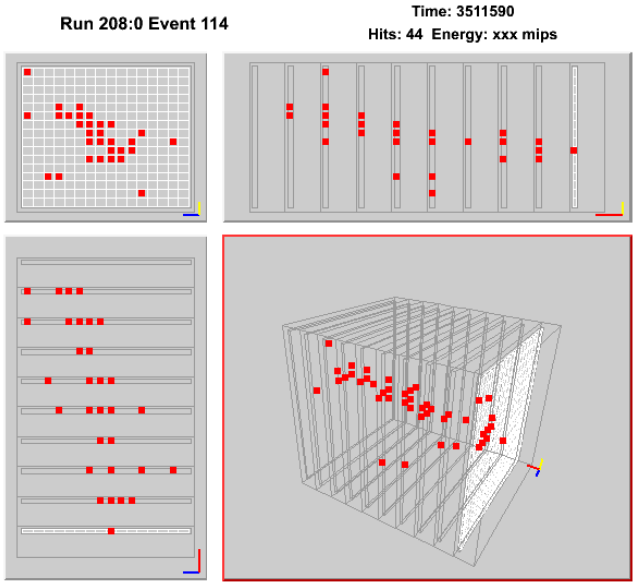
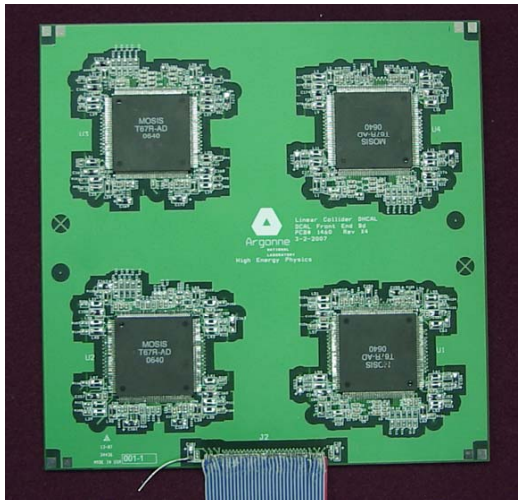
Status and Plans of the RPC-DHCAL Project



José Repond
Argonne National Laboratory

SLAC SiD Meeting, SLAC, January 28 – 30, 2008

Quick overview of the project



Active medium

Resistive Plate Chambers operated in avalanche mode

Electronic readout

Based on DCAL chip (64 channel, digital readout)

Complete readout chain contains Pad- and Front-end boards
Data concentrators
Data collectors
Timing and trigger modules

Prototypes

Assembled 9 – layer calorimeter with 2304 readout channel
Plan to build 1 m^3 physics prototype with 400,000 channels

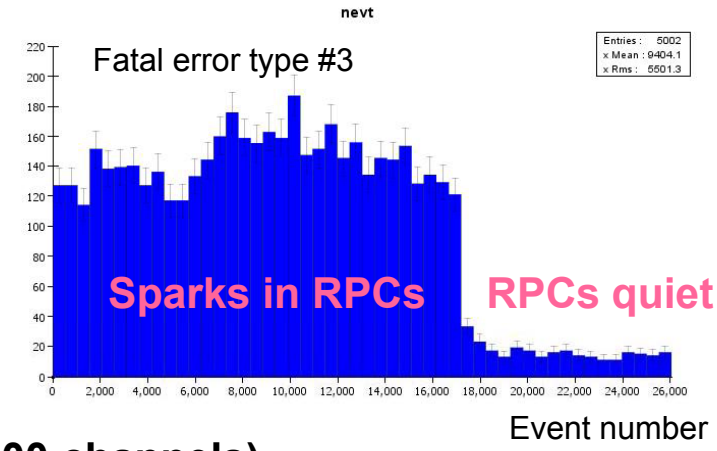
Measurements

Cosmic Rays
Particle beams at FNAL → Vertical Slice Test
Noise rates
Charge injection
Long-term studies

Recent activities I: Analysis of error modes

Since Fermilab run in Summer 2007

Mined data for possible errors or malfunctions



Discovered

14 different errors
Some fatal (data corrupted), some recoverable
Error rate of the order of 5% in 8-layer stack (~2,000 channels)

Improvements to grounding

Eliminated all but one error mode

Last error

Missing data records
Rate <1% of the events
Suspect link between DCON and DCOL
→ detailed studies ongoing

Recent activities II: R&D in preparation of construction

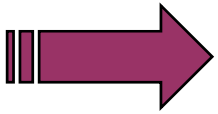
- **Development of simplified pad- and front-end boards**

  Previous boards

  4 and 8 layer boards with blind vias
  ~$1000/board

  New boards

  2/4 and 8 layer boards without blind vias
  ~$100/board
  Boards in hand



If successful might incorporate Data Concentrator on Front-end board

Final design needs final DCAI chips

- **Larger RPCs for prototype section**

  Previous chambers

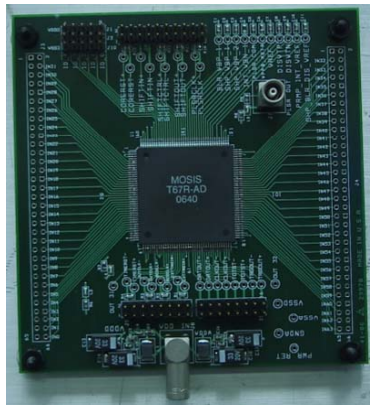
  Used in Vertical Slice Test
  20 x 20 cm^2

  Production chambers

  32 x 96 cm^2
  Glass samples in hand
  Channels to be delivered in 2 weeks

Absolute last developments before construction

- **Last modifications to DCAL chip before production**



50% loss of data when output buffer empty

Not a problem in triggered mode
Problem identified, corrected and simulated

Remove internal test lines

Trivial change already implemented

Removal of asynchronous clear

Needs some design time (~1 week)

Problem with slow control readout

Trivial change already implemented

Additional prototyping NOT required

Need 6,000 chips
Production typically 6 months
Critical path

Recent activities III: Analysis of Muon Data

Two independent analyses

a) Track segement based

Can be applied to hadronic showers

b) Track reconstruction based

→ Results from both very consistent

Data sample

- Two different RPC designs

Default (2-glass)
Exotic (1-glass)

- Various High Voltage settings
- Various Threshold settings

→ About 5,000 – 10,000 events/setting

Number of chambers in the stack	High Voltage in kV	Threshold in DAC counts
8	6.2/5.9	30
		50
		70
9	6.3/6.0	30
		70
		110
		150
		210
7	6.4/5.8	30
		50
		70
		110
		150
		190
		210
8	6.5/6/2	30
		120
		210

Clustering

Build clusters in each layer from touching cells (one side in common)
Determine center of gravity of cluster: x, y

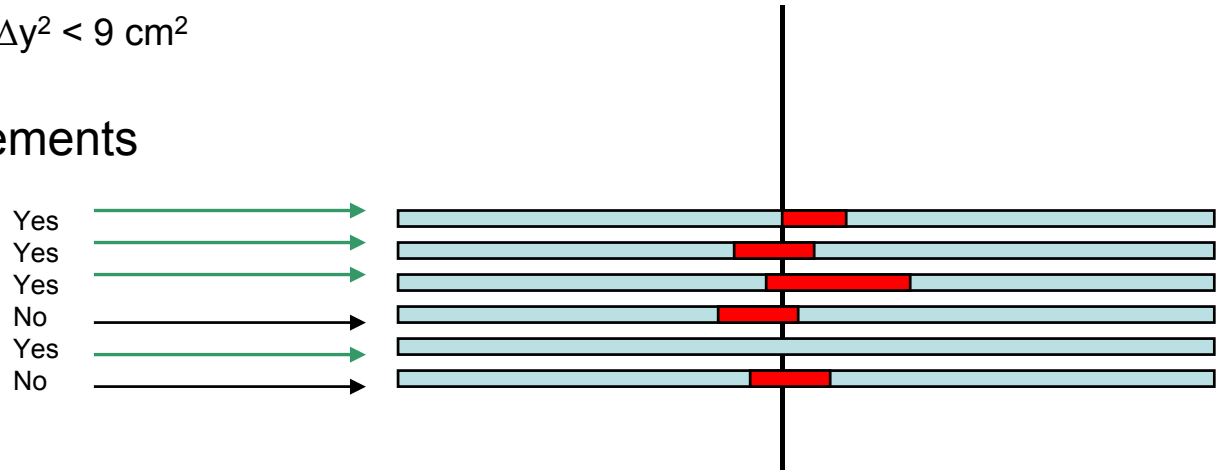
Tracking

Require clusters with 1or 2 hits only (this cut still under study)
Check for aligned clusters in 2 layers

a) above and below the layer being investigated
b) 2 layers directly above if lowest layer in stack
c) 2 layers directly below if highest layer in stack

