Detection of single photons with ThickGEM-based counters

- The reasons behind the choice of THGEM-based PD's
- Characterization and simulations
- PD prototypes and test-beam results
- Large size PD's
- Conclusions

S. Levorato
on behalf of Alessandria, Aveiro, Freiburg, Liberec, Prague, Torino, Trieste Collaboration

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NDIP2011: New Developements in Photodetection 4-8 July 2011, Lyon- France
Why THGEM based counters for single photon detection

**THGEM based photodetectors characteristics:**

- GEM based
- Large surface fraction available for photon converter coating
- Production with standard PCB techniques
- Closed geometry structure
- High gain device
- Fast signal from electron drift (few ns)
- Robust and self supporting

THGEM-PD are a possible and economical affordable alternative to overcome the severe limitations of the actual open geometry gaseous single-photon detectors (MWPC + CsI pc) when large are coverage is needed (low gain, rate capabilities, electrical instabilities, long recovery time after detector trips)
THGEM characterization: parameters

Four years ago an R&D program was started to develop a large size, cheap, robust, fast, high gain, high rate, magnetic insensitive single photon detector for RICH applications, based on THGEM and reflective CsI photocathode.

EXPLORING A MULTI-DIMENSIONAL SPACE:

- Isolating substrate material
- Thickness
- Hole diameter
- Pitch
- Rim size
- Holes and rim production procedure
- Induction field
- Drift field
- Geometrical arrangement
- Gas mixture

To detect ionizing particle:

\[ V_3 < V_2 < V_1 < V_0 \]

\[ V_{drift} = \frac{(V_3 - V_2)}{d_1} \]

\[ V_{induction} = \frac{(V_1 - V_0)}{d_2} \]

\[ \Delta V = V_2 - V_1 \]

THGEM’s with 30 x 30 mm² active area

THGEM

55Fe source
THGEM characterization: production techniques: an overview

1) traditional

2) large rim

3) small rim

4) global etching

our choice: global micro-etching

metallographic section

etching before drilling

off-centered rims

100 μm rim

25 μm rim

uniform and smooth

20 μm galvanic tin instead of photo-resist

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THGEM characterization tests

About 50 different THGEM types have been characterized using X-ray:
- best response only with optimized drift field (specific for each type)
- the rim plays a fundamental role: large rim → large gain
- gain stability guaranteed only for small rim or no rim type
- thicker types provide larger gain too
- production procedures are very important
- good rate capability is guaranteed

Using UV light sources we investigated (with either CsI coated or metal surfaces):
- photoelectron extraction and collection efficiency,
- timing properties of the signal (using 600 ns long light pulses)
- photoelectron detection efficiency with digital r/o

Prototypes of small size THGEM-based PD’s and of 100mm x 100 mm PD’s have been built and tested. Some of the results are shortly presented in the next slides.
RIM role: gain stability

<table>
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<tr>
<th>Name</th>
<th>Diam (mm)</th>
<th>Pitch (mm)</th>
<th>Rim (µm)</th>
<th>Thick (mm)</th>
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<td>0.4</td>
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<tr>
<td>C4</td>
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<td>0.8</td>
<td>100</td>
<td>0.4</td>
</tr>
</tbody>
</table>

55Fe source; uniform irradiation

Long time gain variation

Short time gain variation

START IRRADIATING after ~10 hours at nominal voltage

irradiation at HV switch on (after ~1 day with no voltage)
Gain stability: dielectric surface effect

this effect is seen in GEM’s:

Understanding the gain characteristics of GEMs inside the Hadron Blind Detector in PHENIX.

Fig. 11. Gain as a function of time after HV was on for 3 days. Red points are for a GEM stack comprised of GEMs produced in 2006; blue points are for a stack of 2007 GEMs.

Fig. 12. GEM holes viewed under a microscope. 2006 production GEMs are shown above; 2007 production GEMs are below.
Thickness and rim role

LARGER RIMS ALLOW HIGHER GAINS...

The gain of the electro-chem. polished THGEM is overlapped by the gain of the kapton THGEM.

