# Detailed RPC Avalanche Simulations

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- *"1.5 dimensional " avalanche simulations, update*
  - *Spectra*
  - *Mode of operation*
  - *Space charge effect and time resolution*
  - *Charge-time correlation*
- *Detailed 2 dimensional simulations of single avalanches*
  - *Electric field*
  - *Effective Townsend coefficient*
  - *…*
- *Summary*

## Over the last years we have published several articles on RPC detector physics:

[1] **Space Charge Effects in Resistive Plate Chambers,**
CERN-EP/2003-026, accepted for publication in NIM A, C. Lippmann, W. Riegler

[2] **Detector Physics of RPCs,**
Doctoral Thesis, C. Lippmann, May 2003 (CERN, University of Frankfurt)

[3] **Detector Physics and Simulation of Resistive Plate Chambers,**
NIMA 500 (2003) 144-162, W. Riegler, C. Lippmann, R. Veenhof

[4] **Induced Signals in Resistive Plate Chambers,**
NIMA 491 (2002) 258-271, W. Riegler

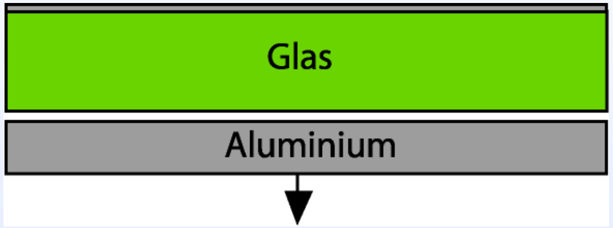
[5] **Signal Propagation, Termination, Crosstalk and Losses in Resistive Plate Chambers,**
NIMA 481 (2002) 130-143, W. Riegler, D. Burgarth

[6] **Detector Physics of Resistive Plate Chambers,**
Proceedings of IEEE NSS/MIC (2002), C. Lippmann, W. Riegler

[7] **Static Electric Fields in an Infinite Plane Condenser with One or Three Homogeneous Layers,**
NIMA 489 (2002) 439-443, CERN-OPEN-2001-074, T. Heubrandtner, B. Schnizer, C. Lippmann, W. Riegler

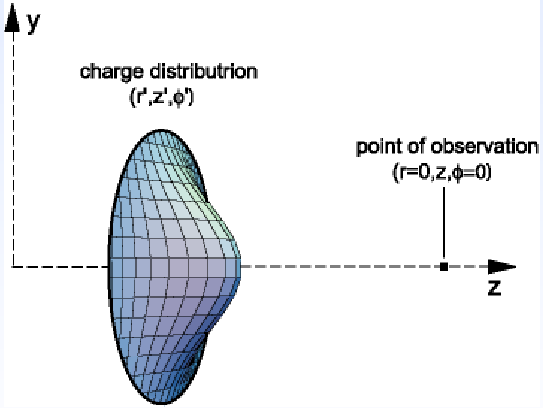
## In this talk we focus on Timing RPCs:

P. Fonte, V. Peskov et al.



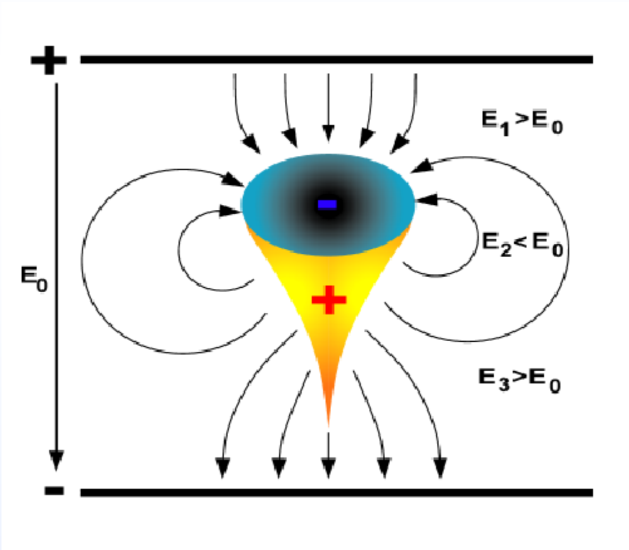

- 0.3mm gas gaps
- 3mm glass, 2mm aluminum
- $C_2F_4H_2$/ i-$C_4H_{10}$/ $SF_6$ (85/5/10)
- HV: 3(6)kV $\Rightarrow$ E: $\approx$100kV/cm

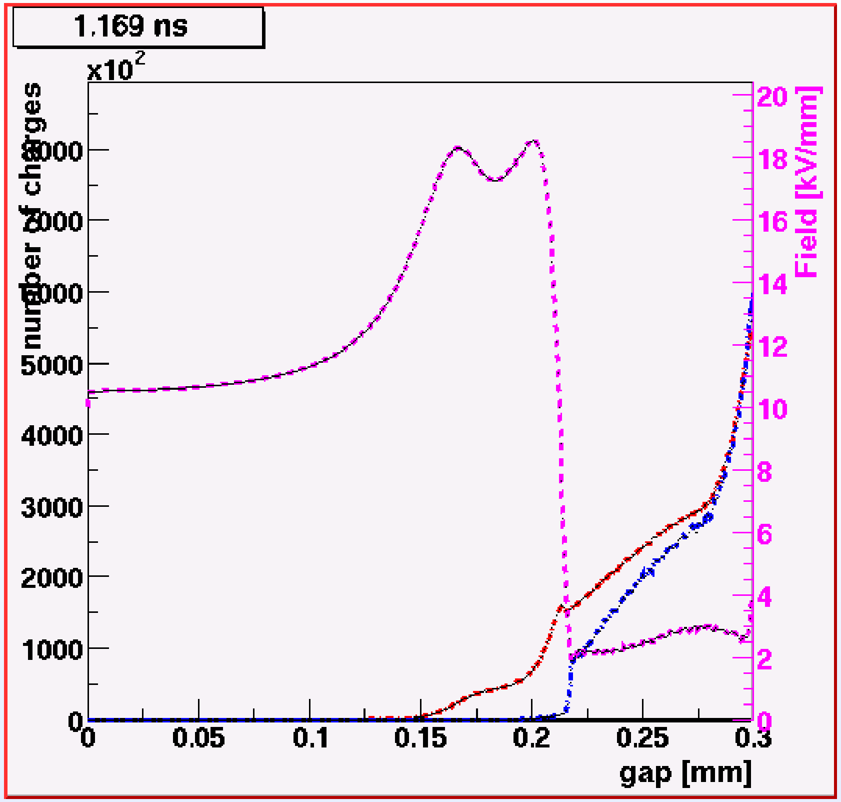
# Space Charge Effects, 1.5D Simulation [1,2,7]




