Discussion points on the NITPC paper

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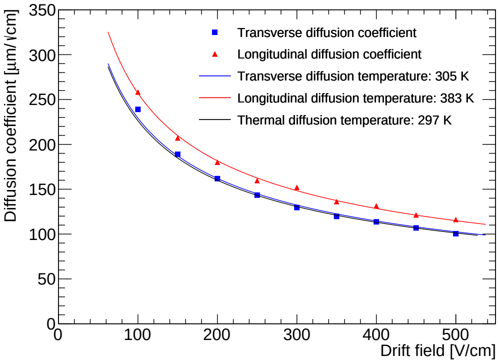
Lepcol meeting

June 29, 2020

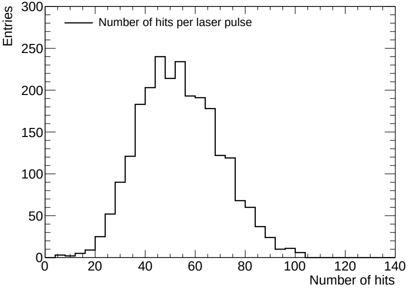
Explanation for the longitudinal drift resolution?

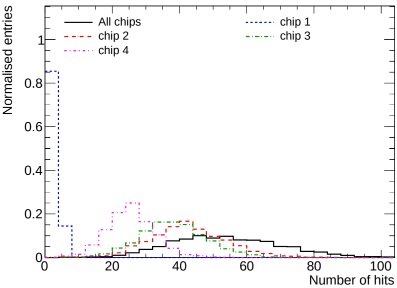


Why is the longitudinal diffusion coefficient larger than the transverse diffusion coefficient?

Why is the longitudinal resolution at zero drift $\sigma_{z0} = 141\,\mu\text{m}$ larger than the transverse resolution at zero drift $\sigma_{x0} = 94\,\mu\text{m}$

Number of hits per chip or in total?





Suggested other measurements

a.o. Jan suggested to do a few more measurements

- More equal number of hits per chip
- Higher laser intensity
- Add oxygen to the gas (More minority carrier(s))
- Measure with SF6 gas, or helium
- Measure at low pressure
- ...

I don't have the time to perform these measurements now as my first priority is to finish my thesis

Appendix

The negative ion TPC

- In a negative ion TPC, ionisation electrons are captured shortly after creation by electronegative molecules (CS_2) and drift to the readout plane as negative ions
- In the amplification region, the electron detaches and a normal avalanche occurs
- The negative ion TPC was introduced to reduce diffusion without the need for a magnetic field [1]
- The negative ion TPC has been applied to directional dark matter search experiments (Drift IId [2])
- From multiple types of ions with different drift velocities, the absolute drift distance can be reconstructed without a trigger

[1] see C. Martoff et al (2000) https://doi.org/10.1016/S0168-9002(99)00955-9

[2] see J. Battat et al (2017) https://arxiv.org/abs/1701.00171

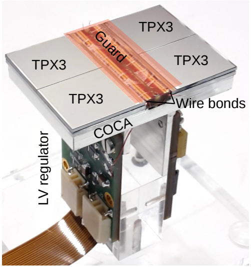
Gas conditions

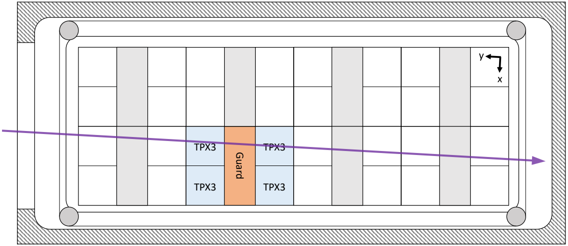
Gas at atmospheric pressure is used in an existing setup:

93.6%	Argon
5.0%	iC_4H_{10} as a quencher
1.4%	CS_2 to capture the electrons and form negative ions
$\sim$ 0.1%	O_2 to make a second type of ions
$\sim$ 0.4%	H_2O is a contamination

The gas contains a small amount of oxygen (650 ppm to 1150 ppm) and water vapor (about 4000 ppm).
The oxygen is required to make a second type of ions: the minority carrier(s).

Experimental setup

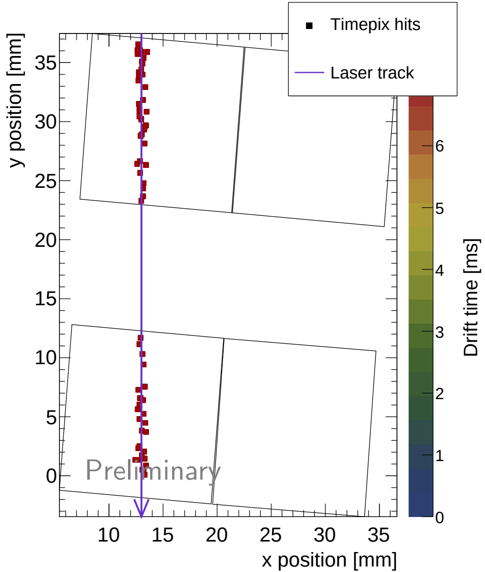




Ionisation in the gas volume is created using a pulsed N_2 laser, directed in the gas volume by a remotely controlled stage