PARAMETERS:
- Diameter = 0.3 mm
- Pitch = 0.7 mm
- Thickness = 0.4 mm
- Rim = variable
- Gas: Ar/CO₂ = 70/30

THGEM with rim = 0.1 mm
THGEM w/o rim
THGEM made of kapton

THGEM electro-chem. polished without rim
THGEM w/o rim THGEM made of kapton
THGEM with rim = 0.1 mm

BUT INCREASING THICKNESS DOES IT TOO

PARAMETERS:
- Diameter = 0.3 mm
- Pitch = 0.3 mm
- Thickness = 0.4 mm
- Rim = variable
- Gas: Ar/CO₂ = 70/30

THGEM with rim = 0.01 mm
THGEM made of kapton
THGEM with different geometry

Results from recently (11) received THGEM set

- Hole diameter: 0.4 mm
- Pitch: 0.8 mm
- Thickness: 0.4 mm
- Rim: 20 μm

- Hole diameter: 0.6 mm
- Pitch: 0.8 mm
- Thickness: 0.6 mm
- Rim: 0

- Hole diameter: 0.8 mm
- Pitch: 0.8 mm
- Thickness: 0.8 mm
- Rim: 0

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Chamber with 1 MAPMT and 3 triple THGEM photon detector prototypes installed

CERN SPS T2-H4 beam line (RD51 test beam) 150 GeV/c μ/π+, beam spot σ ~12 mm, rate ~1 kHz

Two identical small PD prototypes: triple THGEMs with 30 mm x 30 mm active area.

All THGEMs had the same parameters (in mm) thckn. = 0.4, hole diam. 0.4, pitch 0.8, rim 0.01

Gas mixture: Ar/CH₄ 50/50, flow: ~50 l/h

Spherically shaped fused silica radiator focusing Cherenkov light on a thin corona onto the THGEM's

Two possible illuminations: full radiator – partially darkened radiator to avoid multiple photons

A 45 degrees rotation allows to change illumination condition

Two readout configurations used:

analog r/o (all channels together, Cremat CR110 preampl., ORTEC amplifier, AMPTEK MCA 8000A) digital r/o of 32 ch, COMPASS MAPMT r/o (CMAD + ROOF + DREISAM (with F1 TDC) + HOTLINK + CATCH) and standard COMPASS DAQ
THGEM 2010 Test beam results: time development of the signal/imaging

1 MAPMT and 3 triple THGEM photon detector prototypes
CERN SPS T2-H4 beam line (RD51 test beam)
150 GeV/c m+, beam spot ~12 mm, rate ~1 kHz

125 ns is the expected transit time for $e^-$ in 1 cm of Ar-CH$_4$
1.5 kV/cm ($\sim8 \times 10^6$ cm/s)

Time resolution for THGEM:
$\sim8$ ns, no optimisation
THGEM Test beam: illumination regimes

Quartz radiator,
Half of the radiator is darkened at sectors of nearly 40 degrees, 45 degrees rotation allows for non single photon illumination

Both multiplicities are compatible with the expected values from Zemax simulation for the generated photons, the geometrical acceptance and the estimated chamber efficiency

screened radiator → single photon condition
The electric field (orthogonal to the THGEM surface) must be large enough to ensure an effective photoelectron extraction.

The most critical point: the centre of the triangle.

Example of field dependence along the test line for different geometries with $d/p=2$ and different $\Delta V$.

Thickness = 0.6 mm.
The E field in the critical point: a glimpse to the parameter dependence

The electric field (orthogonal to the THGEM surface) must be large enough to ensure an effective photoelectron extraction.

The most critical point: the centre of the triangle.

The THGEM parameters where CsI photocathode is deposited must be optimized to have the highest possible values of $E_z$ in the critical point.
Timing properties of the signal: dependence on the E field

- $G = 0.9 \times 10^5$
- $G = 1.1 \times 10^5$
- $G = 1.4 \times 10^5$
- $G = 2.0 \times 10^5$

Fraction of events outside the Gaussian peak:
- 23%
- 19%
- 11%
- 6%
Timing spectrum: a way to check/monitor the extraction efficiency

Correlation between the tail of the timing peak and the reduced extraction efficiency: an effective method to check the field conditions.
THGEM, field optimization at the photocathode surface

Photoelectron trajectories from a THGEM photocathode, multiplication switched off

Electron drift lines from a track
thickness 0.6 mm, diam. 0.4 mm, pitch: 0.8 mm, ΔV = 500 V

y-Axis [cm]

