THGEM "news"

Mostly Ne-mixtures…

Amos Breskin

Weizmann Institute of Science

Work within CERN-RD51

Weizmann

M. Cortesi, J. Miyamoto, R. Chechik, A. Layshenko

CERN

V. Peskov

Coimbra & Aveiro

J. Veloso, C. Azevedo, J. Escada, J. dos Santos, J. Maia

PTB

V. Dangendorf

Nantes

D. Thers, S. Duval

Milan

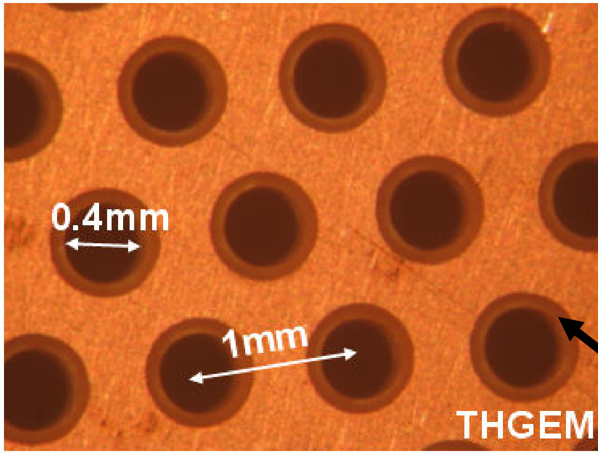
G.Bartesaghi

THGEM Recent review
NIM A **598** (2009) 107

Thick Gas Electron Multiplier (THGEM)

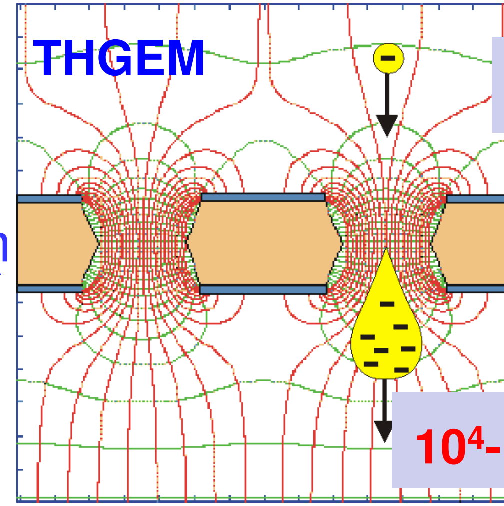
~ 10-fold expanded GEM

Weizmann 2003



small rim prevents discharges

Thickness 0.5-1mm



Double-THGEM: 10-100 higher gains

SIMPLE, ROBUST, LARGE-AREA
Printed-circuit technology

→Intensive R&D
→Many applications

Effective single-electron detection
Few-ns RMS time resolution
Sub-mm position resolution
MHz/mm^2 rate capability
Cryogenic operation: OK
Gas: molecular and noble gases
Pressure: 1mbar - few bar

Similar hole-multipliers:
- Optimized GEM: L. Periale et al., NIM A478 (2002) 377.
- LEM: P. Jeanneret, PhD thesis, 2001.

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Ne-based mixtures

Comparatively low operation voltages

➔ reduced discharge probability, discharge energy and charging-up effects

High gains, even with single-THGEM

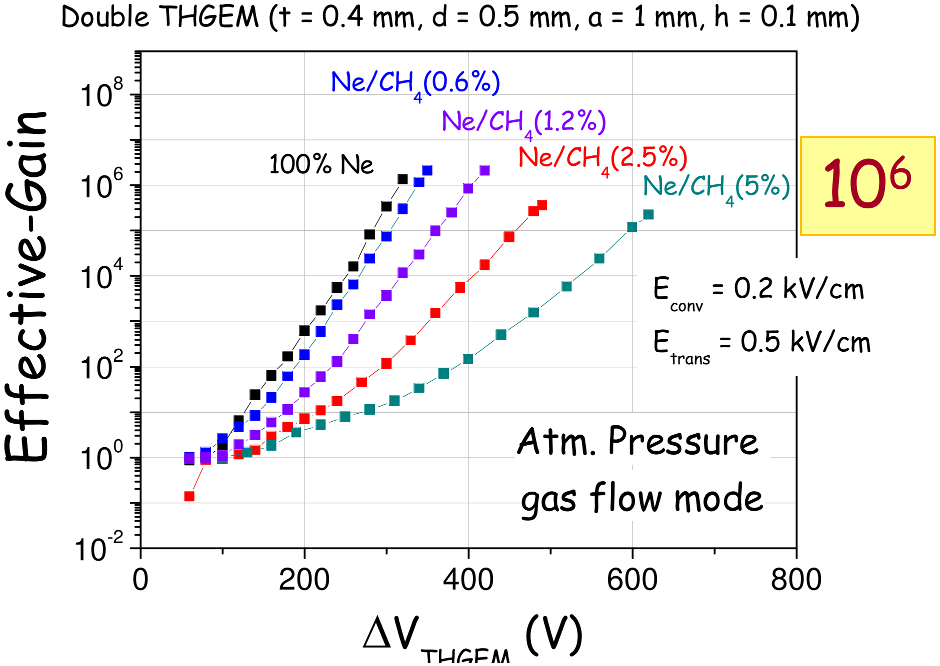
High single-photoelectron gains even in the presence of ionizing background (**higher dynamic range compared to Ar-mixtures**)

Important for RICH: Ne yields ~2.5 fold less MIP-induced electrons than Ar

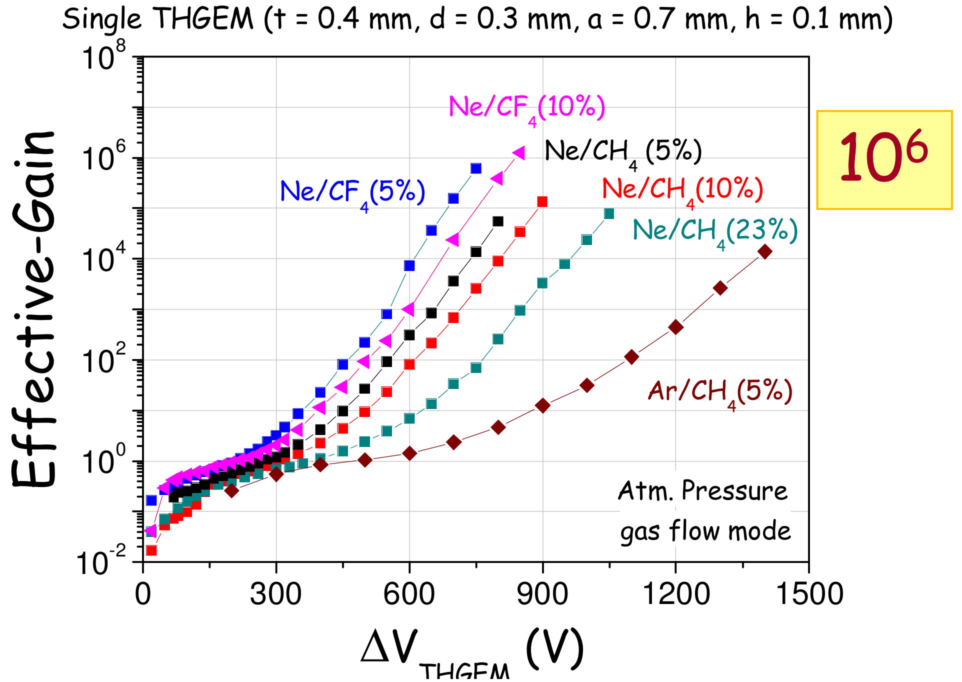
Photon detection efficiency?

Gain: Single/Double THGEM in Ne-mixtures

Double-THGEM
9 keV X-rays



Single-THGEM
CsI PC + UV-light (180 nm)



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**

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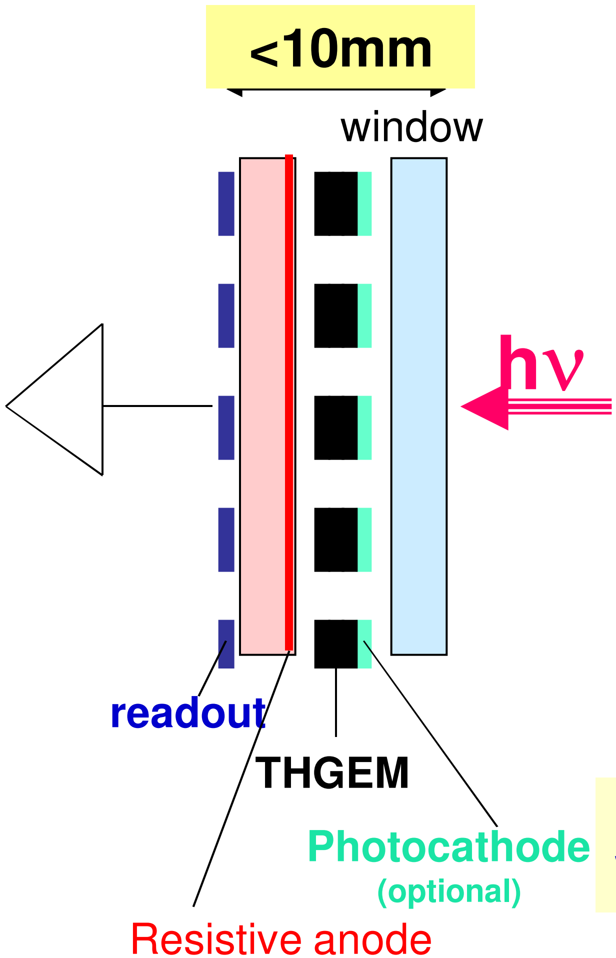
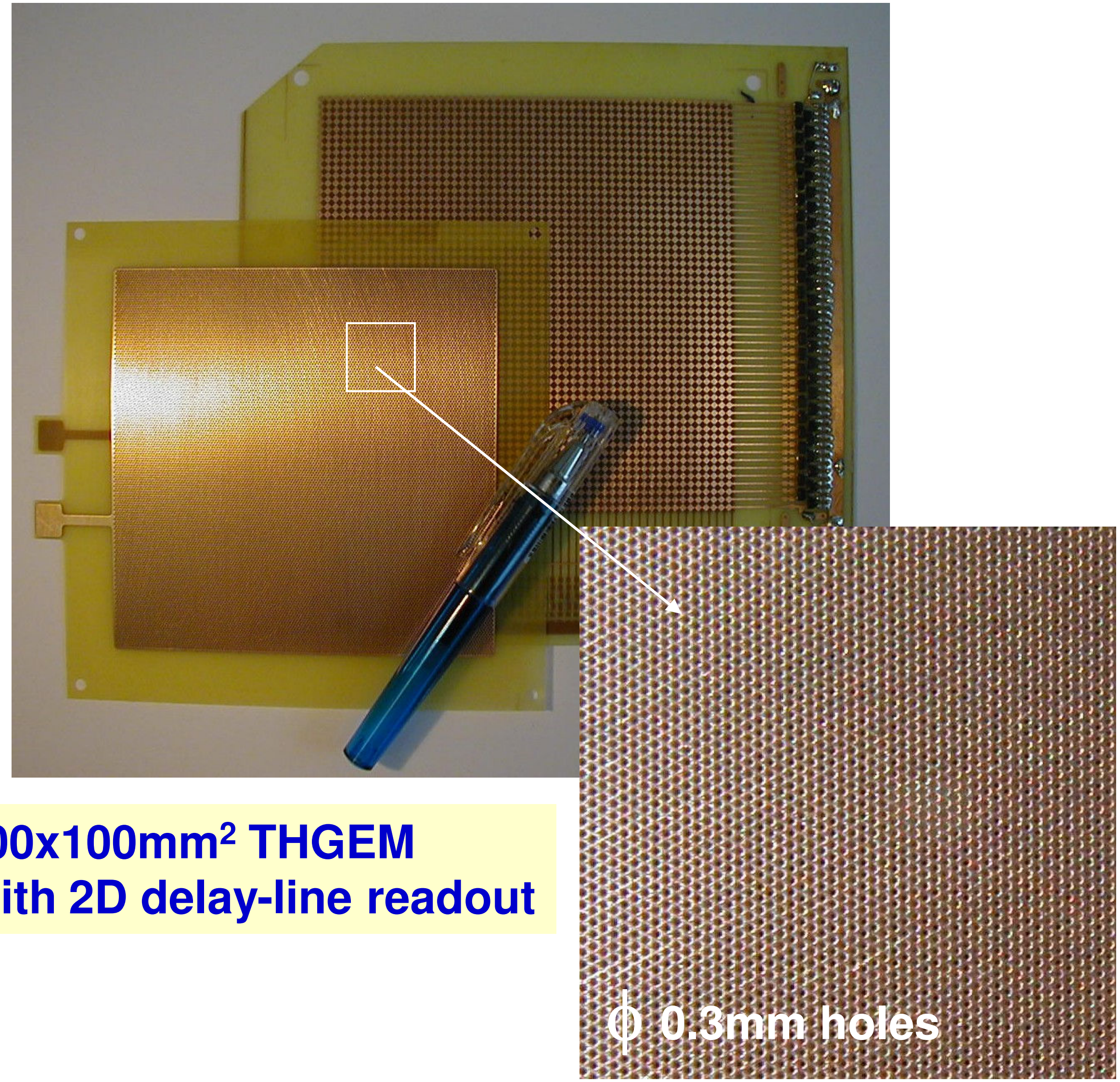
A VERY FLAT IMAGING DETECTOR

Cortesi et al. 2007_JINST_2_P09002





100x100mm^2 THGEM
With 2D delay-line readout

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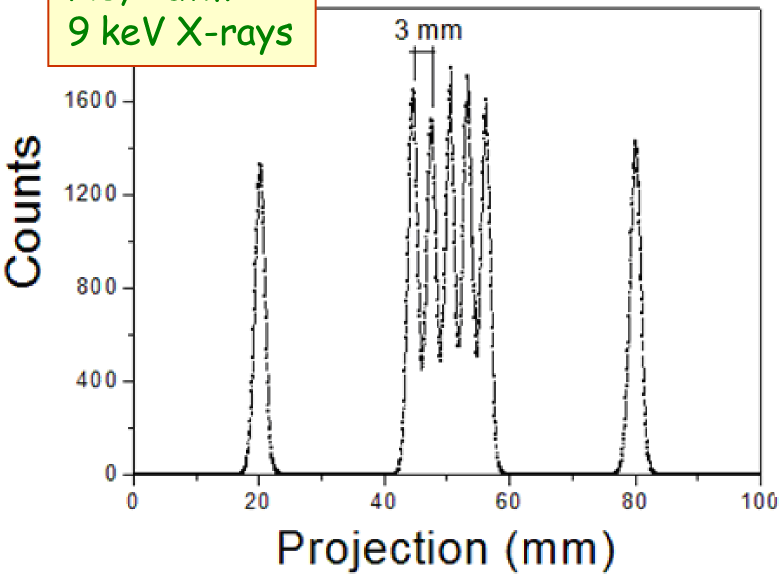
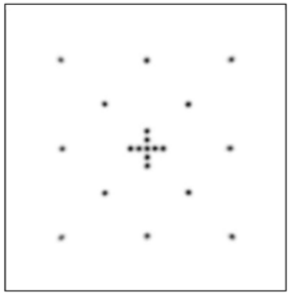
2D imaging: results with soft X-rays

100x100 mm^2 double-THGEM

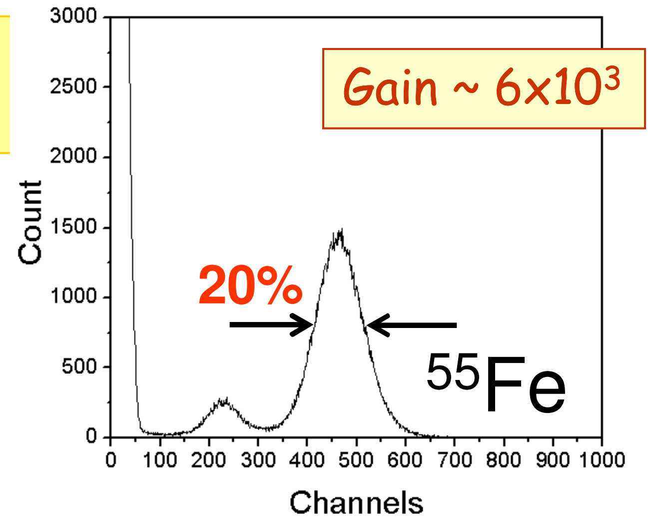
Gain uniformity
± 10%

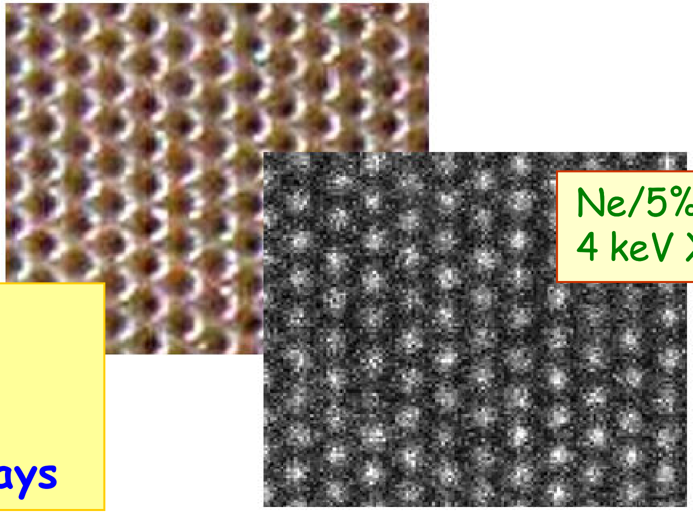
Ne, 1 atm
9 keV X-rays





Gain ~ $6x10^3$





Ne/5%CH_4, 1 atm
4 keV X-rays

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**

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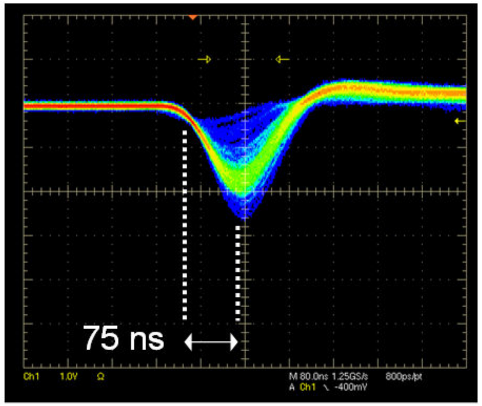
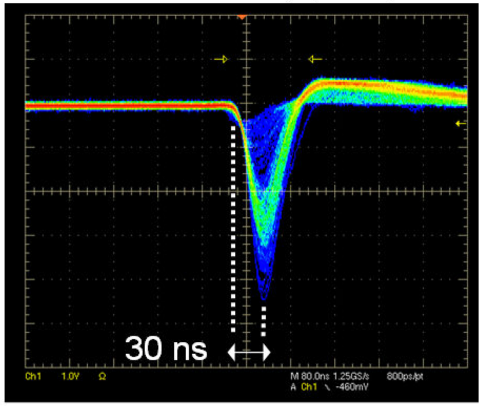
THGEM/Ne-mixtures: Pulse shape

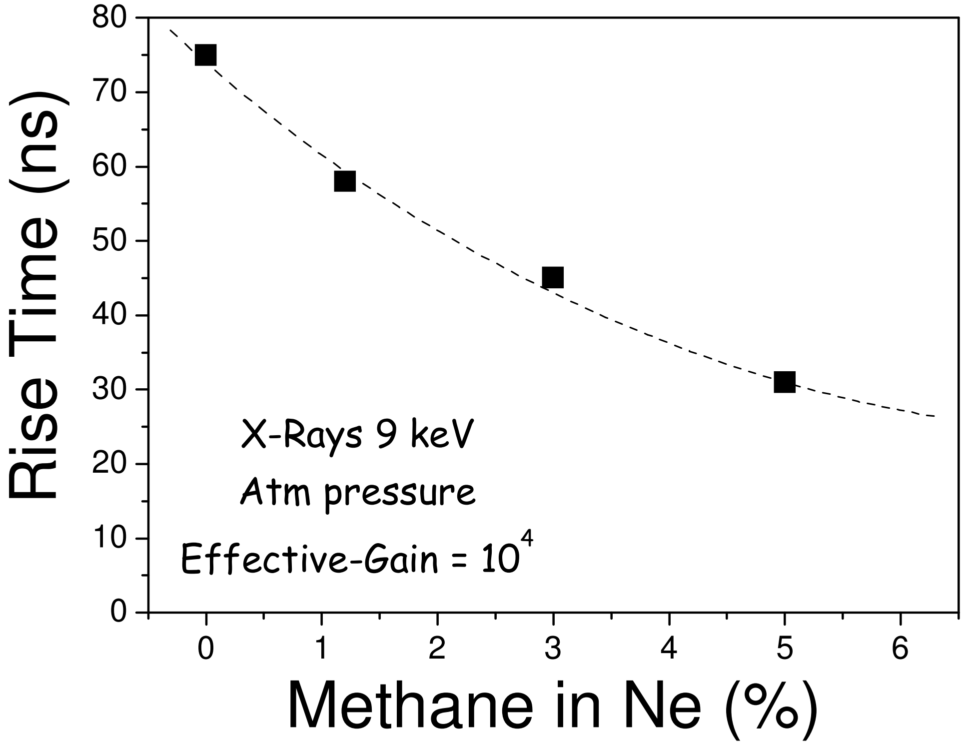
THGEM signals w fast amp

Ne



Ne/CH_4 (5%)





