gating grid concept for ALICE upgrade

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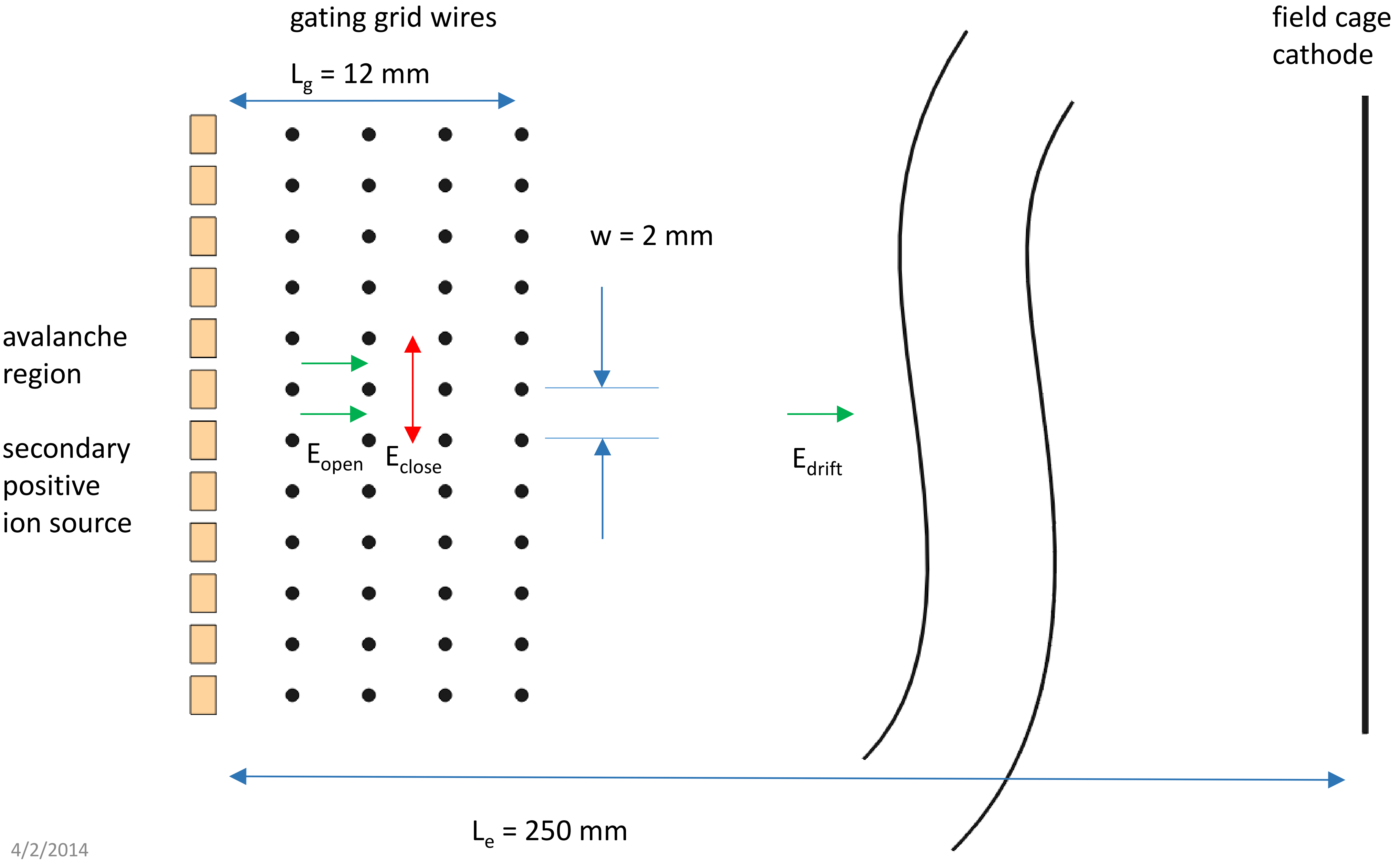
The Technical Design Report for the TPC Upgrade of the ALICE Time Projection Chamber outlines a plan to use GEM detectors for the TPC readout in which there is an estimated positive ion back flow into the drift volume which is 1% of the 2000 gas gain. This positive ion source was estimated to be 40 times[1] the primary ionization and was estimated to cause up to 20 cm distortions of the electron drift path[2]. The assumed ion species used for the distortion estimation are not those with the lowest ionization potential so the space charge could be composed of possibly slower ions[5] in which case still larger distortions would be generated. Given the difficulty of dealing with large distortions and the uncertainty in their amplitude a gating grid would be a reasonable consideration. As stated in the report the anticipated 50 kHz trigger rate precludes using a gating grid of the conventional form that has been used for PEP4, STAR, ALICE, ALEPH and others[3]. However, a modified gating grid design would work.

