Digital Hadron Calorimetry using Gas Electron Multipliers

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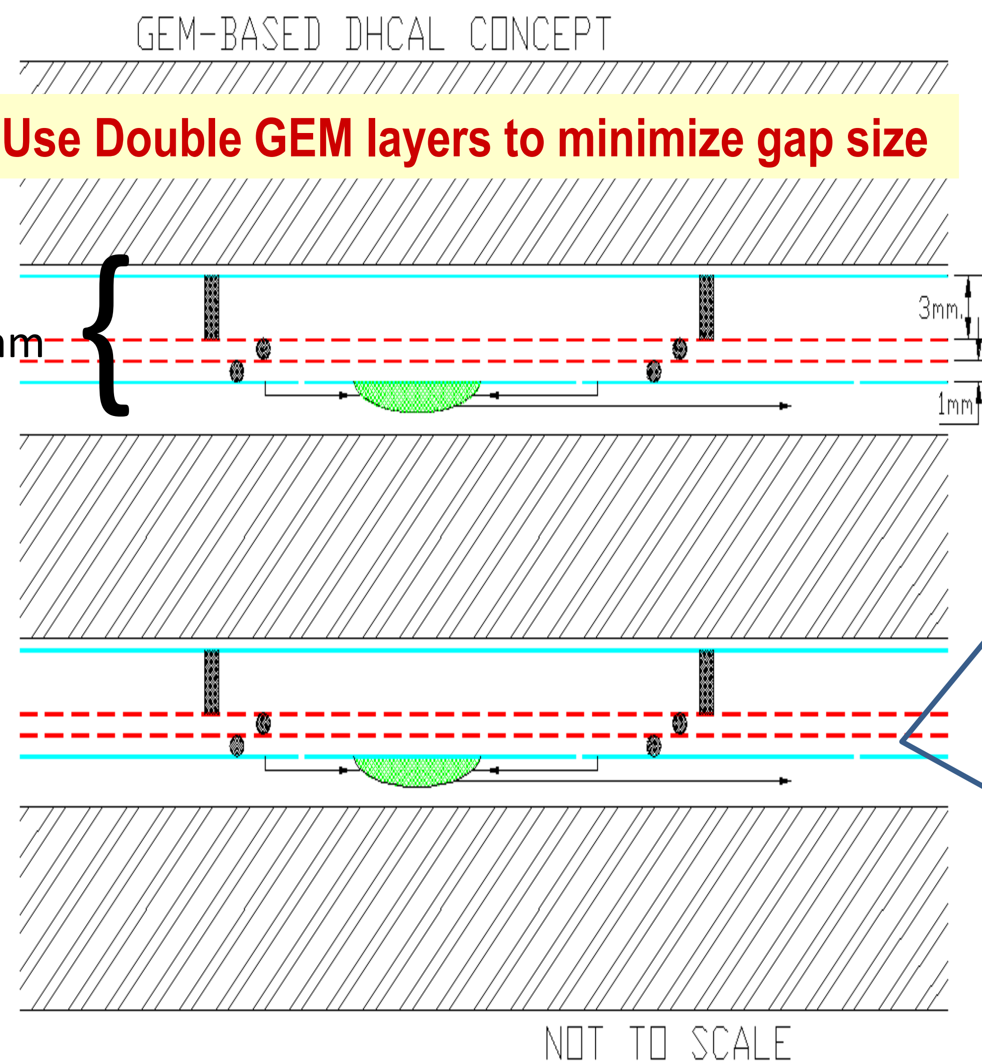
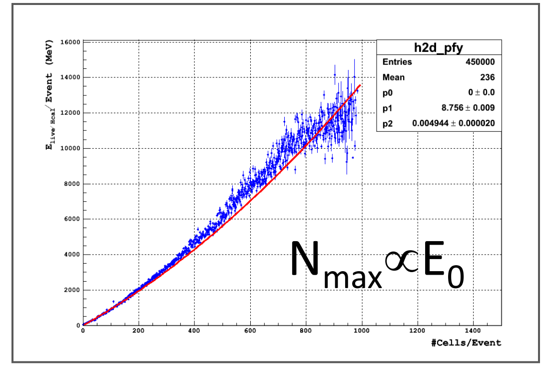
Overview

- GEM/DHCAL basics
- Review of GEM/DHCAL developments
- Results to date
- Plans

- ThickGEM/DHCAL
- THGEM structures
- Recent results/CERN test beam

GEM-based Digital Calorimeter Concept





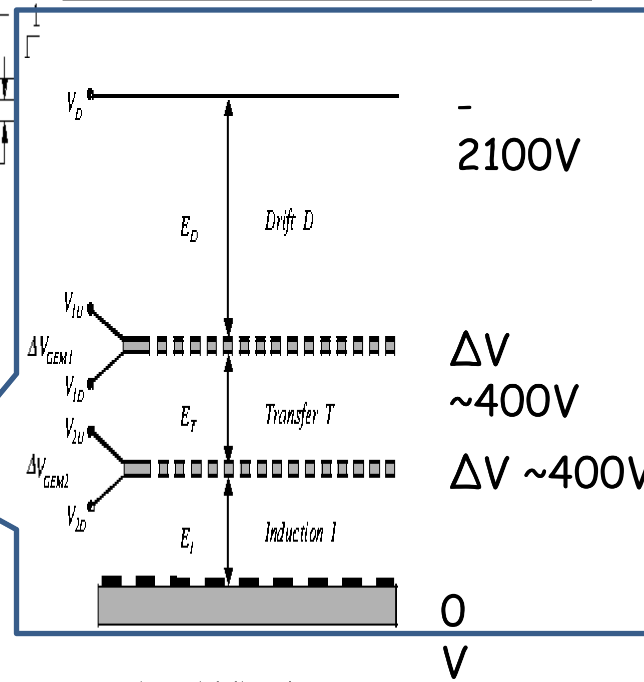


Fig. 1: Schematics of a double-GEM detector.

30x30 prototype GEM chamber and Readout Electronics

Chamber

- GEM Foils(3M)

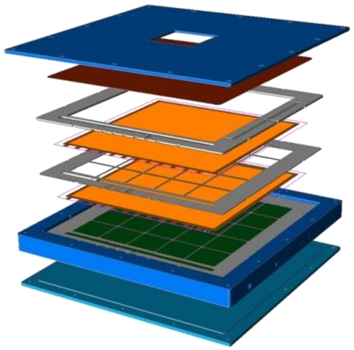
  310x310 mm^2

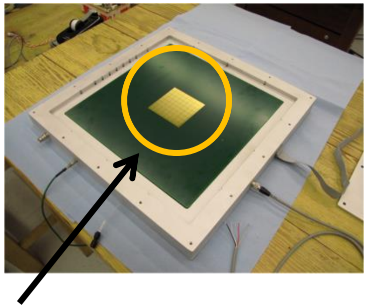
  Active area : 280x280 mm^2

- Active gas volume

  350x350x6 mm^3 → For 3/1/1 gaps

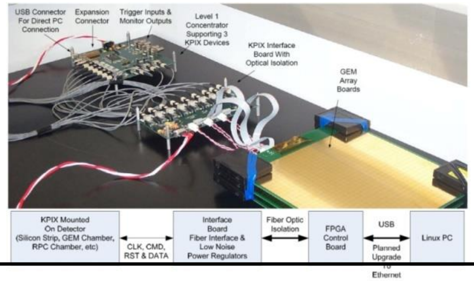
- Readout channels: KPIX(64), DCAL(256)



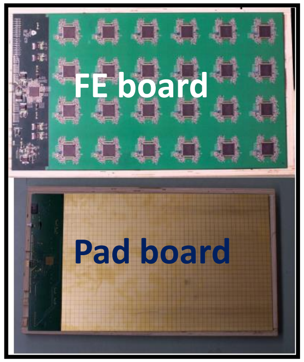


64-readout pads(KPIX)

KPiX readout system/SLAC
- ✓ 13 bit resolution(ADC)
- ✓ Handles 1024 channels/chip,
- ✓ 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)

