Detector Physics of Resistive Plate Chambers

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Work in collaboration with Werner Riegler (CERN)

- **Outline:**
  - **Introduction**
  - **Detector Physics and Simulation of RPCs**
  - **Simulation Results 1**
    - **Efficiency**
    - **Time Resolution**
  - **Space Charge Effects**
  - **Simulation Results 2**
    - **Charge Spectra**
  - **Summary**

What is an RPC?

R. Santonico, R. Cardarelli, NIM 187(1981)377

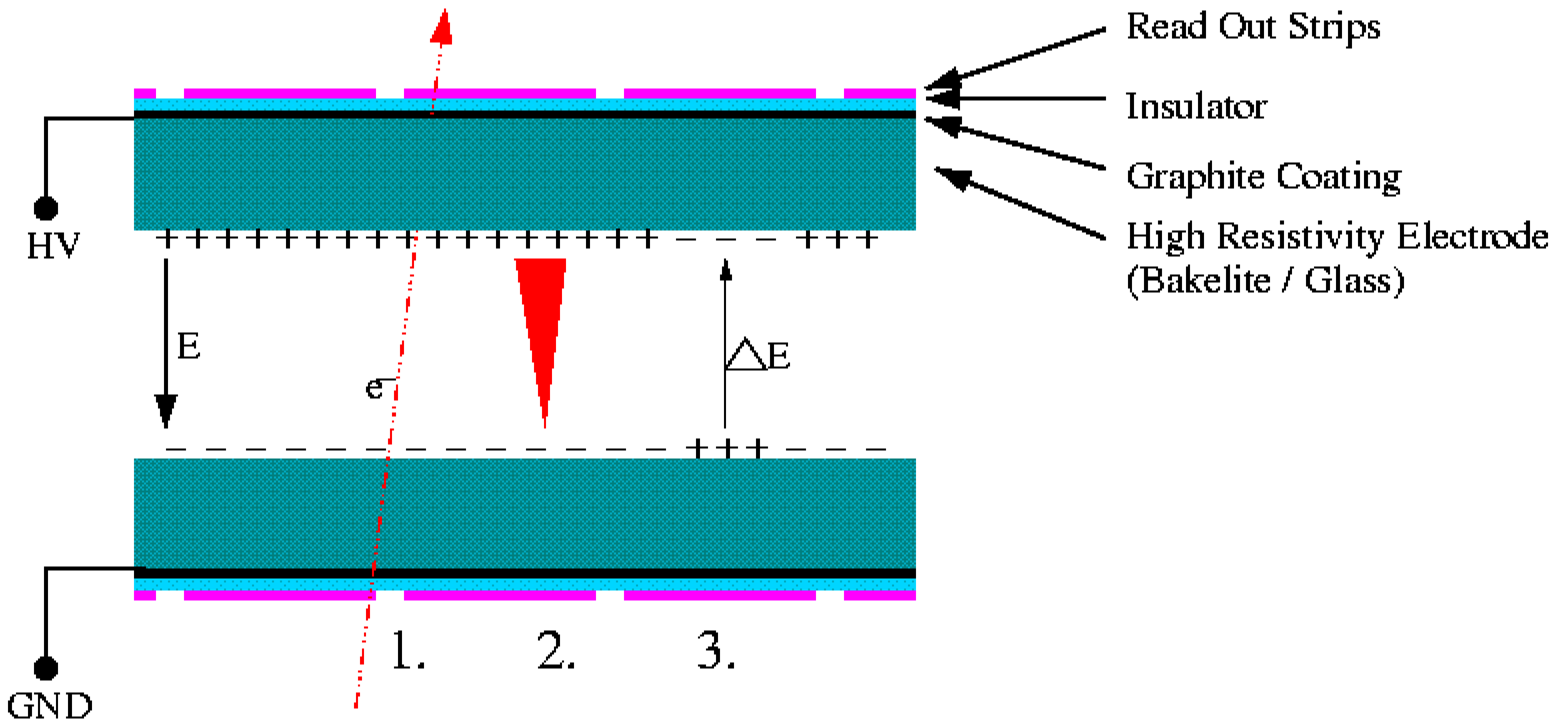
R. Santonico, R. Cardarelli, NIM A263(1988)20

- Gas Detector
- Parallel Plate Avalanche Detector
- Homogeneous high electric field
- Good Time Resolution
- Good for large areas

- Streamer Mode:
  - Large signals
  - Simple Read Out
- Avalanche Mode:
  - Better Rate Capability
- We focus on Avalanche Mode

What is an RPC?

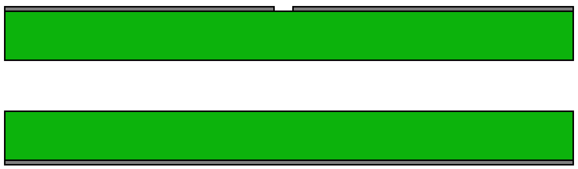
- **How it works**
  1. **Primary ionisation**
  2. **Avalanche**
  3. **Surfaces charged by electrons/ions**
  4. **Charges on electrodes are annihilated with some time constant** t

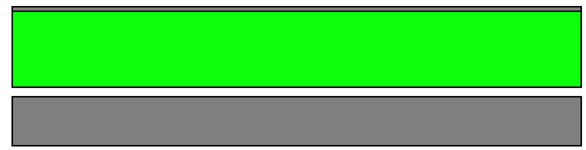


Why Resistive Electrodes?

- In Parallel Plate Avalanche Chambers (Two parallel metal electrodes) sparks lead to the discharge of whole detector (breakdown).
- Can destroy electronics
- Recharging needs time Þ deadtime

Different RPC Types





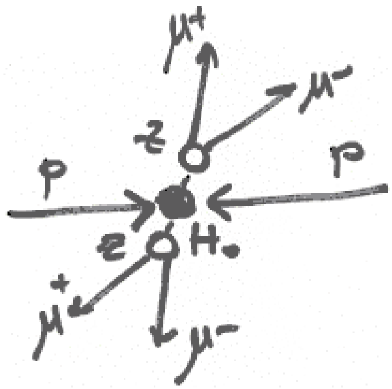
- **Trigger RPCs**
- **Typical values:**
  - **2mm gaps**
  - **2mm bakelite resistive layers,** r » **10^{10}W cm**
  - **$C_2F_4H_2$/Isobutane/SF_6 97/2.5/0.5**
  - **HV » 10kV, E » 50kV/cm**
  - **Typically 2 gap configurations**

- **Timing RPCs**
- **Typical Values:**
  - **0.3mm gas gaps**
  - **Two resistive plates or 1 resistive+1 aluminum**
  - **3mm glass resistive plates,** r » **$2x10^{12}$W cm**
  - **$C_2F_4H_2$/Isobutane/SF_6 85/5/10**
  - **HV » 3(6)kV, E » 100kV/cm**
  - **Typically 4 gap configurations**

Experiments with RPCs: CMS@CERN

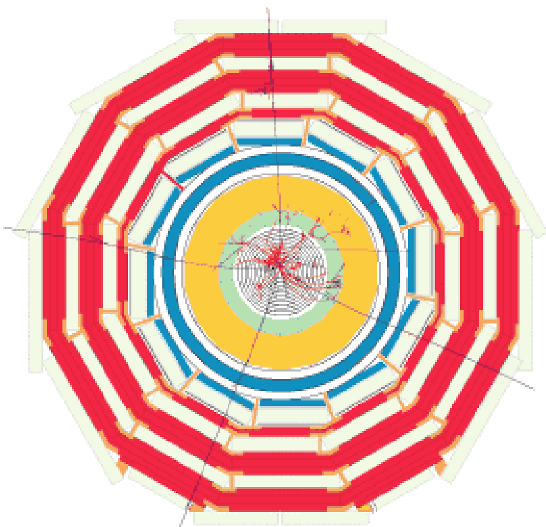
- **CMS (Compact Muon Solenoid)**
- **p-p collisions at 14TeV**
- **Muon Trigger**
- **Area: 3100m^2**

