Updates on the FTM tests in Bari

FTM meeting

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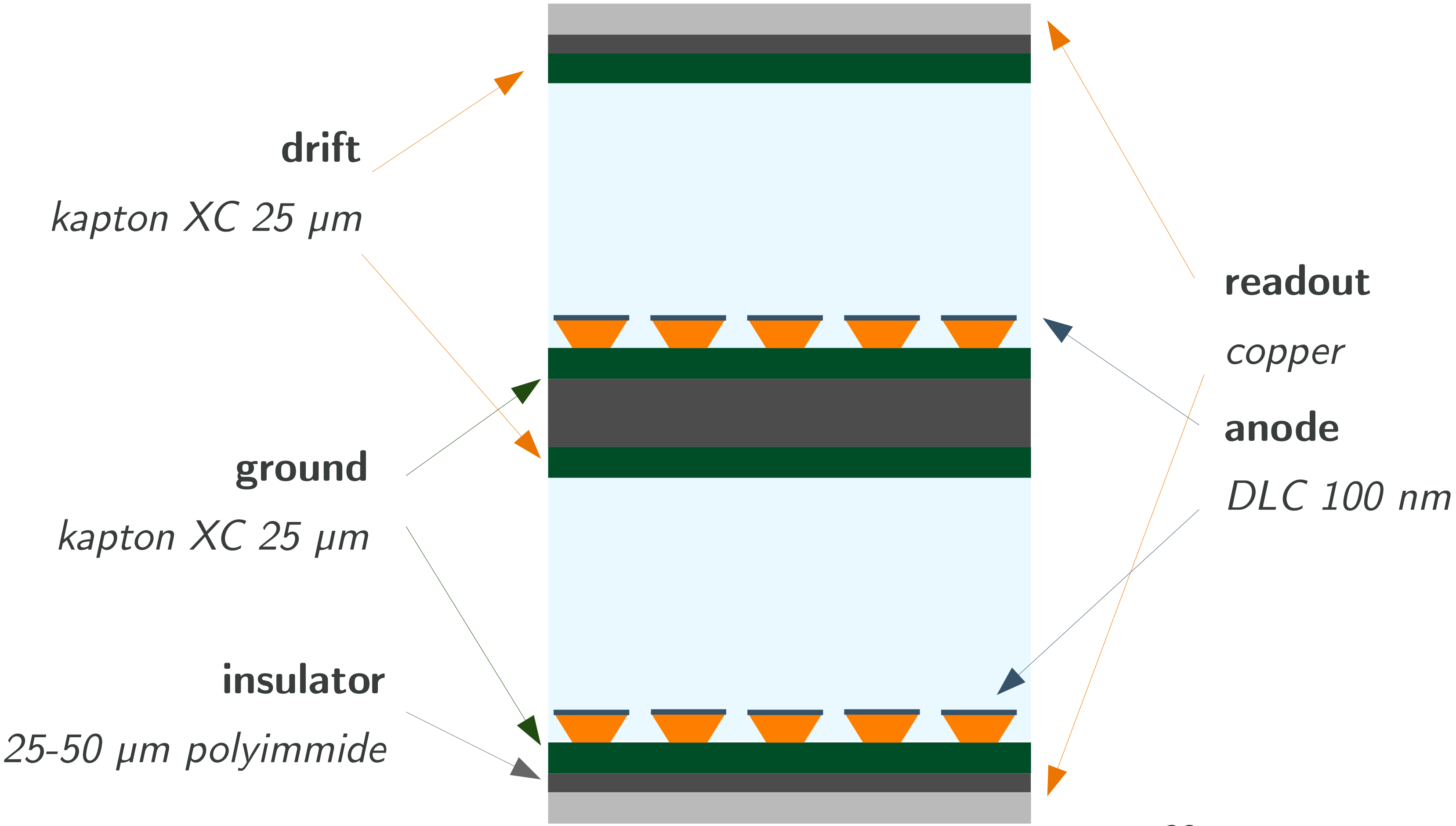
University and INFN Bari

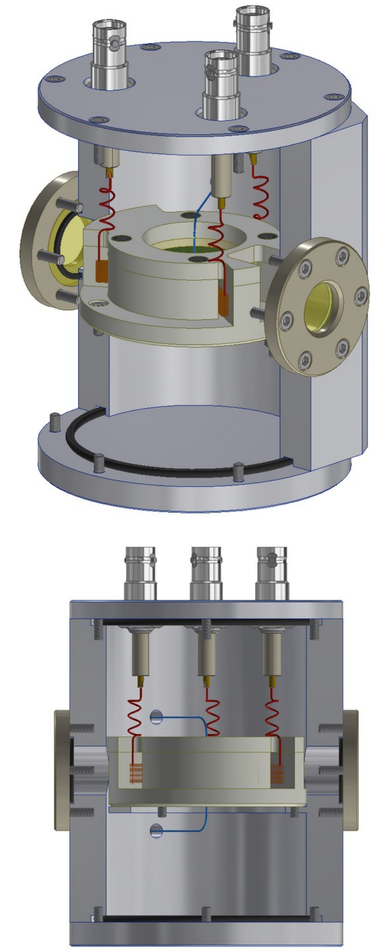
July 29, 2020

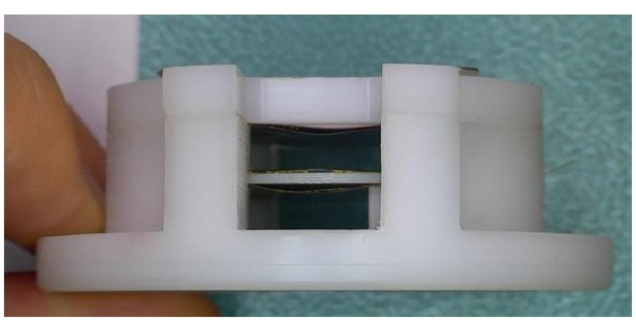
Outline

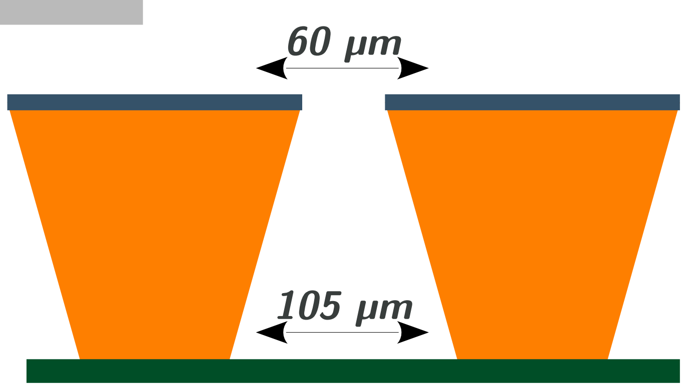
- Prototype design
- Laser test bench
- First test and HV stability
- Characterization tests