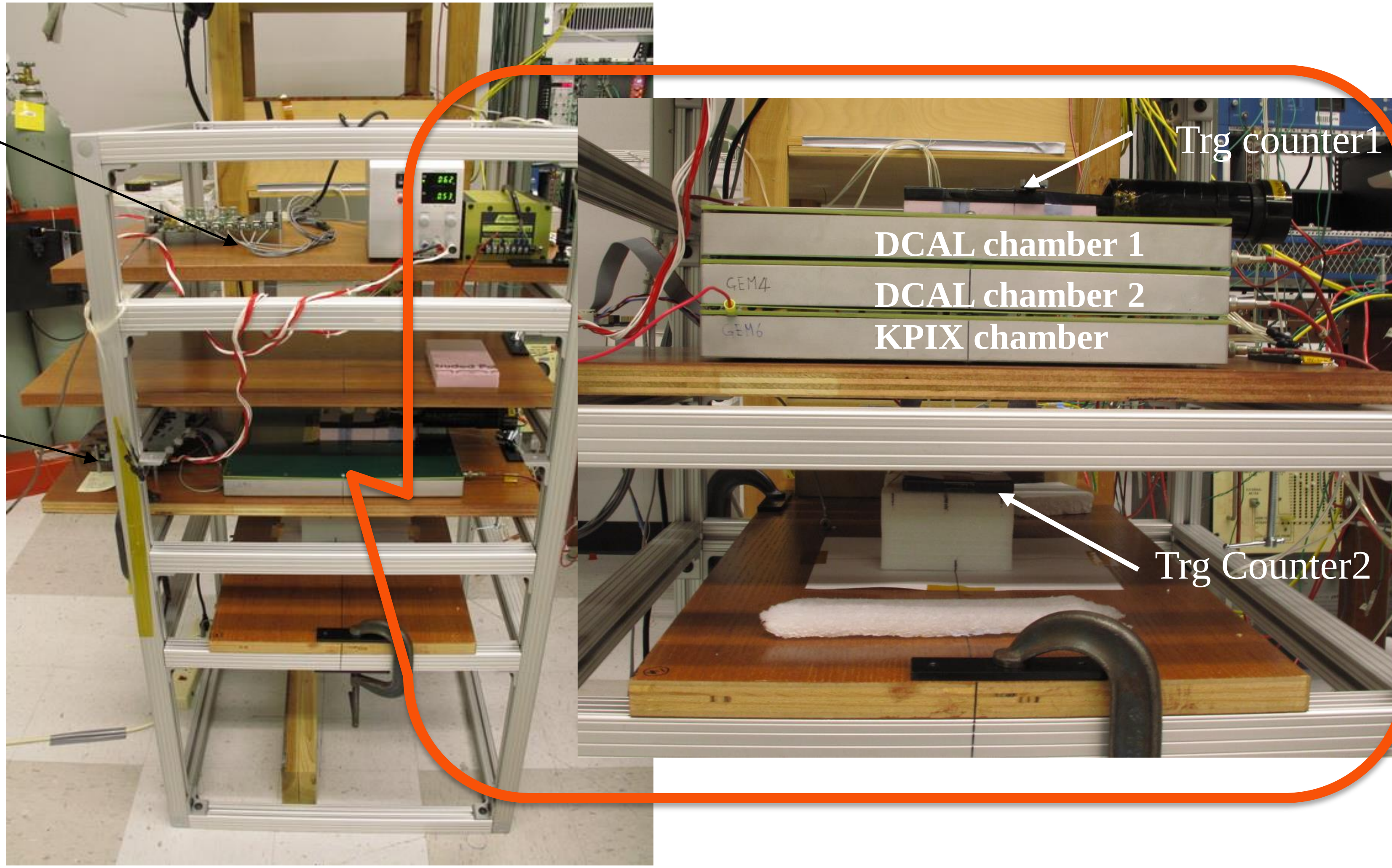


Readout systems

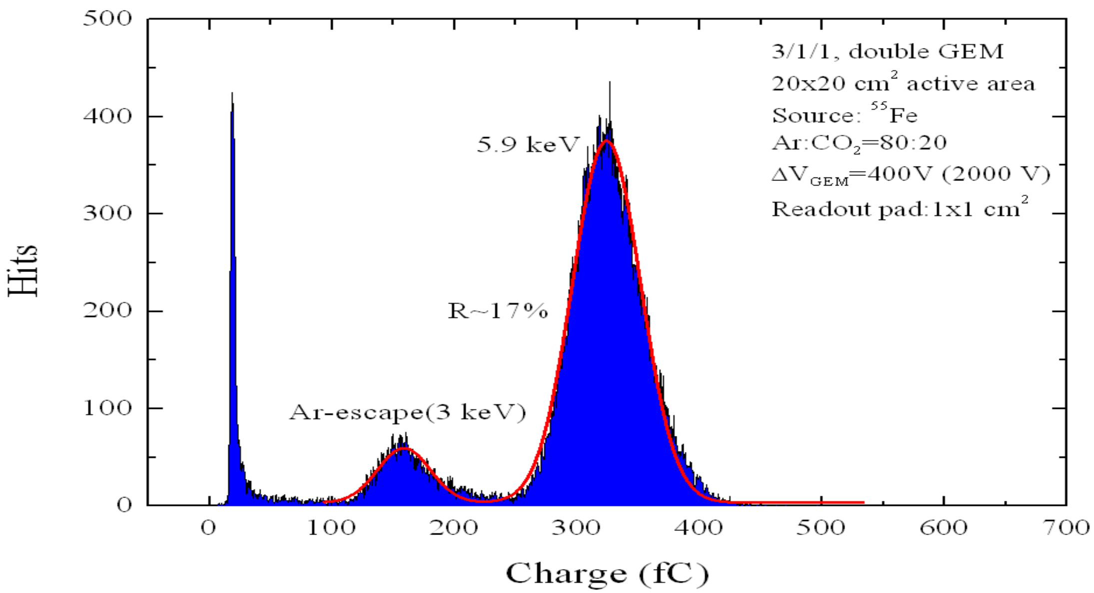
UTA GEM-DHCAL Cosmic Test Stand

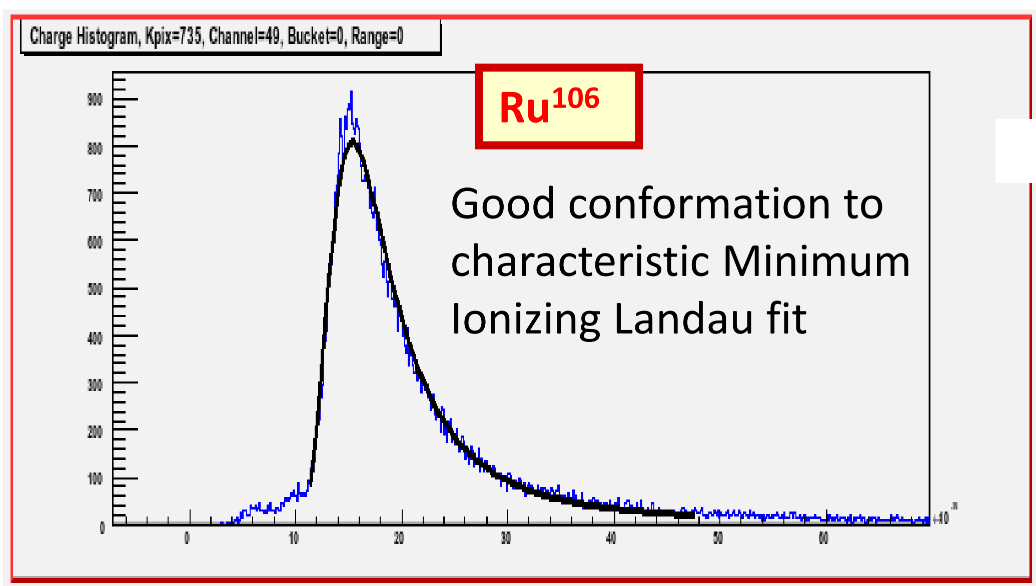
KPiX
FPGA
board

KPiX
Interface
board

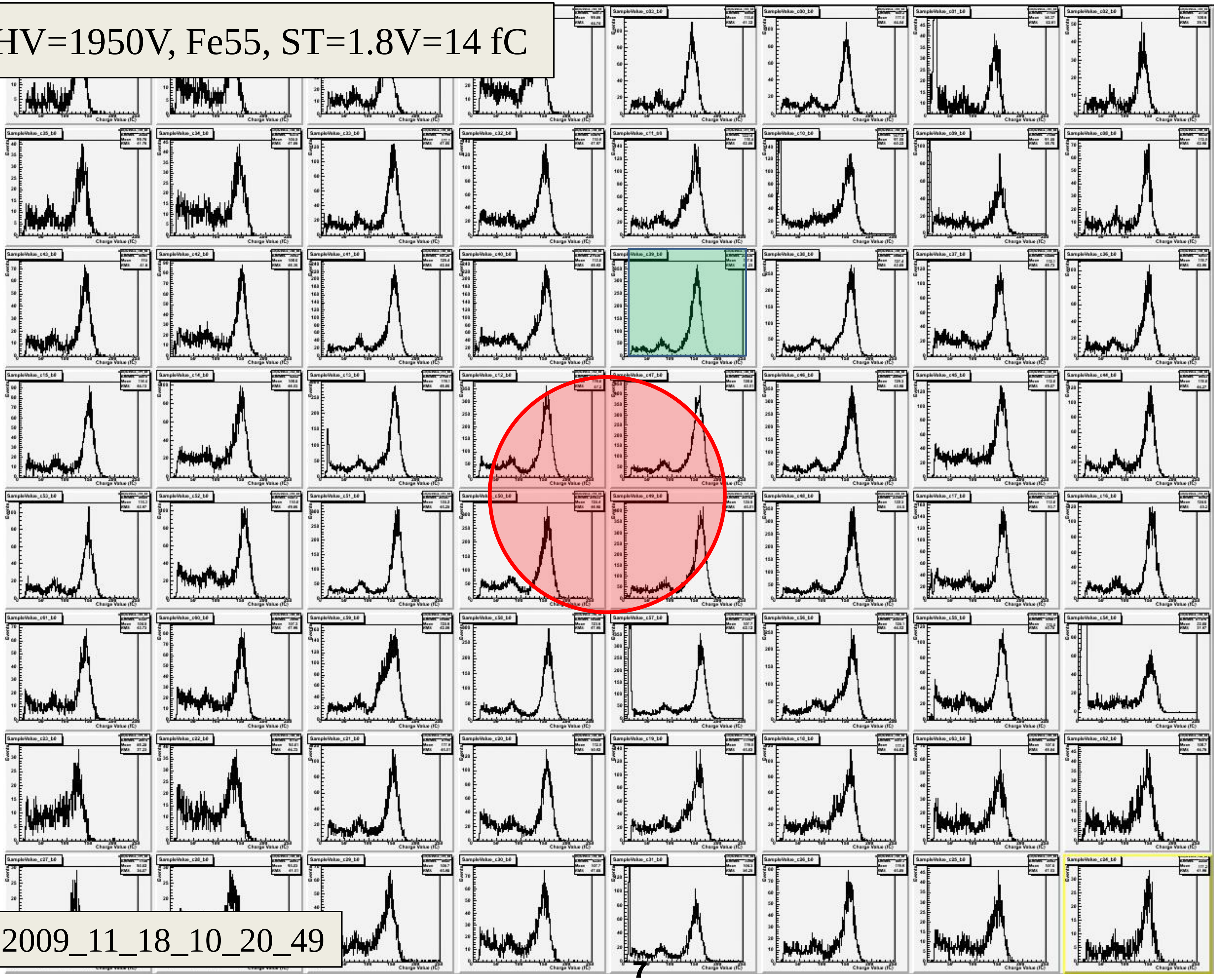


GEM+KPiX7 Fe^{55} and Ru^{106} Spectra





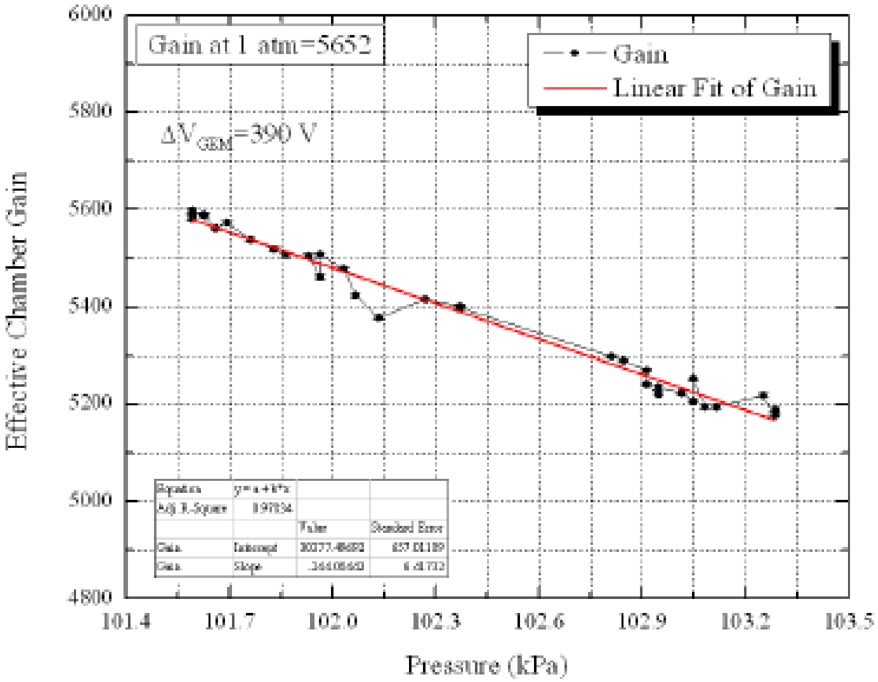
HV=1950V, Fe55, ST=1.8V=14 fC

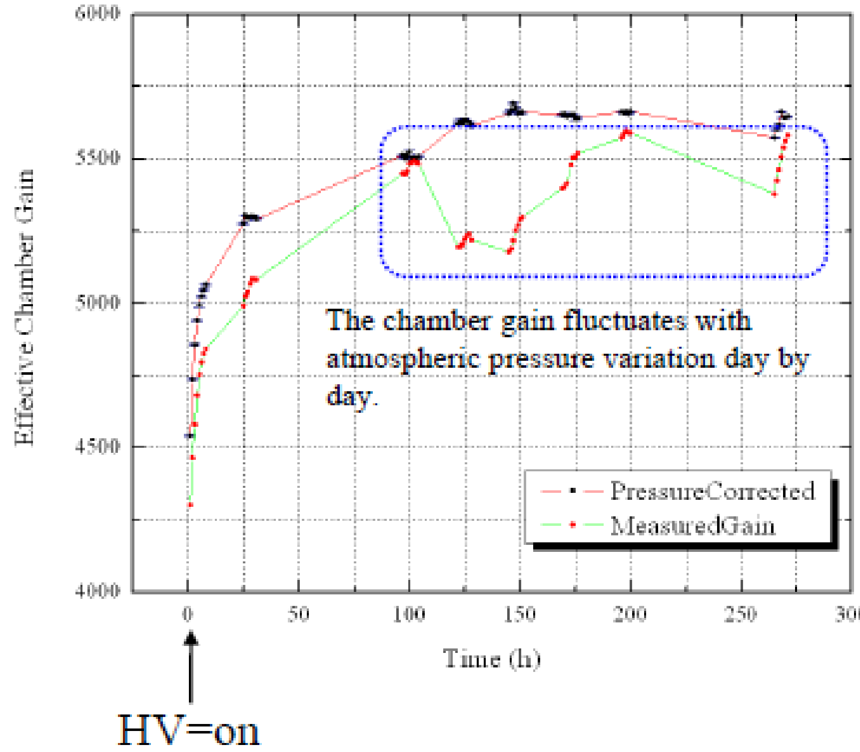


2009_11_18_10_20_49

Pressure Dependence of Gain

HV =1950V (ΔV_{GEM}=390 V)





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

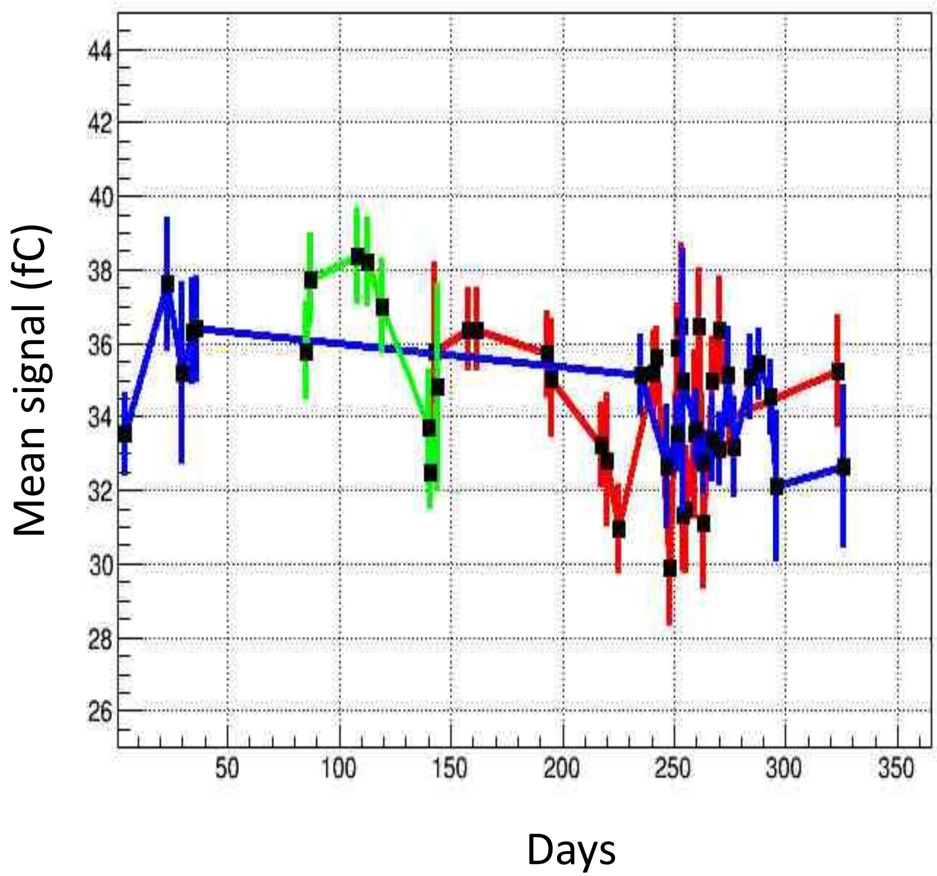
Thus, pressure inside chamber is affected by the atmospheric pressure directly.

This pressure change affects the chamber gain.

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

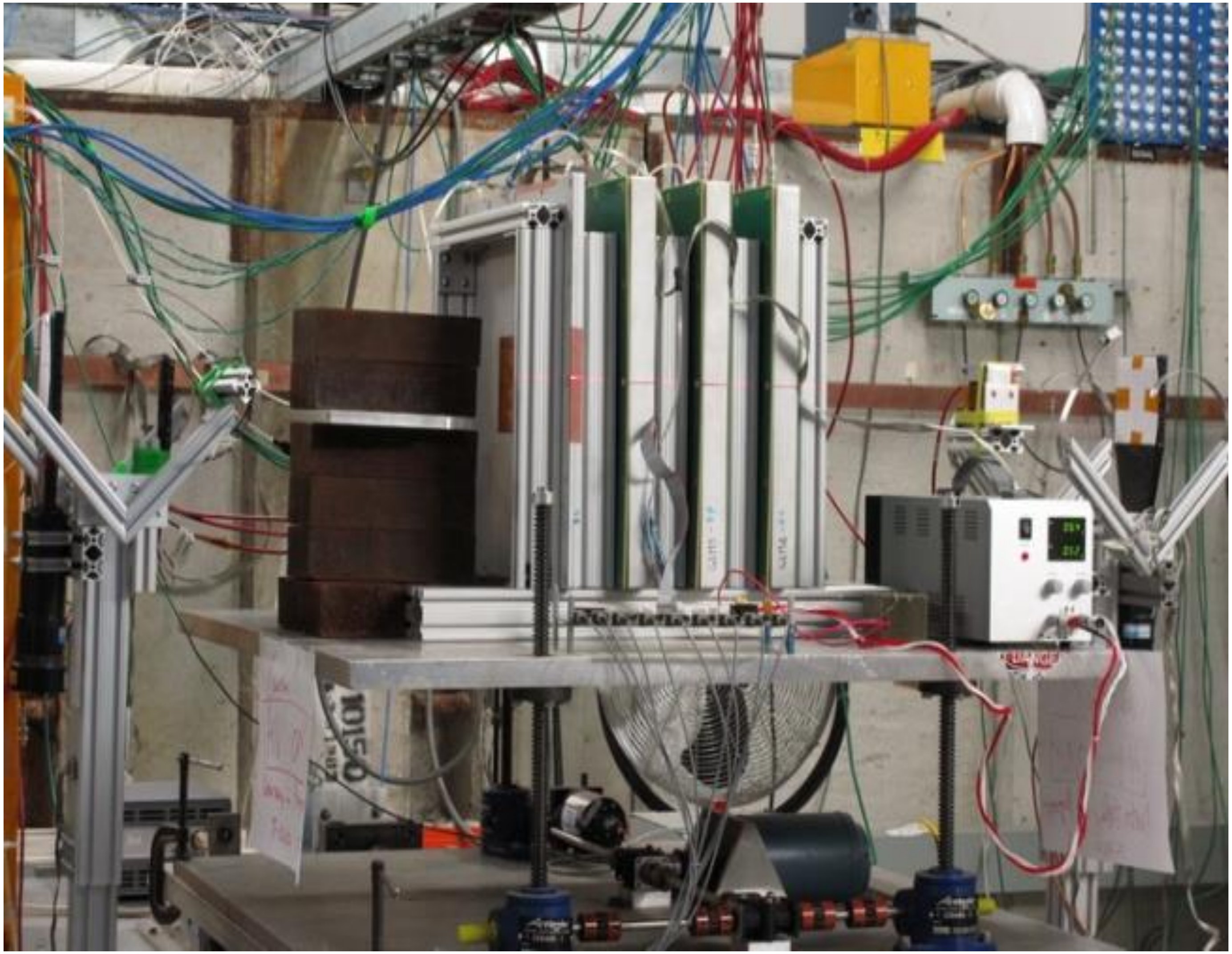
Study the seasonal change of GEM detector gain.

