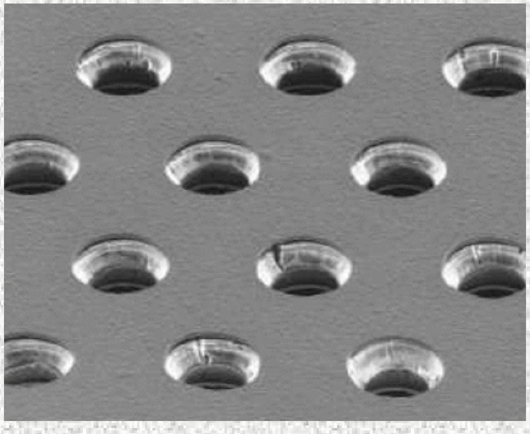
GEM

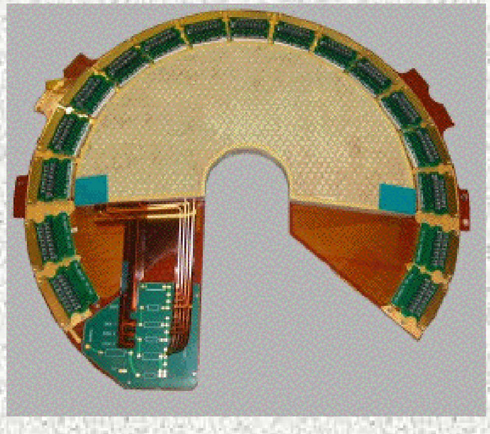
GAS ELECTRON MULTIPLIER DETECTORS: PERFORMANCES AND APPLICATIONS

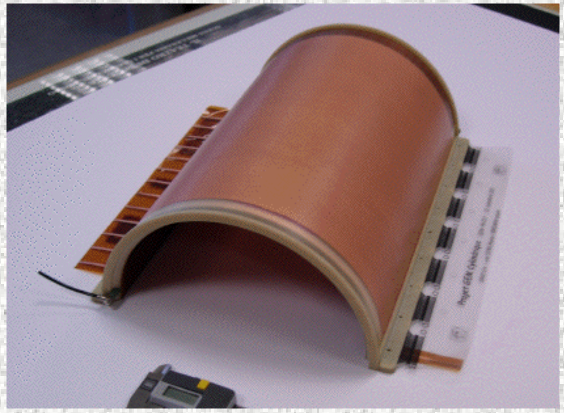
Fabio SAULI

MPGD WORKSHOP

CERN, January 20, 2006

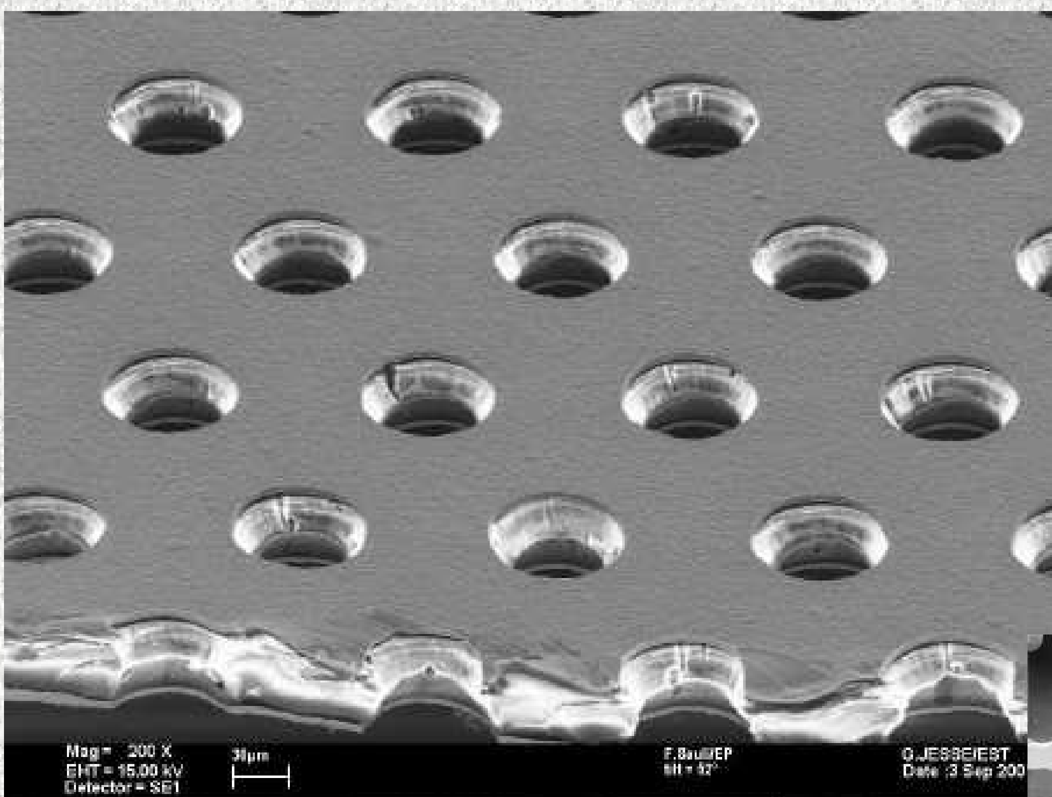




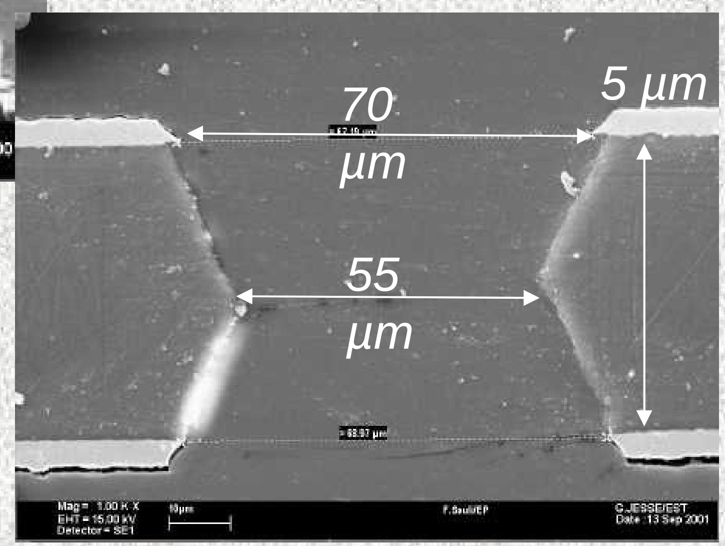


http://gdd.web.cern.ch/GDD/

THIN METAL-COATED POLYMER FOIL CHEMICALLY ETCHED WITH 5-100 HOLES mm^2



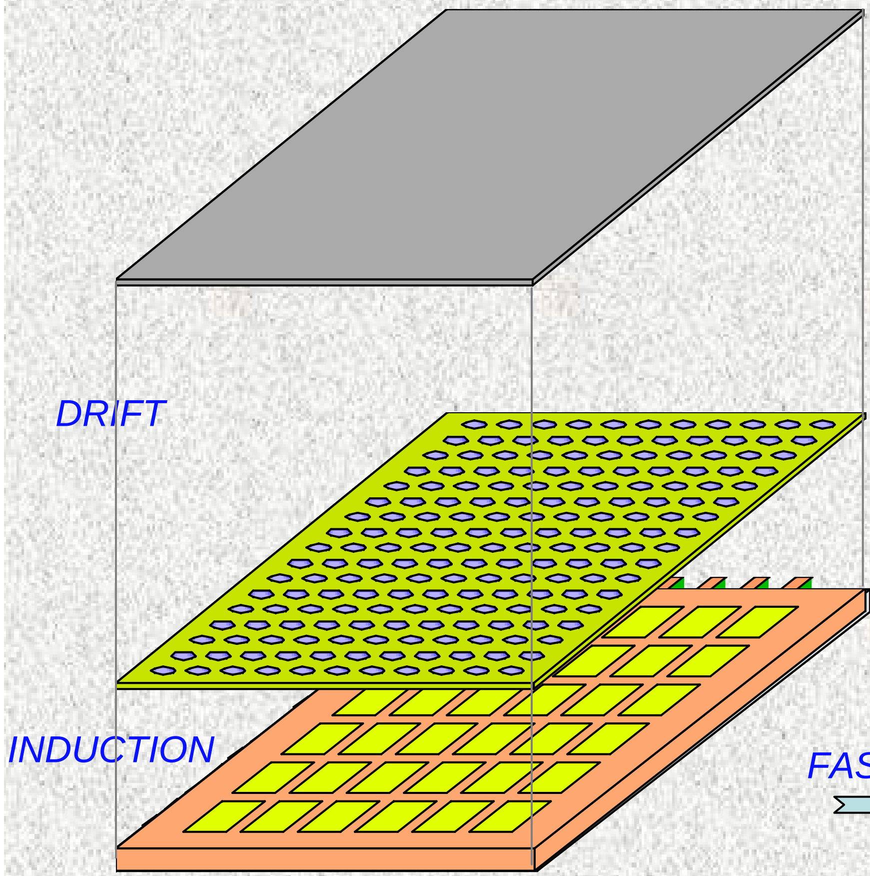
Typically:
- *50 µm Kapton*
- *5 µm Copper*
- *70 µm holes at 140 µm pitch*

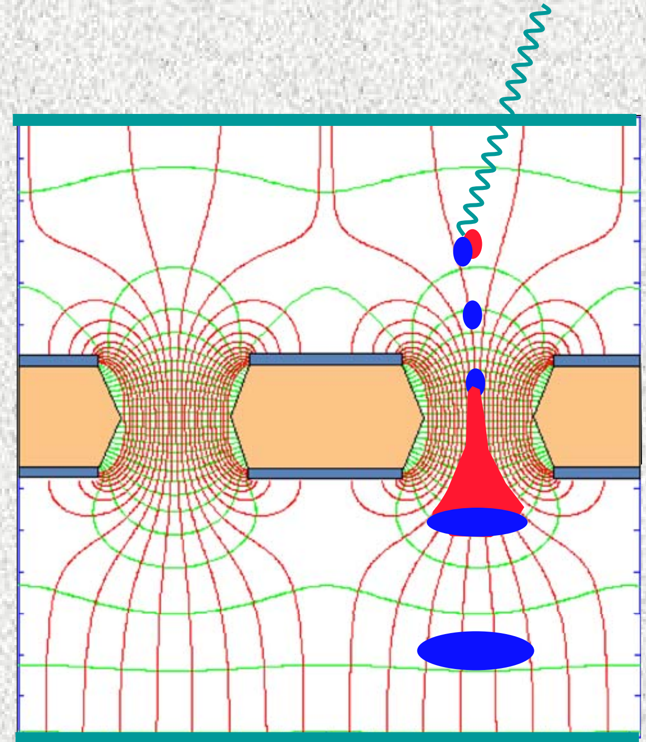


MANUFACTURED BY CERN-TS-DEM
(Rui De Oliveira)

F. Sauli, NIMA 386(1997)531

AMPLIFICATION AND TRANSFER SINGLE GEM DETECTOR:





INDEPENDENT PROPORTIONAL COUNTERS (~ 50/mm^2) ⇒ HIGH RATE CAPABILITY

HIGH VOLTAGE ELECTRODE SEPARATED FROM READOUT ⇒ ROBUSTNESS

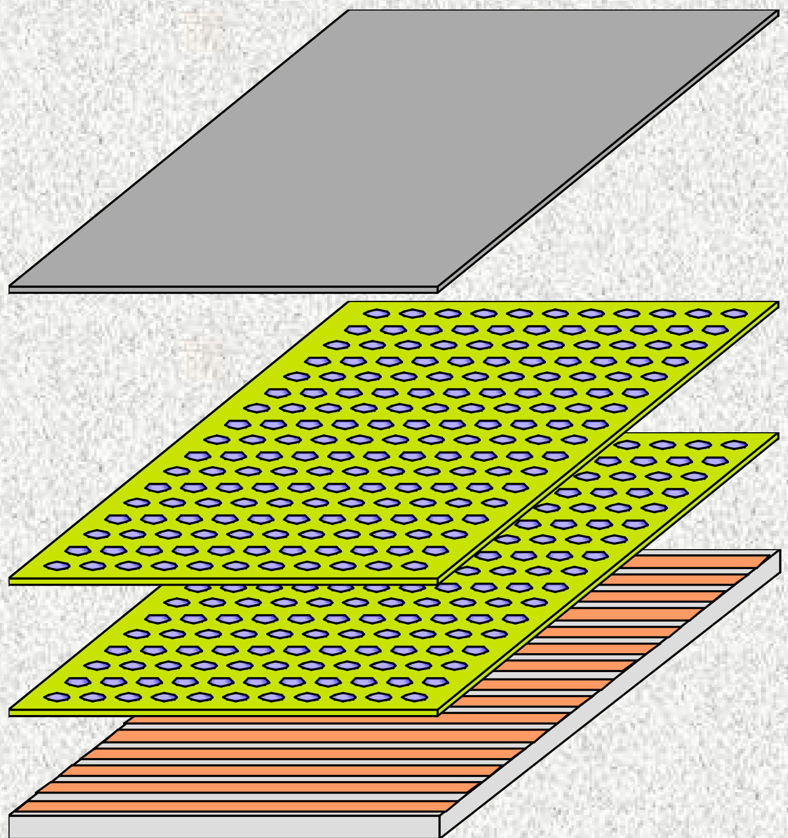
FAST ELECTRON SIGNAL ONLY ⇒ HIGH RATES, GOOD TWO-TRACK RESOLUTION

READOUT ELECTRODE: ARBITRARY PATTERN

MULTIPLE GEM DETECTORS:

HIGHER GAIN

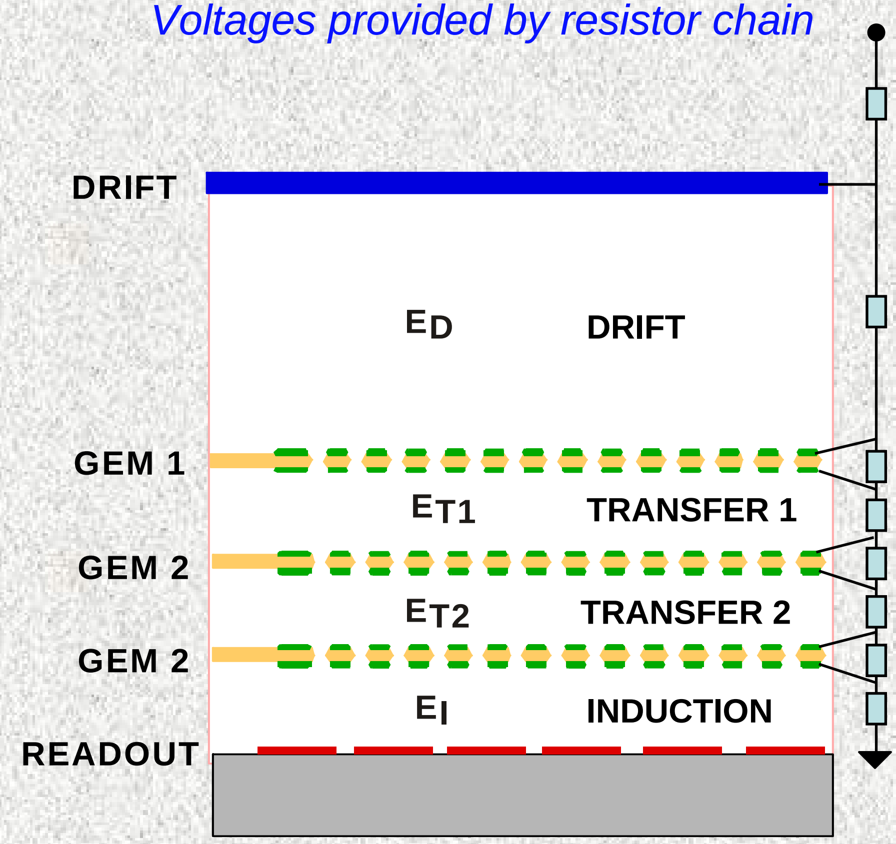
LOWER OPERATING VOLTAGE AND/OR SAFER OPERATION



UP TO 5 CASCADED GEMS TESTED

(for single photoelectron detection)

Voltages provided by resistor chain



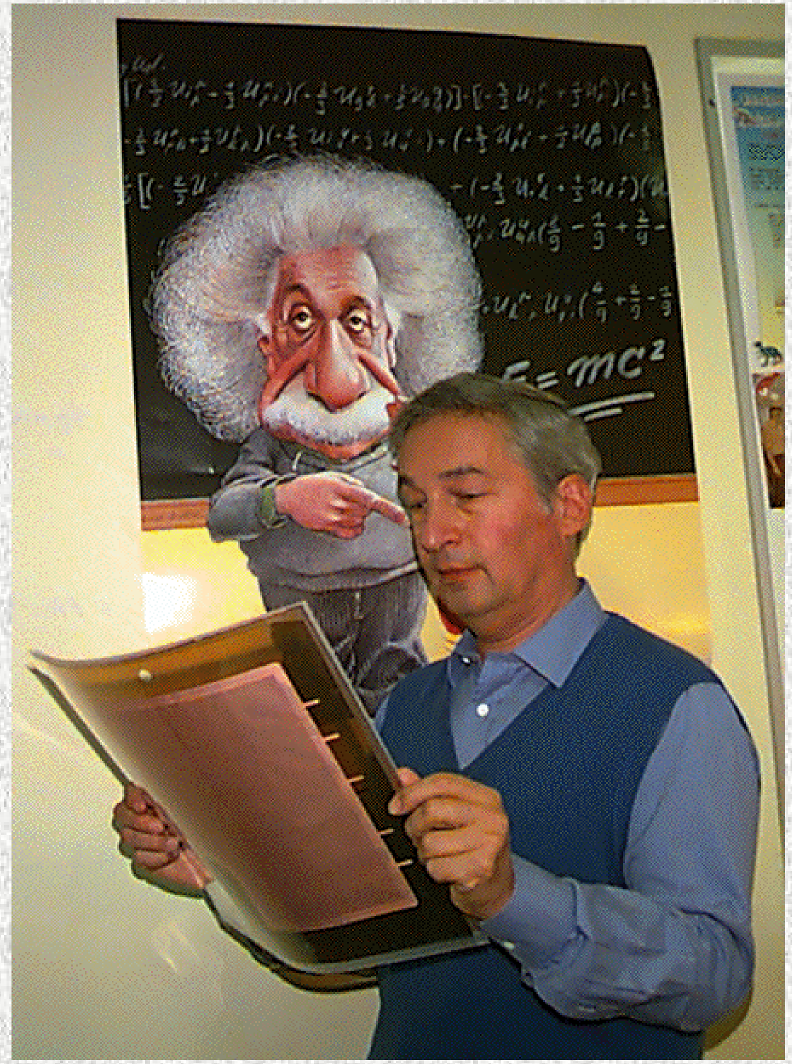
WIDE RANGE OF SHAPES AND SIZES

1500 ÷2000 foils manufactured at CERN
1 cm^2 to 1000 cm^2
30-200 µm holes, 50-300 µm pitch

COMPASS GEM 31x31 cm^2

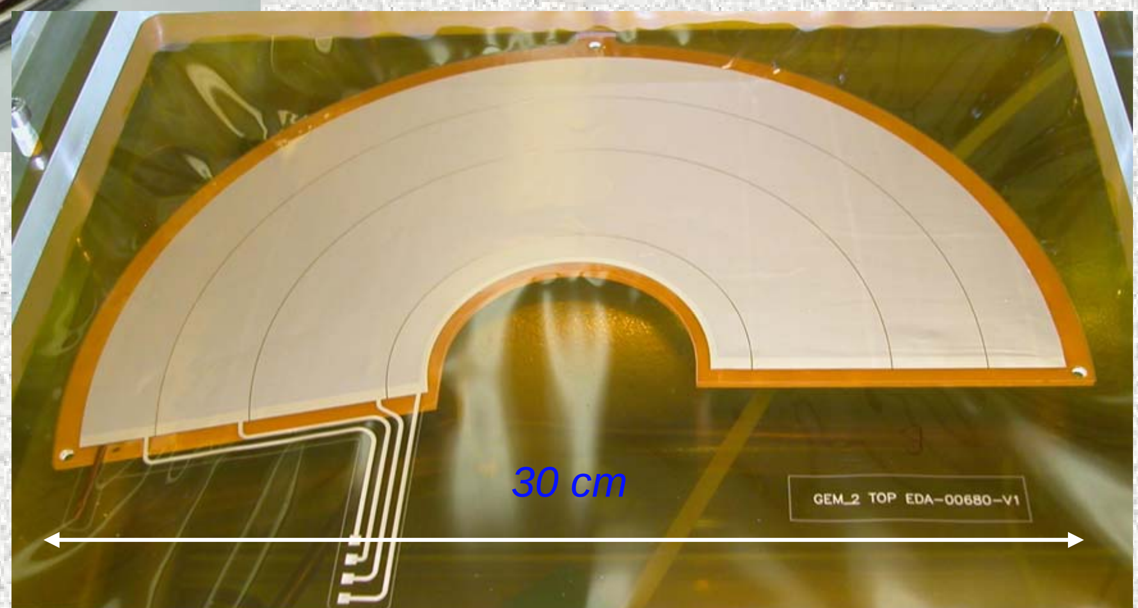
"Standard" GEM:
10x10 cm^2
(available in CERN stockroom)

Nuclear Magnetic Spectrometer (Osaka Univ.)