FTM small-size prototype design

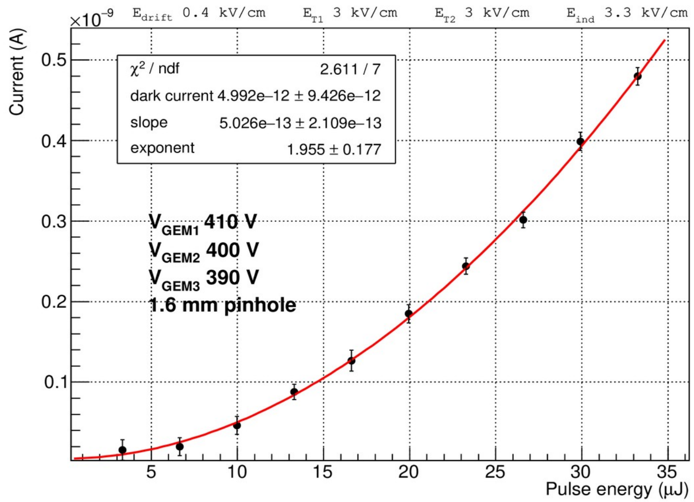








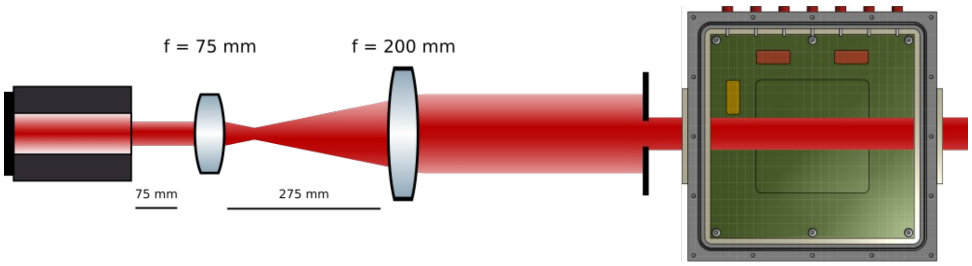
Laser test bench



ionization rate is proportional to square of laser pulse energy

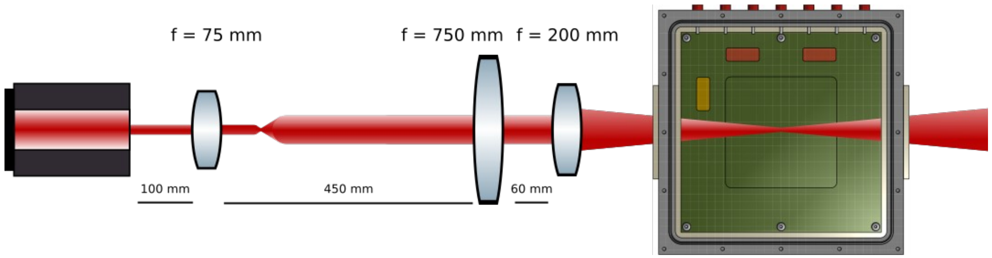
Collimated setup

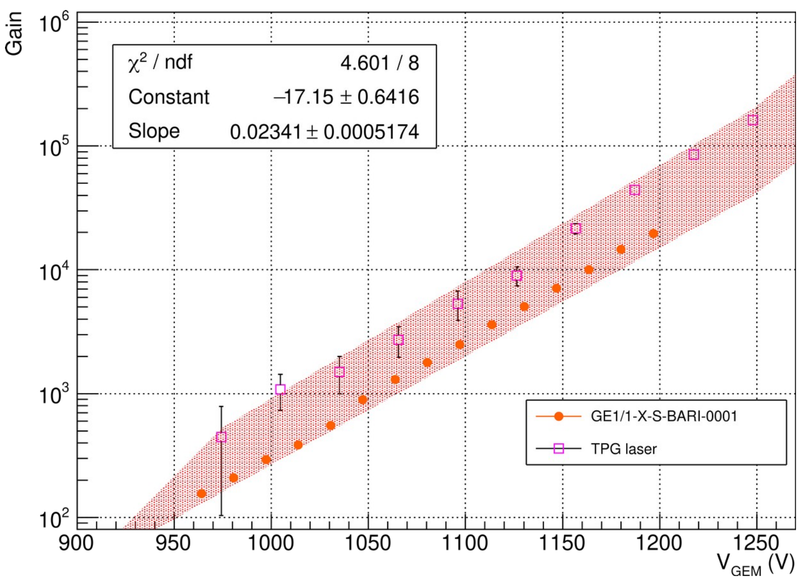
Low-intensity

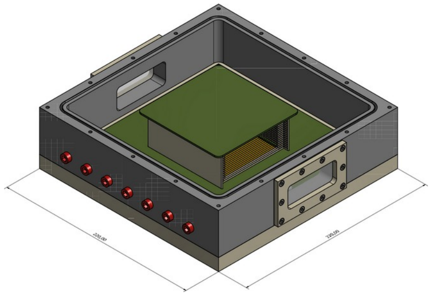


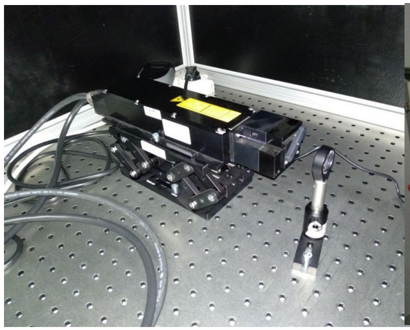
Focused setup

High intensity, point-like ionization



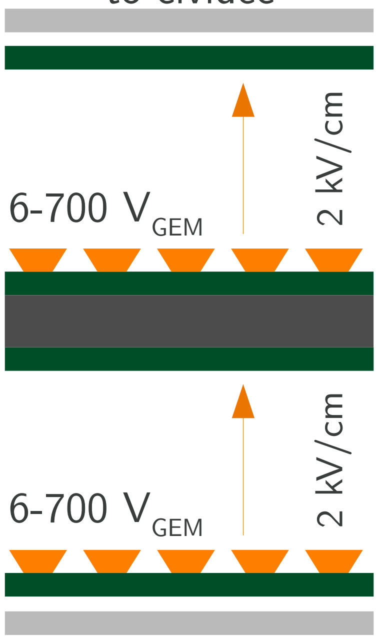


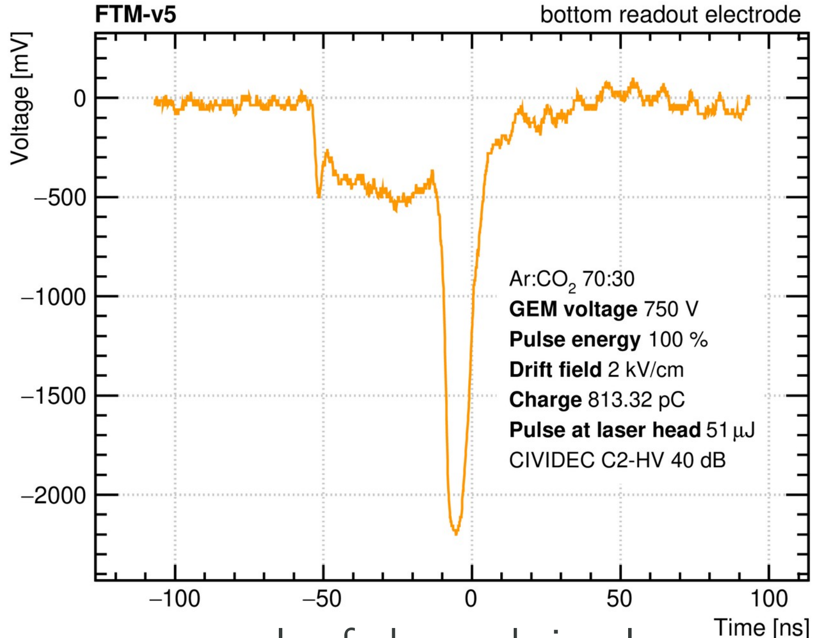




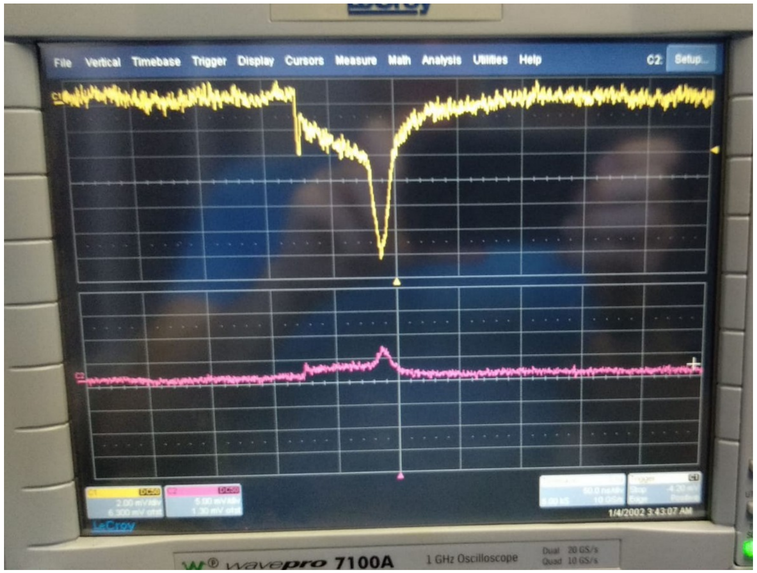
Validation: gain measurements on a triple-GEM TPC

First FTM test in the laser box

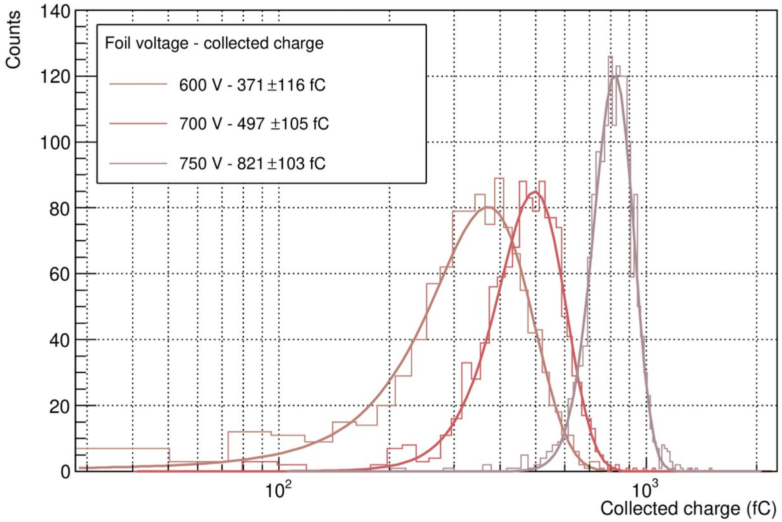




example of observed signal



Transparency (signal on both R/O electrodes)
CH1 scale: 2 mV/div
CH2 scale: 5 mV/div



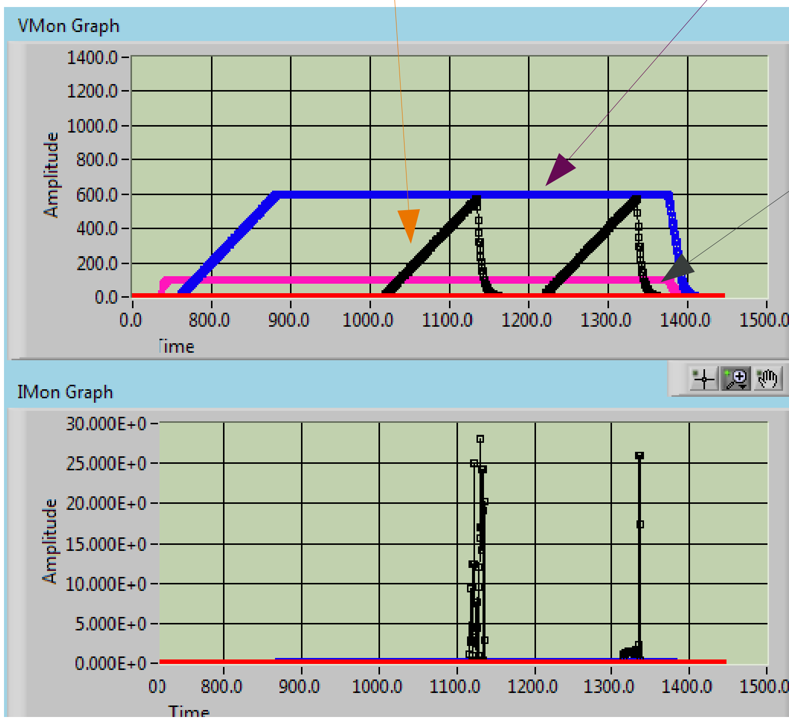
Collected charge distribution at different V_{foil}

Impromptu test, not much to note

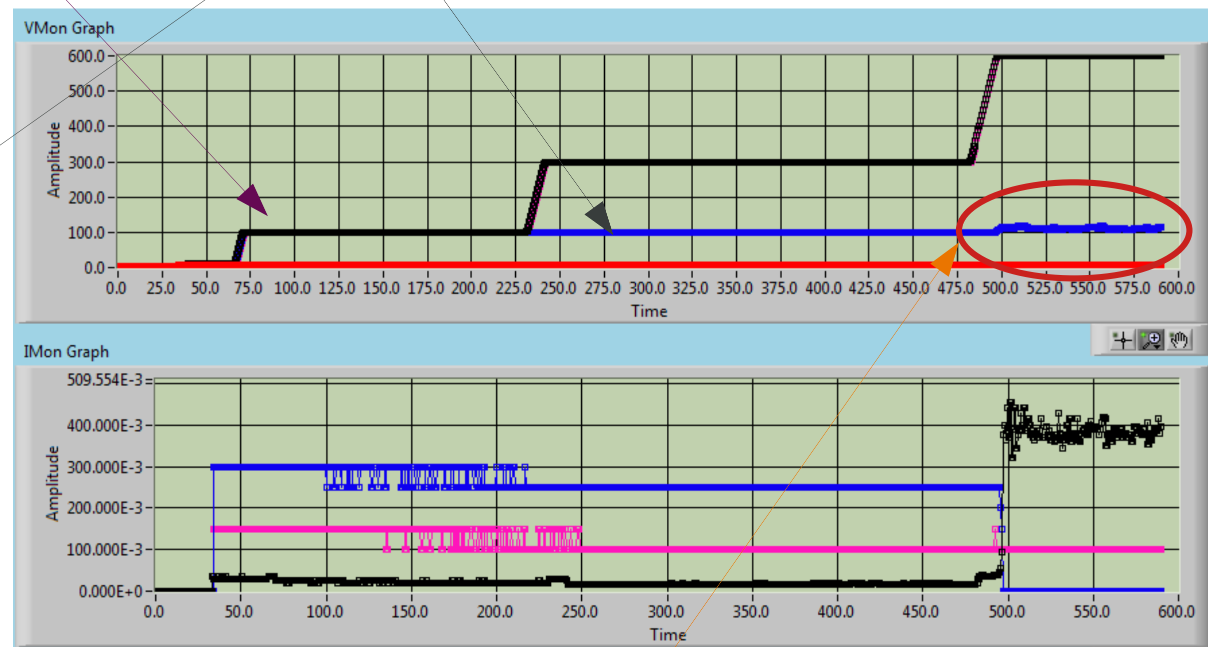
- Gain increasing with V_{foil} (no gain measurement performed)
- Signal transparency on top and bottom electrodes
  - Unable to observe bottom signal in subsequent tests :(

Prototype HV (in)stability

drift anode ground



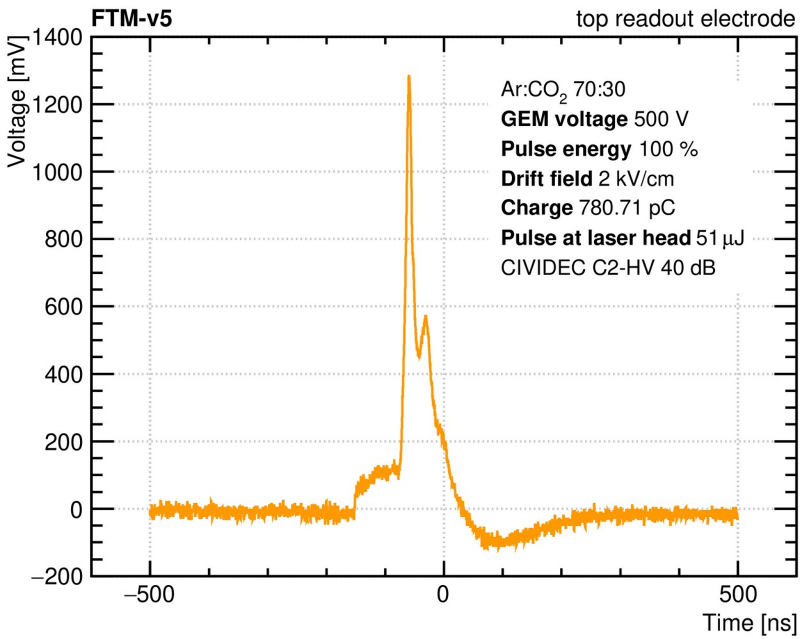
Drift-anode short circuits?



High current drained on anode at V_{foil}>500 V

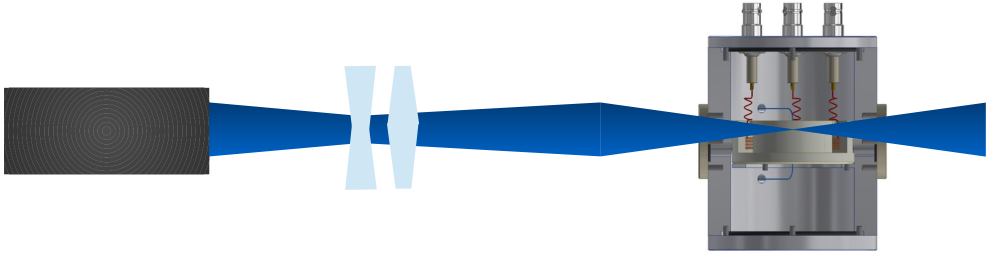
- Prototype was opened and solderings replaced several times
- When V_{foil}>500 V, ground voltage "follows" anode
- Currently unable to operate the prototype with foils beyond 500 V

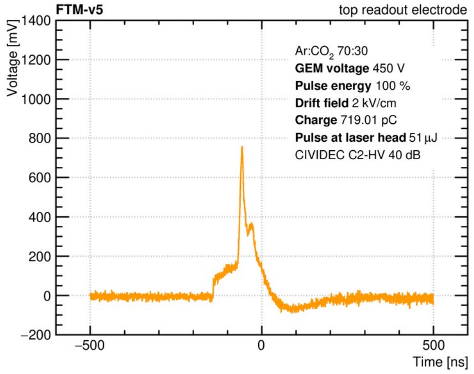
First gain measurement – signal method

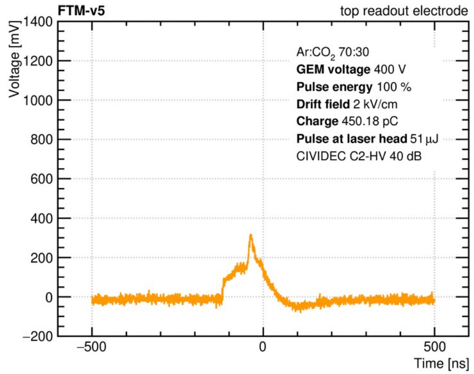


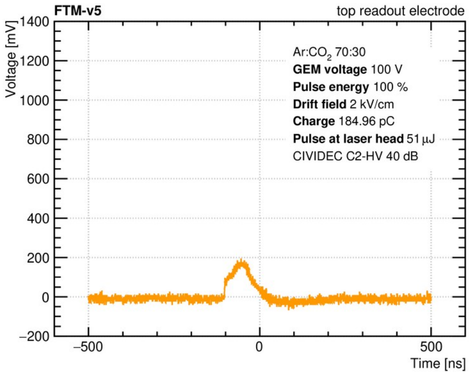
Gain measurement setup (mar 2020)

