Status and perspectives of Gaseous Photon Detectors (GPD) for single photon detection

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In memory of a dear friend and colleague

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The choice of a GPD:

- ❑ Physics goals of the experiment
- ❑ Thresholds on particles to be detected
- ❑ Signature of particles to be detected
- ❑ Role of the RICH in the (off-line) trigger scheme
- ❑ Choice of radiator
- ❑ Matching the wavelength bandwidth

- ✓ Space limitations
- ✓ Localization requirements
- ✓ Photon feedback permitted or not
- ✓ Separating background (ionizing particles) - pattern recognition

GPD design - physical processes in the GPD

GPDs for single photon detection in RICH: Basic requirements

Large area: the only solution for truly large area coverage.
☺ proven square meters coverage.

Small radiation length(X_0)

✓ **Operation in Magnetic field.**

Flat geometry (preferable):
☺ proven (proximity)

Sensitivity to single photons:
gain: > 10^5 CERES, ~n x 10^4 ALICE ~ n x 10^3 PHENIX HBD

⇨ **Insensitivity to intense ionizing background:**
⇨ the main challenge ⇦
the requirements become more and more severe.

✓ **Fast response (sub ns??):** a solid PC and a fast e^- multiplier.

Moderate localization,
Robust (no wires, CsI), Inexpensive

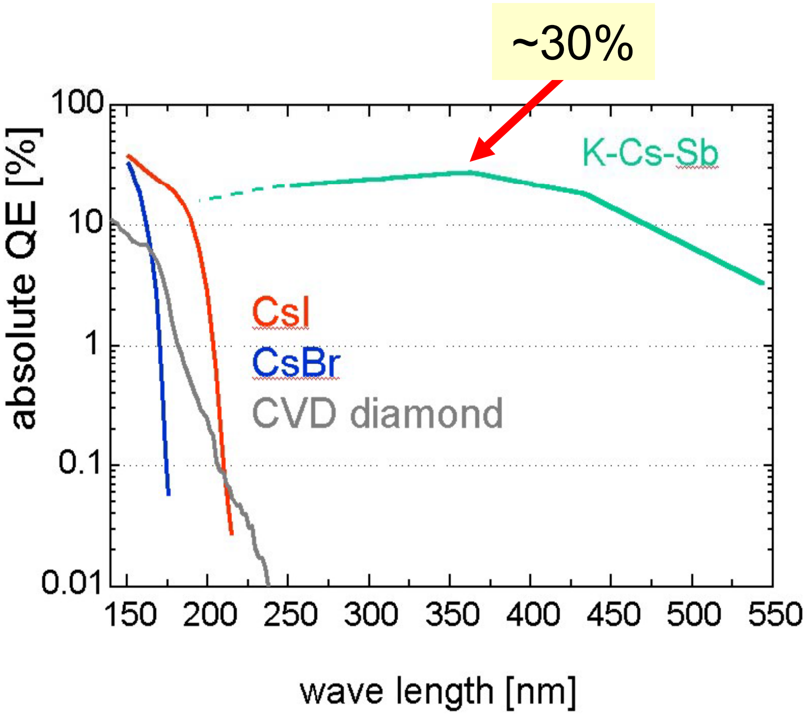
GPD: Physical processes I

<u>Gas-compatible photocathodes:</u>

UV: CsI, CsBr, CsTe,
CVD-diamond…

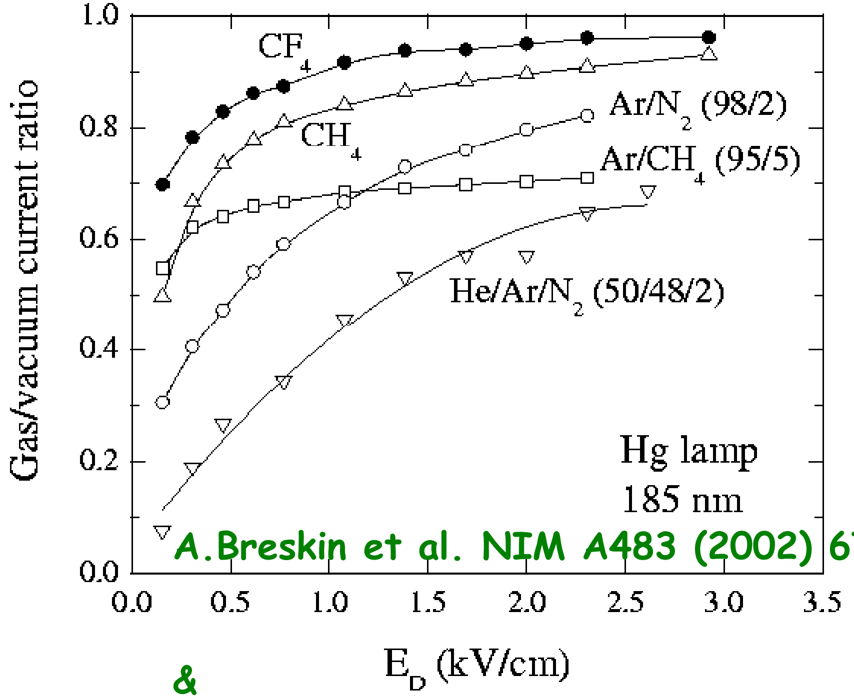
Visible: Cs_3Sb, K-Cs-Sb, Na-K-Sb…

- e- backscattering in gas (QE_{eff}<QE)



M.Balcerzyk et al, IEEE Trans. Nucl. Sci. NS50 (2003) 847

QE_{eff} / QE in gas vs E_{PC}

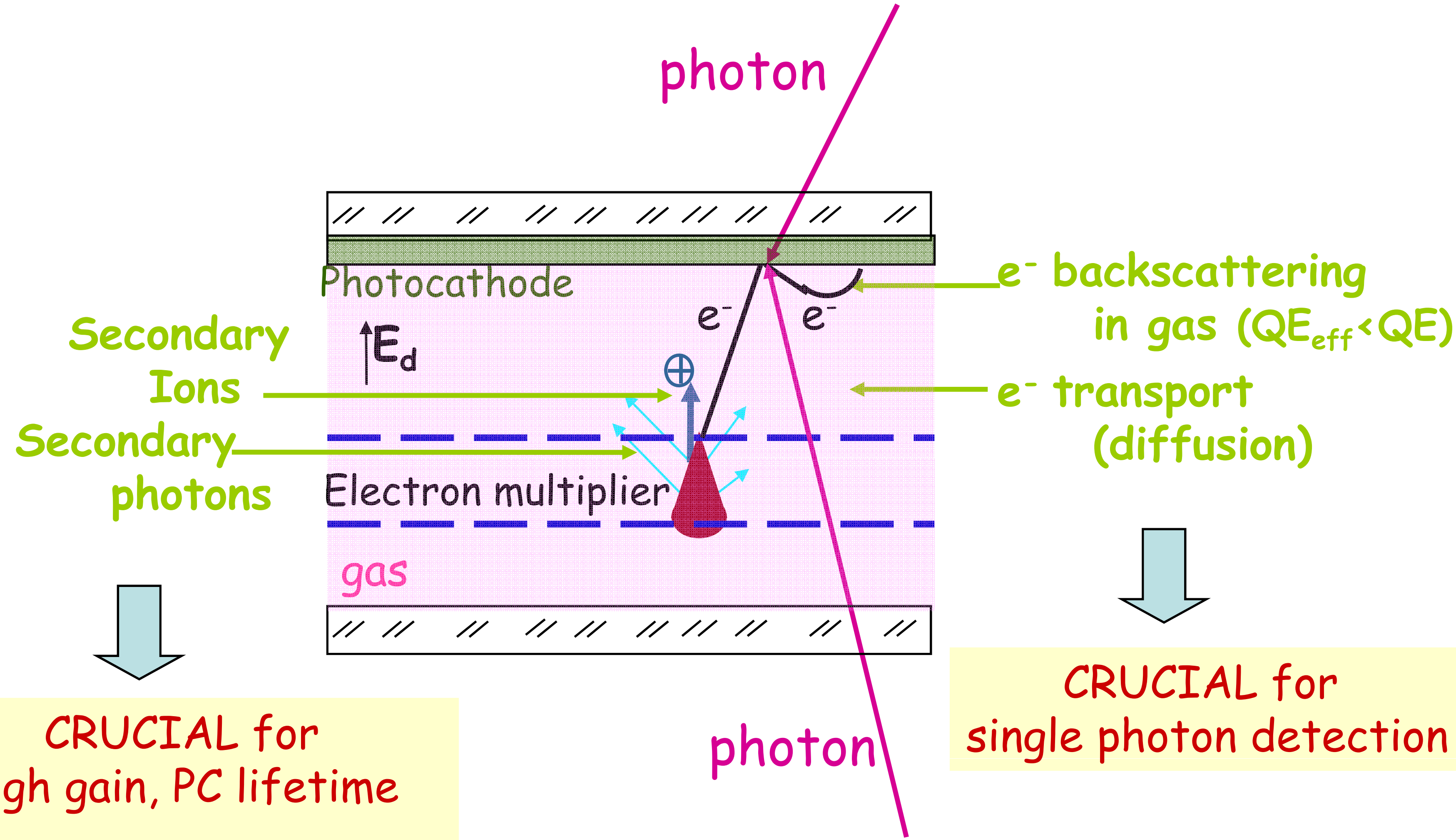


A.Breskin et al. NIM A483 (2002) 670

&

L.C.C. Coelho et al,,NIM in press, available on line

GPD: Physical processes II



CRUCIAL for
high gain, PC lifetime

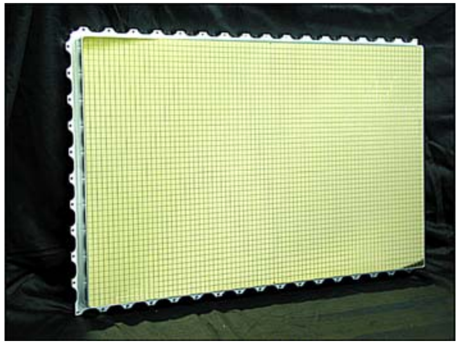
Loss of time & local. info.
of original event

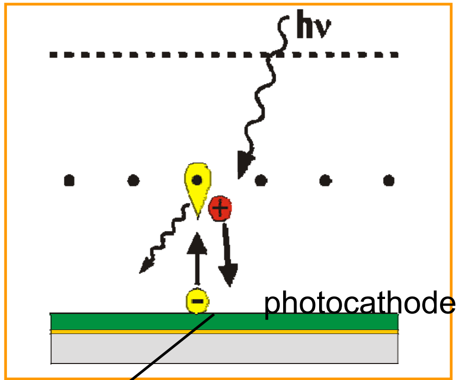
CRUCIAL for
single photon detection

(Solid PC only)

Past :

ALICE, HADES, COMPASS, J-LAB....

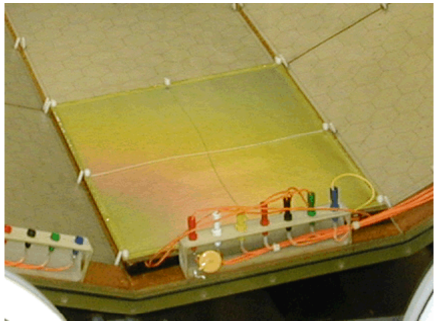


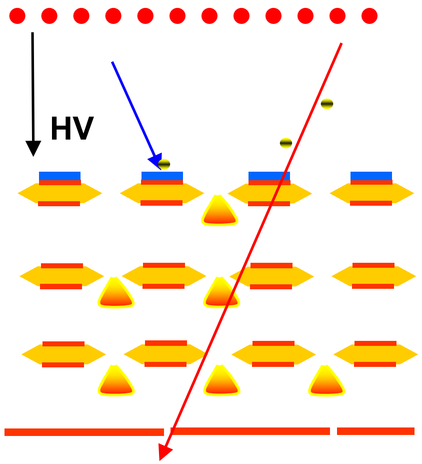


CsI on readout pads

Present:

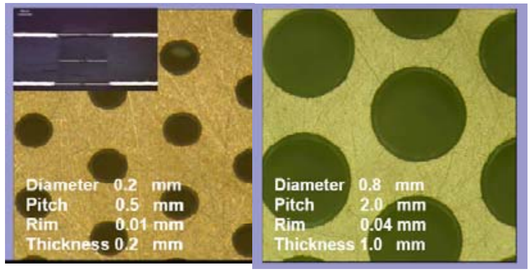
HBD of PHENIX





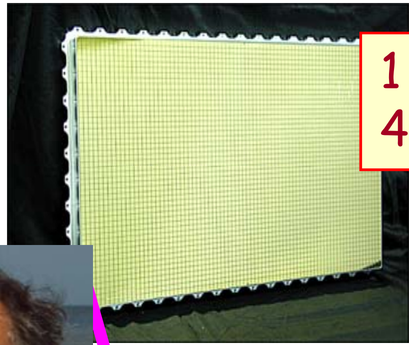
Future:

THGEM,
visible PC ??
sealed devices ???



ALICE RICH Piuz et al. CERN

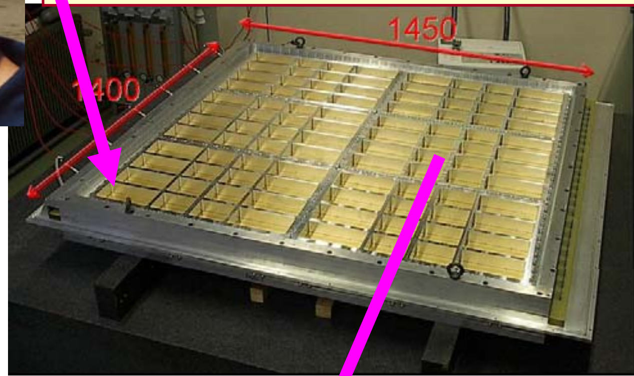
Prox. focus (8 cm), 1.5 cm C_6F_{14} radiator
FEE: Gassiplex 0.7 µs, noise 1000 e-
Large area (total ~12 m^2)



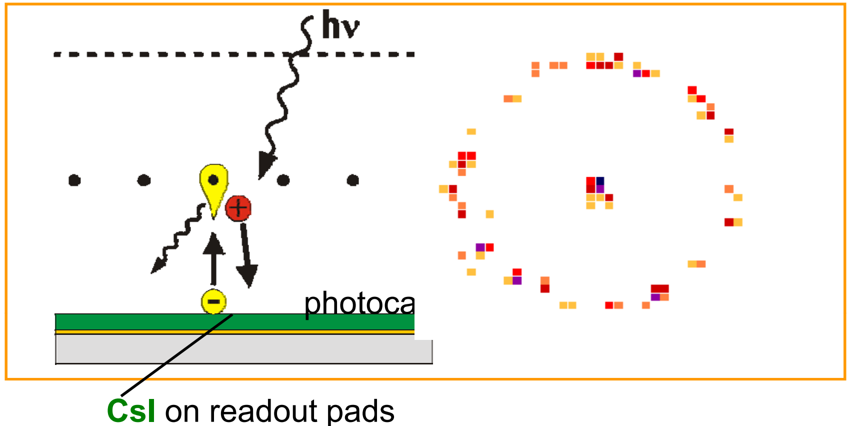
1 detector:
40 x 60 cm^2

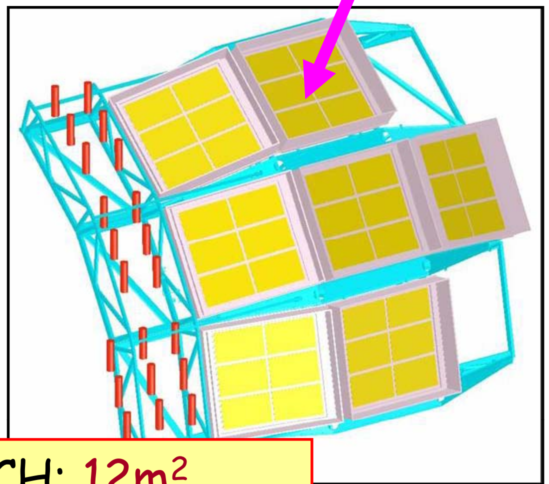
CsI photocathode legacy:
basic research on optimized QE, compatibility w substrates and gases, aging, QE enhancement, large area evaporation, in-situ monitoring, transport and handling. A.Breskin, NIM A371 (1996) 116

6 detectors/module ~2 m^2



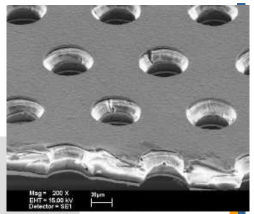
Multiplier open geometry (MWPC, CH_4):
Substantial ph & ion feedback. Gain 10^4.



