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Secondary scintillation in Ar-CF_4 mixtures

Abstract

In order to build a optical time projection chamber that can be used as a tracking detector, it is necessary to study the scintillation proprieties of gases in order to optimize the light emission. A detailed study of the scintillation of Ar-CF_4 mixtures at different concentrations has been performed to study the light emission of the gas in a triple GEM detector.

Goal of the project

The time projection chamber (TPC) is a tracking detector used since several years in particle physics. A possible way to reach an excellent tracking precision of the order of 10 μm, is to exploit the light produced in the Towsand avalanche using a CCD camera for the readout. An immediate advantage of the optical readout is given from the excellent precision achievable with a commercial device like a CCD camera, that guarantees also an easy readout. In order to develop an optical TPC it is necessary to find out the best scintillating gas and to optimize all the parameters of the detector to reach the highest amount of light.

Setup

The prototype of the optical TPC is a triple GEM detector to amplify the signal of the primary electrons. Since it is required an optical readout it is necessary to remove the anode and to put a transparent plexiglass window on the bottom of the detector. An Hamamatsu H7826 PMT positioned underneath the plexiglass allows the collection and the study of the light production. The electrical scheme of the detector is shown in figure 1. The first two GEM are powered with a resistor divider and they work at the same gain: even if a usual triple GEM detector has a higher gain on the first GEM, the choice to balance the gains of the first two amplification stages has been done to allow an increasing in the freedom of the possible voltages that it is possible to study without damaging the first GEM. A second high voltage power supply allows to change independently the second transfer field and the voltage drop across the last GEM can be set with a third power supply. This configuration allows the study of the light yield as a function of the transfer field and of the voltages across the last GEM. The detector was operated with mixtures of argon and CF_4 at different concentrations in order to study their scintillation proprieties.

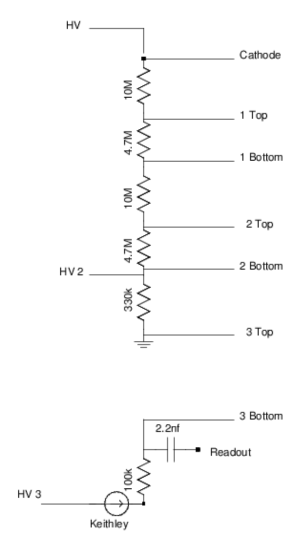

Figure 1: Electrical scheme used to power the triple GEM detector.

Acquisition

To characterize the different mixtures the analysis focused on measuring the ratio between the number photons and electrons produced in the amplification as a function of the field applied on the last GEM and of the second transfer field.

The data acquisition has been done event by event using a scope. For each operative condition ten thousands waveforms have been saved and the number of photons has been estimated as

$$N_{ph} = \frac{Integral\ of\ the\ signal}{Integral\ of\ single\ photon} \cdot \frac{4\pi}{\Omega} \cdot \int d\lambda \frac{1}{T(\lambda)} \cdot \frac{1}{QE(\lambda) \cdot P(\lambda)}$$

where the variables has been estimated as:

- The integral of the signal is the centroid position estimated from the gaussian fit of the distribution of the integrals of all the waveforms.

- The single photon has been calibrated with a LED powered with pulses of different amplitudes. The integral of the single photon is estimated from a gaussian fit in the same way of the signal.
- Ω is the solid angle intercepted from the PMT and has been valued with a Montecarlo simulation.
- $T(\lambda)$ and $QE(\lambda)$ are the transparency of the plexiglass and the quantum efficiency of the photocathode and are integrated over the emission spectra of the gas.

The number of electrons produced in the avalanche has been measured using a Keithley picoamperometer connected to the bottom of the third GEM and the number of electrons is simply the ratio between the current and the interaction rate of the source.

PMT saturation

The PMT used for this setup has a non-linear behavior over $\sim 10^6$ photons/second. The rate and the number of photons for each event were up to $\sim 10^7$ which means that the data at high number of photons need to be corrected for this saturation effect. Fixing the voltage drop over the third GEM and changing the gain of the first two GEMs the current that flows into the detector should be proportional to the number of photons, if no saturation effect is involved. From the data at low gain, so at low number of photons, it is possible to get with a linear fit the parameter which links the current to the number of photons and in this way estimate the real number of photons in the PMT from the measured current. The plot 2 shows the detected number of photons as a function of the real one and the saturation is evident. With a fit of the plot it is possible to extrapolate the correction and in this way to correct all the data.