**The 1.5D simulation was presented at the RPC2001 conference:**

- complete simulation in one dimension (longitudinally)
- but taking into account also the transversal spread (diffusion only) in the calculation of the space charge field

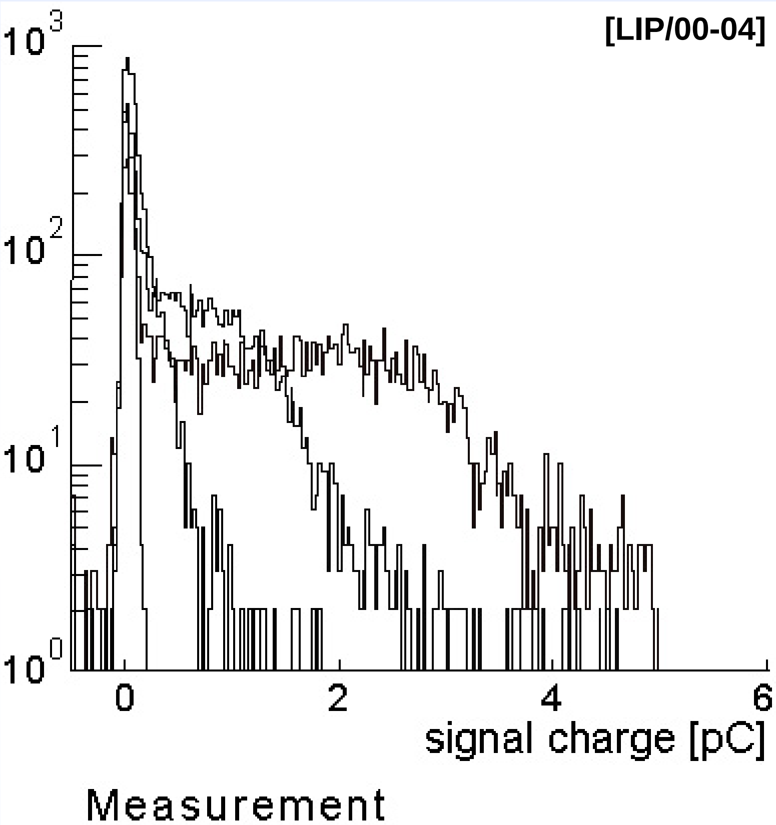


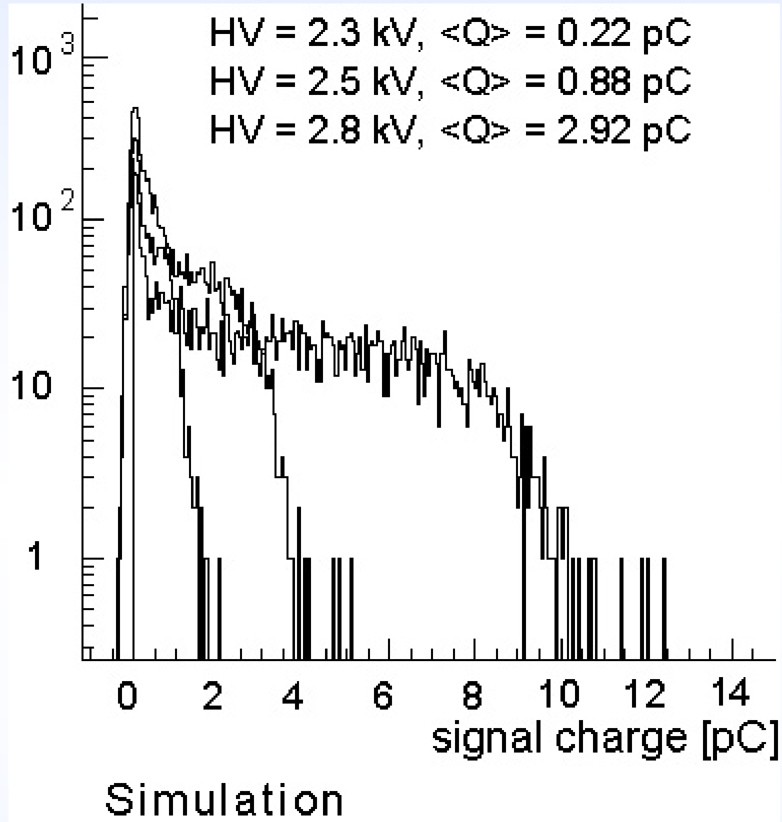




**0.3mm Timing RPC, HV=3kV**
**electrons, positive ions, negative ions, electric field**

# Charge Spectra (Update) [1,2]

## Example: Timing RPC



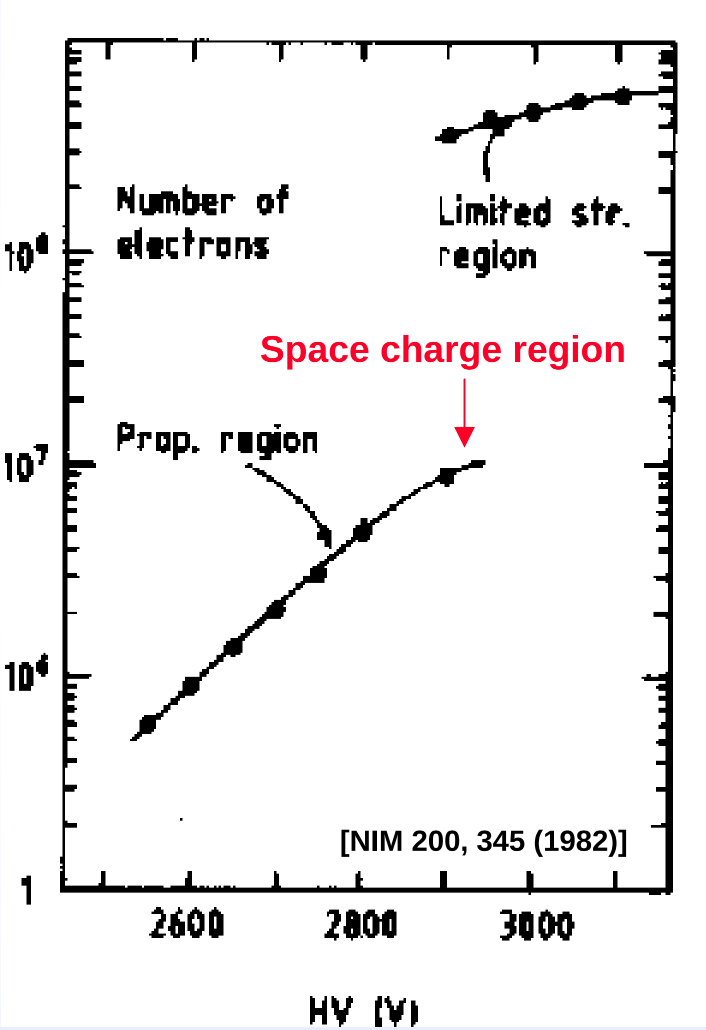




- **Mean values deviate by a factor 2.**
- **Reminder: This has to be compared with a factor $10^7$ difference without inclusion of SCE in simulation! $\Rightarrow$ We consider this good agreement!**
- **SCE is cause of observed 'small' charges and of shapes of charge spectra**

