The MPGD-Based Photon Detectors
for the upgrade of COMPASS RICH-1
and beyond

S. Dalla Torre

INFN - TRIESTE

on behalf of the COMPASS RICH group
COMPASS Spectrometer dedicated to h physics @ SPS (CERN)

Top photon detectors

MAPMTs coupled to lens telescopes

MWPCs+Csl (from RD26): successful but performance limitations, in particular for the 4 central chambers

RICH-1

h-PID range: 3-60 GeV/c

n. of ph.s @ β = 1

3 m

6 m

5 m

Al vessel

MWPC’s

MPGD-based PDs

UV mirror wall

PMTs

beam pipe

radiator gas: C4F10

MWPC’s

MPGD-based PDs

4 new detectors of 600 mm x 600 mm

for COMPASS run 2016

JINST 9 (2014) P01006

NIM A 577 (2007) 455
NIM A 779 (2015) 69


COMPASS RICH-1

Pisa Meeting 2018

MPGD-based photon detectors

Silvia DALLA TORRE
**MWPCs with CsI photocathode, the limitations**

- Severe recovery time (~1 d) after a detector discharge
  - *Ion accumulation at the photocathode*
- Feedback pulses
  - *Ion and photons feedback from the multiplication process*
- Ageing (QE reduction) after integrating a few mC/cm²
  - *Ion bombardment of the photocathode*

→ Low gain: a few times $10^4$ (effective gain: <1/2)
→ “slow” detector

To overcome the limitations:

- Less critical architecture
- suppress the PHOTON & ION feedback
- use intrinsically faster detectors

→ **MPGDs**
Following a 7-year R&D

THGEMs bocck photon feedback

Resistive MICROMEGAS by bulk technology
- traps the ions
- ~100 ns signal formation

60 x 60 cm² detectors formed by 30 x 60 cm active elements

THGEM, detail

77% surface for CsI coating

FUSED SILICA WINDOWS
MESH WIRES
DRIF WIREs
THGEM 1
THGEM 2
MESH
ANODE WITH PAD

CsI coating

HV is applied here through a resistor (mesh @ ground)

Resistor arrays

Signals

PCB

0.07 mm fiberglass

Signal readout from this pad

Bulk MICROMEGAS, detail

Micromesh support pillars (diam. 0.4 mm, pitch 2 mm → 8‰ dead area)
COMPONENT QA in a nutshell

Measurement of the raw material thickness before the THGEM Production, accepted: ± 15 μm ↔ gain uniformity σ < 7%

THGEM polishing with an “ad hoc” protocol setup by us: >90% break-down limit obtained

X-ray THGEM test to access gain uniformity (<7%) and spark behaviour

X-ray MM test to access integrity and gain uniformity (<5%)
CsI coating for THGEMS

- THGEM
- THGEM box
- piston
- 4 evaporators
- Turbopump

QE uniformity
- 3 % r.m.s. within a photocathode
- 10 % r.m.s. among photocathodes
- mean value: 93% of reference
Hardware, commercial by CAEN

- HV control
  - Custom-made (C++, wxWidgets)
  - Compliant with COMPASS DCS (slow control)
  - “OwnScale” to fine-tune for gain uniformity
  - V, I measured and logged at 1 Hz
  - Autodecrease HV if needed (too high spark-rate)
  - User interaction via GUI
  - Correction wrt P/T to preserve gain stability

Gain stability vs P, T:
- \( G = G(V, T/P) \)
- Enhanced in a multistage detector
- \( \Delta T = 1^\circ C \rightarrow \Delta G \approx 12\% \)
- \( \Delta P = 5 \text{ mbar} \rightarrow \Delta G \approx 18\% \)

THE WAY OUT:
- Compensate T/P variations by V
  - Gain stability at 5% level

Scan results on parameter: GainMean

Low Intensity  High Intensity

1 week

In total 136 HV channels with correlated values
**Main Detector Figures**

- **Current sparks in THGEMs**
  - Rate < 1/h per detector
  - Recovery time: ~10 s
  - Fully correlated between the two layers
  - Mild dependence on beam intensity

- **Current sparks in MICROMEGAS**
  - Induced by THGEMs
  - Recovery time: ~1 s

- **Ion backflow:** ~3% level

- **Noise:** 900 electron equivalent (r.m.s.)
  - Channel C: 4pF
Correlation between photons and trajectories

