The quest for a third generation of gaseous Photon Detectors for Imaging Cherenkov Counters

Fulvio Tessarotto

Introduction

Limitations of MWPC’s with CsI

The choice of THGEM detectors

Characterization and optimization

Large area THGEM based PD’s
### Cherenkov Imaging Detectors presently in use or construction in particle and nuclear physics

<table>
<thead>
<tr>
<th>field of Physics</th>
<th>experiment</th>
<th>where</th>
<th>status</th>
</tr>
</thead>
<tbody>
<tr>
<td>heavy and light quark spectroscopy</td>
<td>BABAR</td>
<td>SLAC</td>
<td>active</td>
</tr>
<tr>
<td></td>
<td>superBELLE</td>
<td>KEK</td>
<td>proposal</td>
</tr>
<tr>
<td></td>
<td>CLEO III</td>
<td>CORNELL</td>
<td>active</td>
</tr>
<tr>
<td></td>
<td>COMPASS</td>
<td>CERN</td>
<td>active</td>
</tr>
<tr>
<td></td>
<td>COMPASS2</td>
<td>CERN</td>
<td>active</td>
</tr>
<tr>
<td></td>
<td>future superB</td>
<td></td>
<td>proposal</td>
</tr>
<tr>
<td></td>
<td>PANDA</td>
<td>GSI</td>
<td>preparation</td>
</tr>
<tr>
<td></td>
<td>MIPP</td>
<td>FERMILAB</td>
<td>active</td>
</tr>
<tr>
<td></td>
<td>GlueX</td>
<td>Jlab</td>
<td>preparation</td>
</tr>
<tr>
<td>K physics</td>
<td>P326</td>
<td>CERN</td>
<td>proposal</td>
</tr>
<tr>
<td>B physics</td>
<td>BABAR</td>
<td>SLAC</td>
<td>active</td>
</tr>
<tr>
<td></td>
<td>superBELLE</td>
<td>KEK</td>
<td>proposal</td>
</tr>
<tr>
<td></td>
<td>future superB</td>
<td>CERN</td>
<td>starting</td>
</tr>
<tr>
<td></td>
<td>LHCb</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longitudinal and transverse spin structure of the nucleon, generalized parton distribution function</td>
<td>COMPASS</td>
<td>CERN</td>
<td>active</td>
</tr>
<tr>
<td></td>
<td>COMPASS2</td>
<td>CERN</td>
<td>proposal</td>
</tr>
<tr>
<td></td>
<td>HERMES</td>
<td>DESY</td>
<td>just concluded</td>
</tr>
<tr>
<td></td>
<td>PANDA</td>
<td>GSI</td>
<td>preparation</td>
</tr>
<tr>
<td></td>
<td>PHENIX</td>
<td>BNL</td>
<td>active</td>
</tr>
<tr>
<td></td>
<td>Hall A</td>
<td>JLAB</td>
<td>active</td>
</tr>
<tr>
<td>quark-gluon fusion</td>
<td>ALICE</td>
<td>CERN</td>
<td>starting</td>
</tr>
<tr>
<td></td>
<td>ALICE upgrade</td>
<td>CERN</td>
<td>proposal</td>
</tr>
<tr>
<td>heavy ion physics</td>
<td>BRAMHMS</td>
<td>RHIC</td>
<td>active</td>
</tr>
<tr>
<td></td>
<td>PHENIX</td>
<td>RHIC</td>
<td>active</td>
</tr>
<tr>
<td></td>
<td>ALICE</td>
<td>CERN</td>
<td>starting</td>
</tr>
<tr>
<td>hadron properties in normal and high density nuclear matter</td>
<td>CBM</td>
<td>GSI</td>
<td>preparation</td>
</tr>
<tr>
<td></td>
<td>HADES</td>
<td>GSI</td>
<td>active</td>
</tr>
<tr>
<td>hypernuclei</td>
<td>PANDA</td>
<td>GSI</td>
<td>preparation</td>
</tr>
</tbody>
</table>
Photon Detectors used for RICHs belong to three categories:

**Vacuum based PDs**
- PMTS (*SELEX, HERMES, BaBar*)
- MAPMTs (*HERA-B, COMPASS*)
- Flat panels (*various test beams, proposed for CBM*)
- Hybride PMTs (*LHCb*)
- MCP-PMT (*all the studies for the high time resolution applications*)

**Gaseous PDs**
- Organic vapours: TMAE and TEA (*DELPHI, OMEGA, SLD CRID, CLEO III*)
- Solid photocathodes: CsI (*HADES, COMPASS, ALICE, JLAB-HALL A, PHENIX*)