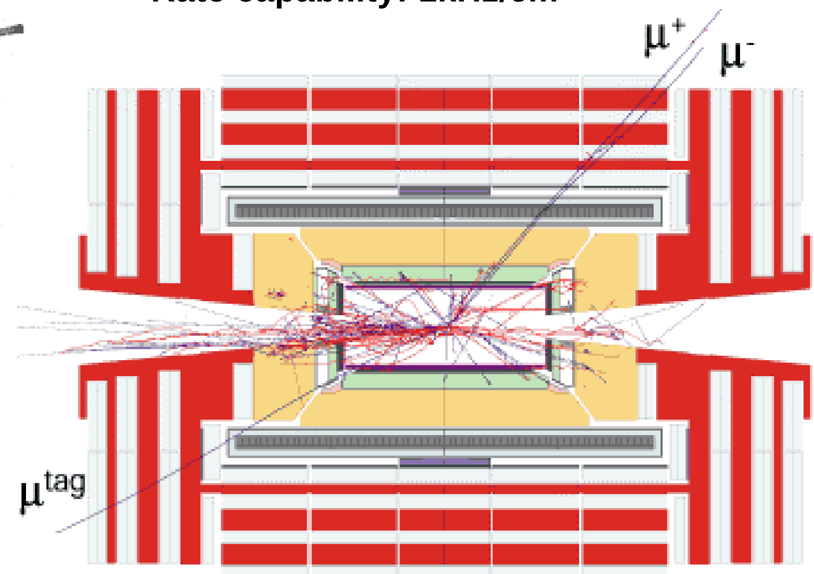
- **They use Trigger RPCs**
  - **Bakelite**
  - **2mm gaps**
  - **E » 50kV/cm**
  - **Gas: Freon + Isobutane**
  - **Time Resolution < 3ns**
  - **Efficiency > 95%**
  - **Rate capability: 1kHz/cm^2**



CMS TDR 3, CERN/LHCC 97-32

http://cmsinfo.cern.ch/

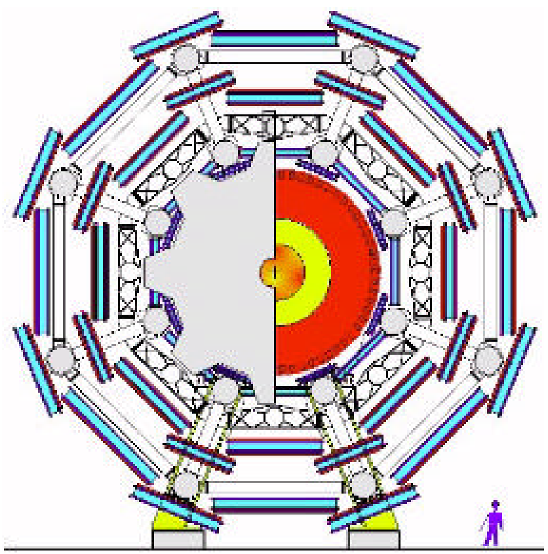




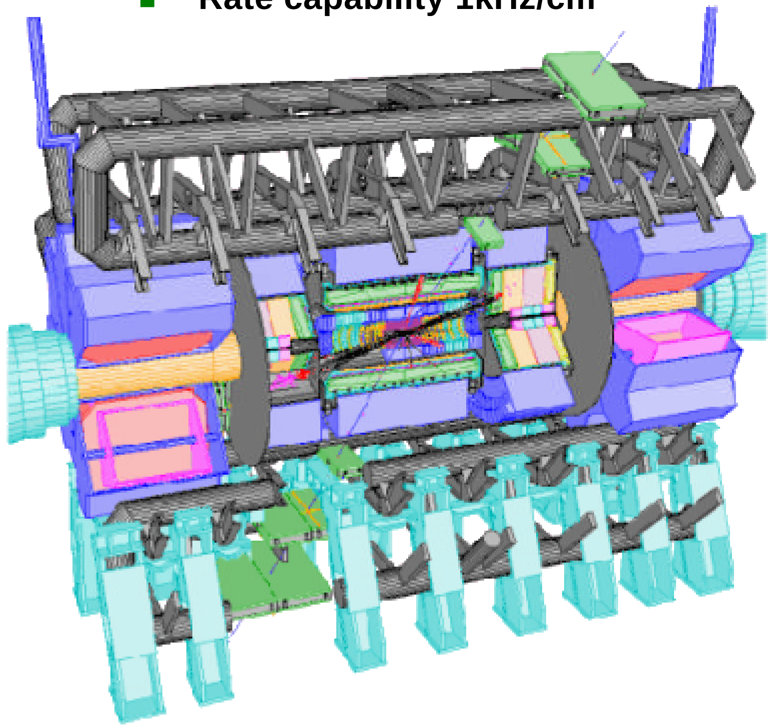
Experiments with RPCs: ATLAS@CERN

- **ATLAS (A Toroidal LHC ApparatuS)**
- **p-p collisions at 14TeV**
- **Muon Trigger**
- **Area: 3650m^2**

ATLAS TDR 10, CERN/LHCC/97-22
http://atlas.web.cern.ch/Atlas/Welcome.html



- **They use Trigger RPCs**
  - **Bakelite**
  - **2mm gaps**
  - **E » 50kV/cm**
  - **Gas: Freon + Isobutane + SF_6**
  - **Time Resolution < 3ns**
  - **Efficiency > 97%**
  - **Rate capability 1kHz/cm^2**

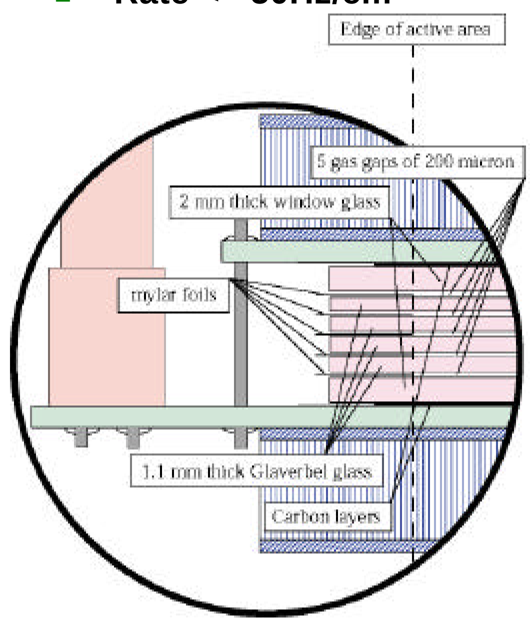


Experiments with RPCs: ALICE@CERN

http://alice.web.cern.ch/Alice/

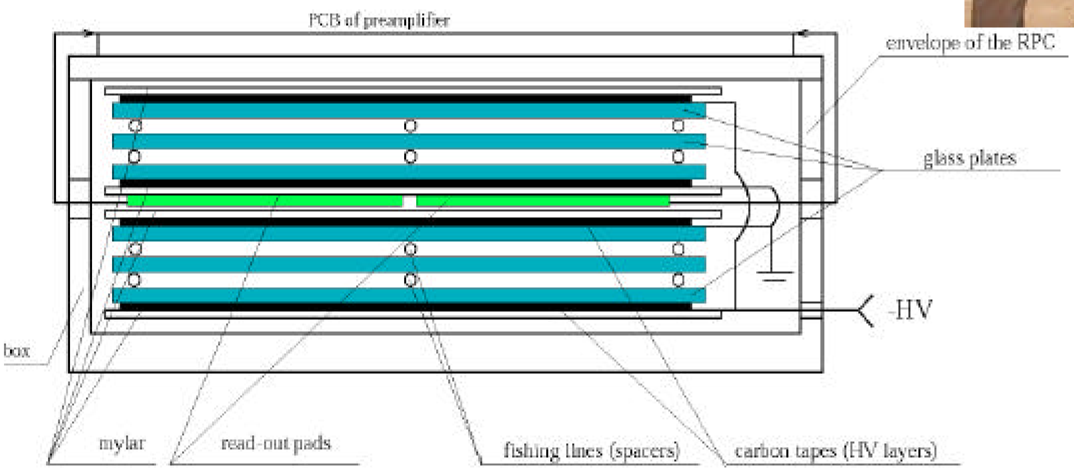
- **MUON Spectrometer:**
  - Dimuon Trigger
  - Area 4 x 36m²
  - 2mm gap Trigger RPCs
  - Bakelite Electrodes
  - *Streamer Mode!*

- **TOF:**
  - Particle ID
  - Area 176m²
  - Multi Gap Timing RPCs
  - Glass Electrodes
  - 2 x 5 x 0.2mm gaps
  - E >= 100kV/cm
  - Efficiency > 98%
  - Time Resolution < 70ps
  - Rate <= 50Hz/cm²