$\Delta R^2 = \Delta x^2 + \Delta y^2 < 9\ cm^2$

Measurements

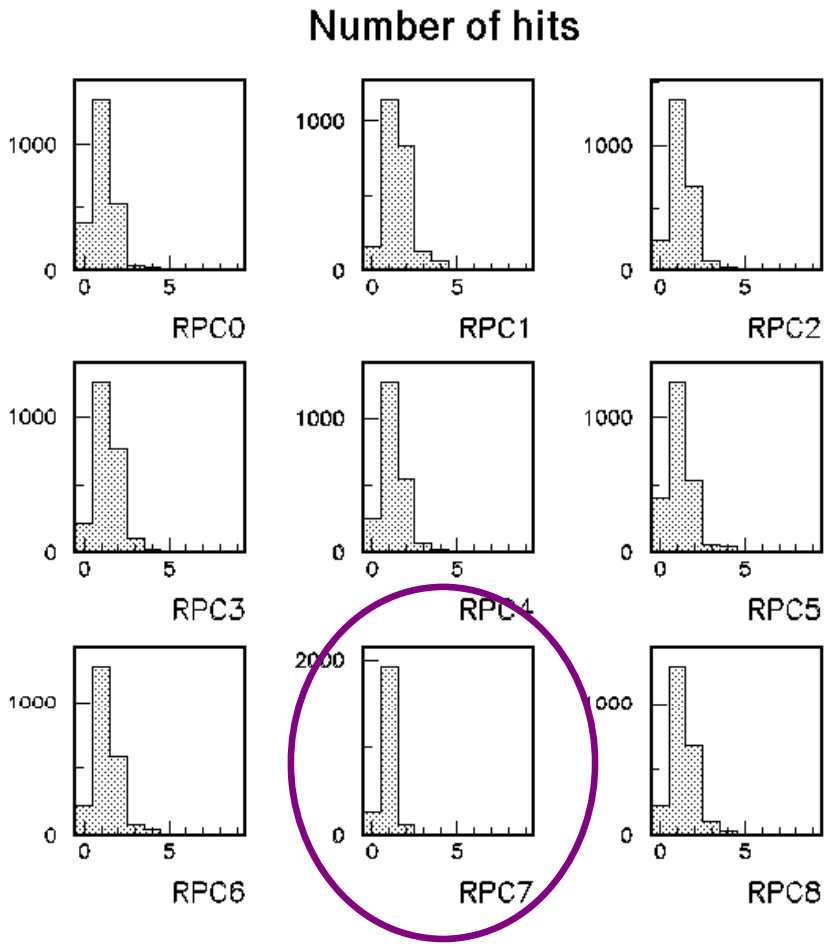


$\Delta R^2 = \Delta x^2 + \Delta y^2 < 10\ cm^2$ for considered a match → Write out multiplicity M of cluster

