Development of THGEM-based photon detectors for COMPASS RICH-1

Fulvio Tessarotto (I.N.F.N. – Trieste) on behalf of an Alessandria, Aveiro, Freiburg, Liberec, Prague, Torino, Trieste Collaboration

COMPASS RICH-1

The choice of new THGEM-based PD’s

Characterization and simulations

PD prototypes and test-beam results

Engineering problems and large size PD’s

Conclusions
**IN THE COMPASS SPECTROMETER**

**Beam:**
160 GeV $\mu^+$
$2 \cdot 10^8 \mu$/spill
(4.8 s/16.8s)
$P_\mu \sim 80\%$

---

**Beam:**
160 GeV $\mu^+$
$2 \cdot 10^8 \mu$/spill
(4.8 s/16.8s)
$P_\mu \sim 80\%$

---

**Polarised Target**

**SM1 dipole**

**SM2 dipole**

**HCAL1**

**Micromegas, DC, SciFi**

**Gems, SciFi, DCs, straws**

**MUON-Filter1, MW1**

**MUON-Filter2, MW2**

**ECAL2, HCAL2**

**STRAWS, MWPC, GEMS, SCIFI**

**GEMS, SCI FI, DCs, STRAWS**

**Trigger-hodoscopes**

**DW45**

**Veto**

**BMS**

---

![Diagram of the COMPASS spectrometer](Diagram.png)

---

COMPASS RICH-1: a large gaseous RICH with two kind of photon detectors providing:

hadron PID from 3 to 60 GeV/c

acceptance: H: 500 mrad V: 400 mrad

trigger rates: up to ~100 KHz

beam rates up to ~10^8 Hz

material in the beam region: 2.4% X₀

material in the acceptance: 22% X₀

detector designed in 1996

in operation since 2002

first PD upgrade in 2006

(total investment: ~ 4 M €)
COMPASS RICH-1 elements
MWPC's with CsI are successfully used, but:
- the effective gain is moderate (~10,000 → p.e. detection eff. ~70%)
- the quantum efficiency is challenged by aging (~1 mC/cm²)
- the signal is slow, coming from the ions drift (~100 ns)
- for larger gains the electrical stability in the experimental environment is limited and the recovery time after a detector trip is long (~1 d)

Performances in terms of rate capability and noise rejection cannot be increased without a change of technology.

At present the only economic way to cover with photon detectors very large surfaces is to use gaseous photon detectors.

The new photon detectors should:
- use a closed geometry to avoid photon feedback
- reduce the ion backflow to the CsI layer
- detect signals from electron drift (few ns)
- use simple and robust components
following the experience of PHENIX HBD

PHENIX HBD, a threshold Cherenkov counter (window-less)
Central message for any similar application
Reversed bias cuts the MIP signal

Aspects non exportable to imaging devices:
detection of >> 1 photon per pad: low gain (5000)
non negligible noise level (~20% single photon signal)
detect photons with $\lambda$ down to \(~110\) nm: chromaticity


PCB technology, thus:

- robust
- mechanically self supporting
- industrial production of large size boards
- economic

Comparing to GEMs

- Geometrical dimensions $X \sim 10$
  - But e$^-$ motion/multiplic. properties do not!
  - Larger holes: dipole fields and external fields are strongly coupled

About gain:

- Large gains are easily obtained (rim !)

About PCB geometrical dimensions:

- Hole diameter: 0.2 – 1 mm
- Pitch: 0.5 – 5 mm
- Thickness: 0.4 – 3 mm

Introduced in // by different groups:
Four years ago we started an R&D program 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:

\[ V_3 < V_2 < V_1 < V_0 \]

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

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

\[ \Delta V = V_2 - V_1 \]
4 rim production methods

1) traditional
   etching before drilling
   off-centered rims

2) large rim
   metallographic section
   100 μm rim

3) small rim
   20 μm galvanic tin instead of photo-resist
   25 μm rim

4) global etching
   uniform and smooth
   our choice: global micro-etching

Chicago, 11/06/2011 - Technology and Instrumentation in Particle Physics Conference, TIPP 2011
Fulvio TESSAROTTO
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

Several prototypes of small size THGEM-based PD’s and of 100mm x 100 mm PD’s have been built and tested.

Here only a flavor about the role of the rim
**Short time gain variation**

<table>
<thead>
<tr>
<th>Name</th>
<th>Diam (mm)</th>
<th>Pitch (mm)</th>
<th>Rim (µm)</th>
<th>Thick (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>0.4</td>
<td>0.8</td>
<td>0</td>
<td>0.4</td>
</tr>
<tr>
<td>C4</td>
<td>0.4</td>
<td>0.8</td>
<td>100</td>
<td>0.4</td>
</tr>
</tbody>
</table>

**55Fe source; uniform irradiation**

Long time gain variation

100 µm rim

no rim

START IRRADIATING after ~10 hours at nominal voltage

Irradiation at HV switch on (after ~1 day with no voltage)

remainder about gain stability and rim
(Silvia dalla Torre, TIPP 2009)
the issue of THGEM gain and rim

**employing large rim** (100 µm)

**minimum rim** (<10 µm)

---

**Graph A.**

- Single and double THGEMs with various gases (Ne, Ar/CH₄(5%), Ar/CO₂(30%)).
- Effective gain vs. ΔV_{THGEM} (Volt).
- Atm. pressure.

**Graph B.**

- Single THGEM with X-rays limit and Ne CH₄ (23%).
- Effective gain vs. ΔV_{THGEM} (Volt).
- Atm. pressure and x-rays and CsI + UV Light.

