Construction and Operation of DHCAL prototype @ Fermilab Test Beam Facility

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1 m^3 – Digital Hadron Calorimeter Physics Prototype

Description

Readout of 1 x 1 cm^2 pads with one threshold (1-bit) → **Digital Calorimeter**
38 layers in DHCAL and 14 in tail catcher (TCMT), each ~ 1 x 1 m^2
Each layer with 3 RPCs, each 32 x 96 cm^2
~480,000 readout channels
Layers inserted into the existing CALICE Analog (scintillator) HCAL and TCMT structures

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

Finally, DONE! (produced 38+14 layers)

Collaboration and Responsibilities

Task	Institutes
Project coordination	Argonne
RPC construction	Argonne
Cassette structure	Argonne
Mechanical structure	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, Argonne
DAQ Software	Argonne, CALICE
High Voltage system	Iowa
Low voltage system	Argonne
Gas mixing and distribution	Iowa
Cables	Argonne, Iowa
Data analysis	Argonne, FNAL, IHEP, Iowa, McGill, Northwestern, UTA

DHCAL Personnel	Heads
Engineers/Technicians	22
Students/Postdocs	8
Physicists	9
Total	39

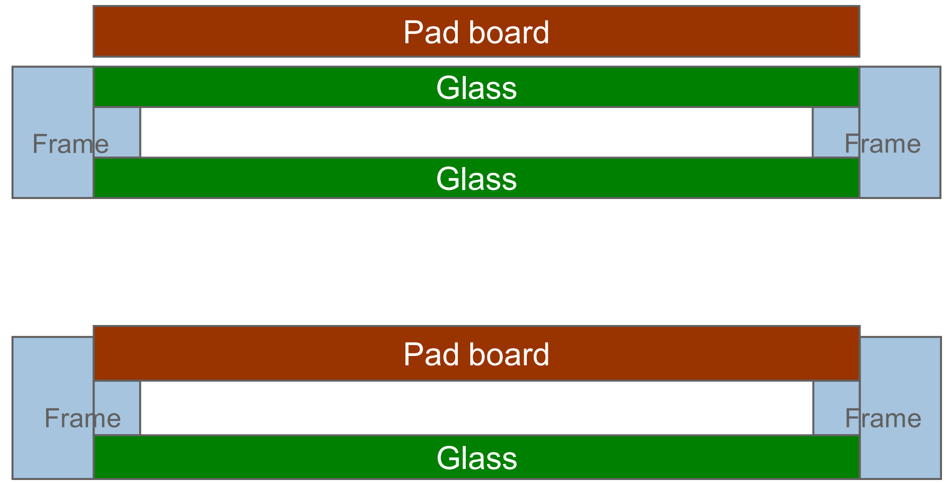
Outline

- RPC construction and testing
- Readout system fabrication and testing
- Cassette assembly and cosmic ray test
- Peripherals
- Operation at Fermilab test beam

RPC Construction

RPC design

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

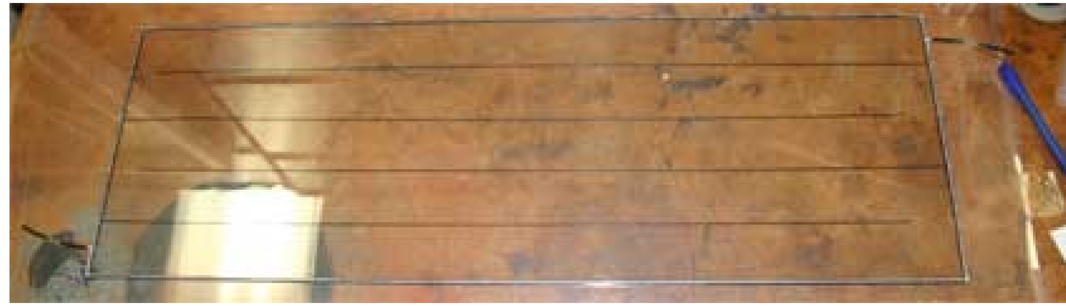


Chambers needed

~114 for DHCAL + 42 for TCMT + spares
at the end, produced ~ 205 RPC's

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 $R_\square = 1 - 5\ \mathrm{M\Omega}$

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

New paint (artist paint) identified

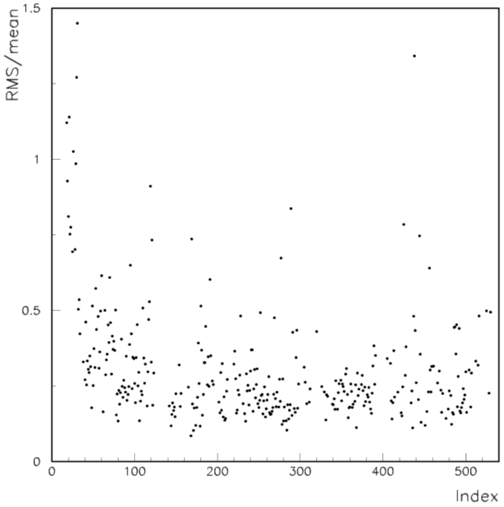
Reasonably cheap
Non toxic
2 component mixture (BLACK and GREEN)
Needs to be sprayed (built a spraying booth)

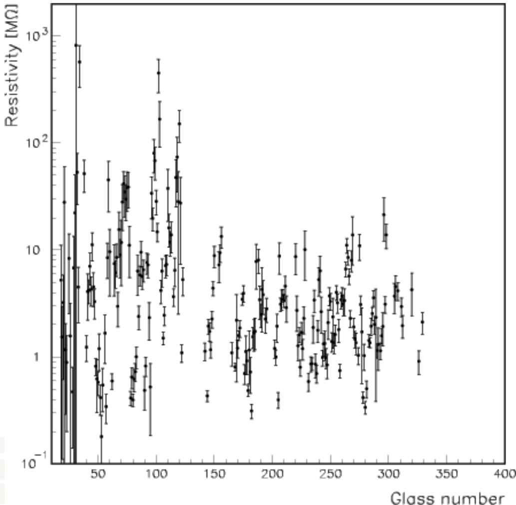
Production

Has been a struggle

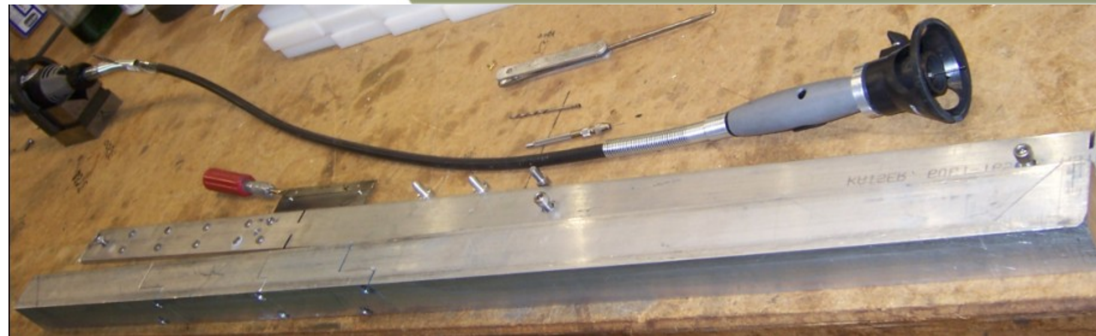
Poor uniformity in a single plate
Mean value not well controlled from plate to plate
Low yield: ~ 60% pass quality cut
Slow – barely match RPC assembly speed

at the end, it worked out





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 produced/day

Production

205 final RPC completed
only ~10 not usable
(due to glass broken or quality issues)

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

- Had ~5 leaking RPCs at the test beam (some due to glue damage

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)

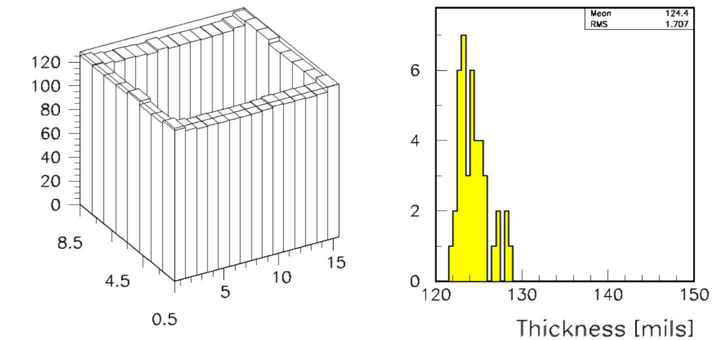
> Only ~5 RPC's have low efficiency regions at corner(s) or along side(s), due to larger gap at those places, all replaced from prototype stack

HV tests

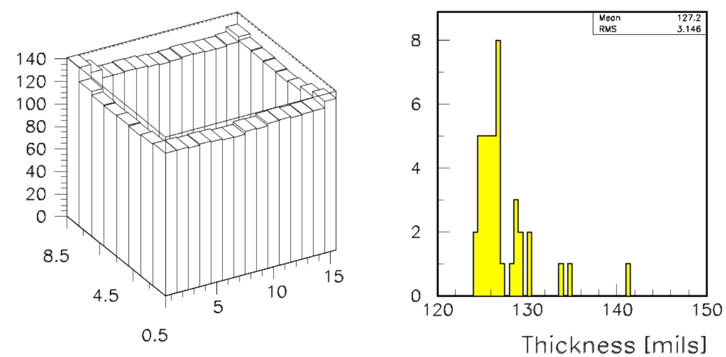
Tests up to 7.0 kV before placing readout board on top
(operating voltage is 6.3 kV)

