A Digital Hadron Calorimeter with Resistive Plate Chambers

Lei Xia

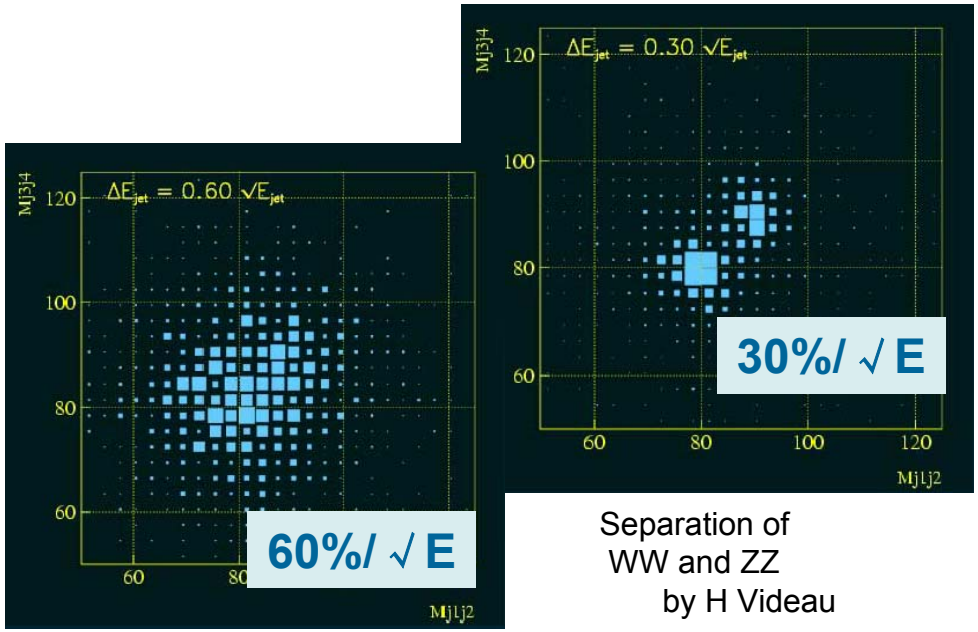
Argonne National Laboratory

LC and Particle Flow Algorithms

- The future linear collider (e^+e^- collision @ TeV scale) will be rich in its physics potential, especially on precision measurements…
  - Has to be met by excellent detector performance
  - Requires unprecedented resolution
- Jets must be measured well enough to discriminate ZZ's and WW's in the final state
  - Goal: 30%/ √E or better, for jet energy resolution
    - Current best: 50%/ √E , ZEUS calorimeter (compensating)
  - Can be achieved by

New approach
Particle Flow Algorithms

Charged **Neutrals**
particles measured with the
Tracker **Calorimeter**



Separation of
WW and ZZ
by H Videau

PFA and Digital HCal

Particles in jets	Fraction of energy	Detector	Resolution [σ^2]
Charged	65 %	Tracker	Negligible
Photons	25 %	ECAL with 15%/ $\sqrt{E}$	$0.05^2 E_{jet}$
Neutral Hadrons	10 %	ECAL + HCAL with 50%/ $\sqrt{E}$	$0.16^2 E_{jet}$
Confusion	Required for 30%/ $\sqrt{E}$		$\leqslant$ **$0.24^2 E_{jet}$**

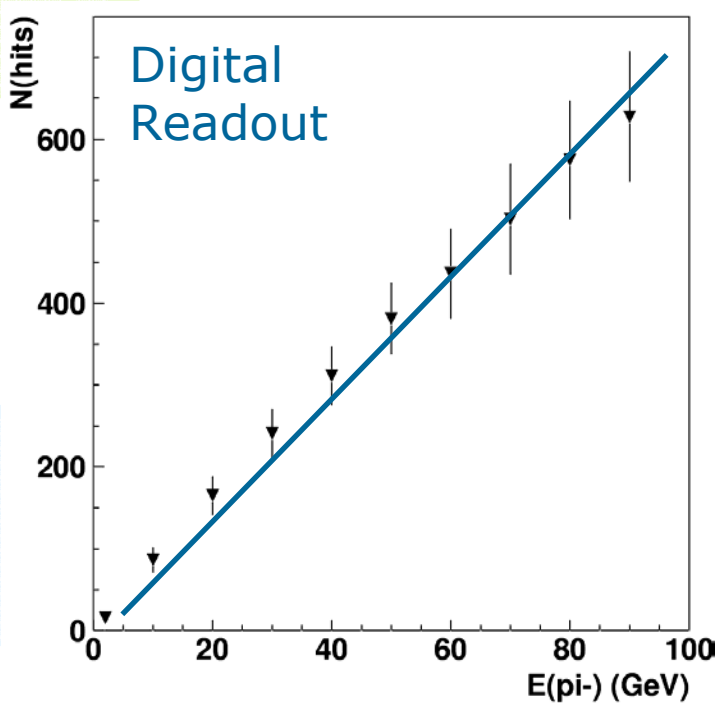
Small number (~10^5) of readout channels + Large number (10 – 18) of bits per channel = **Traditional calorimeter**

