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# ION TRAPPING PROPERTIES OF A SYNCHRONOUSLY GATED TIME PROJECTION CHAMBER

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**ABSTRACT**

Studies have been made of the transmission of positive ions through the gating grid of a time projection chamber operated synchronously at a high rate. With a duty cycle of 25% (22 μs periodic wave form) it has been demonstrated that less than one positive ion in $7 \times 10^{-3}$ transverses the gating grid.

## 1. INTRODUCTION

Time Projection Chambers (TPC's) are charged particle tracking devices that are well suited to the cylindrical geometry of $e^+e^-$ colliding beam experiments [1]. These devices provide a high precision measurement of the position of a charged particle's three dimensional flight path through an axial magnetic field. The large cylindrical fiducial volume around the beam pipe contains only the drift gas in which primary ionization occurs. A TPC is shown schematically in fig. 1. An electric field causes the electrons produced by ionization along the track of high energy charged particles to drift to one end of the TPC where they are detected by a grid of proportional wires. The homogeneity of the electric field is maintained by a field cage encircling the drift path. Accurate position information in the plane perpendicular to the direction of the drifting electrons is determined from the pulses induced on the cathode pads located behind the proportional sense wires. The coordinate along the drift path is determined by measuring the drift time; the specific ionization is determined from pulse heights as measured by the proportional wires.

When TPC's are used in the environment of the colliding beams of an $e^+e^-$ storage ring, special attention has to be given to the build up of positive ions in the large drift volume associated with background originating mainly from "non-beam-beam" interactions and from synchrotron radiation. The main source of this space charge are the ions created in amplification regions surrounding the sense wires. A fraction of these ions are drawn into the drift volume by the field of the high voltage membrane located at the far end of the TPC. The experience of the PEP-4 TPC has demonstrated that if this problem is not addressed, the resulting space charge can seriously distort the trajectories of drifting tracks [2]. Since most of the primary ionization deposited in a TPC is associated with background events, attention has focused on selectively preventing the resulting drift electrons from reaching the sensitive proportional amplification region at the TPC endplates. To this end, several groups have considered the use of a "gating grid" in front of the shielding grid as shown in fig. 2.

The gating grid is operated in one of two states. "Open" is when all wires of the gating grid are at the same potential, and positive ions and electrons pass freely through the grid. "Closed" is when a differential voltage is applied to alternate wires. In the closed state, positive ions and electrons are collected by the grid and therefore fail to pass through. The PEP-4 group has adopted an "asynchronous" gating solution [2], i.e. the gating grid is left in its closed state until such time as a positive trigger decision is reached. Only then, the grid is switched to its open state. This approach prevents most of the unwanted primary ionization from reaching the proportional wires and effectively eliminates substantial positive ion build up in the fiducial region of the TPC. An unattractive feature of this scheme arises from the fact that the TPC is not sensitive during the beam crossing. As an example, the relevant trigger decision for the ALEPH detector at LEP will be reached 1.5 μs after the beam crossing [3]. If another 1.5 μs is allowed to switch the gating grid on, then each end of the TPC would ignore the first 15 cm of its 220 cm drift length.

## 2. SYNCHRONOUS POSITIVE ION TRAPPING

We have studied the feasibility of synchronously opening the TPC gating grid 4 μs before each beam crossing (this gives the electronics sufficient time to settle before the crossing) without the loss of any fiducial volume. In the absence of a valid trigger signal from other detector elements, the TPC gate would shut down shortly after the beam crossing. Such schemes have previously been suggested for low rate applications such as at experiments utilizing fixed target accelerators or linear colliders [4]. Since the synchronous opening of a gating grid is less effective at stopping unwanted electrons before the sense wires, a new mechanism is needed to trap the resulting ions that they produce. We looked into the ability of a gating grid which splits its time between the open and closed states to trap positive ions that would otherwise escape from the proportional region into the drift volume. Since ions drift relatively slowly, they require many gating cycles to penetrate the gating grid and under favourable conditions are pulled to the gating grid along a path shown conceptually in fig. 3.

