Construction and Testing of a Digital Hadron Calorimeter Prototype

For TIPP 2011

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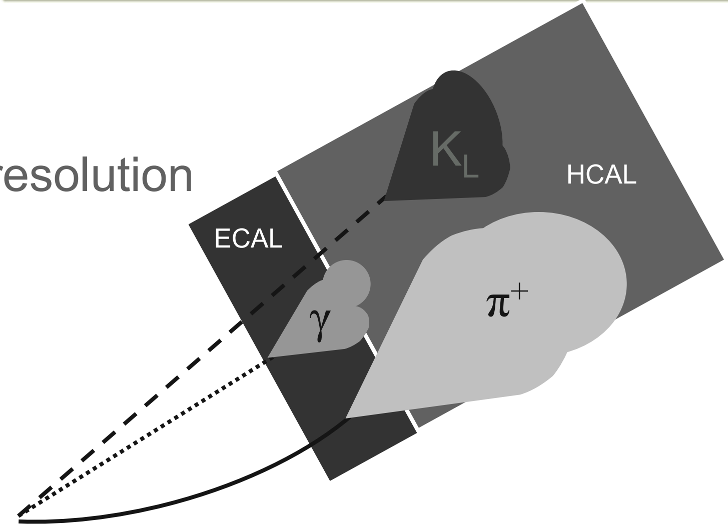
ANL_HEP

Particle Flow Algorithms



The goal: a detector that achieves 30%/√E jet energy resolution
Favored method is to use particle flow algorithms
that measure charged particles with tracker
and measure neutral particles with calorimeter
Requires:
Excellent tracker and high B – field
And a dense calorimeter also inside coil with
high granularity to distinguish
individual particle showers in jets and assign to charged or neutral parent
Argonne's solution: a digital hadron calorimeter (DHCAL) using RPC
chambers and 1 cm x 1 cm readout pads with single bit readout
hit counting sufficient

Particles in jets	Fraction of energy	Measured with	Resolution $[\sigma^2]$
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 (Charged + Photons + Neutral Hadrons)

1 m^3 – Digital Hadron Calorimeter Physics Prototype

Description

Readout of 1 x 1 cm^2 pads with one threshold (1-bit) → **Digital Calorimeter**
Layers inserted into the existing CALICE Analog (scintillator) HCAL and TCMT structures
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

Purpose

Validate DHCAL concept
Gain experience running large RPC systems
Measure hadronic showers in great detail
Validate hadronic shower models (Geant4)

Status

Started construction in 2008
Completed in January 2011
Test beam runs started in Oct. 2010 at Fermilab
More test beam runs through rest of year
Analysis on-going

Collaboration and Responsibilities

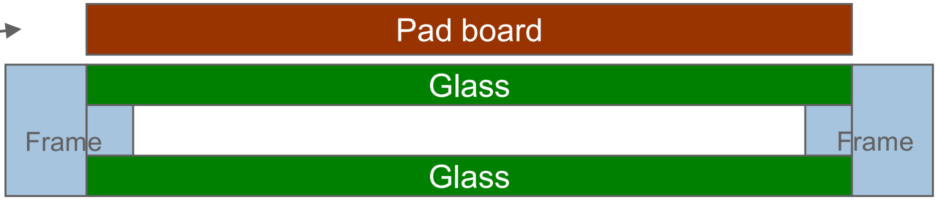
Task	Institutes
Project coordination	Argonne
RPC construction	Argonne
Cassette structure	Argonne
Mechanical structure	DESY
Overall electronic design	Argonne
ASIC design and testing	FNAL, Argonne
Front-end and Pad board design & testing	Argonne
Data concentrator design & testing	Argonne
Data collector 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

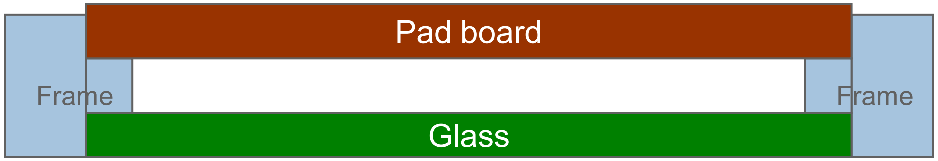
DHCAL Personnel	Heads
Engineers/Technicians	23
Students/Postdocs	7
Physicists	10
Total	40

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)





RPC concept

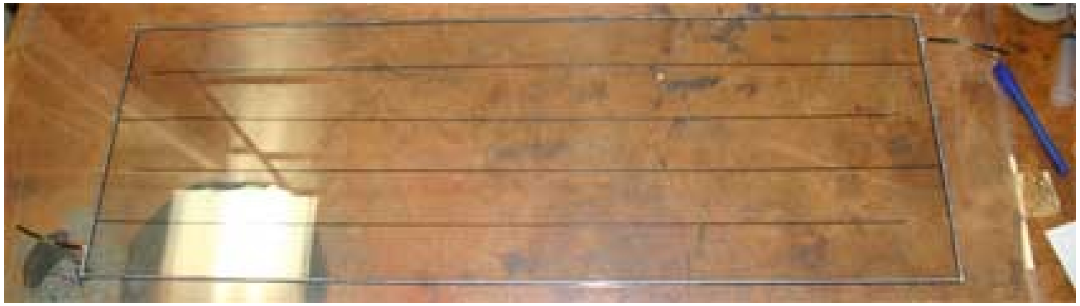
High voltage across gas(Freon+Iso-butane+SF6)
Ionization is amplified by avalanche effect
Signal detected at pad boards

Chambers needed

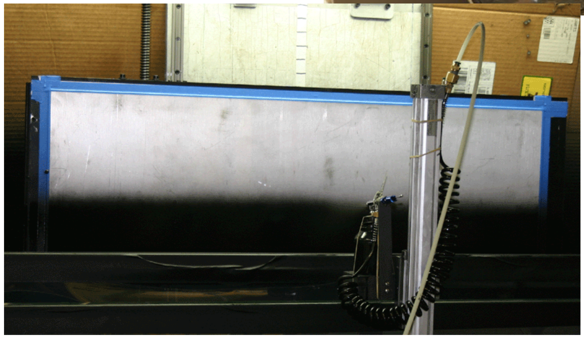
~114 for DHCAL + 42 for TCMT + spares
at the end, produced ~ 205 RPC's

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 $R_{\square} = 1 – 5\ M\Omega$

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

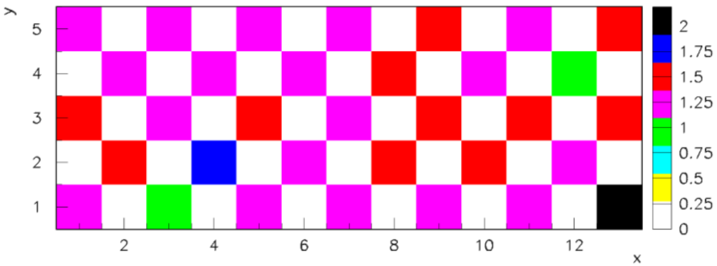
Poor uniformity in a single plate

Mean value not well controlled from plate to plate

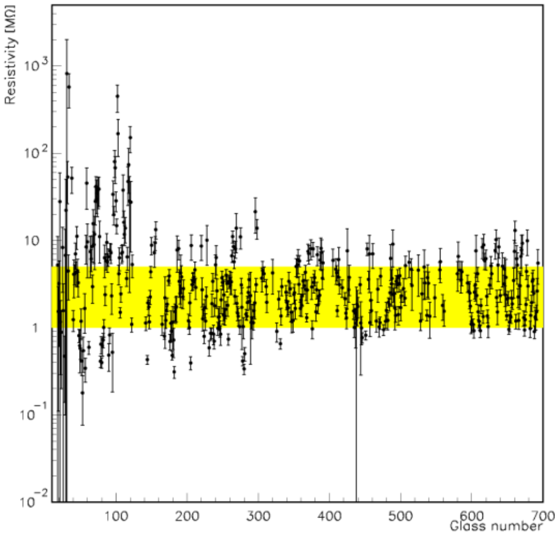
Low yield: ~ 60% pass quality cut

Slow – barely match RPC assembly speed

at the end, it worked out



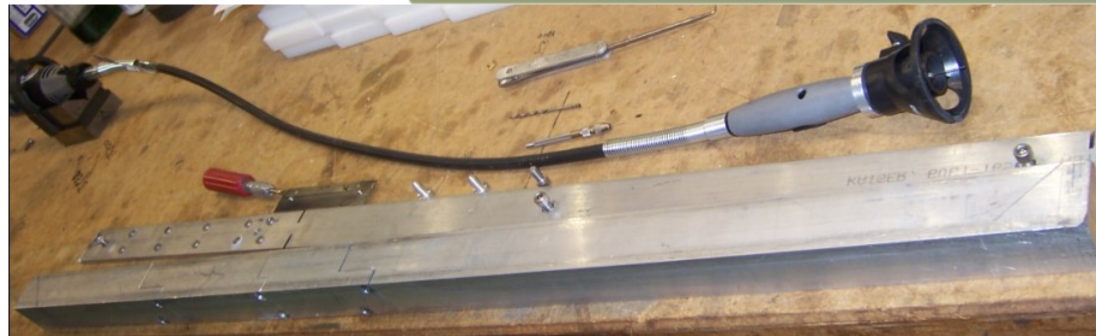
$M\Omega/\square$



RPC Assembly

Cutting frames

Dedicated (adjustable) cutting fixture
Cut length to .2mm precision
Drill holes
Tooling designed at ANL