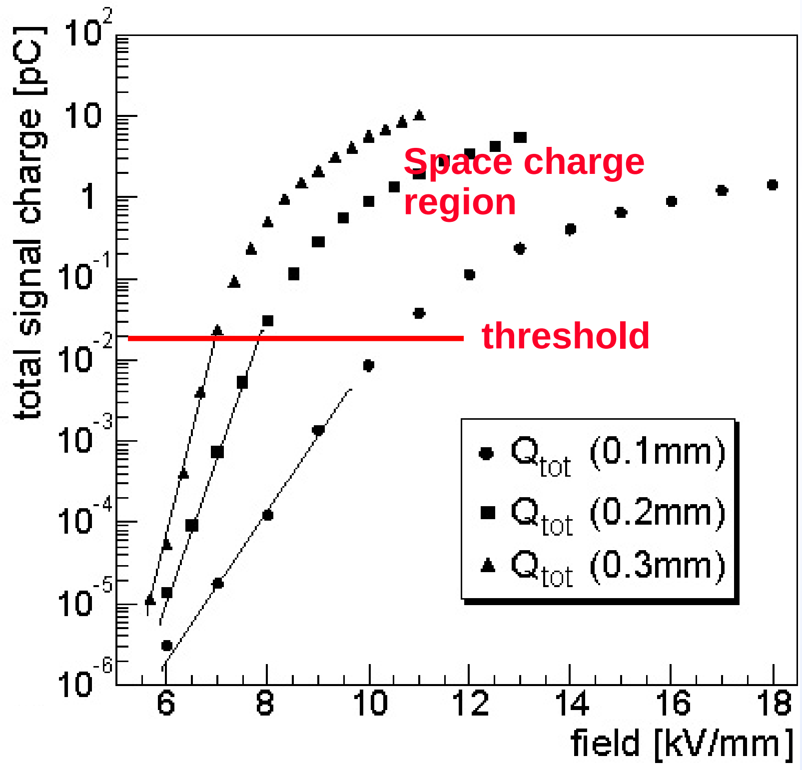
**7GeV pions, T=296.15K, p=970mb** **1.5D simulation**

# Mode of Operation of RPCs [1,2,6]

**Wire chamber/ Geiger-Müller-counter:**



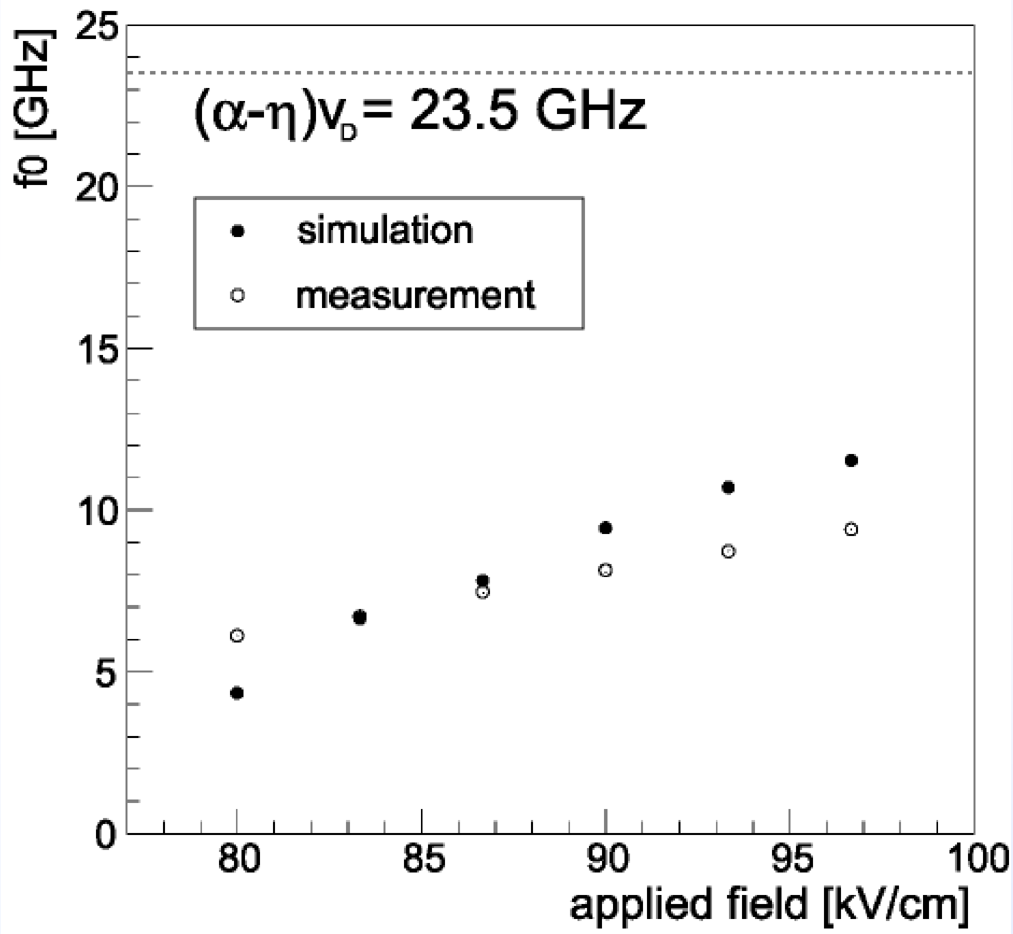

- **Timing RPC (simulation)**
- **Proportional region below threshold**
- **Large space charge region**




**1.5D simulation**

# Signal Rise, Comparison to Measurement [1,2]

- In [IEEE trans. nucl. science vol48, no4, 2001] it is shown that sending an exponentially rising signal through a general linear network, the outcome is still exponential.
- Then the value $f_0=(\alpha-\eta)v_D$ can be measured using two separate thresholds.

