THGEM Operation in Ne & Ne-Mixtures*

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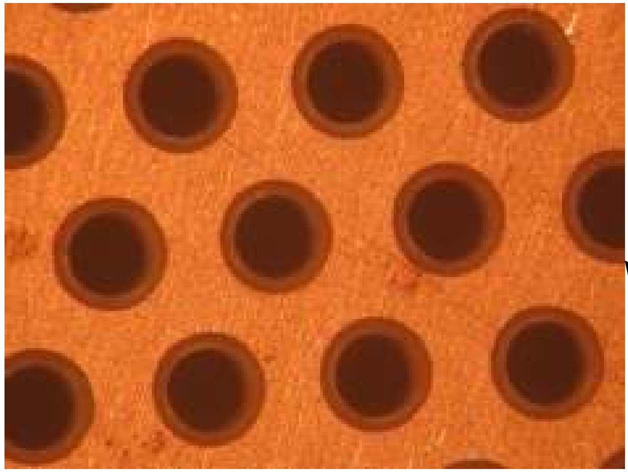
* Work pursued within the framework of CERN-RD51

For more info: THGEM in Ne & Ne/CH_4
CORTESI *et al. submitted to JINST*
(arXiv:0905.2916); RD51-Publications.

Thick-GEM (THGEM) multipliers

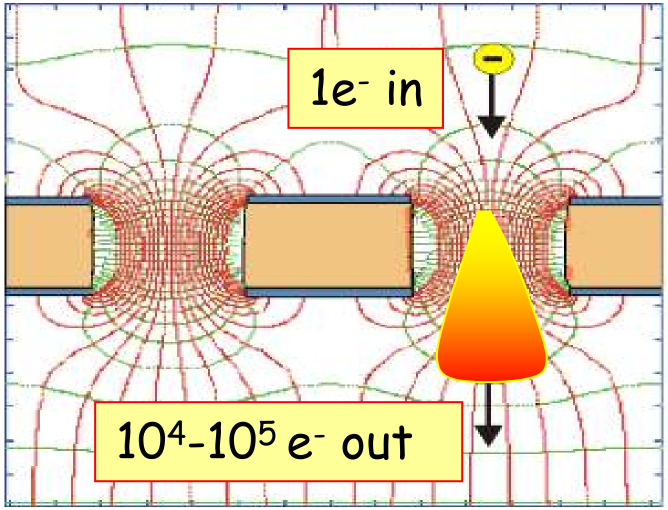
Manufactured by standard PCB techniques of precise drilling in G-10 (and other materials) and Cu etching.

Other groups independently developed similar structures:
-) Optimized GEM: L. Periale et al., NIM A478 (2002) 377.
-) LEM: P. Jeanneret, PhD thesis, 2001.



0.1 mm rim to prevent discharges

E~40kV/cm



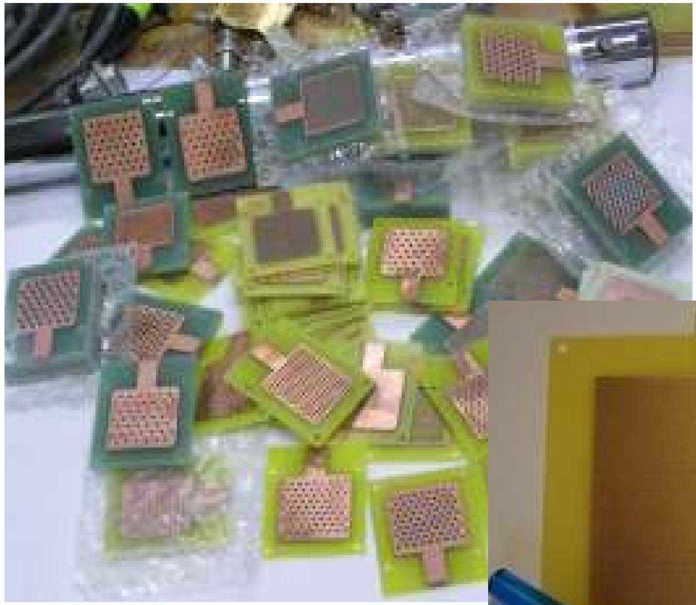
Hole diameter	d = 0.3 - 1 mm
Distance between holes	a = 0.7- 7 mm
Plate thickness	t = 0.4 - 3 mm

Effective single-photon detection
8ns RMS time resolution
>MHz/mm^2 rate capability
Broad gas & pressure selection
Sub-mm position resolution
Cryogenic operation: OK

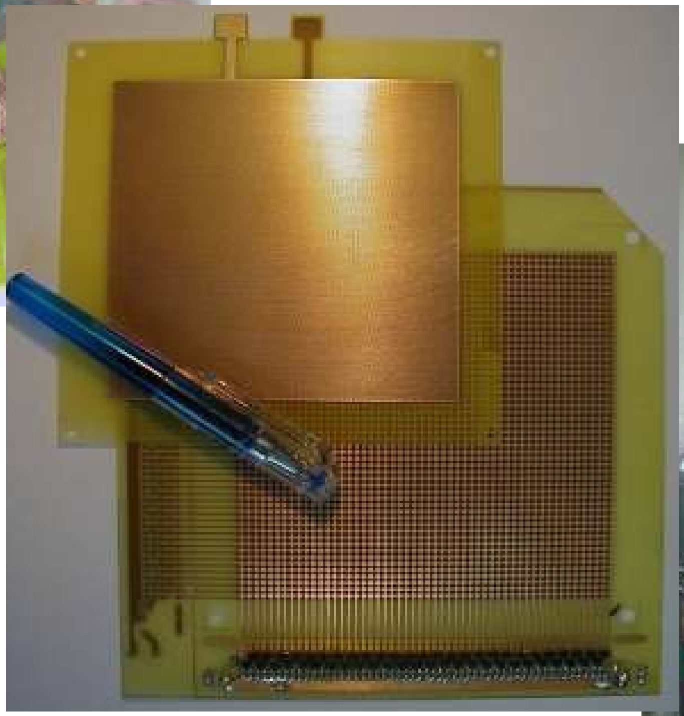
THGEM Recent review by BRESKIN *et al.*
http://dx.doi.org/10.1016/j.nima.2008.08.062

The THGEMs at Weizmann

3x3 cm^2: basic studies, many geometries



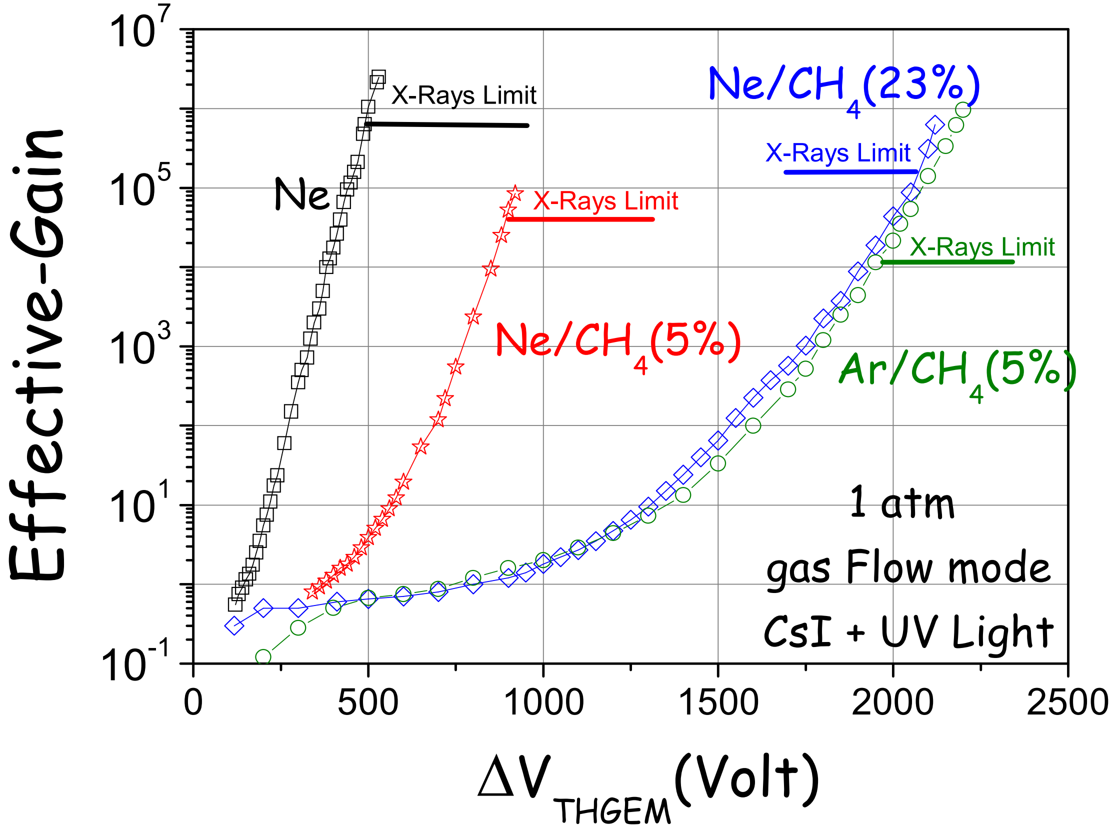
10x10 cm^2: 2D imaging



Future: 30x30 cm^2

Gain: Single THGEM (t=0.8mm)

single THGEM (t = 0.8 mm, d = 0.5 mm, a = 1 mm, rim = 0.1 mm)



