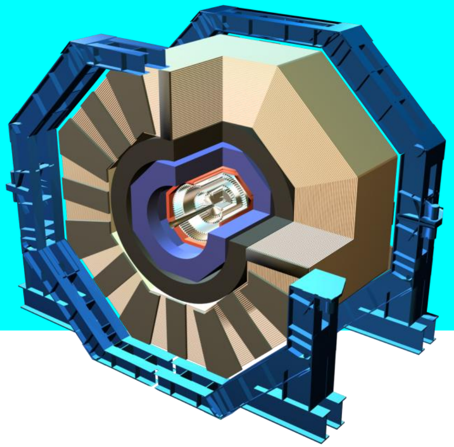
GEM-based Digital Hadron Calorimetry

+ Update on very recent THGEM results

Calorimeter for ILC



SiD

Andy White

For the GEM-DHCAL Group

U. Texas at Arlington, SLAC, Aveiro/Coimbra, Weizmann

With many thanks to our SLAC (KPiX), ANL (DCAL), and Weizmann colleagues!

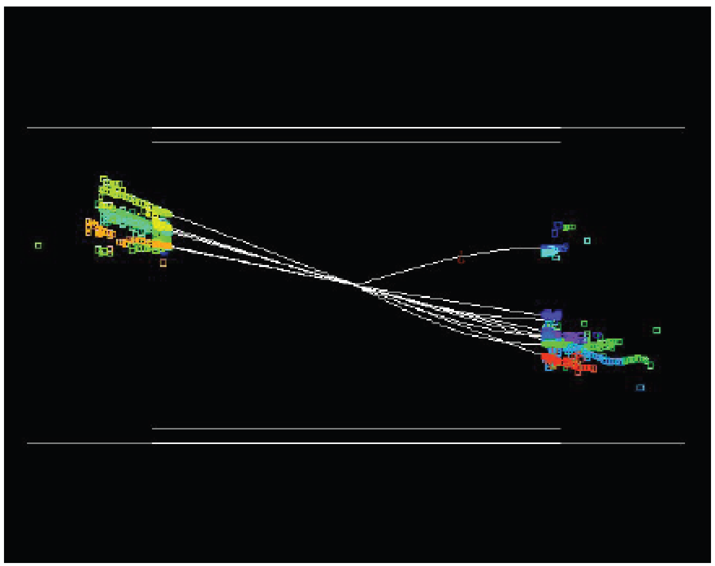
Digital hadron calorimetry - ILC

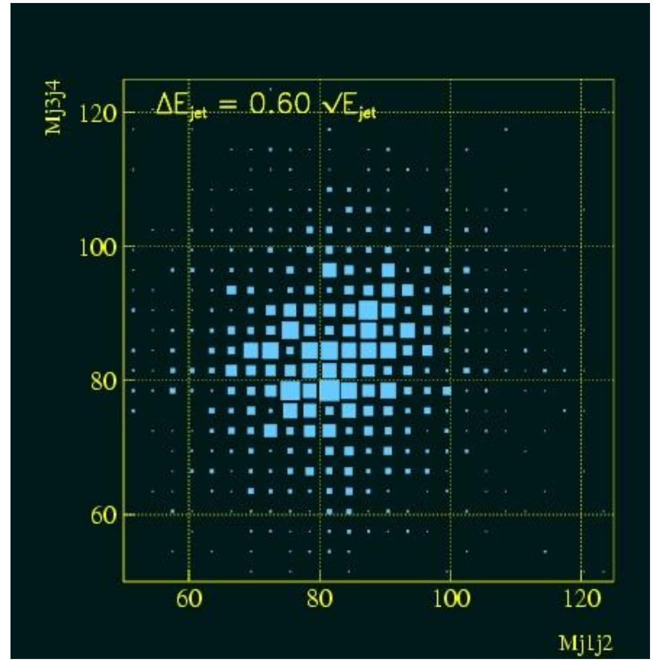
- Need for high resolution energy measurements of jets
- example: separation of W, Z in hadronic mode
- Three components of jet energy in calorimeter:
  1) electromagnetic – measured well in e.m. calorimeter
  2) charged hadrons – track(s) + cluster(s) in hadron and e.m. calorimeter
  3) neutral hadrons – cluster(s) in hadron and e.m. calorimeter
- Use momentum measurement of charged hadrons in magnetic field, track them to energy clusters in hadron calorimeter, remove associated energy – remainder is neutral energy ("Particle flow algorithm")

⇨ Must track charged hadrons in calorimeter !

Importance of good jet energy resolution

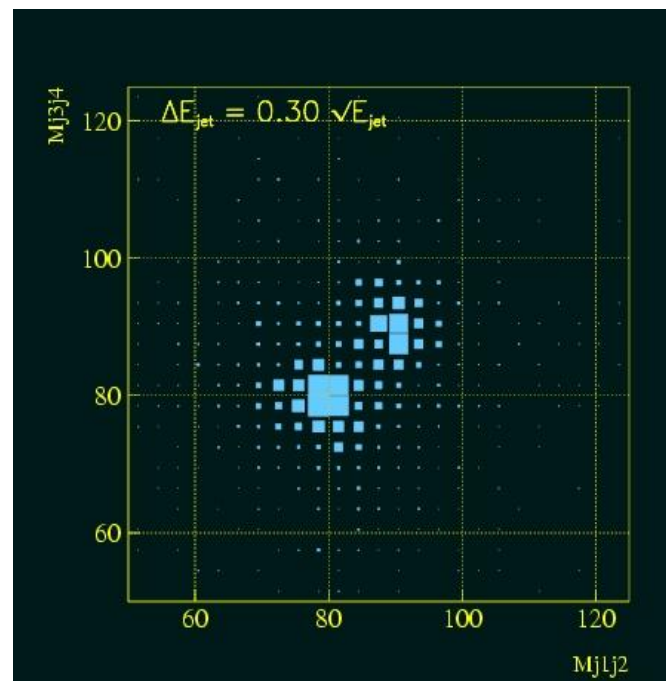
Simulation of W, Z reconstructed masses in hadronic mode.





60%/√E

30%/√E

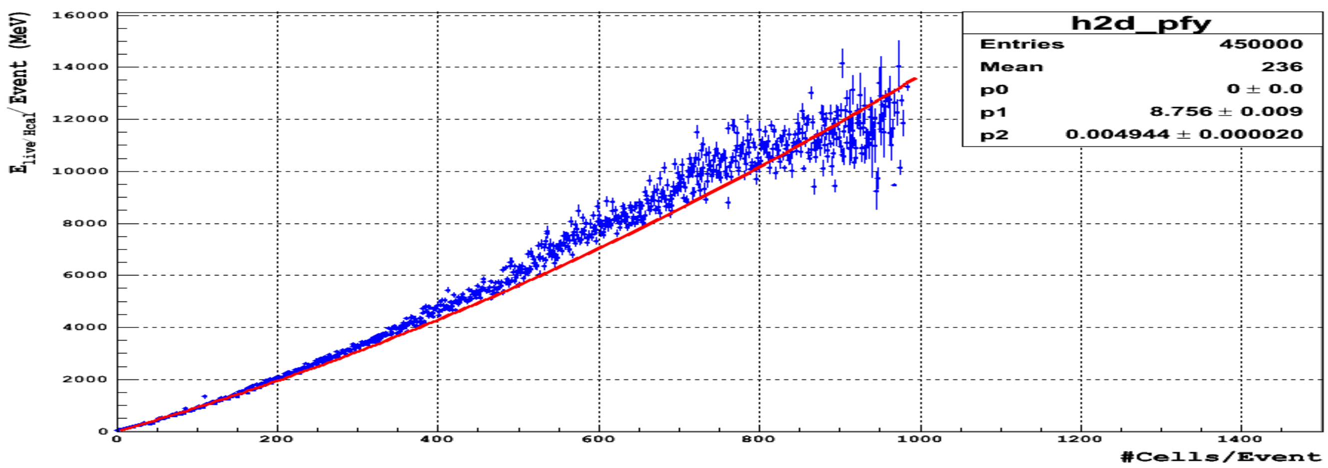


(from CALICE studies, H.Videau)

Digital hadron calorimetry

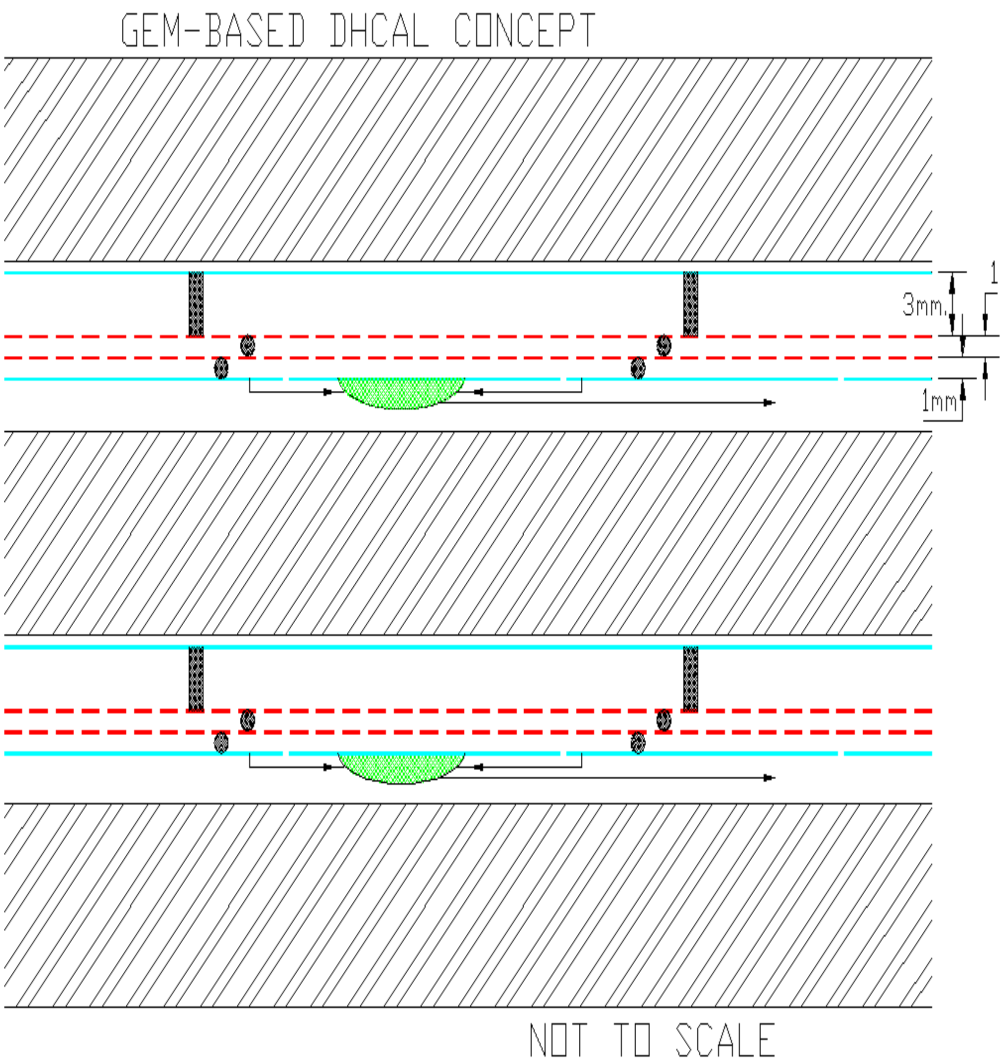
A new approach:

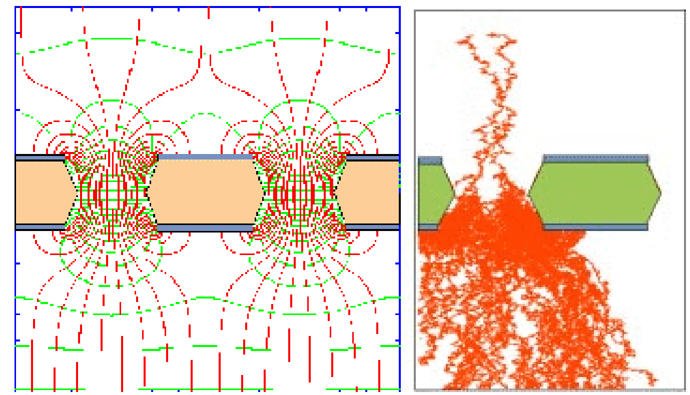
- use small cells (~1cm x 1cm), cell is either ON or OFF.
- high granularity allows charged track following
- good correlation between energy and number of cells hit.
- requires development of "Particle Flow Algorithm" to associate energy clusters/tracks.



V. Kaushik MS Thesis

GEM/DHCAL active layer concept





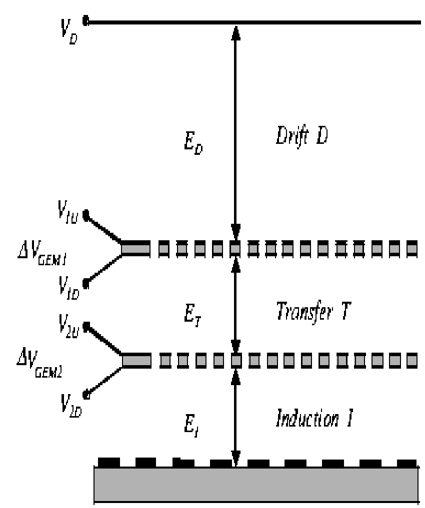


Fig. 1: Schematics of a double-GEM detector.

-2100V

ΔV ~400V

ΔV ~400V

0V

GEM DHCAL Developments

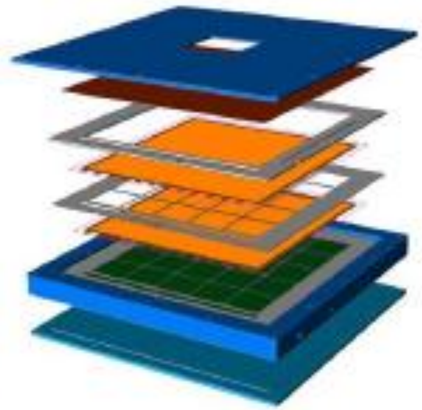
- GEM detector with an optimal gas flow spacer design, constructed and integrated with SLAC KPiX V7 (64-channel) readout.
- Two dimensional readout of 30cm x 30cm chamber using KPiX successful.
  - Benchmark Fe^{55} from single channel analog electronics
- Three additional 30cm x 30cm chambers constructed.
  - One at ANL for DCAL chip readout testing (for 40-layer stack)
  - Two at UTA for continued chamber characterization
- Completed the design of 30cm x 100cm GEM foil.
  - Construction of first five 30cm x 100cm foils has begun at CERN GDD workshop, Feb. 2010
- Mechanical design considerations for large chamber construction in progress.