---

**THGEMs**

- Dim.: 0.4 mm
- Pitch: 0.8 mm
- Thckn.: 0.4 mm

---

**Gain limited to ~10^5 in test beam:**

MORE WORK REQUIRED
THGEM's with rim and without rim

- **Hole Diameter**: 0.4 mm
- **Pitch**: 0.8 mm
- **Thickness**: 0.4 mm
- **Rim**: 20 µm

- **Thickenss**: 0.6 mm
- **Rim**: 0

- **Hole Diameter**: 0.4 mm
- **Pitch**: 0.8 mm
- **Thickness**: 0.8 mm
- **Rim**: 0

---

Chicago, 11/06/2011 - Technology and Instrumentation in Particle Physics Conference, TIPP 2011

Fulvio TESSAROTTO
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.
It is important to use an appropriate mesh granularity.
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.
Simulations with ANSYS and GARFIELD

Thickness = 600 µm
Metal = 30 µm
Pitch = 1000 µm
$\Delta V = 2000$ V
Fillet = 30 µm
Drift = 2 mm
Induction = 2 mm
$E_{\text{drift}} = 0$ V/cm
$E_{\text{ind}} = 3$ kV/cm
$\phi_{\text{hole}} = 400$ µm

Gas: Argon (50%) / Methane (50%)

1 event distribution for a single hole in 3D
test beams: oct 2009 and aug 2010

Dedicated trigger system (scintilators)

Small 30x30 THGEM

100x100 THGEM
Chamber with 1 MAPMT and 3 triple THGEM photon detector prototypes installed

CERN SPS T2-H4 beam line (RD51 test beam)
150 Gev/c m+ , beam spot s ~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)
thickn. = 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
Signal space and time distributions

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

CERN SPS T2-H4 beam line (RD51 test beam)
150 Gev/c m⁺, beam spot s ~12 mm, rate ~1 kHz

125 ns is the expected transit time for e⁻ in 1 cm of Ar-CH₄ a 1.5 kV/cm (~8x10⁶ cm/s)

Time resolution for THGEM:
~ 8 ns, no optimisation

Chicago, 11/06/2011 - Technology and Instrumentation in Particle Physics Conference, TIPP 2011
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
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.
Photoelectron extraction from time response

\[ G = 0.9 \times 10^5 \]

\[ G = 1.1 \times 10^5 \]

\[ G = 1.4 \times 10^5 \]

\[ G = 2.0 \times 10^5 \]

Fraction of events outside the gaussian peak:

- 23%
- 19%
- 11%
- 6%
photoelectron trajectories from a THGEM photocathode, multiplication switched off
thickness 0.6 mm, diam. 0.4 mm, pitch: 0.8 mm, $\Delta V = 1500$ V

external field above the THGEM: 0

all $e^-$ enter the holes

$e^-$ projected trajectories
correlation between the tail of the timing peak and the reduced extraction efficiency: an effective method to check the field conditions
Important open problem: reduction of IBF

**Typical charge sharing**

- THGEM 1
  - 26% Drift
  - 1% Induction

- THGEM 2
  - 5% Drift
  - 4% Induction

- THGEM 3
  - 68% Drift
  - 49% Induction

- Anode
  - 47% Drift
  - 4% Induction

When the effective gain is $10^6 \rightarrow \sim 500000 \text{ ions/(detected photon)}$ 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 → a different architecture is needed.

Chicago, 11/06/2011 - Technology and Instrumentation in Particle Physics Conference, TIPP 2011

Fulvio TESSAROTTO
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
THGEM Quality checks

COMPASS THGEM pcb’s are produced by an industrial pcb Company: ELTOS S.p.A. (Arezzo - Italy)

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

removed by ultrasonic bath

local defect from Ni-Au coating: refused piece
Test production of large size THGEMs

600 x 600 mm² → ~600,000 holes/piece (cost: ~0.001 €/hole)
Ø: 0.4, pitch: 0.8, thickness: 0.6 mm, rim: 5 μm (micro-etching), Ni-Au coating

Chicago, 11/06/2011 - Technology and Instrumentation in Particle Physics Conference, TIPP 2011
Fulvio TESSAROTTO
PLURITEC MULTISTATION EVOLUTION

- 180,000 turns/min
- 20,000 holes/hour
- Storage: 840 tools
- Controlled diam., depth and run-out

Working area: 630 x 765 mm²
THGEM segmentation studies

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.

Maximum voltage for Strip of Thickness 1 mm

\[ y = 751.84 \ln(x) + 2488.8 \]

Distance [mm]

Maximum Voltage [V]

0.8 mm → 2% dead area
Main goal:

- an opportunity to approach the large size, reduced dead zone detectors, as required for RICH-1 – engineering effort
The 300 mm x 300 mm prototype PD

Some details
The 300 mm x 300 mm prototype PD

Some pictures
The 300 mm x 300 mm prototype PD
Towards 600 mm x 600 mm PD's
COMPASS RICH-1 PD upgrade

- Al vessel
- MWPC’s + CsI
- UV mirror wall
- PMTs
- Beam pipe
- Radiator gas: C\textsubscript{4}F\textsubscript{10}
COMPASS RICH-1 PD upgrade

- Al vessel
- MWPC’s + CsI
- THGEMs + CsI
- UV mirror wall
- PMTs
- beam pipe
- radiator gas: $C_4F_{10}$

Foreseen during CERN shut-down 2013-14
THGEMs represent a good choice for single UV photon detectors: pcb technology is o.k. provided appropriate parameters are chosen

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

“All the rest is engineering”. Many challenges to overcome before achieving large size, cheap, robust, fast, high gain, high rate, magnetic insensitive single photon detectors, but we are progressing

COMPASS RICH-1 will probably be the first to use THGEM-based PDs