Gas Electron Multiplier Detectors and its Application in High Energy Physics

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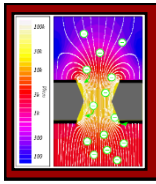


Introduction to GEM

➢ Outline

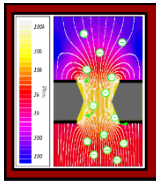
✓ Introduction to GEM detector
- GEM applications

✓ GEM activities in Korea

✓ GEMs at UTA/Digital Hadron Calorimeter (DHCAL)
- FNAL beam test results

✓ Future works
- Large GEM design concept for DHCAL development
- GIA

✓ Summary



History of Gas Detectors

GM counter(1928),

Proportional Counter(1940s)

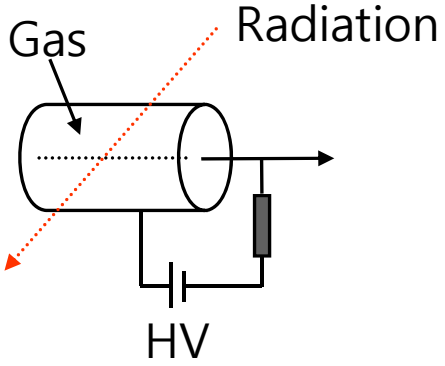
MWPC(1968)
(Multi-Wire Proportional Chamber
George Charpak, Novel prize 1992)

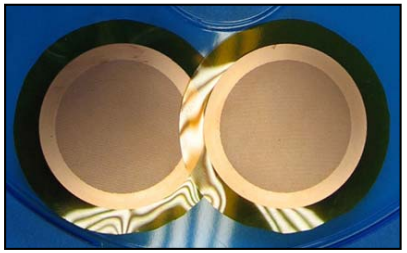
MSGC(1988)

(Microstrip Gas Chamber)

GEM(1997)

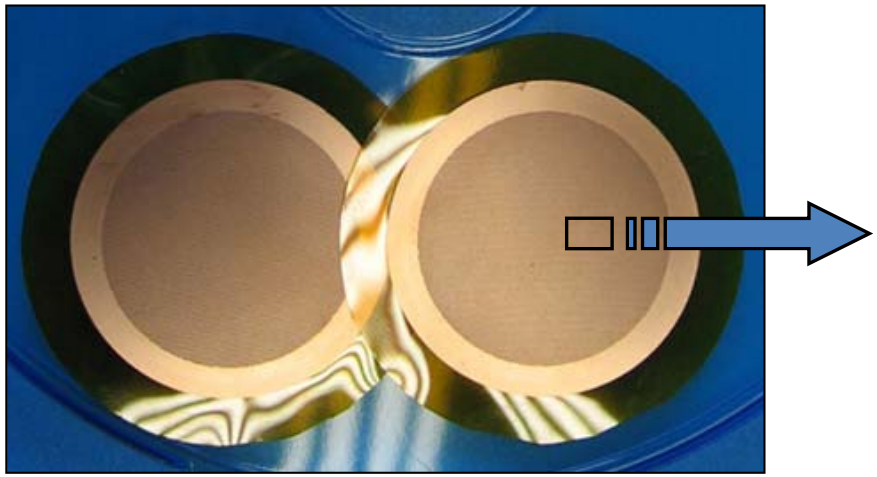
(Gas Electron Multiplier)

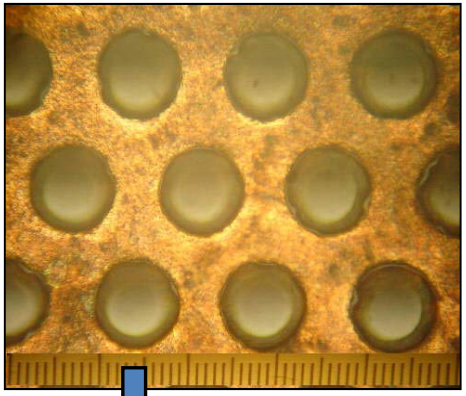


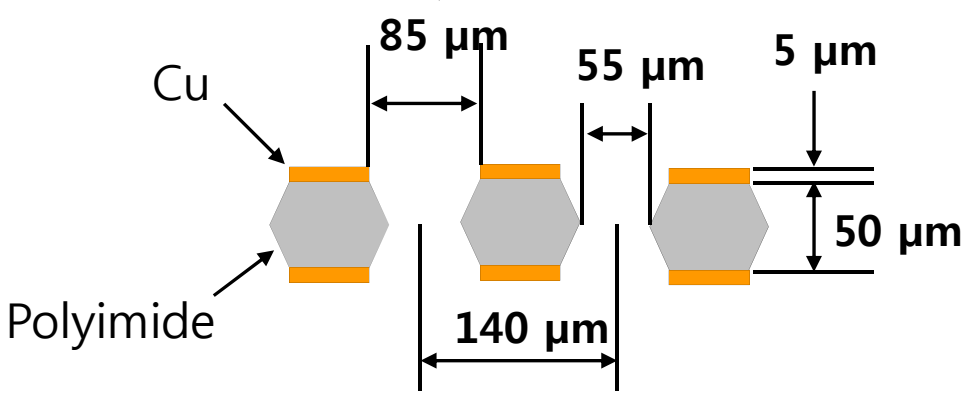


F. Sauli & R. D. Oliveira CERN
NIM A386, 531, 1997

GEM Foils(3M)



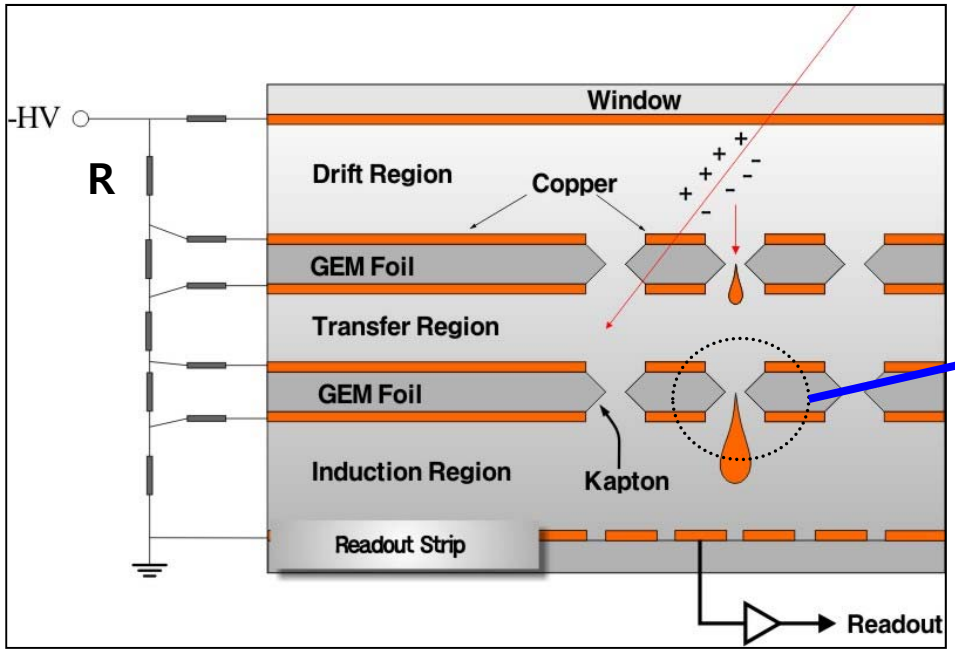


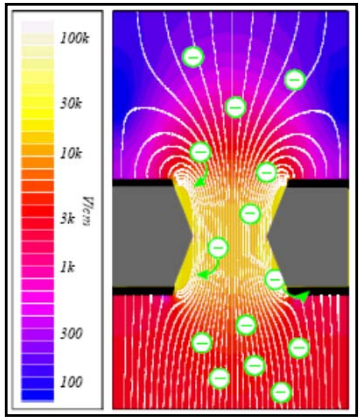


Demerits of traditional gas detectors: requires high voltage to get high gain → GEM can be operated at low voltages

Typical Structure of GEM Detector

- GEM detector is composed of a chamber, HV supplier, anode board, readout electronics, and DAQ program





Electron Avalanche

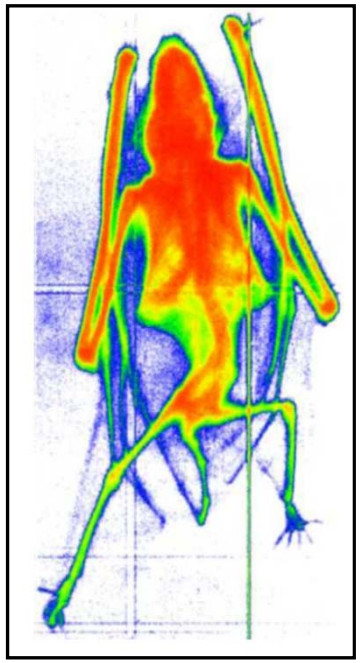
→ Amplification

Chamber filled with gas $Ar:CO_2 = 80:20$

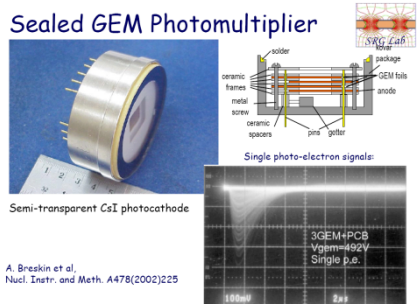
GEM Applications

First observation of X-ray image with GEM detector

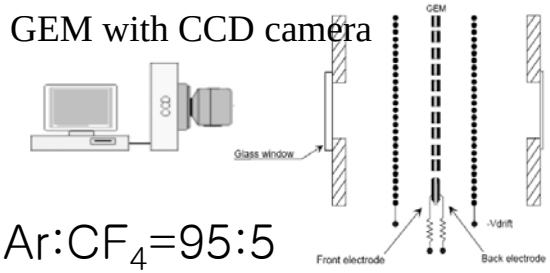
340 h, 36.5×10^6 counts



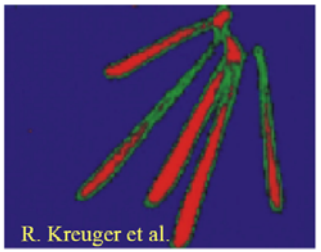
A. Bressan et al, Nucl. Instr. and Meth. A 425(1999)254
F. Sauli, Nucl. Instr. and Meth.A 461(2001)47



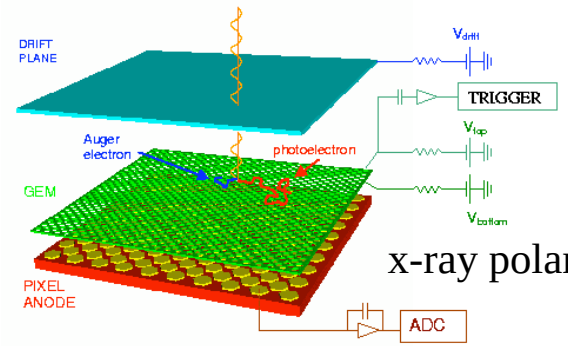
GEM with CCD camera



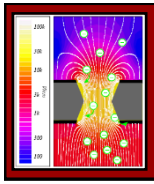
$Ar:CF_4=95:5$



- GEM with CCD camera
- GEM as an x-ray polarimeter
- Sealed off type GEM based PMT
- GEM as an preamplifier in other type gas detectors(Micromegas, MSGC)