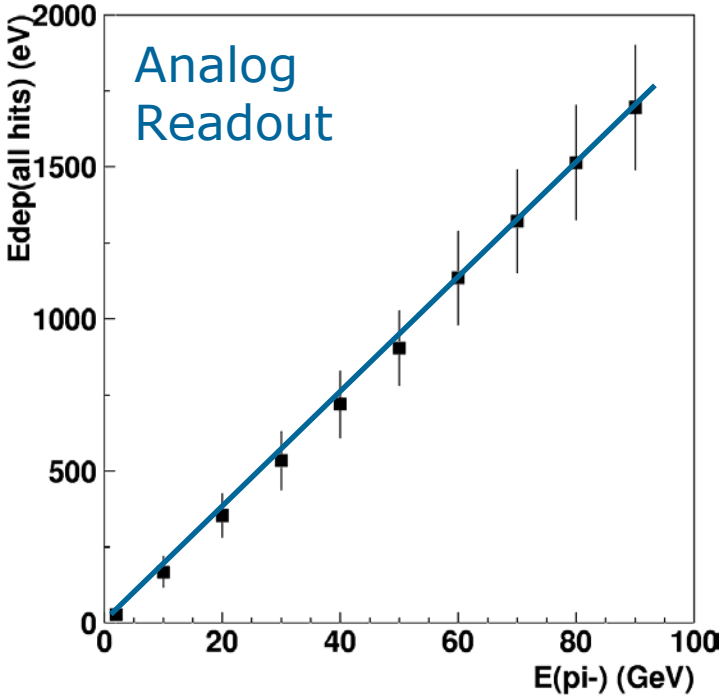
Excellent single particle resolution, but not going to work for PFA

Large number (~10^8) of readout channels
$0.5 \times 0.5 cm^2$ for ECAL
$1 \times 1 cm^2$ for HCAL
+
ECAL: large number of bits per channel
HCAL: small number (1 – 2) of bits per channel
=
Digital hadron calorimeter

Reduces 'confusion' term
Preserves single particle (hadrons) resolutions

Digital HCal





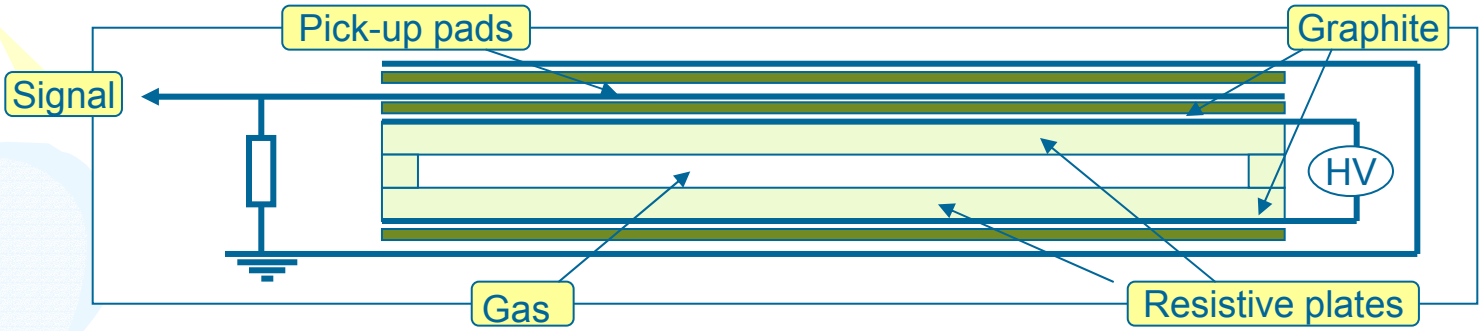
- Monte Carlo study support digital approach
  - Good linearity: number of hits vs. particle energy
  - Comparable single particle energy resolution
  - Full PFA demonstrated with MC simulation
    - See S. Kuhlmann, S. Magill's talk at Victoria LC workshop
- Digital concept made new technology possible
  - Resistive Plate Chamber (RPC) as the active medium

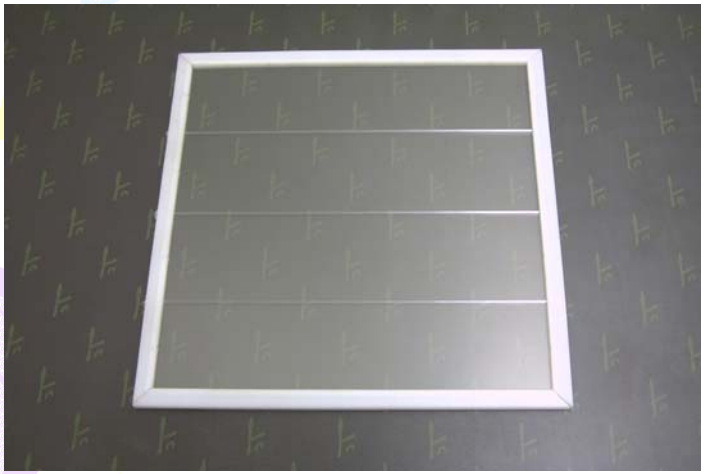
Resistive Plate Chamber (RPC)