**Si PDs**
- Silicon PMs (*first tests only recently*)
photoconverting vapours are no longer in use, a part CLEO III (rates! time resolution!)

the present is represented by MWPC (open geometry!) with CsI
  - the first prove (in experiments!) that coupling solid photocathodes and gaseous detectors works
  - Severe recovery time (~ 1 d) after detector trips
  - Aging
  - Moderate gain: < $10^5$ (effective gain: <1/2)

The way to the future: ion blocking geometries
  - GEM/THGEM allow for multistage detectors
    - With THGEMs: High overall gain ↔ pe det. efficiency!
    - Good ion blocking (up to IFB at a few % level)
    - MHSP: IFB at $10^{-4}$ level
  - opening the way to gaseous detectors with solid photocathodes for visible light

First step in this direction: PHENIX HBD

LARGE SENSITIVE AREAS ↔ GASEOUS PDs
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

![Image of MWPCs]

cluster amplitude distribution:

- effective gain ~ $10^4$
- pe detection efficiency ~ 70%

NDIP 2008, 19/06/2008 - Aix – Les - Bains
Few months after the end of the run

Highest photon flux region

Accidental exposure to air of one CsI cathode

Accumulated charge: ~1 mC/pad
CsI surface at microscope (x 1000)

normal

“white strip”

10 μm
Aging effect from ion bombardment (Alice HMPID)

Irradiation with $^{90}$Sr source of 3 positions located on the Cherenkov ring, subsequent test beam analysis and 2-d scan of cathode photocurrent

H. Hoedlmoser et al., NIM A 574 (2007)28; H. Hoedlmoser, CERN-THESIS-2006-004
GEMs and THGEMs

GAS ELECTRON MULTIPLIER (GEM)
Thin metal-coated polymer foils
70 µm holes at 140 mm pitch

Manufactured by standard PCB techniques of precise drilling and Cu etching.

Hole diameter \( d = 0.3 - 1 \text{ mm} \)
Pitch \( a = 0.7 - 7 \text{ mm} \)
Thickness \( t = 0.4 - 3 \text{ mm} \)

ECONOMIC & ROBUST

Why do we try with THGEMs and reflective photocathode?

No need of high space resolution (> 1 mm)
Large area coverage (5.5 m² for COMPASS RICH)
- industrial production
- stiffness
- robust against discharge damages

For reflective photocathodes,
- no need to keep the window at a fixed potential (2nm Cr → -20%)
- possibility of windowless geometry
- higher effective QE (larger pe extraction probability)
→ small photoconversion dead zones (<20%; GEM ~ 40%)
Large gain
THE RELEVANCE OF HIGH GAINS

Signal amplitude follows Polya distribution:

- Threshold always critical!
- Limited pe detection efficiency, performance instabilities

With good electronics:
- Threshold no longer critical
- Good pe detection efficiency, stable behaviour

Gain $\approx 10^4$

Gain $\approx 10^6$

NDIP 2008, 19/06/2008 - Aix – Les - Bains

Fulvio TESSAROTTO
EXAMPLES OF THGEMS

A MULTIPARAMETER SPACE TO EXPLORE!

4 geometrical parameters: diameter pitch rim thickness
+ material + production procedure

**W₂:**
D=0.3 mm  
Pitch=0.7 mm  
Rim=0.1 mm  
Thick=0.4mm

**P₁:**
D=0.8 mm  
Pitch=2 mm  
Rim=0.04 mm  
Thick=1mm

**R₃:**
D=0.2 mm  
Pitch=0.5 mm  
Rim=0.01 mm  
Thick=0.2mm
EXAMPLES OF THGEMS

A MULTIPARAMETER SPACE TO EXPLORE!

4 geometrical parameters: diameter pitch rim thickness
+ material + production procedure

P₁:
D=0.8 mm
Pitch=2 mm
Rim=0.04 mm
Thick=1mm

R₃:
D=0.2 mm
Pitch=0.5 mm
Rim=0.01 mm
Thick=0.2mm

W₂:
D=0.3 mm
Pitch=0.7 mm
Rim=0.1 mm
Thick=0.4mm

24 different THGEMS characterized so far

NDIP 2008, 19/06/2008 - Aix – Les - Bains

Fulvio TESSAROTTO
CHARACTERIZATION

small prototypes – active surface (30 x 30) mm²

1 THGEM layer for this activity

Ar/CO₂ 70/30

To detect ionizing particle: V₃ < V₂ < V₁ < V₀
LAB STUDIES AT CERN AND TRIESTE

- so far using Cu X-ray
- spectra are collected
- currents are measured at HV
  - homemade instruments (~100 €)
    - with ~1 pA resolution
  - data collection via pictures and image recognition

