# GEM DHCAL for the ILC and Beyond

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## Outline

- What is High Energy Physics?
- Particle Accelerators and Detectors
- GEM DHCAL Development w/ KPiX
- How could HEP used for everyday lives?
- Conclusions

# We always wonder…

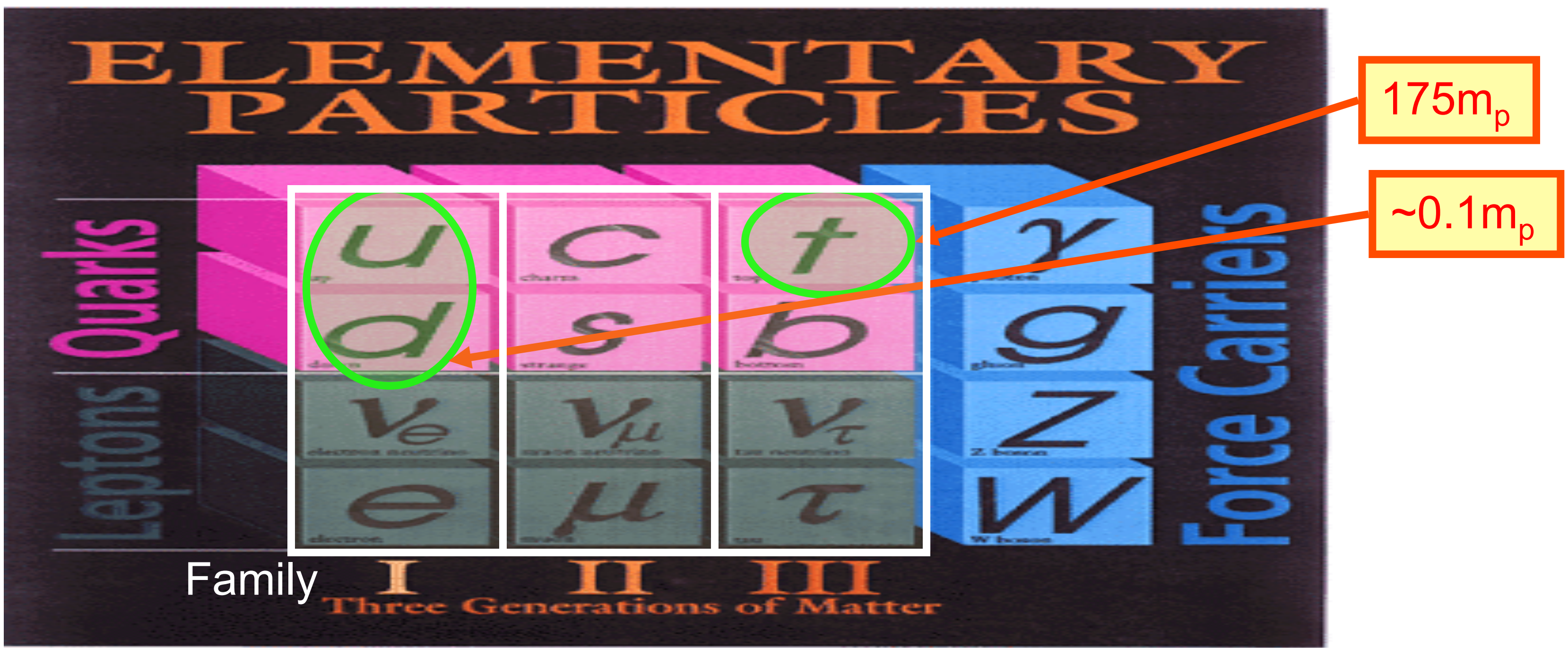
- What is the universe made of?
- How does the universe work?
- What are the things that holds the universe together?
- What are the governing principles of the universe?
- How can we live in the universe well?
- Where do we all come from?
- High Energy Physics looks into smallest possible things to find the answers to these deep questions

# High Energy Physics

- Definition: A field of physics that pursues understanding the fundamental constituents of matter and basic principles of interactions between them
- Known interactions (forces):
  - Gravitational
  - Electro-Weak
  - Strong
- Current theory: The Standard Model of Particle Physics
  - Unified Weak and Electromagnetic: SU(2)xU(1)
  - Strong Interaction: SU(3)
  - Currently:SU(3)xSU(2)xU(1)
  - Meaning: 8+4 mediators for forces

# The Standard Model of Particle Physics

- The Standard Model of Particle physics provides prescriptions for fundamental constituents of matter and the forces between them
  - So the secret and the birth of the universe
- The Standard Model has been extremely successful




- Three families of leptons and quarks together with 12 force mediators ➔ Simple and elegant!!!

# Good, but still lots we don't know…

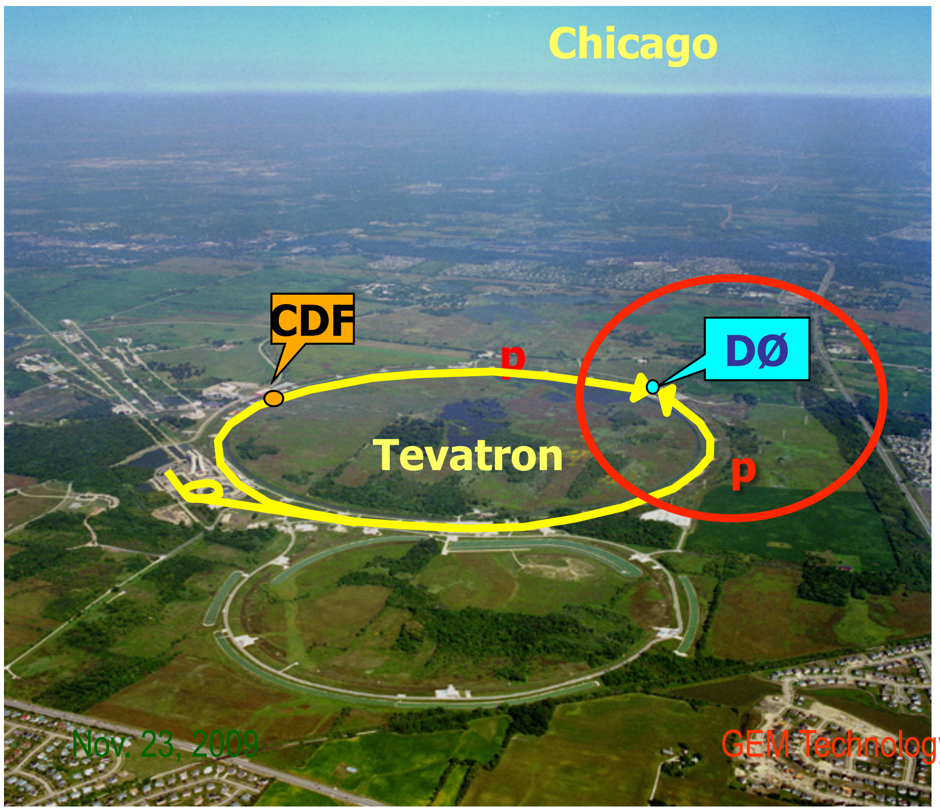
- Why are there three families of quarks and leptons?
- Why is the mass range so large ($0.1m_p$ – $175\ m_p$)?
- How do matters acquire mass?
  - Higgs mechanism but where is the Higgs, the God particle?
- Why is the matter in the universe made only of particles?
  - What happened to anti-particles? Or anti-matters?
- Why are there only three apparent forces?
- Is the picture we present the real thing?
- How is the universe created? Where do we come from?
- Are there any other theories that describe the universe better?

# What are the roles of particle accelerators?

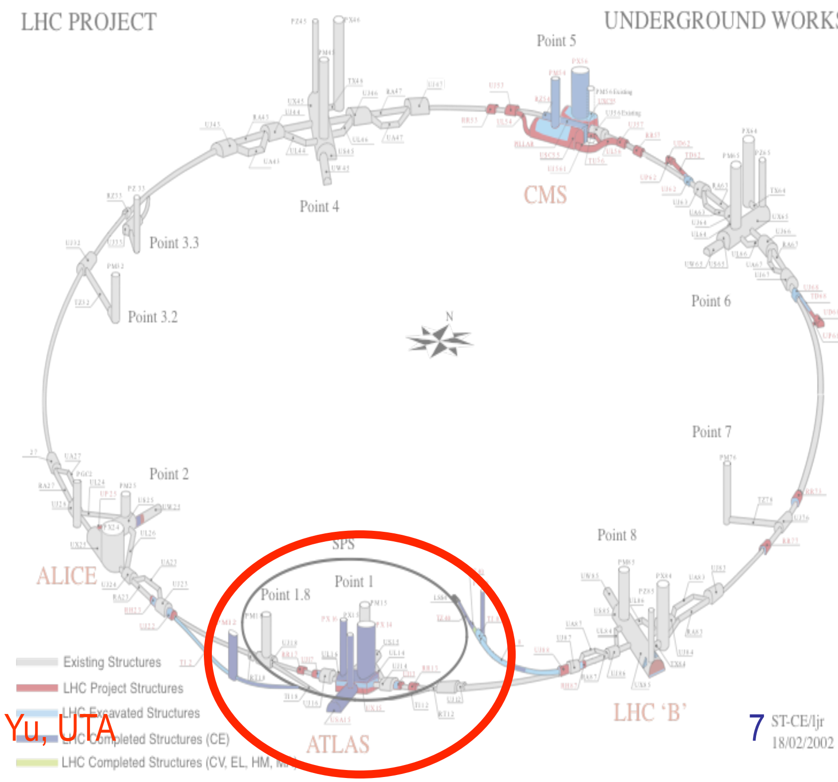
- Acts as probing tool
  - The higher the energy ➔ The shorter the wavelength
  - Smaller distance to probe
- Two method of accelerator based experiments:
  - Collider Experiments: pp, pp, $e^+e^-$, ep
    - CMS Energy: $\sqrt{s} = 2\sqrt{E_1 E_2}$
    - Hadron colliders act as discovery machines
    - Lepton colliders are for precision measurements
  - Fixed Target Experiments: Particles on a target
    - CMS Energy: $\sqrt{s} = \sqrt{2E_1 M_T}$
  - Each probes different kinematic phase space

# Fermilab Tevatron and LHC at CERN

- Present world's Highest Energy proton-anti-proton collider
  - 4km circumference
  - $E_{cm}$=1.96 TeV (=6.3x$10^{-7}$J/p➔ 13M Joules on $10^{-12}$m$^2$)
  - Þ Equivalent to the kinetic energy of a 20t truck at the speed of 130km/hr

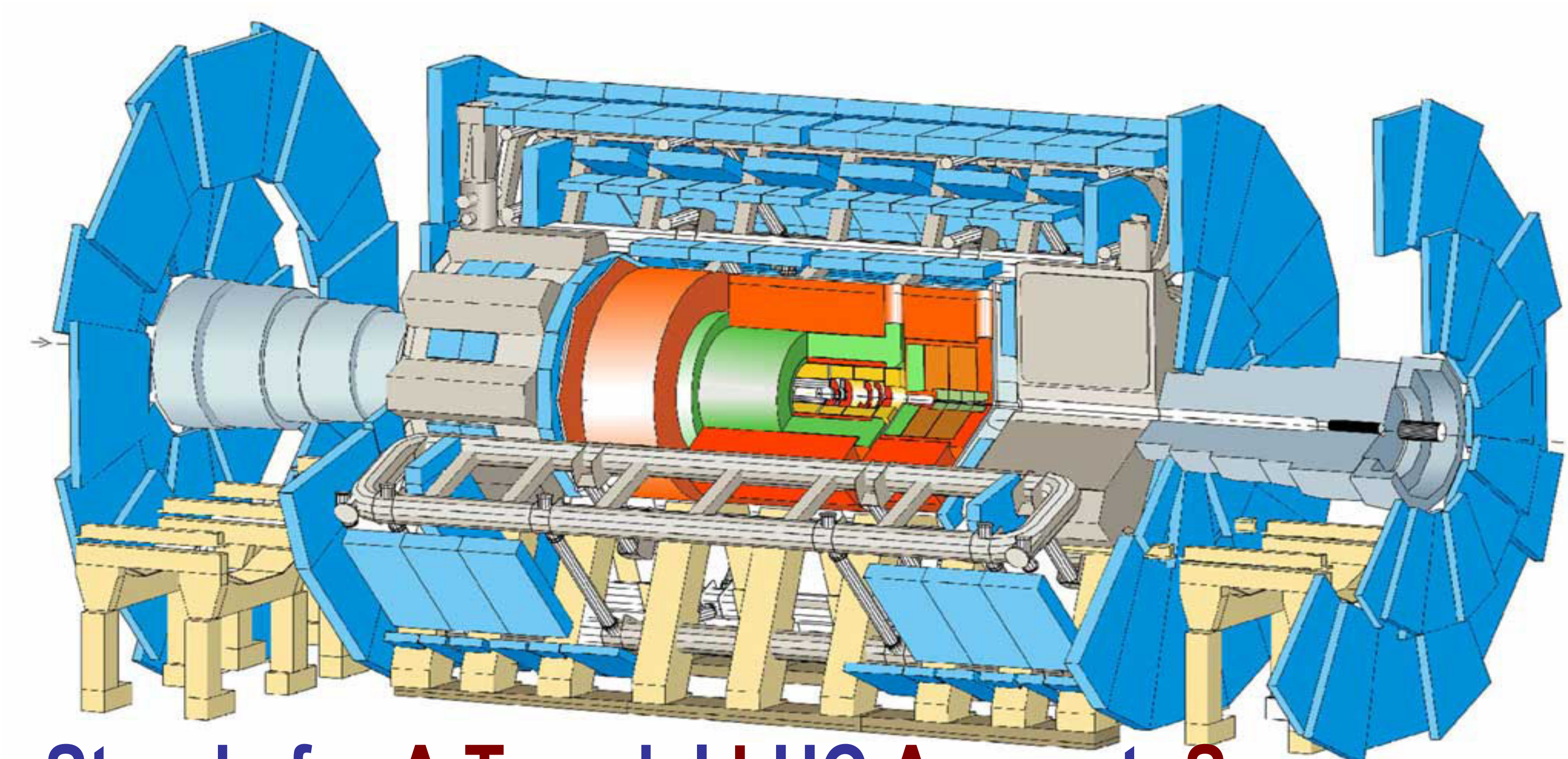



- World's Highest Energy proton-proton collider, turned on last Friday, Nov. 20 and the first collision today!!!
  - 27km circumference (100m underground)
  - $E_{cm}$=14 TeV (=44x$10^{-7}$J/p➔ 1000M Joules on $10^{-12}$m$^2$)
  - Þ Equivalent to the kinetic energy of a 20t truck at the speed 1140km/hr



