Digital Hadron Calorimetry for the International Linear Collider Using Gas Electron Multiplier Technology

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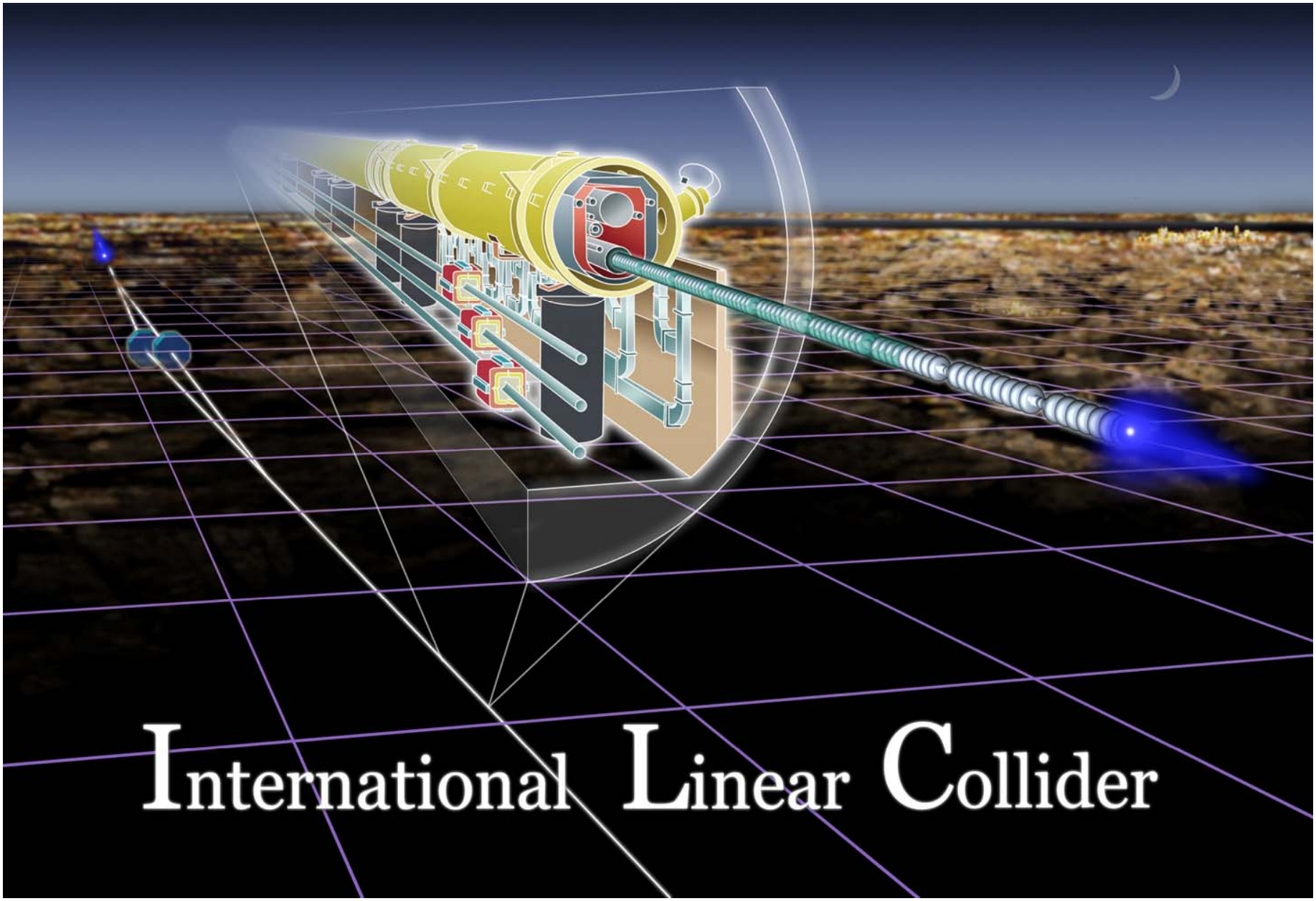
(for the GEM-DHCAL group:
UTA, U.Washington, Changwon Natl.U. (Korea), Tsinghua U.)
and the CALICE Collaboration

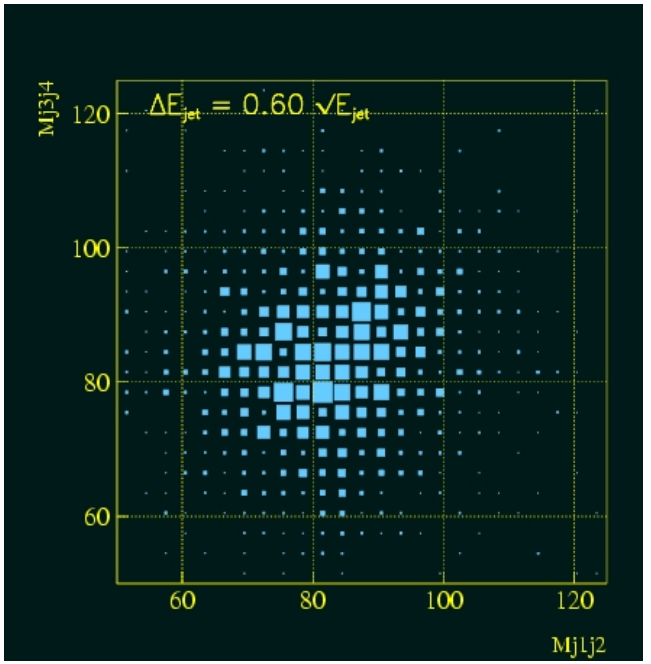

International Linear Collider

Linear Collider Physics

- A program of e^+e^- *discovery* and *precision physics* at 1TeV
- Understanding the Electroweak sector
  - Origin of mass – Higgs physics…couplings
    e.g. g_{tth}, g_{hhh} - > separate Zh from WW, ZZ -> jets
  - EW Symmetry breaking – Supersymmetry?
- Precision studies of the massive top quark
- Search for New Physics: W', Z', leptoquarks, ….

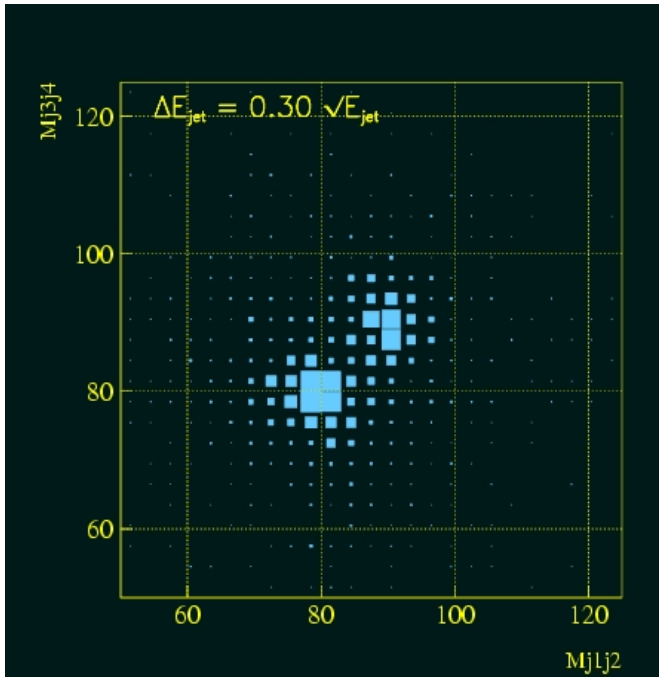
  …, extra dimensions
- Much of this physics program requires high precision measurements of jet energies and jet-jet invariant masses - > hence the need for a new approach to hadronic calorimetry.

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)

Digital hadron calorimetry

- **Particle Flow Algorithm** approach:

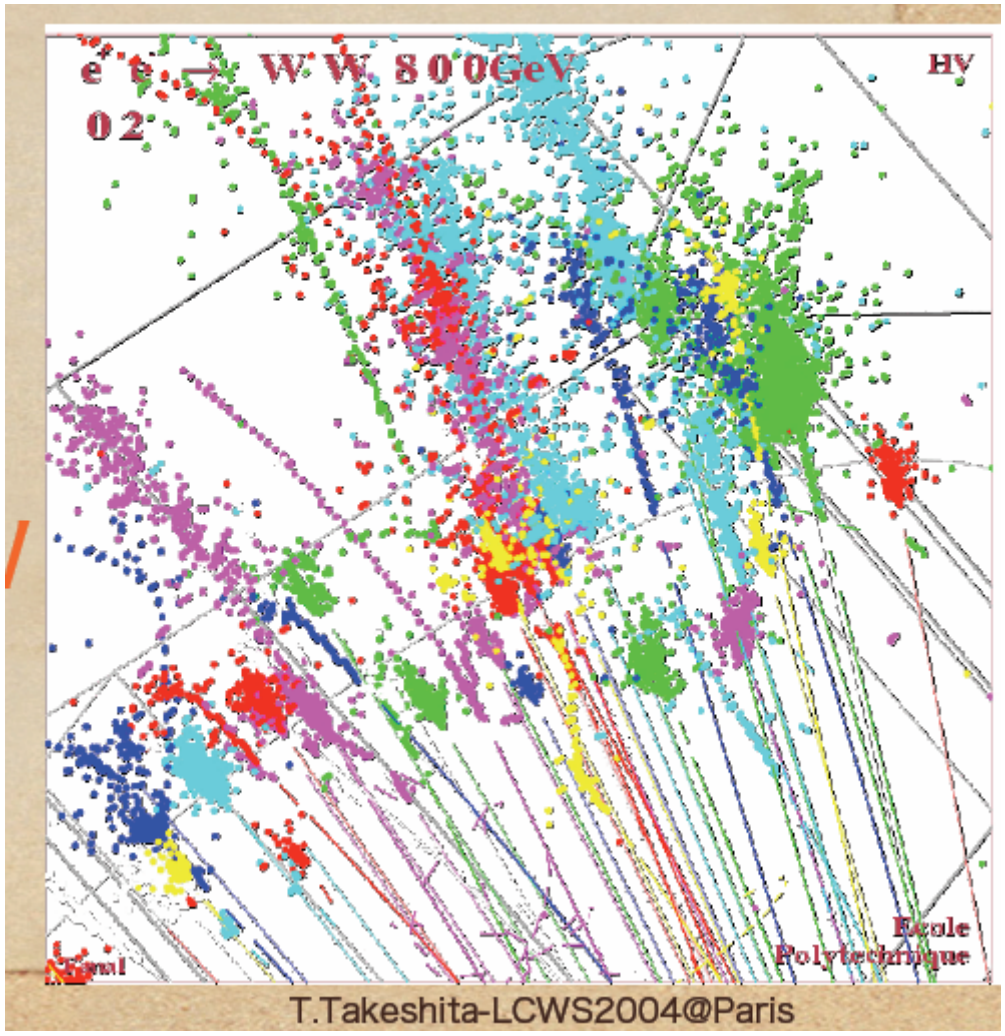
Use momentum measurement of charged hadrons in magnetic field, track them to energy clusters in hadron calorimeter, remove associated energy; measure electrons and photons in electromagnetic calorimeter – remainder is neutral energy ("Energy flow algorithm")

⇨ Must track charged hadrons in calorimeter !