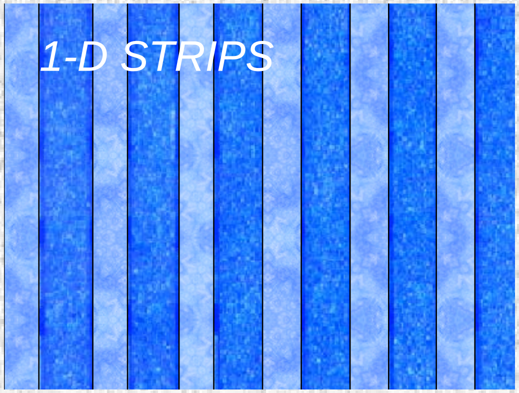


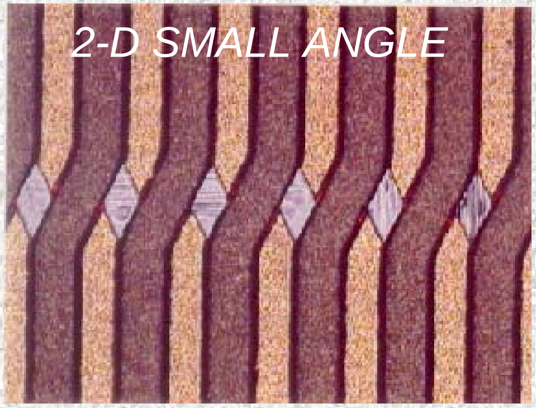
Round GEM (30 cm Ø)
ESA prototype

Half-Moon (TOTEM T2)



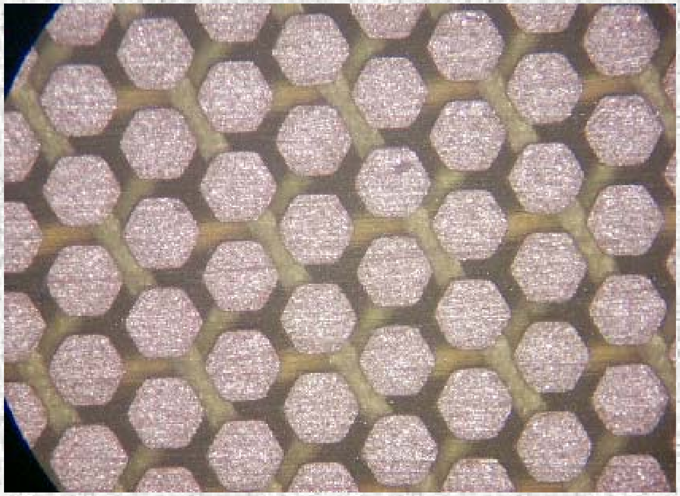
VARIOUS READOUT PATTERNS ON ANODE:

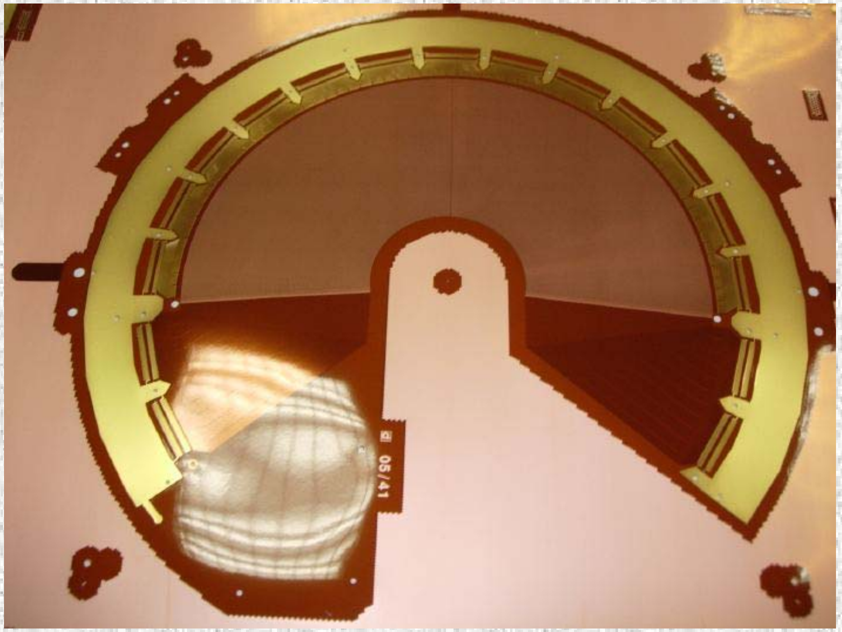




STIPS AND PADS (TOTEM):

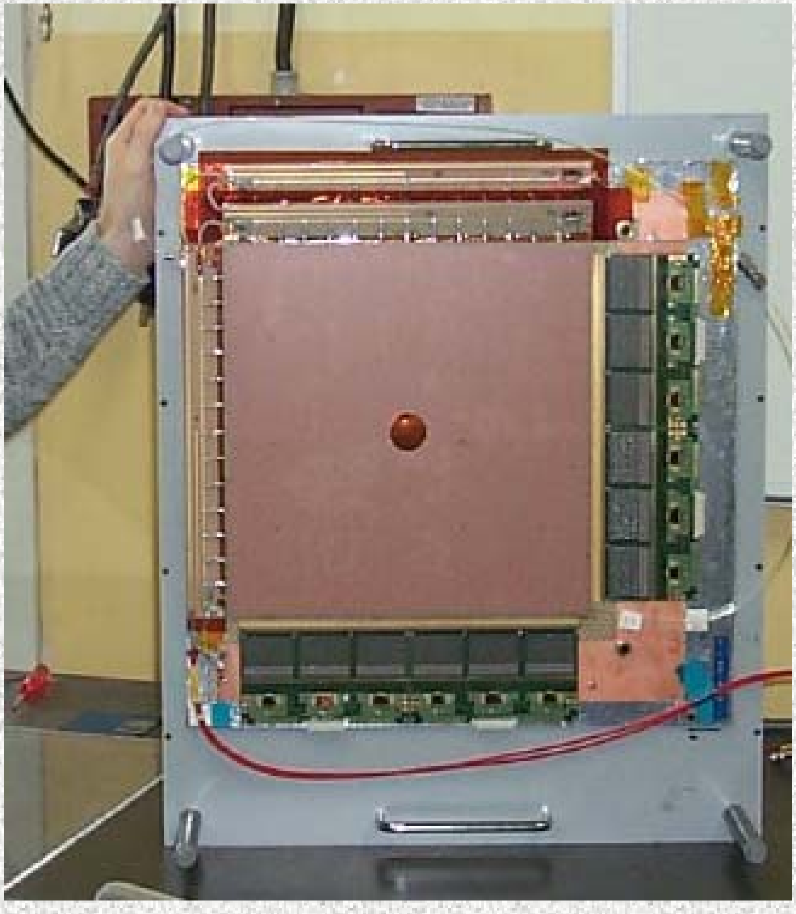
PADS





SIMPLE, LIGHT CONSTRUCTION

COMPASS Triple-GEM detector
31x31 cm^2 active, 2-D readout:

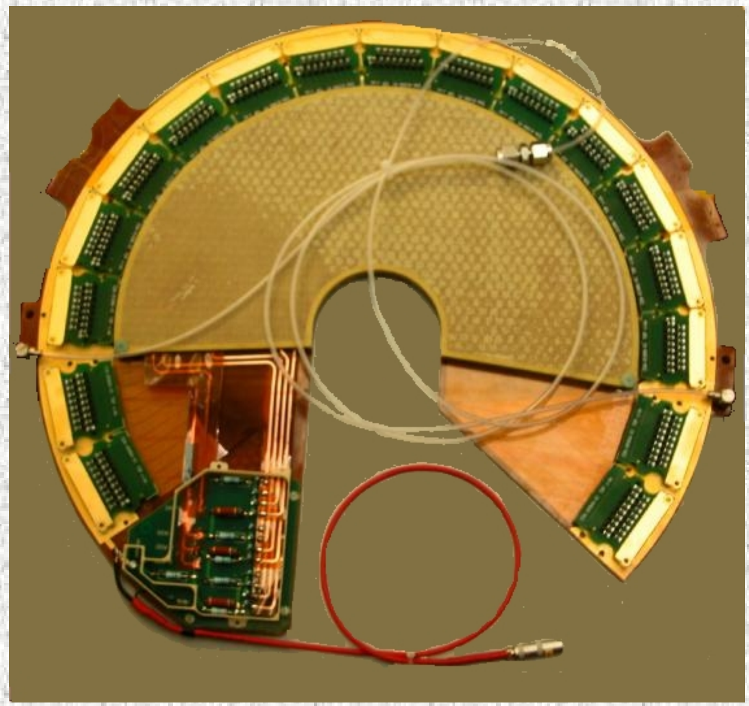


22 detectors operational

Thickness ~ 0.7% X_0 in active area

Can be reduced to ~ 0.15% X_0
A. Bondar et al, NIMA 556(2006)495

TOTEM Triple-GEM (Forward CMS)
30 cm Ø, strips&pads readout

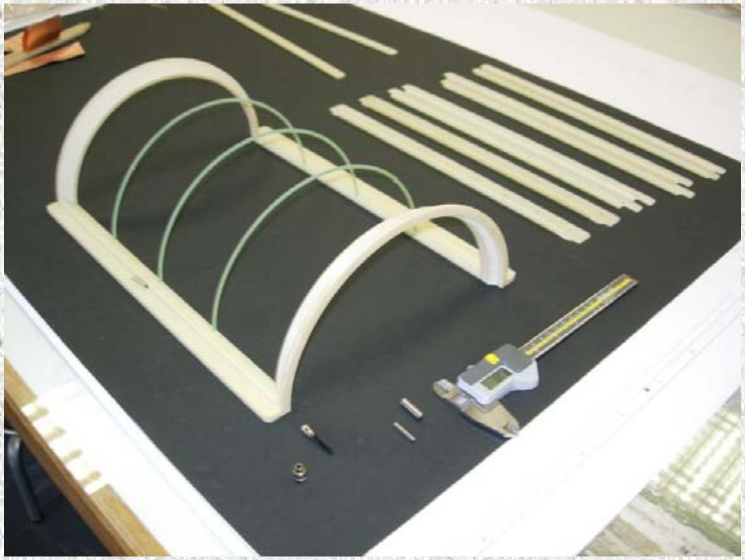


50 detectors in construction

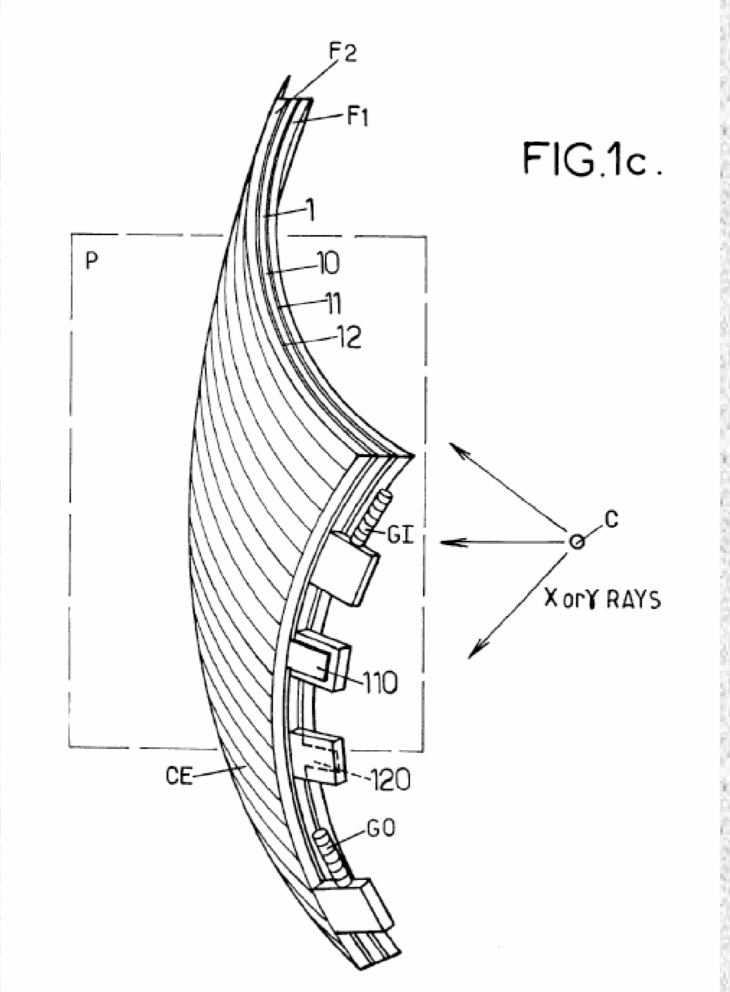
CYLINDRICAL GEM DETECTOR

CERN-PH-DT2 (NA49 UPGRADE?)

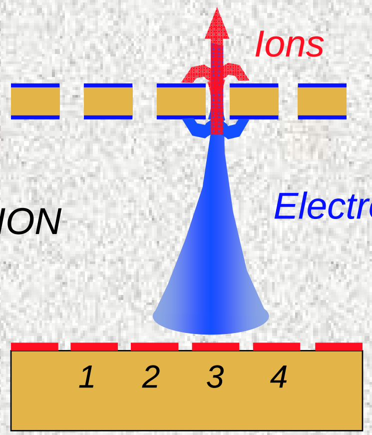
Eric David and Miranda Van Stenis



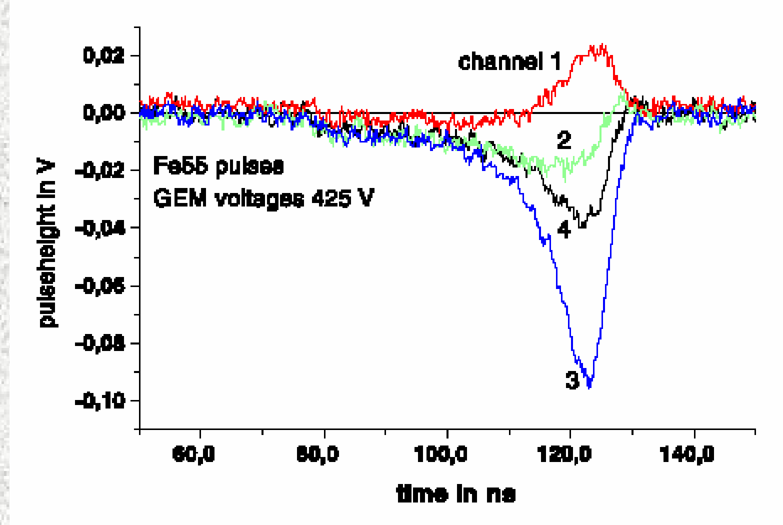
SPHERICAL GEM DETECTOR:



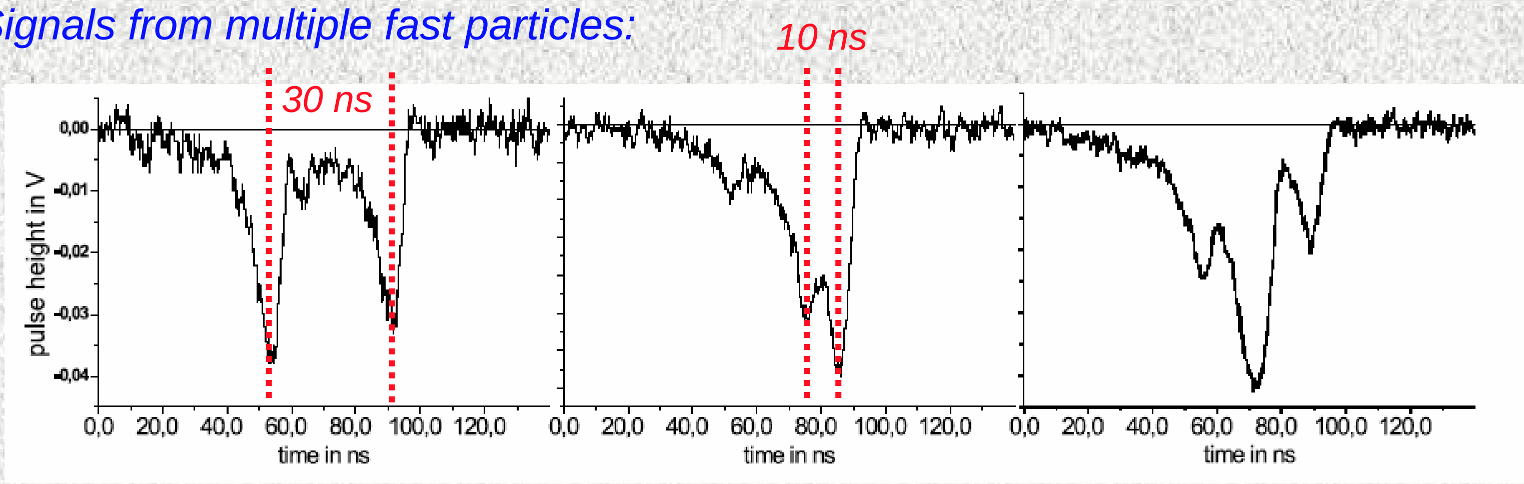
FAST ELECTRON SIGNAL ONLY
Excellent multi-track resolution!



Signals on adjacent strips (500 µm pitch)



Signals from multiple fast particles:

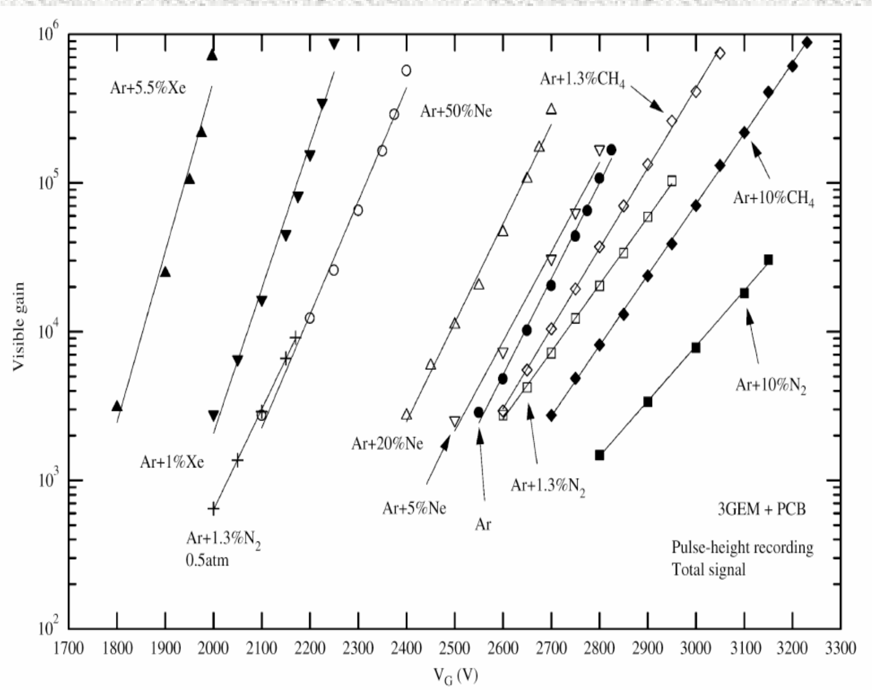


$A\text{-}CO_2$ 70-30, 5kV cm^{-1} w = 7.5 cm µs^{-1}

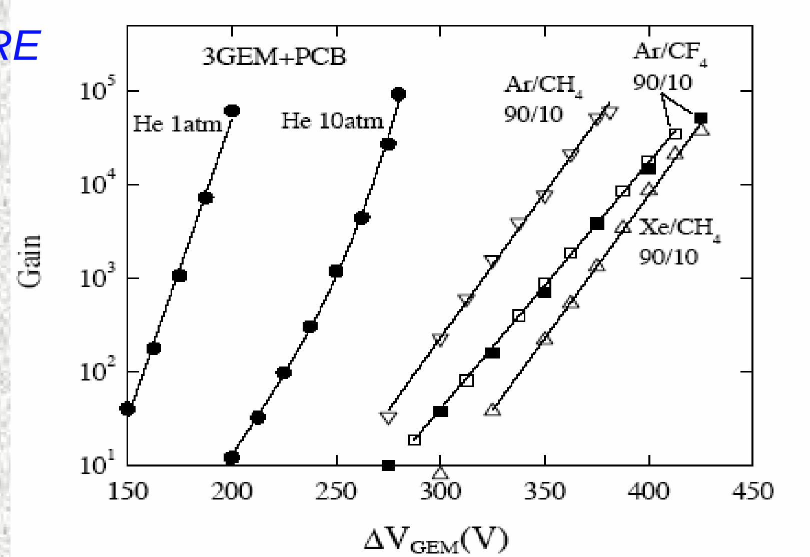
M. Ziegler, PhD dissertation (2002)

HIGH GAINS IN VIRTUALLY ANY GAS MIXTURE

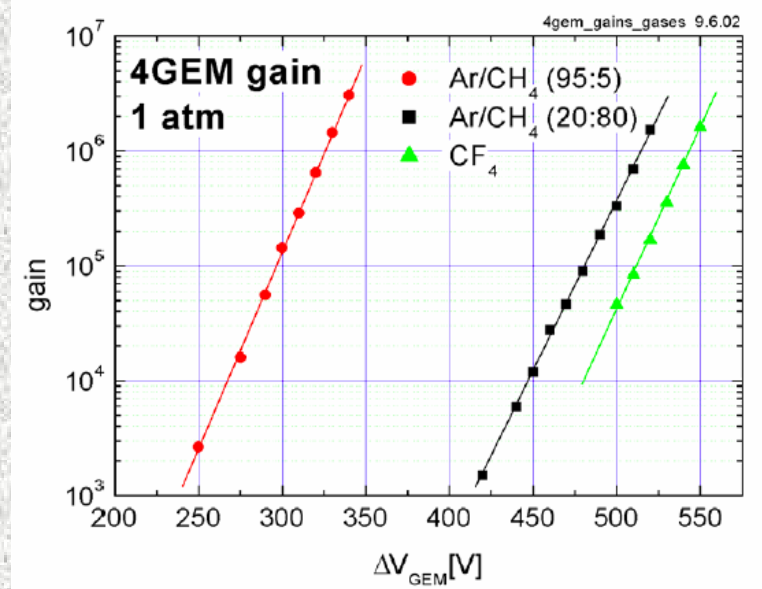
Noble Gases Mixtures (Development of GEM photomultipliers)



A. Buzulutskov et al, NIMA 443(2000)164

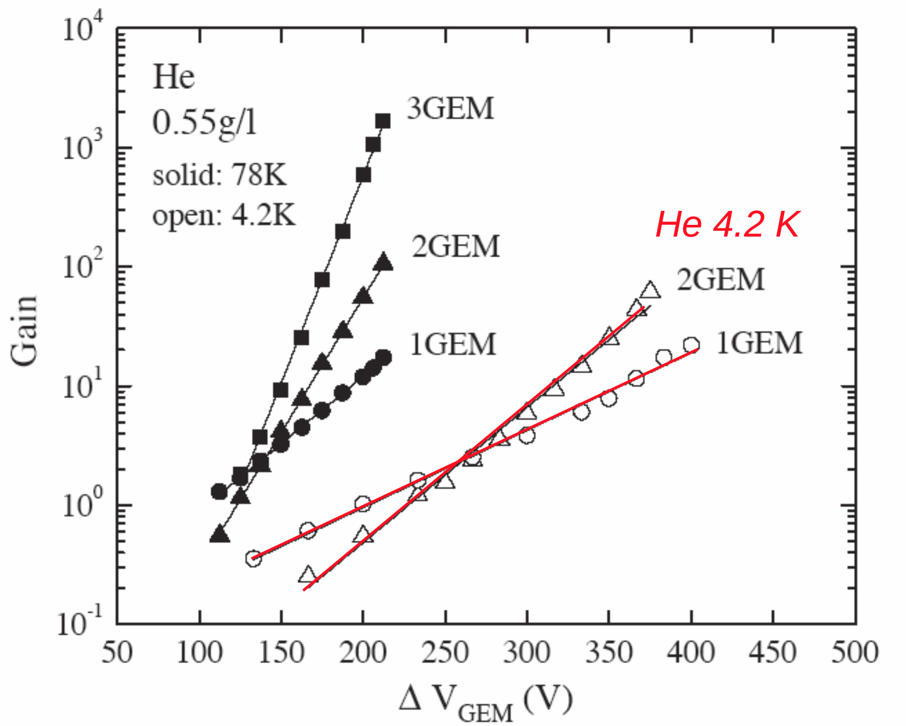


A.Bondar et al, NIMA 496(2003)325



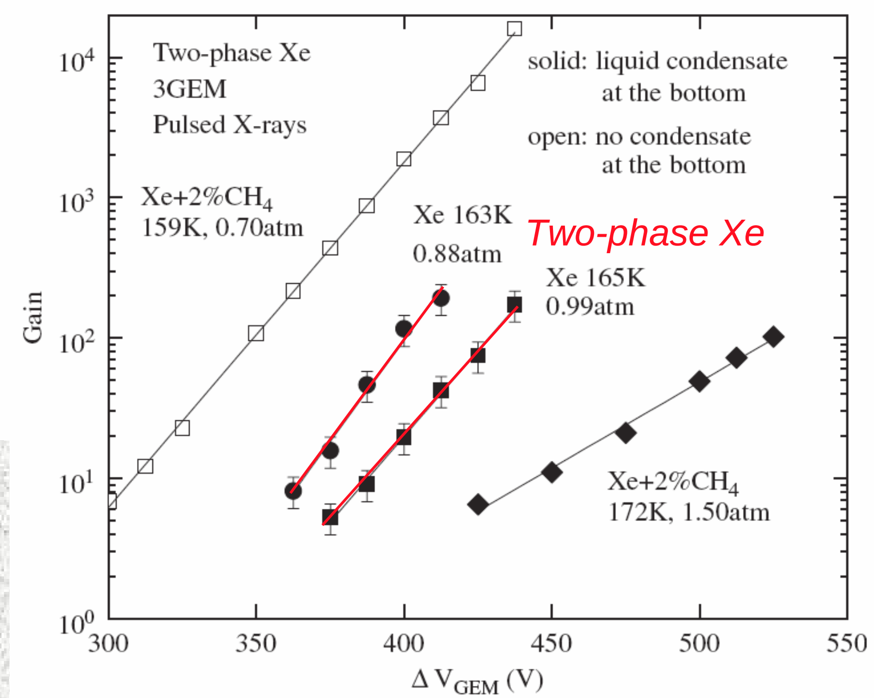
D. Mörmann et al, NIMA

LOW TEMPERATURE NOBLE GASES:



A. Buzulutskov et al, NIMA 548(2005)487

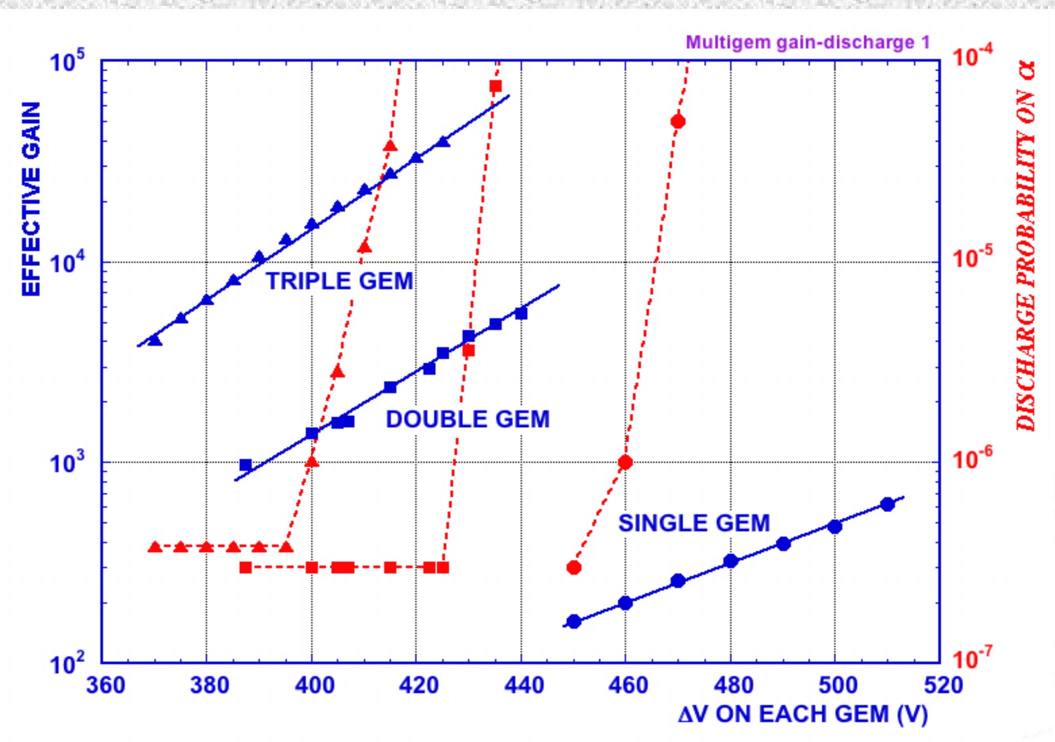
TWO-PHASES CRYOGENIC DETECTORS:



A. Bondar et al, NIMA 556(2006)273

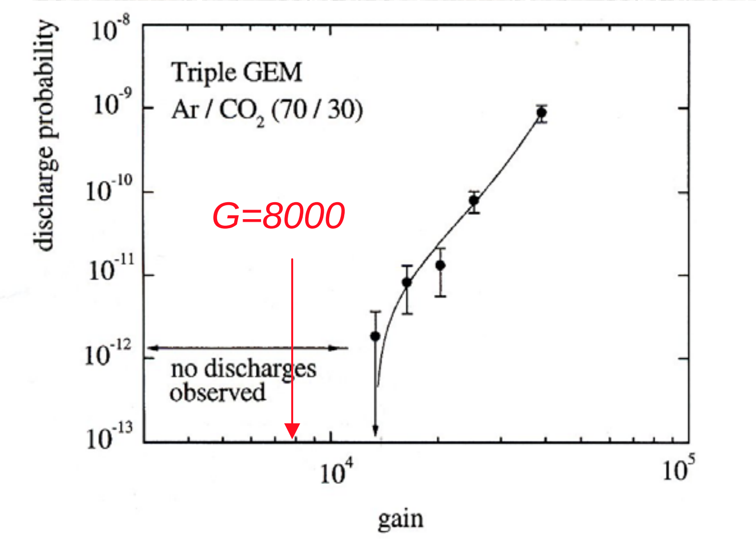
MULTIGEM: HIGH GAINS IN HOSTILE ENVIRONMENT

DISCHARGE PROBABILITY ON EXPOSURE TO 5 MeV α (from internal ^{220}Rn gas)



S. Bachmann et al, NIMA 479(2002)294

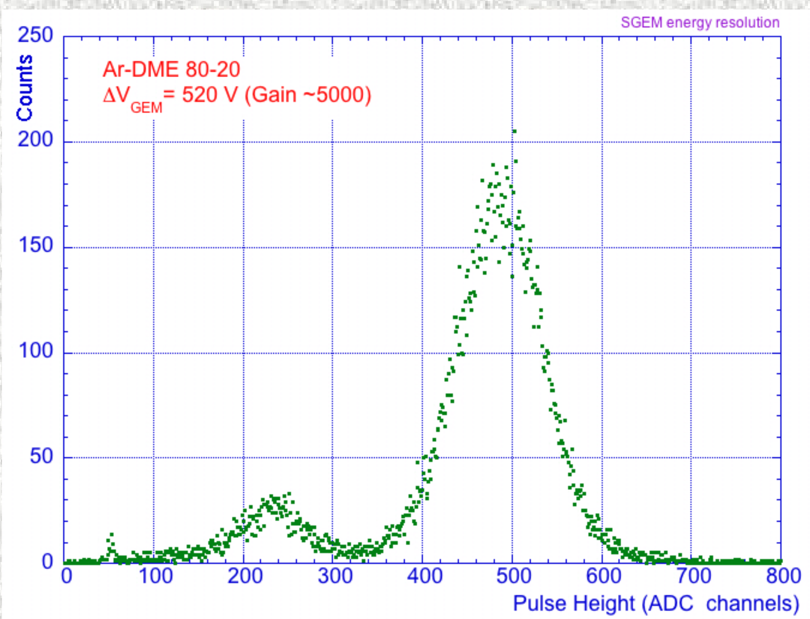
TEST AT PSI πM1 beam:
No discharges in 12 hrs of operation at gain 10^4
(and 4 years of operation in COMPASS!)



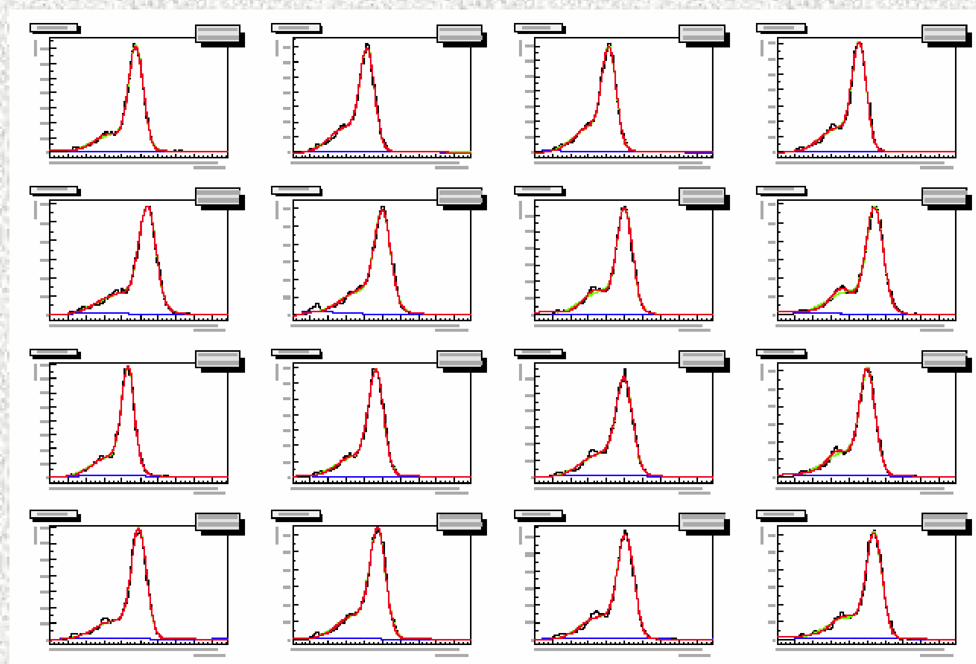
S. Bachmann et al, NIMA 470(2001)548

GEM DETECTORS PERFORMANCE: ENERGY RESOLUTION AND GAIN UNIFORMITY

5.9 keV ^{55}Fe : 20% FWHM

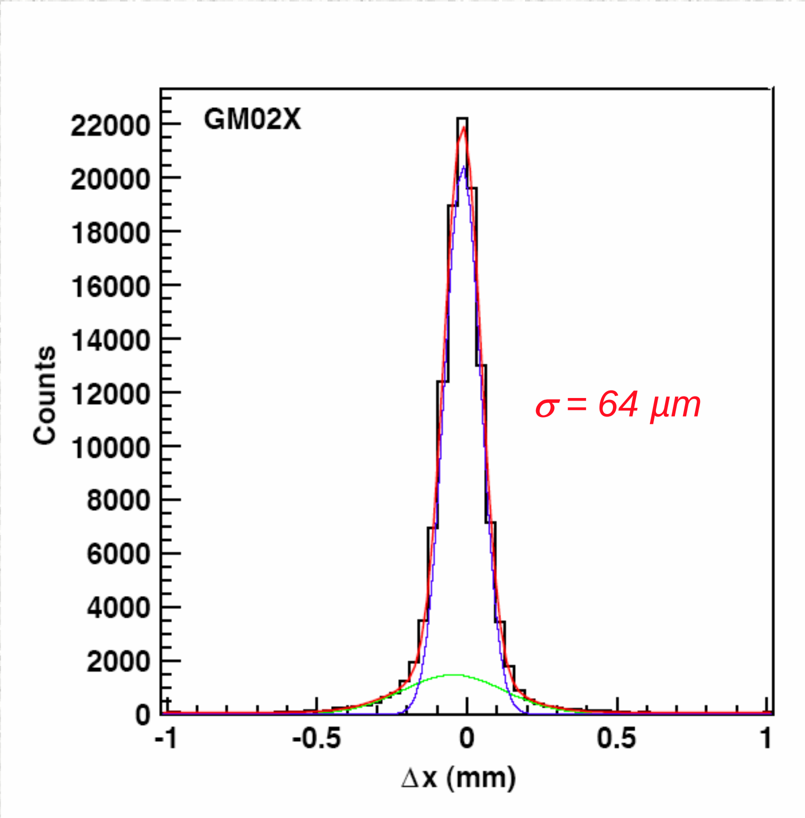


COMPASS CHAMBERS (31x31 cm^2)
PH spectra on 9 keV X-rays in 16 points
Maximum gain variation $\pm$ 15%



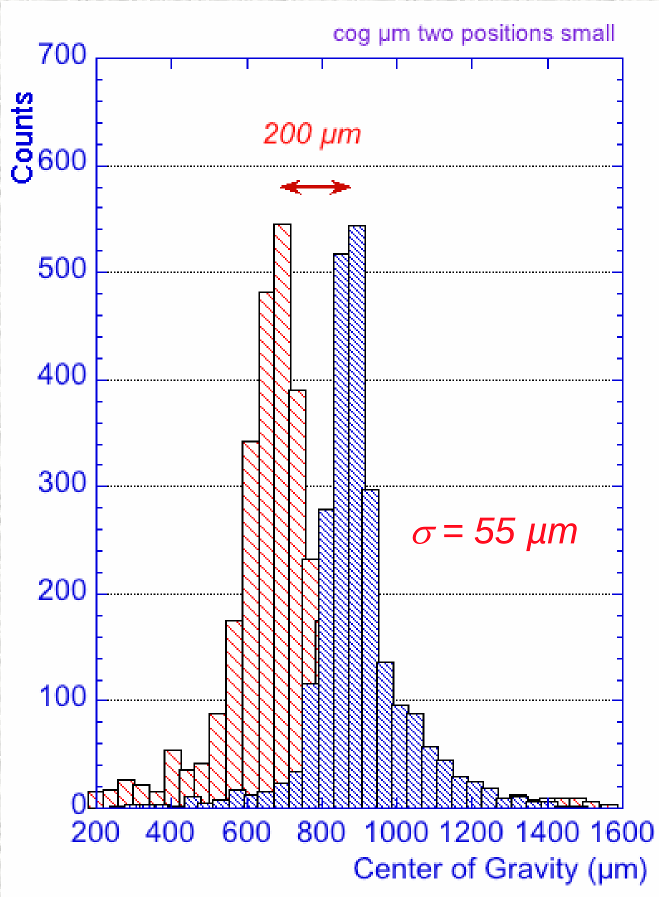
(Hole's diameter tolerance: $\pm$ 2.5 μm)

RESIDUALS FOR MINIMUM IONIZING PARTICLES (COMPASS TRACKER):



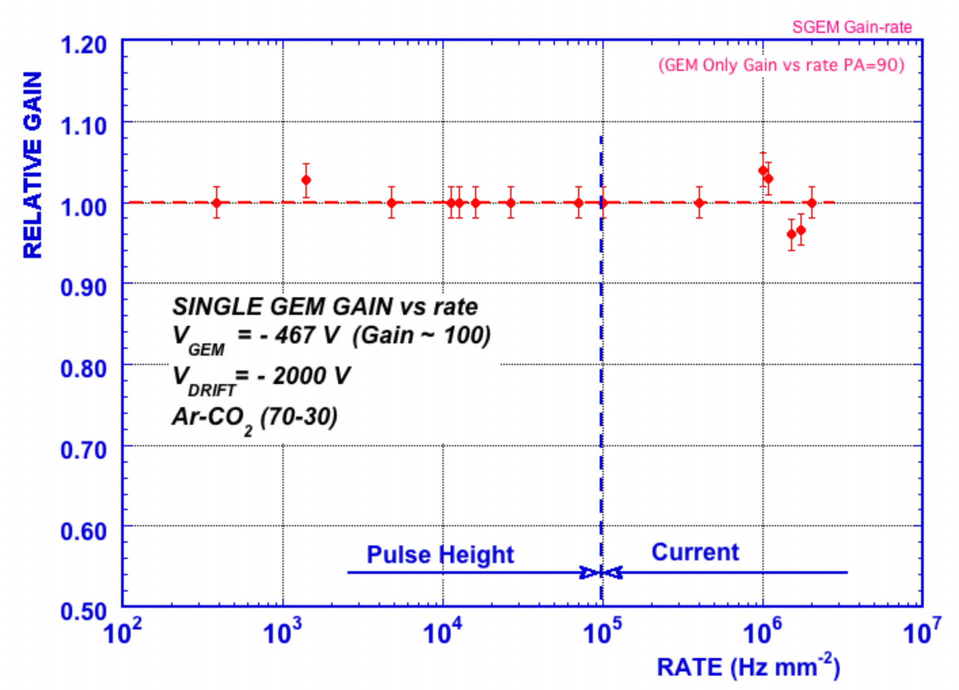
B. Ketzer et al, NIMA 535(2004)314

SINGLE PHOTOELECTRON (CsI-Coated T-GEM) Center of gravity distribution for two UV light beams, 200 µm apart:



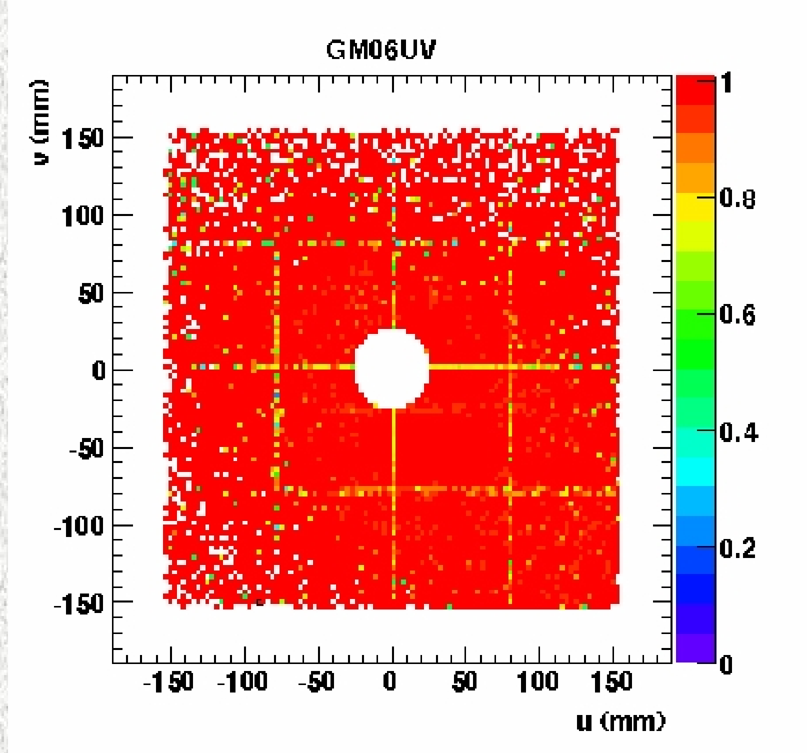
T. Meinschad et al, NIMA 535(2004)324

RATE CAPABILITY (5.9 keV X-rays): > 2.10^6 mm^{-2}



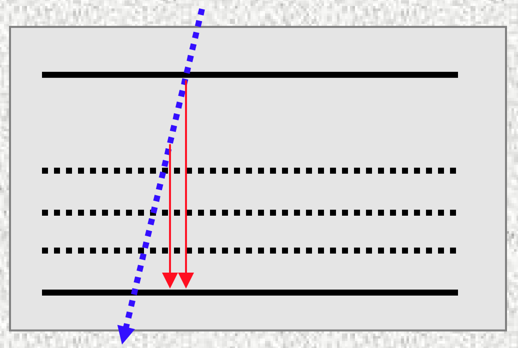
J. Benlloch et al, IEEE NS-45(1998)234

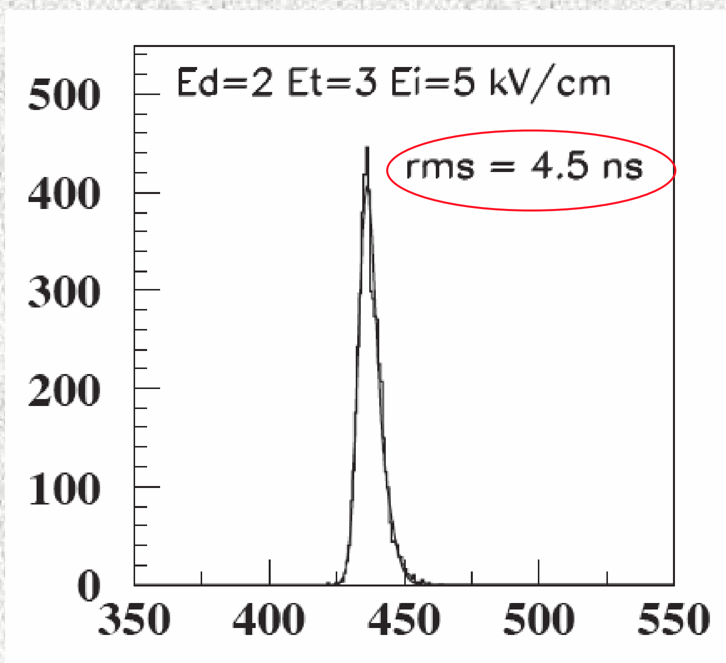
EFFICIENCY IN RUNNING CONDITIONS (COMPASS TGEM TRACKER) ~ 97.2 %
High intensity runs (25 kHz mm^{-2})



B. Ketzer et al, NIMA 535(2004)314

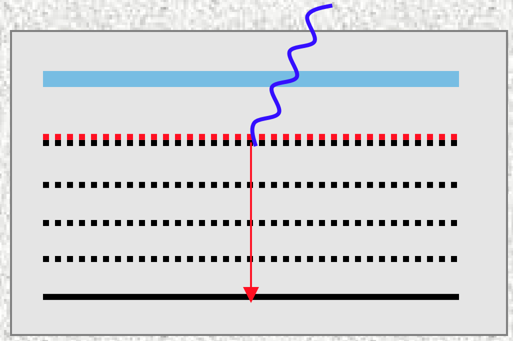
CHARGED PARTICLES
Using a fast gas (A-CO_2-CF_4)
LHCb muon trigger

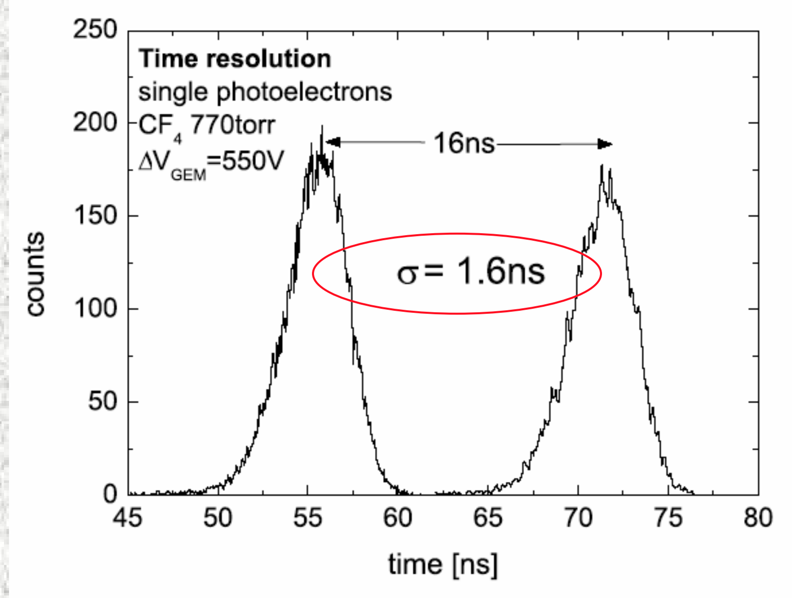




M. Alfonsi et al, NIMA A535(2004)319

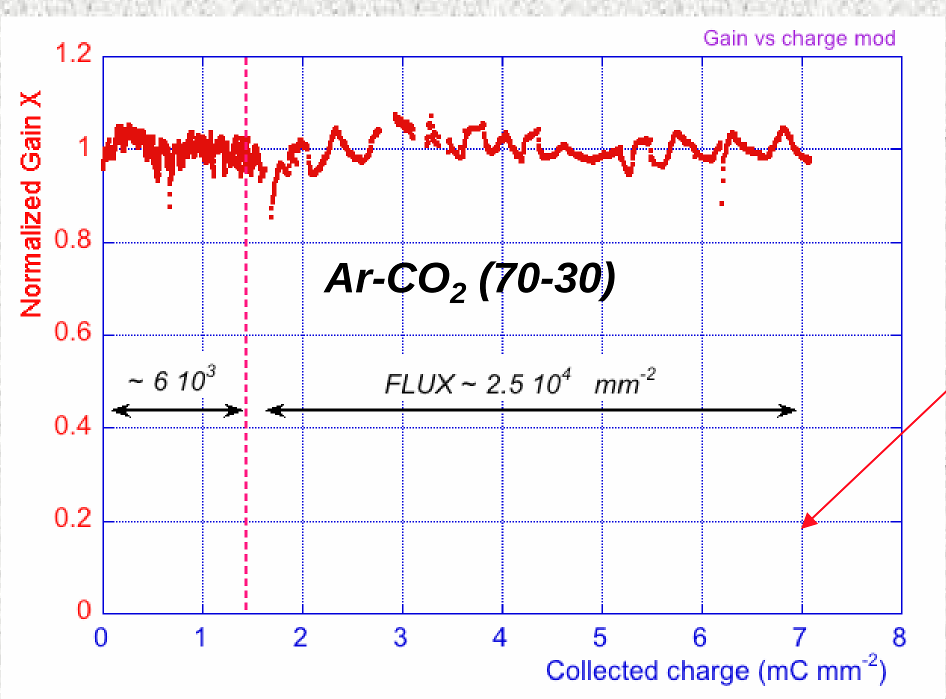
INTRINSIC TIME RESOLUTION:
4-GEM with reflective photocathode
(isochronous electrons)





D. Mormann et al, NIMA 504(2003)93

GAIN vs COLLECTED CHARGE (on continuous X-rays irradiation)



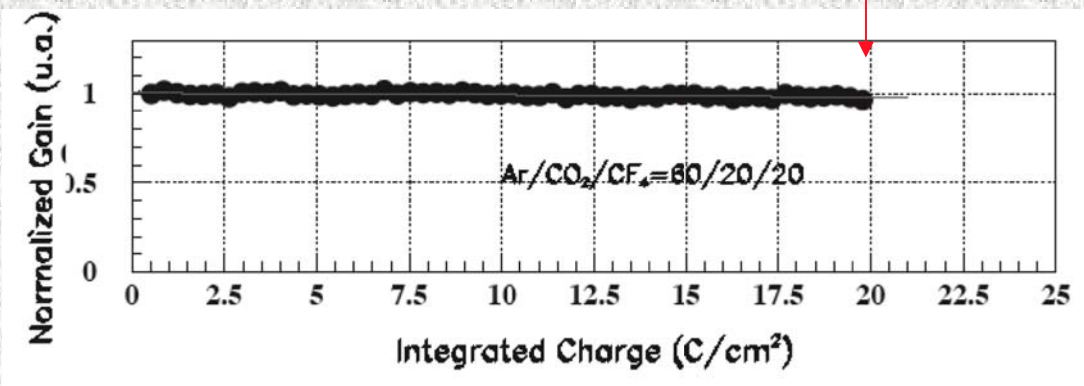
C. Altunbas et al, NIMA 515(2003)249

1 mC ~2 •10^{10} min.ion. particles
(30 electrons/track, gain 10^4)

7 mC mm^{-2} ~ 10^{11} mips mm^{-2}

200 mC mm^{-2} ~ 4 •10^{12} mips mm^{-2}

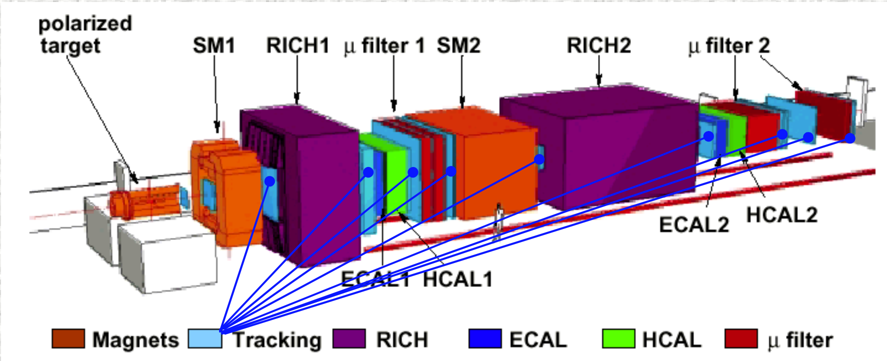
Ar-CO_2-CF_4 (80-20-20)