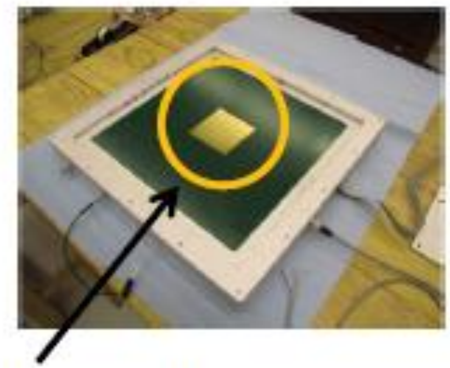
30cm x 30cm GEM with 8x8 pads

- GEM Foils(3M)
  - $310 \times 310\ mm^2$
  - Active area : $280 \times 280\ mm^2$

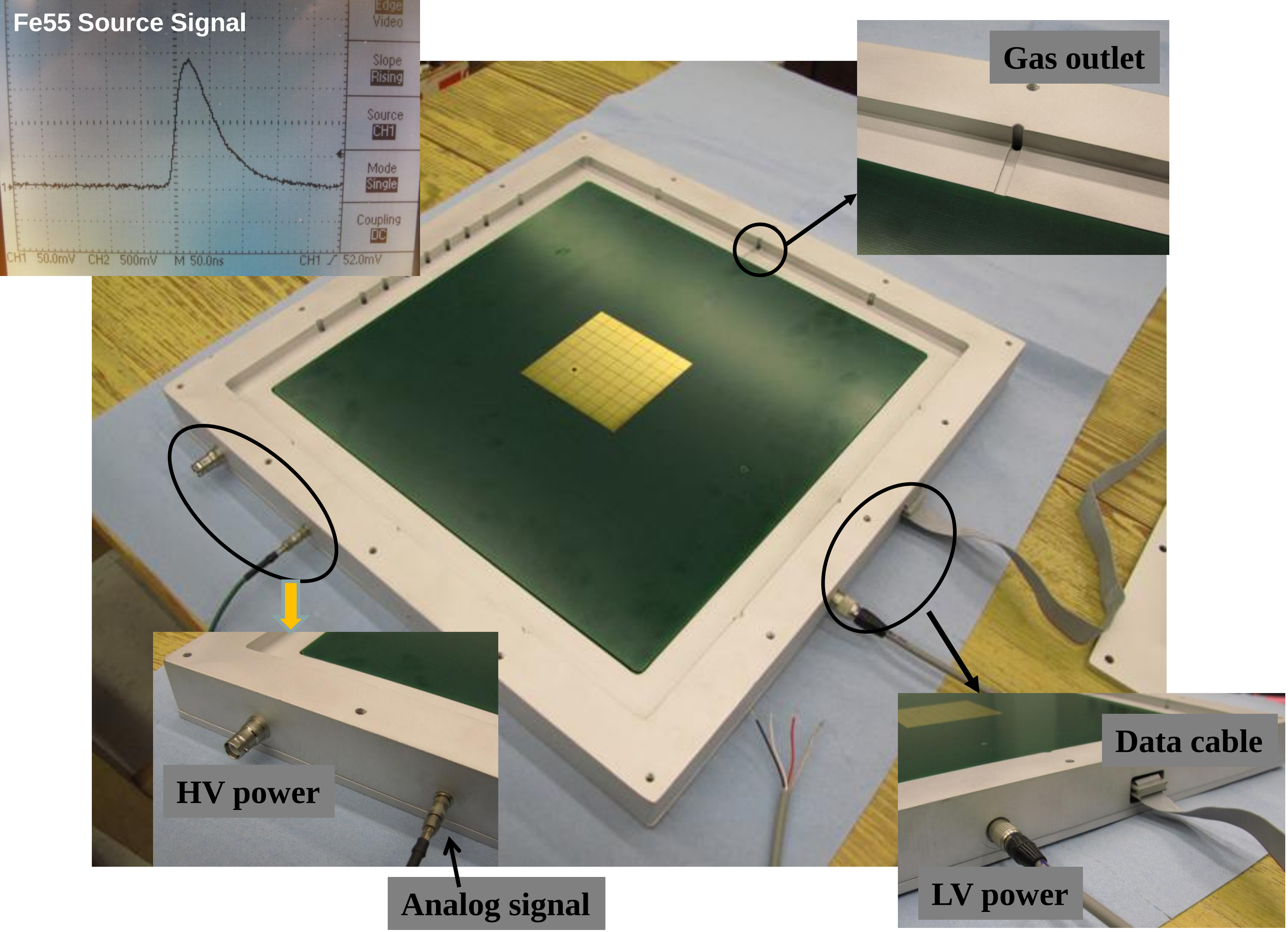
Chamber

- Active gas room
  - $350 \times 350 \times 6\ mm^3$ → For 3/1/1 gaps(d/t/i
- 64 readout channels($1 \times 1\ cm^2$)



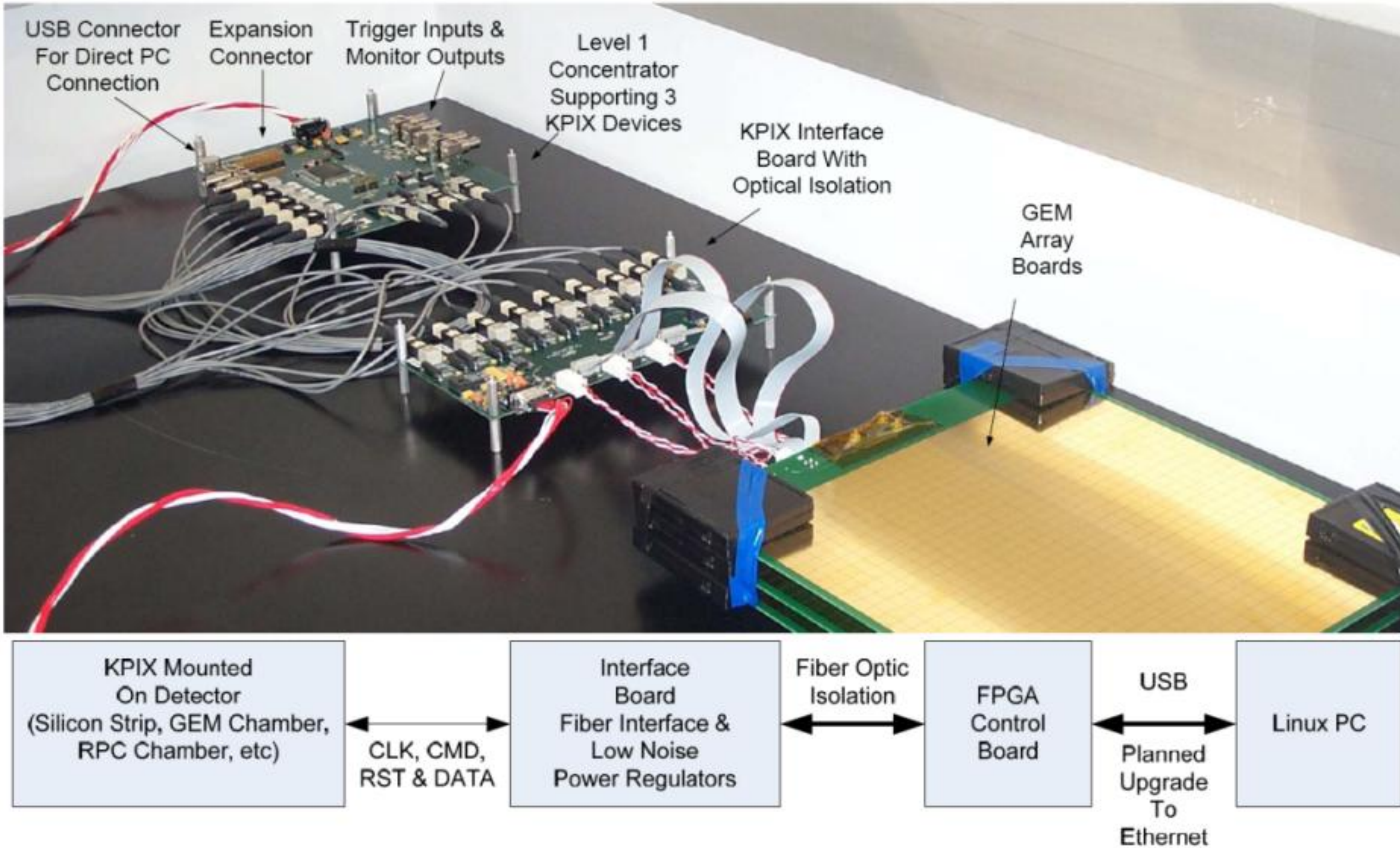


64-readout pads

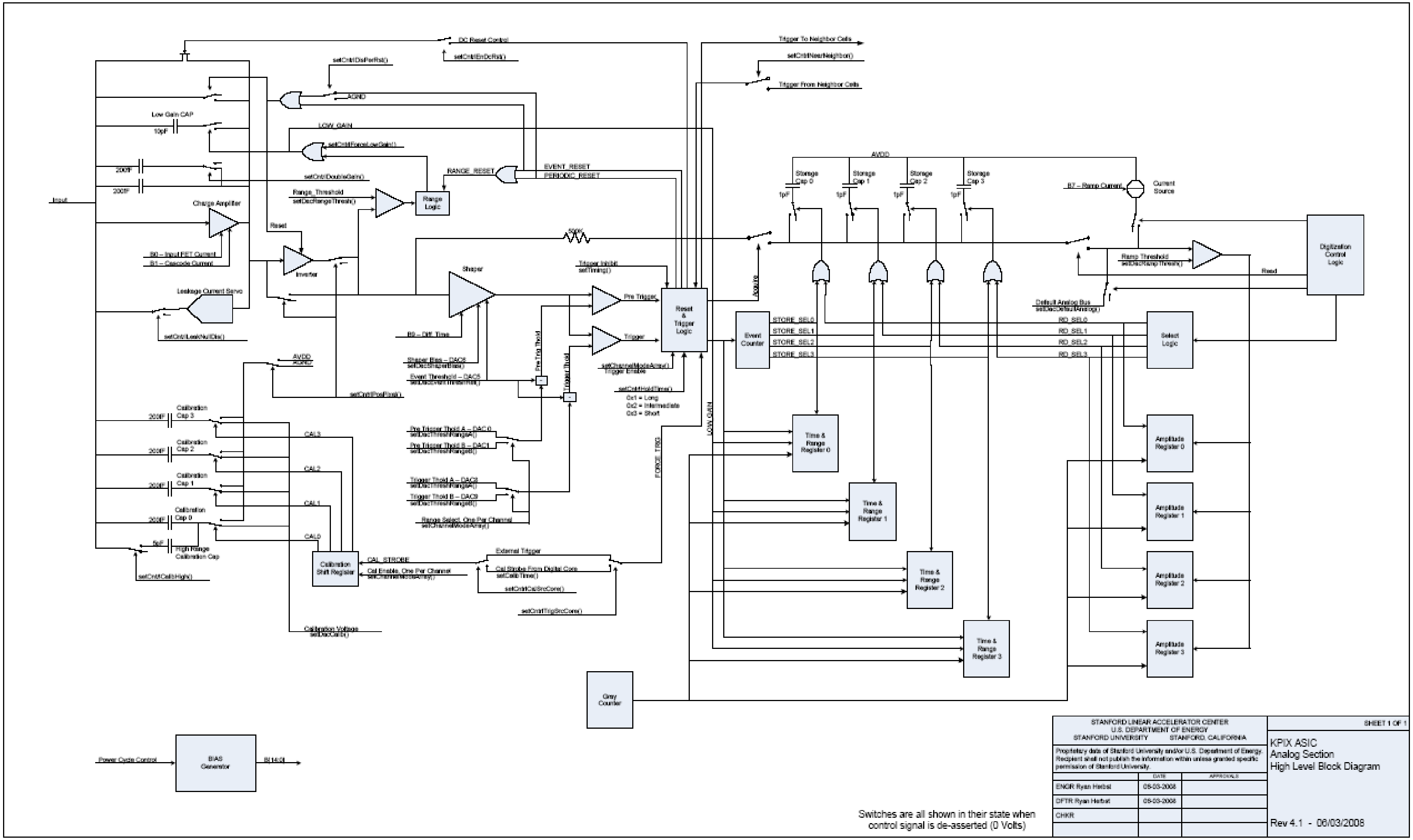


Fe55 Source Signal
Edge
Video
Slope
Rising
Source
CH1
Mode
Single
Coupling
DC
CH1 50.0mV CH2 500mV M 50.0ns CH1 ∕ 52.0mV
Gas outlet
HV power
Analog signal
Data cable
LV power