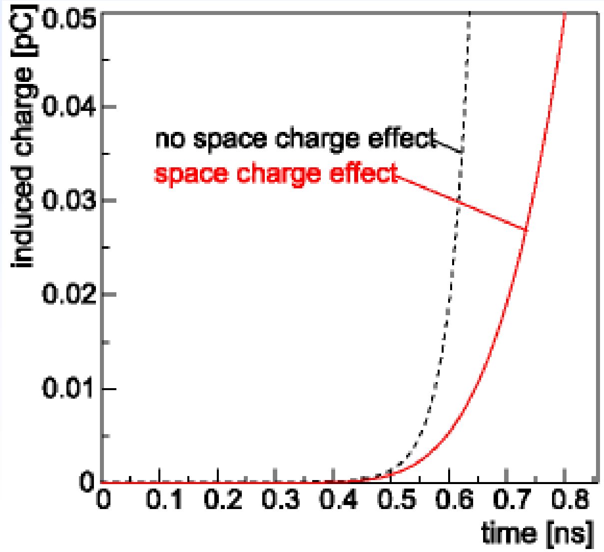


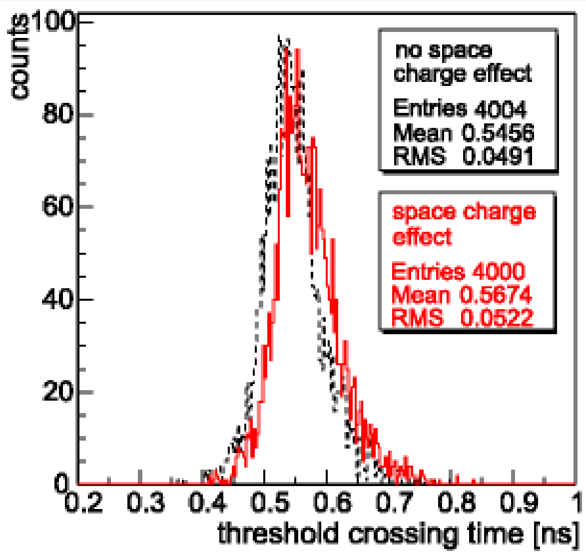

- Calculation with $\alpha$, $\eta$ and $v_D$ taken from MAGBOLTZ and IMONTE gives for the described Timing RPC values around $f_0$ = 23.5GHz.
- **Values around 8GHz are measured!** [P.Fonte, „resistive plate chambers for time of flight“, talk given at GSI, May 13-16, 2002]
- But: Simulation with Space Charge Effect shows quite good agreement with measurement.

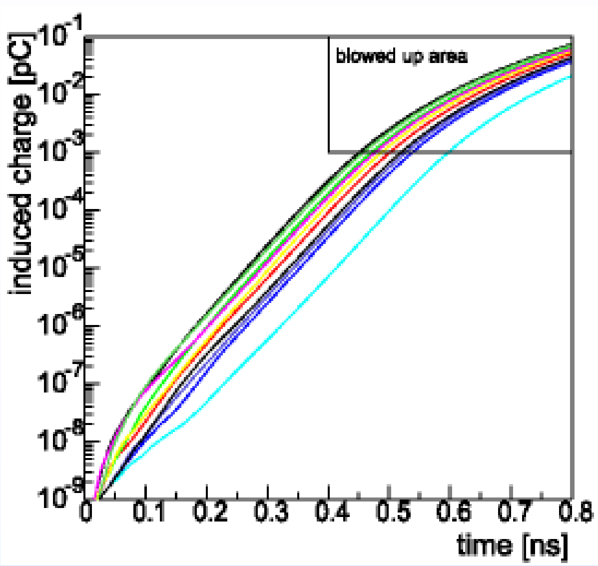
$\Rightarrow$ Assumption, that signal rise is exponential at the threshold level, is wrong.

