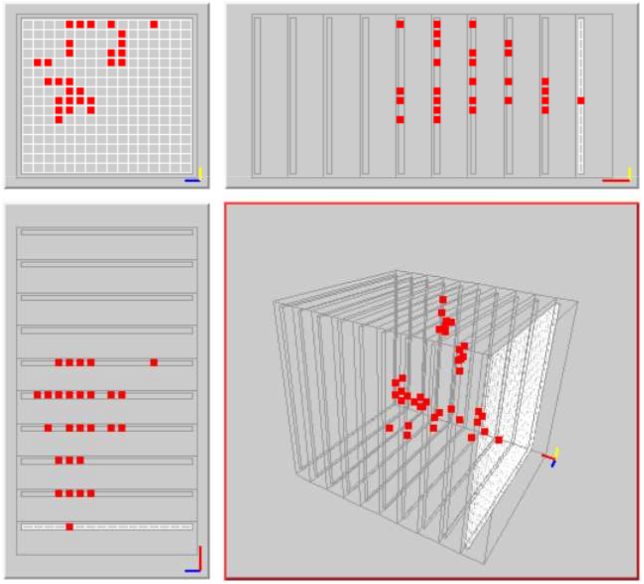
A Calorimeter with Resistive Plate Chambers

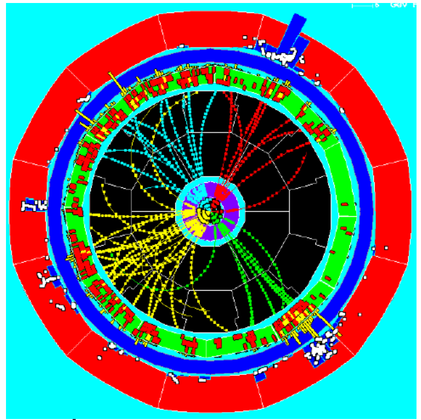


José Repond
Argonne National Laboratory

Seminar at University of Virginia, Charlottesville, VA
October 21, 2009

Outline

I Introduction: Why do Jet Physics?



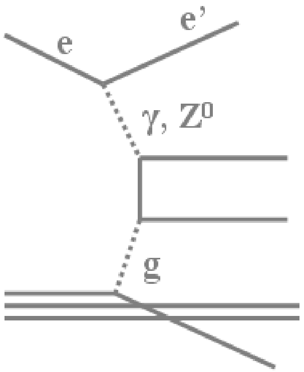
At high energy particle colliders

Observation of collimated **jets of hadronic particles**

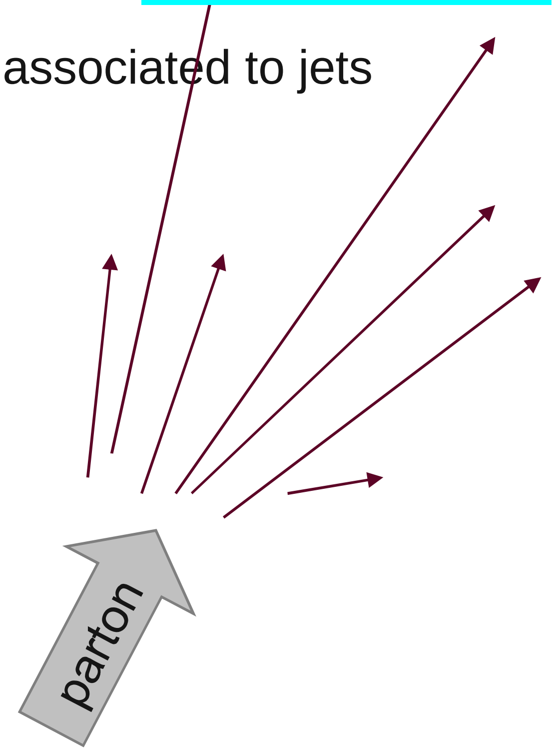
Given an appropriate algorithm, particle in events can be associated to jets

$$\{p_1, p_2, \ldots p_n\} \rightarrow \{J_1, J_2, \ldots J_N\}$$

with $n \gg N$

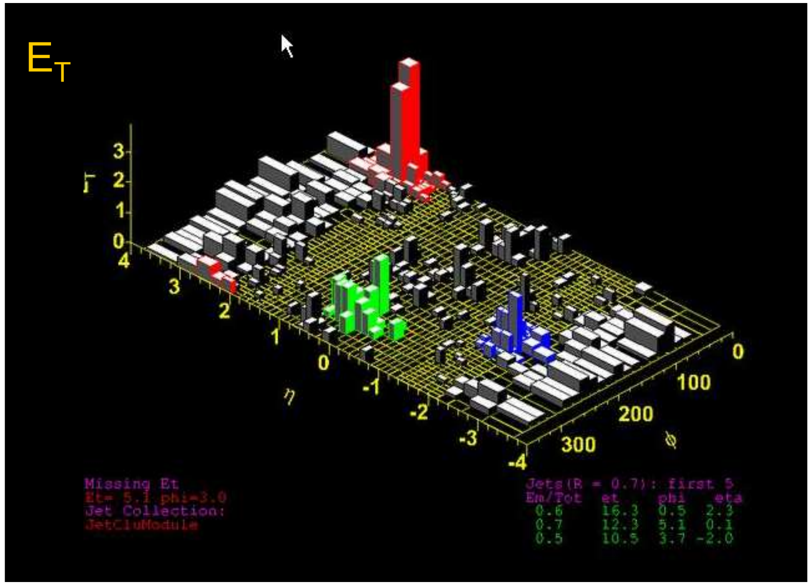


Jets can be associated with partons of underlying hard scattering



Reconstruct momentum of partons
study short distance QCD
heavy particles decaying into qq, e.g. $W^{\pm}$, Z^0

Traditional Jet Measurement



Uses calorimeter alone

→ Example of CDF live event

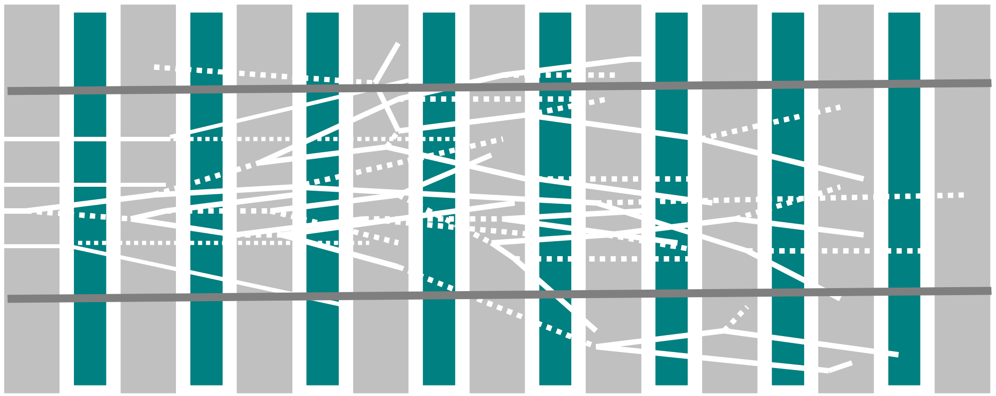
Calorimeter: sandwich design

Used by most calorimeters at colliders

→ Alternating layers of

Absorber plates to incite shower and
Active media (detectors) to count charged particles traversing it

Energy summed up in (large) ‘Towers’



$$E_{jet} \propto \sum N_{\text{charged}}$$

Compensation

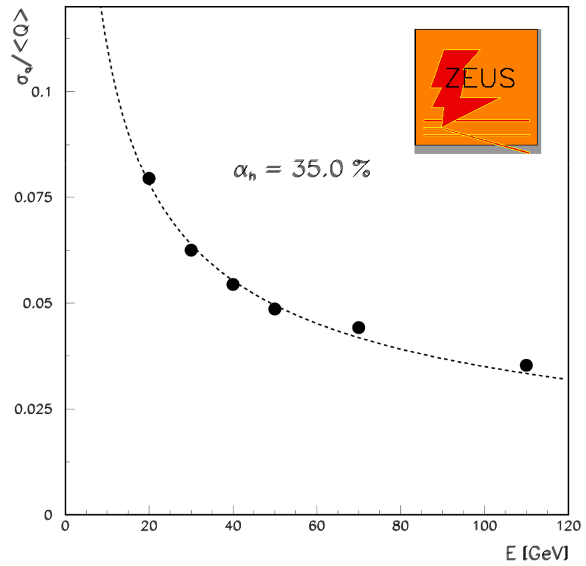
Calorimeter measures photons and hadrons in jet

Typically with different response: $e/h \neq 1$
Leads to poor jet energy resolution of > $100\%/\sqrt{E_{jet}}$

ZEUS tuned

Scintillator and Uranium thickness to achieve $e/h \sim 1$

→ **Best single hadron energy resolution ever**



$35\%/\sqrt{E}$ → $50\%/\sqrt{E}$ Jet Energy Resolution

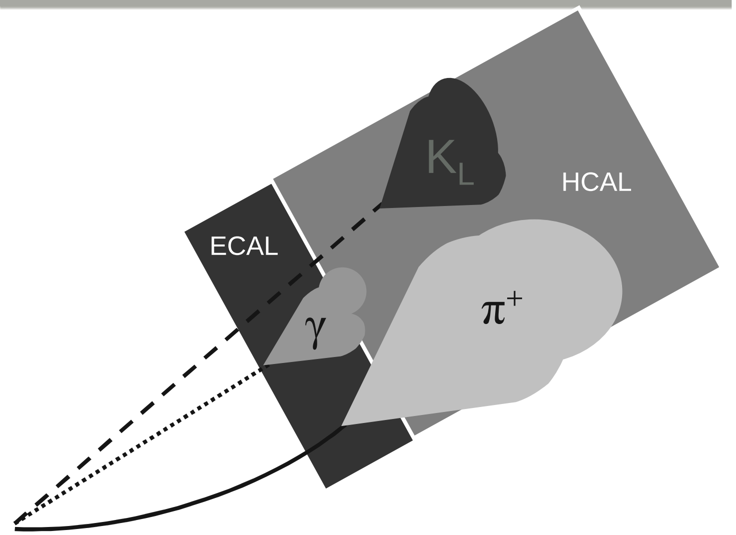
At a future e^+e^- Linear Collider

Goal of

$$\sigma/E_{jet} = 30\%/\sqrt{E_{jet}}$$

New approach

II Particle Flow Algorithms



The idea…

Charged particles / **Neutral particles** — measured with the — **Tracker** / **Calorimeter**

Particles in jets	**Fraction of energy**	**Measured with**	**Resolution** [σ^2]
Charged	65 %	Tracker	Negligible
Photons	25 %	ECAL with 15%/√E	$0.07^2\ E_{jet}$
Neutral Hadrons	10 %	ECAL + HCAL with 50%/√E	$0.16^2\ E_{jet}$
Confusion	Required for 30%/√E		**$\leq 0.24^2\ E_{jet}$**

18%/√E

Requirements for detector

→ Need excellent tracker and high B – field
→ Large R_l of calorimeter
→ Calorimeter inside coil
→ Calorimeter with **extremely fine segmentation**
→ Calorimeter as dense as possible (short X_0, λ_I)

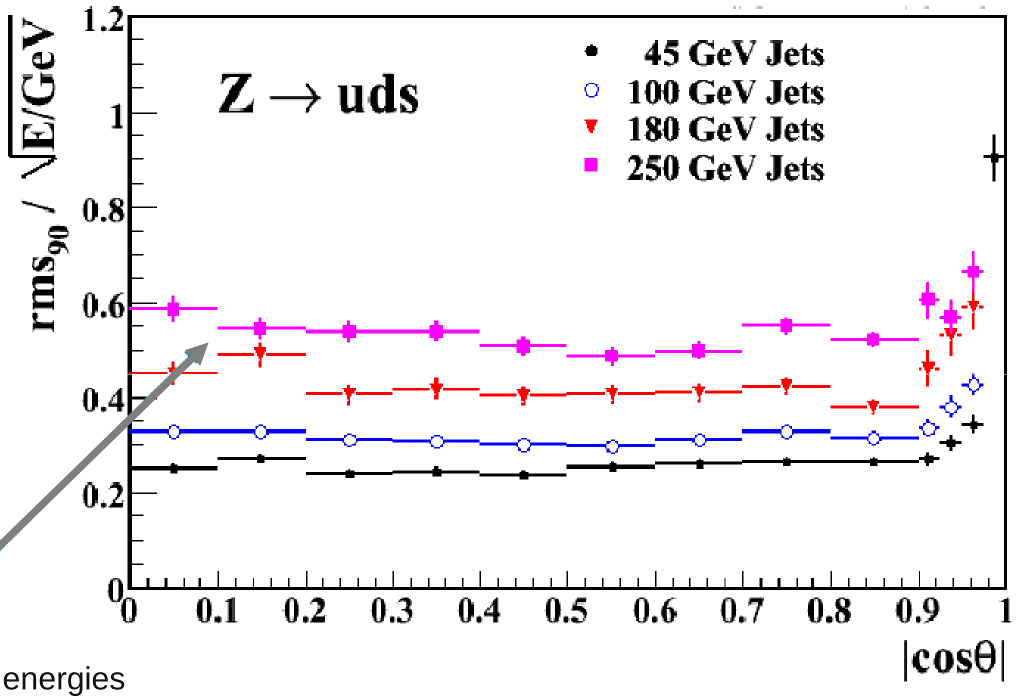
PANDORA PFA

Developed by

Mark Thomson (University of Cambridge)
Based on GEANT4

Current performance

E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$	σ_E/E_j
45 GeV	24.9 %	3.7 %
100 GeV	30.7 %	3.1 %
180 GeV	43.0 %	3.2 %
250 GeV	52.2 %	3.3 %



Leakage at high jet energies

ILC performance goal achieved

Open question

Are hadronic showers simulated properly? (see later)

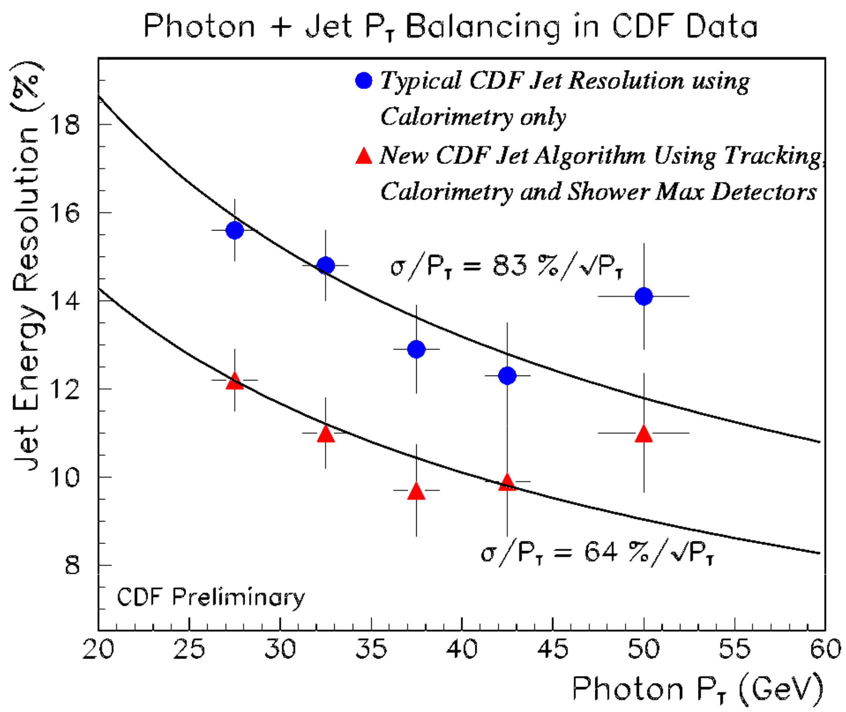
Do PFAs really work?

Applied to existing detectors

ALEPH, CDF, ZEUS…

→ **Significantly improved resolution**

YES! But that is not the issue…



Goal for future e^+e^- Linear Collider Detectors

Design a detector optimized for the application of PFAs

Huge simulation and hardware effort underway

→ Asia, Africa, America, and Europe

III CALICE Collaboration

Calorimeter for ILC

Goals

Development and study of finely segmented calorimeters for PFA applications

Strategy

Study of physics, proof of technological approach → **physics prototypes**
Development of scalable prototypes → **technical prototypes**

Projects

Calorimeter	Technology	Detector R&D	Physics Prototype	Technical Prototype
ECALs	Silicon - Tungsten	Well advanced	Exposed to beam	Design ~ completed
	MAPS - Tungsten	Started		
	Scintillator - Lead	Well advanced	Exposed to beam	
HCALs	Scintillator - Steel	Well advanced	Exposed to beam	Design ~ completed
	RPCs - Steel	**Well advanced**	**Being constructed**	**(Design started)**
	GEMs- Steel	Ongoing		
	MicroMegas - Steel	Started		
TCMTs	Scintillator - Steel	Well advanced	Exposed to beam	?

4 regions

14 countries

51 institutes

> 300 physicists

IV Hadron Calorimeters

Within the PFA paradigm

HCAL's role is to measure neutral hadrons (n, K_L^0)

Fine segmentation is important → 1 x 1 cm²

Short interaction length λ_I

Absorber choices

With 1 X_0 sampling: Fe, Cu

With > 1 X_0 sampling: W, Pb, U

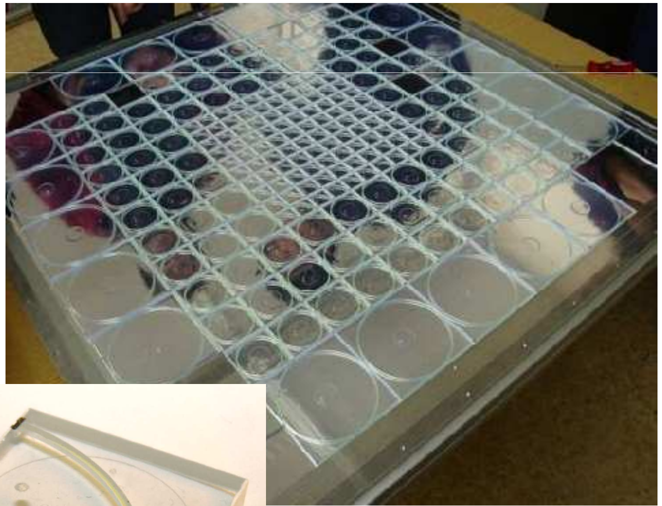
Material	A/Z	λ_I [cm]	X_0 [cm]	λ_I/X_0	$t_{passive} \equiv 4\lambda_I$ [cm]	Number of layers
Fe	56/26	16.8	1.8	9.3	67	38
Cu	64/29	15.1	1.4	10.8	42	60
W	184/74	9.6	0.35	27.4	38	110
Pb	207/82	17.1	0.56	30.5	68	122
U	238/92	10.5	0.32	32.8	42	181

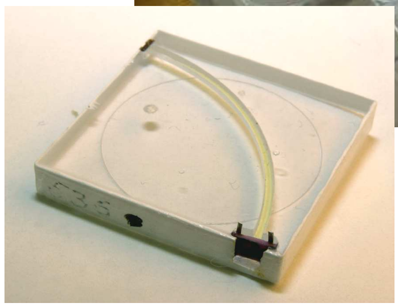
Active Media

Multi-bit readout (AHCAL)
(analog)

- Scintillator pads

3 x 3 cm^2 cells
SiPM or MPPC readout

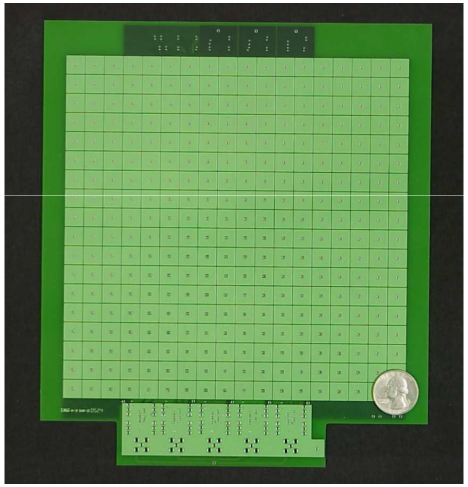




Single-bit readout (DHCAL)
(digital)

- **Resistive Plate Chambers** (RPCs)
- Gas Electron Multipliers (GEMs)
- Micromegas

1 x 1 cm^2 pads



DHCAL trades the high-resolution readout of a small number of towers with1-bit readout of a large number of pads