GEM-DHCAL/KPiX boards with Interface and FPGA boards



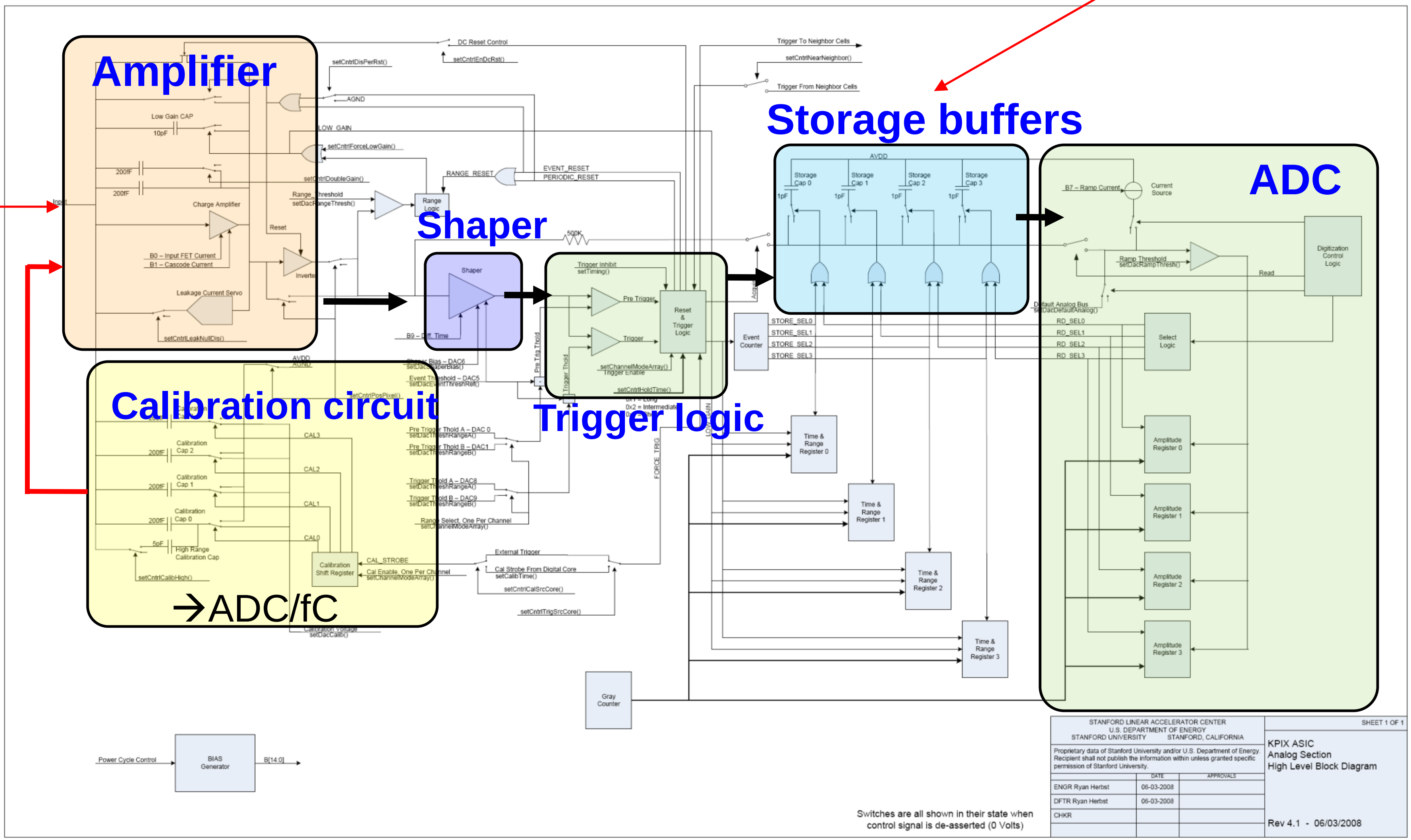
KPiX functional diagram



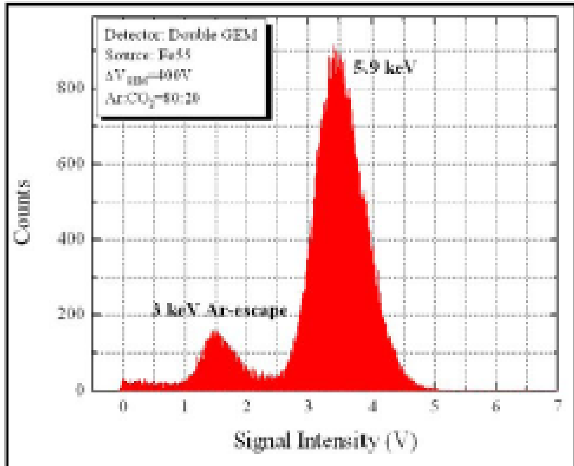
KPiX Readout scheme

DHCAL anode pad

4-deep "pipeline"



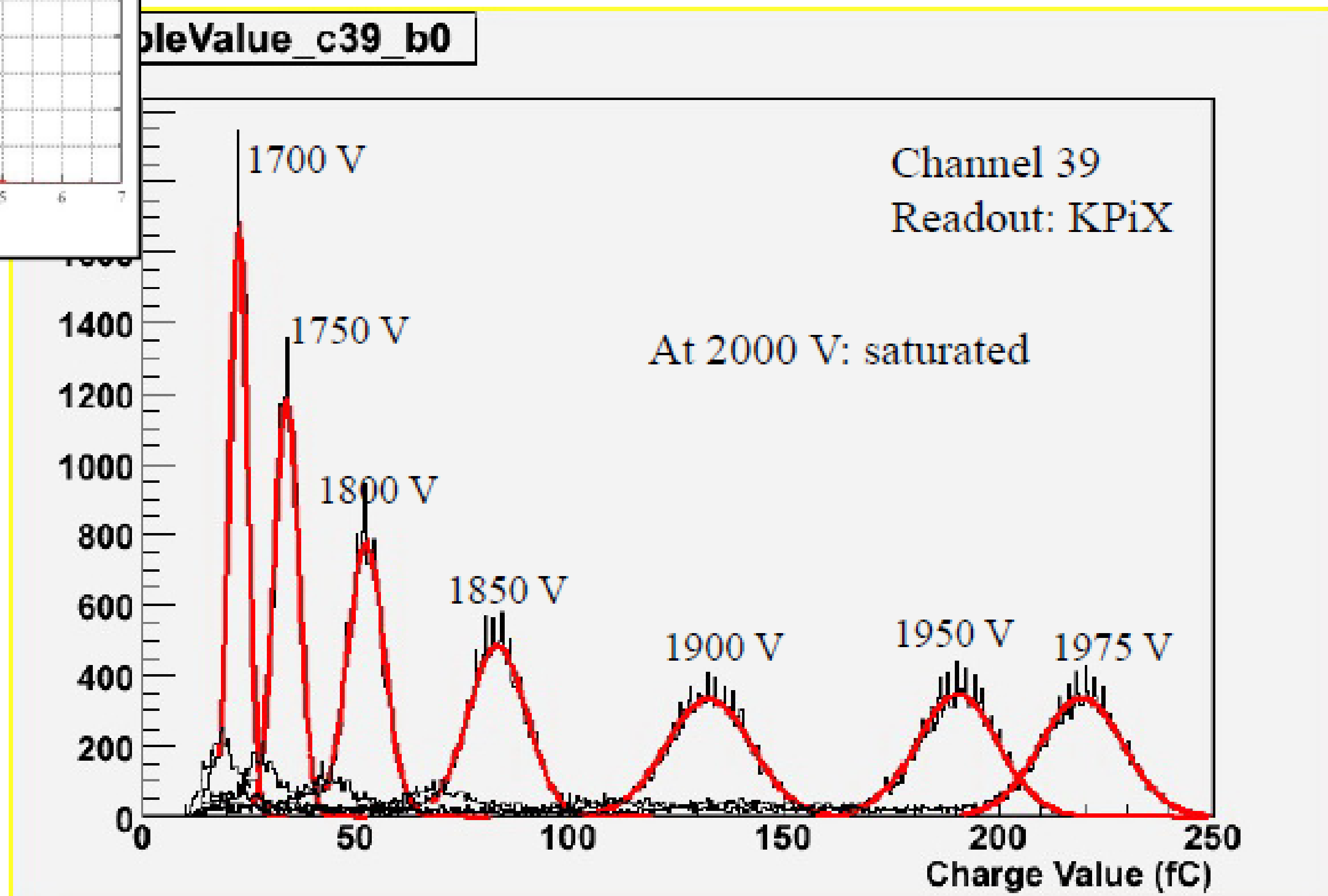
30cm x 30cm GEM with 8x8 pads



Typical Fe55 spectrum from an Ar-based gas detector

Readout:
A225+A206(AmpTek)

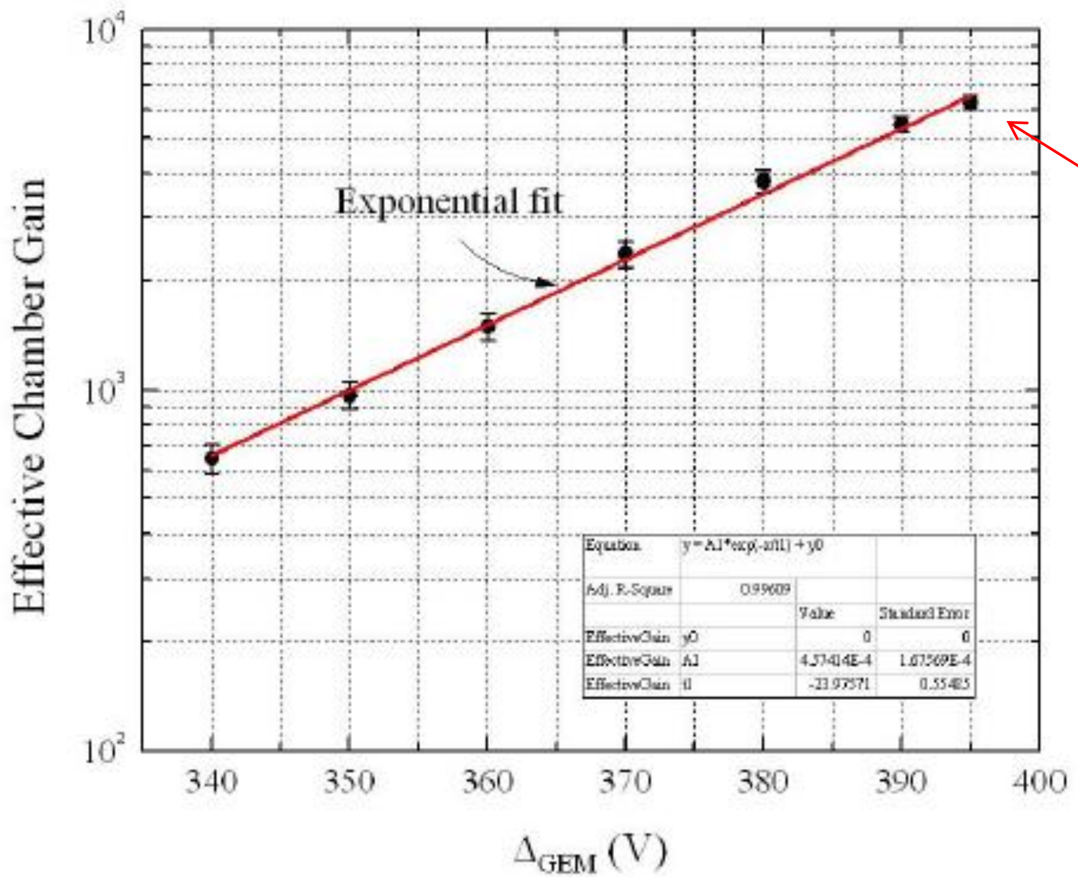
Single Channel



Fe55 peak @ 1980V
is at ~235fC

Multi-channel KPiX

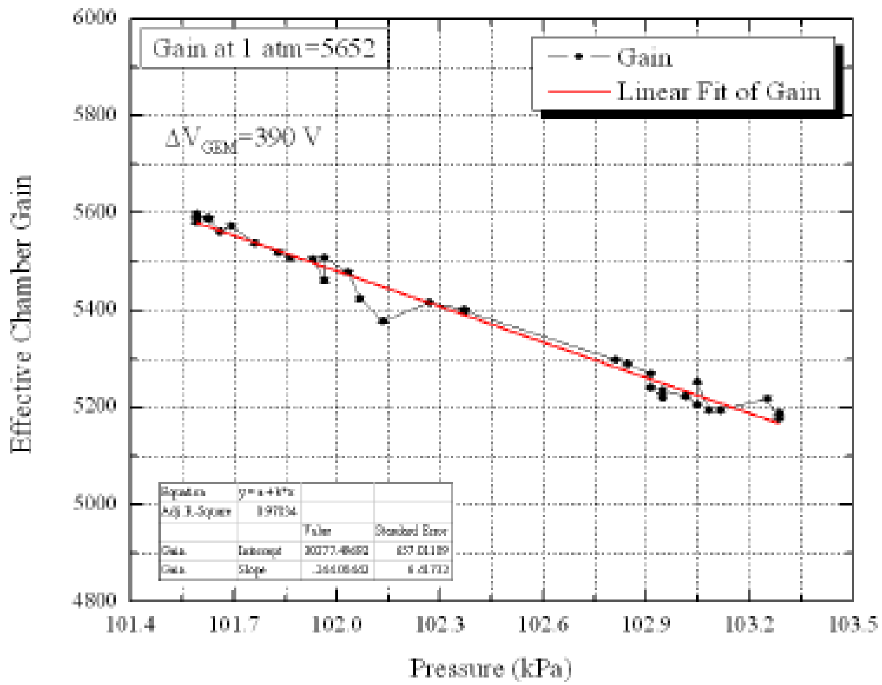
30cm x 30cm GEM with 8x8 pads

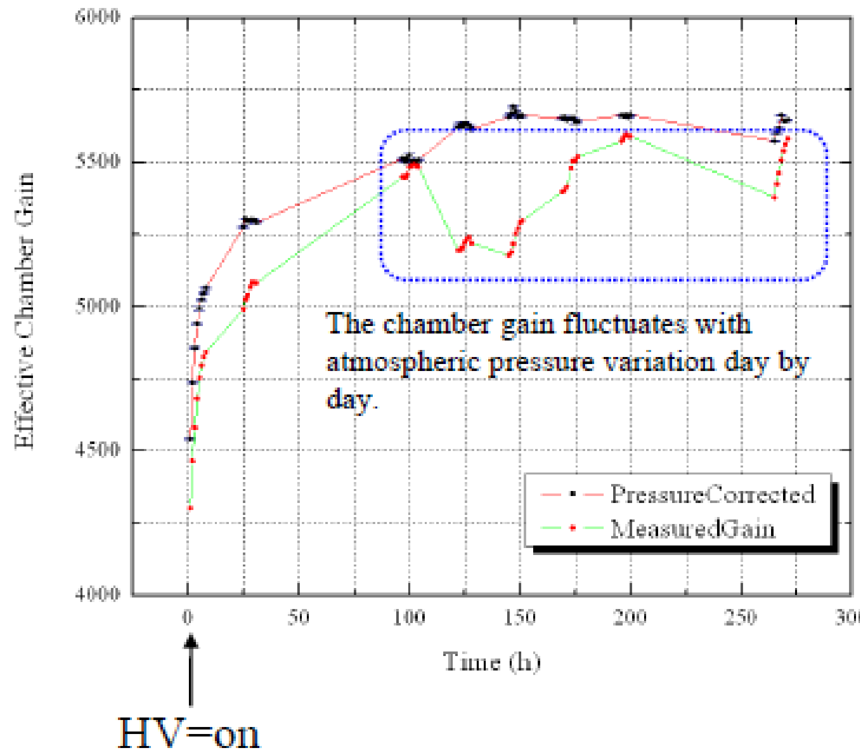


Typical operating point:
Gain ~6000

30cm x 30cm GEM with 8x8 pads

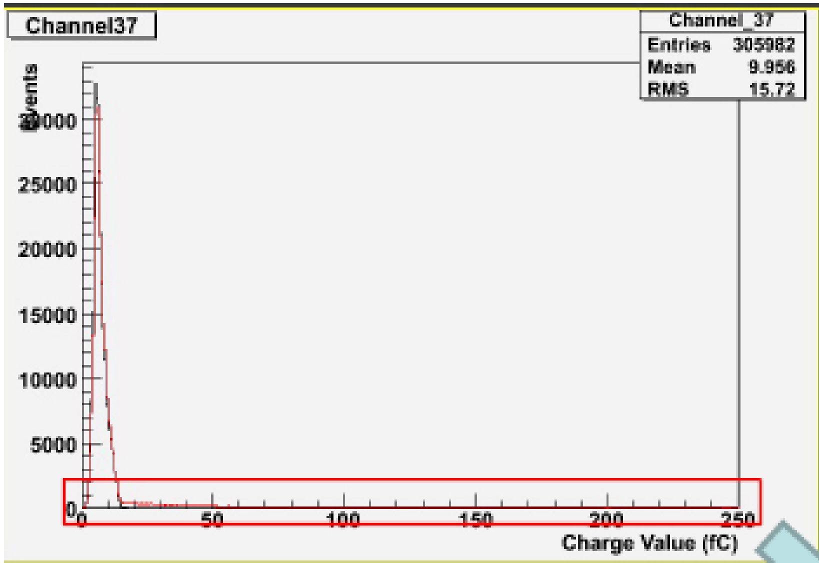
HV =1950V (ΔV_{GEM}=390 V)



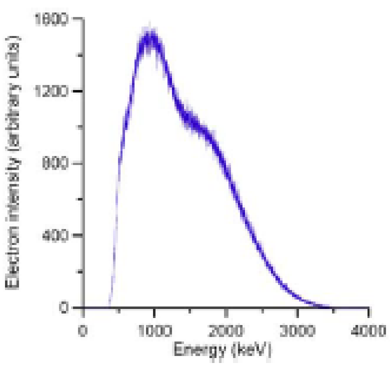


We use an open gas system (gas flows at atmospheric pressure).
Thus, pressure inside chamber is affected by the atmospheric pressure directly.
This pressure change affects the chamber gain.
The chamber gains were recalculated to the values at 1 atm.