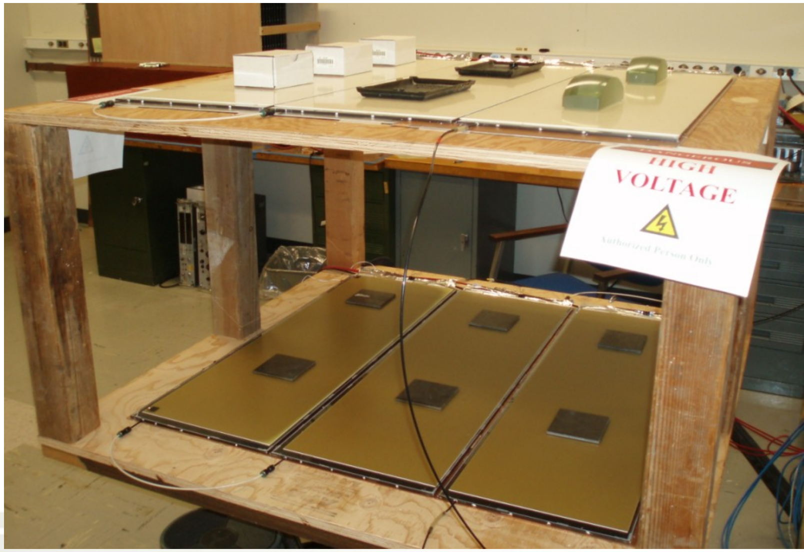
> NO HV issues at test beam, due to RPCs

RPC 001



RPC 012





Cosmic Ray Test Stand I

(for first chambers)

Chamber characterization using cosmics and noise

Testing of early FE board versions

Test stand

Up to 9 RPCs tested at once

Operation of RPCs

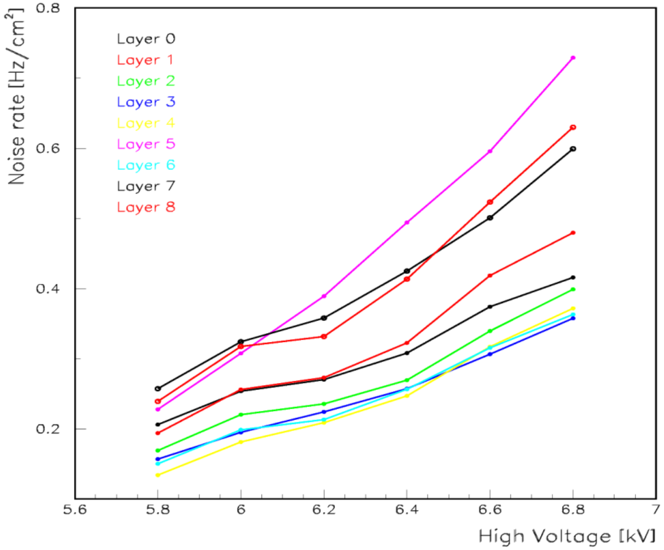
High voltage scans from 5.8 to 6.8 kV

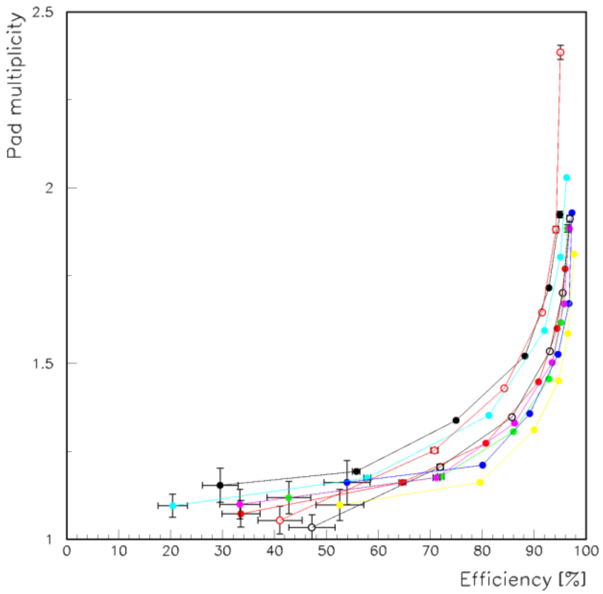
Data taking

noise and cosmics

Triggered, trigger-less operation

Triggered Data: Standard tests

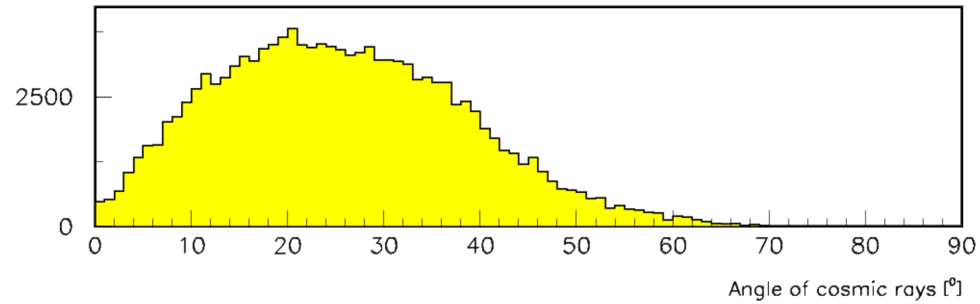


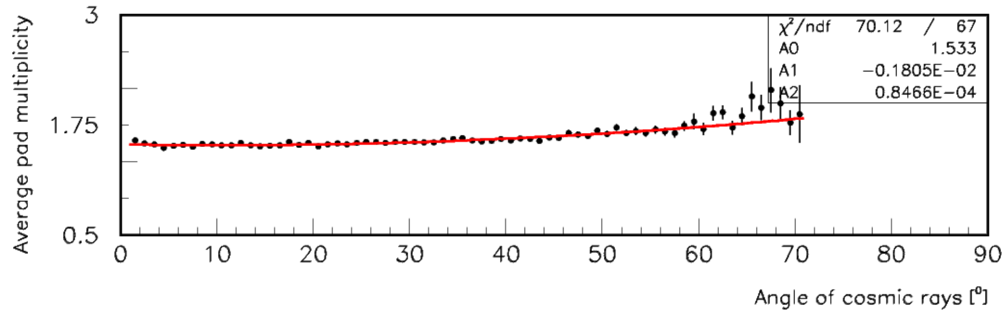


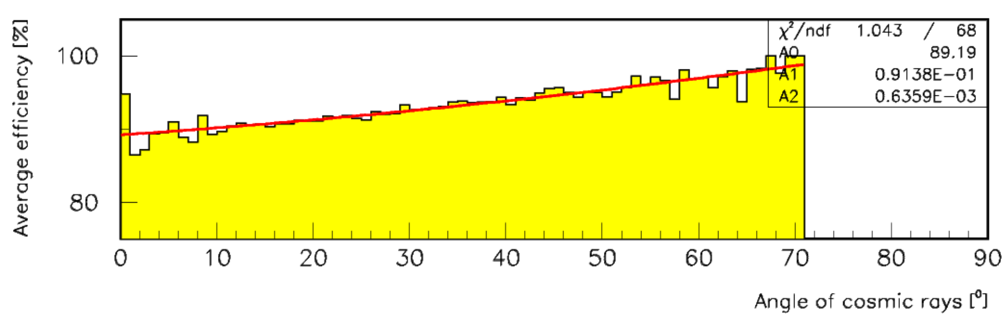
Trigger-less Mode

Analyze Cosmic Rays

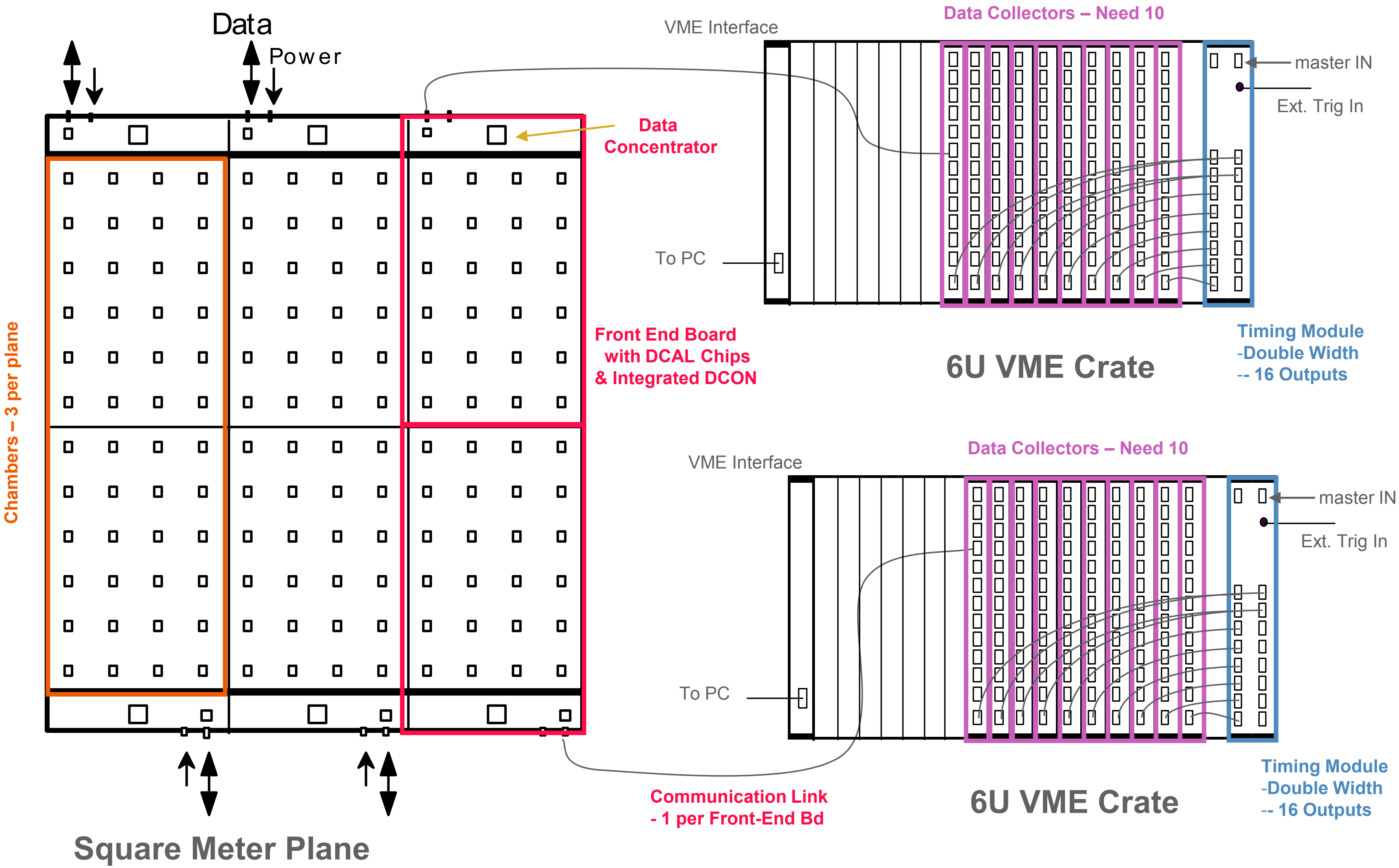
Angle of Incidence Dependence!



