Development of GEM-Based Digital Hadron Calorimetry using the SLAC KPiX Chip

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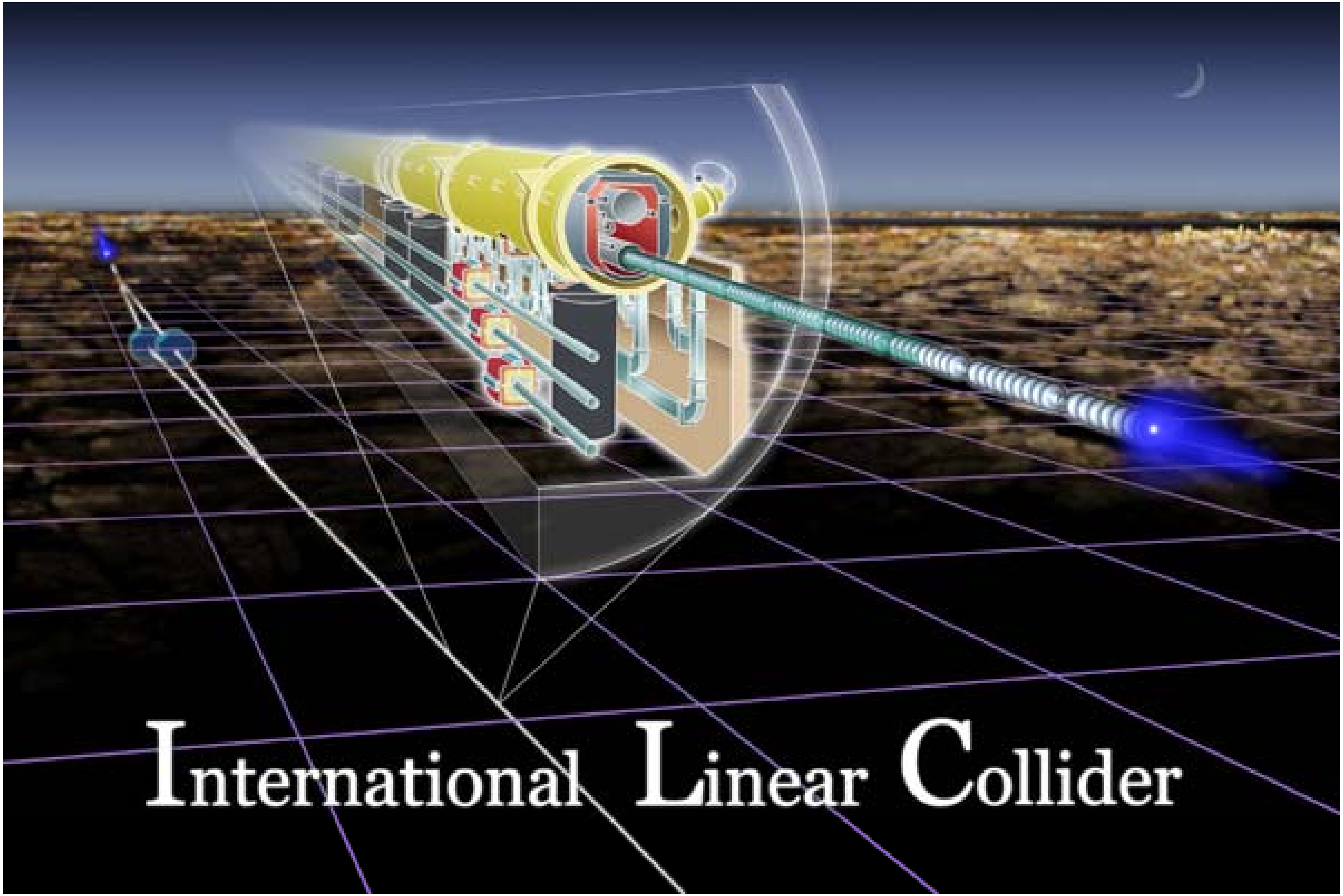
for the GEM-DHCAL Group

(UTA – CNU)

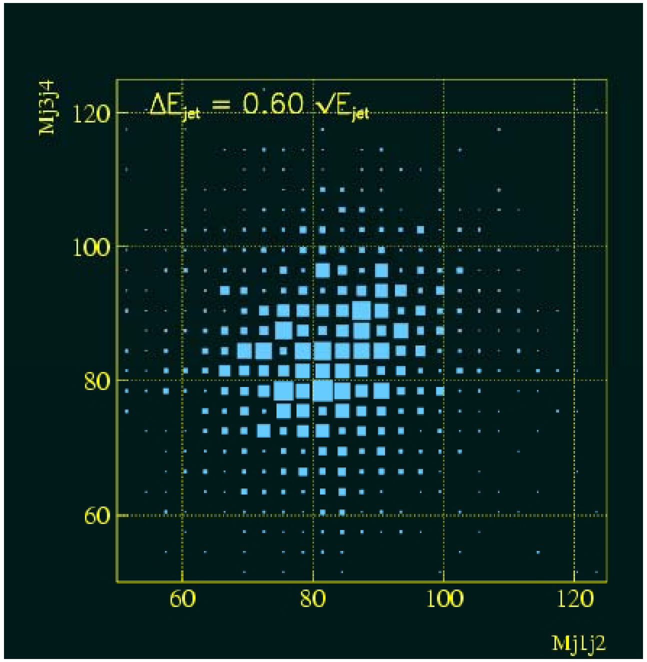
With many thanks to SLAC colleagues:

M. Breidenbach, G. Haller, D. Freytag, R. Herbst

MPGD2009, Crete, June 2009

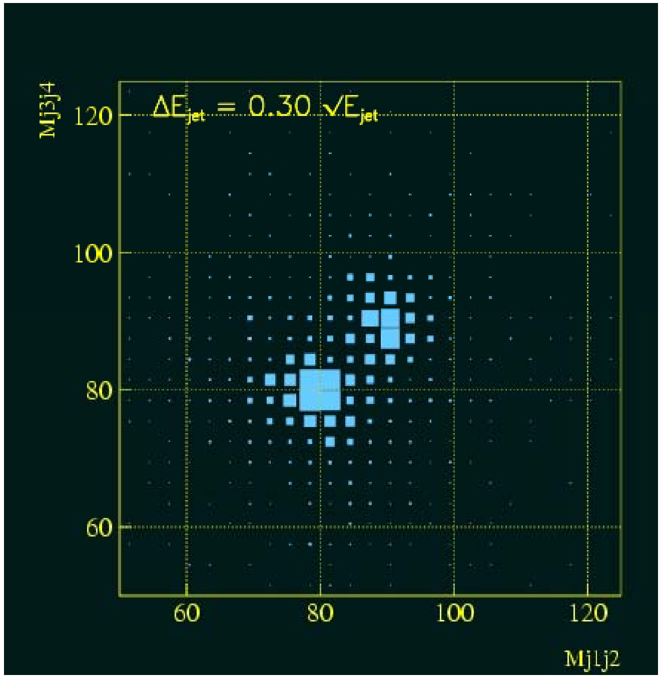

International Linear Collider

Importance of good jet energy resolution



60%/√E

Simulation of W, Z reconstructed masses in hadronic mode.

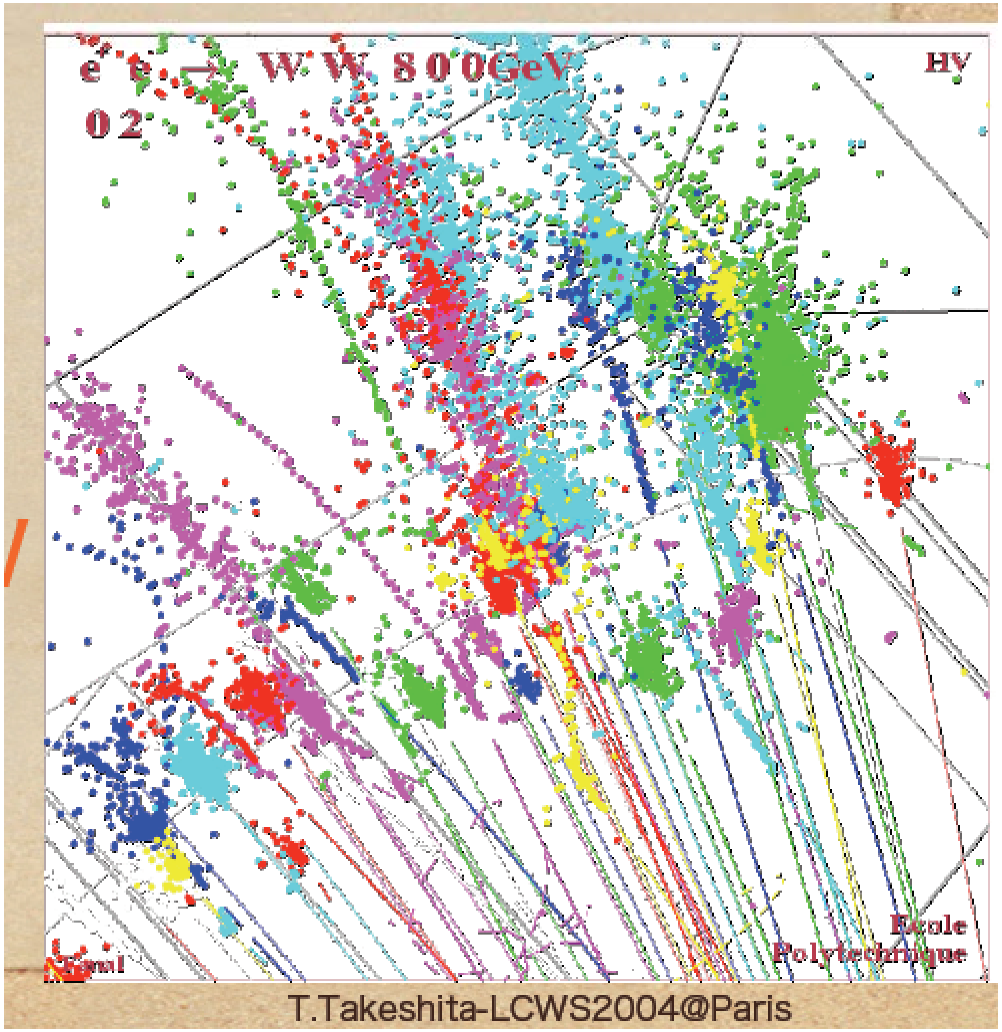


30%/√E

(from CALICE studies, H.Videau,

shown at ALCPG/Cornell: M. Schumacher)

Don't underestimate the complexity!



Particle Flow Algorithm challenge – separate the showers, associate with charged tracks!

NB. Also more complication with increasing Ejet, more collimation, higher CM energies (CLIC).

Digital hadron calorimetry

- **Particle Flow Algorithm** approach:

Use momentum measurement of charged hadrons in magnetic field, track them to energy clusters in hadron calorimeter, remove associated energy; measure electrons and photons in electromagnetic calorimeter – remainder is neutral energy ("Energy flow algorithm")

⇨ Must track charged hadrons in calorimeter !

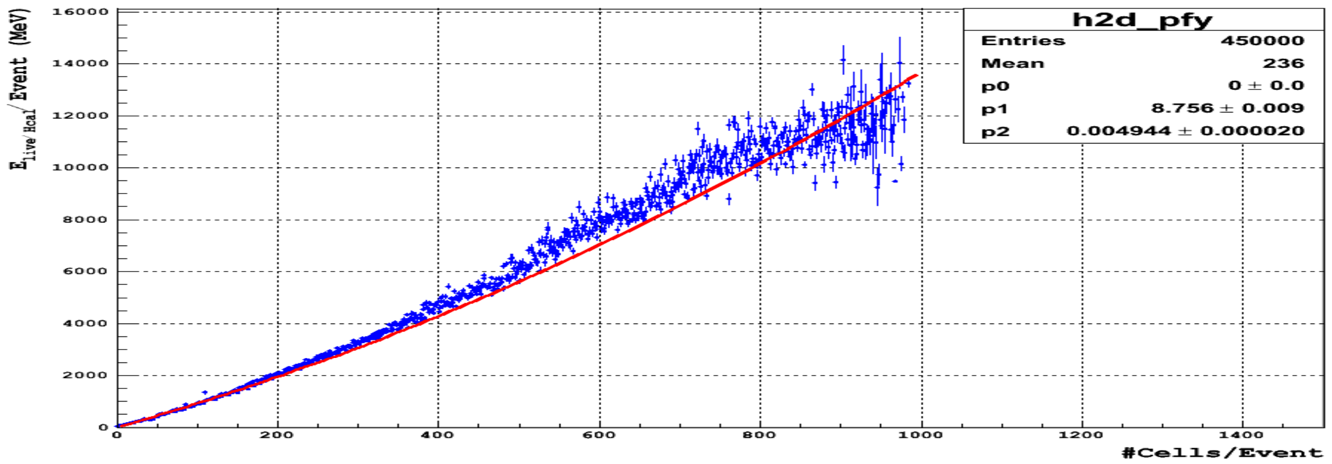
⇨ Must minimize "confusion term" – mis-assignment of energy depositions.

⇨ Must measure neutral energy directly with reasonable resolution.

Digital hadron calorimetry (2)

Our 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.



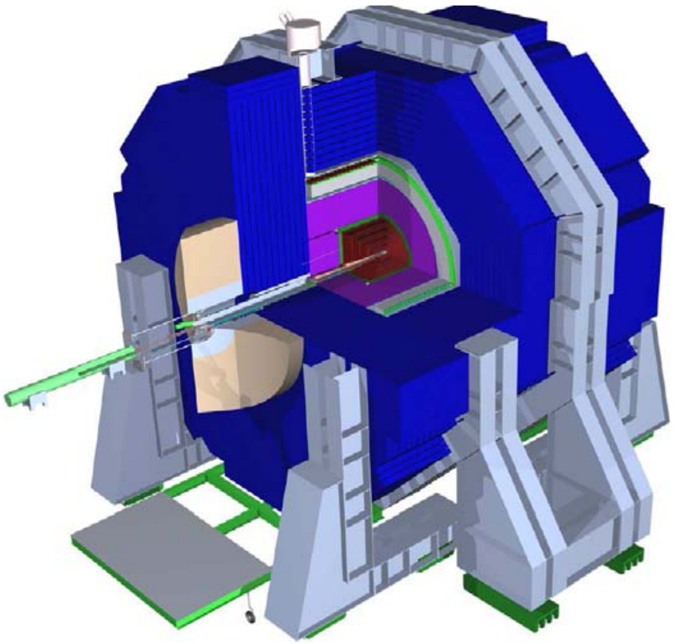
Venkat Kaushik, Masters' Thesis, UTA 2006

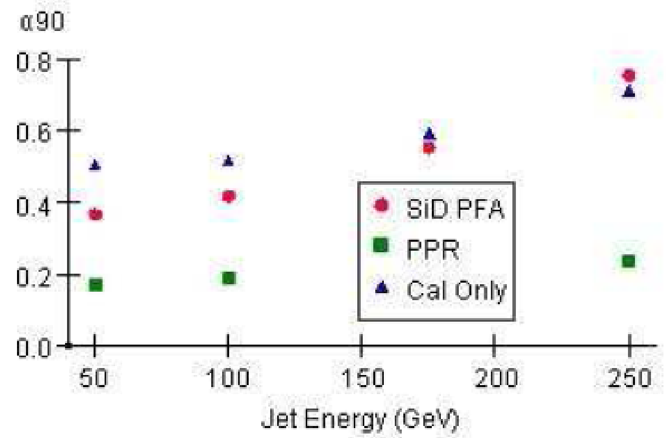
Digital hadron calorimetry

The development of Particle Flow Algorithms and the associated possible technological applications have been identified as top priority items by the SiD and ILD detector concepts, by the ILC Detector R&D Panel, and by the U.S. DoE and NSF.

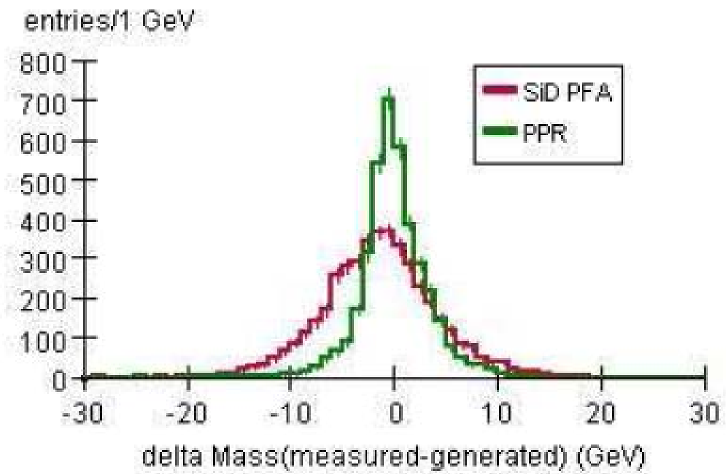
In the U.S. we are hoping that this translates into the provision of enhanced resources for PFA development and for bringing the various alternative technologies to an equal level of development in time for technology choices by 2012.

