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

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Digital Hadron Calorimeter Development

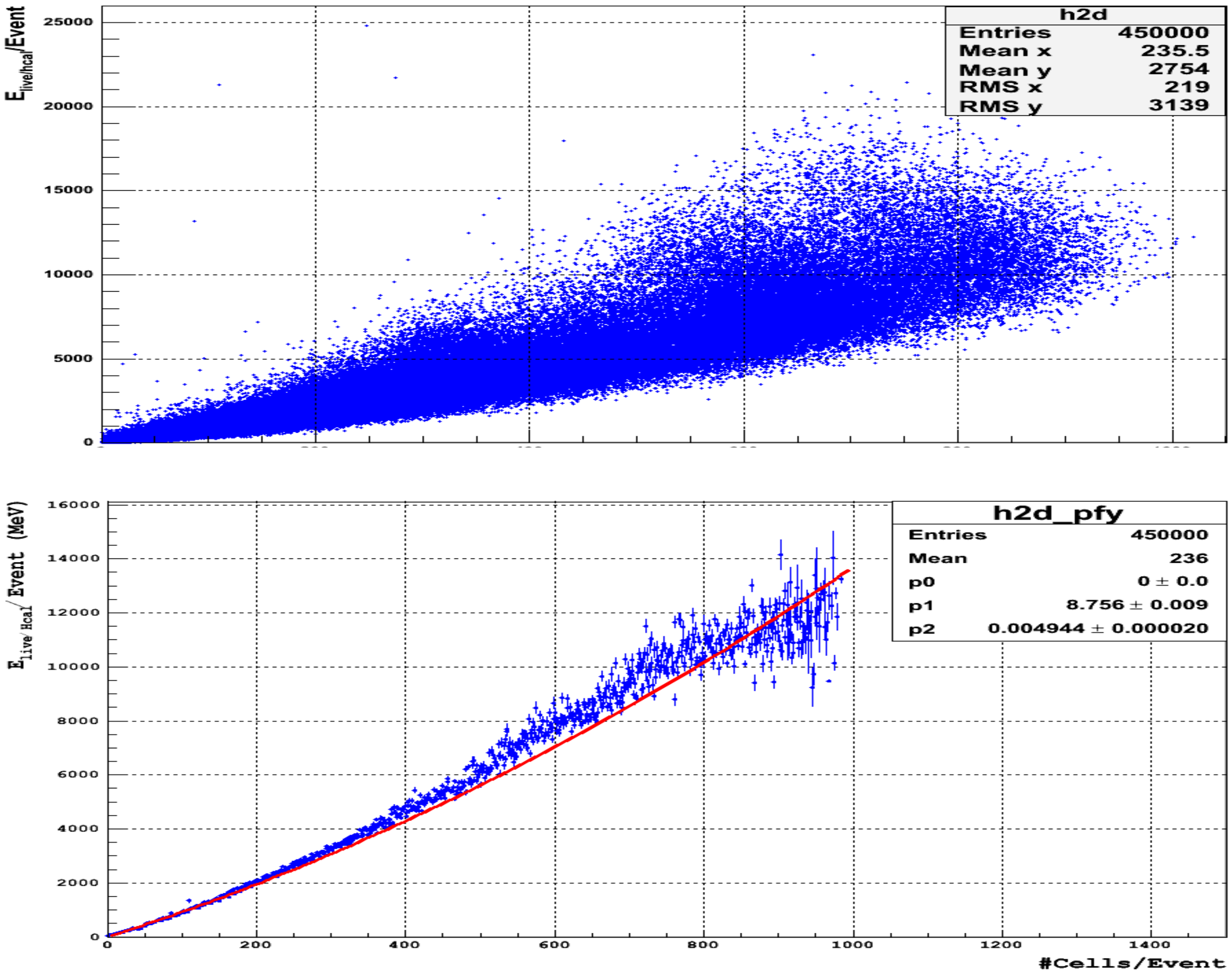
Linear Collider calorimetry development path at UTA:

- Motivated by the physics potential!
- Can digital + energy flow approach work ??
- Search for robust/low cost/flexible technology
- GEM technology has required characteristics

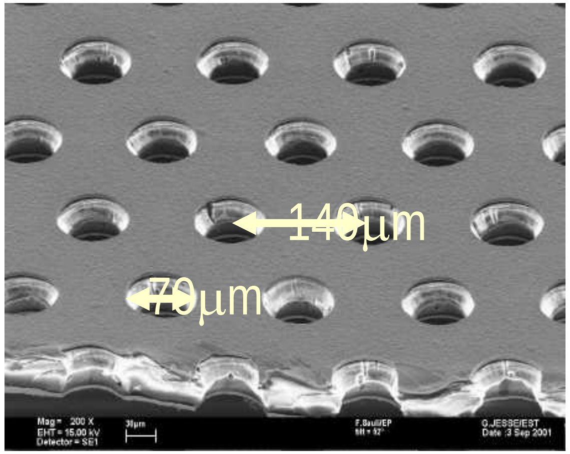
But … need to:

- understand/operate GEM systems (done)
- develop GEM/DHCAL design – in progress
- prototype/test GEM active DHCAL layer - in progress
- develop full calorimeter design

Digital calorimetry – counting cells



GEM foil etching



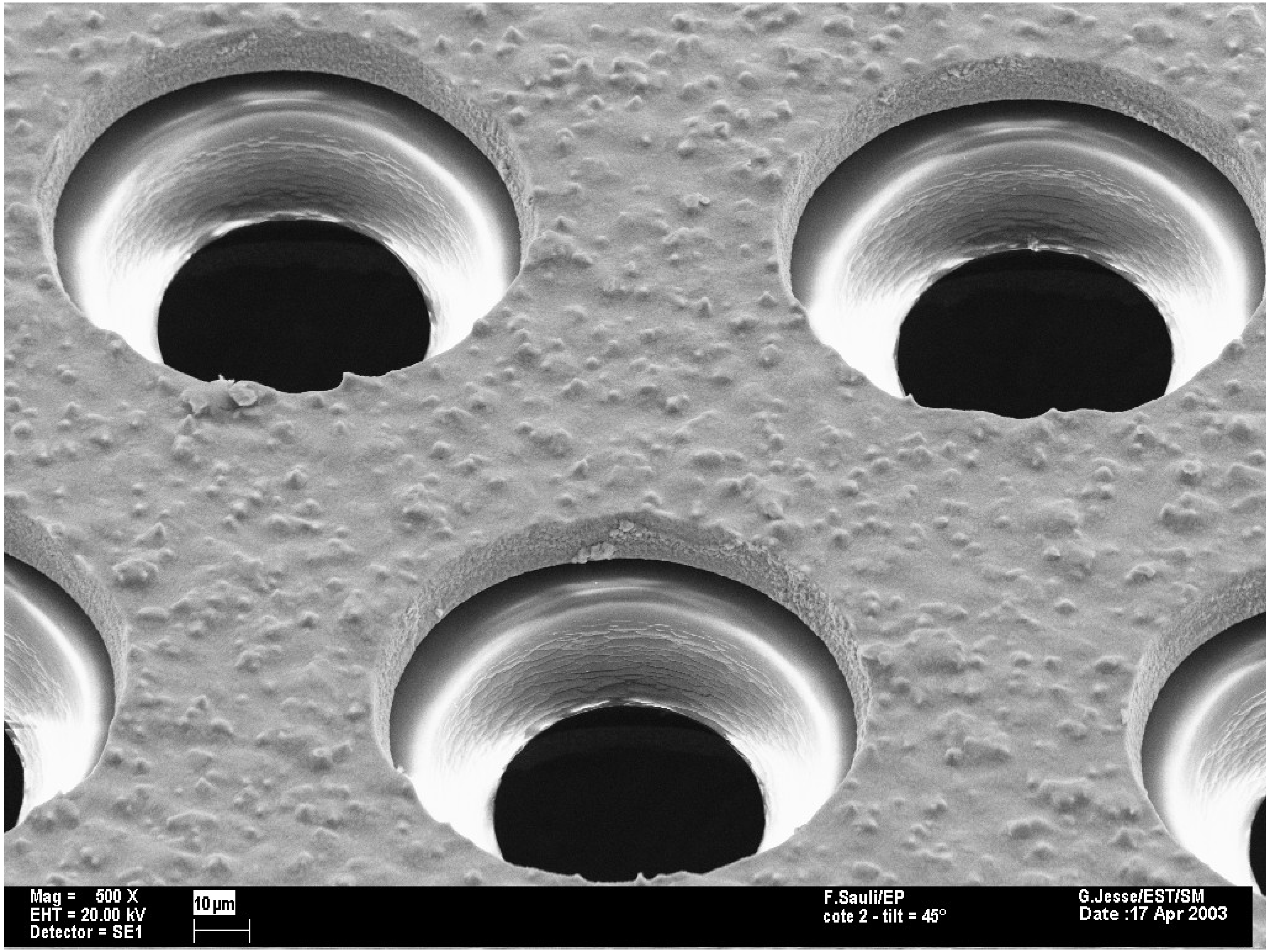
GEM field and multiplication

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

Subtractive 3M Mass Produced GEM

Chicago
Purdue
3M
GEM

SEM
Courtesy
Fabio
Sauli



Double GEM schematic

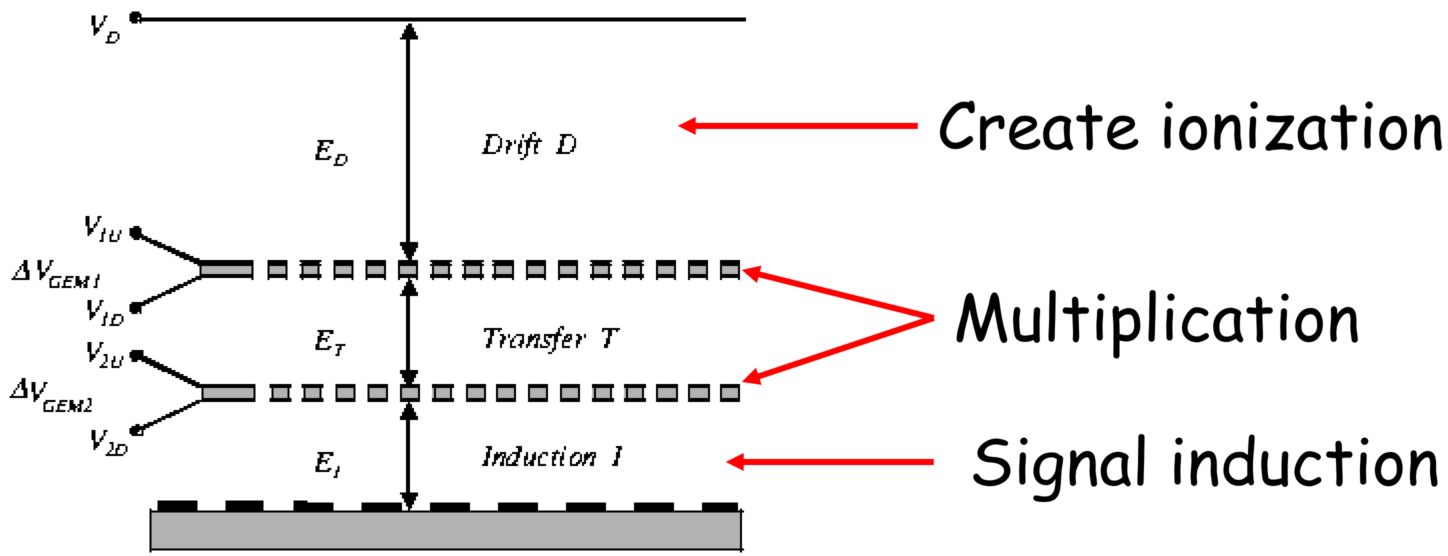


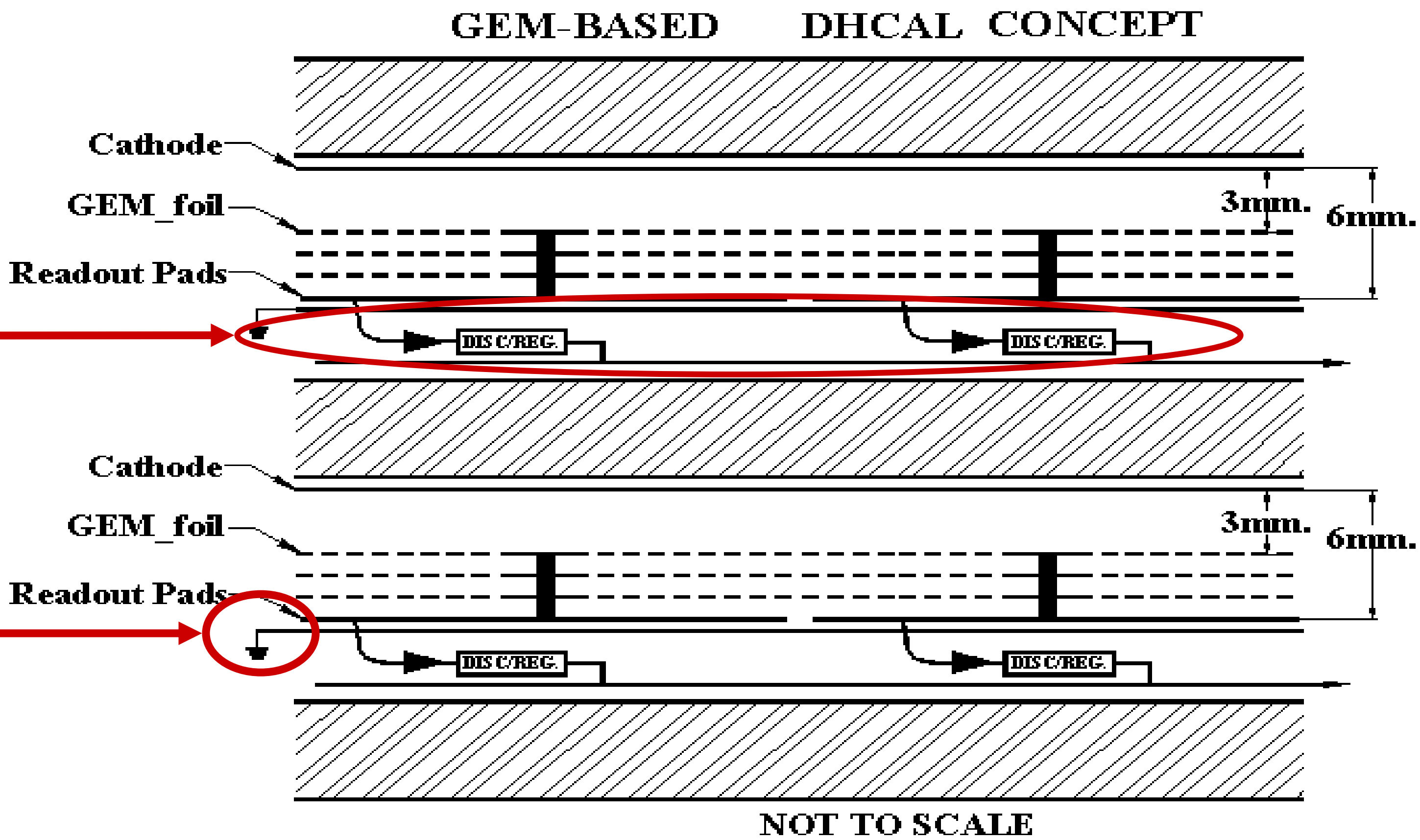
Fig. 1: Schematics of a double-GEM detector.