Outlined in the following is a concept for a gating grid that could be used for the ALICE upgrade which would block large fraction of the positive ion back flow from the gain region while still utilizing 75% or more of the full luminosity data rate.

See following diagram, discussion of operation and table of operating parameters:



gating grid wires
L_g = 12 mm
field cage
cathode
w = 2 mm
avalanche
region
secondary
positive
ion source
E_{open}
E_{close}
E_{drift}
L_e = 250 mm

Alice upgrade gating grid operation.

$$T_o = \frac{L_g}{K_I \cdot E_o}$$

Gating grid open time. The grid can be open as long as the ions remain in the gating grid channel.

$$T_c = \frac{w}{K_I \cdot E_c}$$

Gating grid close time. The time required to sweep out the ions.

$$T_p = T_o + T_c$$

Period of gating grid drive signal

$$T_a = T_o - T_e$$

Time that TPC is active (can receive triggers) is equal to the gate open time minus one transit time for electrons in the TPC drift volume

$$A = \frac{T_a}{T_p} = \frac{T_o - T_e}{T_o + T_c}$$

TPC live time fraction

Parameter definitions with example values

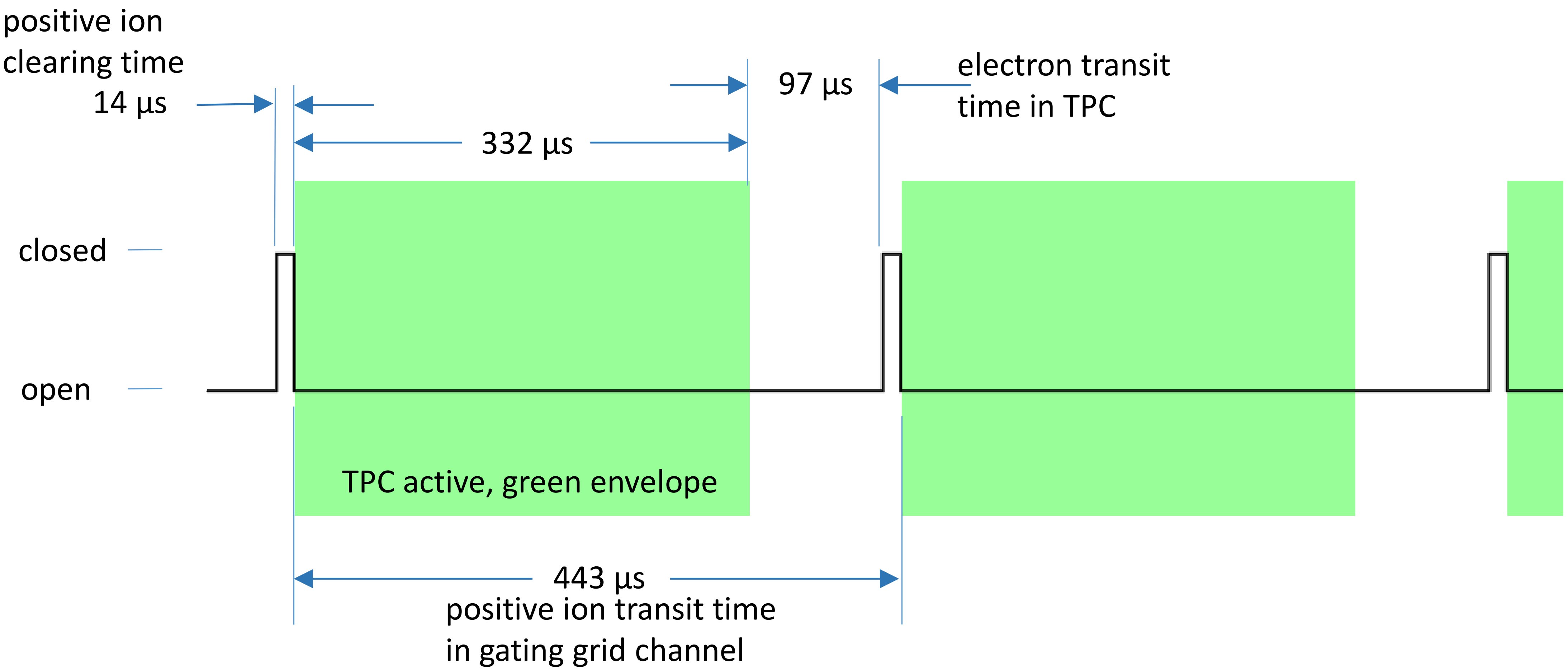
			ref
L_g	gating grid channel length	12 mm	
K_I	Ion mobility, CO_2+ in Ne	7 $cm^2/V\cdot sec$	6
E_o	drift field in open grid, same as in TPC drift volume	400 V/cm	4
$T_o = L_g/K_I \cdot E_o$	time gate is open	429 μs	
w	gating grid channel width	2 mm	
E_c	capture field, gate closed	2000 V/cm	

			ref
$T_c = w/K_I \cdot E_c$	time gate is closed, ion capture time	14 μs	
$T_p = T_o + T_c$	gating grid drive period	443 μs	
freq = $1/T_p$	gating grid drive frequency	2.3 kHz	
duty cycle	gating grid drive duty cycle	3 %	
L_e	TPC drift length	250 cm	4
v_e	electron drift velocity	2.58 cm/μs	4
$T_e = L_e/v_e$	electron transit time in TPC drift volume	97 μs	4
$T_a = T_o - T_e$	TPC active time, receiving triggers	332 μs	