## 3. APPARATUS

Tests were performed on a small TPC with a 10 x 10 $cm^2$ endplate shown in fig. 4. The gating grid had a 2 mm pitch and its spacing with respect to the other wires is shown in fig. 2. The field, sense, ground and gating wires had diameters of 100, 20, 100 and 100 microns respectively. The gating grid bias voltage $V_g$ was -87.5 V. To switch the gate from its open to its closed state, an additional voltage $\Delta V_g$ was added or subtracted to alternate gating grid wires to produce the field configuration shown in fig. 2(b). Above the grids was a 9.5 cm long drift volume bounded at its ends by the gating grid and a high voltage membrane. The drift volume was surrounded by a field cage consisting of wires spaced every 5 mm. The electric field strength was 120 V/cm in the drift region and 140 V/cm between the gating and shielding grids. The field wires were held at ground potential, and the sense wires were operated at +1350 V. The chamber was filled with 80:20 argon-methane at atmospheric pressure. The field configuration chosen would be appropriate for a TPC with a lower methane concentration. Since ion drift velocities are insensitive to the small methane concentrations involved, our results are valid for other argon-methane mixtures of less than 20% methane. A picoammeter was used to measure either the sense wire current or the membrane current. The gating voltages $\pm\Delta V_g$ were generated by a FET based circuit which was capable of switching up to ± 60 V with a rise time of 100 ns. The circuit was driven by pulsers in a periodic fashion to simulate the synchronization to the beam crossings. The gate open and gate closed times were independently adjustable.

## 4. TEST RESULTS

Our objective was to study the ion trapping efficiency of the gating grid. Collimated 26 keV X-rays were injected into the region between the gating and ground grids. The resulting electrons underwent proportional gain at the sense wires, thus producing many positive ions behind the gating grid. Since this produced no ionization in the drift volume, it avoided the complication of correcting the data for the transparency of the gating grid for drift electrons. With the gate open ($\Delta V_g$ = 0 V), approximately 7% of all ions penetrated into the drift region as determined by the ratio of the membrane and sense wire currents. Since it is this penetration which is troublesome, it is appropriate to define the gating grid transparency as the ratio of the membrane (ion) current under "trapping" conditions to the current measured with $\Delta V_g = 0$ Volts. We operated the grid at several different duty cycles by opening the grid at different frequencies, but always with the same 6 μs open time (fig. 5). We measured the grid transparency as a function of the frequency of gate openings. The 6 μs gate open time was motivated by a design estimate for the ALEPH detector being built for use at LEP. Fig. 6 shows data obtained for various values of $\Delta V_g$. The LEP collision frequency of 44 kHz is marked by the arrow, and for sufficiently large $\Delta V_g$, ion transparencies of less than 1% were obtained. Note that this supression comes on top of the 7% transmission inherent in the chamber geometry, i.e. an overall transmission of less than 0.07% was achieved.

## 5. COMPUTER SIMULATION

A computer model was developed to simulate the behaviour of the test chamber. Positive ions were assumed to start from isotropic distributions about the sense wires. The results of the model are shown in fig. 7. The simulation reproduced the behaviour of the data to within $\Delta V_g = 5$ V, and verified our conceptual picture of fig. 3.

## 6. CONCLUSIONS

We have demonstrated the feasibility of a synchronous gating scheme for operating a TPC. Even at high beam crossing rates such as those of the LEP $e^+e^-$ collider, synchronous gating can provide a reduction of better than two orders of magnitude due to its ion trapping features. The improvement results from the ability of the gating grid to attract and to trap ions moving back towards the drift region during the fraction of the duty cycle when the gating grid is in its closed state. The reduction is independent of whether or not electrons are penetrating the gating grid in the other direction. With synchronous gating a TPC is fully sensitive as the beams collide, thus avoiding the sacrifice of fiducial volume as in the asynchronous case.

REFERENCES

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[2] P. Nemethy et al., Gating time projection chamber, LBL Internal Report, November 1982.

[3] ALEPH Collaboration Technical Report 1983, CERN/LEPC/83-2, page 11.1.

[4] See for example, SLAC linear collider conceptual design report, SLAC Report-229 (1980);

Letter of Intent: The PEP-4 facility (TPC) as the initial detector at SLC, Ames laboratory, Iowa State University, Johns Hopkins University, LBL, UCLA, UC-Riverside, University of Massachusetts (1982);

S. Benso et al., The time projection chamber, AIP Conference proceedings No. 108 (1984) p. 123.

## FIGURE CAPTIONS

Fig. 1 Schematic diagram of a TPC.

