Application of Large Scale Gas Electron Multiplier Technology to Digital Hadron Calorimetry

Andy White

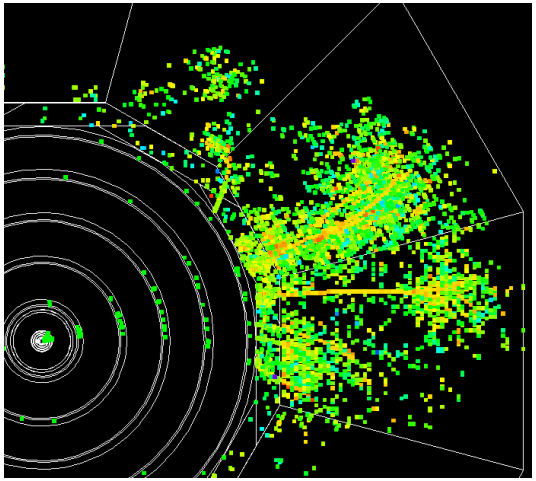
University of Texas at Arlington

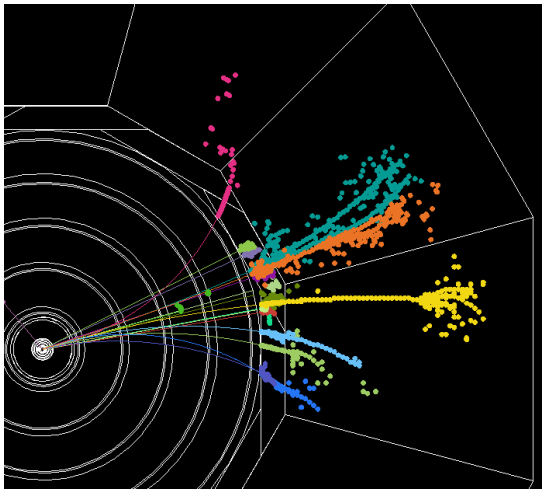
For GEM DHCAL Group

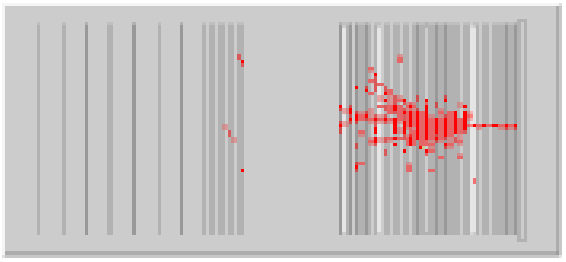
SiD Workshop SLAC 2012

- Introduction
- KPiX and DCAL Integration
- FTBF Beam Test Setup
- Beam Test Analysis Results
- Large Chamber Development
- GEM DHCAL Plans
- Summary

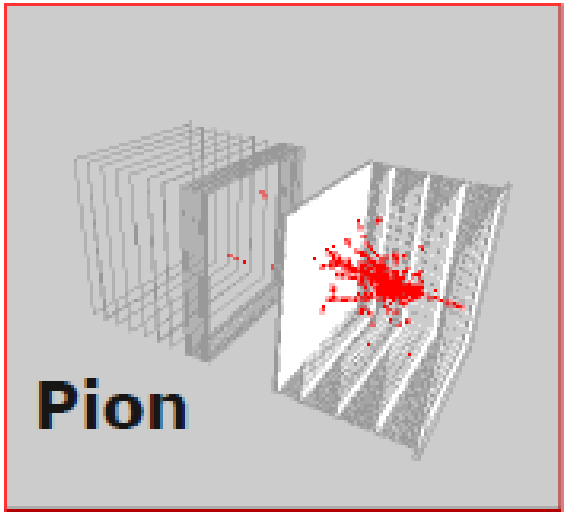
Motivation
Particle Flow Calorimetry – technology choice







Results from RPC stack



The Goals

- Develop and construct precision calorimetry for future accelerators
- Demonstrate suitability of DGEM layer as active element of DHCAL
- Construction/testing of DGEM chamber/layers of various sizes – to $1m^2$.
- Study of the response of double-GEM chambers to charged particles
- Use of analog (KPiX) and digital (DCAL) readout with GEM.
- Debugging series of KPiX chips with SLAC.
- Measurement of DGEM chamber/layer characteristics
- Understanding of issues with chambers/layers (sparks, cross-talk,…)
- Develop large GEM foils with CERN MPGD Workshop.
- Develop design (frame/spacers/gas/HV…) for large chambers (~1m x 33cm).
- Establish operating conditions for large GEM/DHCAL chambers

GEM-based Digital Calorimeter Concept

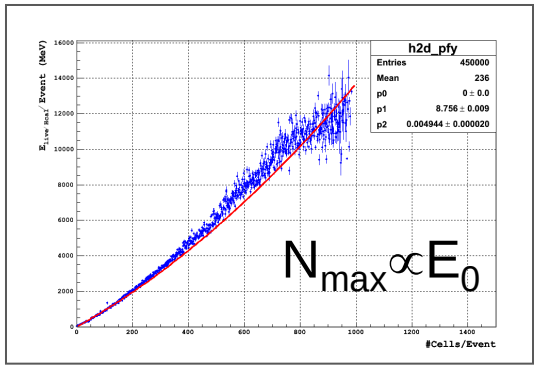
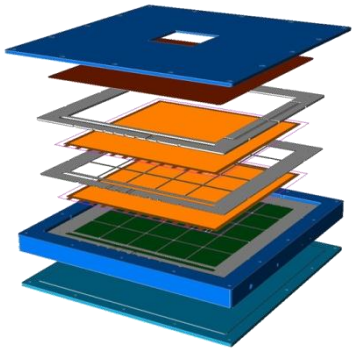


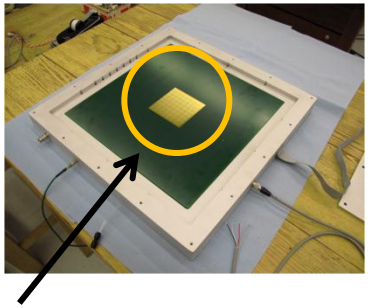
Fig. 1: Schematics of a double-GEM detector.

30x30 prototype GEM chamber and Readout Electronics

Chamber

- GEM Foils(3M)
  - 310x310 mm^2
  - Active area : 280x280 mm^2
- Active gas volume
  - 350x350x6 mm^3 → For 3/1/1 gaps
- Readout channels: KPIX(64), DCAL(256)



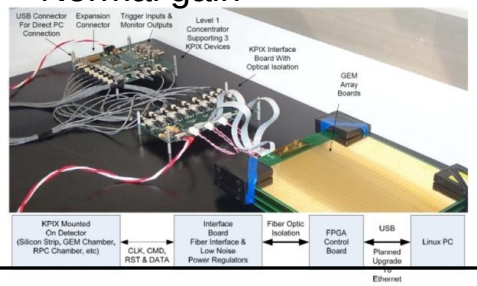


64-readout pads(KPIX)

Readout systems

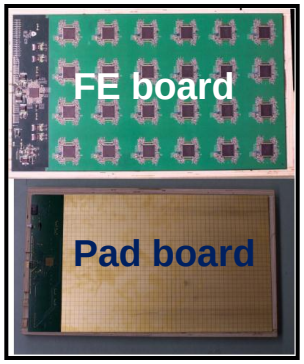
❖**KPiX readout system/SLAC**

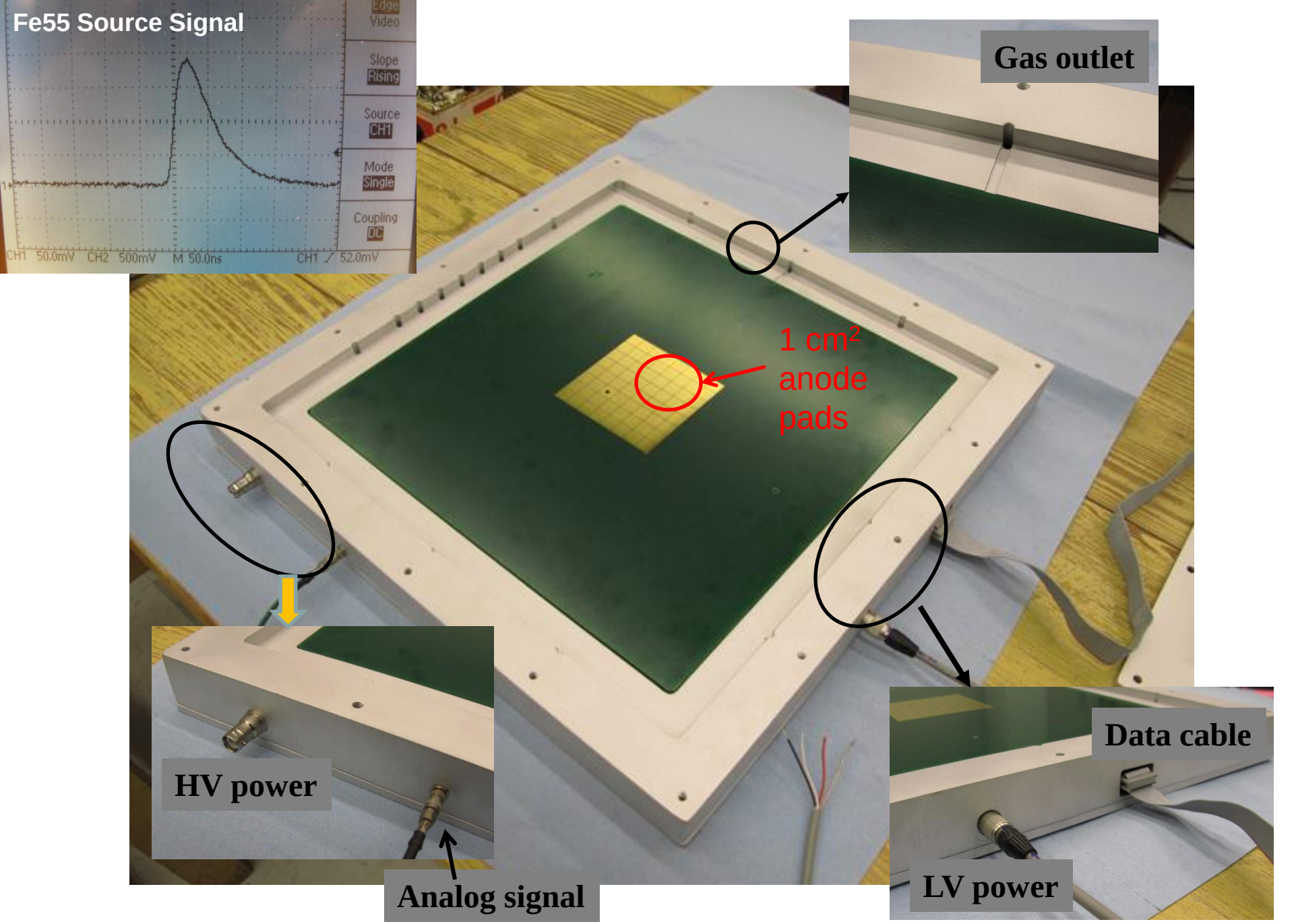
- ✓ 13 bit resolution(ADC)
- ✓ Designed to handle 1024 channels/chip, currently 64/chip (ver.7)
- ✓3 gain ranges
- Normal gain



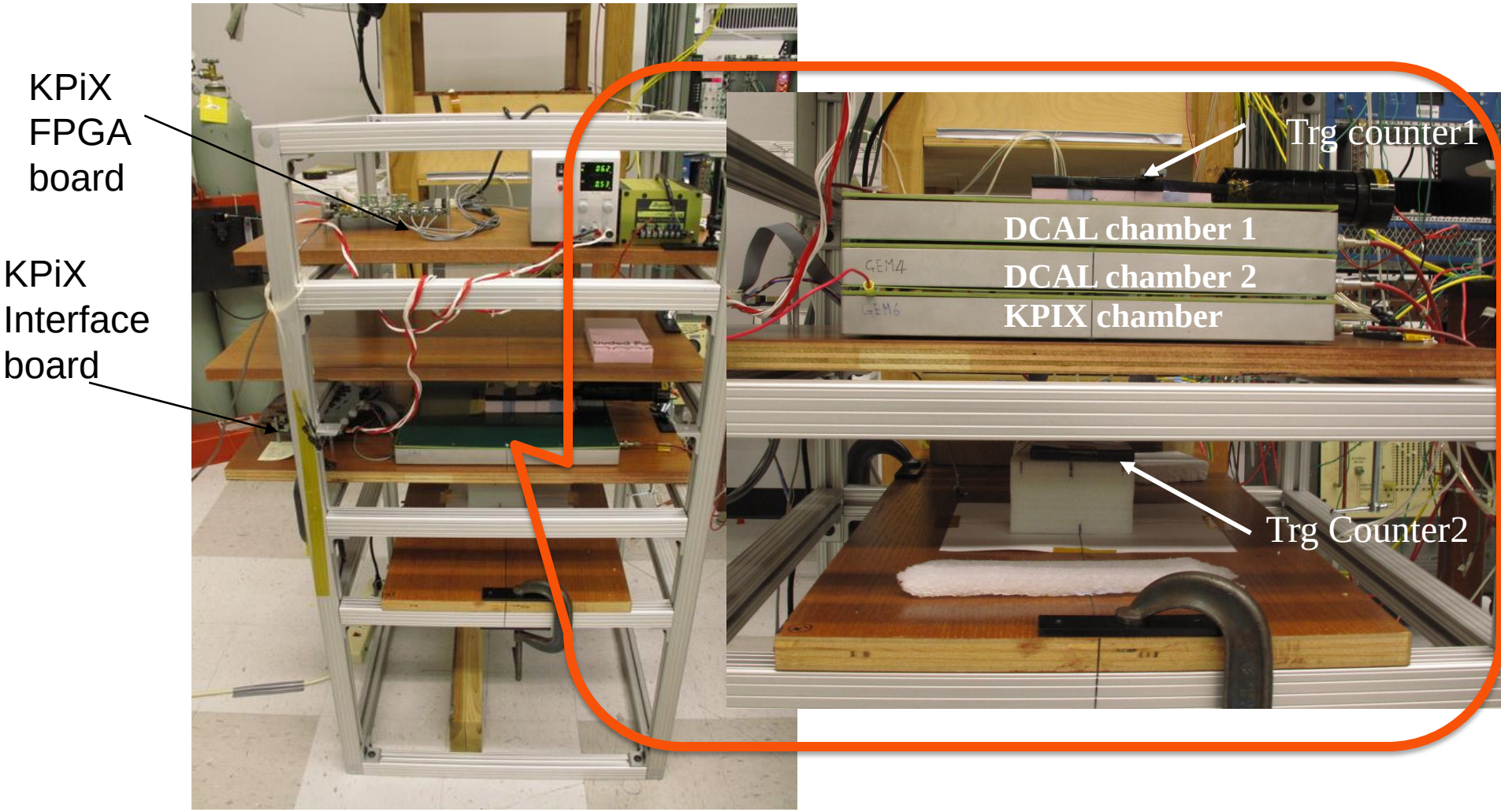
❖**DCAL readout system/ANL**

- ✓ 1 bit resolution(ADC)
- ✓ 64 channels/chip
- ✓2 gain ranges
- High gain for GEMs (10 fC~200 fC signals)
- Low gain for RPCs (100 fC~10 pC signals)




Fe55 Source Signal
Edge
Video
Slope
Rising
Source
CH1
Mode
Single
Coupling
DC
CH1 50.0mV CH2 500mV M 50.0ns CH1 ∕ 52.0mV
Gas outlet
1 cm²
anode
pads
HV power
Analog signal
Data cable
LV power

