Construction and Testing of the CALICE Digital Hadron Calorimeter

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CHEF2013, Calorimetry for High Energy Frontier
April 22-25, 2013 Paris, France

Digital Hadron Calorimeter (DHCAL)

Concept of the DHCAL

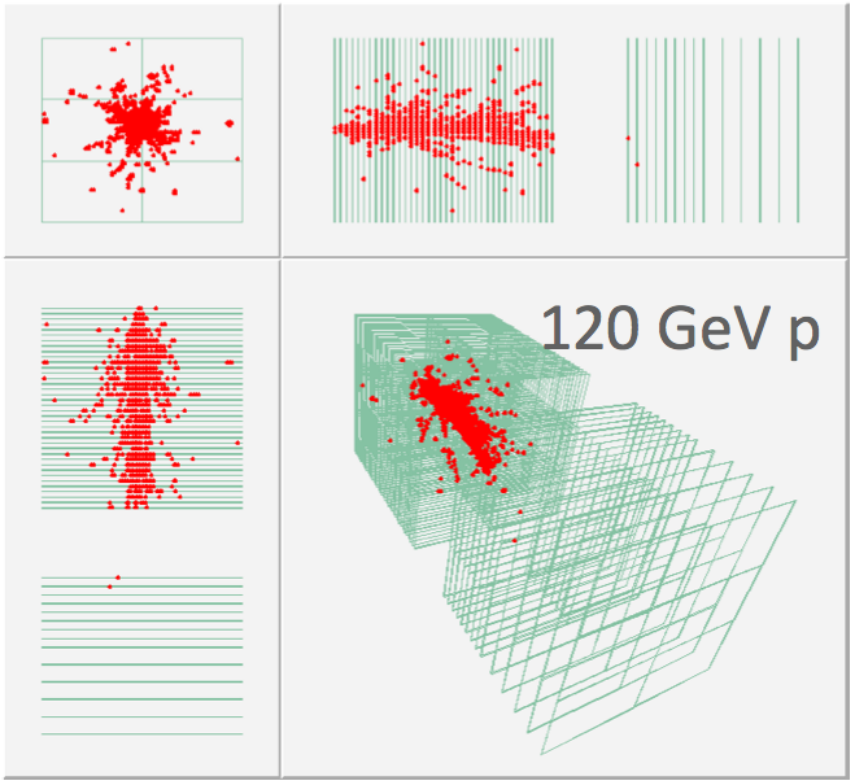
• Imaging hadron calorimeter optimized for use with PFA

• 1-bit (digital) readout

• 1 x 1 cm^2 pads read out individually (embedded into calorimeter!)

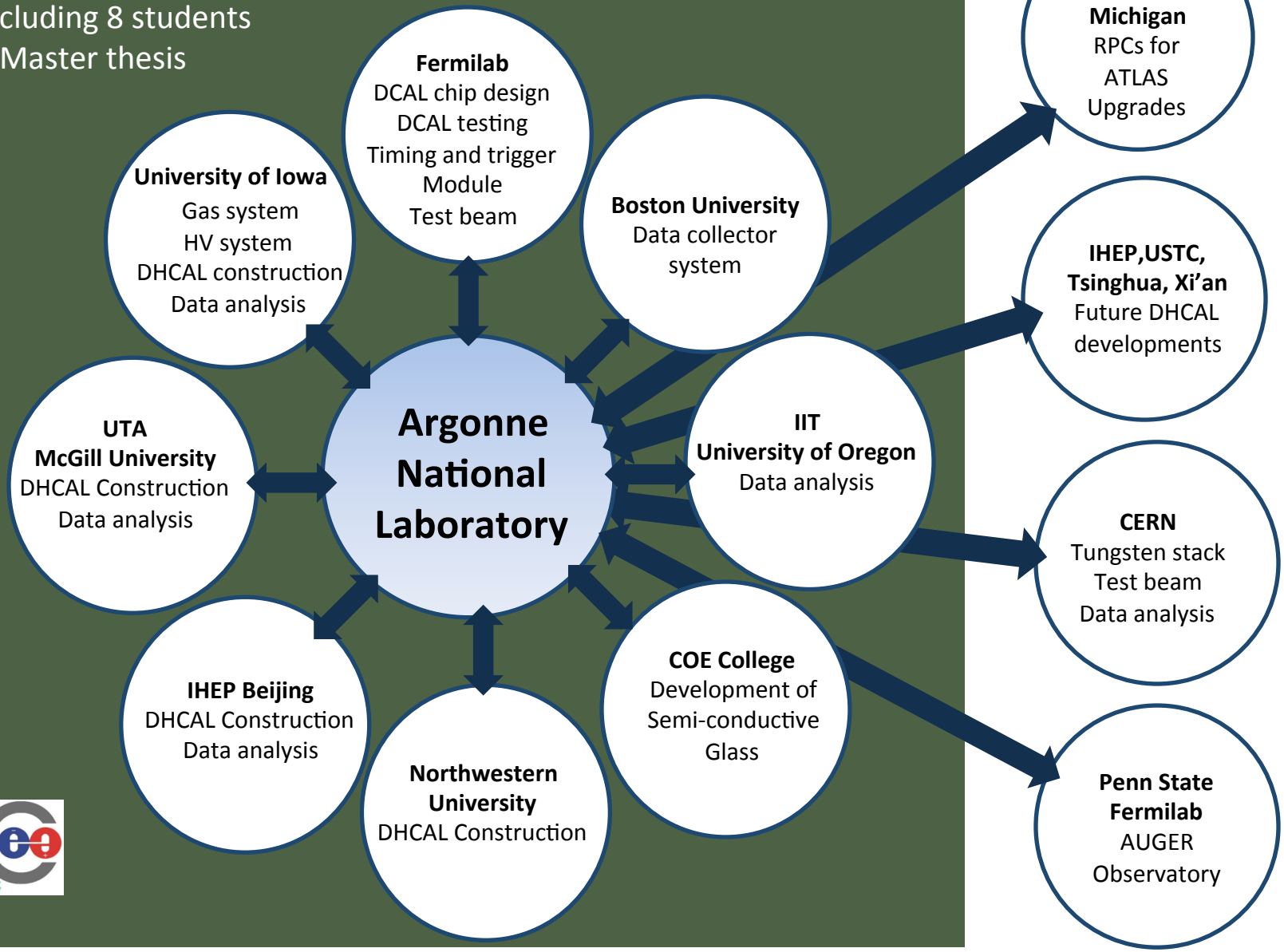
• Resistive Plate Chambers (RPCs) as active elements, between steel/ tungsten

- Each layer with an area of ~ 1 x 1 m^2 is read out by 96 x 96 pads.
- The DHCAL prototype has up to 54 layers including the tail catcher (TCMT) ~ 0.5M readout channels (world record in calorimetry!)



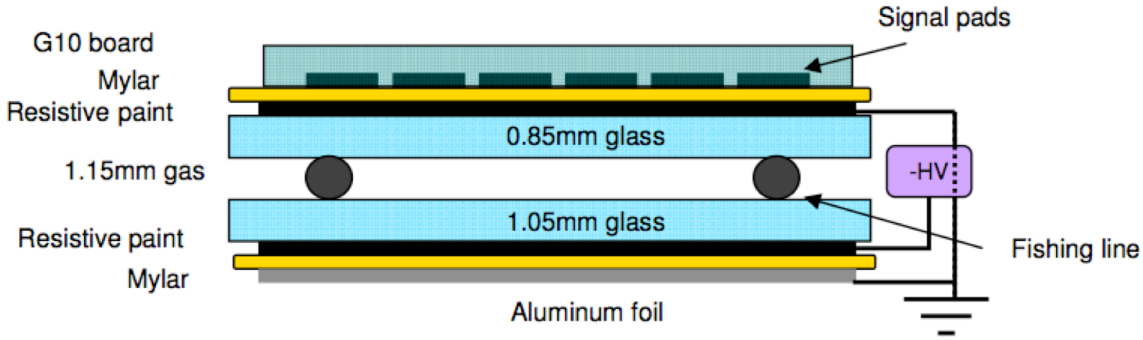
The DHCAL Collaboration

40 people, including 8 students
→ 2 PhD, 1 Master thesis

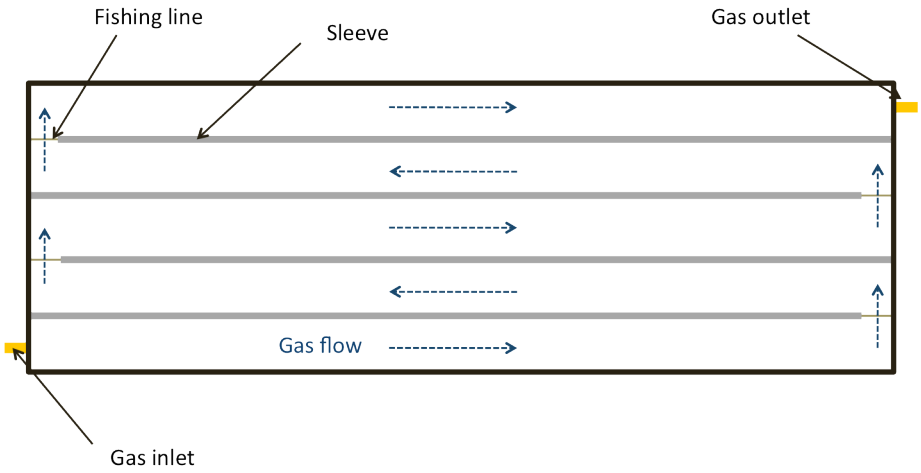


CALICE Calorimeter for ILC

Resistive Plate Chambers (RPCs)