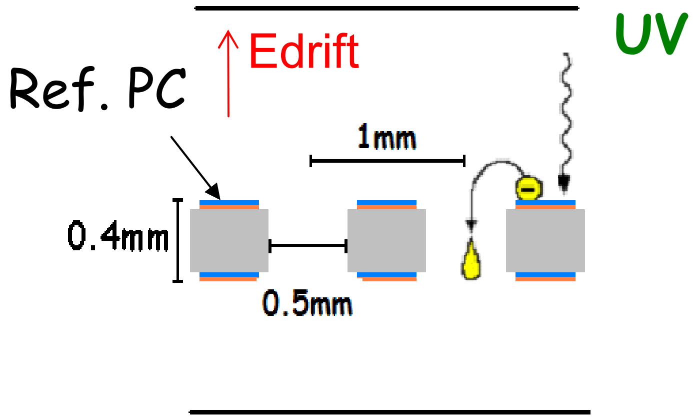


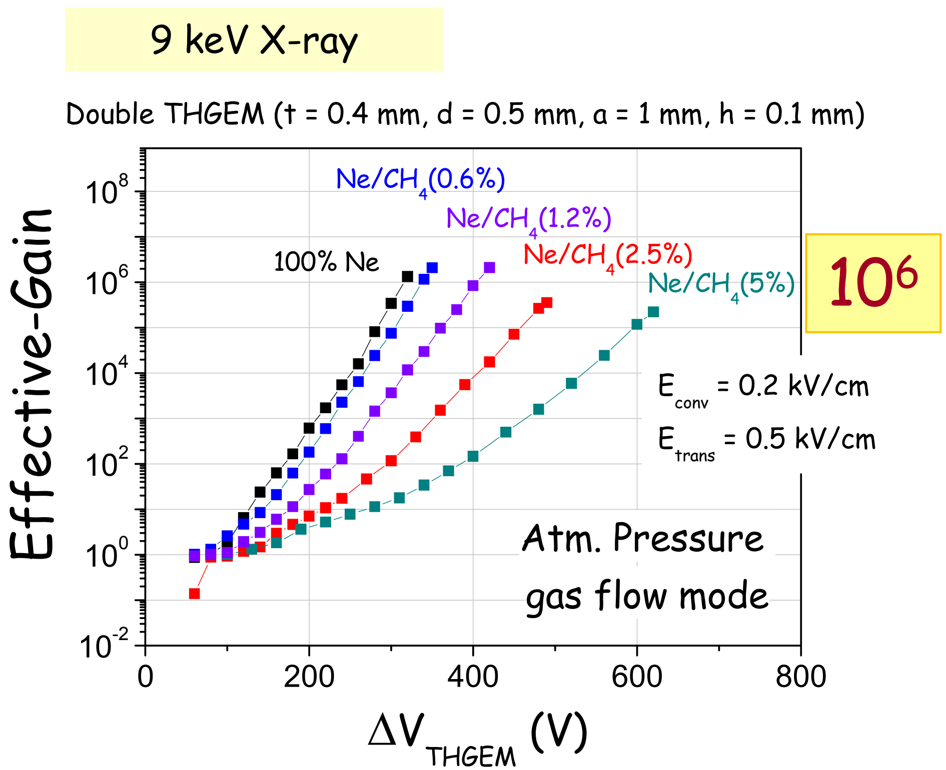
Photo-e$^-$ extraction from Reflective photocathode & focusing by dipole field requires E_{drift} =0kV/cm

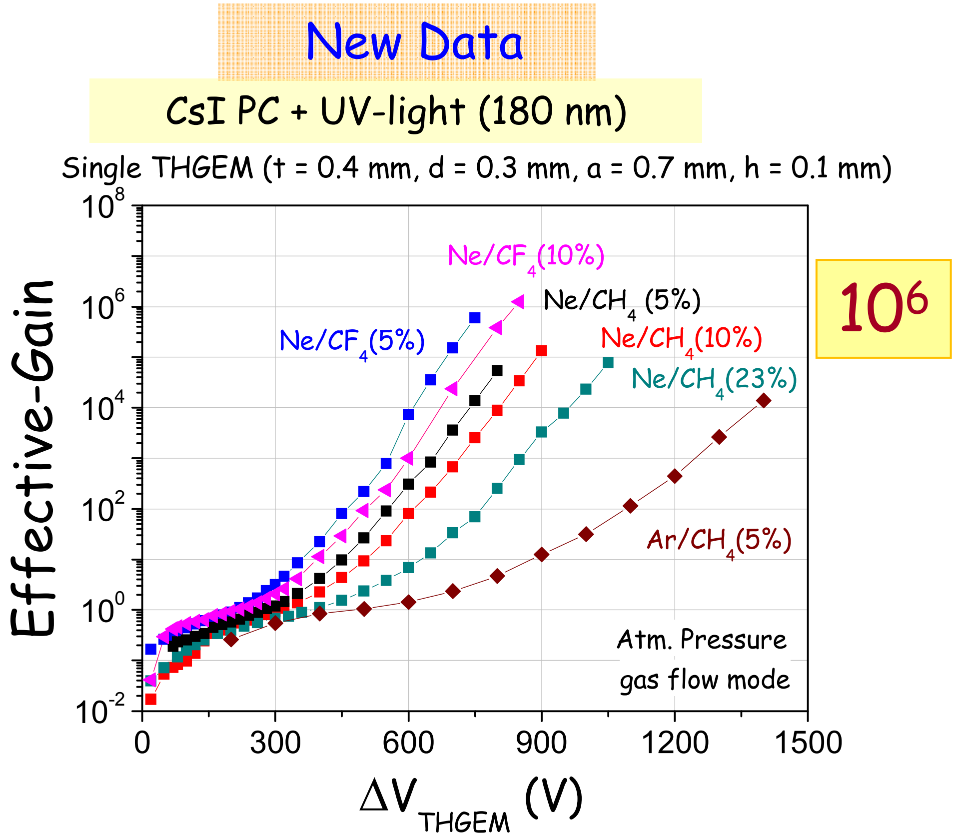
High gain in Ne and Ne-methane

low voltage @ low CH$_4$ concentrations

In Ne-Mixtures Larger dynamic range compared to Ar/CH$_4$

Gain: Single/Double THGEM (t=0.4mm)





Very high gain in Ne and Ne mixtures, even with X-rays

At very low voltages !!

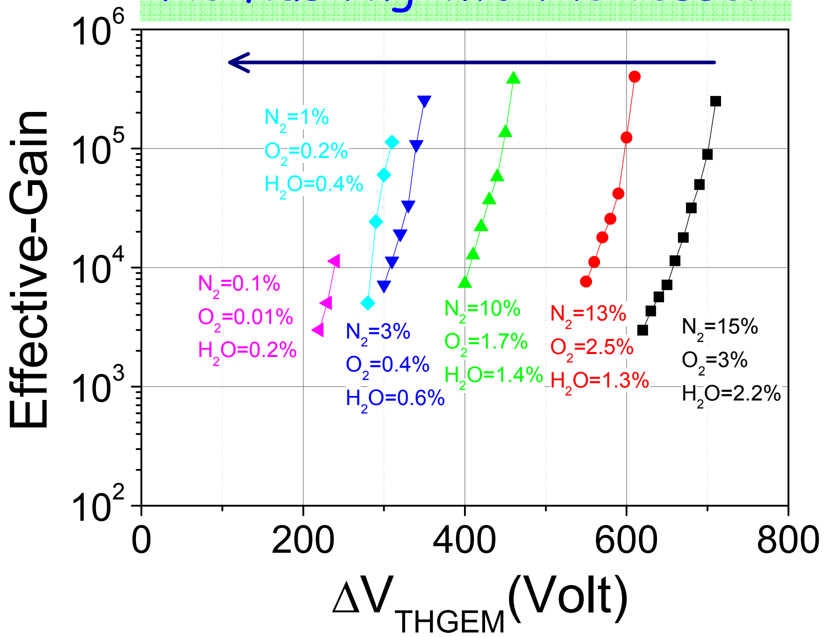
2-THGEM 100% Ne: Gain 10^6 @ ~300V

1-THGEM Ne/CF_4(10%): Gain > 10^6 @ ~800V

THGEM operation: Gas Impurities

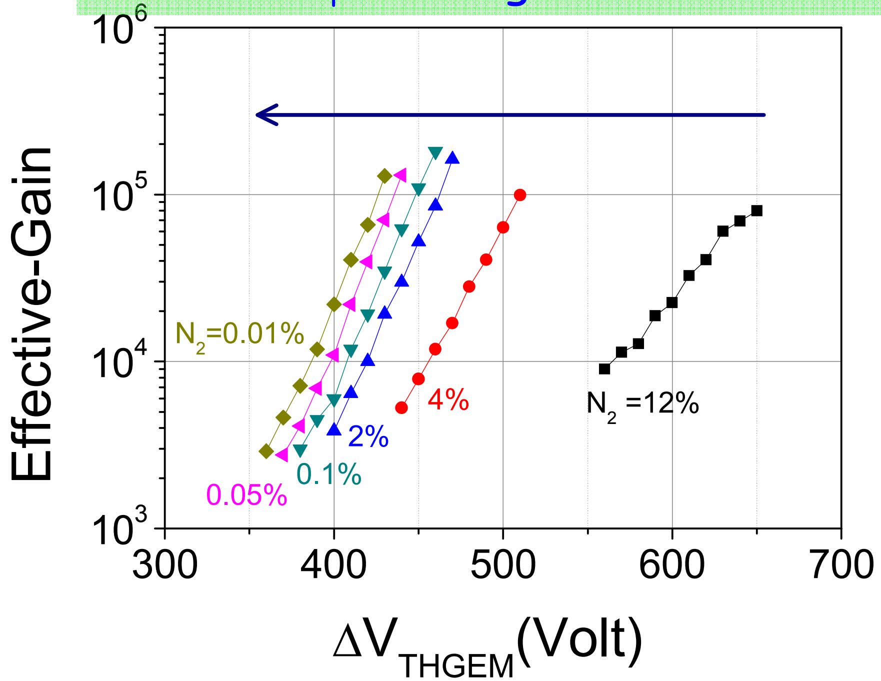
Double-THGEM detector
(t=0.4mm, d=0.5mm, a=1mm, rim=0.12mm)
Gain measured with X-rays (6 keV)

Ne flushing into the vessel



In the figs: N_2 represents all impurities
(N_2, H_2O, O_2, Ar etc.)
'Purification' by continuous
Ne gas flow (20 hours)

$Ne/5\%CH_4$ flushing into the vessel



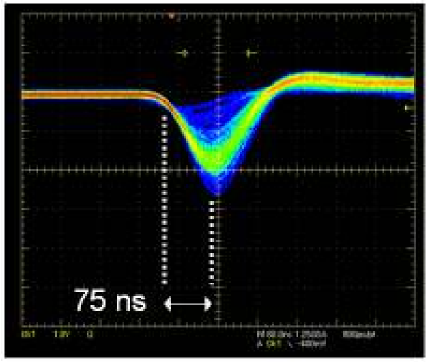
As the impurities are removed:
1) Lower operational Voltages
2) In **Ne** → Max. Gain drops
In **Ne/CH$_4$** → Same Max. Gain

Impurities affect gain in Ne but not in Ne/CH$_4$!

