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PROPOSAL TO INVESTIGATE THE FEASIBILITY OF A NOVEL CONCEPT IN PARTICLE DETECTION

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Abstract

A new approach to the problem of high energy particle detection is described, in which parallel electric and magnetic fields are employed. It appears that a particular regime of operating conditions will allow a very substantial suppression of diffusion transverse to the fields in a suitably prepared drift chamber. If the more optimistic estimates are in fact achievable, single track-segment measurement errors of only a few tens of microns in a volume $\sim 1\ m^3$ should be feasible. Additional benefits are the possibilities of unambiguous spatial reconstruction, as well as high data rate capability, high multitrack efficiency, and easy applicability to 4π geometry. A program is outlined which is designed to gain further experience with the concept, provide needed data about electronic diffusion within various gas/field environments, and hopefully lead to practical detectors.

I. Introduction

Consider, for example, the experimental difficulties confronting the physicist who wishes to detect in entirety an event occurring in PEP. He must operate in high backgrounds, have very good spatial resolution in order to measure momenta, expecially when e-p collisions are studied, be able to reconstruct many tracks occurring over 4π unambiguously, identify particle types, as well as measure the neutrons, K's and γ's. For the latter purposes, the more compact the detector, the better. It is clear this is not an easy task with present technology, and that better physics could be done if substantial improvements were to be achieved. The concept developed below may provide significant steps toward a detector satisfying these goals.

II. The Axially-focused Time-projector Detector

Fig. 1a shows a cylindrical volume of gas, in which axial electric and magnetic fields are superimposed, such that E x B = 0 everywhere. Fig. 1b depicts a symmetric configuration appropriate to colliding beams, but the basic ideas are contained in Fig. 1a. A high energy track penetrating this volume will experience magnetic deflection (neglecting trajectories parallel to the symmetry axis). The ionization trail left behind instantly starts drifting towards the end caps, electrons toward the positive, ions toward the negative.

Considering only the electrons, in a suitable gas such as methane they can be drifted a distance of 1 m with a surprisingly small dispersion, given by $\sigma_z = \sqrt{2DT}$ where

σ_z = linear resolution along z

D = diffusion constant

T = total drift time.

Limited experimental results exist.[1] A Saclay group drifted (without magnetic field) in methane for about 50 cm and obtained a linear resolution in z of 1.25 mm FWHM, corresponding to a σ_z of $\sim$0.55 mm. The addition of a parallel magnetic field is expected to have no effect on σ_z.[2]

In the directions transverse to z, the magnetic field if sufficiently intense can lead to a very substantial reduction in the diffusion. The physical basis behind this statement is quite simple; the electrons try to execute helical orbits due to the bending caused by the magnetic field. Intuitively, one expects that lateral diffusion cannot exceed 2R per collision, where R is some average radius of the electons' cyclotron orbit. This is expected to hold only if the gas is sufficiency dilute, or the field sufficiently intense that at least 1/2 orbit is completed between collisions with gas molecules. A more rigorous treatment[2] gives a rather suprisingly simple result: in the presence of a magnetic field, the transverse diffusion coefficient D effectively transforms to

$$D \rightarrow \frac{D}{(1 + w^2\tau^2)}$$

Here w is frequency $\frac{eB}{m} = 1.76 \times 10^7$ rad/sec-gauss and τ is the mean time between electron-gas collisions. If one can arrange to have $w\tau >> 1$, one has at hand a very promising situation!

Returning to the discussion of the electrons drifting and diffusing along z, let us imagine an ideal detector situated on the endcap towards which the electrons drift. For example, consider a honeycomb of detectors, each a small fraction of a mm in size, and capable of supplying accurate time information as well as precise r and ϕ values, i.e., their locations. The basic data then consist of a string of r, ϕ, and t values characterizing the particular track. But we have an additional datum: t_o, the trigger time, given by the bunch intersection, and/or external detectors like scintillators. Thus the spatial position of the i^{th} track segment is given by r_i, ϕ_i, $v(t_i - t_o)$. This gives unambiguous information, since the projection is in time, not space, and there is only one time origin per real event. This capability should enormously simply reconstruction. The problem of background will be dealt with further on, as will some possible kinds of end cap detectors.