RPCs are…

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

No ageing ever observed with glass RPCs





>10 test chambers build at ANL

Gas mixture
Working condition
Chamber configuration
Readout

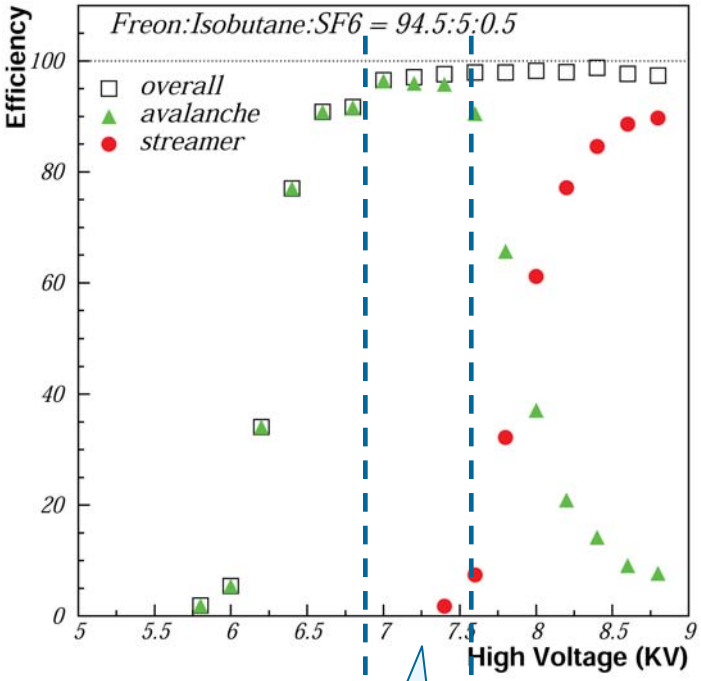
1 full size chamber built and tested

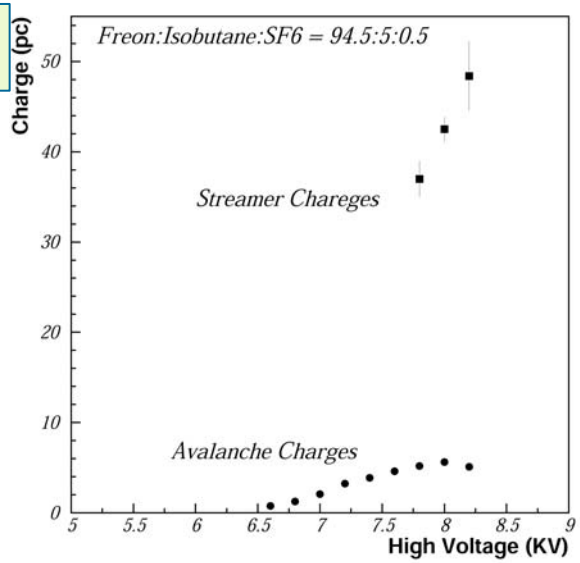
RPC single pad test: signal and operating mode

Tests\mode	Avalanche	Streamer
Gas mixture	Freon:IB:SF_6 = 94.5:5:0.5	
Charge (pc)	0.1 - 5	> 30
Efficiency	>98%	~95%
HV plateau	~600V	-
Noise rate	0.1-0.2Hz/cm^2	~1 Hz/cm^2
Rate capability*	~100 Hz/cm^2	~1 Hz/cm^2