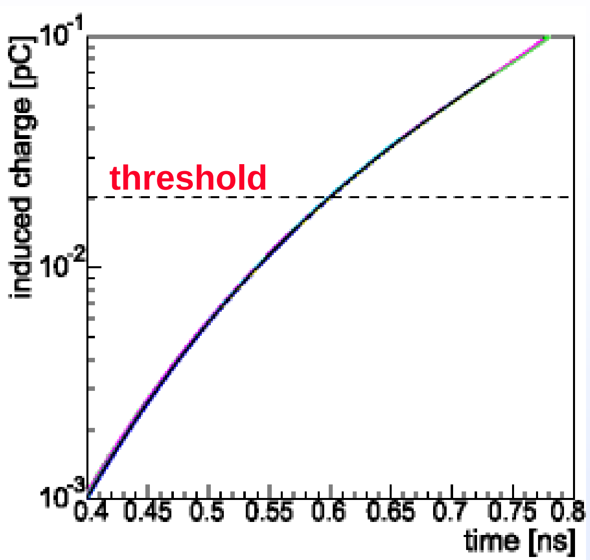
1.5D simulation

# Space Charge Effect and Time Resolution [1,2]



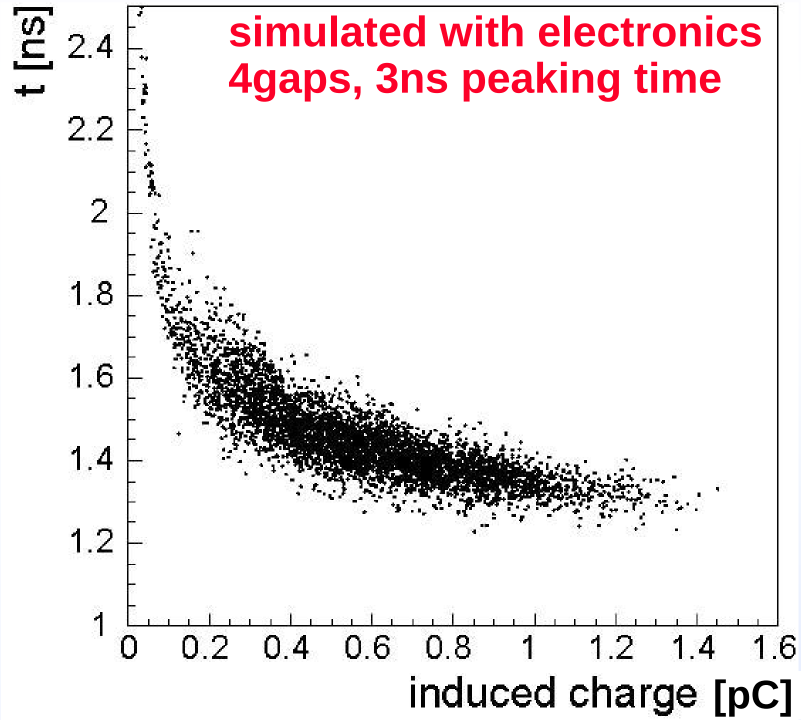



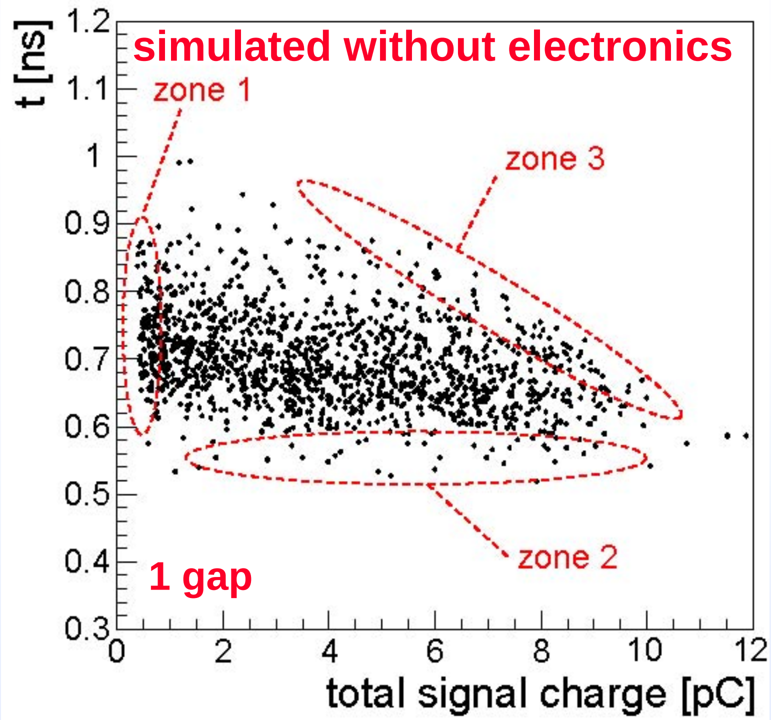

- **Signal rise is affected by space chare effect at threshold level.**
- **But: time resolution (r.m.s.) is not affected!**
- **Why?**
- **The 10 different avalanches from the left plot are overlayed at the right plot.**
- **The growth of all avalanches is affected by the space charge effect similarly.**

**1.5D simulation**

# Charge-Time-Correlations [1,2]

- Reasons are mainly electronics (Finite risetime of amplifier ⇒ time slewing).
- But also (small) detector intrinsic effects:
  - Zone 1: Given by threshold.
  - Zone 2: Signals with fast rise are NOT correlated to charge.
  - Zone 3: Signals with slow rise are correlated to charge.




1.5D simulation

# 2-D Simulations [1,2]

electric field of a charged ring with radius r' at position z' :

- The gas gap is divided in a two dimensional grid of the longi-tudinal and radial coordinates.
- We assume cylinder symmetry of the avalanche.
- The avalanche is simulated by dividing the development into time steps and calculating the electric field (longitudinal and radial component) at every point within the avalanche at each time step.
- Mirror charge rings in the (conductive aluminium) anode are added.

$$E_r(r,z,r',z') = \frac{Q}{4\pi\varepsilon_2}\,\frac{2}{r\,a^2\,b}\left[c^2\,E\left(\frac{-4rr'}{b^2}\right) + a^2\,K\left(\frac{-4rr'}{b^2}\right)\right],$$

$$E_\phi(r,z,r',z') = 0\,,$$

$$E_z(r,z,r',z') = \frac{Q}{4\pi\varepsilon_2}\,\frac{4(z-z')}{a^2 b}\,E\left(\frac{-4rr'}{b^2}\right)\,.$$

where

$$a^2 = (r+r')^2 + (z-z')^2\,,$$

$$b^2 = (r-r')^2 + (z-z')^2\,,$$

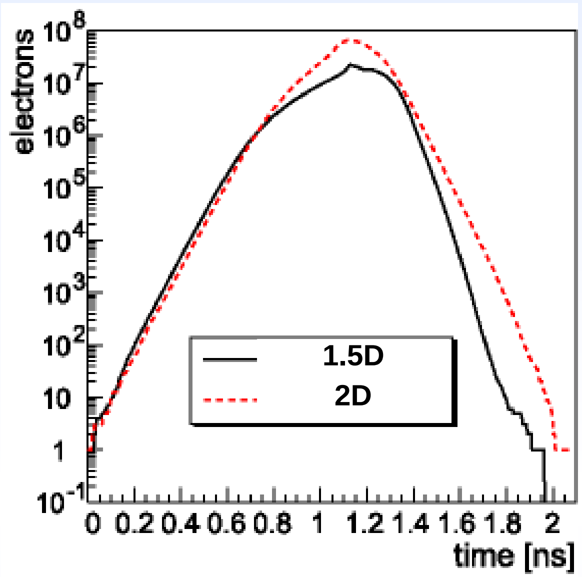
$$c^2 = r^2 - (r')^2 - (z-z')^2$$

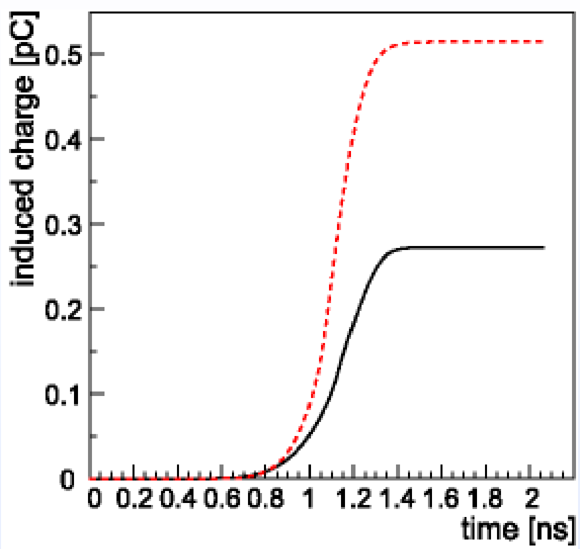
and

$$K(x) = \int_0^{\frac{\pi}{2}} \frac{1}{\sqrt{1-x\sin^2(\xi)}}\,d\xi \quad , \quad E(x) = \int_0^{\frac{\pi}{2}} \sqrt{1-x\sin^2(\xi)}\,d\xi\,.$$

- The gas parameters (Townsend coefficient, attachment coefficient, drift velocity, diffusion coefficients) are calculated dynamically at each grid point.

