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E cross B electron drift in LAr

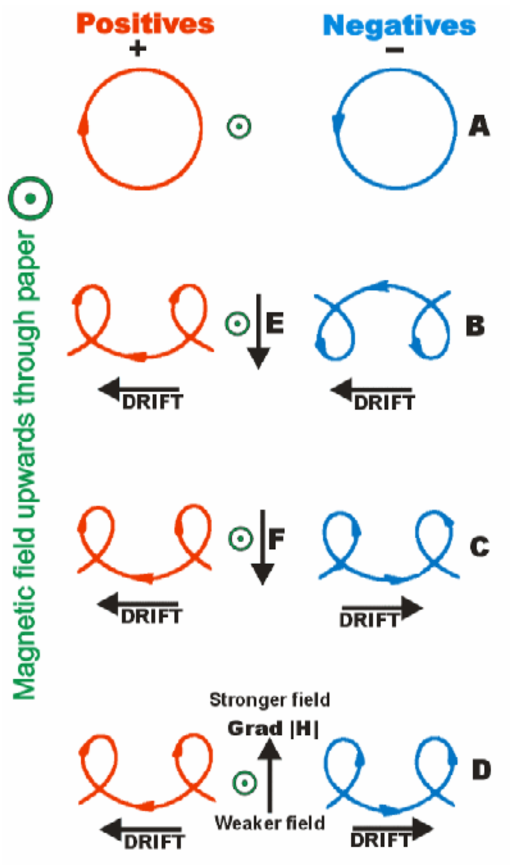
Abstract

We calculate the E X B drift angle in Liquid Argon (LAr).
The drift angle for 1 Tesla and 500 V/cm is 50 mrad (3 degrees)

Use of a magnetic field along with a LArTPC has been discussed by several authors. We look here at the drift of electrons under the combined electric and magnetic fields.

This problem has been well addressed in applications of gas drift chambers and Silicon detectors.

For the simplest interesting case, with the E field at right angles to the B-field, and in vacuum, the electrons start out from rest and follow the electric field. As soon as they move they curve with a radius proportional to charge * velocity / B.
Hence their motion starts out with ”zero” radius and leads to a cycloid-like trajectory that makes a scalloped path . There is a nice animated version on
http://www.phys.hawaii.edu/~teb/java/ntnujava/emField/emField.html



In LAr the electrons execute only a small part of the path before they collide with an Argon atom. One can reasonably assume that they stop and forget their direction at that time, and start over fresh.

The result is a small motion in the E X B direction. The macroscopic motion is generally in direction of the E field, but deviating by a small angle from the direction.

The July 2000 PDG physics booklet has a formula for the resulting drift:

The probability to have at least one ionization encounter is $1 - \exp(-\Delta/\lambda)$ and the thickness of the gas layer for 99% efficiency is $t_{99} = 4.6\lambda$. Depending on the gas, some 65–80% of the encounters result in the production of only one electron; the probability that a cluster has more than five electrons is smaller than 10%. However the tail of the distribution is very long and the yield of ionization electrons is 3–4 times that of the ionization encounters. The secondary ionization happens either in collisions of (primary) ionization electrons with atoms or through intermediate excited states. The process is non-linear and gas mixtures may have larger yields than each of their components. See also the discussion in Sec. 23.7.

Under the influence of electric and magnetic fields the ionization electrons drift inside the gas with velocity $\boldsymbol{u}$ given by:

$$\boldsymbol{u} = \mu|\boldsymbol{E}|\frac{1}{1+\omega^2\tau^2}\left(\widehat{\boldsymbol{E}} + \omega\tau(\widehat{\boldsymbol{E}}\times\widehat{\boldsymbol{B}}) + \omega^2\tau^2(\widehat{\boldsymbol{E}}\cdot\widehat{\boldsymbol{B}})\widehat{\boldsymbol{B}}\right) \qquad (24.7)$$

where $\widehat{\boldsymbol{E}}$ and $\widehat{\boldsymbol{B}}$ are unit vectors in the directions of the electric and magnetic fields respectively, μ is the electron mobility in the gas, ω is the cyclotron frequency eB/mc, and $\tau = \mu m/e$ is the mean time between collisions of the drifting electrons. The magnitude of the drift velocity depends on many parameters; typical values are in the range 1–8 cm/μs.

In a quite common geometry, the drift electric field is perpendicular to the magnetic field. In this case the electrons drift at an angle ψ with respect to the electric field direction such that $\tan\psi = \omega\tau$.

Here is the Excel sheet; I am attaching a "live " version to the DocDB as well. We calculate the time tau between collisions from the Argon density. This ignores the finite size of the Argon atom. On the other hand we ignore any "memory" effects at collision time. The two effects go in opposite direction. I don't know to what degree they cancel each other out.

