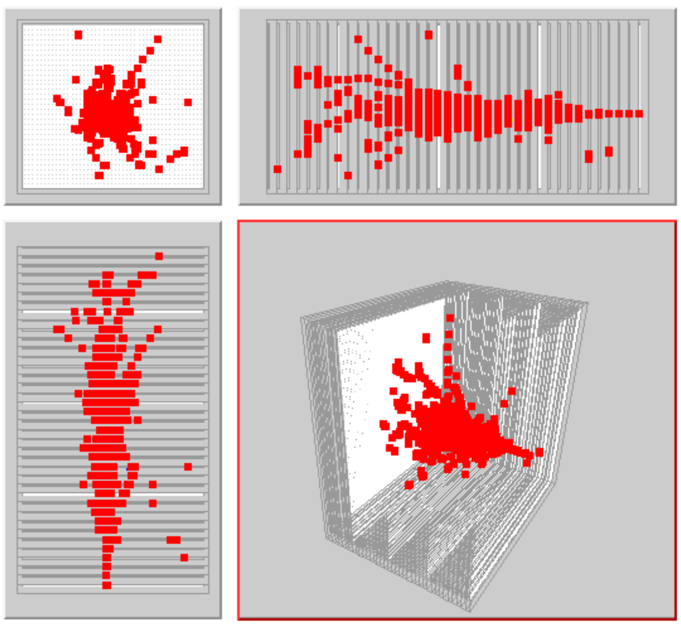
Construction of a Digital Hadron Calorimeter with Resistive Plate Chambers



José Repond
Argonne National Laboratory

International Linear Collider Workshop 2010
Institute of High Energy Physics
Bejing, People's Republic of China
March 26 – 31, 2010

RPC DHCAL Collaboration

CALICE
Calorimeter for ILC

Argonne

Carol Adams
Mike Anthony
Tim Cundiff
Eddie Davis
Pat De Lurgio
Gary Drake
Kurt Francis
Robert Furst
Vic Guarino
Bill Haberichter
Andrew Kreps
Zeljko Matijas
José Repond
Jim Schlereth
Frank Skrzecz
(Jacob Smith)
(Daniel Trojand)
Dave Underwood
Ken Wood
Lei Xia
Allen Zhao

Boston University

John Butler
Eric Hazen
Shouxiang Wu

Fermilab

Alan Baumbaugh
Lou Dal Monte
Jim Hoff
Scott Holm
Ray Yarema

IHEP Beijing

Qingmin Zhang

University of Iowa

Burak Bilki
Edwin Norbeck
David Northacker
Yasar Onel

McGill University

François Corriveau
Daniel Trojand

UTA

Jacob Smith
Jaehoon Yu

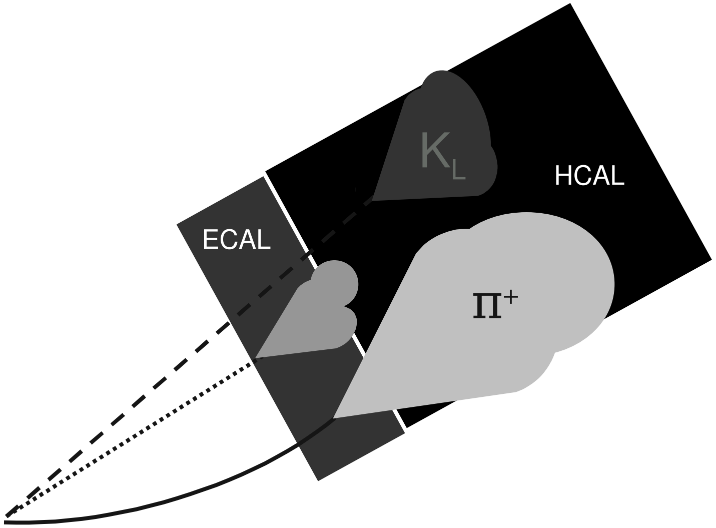
RED = Electronics Contributions
GREEN = Mechanical Contributions
BLUE = Students
BLACK = Physicist

Argonne NATIONAL LABORATORY
BOSTON UNIVERSITY
Fermilab
Institute of High Energy Physics
Chinese Academy of Sciences
The University of Iowa
McGill
The University of Texas ARLINGTON

Particle Flow Algorithms

The idea…

Charged particles	measured with the	**Tracker**	
Neutral particles		**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			**$\leq 0.24^2\ E_{jet}$**

18%/√E (Charged + Photons + Neutral Hadrons)

Required for 30%/√E

Requirements for detector system

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

Counting # of hits sufficient → 'digital readout'

thin active medium (Calorimeter inside coil; Calorimeter as dense as possible)

RPC

1 m³ – Digital Hadron Calorimeter Physics Prototype

Description

Readout of 1 x 1 cm² pads with one threshold (1-bit) → **Digital Calorimeter**
40 layers each ~ 1 x 1 m²
Each layer with 3 RPCs, each 32 x 96 cm²
~400,000 readout channels
Layers to be inserted into the existing CALICE Analog (scintillator) HCAL structure

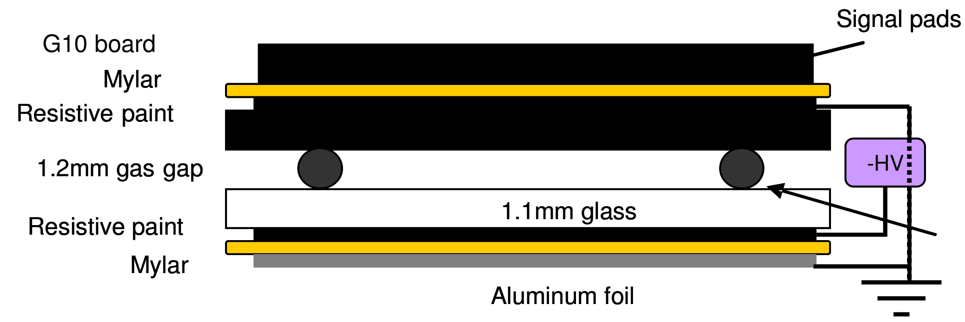
Purpose

Validate DHCAL concept
Gain experience running large RPC systems
Measure hadronic showers in great detail
Validate hadronic shower models

Status

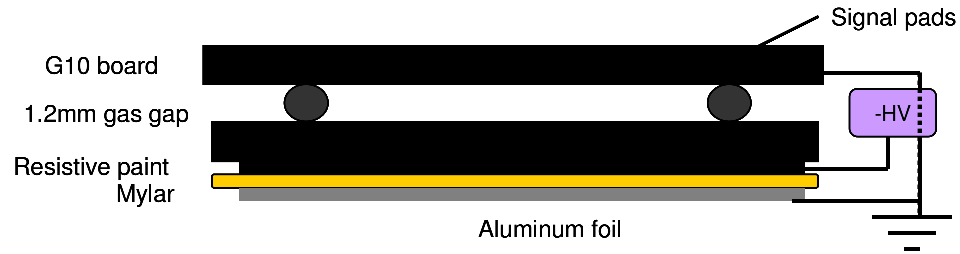
Started construction in 2008 - 09

RPC Construction



RPC design

2 – glass RPCs
1 – glass RPCs (developed at Argonne)
Gas gap size 1.1mm
Total RPC thickness < 3.4mm
Dead area ~5% (frame, fishing lines)