From Event Display
- Ring centre calculated from particle trajectory
- Detected photoelectrons: hits on the sensors

For reference:
\[ \theta (\beta = 1) = 52.5 \text{ mrad} \]

\[ p = 3.5 \text{ GeV/c} \]
\[ \theta = 34 \text{ mrad} \ (\pi \text{ hypothesis}) \]

\[ p = 3.8 \text{ GeV/c} \]
\[ \theta = 38 \text{ mrad} \]

\[ p = 4.8 \text{ GeV/c} \]
\[ \theta = 43.5 \text{ mrad} \]

\[ p = 7.8 \text{ GeV/c} \]
\[ \theta = 49 \text{ mrad} \]

\[ p = 8.4 \text{ GeV/c} \]
\[ \theta = 49.5 \text{ mrad} \]
Residual distribution for individual photons (preliminary $\pi$-sample): $\theta_{\text{calculated}} - \theta_{\text{photon}}$

- ** photon_residual_2 **
  - Entries: 47807
  - Mean: 0.3553
  - RMS: 2.056
  - $\chi^2$/ndf: 62.12/14
  - Constant: 2513 $\pm$ 19.0
  - Mean: $-0.001523 \pm 0.016607$
  - Sigma: 1.832 $\pm$ 0.027
  - Sigma: 1.8 mrad

- ** photon_residual_4 **
  - Entries: 30644
  - Mean: 0.7249
  - RMS: 2.309
  - $\chi^2$/ndf: 34.65/17
  - Constant: 1614 $\pm$ 14.3
  - Mean: $0.562 \pm 0.017$
  - Sigma: 1.751 $\pm$ 0.021
  - Sigma: 1.7 mrad

- ** photon_residual_11 **
  - Entries: 20106
  - Mean: 0.5085
  - RMS: 2.54
  - $\chi^2$/ndf: 51.02/11
  - Constant: 1081 $\pm$ 12.0
  - Mean: $-0.05879 \pm 0.01887$
  - Sigma: 1.555 $\pm$ 0.021
  - Sigma: 1.6 mrad

- ** photon_residual_13 **
  - Entries: 20887
  - Mean: 0.04575
  - RMS: 2.497
  - $\chi^2$/ndf: 58.47/17
  - Constant: 1083 $\pm$ 11.8
  - Mean: $-0.272 \pm 0.020$
  - Sigma: 1.747 $\pm$ 0.026
  - As expected

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MPGD-based photon detectors

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GAIN FROM A PURE PHOTON SAMPLE

From electronic noise → Threshold

From threshold & gain → photoelectron detection (effective) efficiency > 80%

For comparison, in MWPCs: ~50-60%

Gain = 13445 +/- 144.943

Gain = 13854 +/- 205.862

From the extrapolated exponential an estimate of the noise level under the signal: ~10%
DETECTED PHOTONS per RING

<table>
<thead>
<tr>
<th>h_n_VS_theta_after</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Entries</td>
<td>56</td>
</tr>
<tr>
<td>Mean</td>
<td>39.82</td>
</tr>
<tr>
<td>RMS</td>
<td>14.04</td>
</tr>
<tr>
<td>$\chi^2 / \text{ndf}$</td>
<td>27.66 / 13</td>
</tr>
<tr>
<td>$p_0$</td>
<td>1808 ± 147.7</td>
</tr>
<tr>
<td>$p_1$</td>
<td>9.477 ± 6.200</td>
</tr>
</tbody>
</table>

- **Extrapolate to 52.5 mrad**, number of photons = 12.0493
- **First part of the function**, signal = 10.9547
- **Second part of the function**, noise = 1.09458

$$N(\theta_{\text{Ch}}) = p_0 \cdot \sin^2 \theta_{\text{Ch}} + p_1 \cdot \theta_{\text{Ch}}$$

Blue: after Poisson correction

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DETECTED PHOTONS per RING

\[ N(\theta_{Ch}) = p_0 \cdot \sin^2 \theta_{Ch} + p_1 \cdot \theta_{Ch} \]

- Extrapolate to 52.5 mrad, number of photons = 2.0493
- First part of the function, signal = 1808.9 ± 147.7
- Second part of the function, noise = 9.477 ± 6.200