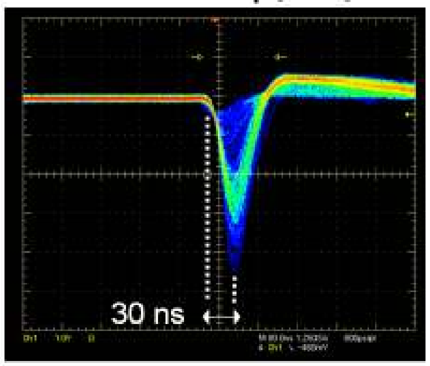
Energy Resolution & rise-time

THGEM signals w fast amp

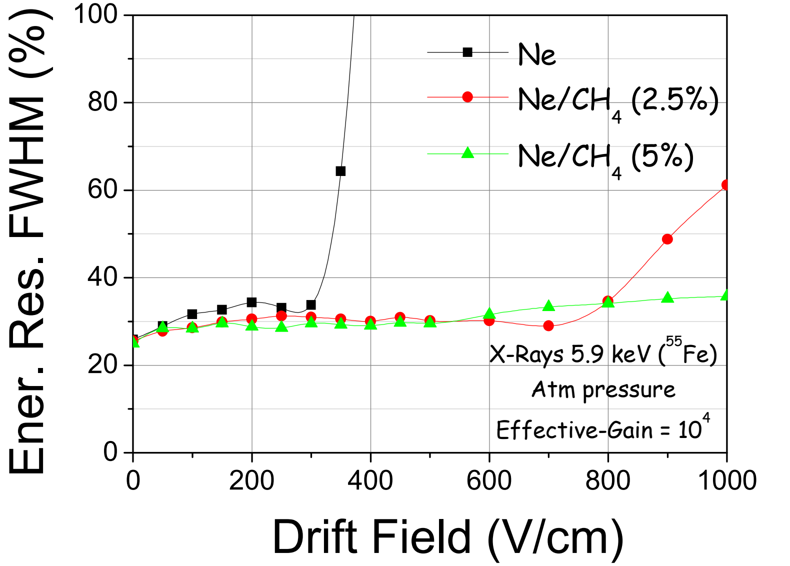
Ne

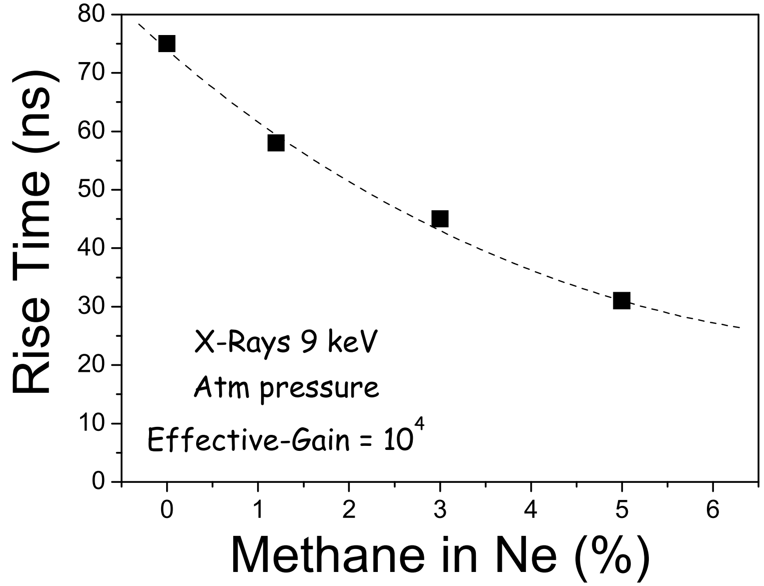


Ne/CH_4 (5%)



THGEM (t = 0.8 mm, d = 0.5 mm, a = 1 mm, h = 0.1 mm)



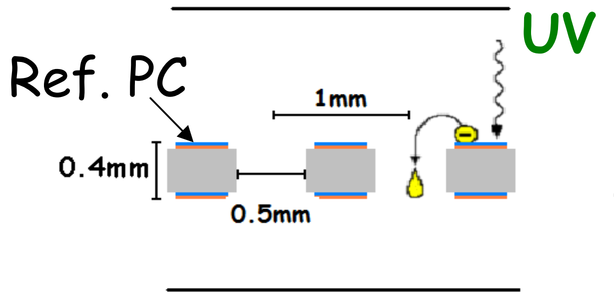


Increasing %CH_4 ->

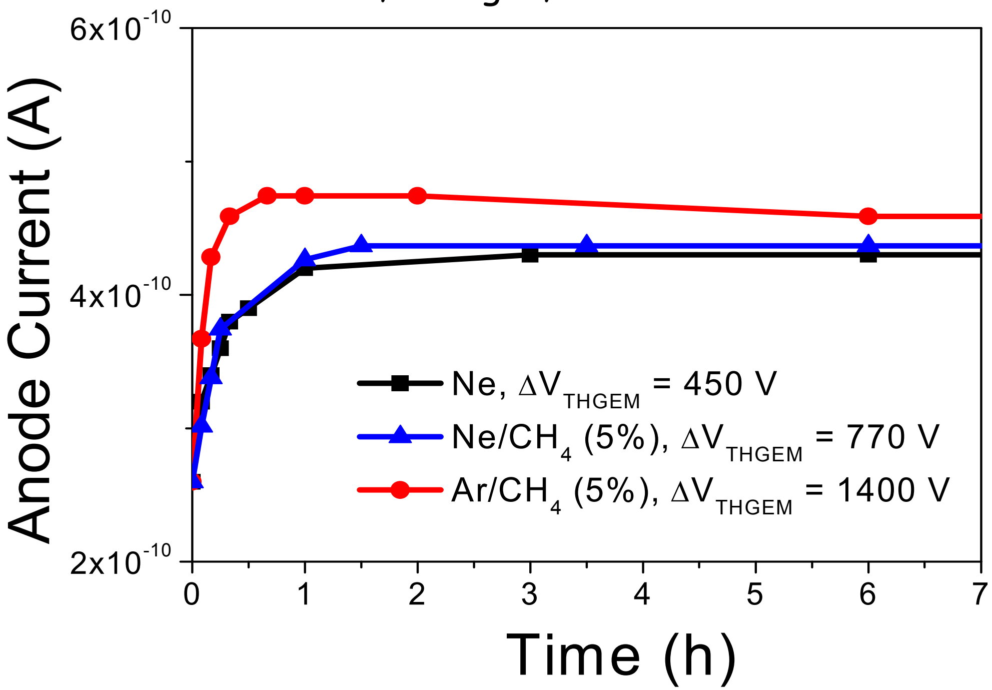
higher voltages &

faster avalanches

Long-Term Stability (after gas stabilization)



Single THGEM (t=0.4mm, d=0.5mm, a=1mm, rim=0.12mm)
Gain = 10^4, UV light, e^- flux ≈ 10^4 Hz/mm^2

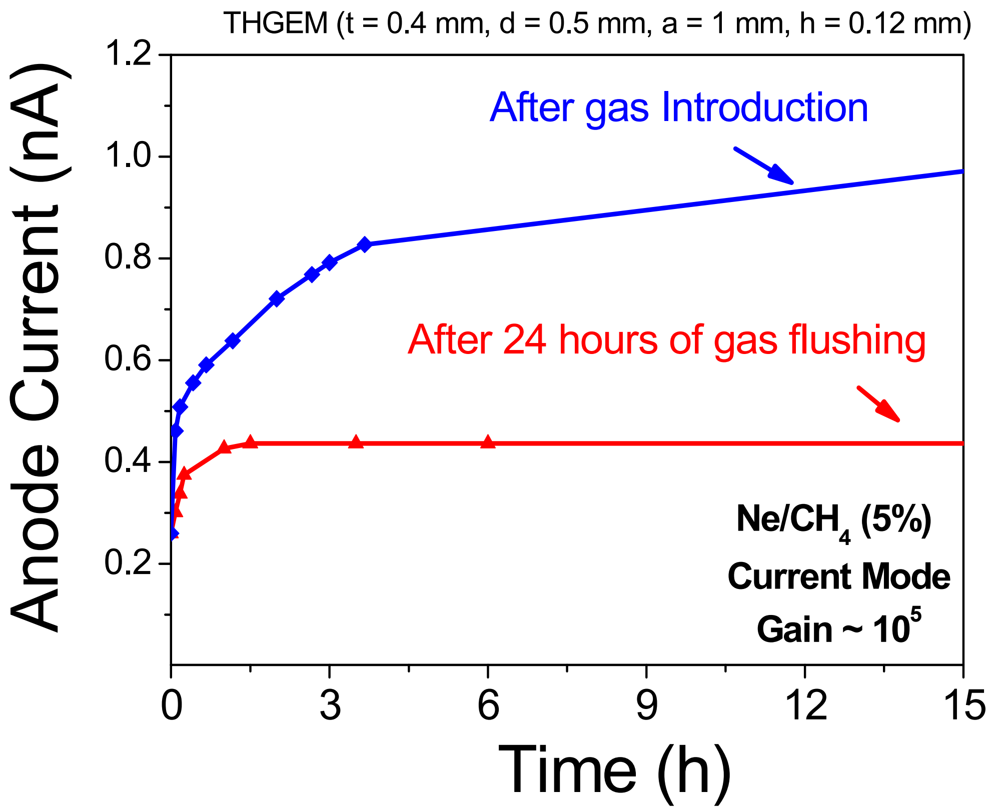


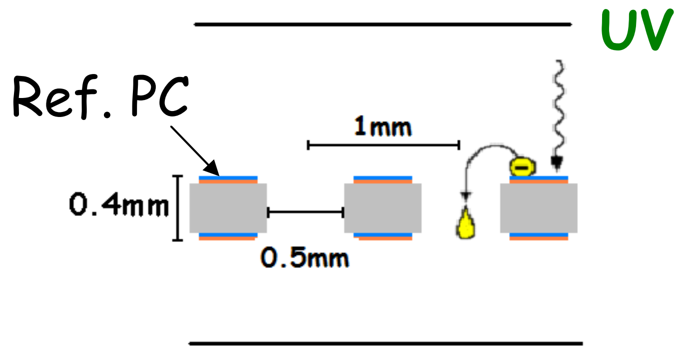
Insulator Charging up ➔
few hours of stabilization
gain variation~ x2, depends on:
- voltages, currents, gas, materials

Stabilization time function of:
- Total gain (potentials)
- Counting rate (current)
- Material & hole-geometry
- Production method (adsorbed chemicals)
- Gas & purity

Long-Term Stability: Gas Impurity

Single THGEM (t=0.4mm, d=0.5mm, a=1mm, rim=0.12mm)
Gain = 10^4, UV light, e^- flux ≈ 10^4 Hz/mm^2