Comparison of HCAL active media

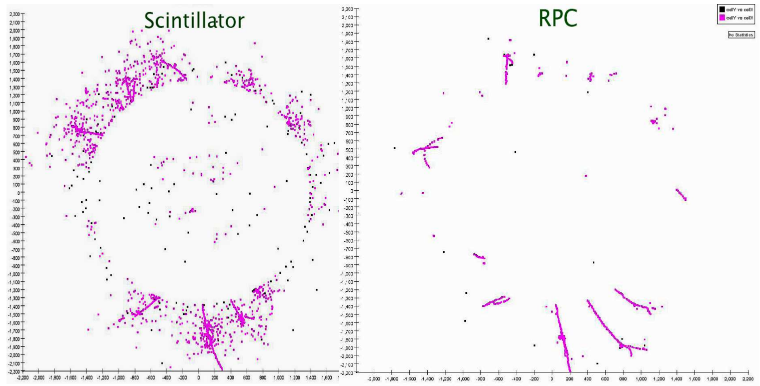
	Scintillator	GEMs/Micromegas	RPCs
Technology	Proven (SiPM?)	Relatively new	Relatively old
Electronic readout	Analog (multi-bit) or Semi-digital (few-bit)	Digital (single-bit)	Digital (single-bit)
Thickness (total)	~ 8mm	~8 mm	~ 8 mm
Segmentation	3 x 3 cm^2	1 x 1 cm^2	1 x 1 cm^2
Pad multiplicity for MIPs	Small cross talk	~ 1.0	Measured at 1.4/1.0
Sensitivity to neutrons (low energy)	Yes	Negligible	Negligible
Recharging time	Fast	Fast	Slow (< 100 Hz/cm^2)
Reliability	Proven	Sensitive	Proven (glass)
Calibration	Challenge	?	Expected to be straighforward
Assembly	Labor intensive	Somewhat labor intensive	Somewhat labor intensive
Cost	Not cheap (SiPM?)	Expensive foils	Cheap

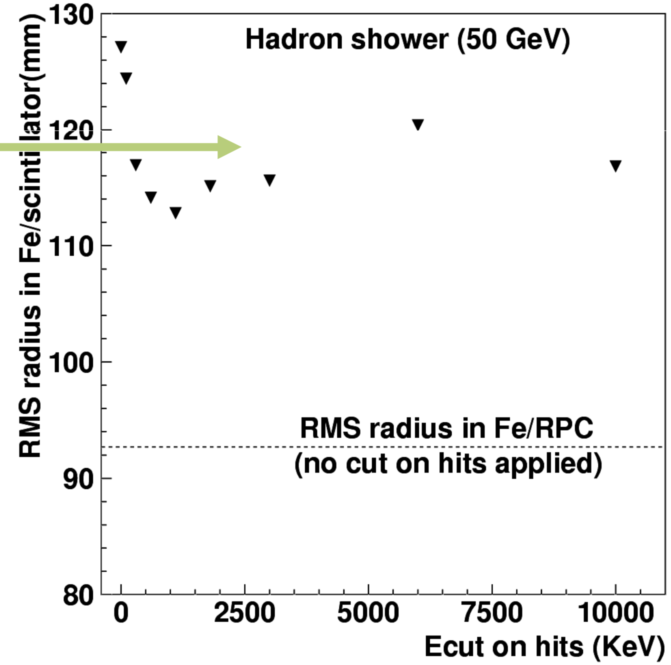
Areas of concern

Sensitivity to slow neutrons

	Scintillator	RPC Gas
Molecule	$C_6H_5CH=CH_2$	$C_2H_2F_4$
Density	1.032 g /cm^3	4.3 x 10^{-3} g/cm^3
Thickness	5 mm	1.2 mm
Sensitivity to slow neutrons	small	negligible
Hadronic shower radius	**larger**	smaller
Single particle resolution	better	**worse**

Identical events



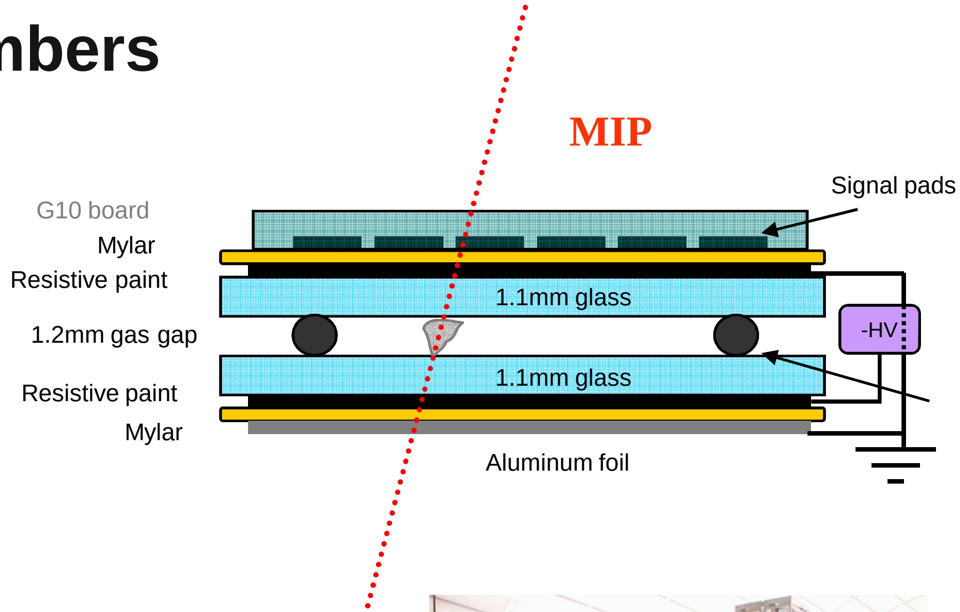


K_L^0

Momentum [GeV/c]	5	10	20
$\sigma = x\sqrt{E}$ Scintillator		(54.2)	(55.5)
$\sigma = x\sqrt{E}$ RPC	0.57	0.66	0.64

Tradeoff…

V Resistive Plate Chambers



Developed in the 1980's

Many applications

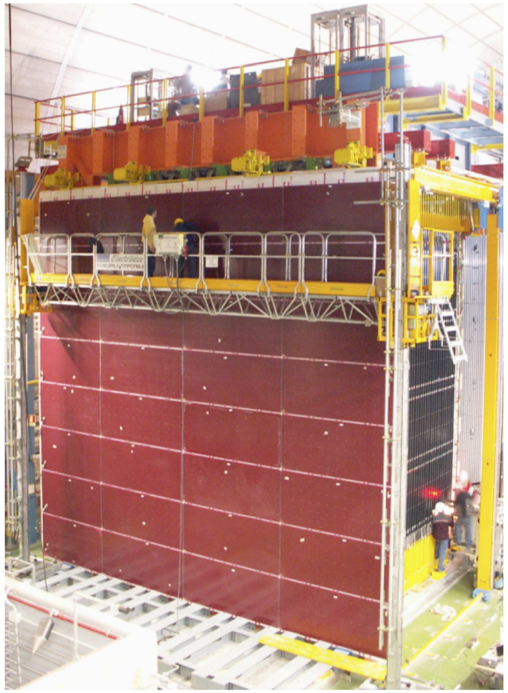
ATLAS and CMS (muon system)
ALICE (TOF, muon system)
Belle and BaBar (muon system)
Phenix, STAR (TOF, muon system)
OPERA (neutrino detection)
....

Operation

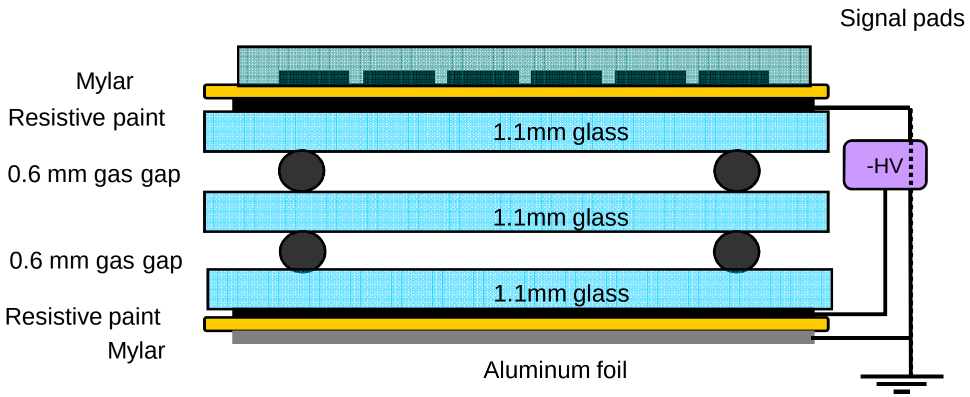
at higher HV: Streamer mode (large signal ~ 10's of pC)
at lower HV: Avalanche mode (smaller signal 0.1 – 10 pC)

Readout

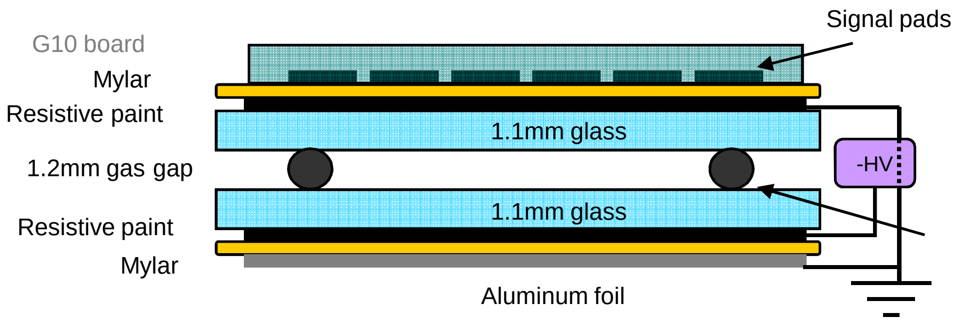
Strips



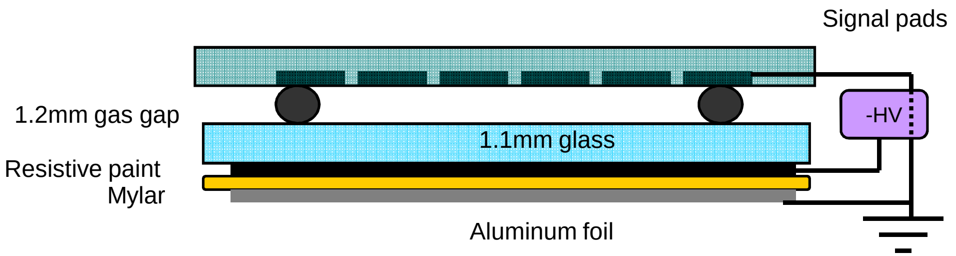
Our RPC Designs



Multigap – RPC
(mostly used for Time-of-Flight)



Standard 2-glass Design



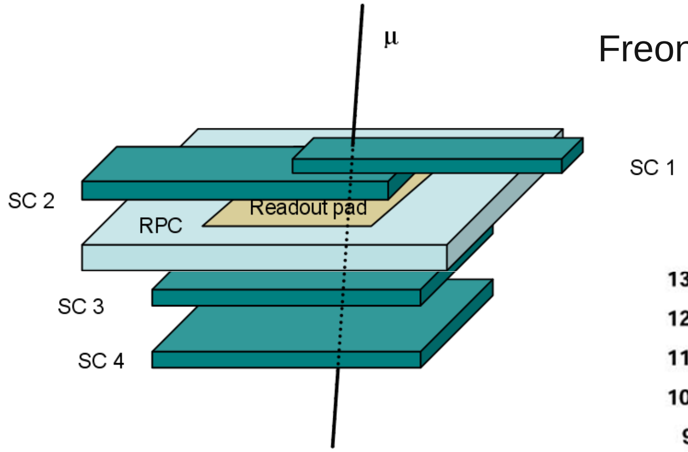
'Exotic' 1-glass Design
(our own invention)

Measurements with an Analog Readout

Published as G.Drake et al., N.I.M. 3 A578, 88 (2007)

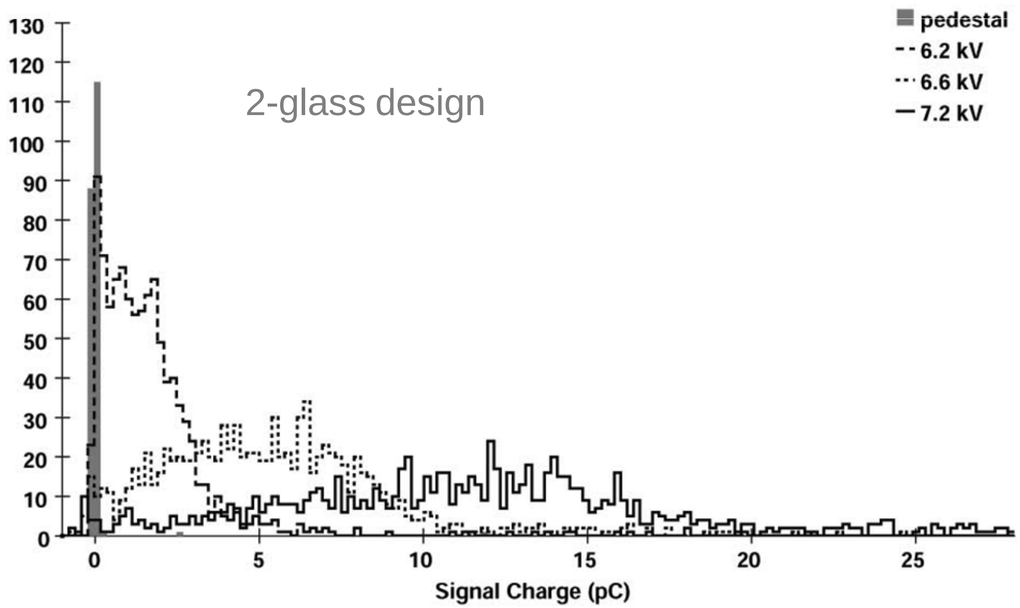
Used CDF's RABBIT system with 14-bit resolution
Utilized cosmic rays (readout triggered by scintillators)
Chambers flushed with typical mixture for avalanche mode

Freon R-134A : Isobutane : Sulfur Hexafluoride = 94.5 : 5.0 : 0.5



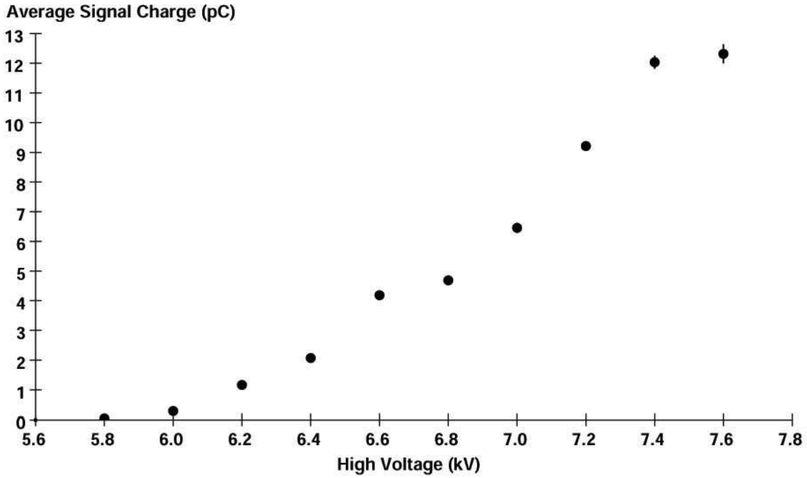
Avalanche signal charges 0.1 – 10 pC

Readout with single pad of 16 x 16 cm^2



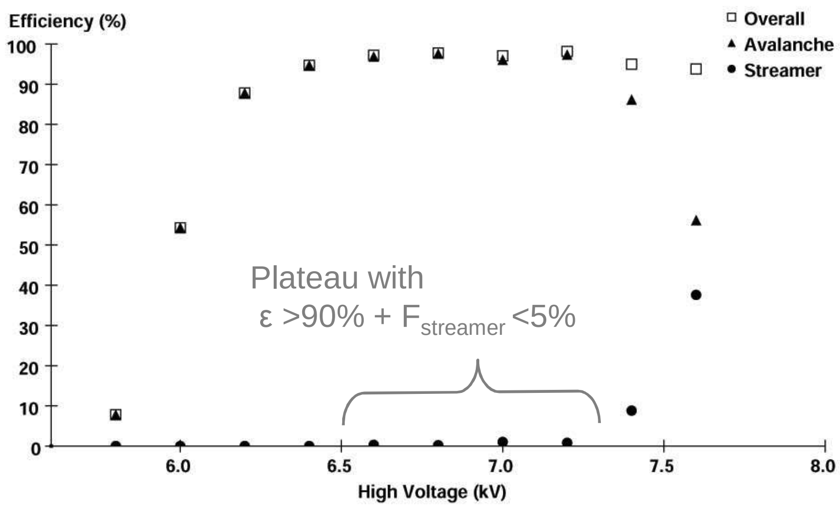
Readout with single pad of 16 x 16 cm^2

2-glass RPC



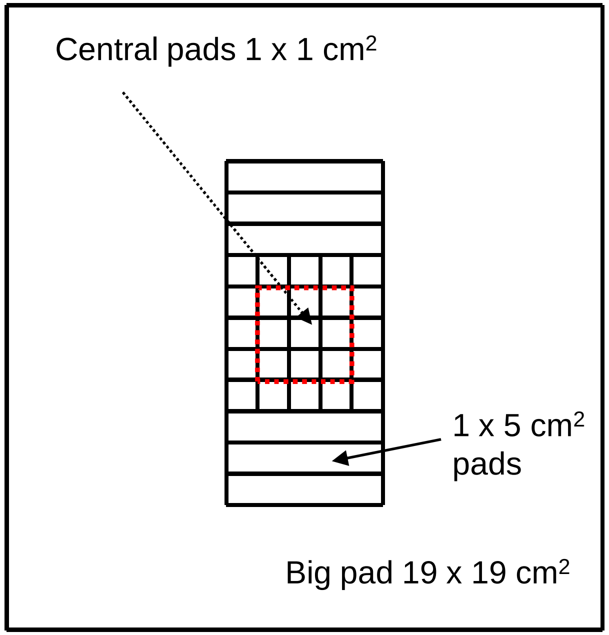
~ Linear increase of signal charge with high voltage

2-glass RPC



Streamers develop at higher HV
Wide plateau with high efficiency and few streamers

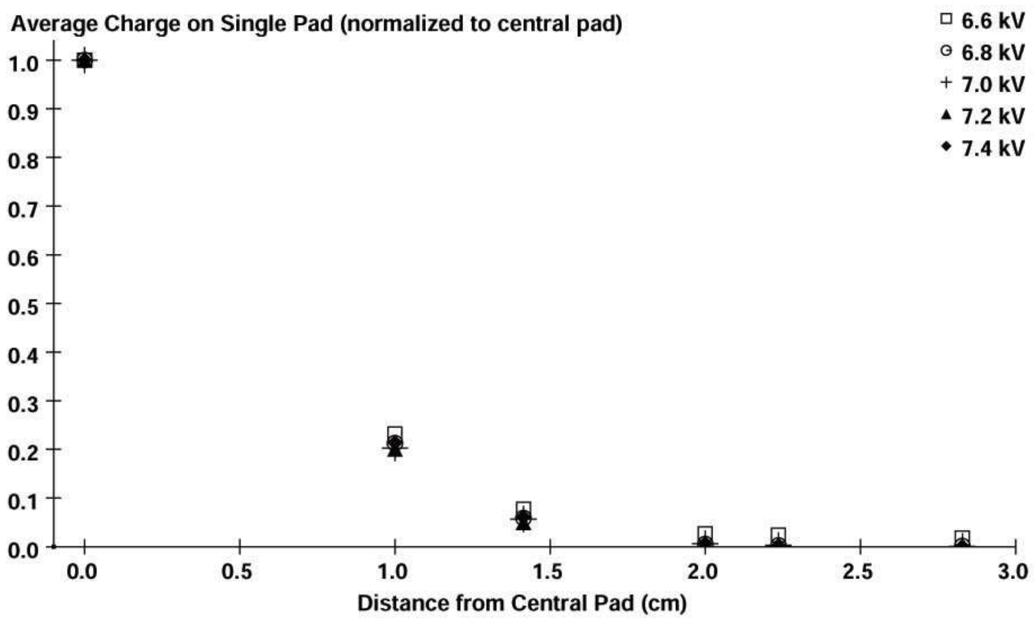
Readout with multiple 1 x 1 cm^2 pads



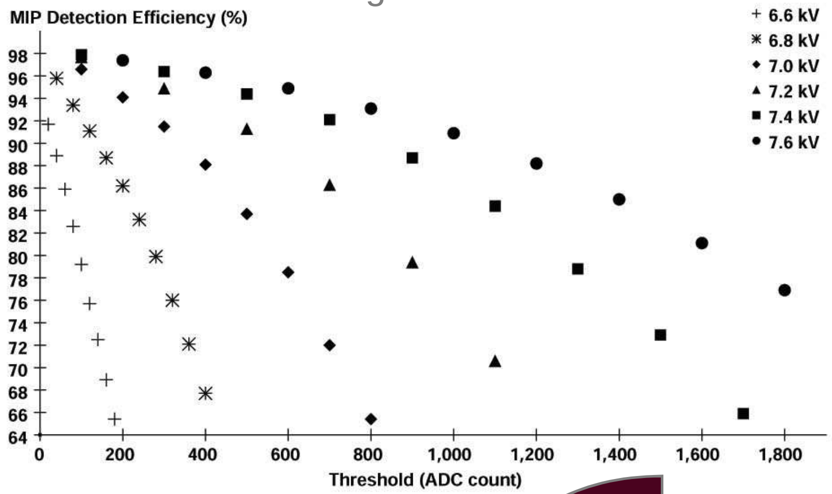
Only take events where highest Q in central 3 x 3 array
'Hit pad' defined as pad with highest Q

