GEM-based

Digital Hadron Calorimetry

Snowmass Meeting

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(for the GEM-DHCAL group:

UTA, U.Washington, Tsinghua U., Changwon National University, KAERI-Radiation Detector Group)

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

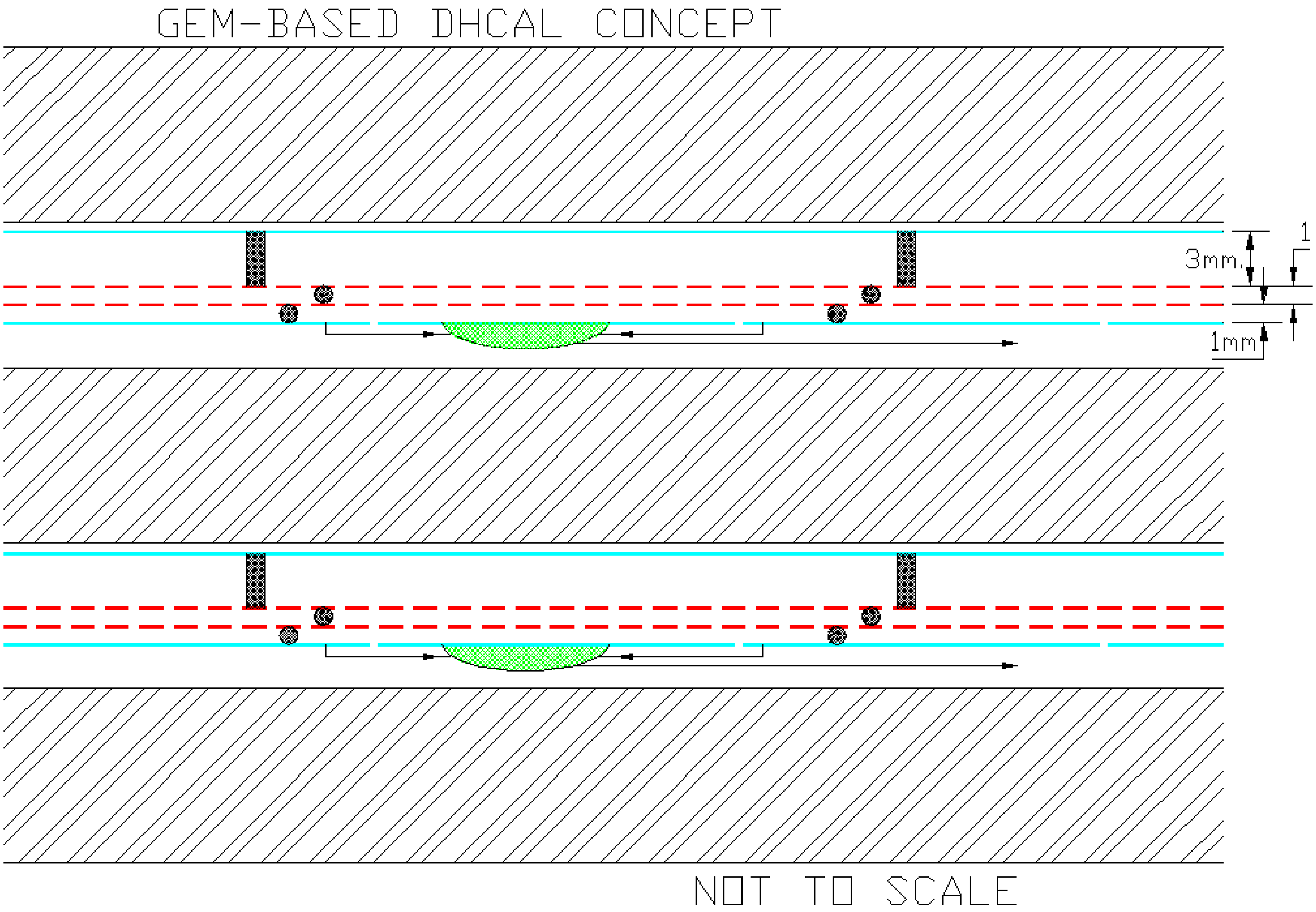
- Operates at modest voltages   ~400V/GEM

- Fast (if needed e.g. for forward calorimetry) – electron collection, not ion drift.

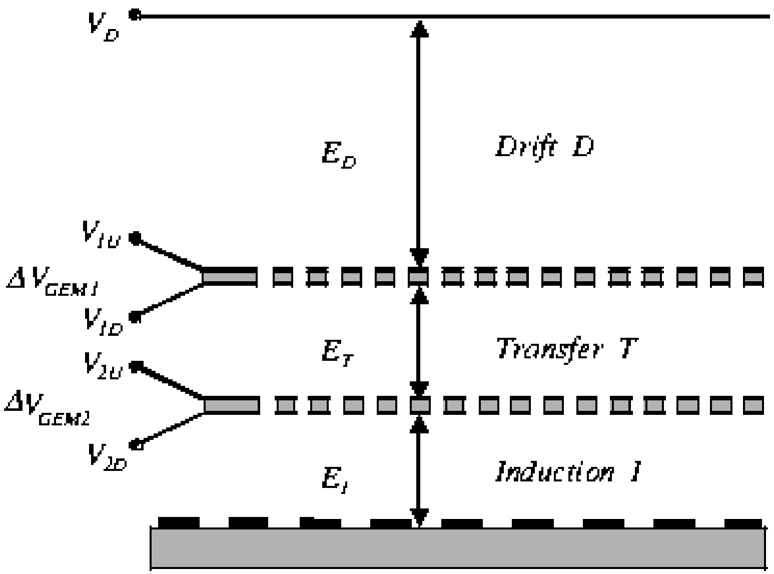
- A lot of parallel GEM development for LC/TPC systems and other experiments (e.g. T2K)

- Shares ASIC development with RPC.

GEM-based Digital Calorimeter Concept



GEM – operation



-2100V

ΔV ~400V

ΔV ~400V

0V

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

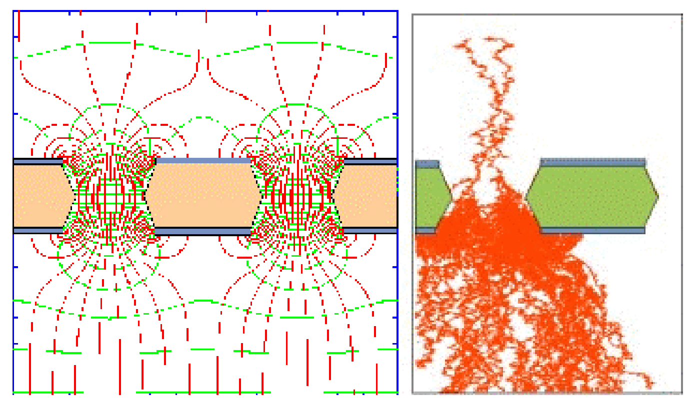
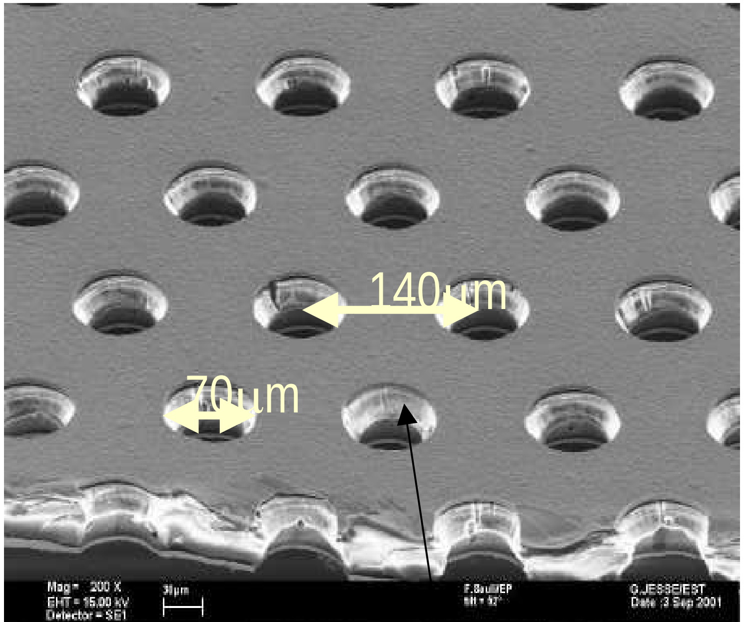


Fig. 15(a) Electric Field and (b) an avalanche across a GEM channel

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.

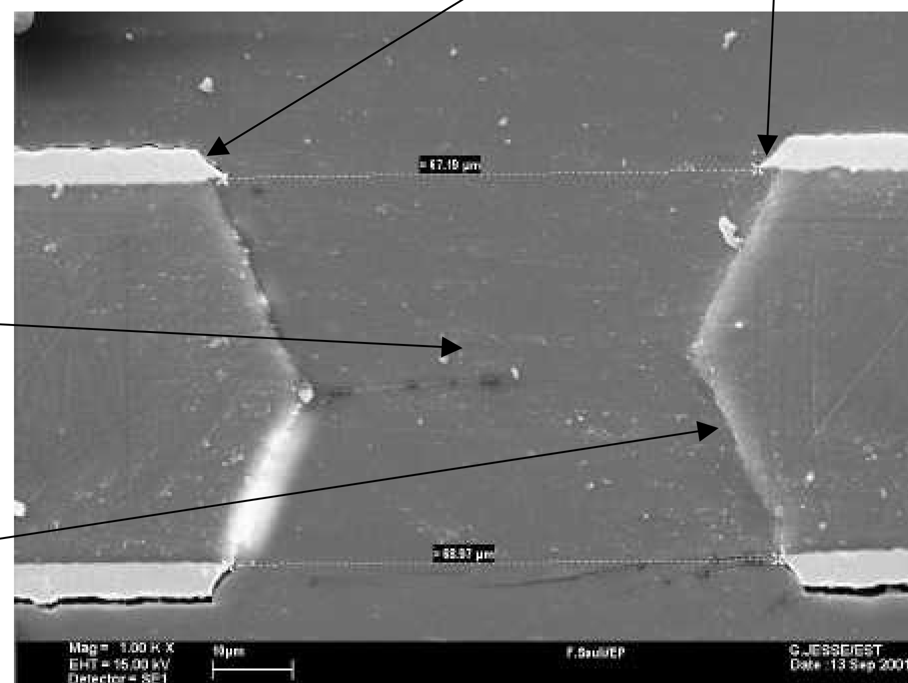
GEM – production



Copper edges

Hole profile

Exposed kapton



Performance parameters

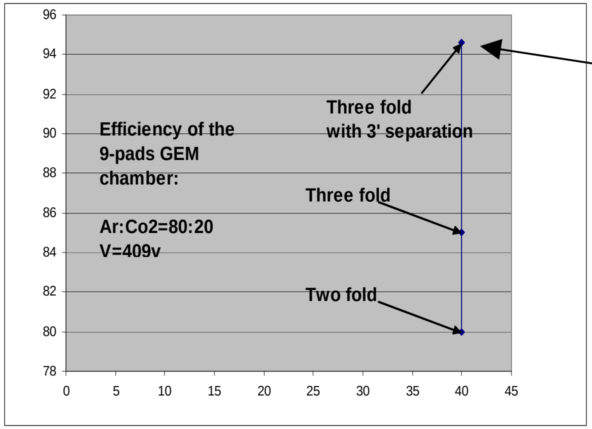
Minimum cell size

- currently 1x1 cm2, but could be much smaller (100μm) if needed e.g. to improve linearity of hits vs. energy relation.

- could include some “special” higher granularity layers if needed for PFA...