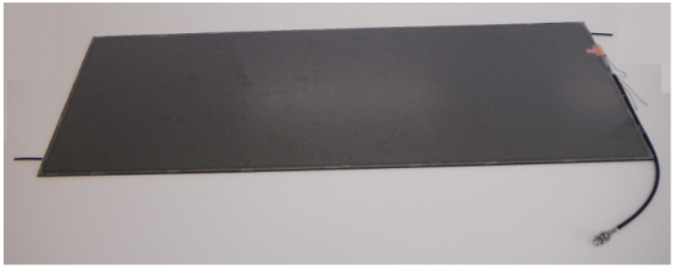


Gap size and gas flow uniformity is maintained via fishing line channels

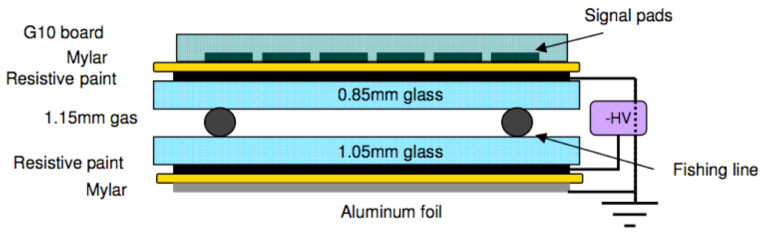


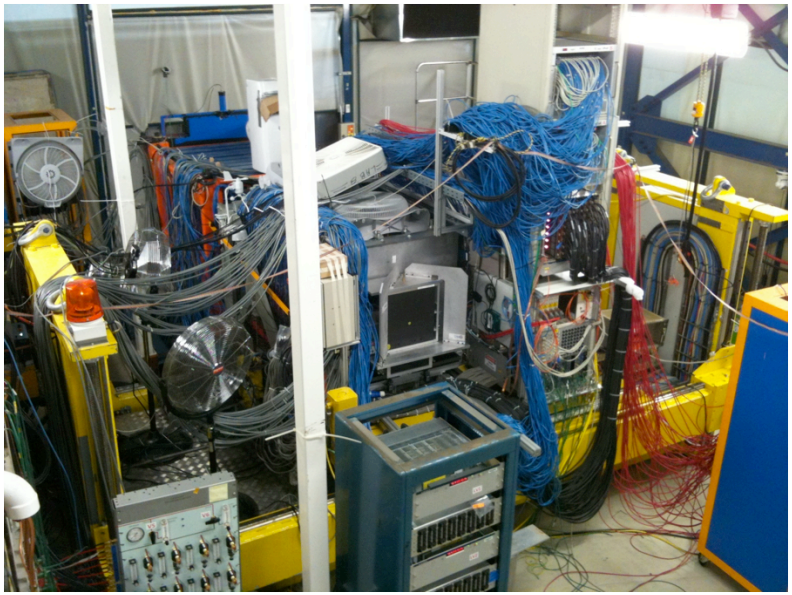
How it works

1. Charged particle ionizes gas (Freon+Iso-butane +SF6)
2. The free e^- initiates an avalanche in the gas gap in the electric field
3. Charge induced on pads
4. Charge pulse flows to ASICs for processing (amplifier, threshold, etc.) and data acquisition



DHCAL Construction





Stages of Construction

- RPC Painting
- RPC Construction
- Front-end electronics
- Cassette Assembly
- Back-end electronics
- Gas System
- DAQ Software
- Event builder and display

RPC Painting

Challenges/Requirements

- Provide uniform surface resistivity

1-5(10) $^{M\Omega}/_{\square}$ on thin (thick) glass

  - high R reduces rate capability
  - low R increases multiplicity

- Maximize coverage of paint (HV) across RPC
- Produce ~ 500 sheets

The Paint

2-component artist (airbrush) paint
needs to be mixed and sprayed
(paint booth and spray gun)

Paint Booth:

large structure to exhaust fumes and
instrument step motors for gun control

Spray Gun:

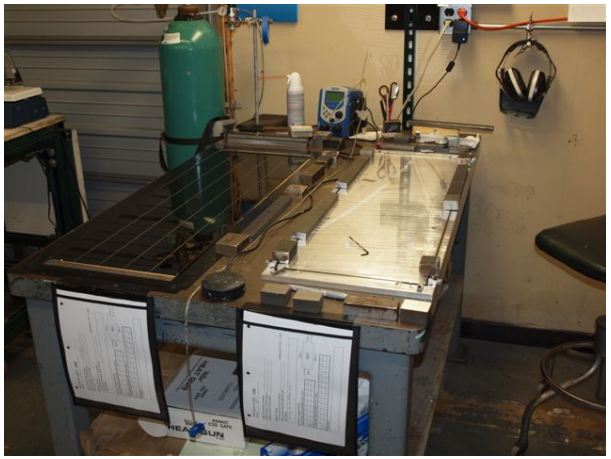
Commercial paint gun with fine control and
rugged construction (easy to clean)
Uses nitrogen (dry gas) to carry paint

Production Procedure

Mix paint
Clean glass
Mask rims
Operate booth → 8 sheets/day
Clean tools

RPC Assembly and Quality Control

Assembly
Cut frames (sets gap size)
Assemble and glue chambers
1 RPC/day/tech



<u>RPC Quality Control and Validation</u>

Pressure tests – chambers are sealed

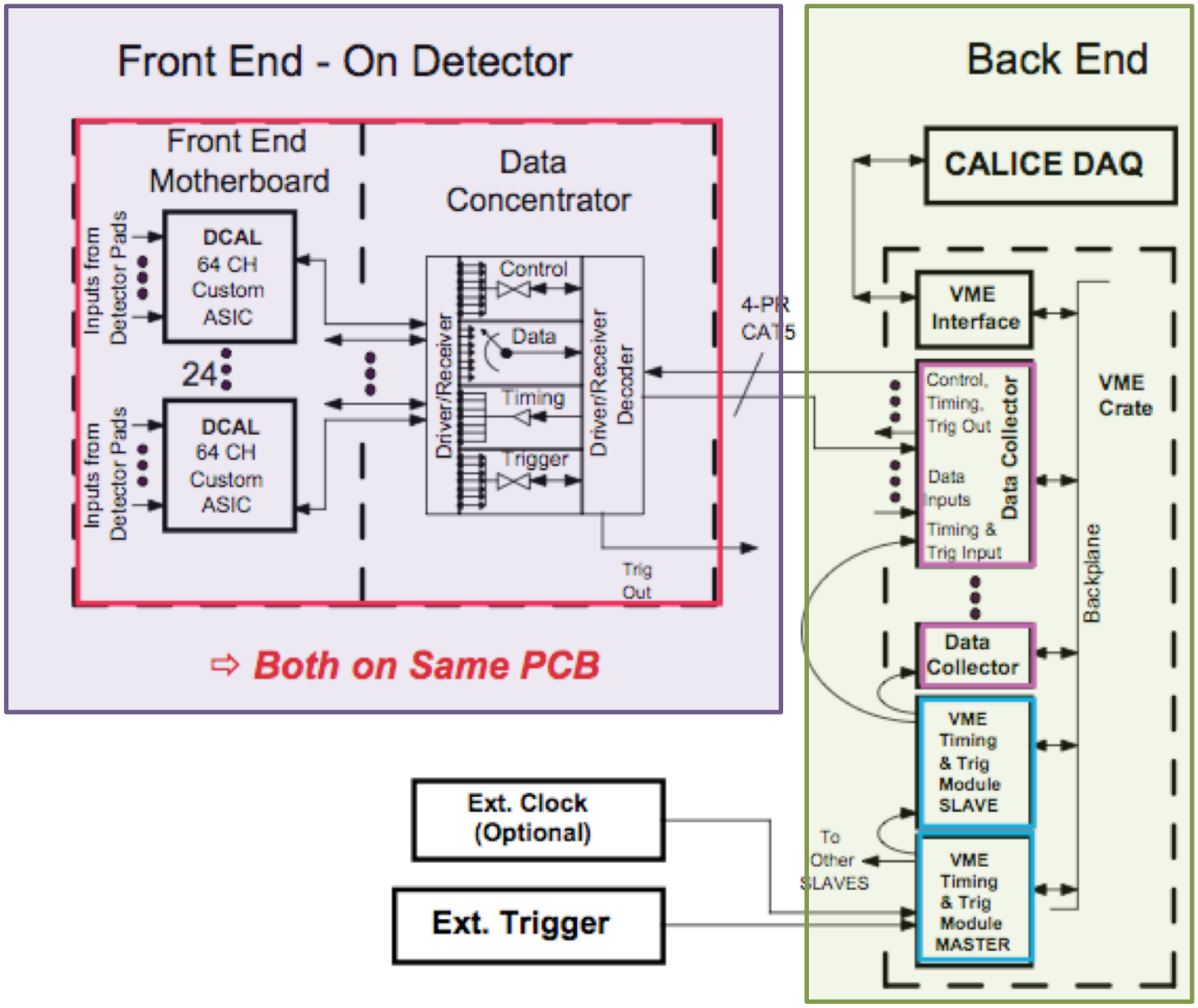
Gap size measurement – maintain uniform electric field in gas gap