Experiments with RPCs: HARP@CERN

- **HARP (HAdRon Production experiment)**
- **Particle ID (electrons-pions) with RPC TOF**
- **First experiment to actually run with Timing RPCs:**
  - **4 x 0.3mm gaps**
  - **Glass resistive plates 4 x $10^{12}\,\Omega$cm**
  - **E $\approx$ 100kV/cm**
  - **Time Resolution < 100ps**
  - **Efficiency > 98%**



HARP, Proposal for an RPC TOF system, CERN, 2000, http://harp.web.cern.ch/harp/

Detector Physics and Simulation of RPCs

Motivation

- **Why simulate RPCs?**
  - **Quite new Technology:**
    - **Trigger RPC with 2mm gap » 1981**
      NIM 187(1981)377
    - **Timing RPC with thinner gap » 1995**
      A new type of resistive plate chamber: the multigap RPC, CERN/PPE/95-166
    - **Now the first complete model for RPCs**
  - **Open questions:**
    - **Why are RPCs working that well?**
      P. Fonte, High resolution Timing of MIP's with RPCs – a model, NIM A456 (2000) 6-10
    - **Good detection efficiency needs**
      - **Many primary clusters**
      - **Large gain**
    - **Large gain leads to huge charges (exponential multiplication)**
    - **Need huge suppression factor to keep charges small (Space Charge Effect?)**
    - **Can avalanches progress under such strong field distortions?**
    - **Other Effects (Surface electron emission)?**

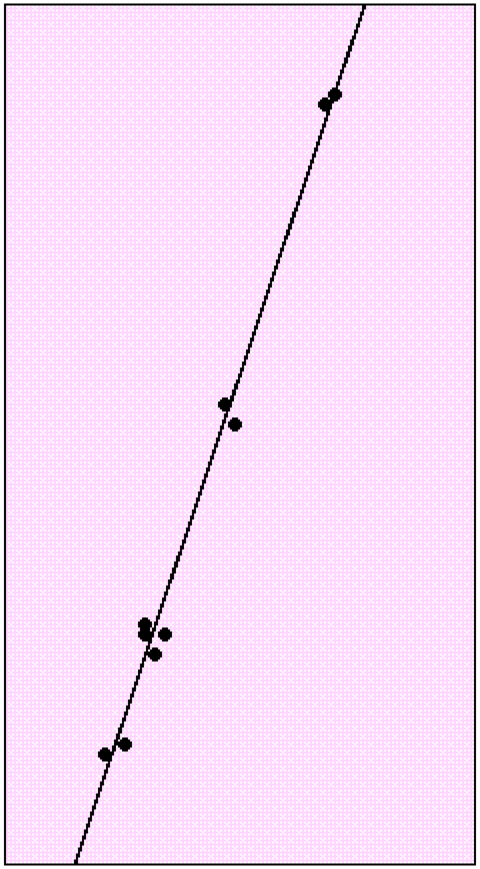
Simulation Input

- **Primary ionization: HEED (Igor Smirnov)**
- **Townsend, attachment coefficient: IMONTE (Steve Biagi)**
- **Diffusion, drift velocity: MAGBOLTZ 2 (Steve Biagi)**
- **Avalanche fluctuations: Werner Legler (1960)**
- **Space Charge Field: CERN-OPEN-2001-074**
- **Frontend electronics + noise: analytic**

Simulation procedure 1, No Space Charge Fields

1. The gas gap is divided into several steps.
2. We assume that the particle tracks are always perpendicular to the detector.
3. The primary clusters are distributed onto the steps.
4. The charges in the gas gap are multiplied and drifted towards the anode.
5. The induced current is calculated.
6. Steps 4 – 5 are repeated until all electrons have left the gas gap.

Primary Ionization



- **Coulomb interactions of charged particles with gas molecules**
- **Mean number of events per cm (HEED):**

Gas	Helium	Argon	Xenon	i-C_4H_{10}
n (events/cm)	4.2	23	44	84

- **Events are Poisson distributed around the mean number n:**

$$P_k^n = \frac{n^k}{k!} e^{\ n}$$

n = average number of events
k = actual number of events

- **Maximum detection efficiency:**

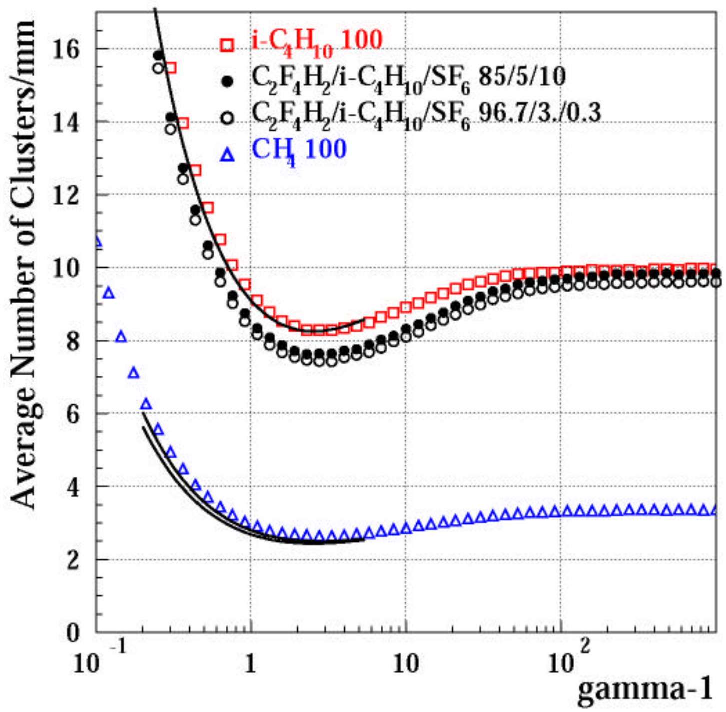
Gas	gap thickness	Eff (%)
Helium	0.3mm	12
	2mm	57
i-C_4H_{10}	0.3mm	92
	2mm	100

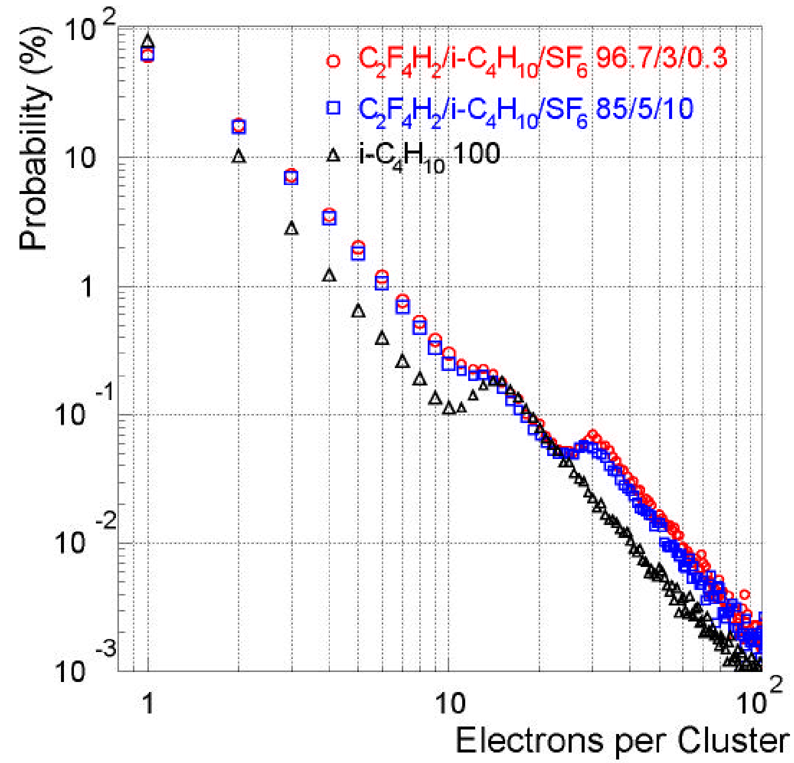
$$\text{Eff} = 1 - e^{-n}$$

- **n (events/cm) is very important for efficiency**

http://consult.cern.ch/writeup/garfield/examples/gas/Welcome.html#stat

Simulation Input: Primary Ionization

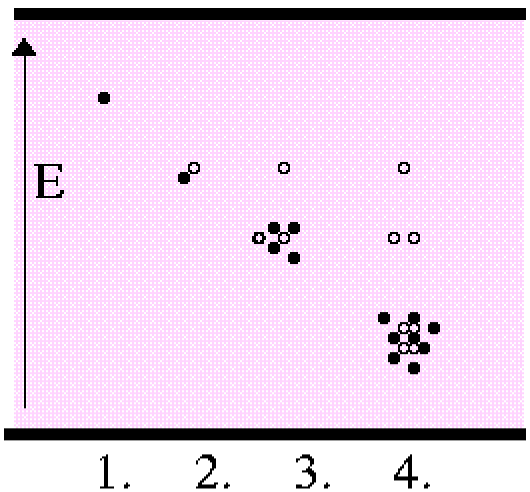




- **HEED data = symbols**
- **Measurements (for iC_4H_{10} and CH_4) = lines**
  F.Rieke et al., Phys.Rev. A6, 1507 (1972)
- **n » 10 Clusters/mm for a 7GeV pion**
- **Mean free path l » 0.1mm**