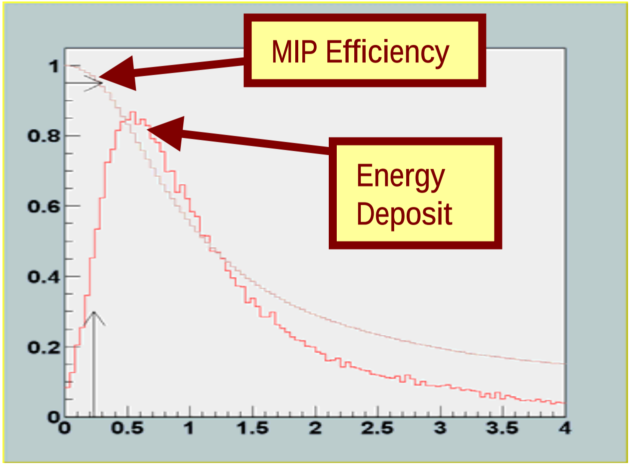
MIP efficiency

- Measured at 94.6%, agrees with simulation with given threshold



Eff. = 94.6%

after ensuring that cosmics must hit a pad



Performance parameters

-The specific effects of pad separators will be measured with the 500 channel prototype.

- Losses at module walls/boundaries: expect ~5mm edge.

Response to neutral particles

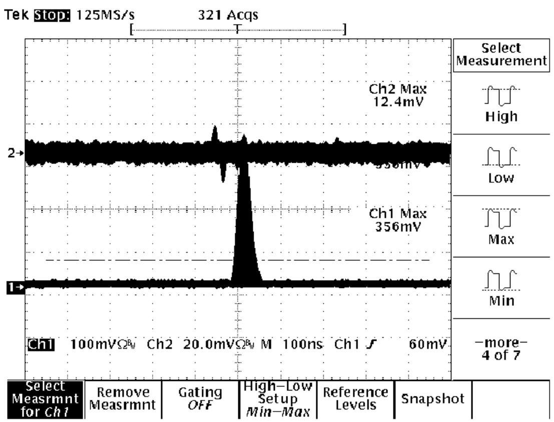
- Ar/CO2 gas , no hydrogen, could add? Still under study (benefit of compact showers vs. neutral energy loss).

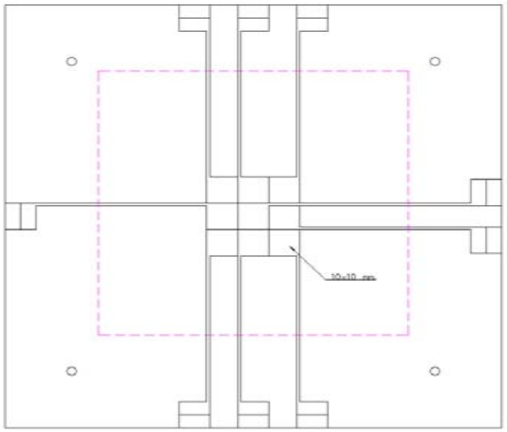
Intrinsic noise

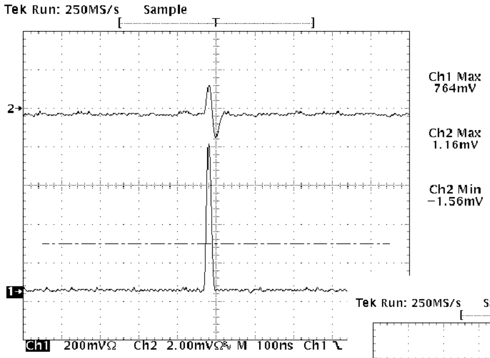
S/N for minimum ionizing electrons has been measured at 100:1 by Sauli/CERN-GDD using strip readout. Studies at UTA ongoing.

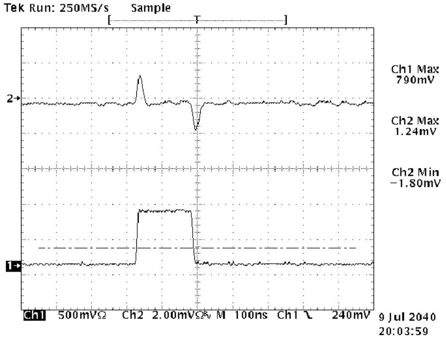
Performance parameters

Cross talk









-9-pad (3x3) GEM Chamber – double GEM

- Ar/CO2 80:20

- HV = 409V across each GEM foil

- Threshold 40mV -> 95% efficiency

- Sr-90 source/scintillator trigger

-> Result: Average multiplicity = 1.27

(further studies of dependence on pad region hit will be made with the 500-channel prototype)

Performance parameters

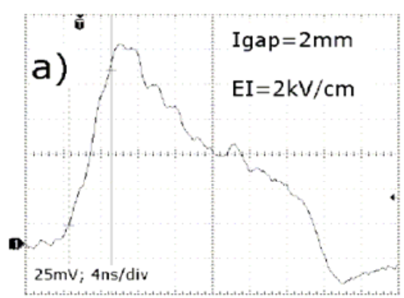
Uniformity of response

Space – to be studied with 500-channel prototype using cosmics and possibly testbeam.

Time – performance of small prototype is very stable over months of operation. Efficiency for given threshold does not vary.

Speed/Timing

Intrinsically fast – uses electron signal as opposed to ion drift/MWPC. Leading edge ~few ns:



WIS/27/02-July-DPP

Shower spread and containment

Relative insensitivity to neutrons limits shower spreading.

Projected 4λ for HCal -> need for tail-catcher?

Reliability, operational reqs. , safety, risks

GEM: A new concept for electron amplification in gas detectors

F. Sauli

CERN, CH-1211 Genève, Switzerland

Received 6 November 1996

Proveness: state of the art

GEMs well studied for HEP (tracking, triggering, cal,...) and other (medical imaging) applications. Many results and long term stability and aging

Aging

"In standard operation conditions, with Ar/CO2 (70:30) gas filling and operated at an effective gain of 8:5 x 10^3; no change in gain and energy resolution is observed after collecting a total charge of 7 mC/mm^2; corresponding to seven years of normal operation."

M.C. Altunbas et al. / Nuclear Instruments and Methods in Physics Research A 515 (2003) 250 249–254

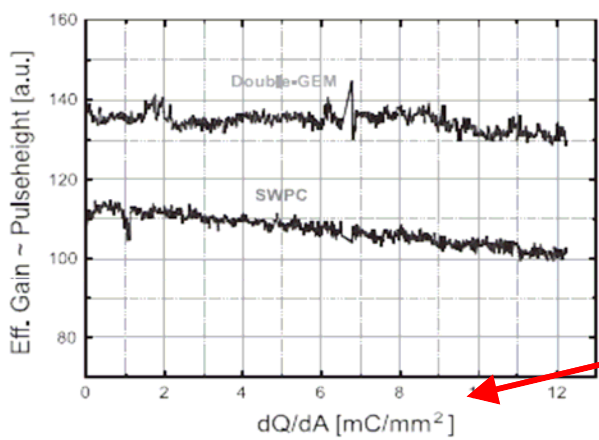


Fig. 3. Previous aging measurement of a double-GEM detector with Ar–CO_2 (70:30): effective gain versus accumulated charge dQ/dA.

~10^{12} part/mm^2

Reliability, operational reqs. , safety, risks

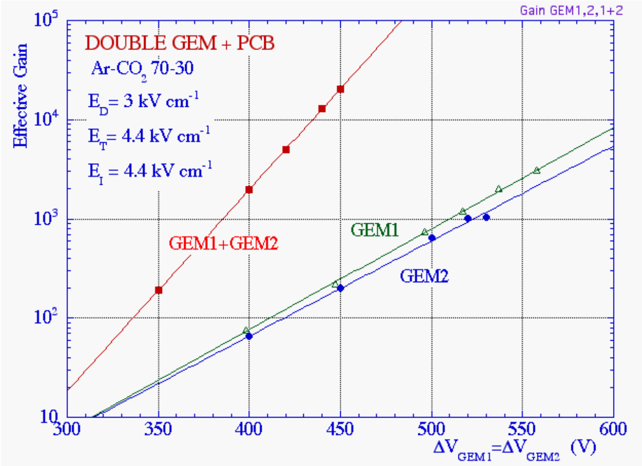
Effect of magnetic field

Being simulated.

Barrel: E radial, B axial -> expect some offset of signal w.r.t. anode pads? Effect of "spiraling electrons, physical barriers (foil separators?)

High Voltage

Each GEM runs at ΔV ~400V, total HV across DGEM ~2100V



CERN GDD group

At ΔV ~400V, factor of 2 increase in gain for 20V change in HV

Reliability, operational reqs. , safety, risks

Operational robustness

"From our present experience GEM foils appear very robust against damages caused by discharges; during the test beam exposures, the detector could withstand without damages thousands of discharges"

S. Bachmann et al. / Nuclear Instruments and Methods
in Physics Research A 470 (2001) 548–561

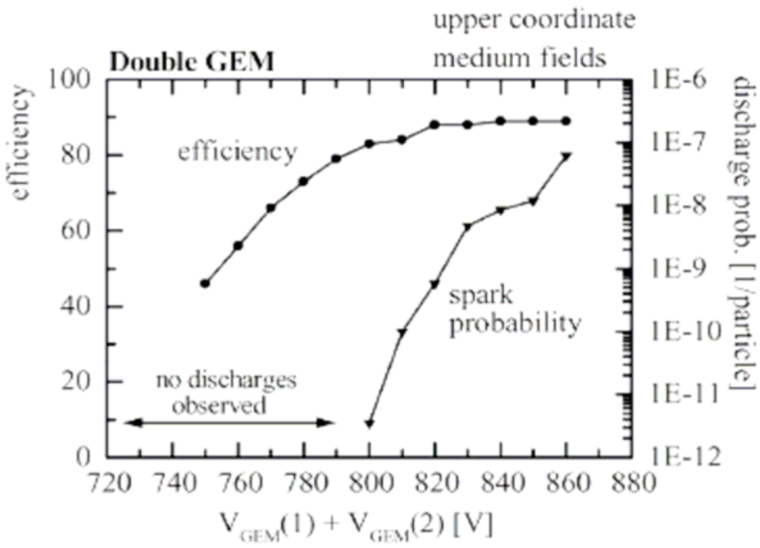


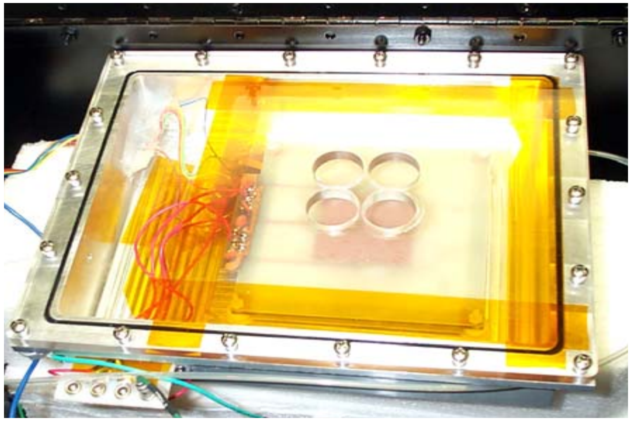
Fig. 11. Discharge rate and efficiency for the detection of minimum ionising particles.