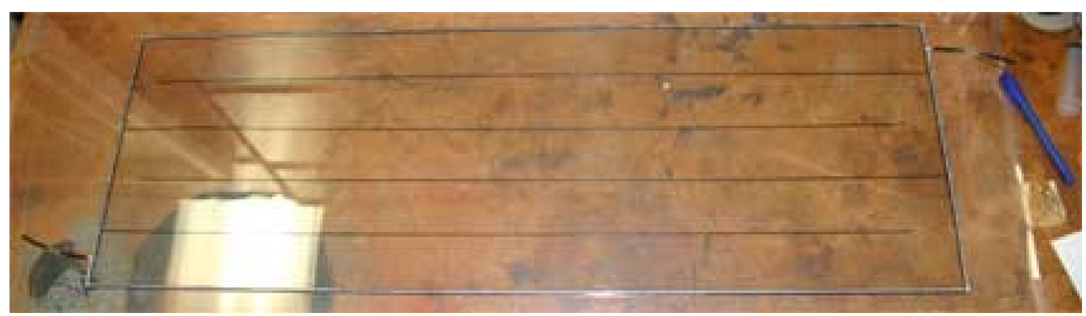


Chambers needed

~114 + spares

Material

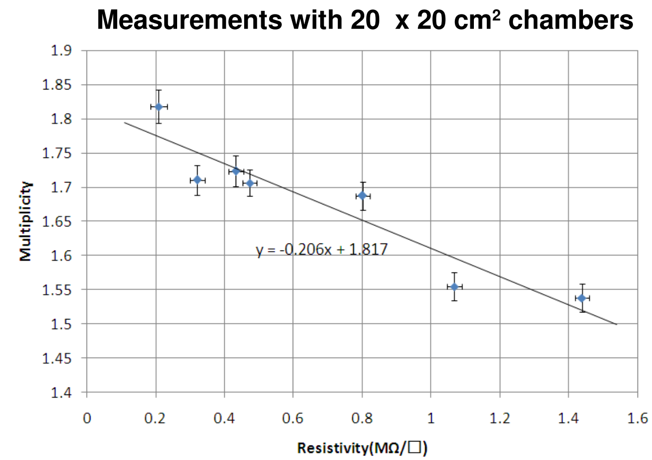
Glass in hand for 300 chambers
Kilometers worth of PVC frame extruded



Assembly steps

Spraying of glass plates with resistive paint
Cutting of frame pieces
Gluing frame
Gluing glass plates onto frame
Mounting of HV connection, etc.

Spraying of the glass sheets



Challenge

Produce a uniform layer with $R_{\square} = 1 - 5\ M\Omega$

value affects pad multiplicity
value only critical for thin plate, thick plate can be lower/higher

New paint (artist paint) identified

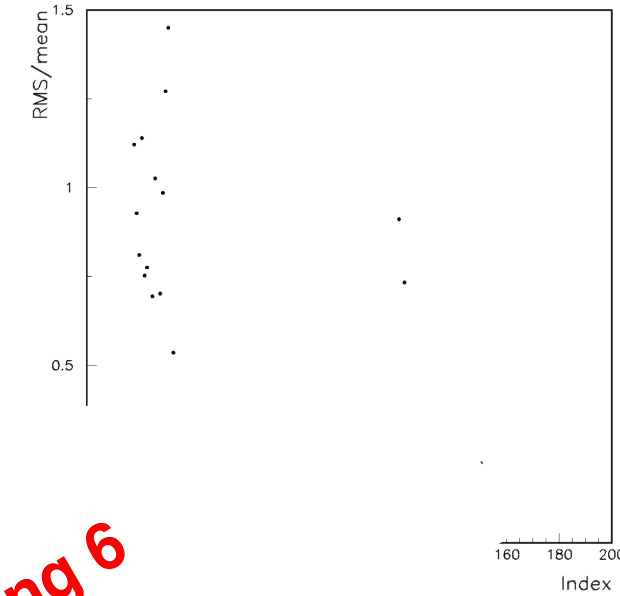
Reasonably cheap
Non toxic
2 component mixture (BLACK and GREEN)
Needs to be sprayed

Production

Has been a struggle

Poor uniformity in a single plate
Mean value not well controlled from plate to plate
Low yield: ~ 60% pass quality cut
Slow – barely match RPC assembly speed

Improving paint spraying



Exhaustive studies of spraying conditions

- Environmental Temperature, humidity
- Airbrush pressure, flow rate, nozzle cleanliness
- Paint ratio and quality
- Horizontal and vertical slide speed
- Air movement in booth

Improvement 1:

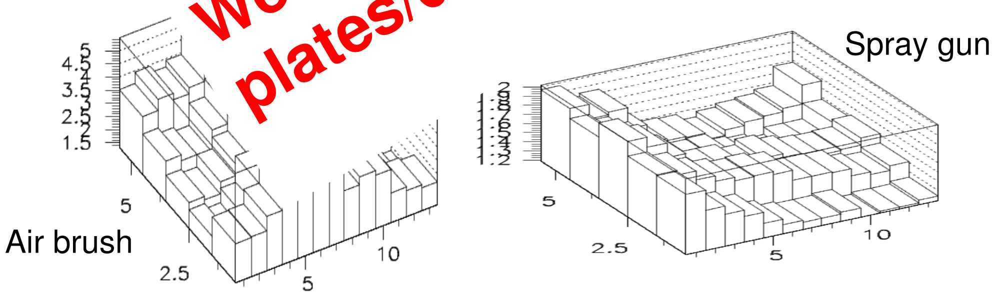
Replaced pneumatic slide with stepper mo
→ significant improvement in uniform

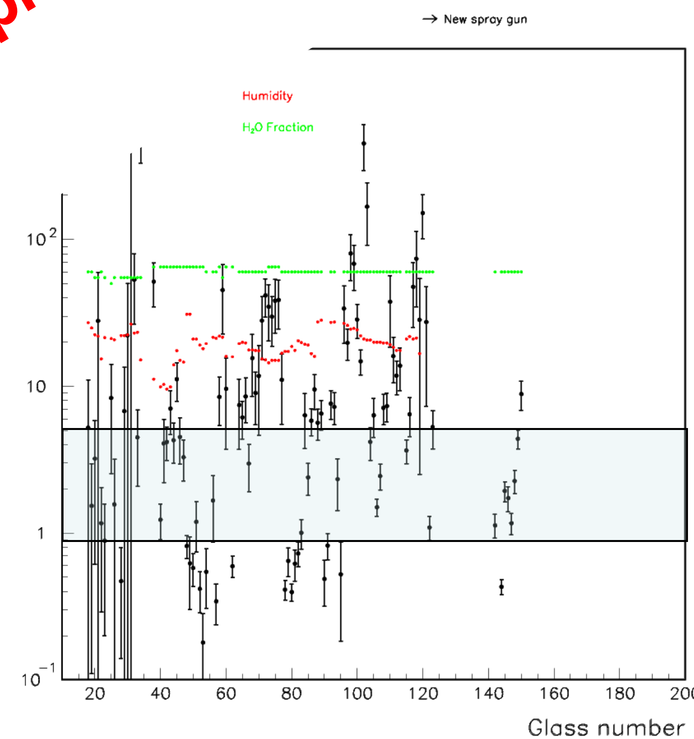
Improvement 2:

Replaced airbrush
→ significant
→ much
→ m ...s)

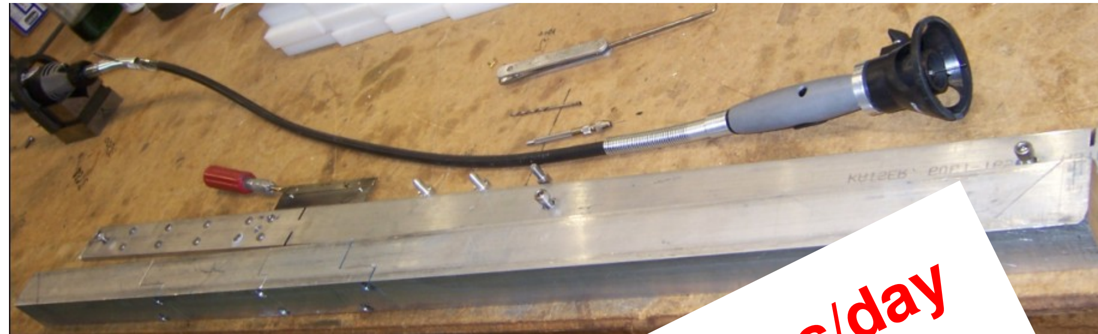
We have achieved our goal of spraying 6 plates/day

Resist





RPC Assembly



Cutting frames

Dedicated (adjustable) cutting fixture
Cut length to .2mm precision
Drill holes

Assembly

Dedicated gluing fixture
Frame/gap glued to ~0.1mm precision
Very time consuming process:
~1 RPC/day/tech, 3 RPC produc

Production

50+ final RPC ... etion
Full spe

We have achieved our goal of producing 3 chambers/day

Quality assurance

1 mil = 25 µm

Pressure tests

Test with 0.3 inch of water pressure
Pass if pressure drop < 0.02 inch in 30 seconds
Chambers not passing 1st test are repaired
All repaired chambers passed 2nd test so far

Gap size measurement

Thickness of all chambers measured along the edges
(since glass is very uniform → measure of gap size)
Gap sizes at edges within 0.1 mm
(central region uniform due to fishing lines)
Corners typically thicker (up to 0.3 – 0.4 mm)
(only affects very small region)

