Gas Electron Multiplier Technology for Digital Hadron Calorimetry

LCD Meeting

May 2, 2005

Andy White

(for the GEM-DHCAL group:

UTA, U.Washington, Tsinghua U.)

OVERVIEW

- Goals of GEM-DHCAL program
- Brief statement of DHCAL requirements
- GEM-DHCAL design concept
- GEM – basics of foils, stability,...
- UTA GEM prototypes
- Results on crosstalk, multiplicity
- Signal sizes
- Medium scale prototype plans
- $1m^3$ stack plans

Note: Simulation, PFA, ASIC, test beam trigger/timing NOT discussed.

Goals of DHCAL/GEM Project

∗ Design and construct a Linear Collider Detector calorimeter system based on GEM technology.

∗ Build/study GEM systems (in process)

∗ Define operational characteristics of GEM system (in process)

∗ Understand DHCAL/GEM systems in terms of proposed LC detector design concepts (in process)

∗ Construct full size test beam module and beam test (planning)

∗ Use test beam results to develop PFA for GEM-based DHCAL (started)

∗ Develop full DHCAL/GEM calorimeter system design.

Digital Hadron Calorimetry

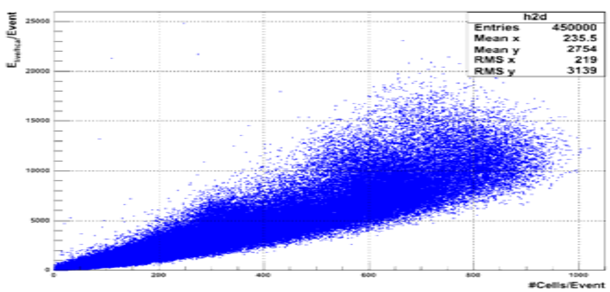
Physics requirements emphasize segmentation/granularity (transverse AND longitudinal) over intrinsic energy resolution.

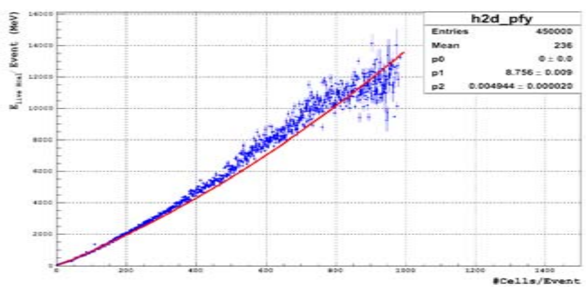
- Depth $\geq 4\lambda$ (not including ECal ~ 1λ) + tail-catcher(?)

-***Assuming PFlow***:

- sufficient segmentation (#channels) to allow efficient charged particle tracking.

- for "digital" approach – sufficiently fine segmentation (#channels) to give linear energy vs. hits relation





- efficient MIP detection (threshold, cell size)

- intrinsic, single (neutral) hadron energy resolution must not degrade jet energy resolution. →

Digital Hadron Calorimetry

- A hit should be ***a*** hit -> keep multiplicity/crosstalk low to aid in pattern recognition/PFA

- Comparable granularity to the ECal – continuous tracking of charged particles.

- Provide efficient muon tracking through the calorimeter.

- Long term stable operation .

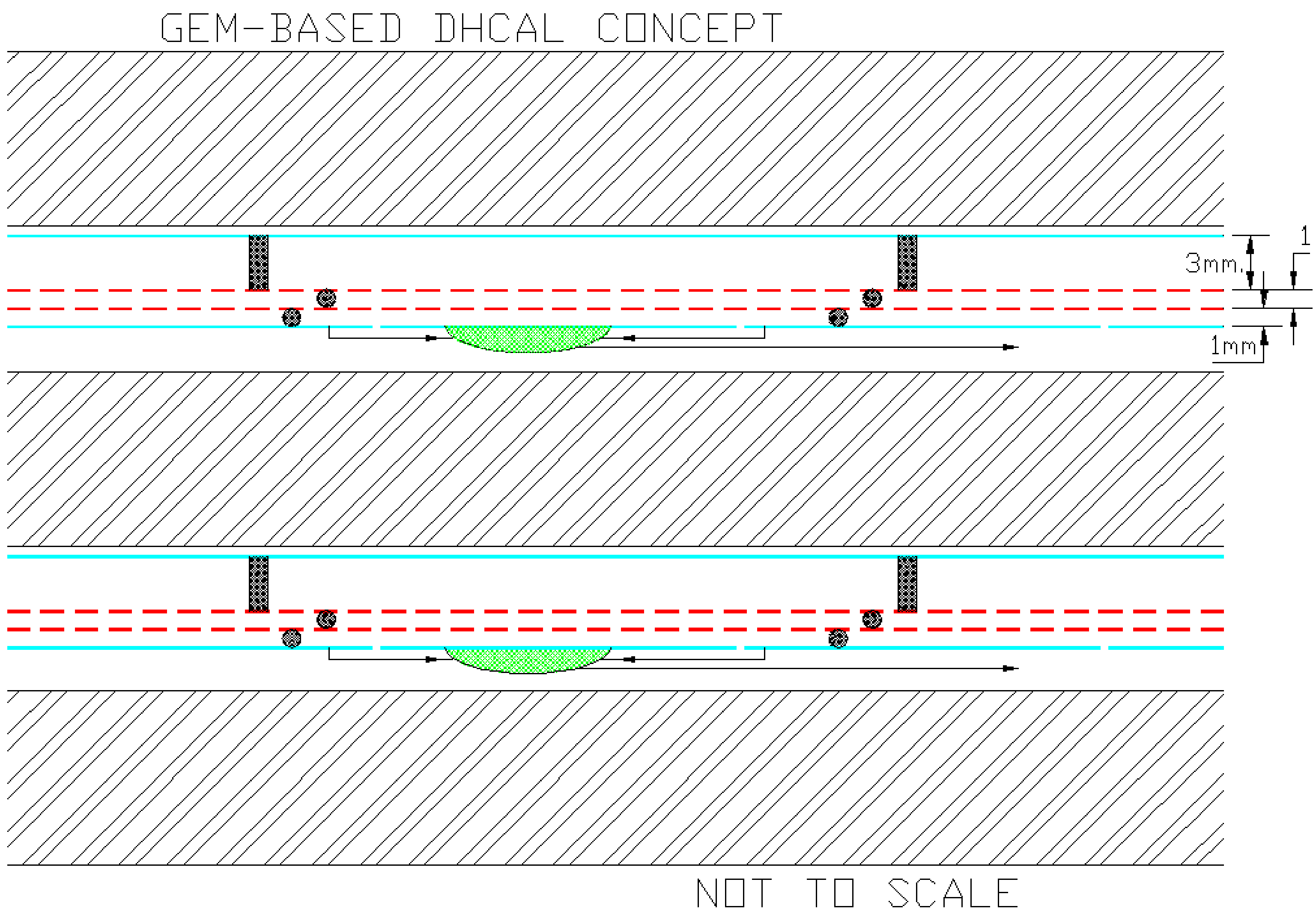
- Minimal module boundaries/dead areas.

- Stable technology – little/no access to active layers(?)

Why GEM ?

- A flexible technology with easy segmentation to well below the cell size needed for digital hadron calorimetry
- An alternative to RPC, Scintillator
- Works well with simple gas mixture (Ar/CO_2)
- Demonstrated stability against aging
- Operates at modest voltages ~400V/GEM
- Fast (if needed) – electron collection, not ion drift.
- A lot of parallel GEM development for LC/TPC systems and other experiments (e.g. T2K)
- Shares ASIC development with RPC.

GEM-based Digital Calorimeter Concept



GEM – production

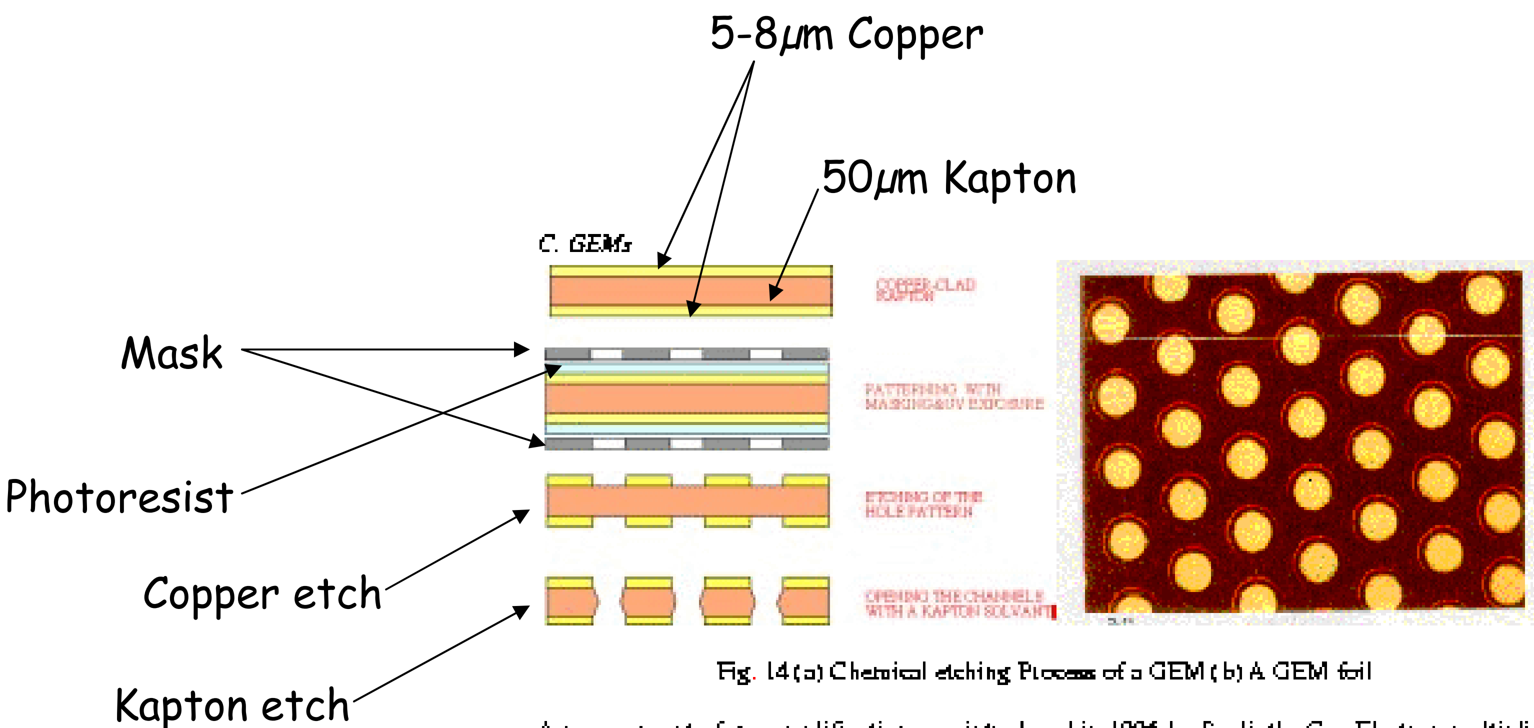
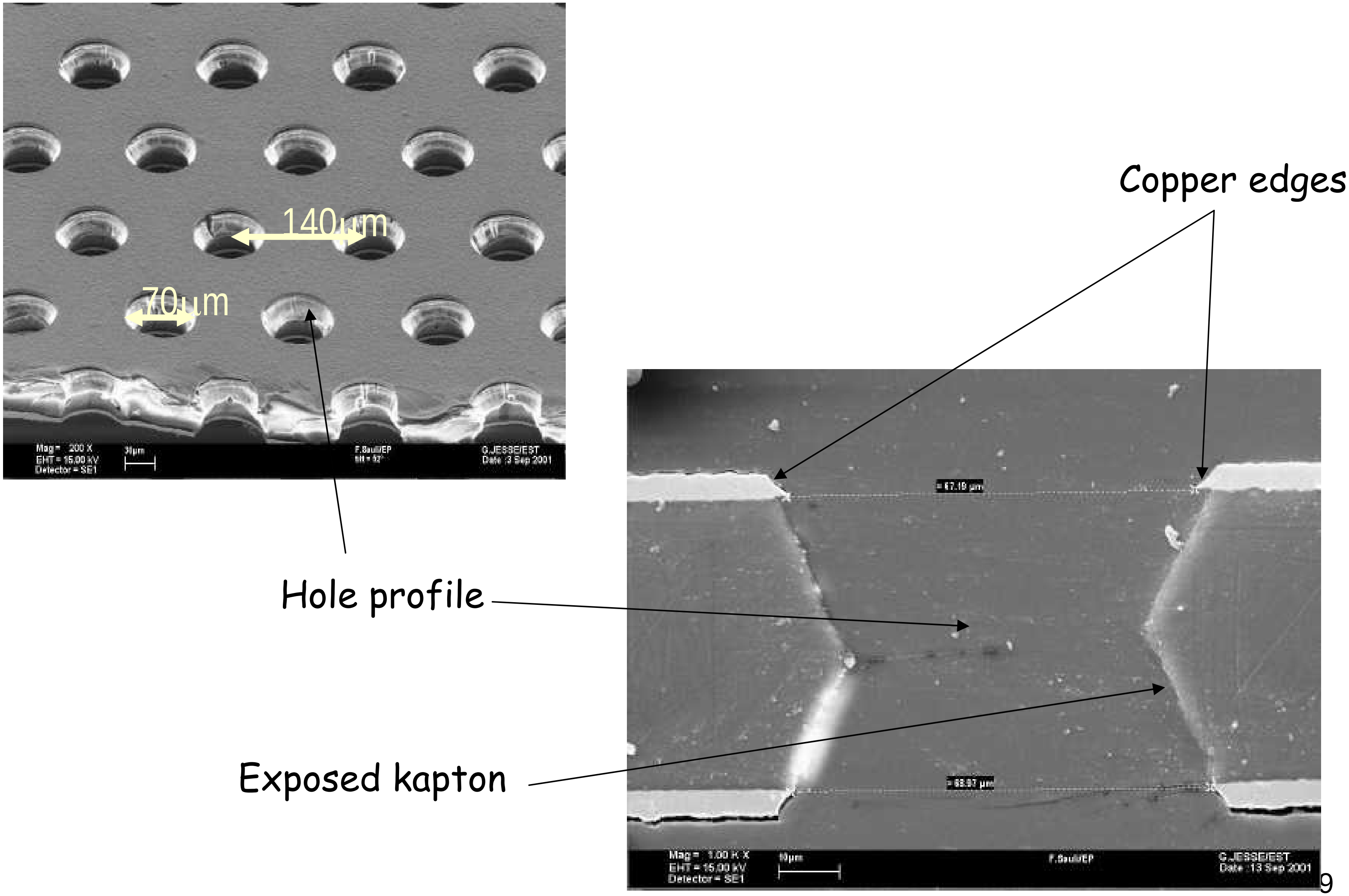


Fig. 14 (a) Chemical etching Process of a GEM (b) A GEM foil

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).

F. Sauli 1996

GEM - production



GEM – operation

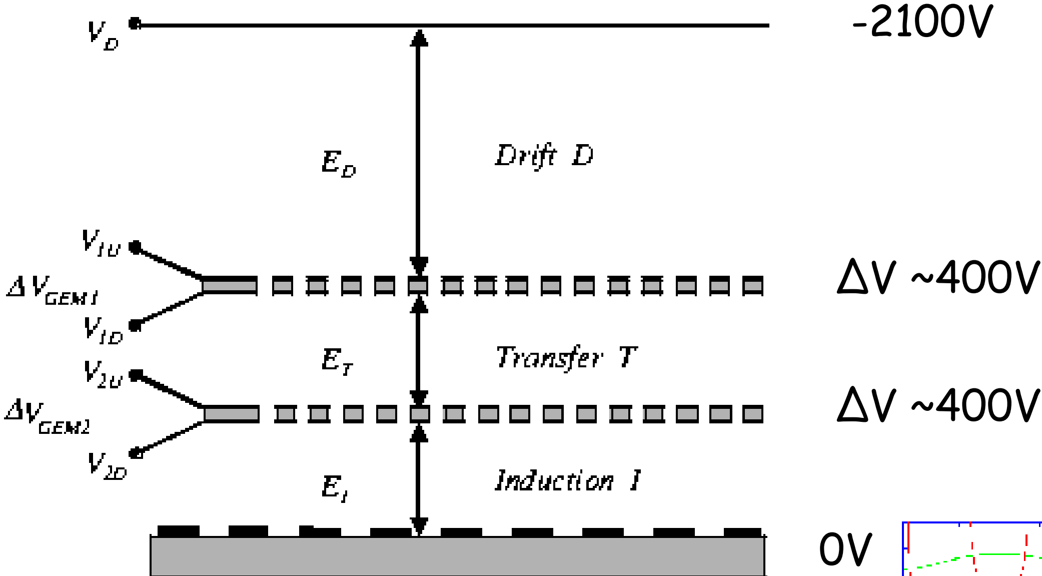


Fig. 1: Schematics of a double-GEM detector.

