The MPGD-Based Photon Detectors

for the upgrade of COMPASS RICH-1

and beyond

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INFN - TRIESTE

on behalf of the COMPASS RICH group
COMPASS RICH-1

COMPASS Spectrometer dedicated to $h$ physics
@ SPS (CERN)

Top photon detectors

MAPMTs coupled to lens telescopes

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

h-PID range: 3-60 GeV/c

MWPCs + MPGD-based PDs

4 new detectors of 600 mm x 600 mm

JINST 9 (2014) P01006

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


n. of ph.s @ $\beta = 1$
GASOUS PHOTON DETECTORS so far

**MWPCs + CsI**

**RD26 development**

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

Reduced wire-cathode gap because of:

- Fast RICH (fast ion collection)
- Reduced MIP signal
- Reduced cluster size
- Control photon feedback spread
Following a 7-year R&D

2 layers of staggered THGEMs:
- pre-amplification
- transversally enlarged avalanche

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

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

PADs: 8x8 mm²

0.07 mm fiberglass

Signal read-out from this pad

PCB

HV

77% surface for CsI coating

FUSED SILICA WINDOWS
MESH WIRES
DRIF WIRES
THGEM 1
THGEM 2
MESH
ANODE WITH PADS

modular structure: one module = 600x300 mm²

PADs: 8x8 mm²

THGEM, detail
**COMPONENT QA in a nutshell**

- **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%)

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

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**Components**

- MPGD2019
- MPGD-based photon detectors

**Speaker**

Silvia DALLA TORRE

**Institution**

INFN

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**Slide Number**

5
CsI coating for THGEMS

THGEM

THGEM box

piston

4 evaporators

Turbopump

QE measurement

QE uniformity

- 3 % r.m.s. within a photocathode
- 10 % r.m.s. among photocathodes
- mean value: 93% of reference
Assembling CsI coated THGEM in a dedicated glove box flushing with N₂
The HV system

HV CONTROL

MAIN CHALLENGES

- In total 136 HV channels with highly correlated values
- Stabilize and equalize the gain in the 16 sectors
- Gain stability vs P, T:
  - \( G = G(V, T/P) \)
  - \( \Delta T = 1^\circ C \Rightarrow \Delta G \approx 12\% \)
  - \( \Delta P = 10 \text{ mbar} \Rightarrow \Delta G \approx 20\% \)
- THE WAY OUT:
  - Compensate T/P variations by V

Gain stability at the 6% level!
Gain uniformity at the 5% level!

83 days
180 days
Spark rate/d per detector

Hardware in the experimental Hall

P/T sensors → RPi → HV Crate → Hybrid Detectors

(DIM) → (HVC) → (CAEN HV Control Protocol)

Control Terminal

GUI

Hybrid High Voltage Control

COMPASS Detector Control System

(HVCM)

(DIM)

(DIM)

(DIM)

Interpreter

Gain stability at the 6% level!
**HV segmentation**

- **MAIN CHALLENGES**
  - In total 136 HV channels with highly correlated values
  - Stabilize and equalize the gain in the 16 sectors
  - Gain stability vs P, T:
    - $G = G(V, T/P)$
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- **THE WAY OUT**
  - Compensate T/P variations by V
  
  
  
  
  
  

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Gain stability at the 6% level!

Gain uniformity at the 5% level!

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Further progress in this field:

- "A Scalable System Gaseous with SoC Detector for Levorato’s talk"
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
- Rate < 1/d
- Correlated with THGEM sparks: 70%
- Recovery time: ~1 s

Noise (r.m.s.):
- on average 900 electron equivalent
- Channel C: 4pF

Ion backflow: ~ 3% level
Correlation between photons and trajectories

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

- Ring center calculated from particle trajectory
- Detected photoelectrons: hits on the sensors
Residual distribution for individual photons (preliminary):

\[ \theta_{\text{calculated}} - \theta_{\text{photon}} \]

According to design figures

Sigma: 1.8 mrad
GAIN FROM A PURE PHOTON SAMPLE

From electronic noise $\rightarrow$ Threshold

From threshold & gain $\rightarrow$ **photoelectron detection** (effective) **efficiency > 80%**

For comparison, in MWPCs: $\sim$50-60%

Gain = 13445 +/- 144.943

From the extrapolated exponential an estimate of the noise level under the signal: $\sim$10%

Gain = 13854 +/- 205.862

1 ADC channel = 300 electrons

Entries: 45684
Mean: 46.07 $\pm$ 0.1947
RMS: 41.61 $\pm$ 0.1376
Underflow: 0
Overflow: 0
Integral(w): 4.568e+04
$\chi^2$/ndf: 176.2 / 153
Prob: 0.09668
p0: 988.6 $\pm$ 21.6
p1: 0.02231 $\pm$ 0.00024

