

# Gas Argon Time Projection Chamber Optimization

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## Introduction

A gaseous argon time projection chamber (GARtPC) is investigated through this project in the hope of obtaining the low energy threshold  $O(50\text{keV})$  and spatial resolution  $O(100\mu\text{m})$  required for directional tracking of low energy nuclear recoils.

In GARtPC, Electrons' transverse diffusion impairs spatial resolution but can be suppressed by multi-atom molecule. Using PyBoltz<sup>1</sup>, this project minimizes normalized transverse diffusion,  $D_T$ , by finding the optimized pressure, dopant (fraction), and electric field while preserving the signal for low energy recoils.

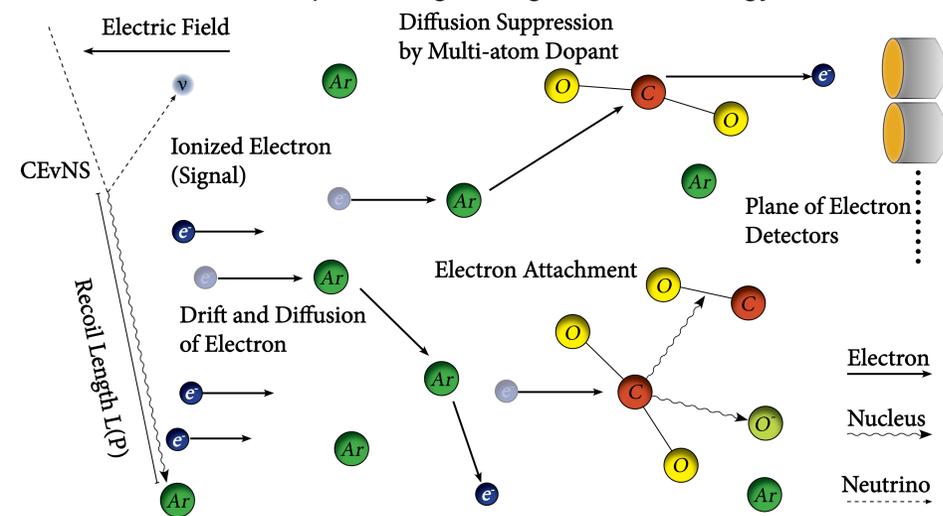


Fig. 1: Details of GARtPC is conceptualized above by selecting coherent elastic neutrino-nucleus scattering (CEvNS) as target event.

To better understand the effect of dopant type and concentration on  $D_T$ , three functions are proposed and examined, based on Blanc's law, to combine the information of component gases and predict  $D_T$  of gas mixture

$$f_1 = (2a_{1i} \frac{D_{TCM}}{W_M})^{1/2} \quad f_2 = (\sum x_i \frac{a_{2i}}{D_{Ti}})^{-1} \quad f_3 = (\sum x_i \frac{a_{3i}}{D_{Ti}^2})^{-1/2}$$

where  $D_{TCM}$ ,  $W_M$  being the conventional diffusion coefficient, drift velocity predicted by Blanc's law,  $D_{Ti}$  the pure gas  $i$ 's  $D_T$ ,  $a$  the correction coefficients.

Other effects that could impair GARtPC's performance are also considered. Electron attachment rate is confirmed to be zero for the interested parameters. To address the pressure dependent recoil range, reduced normalized diffusion is introduced to optimize resolution:  $RD_T = D_T/L(P)$  with  $L(P)$  being the average nuclear recoil length for recoil energy from 10 to 100keV at pressure  $P$ .

## Acknowledgement & Reference

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<sup>1</sup>Atoum, B. Al, et al. "Electron Transport in Gaseous Detectors with a Python-Based Monte Carlo Simulation Code." Computer Physics Communications, vol. 254, 2020, p. 107357.