M. Alfonsi et al, NIMA 518(2004)106

TRIPLE GEM TRACKER FOR COMPASS (NA58)

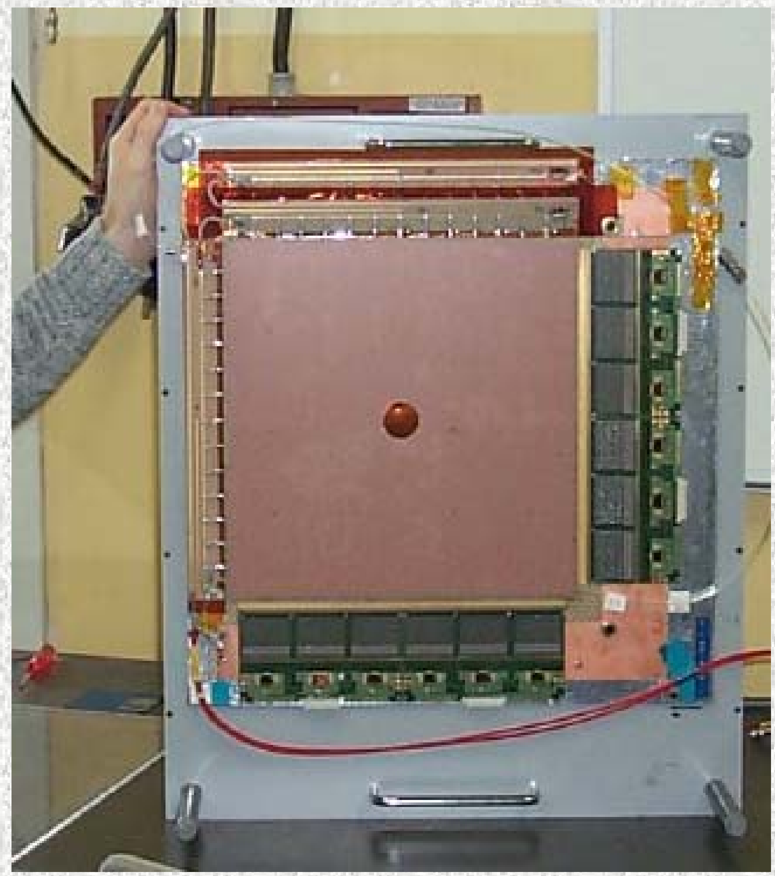
High rate forward spectrometer:
~ 5.10^7 polarized 160 GeV μ^+/s on polarized ^{6}LiD target



22 Detectors, 31x31 cm^2 active area
2-D Analogue readout (APV25)

Data taking since 2001

http://wwwcompass.cern.ch/



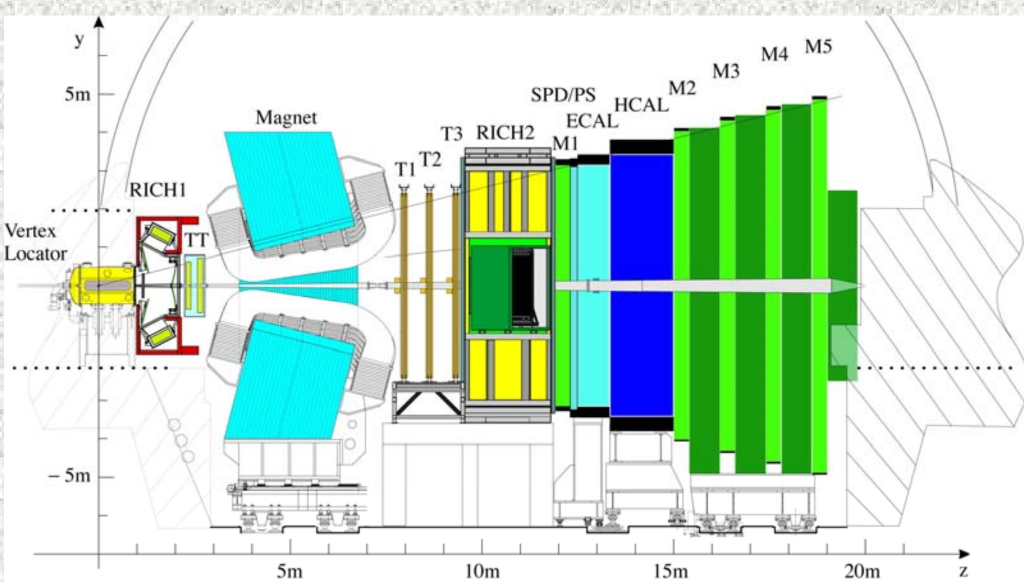
COMPASS TRIPLE-GEM CHAMBERS

Light all-glued construction:
0.7% X_0 in active area

Bernhard Ketzer

C. Altumbas et al, NIMA 490(2002)177

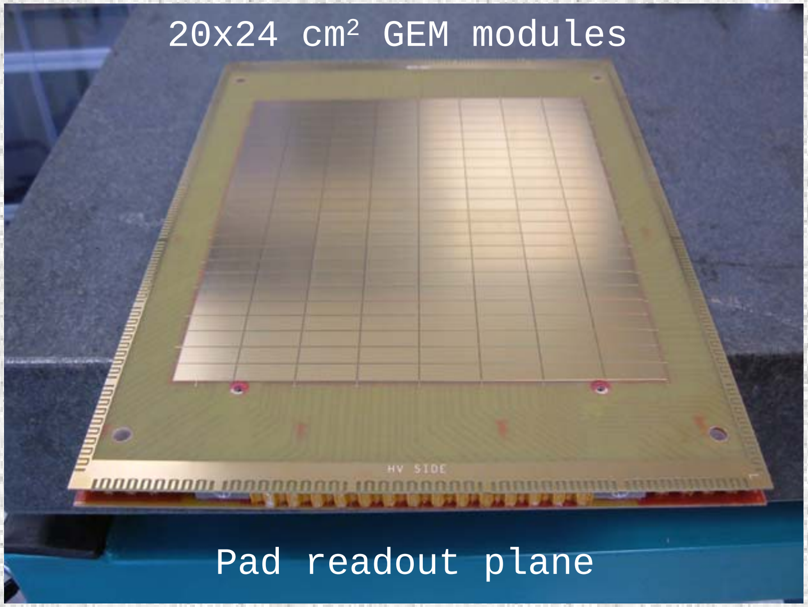
FAST MUON TRIGGER FOR LHCb



Rate - 5 kHz mm^{-2}
Time resolution 4.5 ns rms
No aging up to integrated charge of 20 mC mm^{-2} (15 LHCb years)

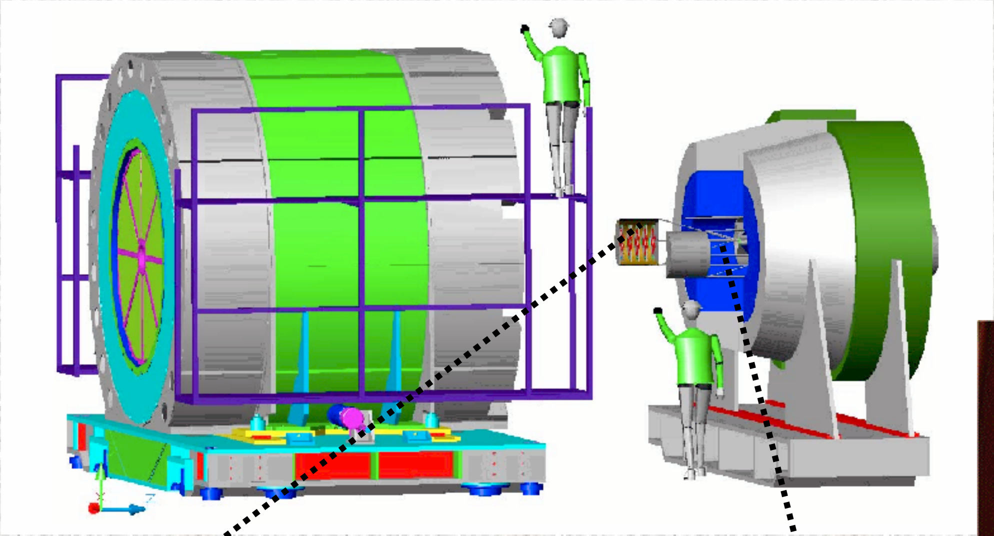
M. Alfonsi et al, NIMA 535(2004)319

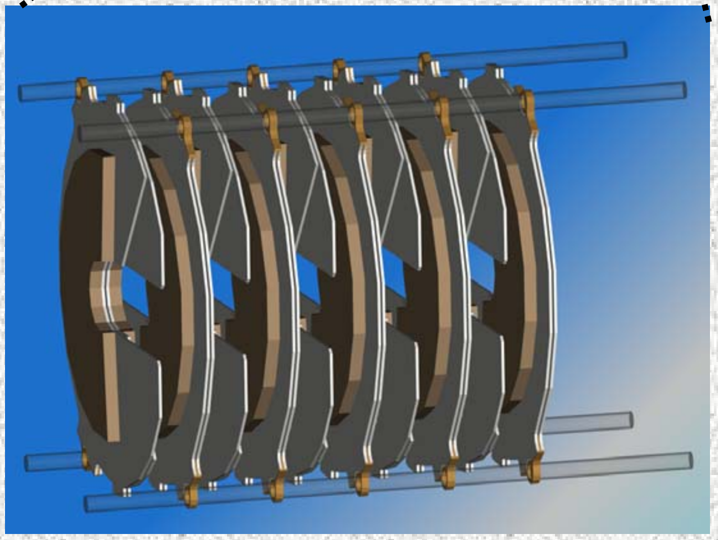
Alessandro Cardini



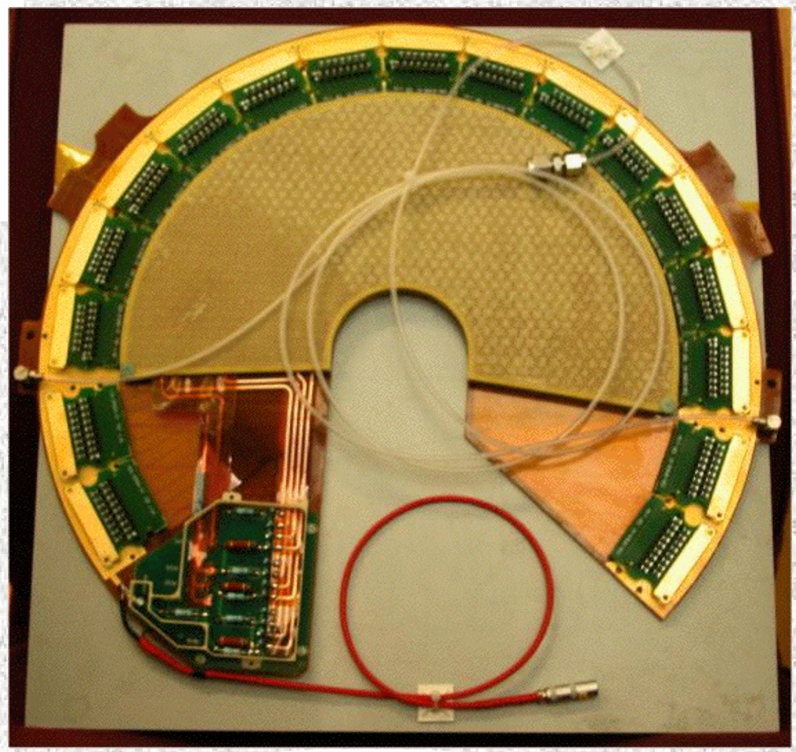
T2: TWO-ARMS FORWARD TRACKER IN CMS

TOTEM





Half-Moon Triple-GEM chambers
Inner Ø: 80 mm   Outer Ø 300 mm
40 Detectors in construction
(Helsinki-CERN)



Leszek Ropelewski

GEM-TPC FOR LEGS (LASER ELECTRON GAMMA SOURCE) AT BNL

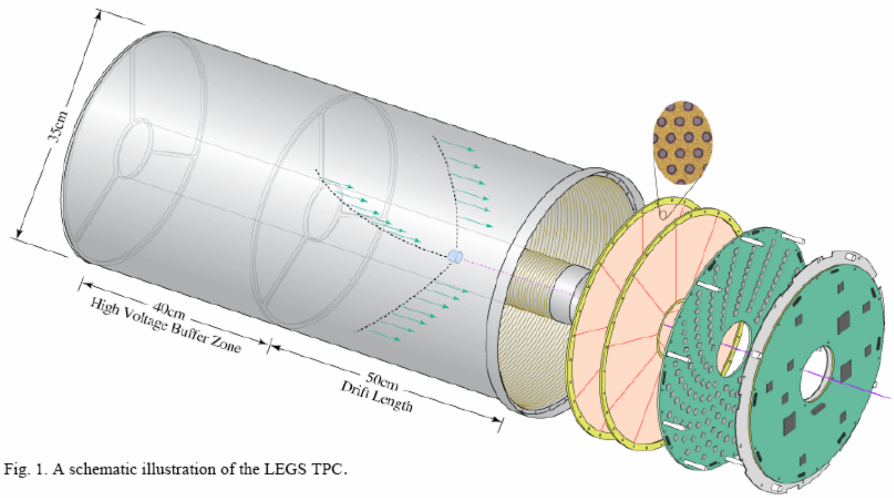
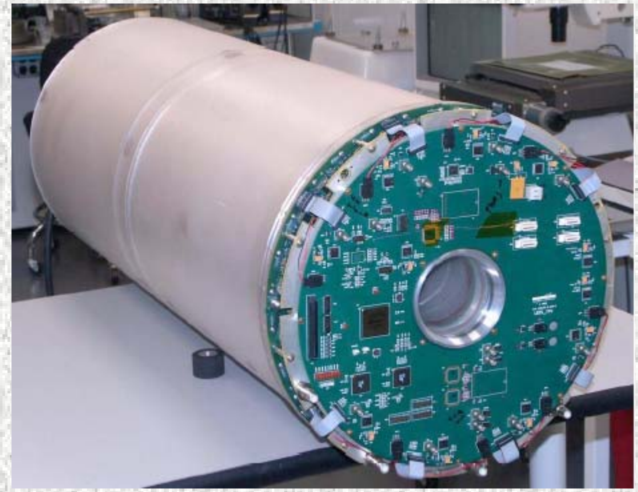
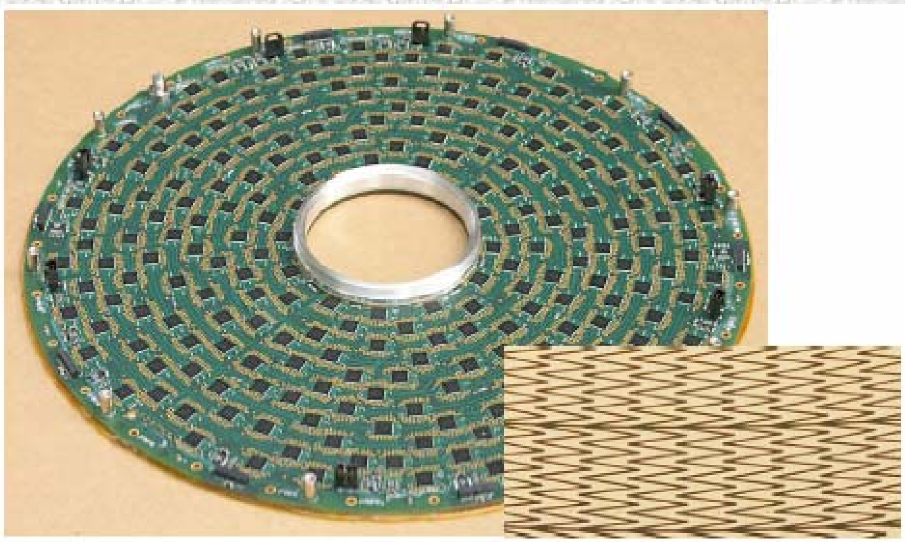


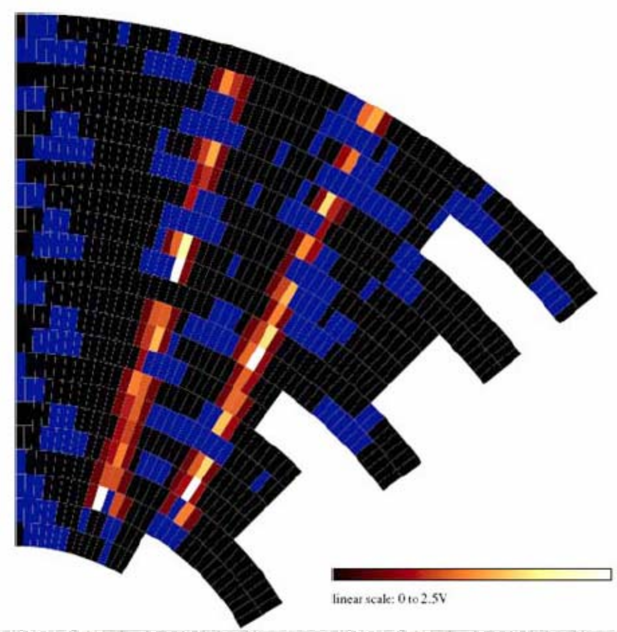
Fig. 1. A schematic illustration of the LEGS TPC.



CHEVRON PAD READOUT

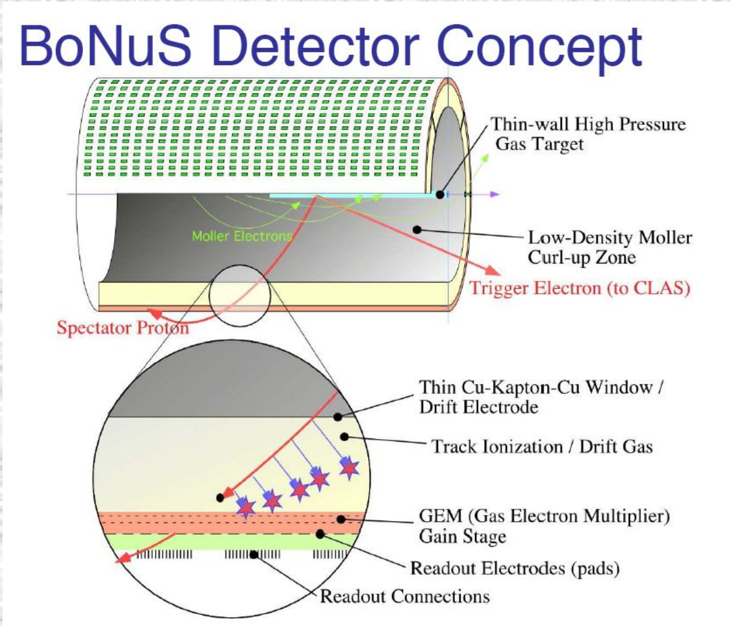


Double cosmic track in prototype:



B. Yu et al, IEEE Nucl. Sci. Symp. (Puerto Rico 2005)

RADIAL TPC FOR BoNuS (Barely Off-Shell Nucleon Structure, CLAS Collaboration, JLAB)

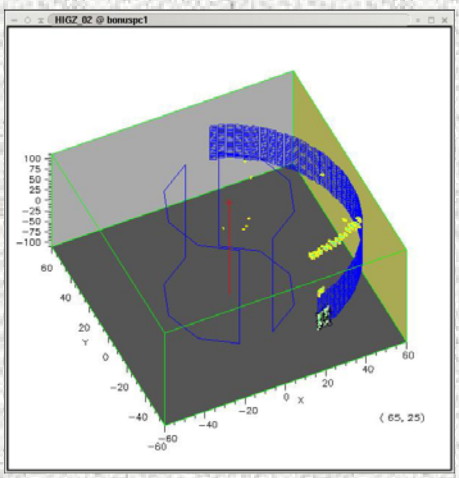


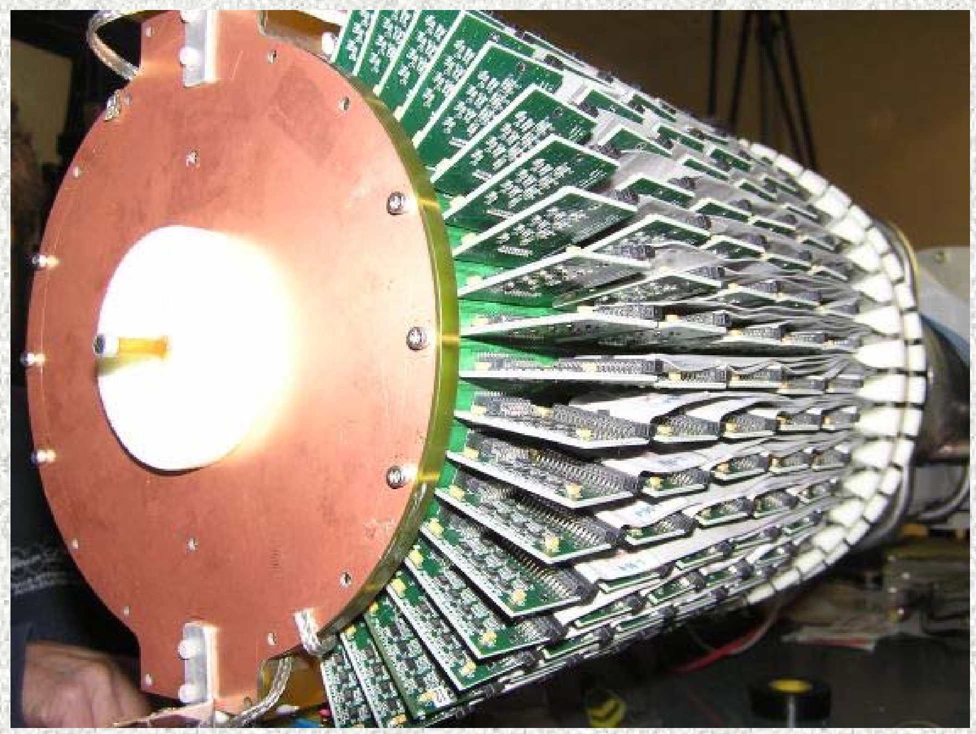
$e^- d \longrightarrow e^- n p$ Low energy proton spectator

