Neutron and beta imaging with Micromegas detectors with optical readout

MPGD 2022 – 15/12/2022

(Université Paris-Saclay, CEA, IRFU)
F.M. Brunbauer, L. Ropelewski, E. Oliveri (CERN)
F. Beau, L. Devel, C. Malgorn (Université Paris-Saclay, CEA, Institut Joliot)
F.J. Iguaz-Gutierrez (Soleil Synchrotron)
A. Sari (Université Paris-Saclay, CEA, List)
CONTEXT

LIGHT PRODUCTION MECHANISMS

LIGHT DETECTION DEVICES

DETECTOR CHARACTERIZATION WITH X-RAY SOURCES

APPLICATIONS

B-IMAGING

PRELIMINARY RESULTS WITH TRITIUM SAMPLES

NEUTRON RADIOGRAPHY

PRELIMINARY RESULTS WITH A NEUTRON SOURCE

CONCLUSION AND PERSPECTIVES
Advantages:

- 2D pixelized readout of high granularity
- Megapixel resolution from commercial cameras
- Integrated imaging approach

Applications:

- Real-time neutron imager
- β imager for sub-becquerel activity measurement
**Scintillation**

Prompt emission of photon after absorption of incident radiation.

(1 ns to 1 μs)

**Primary scintillation**

Coming from the excitation of the gas due to incident particles.

**Secondary scintillation**

Coming from avalanche amplification.

**Fluorescence**

Gas mixture: Ar/CF$_4$
Hamamatsu CMOS camera

Readout noise

| Standard scan | 0.43 electrons rms |
| Ultra quiet scan | 0.27 electrons rms |

Pixels

| Number | Size |
| 4096 x 2304 | 4.6 µm x 4.6 µm |

Dark current

| Cooling | Sensor temperature | Dark current |
| Air | - 20 °C | 0.016 e⁻/pixels/s |

Minimum exposure time

| Mode       | Rate      |
| Standard   | 1 µs/frame |
| Ultra quiet | 100 ms/frame |
LIGHT DETECTION

- Scintillation spectrum of Ar 80% - CF4 20% gas mixture
- QE of ORCA Quest camera
- ITO optical transmission of 25 nm thickness
DETECTOR CHARACTERIZATION WITH X-RAY SOURCES
DETECTOR CHARACTERIZATION WITH X-RAYS

Bulk on glass from CERN and IRFU

- Charge readout test in Argon+5%Iso: gain above $10^4$ and FWHM reaches 16%
- Coated glass with 150 nm of ITO (Indium Thin Oxide)
- Pillars with hexagonal pattern and large pitch (6 mm)

Charge readout spectrum in Ar/Iso 5%

S. Aune, T. Benoit, M. Kebbiri
X-ray radiography (20 kV) – Ar/CF₄(20%)

- High gain: 1 min exposure time gives images with good contrast
SOLEIL BEAM TEST (16/11-18/11)

Synchrotron Soleil (4 keV – 15 keV)

Goals

- Determination of Point Spread Function
- Spatial resolution dependence on drift gap, drift field and beam energy
- Detector homogeneity

PRELIMINARY

1x1mm beam, Primary Scintillation
(Va=0 V, Vd=0 V)

1x1mm beam, Amplification
(Va=400 V, Vd=210 V)

0.035x0.035mm beam, Amplification
(Va=400 V, Vd=210 V)
$35 \times 35 \, \mu m^2$ beam, 6keV, Drift gap = 3 mm

PRELIMINARY

PSF(Vdrift)
- Vamp = 35 kV/cm
- Vamp = 37 kV/cm
- Vamp = 39 kV/cm
- Vamp = 41 kV/cm
- Vamp = 42 kV/cm

PSF Sigma (µm)

Reduced drift field (V/cm)

Trans. diff. coeff. (nmбар~2 cm~1/2)
- Ar 90%, CF4 10%
B-IMAGING

PRELIMINARY RESULTS WITH TRITIUM SAMPLES

NEUTRON RADIOGRAPHY

PRELIMINARY RESULTS WITH A NEUTRON SOURCE
Tumor heterogeneity: different cell types inside a tumor

- Heterogeneity effect on drug targeting?
- Will help the developing of more efficient drugs
- Requires better detection sensibilities

Molecule labelling and tracking with tritium

Pharmaceutical needs at the cell level for drug development:

- Assess the **drug distribution** among cells
- Evaluate the impact of the cell heterogeneity on drug biodistribution
- At the cell level: Quantification of $^3$H concentration in **single cell** samples
PRELIMINARY RESULTS WITH TRITIUM SAMPLES