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

Fig. 3 Conceptual picture of synchronous ion trapping.

Fig. 4 Schematic of the test chamber.

Fig. 5 Time diagram for gating voltages.

Fig. 6 Measurement of gating frequency vs gating grid ion transparency.

Fig. 7 Simulation of gating frequency vs gating grid ion transparency.

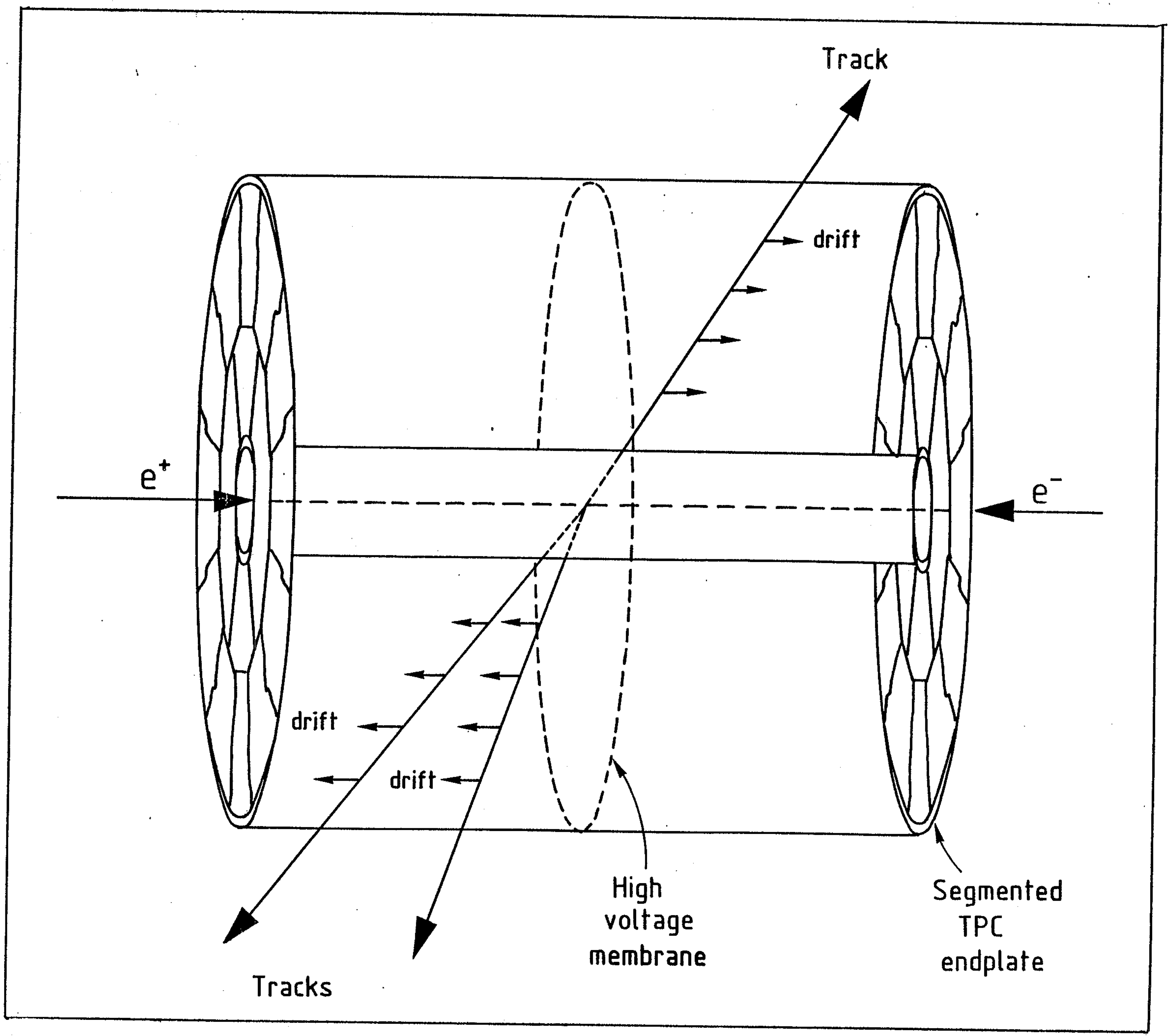
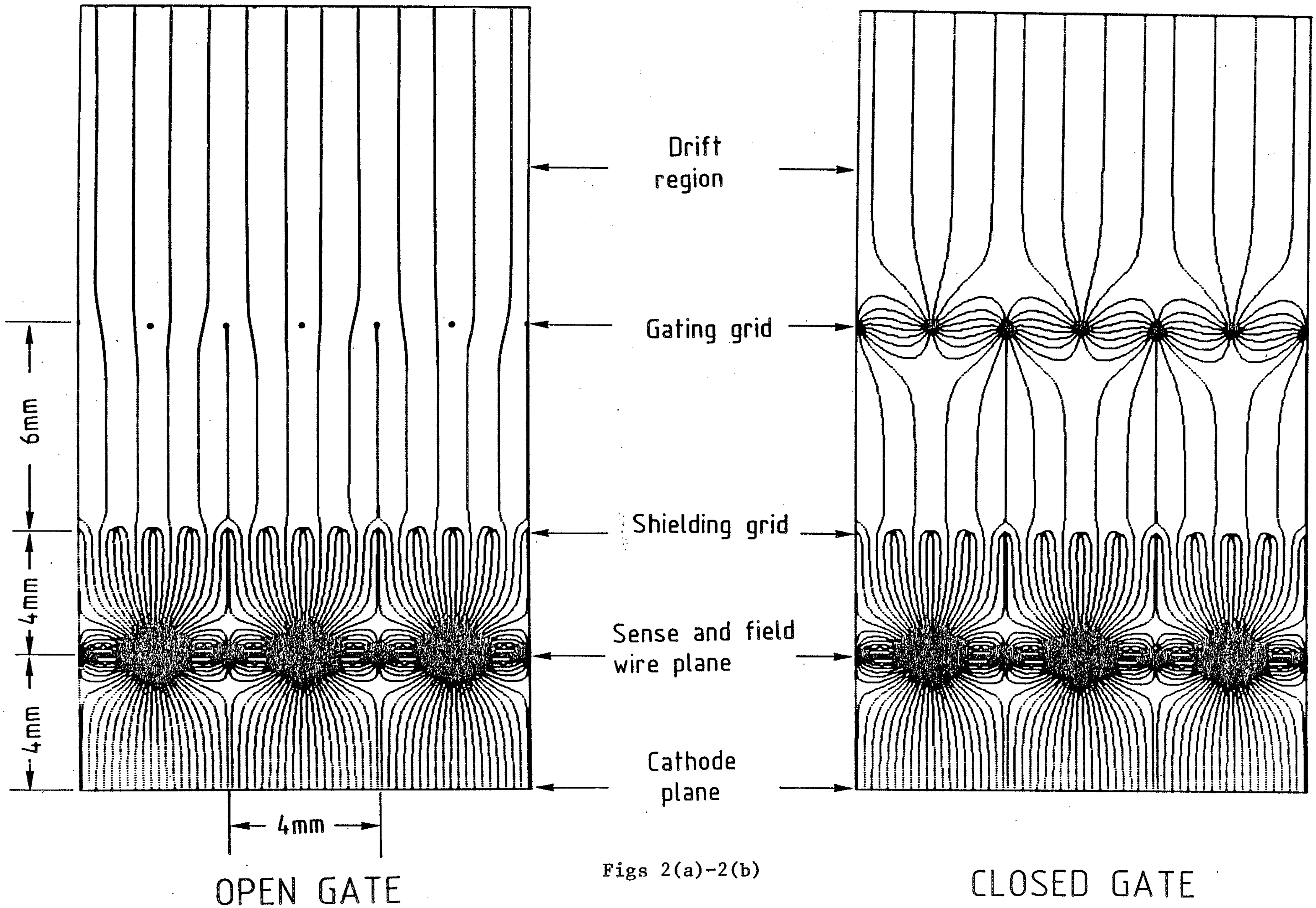
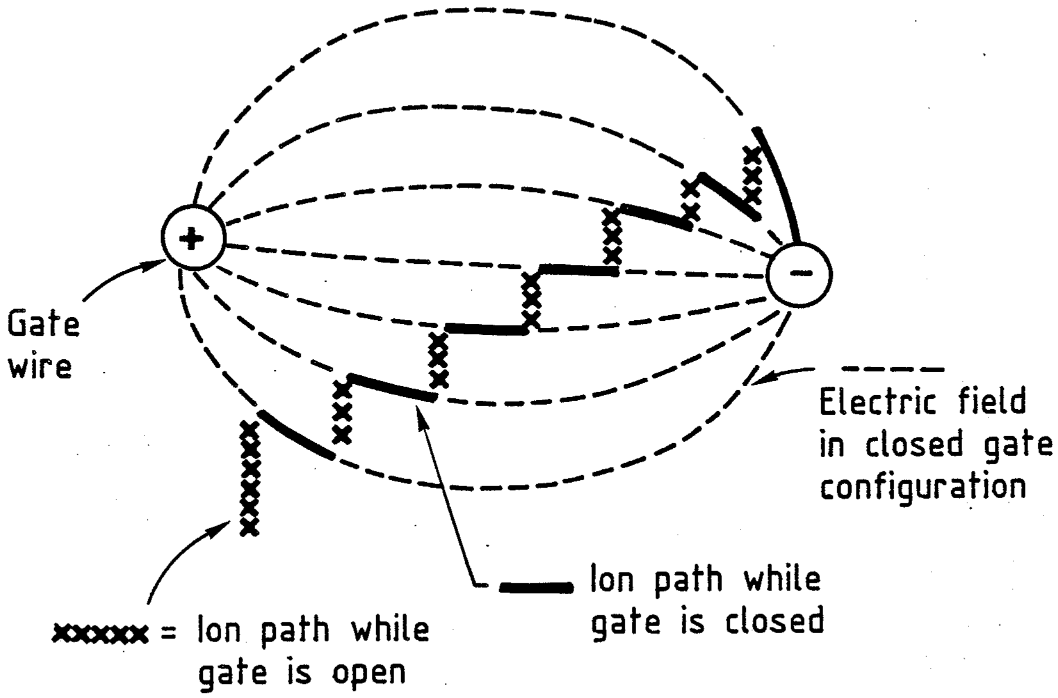