Increasing %CH_4 -> higher voltages & faster avalanches

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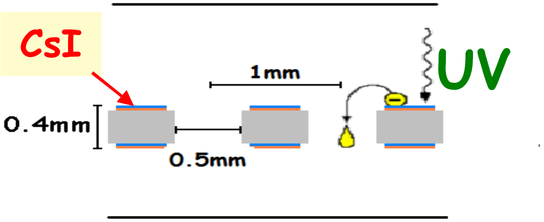
Long-Term Stability

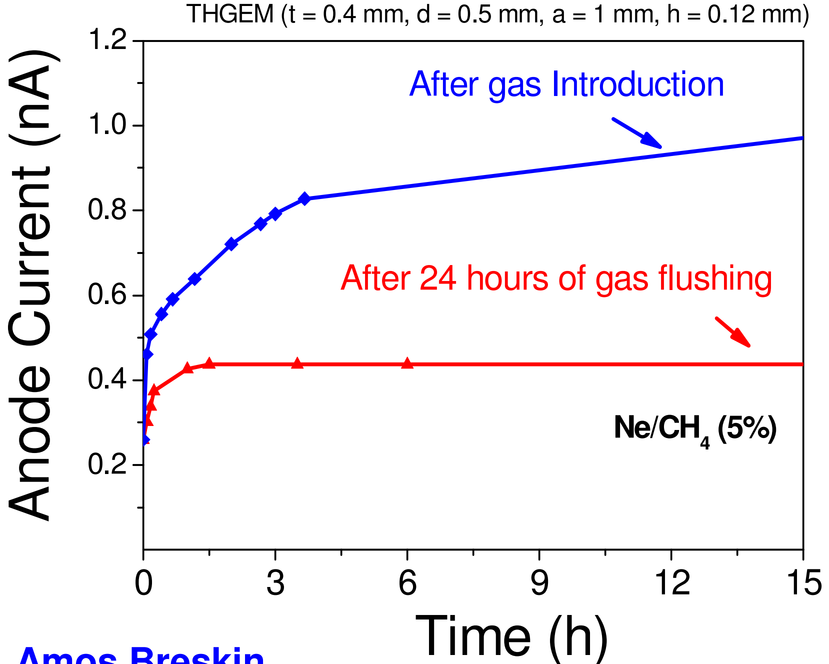
- Gain stability was previously measured (CERN, TRIESTE, WEIZMANN).
- Best stability (Trieste): Holes with no rim – but: no-rim resulted in 10-100 times lower gain
- Results (charging up, substrate polarization) are function of many parameters:

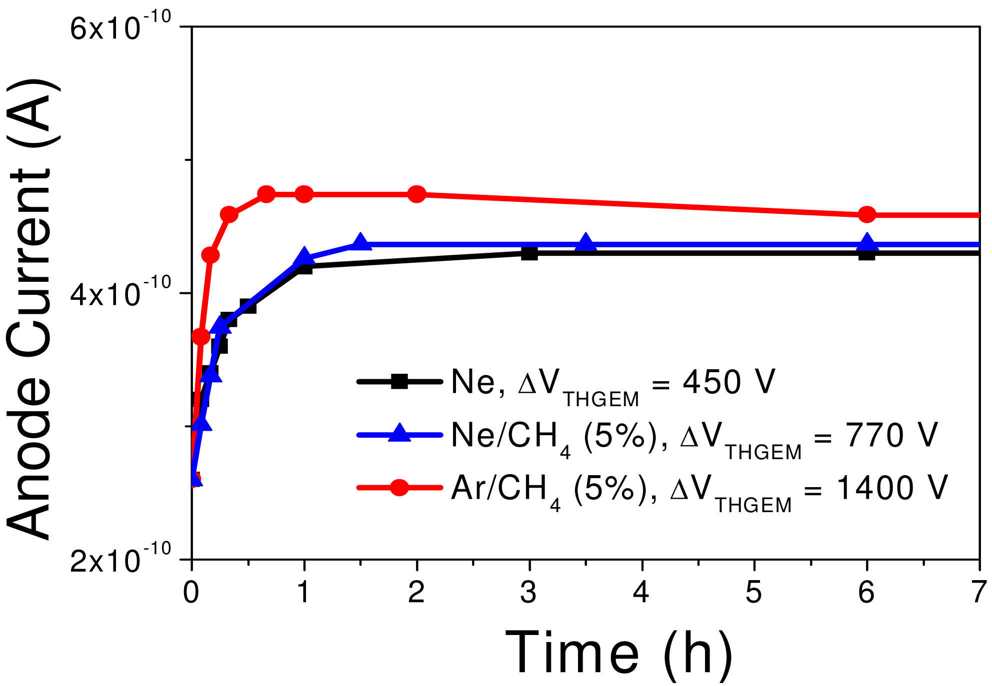
substrate material, rim size around hole, HV value, gain, radiation flux, surface resistivity (pumping prior to gas flushing and duration of flushing)…etc

- Results are not "dramatic" but **require further detailed studies**.



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





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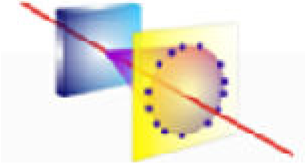
UV-photon detectors

RICH



Noble-liquids

RICH needs:
high efficiency for photons
low sensitivity to MIPs & background
Stability (CsI, gain)
low discharge rate

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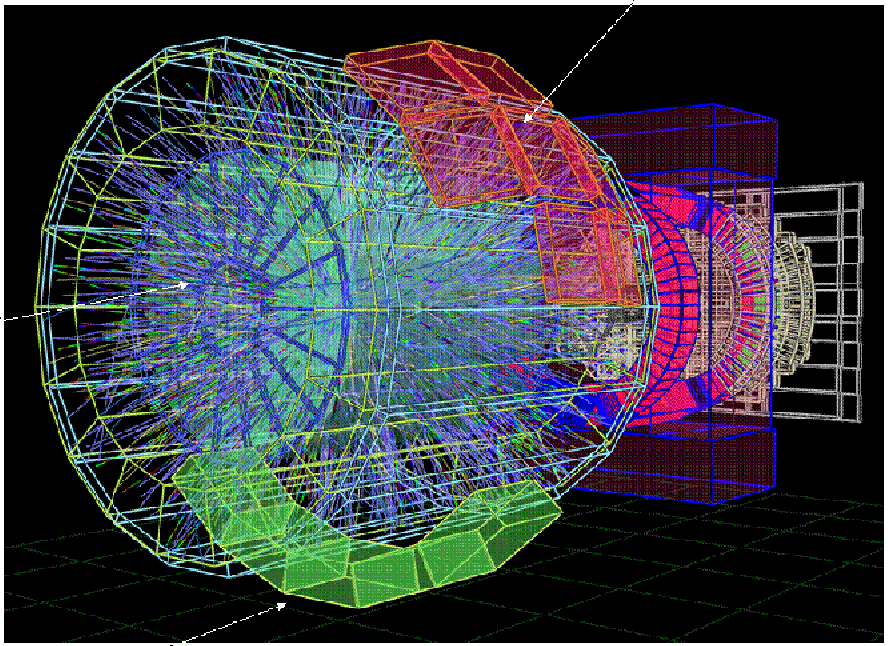
R&D activity for upgrades of ALICE & COMPASS RICH

EXEMPLE: ALICE

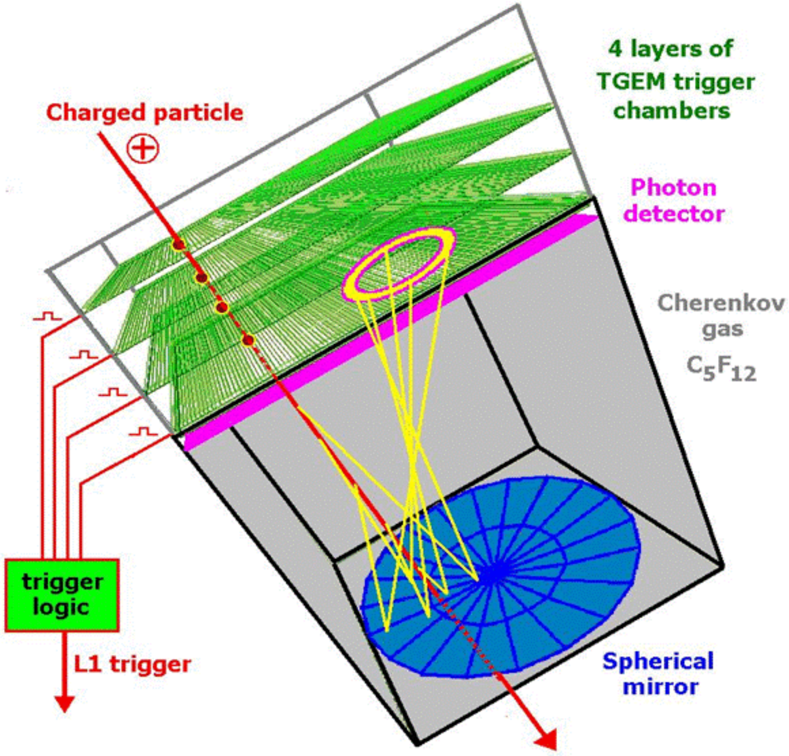
ALICE RICH modules

ALICE detector



Possible position of VHMPID modules

Very High Momentum Particle Identification Detector (VHMPID)



Recent beam-tests @ CERN of **THGEMS/CsI UV-RICH** proto
Martinengo/Peskov talk

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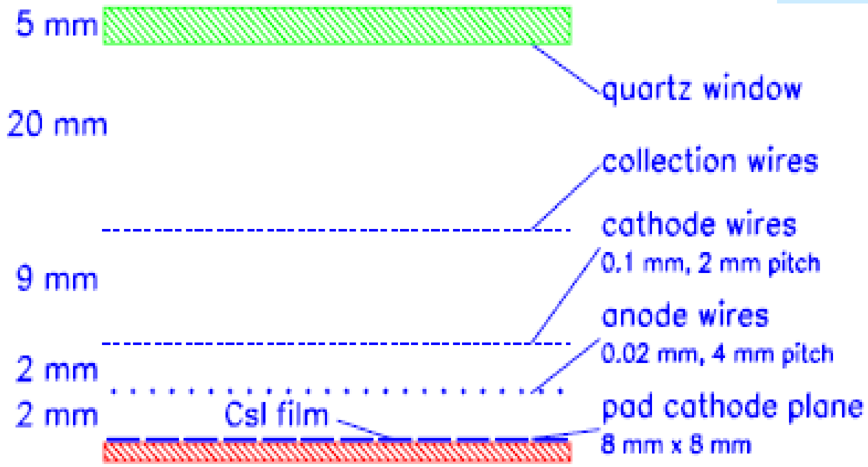
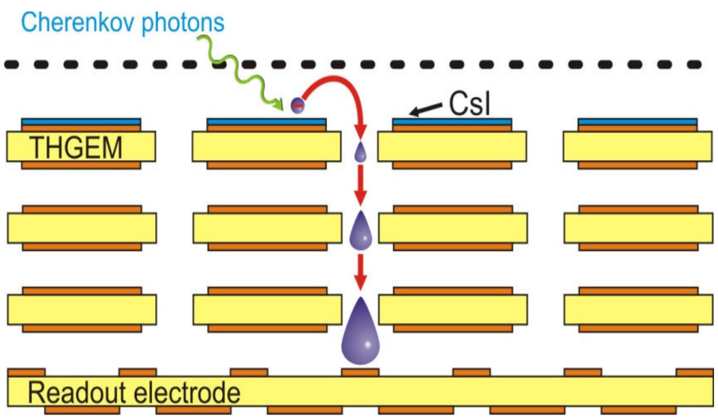
Two UV-photon options considered for ALICE & COMPASS RICH

MWPC **? ➔** **THGEM (RETGEM)**





Open geometry:
Photon & ion feedback
➔gain limit
➔PC aging
PC excitation effects
MIP sensitivity

Closed geometry:
No photon feedback
Reduced ion feedback
Reduced MIP sensitivity
➔high gains
➔Lower PC aging
More robust, simpler

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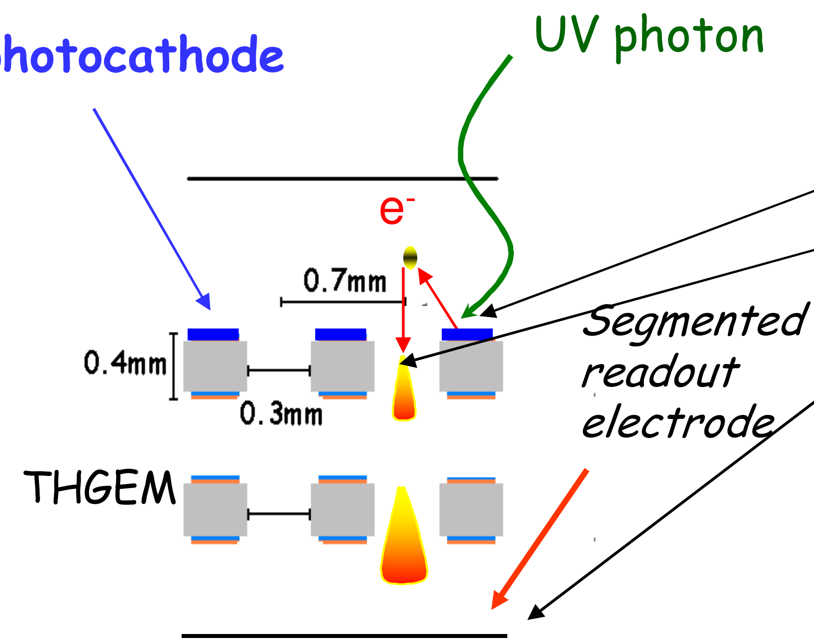
Double-THGEM photon-imaging detector ➔ RICH

Chechik NIM A553(2005)35



Reflective CsI PC on top of THGEM:

- Photoelectron extraction efficiency
- collection efficiency into holes

- Photon detection above threshold

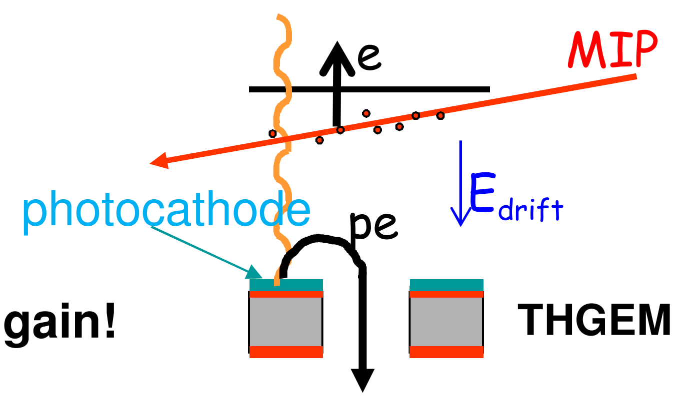
Unique:

Slightly **reversed E_{drift}** (50-100V/cm)

➔ Good photoelectron collection

➔ low sensitivity to MIPS **(~5%)**

➔ **background suppressing & higher gain!**



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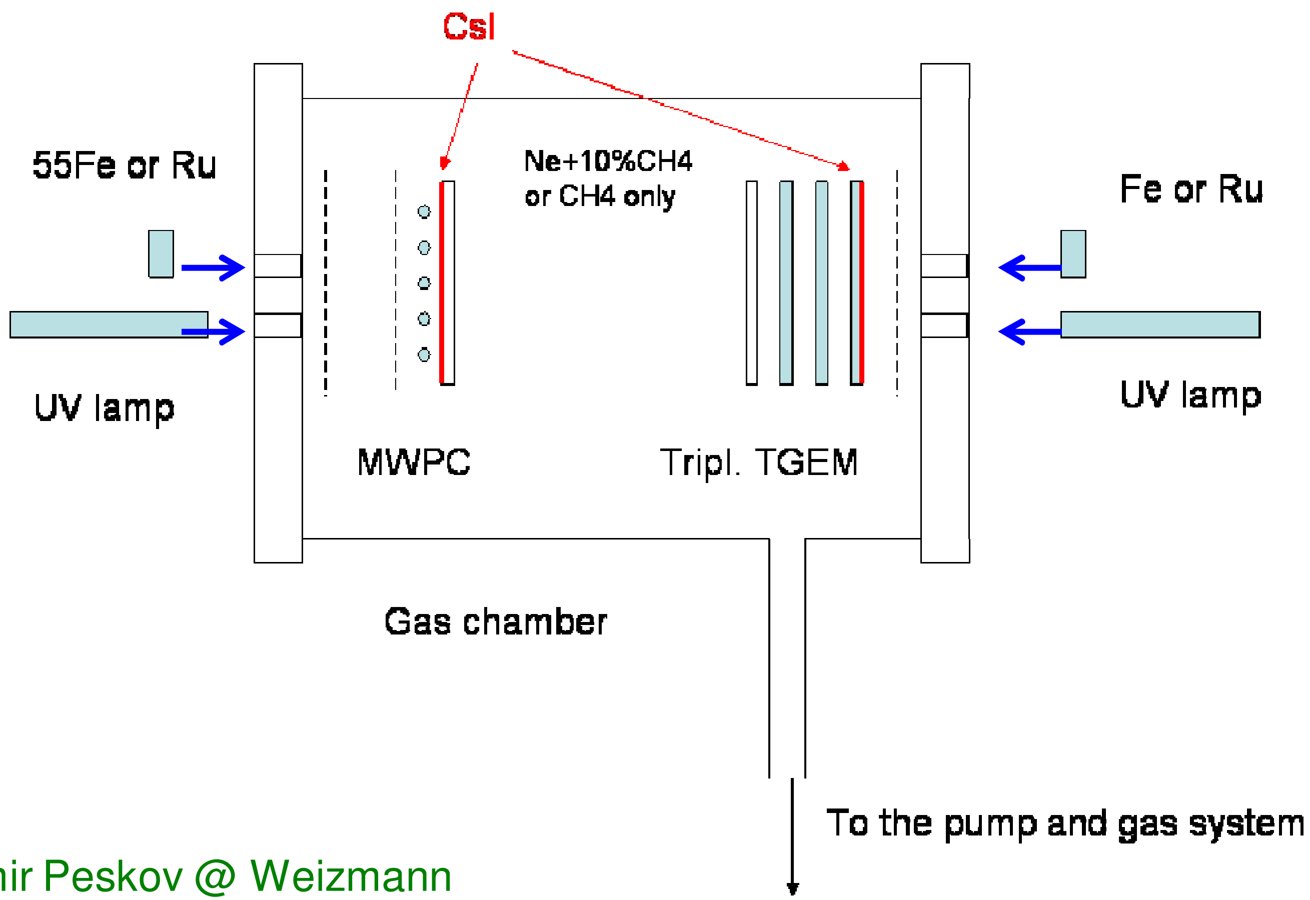
What should be compared?