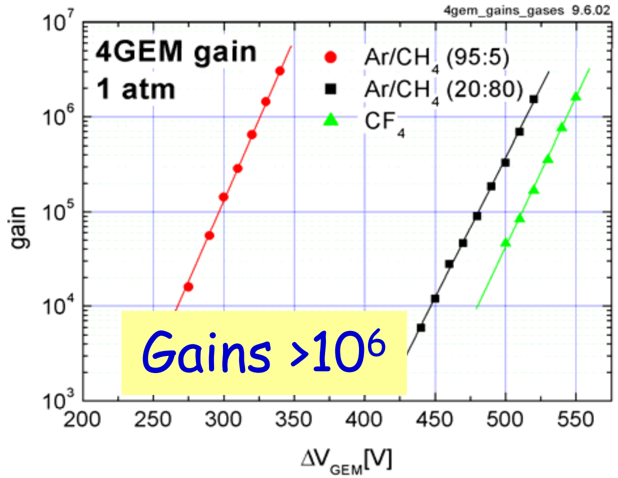


ALICE-RICH: 12m^2

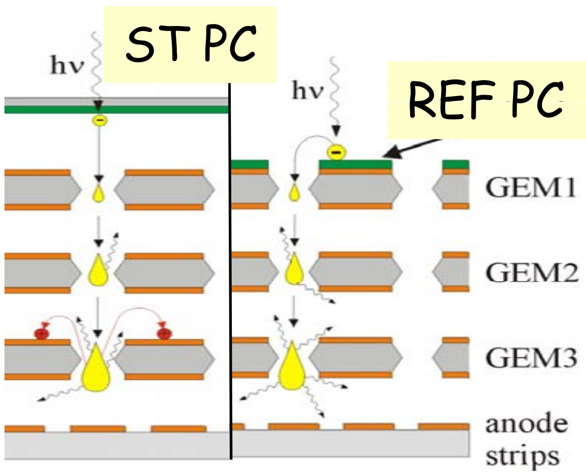
GEM-based multipliers for GPDs



Thin, fast (0.3-1.6ns)
$60 \times 50\ cm^2 \rightarrow 140 \times 50\ cm^2$

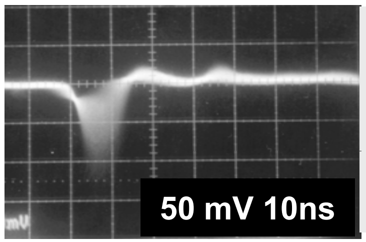


- High gain in cascaded GEMs.
- Also in noble & scintillating gases.
- Full efficiency to single photons
  With ST or REFLECTIVE PC .

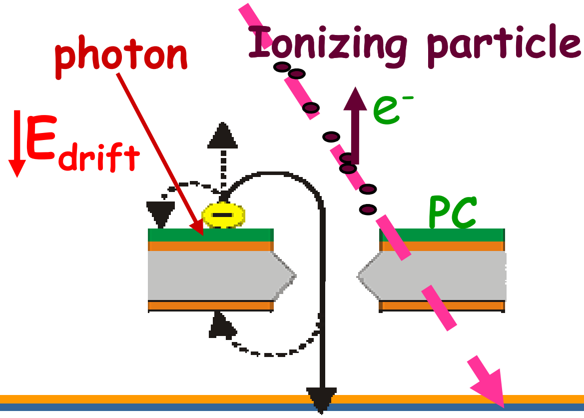


Multiplication in holes => Closed geometry =>
- No ph. Feedback.
- Reduced ion feedback (~few%)

REFLECTIVE PC + reversed Edrift =>
- Reduced sensitivity to ionizing BG



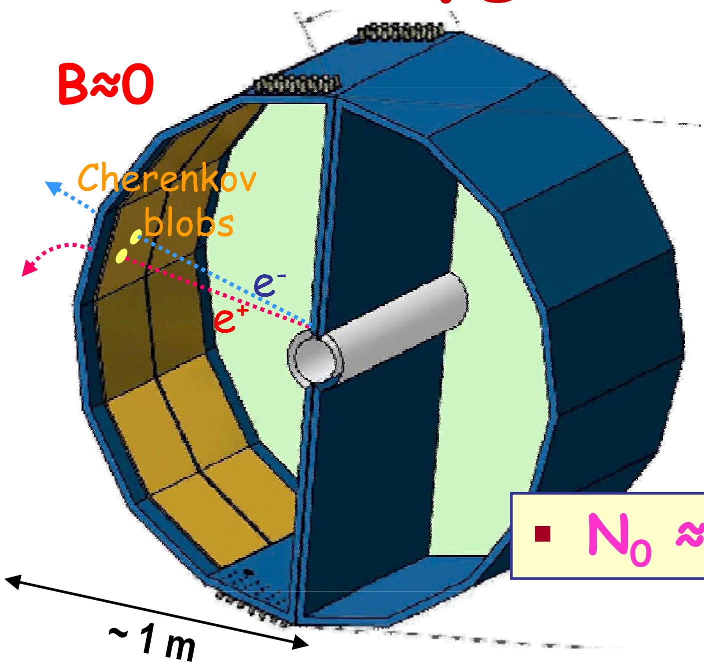
1 atm CF_4
gain 10^5
single e^-
no ph. feedback.



D. Moerman,
PhD Thesis
2005 JINST,
TH004

PHENIX Upgrade (PHENIX HBD)

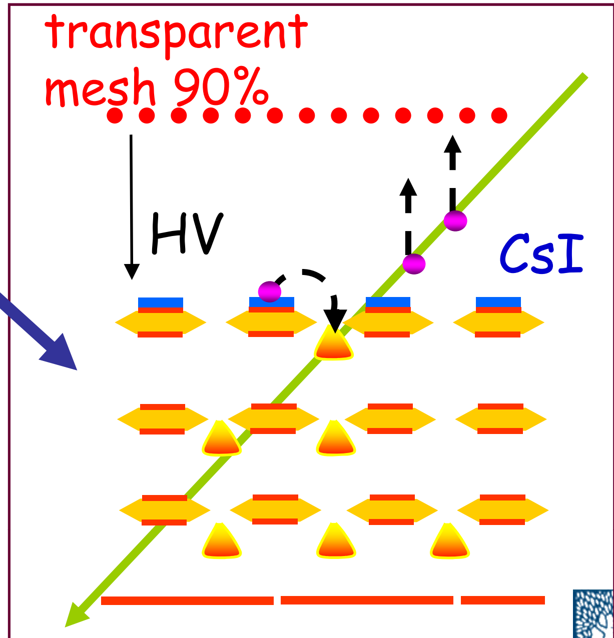
A. Milov et al.
J. Phys. G34, S701 2007



RICH added around the interaction region.
Goal: identify low-mass e^--pairs (π^0, γ) to reduce X300 combinatorial BG.
But: limited to 50 cm length.
Solution: Radiator gas = Working gas = CF_4.
Proximity=> Radiating particles produce blobs, diameter ~ 3.6 cm.

- **$N_0 \approx 840\ cm^{-1}$ (x6 larger than any e/π RICH)**

- The GPD of choice is a multi-GEM +REF PC
- Relies on CsI preparation knowledge and techniques from CERN:
  Gold-coated GEM,
  in-situ QE monitoring, QE enhancement,
  PC transport and storage.
- CsI QE match to CF_4

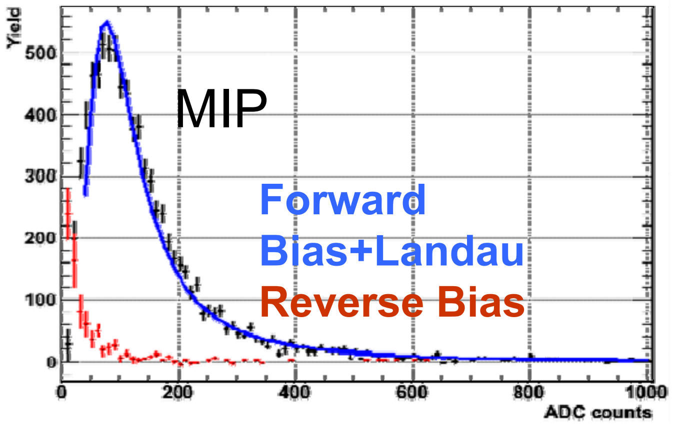


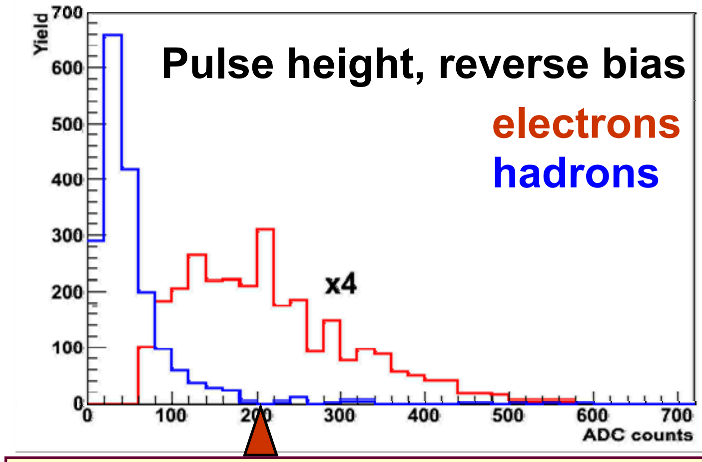
Confirmed Hadrons blindness

Of a 3GEM + CsI module.

Z. Fraenkel et al. NIM A546 (2005) 466
A. Milov et al. J. Phys. G34, S701 2007

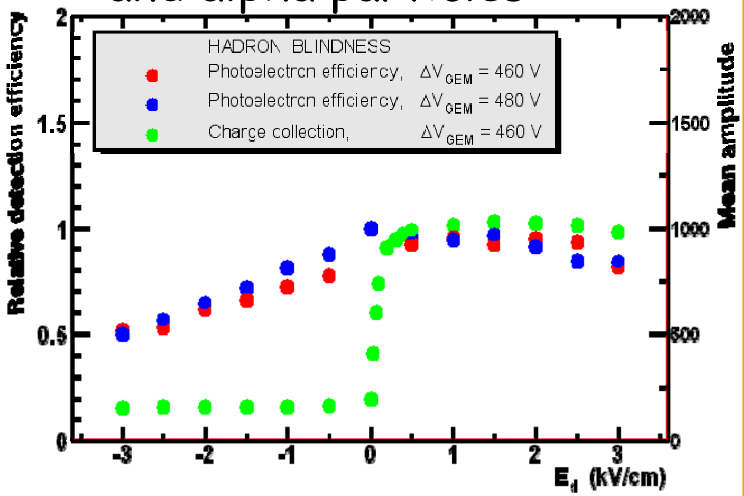
Tested in PHENIX with p-p collisions at RHIC April-June '06

