How Can We Improve the Performance of GEM Detectors ?

Craig Woody

BNL

Instrumentation Seminar

April 18, 2007

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Outline

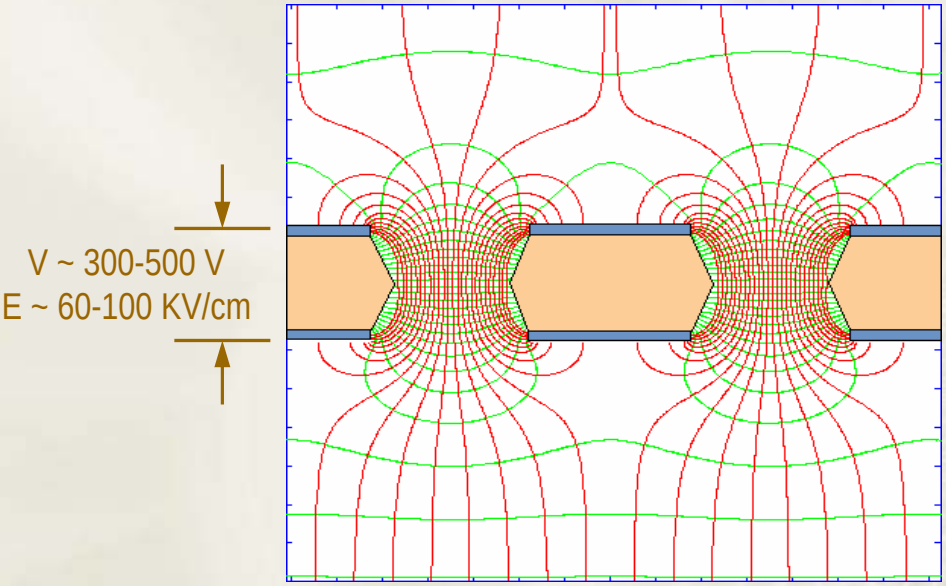
- Principle of operation and fabrication
- What are the problems ?
- Studies to find improvements
- Applications here at BNL

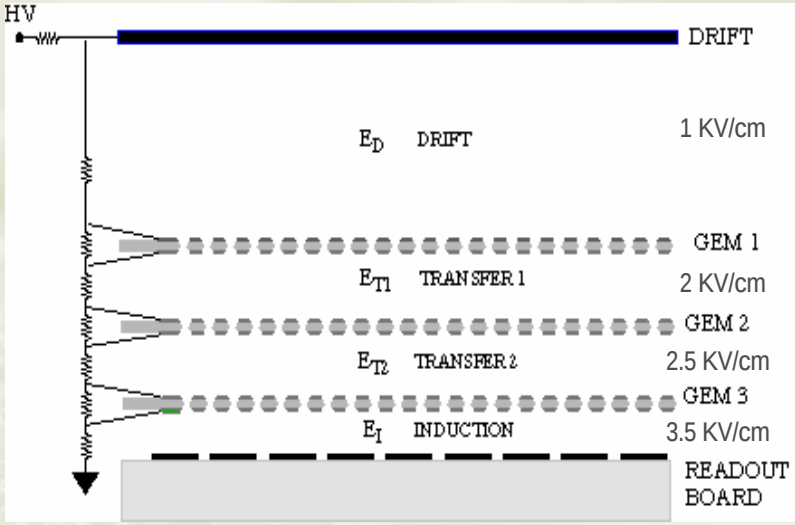
  - PHENIX HBD

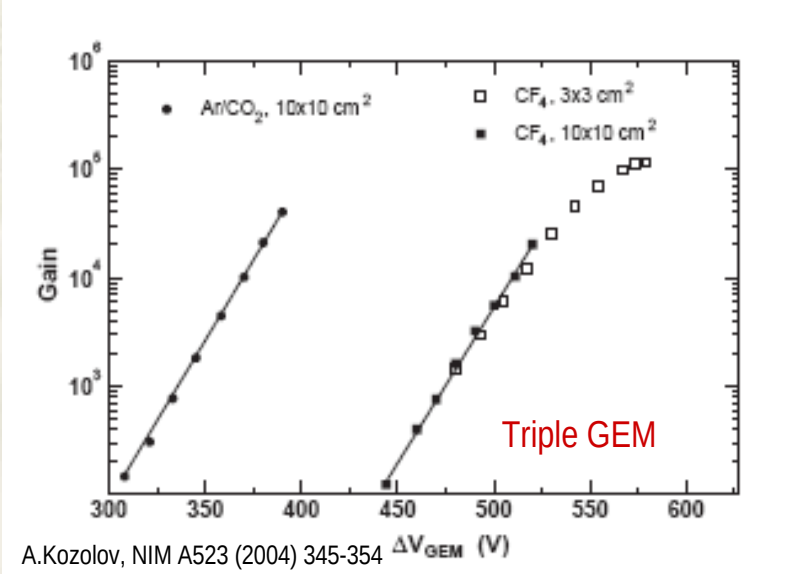
  - STAR Forward GEM Tracker

  - LEGS TPC

GEM Operation







A.Kozolov, NIM A523 (2004) 345-354

Achieve gas gains ~ 10-20 per foil

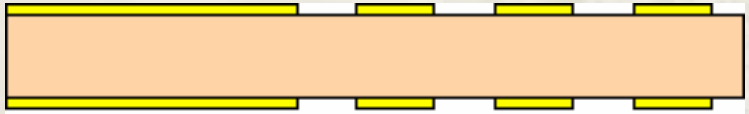
~ 10^3-10^4 or higher in triple GEM structures

GEM Fabrication

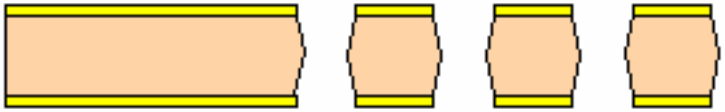
Chemical Etching Process

50 μm polyimide foils/ 5 μm Cu

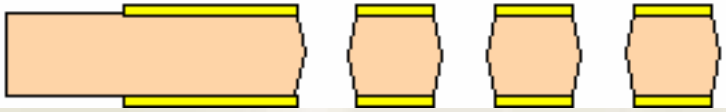
Copper etching (70 μm holes spaced 140 μm)

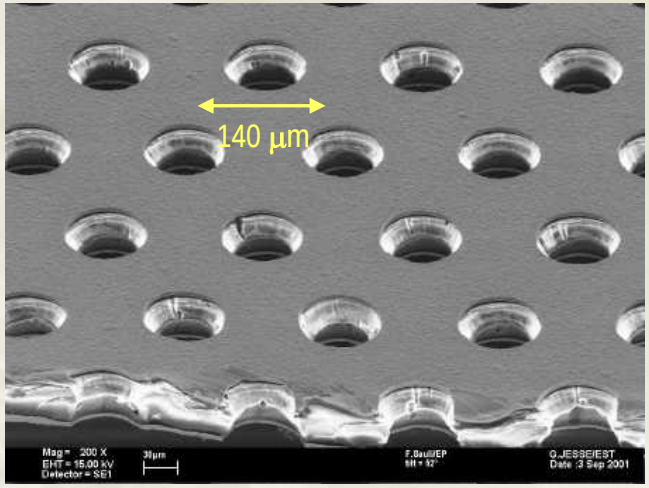


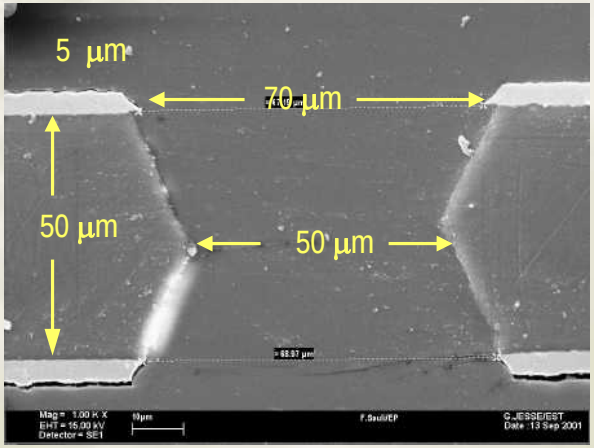
Polyimide etching (50 μm holes)



Edge finishing







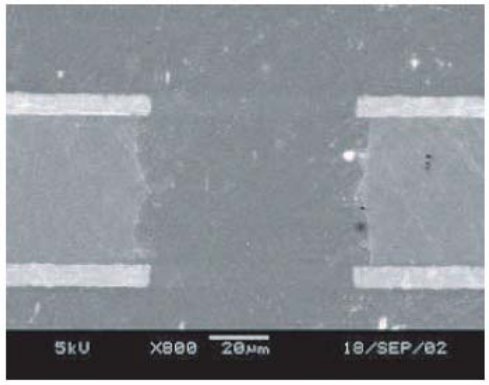
Chemical etching inherently produces conical shaped holes

GEM Fabrication

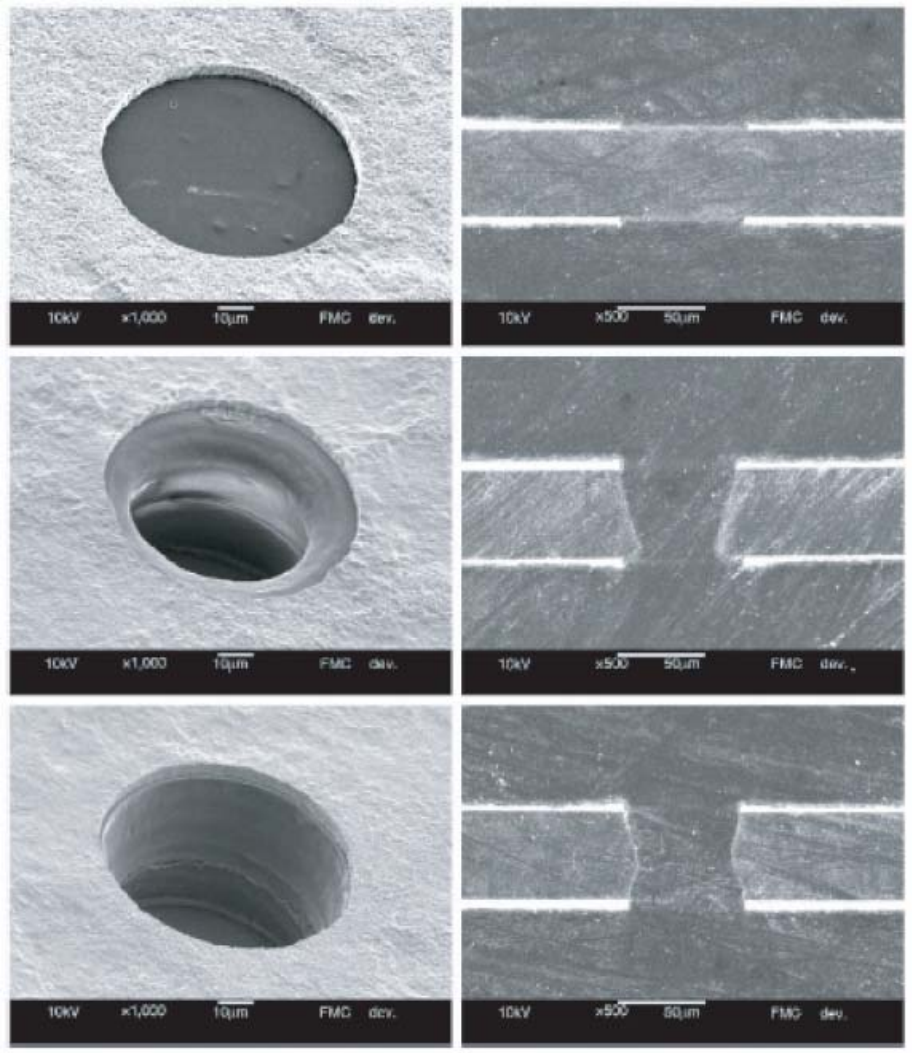
Laser/Plasma Etching Process (CNS-Tokyo/Riken/Scienergy)

- Chemically etch copper
- Etch polyimide with CO_2 laser
- Plasma etch resulting hole

Results in more cylindrical hole, but over etching leads to instability



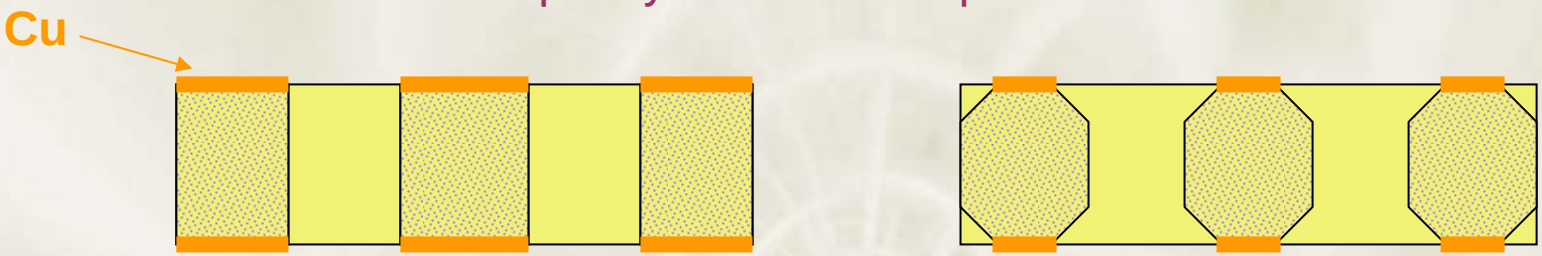
Example of only plasma etching



Y.Yamaguchi Thesis (March 2007)

Thick GEMs (TGEMs)

Developed by Breskin's Group at Weizmann

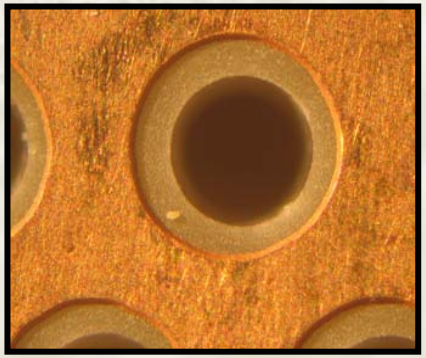


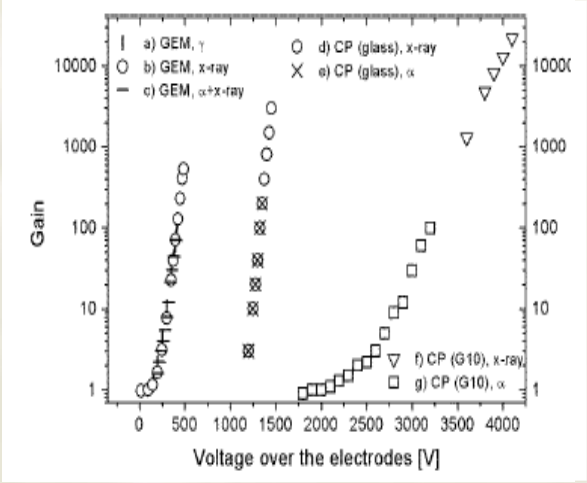
First prototype
Periale et al., NIM A478,2002,377
~10^4 maximum gain

Improved TGEM
Ostling et al ., IEEE Nucl. Sci 50,2003,809
~10^5 maximum gain

TGEM is manufactured using standard precision PCB manufacturing techniques

Thickness ~ 1-2 mm
Hole size ~ 0.3-1.0 mm
Spacing 1-3 mm





V.Peskov, Micropattern Detector Workshop, 2006 NSS/MIC, San Diego

What are the Problems ?