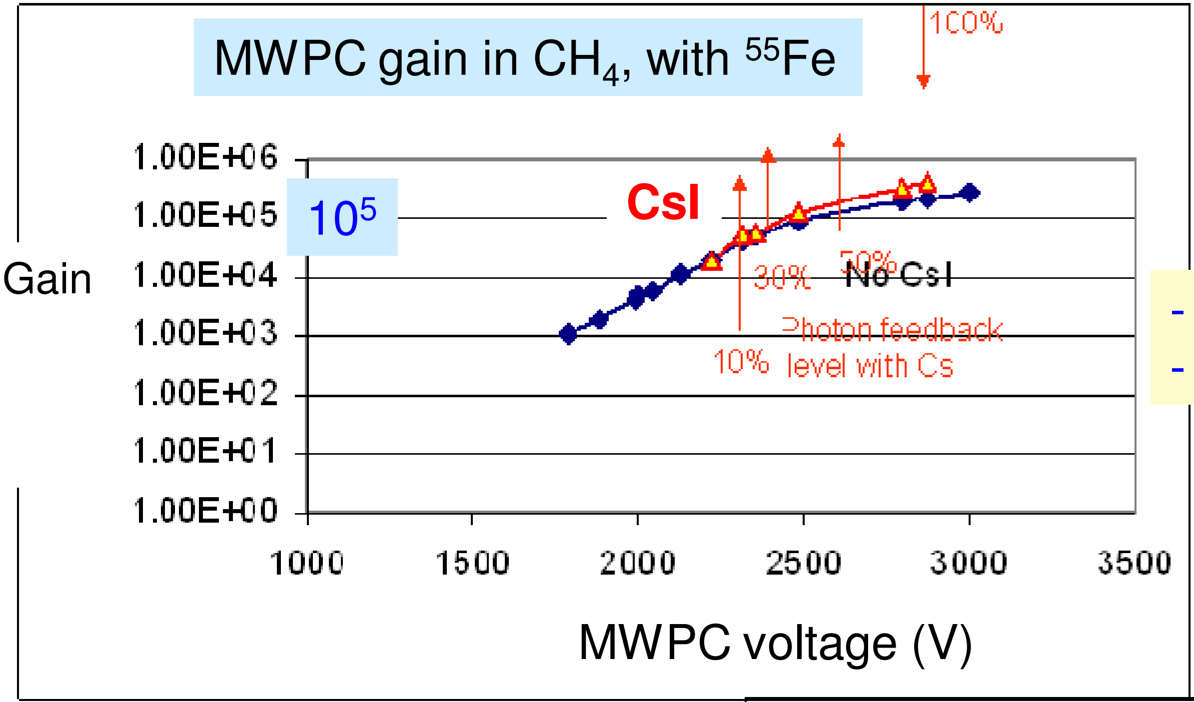
- Maximum gain before feedback (secondaries)
- Operation UV+ charged particle background (lab/beam)
- Stability
- Discharge limits (gain limit)
- Photon detection efficiency

Experimental setup



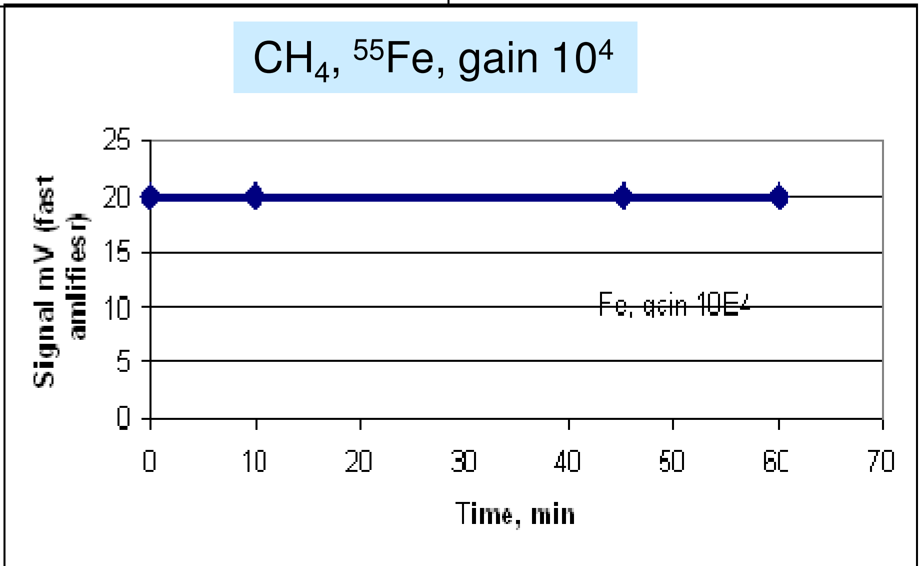
Vladimir Peskov @ Weizmann

MWPC: photon-feedback & gain stability



- No sparks in presence of Ru
- **Photon feedback >2x10^4**

Excellent short-term stability



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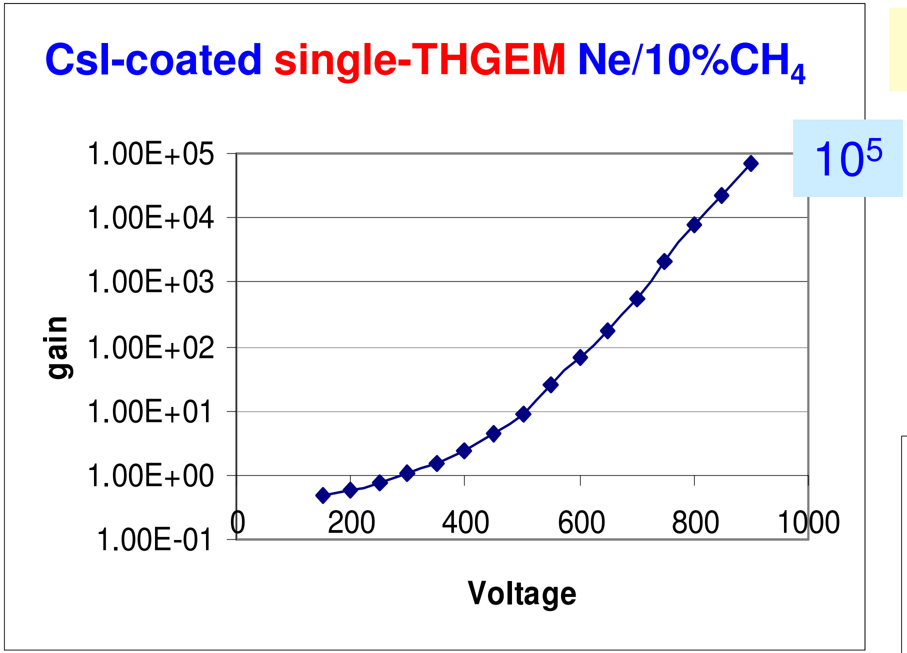
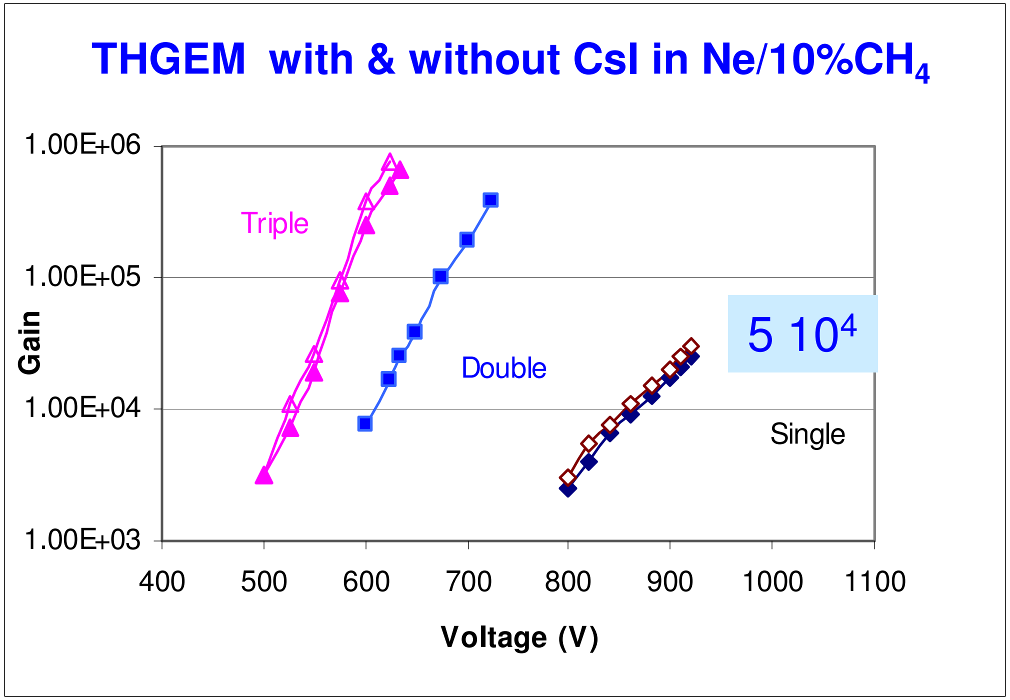
Gain of THGEMs



UV photons only



^{55}Fe+UV photons

with ^{55}Fe max gain slightly drops

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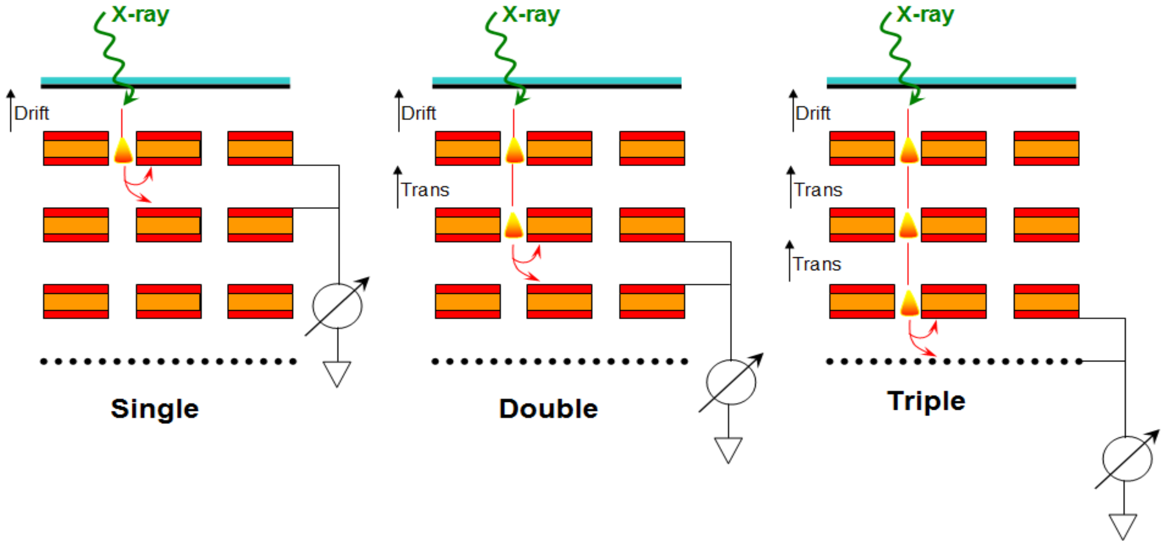
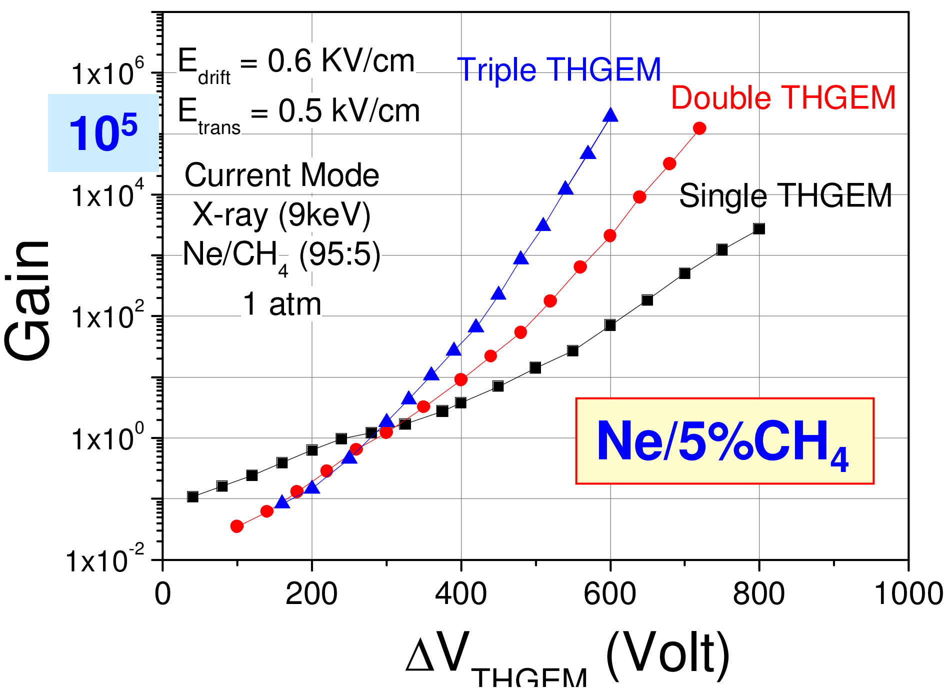
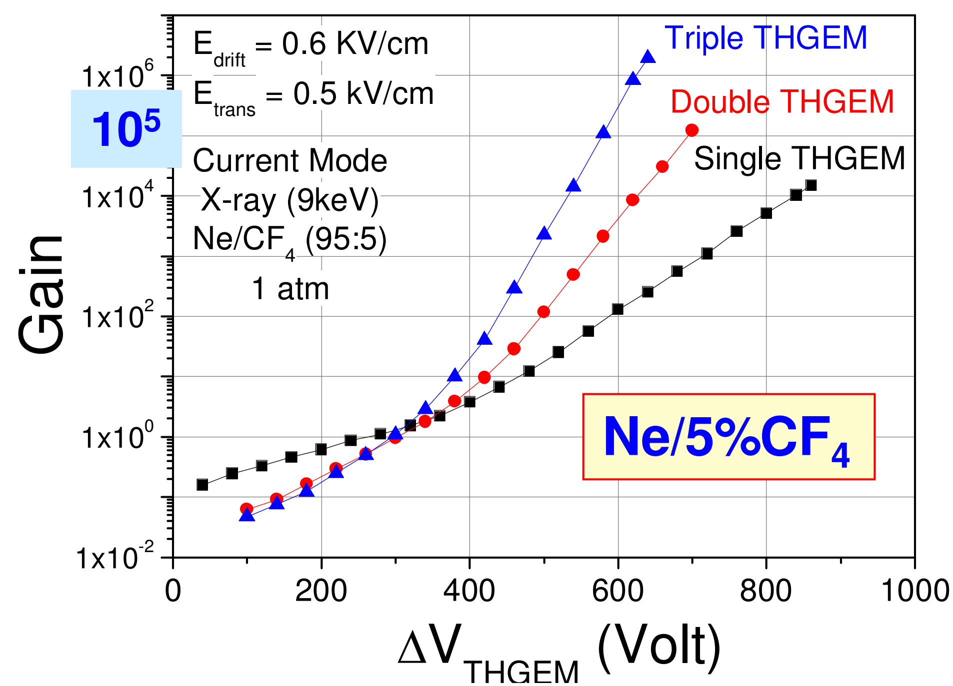
Gain in 1-, 2-, 3-THGEM



THGEM:
thickness t=0.4 mm, holes d=0.3 mm, rim h=0.1 mm, pitch a = 1 mm.
Conversion gap 10 mm , transfers and induction gaps 2 mm





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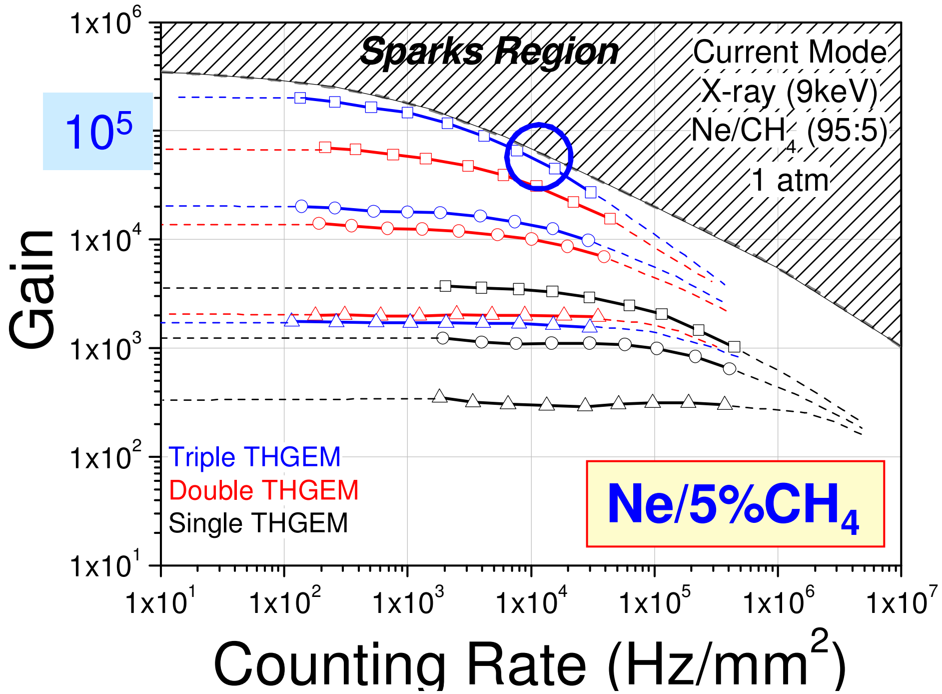
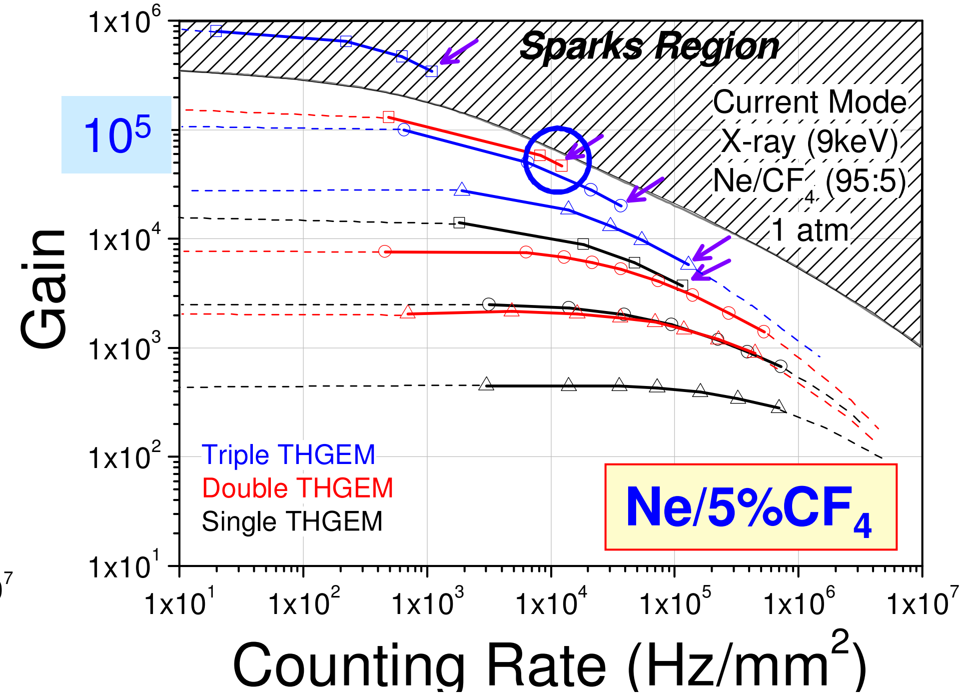
Similar HV for similar gains

1-, 2-, 3-THGEM:Gain limit vs rate: x-rays





MAX-gain decrease with rate observed, similarly to other gas-detectors ➔ Rather limit

In this geometry, with 3-THGEM:

Ne/5%CH_4 & Ne/5%CF_4 @ 10^4Hz/mm^2 (x-rays) ➔ max-gain of ~6×10^4

(~250 electrons)

➔ 1.5 x 10^7 electrons

10^5Hz/mm^2 UV photons ➔ 5 x 10^6 electrons (gain 5 x 10^6)