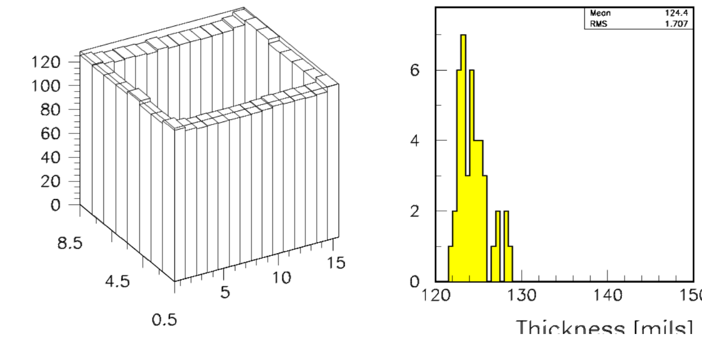
HV tests

Tests up to 7.2 kV before placing readout board on top
(operating voltage is 6.3 kV)

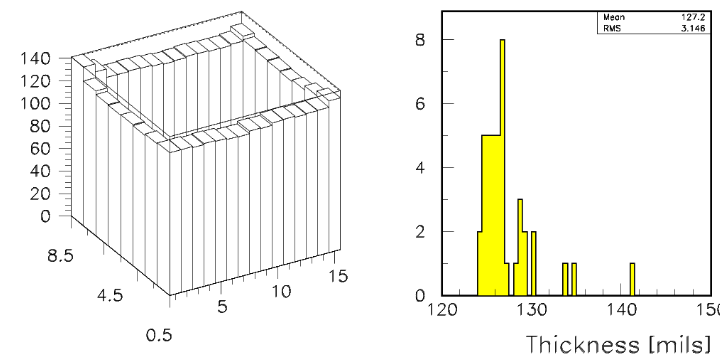
Only 4 rejects so far

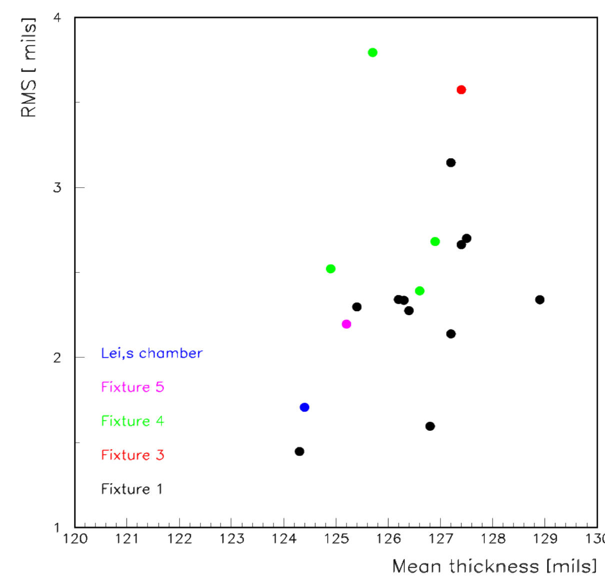
2 with two thick sheets of glass
1 with tubing (around fishing lines) wrong
1 with gas inlet/outlet in wrong place, glass cracked

RPC 001



RPC 012

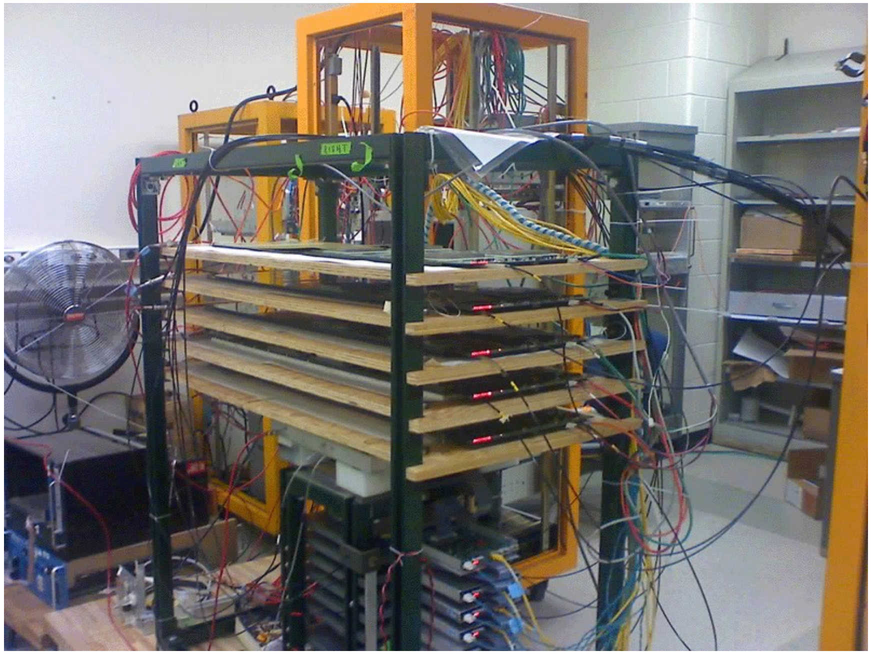




Test of production RPC with full size board

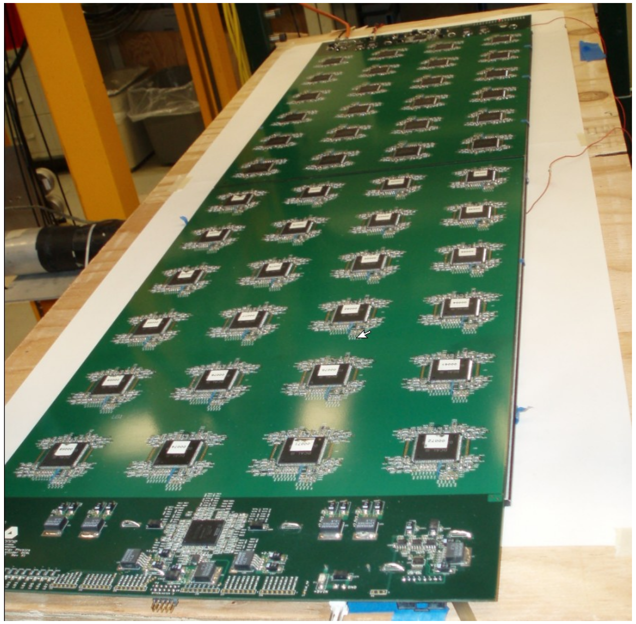
Setup

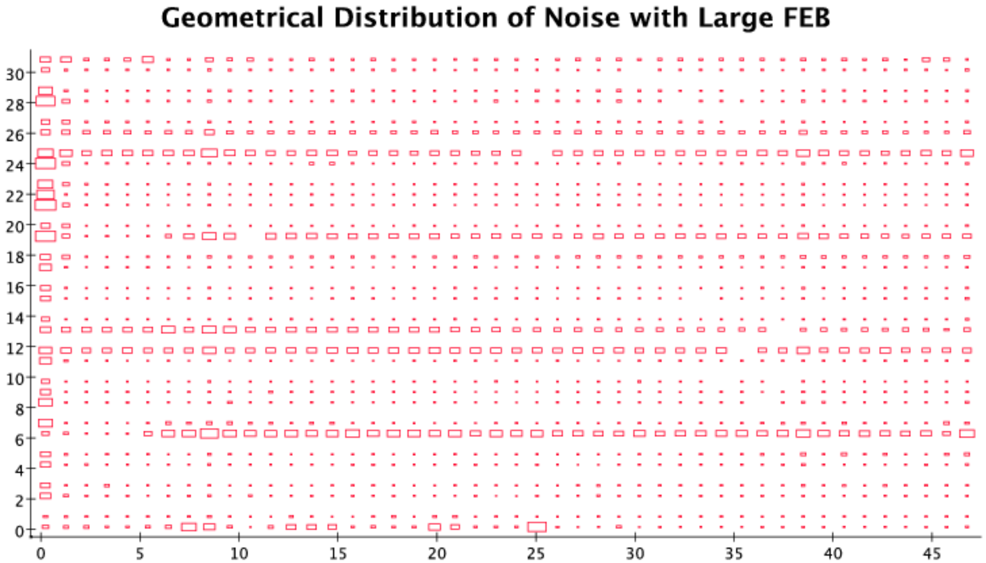
Uses up to 7 small chambers from VST
Currently 5 large chamber with 7 readout boards
Will increase to ~10 large chambers with 20 ROBs
Will be used for RPC/FE board check out