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

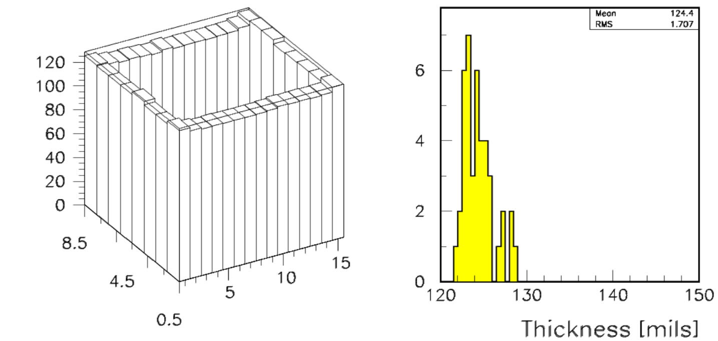
Gap size measurement

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

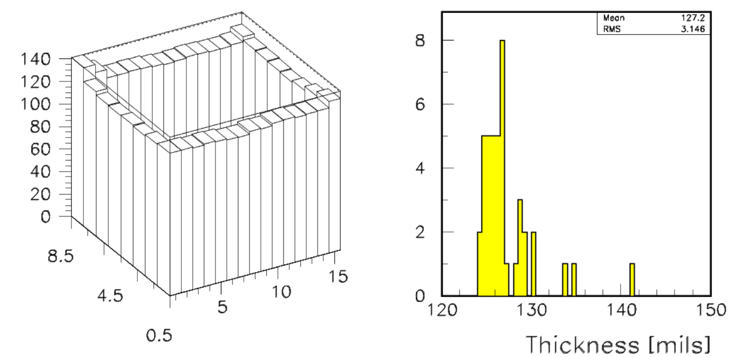
HV tests

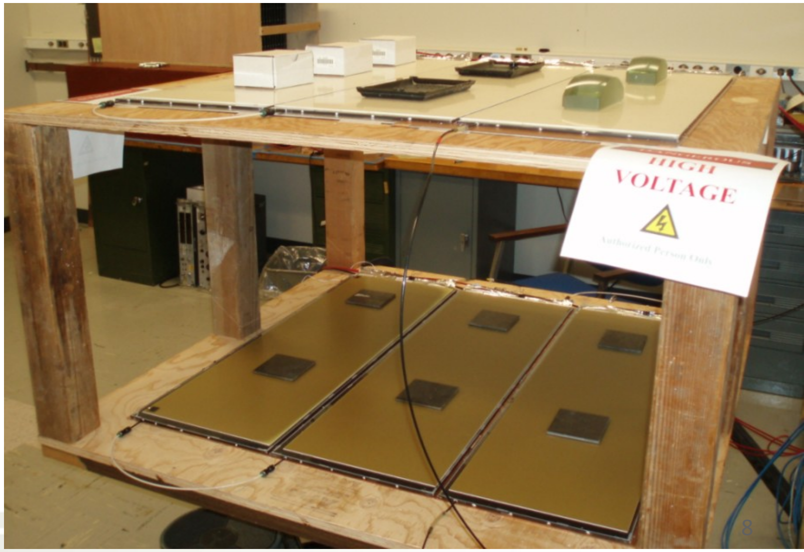
Tests up to 7.0 kV before placing readout board on top
(operating voltage is 6.3 kV)

RPC 001



RPC 012





Cosmic Ray Test Stand

Up to 9 RPCs tested at once

Testing of early FE board versions

First batch of chambers

Chamber characterization using cosmics and noise

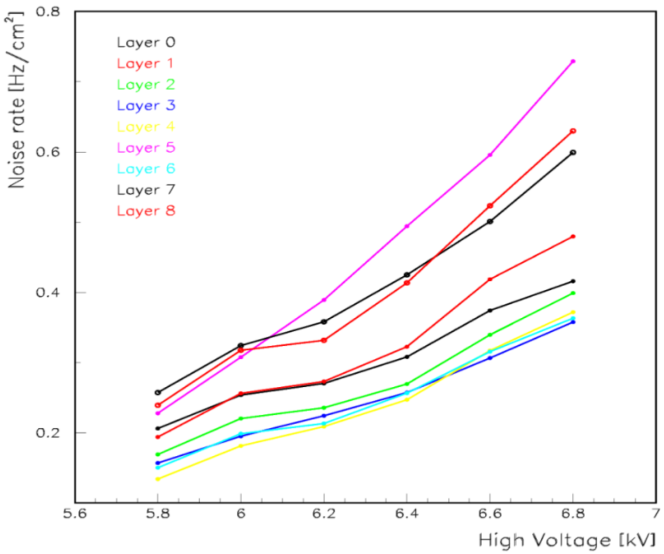
Noise measurements

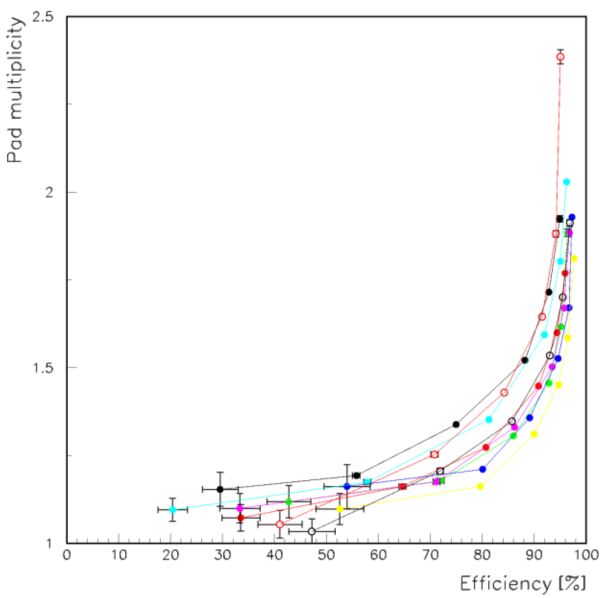
High voltage scans from 5.8 to 6.8 kV

Triggered, trigger-less operation

Cosmic Ray Test Stand (cont.)