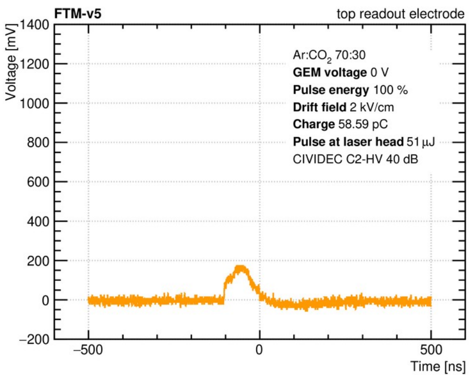
- Focused laser beam, max energy (51 uJ), 100 Hz
- Direct signal readout (preamplifier + oscilloscope) on top electrode
- Gain measurement method: **direct primary charge measurement**





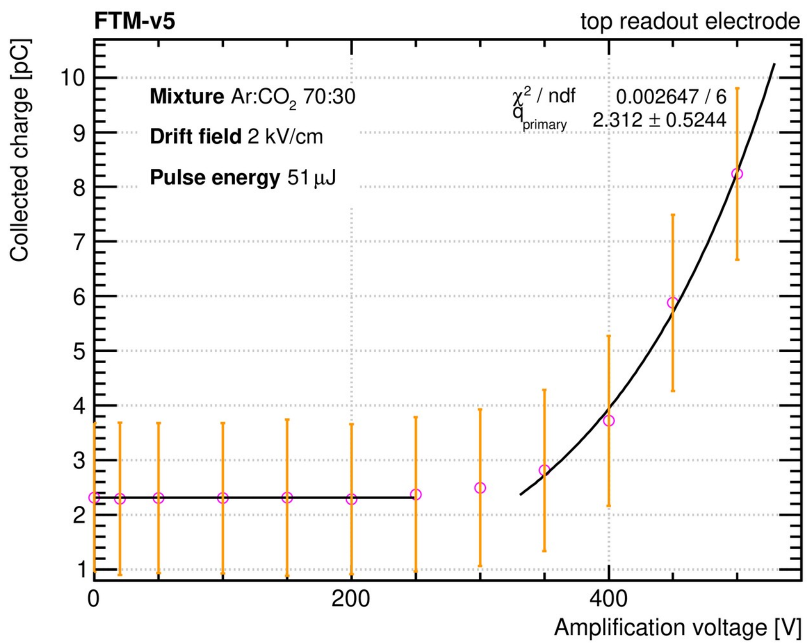






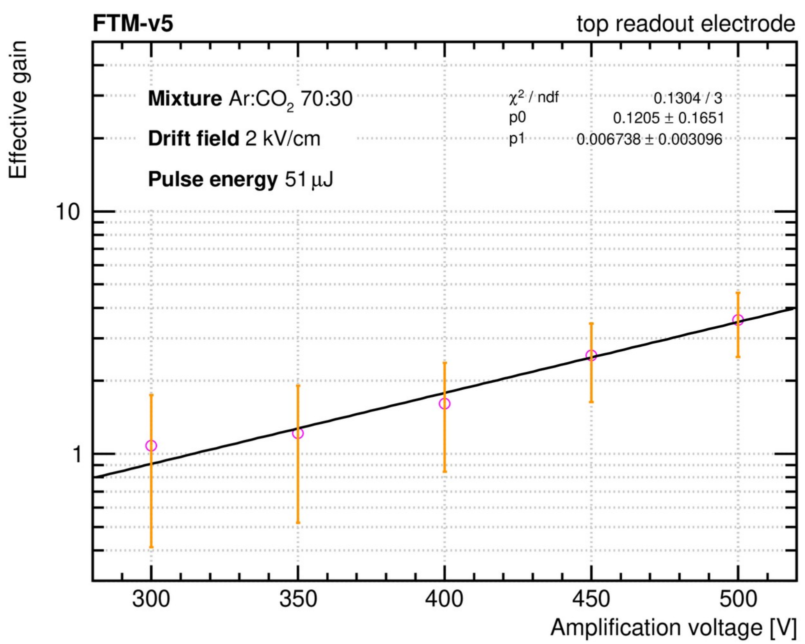
- ~ 10000 signals collected at each foil voltage
- A signal is observed even at 0 V (electrons collected by the DLC anode)
- Signal amplitudes at 0 and 100 V are the same

First gain measurement – signal method



Collected charge vs foil voltage

- Exponential fit at high V_{foil}
- Constant fit at $V_{foil} < 200$ V
  - → Primary charge estimation: 2.31 pC
- Average collected charge vs laser pulse energy is not quadratic (hint at some non-linear effect)



Gain curve interpretation

- High primary charge (10^7 electrons)
- Low gain (<10), may be due to
  - Space charge
  - Foil charging up
  - Resistivity

New goal: repeat measurements at lower laser beam intensity

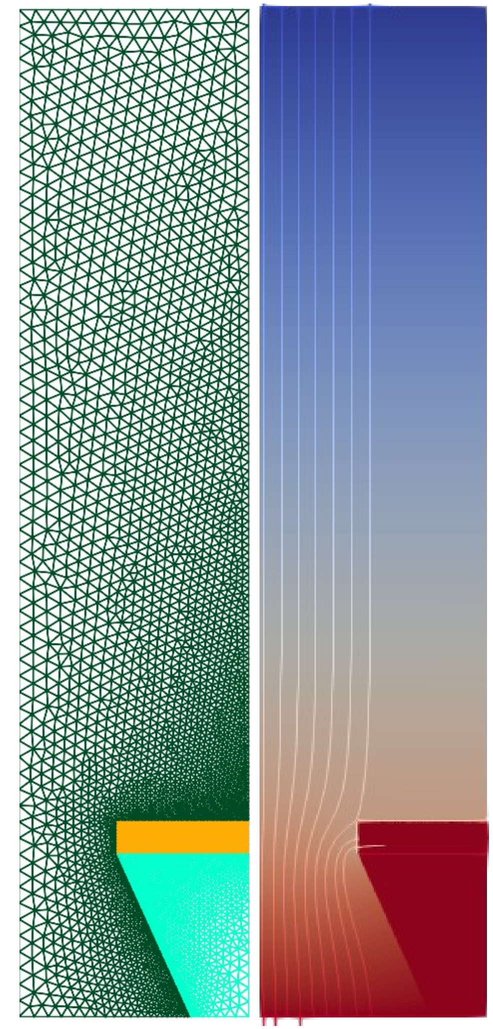
COVID interlude

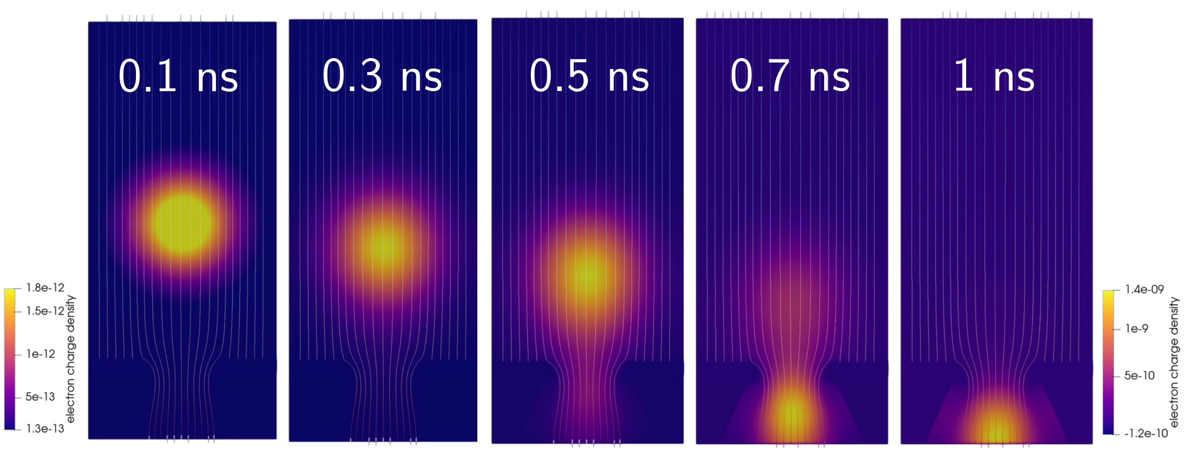
Trying to investigate the high flux behaviour

Simulation of a high primary charge event in a single hole

- Transient simulation
  - ➔ **Garfield is inappropriate**
  - ➔ **Gmsh + Elmer**
- 2D cylindrical-symmetric geometry
- FEM approach (non-Monte Carlo)
  - ➔ Unable to simulate avalanche fluctuations
- Three coupled PDEs:

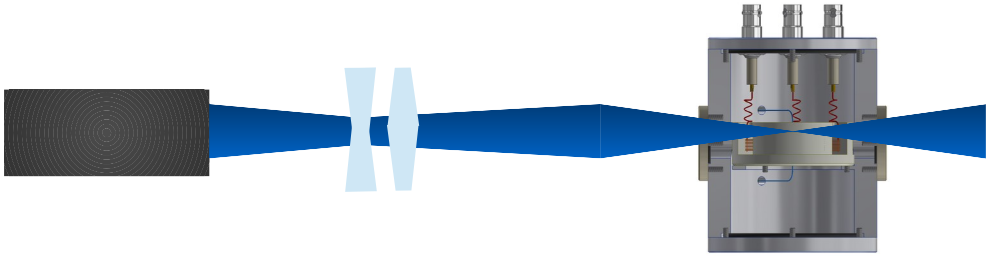
$$\begin{cases} \nabla^2 V = \frac{1}{\epsilon_0}(\rho_i - \rho_e) & \text{Potential} \\ \frac{\partial \rho_e}{\partial t} = \alpha|\vec{v_e}|\rho_e - \eta|\vec{v_e}|\rho_e - \nabla\cdot(\vec{v_e}\rho_e) + D_e\nabla^2\rho_e & \text{Electron cloud} \\ \frac{\partial \rho_i}{\partial t} = \alpha|\vec{v_e}|\rho_e - \nabla\cdot(\vec{v_i}\rho_i) & \text{Ion cloud} \end{cases}$$





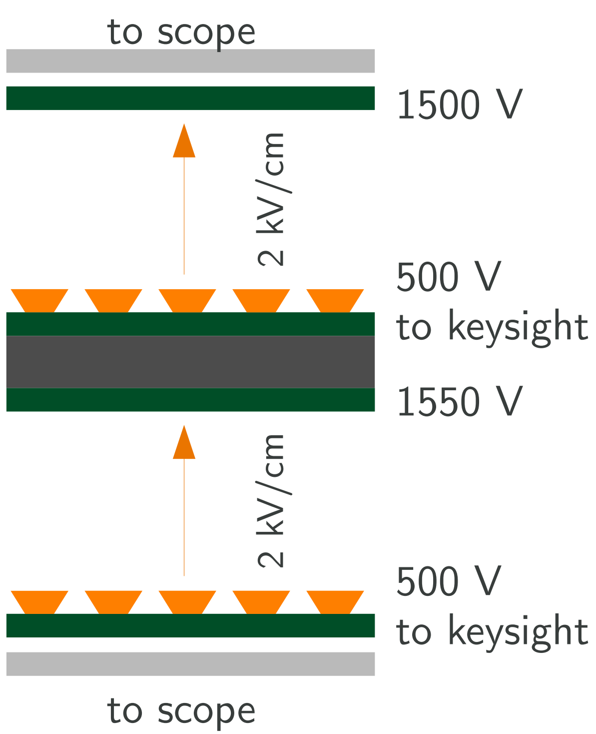
- Heavy calculations (~30h to simulate a single event)
- Currently too preliminary for quantitative results