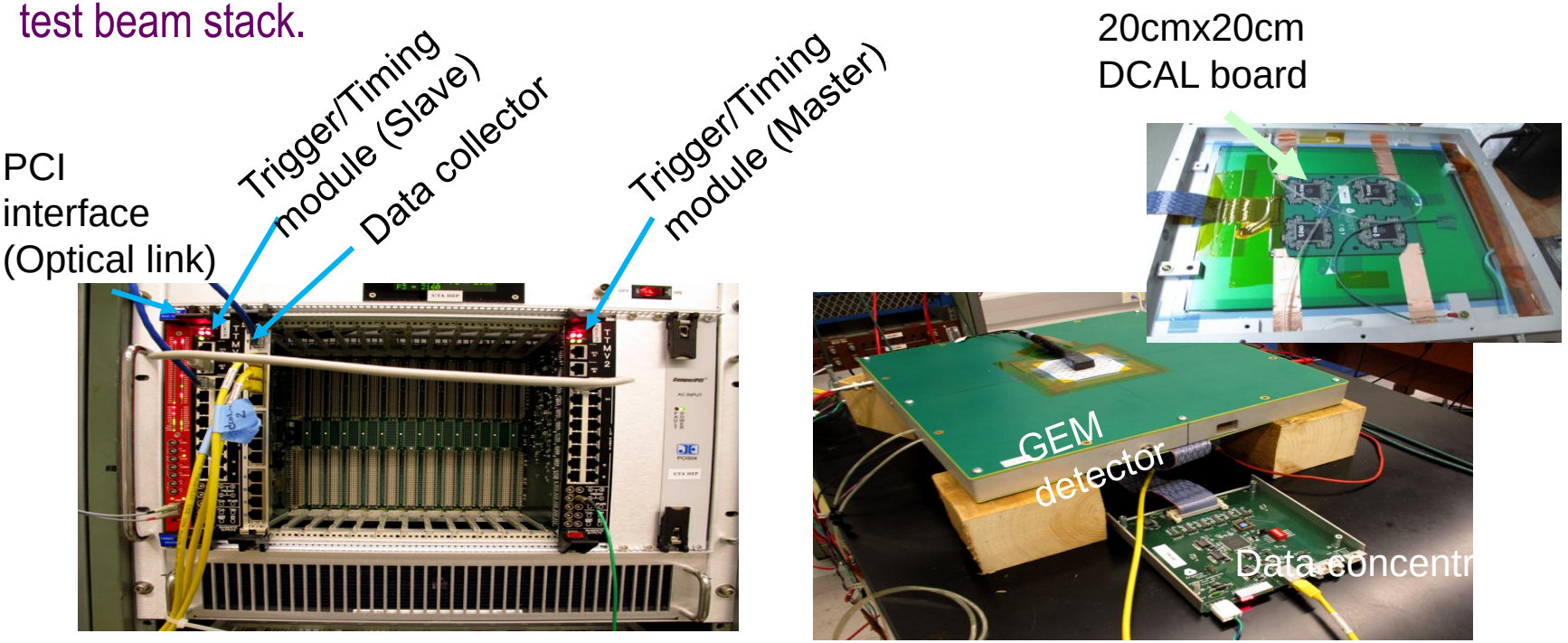
UTA GEM-DHCAL Cosmic Test Stand



GEM Integration with DCAL Chip

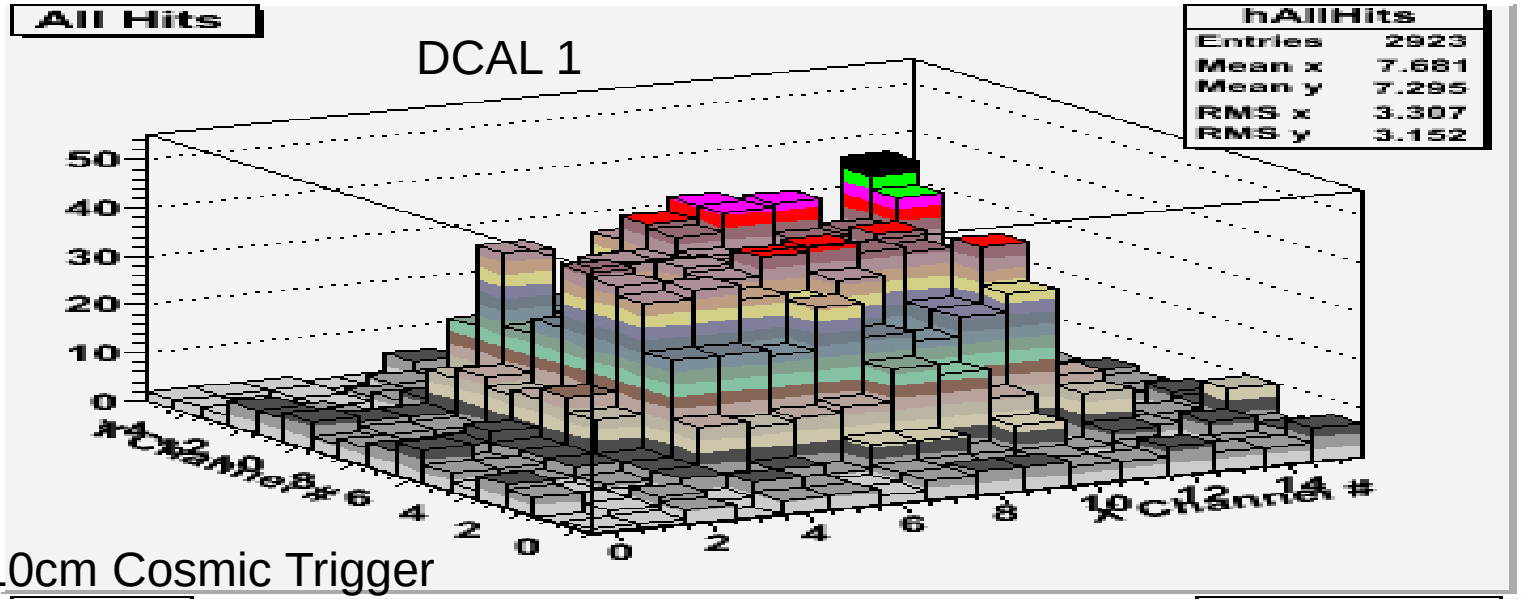
Goal: Enable readout of GEM/DHCAL planes via DCAL as the readout electronics of a $1m^3$ stack ➔ Chip has been well tested with RPC DHCAL stack (ANL)

- Use DCAL in high-gain mode to establish MIP signals.
- Determined noise level for DCAL/GEM combination
- Determined operating threshold(s) for DCAL
- Determine efficiency/uniformity/multiplicity for GEM/DCAL
- Understand issues of using DCAL readout system with $1m^2$ GEM/DHCAL planes in a test beam stack.

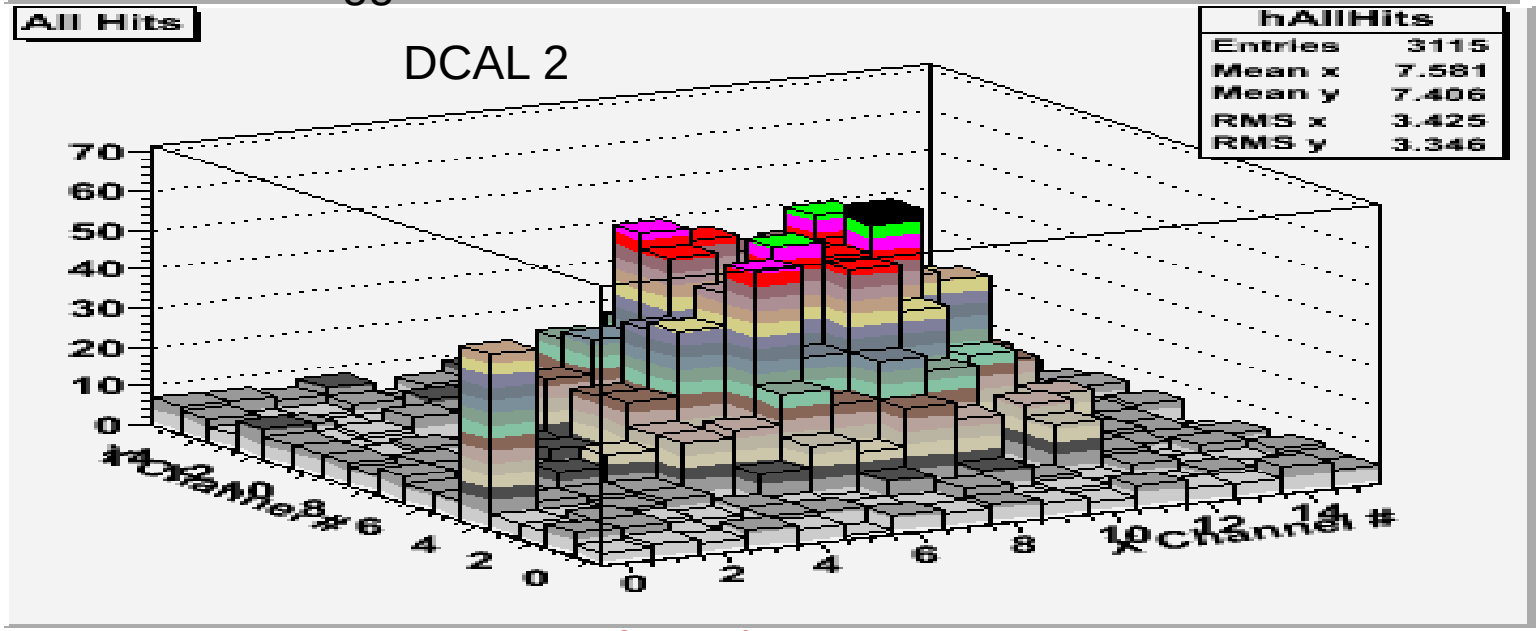


*Many thanks to ANL colleagues! J. Repond, L. Xia, G. Drake, J. Schleroth, J. Smith (UTA student at ANL) and H. Weerts.

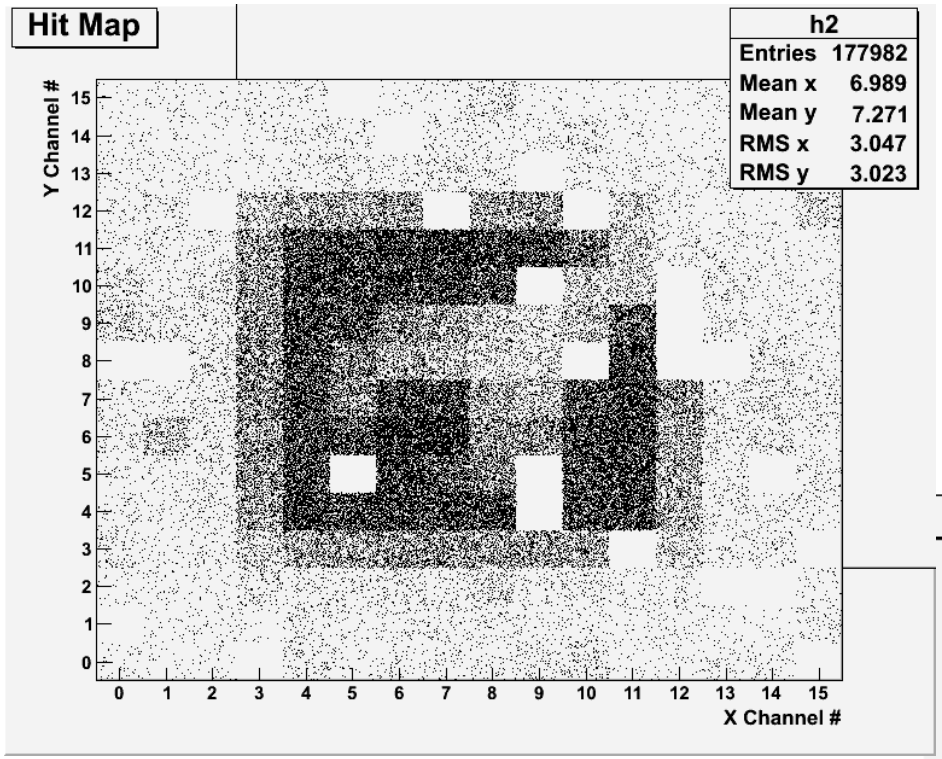
Cosmic Rays with DCAL and Ext. Trg

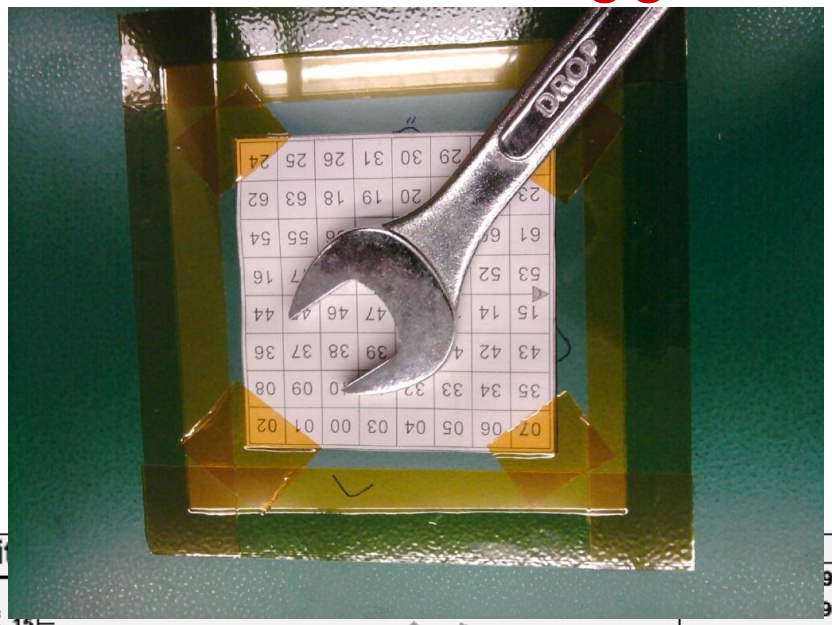


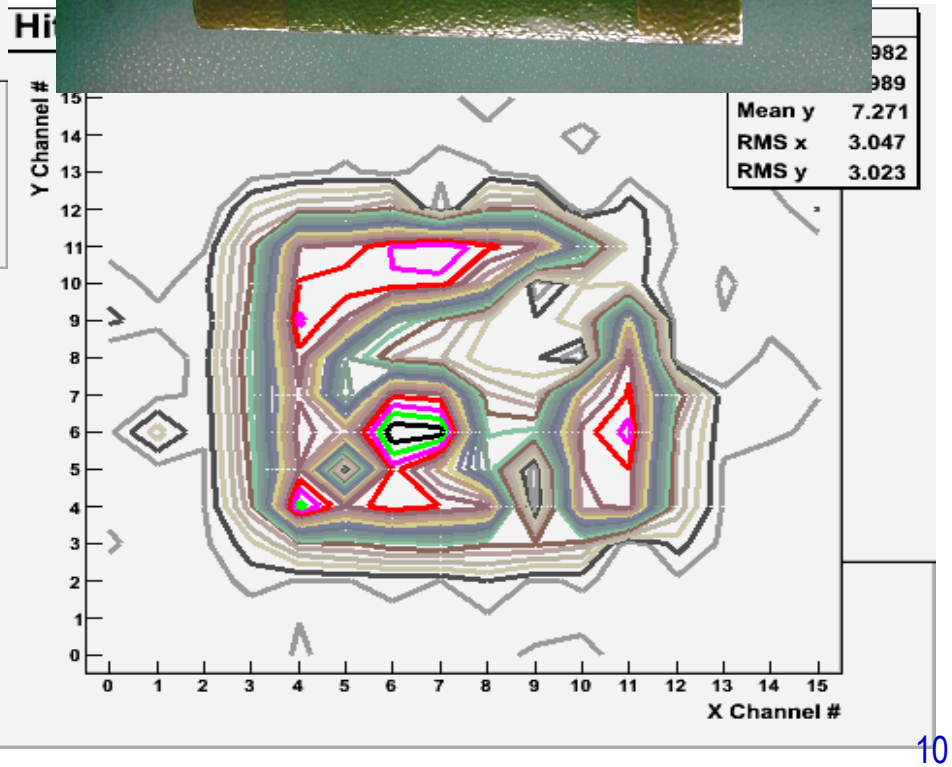
10cmx10cm Cosmic Trigger



Radioactive Source Run with Internal Trigger





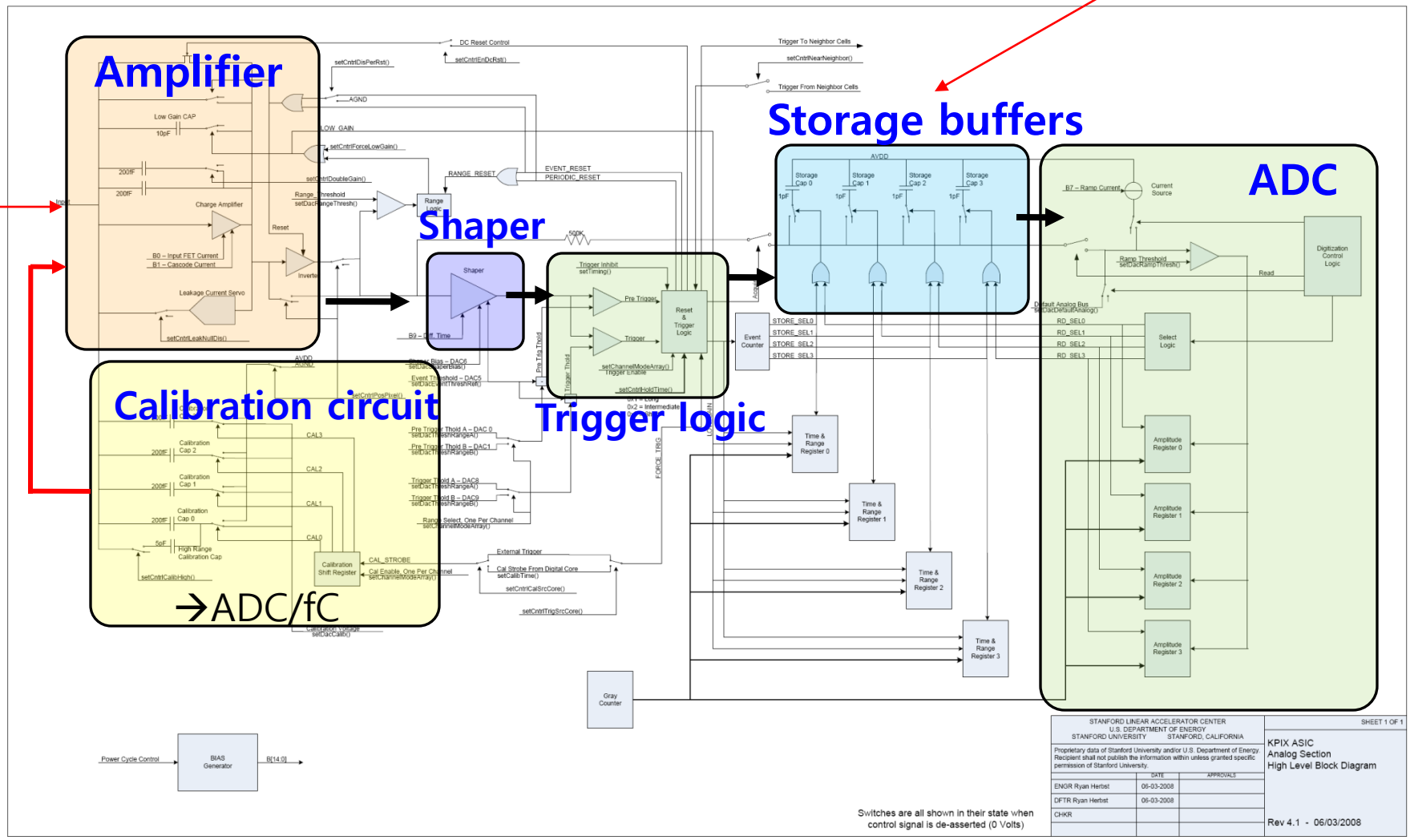


Noisy channels masked out

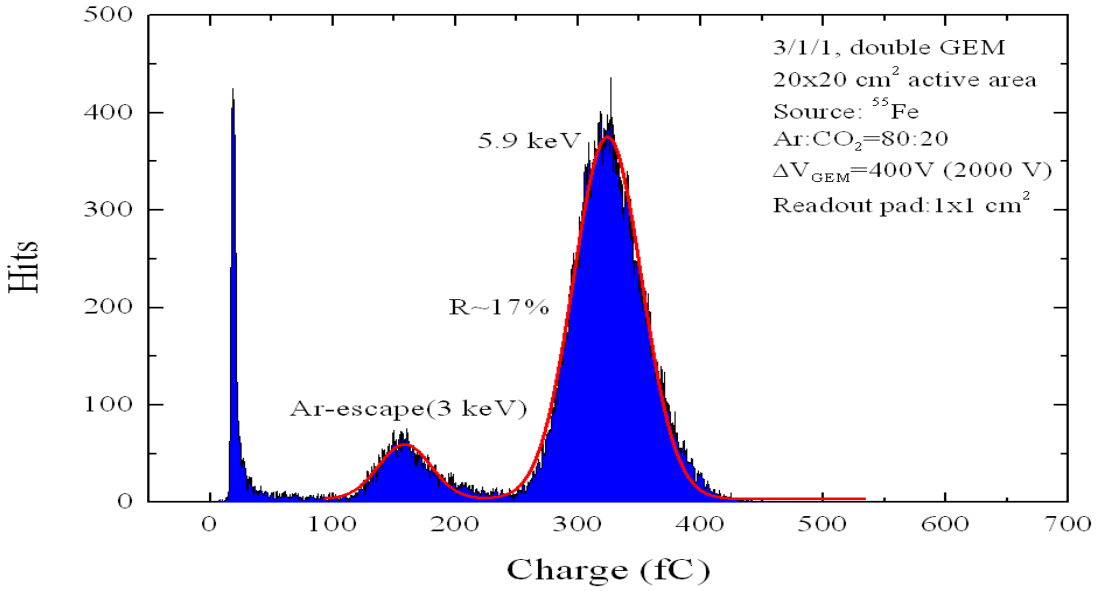
DHCAL anode pad

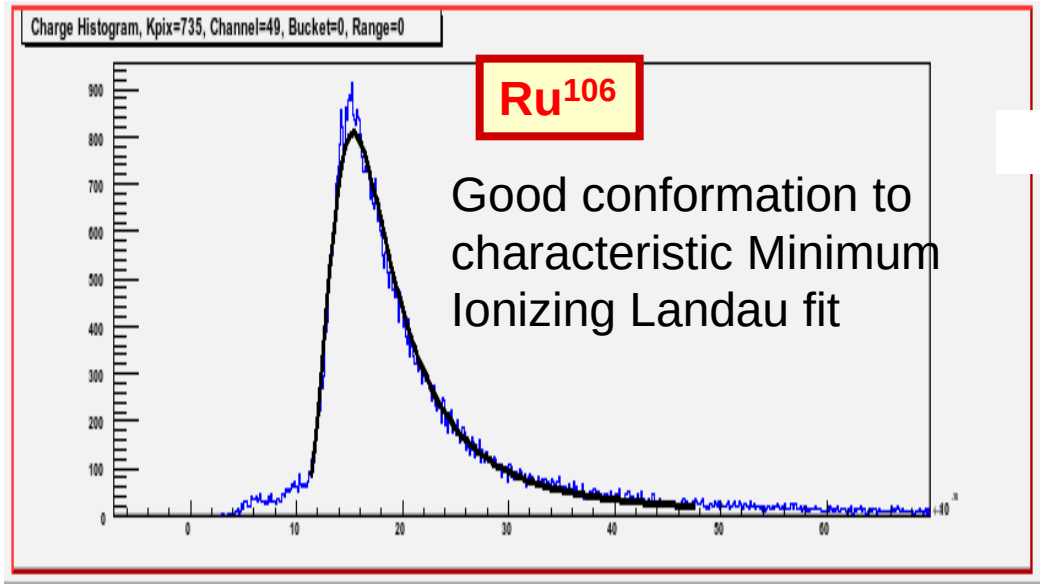
KPiX Readout scheme (SLAC)