Triggered Data: Standard tests

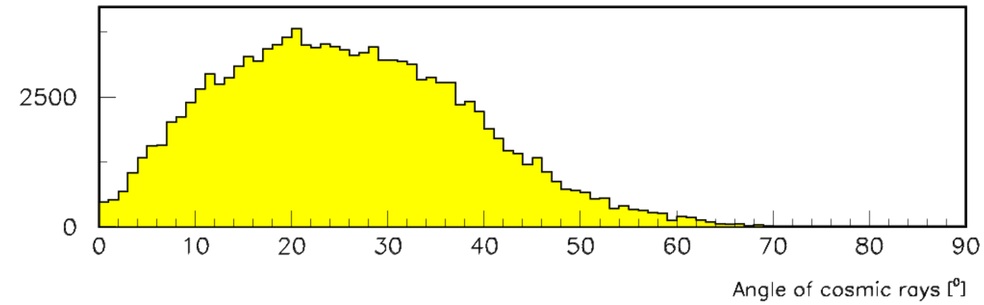


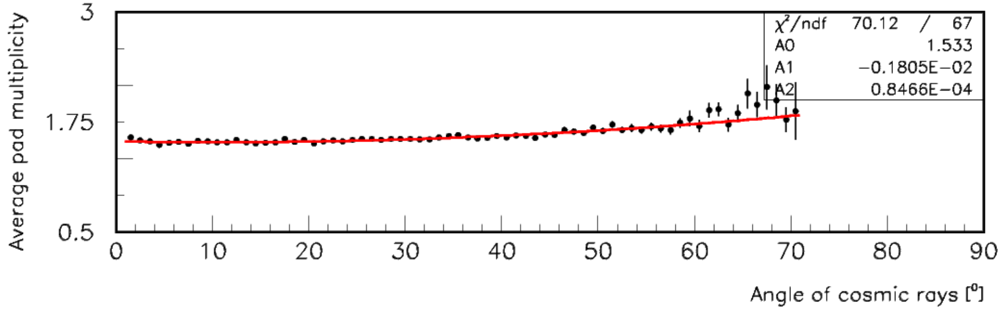


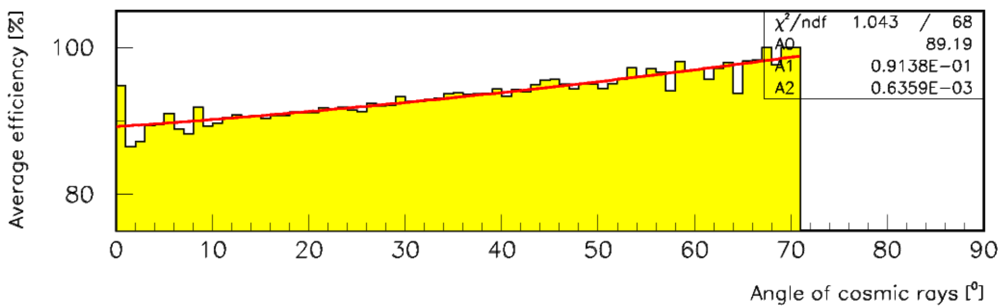
Trigger-less Mode

Analyze Cosmic Rays

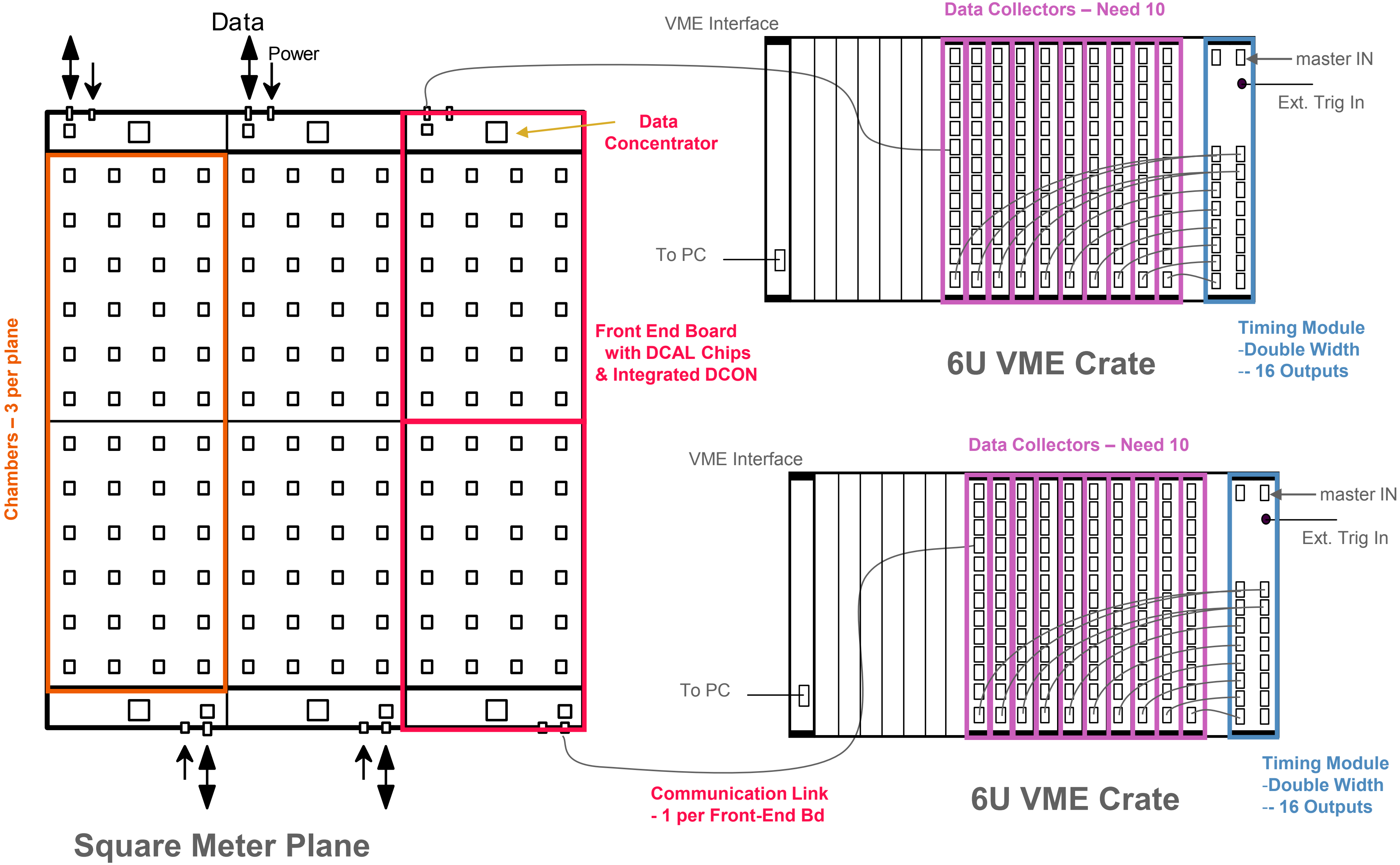
Angle of Incidence Dependence!



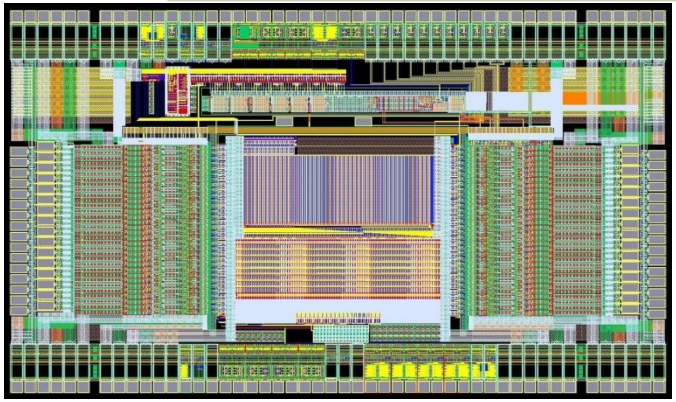




Readout system overview



The DCAL Chip

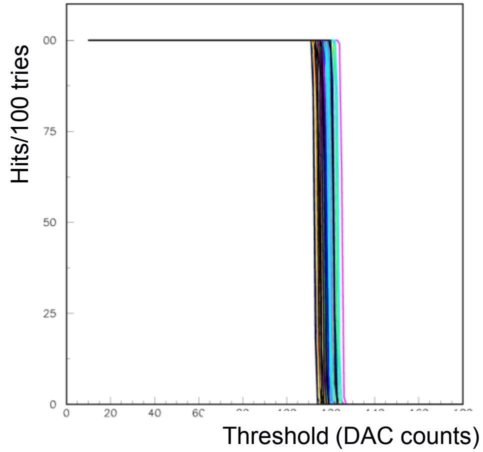


Developed by

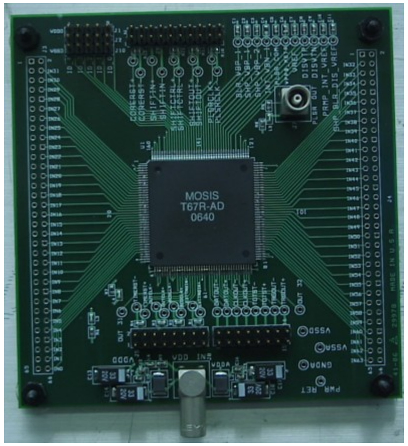
FNAL and Argonne

Input

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



Threshold



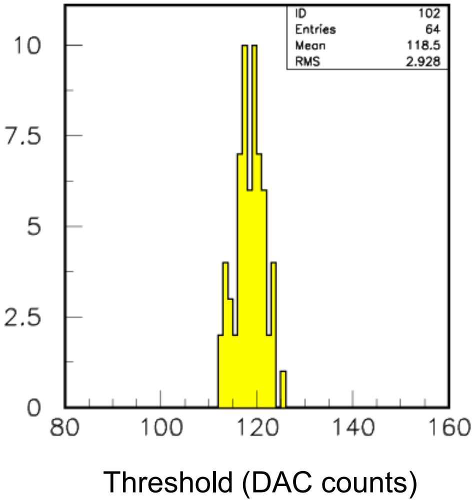
Set by 8 – bit DAC (up to ~600 fC)
Common to 64 channels

Readout

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

Versions

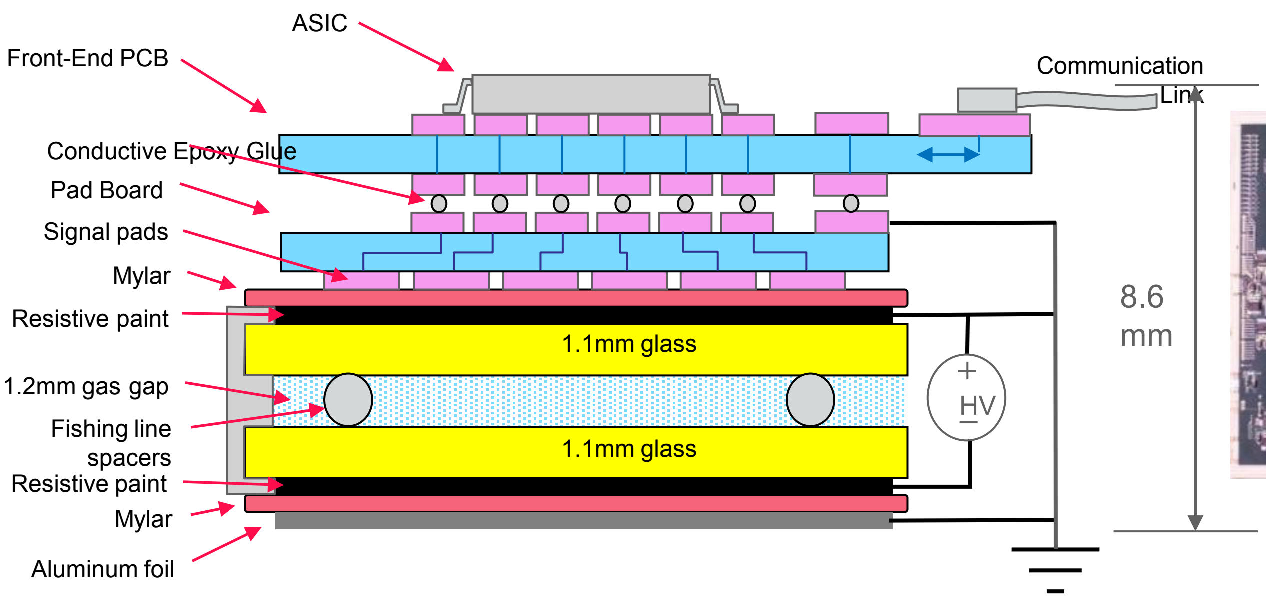
DCAL I: initial round (analog circuitry not optimized)
DCAL II: some minor problems (used in vertical slice test)
DCAL III: no identified problems (final production: used in current test beam

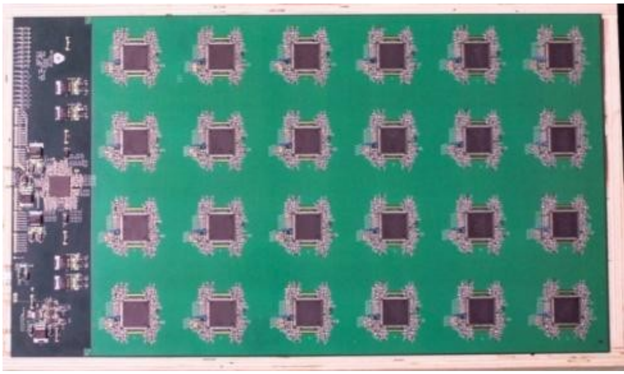


Production of DCAL III

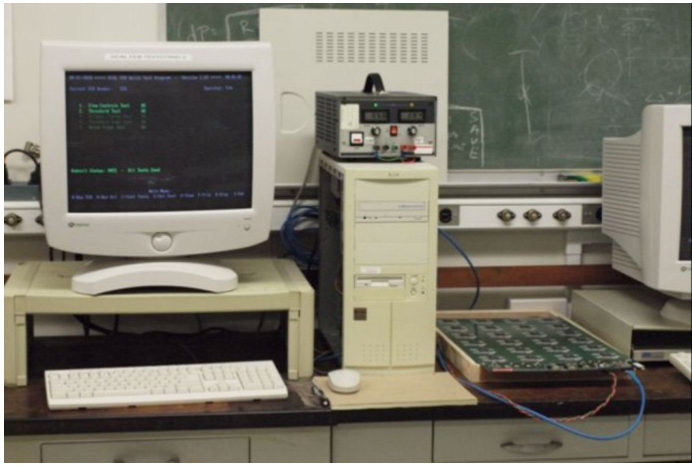
11 wafers, 10,300 chips, fabricated, packaged, tested