- **Cluster Size Distribution**
- **Average » 2.45 electrons**
- **Long Tail**

Avalanche Multiplication in an uniform field



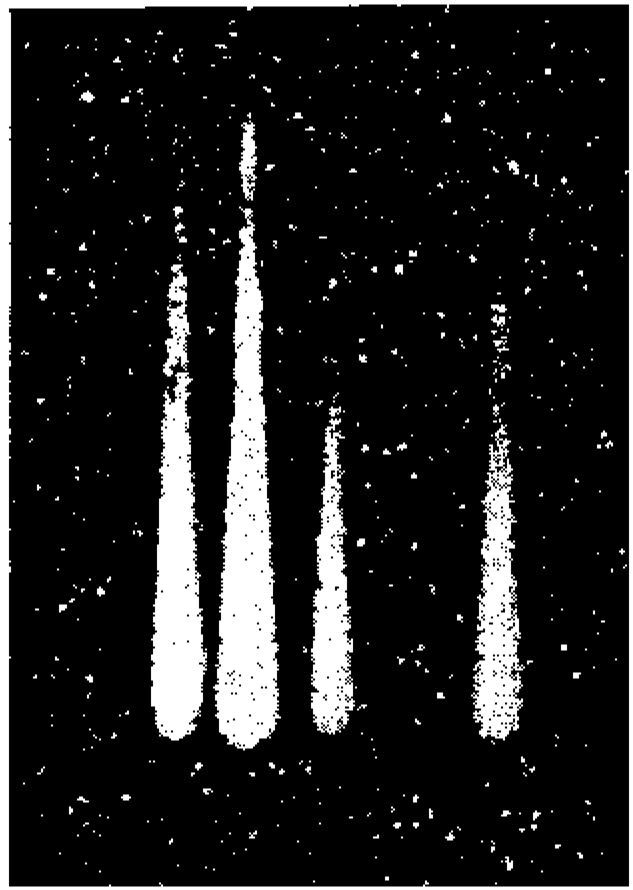
α = Townsend Coefficient
η = Attachment Coefficient

$$dn = [\alpha - \eta]\, n\, dx \quad \Rightarrow \quad \overline{n}(x) = n_0 e^{(\alpha-\eta)x}$$

But: $\alpha = \alpha(E) \qquad \eta = \eta(E)$

E constant? Space Charge Fields?

- **Combined Cloud Chamber – Avalanche Chamber:**



H. Raether, Electron avalanches and breakdown in gases, Butterworth 1964

Simulation Procedure: Avalanche Fluctuations

W. Legler, 1960: Die Statistik der Elektronenlawinen in elektronegativen Gasen bei hohen Feldstaerken und bei grosser Gasverstaerkung

Assumption: ionization probability independent of the last collision

$$\frac{dP(n,x)}{dx} = -P(n,x)n(\alpha+\eta) + P(n-1,x)(n-1)\alpha + P(n+1,x)(n+1)\eta$$

General solution:

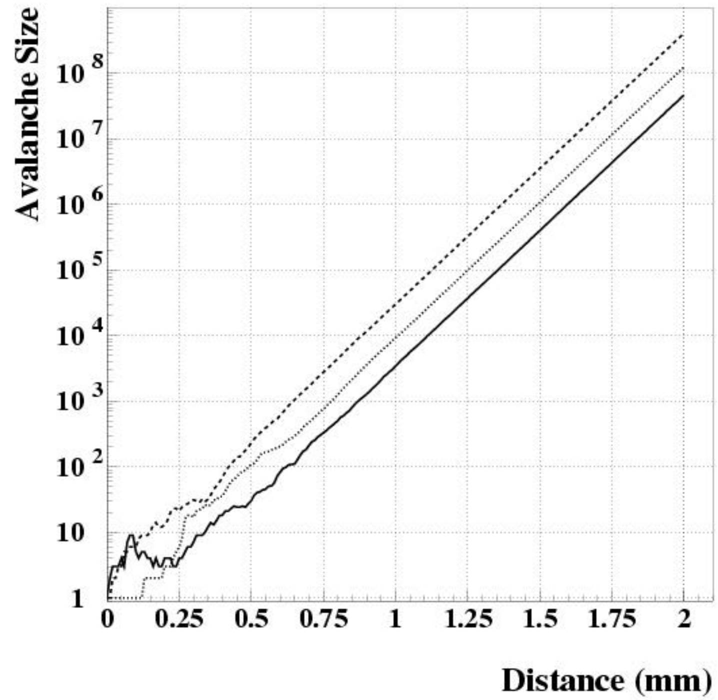
$$\overline{n}(x) = e^{(\alpha-\eta)x} \qquad k = \frac{\eta}{\alpha}$$

$$P(n,x) = k\frac{\overline{n}(x)-1}{\overline{n}(x)-k} \qquad n=0$$

$$= \overline{n}(x)\left(\frac{1-k}{\overline{n}(x)-k}\right)^2\left(\frac{\overline{n}(x)-1}{\overline{n}(x)-k}\right)^{n-1} \qquad n>0$$

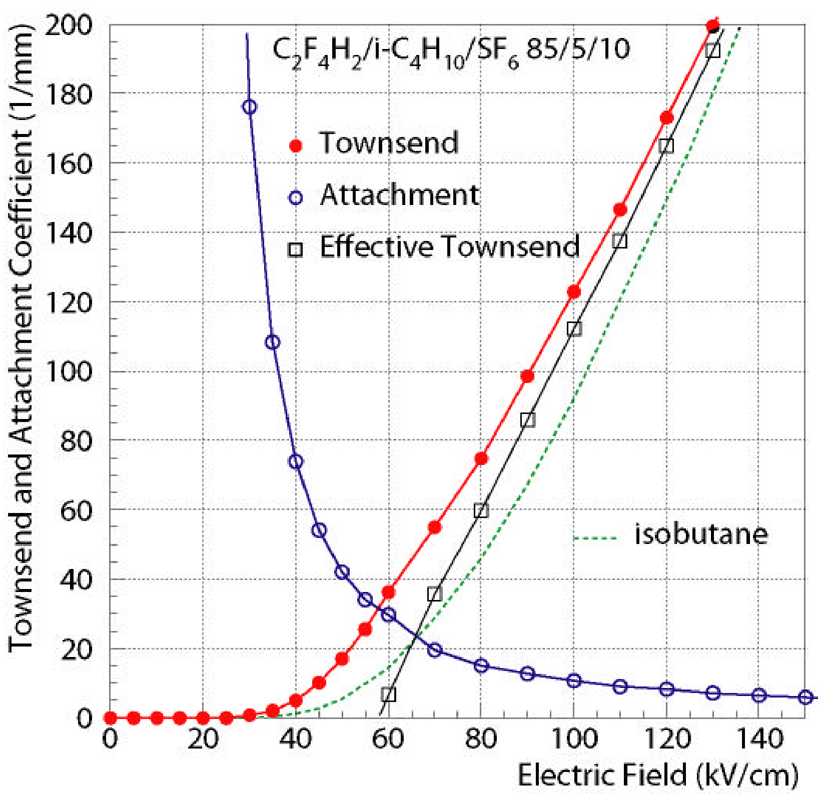
Variance:

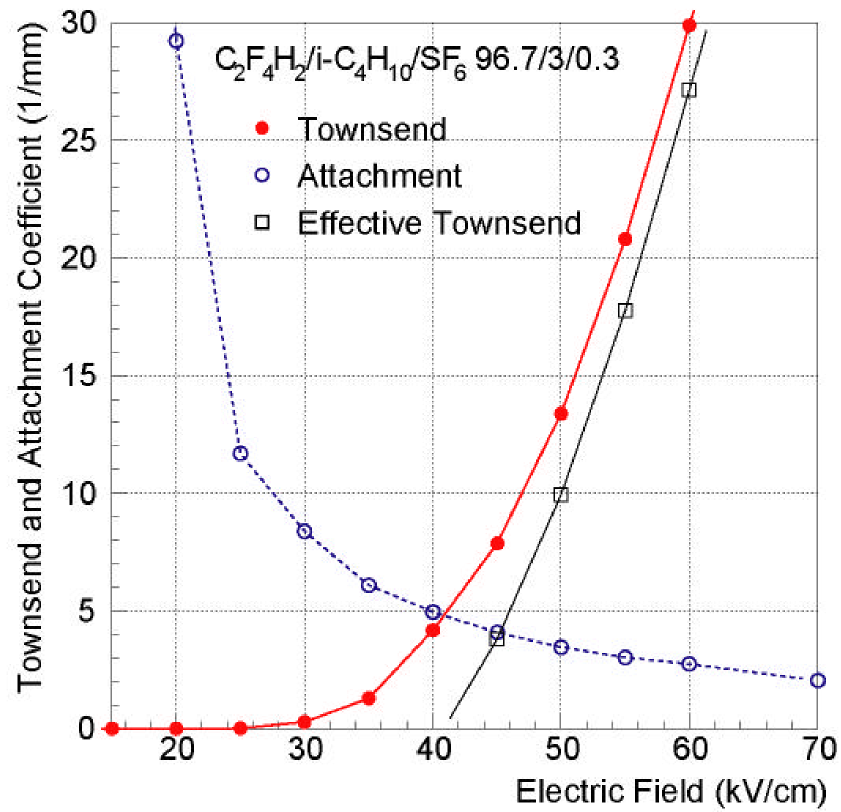
$$\sigma^2(x) = \left(\frac{1+k}{1-k}\right)\overline{n}(x)\left(\overline{n}(x)-1\right)$$



Avalanches started by a single electron

Simulation Input: Gas Parameters (IMONTE)

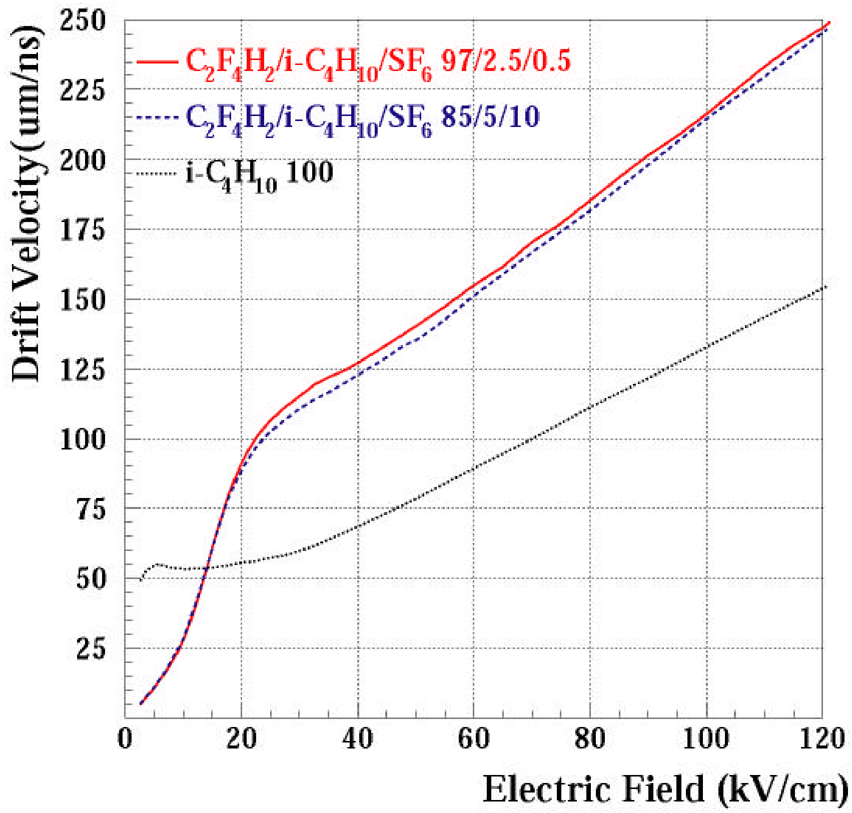




- **Effective Townsend Coefficients:**
  - **Timing RPC** » **110/mm**

- **Effective Townsend Coefficients:**
  - **Trigger RPC** » **10/mm**

Simulation Input: Drift Velocity (MAGBOLTZ)



- **Drift Velocities:**
  - **Trigger RPC » 130 mm/ns, T » 15ns**
  - **Timing RPC » 220 mm/ns, T » 1.4ns**

Simulation Procedure: The Signal Induction

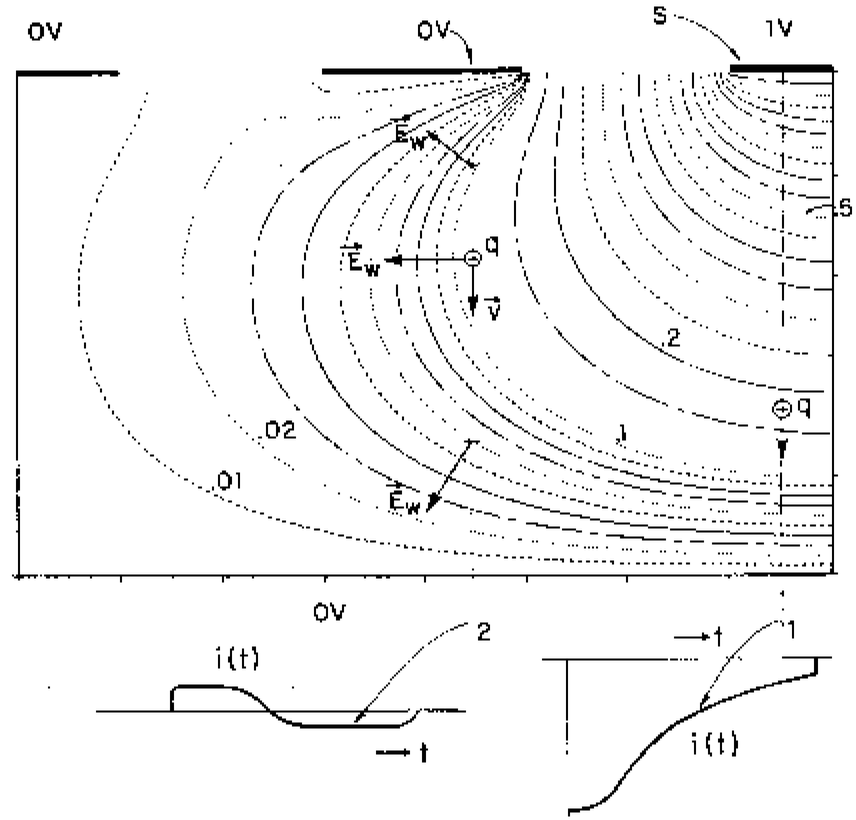
- **We use the Weighting Field Formalism:**
- **Induced current:**

$$i(t) = \vec{E}_W \cdot \vec{v}(t)\; q\; N(t)$$

$\vec{E}_w$ is the normalised weighting Field and

$N(t)$ is the number of charge carriers moving with velocity $\vec{v}(t)$

- **The weighting field is the electric field in the gas gap if we put the one read out strip on 1V and ground all other electrodes.**
- **Has nothing to do with the electric field!**