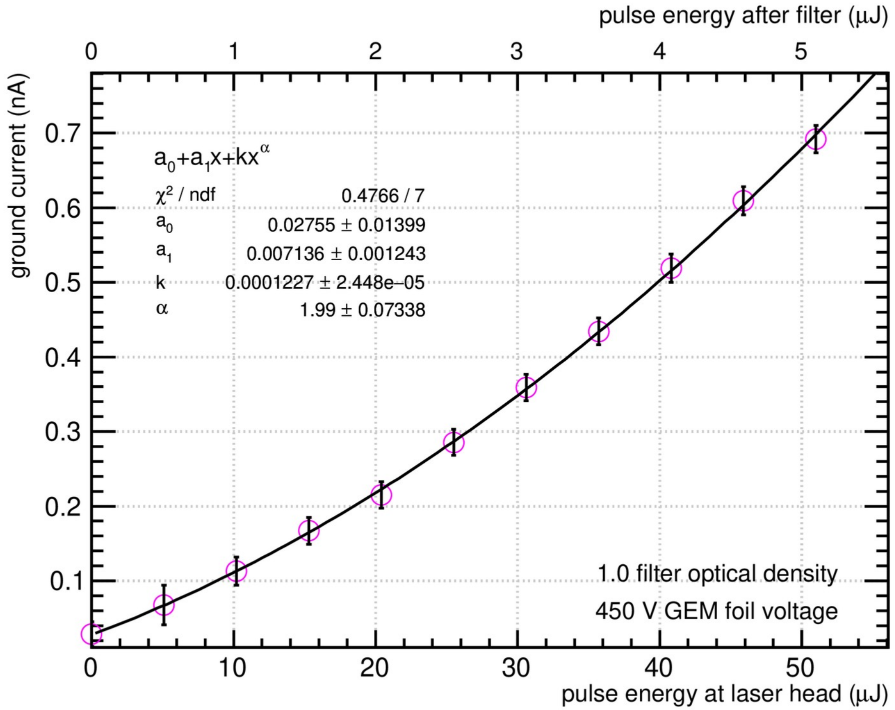
Second gain measurement – current method



Laser ionizes the gas in the top layer

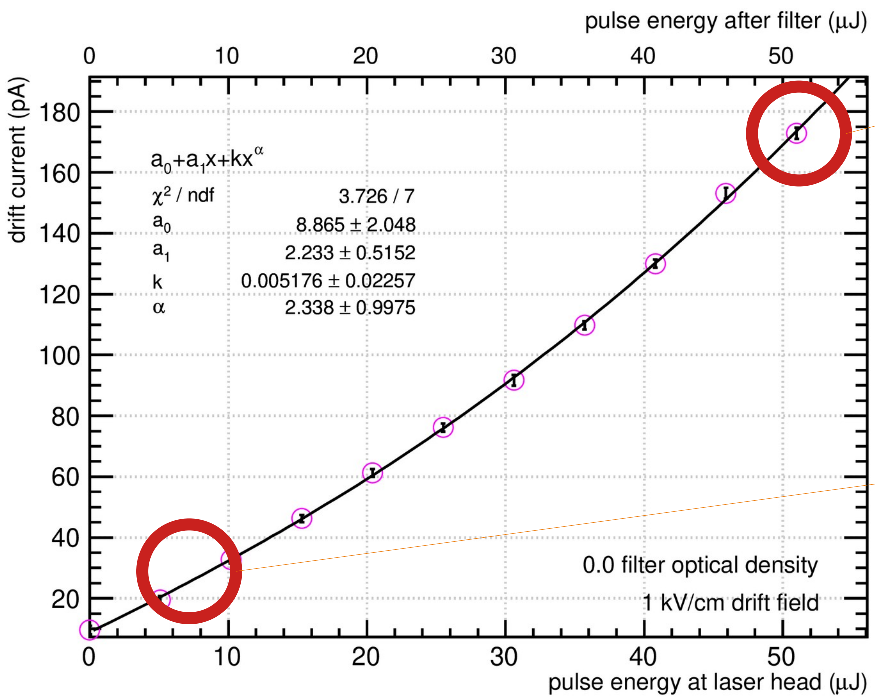
- **Optical setup** same as before
- **Current readout** Keisight B2981A femtoammeter connected to both ground electrodes
- **Measurement aim** estimate gain from direct primary current measurement at low laser energy

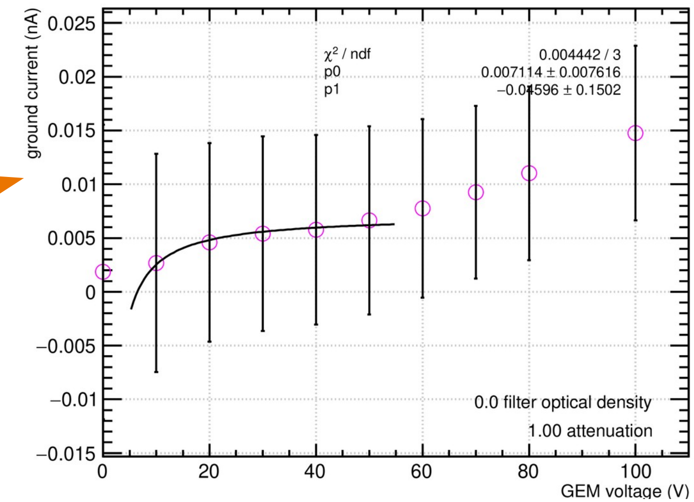




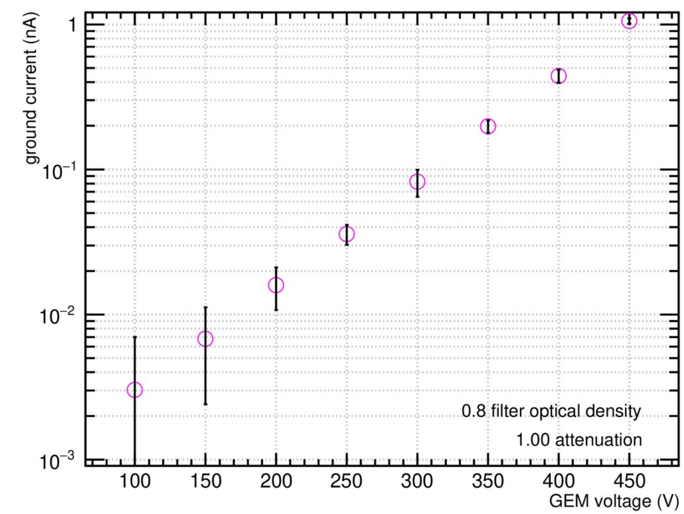
Current vs pulse energy plot at increasing filter optical densities
Quadratic trend recovered at E_P<8 uJ

Ground current and primary current





Primary current is measured at 51 uJ
$i_p = 7$ pA



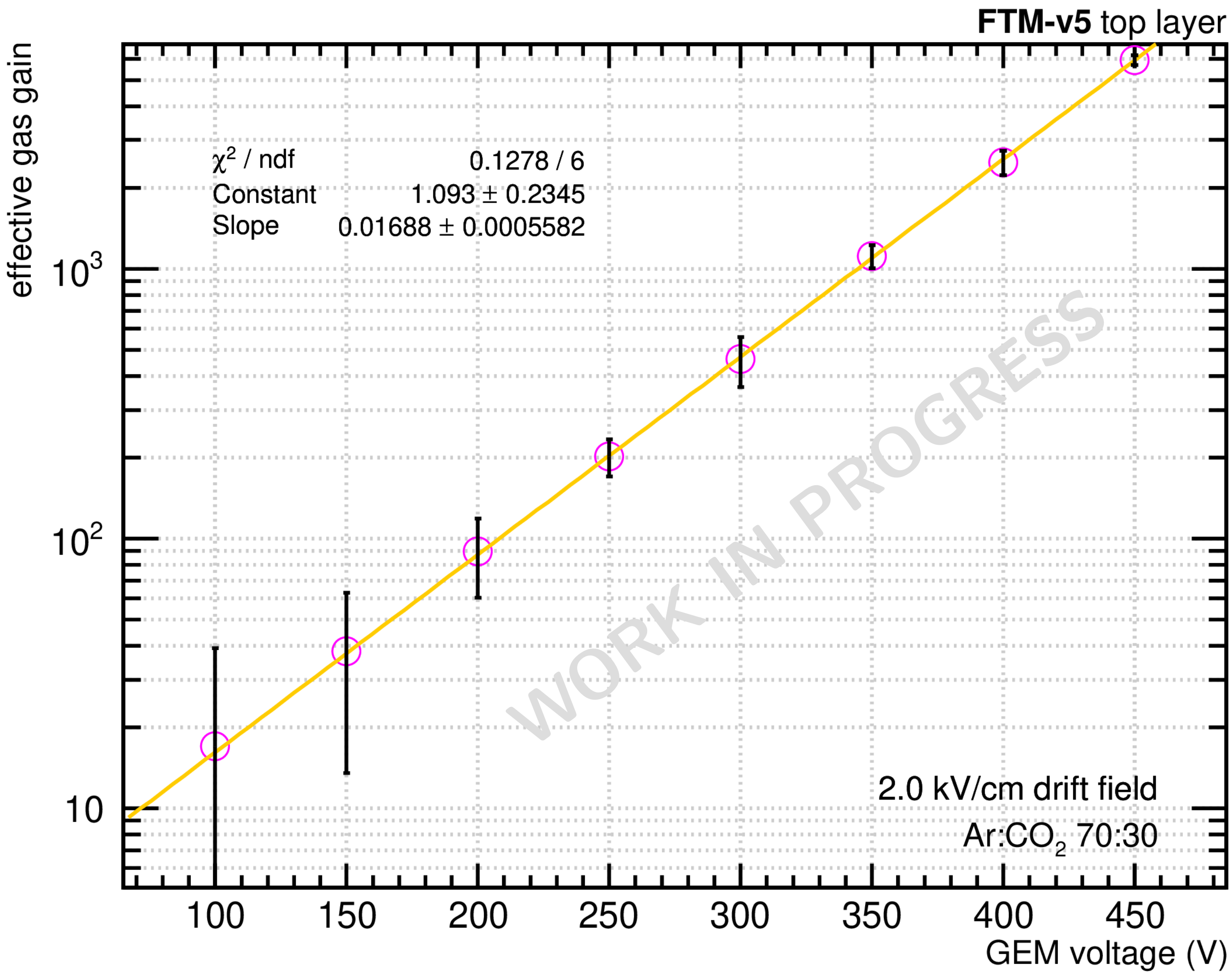
"amplified" current is measured at 8 uJ

It is not possible to measure the primary current from the femtoammeter at low pulse energies → primary ionization current measured at maximum beam energy

$$i_P@8\mu J = i_P@51\mu J \left(\frac{8\mu J}{51\mu J}\right)^2$$

i_P = 0.178 pA at 8 μJ

Effective gain (work in progress)



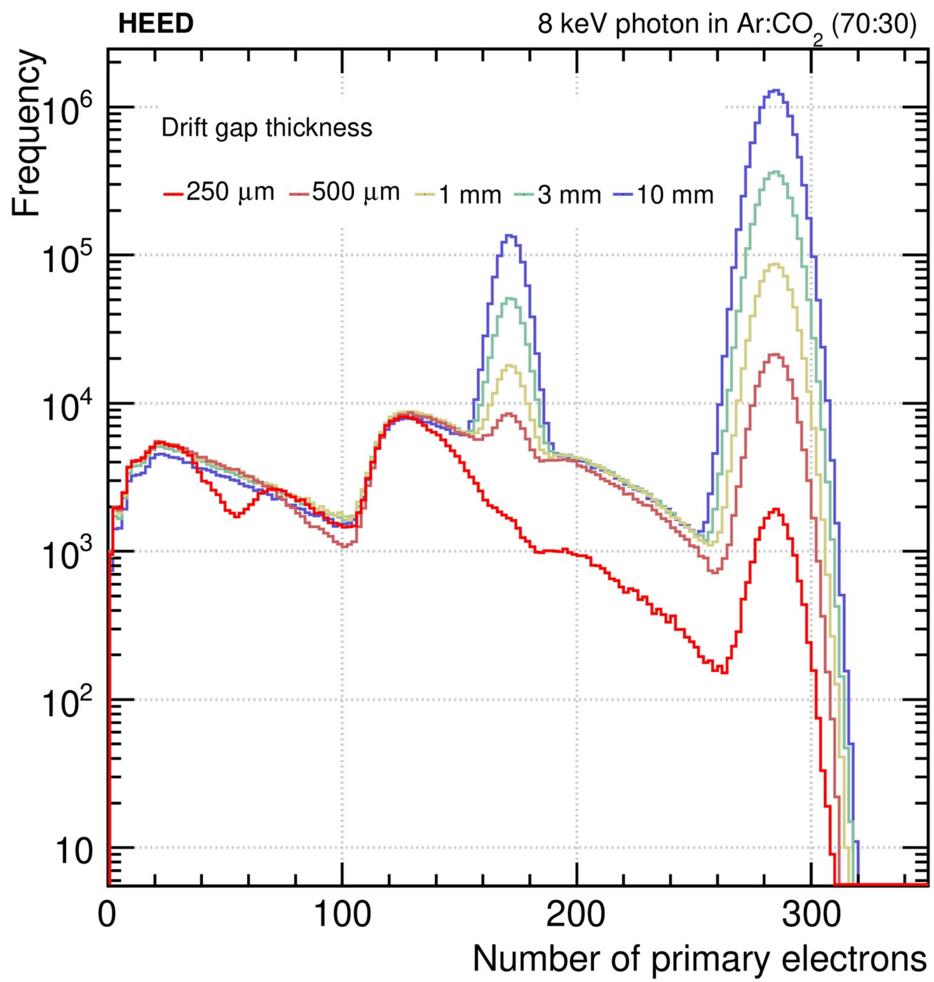
- At 450 V gain of 6000 seems too high
- Error on primary current is neglected here (would be 100 %)
  - ➔ Measurements to be repeated trying to reduce the noise
- The current measured at the foil bottom in the plateau at ~ 20 V may not be equal to the full primary ionization current

Immediate next steps

- Current measurements
  - ➔ Noise reduction
  - ➔ Primary current measured from cathode
- Reading **signals** again
  - ➔ **Spectrum** at decreasing laser energies
  - ➔ **Single-electron** spectrum?