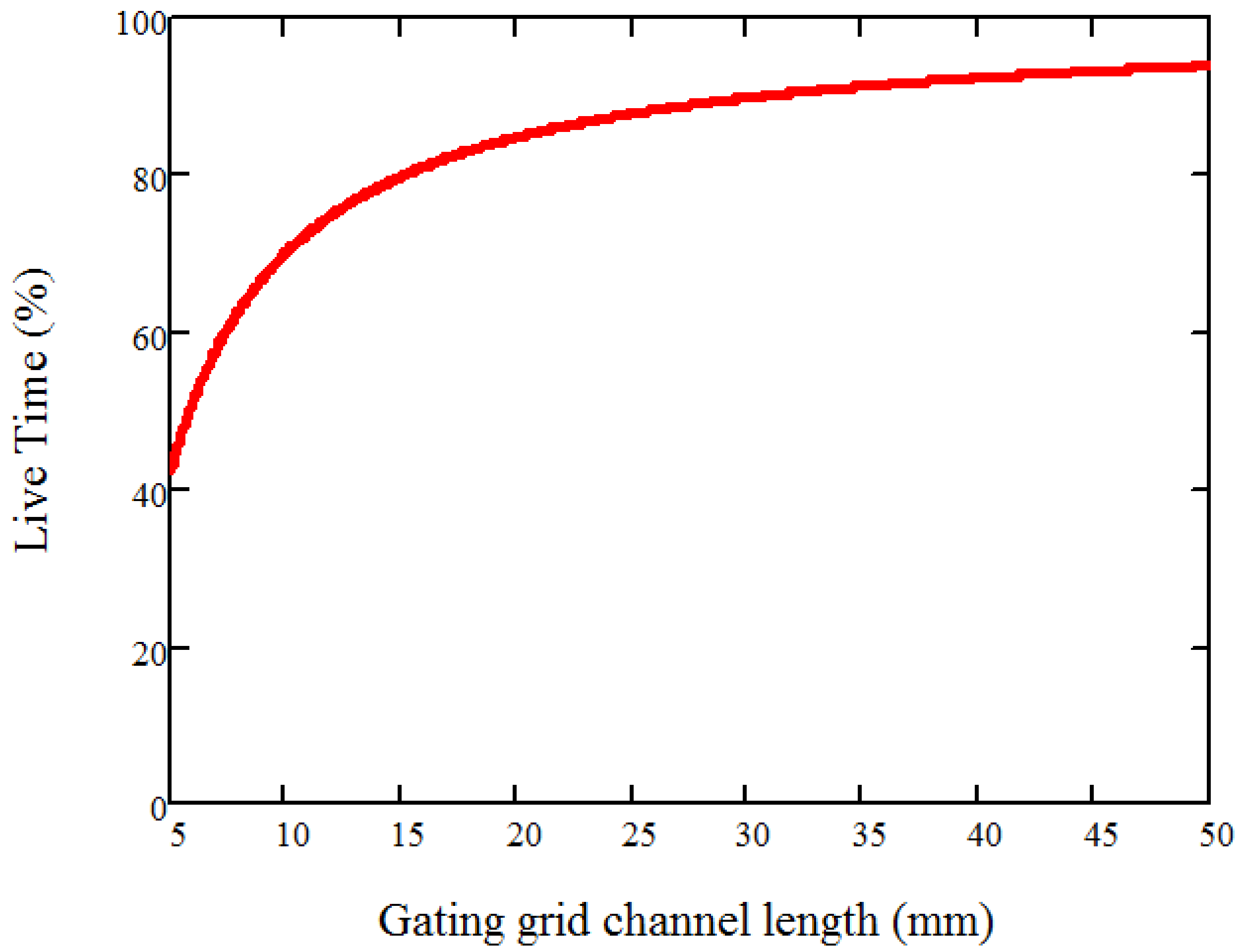
$$A = \frac{T_o - T_e}{T_p} = 75 \cdot \%$$

TPC live time fraction for this example.

wave form for gating grid example



Increasing the gating grid channel length or reducing the positive ion velocity increases the active fraction since the wait for the last event electron transit time constitutes a smaller fraction of the total period. See active fraction dependence on gating grid channel length in the following slide:



Fraction of TPC live time as a function of the length of the gating grid channel. A 30 mm channel length gives a live time of 90 %.