PFA performance for SiD detector concept



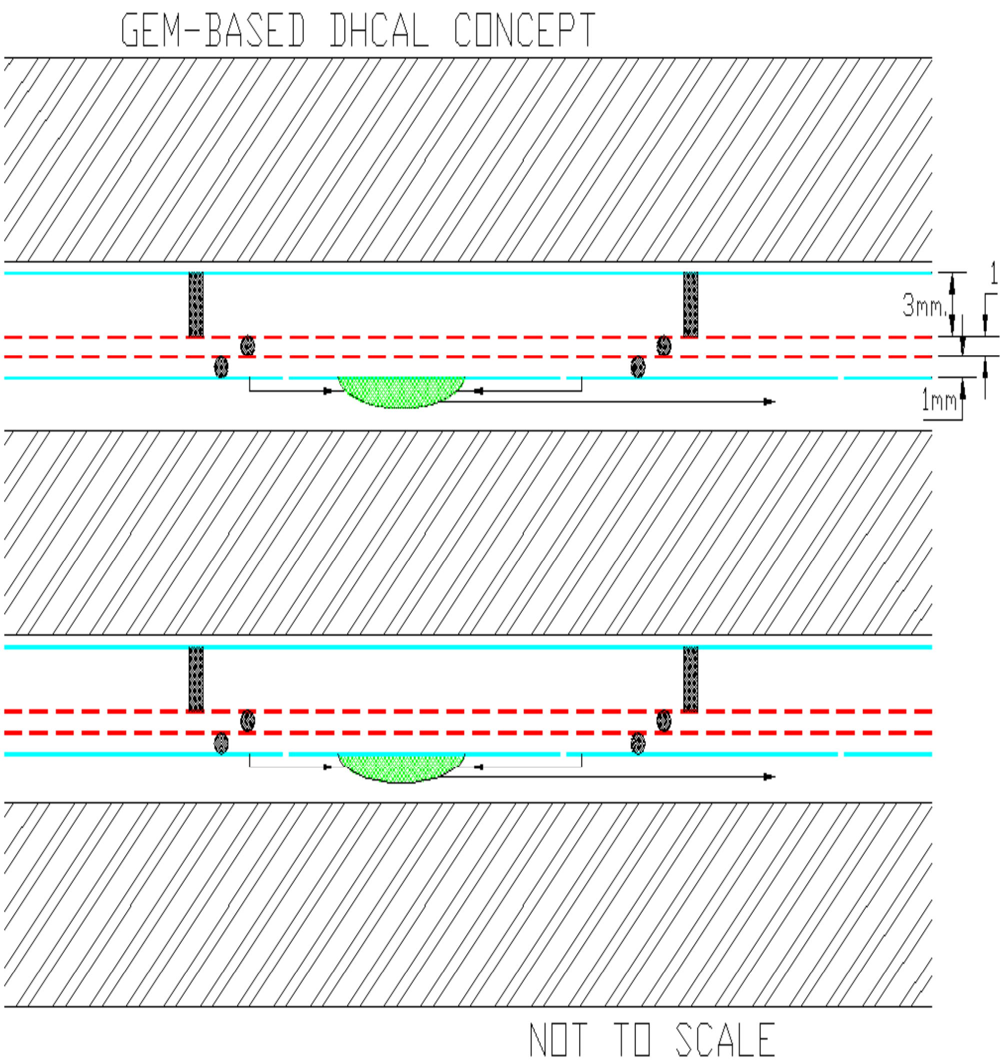


We have indications that we can achieve the required performance for ILC physics…but what is the best choice of technology for implementation of a digital hadron calorimeter?



ZZ sample

GEM/DHCAL active layer concept



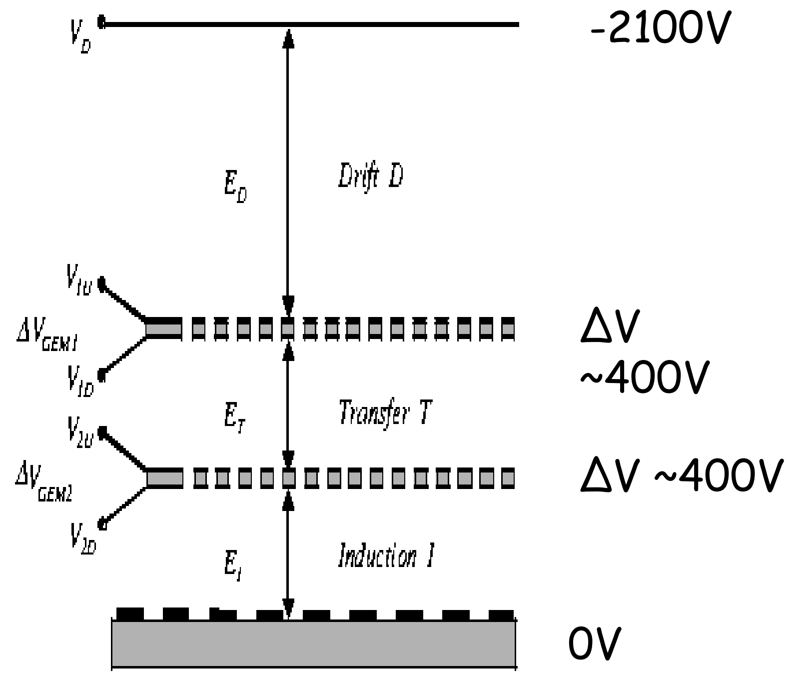
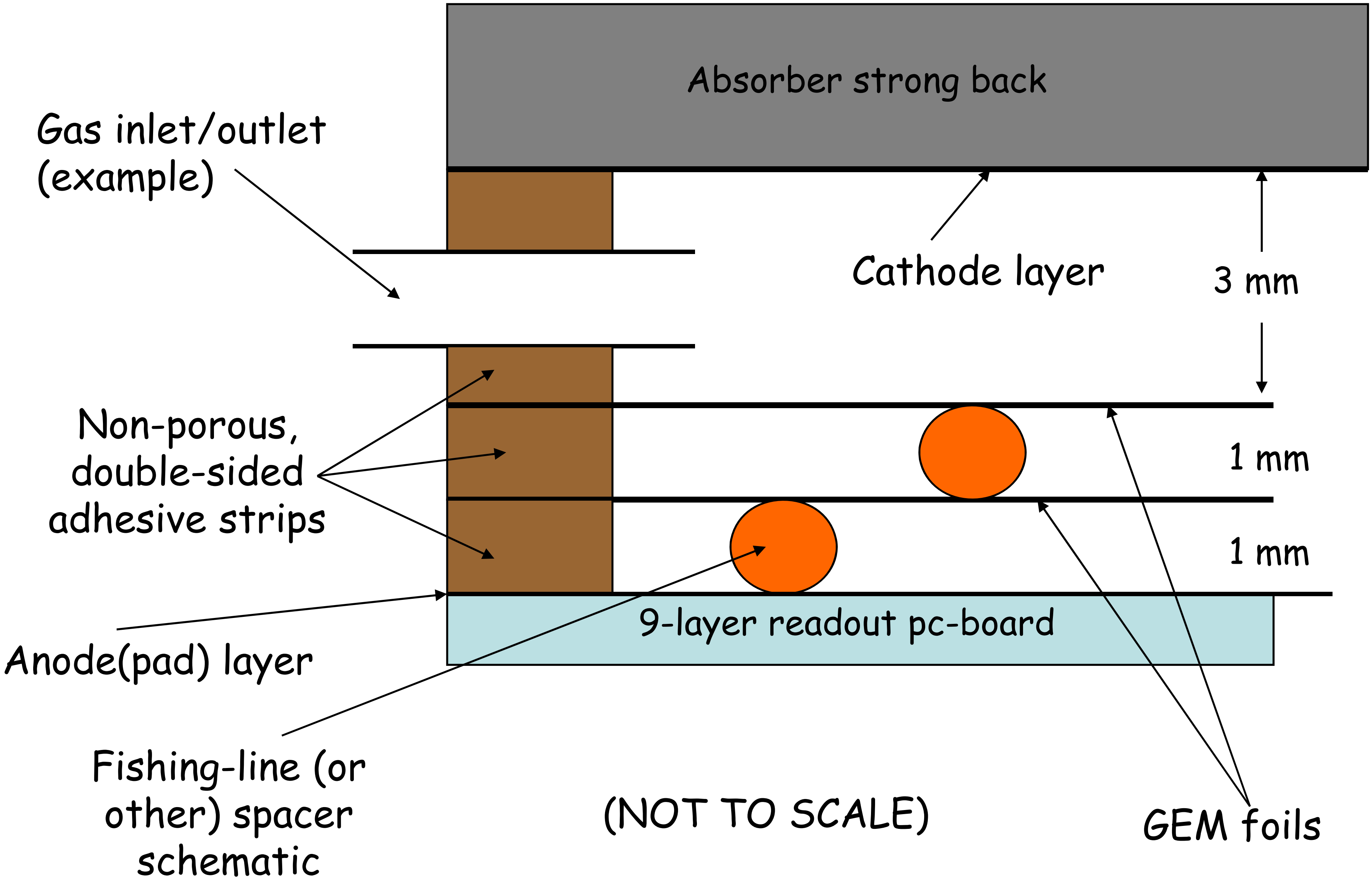


Fig. 1: Schematics of a double-GEM detector.

Development of GEM sensitive layer



GEM Measurement – small prototypes

- 9-pad (3x3) GEM Chamber – double GEM (10cm x 10cm) CERN foils

- Threshold 40mV -> 95% efficiency

- Sr-90 source/scintillator trigger

-> Result: Average multiplicity = 1.27

(cf. e.g. RPC typical multiplicity of 1.6 – 1.7)

Lower multiplicity helps reduce the confusion term in a Particle Flow Algorithm.

Now using 30cm x 30cm GEM foils from 3M...with KPiX chip readout from SLAC.

KPiX/GEM/DHCAL readout

KPiX is an advanced chip designed to operate in the synchronous environment of the ILC.

-> Up to the present v7 KPiX chips have had 64-channels

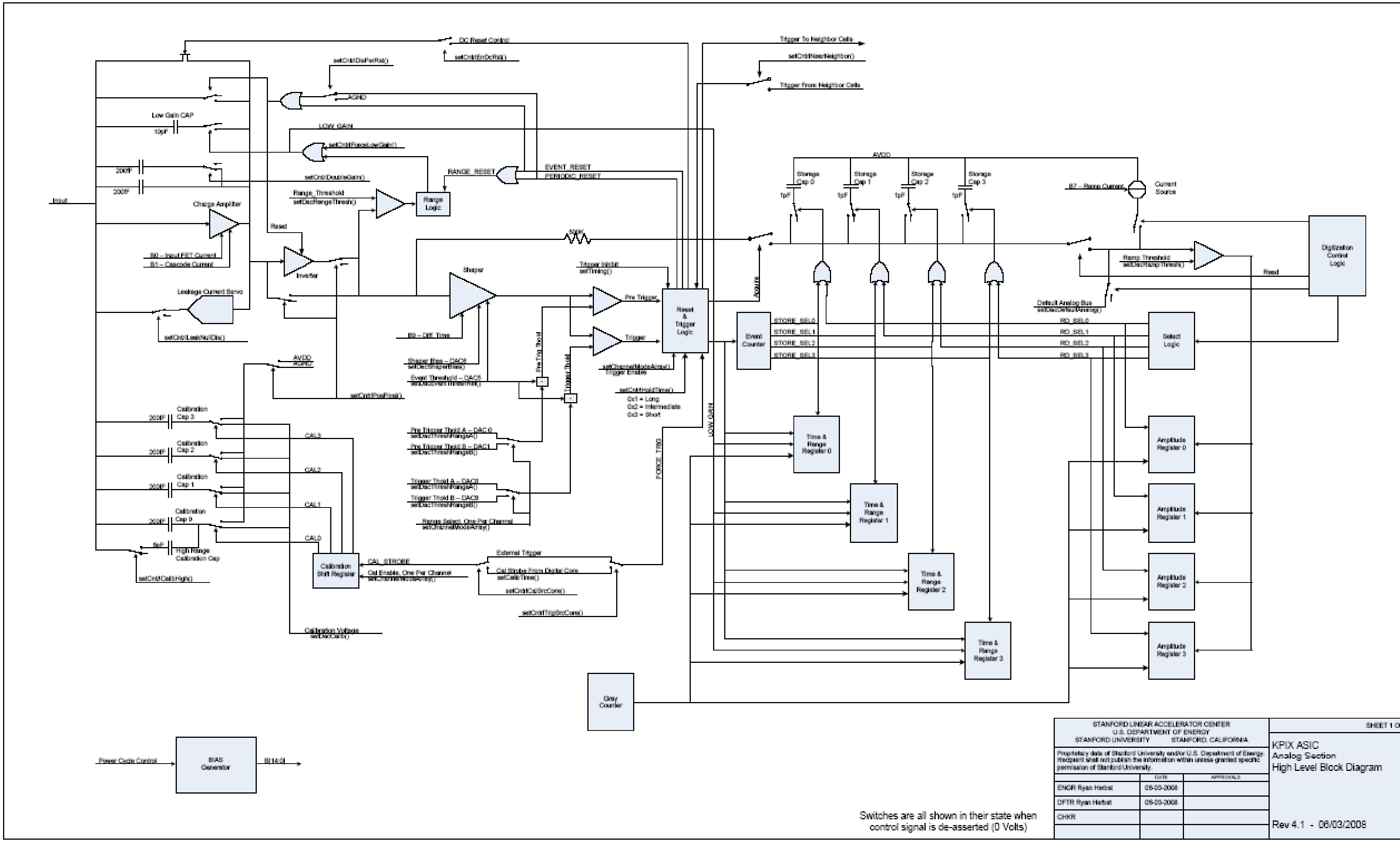
-> Soon to move to 256 channels, then to 1024 channels.

The synchronous nature of KPiX provides challenges when running with asynchronous sources – cosmics, sources, asynchronous test beams (e.g. FNAL MTBF)

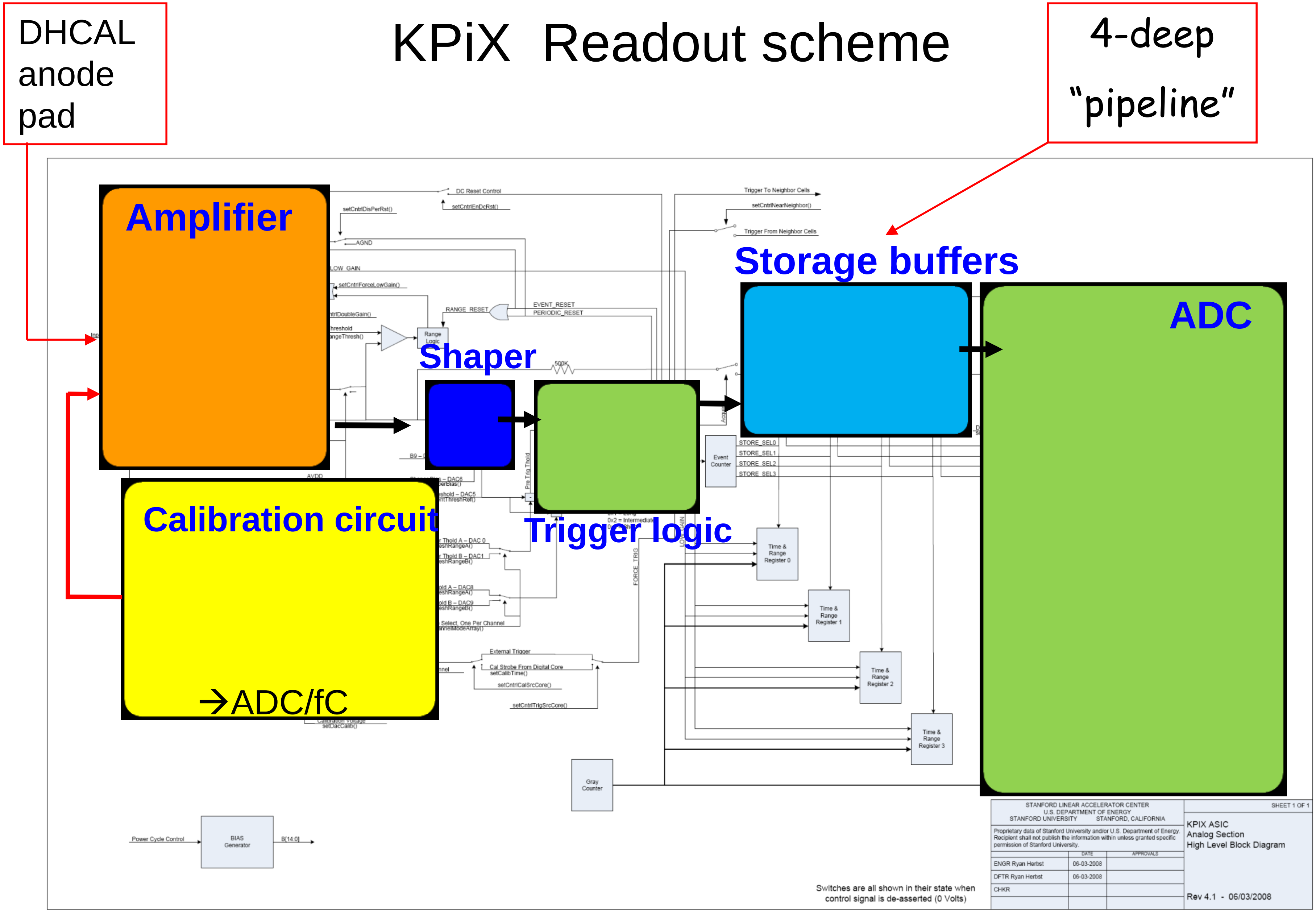
-> There is some hope that SLAC will provide a synchronous e^- beam in ~1 year. (CERN, Fermilab?)

Meanwhile we run at rather low efficiency 5-10% as only part of real time is available for "data acquisition" in the KPiX timing cycle.