# LHC @ CERN Aerial View

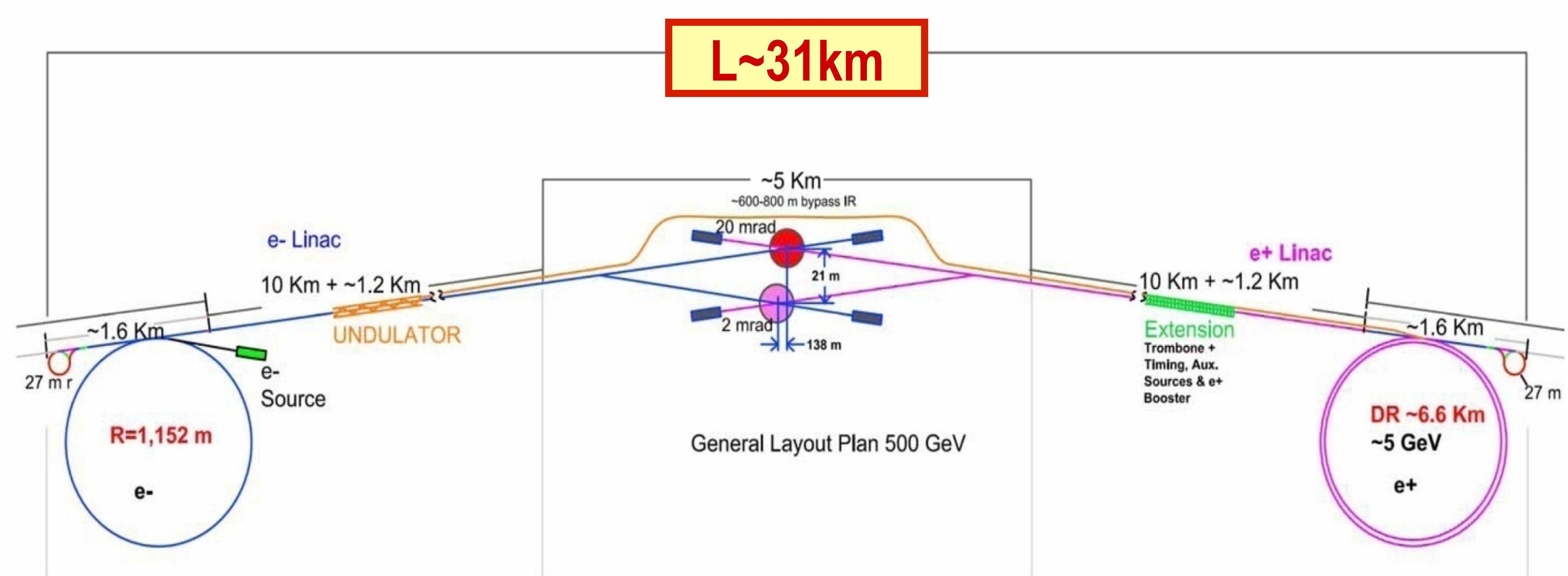
# The ATLAS Detector

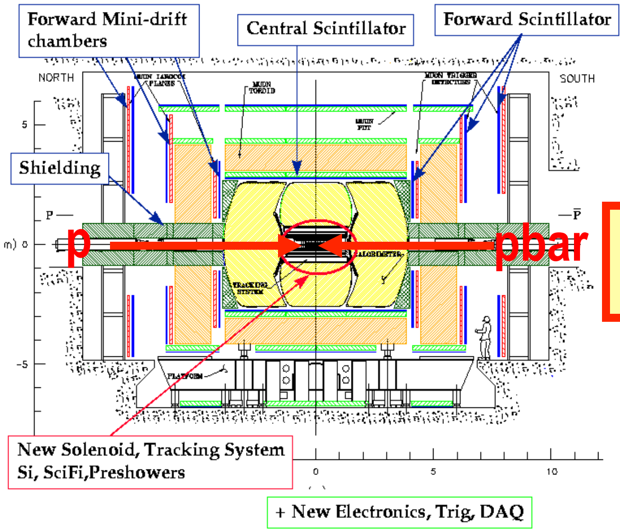


- **Stands for A Torodal LHC ApparatuS**
- **Weighs 10000 tons and 10 story tall**
- Can inspect **1,000,000,000** collisions/second
- Will record **~ 200 pp collisions/second**
- Will record over **2x10$^{15}$** (2,000,000,000,000,000) bytes each year (2 PetaBytes).

# The International Linear Collider

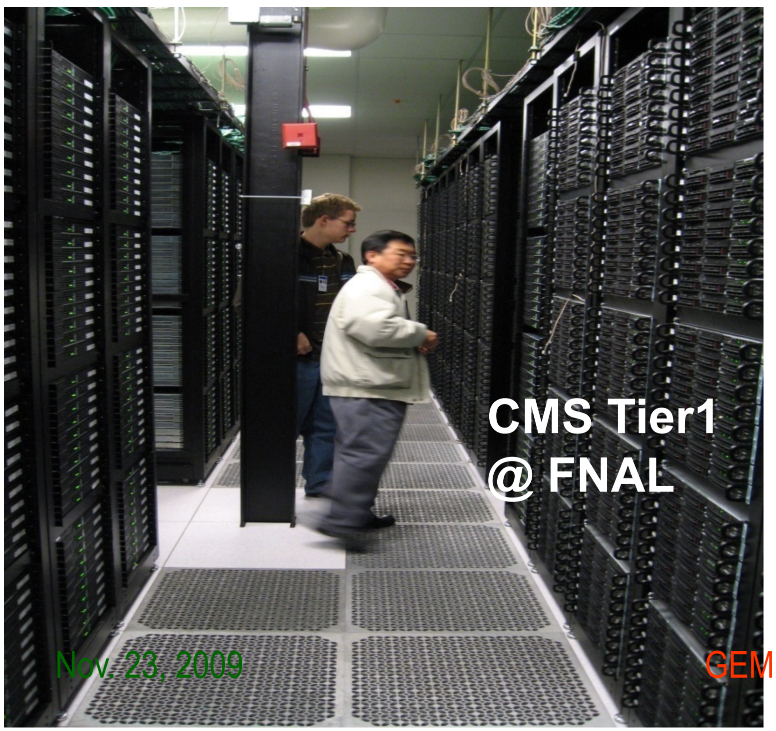
- An electron-position collider on a straight line
- CMS Energy: 0.5 – 1 TeV
- 10~15 years from the approval of the project
- Takes 10 years to build the accelerator and the detector



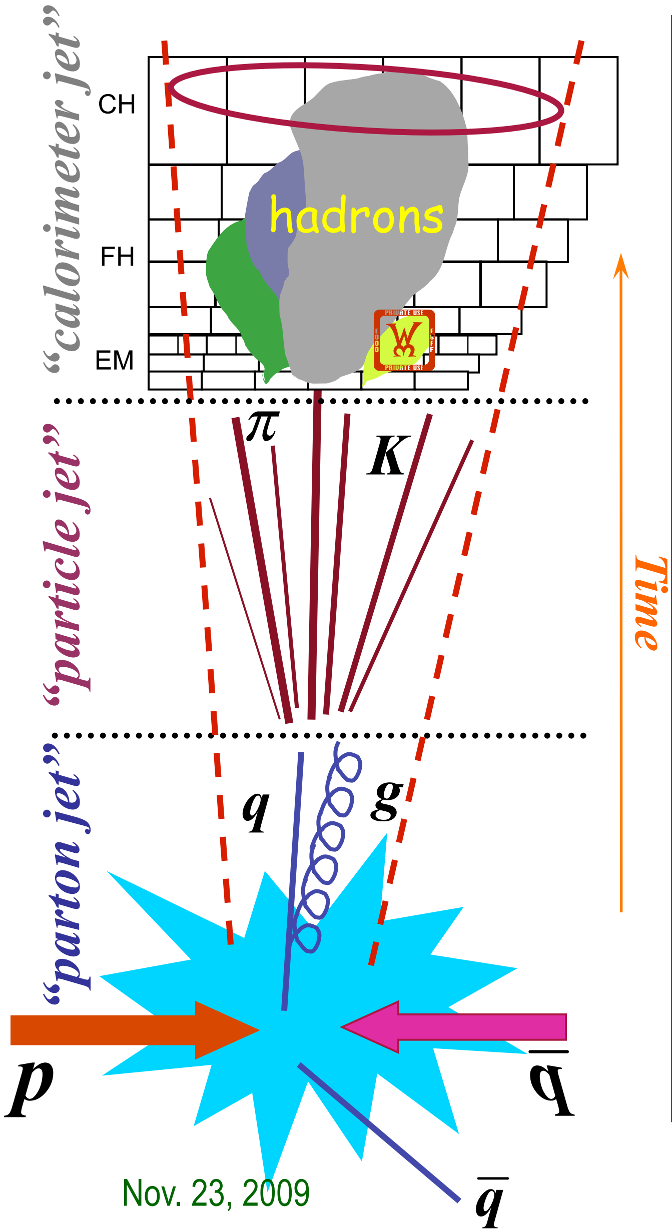


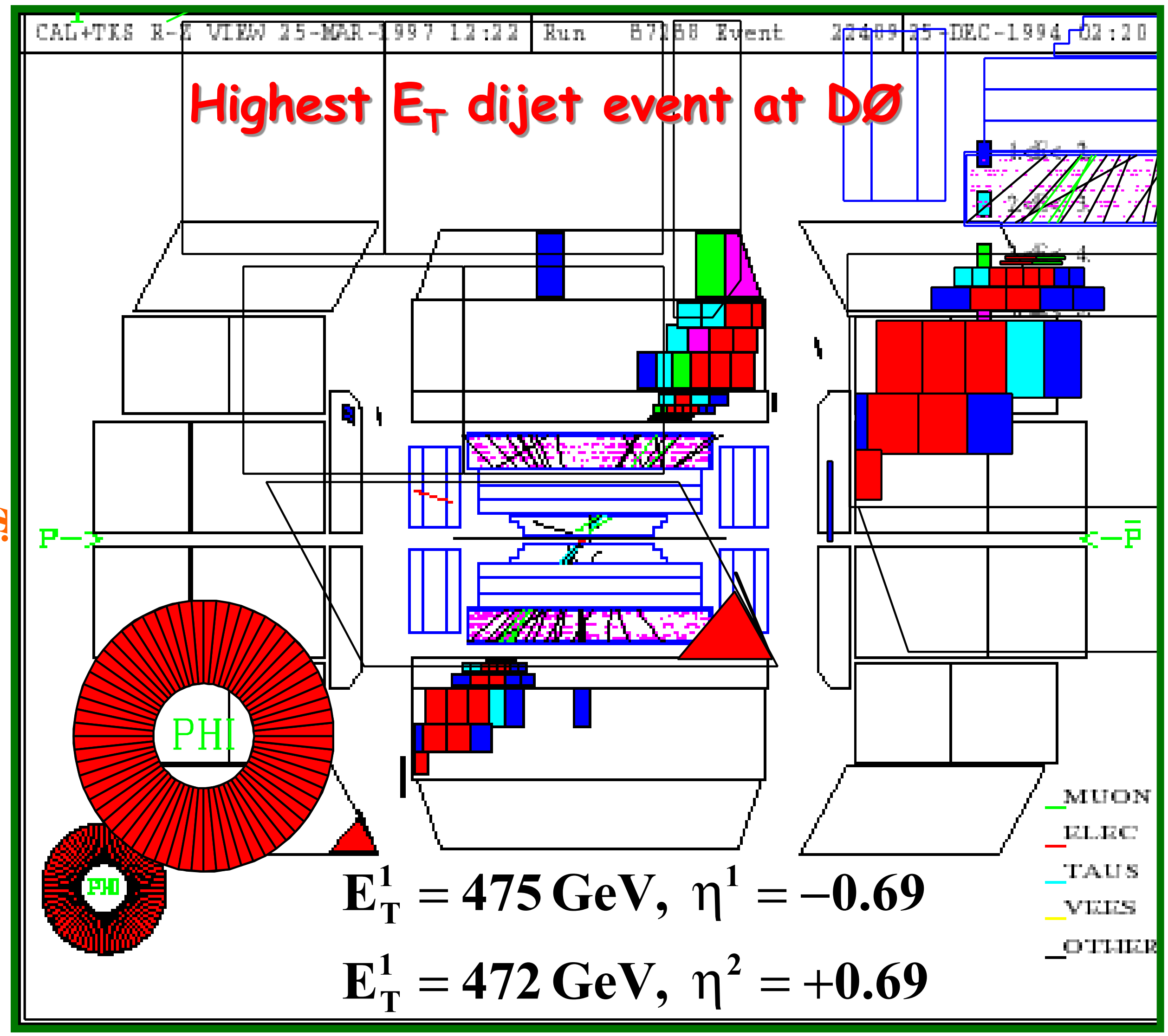

Digital data

Data Reconstruction



# How does an Event Look in a HEP Detector?



# Gas Electron Multipliers

## GEM foil etching

C. GEMs


Fig. 14 (a) Chemical etching Process of a GEM (b) A GEM foil

A new concept of gas amplification was introduced in 1996 by Sauli: the Gas Electron multiplier (GEM) [27] manufactured by using standard printed circuit wet etching techniques' schematically shown in Fig. 14(a). Comprising a thin (~50 μm) Kapton foil, double sided clad with Copper, holes are perforated through (fig. 15b). The two surfaces are maintained at a potential gradient, thus providing the necessary field for electron amplification, as shown in Fig. 15(a), and an avalanche of electrons as in Fig. 15(b).

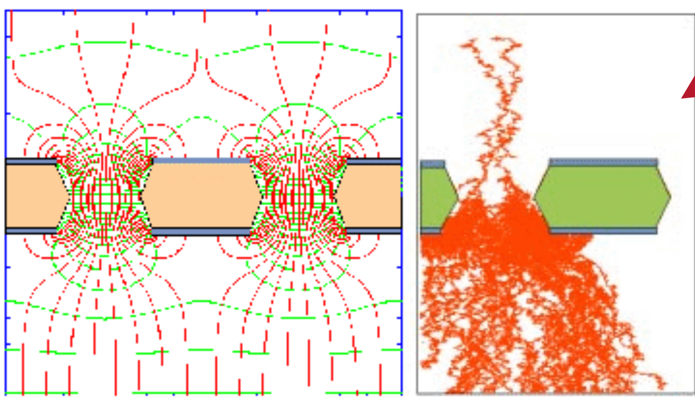
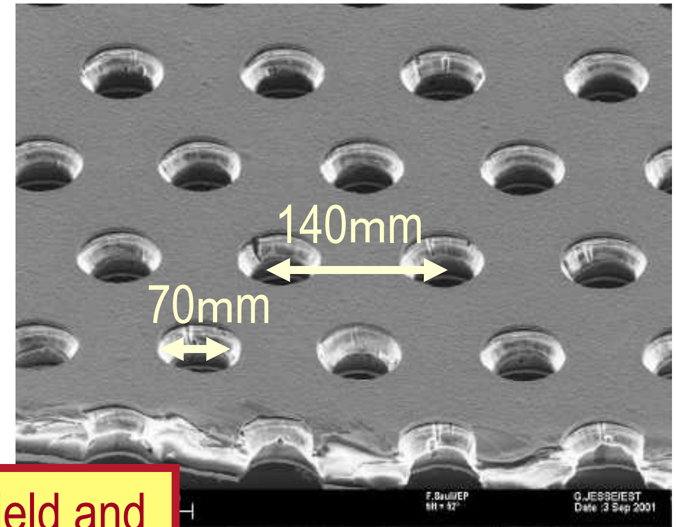


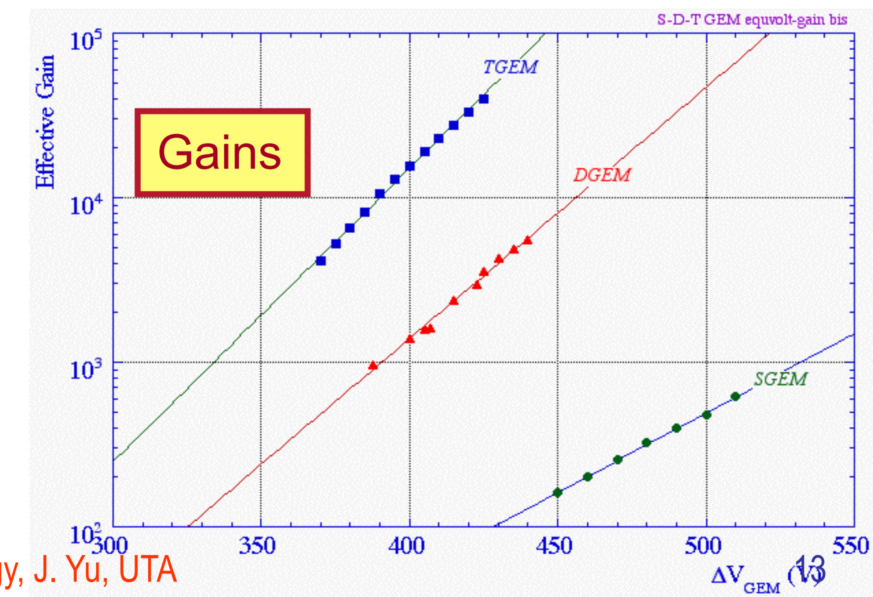
Fig. 15(a) Electric Field and (b) an avalanche across a GEM channel

Coupled with a drift electrode above and a readout electrode below, it acts as a highly performing micropattern detector. The essential and advantageous feature of this detector is that amplification and detection are decoupled, and the readout is at zero potential. Permitting charge transfer to a second amplification device, this opens up the possibility of using a GEM in tandem with an MSGC or a second GEM.