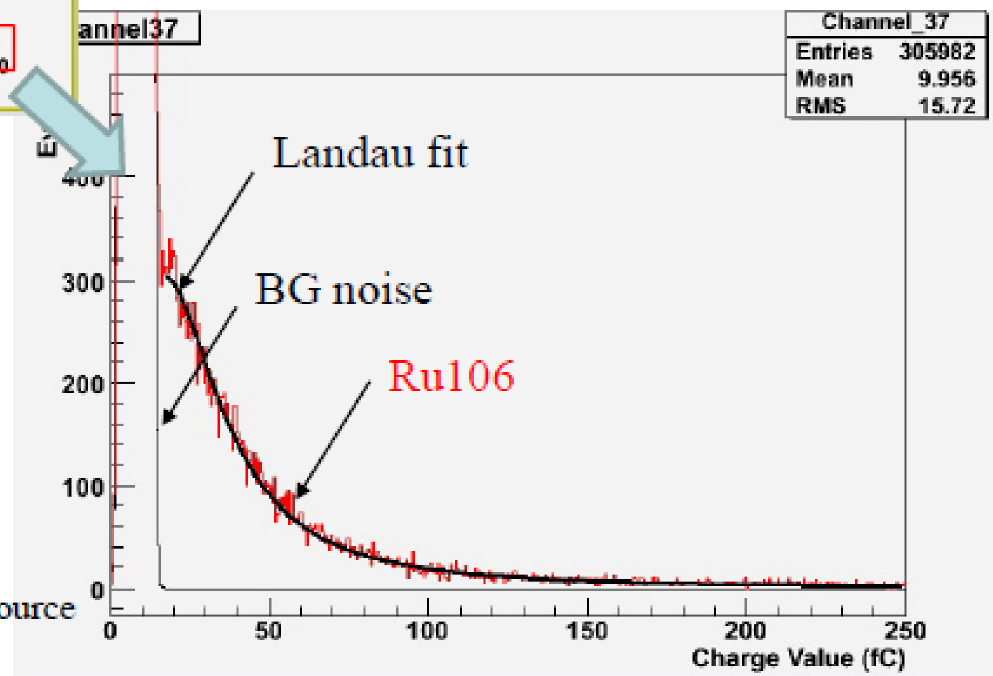
30cm x 30cm GEM with 8x8 pads: ^{106}Ru



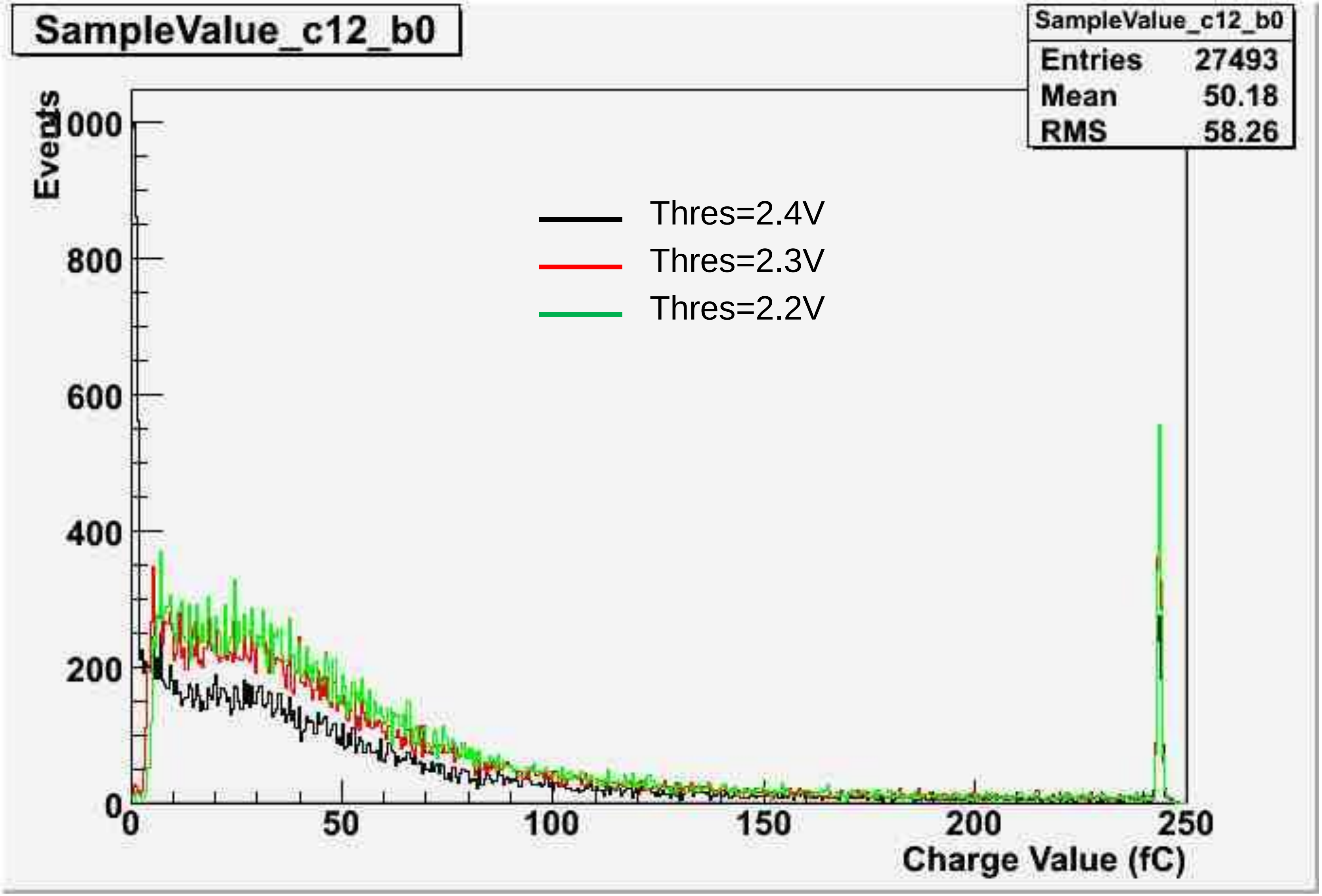
Ru106, 1960V, ST=2.4V=2 fC
Background, 1960V, ST=2.4V=2 fC



Energy spectrum of Beta emission from a Ru106 source

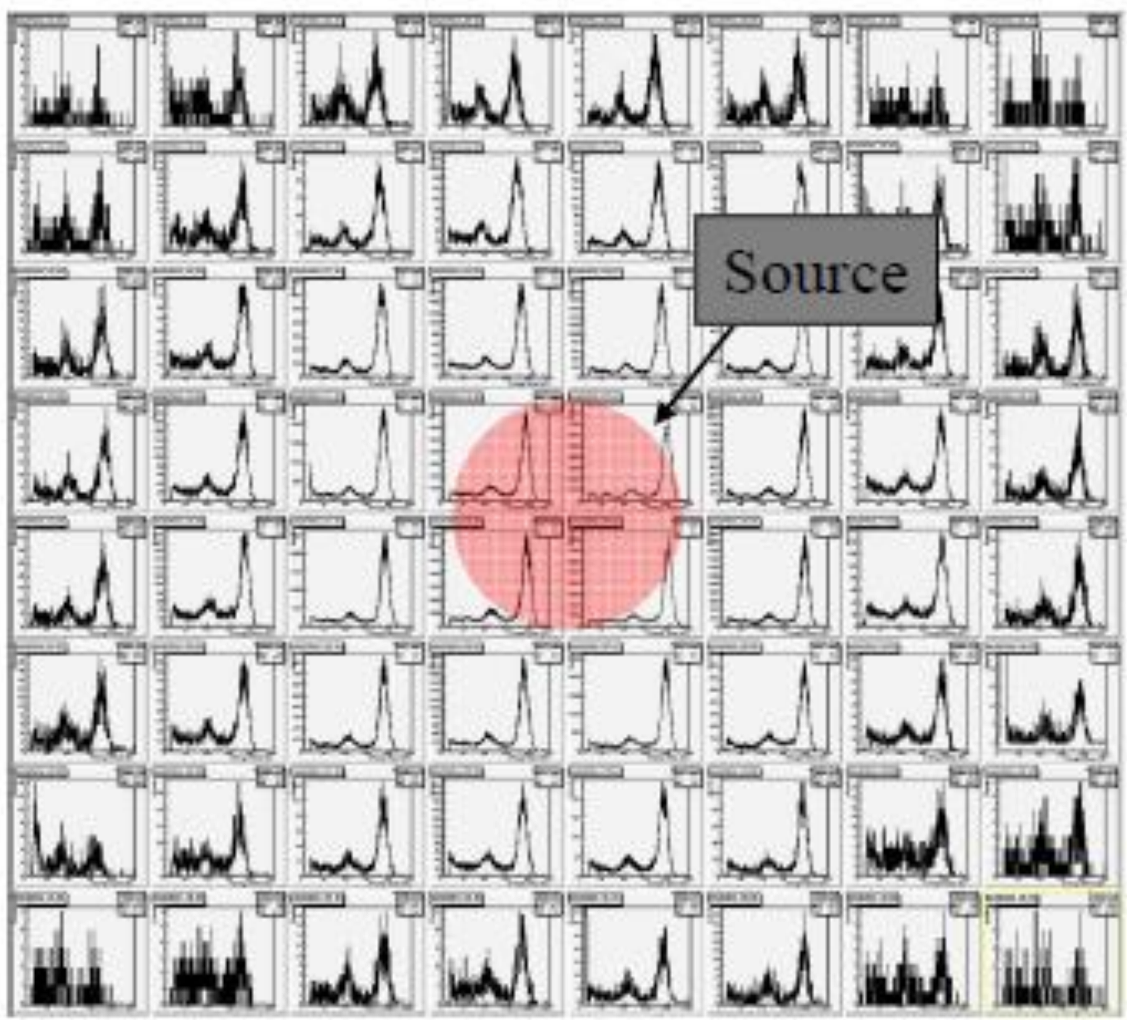


30cm x 30cm GEM with 8x8 pads: ^{106}Ru

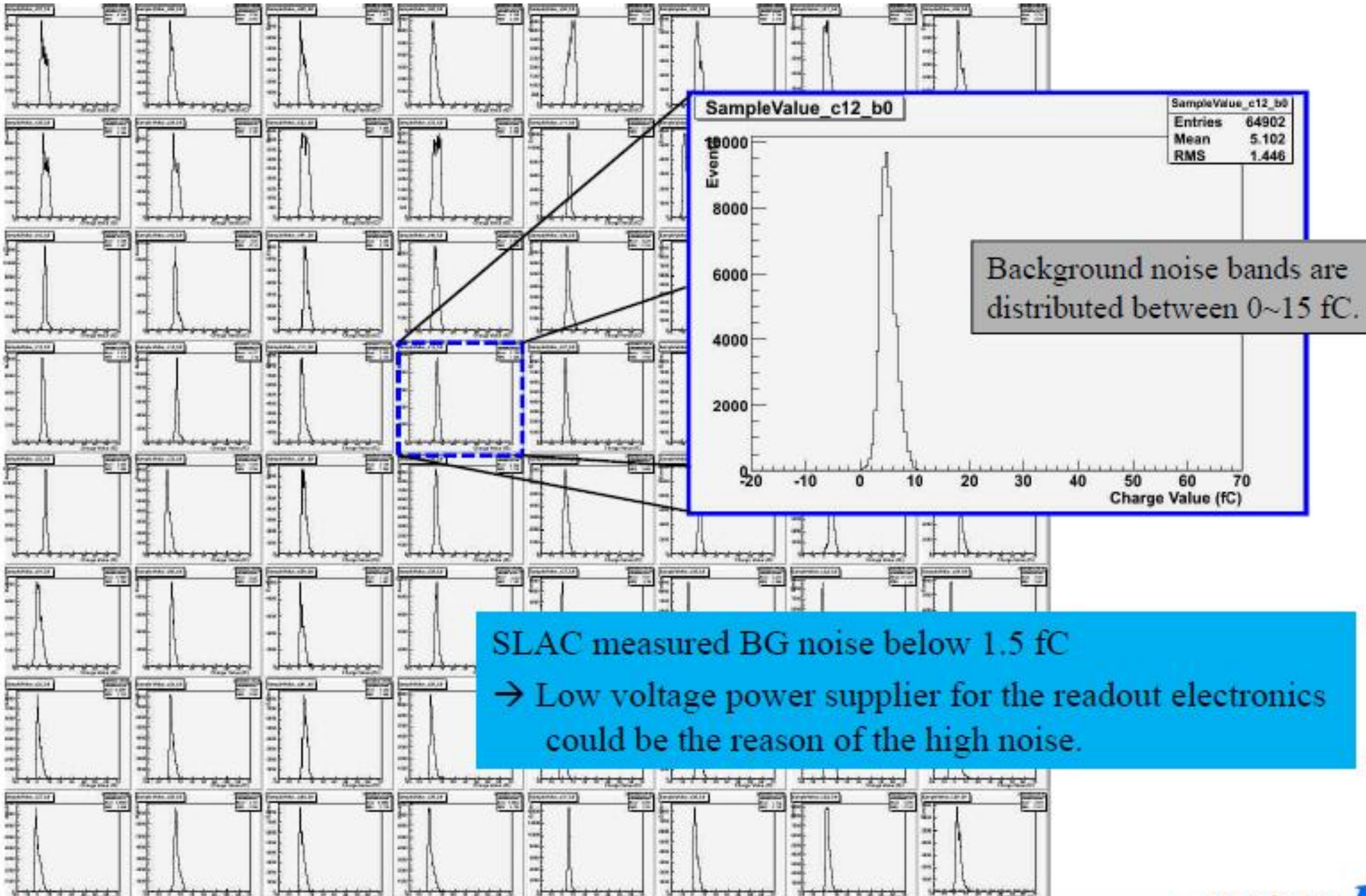


Map for Fe^{55} GEM+KPiX7

Source (Fe55) was put on the detector window.
Each histogram corresponds to each anode pad on the readout board.