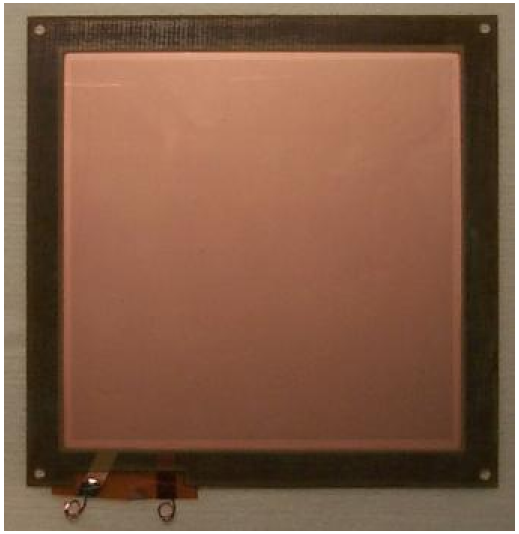
S. Bachmann et al. / Nuclear Instruments and Methods
in Physics Research A 46 461 (2001) 42–46

Reliability, operational reqs. , safety, risks

Mechanical rigidity/flexibility/fragility

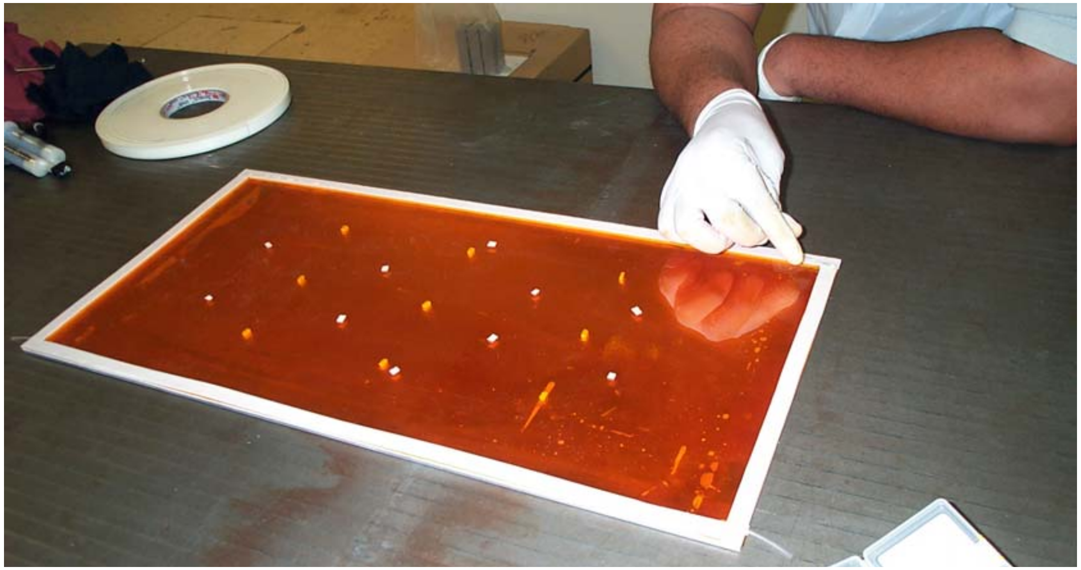
Foils: 10cm x 10cm foils have been handled initially in Class 1000 clean room. Subsequent experience – DGEM chamber stacked and unstacked many times in normal lab environment with NO problems. Always turns back on with same performance.





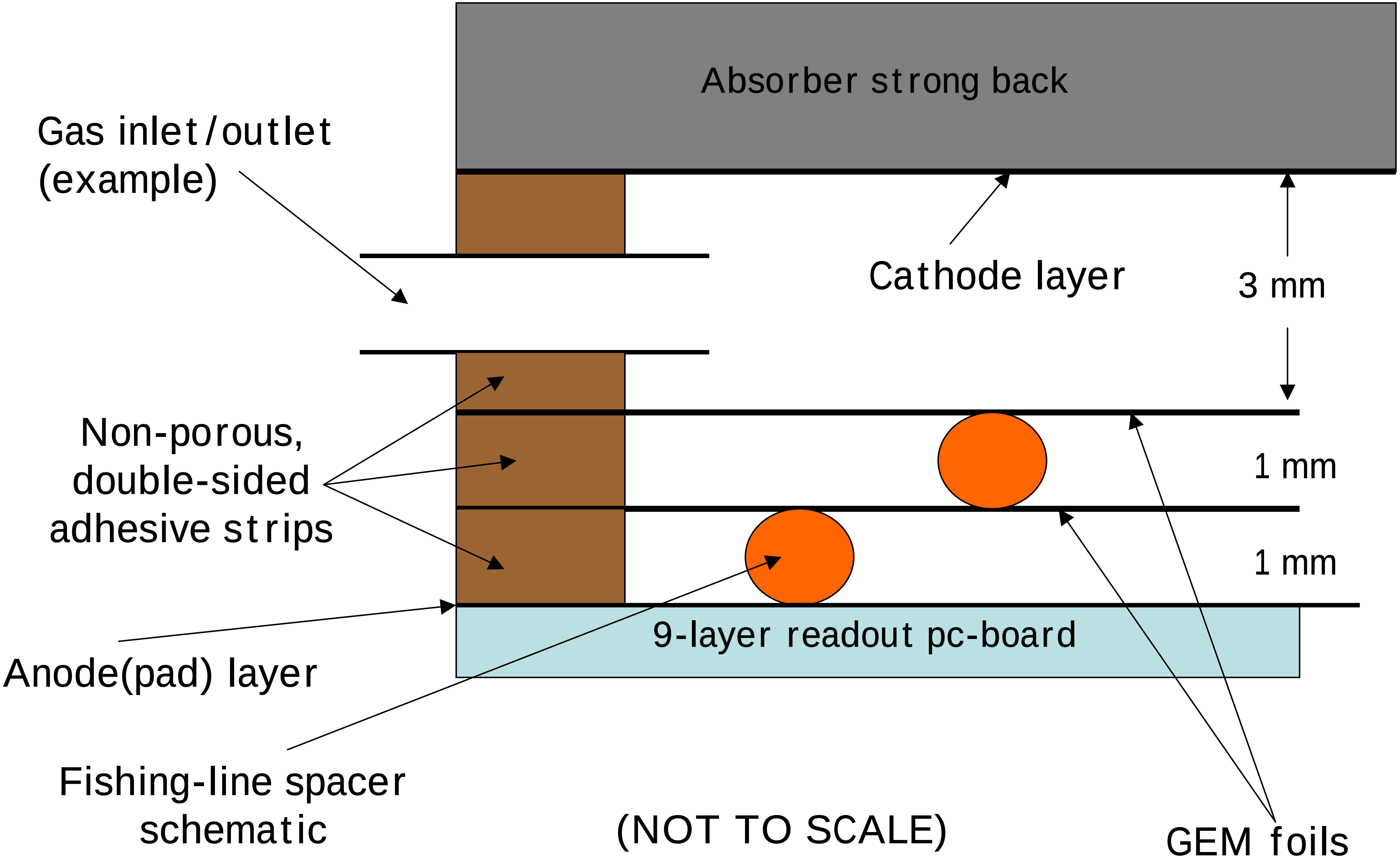
Reliability, operational reqs. , safety, risks

Expect same to be true for new 3M 30cm x 30cm foils



Each active layer is assembled on a thin layer of absorber as a strongback – significantly enhances rigidity and stability.

Development of GEM sensitive layer

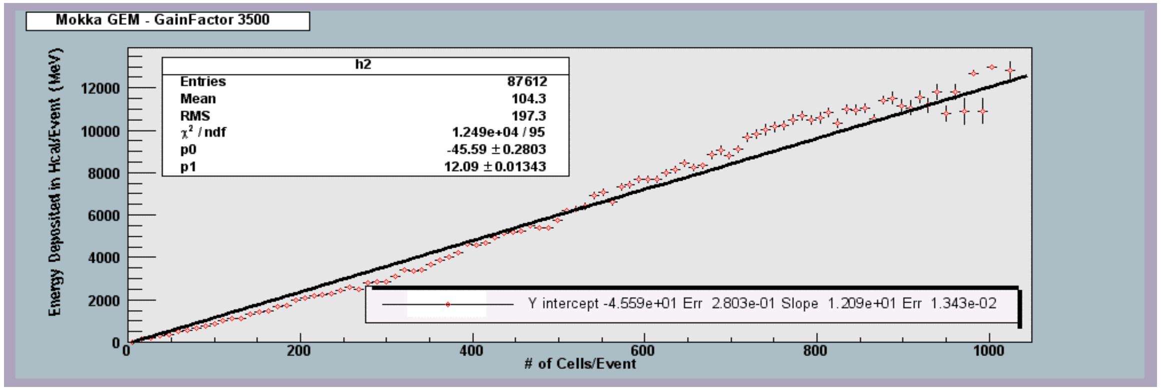


Limitations

Analog+digital

Both can be done (and "semi-digital") but at a cost! Hopefully we would have sufficient confidence in the purely digital approach to NOT need to include analog option from the start!?

This is not just a PFA issue – just using the calorimeter standalone requires a good linearity in the Energy vs. Hits relation.



Limitations

Rate capabilities, occupancy, segmentation: forward region?

Rate: CERN measurements -> > 105 Hz/mm^{-2} (NIM A 470 (2001) 548)

Occupancy: a hit is a hit! …unless semi-digital or analog approach is used.

Segmentation: essentially no limitation.

Forward region – yes!

Compatibility/dependence – other subsystems

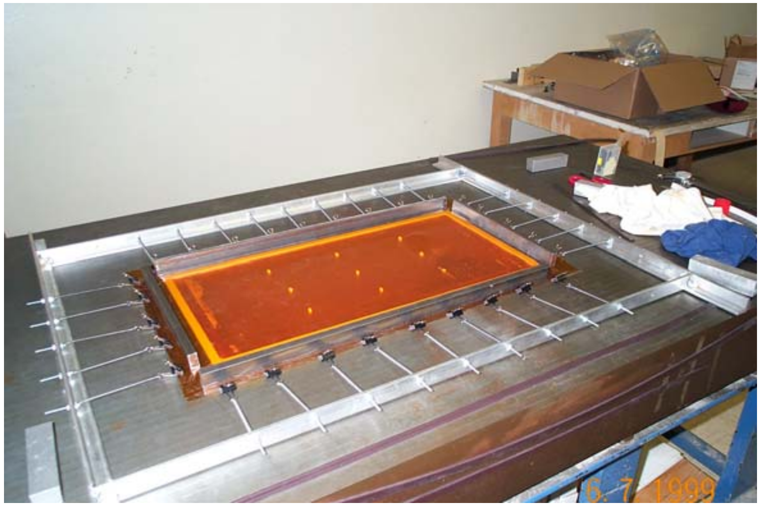
1cm^2 segmentation (or less) good match to SiW ECal segmentation.

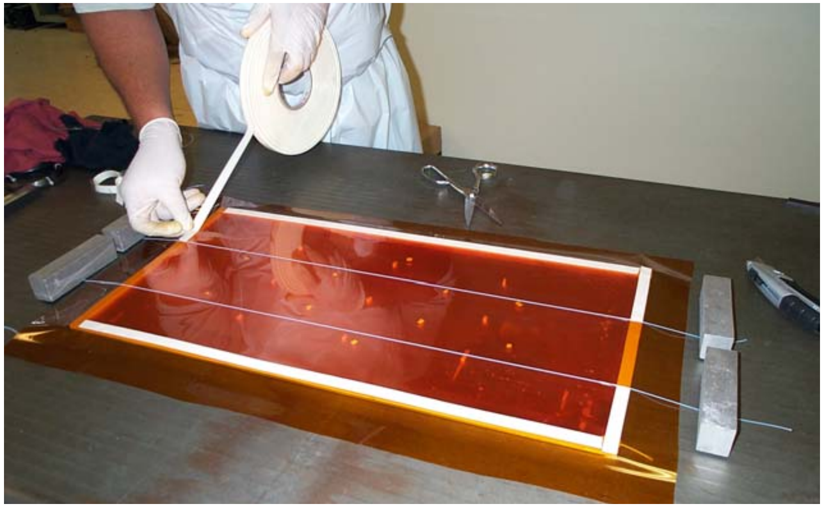
No other particular subsystem issues known at present.

Challenges

Construction/assembly

Developing foil handling/stretching/mounting techniques:





Several approaches to foil spacers, layer wall minimization, ...

Assembly straightforward – should lend itself to automation.

Challenges

Signal collection/routing

Charge collected on anode pads. Thin (~1mm) readout layer.

Regional ASIC's with analog and digital functionalities – care with design. This aspect shared with RPC and based on work at ANL/FNAL.

Calibration

Monitor and maintain threshold level for each channel for definition of a digital hit (signal above threshold). Monitor rate of hits/channel.

Electronics calibration/stability – pulser/DAC system.

Costs

Minimize foil costs. Discussions with 3M indicate a large cost reduction for high volume. Keep to <\$1000/m^2. Foil cost would be 5% of HCal cost.

Conclusions

- GEM technology offers an attractive solution to digital hadron calorimetry.

- Flexible configuration, highly segmentable.

- Fast signals.