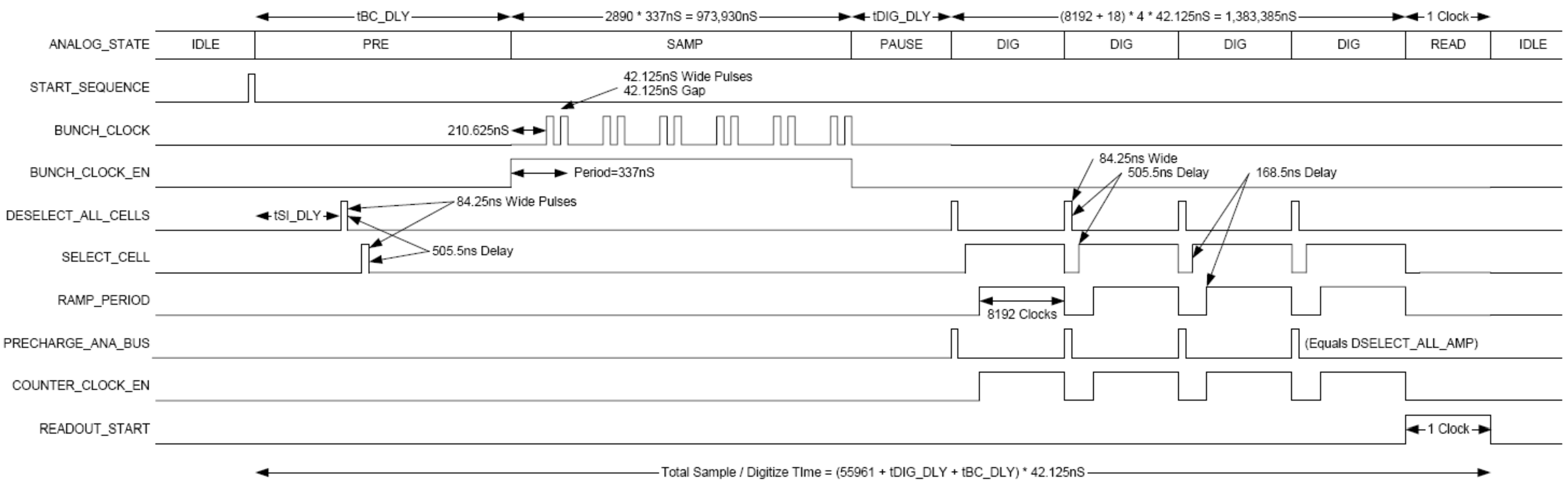
KPiX functional diagram



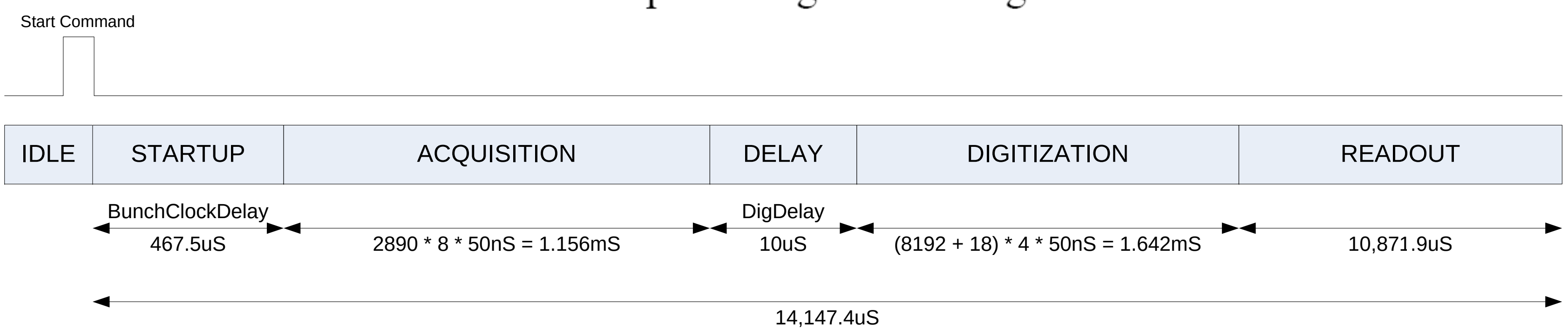
KPiX Readout scheme



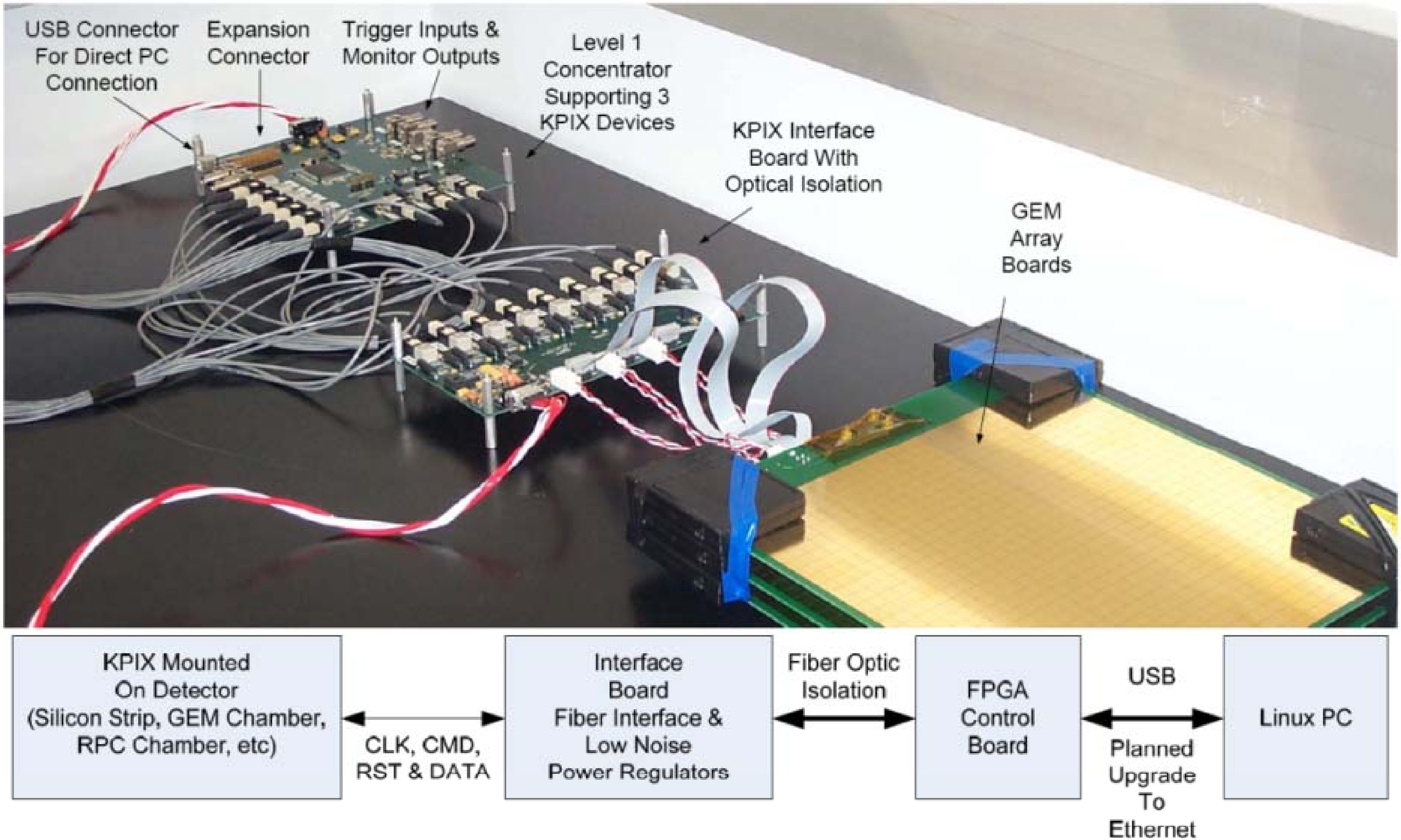
Timing chart for kpix



Sample & Digitize Timing



GEM-DHCAL/KPiX boards with Interface and FPGA boards

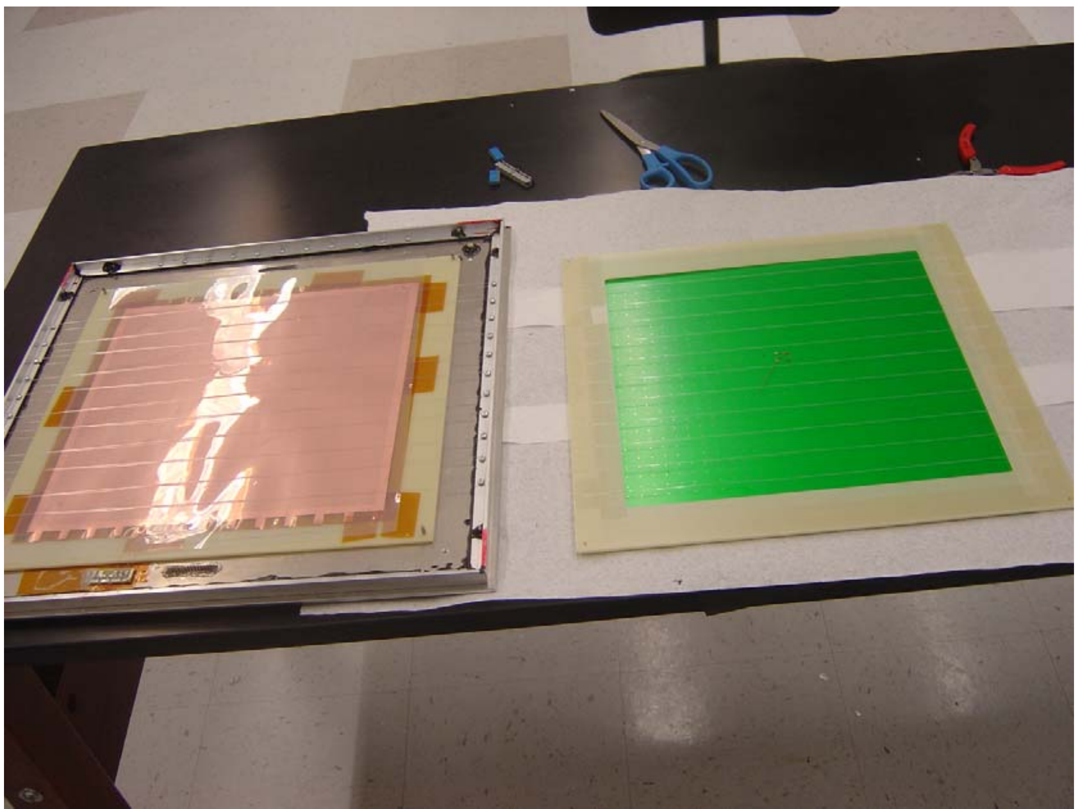


Redesigned GEM chamber – all fishing line spacer

- KPiX anode board with extra electronics protection

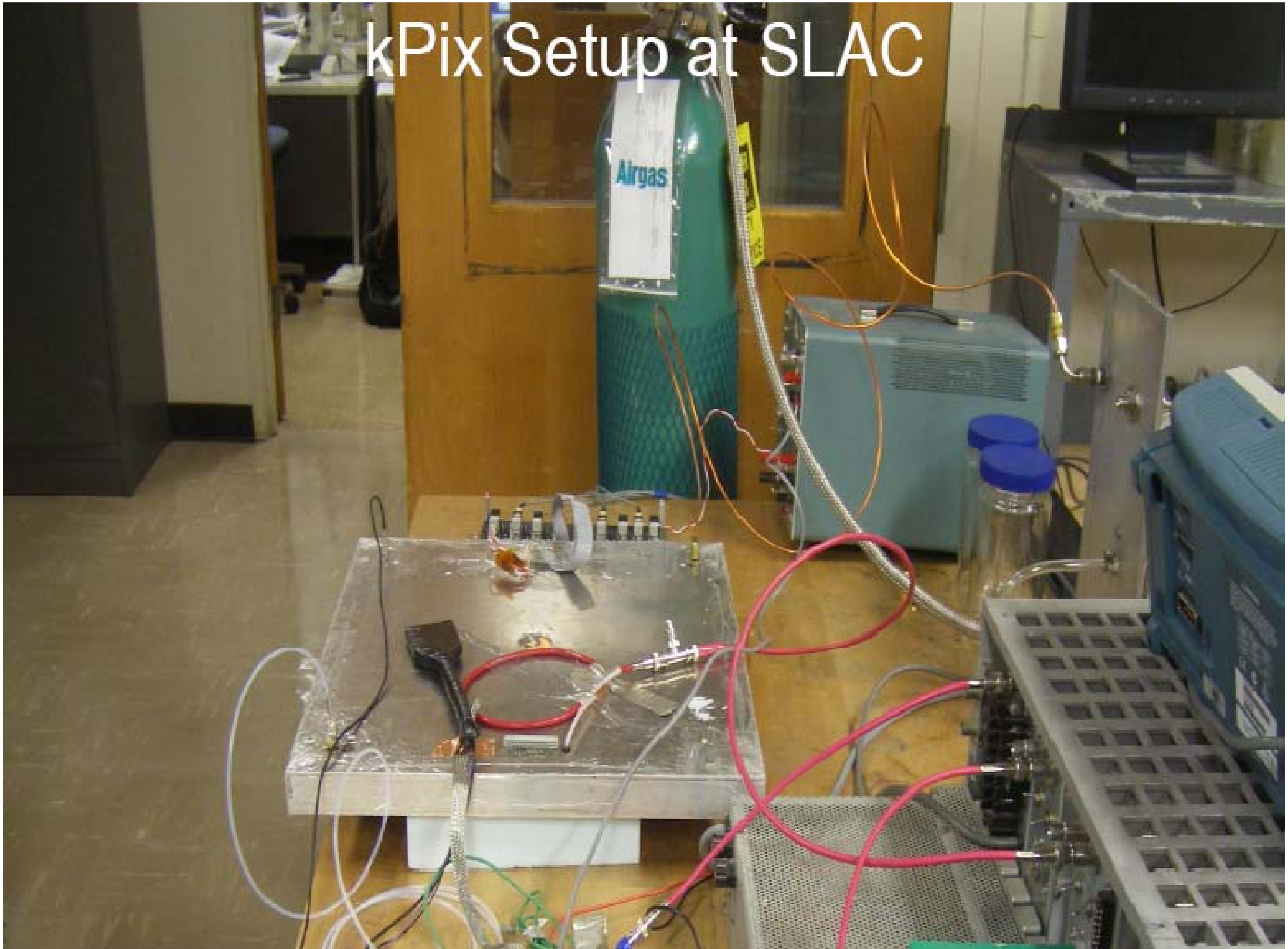
- Better/more direct gas flow through ionization gap

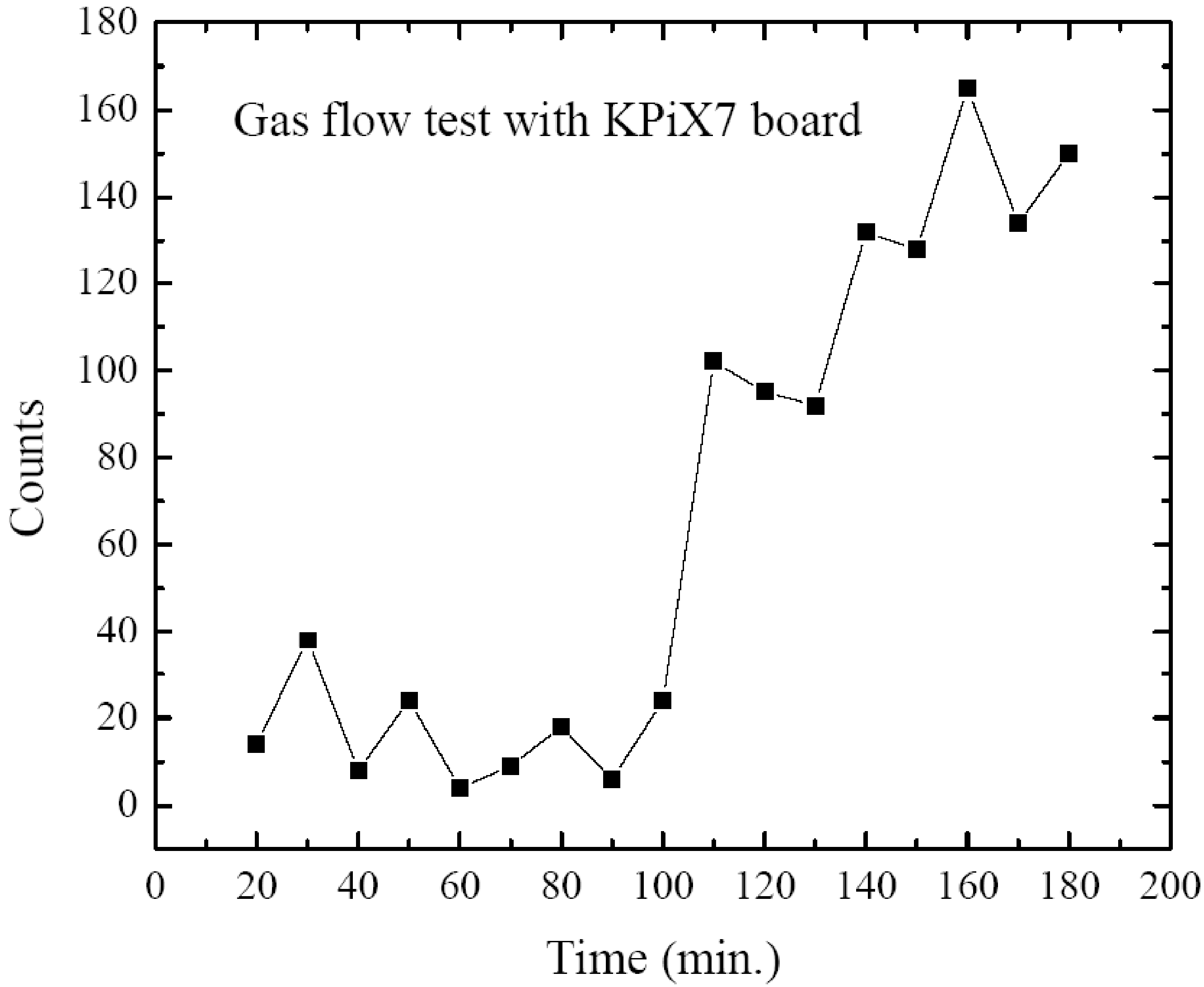
- No large dielectric spacer(s) – previously killed signal in earlier chamber