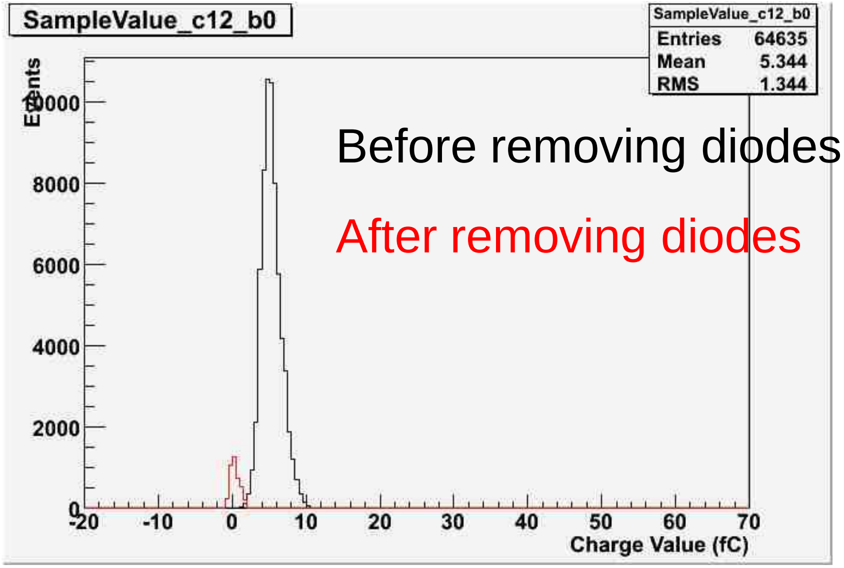
30cm x 30cm GEM with 8x8 pads: Bkgd



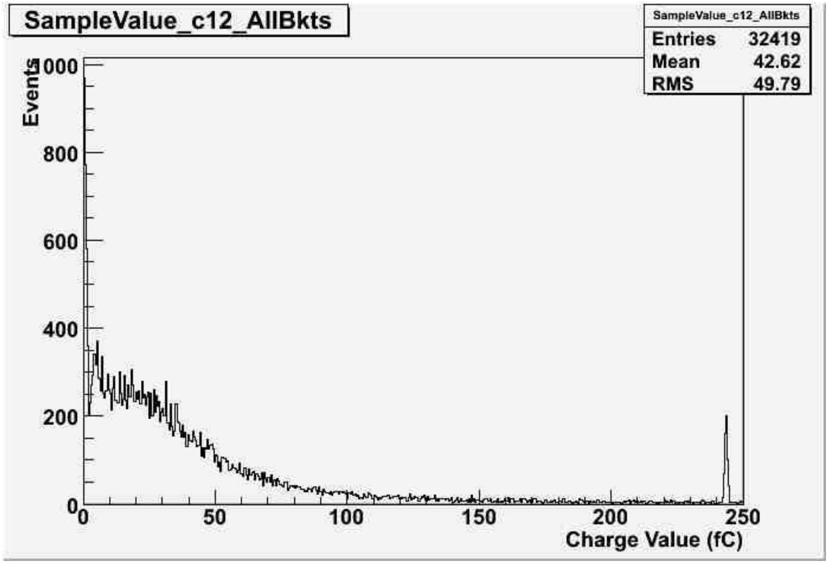
SLAC measured BG noise below 1.5 fC

→ Low voltage power supplier for the readout electronics could be the reason of the high noise.

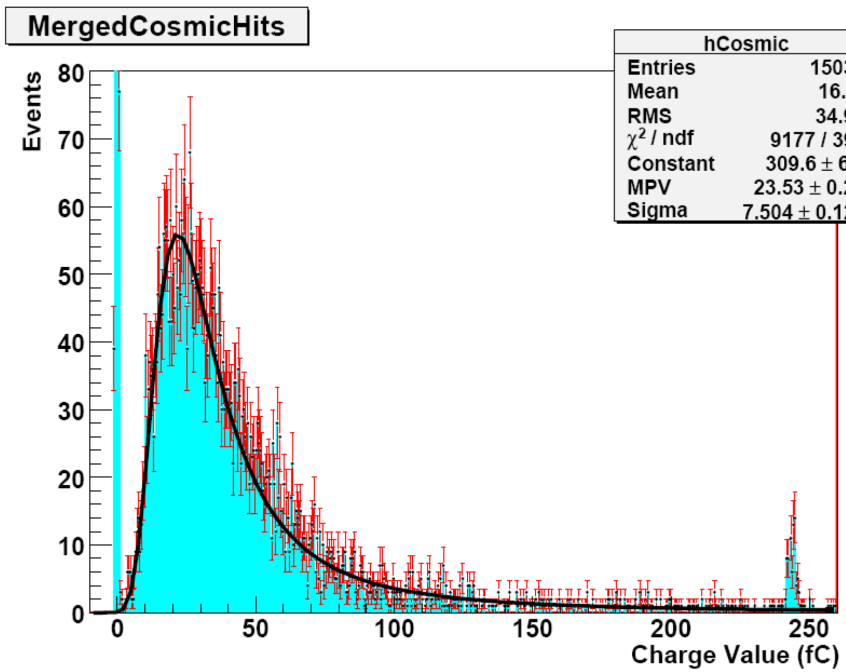
30cm x 30cm GEM with 8x8 pads: ^{106}Ru



Not all e- are Min-I in chamber (+ range of angles) -> use cosmics/beam for next tests

