Status of GEM-based Digital Hadron Calorimetry

Snowmass Meeting

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

Overview

- GEM/DHCAL basics
- Example measurements (efficiency, multiplicity)
- Current project – 30 x 30 cm^2 area chambers
- New 30 x 30 cm^2 GEM foils from 3M
- New collaborators
- Next step: 1m^3 prototype

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(?)

- Fast response/recovery for forward region.

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

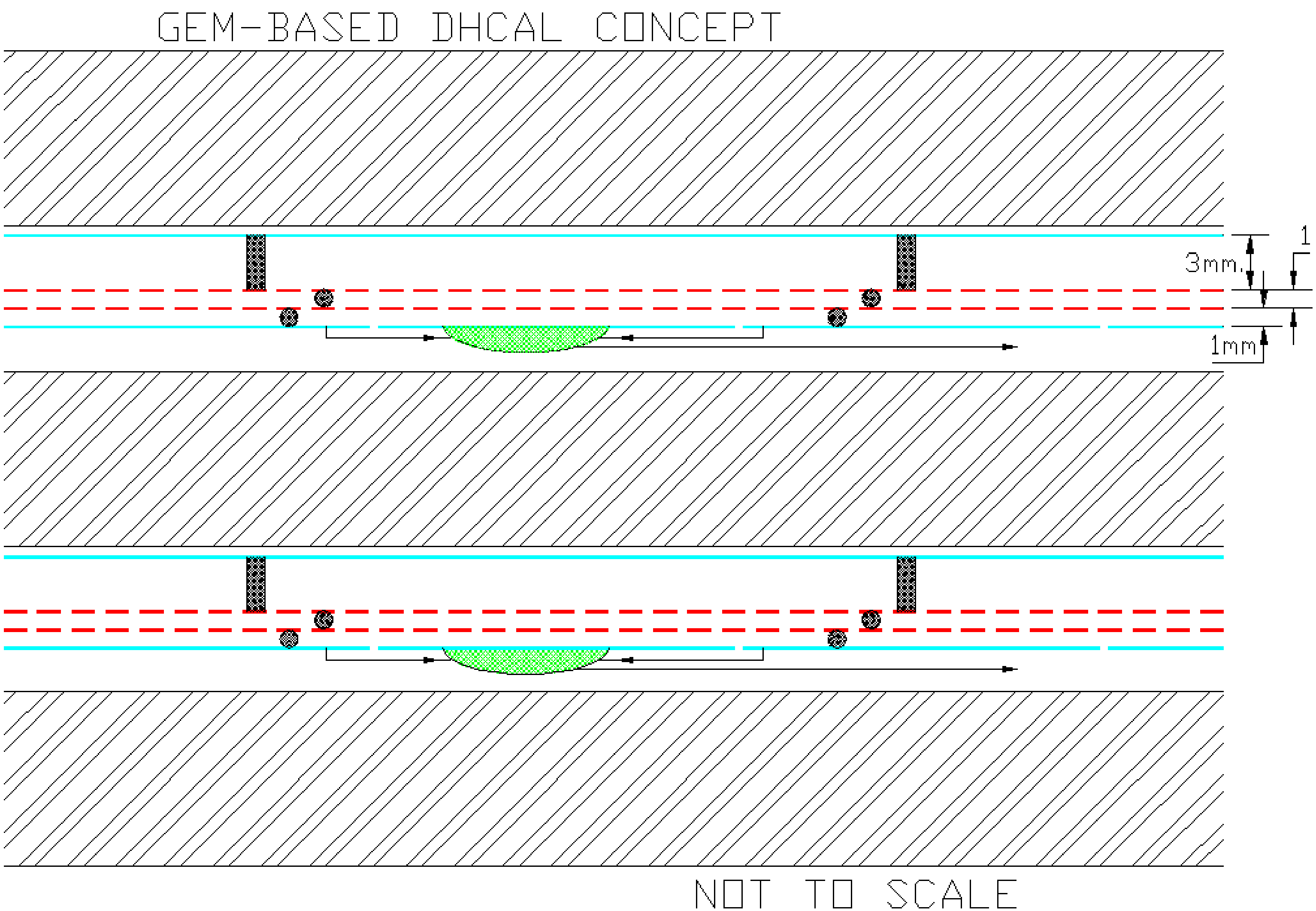
- Operates at modest voltages ~400V/GEM

- 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

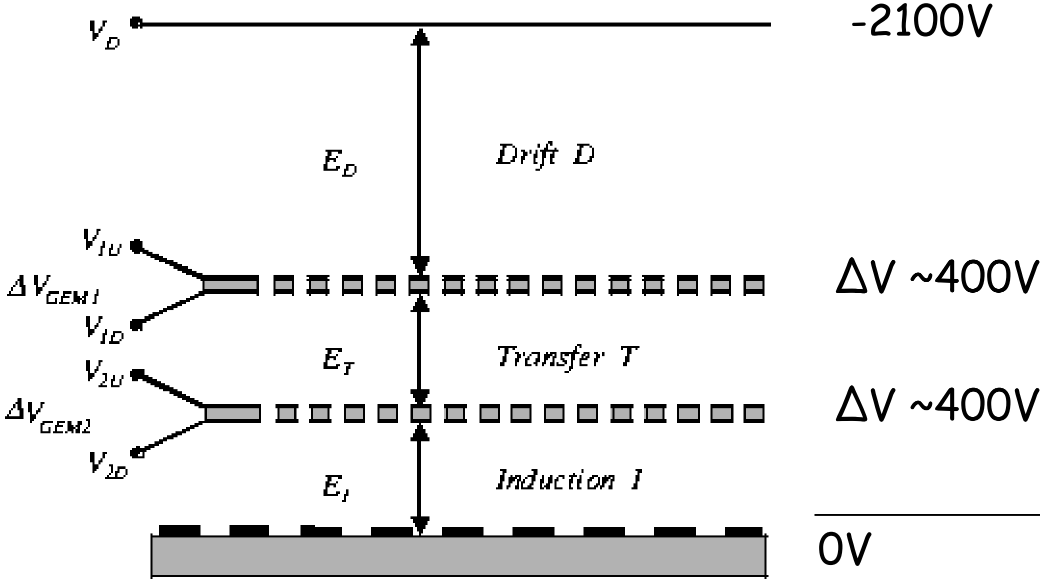
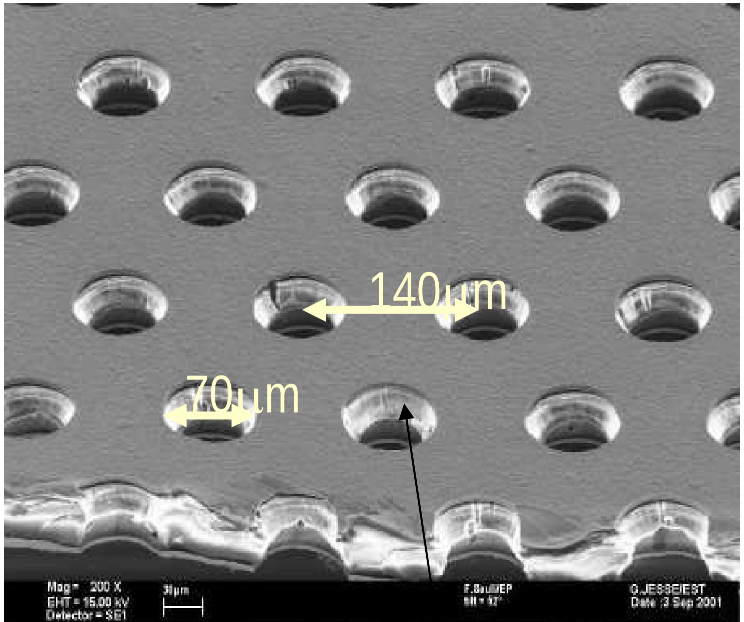


Fig. 1: Schematics of a double-GEM detector.