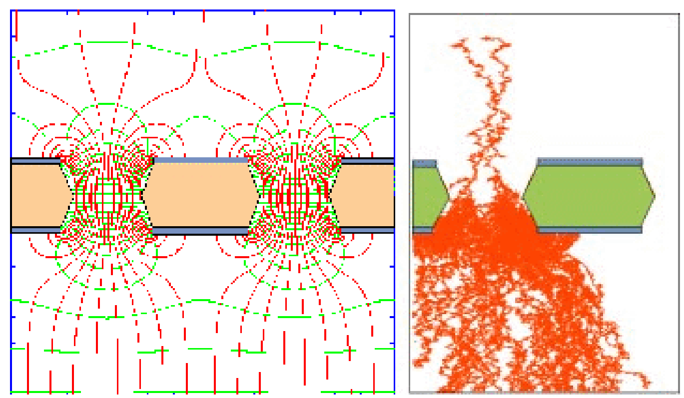


Fig. 15(a) Electric Field and (b) an avalanche across a GEM channel

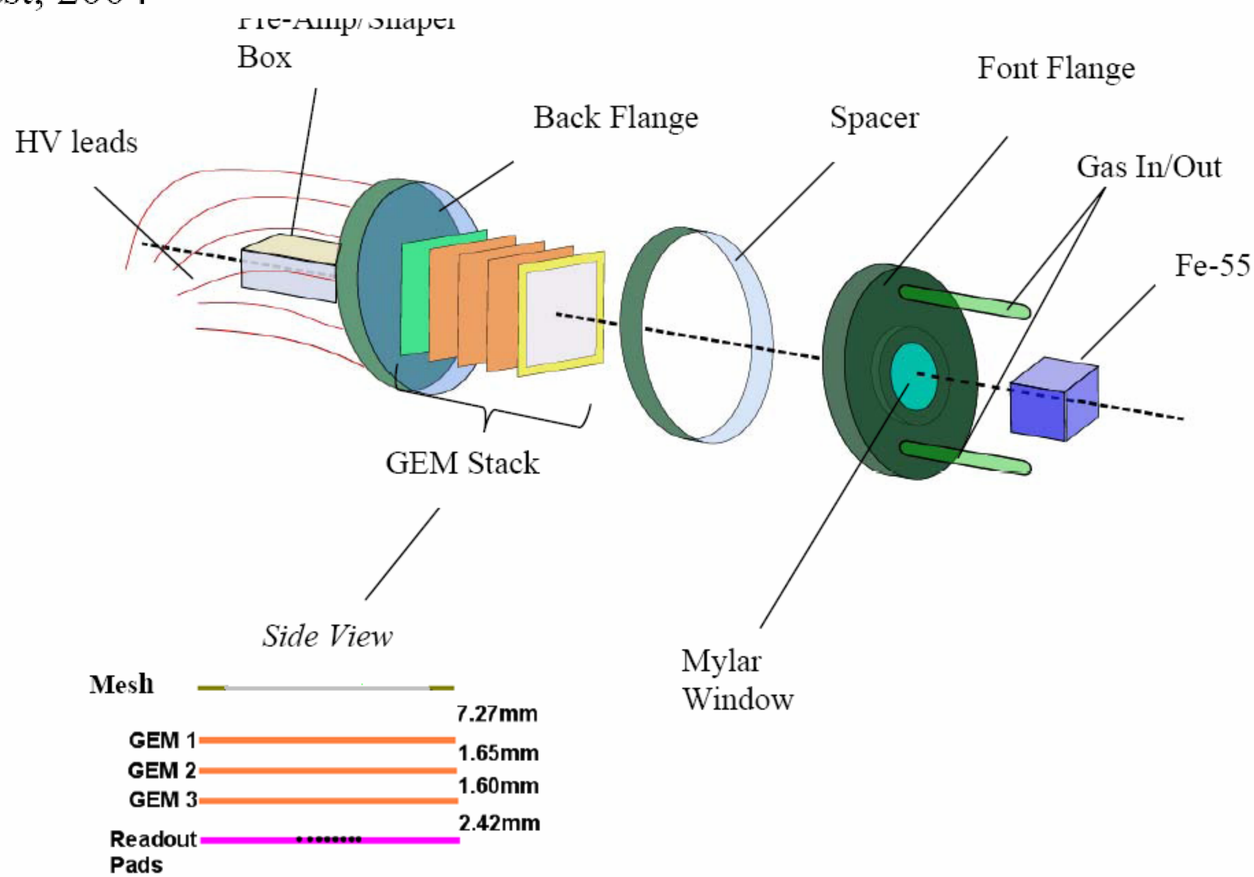
Coupled with a drift electrode above and a readout electrode below, it acts as a highly performing micropattern detector. The essential and advantageous feature of this detector is that amplification and detection are decoupled, and the readout is at zero potential. Permitting charge transfer to a second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

A Comparative Study of GEM Foils from Different Manufacturers

Bob Azmoun†, Georgia Karagiorgi ‡, Craig Woody†,

†Brookhaven National Lab
‡Florida Institute of Technology

August, 2004



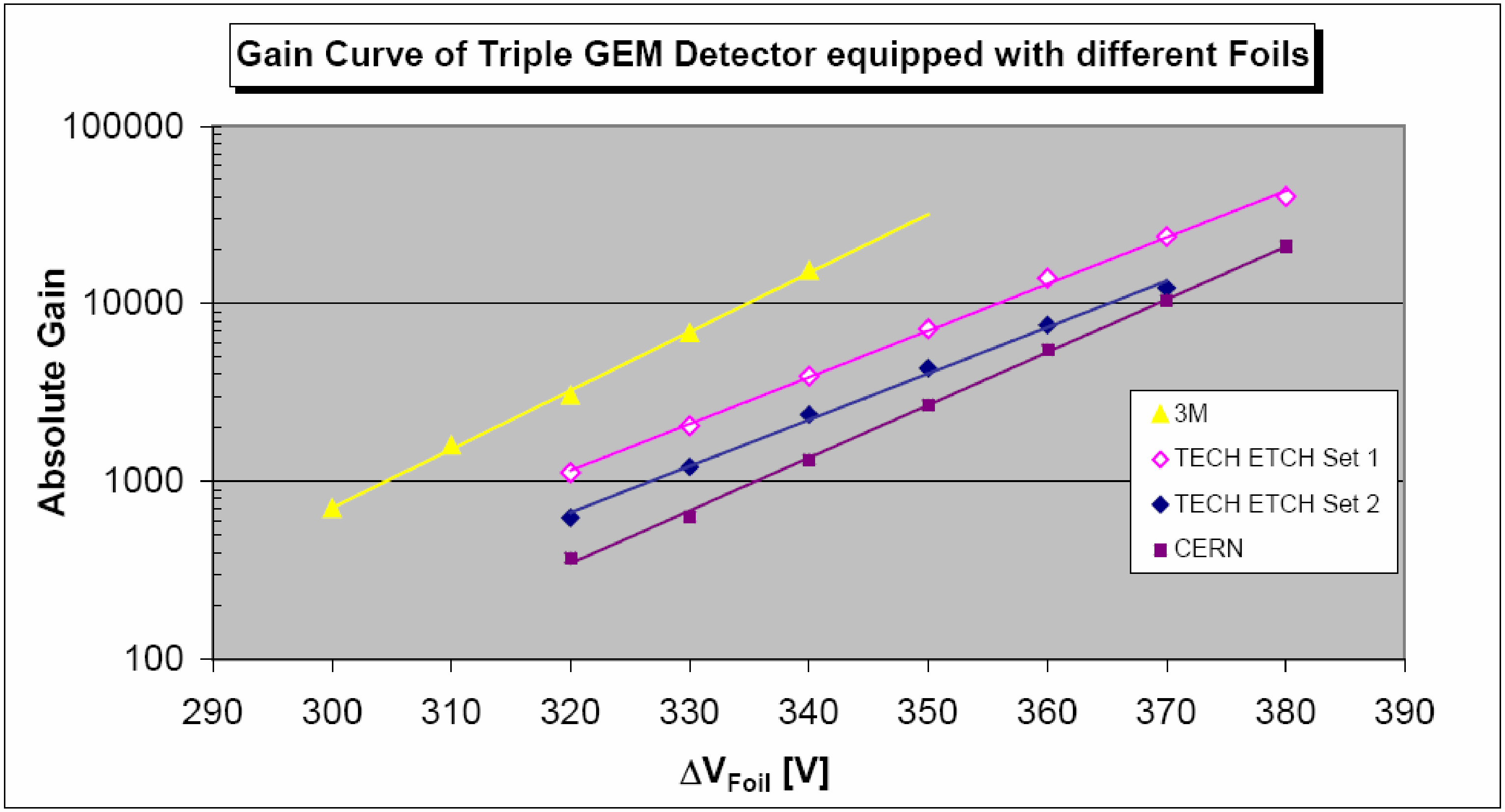
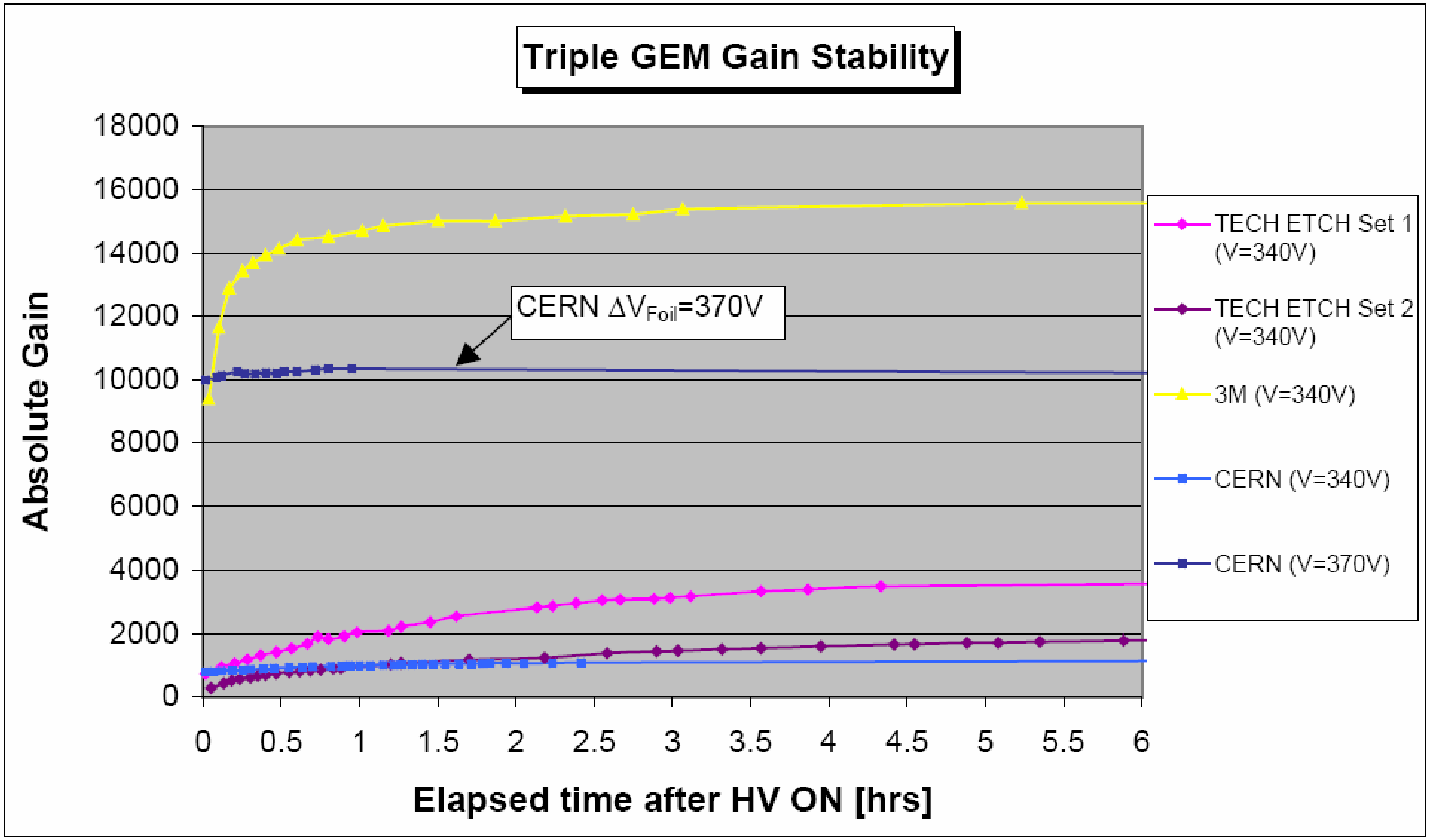


Figure 2: Absolute Gain vs. Potential Across the Foils (potential across all three foils were equal, and the field within the transfer and induction gaps were held constant).

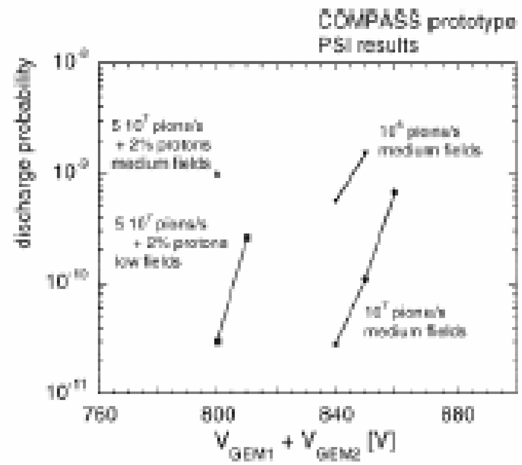


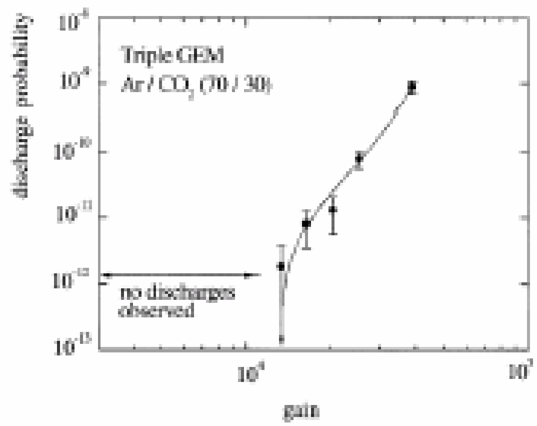
Triple GEM Gain Stability
Absolute Gain
Elapsed time after HV ON [hrs]
CERN ΔV_{Foil}=370V
TECH ETCH Set 1 (V=340V)
TECH ETCH Set 2 (V=340V)
3M (V=340V)
CERN (V=340V)
CERN (V=370V)
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6

GEM Discharge Probability

πM1-beam at PSI:

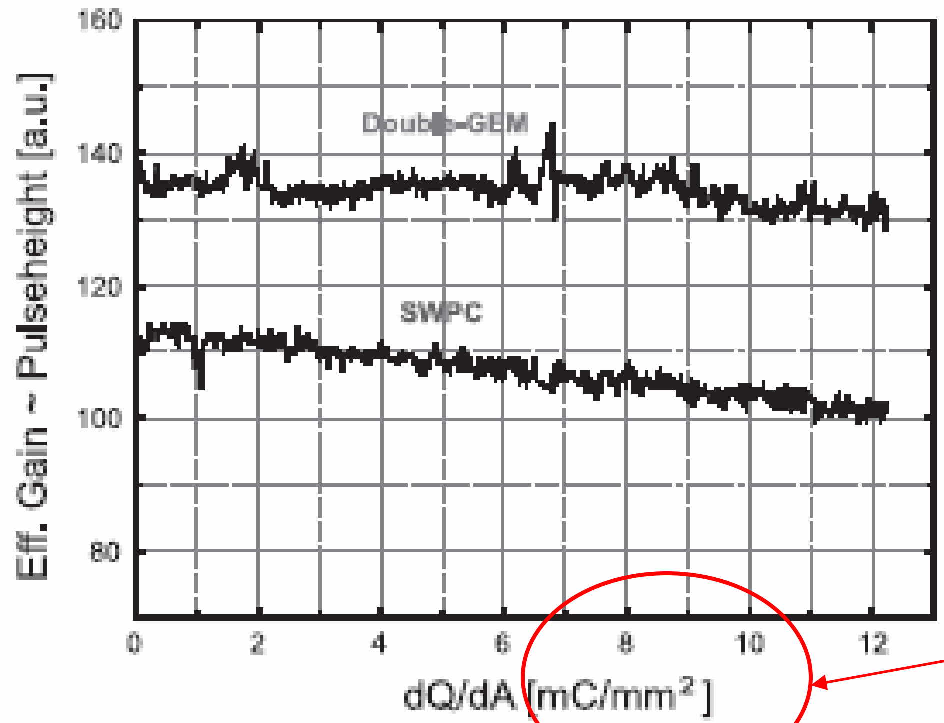
- 5 x 10^7 pions/s
- after irradiation with 10^{12} π at highest intensity no discharges observed
- Increasing the gain > 10^4: several thousand discharges → fully operational until end of test beam





COMPASS – triple GEM, CERN-made foils

GEM – aging

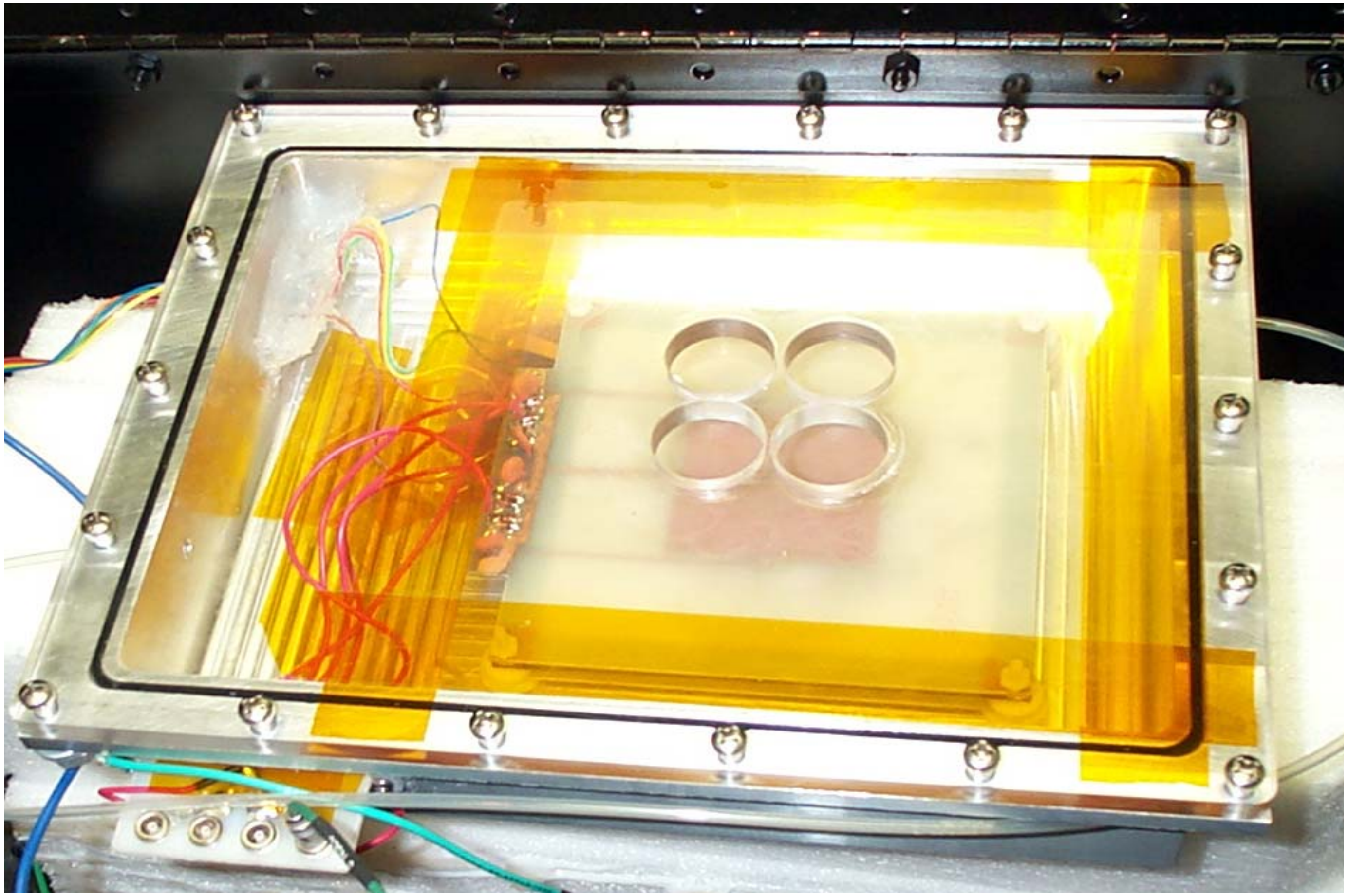


~10^{12} part/mm^2

Fig. 3. Previous aging measurement of a double-GEM detector with Ar–CO_2 (70:30): effective gain versus accumulated charge dQ/dA.