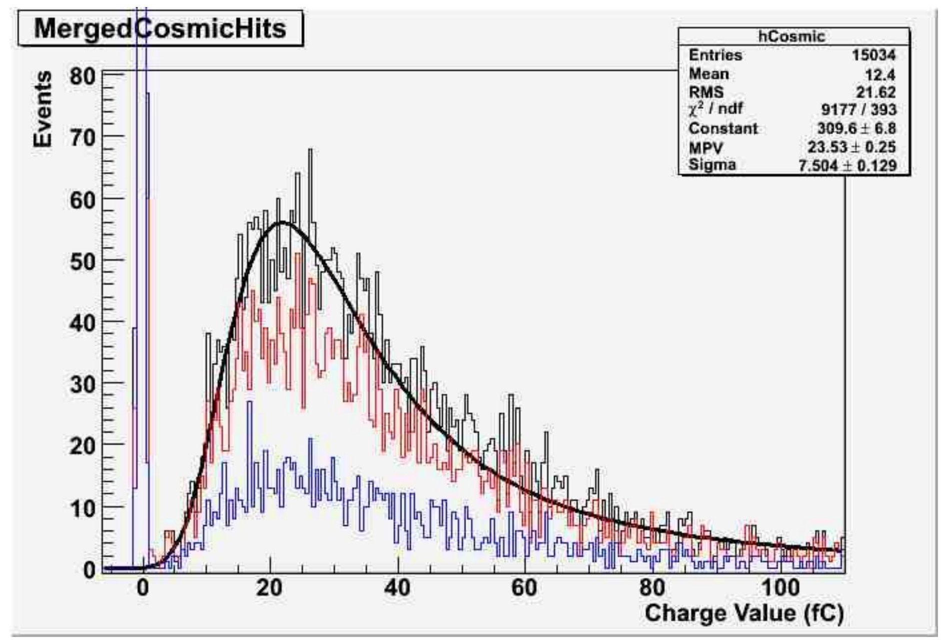


Cosmic data – two runs merged



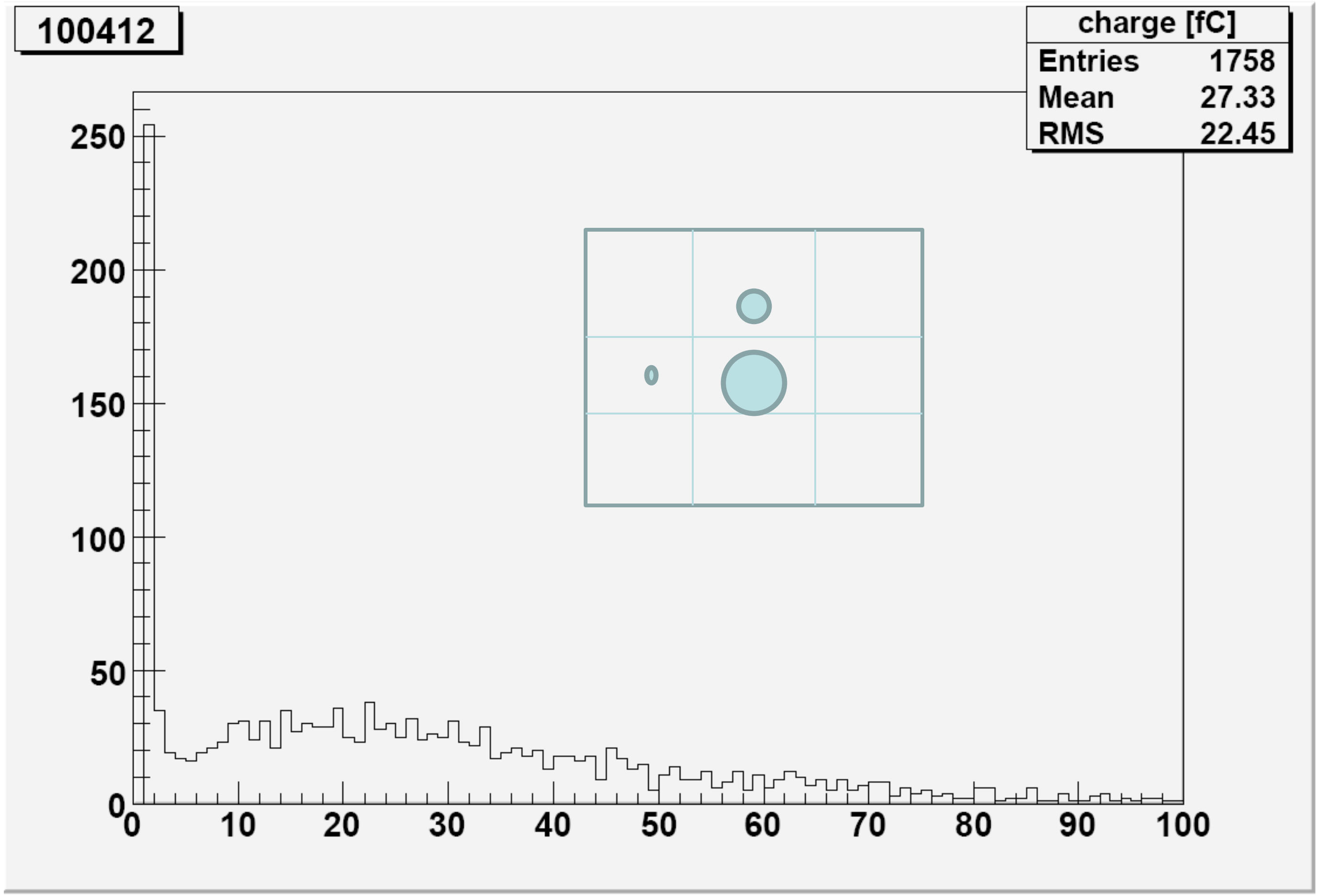
Highest charge only used

2010_04_12_10_48_52
2010_04_14_10_57_40
Summed Hits



Dieter Freytag's (SLAC) Cosmic Analysis

- Highest charge plus charges from adjacent cells

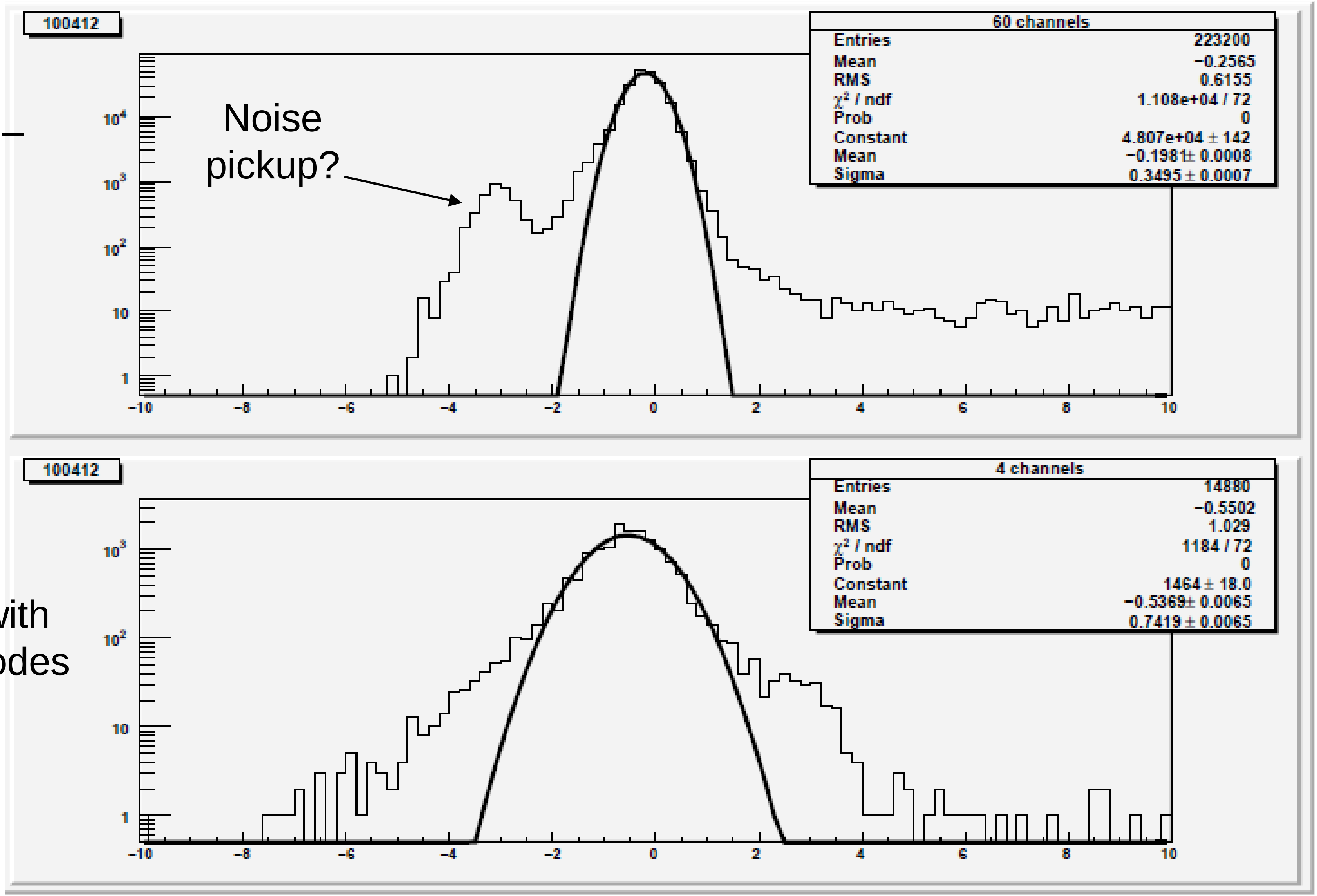


fC

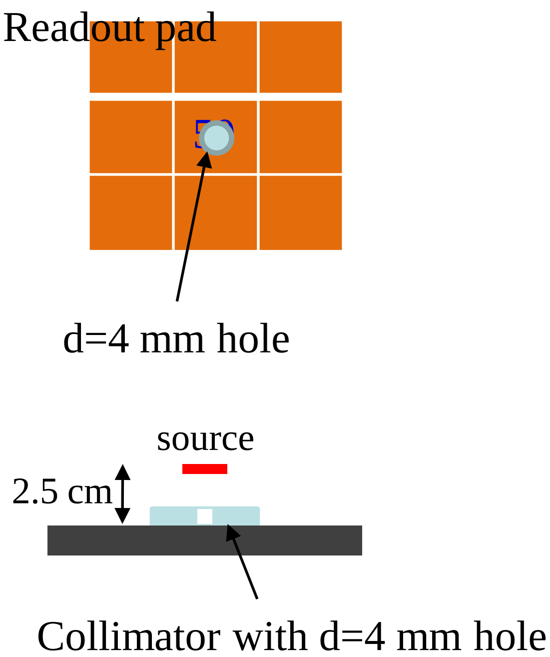
Gaussian fits to noise peak (D.Freytag - SLAC)

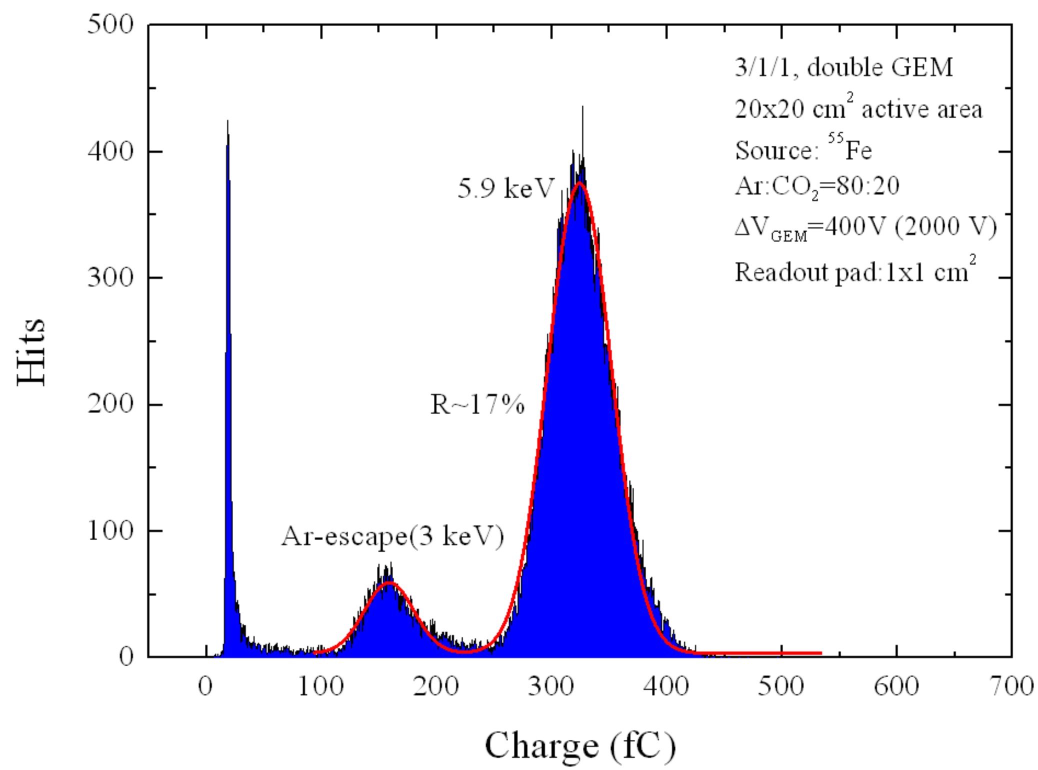
60 Channels – no protection diodes

4 Channels with protection diodes



Fe55 spectrum from GEM4
with new GEM foils from CERN

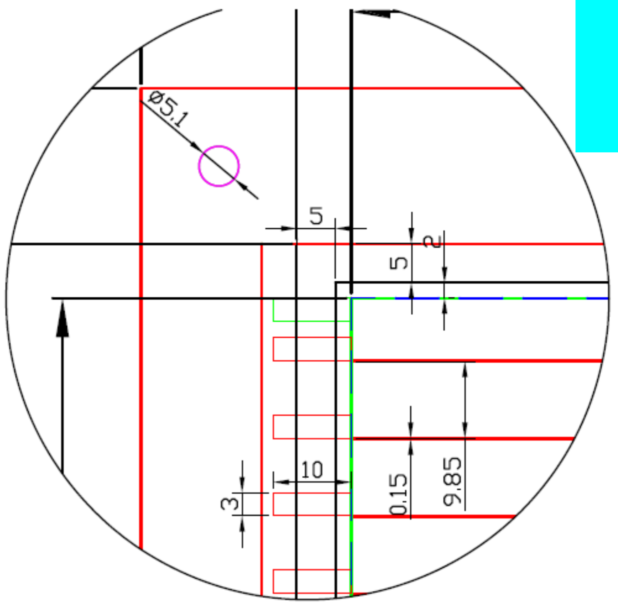




GEM DHCAL Plans

- Through mid 2010
  - Complete 30cm x 30cm chamber characterization using radioactive source, cosmic ray and particle beams
    - Need to understand electronic noise affecting MIPs ✓
  - Start producing 33cm x 100cm GEM foils
  - Begin construction of 33cm x 100cm GEM unit chambers and characterize them using source, cosmic ray and particle beams
- Mid 2010 – Late 2011
  - Complete construction of fifteen 33cm x 100cm chambers and construct five 100cm x 100cm GEM DHCAL planes
  - Beam test GEM DHCAL planes in the CALICE beam test stack together with RPC
  - If available construct TGEM chambers (initial test of a 10 x 10 cm^2 TGEM board with KPiX-7 readout set for May at the Weizmann Institute – new results -> see later!)