What about $w\tau$? Let us continue with the example of the Saclay group, but adding a strong magnetic field. Since $w = \frac{eB}{m}$, this detector will work better with stronger fields, so I choose B = 56 Kgauss. This value corresponds to $w = 10^{12}$ rads/sec or $\sim$170 GigaHz. Unfortunately, the mean time between collisions τ is not directly known, but must be inferred. Taking the Saclay values, D is found to be .2 m^2/sec. The theory of diffusion relates D to

$$D = \frac{Vl}{3}$$

where

V = speed of electrons (not drift velocity)

l = mean free path.

The velocity will be taken to be thermal, i.e. 1×10^7 cm/sec; this would be an untenable assumption for the case of electrons in noble gases, but should be quite good for polyatomic molecules like CO_2 and methane. In support of this assertion, Fig. 2a shows that for E/p ratios around 1 (in units of volts/cm/torr: typical operating conditions are $\sim$760 volts/cm at 760 torr) electrons in CO_2 are practically thermal. No data exist for methane, to my knowledge.

Thus

$$\tau = \frac{1}{V} = \frac{3D}{V^2} = .6 \times 10^{-10} \text{ sec}$$

giving $\underline{w\tau = 60}$. I emphasize that considerable margin for error exists in this example, due to indirect evaluation of τ, but the main point should be unmistakably clear: the possibility of a very substantial improvement in measurement capability is within our grasp, and should not require a substantial deviation from familiar operating conditions.

In this example, then, the transverse diffusion σ_x is smaller than σ_z by a factor of 60. A drift region of 1 meter under these conditions should give σ_x of 14 microns! In the ideal honeycomb detector then, with typically hundreds of measurements/track, the momentum accuracy is limited ultimately by multiple coulomb scattering in the gas, which is very small indeed.

An intriguing possibility is worth noting here. The cross section for the heavier noble gases has an extremely deep minimum for electron energies of $\sim$1 ev (Fig. 3). This is the Ramsauer-Townsend effect, the quantum mechanical phenomenon leading to a pronounced transparency. It is conceivable that an appropriate gas mixture can be found which provides simultaneously a high primary ionization density, and large mean free paths, giving larger values of τ than otherwise obtainable. It is recognized that the agitation energy corresponding to this minimum is large, leading to increased diffusion so that the benefits will be at least partially offset.

III. Discussion

A. The expected advantages of this detection, then, are several fold:

1. Possibility of unambiguous reconstruction in space
2. High multitrack efficiency
3. Simplicity-primary component of detector is a gas volume: no wires, planes, etc.
4. The higher the magnetic field, the better it works.
5. Adaptability to 4π geometry
6. No preferred directions [except exactly along z]. Highly inclined tracks would be registered with even better resolution, since effective ionization is increased by $1/\sin\theta$, where θ is a polar angle with respect to z.
7. Extremely high spatial resolution
8. Intrinsically high time resolution.

The last point deserves further clarification. Keeping in mind that the maximum drift time τ will not be shorter than 10 μsec at atmospheric pressures, one may expect additional tracks to have traversed the detector within the data acquisition interval following an event trigger. In Spear II, for example, bunches are separated by ∿200 nsec. Bunches prior and/or subsequent to the event trigger bunch will give right-half and left-half vertices which do not match, differing by 4 cm (assuming drift velocity of 10^7 cm/sec) since left and right images move in opposite directions (Fig. 1b).

A beam-gas interaction occurring precisely at the point where the real event vertex has "drifted" constitutes the only real possibility of ineradicable background. This would not seem to be very important. Thus, the presence of extra tracks should not pose serious problems, for two reasons:

1. Background tracks reconstruct to the wrong time origin, or wrong space origin, or both
2. The unambiguous track reconstruction capability reduces the possibility of "interference" with real-event tracks the extent of this nuisance depends on the nature of the end cap detector, as well as a number of other electronic factors, to be dealt with below.

B. Unsolved Problem

While the quality of information reaching the end caps may be very high, is there any way to obtain it? A number of possibilities would seem to exist:

1. "Ideal Honeycomb" detector. It may be possible to obtain sufficient gain on a ball-wire geometry (Fig. 4) operated as a proportional counter or geiger counter.
2. Sectors of small MWPC's judiciously arranged, and employed to give information along the wire length, either by current division, induced pulses, or conceivably by positioning charge-coupled semiconductor devices under the wire to sense the positive ions.

The ball-wire detector can act as a double-drift chamber in the following sense. An electron drifting straight into the ball will feel little tendency to cut across the magnetic field lines, and will give a count at time $t_1 = (L - X_i)/v$. An electron finding itself near the boundary will necessarily have to cross the magnetic field to reach the ball, and its effective velocity will be slowed down essentially by the same factor, 60 in this example. Thus, ball detectors not centrally disposed along the projected track will give delayed counts at $t_2 = (L - X_i)/v + \frac{(R - r_o)}{60v}$, acting as a sort of vernier.