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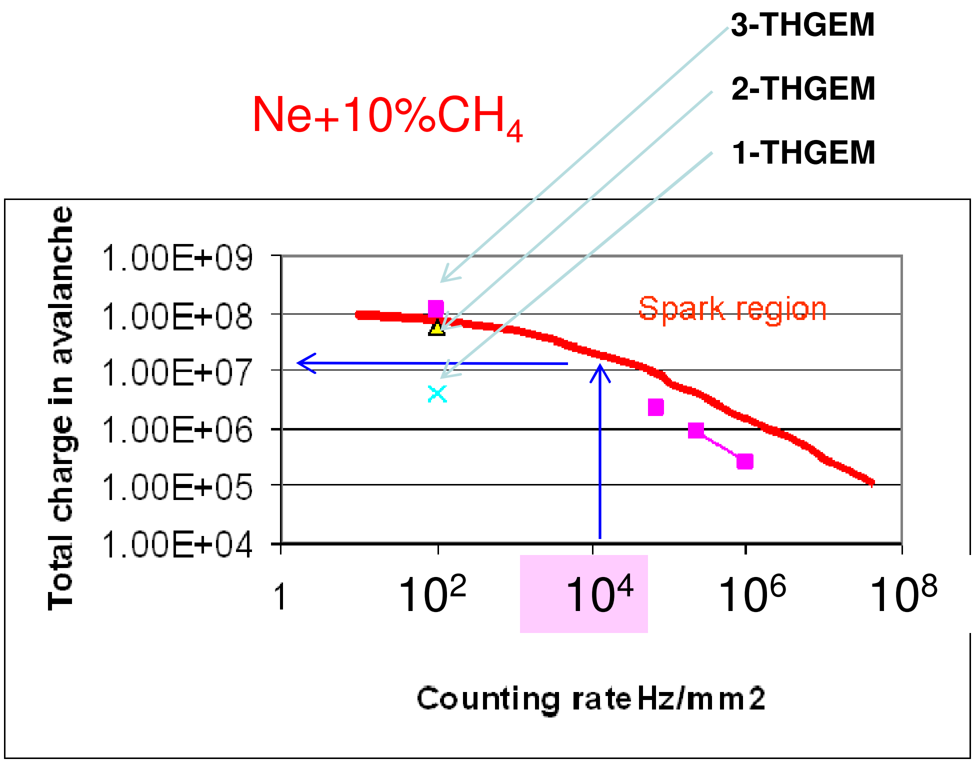
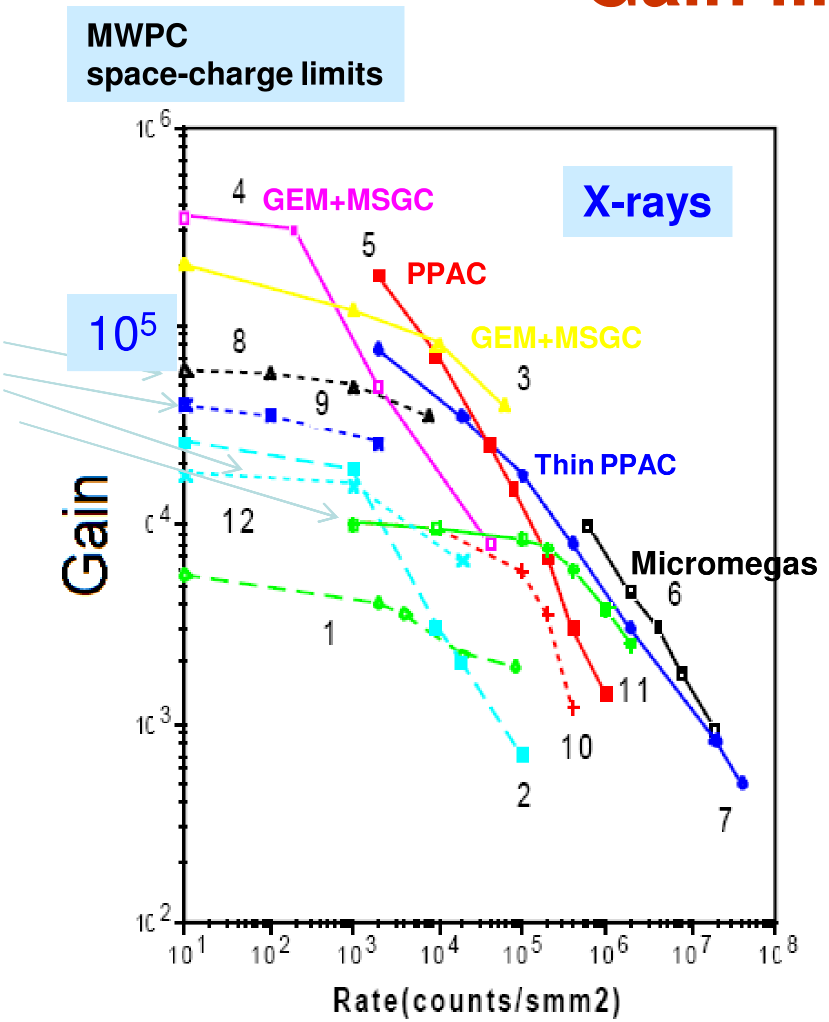
Results with CsI coated TGEMs



… qualitatively the same limit as with the uncoated THGEM

Gain limit vs rate



rate limits:

Local field distortion due to space charge
Charging up of insulating surfaces
Field emission from the cathode
Ejection of electron jets from cathode due to ion bombardments

➔ rate-limiting spark breakdown

The maximum achievable gain (curves 1-7), as a function of X-ray flux, for various detectors: 1) diamond-coated MSGC (1 mm pitch), 2) diamond-coated MSGC (1-mm pitch), 3) MSGC (2 mm pitch) combined with GEM, 4) MSGC (1 mm pitch) combined with GEM, 5) PPAC (3-mm gap), 6) MICROMEGAS, 7) thin gap (0.6mm) PPAC, 8-12) space-charge gain limit as a function of rate for the MWPC.

Fonte P., Peskov V. and Ramsey B.D., Which gaseous detector is the best at high rate? (http://www.slac.stanford.edu/pubs/icfa/summer98/paper2/paper2.pdf).

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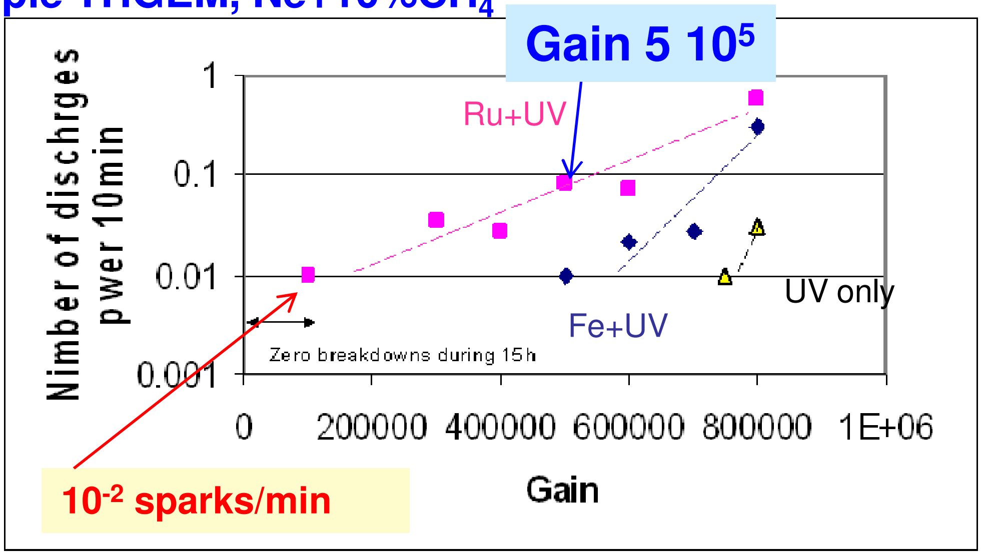
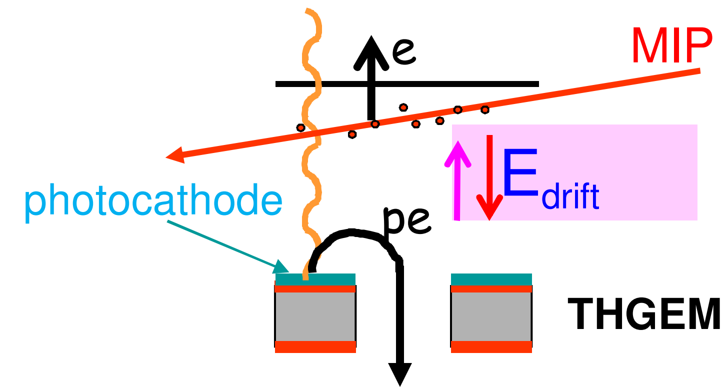
THGEM: Discharge rate

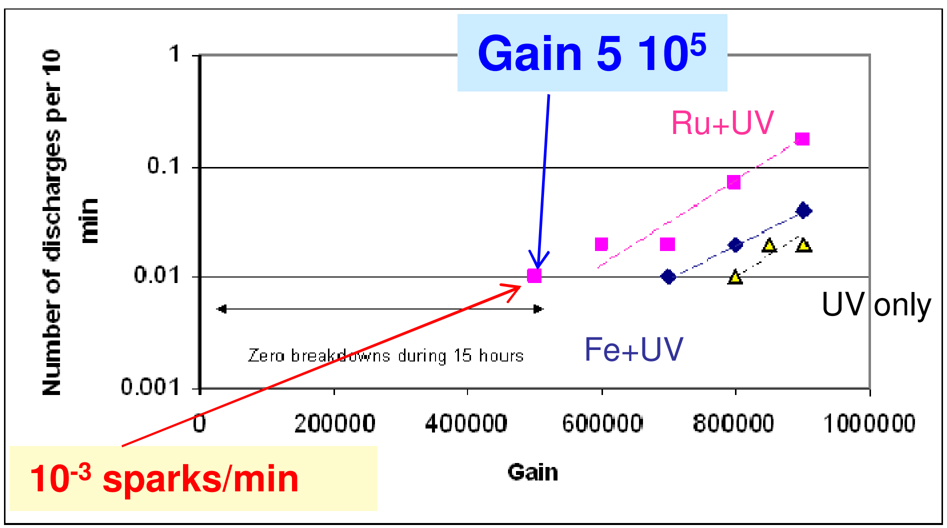
Triple THGEM, Ne+10%CH_4



Counting-RATES:
Ru ~100 Hz/ cm2
Fe ~10KHz/cm2

Normal drift field





Reversed drift filed

@ gain **5x10^5** the breakdown rate with **reversed drift** field is almost **10 times lower**
With ~same pe collection efficiency

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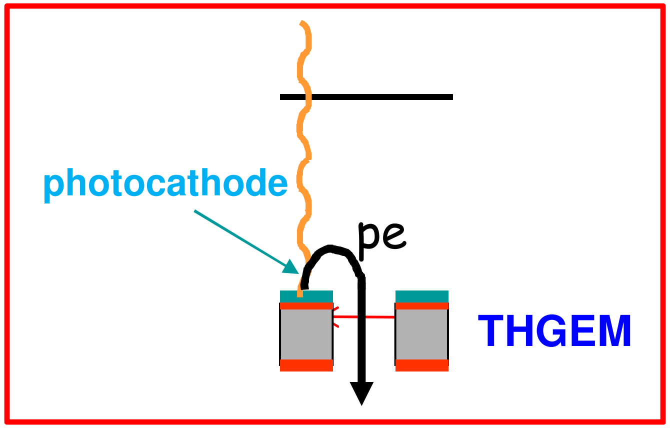
Photon detection efficiency

To prove that Ne-based mixtures can be beneficial for **RICH** ➔
R&D to demonstrate, as a first step, that in Ne-mixtures one can reach:

- good photoelectron **extraction** from CsI photocathode ε_{extr}

- good photoelectron **collection efficiency** ε_{coll}

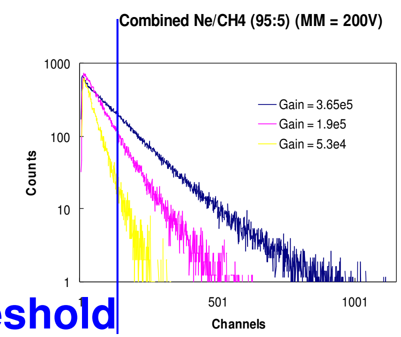


$$\varepsilon_{effph} = QE \times A_{eff} \times \varepsilon_{extr} \times \varepsilon_{coll}$$

QE in vacuum | Effective area | Extraction efficiency, Backscattering in gas | Collection into holes

- high gain: high electron **detection efficiency** above threshold ε_{photon}

$$\varepsilon_{photon} = \varepsilon_{effph} \times fp_{th}$$



threshold

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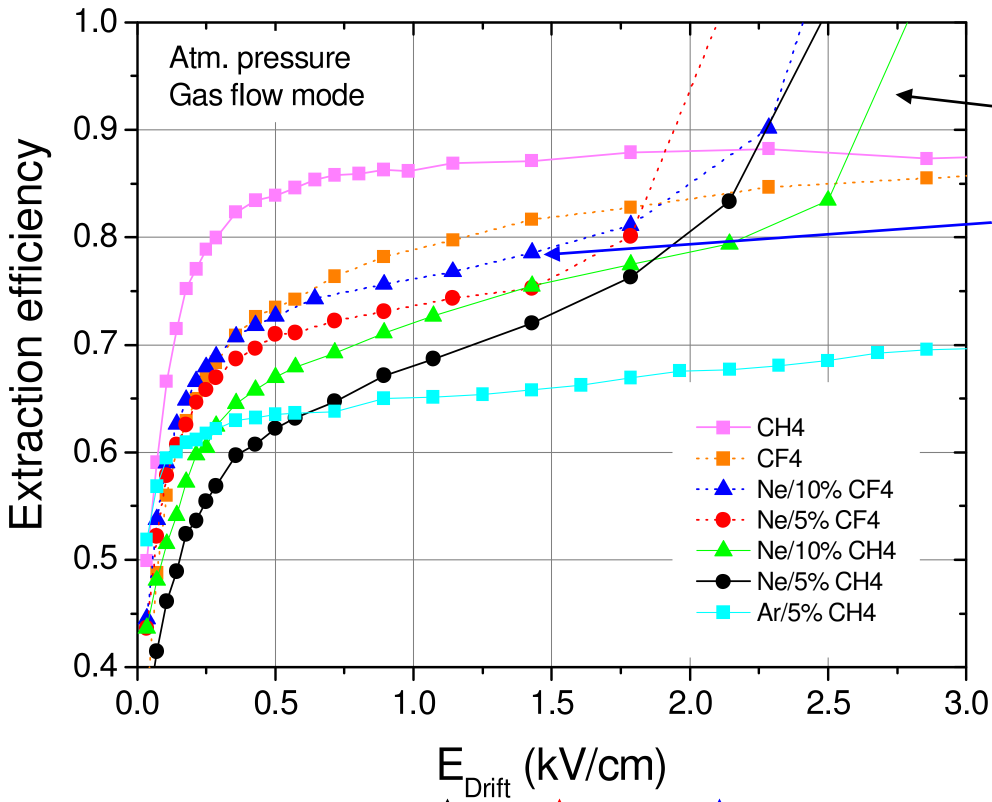
Photoelectron extraction from CsI

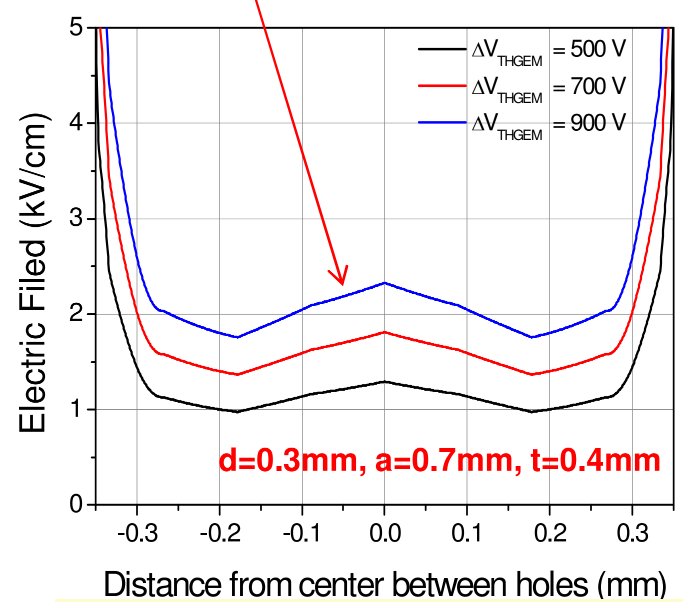


Azevedo et al. arXiv:0909.5357

feedback

$Ne/10\%CF_4$ ~as good as CF_4

e.g. value for **$Ne/10\%CF_4$**



Electric field at THGEM electrode surface

Thicker THGEM→ higher fields

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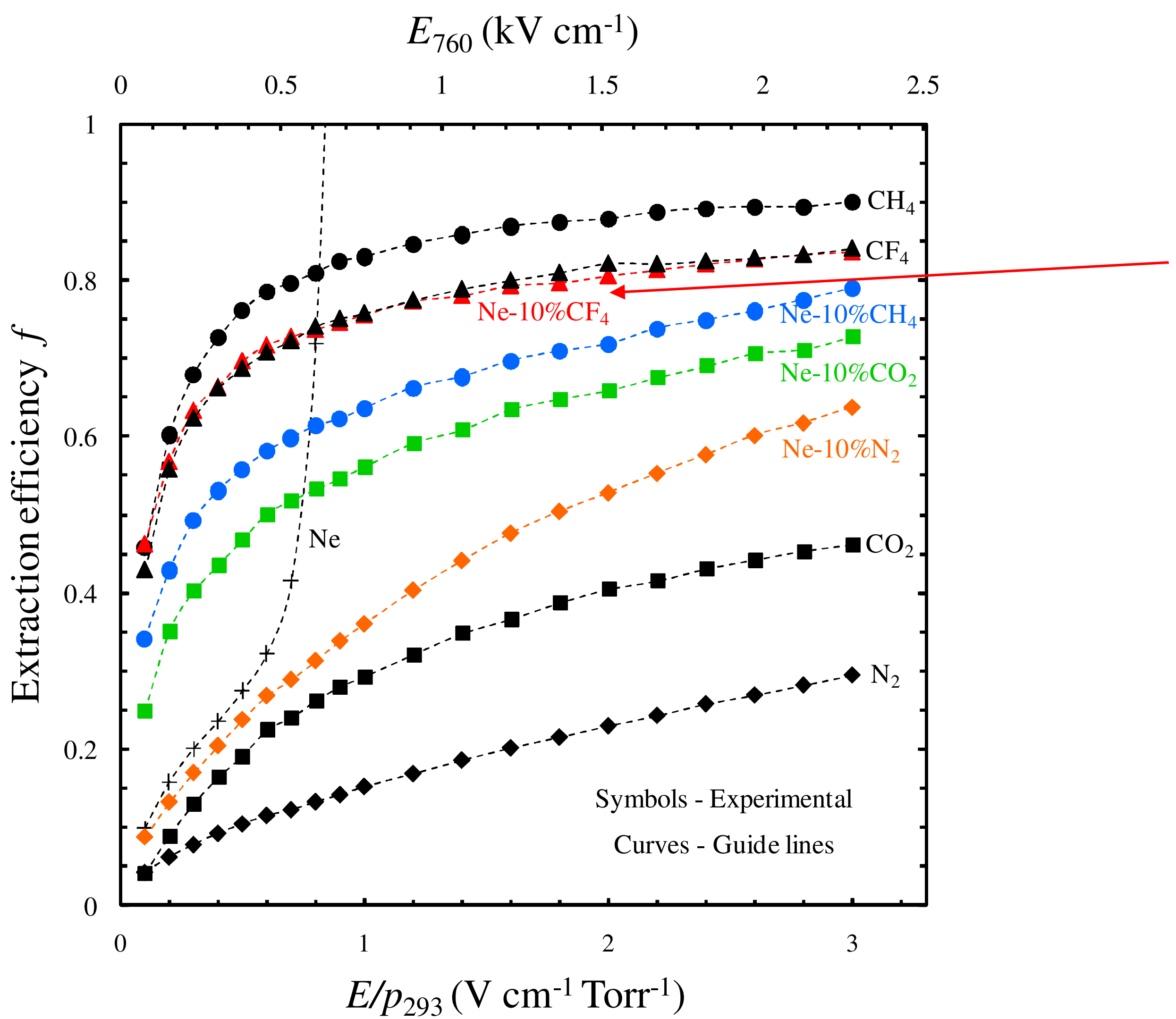
Extraction efficiency from CsI: simulations vs experiments

Escada et al. arXiv:0909.2965



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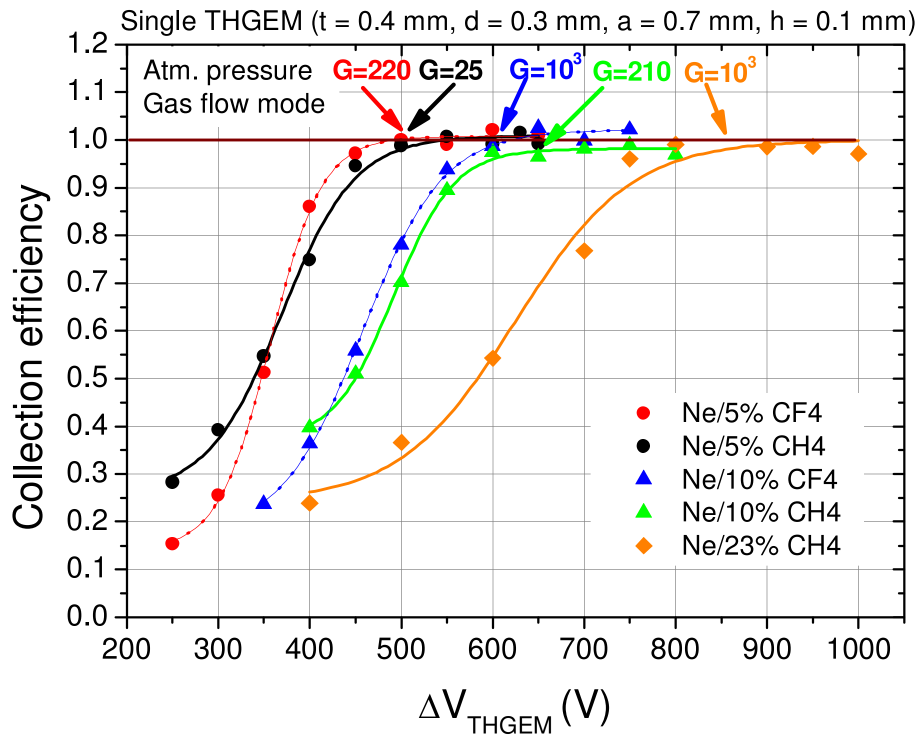
Photoelectron collection into THGEM holes