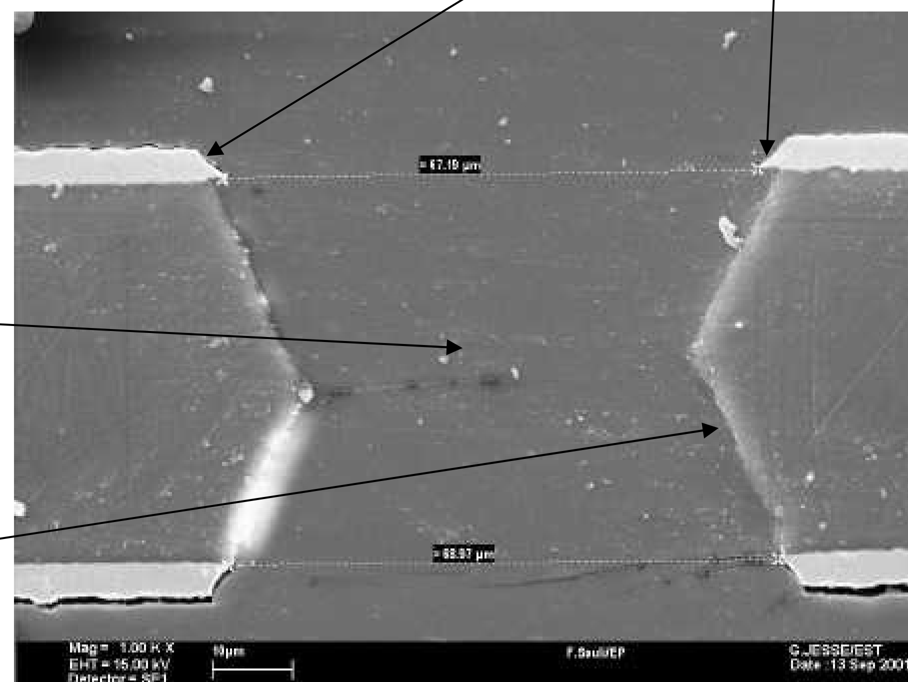
GEM – production



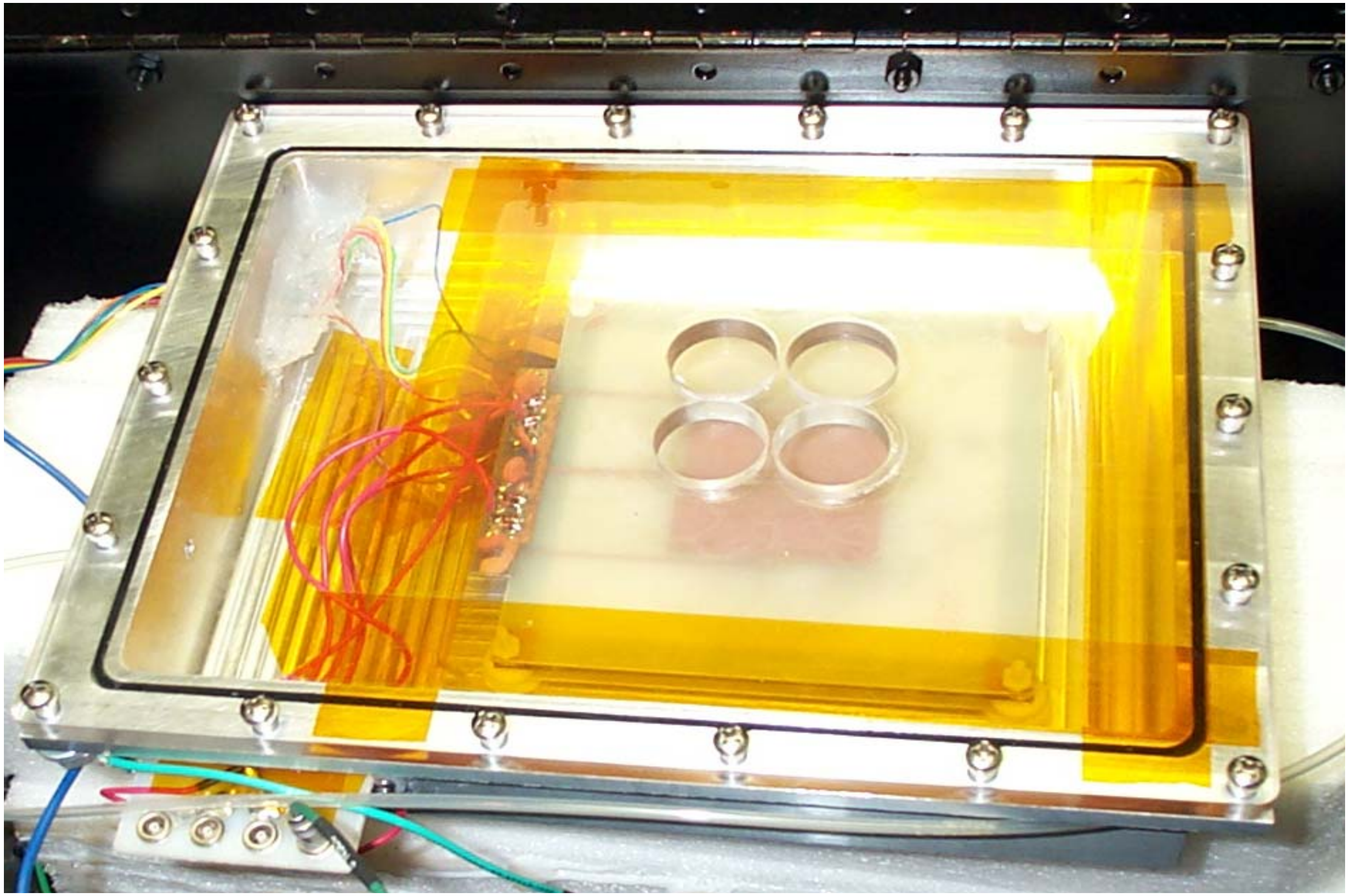
Copper edges

Hole profile

Exposed kapton

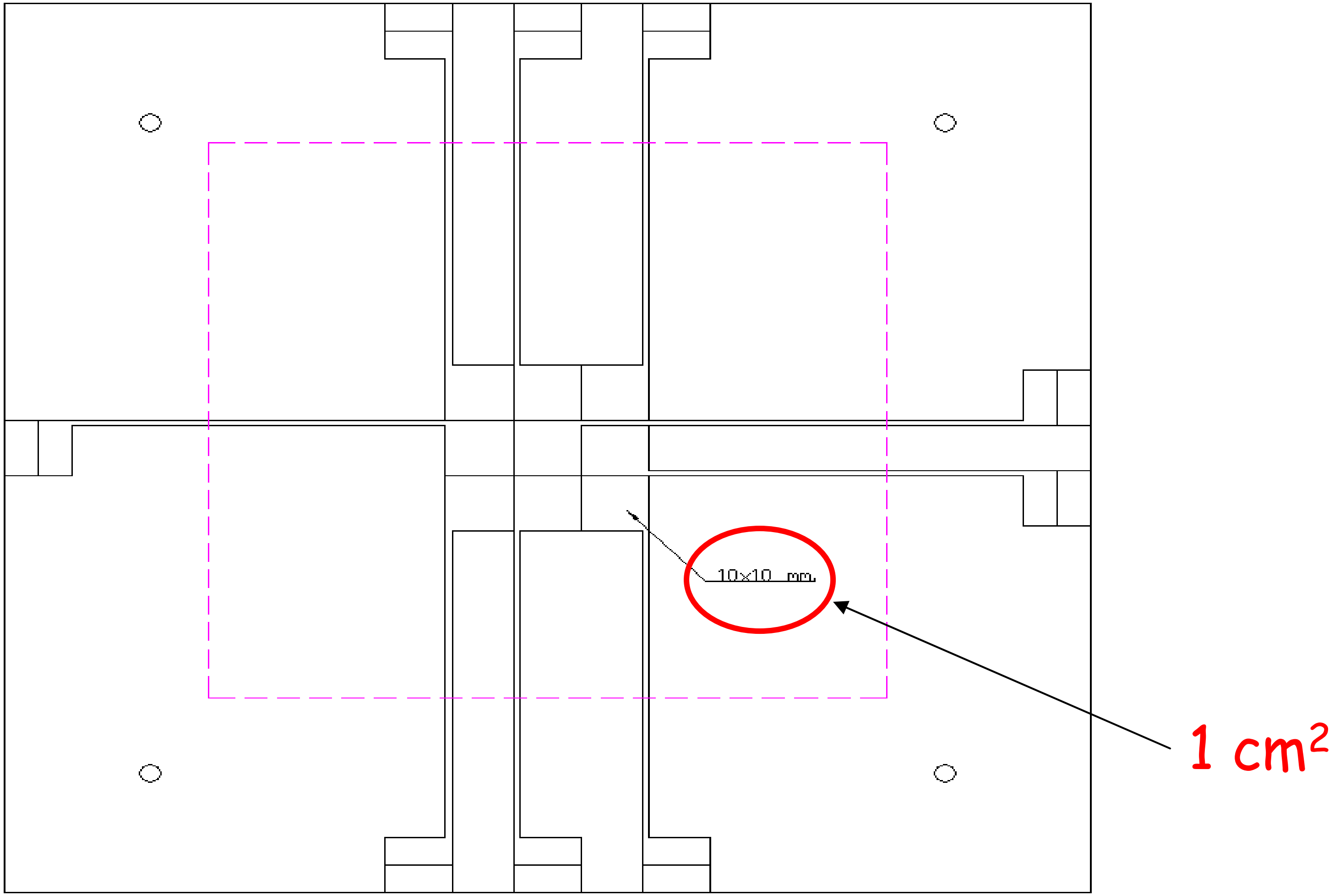


UTA GEM - initial prototype

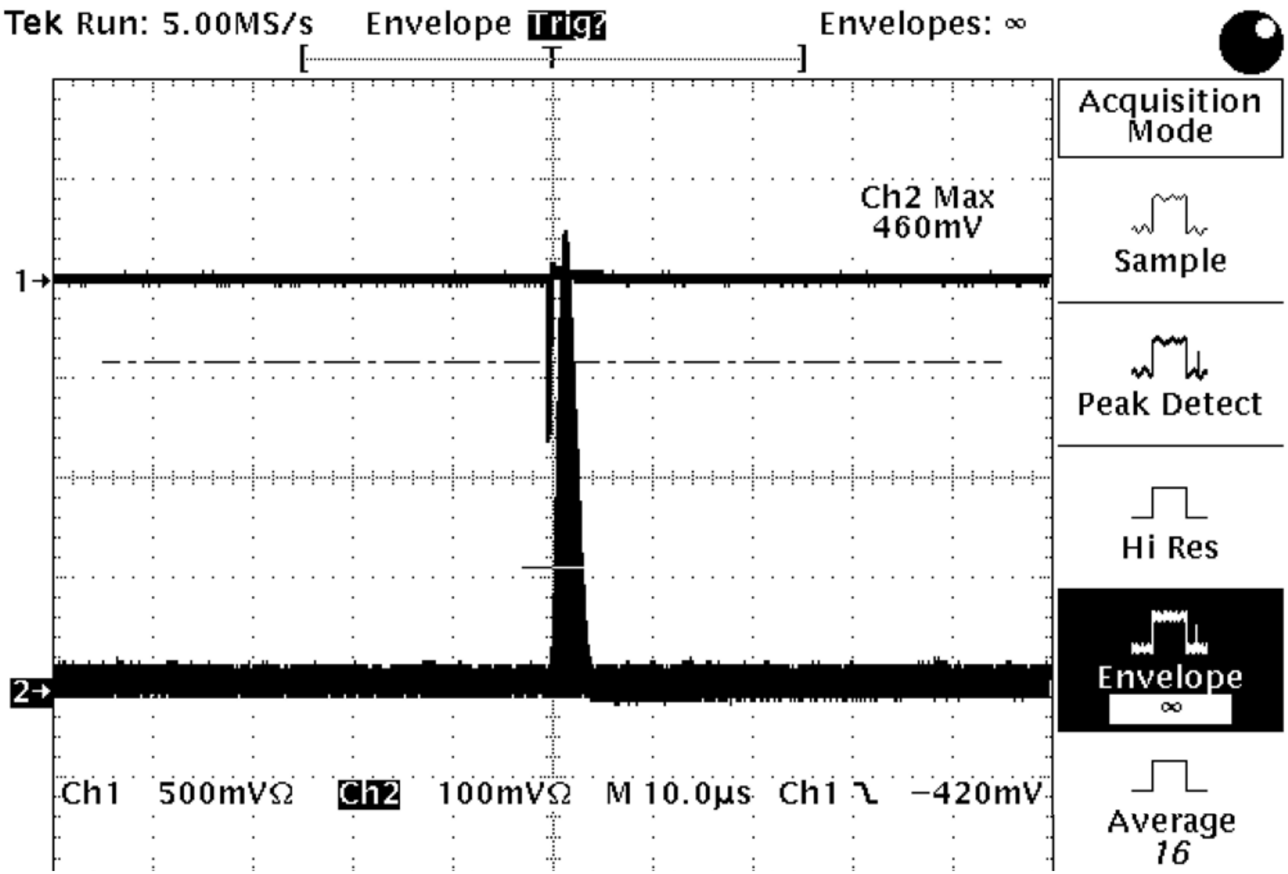


UTA GEM-based Digital Calorimeter Prototype

Nine Cell GEM Prototype Readout



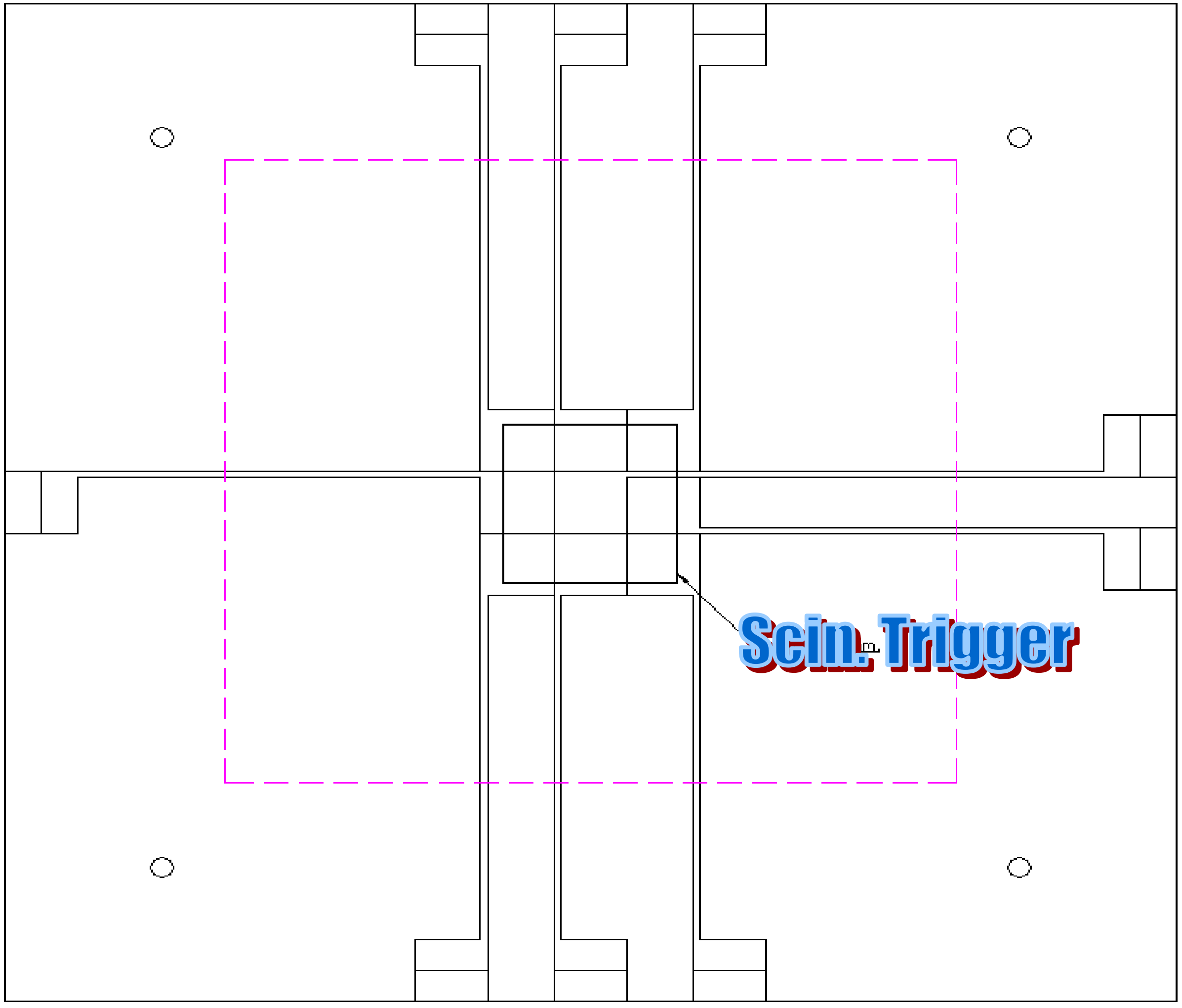
UTA GEM Calorimeter prototype - typical signal