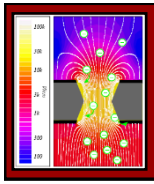
x-ray polarimeter



GEMs in Korea

➢ Sequence

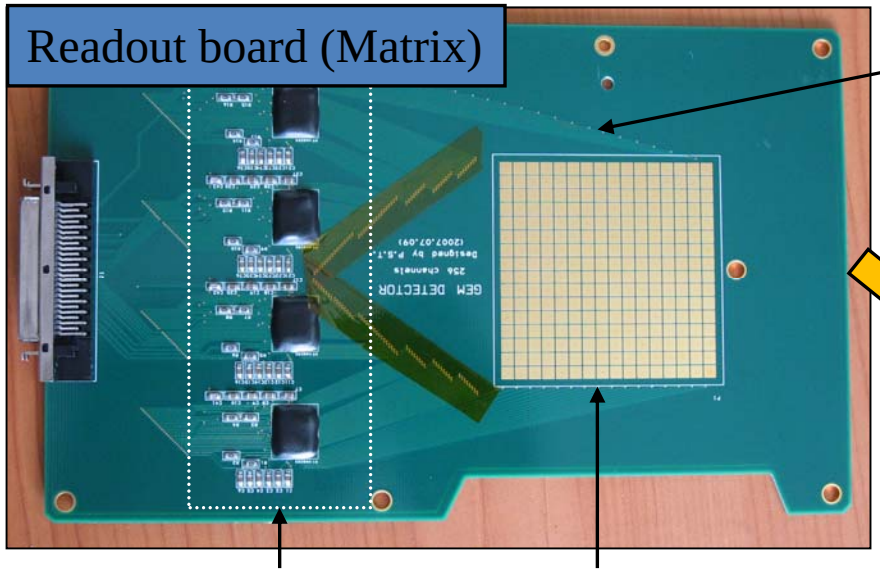
- ✓ Introduction to GEM detector
  - GEM applications in various fields
- ✓ GEM activities in Korea
- ✓ GEMs at UTA/Digital Hadron Calorimeter (DHCAL)
  - FNAL beam test results
- ✓ Future works
  - Large GEM design concept for DHCAL development
  - GIA
- ✓ Summary

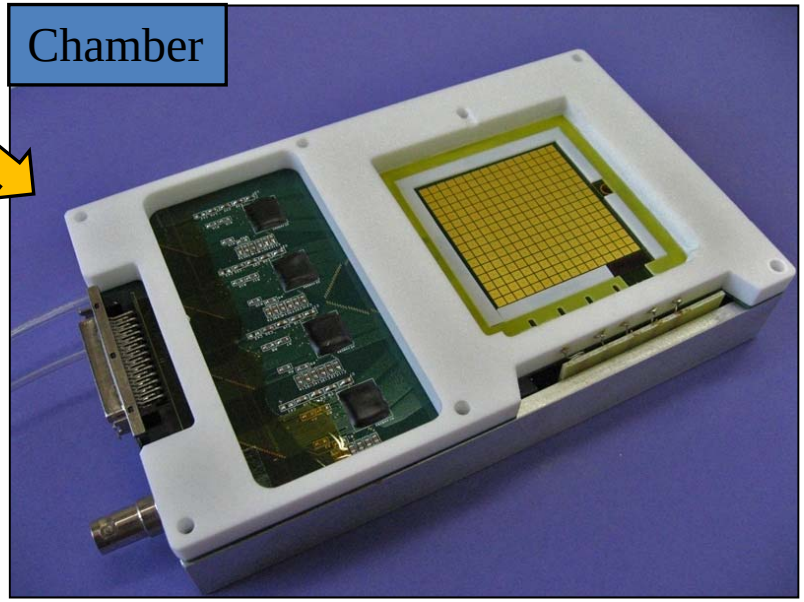


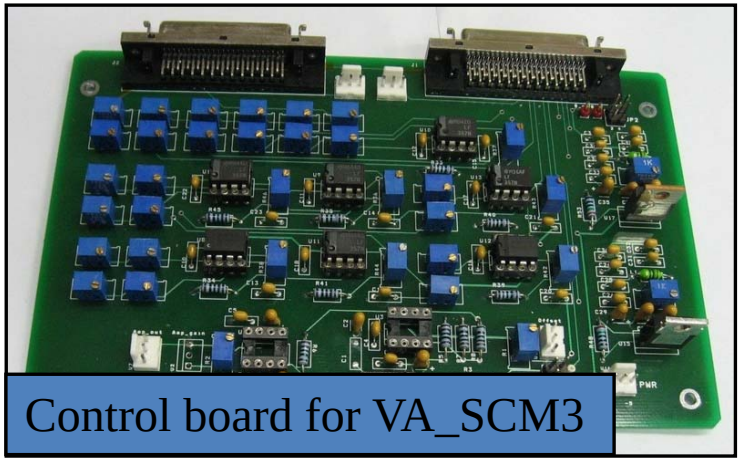
GEM detectors in Korea

- The first trial was in early 2000. KAERI and MAGELtech tried to develop GEM based radiation image detector.
- In 2006~2008, Changwon National University/University of Texas at Arlington collaborated to develop GEM based digital imaging device. Grants from **KOSEF**
- For now, no active research is going on.

Matrix-type readout board/Chamber

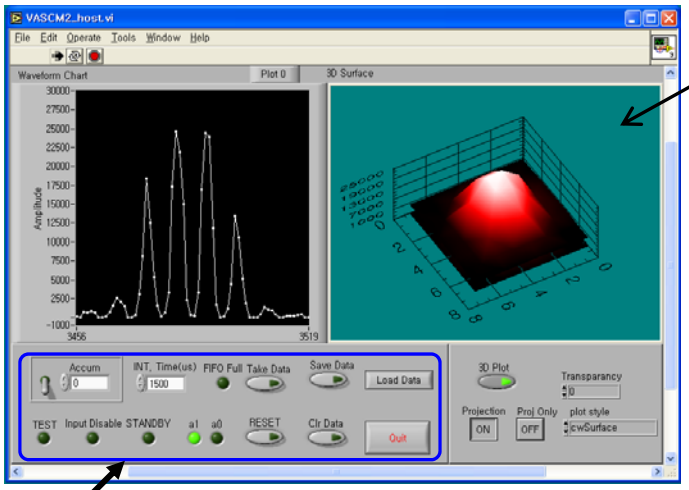




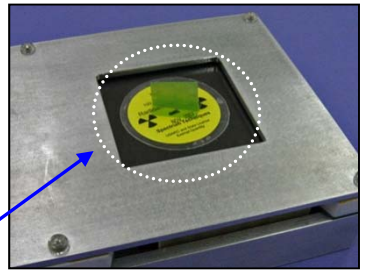


- ✓Readout pad: 3x3 mm^2, pitch=3.3 mm
- ✓No cable connection is required between the readout electrodes and the inputs of the CSP.

Intensity Distribution of a ^{55}Fe



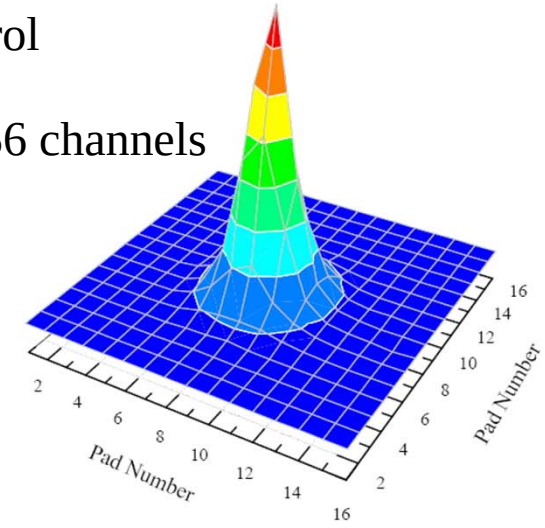
Real time intensity profile monitor

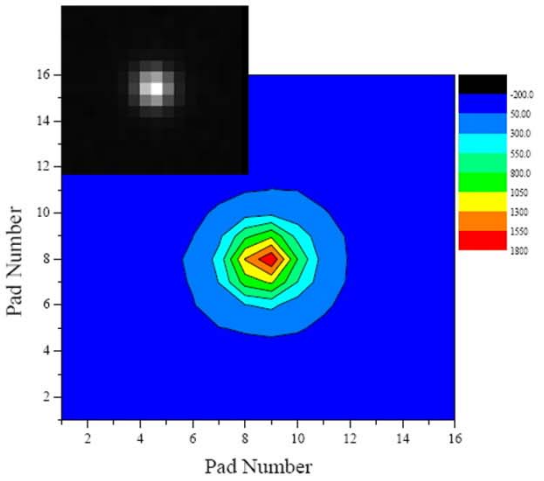


^{55}Fe

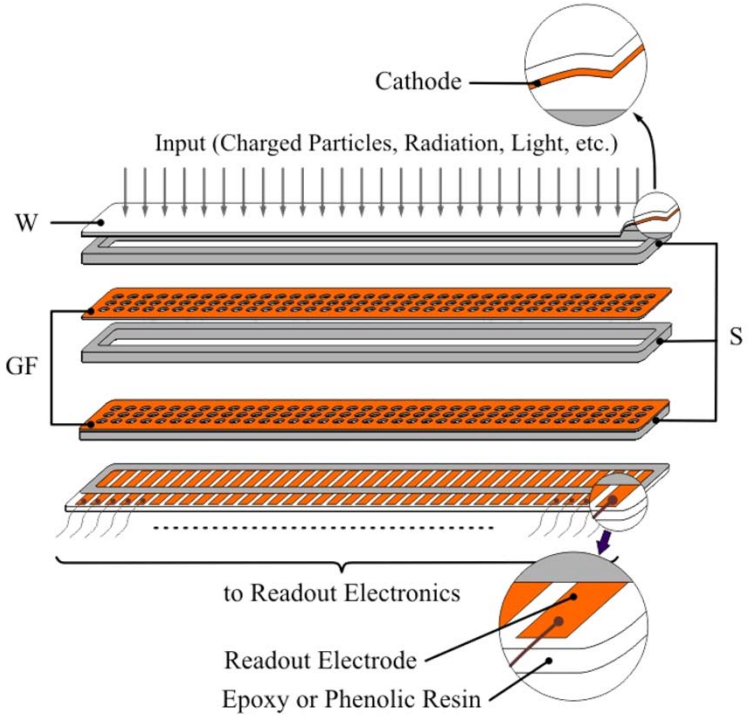
Preamp. control

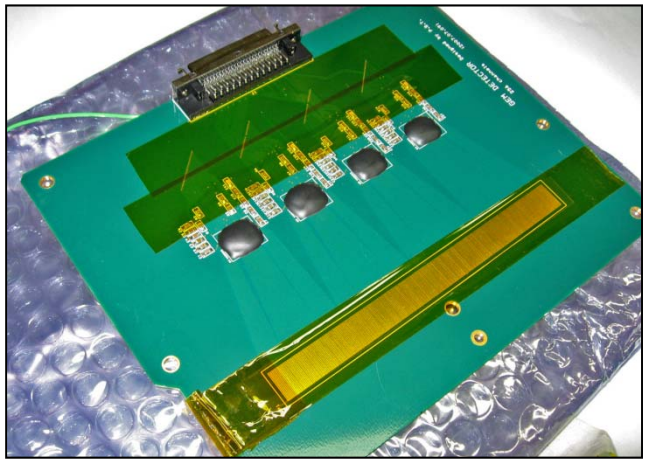
16x16=256 channels



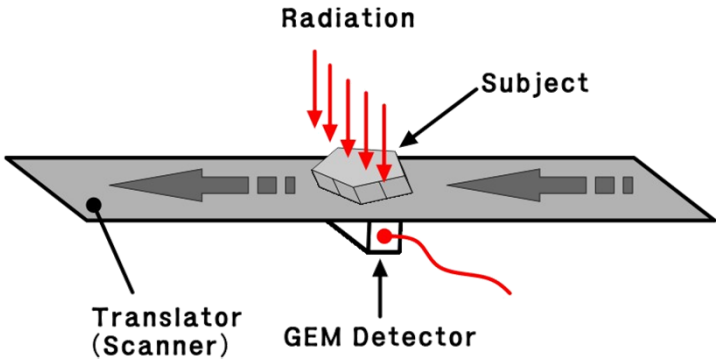


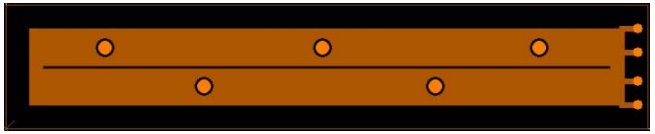
Linear Array Detector with Scanner(512 ch)