—> low density, large acceptance detector

Radial GEM TPC with pixel readout
3200 pixels, ALICE ALTRO ADC

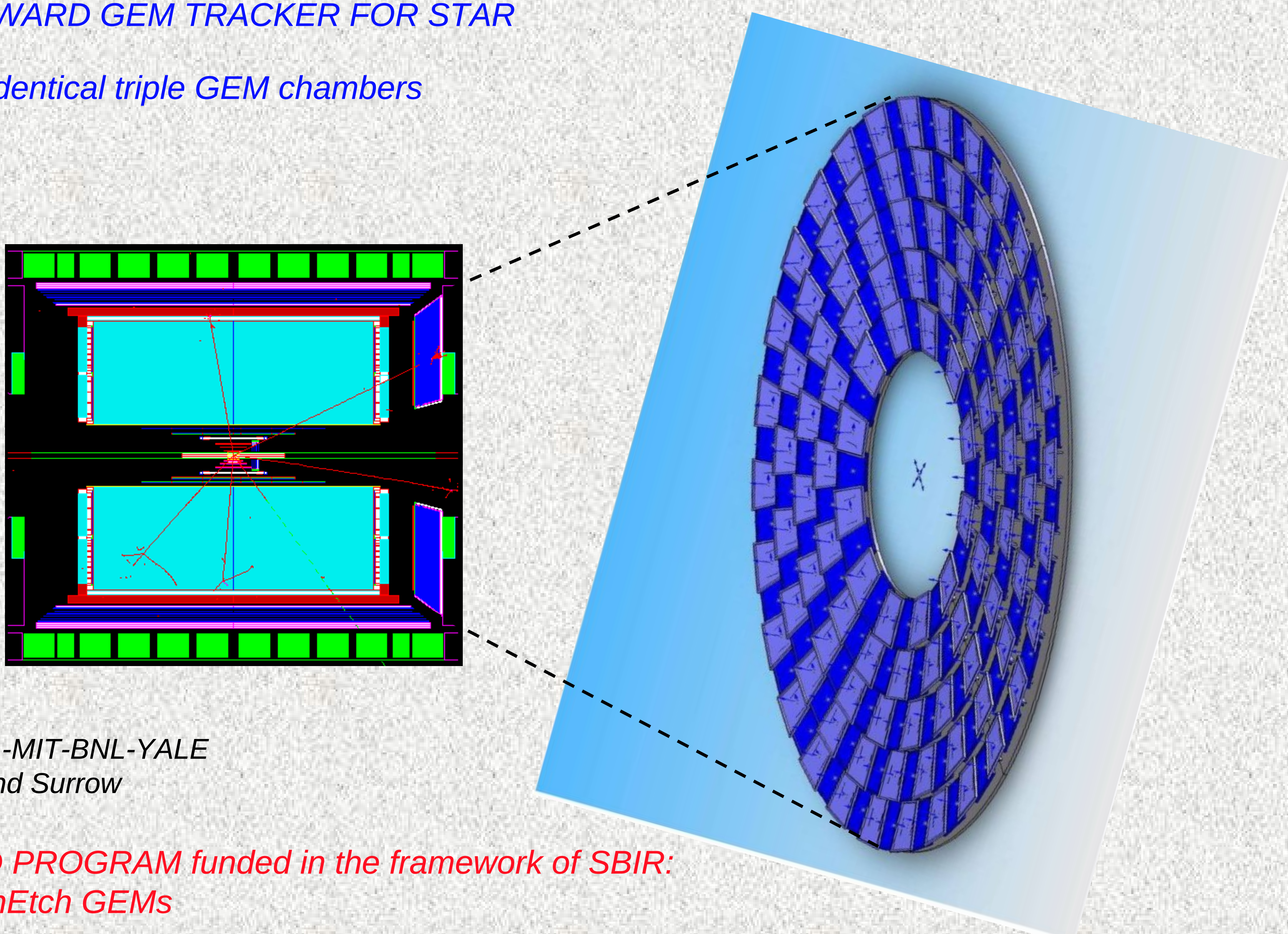
GEMS from TechEtch





FORWARD GEM TRACKER FOR STAR

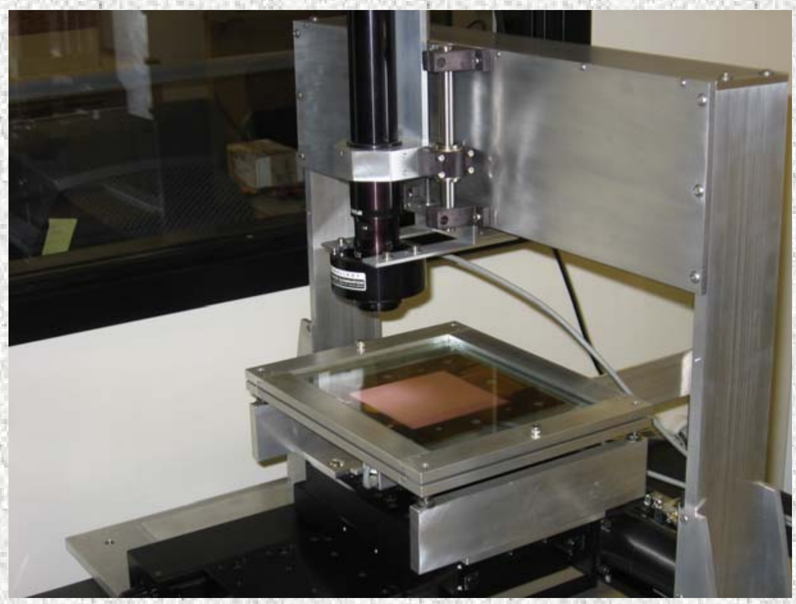
180 identical triple GEM chambers



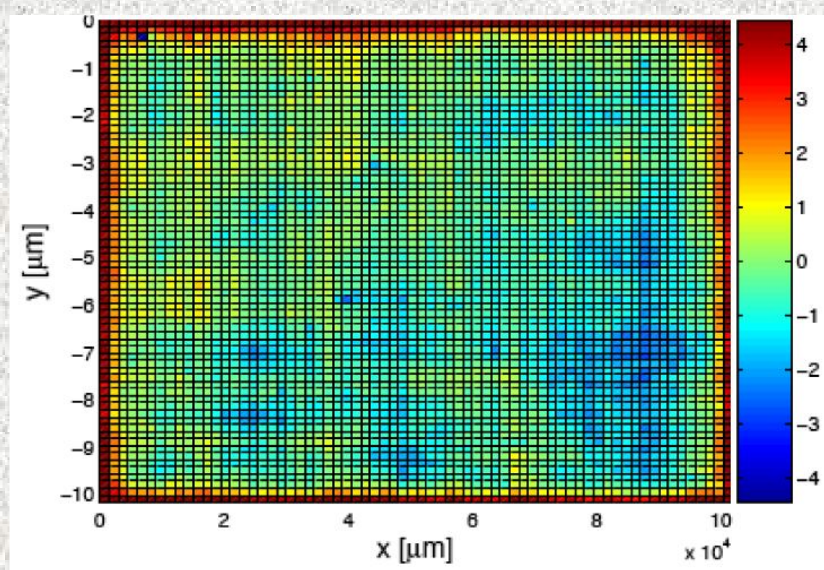
ANL-MIT-BNL-YALE
Bernd Surrow

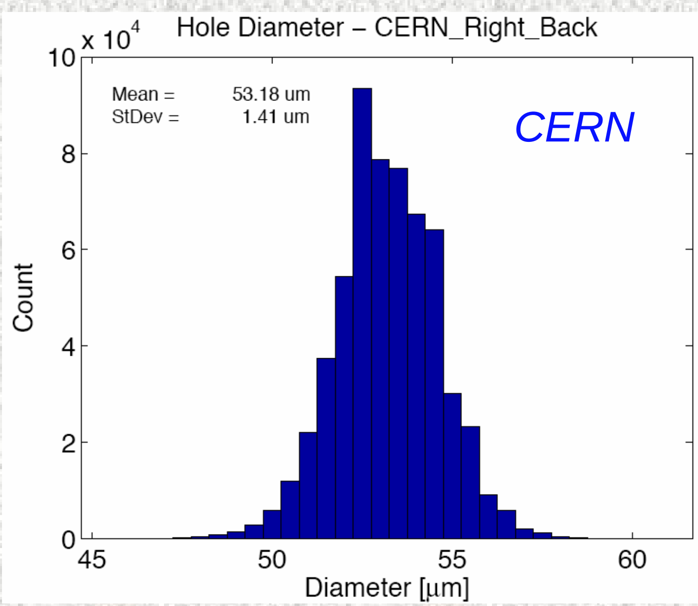
R&D PROGRAM funded in the framework of SBIR:
TechEtch GEMs

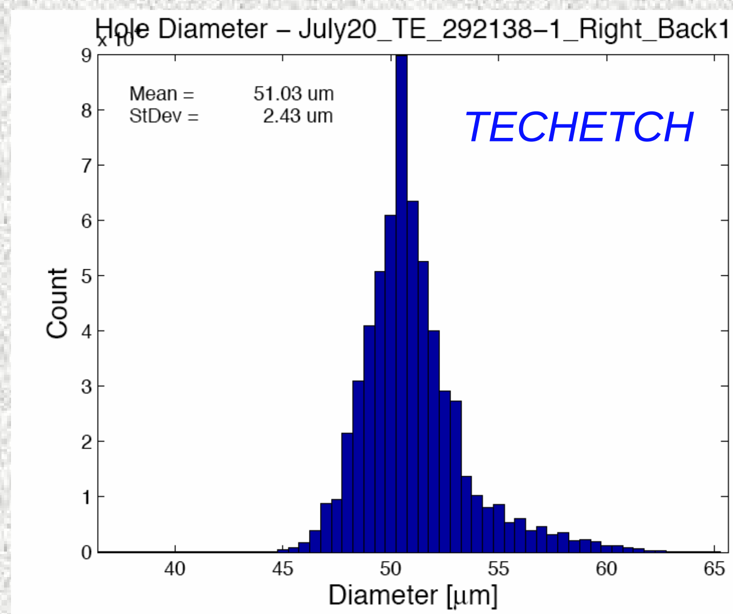
MIT OPTICAL SCANNER



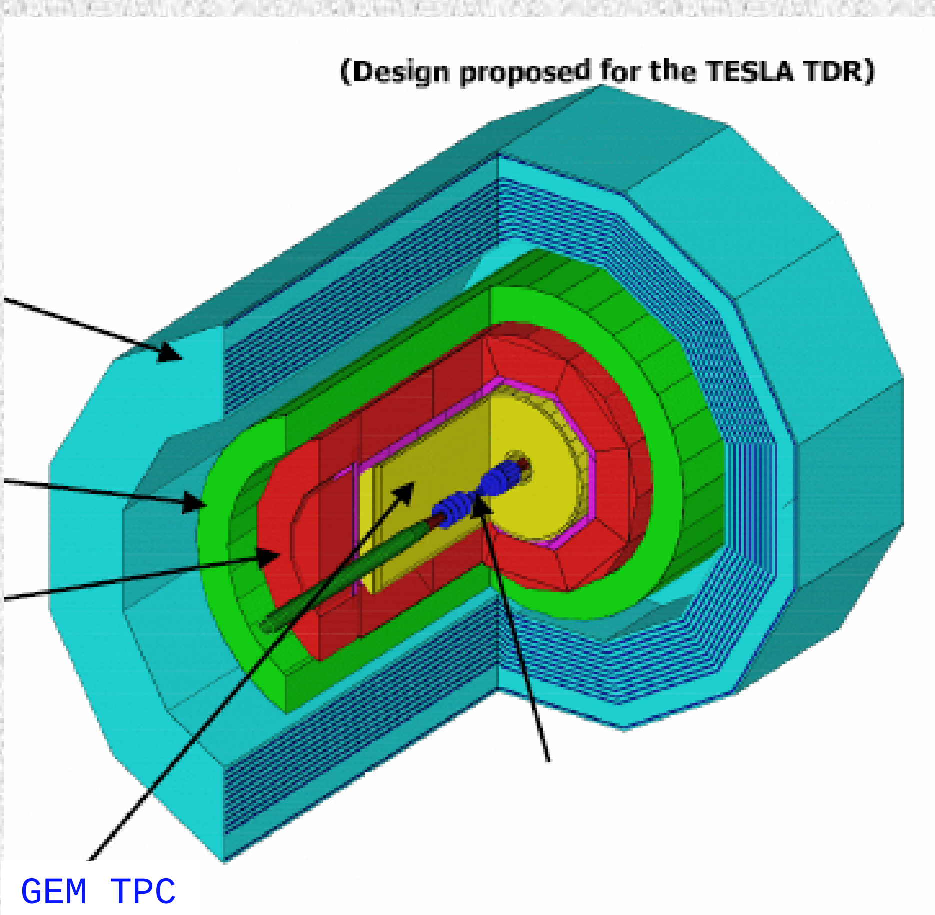
TechEtch GEMs Inner diameter distribution







GEM TPC FOR THE INTERNATIONAL LINEAR COLLIDER



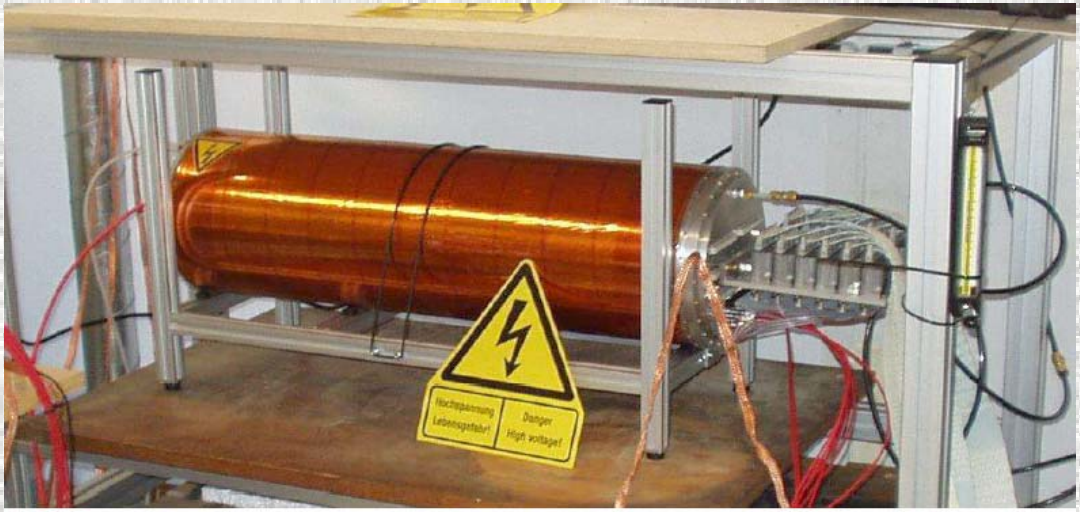
ADVANTAGES OF GEM READOUT:

- *Fast signals (no ion tail): ΔT~20 ns*
- *Narrow pad response function: Δs ~ 1 mm*
- *Very good multi-track resolution: ΔV ~ 1 mm^3 (Standard MWPC TPC ~ 1 cm^3)*
- *Ion feedback suppression: $I^+/I^- < 0.1\%$*
- *No ExB distortions*
- *Freedom in end-cap shapes*
- *Robust, radiation resistant*

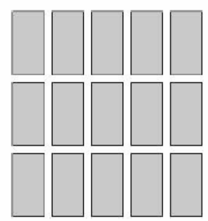
ILC TPC R&D GROUPS (~ 40):
DESY, Aachen, Karlsruhe, LBL, Saclay, Orsay, Vancouver, Carleton, KEK,…..

TPC: 250 cm long, 140 cm radius
~ 40 m^3
4 T operation

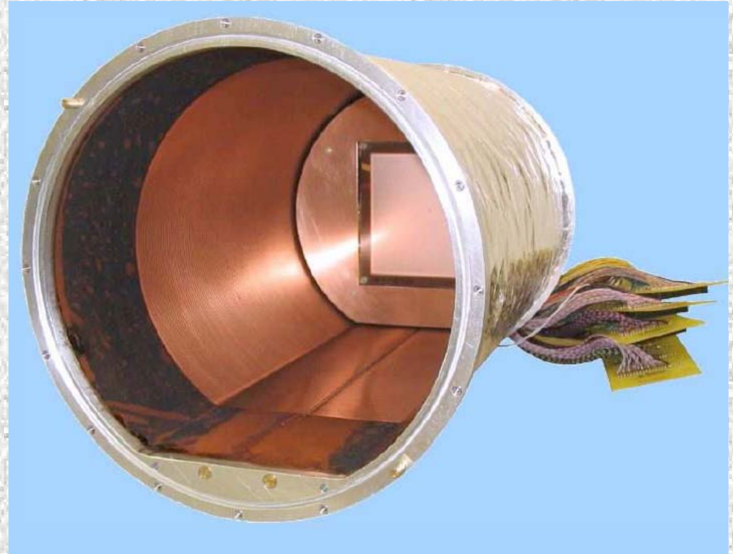
DESY GEM-TPC: 80 cm drift



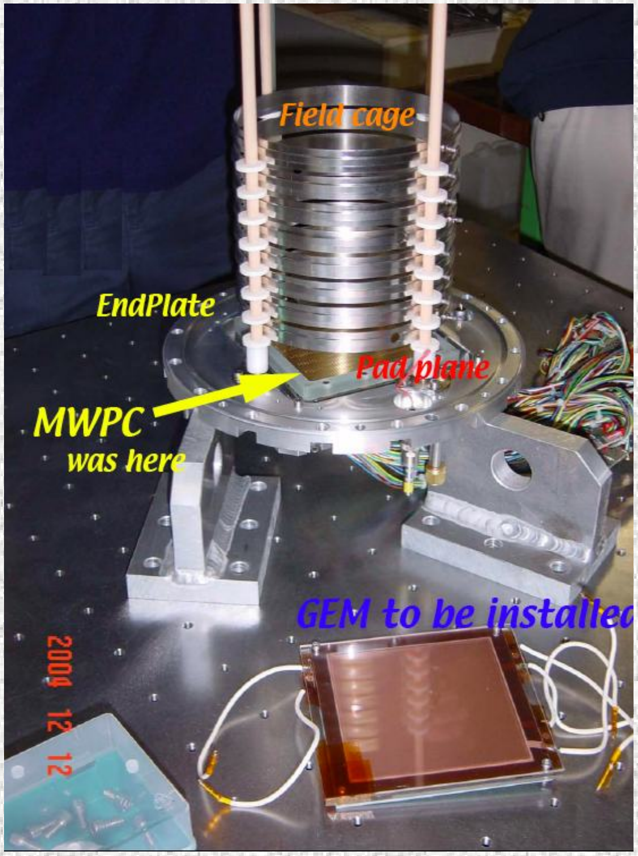
2.2x6.2 mm^2
pads readout



AACHEN GEM-TPC:



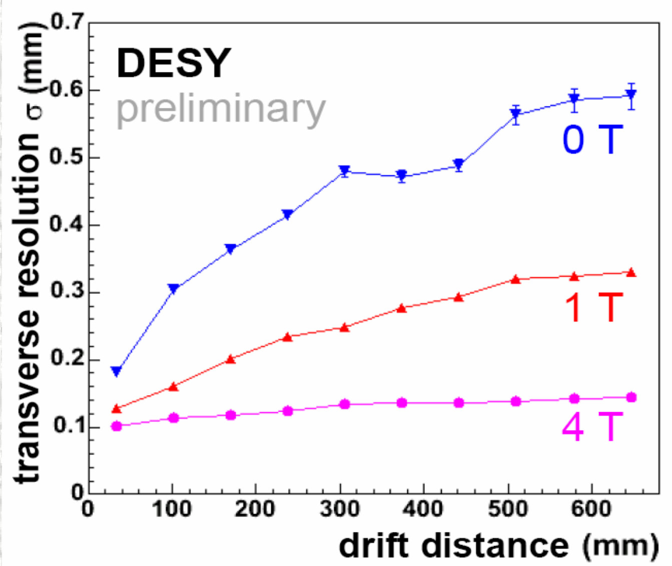
Asian GEM TPC:



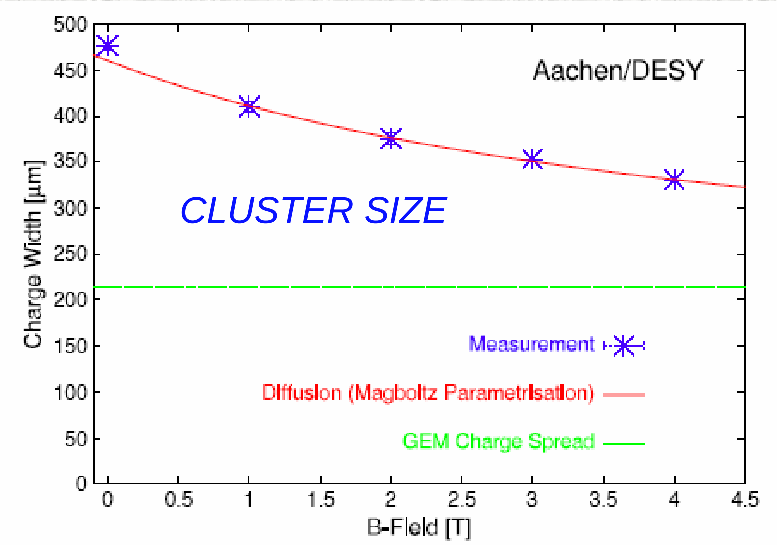
AACHEN-DESY GEM-TPC RESULTS

MAGNETIC FIELD:

BETTER SPACE ACCURACY



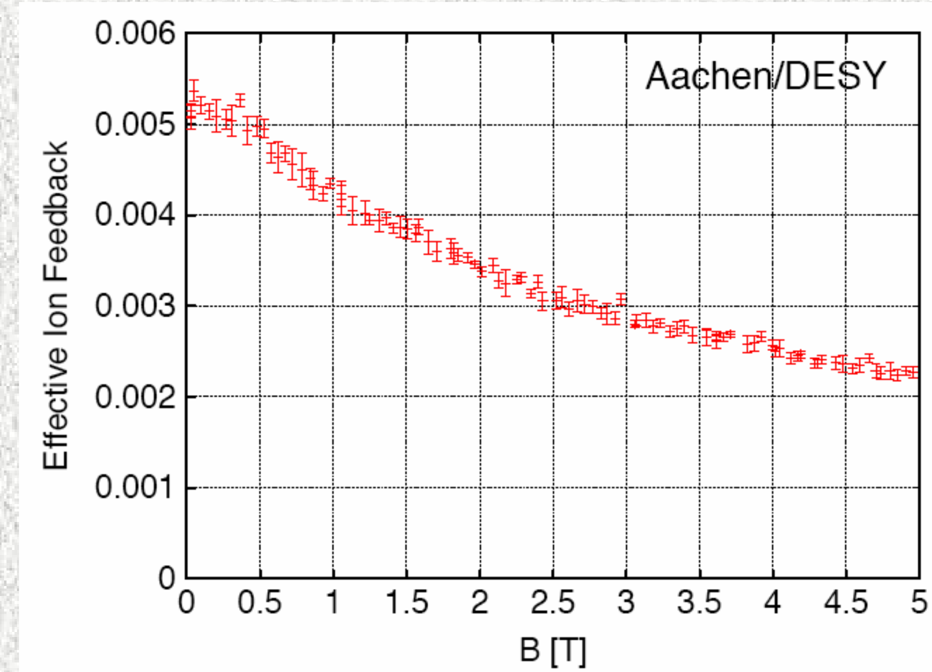
BETTER TWO-TRACK RESOLUTION:



REDUCED FRACTIONAL ION FEEDBACK:

Fractional Ion Feedback:

$$FIF = \frac{\text{Ion current into drift volume}}{\text{Electron current on anode}}$$

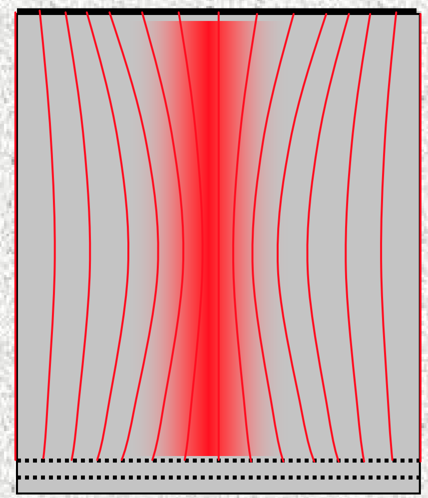


M. Killenberg et al, NIMA 530(2004)251

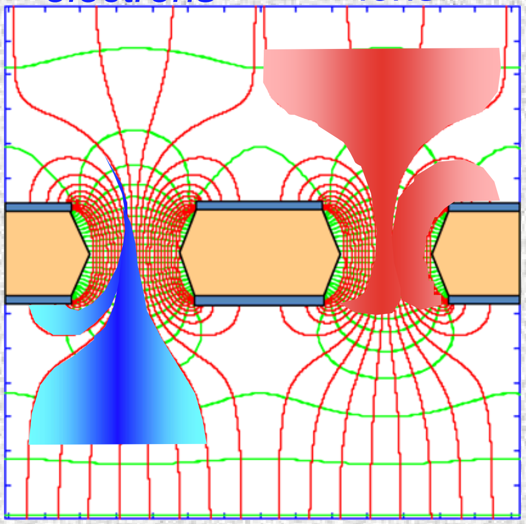
Stefan Roth

ION FEEDBACK (BACKFLOW)

Slow ions accumulate in drift space and distort the electric field



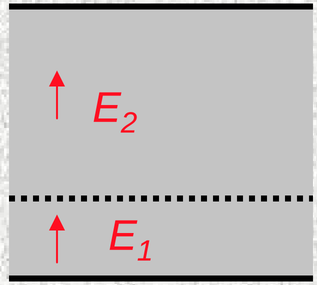
GEM structures:
Convolution of electron and ion transmission
Depends on fields, geometry, gas..