8x8 anode pad layout

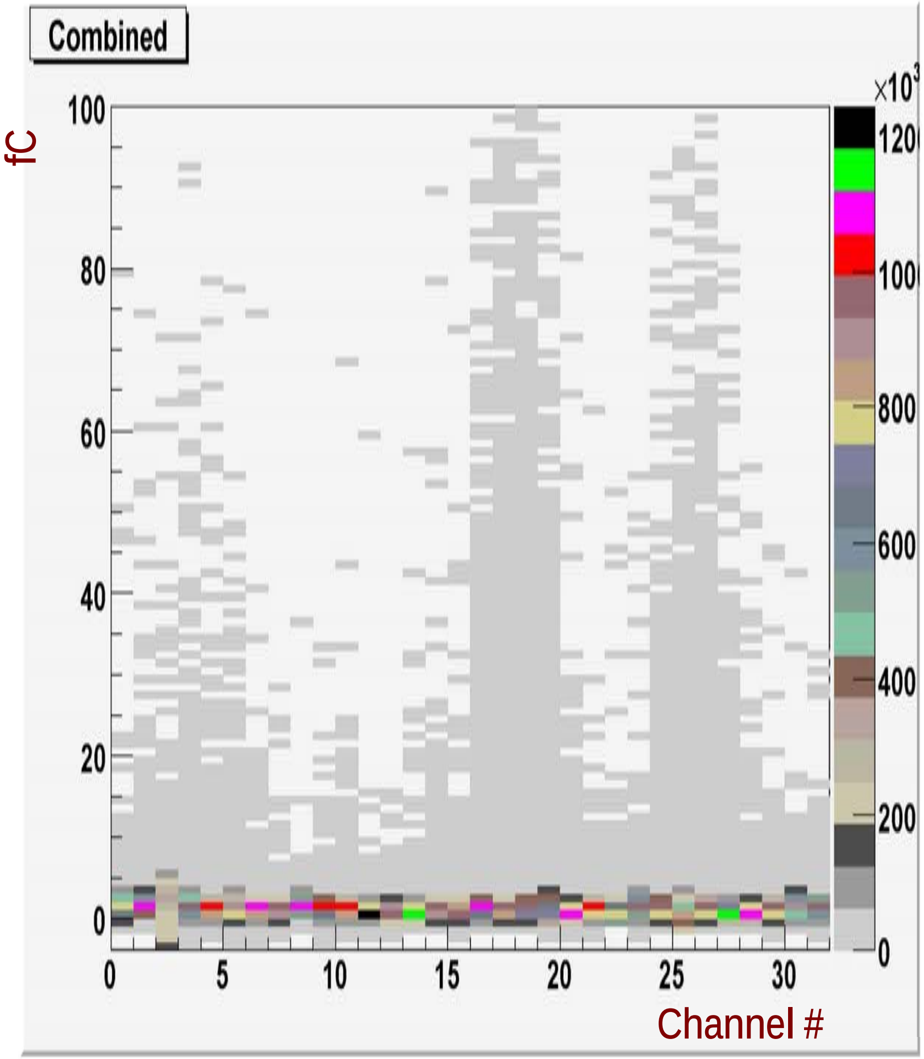
GEM chamber with KPiX v4 – early 2008

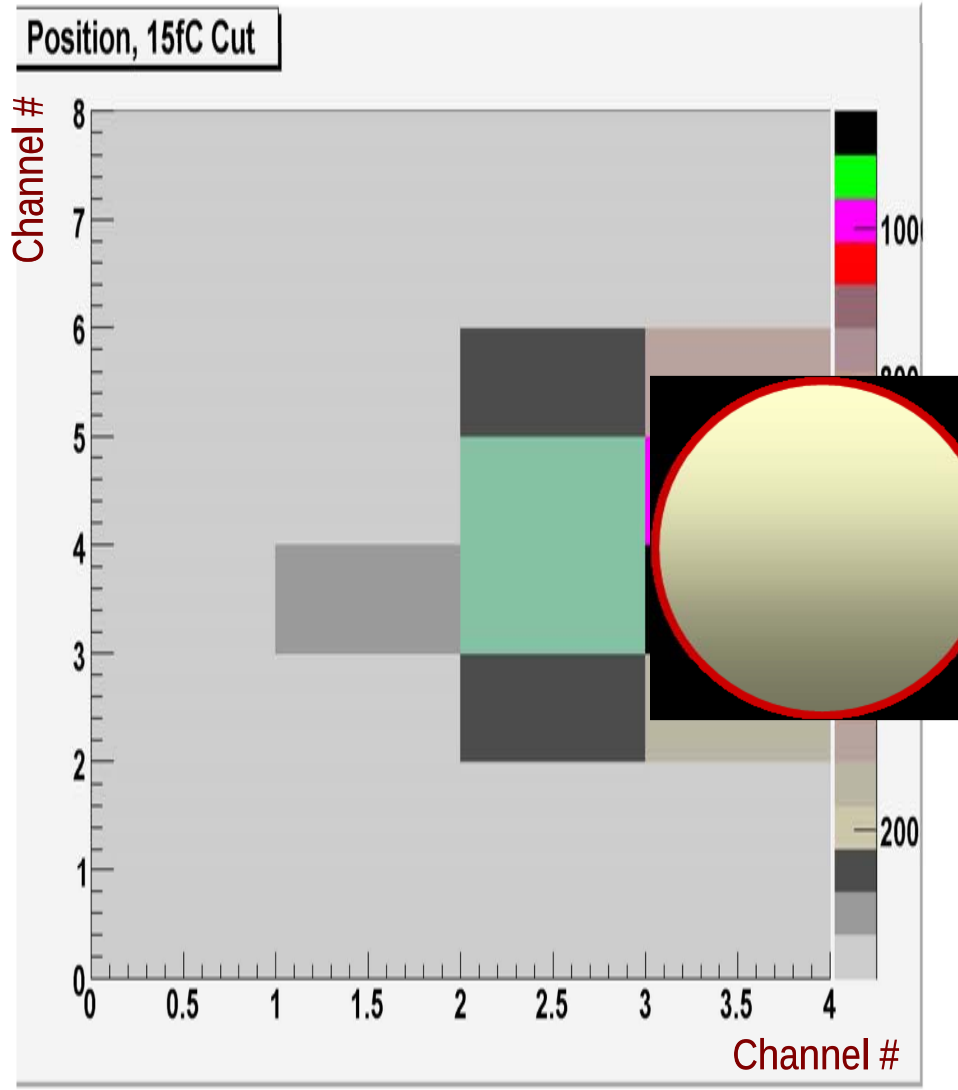




30cm x 30cm GEM chamber turn-on after opening/restarting gas flow

GEM + KPiX long source run at SLAC 2008





KPiX internal calibration

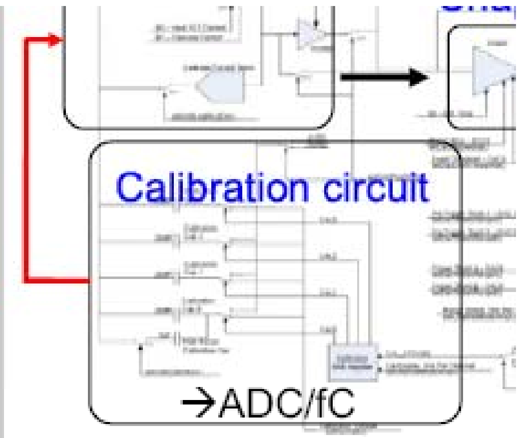
KPiX has an on-board calibration system that allow a cycle of ramped charge injection/read out from a DAC.

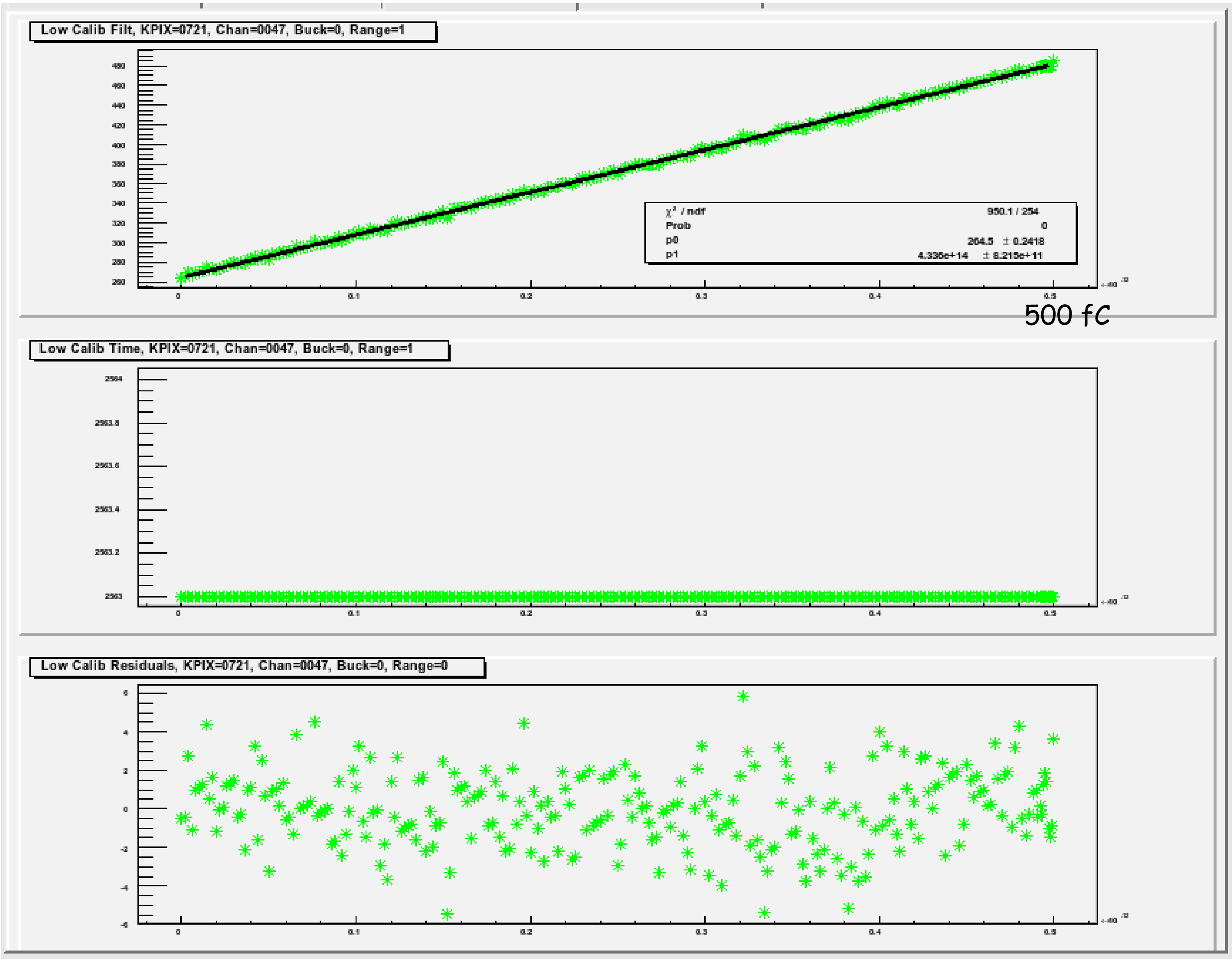
- TSMC claim capacitors accurate to 0.1% - checked out within groups of four. If this holds, this would reduce the problem of obtaining absolute gains in one channel by a factor of ~1000.

- We have tested this system and used the results to produce calibrated data for source runs – see later.

KPiX internal calibration

Low gain mode





GEM-DHCAL chamber studies with Ru106

We have made studies with Ru106, Fe55, and cosmics in self- and external trigger modes. The results presented here are for Ru106 with self trigger.

- establish chamber characteristics as precursor to building 1m x 33cm submodules for test beam exposure

- learn use of KPiX for asynchronous data taking

- checkout operation of KPiX – timing, pipeline,…prepare for 256-, 1024-channel KPiX

- measure hit multiplicity, understand noise source(s).

Ru106 electron source spectrum

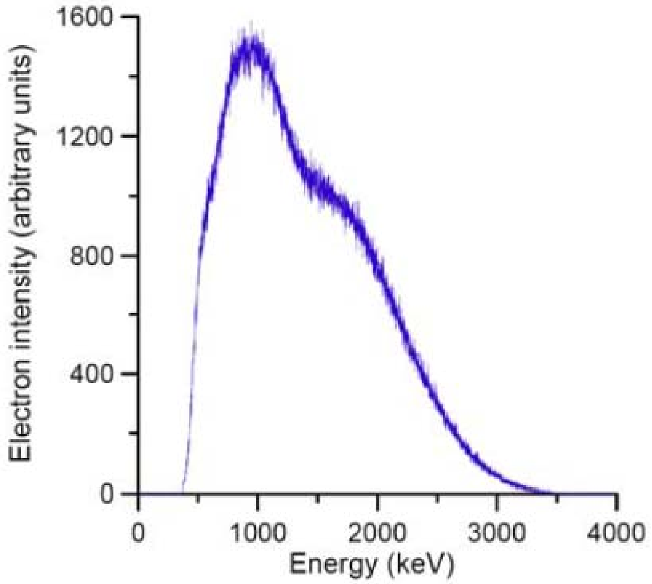


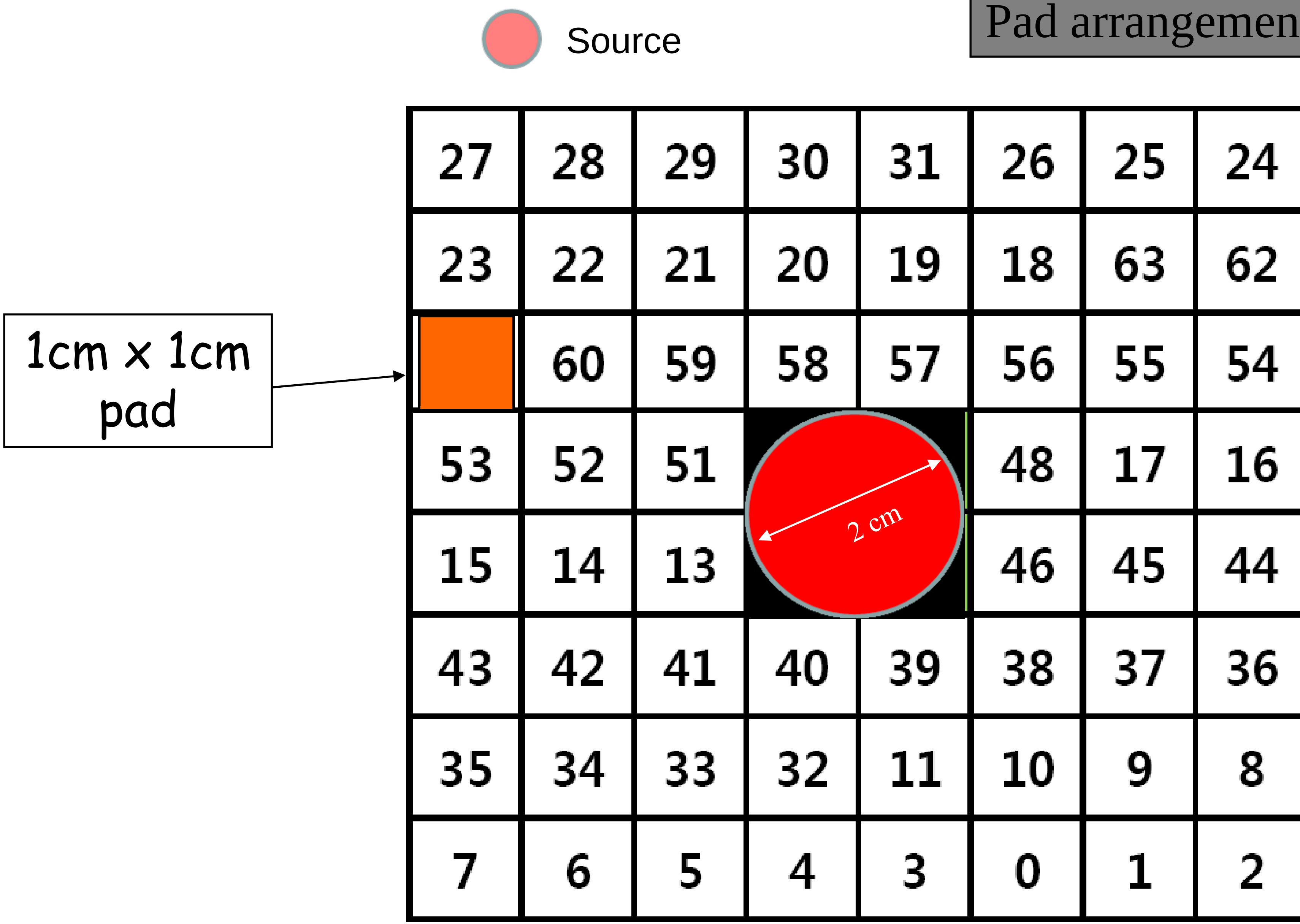
Figure 8. Reconstructed beta emission spectrum of Ru-106 plaque.

24th Summer School and International Symposium on the Physics of Ionized Gases IOP Publishing
Journal of Physics: Conference Series **133** (2008) 012002 doi:10.1088/1742-6596/133/1/012002

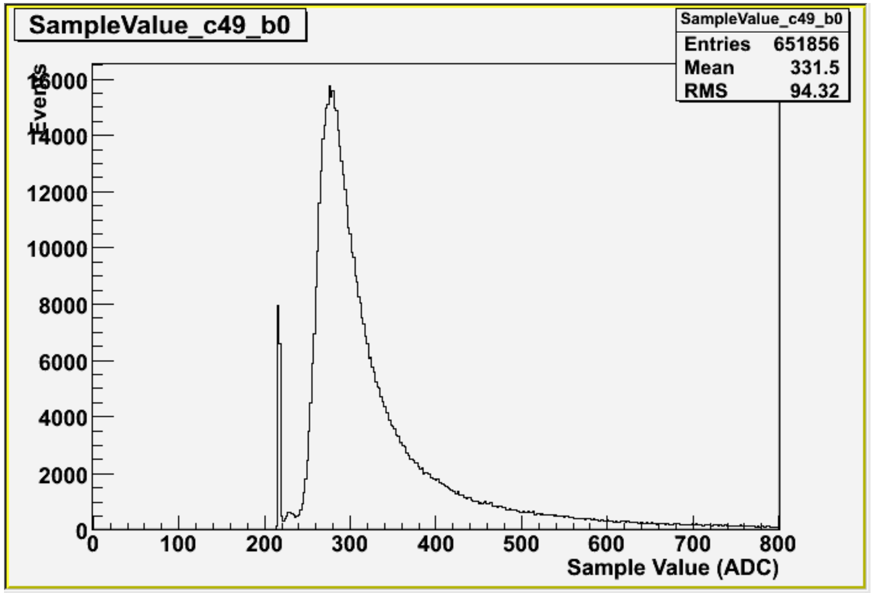
Energy deposition model based on electron scattering cross section data from water molecules

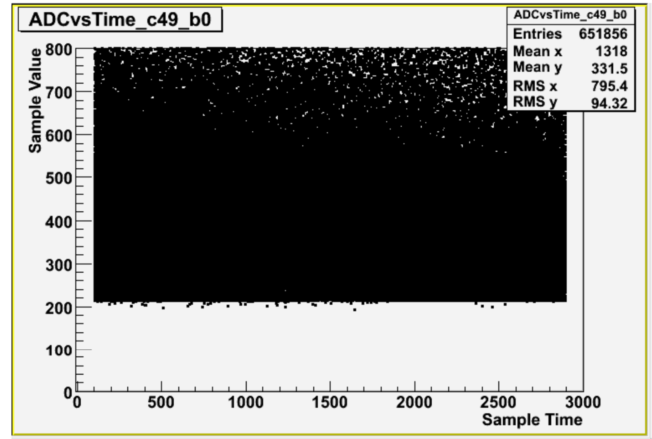
A.Muñoz[1], J. C. Oller[1], F. Blanco[2], J. D. Gorfinkiel[3], P. Limão-Vieira[4], A. Maira-Vidal[5], M. J. G. Borge[5], O. Tengblad[5], C. Huerga[6], M. Téllez[6] and G. García[7]