FrontEnd/DCON board + Pad board



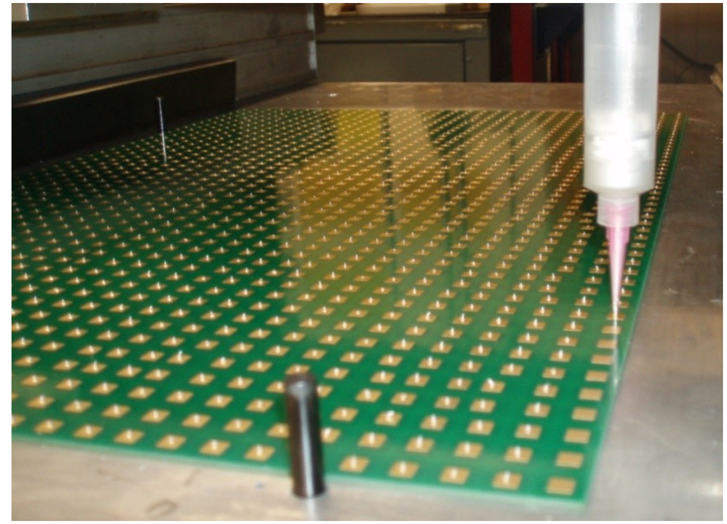


- Build FE and pad boards separately to avoid blind and buried vias (cost and feasibility issue)
- Each board contains 1536 channels and 24 ASICs
- The data concentrator is implemented into the same board
- Glue the two boards together with conductive epoxy
- FE board need to pass computer test before 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 on contacts in less than 3 hours



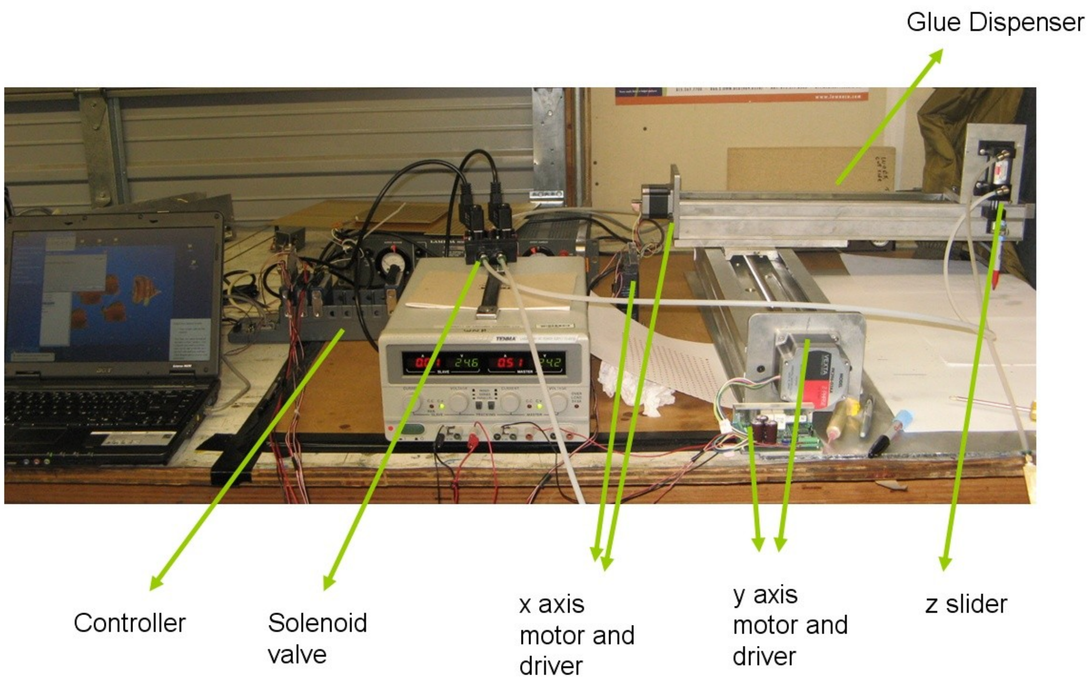
Fixture

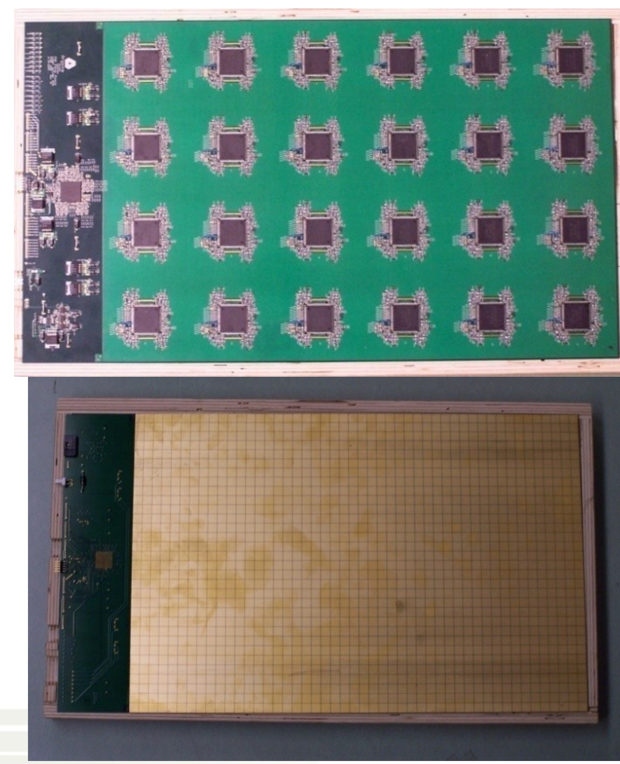
Designed, built and commissioned

Production

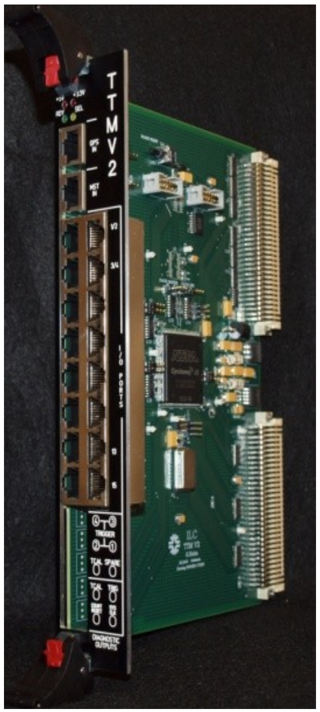
~25 minutes needed/board
can glue > 10 boards/day