Conclusion

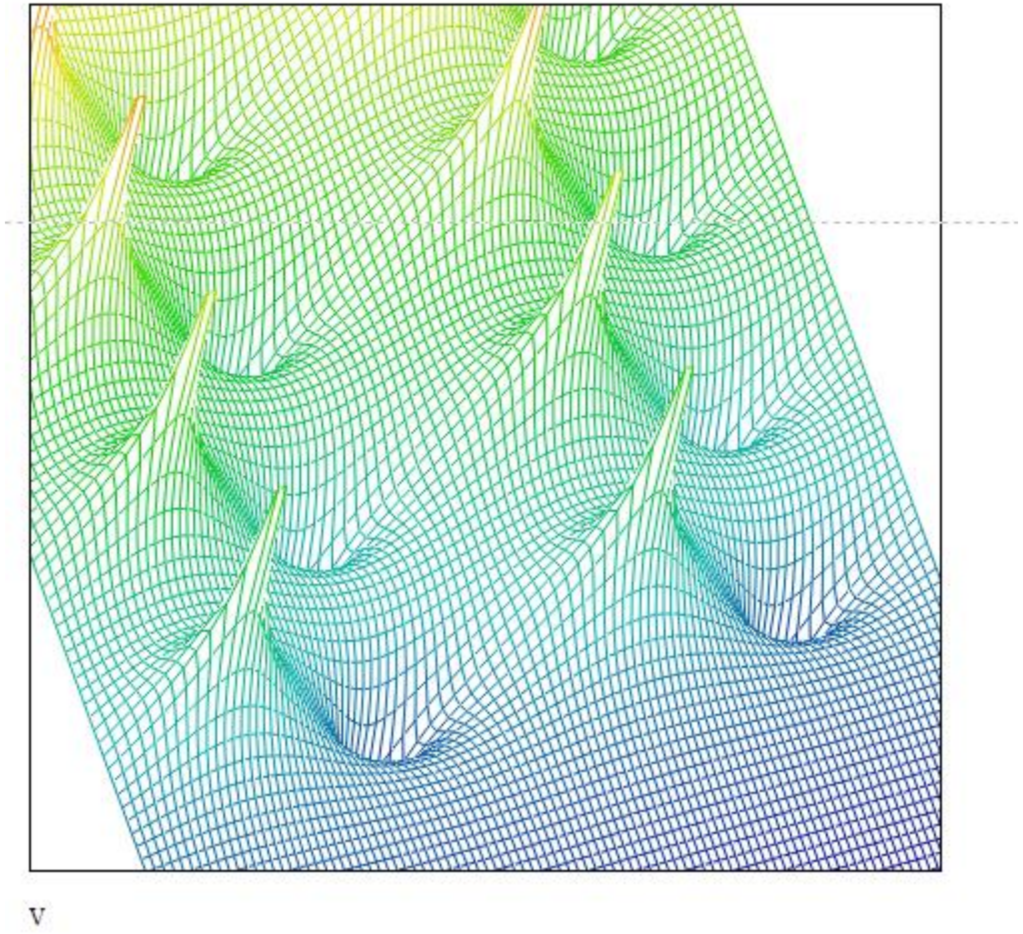
A relative straight forward gating grid system could provide large fraction exclusion of the back flow positive ions in the drift volume. This provides a factor of 40 reduction in the space charge distortion from what is estimated in the ALICE upgrades proposal with a very minor loss in data collection time. A loss of 25 % would soon be made up for as the luminosity from the LHC increases beyond the design goal. Currently there is large uncertainty in the positive ion species and consequently the space charge distortion could by significantly larger than what is estimated in the upgrades proposal. The gating grid would provide insurance against this potential problem. If 25 % data loss is unacceptable then the grid design can be easily modified to provide only 10 % loss in data collection time.

Note: The concept is illustrated here with a stack of grid wires, i.e. a stack of conventional gating grids. However, it may be mechanically more straight forward to use a stack of foil mesh grids using the same technology that was developed to stretch and mount the GEM foils. The ion collection fields would then be parallel to the normal drift field but would reverse direction at each foil crossing.