From CERN-open-2000-344, A. Sharma




GEM field and multiplication




Gains

# How does a GEM chamber work?

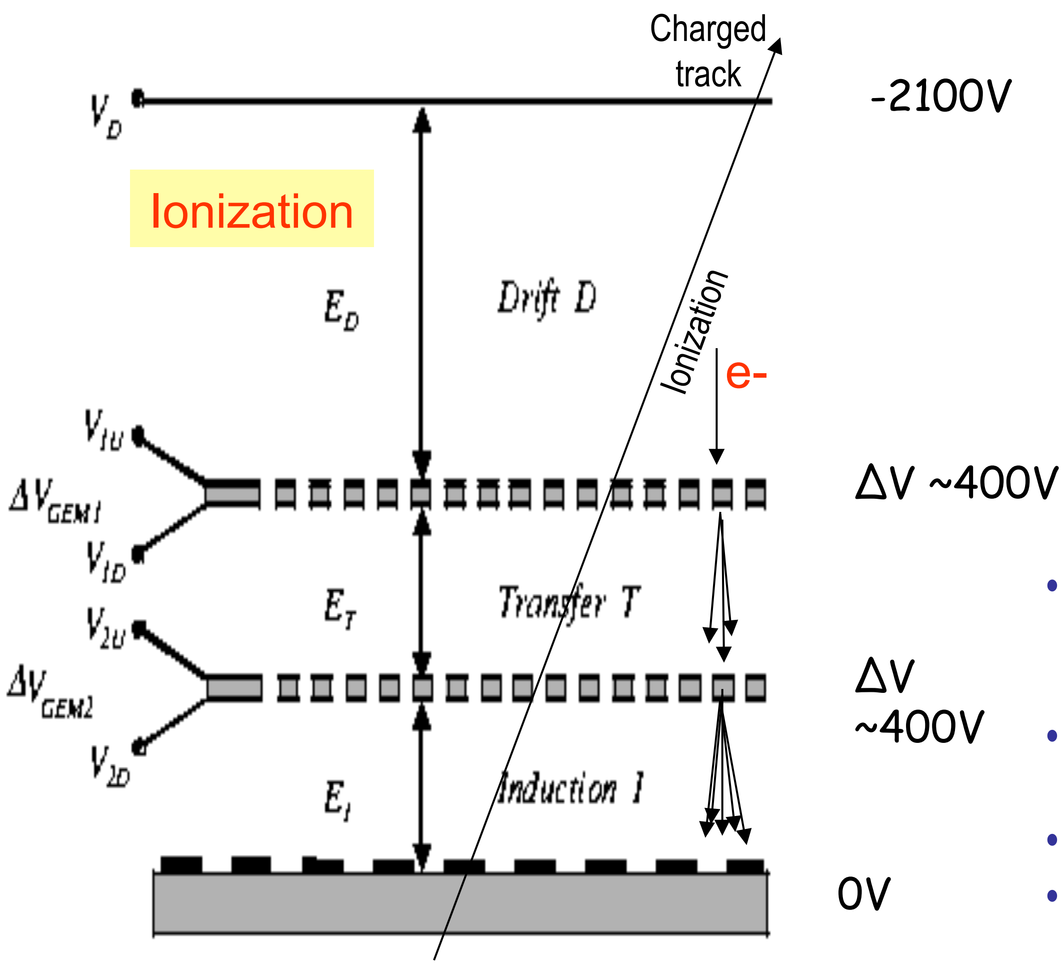



Fig. 1: Schematics of a double-GEM detector.

How large is the electric field across a GEM foil?

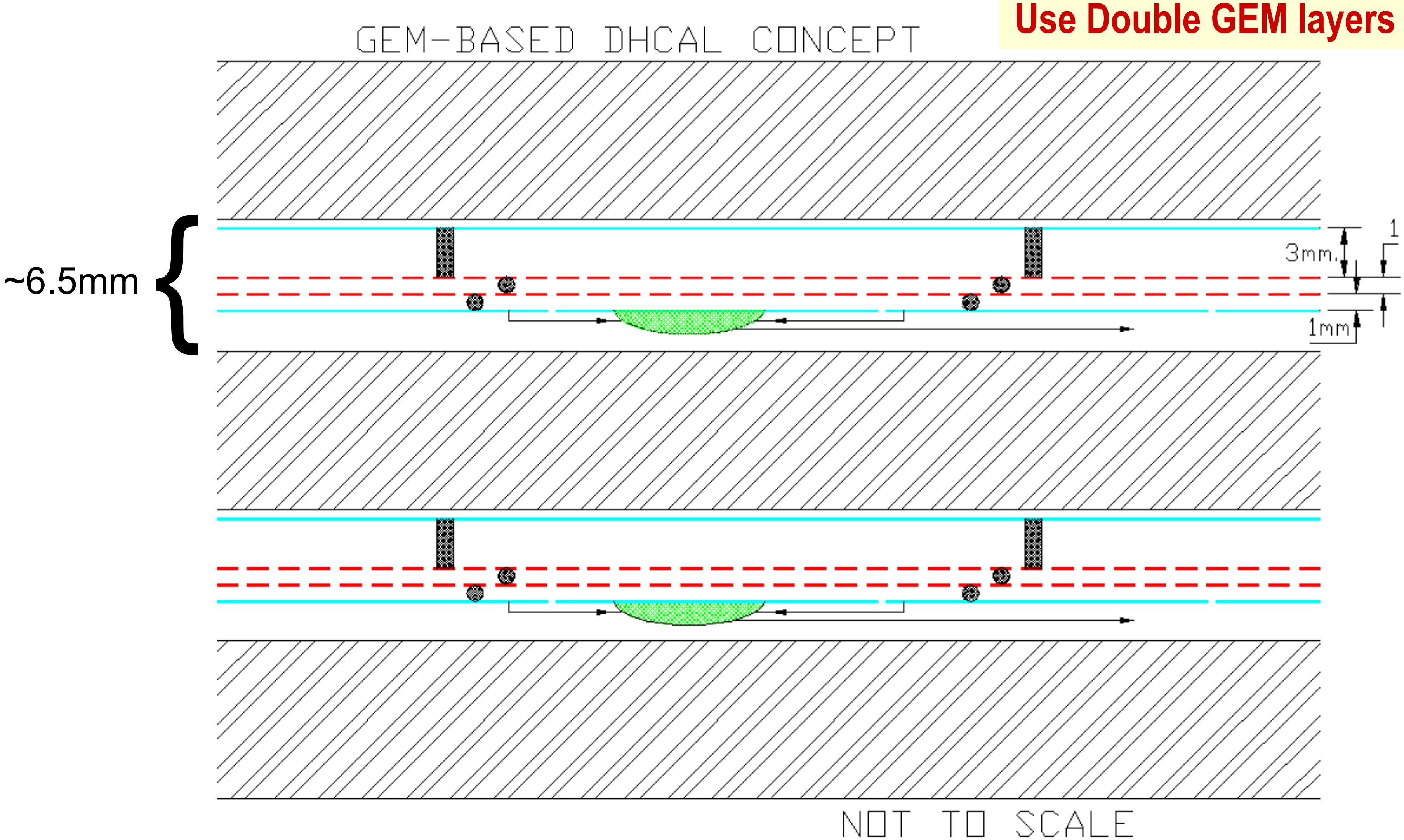
$E = V/d$

$= 400V/6\times10^{-5}cm \sim 6.7\times10^{5}V/cm$

- Sensitive to a wide range of particles, from low E γ-rays and X-rays to several TeV charged particles
- Flexible with high position resolution and high efficiency ➔ Good imaging device
- Relatively low operational voltage
- Can operate with normal operational gas – $ArCO_2$ or other noble gasses (such as Xe)
- Short response time ~ 50ns
- **High gain ($10^2$ /layer @400V)**
- Robust to high flux radiation

# GEM-based Digital Calorimeter Concept

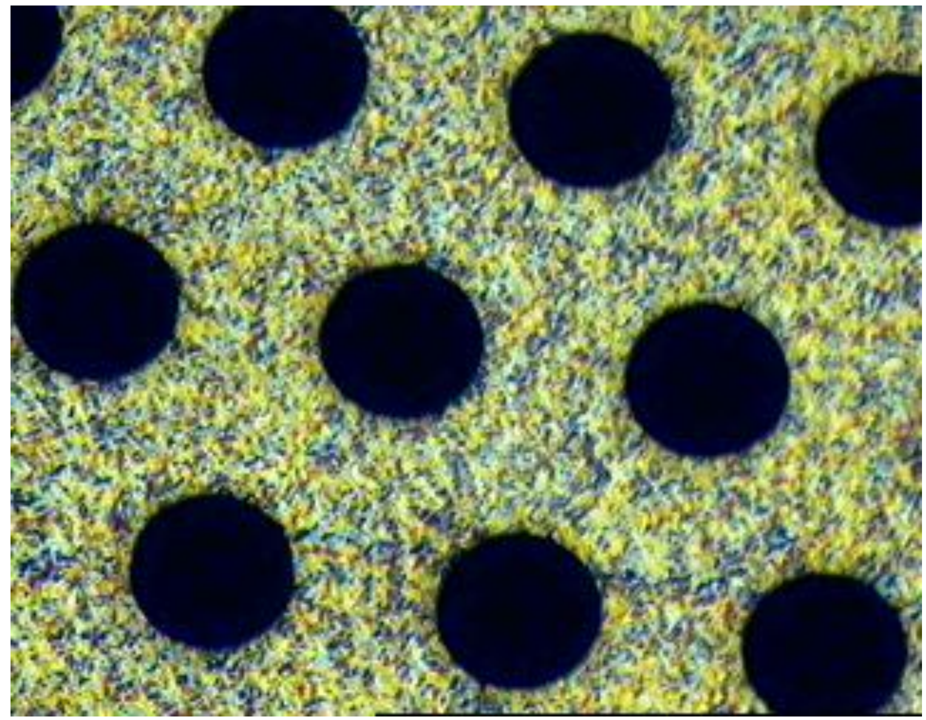
**Use Double GEM layers**



# UTA 30cm x 30cm 3M GEM foils

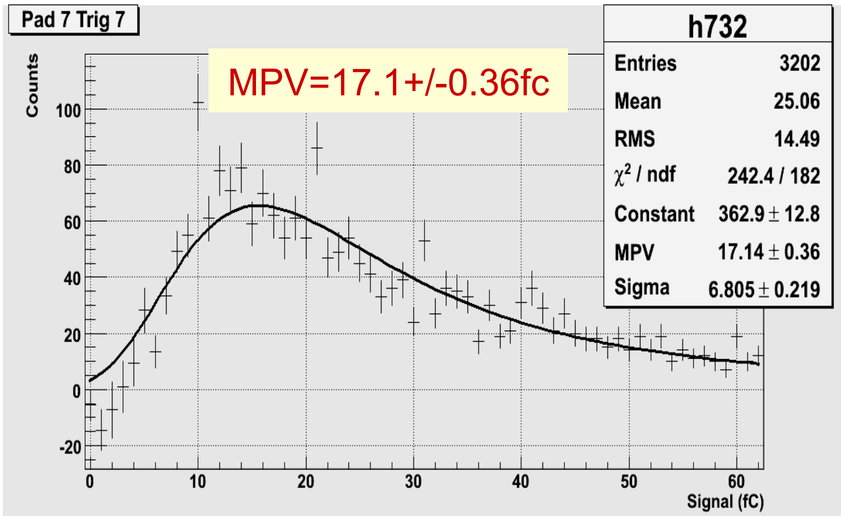
12 HV sectors on one side of each foil.

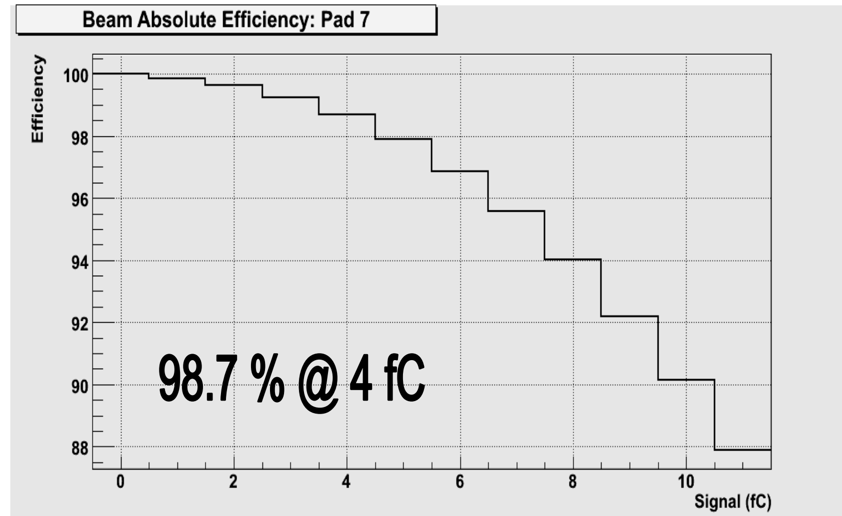
Magnified section of a 3M GEM foil.