Backup

Why a laser test bench for the FTM

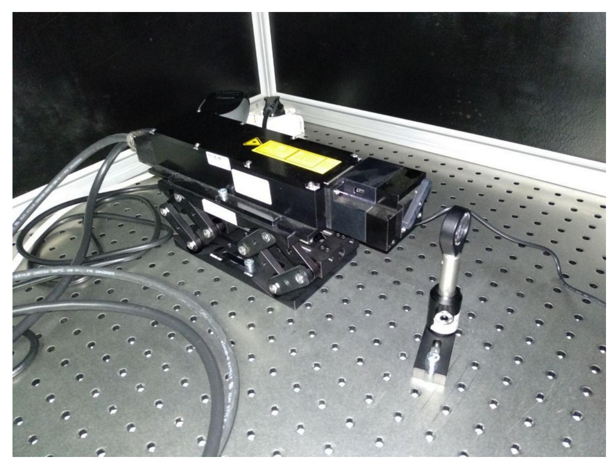


No distinct photopeak at gaps $<$ 500 µm $\rightarrow$ **X-ray energy deposit is subjected to large fluctuations**

Laser beams can be used as ionization sources in gas gaps of any volume with small fluctuations

Laser specs

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-GEM time resolution
Spatial mode	TEM_{00}	Gaussian beam Beam quality < 1.5



Laser-gas interaction

Ionization energy in Ar/CO2 70/30: **13-15 eV**

Typical laser photon energy: ~**4.7 eV** @ 266 nm ← **too low!**

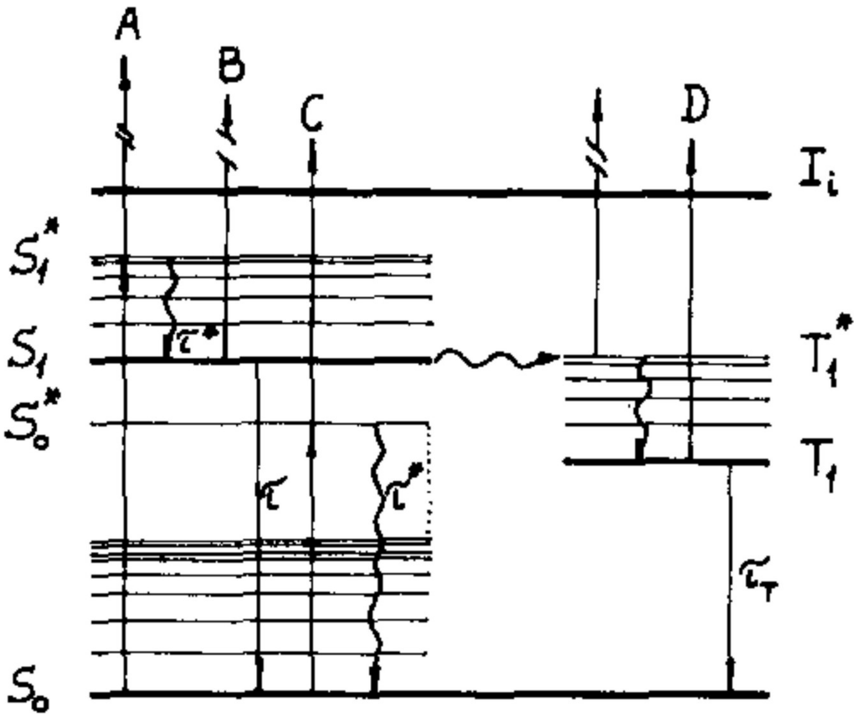
Laser ionization made possible by **multi-photon absorption** of impurity molecules:

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

n-photon cross-section equivalent

ionization rate density

laser beam flux



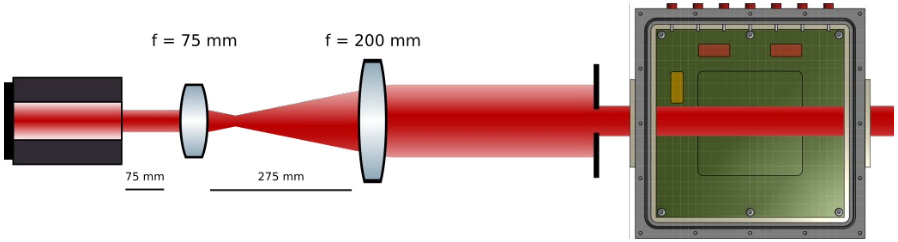
Benzene energy spectrum, divided in ground, excited and ionized states

At low beam intensity, two-photon ionization dominates:

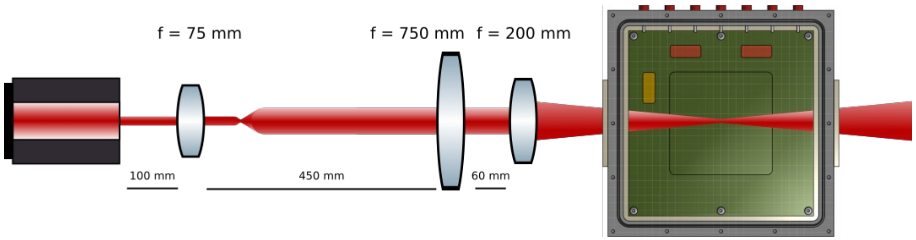
$$\text{ionization rate} \propto (\text{later beam intensity})^2$$

Optical setup preparation

Collimated setup



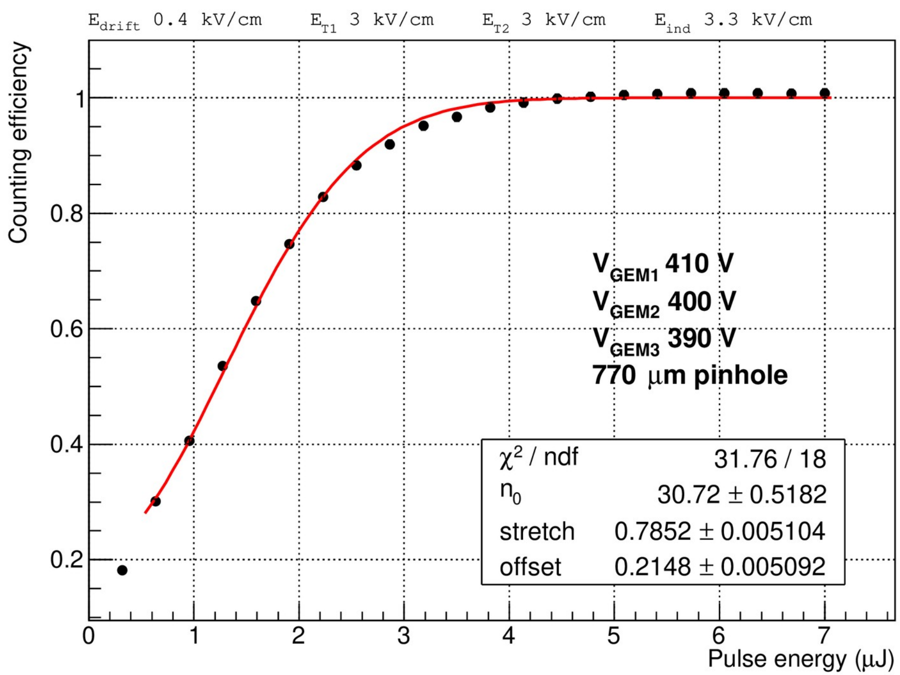
Focused setup



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

Estimation of primary ionization rate

Problem Determining the number of primaries created by a single laser pulse



Solution Measuring the counting efficiency scan vs laser pulse energy @ 100 Hz:

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

Assumption Primary electron number is Poisson-distributed

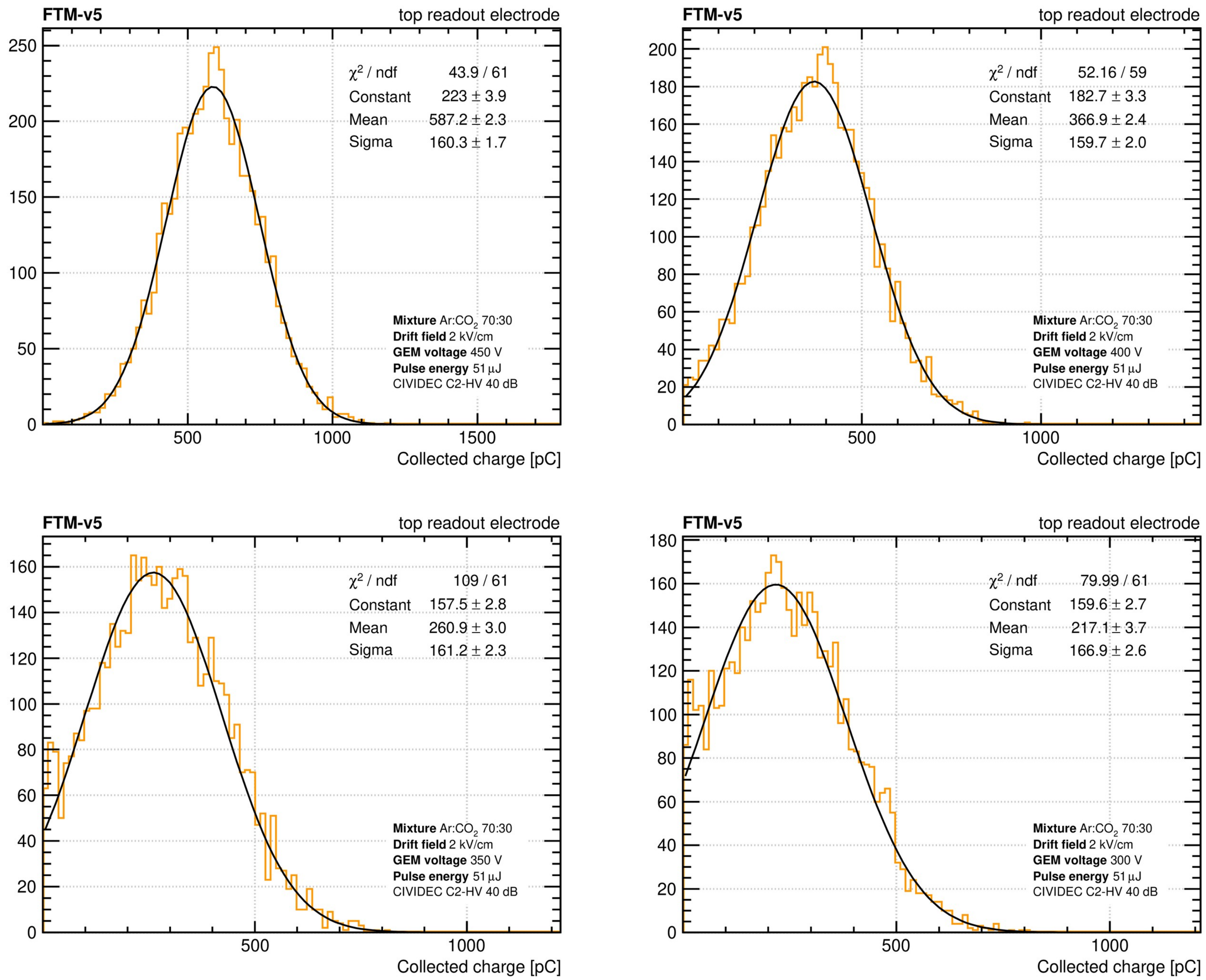
$$\epsilon = 1 - \sum_{n=0}^{n_t h} \frac{\exp[n_0(E/E_0)^2]}{n!} n_0^n (E/E_0)^{2n}$$