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

⇨ Must measure neutral energy directly with reasonable resolution.

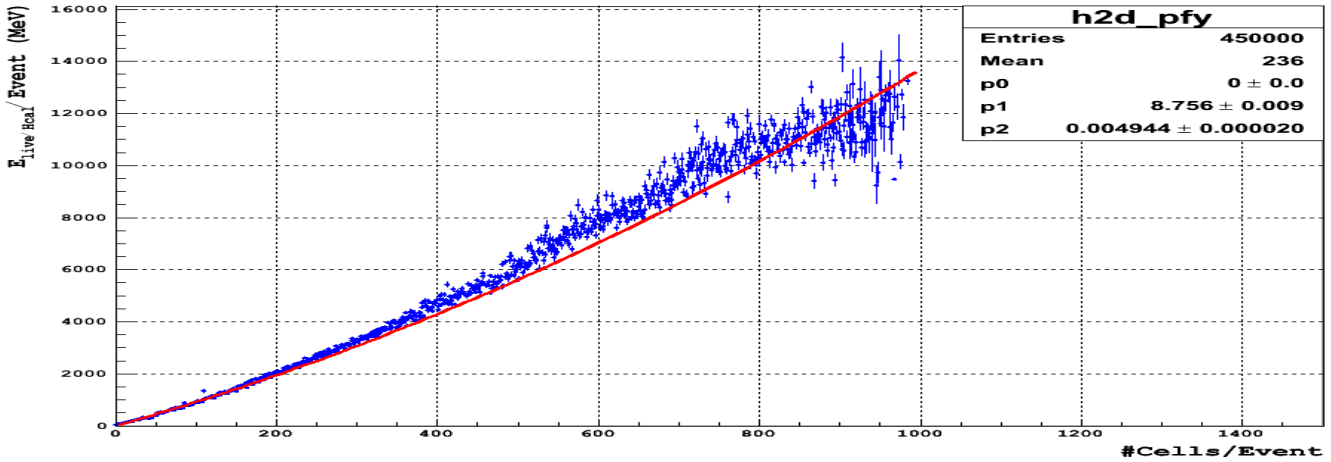
Don't underestimate the complexity!



Digital hadron calorimetry (2)

A new approach:

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



Digital Calorimeter Implementation

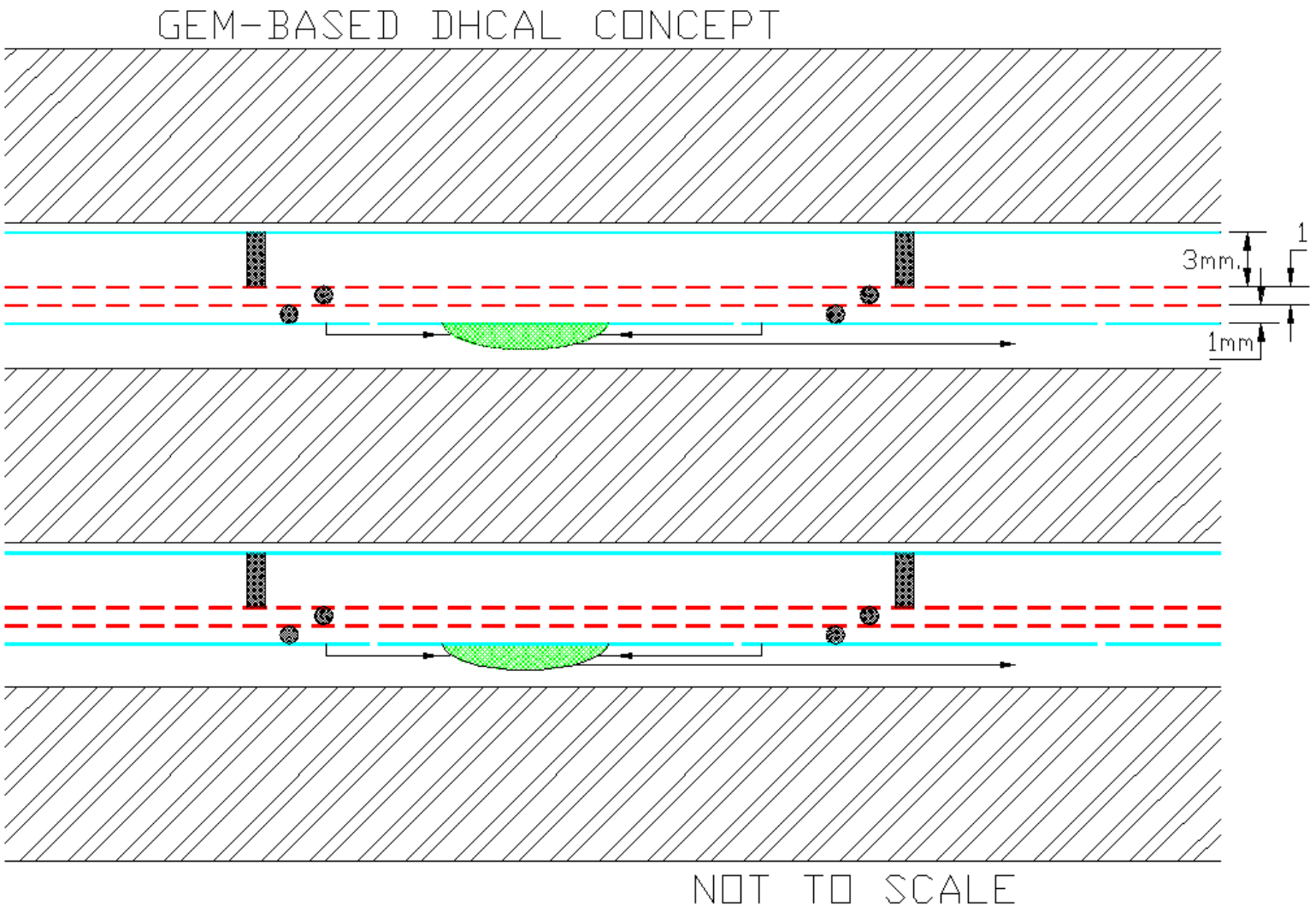
We have chosen a new approach:

Gas electron multiplier/1cm x 1cm pads:

- easy to implement small cells
- fast
- robust

Other options being studied include Resistive Plate Chambers with O(1cm^2) cells, Scintillator/Fiber/SiPM tiles with O(3cm x 3cm) cells, and Micromegas probably also with O(1cm^2) cells.

GEM-based Digital Calorimeter Concept



GEM Foils from 3M

- 30cm x 30cm foils made with three types of coating:

  a) bare copper

  b) "organic polymer" coating

  c) gold plating

- HV tests made on all three types -> conclusion is that we prefer to use the uncoated foils.

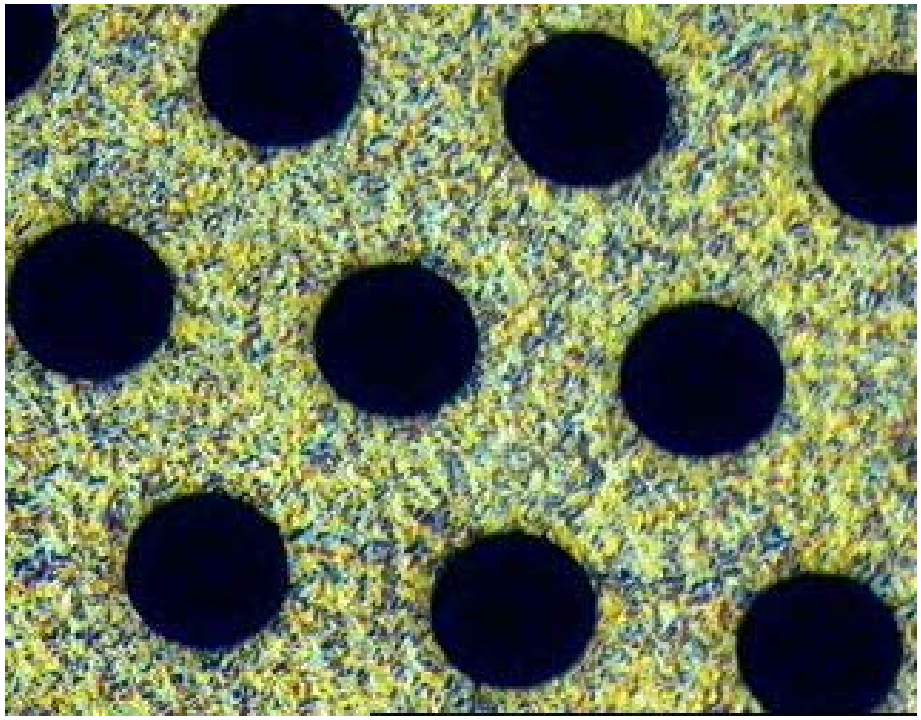
- We are using the uncoated foils in our current 30cm x 30cm chambers.