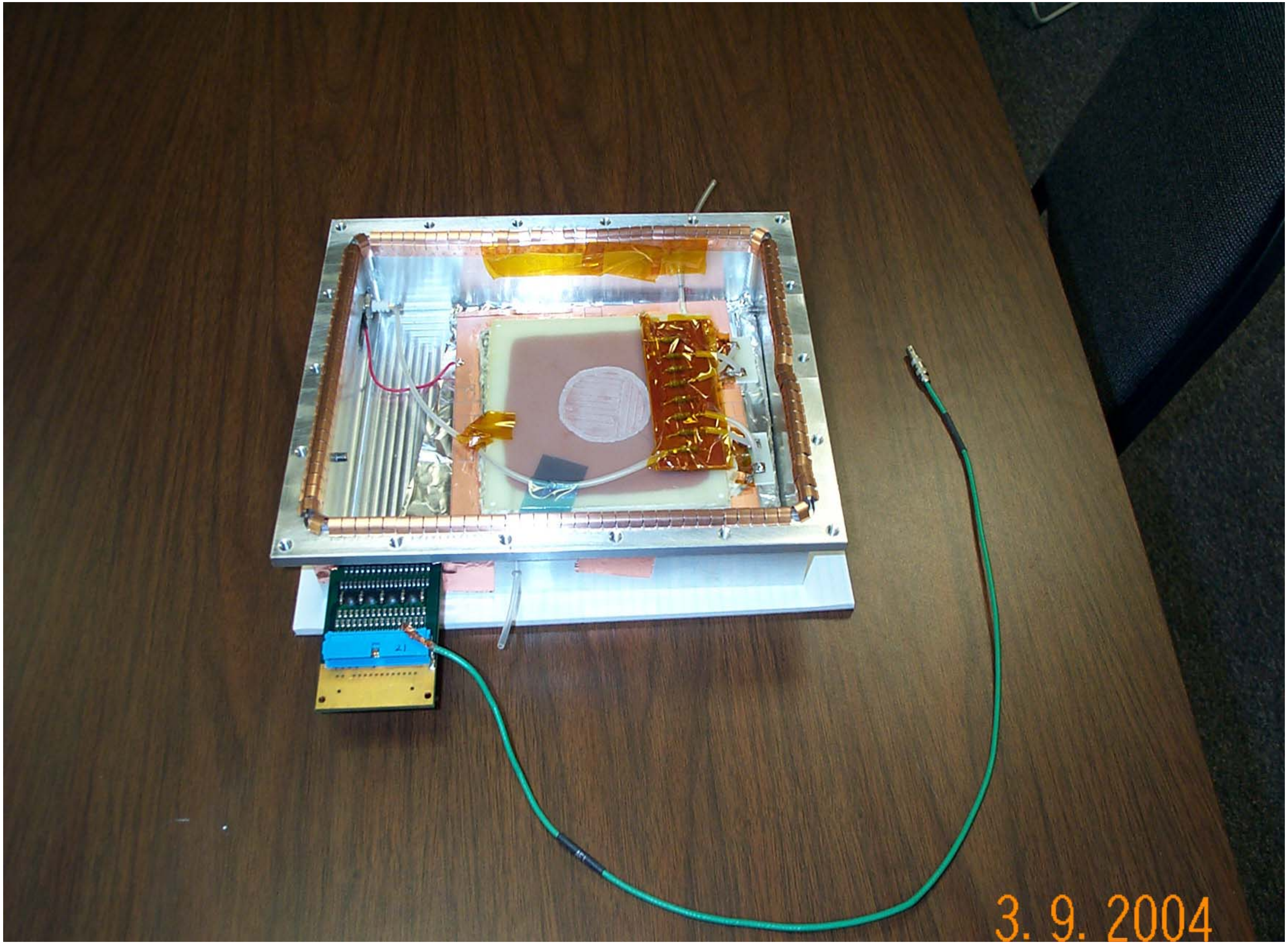
From S.Bachmann et al. CERN-EP/2000-151

Design for DHCAL using Triple GEM

Embeded onboard readout

Ground to avoid cross-talk

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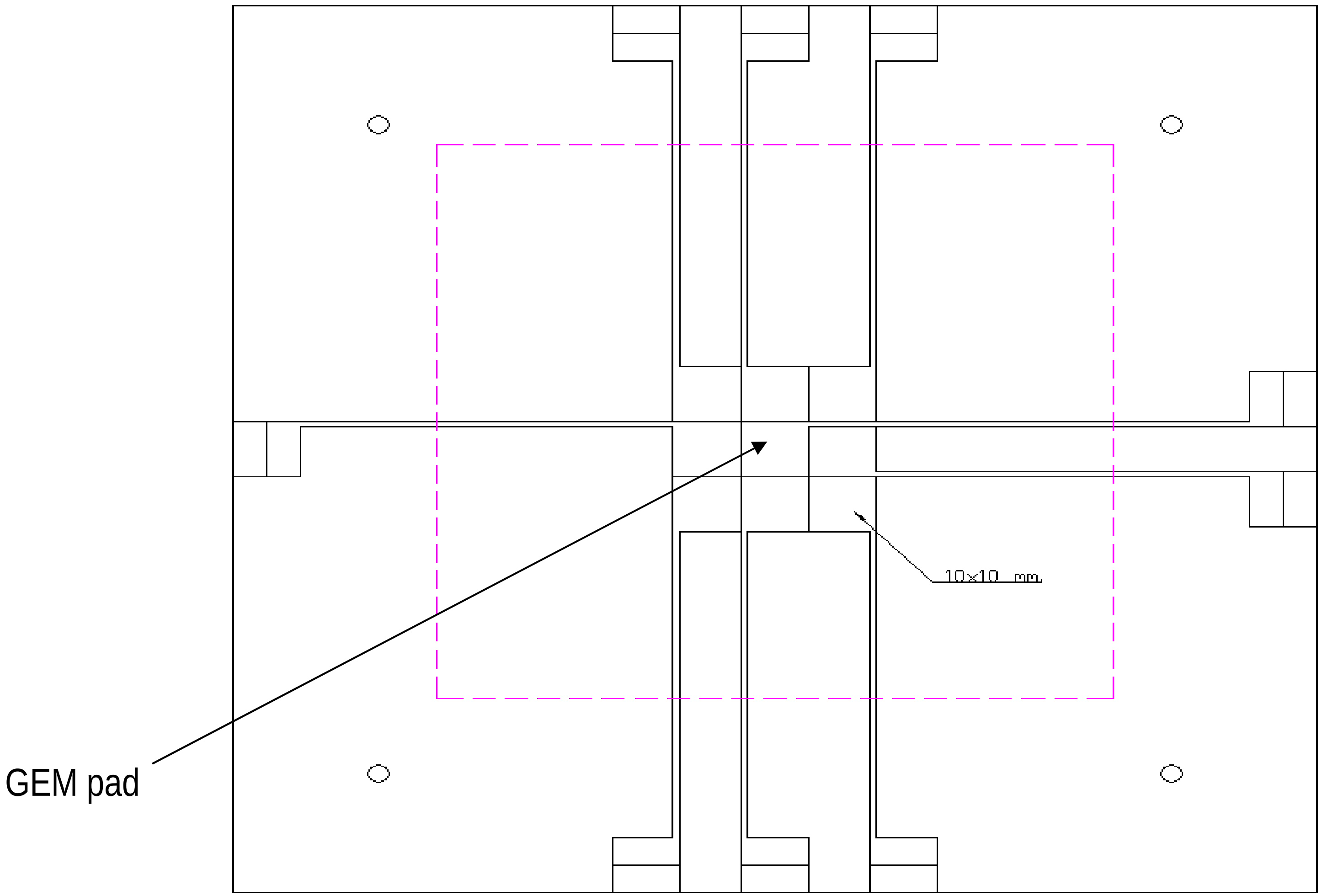
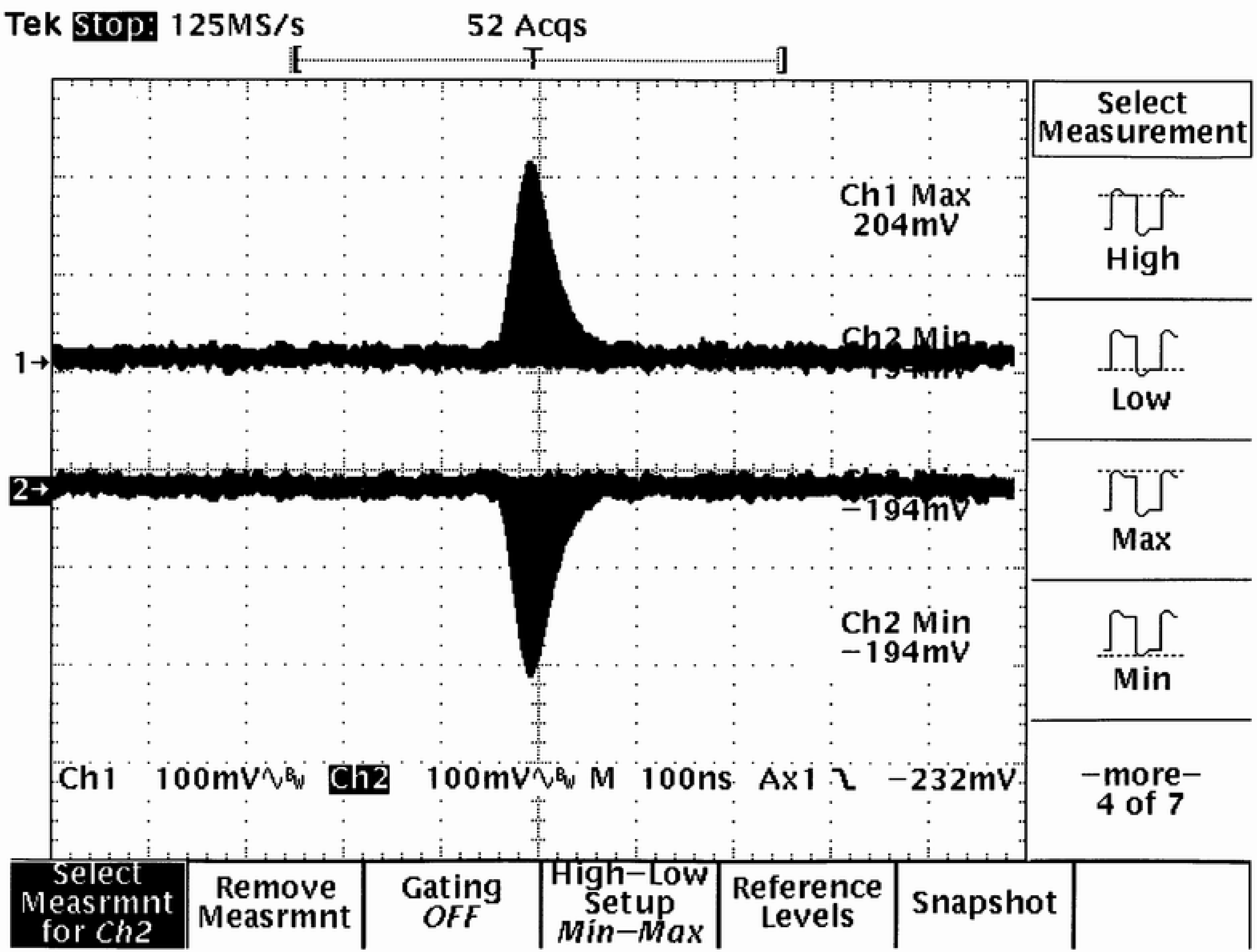
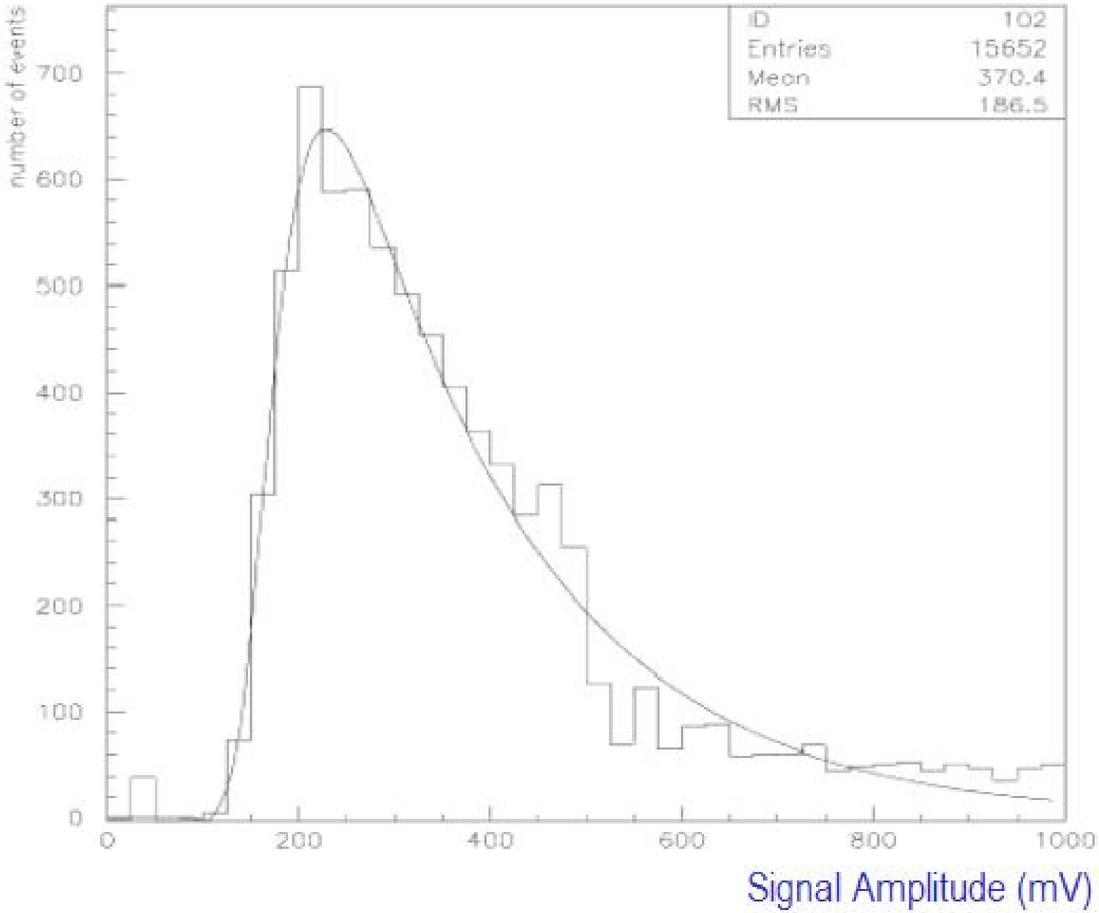
Nine Cell GEM Prototype Readout

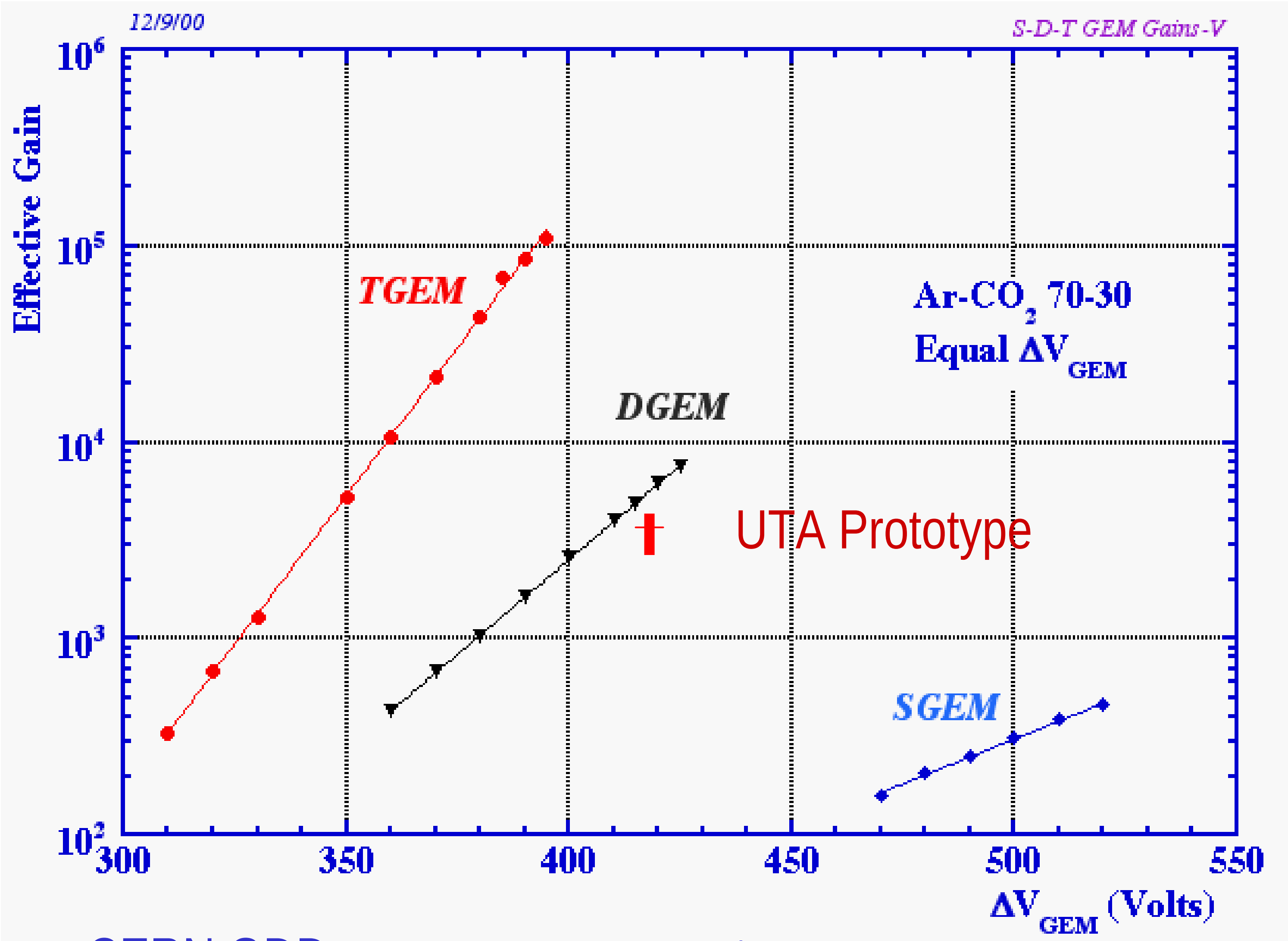



Tek Stop: 125MS/s
52 Acqs
Ch1 Max
204mV
Ch2 Min
-194mV
Ch1 100mV Ch2 100mV M 100ns Ax1 -232mV
Select Measurement
High
Low
Max
Min
-more-
4 of 7
Select Measrmnt for Ch2
Remove Measrmnt
Gating OFF
High-Low Setup Min-Max
Reference Levels
Snapshot