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

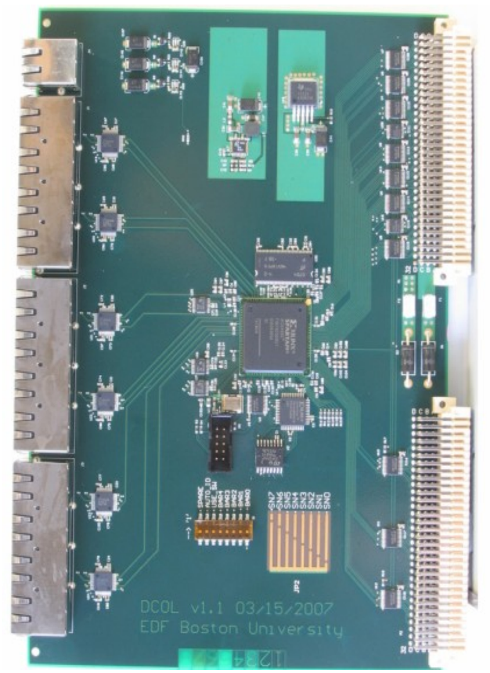




Back end electronics
1. Timing and Trigger Module (TTM)
2. Data Collector DCOL

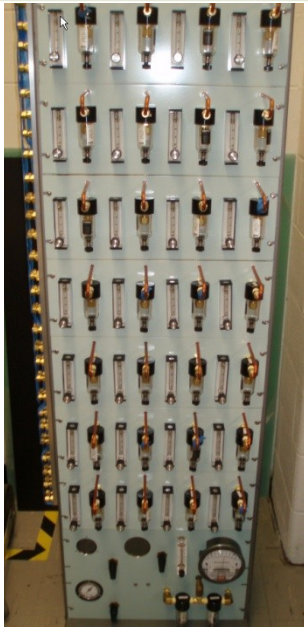


Fermilab



BOSTON UNIVERSITY

Power supply systems
1. Low voltage system
2. High voltage system



Gas System

The University of Iowa

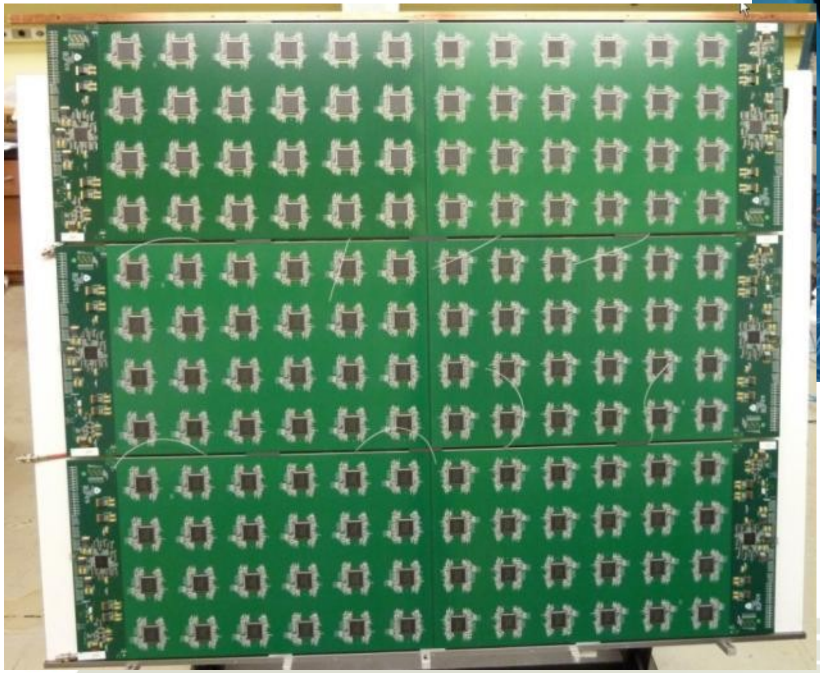
Cassette Assembly

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
- steel and copper plates

Cassette Testing

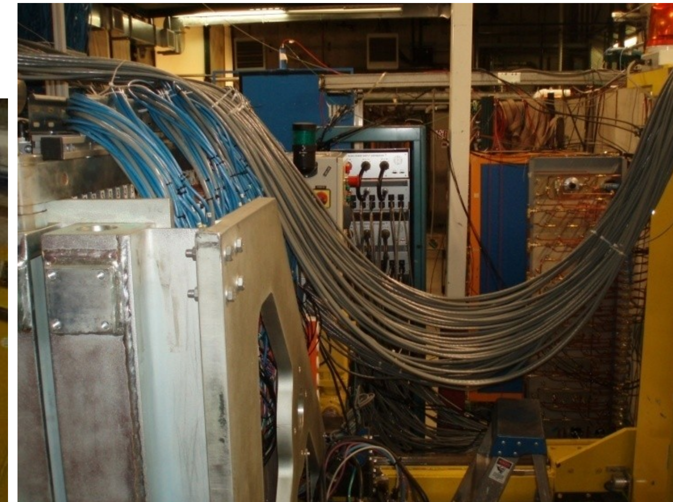
- Cassettes were tested with CR
  before shipping to FTBF

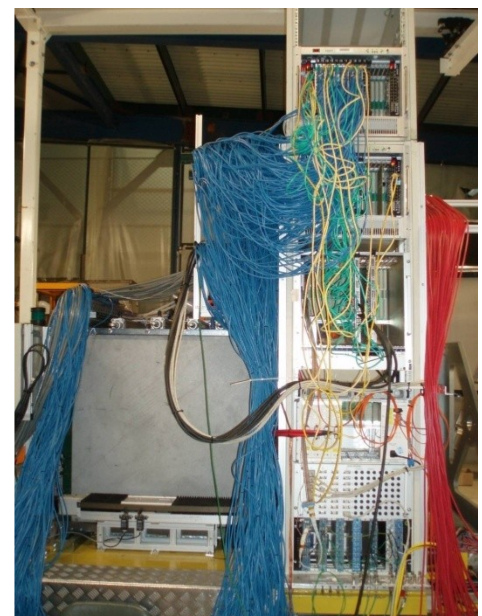


38+14 cassettes assembled

Transportation to FNAL and installation

Installation into CALICE structure at FNAL

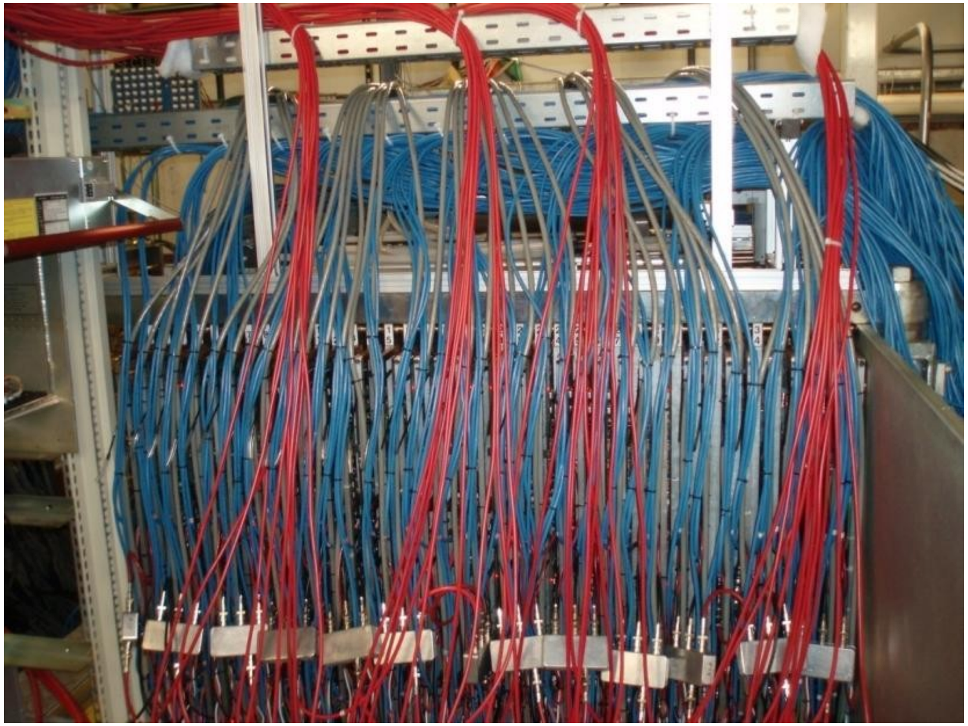




Installation complete!

Cabling up

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



The RPC DHCAL Testbeam Story

Sep 2008 – Sep 2010
Construction
DHCAL

Oct 2010
Testbeam
DHCAL + NIU's Scintillator TCMT

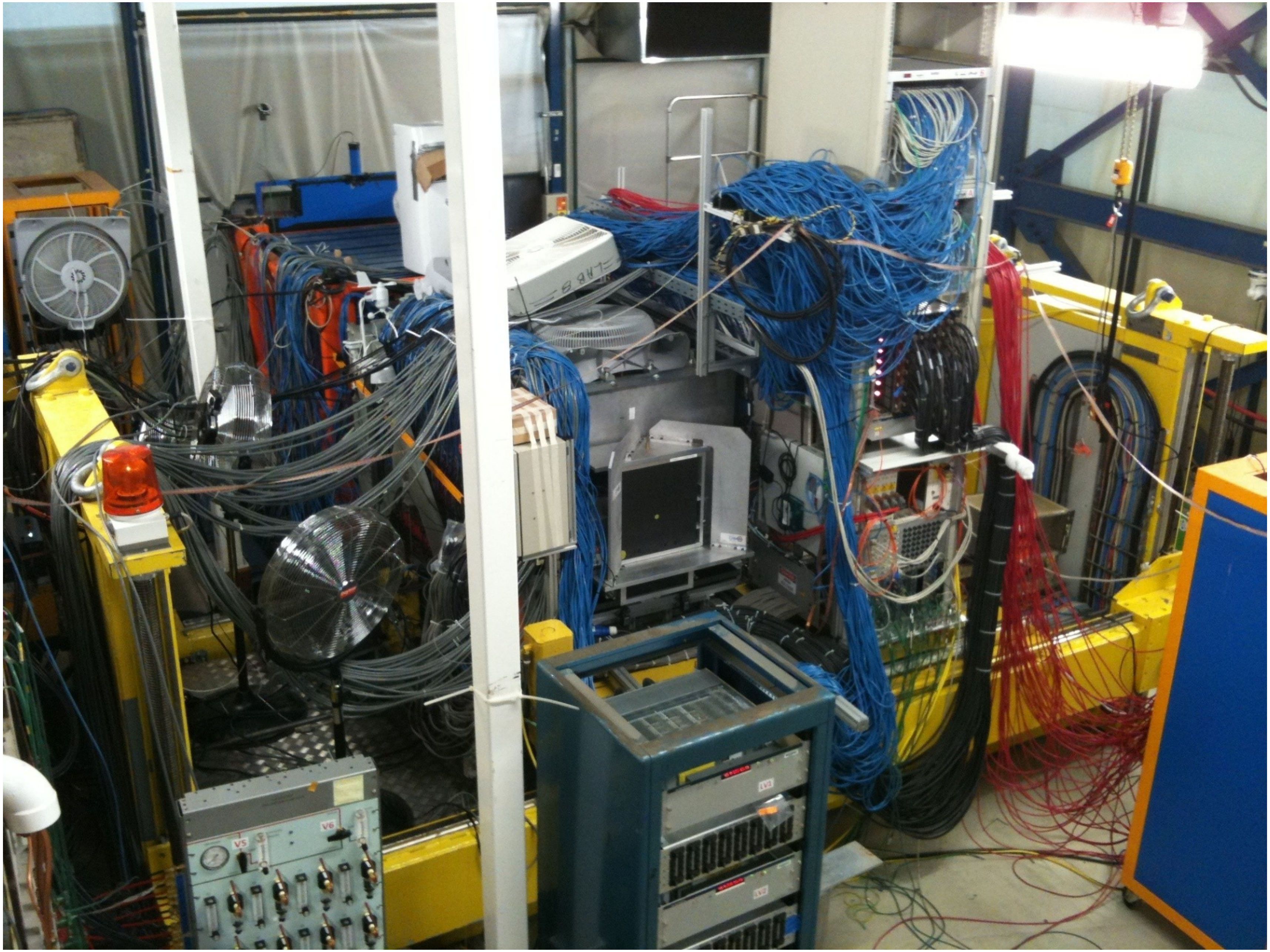
Nov 2010 – Jan 2011
Construction
Of RPC TCMT