See following slides for more realistic fields with wires. Don’t get 100%

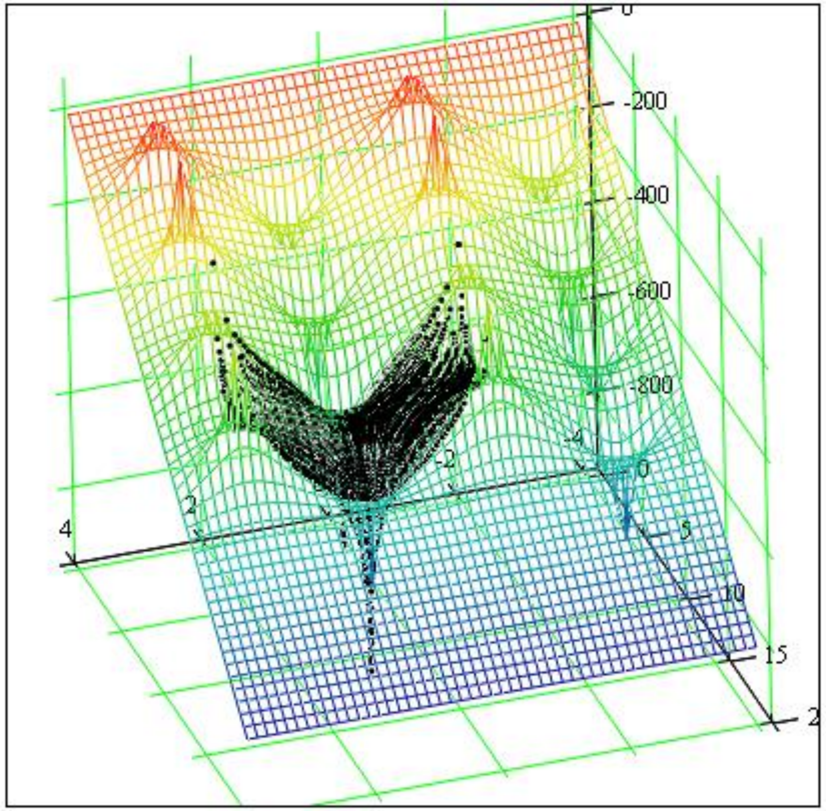
References

1. ALICE Collaboration, *Technical Design Report for the Upgrade of the ALICE Time Projection Chamber*, ALICE-TDR-016, March 3, 2014, p. 86-88.
2. Ibid., p. ii
3. Ibid., p. i, 2
4. Ibid., p. 6, Table 1.1
5. W. Blum and L. Rolandi, *Particle Detection with Drift Chambers*, Springer-Verlag, 1994, p. 62-65. Earl W. McDaniel and Edward A. Mason, *The Mobility and Diffusion of Ions in Gases*, John Wiley & Sons, 1973, p. 10,29,39,40. In the STAR experiment the required correction for space charge distortion is 3 times (Gene Van Buren private communication) the predicted space charge density http://www-rnc.lbl.gov/~wieman/TPC%20Rev%202006%20abrv%20for%20Ron.pdf (H. Wieman). This could be due to charge transfer to slower unidentified contaminants.
6. R. Veenhof, *Calculations for the Alice TPC read-out* http://rjd.home.cern.ch/rjd/Alice/neon_mobility.html. S. Rossegger, J. Thomas, *Space-charge effects in the ALICE TPC: a comparison between expected ALICE performance and current results from the STAR TPC*, Internal Note/ ALICE-INT-2010-017 version 1.0. H.W. Ellis and E.W. McDaniel, D.L. Albritton, L.A. Viehland, L.L. Lin and E.A. Mason, *Transport Properties of Gaseous Ions Over a Wide Energy Range*. *Part* II, Atomic Data and Nuclear Data Tables 22, 179-217 (1978). Original source: T. Koizumi, N. Kobayashi, and Y. Kaneko, J. Phys. Soc. Japan 43, 1817 (1977) This data only goes down to a field of 2000 V/cm, but this is still in the low field region, i.e. ion energies are thermal, so it should be reasonably accurate for the range considered in this example using 400 V/cm.