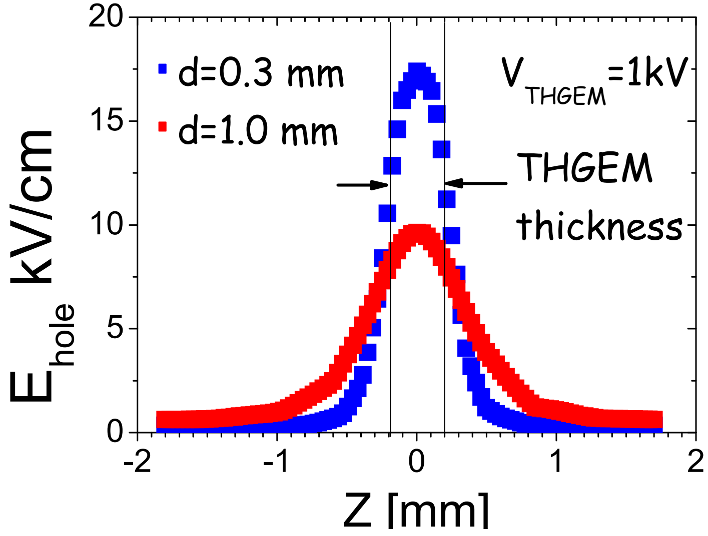


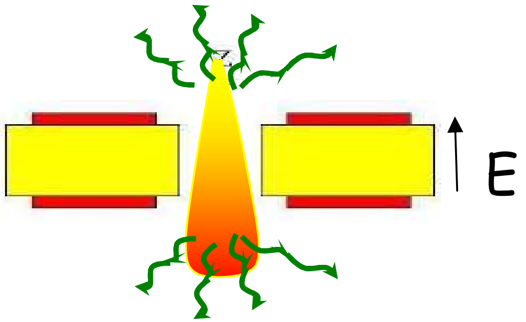


Impurities effects on long-term stability:
-) Higher variation of Gain
-) Longer Stabilization time

THGEM - hole diameter & avalanche

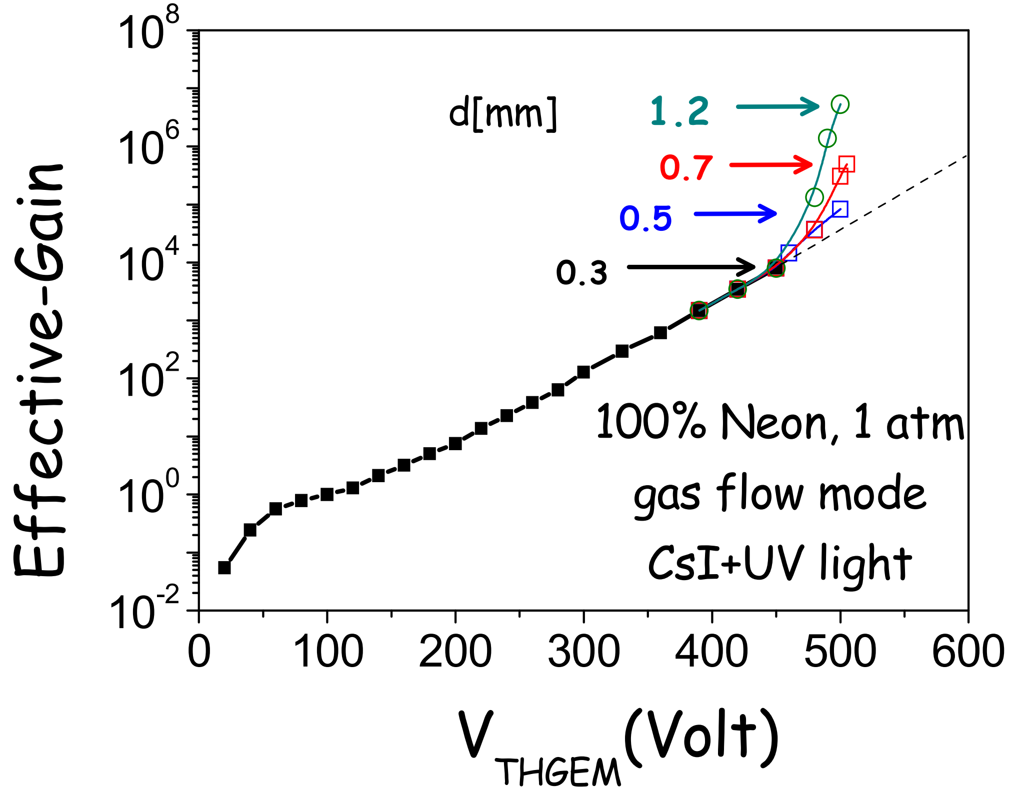
Maxwell Software calculation



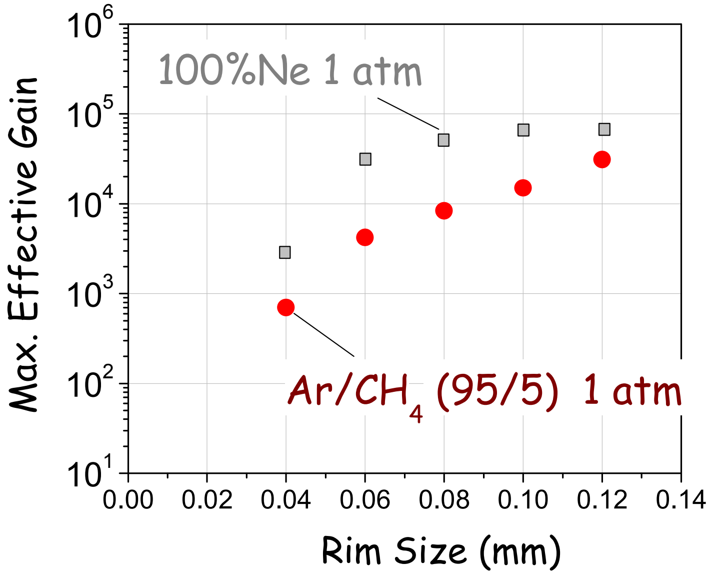


Avalanche & photons
Outside the hole.
Ne, Ar have energetic photons
Need to optimize sizes and fields according to the gas.

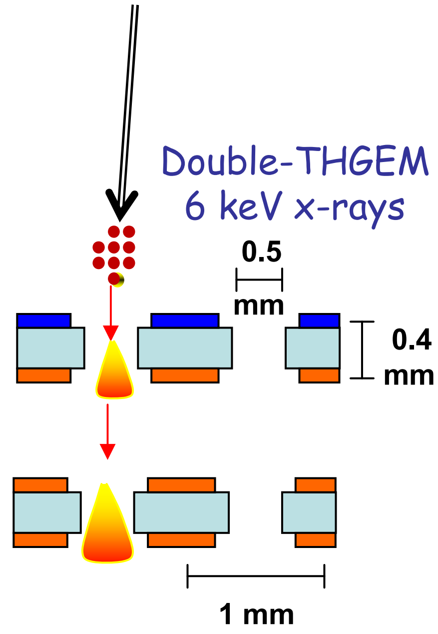
Avalanche de-confinement
(Field extends out of the THGEM holes)
Photon-induced secondary effects depend on THGEM geometry and filling gas.



THGEM - Rim effect



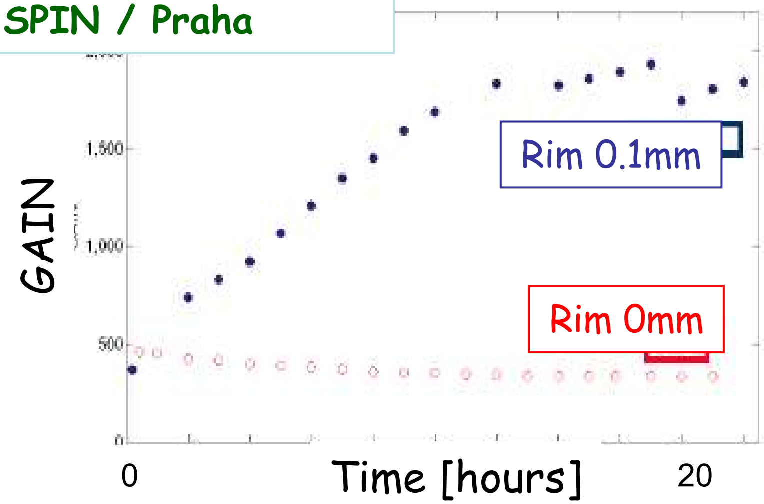
THGEMs produced by chemical etching (no mask) @ PE, Israel



Larger rim →
Higher voltages &
Higher gains

But: Larger rim →
up-charging
& longer stabilization

From: J. Polak/Trieste @ SPIN / Praha

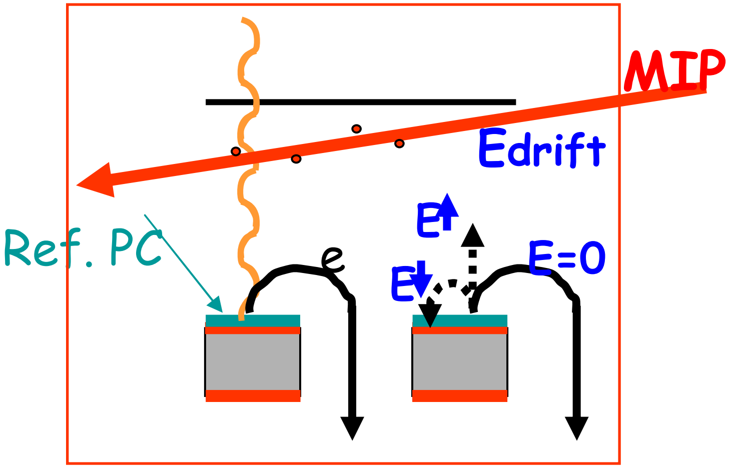


Further R&D in progress @ CERN-RD51
e.g.: zero rim-> no up charging, but @ lower gain

Photon detectors for RICH:

reflective CsI PC deposited on the THGEM

Photoelectron collection efficiency

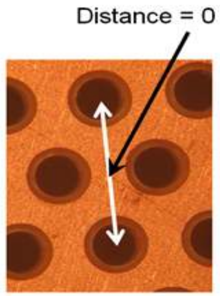


Focusing is done by the hole dipole field.