HV tests – tests connections in cassette environment

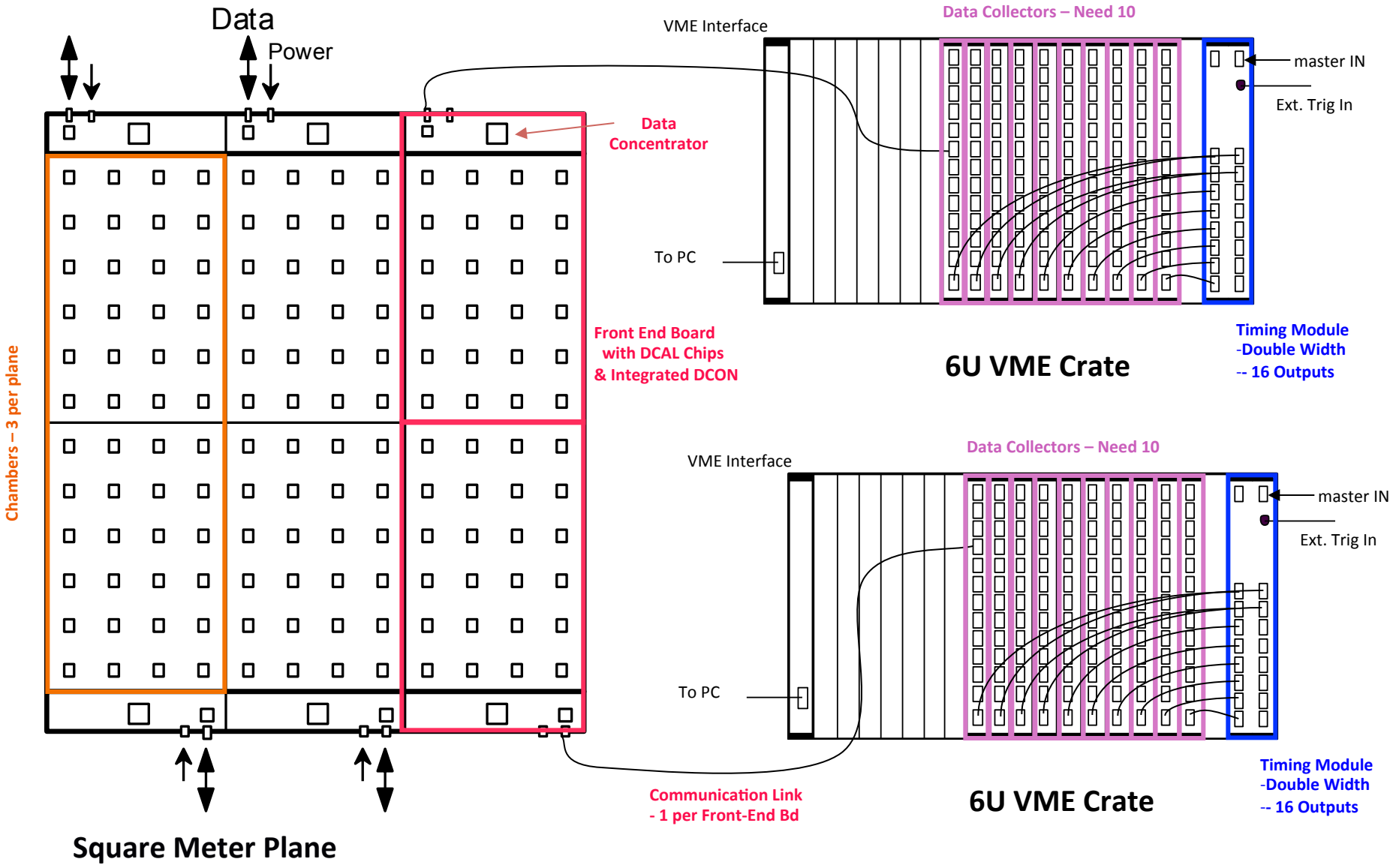
Cosmic Ray Test Stand (9 RPCs stacked vert.)
- validate production
- test front-end electronics
- noise measurements
- HV scans → multiplicity and efficiency

> 95% of the RPCs pass the quality control tests

Electronics Overview



Readout System Overview



The DCAL Chip

Developed by

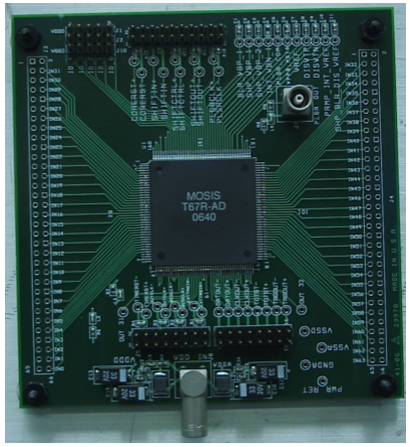
FNAL and Argonne

Input

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

Threshold

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



Readout

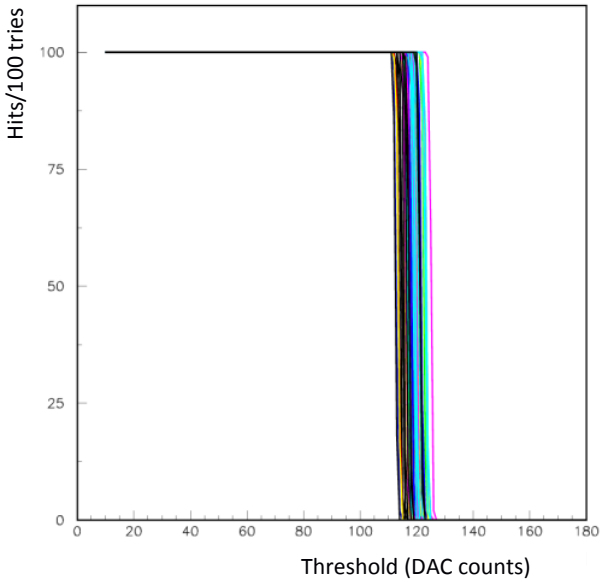
Triggerless (noise measurements)
Triggered (cosmic, test beam)

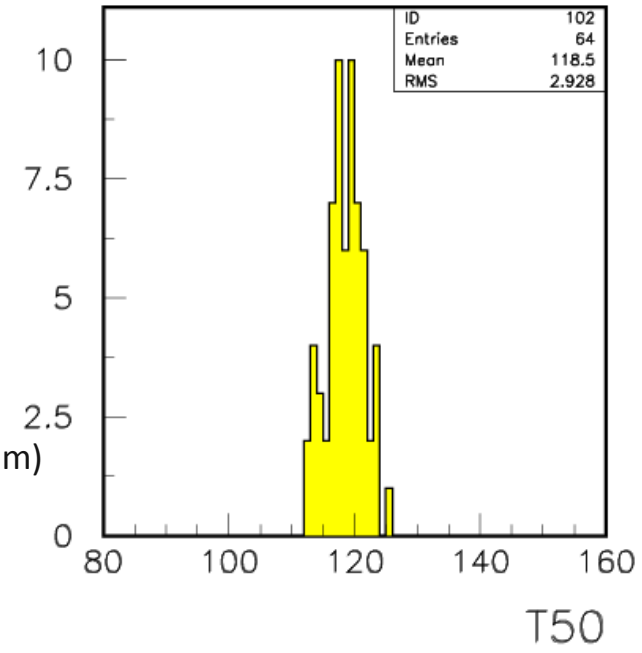
Versions

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)