This delayed response may provide an advantage, in that each count of a scaler beyond t_1 corresponds to 1/60 of the distance interval, and is a precise measurement of $R - r_o$.

IV. Program

I propose to pursue the following program:

A. Promote discussion of these ideas among interested physicists for criticism and possible collarobative work.

B. Search the literature more completely for electron-molecule data.

C. Set up an apparatus to measure the "entrainment factor" $(1 + w^2\tau^2)$ under fairly realistic conditions. The essential ingredient is some magnet capable of 20 Kg over a gap of 6 to 12 inches, with reasonably stringent demands on uniformity.

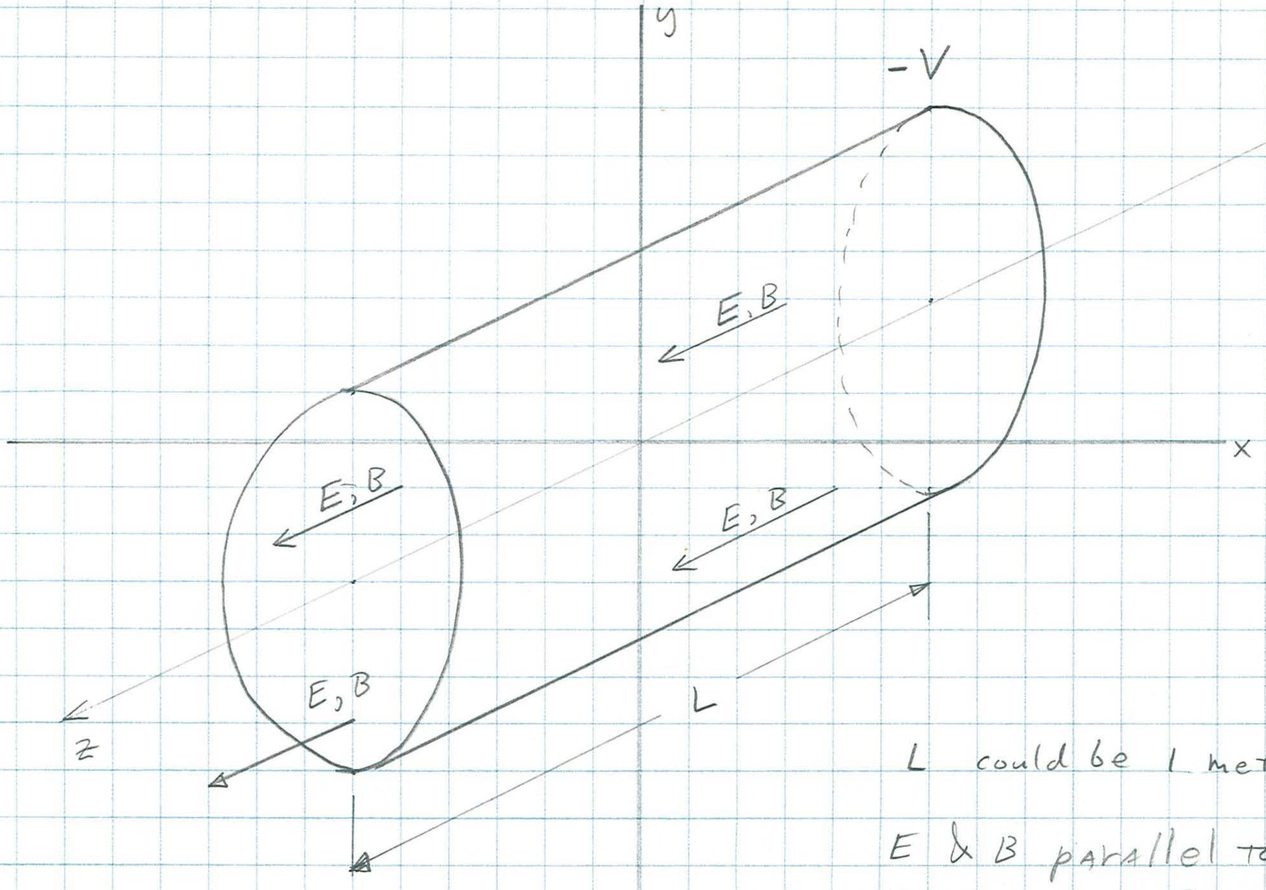
D. Study the end cap detector problem.