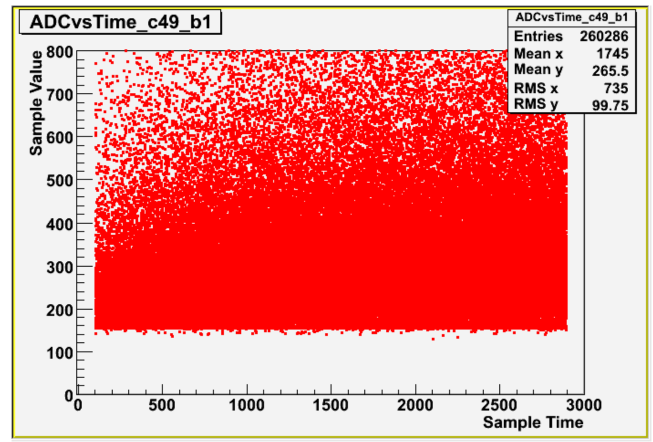
Pad arrangement

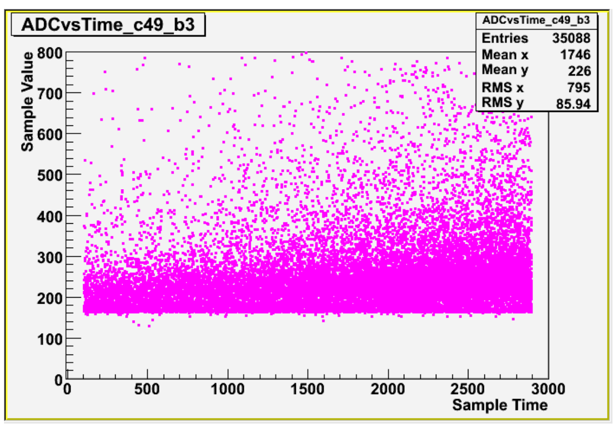


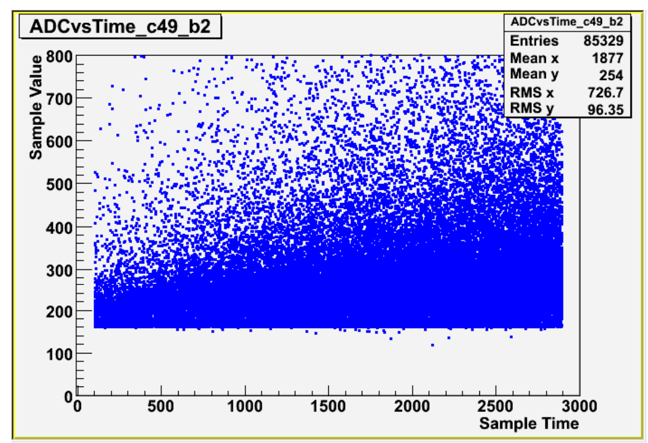
Self trigger, with Ru106



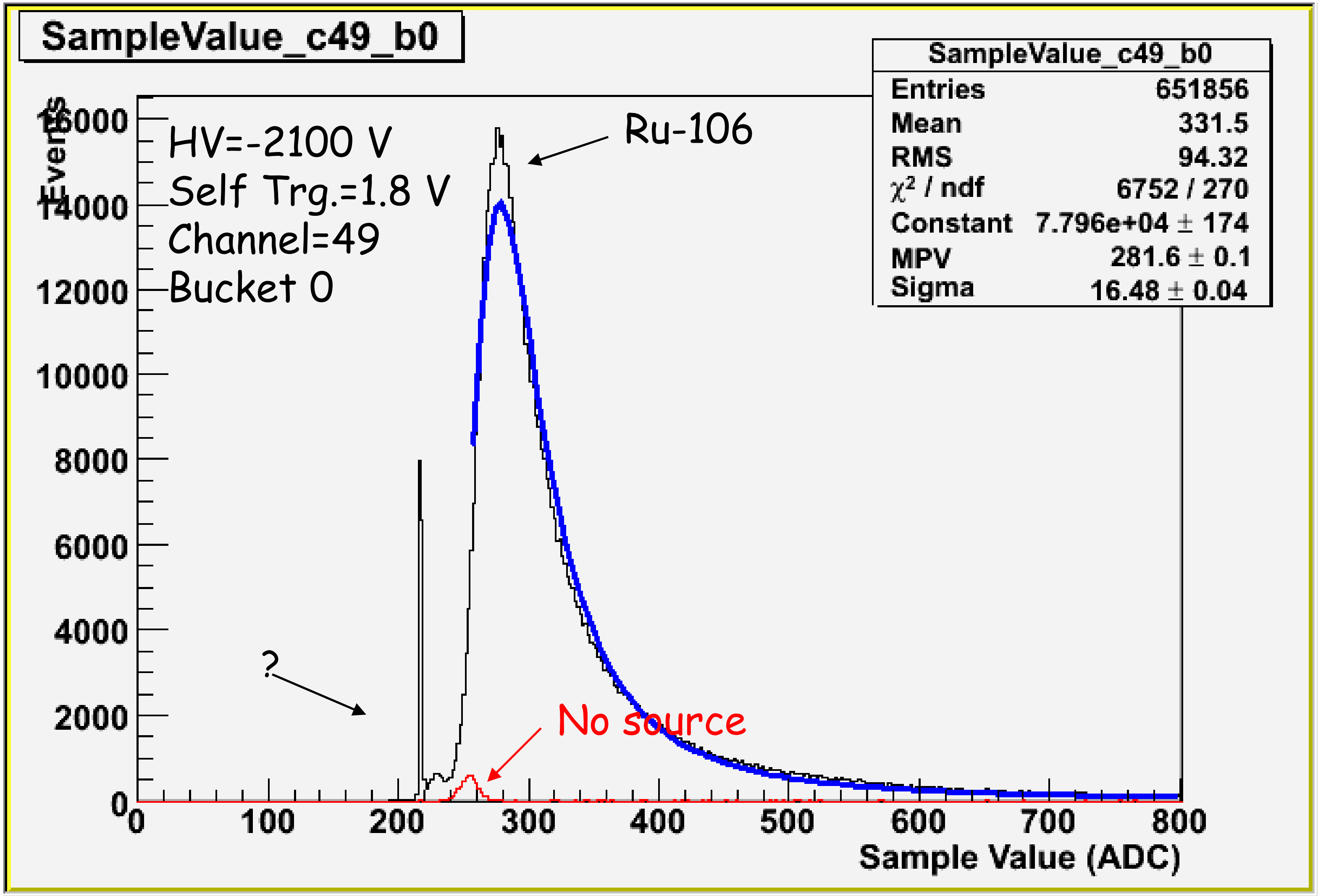




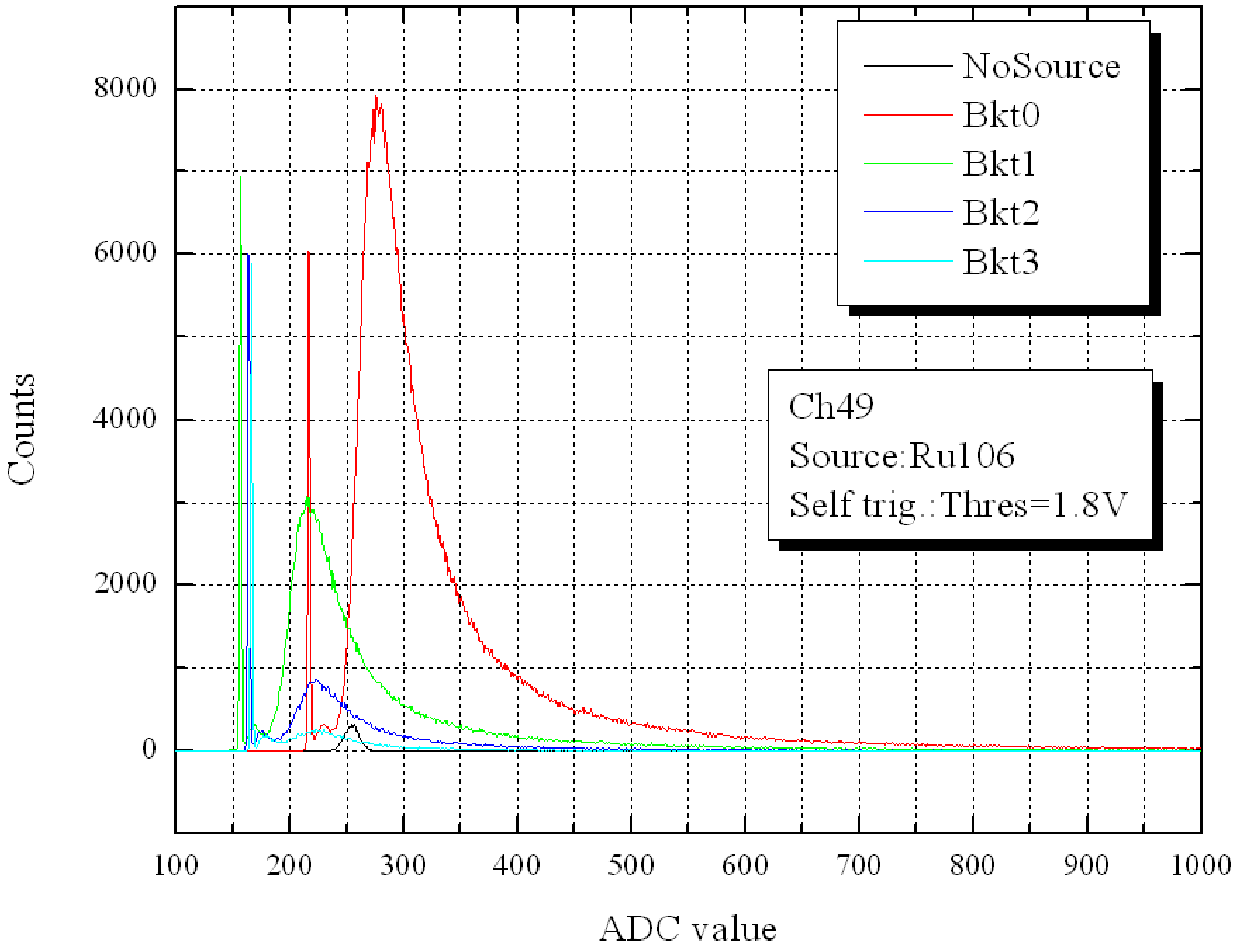




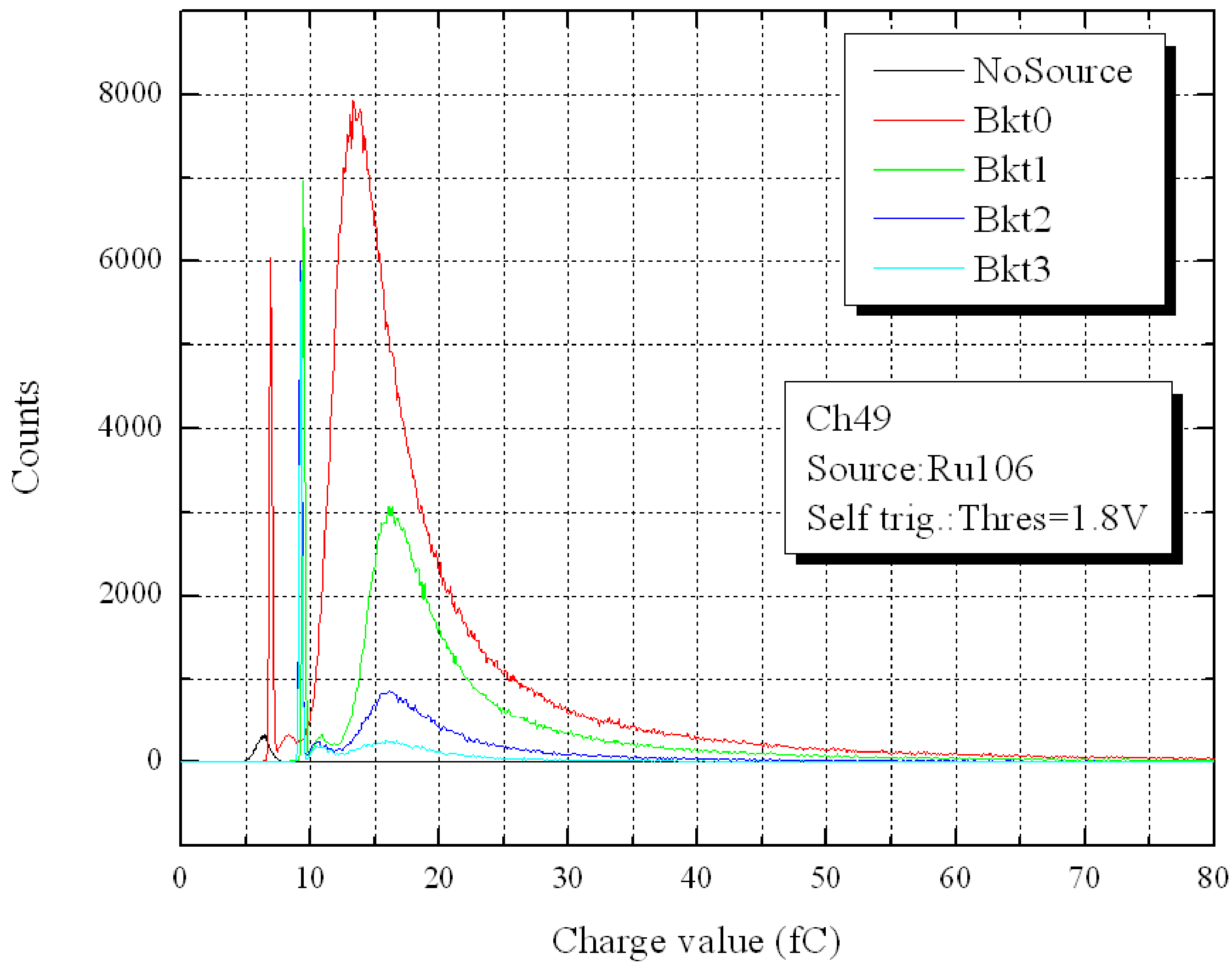
Example of results from tests of GEM with KPiX v.7