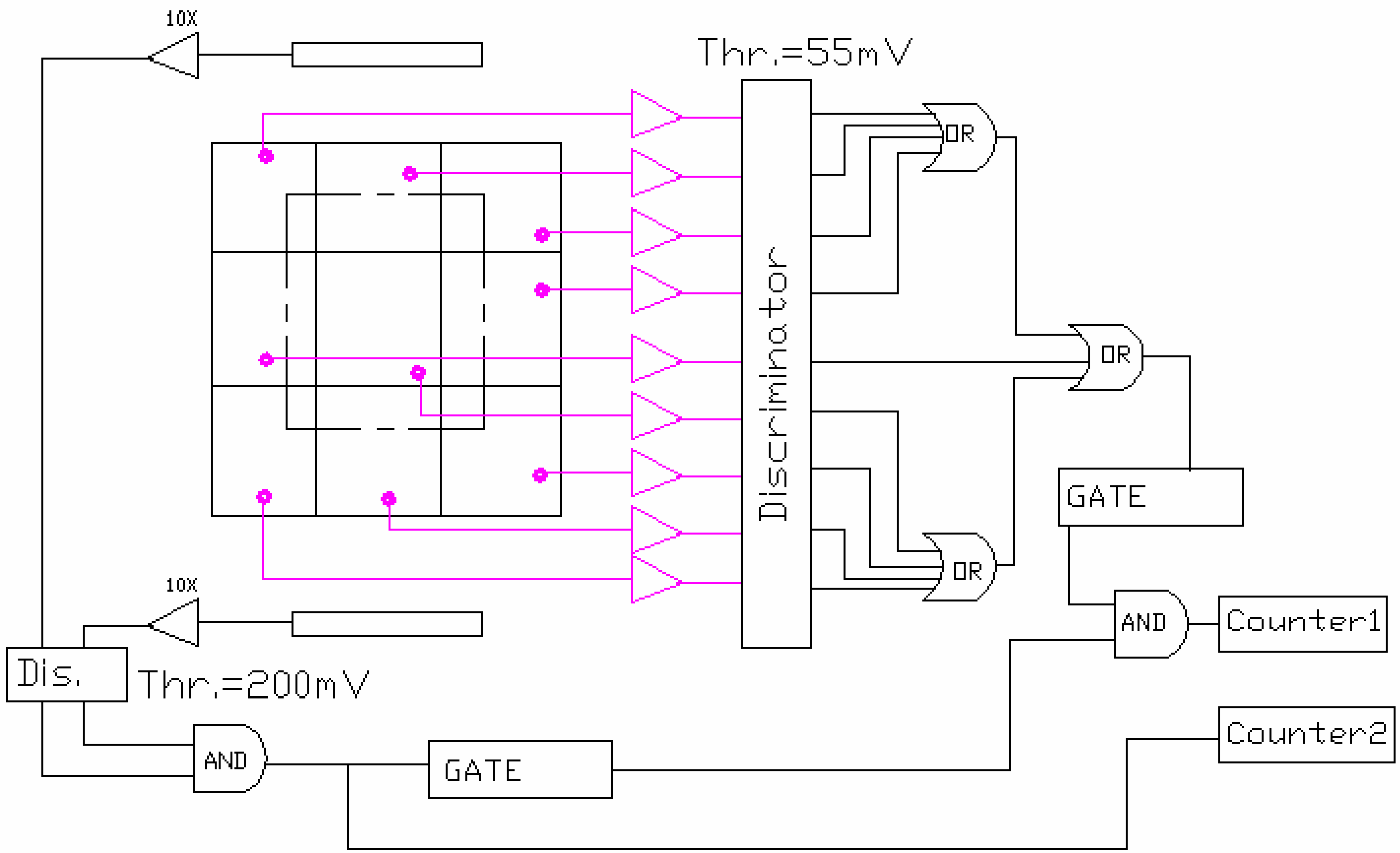
Single cosmic event: upper = trigger,

lower = preamp output

GEM Efficiency Measurement



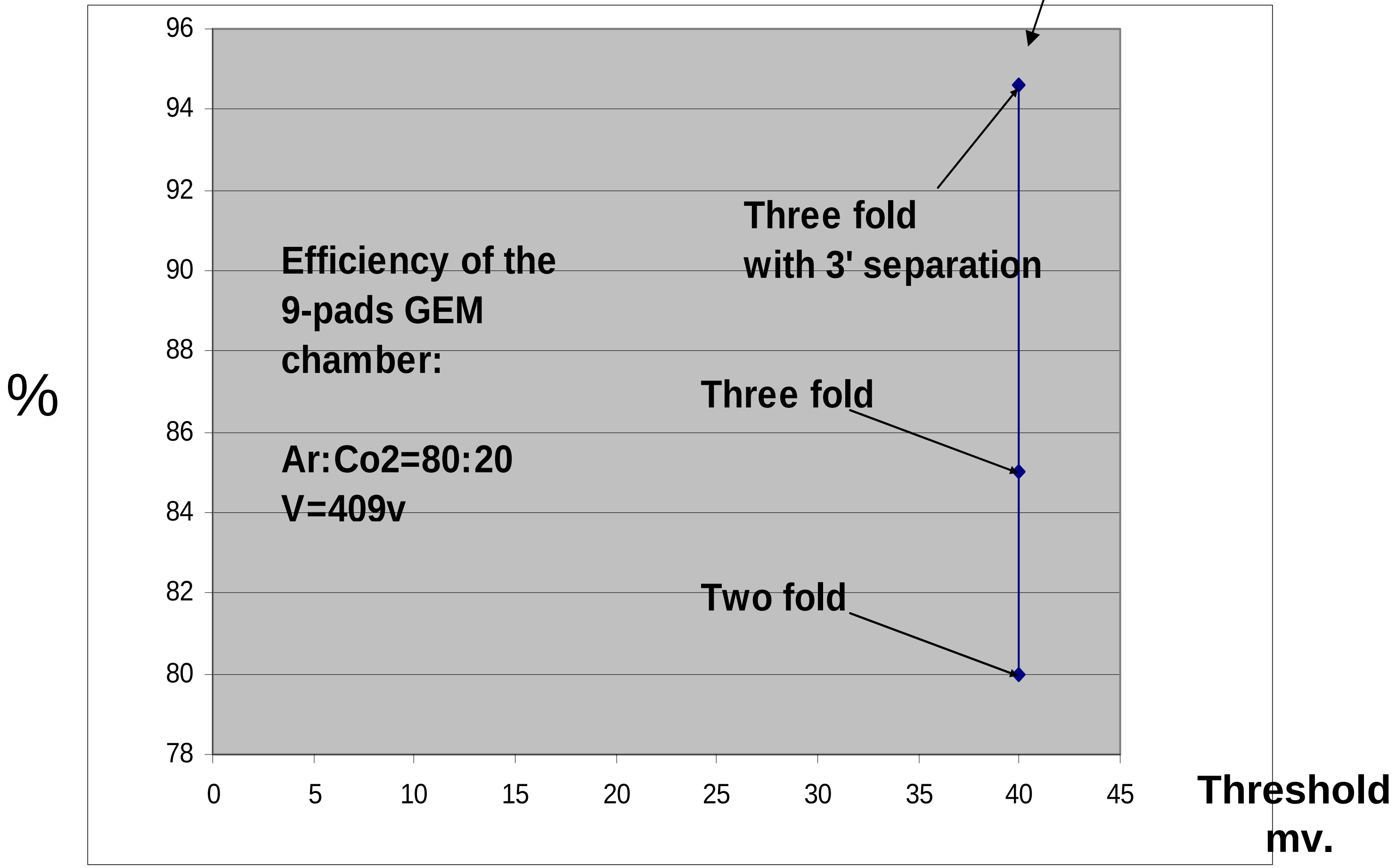
Setup for 9-pad GEM efficiency measurement



GEM efficiency measurement using cosmic rays

Eff. = 94.6%

after ensuring that cosmics must hit a pad

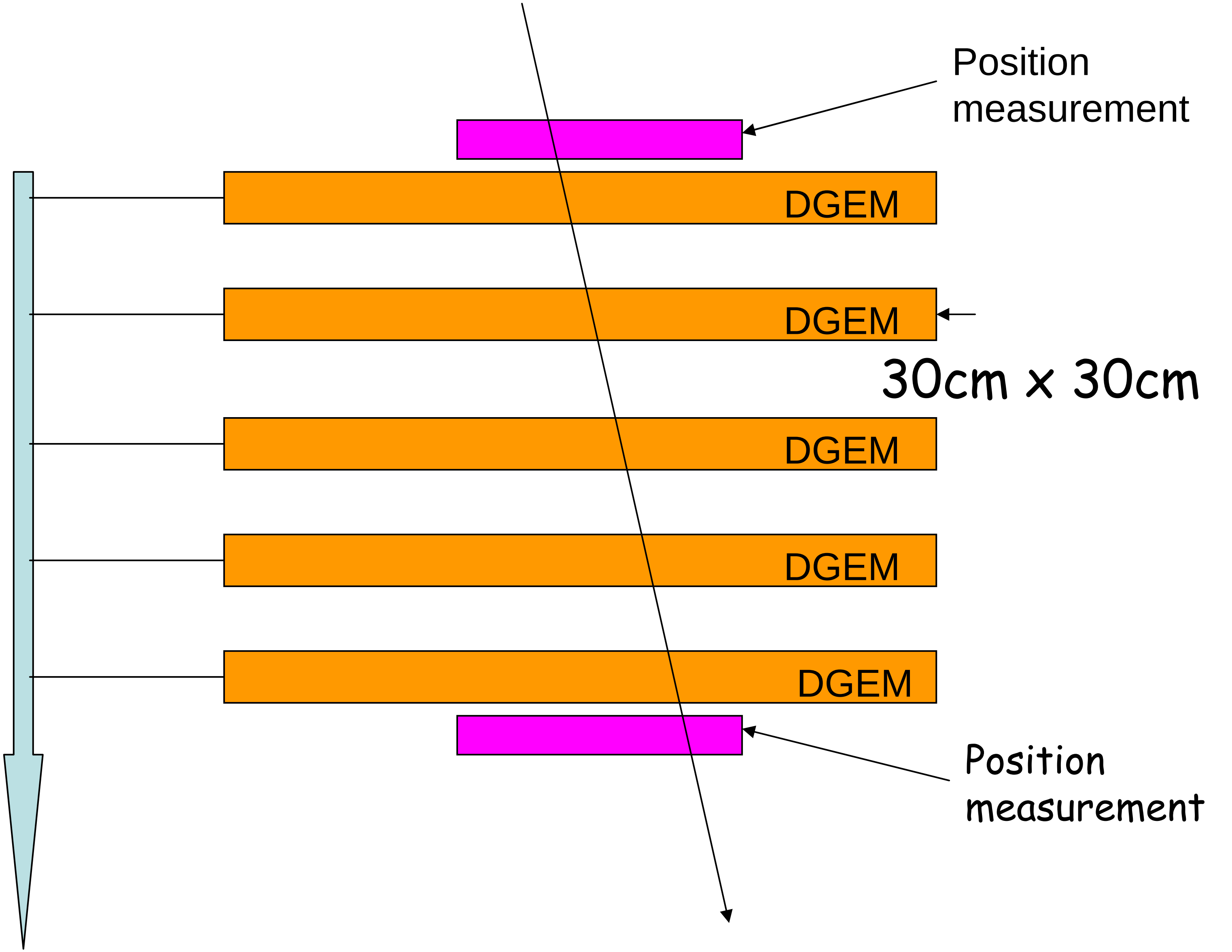


GEM Multiplicity Measurement

- 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

Current project: 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)

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

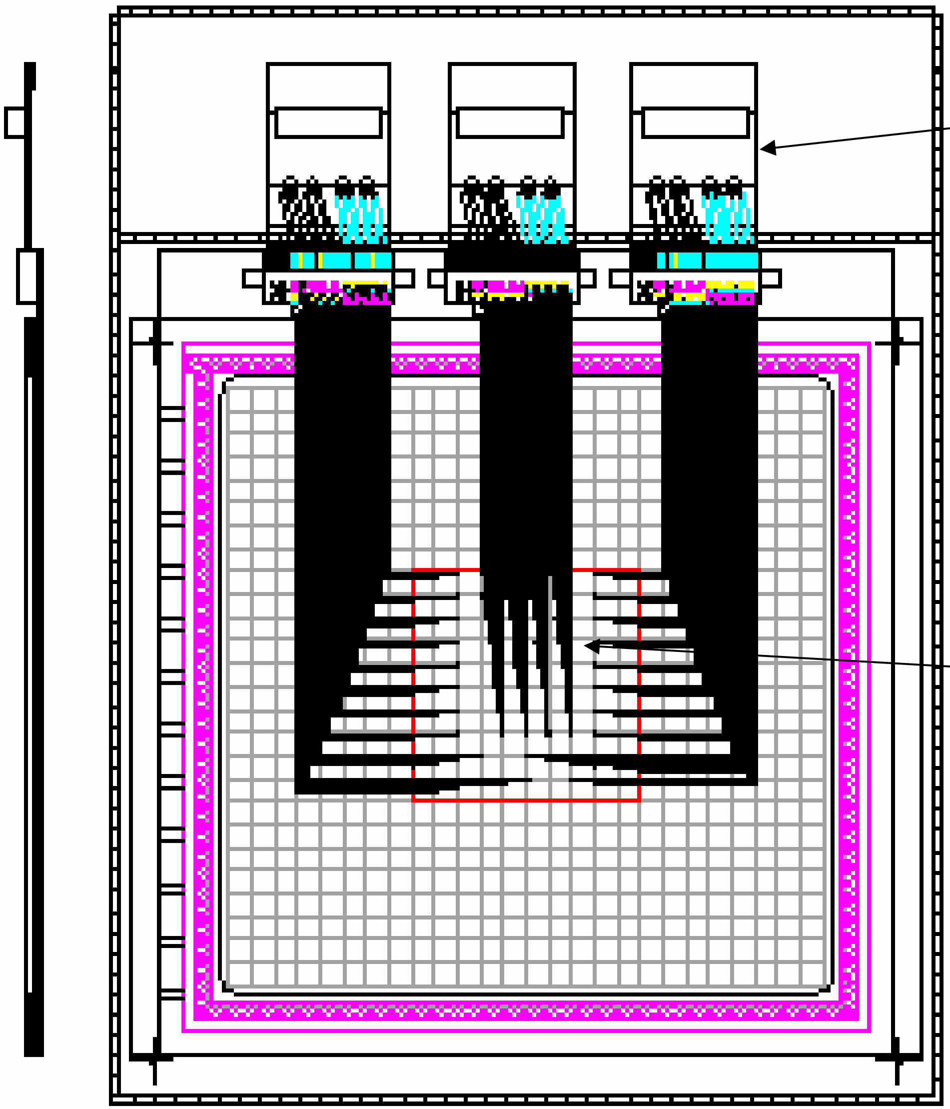
- Effects of layer separators

- 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.

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

305mm x 305mm layer - electronics

- Amplifier cards: need 3/double-GEM chamber x 5 chambers -> 15 + 5 (spares)

- Much appreciated help from Fermilab PPD/Electronics: original drawings (1989!) were lost -> reverse engineered by Fermilab -> new cards completed.

Large GEM foil production

- Iterations on a large (30cm x 30cm) foil design from Dean Karlen.

- Details of – HV connections

  - HV sector gap dimension

  - Peripheral foil design

- Production of 30 foils (80 actually made) completed

- 30 foils delivered –> construction/testing of large DGEM chambers.

- Continuing discussion of 1m x 30cm foils production.

T2K large GEM foil design

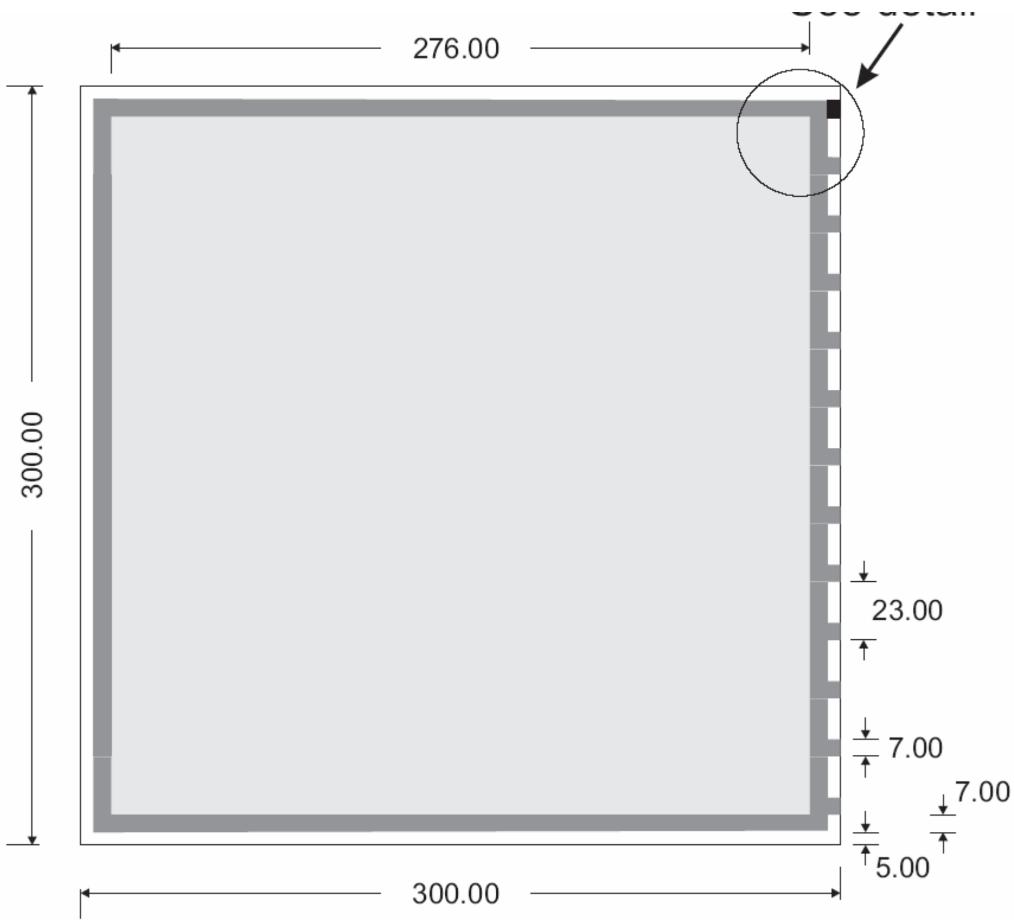
Institutes cooperating on foil production:

- 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)