# Comparison of 1.5-D and 2-D Simulations [1,2]



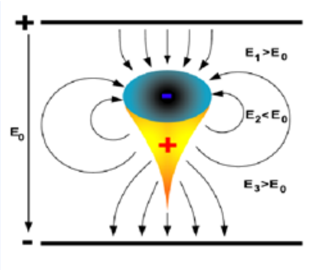




- **The space charge effect is a bit stronger in the 1.5-D simulation. Reasons:**
  1) **In the 1.5D simulation, the field is calculated only at the center of the avalanche, where the field is strongest.**
  2) **In the 1.5D simulation, there is no radial repulsion of electrons ⇒ Charge density higher.**

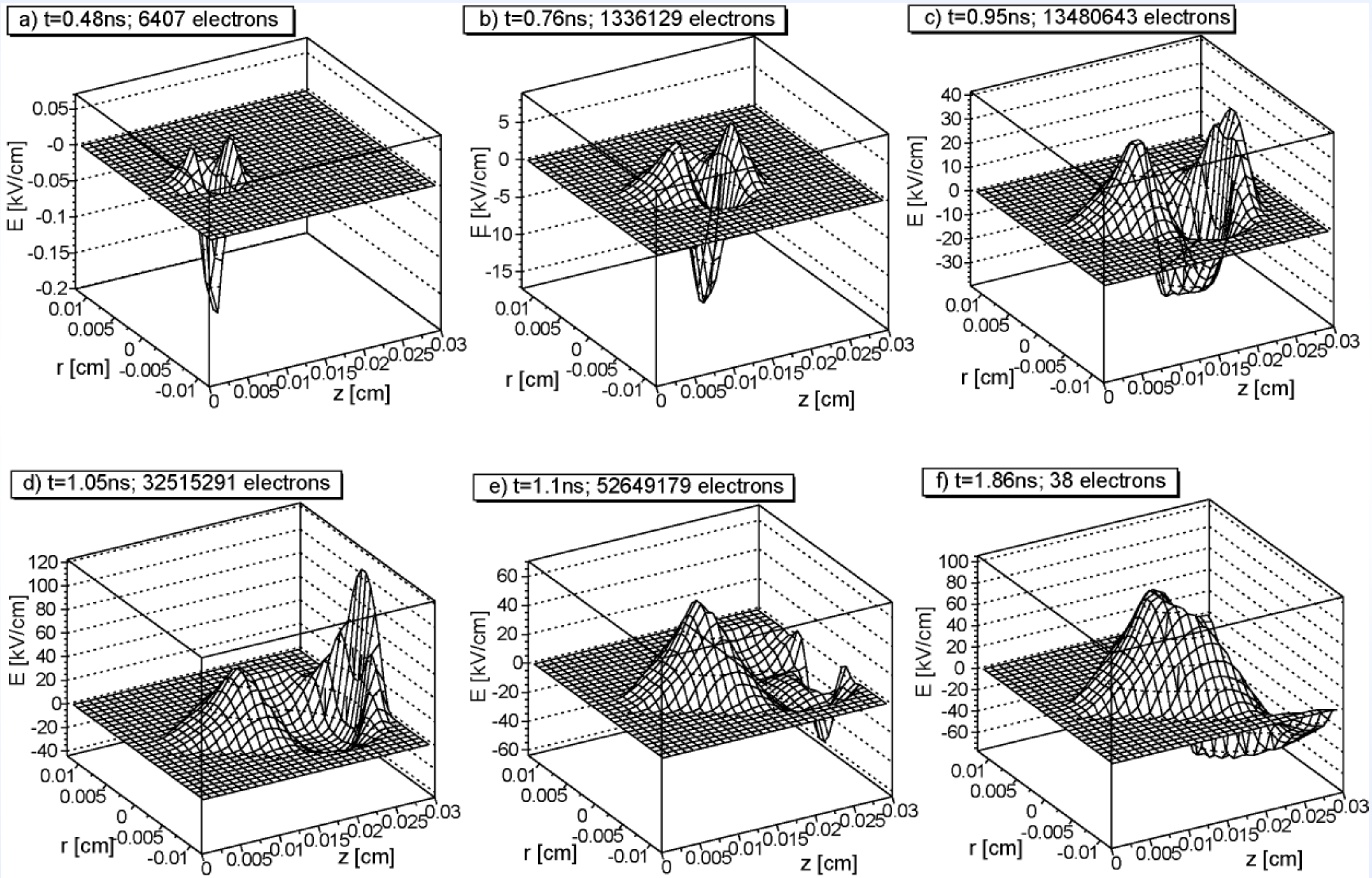
**⇒ Calculated space charge field is stronger in the 1.5D case.**

- **Induced current deviates by about a factor 2.**

Avalanches were started with 1 electron at Cathode in a 0.3 mm gap Timing RPC at HV=2.8kV.