Charged contained within ~ 1.5 cm Independent of HV

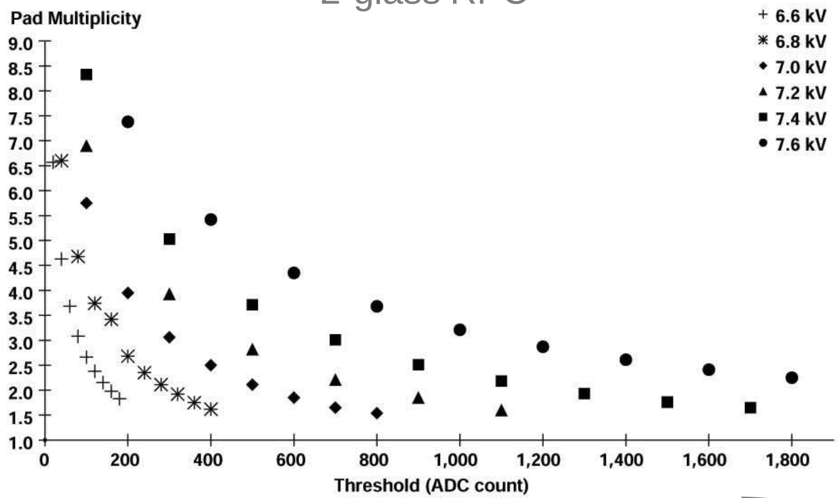
2-glass RPC



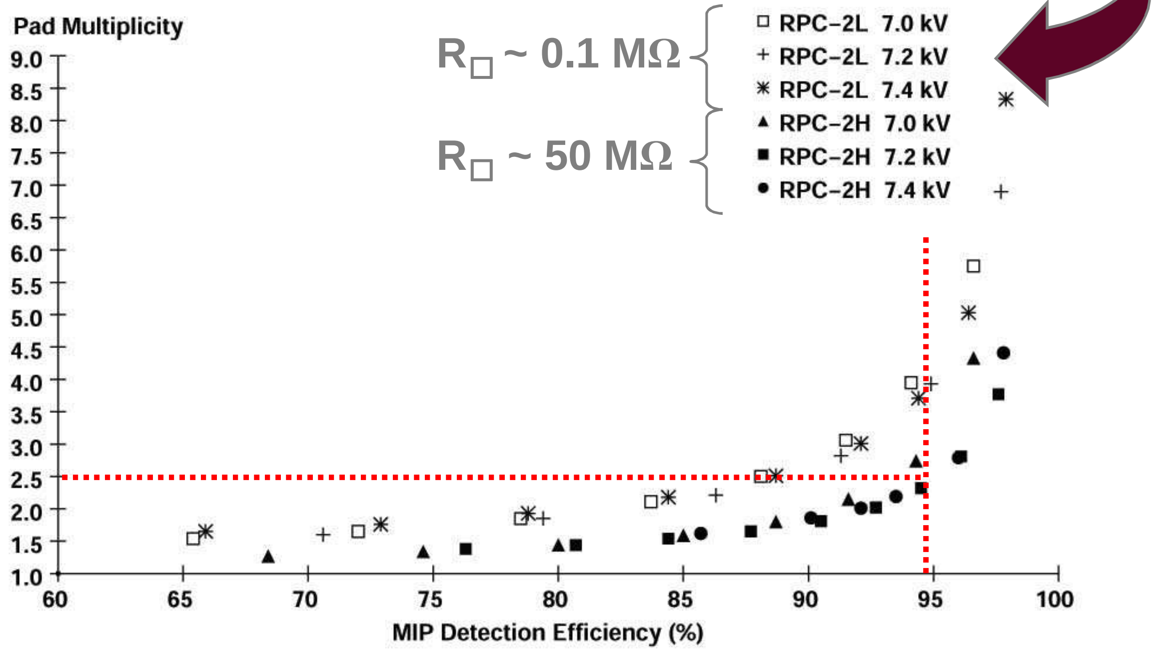
2-glass RPC



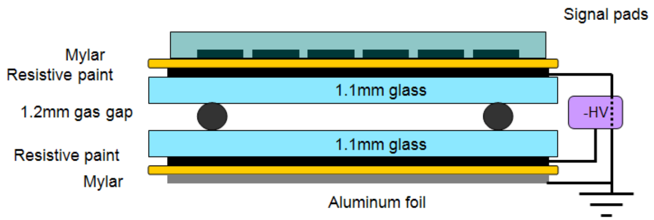
2-glass RPC



2-glass RPC

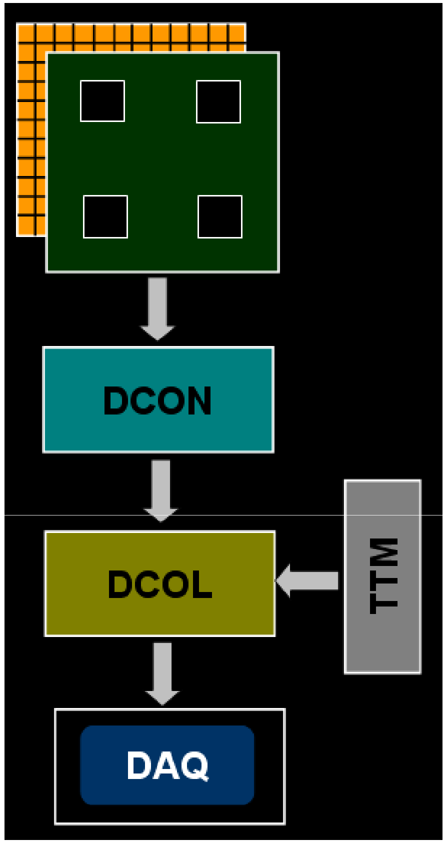


Higher surface resistivity decreases Pad multiplicity



VI Digital Readout System

Optimized for the readout of a large number of channels



Centered around the DCAL front-end chip

Readout board consists of a pad- and a front-end board

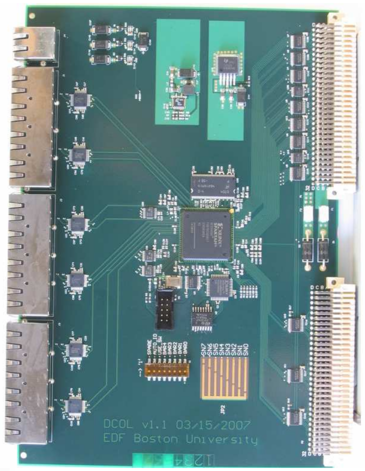
→ Avoid cross talk from digital lines into analog inputs
→ No costly blind or burried vias
→ Connection via conductive glue

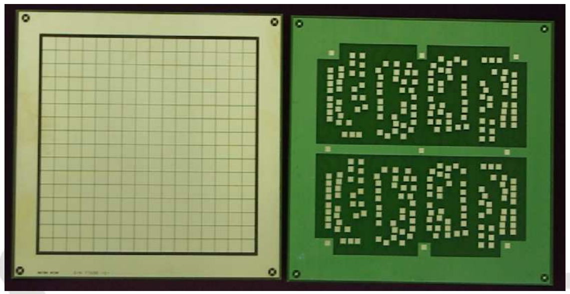
1 Data Concentrator per Readout Board

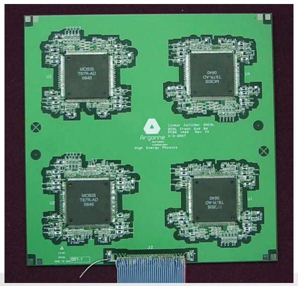
1 Data Collector per 12 Data Concentrators

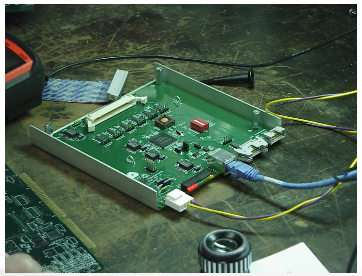
1 Timing and trigger module per system

→ provides clocks and resets to front-end
→ distributes trigger signals to front-end

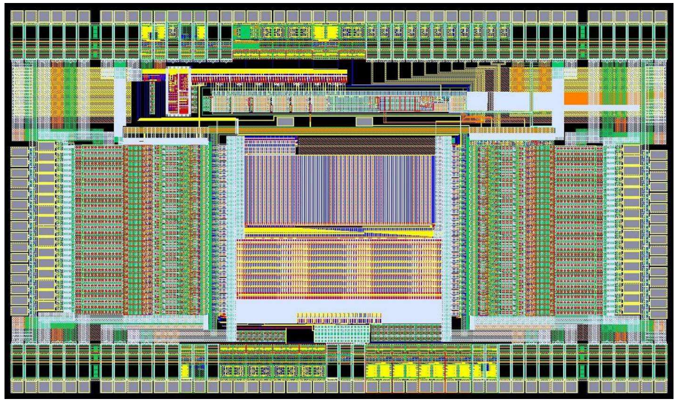








The DCAL Chip

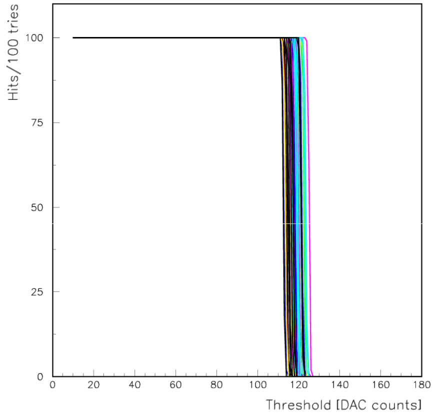


Developed by

FNAL and Argonne

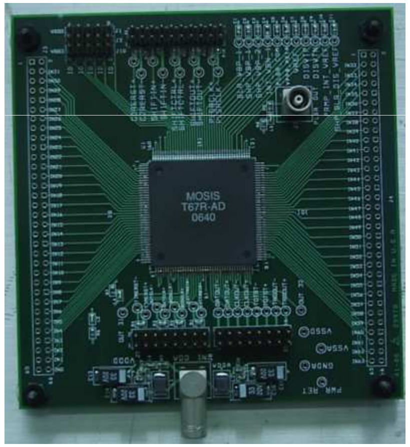
Input

64 channels
High gain (GEMs, micromegas…) with minimum threshold ~ 5 fC
Low gain (RPCs) with minimum thrshold ~ 30 fC



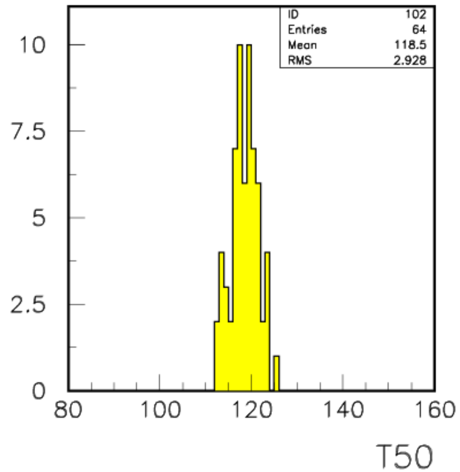
Threshold

Set by 8 – bit DAC (up to ~600 fC)
Common to 64 channels



Readout

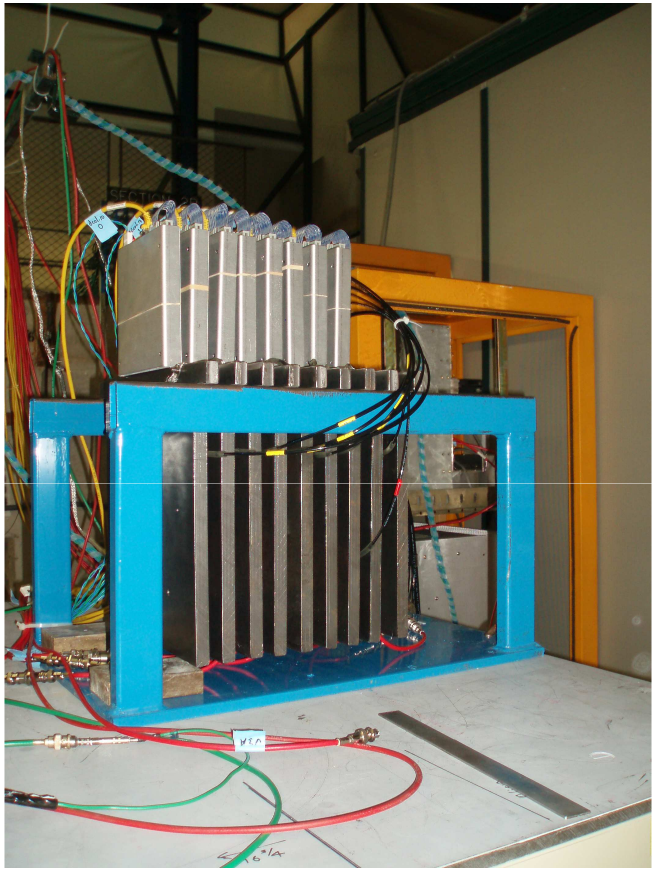
Triggerless (noise measurements)
Triggered (cosmic, test beam)



Versions

DCAL I: initial round (analog circuitry not optimized)
DCAL II: some minor problems (used in vertical slice test)
DCAL III: no identified problems (final production)

VII Vertical Slice Test



Small prototype calorimeter

20 x 20 cm^2 RPCs (based on two different designs)
Up to 10 chambers → 2560 readout channels

Electronic readout

Complete chain as for larger system

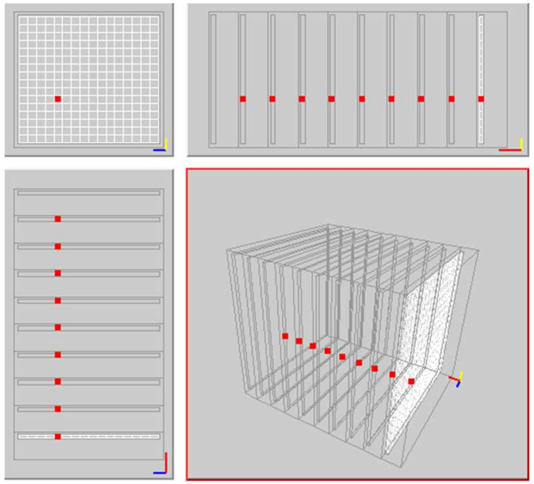
Tests with

Cosmic rays at Argonne
Fermilab test beam
(μ, 120 GeV p, 1 – 16 GeV π^+, e^+)

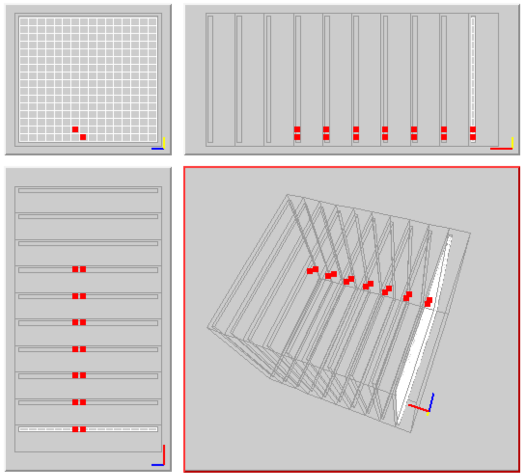
Very successful → Extrapolation to larger system

A few nice events from the testbeam….

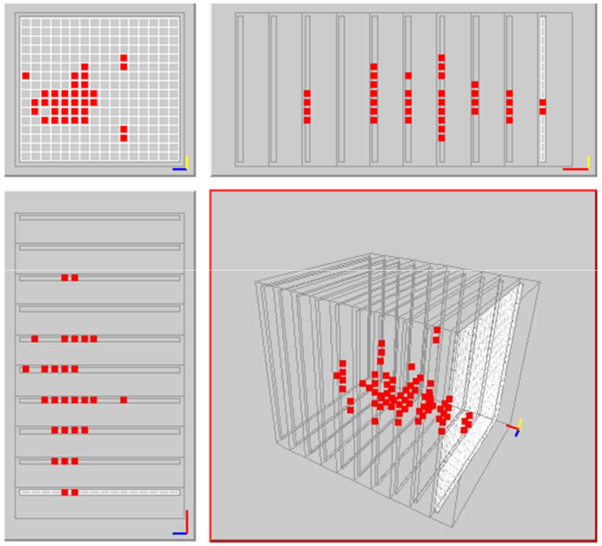
A perfect μ

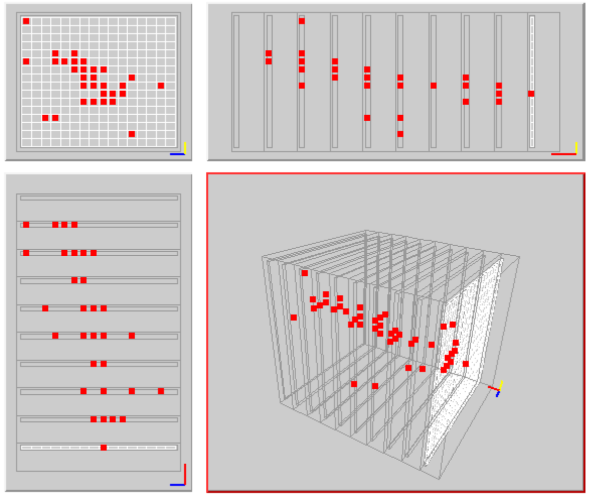


2 perfect μ's

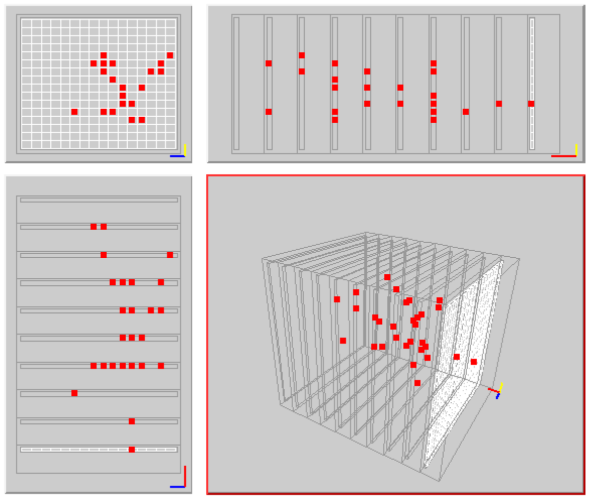


A e^+ shower





π^+ showers



VIII Simulation of the Tests

Monte Carlo Simulation = Integration of current knowledge of the experiment

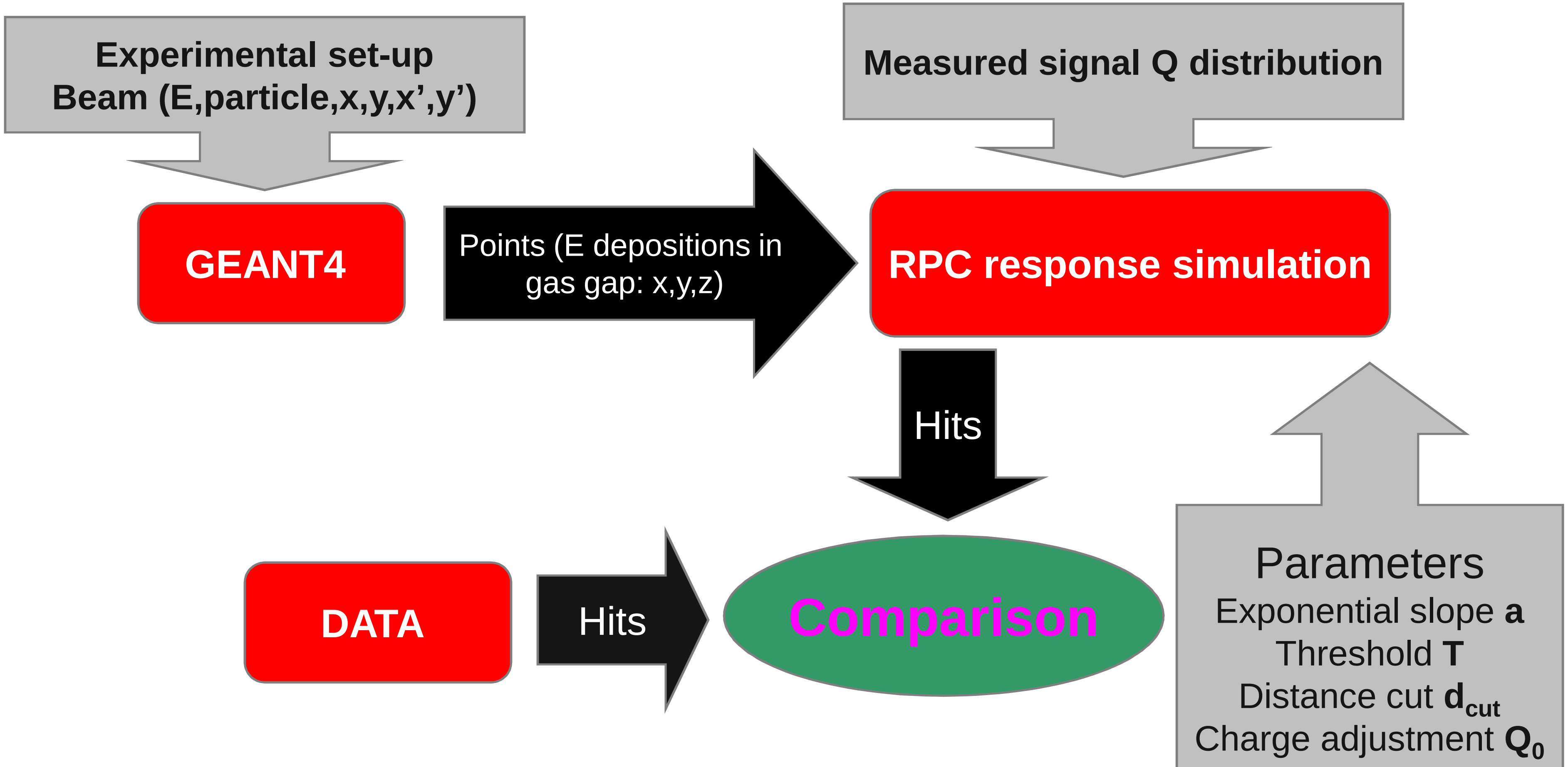
Perfect knowledge → Perfect agreement with data