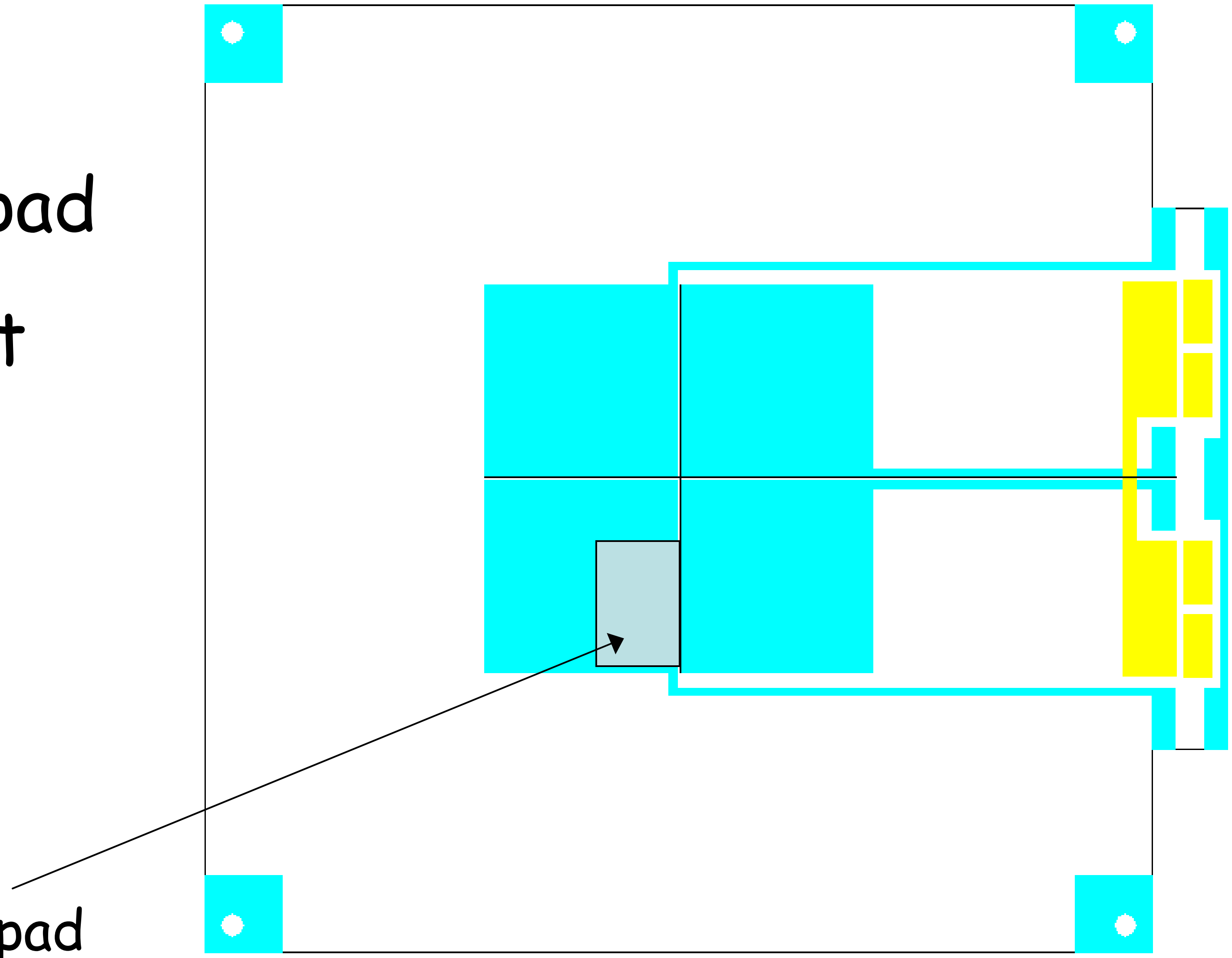
Nuclear Instruments and Methods in Physics Research A 515 (2003) 249–254

UTA GEM - initial prototype



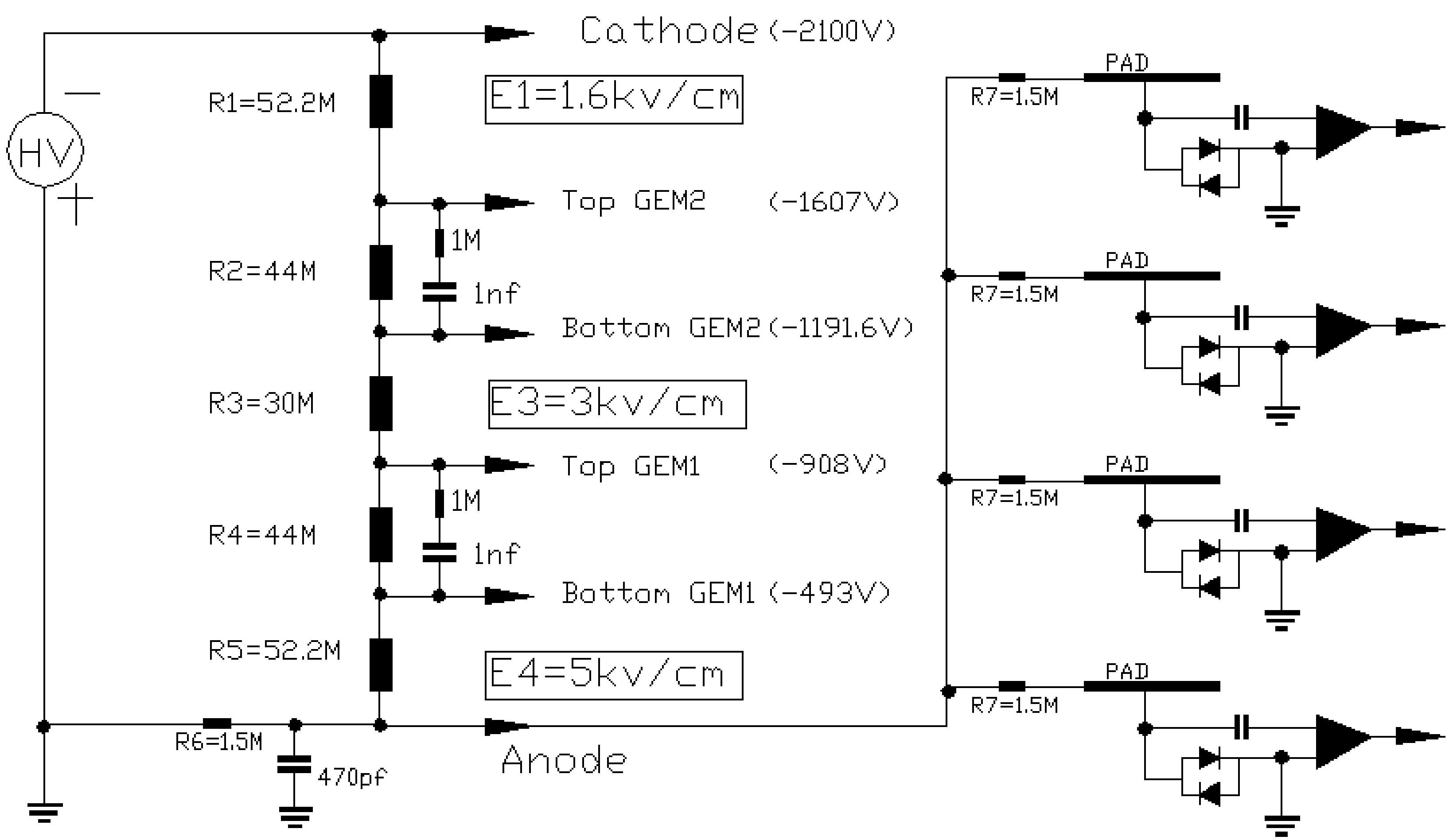
UTA GEM-based Digital Calorimeter Prototype