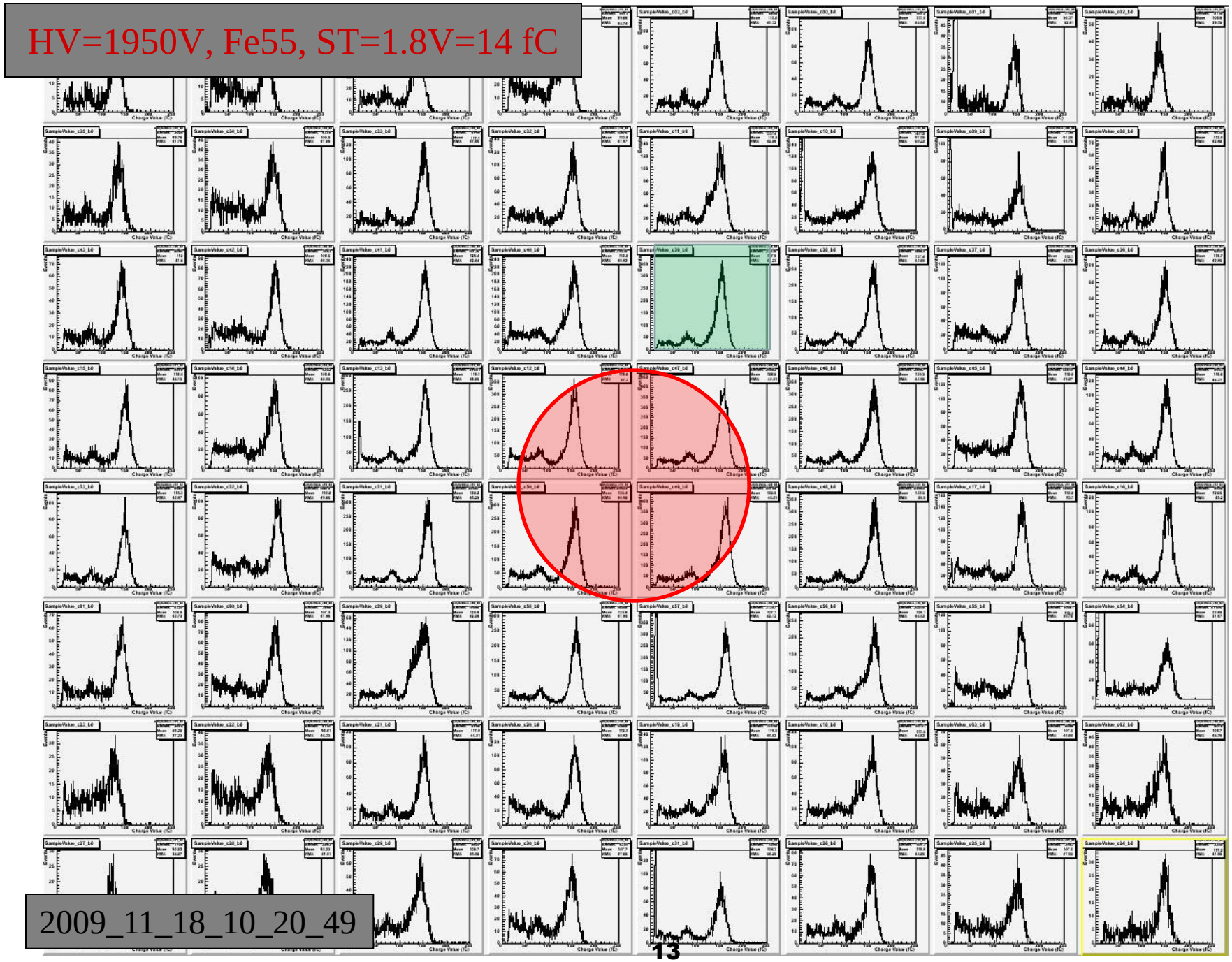
4-deep "pipeline"



GEM+KPiX7 Fe^{55} and Ru^{106} Spectra

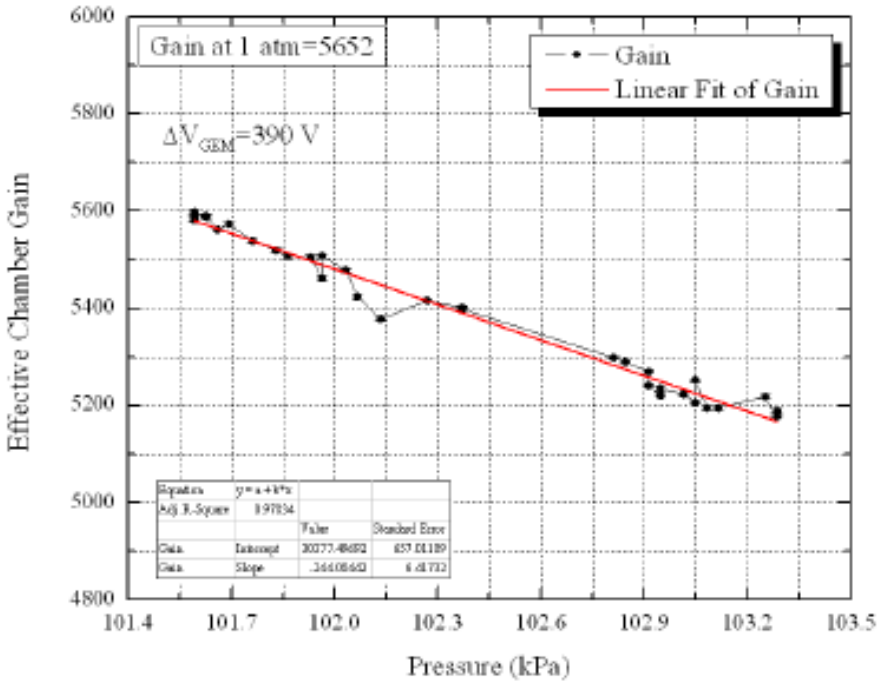


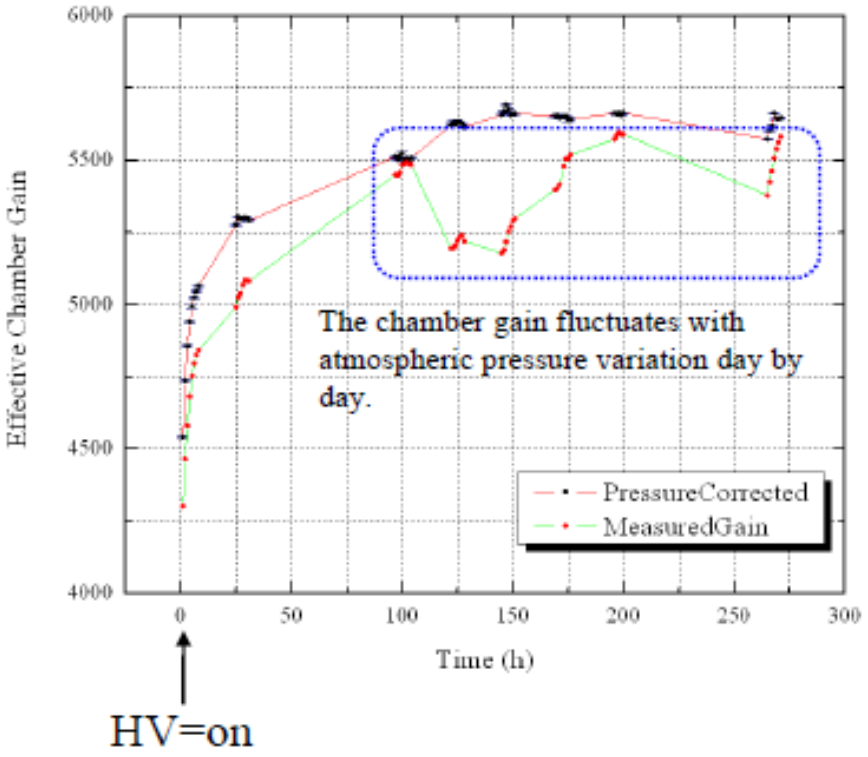



HV=1950V, Fe55, ST=1.8V=14 fC
2009_11_18_10_20_49

Pressure Dependence of Gain

HV =1950V (ΔV_{GEM}=390 V)





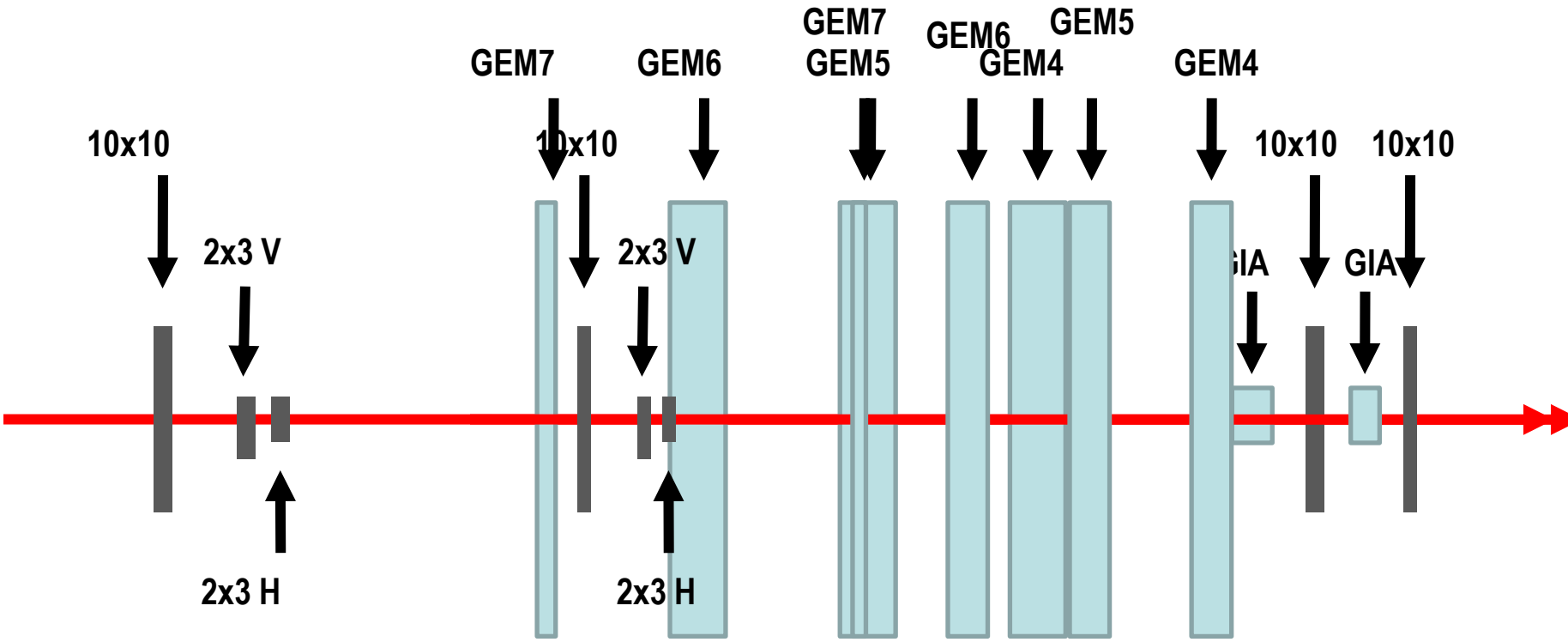
We use an open gas system (gas flows at atmospheric pressure).

Thus, pressure inside chamber is affected by the atmospheric pressure directly.

This pressure change affects the chamber gain.

The chamber gains were recalculated to the values at 1 atm.

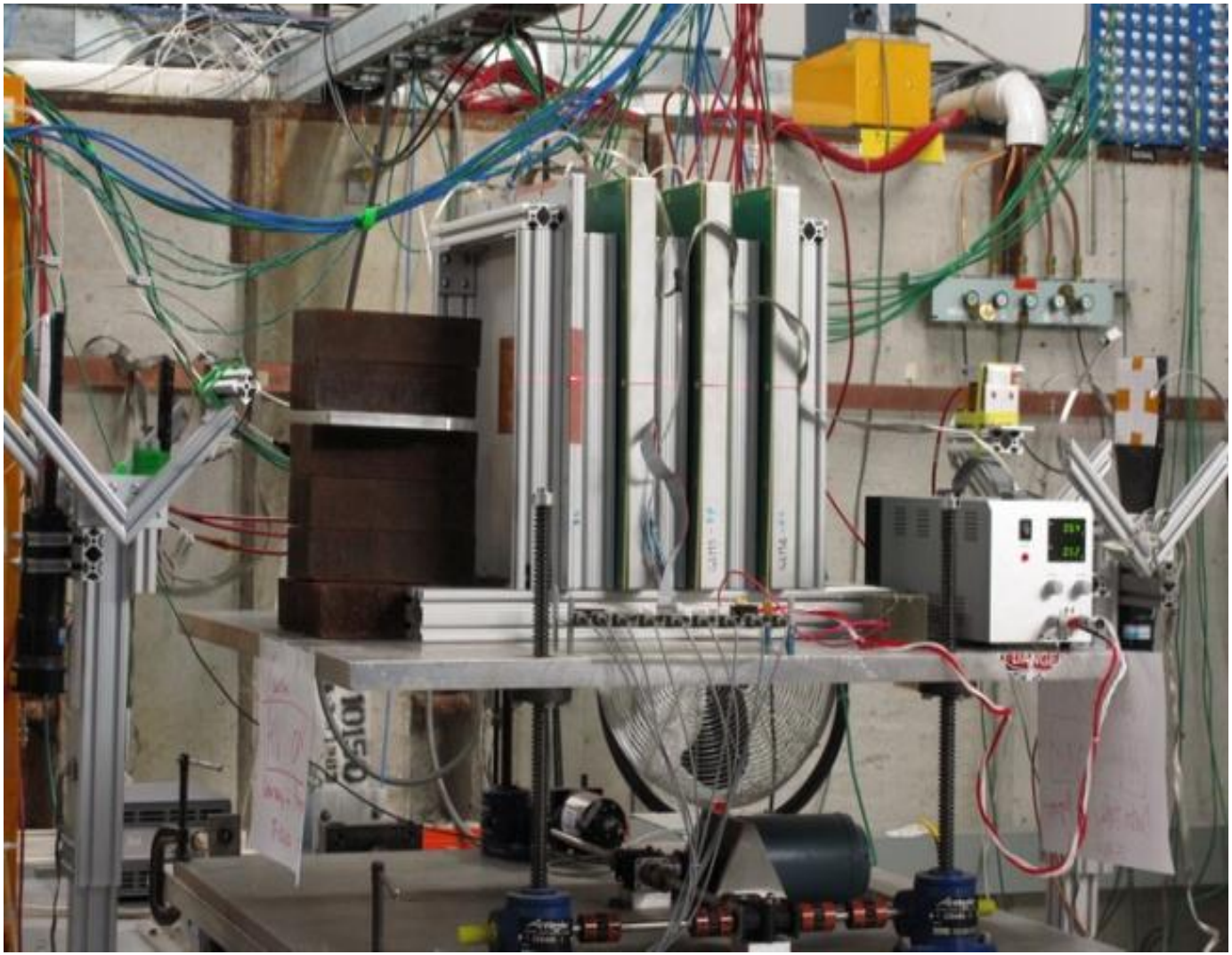
T-1010 Experiment Setup



GEM6: Read out by 13bit KPiX designed for the ILC time line
GEM7, GEM5, GEM4: Read out by 1bit DCAL chip by ANL and FNAL
GIA: Medical image intensifier prototype with 12 bit ADC in-house readout
Triggers formed off the motion table:

1. 10x10 coincidences for guaranteed beam penetration through the detector array
2. 2x3 coincidences arranged perpendicular to each other for 2x2 coverage in the center of the detector array
3. Coincidence of 1*2: Guaranteed beam penetration with center 2x2 coverage (efficiency ~95%)

