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GATING IN THE ALEPH TIME PROJECTION CHAMBER

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Abstract: The ALEPH TPC at LEP will use a gating grid to prevent distortions caused by space charge buildup in its 2.2 meter drift region. Sets of measurements have demonstrated the feasibility of a "synchronous ion trapping" mode of gating, which reduces the positive ion flux through the grid by more than two orders of magnitude. A novel mode of gating will be discussed which would permit static operation of the gate, thereby avoiding the complexity of switching between the open and closed states of the gate. This mode would rely on the dissimilar gate penetration properties of electrons and ions in the presence of a magnetic field, and it may also provide a way to

partially compensate for the $\vec{E} \times \vec{B}$ effect at the sense wires. A combination of these different modes is proposed for the ALEPH TPC.

1. Introduction

Time Projection Chambers (TPC's) [1] are charged particle detectors which are particularly adept at resolving complex many-track events. A schematic of the ALEPH TPC at LEP (CERN) [2] is shown in fig. 1. This TPC is comprised of two equal cylindrical sections, each of which has a 2.2 meter drift length and a 3.6 meter diameter. The Ar-CH_4 gas mixture inside the TPC is held at atmospheric pressure. A large axial magnetic field of 1.5 T will be employed.

Depending on the background conditions, the operation of a TPC in a continuously sensitive mode can pose a severe problem: the buildup of space charge in the drift region. This space charge is comprised of positive ions which are mainly produced during the proportional amplification at the sense wires and which subsequently enter the drift region. Once in the drift region, the space charge can alter the local electric field, causing unwanted track distortions [3]. For this reason, it was decided at an early stage of the ALEPH TPC project to implement an extra grid of wires which would act to dramatically reduce the number of positive ions in the drift region.

This extra grid of wires, or "gating grid" [4], is installed between the shielding grid and the drift region (see fig. 2). The gating grid is either in the "open" state or the "closed" state. In the open state (fig. 2a), the potential V_g is placed on the gate wires so that the gate is transparent to the passage of drifting charged particles. In the closed state (fig. 2b), the potentials $V_g \pm \Delta V_g$ are placed on alternate wires of the grid so that the resulting dipole fields render the gate opaque to the passage of ions. By closing the gate, positive ions created at the sense wires can be prevented from entering the drift region.

The gating grid may be operated in one of several different modes. Schematic diagrams of four of these modes are shown in fig. 3. The PEP-4 collaboration [4], with 2.45μs between beam crossings, opens the gate only after a positive trigger is generated, i.e., asynchronously (fig. 3a). The major disadvantage of this gating mode is that the TPC cannot be sensitive until a certain time (≈2μs) after the beams have crossed. Consequently, data from about 10 cm of the drift length in front of the endplates of the TPC are lost.

More recently, the ALEPH collaboration has shown [5] that "synchronous ion trapping" (fig. 3b) could be a viable solution to the space charge problem in the ALEPH TPC at LEP (which will operate with 22.5μs between beam crossings). In this mode, data from the regions in front of the endplates are not lost because the gate is held open during every beam crossing. The gate is closed roughly 3μs after the beam crossing unless a positive trigger is generated, in which case the gate is kept open to allow electrons to reach the amplification region. For a given duty cycle of the gate, an appropriate ΔV_g can be found such that all positive ions are neutralized at the gating grid and none escape into the drift region.

The mechanism of synchronous ion trapping is illustrated in fig. 4. Ions follow the drift field lines when the gate is open and they follow the gating grid field lines when the gate is closed. Under the proper conditions, the positive ions emanating from the amplification region will be neutralized at the gating grid wires after following the path indicated in fig. 4.