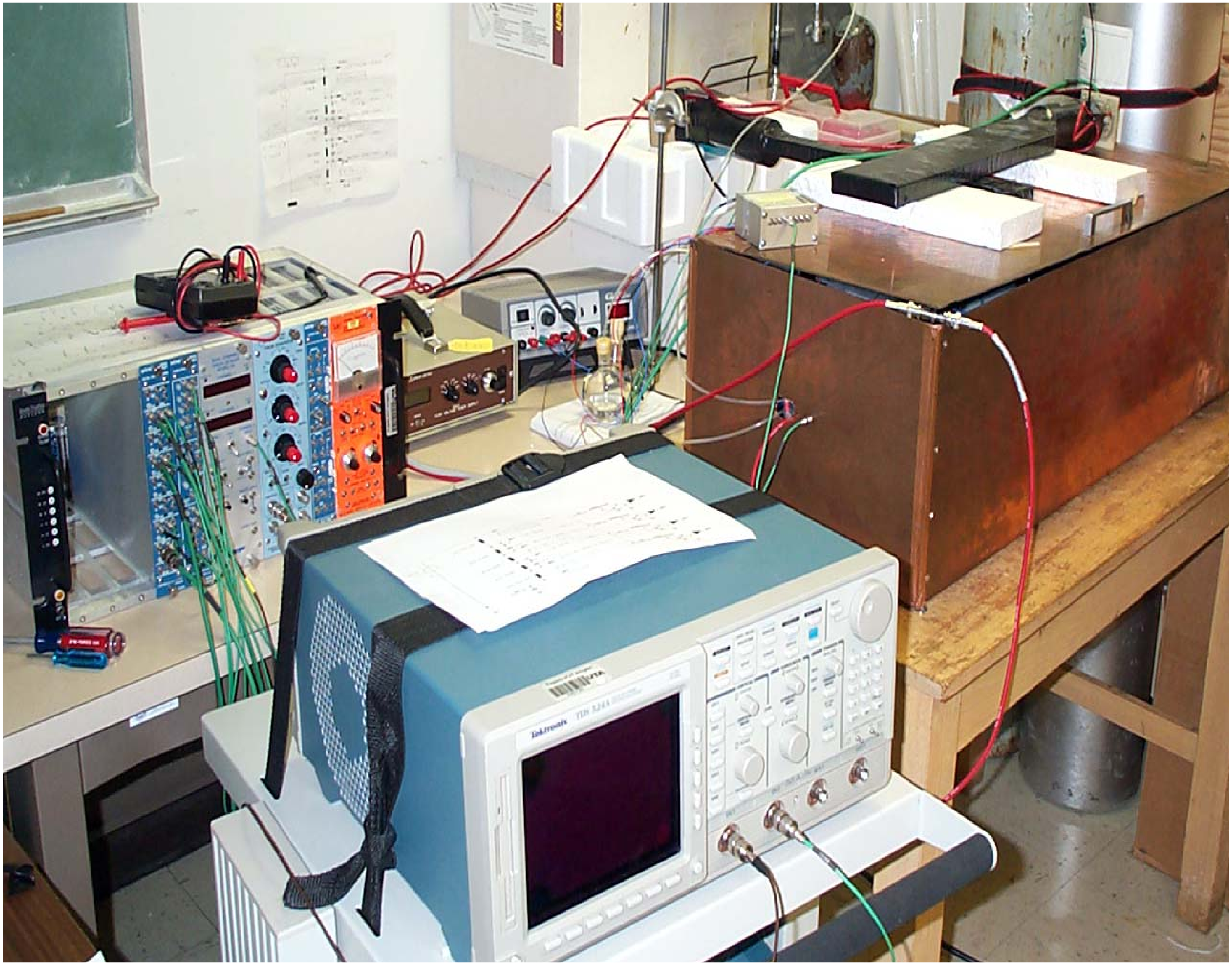
Anode pad layout



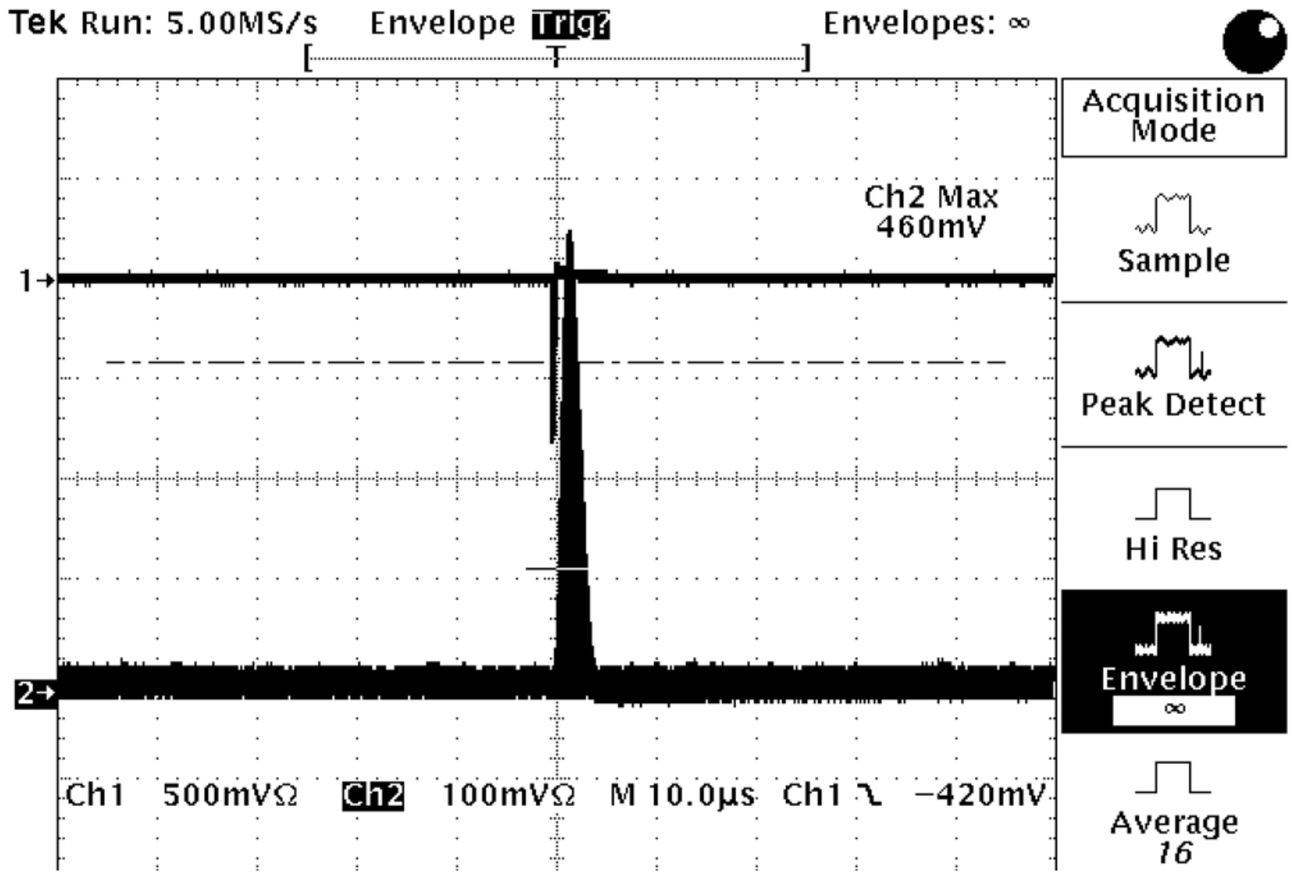
1x2 cm^2 pad

UTA GEM prototype - high voltage



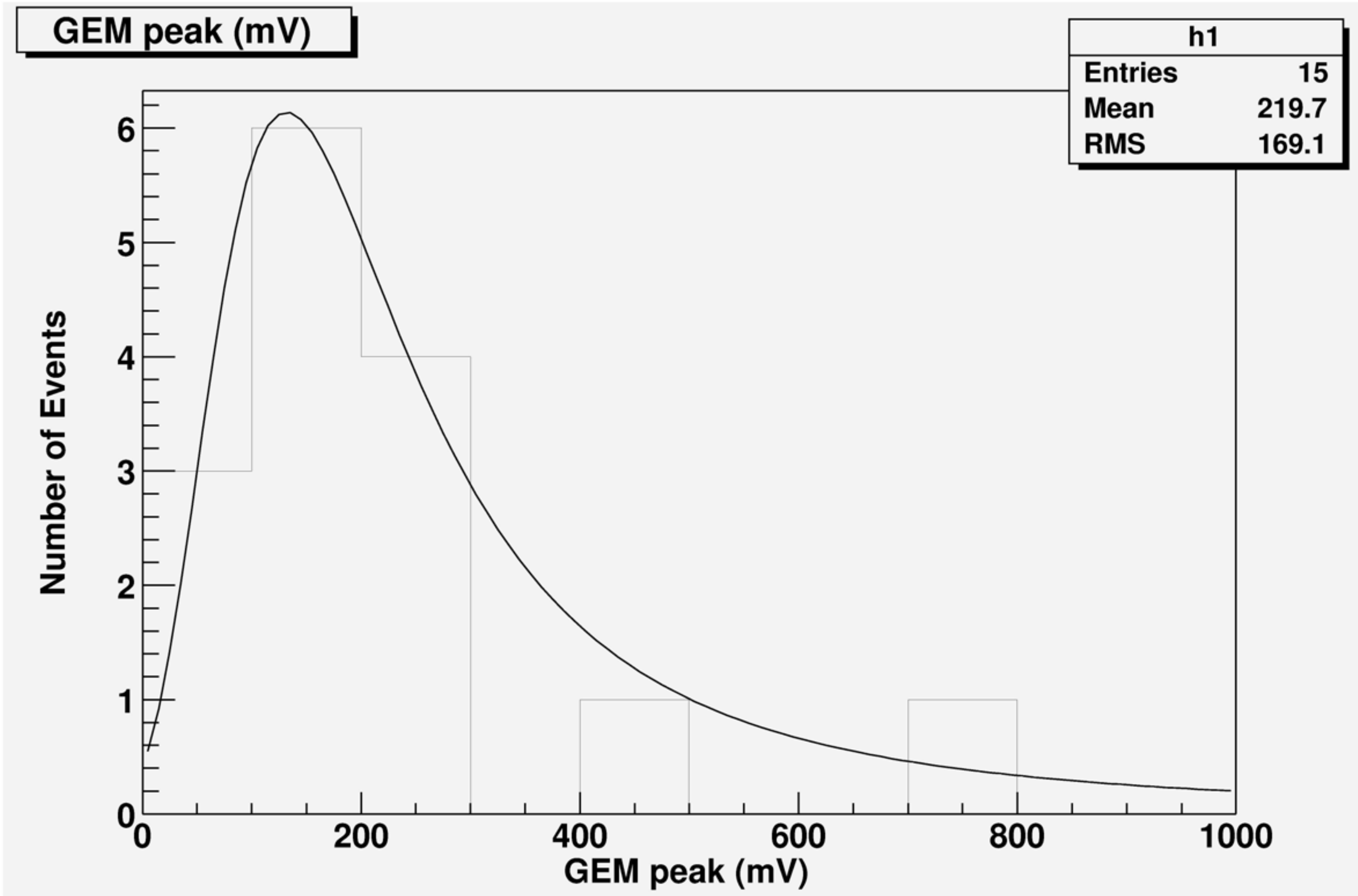


UTA GEM Calorimeter prototype



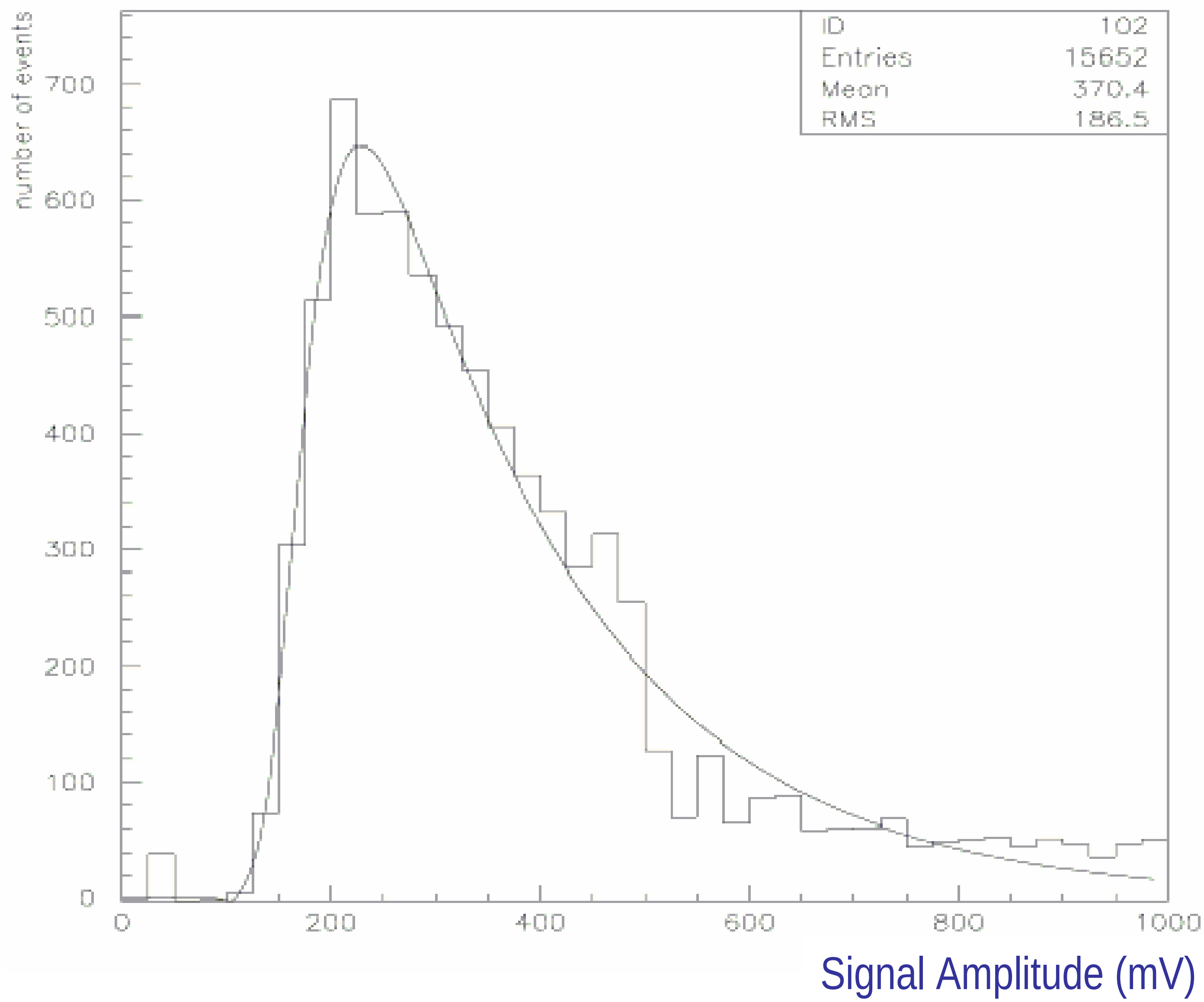
Single cosmic event: upper = trigger,

lower = preamp output



(First!) GEM cosmic signal distribution with Landau fit

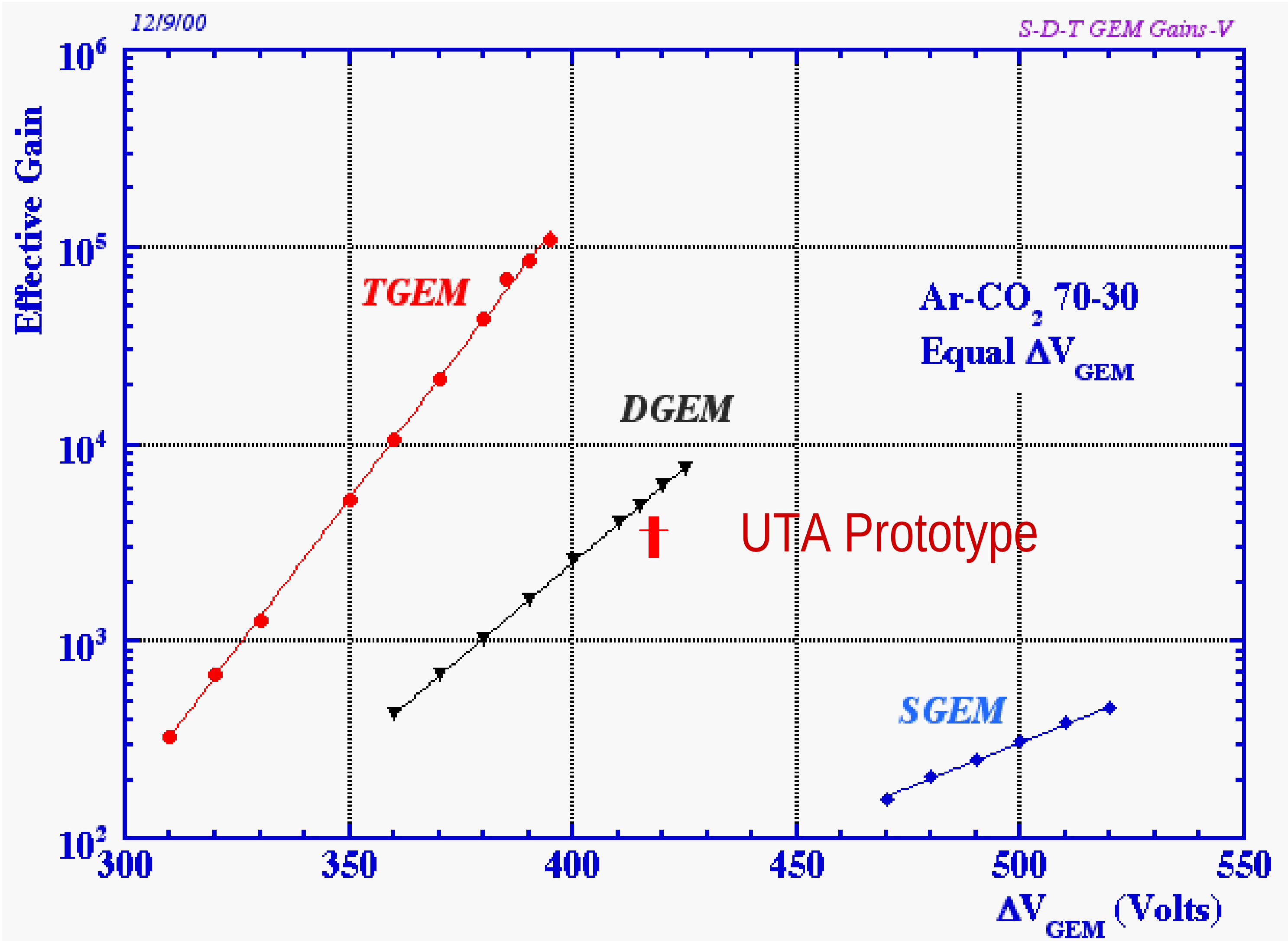
Landau Distribution from Cs^{137} Source



GEM/MIP Signal Size Computation

- Double GEM – applied 419V/stage
- Total Ionization (*C*): ~93 i.p./cm (F.Sauli/1997)
  - ➔ 48 e^-/MIP (5mm gap)
- Double GEM Intrinsic Gain: *G*
- Charge preamp sensitivity (G_c) : 0.25 $\mu V/e^-$
- Voltage amp. X10 (G_V)
- Output signal = $C \times G \times G_C \times G_V$
- Observed ~370mV signal (mean of Landau)
  - ➔ ***G*** **= 3100** ± 20%

Measured UTA GEM Gain



CERN GDD group measurements

Experience using GEM foils

- So far we have used the small (10cm x 10cm) framed GEM foils from CERN/GDD.

- Started out in a Class 1000 clean room – for first prototype assembly.

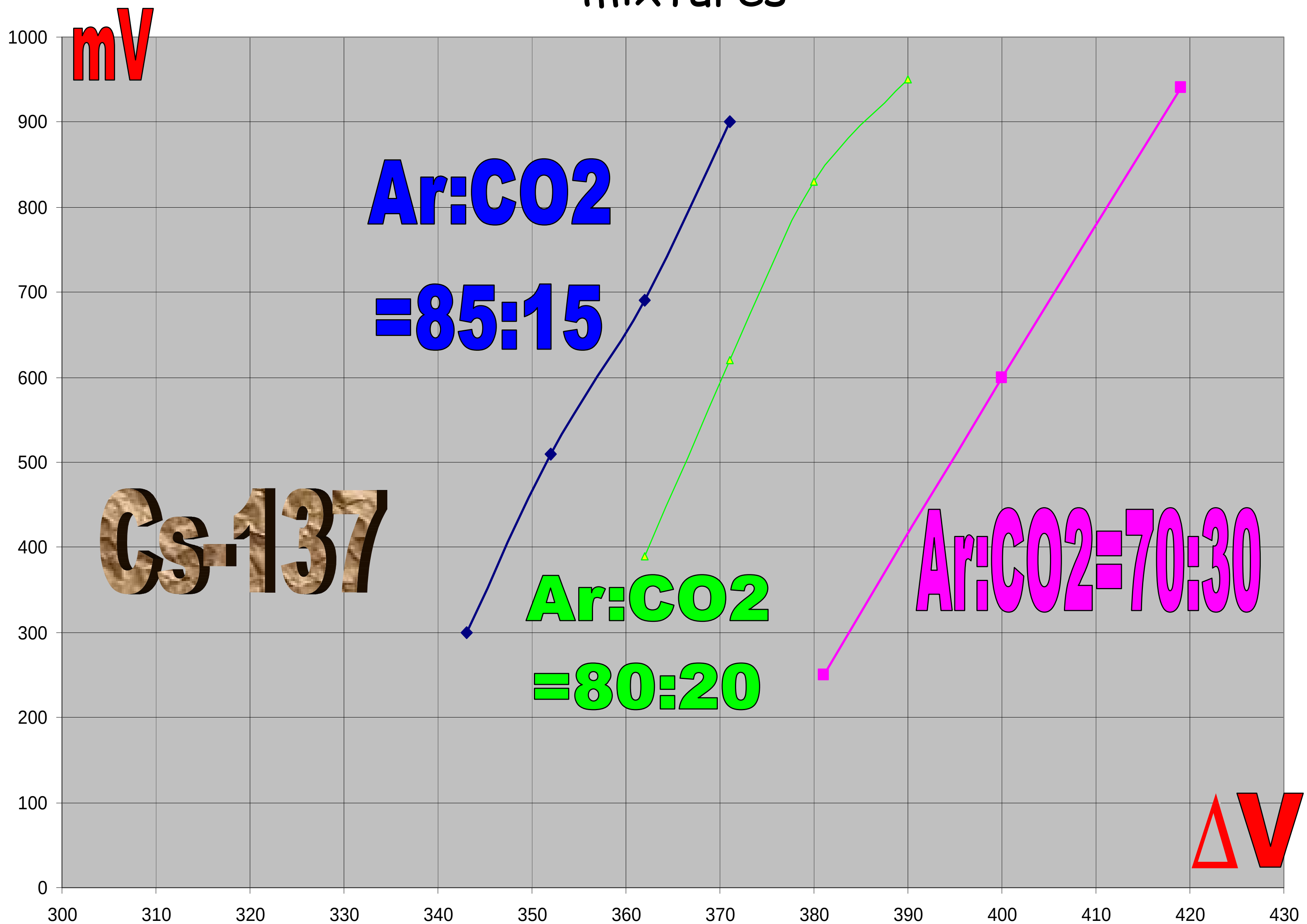
- Later experience showed that foils can be "handled" carefully in normal lab. environment.

- We have assembled/disassembled our prototypes many times – they *always* work when you turn them on!

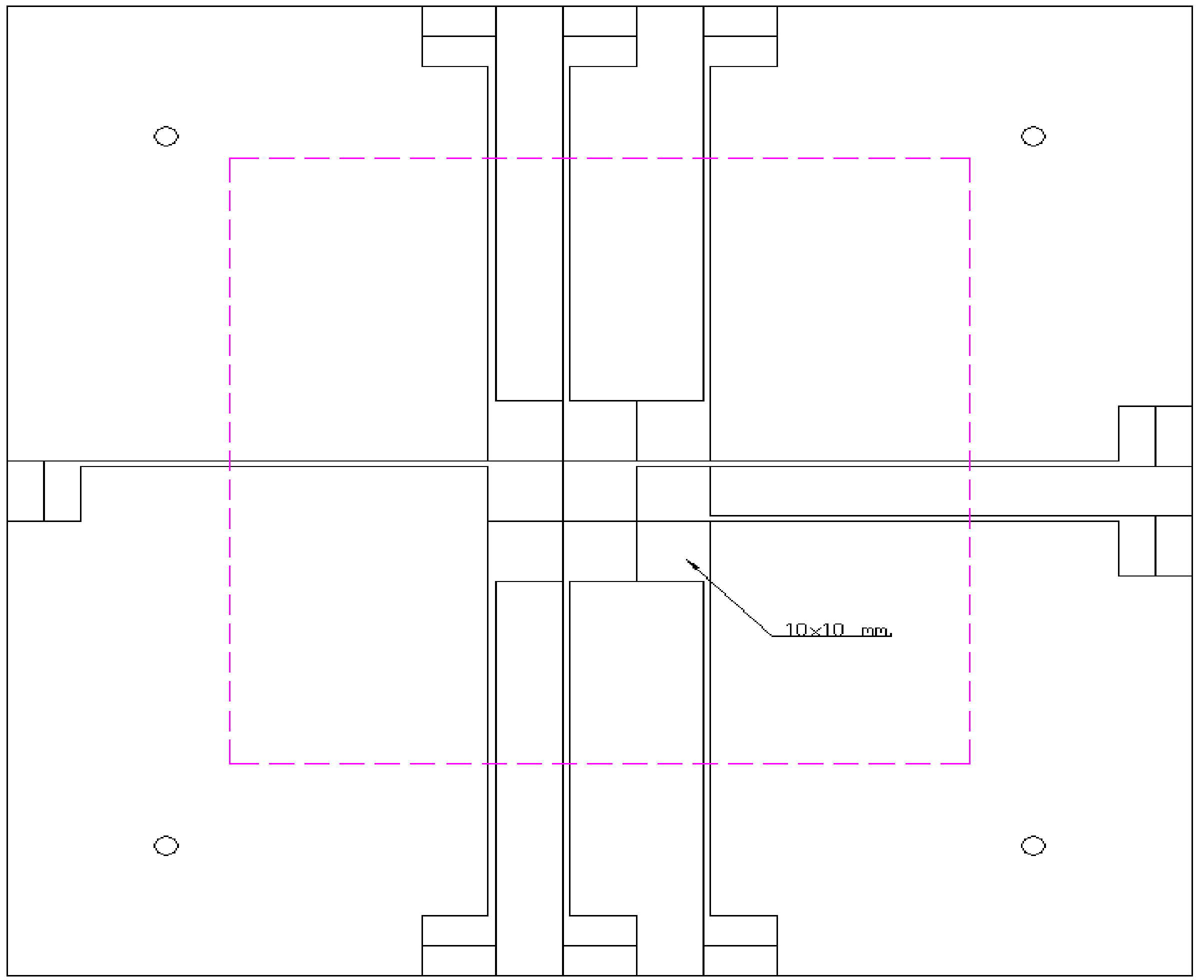
- Typical current ~few nA

- We provoked discharges and examined foils – damage found in few holes limited area – fixed by drop of acid.

GEM signal levels for various gas mixtures

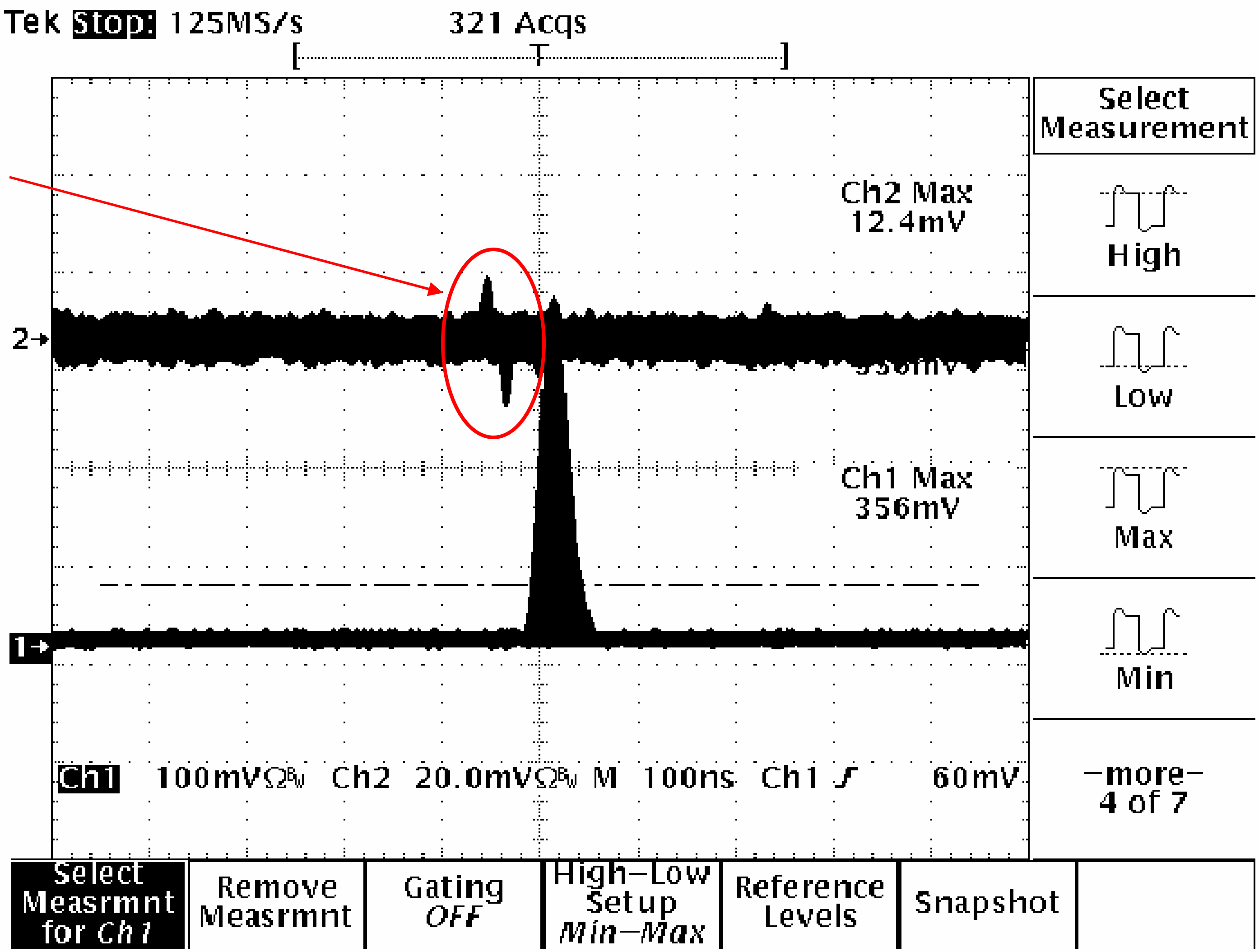


Nine Cell GEM Prototype Readout

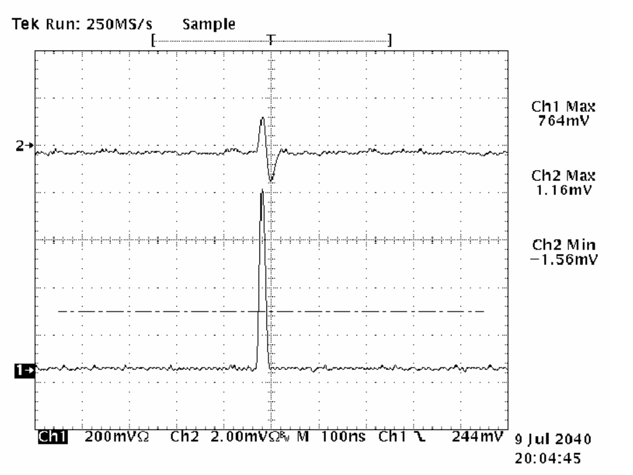


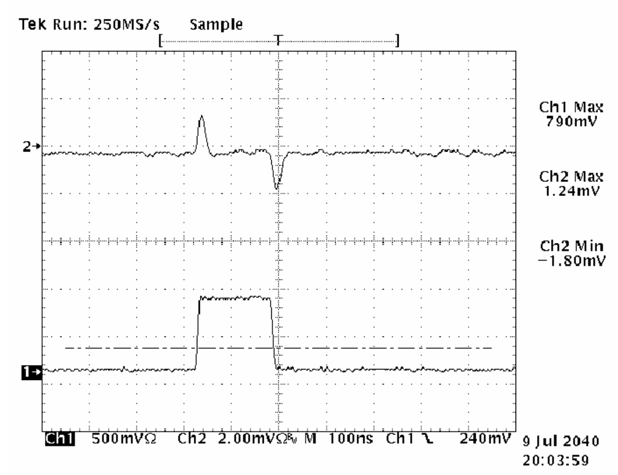
Typical crosstalk signal (prototype)