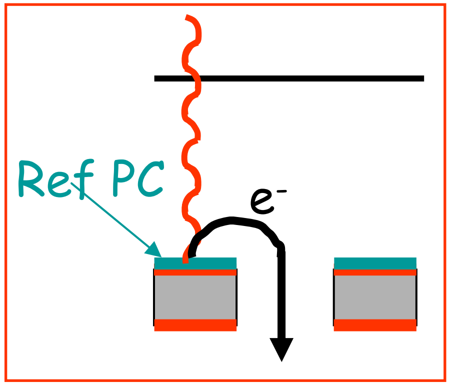
- Maximum efficiency obtained in $Ar/5\%CH_4$ at E_{drift} =0.
- Slightly reversed E_{drift} (50-100V/cm) =>
  good photoelectron collection & low sensitivity to MIPS
  (e.g. proved with multi-GEM detectors of PHENIX)

Currently **R&D for upgrade of COMPASS & ALICE RICH**

PC Electric Field and e⁻ Extraction

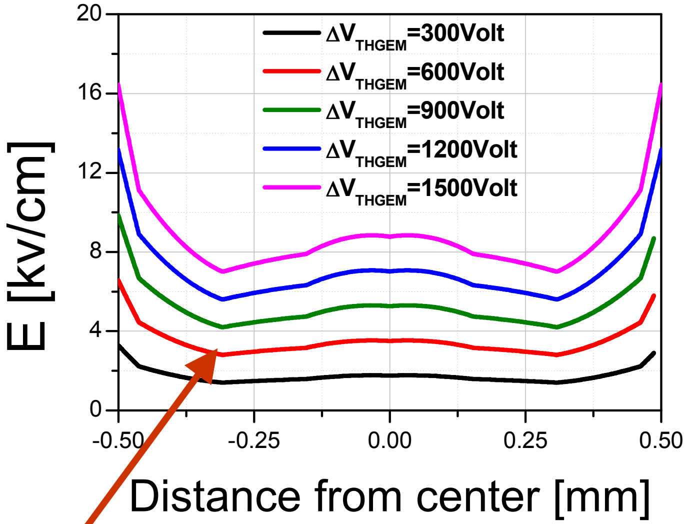


The hole dipole field creates electric field on the PC surface

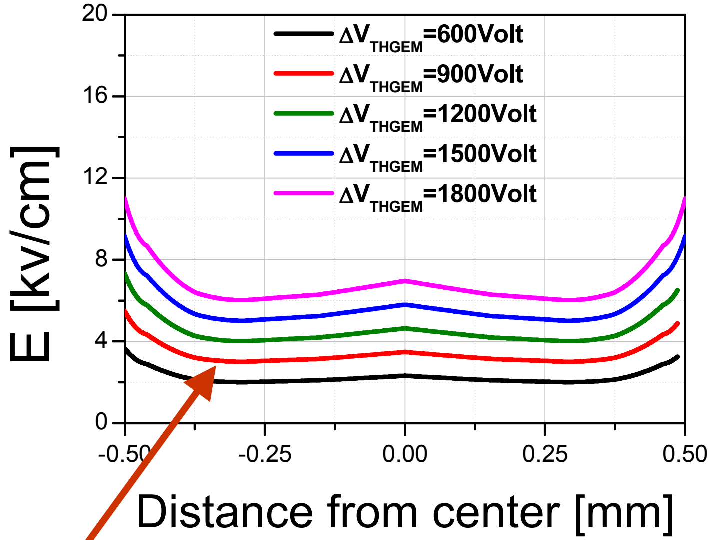


Maxwell Software calculation

d=0.3, t=0.4, a=1mm



d=0.3, t=0.8, a=1mm



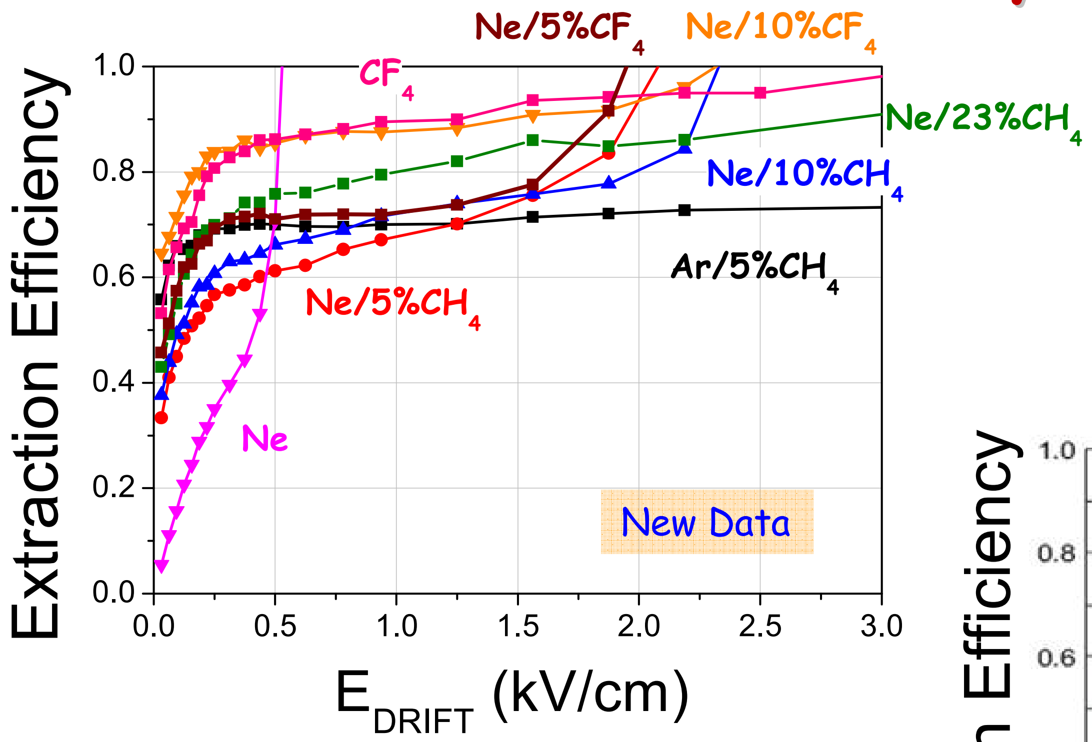
In Ne/5%CF_4 @ gain~10^6 (1-THGEM)
typ. V_{THGEM}~800 V ➔ E>3.5kV/cm

In Ne/5%CH_4 @ gain~10^6 (1-THGEM)
typ. V_{THGEM}=900 V ➔ E>3kV/cm

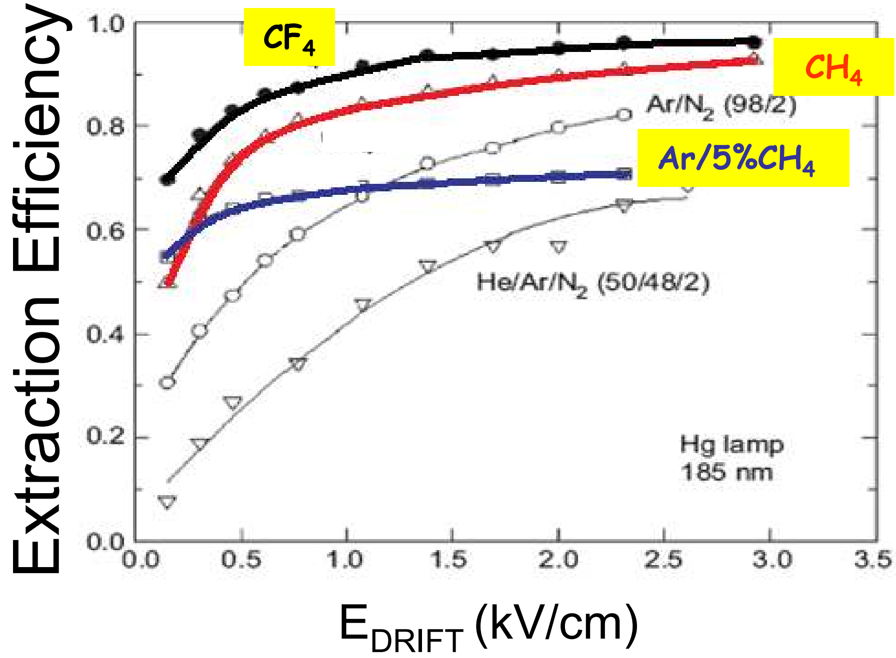
RICH Requires:

- High E on the PC surface (for e-extraction ➔ high QE).
- Good e⁻ focusing into the holes (for high detection efficiency).

Extraction efficiency w CsI ref. PC



- -) photoelectron extraction increases with CH_4
- -) very high photoelectron extraction in Ne/10%CF_4 (90%) similar to CF_4



Breskin & Chechik
NIMA **595 (2008)** 116

Example: For typical operation voltages in Ne/5%CH_4 (E ~ 2.8-3 kV/cm):
Effective QE ~ 70% (similar to Ar/5%CH_4!)

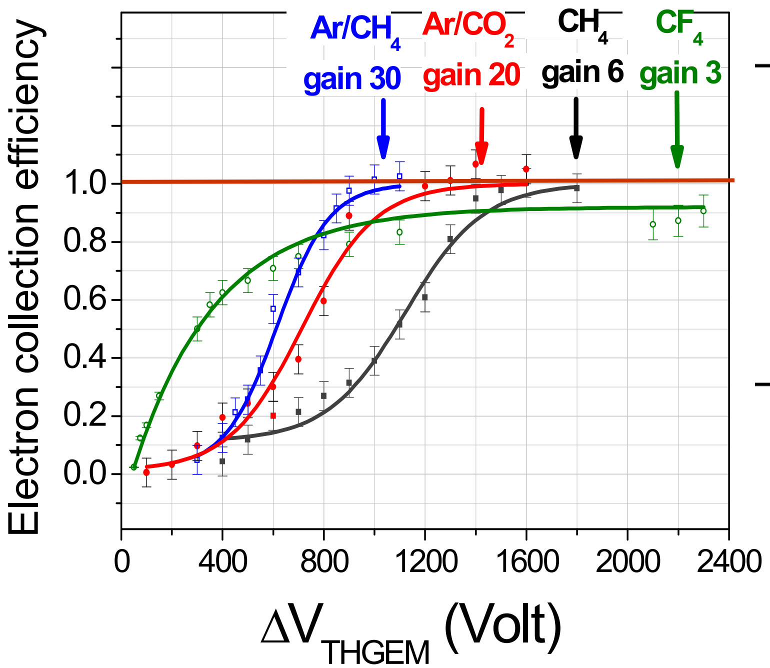
Electron collection efficiency

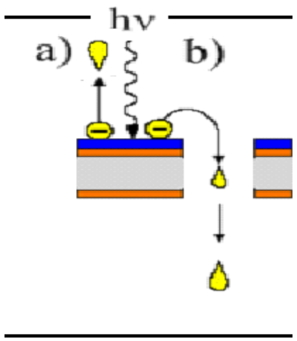
3x3cm² THGEM (thickness = 0.4 mm, hole diameter = 0.3 mm, pitch = 0.7 mm, rim = 0.1 mm)