- GEMs were invented at CERN and most GEMs which have been used in actual experiments have been produced there
  - CERN is not a commercial manufacturer of GEM foils (but CERN holds the patent !)
  - Reliability, reproducibility, availability
- Gain stability and uniformity
  - Most applications so far have been for tracking purposes, which are less sensitive to gain variations and instabilities
- Rate dependence
  - GEMs have been shown to work in high rate environments, but again, mostly for tracking applications
- Discharge probability

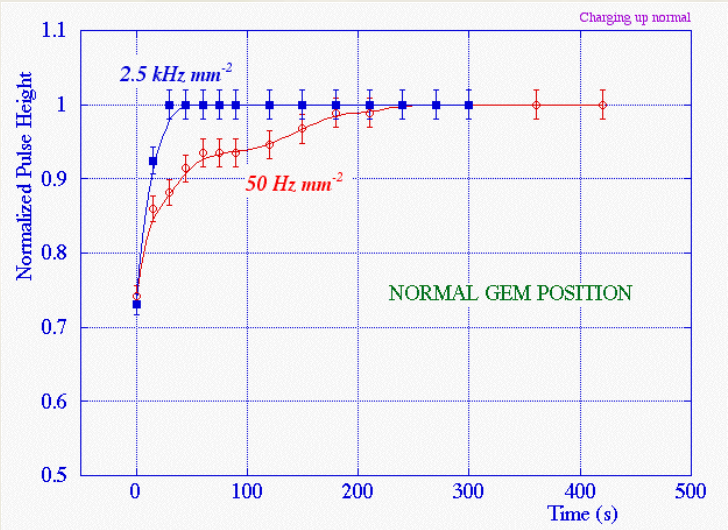
Tech-Etch

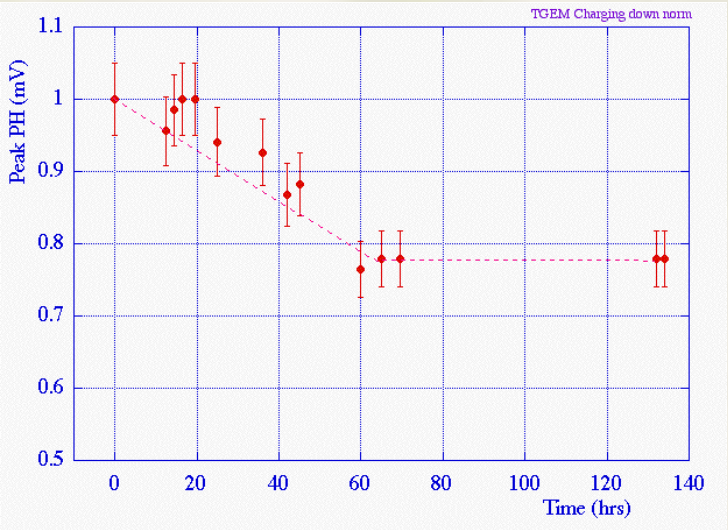
Photoetching and Flexible Circuit manufacturer in Plymouth, MA (with facilities also in Fall River, MA and Litchfield, MN)

Phase I SBIR: 2005-2006
Phase II SBIR: 2006-2008

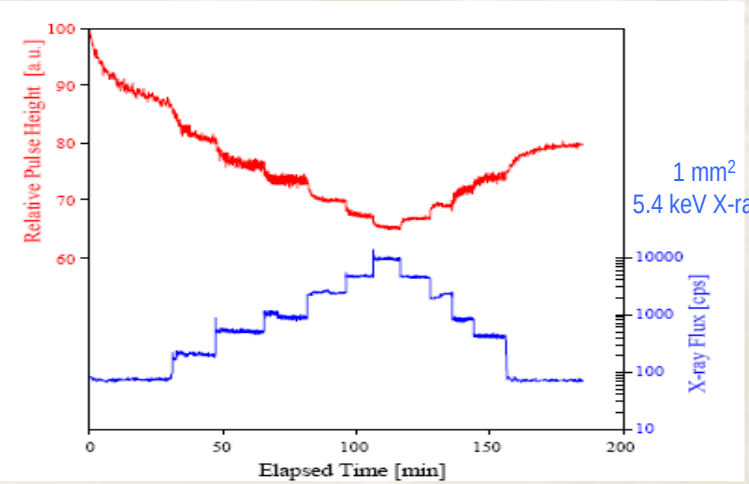
"Commercial and Cost Effective Production of GEM Foils"

Charging and Discharging Effects in GEMs





COMPASS GEMs, C.Altunbas et.al., NIM A490 (2002) 177-203



B.Yu, 2002 IEEE NSS/MIC Conf. Rec.

Charge up effects are well known in GEM foils

- Charge up/charge down times are long (hours → days)
- Effects are rate dependent
- Effects depend on previous charge history

Possible Causes of Charging Effects

- **Polarization of the dielectric**
  - **Inherent, but seems to vary from one foil to another**

- **Factors in the manufacturing process ?**
  - **Polyimide material**
  - **Hole geometry**
  - **Mask alignment, precision, quality control**
  - **Chemical etching process**
  - **Post etching and cleaning process**

Polarization of the Dielectric

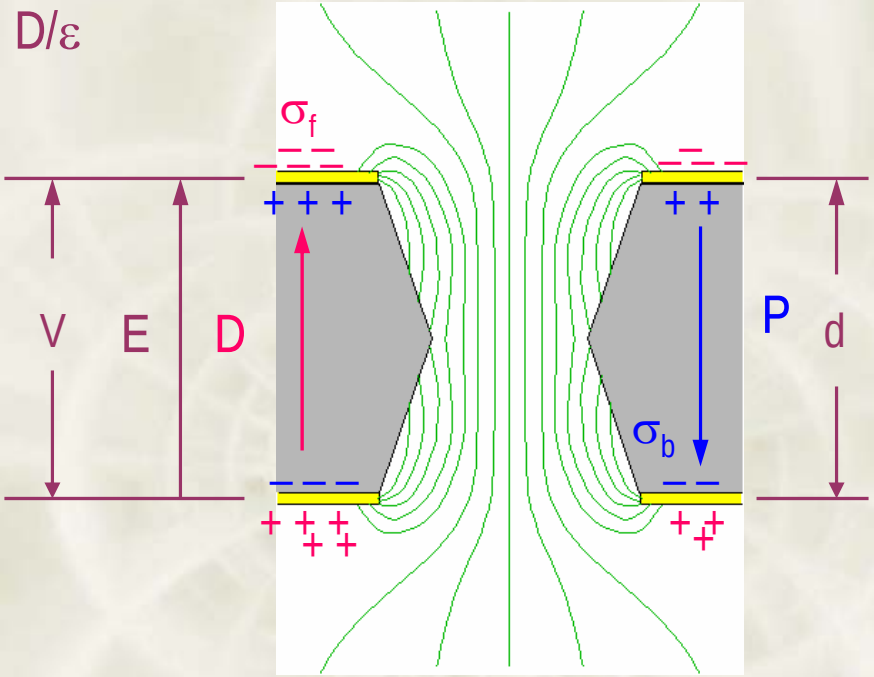
$E=(1/\varepsilon_0)(D-P)= D/\varepsilon$

$\varepsilon = \varepsilon_0\varepsilon_r$

$D = \sigma_f$

$P = \sigma_b$

$E = \sigma_f - \sigma_b$



Theory:

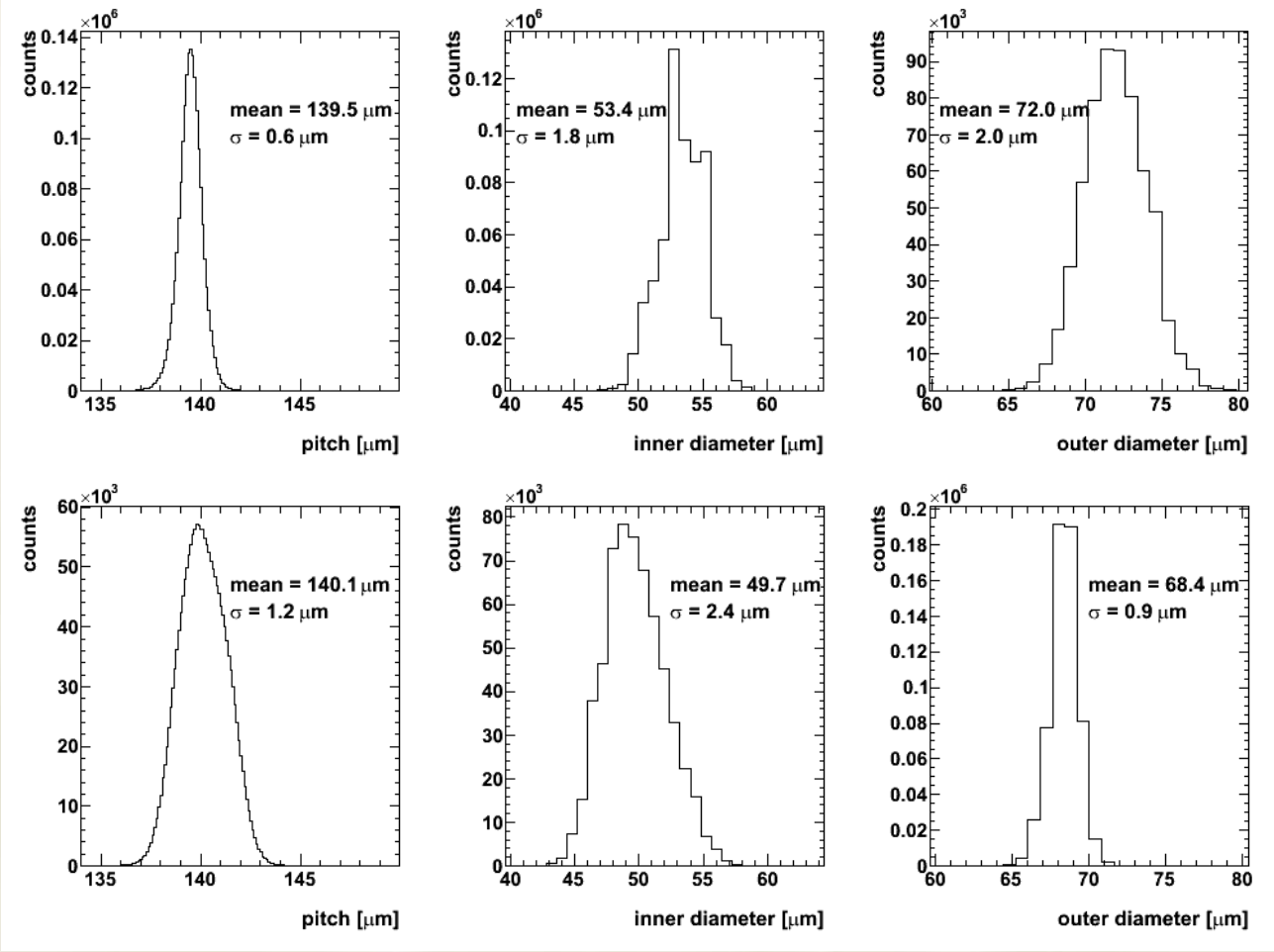
Insulator polarizes causing additional charges to move onto the conductor, increasing the electric field inside the holes

⇒ Gain increase

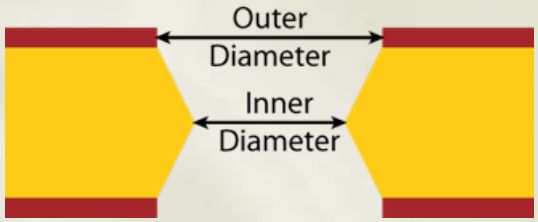
Properties of Polyimide Materials

	Kapton (®Dupont)	Apical (CERN) (®Kaneka Corp)
Delectric Strength (v/mil)	7000	6900
Dielectric constant	2.7 - 3.1	2.7 – 3.1
Volume resistivity (ohms/cm)	10^{17}	$>10^{16}$
Water Absorption	1.8 % @100%RH	1.7 % (immersion for 24 hrs)

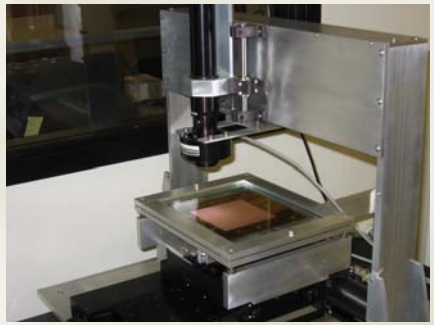
Hole Size Variation



Tech-Etch



Measured with optical scanner at MIT

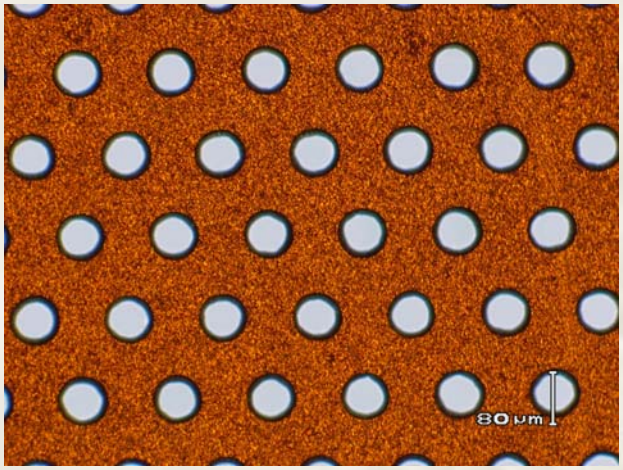


F.Simon, U.Becker, B.Tamm, S.Hertel

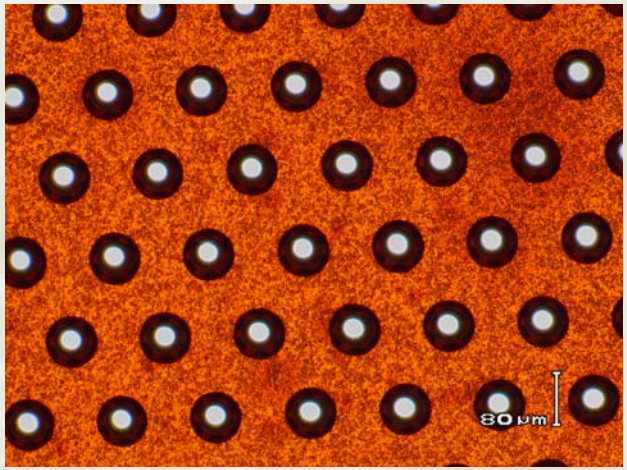
CERN

Hole Sizes of CERN and Tech-Etch GEMs are similar (in general…)

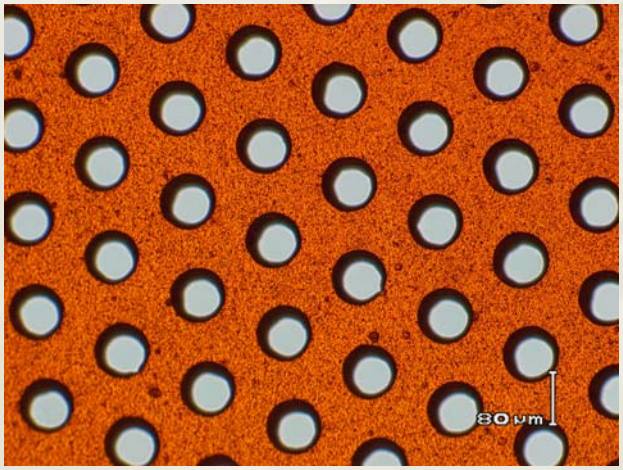
Hole Geometry



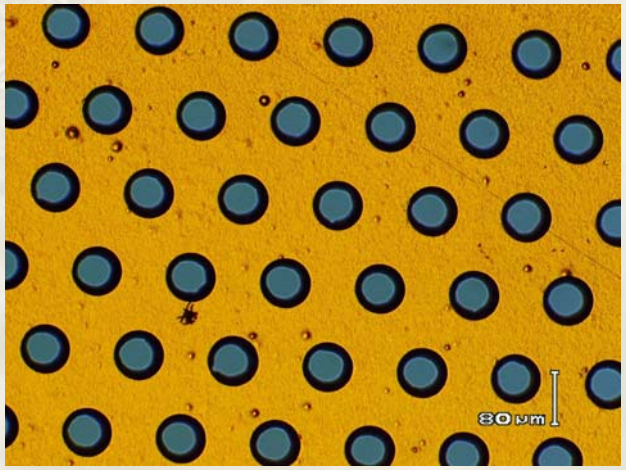
CERN (10x10 cm^2)



3M (10x10 cm^2)