2. Current Gating Ideas

2.1 Static Mode

In the presence of a magnetic field, electrons and ions both obey equation (1) but their velocities and paths may be different. This can be understood from the dependence of the drift velocity $\vec{v}_d$ on $\omega\tau$ and the electric ($\vec{E}$) and magnetic ($\vec{B}$) fields [6]:

$$\vec{v}_d = \mu/(1 + \omega^2\tau^2)[\vec{E} + \omega\tau(\vec{E} \times \vec{B})/|\vec{B}| + \omega^2\tau^2(\vec{E}\bullet\vec{B})\vec{B}/B^2] \quad (1)$$

where $\omega = eB/mc$ = cyclotron frequency, $\tau = \tau(E)$ = mean collision time, and μ = mobility. While electrons can have $(\omega\tau)^2 \gg 1$ in a 1.5 T magnetic field and suitable gases[1], ions have $(\omega\tau)^2 \ll 1$. Consequently, the behaviour of ions will be dominated by the $\vec{E}$ term in equation (1), but electrons with large $\omega\tau$ will be dominated by the $\vec{E}\bullet\vec{B}$ term. Hence, ions will primarily follow the electric field lines whereas electrons will mainly follow magnetic

[1] For example, Ar:CH_4 91:9.

field lines. This effect can be exploited to trap drifting ions at the gate while simultaneously allowing most drifting electrons to pass through. For example, at ΔV_g = 40 V and B = 1.2 T, the ion transparency of the gate <0.01%, while the electron transparency is ≈75%. Using this property of the gate, one could conceivably use a simple DC voltage ΔV_g on the gate [7] and thereby avoid the complication of switching (fig. 3c).

2.2 Gating With $\vec{E} \times \vec{B}$ Compensation

Another consequence of equation (1) is that the spatial resolution in TPC's with high $\omega\tau$ is dominated by the $\vec{E} \times \vec{B}$ effect near the sense wires [8], which causes a spreading of electrons in the $\vec{E} \times \vec{B}$ direction. Also, the use of static gating would lower the number of electrons which reach the sense wires, thereby further reducing the resolution. However, there is a process by which one could compensate for this loss of resolution or even make an overall improvement therein. With the proper geometry and potentials ΔV_g at the gating grid, it is possible to partially compensate for the $\vec{E} \times \vec{B}$ effect at the sense wires by exploiting the $\vec{E} \times \vec{B}$ effect which also exists at the gating grid (fig. 5).

2.3 Gating of Electrons

The gating modes discussed above prevent the buildup of space charge in the drift region by neutralizing the positive ions at the gating grid. However, the lifetime of a wirechamber is limited by the integrated charge on the sense wires [9], so it would be advantageous to keep unwanted background electrons out of the amplification region. Measurements have shown [7] that the gating grid can be closed to electrons by increasing ΔV_g , e.g., in a 1.5 T field $\Delta V_g \approx$ 220 V is the appropriate closing voltage.

2.4 Mixed Mode

Since ΔV_g is fixed in the static mode (at a voltage which makes the gate ≈75% transparent to electrons), a further reduction in the electron flux into the amplification region can only be achieved by switching to a higher ΔV_g This higher ΔV_g is used only during times when it is desirable to exclude electrons, i.e., after a negative trigger decision. A timing diagram of this new gating mode, "mixed" mode, is shown in fig. 3d. This mode is the same as ion trapping mode except that the gate is held in the static configuration during the gate open period. In this way, not only is the space charge problem significantly reduced, but also the lifetime of the chamber is markedly increased.

3. Conclusion

Mixed mode with $\Delta V_{gl} = 0$ (see fig. 3) effectively eliminates the problem of positive ions in the drift region, avoids the loss of fiducial TPC volume, and significantly lengthens the chamber lifetime. Mixed mode with $\Delta V_{gl} > 0$ may in addition provide the ALEPH TPC with a means of improving the detector resolution via $\vec{E} \times \vec{B}$ compensation. The ALEPH TPC will operate in mixed mode, but the exact ΔV_{gl} which will be employed depends on the results of $\vec{E} \times \vec{B}$ compensation measurements currently underway.