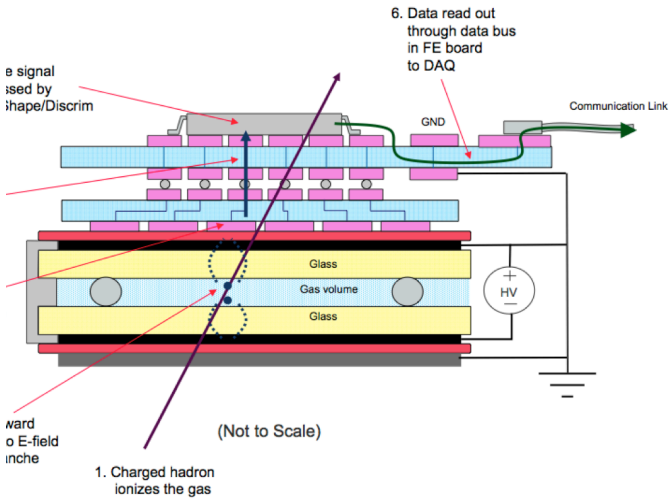
Production of DCAL III

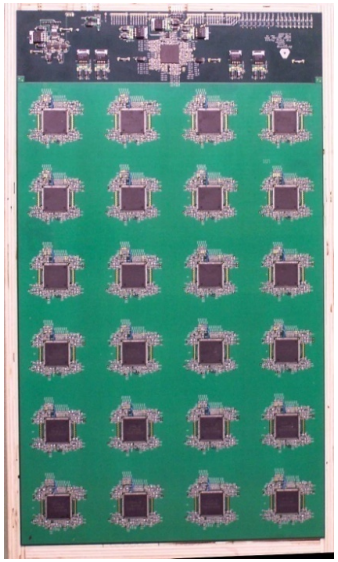
11 wafers, 10,300 chips, fabricated, packaged, tested





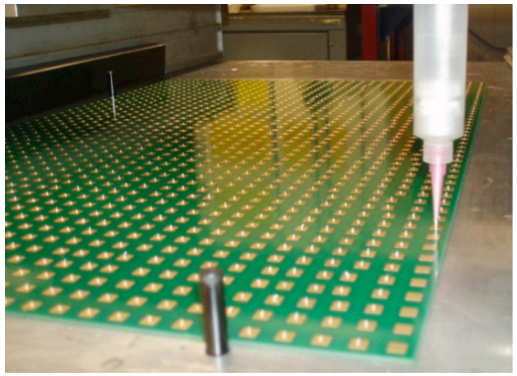
Front-end Electronics and Gluing





Front-end board (FEB) assembly

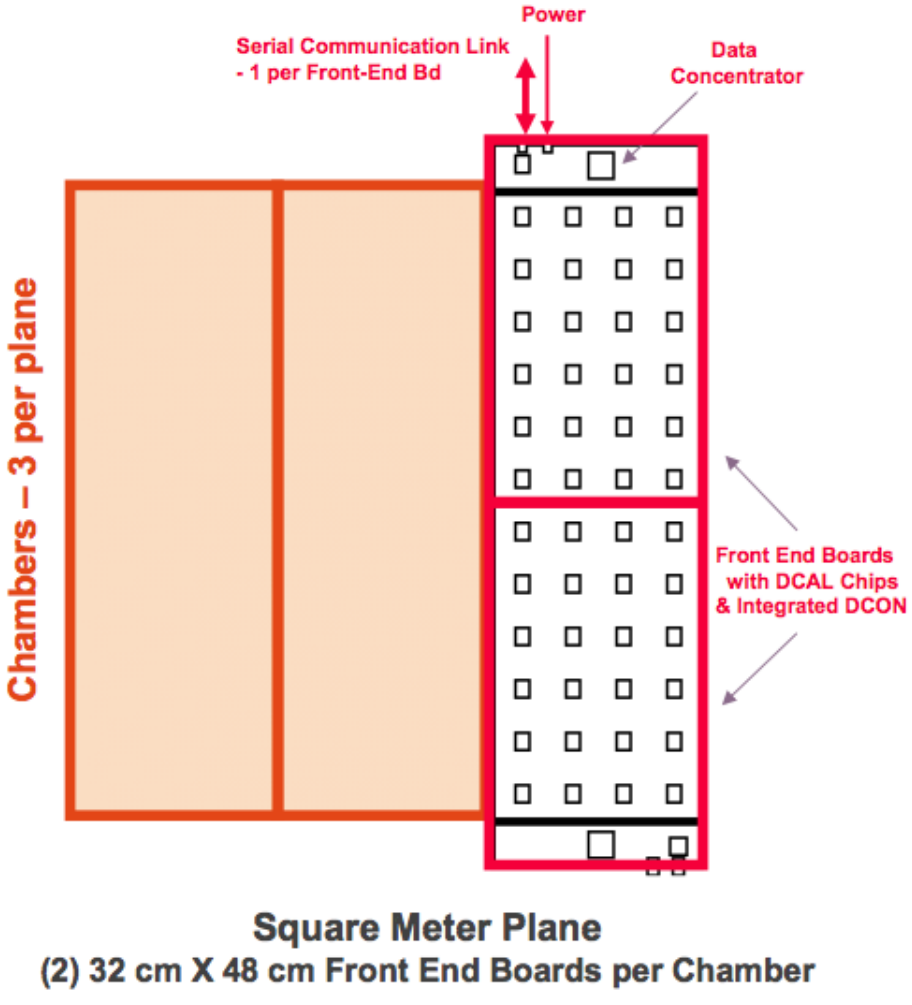
- Build electronics and pad boards separately to avoid blind and buried vias
- Each FEB contains 1536 channels
- A data concentrator is implemented
- Test electronics (noise rates, threshold curves,…)



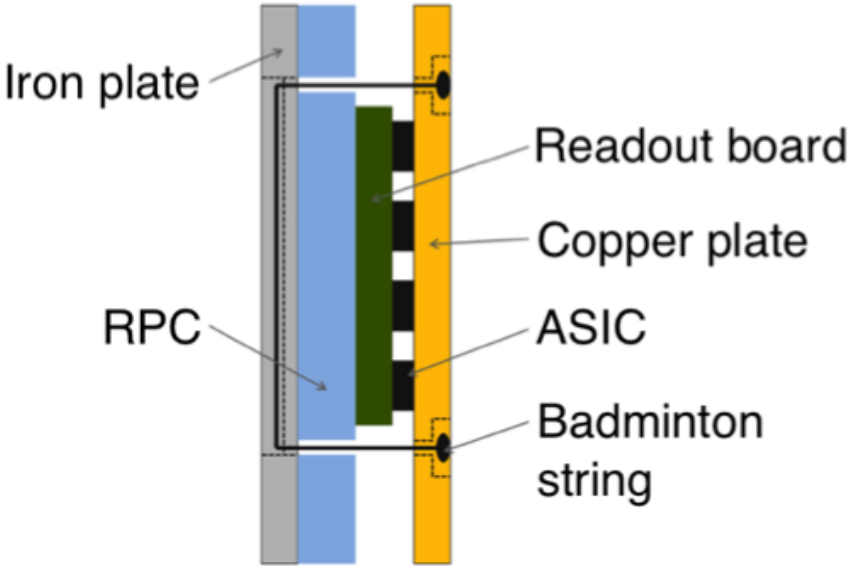
Glue Robot

- Glue is a conductive epoxy
- Robot precisely places glue dots
- 0.001” thick plastic film used as spacers
- dried in oven over night
- 10 boards/day
- >300 FEB fabricated

Cassette Design



- structurally hold RPCs within steel structure
- large copper and steel sheets
- 3 RPCs for each cassette
- 6 FEBs readout RPCs
- maintain FEB contact with RPC (badminton strings
- cool electronics (Cu)