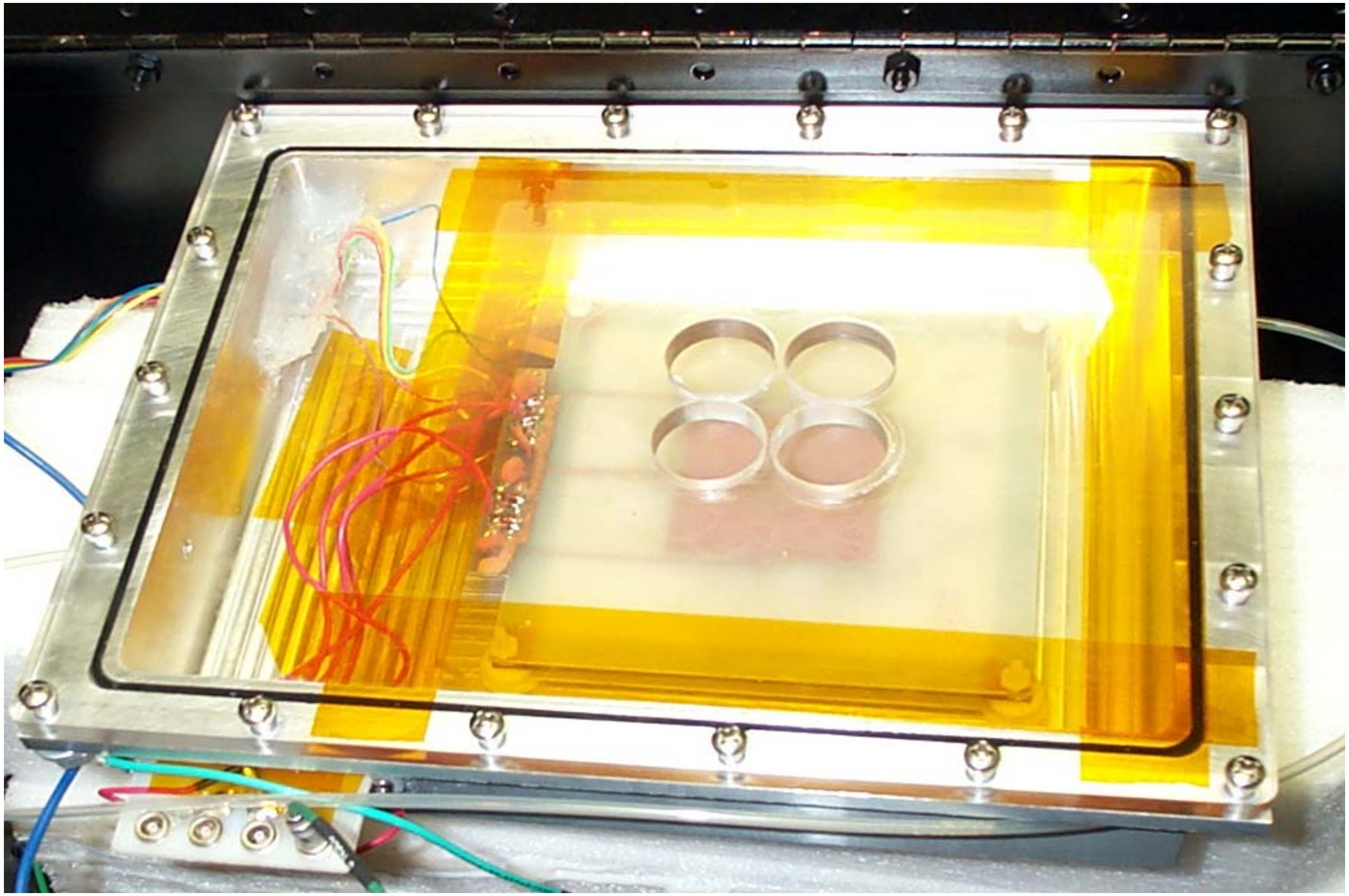
- Stable operation.

- Relatively low HV operation.

- Safe gas mixture.

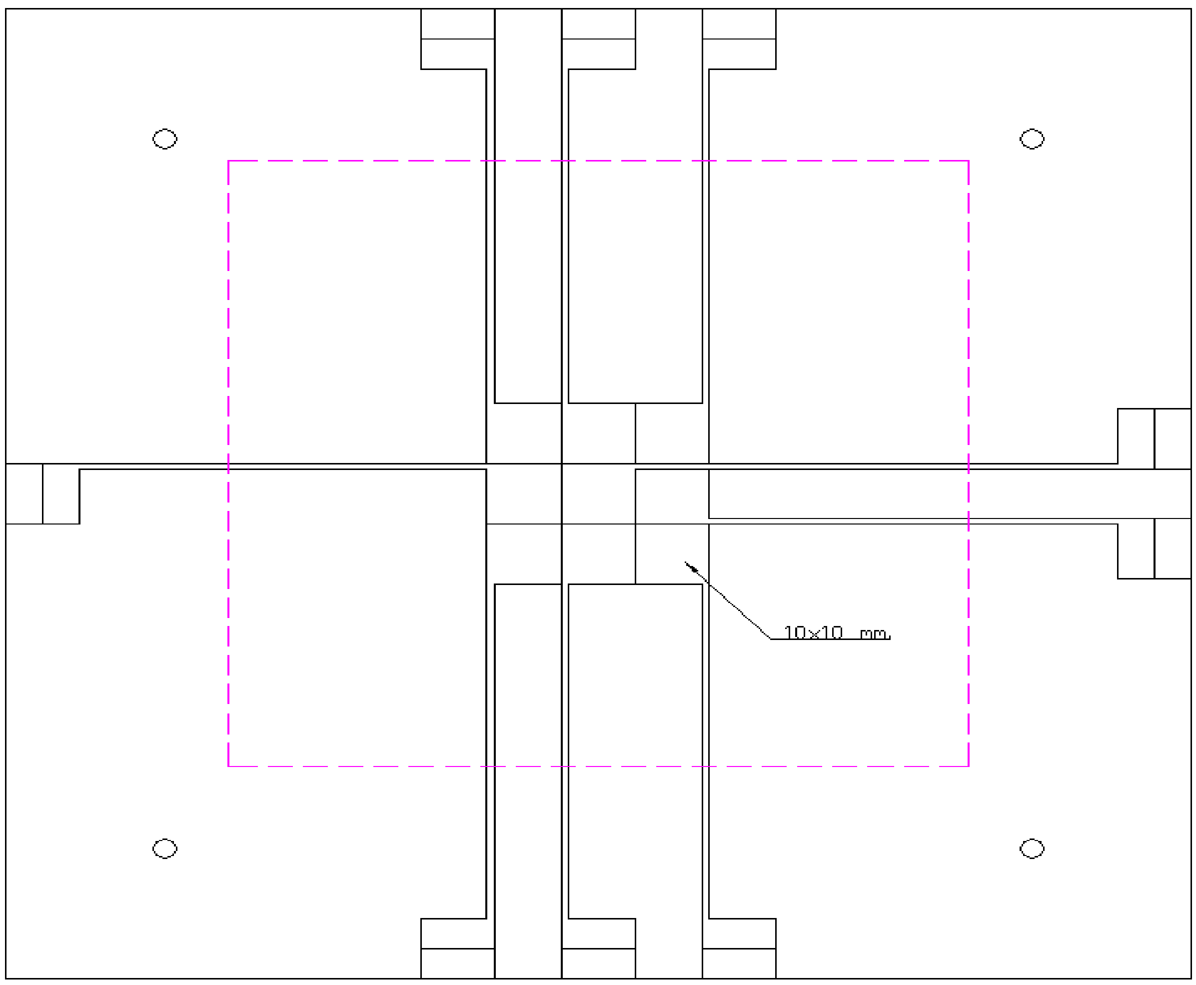
- Shared GEM development with other applications.

UTA GEM - initial prototype



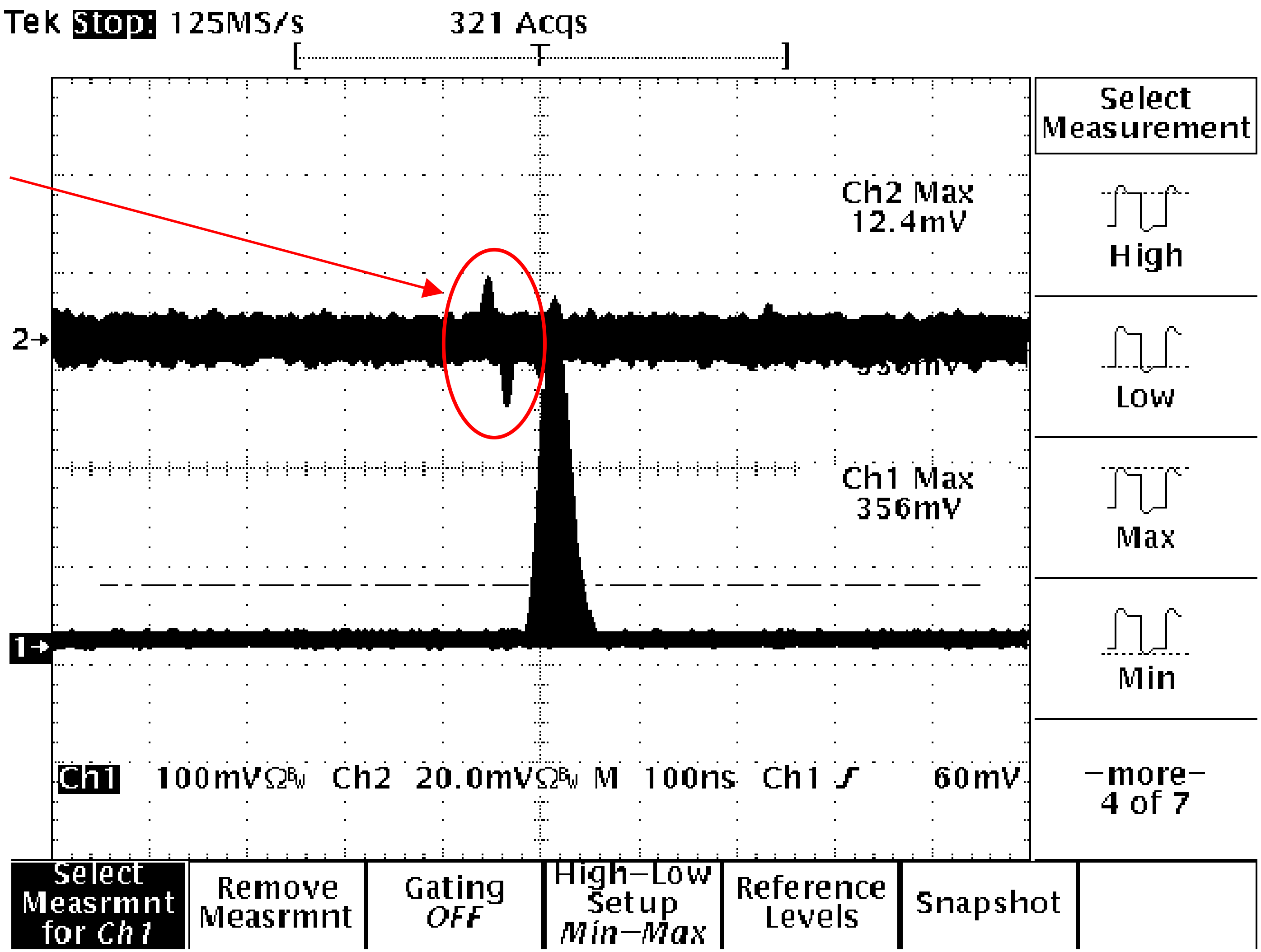
UTA GEM-based Digital Calorimeter Prototype