Landau Distribution from Cs^{137} Source



Measured UTA GEM Gain



CERN GDD group measurements

Further GEM Studies with Cs-137 Source

- Cosmic running on small pads is painfully slow
- Cs-137 -> electrons and gammas
- ...but low energies

RADIONUCLIDE DATA SHEET FOR Cs-137

7/25/97

Cesium-137 55 protons 82 neutrons

Radiation:

Major Betas:

Max E (MeV)	Avg E (MeV)	# per 100 dis
0.512	0.157	95
1.173	0.415	5 (Ba-137)

Major Gammas:

E (MeV)	# per 100 dis
0.662	90

Half-life: 30.17 years or 1.10E+04 days

Doses:

External:

Max. Beta range in air	490 cm or 16.1 ft
Max. Beta range in water	0.53 cm
Gamma factor	4.24 mR/h per 1 mCi at 30 cm
Ave. gamma E	662 keV

Skin Dose: Reported for 1 uCi over 1 sq cm of skin
Disk Source: 5,730 mrad/hr (beta)
Point Source: 5,730 mrad/hr (beta)
? mrad/hr (gamma)

Min. Ingestion ALI: 100 uCi equals 5 rem TEDE (Whole Body)

Min. Inhalation ALI: 200 uCi equals 5 rem TEDE (Whole Body)

Shielding Information:

Max. range for beta: Plastic = 0.53 cm
Aluminum = 0.25 cm

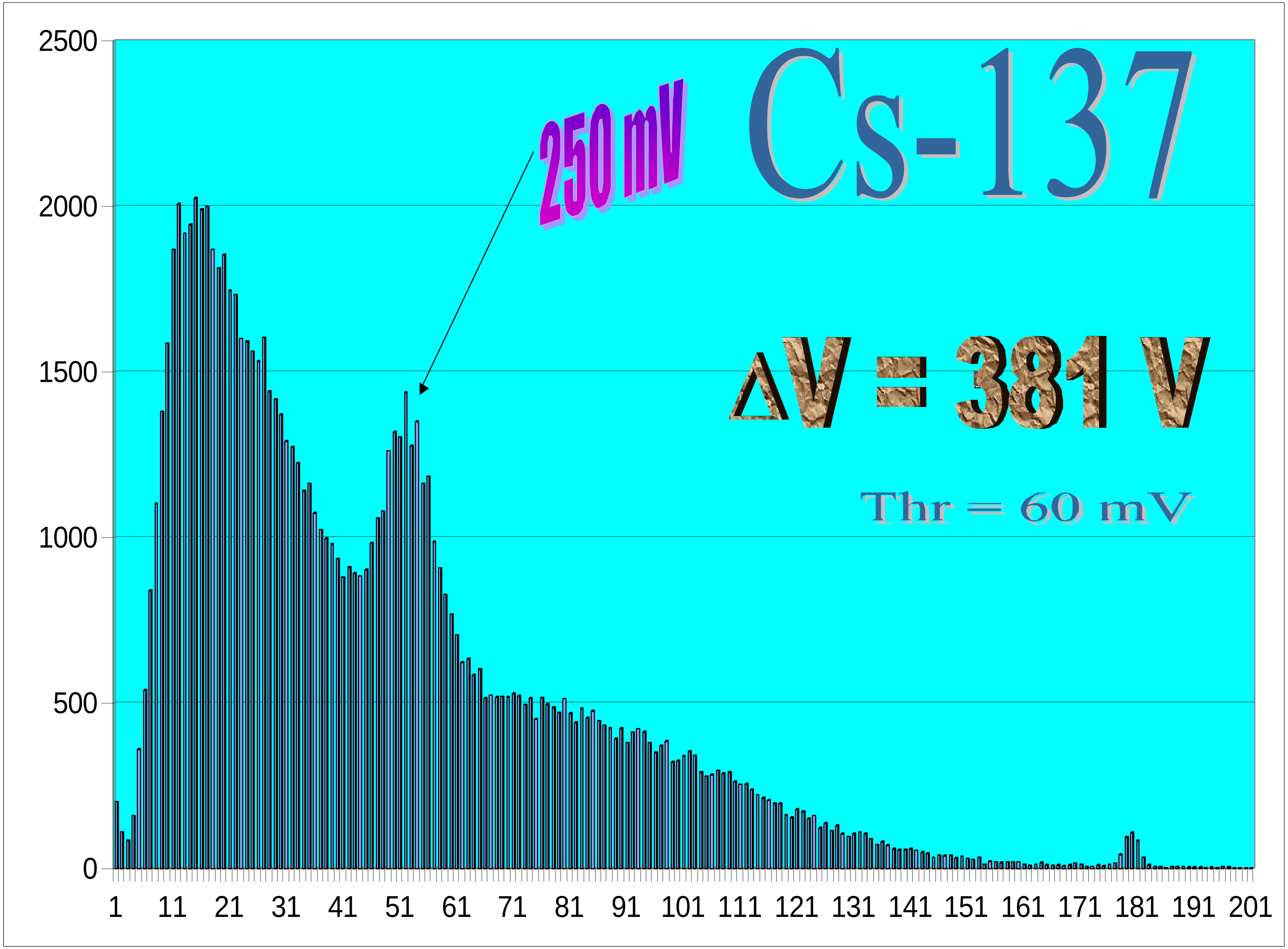
Tenth Value Thickness For average gamma: Concrete = 13 cm
Lead = 1.7 cm

Detection Information: Usable Detectors listed with estimated efficiencies
(Use efficiencies listed on instrument when available)

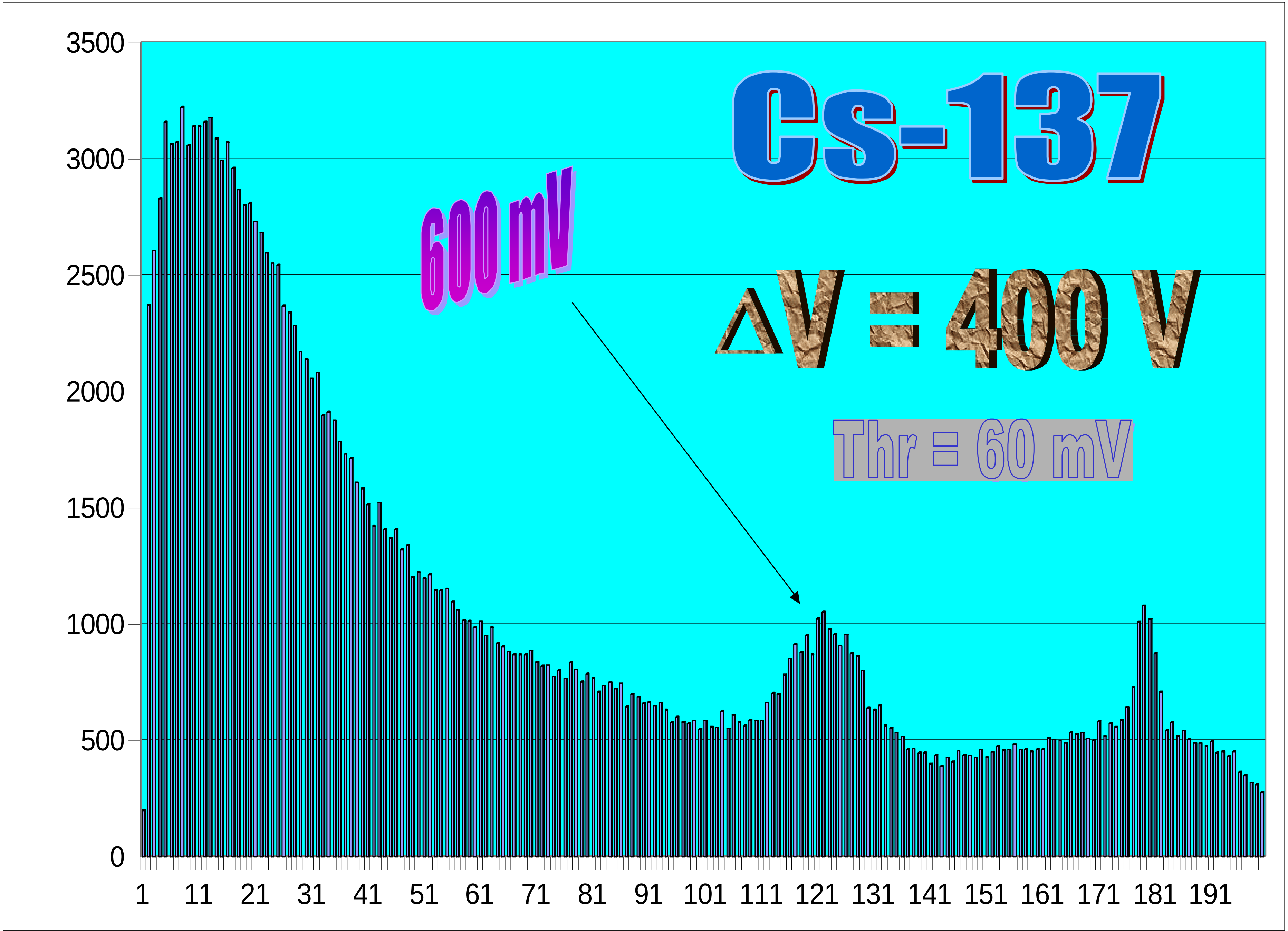
Ludlum 3 with pancake probe at 1 cm: 7%
Ludlum 3 with NaI probe near surface: 4%
Liq. Scint. Counter: 90%
Gamma Counter: 30%

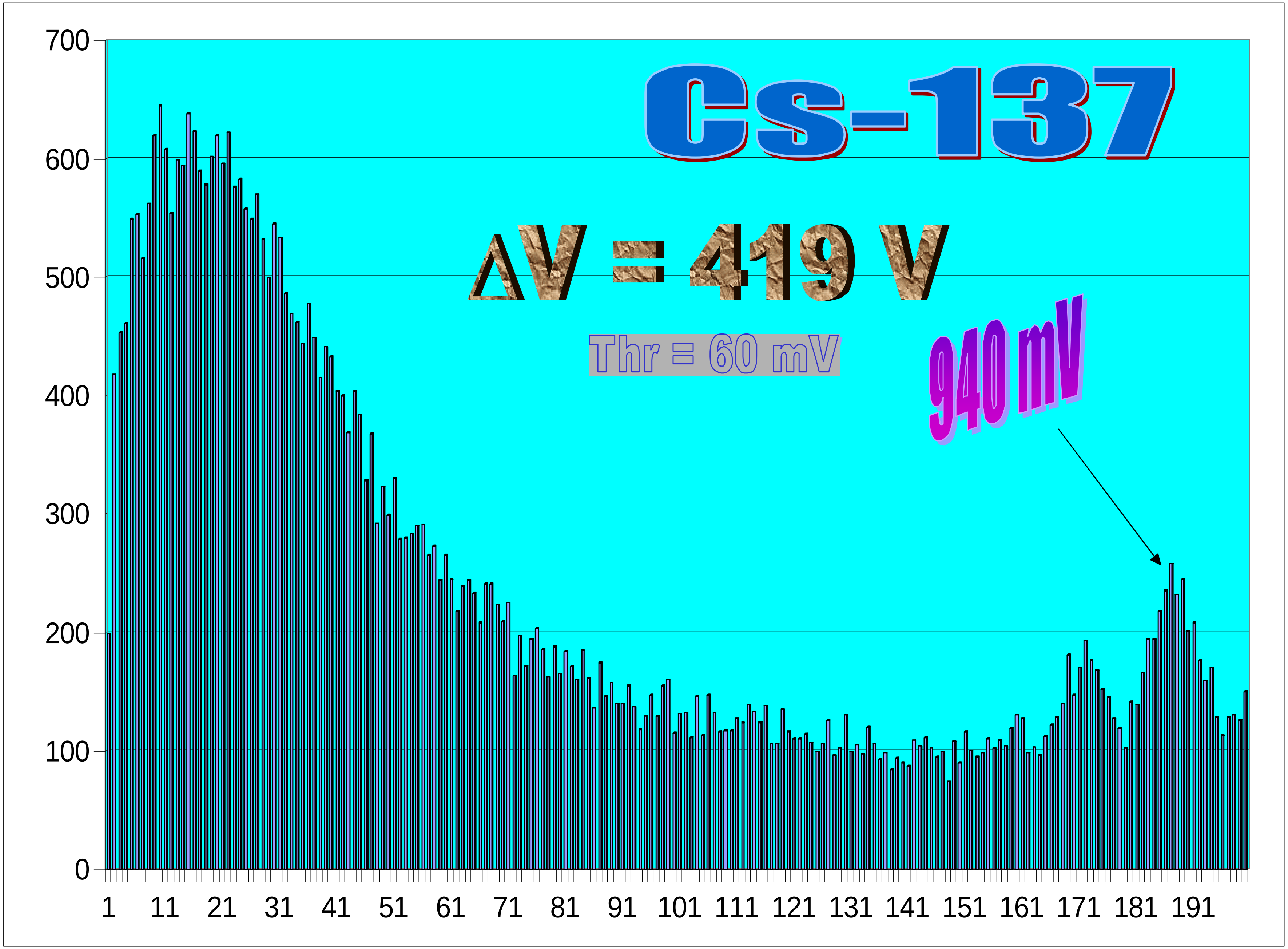
Action Quantities

Bench top quantity must be less than 1,000 uCi
Containers require labeling when greater than 10 uCi
Rooms requires posting when there is greater than 100 uCi
Contamination lasting more than 24 hours require NRC notification when greater than 500 uCi