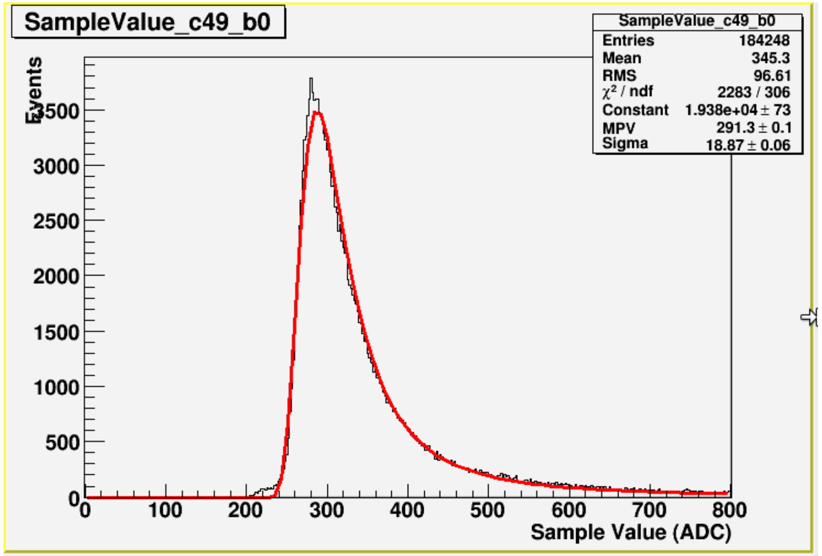
Un-calibrated data/Ch49

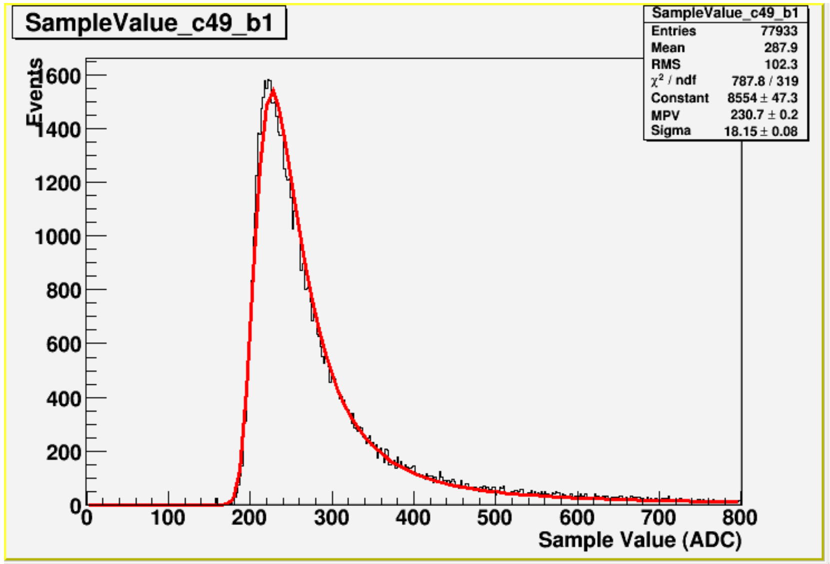


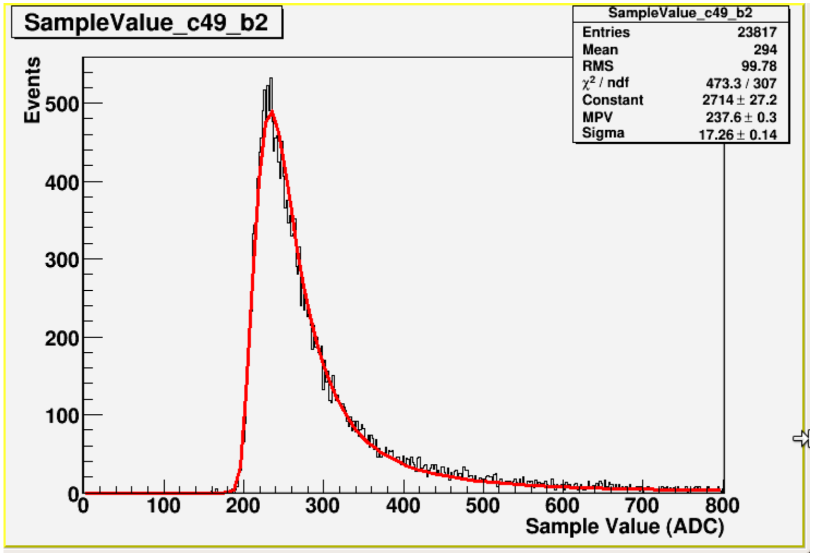
Calibrated data/Ch49

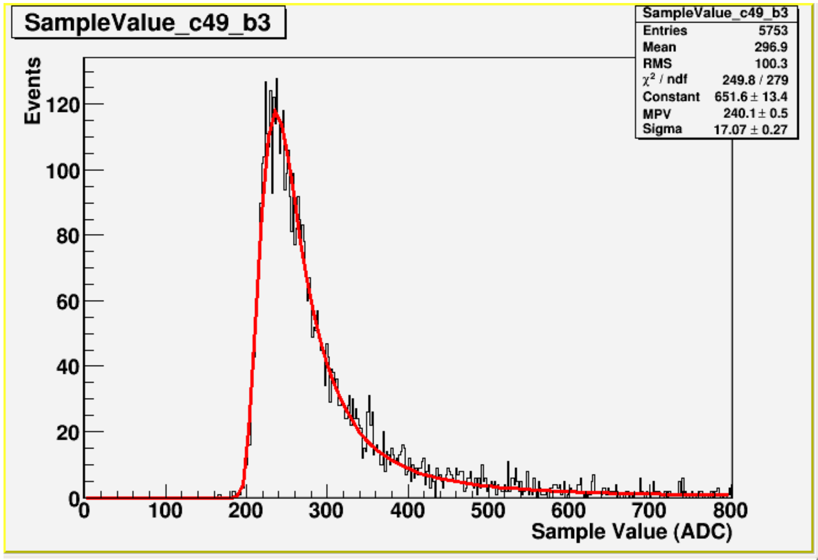


Result of threshold run, Ch49, Thres=1.8 V=128.56 ADC

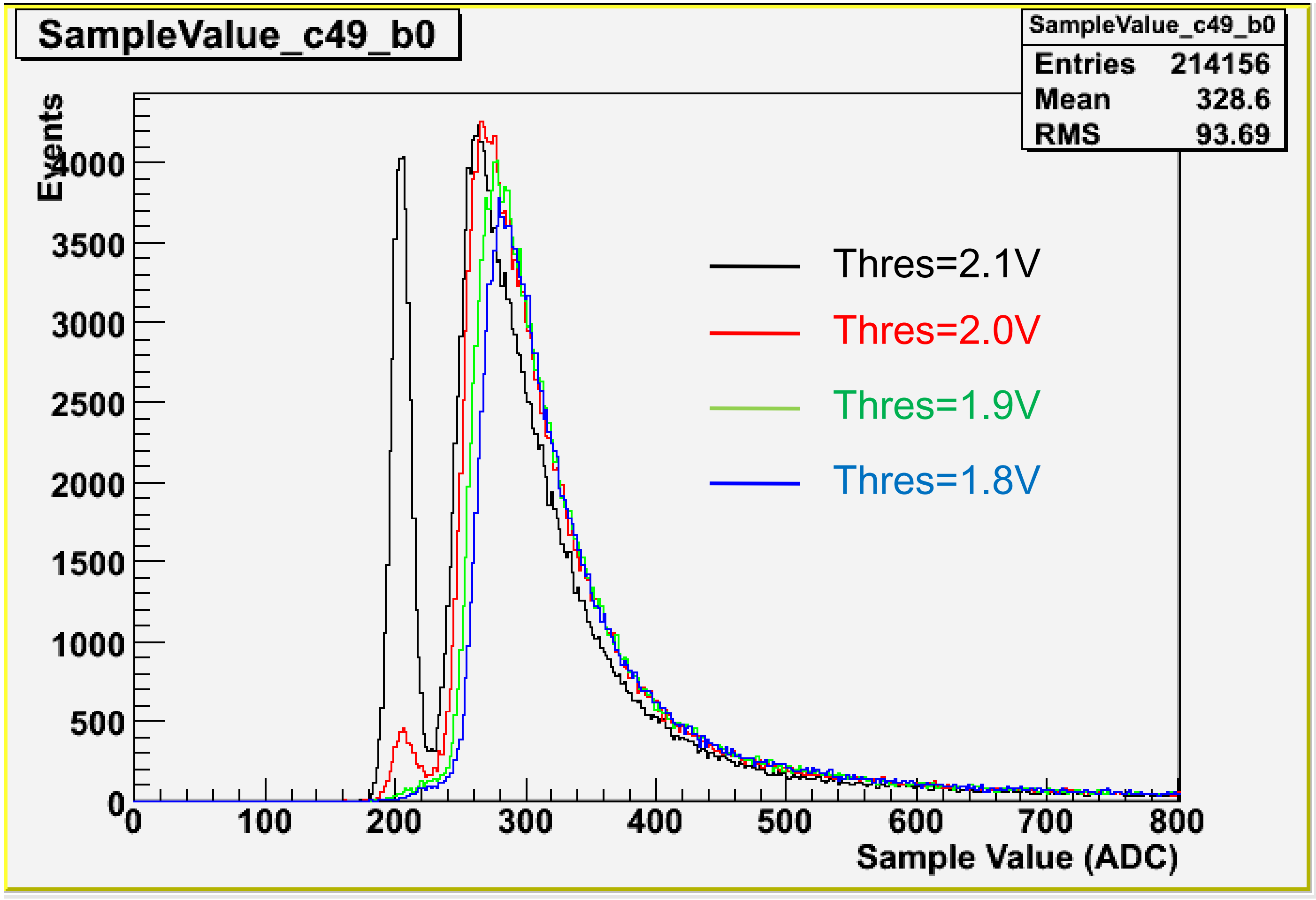








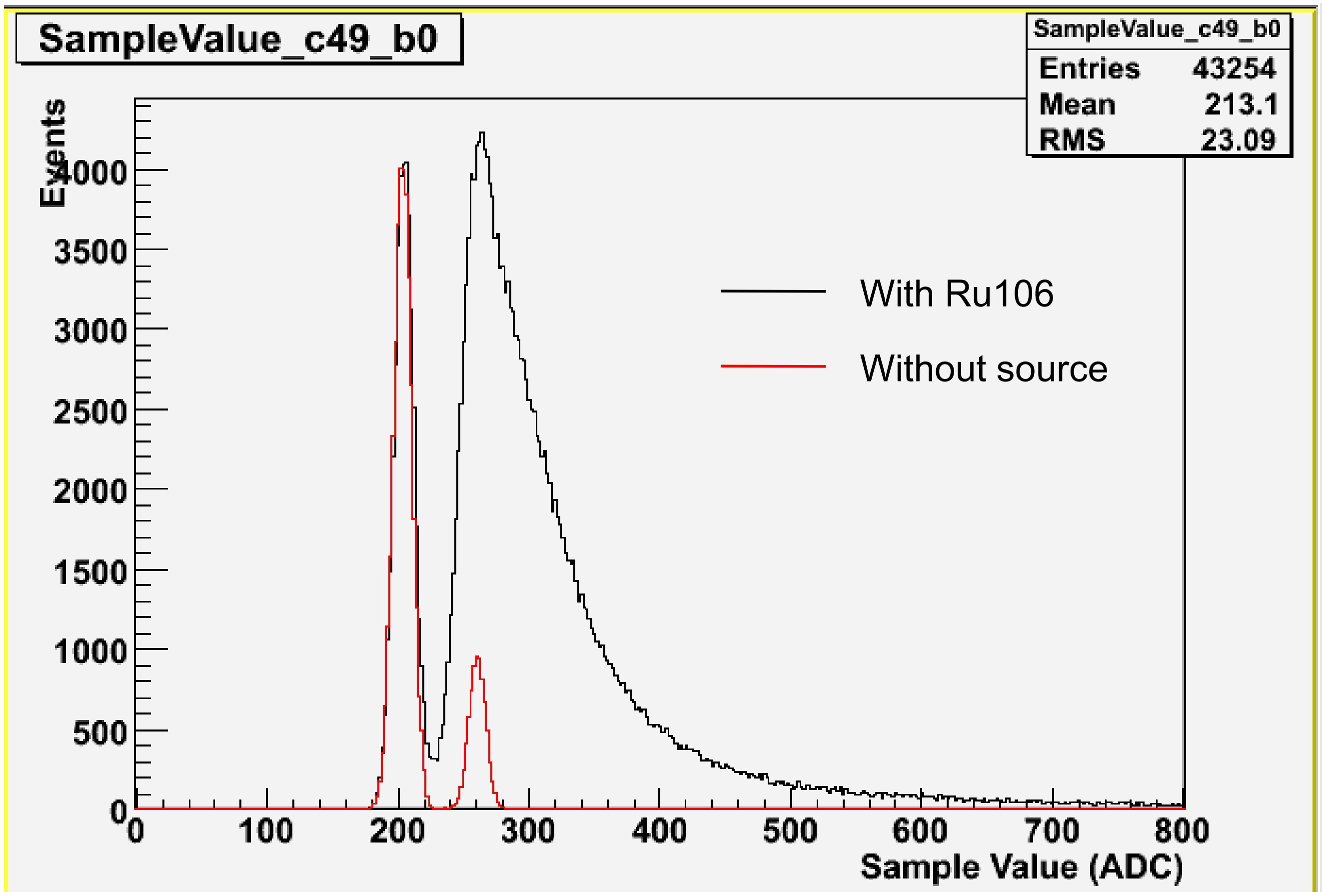
Result of threshold run – bucket 0 HV=2100 V



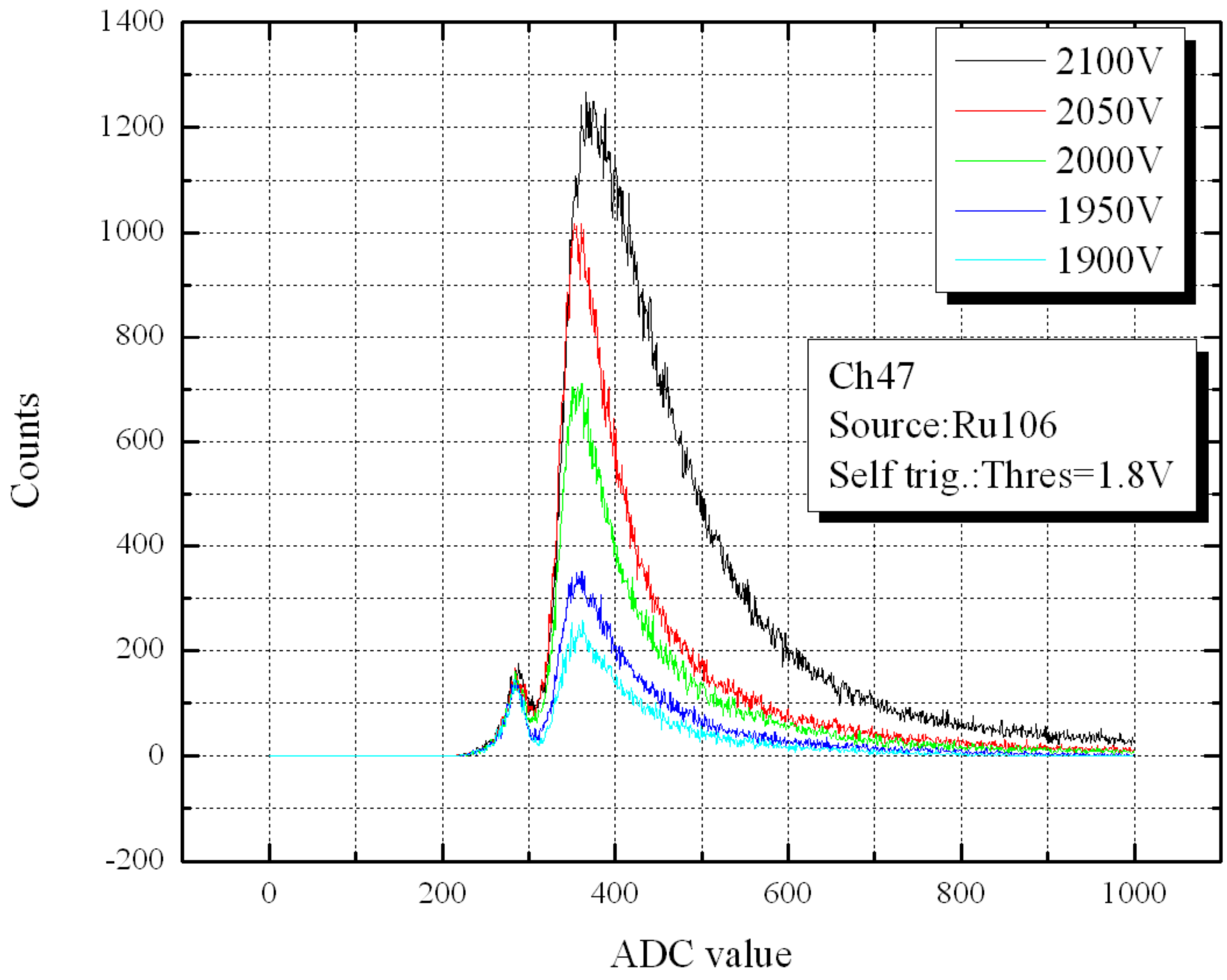
For Ch 49: Thres=1.8V=128.56 ADC, 2.1 V=73.46 ADC

Result of background measurement

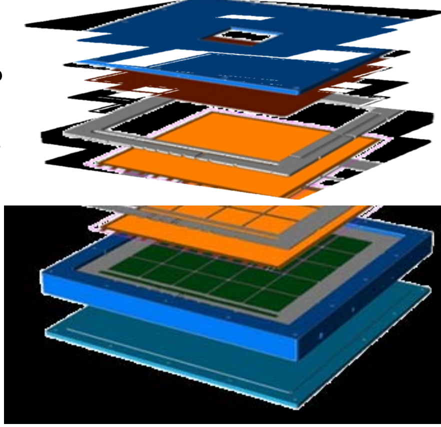
HV=2100V, Gas=Ar:CO2=80:20, 30 ccm
Self Trigger, Trg ch=27,47,49,50, Rate limit=20 Hz
Ext. Trg. Cable connected



HV dependence

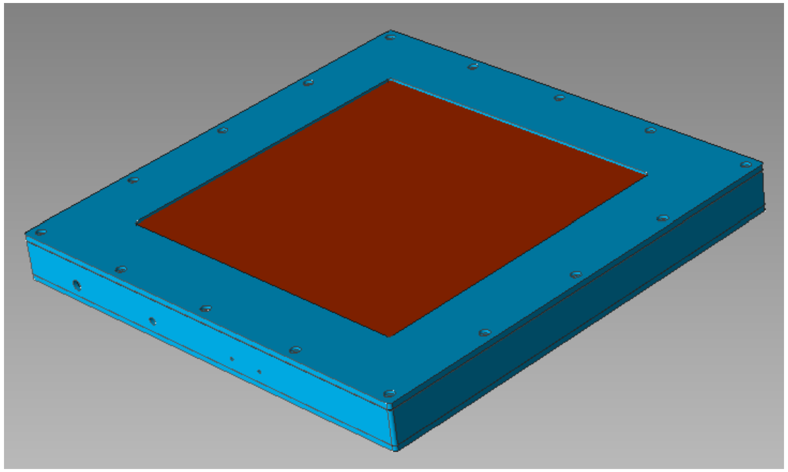


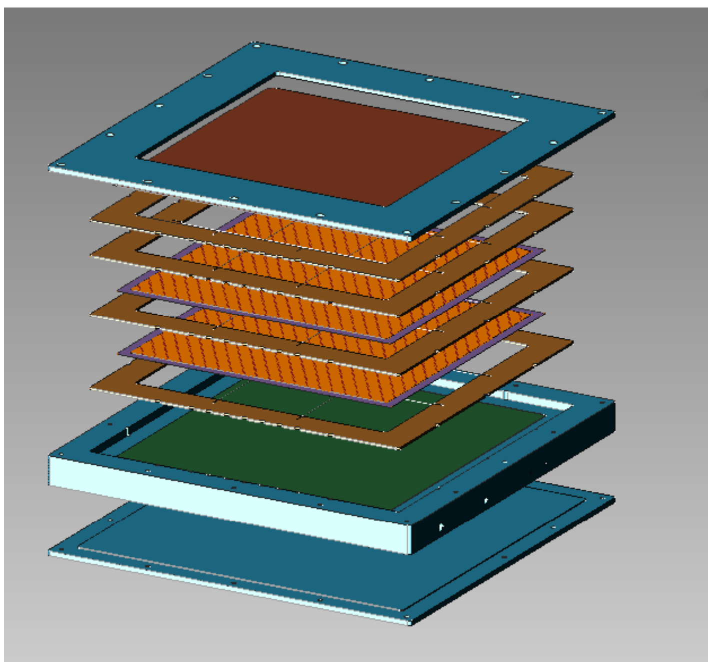
GEM DHCAL Plans - I

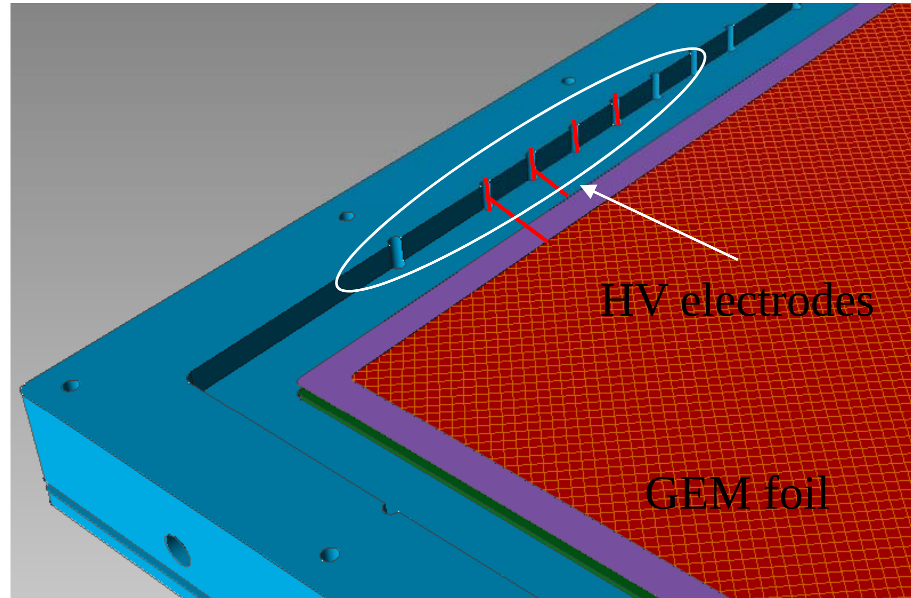


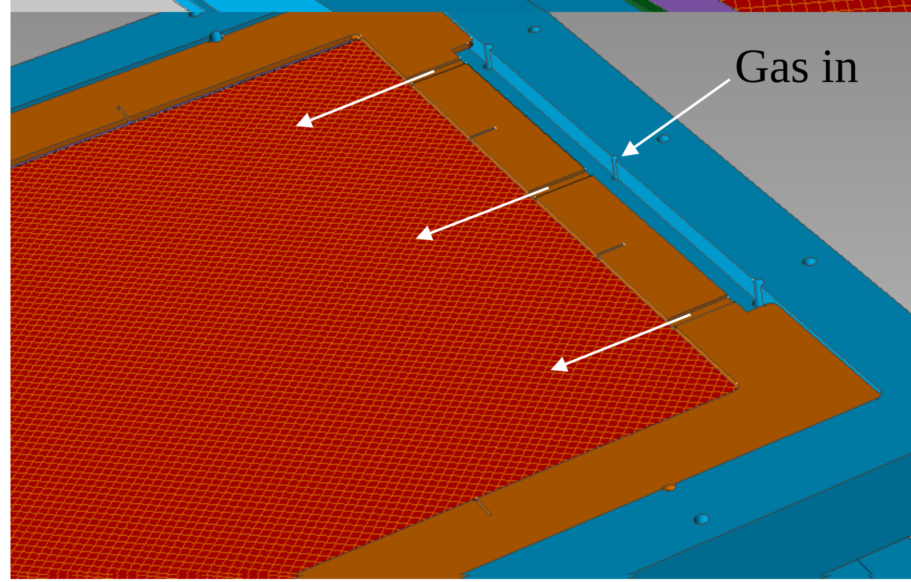
- Through Fall 2009
  - 30cmx30cm chamber
    - Constructed a new chamber (last week) with optimized gas flow design
    - Characterizing the chamber with sources and cosmic rays using 64 channel KPiX v7 at UTA
    - Characterize the chamber in particle beams
      - Signal, noise characteristics, efficiencies, gains, etc
  - 33cmx100cm unit chamber
    - Finalize 33cmx100cm (32cmx96cm active area) large GEM foil silkscreen design