3M 30cm x 30cm GEM foils

12 HV sectors on one side of each foil.

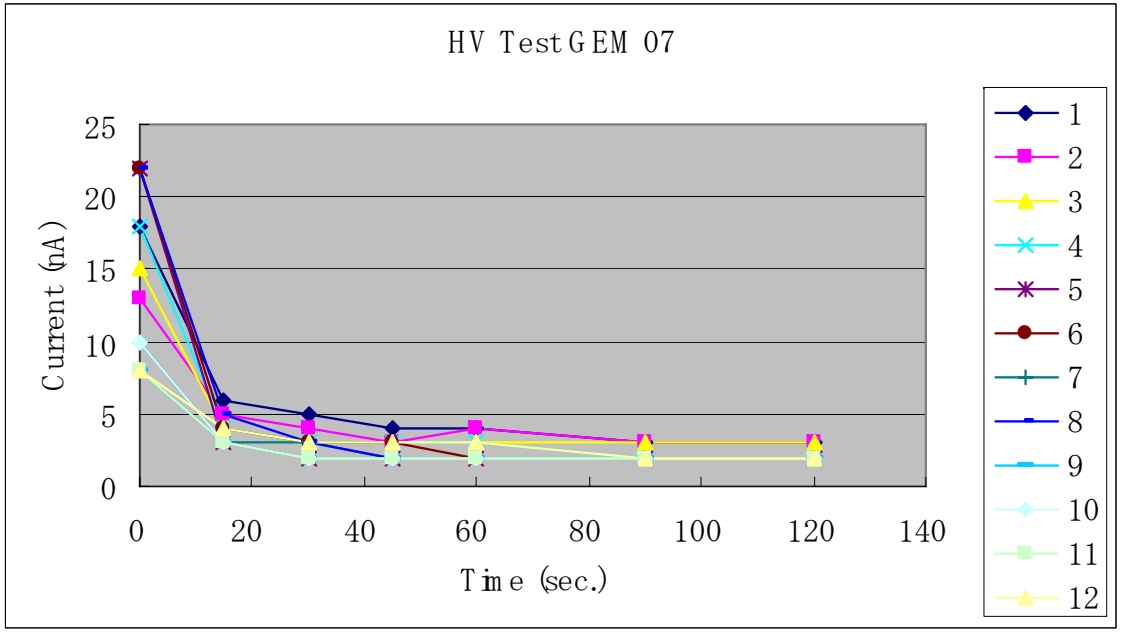
HV Sector Boundary

Magnified section of a 3M GEM foil.

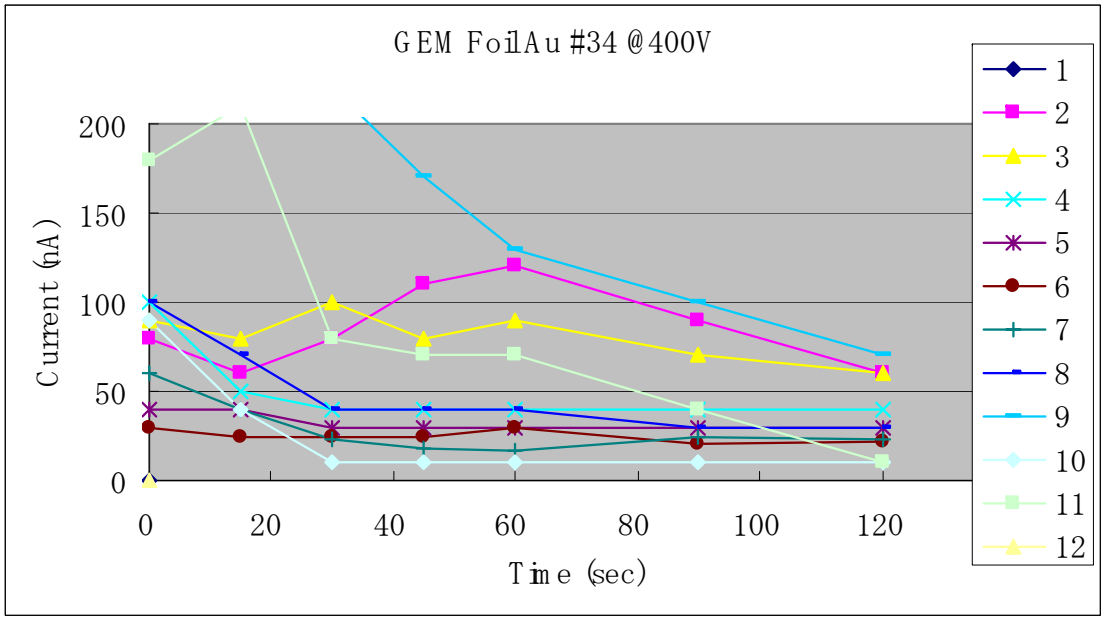


HV tests on coated/uncoated GEM foils

Uncoated



Gold Coated



3M Long (90cm) GEM Foil Design

-We are working with 3M to develop larger foils for the $1m^3$ prototype stack (the $30x30cm^2$ foil development did not require 3M process modification).

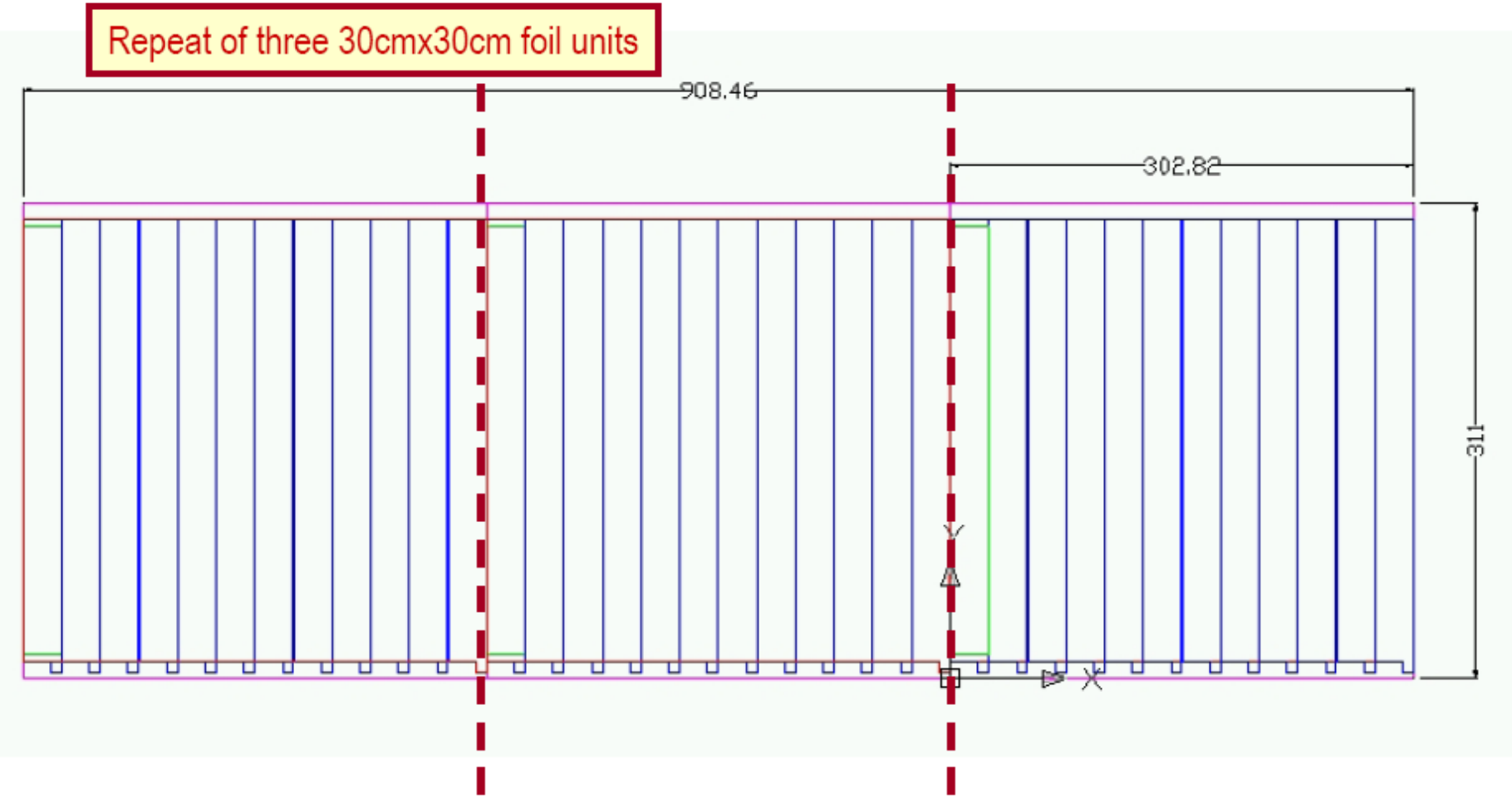
- New artwork (masks) but deriving from the 30cm x 30cm foil development.

- Small area needed for re-registration as foil moves through etching station.