Readout board for linear array type GEM detector





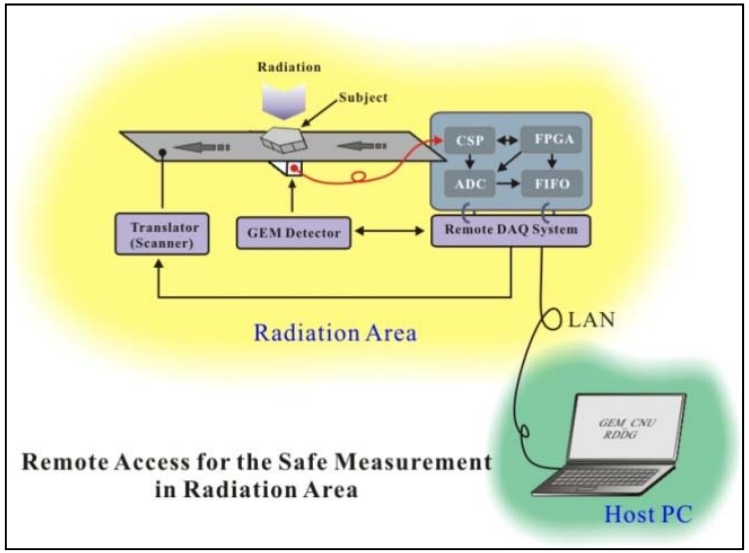
Linear array type GEM foil

Active area= 120×0.37 mm^2

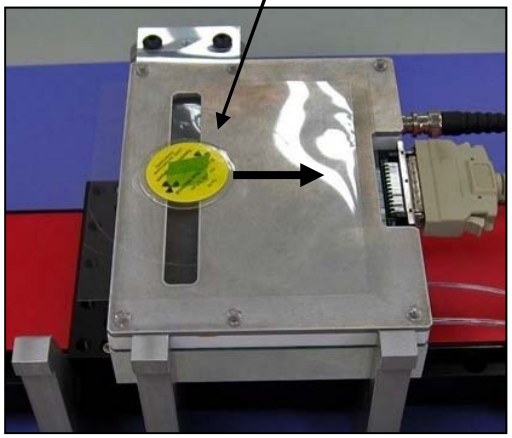
Hole pitch= 140 μm

Digital X-ray image with linear array type readout structure of GEM detector

Source : ^{55}Fe, 100 μCi → 100 data were averaged

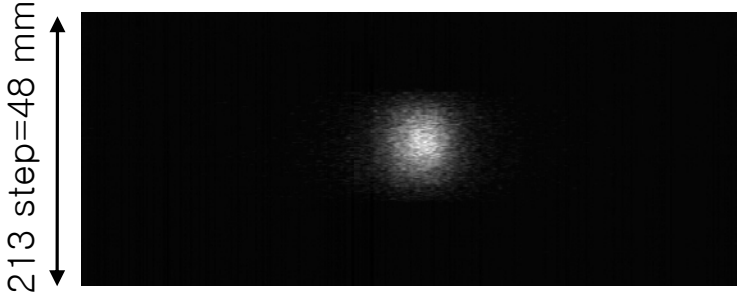


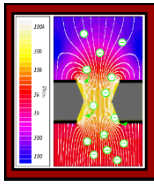
Radiation Source : ^{55}Fe (100 μCi)



Integration time: 10 ms
Time required to move one step: 200 ms
Average: 100 data at each position
# of scan: 213

→ Scan time=1,200x213=255,600 ms





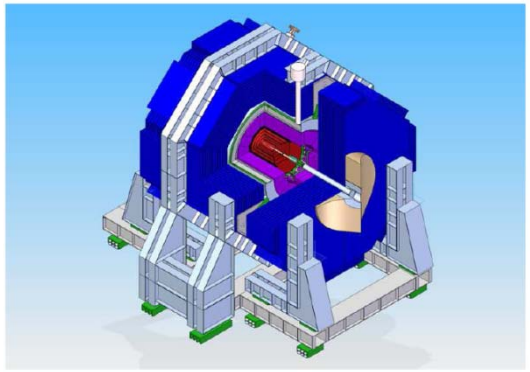
GEMs at UTA

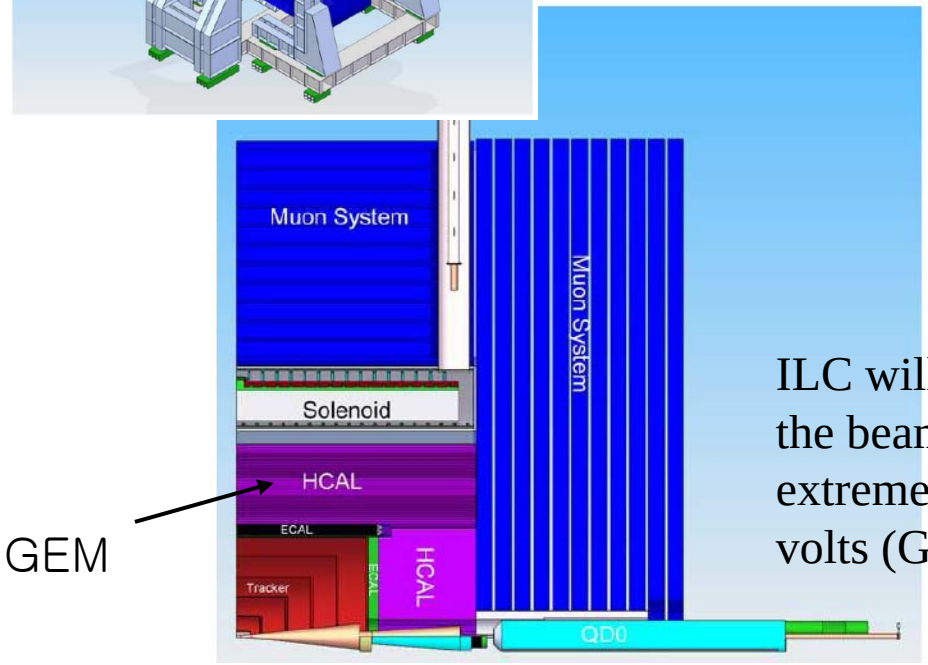
➢ Sequence

- ✓ **Introduction to GEM detector**
  - GEM applications in various fields
- ✓ **GEM activities in Korea**
- ✓ **GEMs at UTA/Digital Hadron Calorimeter (DHCAL)**
  - **FNAL beam test results**
- ✓ **Future works**
  - **Large GEM design concept for DHCAL development**
  - **GIA**
- ✓ **Summary**

International Linear Collider(ILC)

ILC: electron-positron collider



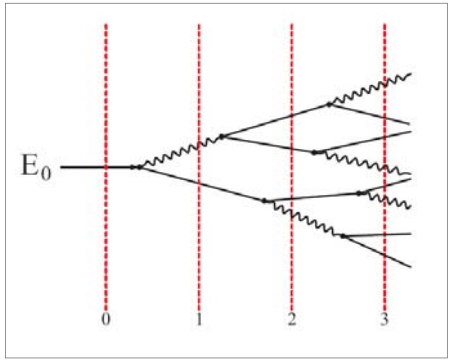


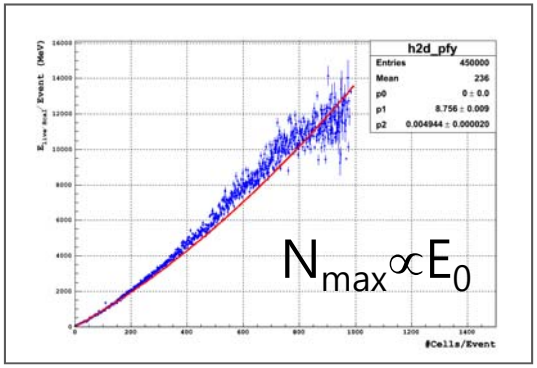
We have been developing GEM detectors to use it as sensitive gap detectors in digital hadron calorimeters(DHCAL) which are possible candidates of detectors in future linear collider, ILC.

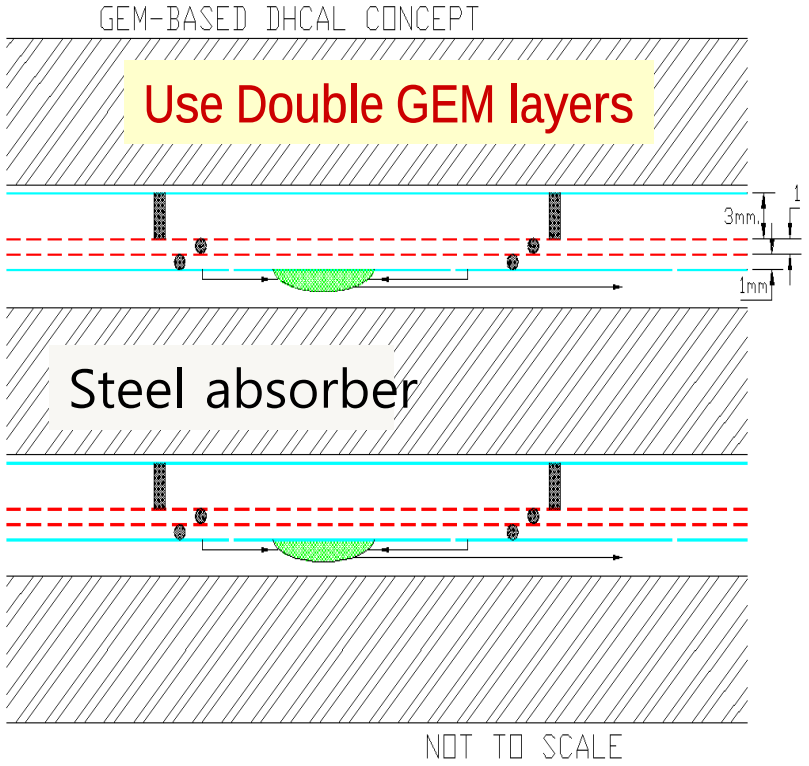
ILC will stretch approximately 31 km in length, the beams collide 14,000 times every second at extremely high energies-500 billion-electron-volts (GeV).

*LHC(CERN): proton-proton collider
*TEVATRON(FNAL): proton-antiproton collider

GEM-based Digital Hadron Calorimeter Concept



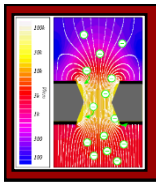




- The energy of the incident particle is directly proportional to the maximum number of particles in the shower.
- Thus, it is important to **count** total number of particles in the shower.
- **"Count"→ digital method** in the data acquisition.

→ Digital Hadron CALorimeter (DHCAL)

- Passive (material) and Active (GEM) layers
- Increase spatial resolution (1 x 1 cm² readout pads)



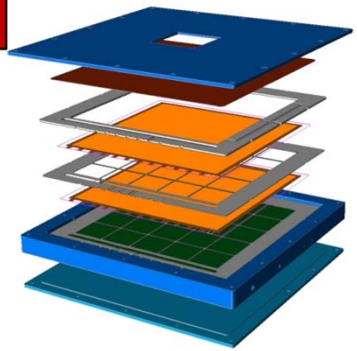
Why GEM's for DHCAL?