Nine Cell GEM Prototype Readout

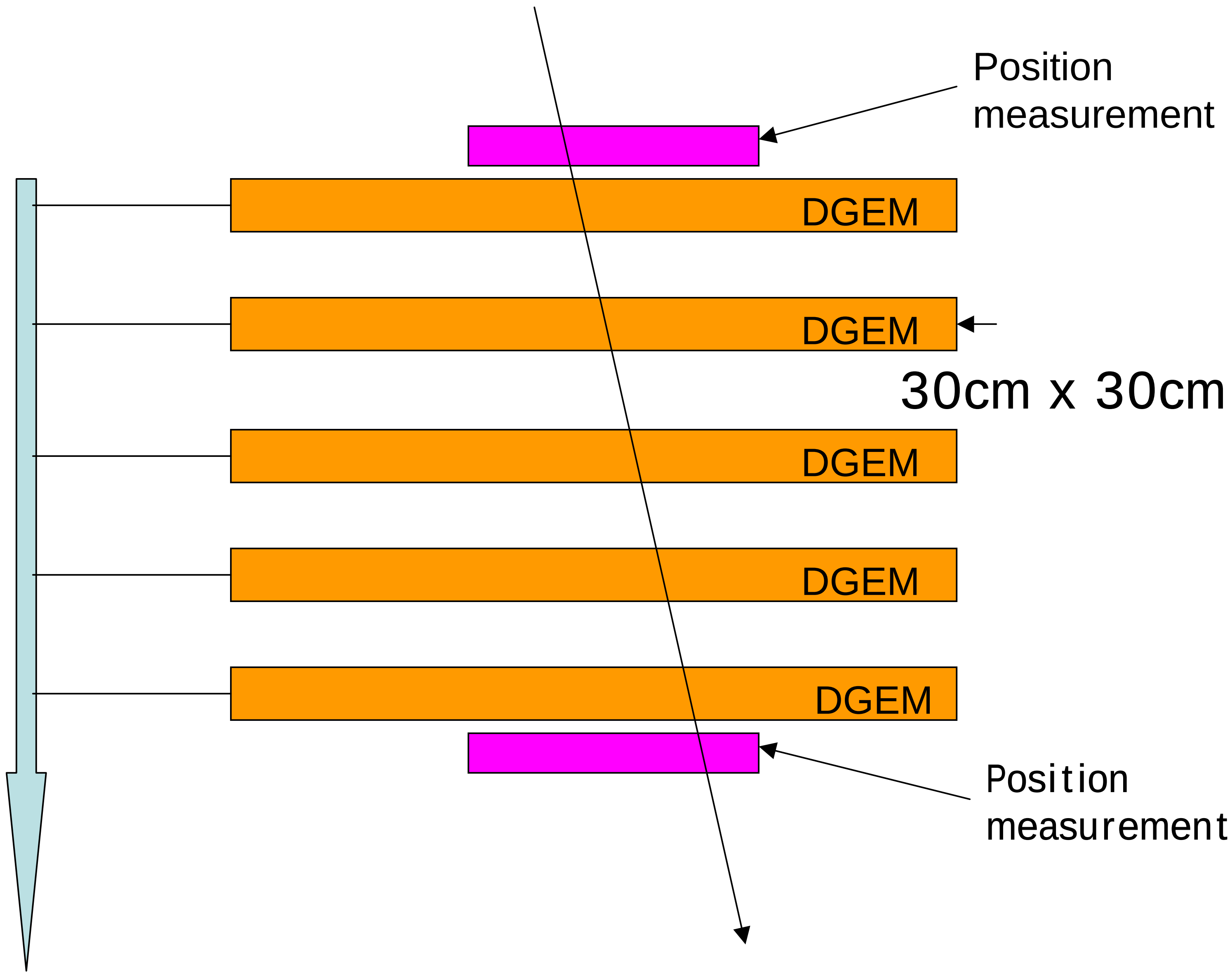


Typical crosstalk signal (prototype)

Typical
“up/down”
structure
of
crosstalk

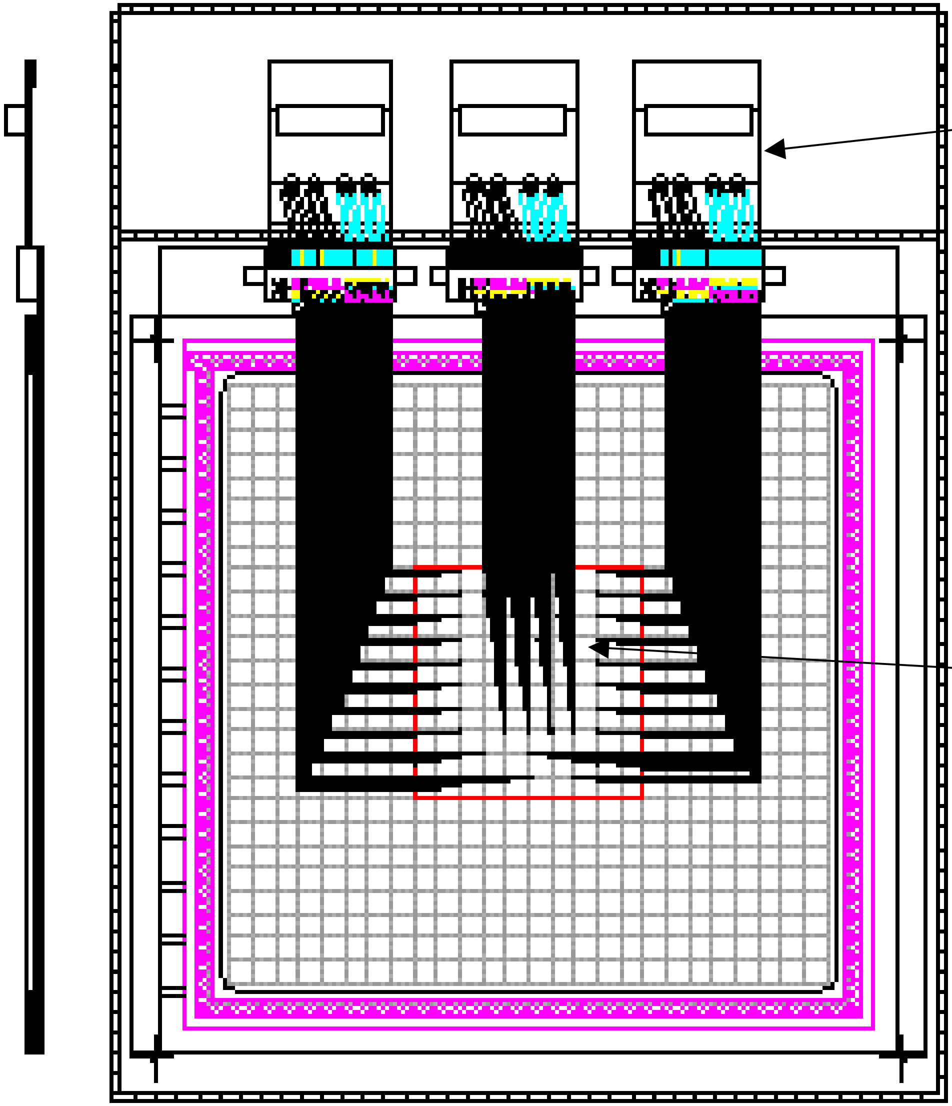


Cosmic stack using Double GEM counters



Readout system design being studied by U.Washington - will use BES muon system electronics from Tsinghua University – IHEP(Beijing)

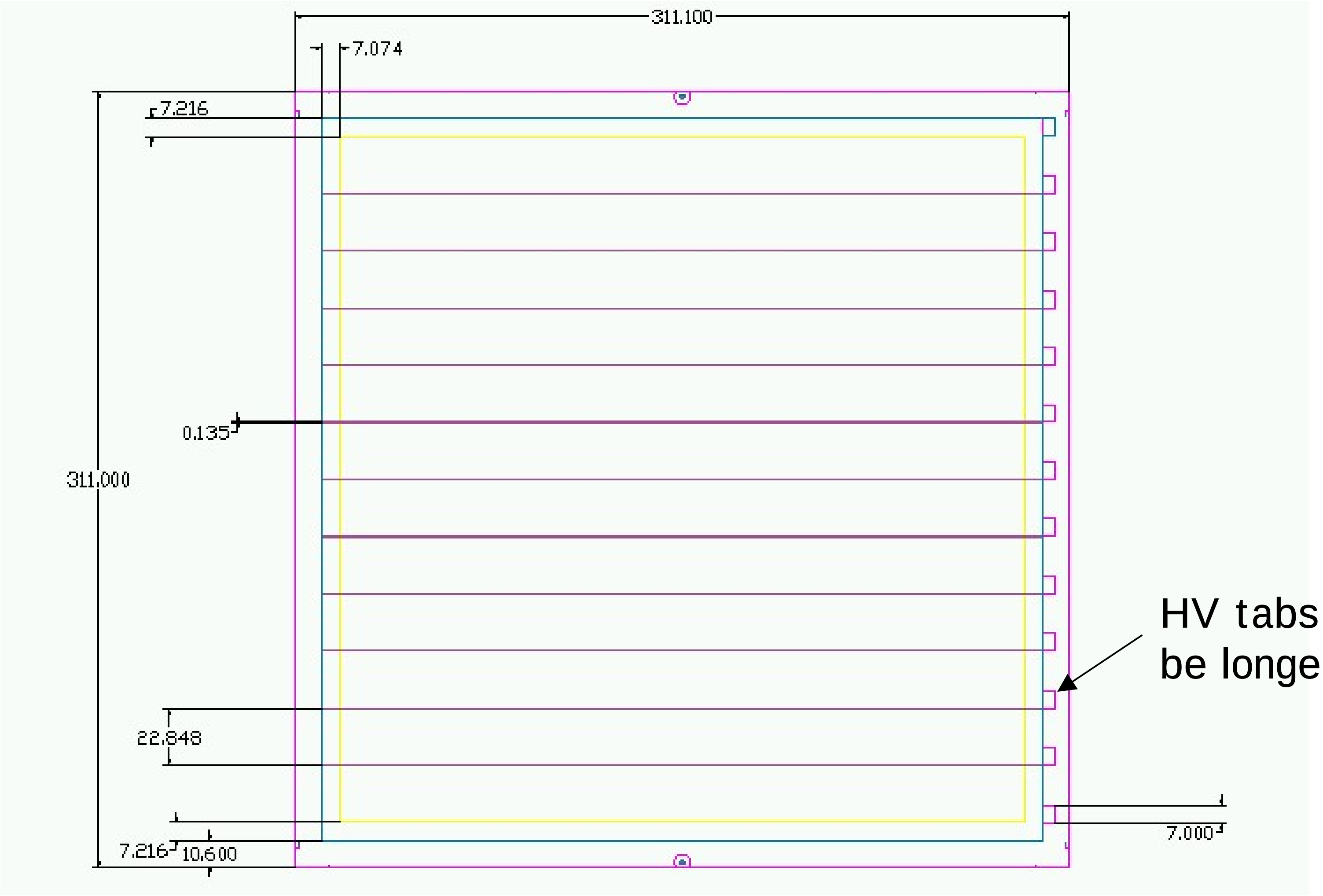
305mm x 305mm layer



Trace edge connector -> Fermilab 32 ch board – new production by Fermilab PPD Electronics