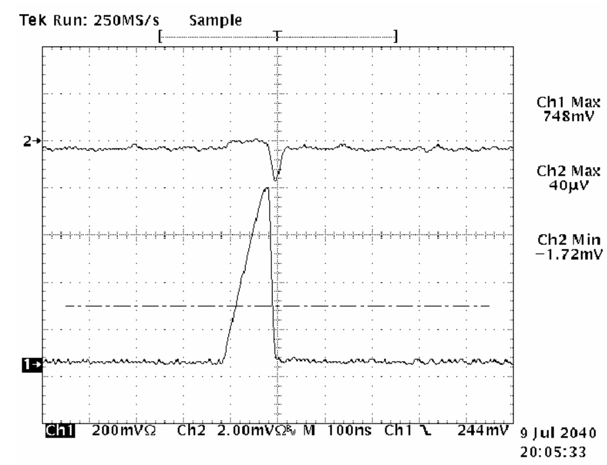
Typical "up/down" structure of crosstalk

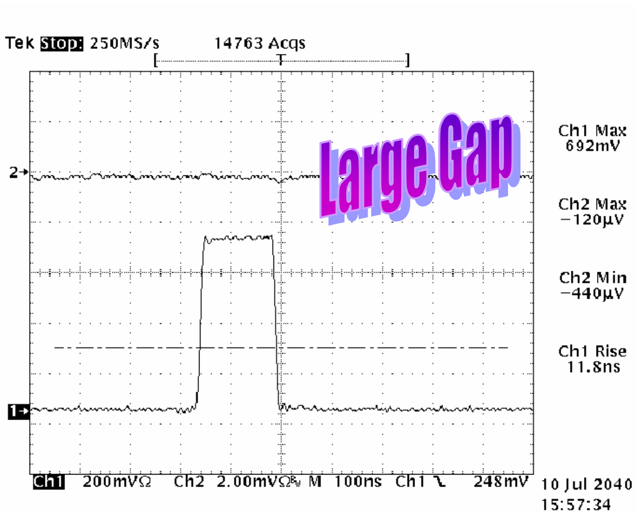


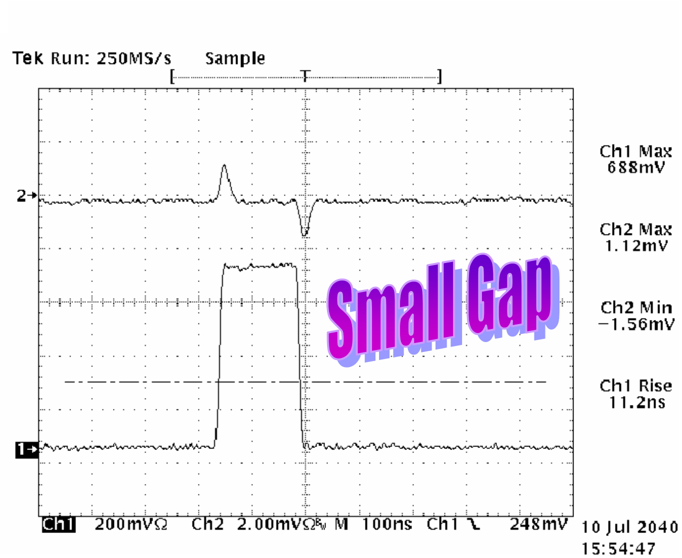
Crosstalk studies

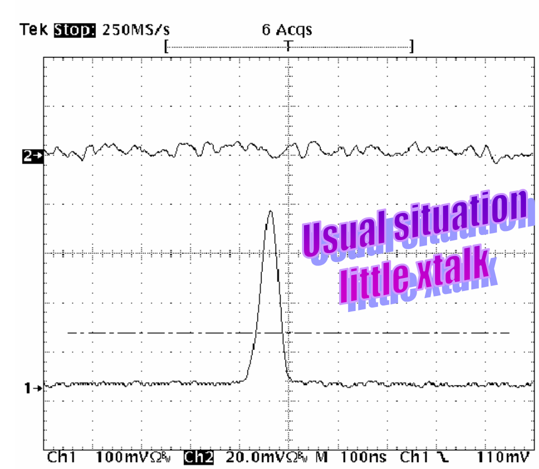




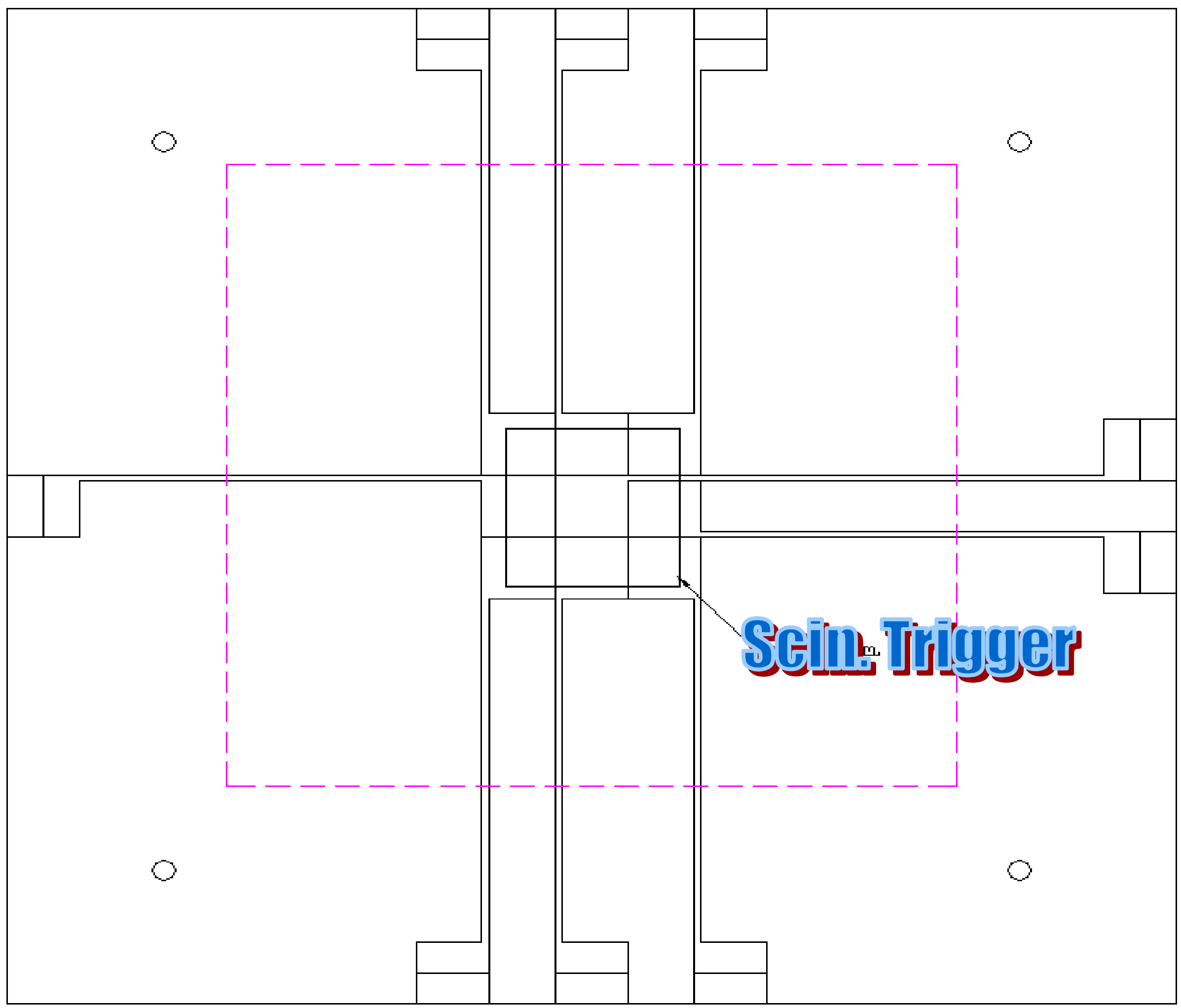




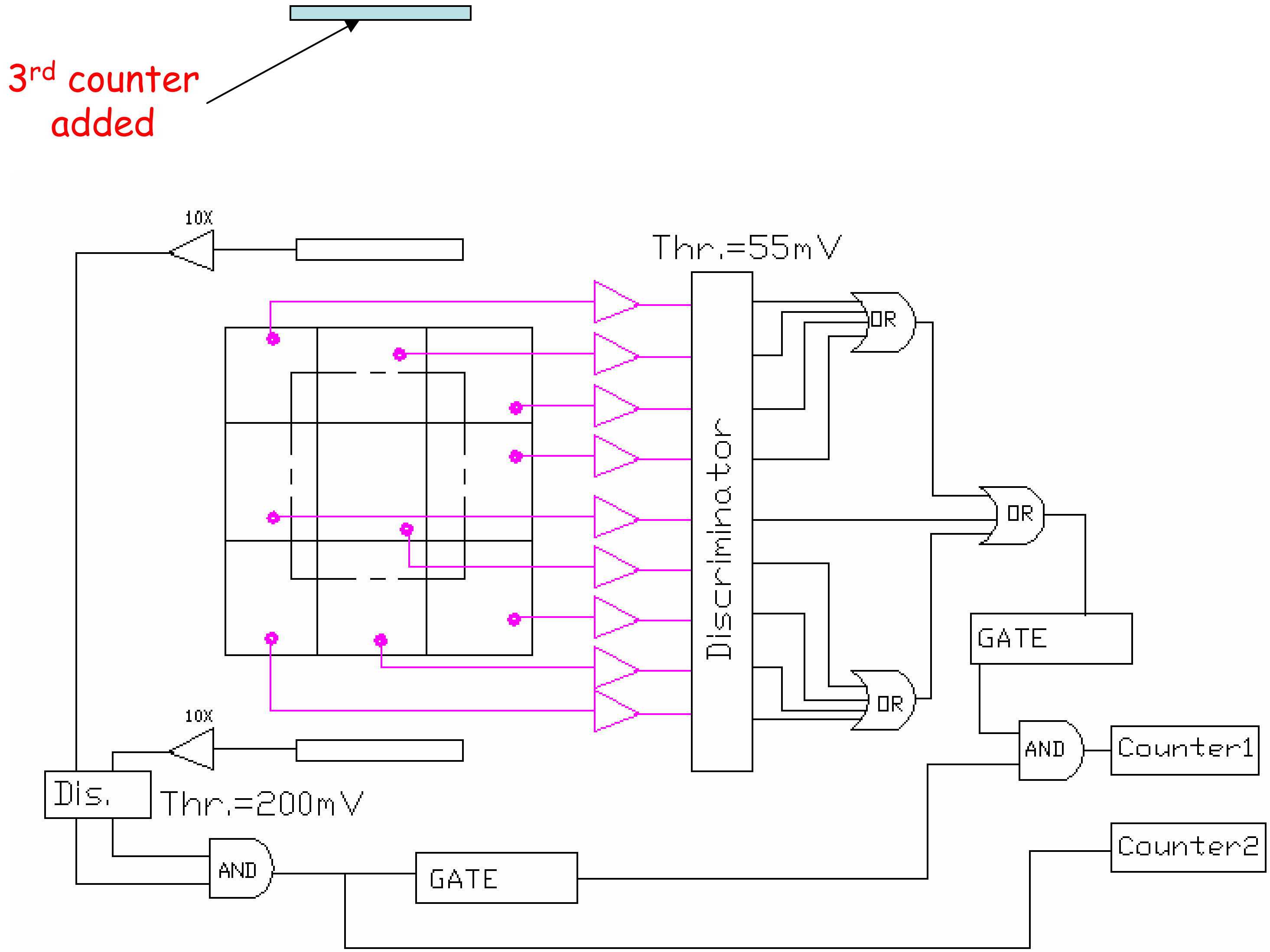




GEM Efficiency Measurement



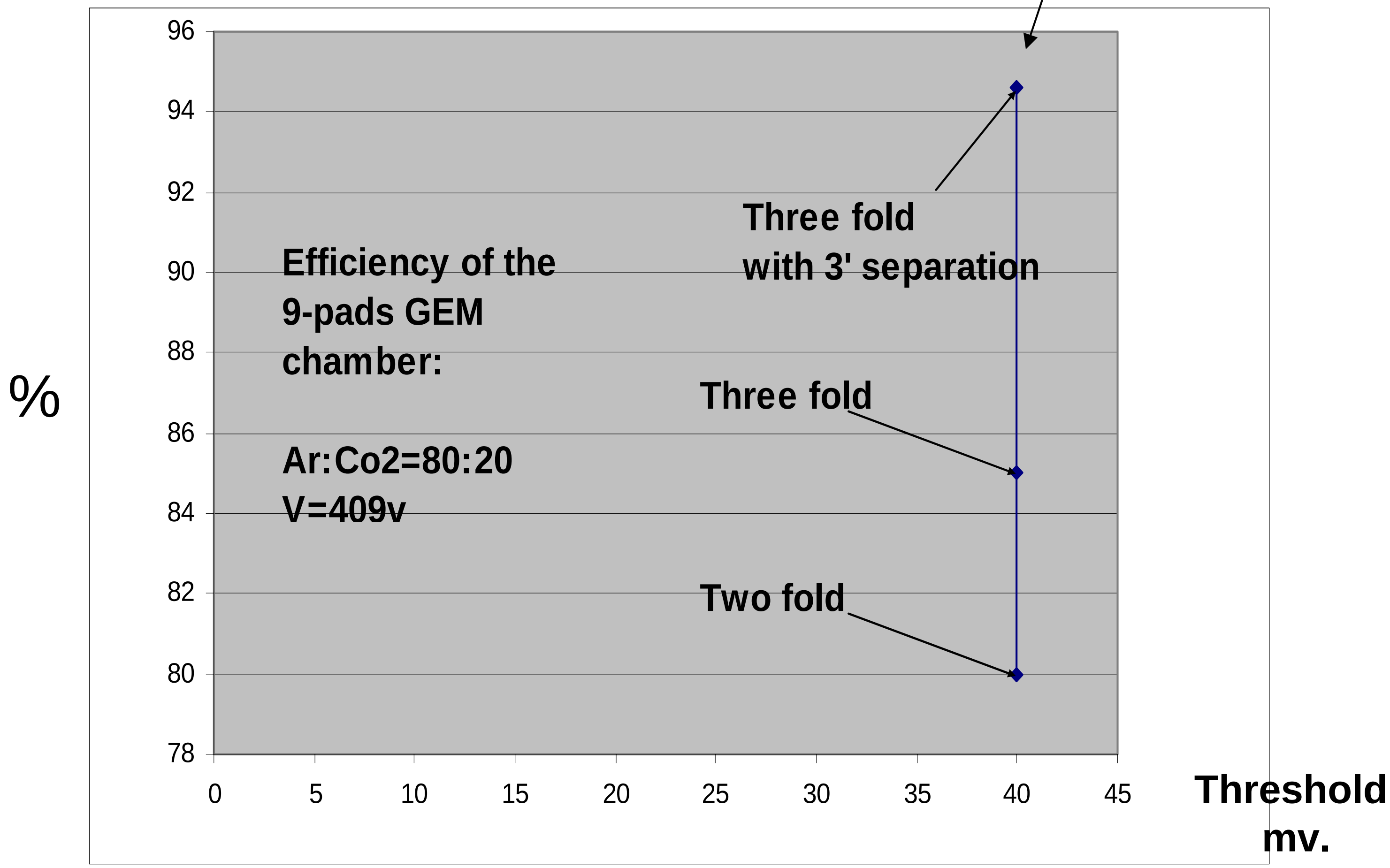
Setup for 9-pad GEM efficiency measurement



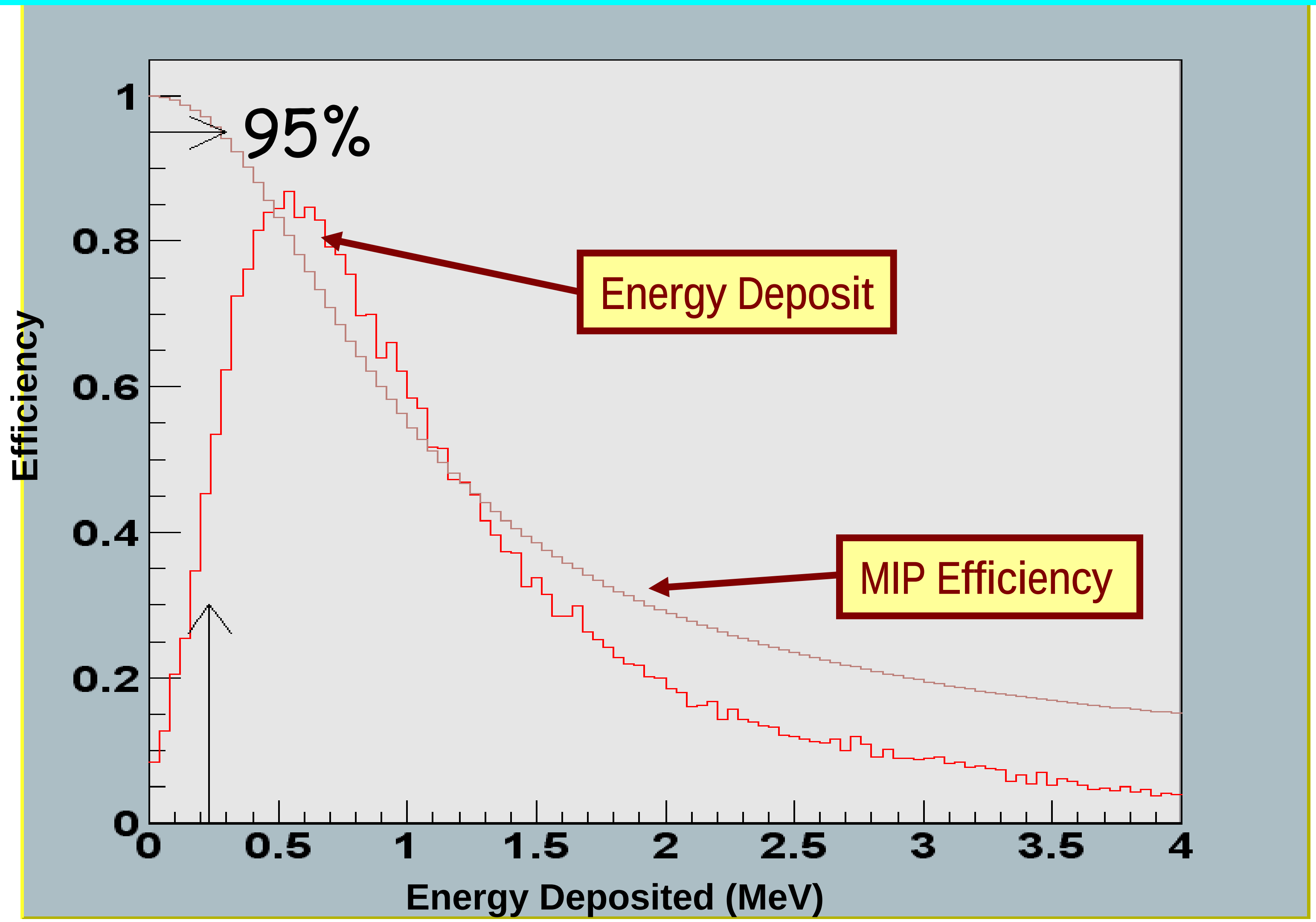
GEM efficiency measurement using cosmic rays

Eff. = 94.6%

after ensuring that cosmics must hit a pad



GEM/DHCAL MIP Efficiency - simulation



GEM Multiplicity Measurement

- 9-pad (3x3) GEM Chamber – double GEM
- Ar/CO_2 80:20
- HV = 409V across each GEM foil
- Threshold 40mV -> 95% efficiency
- Sr-90 source/scintillator trigger

-> Result: Average multiplicity = 1.27

GEM/DHCAL signal sizes

Goal: Estimate the minimum, average and maximum signal sizes for a cell in a GEM-based digital hadron calorimeter.

Method: Associate the average total energy loss of the Landau distribution with the total number of electrons released in the drift region of the GEM cell.