Blue: after Poisson correction

Characterization on-going
h-PID at high $p$ ($> 6-8$ GeV/c)

- Required for physics at the future ELECTRON-ION COLLIDER (EIC)
  - Collider-specific issues
    - shorter radiator to control setup sizes (advantages also for fixed target)
      namely more detected photons per unit radiator length
      → increased resolution
    - Operation in magnetic field
  - An interesting option
    - Exploit the extremely far VUV region (~120 nm) with a windowless RICH and gaseous photon detectors, test beam @ Fermilab
MOVING FURTHER WITH MPGD-based PDs

In the frame of
- Generic R&D for EIC – eRD6
- INFN – RD_FA

resistive MM
with small
pad size
O(10 mm²)

ALREADY ON GOING

GEM vs THGEM as photocathodes

Issues related to hybrid MPGD-based PDs operated in C-F atmosphere:
- photoelectron extr
- detector gain
- ageing

C. D. R. Azevedo et al., 2010 JINST 5 P01002
A VERY RECENT NEW OPTION FOR THE R&D

Csl, the only standard photoconverter compatible with gaseous atmospheres, has problematic issues, main ones:

- It does not tolerate exposure to air (H₂O vapour, O₂)
- Ageing by ion bombardment

Antonio Valentini et al. – INFN Bari
Italian patent application n. 102015000053374

- Photocathodes: **diamon film obtained with Spray Technique making use of hydrogenized ND powder**
  - Spray technique: T ~ 120° (instead of >800° as in standard techniques)

Coupling of ND photoconverter and MPGDs?

an exiting perspective with several open questions

- Compatibility, performance with gas?
- Radiation hardness?
- Ageing?

47 % (!)

CsI, the only standard photoconverter compatible with gaseous atmospheres, has problematic issues, main ones:

- It does not tolerate exposure to air (H₂O vapour, O₂)
- Ageing by ion bombardment

L.Velardi, A.Valentini, G.Cicala al., Diamond & Related Materials 76 (2017) 1
SUMMARIZING ...

- **MPGD-based photon detectors** accomplish their mission in COMPASS RICH-1
  - From preliminary characterization exercises:
    - stable gain, large gain, good number of detected photoelectrons

- Technological achievement - for the **FIRST TIME**:
  - **single photon detection** is accomplished by MPGDs
  - THGEMs used in an experiment
  - MPGD gain > 10k in an experiment

- **MPGD-based photon detectors have a mission in the future of hadron physics**
THANK YOU
MORE INFORMATION
COMPASS RICH-1, gas transparency
- gas cleaning by on-line filters,
- separate functions:
  - Cu catalyst, ~ 40°C for O₂
  - 5A molecular sieve, ~ 10°C for H₂O

HANDLING THE VUV DOMAIN

Csl gasous sensors used in several Cherenkov detectors

\[(n-1) \text{ r.m.s (assuming Frank and Tamm):} \]

\[30 \times 10^{-6} \quad 46 \times 10^{-6}\]

MAPMT with UV extended window

MQWPCs with Csl photocathode

Refractie index

transmission through 1.87 m, corresponding to:

\[\text{H}_2\text{O}: \sim 1 \text{ ppm}, \quad \text{O}_2: \sim 3 \text{ ppm}\]
OUR THGEM DESIGN

- Thickness: 0.4 mm, hole diameter: 0.4 mm, pitch: 0.8 mm
- 12 sectors on both top and bottom, 0.7 mm separation
- 24 fixation points to guarantee THGEMs flatness
- Border holes diam.: 0.5 mm
- Two THGEMs side by side to form the 60 x 60 cm² surface
- Pillars in PEEK
FIELD SHAPING ELECTRODES AT THE EDGES

THGEM border study

large field values at the chamber edges and on the guard wires

isolating material (Tufnol 6F/45) protection

Field shaping electrodes in the isolating material protections of the chamber frames
Selecting good hit candidates (A0<5 ADC units, 0.2<A1/A2<0.8)

Clusterization to separate MIPs

Hybrid MPGD (novel detector)

MWPC (old detector)