With an external field above the THGEM = 0 all e⁻ enter the holes

x cross-section

Anodic current in a THGEM detector versus the external electric field applied: a measurement

Gas: CO₂ 30%, Ar 70%, T=300 K, p=1 atm

Particle: 50 equally spaced points

Electron drift lines from a track

Anodic current in a THGEM detector versus the external electric field applied: a measurement

Gas: CO₂ 30%, Ar 70%, T=300 K, p=1 atm

Particle: 100 equally spaced points

Electron drift lines from a track

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Gas: CO₂ 30%, Ar 70%, T=300 K, p=1 atm

Particle: 100 equally spaced points
The Ion Back Flow problem, still an open question

typical charge sharing between electrodes in a triple THGEM detectors

When the effective gain is $10^6 \rightarrow \sim 500000$
ions/(detected photon) back to the photocathode

a factor 10 less is needed

Scanning $\Delta V_{1,2,3} E_{\text{transfer}}$
$E_{\text{induction}}$ results in a few %
variation of the IFB\rightarrow
a different architecture is needed

Different techniques under investigation via simulations and tests.

See C. SANTOS poster in session PIV
Open points before going to large size

1) Strict THGEM quality test protocol
2) Final segmentation to be optimized
3) Final choice of HV distribution system and power supply
4) THGEM planarity and mechanical/electrical stability to be guaranteed
5) Quality and uniformity of very large THGEM to be demonstrated
6) Chamber border effects and dead areas to be minimized

Our effort towards a solution
THGEM quality checks

Defects are detected by a quality check procedure when THGEMs are received.

COMPASS THGEM pcb’s are produced by an industrial pcb Company: ELTOS S.p.A. (Arezzo - Italy)
Samples of 20 different types measured to determine the breakdown voltage and study the effect of discharges. This information is useful to properly define the THGEM segmentation.
Towards a large size detector: gain issues and layer specialization

- Stable gain (<20% variation) can be achieved both with small rim or thicker THGEMS.

- For large size detectors the rim uniformity control over a large area is extremely critical already at the level of 100 x 100 mm² detector.

- High field in the critical point is mandatory to achieve good ph-electron extraction efficiency (gas choice!)

  ➢ Each layer must be “specialized” for a main function

  ➢ To achieve stable high gain it is necessary to go to thicker THGEM instead of THGEM with rim to equip large areas

  ➢ The first layer geometrical parameters must be adapted to achieve the highest $E_z$ on the CsI surface with the lowest gain possible (IBF reduction)

  ➢ IBF simulations and study are in progress, probably a dedicated layer is needed

  ➢ Charge splitting may help in achieving higher gains
Towards large size detectors, 300x300 mm² prototype project

Some details from the prototype technical drawing project
Towards large size detectors, 300x300 mm² prototype realization

Preliminary test / characterization of each layer: The behavior of the large size detector can be correctly predicted from the small size detector studies
Towards large size detectors, 300x300 mm² prototype mounting
Towards large size detectors, 300x300 mm² prototype mounting
300 x 300 mm² prototype: mounting

Tests will start soon...
Keep tuned
Conclusions & Outlook

THGEMs represent a good choice for single UV photon detectors: pcb technology is o.k.

Almost all principle aspects have been validated and understood using small size prototypes:

- effective single photon detection,
- large and stable gain,
- fast signals

Optimization still to be performed on many details, and open points but possible solutions are not so far: layer specialization can help in this direction.

Still there are many challenges to overcome before achieving large size, cheap, robust, fast, high gain, high rate, magnetic insensitive single photon detectors.
Conclusions & Outlook

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Thank you!
In case of need....extra slides
Photoelectron extraction

Electrostatic calculations are essential to optimize our THGEMs. Critical points:
- Effective CsI Q.E. depends on the electric field at the CsI surface, and e focusing is done by dipole field.
- The backscattering effect depends on the gas and on the field too.
- The collection of photoelectrons in the holes for multiplication is difficult to measure and critically depends on geometry and fields.

Combine measurements and simulations (ANSYS+ Garfield).

Electron drift lines from a track:
- Particle: th. 0.6 mm, diam. 0.4 mm, pitch: 0.8 mm, $\Delta V = 1500$ V.
- Gas: CO$_2$ 30%, Ar 70%, T=300 K, p=1 atm.