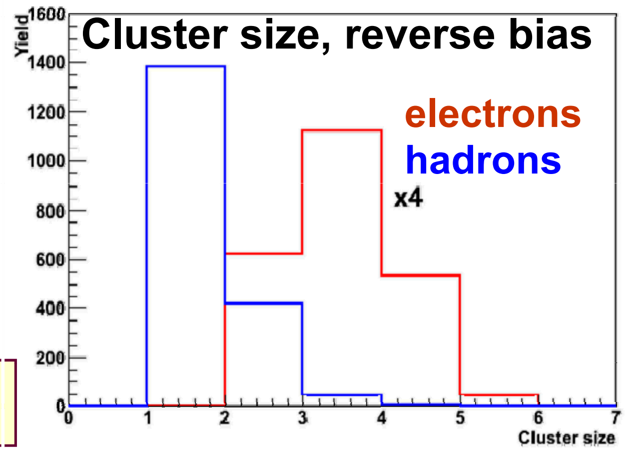




e/π rejection ~85% at ε_e ~90 %

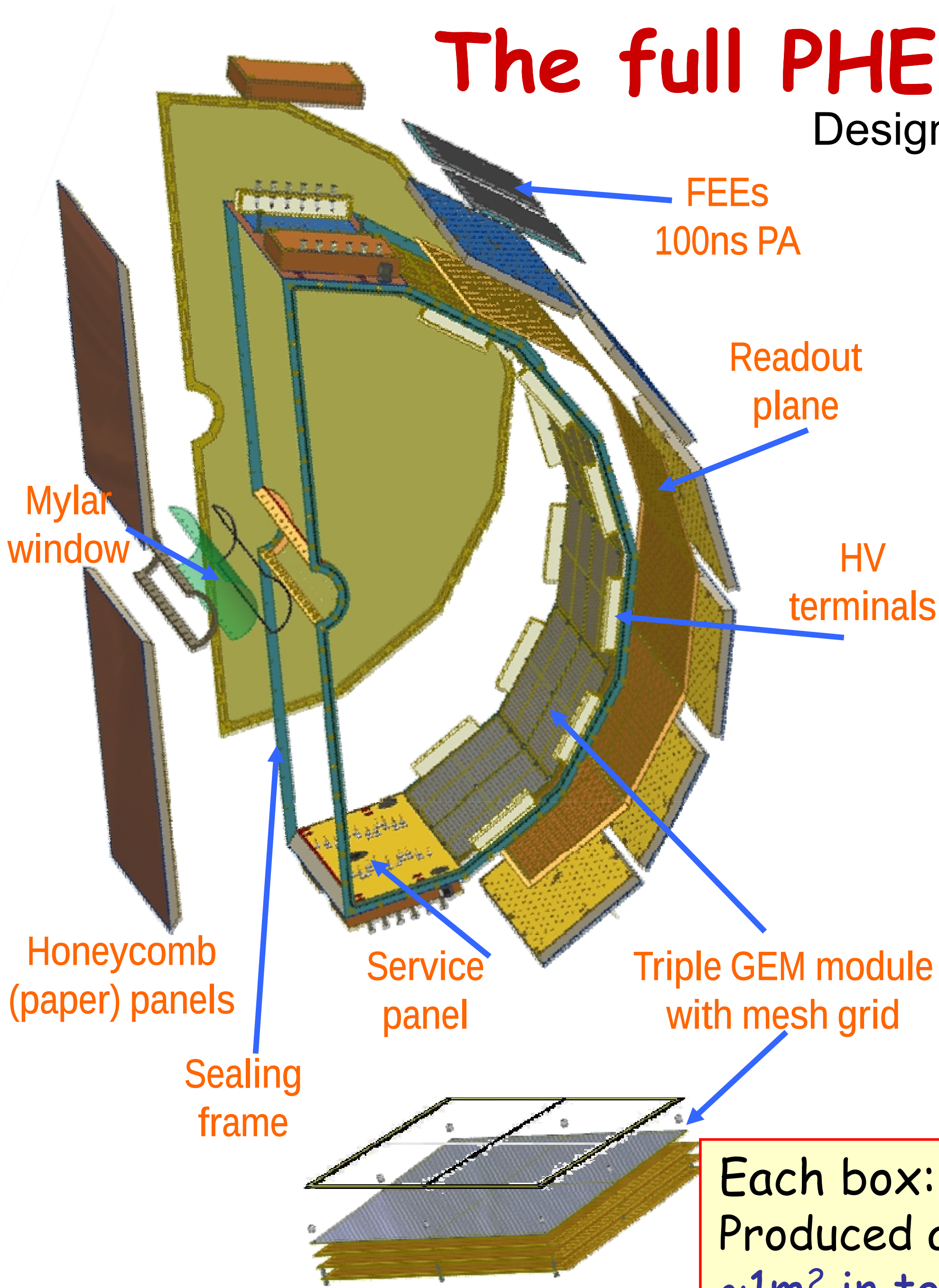
Tested with 1GeV/C pions and alpha particles





The full PHENIX HBD detector

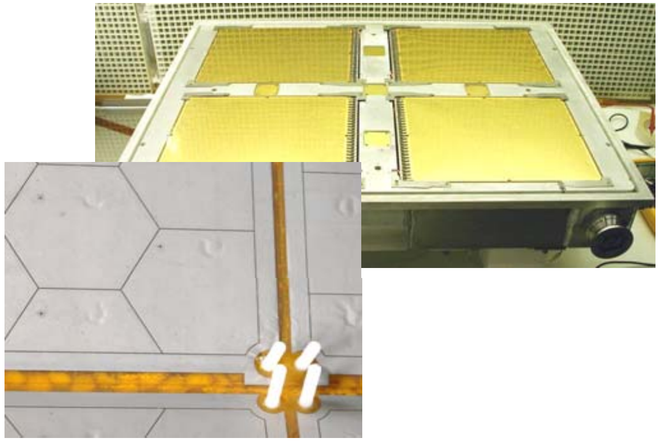
Design & built at WIS, PC & assembly at SUNY



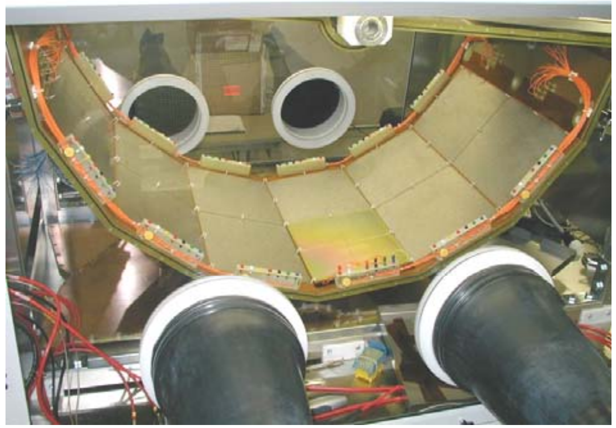
- Made of 2 boxes, R~60cm •B=0
- Entire volume filled with CF_4
- Minimum material : PCB boards, honeycomb panels, GEMs, glue => The detector fits under $3\%X_0$.
- Tight: The readout plane serves also as the gas seal.
- Detector construction involves ~350 gluing operations per box.
- Light is registered by 12 GPDs modules in each box .
- Signal is read on hexagonal pads, pad size ≤ blob size.
- Expected ~36 photoelectrons from each primary electron.
- Total event rate ~ 1 MHz

Each box: 12 GPDs, $23x27cm^2$ (support frames)
Produced at CERN (133 produced, 72 installed)
~$1m^2$ in total.

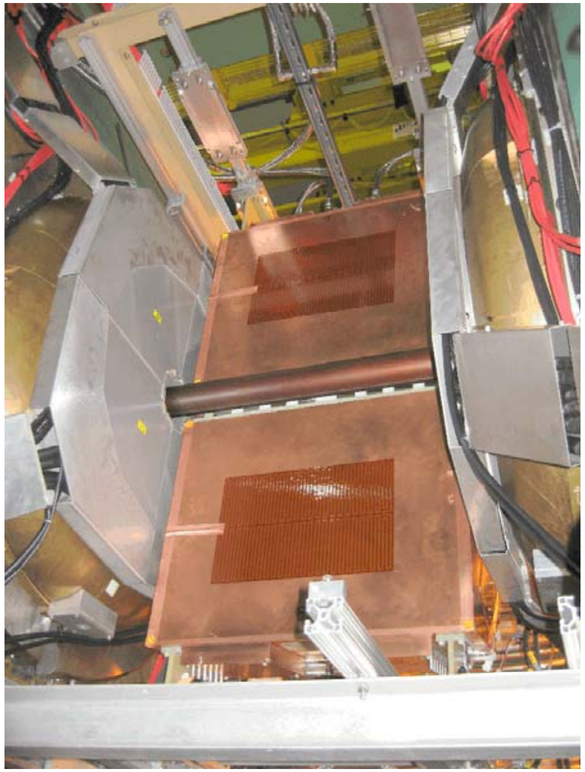
1 GPD module

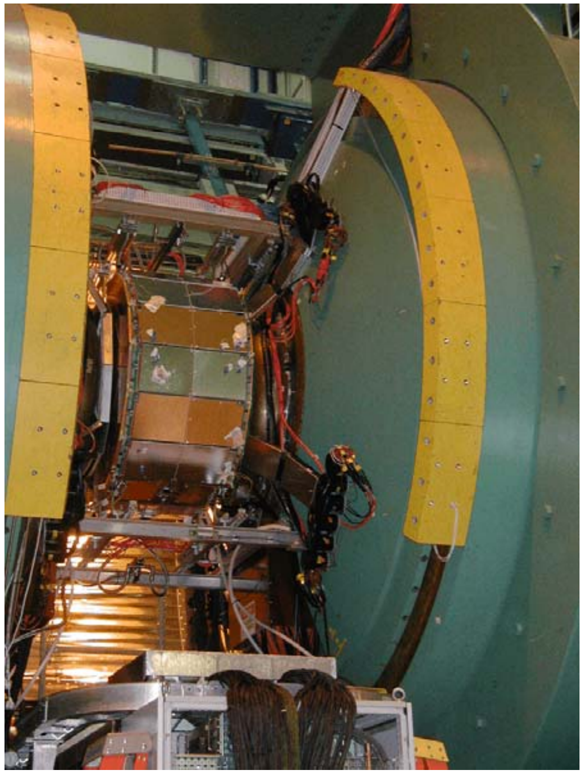


mounting and gluing in glove box



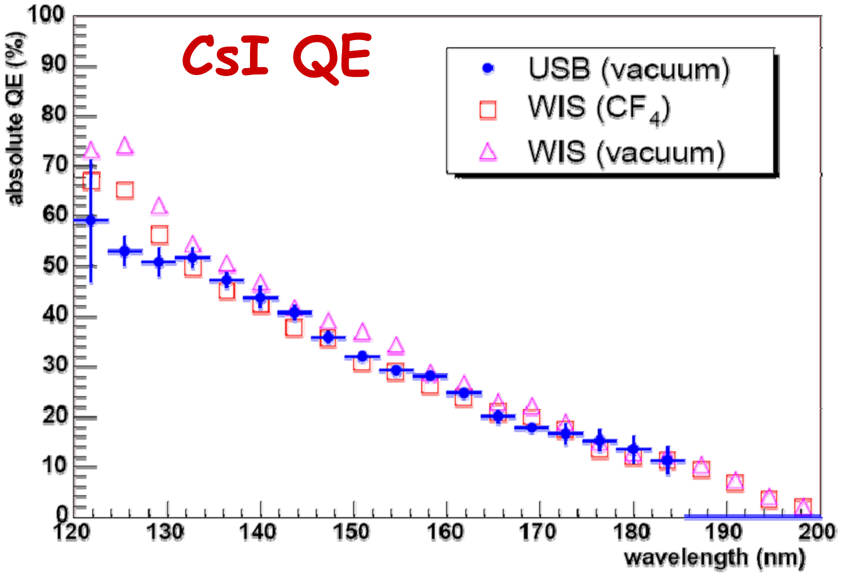
HBD West (front side) Installed Sep 06



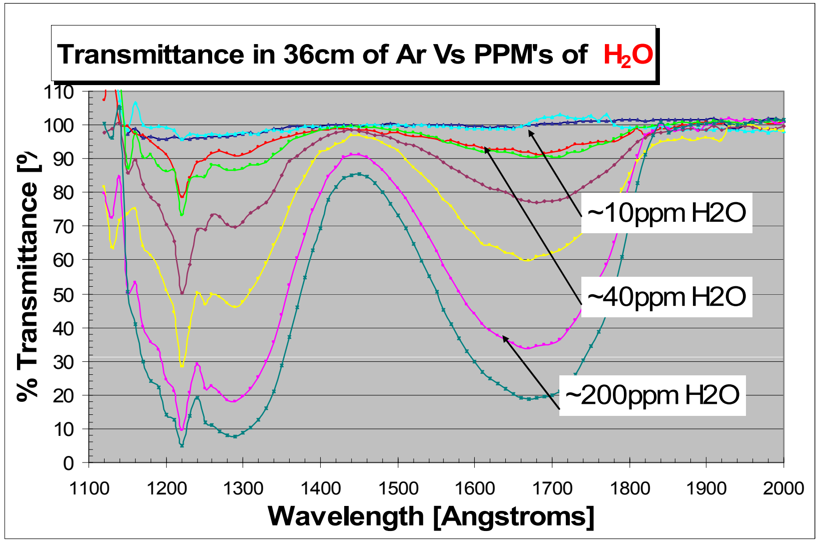


HBD East (back side) Installed Oct 06

PC QE and gas quality

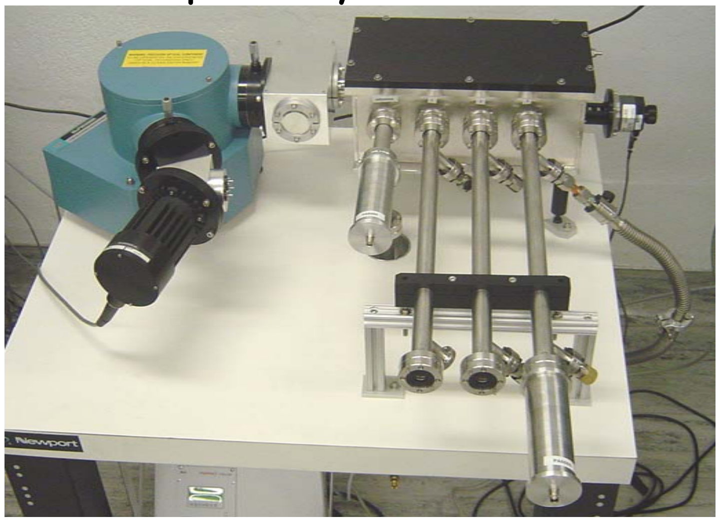


Windowless RICH:
No limitation of window cutoff.
Photons down to 120nm (~10 eV).
Gas transmission is important.



H_2O & O_2 must be kept at the few ppm.

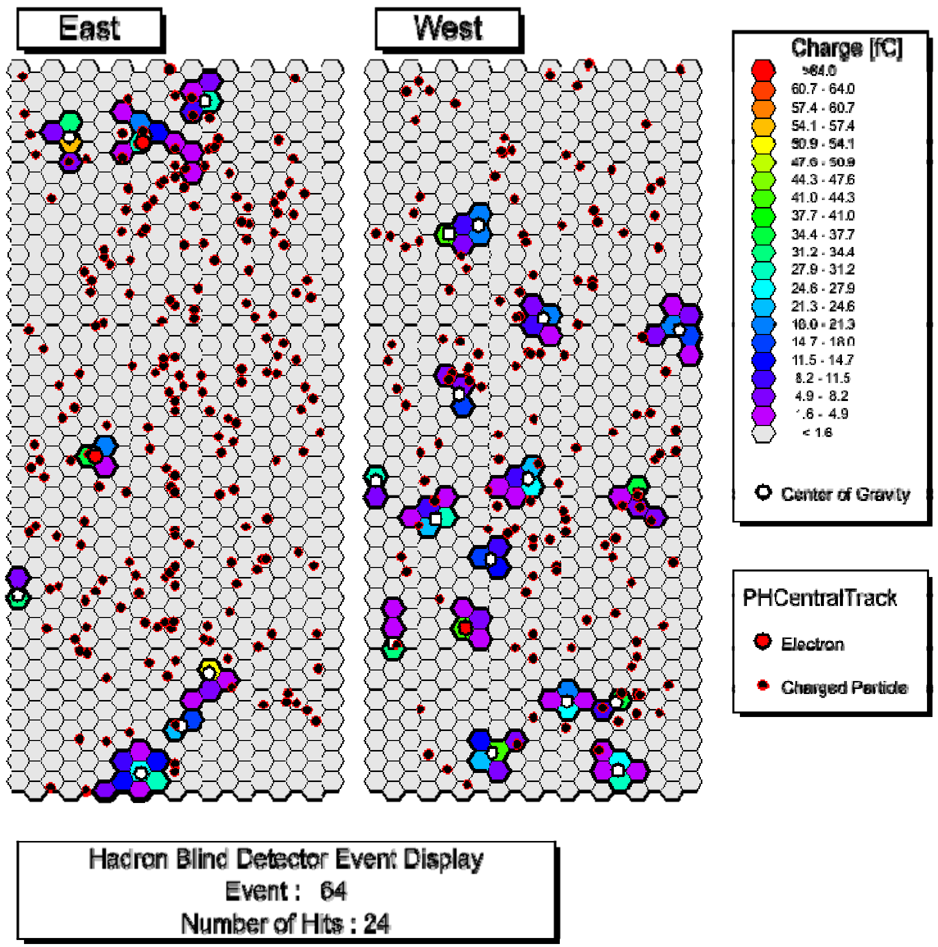
high gas flow +
continuous monitoring of gas transparency in both boxes