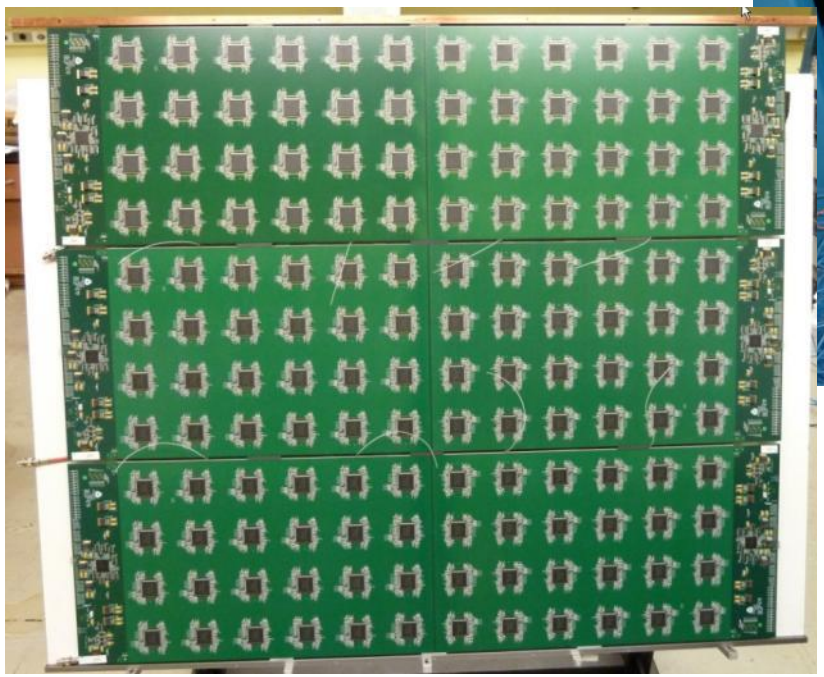
Cassette Assembly

Assembly

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

Cassette Testing

- Cassettes are tested in the cosmic ray test stand



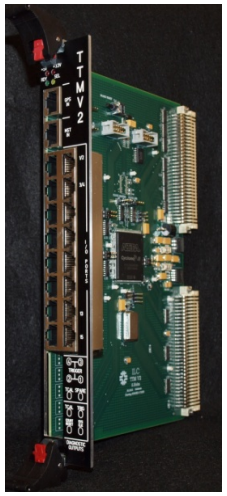
Supporting Systems

Back-end Electronics
(2 VME crates)
2 Trigger and Timing Modules
20+ Data Collectors

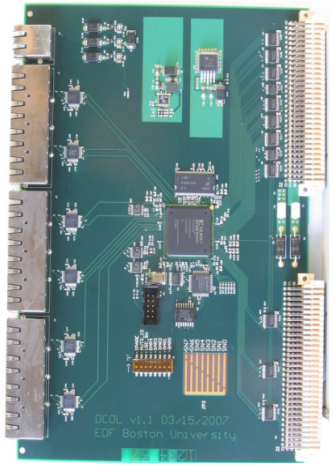
Low voltage distribution for FEBs

Gas System
- mixer and bubbler racks
- 1 channel feeds 6 RPCs
- leaky layers have individual supply

TTM



DCOL



mixer

bubbler

Fermilab

BOSTON UNIVERSITY

Argonne NATIONAL LABORATORY

THE UNIVERSITY OF IOWA

DHCAL in Test Beams

FNAL

Oct 10
Jan 11
Apr 11 (w/ CALICE SiW ECAL)
June 11

> 20M events

FNAL

Nov 11

~ 2M events

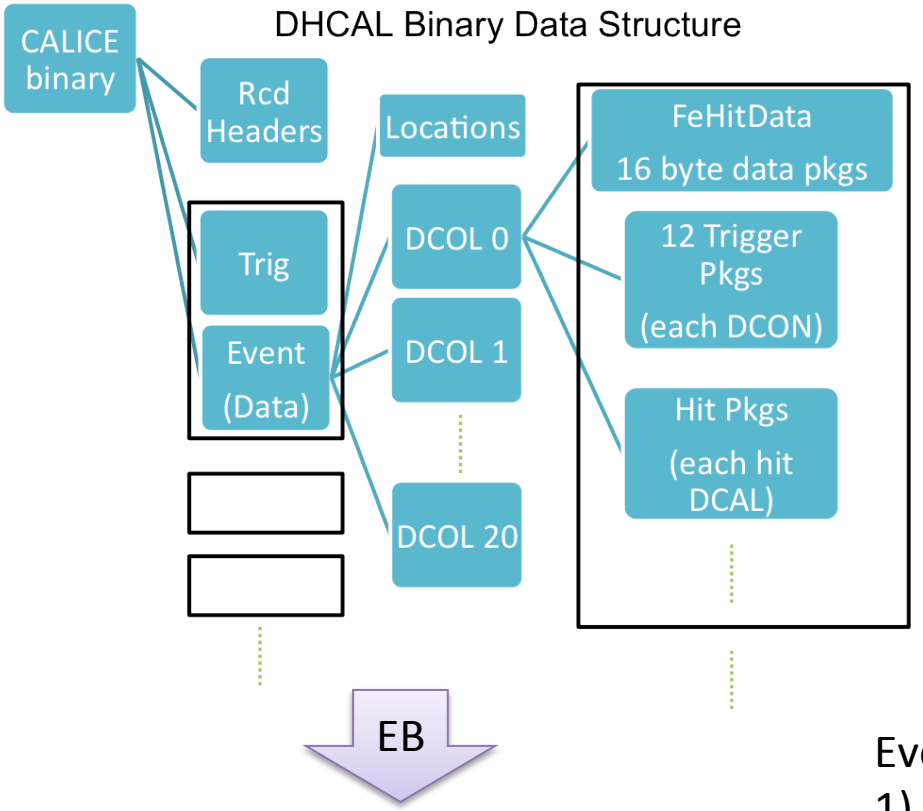
CERN

May 12
June 12
July 12
Nov 12

> 40M events

Event Builder

Event builder processing raw DHCAL data to convert complex binary format to a simple ASCII n-tuple format for data analysis



FeHitData contains FEB data for ASICS and data concentrator

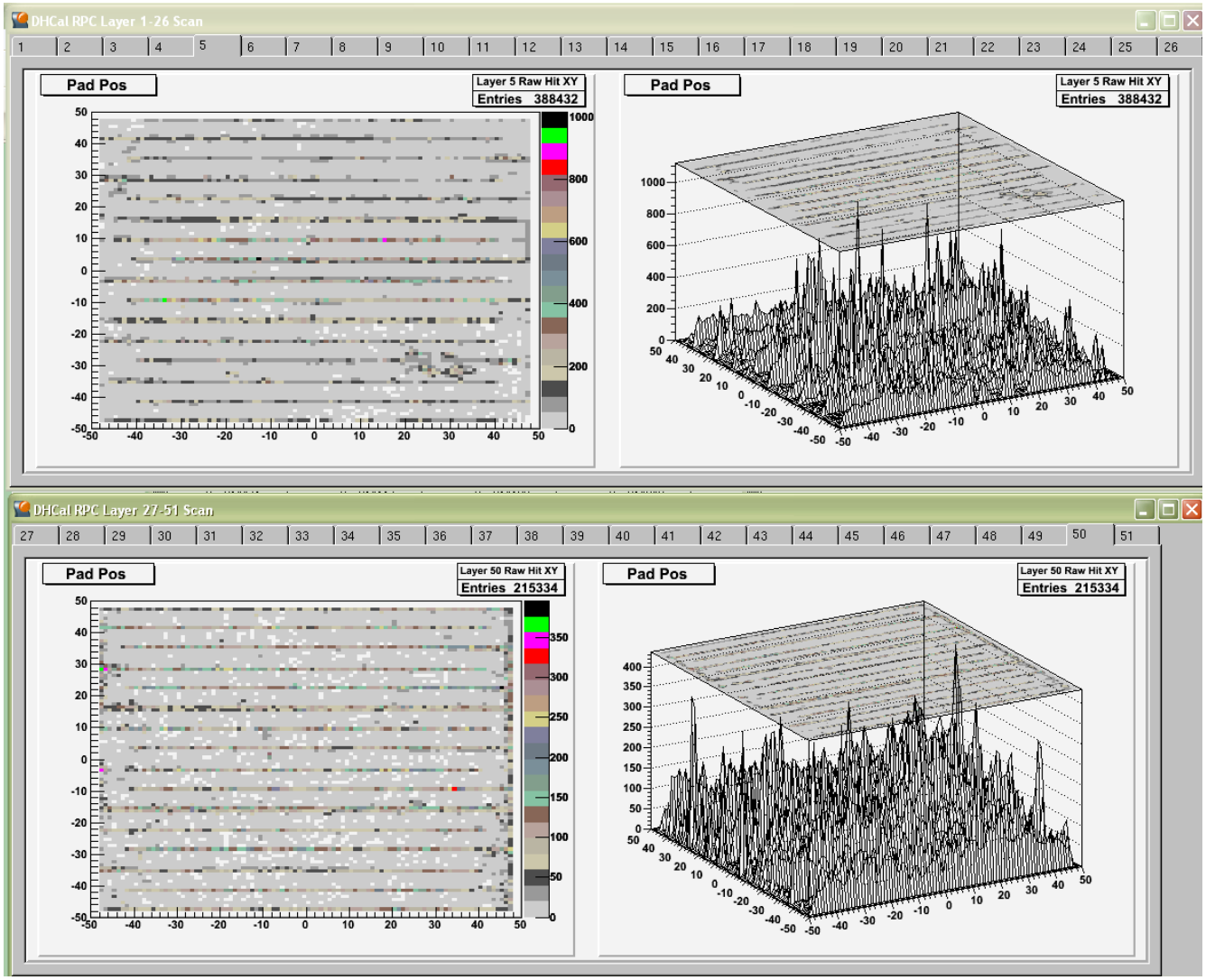
- location – address in system
- timestamps (100 ns resolution) relative (to clock) time bin of readout
- hit pattern in ASIC
- checksums