* to be tested

Preferred mode





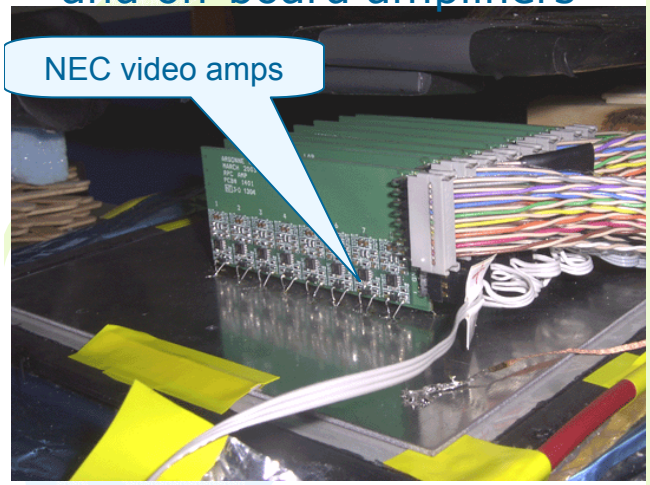
Chamber technology well understood

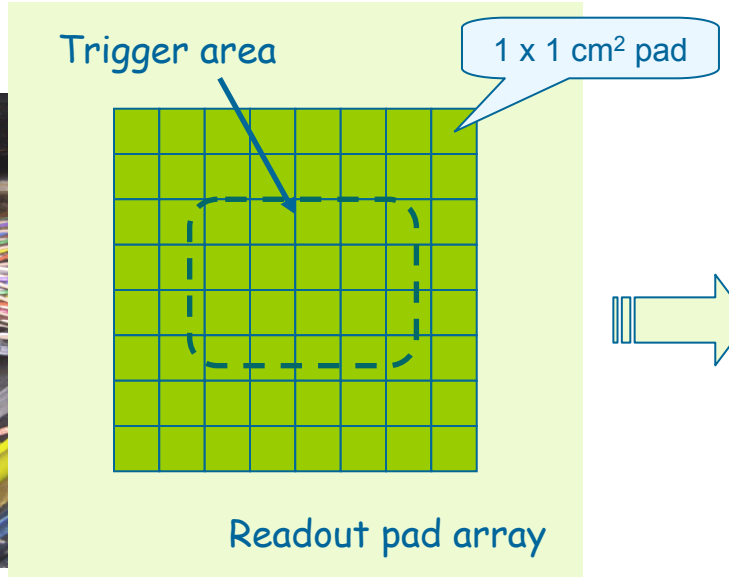
Avalanche Plateau ~600V

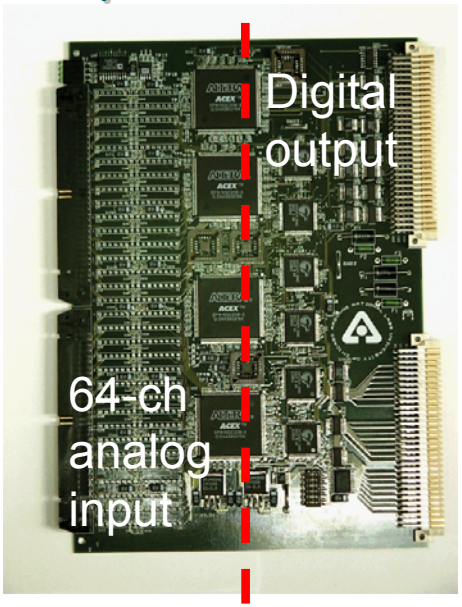
Efficiency > 95%
Streamer < few %

RPC multi-pad test: digital readout system

RPC with multi-pad
and on-board amplifiers

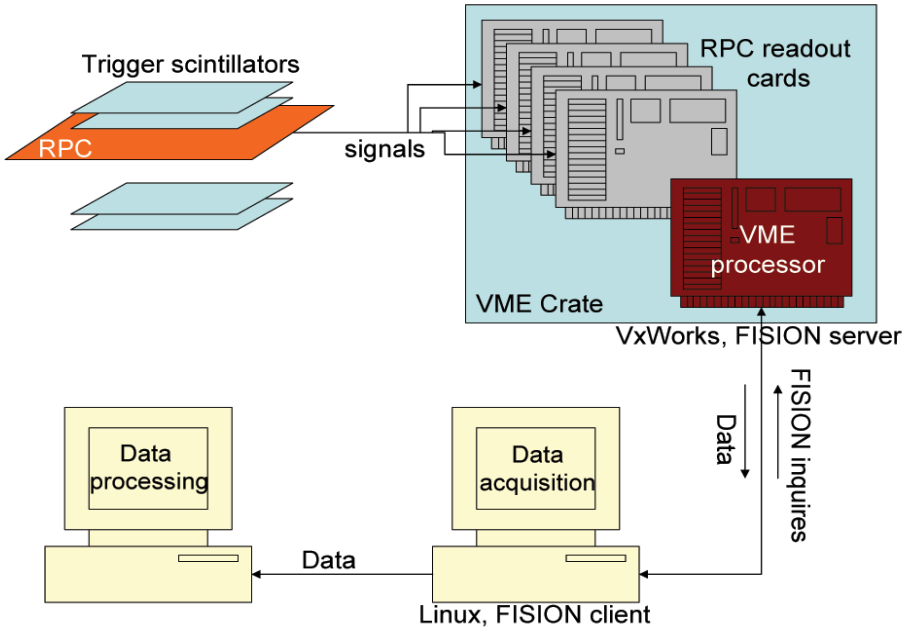