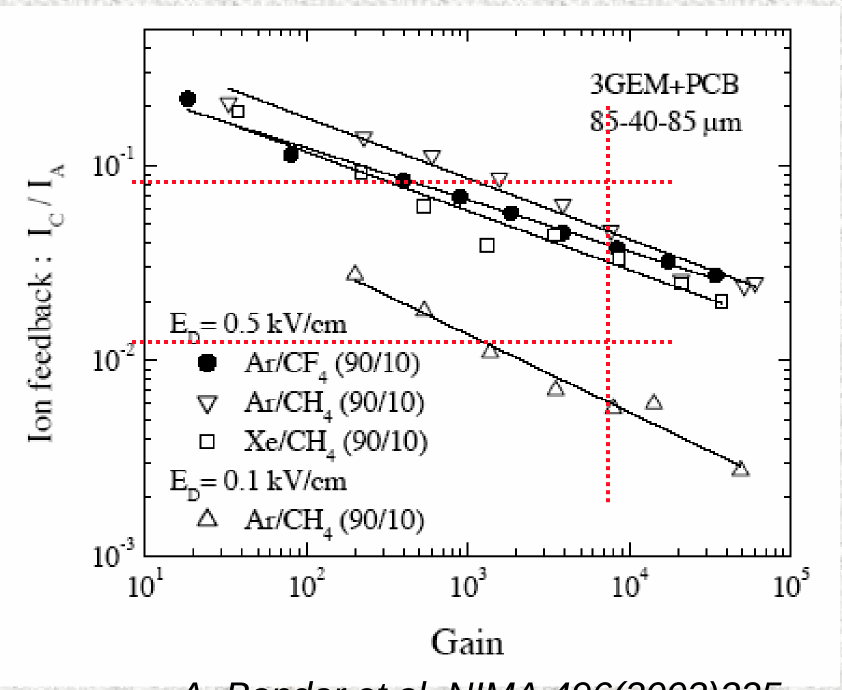


CHARGE TRANSMISSION THROUGH GRIDS

Parallel Plate:

$$T_{ions} \geq \frac{E_2}{E_1}$$





A. Bondar et al, NIMA 496(2003)325

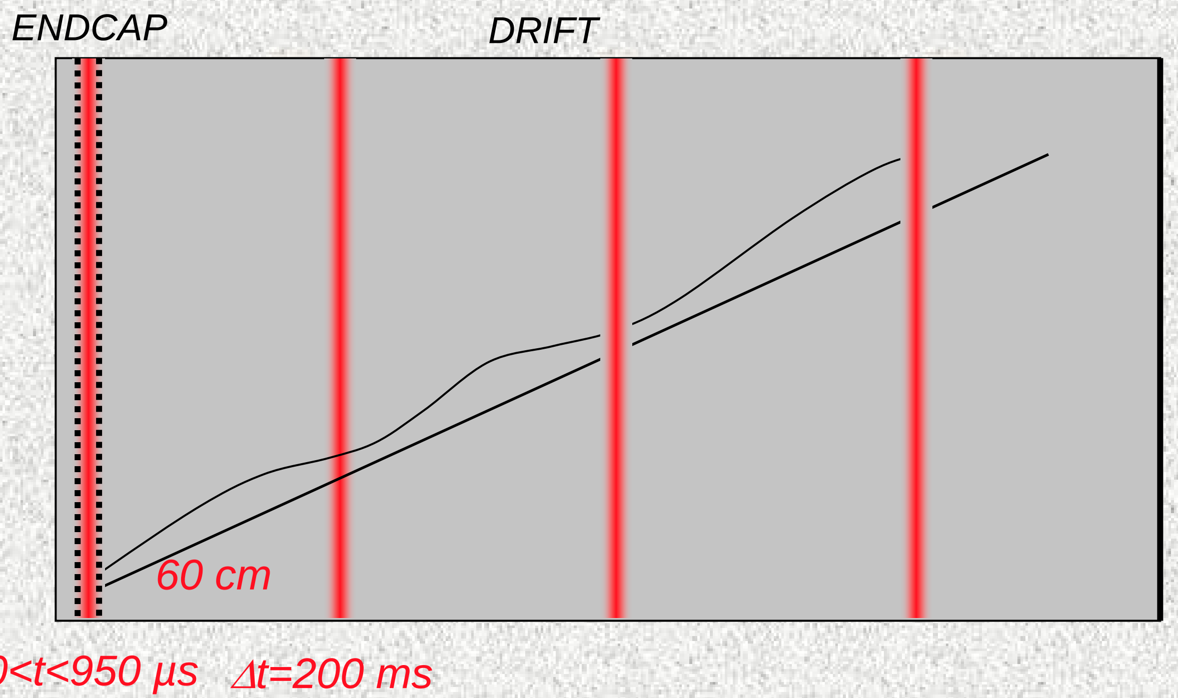
SPILL STRUCTURE AT ILC:

In A-CH_4 90-10:

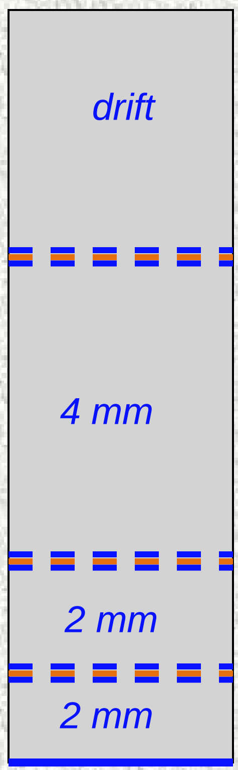
E_{DRIFT} = 150 V cm^{-1} w^- (electrons): 6 cm μs^{-1} $w^+(CH_4^+)$: 2.9 µm μs^{-1}

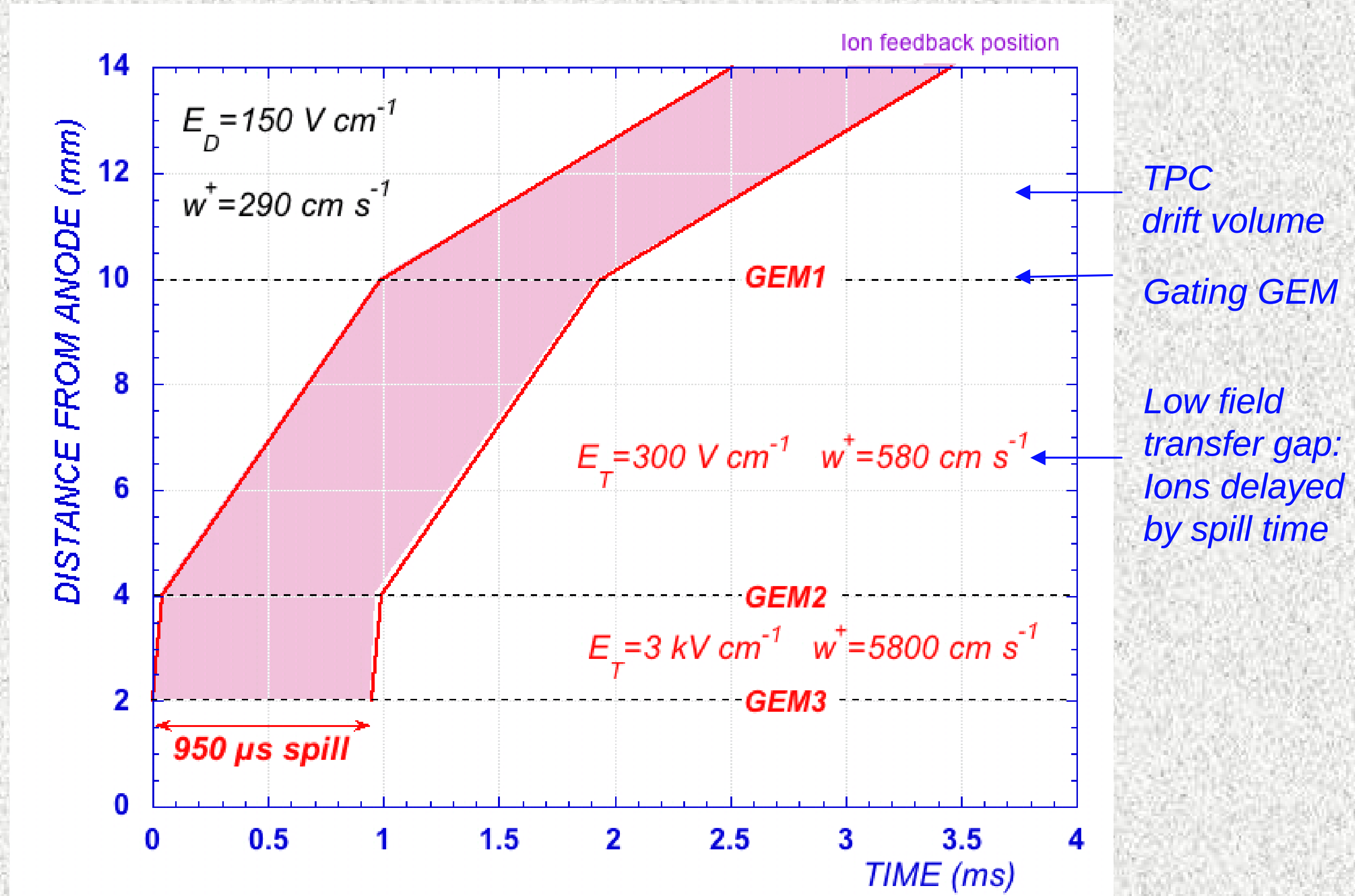
TPC, 2 m long:

Total collection time: electrons ~ 40 µs ; ions ~ 0.7 s



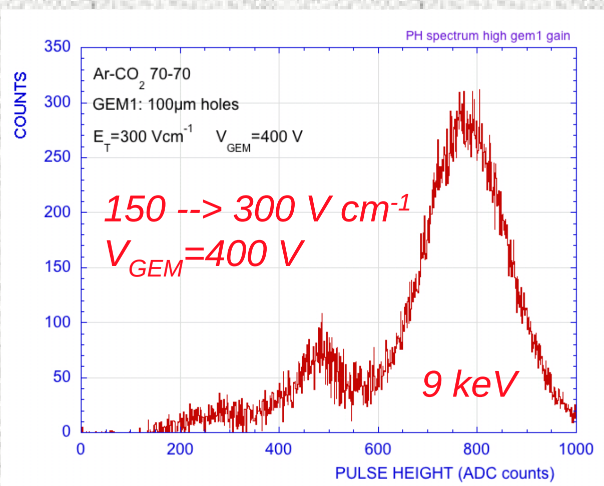
ION FLOW IN A TRIPLE GEM TPC:



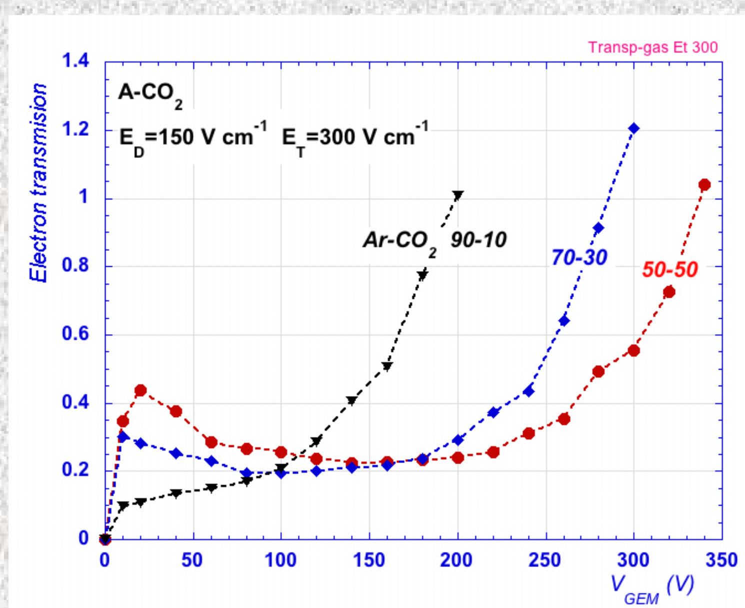


? GEM CHARGE TRANSMISSION INTO LOW FIELDS

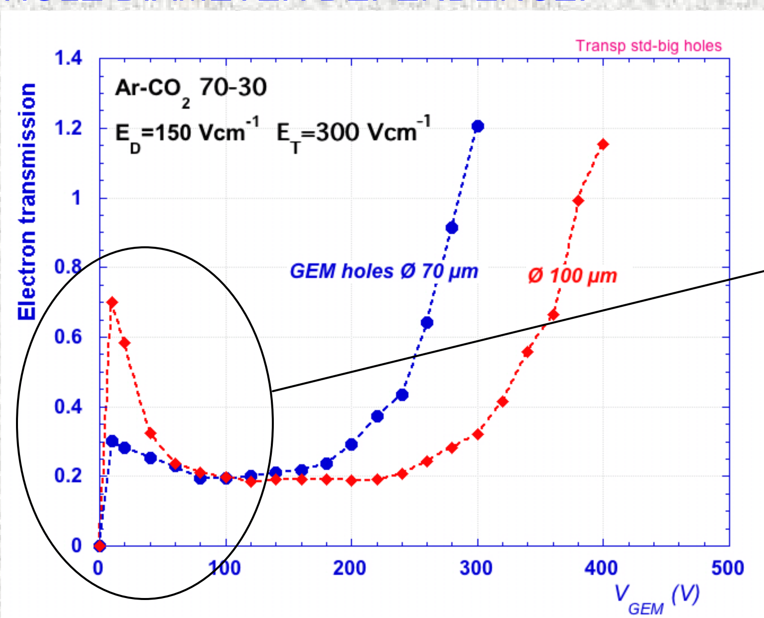
GEM LOW FIELD TRANSMISSION:



GAS DEPENDENCE (Transverse diffusion):



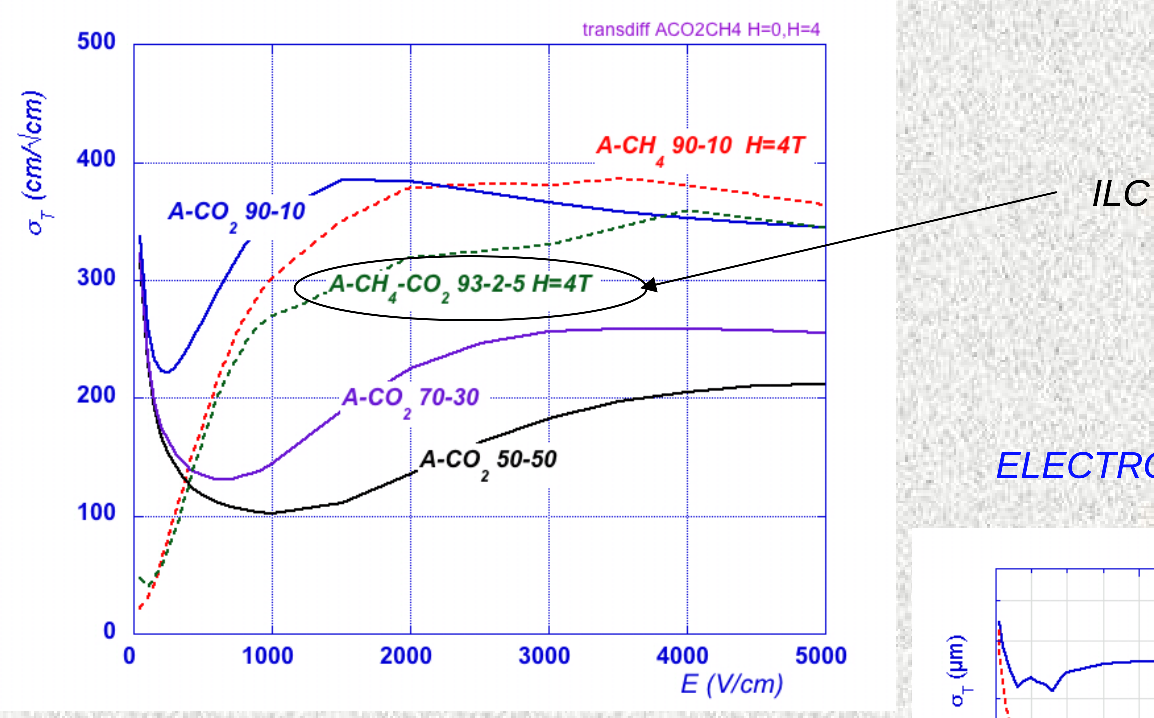
HOLE DIAMETER DEPENDENCE:



GATING WITH 10 V!

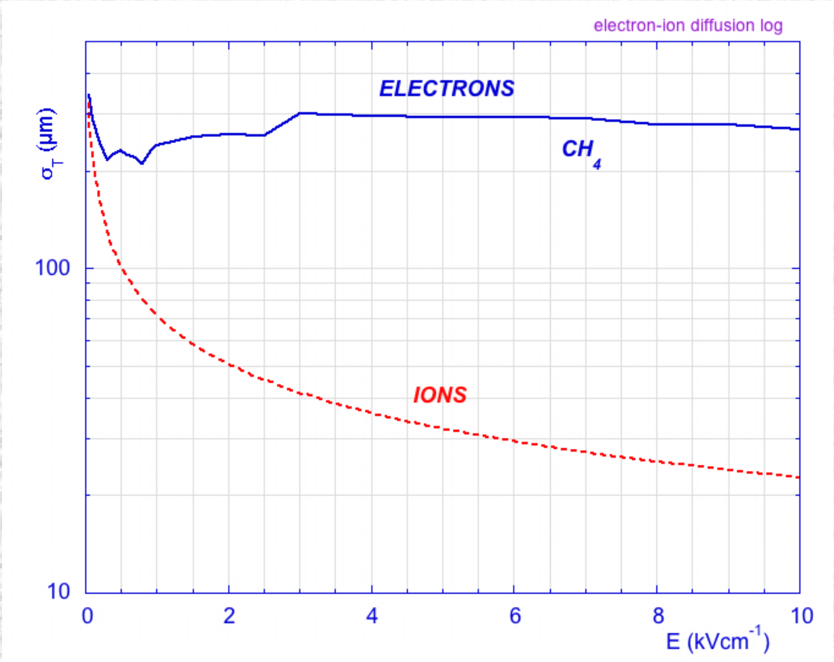
F. Sauli, L. Ropelewski, P. Everaerts, NIMA in press (Jan. 2006)

TRANSVERSE ELECTRON DIFFUSION:

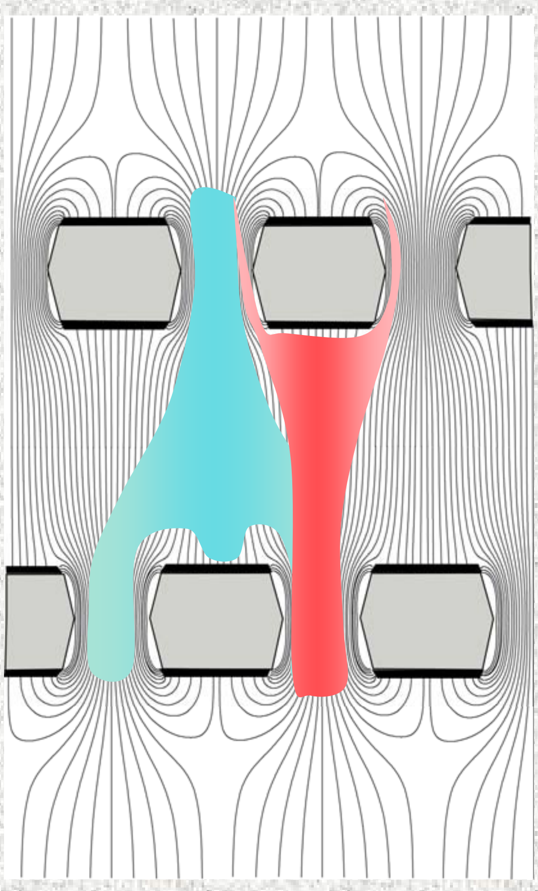


Computed with MAGBOLTZ

ELECTRON AND ION DIFFUSION:

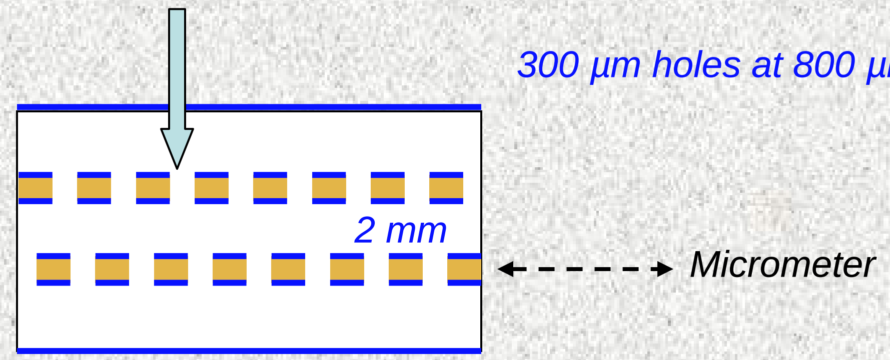


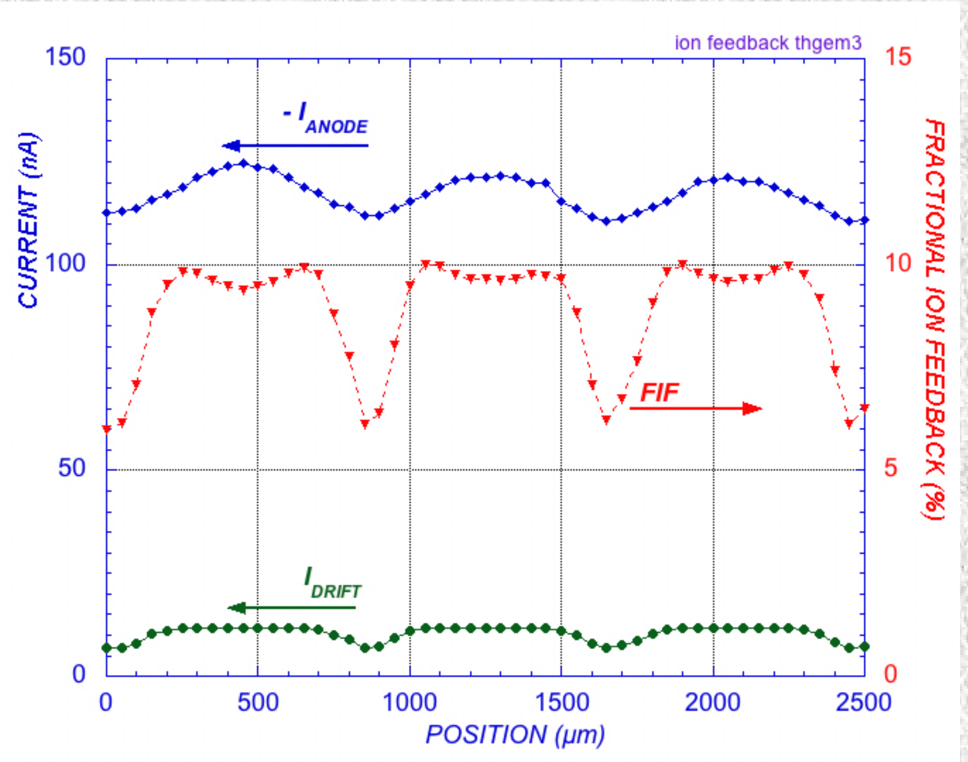
OFFSET GEM PAIR:



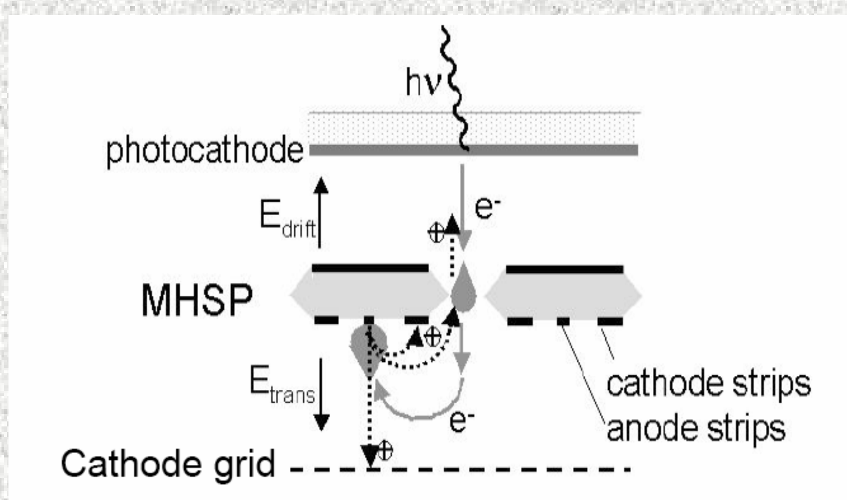
GEM POSITION SCAN (Using Breskin's Thick GEMs):