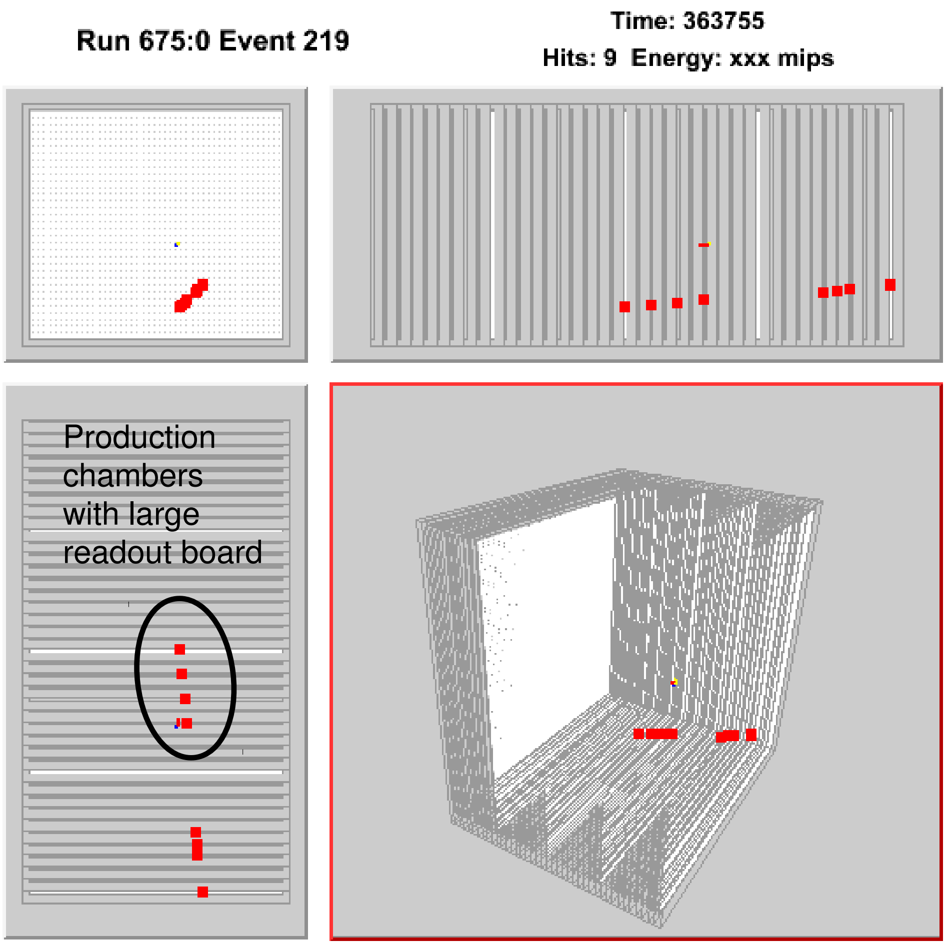
Data taking

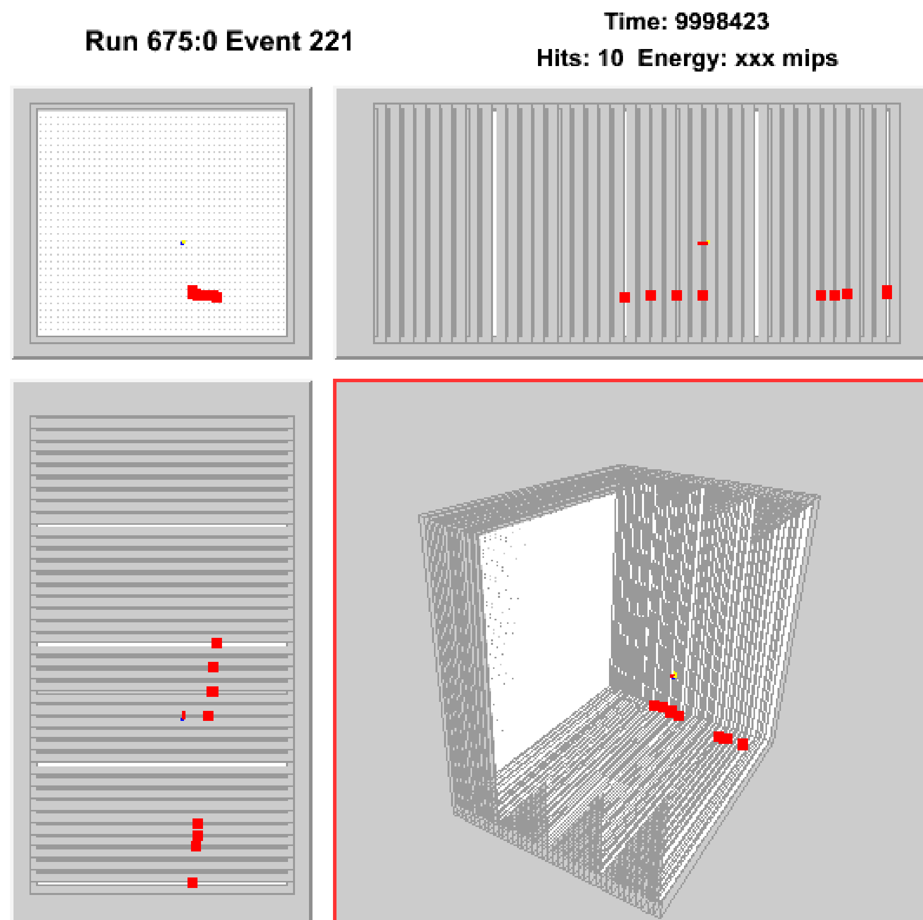
First events on 9/11/2009
Collected large sets of Cosmic Ray/Noise/Q_{inj} runs





Cosmic ray events with single tracks





Cosmic ray data analysis in progress

Cosmic ray test stand

Current issue

Uses scintillator trigger, which only map out 10 x 10 cm^2
Low trigger rate (~10/min)
Takes for ever to map out entire chamber

Planned changes

Remove VST chambers and trigger counters
Expand to ~10 large RPCs
Run in self-trigger (triggerless) mode

Challenges

Need new event builder (rely entirely on timing information of hit pachakges
Find cosmic rays within large volume of RPC noise hits
Worked with VST, should be feasible
Data size ~ 10 GB/day (need timely data processing)

Cassette test stand

Completed cassettes to be inserted into hanging file structure for additional tests
Expect to run in self-triggered mode

Cassettes

Purpose

Protect RPCs, cool front-end ASICs, compress RPCs/FE boards

Design

1 x 2mm copper sheet + cooling tube on top
1 x 2mm stainless steel sheet

Will fit into CALICE Analog HCAL structure
Uses nylon strings to compress the two sheets

Prototypes

First one built with all final dimensions
Tested out with 3 RPCs and 6 FE boards
Assembled again with 3 RPCs and 6 mock-up boards
Inserted into the CALICE Analog HCAL absorber structure

Assembly

Not expected to be labor-intensive

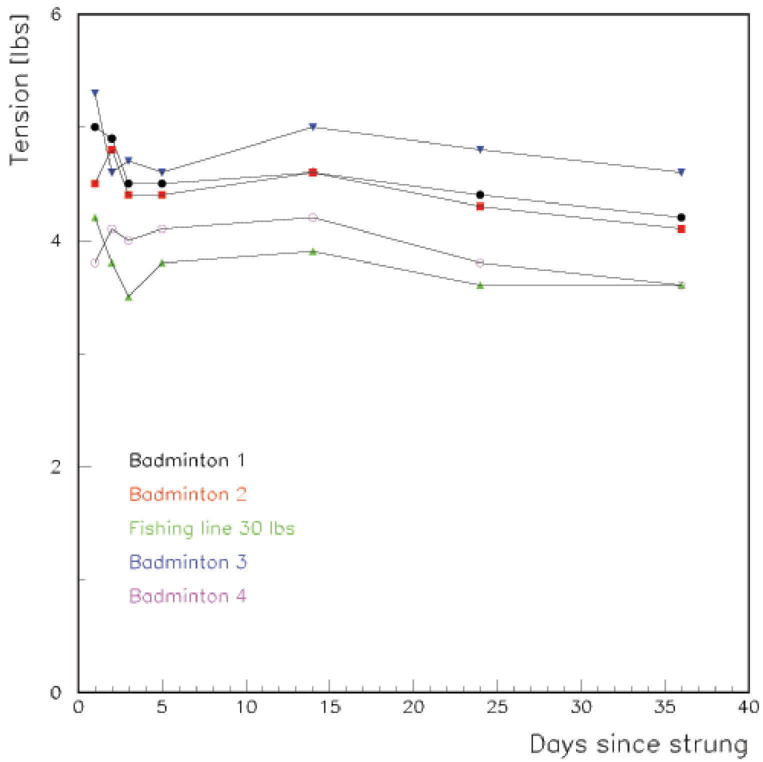
Cassette design: press two plates together