4. Figure Captions

1. Schematic diagram of the ALEPH TPC.

2. Grid configuration and field map for (a) gating grid open and (b) gating grid closed.

3. Timing diagrams of (a) Asynchronous mode, (b) Synchronous Ion Trapping mode, (c) Static mode, and (d) Mixed mode (ΔV_{gl} is the lower ΔV_{g}, ΔV_{gh} is the higher ΔV_{g})

4. Conceptual picture of Synchronous Ion Trapping.

5. Schematic representation of $\vec{E} \times \vec{B}$ compensation (ground grid omitted for clarity). Line indicates the path of a drifting electron.

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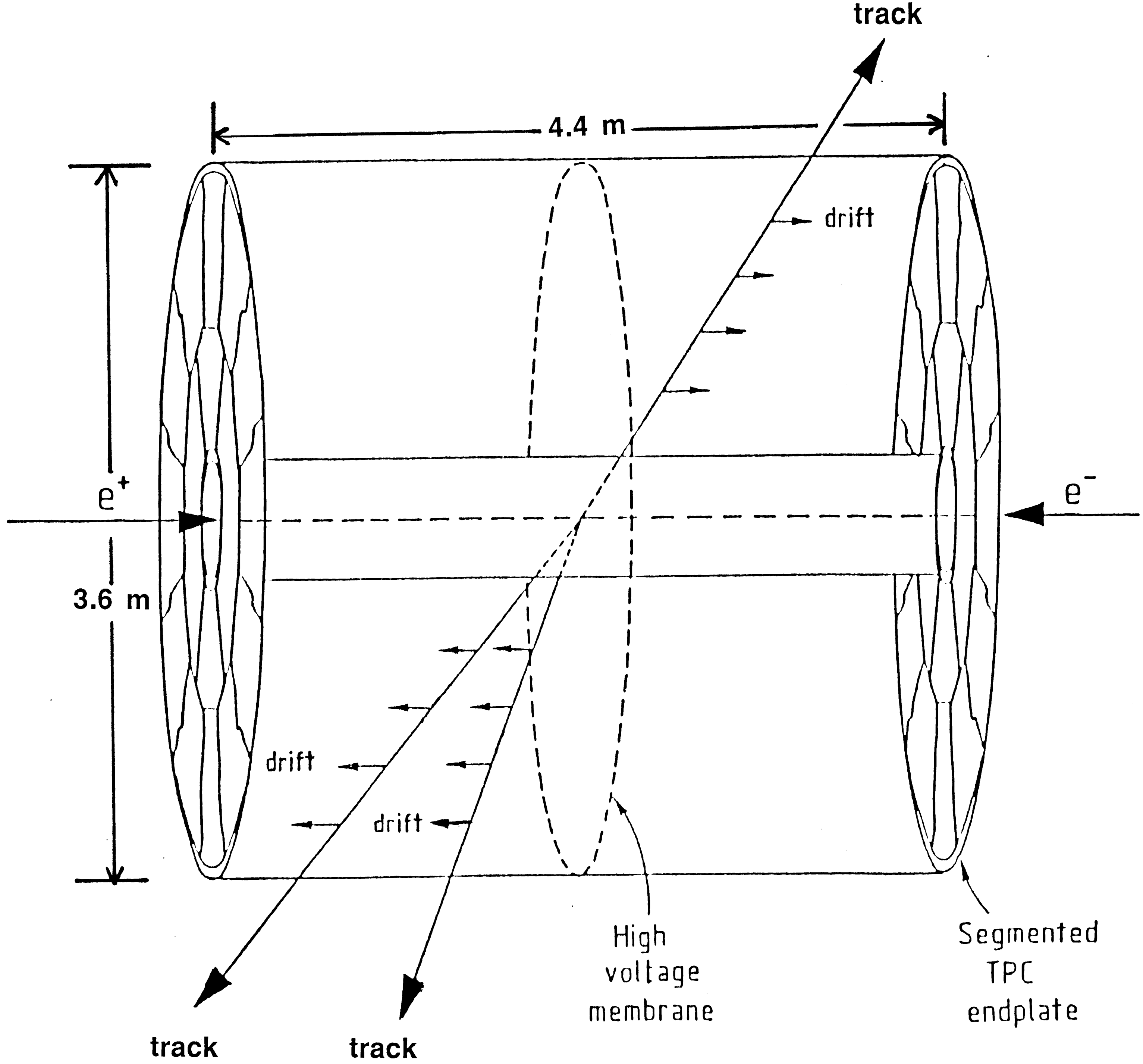