Track
drift
$e^+$
$e^-$
drift
drift
Tracks
High
voltage
membrane
Segmented
TPC
endplate

Fig. 1


Drift region
Gating grid
Shielding grid
Sense and field wire plane
Cathode plane
6mm
4mm
4mm
4mm
OPEN GATE
CLOSED GATE

Figs 2(a)-2(b)



Gate
wire
Electric field
in closed gate
configuration
Ion path while
gate is closed
xxxxx = Ion path while
gate is open


Fig. 3

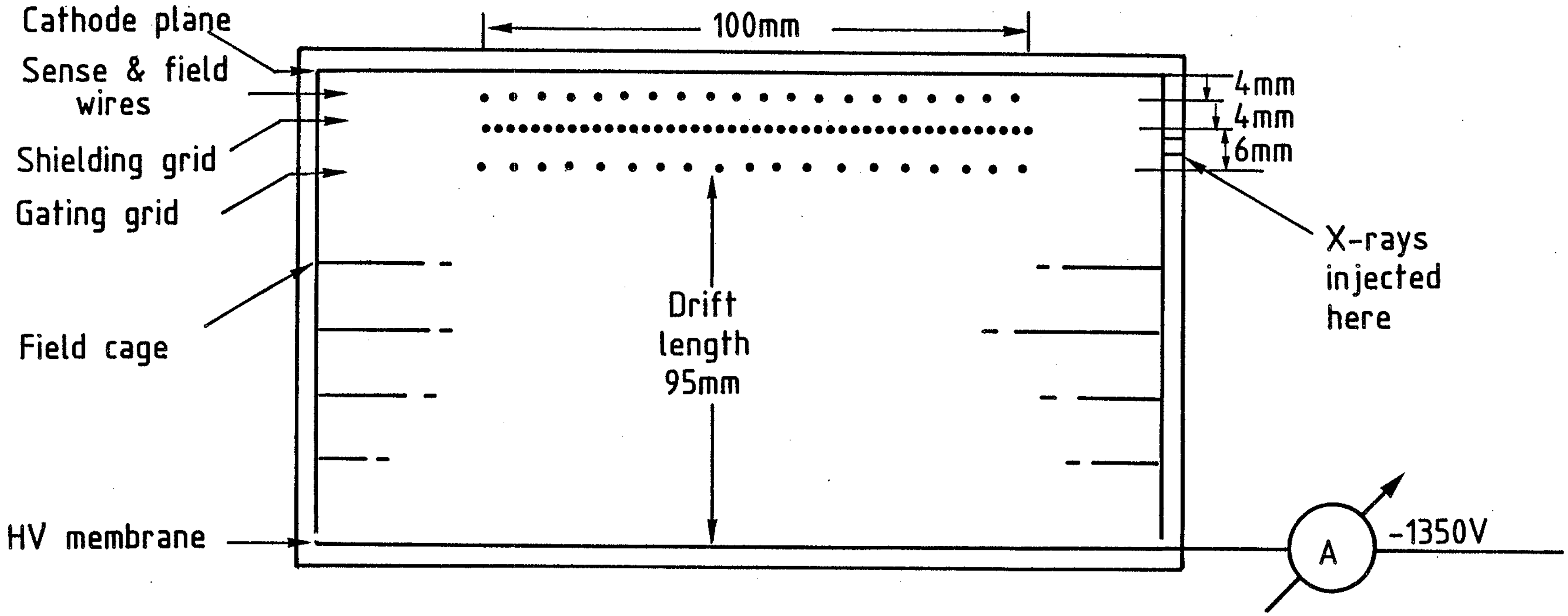

Cathode plane
Sense & field wires
Shielding grid
Gating grid
Field cage
HV membrane
100mm
4mm
4mm
6mm
X-rays injected here
Drift length 95mm
A
-1350V