Missing knowledge → Not necessarily disagreement with data

Disagreement with data → Missing knowledge, misunderstanding of experiment

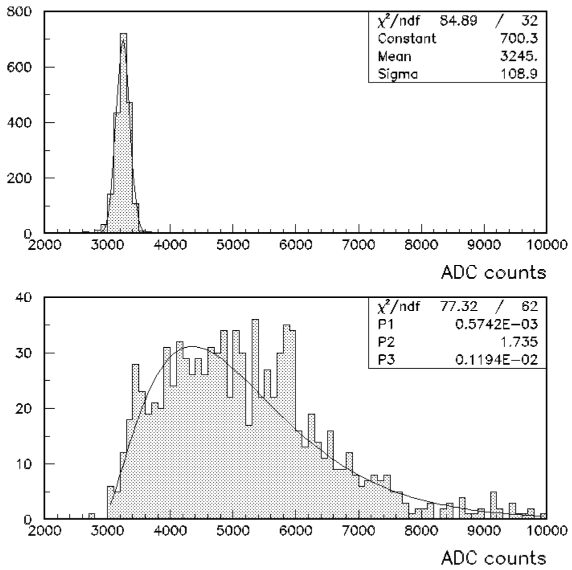
Perfect agreement with data → Not necessarily perfect knowledge

Simulation Strategy

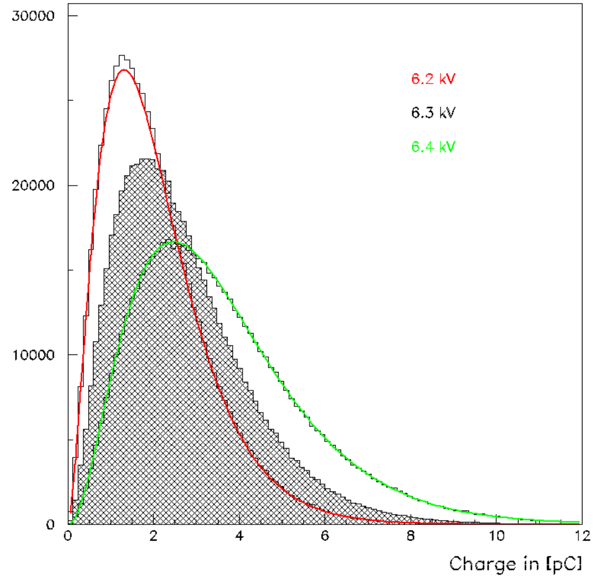


With muons – tune **a**, **T**, ($\mathbf{d_{cut}}$), and $\mathbf{Q_0}$
With positrons – tune $\mathbf{d_{cut}}$
Pions – no additional tuning

Measured charge distribution
for HV = 6.2 kV

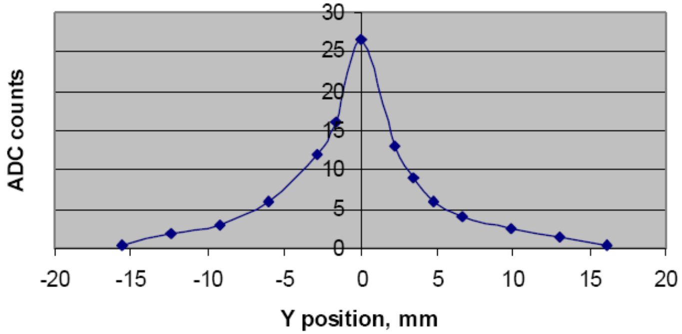


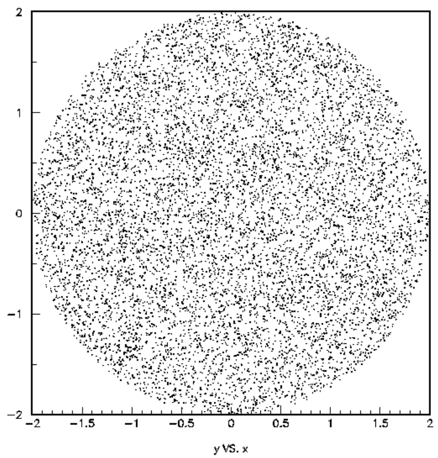
Generated charge distributions
for different HV settings

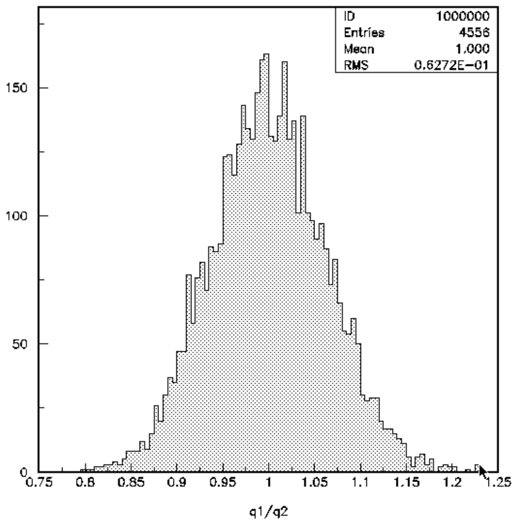


Throw 10,000 points in
x,y plane, calculate charge Q(r),
sum up charge on 1 x 1 cm^2 pads

Measured charge distribution as
function of y in the pick-up plane







D.Underwood et al.

Overall reconstructed charge
with 10,000 throws

IX Measurements with the VST

Rate dependence of RPCs – published in **JINST**

Unique contribution to understanding of RPCs, essential for operation of DHCAL

Calibration with muons – published in **JINST**

Measurement of efficiencies, pad multiplicities and noise rates

Response to Positrons – published in **JINST**

First showers in a DHCAL, validity of concept, understanding of DHCAL response

Hadron showers in a DHCAL – published in **JINST**

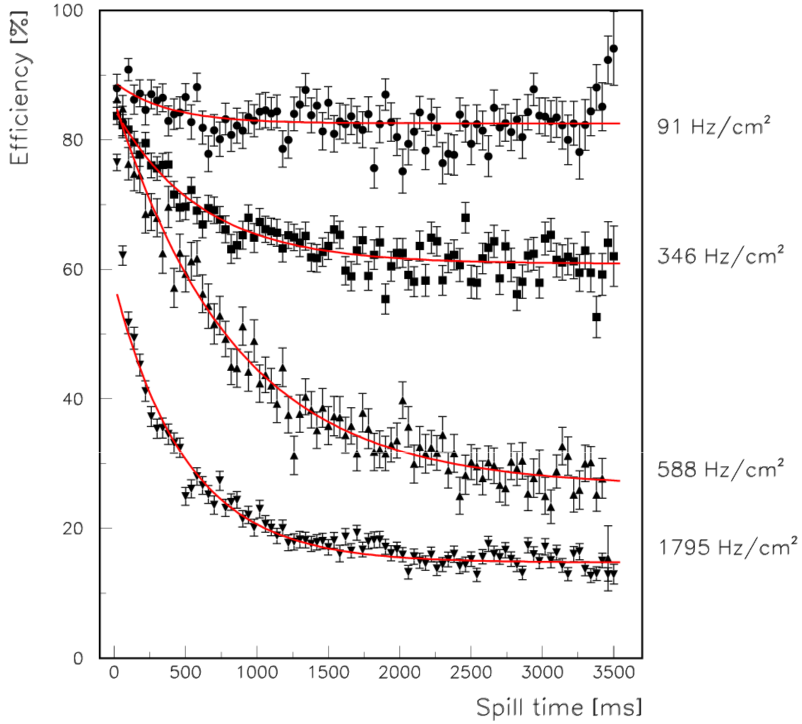
Including predictions for larger prototype calorimeters

Environmental dependence paper – draft exists, plots (almost) finalized

Essential information for operation of DHCAL

Measuring and Calculating the Rate Capability

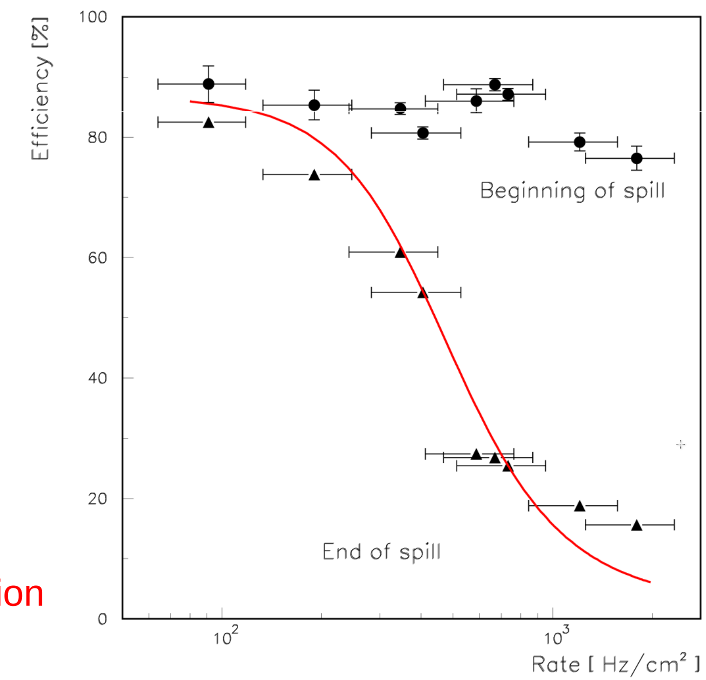
Measurements in FNAL test beam



Fits theoretically motivated

Developed analytical model to calculate drop in efficiency

Based on assumption of voltage drop due to current through RPC

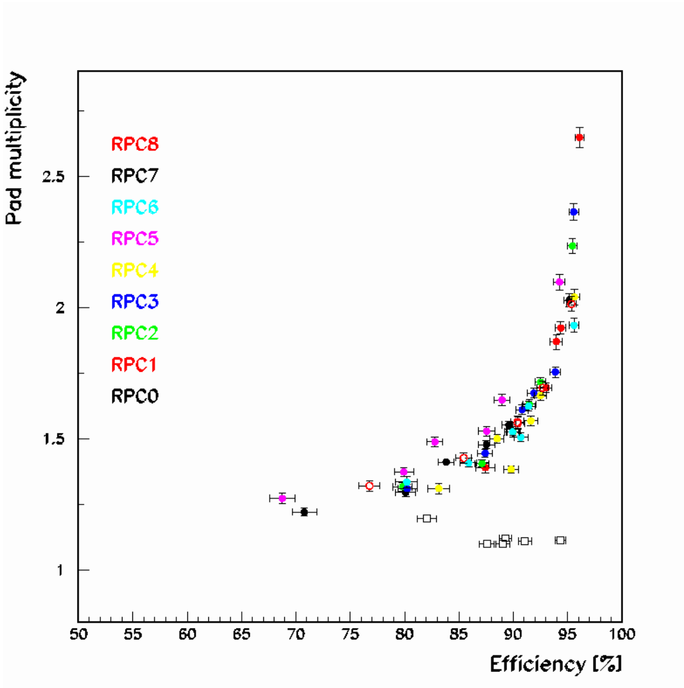


Analytical prediction

Effect not (yet) implemented in simulation

Published in 2009 JINST 4 P06003

Measuring the Muon Response



Broadband muons

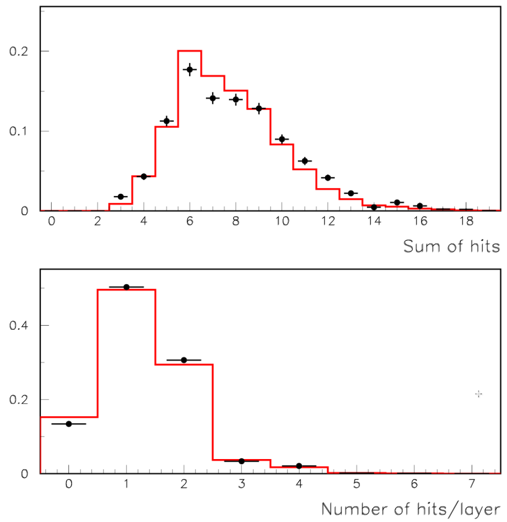
from FNAL testbeam (with 3 m Fe blocker)

Used to measure efficiency and pad multiplicity of RPCs
→ calibration constants

Tuned

slope **a**
threshold **T**
charge adjustment $\mathbf{Q_0}$

→ reproduce the distributions of the sum of hits and hits/layer



Data

Monte Carlo simulations
after tuning

Published as B.Bilki et al., 2008 JINST 3 P05001
Published as B.Bilki et al., 2009 JINST 4 P04006

Measuring Positrons Showers

Positrons at 1, 2, 4, 8, 16, GeV

from FNAL testbeam (with Čerenkov requirement)

Tuned

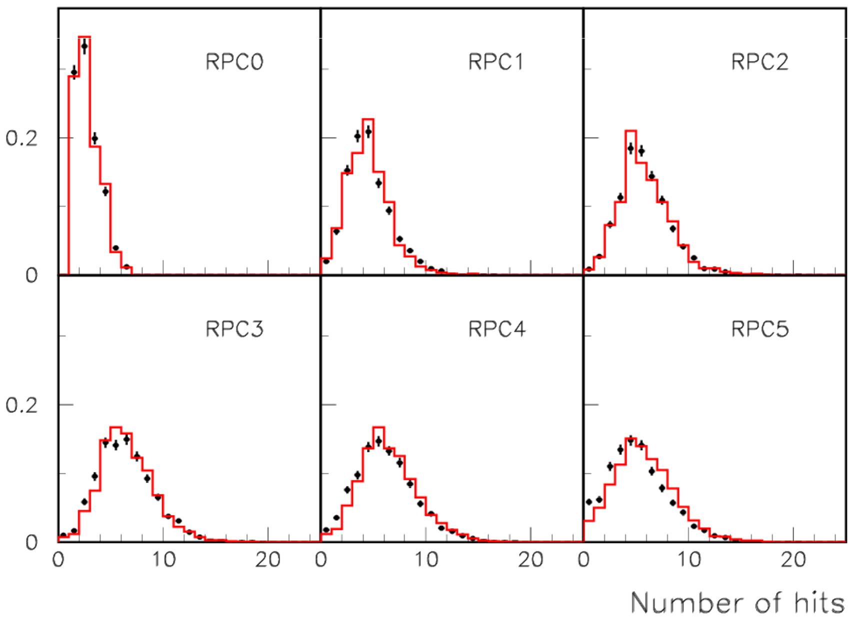
distance cut $\mathbf{d_{cut}}$

→ reproduce distributions in individual layers (8 GeV data)