30cmx100cm GEM Foil Design

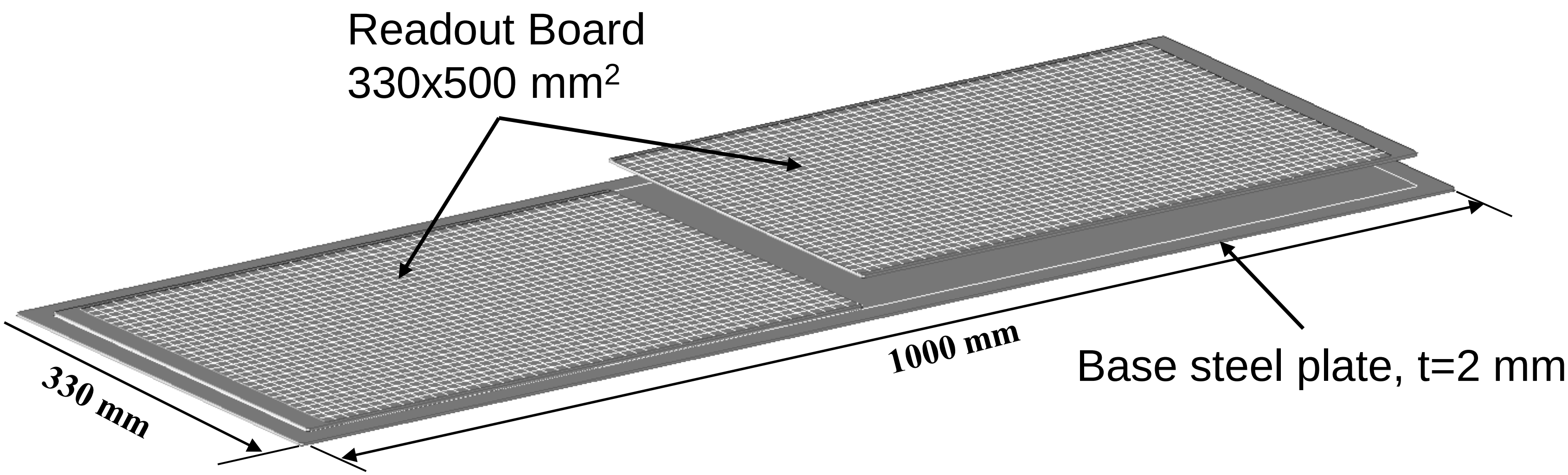


Active area 468x306x2 mm^2

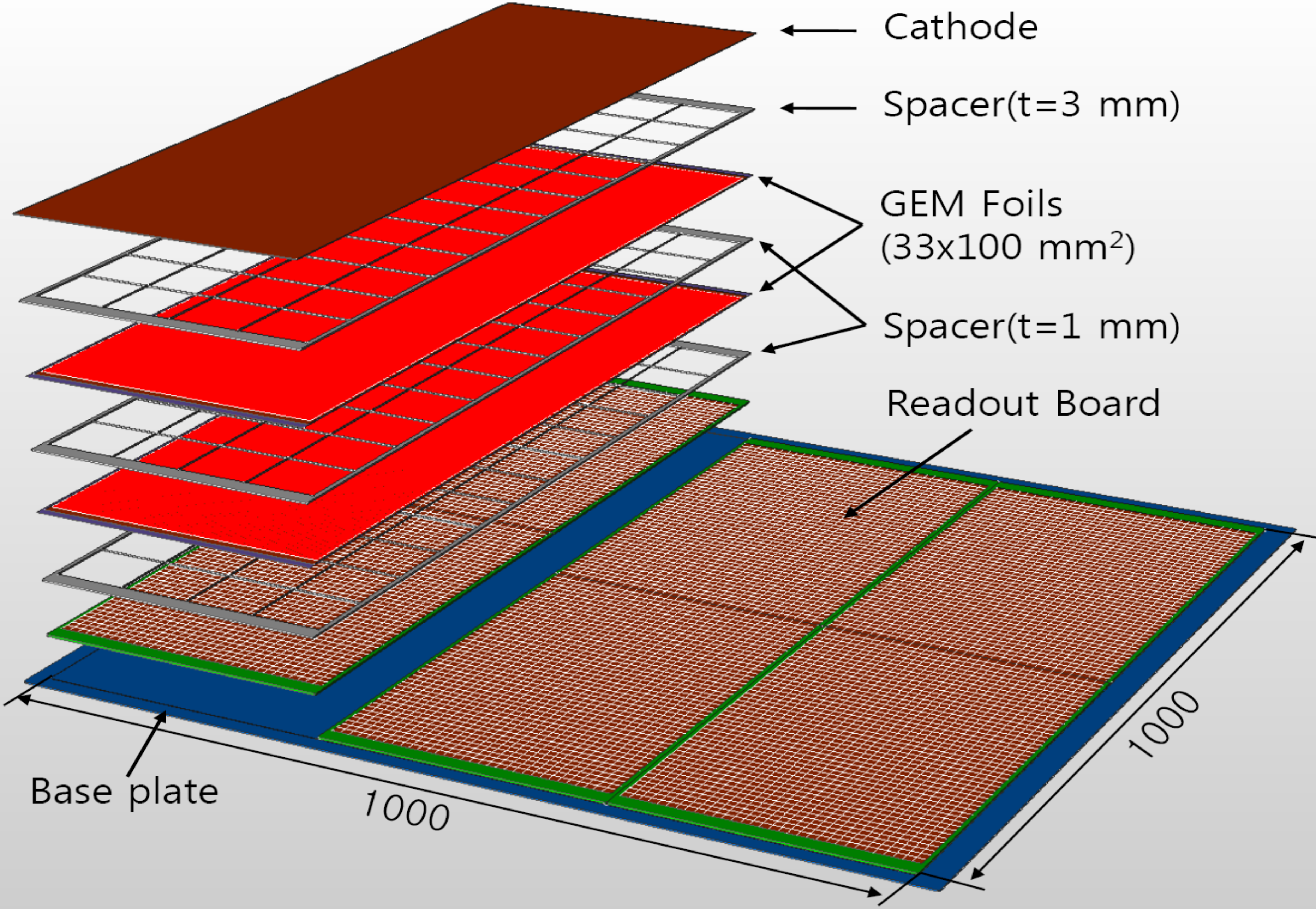
Number of HV sectors = 32x2=64

HV sector dimension= 9.9x479.95 mm^2

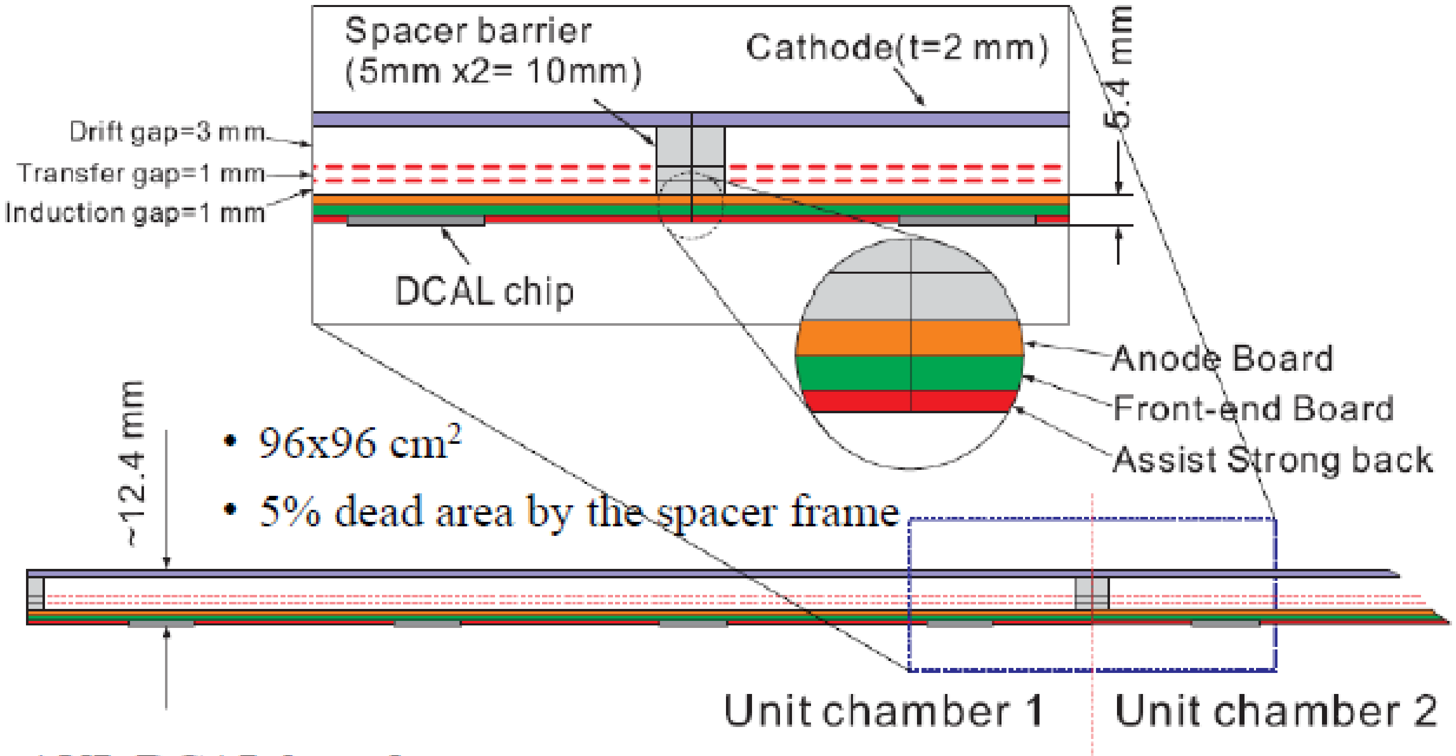
33cmx100cm DHCAL Unit Chamber Construction



UTA's 100cm x 100cm Digital Hadron Calorimeter Plane

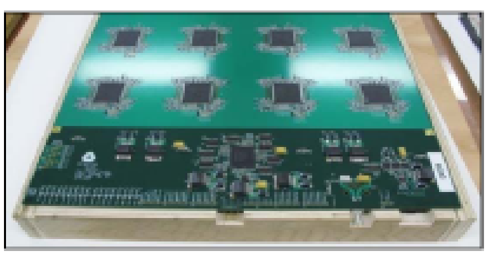


UTA's 100cm x 100cm Digital Hadron Calorimeter Plane



- $96x96\ cm^2$
- 5% dead area by the spacer frame

➢ **ANL DCAL board**



Pad board: $320x480x1.5\ mm^3$

Front-end board: $320x555x1.5\ mm^3$

GEM DHCAL Beam Test Plans

- Phase I ➔ Completion of 30cm x 30cm characterization
  - Mid 2010: using one to two planes of 30cm x 30cm double GEM chamber with 64 channel KPiX7
  - Fall 2010(?) Test of THGEM/KPiX at Fermilab?
- Phase II ➔ 33cm x 100cm unit chamber characterization
  - Mid 2010 – mid 2011 at MTBF: Using available KPiX chips and DCAL chips
- Phase III ➔ 100cm x 100cm plane GEM DHCAL performances in the CALICE stack
  - Early 2011 – Late 2011 at Fermilab's MTBF *or CERN*
  - Five 100cm x 100cm planes inserted into existing CALICE calorimeter stack and run with either Si/W or Sci/W ECALs, and RPC planes in the remaining HCAL

Just in – latest THGEM results!

Weizmann Institute, Aveiro/Coimbra, UTA

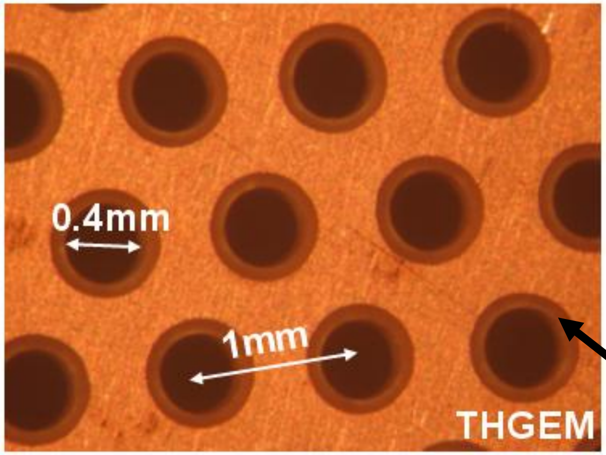
Set up and tested THGEM with KPiX Readout
at Weizmann

Supported by U.S. – Israel Bi-national Science Foundation

Thick Gas Electron Multiplier (THGEM) - DHCAL

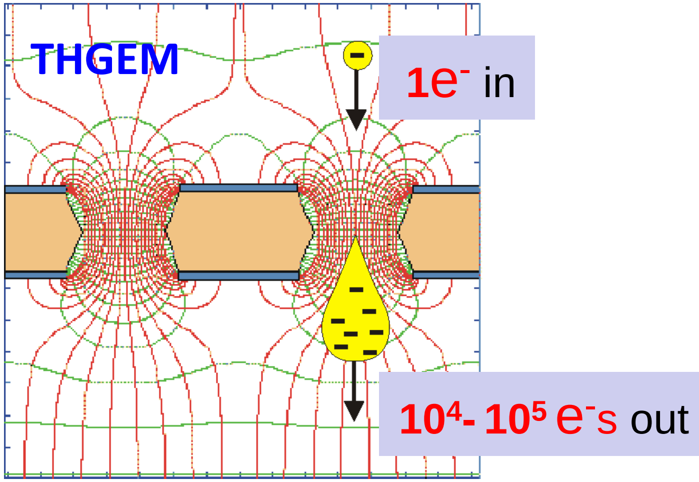
Weizmann Inst.

~ 10-fold expanded GEM



small rim prevents discharges

Thickness 0.5-1mm



Double-THGEM: 10-100 higher gains

SIMPLE, ROBUST, LARGE-AREA
Printed-circuit technology

- Effective single-electron detection
- Few-ns RMS time resolution (MIPs/UV)
- Sub-mm position resolution
- MHz/mm^2 rate capability
- Cryogenic operation: OK
- Gas: molecular and noble gases
- Pressure: 1mbar - few bar
- Magnetic fields: OK

➔ Intensive R&D
➔ Many applications:
- -THGEM/CsI UV detectors for RICH
- -neutron imaging
- -Cryo detectors for Dark Matter
- - Charge sensors for DHCAL

THGEM Recent works:
Review NIM A **598** (2009) 107; 2010 *JINST* **5** P01002
2009 *JINST* **4** P08001

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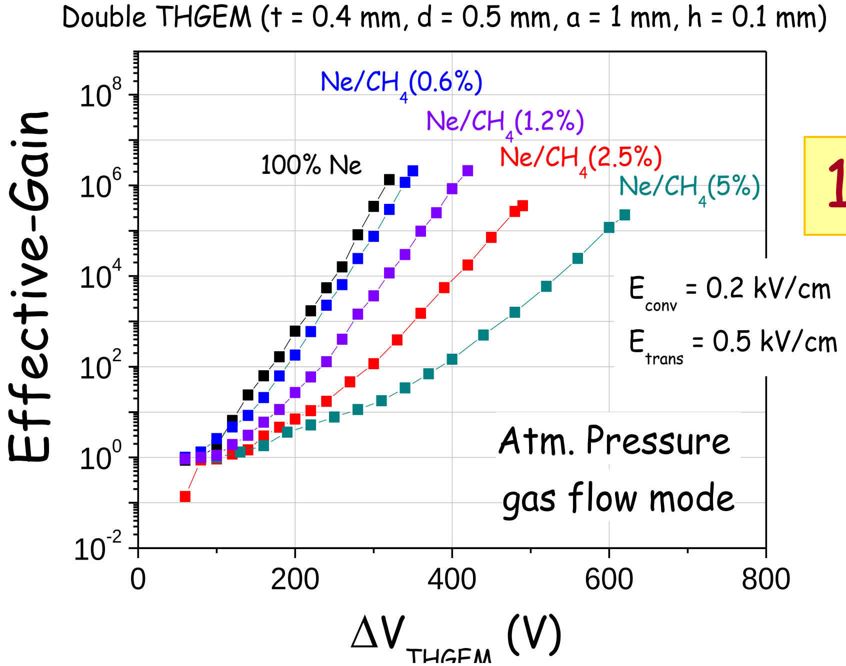
Gain: Single/Double THGEM in Ne-mixtures

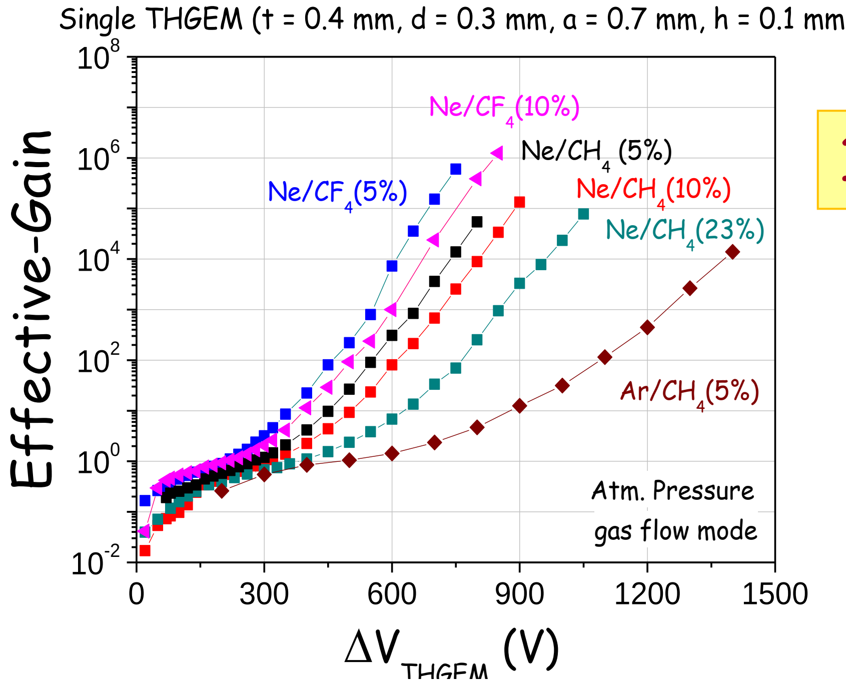
2009 *JINST* 4 P08001

Double-THGEM
9 keV X-rays



10^6

Single-THGEM
CsI PC + UV-light (180 nm)



10^6

Very high gain in Ne and Ne mixtures, even with X-rays

At very low voltages !!

X-rays: 2-THGEM 100% Ne: Gain 10^6 @ ~300V

UV: 1-THGEM Ne/CF_4(10%): Gain > 10^6 @ ~**800V**

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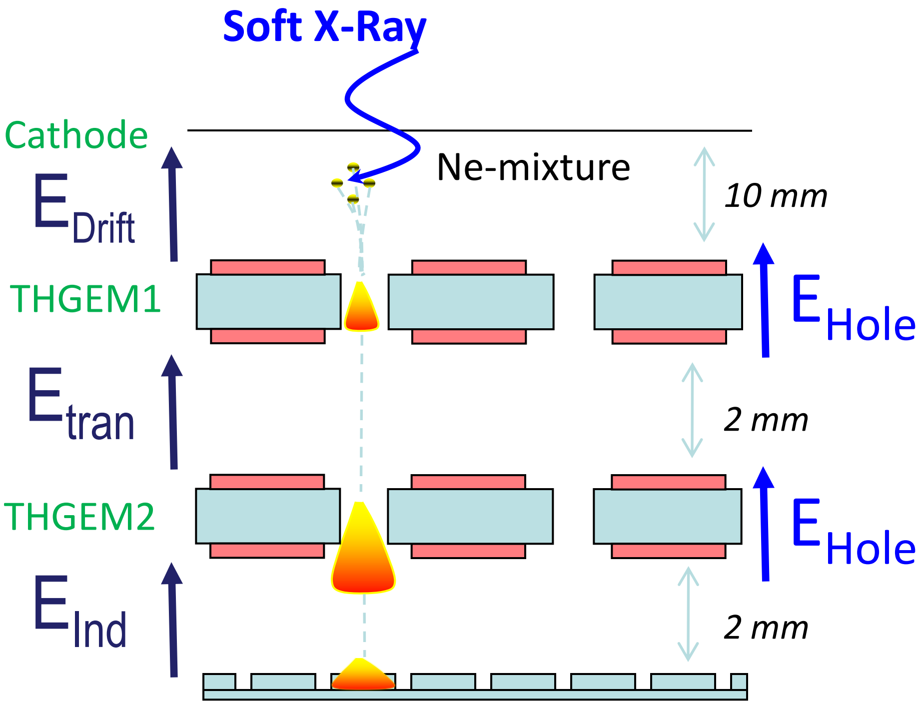
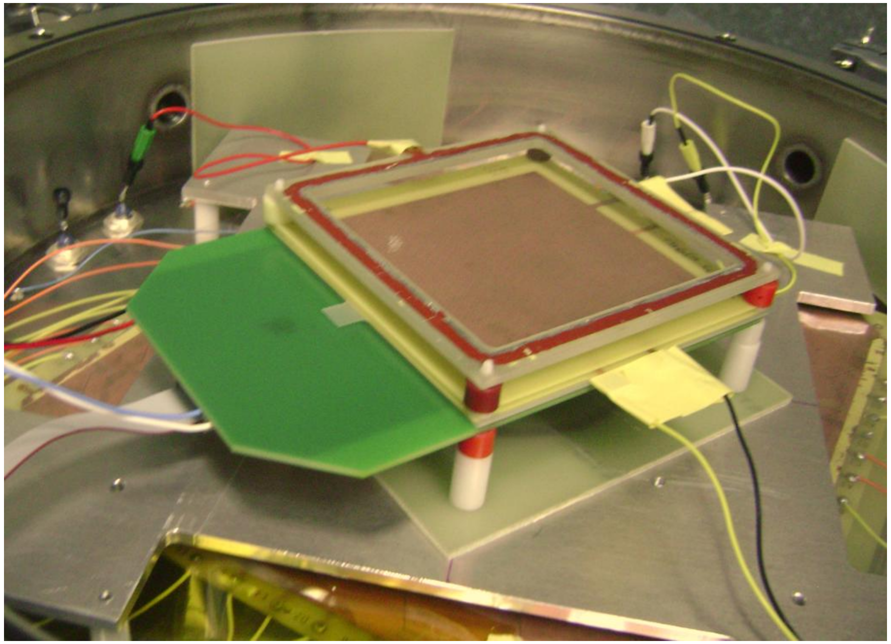
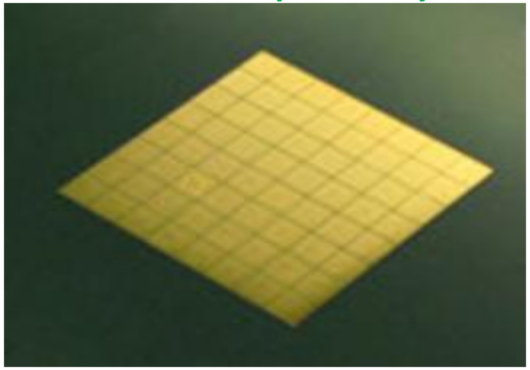
Chamber Prototype – test with X-rays