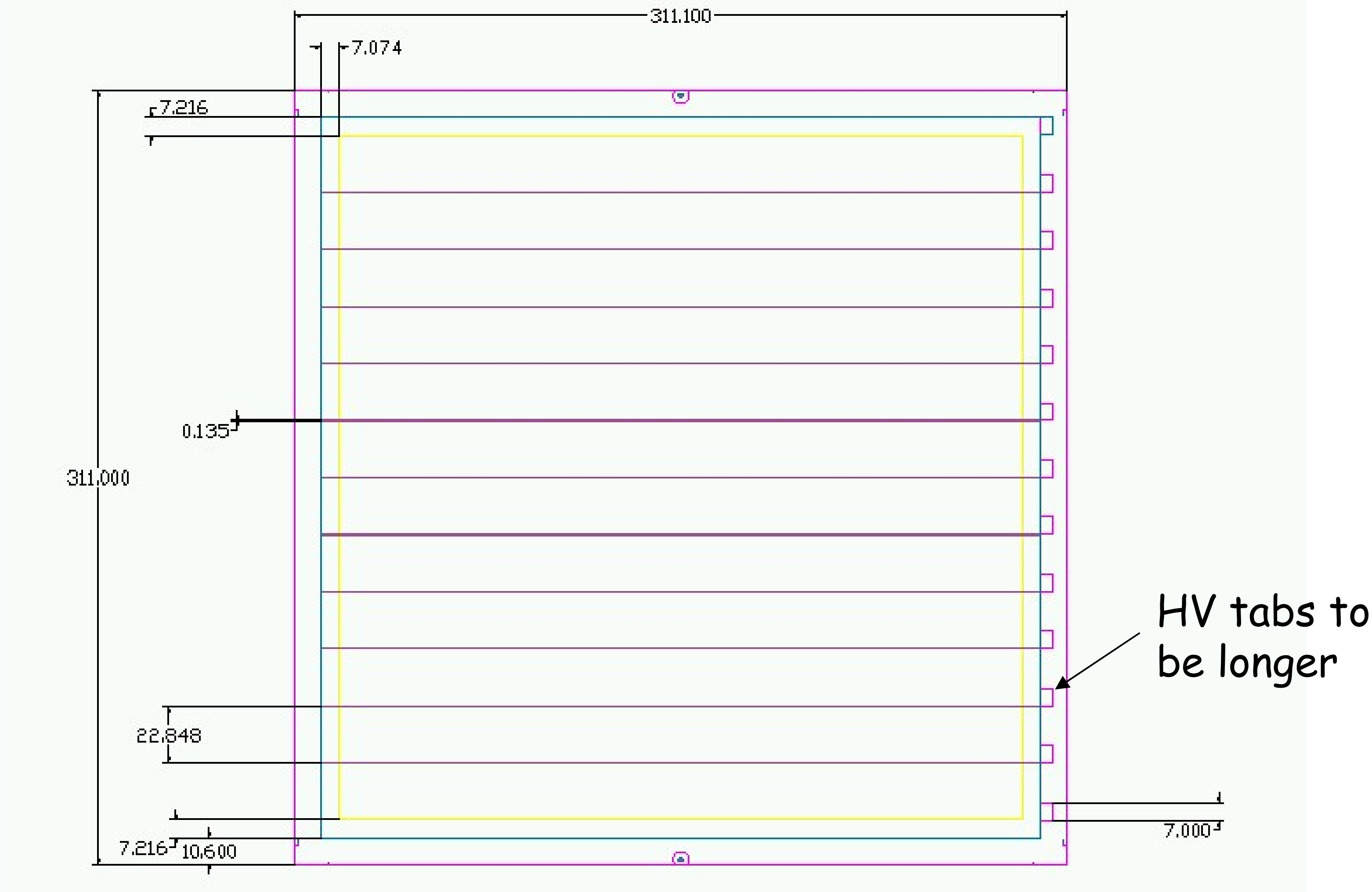
T2K large GEM foil design

Dean Karlen, U.Victoria BC



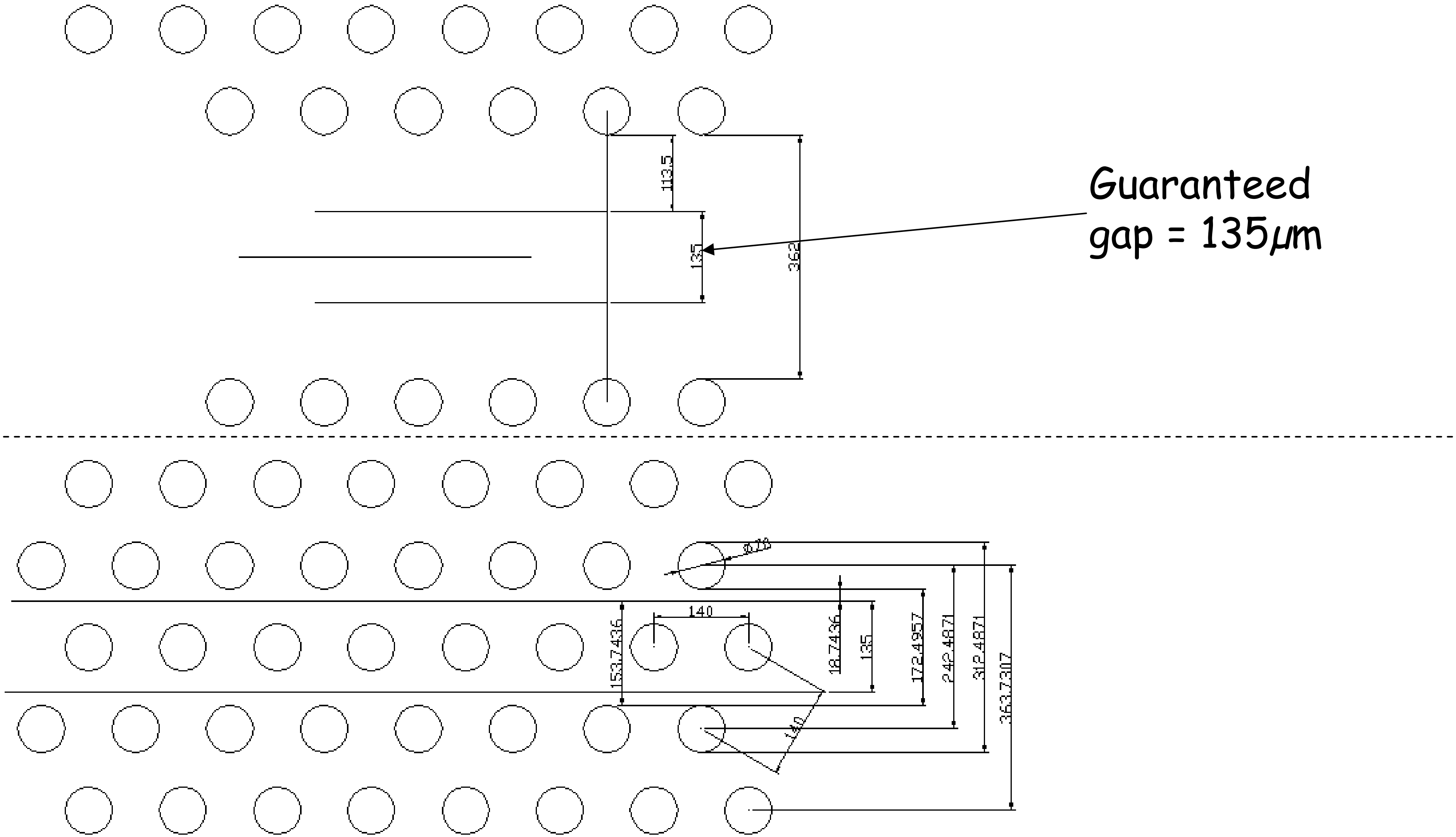
(Close to COMPASS(CERN) foil design)