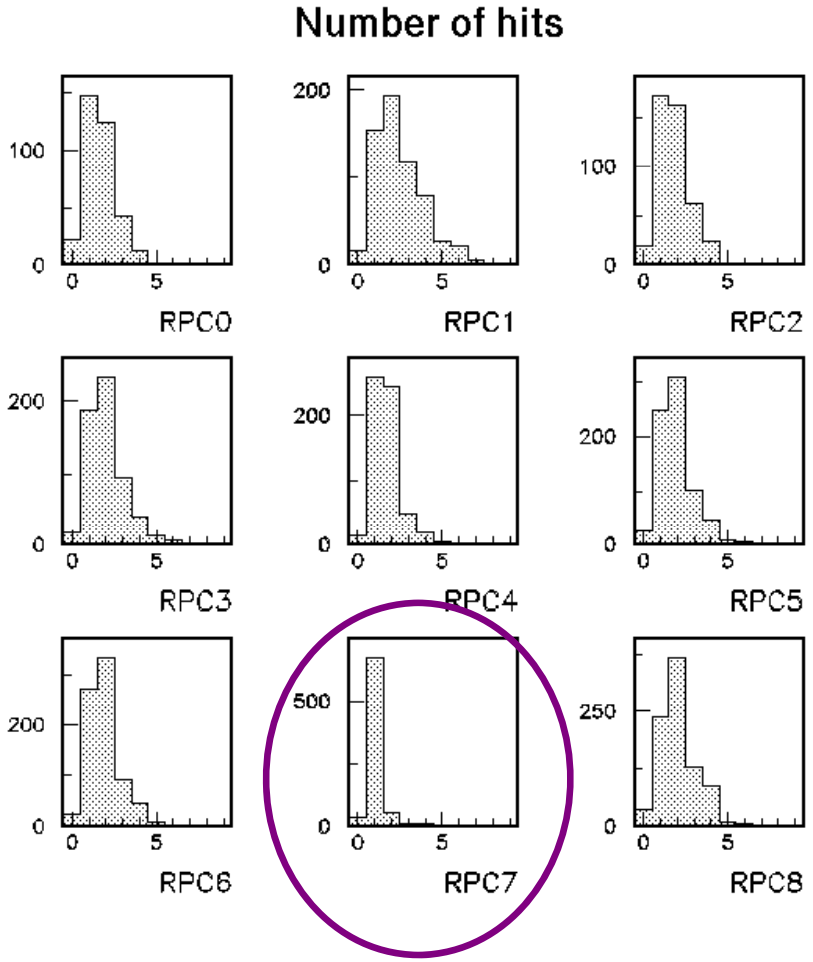
$\geq 10\ cm^2$ → Write out M = 0

Hit distribution for individual chambers

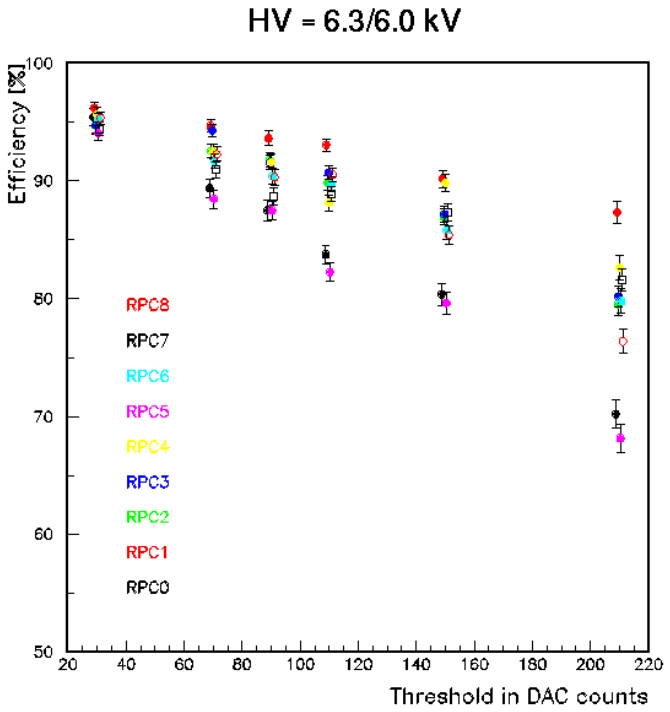
Run 211 – HV = 6.3/6.0 THR = 110

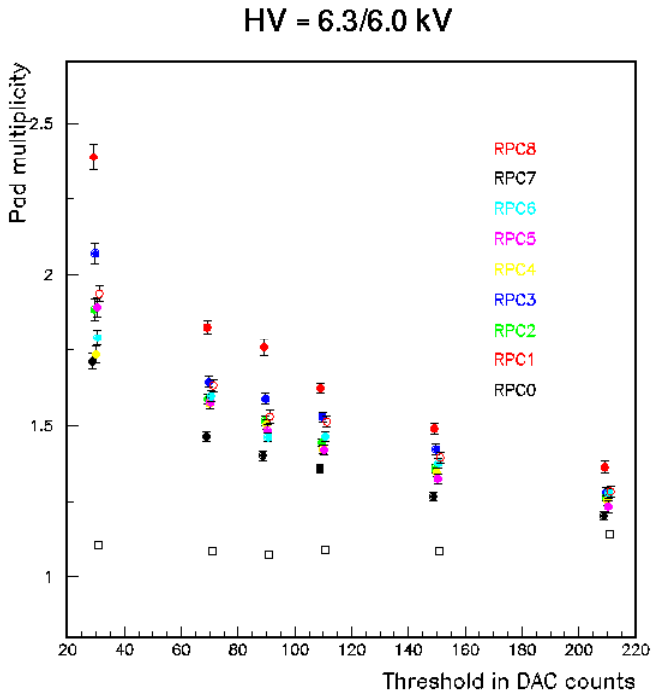


Run 213/4 – HV = 6.5/6.2 THR = 30

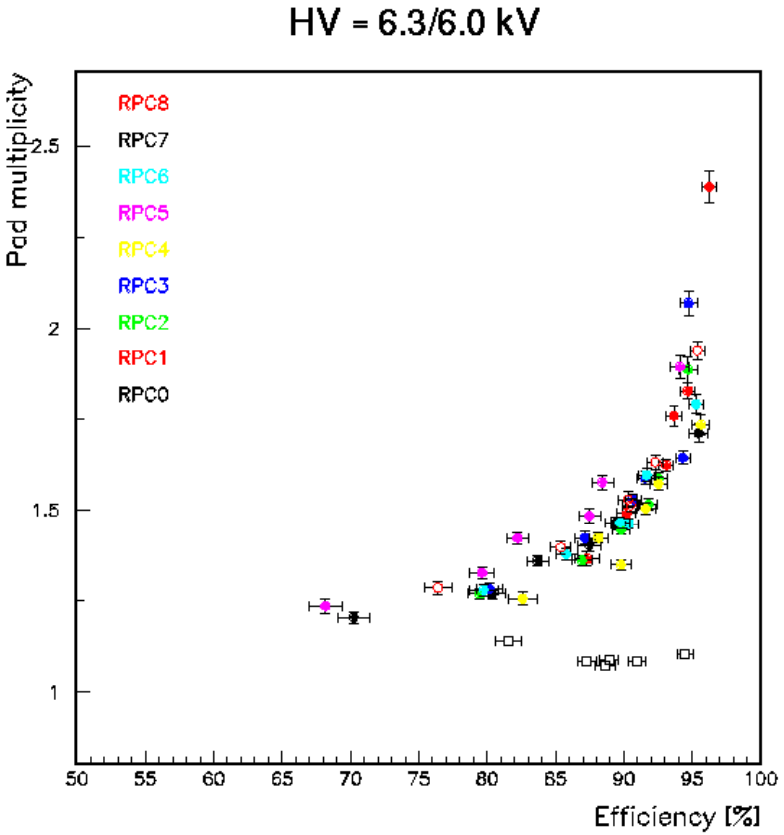


Exotic chamber



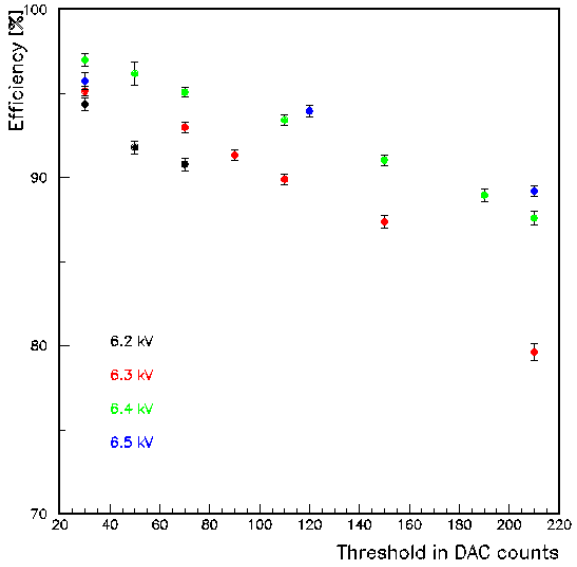


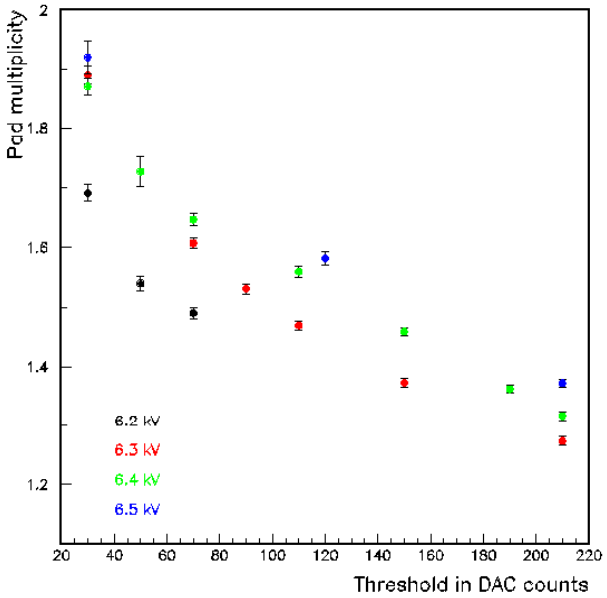
Example – Results at 6.3/6.0 kV



RPC5 – Has lower efficiency (← grounding problem)
RPC1 – Needs lower HV
RPC0 – Needs higher HV
RPC7 – Exotic design

Combined results

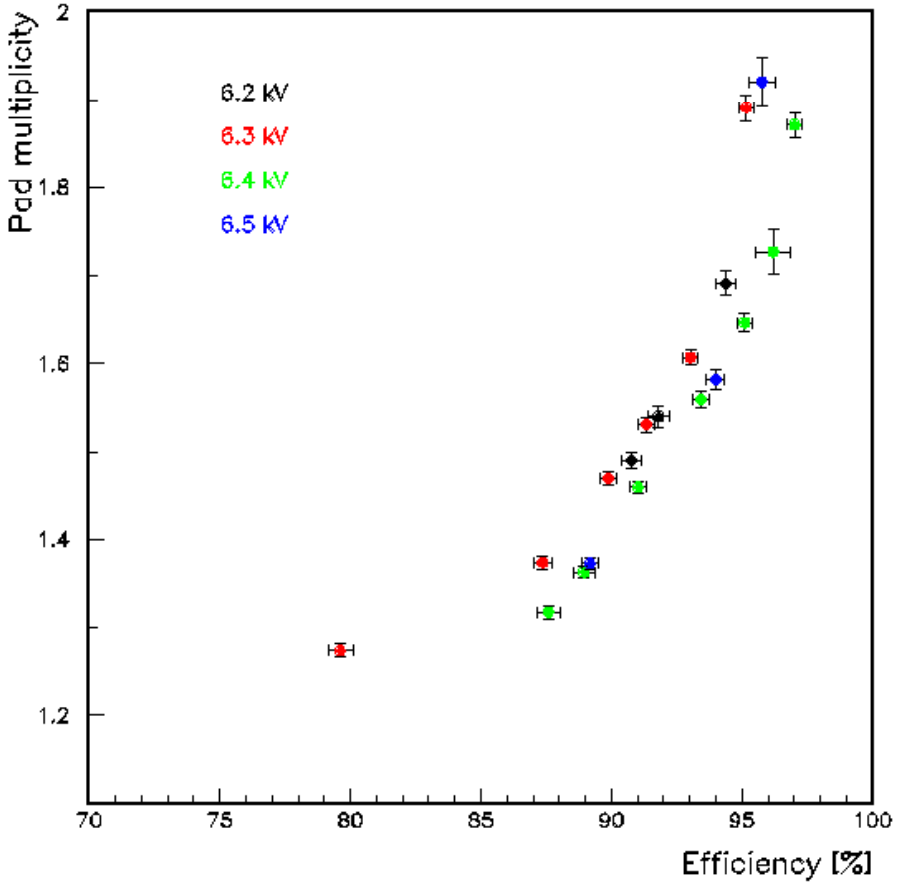




Excluded
- RPC0 – Not working properly
- RPC1 – Needs lower HV
- RPC5 – Has lower efficiency
- RPC6 – Needs higher HV
- RPC7 – Not working properly