T-1010 Experiment Setup



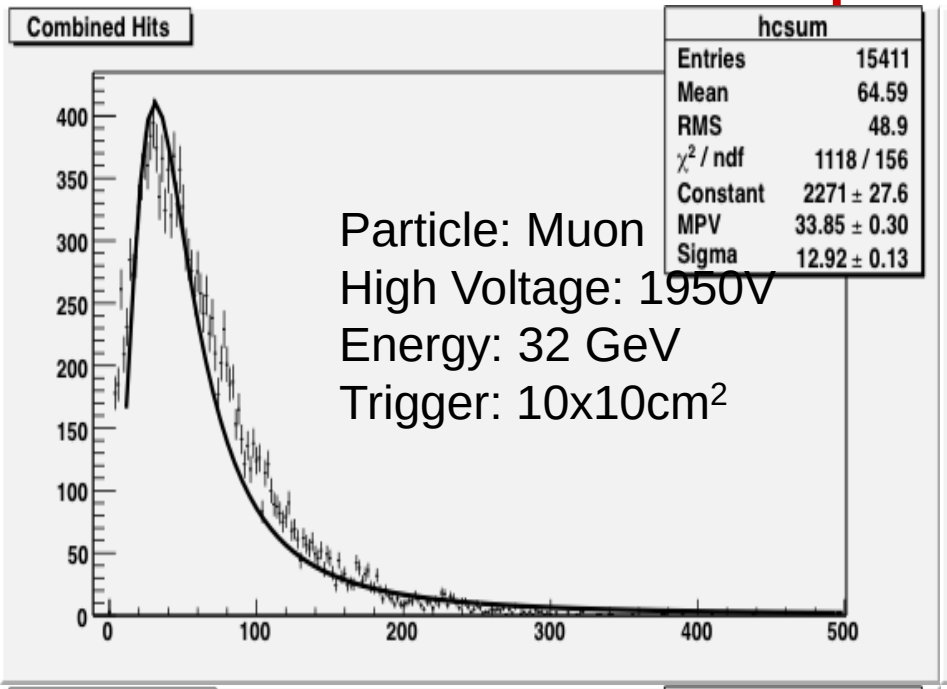
GEM(T-1010) Test Beam Run Plans

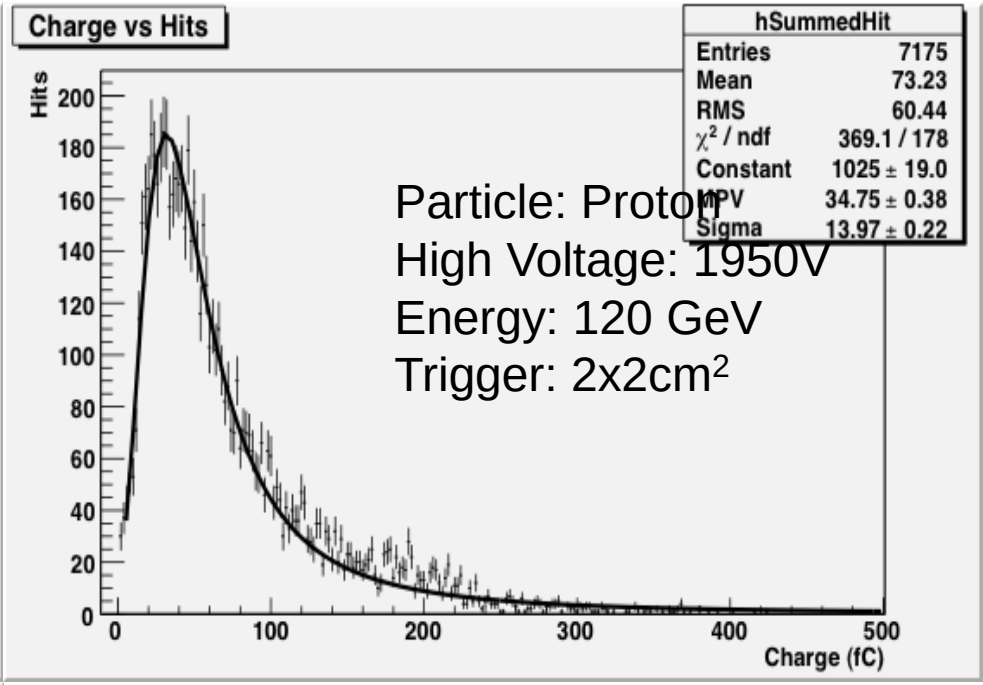
- Response run
  - Measure chamber responses
- DCAL THRESHOLD SCAN
  - Measure efficiency vs threshold
  - Determine the optimal threshold for the three chambers
- HV SCAN
  - Measure response, gain and efficiency vs HV
- POSITION SCAN
  - Measure response, efficiency vs position and determine the uniformity of the chamber efficiencies
- PION RESPONSE & PION SHOWER
  - Measure particle dependence of the chamber responses & test operation under multiple hit environment
- NOISE: Run overnight everyday with random noise trigger ➔ measure noise rate per trigger per pad to 1% precision

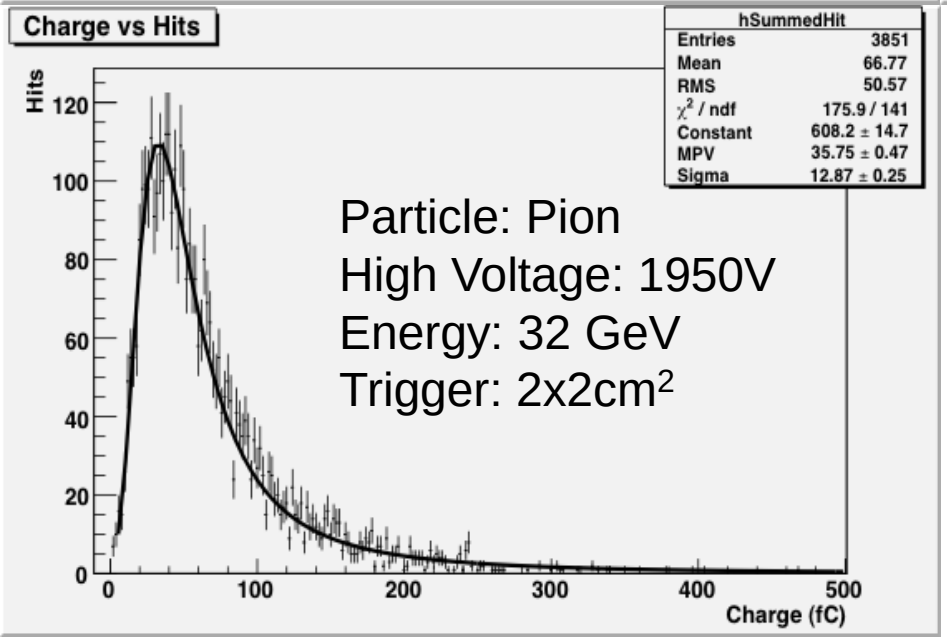
GEM TB Run Schedule

- 32 GeV Muons: first 3 days (8/3 – 8/5)
  - KPiX Resposne
  - DCAL Threshold scan
- 120GeV Protons: 10 days (8/6 – 8/15)
  - KPiX and DCAL HV Scan
  - KPiX and DCAL Position Scan
  - KPiX Response and efficiency
  - DCAL Threshold vs efficiency
  - GIA Response and HV Scan
- 32GeV Pions: 1 day (8/16)
  - KPiX, DCAL and GIA Response
  - GIA HV Scan
  - Pion shower caused by 8in steel bricks in front of the chamber array
- Took over 7M beam events in total of 12.5 days out of 14 days

GEM Response with KPiX

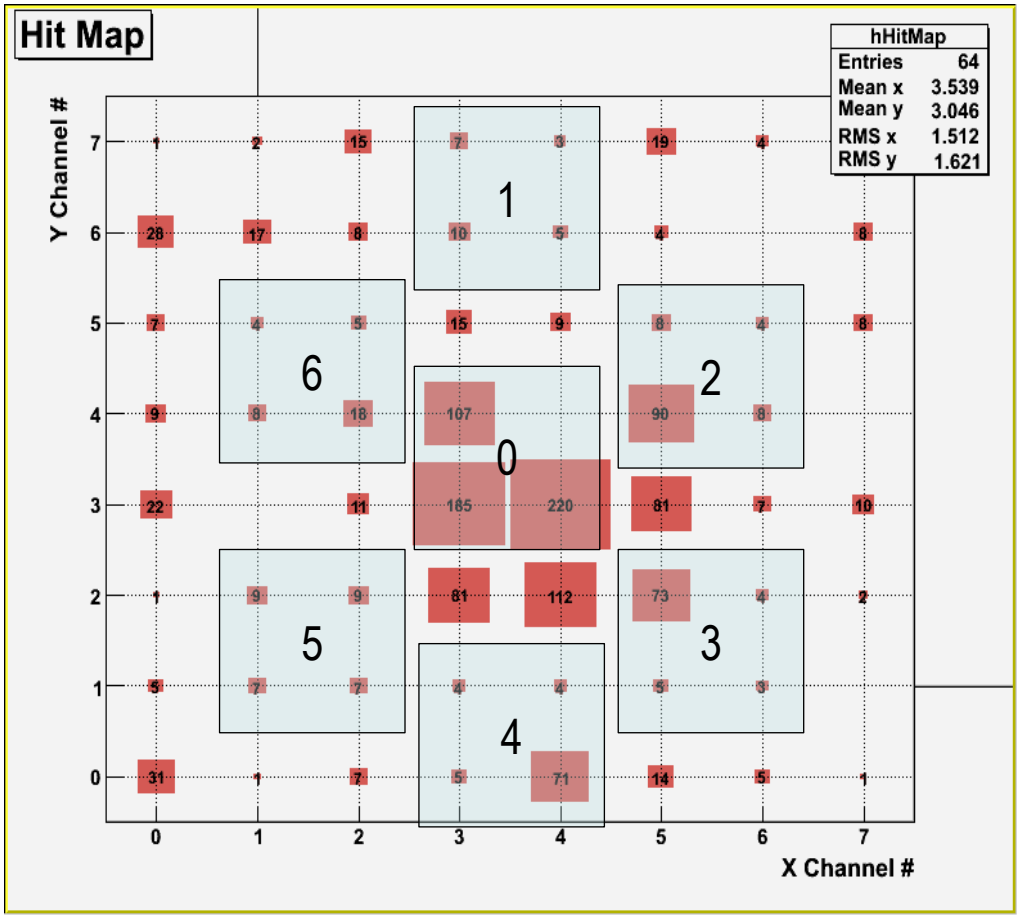




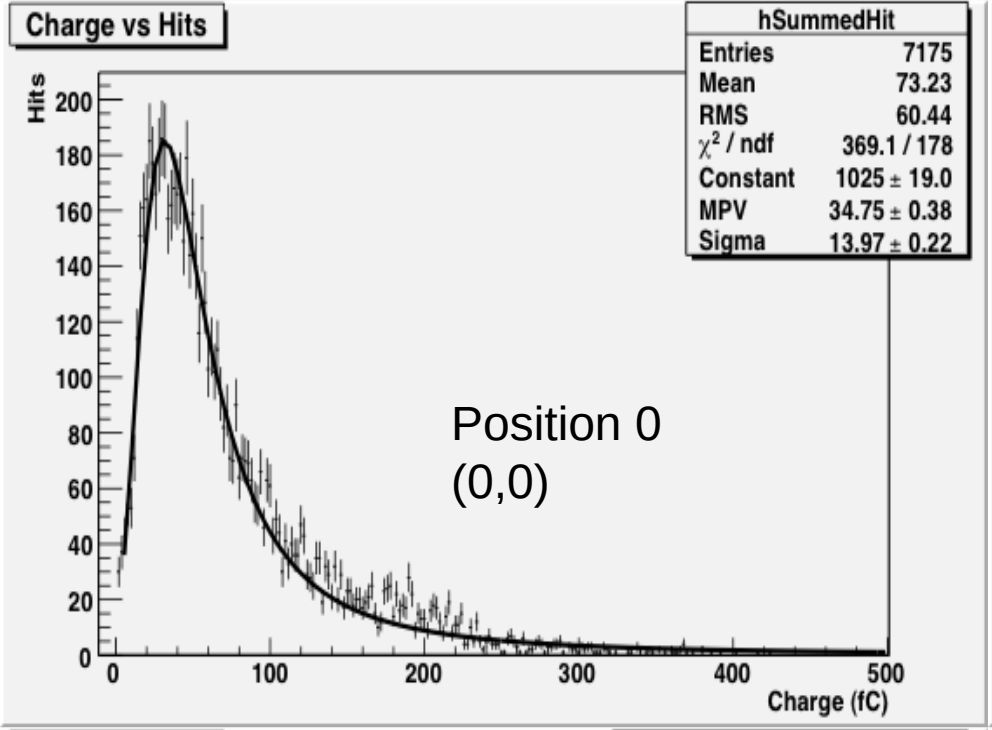


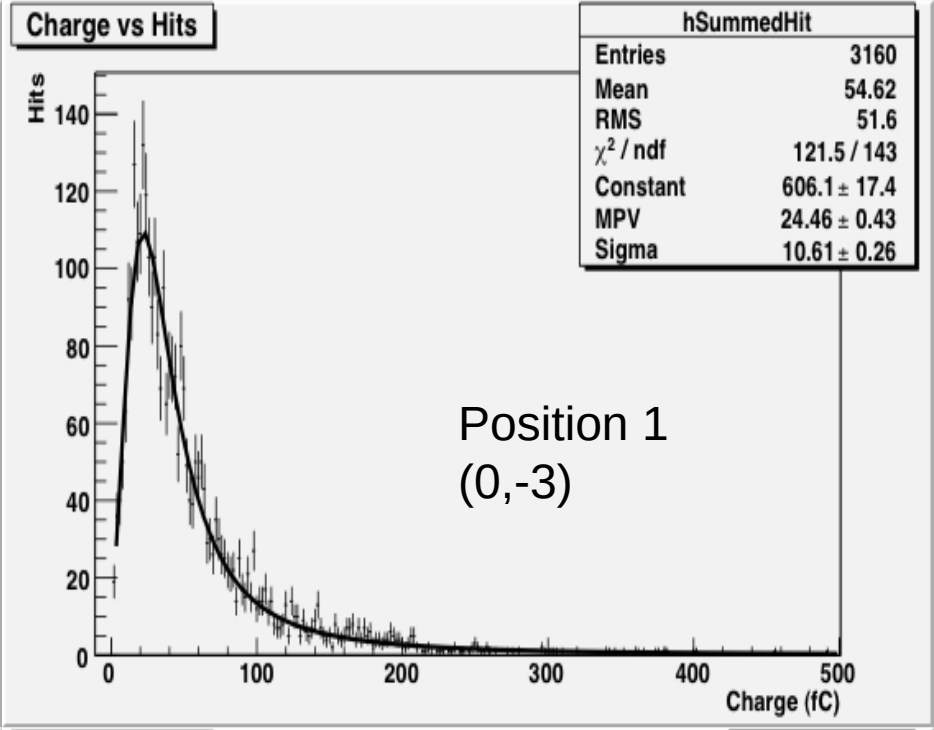
Preliminary results
Pressure corrected

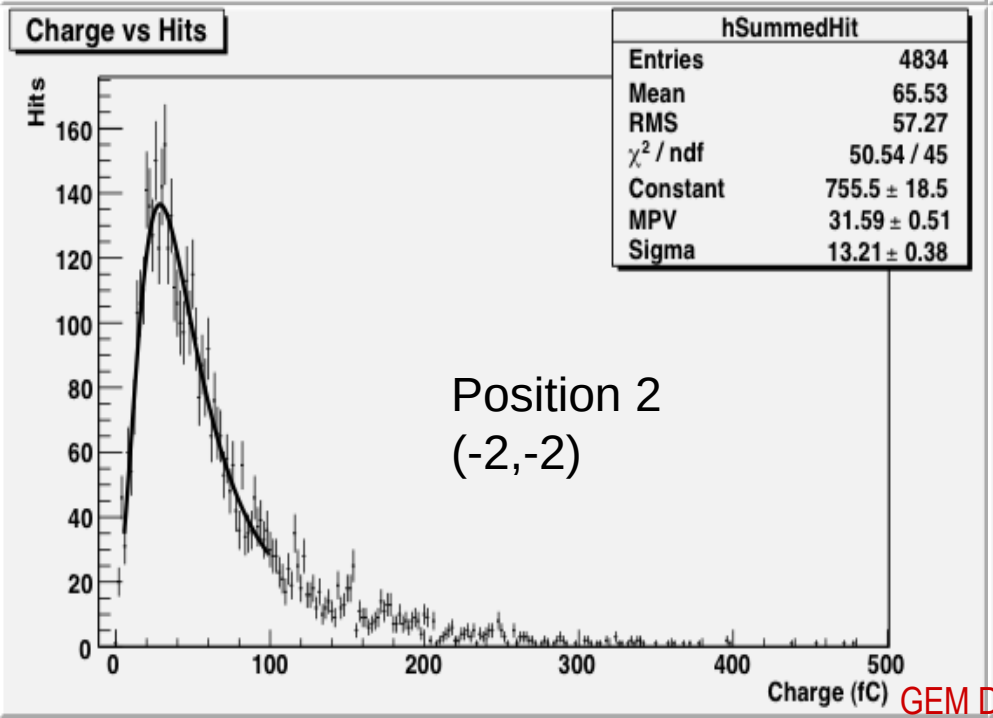
Position scan/hit map

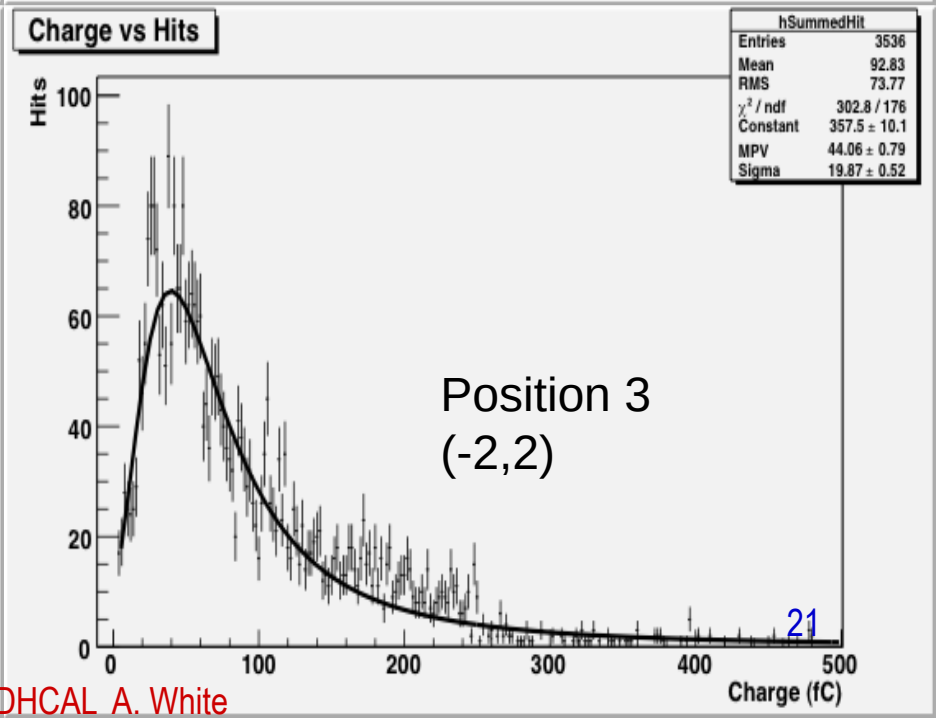


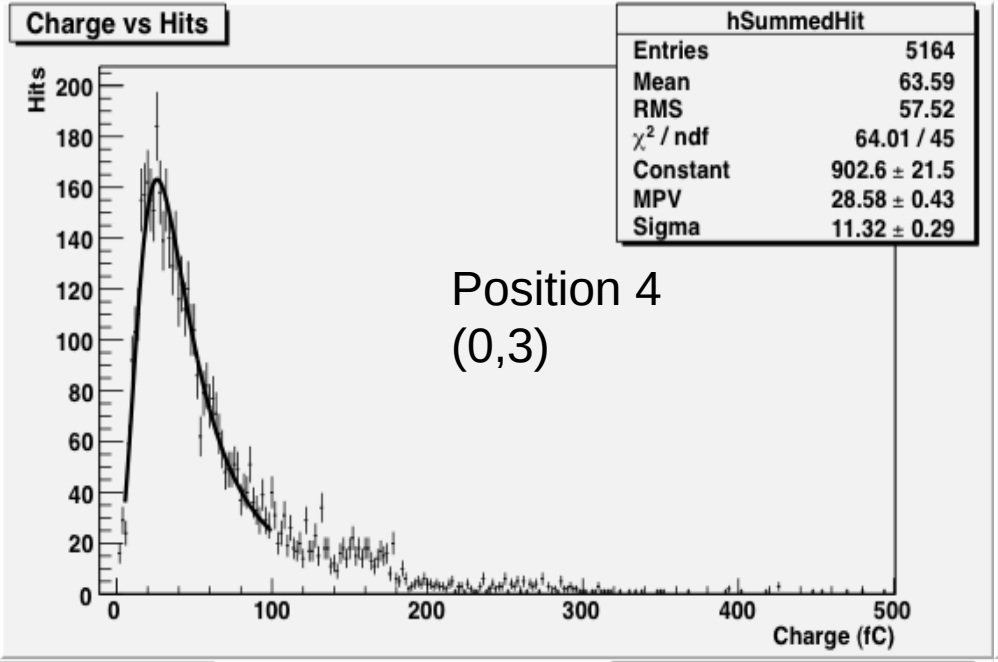
All data pressure corrected
Some data points need to be refit