3M GEM foil design

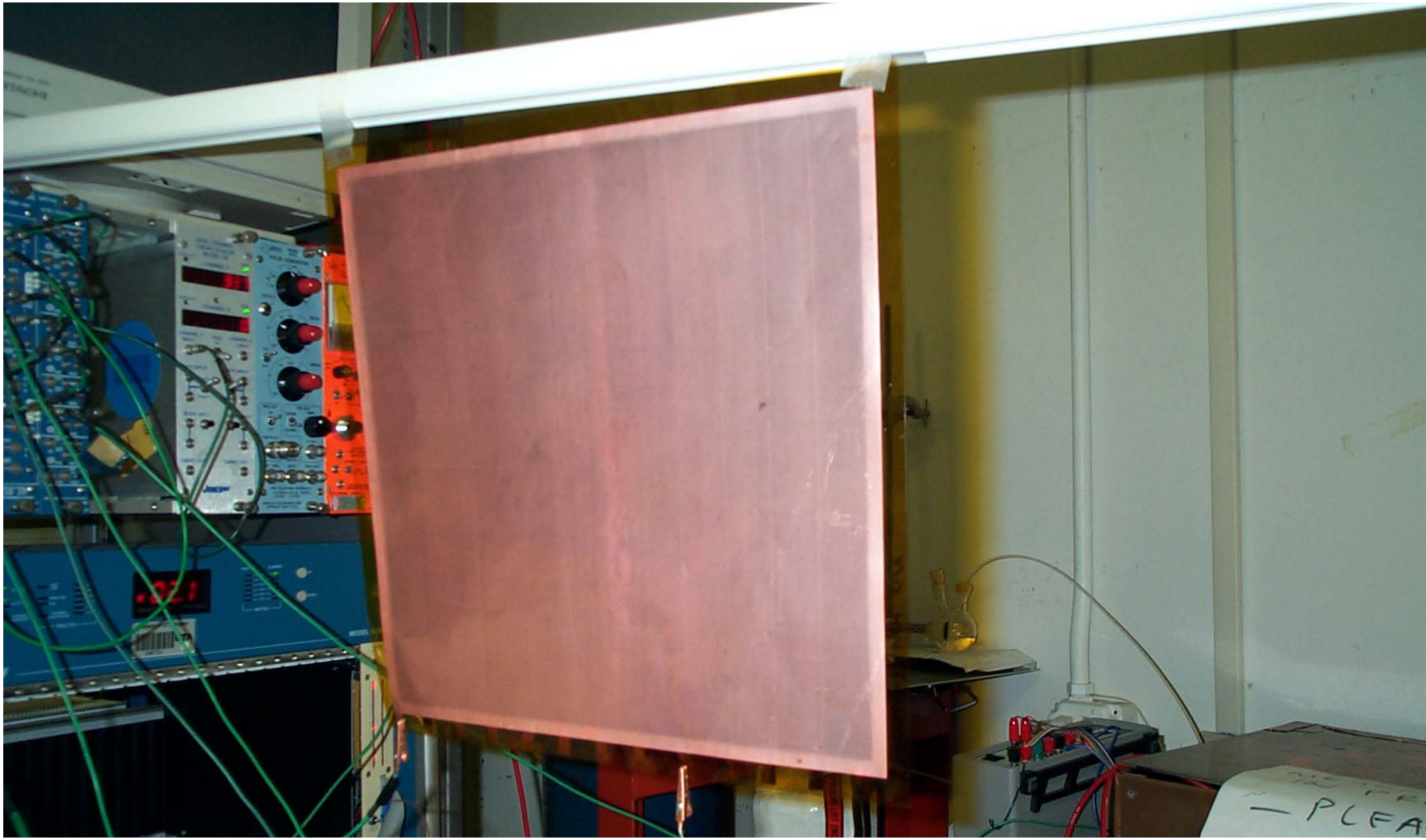


- Now in tooling phase
- Delivery in ~5 weeks

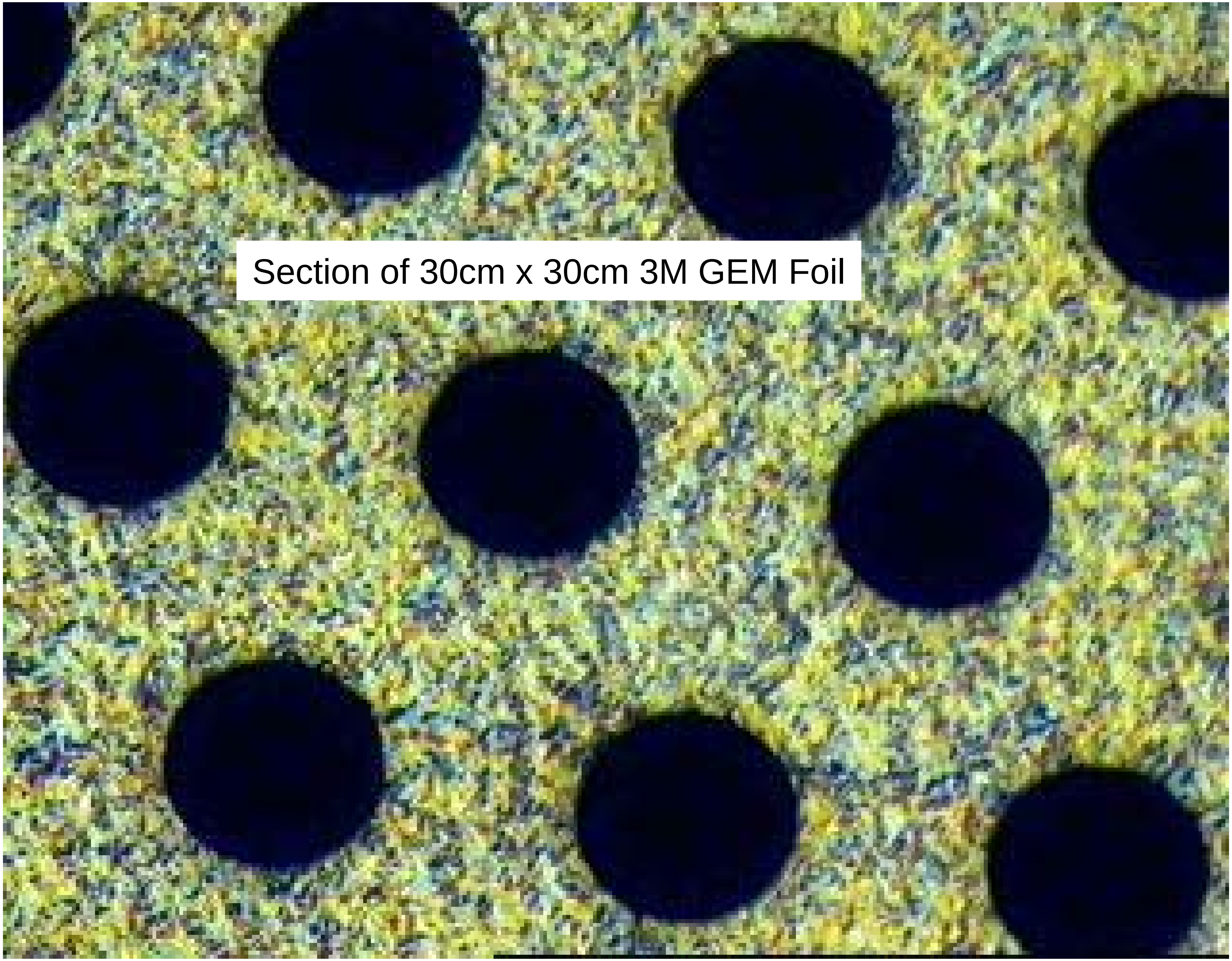
3M - gap between HV sectors

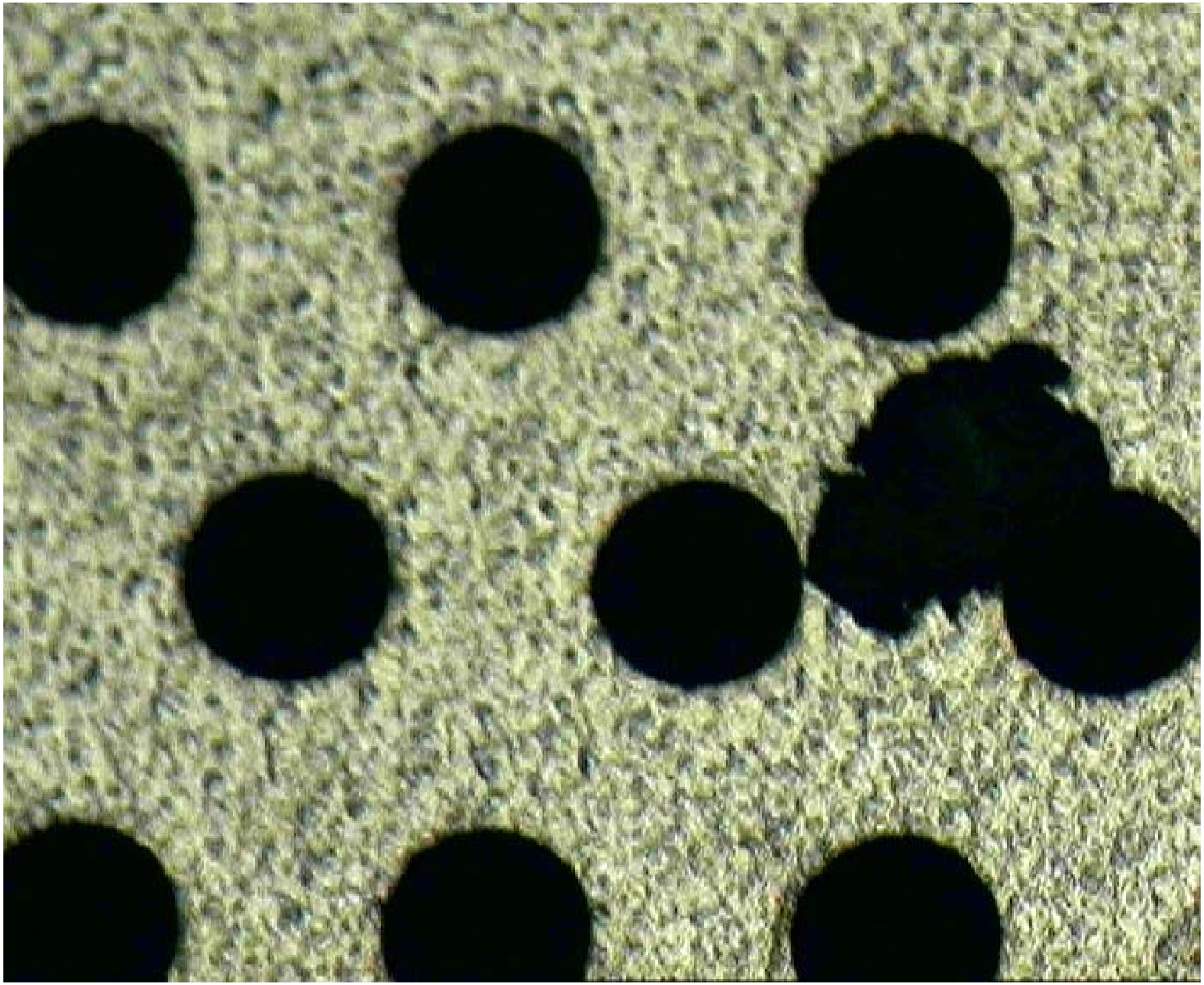


First 30cm x 30cm 3M GEM foils

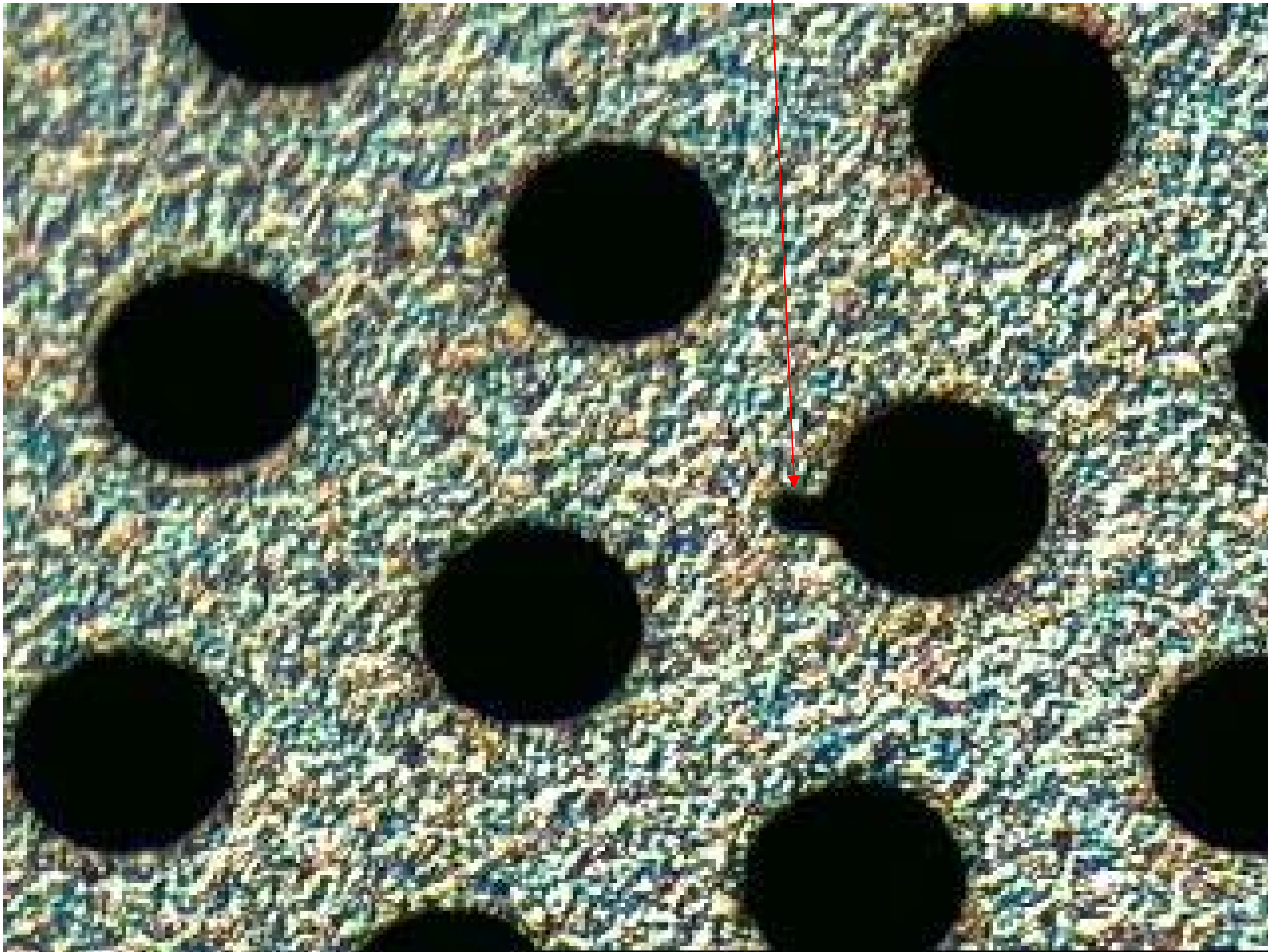


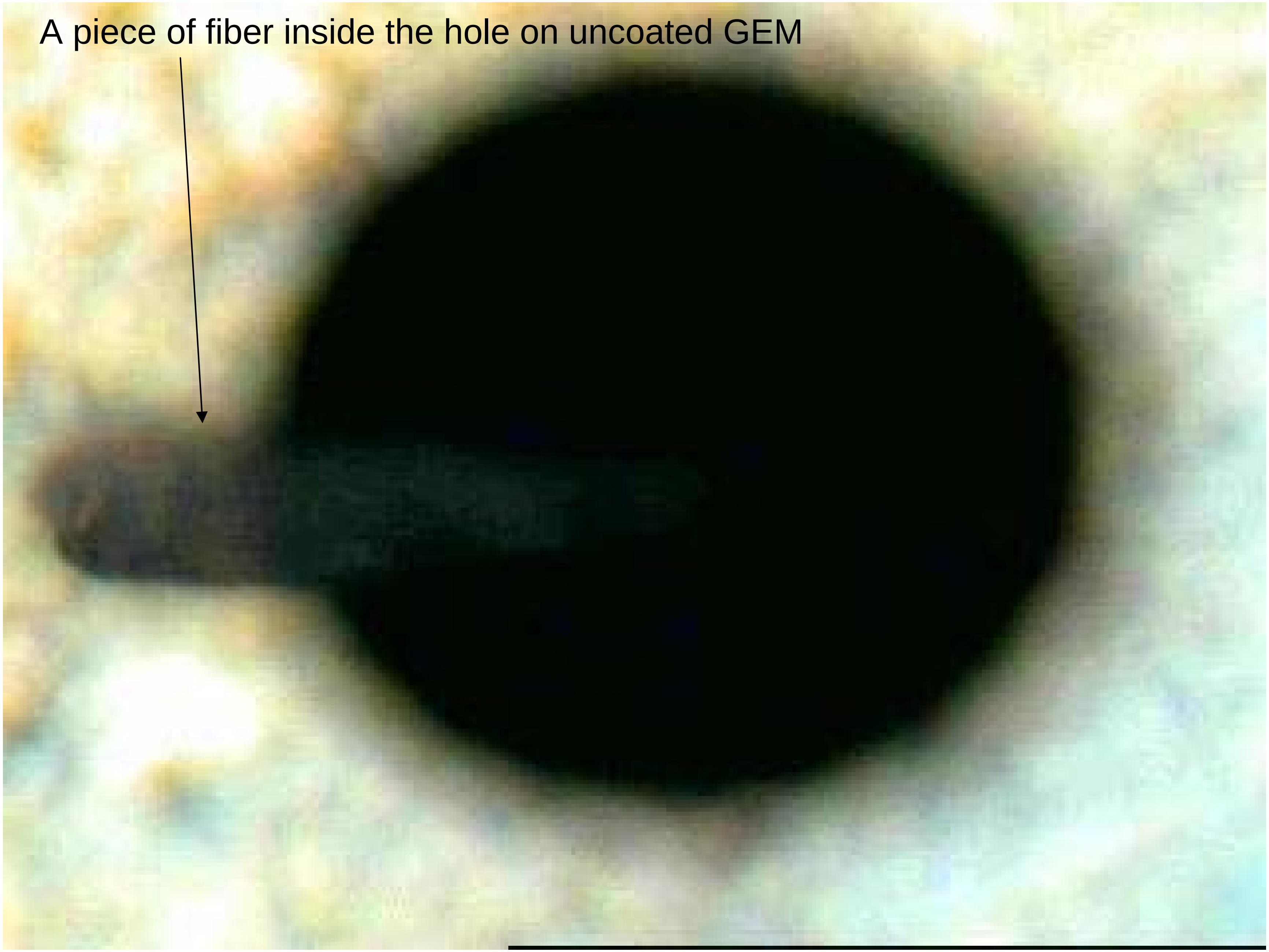
First 30cm x 30cm 3M GEM foils

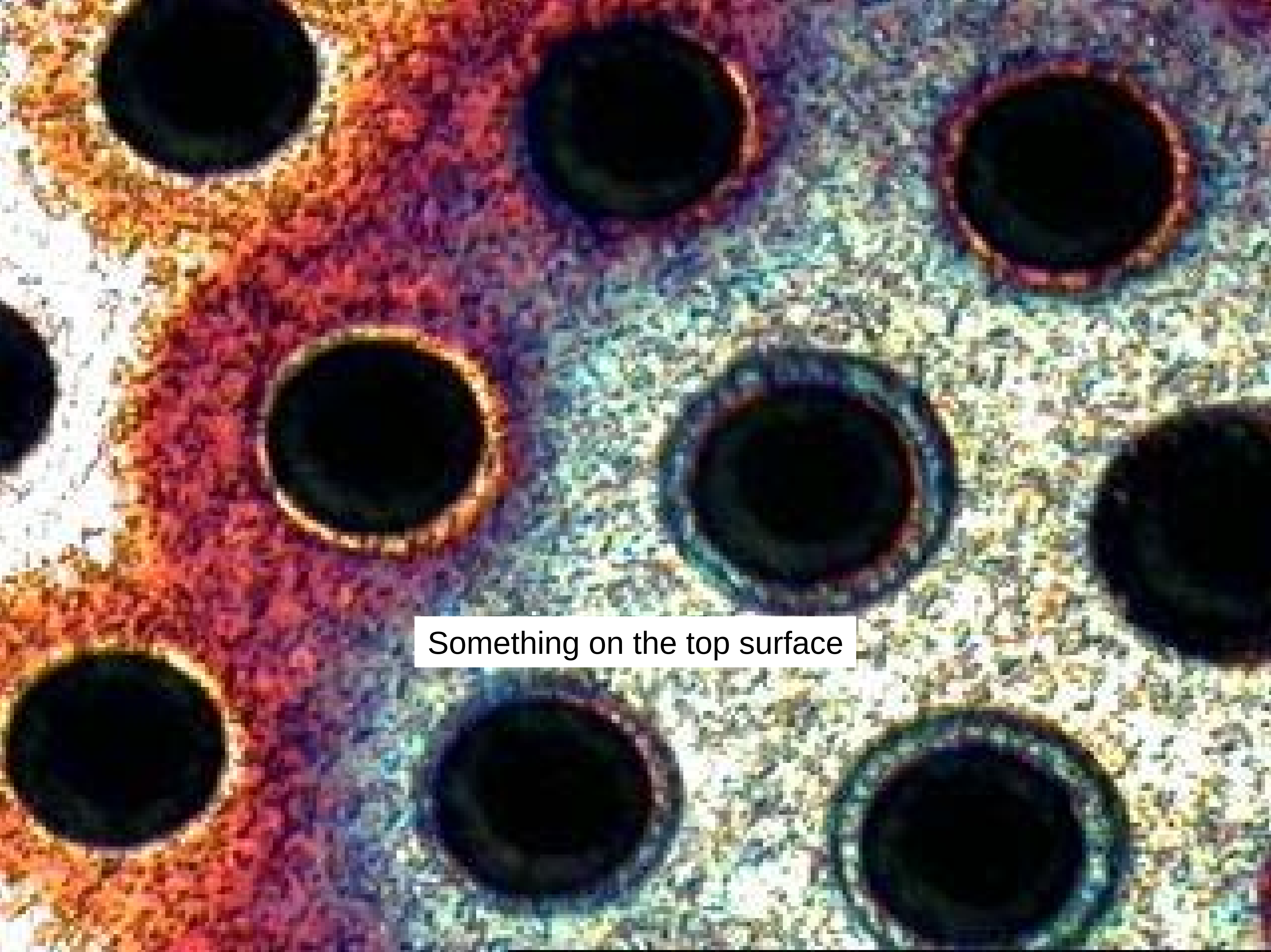

Section of 30cm x 30cm 3M GEM Foil

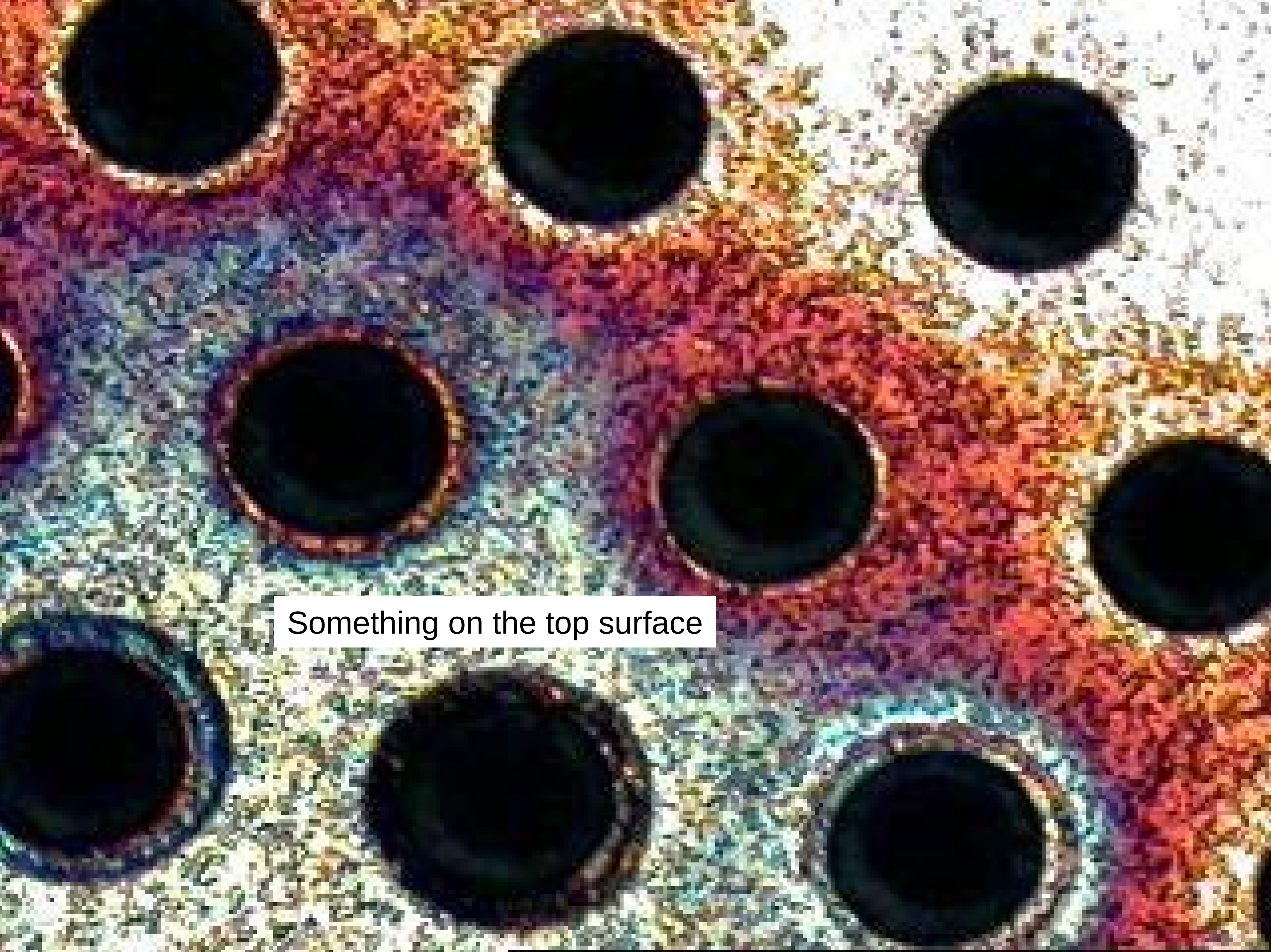


A piece of fiber inside the hole on uncoated GEM

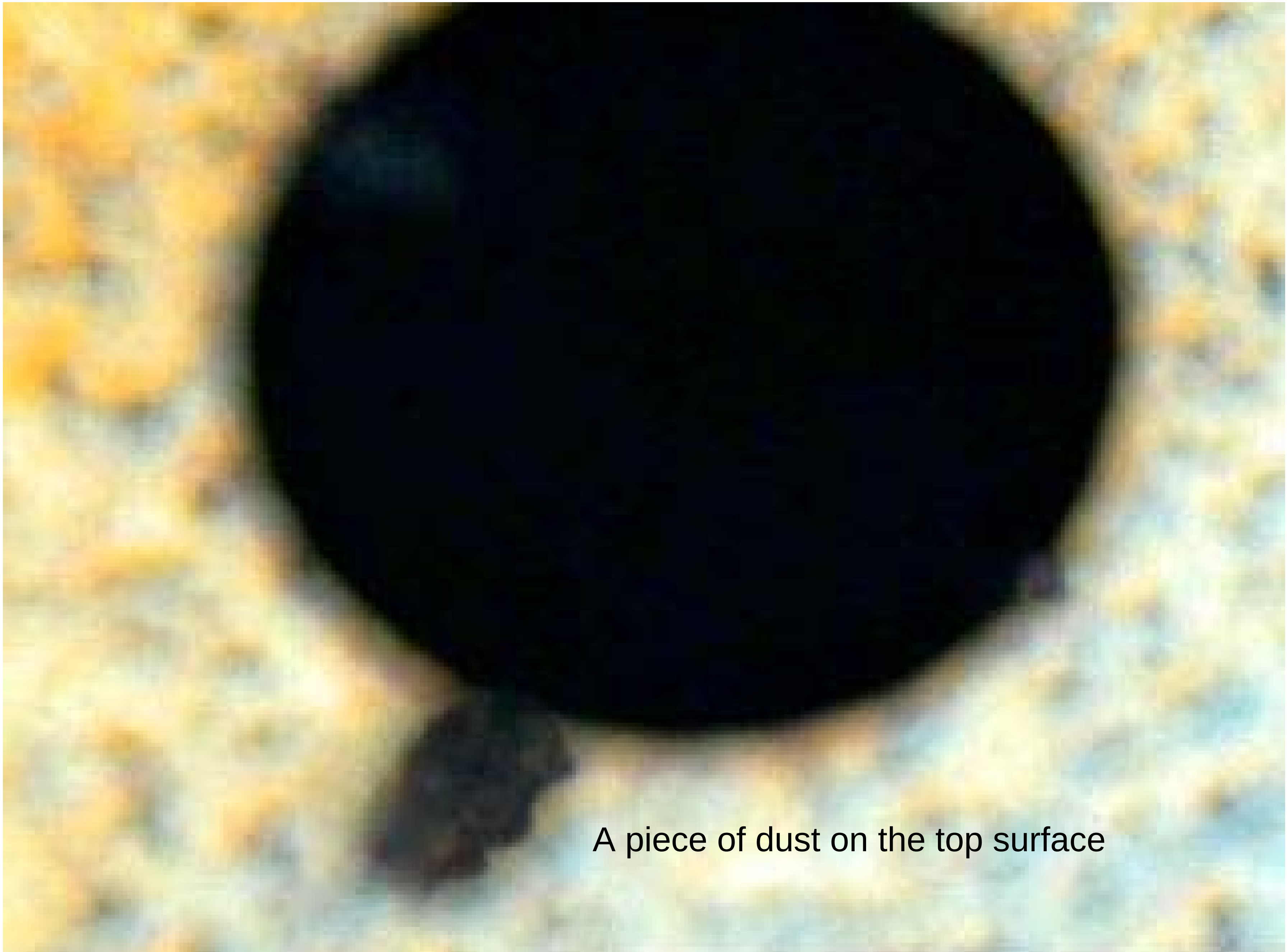



A piece of fiber inside the hole on uncoated GEM