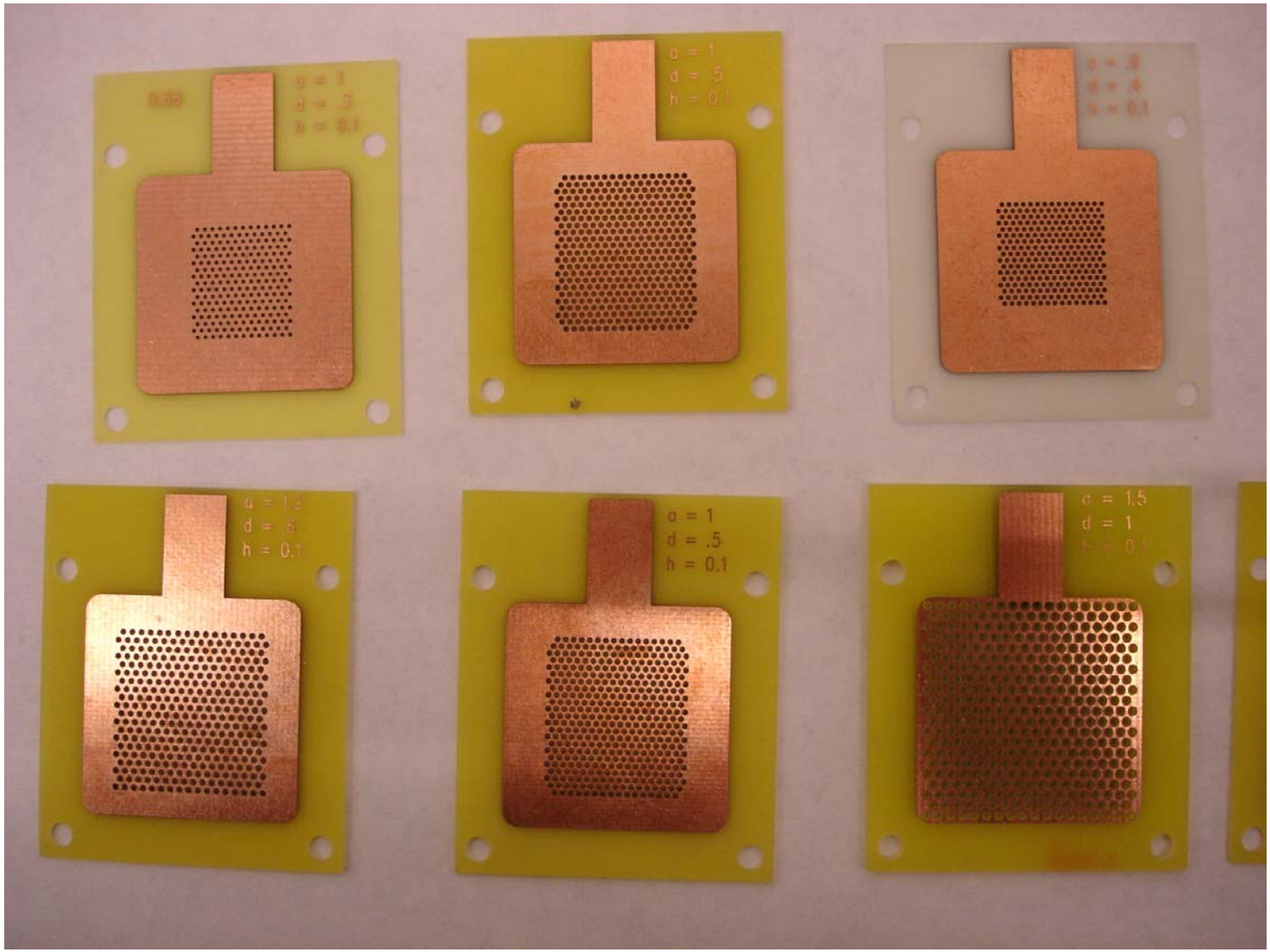
- Anticipate first samples in January '07.

- First long chamber construction will follow 30cm x 30cm chamber construction for a beam test ("Slice Test") at Fermilab in early 2007.

Proposed Initial 3M 30cmx100cm Foil Design

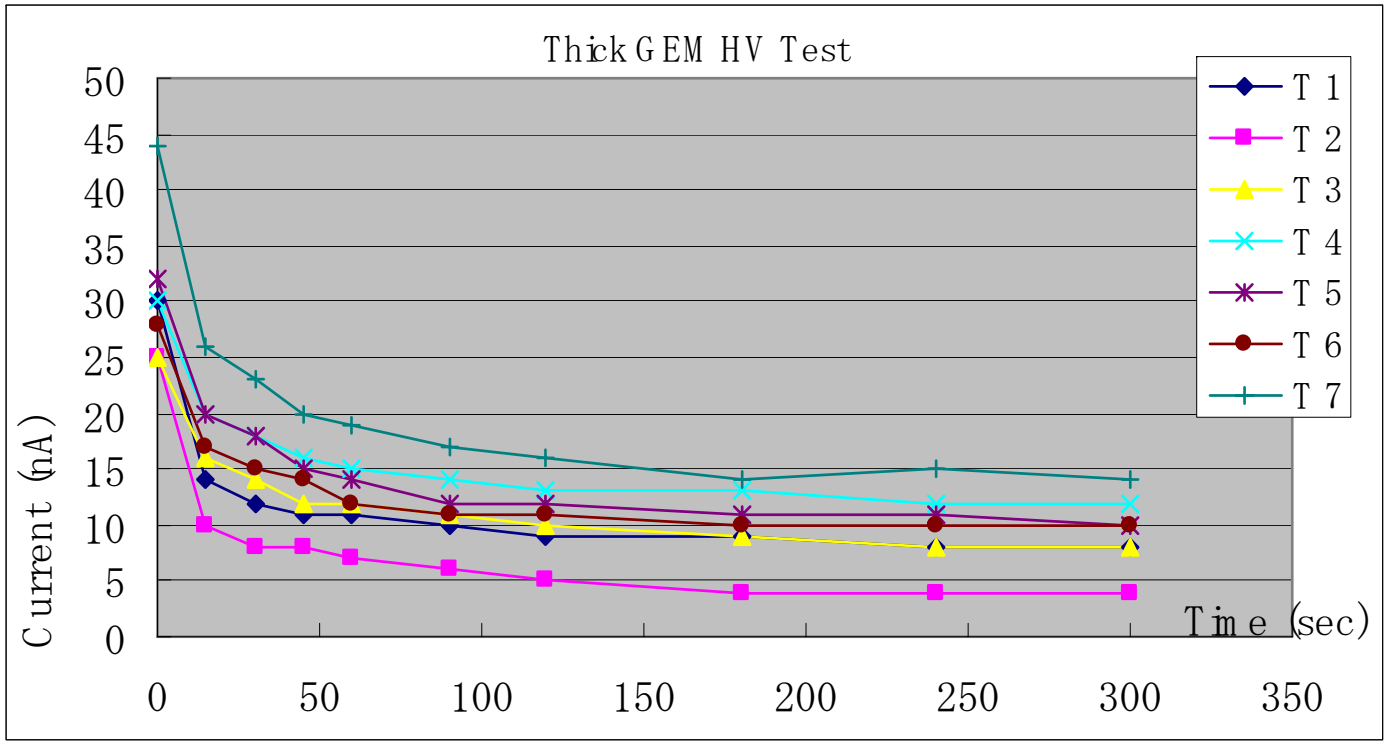


Samples of "Thick Gem" active layers.

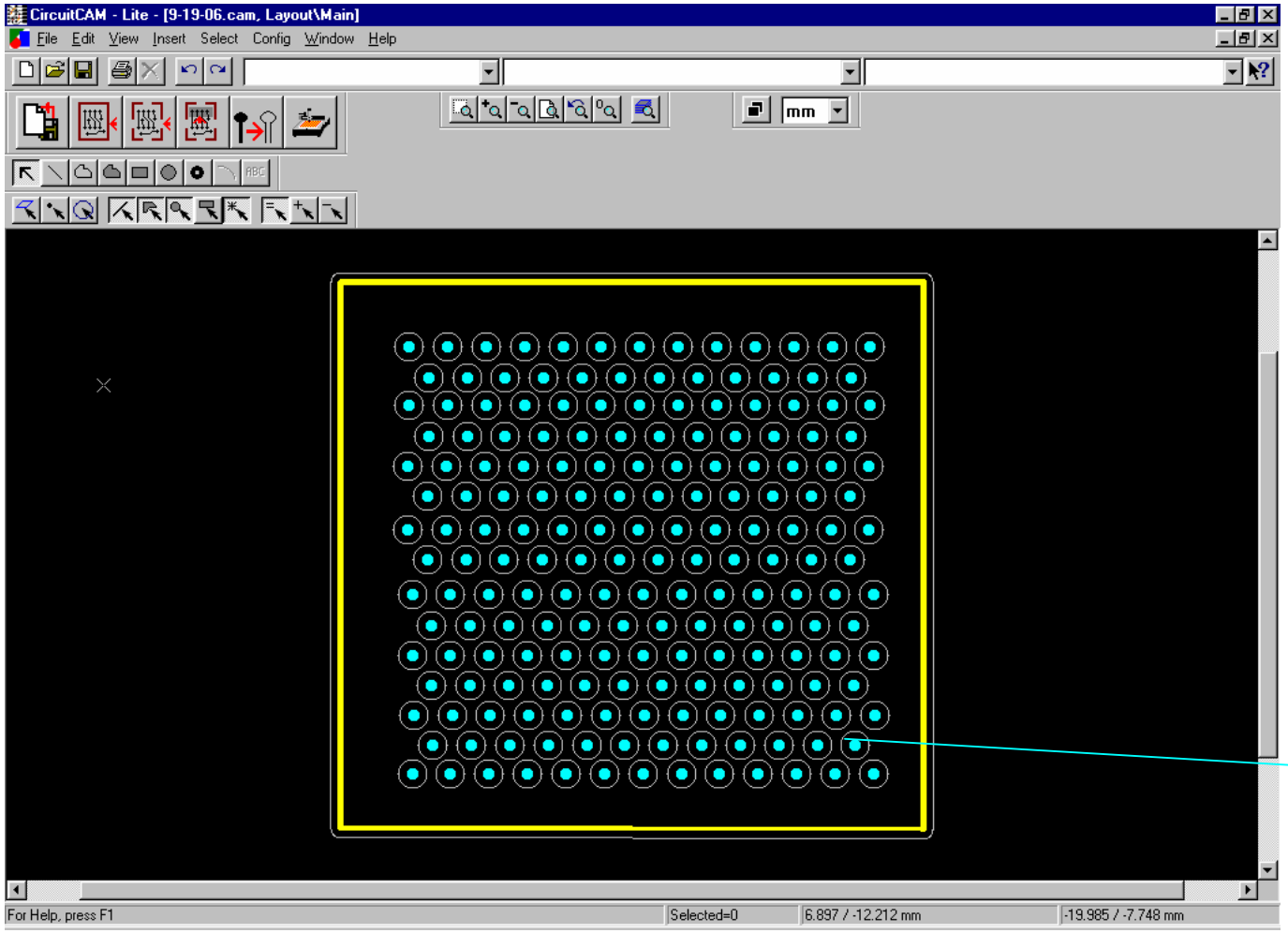


First TGEM current results

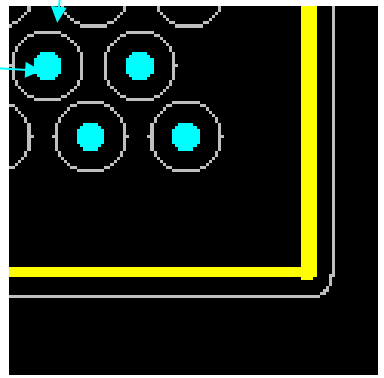
Thick GEM ID	0	15	30	45	60	90	120	180	240	300	Voltage (V)
T 1	30	14	12	11	11	10	9	9	8	8	1000
T 2	25	10	8	8	7	6	5	4	4	4	1000
T 3	25	16	14	12	12	11	10	9	8	8	1700
T 4	30	20	18	16	15	14	13	13	12	12	1700
T 5	32	20	18	15	14	12	12	11	11	10	1700
T 6	28	17	15	14	12	11	11	10	10	10	1700
T 7	44	26	23	20	19	17	16	14	15	14	2000



Thick GEM Development at UTA



0.5mm inner,
0.7mm outer



Development of 30cm x 30cm GEM chamber(s)

- Foils HV tested.