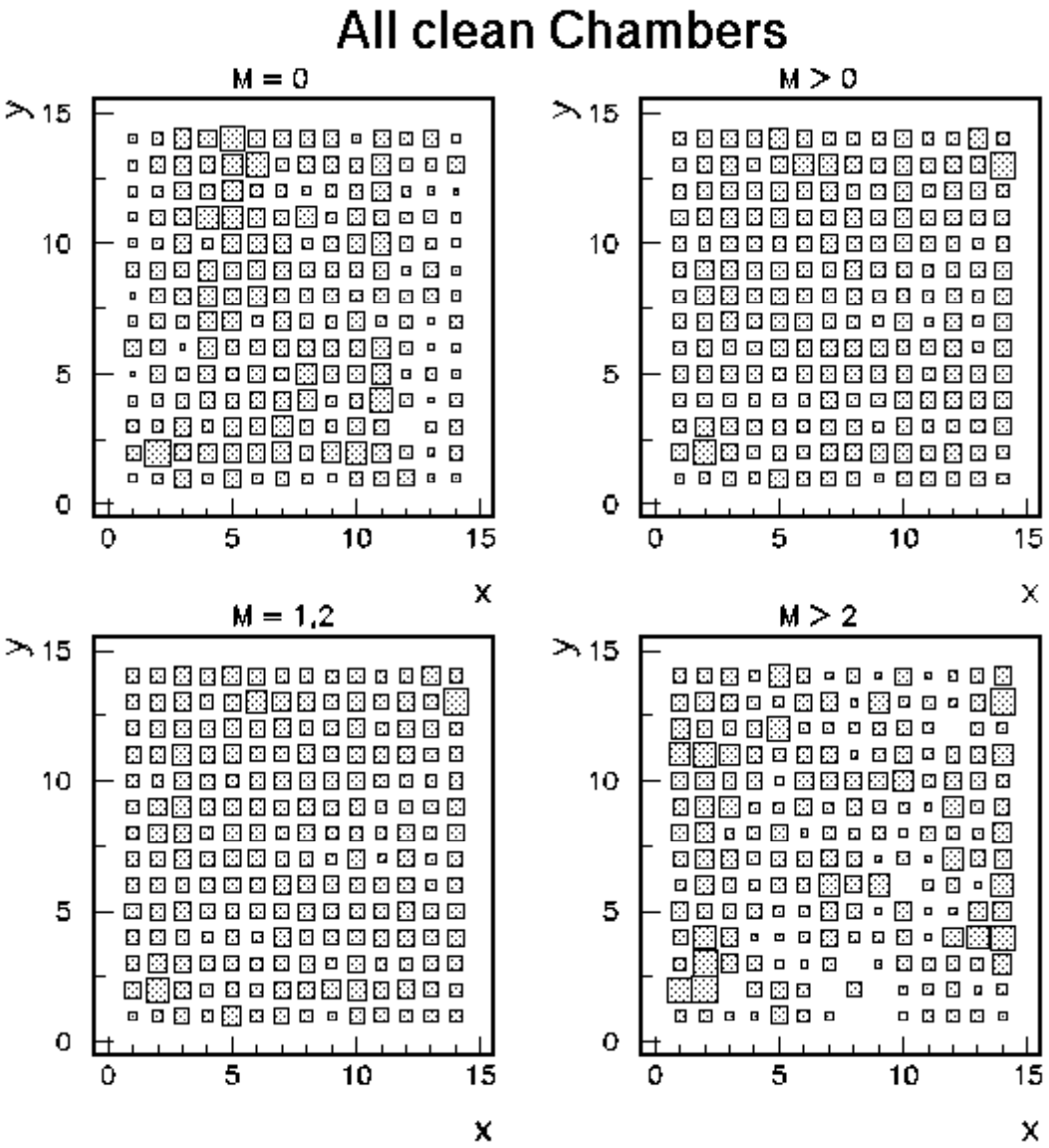
→ left with RPC 2,3,4,8

All problems later traced back to unfortunate grounding scheme



Distribution of hits/no hits

→ Exclude RPC0, RPC4, RPC5

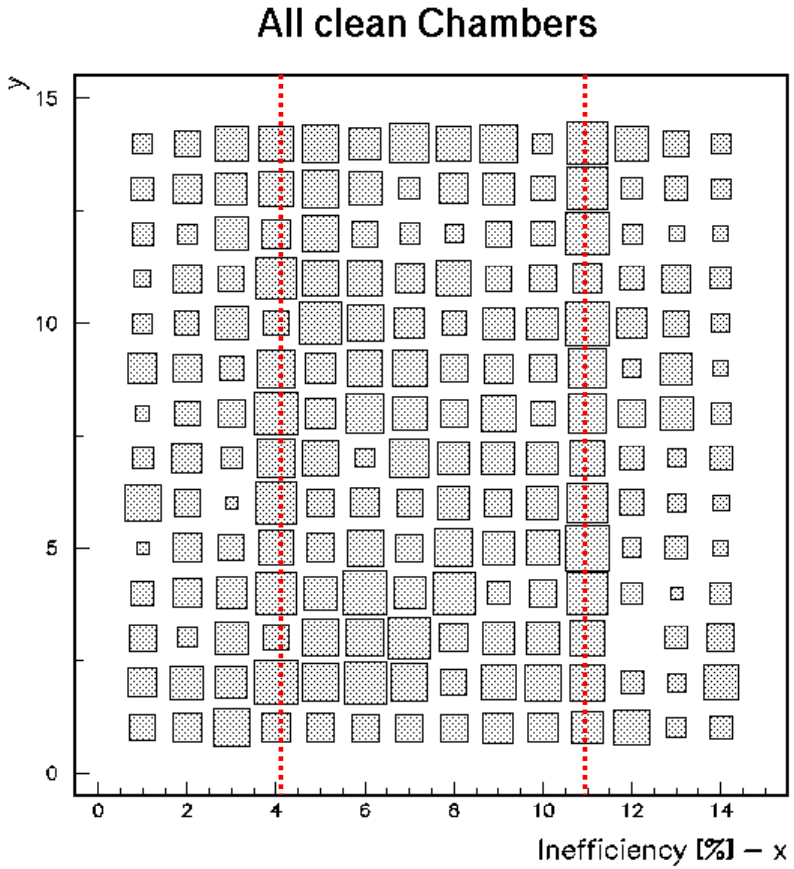


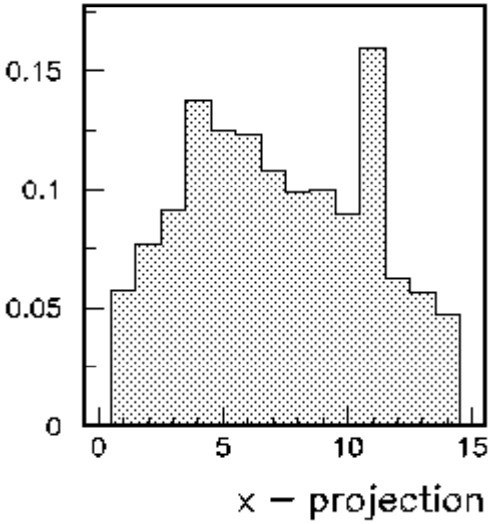
Higher hit multiplicity at low/high x

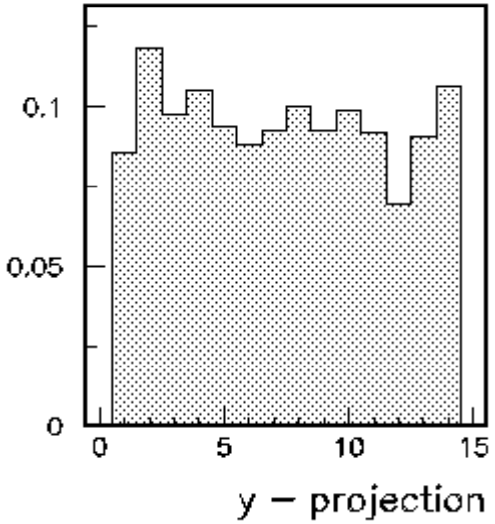
(later traced back to office clips holding front-end board onto the chamber)

Inefficiency

$$\not\varepsilon = N(M=0)/N_{Total}$$







Clear evidence for loss of efficiency around fishing lines

Paper draft written

Should be submitted within two weeks

Calibration of a Digital Hadron Calorimeter with Muons

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Abstract. The calibration procedure of a finely granulated digital hadron calorimeter with Resistive Plate Chambers as active element is described. Results obtained with a stack of nine layers exposed to the Fermilab test beam are presented.

Keywords: Calorimetry, Linear Collider, Particle Flow Algorithms, Resistive Plate Chambers.
PACS: 29.40.Vj, 29.40.Cs, 29.40.Mc, 29.40.Wk

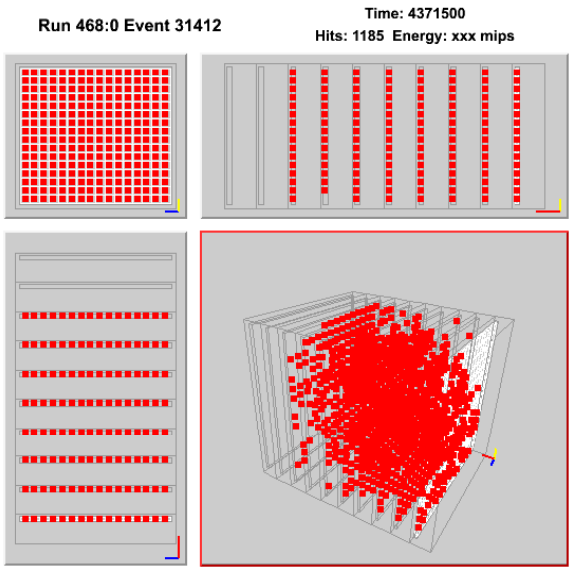
INTRODUCTION

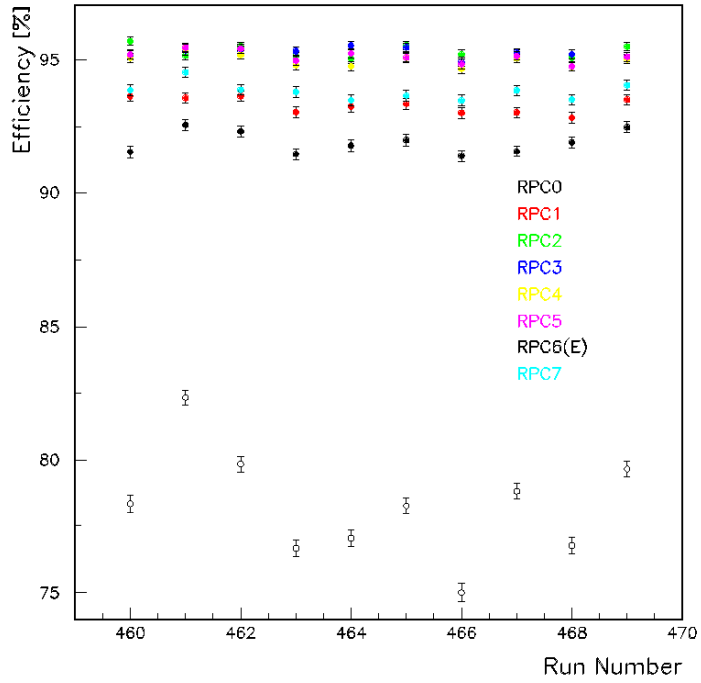
Particle Flow Algorithms (PFAs) attempt to measure all particles in a jet (originating from the interaction point) individually, using the detector component providing the best momentum/energy resolution. Charged particles are measured with the tracking system (except for high momenta, where the calorimeter provides a better measurement), photons are measured with the electromagnetic calorimeter (ECAL), and neutral hadrons, i.e. neutrons and K_L^0's, are measured with both the ECAL and the hadronic calorimeter (HCAL). The energy of a jet is reconstructed by adding up the energy of the individual particles identified as belonging to the jet. The major challenge in this approach to the measurement of jet energies lies in the identification of energy deposits in the calorimeter belonging to either a charged or neutral particle. Hence the requirement of calorimeters with very fine segmentation of the readout. Additional details on PFAs and the requirements for calorimetry can be found in references [1,2].

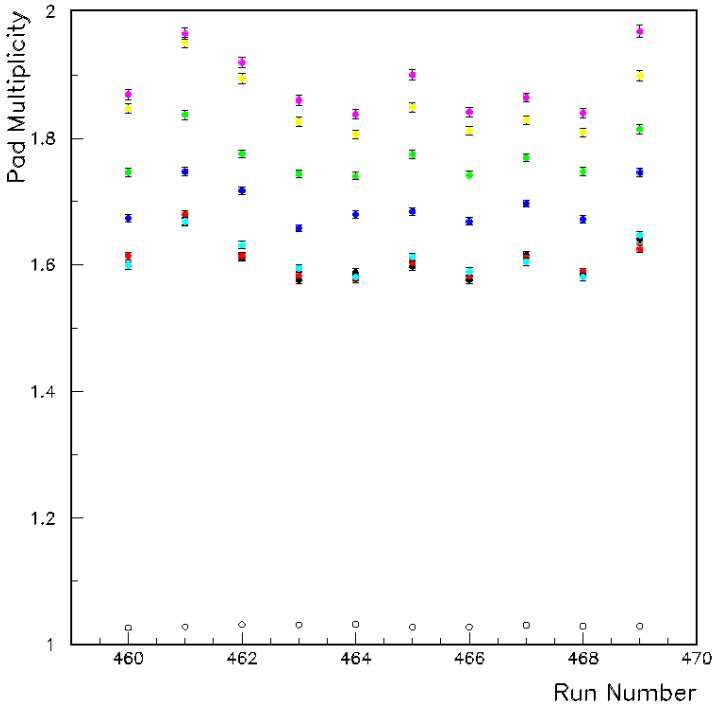
In this context this paper reports on the development of a finely granulated HCAL using Resistive Plate Chambers (RPCs) as active medium. In preparation for the construction of a larger prototype module, a stack of nine chambers was assembled and exposed to the muons, electrons and pions of the Fermilab test beam. Following the description of a general calibration procedure for such calorimeters, the measurements performed with the broad-band muon beam are described in detail.