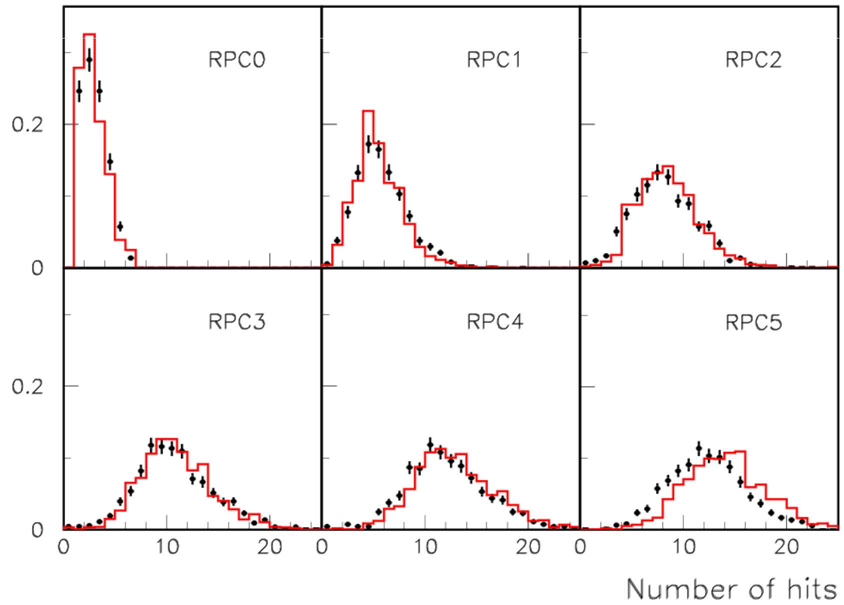
Data

Monte Carlo simulations

2 GeV e^+

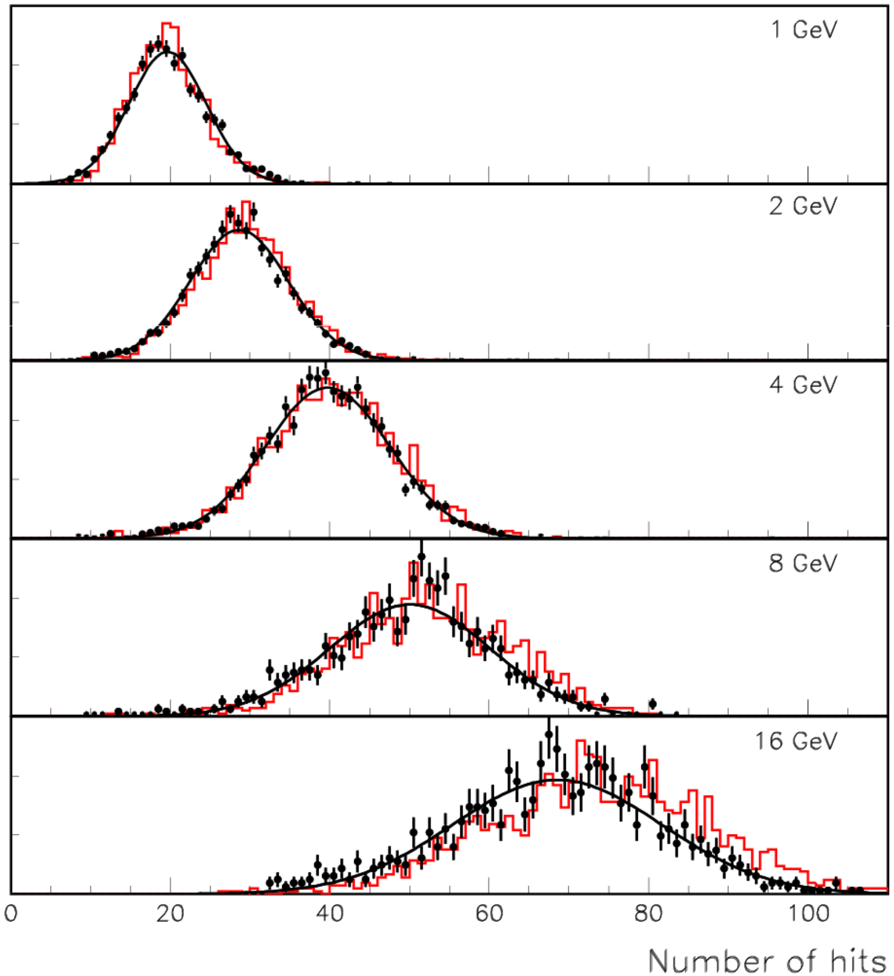


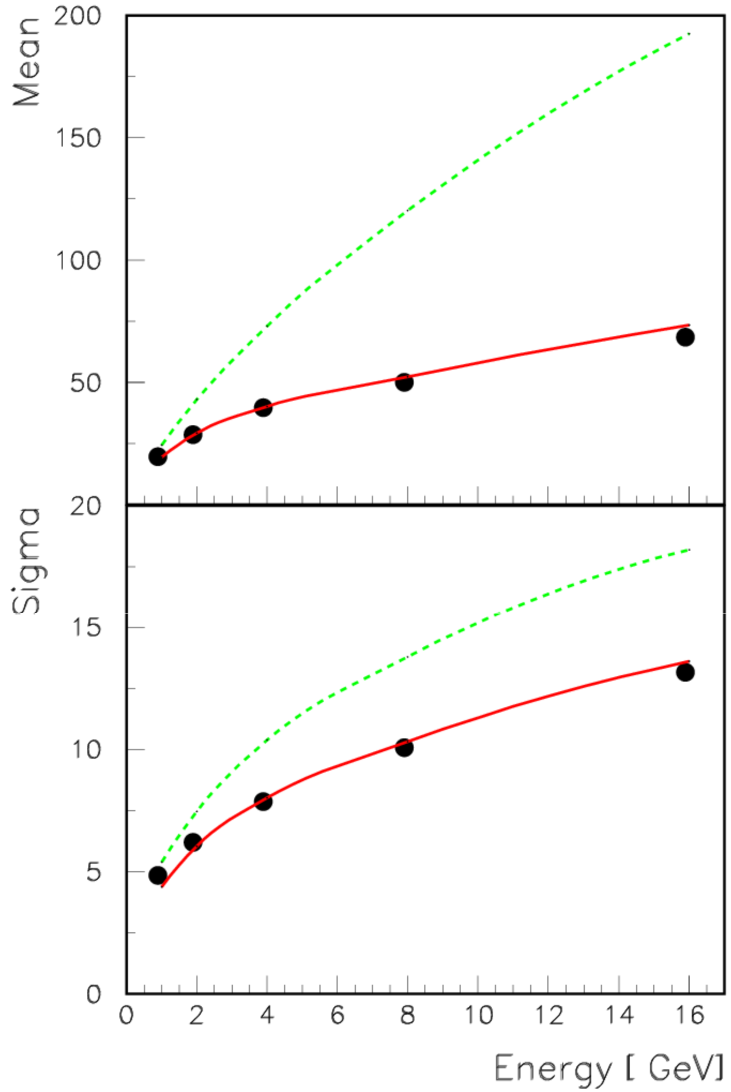
8 GeV e^+



Published as B.Bilki et al., 2009 JINST 4 P04006

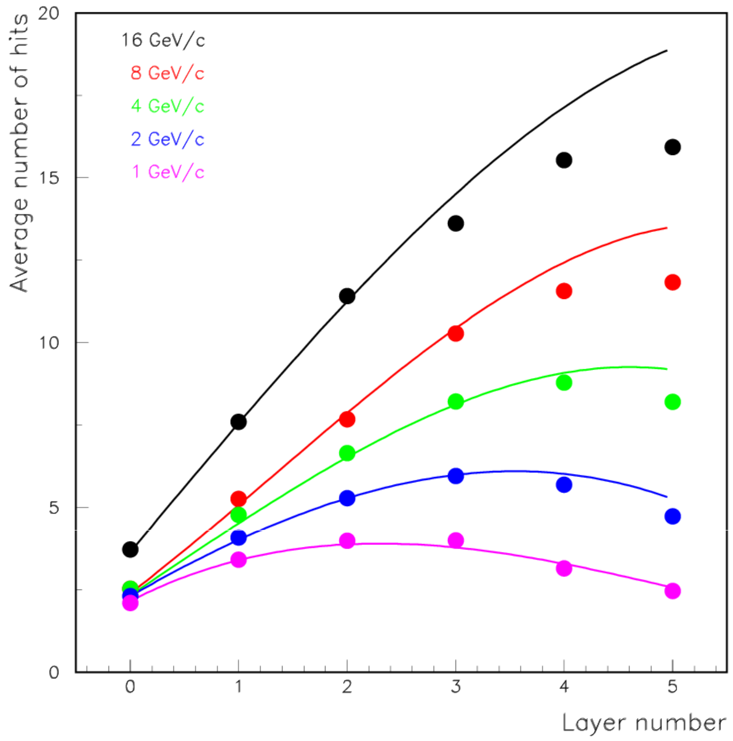
Data
Monte Carlo simulations – 6 layers
Monte Carlo simulations – Infinite stack



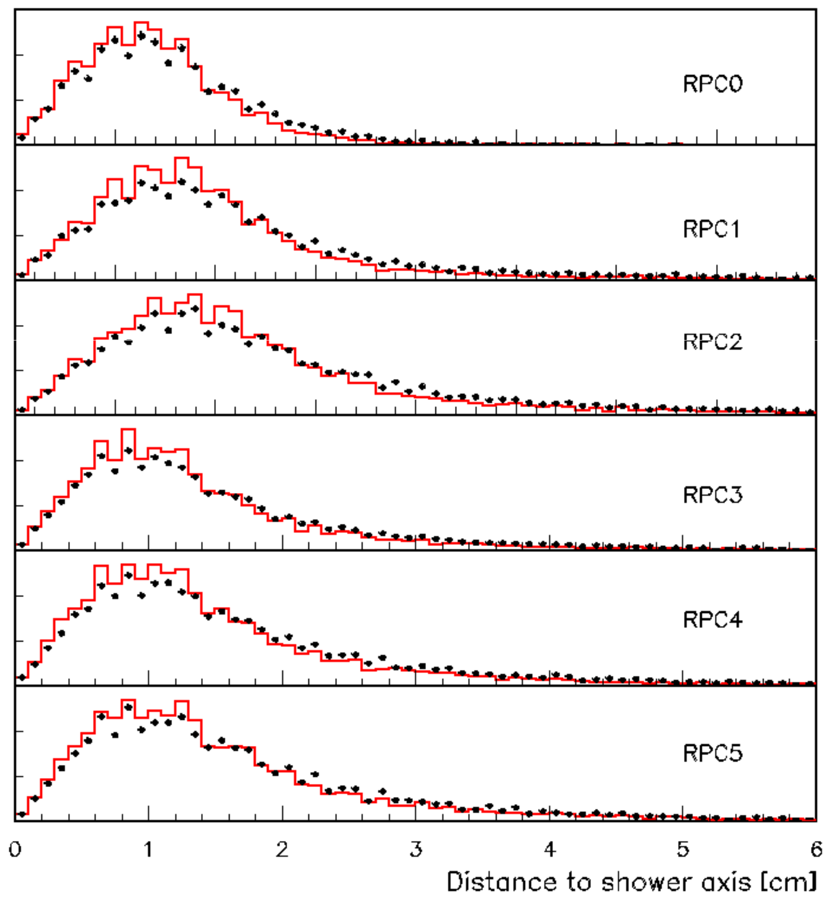


Published as B.Bilki et al., 2009 JINST 4 P04006

Longitudinal shower shape



Lateral shower shape for 2GeV e^+



Effects of high rates seen

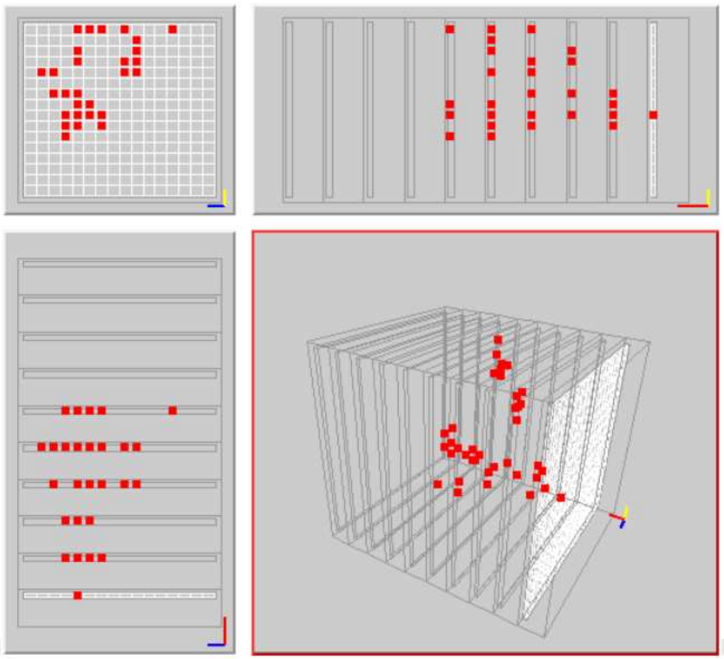
Published as B.Bilki et al., 2009 JINST 4 P04006

Measuring Pion Showers

Momentum [GeV/c]	Stack of iron bricks	Number of events	Beam intensity [Hz]	Fraction of events without veto from the Čerenkov counters[%]
1	No	1378	547	6.0
2	No	5642	273	5.9
	Yes	1068	80	57.3
4	No	5941	294	15.5
8	No	30657	230	24.6
16	No	29889	262	28.0

Trigger =

Coincidence of 2 scintillator paddels + veto from either Čerenkov counter

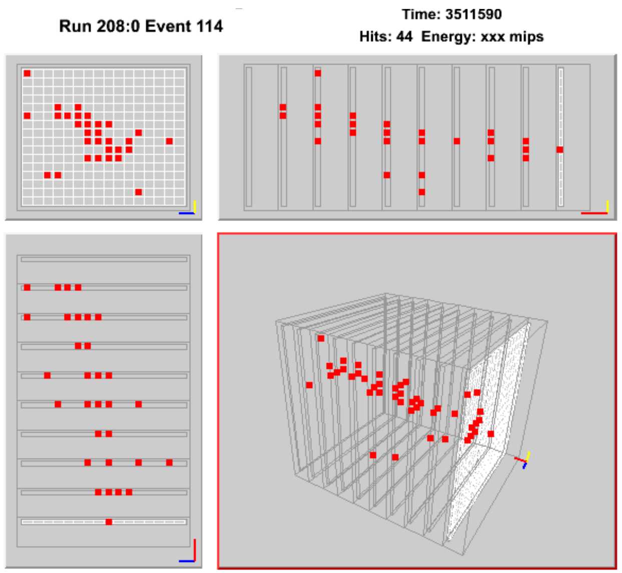


6 layer stack corresponding to 0.7 λ_I

Published as B.Bilki et al., 2009 JINST 4 P10008

Event Selection

Requirement		Effect
At least 3 layers with hits		Rejects spurious triggers
Exactly 1 cluster in the first layer		Removed upstream showers, multiple particles
No more than 4 hits in first layer		Removed upstream showers
Fiducial cut away from edges of readout		Better lateral containment
Second layer	At most 4 hits	MIP selection
	At least 5 hits	Shower selection



Published as B.Bilki et al., 2009 JINST 4 P10008

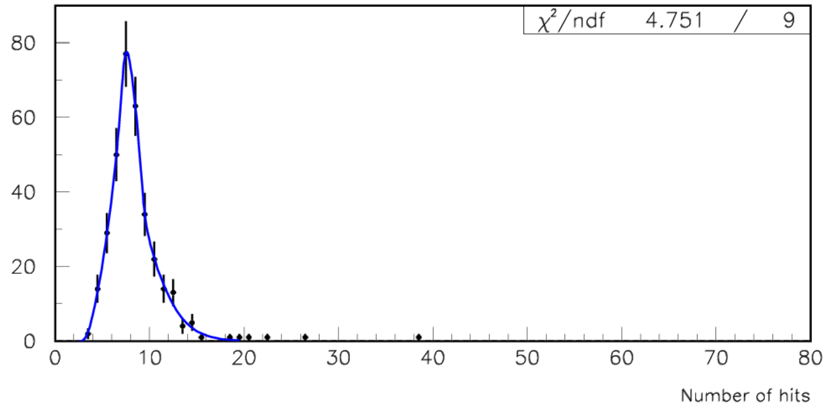
Brick data

Secondary beam with +2 GeV/c selection

Fe blocks in front of RPCs

~ 50 cm deep corresponding to 3 λ_I
→ 97% of π interact
→ ΔE_μ ~ 600 MeV

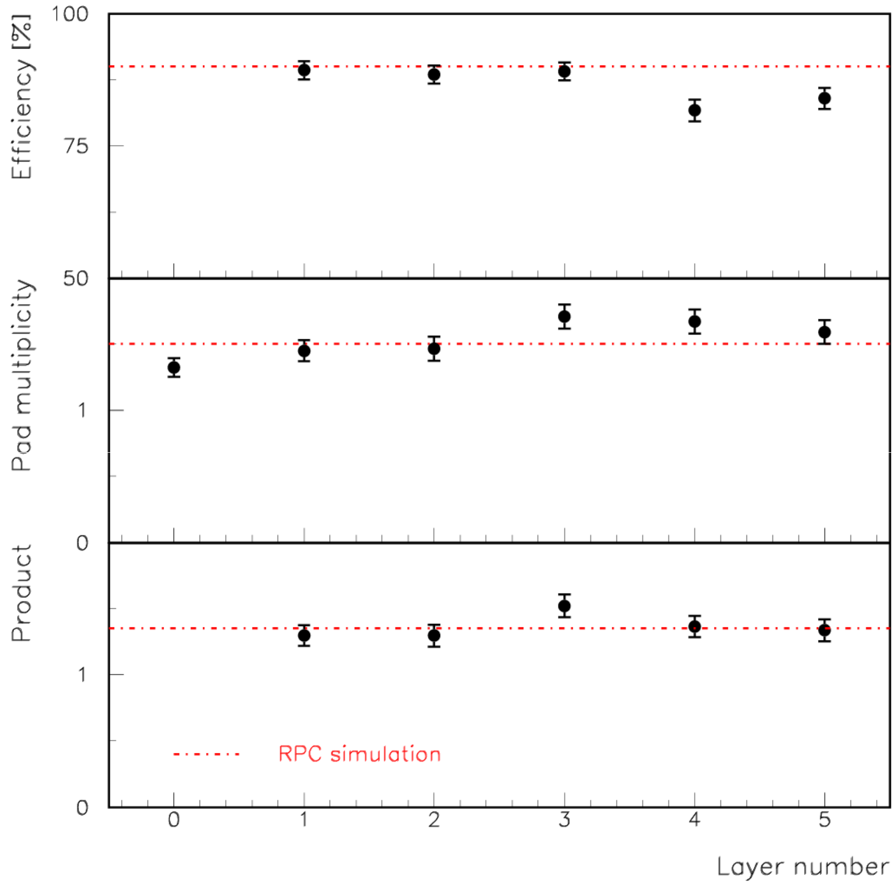
Sum of hits in the DHCAL (RPC0 – RPC5)



→ Emperically fit to

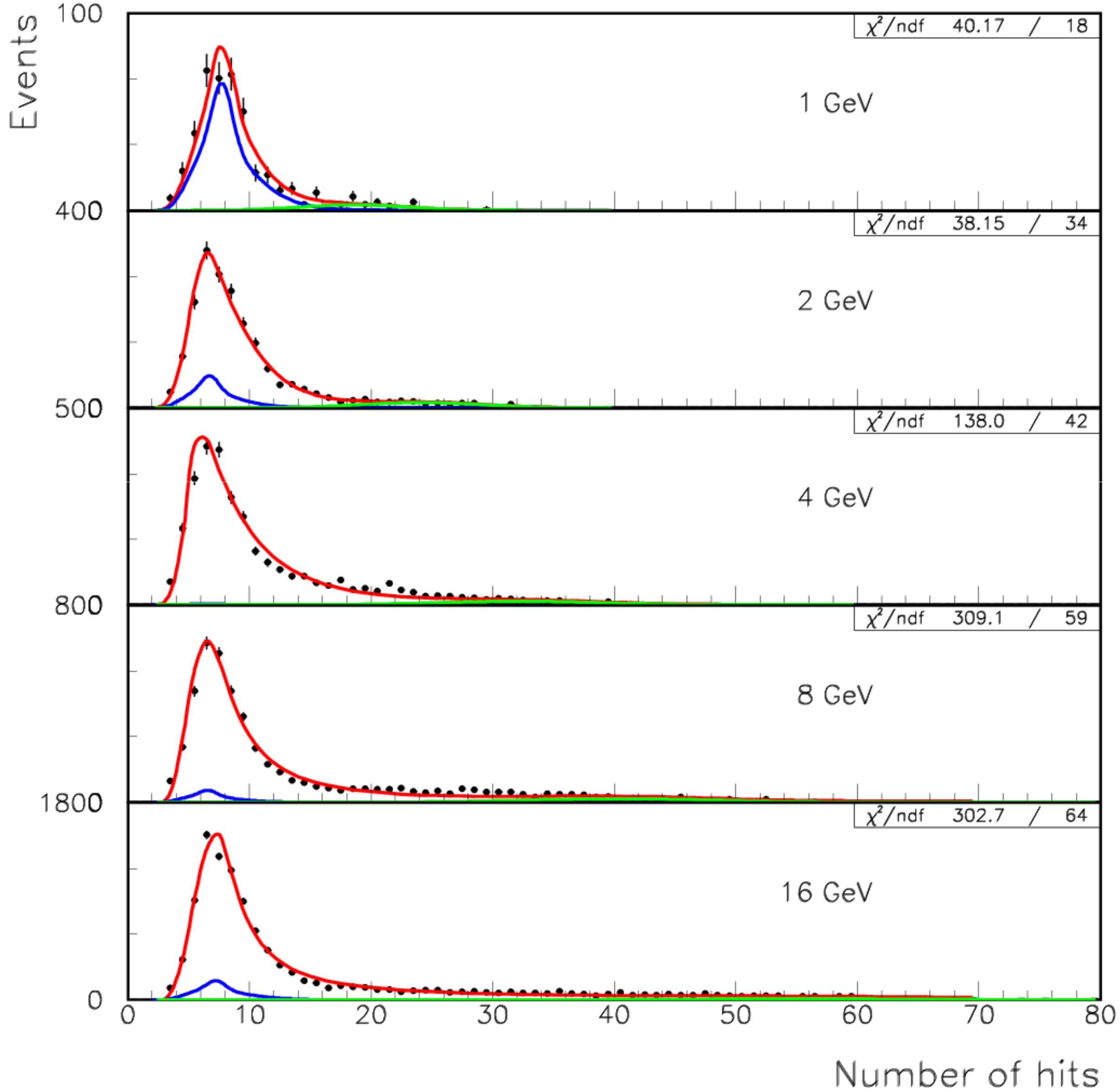
$$\mathbf{y} = \alpha \mathbf{e}^{-\frac{1}{2}\left(\frac{\mathbf{x}-\beta}{\gamma}\right)^2} + \delta(\mathbf{x}-\mathbf{x}_0)^\epsilon \mathbf{e}^{\phi(\mathbf{x}_0-\mathbf{x})}$$