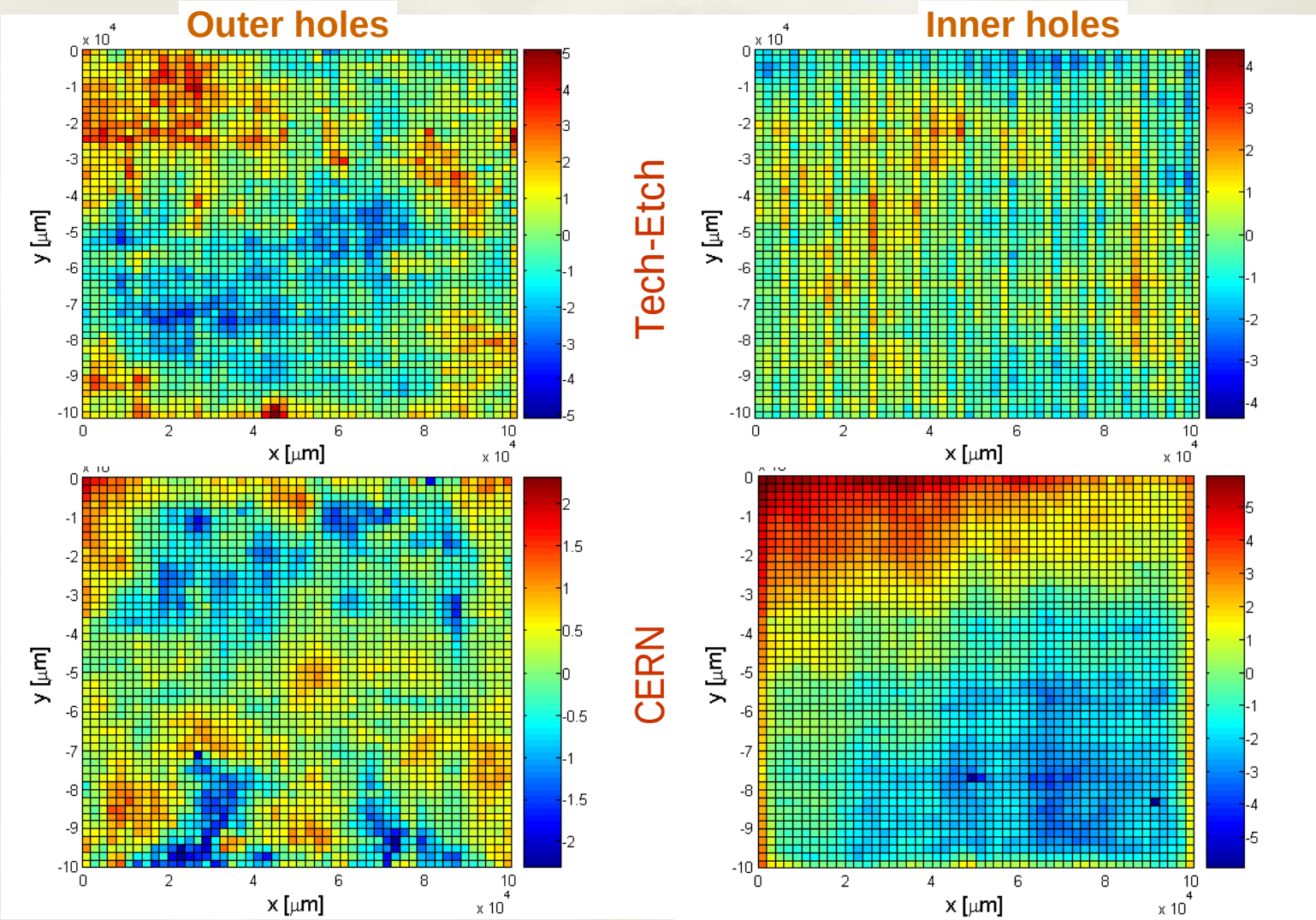
Tech-Etch (10x10 cm^2)



CERN HBD GEM (23x27 cm^2)

Hole size variations can lead to large variations in overall gain and gain stability

Homogenity of Hole Pattern



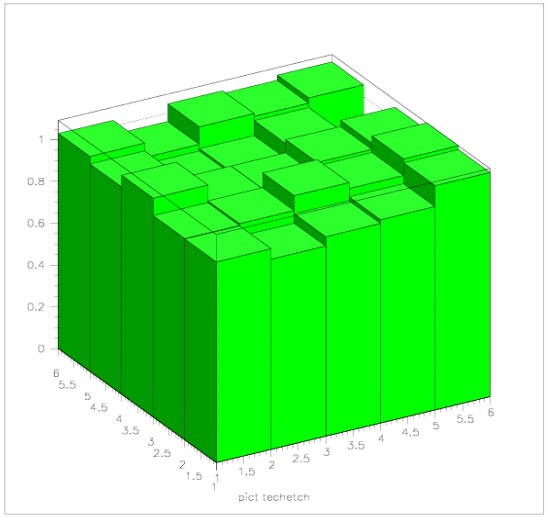
Homogeneity of CERN and TE foils are similar

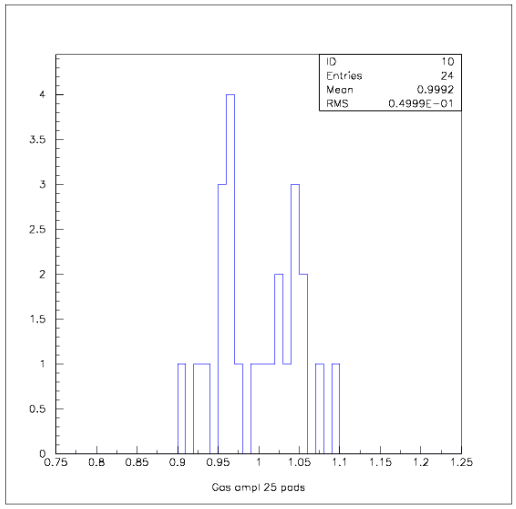
F.Simon (MIT)

Gain Uniformity - Tech-Etch GEMs

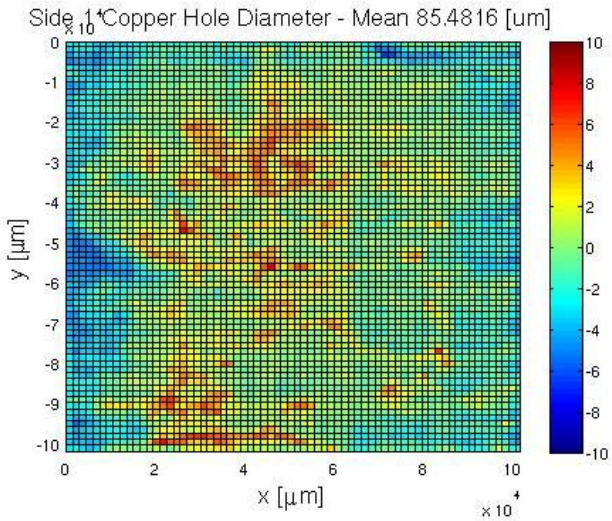
TE 356526-4
10x10 cm^2

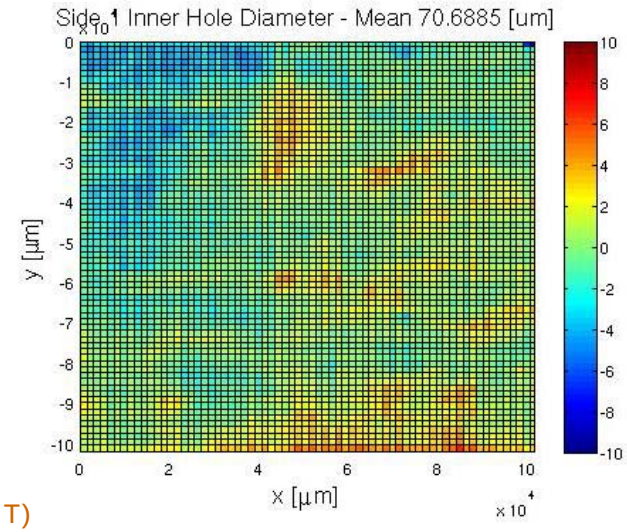
RMS = 5%





N.Smirnoff (Yale)

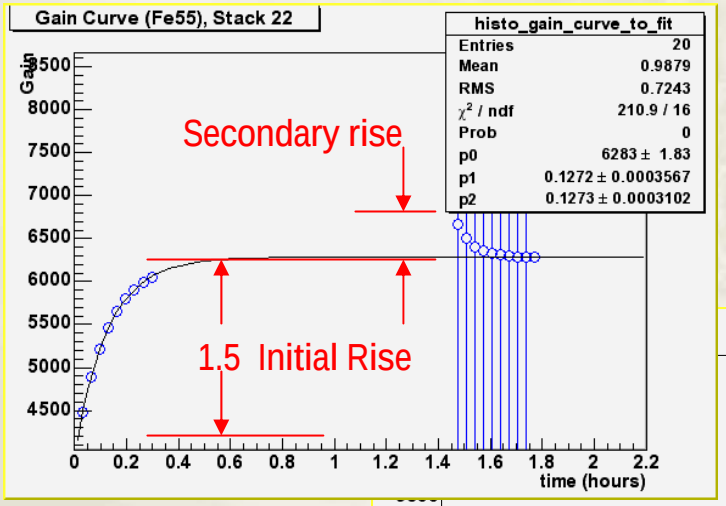




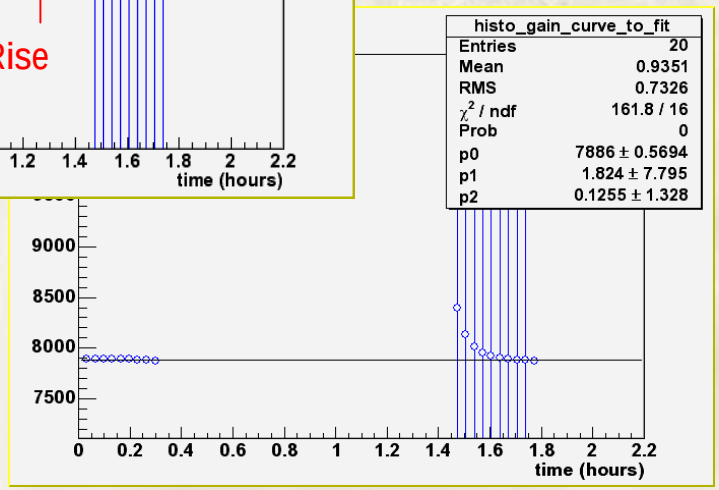
F.Simon (MIT)

Gain Uniformity - HBD GEMs

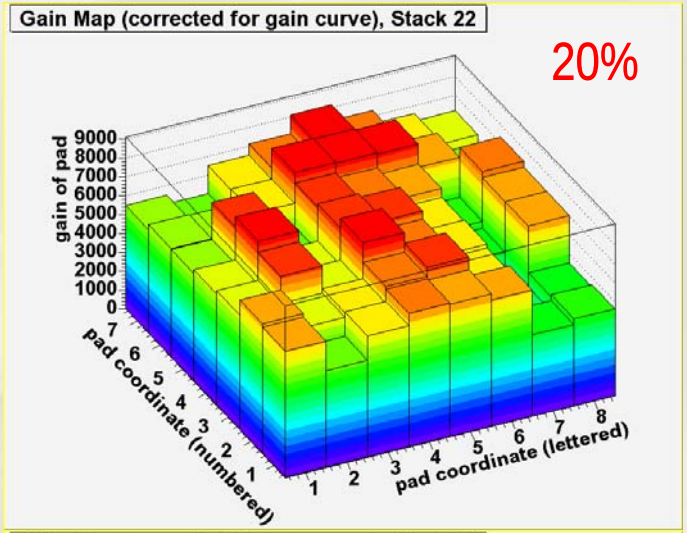
Single pad is irradiated with a 8 KHz ^{55}Fe source for ~ 20 min. Then all other pads are measured, and the source is returned to the starting pad.

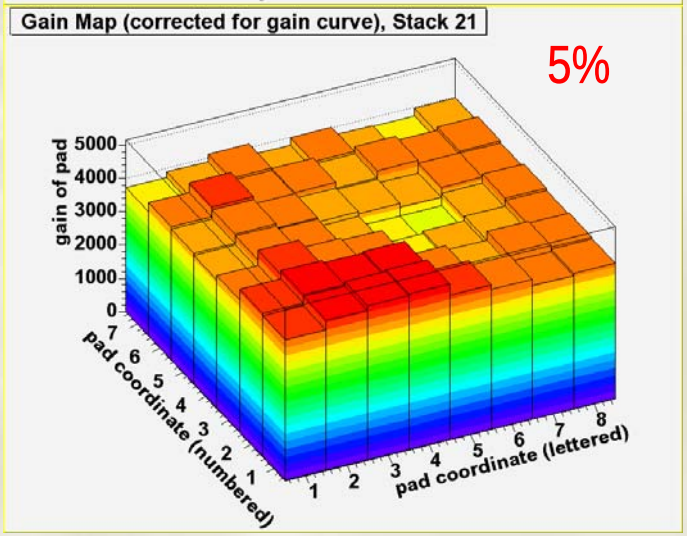


J.Kamin (Stony Brook)