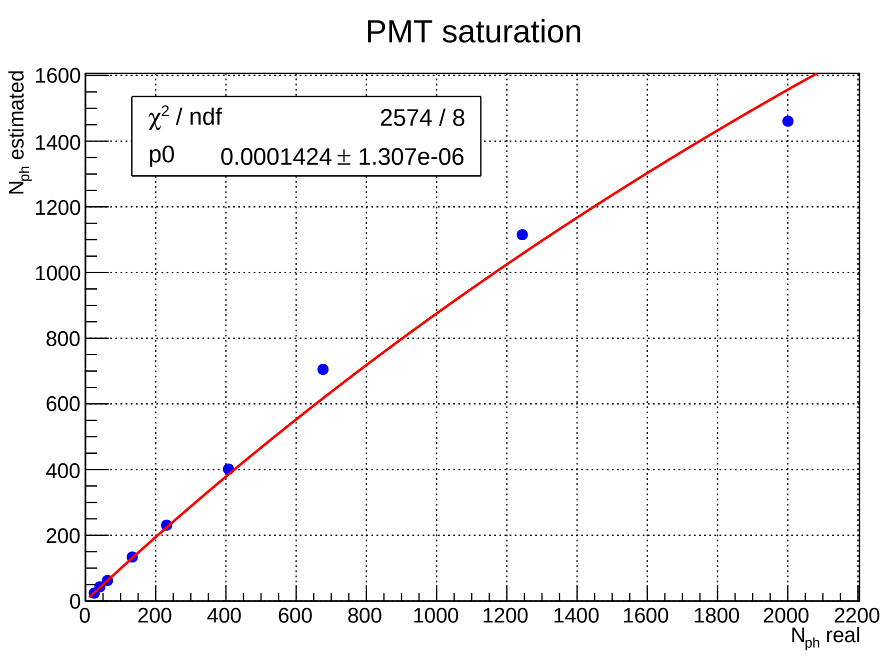

Figure 2: Number of photons detected as a function of the real number of photons. The presence of the saturation at high number of photons makes the response of the PMT non linear.

In figure 3 it is possible to see the effects of the correction over a set of data. The decreasing trend present in the data at high field is just an effect of the saturation and it disappears after applying the correction. Nevertheless the last point of the corrected data has still a decrease due to an undercorrection: the fit has a bad χ^2 and the data on the plot in figure 2 are up to 2000 photon, so for all the points above this threshold the correction can not be estimated properly.

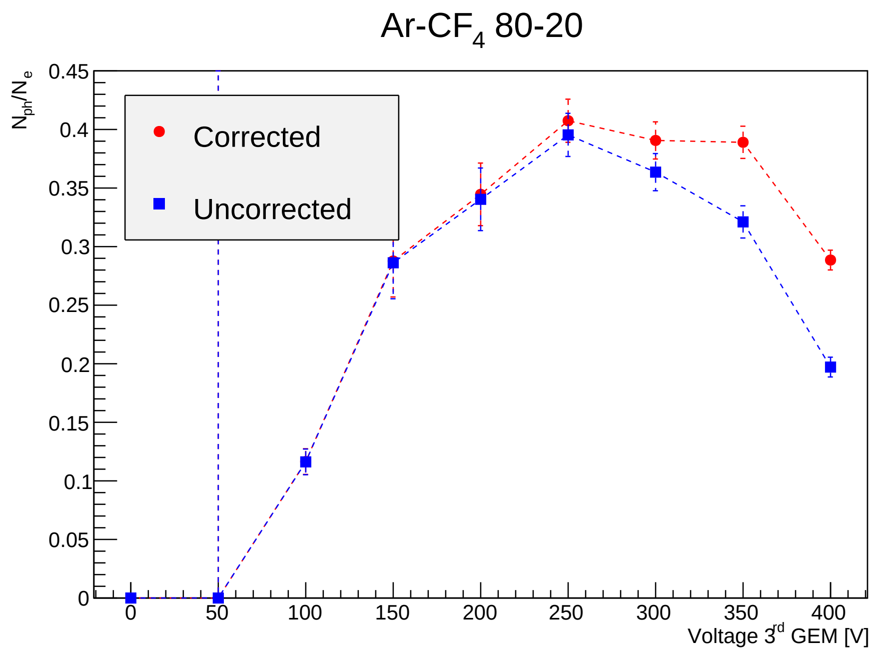

Figure 3: Effect of the correction on a set of data. At high voltages, when the number of photons is over 2000, the extimation of the correction is no longer effective and the data still present a decreasing.