Fig. 4

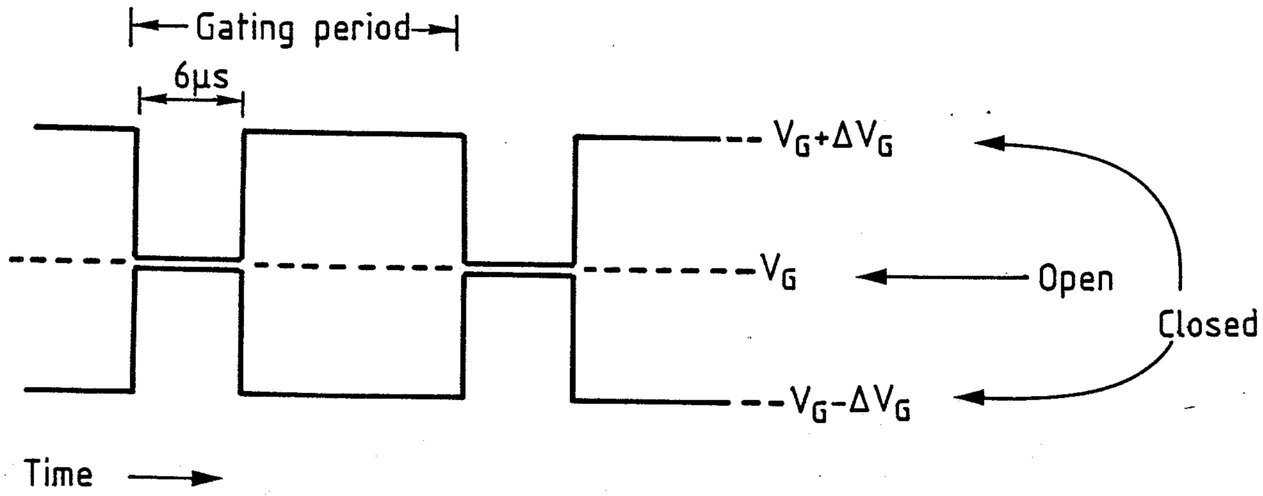



Fig. 5

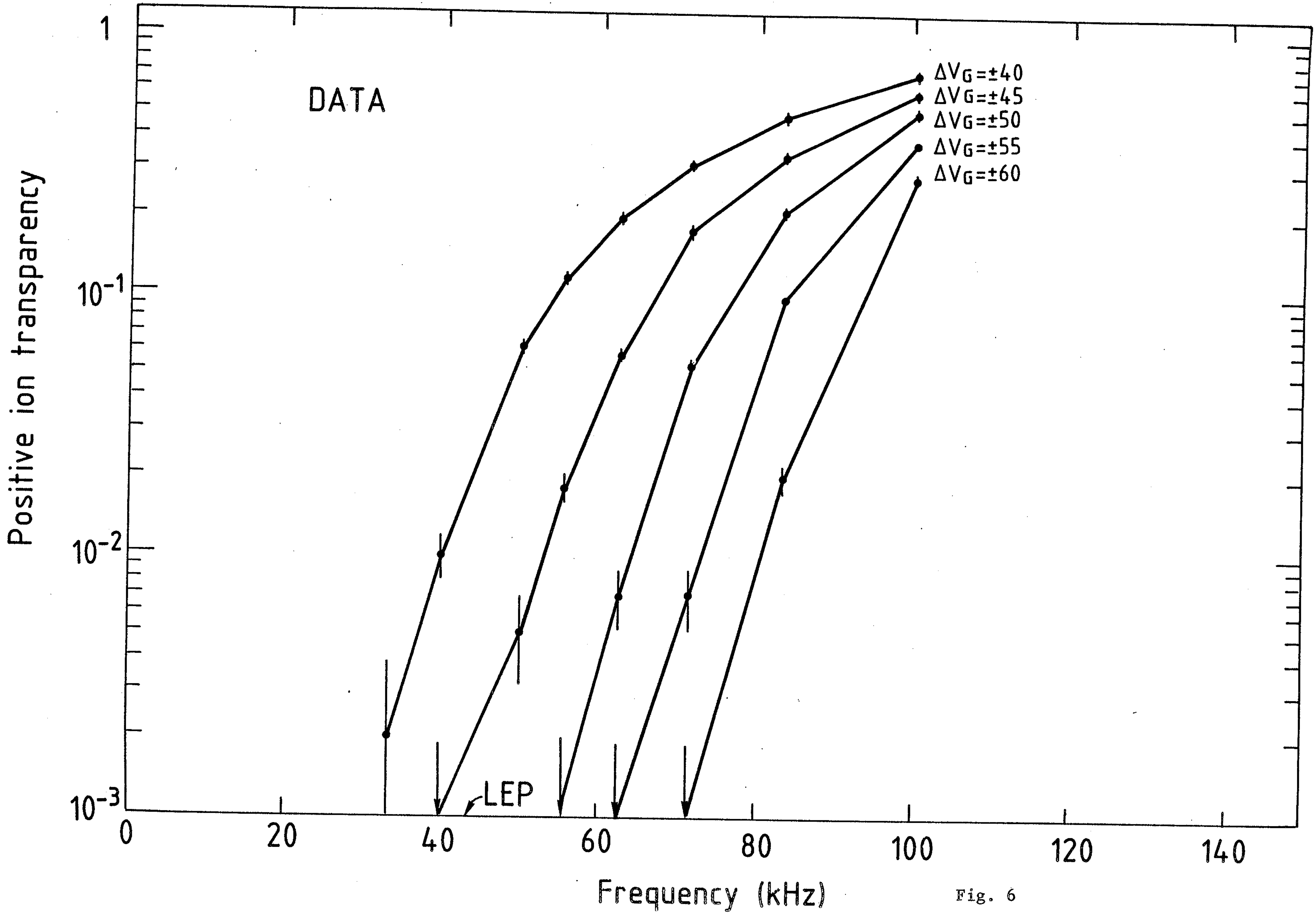

DATA
ΔVG=±40
ΔVG=±45
ΔVG=±50
ΔVG=±55
ΔVG=±60
LEP
1
10⁻¹
10⁻²
10⁻³
0
20
40
60
80
100
120
140
Positive ion transparency
Frequency (kHz)