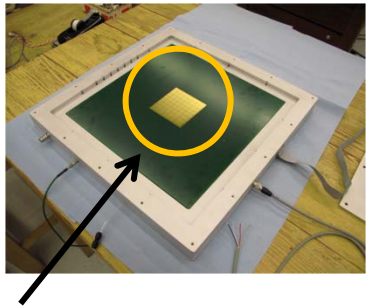
- Flexible configurations: allows small anode pads for high granularity
- Robust: survives ~10^{12} particles/mm^2 with no performance degradations
- Fast: based on electron collection, ~few ns rise time
- Short recovery time → can handle high rates
- Uses simple gas (Ar/CO_2) – no long-term issues
- Runs at relatively low HV (~400V across a foil)
- Stable and robust operations

30x30 prototype GEM chamber and Readout Electronics

Chamber

- GEM Foils(3M)
  - 310x310 mm^2
  - Active area : 280x280 mm^2
- Active gas room
  - 350x350x6 mm^3 → For 3/1/1 gaps
- 64 readout channels

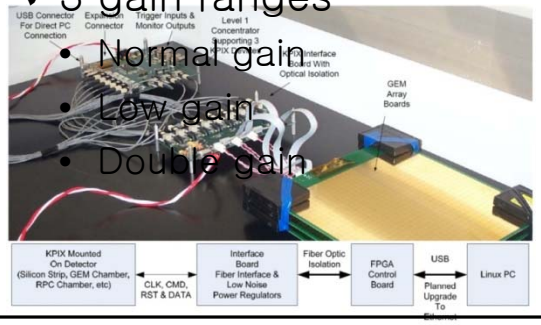




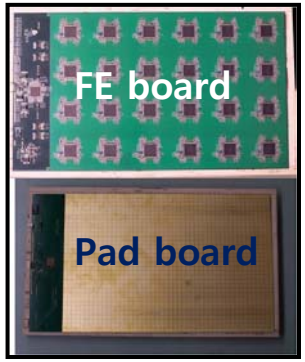
64-readout pads

Readout system

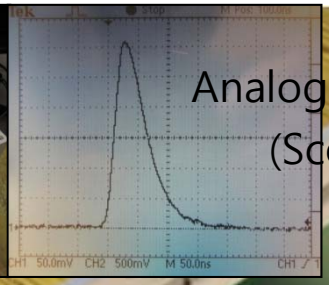
❖KPiX readout system/SLAC
- ✓ 13 bit resolution(ADC)
- ✓ Designed to handle 1024 channels/chip, currently 64/chip (ver.7)
- ✓3 gain ranges
  - Normal gain
  - Low gain
  - Double gain



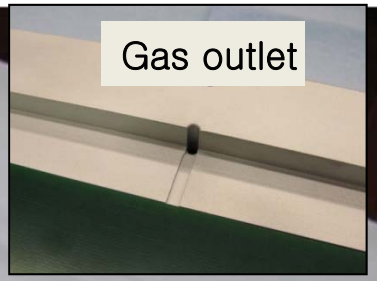
❖DCAL readout system/ANL
- ✓ 1 bit resolution(ADC)
- ✓ 64 channels/chip
- ✓2 gain ranges
  - High gain for GEMs (10 fC~200 fC signals)
  - Low gain for RPCs (100 fC~10 pC signals)



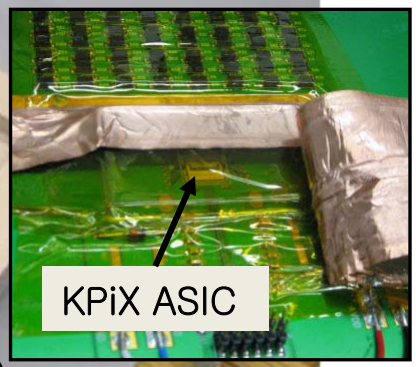
Chamber frame and readout board



Analog signal from Fe55
(Scope image)

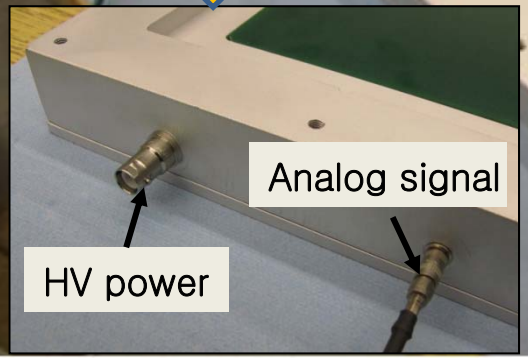


Gas outlet



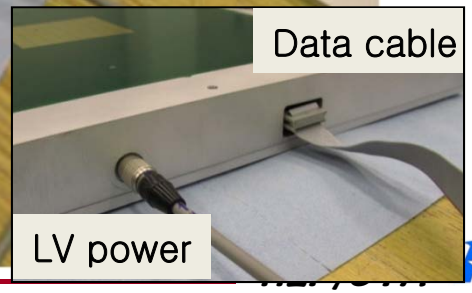
KPiX ASIC

Anode pads
8x8=64 channels



Analog signal

HV power

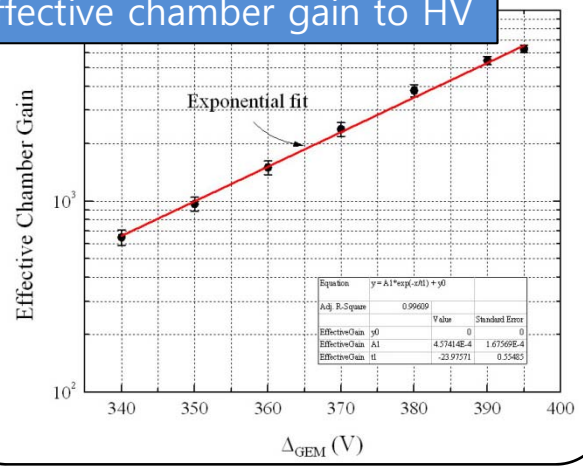


Data cable

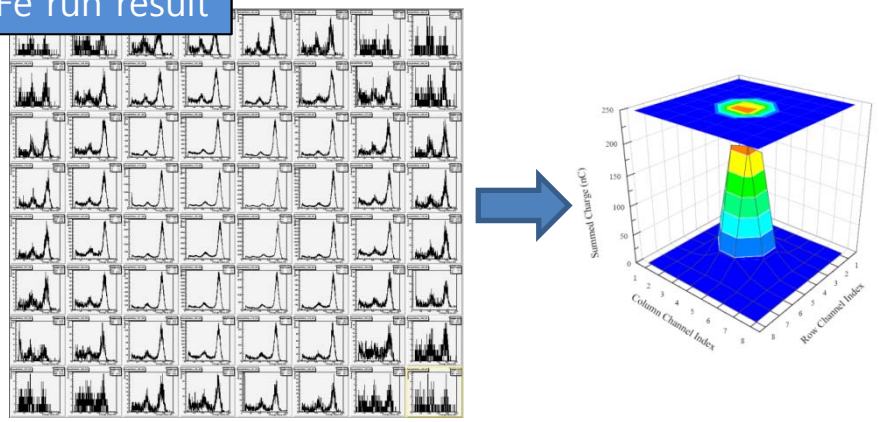
LV power

Some test results with 30x30 cm^2 chamber/KPiX

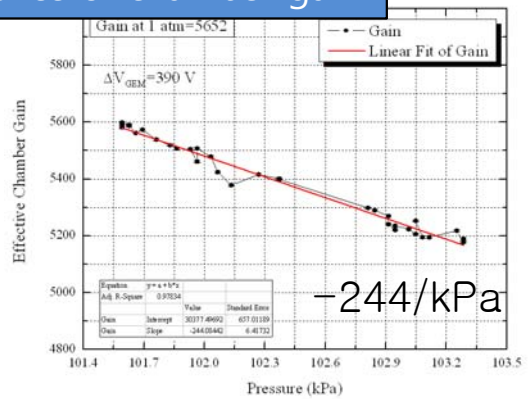
Effective chamber gain to HV



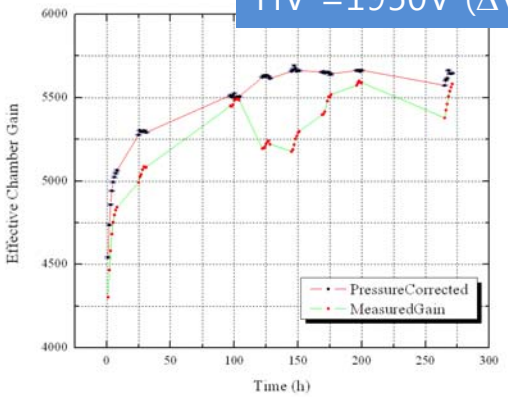
^{55}Fe run result



Pressure dependence of chamber gain

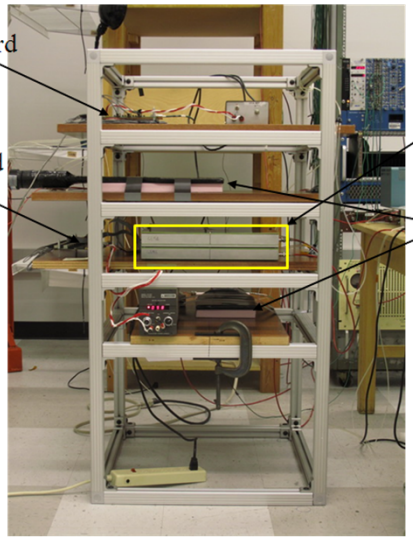


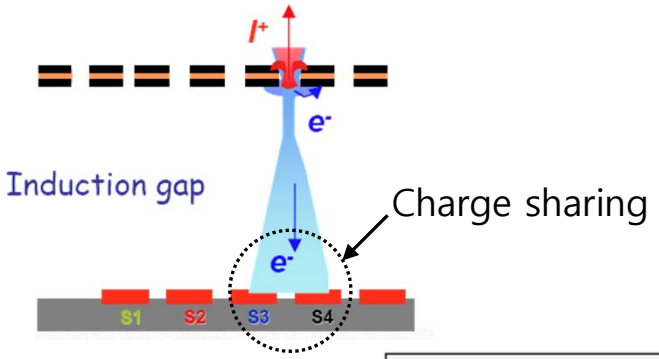
HV =1950V (ΔV_{GEM}=390 V)