track
4.4 m
drift
e+
e-
3.6 m
drift
drift
High
voltage
membrane
Segmented
TPC
endplate
track
track

Fig. 1

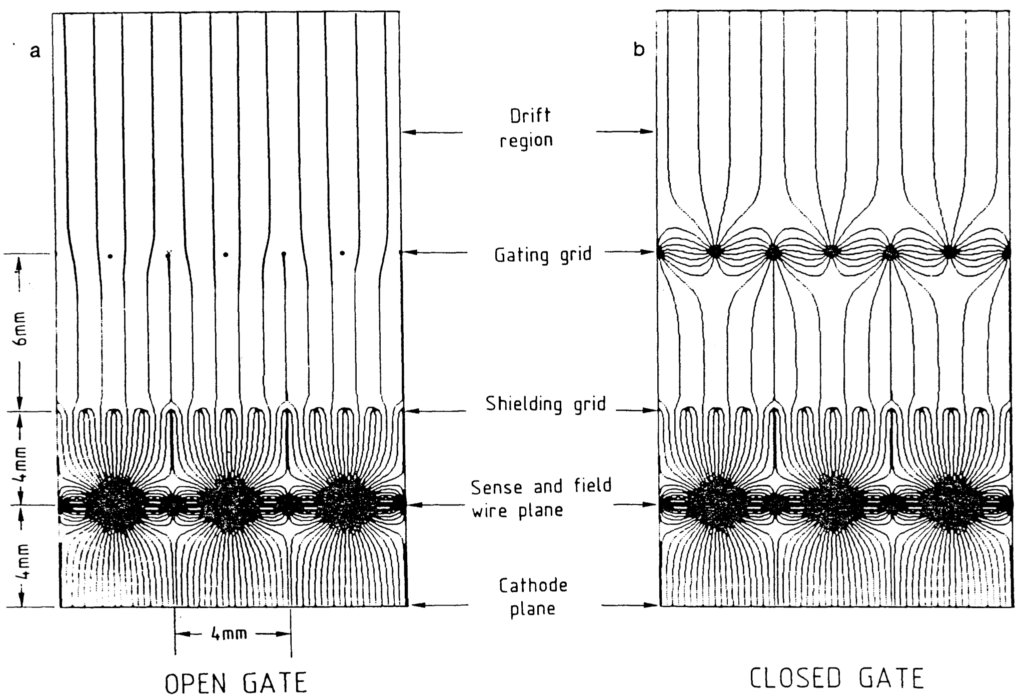
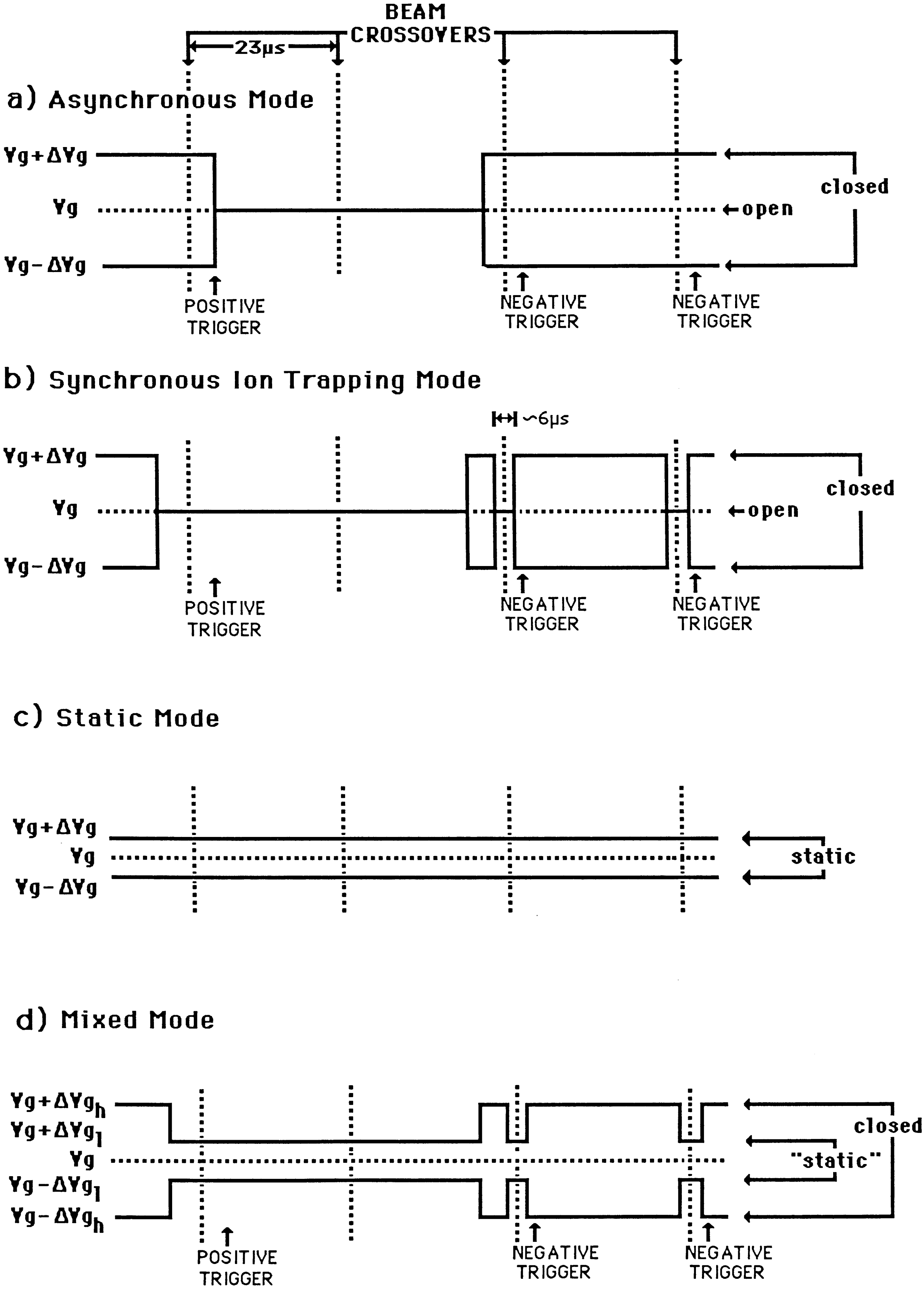