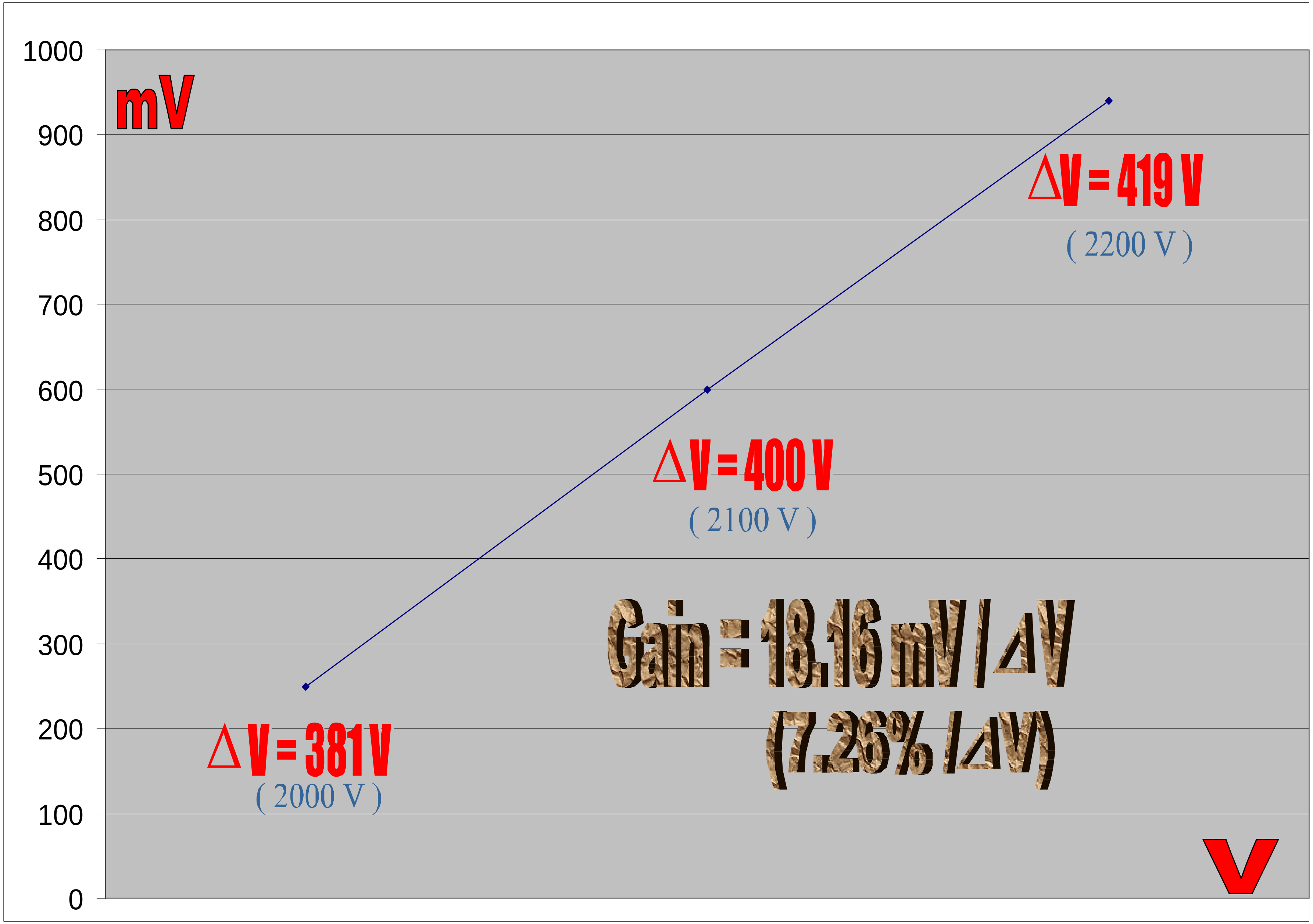


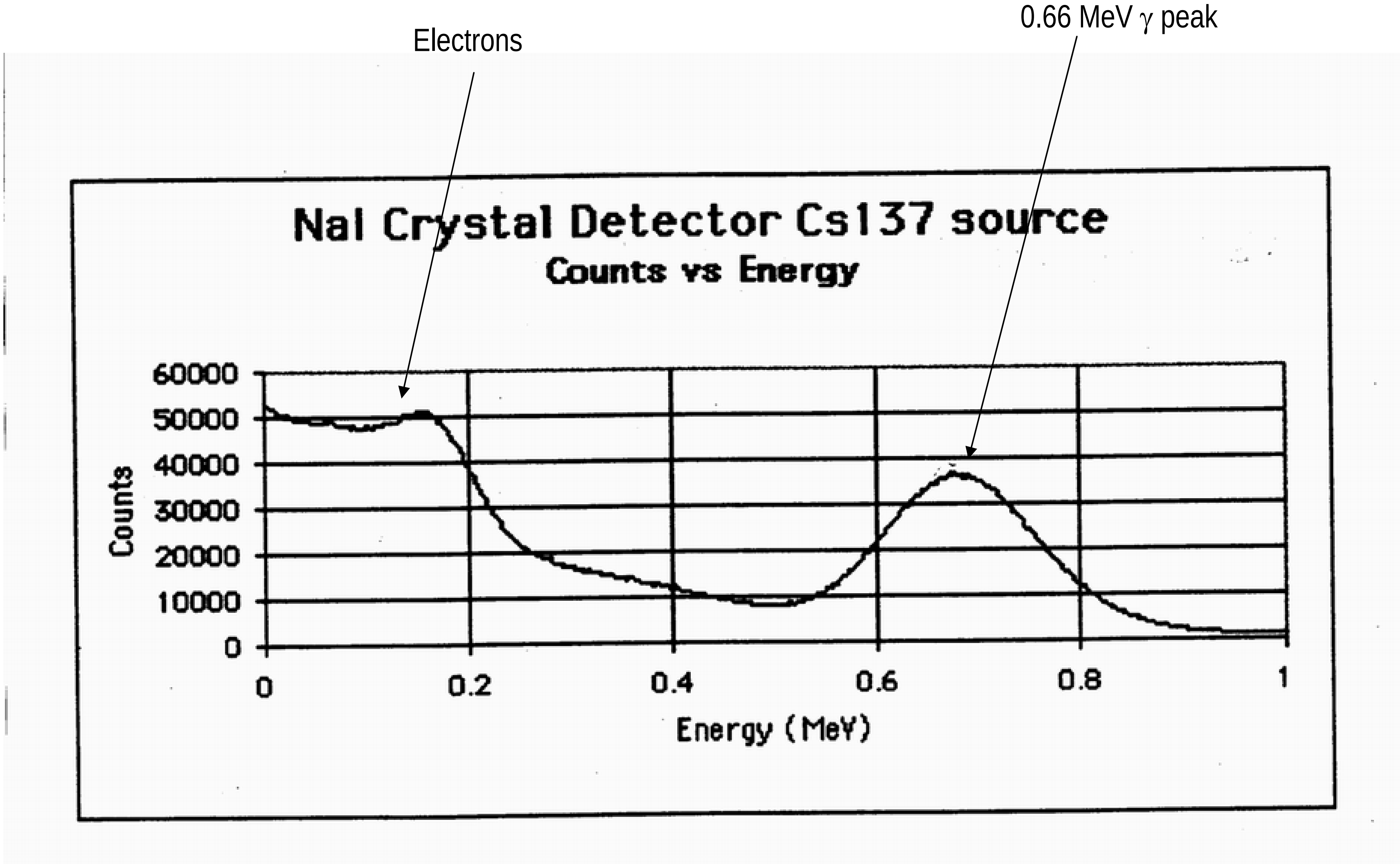
2500
2000
1500
1000
500
0
1
11
21
31
41
51
61
71
81
91
101
111
121
131
141
151
161
171
181
191
201
250 mV
Cs-137
ΔV = 381 V
Thr = 60 mV


Cs-137
ΔV = 400 V
Thr = 60 mV
600 mV
3500
3000
2500
2000
1500
1000
500
0
1 11 21 31 41 51 61 71 81 91 101 111 121 131 141 151 161 171 181 191



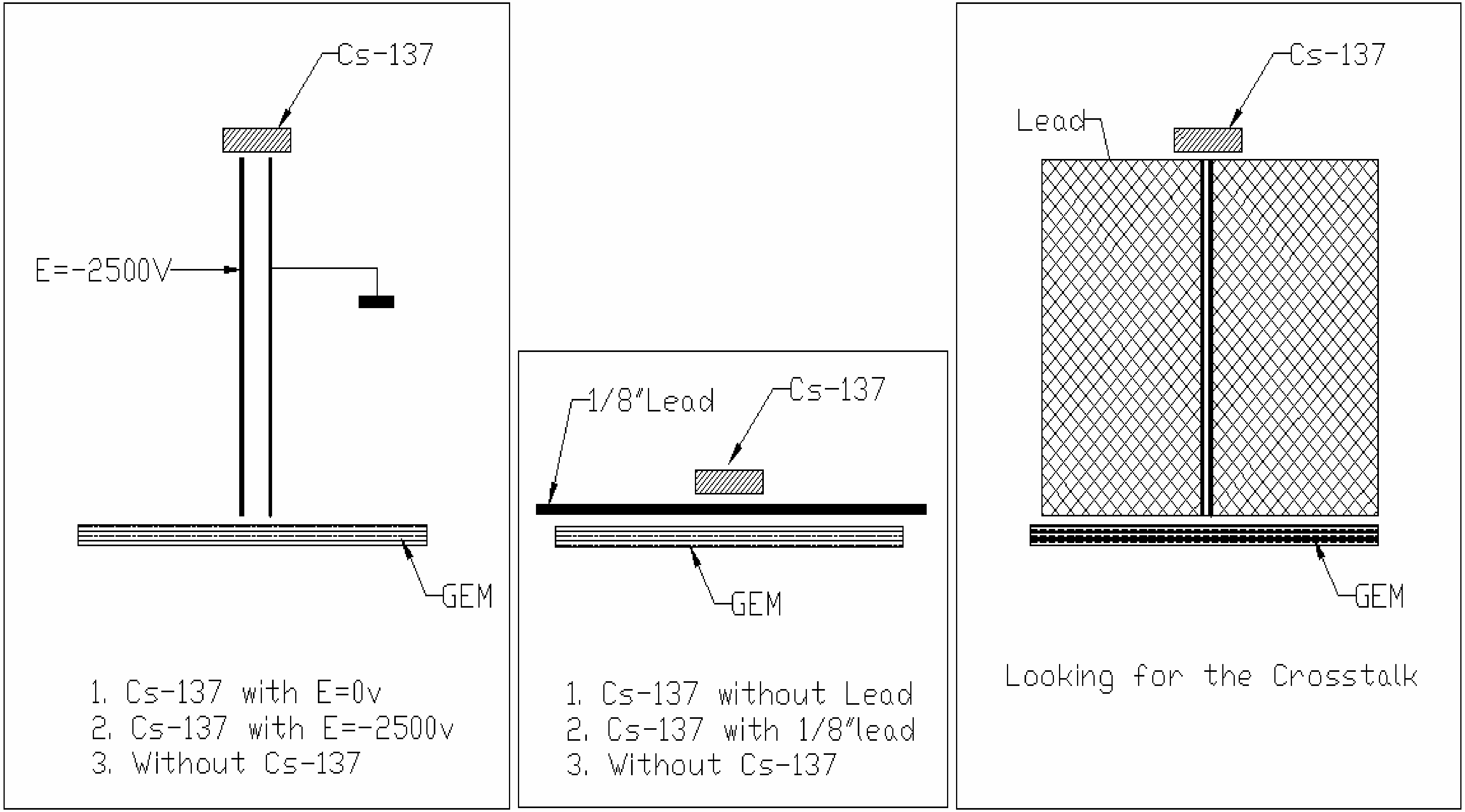
Cs-137
ΔV = 419 V
Thr = 60 mV
940 mV
700
600
500
400
300
200
100
0
1 11 21 31 41 51 61 71 81 91 101 111 121 131 141 151 161 171 181 191

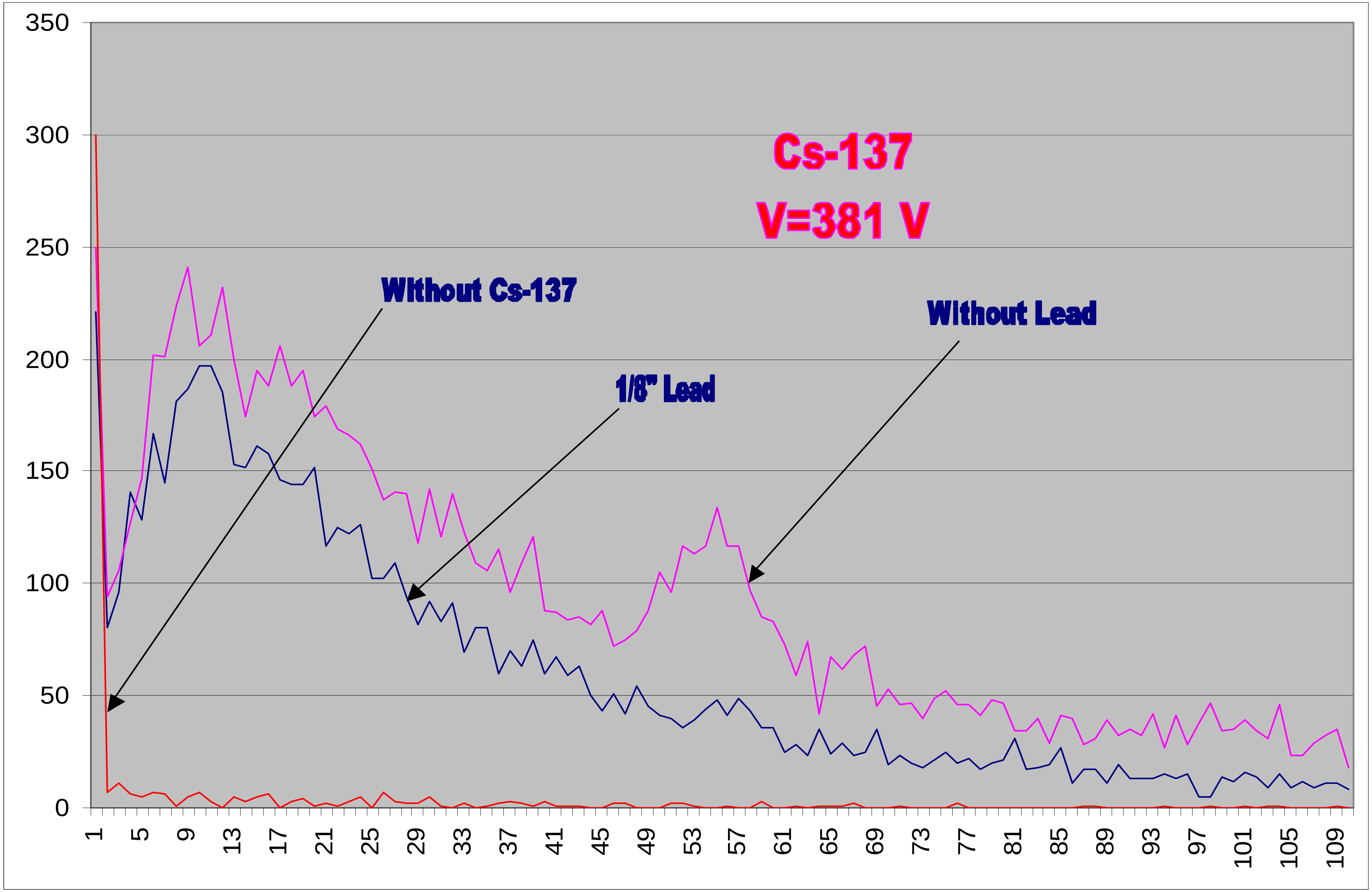

mV
1000
900
800
700
600
500
400
300
200
100
0
ΔV = 419 V
(2200 V)
ΔV = 400 V
(2100 V)
ΔV = 381 V
(2000 V)
Gain = 18.16 mV / ΔV
(7.26% / ΔV)
V



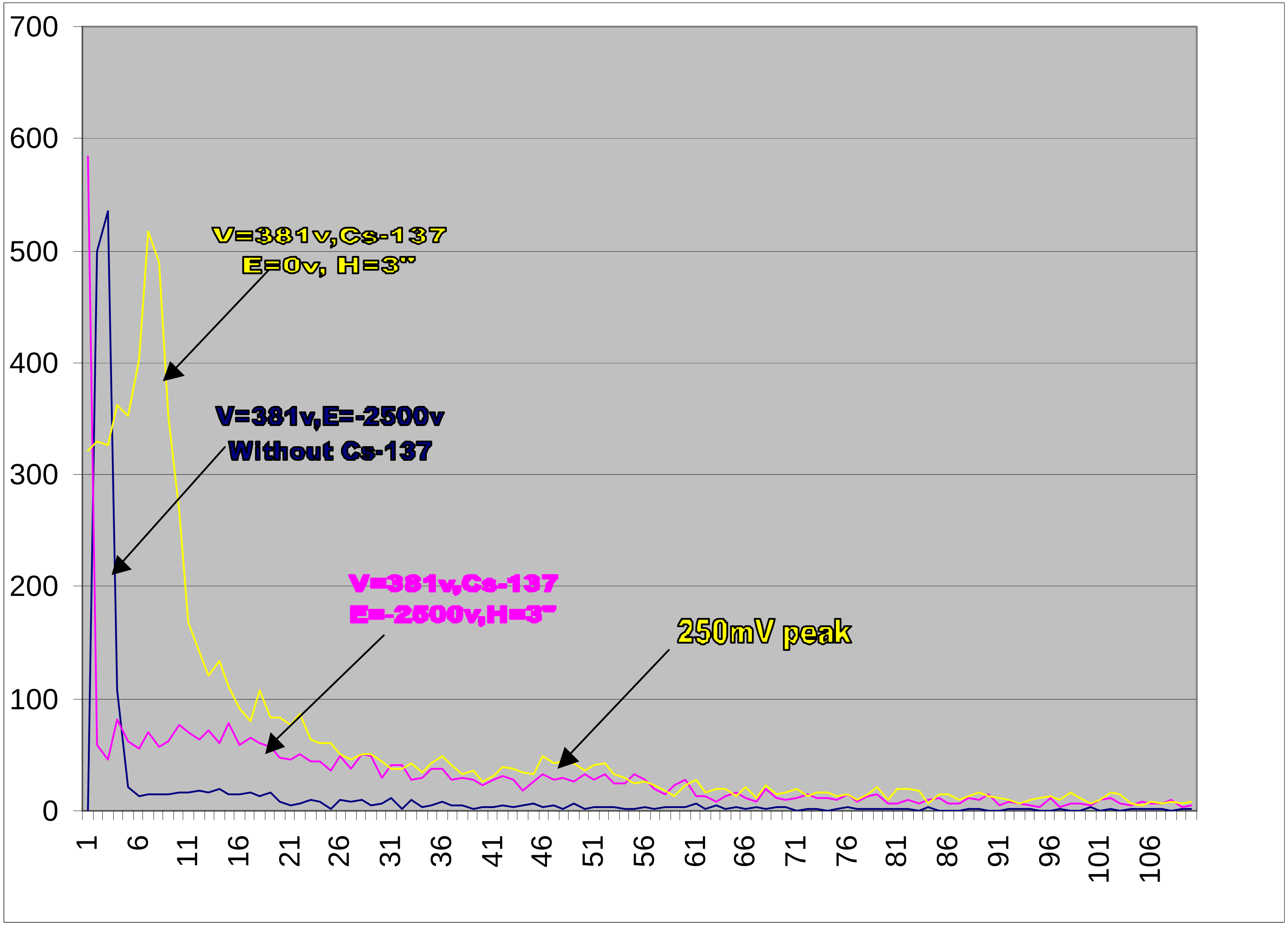
Electrons
0.66 MeV γ peak
NaI Crystal Detector Cs137 source
Counts vs Energy
Counts
60000
50000
40000
30000
20000
10000
0
0
0.2
0.4
0.6
0.8
1
Energy (MeV)