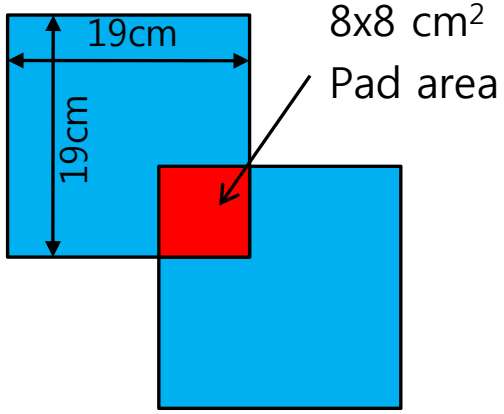


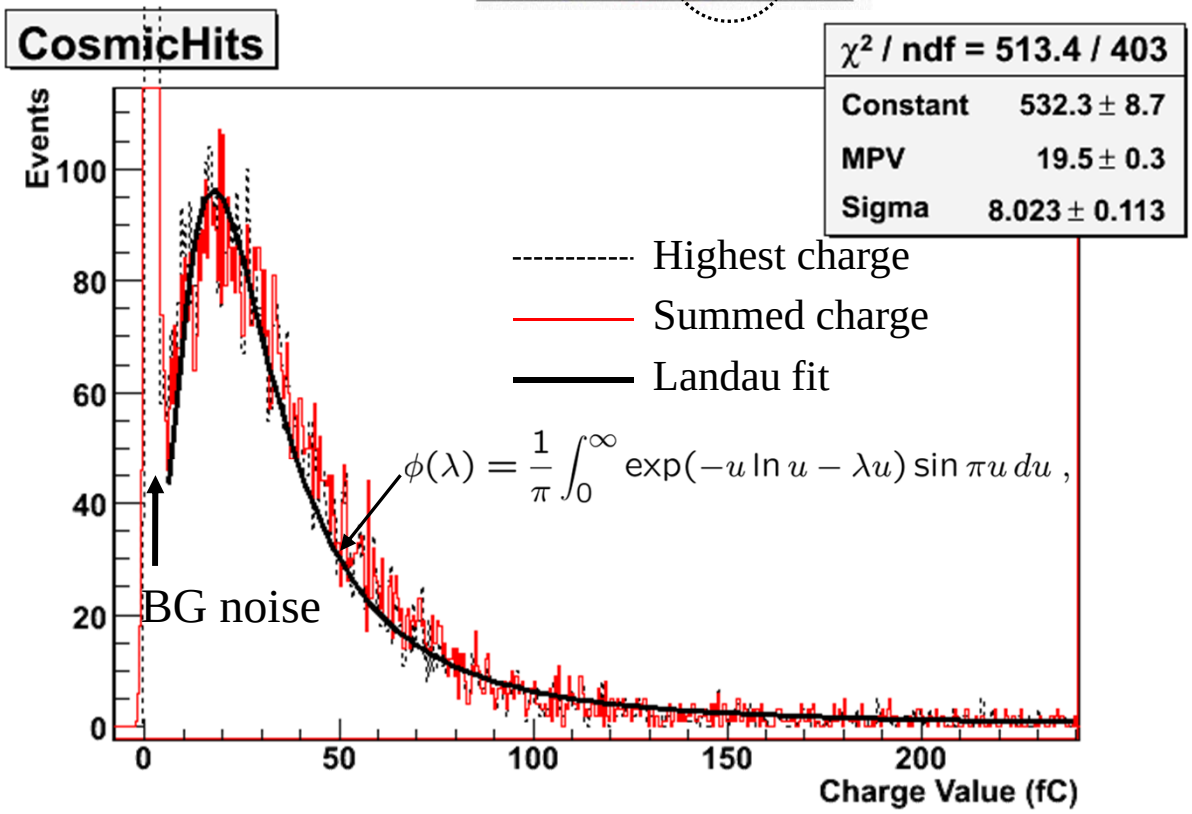
We use an open gas system (gas flows at atmospheric pressure).
Thus, pressure inside chamber is affected by the atmospheric pressure directly.
This pressure change affects the chamber gain.
The chamber gains were recalculated to the values at 1 atm.

Cosmic run/KPiX



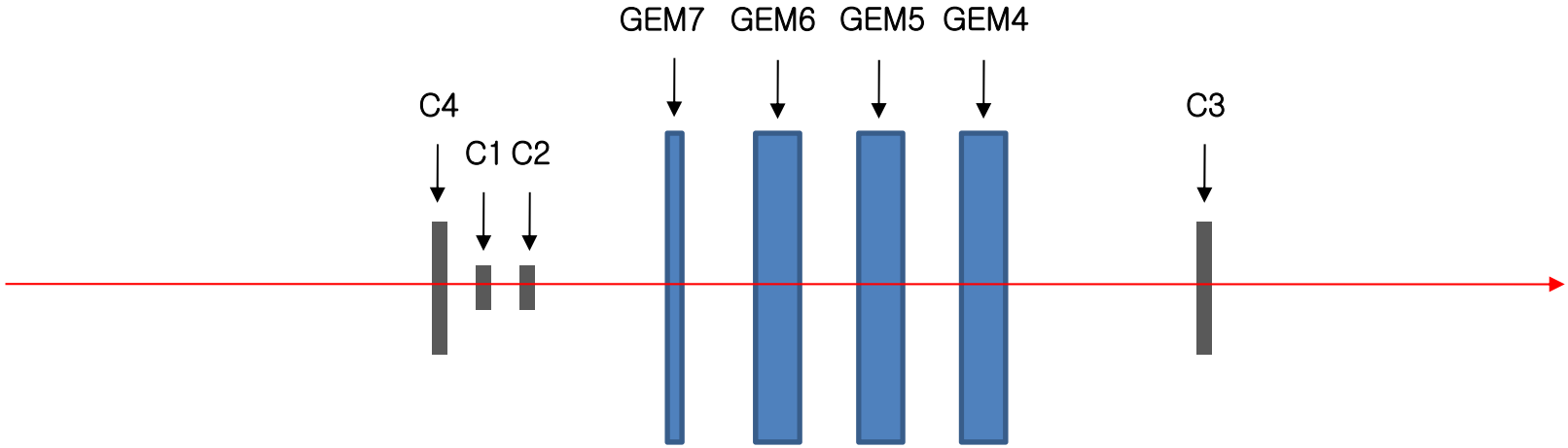






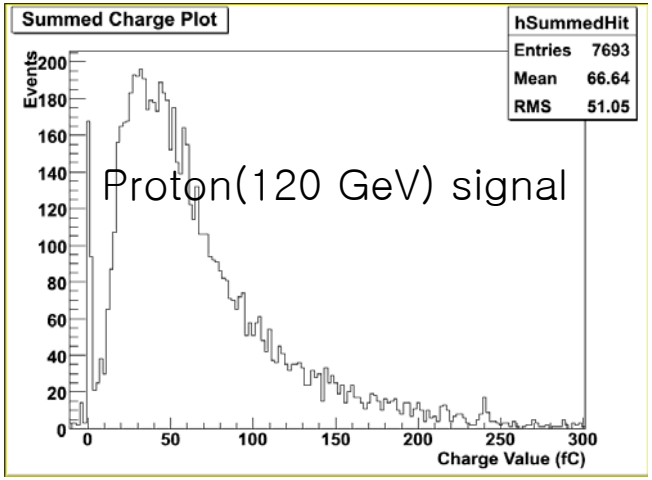
FNAL beam test/Setup

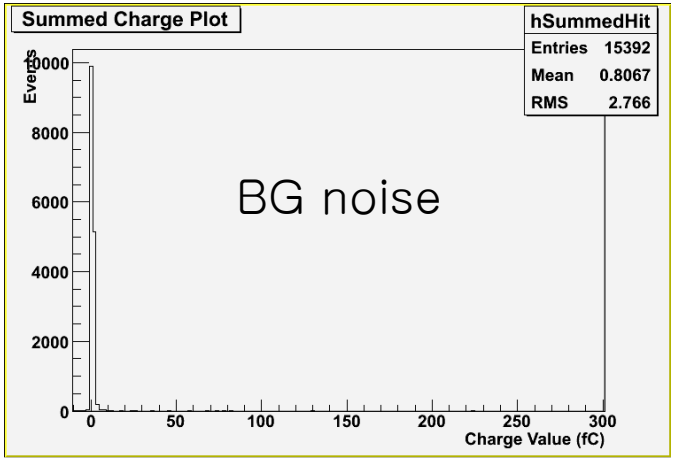
GEM6: KPIX
GEM7, GEM5, GEM4: DCAL
C1,C2: 2x3 cm^2 → 2x2 cm^2 overlap
C3,C4:10x10 cm^2

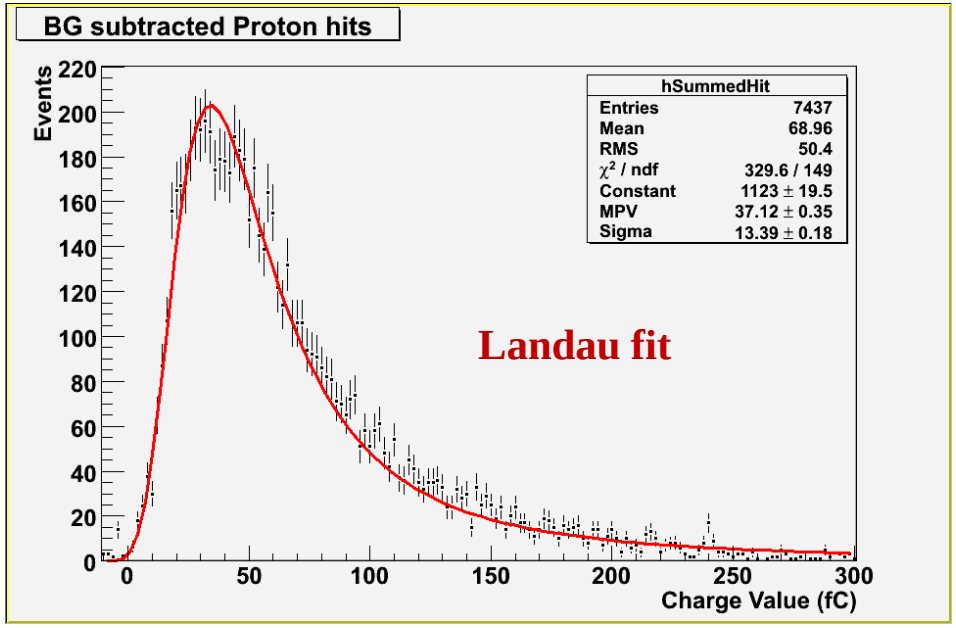


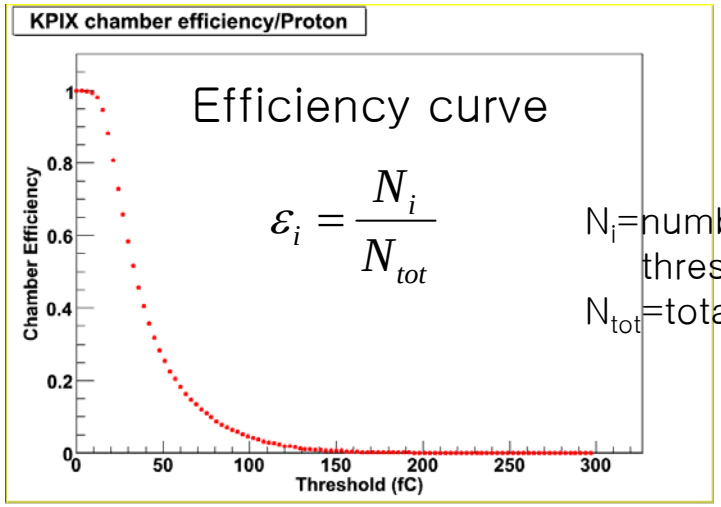
120 GeV Proton
4-coincidence rate at 25,000 cnts=22000/spill
KPIX duty factor=kpix trg/4-coincidence=~0.17%