- Jigs made to mount foils, stack chamber.

- Initial multilayer anode board made to work with Fermilab QPA02-based preamp cards.

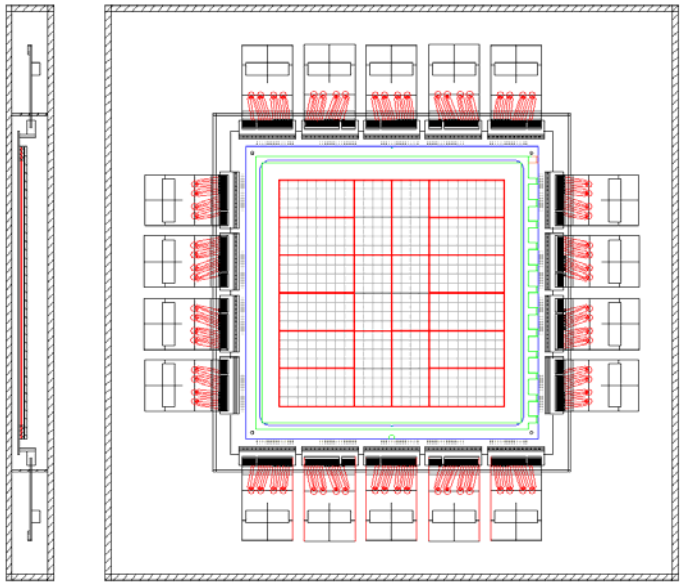
- Verify aspects of chamber operation:

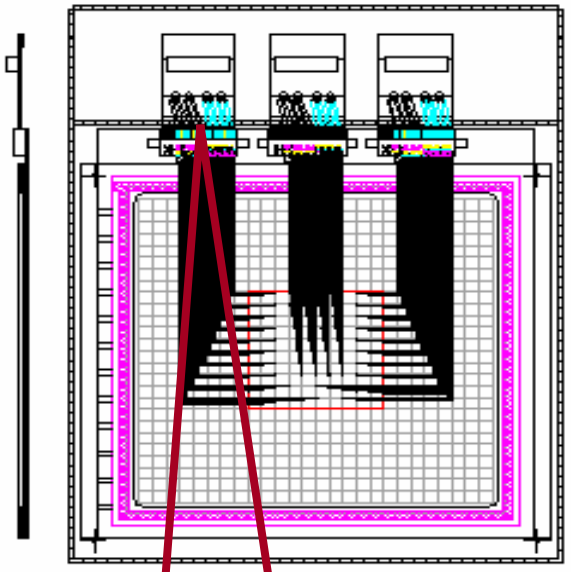
  - stability

  - characteristics (cf. 10cm x 10cm chamber using CERN foils, Ar/CO_2 80:20, efficiency 95%, average hit multiplicity, 1.27)

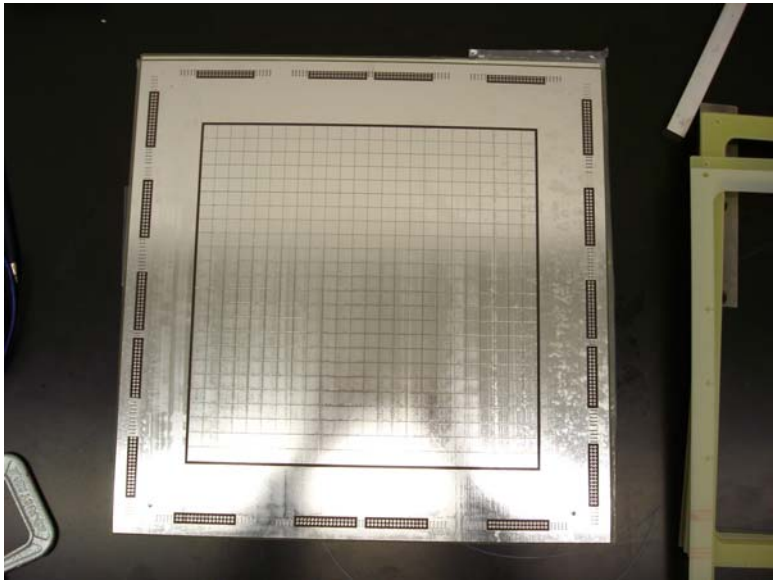
- Used for Korea/KAERI beam tests in May - Estimate ~2 x 10^{12} e-/pad in 2000 sec. (~ 1.6 x 10^{-2} mC/mm2) and GEM chamber continued normal operation.

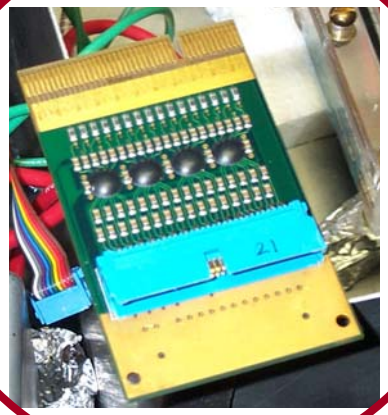
30cm x 30cm GEM chamber(s)





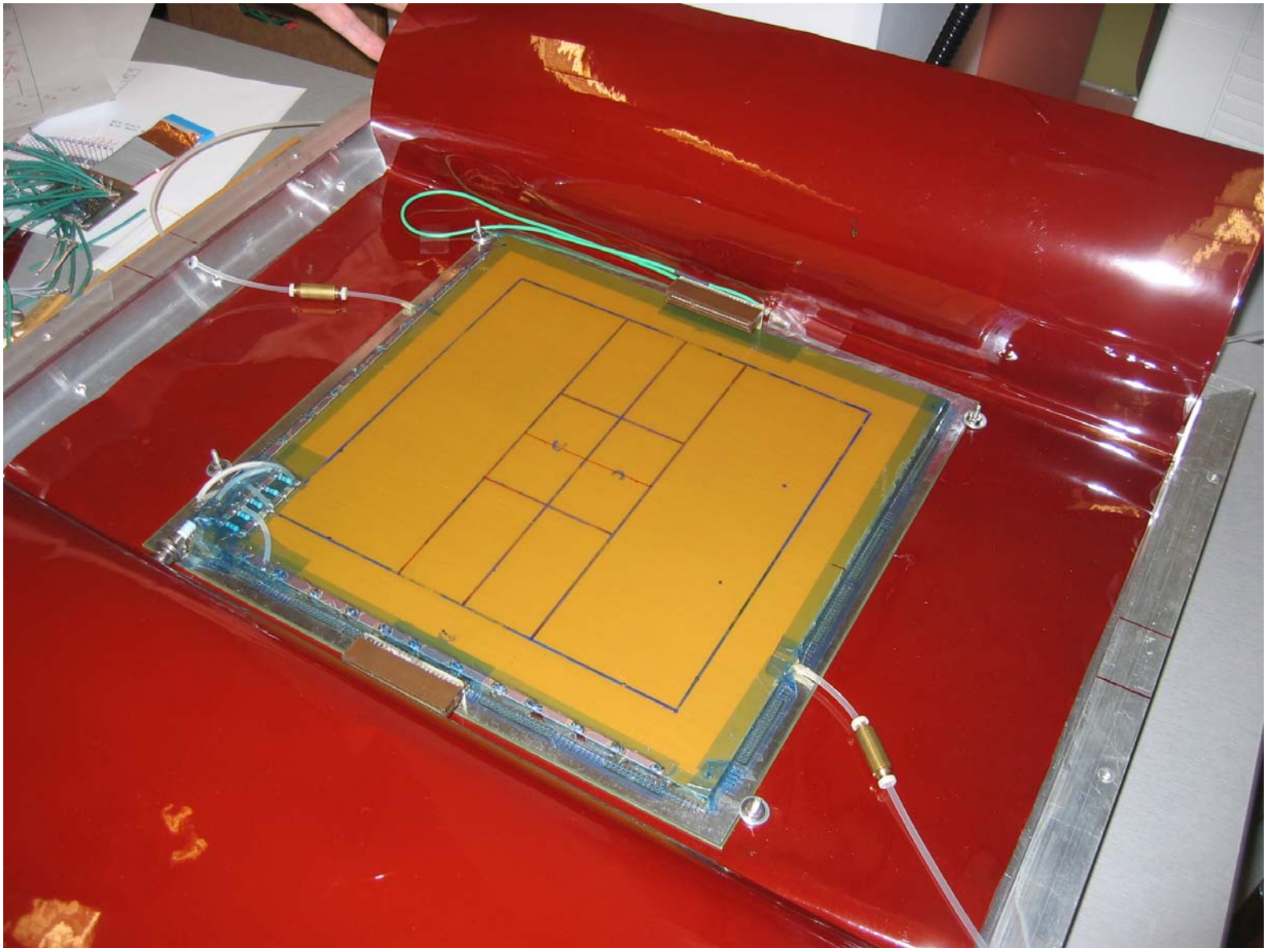
Anode boards designed to read 96 pads in the center