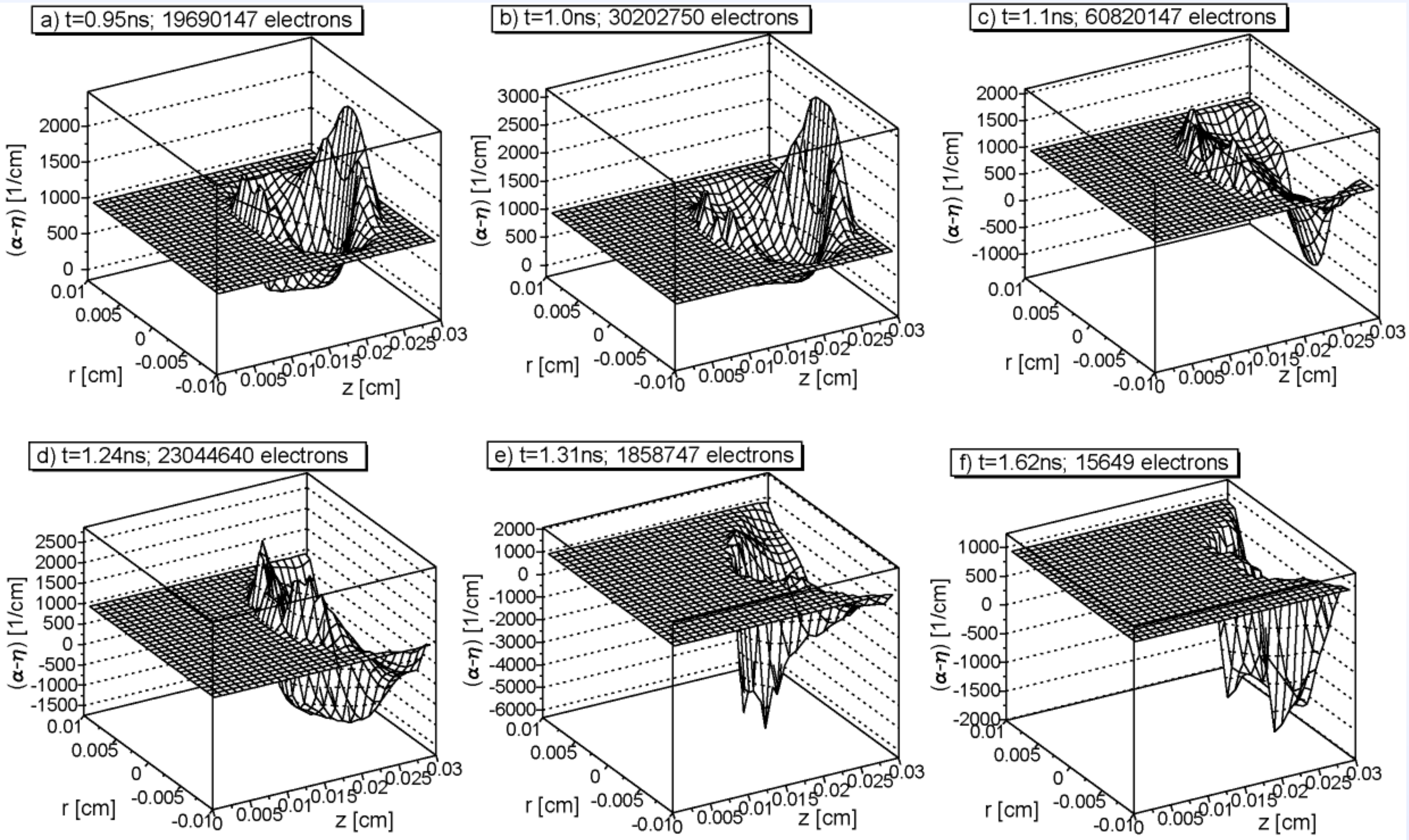



# 2D- Simulation: Space Charge Field [1,2]




**The space Charge Field reaches the same order of magnitude as the applied electric field!**

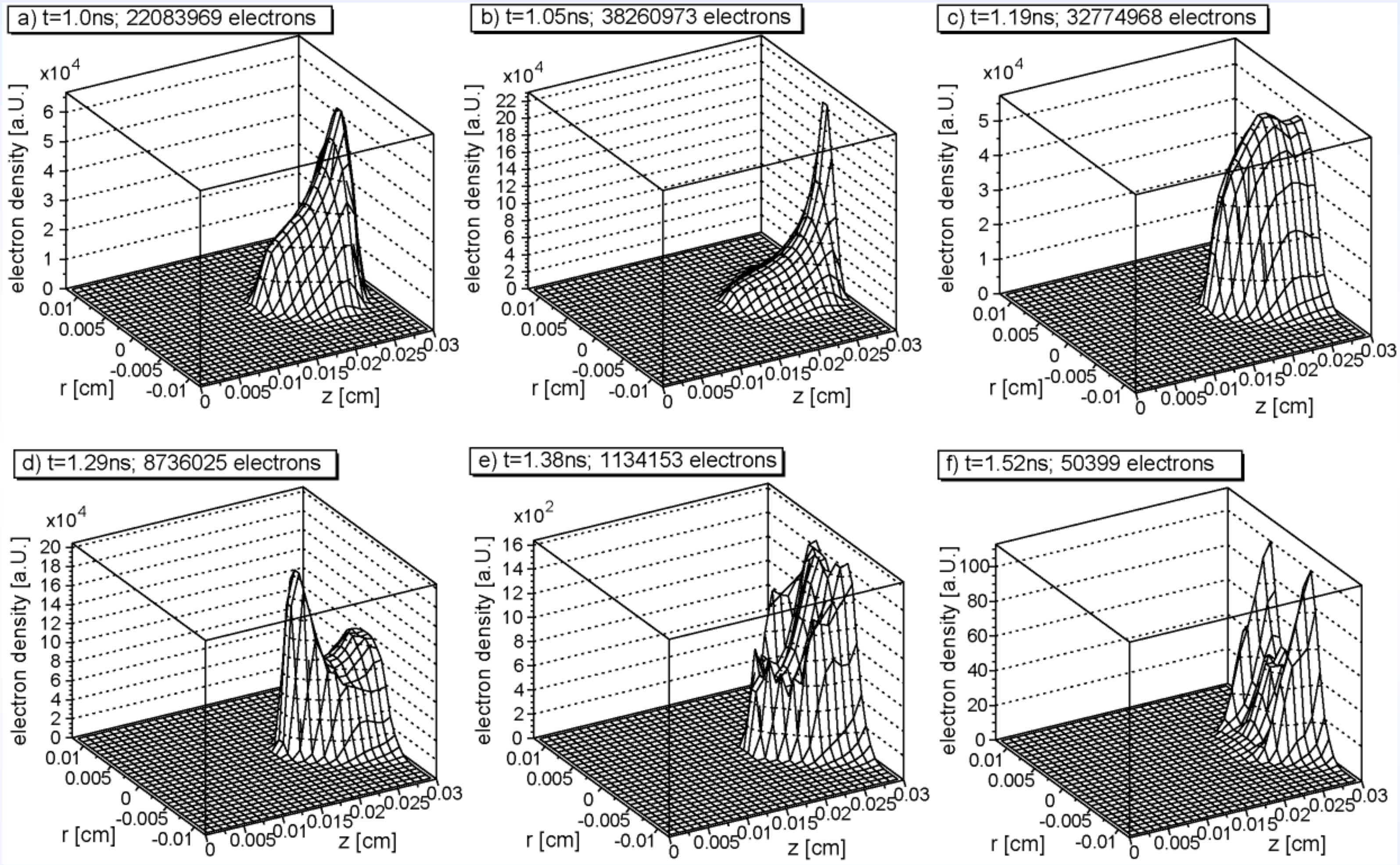
# 2D- Simulation: Effective Townsend Coefficient within the avalanche [1,2]