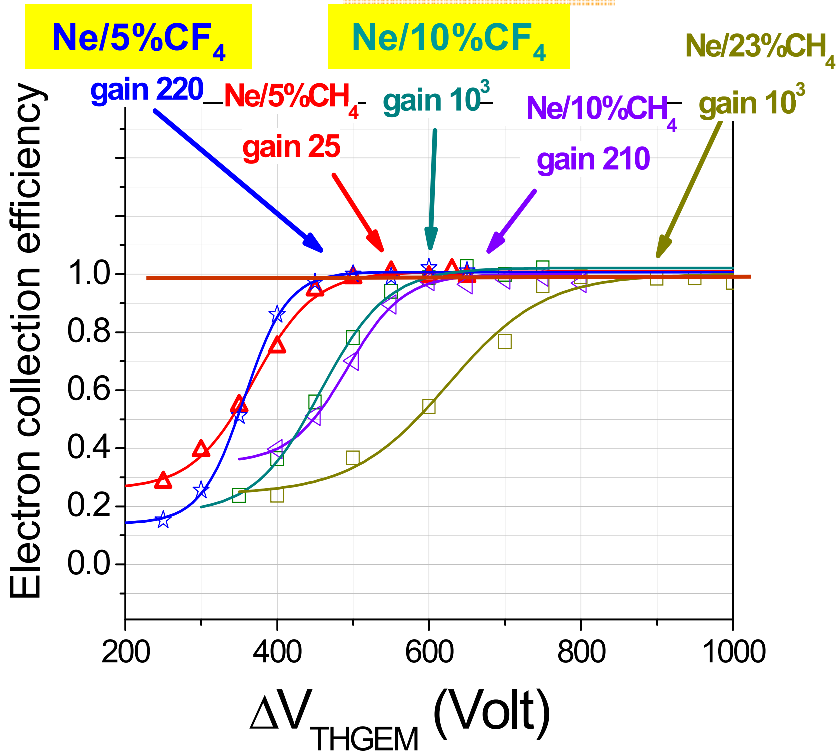
Method: Pulse-counting of the fraction of single-e^- events reaching the THGEM bottom

New Data

Shalem *et al.* *NIMA* **558 (2006)** 475



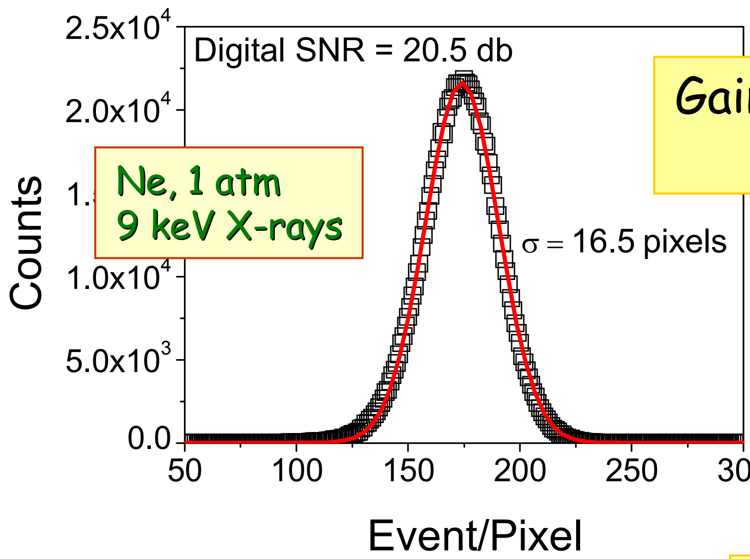




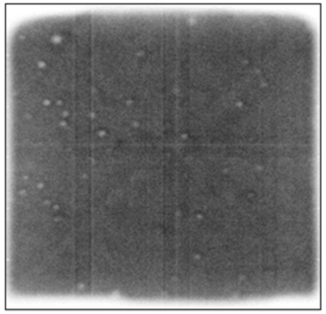
THGEM large hole dimensions ➔ efficient e^- collection into the hole:
↳ full single-e^- detection efficiency @ gain <100 (depends on %CH_4)

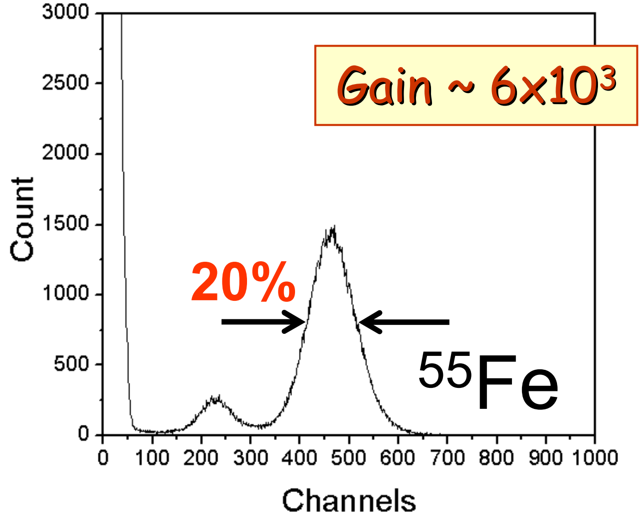
2D imaging: results with soft X-rays

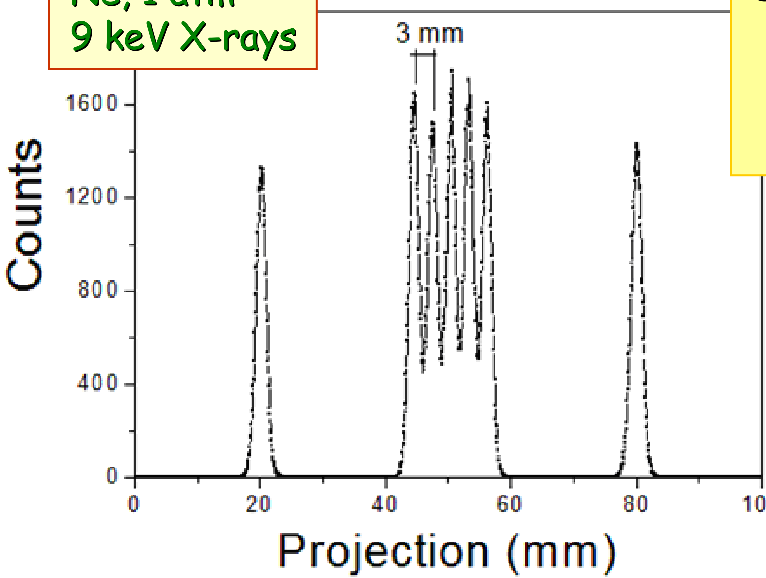
100x100 mm^2 D-THGEM



Gain uniformity
± 10%

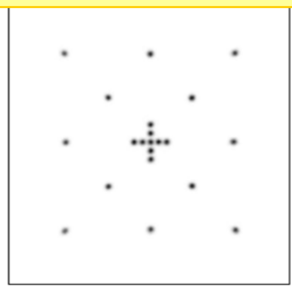


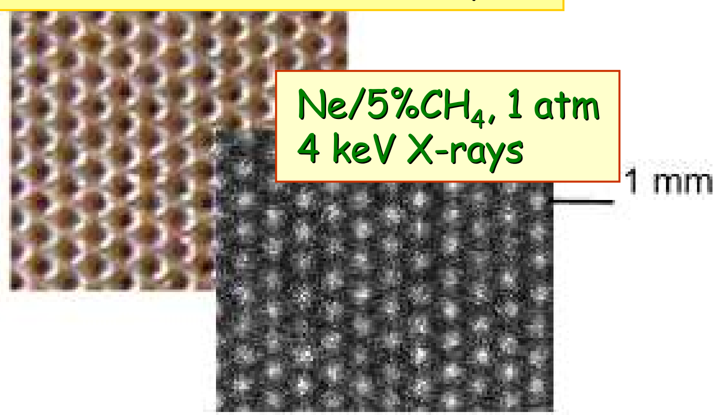




Spatial Resolution (FWHM)

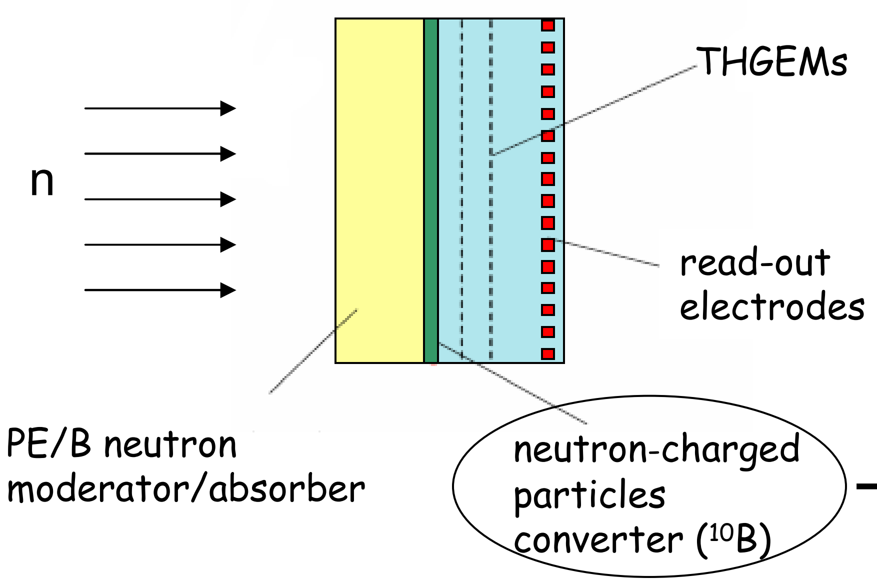
- $Ar/5\%CH_4$ ➔ 0.7 mm with 9 keV X-rays
- Ne ➔ 1.4 mm with 9 keV X-rays
- $Ne/5\%CH_4$ ➔ 0.3 mm with 4 keV X-rays





2D imaging: results with Neutrons

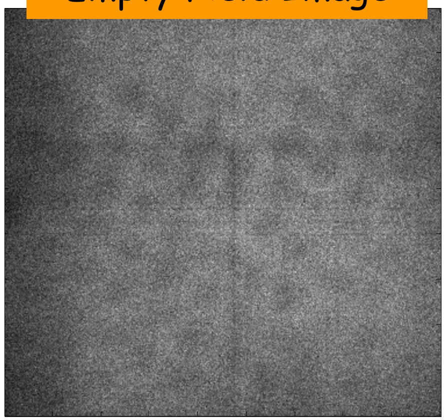
A fast neutron spectrometer + imaging of flux for BNCT applications



Basic idea:
Bonner-sphere spectroscopy (moderator + thermal neutron detector) in a flat geometry setup with imaging capability

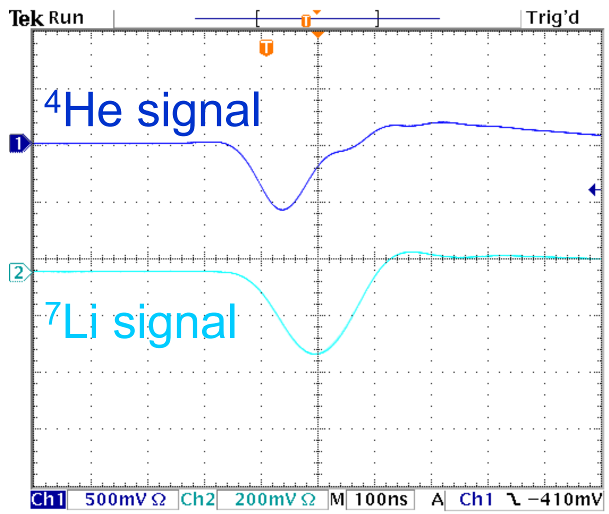
$$^{10}B + n \rightarrow {}^{7}Li + {}^{4}He + \gamma (94\%)$$

Empty Field Image



Preliminary data:
5.9 MeV neutron
Gain~10^4 in Ne @ n-flux:
~$1.6 \cdot 10^5$ n/cm^2/s

Good Homogeneity &
Good detector stability



THGEM properties: Summary (1)

1) MM-scale dimensions

Economic production (10^4 holes =300$)

Versatile geometry & robust (not destroyed by sparks).