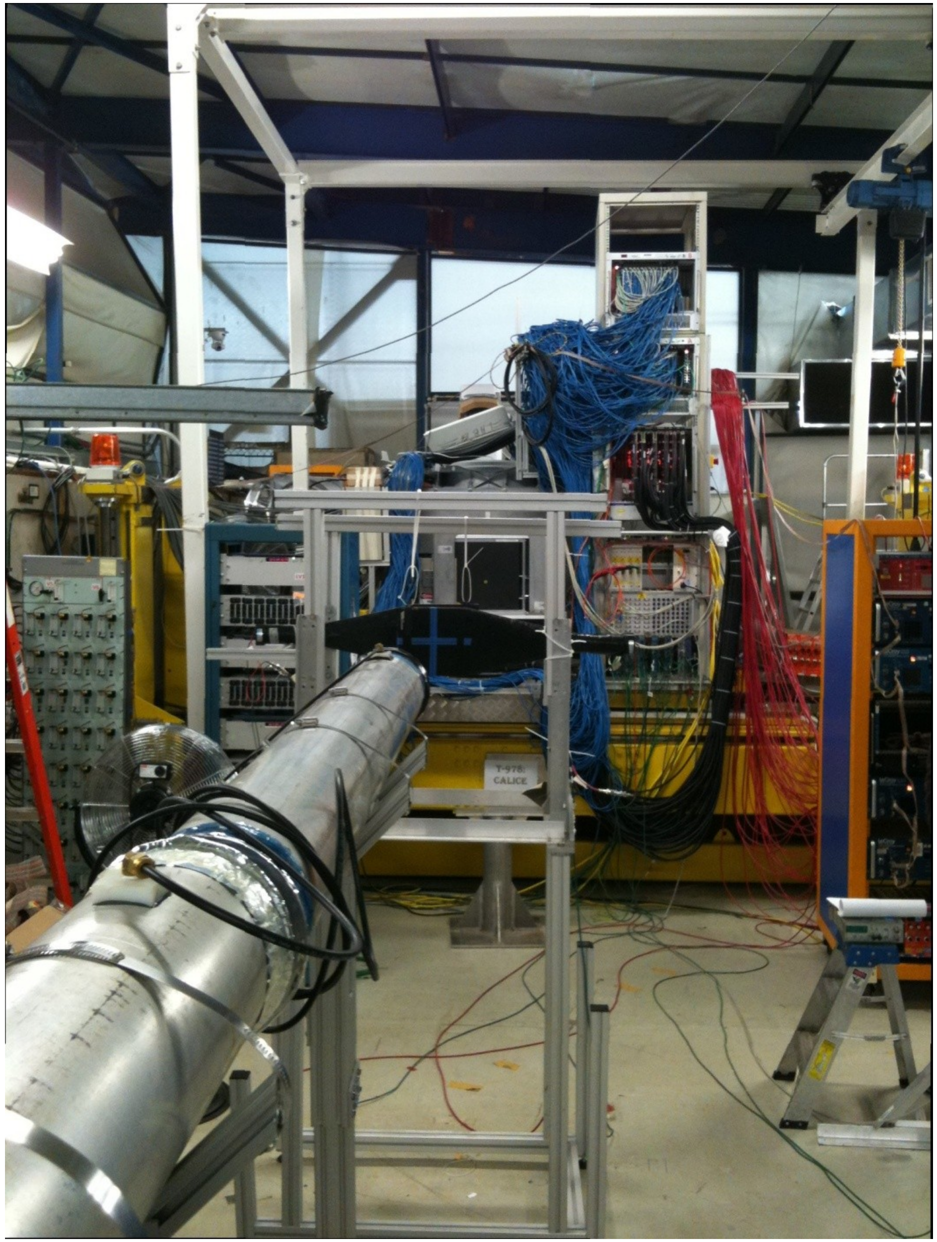
Feb 2011
Testbeam
Un/Installation
DHCAL
+ NIU's TCMT
-NIU's TCMT
+RPC TCMT

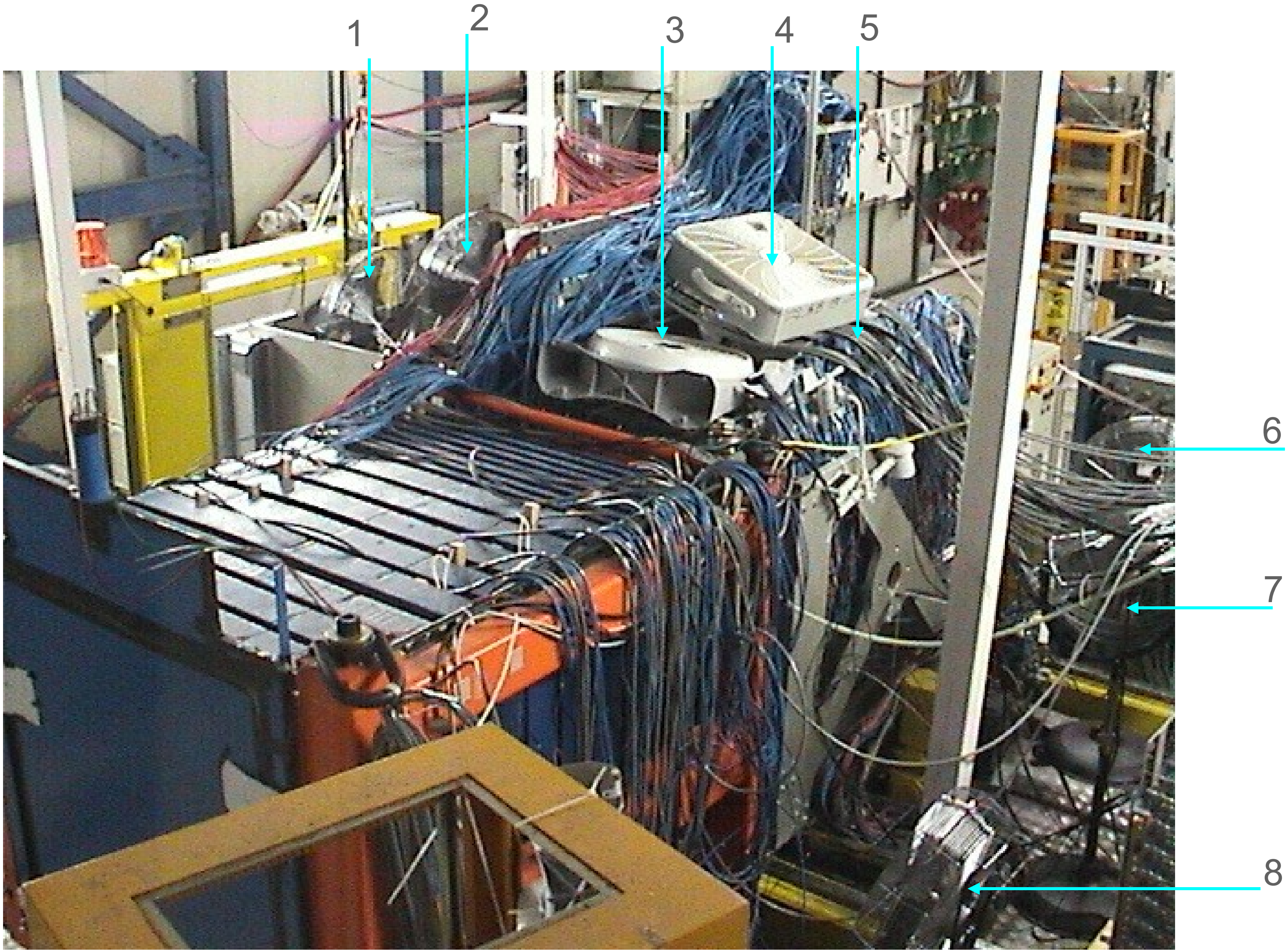
April 2011
Testbeam
DHCAL
+RPC TCMT
+CALICE Si/W ECAL

May/June Testbeam

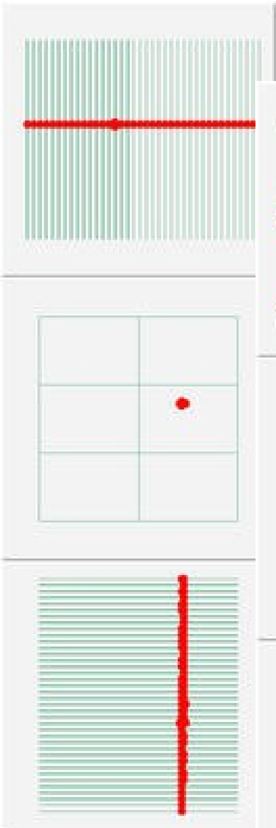
Future Testbeam?