One quad (4 chips) is read out

Event display



Event display of negative ion track

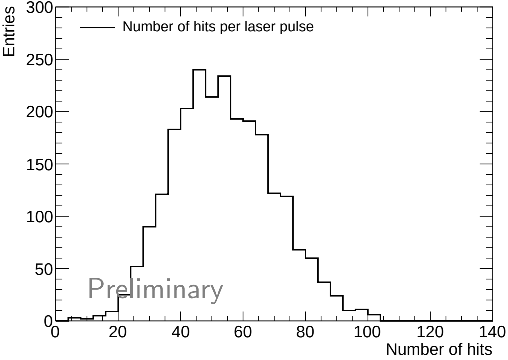
- 64 hits
- $E_{drift} = 300\,V/cm$

Run parameters

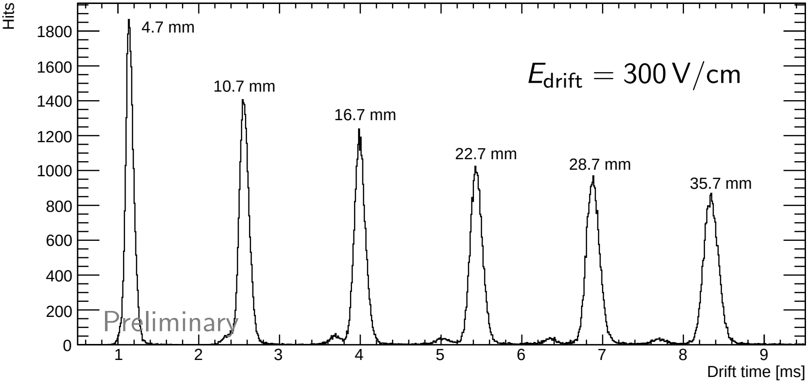
Number of runs	9
Run duration	17 minutes
E_{drift}	100 – 500 V/cm
V_{grid}	-380 V
Threshold	515 e^-
Temperature	295.9 – 297.0 K
Pressure	1030 – 1029 mbar
Oxygen concentration	650 – 1150 ppm
Water vapor concentration	$\sim$ 4000 ppm

Nikhef

Number of hits per laser pulse



Drift time spectrum



The majority carrier and minority carrier(s) cause two distinct peaks

Fit of double Gauss

Do a 'global' fit per run of two Gaussians per drift distance:

$$g(t) = \frac{(1 - f_2 - f_{\text{noise}})n_{\text{hits}}}{\sigma_1\sqrt{2\pi}} \exp\left(-\frac{(t-\mu_1)^2}{2\sigma_1^2}\right) + \frac{f_2 n_{\text{hits}}}{\sigma_2\sqrt{2\pi}} \exp\left(-\frac{(t-r_2\mu_1)^2}{2\sigma_2^2}\right) + \frac{f_{\text{noise}}}{u_{\text{width}}} n_{\text{hits}}, \quad (1)$$

Fit per run:

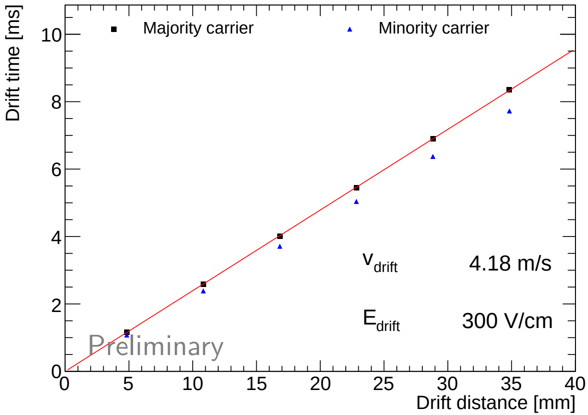
- ratio of Gaussian constants f_2
- ratio of mobility r_2

Fit per drift distance:

- standard deviations σ_1 and σ_2
- mean μ_1
- offset f_{noise}

Nikhef

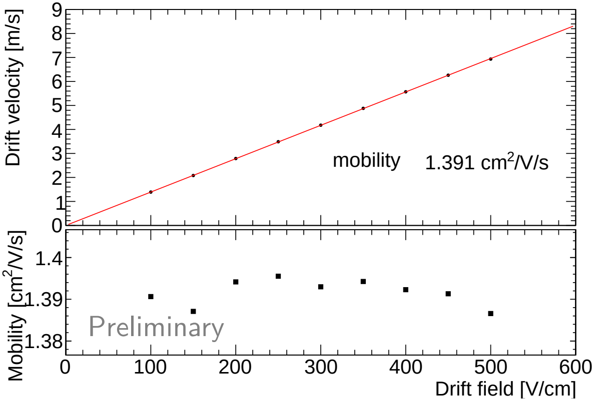
Drift velocity



The drift velocity is a few m/s

The minority carrier(s) are 8.1% faster

Mobility



The mobility is $1.391(3)\,\mathrm{cm}^2/\mathrm{V}/\mathrm{s}$

Diffusion

The transverse and longitudinal diffusion ($i = x, z$) are described by:

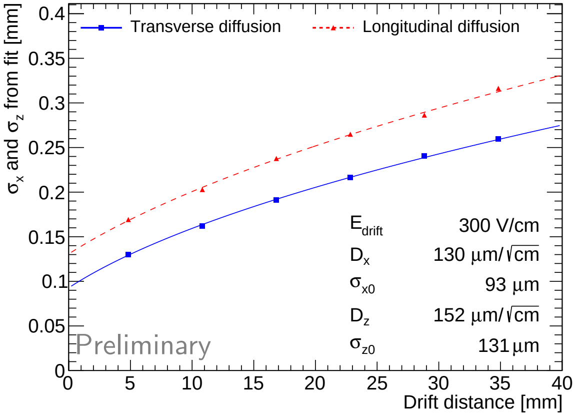
$$\sigma_i^2 = \sigma_{i0}^2 + D_i^2 z, \tag{2}$$

where σ_{i0} is the standard deviation at zero drift, D_i the diffusion coefficient, and z the drift distance.
In the thermal limit the diffusion coefficient is given by:

$$D_{\text{thermal}} = \sqrt{\frac{2k_{\text{B}}T}{eE}}, \tag{3}$$

where k_{B} is Boltzmann constant, T is the temperature, e is the charge of the ion, and E is the electric field strength.

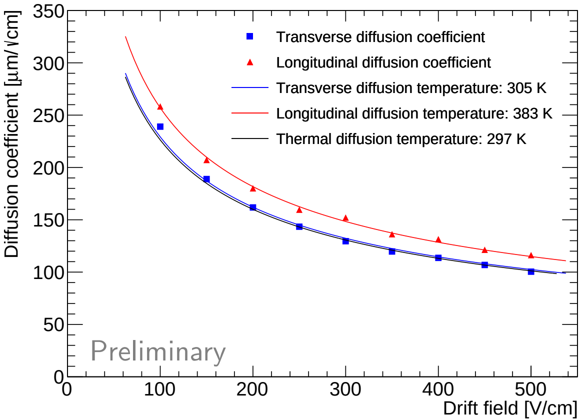
Diffusion



The resolution at zero drift is explained by the laser beam width

Plus some small per shot variations, and for the longitudinal diffusion unrecognised minority carriers

Diffusion as a function of drift field strength



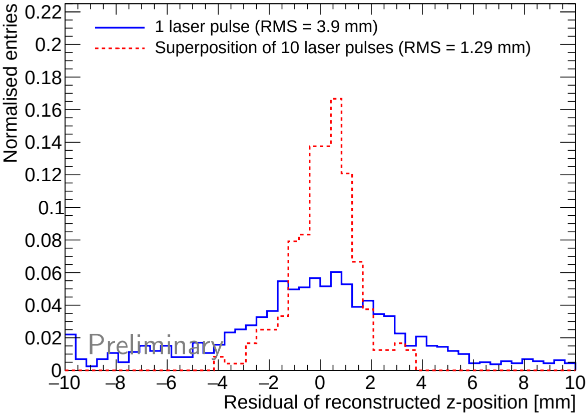
The diffusion follows the thermal $1/\sqrt{E_{\mathrm{drift}}}$ dependence well

The transverse diffusion is close to the thermal limit

Fiducialisation

- The difference in drift velocity between the majority carrier and minority carrier(s) can be used to reconstruct the drift distance without a trigger
- About 4.4% of the hits are attributed to the minority carrier(s), whose mobility is 8.1% higher than that the majority carrier.
- The reconstruction proceeds by performing per event a maximum likelihood fit of Equation (1) (the double Gaus) to the measured relative arrival time of ions from one or more laser pulses

Fiducialisation



Efficiency is 66% for 1 pulse, and 100% for 10 pulses

A negative ion TPC at the ILC?

- The negative ions have reduced diffusion, which is advantageous in the longitudinal direction but not small enough in the transverse direction for the ILD TPC
- The magnetic field does not reduce the diffusion much further because of the small $\omega\tau$ (this also means little $\mathbf{E} \times \mathbf{B}$ effects)
- The slow drift velocity is not a problem for the collection of charge, but different bunch crossings may not be well separated

This negative ion TPC does not meet the requirements for the ILD TPC

Conclusions

- The GridPix quad was used as a negative ion TPC readout
- The mobility was measured to be 1.391(3) $cm^2/V/s$ for 93.6/5/1.4 gas mixture of $Ar/iC_4H_{10}/CS_2$ with a small amount of oxygen and water vapor at a pressure of 1030 mbar and a temperature of 297 K
- The transverse and longitudinal diffusion have an effective thermal diffusion temperature of 305 K and 383 K
- Fiducialisation was applied and has an expected precision of 1.29 mm
- The small diffusion without the need for a magnetic field might be of interest to e.g. directional dark matter search experiments

The full paper will be released soon