Azevedo et al. arXiv:0909.5357



Even at low gain ➔ 100% collection efficiency in Ne-mixtures

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Expected THGEM UV detector performance

Azevedo et al. arXiv:0909.5357

Gas	ΔV_{THGEM} *(V)*	*Gain (UV)*	*QE* *170nm*	A_{eff} This THGEM	A_{eff}[1] Optimal THGEM	ε_{extr}	ε_{coll}	ε_{effph} **This THGEM**	ε_{effph}[2] **Optimal THGEM**
Ne/CH_4(95/5)	800	5.4E4	0.3	0.54	0.91	0.73[2]	1	0.12	0.20
Ne/CH_4(90/10)	900	1.3E5	0.3	0.54	0.91	0.79[3]	1	0.13	0.22
Ne/CF_4(95/5)	750	6.0E5	0.3	0.54	0.91	0.76[3]	1	0.12	0.21
Ne/CF_4(90/10)	**850**	**1.2E6**	0.3	0.54	0.91	**0.83**[4]	1	**0.14**	**0.23**

@ 170nm

[1] Optimal THGEM: t = 0.4 mm , d = 0.3 mm, a = 1 mm; h = 0.01 mm,
[2] Value for 1.5 kV/cm photocathode electric field
[3] Values for 2kV/cm photocathode electric field

$$\varepsilon_{photon} = \varepsilon_{effph} \times fp_{th}$$ → **expected ~0.2 for fp_{th}~0.9**

Wire chamber: ***fp_{th}*~0.65** in COMPASS (in beam)
***ε_{effph}* ~0.2 @170nm**

[Silvia]

Need RICH-THGEM-proto beam studies to determine ε_{photon}

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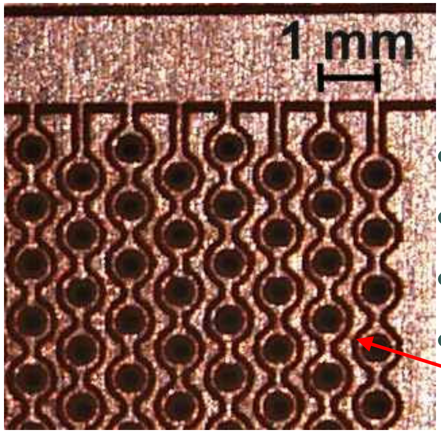
THCOBRA: a patterned THGEM for ion blocking

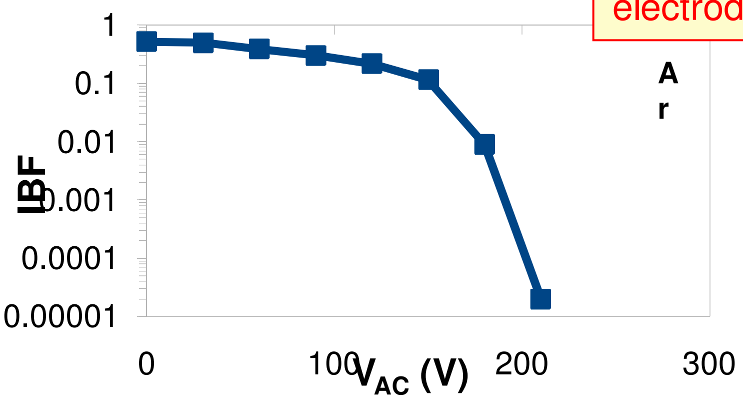
Azevedo et al. Aveiro/Coimbra/Weizmann

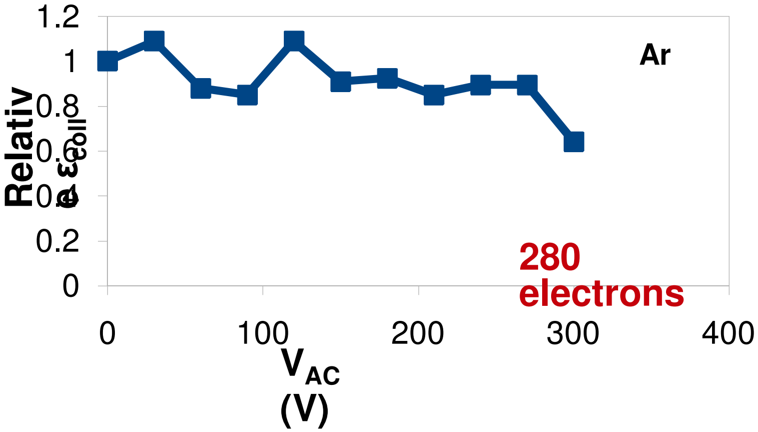
Ion reduction:
less feedback, less PC aging

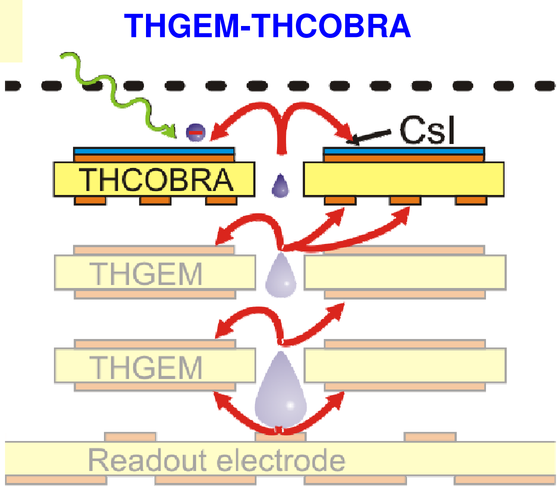


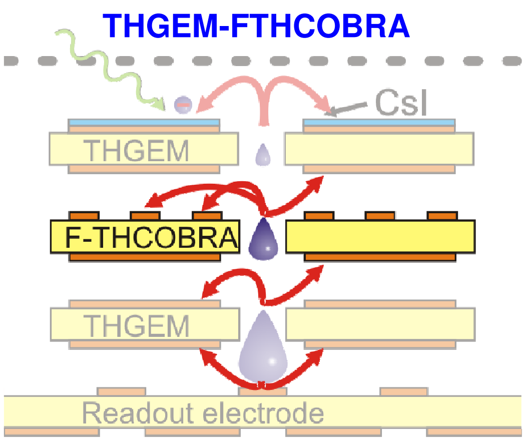
- Pitch = 1 mm
- Hole diameter = 0.3 mm
- Rim = 0.1 mm
- Thickness = 0.4 mm

Ion blocking electrodes







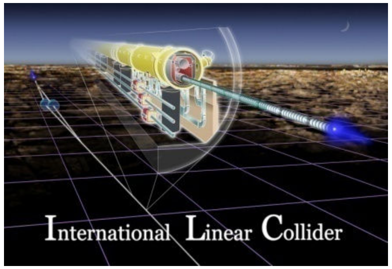


Need to block ions without loosing primary electrons/photoelectrons

Previous success: FRMHSP/GEM/MHSP
Ion blocking factor10^4 & full electron collection

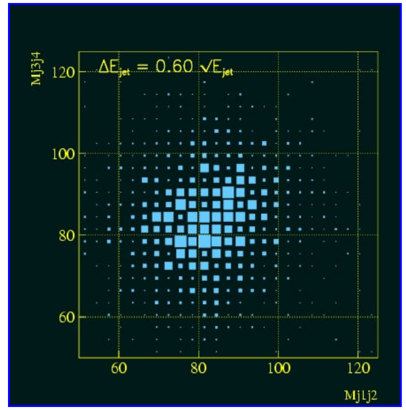
Other THGEM applications

THGEM-based Digital Hadron Calorimetry



Precision studies of new physics

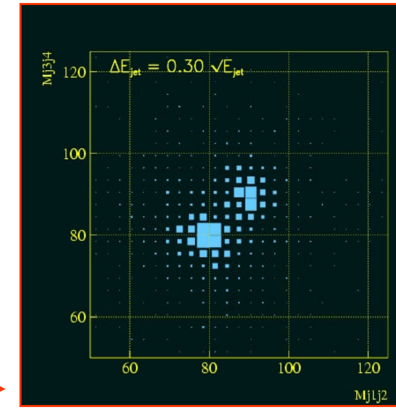
ILC: Separate W,Z boson masses on event-by event basis



60%/√E

Best JET resolution with traditional calorimetry

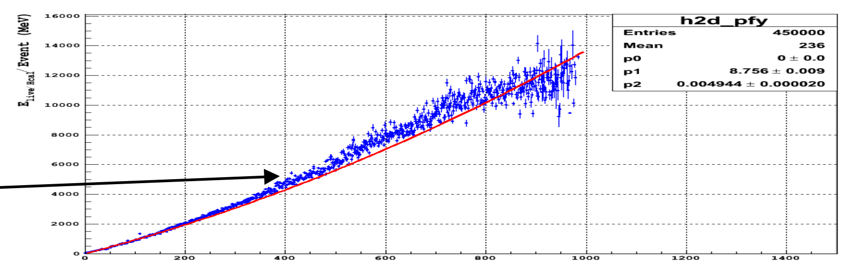
Need 30%/√E



Generally need σ/E_{jet} ~3-4%

Digital calorimetry

associate "hits" with charged tracks, remove hits, measure neutrals in calorimeter using **hits vs. energy**



Particle Flow Algorithms now achieve the required energy resolution!

Implementation requires thin, efficient, highly segmented, compact, robust medium, hence attraction of using THGEM's.

(**competitors**: GEM, Micromegas, RPC)

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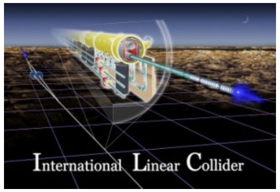
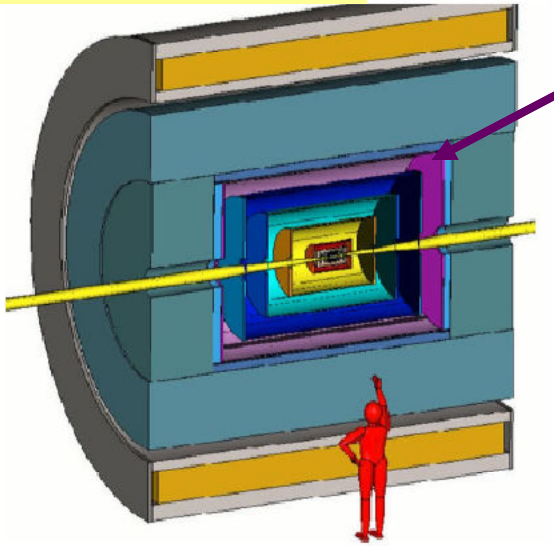
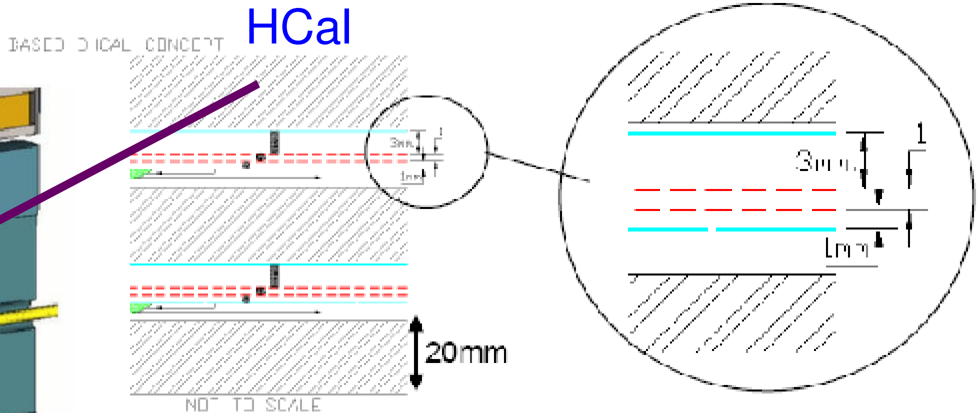
New concept: Digital Hadron Calorimetry for the ILC

UTA/Weizmann B**SF Grant w Andy White**



General detector scheme





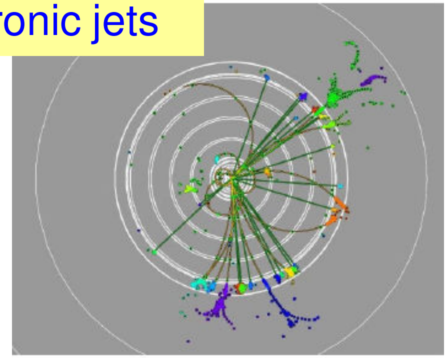
1m^2 in process:
GEMs ➔ THGEMs

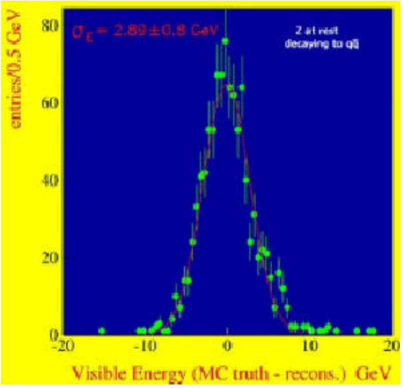
few-cm^2 cells

2 sampling layers (**out of 40**) with THGEM-based elements

Sampling jets + advanced pattern recognition algorithms
➔ Very **high-precision jet energy** measurement.

Simulated event w 2 hadronic jets





Reconstructed jet:
Simulated energy resolution
σ/E_{jet} ~ 3%
(CALICE)

THGEM advantage: simple, robust
Digital counting: possible gain fluctuations not important

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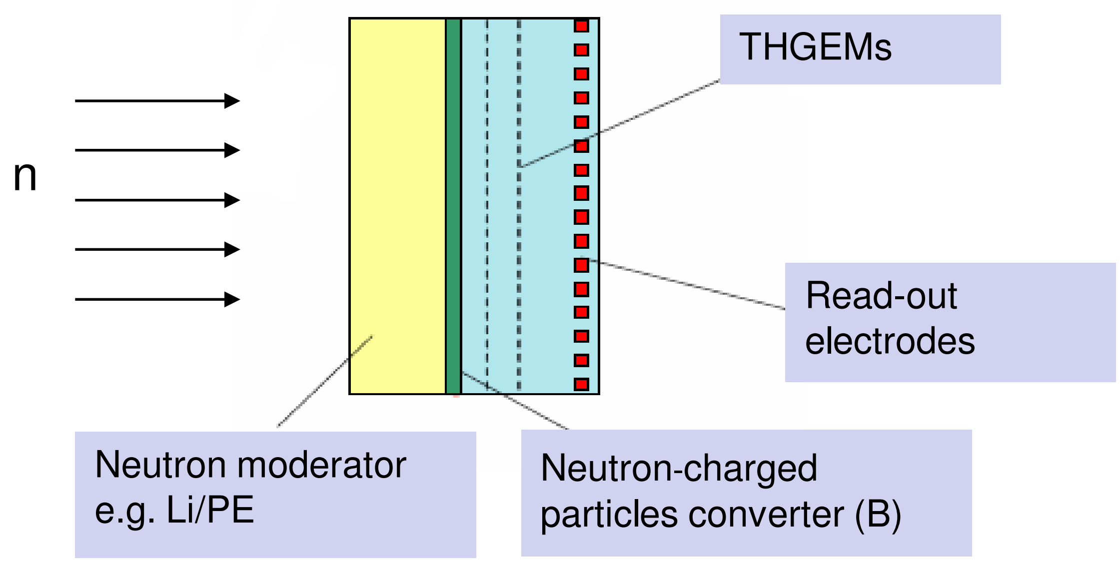
Position-Sensitive fast-n Dosimetry

PTB/MILANO/WEIZMANN/SOREQ

NEW CONCEPT: **moderator plates** of different thicknesses in front of a **position sensitive thermal neutron detector**.

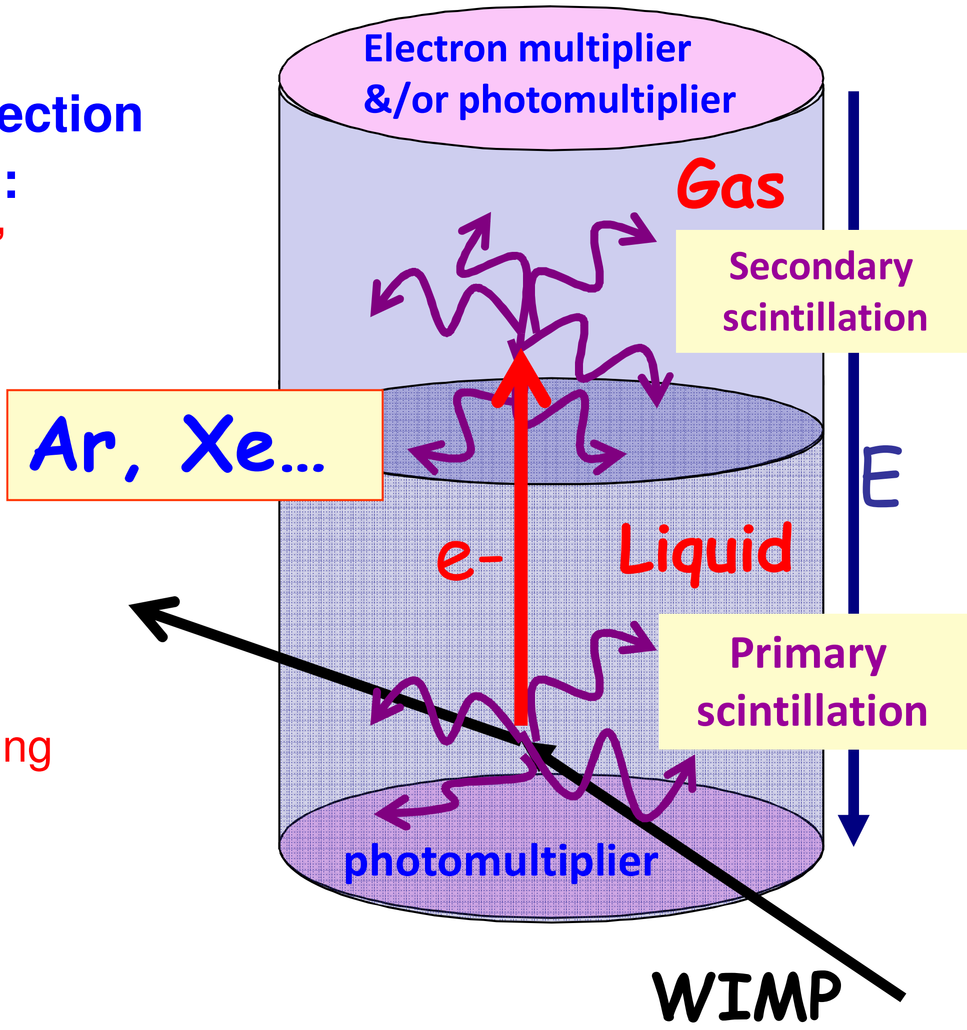
The idea is very similar to that of **Bonner spheres.**
Detector - **insensitive to**



Successful Beam-tests at PTB. Stable THGEM operation under high n-flux. Data under analysis. Application: BNCT (Boron neutron capture therapy

Noble-gas detectors

Charge &/or scintillation-light detection
in liquid phase
or
Charge &/or scintillation-light detection
In gas phase of noble liquids:
"TWO-PHASE DETECTORS"



Possible applications:

- Noble liquid ionization **calorimeters**
- Noble-Liquid **TPCs** (**solar neutrinos**)
- Two-phase detectors for **Rare Events** (**WIMPs, ββ-decay, ν …**)
- Noble-liquid γ**-camera** for medical imaging
- Gamma astronomy
- Gamma inspection
- .....

