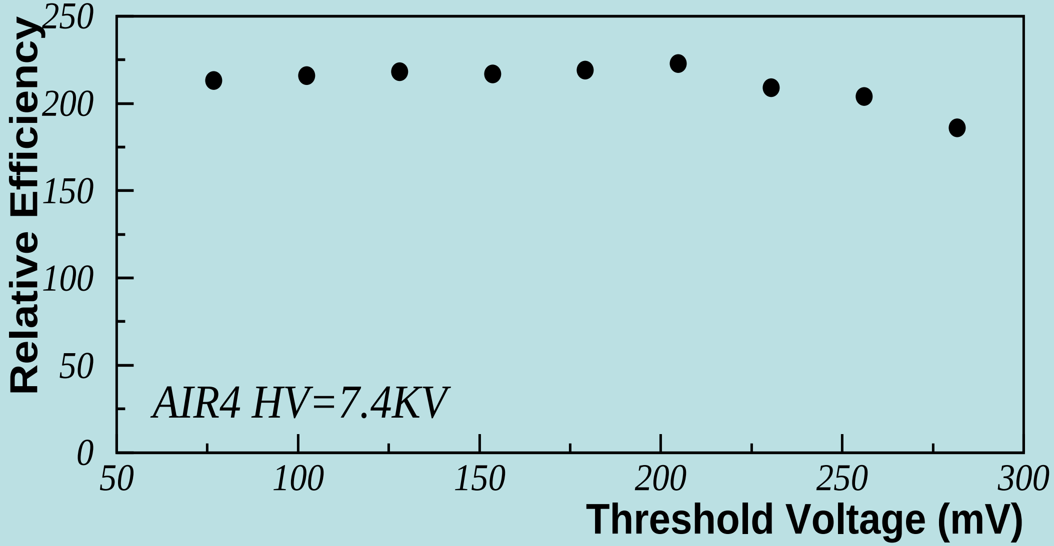


Avalanche Mode with Digital Readout

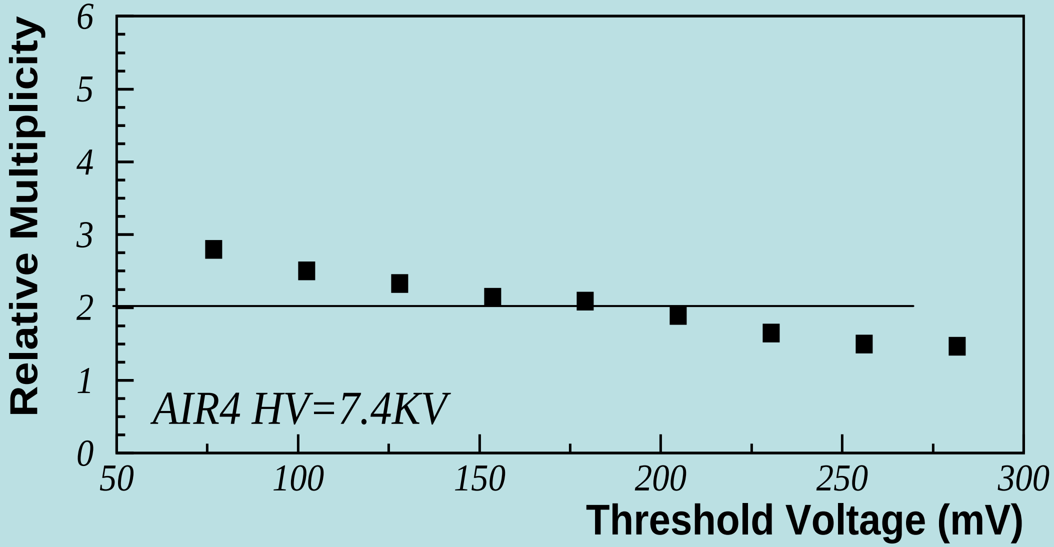
Efficiency and Multiplicity

Measurements
done with 3x3 pads





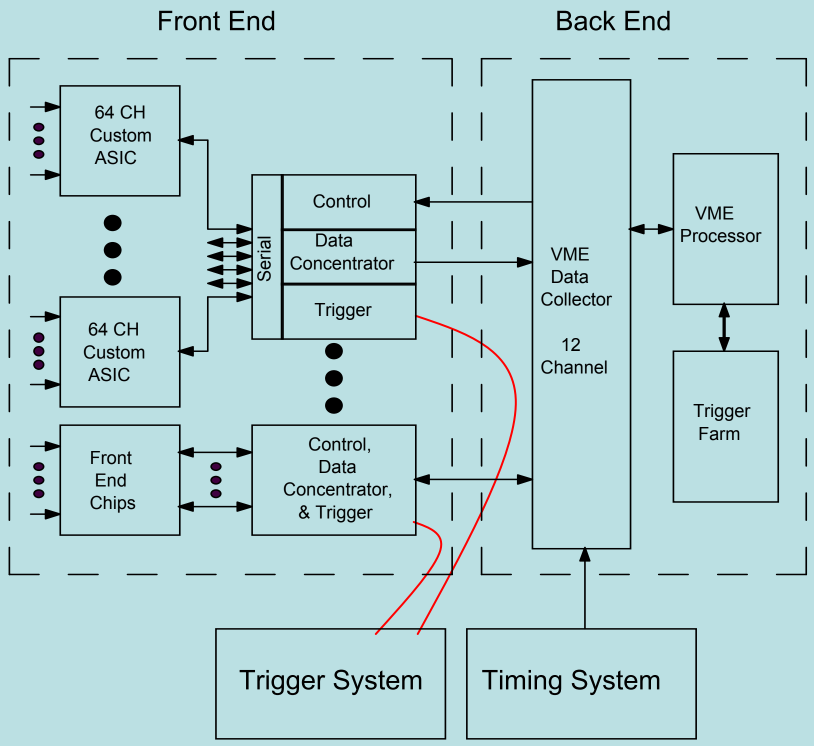
Multiplicity after correction of trigger bias (requirement of signal in central pad)
~1.4



Radius of induced charge about 1 mm

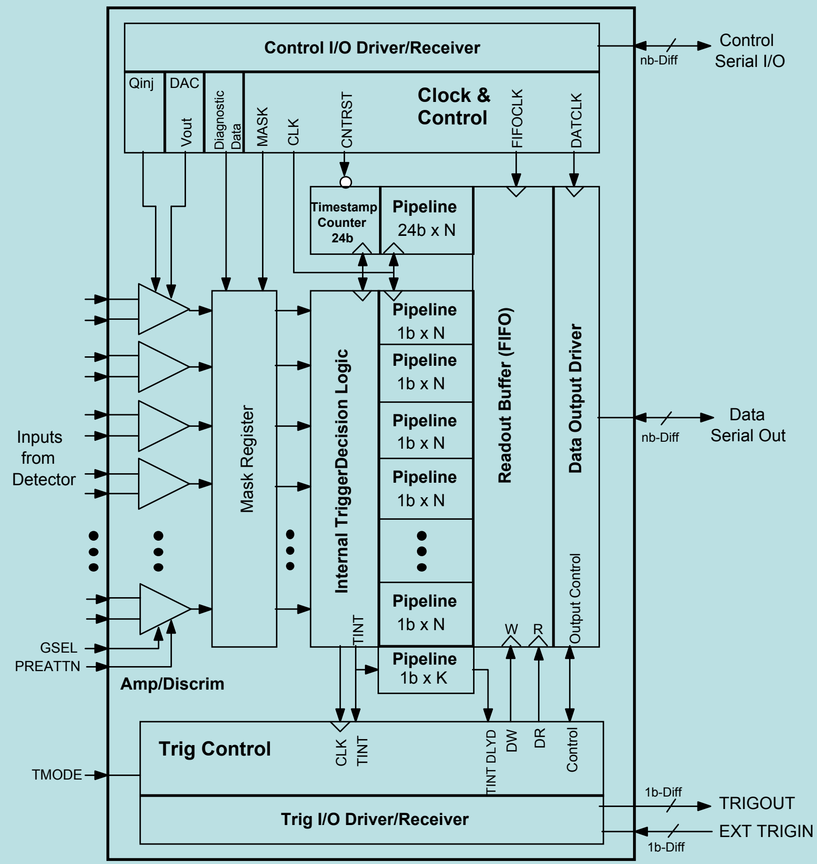
Future System Architecture for 1 m^3

- **System Overview**
  - ***Front End***
    - ASIC Front End
    - Data Concentrators Near Chambers
      - Control
      - Data Concentration
      - Trigger
  - ***Back End***
    - VME Data Collectors
    - Computing / Storage
  - ***Also***
    - Trigger System
    - Timing System



Front End ASIC

- **Basic Architecture**
  - Front End Amplifier & Discriminator Senses Hits Above Threshold
  - 24-Bit Timestamp Counter Runs at 10 MHz
  - Comparator States Clocked into Shift Register
  - Save States & Timestamp on Ext. Trig. or Self-Trigger
  - Serial I/O – Separate Data, Control, & Trigger
  - Services 32-64 CH