With regard to C and D, I believe that sufficient opportunity exists for several physicists to join me in what may be extremely productive work. If the concept proves worthy, plans could be laid for a full scale detector for Spear II or PEP.

Finally, it is difficult to estimate cost without knowing whether an appropriate magnet exists and is available. Cost estimates should be available shortly. In the meantime, I welcome criticism and suggestions.

References

1. J. Saudinos, "Operation of Large Drift Length Chambers" in Proceedings of the International Conference in Nuclear Instrumentation, p. 316, Frascati, 1973, and refs. therein.
2. J. S. Townsend, "Electrons in Gases" Hutchinson's Scientific, London, 1948 and S. Brown "Introduction to Electrical Discharges in Gases," John Wiley and sons, N.Y. 1966.



L could be 1 meter

E & B parallel to z axis, uniform. Sign of E·B is irrelevant.

Fig 1a

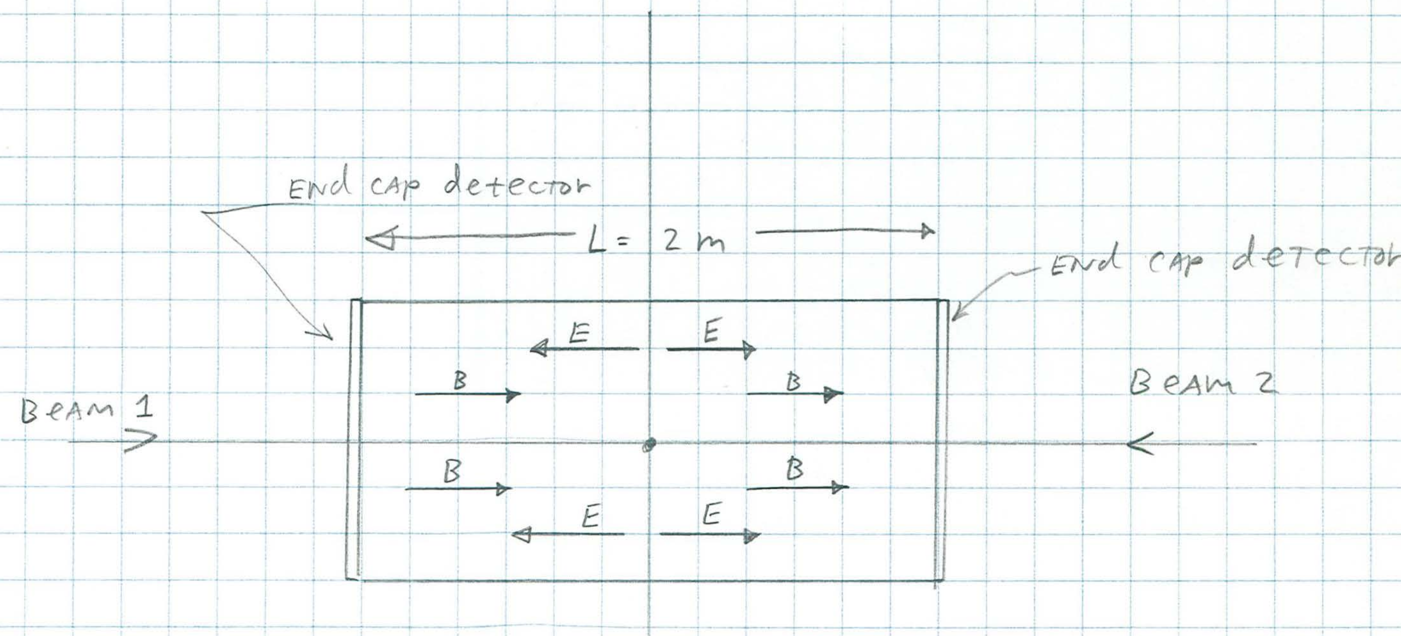


Fig 1b. colliding beam geometry, using thin foil in plane z = 0 to establish a symmetric electric field.