E_0 = reference pulse energy n_0 = primary electrons per laser pulse at E_0

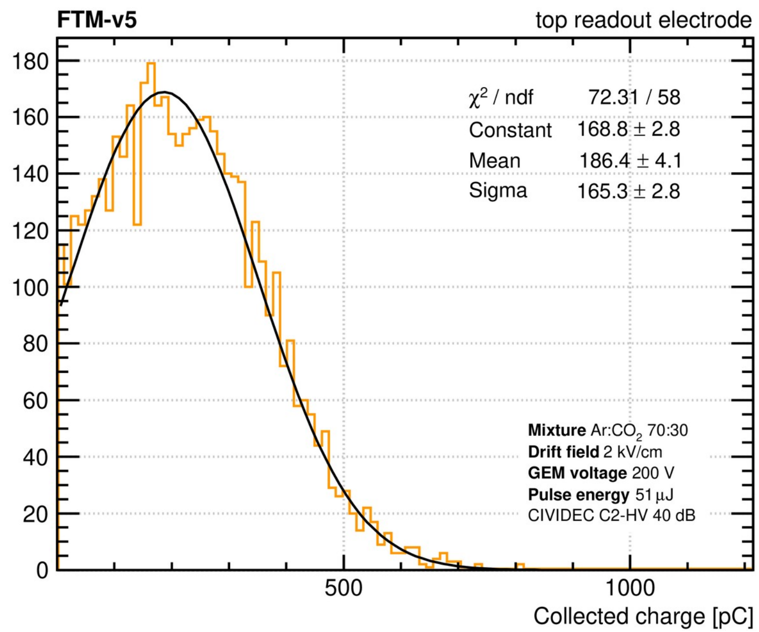
n_{th} = n. of primary electrons corresponding to the discriminator threshold

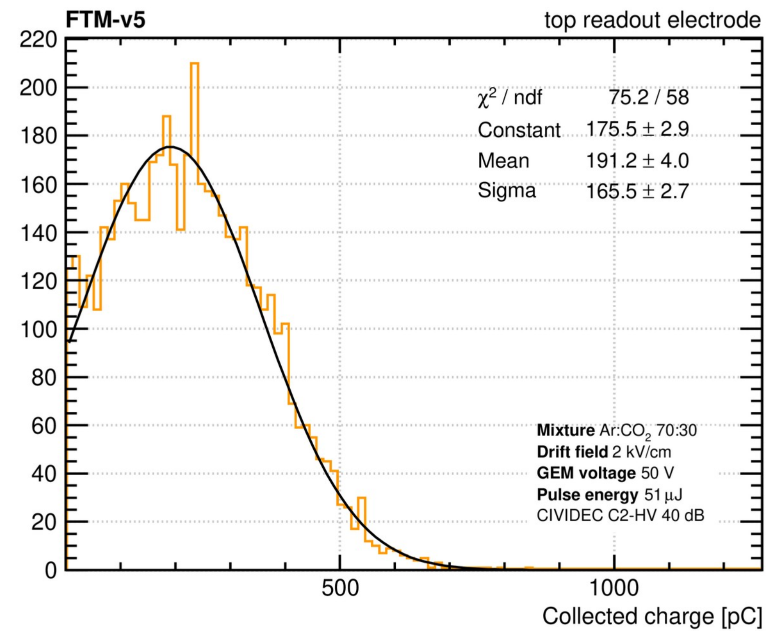
Result: n_0 = 30.7 ± 0.5 electrons at 10 μJ in the active gas volume

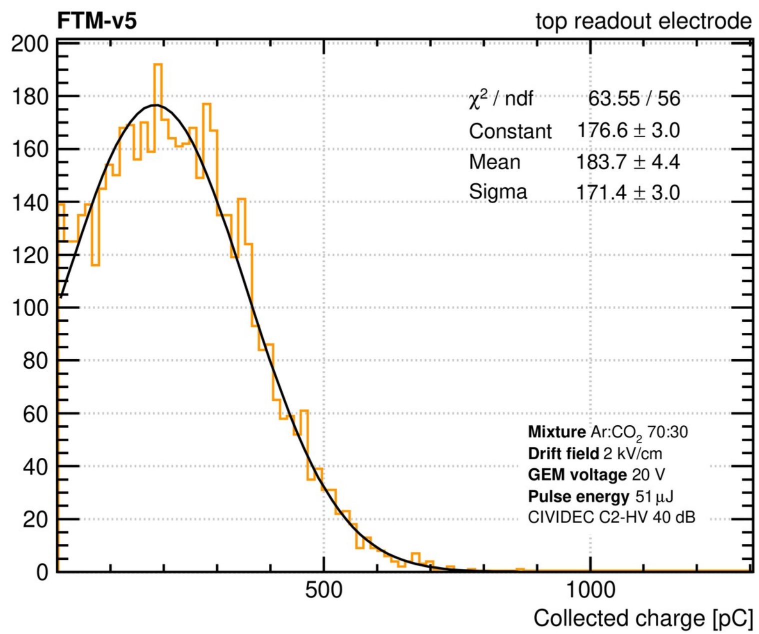
Charge spectra at different gains – mar 2020

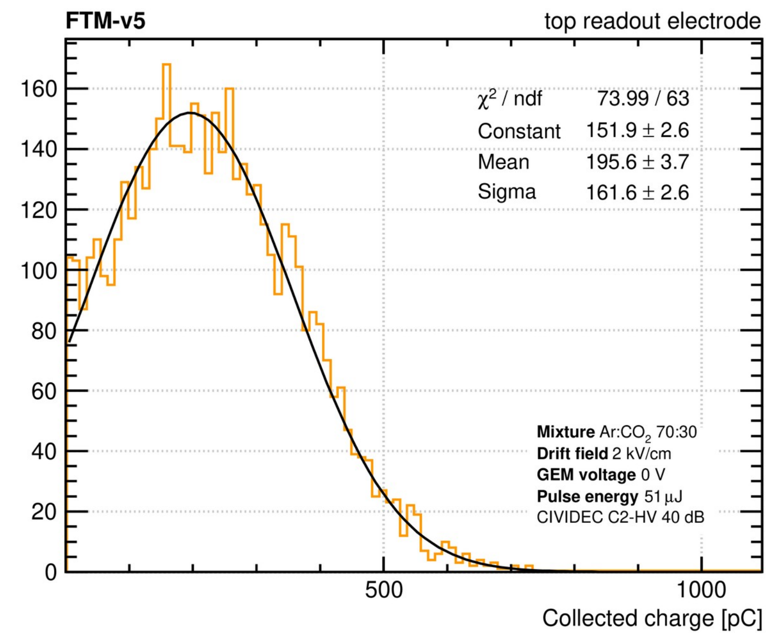


Charge spectra at different gains – mar 2020

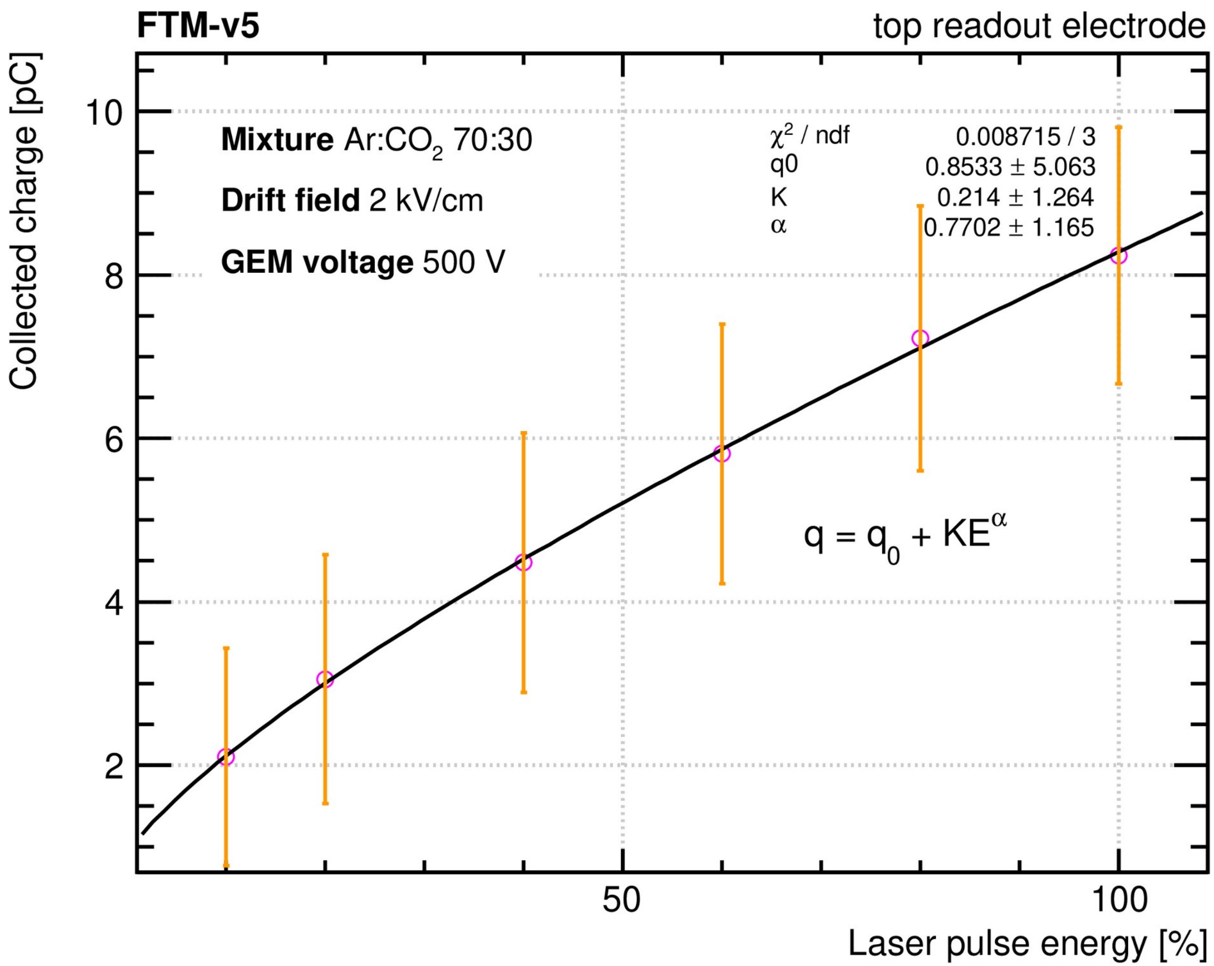






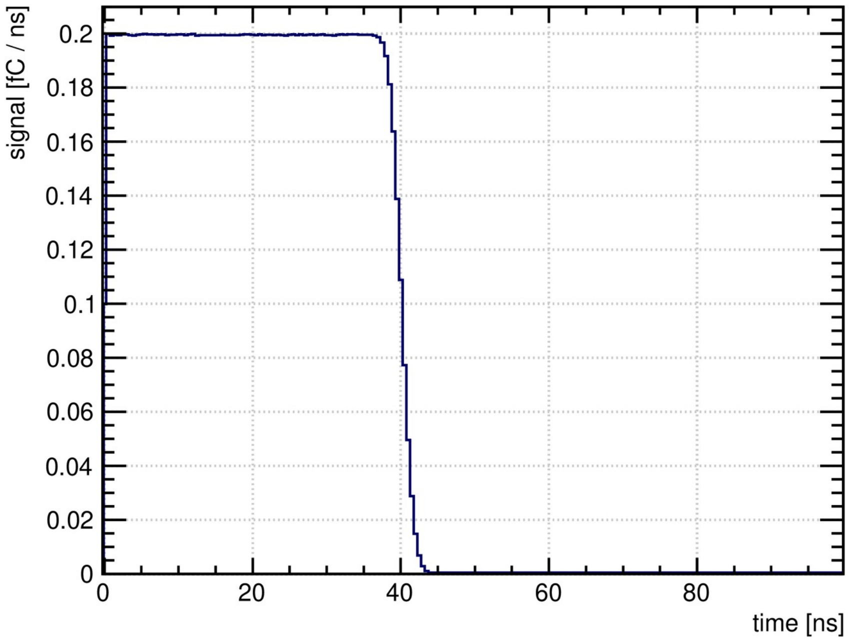


Laser pulse energy scan - mar 2020

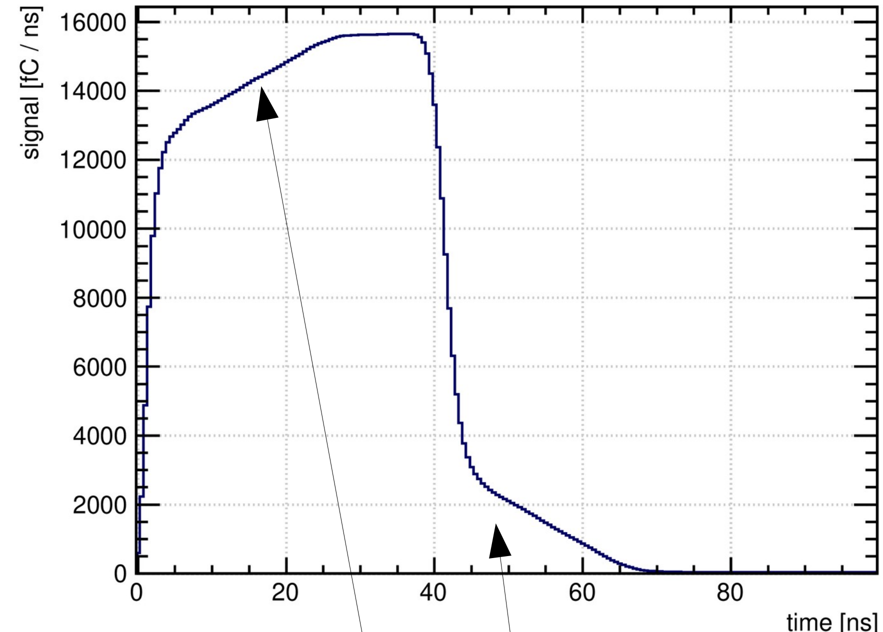


- Expected: quadratic
- Observed: possibly linear
- Linear trend of ionization vs pulse energy is expected in high laser flux regime
- Two possibilities:
  1. Loss of quadratic behaviour in the primary ionization itself
     - To be confirmed or rejected by measuring laser energy scan at low amplification fields
  2. The amplification is not linear (non-proportional regime) because of the large primary charge
     - Measurements to be repeated with strong laser attenuation