300 µm holes at 800 µm pitch

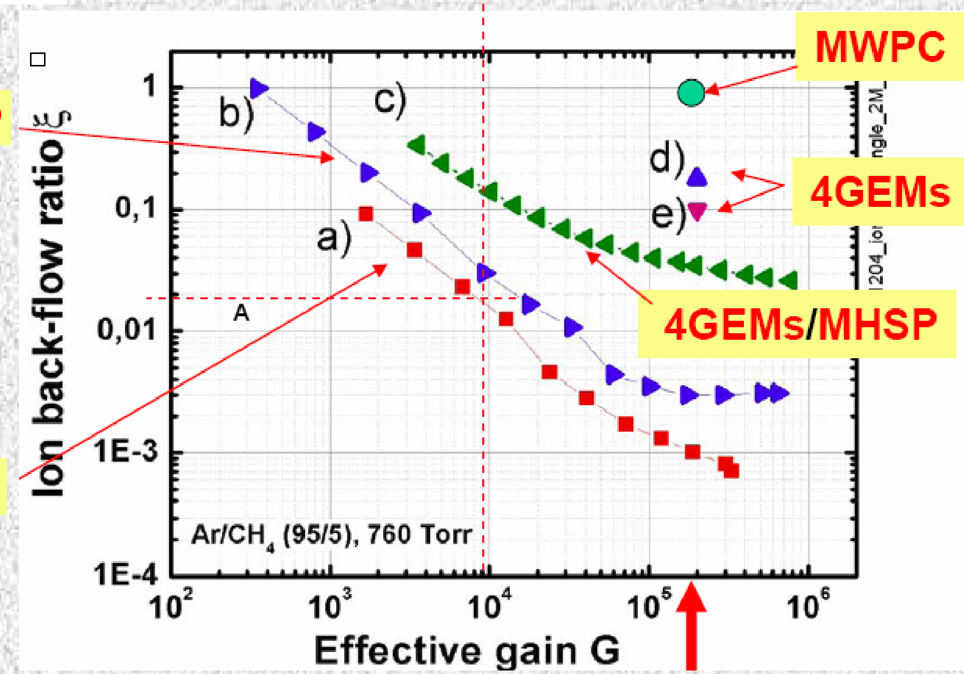




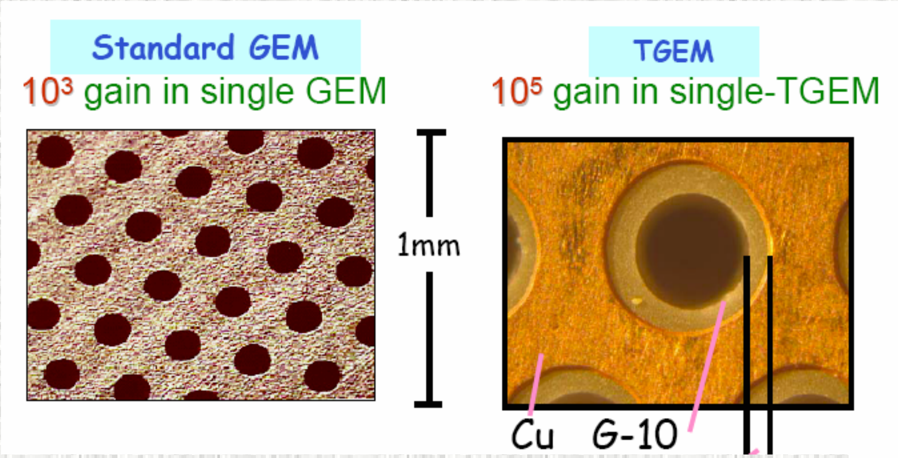
MICROHOLE AND STRIP PLATE (MHSP)



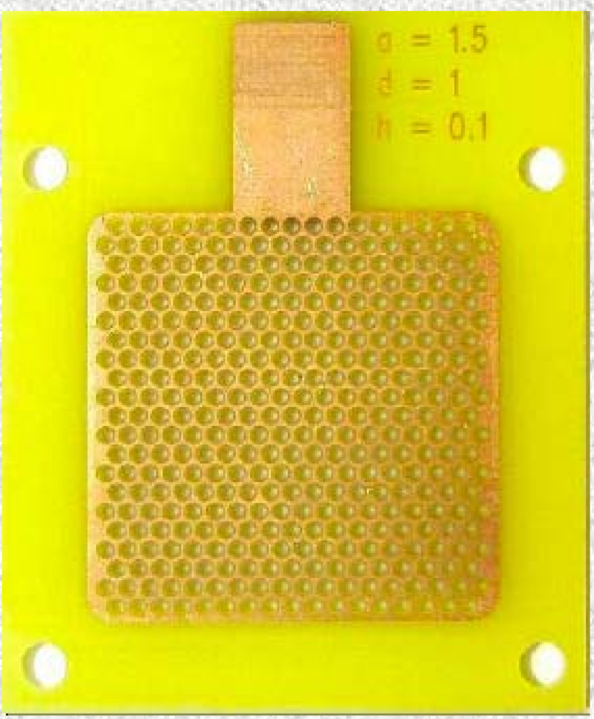
J.M.Maia et al. NIMA 504(2003)364

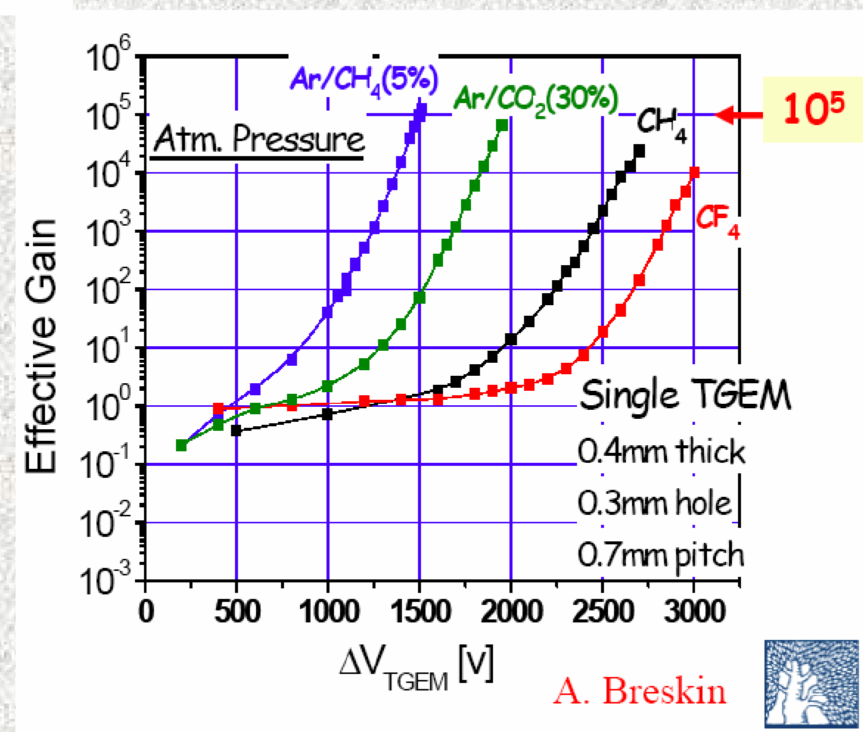


A. Breskin, Baune (2005)



THICK GEM
(A. Breskin et al, WIS)

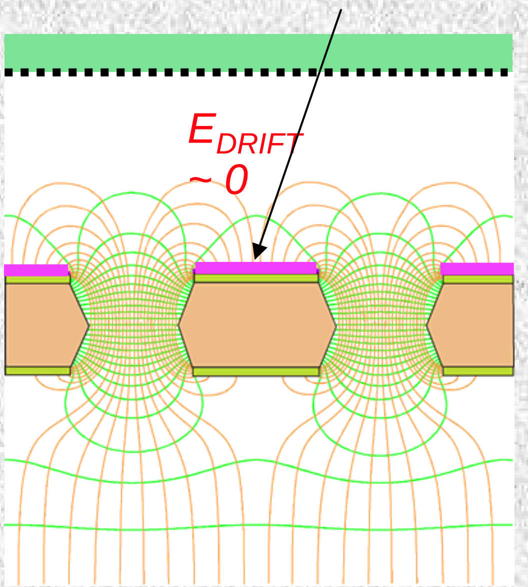




R. Chechick et al, NIMA 553(2005)35

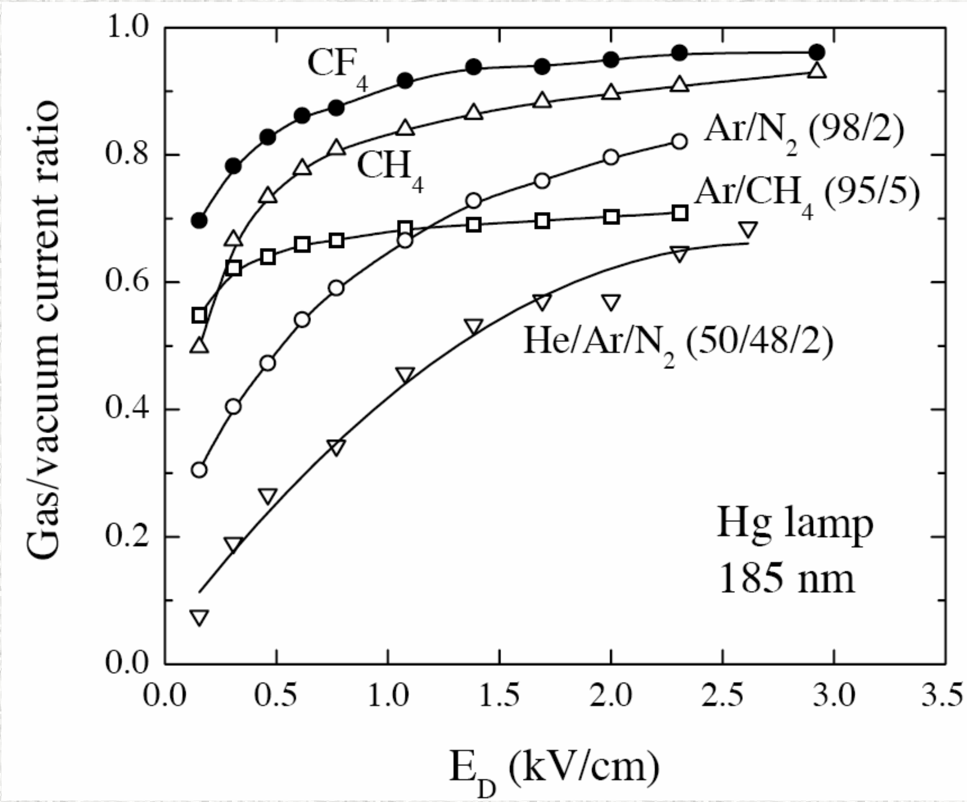
PHOTON DETECTION WITH GEM

Reflective Photocathode deposited on upper GEM face



R. Bouclier et al, IEEE Trans. Nucl. Science NS-44(1997)646

CsI photocathode in gas detectors
Efficiency relative to vacuum (at 185 nm):

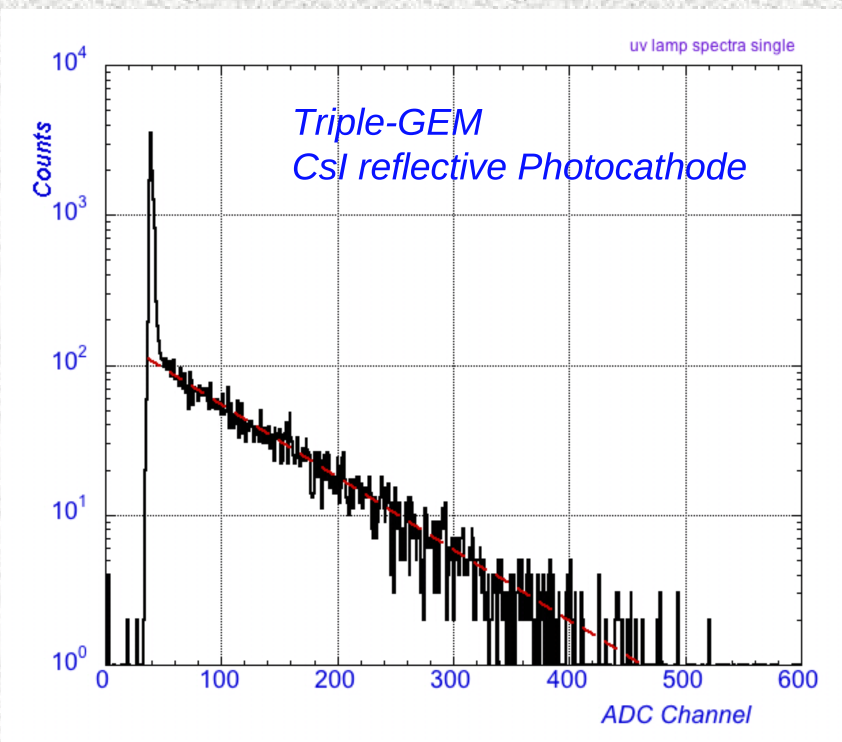


A. Breskin et al, Nucl. Instrum. Methods A483(2001)670

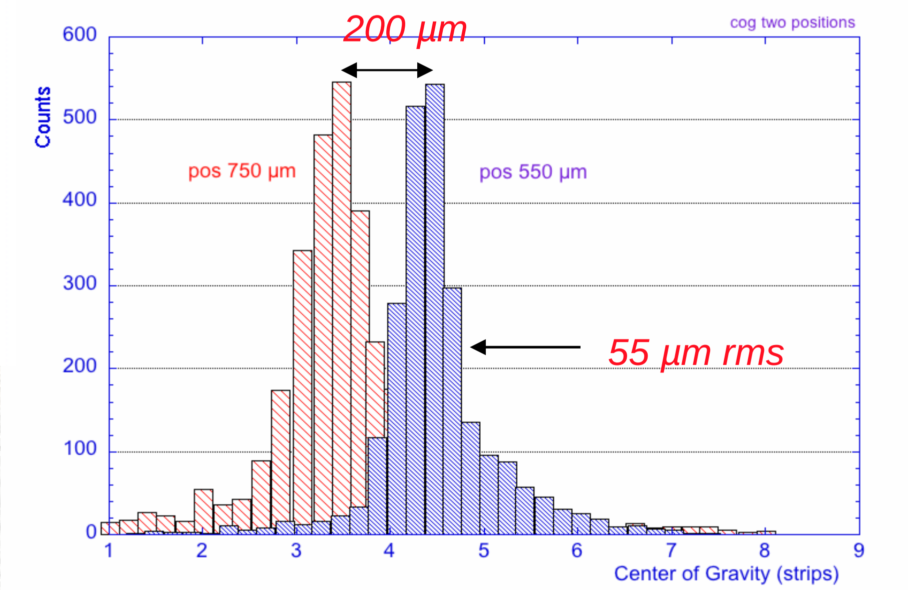
D. Mormann et al, Nucl. Instr. and Meth. A478(2002)230

TRIPLE-GEM WITH CsI PHOTOCATHODE

Single photoelectron PH spectrum:



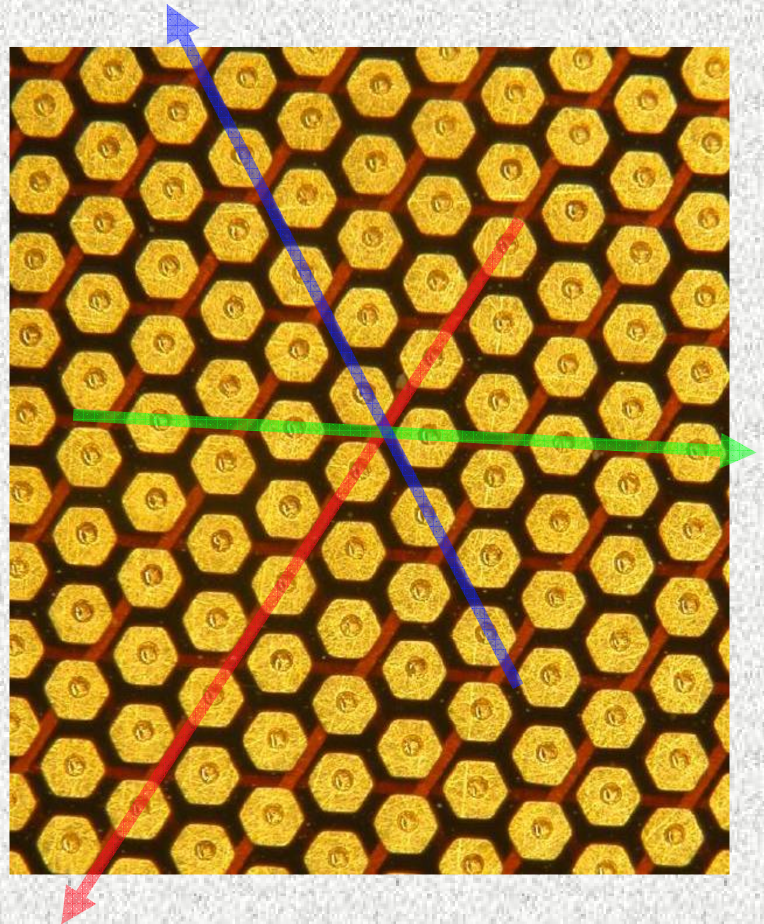
Single photoelectron space accuracy
Center-of-gravity distribution for two collimated UV beam positions, 200 µm apart:



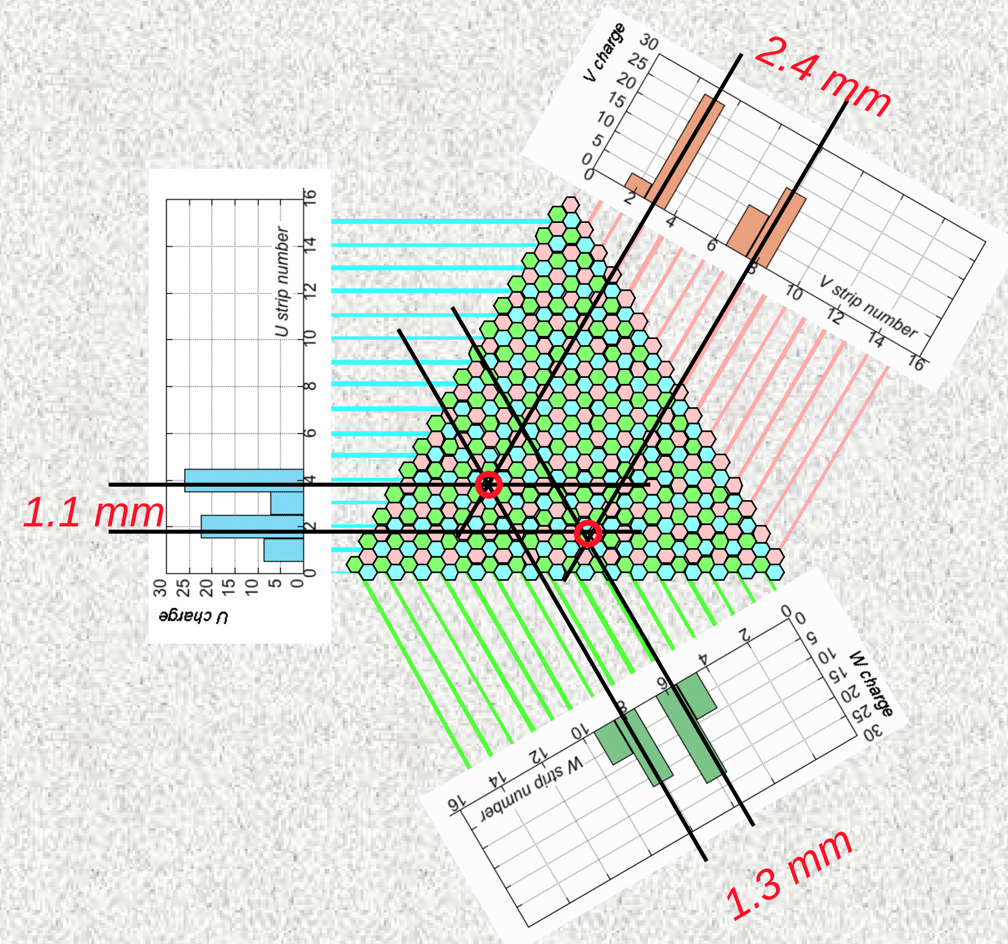
T. Meinschad, L. Ropelewski and F. Sauli, NIMA 535(2004)324

HEXABOARD READOUT

Hexagonal pad rows, 500 µm Ø
Interconnected along three directions:



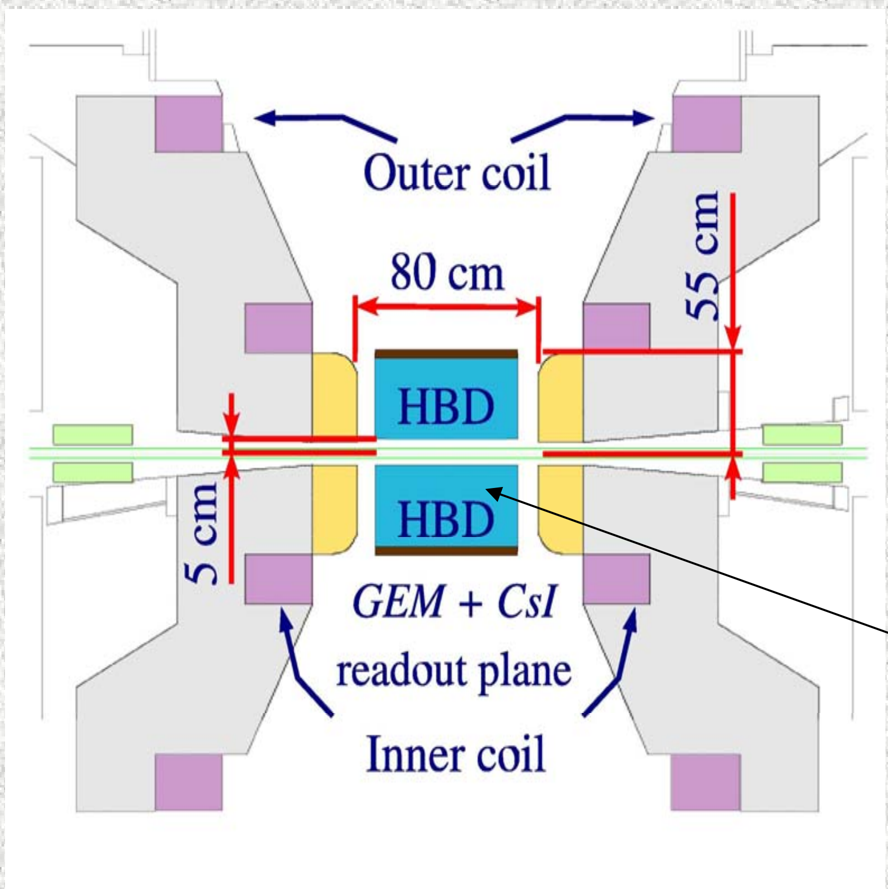
DOUBLE PHOTON EVENT:



S. Bachman et al, NIMA 478(2002)104
F. Sauli, NIMA 553(2005)18

FAST RICH (<2 ns resolution)

PHENIX UPGRADE - HADRON BLIND DETECTOR

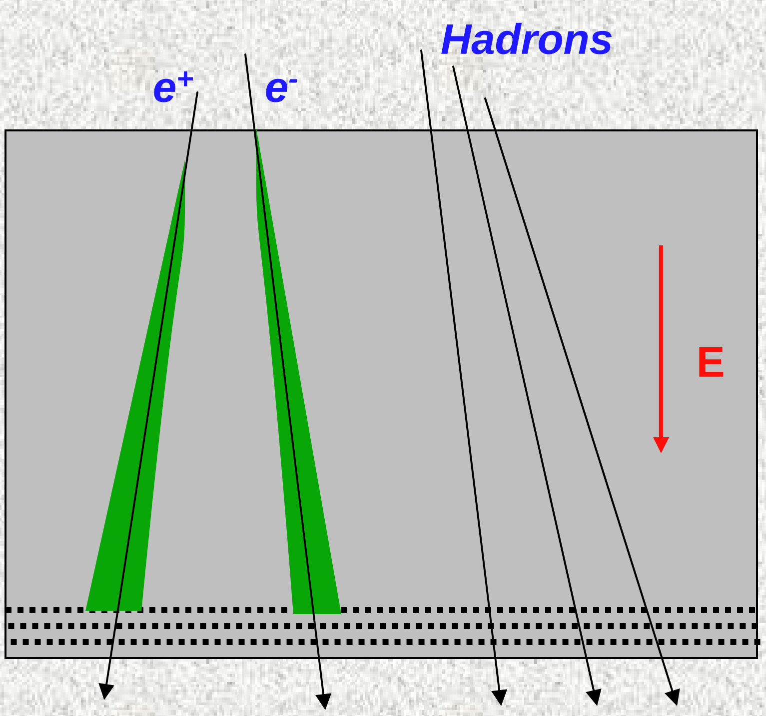


AIMS:
IMPROVE HADRON REJECTION
REDUCE COMBINATORIAL BACKGROUND

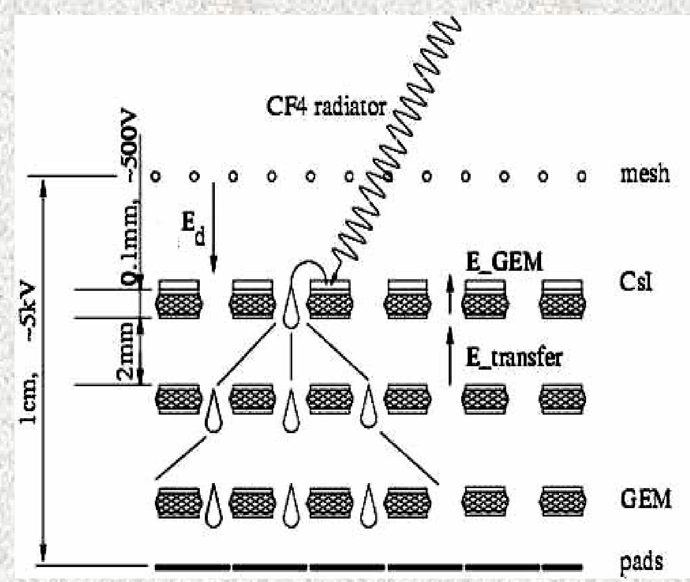
WINDOWLESS RICH DETECTOR WITH CF_4 GAS RADIATOR