Recent activities IV: Cosmic Ray Data

Run Number	# of events	Empty events	Out of time	More than 1000 hits	Dead cells
460	32539	2939	49	1	12
461	39633	3787	208	0	11
462	37602	3338	13	0	11
463	34473	3191	21	0	11
464	34365	3059	52	0	11
465	35398	3192	54	0	11
466	31253	2885	56	0	11
467	38744	3426	32	0	11
468	35495	3190	21	1	11
469	35731	3172	12	0	11
Total	**355233**	**32179**	**518**	**2**	**11**

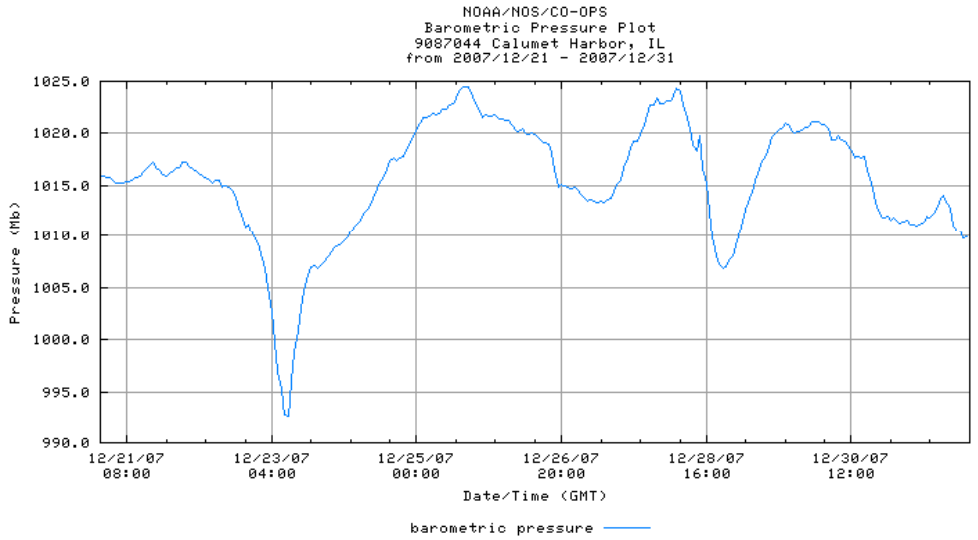




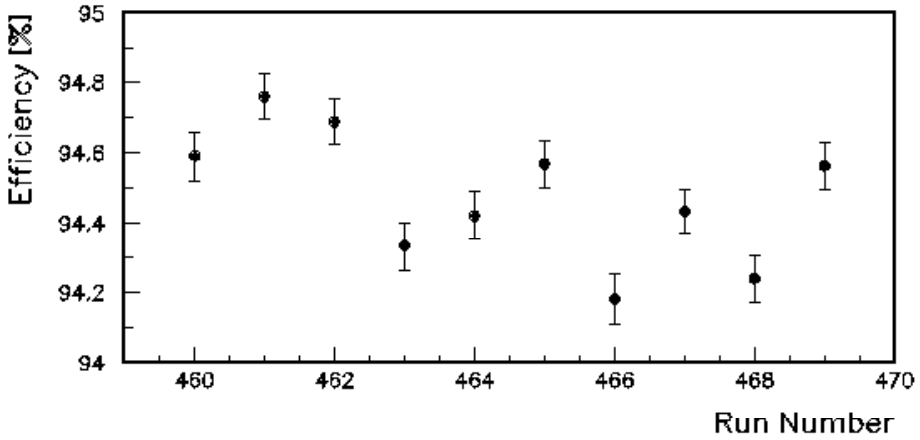


Noticed correlation in efficiencies and pad multiplicities

10 days

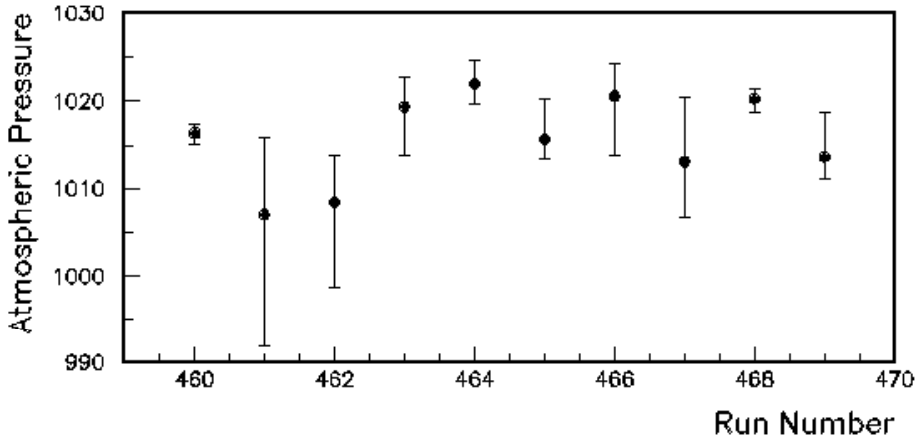


Barometric pressure at Calumet Harbor, IL

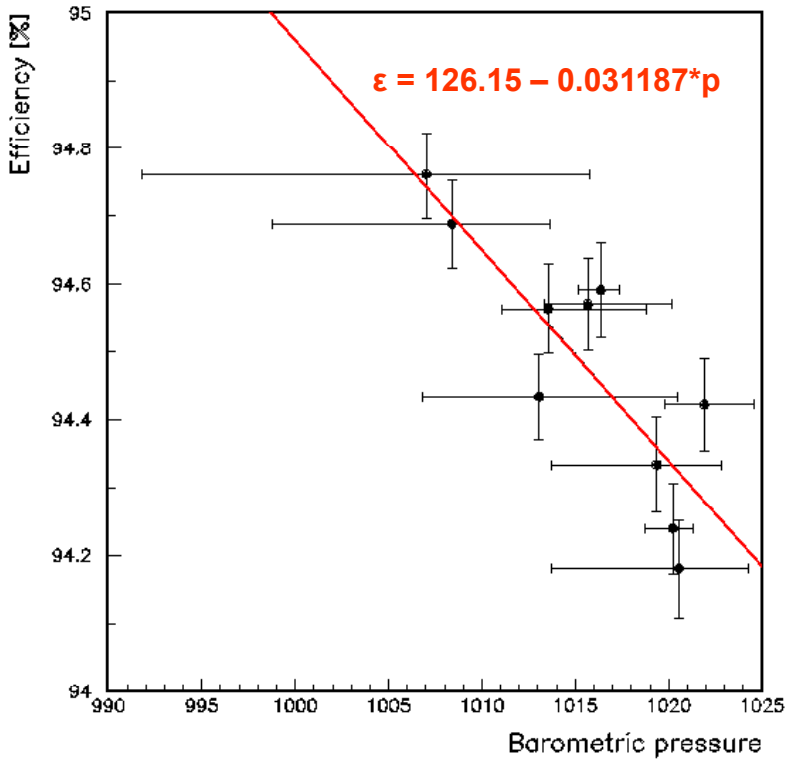


Average over all non-exotic chambers

Higher pressure → lower efficiency

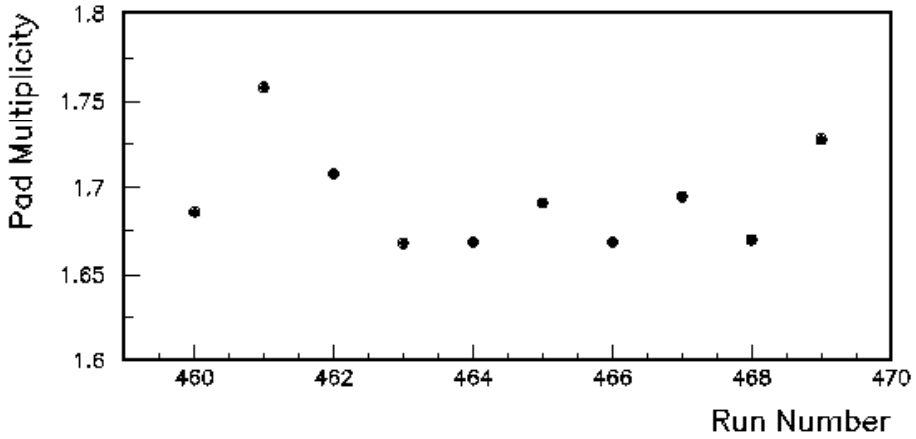


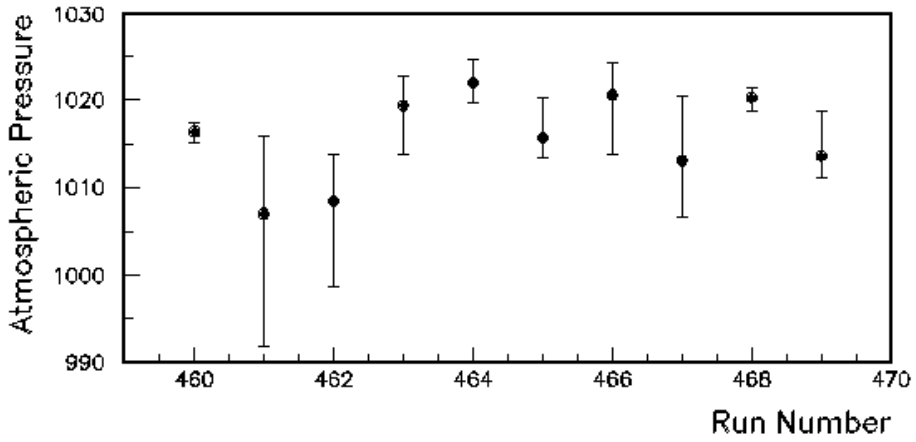
Error bars on pressure show range



$\Delta\varepsilon/\varepsilon = -0.34\ \Delta p/p$

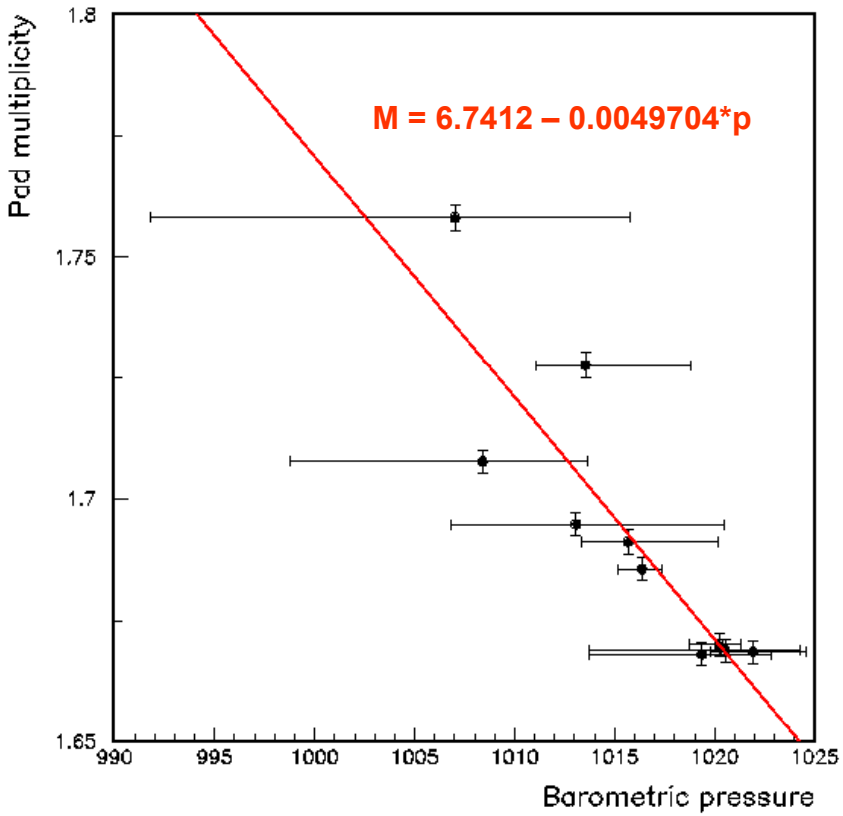
Error bars on pressure set to 0 for fit





Average over all non-exotic chambers