- Red: 2012, blue: 2013, green:2014

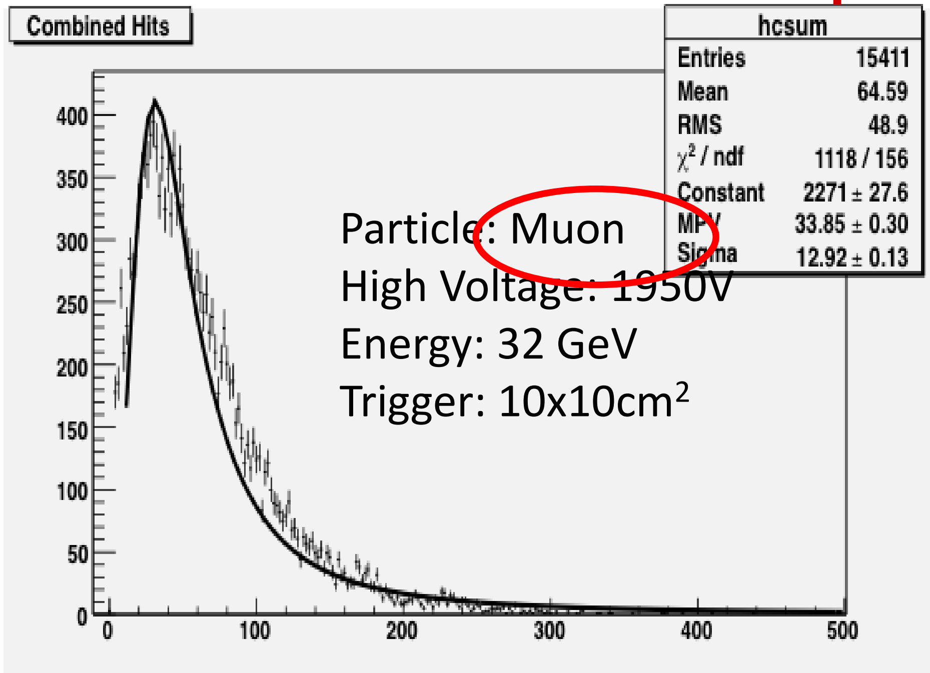


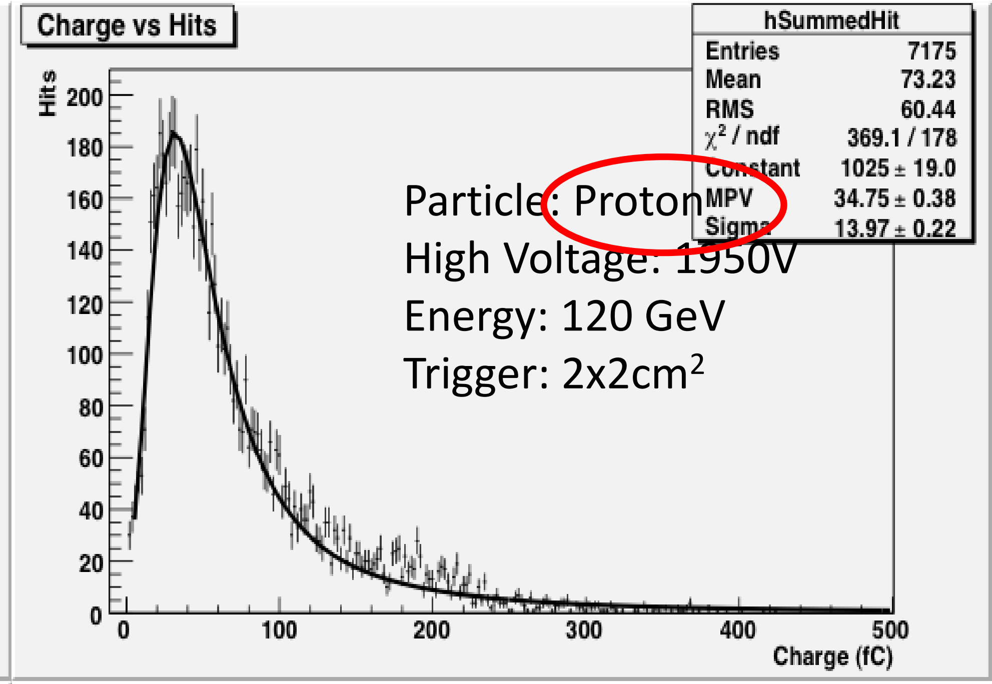
Yvonne Ng – UTA Student

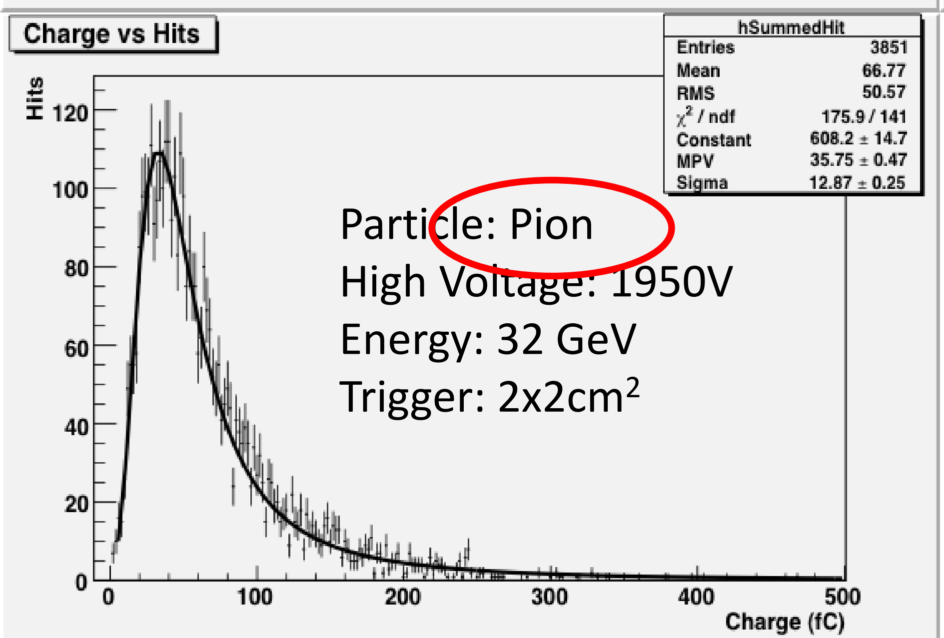
T-1010 Experiment Setup



GEM Response with KPiX

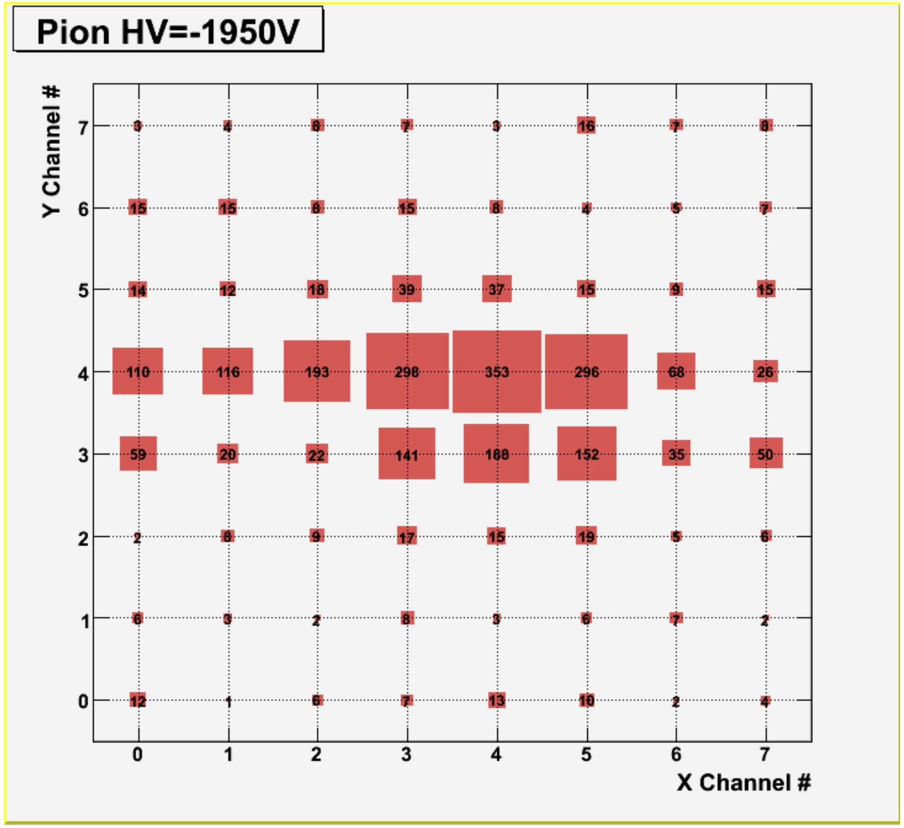


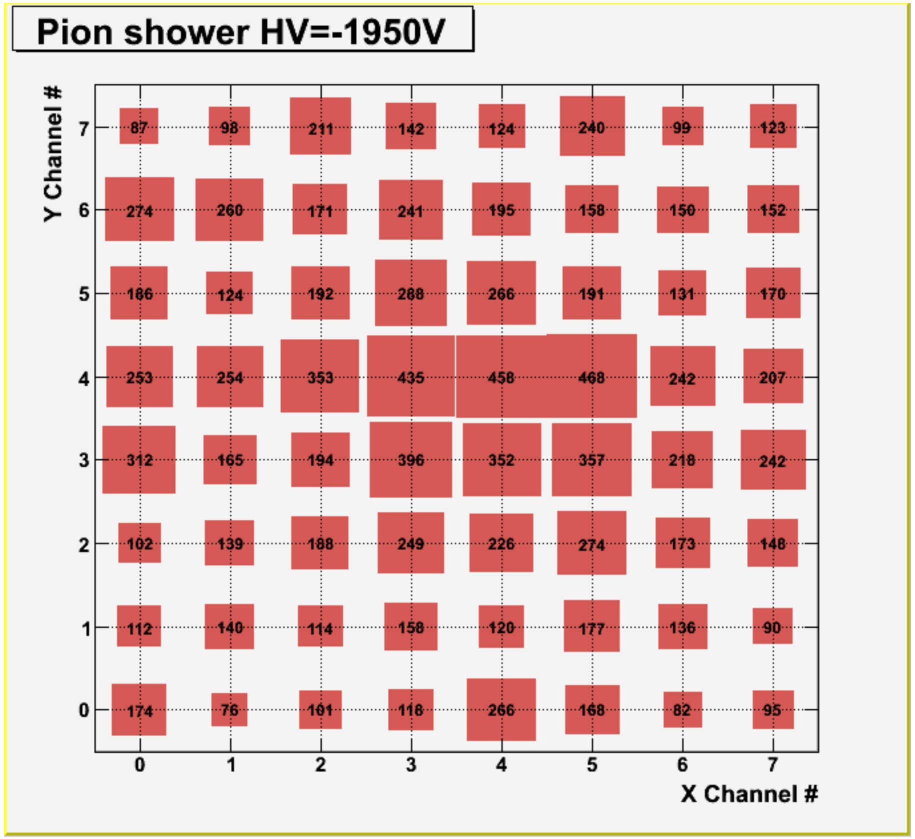




Results pressure corrected

Hit Map for Pions vs Pion Showers (KPiX)