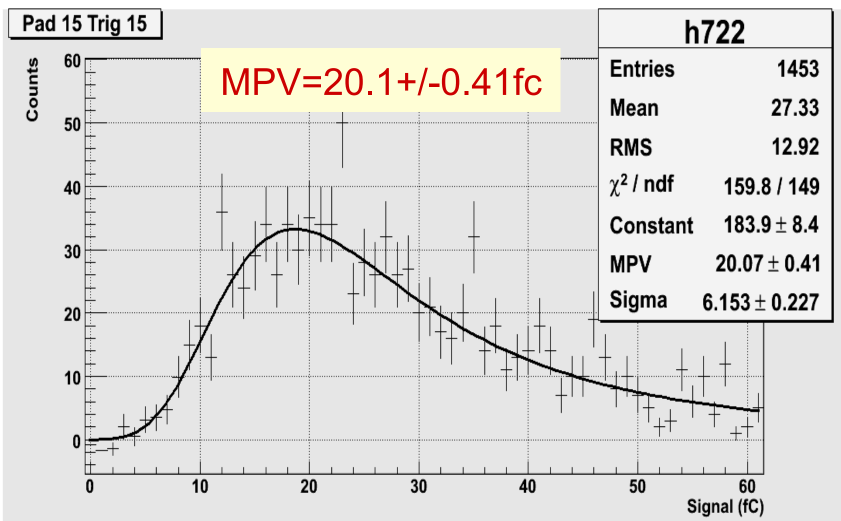


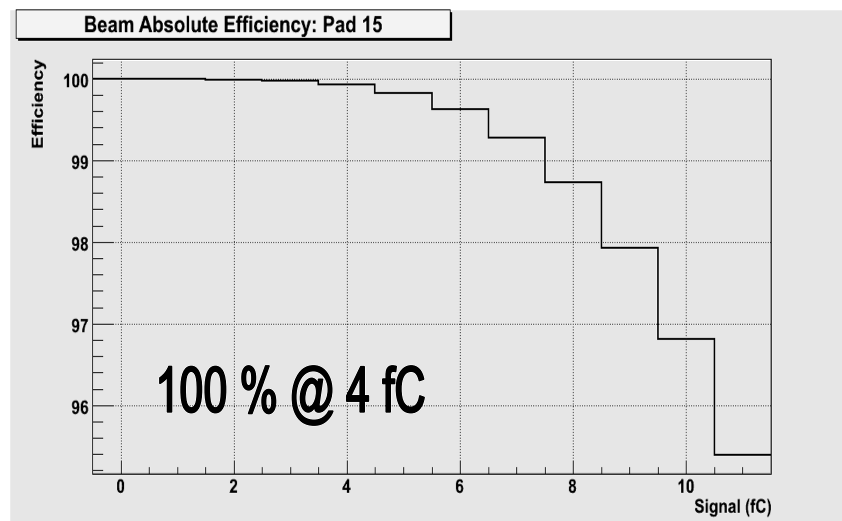
HV Sector Boundary

# Absolute Efficiency vs Threshold w/ 120GeV P

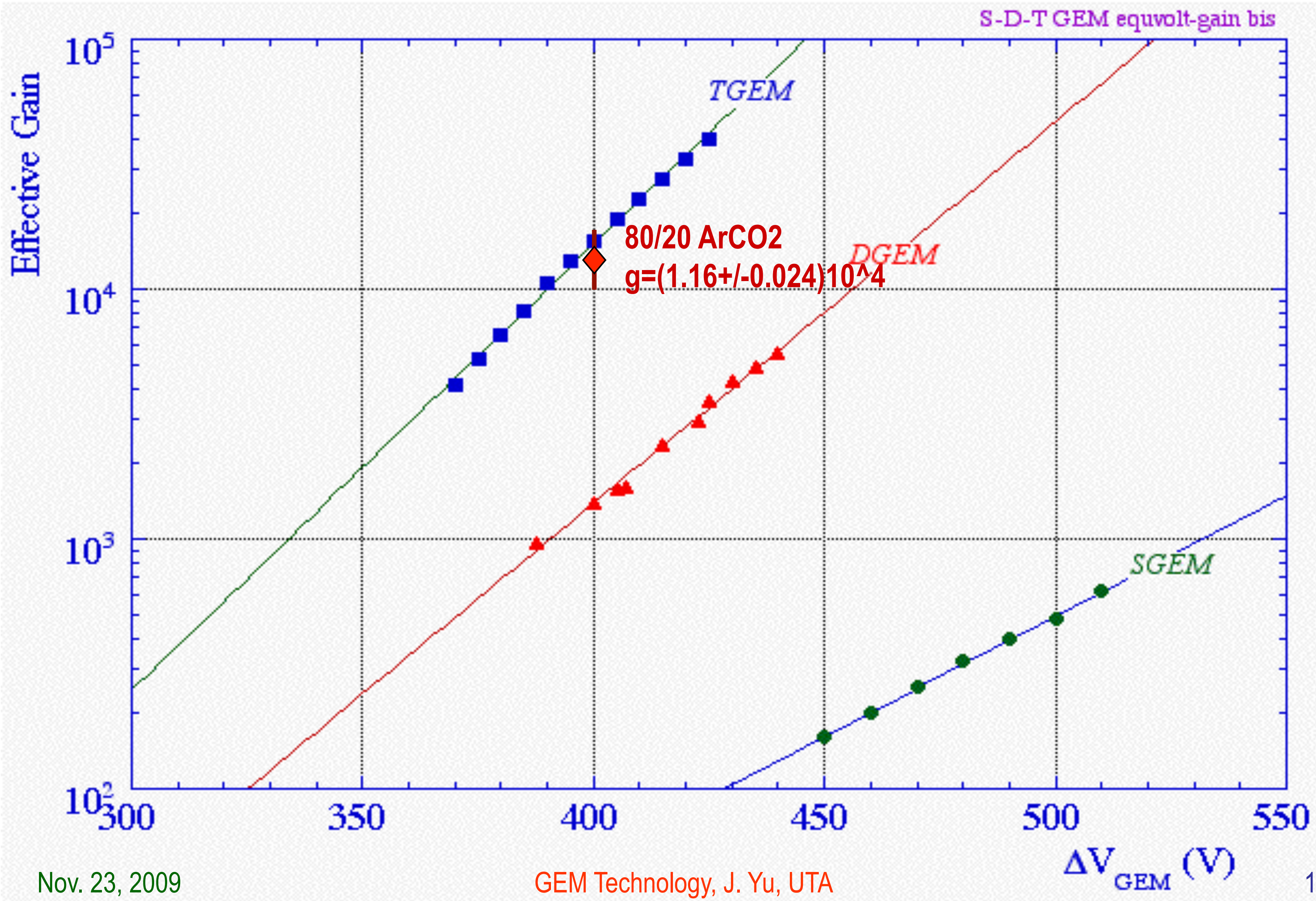


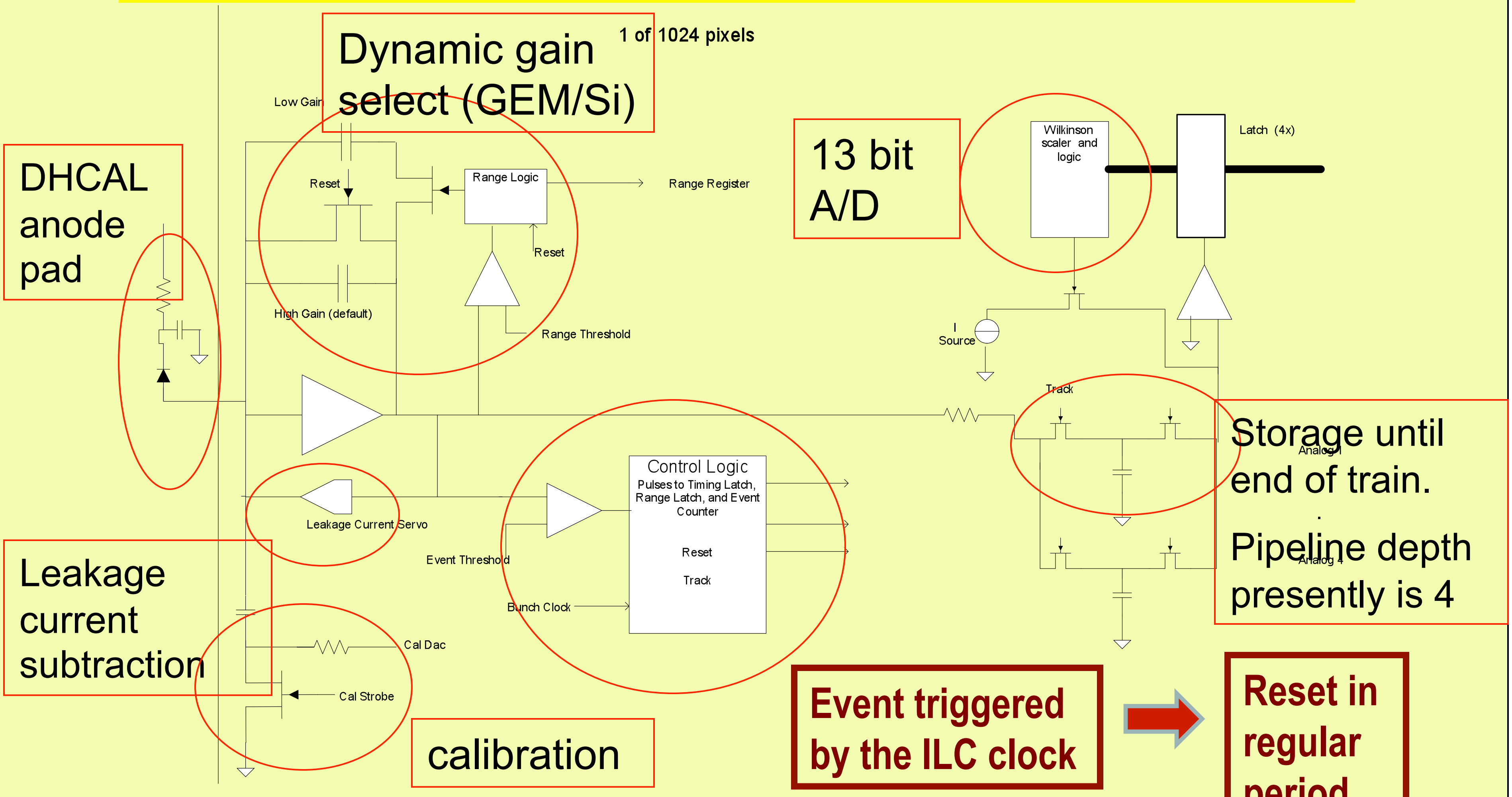



# UTA GEM Chamber Gain



# High Density KPiX Analog Readout for GEM DHCAL



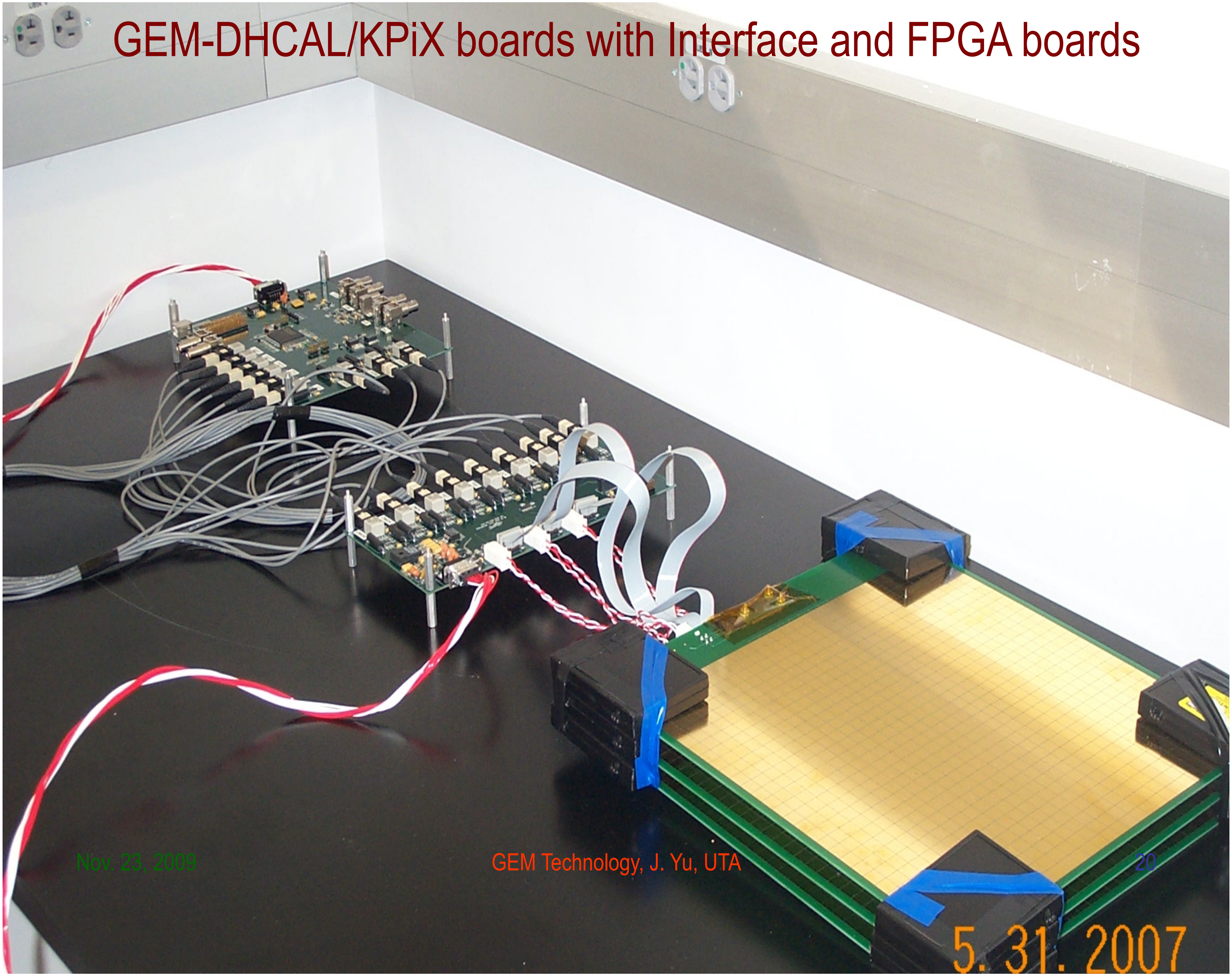

Simplified Timing:

There are ~ 3000 bunches separated by ~300 ns in a train, and trains are separated by ~200 ms.

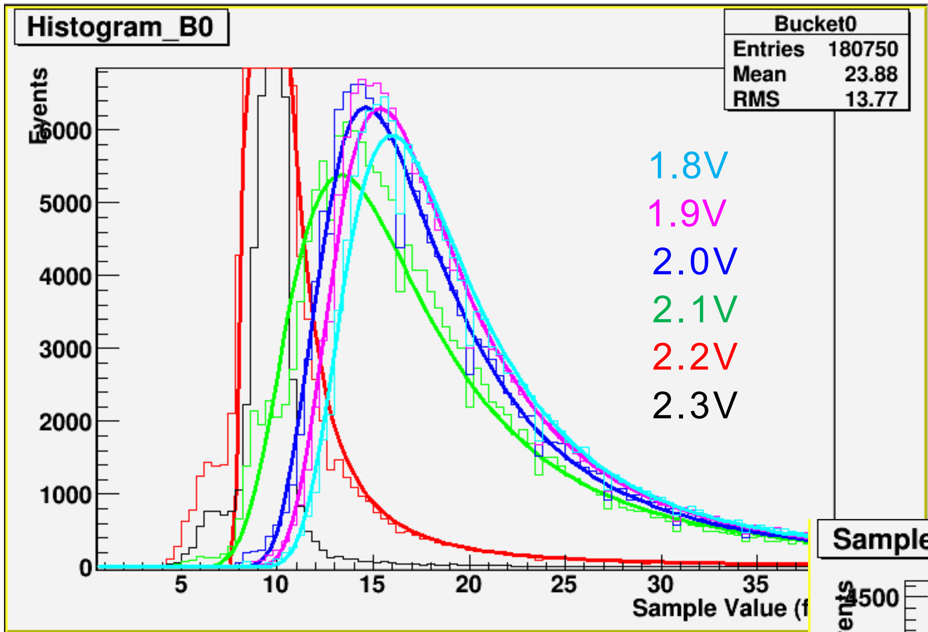
Say a signal above event threshold happens at bunch n and time T0.
The Event discriminator triggers in ~100 ns and removes resets and strobes the Timing Latch (12 bit), range latch (1 bit) ar
The Range discriminator triggers in ~100 ns if the signal exceeds the Range Threshold.
When the glitch from the Range switch has had time to settle, Track connects the sample capacitor to the amplifier output. (
The Track signal opens the switch isolating the sample capacitor at T0 + 1 micro s. At this time, the amplitude of the signa
Reset is asserted (synched to the bunch clock) . Note that the second capacitor is reset at startup and following an event, wh
while processing an event)
The system is ready for another signal in ~1.2 microsec.
After the bunch train, the capacitor charge is measured by a Wilkinson converter.