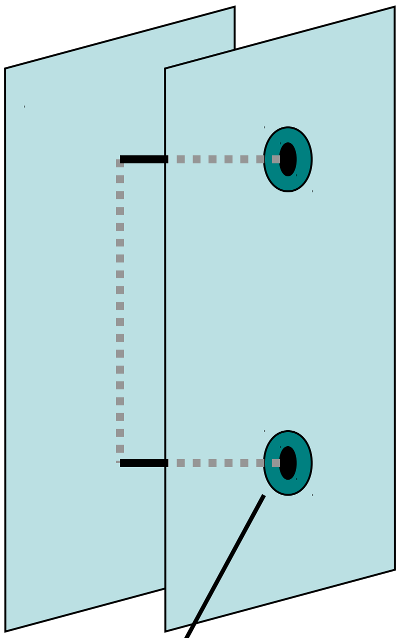
Compression needed

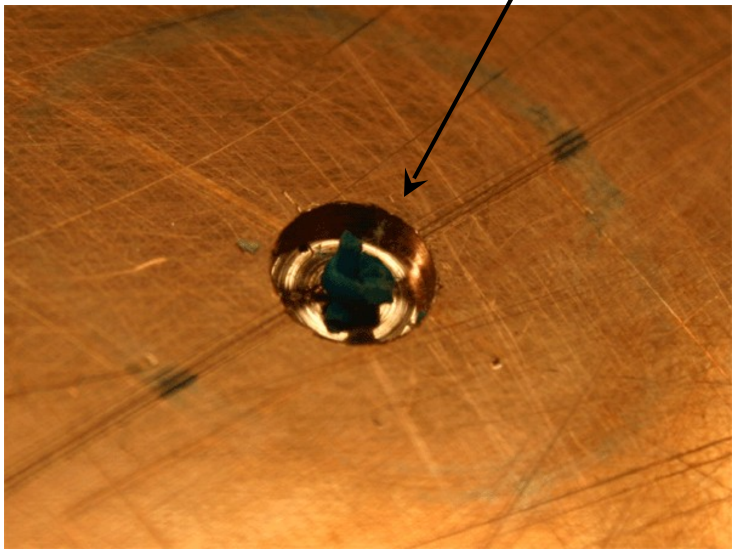
To ensure good thermal contact with ASICs
To ensure good contact between RPCs and pad boards
(minimizes pad multiplicity)

Solution

Use tensioned string between plates
Several candidate strings tensioned to 4 - 5 pounds
No significant drop over 30 days







Peripherals

Gas

Mixing rack – done
Distributing rack – almost done
- Recently decided not to expand old rack
- Parts for a new rack (partially) arrived
- New rack assembly in progress

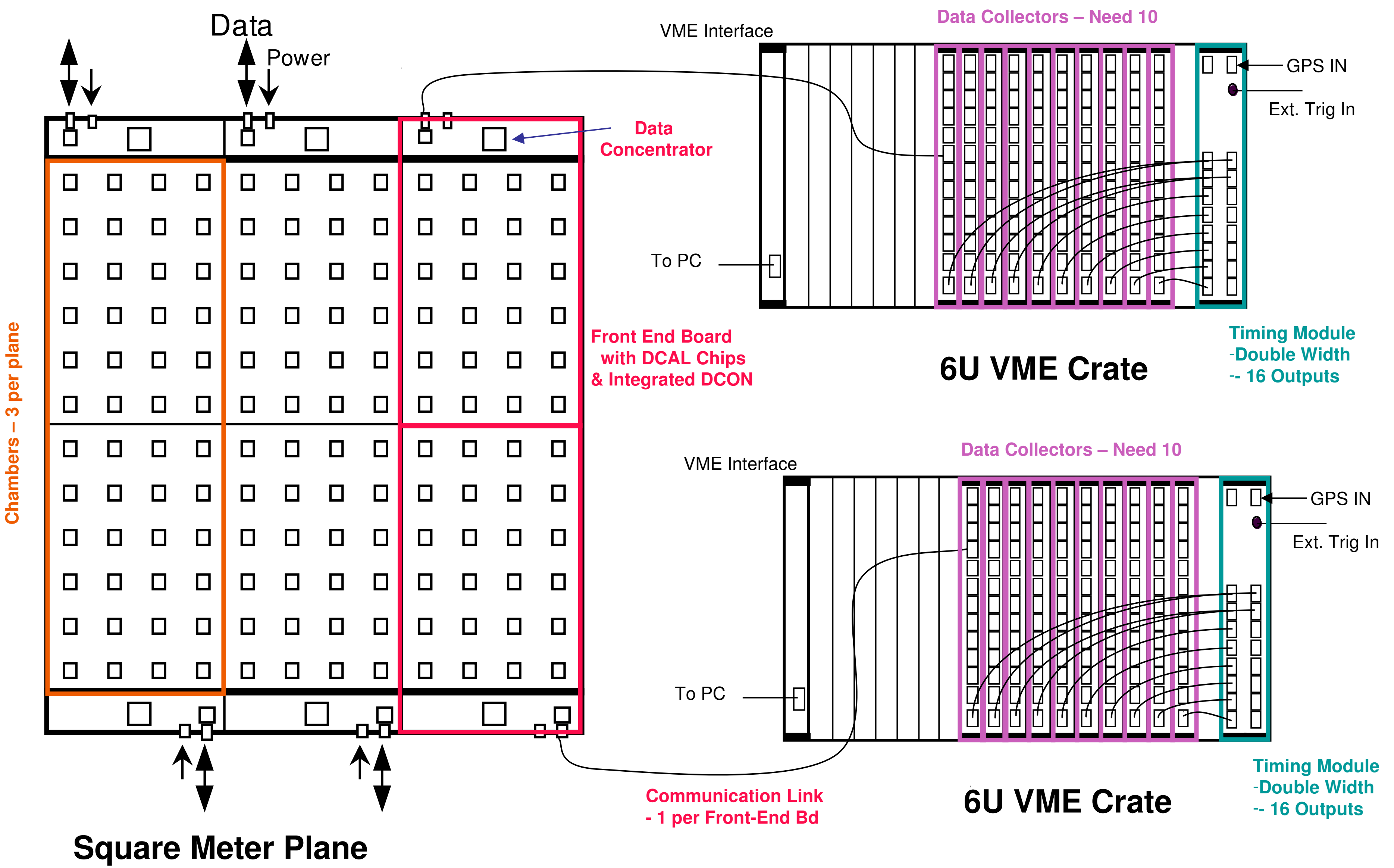
Low Voltage

7 Wiener power supplies in hand
1st distribution box built and in use
Torture tests at full load (8 FE boards) successful

High Voltage

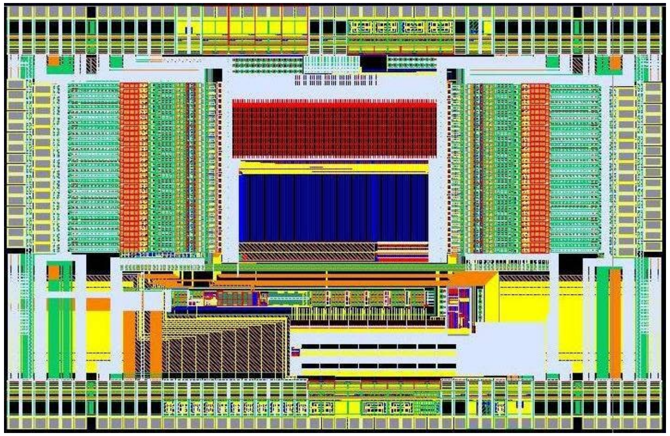
Units in hand
Computer control programs commissioned