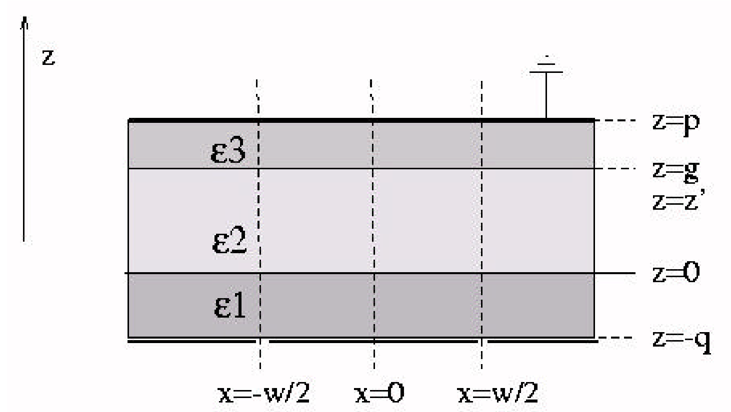


S. Ramo, Currents induced in electron motion, PROC. IRE 27 (1939), 584

W. Riegler, Induced signals in Resistive Plate Chambers, CERN-EP-2002-024

Simulation Input: The Weighting Field

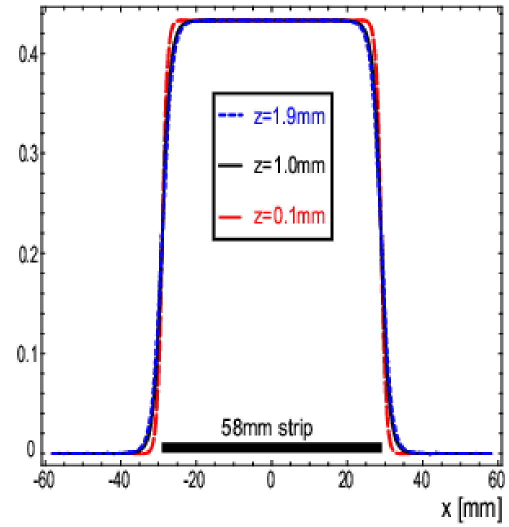
- **Analytic expression for the weighting field (z-component) of a strip electrode**
- **Allows calculation of induced signals and crosstalk in 3 layer RPC geometries**



$$E_z(x,z) = V_1\,\varepsilon_1\,\frac{2}{\pi}\int_0^\infty d\kappa\ \cos(\kappa\ x)\ \sin(\kappa\ \frac{w}{2})\ F_2(\kappa,z)$$

with

$$F_2(\kappa,z) = -\frac{2}{D(\kappa)}[(\varepsilon_2+\varepsilon_3)\left(e^{-\kappa(q+z)} + e^{-\kappa(2p+q-z)}\right) - (\varepsilon_2-\varepsilon_3)\left(e^{-\kappa(q+2g-z)} + e^{-\kappa(2p+q-2g+z)}\right)]$$



T.Heubrandtner, B.Schnizer, C.Lippmann and W.Riegler, Static electric fields in an infinite plane condenser with one or three homogeneous layers, NIM A489 (2002) 439-443

Efficiency, Analytic Formula

- **An order of magnitude formula for the efficiency of single gap RPCs:**

$$Eff = 1 - e^{-\frac{d}{\lambda}(1-\frac{\eta}{\alpha})}\left[1 + \frac{Q_t(\alpha-\eta)}{E_W\, e_0}\right]^{\frac{1}{\alpha\lambda}}$$

d = gapwidth
λ = mean free path
Q_t = charge threshold
α = Townsend Coefficient
η = Attachment Coefficient

- **Only the first cluster (1 electron) taken into account**

W. Riegler, R. Veenhof and C. Lippmann, Detector physics and Simulation of resistive plate chambers, CERN-EP-2002-046, submitted to NIM

- **Efficiency depends not only on the effective Townsend coefficient but also on** h

- **No attachment, zero threshold:**

$$\eta = Q_t = 0 \quad \Longrightarrow$$

$$Eff = 1 - e^{-\frac{d}{\lambda}}$$

$e^{-\frac{d}{\lambda}}$ is the probability to find no cluster in the gap

Time Resolution, Analytic Formula

- **An order of magnitude formula for the time resolution of single gap RPCs:**

$$\sigma_t = \frac{1.28}{(\alpha - \eta) v_D}$$

v_D = Drift Velocity
α = Townsend Coefficient
η = Attachment Coefficient

A.Mangiarotti, A.Gobbi, On the physical origin of tails in the time response function of spark counters, NIM A482(2002), 192-215

W. Riegler, R. Veenhof and C. Lippmann, Detector physics and simulation of resistive plate chambers, CERN-EP-2002-046, Subm. to NIM

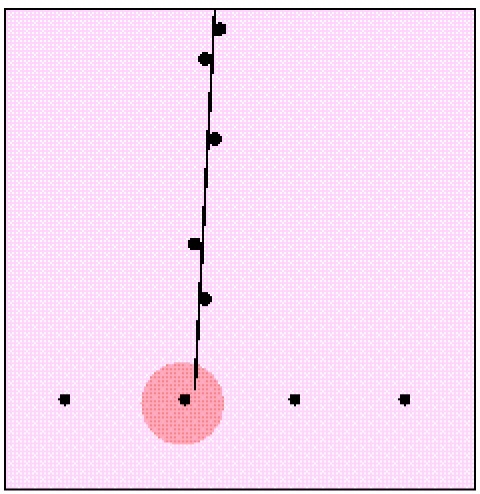
Reminder: Time Resolution of Wire Chambers

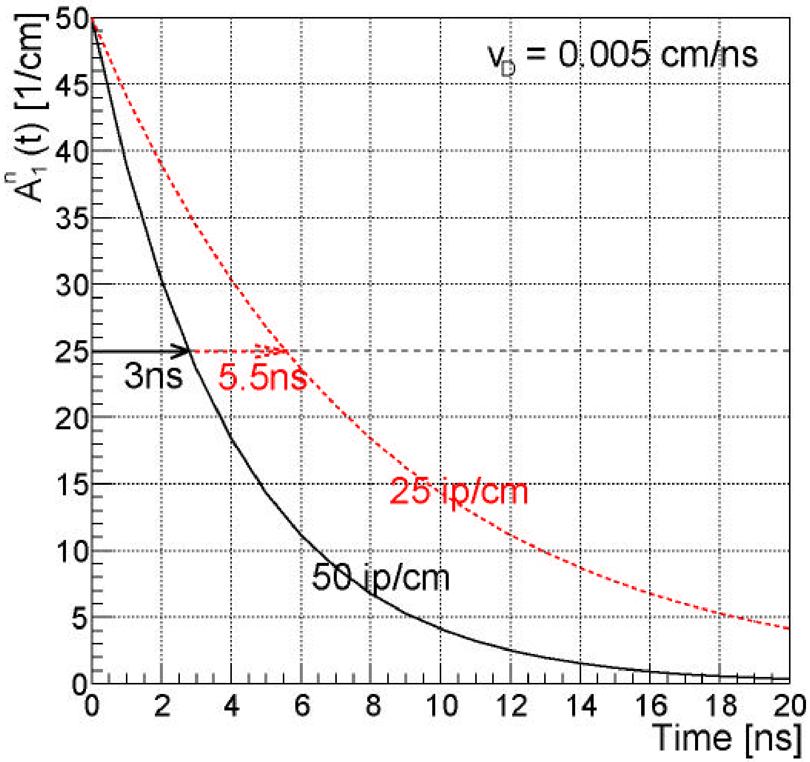
- **Limited time resolution of Wire and Micropattern Chambers (GEM, …)**
- **Space distribution of the cluster closest to anode:**
  - **Exponential distribution**