event TS	IL/-1	trigger tag	-1
hit TS	x	y	z
hit TS	x	y	z

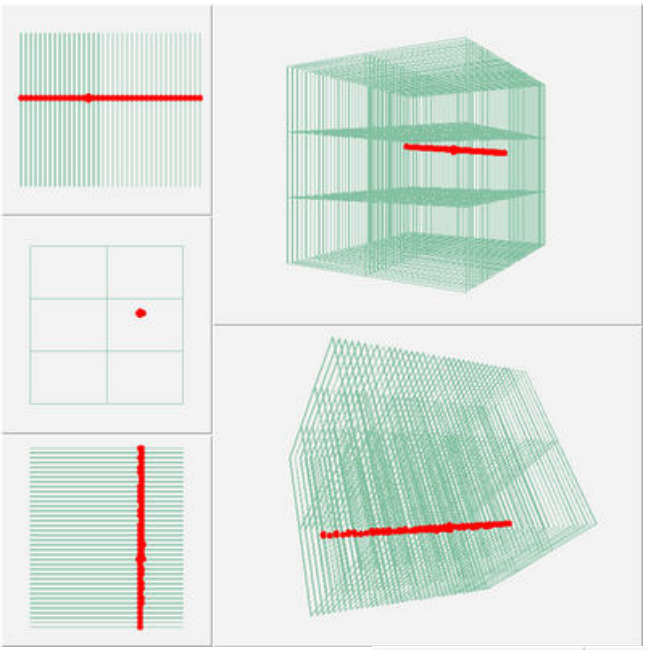
Event builder functions:

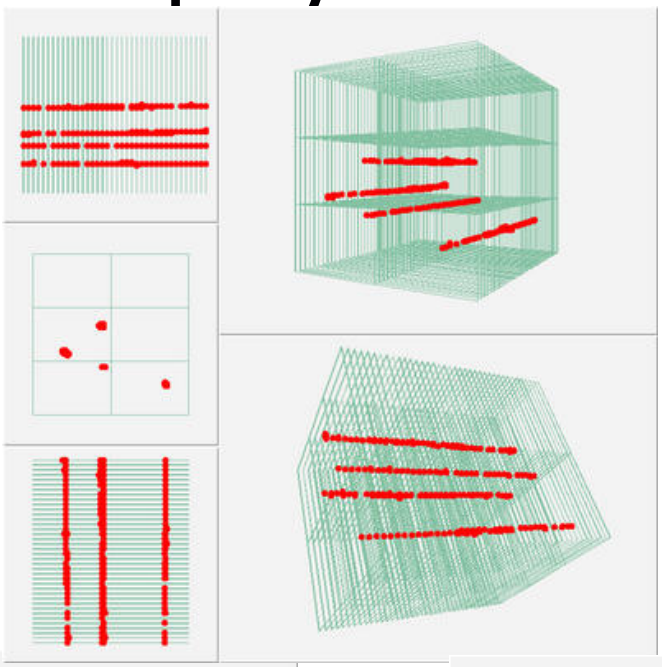
1) Filters corrupt data
2) Processes trigger/alt. detector information
3) scans neighbor events for misplaced events
4) maps locations to coordinates
5) writes ASCII file for data analysis

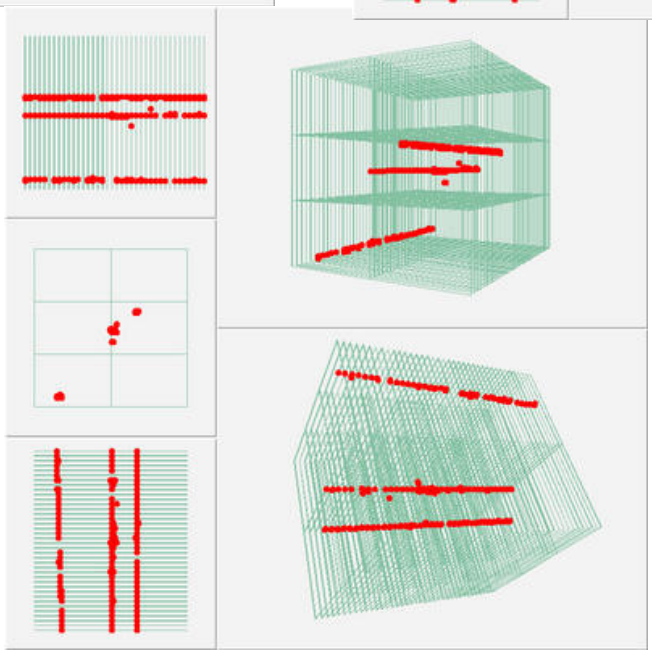
Noise Runs (Triggerless)