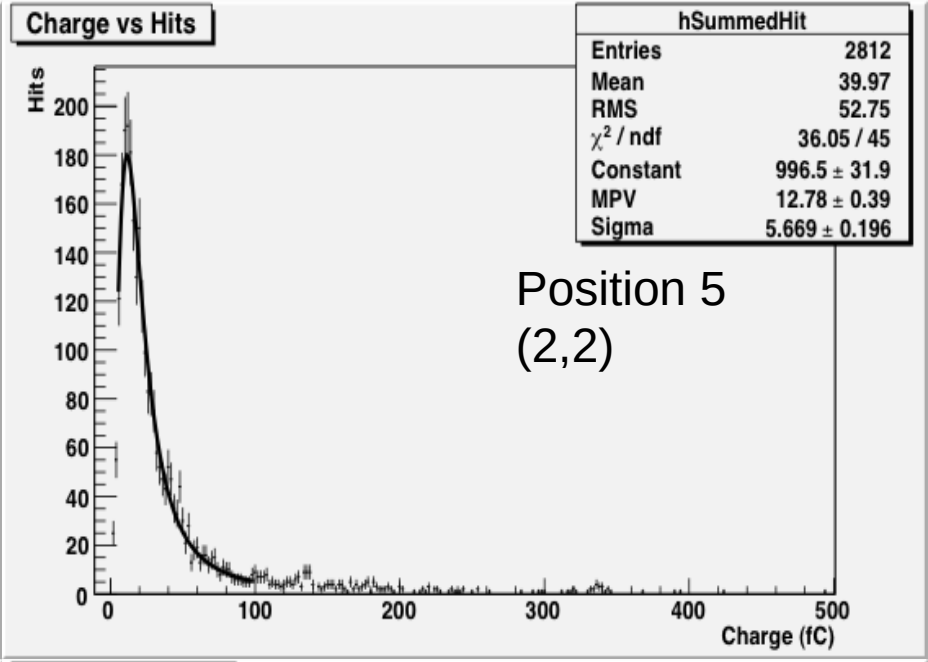

Charge vs Hits
hSummedHit
Entries 7175
Mean 73.23
RMS 60.44
χ² / ndf 369.1 / 178
Constant 1025 ± 19.0
MPV 34.75 ± 0.38
Sigma 13.97 ± 0.22
Hits
Charge (fC)
Position 0
(0,0)

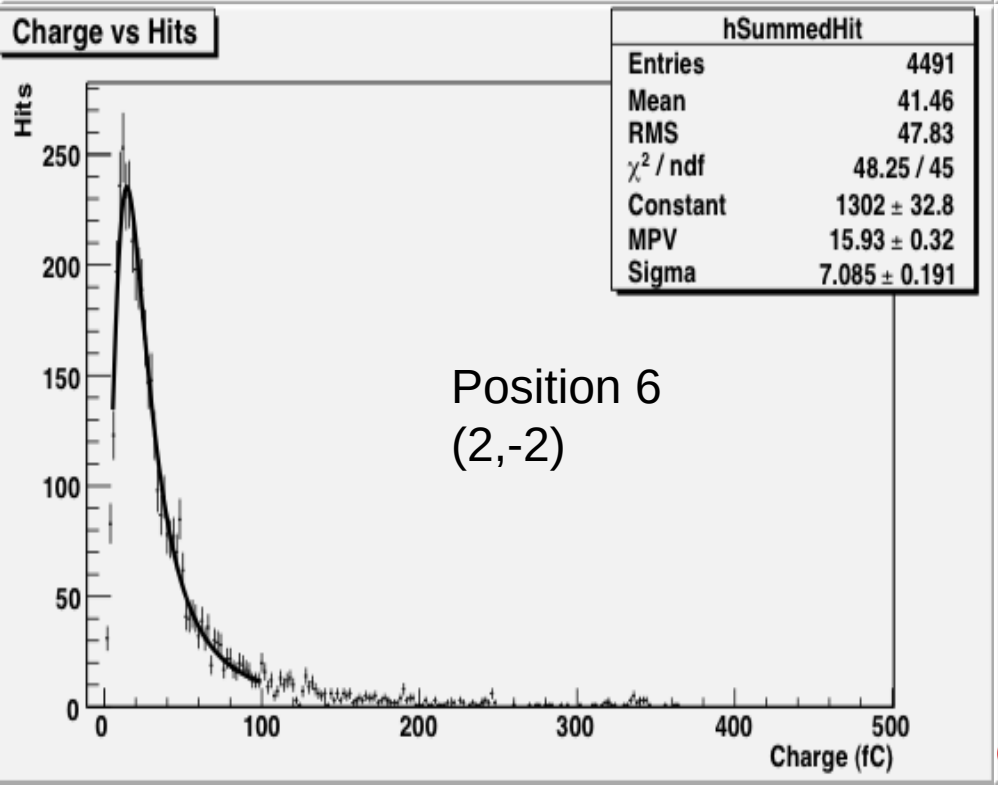

Charge vs Hits
hSummedHit
Entries 3160
Mean 54.62
RMS 51.6
χ² / ndf 121.5 / 143
Constant 606.1 ± 17.4
MPV 24.46 ± 0.43
Sigma 10.61 ± 0.26
Hits
Charge (fC)
Position 1
(0,-3)

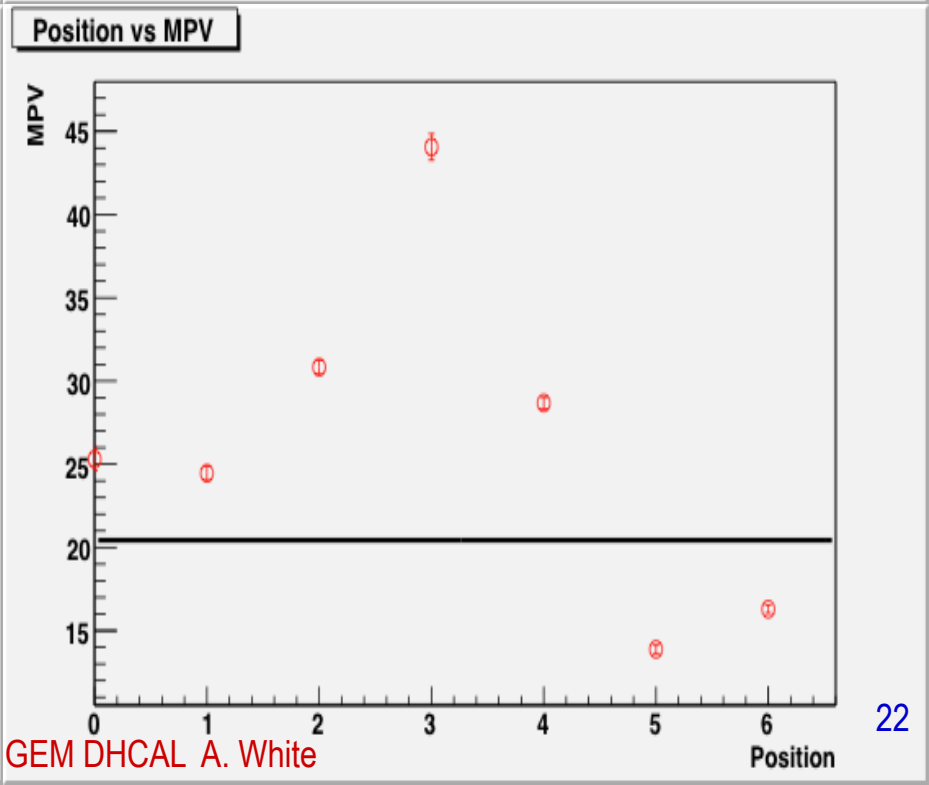

Charge vs Hits
hSummedHit
Entries 4834
Mean 65.53
RMS 57.27
χ² / ndf 50.54 / 45
Constant 755.5 ± 18.5
MPV 31.59 ± 0.51
Sigma 13.21 ± 0.38
Hits
Charge (fC)
Position 2
(-2,-2)


Charge vs Hits
hSummedHit
Entries 3536
Mean 92.83
RMS 73.77
χ² / ndf 302.8 / 176
Constant 357.5 ± 10.1
MPV 44.06 ± 0.79
Sigma 19.87 ± 0.52
Hits
Charge (fC)
Position 3
(-2,2)

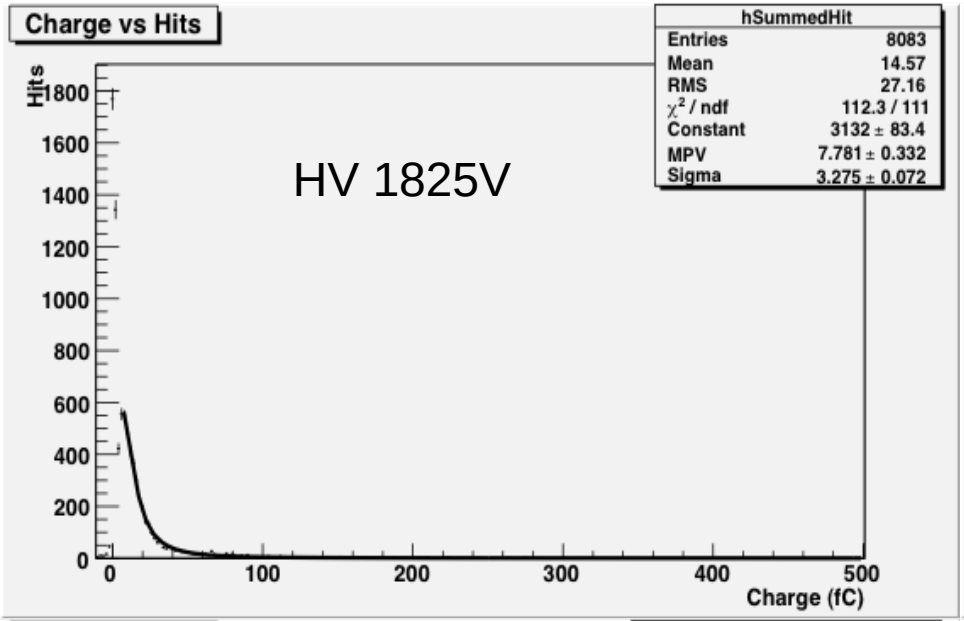

Charge vs Hits
hSummedHit
Entries 5164
Mean 63.59
RMS 57.52
χ² / ndf 64.01 / 45
Constant 902.6 ± 21.5
MPV 28.58 ± 0.43
Sigma 11.32 ± 0.29
Hits
Charge (fC)
Position 4
(0,3)

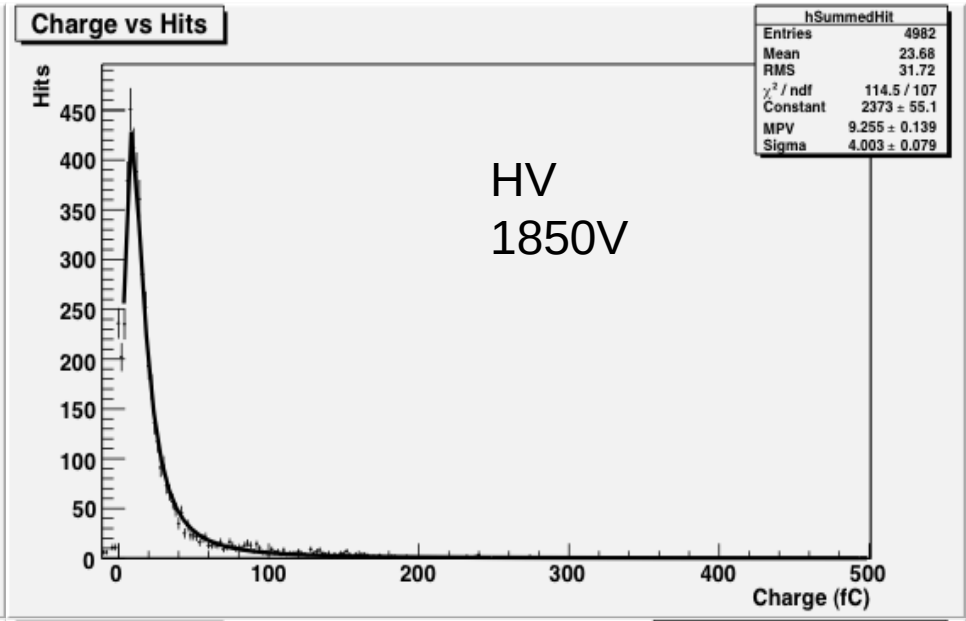

Charge vs Hits
hSummedHit
Entries 2812
Mean 39.97
RMS 52.75
χ² / ndf 36.05 / 45
Constant 996.5 ± 31.9
MPV 12.78 ± 0.39
Sigma 5.669 ± 0.196
Hits
Charge (fC)
Position 5
(2,2)

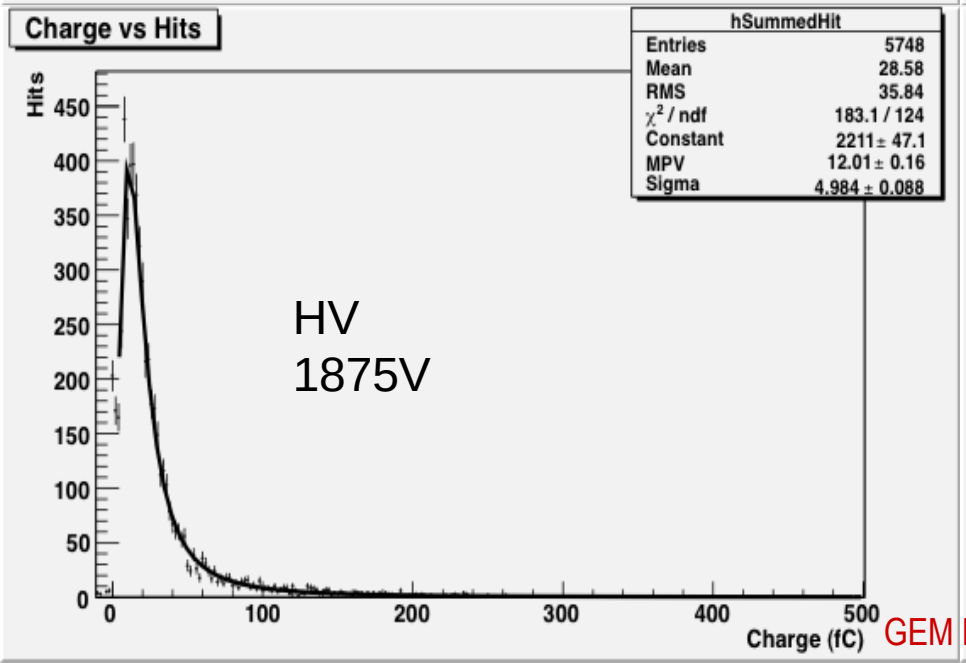

Charge vs Hits
hSummedHit
Entries 4491
Mean 41.46
RMS 47.83
χ² / ndf 48.25 / 45
Constant 1302 ± 32.8
MPV 15.93 ± 0.32
Sigma 7.085 ± 0.191
Hits
Charge (fC)
Position 6
(2,-2)

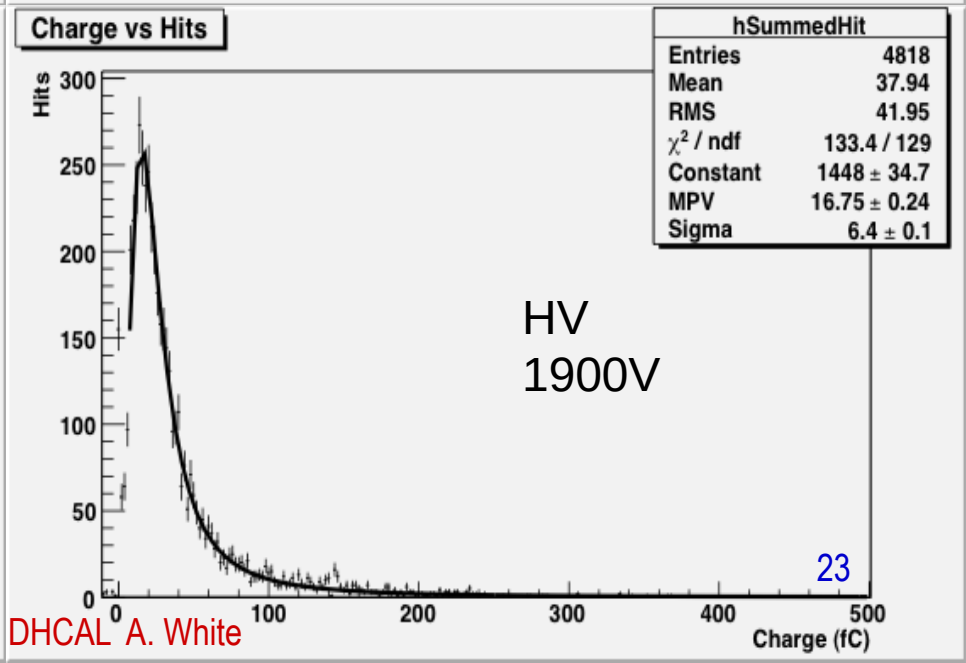

Position vs MPV
MPV
Position

HV Dependence and Gains (KPiX)