![Energy Spectrum](image1)

Data: A7W0R063_B
Model: Gauss
Chi^2/DoF = 8.1997
R^2 = 0.98288

- y0 0 ±0.1
- xc1 358.3194 ±1.127
- w1 59.83813 ±2.336
- A1 1173.67306 ±38.888
- xc2 499.6193 ±0.18222
- w2 67.19041 ±0.38037
- A2 8612.61426 ±41.123

Counts vs. ADC channels

1 nF to 100 nF feedback capacitor
10 MΩ feedback resistor:
VISHAY CNS020(± 0.02%, ± 10 ppm/°C)

CMOS Operational Amplifier: AD 8607

NDIP 2008, 19/06/2008 - Aix – Les - Bains
GAIN STABILITY

<table>
<thead>
<tr>
<th>THGEM</th>
<th>Diameter (mm)</th>
<th>Pitch (mm)</th>
<th>Rim (mm)</th>
<th>Thick (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W_2$</td>
<td>0.3</td>
<td>0.7</td>
<td>0.1</td>
<td>0.4</td>
</tr>
</tbody>
</table>

large variation of the gain versus time

NDIP 2008,  19/06/2008  -  Aix – Les - Bains
It is now clarified that the good stability (within ~20-30%) is obtained with small rim (< 20 μm).

<table>
<thead>
<tr>
<th>THGEM</th>
<th>Diameter (mm)</th>
<th>Pitch (mm)</th>
<th>Rim (mm)</th>
<th>Thick (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W₂</td>
<td>0.3</td>
<td>0.7</td>
<td>0.1</td>
<td>0.4</td>
</tr>
</tbody>
</table>

large variation of the gain versus time

Peak Position (ADC channels) vs. Time (sec) for W₂ THGEM with specific parameters:

- 5 h duration
- 4 days time scan
- Cleaned R3 = THGEM: d=0.2 mm; pitch=0.5 mm; rim=0.01 mm; thick=0.2 mm.

Delta V (THGEM) = 1.05 KV
Einduction = 3 KV/cm
Edrift = 2.1 KV/cm
Uncollimated 55Fe source
Rate = 260 Hz

NDIP 2008, 19/06/2008 - Aix – Les - Bains
Understanding the gain characteristics of GEMs inside the Hadron Blind Detector in PHENIX.


Fig. 11. Gain as a function of time after HIV 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.
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

![Graph showing gain vs. Delta V (KV) with different rim thicknesses and THGEM types.](attachment:graph.png)
BUT INCREASING THICKNESS DOES IT TOO

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

PARAMETERS:
• Diameter = 0.3 mm
• Pitch = 0.6 mm
• Thickness = 0.6 mm
• Rim = 0 mm
• Gas: Ar/CO₂ – 70/30

Delta V (KV)

Gain

RIM: 0
RIM: 0.01 mm
RIM: 0.1 mm

THGEM electro-chem. polished without rim
THGEM without rim
THGEM with rim=0.1 mm
THGEM made of kapton
THGEM with different geometry

NDIP 2008, 19/06/2008 - Aix – Les - Bains
Fulvio TESSAROTTO
ARE THGEM DEVICES FOR HIGH RATES?

PARAMETERS:
- Diameter = 0.3 mm
- Pitch = 0.7 mm
- Thickness = 0.4 mm
- Rim = 0 mm
- Gas: Ar/CO₂ – 70/30

RECALL:
120 kHz/mm², 300 e⁻ → single photoelectron rates of ~35 MHz/mm²

PARAMETERS:
- Diameter = 0.3 mm
- Pitch = 0.7 mm
- Thickness = 0.4 mm
- Rim = 0.1 mm
- Gas: Ar/CO₂ – 70/30

E\text{\textsubscript{induction}} = 3.5 KV/cm, E\text{\textsubscript{drift}} = 1.5 KV/cm

120 kHz/mm²
PARAMETERS:
- Diameter = 0.3 mm
- Pitch = 0.7 mm
- Thickness = 0.4 mm
- Rim = variable
- Gas: Ar/CO₂ – 70/30

To detect ionizing particle: \( V_3 > V_2 > V_1 > V_0 \)

**TUNING CHAMBER PARAMETERS**

**DRIFT SCAN**

**INDUCTION SCAN**

X-Ray Source: ~1 mm², rate ~1.7KHz.
Monitoring currents during an "induction scan"

$\text{ThGEM} = \text{C4} \quad \delta V = 1820 \text{V} \quad \text{DRIFT} = 3 \text{ kV/cm}$

$E_{\text{ind}}$ changes the charge shearing between THGEM bottom and anode
CsI evaporation at CERN