- 1024 channel 13 bit ADC chip
- Developed for Si/W ECAL@ SLAC

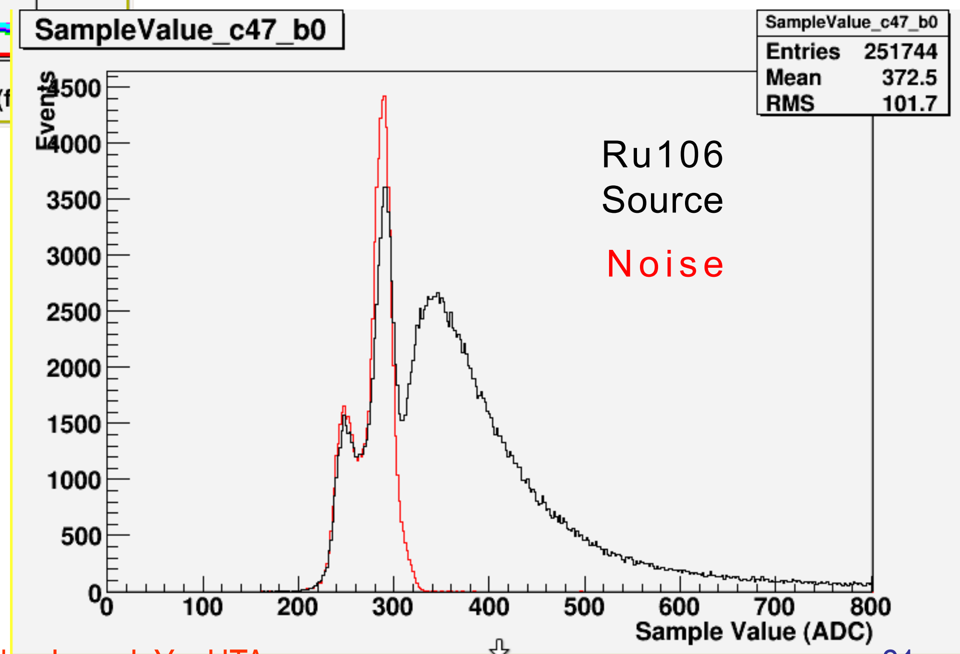
# GEM-DHCAL/KPiX boards with Interface and FPGA boards



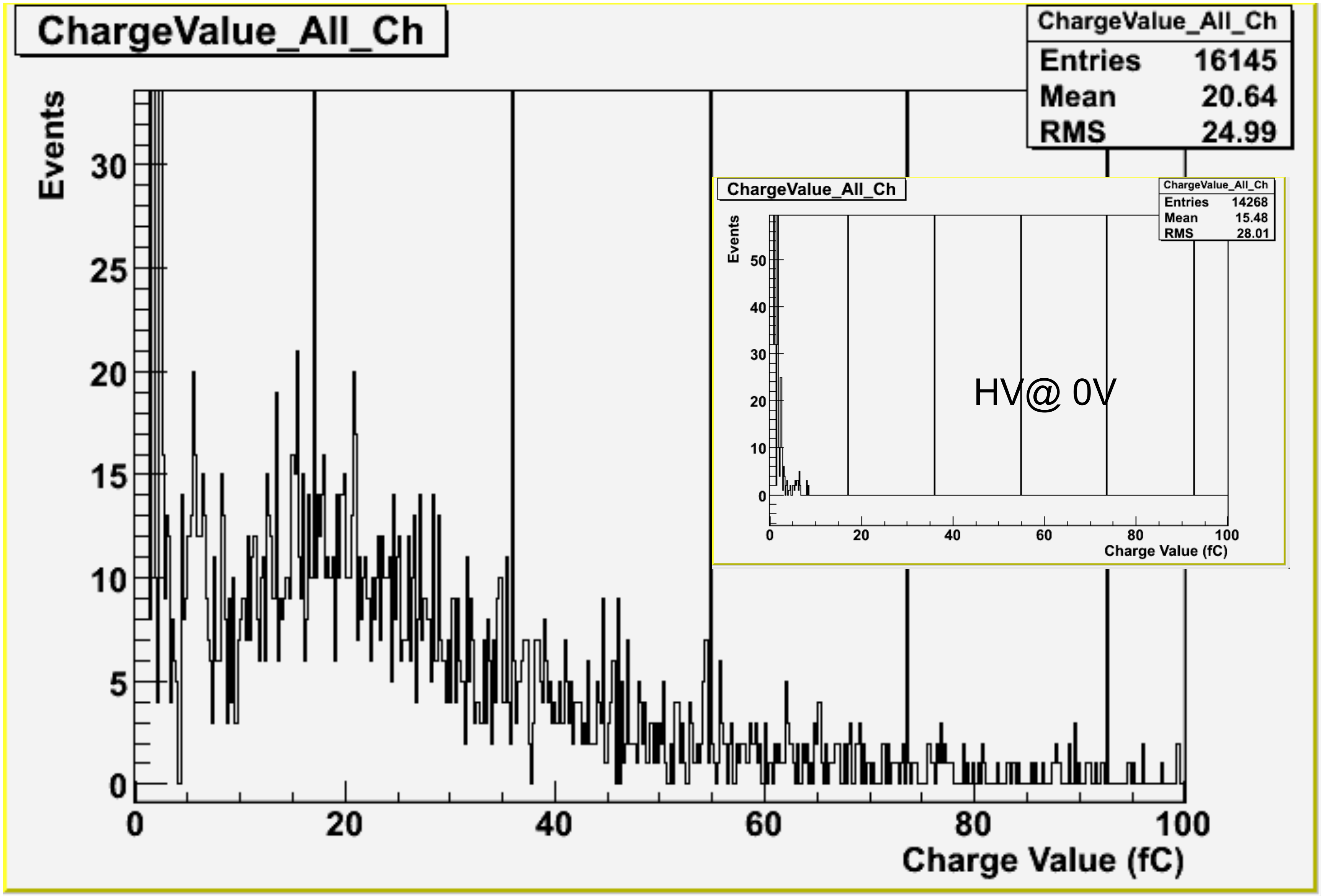
# KPiX Self Trigger Threshold and Noise Scan

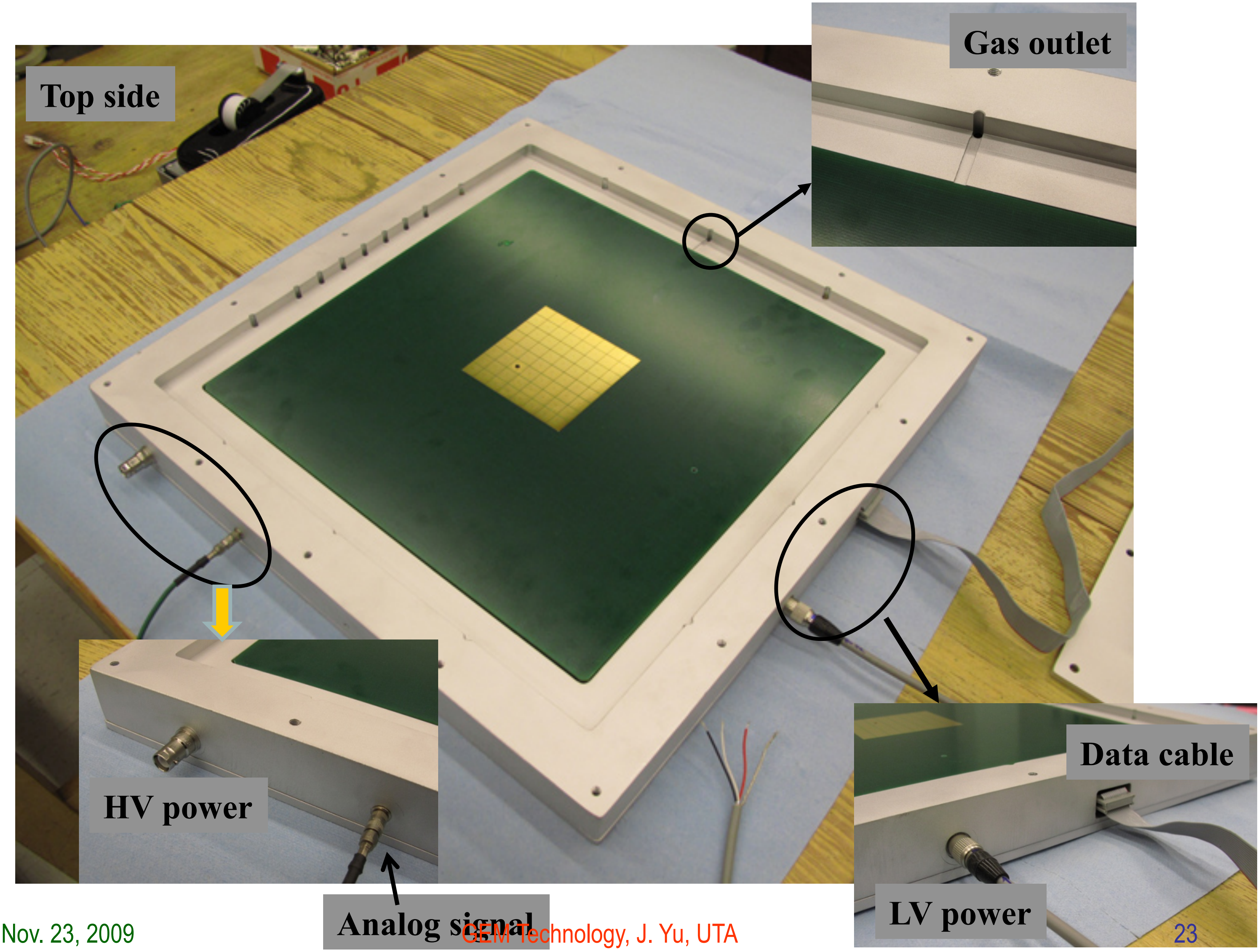



- Threshold at -2.0V most optimal
- Observe clear Landau distribution of β from $Ru^{106}$