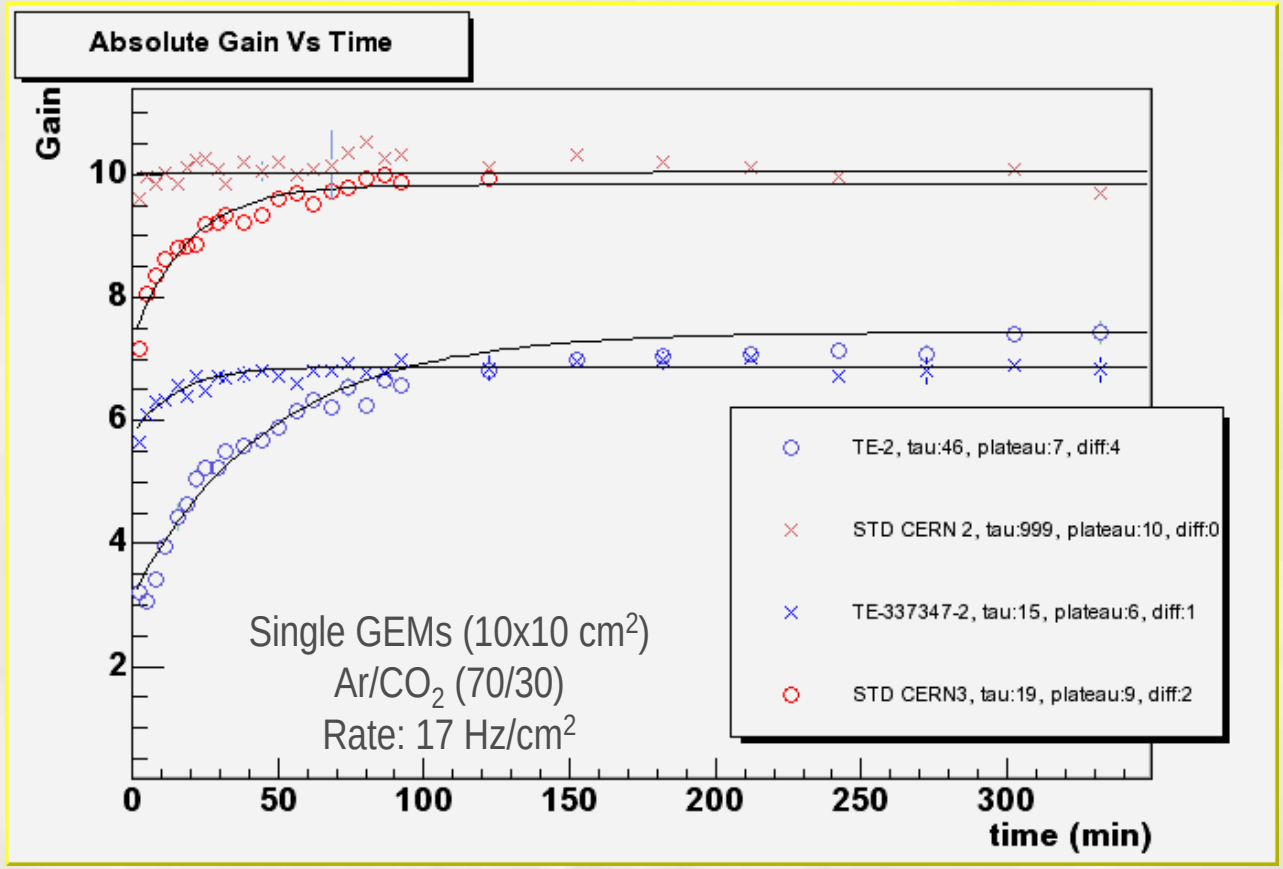


Gain increases range from a few % to ~ 2





Gain vs Time

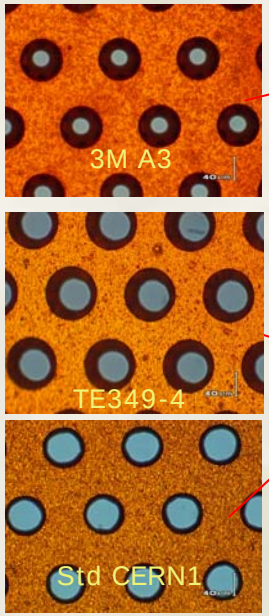


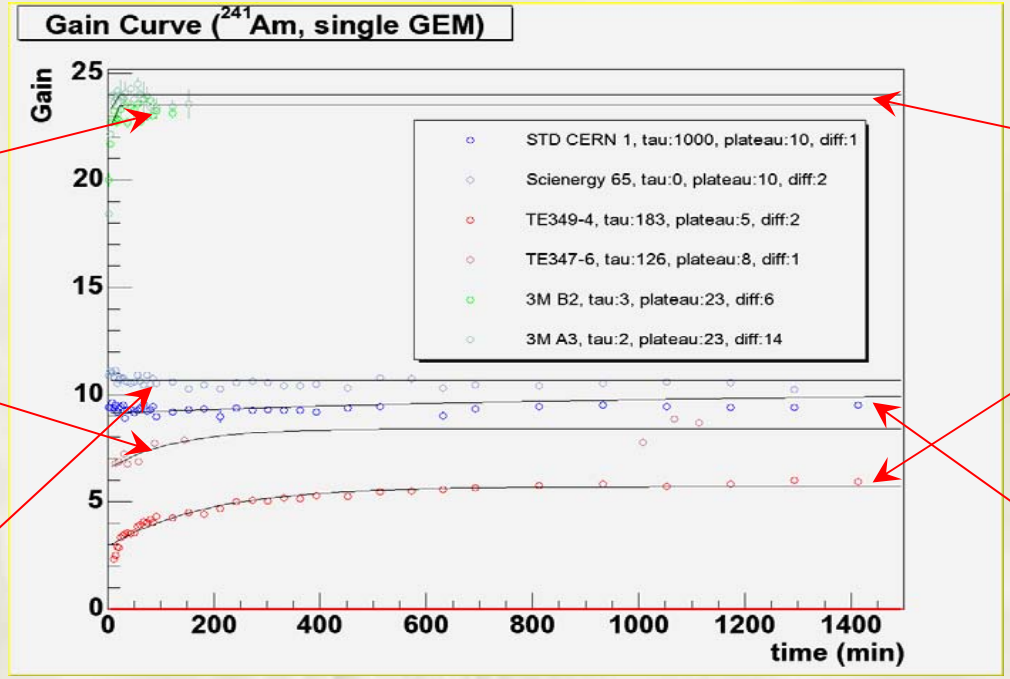
B.Azmoun (BNL)

Both CERN and Tech Etch GEMs show gain increase with time (some more than others…)

Gain Changes Depend on Hole Geometry

More Polyimide Exposed

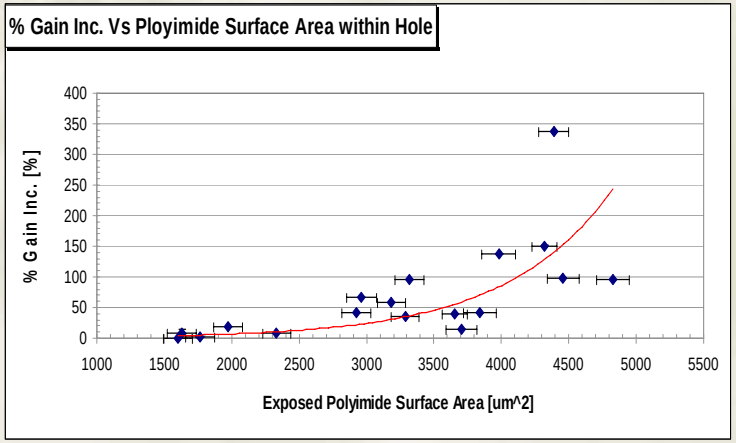




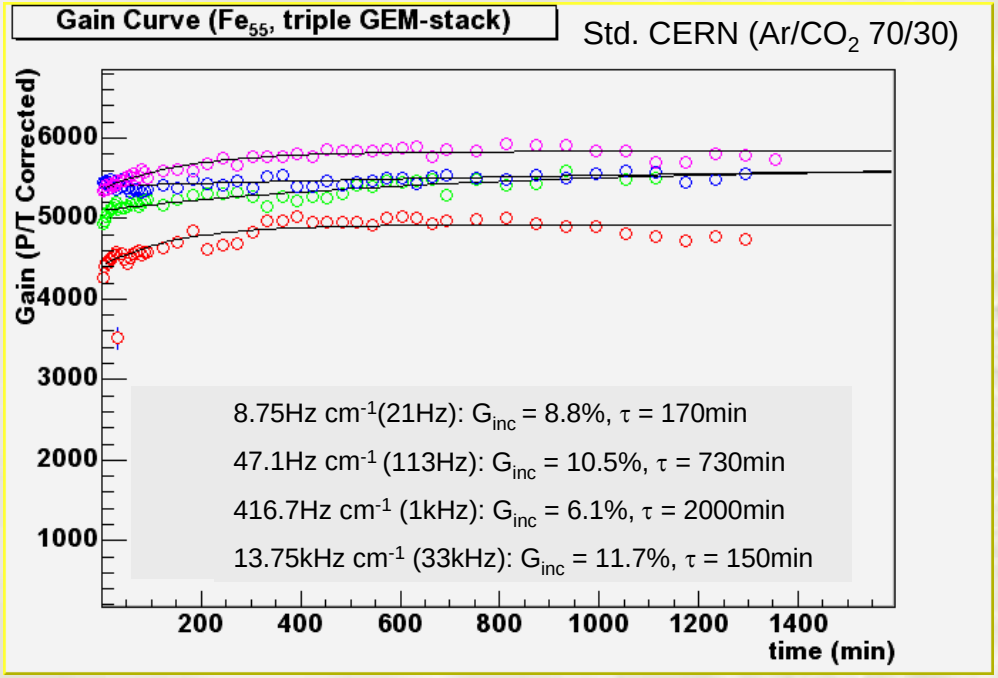
B.Azmoun (BNL)

More exposed polyimide
(more conical hole)

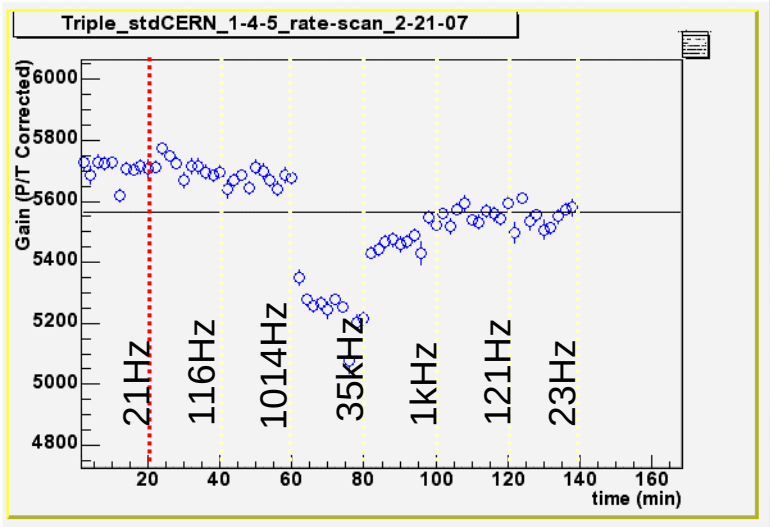
⇒ Larger gain increase



Rate Dependence



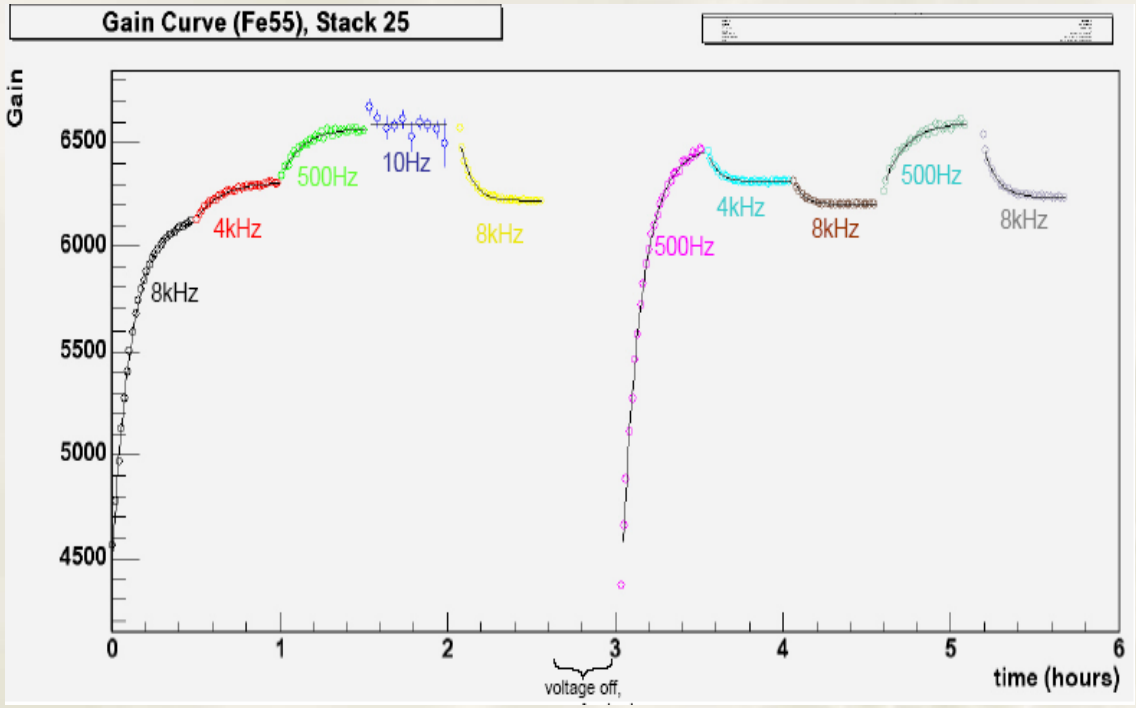
B.Azmoun, J.Herstoff (BNL)

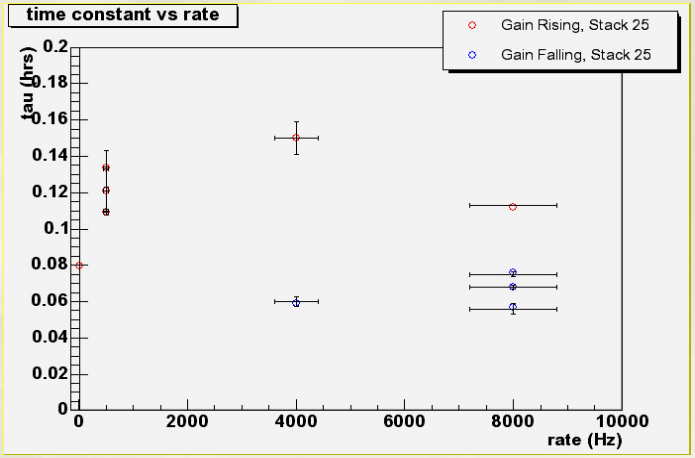


Similar to Bo's result

Small rate dependence seen in small (10x10 cm^2) CERN GEMs

Rate Dependence – HBD GEMs



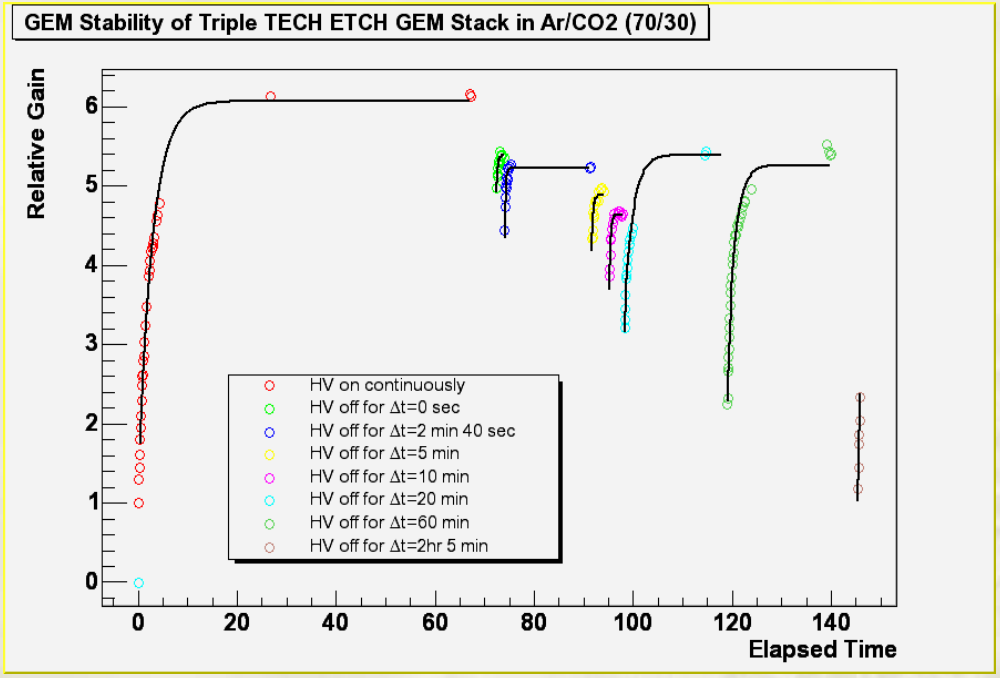


Charge up time constant is longer than discharge time constant

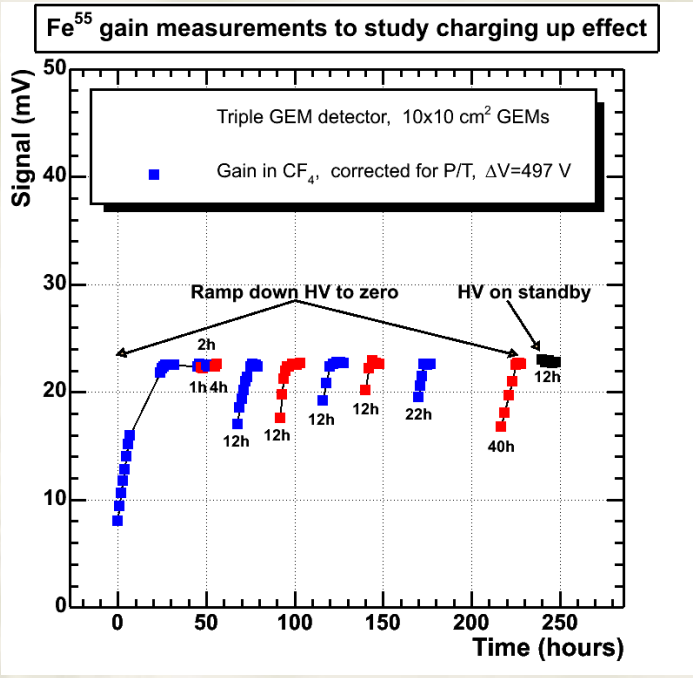
J.Kamin (Stony Brook)