8x8 anode pad layout



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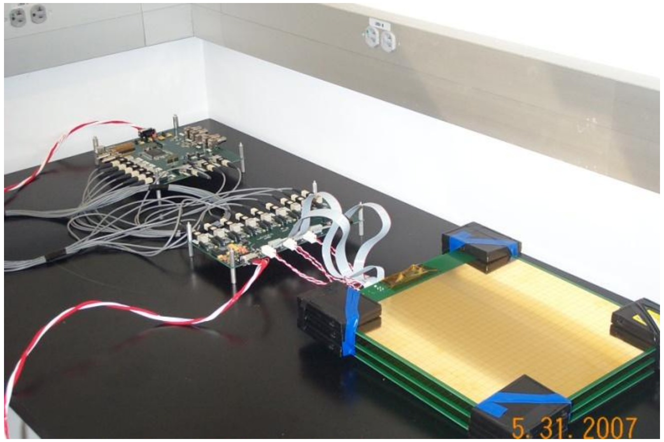
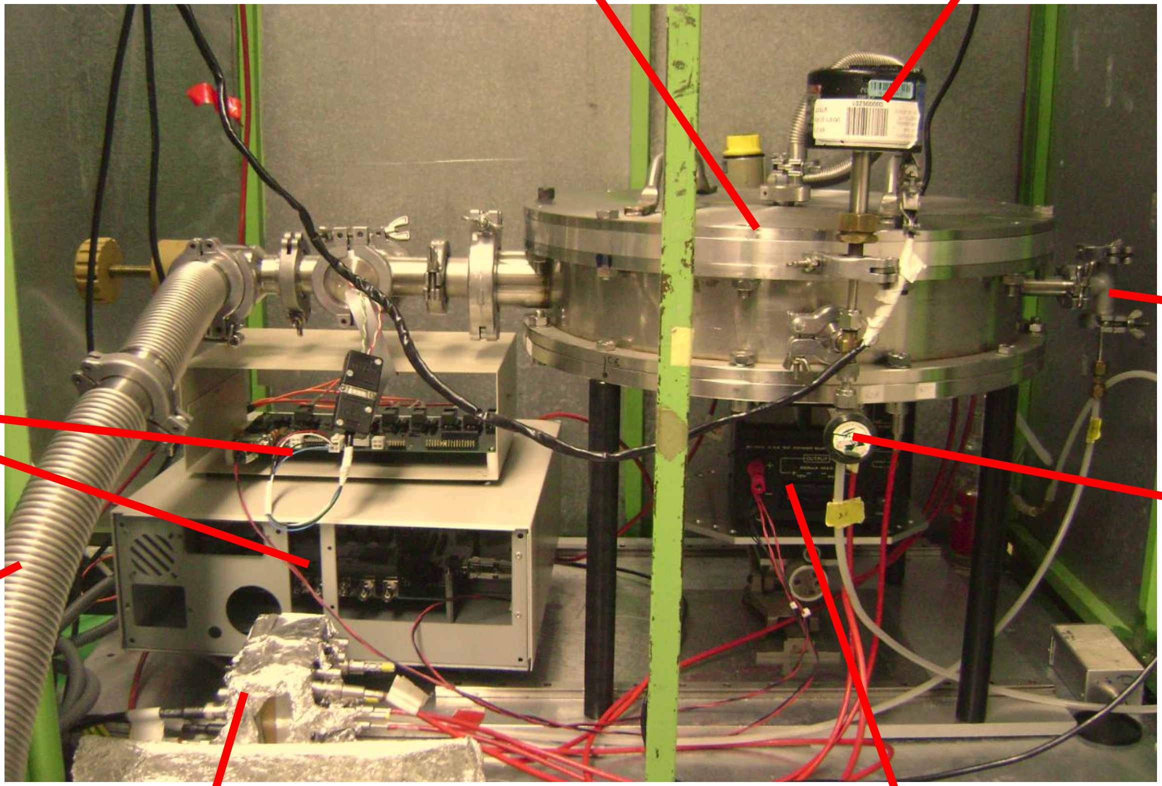
100x100mm^2 THGEM

Thickness → 0.4 mm
Hole diam. → 0.5 mm
Pitch → 1.0 mm
Rim → 0.1 mm



THGEM Chamber Setup 2



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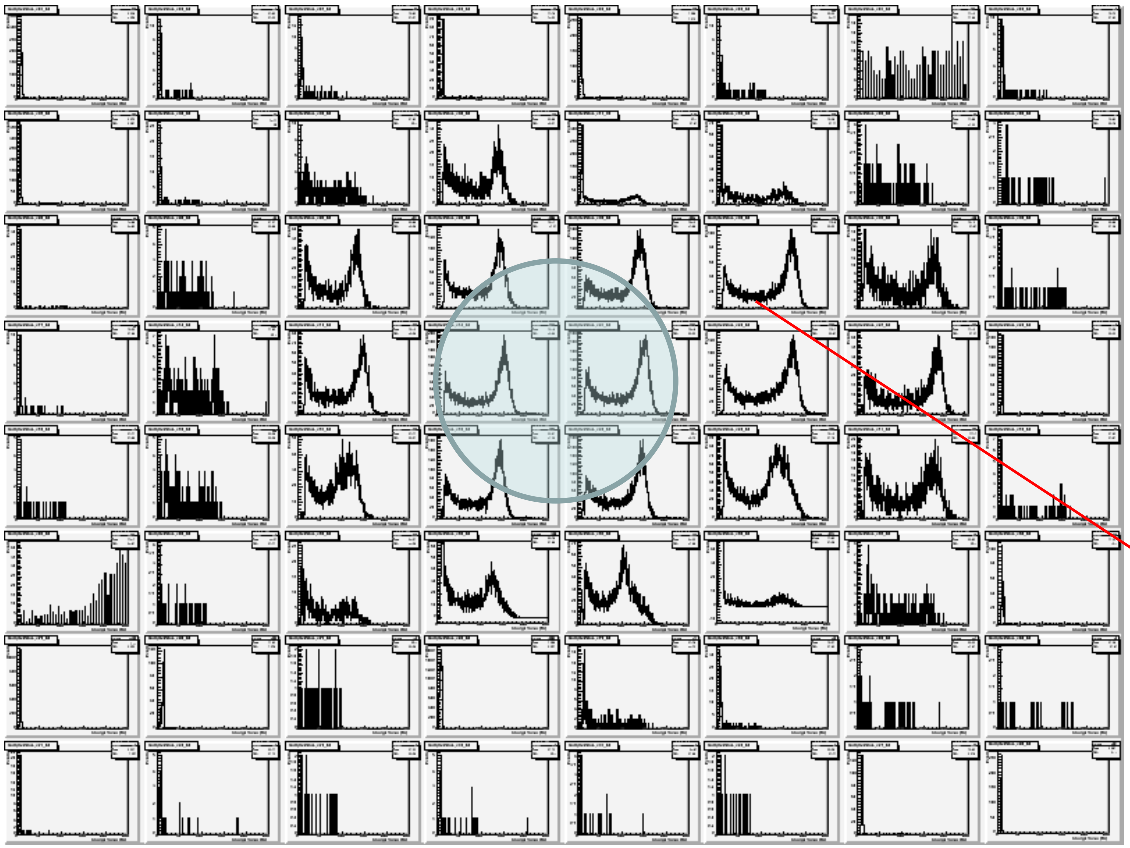
THGEM + KPiX: Preliminary results 1

Double THGEM detector – Self Trigger operation

Irradiation: 6keV non-collimated x-rays



Tails due to charge sharing between neighbor pads

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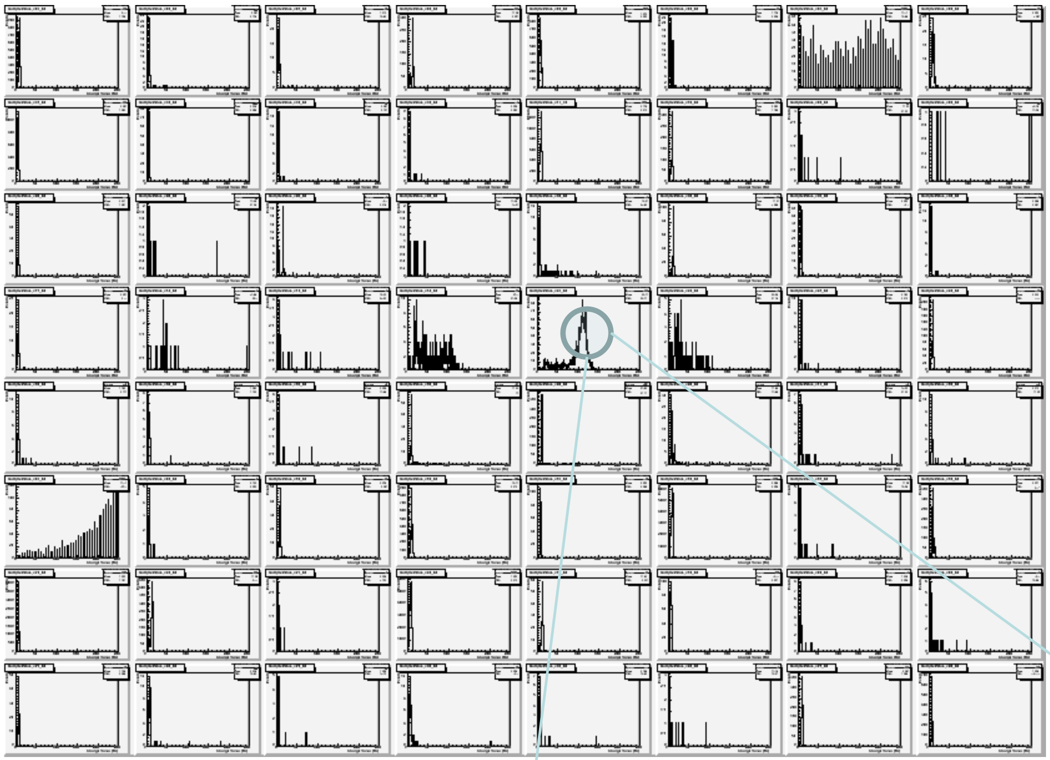
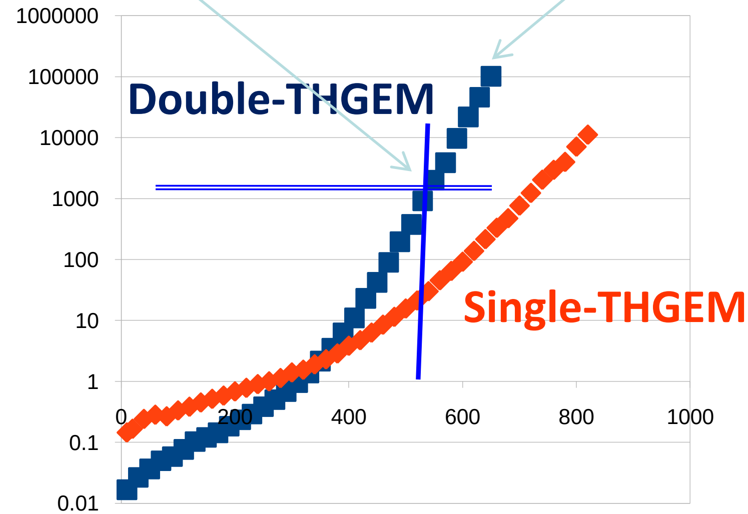
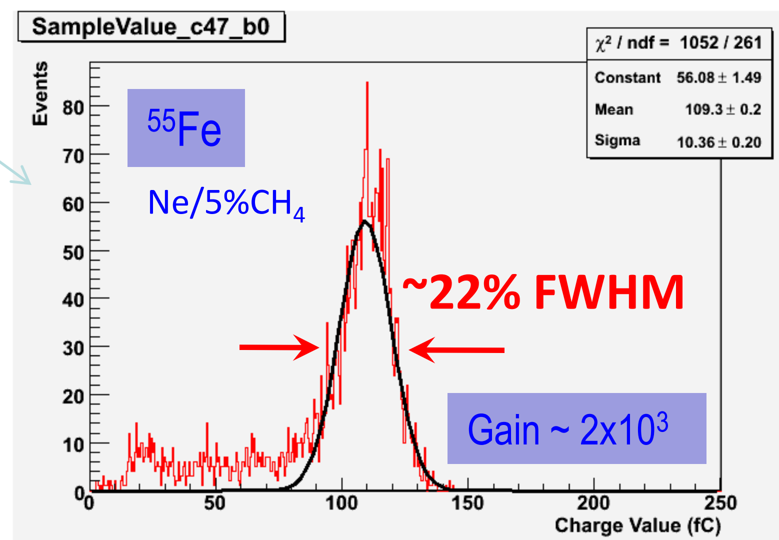
THGEM + KPiX: Preliminary results 2

Operation Gain ~ $2x10^3$

Max Gain ~ 10^5







^{55}Fe X-rays (5.9 keV) **COLLIMATED**

STABLE LONG-TERM OPERATION WITH ^{55}Fe

Weizmann Inst.

THGEM - plans

- Regular double-GEM gives min-I peak ~20fC with gain ~5,000
- Would like ~50fC -> Gain ~10^4
- Use single THGEM @ 800V ?
- double THGEM disfavored by DHCAL thickness considerations (leading to increased solenoid costs in an ILC detector design).

- …further source/cosmic tests
- Test beam of THGEM-DHCAL prototype at CERN/Fermilab in Summer/Fall 2010??
- Production of large area THGEM?

Extra slides

Merged Cosmic run