All sectors provide the same time response

MPGD-based photon detectors

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Noise

photons

MIPs

APV saturation

MIP suppression by strong reversed bias
After 7 years of R&D

THGEM characterization, performance

- 100 μm rim
- no rim

Photoelectron extraction

- Photon yield (blue)
- Charged Particles (red)
- vs Drift Field

IBF (Ion Back Flow) suppression

- Tripple THGEM: IBF suppression (<5%) by staggering plates

IBF suppression (<3%) introducing a MM stage: no need of high Transfer electric field
- Hybrid architecture

Time resolution
~7 ns

UV light scan vs E_drift

Cherenkov light detection in TB
**THGEMs, lessons**

- Full vertical correlation of current sparks THGEM1 & THGEM2
- Recovery time <10 s (our HV arrangement)
- Spark rate: ~ no dependence on beam intensity and even beam on-off
- Discharge correlation within a THGEM (also non adjacent segments) and among different THGEMs (cosmics ?)
- Total spark rates (4 detectors): ~10/h

**MICROMEGAS, lessons**

- MM sparks only when a THGEM spark is observed (not vice versa)
- Recovery time ~1s (our HV arrangement)
- The only real issue: dying channels (pads)
  - Local shorts, larger current, no noise issue
  - 2.5 % developed in 12 months
  - Dirty gas / dust from molecular sieves & catalyst?

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**Graphs:**

- Spark rate vs. beam intensity
- Current vs. time
NOISE FIGURES

MWPCs (0.2 pF): $\langle \sigma \rangle \sim 700 \ e^{-}$

Hybrids (4 pF): $\langle \sigma \rangle \sim 900 \ e^{-}$
CONSTRUCTION & ASSEMBLY

- Complex mechanics
- Wire planes
- Glueing the support pillars
- Automatized glueing
- Detector layers
- THGEM staggering
ASSEMBLY in a nutshell

Pre-assembly w/o CsI

Onto the RICH

glovebox also to mount the active module onto the RICH

final assembly of the active module assembly with CsI in glovebox
**CsI QE measurements at coating**

19 CsI evaporations performed in 2015 - 2016 on 15 pieces: 13 THGEMs, 1 dummy THGEM, and 1 reference piece (best from previous coatings)

11 coated THGEMs available, 8 used + 3 spares

<table>
<thead>
<tr>
<th>THGEM number</th>
<th>evaporation date</th>
<th>at 60 degrees</th>
<th>at 25 degrees</th>
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<tbody>
<tr>
<td>Thick GEM 319</td>
<td>1/18/2016</td>
<td>2.36</td>
<td>2.44</td>
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<tr>
<td>Thick GEM 307</td>
<td>1/25/2016</td>
<td>2.65</td>
<td>2.47</td>
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<td>Thick GEM 407</td>
<td>2/2/2016</td>
<td>2.14</td>
<td>2.47</td>
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<td>Thick GEM 418</td>
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<td>2.79</td>
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<td>Thick GEM 410</td>
<td>2/15/2016</td>
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<td>Thick GEM 429</td>
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<td>2.75</td>
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<td>Thick GEM 334</td>
<td>2/29/2016</td>
<td>2.77</td>
<td>3.00</td>
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<tr>
<td>Thick GEM 421 re-coating</td>
<td>3/10/2016</td>
<td>2.61</td>
<td>2.83</td>
</tr>
</tbody>
</table>

Reference piece: 7/4/2016 3.98 3.76

QE measurements indicate

\[
I_{Normalized} = \frac{I_{CsI} - I_{CsI\,Noise}}{I_{Ref} - I_{Ref\,Noise}}
\]

\[
<\text{THGEM QE}> = 0.73 \times \text{Ref. piece QE with s.r.m. of 10%}
\]

in agreement with expectations (THGEM optical opacity = 0.78)

QE is the result of a surface scan (12 x 9 grid, 108 measurements)

Good uniformity, in the example \( \sigma_{QE} / <QE> = 3\% \)
**CONSTRUCTION & ASSEMBLY**

- **Complex and precise mechanics**
- **Assembly in clean room**
- **Machine controlled glue-dispenser**
- **Including photocathode in glovebox**
- **Glovebox also to mount the active module onto the RICH**
READ-OUT and SERVICES

read-out:
already available for the MWPCs with CsI

FE chip APV25
LV supply
COOLING
Gas lines
P, T sensors

150 ns