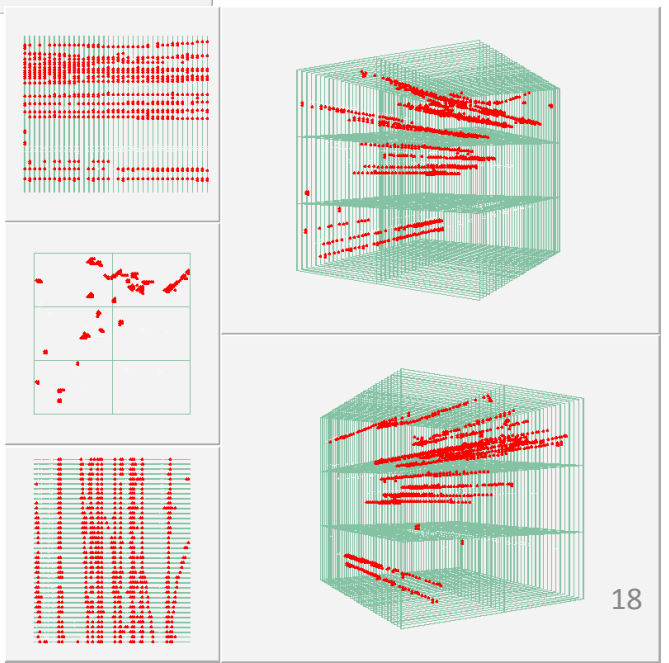


Event Displays: Muons

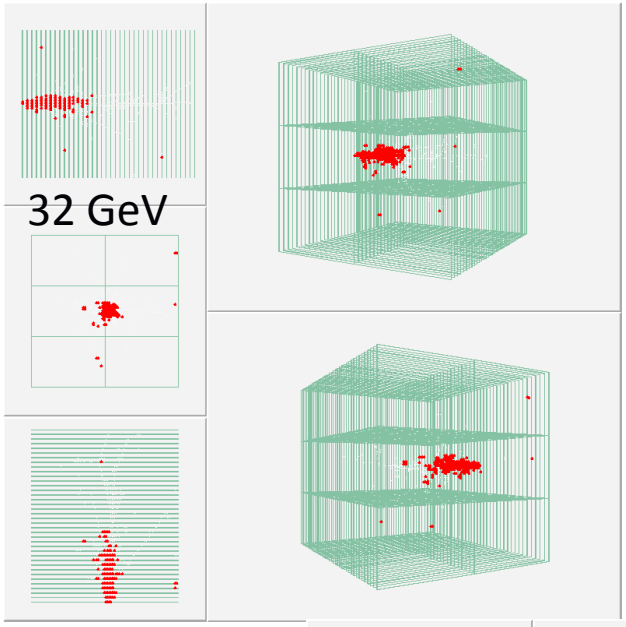


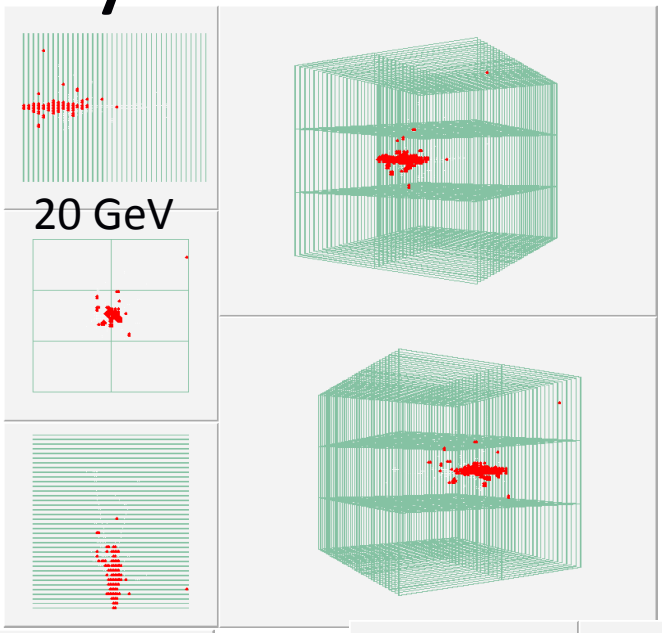


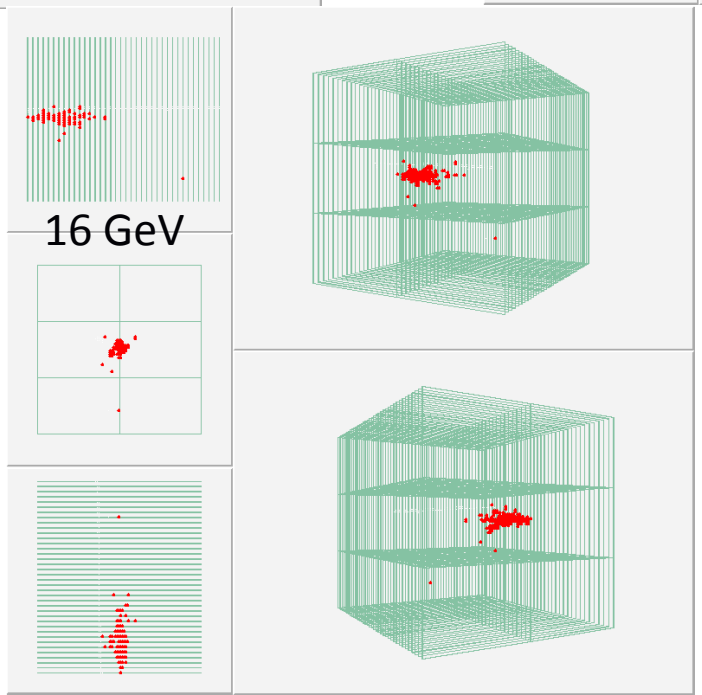


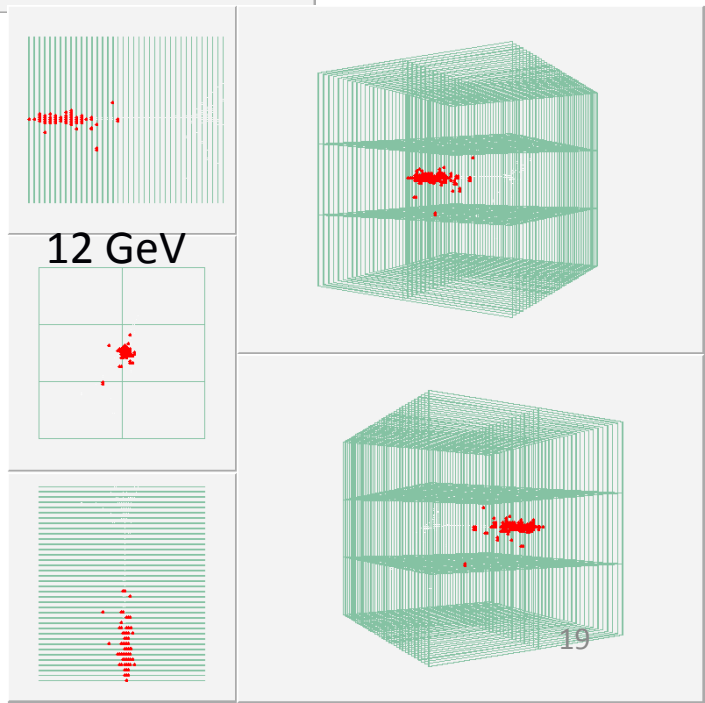


Event Displays: Positrons

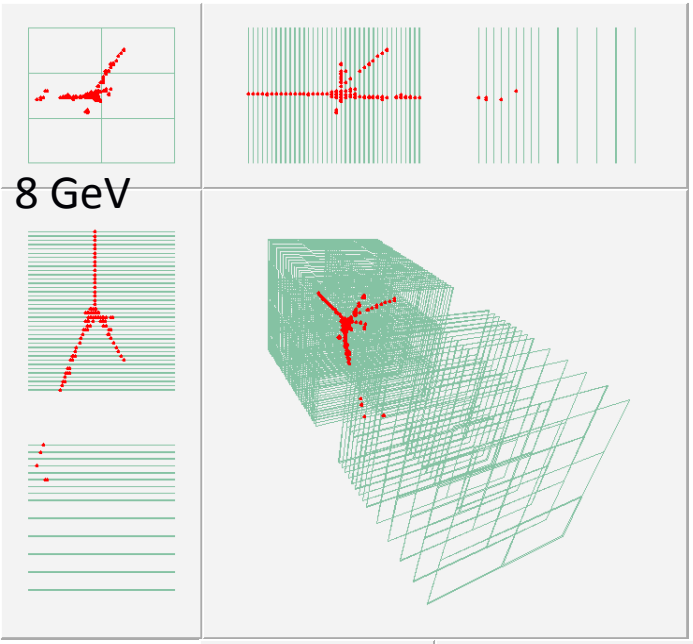


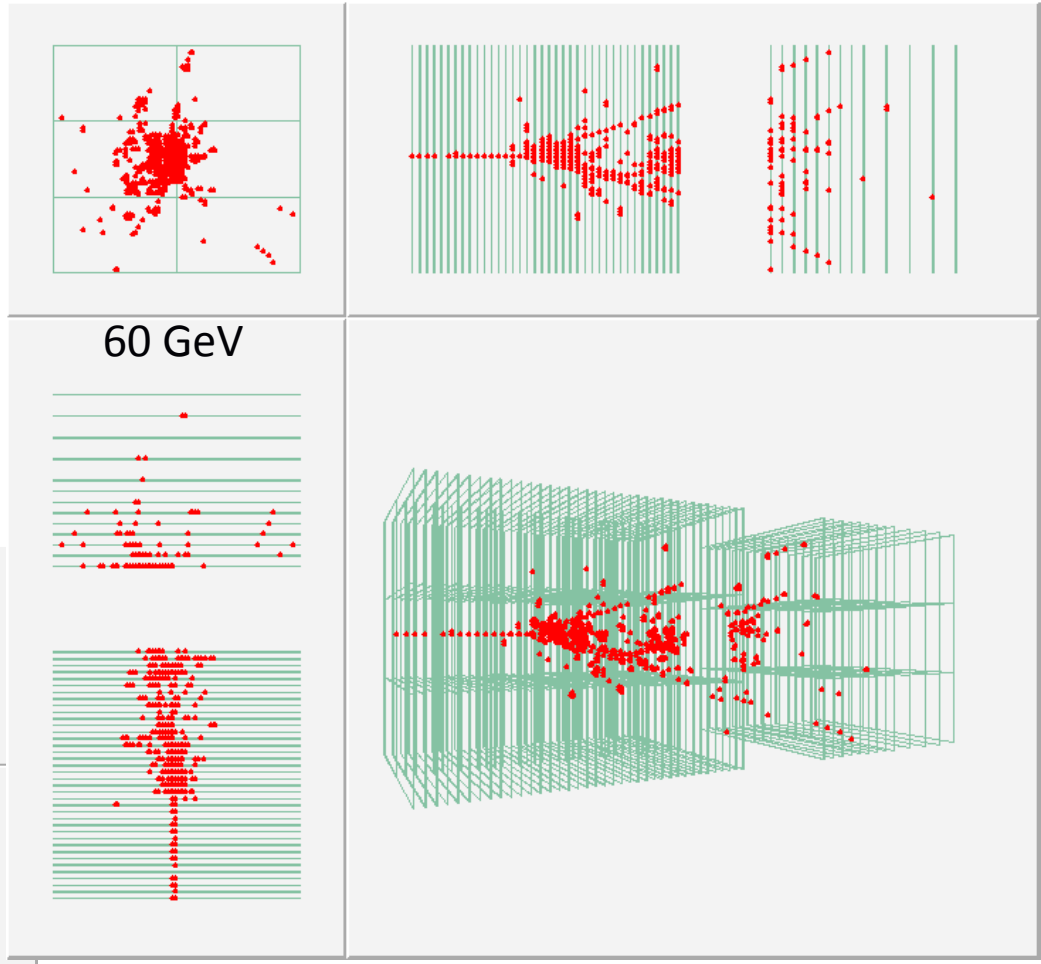


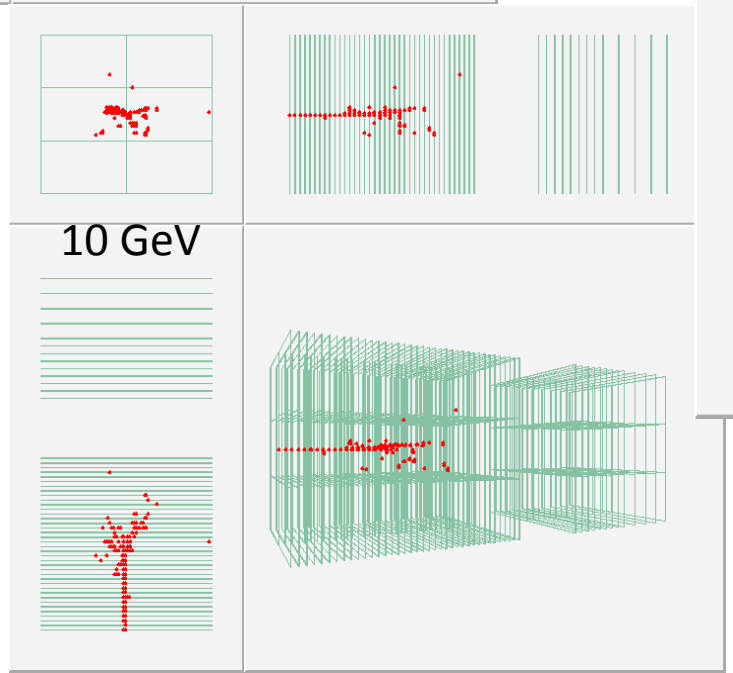




Event Displays: Pions

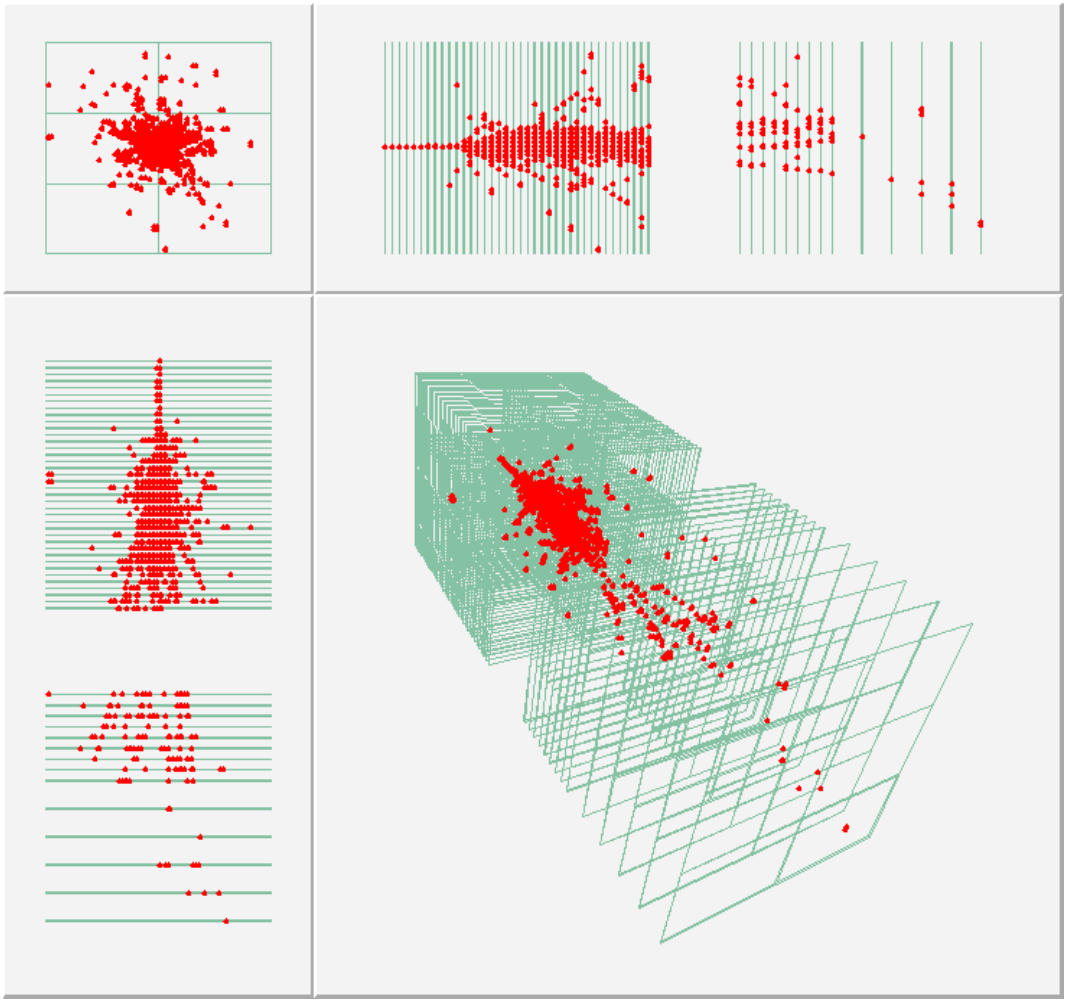