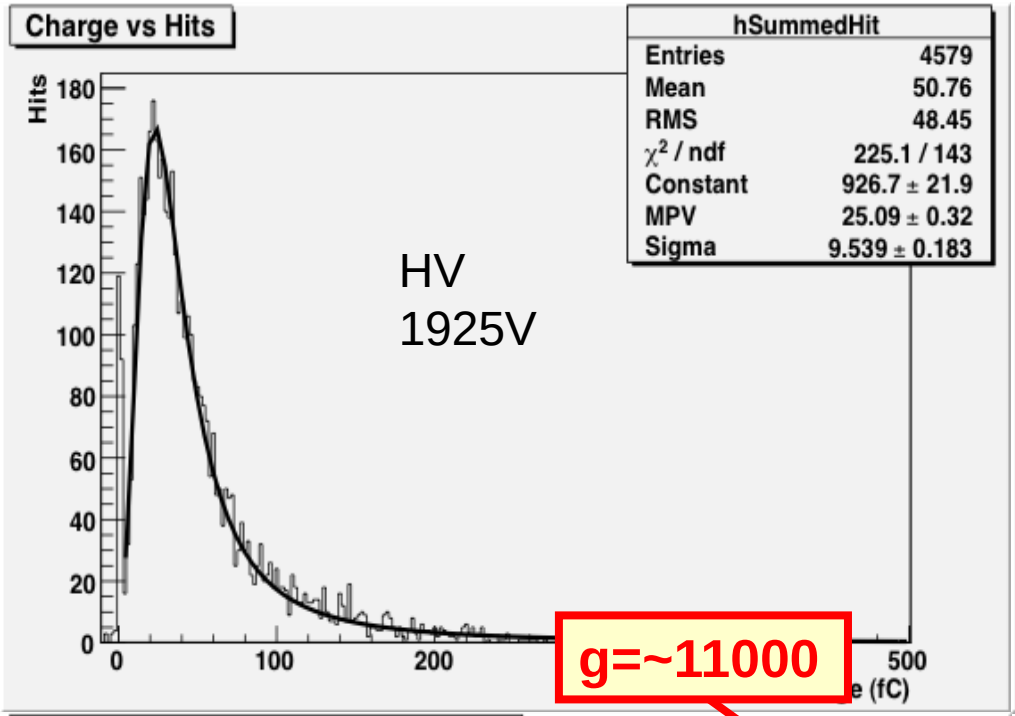


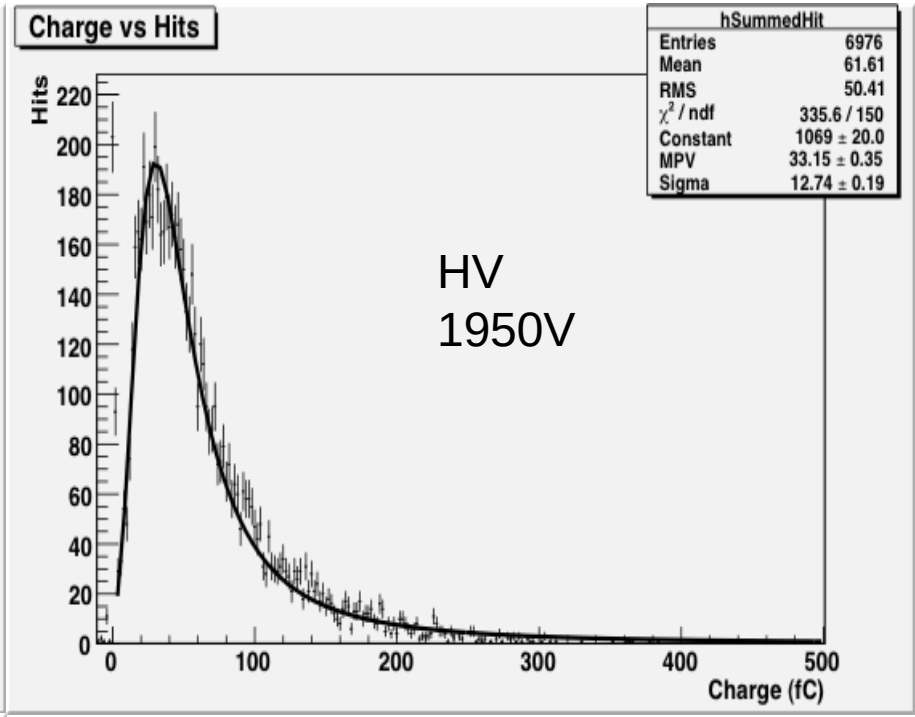


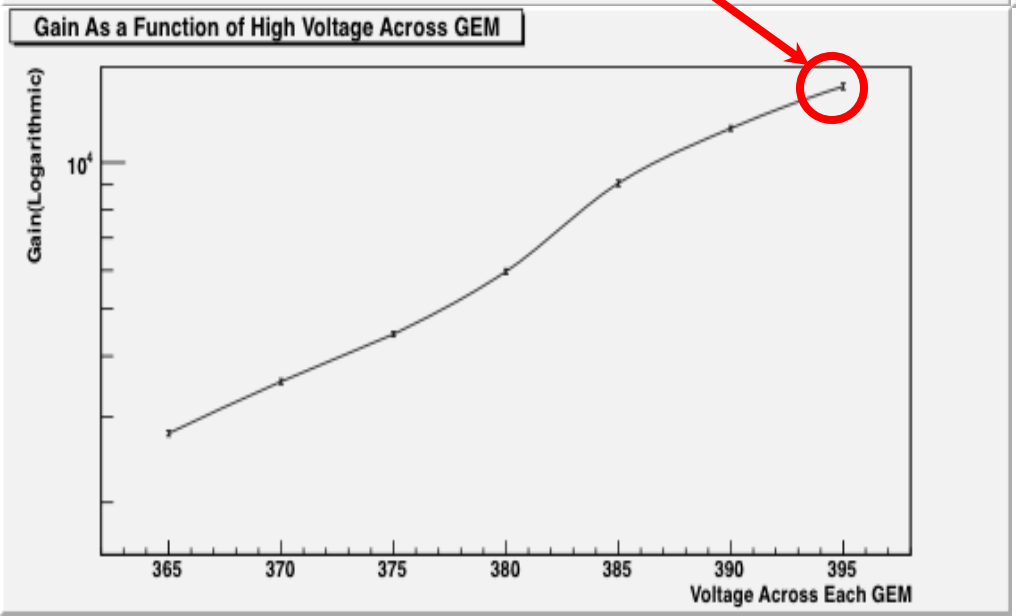




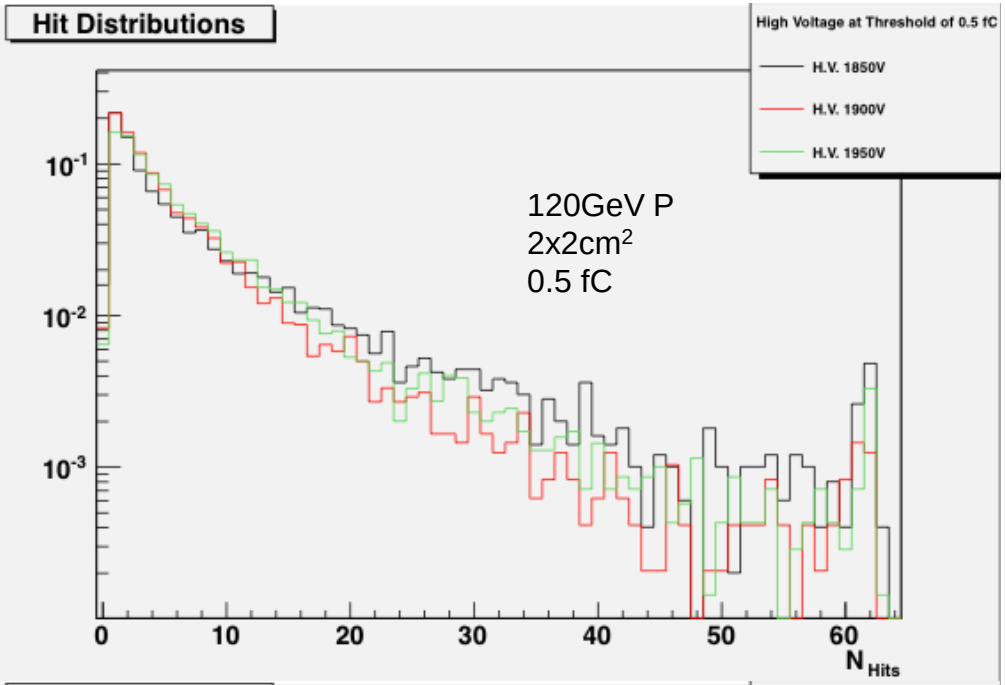
HV Dependence and Gain (KPiX)

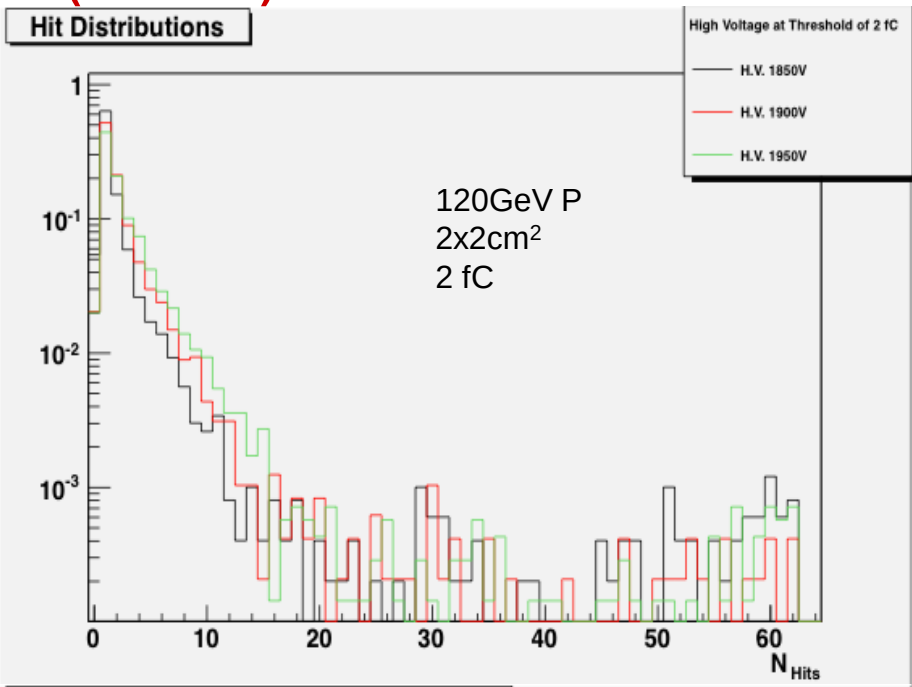


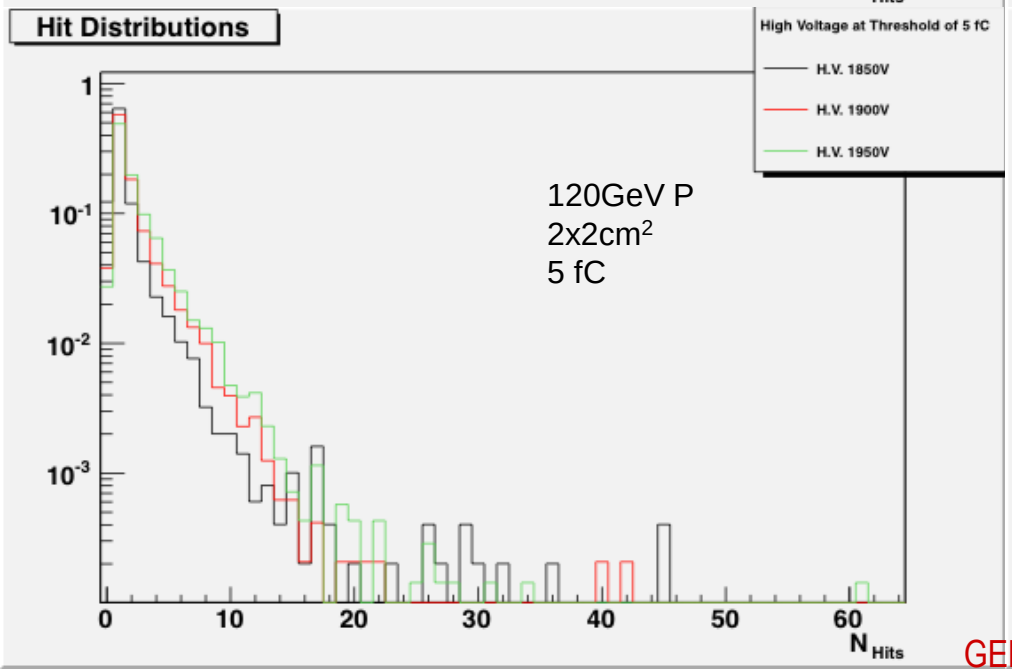


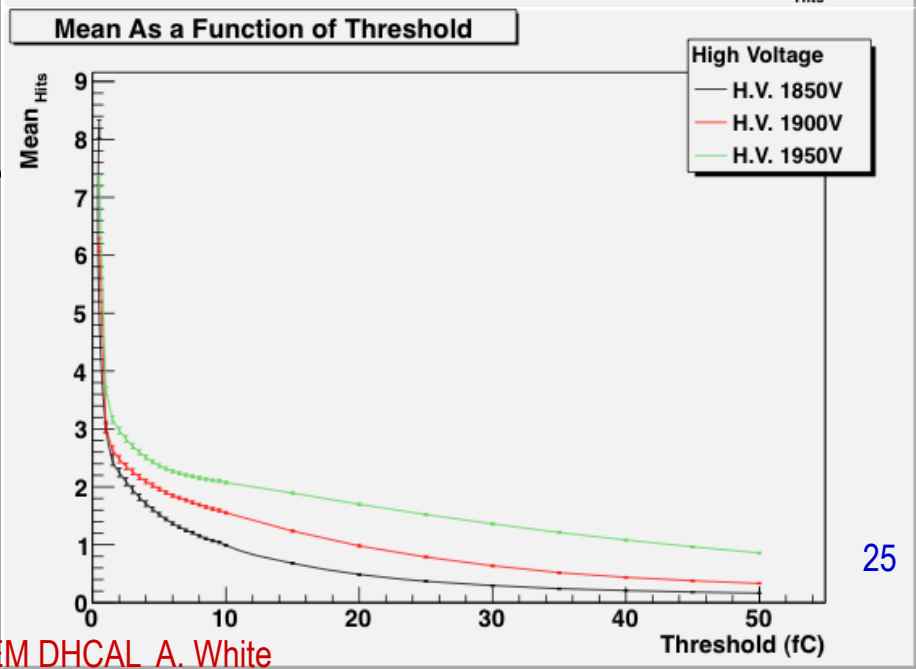


Nhits vs HV (KPiX)

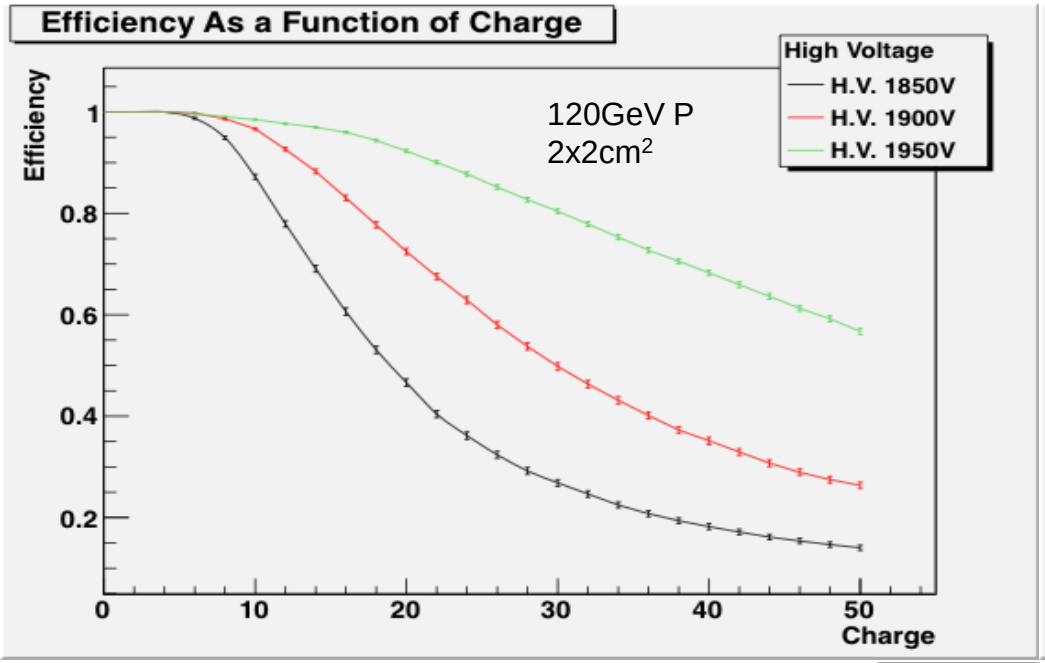


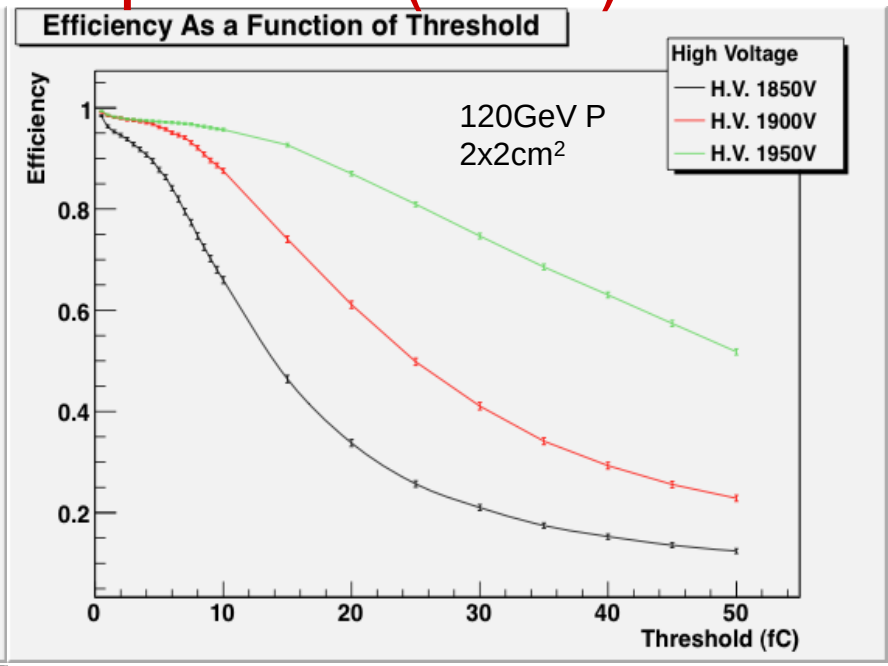


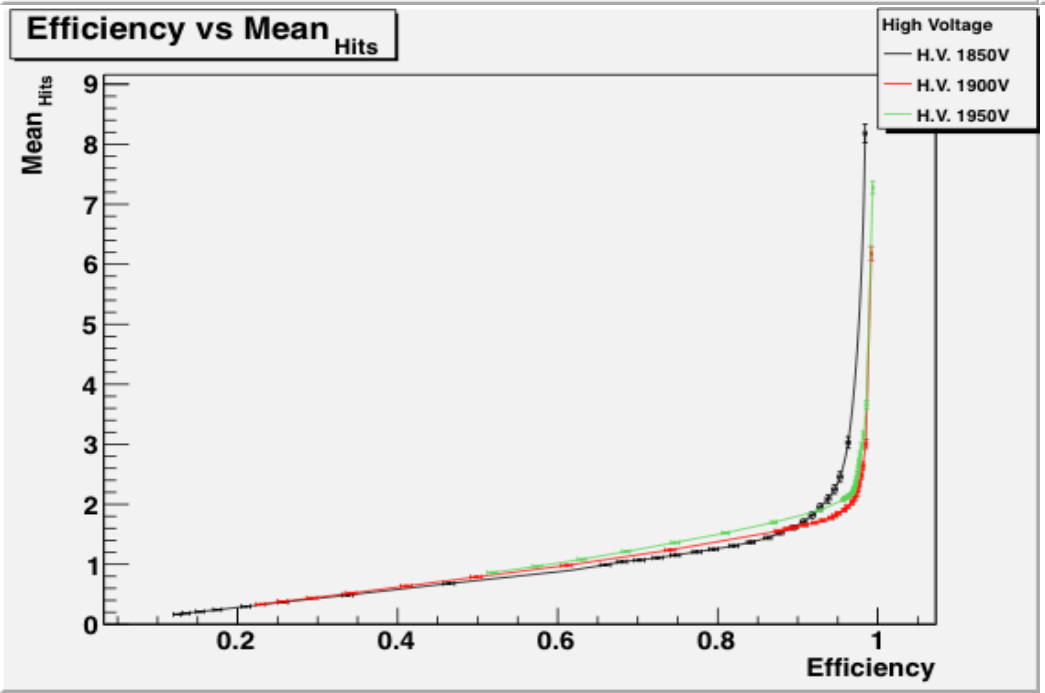




Efficiencies and Hit multiplicities (KPiX)