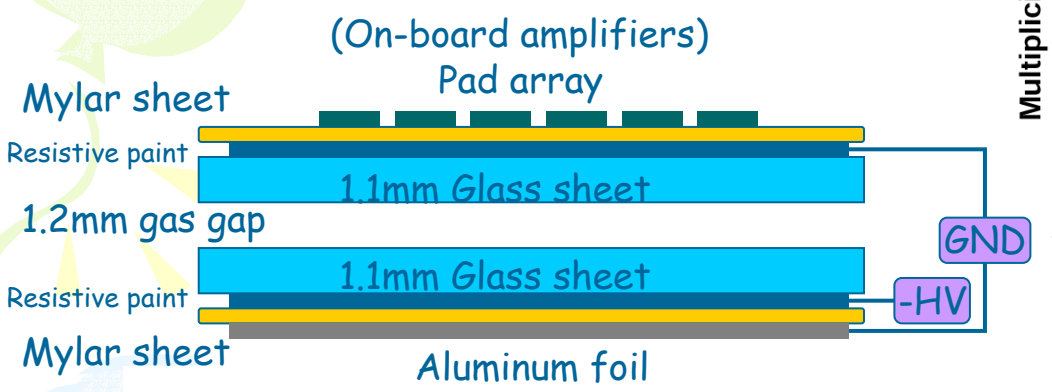
Built VME readout system

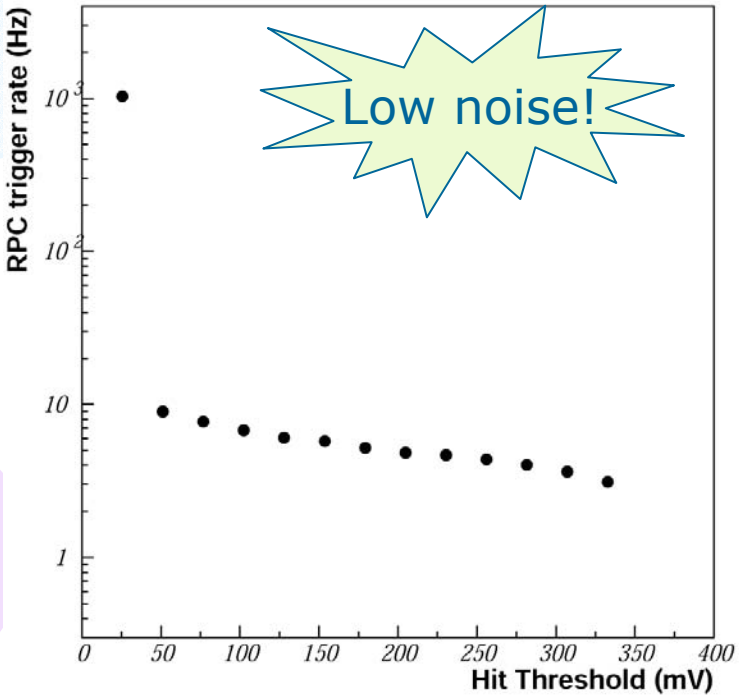
handles 64 channels
Programmable threshold
provides time stamp and hit pattern
100 ns time resolution
self-triggered readout

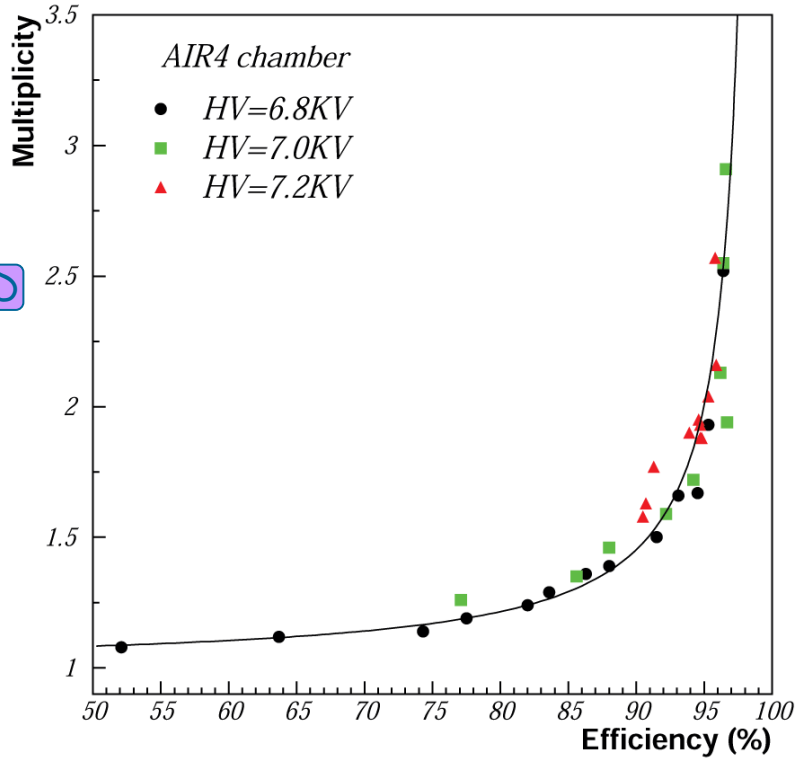


Lei Xia, ANL-HEP

Efficiency and hit multiplicity: configuration 1







Hit multiplicity M

~1.6 – 1.7 (eff ~ 95%)