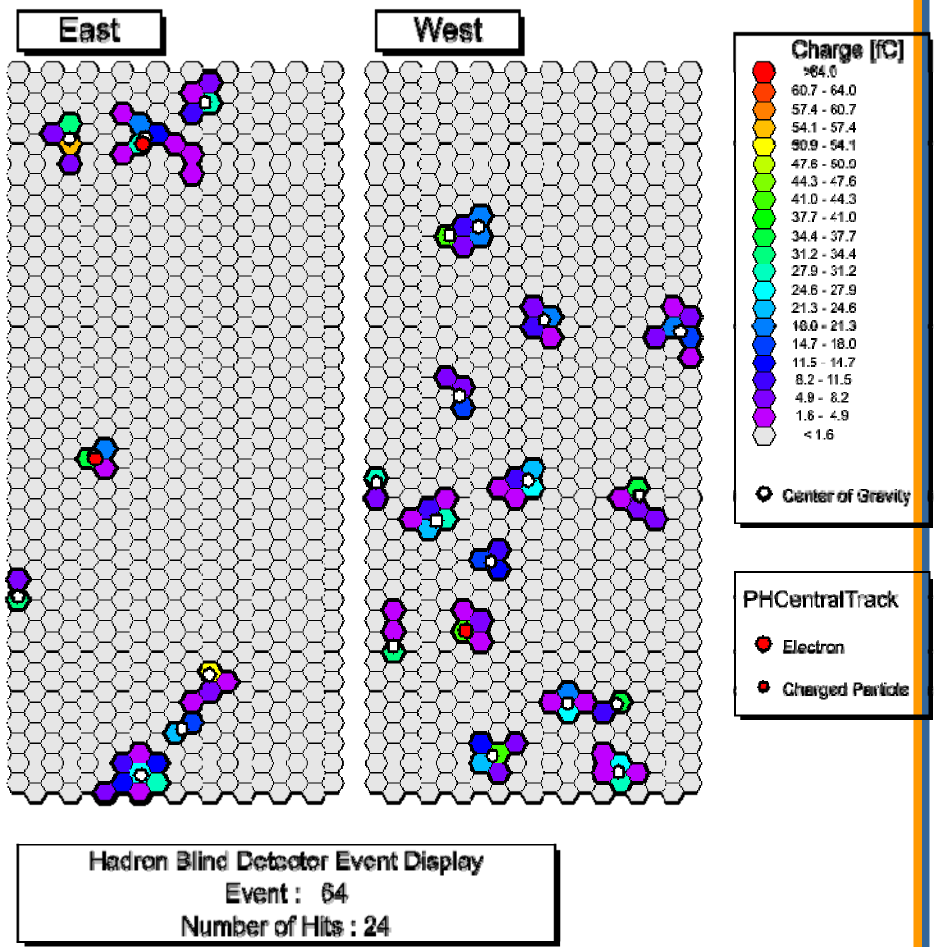


Monochromator (120-200 nm)

Event display (simulation).

Real events are not published yet





2007 engineering run (Au-Au, p-p, $\sqrt{s_{NN}}$ = 200 GeV)

I. Tserruya, Private communication

- The HBD was commissioned during the 2007 RHIC run.
- **The HBD operated smoothly for several months , gas gain of 5000.**
- **The CF_4 recirculation gas system: after several weeks of gas flow through the detector a transmittance of ~80-90% was achieved at a flow of 4 lpm.**
- **The entire readout chain worked smoothly.**
- **The noise performance: pedestal rms 0.15 fC or 0.2 p.e. at a gain of 5000.**
- **A few billion minimum bias Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV were collected.**

Preliminary results show:

clear separation between electrons and hadrons in reverse bias mode

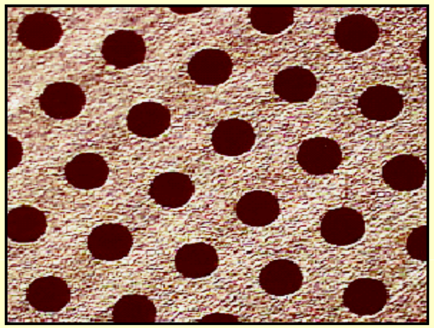
very good electron detection efficiency

THGEM – a new generation of multipliers

Developed <u>independently</u> from:
Optimized GEM: PCB based hole-multipliers / drilled holes.
L. Periale et al., NIM A478 (2002) 377.
LEM: Vetronite-based hole-multipliers / drilled + etched holes.
P. Jeanneret, PhD thesis, Neuchatel University, 2001.
LEM made of virgin Teflon PCB, P.S.Barbeau et al, IEEE NS50 (2003) 1285.

Manufactured by standard PCB techniques of precise drilling in G-10 (and other materials) and Cu etching. **ECONOMIC & ROBUST !**

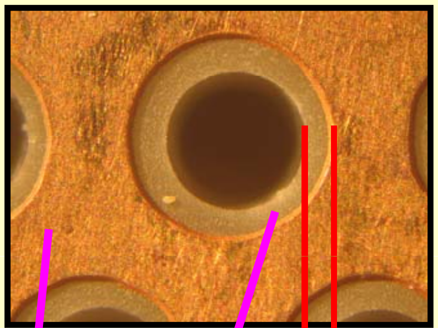
Standard GEM
10^3-10^4 gain in single GEM



F. Sauli

1mm

THGEM
10^5 gain in single-TGEM



Cu G-10

Hole diameter d = 0.3 - 1mm
Pitch a = 0.7- 7mm
Thickness t = 0.4 - 3mm

0.1 mm rim: prevents discharges → high gains!

R. Chechik et al. NIM A535 (2004) 303
C. Shalem et al. NIM A558 (2006) 475 & NIM A558 (2006) 468

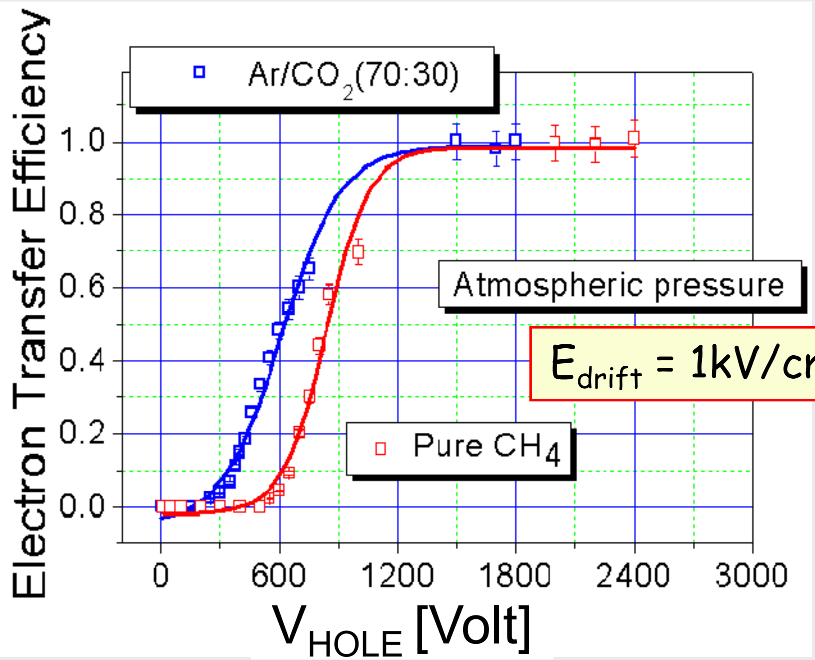
THGEM operation

C. Shalem et al. NIM A558 (2006) 475
& NIM A558 (2006) 468

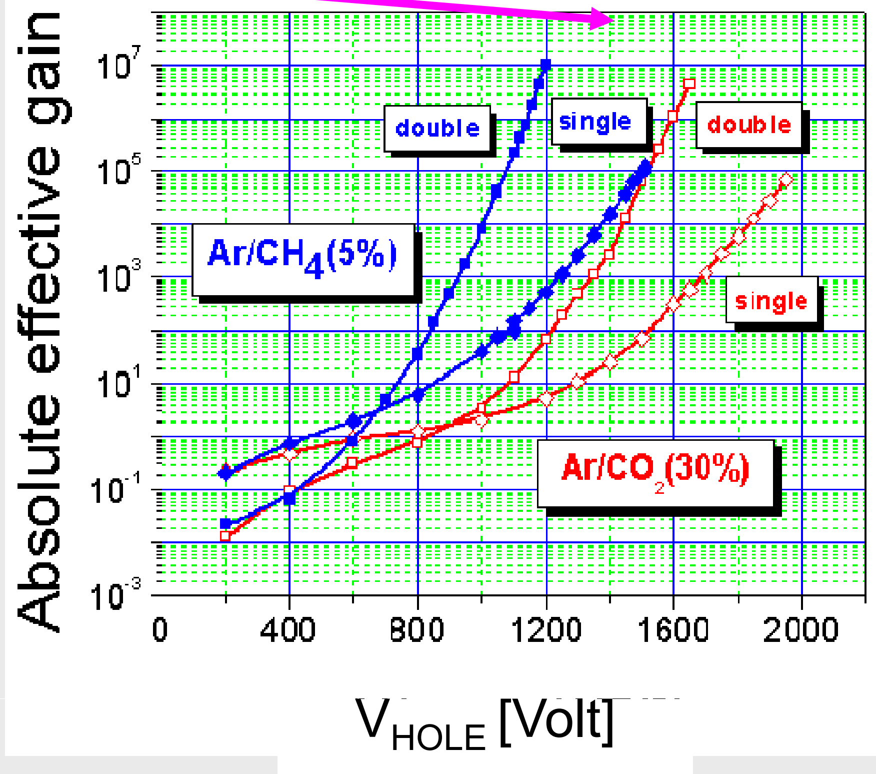
- Operation principle identical to GEM. Similar voltages and E fields.

- Holes much larger than e^- diffusion.
  - full e^- transfer efficiency into the holes:

★ from the conversion gap
- good single-e^- detection eff. @ gain <100
- good E_{res} with ionizing radiation



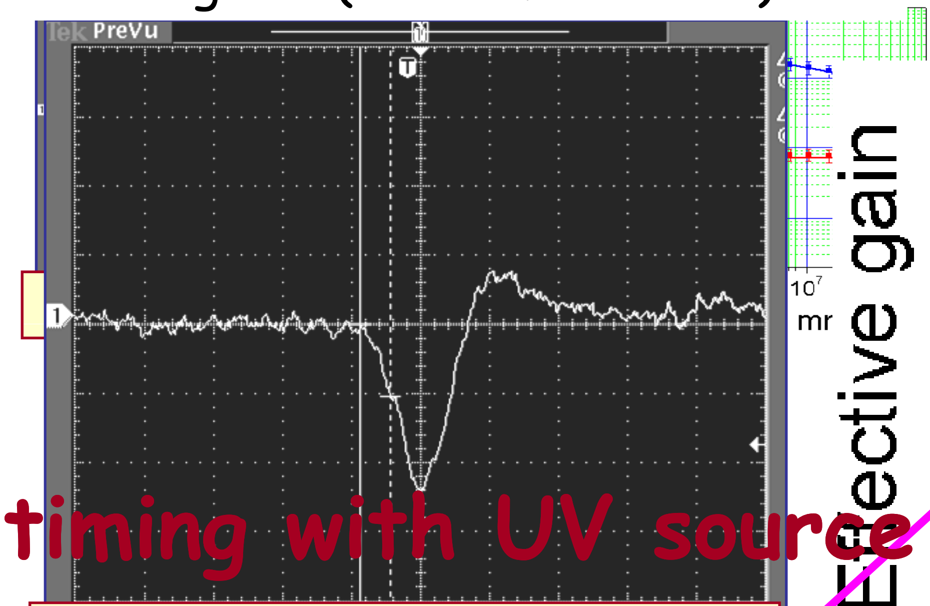
★ in the transfer gap
-> efficient cascading of THGEMs



Single THGEM Gain 10^4-10^5 (single e^-)
Double THGEMs gain 10^6-10^7 (single e^-)

THGEM operation (double THGEM)

Fast signals (rise time < 10 ns)