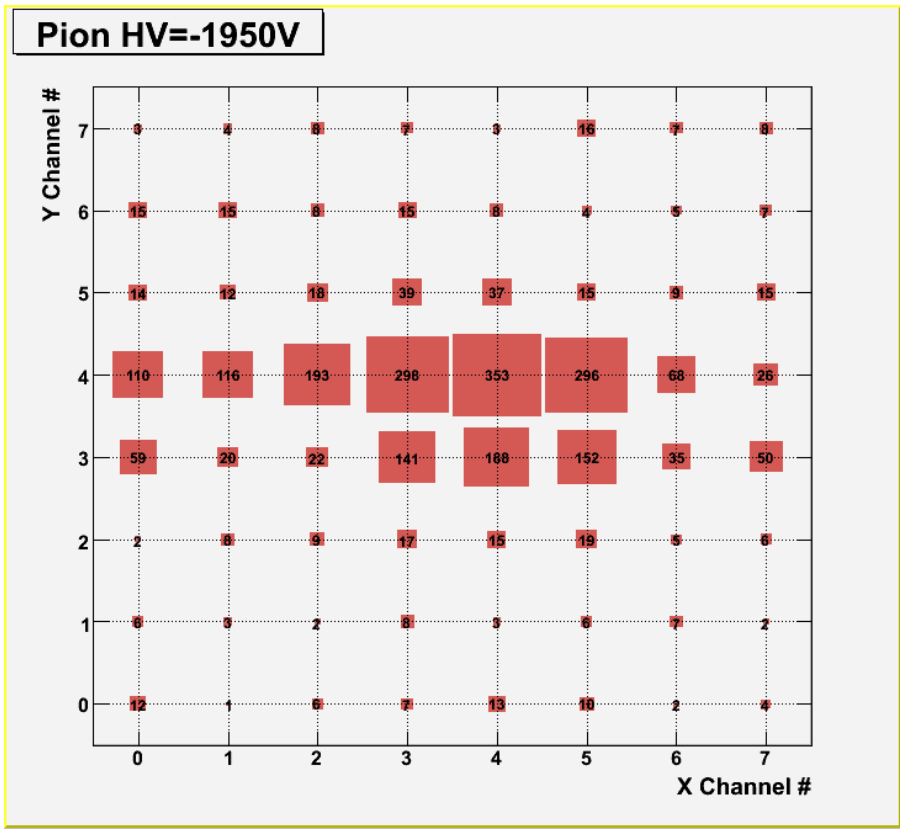


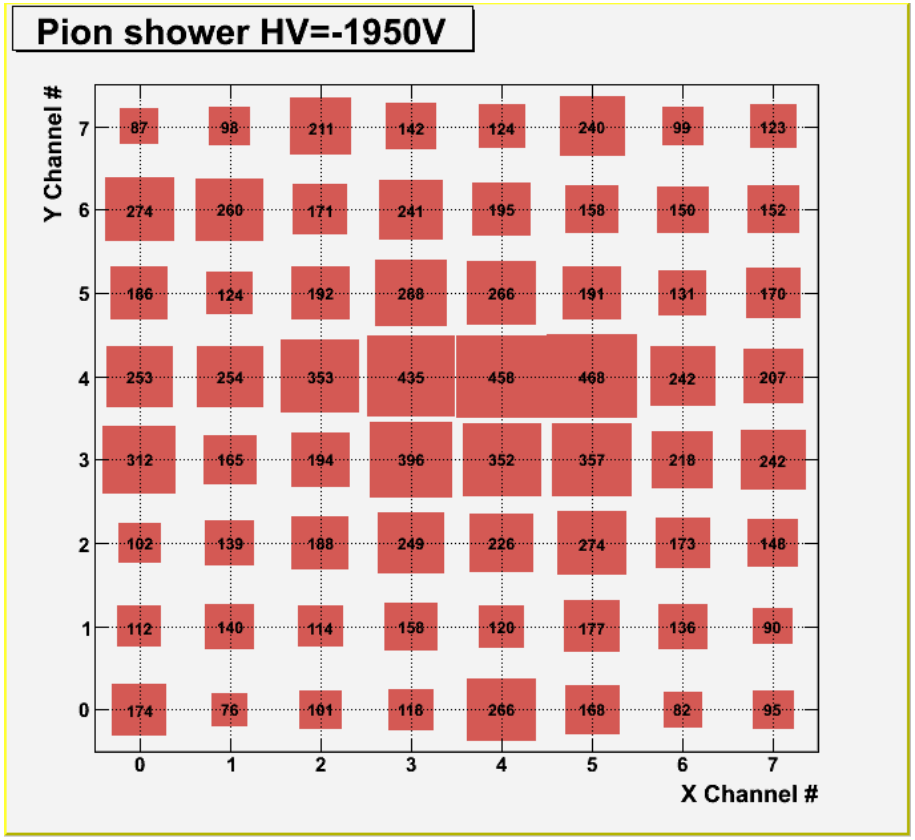




Preliminary results, pressure corrected

Hit Map for Pions vs Pion Showers (KPiX)

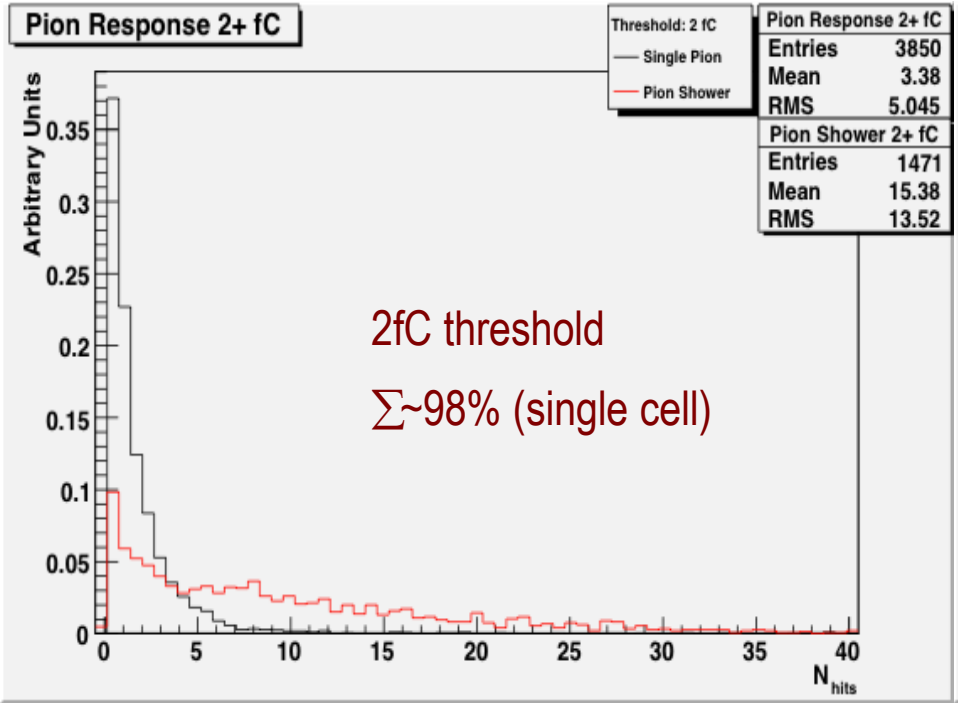


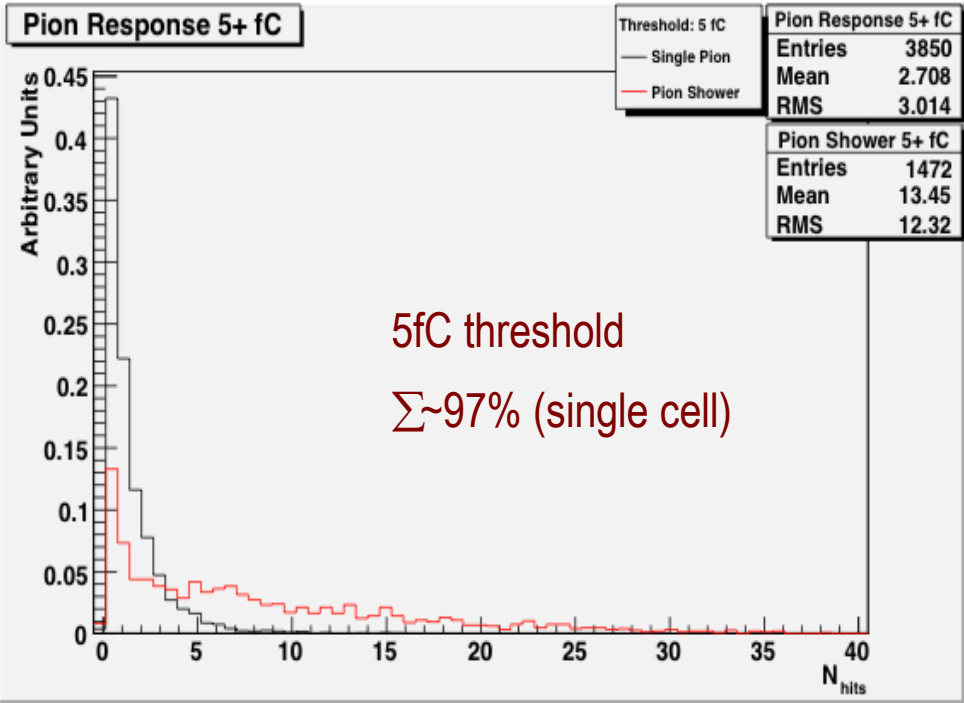


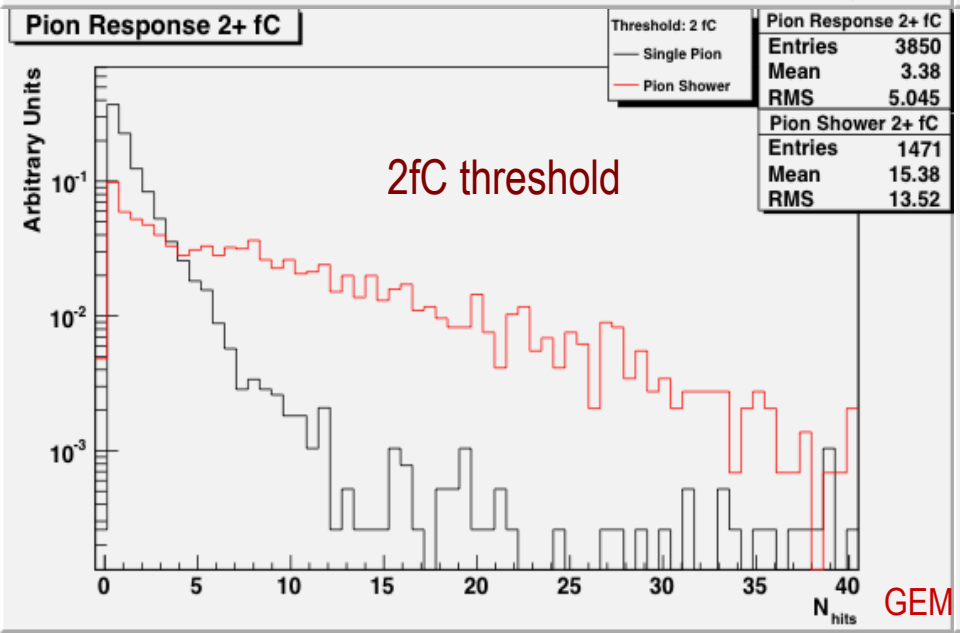
Hits above 5fC were counted and normalized to 1000

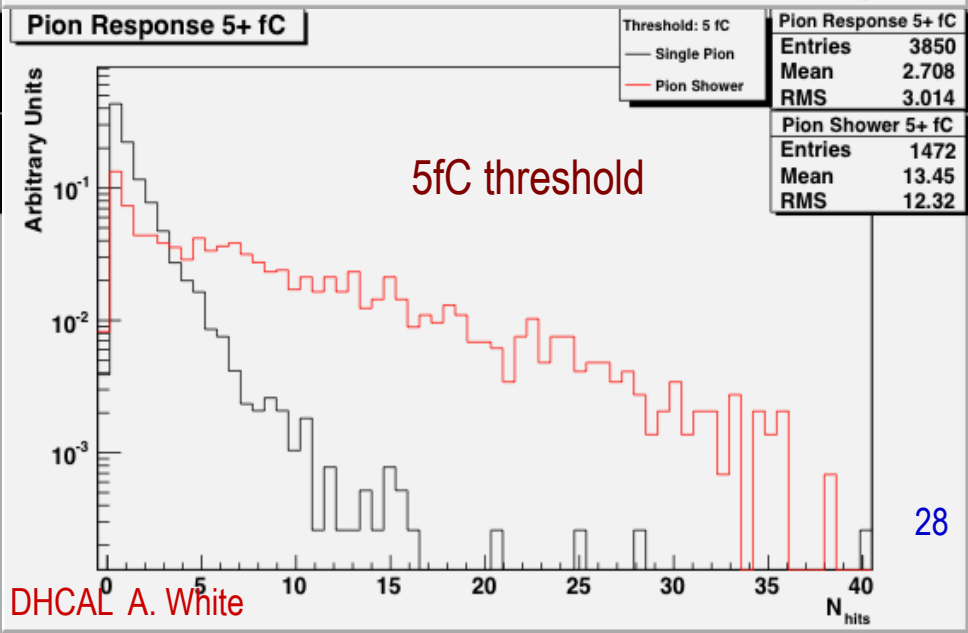
Demonstrates the KPIX capability to take many hits simultaneously

Hit Count Distributions for Pions vs Pion Showers (KPiX)