Results

In figure 4 it is plotted the ratio between number of photons and electrons as a function of the voltage drop of the third GEM for different transfer fields and with Ar-CF_4 80-20. It is evident that the voltage of the last GEM can affect the scintillation of the gas and all the measures at low transfer field has a similar behavior. At a transfer field of 4000 kV/cm the ratio is about an half of the other data an this effect is compatible with the probability of attachment which, according to the simulations, is negligible up to 2 kV/cm and about 60% at 4 kV/cm. The plot shows that at high voltages the scintillation reaches a plateau for all the transfer fields: the point in the red circles are the points with more than 2000 photons and their decrease is due to the undercorrection.

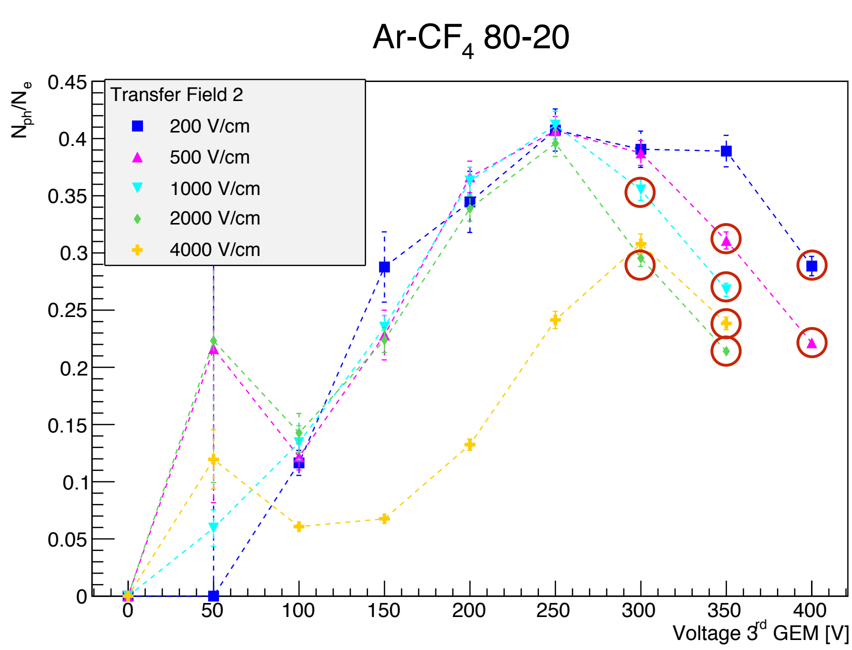

Figure 4: Ratio between the number of photons and electrons as a function of the voltage drop of the last GEM for different transfer fields. The points inside the red circles are the undercorrected ones.

Figure 5 shows for a transfer field of 500 kV/cm the N_{ph}/N_e for different gases as a function of the voltage of the third GEM. The highest scintillation is reached for Ar-CF_4 80-20 and it is about 0.4 N_{ph}/N_e. Ar-CF_4 60-40 seems to be better at very high voltages but it is still an effect due to the undercorrection: with more quencher there will be less charge and so the total number of photons will be lower in 60-40 than in 80-20 and so only the data for 80-20 has a significant undercorrection.