Readout system overview



Square meter plane with Readout boards

The DCAL Chip

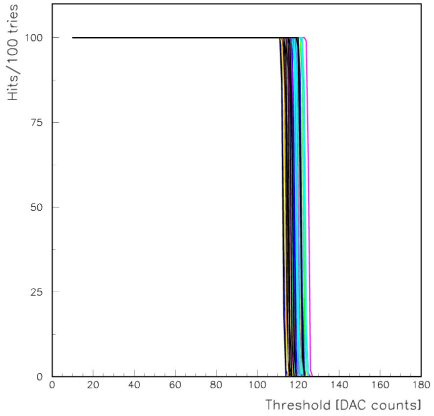


Developed by

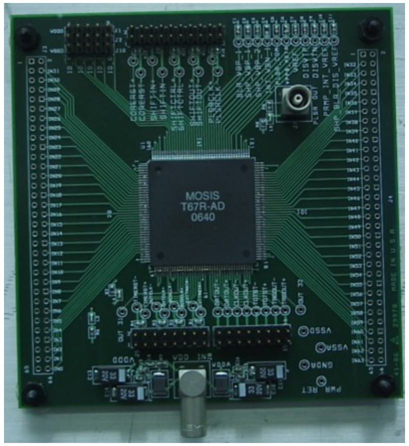
FNAL and Argonne

Input

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



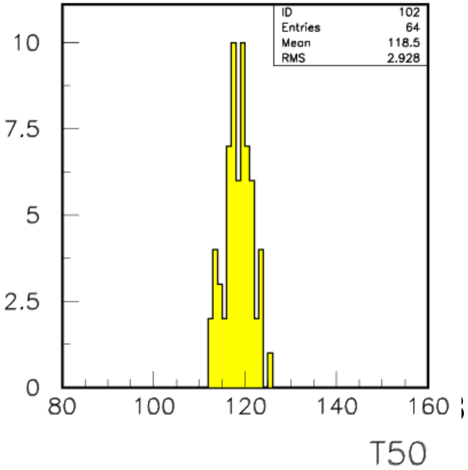
Threshold



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)

Status of DCAL Production

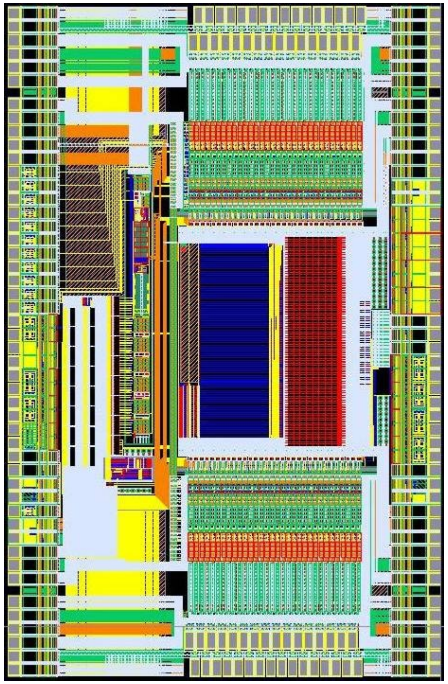
Chip fabrication

11 wafers, 10,300 chips fabricated and packaged

Chip testing

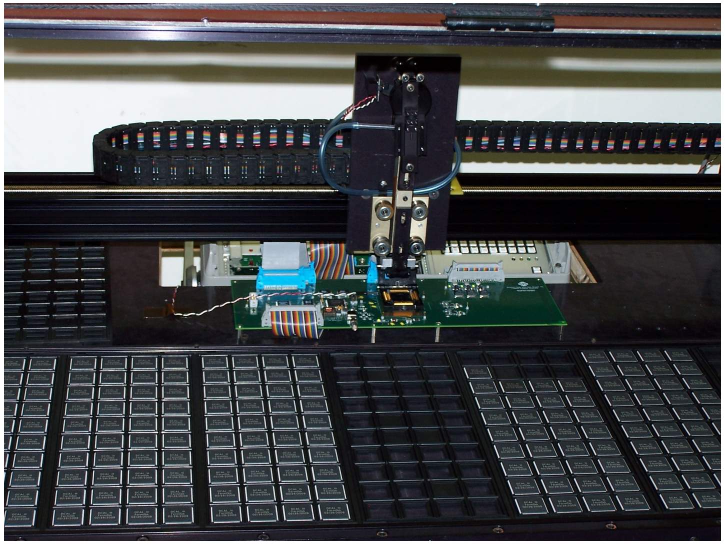
Extensive tests on a small number of chips at Argonne
Robotic test of all chips at Fermilab

→ 8644 good parts = 84% yield
(need 5472 for cubic meter)



DCAL3 Layout

Fermilab

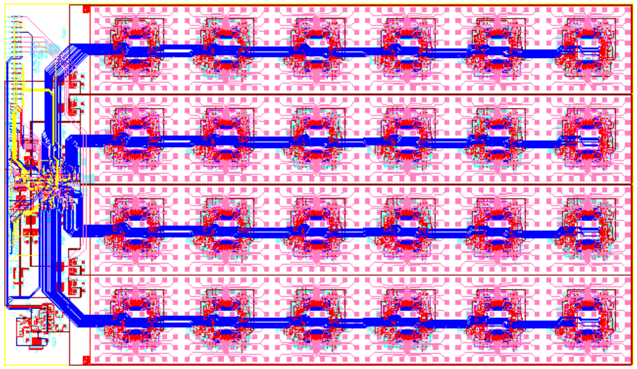


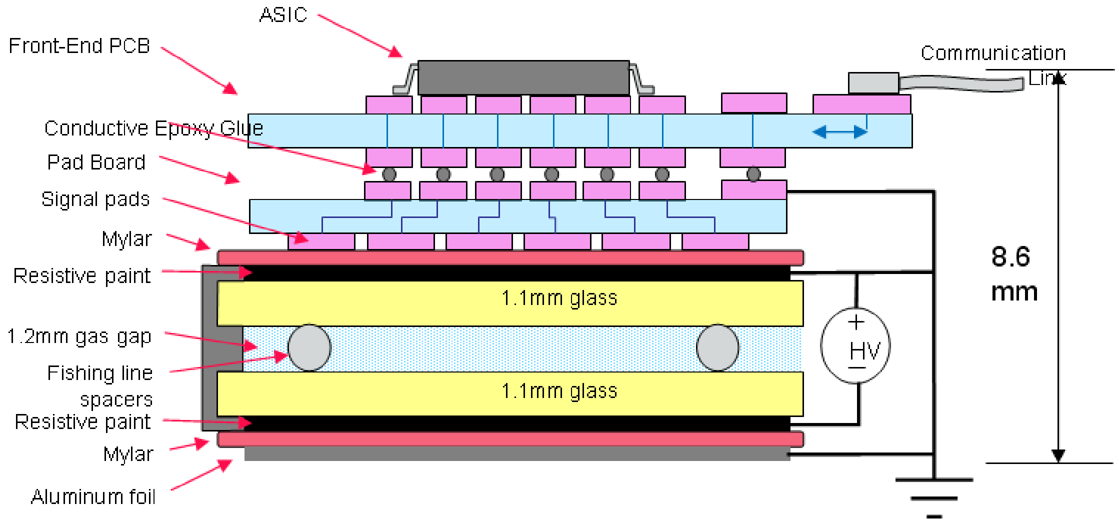
Robotic Chip Tester

Chip Storage (~1/2 total)

⇨ ***Complete***

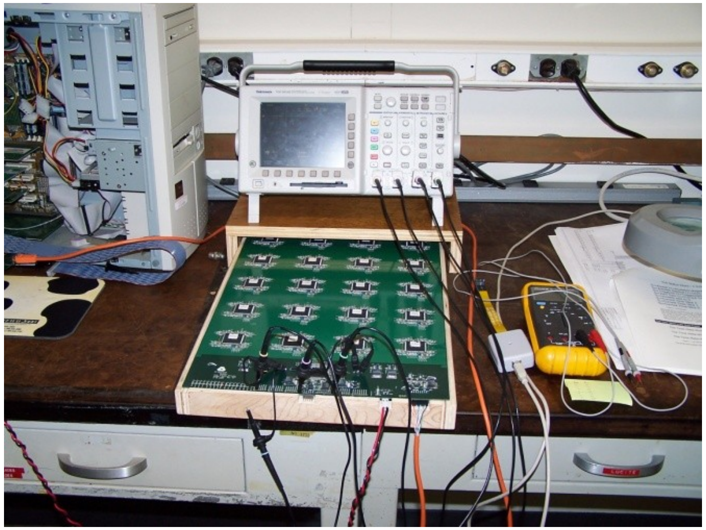
Readout Board





Pad- and Front-end board + Data concentrator = Readout board

Built Pad- and Front-end boards separately
This avoids blind and buried vias (cost and feasibility)
Boards connected with conductive epoxy