Further GEM Studies with Cs-137 Source





-> Peak suppressed with lead sheet



-> Low energy peak (electrons) killed by transverse E field

Further GEM Studies with Cs-137 Source

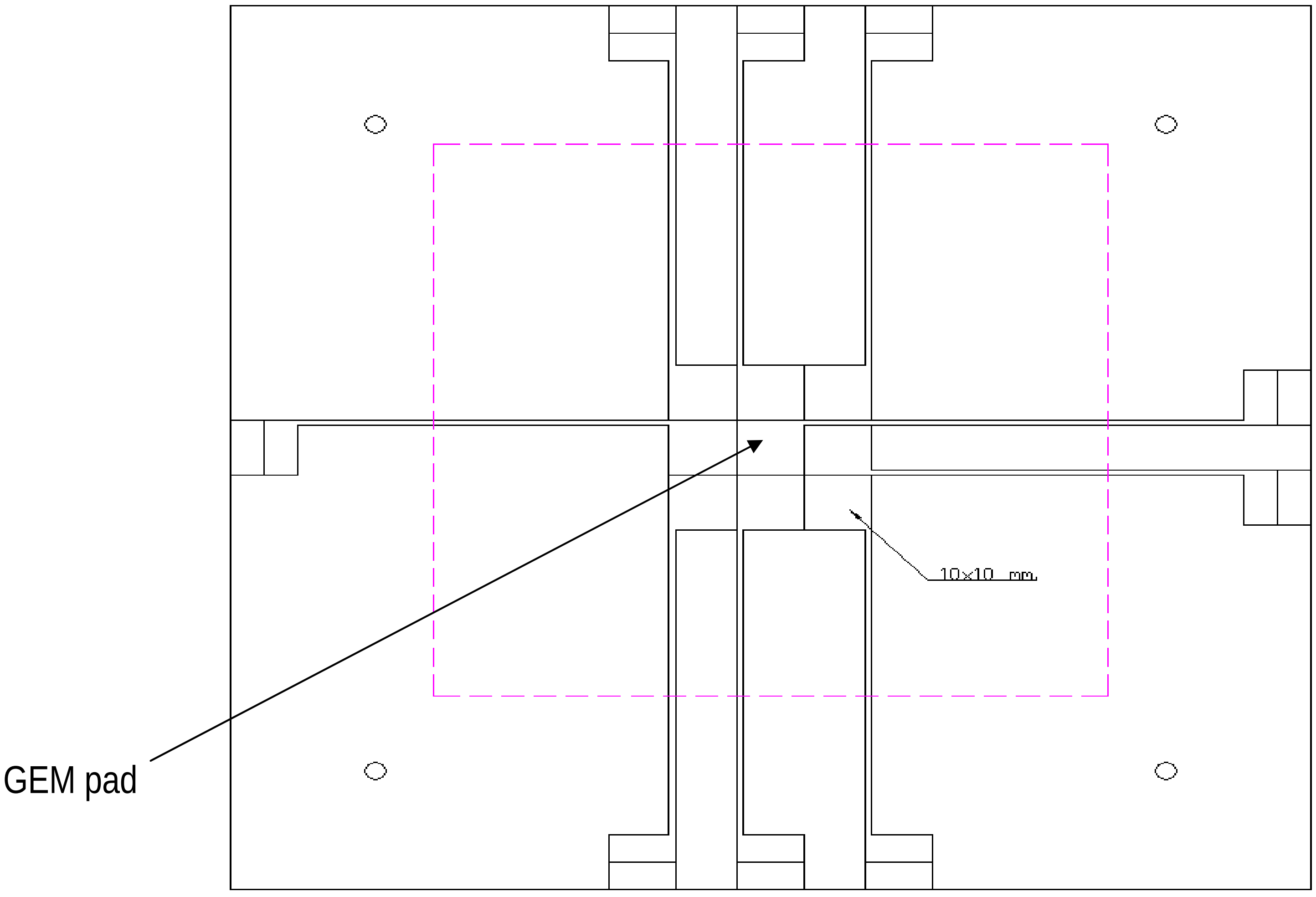
-> "Interesting" results from Cs-137…but maybe not so relevant for GEM studies

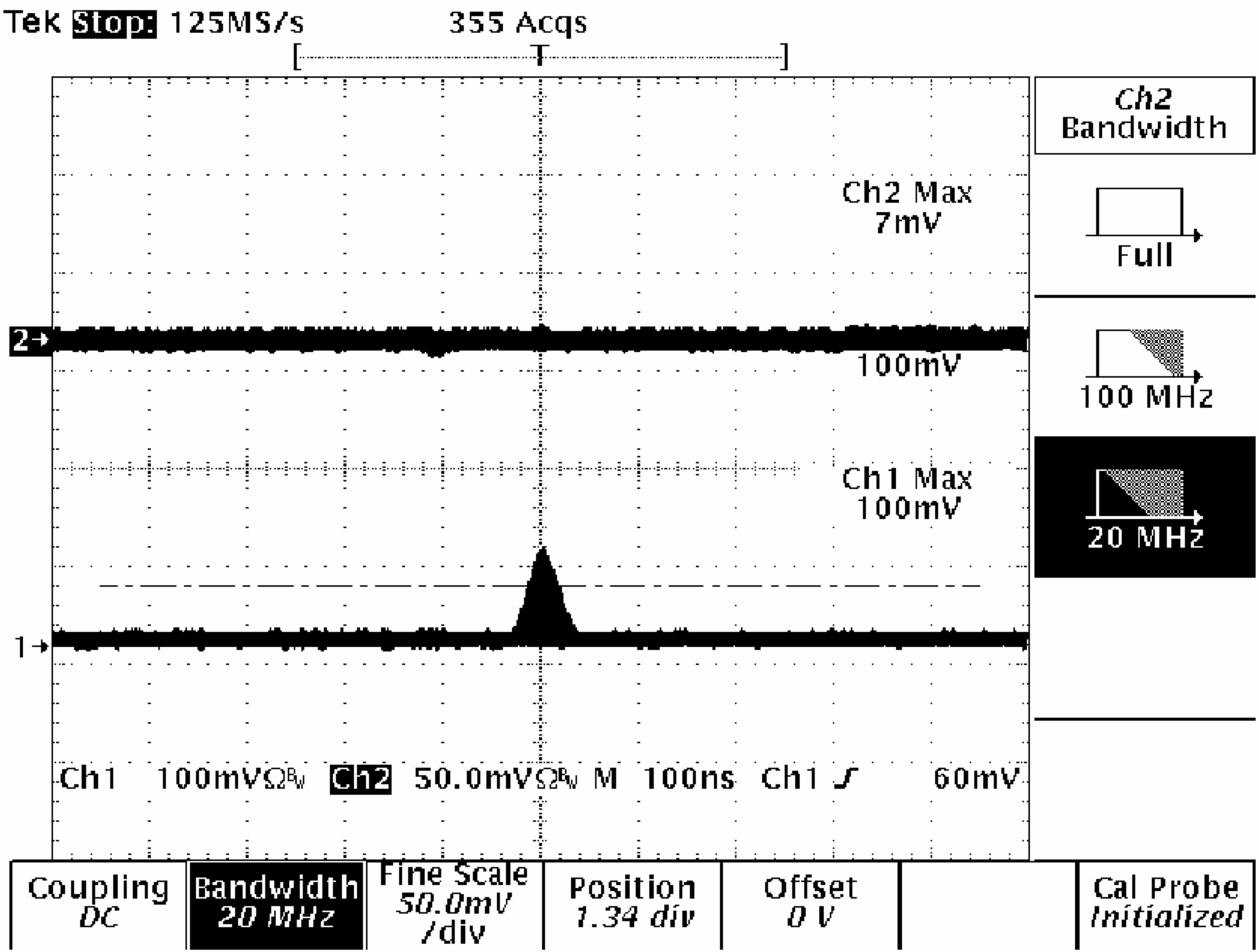
-> Ruthenium source on order 3.5 MeV electrons… should give much clearer probe of GEM response

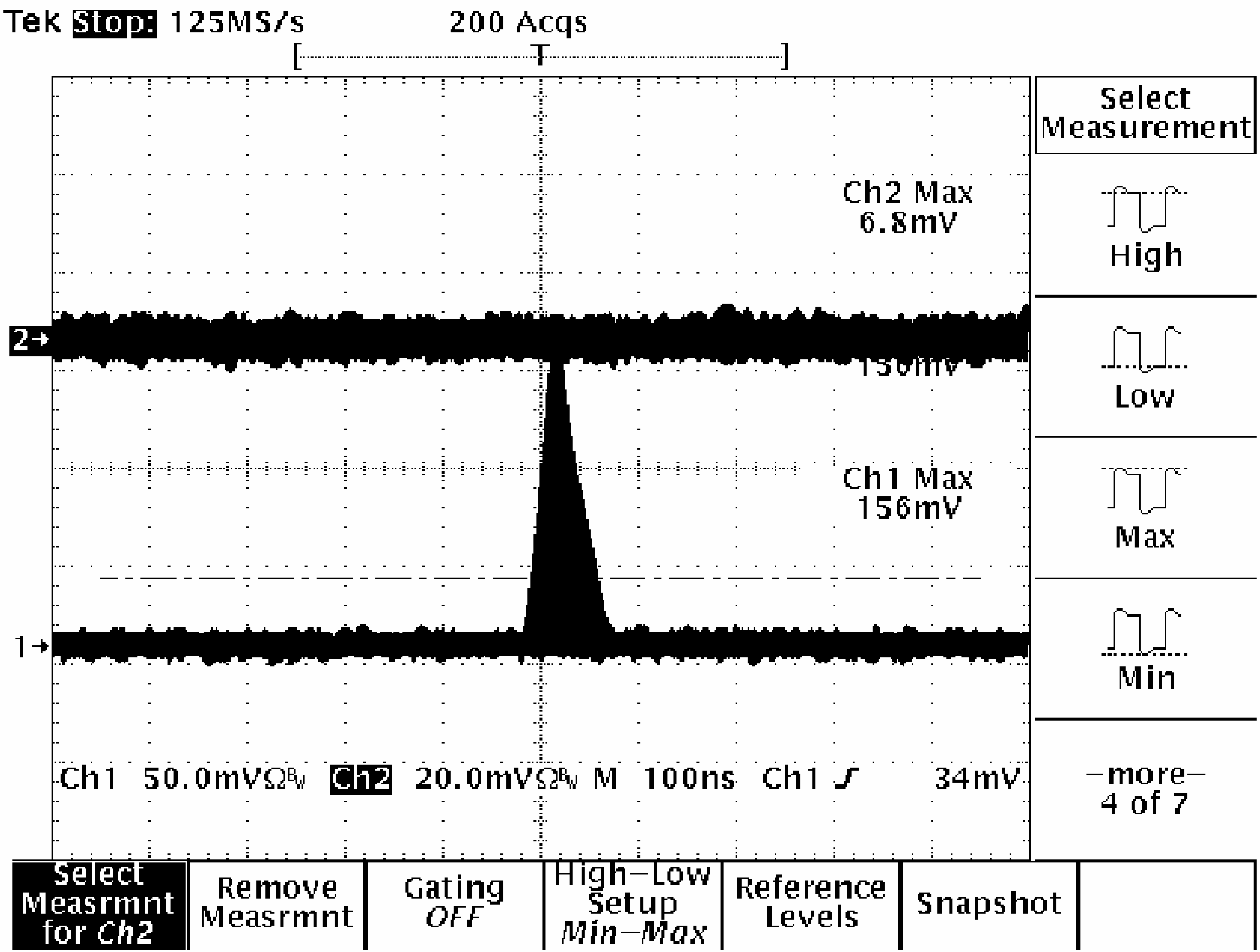
First look at cross-talk

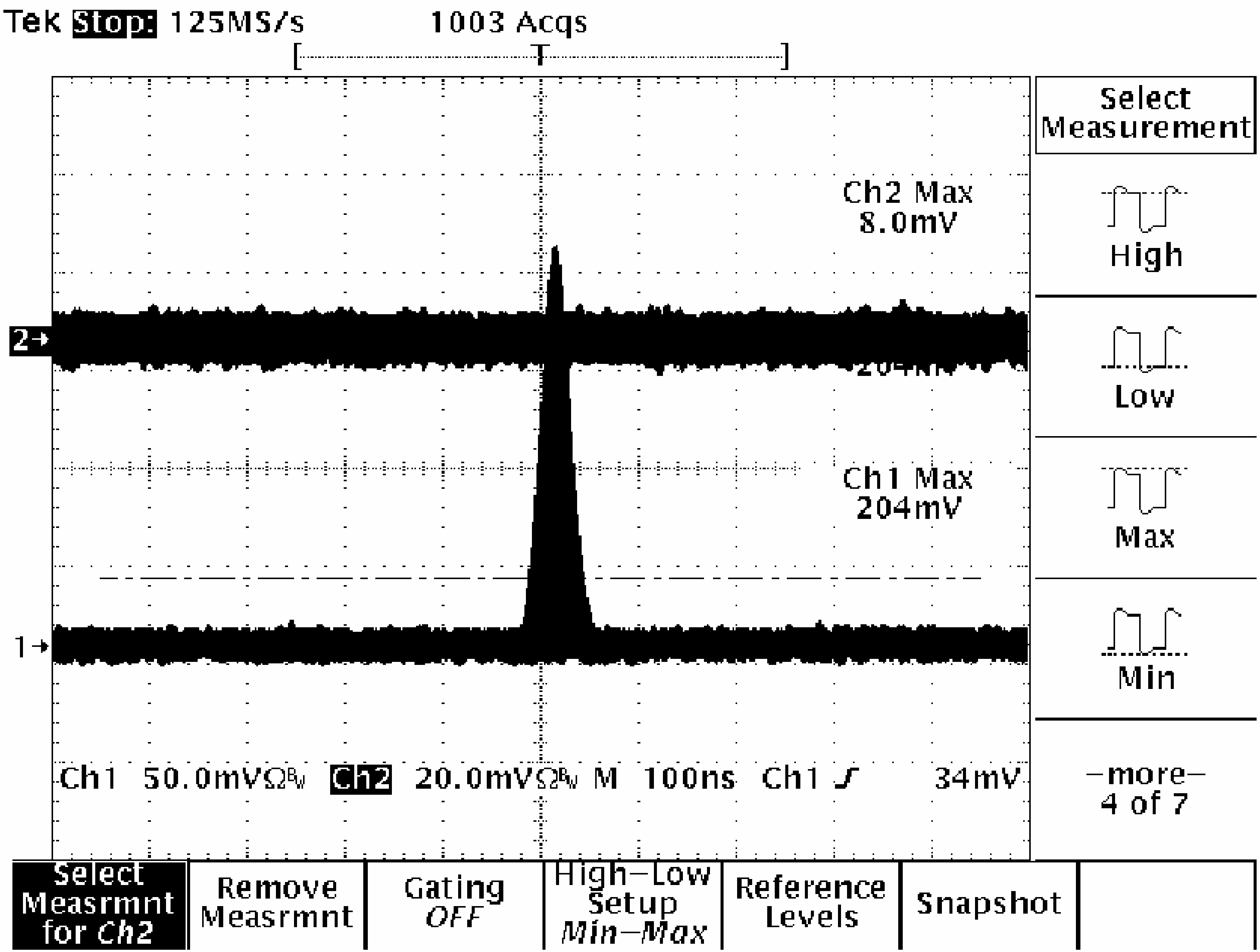
- Use two channels of Fermilab 32-channel board.
- Position source over central pad (of 3 x 3 array) using a 3" high colimator.
- Look at peak signals on adjacent pad as signal size varied on central pad – visual results from scope.
- Study limited by minimum noise level.
- First results indicate cross-talk at ~few% level.