Calibration close to expected values
→ no corrections applied



In the following this will be our μ signal shape

MIP Selection



Fit to 3 components

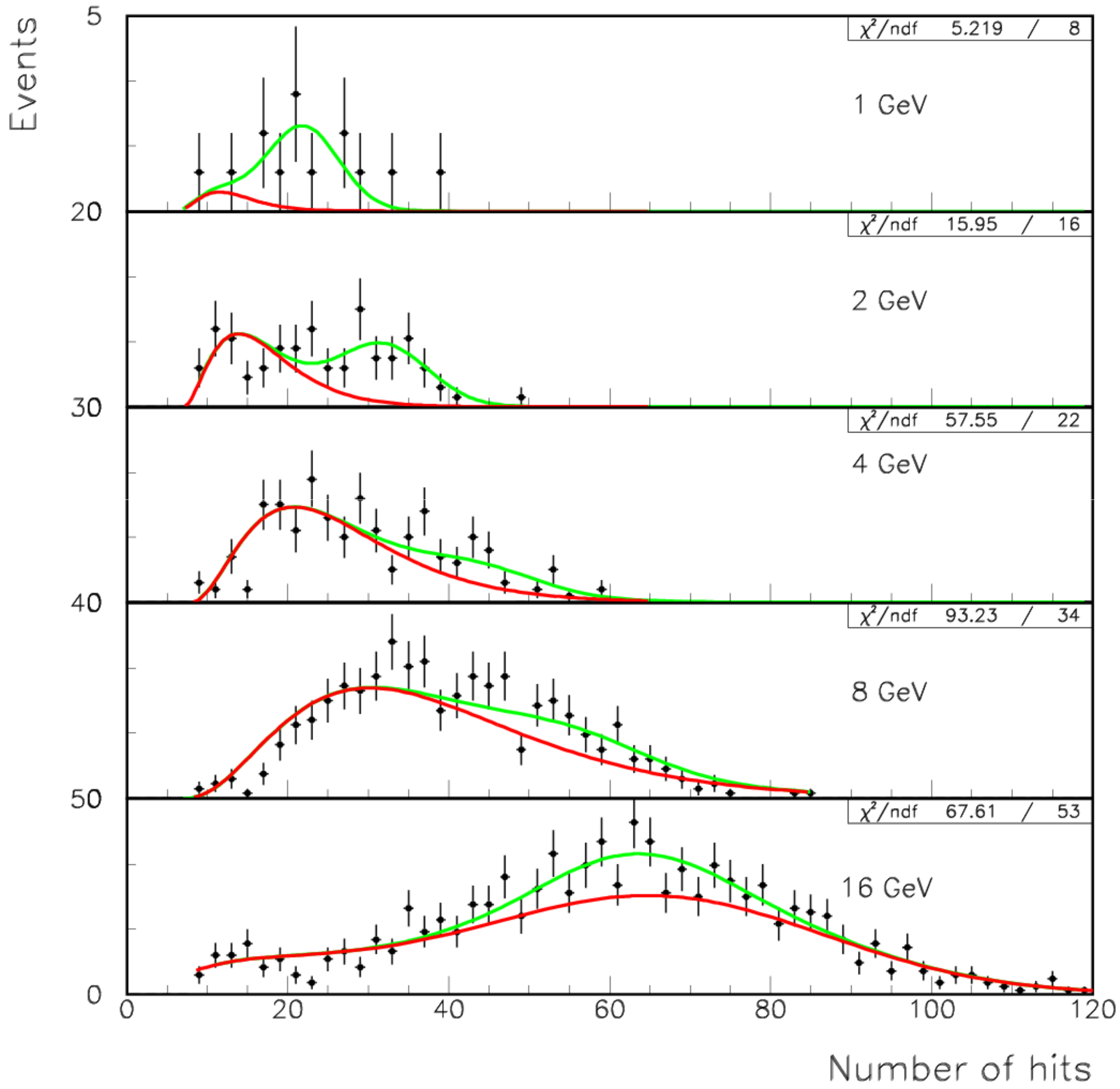
- **Muons** (from brick data)
- **Pions** (from MC, not shown)
- **Positrons** (from MC)

(red line sum of 3 components)

MC curves = absolute predictions, apart from general scaling due to efficiency problems (rate)

Published as B.Bilki et al., 2009 JINST 4 P10008

Shower Selection



Fit to 2 components

- Pions (from MC)
- Positrons (from MC)

MC curves = absolute predictions, apart from general scaling due to efficiency problems (rate) at 16 GeV (-9%)

Reasonable description by simulation

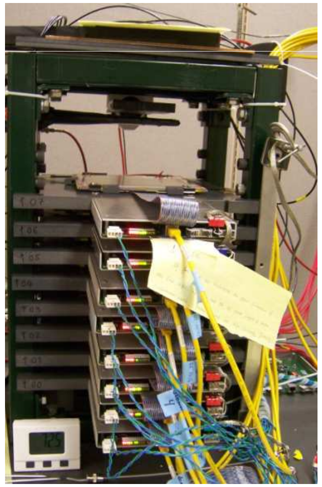
Positron contamination at low energies

Not many pions at low energies

Published as B.Bilki et al., 2009 JINST 4 P10008

Environmental Dependence of the Performance of RPCs

Ambient temperature Air pressure Air humidity	⟷	Noise rate MIP detection efficiency Pad multiplicity



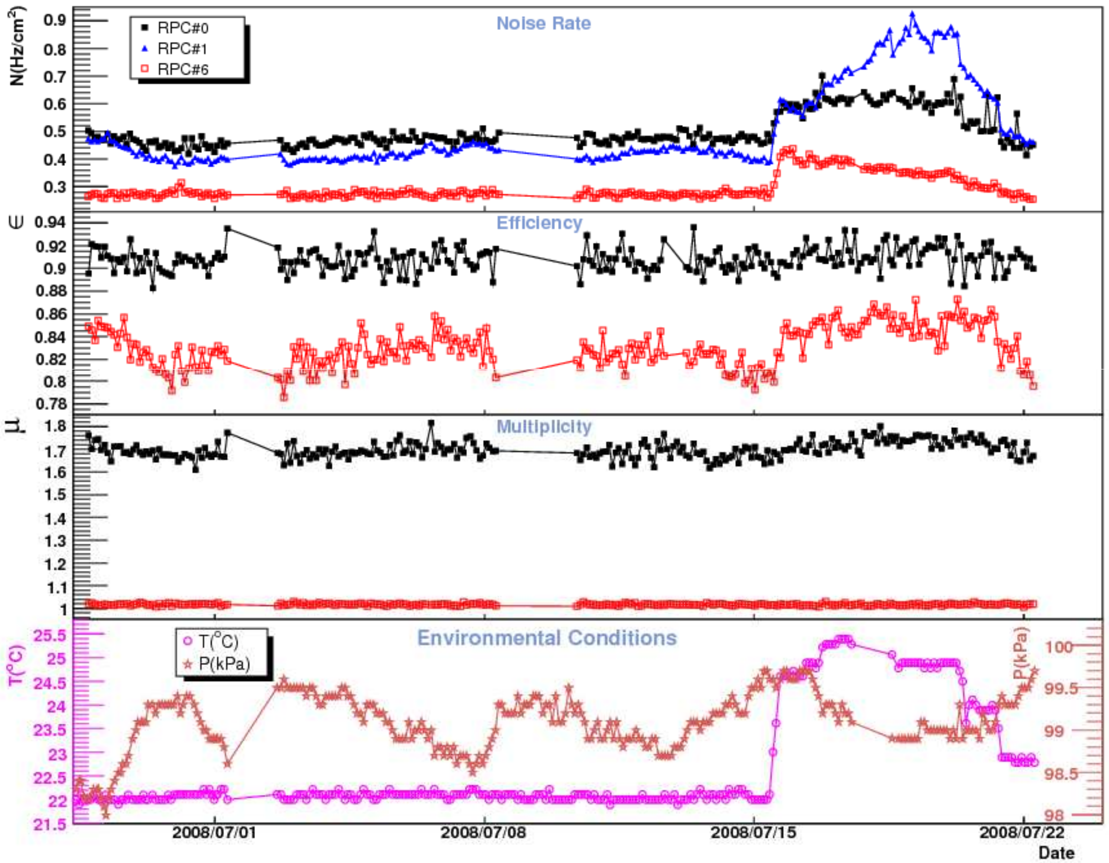
Understanding of noise/role of gas

Why do we need to flush the gas?
What goes wrong in old gas?

Understanding of the stability/calibration of the system

Corrections for environmental conditions?

Sample of the data collected over ~ 1 month

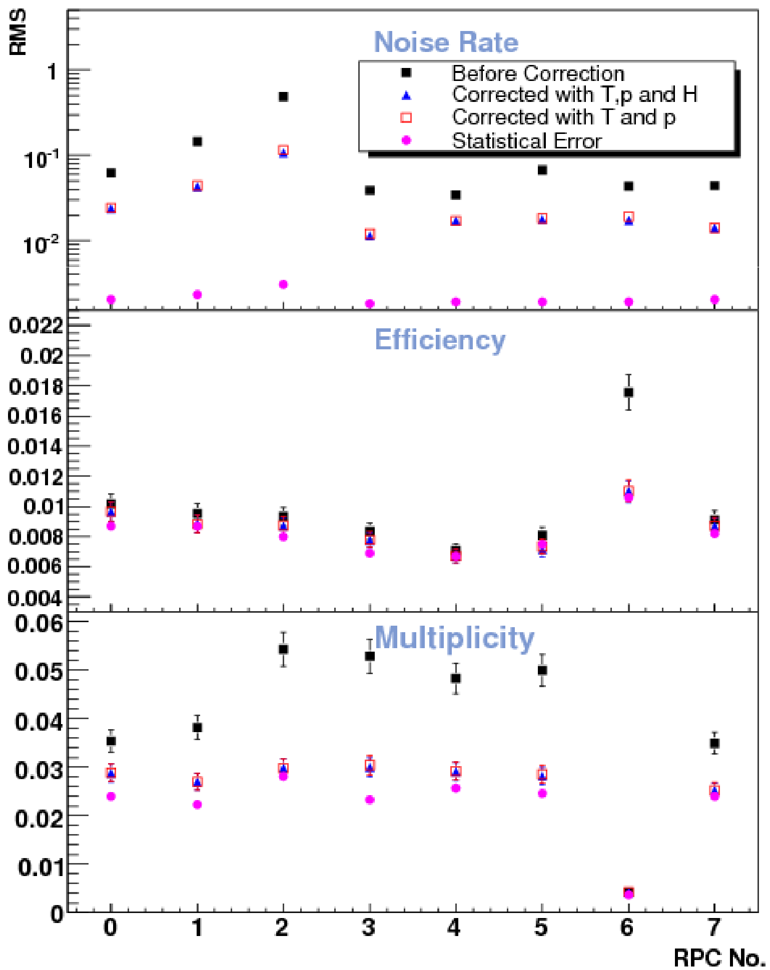


2-glass RPC
2-glass RPC
1-glass RPC

Fluctuations in the performance as well as in the environmental conditions

Linear correction for the environment

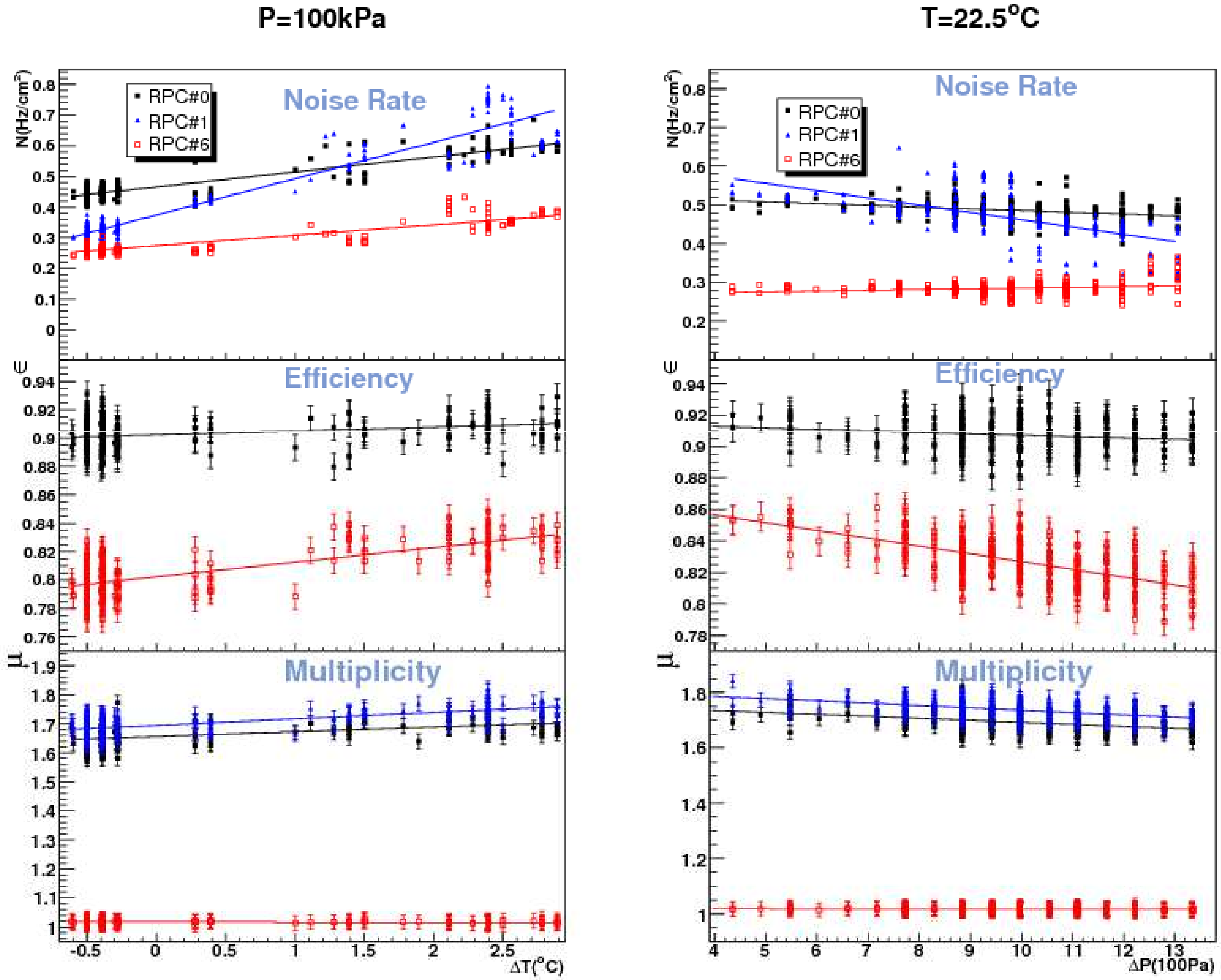
$$F_i(T,p,H) = F_{i,0} + b_{T,i}\Delta T + b_{P,i}\Delta p + b_{H,i}\Delta H \qquad \text{with } i = N, \varepsilon, \mu$$



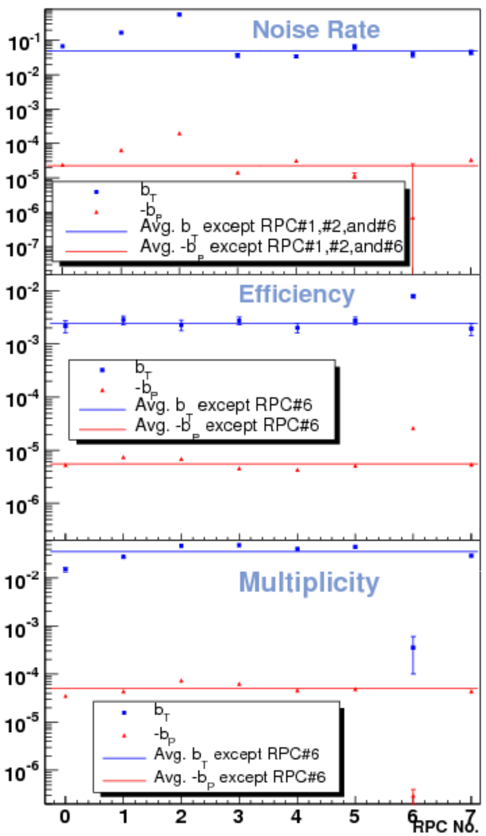
Corrections work well for ε,μ

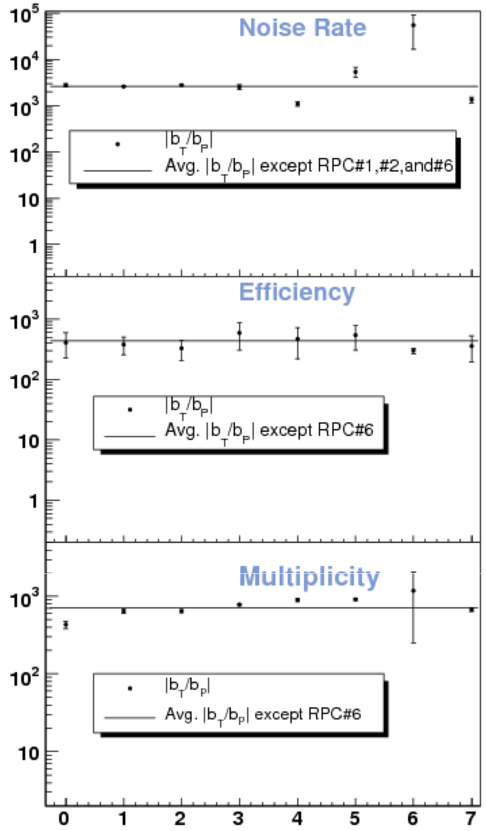
Width of noise rate still above statistical error

Sample of slopes of environmental dependence



Slopes of environmental dependence





More or less consistent slopes for different chambers

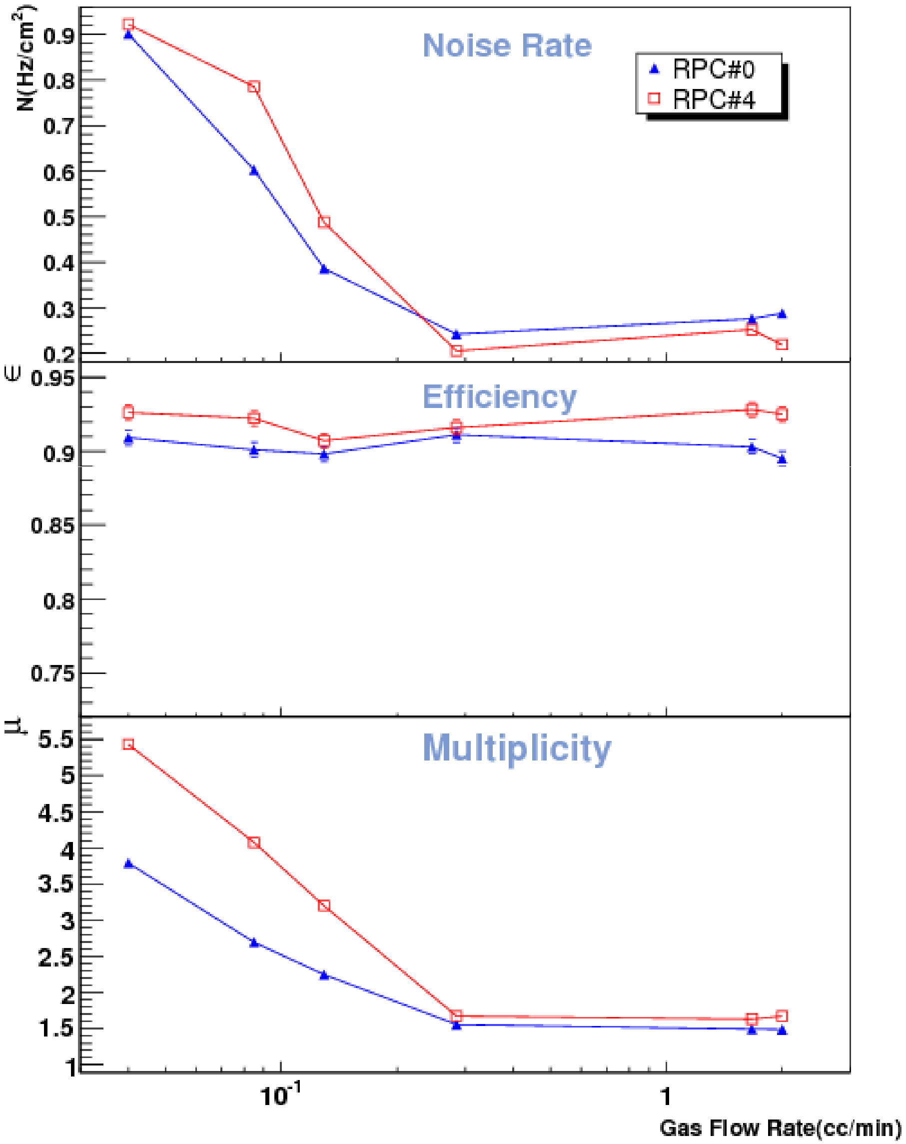
If effects entirely due to changes in mean free path in gas

→ b_T/b_p ~ 338 Pa/^{0}K

Roughly correct for ε,μ
Much larger for N
(other factors contribute to noise rate)

Performance variable	Changes for ΔT = 1 ^{0}C			Changes for Δp= 100 Pa		
RPC design	2-glass		1-glass (Good)(%)	2-glass		1-glass (Good) (%)
	Good(%)	Damaged(%)		Good(%)	Damaged(%)	
Noise rate	14±1.6	42±1.2	13±1.8	0.70±0.037	1.73±0.028	0.02±0.69
Efficiency	0.26±0.051	0.28±0.0559	0.98±0.078	0.06±0.001	0.08±0.001	0.32±0.001
Pad multiplicity	2.0±0.09	2.0±0.09	0.035±0.0250	0.30±0.002	0.26±0.002	0.003±0.001

Dependence on gas flow



Noise rate and pad multiplicity rise dramatically for flow rates below 0.3 cc/min

→ Corresponds to 8 volume changes/day

This data is without beam activity

(better understanding of the underlying mechanism for accidental noise hits would be very useful)