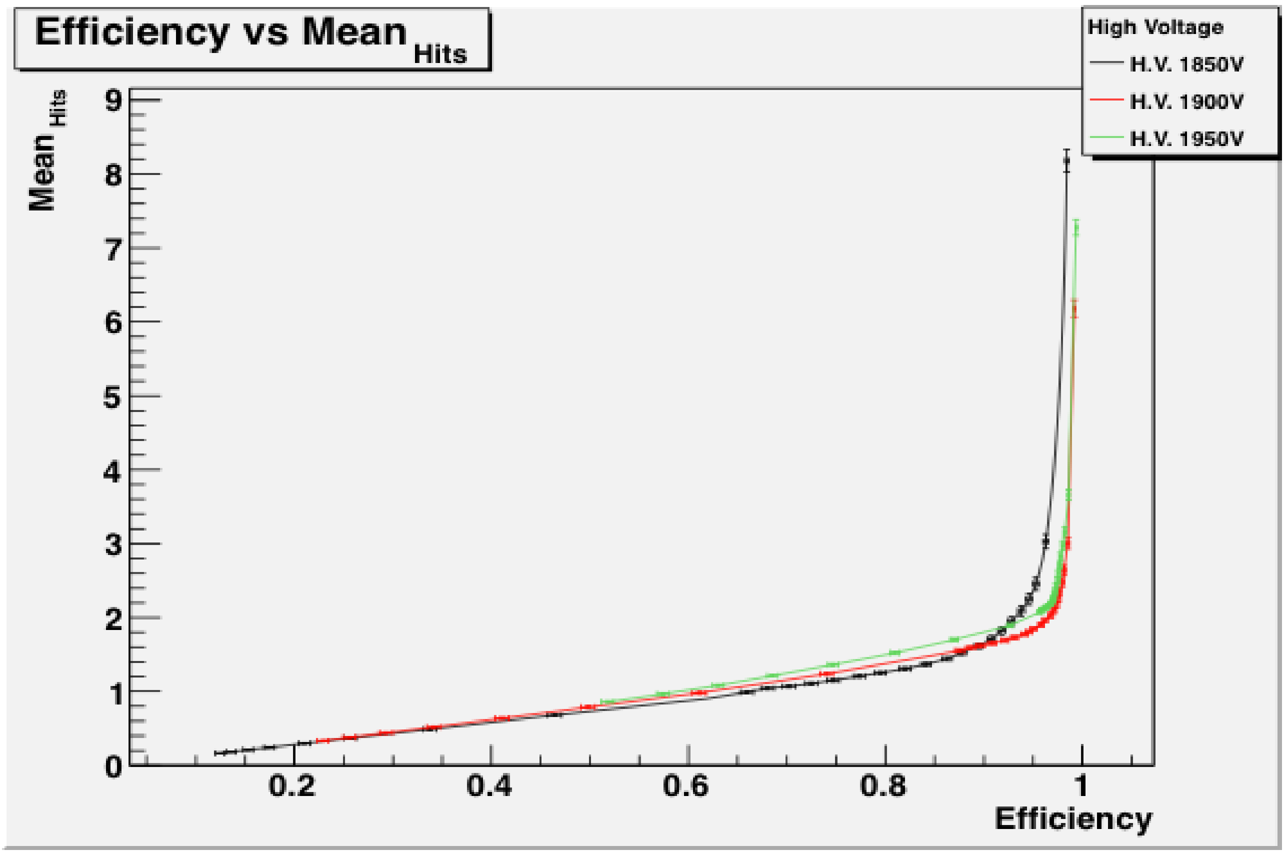




Hits above 5fC were counted and normalized to 1000

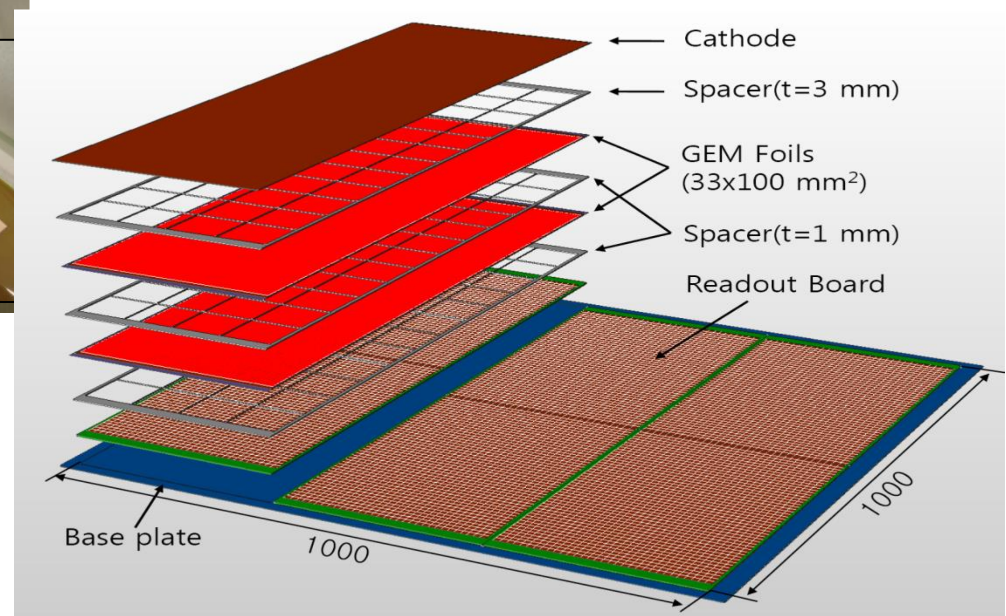
Demonstrates the KPIX capability to take many hits simultaneously

Efficiencies and Hit multiplicities (KPiX)



Results pressure corrected

Toward 100cmx100cm GEM Planes



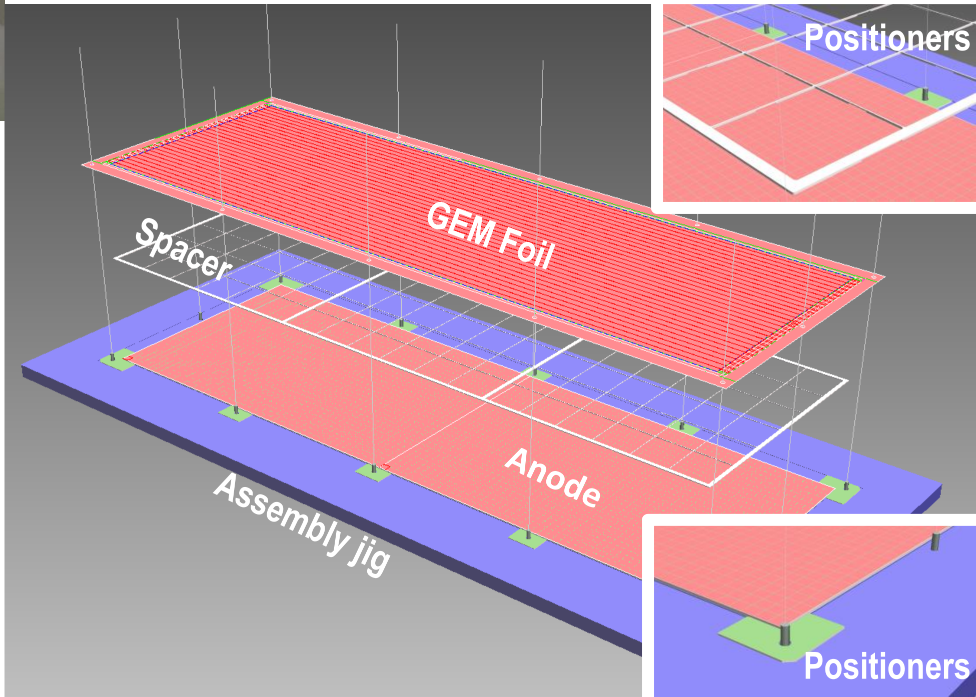
Each of the GEM 100cmx100cm planes will consist of three 33cmx100cm unit chambers

Toward 100cmx100cm GEM Planes!!

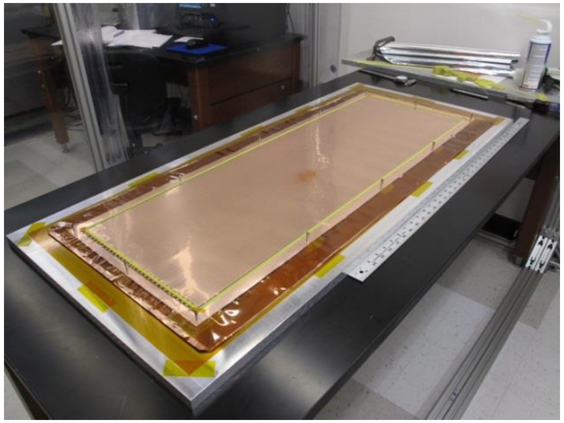
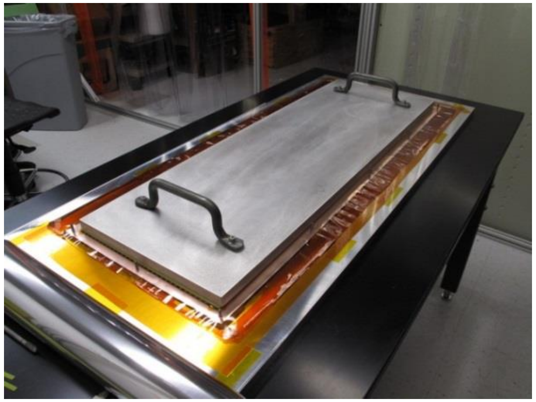
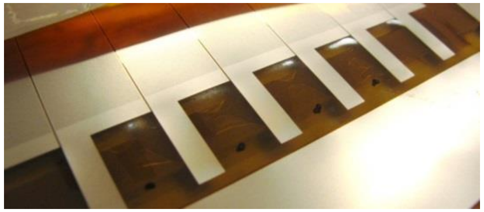
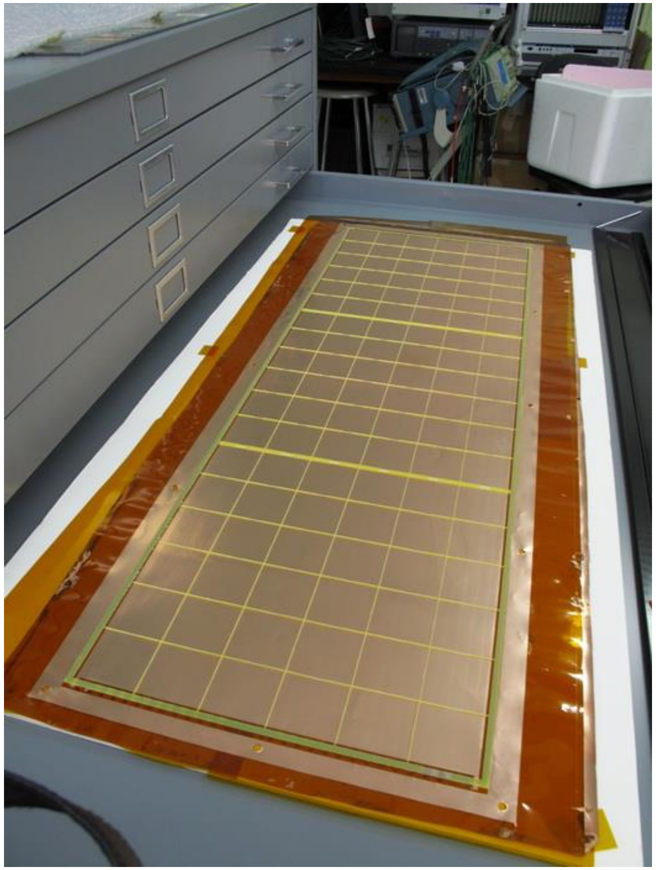
Class 10,000 clean room (12'x8') construction completed

Two 33cmx100cm chamber parts delivered

Jig for 33cmx100cm chamber being procured



Preparation for LGEM Assembly

Current situation:

- Waiting resumption of detector R&D support
- Characteristics of GEM chambers (Eff. vs. mult, long term stability) show suitability fro DHCAL application.

Next:

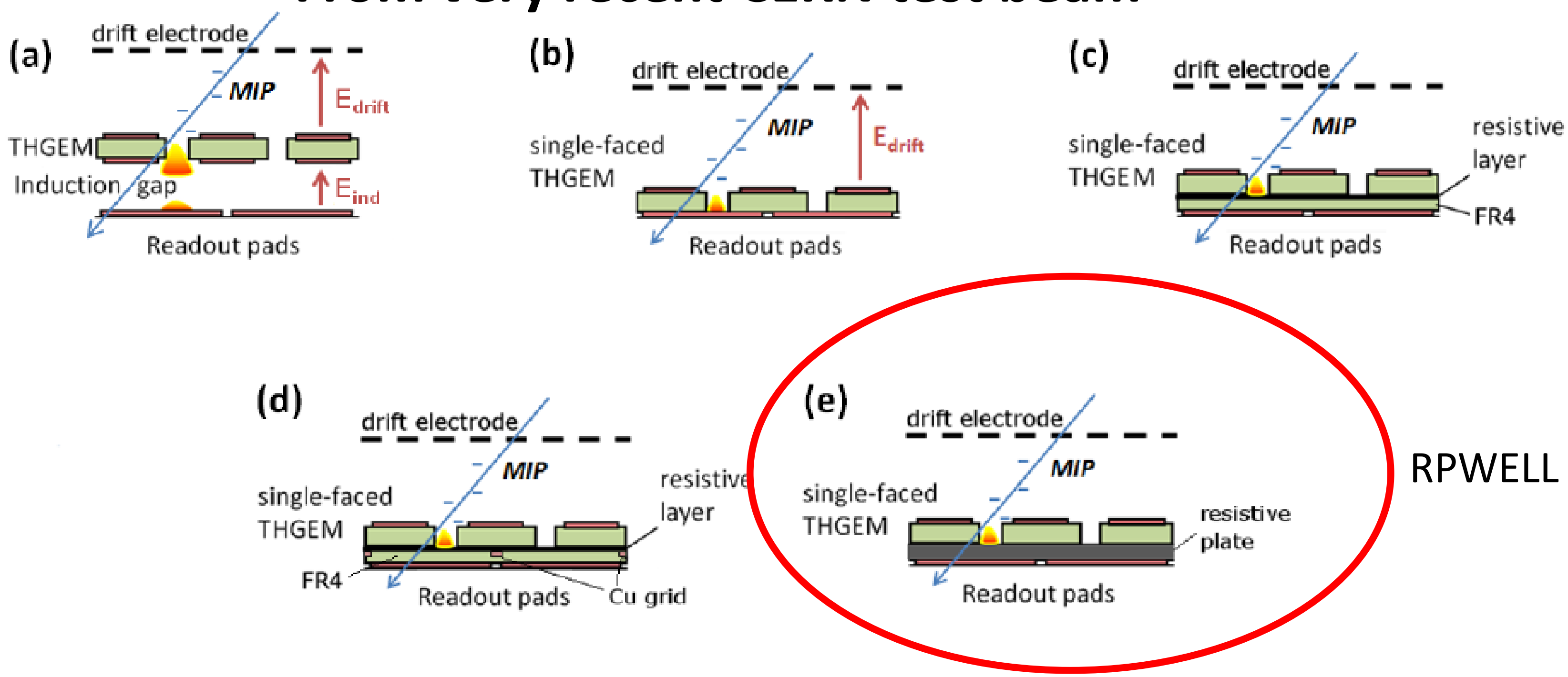
- Complete one 33cm x 100cm chamber
- Test chamber in lab
- Build two more chambers
- Beam test with KPiX/synchronous beam at SLAC ESTB

DHCAL – Thick GEM

ThickGEM technology developed at Weizmann Institute of Science, Israel
Tested in collaboration with Portugal (Aveiro, Coimbra), US(SLAC,UTA)

Slides courtesy Dr. Shikma Bressler (WIS)

From very recent CERN test beam



Recent advances with THGEM detectors

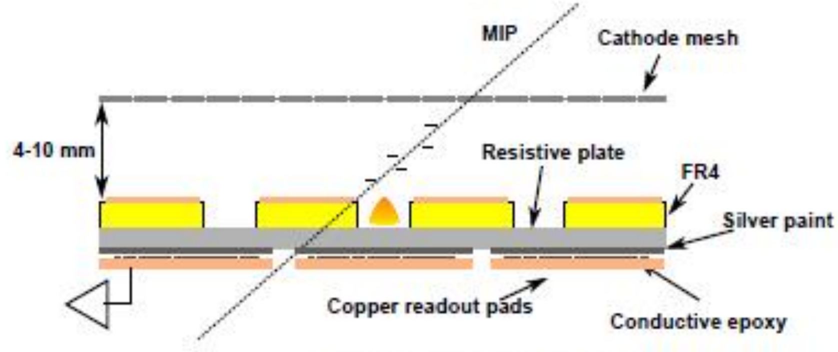
S. Bressler*, L. Arazi, L. Moleri, M. Pitt, A. Rubin and A. Breskin

2012 JINST 7 C05011

The RPWELL

***R**esistive **P**late **WELL**:*

- WELL coupled to materials with large bulk resistivity
- The charge is induced on the readout pads
- The avalanche charge flows through the plate to the anode (doesn't propagate sideways)
  - Less cross talk ? (under study)