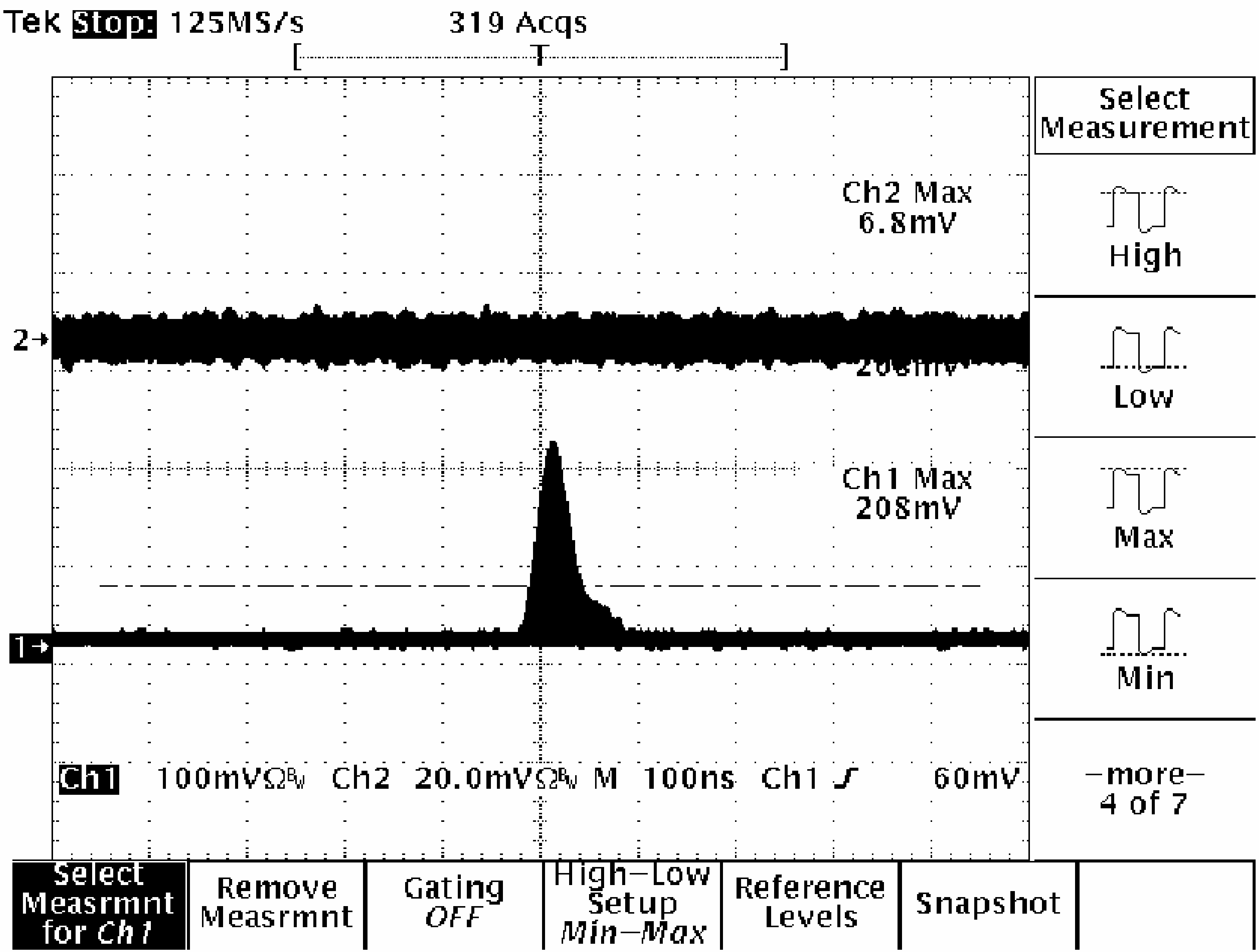
Nine Cell GEM Prototype Readout

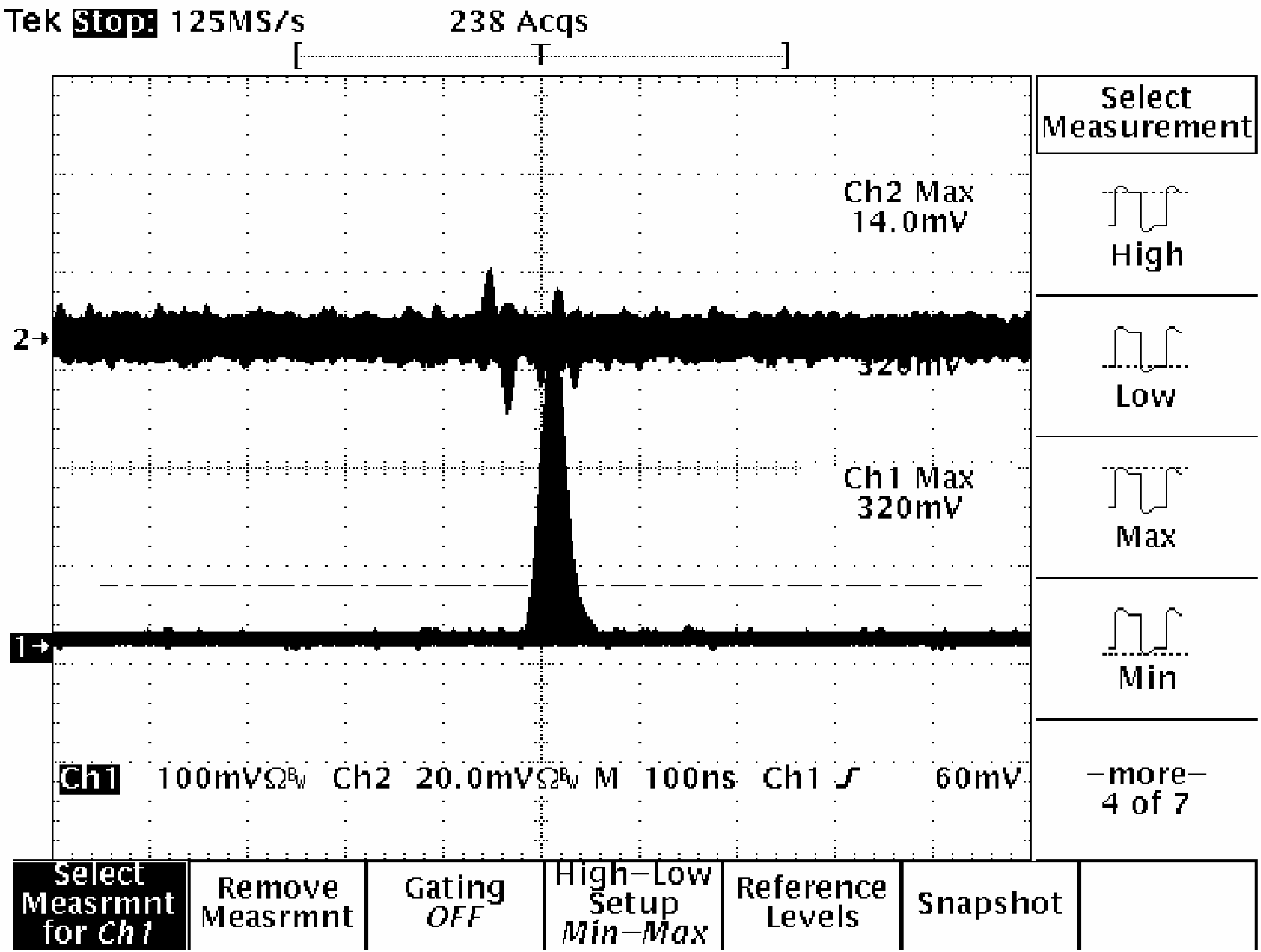


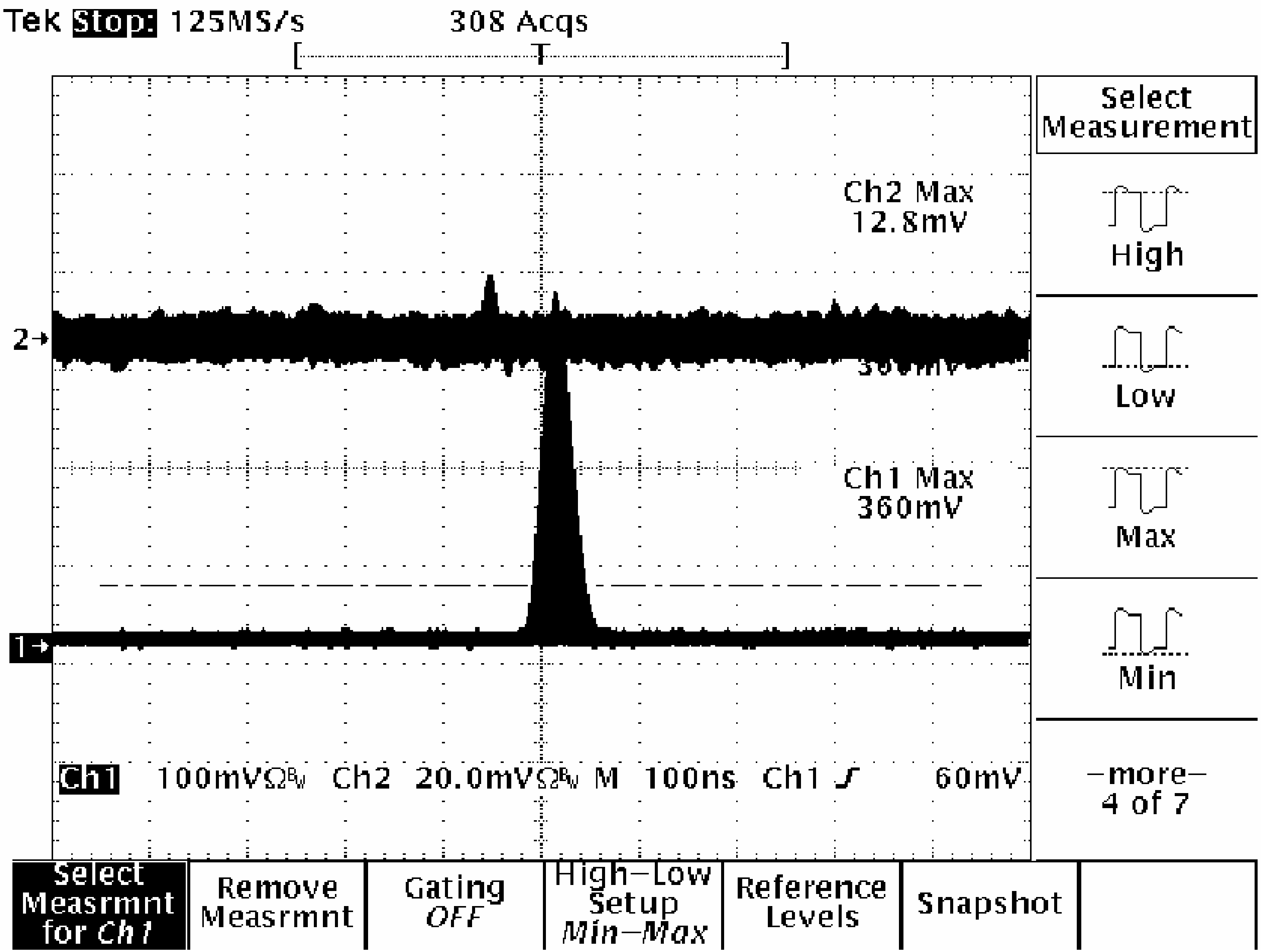

Tek Stop: 125MS/s
355 Acqs
Ch2 Max
7mV
100mV
Ch1 Max
100mV
Ch1 100mV Ch2 50.0mV M 100ns Ch1 60mV
Ch2
Bandwidth
Full
100 MHz
20 MHz
Coupling
DC
Bandwidth
20 MHz
Fine Scale
50.0mV
/div
Position
1.34 div
Offset
0 V
Cal Probe
Initialized


Tek Stop: 125MS/s 200 Acqs
Ch2 Max
6.8mV
Ch1 Max
156mV
Ch1 50.0mV Ch2 20.0mV M 100ns Ch1 34mV
Select Measurement
High
Low
Max
Min
-more-
4 of 7
Select Measrmnt for Ch2
Remove Measrmnt
Gating OFF
High-Low Setup Min-Max
Reference Levels
Snapshot


Tek Stop: 125MS/s 1003 Acqs
Ch2 Max
8.0mV
Ch1 Max
204mV
Ch1 50.0mVΩBW Ch2 20.0mVΩBW M 100ns Ch1 34mV
Select Measurement
High
Low
Max
Min
–more–
4 of 7
Select Measrmnt for Ch2
Remove Measrmnt
Gating OFF
High–Low Setup Min–Max
Reference Levels
Snapshot


Tek Stop: 125MS/s
319 Acqs
Select Measurement
Ch2 Max
6.8mV
High
Low
Ch1 Max
208mV
Max
Min
Ch1 100mVΩ ᴮw Ch2 20.0mVΩ ᴮw M 100ns Ch1 ƒ 60mV
−more−
4 of 7
Select Measrmnt for Ch1
Remove Measrmnt
Gating OFF
High−Low Setup Min−Max
Reference Levels
Snapshot


Tek Stop: 125MS/s
238 Acqs
Select Measurement
Ch2 Max
14.0mV
High
Low
Ch1 Max
320mV
Max
Min
Ch1 100mVΩBW Ch2 20.0mVΩBW M 100ns Ch1 ƒ 60mV
−more−
4 of 7
Select Measrmnt for Ch1
Remove Measrmnt
Gating OFF
High−Low Setup Min−Max
Reference Levels
Snapshot


Tek Stop: 125MS/s
308 Acqs
Select Measurement
Ch2 Max
12.8mV
High
Low
Ch1 Max
360mV
Max
Min
Ch1 100mVΩ Bw Ch2 20.0mVΩ Bw M 100ns Ch1 ƒ 60mV
–more–
4 of 7
Select Measrmnt for Ch1
Remove Measrmnt
Gating OFF
High–Low Setup Min–Max
Reference Levels
Snapshot

Multichannel Electronics

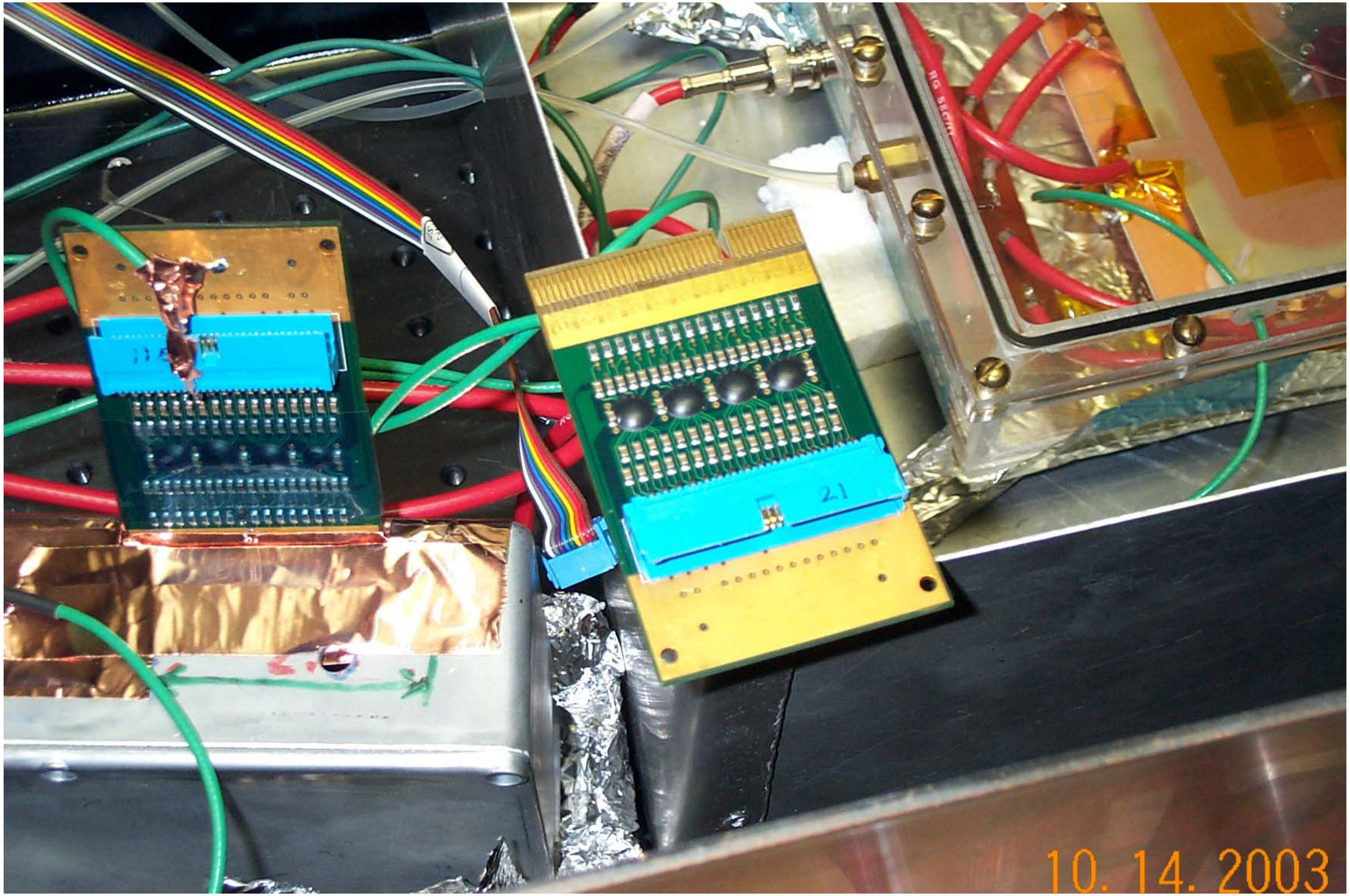
- UTA is working with DHCAL-RPC group (Argonne) and Fermilab PPD to specify requirements for readout electronics.

- Currently using 32-channel boards developed for silicon detector readout at Fermilab.

- Use of same readout scheme for GEM and RPC solutions – with optional gain changes (higher for GEM, lower for RPC/avalanche mode).

- ASIC (including HV) system work with Fermilab. Develop a 64-channel(?) solution – 8x8 cm^2 array of 1x1 cm^2 cells.