(10 x 10) – 4 = 96 pad active area

3M GEM foil design



- Now in tooling phase
- Delivery in ~5 weeks

GEM-DHCAL Issues

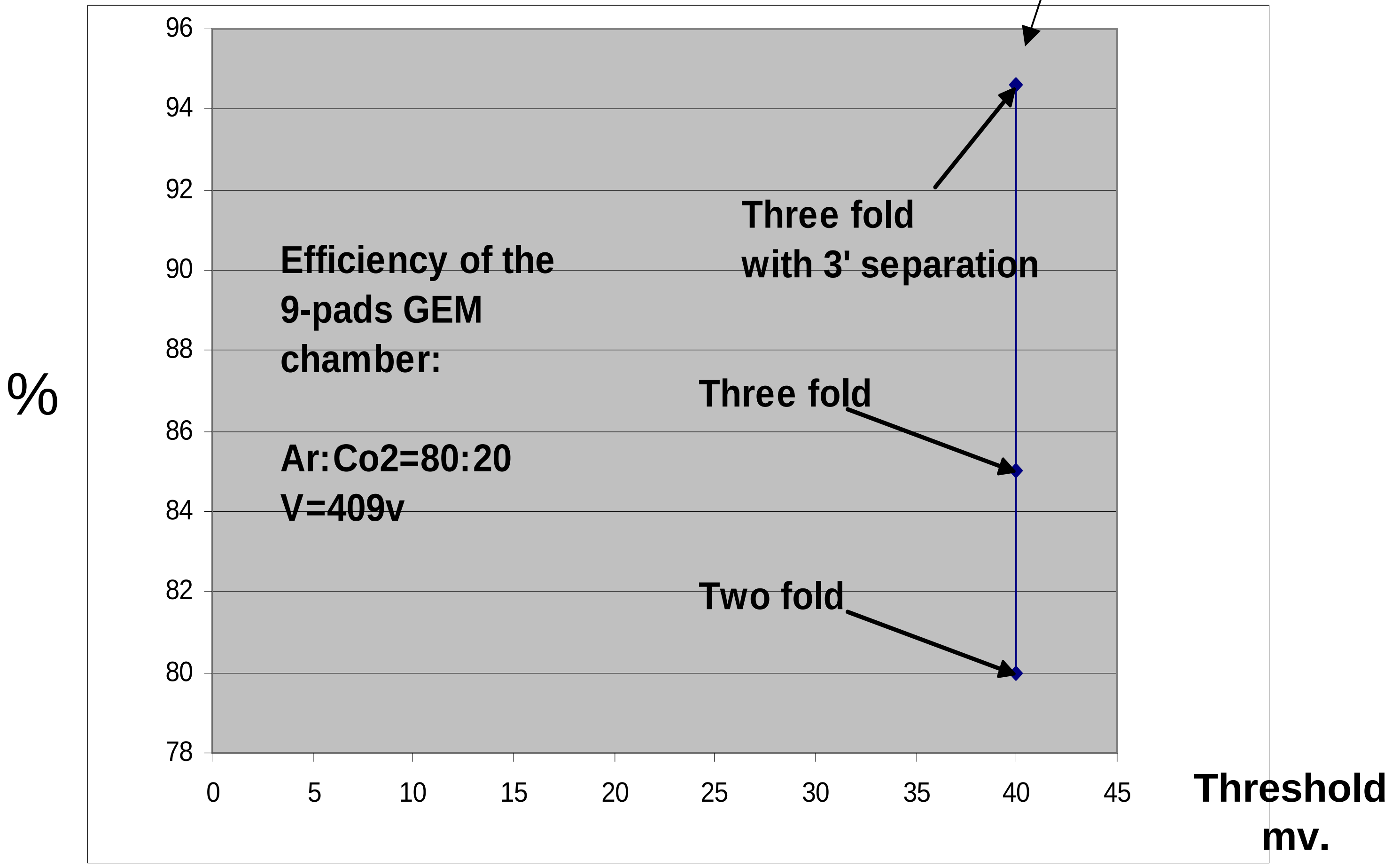
- Minimum cell size

Currently 1x1 cm2, can be much smaller if needed(?), option for some “high resolution” layers through HCal?

GEM efficiency measurement using cosmic rays

Eff. = 94.6%

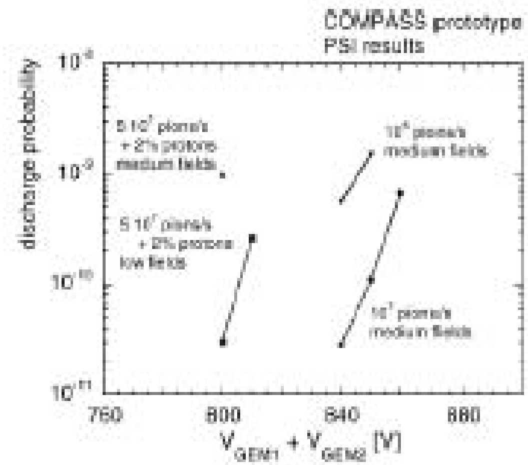
after ensuring that cosmics must hit a pad

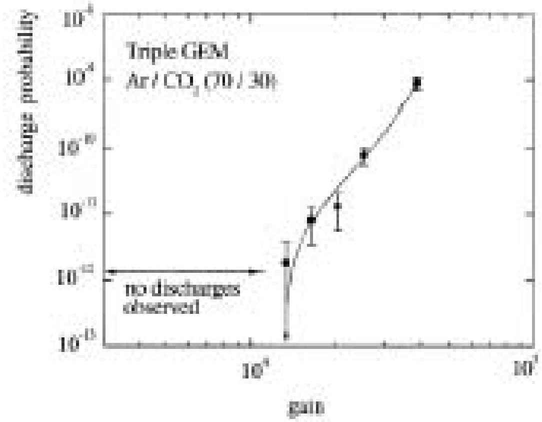


GEM Discharge Probability

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

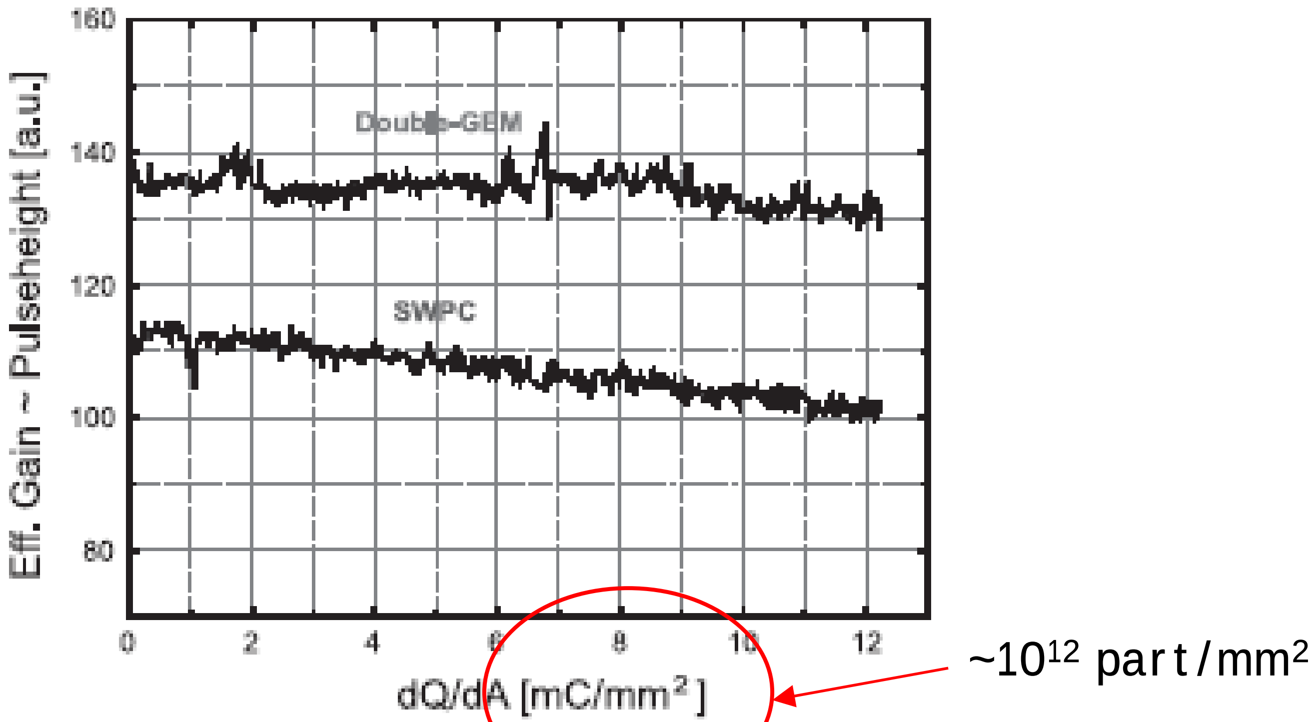


Fig. 3. Previous aging measurement of a double-GEM detector with Ar–CO_2 (70:30): effective gain versus accumulated charge $\mathrm{d}Q/\mathrm{d}A$.

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

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.

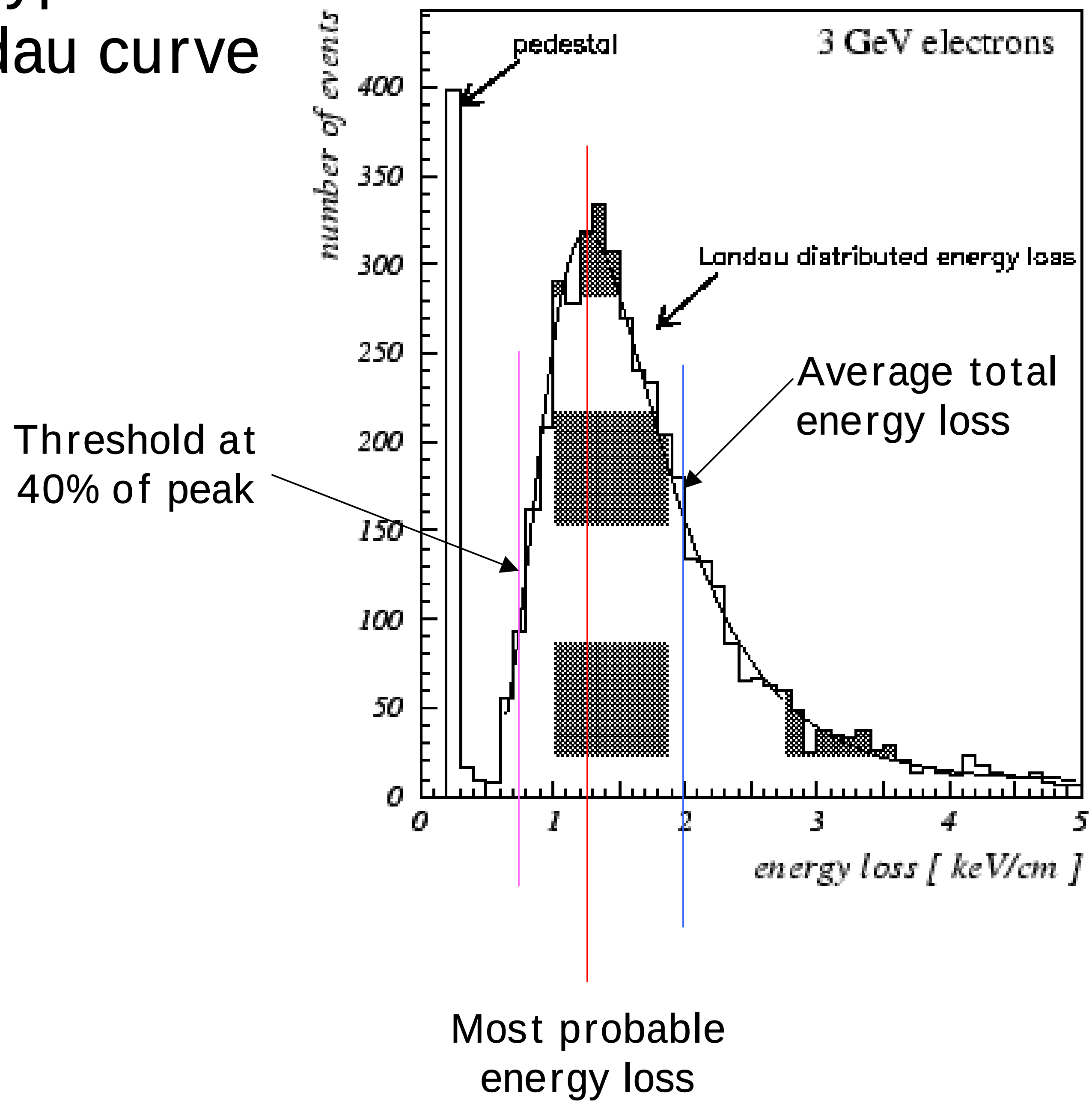
Characteristics of the Landau energy loss distribution

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.