Higher pressure → lower multiplicity

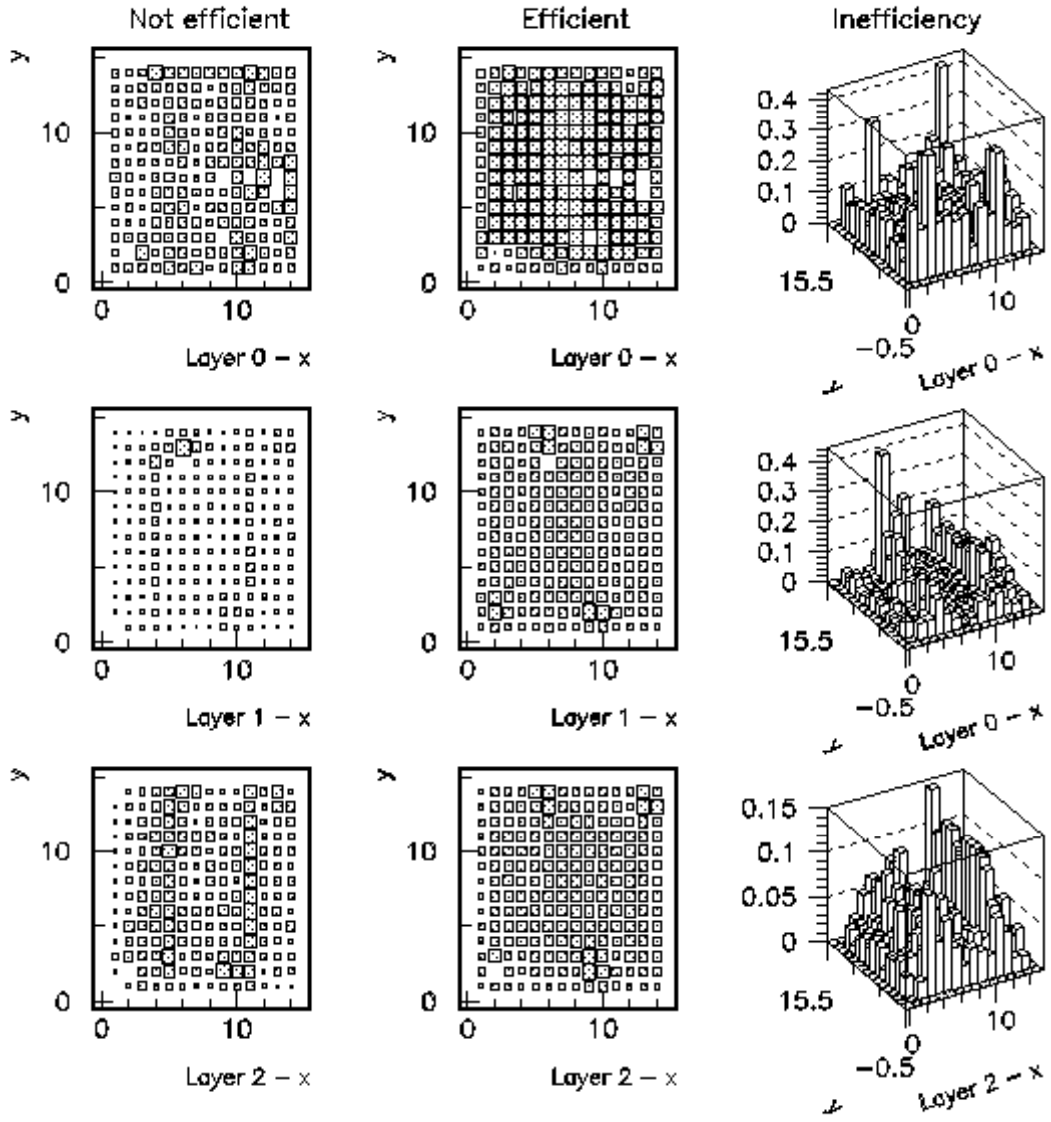


Error bars on pressure show range

$\Delta M/M = -3.0\ \Delta p/p$

Error bars on pressure set to 0 for fit

Large statistics – Detailed x-y Maps



Clear drop in ε around fishing lines

Enhanced ε around clips

Recent activities V: Analysis of Positron Data

Two independent analyses

a) Study of energy response
b) Study of longitudinal development

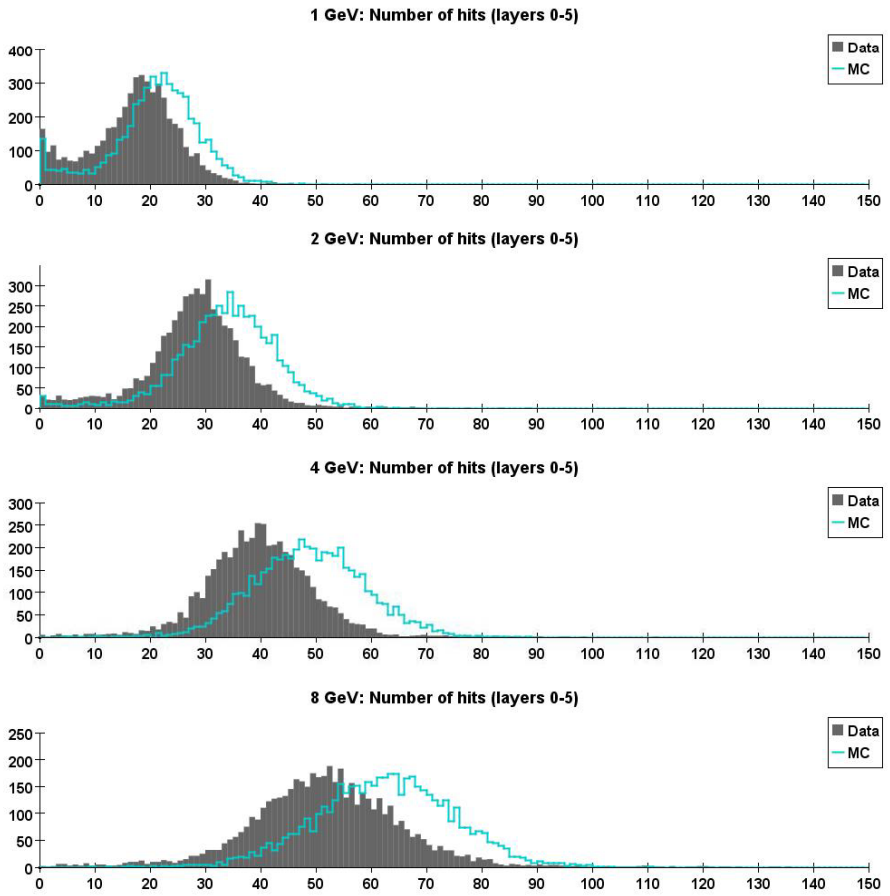
→ Results still very preliminary

Data sample

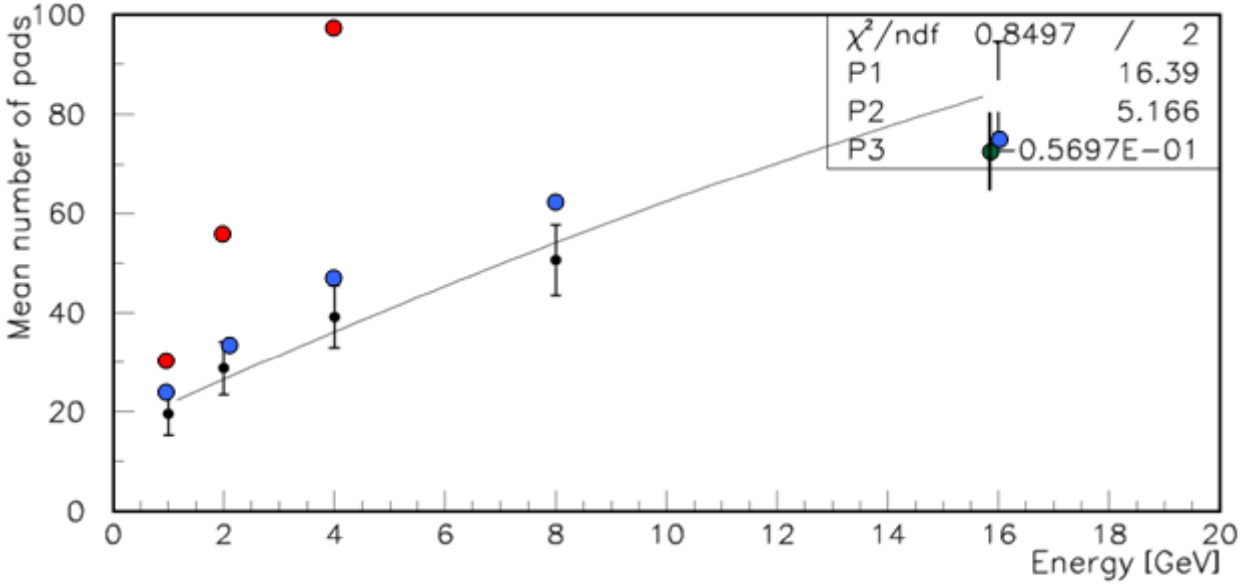
- Data at 1, 2, 4, 8, and 16 GeV

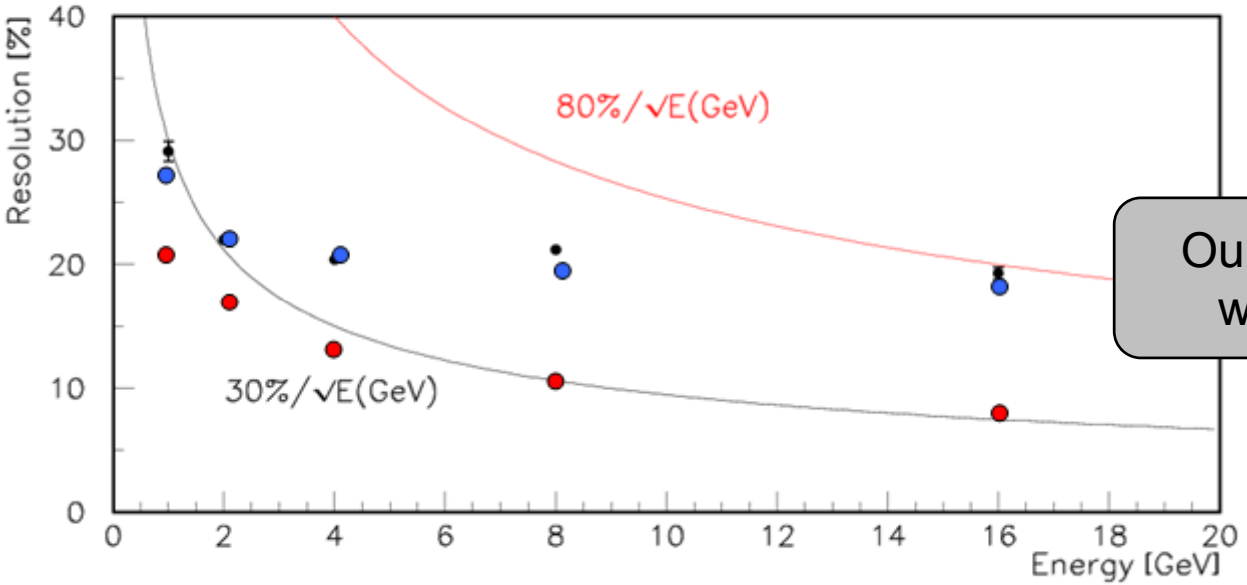
Monte Carlo simulation

- Needs calibration constants from μ-runs
- Needs careful implementation of pad multiplcities
- Current comparison based on assumptions and ignoring details



Energy response and resolution





Data with 6 layers

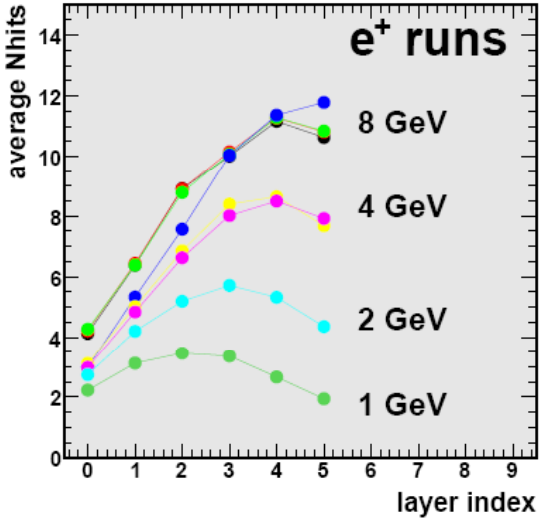
Monte Carlo simulation with 6 layers

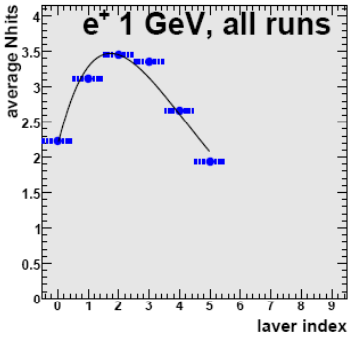
Monte Carlo simulation with infinite depth

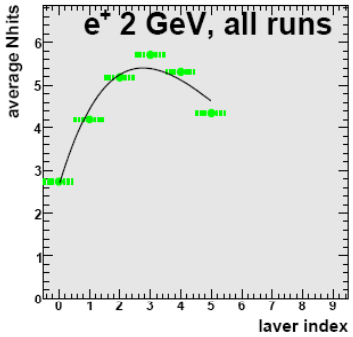
