Performance of the chromium GEM detector

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Outline

» Motivation
» Front-end and readout system
» GEM with reduced Cu content
» Gas flow studies
» Gas mixtures studies
  – GEM relative gas gain variation
  – GEM energy resolution
» Long term stability
» Summary
Motivation

» Very significant reduction of the fluorescence radiation from Cu
   – GEM foils with much reduced Cu content
» Optimization of the detection efficiency of soft X-ray photons
   – Xe-based gas mixtures
   – Kr-based gas mixtures
» Optimization of the energy resolution
   – Detector properties
     • Different gas mixtures
     • Optimum gas gain (signal dynamic range)
     • Temperature and pressure corrections
     • Readout electronics and software configuration
» Long term stability
   – Gas gain variation
Readout system

New front-end electronics under the tests

See talk by Tomasz Fiutowski
“GEMROC2 – a self-triggered ASIC”

Thursday 14:30 - 14:50

- Switchable gain and signal polarity
- Self triggered mode
- Zero suppression and derandomization
- Ethernet interface for data readout – 2 Gbit/s throughput
Special GEM with reduced Cu

» Produced out of standard GEM foils
  – Etched Cu layers
  – Copper grid leftover to keep good mechanical and electrical GEM foil properties
    • Width 100 µm every 1 cm
  – Remains very thin (100 nm) Cr layer
» Drift electrode
  – The same post-processing
» Readout structure
  – Keep untouched
  – Most of the cooper remains on it
» The foils were produced by Techtra
  – Many thanks to Piotr Bielówka
Standard GEM foil vs. GEM-Cr

Standard GEM foil

GEM-Cr foil
## Gas flow studies

<table>
<thead>
<tr>
<th>Gas flow [ml/hour]</th>
<th>Time to exchange one detector volume in [hour]</th>
<th>Relative change of gas gain</th>
<th>Relative change of energy resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>249</td>
<td>1.3</td>
<td>1.00</td>
<td>1.000</td>
</tr>
<tr>
<td>145</td>
<td>2.2</td>
<td>0.97</td>
<td>1.004</td>
</tr>
<tr>
<td>121</td>
<td>2.6</td>
<td>0.95</td>
<td>1.000</td>
</tr>
<tr>
<td>80</td>
<td>3.9</td>
<td>0.85</td>
<td>1.026</td>
</tr>
<tr>
<td>60</td>
<td>5.2</td>
<td>0.79</td>
<td>1.070</td>
</tr>
</tbody>
</table>

- Standard GEM used
- Standard gas mixture – Ar/CO₂ (70/30)
- Stable condition (HV, etc., correction for gas temperature and pressure)
Gas gain correction for gas T and p

- Uncorrected peak position (blue)
- Corrected peak position (orange)
- Gas temperature (green)
- Gas pressure (red)
GEM-Cr results for different gas mixtures

- All presented below results are for the GEM-Cr detector
  - They are presented in a chronological order
- The gas flow was set to at least 250 ml/h
- The gas gain was similar in all of the measurements
- The detector was biased and in operation for a long time
- The measurement were done in the same conditions
  - The only significant variation was due to the atmospheric pressure changes
  - The temperature was quite stable +/-1 C
  - All the others parameters were constant
Signal saturation (of individual hits)
Larger dynamic range needed – GEMROC2
Ar/CO$_2$ (70/30) gas mixture

Energy resolution Fe-55 (FWHM) - 19.8% @ 3860V
Ar/CO₂ (70/30) gas mixture

Relative gas gain map

Energy resolution map
Xe/CO₂ (90/10) gas mixture

Energy resolution Fe-55 (FWHM) – 20.3% @ 4000V
Xe/CO$_2$ (90/10) gas mixture

Relative gas gain map

Energy resolution map
Xe/TMA (95/5) gas mixture

Energy resolution Fe-55 (FWHM) – 18.9% @ 2420V
Xe/TMA (95/5) gas mixture

Relative gas gain map

Energy resolution map
Kr/CO$_2$ (80/20) gas mixture

Energy resolution Fe-55 (FWHM) – 18.2% @ 4080V
Kr/CO₂ (80/20) gas mixture

Relative gas gain map

Energy resolution map
Relative gas gain maps for Kr/CO₂ (80/20) @ 4010-4110 V
Summary for different gas mixtures studies

<table>
<thead>
<tr>
<th>Gas mixture</th>
<th>Energy resolution [%]</th>
<th>HV [V]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ar/CO₂ 70/30</td>
<td>19.8</td>
<td>3860</td>
</tr>
<tr>
<td>Xe/CO₂ 90/10</td>
<td>20.3</td>
<td>4080</td>
</tr>
<tr>
<td>Xe/TMA 90/10</td>
<td>18.9</td>
<td>2420</td>
</tr>
<tr>
<td>Kr/CO₂ 80/20</td>
<td>18.2</td>
<td>4080</td>
</tr>
</tbody>
</table>