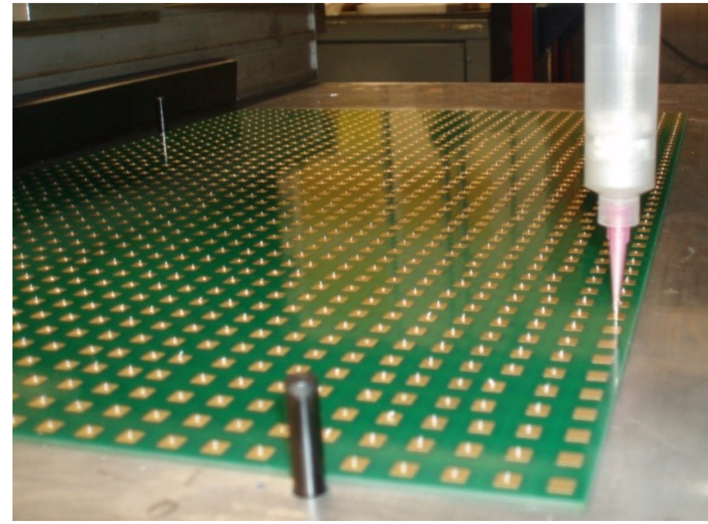
Status

9 boards built and checked in 4 versions
8 boards glued and tested with RPCs

→ Torture tests: operation 100% error free
→ Data concentrator firmware finalized
→ 300 Boards being fabricated (expected back soon)

Gluing fixture for Pad- and FE-boards

Challenge: 1536 glue dots in less than 3 hours



Fixture

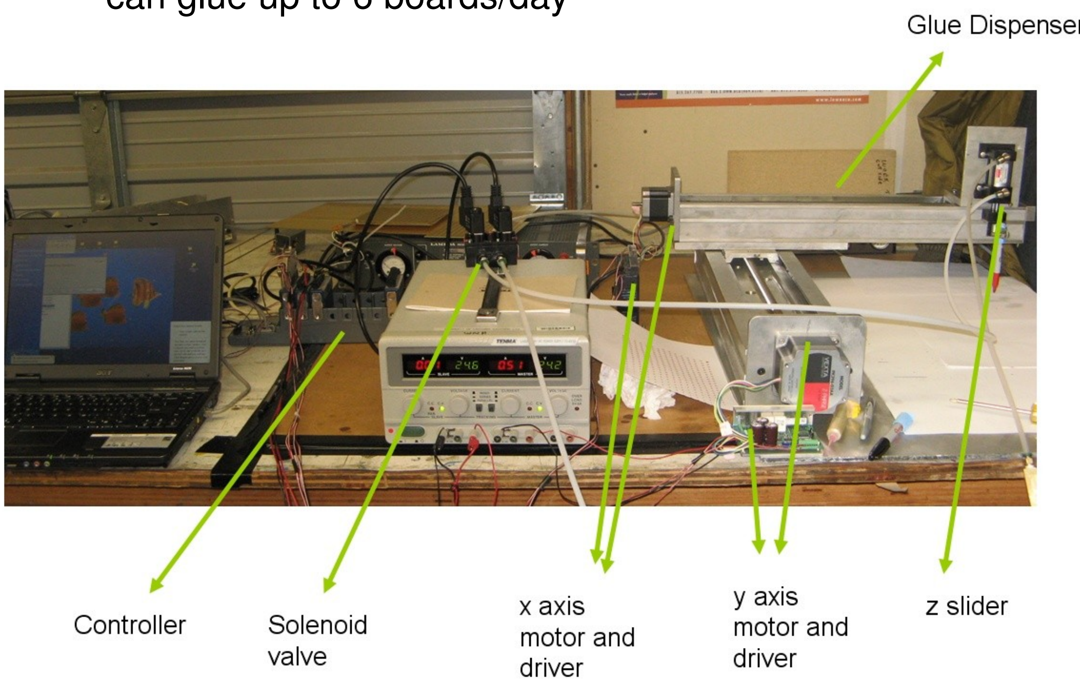
Designed, built and commissioned

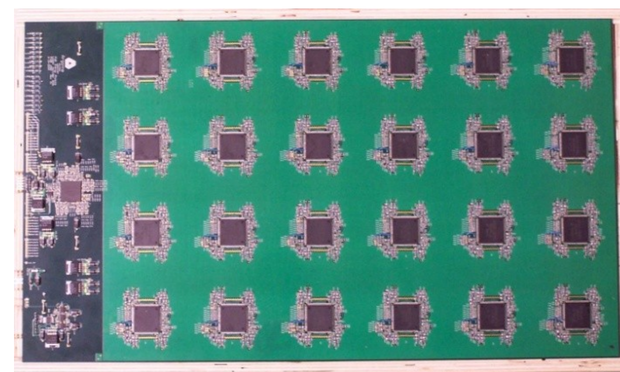
Practice

Glued 8 full size boards successfully

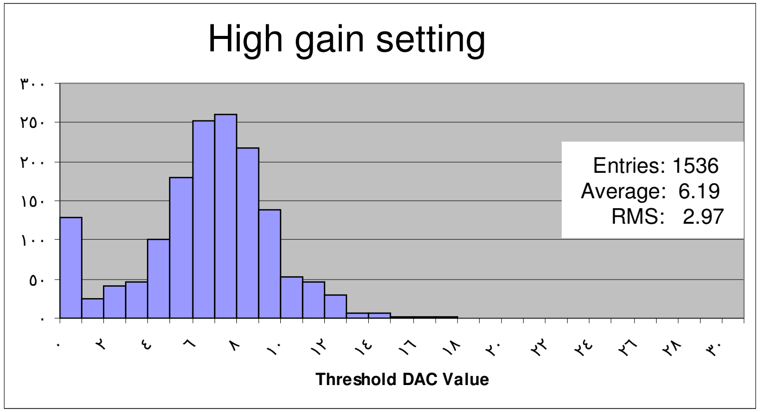
Production

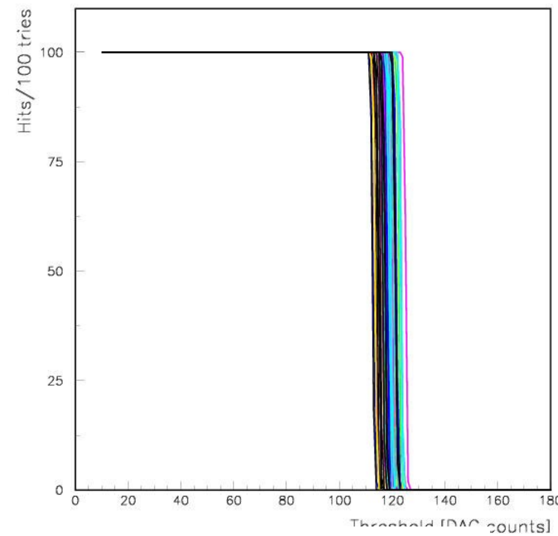
~55 minutes needed/board
can glue up to 6 boards/day