**The effective Townsend Coefficient ranges from +3000/cm to –6000/cm!**

**2D simulation**

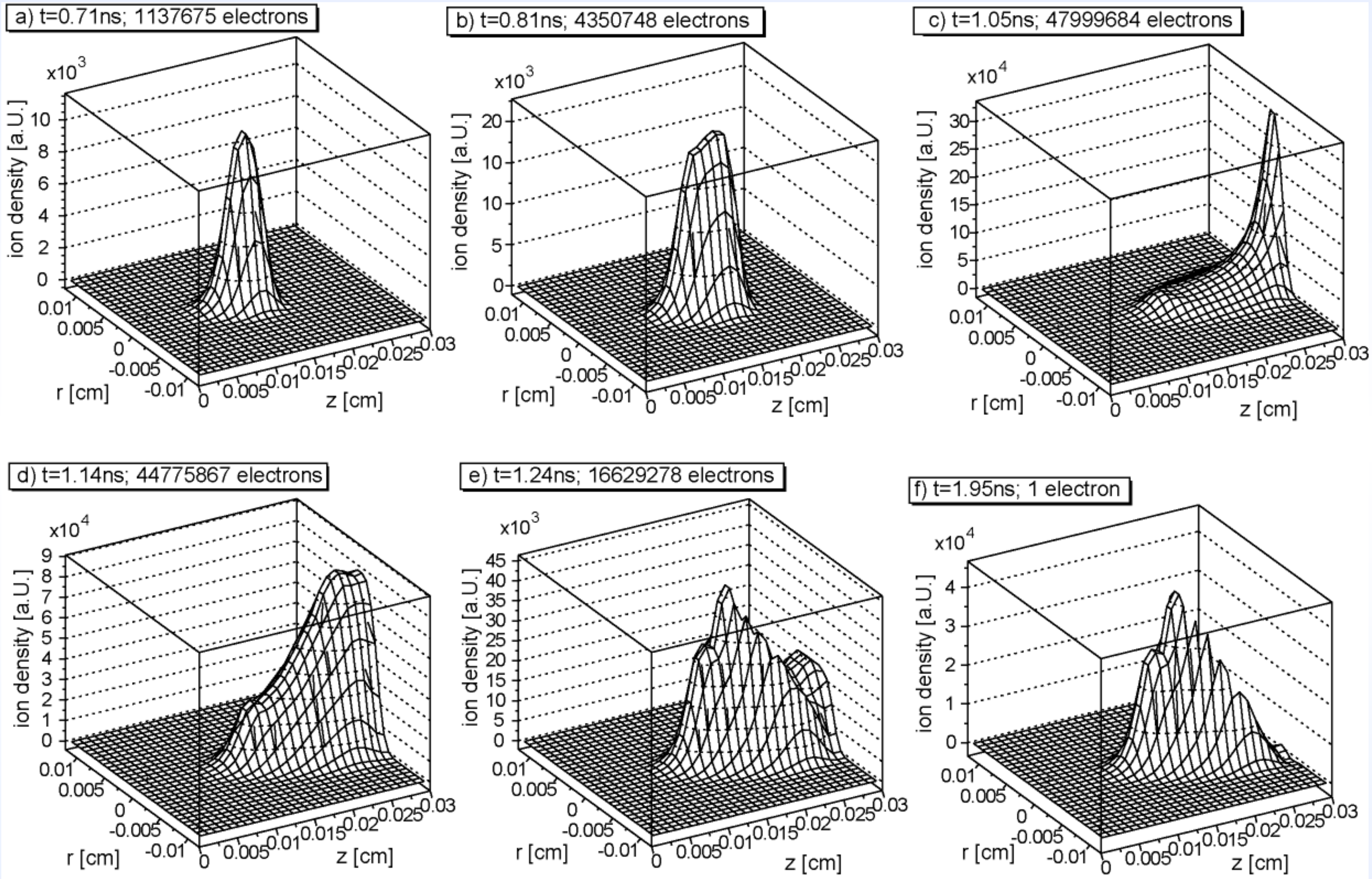
# 2D- Simulation: Electron density [1,2]




**In the final stage of the avalanche there is strong attachment of electrons, especially in the center of the avalanche!**

**2D simulation**

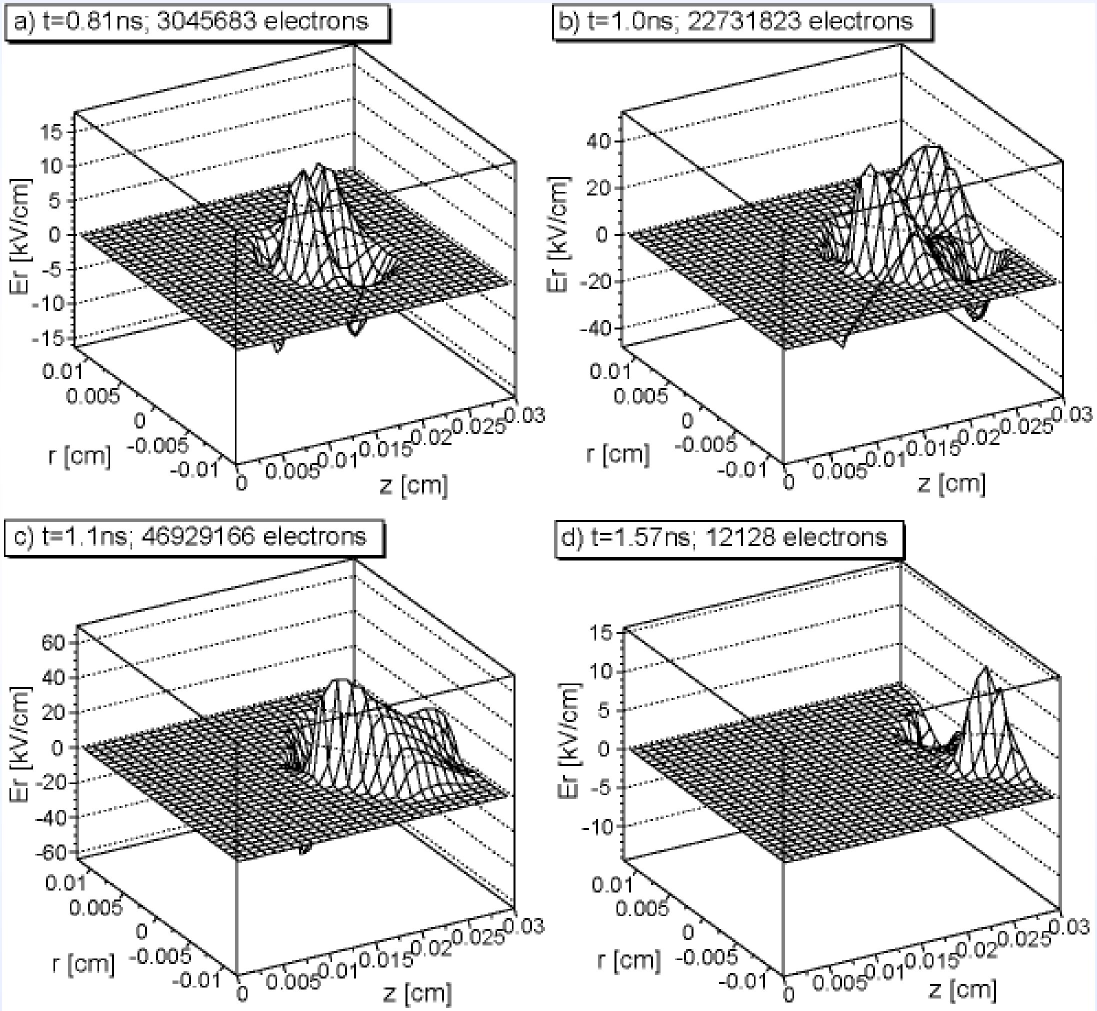
# 2D- Simulation: Density of Positive Ions [1,2]




**Through electron attachment a lot of negative ions are formed at the final stage!**

# 2D- Simulation: Radial Space Charge Field within the avalanche

[1,2]




**The radial space charge field reaches almost the order of magnitude of the applied electric field!**

# Summary

- Over the last three years we have systematically studied many aspects of RPC detector physics (See list on slide 2).

- Space charge effects are very prominent in this detector.

- The space charge effect is already influencing the signal rise at the threshold level.

- The time resolution is not affected by space charge effects.

- Charge-time-correlations have mainly electronic reasons, but also some detector intrinsic reasons.

- The more detailed 2D simulation supports the 1.5D results.

Outlook: In order to reproduce streamers, photon effects have to be included … there is more to do!