- $E_{z} = -543$ V/cm: Collection efficiency is o.k.
- $E_{z} = +57$ V/cm: electron loss
- $E_{z} = -1043$ V/cm: Low collection efficiency
Photoelectron extraction

Ar/CH$_4$: 40/60; 60/40

\[ E_z \sim \exp(diam.) \]

\[ E_z \sim 1/(pitch)^4 \]

The behaviour predicted by the simulation is confirmed!

C. D. R. Azevedo et al., 2010 JINST 5 P01002
Characterization: 1- geometrical and production parameters

<table>
<thead>
<tr>
<th>Name</th>
<th>Diam (mm)</th>
<th>Pitch (mm)</th>
<th>Rim (μm)</th>
<th>Thick (mm)</th>
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<td>0.6</td>
</tr>
</tbody>
</table>

Small sensitivity to pitch
Max gain prop. 1/(hole diameter)

Optimized Induction and Drift fields and rate ~ 1±2 kHz/mm²

120 kHz/mm² 300 e⁻ → single photoelectron rates of ~35 MHz/mm² → good rate capability
Single photon detection

Our goal single photon detection!

Amplitude distribution for single photon signals

Effective gain = 0.91 \cdot 10^6

stable detector behavior at gains approaching 10^6
It’s the gain of a PMT!
Work in progress: in March ’09 (TIPP09) it was 10^5

converted UV photon rate: 4 kHz

Ar/CH_4: 50/50

Parameters:
- Diam. = 0.4 mm
- Pitch = 0.8 mm
- Thckn. = 0.4 mm
- Rim = 10 \mu m

ΔV_1 = 1600 V
ΔV_2 = 1600 V
ΔV_3 = 1500 V
E_{drif} = 0 V/cm
E_{tr1} = 1500 V/cm
E_{tr2} = 1500 V/cm
E_{end} = 3000 V/cm
Our first detection of Cherenkov light

Triple THGEM (CsI) Ar/CH₄ 50/50 Diam=0.4 mm, pitch=0.8, Thick=0.4, rim ≤10 μm (GE)

-External illumination: pulsed UV laser, monitoring currents, analog readout, digital readout in single photon mode
-Adjustable quartz radiator - Cherenkov photons

Detector behaves in the same way as in the LAB: Gain up to 10⁶, good reproducibility, full control
Timing properties

First indication of Cherenkov light

2 different positions of radiator (change of 20mm)

Max. sustainable gain for stable operation: ~ $10^5$

More studies are needed in beam conditions (mip ionization, Ion Back Flow….)

Laser (no beam)

$\sigma = 8.8 \text{ ns}$

High intensity beam

$\sigma = 9.3 \text{ ns}$
Understanding the charging up

It has been done for standard GEMs: a lengthy iterative procedure to simulate the time dependent process
M Alfonsi, G. Croci, R. Veenhof et al., not yet published

[studies in the context of the RD51 effort to provide adequate simulation tools for MPGDs ]

Example of how the equipotential surfaces are modified by the presence of a charge on the THGEM rim surface. This work is just beginning.
In order to achieve a realistic description of the THGEM electric field configuration a comparative study has been performed: at the beginning the results from ANSYS and COMSOL were not completely consistent; after few bug fixing now the agreement is good.
Performance limitations of MWPC with CsI

1) MWPCs with CsI photocathodes in COMPASS:
   - beam off: stable operation up to > 2300 V
   - beam on: stable operation only up to ~2000 V
   (in spill→ ph. flux: 0 - 50 kHz/cm², mip flux: ~1 kHz/cm²)
   Whenever a severe discharge happens, recovery takes ~1 day.
   Similar behavior reported from JLAB Hall-A

2) Photocathode aging:
   - our information from accidental contamination
   - detailed study by Alice team

[Diagram showing PD Absolute GAIN vs Voltage with data points and effective gain ~ $10^4$, pe detection efficiency ~ 70%]

[Image: Photograph of MWPCs with CsI photocathodes]
Few months after the end of the run

- highest photon flux region
- accumulated charge: ~1 mC/pad
- accidental exposure to air of one CsI cathode
CsI surface at microscope (x 1000)

normal

“white strip”

10 µm