## Results & Discussion

### Pressure

$RD_T$  is simulated for dopants, including  $C_4H_{10}$ ,  $CF_4$ ,  $CH_4$ ,  $CO_2$ , dimethyl ether (DME), ethane, and propane, in variable space: doping fraction (5-15%), electric field  $E$  (100-400V/cm), gas pressure  $P$  (1-5bar). For all dopants, minimal  $RD_T$  is reached at 1bar, which is also easy to implement in an actual setup. Thus, pressure of GARtPC is set to 1bar for all following optimization.

### Dopant(s)

Under 400V/cm,  $f_1, W_M, f_2, f_3$  are calculated and compared to simulation of argon with single dopant.

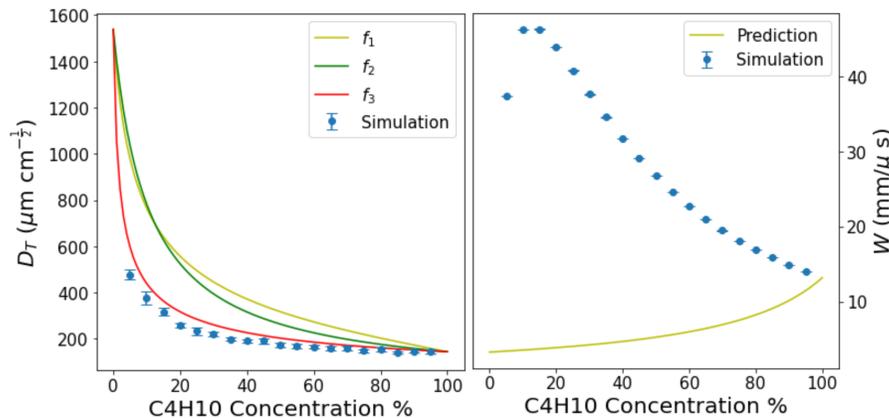


Fig. 2: Prediction functions compared with simulation results for Ar with  $C_4H_{10}$ . Left: normalized transverse diffusion; Right: drift velocity.

For most gas mixtures,  $f_1$  and  $W_M$  differ significantly from the simulation. Thus, only  $f_2, f_3$  are further considered. To better predict  $D_T$  for doping concentration (5-15%),  $f_2, f_3$  are fit with simulation data to find dopant  $i$ 's correction coefficient  $a_{2i}$ ,  $a_{3i}$ , listed with  $J/N$ , the sum of difference square over the number of data points, in Table.1 column 2-5.

These coefficients are then used to predict diffusion for gas mixture of three: 80% Ar, one basic dopant ( $CO_2$ /DME), and another.  $J/N$  of  $f_2^*, f_3^*$  are in Table.1 column 6-9. All actual simulations match the inverse trend that  $f_2^*, f_3^*$  predict, meaning the minimal  $D_T$  will always be achieved by a single dopant at the highest-allowed concentration.

Table.1	$a_2$	$J_2/N$	$a_3$	$J_3/N$	$J_2/N (CO_2)$	$J_3/N (CO_2)$	$J_2/N (DME)$	$J_3/N (DME)$
$C_4H_{10}$	0.291	1512	0.793	190	1,473	341	1,237	179
$CF_4$	0.166	665	0.504	37	1,741	122	1,526	68
$CH_4$	0.41	2383	0.922	281	714	452	516	266
$CO_2$	0.254	153	0.74	603	N/A	N/A	890	335
DME	0.199	101	0.599	726	979	310	N/A	N/A
Ethane	0.316	1920	0.767	439	978	472	1,130	146
Propane	0.287	1494	0.751	167	1,459	400	1,519	75