First deposit: tritiated glucose

- Activity measurement limits and dynamic range → Activities: 0.3 Bq and 60 Bq
- Spatial resolution → gap between drops: 2 cm – 1 cm – 5 mm
PRELIMINARY RESULTS WITH TRITIUM SAMPLES

**Integration method:**

- 60 Bq drops positions are well assessed
- 0.3 Bq drops hardly visible

Ar/CF$_4$(20%)
PRELIMINARY RESULTS WITH TRITIUM SAMPLES

Clustering method:

- Both 60 Bq and 0.3 Bq drops positions are well assessed
- Better signal-to-noise ratio and counting events capability

Clusters barycenter histogram

20000 frames of 100 msec (33 min), individual pixel background thresholding, 20% of CF4
Micromegas-based neutron imager

$^{10}$B$_4$C neutron-to-charge converter

- **Thermal neutrons** absorbed by 2 µm thin $^{10}$B$_4$C layer
- Conversion efficiency: 5%
- $(\alpha$ or Li) fragments causes strong ionisation compared to electrons
- Drawback: fragments long range in the gas (5 mm)

Acquisition modes:

- **Event-by-event**: track reconstruction:
  potentially higher resolution (100 µm), better $\gamma$-to-n suppression
- **Integrated**: real-time radiography:
  $\gamma$-to-n suppression less efficient
PRELIMINARY RESULTS WITH A NEUTRON SOURCE

Experimental set-up

OMNIS set-up schema
PRELIMINARY RESULTS WITH A NEUTRON SOURCE (CERN GDD)

Drift field affects the diffusion in the gas

Diffusion spreads the light
CONCLUSION

What we have done

- Several types of Micromegas on glass were built and tested
- Setups of optical readout detectors for neutron and beta detection
- Detector characterization at X-ray facilities, with beta samples and neutron sources
- Image processing in progress

Outlook

- Beam test at Soleil accelerator: spatial resolution measurement and determination of point spread function
- Investigate image treatment methods
- $\beta$-imaging: tests on isolated single tumor cells
- Neutron radiography: Irradiation at neutron facilities
THANK YOU
BACK UP
PRELIMINARY RESULTS WITH TRITIUM SAMPLES

Clustering method:

<table>
<thead>
<tr>
<th></th>
<th>Mean activity (Bq)</th>
<th>Mean STD (Bq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High activity</td>
<td>8,4</td>
<td>0,74</td>
</tr>
<tr>
<td>Low activity</td>
<td>0,087</td>
<td>0,022</td>
</tr>
</tbody>
</table>

Charge readout coupling

Optical readout
Light production mechanisms

**Scintillation**: excited atoms or molecules emit photons during de-excitation.

- **Phosphorescence**: Delayed emission of photons after absorption. (1 ms to 100 s)
- **Fluorescence**: Prompt emission of photon after absorption of incident radiation. (1 ns to 1 µs)
- **Electroluminescence**: Electrons with energy lower than ionization threshold just excite atoms or molecules.

**Primary scintillation**: From the creation of primary electron coming from the excitation of gas due to incident particles.

**Secondary scintillation**: From the creation of secondary electrons taking place during avalanche amplification.

Light yield: amount of light determines the signal to noise ratio. It depends on electric field, pressure and gas mixture.
PRELIMINARY RESULTS WITH TRITIUM SAMPLES

β particle range in Ar-Isobutane gas mixture
DETECTOR CHARACTERIZATION WITH X-RAYS

X-ray radiography

- MTF measurement

60 sec exposure time lead target radiography with simple background suppression.
SOLEIL BEAM TEST (16/11-18/11)

Va=550 V, Vd=210 V
SOLEIL BEAM TEST (16/11-18/11)

$V_a = 550 \text{ V}$, $V_d = 210 \text{ V}$
FWHM = 40.4519
Mean MCA = 287.689
Resolution = 0.14061

Fit des mesures experimentales
Premiere gaussienne
Deuxieme gaussienne
Bruit

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Entries</td>
<td>964</td>
</tr>
<tr>
<td>Mean</td>
<td>271.2</td>
</tr>
<tr>
<td>Std Dev</td>
<td>54.17</td>
</tr>
<tr>
<td>f/1/100</td>
<td>717.5/224</td>
</tr>
<tr>
<td>Gauss Amp</td>
<td>2798 ± 10.7</td>
</tr>
<tr>
<td>Gauss Mean</td>
<td>287.7 ± 0.1</td>
</tr>
<tr>
<td>Gauss Stg</td>
<td>17.18 ± 0.65</td>
</tr>
<tr>
<td>Rkg</td>
<td>67.83 ± 1.56</td>
</tr>
</tbody>
</table>