A. Rubin et. al, JINST 8 P11004 2013

Tested materials

Material	Dimensions [mm]	Bulk resistivity [Ωcm]
VERTEC 400 glass	36×31×0.4	8×10^{12}
HPL Bakelite	29×29×2	2×10^{10}
Semitron ESD 225	30×30×2	2×10^{9}
Semitron ESD 225	30×30×4	3×10^{9}

RPWELL

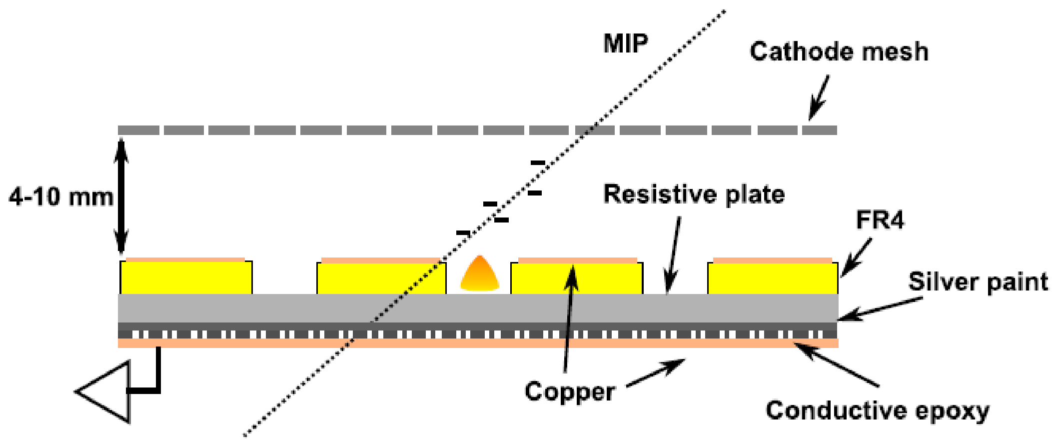
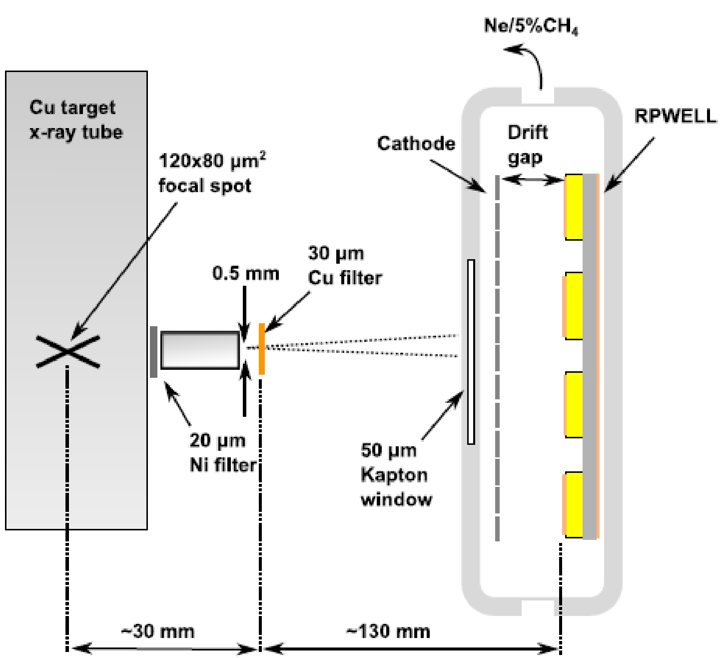
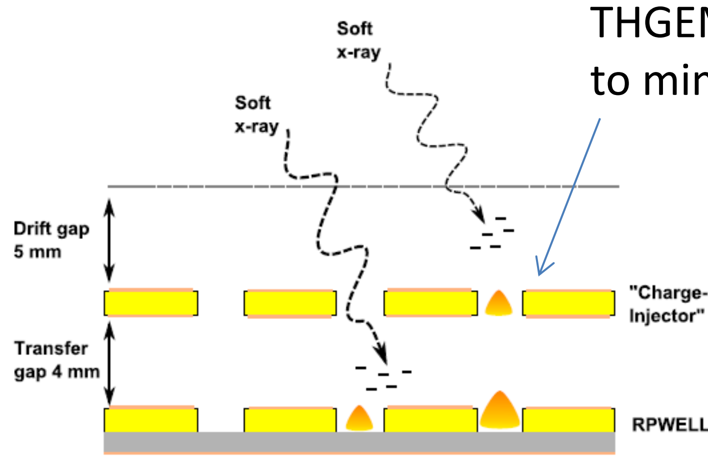


Figure 1. The Resistive-Plate WELL (RPWELL) configuration with a resistive anode and a readout electrode. The WELL, a single-faced THGEM, is coupled to a copper anode via a resistive plate. Charges are collected from the copper anode. In some experiments the WELL was directly coupled to the metal anode.



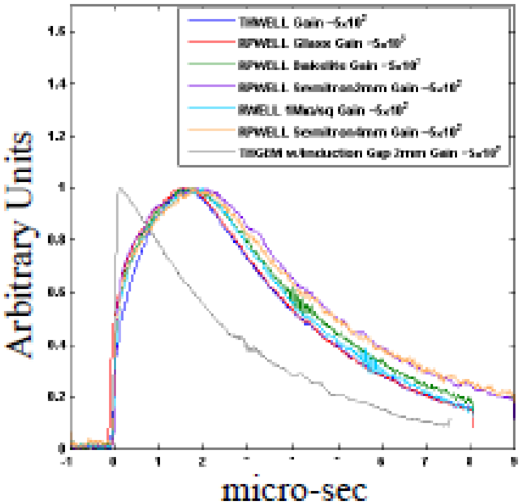


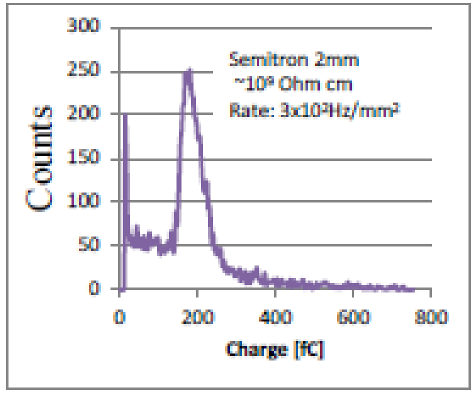
THGEM “preamp” to mimic HIPs

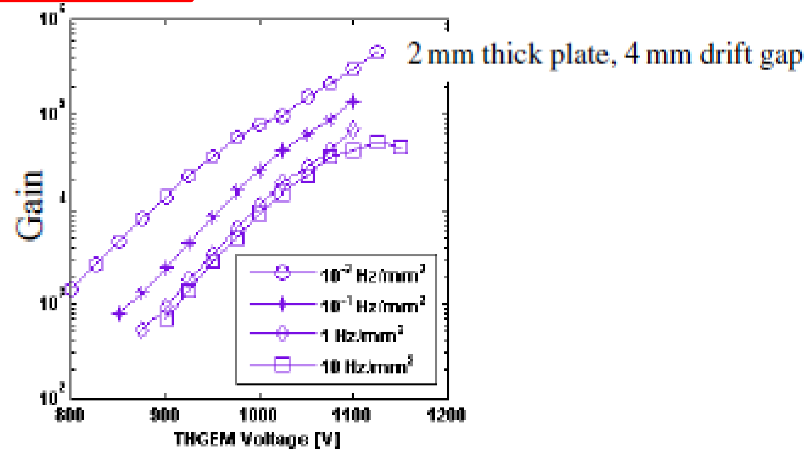
Focus on thin Semitron ESD 225 layers

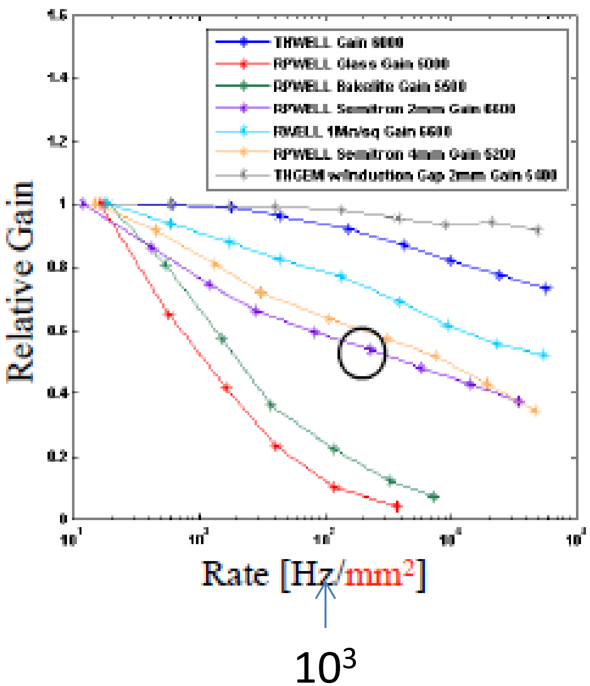
RPWELL 10^9 Ωcm - 2 mm layer

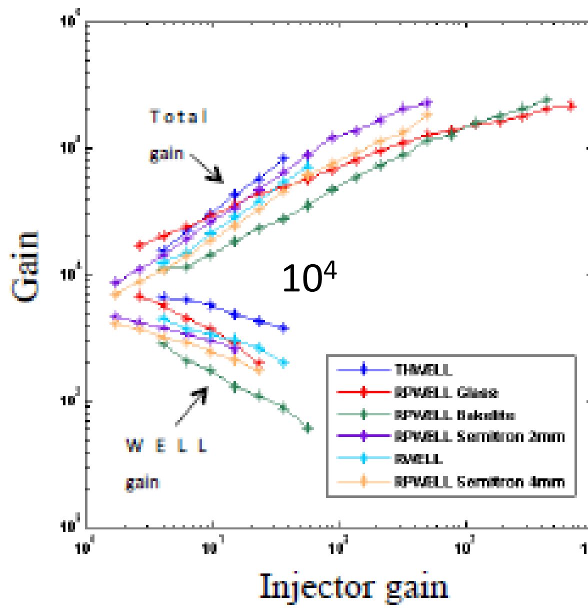
A. Rubin et. al, JINST 8 P11004 2013









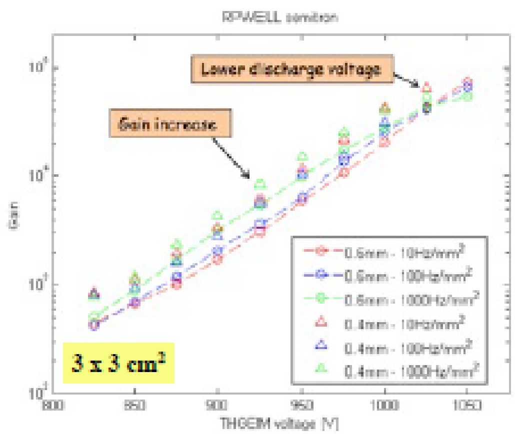


- Same pulse shape as standard well
- ~20% Energy resolution
- Gain saturation at high irradiation rate
- < 50% gain drop over 4 orders of rate magnitudes
- **No discharges at high rate of HIPs**

Laboratory studies with X-Rays

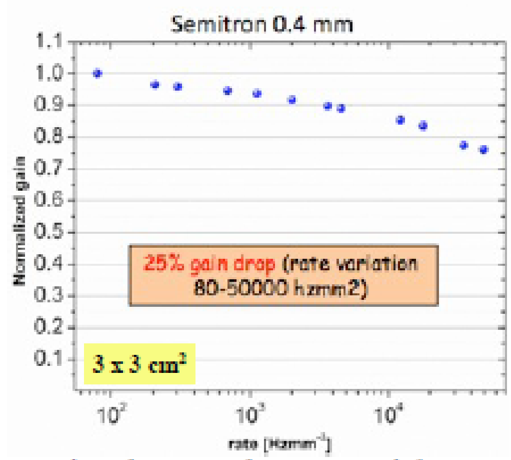
Focus on thin Semitron ESD 225 layers

Improved performance with thinner (0.4 & 0.6 mm) layers - **R~#10^8 Ωcm**



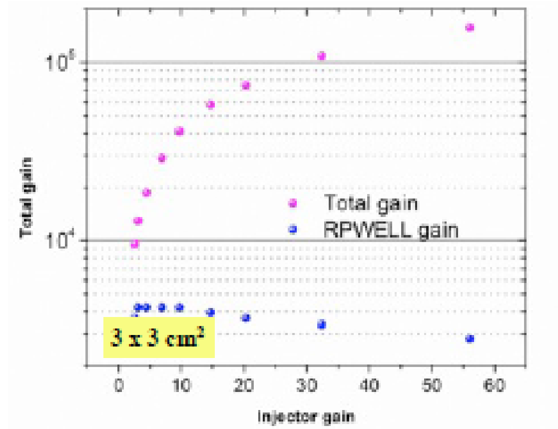
Higher gain for the same voltage

- Smaller anode-cathode gap



Gain drops slower with rate

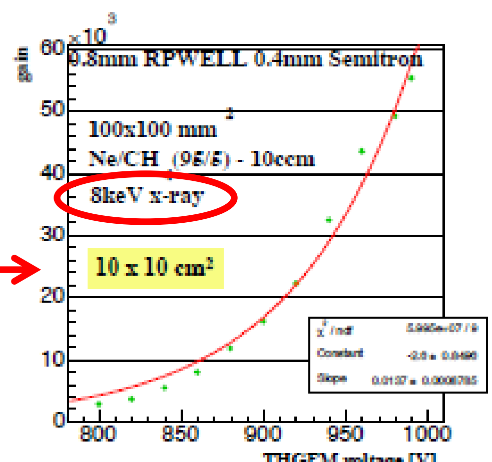
- Lower resistivity

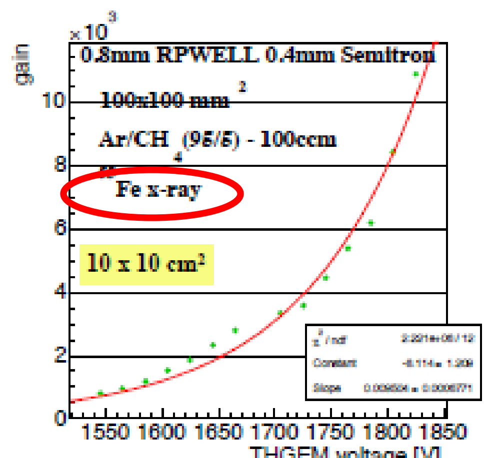


Stable with HIPs

- Observe gain saturation

Decided:
Build 10 x 10 cm^2 proto.
with 0.4 mm Semitron layer
Test in the lab
Test in the beam