32-channel board from Fermilab

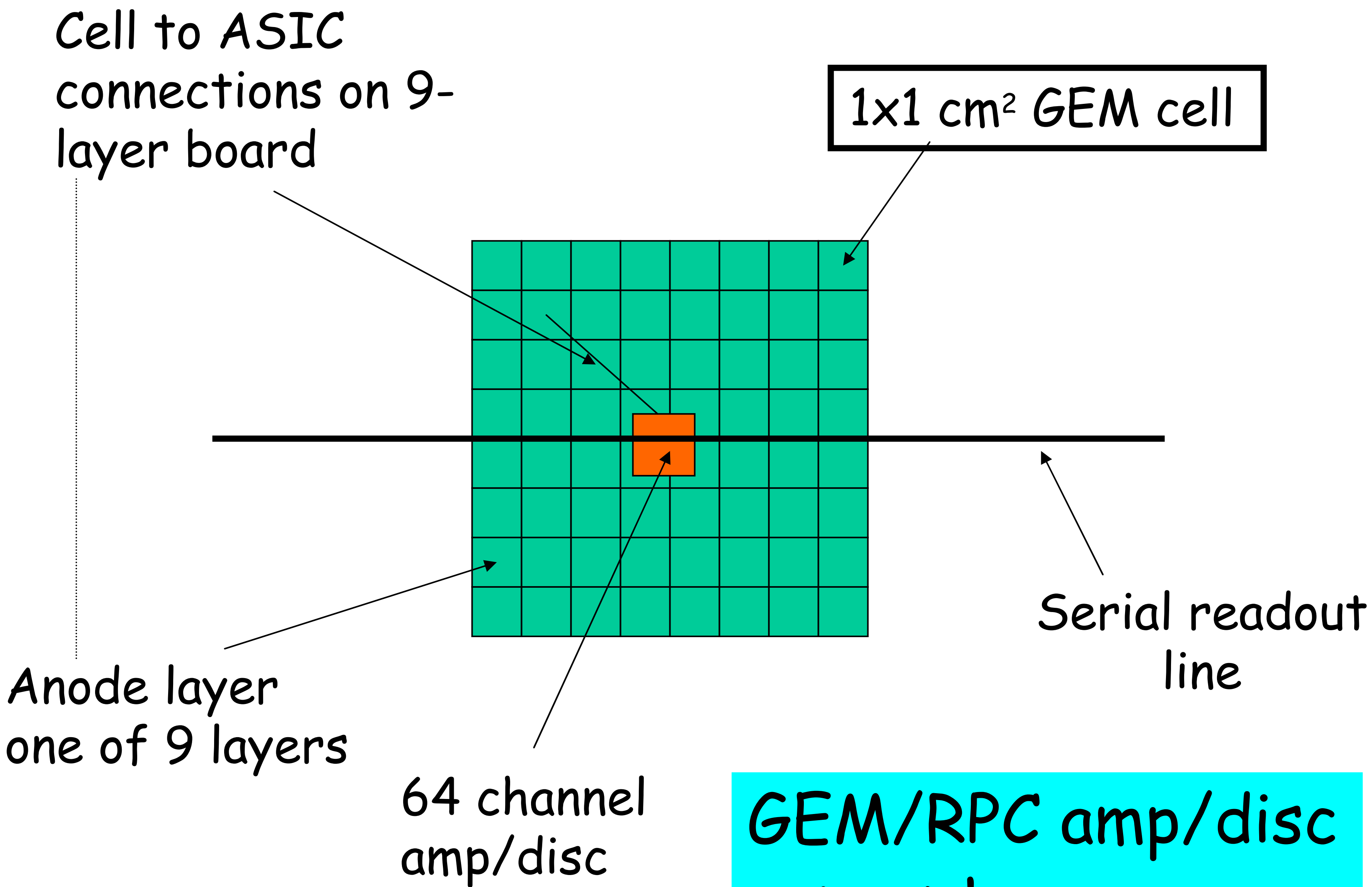


Multichannel Electronics

Current status:

Fermilab system requires very efficient RF shielding between input and output stages to prevent oscillations/noise – suitable enclosure under development.

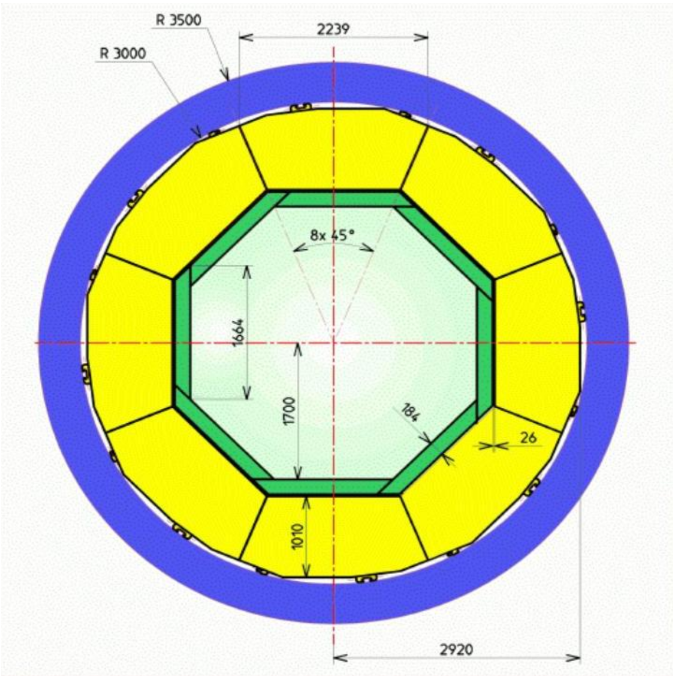
Use of this system is a temporary measure – will use for cosmic stack until joint GEM/RPC system is developed (discussions at this meeting).

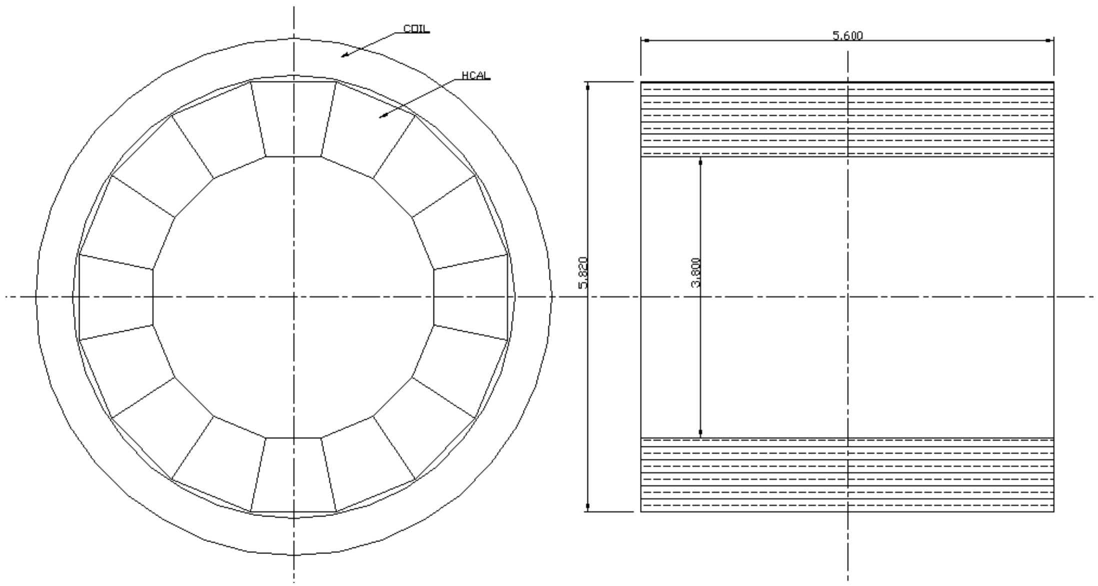


GEM/RPC amp/disc concept

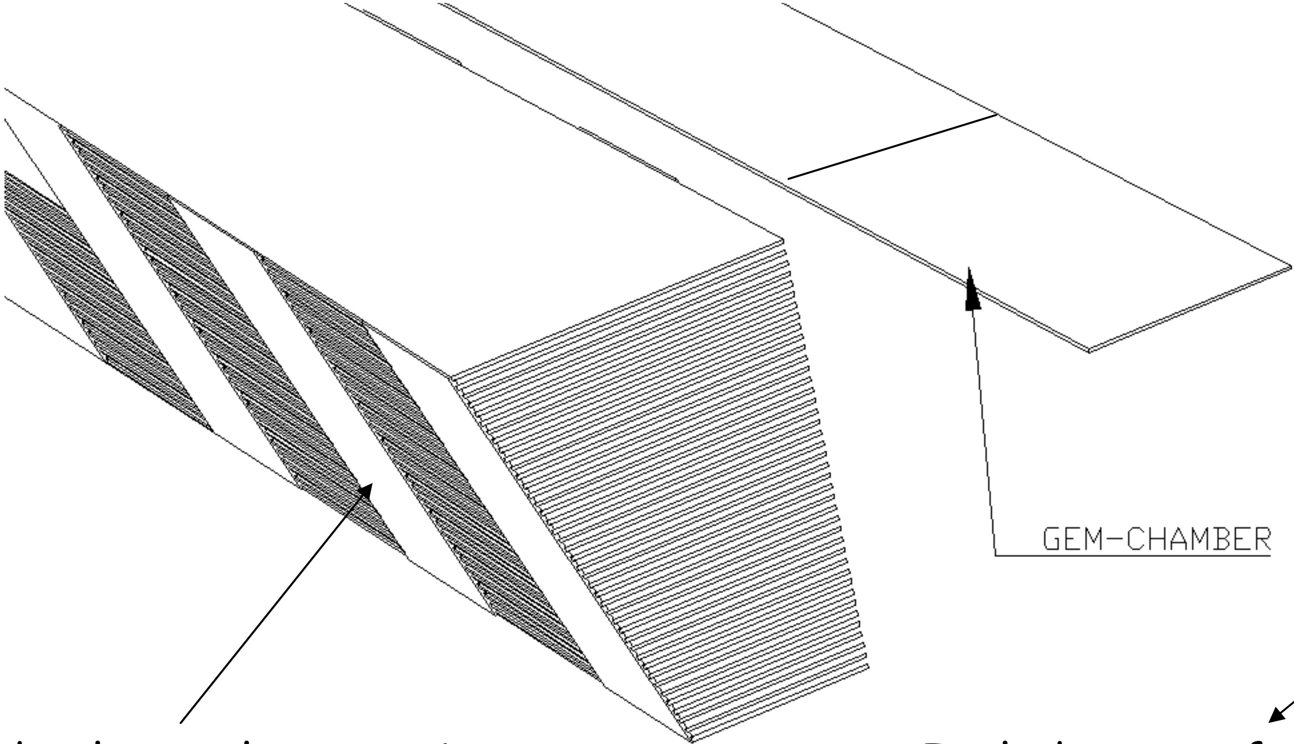
Development of module concepts

TESLA - HCAL Layout





DHCAL/GEM Module concepts



GEM layer slides into gap between absorber sheets

Side plates alternate in adjacent modules

Include part of absorber in GEM active layer - provides structural integrity

DHCAL-GEM Layer structure

- GEM layer + electronics layer ~9mm

- Absorber thickness 16mm x 40 layers

-> ~ 4 interaction lengths for HCAL
(plus ~1λ for ECAL)

This needs to be studied/optimized !
- do we need 40 layers?
- do we need uniform depth segmentation?

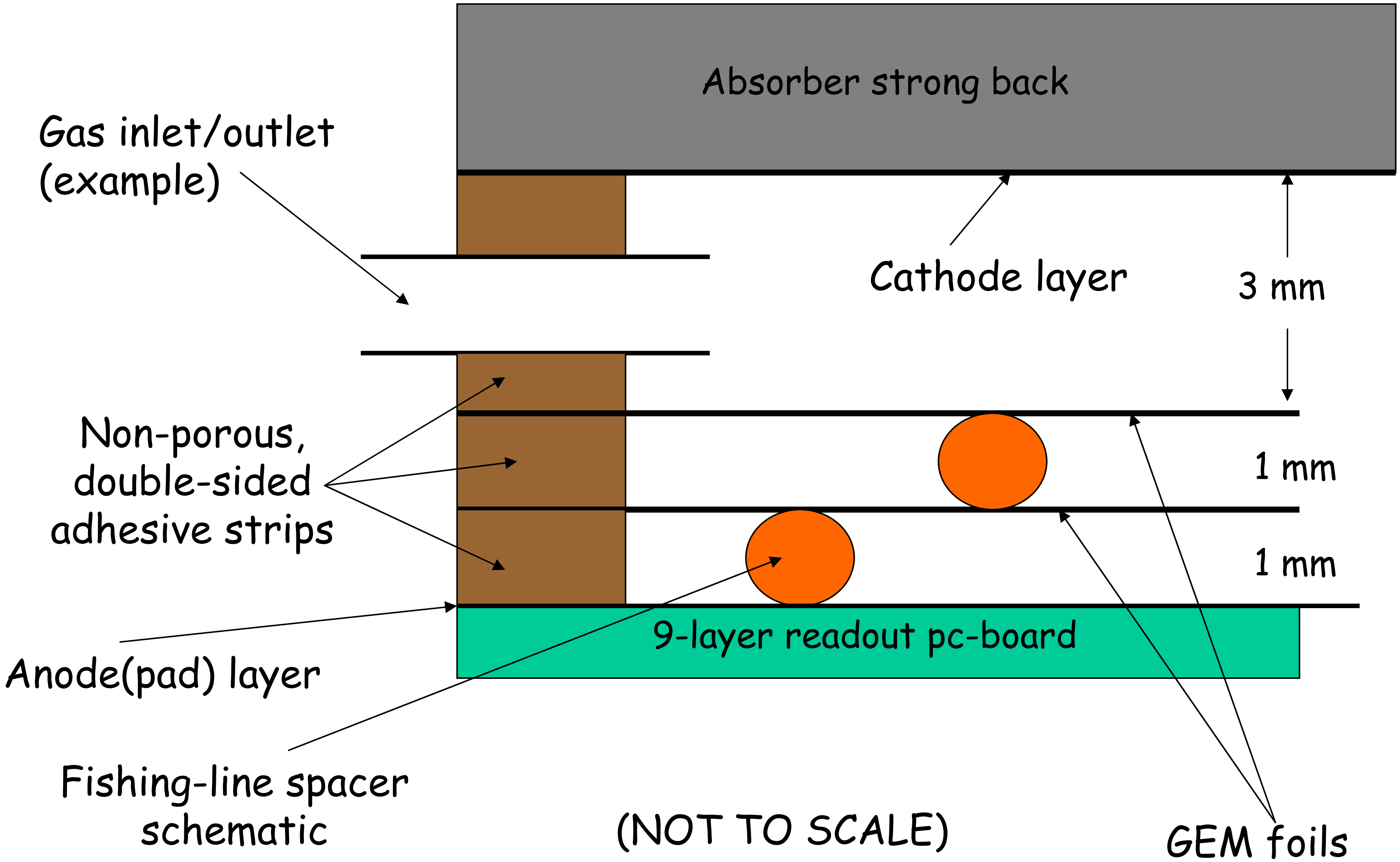
- 10x10 mm^2 cell size -> ~1.5 x 10^7 channels for DHCAL-GEM (with 40 depth layers)

Development of GEM sensitive layer

Requirements:

- minimize overall thickness
- develop robust design
- maintain 1mm, 3mm gaps in GEM structure
- maintain active layer flatness – absorber slice
- minimize "dead" boundary areas
- maintain integrity of gas volume
- design for ease of construction!

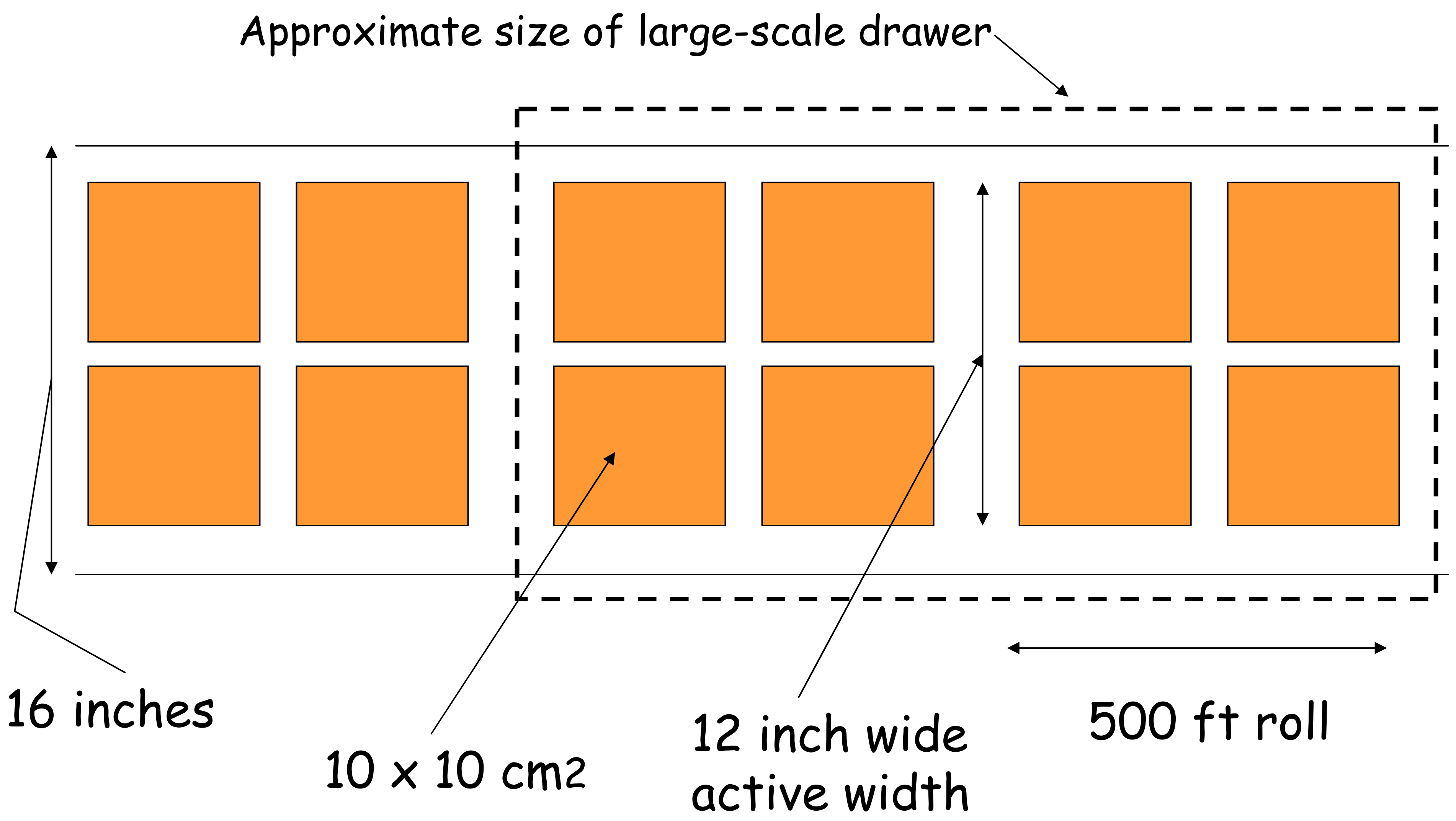
Development of GEM sensitive layer



Development of GEM sensitive layer

- Current activities:
  - Identify materials for layer construction
  - Specify interlayer spacings/spacers
  - Try out assembly ideas
  - Build large (1ft x 2ft) mechanical prototypes
  - Iterate on assembly procedures
  - Specify/document final procedure prior to assembly of large, working active layer(s).

