New laser setup in Bari for MPGD gain measurements

RD51 mini-week

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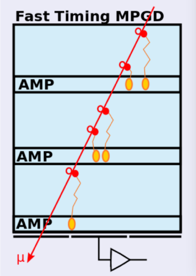
New laser setup in Bari for MPGD gain measurements

Outline

- Laser setup requirements for the FTM
- The laser specifications and optical setup
- Characterization of a triple-GEM prototype in the laser box

Requirements for the characterization of the FTM

Fast Timing MPGD



Working principle and time resolution

$$\sigma_t = \lambda / N v_{\text{drift}}$$

λ = ionization mean free path

N = number of stages

1. Signal pickup by external readout: **only resistive electrodes**

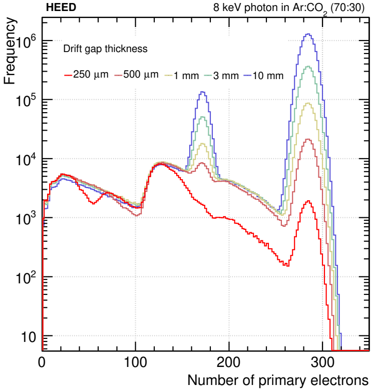
   Gain calibration with non-monochromatic sources is made difficult: no copper electrode for fluorescence conversion

2. Tiny drift gaps (250 μm)

   Cannot perform gain calibration by conventional sources (X-rays)

New small-size ($\sim 4 \times 4\,\text{cm}^2$) prototype currently under tests in Bari

X-ray photon conversion in gas mixture



No distinct peak at gaps $< 500\,\mu\text{m}$ → **X-ray energy loss is subjected to large fluctuations**

Laser specifications and optical setup

Principles of laser-gas interaction

- Photons in lasers have **too low energy** ($\sim 4.7\,\text{eV}$ @ 266 nm) to ionize typical counting gas molecules (13-15 eV)
- Common mixtures contain some ppm impurity molecules with low ionization potential ($\sim 9\,\text{eV}$) → laser ionization is possible by **multi-photon processes**:

  $$\frac{R}{V} = N\sigma^{(n)}\phi^{n}$$

  R/V = ionization date density

  N = molecule concentration

  $\sigma^{(n)}$ = n-photon cross-section equivalent

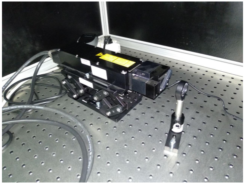
  ϕ = beam flux
- At low intensities, two-photon ionization dominates:

  $$\frac{R}{V} = \left(\frac{\lambda}{hc}\right)^{2} N\sigma^{(2)}I^{2}$$

  Primary current in detector is proportional to **square of laser pulse energy**

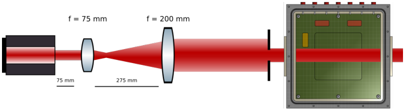
Specifications of the laser setup

Pulse energy	51 μJ	can provide a MIP-like energy deposit
Waist radius	400 μm	low angular divergence
Wavelength	266 nm/4.7 eV	two-photon ionization of hydrocarbons
Pulse duration	1 ns FWHM	lower than triple-GEMs time resolution
Spatial mode	TEM_{00}	gaussian beam beam quality <1.5

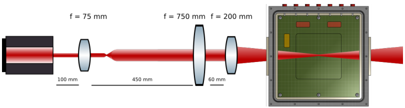


Optical setup preparation

Collimated setup



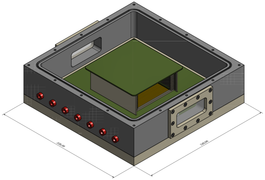
Focused setup

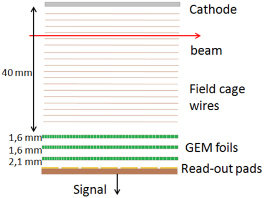


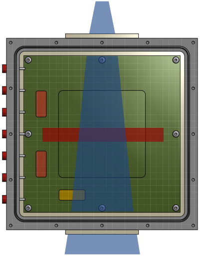
	Collimated	**Focused**
Waist radius	1500 µm	23.4 µm
Angular divergence	0.06 mrad	$\sim$ 5 mrad
Beam intensity	34 µJ/mm^2	3×10^4 µJ/mm^2
	Optical filter + Pinhole to reduce pulse energy	Point-like primary ionization

Characterization of a triple-GEM detector in the laser box

The time projection GEM prototype

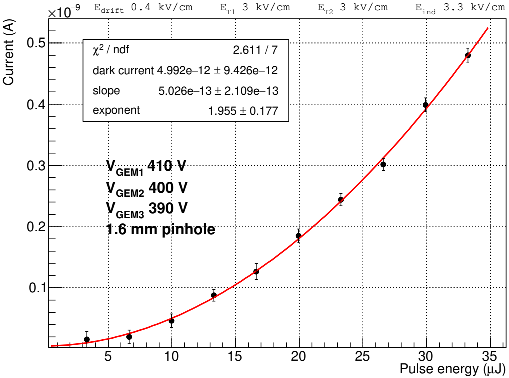


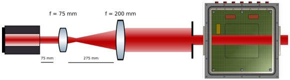




- 40 mm drift gap, suitable for benchmarking of the laser setup
- beam passes throught **quartz windows** (transparent to UV)
- signal readout on 2 rows of 60 pads ($6 \times 2\,\mathrm{mm}^2$ each)
- the small instrumented area compared with the total gas volume complicates the gain calibration with X-rays

