Radiation studies on resistive bulk-micromegas chambers at the CERN Gamma Irradiation Facility

B. Alvarez Gonzalez\textsuperscript{1}, J. Bortfeldt\textsuperscript{1}, M. T. Camerlingo\textsuperscript{2}, E. Farina\textsuperscript{1,3}, P. Iengo\textsuperscript{1}, L. Longo\textsuperscript{4}, J. Samarati\textsuperscript{1}, O. Sidiropoulou\textsuperscript{1,5}, J. Wotschack\textsuperscript{1}

(1) CERN (2) Universita e INFN, Napoli (3) Universita e INFN, Pavia (4) Universita del Salento (5) Julius-Maximilians-Universitat Wurzburg

July 7\textsuperscript{th}, 2017
Overview

- Introduction
- Gamma Irradiation Facility
- Towards HL-LHC
- MicroMegas set-up
- Results
- Conclusions

**MicroMegas**: *Micro mesh gaseous structure*
Introduction

- Study the detector behavior under **high irradiation** and **long-term aging** of resistive MicroMegas detectors

Two **resistive bulk-Micromegas detectors** were installed in **May 2015** at the **CERN Gamma Irradiation Facility (GIF++)**
- Those detectors were exposed to an intense gamma irradiation
- The desired accumulated charge of more than **0.2 C/cm^2** has been reached corresponding to **10 years of HL-LHC** operation

**Results after 2 years of irradiation will be presented**
Located in the north area of the SPS accelerator at CERN

Flux of **high energy photons** *(662 KeV)* together with the availability of **high energy charged particle beams**

\[ ^{137}\text{Cs} \approx 14 \text{ TBq} \] gamma source of irradiation, half-life of 30 years

\[ ^{137m}\text{Ba} \] emits **gamma rays** with a main photon peak at **662 keV**
CERN Gamma Irradiation Facility (GIF++)

- Measurements and simulations (*Geant4*) of the photon field were provided and used as benchmarks for our measurements.

- **Filter system** permits the attenuation of the photon rate in several steps to reach *attenuation factors* of several orders of magnitude ($\sim 10^4 - 10^5$)

![Diagram](image_url)

<table>
<thead>
<tr>
<th>Nominal Attenuation</th>
<th>Filter Combination</th>
<th>Measured data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Dose Rate</td>
</tr>
<tr>
<td>1</td>
<td>A1 B1 C1</td>
<td>470.00</td>
</tr>
<tr>
<td>1.5</td>
<td>A1 B2 C1</td>
<td>400.00</td>
</tr>
<tr>
<td>2.2</td>
<td>A1 B1 C2</td>
<td>211.00</td>
</tr>
<tr>
<td>4.6</td>
<td>A1 B1 C3</td>
<td>105.00</td>
</tr>
<tr>
<td>10</td>
<td>A2 B1 C1</td>
<td>55.00</td>
</tr>
<tr>
<td>100</td>
<td>A3 B1 C1</td>
<td>6.50</td>
</tr>
<tr>
<td>100</td>
<td>A1 B3 C1</td>
<td>6.20</td>
</tr>
<tr>
<td>464</td>
<td>A1 B3 C3</td>
<td>1.59</td>
</tr>
<tr>
<td>4642</td>
<td>A2 B3 C3</td>
<td>0.22</td>
</tr>
<tr>
<td>46415</td>
<td>A3 B3 C3</td>
<td>0.05</td>
</tr>
</tbody>
</table>
The high source activity produces a very intense background gamma field allowing to accumulate doses equivalent to High Luminosity LHC experimental conditions in a reasonable time.
Resistive MicroMegas is a well established technology to be used with many applications. For example in ATLAS for the New Small Wheel (NSW) project. ATLAS will replace the current two small wheels (CSC, MDT, TGC).

Very high rate (15 kHz/cm²) at high luminosity (5x10^{34} cm⁻²s⁻¹).

Some irradiation tests in resistive MM were done in the past.