GEM foil profile for large scale prototype(s)

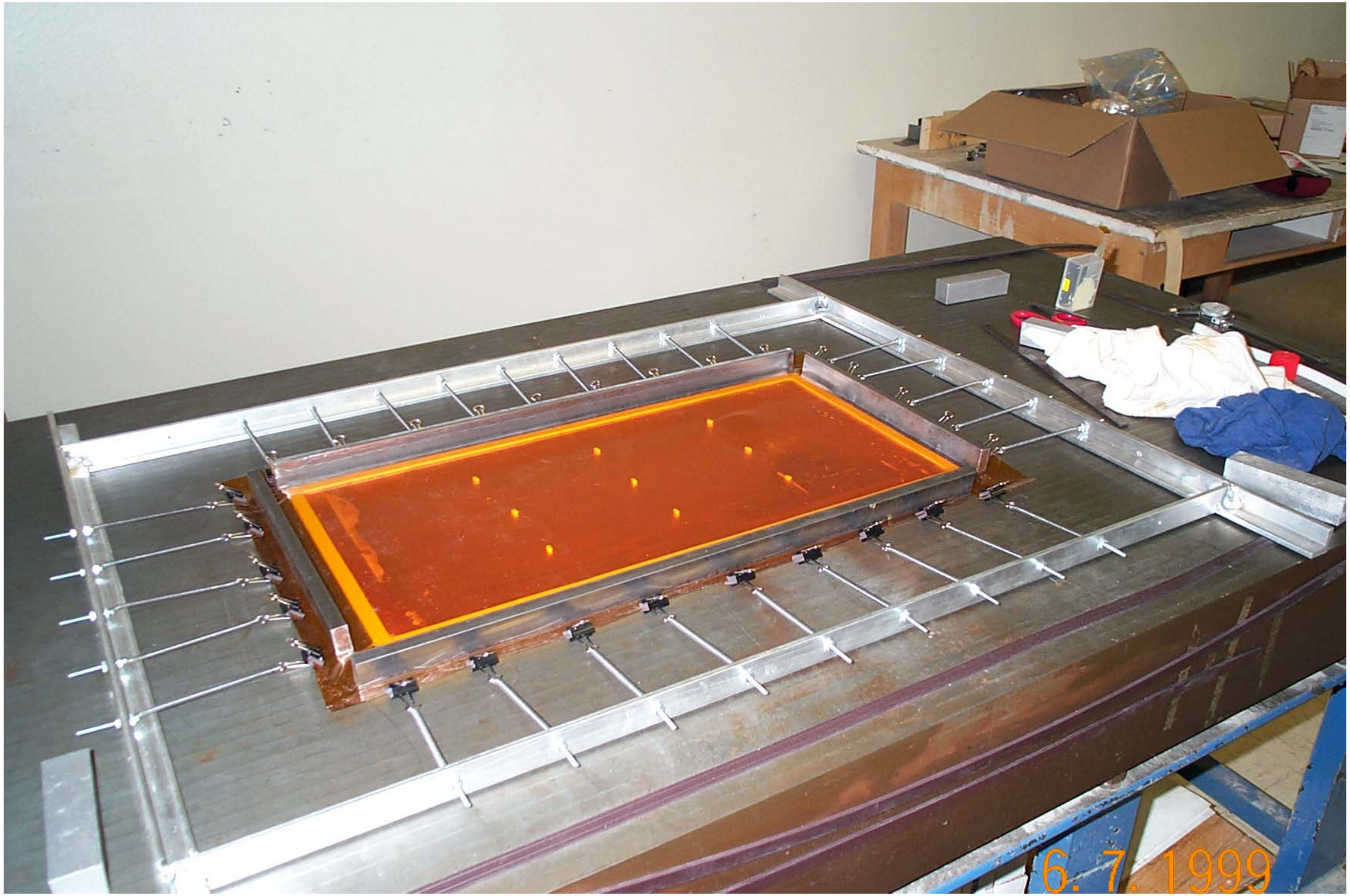


Coating the absorber slice with adhesive for the cathode layer

Stretching the “GEM” layer with frame

"GEM" layer ready for laying down

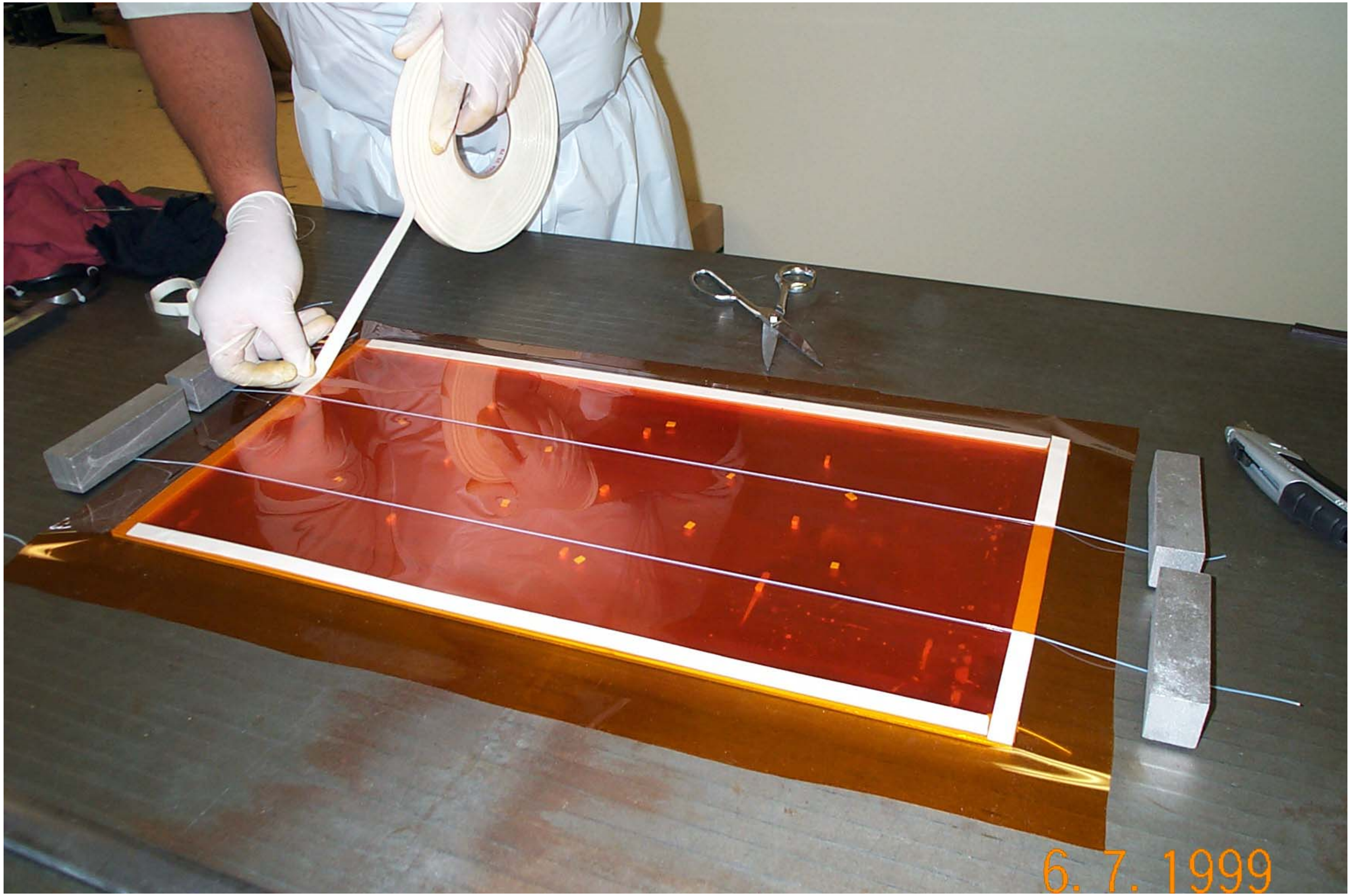
3mm side walls and spacers installed



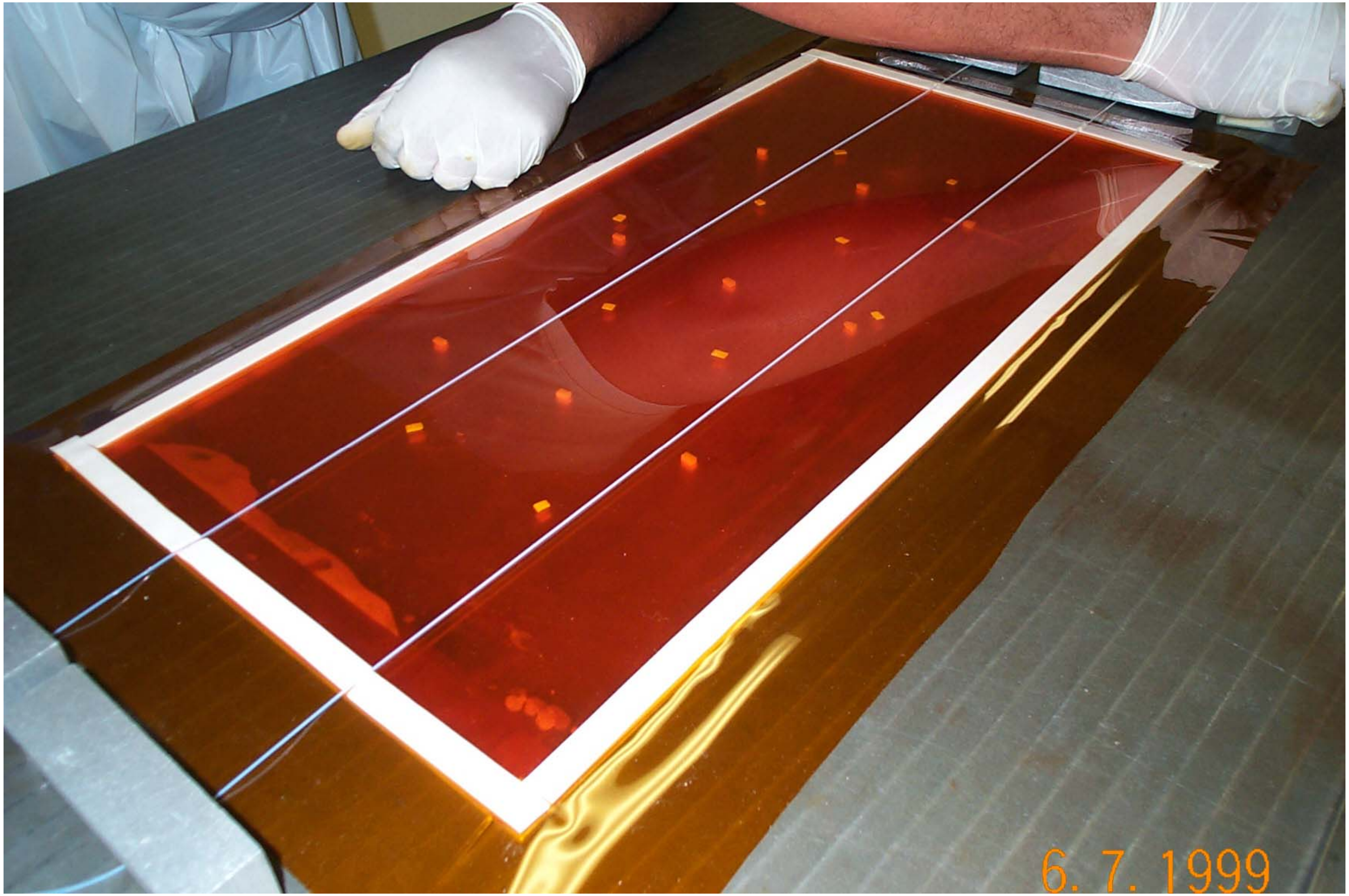
“GEM” foil laid down over side walls and sides weighted

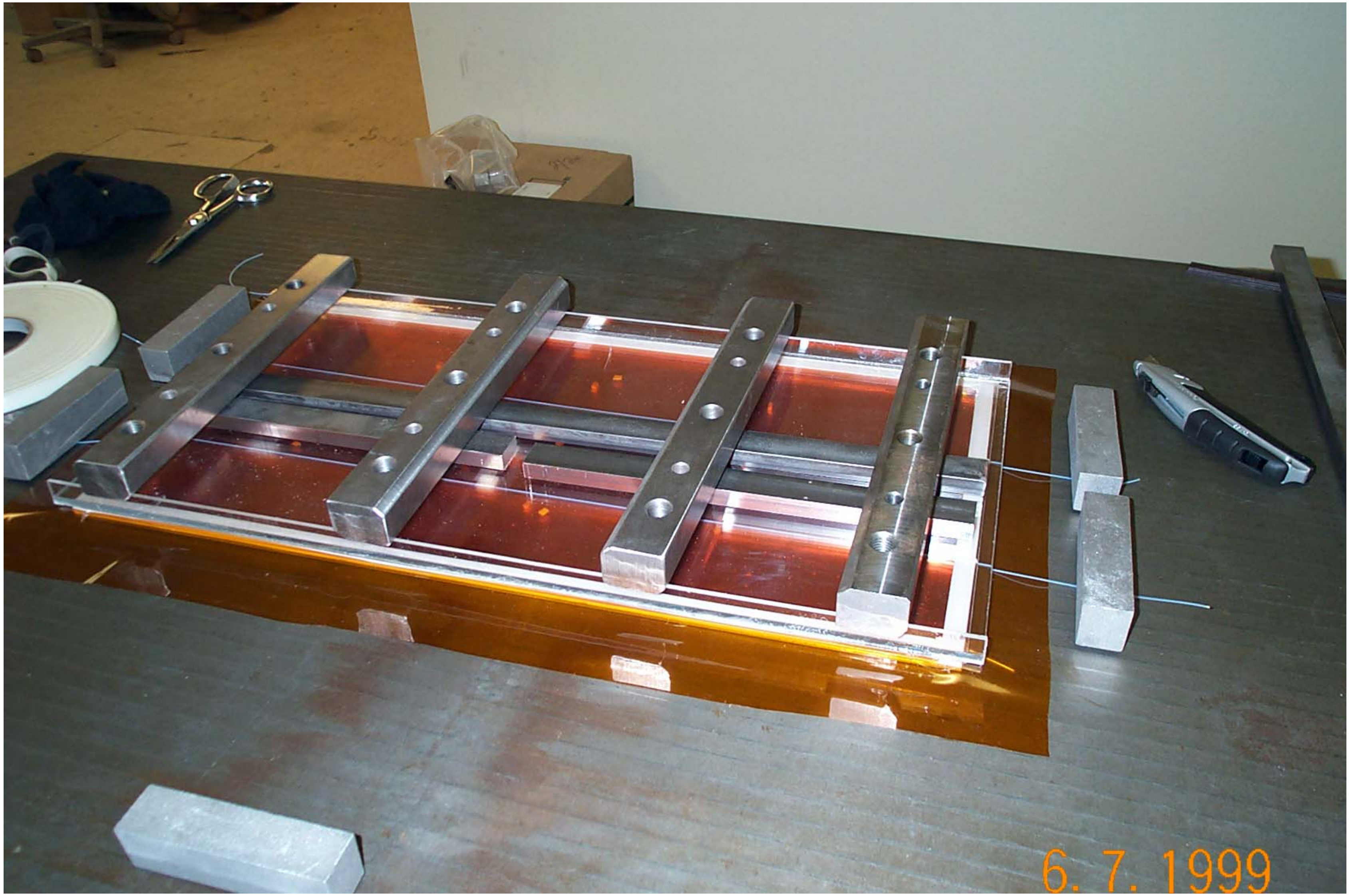
1mm side walls installed plus
spacers and gas in/outlets

Sealing corners of walls



Installing 2nd 1mm walls and fishing line spacers


6. 7. 1999



Final “GEM” foil installed, “PC board” installed, and whole assembly weighted

FY04 -> FY05 (as personnel/costs allow)

- Build and operate a complete working drawer
- Refine drawer design and construct several working drawers
- Build vertical arrangement of several drawers and demonstrate track finding for cosmic rays.
- Develop readout scheme for test beam stack
- Engineering studies for calorimeter module and test beam stack

FY05 -> FY06

- Complete test beam stack design and readout scheme design
- As funding allows: acquire materials to construct 40-layer stack (drawers, plates, supports, electronics)

As funding allows: begin construction of drawers for 40-layer stack, and begin steel stack assembly