Efficient coupling with photocathodes/convertors

Single-electron sensitivity

Rim important for high achievable gain → longer stabilization time (not dramatic)

High-rate capability (~10MHz/mm^2 @ ~10^4 in Ar/CH_4 w single photoelectrons)

Timing: ~10 ns (β, cosmic), ~1-2 ns (multi-photon pulse)

2) Large multiplication in Ne, Ne/CH_4 & Ne/CF_4 @ low operation voltages:

→ Reduced probability of sparks due to defects and less charging-up

→ Large holes diameter → good e-collection already @ low gains (<10^3)

→ Large Dynamic Range (prevent discharge due to high ionizing background)

<u>Single electron (UV-light)</u>
Single THGEM 10^{5-6}(0.4mm) – 10^6(0.8mm)
Double THGEMs gain 10^6-10^7 (0.4mm)

<u>soft x-rays</u>
Only ~10x lower gain

THGEM properties: Summary (2)

3) UV detectors:

→ Single photon detection: gain >10^6

(higher gain → *more photons per ring*)

→ 0.3mm holes/1mm pitch ➔ CsI coverage ϵ_{PC} = 78-90%

depending on the rim size (0.1-0 mm)

→ CsI QE @ 170 nm = 30%

→ Extraction efficiency in Ne/10%CF_4 ➔ ϵ_{extr} = 90%

→ Electron Collection Efficiency ➔ ϵ_{coll} = 100% for gain > 10^3

→ Effective Quantum Effiency:

$$QE_{eff} = QE \times \epsilon_{extr} \times \epsilon_{extr} \times \epsilon_{coll} \sim 21\text{-}24\%$$

Detection efficiency = QE_{eff} x electronic-threshold factor (0.8-0.95)

Presently in RICH for COMPASS:

MWPC in CH_4, typ. gain ~ 10^4; Effective Quantum Efficiency (@ 170 nm) ~ 20%

Ongoing: IMAGING test to see if in Ne/CF_4 there are no photon-feedback "satellites"

4) Localization resolution (x-rays):

THGEM: 0.5mm holes, 1mm pitch & 2mm readout pitch ➔

1.4mm FWHM in Ne w. 9keV - 0.3mm FWHM in Ne/5%CH_4 w. 4keV

Applications

Applications under consideration:
in High Energy Physics, Nuclear Astrophysics, "Exotic Physics" (rare events, dark matter), Medical Imaging, n Radiography, etc

Our ongoing R&D

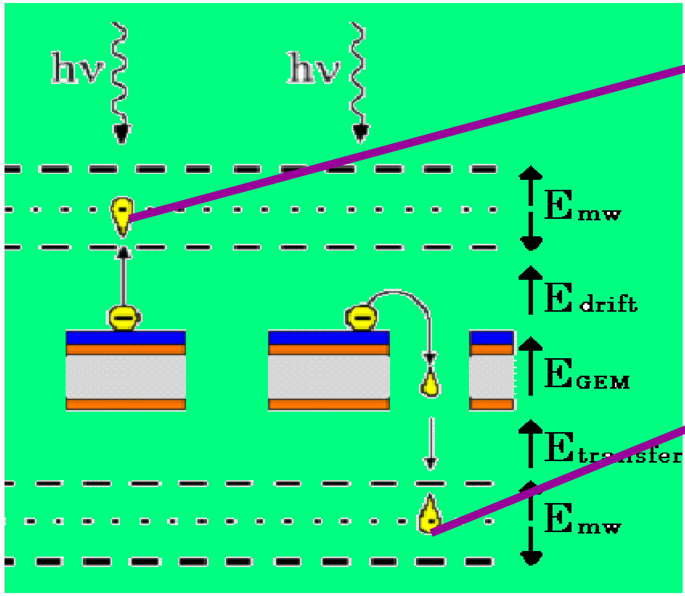
- Economic THGEM production technique & materials
  e.g. CIRLEX (polyimide), TEFLON, KEVLAR, CERAMICs etc.
- Timing/localization with particle beams
- 2-phase mode in noble gases & liquids (w BINP, YALE, Coimbra)
- Cryogenic Gas Photomultiplier for LXe γ-Camera (w Nantes)
- Search for saturated gain mode (with V. Peskov)
  important for single photons and MIPS
- Neutron imaging detectors (with PTB, Milano, Soreq)
- Sampling elements in Digital Hadron Calorimetry
  (with Andy White/Arlington)

Electron Collection Efficiency

the efficiency to focus an electron into the THGEM methodology

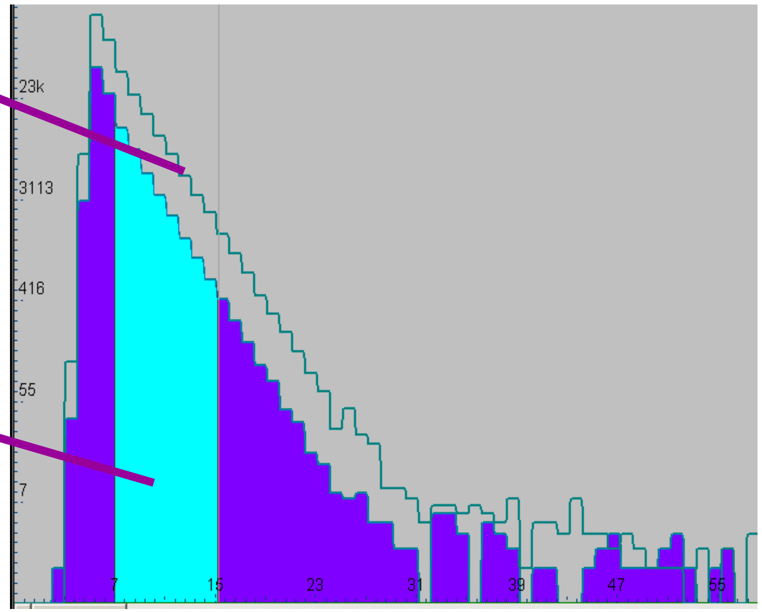
Pulse counting measurement:

- Based on single e^- pulses
- Same pc, lamp, gain and electronics, different e^- path.
- Comparing counting rate provides the fraction of single e events reaching THGEM bottom.



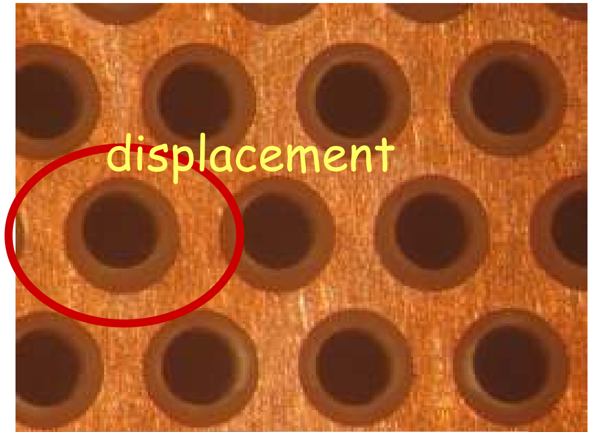
(1) normalization

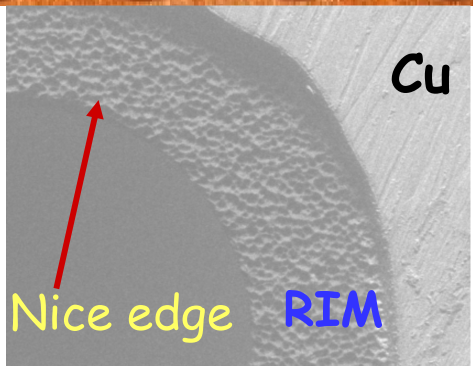
(2) efficiency measurment



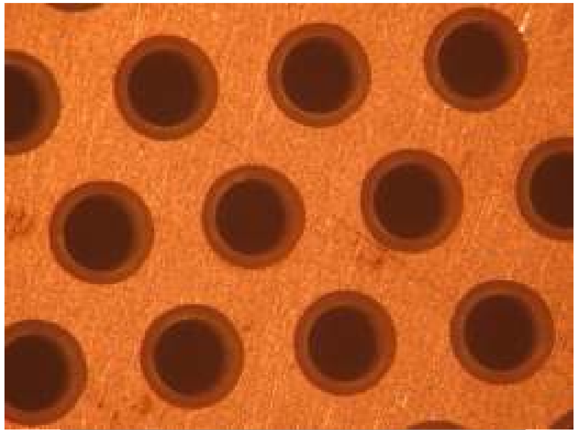
THGEM production methods

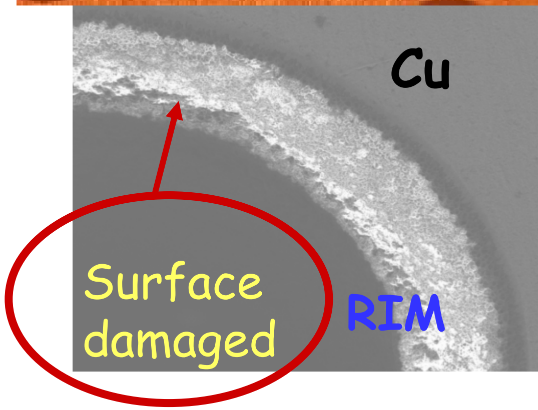
With mask, Weizmann
Etch w mask + drill
Large rim