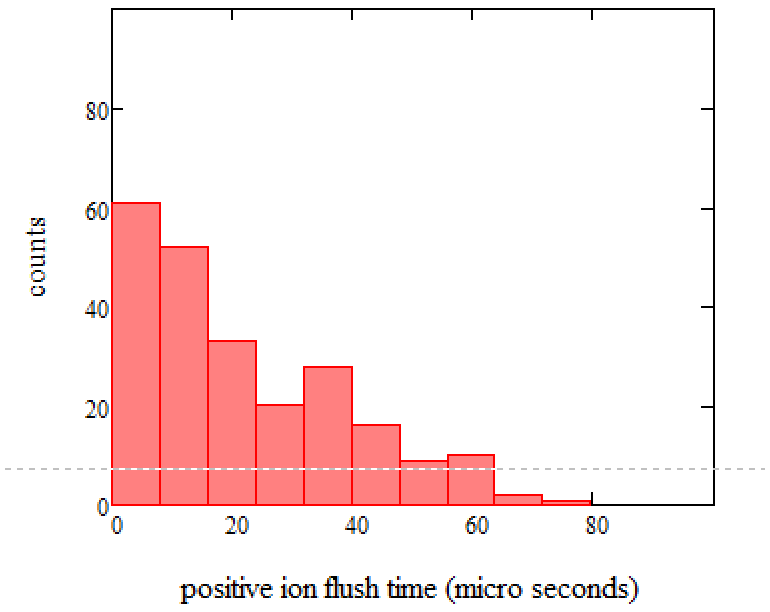


Potential surface with grid wires

positive ion drift with diffusion

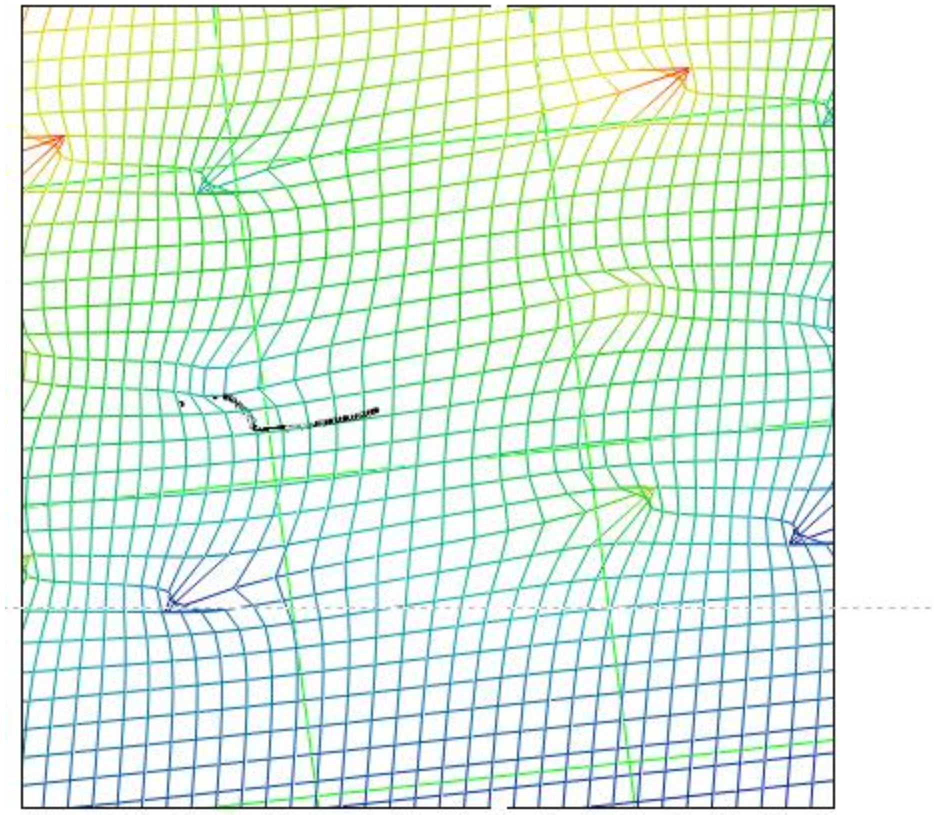


distribution of collection times



99 % collected in 63 μs

Straggler



Example of long collection time (69 μs) for an ion caught on a saddle point