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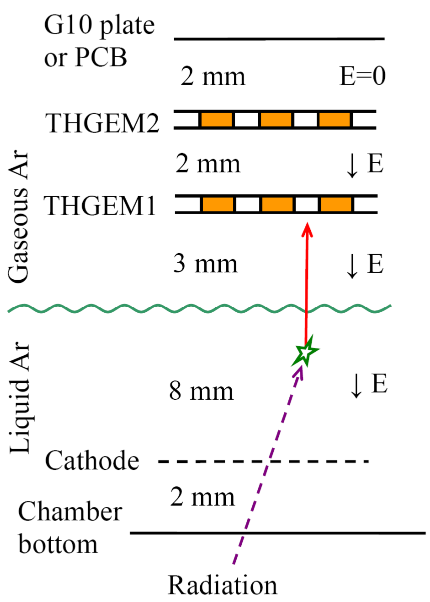
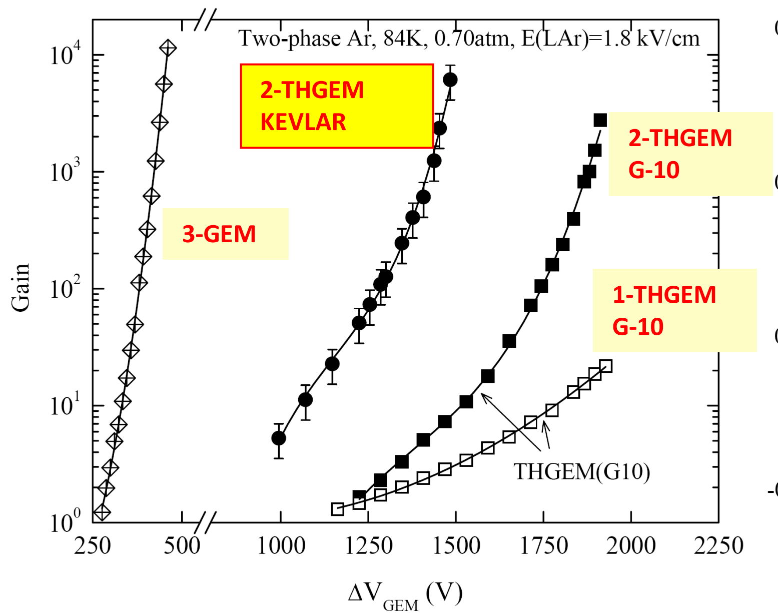
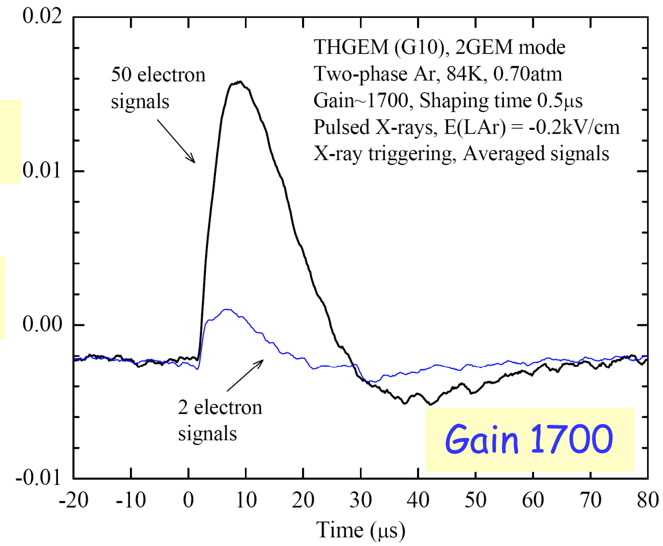
First results with double-THGEM in 2-phase LAr @ 84K

Bondar et al. **2008 JINST 3 P07001**







Experimental setup at Budker-Novosibirsk

Stable operation in two-phase Ar, T=84K
Double-THGEM ➔ Gains: $8x10^3$

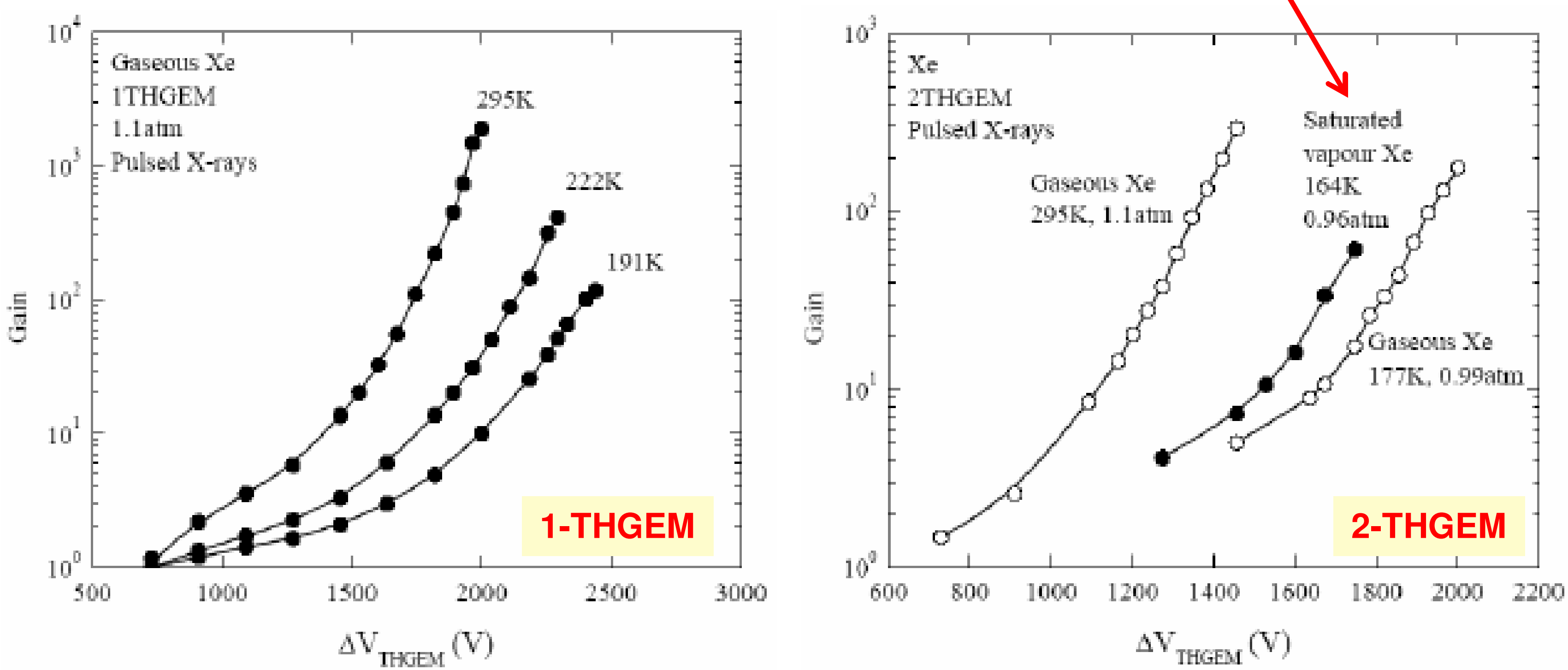
Signals in double-THGEM induced by 2 & 50 primary electrons

Good prospects for CRYOGENIC GAS-PHOTOMULTIPLIER operation in noble liquids!

First results with double-THGEM in 2-phase LXe @ 164K

Buzulutskov et al. Budker Inst. (unpublished)

Nov. 2009

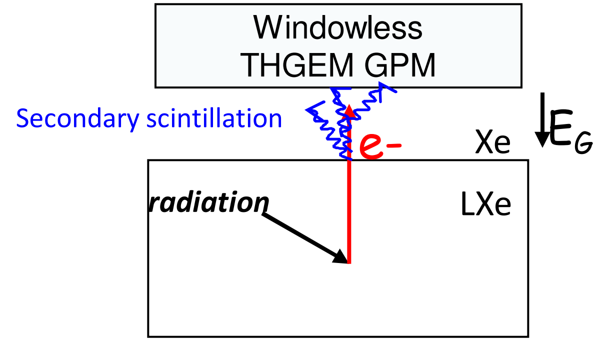


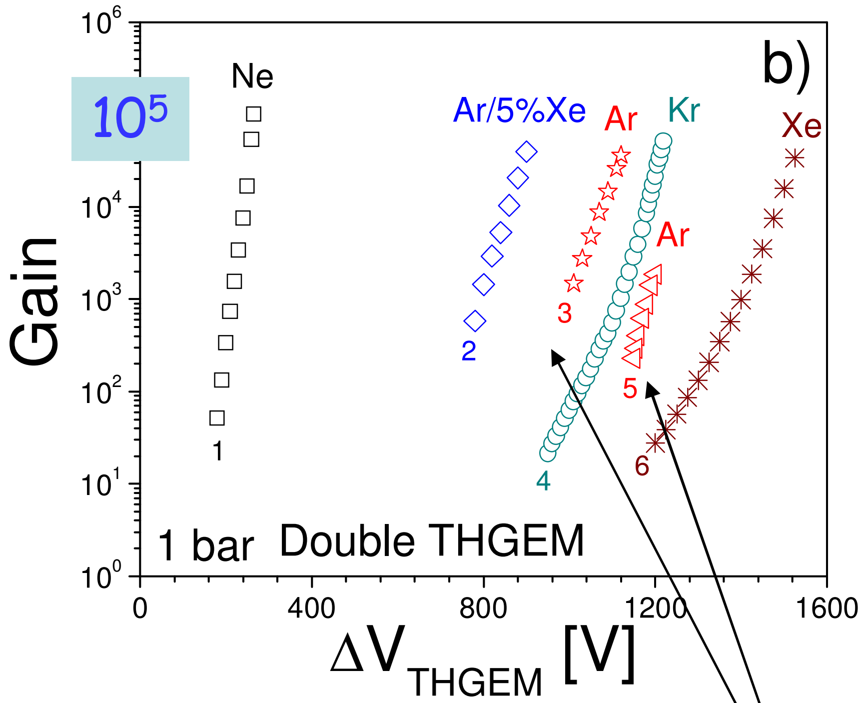
Gain limit in 2-phase mode: “technical”➔ HV feedthrough

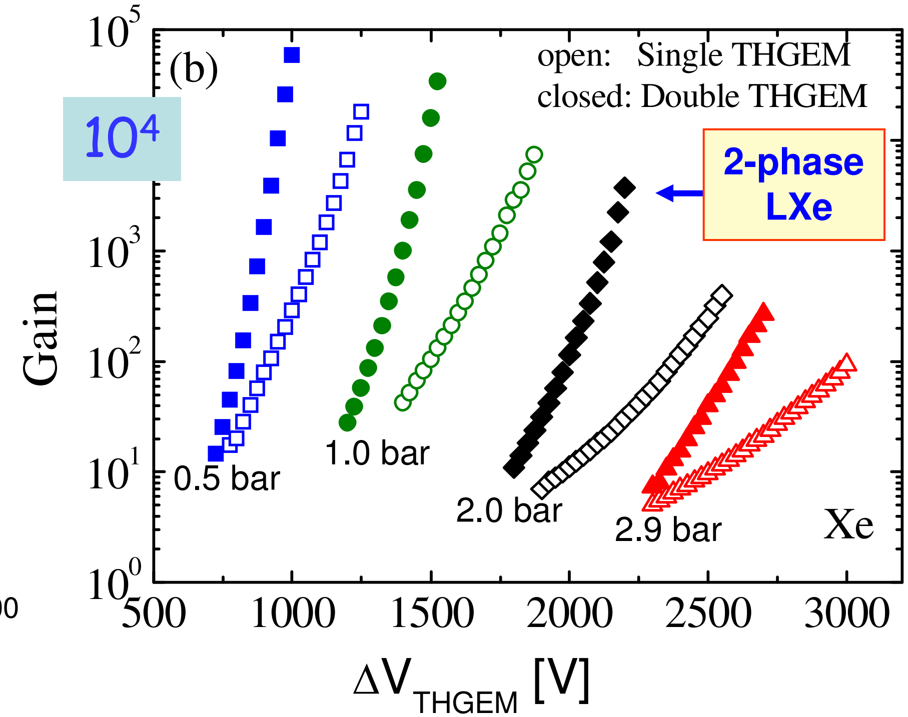
THGEM in noble gases

Alon et al. 2008_JINST_3_P01005

THGEM operation possible in **noble gases** due to <u>avalanche confinement in holes</u>
➔ Possible use in windowless 2-phase noble-liquid TPCs







Role of impurities, particularly $\mathbf{N_2}$:
investigated
Of extreme relevance in noble-liquid detectors!

High pressure operation
confirmed

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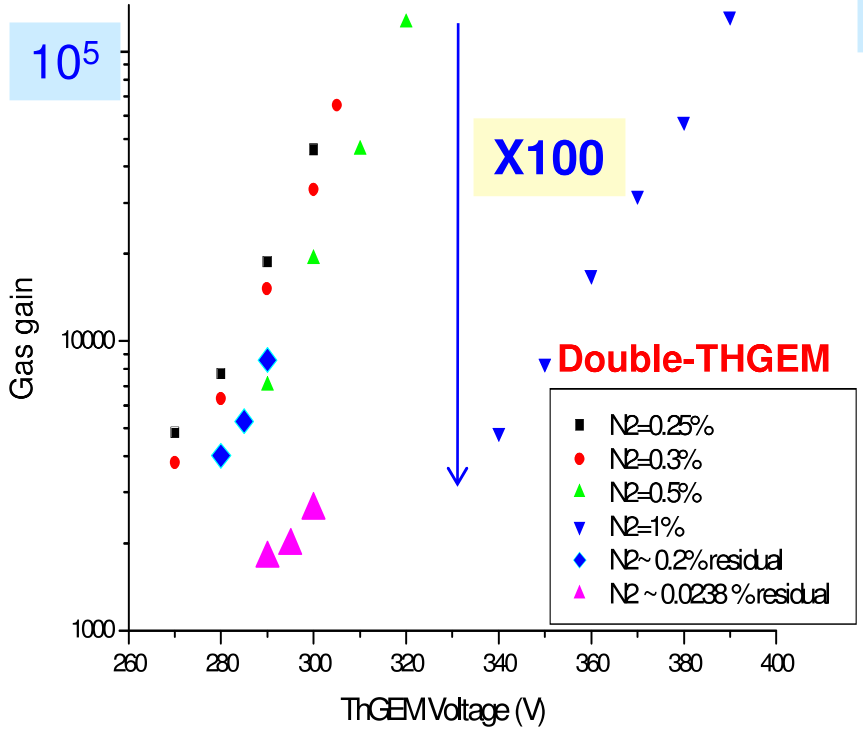
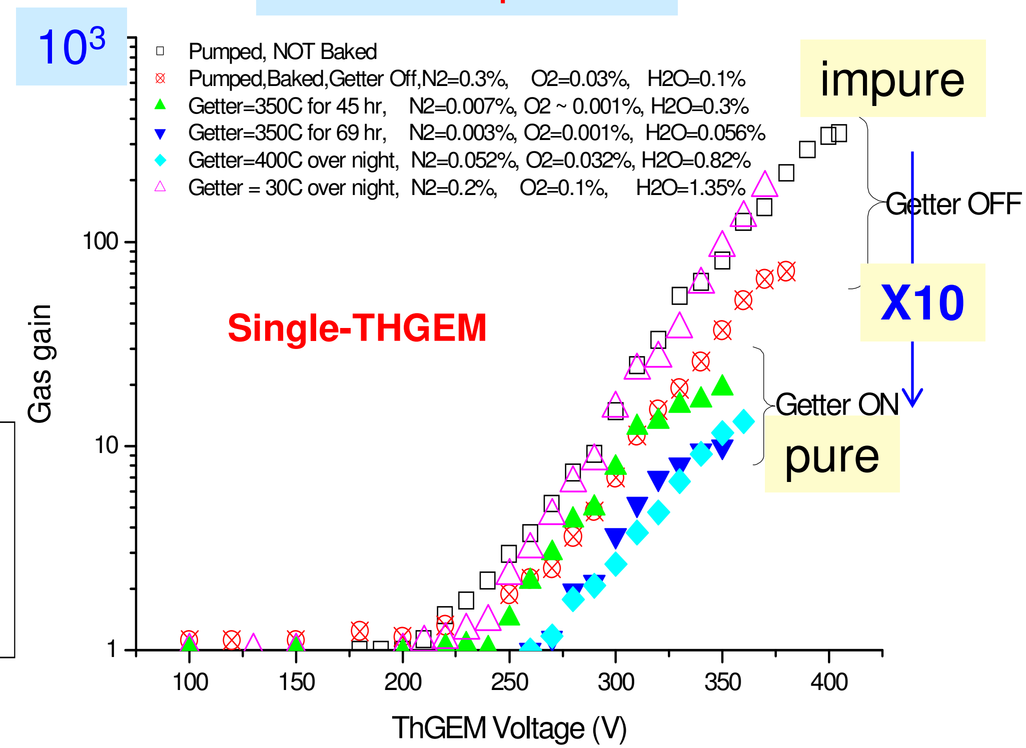
THGEM: Role of impurities in Ne

Miyamoto et al. Weizmann, in preparation

^{55}Fe x-rays
Ne/N_2 mixtures



^{241}Am alphas
Ne with impurities

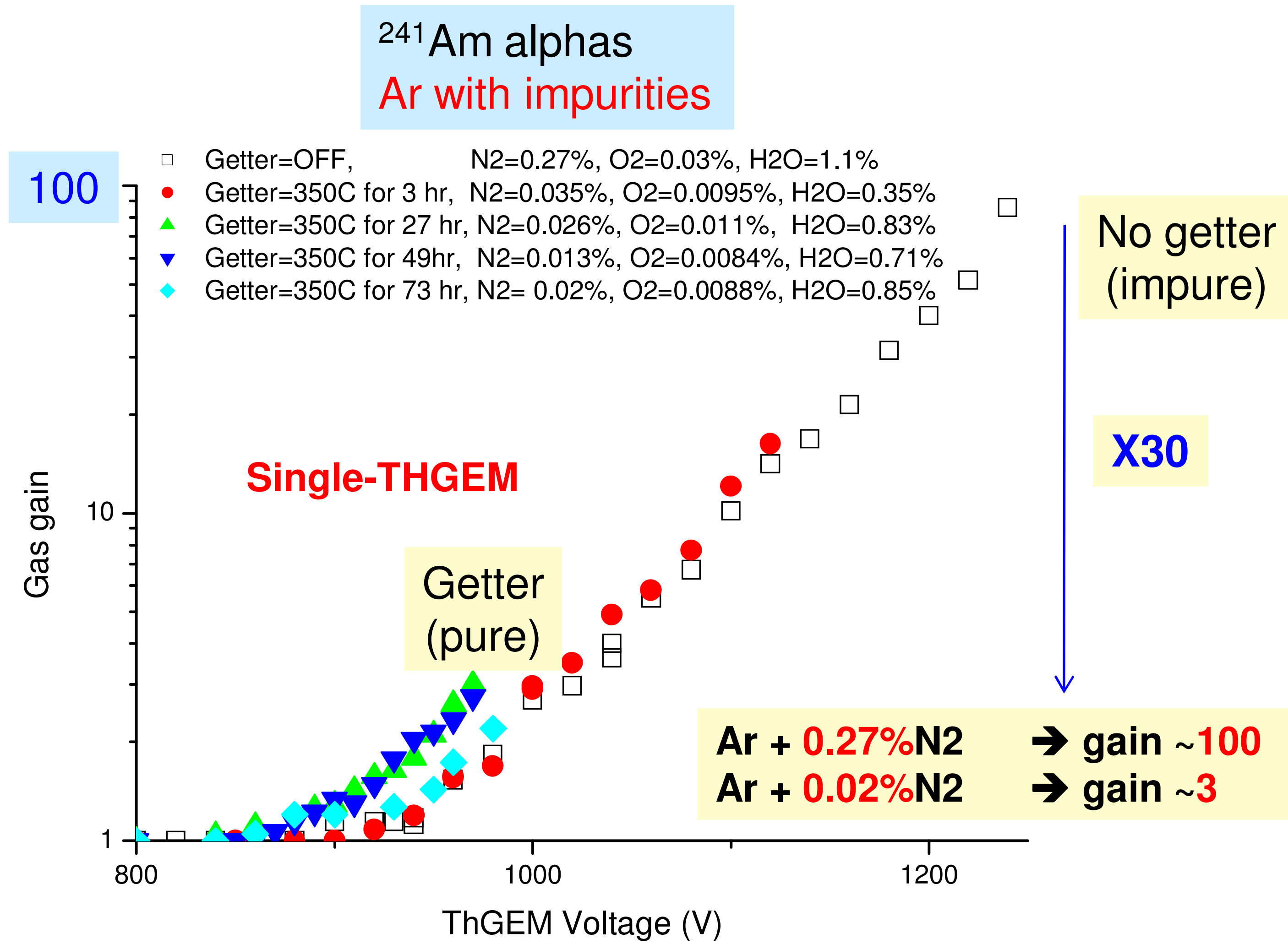


Ne + 1%N2 ➔ gain ~2x10^5
Ne + 0.02%N2 ➔ gain ~3x10^3

Alphas used to allow measuring even at close-to-unity gains
Most significant impurity: N_2

THGEM: Role of impurities in Ar

Miyamoto et al. Weizmann, in preparation



Use Ar/N_2 mixtures?