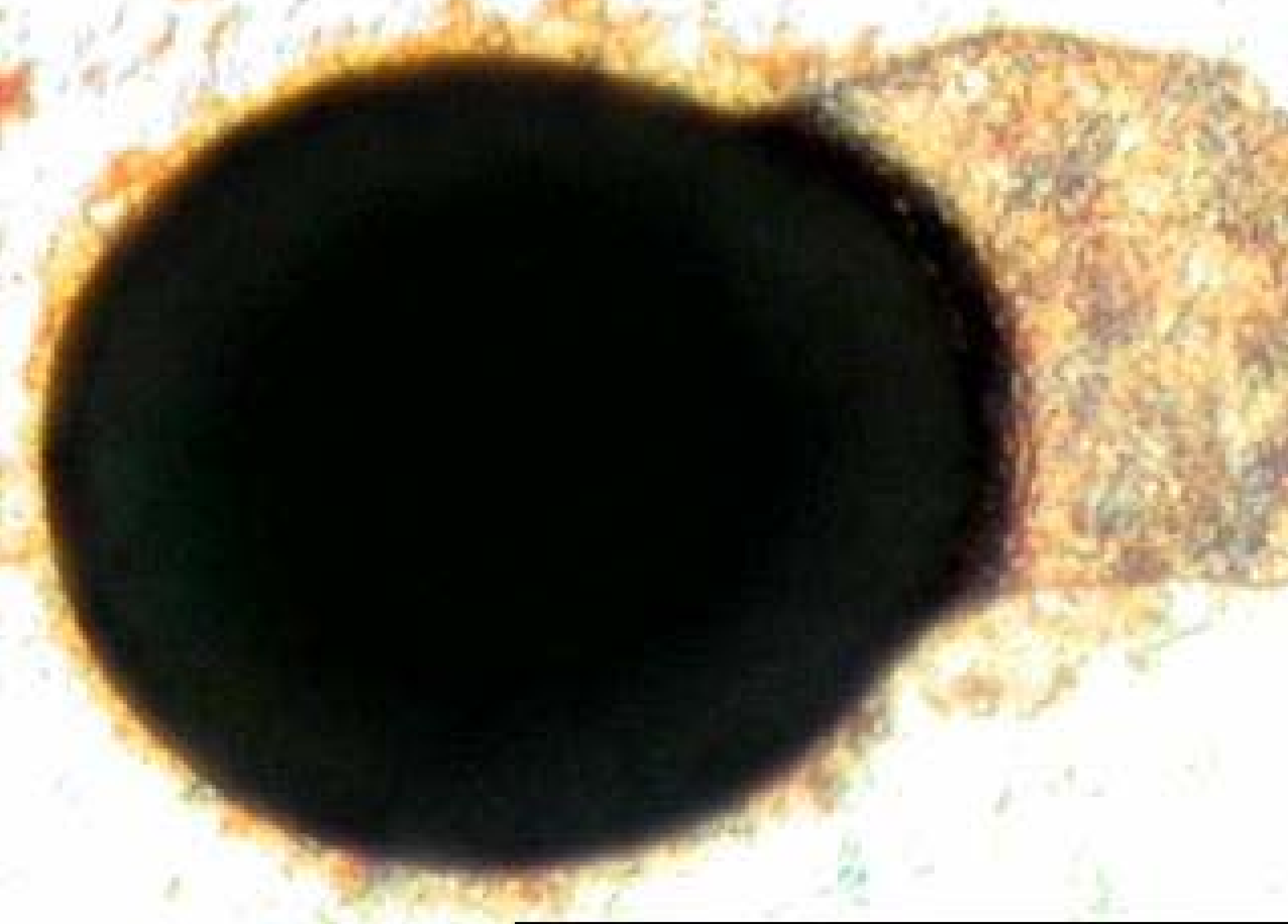

Something on the top surface

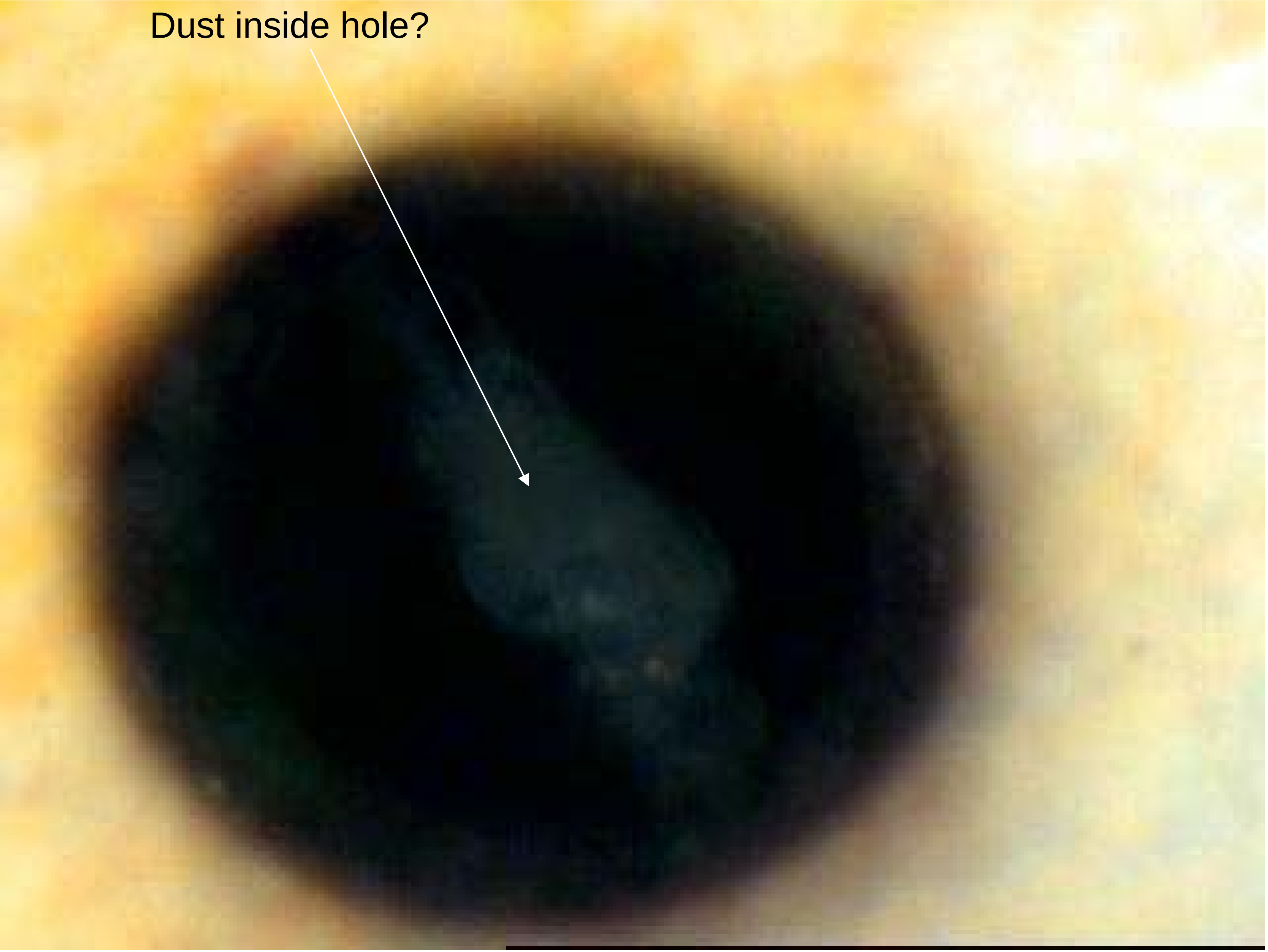

Something on the top surface

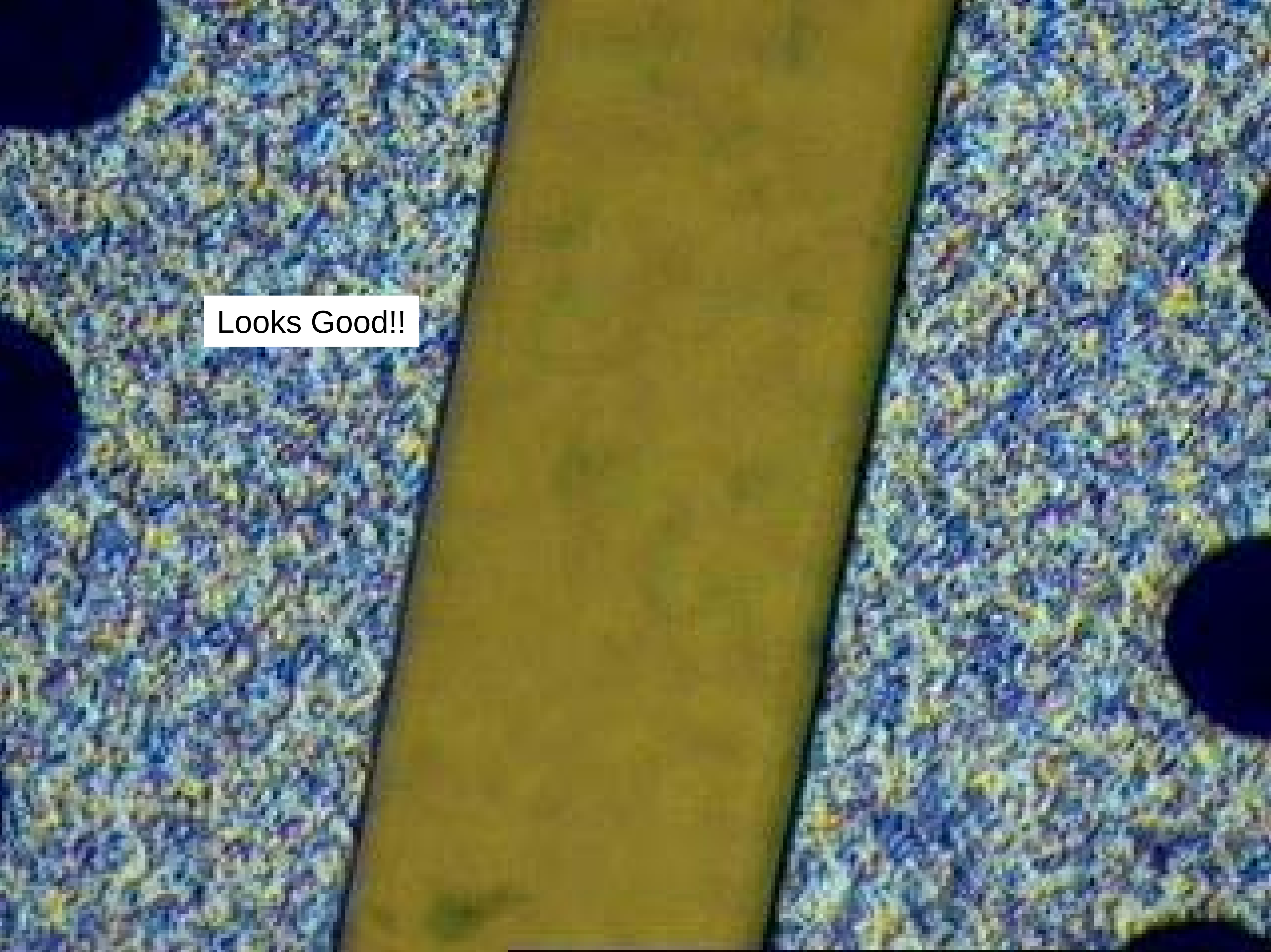

Something inside hole on the coated foil
On top surface


A piece of dust on the top surface

A “bad” hole on the coated foil?




Dust inside hole?


Looks Good!!

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...

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:

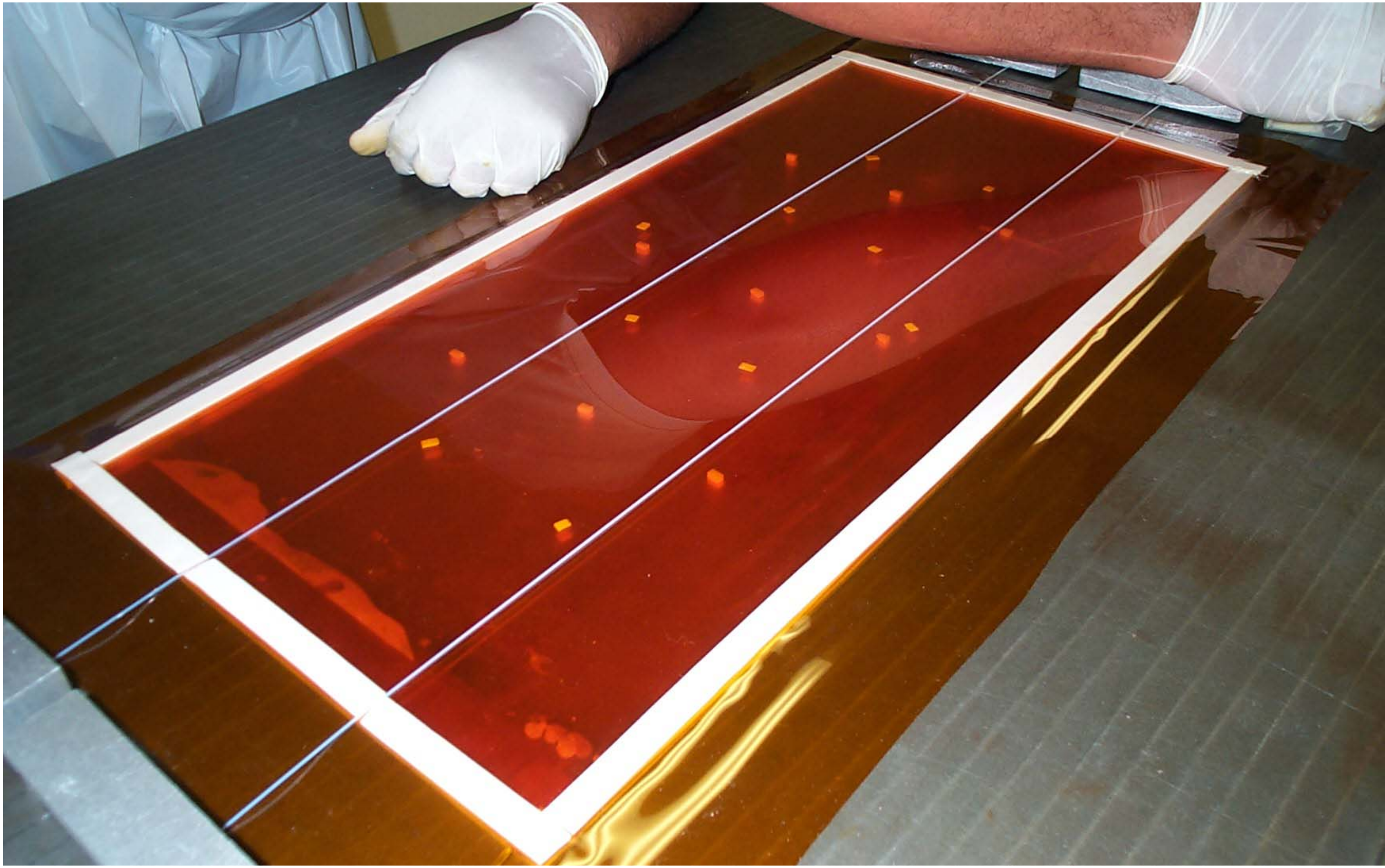
DGEM fabrication+characterization $100K (awarded!) , 2 years, to KST.