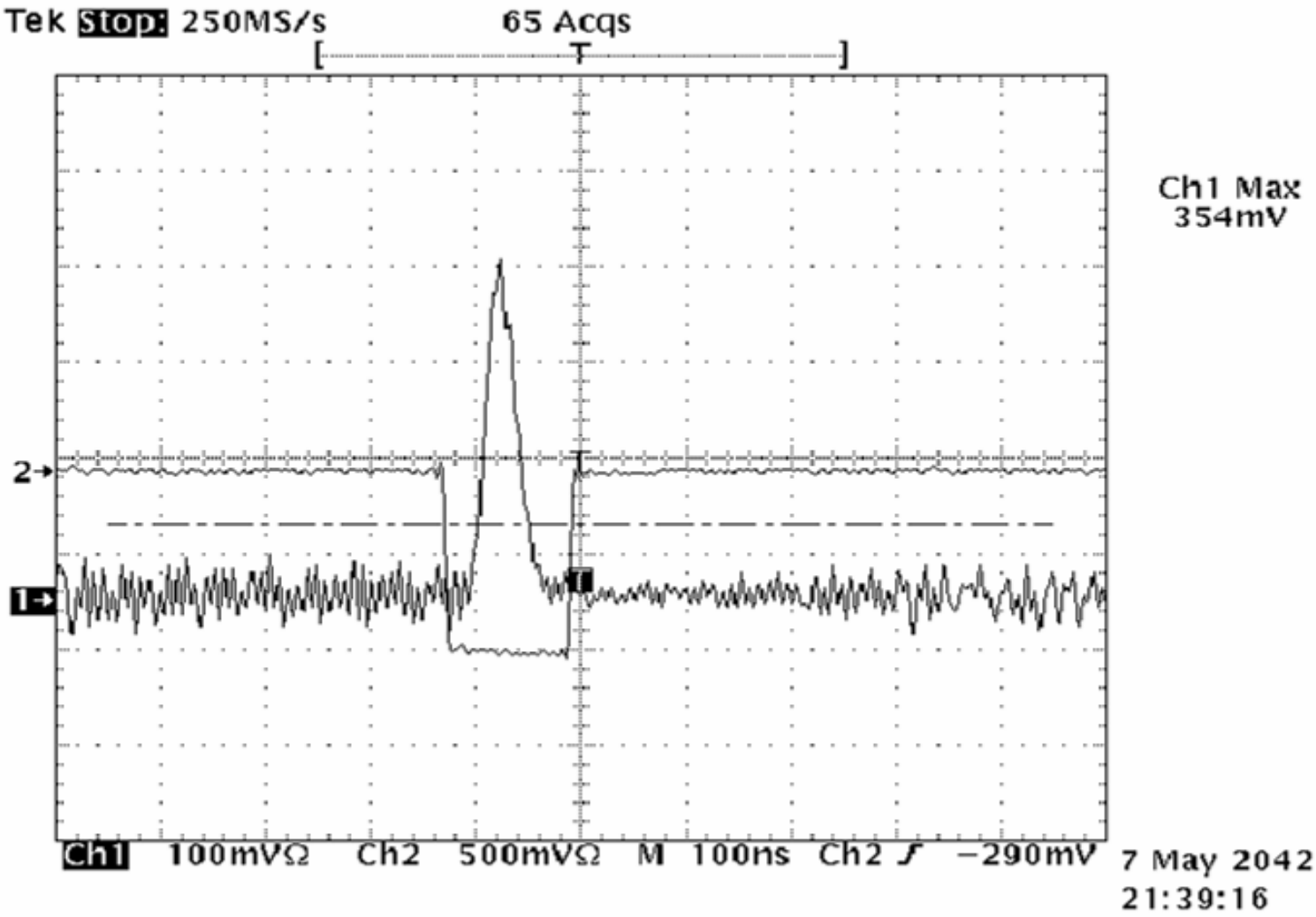


Use 32 channel FNAL preamps

30cm x 30cm GEM chamber



Signal from the 30x30 D-GEM Detector



GEM-DHCAL Readout

- Early studies used discrete electronics.

- Evolving towards chip-based readout for individual/multiple chamber beam tests and $1m^3$ stack.

- $1m^3$ stack will have 400,000 channels and final ILC Digital Hadron Calorimeter will have $O(10^8)$ channels.

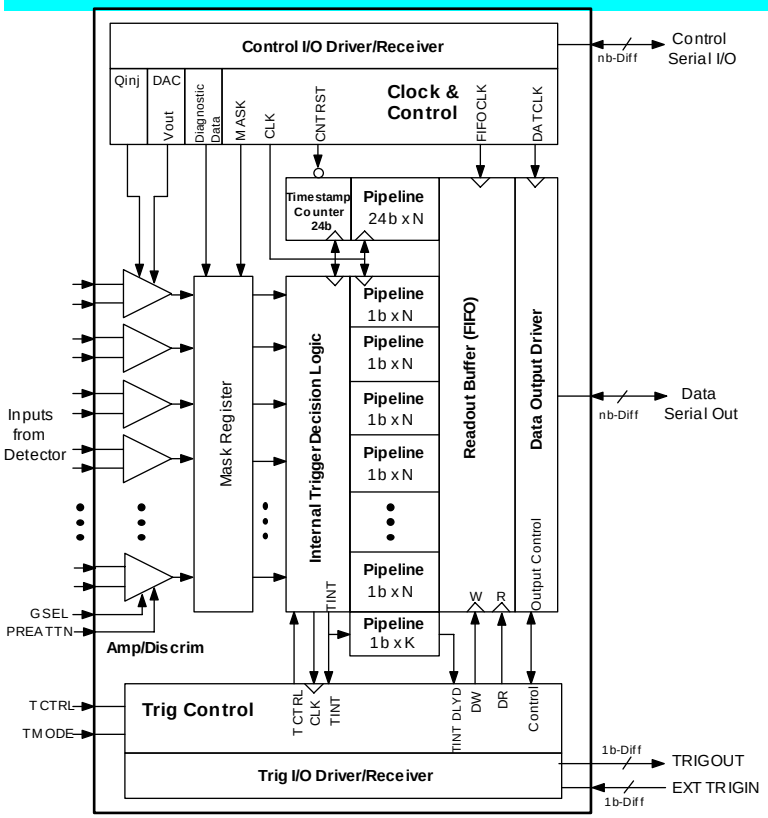
- Two options (so far):

1) DCAL (ANL/Fermilab) – v2. Packaged chips – initially high profile, then low profile?

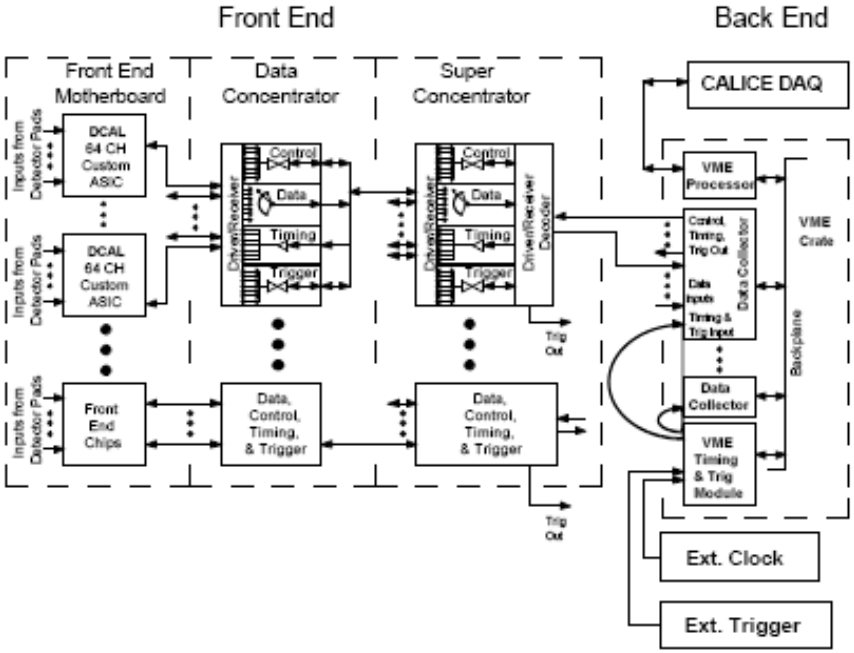
2) KPiX (SLAC) – v3 (with GEM mods.) 64 ch, under test at SLAC – "very encouraging"; v4 with 64/128/1024(?) channels – availability??