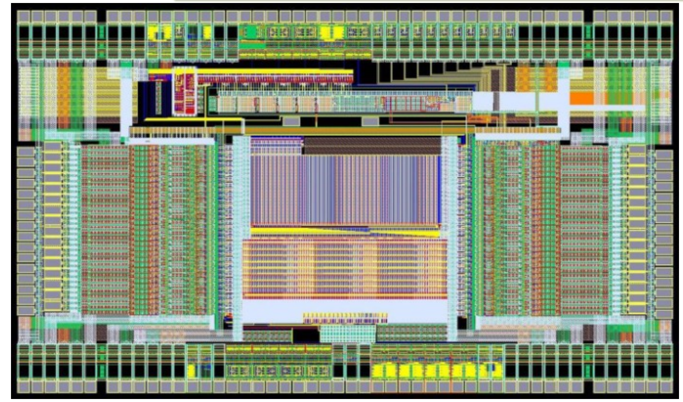




2. Readout system overview



The DCAL Chip

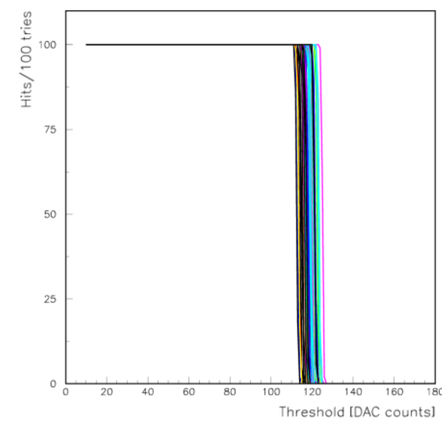


Developed by

FNAL and Argonne

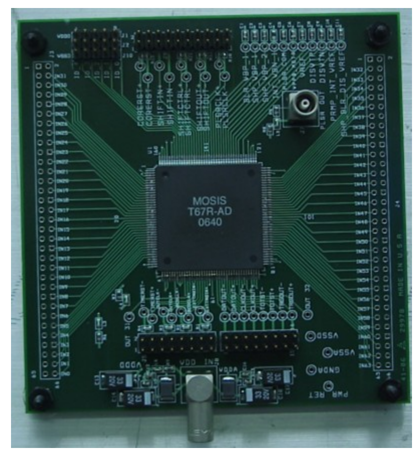
Input

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



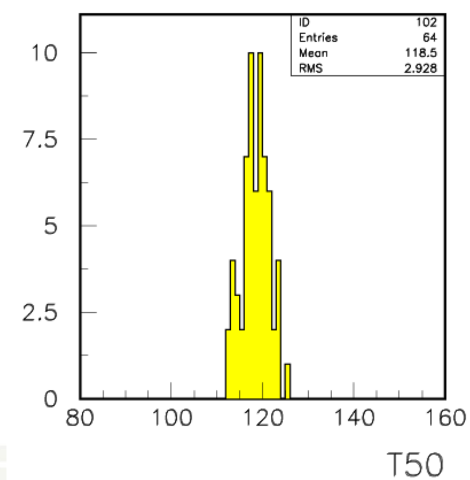
Threshold

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



Readout

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



Versions

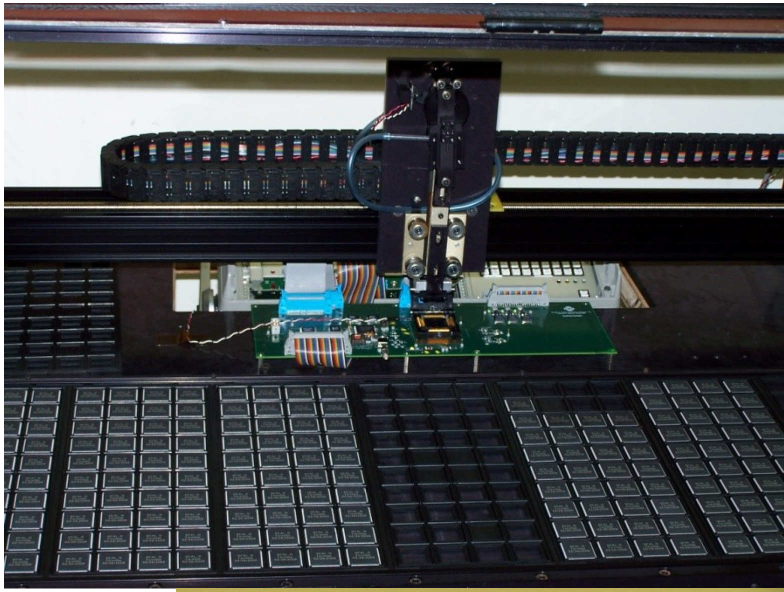
DCAL I: initial round (analog circuitry not optimized)
DCAL II: some minor problems (used in vertical slice test)
DCAL III: no identified problems (final production: used in current test beam)

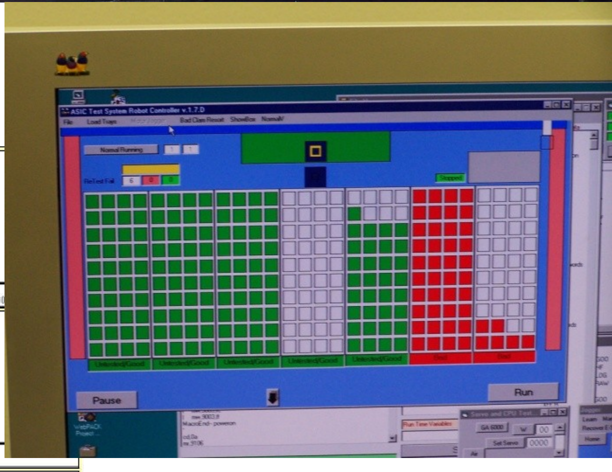
Production of DCAL III

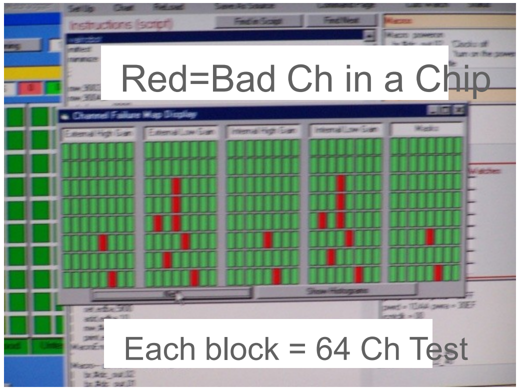
11 wafers, 10,300 chips, fabricated, packaged, tested

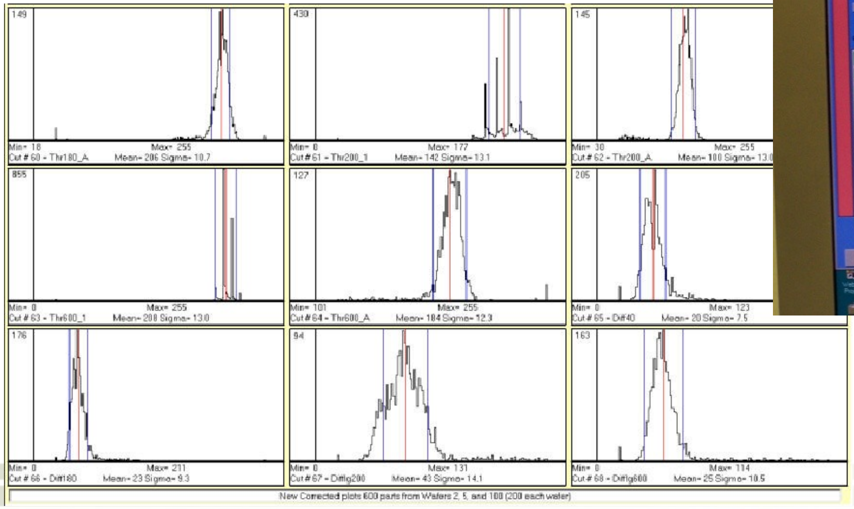
DCAL III testing at Fermilab

- Fermilab Chip-Testing Robot
  - 78 parameters measured per chip
  - Test mode:
    - No cuts applied, Measure parameters
  - Checkout mode
    - Apply cuts, Robot sorts
  - Robots sorts good chips & bad chips into trays
  - ~1 minute per chip, ~400chips/day
- Result:
  - Yield 84% in single pass
  - Scanned the ‘bad’ chips again with loose cut to recover more chips (only need 5472 for the $1m^3$ and 1872 for the TCMT)