Noise subtracted Proton charge signal distribution







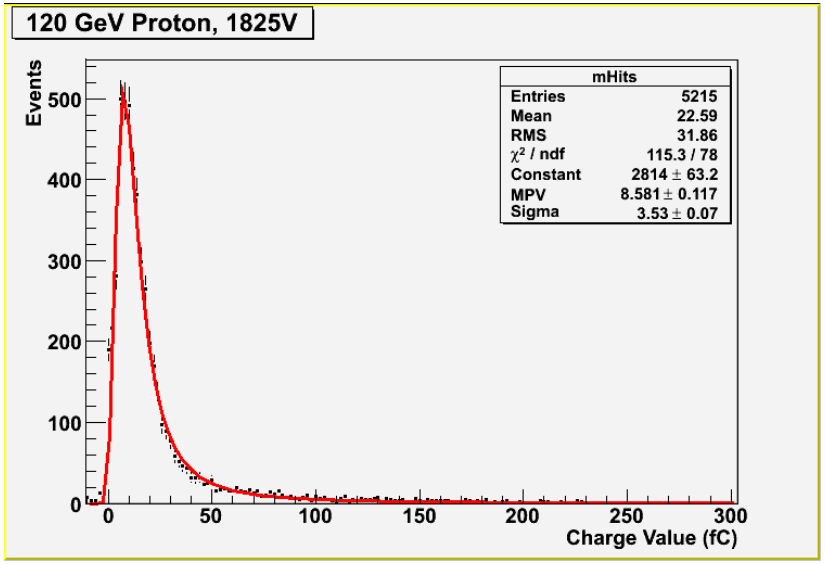


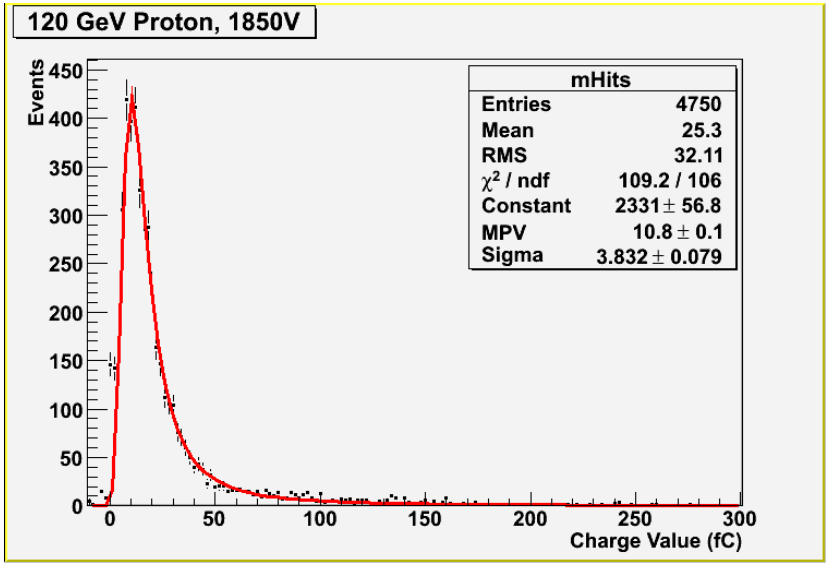
N_i=number of hits above threshold

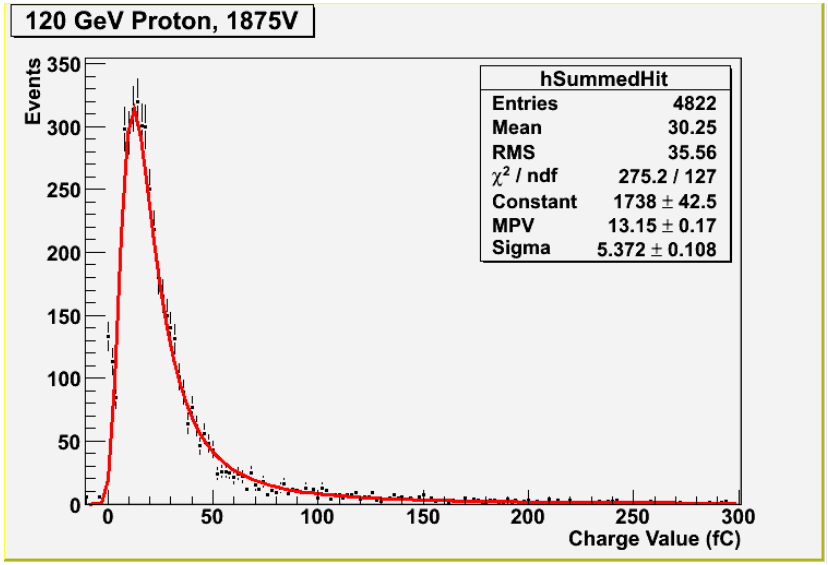
N_{tot}=total number of hits

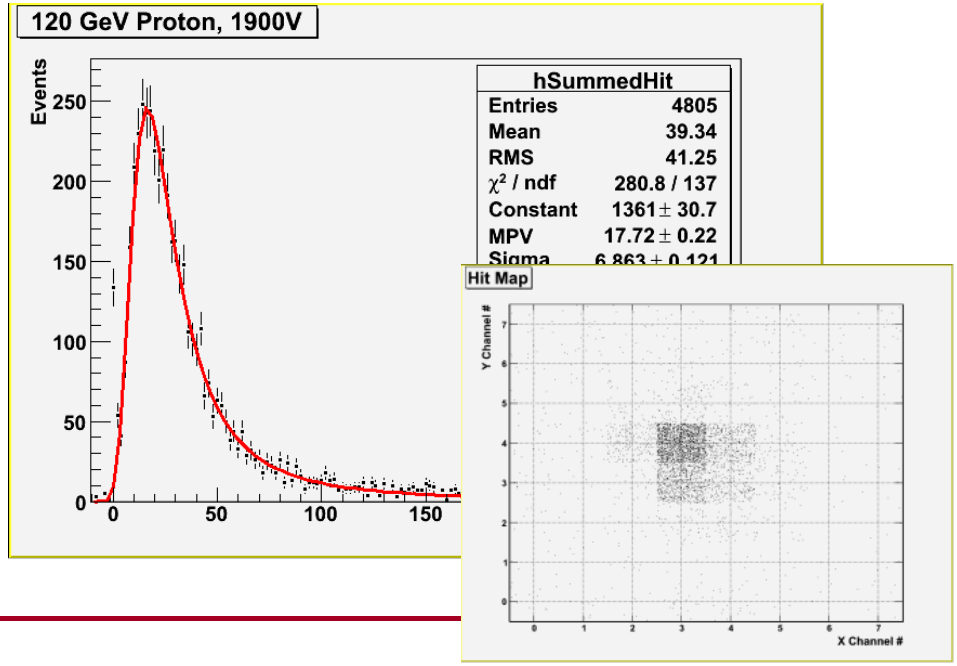
-11~501 fc, 256 bins

HV scan with 120 GeV Proton beam

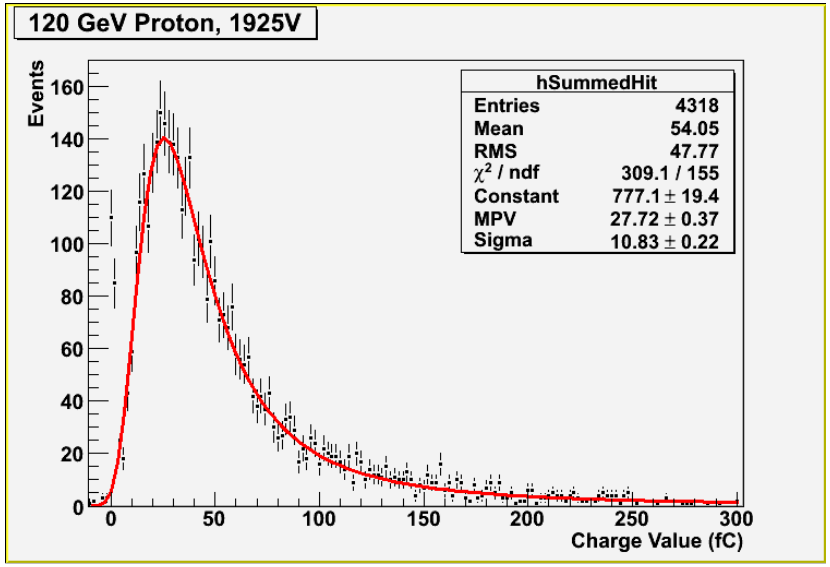


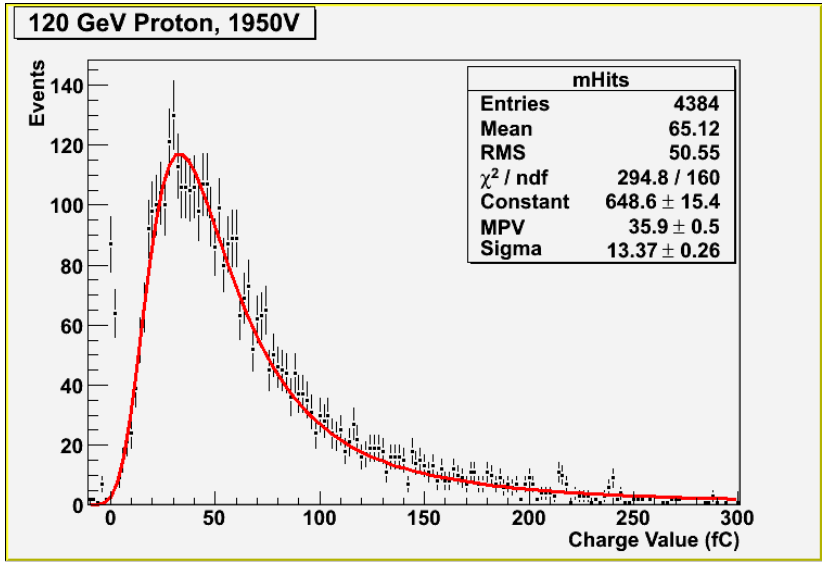


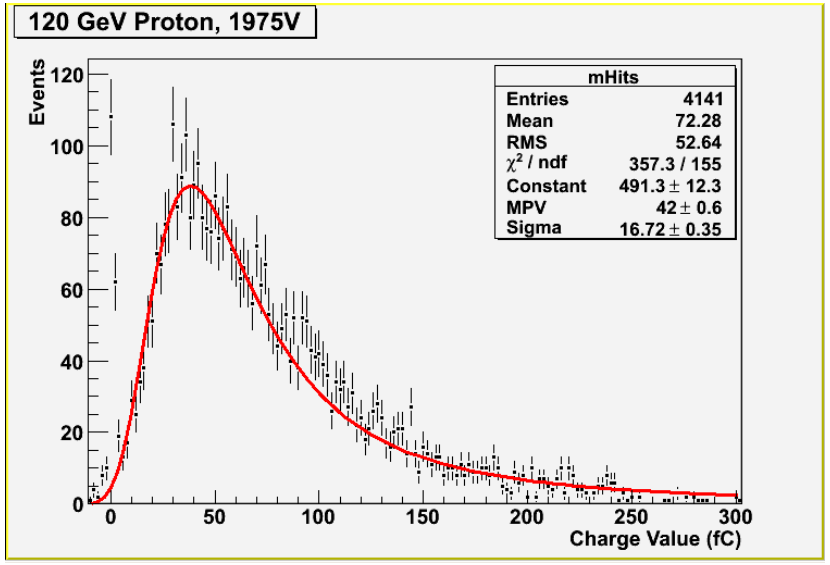


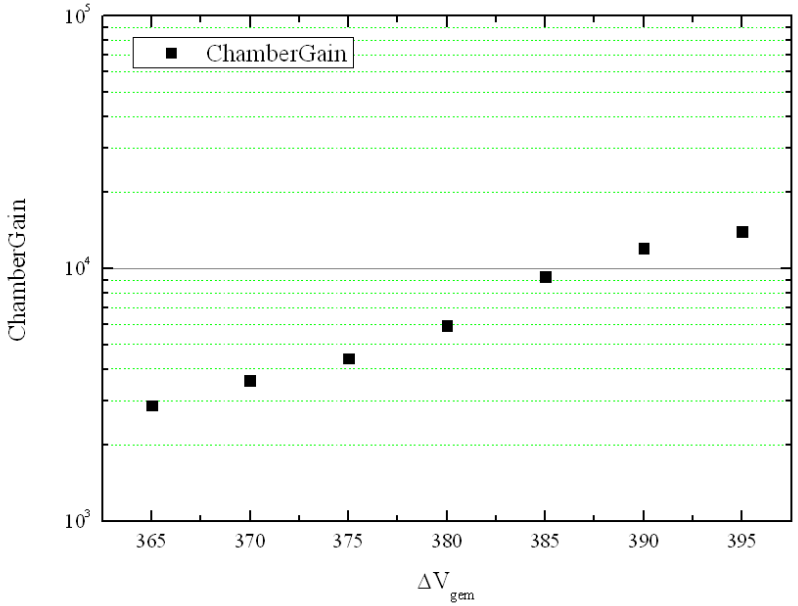


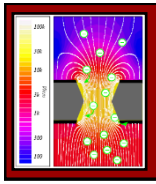
HV scan, Proton 120 GeV









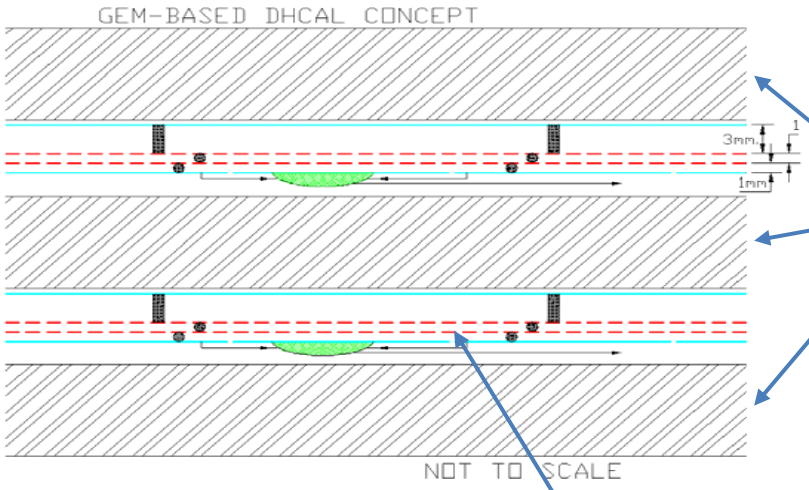


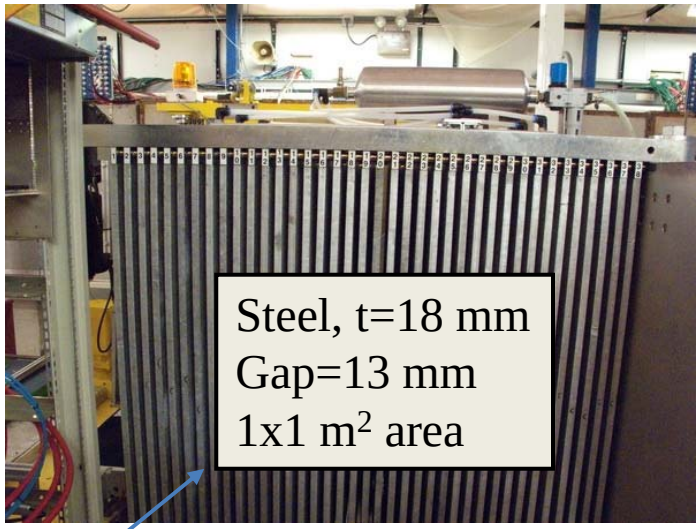
Large GEM design concept for DHCAL development