New studies:
- Long-term irradiation
- Measurements of the detector performance under high irradiation

*For more details about the NSW project, see Paolo Iengo’s talk: https://indico.cern.ch/event/466934/contributions/2590420/
Description of the MicroMegas used in GIF++

- Two resistive bulk-micromegas chambers (T5 & T8) built @ CERN
  - Active area of $10 \times 10 \text{ cm}^2$
  - Single readout plane with strip pitch $400 \ \mu m$ and strip width $300 \ \mu m$
  - Readout strips covered with a $50 \ \mu m$ thick Kapton foil carrying high resistivity ($\sim 1 \Omega / \text{sq}$) carbon strips → spark protection
  - The gas volume is divided in two by a metallic micro-mesh
  - Mesh consisting of $18 \ \mu m$ diameter wires with $64 \ \mu m$ pitch
  - Amplification gap of $128 \ \mu m$, drift gap of $5 \ mm$

These are gaseous particle detectors detecting particles by amplifying the charges that have been created by ionisation in the gas volume.
Data-taking and Working Conditions

- Data acquired with **APV-25** front-end ASICs and RD51 Scalable Readout System (**SRS**)

**Data-taking** varying attenuation filters and amplification voltages

- **Att. Factors:** 1, 2.2, 4.6, 10, ..., 100
- **Amplification Voltage Scan:** 420-540 V
- **Drift Field:** 600 V/cm
- **Source ON/OFF + Muon Beam**

**Working conditions:**

- **Gas:** ArCO$_2$ 93%, 7%, **Gas Flow:** 5 l/h
- **Operating Gain:** $\sim$ 5x10$^3$
RESULTS
Integrated Charge

- **Goal**: to accumulate the equivalent integrated charge expected after 10 years of HL-LHC operation.
- After $\sim 2$ years of exposure to an intense $\gamma$ irradiation the desired accumulated charge of more than $0.2 \text{ C/cm}^2$ has been reached.

Chambers exposed at GIF++ from May 2015 to June 2017.
Detection Efficiency Measurements

Efficiency measured w.r.t reference detectors using **muon tracks**

- **May 2015:** muons from cosmic rays at the CERN *RD51 GDD lab*
- **May 2017:** GIF++ muon beam

Both datasets reach **full efficiency** around **500 V**

- **Voltage** was not corrected by *T, P and H*

**No degradation** of the **efficiency** observed due to irradiation
Gain measurements were conducted on T5 and T8 chambers using an $^{55}$Fe source in the RD51 GDD lab in May 2015 and 2017.

**Experimental set-up**

![Diagram of the experimental set-up]

\[
\text{Gain} = \frac{\text{Current from the mesh}}{\gamma \text{ conversion Rate} \times q_e^{-} \times N_e \text{ per } \gamma}
\]

- No significant changes on the gain are observed for any of the two chambers
- No degradation of the gain observed due to irradiation
Study the current as a function of the amplification voltage and attenuation factor.

Slight difference due to atmospheric conditions: T, P and H.

In April 2017, T8 was moved further from the source from 1 m to about 1.35 m.

The current difference follows:

\[ l_1 \times d_1^2 = l_2 \times d_2^2, \text{ if } d_2 > d_1 \rightarrow l_2 < l_1 \]
Current vs Voltage and Attenuation Factor

- Study the current as a function of the amplification voltage and attenuation factor
- Slight difference due to atmospheric conditions: T, P and H

In April 2017, T8 was moved further from the source from 1 m to about 1.35 m
The current difference follows:

\[ l_1 \cdot d_1^2 = l_2 \cdot d_2^2, \text{ if } d_2 > d_1 \rightarrow l_2 < l_1 \]
Current vs Voltage and Attenuation Factor – T5

Current Measurements at GIF++

Nov 17th, 2016

- T Chamber 5 (K multiplied by 10^5)
- Current = K x exponential(slope x V)
- Att. 1: K = 0.245, slope = 0.027
- Att. 2.2: K = 0.100, slope = 0.028
- Att. 4.6: K = 0.027, slope = 0.028
- Att. 10: K = 4.493, slope = 0.017
- Att. 33: K = 0.001, slope = 0.032
- Att. 69: K = 0.000, slope = 0.033