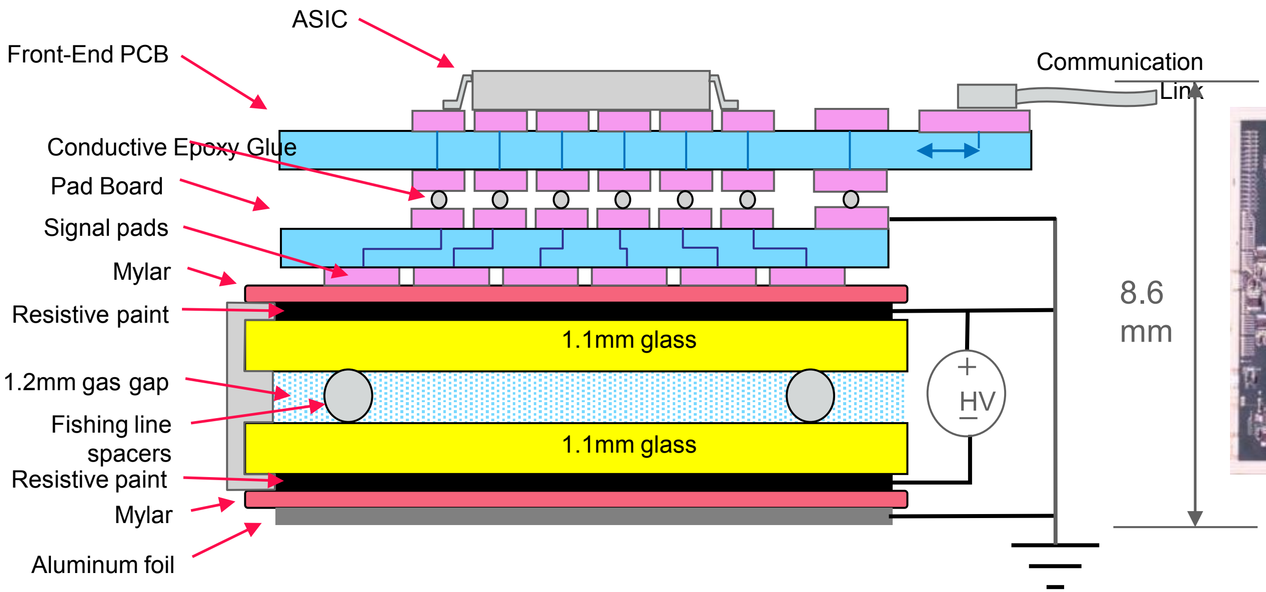


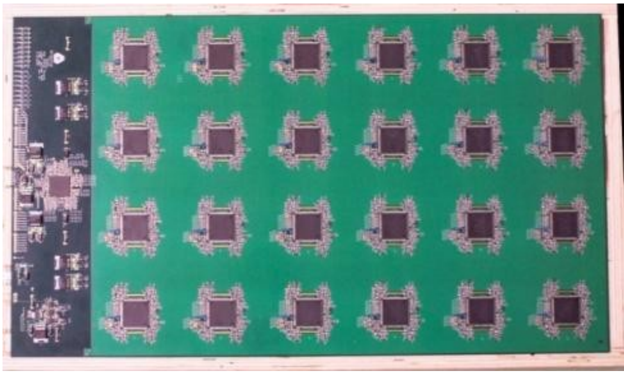




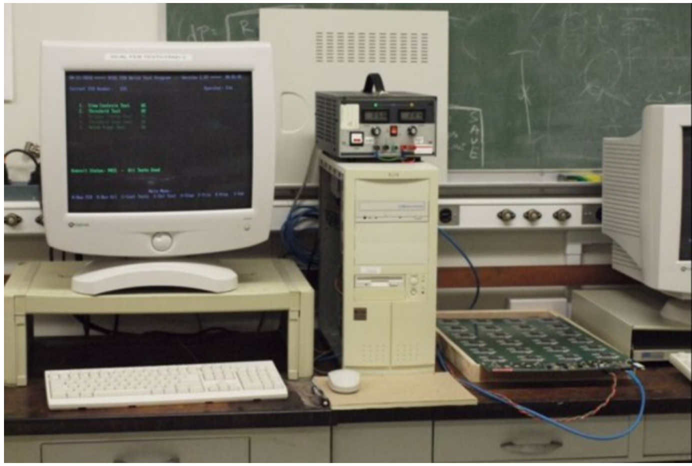


FrontEnd/DCON board + Pad board



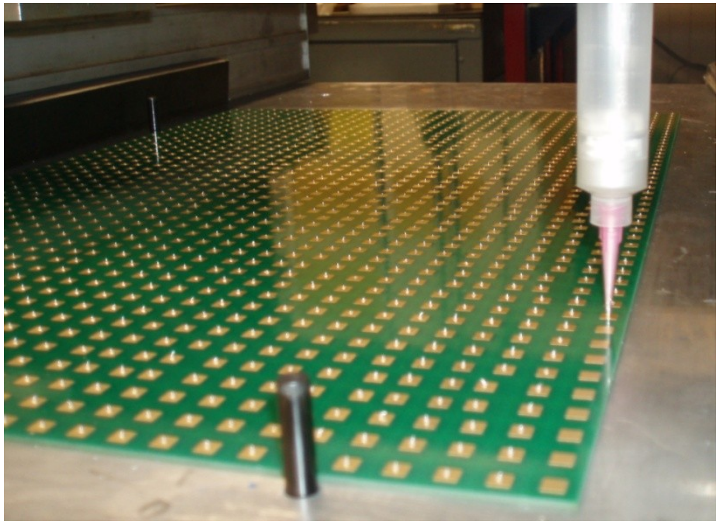


- Build FE and pad boards separately to avoid blind and buried vias (cost and feasibility issue)
- Each board contains 1536 channels and 24 ASICs
- The data concentrator is implemented into the same board
- Glue the two boards together with conductive epoxy
- FE board need to pass computer test before gluing
  - Extensive tests (S-curves, noise rates…)
  - 3 – 6 hours/board
  - Accepted boards with less than 4/1536 dead channels



Gluing fixture for Pad- and FE-boards

Goal:1536 glue dots in less than 3 hours



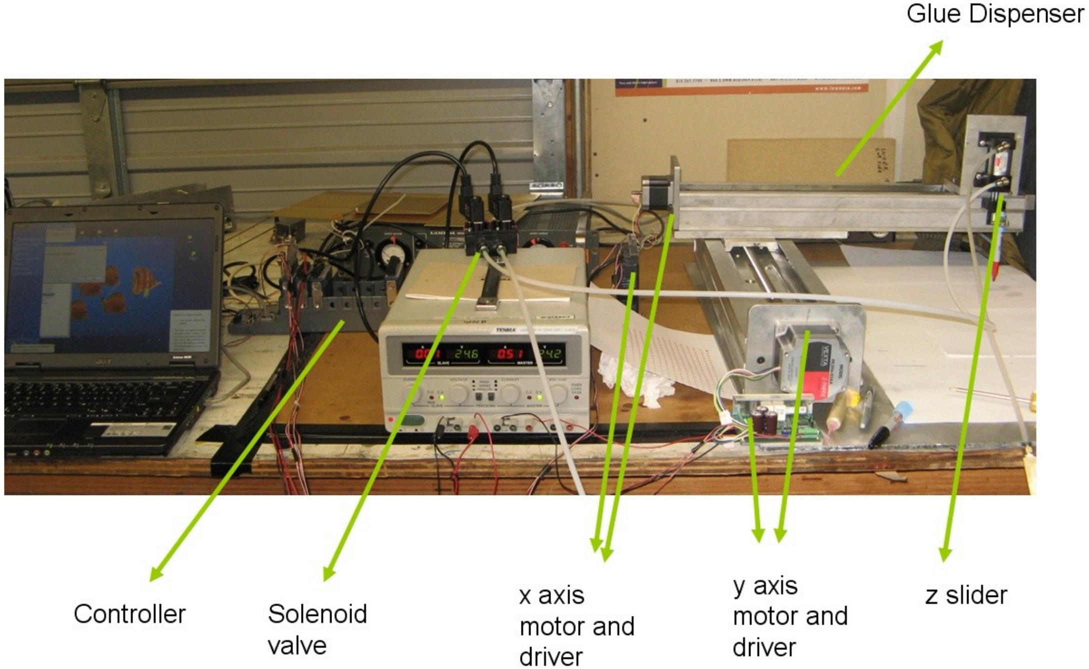
Fixture

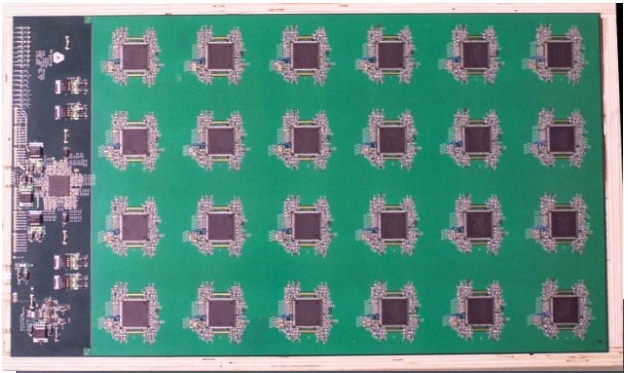
Designed, built and commissioned

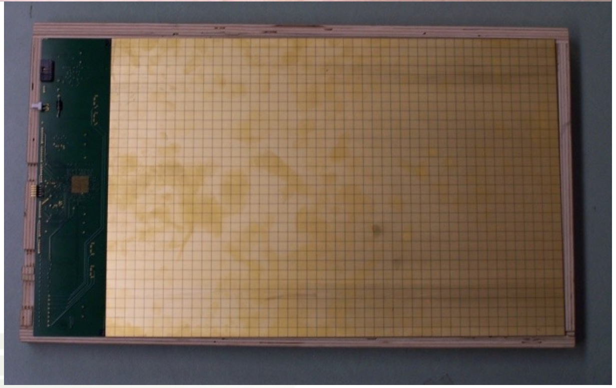
Production

~25 minutes needed/board
can glue > 10 boards/day

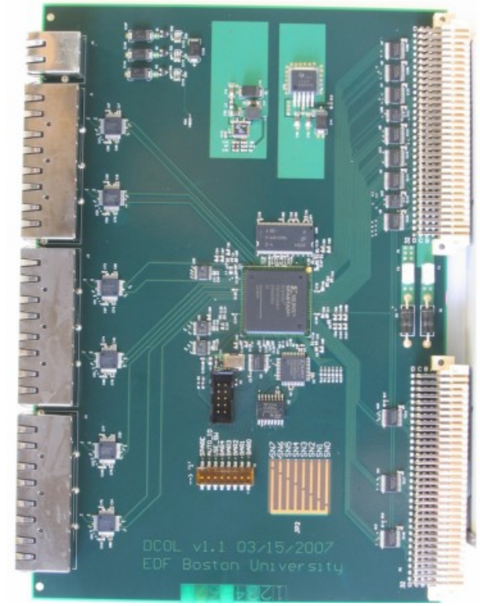
at the end: 300+ FE board fabricated/tested/glued