HBD GEMs exhibit similar behavior
Plateau depends on rate history

Gain Changes vs HV On/Off



B. Azmoun (BNL)

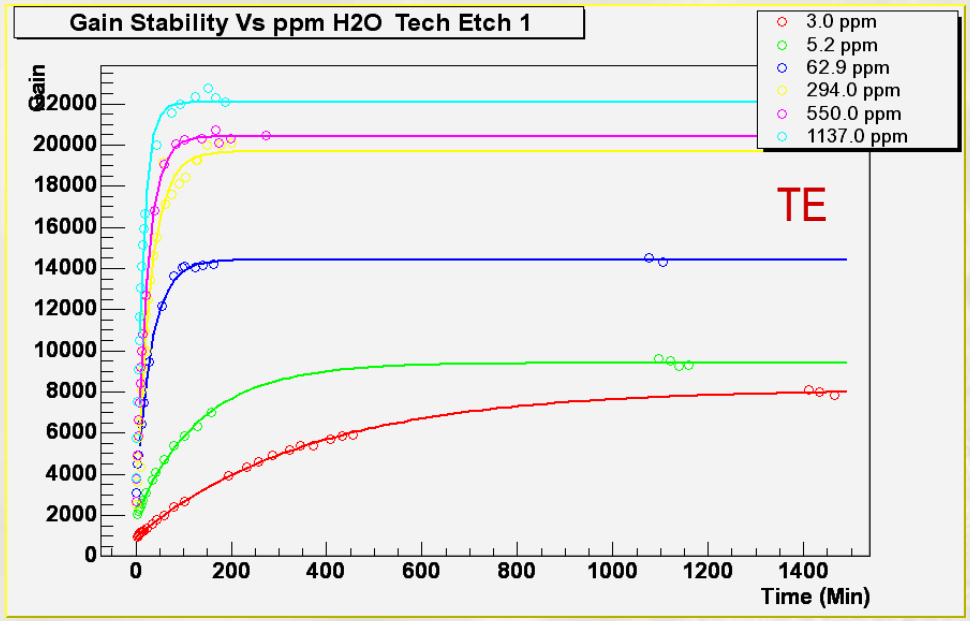


I. Ravinovich (Weizmann)

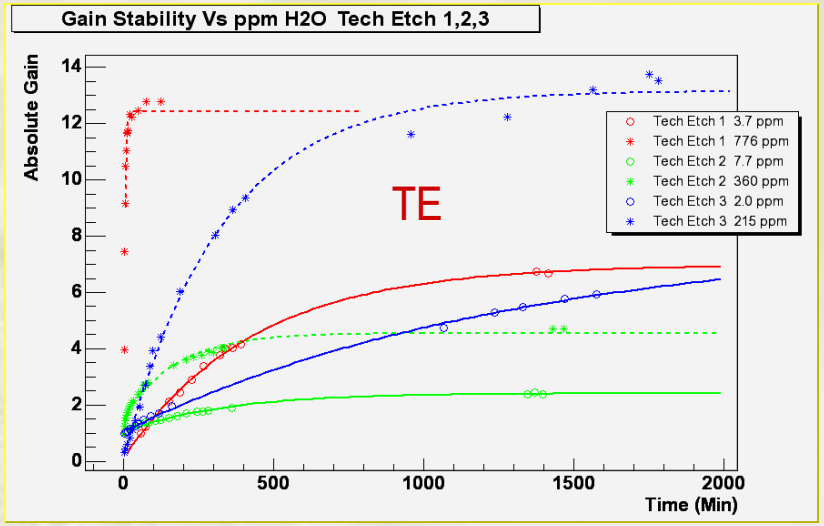
Gain decreases after turning off HVas a result of discharging of GEM

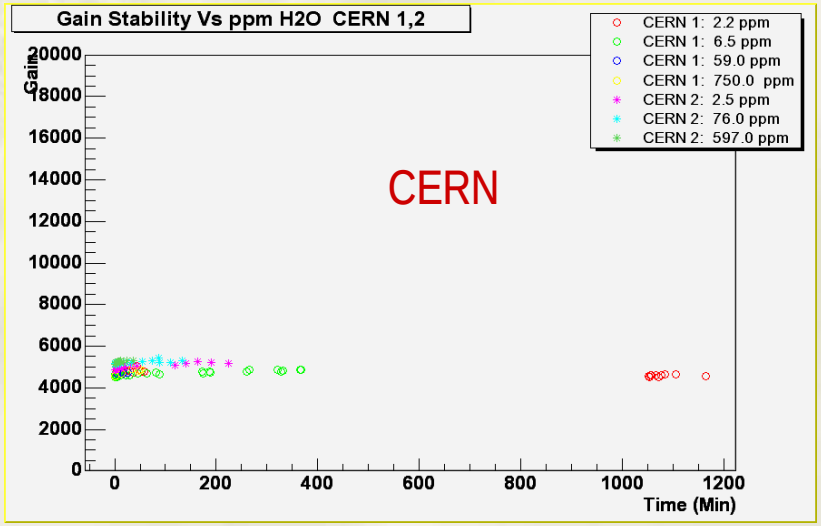
Amount of decrease depends on time voltage is off

Gain Stability vs Water Content of Operating Gas



B. Azmoun (BNL)



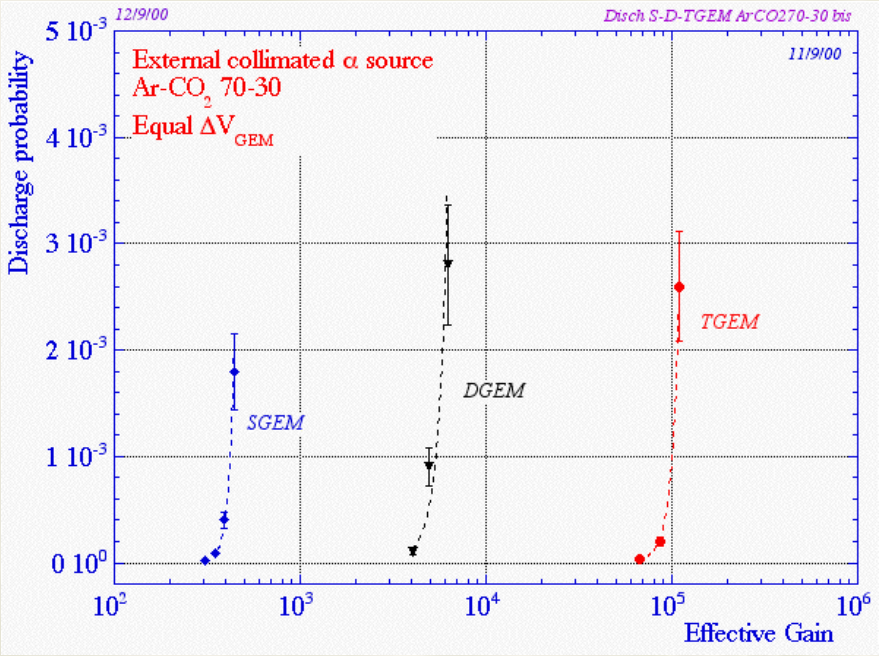


Low water vapor $\Rightarrow$ low, slow rise

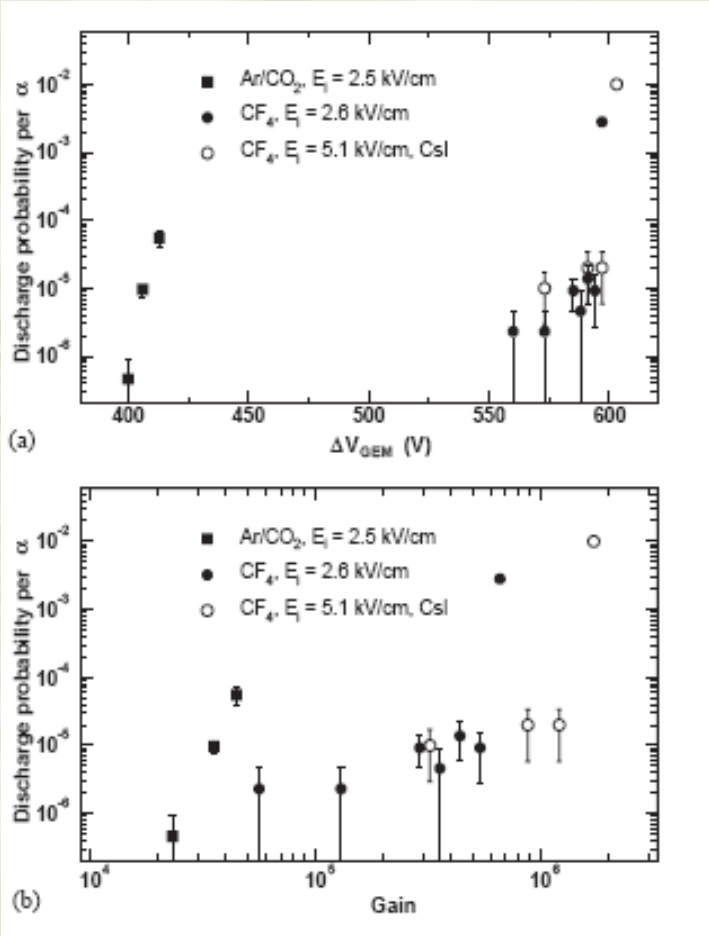
High water vapor $\Rightarrow$ high, fast rise

Water in the gas may change surface conductivity of the dielectric

Discharge Probability



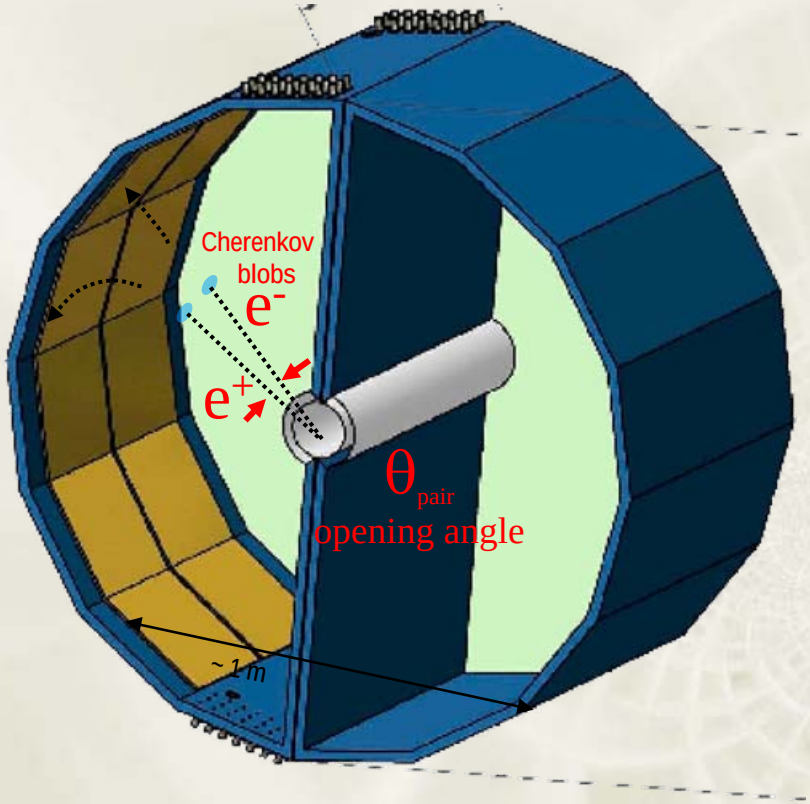
S. Bachmann et al, CERN-EP/2000-151



A.Kozolov, NIM A523 (2004) 345-354

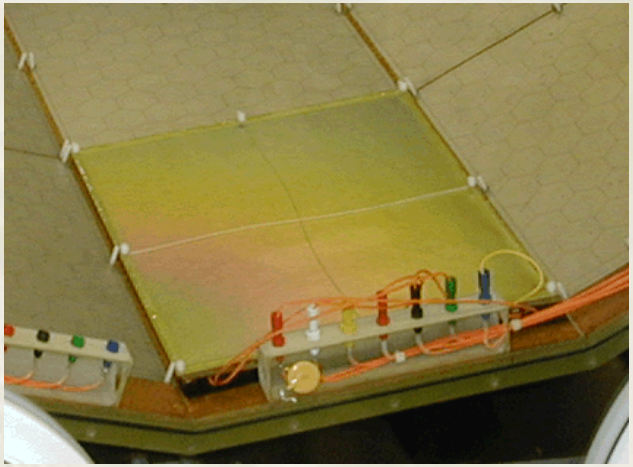
Discharges are nevertheless common in all GEMs due to imperfections, dust, etc and can can cause damage to the GEM foils

The PHENIX Hadron Blind Detector (HBD)



Proximity Focused Windowless
Cherenkov Detector

Radiator gas = Working gas
Gas volume filled with pure CF_4 radiator

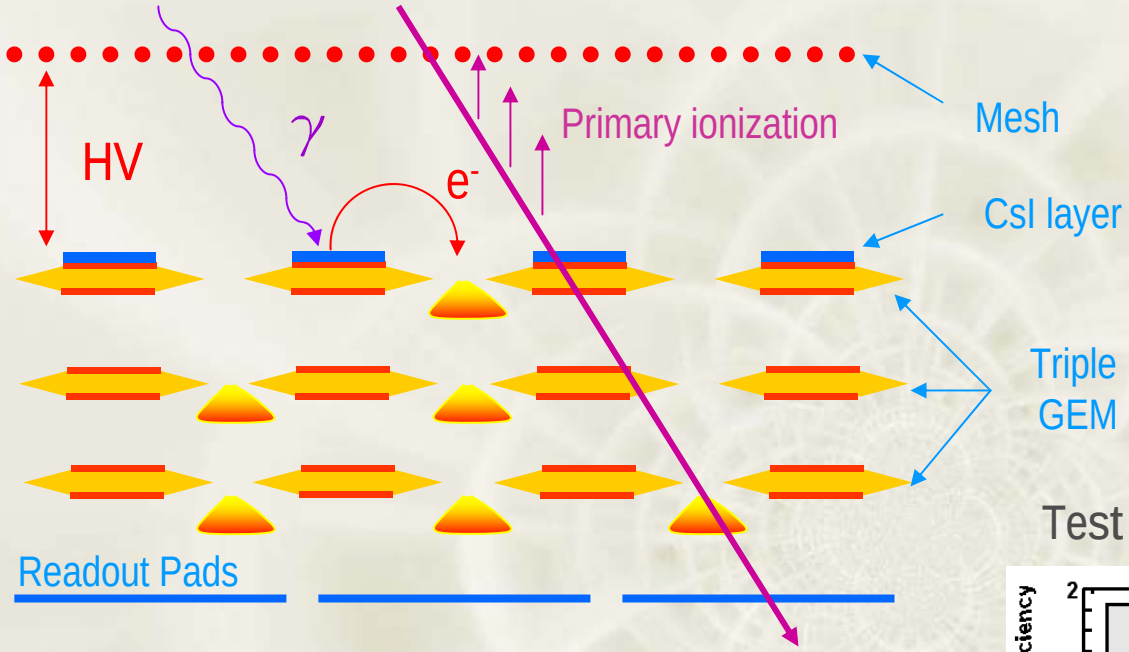


24 Triple GEM Detectors
(12 modules per side)
Area = 23 x 27 cm^2

- Mesh electrode
- Top gold plated GEM for CsI
- Two standard GEMS
- Kapton foil readout plane

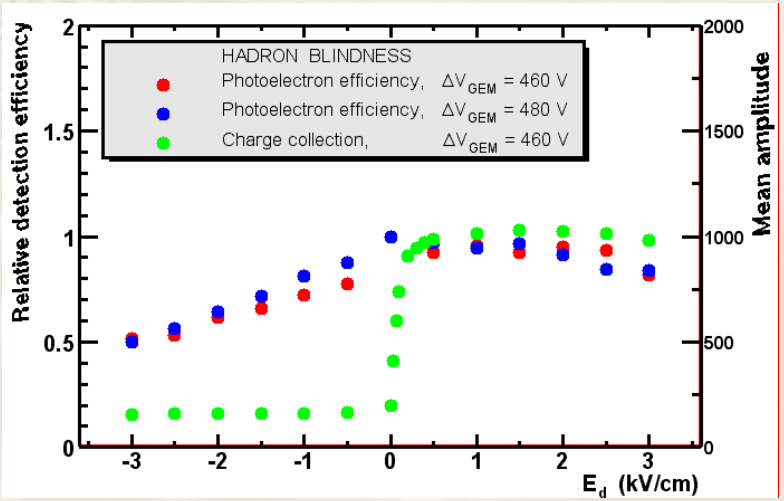
One continuous sheet per side
Hexagonal pads (a = 15.6 mm)

The Hadron Blind Concept



Primary ionization signal is greatly suppressed at slightly negative drift field while photoelectron collection efficiency is mostly preserved

Test with UV photons and α particles



Z.Frankel et.el., NIM A546 (2005) 466-480.
A.Kozolov et.al. NIM A523 (2004) 345-354.