Conceptual design of readout pad

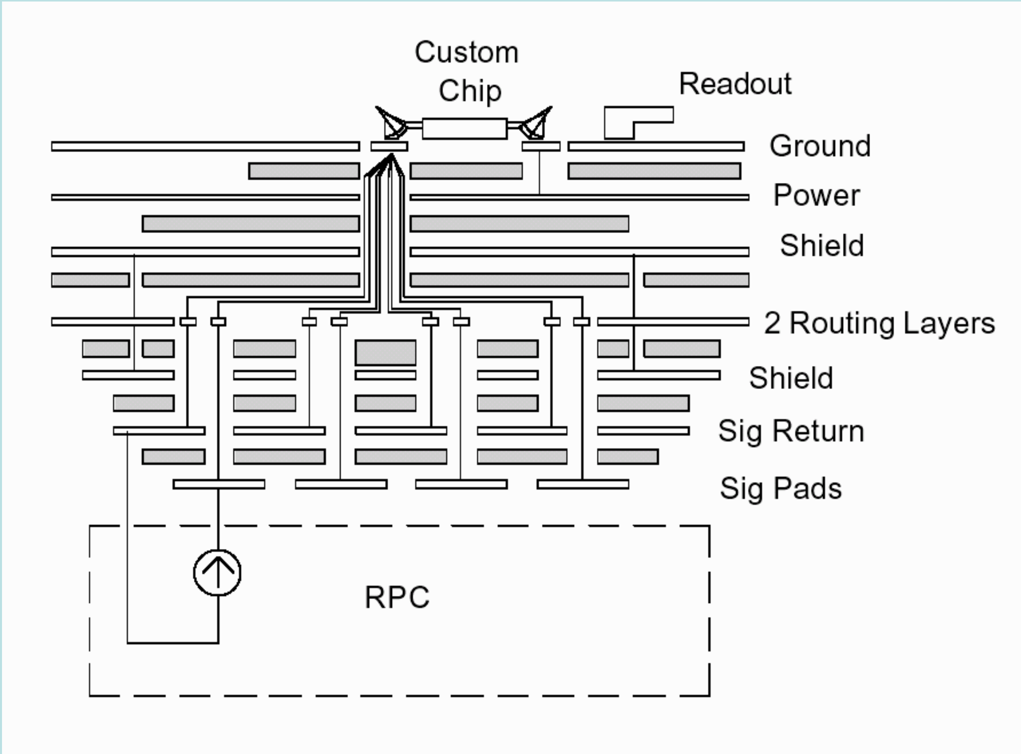
Attempt to minimize **cross-talk**

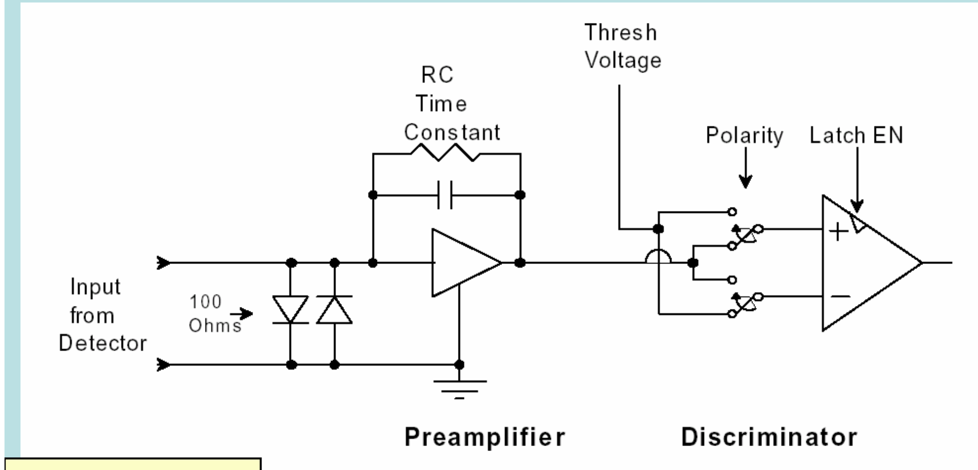
Overall **thickness** 2 - 3 mm

One ASIC for **64 channels**

Will need **6250 ASICs** for 1 m^3 prototype

First version of boards being laid out





ASIC: Analog signal processing

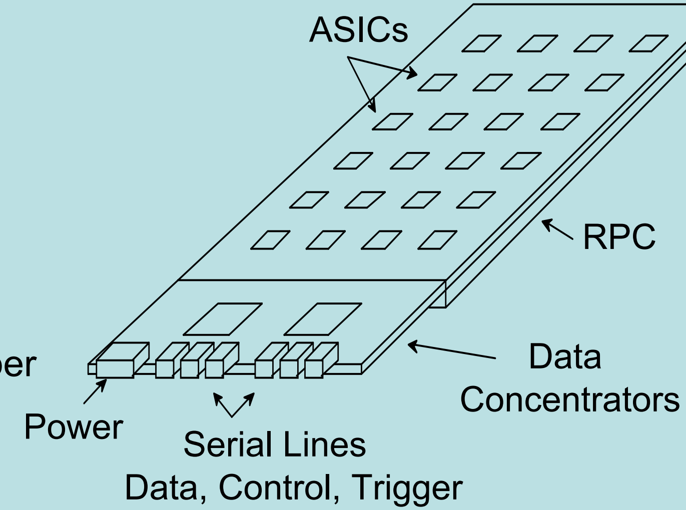
Each channel has a **preamplifier**

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

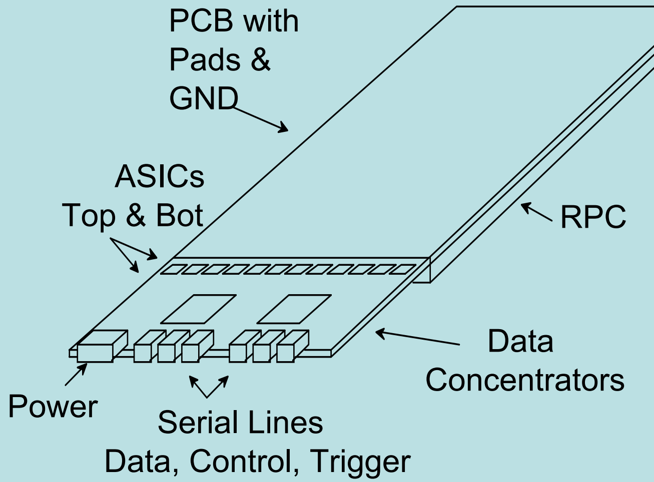
G Drake, ANL

Physical Configuration

- **ASICs On Chamber**
  - One RPC Chamber Consists of Several 8x8 Arrays with Chips
  - Design Issues: Digital Noise, Buried Digital I/O
  - Arrange Data Concentrators on Outside Edge of Chamber



- **ASICs Off Chamber**
  - One RPC Chamber Consists of Several 8x8 Arrays, No Chips
  - Signals from Pads Routed to Edge on Internal Layers of the PCB
  - Arrange ASICS and Data Concentrators on Outside Edge of Chamber
  - Design Issues: Crosstalk, Routing Layers, Capacitance, Noise



American Linear Collider
Physics Group

Conceptual Design of the
Amplifier/Discriminator/Timestamp (ADT) ASIC

Gary Drake, José Repond, Dave Underwood, Lei Xia
Argonne National Laboratory

Charlie Nelson

Fermilab

Version 1.20 February 23, 2004

ASIC Specification
41 pages

ASIC Specification

- **Implementation with Other Detectors**

Parameter	Linear Collider RPCs	Linear Collider GEMS	NUMI Off-Axis RPCs	Linear Collider Scintillator
Type	Avalanche	(Gas)	Streamer	Solid, Si PMs
Geometry	Pads	Pads	Strips	Tiles w/Fibers
Capacitance	10-100 pF	10-100 pF	110 ohm Transmission Line	~10 pF