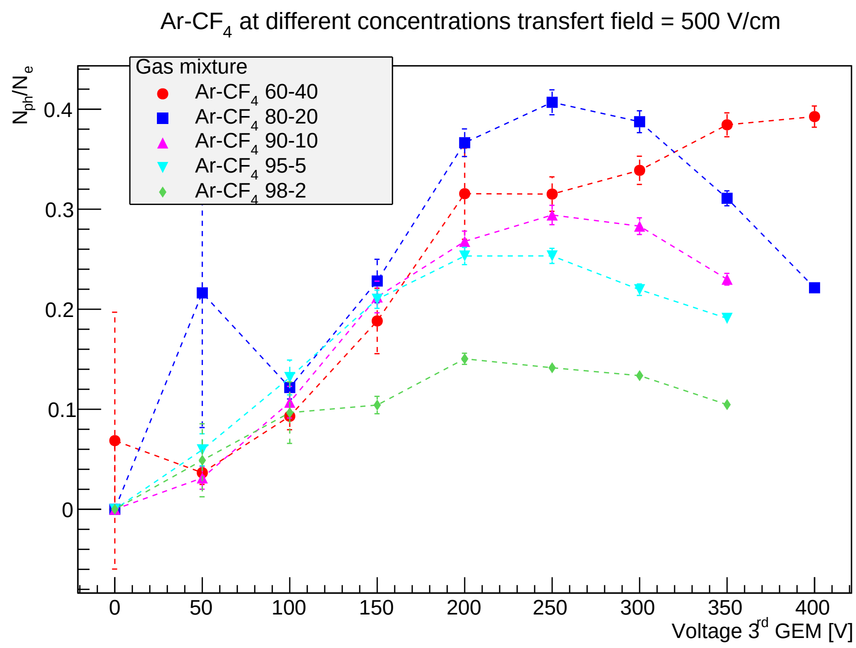

Figure 5: Ratio between the number of photons and electrons as a function of the voltage drop of the last GEM for different gas mixtures.

The plot 6 shows for Ar-CF_4 80-20 the charge in the detector as a function of the voltages of the third GEM at different transfer fields. Since higher charge means higher light a transfer field of 2000 kV/cm will ensure the highest light inside the optical TPC.

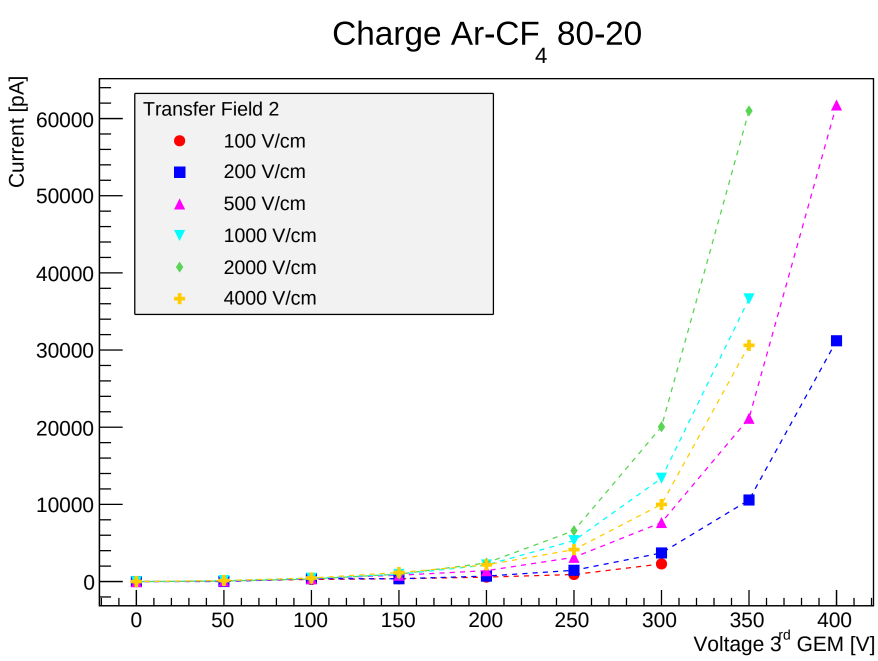

Figure 6: Charge produced in the avalanche as a function of the voltage drop of the last GEM for different transfert fields. 2000 kV/cm ensures the highest gain achievable.

Study of the waveforms

The acquisition of the waveforms allows a detailed study of the signal. Figure 7 shows an average waveform from the PMT for Ar-CF_4 80-20 at different transfer fields.