DCAL chip ANL/FNAL

RPC and GEM capabilities



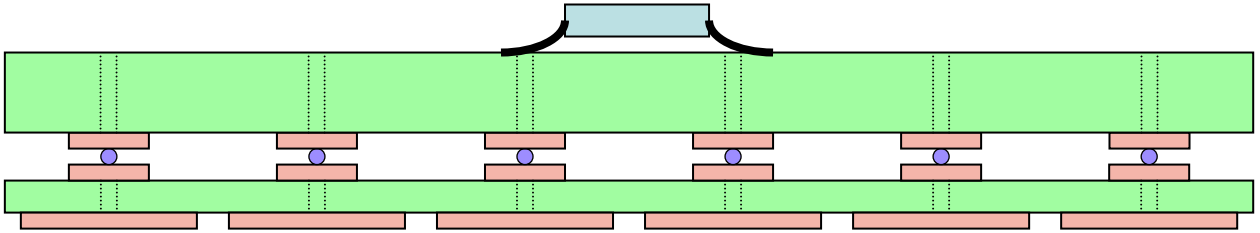
Gary Drake, ANL

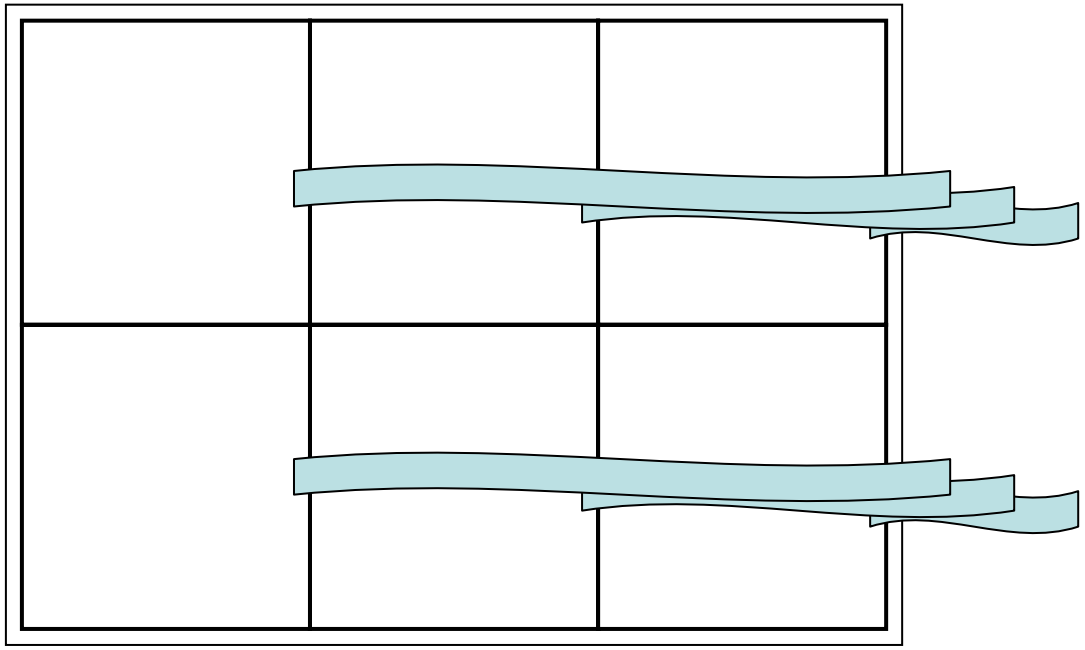


GEM signals:

minimum signal ~10fC,
maximum signal ~few pC

GEM and RPC DCAL Chip Front end board and readout connections

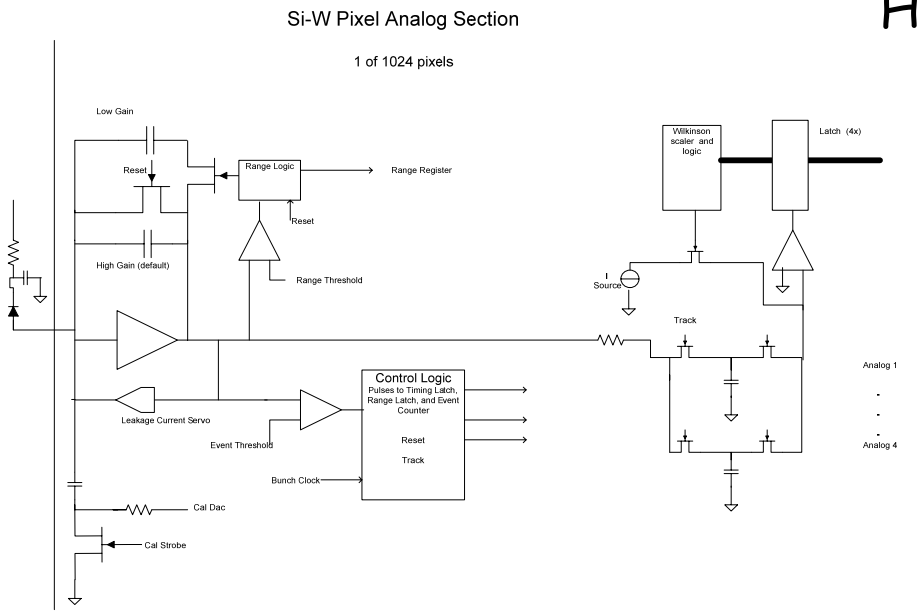


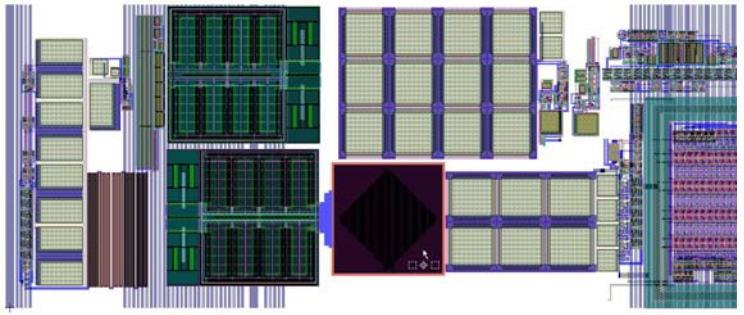


KPiX Readout chip/SLAC

Analog output. Two gain ranges

High: 0 – 500fC, Low: 0 – 10pC



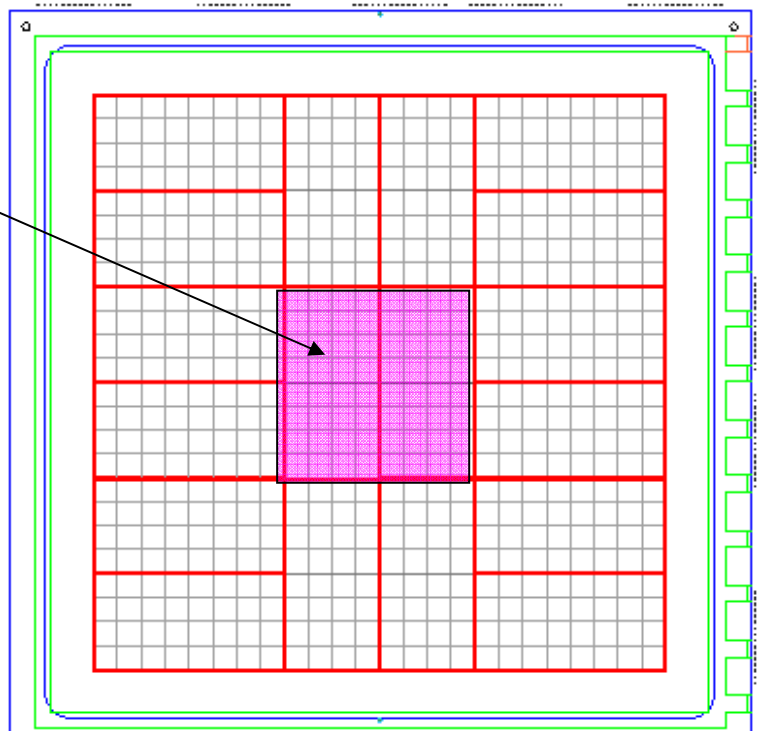


v3 – 64 channels – September 2006 (with GEM changes)

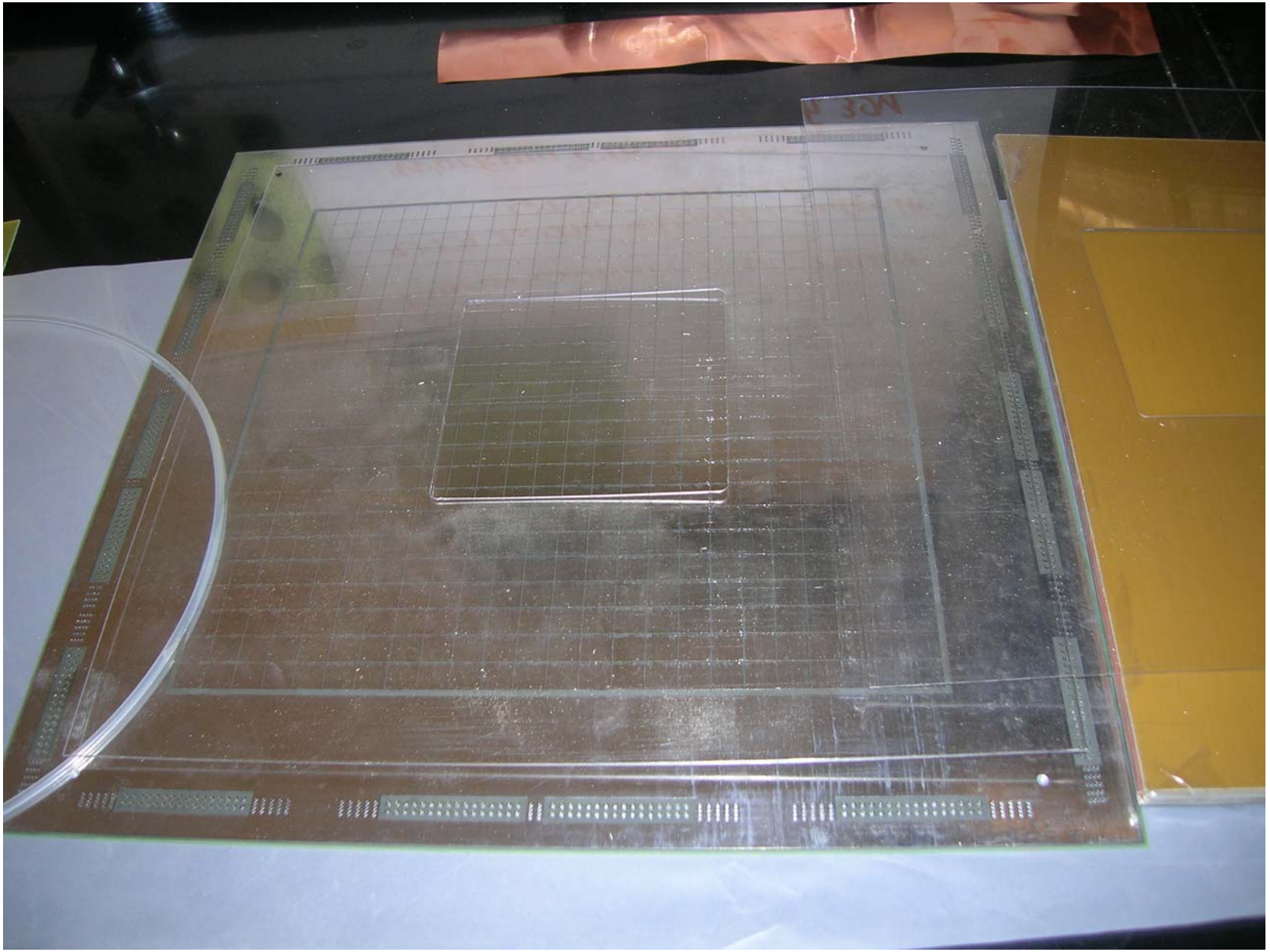
v4 – 64/128/1024 channels(??) end of 2006/early 2007?