- **Primary ionization is drifted away from GEM and collected by a mesh**
- **UV photons produce photoelectrons on a CsI photocathode and are collected in the holes of the top GEM**
- **Triple GEM stack provides gain ~ few x 10^3**
- **Amplified signal is collected on pads and read out**

Photocathode Production and Detector Assembly

"Clean Tent" at Stony Brook

Laminar Flow Hood

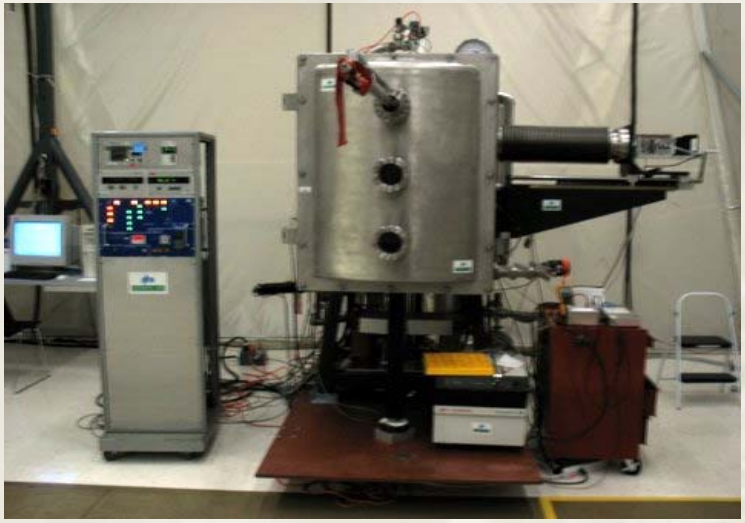
High Vacuum GEM Storage Container

CsI Evaporator and quantum efficiency measurement

Large glove box
$O_2 < 5$ ppm
$H_2O < 10$ ppm

Class 10-100 (N < 0.5 μm particles/m^3)

Evaporator and QE Measurement

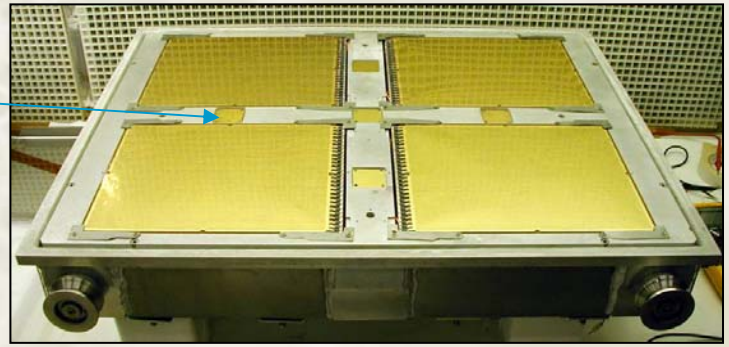


Produces 4 photocathodes per evaporation

- Deposit 2400 – 4500 Å CsI @ 2 nm /sec
- Vacuum ~ 10^{-7} Torr
- Contaminants measured with RGA

Virtually no water !

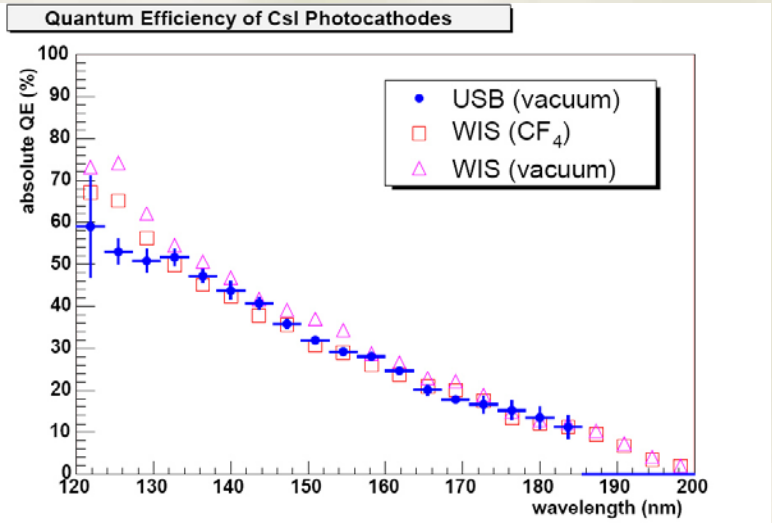
Small "chicklets" evaporated at same time for full QE measurement (120-200 nm)



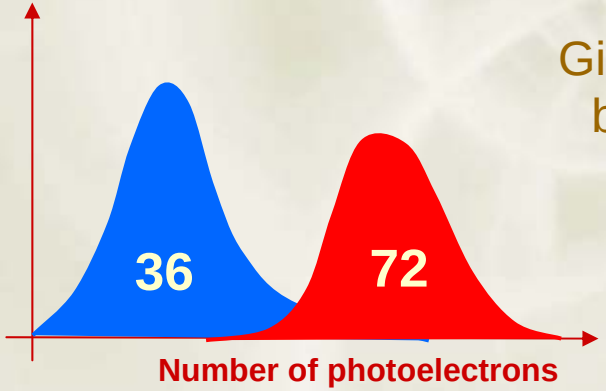
- Measures photocathode quantum efficiency in situ from 165-200 nm over entire area
- Photocathodes transported to glove box without exposure to air

Photocathode Quality

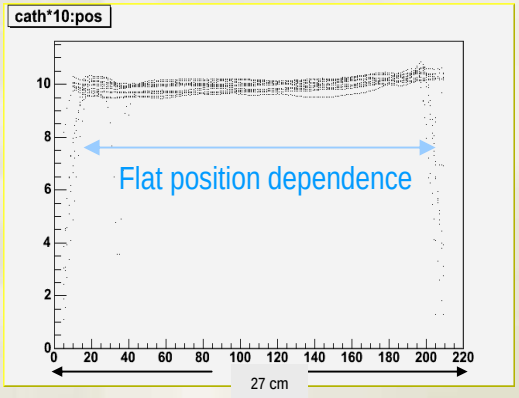
Large bandwidth of CF_4 (6-11.5 eV), windowless construction and high QE of CsI in deep VUV gives very large N_0 (840 cm-1)



Expect ~ 36 p.e. per blob

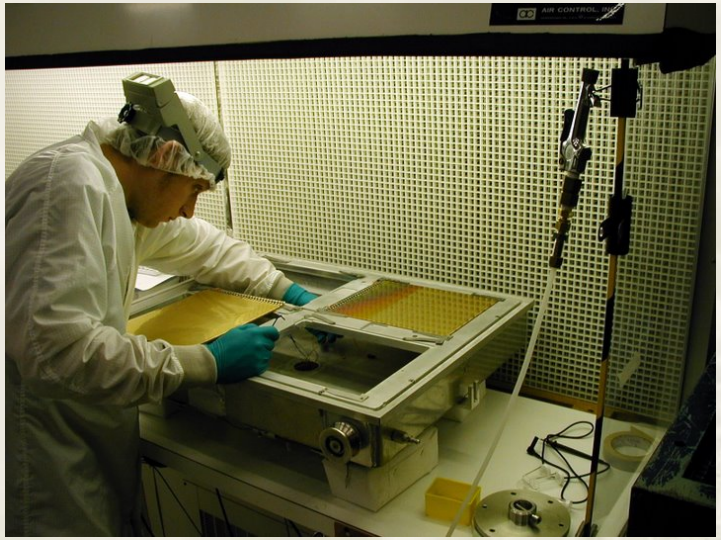


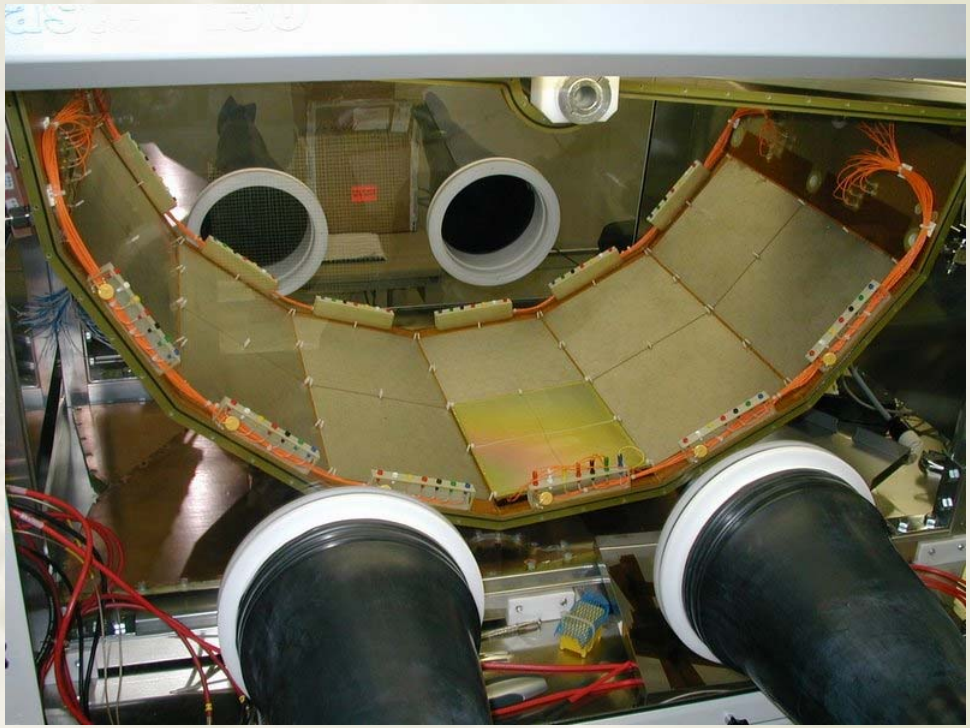
Gives good separation between single and double electrons