GEM II prototype design

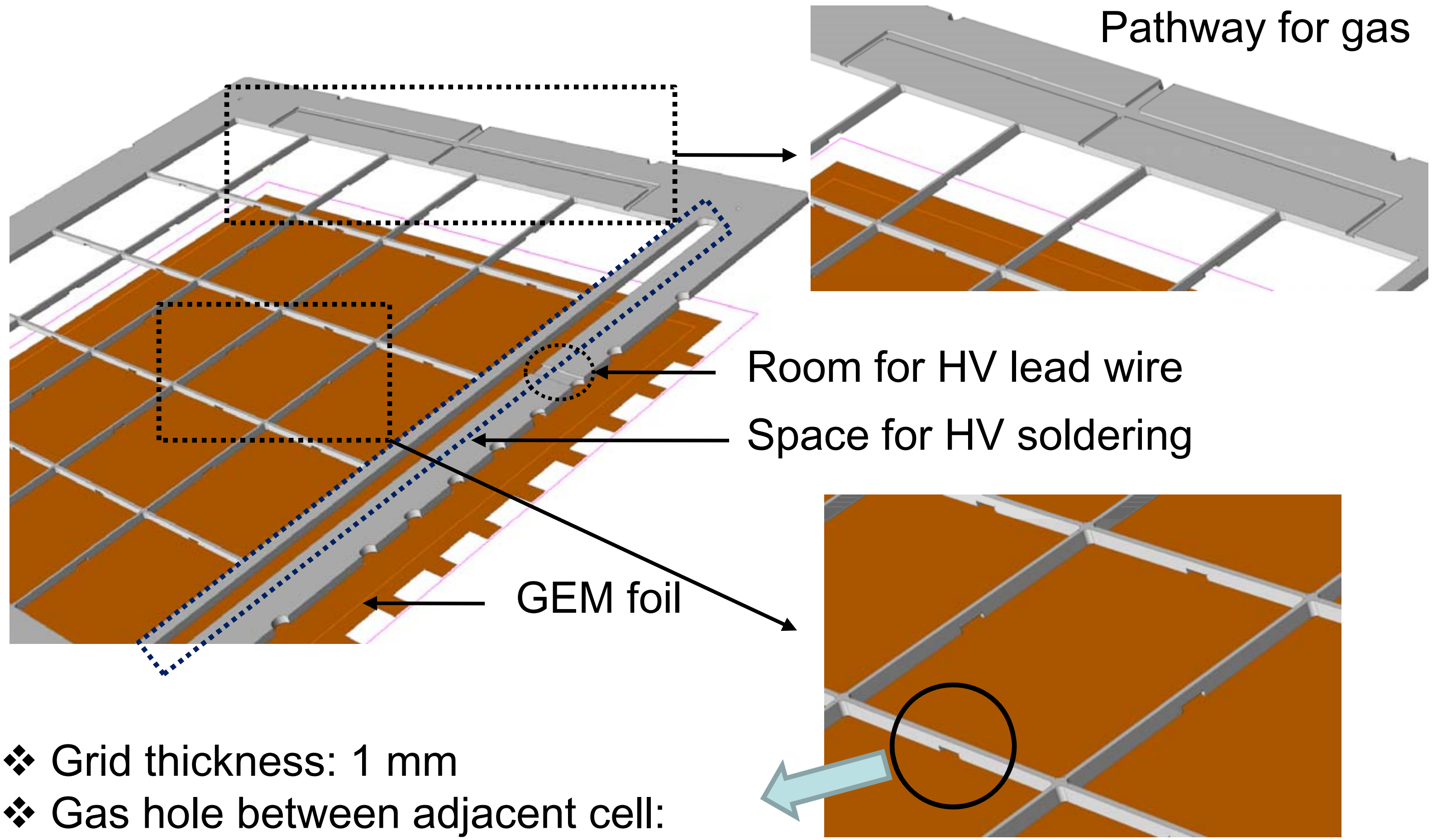






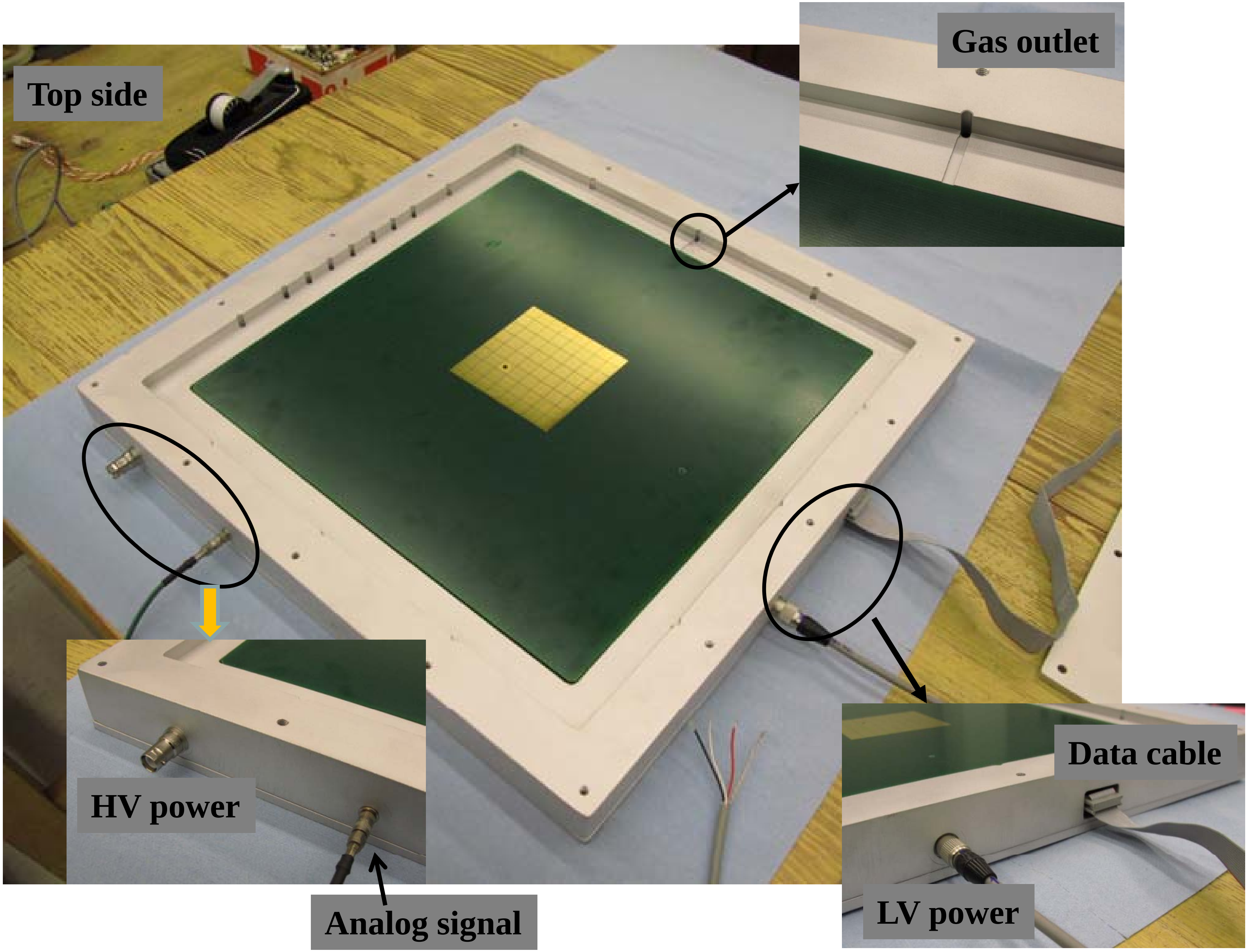


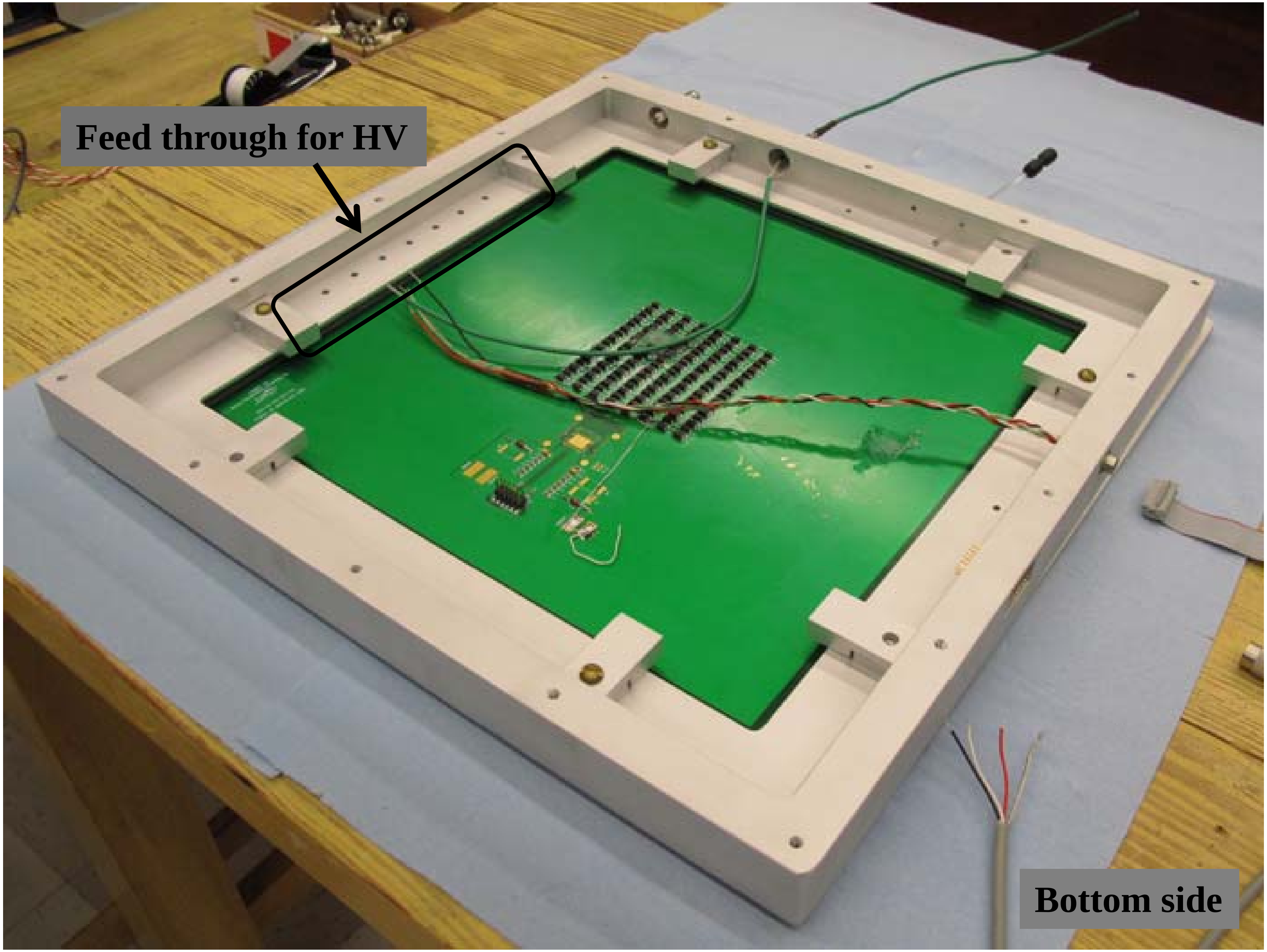
Modified Spacer



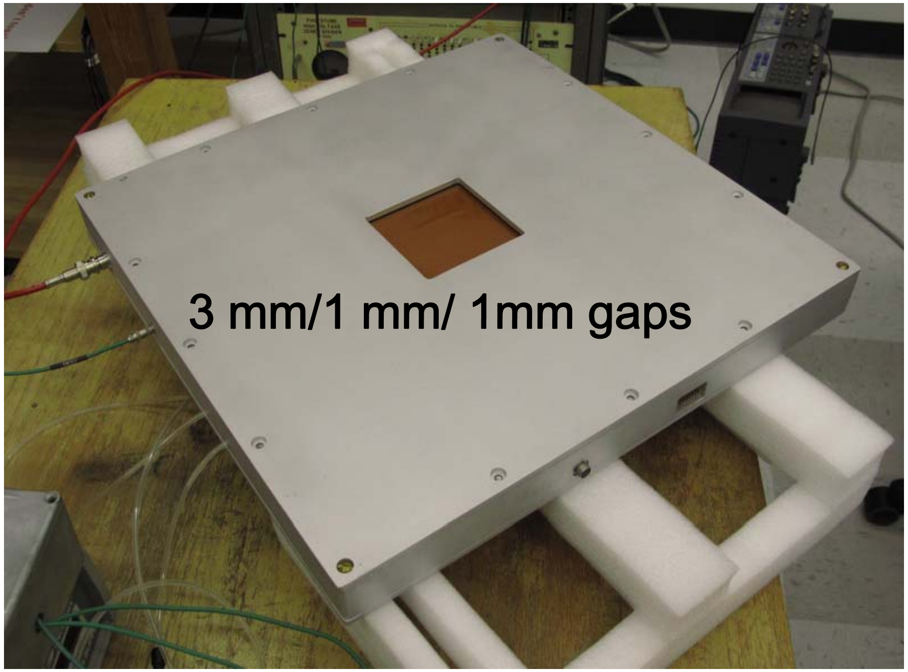
- ❖ Grid thickness: 1 mm
- ❖ Gas hole between adjacent cell:

→5x1 mm^2 for 3 mm spacer
→5x0.5 mm^2 for 1 mm spacer


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


Feed through for HV
Bottom side

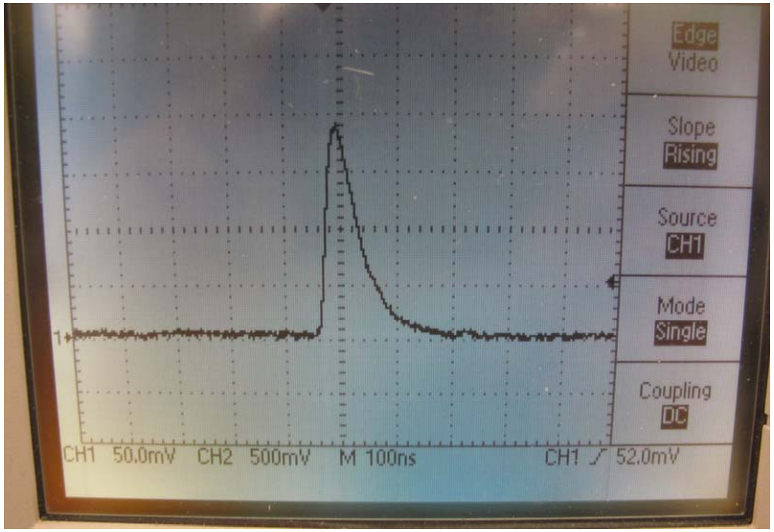
First operation of the new chamber

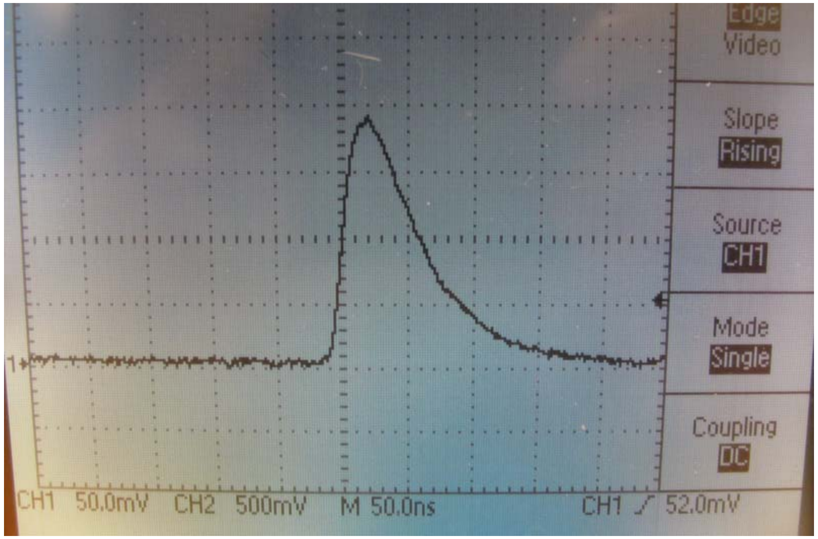


Analog signals were observed with a pre-amplifier(QPA02,FermiLab).