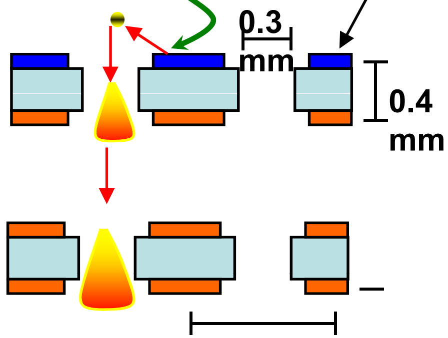


timing with UV source

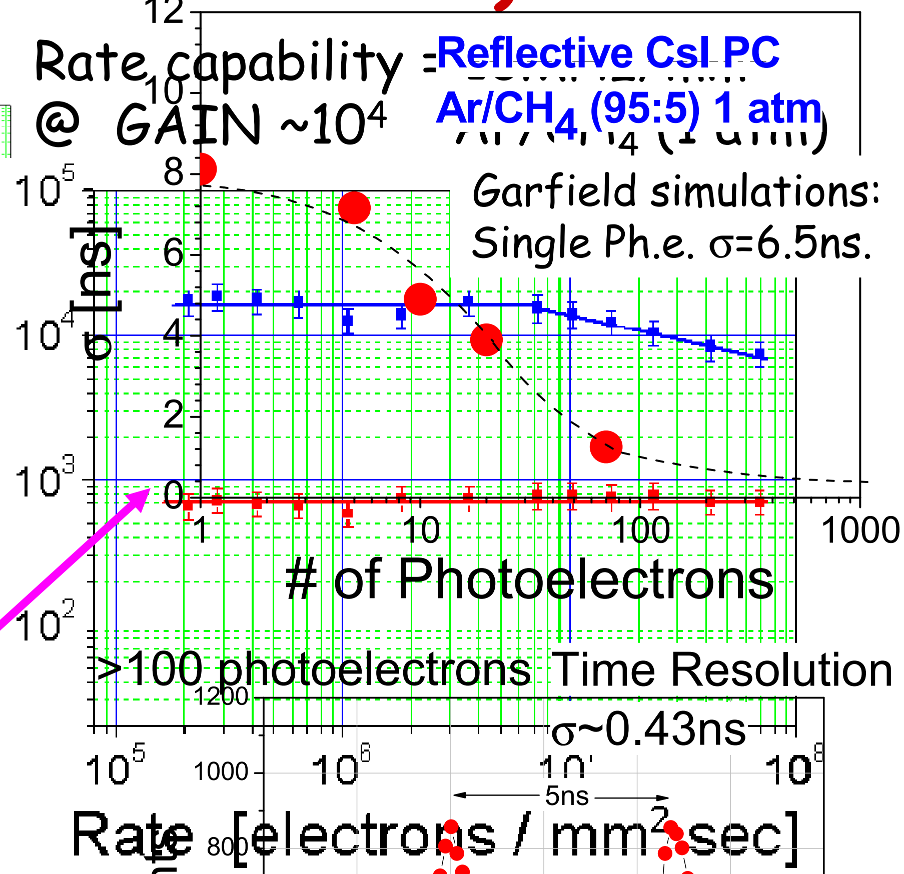
1 atm. $Ar/30\%CO_2$

pulsed UV lamp

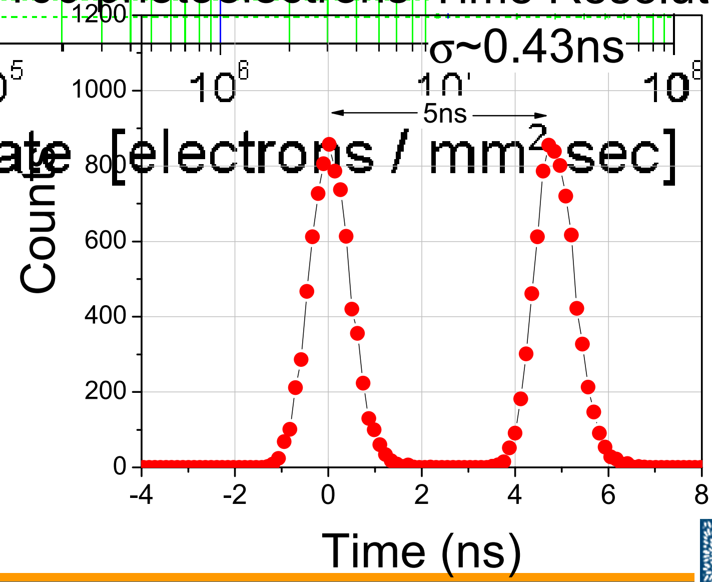
Reflective CsI PC



Rate capability
@ GAIN ~10^4



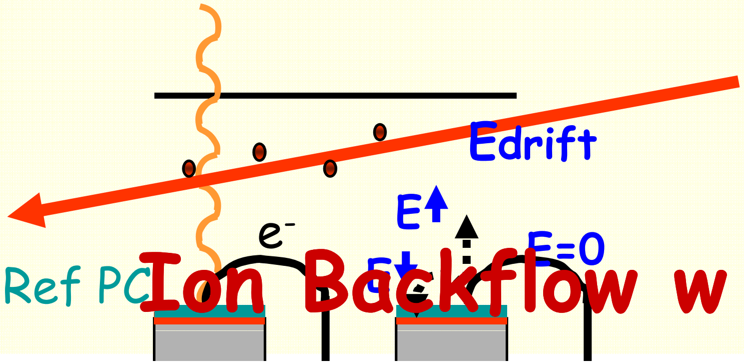
>100 photoelectrons Time Resolution
σ~0.43ns

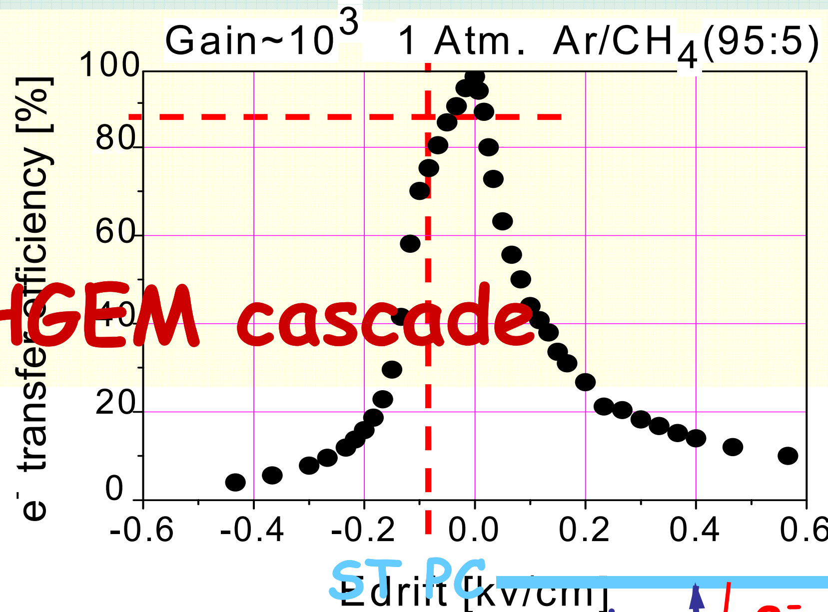


THGEM Photon detector w reflective PC

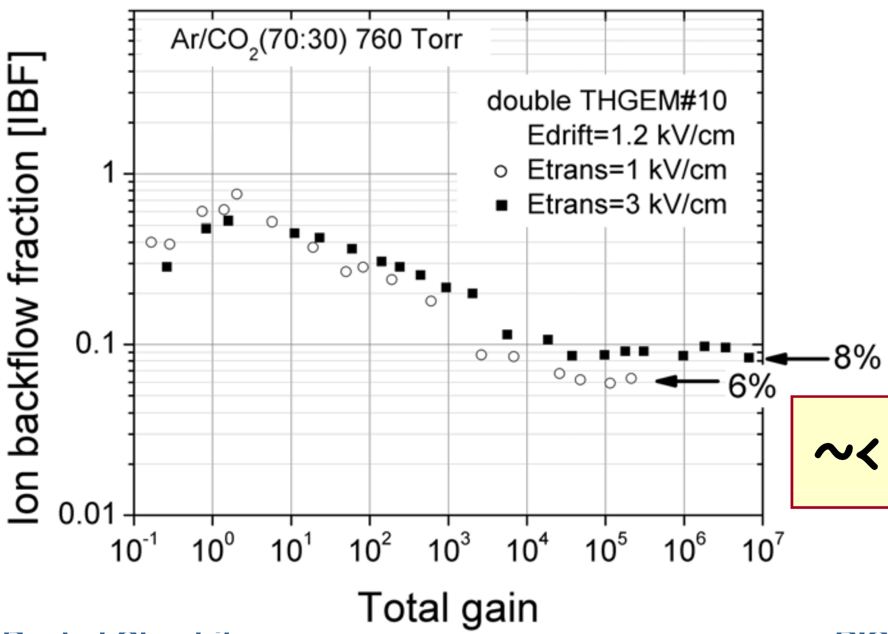
R. Chechik et al. NIM A553 (2005) 35

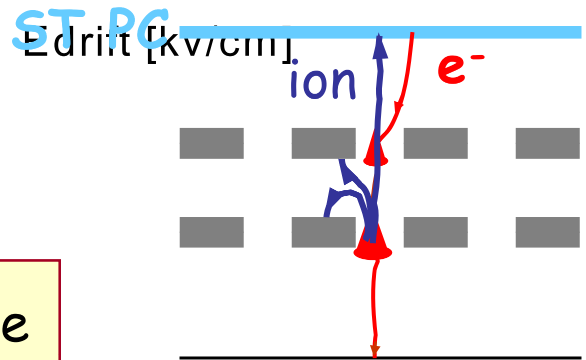
Ph. e^- focusing is due to hole dipole field. Maximum efficiency @ E_{drift} =0.
W slightly reversed E_{drift} (50-100V/cm) => low sensitivity to MIPS !
Effective area for the reflective PC ~ GEM (~80%)





Ion Backflow w THGEM cascade

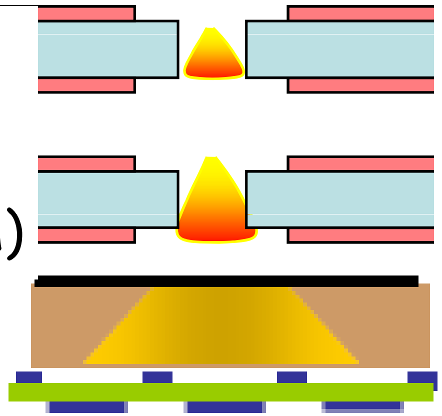




~< 4-GEM cascade

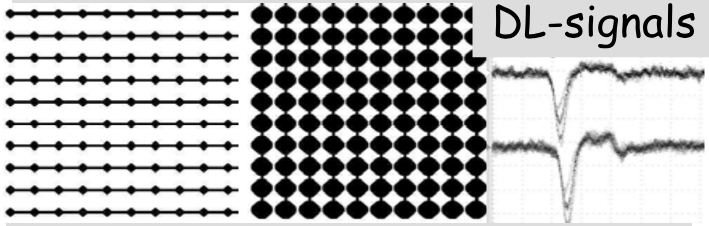
THGEM imaging-detector with economic readout

- 2x 10x10cm^2 THGEMs
- Resistive anode (size match)
- 2-sided pad-string readout
- Delay-line readout (SMD)



0.4mm thick,
0.5mm Ø holes,
1mm pitch

front side back side X & Y DL-signals

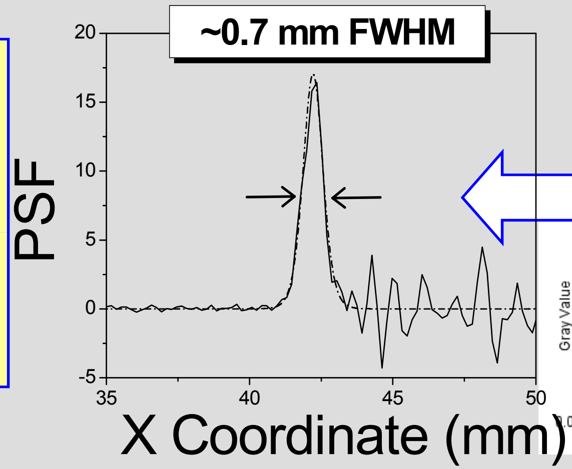


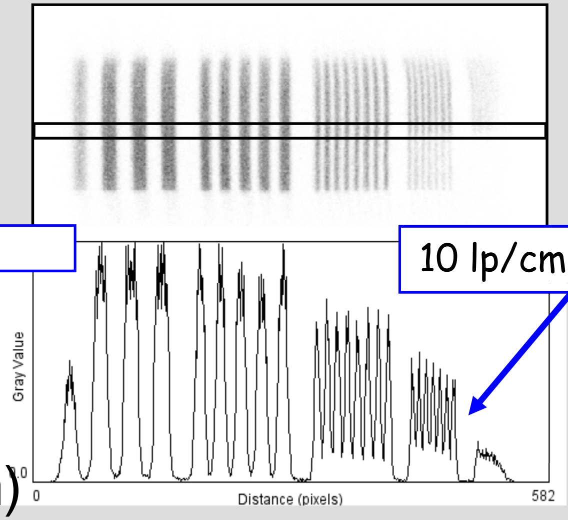
Equal charge on front & back sides

Tested with 6-8 keV X-rays.

Gain homogeneity ± 10% FWHM

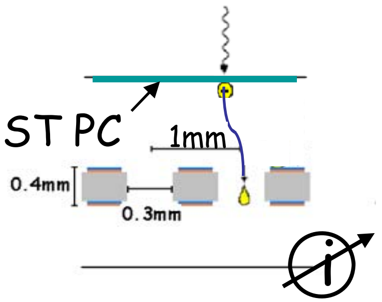
1mm THGEM Pitch +
2mm Readout Pitch +
Interpolation ➔
Sub-millimeter Resolution
(~0.7 mm FWHM)



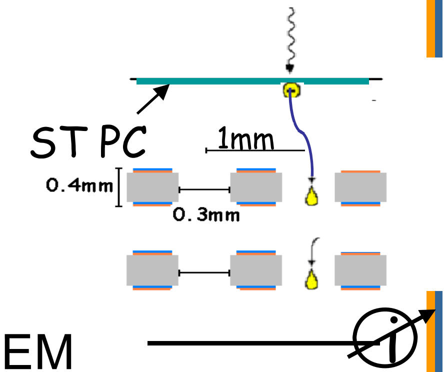


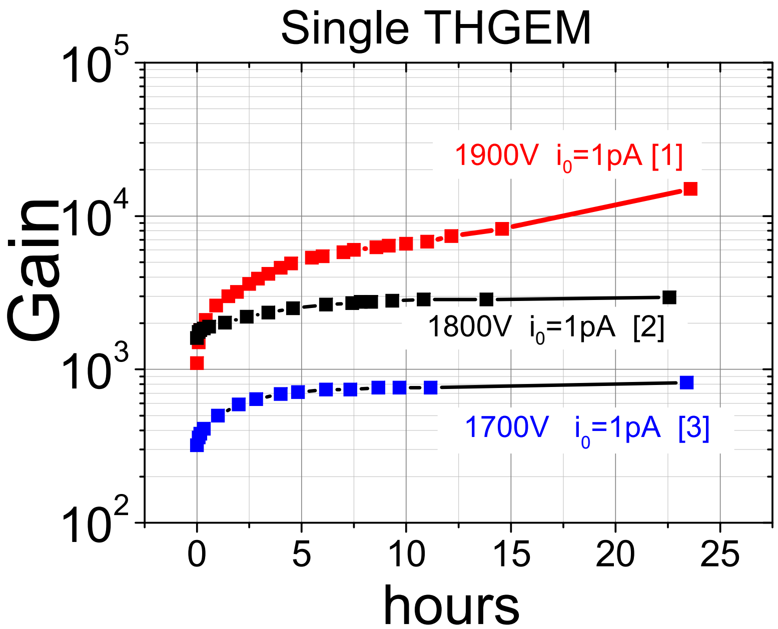
THGEM Long-term stability (1)

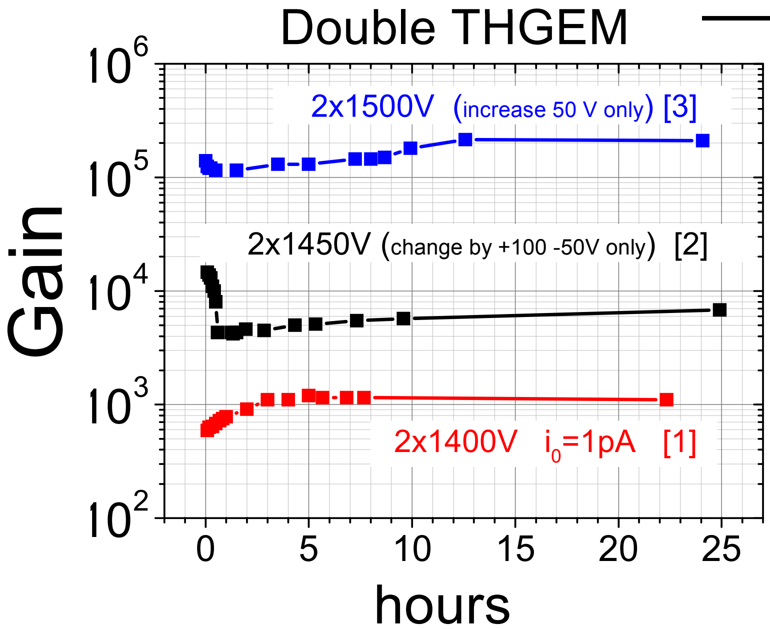
R. Chechik et al. Proceedings of SNIC2006, eConf C0604032, 0025 (2006)



- UV + ST PC.
- $5x10^5$ e^-/mm^2 (equiv. to 1kHz/mm^2 x-ray).
- Possible additional effects from p, temp & HV instability.