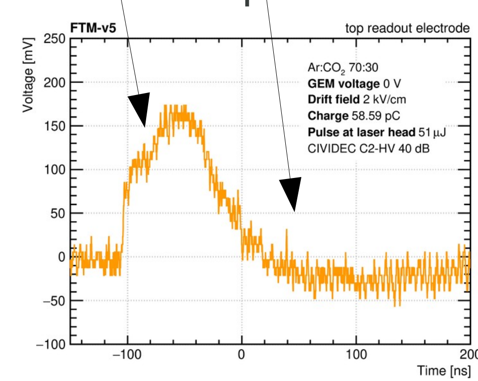
Simulated signal in ionization regime with shaping effects



Without preamplifier

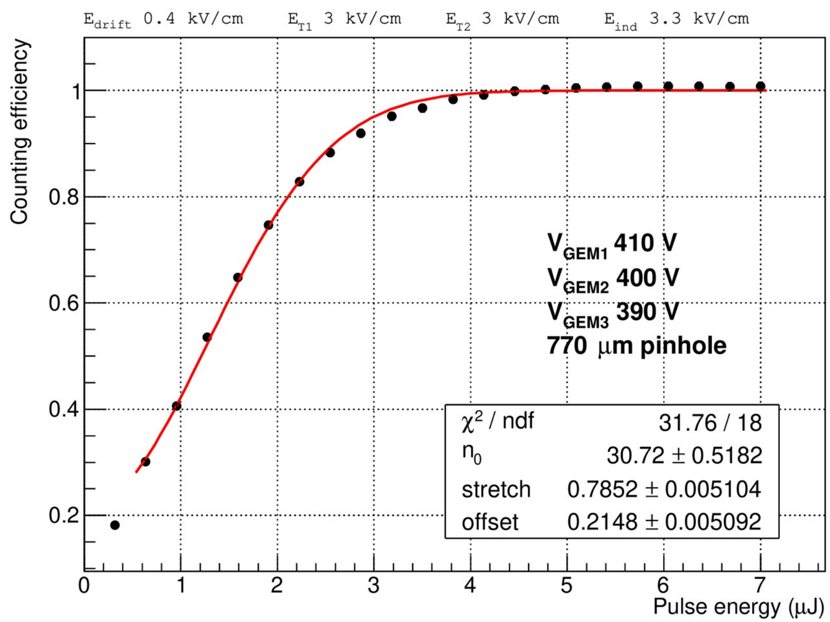


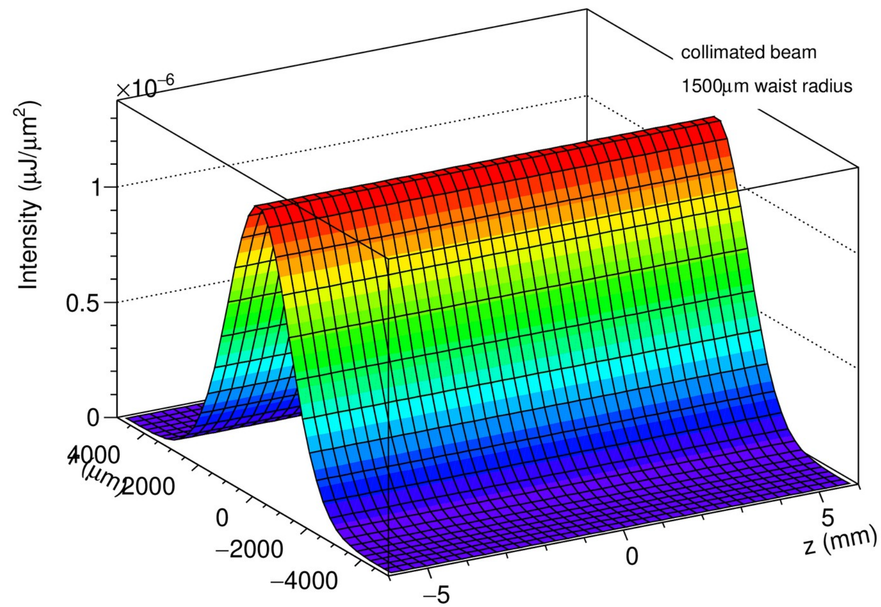
With amplifier



- "Bare" signal is convoluted with response function
- Slower signal rise and fall segments
- Longer overall signal
- Good comparison with measured signal

Estimation of the two-photon laser ionization cross-section





Calibration referring to the following beam setup:

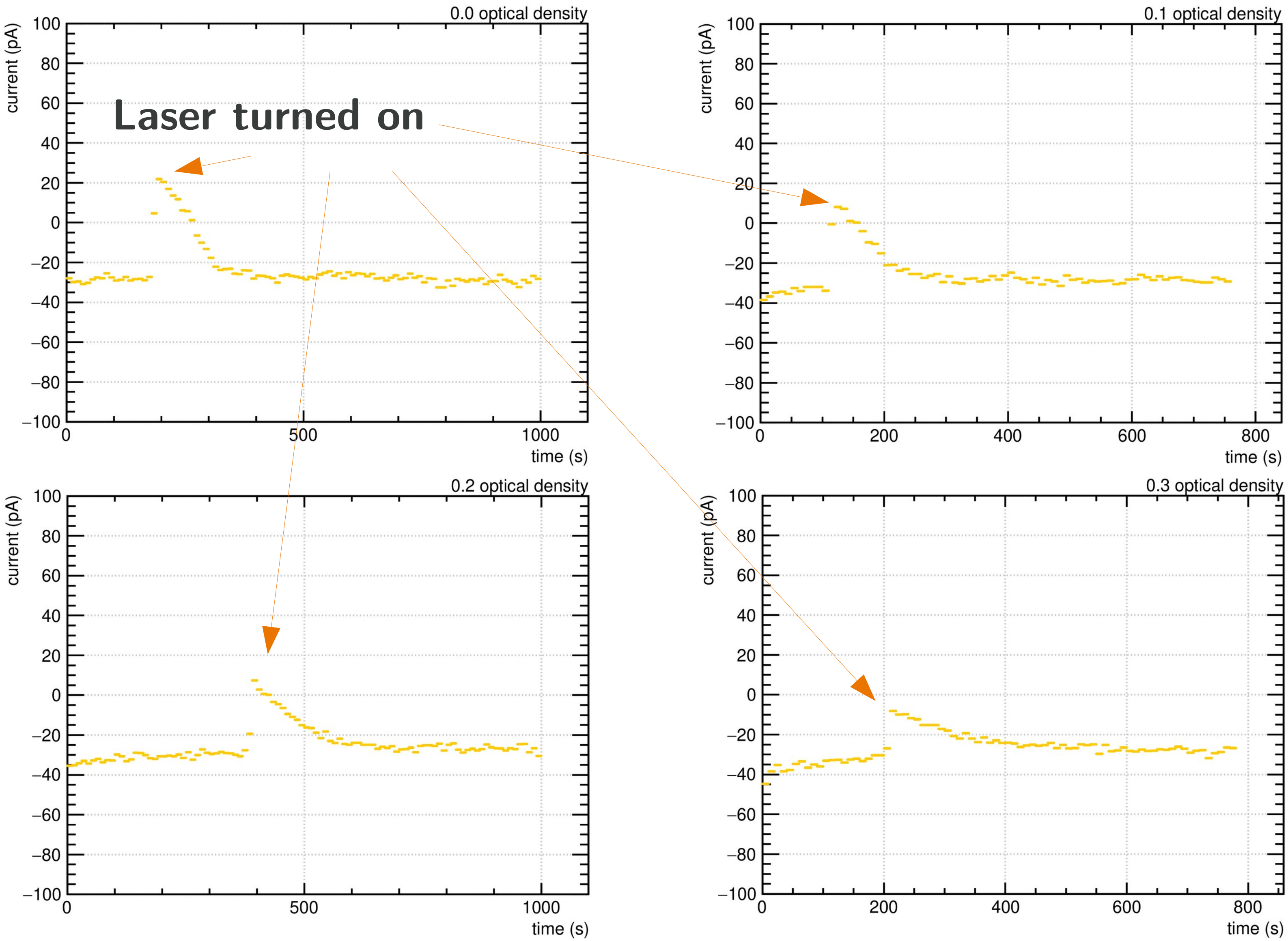
- 1500 μm waist radius
- Collimated beam
- 770 μm pinhole radius
- 10 μJ pulse energy
- 30 e⁻ created per laser pulse

Found two-photon cross-section by numerical integration:

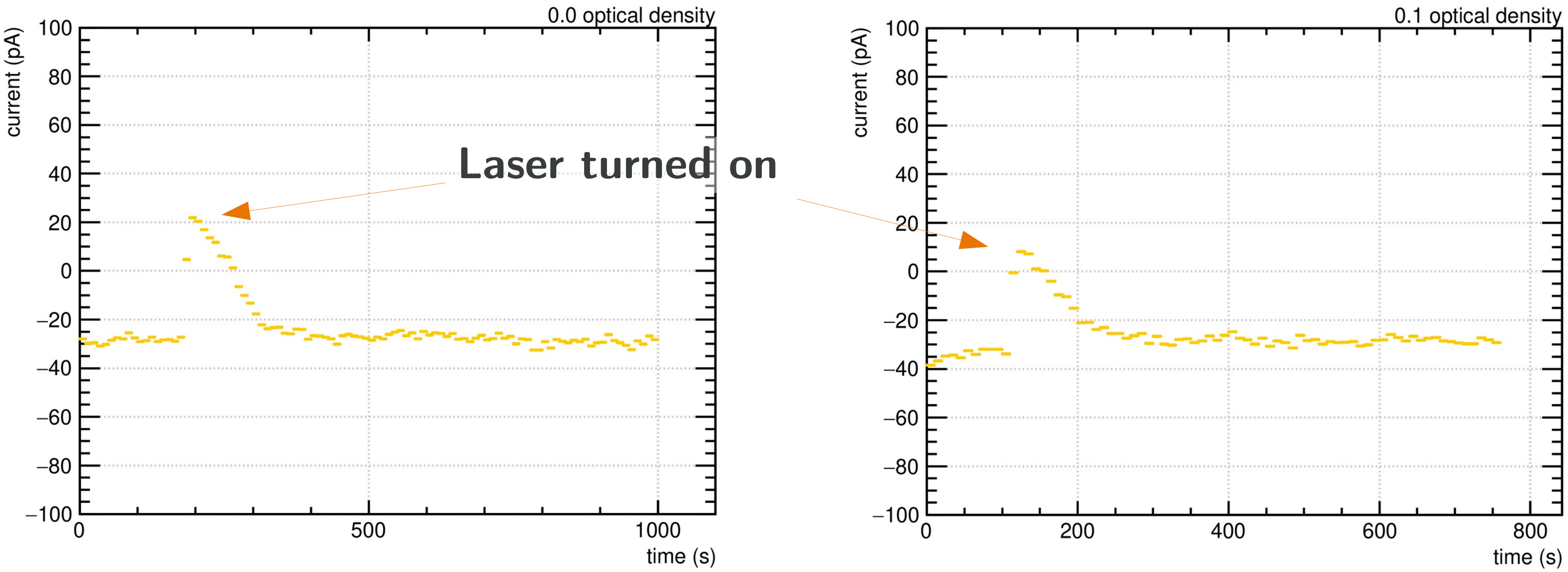
$$\frac{N\sigma^{(2)}}{(h\nu)^2} = \frac{R}{\int dxdydz\, I(x,y,z)^2} = 29.5 \times 10^8 \mathrm{mm}^4/\mu\mathrm{J}^2$$

Ionization in the bottom layer – july 2020

I tried to measure the ground current at different laser attenuations $(0.0<OD<0.5)$