Fig. 2. Grid configuration and field map for (a) gating grid open and (b) gating grid closed.

Fig. 3 Timing diagrams of the gating modes.



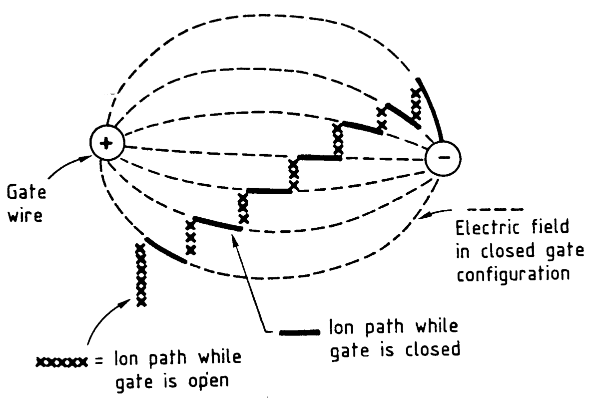


Fig. 4: Conceptual picture of synchronous ion trapping.

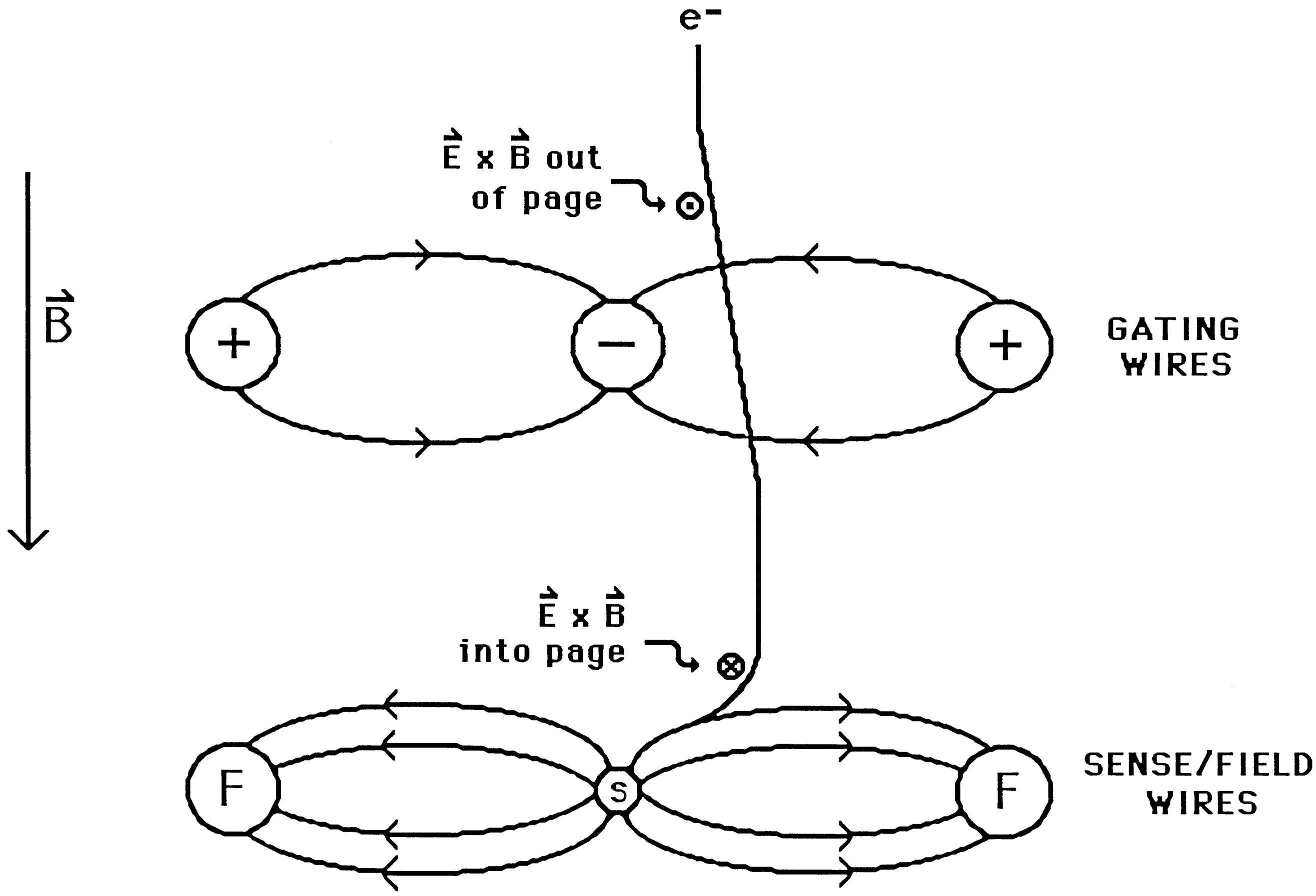


Fig. 5 Schematic diagram of E x B compensation. (Ground grid omitted for clarity.)