THGEMs require a few hours of stabilization (gain variation ~ factor 2.)
- Stabilization time depends on total gain/current
- on history, namely time after THGEM & gas introduction.

THGEM Long-term stability (2)

R. Chechik et al. Proceedings of SNIC2006, eConf C0604032, 0025 (2006)

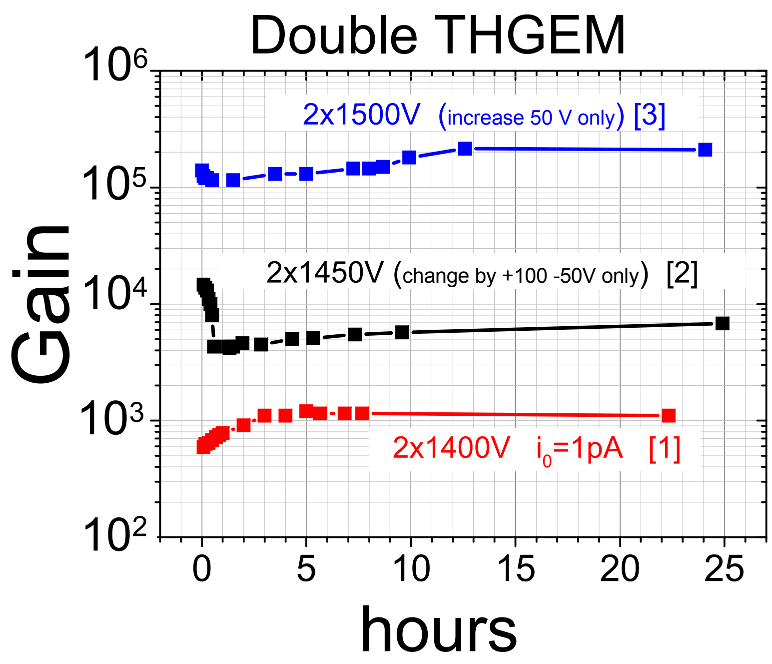
Stabilization time depends on geometry

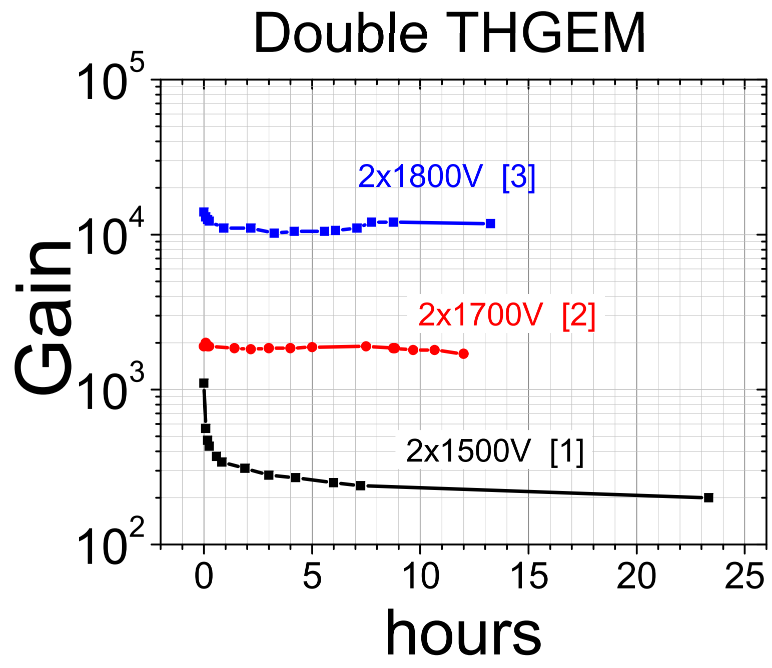
0.4mm thick,
0.3mm Ø holes,
1mm pitch

Larger holes

0.4mm thick,
0.6mm Ø holes,
1mm pitch

Shorter stabilization time





Effect of the bare insulator??
Rim? hole walls?

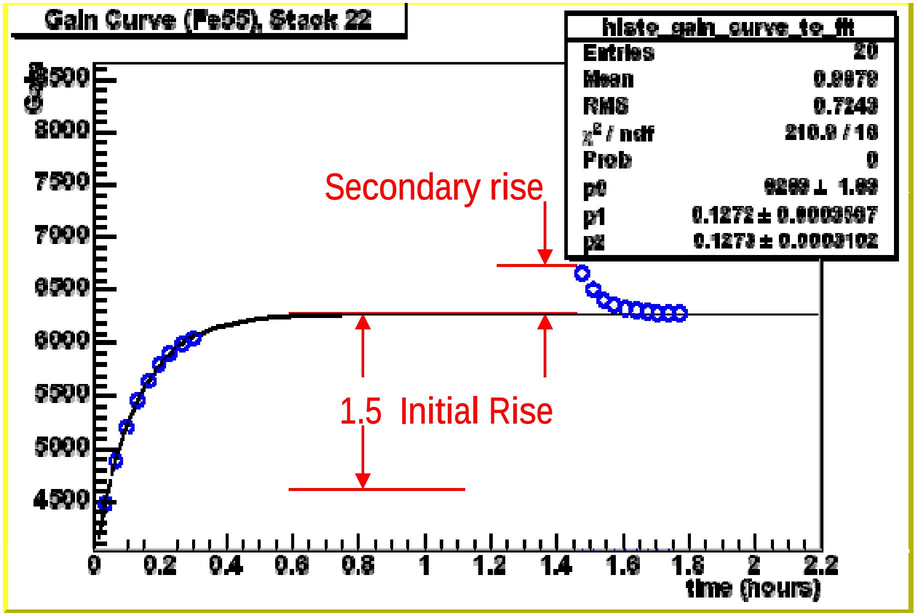
GEM gain stability from PHENIX HBD tests

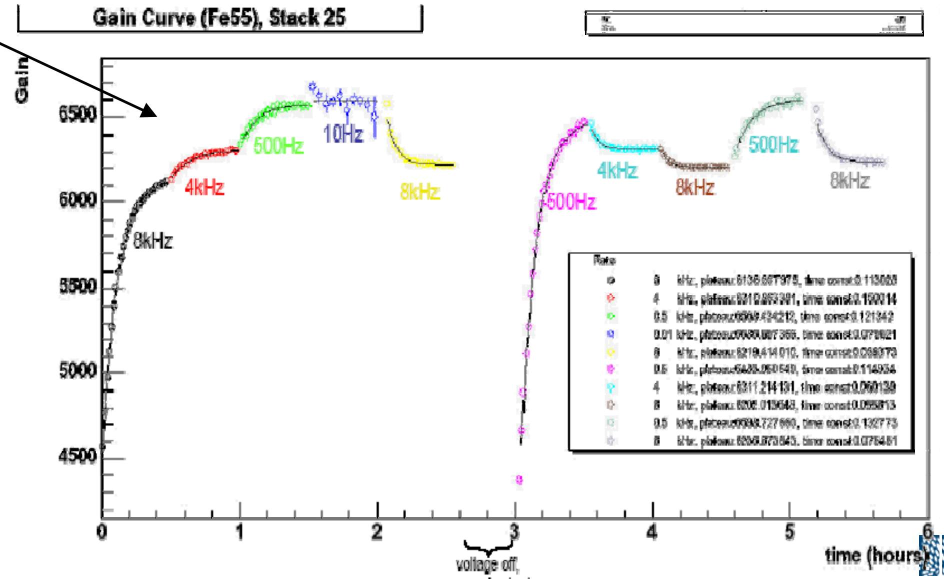
A. Milov et al. J. Phys. G34, S701 2007

- The Gain is observed to initially rise by a few % up to a factor 2.
  It reaches a plateau in 30 minutes.

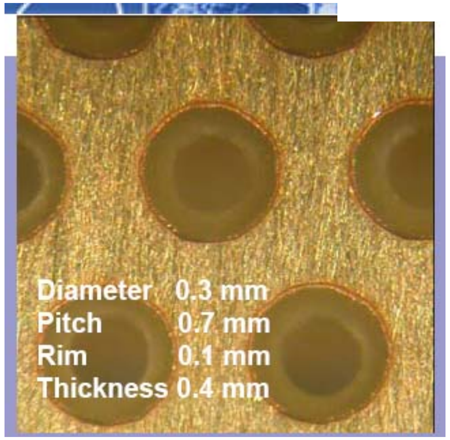
- The gain increase is rate dependent.

- The rate at PHENIX is low. PHENIX is Ok with a stabilization time of a few hours.

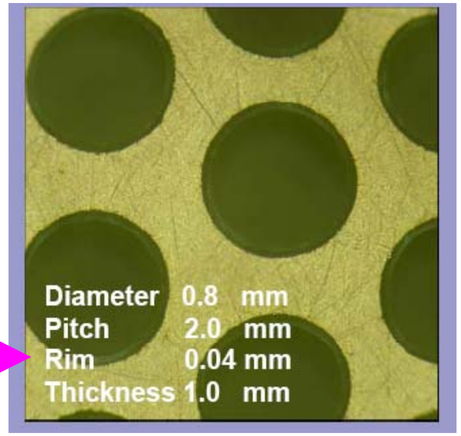


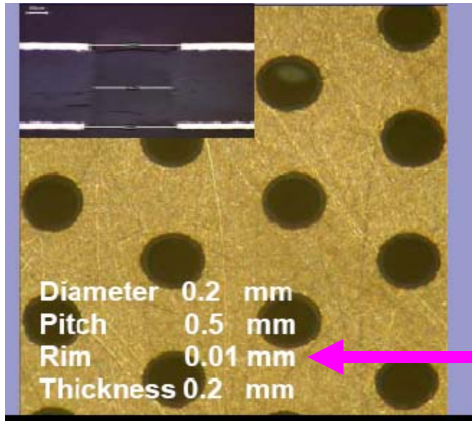


New THGEM production
techniques and materials

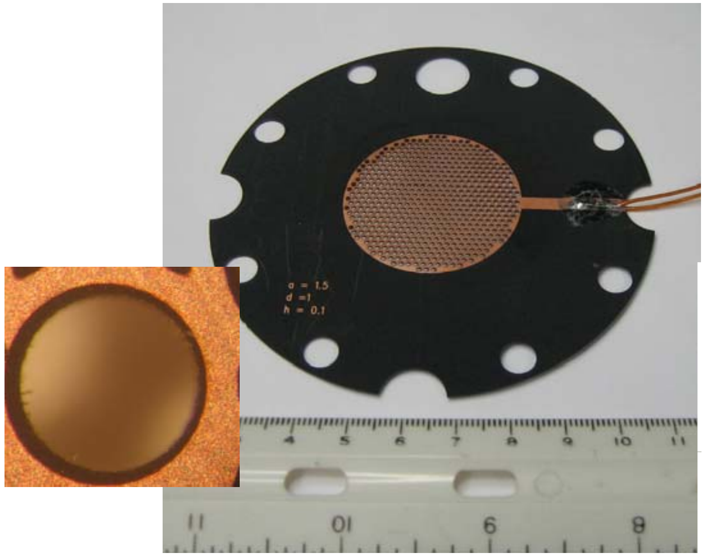


Weizmann THGEM
Rim = 0.1mm





L. Ropelewski & Rui De Oliveira – CERN
- Simple production sequence
- Reduce rim size (0.04-0.01mm !!!)
- Improve metal edges.
- Preliminary results: good gain.
  ? stability improved ?

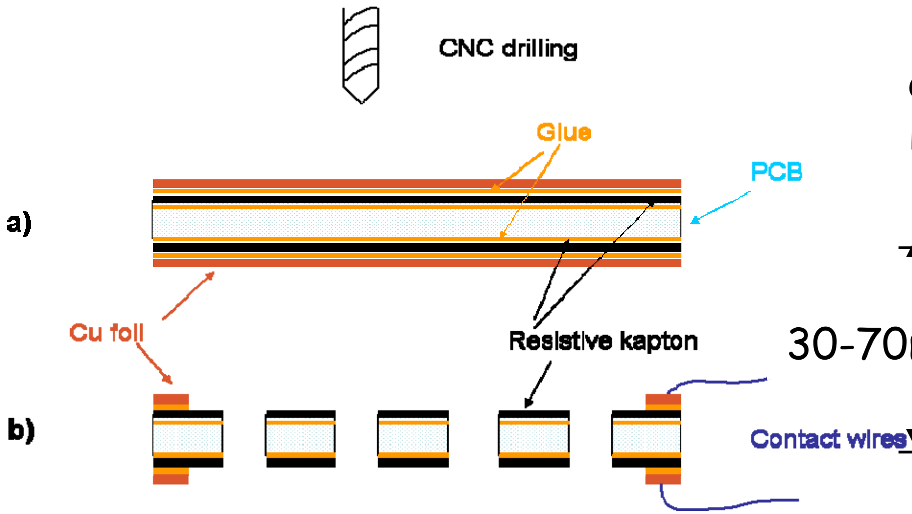


CIRLEX(polyimide)-THGEM. (radiation clean).
Proposed as a possible upgrade for XENON,
Collaboration UCONN / YALE / WEIZMANN
Preliminary results (M. Gai et al. arXiv:0706.1106) :
Single CIRLEX-THGEM Gain ~10^4 (at low pressure)

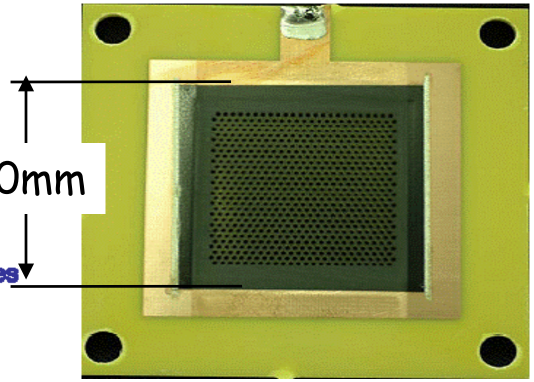
Resistive ThickGEM-RETGEM:"Discharge-proof"

Developed by V.Peskov et al.