Observation of multi-photon ionization



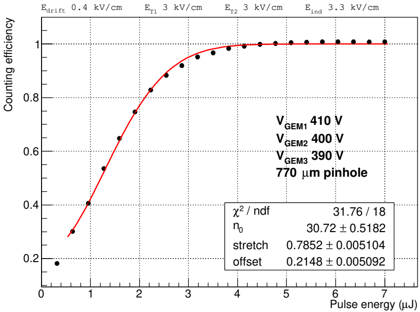


- collimated setup (low intensity)
- anode current ∝ primary ionization rate
- ionization rate ∝ (pulse energy)^m for m-photon absorption

$\boldsymbol{m = 1.96 \pm 0.18}$, compatible with **two-photon absorption**

Estimation of primary ionization rate

Problem How to determine the number of primaries created by a single laser pulse?



Counting efficiency scan vs laser pulse energy @ 100 Hz:

$$\epsilon = \frac{\text{anode signal rate}}{\text{laser pulse rate}}$$

Assuming Poisson fluctuations on primary electron number,

$$\epsilon = 1 - \sum_{n=0}^{n_{th}} \frac{\exp\left[n_0 (E/E_0)^2\right]}{n!}\, n_0^n (E/E_0)^{2n}$$

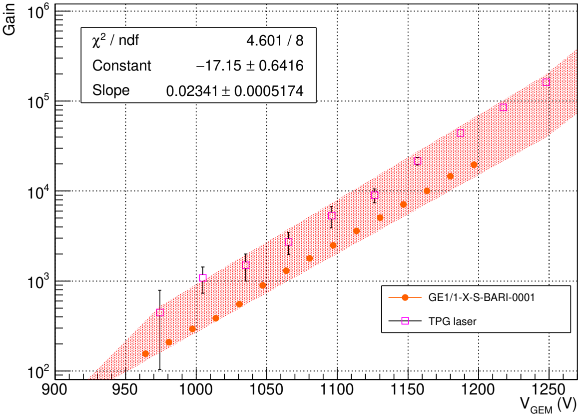
E_0 = reference pulse energy $\qquad$ n_0 = primary electrons per laser pulse at E_0

n_{th} = n. of primary electrons corresponding to the discriminator threshold

$\boldsymbol{n_0 = 30.7 \pm 0.5}$ **electrons** at 10 μJ in the active gas volume

Waiting for confirmation from: primary ionization current, single-electron spectrum

Gain curve measurement

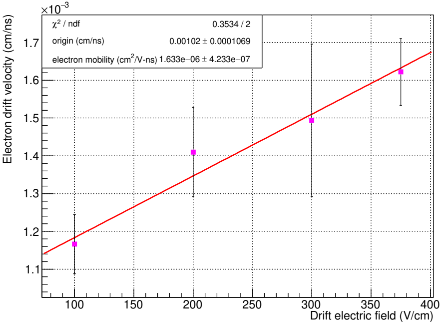


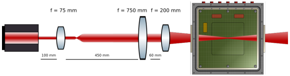
$$G_{\text{eff}} = \frac{\text{anode current}}{n_p \times q_e \times \text{laser rate}}$$

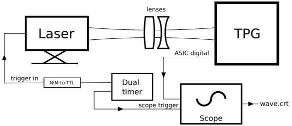
$n_p = 30.7$@$10\,\mu$J pulse energy

Compatible with the gain curves of CMS GE1/1 chambers tested at CERN and in Bari

Timing measurements







- optical setup in focused configuration: **point-like ionization**
- laser pulse emission triggered by external clock
- detector digital signals acquired by a scope
- the average signal arrival time is plotted at different ionization positions in the drift gap
- **electron drift velocity** is given by a linear fit

$$(1.63 \pm 0.42) \times 10^{-6}\,\mathrm{cm}^2/\mathrm{V}\cdot\mathrm{ns}$$

electron mobility in Ar:CO_2 (70:30)

$$2.36 \times 10^{-6}\,\mathrm{cm}^2/\mathrm{V}\cdot\mathrm{ns}$$

from a `Magboltz` simulation

Conclusions and summary

Setup for the characterization of small-gap MPGDs

- Validation with triple-GEM chamber
- **Collimated** low intensity setup for gain calibration
- **Focused** high intensity setup for timing measurements

Future development

- Comparison with other gain calibration techniques with lasers
  - direct **primary current measurement**
  - **single-electron** response
- The UV laser bench is **ready for the characterization of the FTM**
- Femtosecond laser for time resolution measurements on the FTM