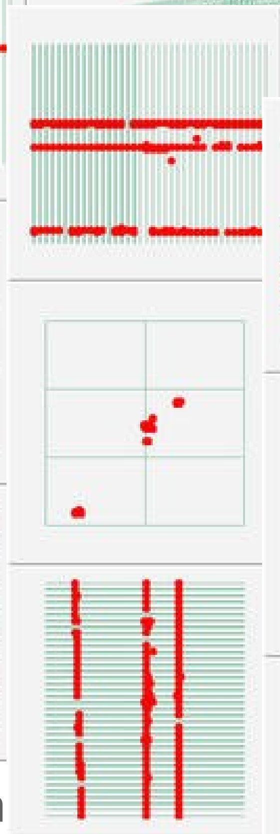

T-978
CALICE


1
2
3
4
5
6
7
8

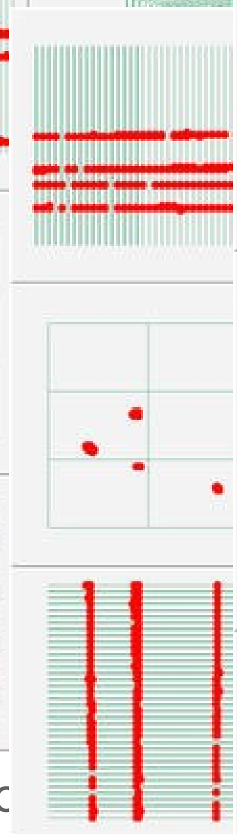
First beam: muons



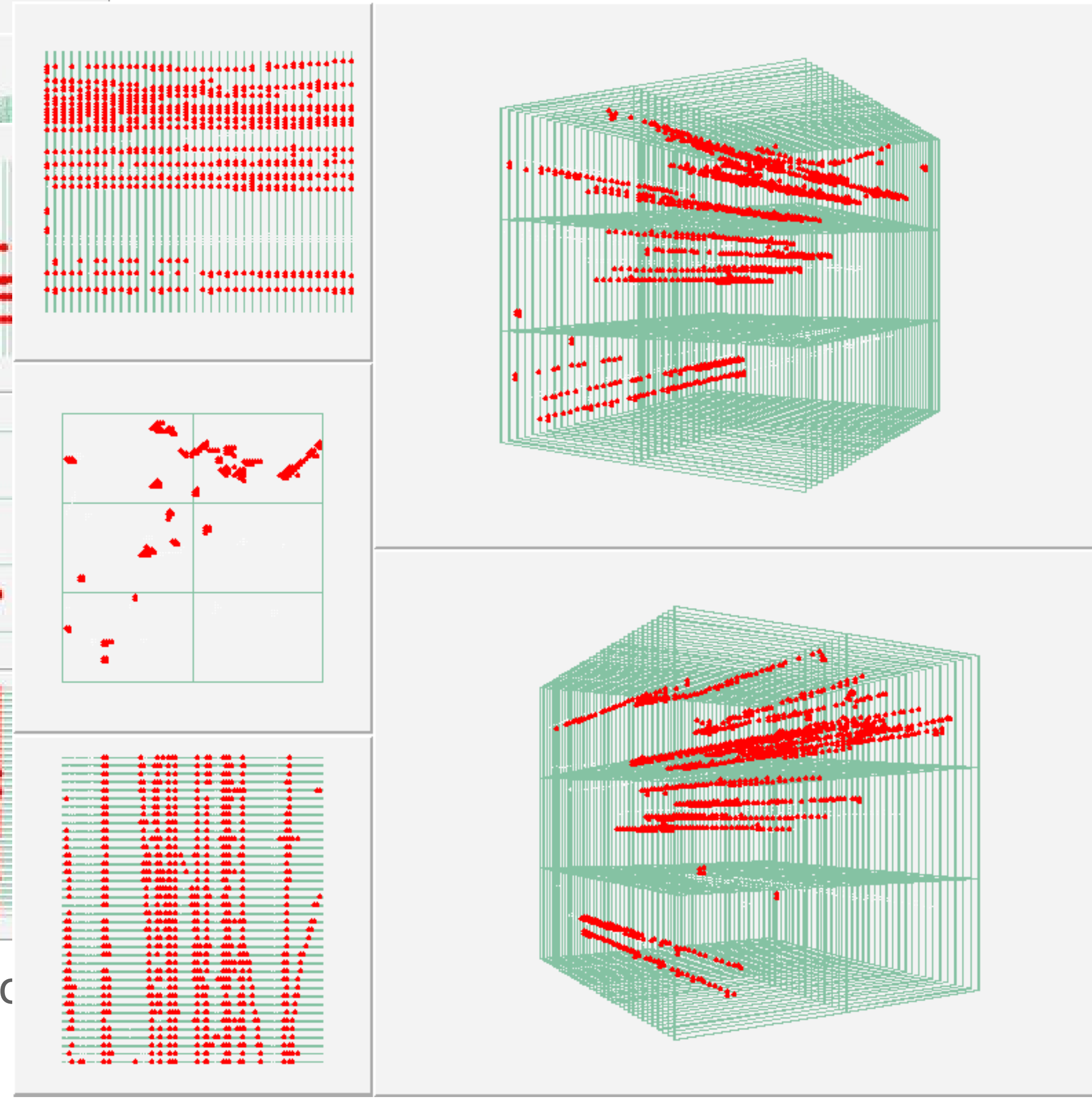
One muon



Three muc



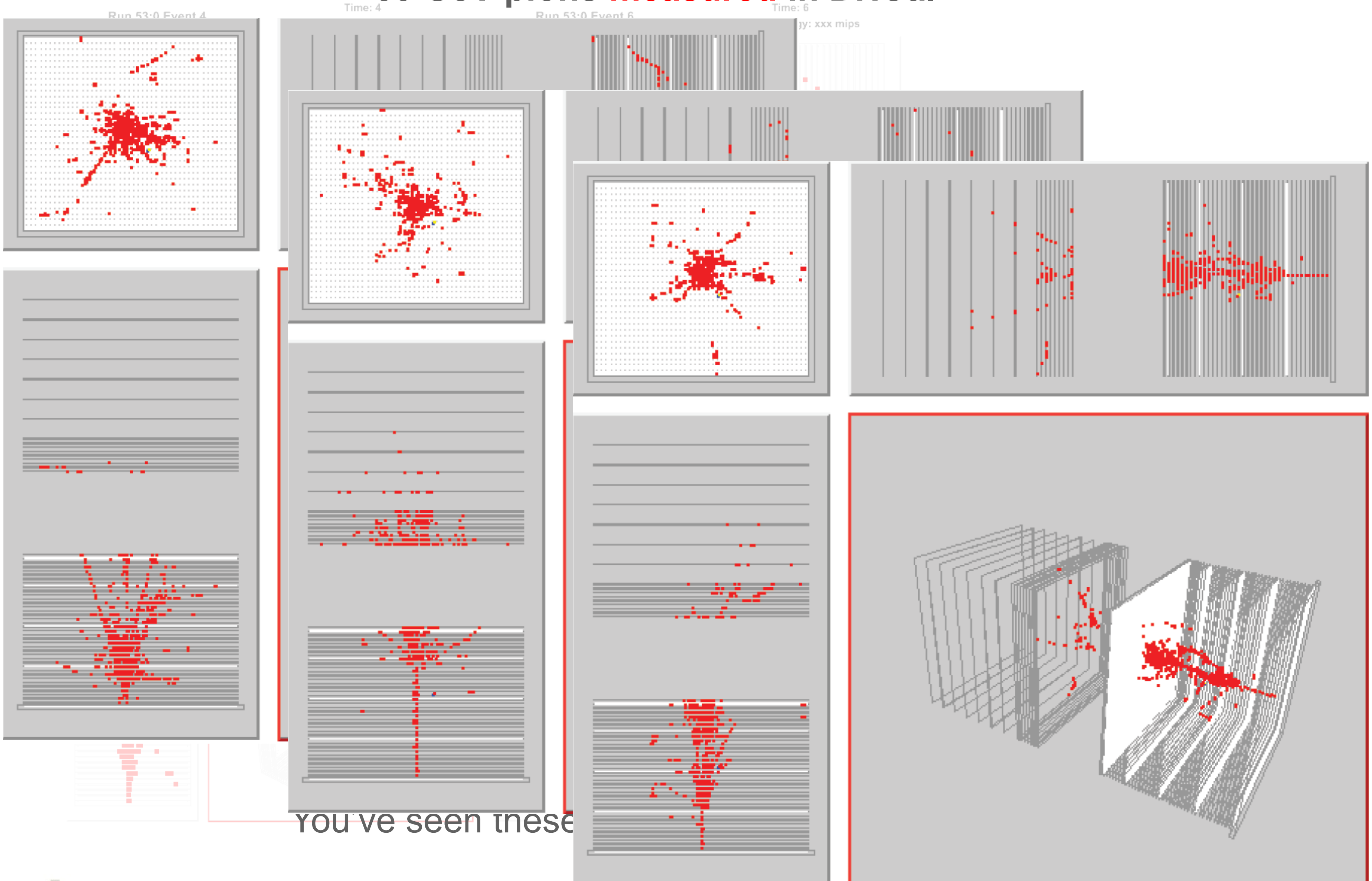
Four muc



A lot of muons

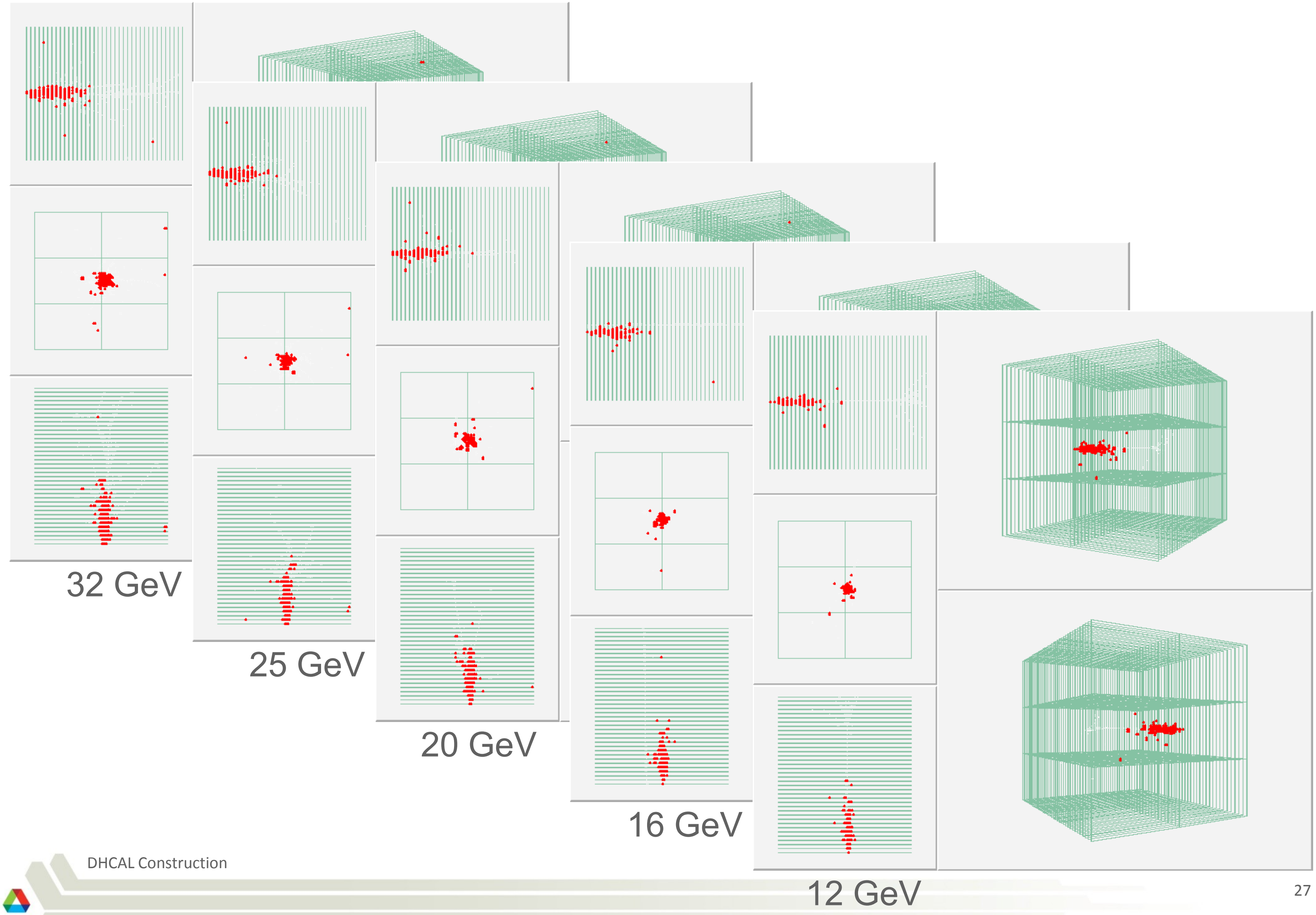
Next: pions

60 GeV pions **measured** in DHCal

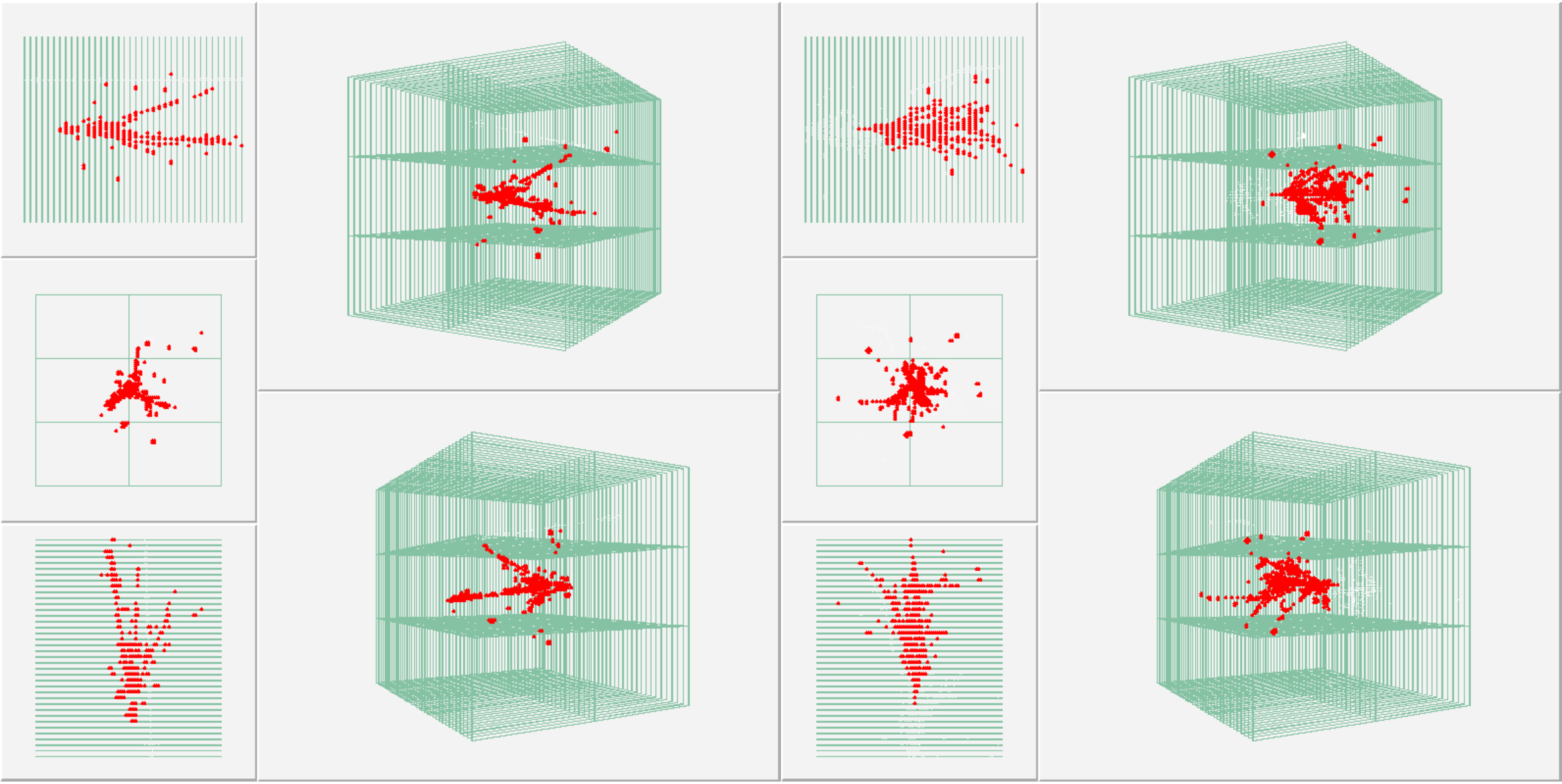


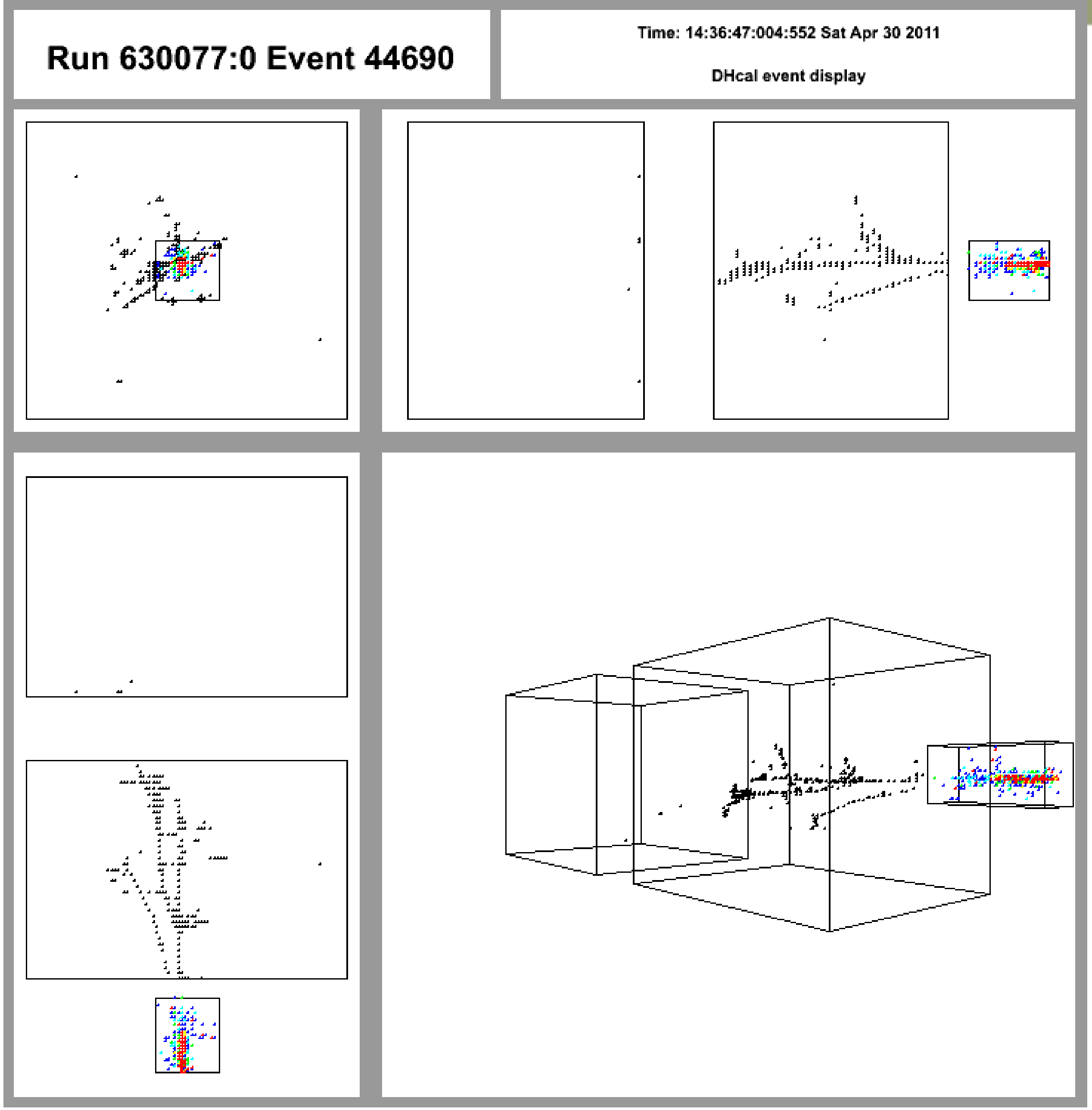
Now, the real thing!

And also positrons



And occasionally, neutral hadron




Run 630077:0 Event 44690
Time: 14:36:47:004:552 Sat Apr 30 2011
DHcal event display

Summary

- The construction of the DHCAL prototype (+TCMT) is complete
- Test beam at Fermilab started last Oct.
- DHCAL prototype (+TCMT) works extremely well
- A lot of good data collected, analysis is on-going
- First look of the data is very encouraging!
- More test beam/more data is on the way
  - 5 to 6 more weeks in May/June

- Project led by Argonne
- Involves local Universities
- Many students involved in all phases: construction, operation and analysis