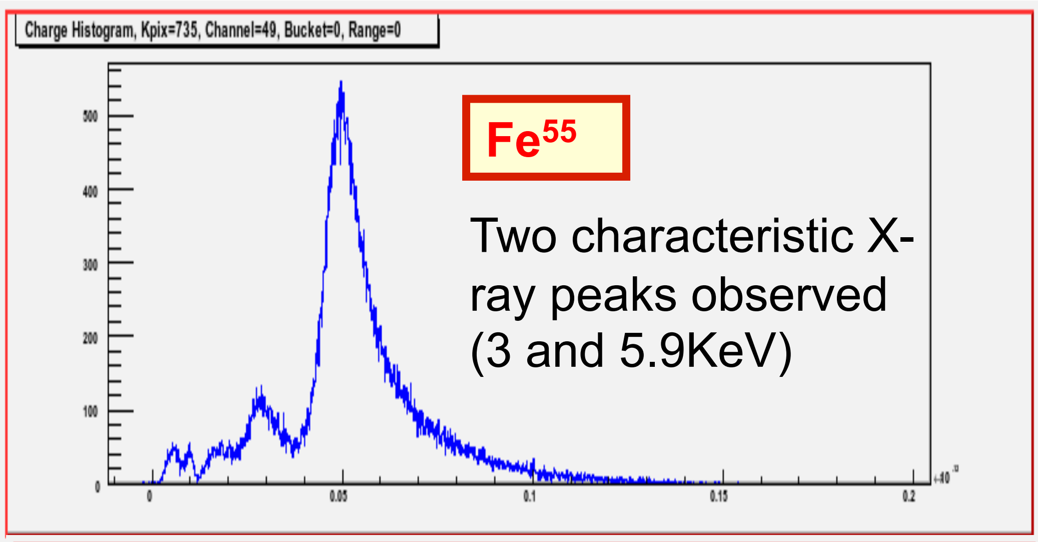


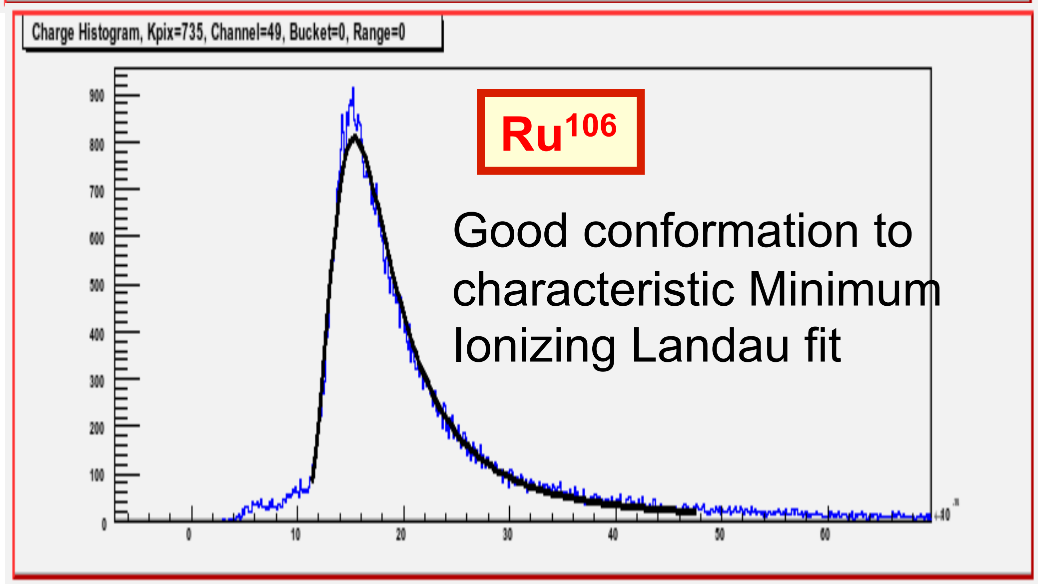
# Cosmic Ray Data with External Trigger

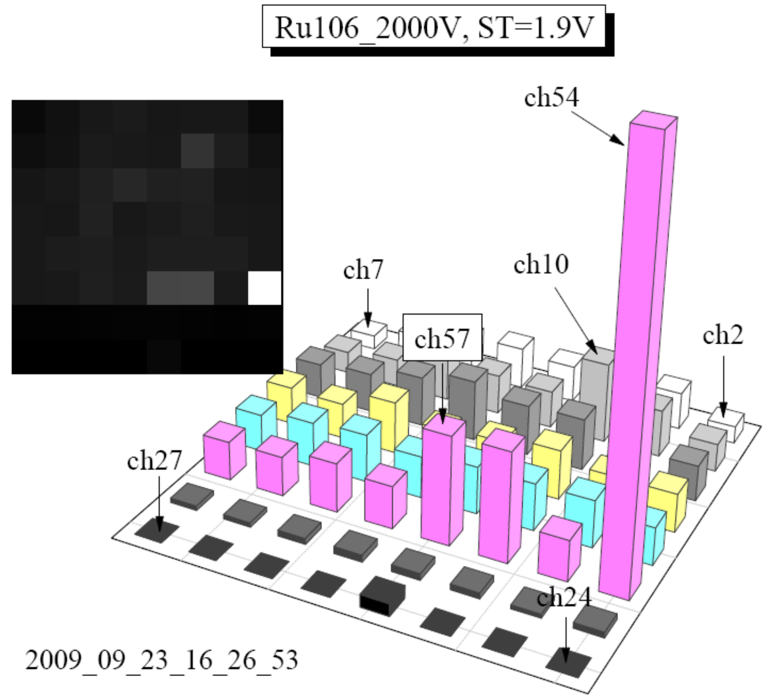


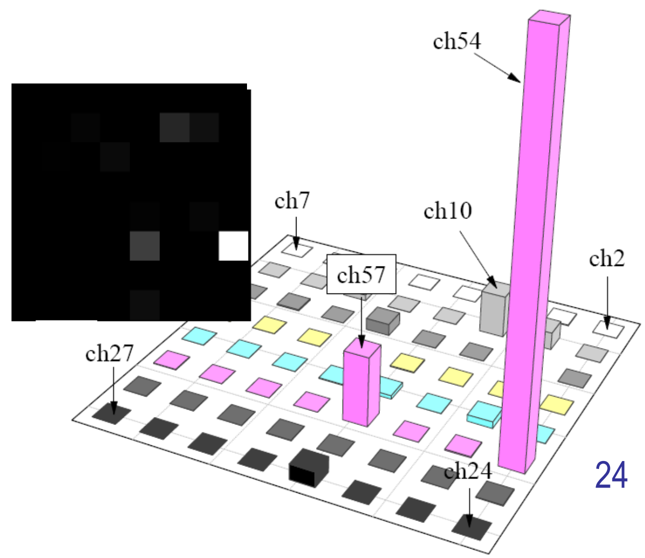

Top side
Gas outlet
HV power
Analog signal
Data cable
LV power

# GEM+kPiX $Fe^{55}$ and $Ru^{106}$ Spectra

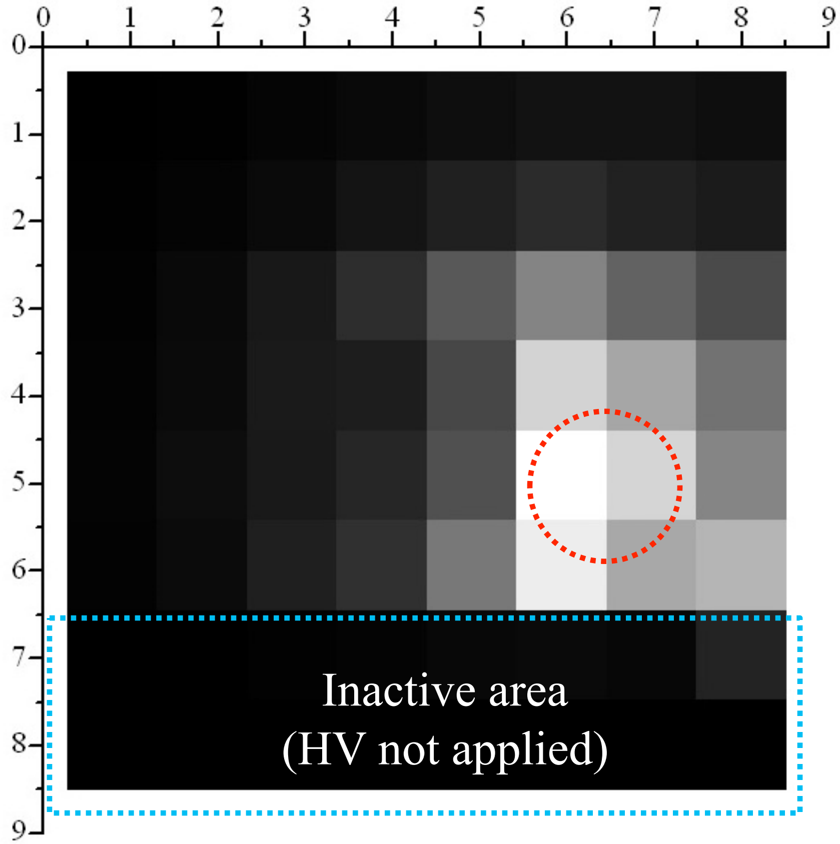


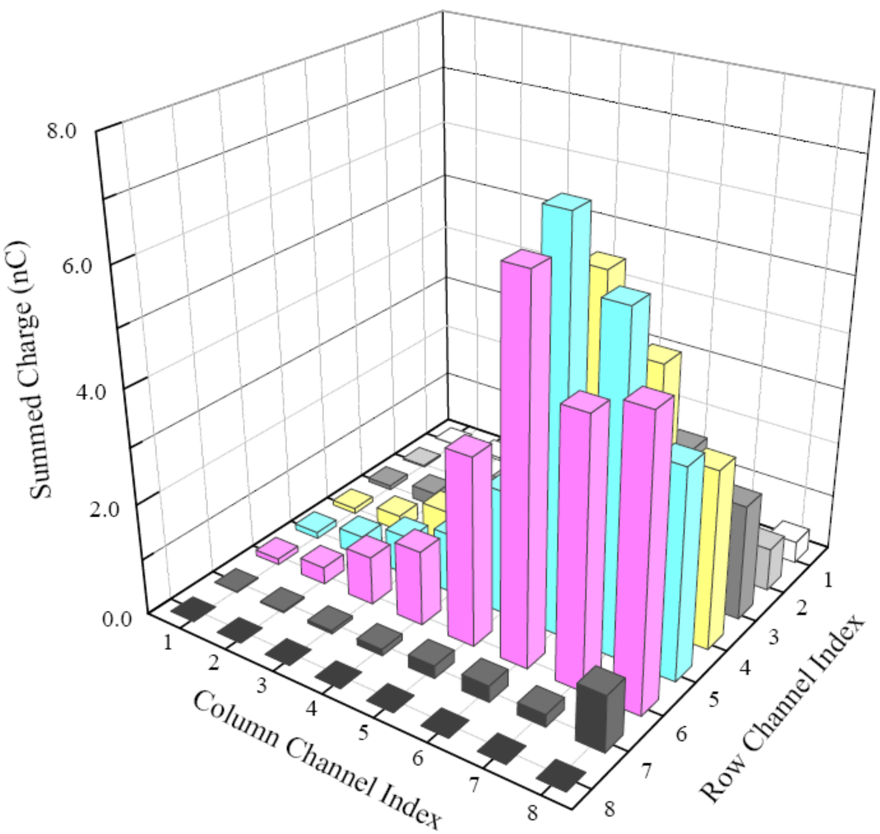



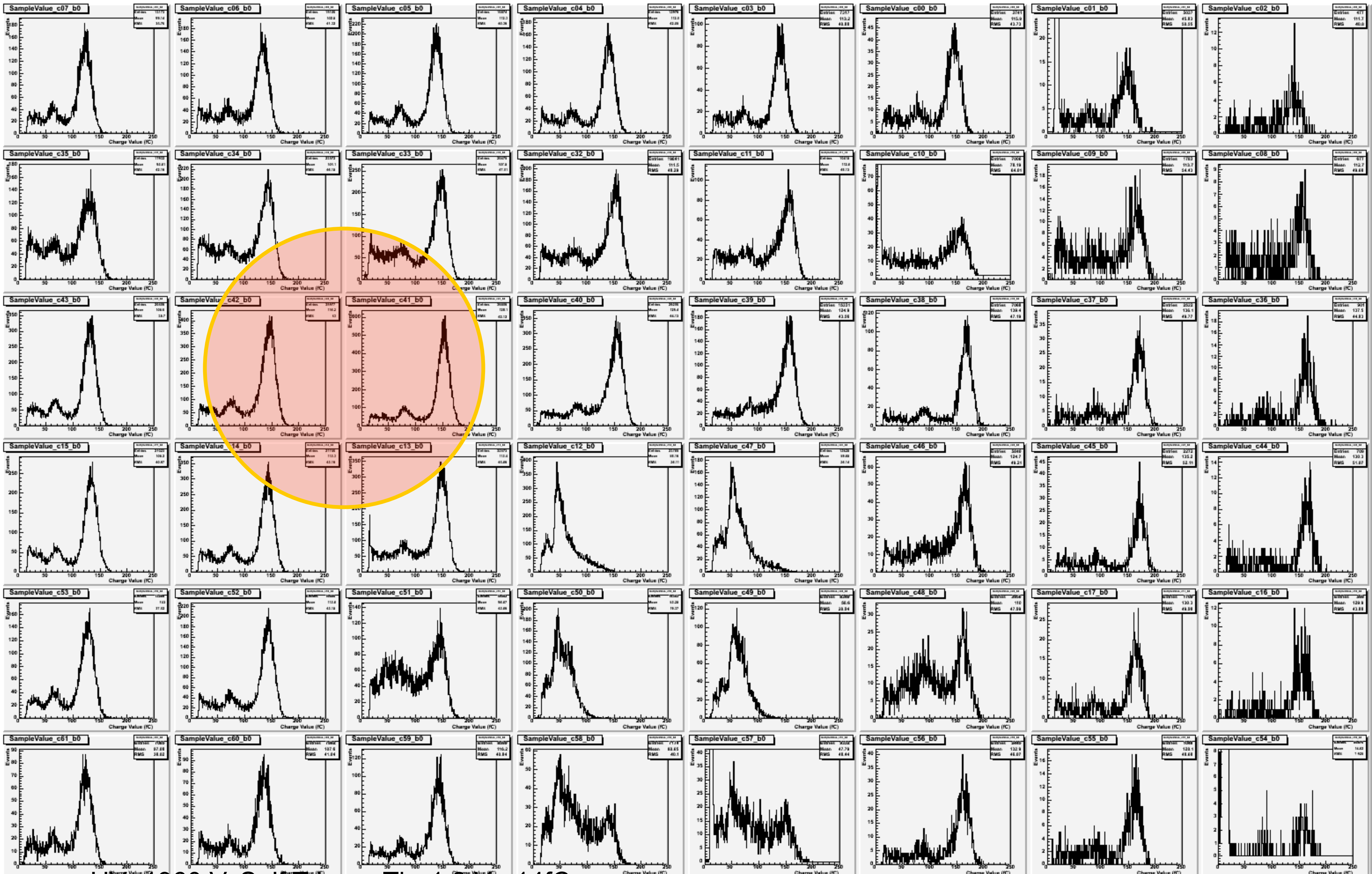
# Charge Weighted Lego for Fe55




HV=1960 V, Self Trigger Th=1.8 V= 14fC

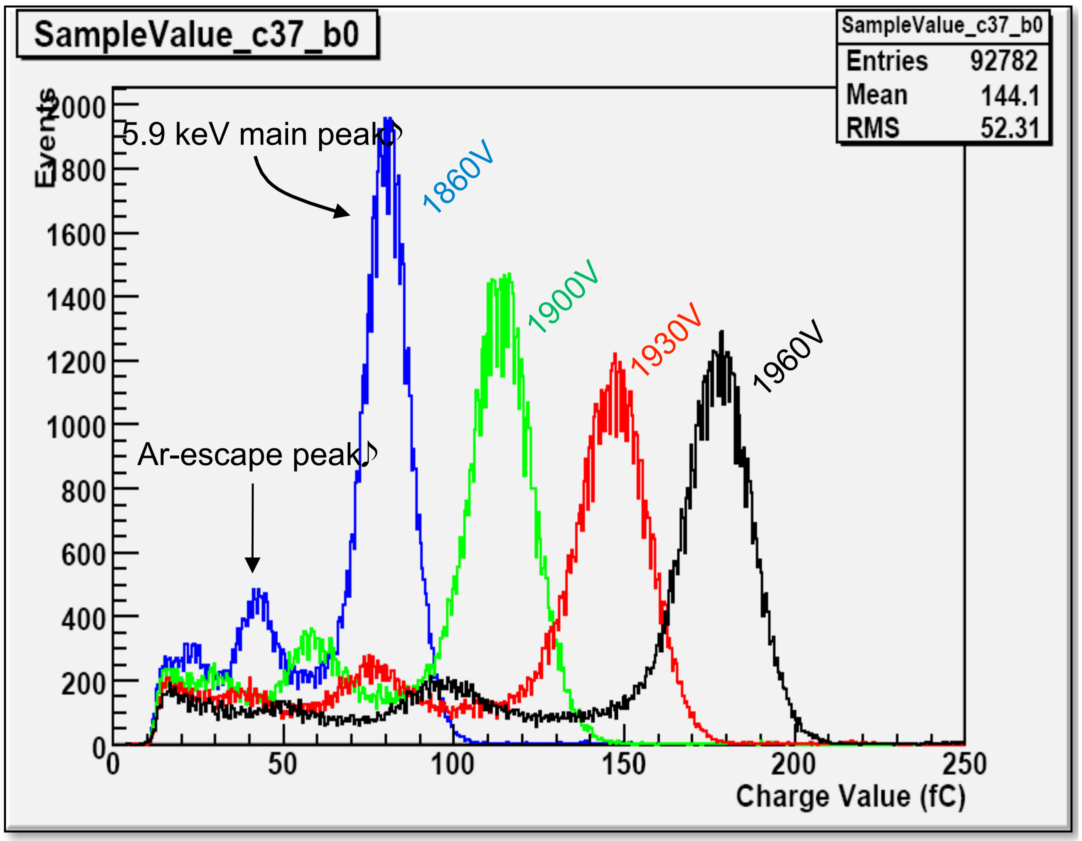
# Histogram Map for Fe55

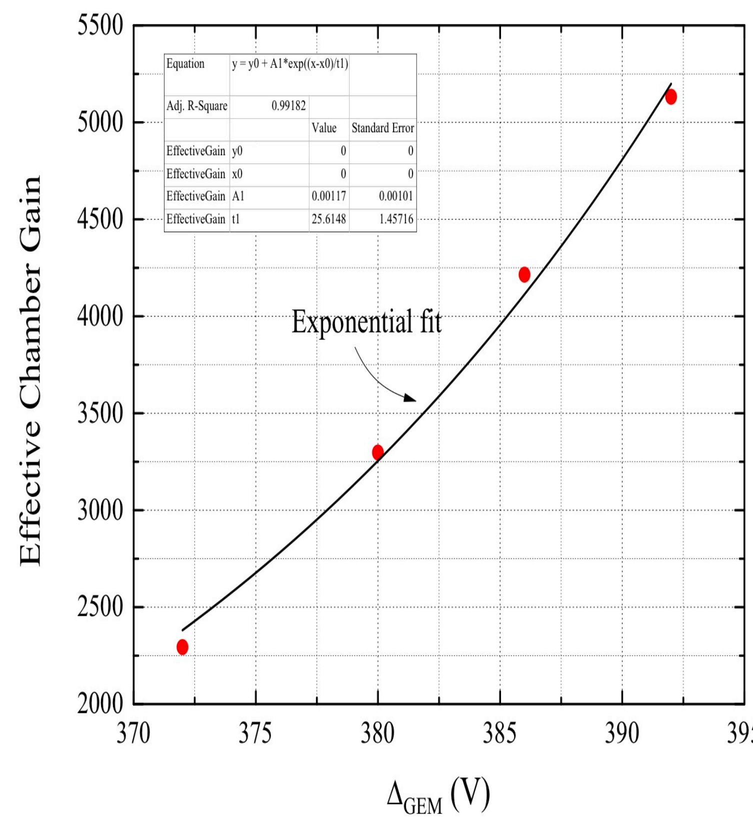



HV=1960 V, Self Trigger Th=1.8 V= 14fC

# $^{55}$Fe Spectrum vs HV and Chamber Gain

**Fe55**, Self Trigger Th=2.1V=8 fC



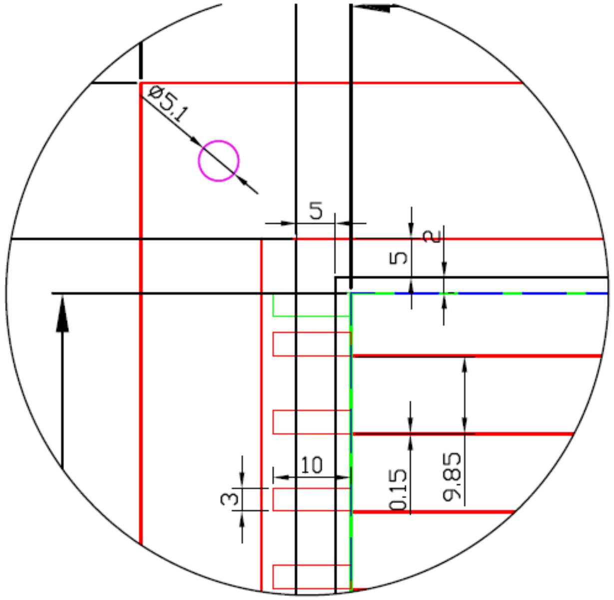




- ✓ Fe55: Observed both 5.9 keV main peak, 3 keV Ar-escape peak
- ✓ Effective gain consistent with previous results