Ionization in the GEM drift region

A charged particle crossing the drift region will have a discrete number of "primary" ionizing collisions (ref. F.Sauli, CERN 77-09, 1977).

An ejected electron can have sufficient energy to produce more ionization. The sum of the two contributions is referred to as the "total ionization". In general,

$$n_T = n_P * 2.5$$

Using Sauli's table, we calculate n_T = 93.4 ion pair/cm for Ar/CO_2 80/20 mixture.

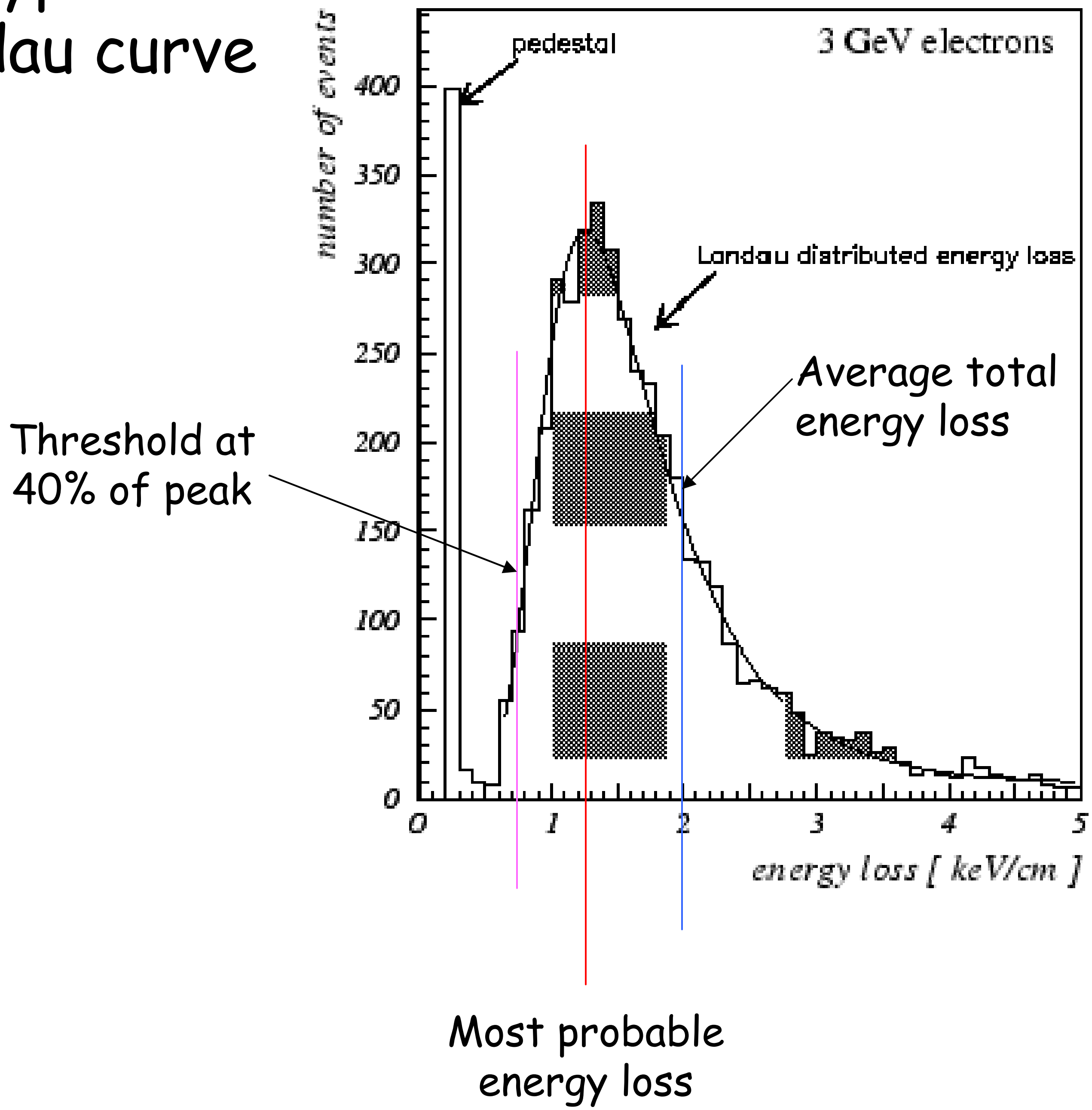
Characteristics of the Landau energy loss distribution

The Landau distribution is defined in terms of the normalized deviation from the "most probable energy loss", which is associated with the peak of the distribution – see the following slide.

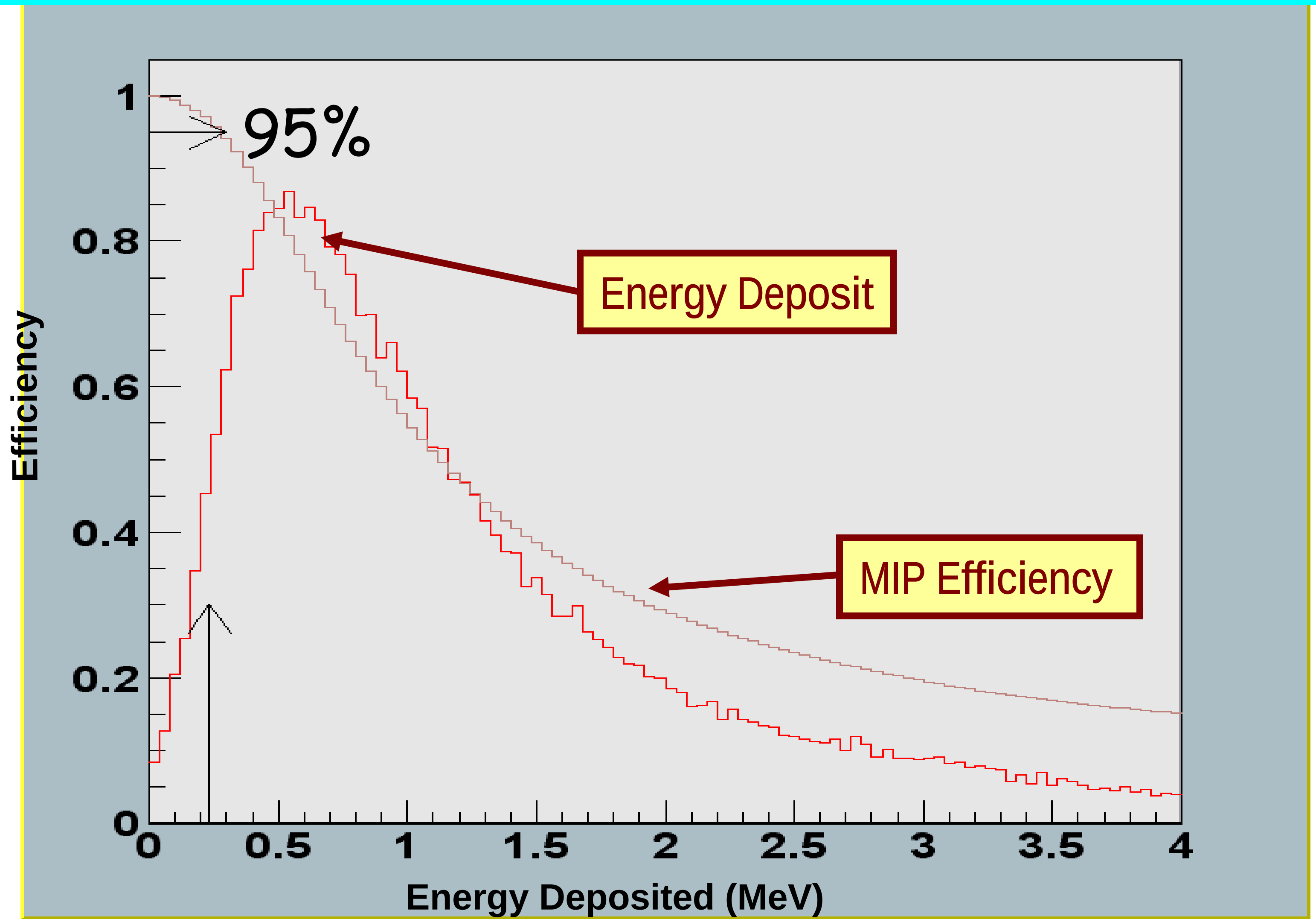
The average total energy loss occurs at about 50% of the peak (on the upper side). This is the point we associate with the quantity n_T.

In order to set a value for the minimum signal, we need to chose a point on the low side of the peak corresponding to a certain expected efficiency. From our GEM simulation, we find that we expect a 95% efficiency with a threshold at ~40% of the peak value – result from simulation (J.Yu, V.Kaushik, UTA)

Typical Landau curve



GEM/DHCAL MIP Efficiency - simulation



Calculating our GEM signal levels

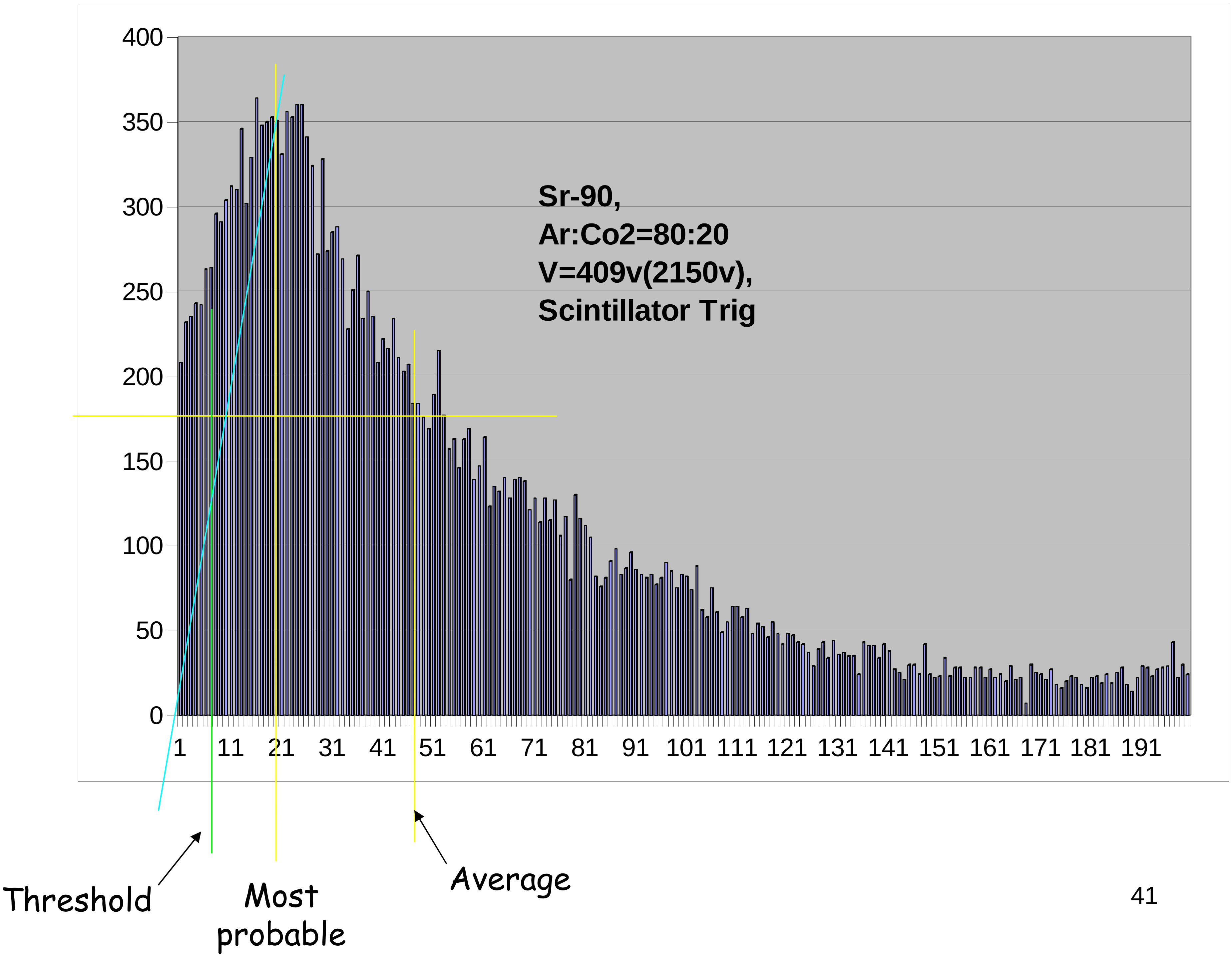
Looking at the following slide for Ar/CO_2 80/20 we see that the average total energy loss occurs at a signal size that is ~5x that for a minimum signal at 40% of the peak height on the low side of the peak.

So then, if n_T = 93.4 ion pair/cm, then we expect ~28 total electrons on the average per MIP at normal incidence on our 3mm drift region. This gives 5.6 electrons for the minimum signal.

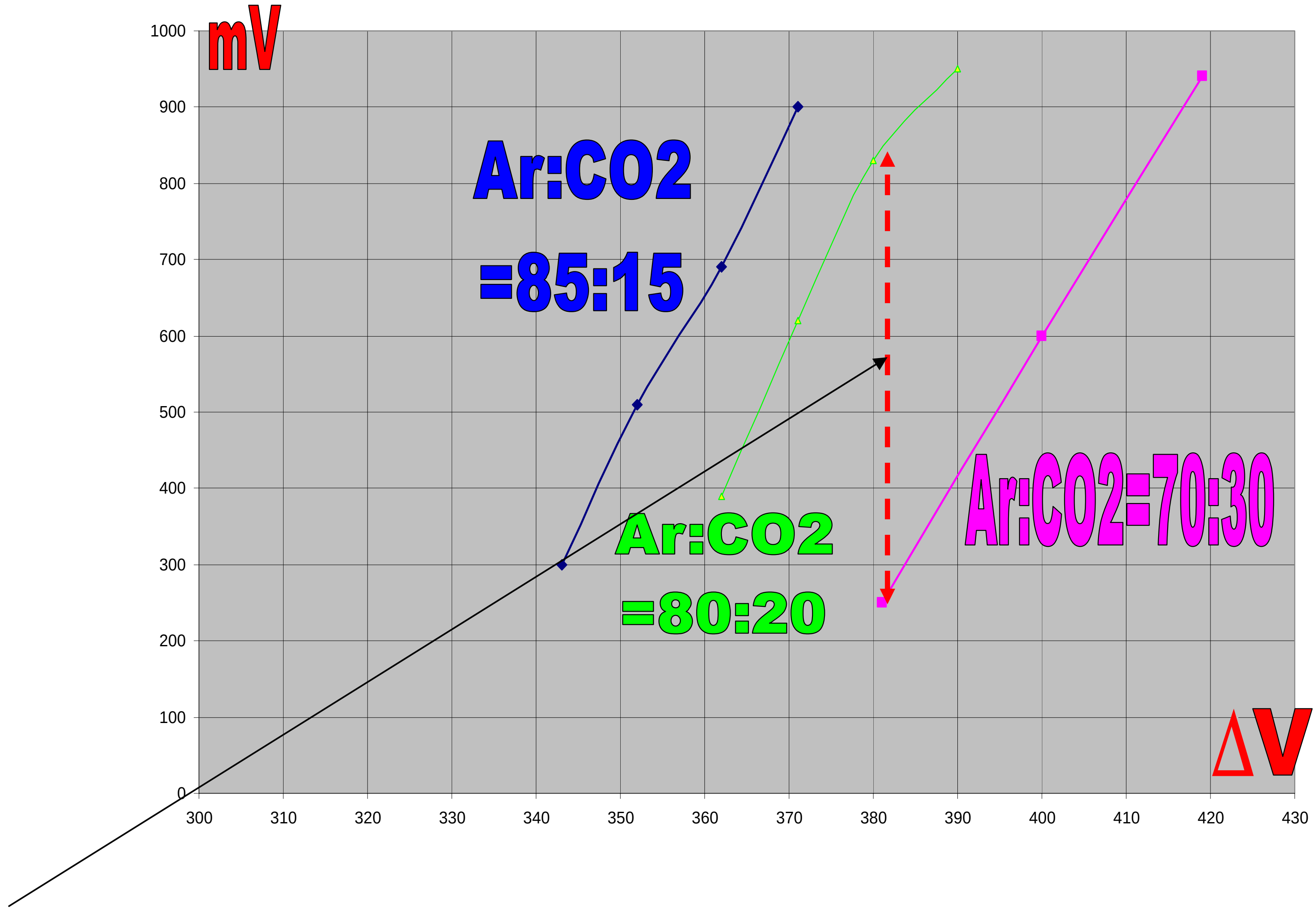
The gain we measured for our 70/30 mixture was ~3500, and we see a factor x3 for 80/20 (see following plot). Putting this all together, we expect

Minimum signal size = $5.6 \times 3{,}500 \times 3 \times 1.6 \times 10^{-19}$

= 10 fC



Sr-90,
Ar:Co2=80:20
V=409v(2150v),
Scintillator Trig
400
350
300
250
200
150
100
50
0
1 11 21 31 41 51 61 71 81 91 101 111 121 131 141 151 161 171 181 191
Threshold
Most probable
Average



~ factor of 3 increase in signal at same voltage for 80:20 vs 70:30

Calculating our GEM signal levels

We also expect:

Most probable signal size ~20 fC
Average signal size ~50fC

These estimates are essential input to the circuit designers for the RPC/GEM ASIC front-end readout.