$$A_1^n(x) = ne^{-nx}$$

- **Time distribution of that cluster:**

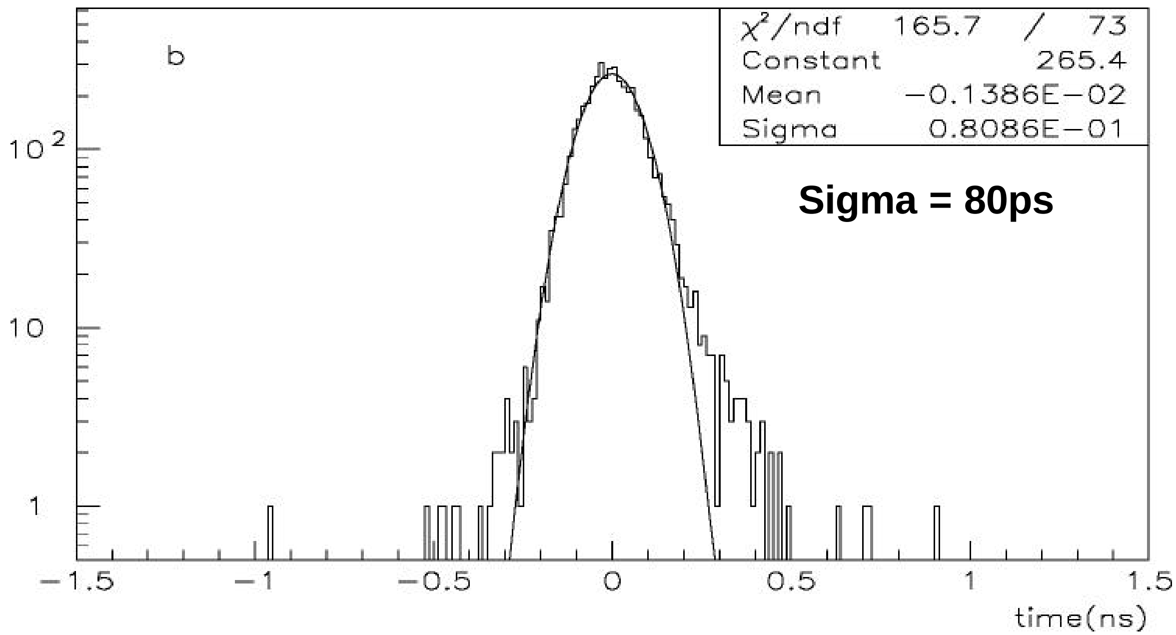
$$A_1^n(t) = ne^{-nv_D t}$$





Time Resolution of RPCs

- Compared to Wire Chambers RPCs reach much better time resolutions because the avalanche growth starts instantly
- Fast Signal Induction during avalanche development



V. Ammosov et al, Four-gap glass RPC as a candidate to a large area thin time-of-flight detector, CERN, 2002, http://harp.web.cern.ch/harp/

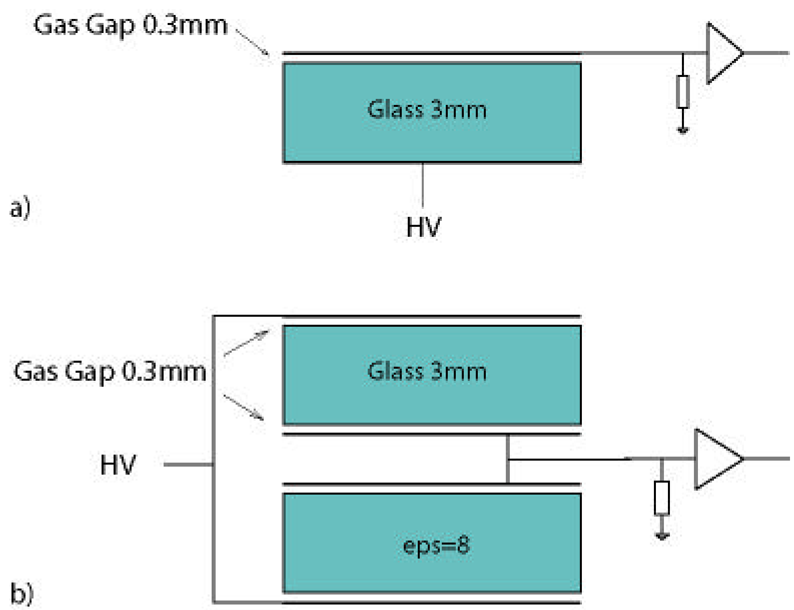
Efficiency and Time Resolution; Simulation Results

Reminder: Simulation Procedure, One dimensional Simulation

1. The gas gap is divided into several steps.
2. The primary clusters are distributed onto the steps.
3. The charges in the gas gap are multiplied and drifted towards the anode.
4. The induced current is calculated.
5. Steps 3 – 4 are repeated until all electrons have left the gas gap.

- No Diffusion
- No Space Charge Effect
- No Photons

Simulation of Timing RPCs



- **We simulate Timing RPCs in one and four gap configurations as in:**

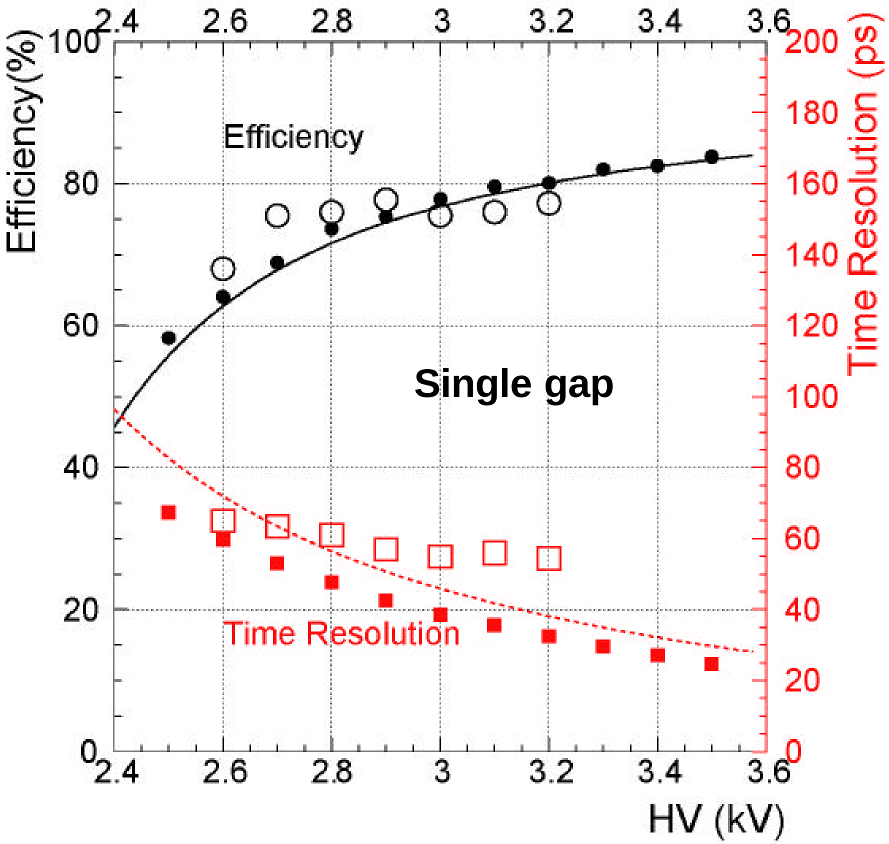
  P. Fonte et. al., NIM A449 (2000) 295-301

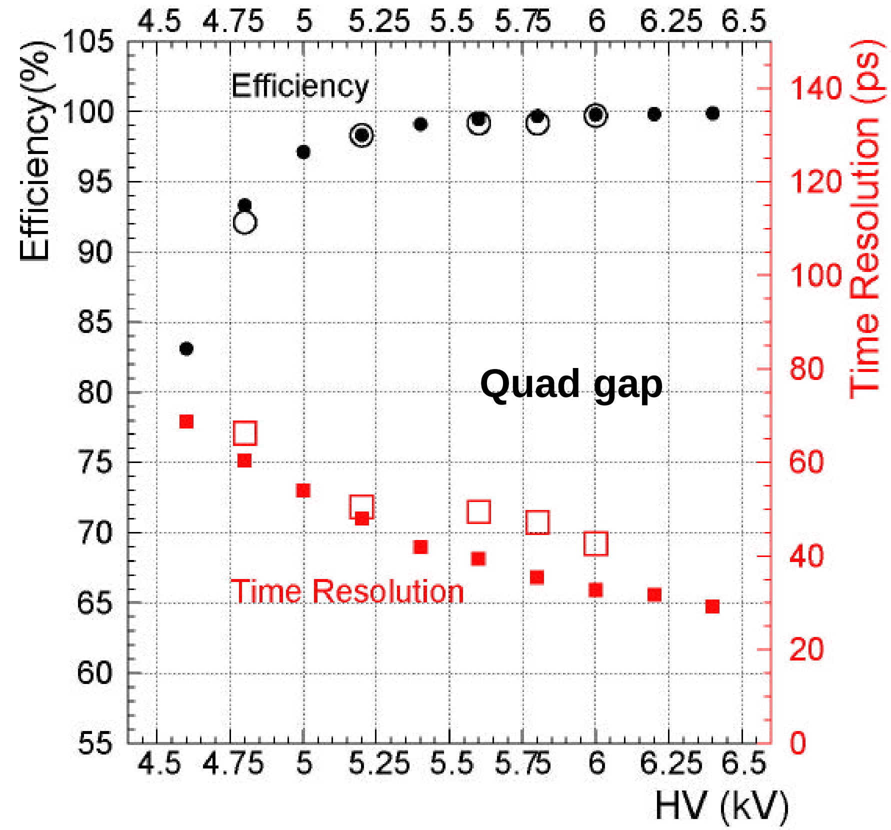
  A. Akindinov, P. Fonte et. al., CERN-EP 99-166