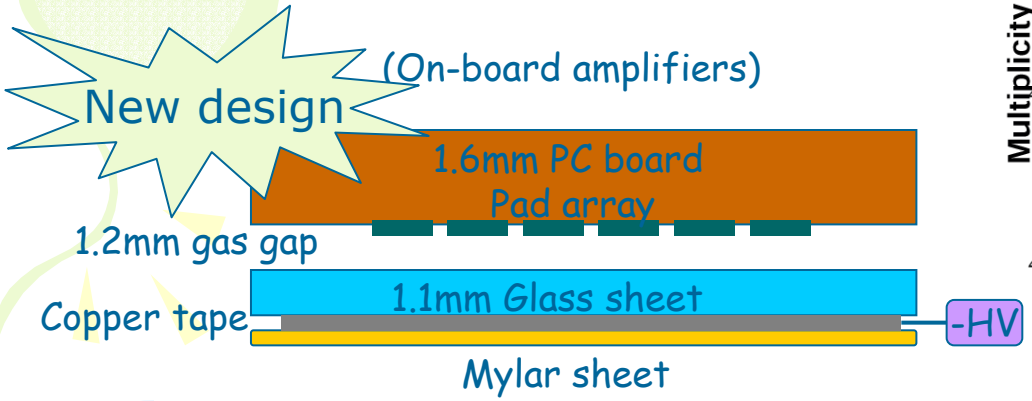
~1.4 – 1.5 (eff ~ 90%)