- Measurements with premixed gas mixtures
- Kr-based gas mixture seems to be the most suitable
  - Relatively low cost (in comparison to Xe)
  - The best energy resolution
  - Low escape peak intensity and energy (for L-line)
- The dead volume in the detector shall be reduced or eliminated
  - The volume between the Kapton window and the drift electrode
  - Will result in better efficiency and more uniform response
Long term stability

Detector operation (with some stops)

- Started in June 2016 and operational till now
- Many measurements performed during this time
  - Detector and readout repeatedly controlled with Ar/CO₂ (70/30) gas mixture
  - Constant measurement of the gas gain and energy resolution for last 4 months
    - Ar/CO₂ (70/30) and Fe-55
    - Still ongoing tests
Relative gas gain maps – long term stability

(a) Ar/CO$_2$ (70/30) 2016-06-03, HV 3840.
(b) Xe/CO$_2$ (90/10) 2016-06-29, HV 4000.
(c) Ar/CO$_2$ (70/30) 2016-10-28, HV 3875.
(d) Xe/TMA (95/5) 2016-11-09, HV 2420.
(e) Ar/CO$_2$ (70/30) 2017-01-02, HV 3900.
(f) Kr/CO$_2$ (80/20) 2017-01-11, HV 4080.
Energy resolution – long term stability

(a) Ar/CO₂ (70/30) 2016-06-03, HV 3840.
(b) Xe/CO₂ (90/10) 2016-06-29, HV 4000.
(c) Ar/CO₂ (70/30) 2016-10-28, HV 3875.
(d) Xe/TMA (95/5) 2016-11-09, HV 2420.
(e) Ar/CO₂ (70/30) 2017-01-02, HV 3900.
(f) Kr/CO₂ (80/20) 2017-01-11, HV 4080.
Long term stability

<table>
<thead>
<tr>
<th>Gas mixture</th>
<th>Time period [d]</th>
<th>max R_gg</th>
<th>min R_gg</th>
<th>sigma R_gg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ar/CO₂ 70/30</td>
<td>0</td>
<td>1.250</td>
<td>0.801</td>
<td>0.069</td>
</tr>
<tr>
<td>Xe/CO₂ 90/10</td>
<td>26</td>
<td>1.472</td>
<td>0.559</td>
<td>0.166</td>
</tr>
<tr>
<td>Ar/CO₂ 70/30</td>
<td>147</td>
<td>1.356</td>
<td>0.721</td>
<td>0.090</td>
</tr>
<tr>
<td>Xe/TMA 90/10</td>
<td>159</td>
<td>1.472</td>
<td>0.556</td>
<td>0.166</td>
</tr>
<tr>
<td><strong>Ar/CO₂ 70/30</strong></td>
<td><strong>213</strong></td>
<td><strong>1.584</strong></td>
<td><strong>0.555</strong></td>
<td><strong>0.205</strong></td>
</tr>
<tr>
<td>Kr/CO₂ 80/20</td>
<td>222</td>
<td>1.538</td>
<td>0.584</td>
<td>0.194</td>
</tr>
<tr>
<td>Ar/CO₂ 70/30</td>
<td>245</td>
<td>1.471</td>
<td>0.594</td>
<td>0.181</td>
</tr>
<tr>
<td>Ar/CO₂ 70/30</td>
<td>287</td>
<td>1.624</td>
<td>0.585</td>
<td>0.176</td>
</tr>
</tbody>
</table>

- Clearly seen significant degradation of the detector after using the TMA
- Detector not recovered after switching to standard gas mixture
  - Slight decrease of the standard deviation of the relative gas gain values
Long term stability - gas gain changes

- Result of the constant GEM detector irradiation with Fe-55
  - About 1000 h with ~20 cps/mm² for the whole detector area
  - Peak position corrected for T and p changes
- Significant decrease of the absolute gas gain
- Visible changes of relative gas gain maps
GEM-Cr new foil and after irradiation

- Visual inspection shows no differences between the foils
  - No cracks or other indication of problems detected
    - Surface of the foil and holes look similar
  - All foils used for measurement were investigated
Summary

» Results
  – Promising results especially with Kr/CO$_2$ gas mixture
  – Energy resolution at the level of 18% for the whole detector
    • After all corrections
  – Significant changes of the relative gas maps
    • Degradation of the signal height (gas gain) with the time
      – Especially for TMA admixture
  – GEM Cr may be acceptable for the applications with low expected cumulative dose
    • Needs further investigation

» Plans for near future
  – Detector
    • Continue operation of the chromium GEM detector until it is completely aged or destroyed
    • Testing new detector without TMA
    • Estimation the ageing rate (dose)
  – Front-end electronics
    • Repeat the measurements with the GEMROC2 ASIC
References

» Front-end electronics

» DAQ hardware and software

» GEM-Cr Detector
   – B. Mindur et al., *First X-ray measurement results with the chromium GEM detector*, presentation @ MPGD 2016
   – *Soon we would like to publish all the results in JINST*
BACKUP Slides
Energy resolution maps for Kr/CO₂ (80/20) (@ 4010-4110 V)
Results of a discharge in the detector

GEM top

GEM middle
X-ray photon absorption

Absorption coefficient vs energy for Ar, Kr, Xe gases in 3 mm thickness of the drift gap