# Large GEM Foil Development with CERN

- The size of the foils are 33cmx100cm, the same as the physical size of the unit chamber
  - Active area is 33cmx100cm
  - Is this realistic to think of constructing a chamber with the same physical size foils?
- Foils will be delivered in eight weeks or so once the design is completed and once the hole etching technique is verified
  - One-side hole etching technique development completed

# UTA Large GEM Foil Design




Active area 468x306x2 mm$^2$♪

♪

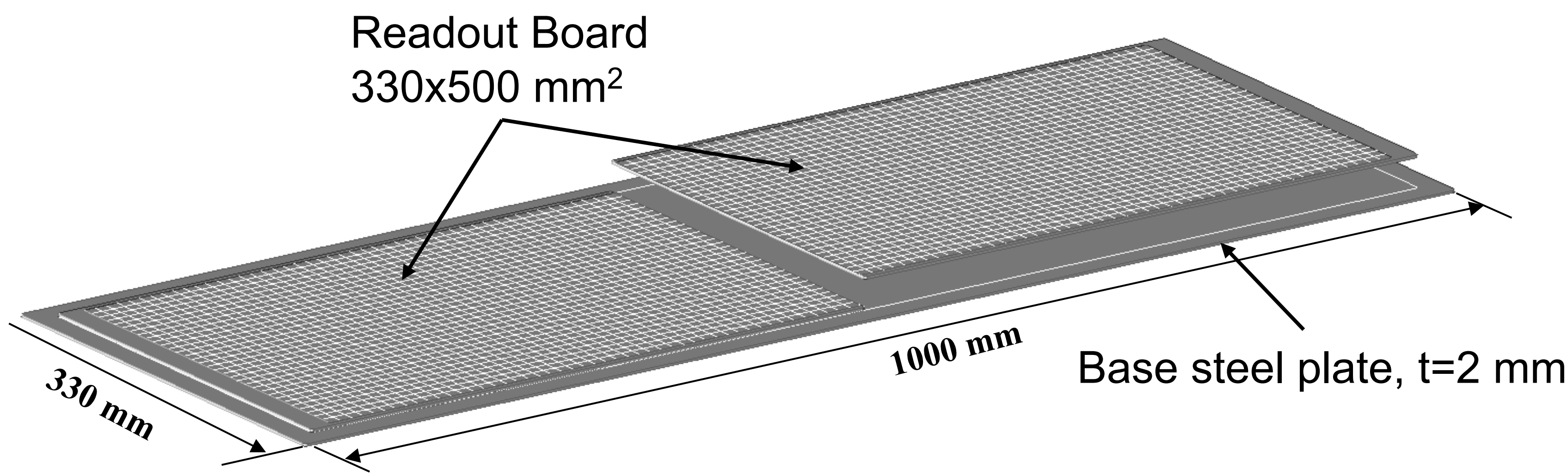
Number of HV sectors = 32x2=64♪

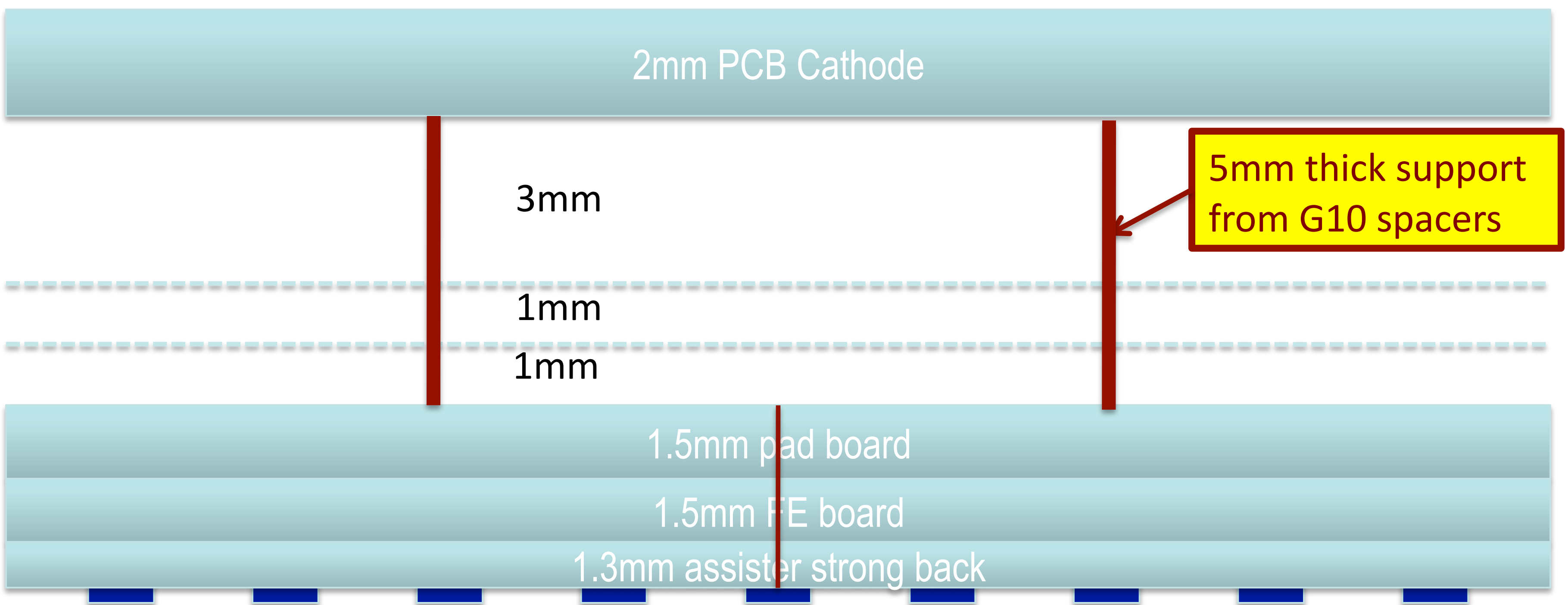
♪

HV sector dimension= 9.9x479.95 mm$^2$♪

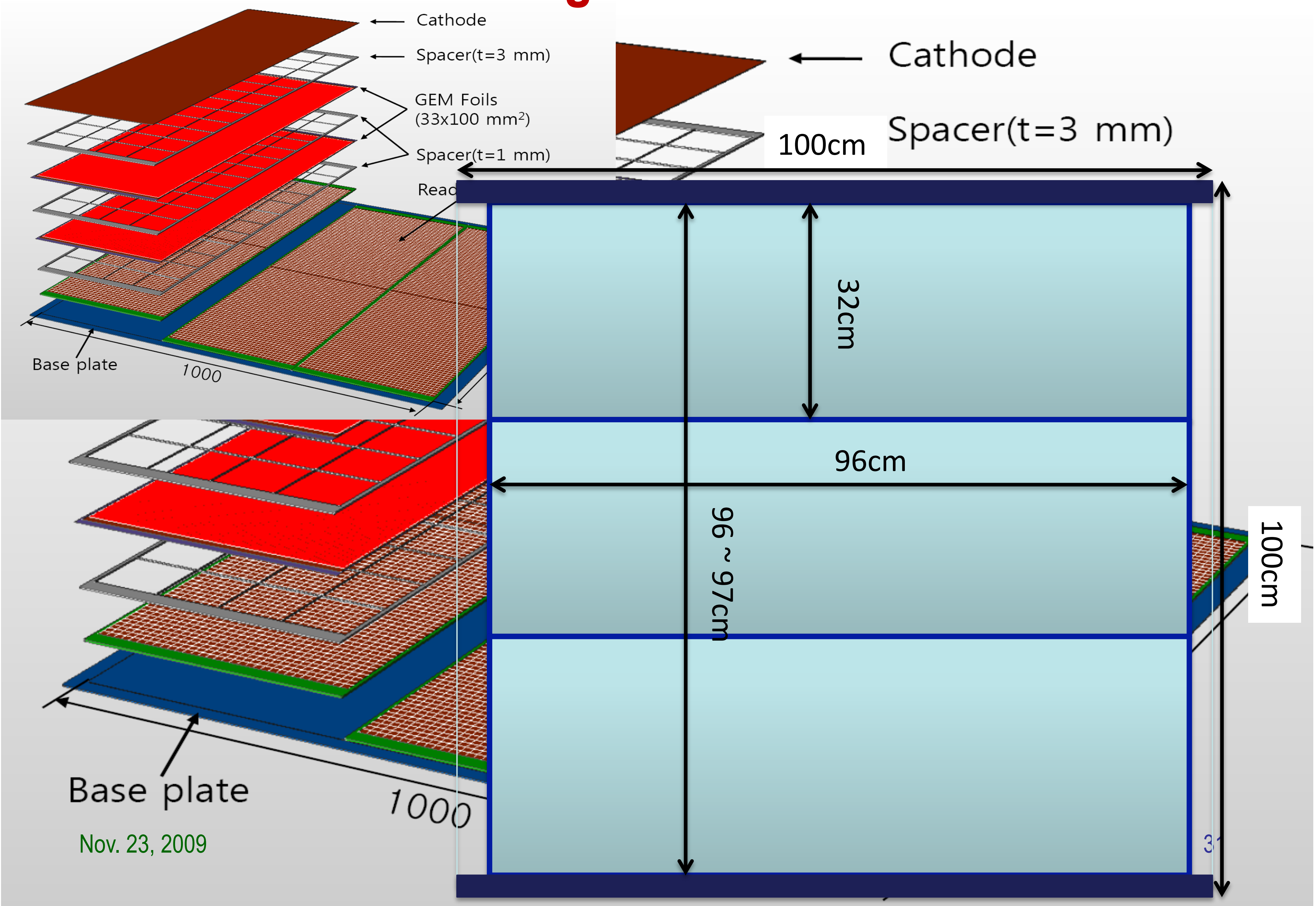
♪

# 33cmx100cm DHCAL Unit Chamber



# UTA's 100cmx100cm Digital Hadron Calorimeter Plane

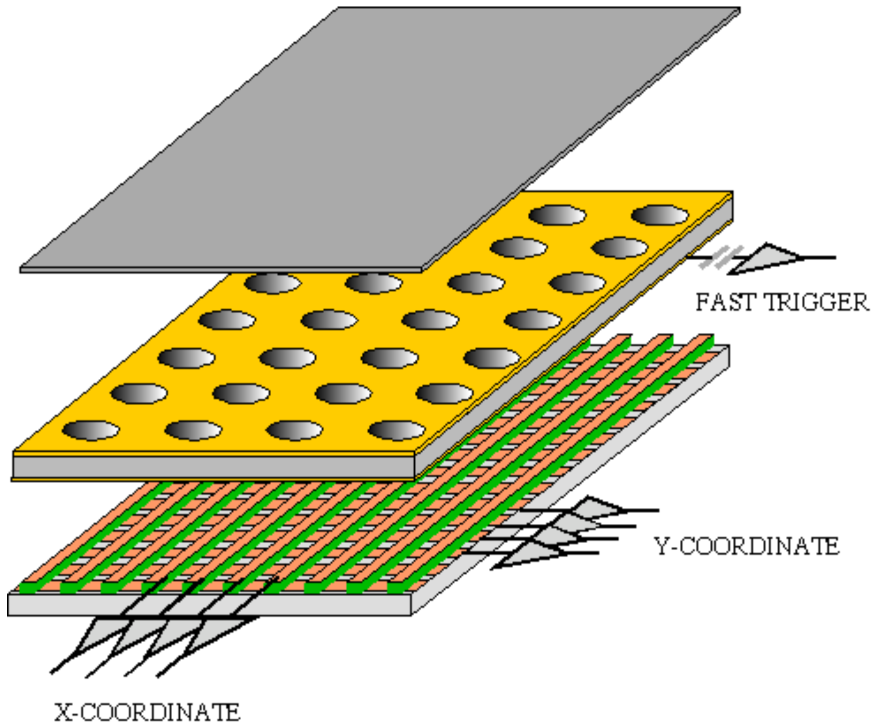


# GEM DHCAL Beam Test Plans

- Phase I → Completion of 30cmx30cm characterization
  - Late 2009 – Early 2010: using one plane of 30cmx30cm double GEM chamber with 64 channel KPiX7
- Phase II → 33cmx100cm unit chamber characterization
  - Early 2010 – Late 2010 at MTBF, using 256 channel v8 KPiX chips
  - Possible beam test and characterization of TGEM prototype using 256 channel v8 KPiX chips
- Phase III → 100cmx100cm plane GEM DHCAL performances in the CALICE stack
  - Late 2010 – Mid 2011 at Fermilab's MTBF
  - Five 100cmx100cm planes inserted into existing CALICE calorimeter stack and run with either Si/W or Sci/W ECALs and RPC planes in the remaining HCAL