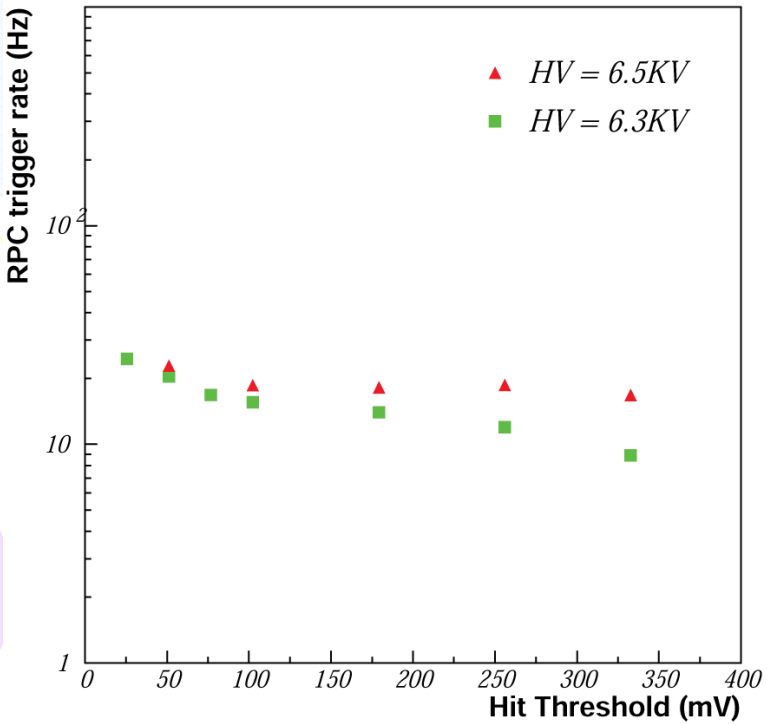
Low noise

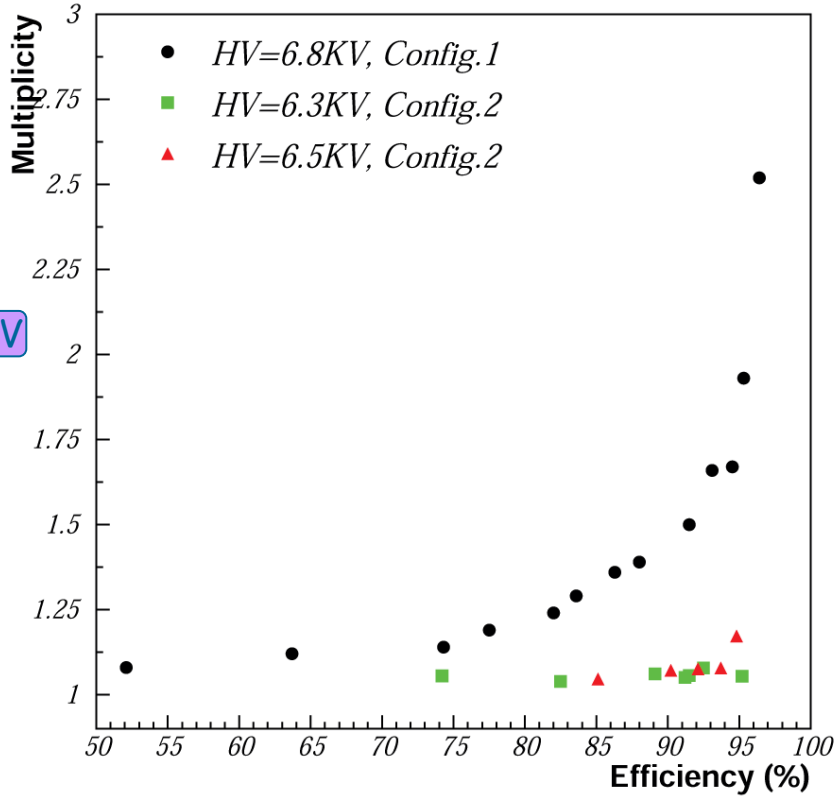
~ 0.1 Hz/cm^2

M not sensitive to operating HV

Efficiency and hit multiplicity: configuration 2







Hit multiplicity M ~ 1.1

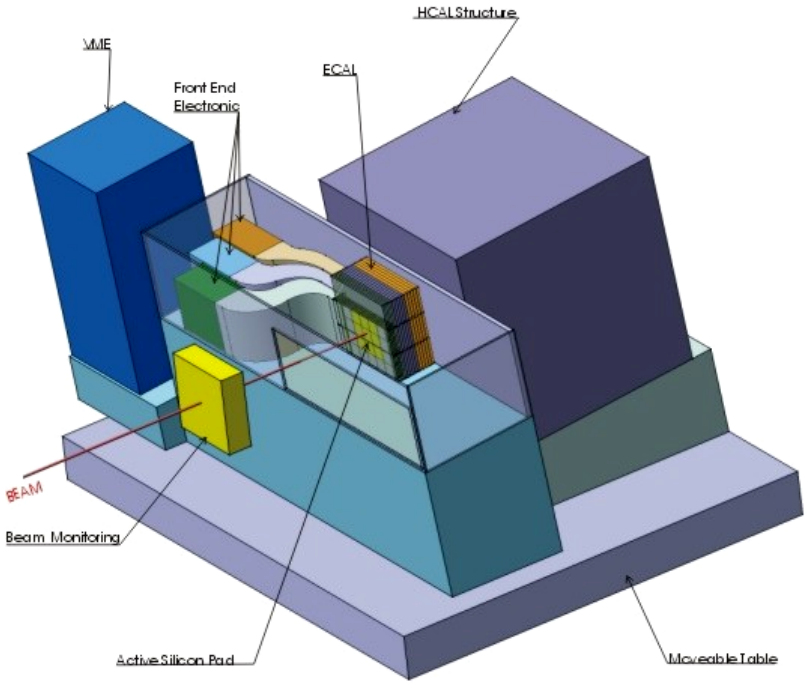
efficiency > 95%
independent of operating HV
independent of hit threshold

Low noise

~ 0.2 – 0.3 Hz/cm^2

Current goal: 1m³ DHCal test section

Goal: 1 m³ prototype section
To be tested in particle beams together with ECAL prototype (-- CALICE collaboration)

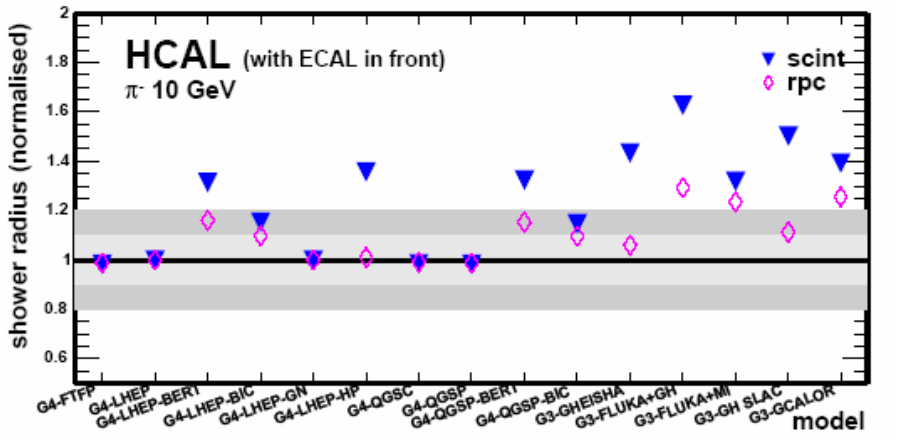


Prototype section

1 m³ (to contain most of hadronic showers)
40 layers with 20 mm steel plates as absorber
Lateral readout segmentation: 1 cm²
Longitudinal readout segmentation: layer-by-layer

Total # of channels: ~ 400,000

Comparison of hadron shower simulation codes by G Mavromanolakis



Motivation for construction and beam tests

Validate RPC 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 Analog HCAL

Electronic readout system

40 layers à 1 m^2

1 cm^2 readout pads

400,000 readout channels

Real challenge

Cheap ($\leqslant$ 1$/channel)