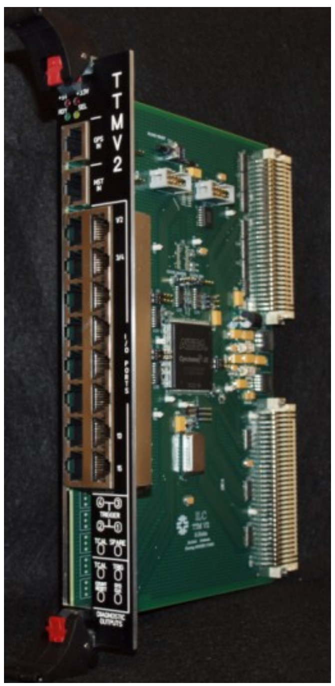
Data Collector Modules



1 Data Collector Module per 12 front-end boards
Need 20 for DHCAL and 8 for TCMT

Designed, built and tested at Boston

BOSTON UNIVERSITY



Timing and Trigger Module

Fermilab

Master TTM controls to up to 16 Slaves
Slave TTM controls up to 16 Data Collectors
Need 1 Master and 2 Slaves for DHCAL+TCMT

Designed and tested at FNAL

Cassette assembly I

Design

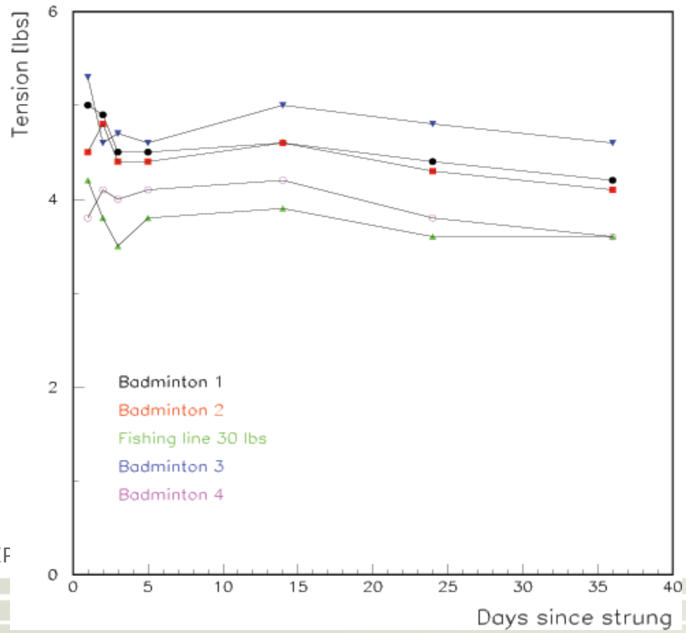
1 x 2mm copper sheet on readout side, in contact with ASIC packaging
1 x 2mm stainless steel sheet on RPC side

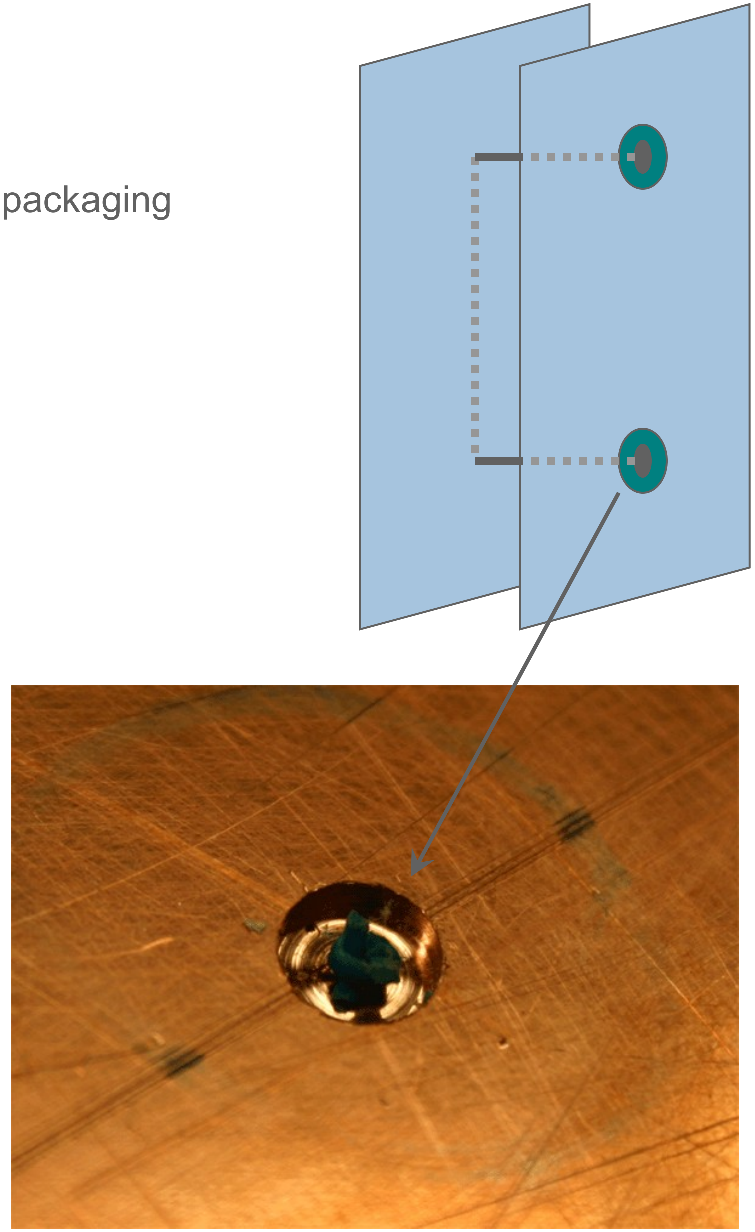
Compression needed

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 tested with 4 - 5 pounds tension
No significant drop over 30 days





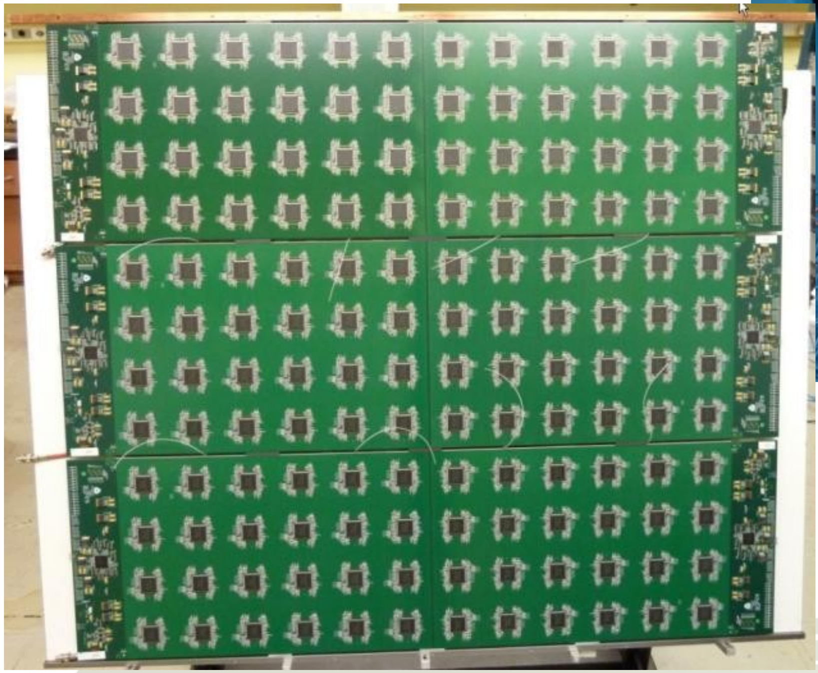
Cassette Assembly II

Assembly

- Cassette is compressed horizontally with a set of 4 (Badminton) strings
- Strings are tensioned to ~20 lbs each, very few broken strings
- ~45 minutes/cassette

Cassette Testing

- Cassettes were tested with CR before shipping to FTBF



38+14 cassettes assembled

Peripherals

Low Voltage Power Supply

Need power to 228+78 front-end boards (+5V)
Acquired 8 Wiener power supplies
Built 8 power distribution boxes