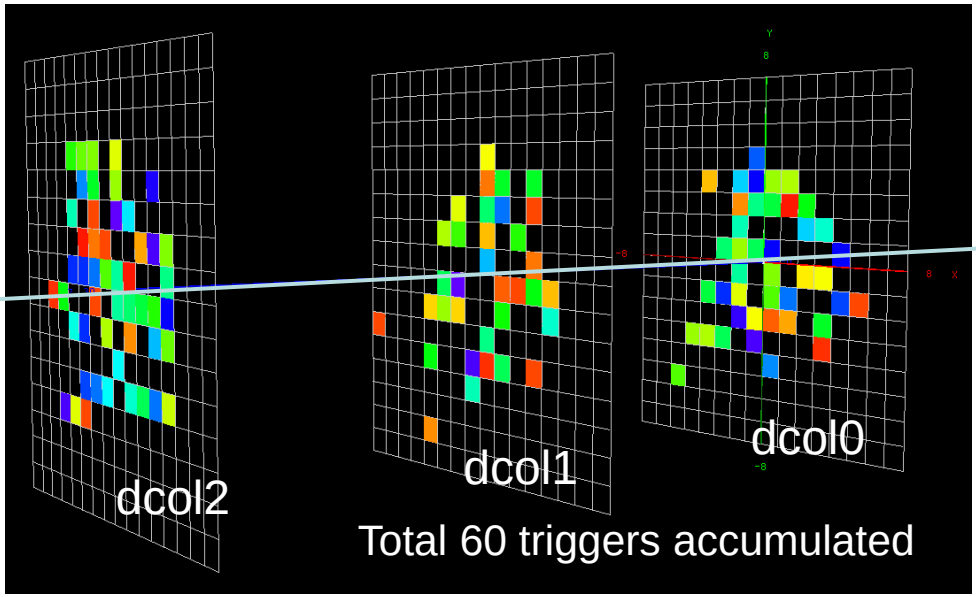




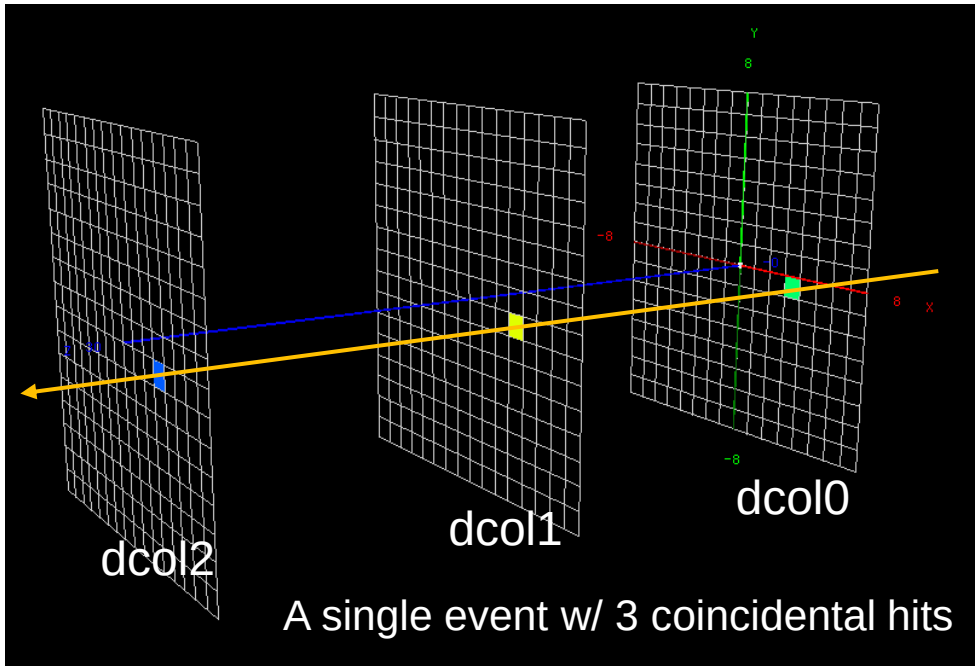


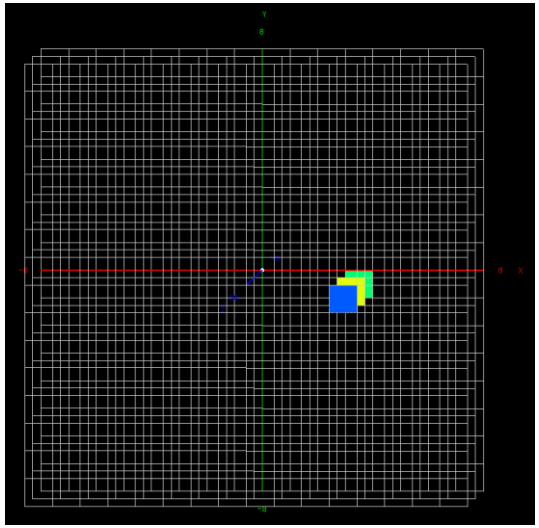


3 DCAL GEM Chamber Event Display

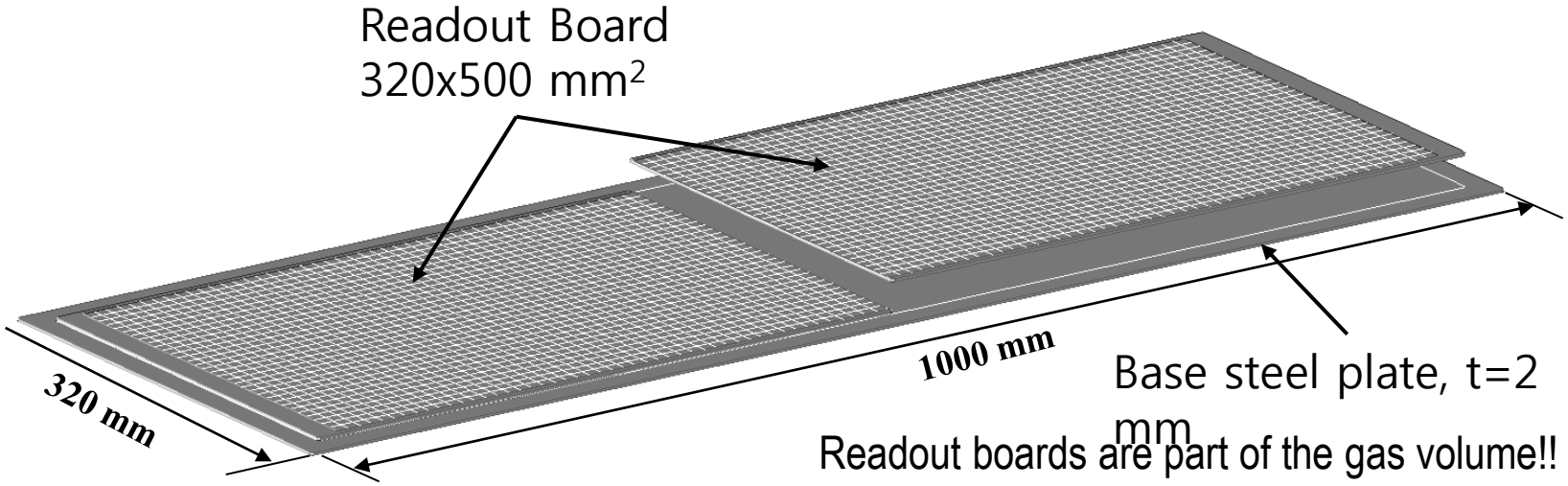


Beam direction

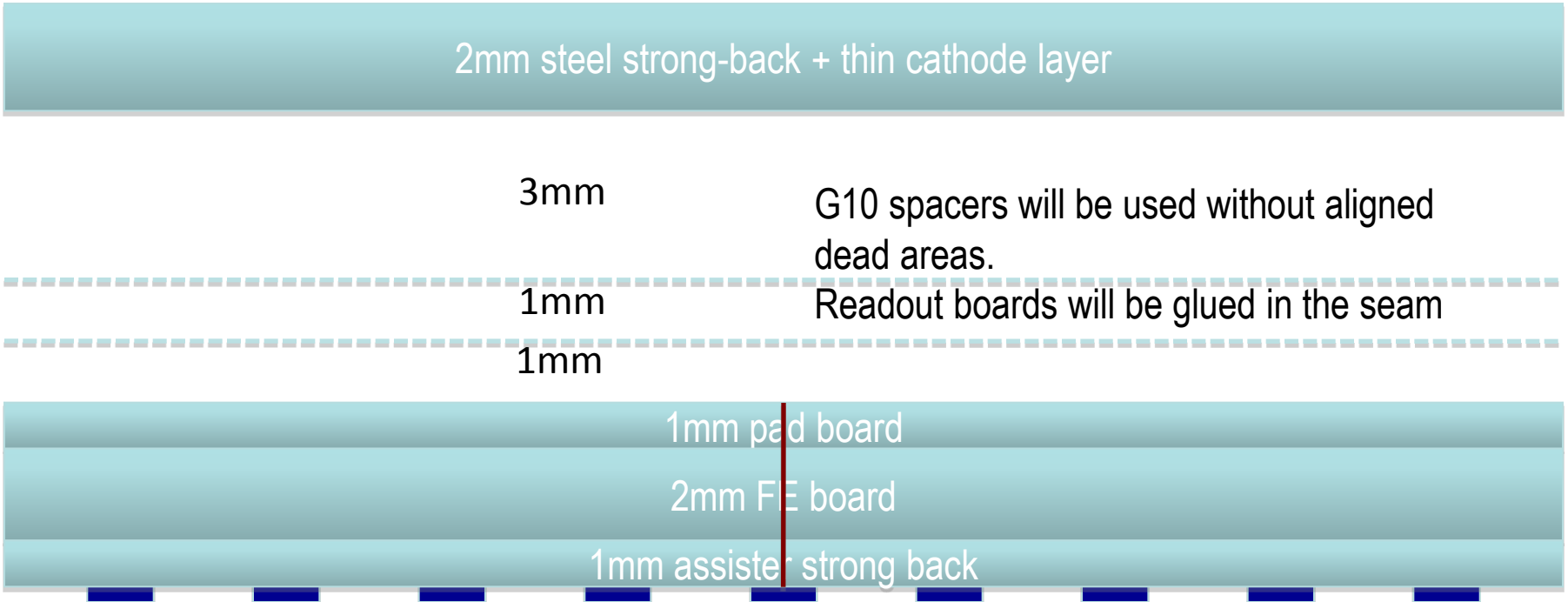




33cmx100cm DHCAL Unit Chamber Construction



Readout boards are part of the gas volume!!
GEM foils with 31 HV strips delivered

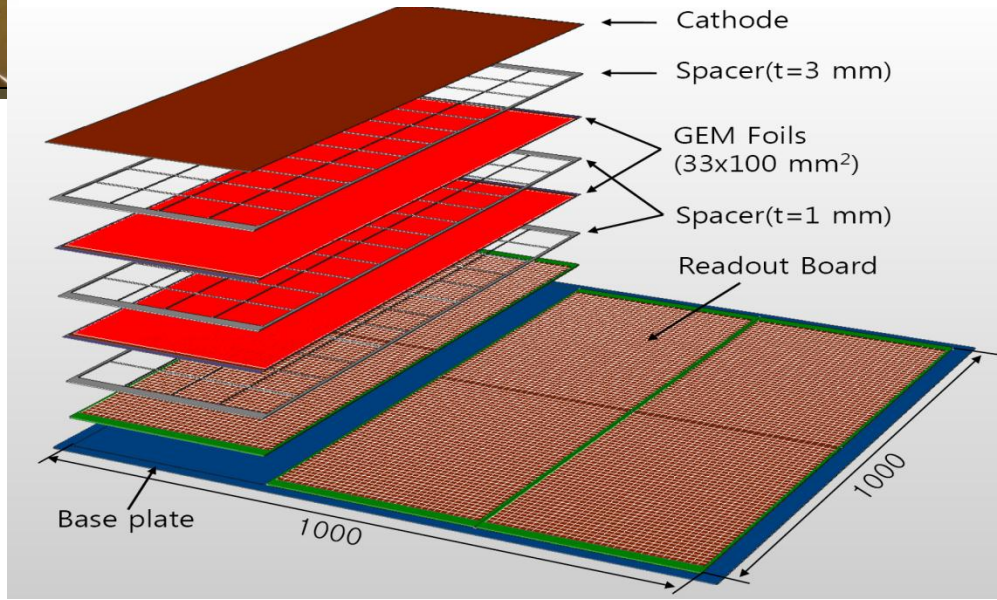


G10 spacers will be used without aligned dead areas.
Readout boards will be glued in the seam

Toward 100cmx100cm GEM Planes

CERN GDD Workshop delivered the first 5 of 33cmx100cm GEM foils in 2010 ➔ Qualification completed.

Foil Name	$N_{strip\text{-}pass}$	$<t_{saturation}>$	N_{strip}>2000s	Qualification	Note
LGEM 1	31	1725 s	4	Pass-med	Strips 1, 2, 10 & 23 >2000s
LGEM 2	30	1692 s	3	Pass-med	Strip 22 failed Strips 4, 5 & 29>2000s
LGEM 3	31	1484 s	0	Pass-high	
LGEM 4	31	1491 s	1	Pass-high	Strip 20 >2000 s
LGEM 5	Untested				Free-Delivered broken



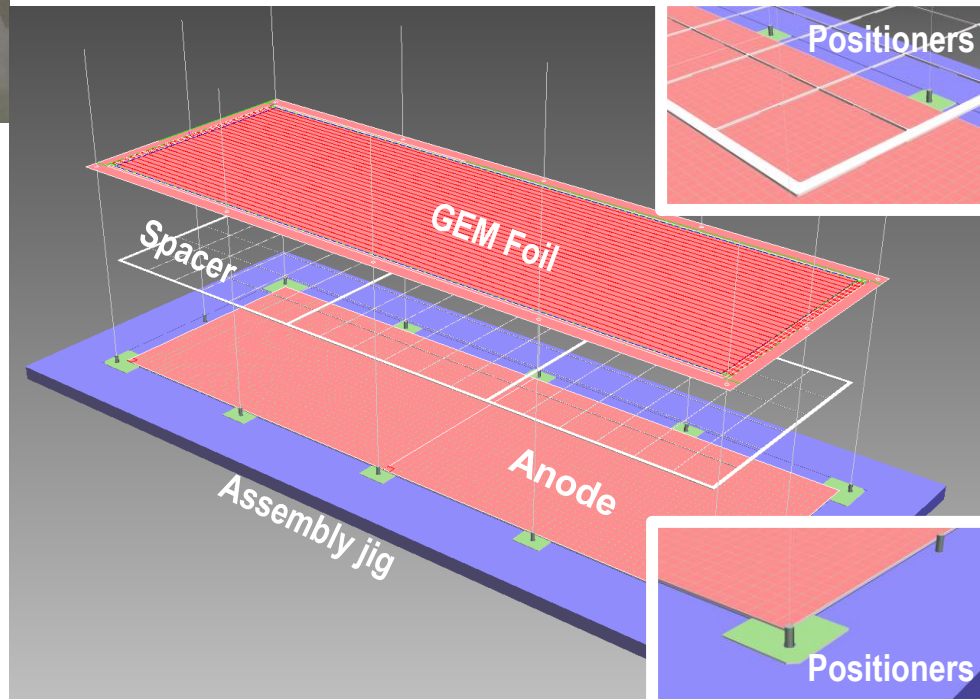
Each of the GEM 100cmx100cm planes will consist of three 33cmx100cm unit chambers

Toward 100cmx100cm GEM Planes!!

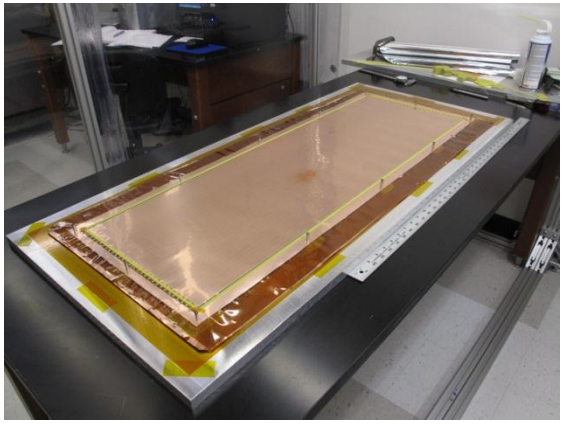
Class 10,000 clean room (12'x8') construction completed

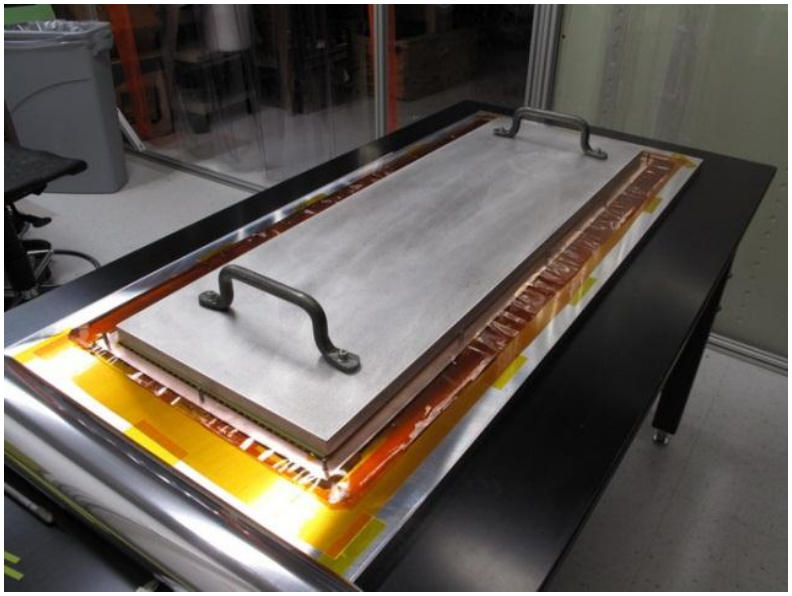
Two 33cmx100cm chamber parts delivered

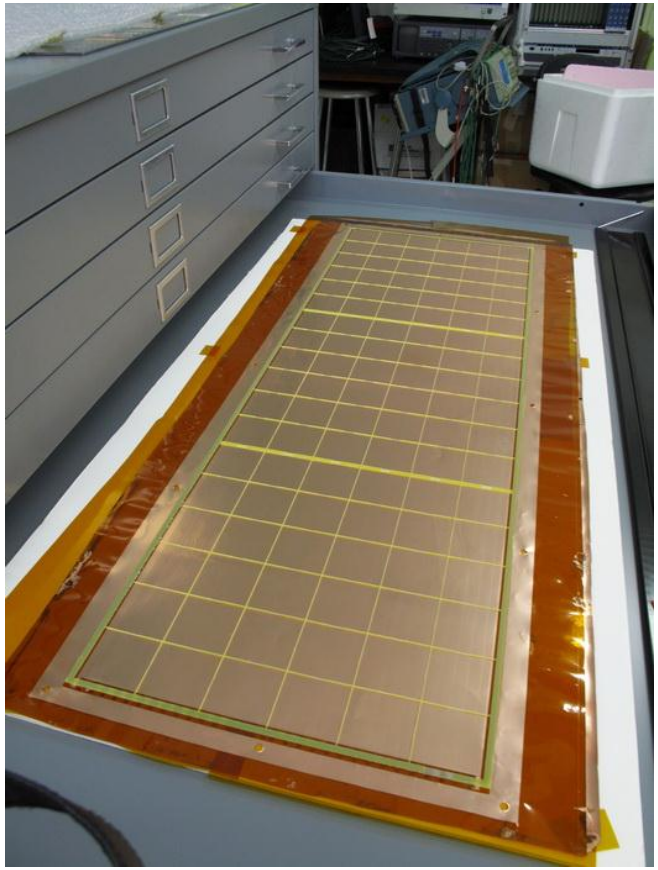
Jig for 33cmx100cm chamber being procured

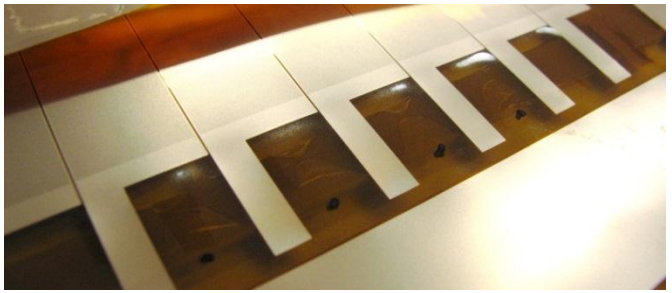


Preparation for LGEM Assembly









Next step: gluing Cathode+drift spacer

GEM DHCAL Plans

- ✓ Phase I (Through late 2011) ➔ Completion of 30cm x 30cm characterization with KPiX and DCAL chip integration
  - Performed beam tests @ FTBF with 30cm x 30cm double GEM chambers, one with KPiX9 and 3 with DCAL
  - Completion of 33cmx100cm large foil evaluation
- Phase II (late 2012 – 2013): 33cm x 100cm unit chamber development and characterization
  - Begin construction of 2 unit 100cmx33cm chambers, one with KPiX and one with DCAL
  - Bench test with sources and cosmic rays and beam tests
  - Construction of 100cmx100cm plane
- Phase III (2014): 100cmx100cm plane construction
  - Construct 6 unit chambers with DCAL for two 100cmx100cm planes
  - Characterize 100cmx100cm planes with cosmic rays and beams
- Phase IV (2015): 100cm x 100cm plane GEM DHCAL performances in the CALICE stack
  - Complete construction of five 100cm x 100cm planes inserted into existing CALICE calorimeter stack and run with either Si/W or Sci/W ECALs, and RPC or other technology planes in the remaining HCAL

Summary

- 30cmx30cm GEM prototype chambers and beam test run
  - KPiX readout: Established good 2D working condition with v9 (512 channel) and took a successful beam test data
  - DCAL integration very successful, took beam test data with three chambers ➔ Trying to understand the beam test data
  - Analyses of over 7M beam test events from Aug. 2011 run in progress
  - Continue taking cosmic ray data with these four chambers
  - Responses seem to be consistent between various runs
    - Finalization of the response to particle dependence – proton, pion and muon
    - Multiplicity vs threshold show reasonable behavior (~1.8 at 98% efficiency)
    - Efficiency at around 98% at 5fC
  - Gains at around 11,000 with 1950V operation HV
    - Need to finalize with refined fits

Summary

- 33cmx100cm unit chamber construction proceeding
  - First 5 foils of 33cmx100cm delivered and qualification completed
  - G10 spacers for the large chamber and the construction parts delivered
  - A clean room needed for foil certification and chamber construction - Class 10,000 clean room of size 12'x8' completed
- Mechanical design being worked out for constructing 33cmx 100cm unit chambers and 1mx1m planes for DHCAL testing
  - Construction jig being procured