Our little calorimeter stack works as a calorimeter

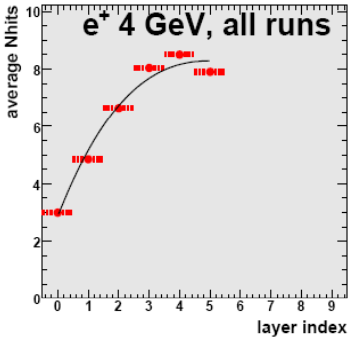
Shower longitudinal profiles

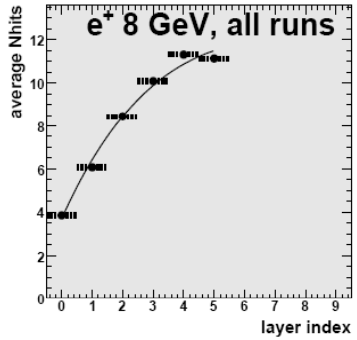
Shower maximum contained in 6 layers
Significant energy leakage (at higher energies)







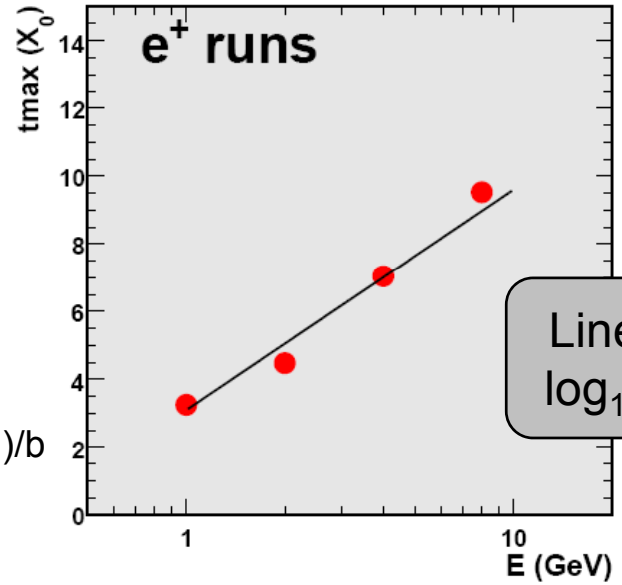




Fit to empirical formula

$$\frac{dE}{dt} = E_0 \cdot b \cdot \frac{(bt)^{a-1} e^{-bt}}{\Gamma(a)} \text{ (with } t = x/X_0)$$

with the shower maximuma at t_{max} = (a-1)/b

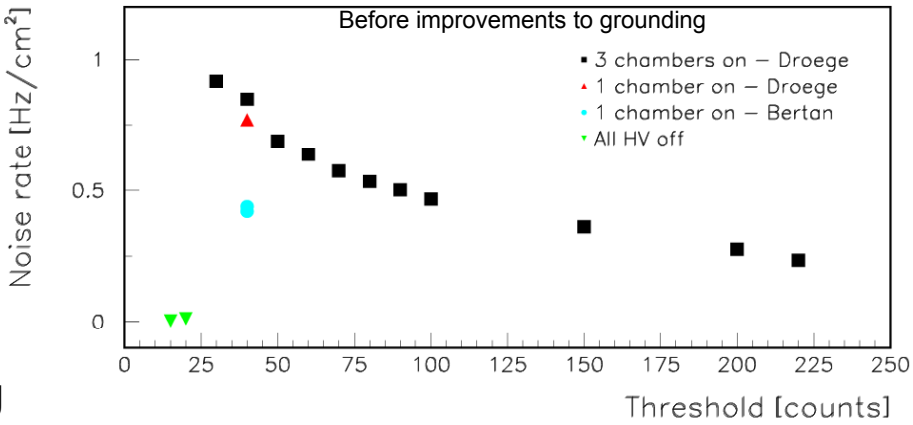


Linear increase with $\log_{10}(E)$ as expected

Recent activities VI: Measurement of Noise Rates

Uses self-triggered mode of DCAL chip

Correction of x2 for data loss



Noise rate very low! With new grounding

Typically 20 – 30 Hz/chamber at a threshold of 30 (default is 110)
Two chambers somewhat noisy (100, 500 Hz/chamber)

→ Probability of a noise hit in 1 m^3 stack P ~ 10^{-2}/event

Environmental impact

Noise rate depends on gas flow (accident!)
Noise rate (might) depend(s) on p,T,H
→ Needs detailed studies, will acquire weather station