High Voltage Power supply

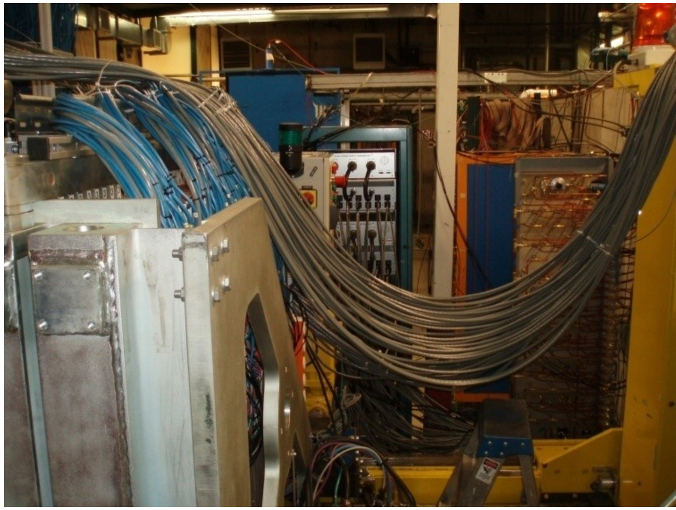
Need 6.3 kV to 38+14 layers (3 RPCs powered by 1 line)
Have 5 LeCroy 4032 power supplies
Have 2 sets of controllers
Developed computer control program

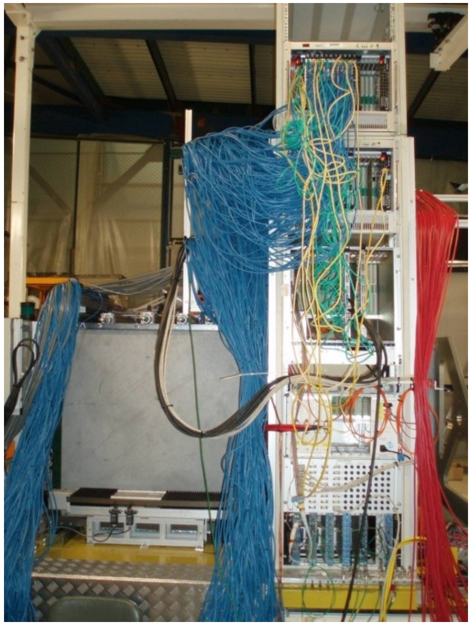
Gas Supply

Need 19+7 lines (2 layers or 6 RPCs per line)
Built mixing rack for 3 gases
Built distribution rack

Transportation to FNAL and installation

Installation into CALICE structure at FNAL

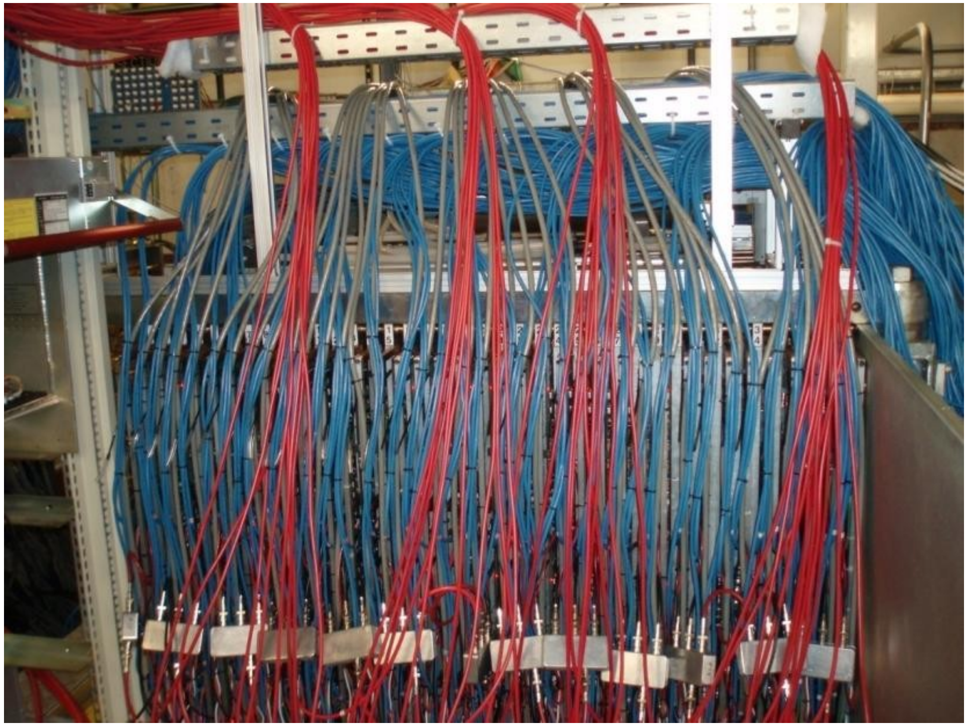




Installation complete

Cabling up

12 hours of hard work
(350,000 readout channels
for the DHCAL alone!)