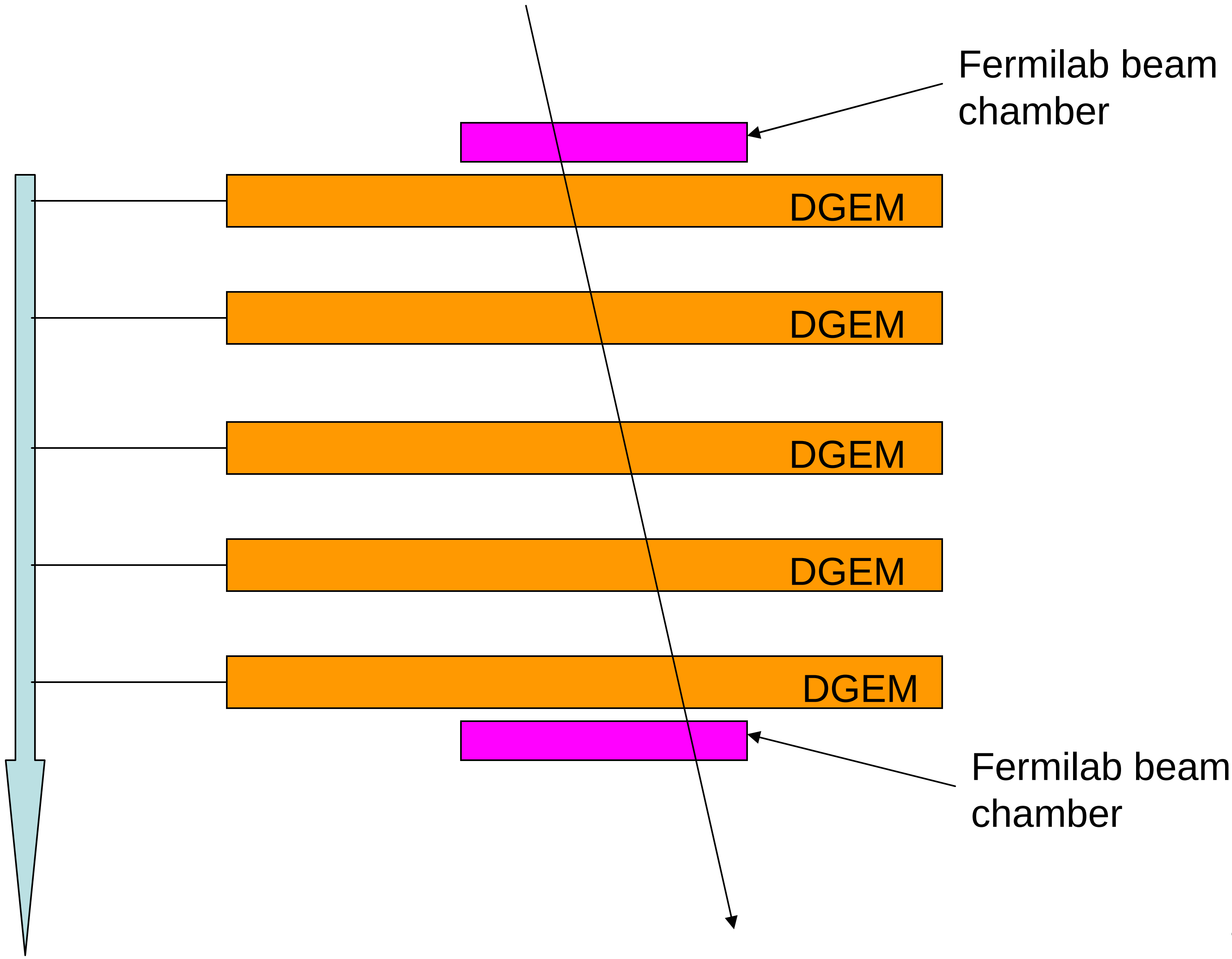
The estimate of the maximum signal size requires input from physics (+background(s)) simulation…

Plans for next GEM assemblies

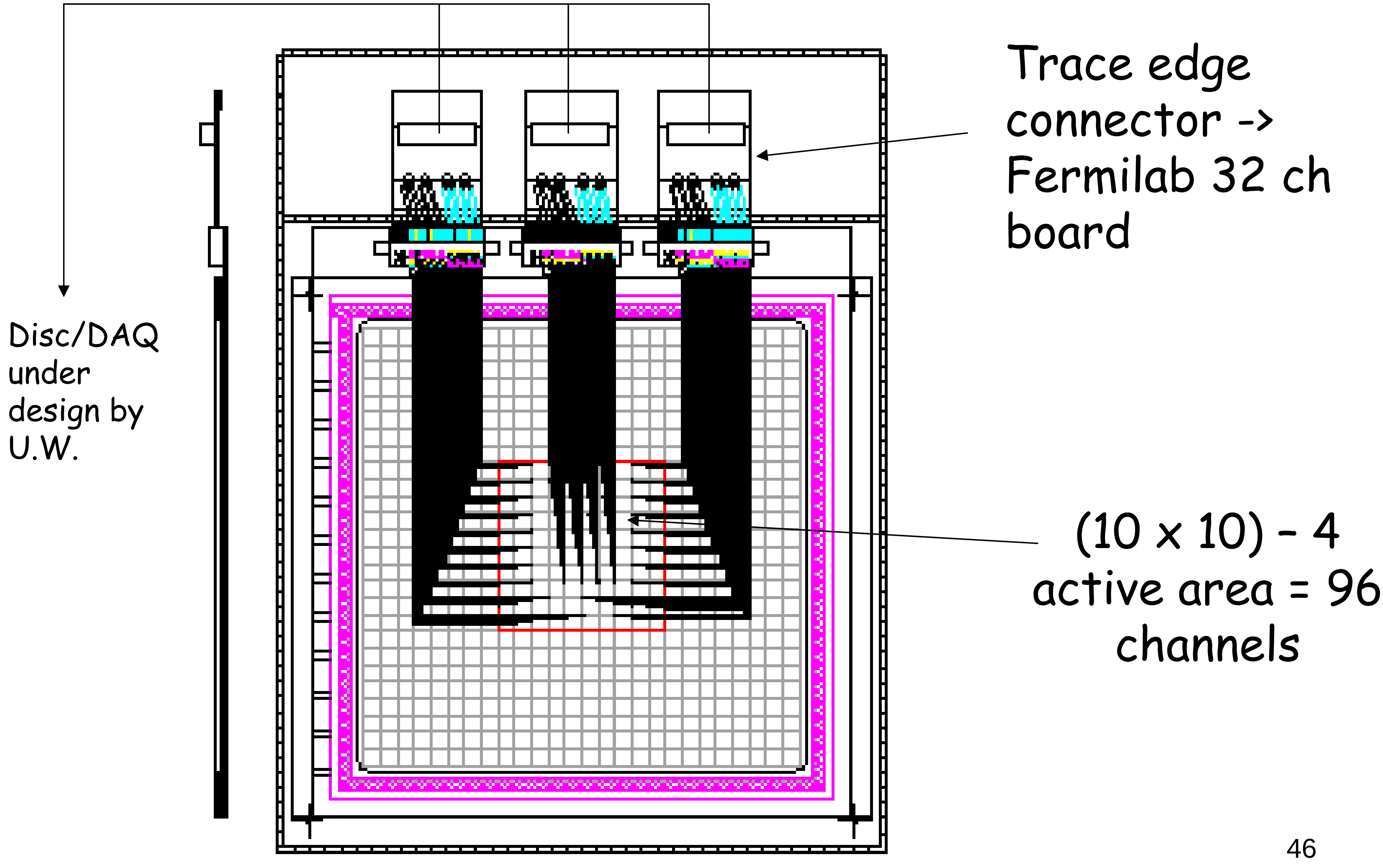
- Produce and use larger GEM foils.
- Intermediate step towards full-size foils for test beam.
- Present 3M process allows ~30cm x 30cm foil production – etch window

- Order placed for foils – masking tool fabrication next week, foil delivery in 5 weeks.
- Assemble 5 layers of DGEM chambers – Spring 2005.

Cosmic stack using Double GEM counters



305mm x 305mm layer



Cosmic stack using Double GEM counters

- Single cosmic tracks.

- Hit multiplicity (vs. simulation)

- Signal sharing between pads (e.g. vs. angle)

- Efficiencies of single DGEM counters

- Effects of layer separators

- Operational experience with ~500 channel system

- Possible test-bed for ASIC when available – rebuild one or more DGEM chambers.

- Proposal submitted to Korean Nuclear Laboratory for beam tests for 500-channel prototype.

T2K large GEM foil design

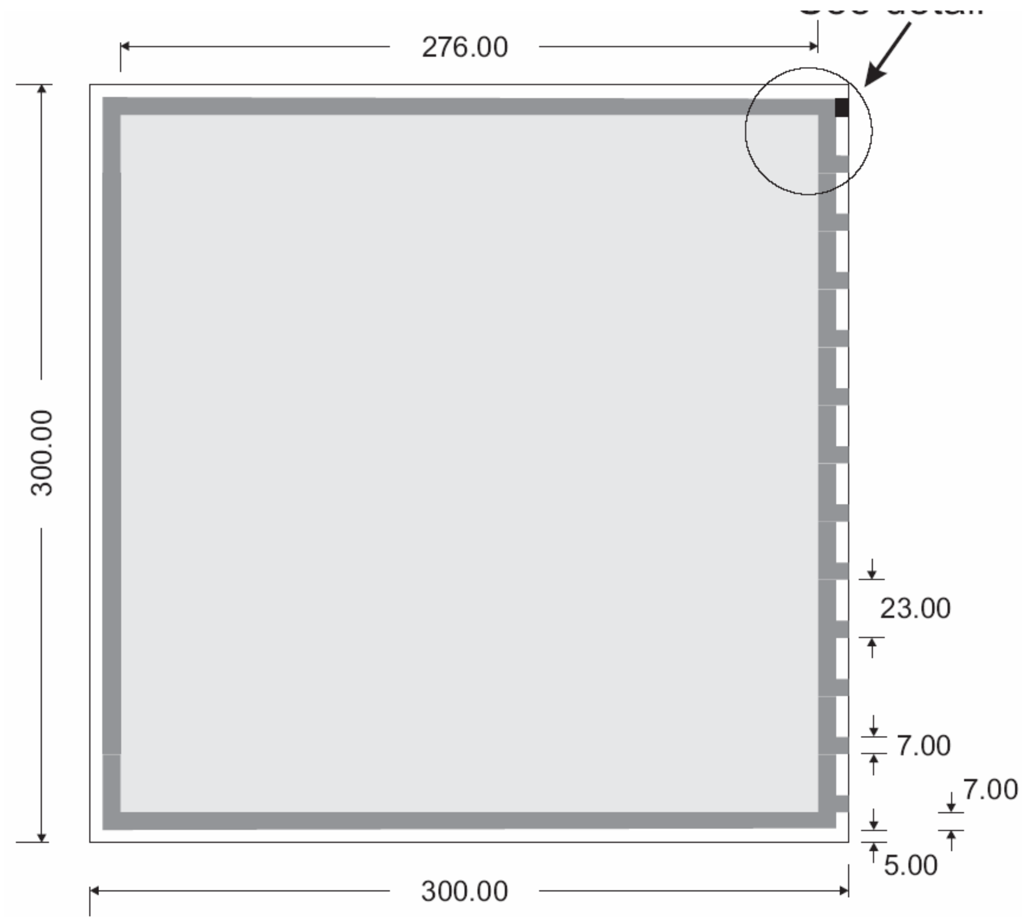
Institutes cooperating on foil production:

- U. Victoria BC (Canada) (T2K and LC TPC)
- U. Washington (DHCAL)
- Louisiana Tech. U. (LC TPC)
- Tsinghua U. (DHCAL)
- IHEP Beijing (GEM development)
- U. Texas Arlington (DHCAL)

(share cost of masks, economy of scale in foil production)

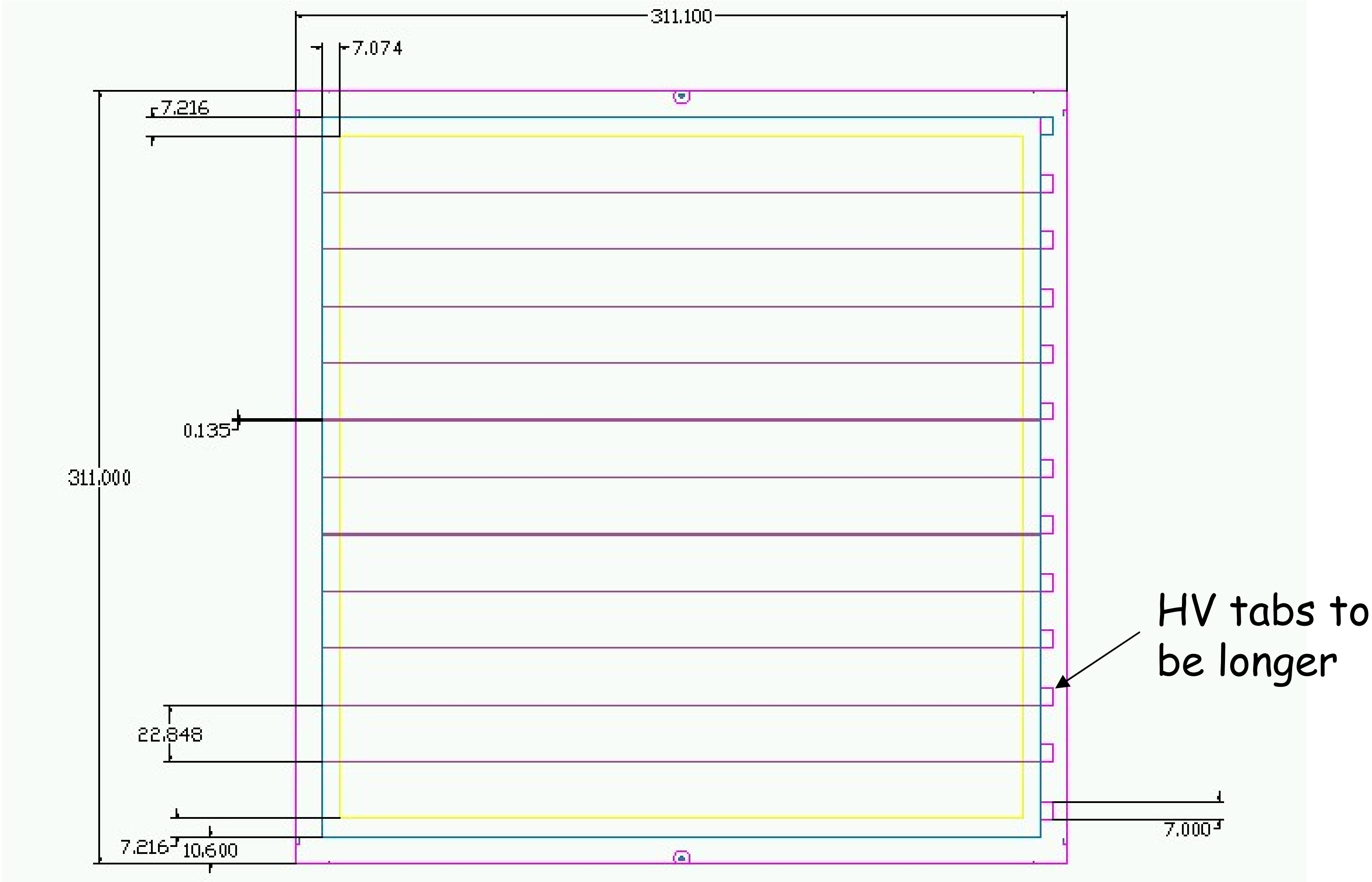
T2K large GEM foil design

Dean Karlen, U.Victoria BC



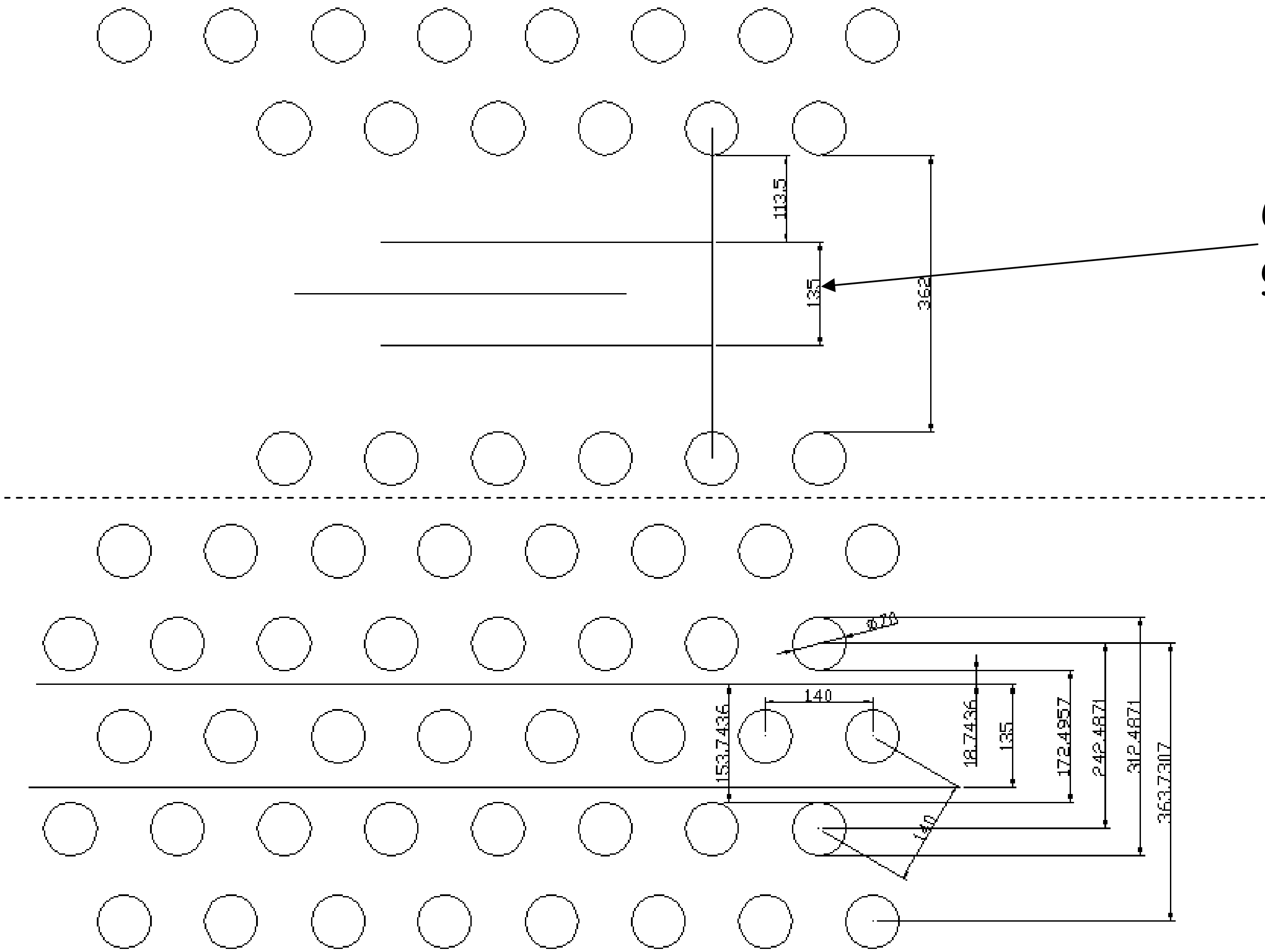
(Close to COMPASS(CERN) foil design)

3M GEM foil design



- Now in tooling phase
- Delivery in ~5 weeks

3M - gap between HV sectors



Guaranteed gap = 135μm

GEM foil costs

- CERN 10cm x 10cm, framed $400 each
- 3M 30cm x 30cm foils
  - in small quantities ~$600 each
  - for 1m^3 stack (720 needed) ~$150 each
  - for final calorimeter (80,000) $?? each

Other potential sources of foils

- Other commercial (TechEtch, Techtra,…)
- Other institutes/countries (visit to Beijing next week)

Proposal to Korean Nuclear Laboratory

- Low energy beam tests with medium size GEM prototype

□별별지 제1-2 호 서식□

원자력연구개발과제계획서(신청용)

(세부과제 또는 단위과제용)

□ 사 업 명	원자력연구기반확충사업		분 야 명	핵심기초연구		
기술분류코드	대분류 500		중분류 510		소분류 513	
□ 과 제 명	국문) 방사능 측정기 개발을 위한 이단-기체전자증폭 검출기의 제작과 그것의 특성에 관한 연구 영문) Fabrication of double GEM(Gas Electron Multiplier) detector for development of radiation measurement instrument and study of its characteristics					
□ 주관연구기관	창원대학교		□ 과 제 성 격: 기초( ), 응용(O), 개발( ), 기타( )			
연구책임자	소속 및 부서명	물리학과	직 위	교수		
	성 명 (한문)	김일곤(金日坤)	전 공	물리(광학)		

연구 개발비	□ 총 연구개발비		□ 연도별 연구개발비: 1차년도	2차년도	3차년도
	정부출연금	100,000천원	50,000천원	50,000천원	천원
	기업부담금	천원	천원	천원	천원
	상대국부담금	한국 측 연구팀에게 기술전수 및 편의제공			
	계	100,000천원	50,000천원	50,000천원	천원

		연도별 참여 연구 인력: 년도	내부	외부	계 (MY)
총 연구기간	2005. 6. 1~ 2007. 1. 31(1년8월)				
제1단계 연구기간	2005. 6. 1~2006. 3. 31 (0년 10월)	1차년도	5	3	8
다년도협약연구기간	2005. 6. 1~2007. 1. 31 (1년 08월)	2차년도	5	3	8
당해연도연구기간	2005. 6. 1~ 2006. 3. 31(0년10월)				

□ 참여 기업	기업체명	(□기업유형)	대표자(성명)	
	주 소	본사 :	(전화번호 :	
	책 임 자	소 속 :	성 명 :	
국 제 공 동 연구비	상 대 국 (연구기관)	University of Texas at Arlington (UTA) - 미국	상대국연구 개 발 비	신청액 : 1,500,000US\$ 확정액 : 700,000US\$
	상 대 국 연구책임자	Jaehoon Yu	상대국연구 개발기간	신 청 :2001~2015 (15년) 확 정 :2001~2007 (8년)

관계규정과 제반 지시사항을 준수하면서 본 연구사업을 성실히 수행할 것을 약속하며 과제계획서를 첨부와 같이 제출합니다.