➢ Sequence

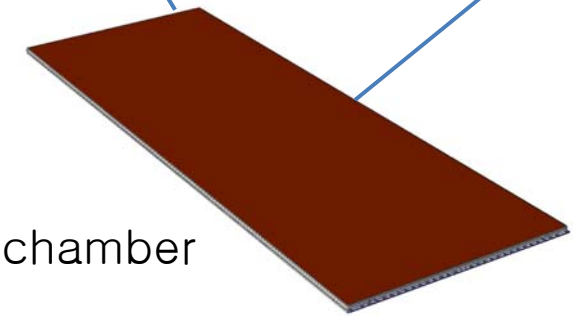
- ✓ **Introduction to GEM detector**
  - GEM applications in various fields
- ✓ **GEM activities in Korea**
- ✓ **GEMs at UTA/Digital Hadron Calorimeter (DHCAL)**
  - **FNAL beam test results**
- ✓ **Future works**
  - Large GEM design concept for DHCAL development
  - GEM based Image Amplifier (GIA)
- ✓ **Summary**

GEM based DHCAL



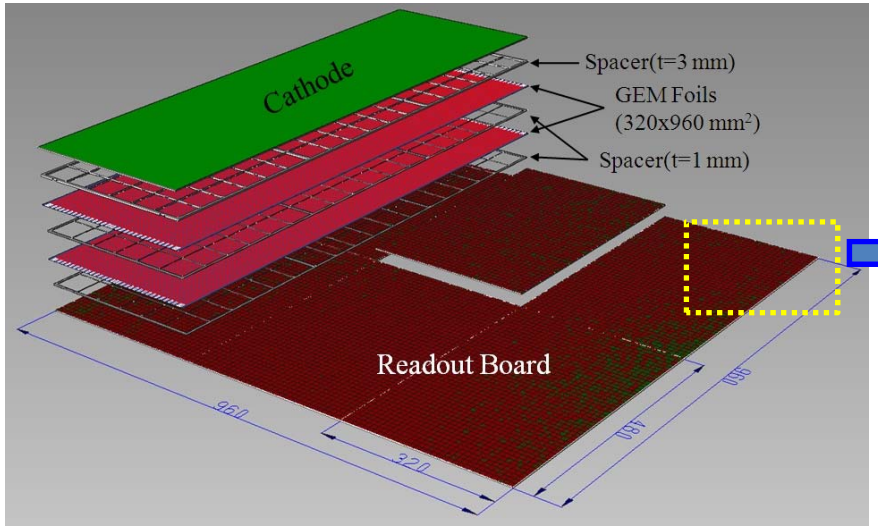


CALICE stack(FNAL)

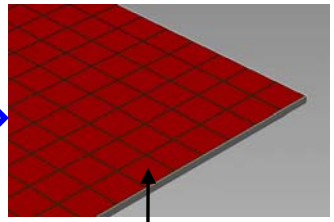


GEM chamber

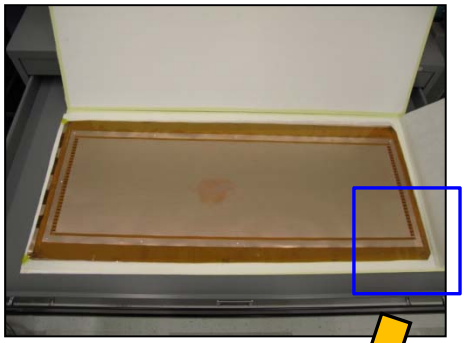
96x96 cm^2 large GEM chamber

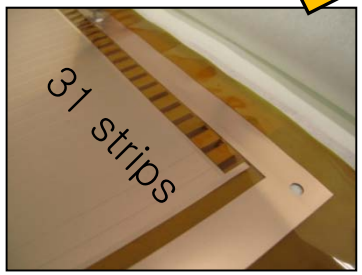


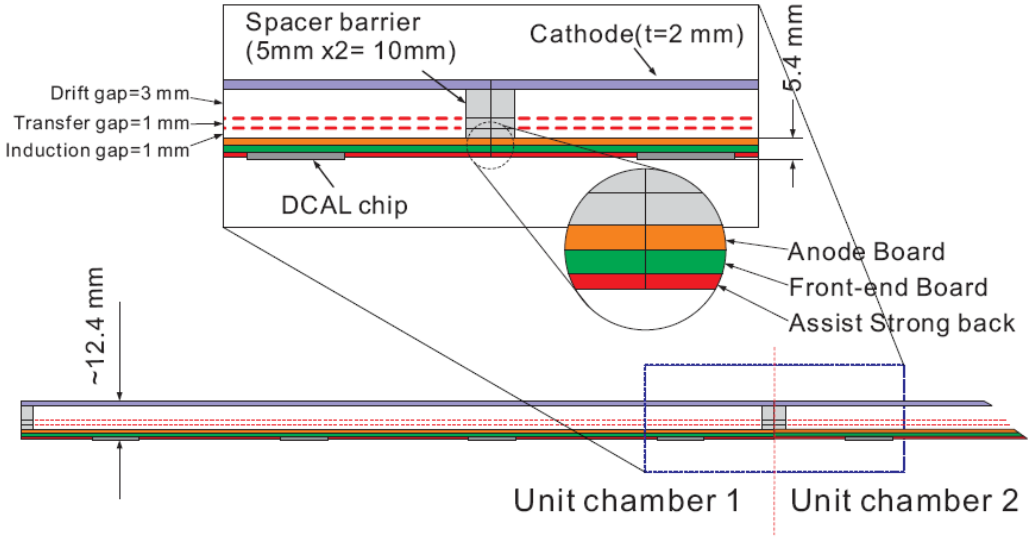
❖ 32x96x3=9216 readout channels/chamber



Anode pad:1x1 cm^2



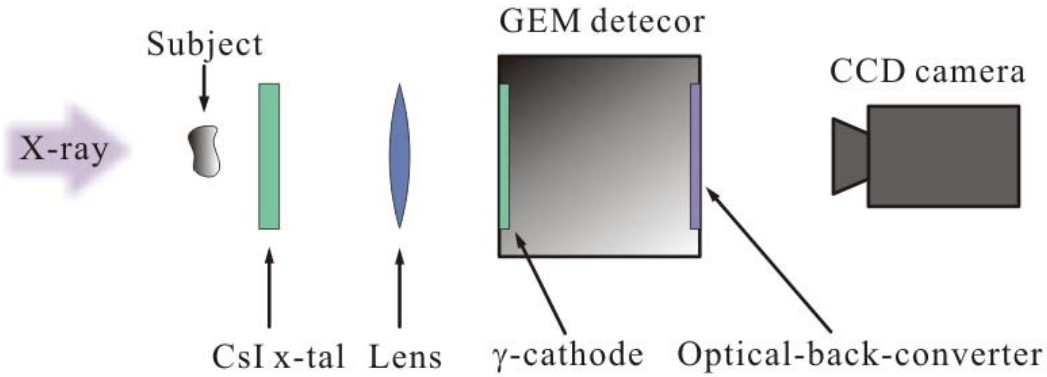


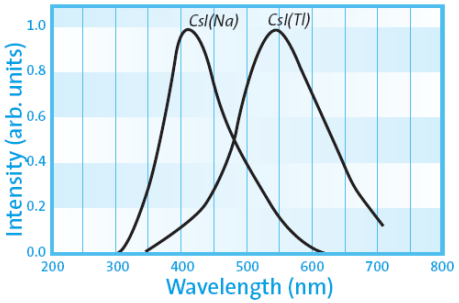


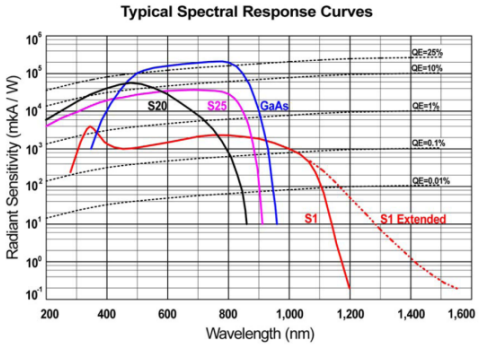
✓CERN-UTA joint developed 32cmx96cm GEM foil