(A. Braem, C. David, M. van Stenis)
THE SMALL PROTOTYPE STRUCTURE

Quartz radiator (truncated cone)

1st THGEM (CsI here, external face)
2nd THGEM
Collection anode
Apertures for gas circulation
Read-out
Wires
Perspectives

Short term plans:
- optimize the parameters of the THGEM with photoconverting CsI layer to achieve maximum photoelectron collection efficiency
- optimize the parameters for the (double) THGEM to be used for the amplification of the signal to provide large and stable gain
- produce a set of 300 x 300 mm² THGEMs to be individually tested, selected and glued on thin 600 x 600 mm² (stesalit) frames
- assemble and test a first complete “full size” prototype chamber

Possible medium term project:
- Upgrade of COMPASS RICH (~4m²) with the new photon detectors in case the COMPASS Collaboration decides for it.

Longer term dream:
- find a configuration to reduce the ion back-flow down to $<10^{-5}$ and operate this large area detectors with visible photoconverter
THE FULL SIZE PROTOTYPE

Al frame

Stesalite frames

Anode pads

THGEMs

1500 mm

600 mm

600 mm
Conclusions

- A third generation of gaseous Photon Detectors for RICH applications, based on micropattern gas detectors, is expected to overcome the performance limits of MWPC’s coupled with CsI photocathodes.
- THGEM seem to be very promising: they are stiff, robust and suitable for industrial production; they are expected to provide high gain, small dead areas and very good photoelectron collection efficiencies.
- An effort to characterize these novel detectors has started with the aim to optimize geometrical parameters, production procedures and working conditions for large area coverage.
- A full size 600 x 600 mm$^2$ prototype will be produced, assembled and tested in the incoming months.
Thanks to the help from many colleagues...

M. Alexeev\textsuperscript{a}, R. Birsa\textsuperscript{b}, F. Bradamante\textsuperscript{c}, A. Bressan\textsuperscript{c}, M. Chiosso\textsuperscript{d}, P. Ciliberti\textsuperscript{c}, G. Croci\textsuperscript{e}, M. Colantoni\textsuperscript{f}, S. Dalla Torre\textsuperscript{b}, S. Duarte Pinto\textsuperscript{e}, O. Denisov\textsuperscript{f}, V. Diaz\textsuperscript{b}, N. Dibiase\textsuperscript{d}, V. Duic\textsuperscript{c}, A. Ferrero\textsuperscript{d}, M. Finger\textsuperscript{g}, M. Finger Jr\textsuperscript{g}, H. Fischer\textsuperscript{h}, G. Giacomini\textsuperscript{i}, M. Giorgi\textsuperscript{c}, B. Gobbo\textsuperscript{b}, R. Hagemann\textsuperscript{h}, F. H. Heinsius\textsuperscript{h}, K. Königsmann\textsuperscript{h}, D. Kramer\textsuperscript{j}, S. Levorato\textsuperscript{c}, A. Maggiora\textsuperscript{f}, A. Martin\textsuperscript{c}, G. Menon\textsuperscript{b}, A. Mutter\textsuperscript{h}, F. Nerling\textsuperscript{h}, D. Panzieri\textsuperscript{a}, G. Pesaro\textsuperscript{c}, J. Polak\textsuperscript{b}, E. Rocco\textsuperscript{d}, L. Ropelewski\textsuperscript{e}, P. Schiavon\textsuperscript{c}, C. Schill\textsuperscript{h}, M. Slunecka\textsuperscript{j}, F. Sozzi\textsuperscript{c}, L. Steiger\textsuperscript{j}, M. Sulc\textsuperscript{j}, M. Svec\textsuperscript{j}, S. Takekawa\textsuperscript{c}, F. Tessarotto\textsuperscript{b}, H. Wollny\textsuperscript{h}

\textsuperscript{a} INFN, Sezione di Torino and University of East Piemonte, Alessandria, Italy
\textsuperscript{b} INFN, Sezione di Trieste, Trieste, Italy
\textsuperscript{c} INFN, Sezione di Trieste and University of Trieste, Trieste, Italy
\textsuperscript{d} INFN, Sezione di Torino and University of Torino, Torino, Italy
\textsuperscript{e} CERN, European Organization for Nuclear Research, Geneva, Switzerland
\textsuperscript{f} INFN, Sezione di Torino, Torino, Italy
\textsuperscript{g} Charles University, Prague, Czech Republic and JINR, Dubna, Russia
\textsuperscript{h} Universität Freiburg, Physikalisches Institut, Freiburg, Germany
\textsuperscript{i} University of Bari, Bari, Italy
\textsuperscript{j} Technical University of Liberec, Liberec, Czech Republic