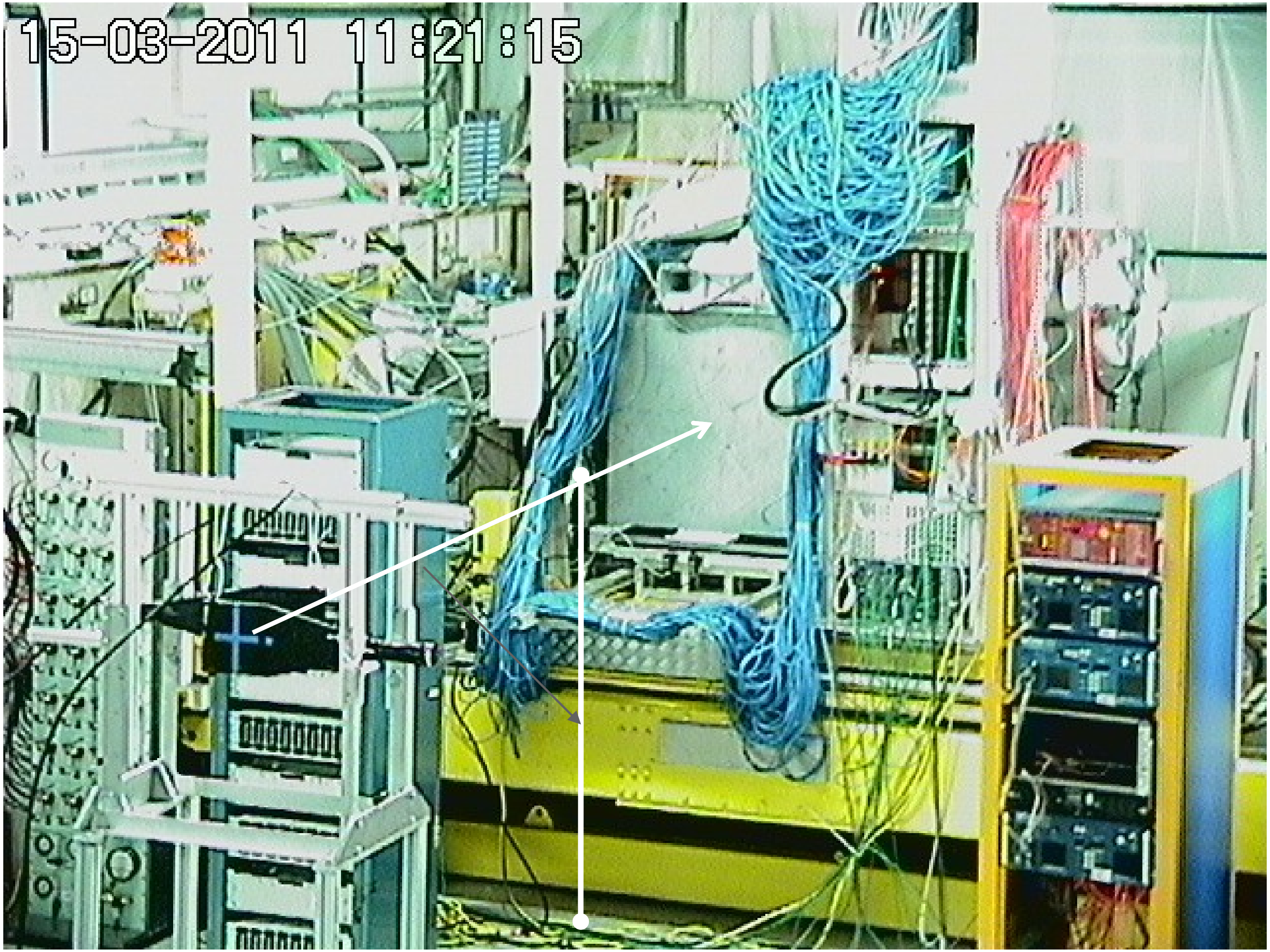
The RPC DHCAL Testbeam Story

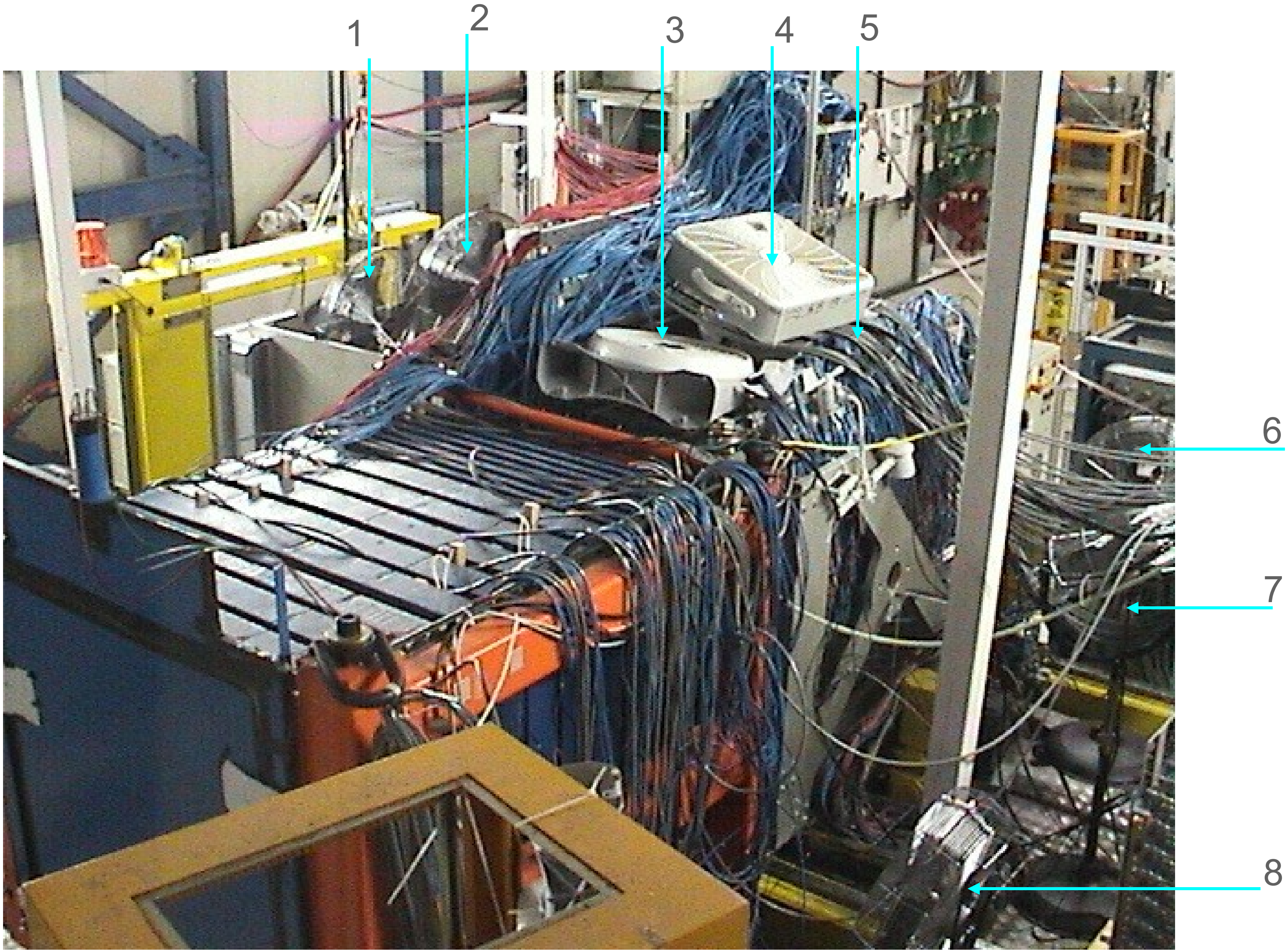
Oct 2010

Testbeam

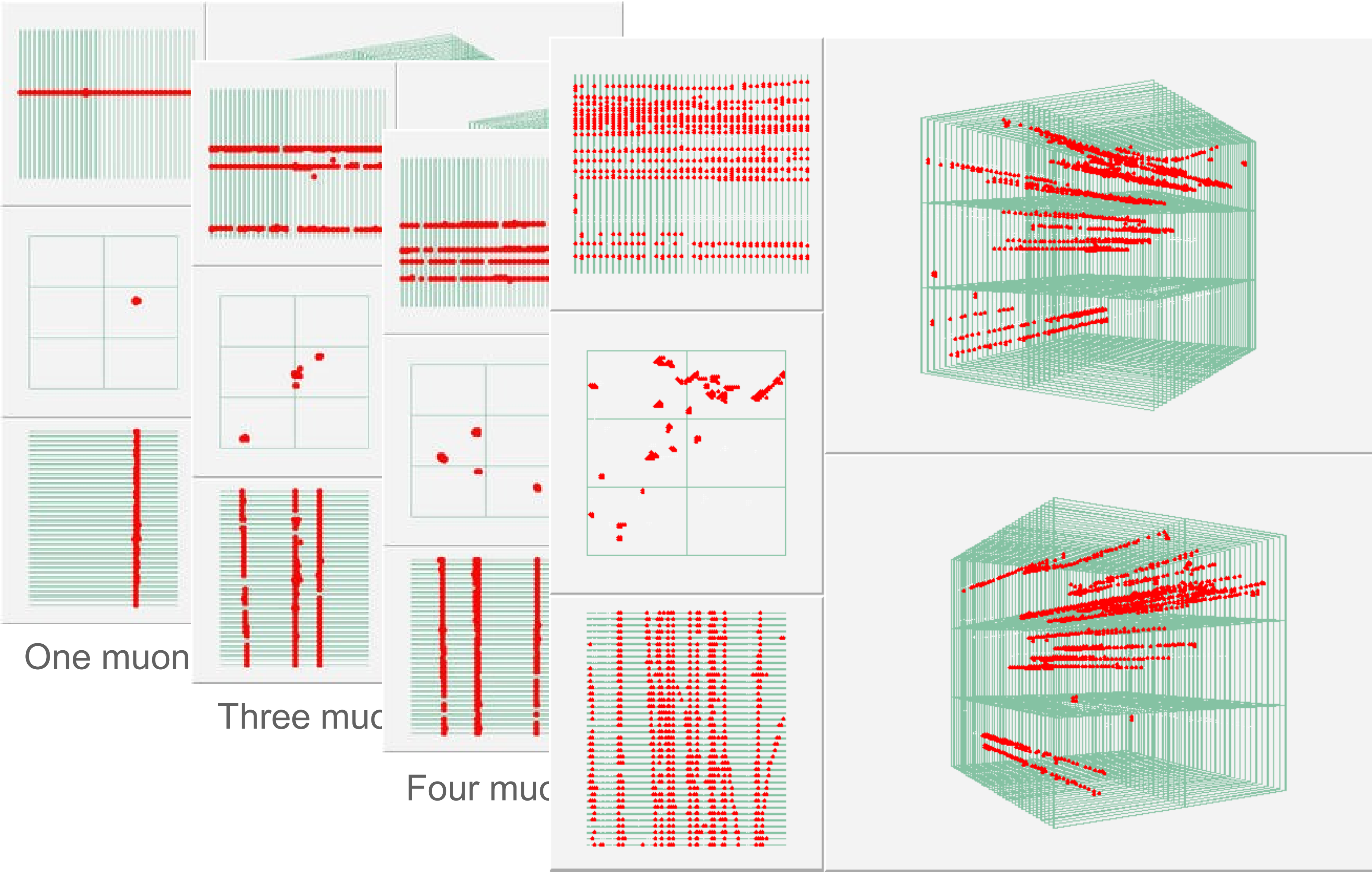
DHCAL +
NIU's
Scintillator
TCMT

At Fermilab




1
2
3
4
5
6
7
8

First beam: muons



One muon

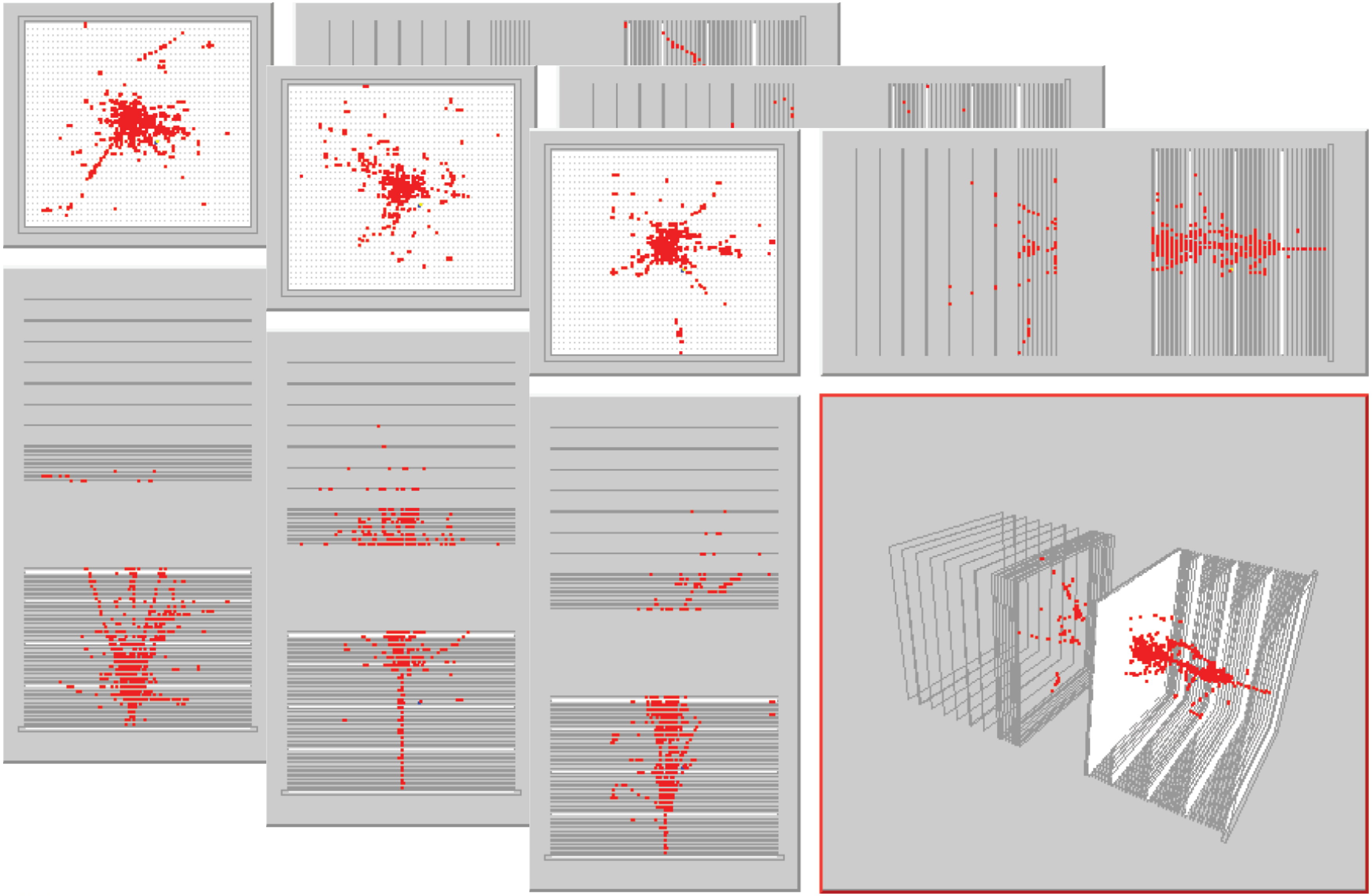
Three muc

Four muc

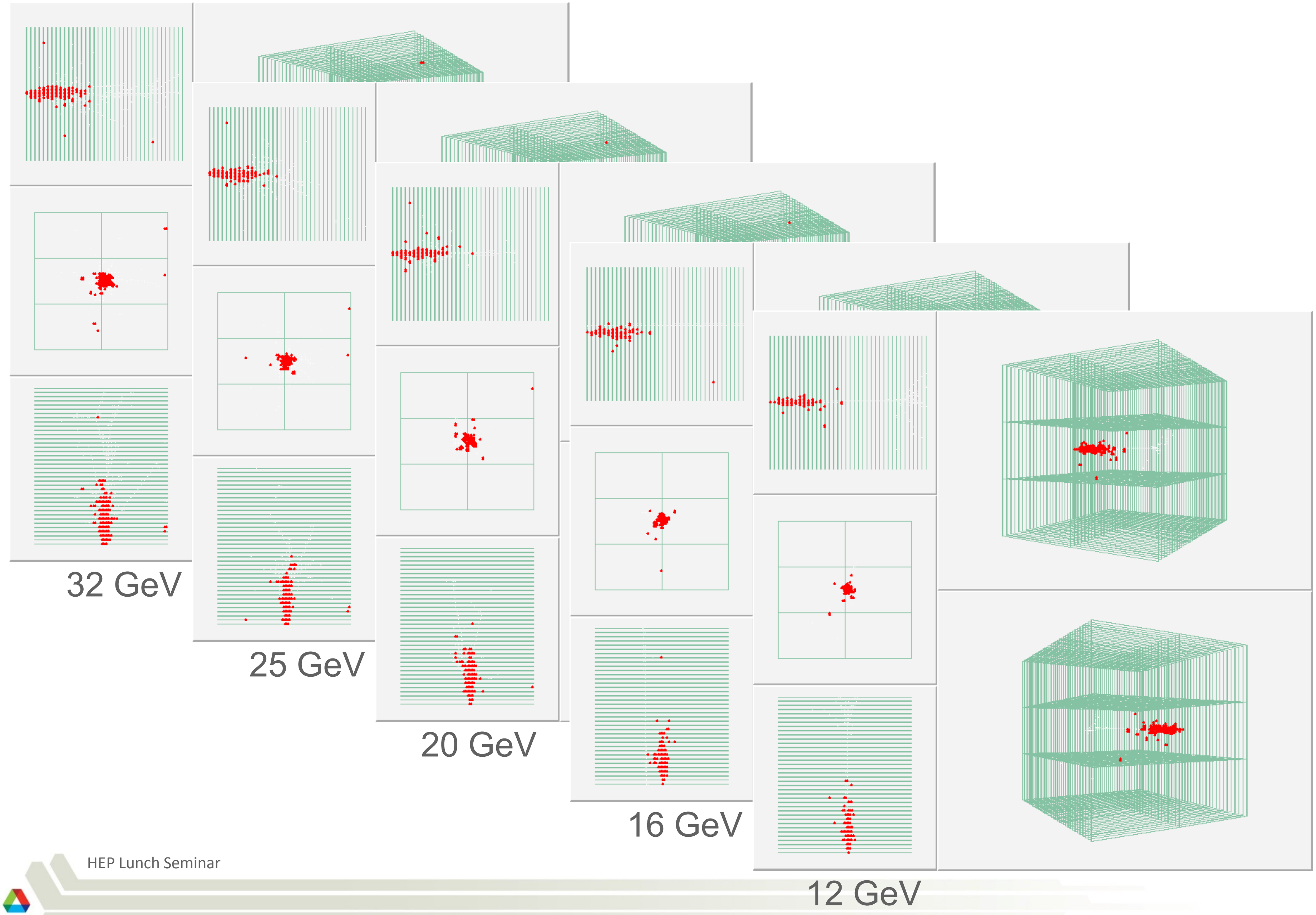
A lot of muons

Next: pions

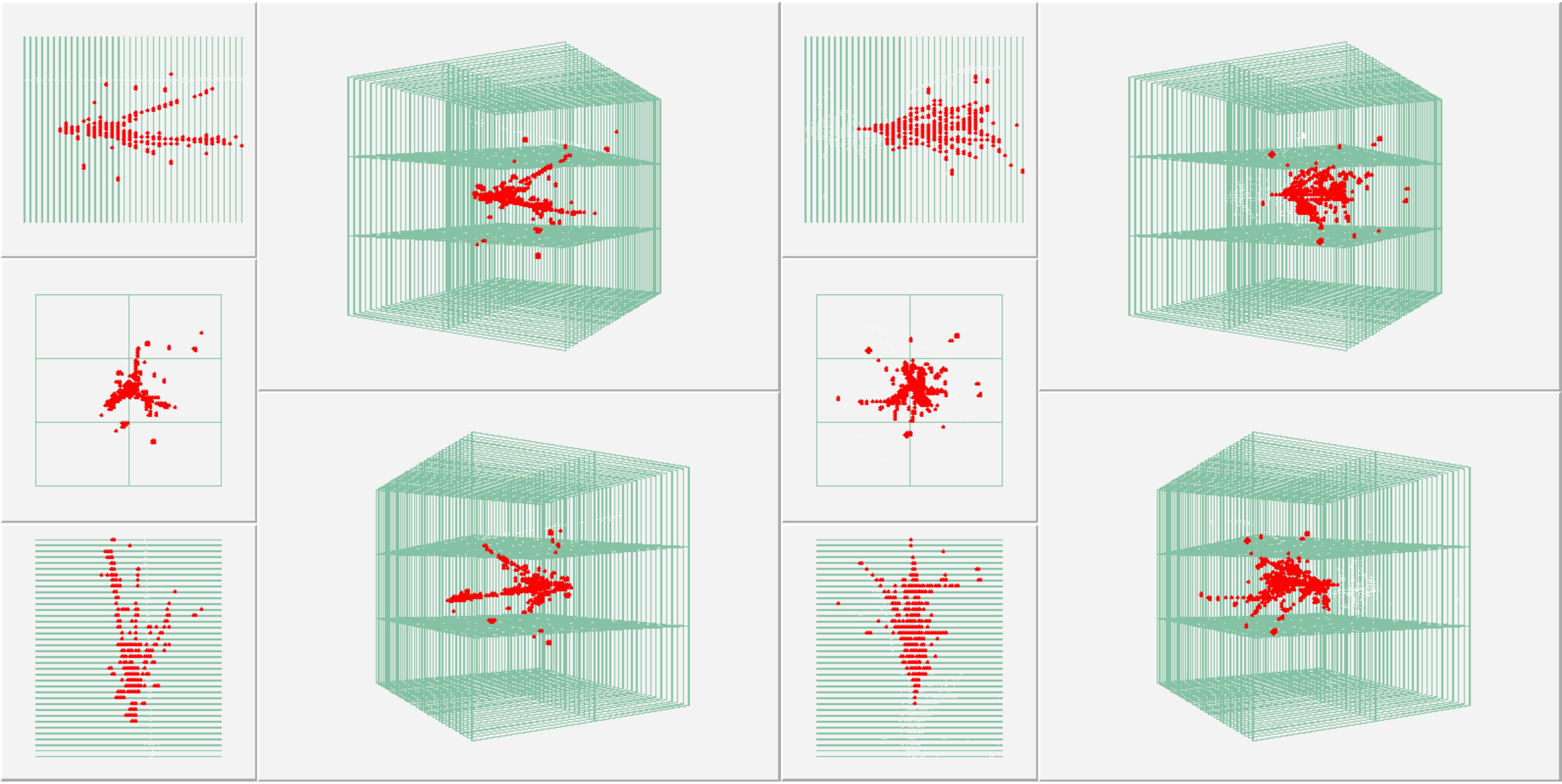
60 GeV pions measured in DHCal



And also positrons



And occasionally, neutral hadron



Relatively smooth operation

- Biggest problem was the old LeCroy HV system
  - Consists of 4 Main Frames, 52+ channels
  - Lost in total 2 Main Frames and 22+ channels during last 3 test beam runs
  - At the end, can not repair fast enough → switched some ch's to Bertan supplies
  - In process of testing a new HV system
- Changed 3 FE boards
- Had 2 LV supply failures
  - 1 fuse blow → due to wrong fuse type
  - 1 OVP tripped → due to old supply + too low OVP threshold settings
- 1 LV distribution box channel repair → wrong wiring
  - 5V and GND connection reversed
- 1 DCol failure → some channels lost TS counter reset signal, replaced
- RPC issues
  - 5 replaced by spares: 4 leaky, 2 dead, 1 noisy
  - 2 pairs exchanged position (T ←→B), to move inefficient region (corner, edge) to the outside
  - 14 RPC showed some level of overall inefficiency, after improved cooling
    - 12 in TCMT, 2 in 1m3
    - They are operated at 6.4 – 6.6 kV to compensate the inefficiency (nominal 6.3 kV), some are still bad
    - Considering some replacement before next beam test

Summary

- The construction of the DHCAL prototype (+TCMT) is complete
- Test beam at Fermilab started last Oct., a lot of good data collected
- DHCAL prototype (+TCMT) works extremely well
- Operation is relatively smooth
- More test beam/more data is on the way