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

Next major step:

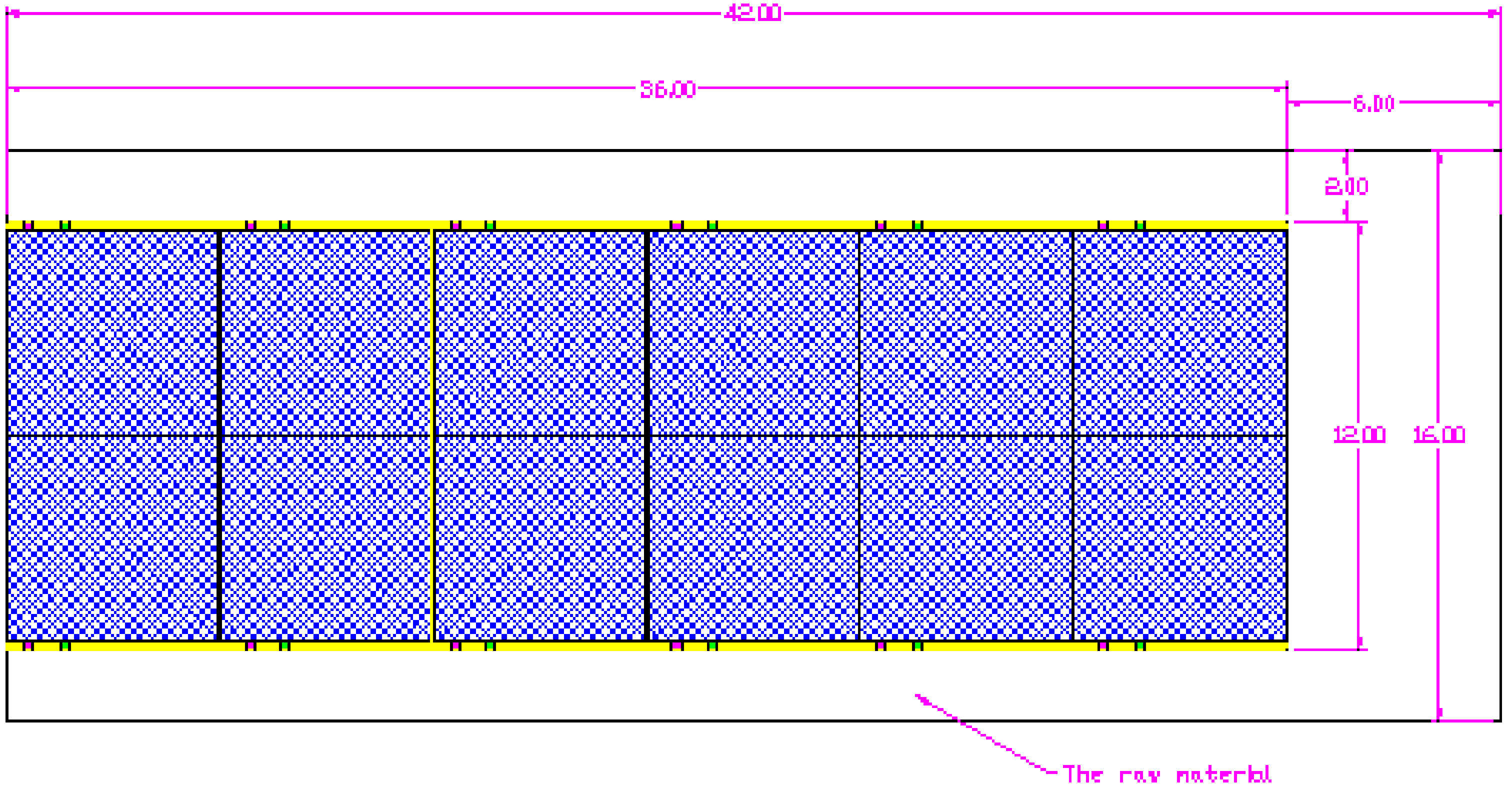
Full-scale ($1m^3$) prototype development

- Comparisons
    - vs. full simulations
    - vs. other technologies (RPC, Scintillator)
- Verification of large scale GEM detector construction, operation, performance,…
- Major issue – funding! MRI (with ECal and RPC/HCal) did not fly…what next…



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

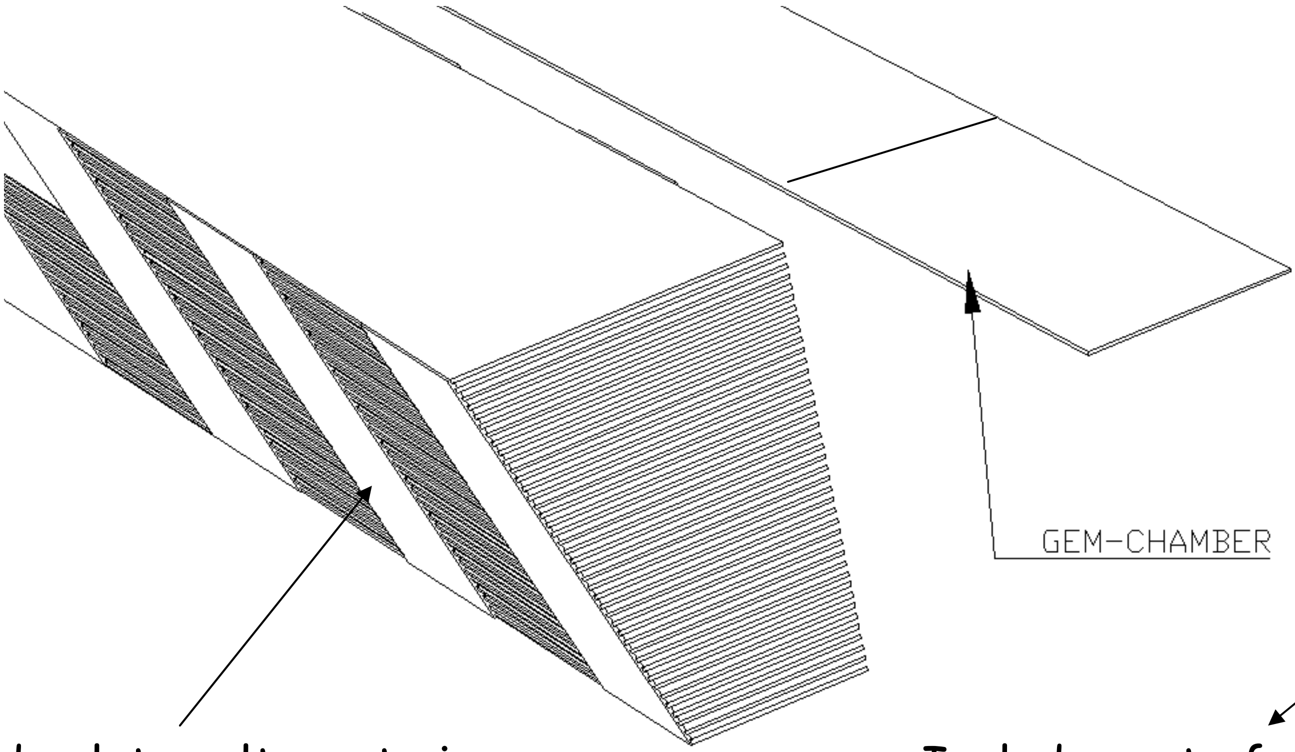
- Double-GEM structure throughout

- 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 to enable large foil production.