WIS-BNL-Stony Brook-NEVIS-Florida IT-RIKEN-Un. Illinois

HADRON BLIND DETECTOR
REVERSE FIELD TPC



PHOTON DETECTOR;
TRIPLE GEM WITH CsI REFLECTIVE PHOTOCATHODE



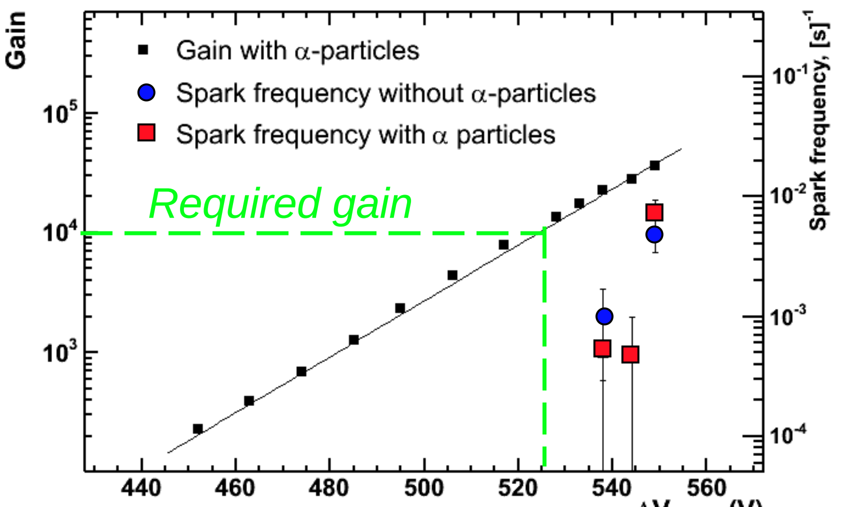
A. Kozlov et al, NIMA 523(2004)344

HBD: BASIC MEASUREMENTS

OPERATION IN PURE CF_4

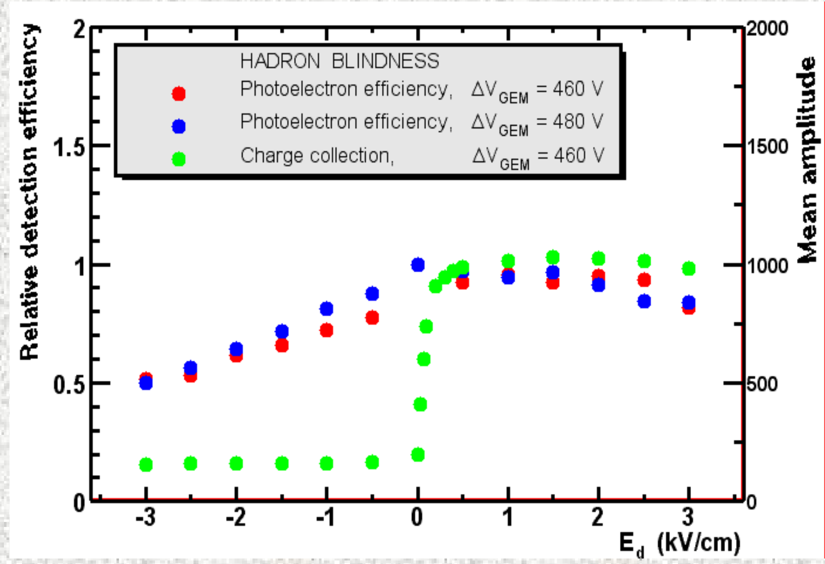
Discharge Probability on exposure to α particles:

HV segmented GEMs 10x10 cm^2

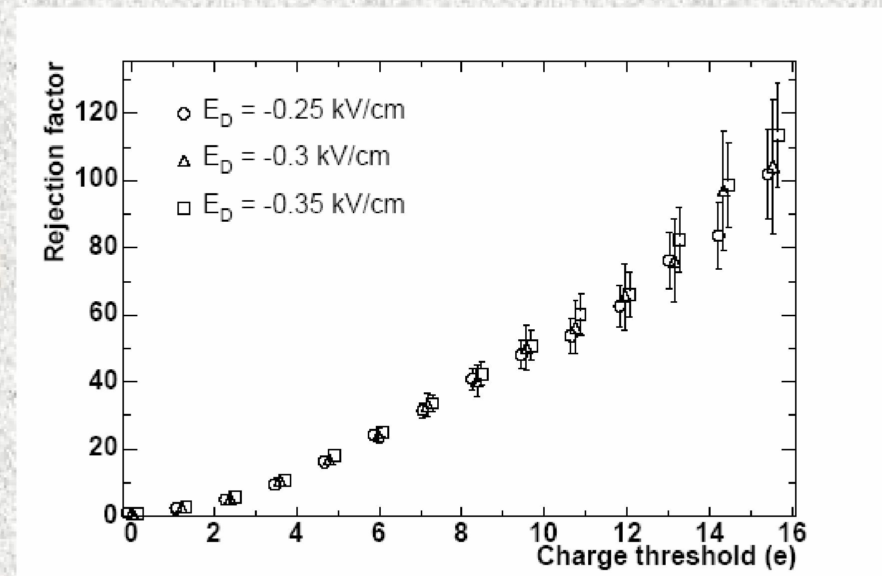


ΔV_{GEM}

DETECTION EFFICIENCY vs DRIFT FIELD:

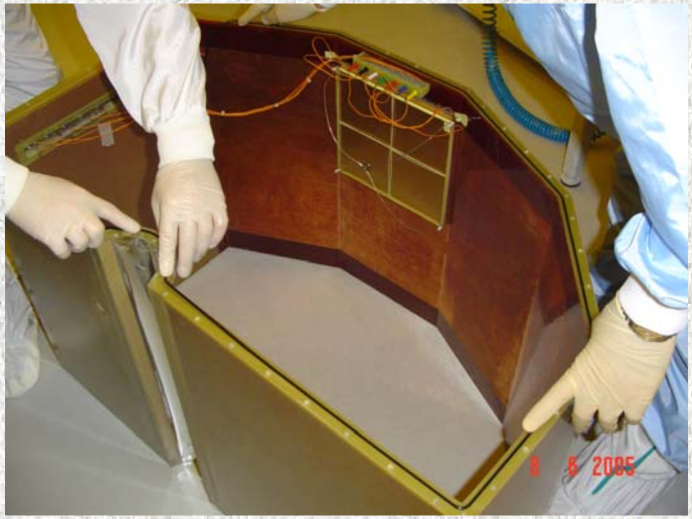


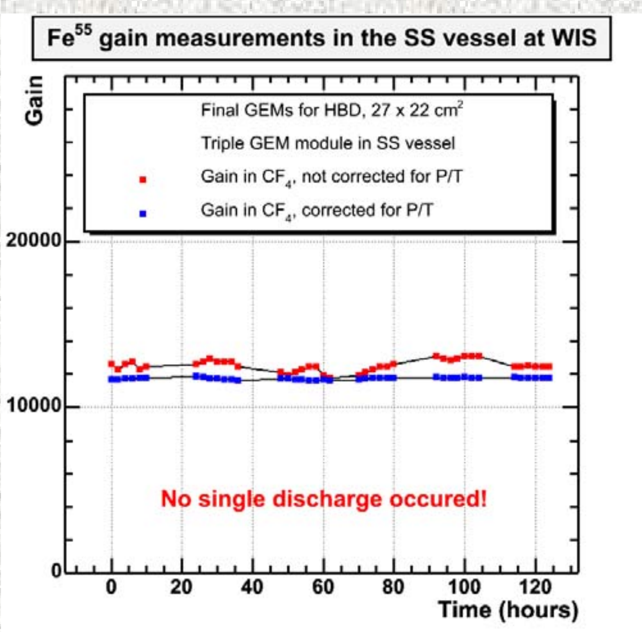
HADRON REJECTION FACTOR:



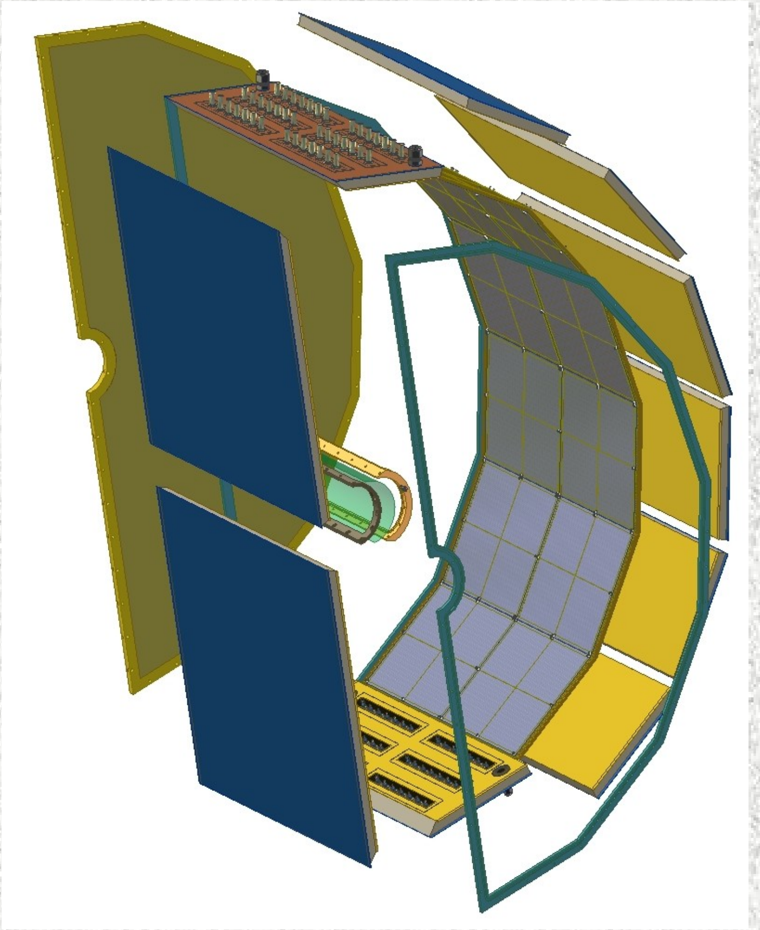
I. Ravinovich, QM 2005

PROTOTYPE CONSTRUCTION





FINAL HDB DESIGN



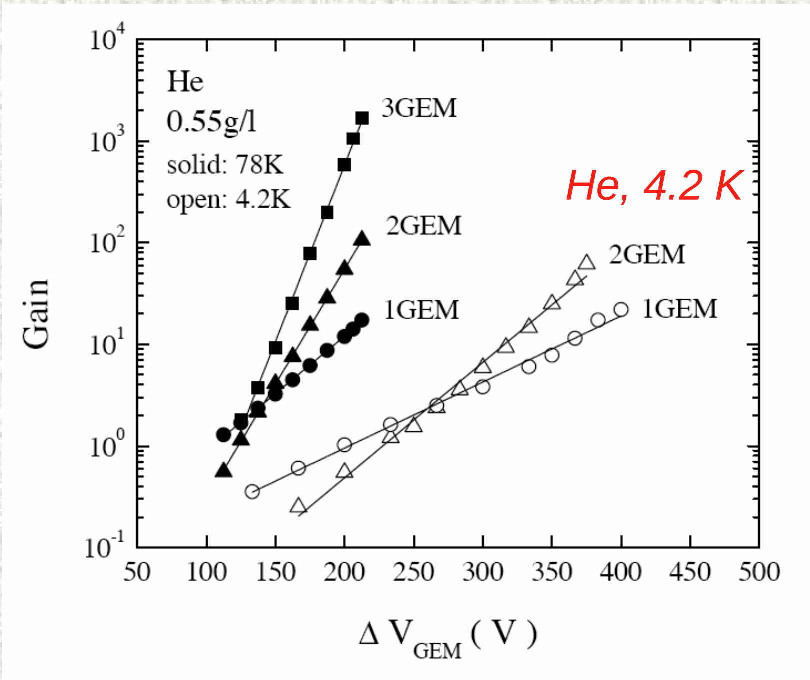
24 TGEM DETECTORS WITH PAD READOUT (IN PRODUCTION AT CERN-EST-DM)

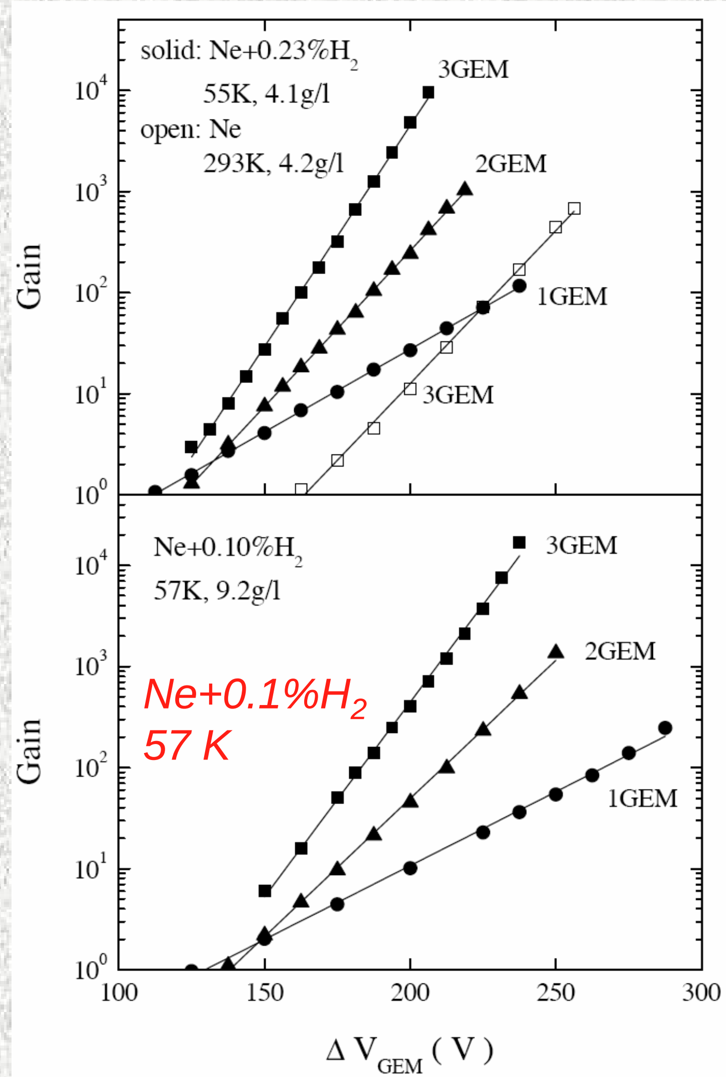
I. Ravinovich, QM 2005

GEM operation in low temperature He and Ne

NEVIS, BNL, BINP Novosibirsk

e-bubble chamber for solar neutrino detection (Bill Willis)

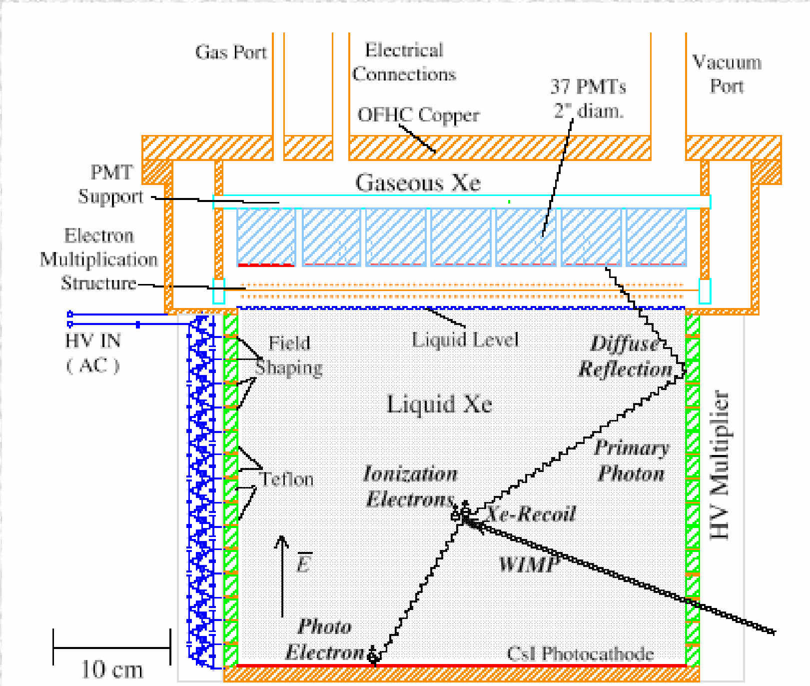




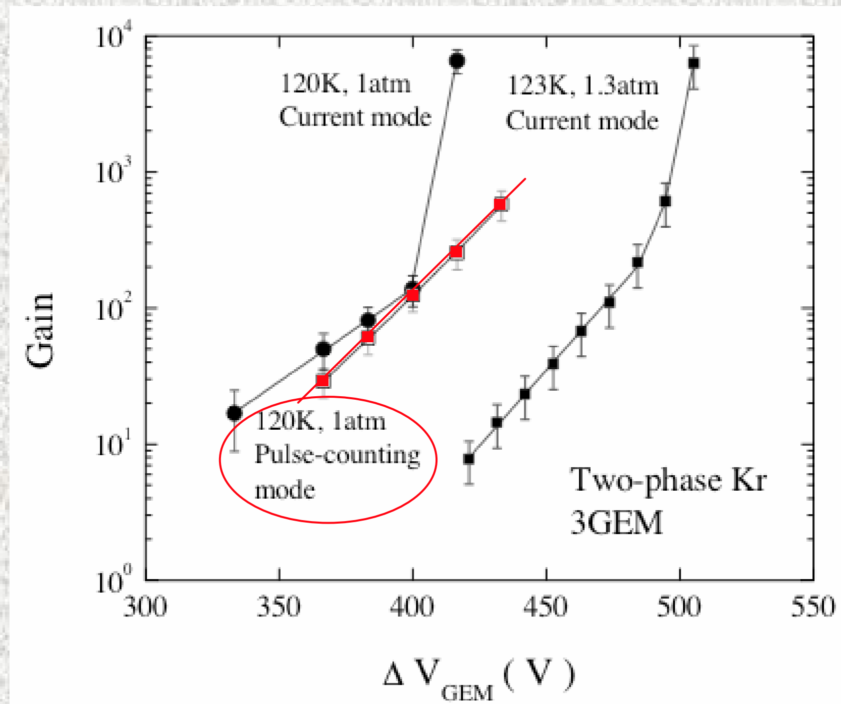
A. Buzulutskov et al, NIMA 548(2005)487

EXTRACTION FROM LIQUID AND MULTIPLICATION IN GAS PHASE

XENON: Dark Matter and WIMPs search

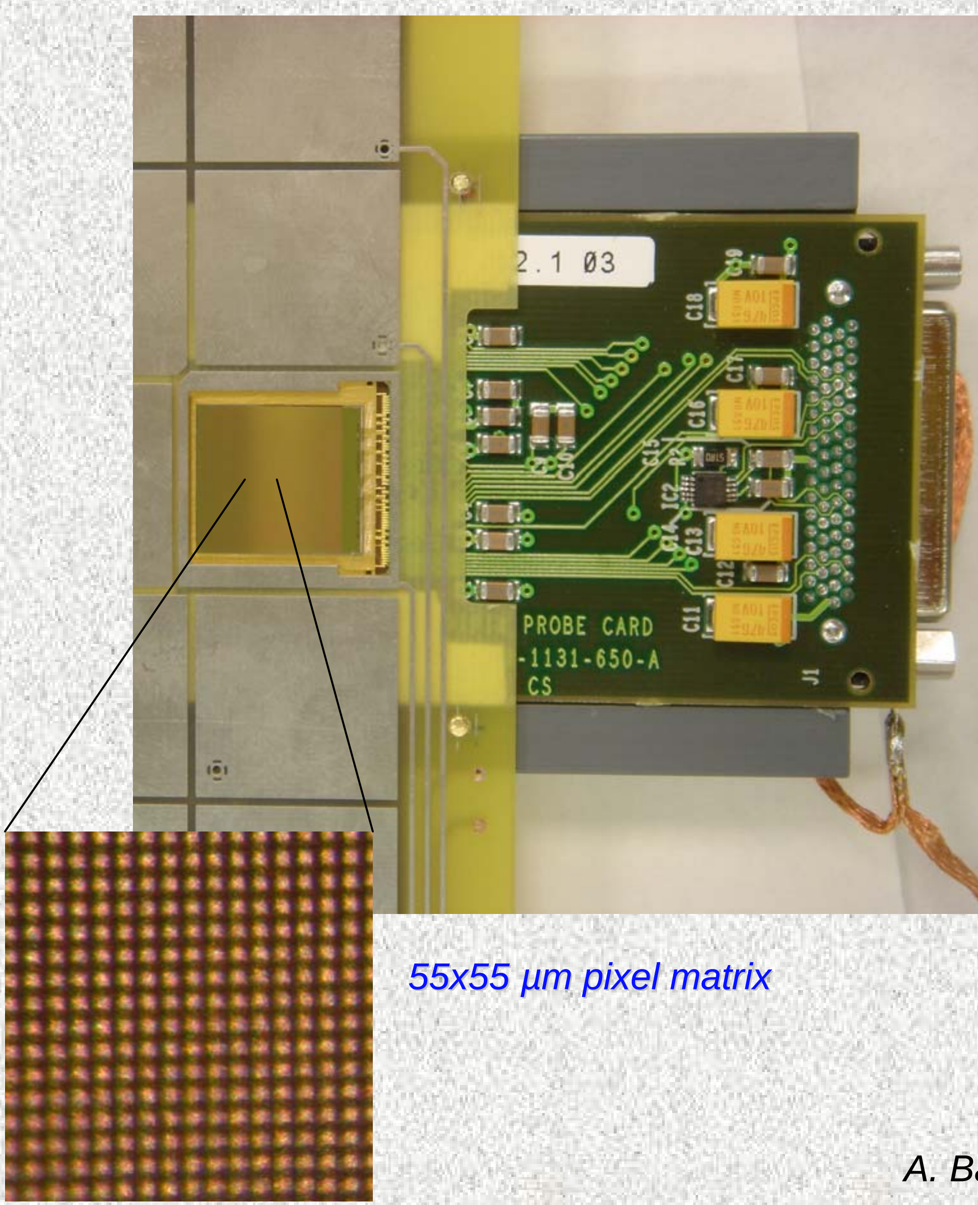


EXTRACTION AND MULTIPLICATION IN Kr:



A. Bondar et al, NIMA 548(2005)439

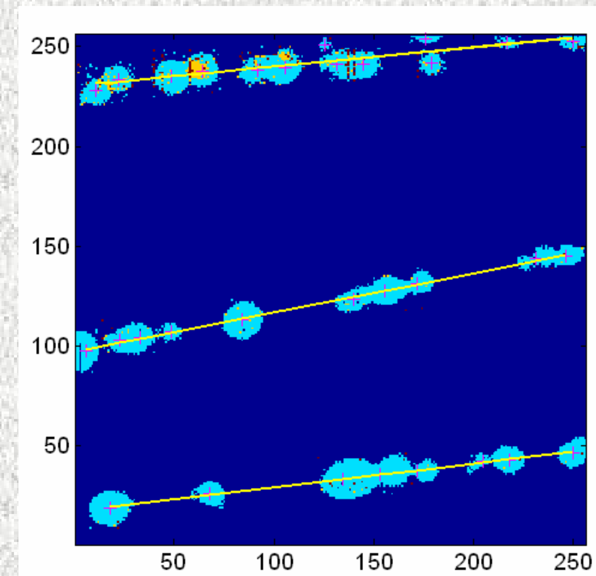
PIXEL READOUT OF GEM DETECTORS: MEDIPIX



55x55 µm pixel matrix

- *Digital readout: preamp / discriminator*
- *Two DAC thresholds (low, high)*
- *Noise RMS ~ 150 e^-/channel*

Triple GEM+MEDIPIX2
A-CO_2 70-30



ROBUST:
No damages to MEDIPIX in 10 months of running

A. Bamberger et al, IEEE NSS (Puerto Rico 2005)

RESEARCH GOALS FOR THE NEAR FUTURE

IMPROVE MANUFACTURING AND TESTING TECHNOLOGY:

- AUTOMATIC TEST FACILITIES
- REPLACE PLASTIC MASKS WITH GLASS (BETTER UNIFORMITY, LARGER SIZES)
- FIND A RELIABLE SECOND SOURCE: TECHETCH, 3M, JAPAN

DEDICATED READOUT ELECTRONICS:

- ADD INTEGRATED DISCHARGE PROTECTION
- FASTER INPUT AMPLIFIERS (5 ÷10 ns SHAPING)
- FRONT-END DATA REDUCTION (COG, ZERO SUPPRESSION,…..)
- PIXEL READOUT, ACTIVE PIXEL ELECTRONICS

OPTIMIZE VERY HIGH RATE PERFORMANCES:

- EXTEND AGING LIMIT
- USE RAD-HARD AND NON-OUTGASSING MATERIALS

~~THE END~~

...TO BE CONTINUED!