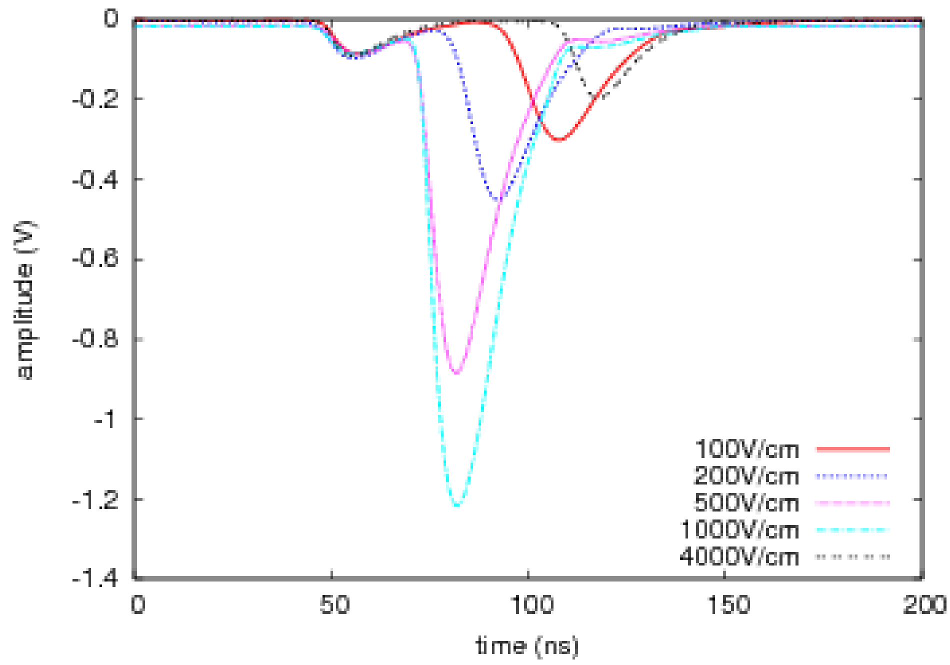

Figure 7: Average waveforms acquired for Ar-CF_4 80-20 at different transfer fields.

The presence of the first bump common to all the waveforms can be explained as the light produced in the second GEM: if the third GEM is off that part of the signal is still present and the difference in time between the two peaks changes with the transfer field. Since this delay is due to the transit time of the electrons it is possible to estimate the electron drift velocity. In figure 8 it is possible to see the comparison between the data and a simulation of the drift velocity: the data can reconstruct the expected shape of the velocity but there is still a factor of about 1.5 to get a perfect agreement. A possible explanation is that the simulation has been done for uniform field while inside the GEM the field is not uniform.

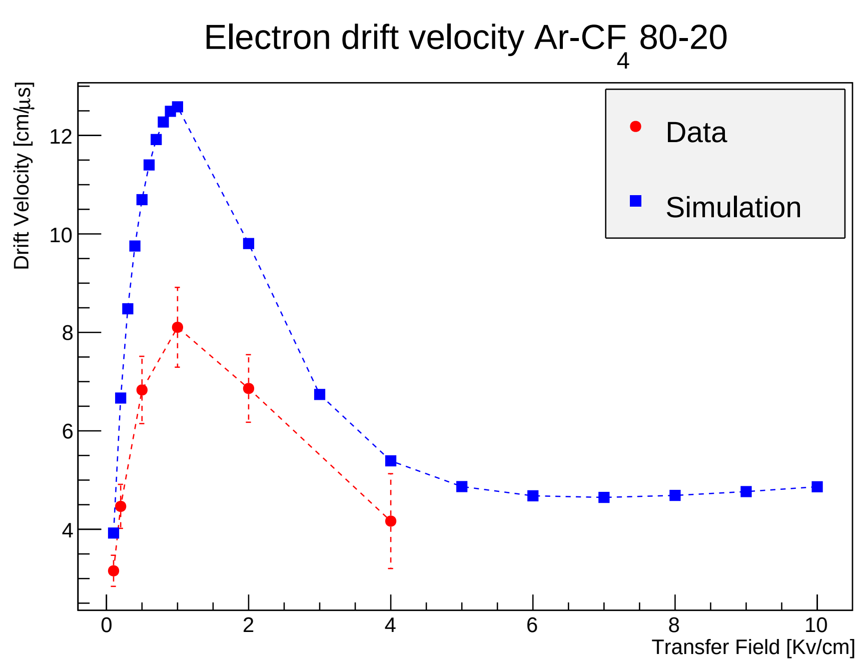

Figure 8: Comparison between the measured drift velocity and a simulation. The data and the simulation has the same trend but the values are in disagreement within a factor of 1.5.

Conclusions

This work allowed a detailed study of the scintillation of different mixtures of Ar-CF_4, with particular effort on 80-20. The best operative conditions for an optical TPC are with 80-20 and a transfer field of 2000 kV/cm at the highest gain which is possible to reach safely with the stack of GEM. In addition it is possible to use the informations of the drift velocity of the electrons to monitor the running conditions of the detector during the operations.