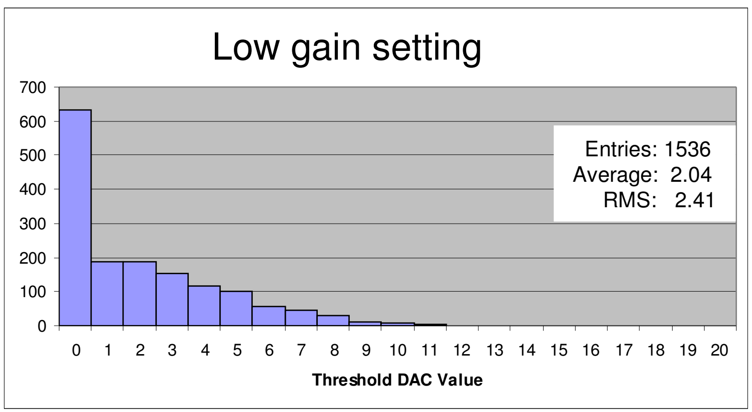


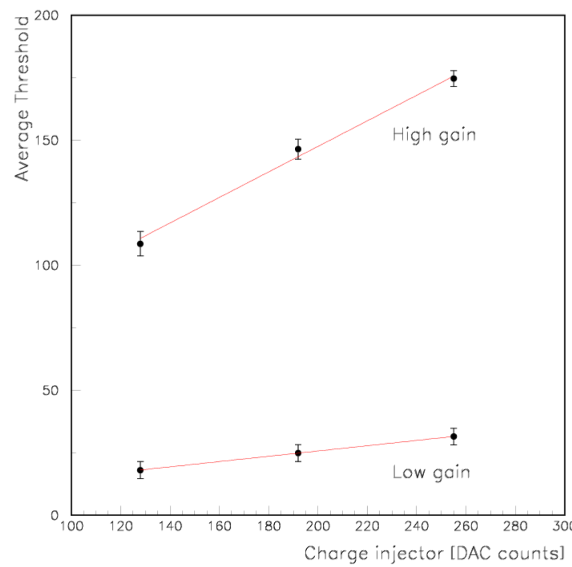
Measurement of electronic noise floor





Channel Uniformity
for Threshold Scans





High Gain:
~0.3 fC / THR_DAC_CNT
→ 75 fC Range

Factor of 6.4

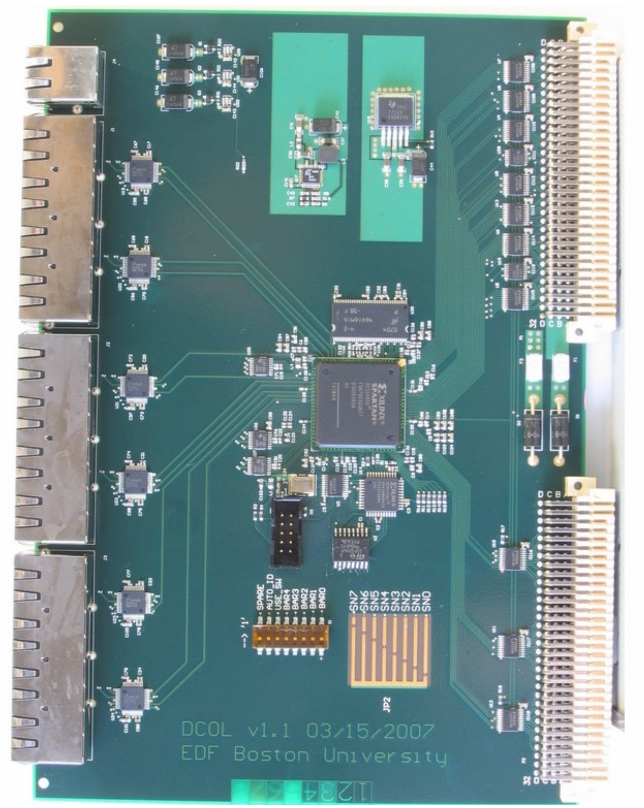
Low Gain:
~1.9 fC / THR_DAC_CNT
→ 480 fC Range
→ Operate ~ 190 fC for RPC

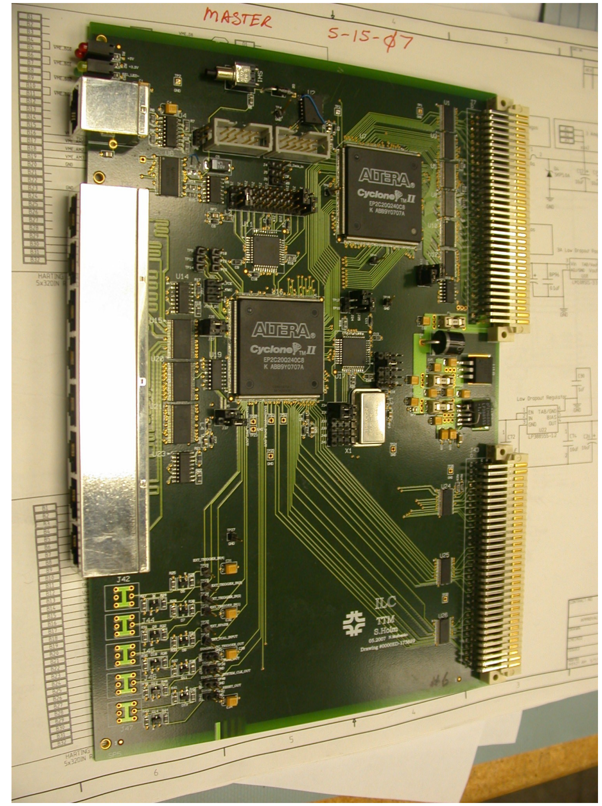
Measurements of Noise Floor
Single channel measurements,
Ext. Trig,, No Pad Bd, No Chamber, No HV
Entire Front End Board, 1536 Channels

Back-end readout

Data Collector (DCOL)

30 produced (20 needed for cubic meter)
Testing 75% done
Firmware finalized





Timing and Trigger Module (TTM)

Redesign

1 Master and Slaves (in different crates)
Added outputs 8 → 16
Design finalized

10 being fabricated (3 needed for cubic meter)

Software

Online software

Based on CALICE system
Development 99% complete
Ready to integrate with CALICE Silicon – W ECAL and TCMT

Event builder

Somewhat tricky: sort data for maching timestamps
Java version operational in Cosmic Ray test stand
New C++ version being developed
Implementation of analysis of trigger-less Cosmic Ray data

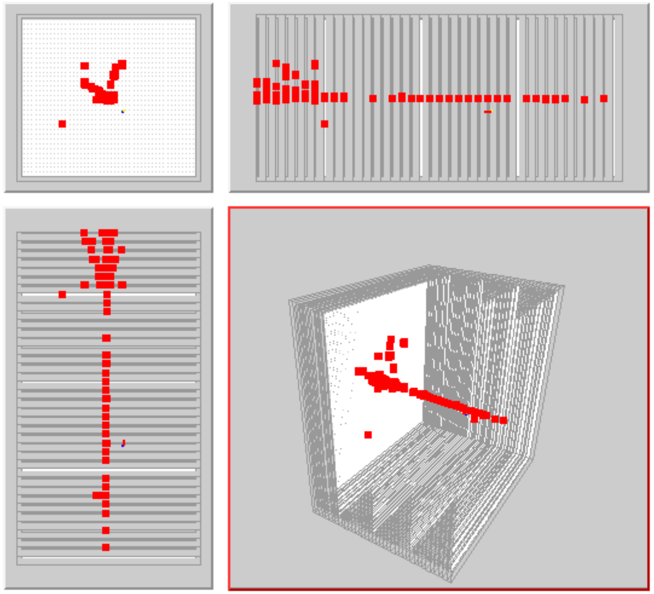
Event display

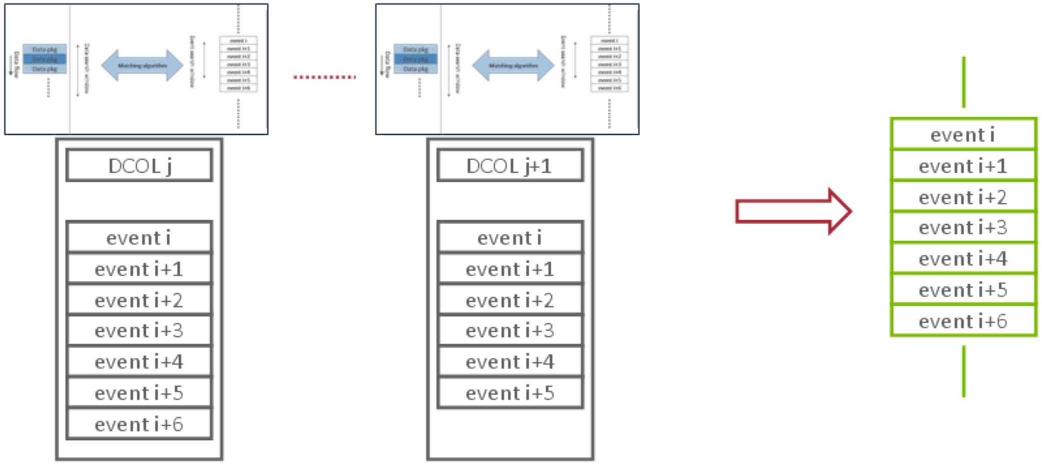
Ready

MC simulation

Simulation of cubic meter in GEANT4
Now implementation into MOKKA
Will keep standalone RPC simulation

Event display of simulated 60 GeV π^+





Physics prototype plans

Task	Dates	Comments
Construction	Complete by June 30th	Should not slip much more…
Cosmic ray testing of cubic meter	April through August	
Installation into Mtest	in September	
1st data taking period	October	DHCAL standalone (with TCMT)
2rd data taking period	December	Combined with ECAL
3rd data taking period	Early in 2011	DHCAL standalone or combined
Disassembly and shipping of stage	March 2011	Hard deadline

Officially on Mtest schedule

Maybe not so hard