Photocathodes were produced with consistently good quantum efficiencies

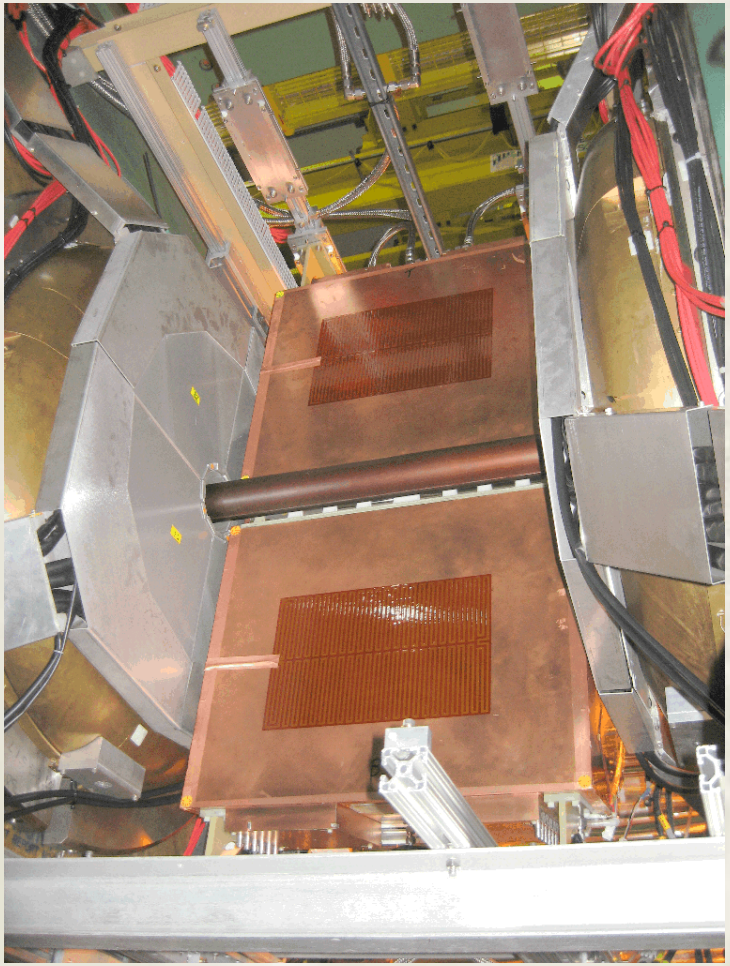
Construction of the Actual Detector



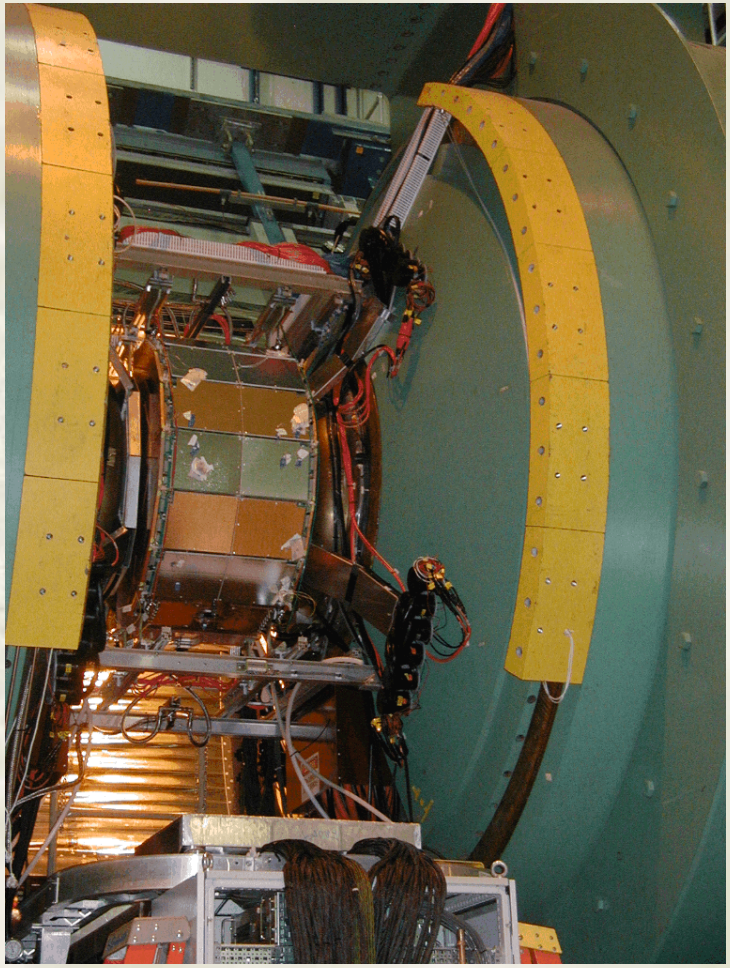


All twelve modules installed in HBD West

HBD Installed in PHENIX Last Fall

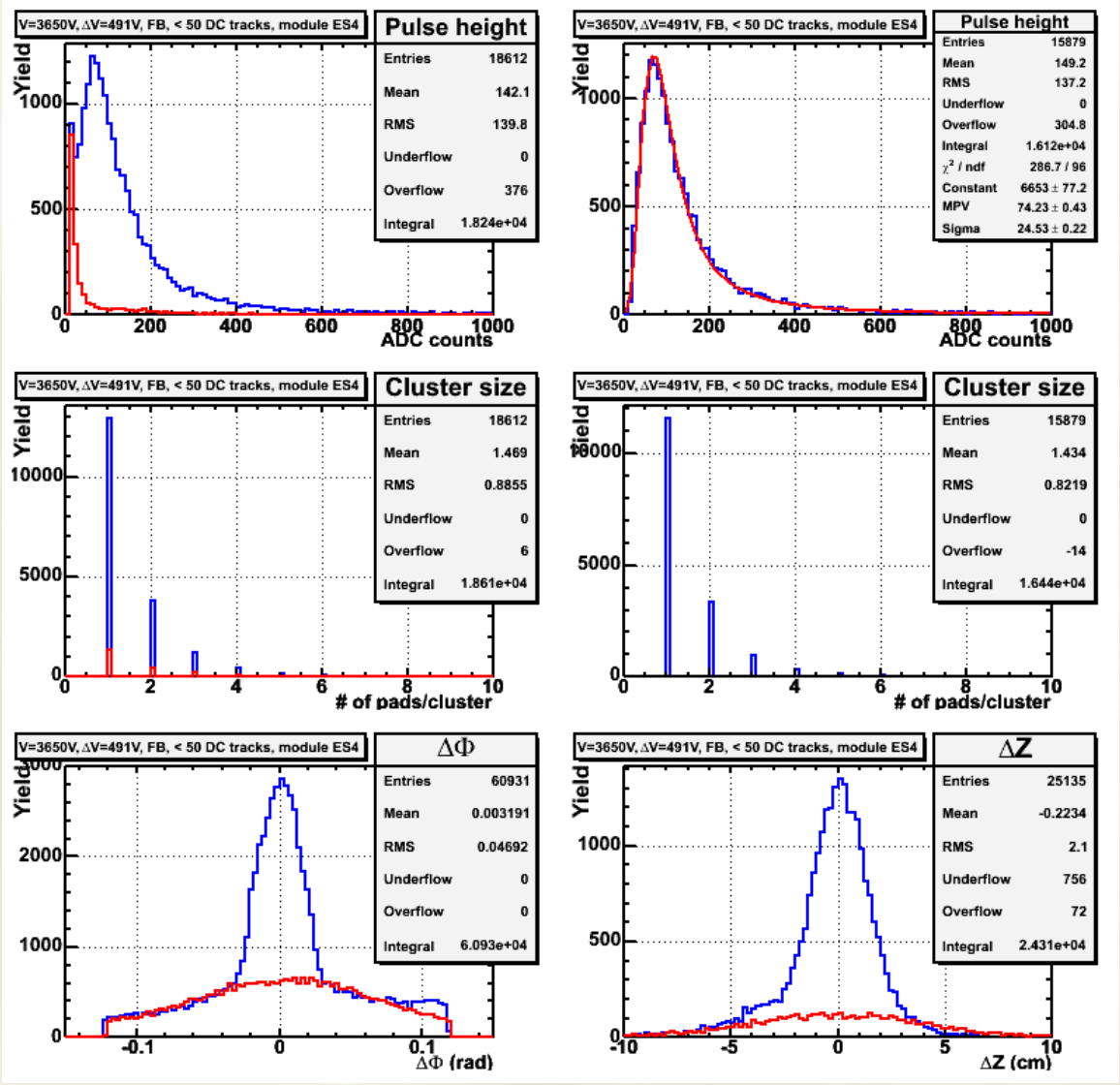


HBD West (front side)
Installed 9/4/06



HBD East (back side)
Installed 10/19/06

HBD Performace – Hadron Response



I. Ravinovich (Weizmann)

Hadrons in PHENIX matched to HBD in Forward Bias Mode

Pulse height

Gas gain ~ 2900

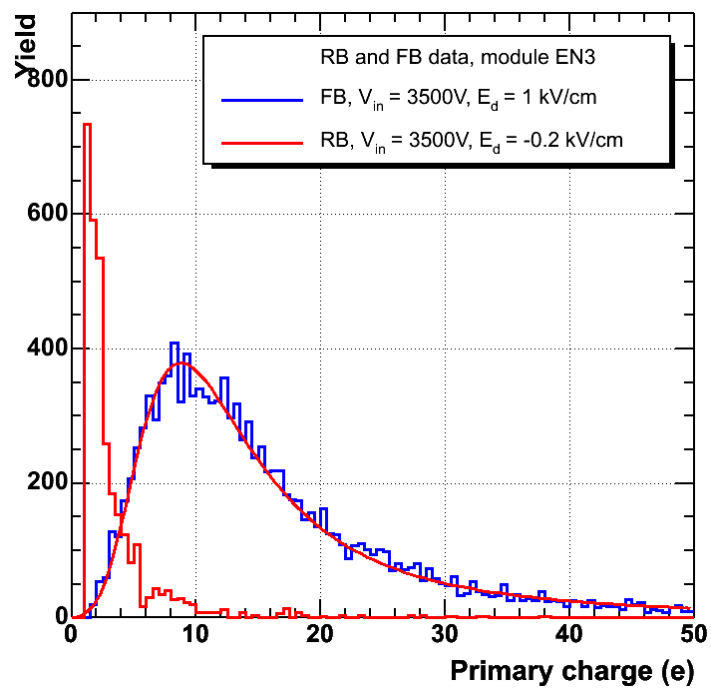
Much larger than expected from lab tests ??

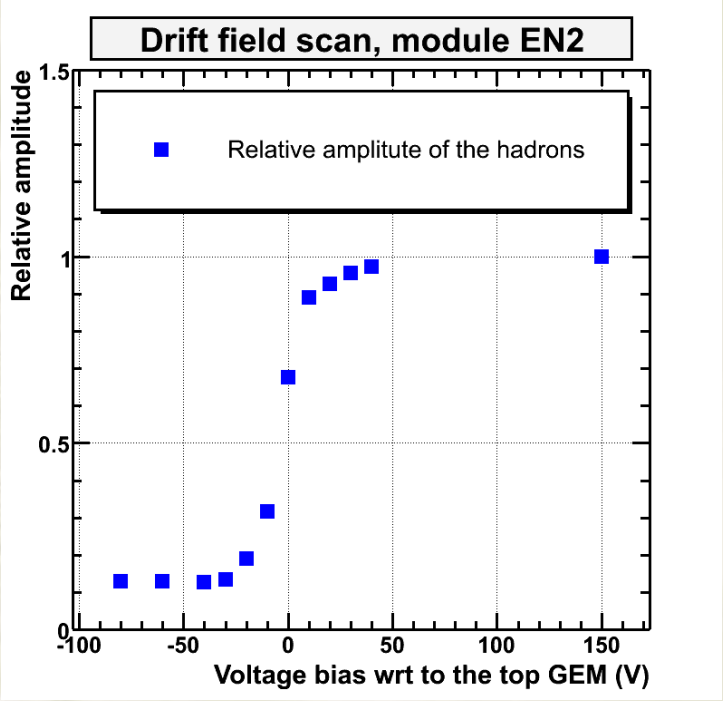
- CsI
- Gas
- Dryness

Cluster Size

Track matching

HBD Performance – Hadron Blindness

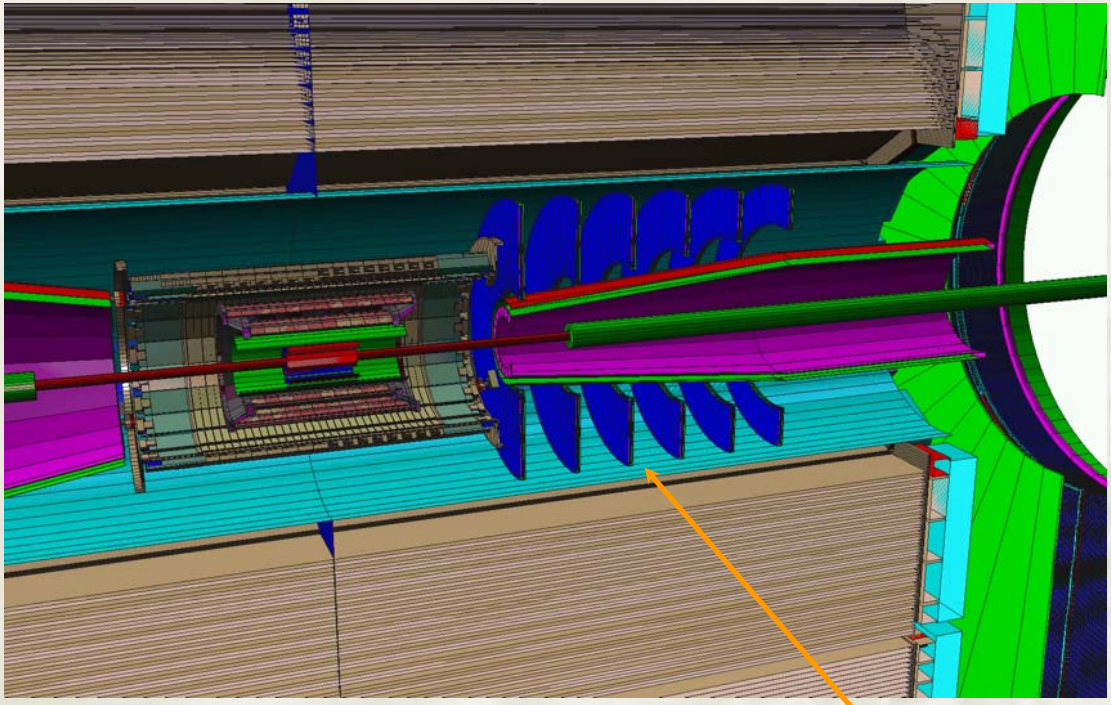




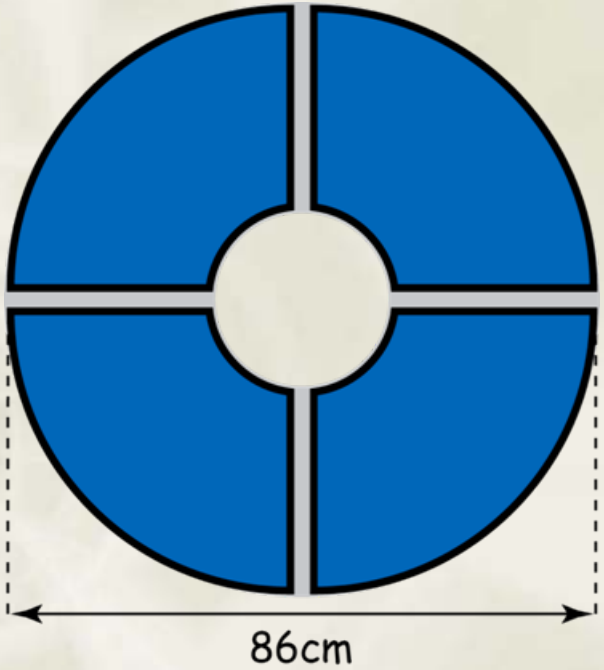
I. Ravinovich (Weizmann)

Hadron blindness observed as expected

STAR Forward GEM Tracker (FGT)



B. Surrow (MIT)



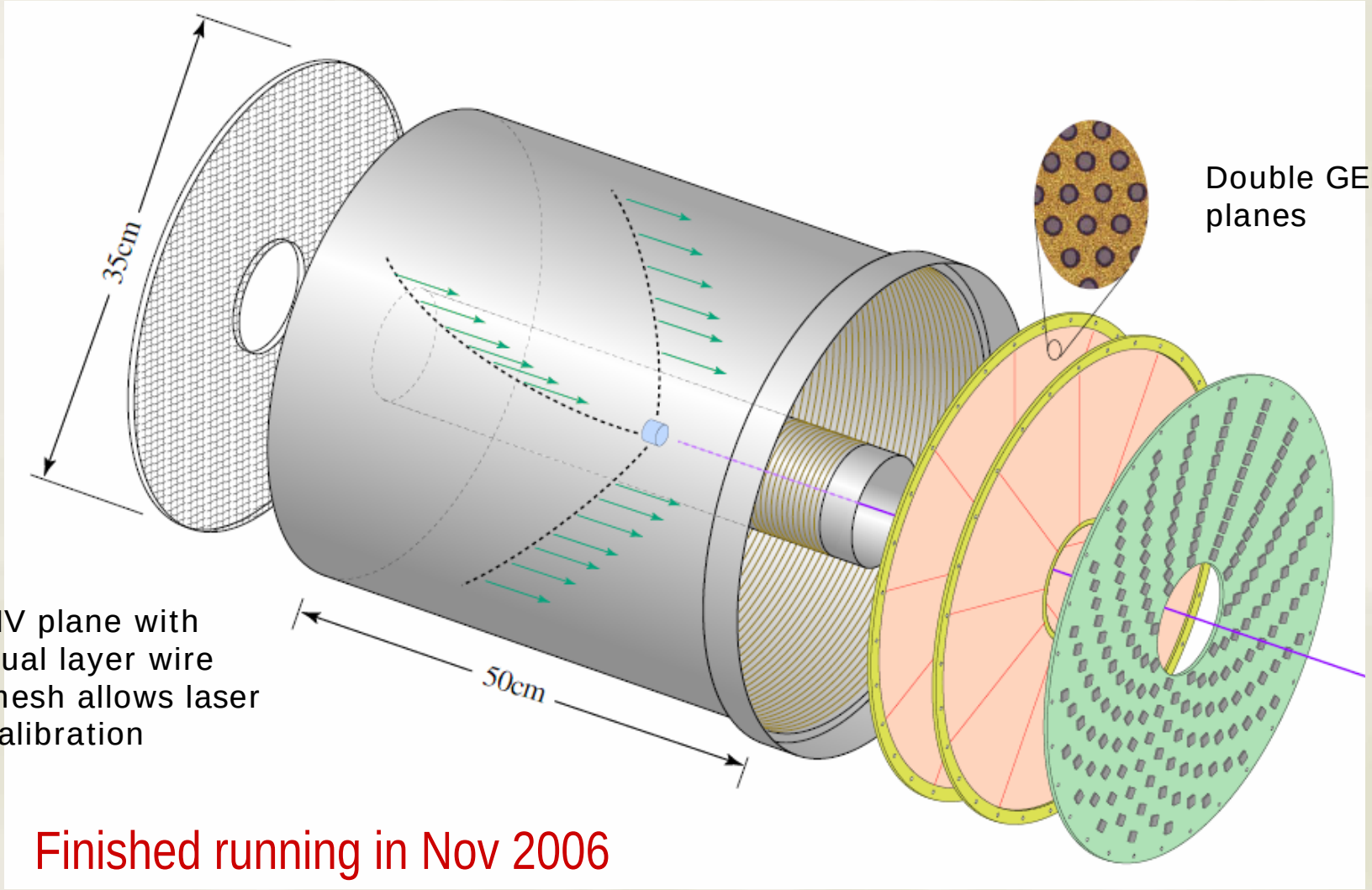
Purpose:
To provide additional tracking in the forward direction in STAR in order to measure high P_T W-production in pp interactions

FGT: Six detector disks

Each disk consists of 4 triple-GEM chambers

GEMs to be supplied by Tech Etch

LEGS TPC



Finished running in Nov 2006

How do we make a better GEM foil ?