Entries: 29356
Mean: 41.31 $\pm$ 0.2427
RMS: 41.59 $\pm$ 0.1716
Underflow: 0
Overflow: 0
Integral(w): 2.936e+04
$\chi^2$/ndf: 172.4 / 153
Prob: 0.1351
p0: 503.8 $\pm$ 14.9
p1: 0.02165 $\pm$ 0.00032
**DETECTED PHOTONS per RING**

<table>
<thead>
<tr>
<th>h_n_VS_theta_after</th>
<th></th>
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<tbody>
<tr>
<td>Entries</td>
<td>116</td>
</tr>
<tr>
<td>Mean</td>
<td>39.52</td>
</tr>
<tr>
<td>RMS</td>
<td>13.04</td>
</tr>
<tr>
<td>(\chi^2 / \text{ndf})</td>
<td>19.19 / 16</td>
</tr>
<tr>
<td>(p_0)</td>
<td>3384 ± 118.0</td>
</tr>
<tr>
<td>(p_1)</td>
<td>46.34 ± 4.90</td>
</tr>
</tbody>
</table>

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

Extrapolate to saturation, number of photon= 12.9
First part of the function = 10.3 +/- 0.4
Second part of the function= 2.6 +/- 0.3
ON-GOING R&D

- Development of an optimized detector for finer spatial resolution based on the hybrid double THGEM + MM and “mini-pads” of size 3mm x 3mm

- Exploring the possibility to use a more robust photocathode in the far UV: hydrogenated nano-diamond crystals

GOAL

- Application: h-PID at high p at the future ELECTRON-ION COLLIDER (EIC)
- Gaseous PDs exploiting the extremely far VUV region (~120 nm) with a windowless RICH
FOR MORE INFORMATION

A modular mini-pad photon detector at high p at the future ELECTRON-ION COLLIDER (EIC) exploiting the extremely far VUV region (~120 nm) with a prototype MPGD-based RICH 2-POSTER detector in diamond & related materials 76 (2017) 1

S. Dasgupta: A modular mini-pad photon detector at high p at the future EIC.

MPGD-based photon detectors

Silvia DALLA TORRE

IEEE NS 62 (2015) 3256

Development of an optimized detector for finer spatial resolution based on the hybrid THGEM + MM and "mini-pad" size 3mm x 3mm

ON-GOING R&D
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
  - First resistive MM used in an experiment
  - For the first time MPGD gain > 10k in an experiment

- **MPGD-based photon detectors have a mission in the future of hadron physics**
THANK YOU
MORE INFORMATION
HANDLING THE VUV DOMAIN

**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

**CsI gasous sensors used in several Cherenkov detectors**

- MWPCs with solid state photocathode (the Rb26 effort)
  - TIC, NA44
  - JLAB-HALL A

**COMPASS, RICH-1**
- CsI area > 5 m²

**PHENIX HBD**
- CsI + GEMs

**CsI QE**

**n-1 r.m.s (assuming Frank and Tamm):**
- 30×10⁻⁶
- 46×10⁻⁶

**MAPMT with UV extended window**

**transmission through 1.87 m, corresponding to:**
- H₂O: ~1 ppm
- O₂: ~3 ppm

**Refractie index**

**CsI + GEMs**

**MPGD2019**

**MPGD-based photon detectors**

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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

Tail of the signal amplitude spectrum

ADC saturation signals, mostly from charged particles
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

Photon yield (blue) & Charged Particles (red)

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MPGD-based photon detectors
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THGEMs, lessons

- Full vertical correlation of current sparks THGEM1 & THGEM2
- Recovery time <10 s (our HV arrangement)
- Spark rates: ~ 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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BEAM INTENSITY from ppp on T6 (AVERAGE per h) x 10^{12}

Spark rate (h^{-1})

Current (μA)

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MPGD-based photon detectors
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MWPCs (0.2 pF): $\langle \sigma \rangle \sim 700 \text{ e}^-$

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

Complex mechanics

Wire planes

Glueing the support pillars

THGEM staggering

Automatized glueing

detector layers
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>
</tr>
</thead>
<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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<tr>
<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>
<td>2/8/2016</td>
<td>2.79</td>
<td>2.98</td>
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<tr>
<td>Thick GEM 410</td>
<td>2/15/2016</td>
<td>2.86</td>
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<tr>
<td>Thick GEM 429</td>
<td>2/22/2016</td>
<td>2.75</td>
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<td>Thick GEM 334</td>
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<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>
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<tr>
<td>Reference piece</td>
<td>7/4/2016</td>
<td>3.98</td>
<td>3.76</td>
</tr>
</tbody>
</table>

QE measurements indicate

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

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 \( \sigma_{\text{QE}} / <\text{QE}> = 3\% \)
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: already available for the MWPCs with CsI

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

150 ns