Bondar et al. 2009 JINST 4 P09013 ; *Ar/N_2 mixtures for two-phase detectors*

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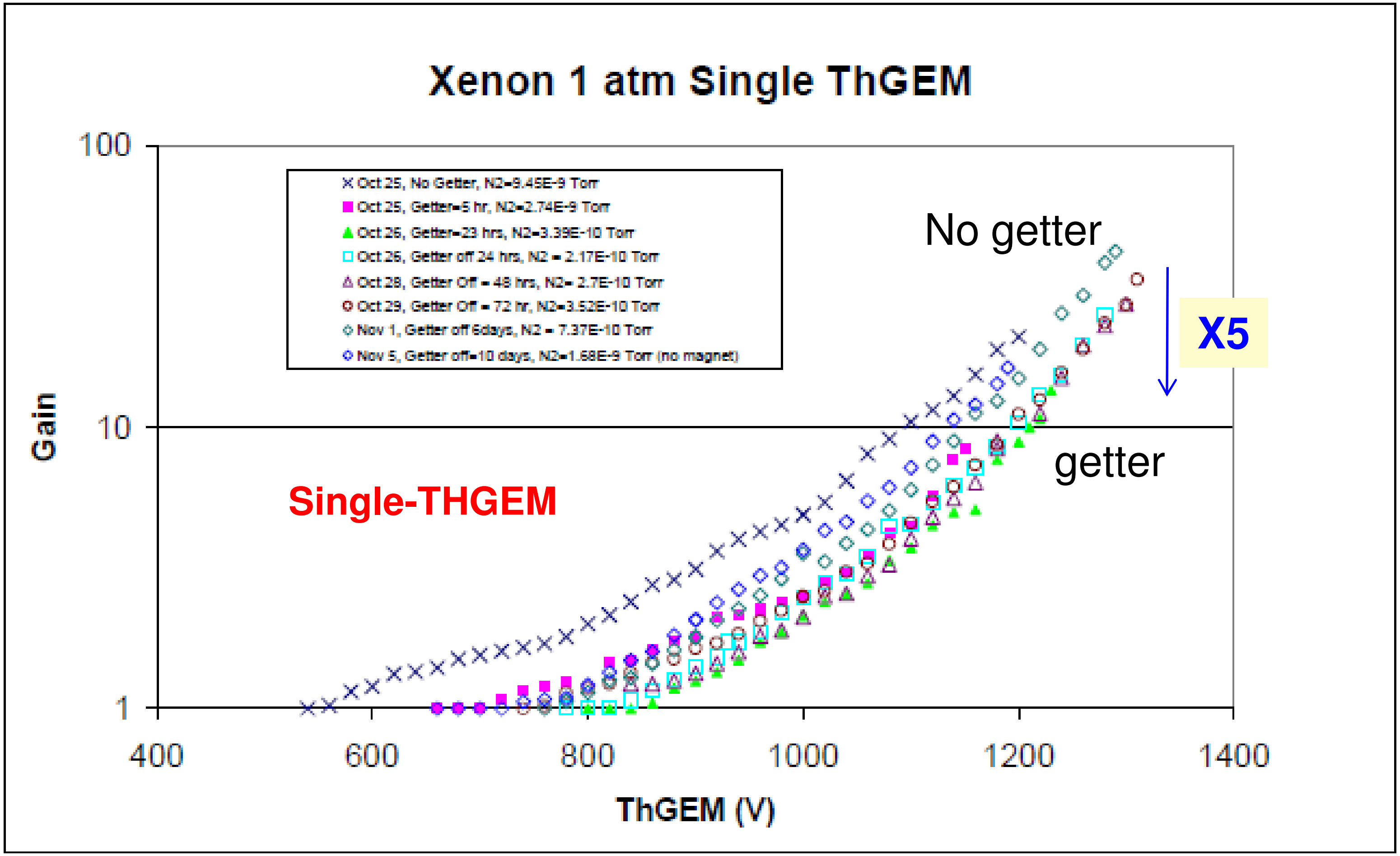
THGEM: Role of impurities in Xe

Miyamoto et al. Weizmann, in preparation

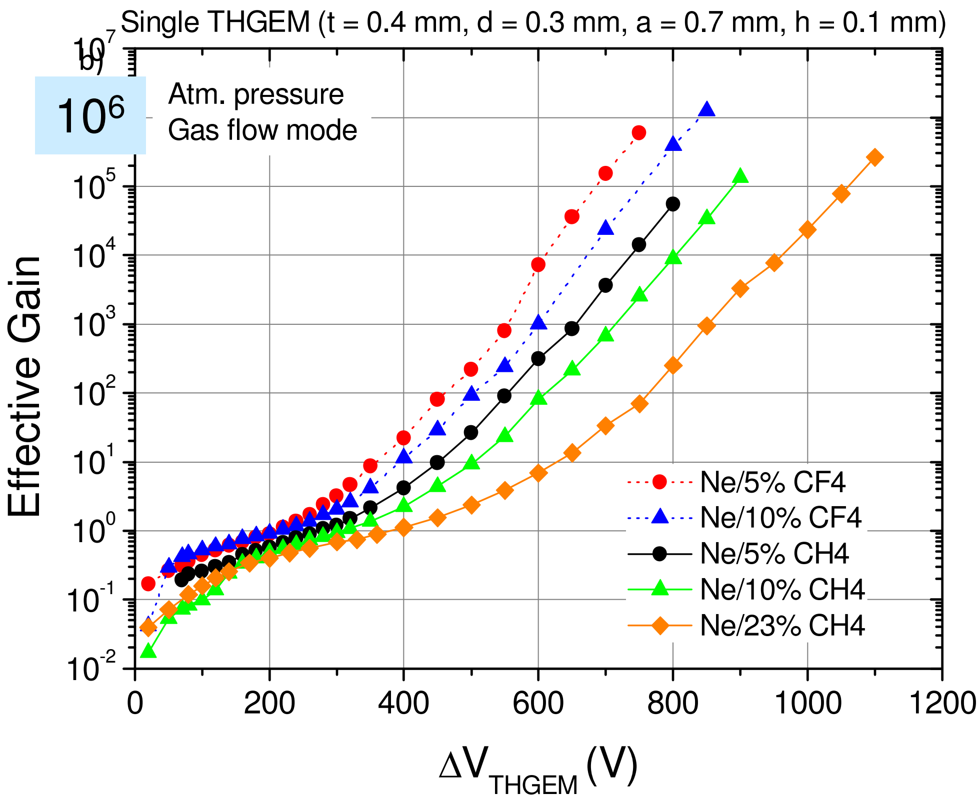


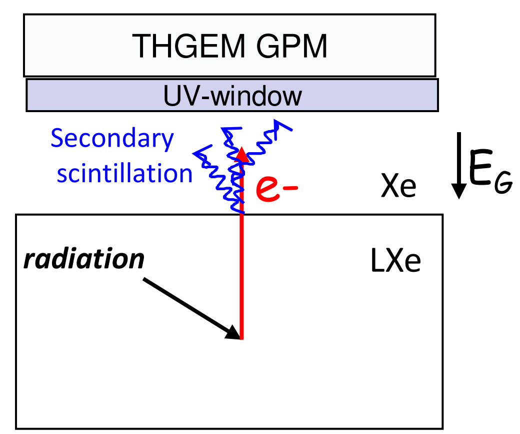
Relatively low gain due to alpha-source (normal to THGEM) geometry

Cryo-GPM with windows

2-phase or liquid scintillators

Best operation, confirmed at RT: **Ne/CH_4 or Ne/CF_4**





GPM w window: better control of counting gas / stability

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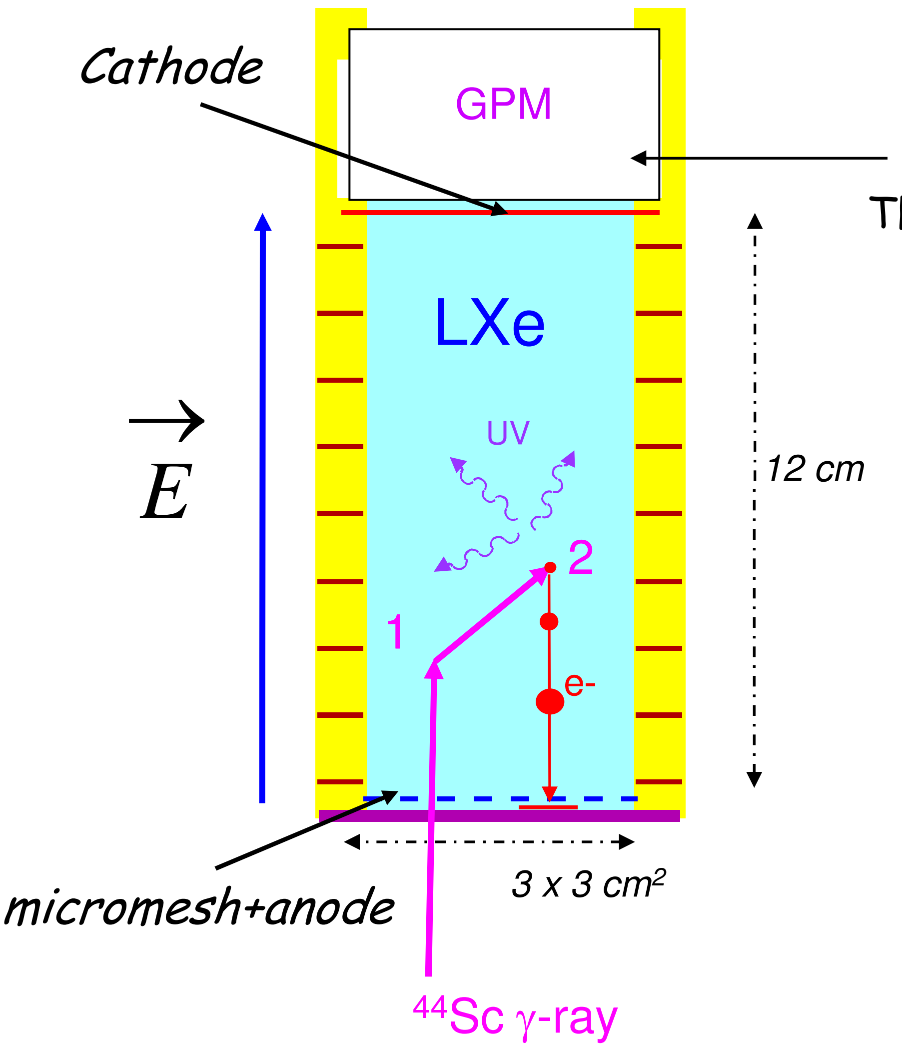
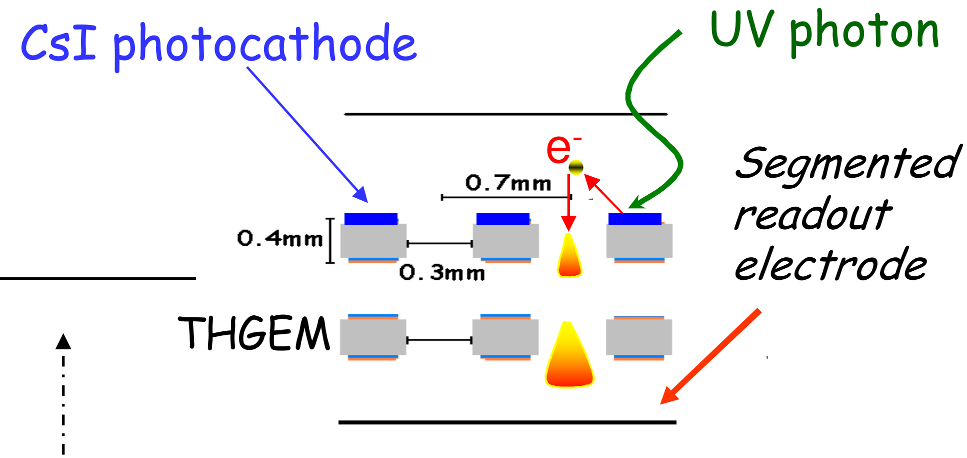
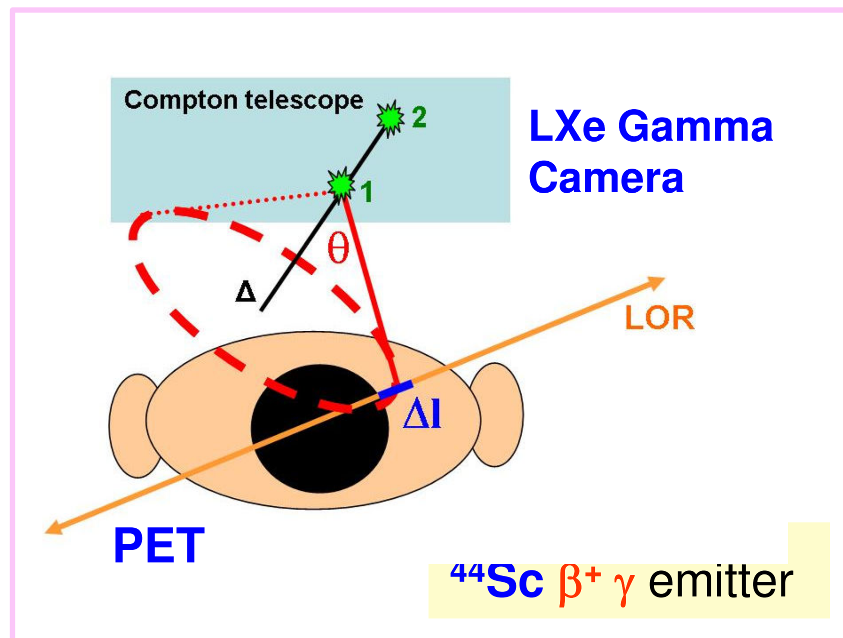
Compton Camera for 3-photon imaging

Subatech-Nantes/Weizmann
Duval et al. arXiv:0909.3191







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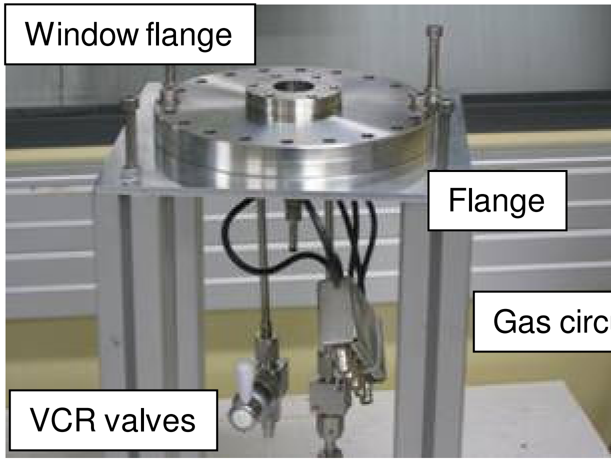
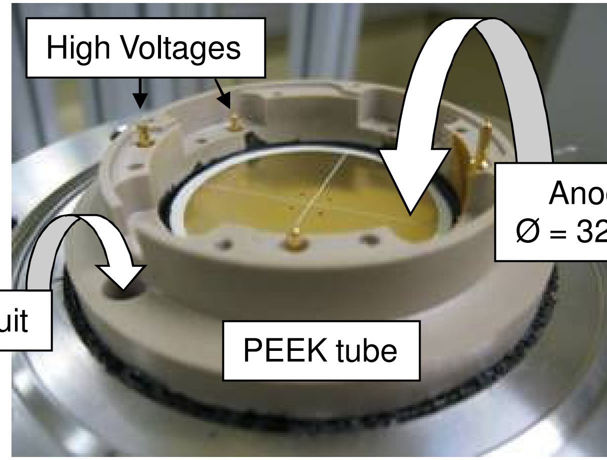
Cryo Gas-PhotoMultiplier GPM proto

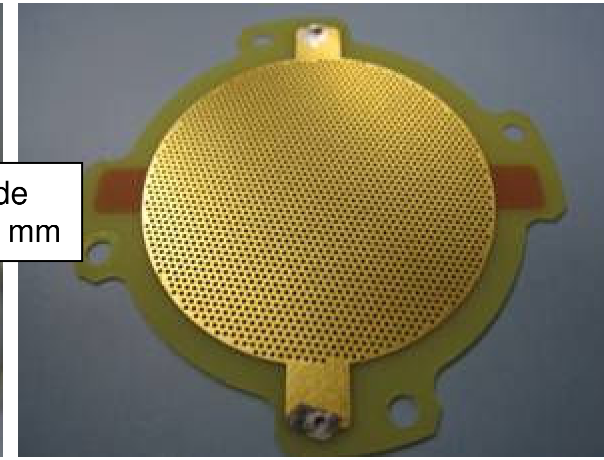
Subatech-Nantes/Weizmann; Duval et al. arXiv:0909.3191



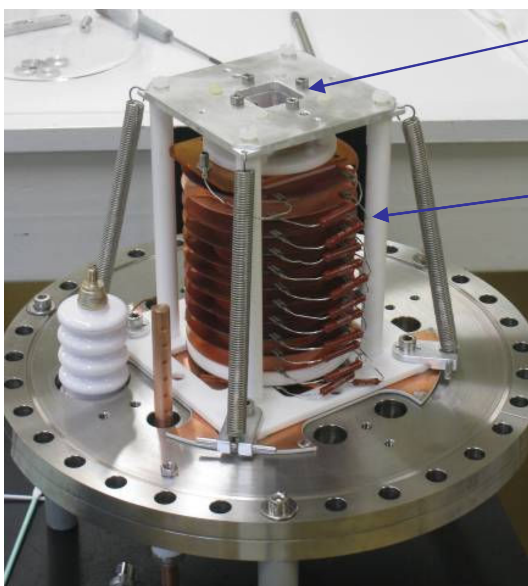
GPM global view



Inner view



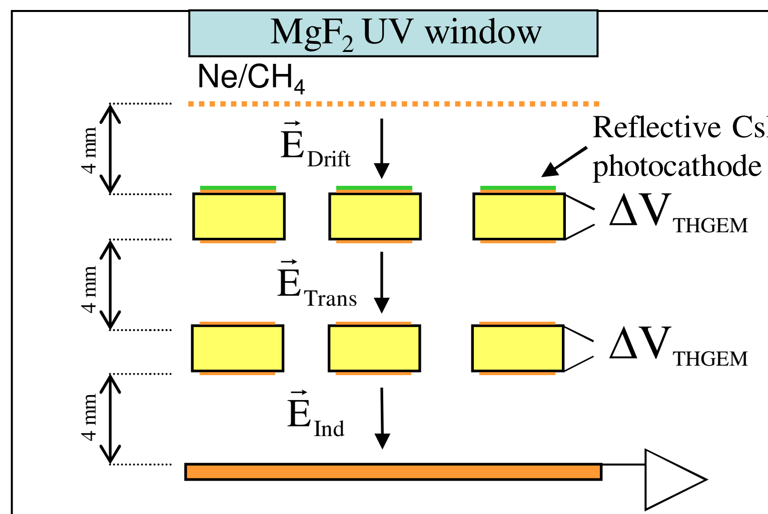
THGEM : thickness = 400 μm
hole Ø = 300 μm
hole spacing = 700 μm
rim size = 50 μm



GPM location

LXe converter with field shaping

**RT tests:
@ Weizmann
Cryo tests:
@ Nantes**



Schematic double-THGEM layout

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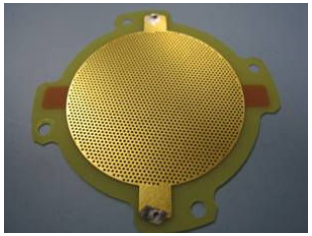
GPM: Double-THGEM vs THGEM+Micromegas

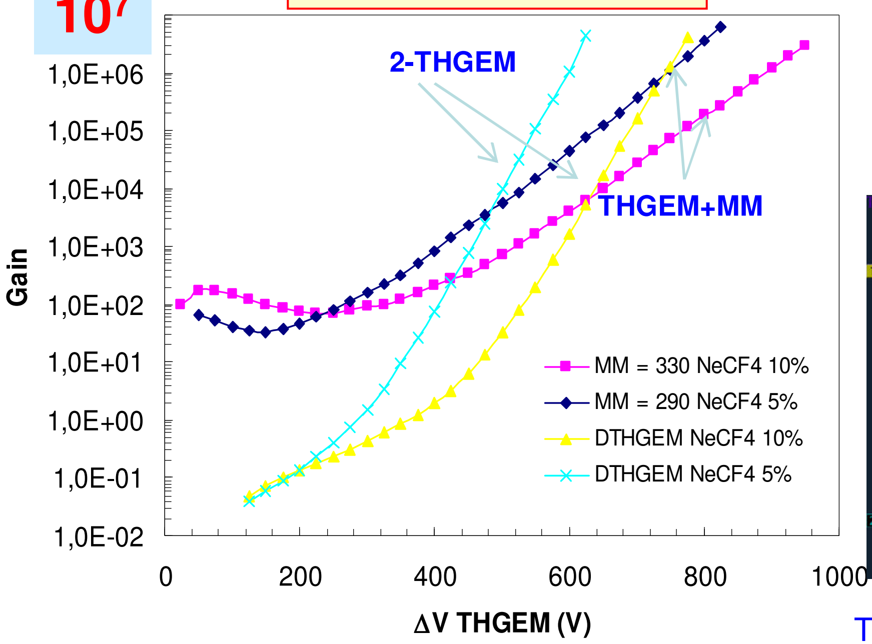
Weizmann/Nantes

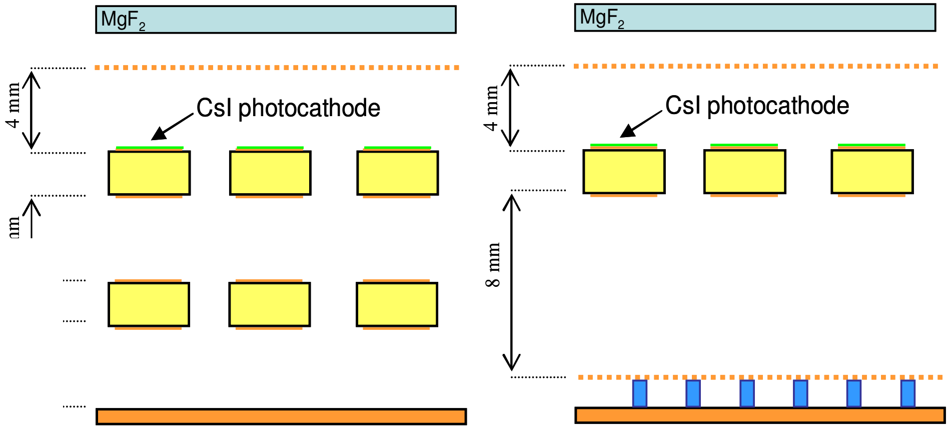
Nov. 2009



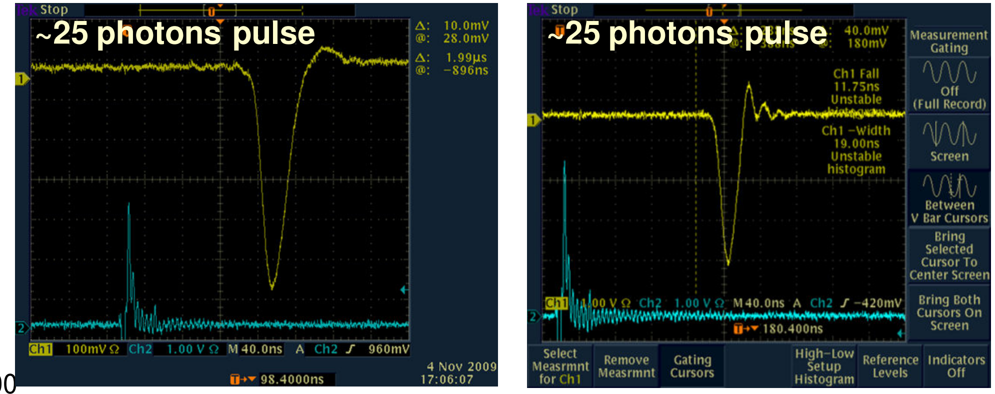
Ne/CF$_4$ (5-10%)