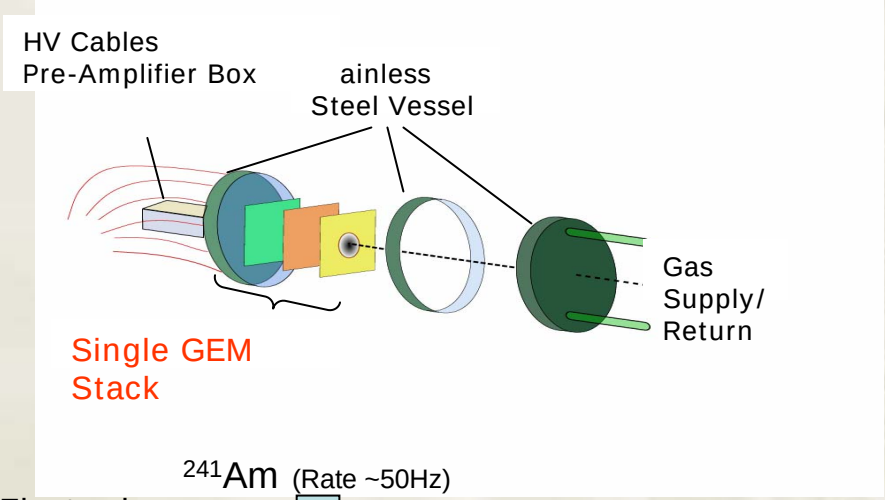
- GEMs appear to exhibit an inherent charging effect due to the polarization of the dielectric in a high electric field that can affect their gain. This effect is observed to some degree in all GEMS, but can vary significantly from one foil to another.
- Factors affecting the charging effect
  - Hole geometry
  - Moisture
  - Rate
- Improvements
  - More cylindrical holes
  - Better control on mask alignment and process chemistry
  - Laser/plasma etching looks promising

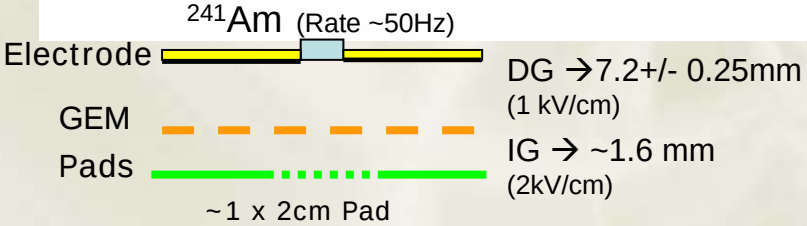
Backup Slides

Single GEM & Triple GEM Measuerments

Single GEM

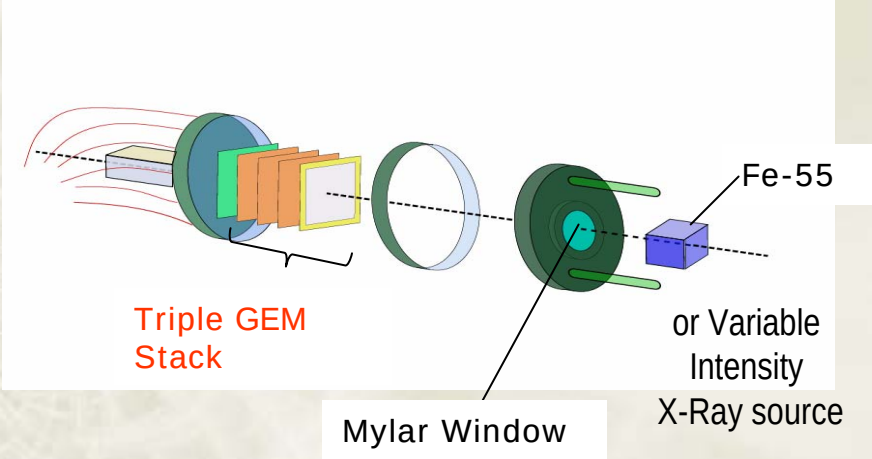
- Source: Am-241 (Activity ~ 80Hz)
- Primary charge ~35,000 e^- over 1cm
- Working Gas = ArCO2 (70/30)

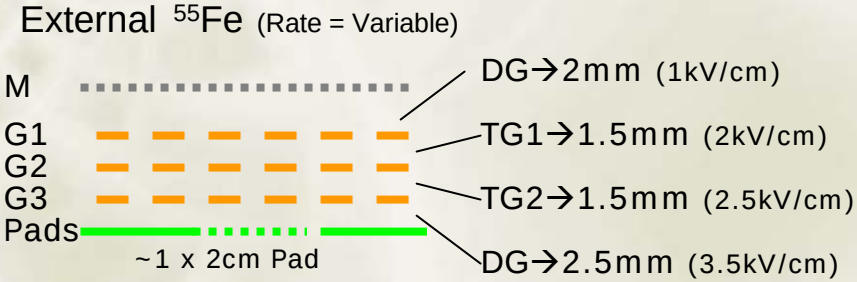




Triple GEM

- Source: Fe-55 (Variable: 10 – 10KHz)
- Primary charge 212 e^-
- Working Gas = ArCO2 (70/30)

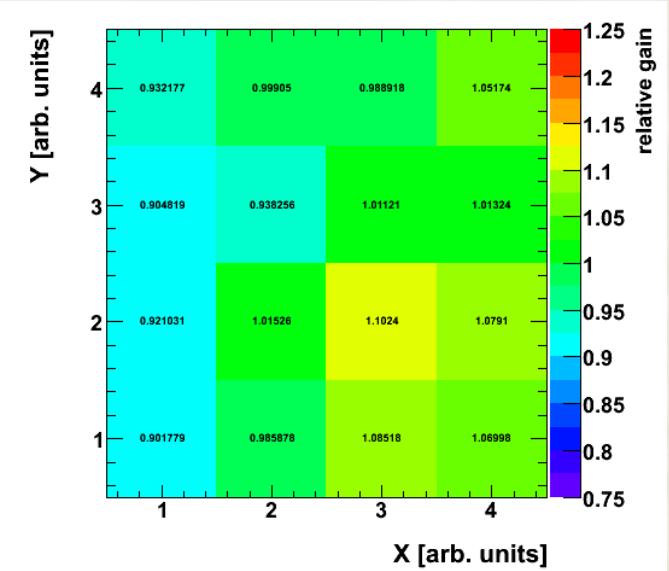




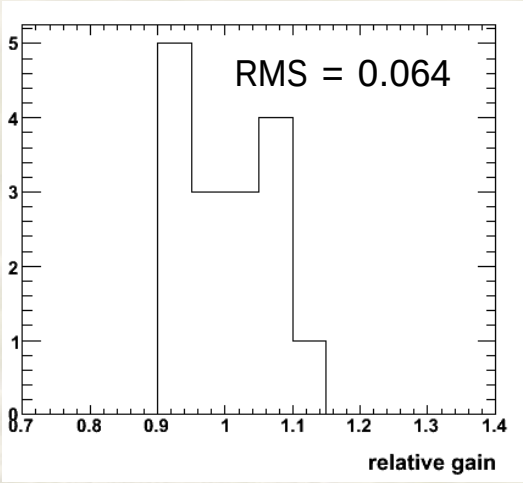
Simultaneously Monitor:

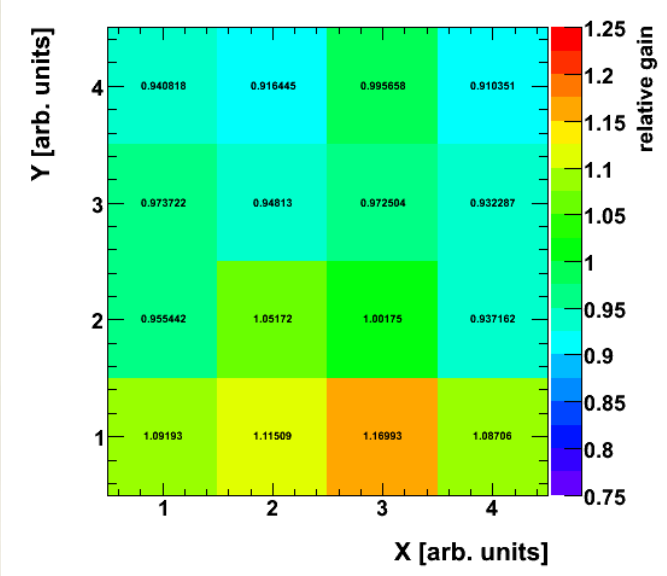
- ppm's of water and oxygen
- Pressure and Temperature of working gas

Gain Uniformity

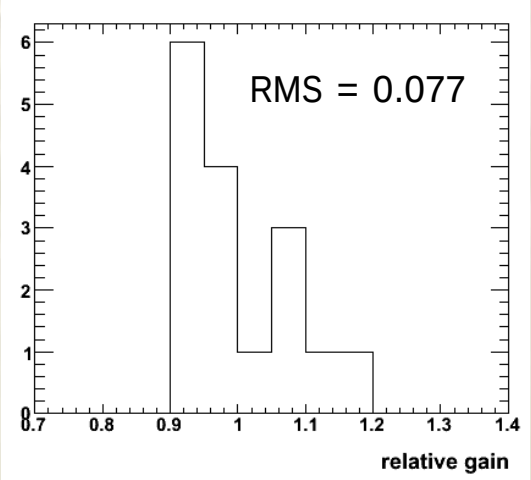


CERN





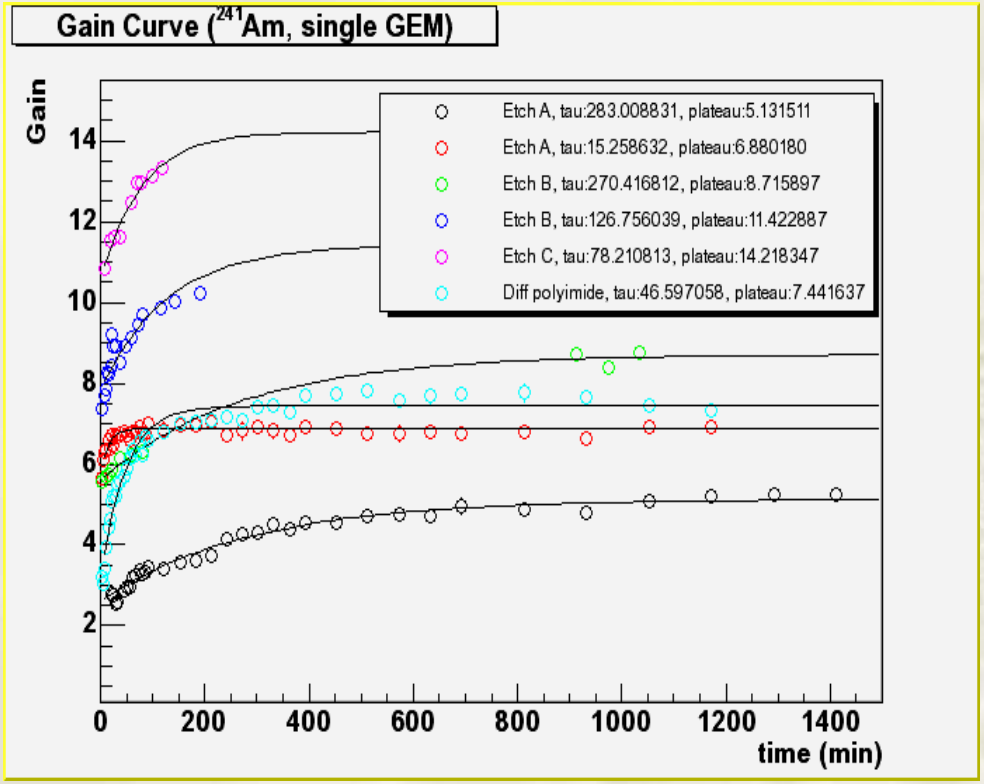
Tech-Etch



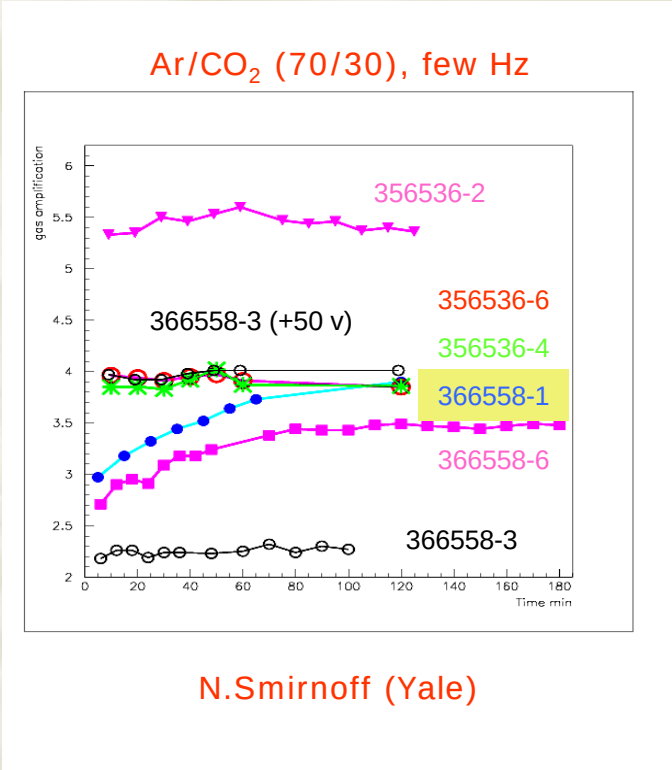
F.Simon (MIT)

Good uniformity for both CERN and TE foil based detectors (measured after charging up of the detectors)

Tech Etch GEMs – Process Variability



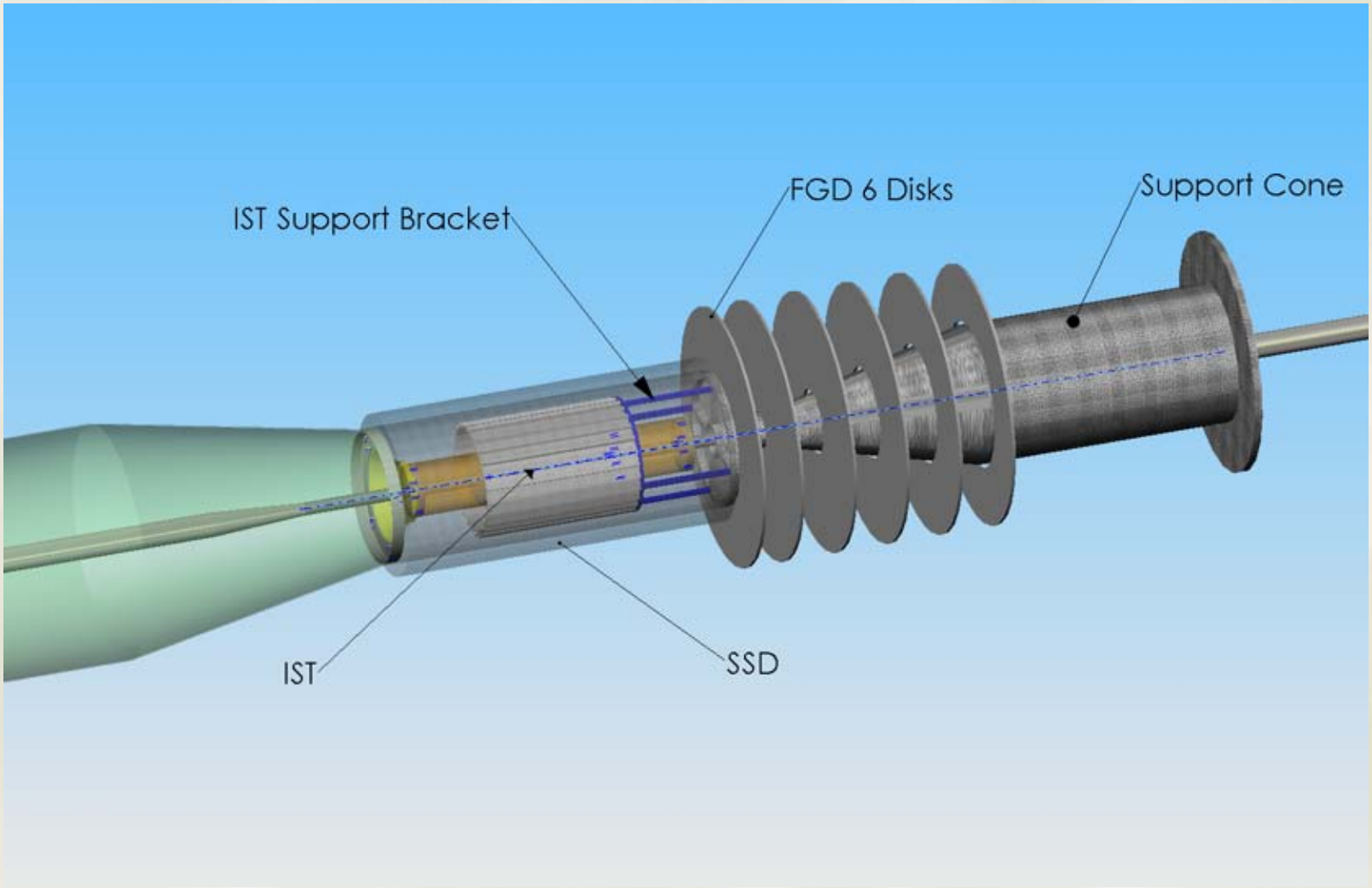
B.Azmoun (BNL)



N.Smirnoff (Yale)

Gain stability not likely due to different polyimide material, etching process, or post etching/cleaning process

STAR Forward GEM Tracker (FGT)



B. Surrow (MIT)