Magnetic field effect on drift electrons in Lar

Reference: PDG booklet , Section 24.5 on Particle Detectors,

Speed of light	299792458	m/s		
Magntic filed strength	1	Tesla		
Electric drift field strength (assumed at right angle to B)	50000	V/m	500	V/cm

Electron mass	9.11E-31	kg		
Electron charge	1.60E-19	A s		
Electron mobility in Lar at boiling (icarus 600 paper)	0.05	m^2 / V s	500	(cm/s) / (V/cm)
Drift velocity at 500 V/cm	1550	m/s	1.55	mm/microsec
mobility from those two numbers mu=	0.031	m^2/V s		
Cyclotron Frequency Omega	1.76E+11	s^-1		
Avogadros's number	6.02E+23	mol^-1		
Argon density	1400	kg/m^3		
Argon atomic number	0.04	kg/mol	40	g/mol
Atoms number for Argon	2.11E+28	atoms /m^3		
Mean spacing d=	3.62018E-10	m		
E-field force on the electron	8.01E-15	N		
aceleration of an electron	8.79E+15	m/s^2		
time between collisions tau =	2.86935E-13	s		
Drift angle from 2002 PDG book psi =	5.05E-02	rad		

For the example of 1 Tesla and 500 V/cm, the drift angle is 0.05 rad.

Summary and Conclusion

In a LArTPC there is a non-zero sideways drift of the electrons on their way to the sensing wire plane. The angle is not large (3 degrees in our example) and expected to be well defined, but must be measured, e.g using high energy cosmic muons that penetrate a cathode plane:

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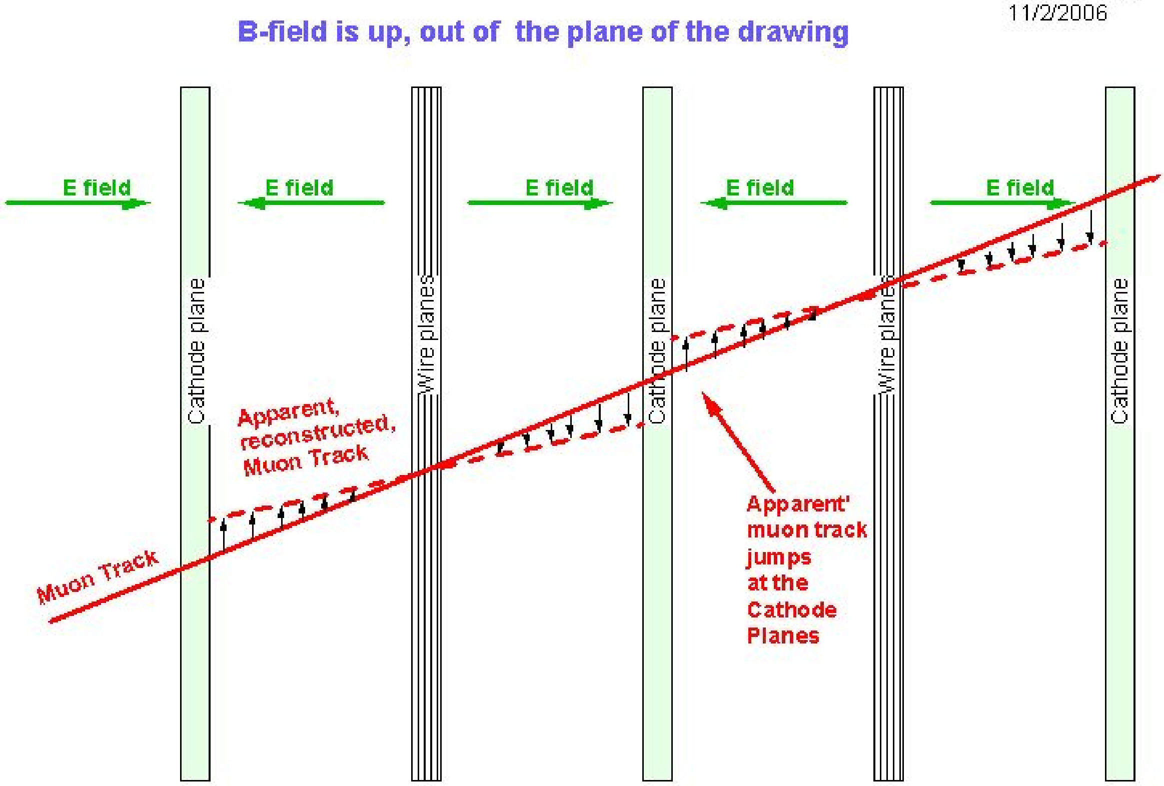
11/2/2006



True and Apparent Muon Track with E cross B Electron Drift