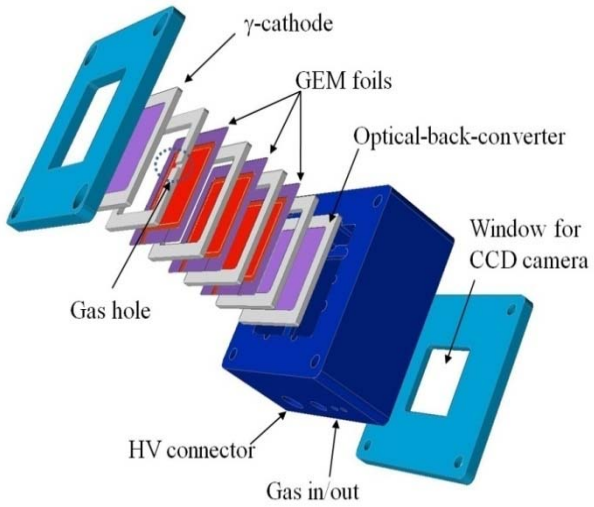
✓Single-side etching technique

GEM-based Image Amplifier concept







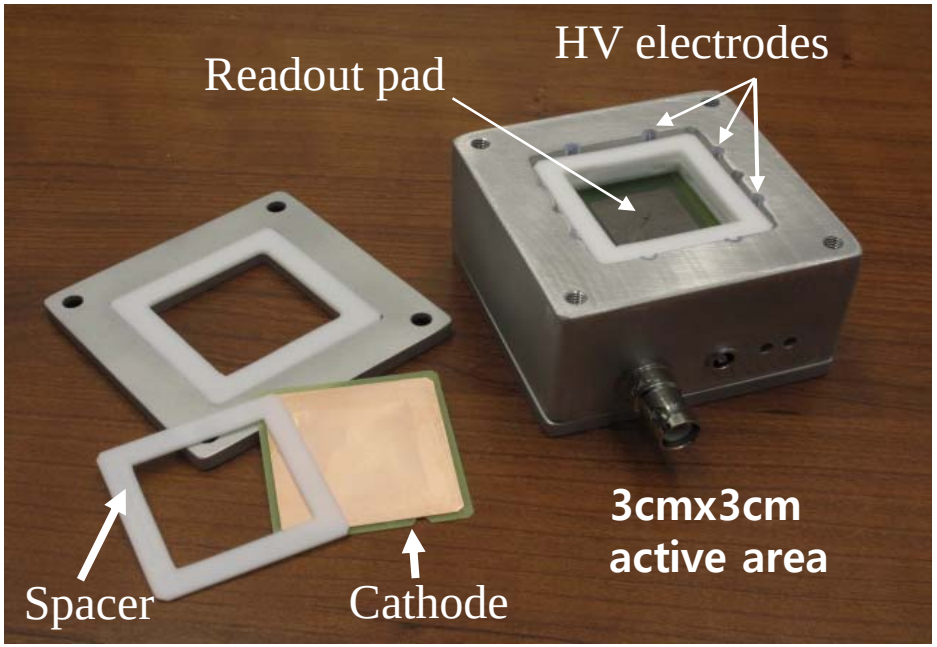


Scintillator:CsI
S-20 photo-converter
Optical-back-converter: $BaFBr:Eu^{2+}$

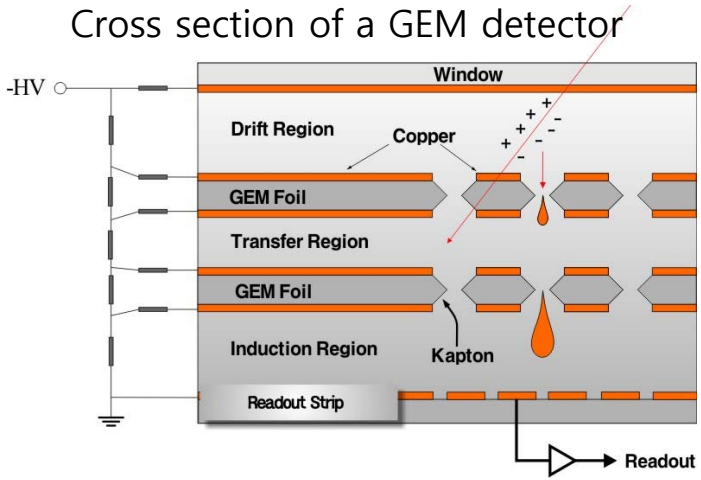
UTA/UT South Western medical center

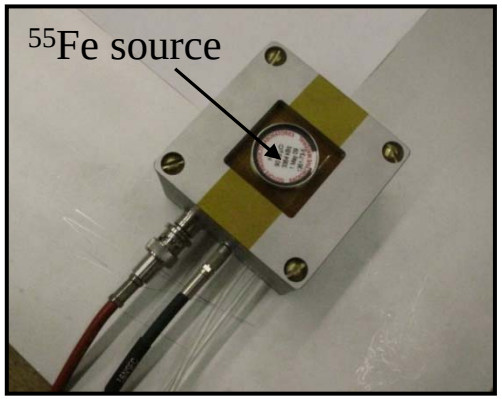
GIA Prototype Chamber

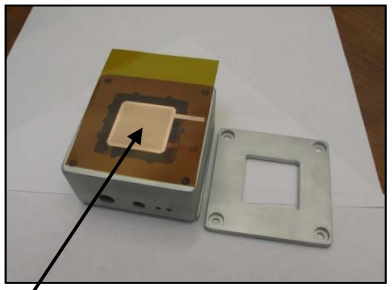
- GEM Foils(CERN)
  - 40x40 mm^2
  - Active area : 30x30 mm^2
- Active gas room
  - 43x43x8 mm^3 → For 5/2/1 gaps
- 2x2 cm^2 readout pad
- Gas: Ar:CO_2=80:20



Cross section of a GEM detector

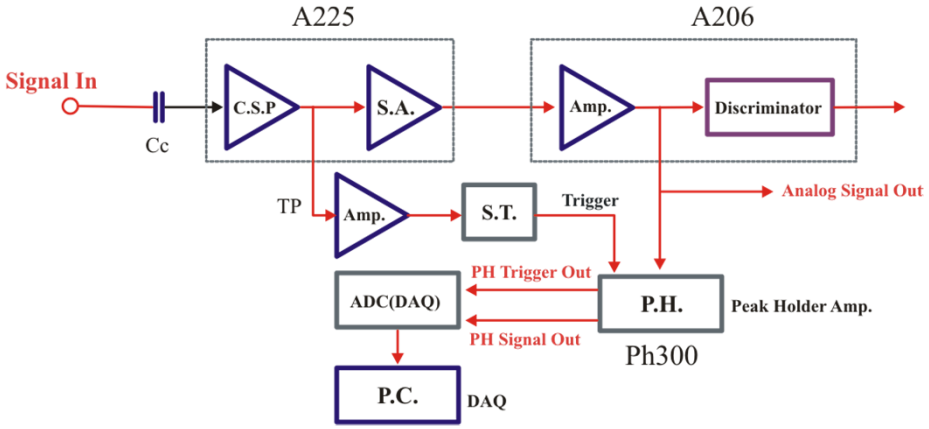


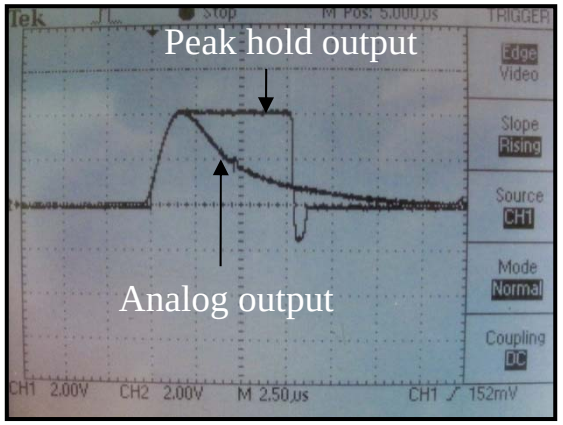


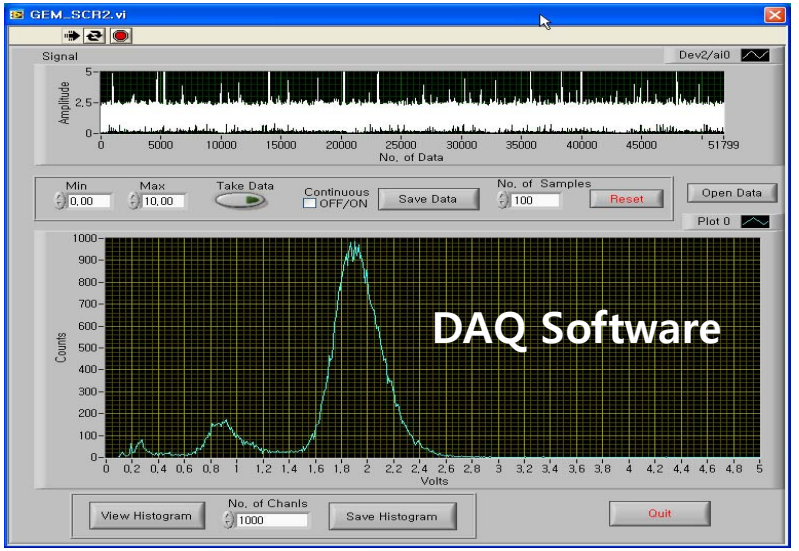


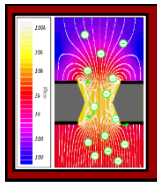
GEM foils: 3x3 cm^2 active area

Single Channel Readout Electronics

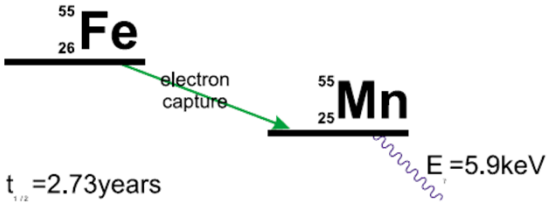


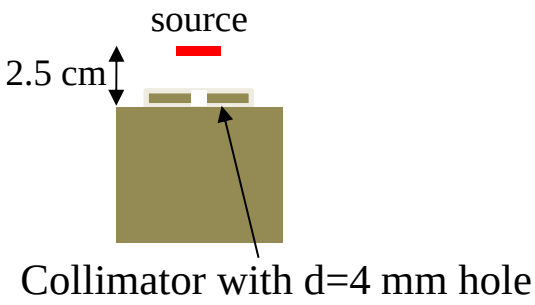


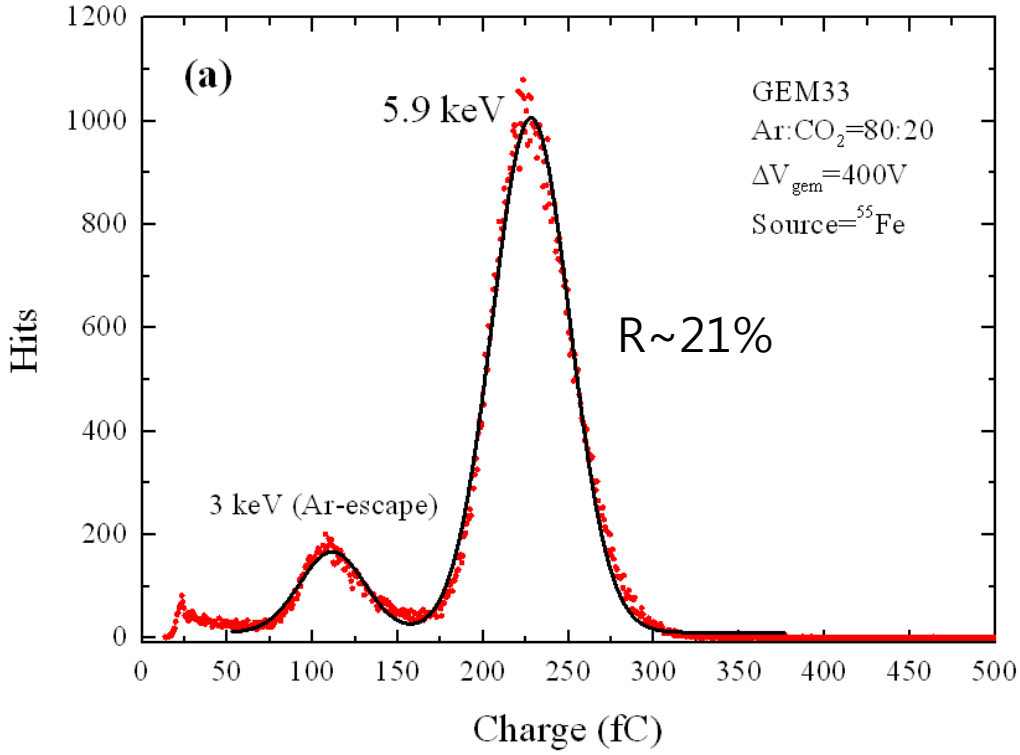




^{55}Fe Spectrum from Ar-based Gas Detector

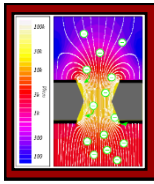






$$\gamma(5.9\text{keV}) \rightarrow e^{-}(2.7\text{keV}) + \gamma_{LM}(0.3\text{keV})[+\gamma_{KL}^{escape}(2.9\text{keV})]$$

γ_{KL}^{escape} has a range of 20 cm in Ar → 3 keV is deposited → Ar-escape peak



Summary

Since the first invention of GEM, many active researches have been in progress all over the world. Other than the original purpose as high energy particle detectors, it has variety of possible applications. Especially, due to the flexibility of its shape and size, it can be considered as a strong candidate for large area radiation detectors.

From the last research(in Korea, 2006~2008, *"Development of One Dimensional Double-GEM Digital Imaging Device for Real-Time and Position-Sensitive Detection of X-ray or Gamma ray."*), we build up valuable technologies such as design of GEM foils, chamber construction, multi channel readout electronics. These could be very helpful for any other applications in which radiation detections are necessary.

I hope there will be good motivations for the development of GEM detectors in Korea in the near future.

Thank you for listening.
감사합니다.