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

Summary

- Many basic GEM chamber studies completed.
- Long term stable operation of small prototype.
- 30cm x 30cm foils delivered – under test.
- 500 channel system next step.
- Working towards 1m^3 stack for test beam.
- Issue is $$ for 1m^3 …

Extra Slides – Signal size measurement

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

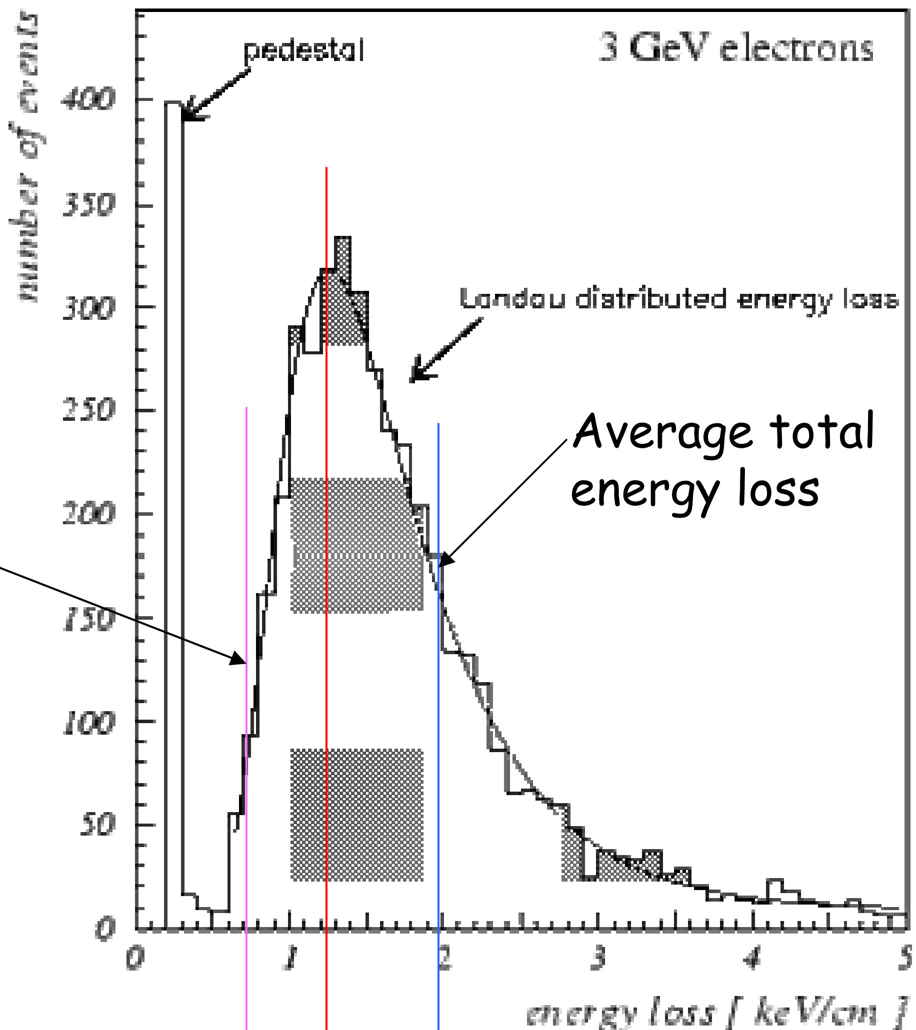
The Landau distribution is defined in terms of the normalized deviation from the "most probable energy loss", which is associated with the peak of the distribution – see the following slide.

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

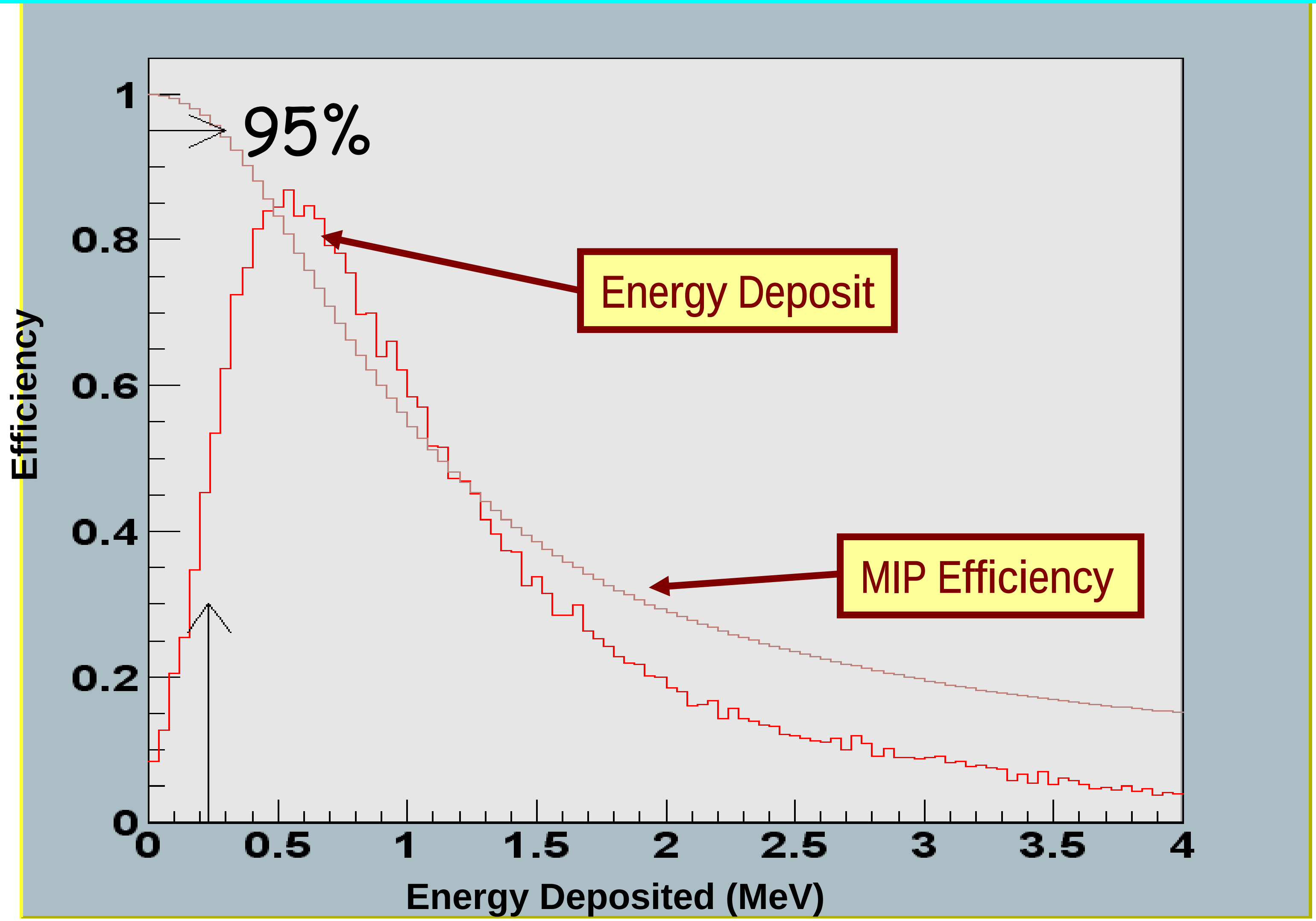
Threshold at 40% of peak



Average total energy loss

Most probable energy loss

GEM/DHCAL MIP Efficiency - simulation



Calculating our GEM signal levels

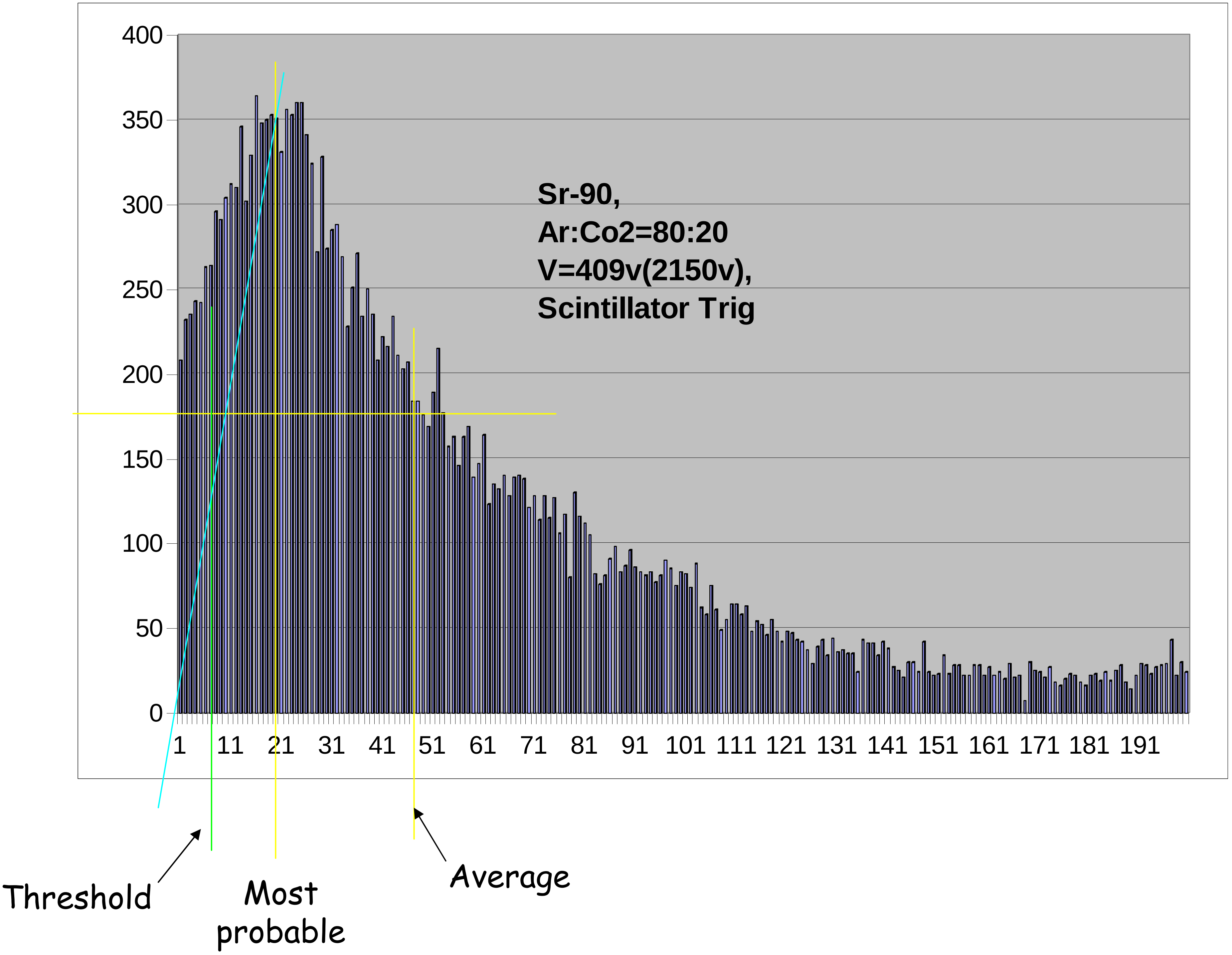
Looking at the following slide for Ar/CO_2 80/20 we see that the average total energy loss occurs at a signal size that is ~5x that for a minimum signal at 40% of the peak height on the low side of the peak.

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.

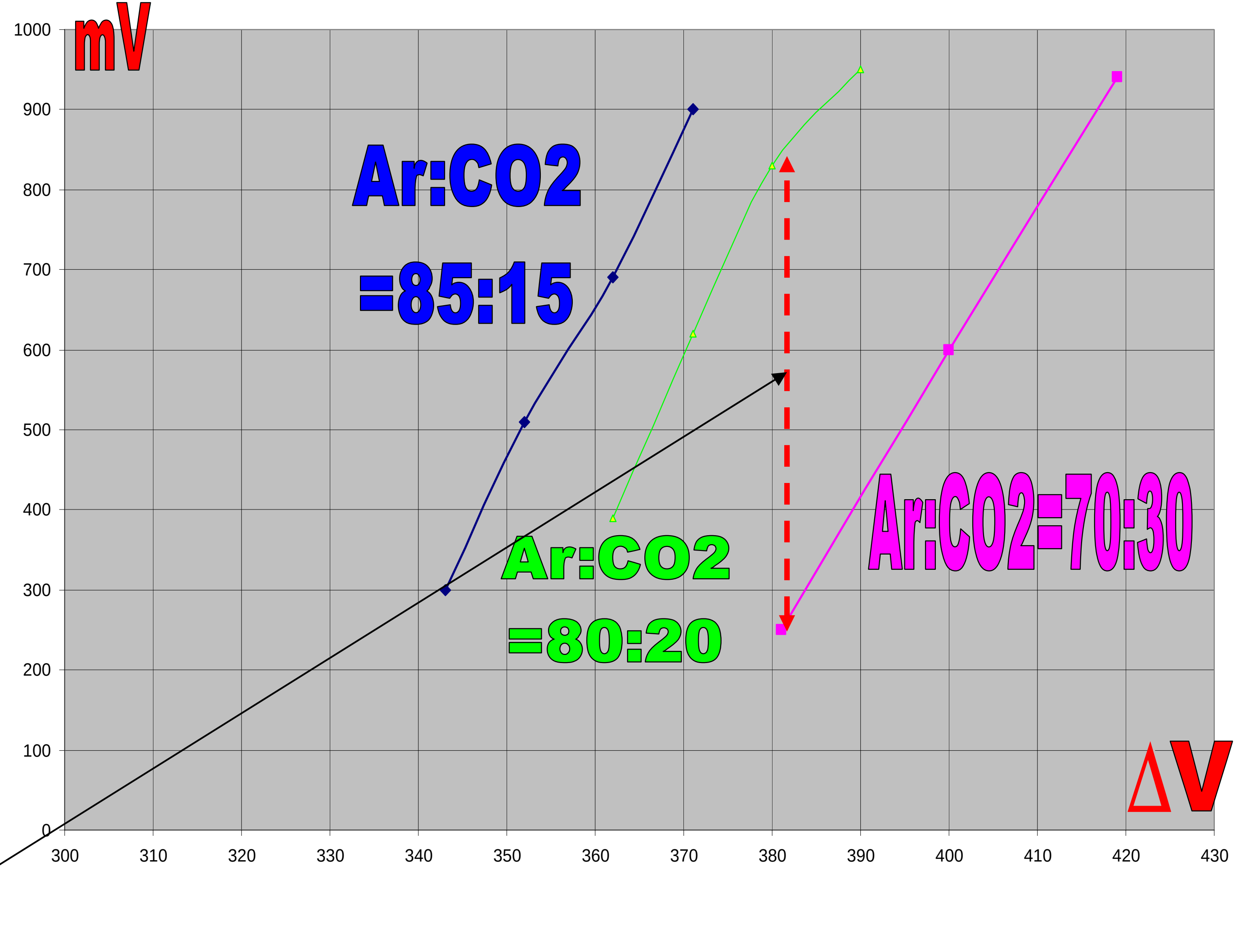
The gain we measured for our 70/30 mixture was ~3500, and we see a factor x3 for 80/20 (see following plot). Putting this all together, we expect

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...