X   The 1 m^3 Physics Prototype

Description

38 layers each 1 x 1 m^2
Interleaved with 20 mm thick steel plates
Re-use of CALICE absorber structure and stage

RPCs

Area = 32 x 96 cm^2 (3 per layer)
Mostly 2-glass design (some 1-glass design)
Thickness

Glass = 1.15 (Cathode) and 0.85 mm (Anode)
Gas gap = 1.15 mm

Readout

350,208 individual channels (~ NOvA)
1-bit readout

Motivation for 1 m^3 prototype

- Validate our technical approach
- Gain experience with larger system
- Make precision measurements of hadronic showers
(helpful for further developments of GEANT4)
- Provide test bed for further technical developments

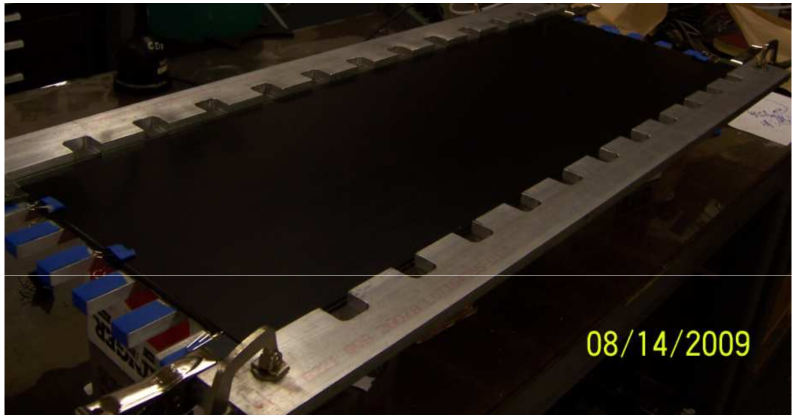
RPC Construction

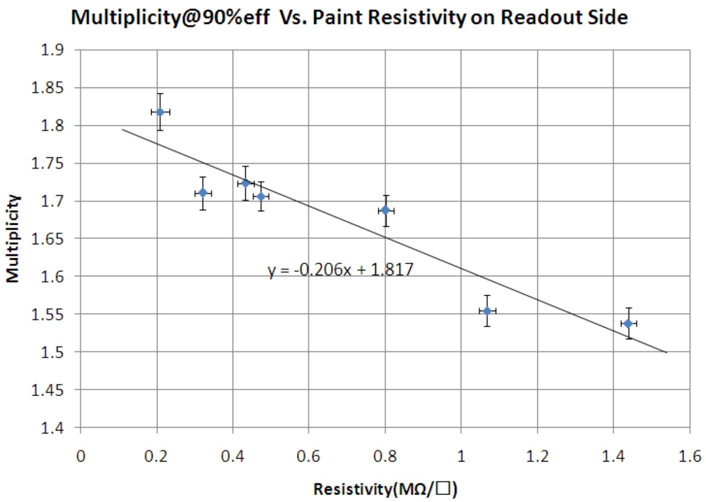
Chambers

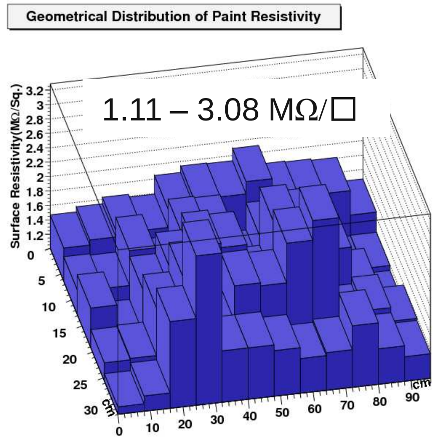
114 + spares needed
So far 8 built

Spraying of resistive paint

Challenge to achieve $R_{\square} = 1 - 5\ M\Omega/\square$
Assembled (automated) spraying booth







Quality Assurance

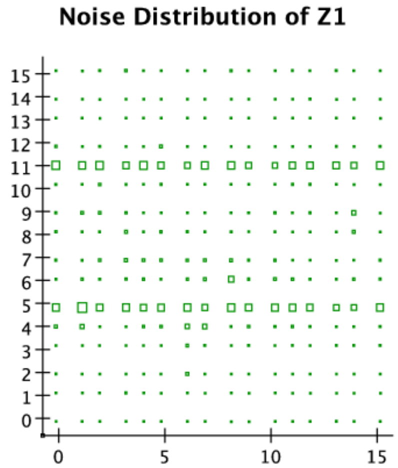
Currently

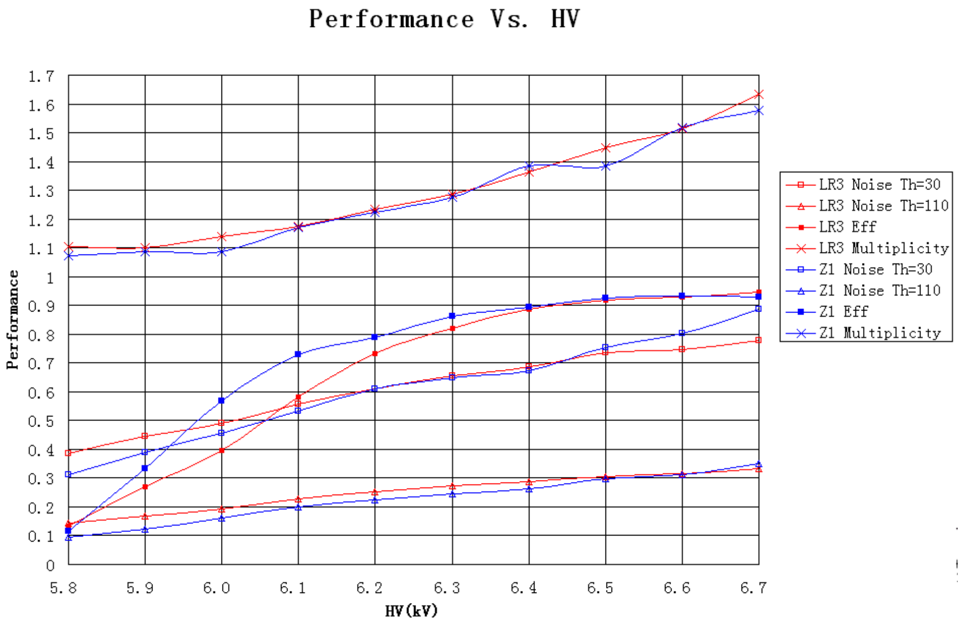
Use old electronics to check out chambers

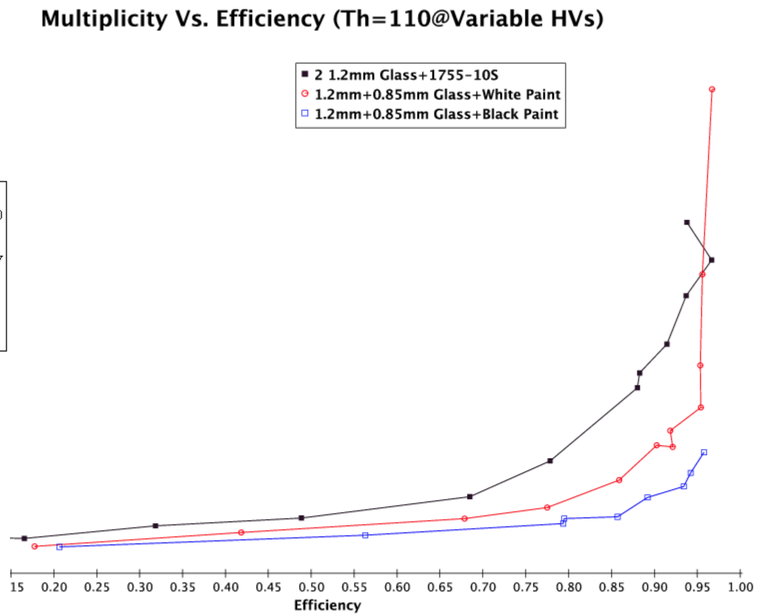
Future

A) Will measure each chamber with new electronics and VST (for tracking)

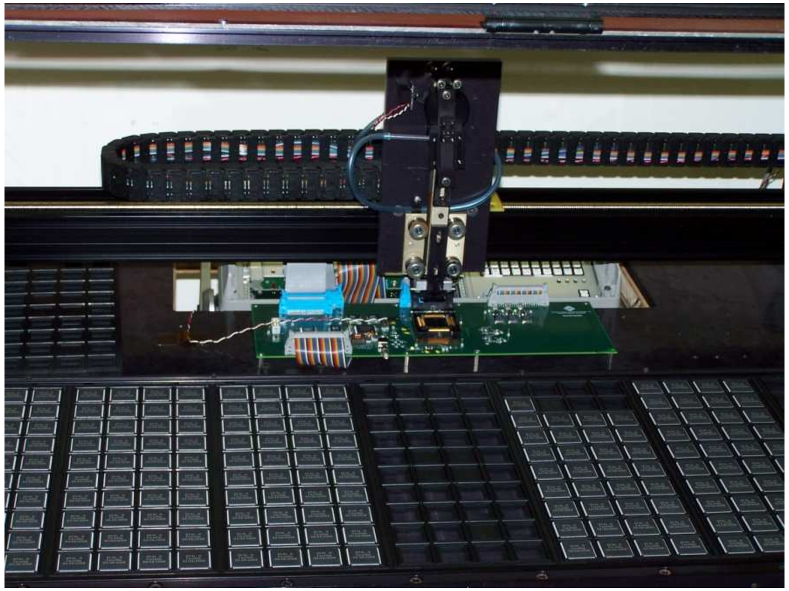
B) Will measure cosmic rays with completed cassettes in hanging file structure







Electronics for the 1 m^3



ASICs

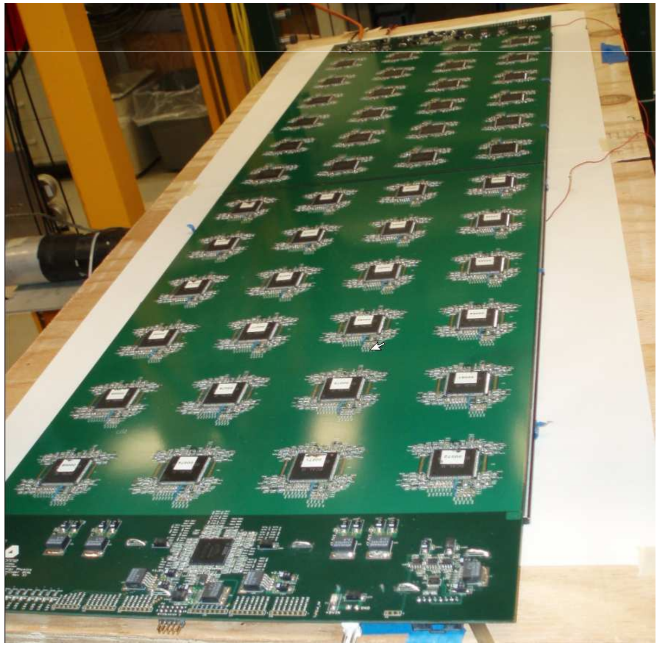
Need 5472 DCAL III chips

→ Robot testing at Fermilab
(over half done)

Front-end board

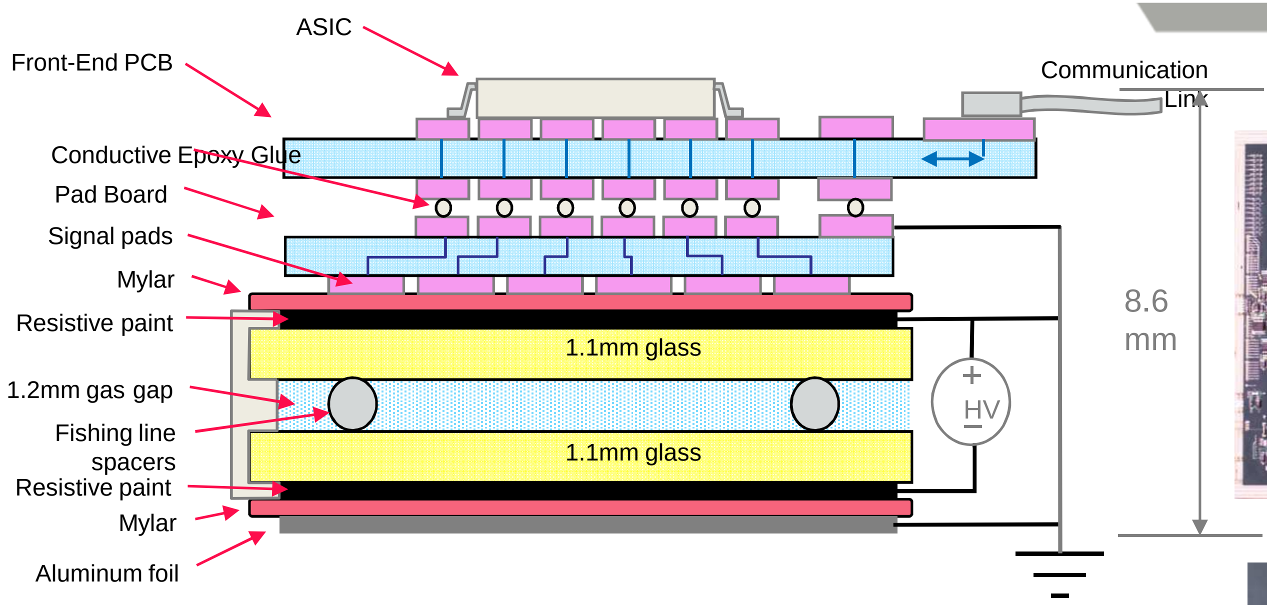
Redesigned
1st prototype works (few small glitches)
2nd prototype begin assembled

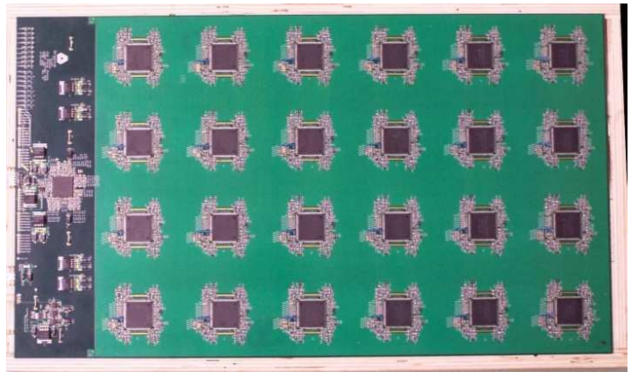
→ Production soon

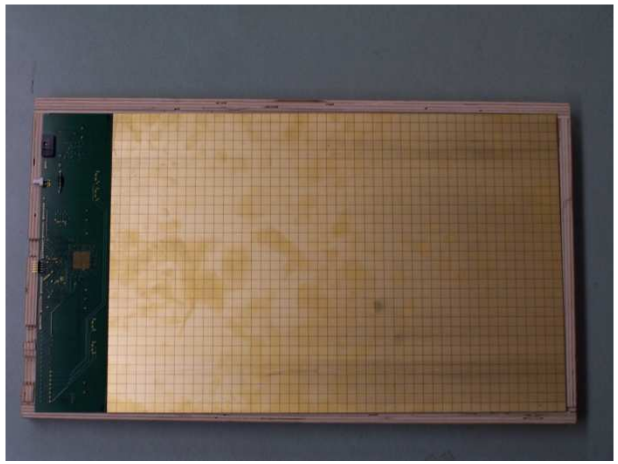


Remainder of system

Data collectors are built and being tested
Timing and trigger modules being redesigned



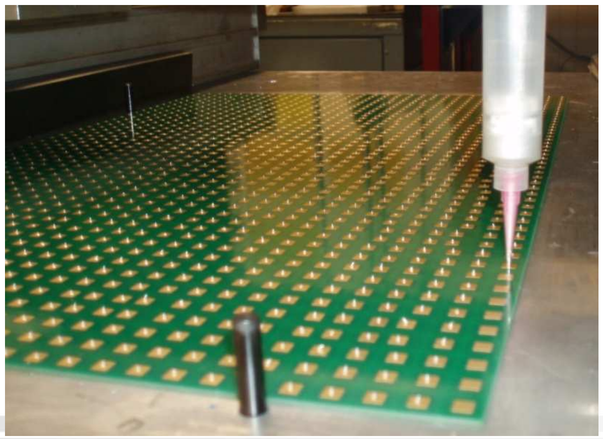




Gluing of the Pad- and Front-end boards

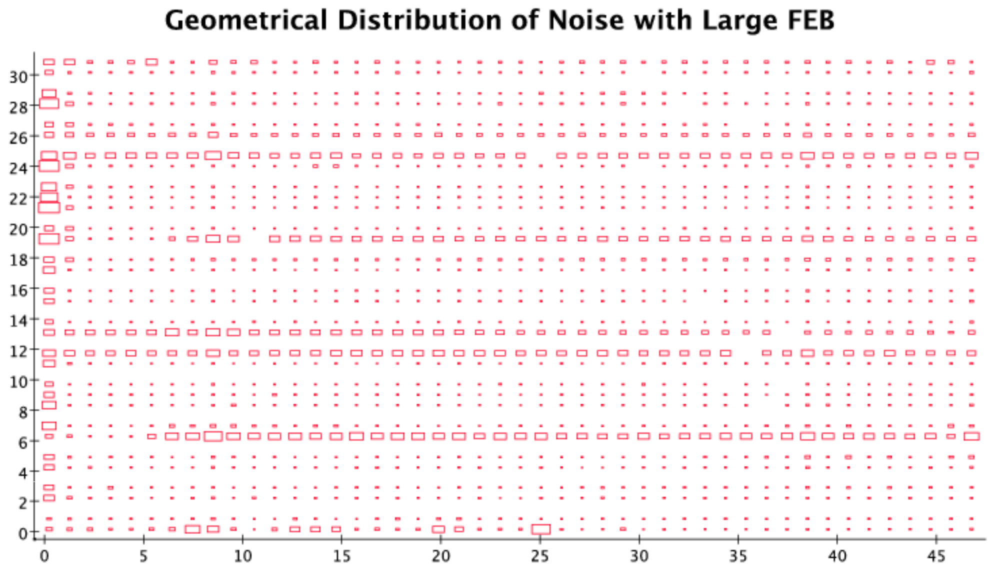
Need to make 1536 connections
Glue starts to harden after 3 – 4 hours