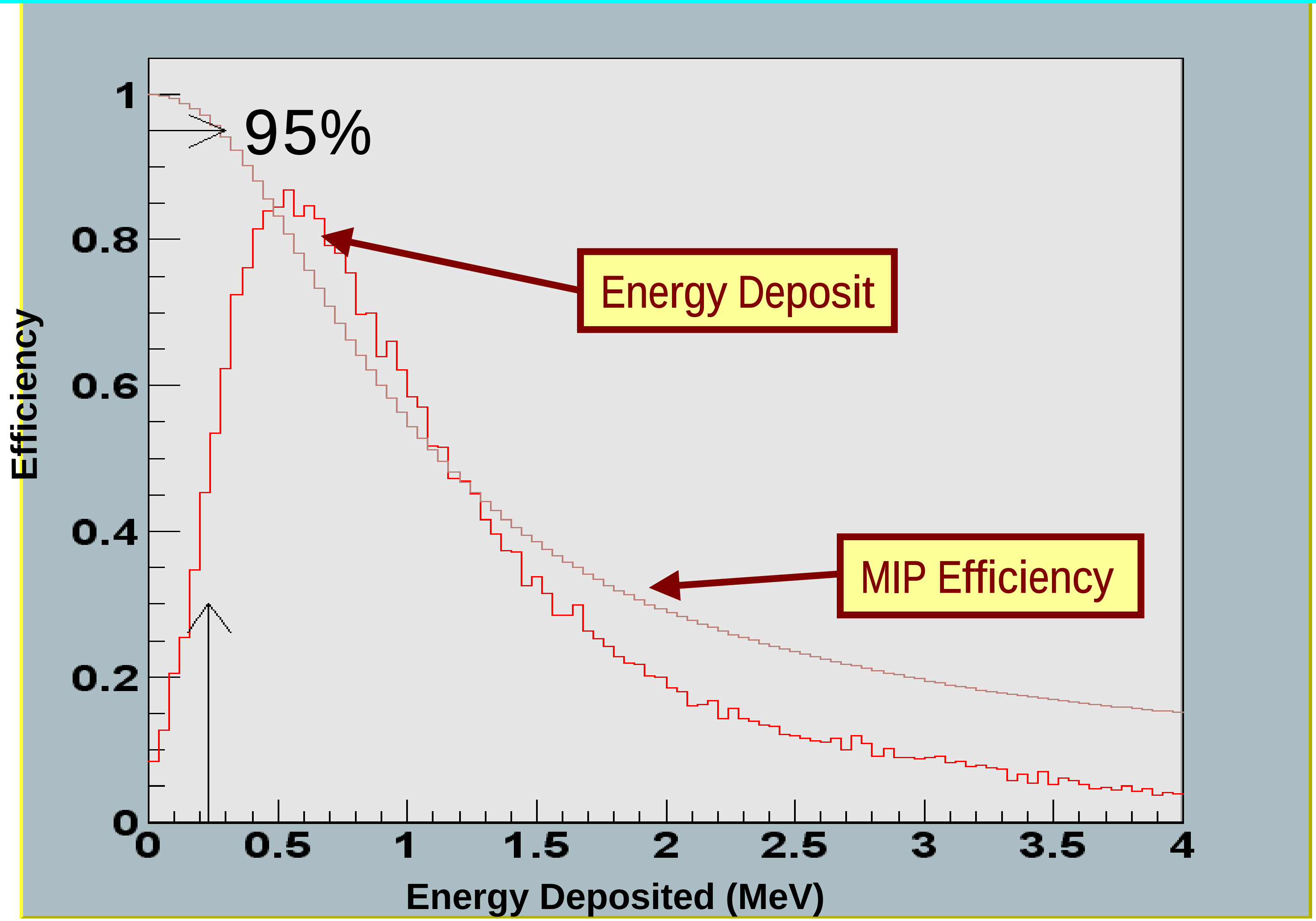
The average total energy loss occurs at about 50% of the peak (on the upper side). This is the point we associate with the quantity n_T.

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

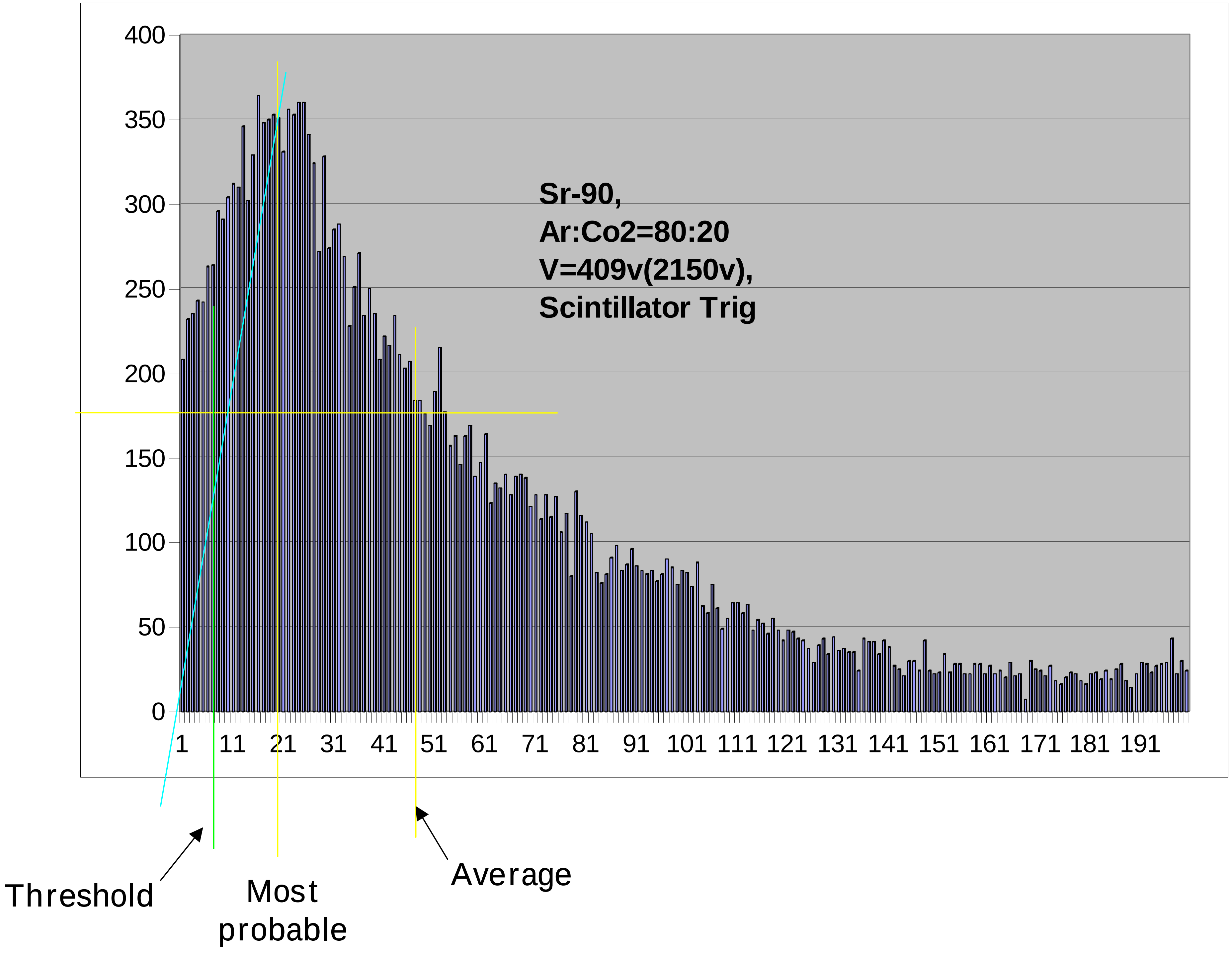
Looking at the following slide for Ar/CO_2 80/20 we see that the average total energy loss occurs at a signal size that is ~5x that for a minimum signal at 40% of the peak height on the low side of the peak.

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 x 3,500 x 3 x 1.6 x 10^{-19}

= 10 fC



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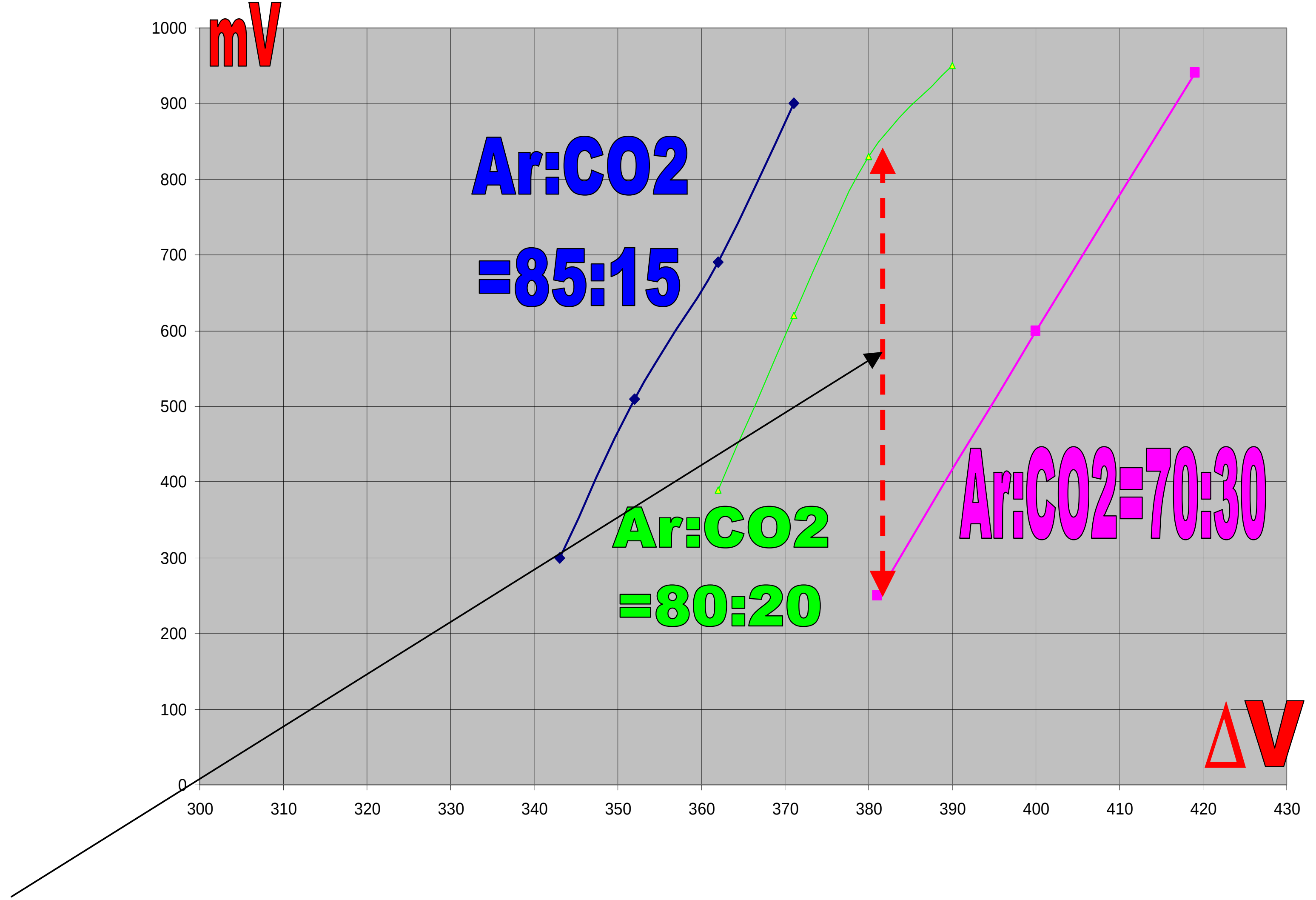
121
131
141
151
161
171
181
191
Sr-90,
Ar:Co2=80:20
V=409v(2150v),
Scintillator Trig
Threshold
Most probable
Average



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

Calculating our GEM signal levels

We also expect:

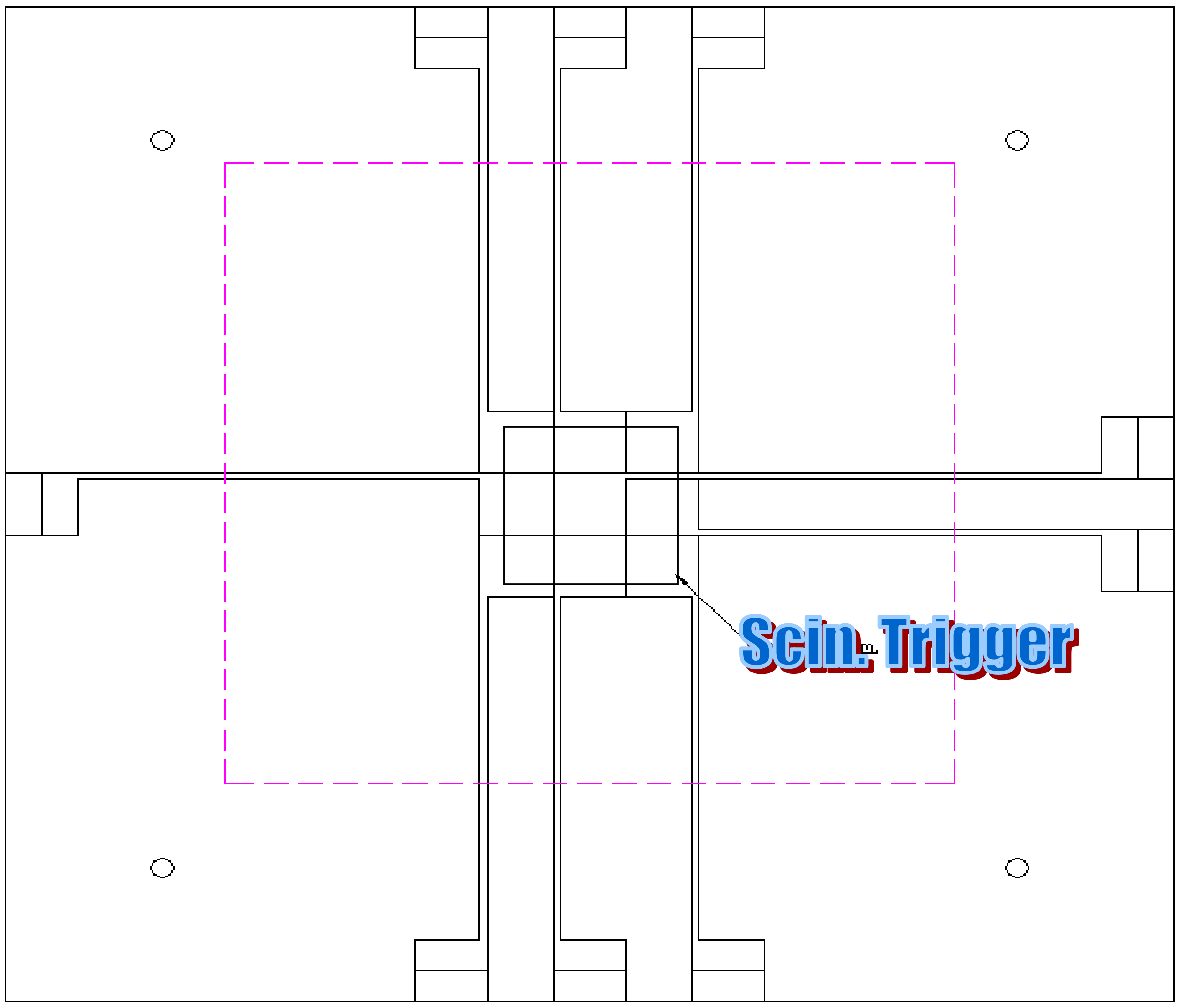
Most probable signal size ~20 fC

Average signal size ~50fC

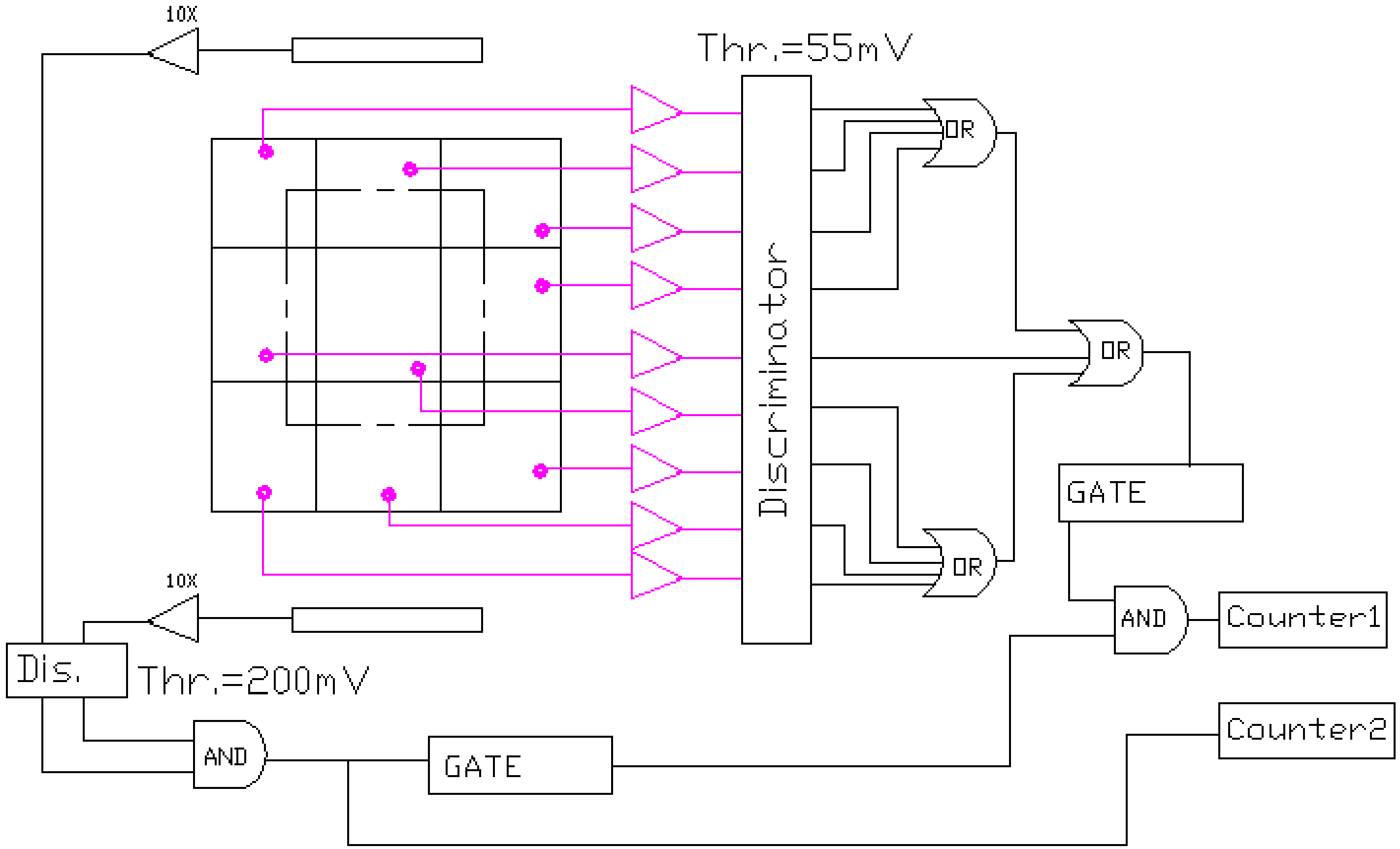
These estimates are essential input to the circuit designers for the RPC/GEM ASIC front-end readout.

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

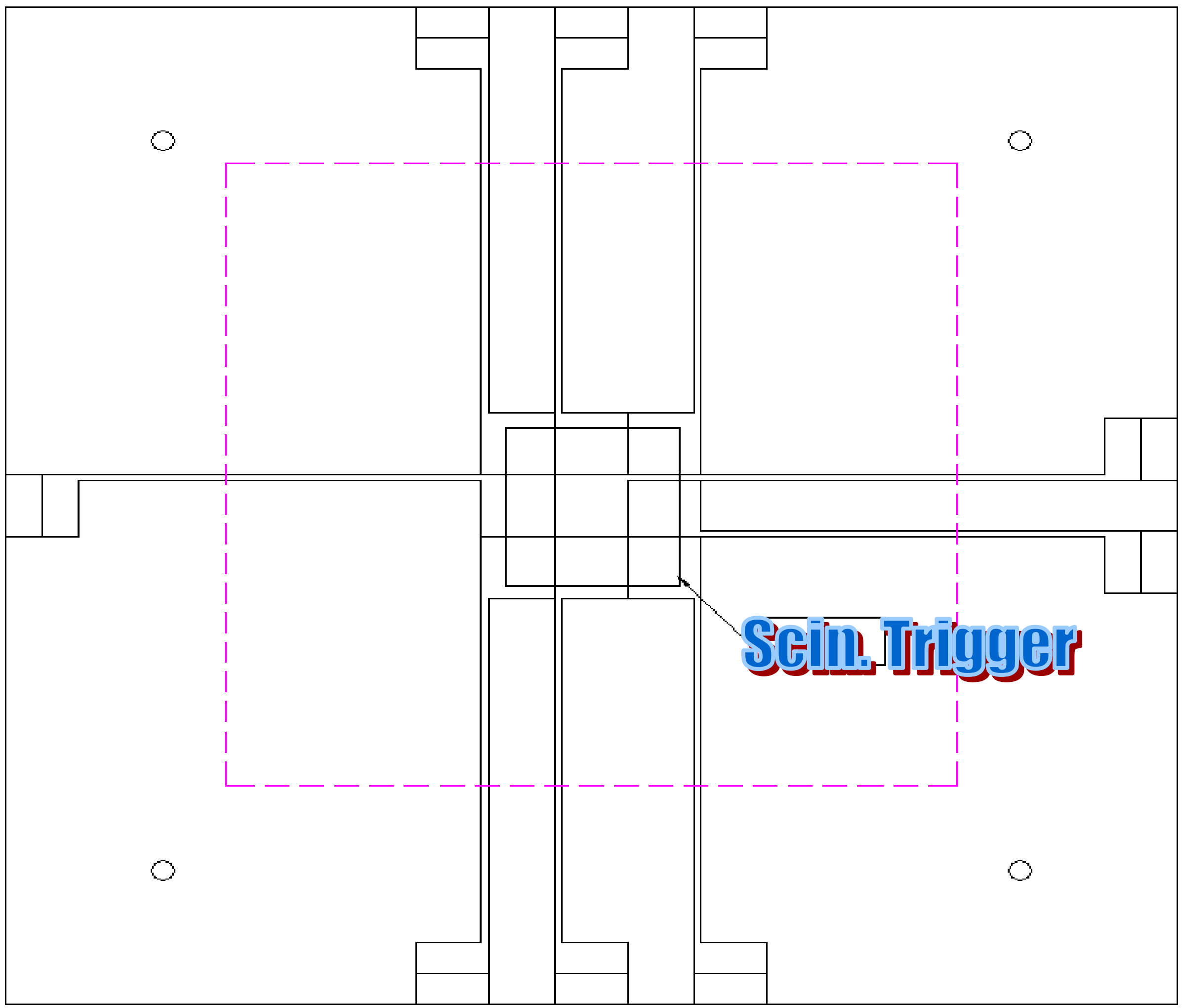
GEM Efficiency Measurement



Setup for 9-pad GEM efficiency measurement



GEM Multiplicity Measurements



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

New collaborators(1):

Visit to Tsinghua University, IHEP Beijing

Developing interest in China for Linear Collider

Detector groups at Tsinghua and IHEP building first GEM prototypes – learning curve, but great facilities and detector expertise.

-> Tsinghua will receive 3M 30cm x 30cm foils and build prototype for comparison with UTA (and others)

-> Tsinghua/IHEP investigating local GEM foil production.

-> Tsinghua has readout system for BES-muon that will work for next GEM/DHCAL prototype (30cm x 30cm), using Fermilab amplifier cards. U.Washington/Tsinghua

-> Use beam at IHEP for GEM prototype tests?

New collaborators(2): Korean Groups

Changwon National University

Large collaboration of Physics and Engineering faculty;generic GEM research and test beam work at KAERI.

Korean Atomic Energy Research Institute

Five years of GEM research for radiation detectors. Will be used for characterization (using test beam) of our large GEM detectors.

Proposals submitted:

DGEM fabrication+characterization $100K, 2 years, to KST.

GEM applications (Portable Rad. Det. + TEM) $300K, 3 years, to KST.

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