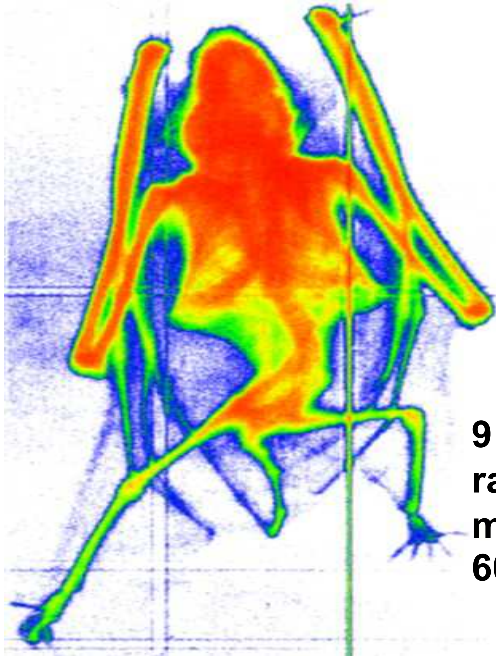
# GEM Application Potential

**Using the lower GEM signal, the readout can be self-triggered with energy discrimination:**



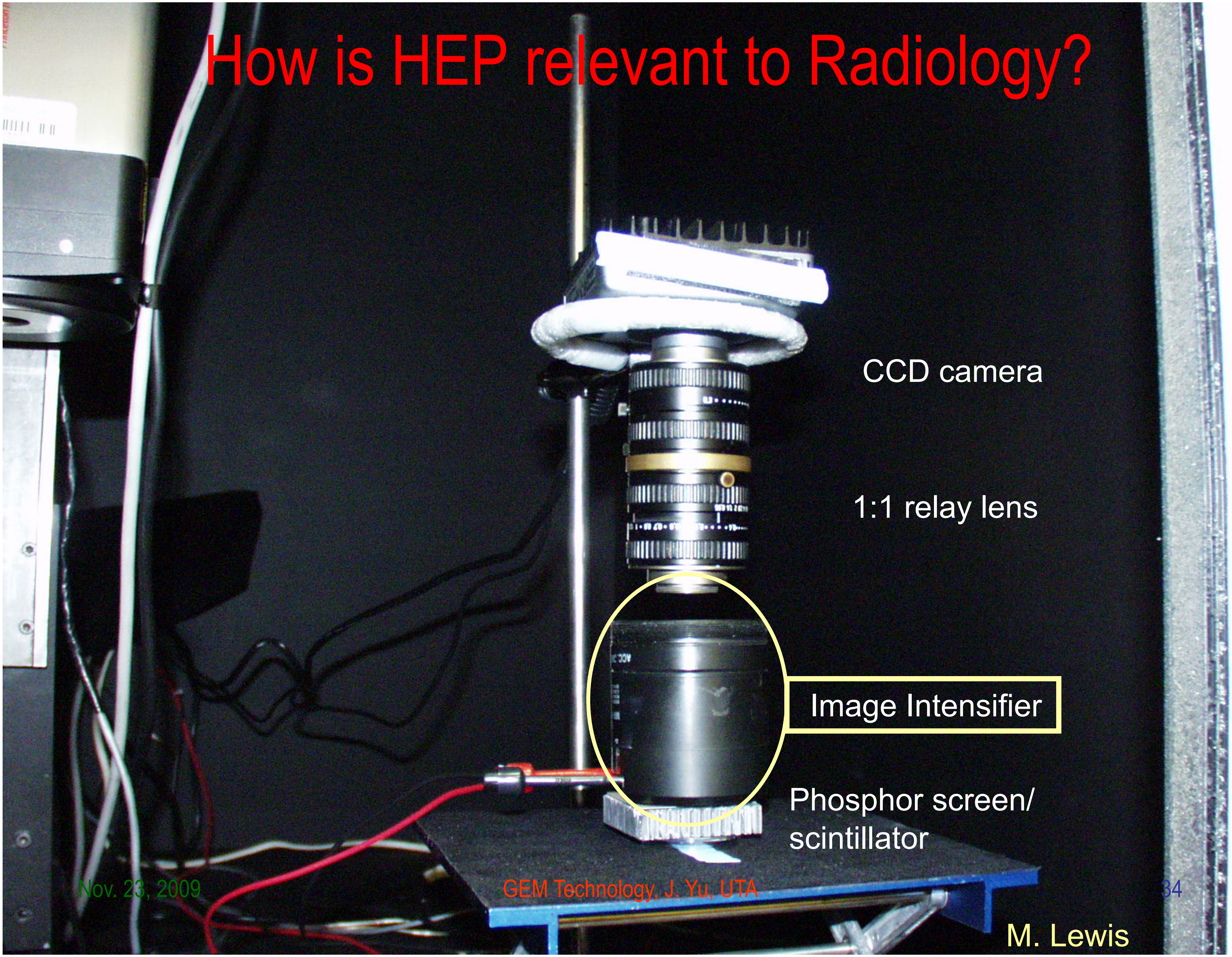

***A. Bressan et al,***
***Nucl. Instr. and Meth. A 425(1999)254***
***F. Sauli, Nucl. Instr. and Meth.A 461(2001)47***

## *FAST X-RAY IMAGING*



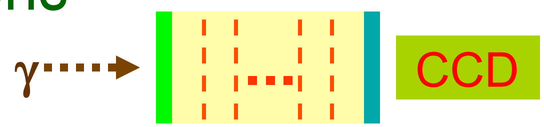
**9 keV absorption radiography of a small mammal (image size ~ 60 x 30 mm²)**

# How is HEP relevant to Radiology?



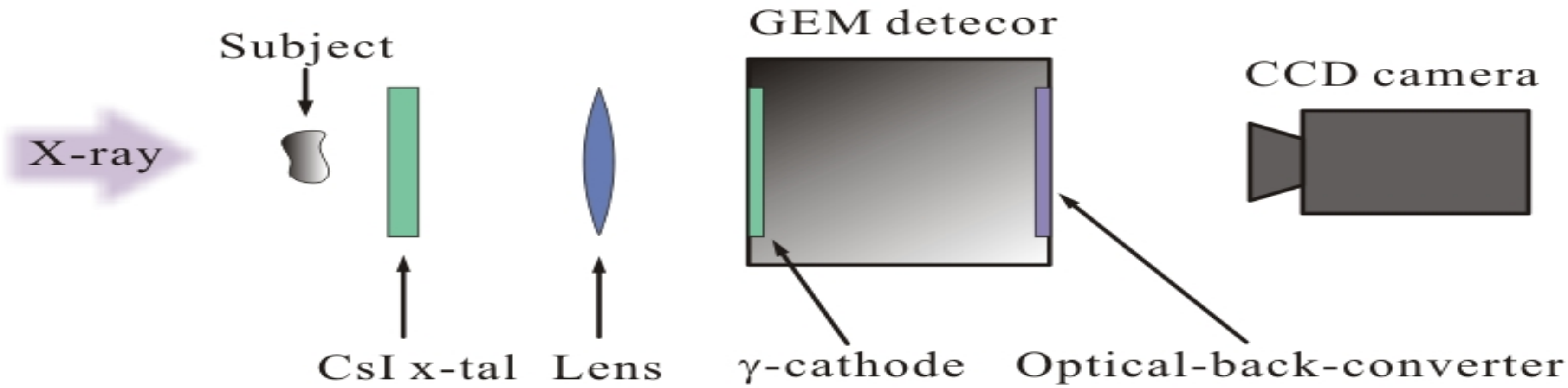
# GIA, GEM-based Image Amplifier

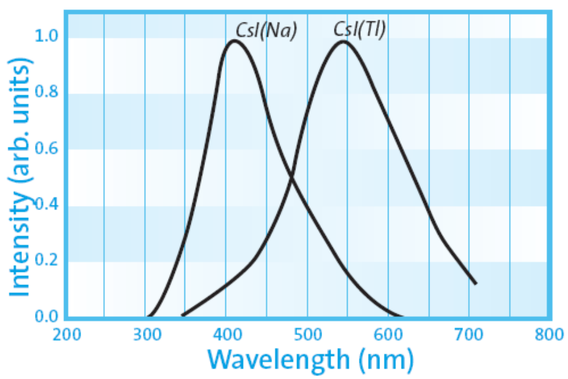
- Improve the resolution of small animal radiation imaging using **G**EM based **I**mage intensity **A**mplifier
  - Replace small aperture microchannel-based image intensifier with a GEM-based detector, increasing field of view
  - →Convert γ-rays into electrons (photo converter)
  - →Amplify the electron signal by as large as needed w/ GEM
  - →Convert electron avalanche back to photons
  - →Feed this to CCD camera

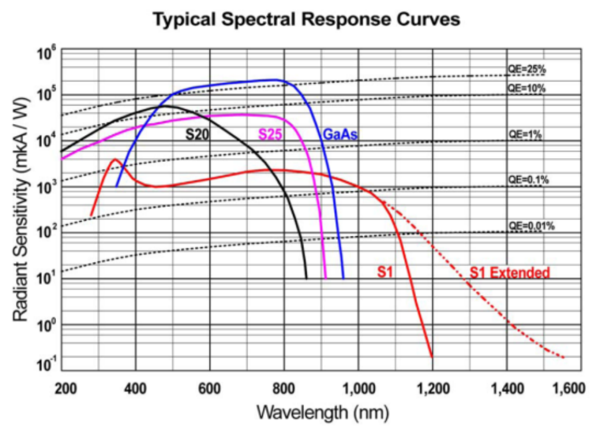


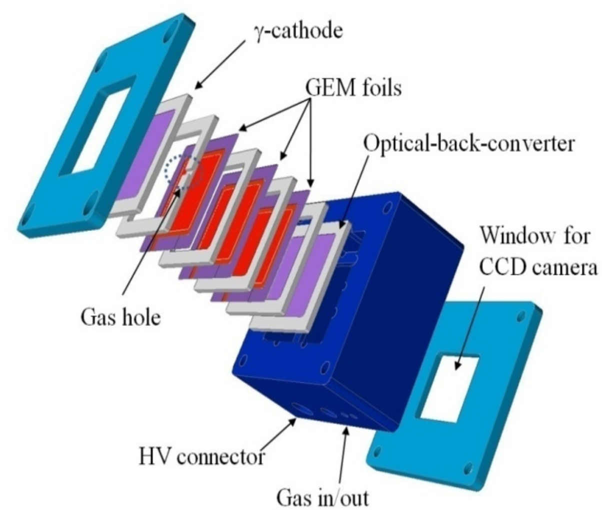

- Move into embedded digital readout of signal using custom DAQ ➔ computerized image

# GIA Chamber Design



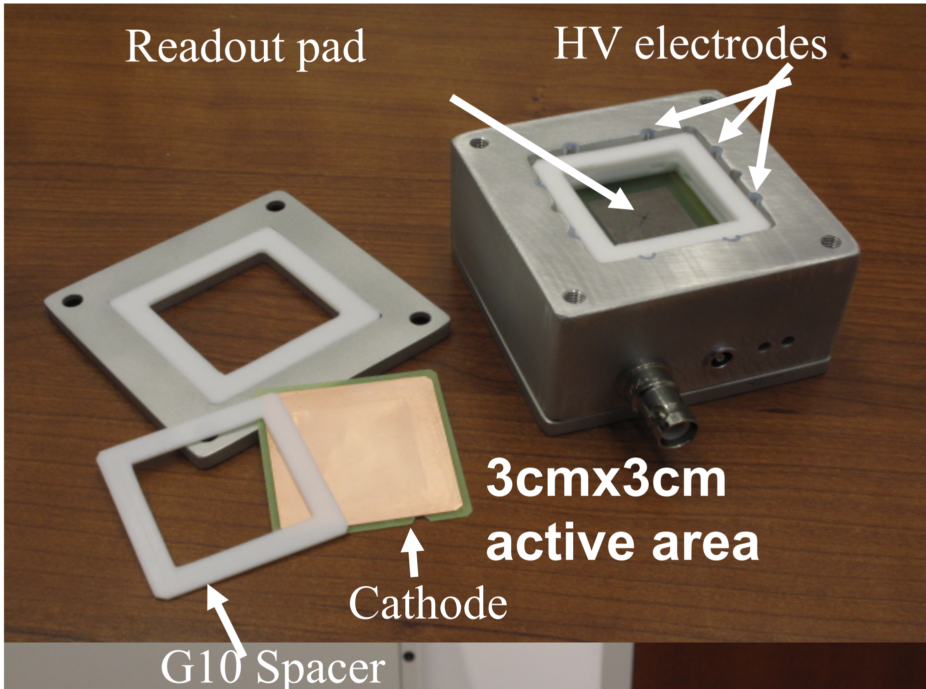



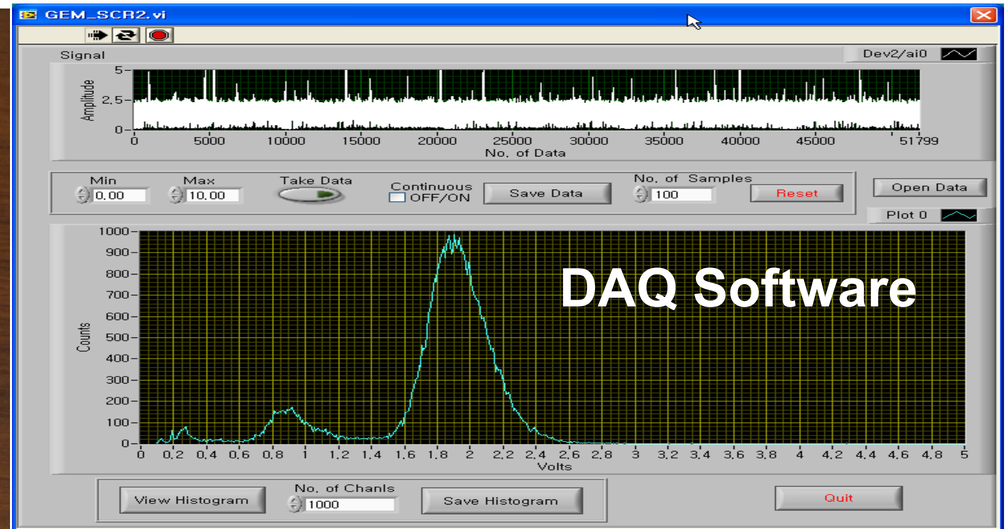



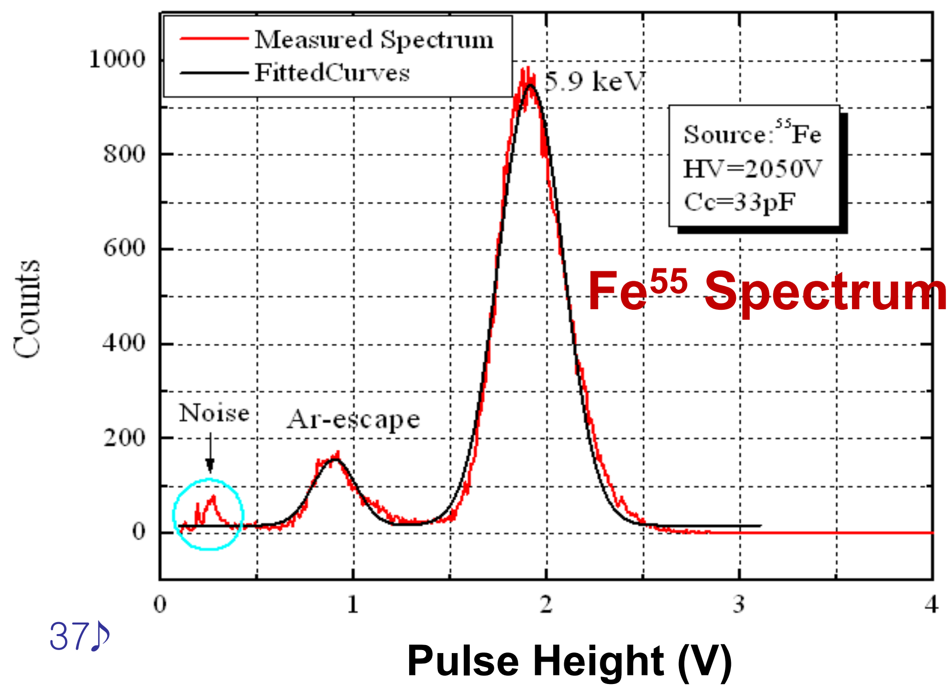

Scintillator:CsI
S-20 photo-converter
Optical-back-converter: BaFBr:$Eu^{2+}$

# GIA Prototype Chamber







# Conclusions

- High Energy Physics uses particle accelerators and precision detectors to unveil the secret of the universe
- Gas Electron Multiplier technology has a remarkable potential to be used in high precision calorimetry
  - And to be used in other types of radiation detectors
    - Medical imaging, homeland security, etc
  - GEM-KPiX readout giving good X-ray and MiP spectra
  - 1mx33cm long foil development with CERN for 1mx1m unit chambers ➔ Large area radiation detector
- Outcome and the bi-product of HEP research impacts our daily lives
  - WWW came from HEP
- GIA chamber construction and initial test complete
- Ultimately we want to understand the rules of the universe to make our lives better