Anode board detail for 64-channel

8cm x 8cm area we would like to read out e.g. using 64-channel KPiX, version 3.0

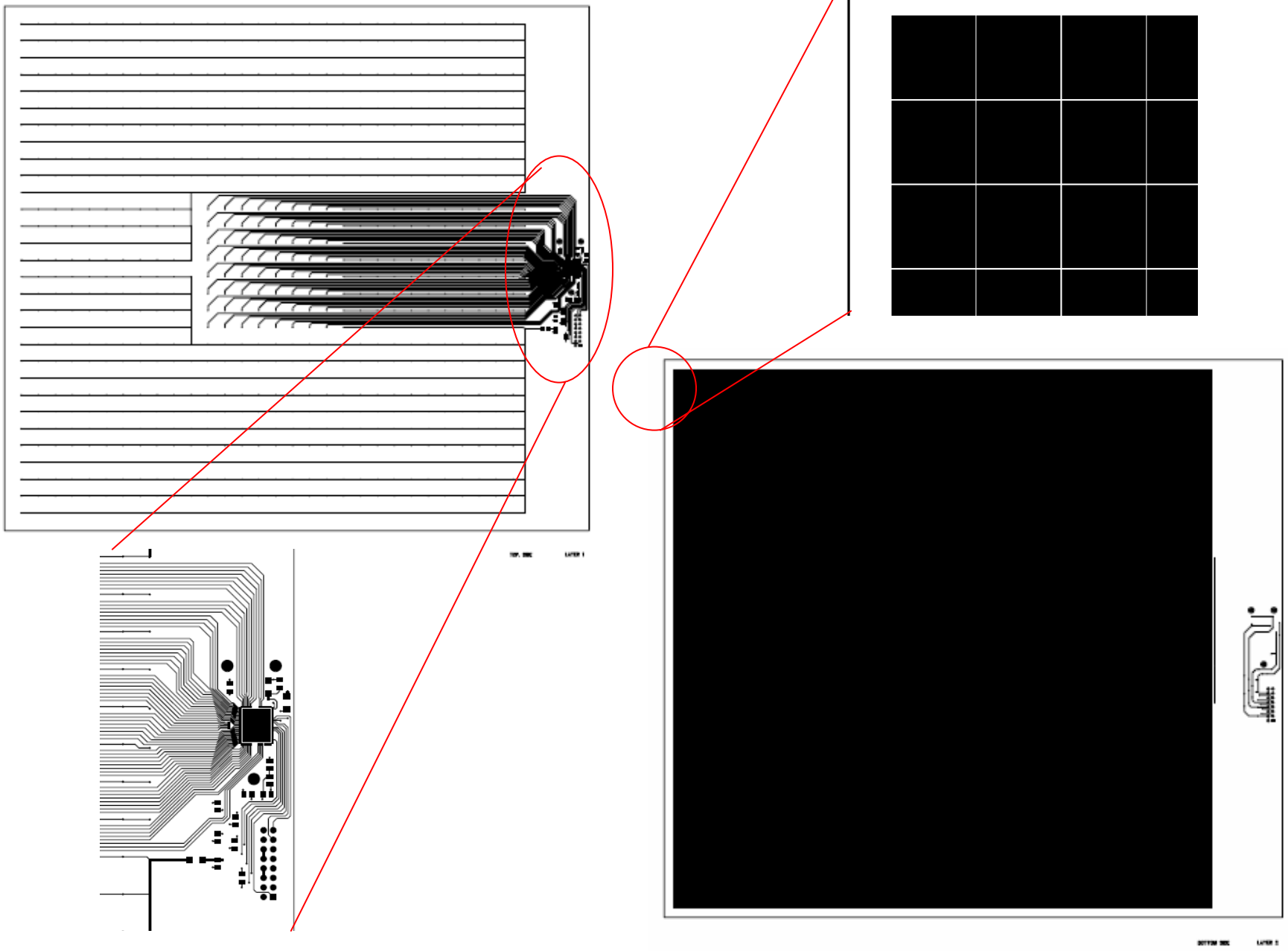


SLAC have developed a 30x30cm^2 anode board, then could move to a larger (20cm x 50cm?) board as a subunit of 1m^2 layer for 1m^3 stack.



KPix-GEM Pad+FEB with detail

M. Breidenbach/R. Herbst
SLAC

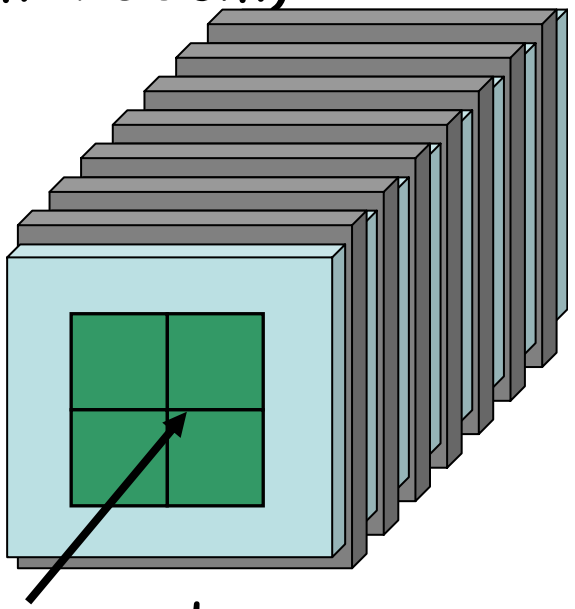


Schedule/budget for GEM-DHCAL

Fall 2006 – Tests of GEM chambers with KPix, DCal chips as chips and boards become available.

- Build 2-3 chambers each for DCAL and KPix for Slice Test.

- build larger GEM chambers (~1m x 30cm) when 3M foils are available.



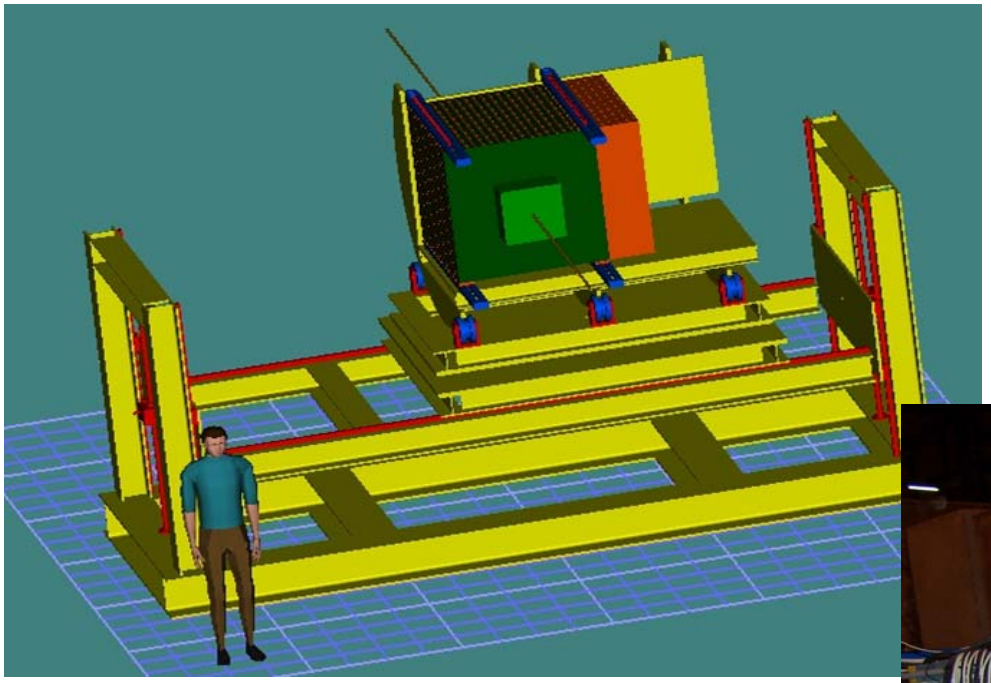
Early 2007 – Slice Test RPC and

GEM chambers with DCAL and v3 KPiX.

2007 – Build full "1m x 1m" GEM active layers and establish procedures for production for GEM $1m^3$ stack.

Late 2007 – start $1m^3$ GEM stack construction.

GEM/DHCAL 1m^3 Test Beam Plans – CALICE Collaboration



CALICE Collaboration stack test at CERN, Fall 2006, move to Fermilab 9/07 for joint tests.

CALICE AHCAL/TCMT

Conclusions

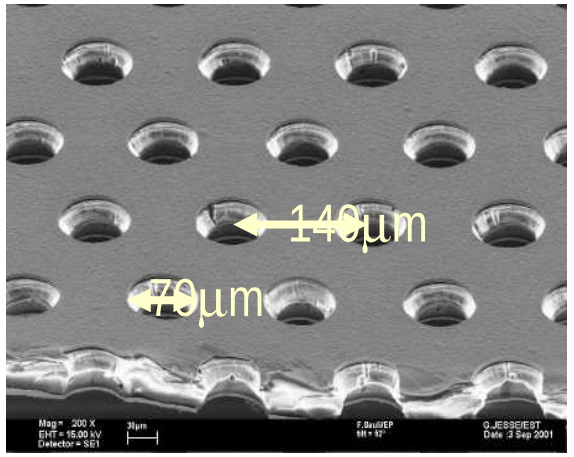
- R&D for a new approach to precise calorimetry for the ILC.

- 30cm x 30cm GEM chambers with 1cm x 1cm anode pads have been sucessfully built and tested.

- Plans are in hand to test high density readout electronics options with GEM chambers.

- The ultimate goal is the construction, and testing of a GEM-Digital Hadron Calorimeter stack using test beams for verification of performance in comparison with GEANT4 simulations – then we can design a calorimeter system for an actual ILC detector.

GEM foil/operation



GEM field and multiplication

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

Invented by Fabio Sauli/CERN