Dummy KPiX board is used as the readout board.

Analog signal from the new chamber



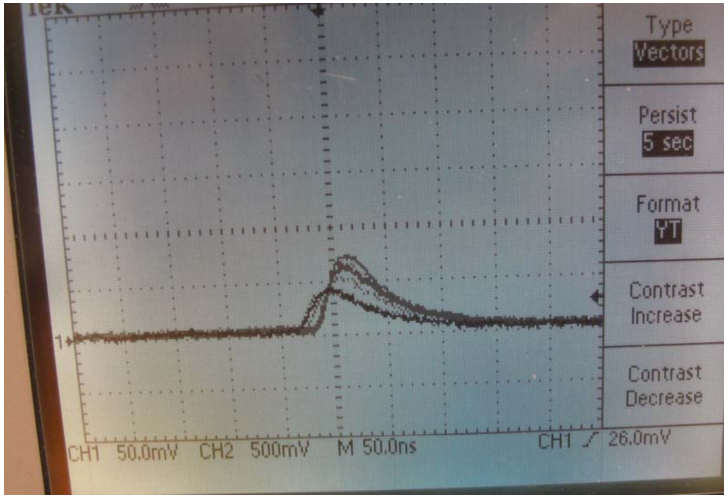


Source: ^{55}Fe

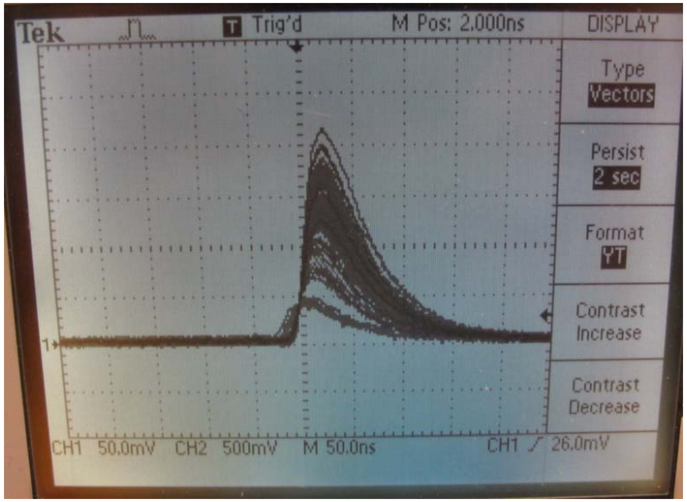
- ❖ Current chamber has ~ 250 ns width
- ❖ New chamber has about <60 ns width

High voltage dependence

HV=-1900V

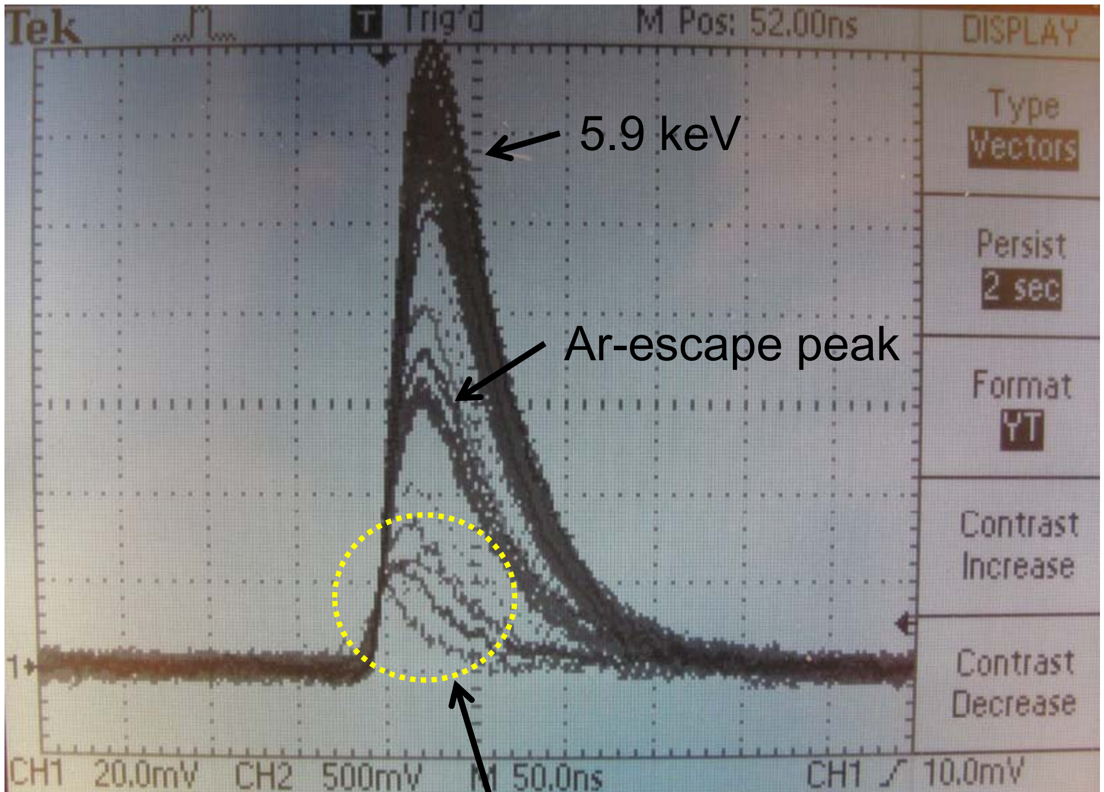


HV=-2000V



Chamber gain strongly depends on the high voltage.

Fe55 spectrum and unknown noise



HV=1900 V

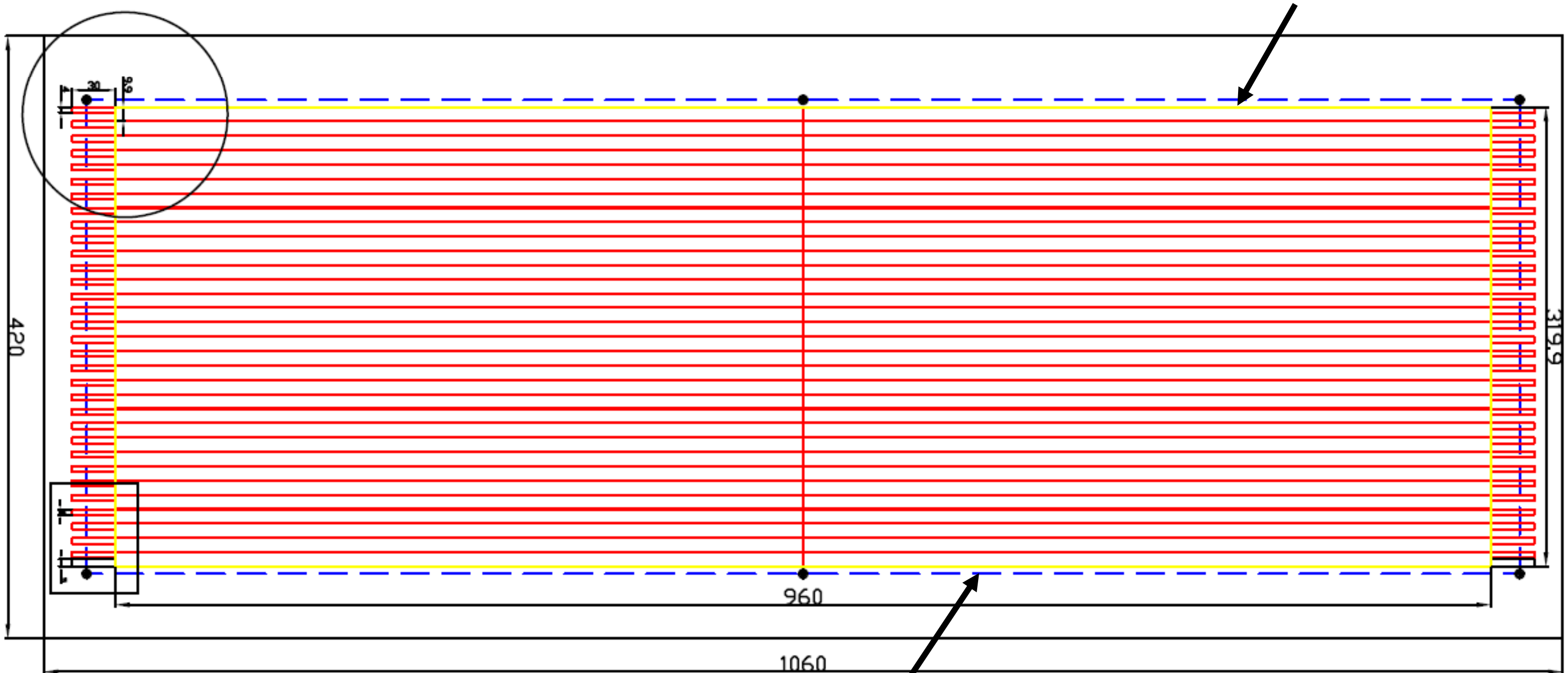
Unknown noise band. This noise is not observed without source – (caused by the charge sharing between adjacent pads?)

Large GEM Foil Discussion with CERN-GDD

- The size of the foils are 33cmx100cm, the same as the physical size of the unit chamber
  - Active area is 32cmx96cm
- 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 is being improved.

Large GEM design

Active area
(yellow dashed)



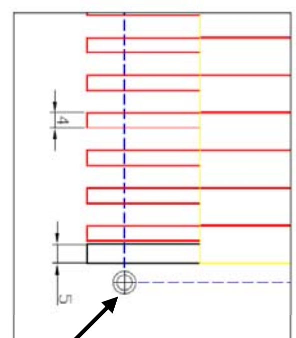
Chamber outline
(blue dashed)

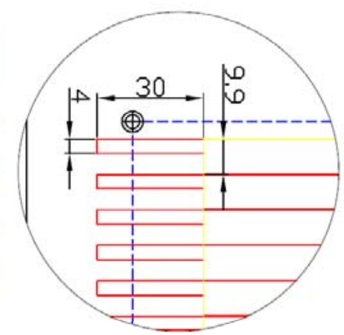
Active area 319.9x960 mm^2
Chamber size=330x1000 mm^2

Number of sectors = 32x2=64
(bottom layer has only one sector)

Sector dimension= 9.9x479.95 mm^2

Gap between sectors = 0.1 mm



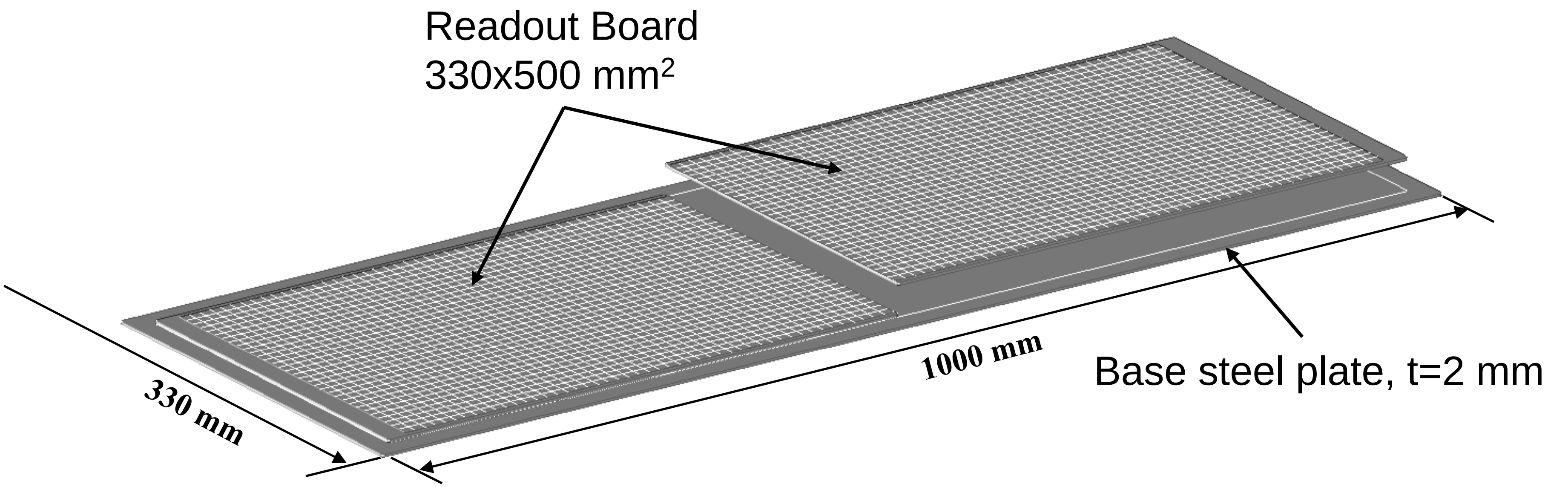


Marking for alignment

GEM DHCAL Plans - II

- Fall 2009 – Late 2009
  - 33cmx100cm thin GEM unit chambers
    - Production and certification of 33cmx100cm foils
    - Characterization of 256 channel v8 KPiX chips
      - Available in Fall 2009
      - Use 30cmx30cm STP chamber
    - Chamber characterizations w/ DCAL chip
    - Construction and characterization of 33cmx100cm thin GEM unit chamber
  - Large Thick GEMs
    - Working with Weizman institute on TGEMs
    - Certification of large TGEMs

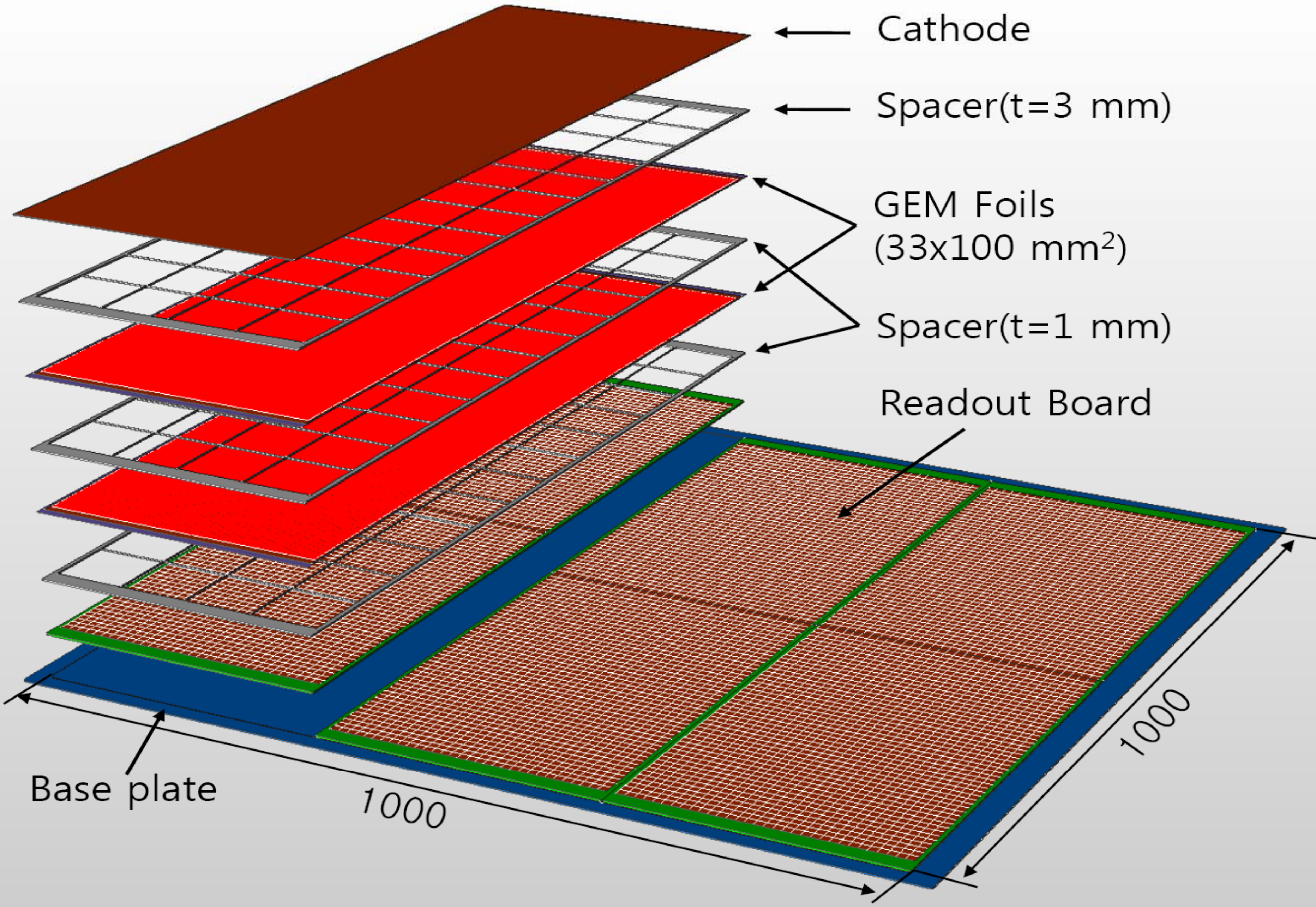
UTA's 33cmx100cm DHCAL Unit Chamber



GEM DHCAL Plans - III

- Late 2009 – Mid 2011
  - 33cmx100cm thin GEM unit chambers w/ DCAL chips
    - Complete production of fifteen 33cmx100cm unit chambers
  - Construct five 100cmx100cm GEM DHCAL planes
    - Using DCAL readout chips
  - Beam test GEM DHCAL planes in the CALICE beam test stack (at Fermilab MTBF) together with RPC
  - TGEMs and RETGEMs
    - Construction and characterization of a prototype chamber using an analog readout chip
    - Beam test of TGEM prototype chamber

UTA's 100cmx100cm Digital Hadron Calorimeter Plane



GEM DHCAL Beam Test Plans

- Phase I → Completion of 30cmx30cm characterization
  - Fall 2009 at MTBF: using one plane of 30cmx30cm double GEM chamber with 64 channel KPiX7

- Phase II → 33cmx100cm unit chamber characterization
  - Late 2009 – mid 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 performance in the CALICE stack
  - Late 2010 – Mid 2011 at 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