Fig. 6

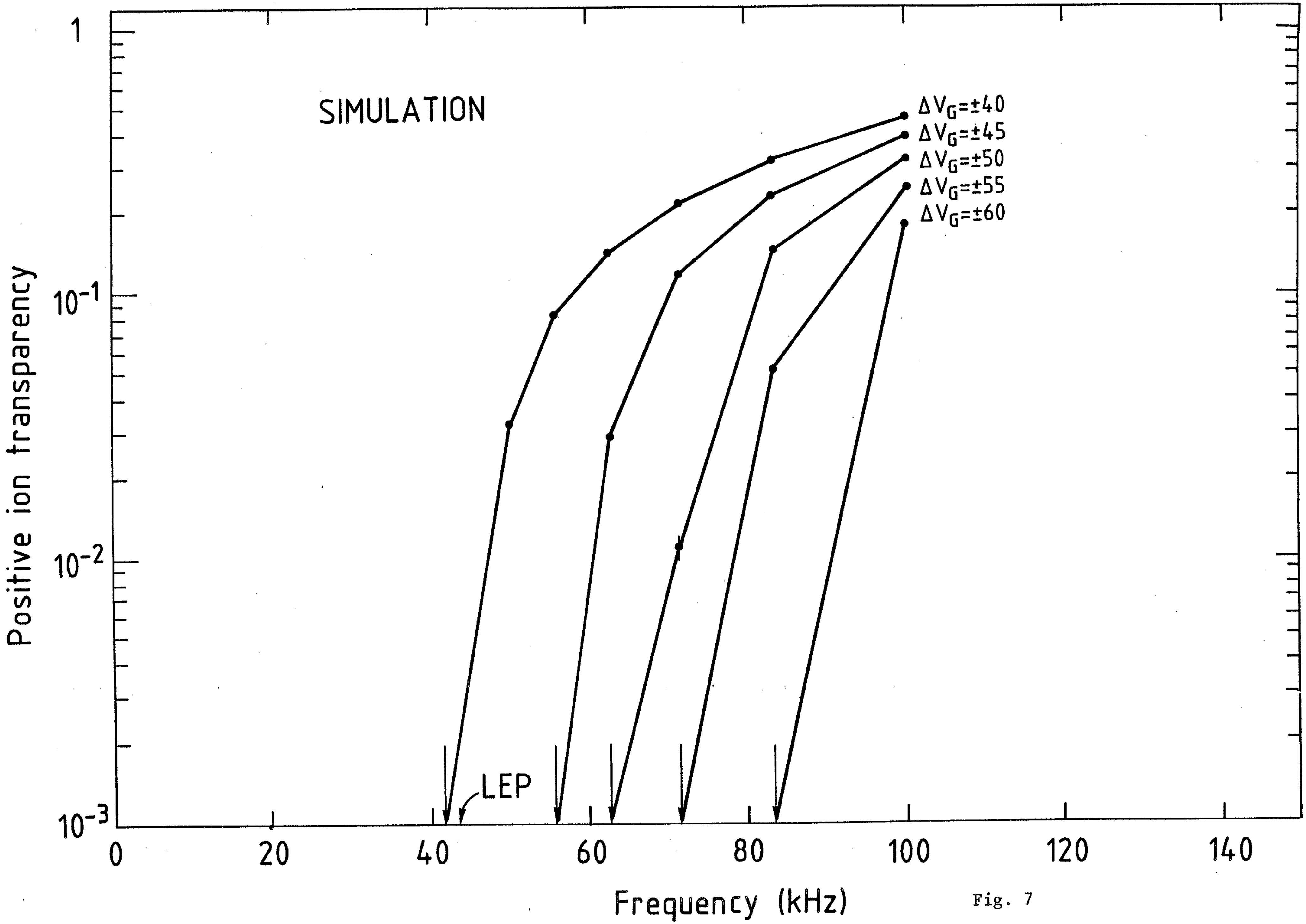

SIMULATION
ΔV_G=±40
ΔV_G=±45
ΔV_G=±50
ΔV_G=±55
ΔV_G=±60
LEP
Positive ion transparency
1
10^-1
10^-2
10^-3
0
20
40
60
80
100
120
140
Frequency (kHz)

Fig. 7