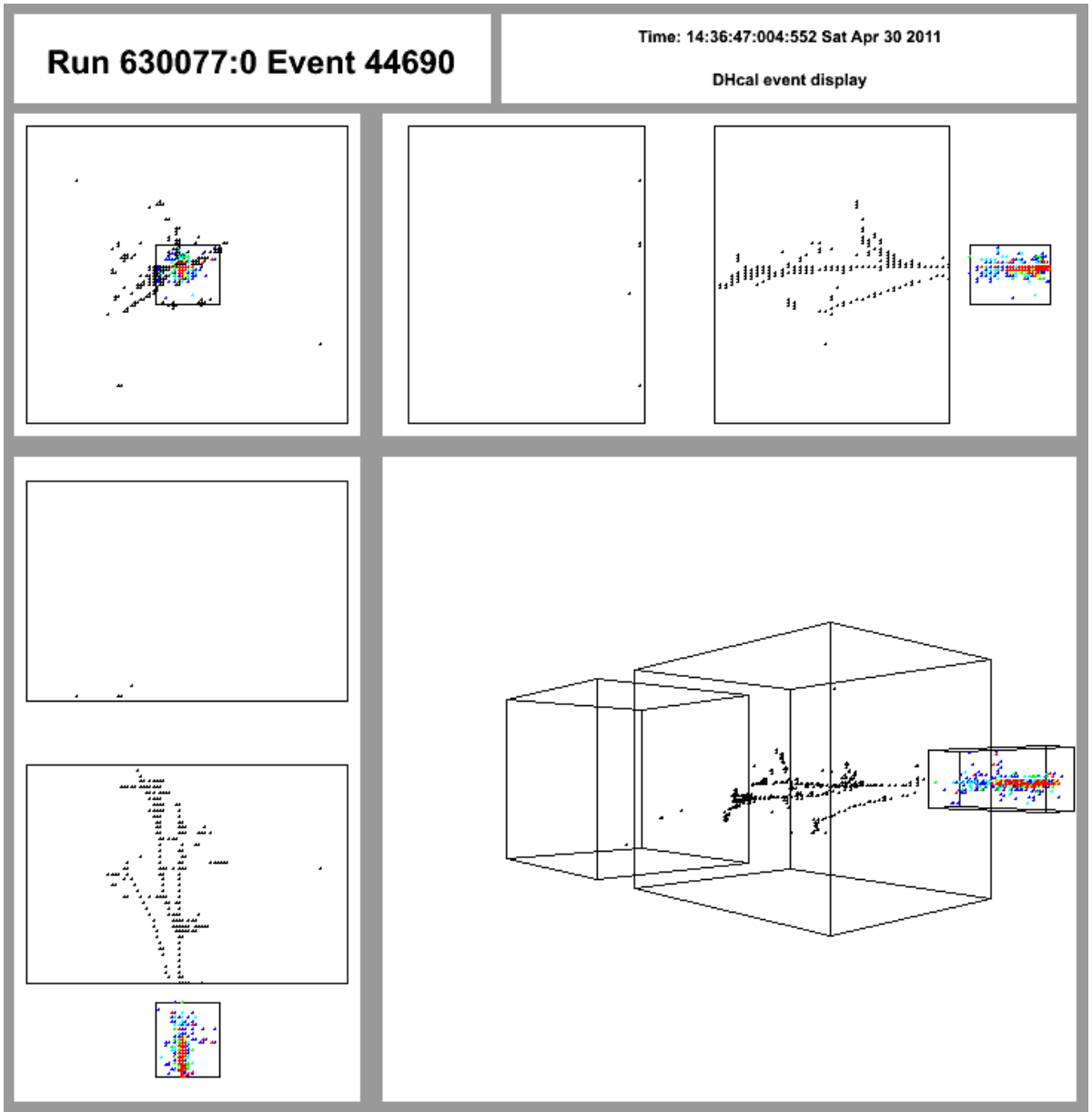
Event Displays: Protons

120 GeV



3D Event Display w/SiW ECAL

40 GeV π^+



Summary

- The construction of the DHCAL prototype (+TCMT) is completed in 2008-2010
- DHCAL prototype (+TCMT) works extremely well with negligible noise levels and robust performance
- Completed the test beam program: 5 TB campaigns at FNAL and 4 at CERN
- ~ 80M events under a rigorous analysis program
- Many publications are underway