RPCs are very quiet

Recent activities VII: Charge Injection

DCAL chip has internal charge injection capability

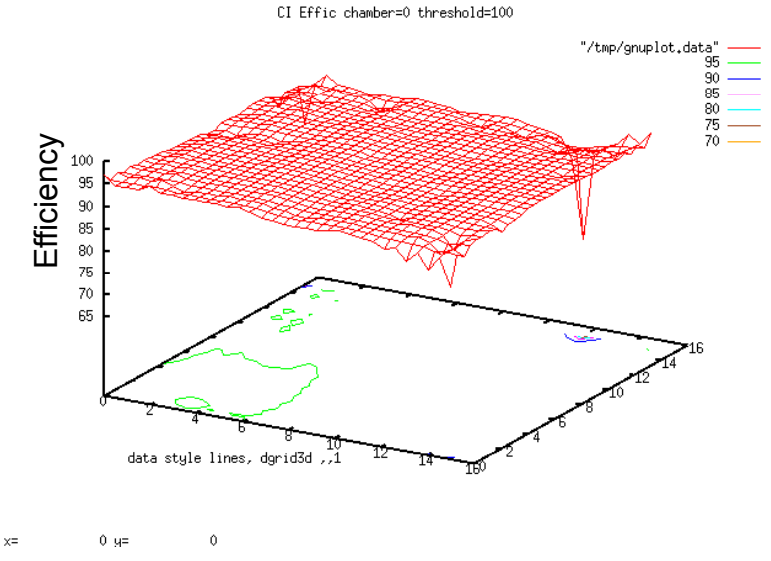
Range < 10 fC, which is unfortunately a bit small

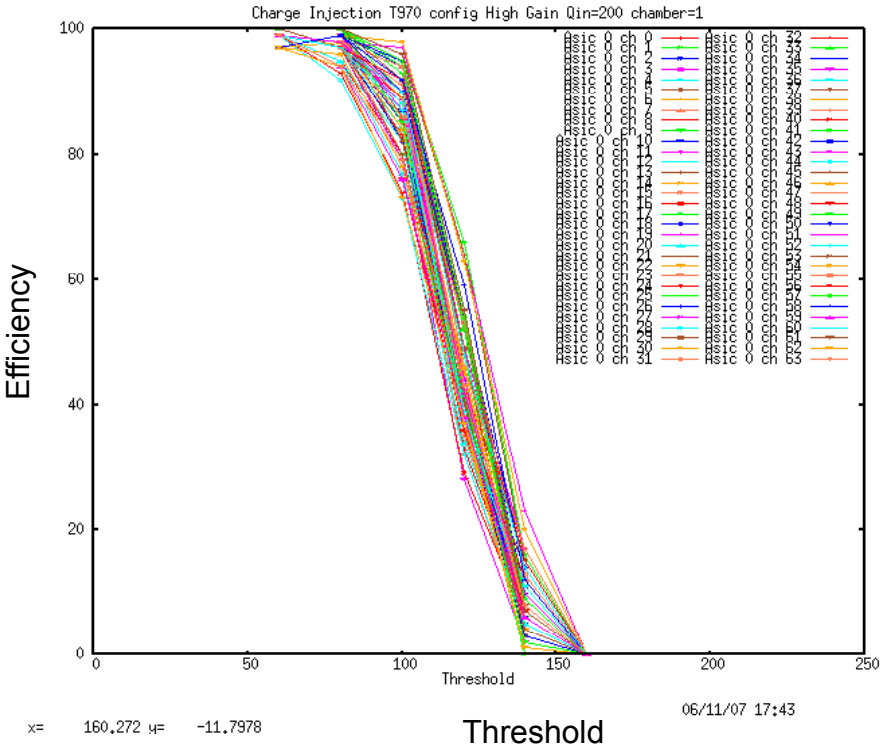
Excellent diagnostics tool

Developed necessary software to perform chage injection runs

Runs with fixed Q_{inj}

Threshold scans in high gain mode





Recent activities VIII: Additional work

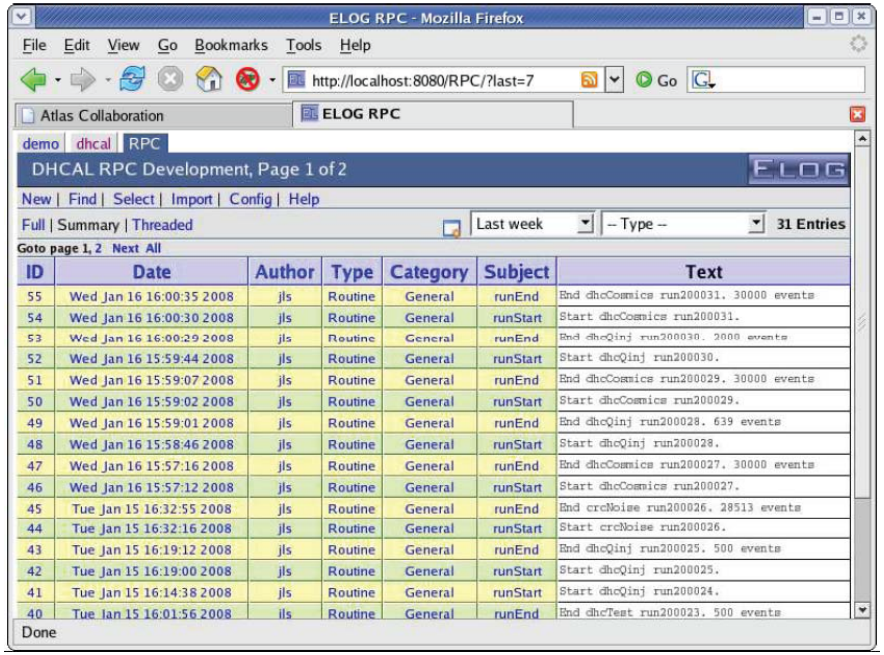
New DAQ software

Based on CALICE framework
Most of it is written, being tested

Module	*Purpose*	*Status*	*Comment*
DaqBusAdapter	Use HAL CAEN Linux bus adapter	Modified	
DaqConfiguration	Customize settings for run types	Modified	Needs additional customization
DaqRunType	Define run types	Modified	Added run type for DHC operation
SubRecordType	Defines types of subrecords	Modified	Added record types to configure and readout DHC
DhcConfiguration	Load configuration records	Coded	Need method to input parameters from ecternal file
DhcbeConfigurationData	Defines structure of DCOL configuration	Coded	
DhcFeConfigurationData	Define structure of DCAL front end configuration	Coded	
DhcEventData	Define structure of front end hit data	Coded	
DhcReadoutConfigurationData	Define structure of settings for readout options	Coded	Needs additional customization
DhcSerialCommand	Template to build command sent to FE chip	Coded	
DhcSeriaHheader	Builds structured message sent to FE chips	Coded	
DhcReadout	Manages the configuration and readout of DCOL	Coded	
DhcVmeDevice	Executes the DCOL access via HEL library	Coded	Not tested
DhcLocation	Define physical location of DCOL	Coded	
DhcLocationData	Template to associate DCOL data with location	Coded	
TtmConfigurationData	Define structure of TTM configuration	Coded	
Ttmreadout	Manages configuration and readout of TTM	Coded	
TtmVmedevice	Executes the TTM access via HAL library	Coded	Not tested
TtmLocation	Defines physical location of TTMs	Coded	
TtmLocationData	Template to associate TTM data with location	Coded	
RunLogger	Create automatic ELOG entries at transitions	Coded	

Development of E-log for future DAQ runs

Adopted module originally developed for ATLAS



High voltage supplies and control

Noise rates with Droege and Lecroy
units similar
Computer controlled system
for one of the systems will be developed

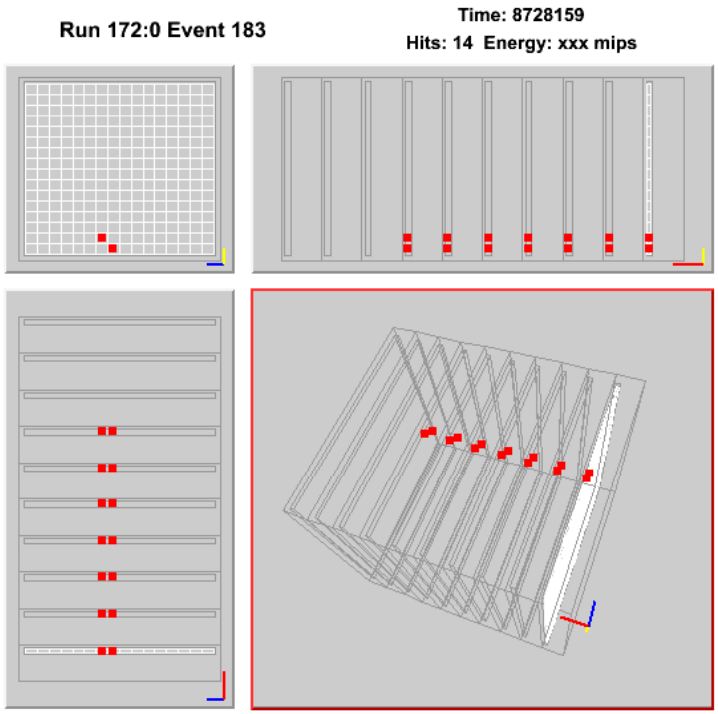
Summary of status

Vertical Slice Test

Was very successful
Proves concept of DHCAL with RPCs
Validates entire electronic readout chain
Several publications in the next few months

Further developments since VST

New Pad- and Front-end board designs
Study of error modes (almost complete)
Detailed long-term studies (ongoing)



Two μ's separated by 1.4 cm

We are ready for the construction of the 1 m^3 physics prototype

Plans

Under all circumstances

Will complete ongoing studies
Will publish results from Vertical Slice Test

Assuming availability of funds

Will complete changes to DCAL chip and will produce chips
Will start assembly of large chambers
Will complete design of integrated Front-end boards and Data Concentrators
Will produce entire readout system

→ ready for test beams in early 2009

Assuming some funds are available

Will consider additional iteration of DCAL chip (larger range of Q_{inj})
Will complete design around new DCAL chip and perform all necesssary tests

Assuming no funds available

Will consider returning to FNAL test beam with ‘perfect’ system
Will look for other things to do…