첨 부 : 원자력연구개발과제계획서(신청용 12부, 협약용 3부)

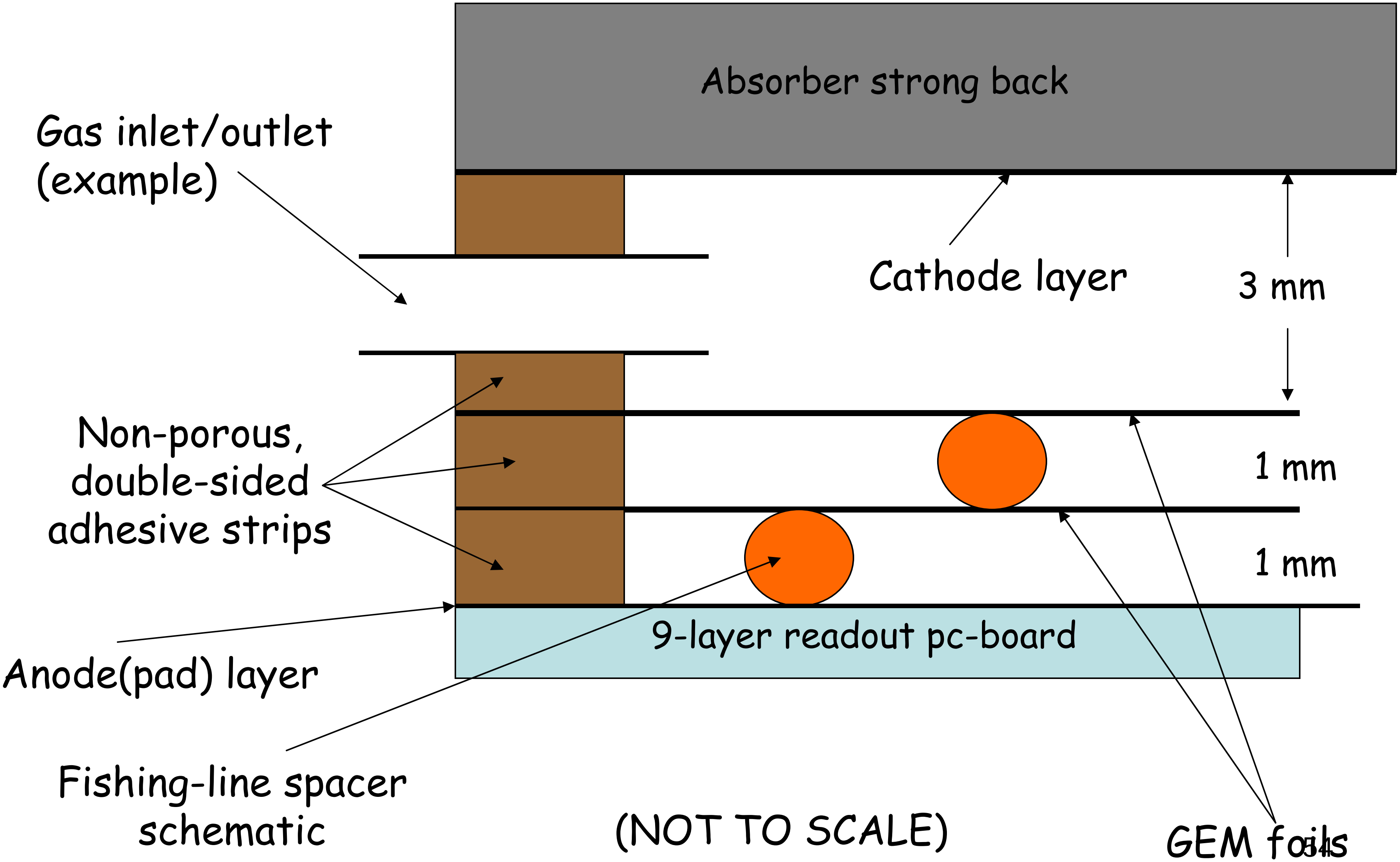
2005년 4월 19일

주관연구책임자 : 김 일 곤 (인)

주관연구기관장 : 김 현 태 [직 인]

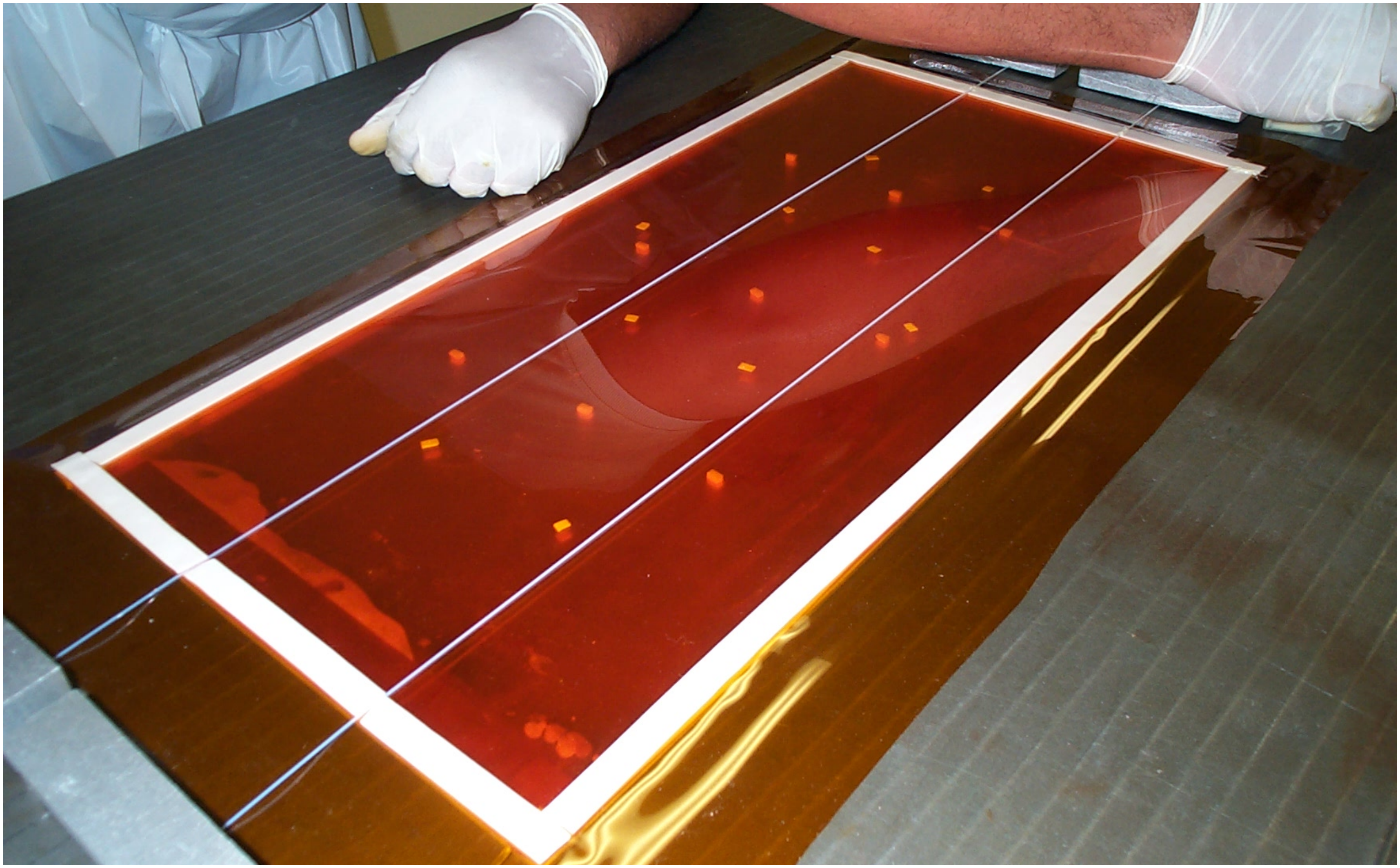
과 학 기 술 부 장 관 귀하

Development of GEM sensitive layer



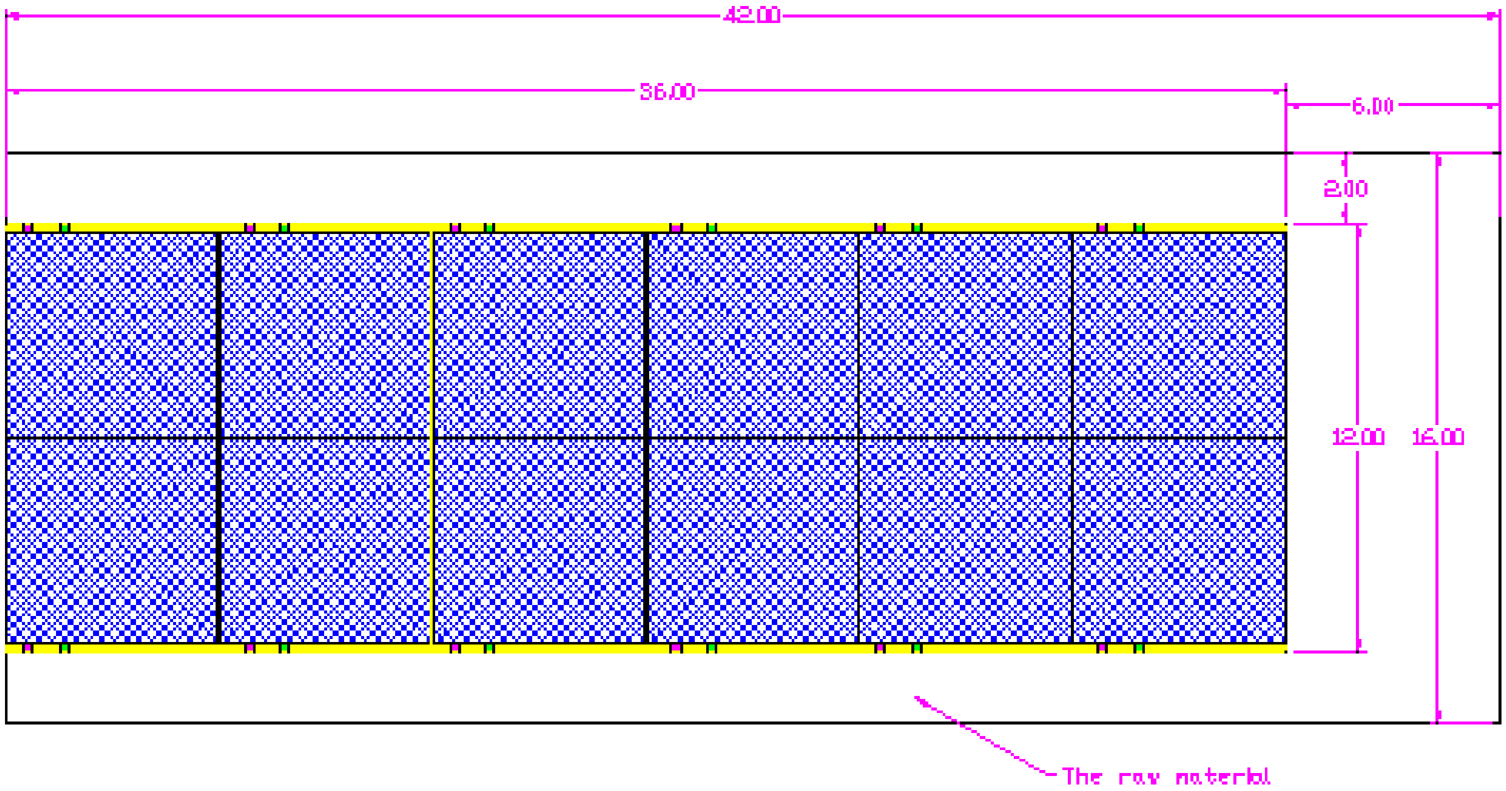
Full-scale (1m^3) prototype development

Frame for stretching/flattening GEM foils



Trying out spacer designs, GEM-cathode, GEM-GEM, GEM-Anode

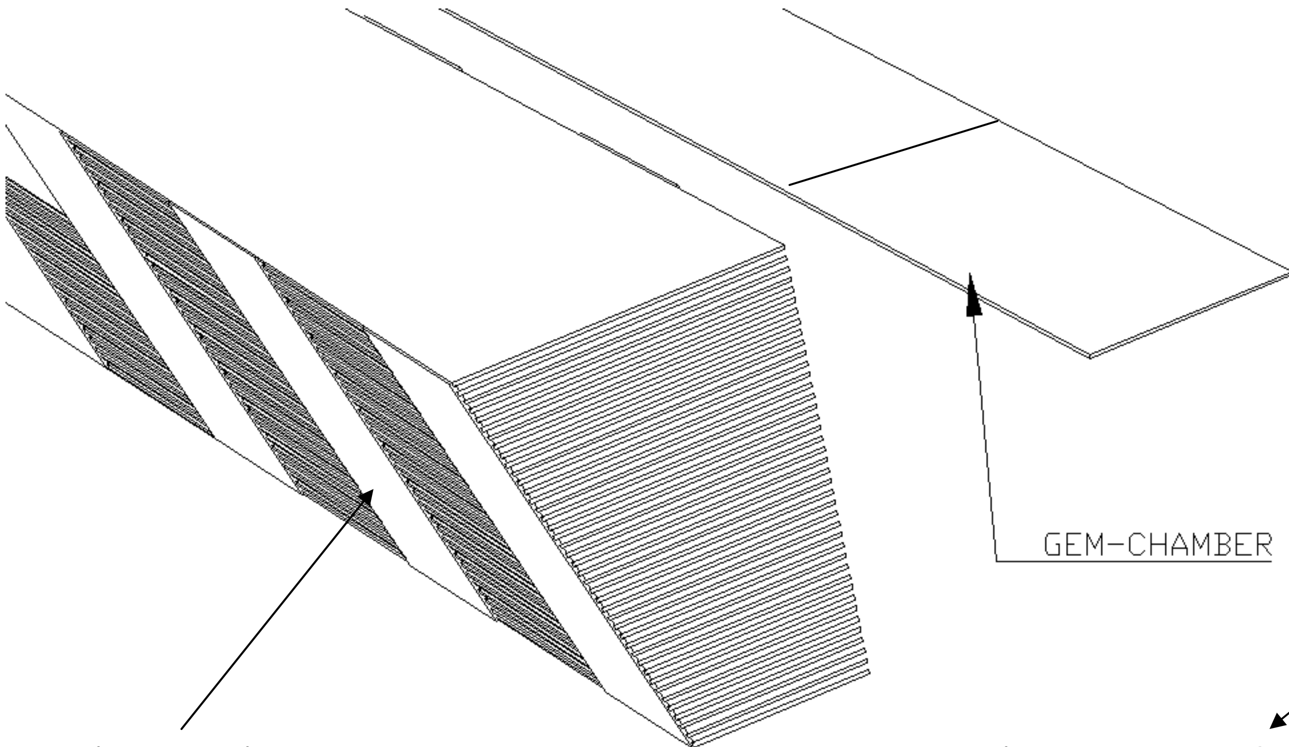
3M GEM foil - large panel design



Full-scale ($1m^3$) prototype development

- 40 layers
- 3 large GEM "panels"/layer
- Double-GEM structure throughout
- 40 layers x 3 panels/layer x 2 x 3 "units"/panel = 720 units
- Fabrication of ~1m x 30cm GEM foils requires some development/process modification by 3M
- Goal is enable large foil production by Fall 2005.

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

CONCLUSIONS

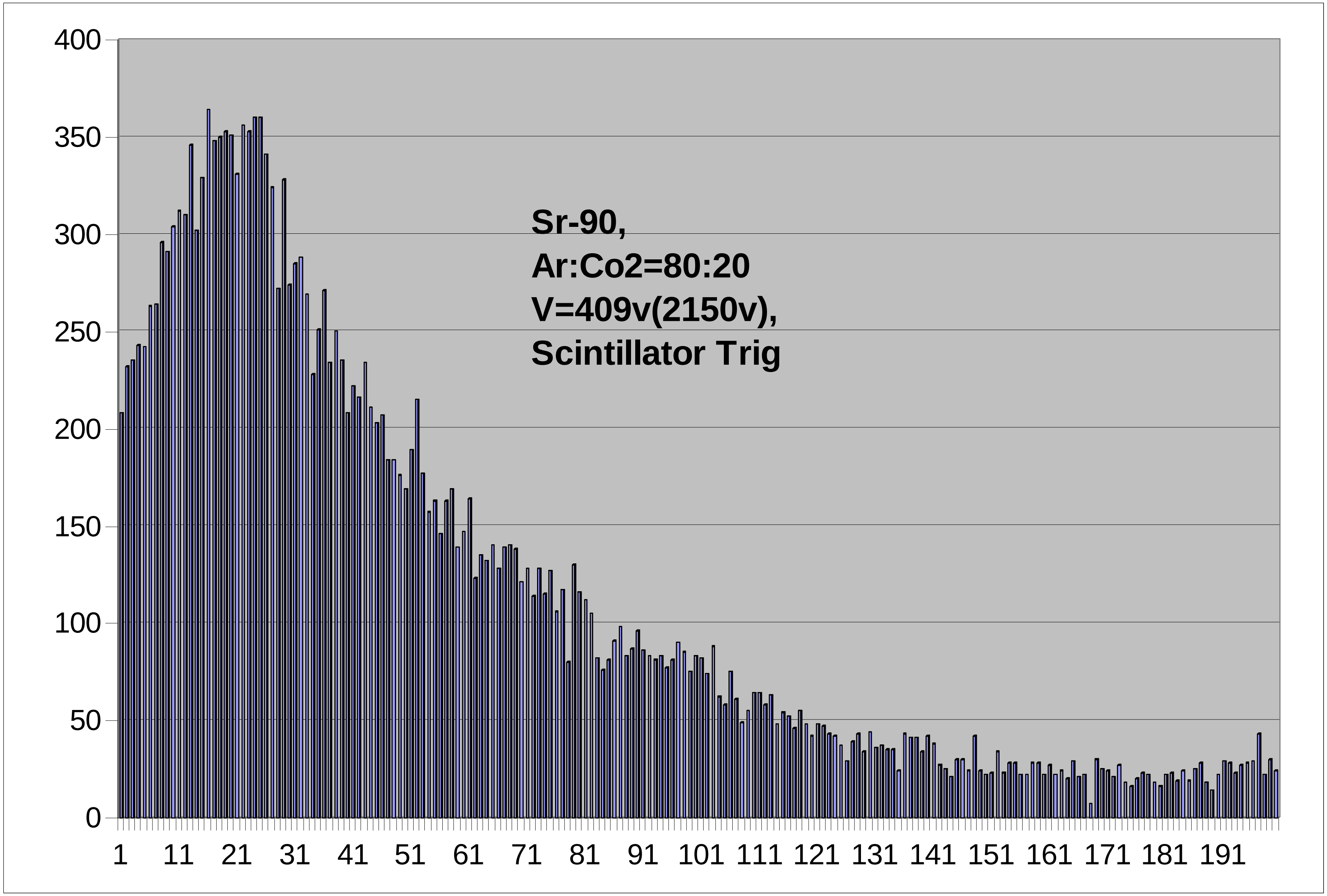
- Prototype studies of GEM detector

- Much learned about construction and operation of GEM's

- Technology well suited to implementation of digital hadron calorimetry

- About to construct 500-channel system

- Plans for $1m^3$ test beam stack in progress


Sr-90,
Ar:Co2=80:20
V=409v(2150v),
Scintillator Trig
400
350
300
250
200
150
100
50
0
1 11 21 31 41 51 61 71 81 91 101 111 121 131 141 151 161 171 181 191