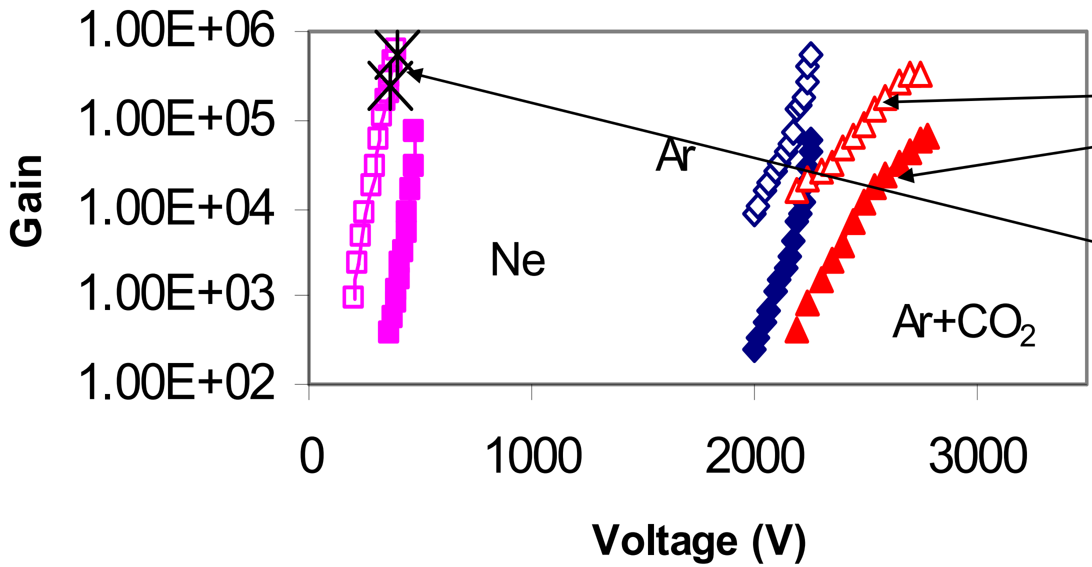
A. Di Mauro et al, to be published in NIM
V. Peskov, private communication



d= 0.3-0.8 mm, a= 0.7-1.2 mm, t= 0.5-2 mm.
Kapton type: 100XC10E Resitivity:200-800kΩ/□



Kapton RETGEM
with reflective
CsI PC:
QE at λ=120 nm
~30%



double RETGEM
Single RETGEM

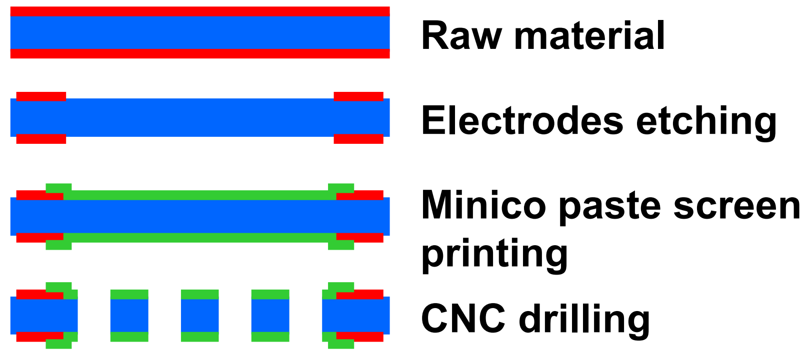
double RETGEM / CsI layer.

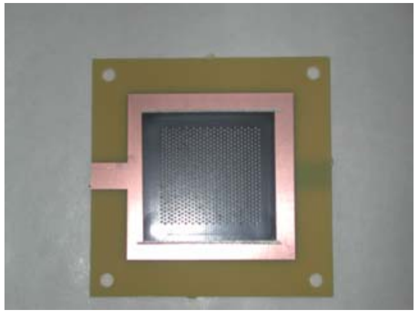
15 min continues discharge =>
no harm to detector or electronics

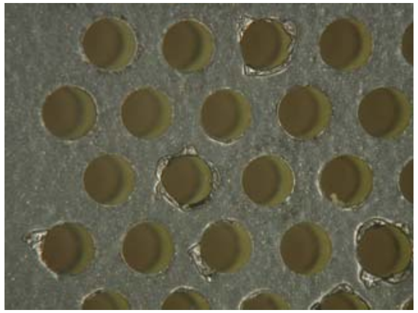
Production of ThickGEM (and resistive)

R. de Oliveira - CERN

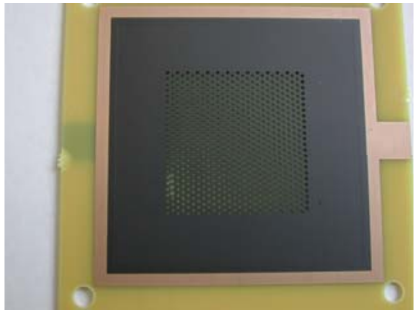
Raw material: 1200mm x 1000mm any thickness
CNC drilling and Screen printing: 600mm x 500mm
estimated resistor accuracy +/- 50% on large sizes
400 Euros for Compass like size (300mm x 300mm) for 1 piece
266 Euros " " " " " (qty 100 pieces)
Holes of 0.2mm pitch 0.5mm (250 000 holes)

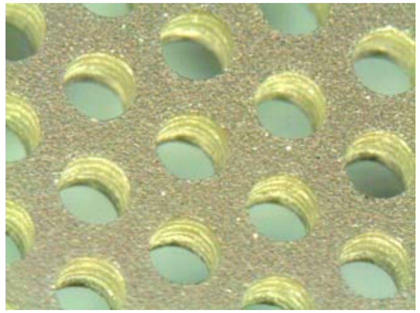






Kapton XC in sheets
200 Ohm/square or 1 MOhm/square



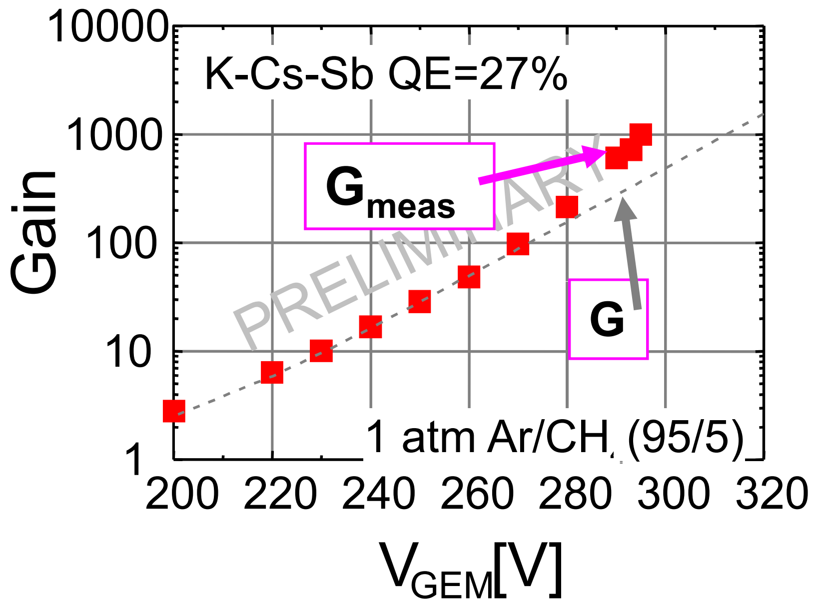


Minico paste from
10 Ohm/square to 1 MOhm/square

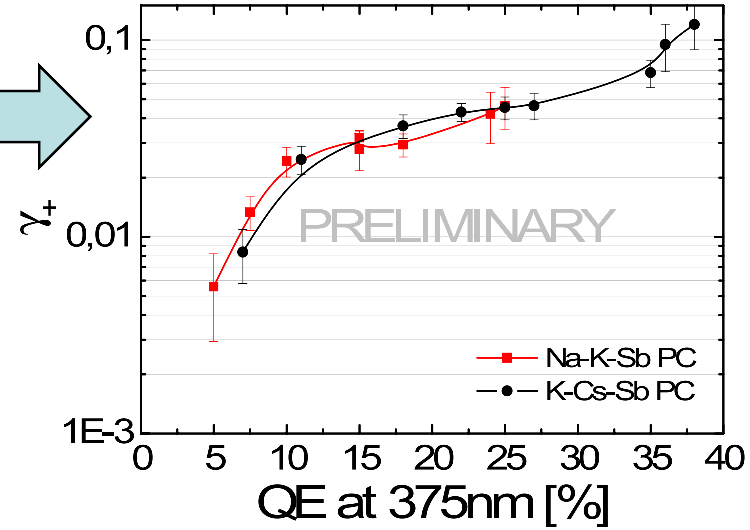
Gaseous detectors with Visible PC

The main problem: ion-induced secondary electron emission from the PC.
=> PC aging. Secondary avalanches. Gain limitation.

M.Balcerzyk et al, IEEE Trans. Nucl. Sci. NS50 (2003) 847
& recent data from WIS



Emission probability per ion = γ_+
Depends on gas, PC QE



With both K-Cs-Sb and Na-K-Sb PCs: Current deviates from exponential

stable operation: < 1 Sec. av. per avalanche ($\gamma_+ \cdot IBF \cdot \varepsilon_{extr} \cdot \varepsilon_{coll} \cdot G < 1$)

For Ar/CH$_4$ (95/5) and G~10^5

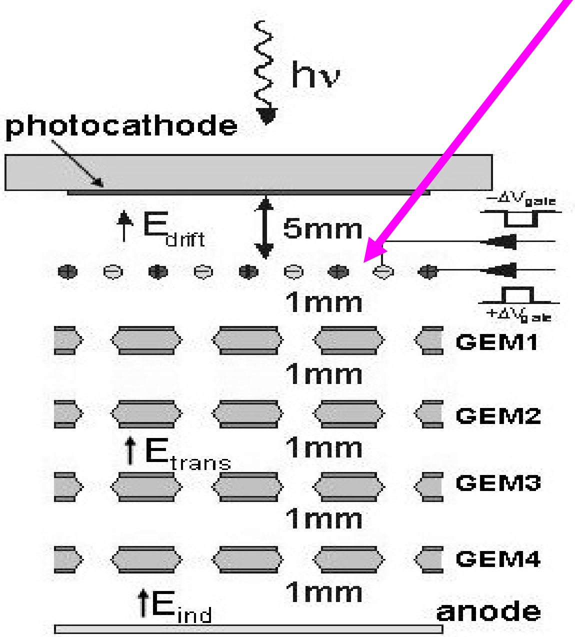
IBF must be <$3.6*10^{-4}$

IBF= i on PC/i on last anode

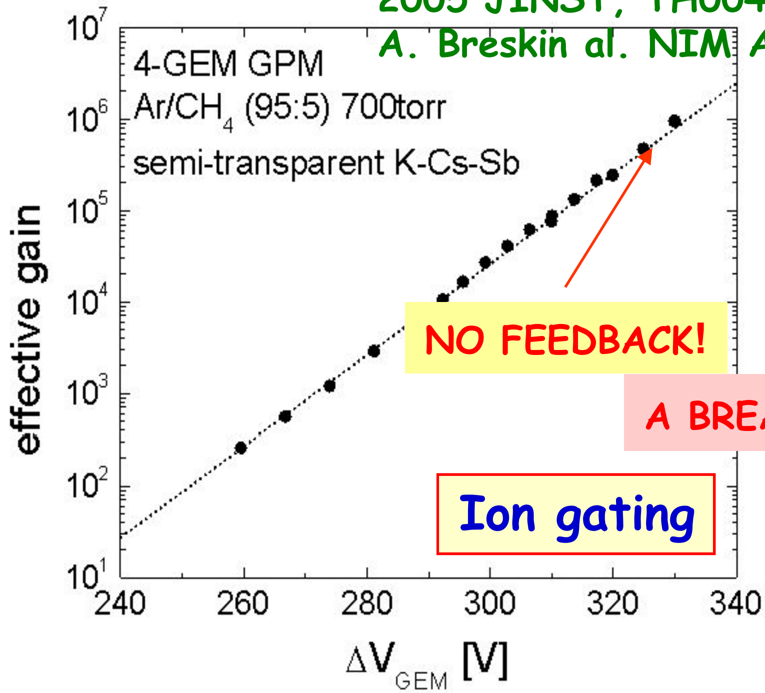
Gaseous detectors with Visible PC

operated with ion gating

D. Moerman, PhD Thesis,
2005 JINST, TH004 &
A. Breskin al. NIM A553 (2005) 46



GATED MULTI-GEM



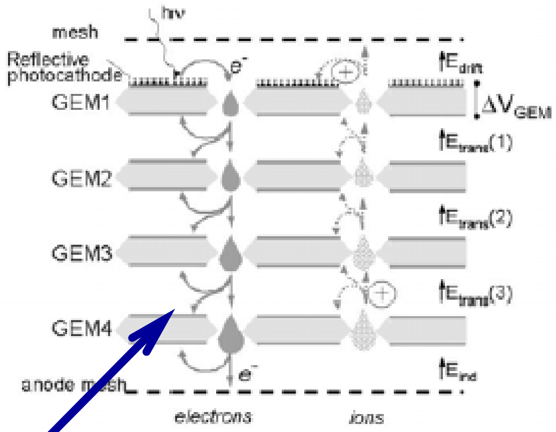
A BREAKTHROUGH!

DC: IBF~0.1 → gain limited to 10^2
Ion gating: IBF~10^{-4} → gain ~10^6
BUT DC mode is preferred:
ion gating is complicated and not always possible
⇨ Should reduce IBF !!

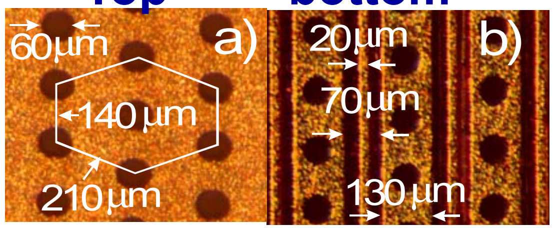
Reducing Ion backflow to the PC

require high field at PC -> ions drift to PC -> More difficult than TPC !!

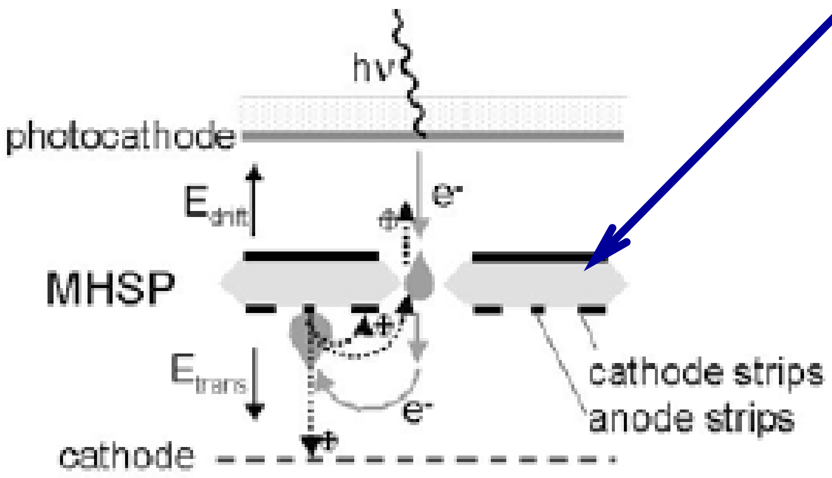
multiple GEMs:
- Ions and e^- follow the same path, only different diffusion.
- Trapping by dipole field on the electrode surface
- Limited possibilities.