10^7





Double-THGEM **THGEM+Micromegas**

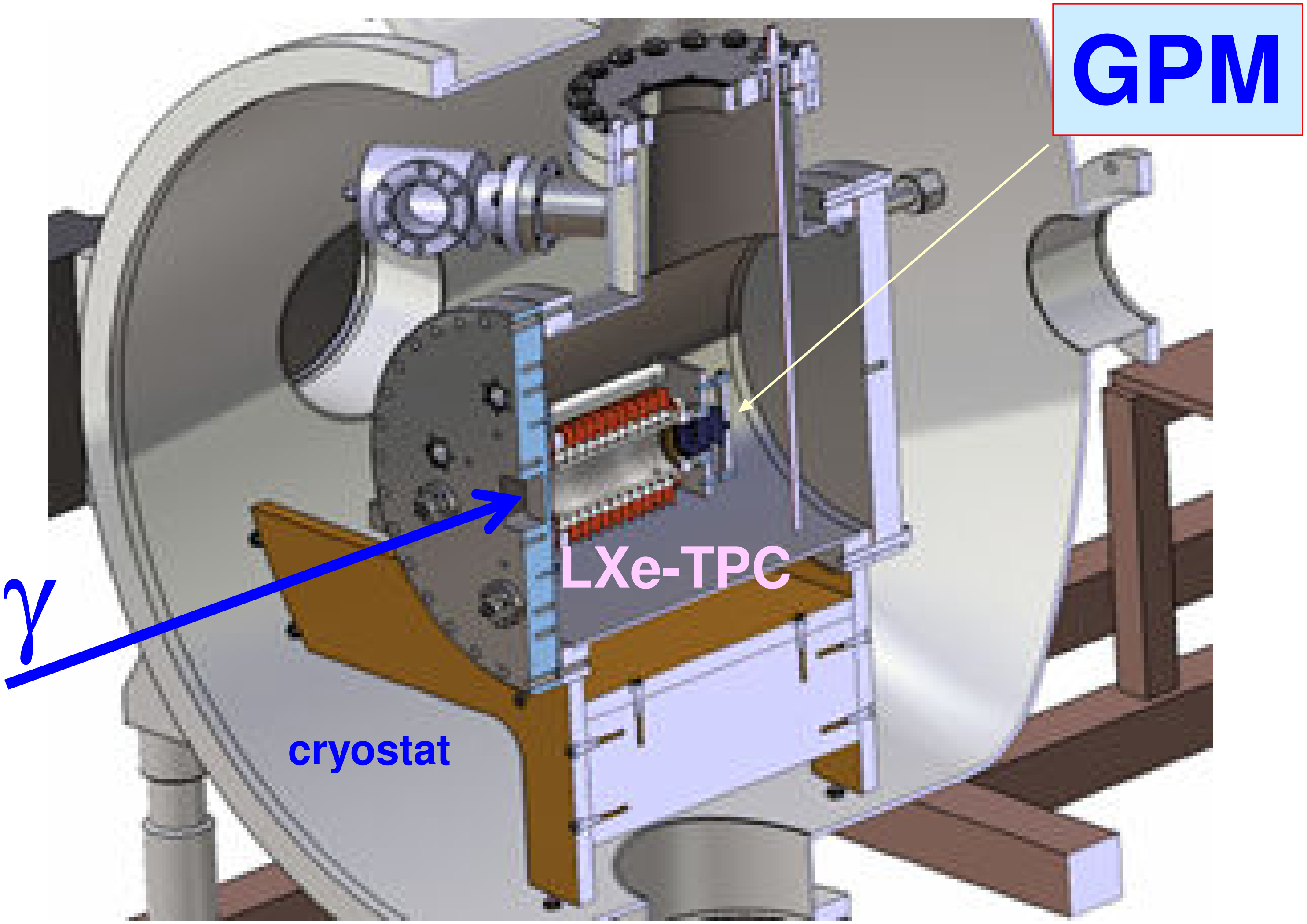


THGEM:
Thickness t=400µm, hole dia d=300 µm, pitch a=700µm, rim R=50µm.
MICROMEGAS:
t 5µm, d 30µm, a 60µm.

Samuel Duval, Ran Budnik & Marco Cortesi

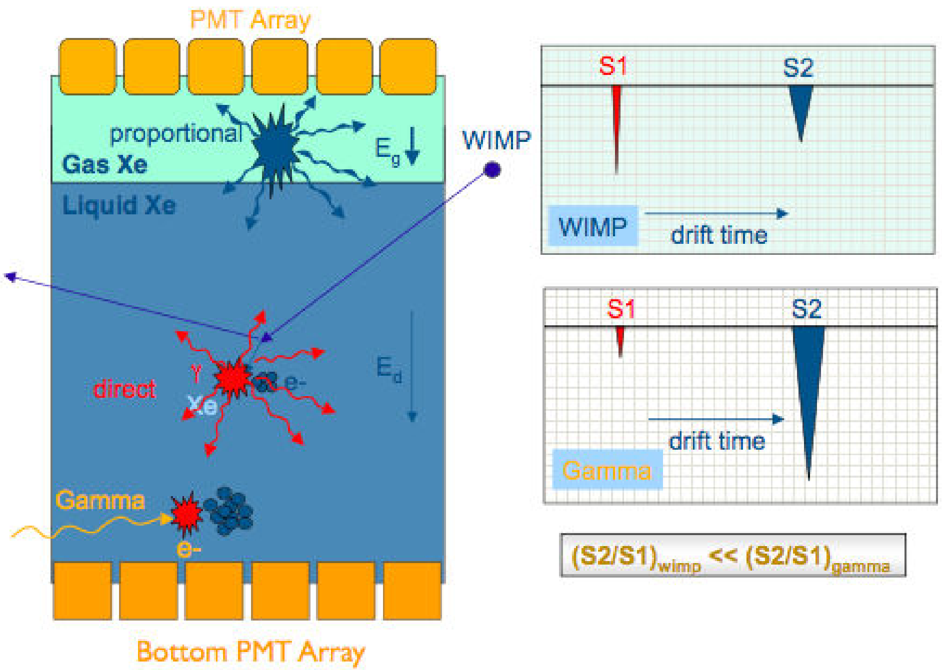
Amos Breskin

XEMIS LXe Compton Camera



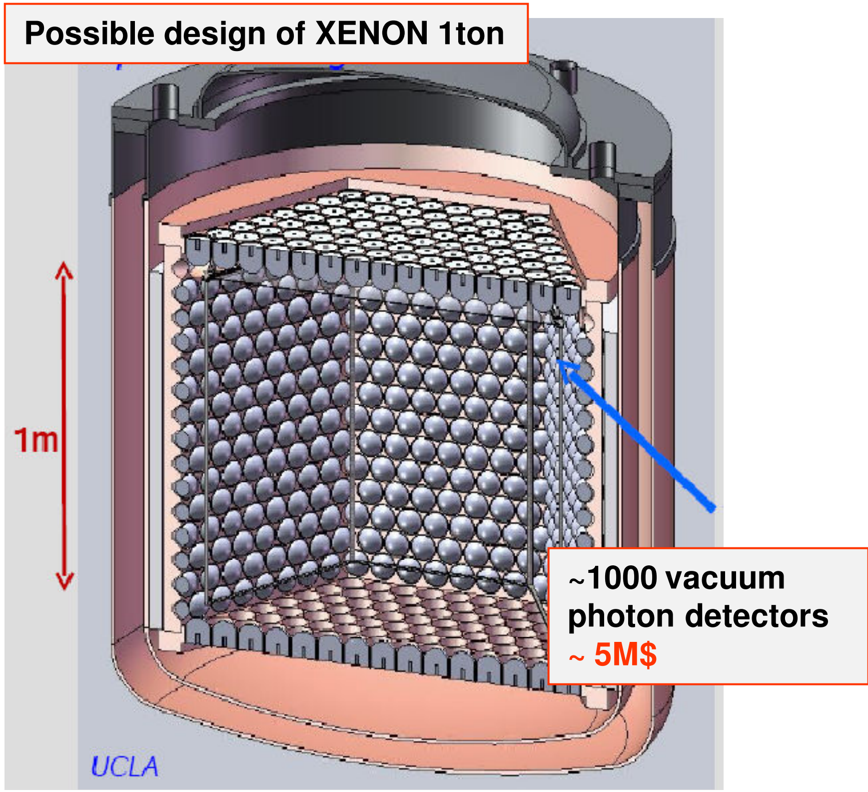
First tests in LXe: Dec. 2009

2-phase DM detectors



A two-phase TPC. WIMPs interact with noble liquid; primary scintillation (S1) is detected by bottom photomultipliers (PMTs) immersed in liquid. Ionization-electrons from the liquid are extracted into the saturated vapor phase, inducing secondary scintillation – detected with top MPTs (S2). The ratio of S2/S1 allows discriminating gamma background from WIMPs recoils, due to the different scintillation-to-ionization ratio of nuclear and electronic recoils.

Expectation: < 1 WIMP interaction/Kg/Day



Possible design of the XENON 1 ton two-phase LXe DM TPC detector with ~ **1000** QUPID vacuum photon detectors. Background: 1mBq/tube

PROBLEMS:
cost & natural radioactivity

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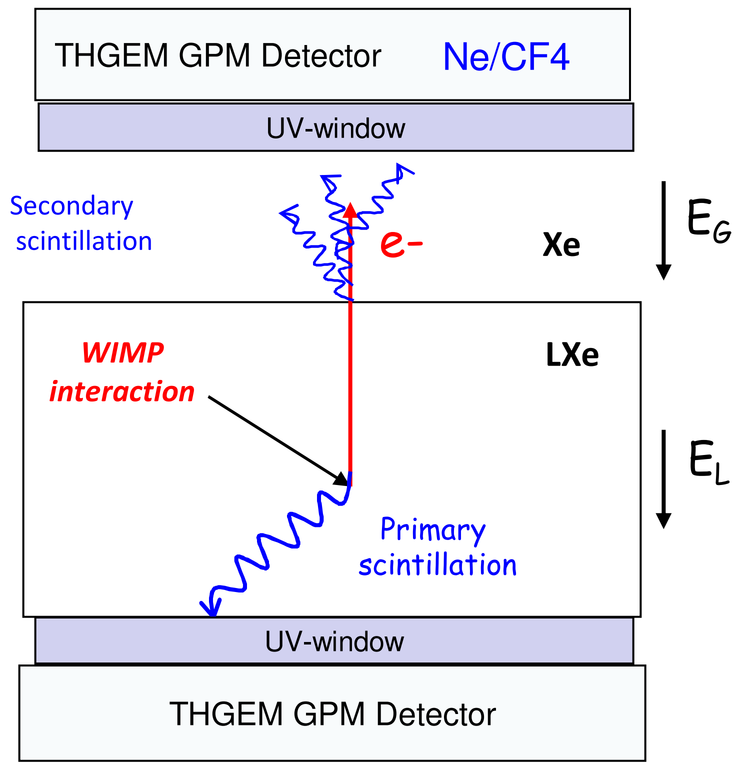
LXe 2-phase DM detector with GPM readout

Proposal submitted to Israel Science Foundation



THGEM-GPMs:

- **Simple, flat, robust**
- **Low-cost**
- **Radio-clean ?**
- **Lower thresholds ?**

2-phase LXe DM TPC-detector concept with **THGEM-GPM readout**, in both liquid and gas phases. WIMP-induced recoils yield primary scintillation detected by bottom GPM immersed in the liquid. The recoil-induced ionization electrons extracted into gas, produce secondary scintillation photons; they are detected with a GPM located above the gas phase.

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Large THGEM electrodes

300x300mm^2 THGEM
90,000 0.5mm diameter holes
(Print Electronics, IL)

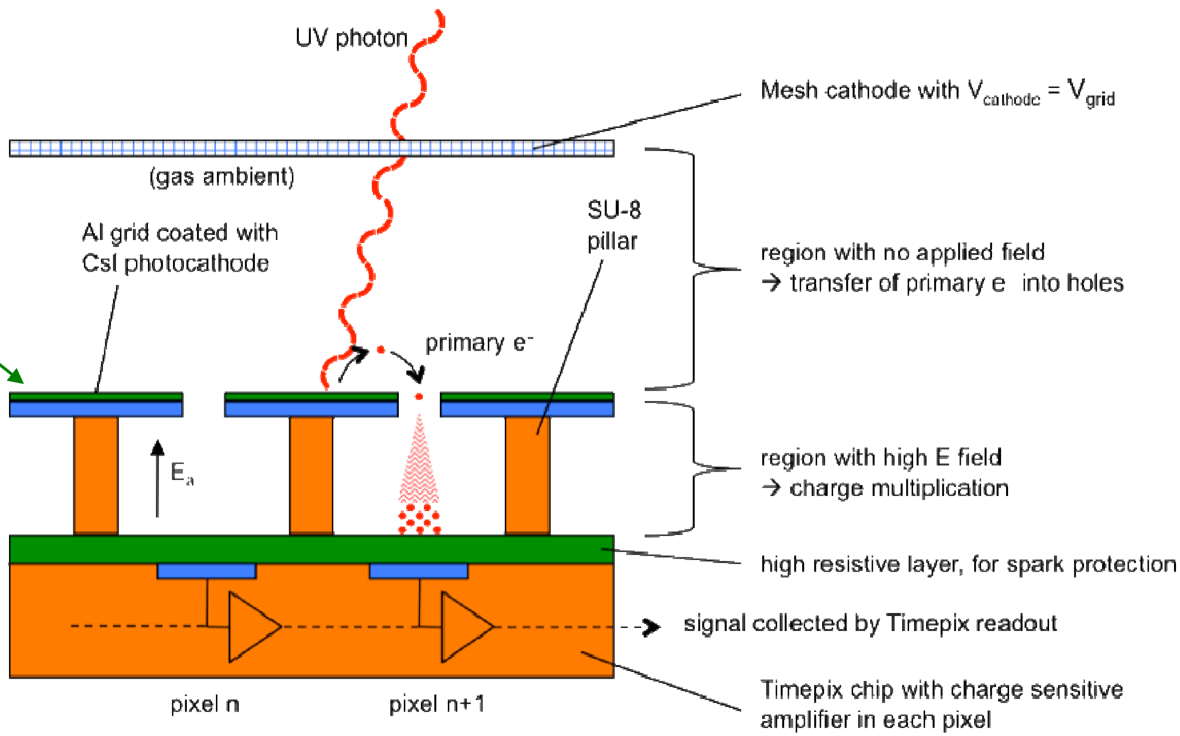
600x600mm^2 THGEM
600,000 0.4mm diameter holes
(Eltos, IT)

Industry: square-meters possible

Status: so far only "mechanical" electrodes

"Dessert" – not THGEM…

CsI



InGrid/Timepix chip → GridPix

Oct. 2009

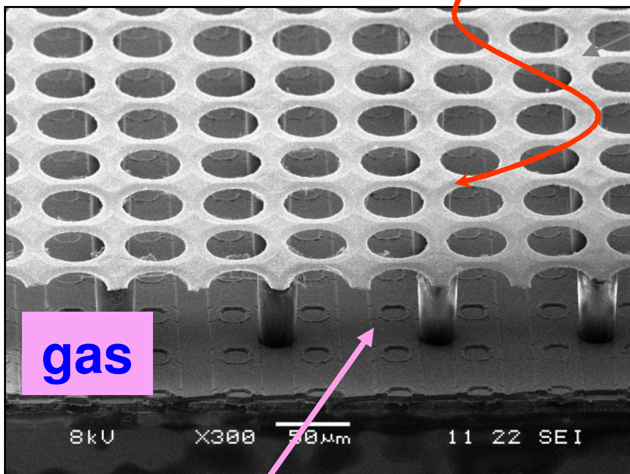
Integrating photon detector & electronics

Twente, NIKHEF, Weizmann

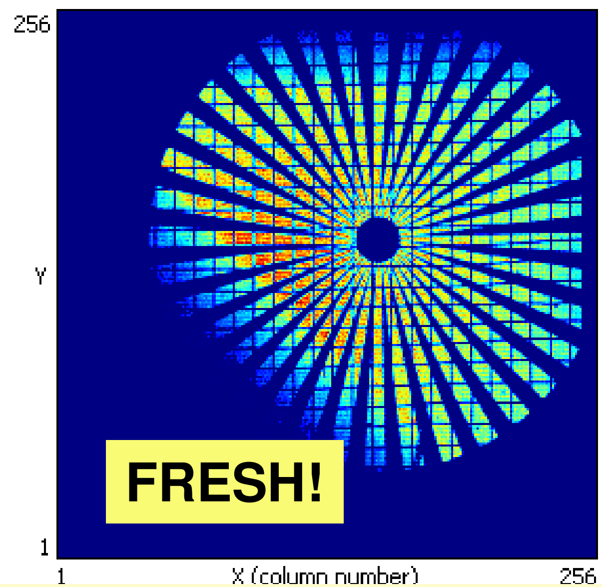
photon

photocathode

MICROMEGAS (InGrid):

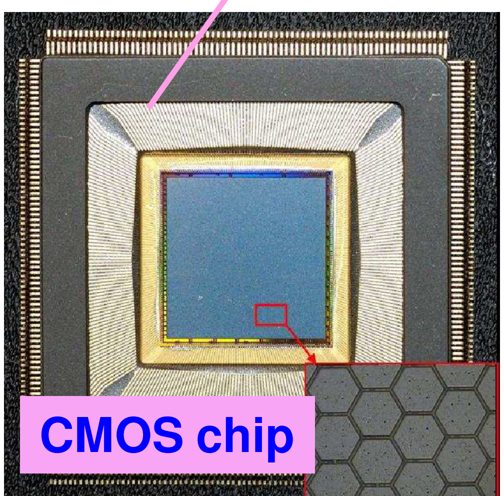


Using silicon foundry technology, **gas detector built directly over the silicon pixel readout chip**.
Below: Analog CMOS ASIC with hexagonal pixels.
High gain & small pixel size ➔ single-photon imaging.



Gain ~ 5 10^4

Joost Melai & Marco Cortesi



Chip area: ***14x14mm²***.
(256×256 pixels of ***55×55 µm²****)*

2D UV Image of a 10mm diameter mask (Oct. 09)

InGrid/Timepix chip

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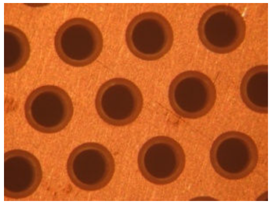
SUMMARY

-  a versatile robust electron multiplier
- Progress in understanding physical processes - but remaining open questions
- RICH: expected photon detection efficiency ~20% @ 170nm
- Various ongoing and potential applications @ **RT & low-T**

UV-photon detectors for RICH

Sampling elements for Digital Hadron Calorimeters

Neutron-imaging detectors

Cryogenic UV-photon detectors for medical imaging and dark matter

Large-area THGEM detector