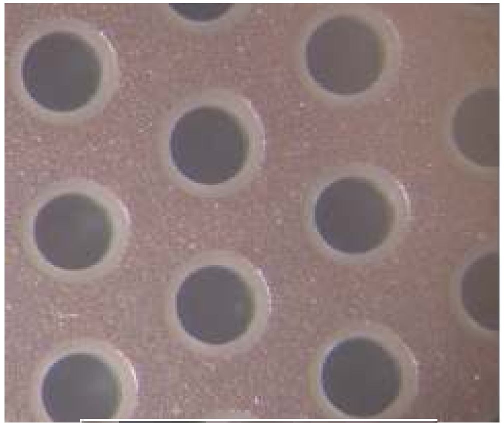


No mask, Weizmann
Drill + etch under the Cu
Small and zero rim



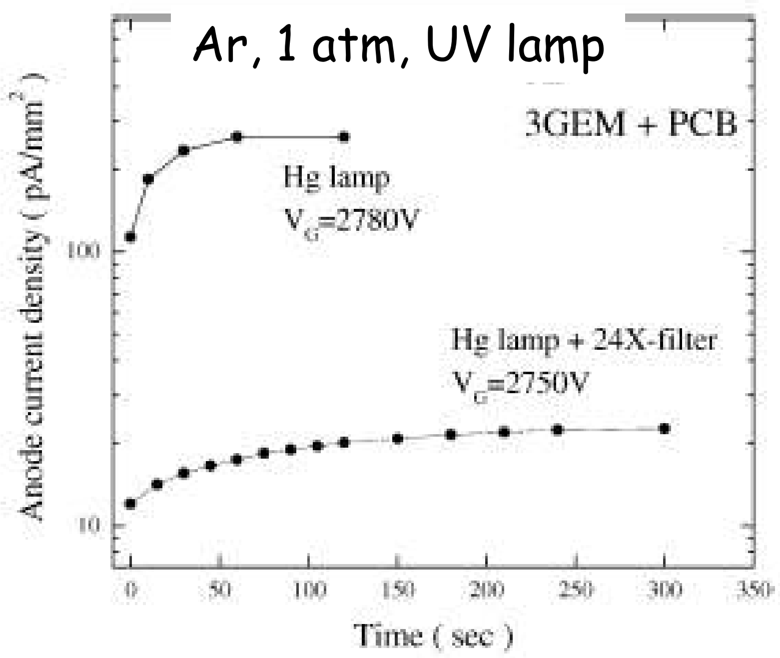


With mask, Eltos, Italy
Drill +etch w mask
Large rim

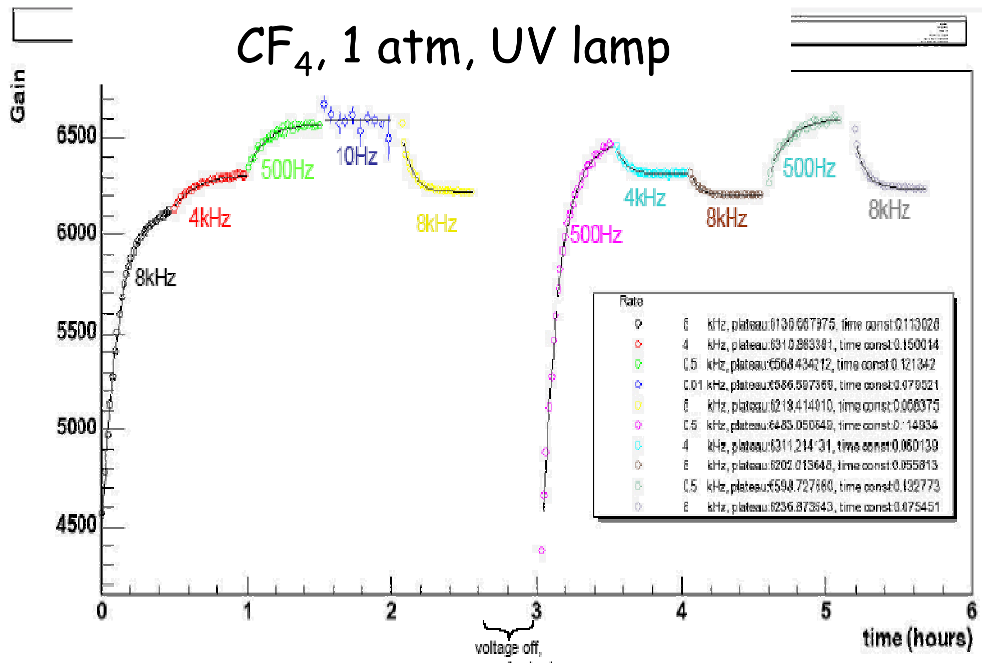


CERN, Zero rim: drill + short etching
to remove sharp edges from drilling.

Similar up charging observed in 3-GEM stabilization time 0.5-3 hour

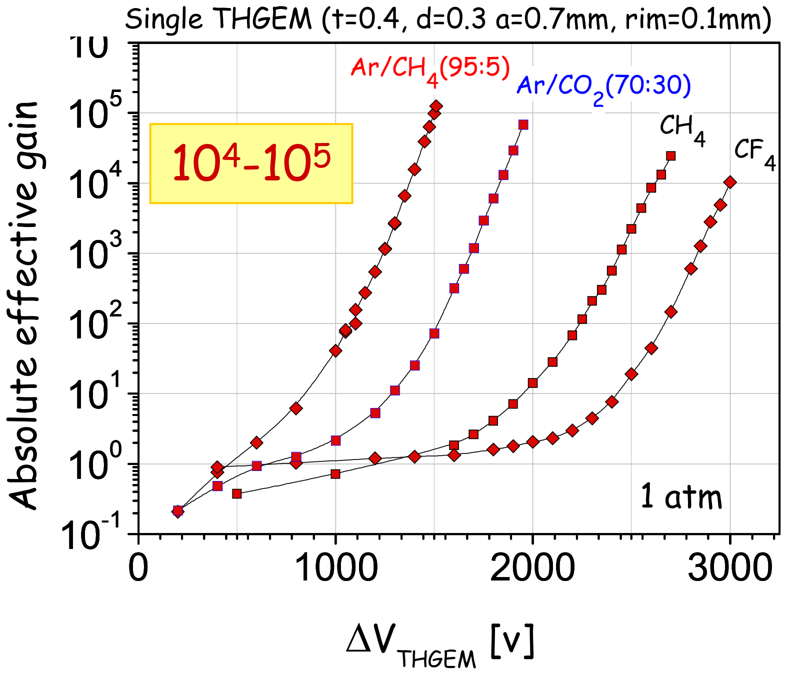


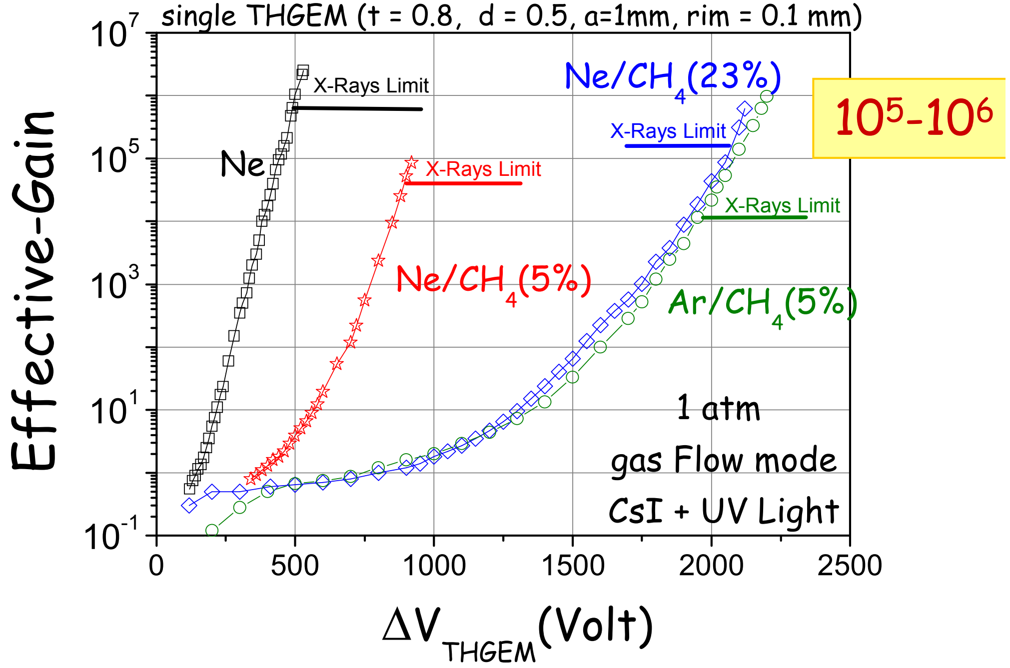
Buzulutskov et al. NIM A442 (2000) 68



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

THGEM operation - single THGEM





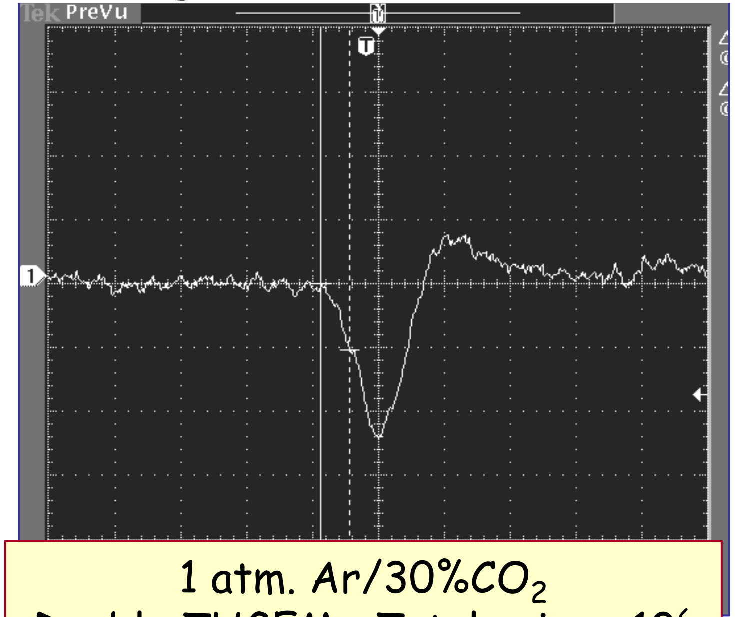
x100 higher gain
compared to single GEM

★ Very high gain in 100% Ne
and Ne mixtures
At very low voltages ☺ !!
100% Ne: Gain 10^5 @ <500V
Lose advantage w increased CH_4 %

THGEM operation - counting rate

w/single photoelectrons

Fast signals (rise time < 10 ns)



1 atm. $Ar/30\%CO_2$
Double THGEM Total gain=~ 10^6

Rate capability = $10 MHz/mm^2$
@ GAIN ~10^4 Ar/CH_4 (1 atm)