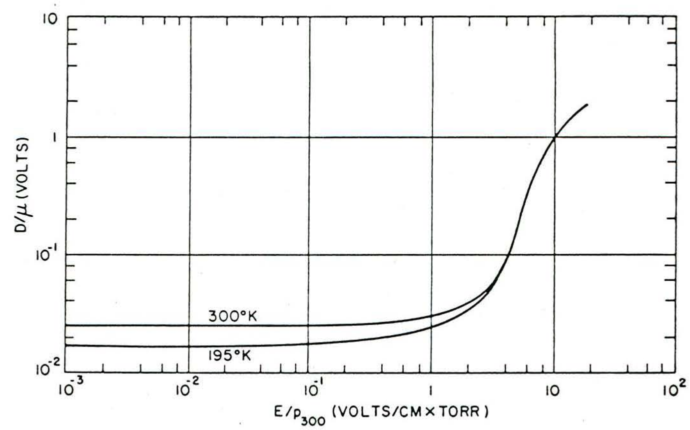


Fig. 4.52 Average energy of electrons in carbon dioxide at 195°K and 300°K.
R. W. Warren, J. H. Parker, Jr. (1962)
PHYREV J1 V128 P2661

Fig 2a, showing thermal behavior of electrons in CO_2 (for $E/p \lesssim 1$)

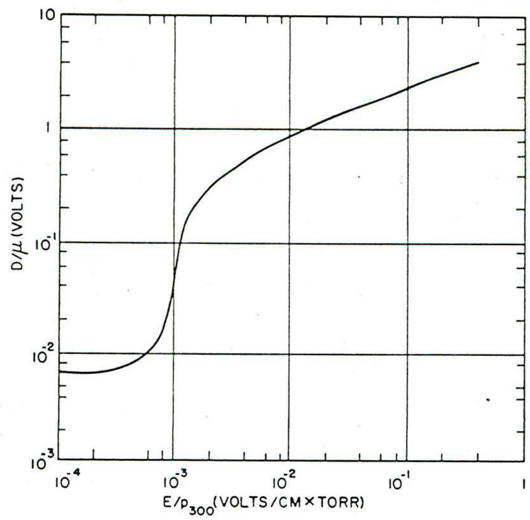
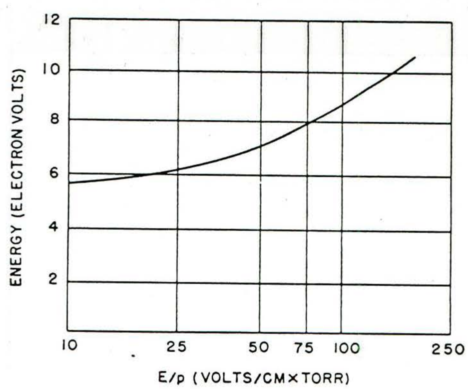


Fig. 4.50 Average energy of electrons in argon at 77°K.
R. W. Warren, J. H. Parker, Jr. (1962)
PHYREV J1 V128 P2661



Average electron energy in argon as a function of E/p.
V. E. Golant (1959)
SPTPHY J790 V4 P680

Fig 2b. Showing non-thermal behavior of electrons in noble gases, due to absence of energy-absorbing inelastic processes.

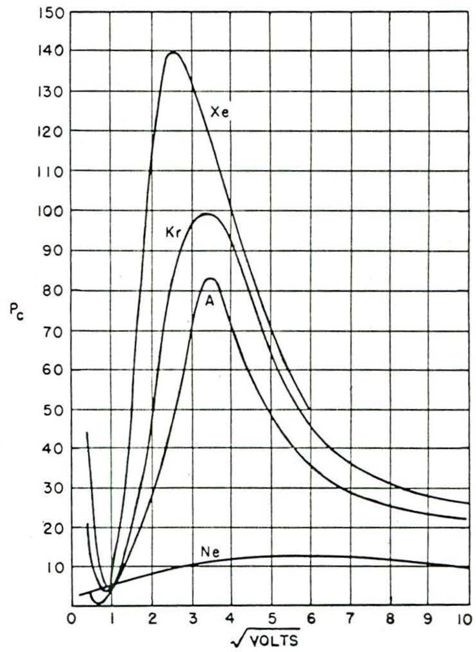


Fig. 2.14 Probability of collision for electrons in Ne, A, Kr, and Xe.*
R. B. Brode (1933)
REVS MOD PHYS J30 V5 P257

Fig. 3. Depicting the window for electrons of ~ 1 eV energy. this energy, corresponding to 40 times room temperature, implies a velocity of 6×10^7 cm/sec, or .6 mm/nsec.

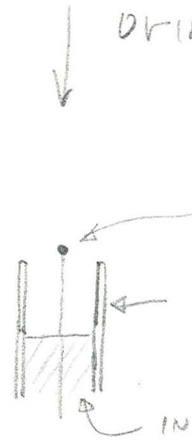


Fig. 4 Ball-wire detector (For honeycomb)