Low cross-talk, noise…

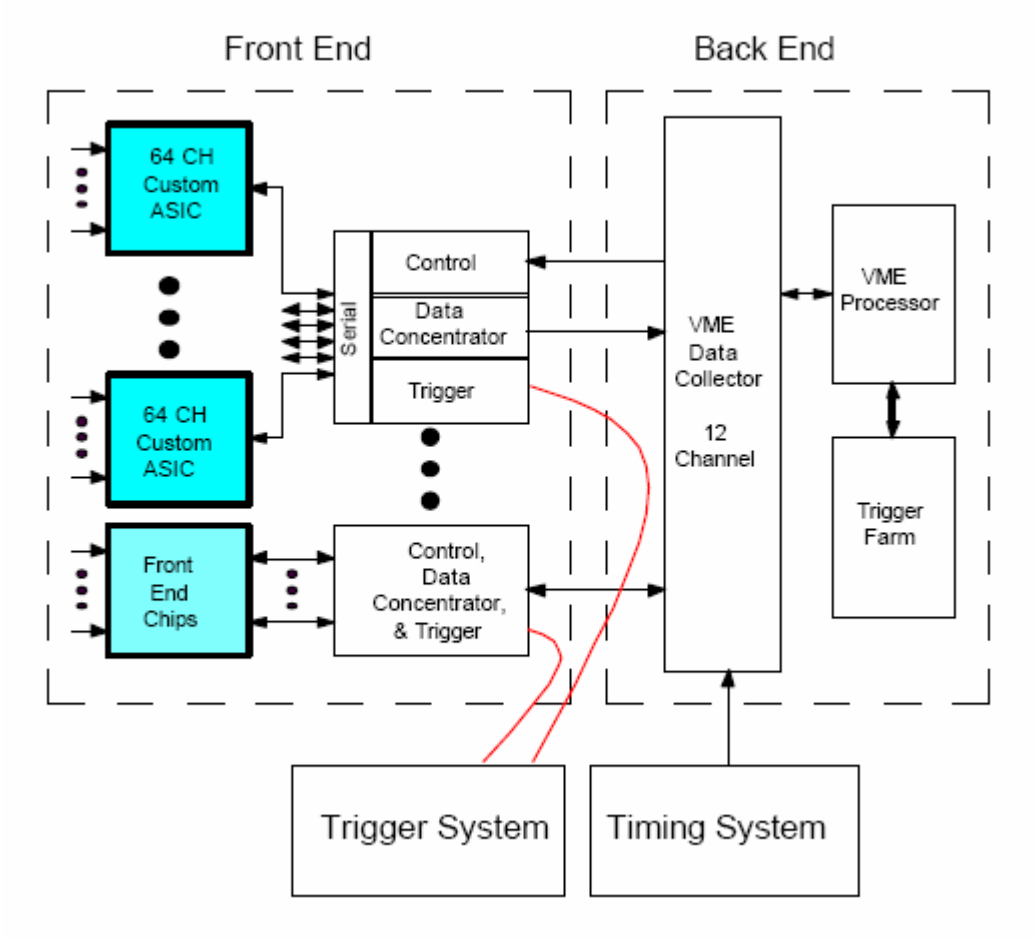
Conceptual design of system

I Front-end ASIC

II Data concentrator

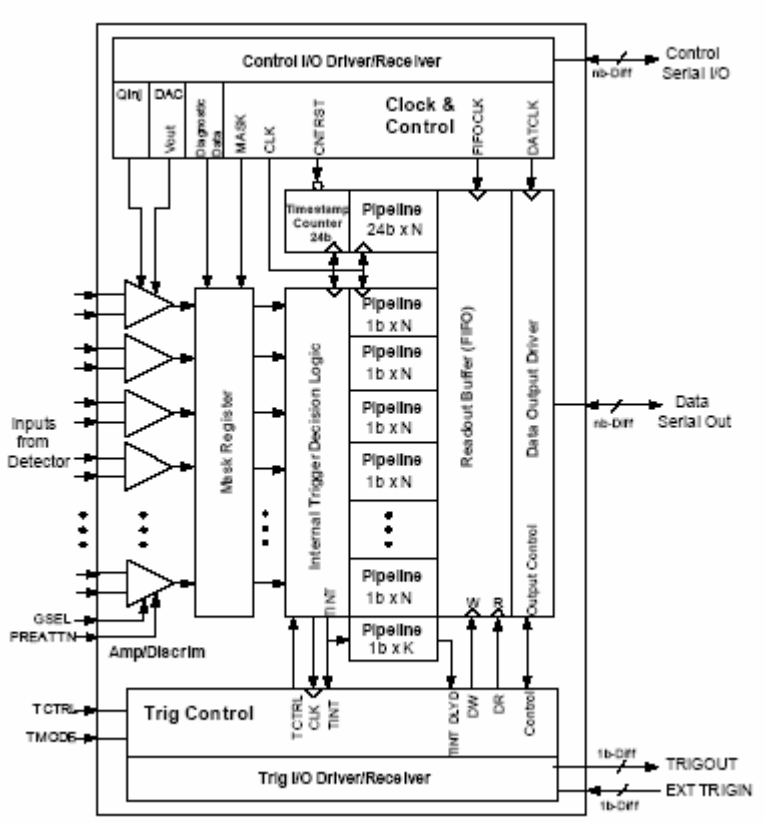
III VME data collection

IV Trigger and timing system



Front-end ASIC

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



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 performance specified in 41 page document
Design work started in June
First submission hopefully in CY2004

Time scales

R&D with chambers

Basically finished!

Electronic readout system

Design and prototype ASIC
Specify entire readout system
Prototype subcomponents

Construction of m^3 Prototype Section

Build chambers
Fabricate electronics

Tests in particle beams

Without and with ECAL in front

FY 2004

CY2004 and early 2005

CY2005

CY2006

Need $$$ to build $1m^3$ test section!

Conclusion

- Digital hadron calorimeter with very fine segmentation is going to be a major breakthrough on jet measurement
- The proposed $1m^3$ test section will improve our knowledge on hadronic showers with much greater details
  - All RPC R&D essentially finished
  - Electronic readout system is being developed
- This is a truly fantastic work! We need support to make it happen…