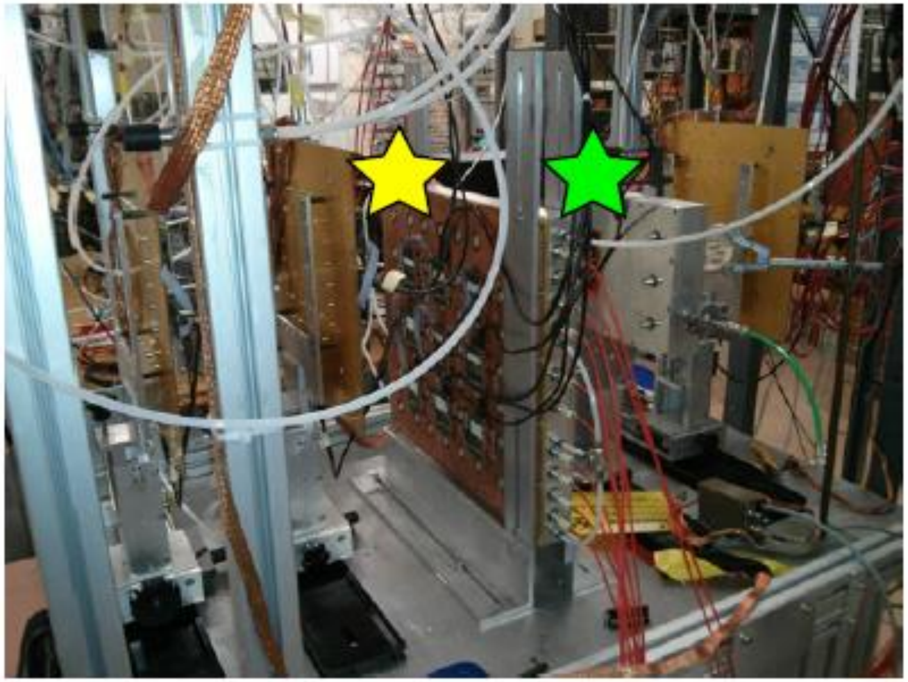
Laboratory studies with X-Rays

Before CERN shutdown

Tests in the beam - happening now

2 detectors setup + telescope installed in SPS/H4 beam area:

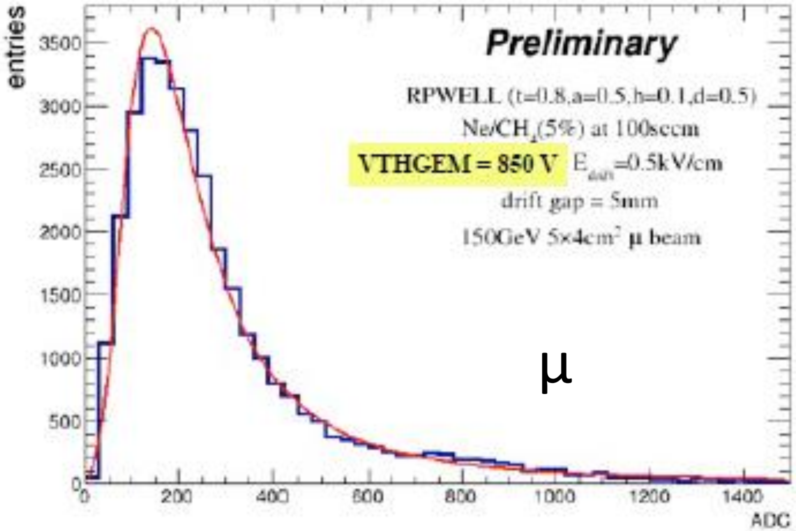
- (yellow star) 0.4 mm 30 x 30 cm^2 RPWELL 0.4 mm Semitron layer
- (green star) 0.8 mm 10 x 10 cm^2 RPWELL 0.4 mm Semitron layer

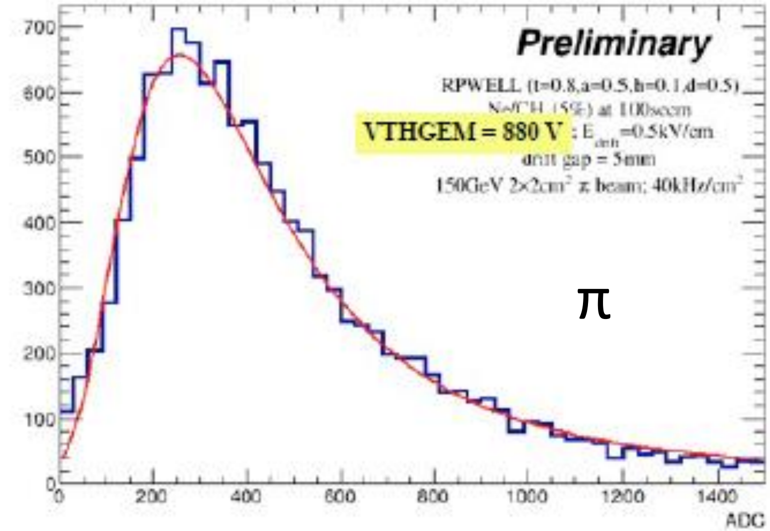


Results - 10 x 10 cm² 0.8 mm RPWELL

Clear Landau distribution

Excellent signal to noise separation in low and high rate beams

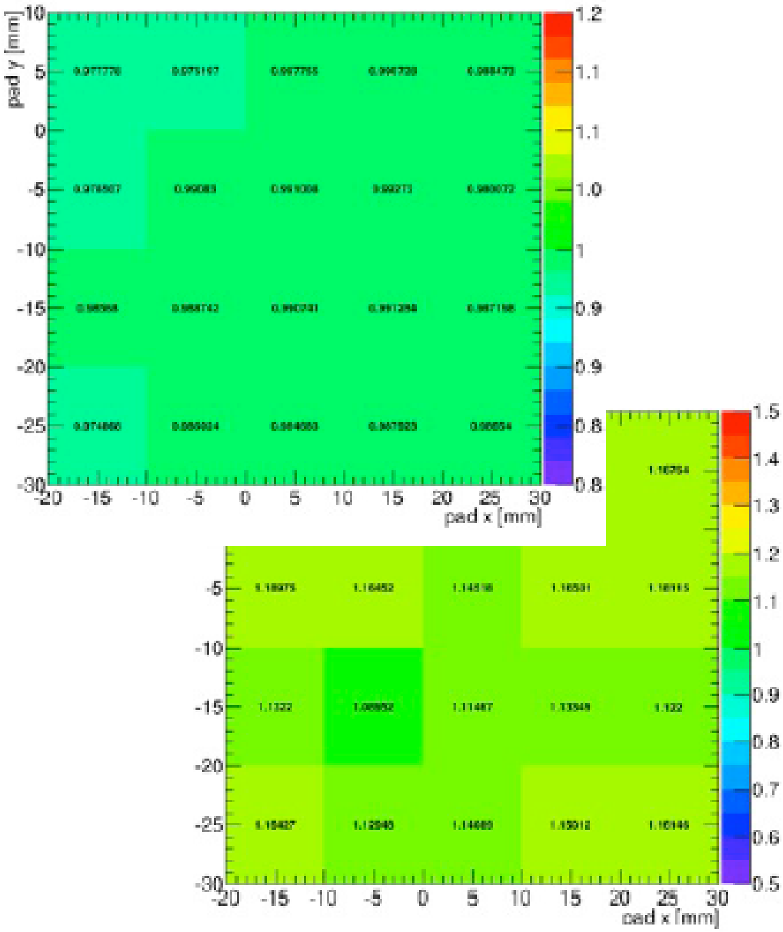




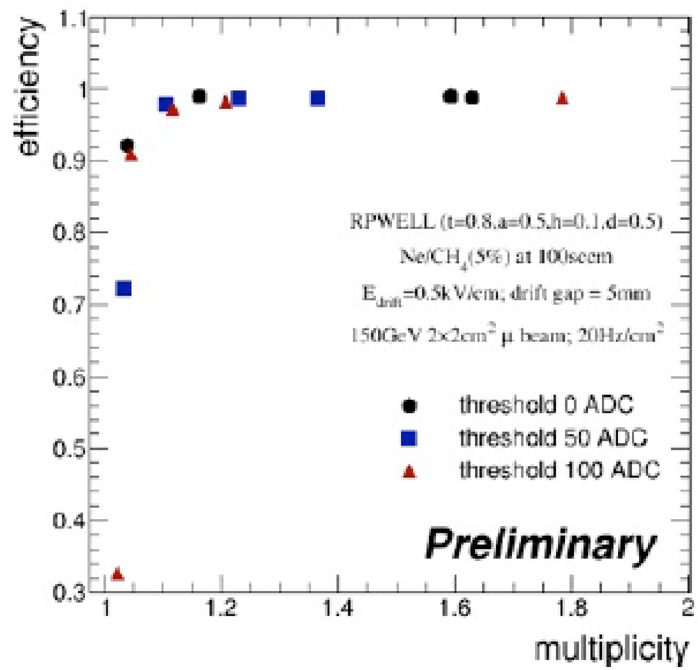
200 ADC counts ~ Q = 4 fC ~ Effective gain = 3000

Results - 10 x 10 cm^2 0.8 mm RPWELL

Pad efficiency



Average pad multiplicity



High efficiency (>98%) at reasonably low multiplicity (1.1) - **preliminary!**

Uniform response

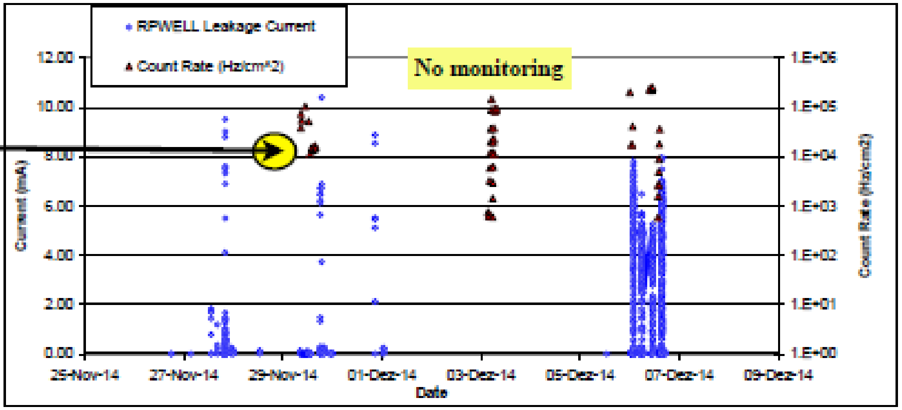
Results - 10 x 10 cm^2 0.8 mm RPWELL

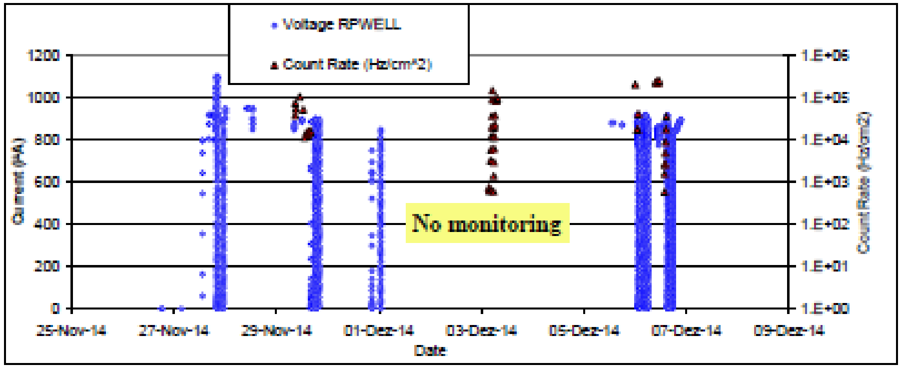
Discharge free*!! Discharge prob < 10^{-10} (first approximation - **Preliminary**)

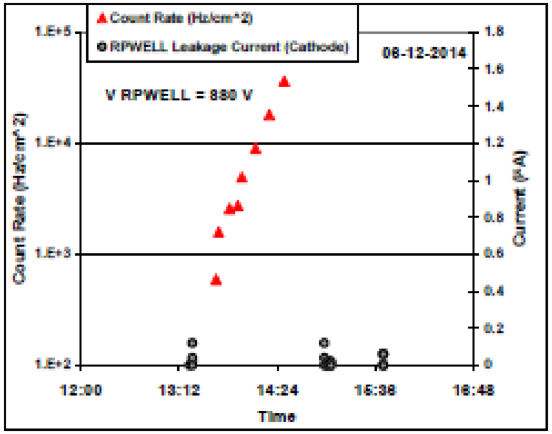
Long Pi run. No current activity

Trips - long term high current - occur rarely

- At very high rates and high gains (at the same time)
- Recovery takes time
- Cause has to be understood







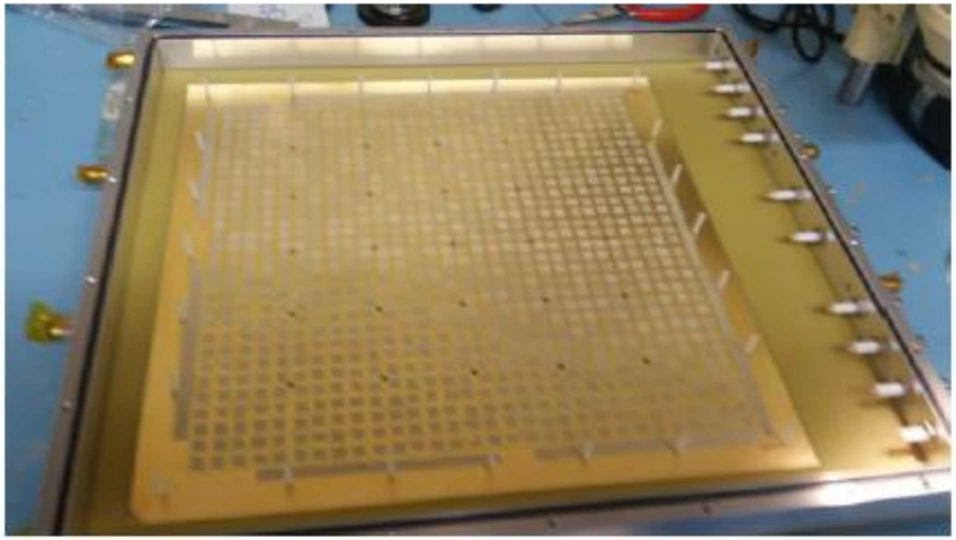
Analysis is on going

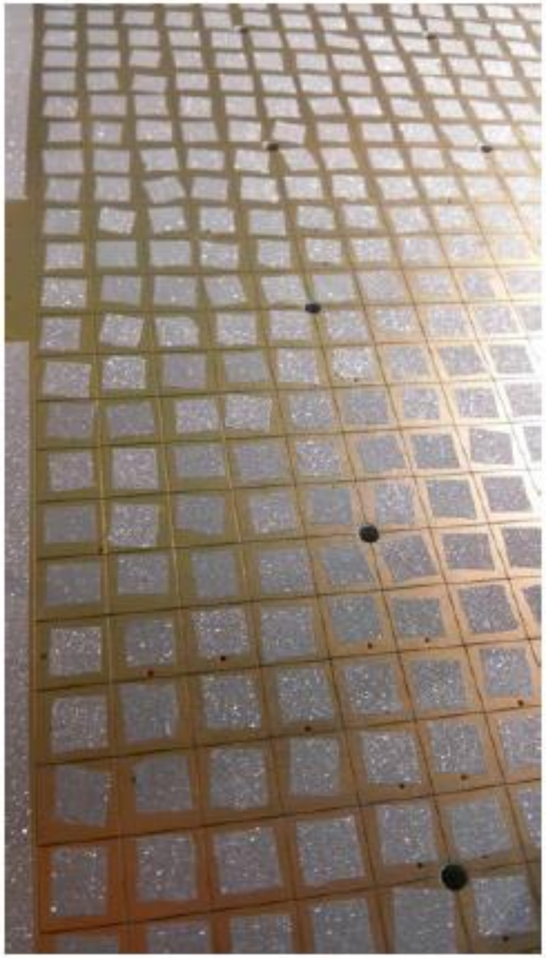
Hand made 30 x 30 cm^2 RPWELL

Two RPWELL 0.4 mm Semitron configurations:

- 10 x 10 cm^2 - 0.8 mm electrode; 3 mm drift
  - Operation in Ne/CH4 and maybe also Ar/Co2
- 30 x 30 cm2 - 0.4 mm electrode; 5 mm drift
  - Electrode of bad quality (not intentionally)

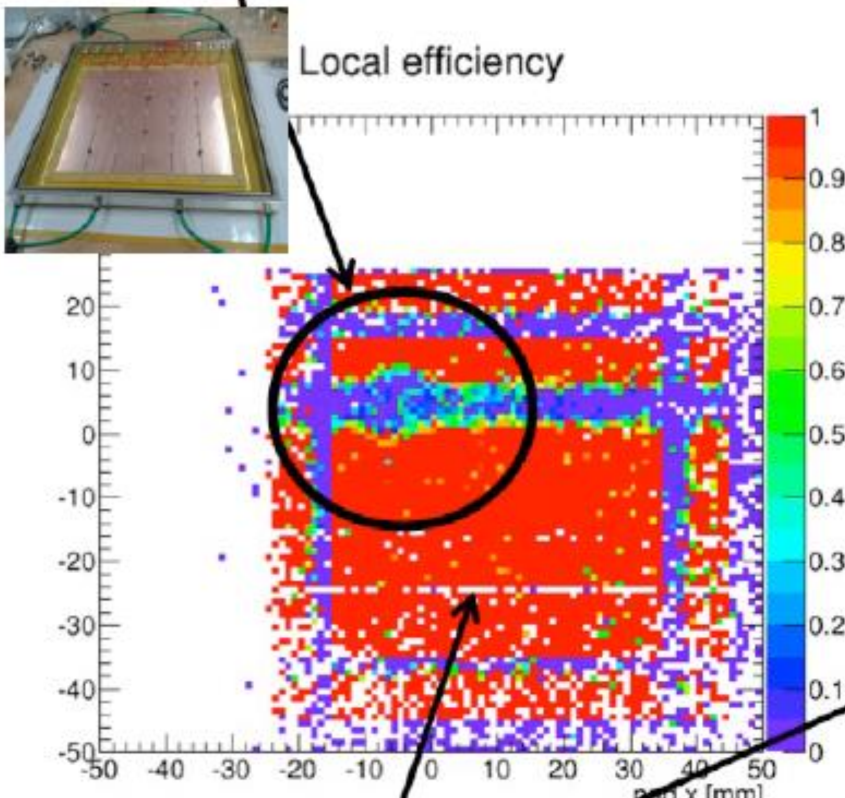
30 x 30 cm^2



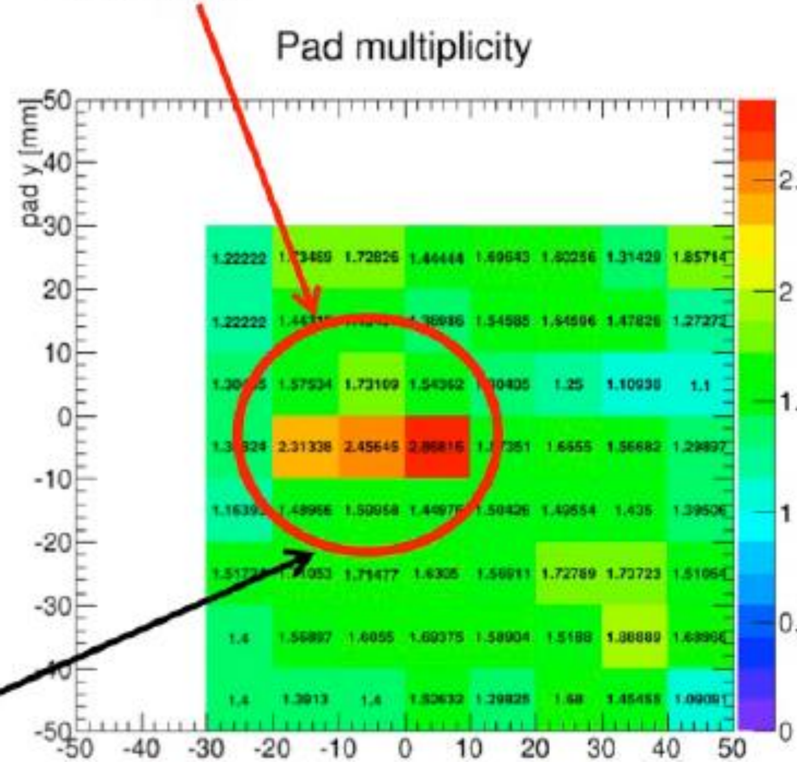


Results - 30 x 30 cm^2 0.4 mm RPWELL

Spacer and strip



Glued pads



Analysis is on going - thresholds can be raised to reduce multiplicity

High pad multiplicity in viducial volume → ~99% eff

DHCAL – Thick GEM

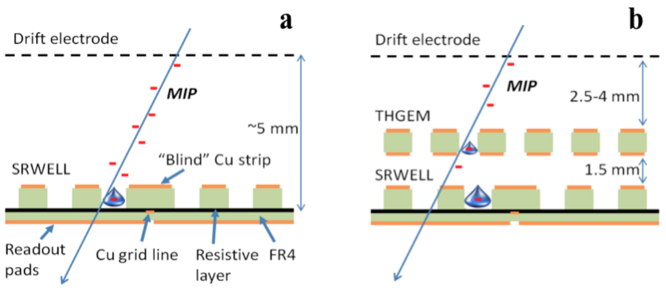
Summary

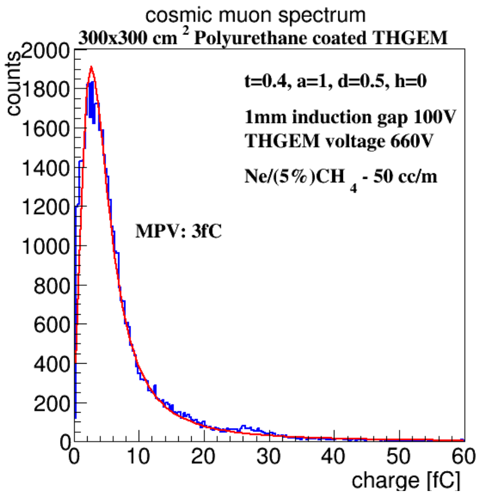
- Three prototypes were tested
  - 0.8 mm thick 10 x 10 cm2 RPWELL; 5 mm drift
  - 0.8 mm thick 10 x 10 cm2 RPWELL; 3 mm drift
  - 0.4 mm thick 10 x 10 cm2 RPWELL; 5 mm drift
- Stable operation at high incoming pion flux
- High efficiency (the detectors can be operated stably at very high gain)
- Low average pad multiplicity
- ~30% gain drop over 4 orders of magnitude of incoming particle flux
- ~10% increase in pad multiplicity at 45 degrees

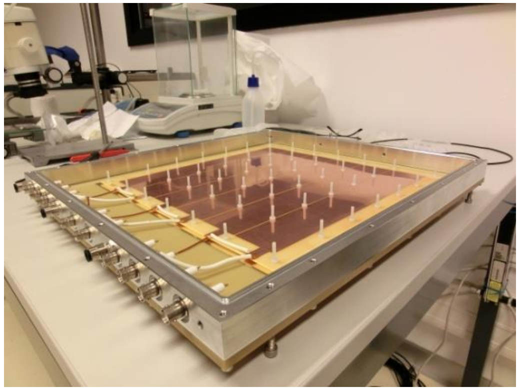
- The numbers are preliminary!!! Analysis is ongoing.

DHCAL – Thick GEM technology

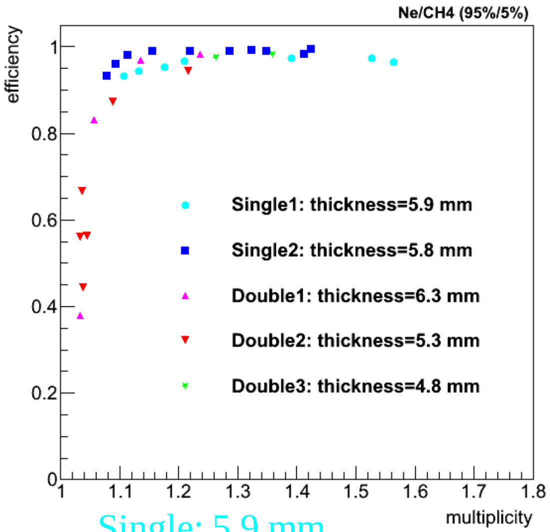
ThickGEM







The DHCAL requirements were met



Single; 5.9 mm
Single; 5.8 mm
Double; 6.3 mm
Double; 5.3 mm
Double; 4.8 mm

(Near) future plans

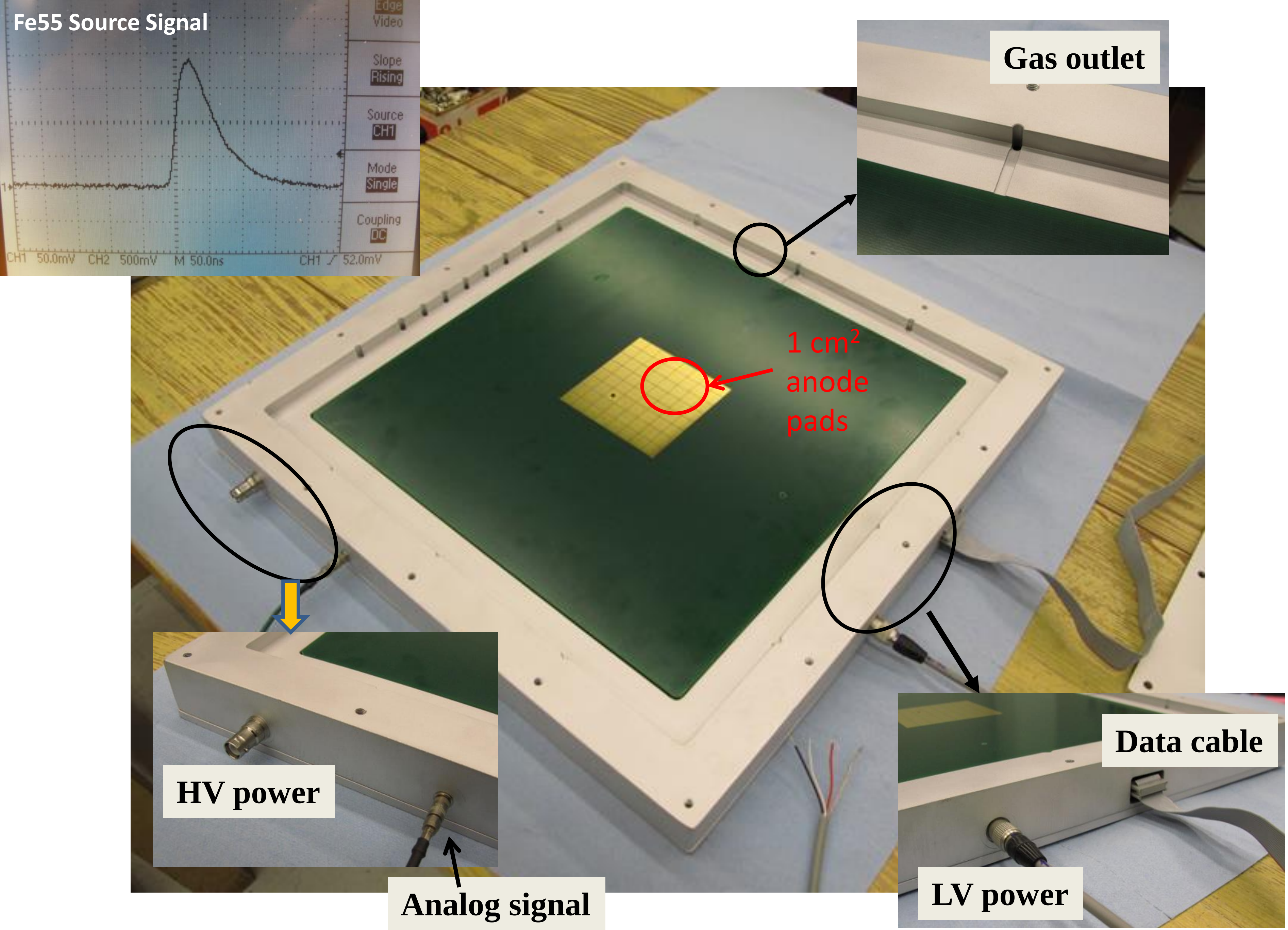
Build meter-scale single-stage detector

- One prototype in collaboration with Israeli industry
- Prototype(s) to test within CALICE's DHCAL module