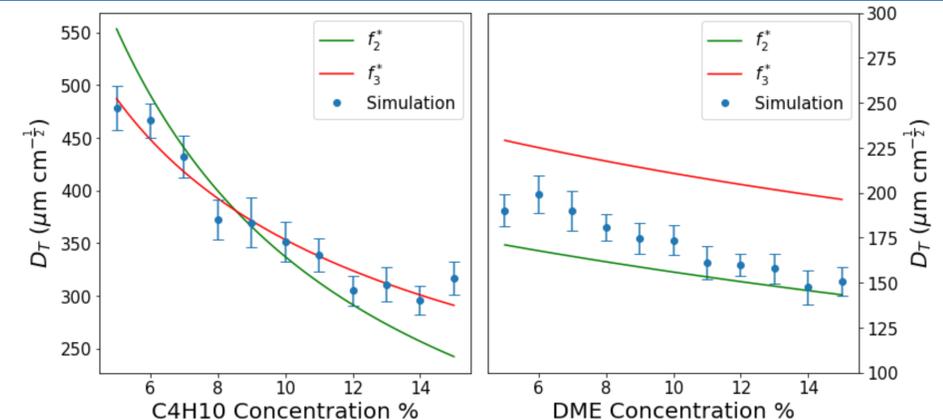


Fig. 3: Prediction functions for  $D_T$  compared with simulation results. Left: Ar with  $C_4H_{10}$ ; Right: 80%Ar with DME and  $C_4H_{10}$ .

### Electric Field

Lastly, simulations are carried out for doping concentration (6-20%) and  $E$  (25-1125V/cm). All dopants produce  $D_{Tmin}$  at 20%, with DME producing the lowest.  $D_{Tmin}$  and corresponding  $E_c$  are listed in Table.2 column 2-3. A clear linear relationship,  $L_{EF}$ , between the optimized electric fields and fraction is found for dopants that greatly suppress the diffusion. Linear fit of each gas listed in Table.2 column 4-6. Guided by  $L_{EF}$ , electric field for 80%Ar20%DME at 1bar is searched at 500 to 650 V/cm and  $D_T$  reaches minimum of  $131.6 \frac{\mu\text{m}}{\sqrt{\text{cm}}}$  at  $570(\pm 5)\text{V/cm}$ , just as predicted.

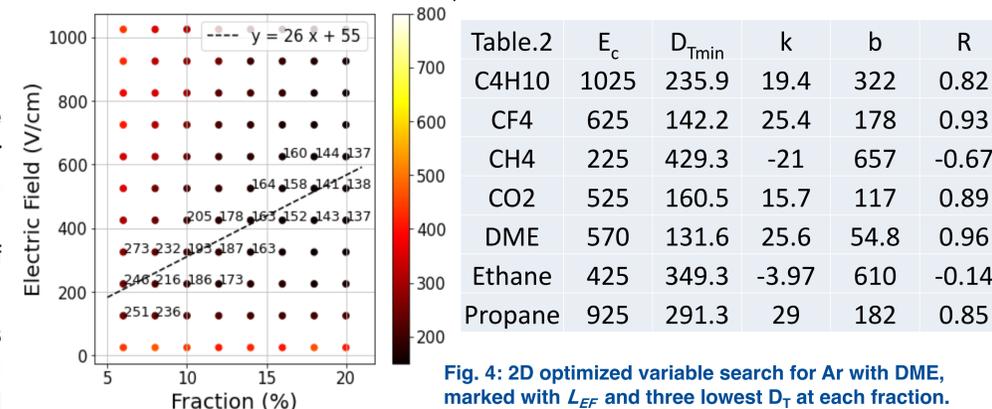


Fig. 4: 2D optimized variable search for Ar with DME, marked with  $L_{EF}$  and three lowest  $D_T$  at each fraction.

### Conclusion

In this project, best settings for GARtPC are found for low-energy nuclear recoils  $O(50\text{keV})$  to achieve the highest spatial resolution: at 570V/cm, 1bar, 80%Ar20%DME leads to minimum  $D_{Tmin}$  of  $131.6\mu\text{m}^{-1}\sqrt{\text{cm}}$ . With this setting, spatial resolution could be improved by about 11 times compared to pure argon or 5 times to 90%Ar10% $CH_4$  under normal conditions.

Not reported in previous literature, prediction function  $f_3^*$  and linear relationship  $L_{EF}$  are discovered and investigated. Though more examination is required, these rules could potentially benefit the community by simplifying the process of finding GARtPC's best parameters.