Introduce a dedicated ion trapping electrode (collaboration WIS-Coimbra)



Bottom thin strips as anodes

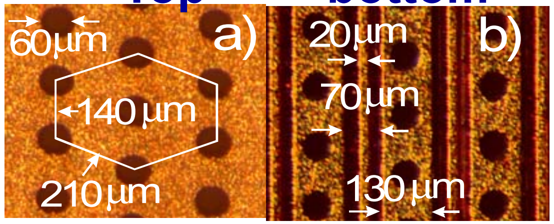


MHSP (micro hole and strip plate):
- Ions and e^- have different paths.
- ions deviated to cathode strips.
- Ions deviated to a cathode electrode.
- Reduce IBF by factor ~5
- last element only.

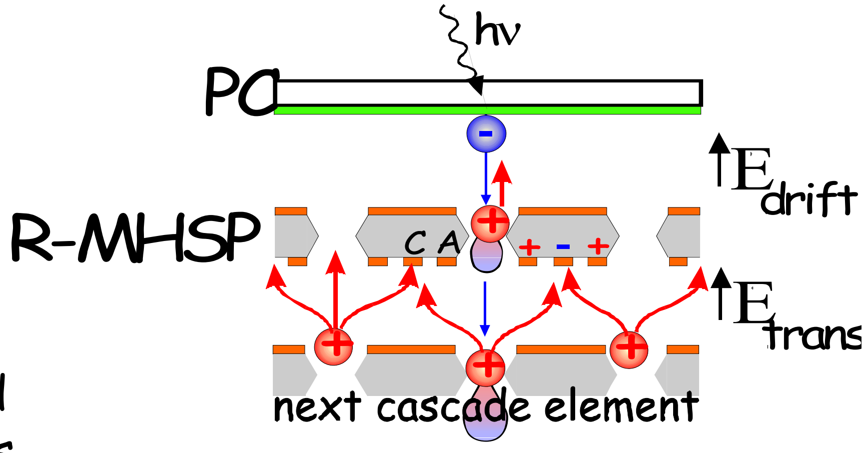
J. M. Maia et al. NIM A523 (2004) 334

better

Top **bottom**



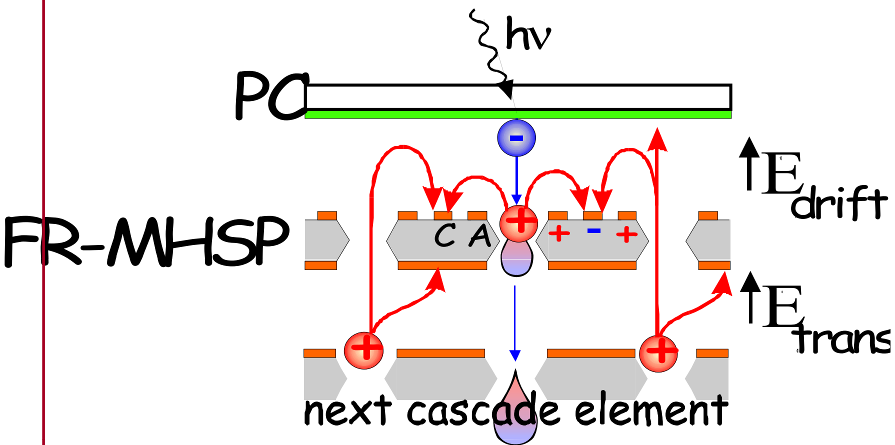
Bottom
thin strips
as cathodes



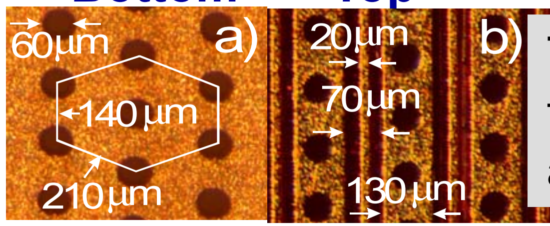
R-MHSP (reversed bias MHSP):

- top element
- all ions from lower electrodes trapped on bottom cathode strips
- electrons are also diverted but some continue to next multipliers.

better



Bottom **Top**



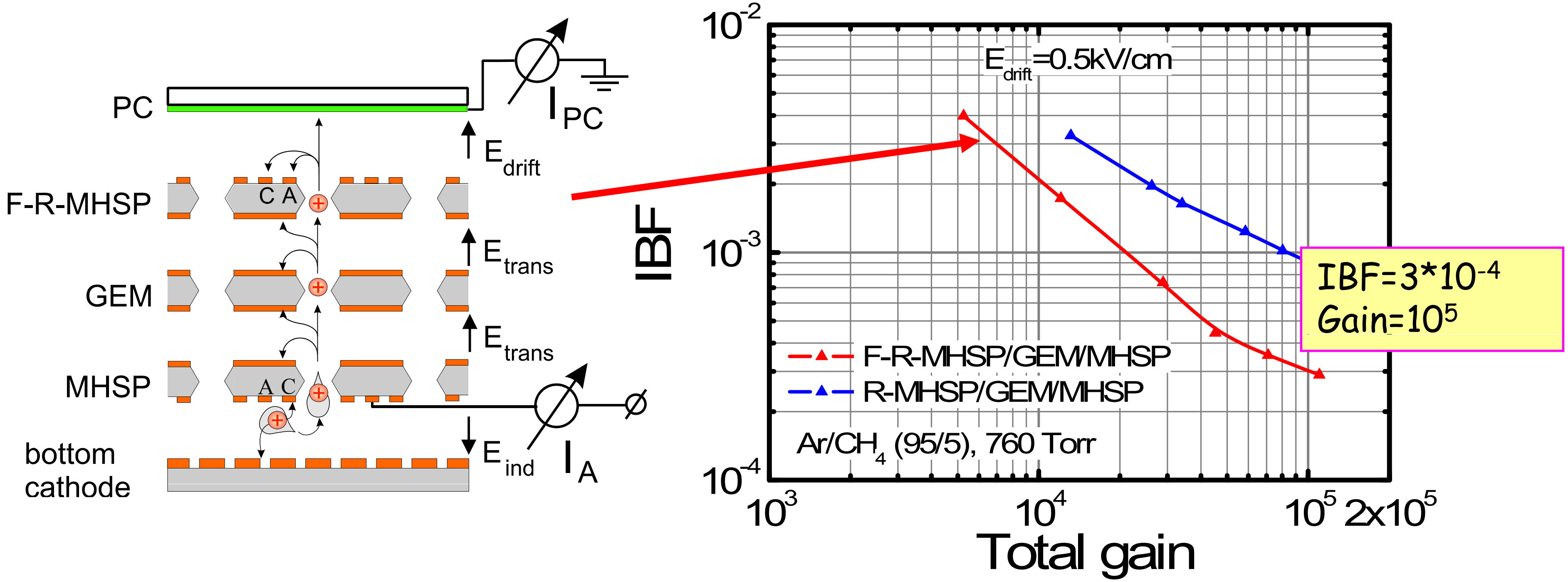
Top
thin strips
as cathodes

FR-MHSP (flipped R-MHSP):

- top element
- all ions from lower electrodes and from its own avalanche trapped on top cathode strips
- electrons are only slightly diverted.

Best IBF

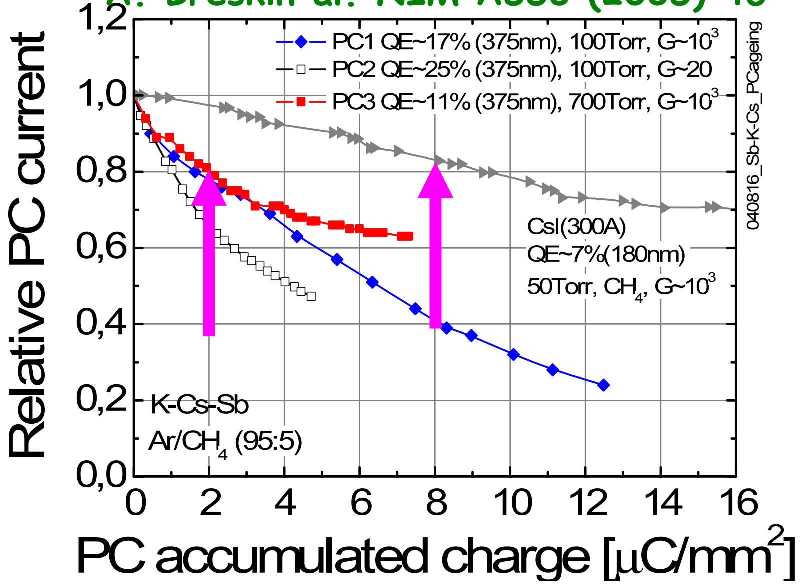
Combination of first <u>and</u> last ion-trapping electrodes.
Total gain 10^5, high field at the PC, IBF 3×10^{-4}.
=> Possible operation in Ar/CH_4 (95/5) with visible PC QE ~ 27%



A. Lyashenko et al. J. Inst. 2 No 08 (August 2007) P08004

K-Sb-Cs PC ageing

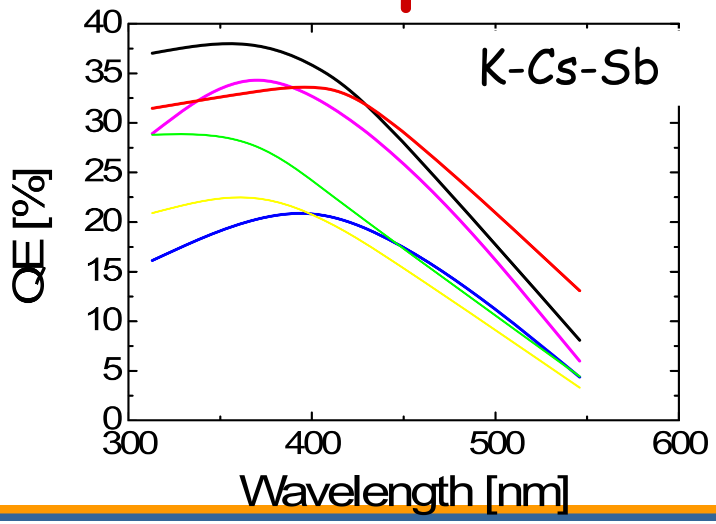
A. Breskin al. NIM A553 (2005) 46

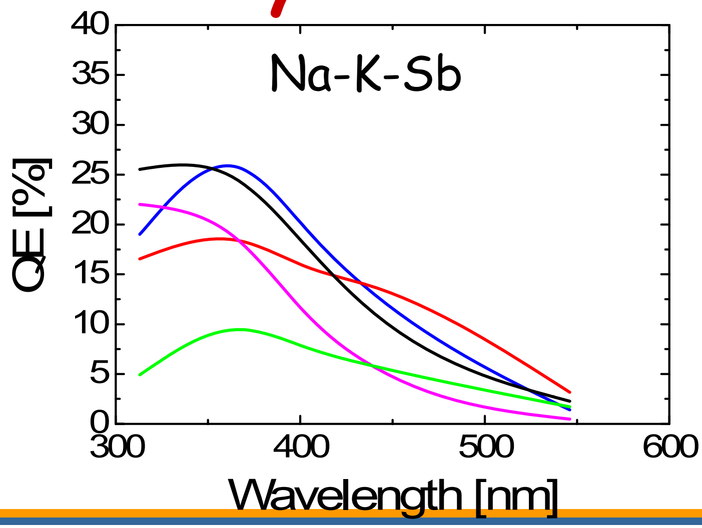


- 20% QE drop @ 2 μC/mm² ion charge on photocathode:
- only ~ 4 x faster drop compared to thin ST CsI (~8 μC/mm²)

RICH experiment: gain=10^5; IBF=$3*10^{-4}$.
•20% QE drop 46 years @ 1kHz/mm² ph.e.
Probably no need for such a high gain !!
• same conditions with a MWPC (IBF=1)
→ 3000 times shorter lifetime: ~5 days!

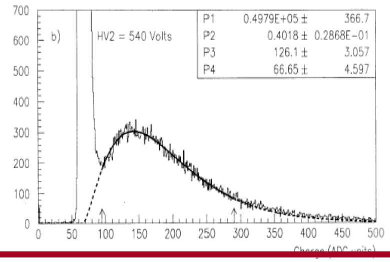
Bialkali PCs produced recently in our lab

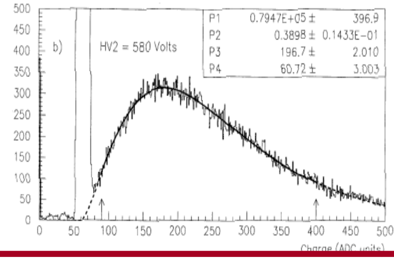




~ Reproducible high QE

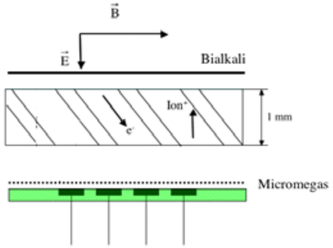
Other ideas and devices under study

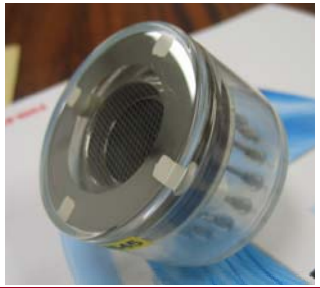




J. Derre et al, NIM A449 (2000) 314

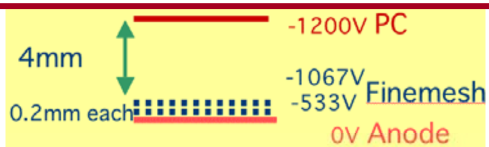
Micromegas: good single electron detection. QE never measured.





J.Va'vra & T. Sumiyoshi, NIM A, 435(2004)334
RICH2004 + Dr. Tokanai (Hamamatsu)

Inclined MCP + micromegas + magnetic field:
Project (unclear) at Hamamatsu.
Latest: gain 10^4 , QE=15%.



J. Va'vra private communication – not new information

Hamamatsu & Sumiyoshi, Tokanai, Va'vra
double-mesh Micromegas, bialkali PC, Ar+10%CH_4 , Ar+10%CF_4.
No deterioration of the PC observed within 5 days
Gain ~6×10^3 , limited by secondary effects.
Not sufficient for single-photon detection.

RPC-based detectors: no news since RICH04

V. Peskov, P. Fonte et al. private communication

Summary

- Some future exists for Gas detectors for RICH
- Promising developments of Thick GEM. Compatible with CsI.
- Sealed flat devices with visible PC and gas multipliers (micromegas,GEMs,MHSP):
  Scientifically feasible.
  Needs study of GEMs/THGEMs of "clean" materials.
  Needs industrial involvement.

SEALED BIALKALI/4-GEM GPM