April 13th, 2017

- T Chamber 5 (K multiplied by 10^5)
- Current = K x exponential(slope x V)
- Att. 1: K = 0.262, slope = 0.027
- Att. 2.2: K = 0.076, slope = 0.028
- Att. 4.6: K = 0.025, slope = 0.029
- Att. 10: K = 0.564, slope = 0.022
- Att. 33: K = 0.062, slope = 0.024
- Att. 69: K = 0.000, slope = 0.009
The detector sensitivity of $\sim 3.8 \times 10^{-3}$ extracted from the measured particle rate from the fully efficient region @ 520 V and the photon observed rate at U1.

This agrees with the Geant4 simulations which include the resistive bulk-micromegas chambers.
Geant4 Simulation

- Simulation including the bulk-micromegas detector design and the GIF++ source spectrum

As result the detector sensitivity, estimated as the number of $\gamma$ depositing an energy more than 26 eV in the gas gap over the total number of generated $\gamma$, is about $\sim 3.8 \times 10^{-3}$
Tracking with muon beam

- Muon tracks distinguished from photons using the *Hough transform*
- **Cluster position difference** between T5 and T8 fitted with a Gaussian:

  ![Graph showing cluster position difference](image)

  - Tracking resolution stable up to *68 kHz/cm$^2$* *(4 times more than the expected rate during the HL-LHC)*
  - The **most probable value (MPV)** of the cluster charge is also shown and is constant up to this very high photon flux
Conclusions

- The *efficiency, gain, particle rate and tracking resolution* measurements for two *bulk-micromegas chambers* have been presented.
- After two years of irradiation at GIF++ with an accumulated charge of more than *0.2 C/cm²* no *aging effects* have been observed in either of the two chambers.
- Studies on the *tracking resolution* performed in *November 2015* have been also shown, stable up to *68 kHz/cm²*.
  - These studies will be repeated for the full accumulated charge.
- **Activities at GIF++ continue:**
  - Irradiation of T5 and T8 chambers
  - Irradiation and muon test beams for other MicroMegas prototypes
- **Acknowledgements:**
  - CERM GIF++ Community
  - CERN *RD51 GDD lab*
  - Nicholas Karastathis for the Geant Simulation

THANK YOU
BACK-UP SLIDES
References

- M. R. Jäkel et al., CERN GIF++, PoS (TIPP2014) 102
- D. Pfeiffer et al., "The radiation field in the Gamma Irradiation Facility GIF++ at CERN", arXiv:1611.00299v1
- M. Raymond et al., The APV25 0.25 $\bar{1}$m CMOS readout chip for the CMS tracker, IEEE Nucl. Sci. Symp. Conf. Rec. 2 (2000), 9/113
- S. Martoiu et al., Development of the scalable readout system for micro-pattern gas detectors and other applications, JINST 8 (2013) C03015
- J. Galán et al., Aging studies of Micromegas prototypes for the HL-LHC, JINST 7 (2012) C01041
- P. V. C Hough, Inc Proc. Int. Conf. on High Energy Accelerators and Instrumentation, 1959
Current Measurements at GIF++

April 13th, 2017

T Chamber 5 (K multiplied by 10^5)

- Att. 1: K = 0.262, slope = 0.027
- Att. 2.2: K = 0.076, slope = 0.028
- Att. 4.6: K = 0.025, slope = 0.029
- Att. 10: K = 0.564, slope = 0.022
- Att. 33: K = 0.062, slope = 0.024
- Att. 69: K = 0.000, slope = 0.009
Current Measurements at GIF++

Current vs Voltage — T8

April 13th, 2017

T Chamber 8 (K multiplied by 10^5)

Current = K x exponential(slope x V)

- Att. 1: K = 0.097, slope = 0.027
- Att. 2.2: K = 0.035, slope = 0.028
- Att. 4.6: K = 0.011, slope = 0.029
- Att. 10: K = 0.002, slope = 0.031
- Att. 33: K = 0.000, slope = 0.058
- Att. 69: K = 0.000, slope = 0.009

Current [µA] vs Voltage [V]