→ built x – y table and dispenser



First board glued successfully

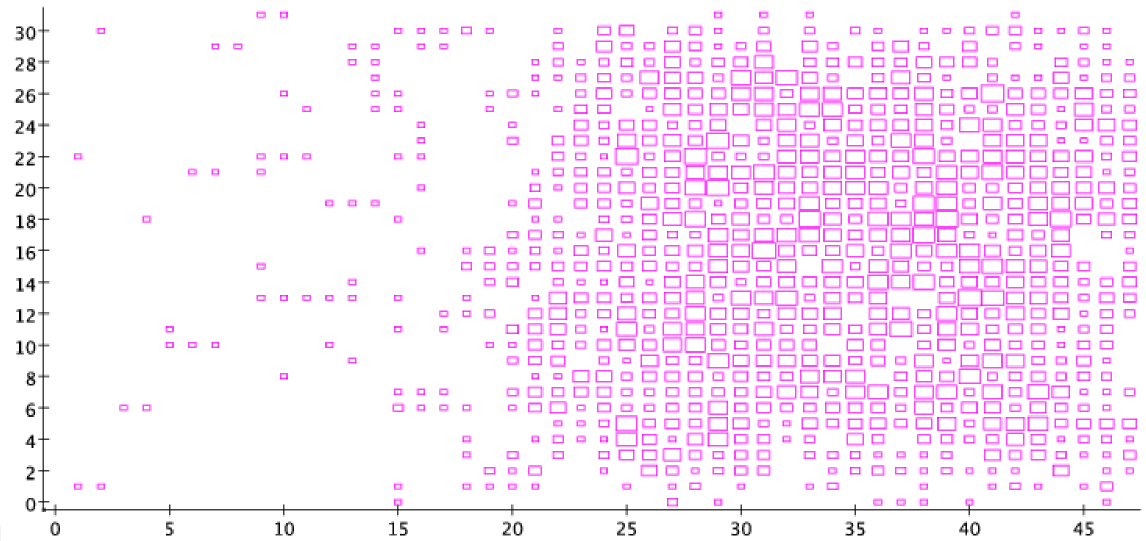
First Noise Run and Cosmic Rays



Higher rates around fishing lines

Used tracking with
VST chambers

Later: will use self-contained
system with large chambers



Peripherals

Gas

Mixing – done
Distributing – almost done

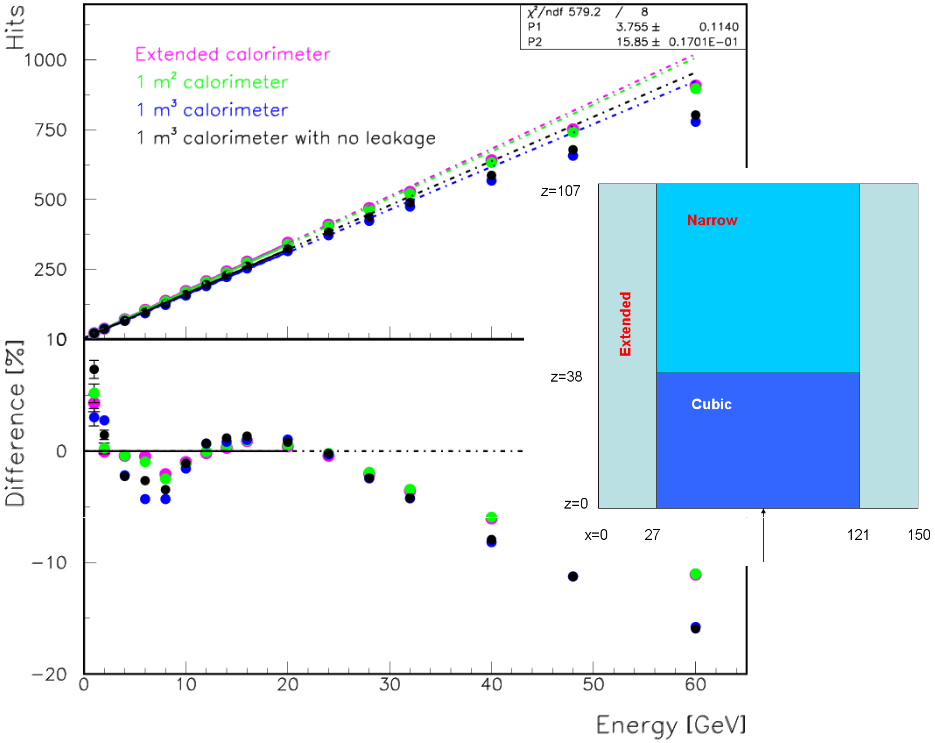
Low Voltage

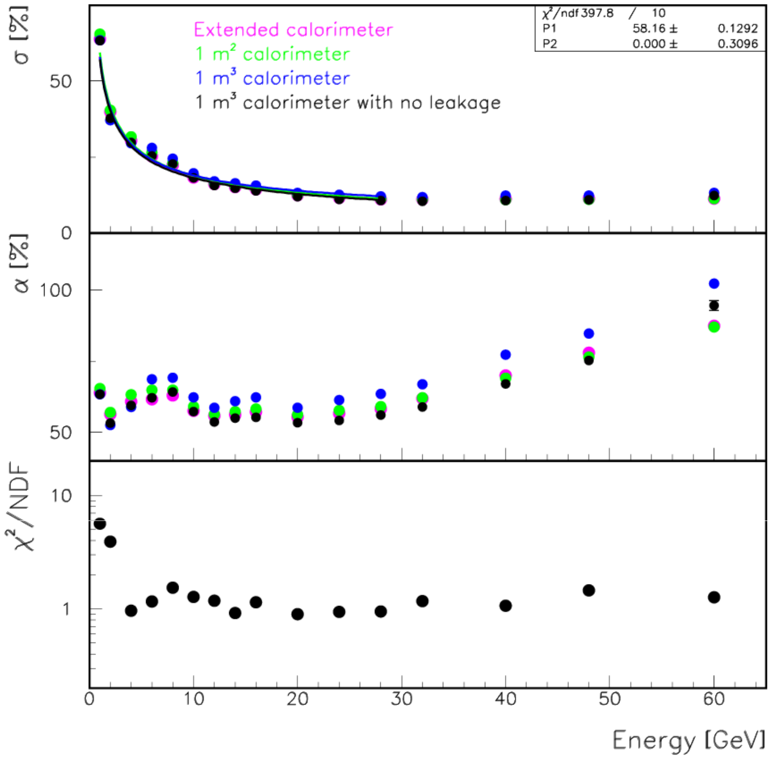
7 Wiener power supplies in hand
1st distribution box built and being tested

High Voltage

Units in hand
Computer control programs commissioned

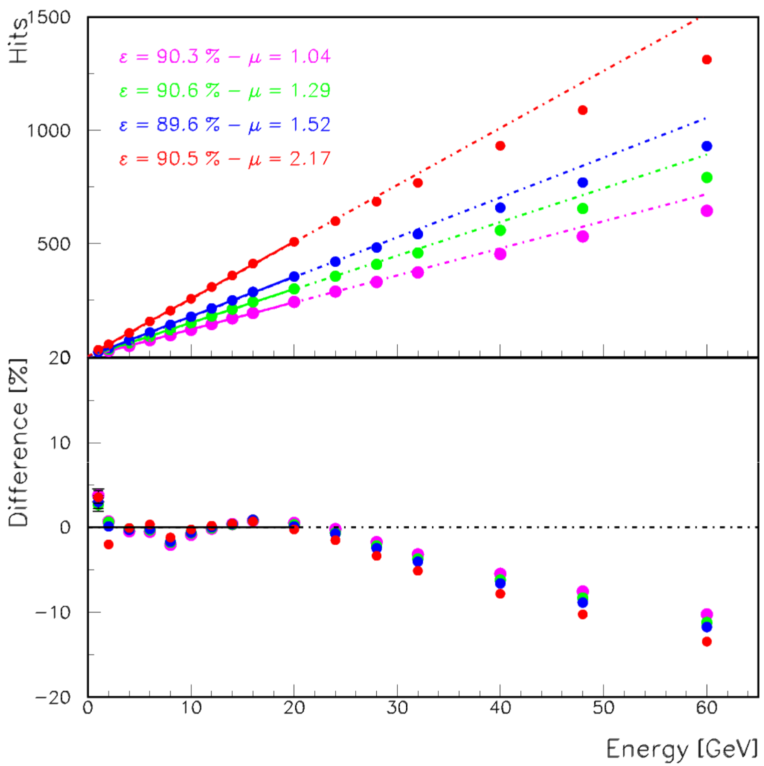
Simulating Larger Systems

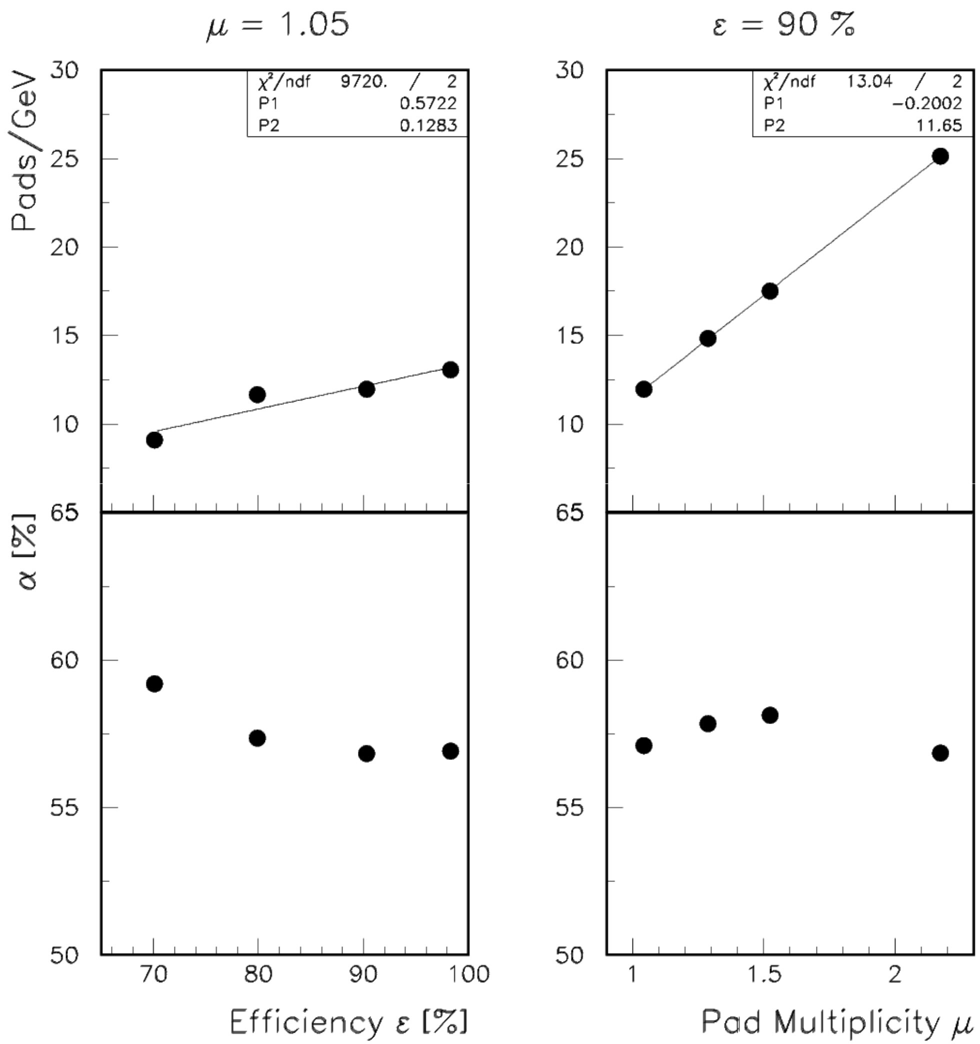




Reasonable Gaussian fits for E > 2 GeV
Discontinuity at E ~ 8 GeV (surprising, changes with physics list)
Non-linearity above E ~ 20 GeV (saturation)
Resolution ~ 58%/√E(GeV) (for E < 28 GeV)
Resolution degrades above 28 GeV (saturation)
Resolution of 1m^3 with containment cut somewhat better than for extended calorimeter

Study of different extended RPC-based calorimeters



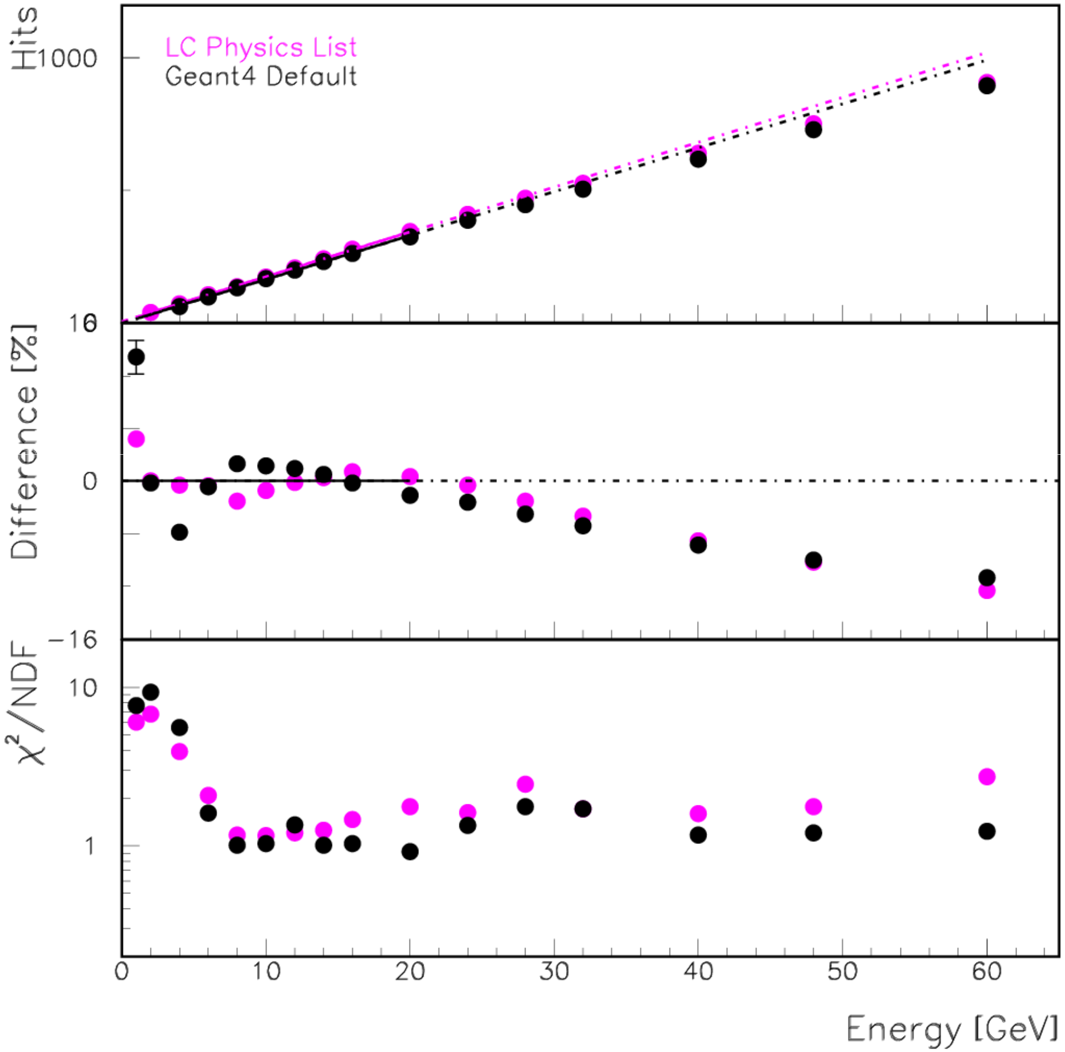


Efficiency and pad multiplicity have only minor effect on resolution (Small μ might be desirable for PFAs)

However values need to be known

Linear calibration corrections for ε,μ will work (P_1 ~ 0)

Study with different GEANT4 physics lists



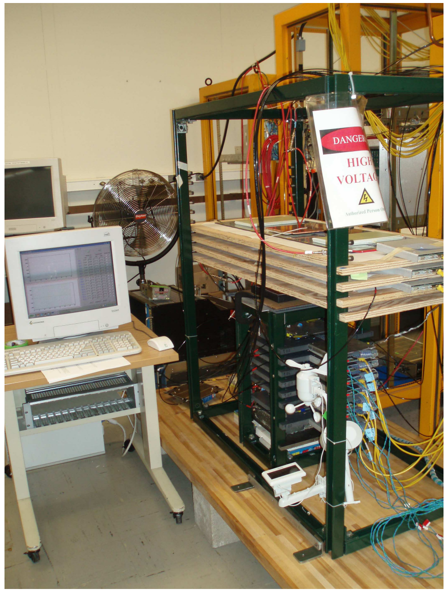
Physics list

List of processes included in the shower simulation

Different approaches (data, parametrizations, calculations…)

Clearly something fishy around 4 – 8 GeV

Tests with the 1 m^3 calorimeter



Cosmic ray tests

Each chamber will be tested in the cosmic ray test stand
Each completed layer will be inserted in hanging file structure
and will be tested with cosmic rays

Fermilab test beam

Tests with μ, $\pi^{\pm}$, $e^{\pm}$
Comparison with various MC models of hadronic showers
Comparison with scintillator – analog HCAL (CALICE)

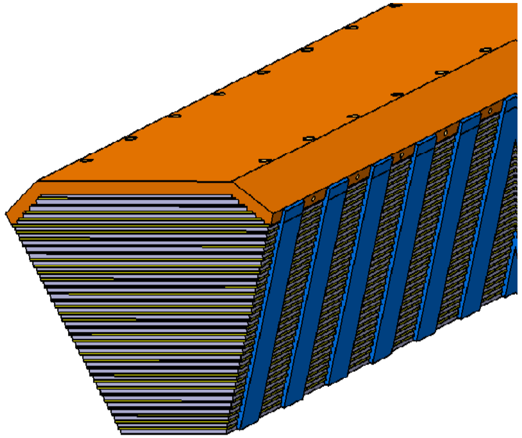
Important for
PFA development

Time scale

First layer to be inserted soon
Construction completed in early 2010
Data analysis in 2010 - 2012

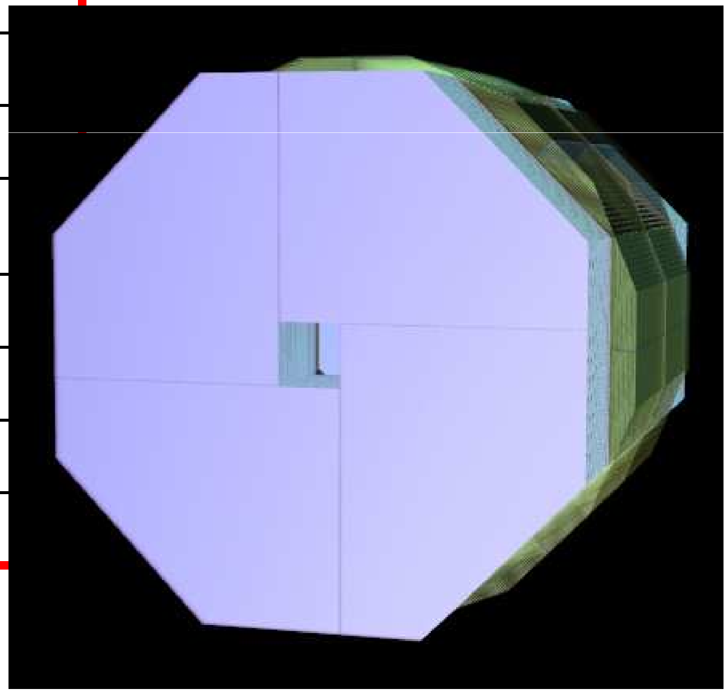
Expect 4 – 5 papers

XI Further Technical Issues

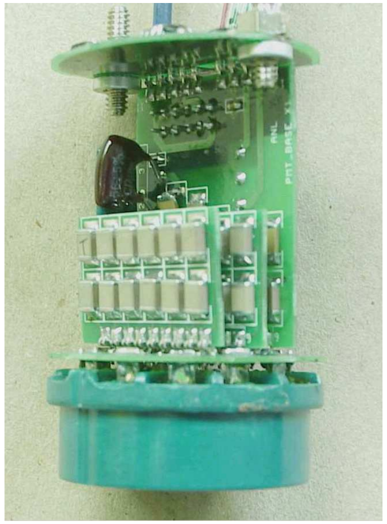


Preparation for Technical Prototype

	Connection	Physics prototype	Technical prototype
RPC	Gas inlet	40	1
	Gas outlet	40	1
	High-voltage supply	40	1
	High-voltage computer control	-	1
Front-end electronics	Low-voltage	120	1
	Cooling water inlet	40	1
	Cooling water outlet	40	1
	Data cables	240	1



R&D Topics for a technical prototype calorimeter



RPCs – mechanical, 1-glass design

(New RPC design invented in and developed by us)

Already started

Gas system – recycling, distribution

Already started

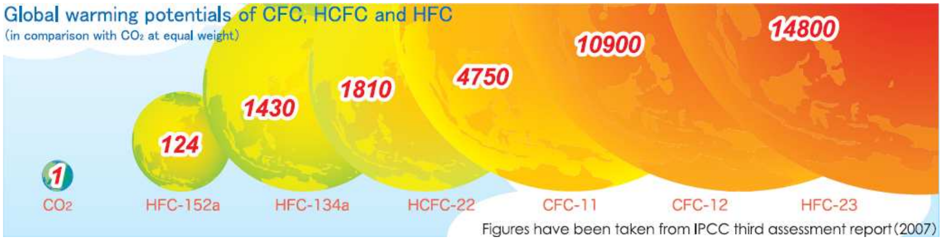
High Voltage – distribution, monitoring

To be started soon

Low Voltage – distribution, monitoring

Front-end – token ring passing, power consumption, channel count, thickness, reliability…

To be started soon



XII Conclusions

For a future Lepton Collider we propose a novel way based on Particle Flow Algorithms (PFAs) for measuring the energy of jets

PFAs require calorimeters with extremely fine segmentation of the readout

We have developed an RPC – based hadron calorimeter with 1 x 1 cm^2 readout pads

Initial tests with a small size calorimeter were quite successful

Currently we are constructing a 1 m^3 physics prototype

→ To be tested in Fermilab test beam in 2010/2011

Further R&D issues remain for a Technical prototype

→ We have started to look into some of them…

(We are always looking for new collaborators with graduate students: Excellent thesis topics)

Responsibilities and collaborators

Task	Responsible institutes
Project coordination	Argonne
RPC construction	Argonne
Cassette structure	Argonne
Mechanical structure (prototype section)	DESY
Overall electronic design	Argonne
ASIC design and testing	FNAL, Argonne
Front-end and Pad board design & testing	Argonne
Data concentrator design & testing	Argonne
Data collector design & testing	Boston, Argonne
Timing and trigger module design and testing	FNAL
DAQ Software	Argonne, CALICE
Data analysis	Argonne, FNAL, Iowa, (UTA)
High Voltage system	Iowa
Low voltage system	Argonne
Gas mixing and distribution	Iowa