Smallest Signal	~100 fC	~5 fC	1 pC	~100 fC
Pulse Width	~5 nS	~3 nS	~100 nS	~20 nS
Rise Time	~2 nS	?	~10 nS	~5 nS
Largest Signal	~10 pC	~100 fC	~100 pC	~10 pC
Noise Rates	~0.1 Hz	?	(~10 Hz)	?
Env. Noise Susceptibility	Low	Low	Mod (High)	Low

Cost Estimate for 1 m^3 Prototype Section

- **Resistive Plate Chambers** (M&S)

Glass	\$3,000
Resistive ink	\$1,000
Channels	\$1,000
Mylar covers	\$1,000
Steel support plates	\$1,500
Bending and screws	\$500
Tubes, glue, RTV, fishing line…	\$2,000
Total chambers	\$10,000 + 50% contingency

- **Electronic Readout System** (M&S)

FE ASIC (FNAL agrees to cover engineering)	\$100,000
FE readout board (pads and ASIC; 360 boards)	\$90,000
Data concentrator boards (need 120; each with 4 FPGAs)	\$45,000
VME readout (40 cards)	\$140,000
Power supplies, optical fibers, HV…	\$60,000
Total electronics	\$435,000 + 50% contingency

Conclusions

- RPC design is well advanced - not considered a problem
- Collaboration on electronics is progressing
- Time scales: FY 2004: complete all R&D
  FY 2005: construct 1 m^3 prototype section
  FY 2006: test in particle beams
- The challenge is funding the electronics

Plans for the next few months

Application of graphite layer

More studies with silk screening

Chamber construction

Assemble larger chamber
Test geometrical efficiency

Assemble chamber based on new design
Measure efficiency, noise rate, streamer fraction…

Multi-channel VME readout

Complete on pad amplifiers
Test chambers in avalanche mode (multiplicity)

Prototype electronic readout system

Specify remainder of system
Initiate designs of subsystems
Prototype subsystems