Study extensively THGEM concepts with broader dynamic range

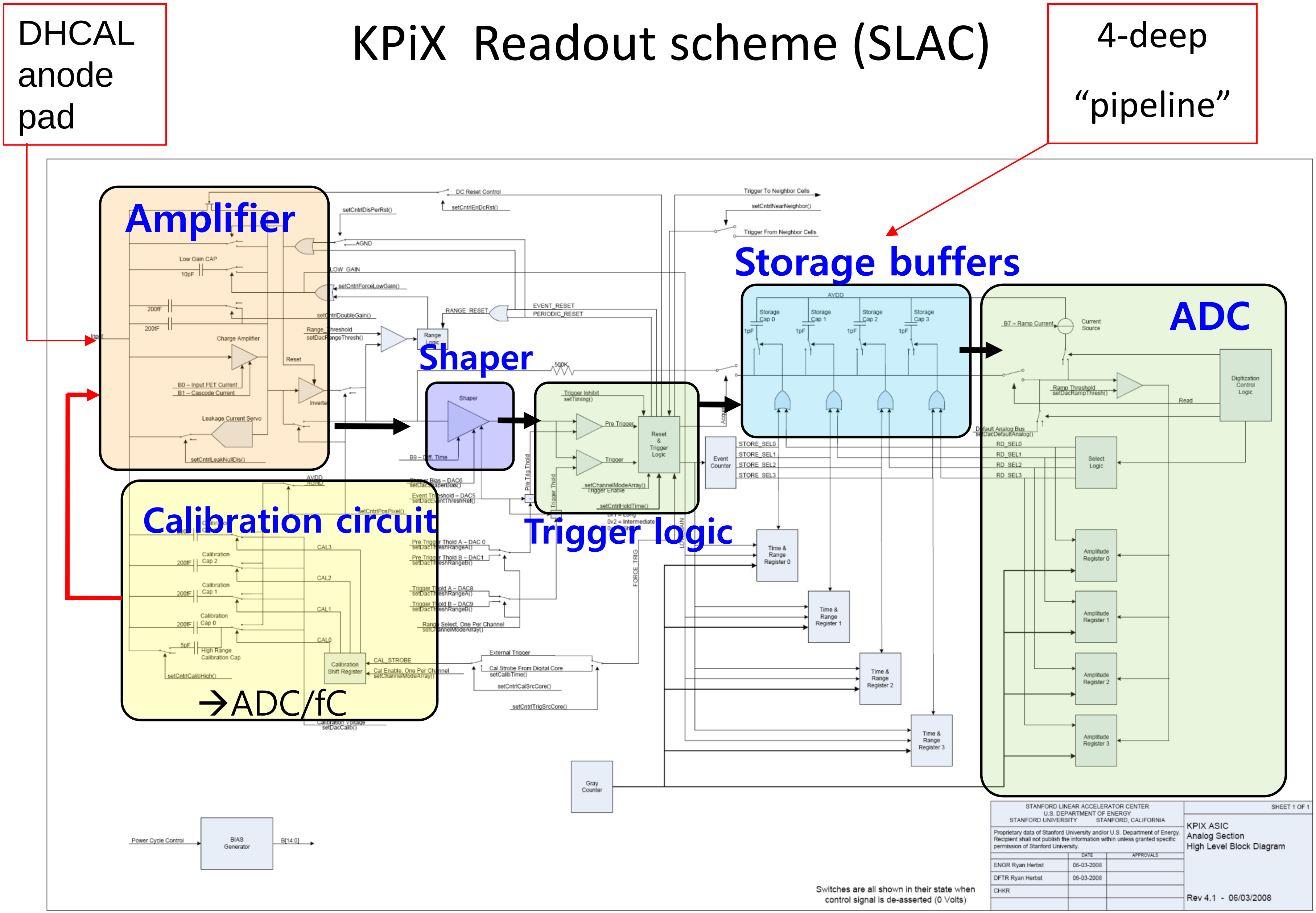
- RPWELL **Rubin 2013 JINST 8 P11004**
- Using newly developed techniques **Bressler 2014 JINST 9 P03005**
- Test in beam of 100 x 100 mm^2 prototype

EXTRA

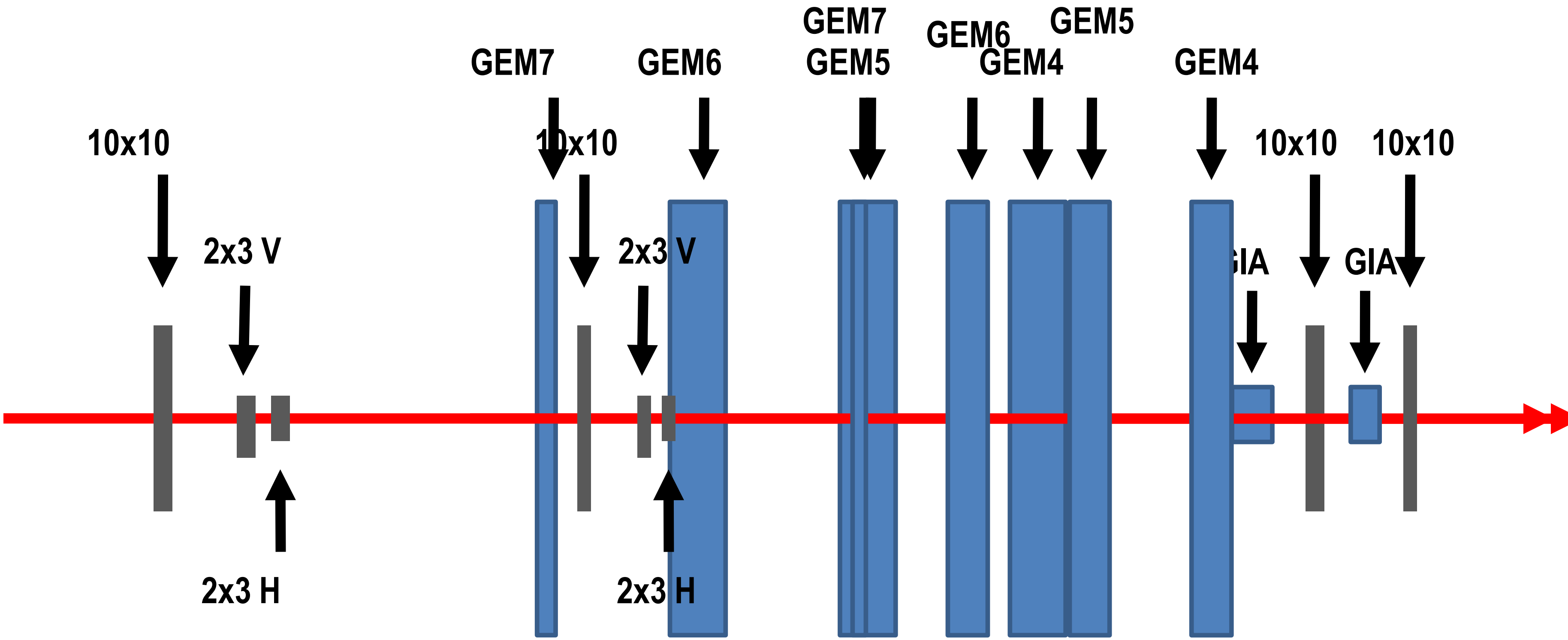


Fe55 Source Signal
Edge
Video
Slope
Rising
Source
CH1
Mode
Single
Coupling
DC
CH1 50.0mV CH2 500mV M 50.0ns CH1 ∕ 52.0mV
Gas outlet
1 cm^2
anode
pads
HV power
Analog signal
Data cable
LV power

KPiX Readout scheme (SLAC)



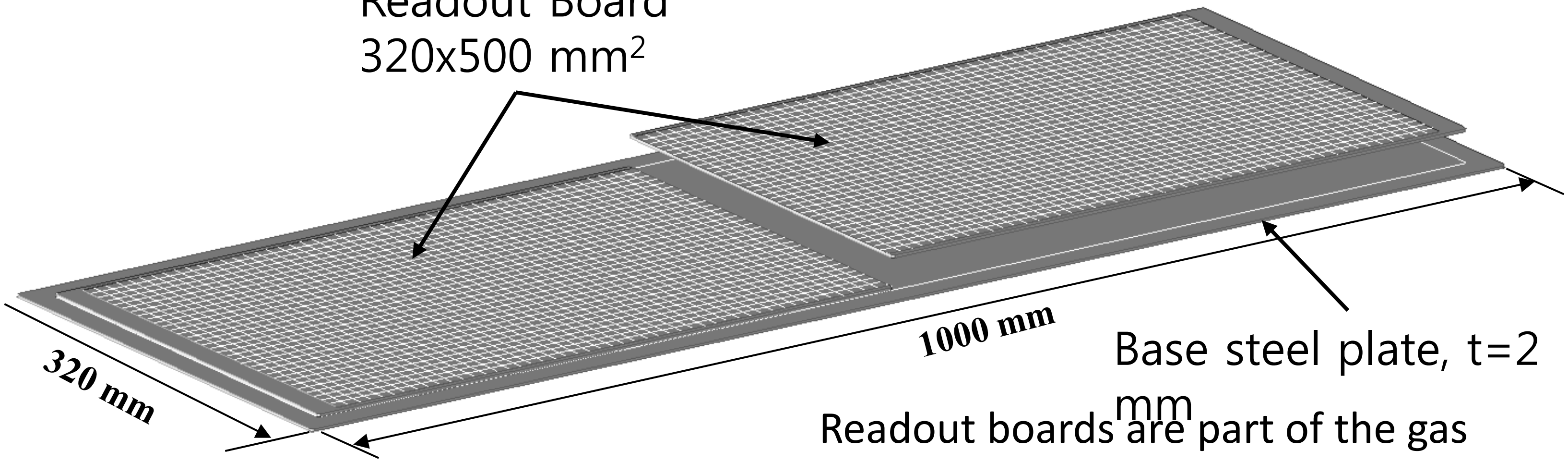
T-1010 Experiment Setup



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%)

33cmx100cm DHCAL Unit Chamber Construction

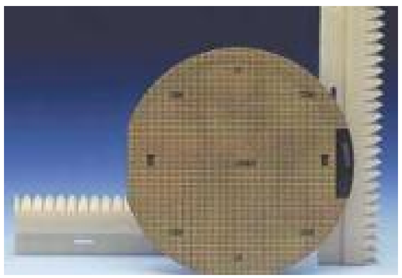


Readout boards are part of the gas volume!!

GEM foils with 31 HV strips delivered

G10 spacers will be used without aligned dead areas.

Readout boards will be glued in the seam



Links:

- Semitron ESd 225 Data Sheet
- Semitron 410C - Conductive Ultem
- Semitron ESd 420 - ESD Ultem
- Semitron ESd 480 - ESd PEEK
- Semitron ESd 500HR - ESd PTFE
- Semitron ESd 520HR - ESd PAI
- Semitron ESd 225 Acetal

Semitron® ESd 225 - Acetal

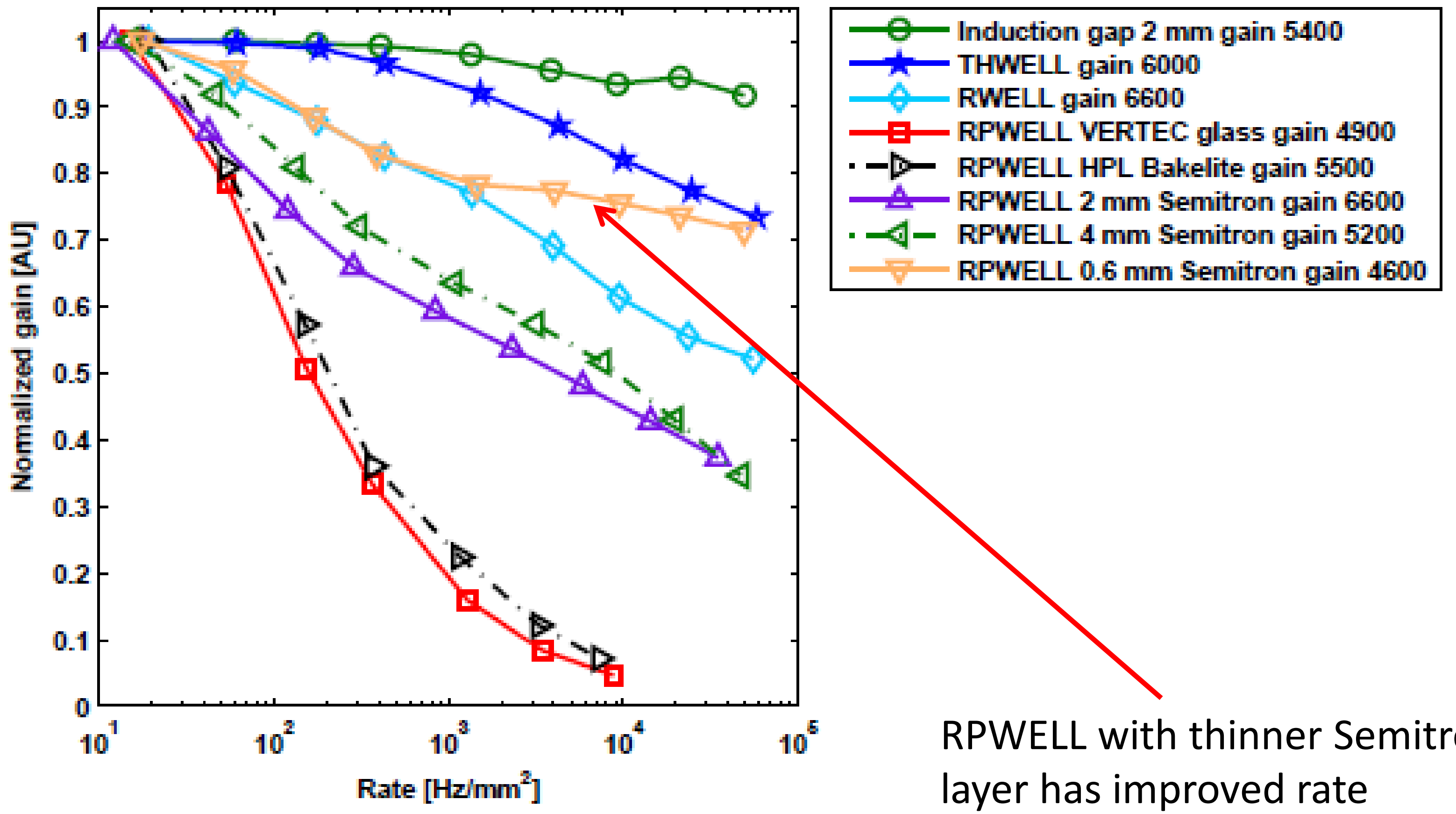
Semitron® ESd 225 Acetal Sheets & Rods

Semitron® ESd products are inherently dissipative and electrically stable unlike many other "dissipative" plastic shapes. They do not rely on atmospheric phenomena to activate, nor are surface treatments used to achieve dissipation. Static electricity is dissipated through these products as readily as it is dissipated along the surface. All of these products dissipate 5 KV in less than 2 seconds per Mil-B-81705C.

- Surface Resistivity of 10^9 to 10^{10} Ohms per square
- Note: Maximum Operating Temperature is 190 F (82 C)
- For higher operating temperatures, consider other materials in the Semitron family. (links on left-side of page)

FEATURES AND BENEFITS

Semitron® ESd 225 is ideal for fixturing used in the manufacturing of hard disk drives or for handling in-process silicon wafers.



RPWELL with thinner Semitron layer has improved rate performance