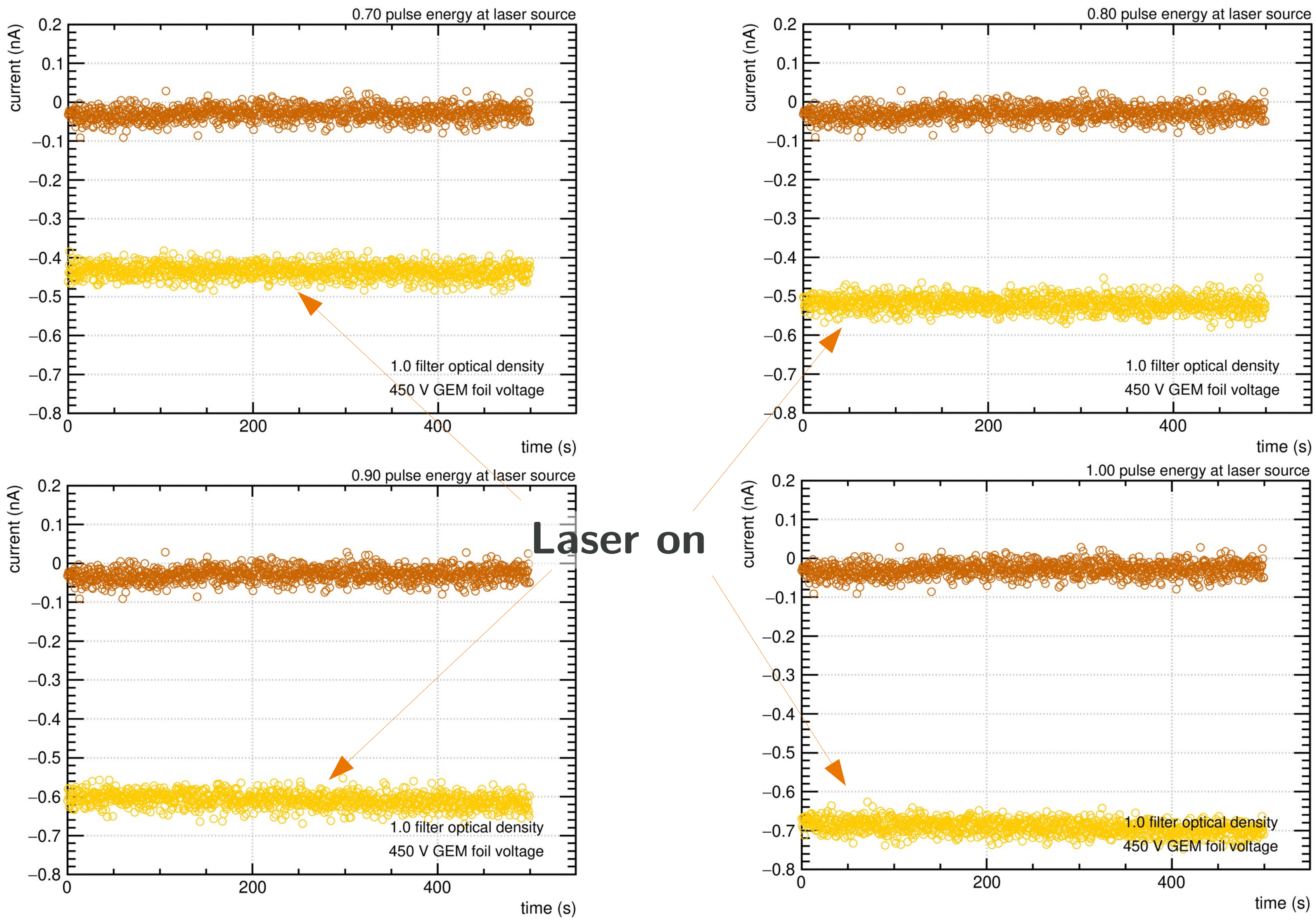
Ionization in the bottom layer: considerations



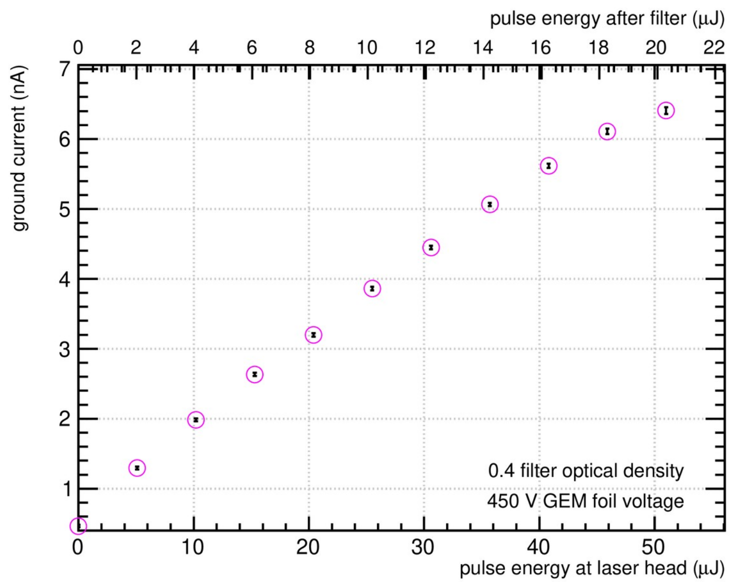
- When the laser is turned on, the current increases sharply, then "exponentially" decreases
- The current "delta" (i_{on}-i_{off}) increases with the laser pulse energy
- Charging up effect?

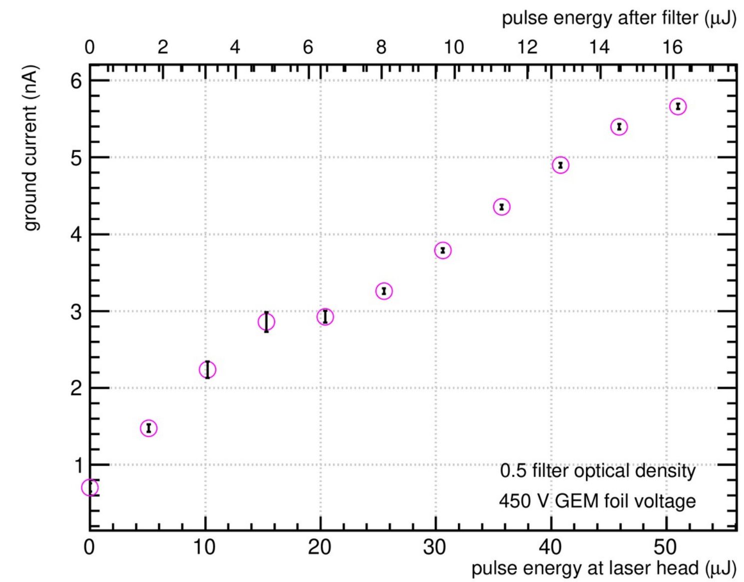
This only happens when the laser is shot in the bottom layer. Subsequent measurements have been done only ionizing in the top layer, where the current remains steady after turning on the laser

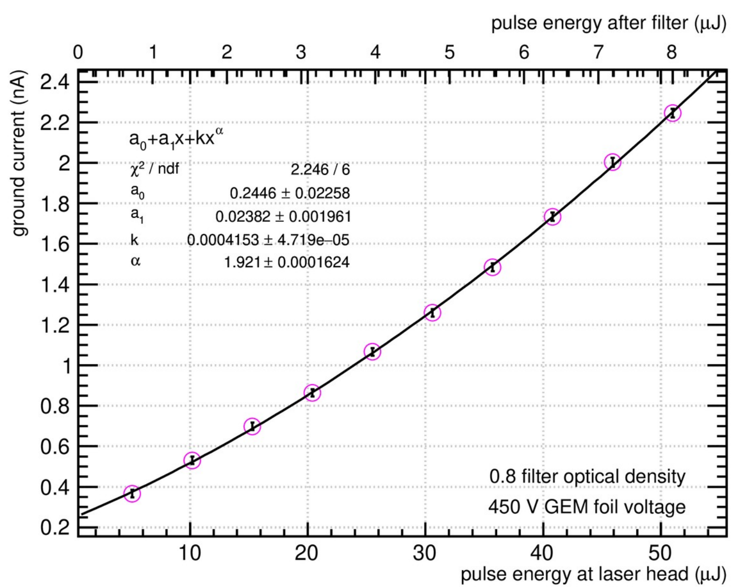
Ionization in the top layer

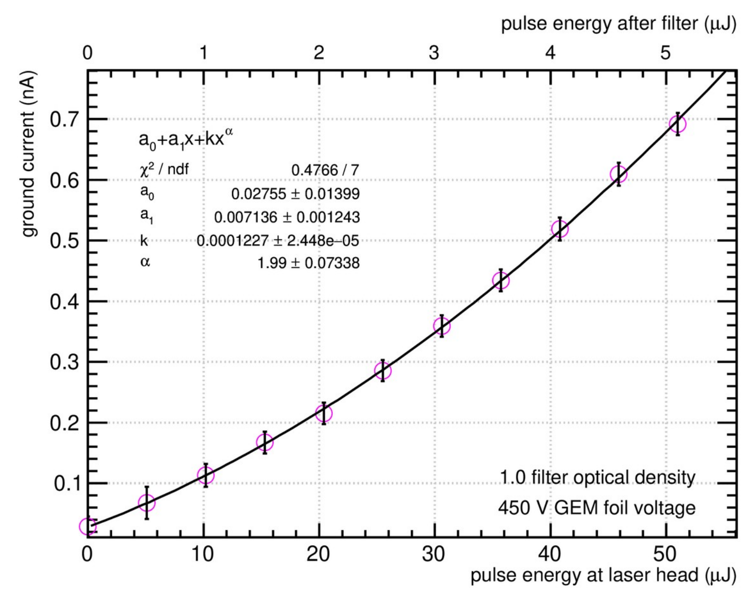


Looking for the quadratic ionization trend





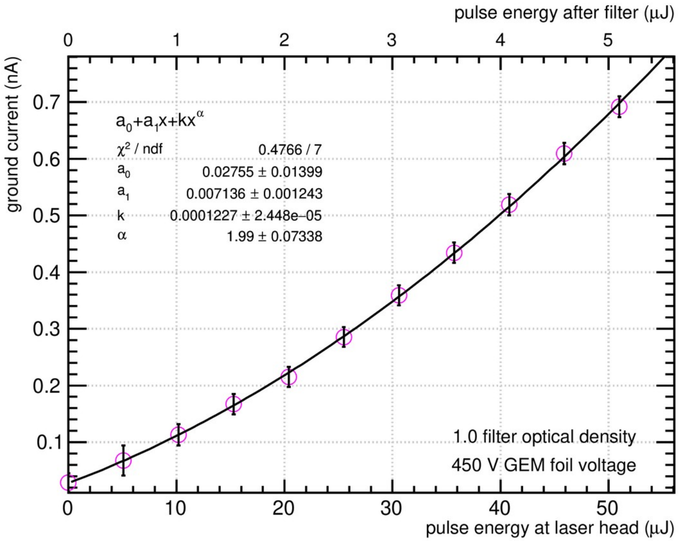




Current vs pulse energy plot at increasing filter optical densities

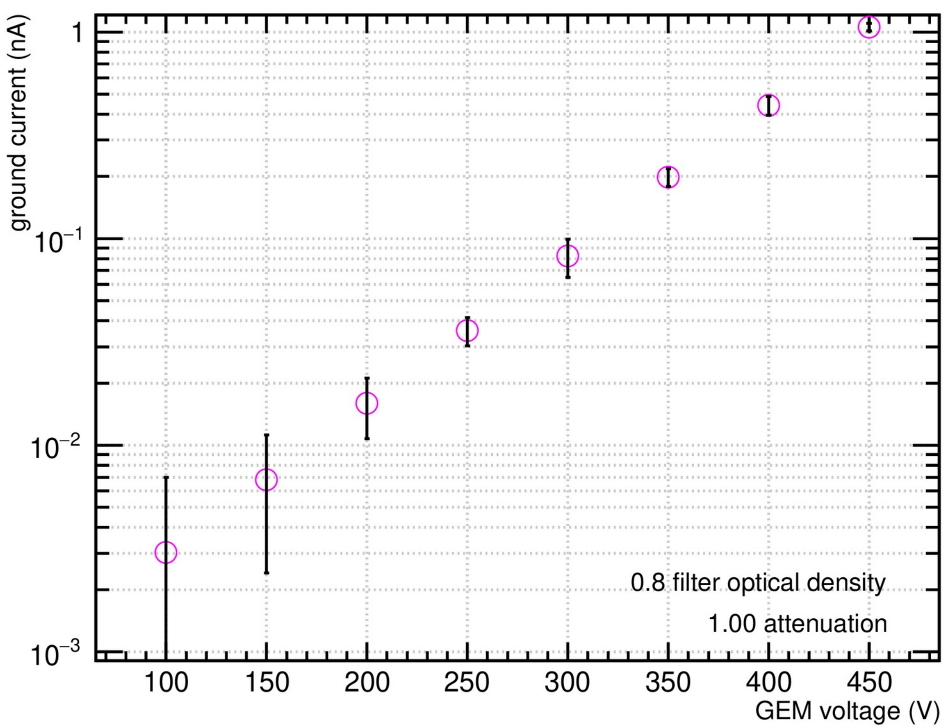
Quadratic trend recovered at E_P<8 uJ

Found quadratic trend at low laser flux



My interpretation is that at high laser fluxes the trend is not quadratic not because saturation in the laser, but because of loss of linearity in the detector due to the high primary charge (space charge, charging up, resistivity effects etc.)

The trend is quadratic at pulse energies < 8 μJ → **current vs amplification field** is measured with filter at OD = 0.8 - 1.0



Ground current measured at OD = 0.8, attenuator 100% → E_P = 8 μJ