  P. Fonte and V. Peskov, preprint LIP/00-04

- **0.3 mm gap(s); glass resistive plates (e=8, r=2x10^{12} Wcm)**
- **$C_2F_4H_2$ / i-C_4H_{10} / SF_6 (85/5/10)**
- **HV: 3(6)kV, E: 100kV/cm**

Efficiency and Time Resolution



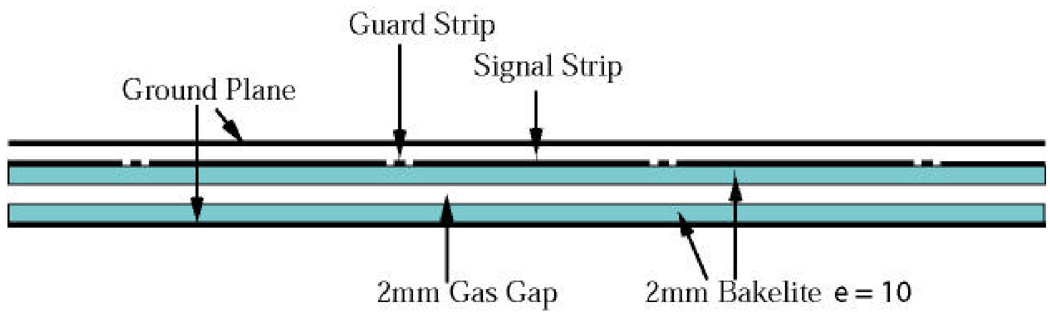


- Open symbols: measurement
- Filled symbols: simulations
- Lines: analytic formula

- 7GeV pions,
- 9.13 clusters/mm
- 20fC threshold
- 200ps amplifier peaking time

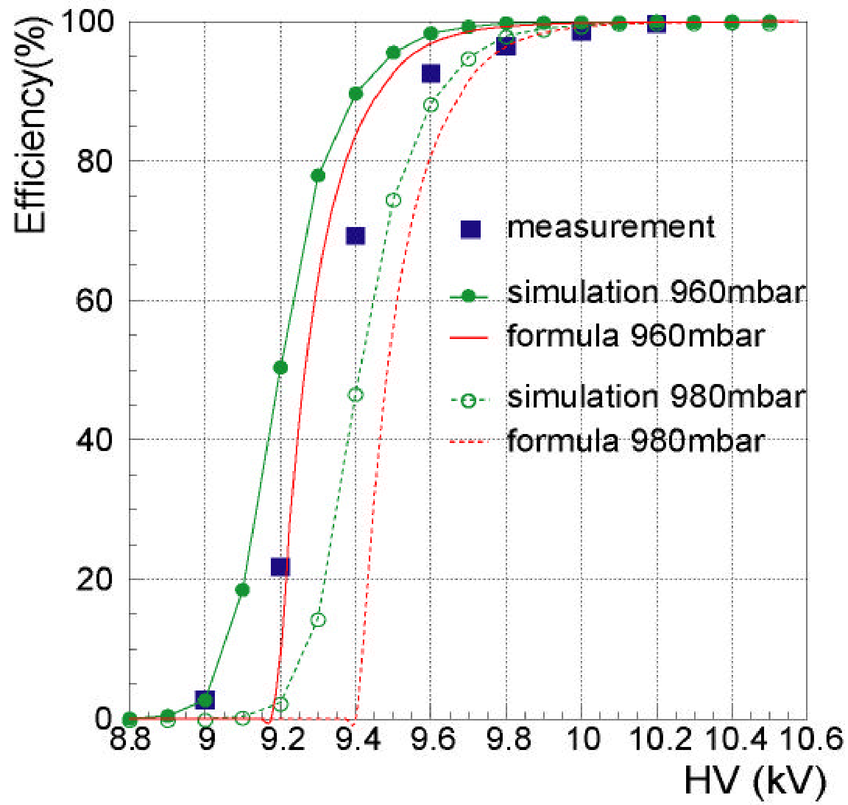
- 1fC noise
- T=296.15K
- p=970mb

Simulation of Trigger RPCs



- Single gap Trigger RPCs
- 2mm gaps
- Like ATLAS, CMS RPCs
  - 120GeV muons,
  - 9.64 clusters/mm,
  - 100fC threshold
  - Amplifier peaking time 1.3ns

- Formula different from Monte Carlo because it uses only first cluster. Here many clusters are important.



Average Charges

0.3mmTiming RPC 3kV

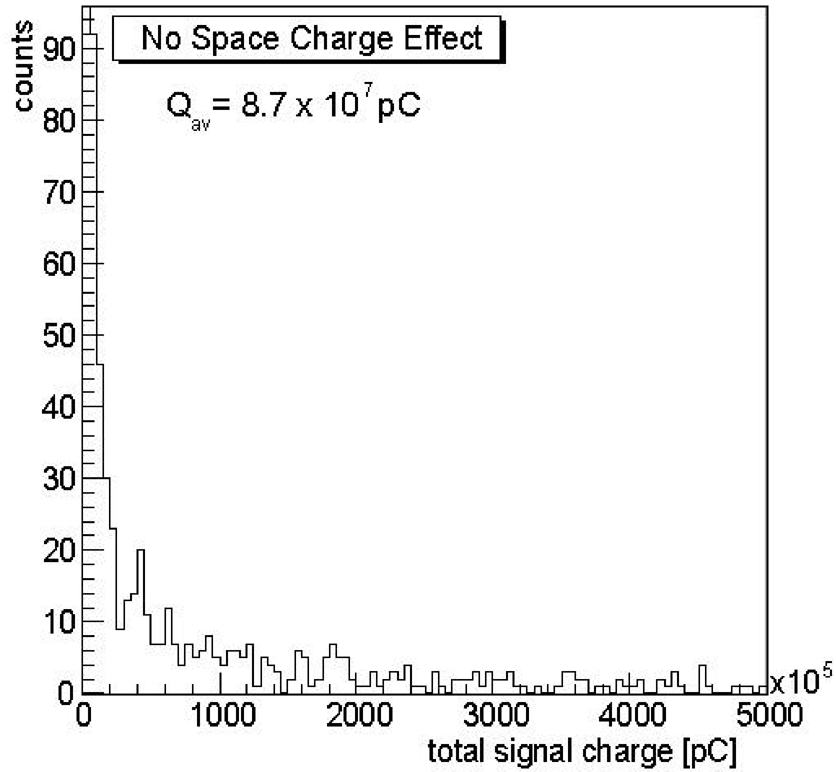
	Simulated	Measured
• Q_{tot} =	$4.6 \cdot 10^{7}$pC	5 pC
• Q_{ind} =	$3.8 \cdot 10^{5}$pC	0.5 pC

2mm Trigger RPC 10kV

	Simulated	Measured
• Q_{tot} =	$2.2 \cdot 10^{3}$pC	40 pC
• Q_{ind} =	$1.0 \cdot 10^{2}$pC	2 pC

$$\overline{Q}_{tot} \approx \frac{e_0 n_{av} \alpha}{\lambda(\alpha-\eta)^2} e^{(\alpha-\eta)d}$$

$$\overline{Q}_{ind} = \frac{E_w}{V_w}\frac{\overline{Q}_{tot}}{\alpha} \approx \frac{E_w}{V_w}\frac{n_{av} e_0}{\lambda(\alpha-\eta)^2} e^{(\alpha-\eta)d}$$



One can show mathematically that with previous assumptions there cannot be a peak in the charge distribution (for the parameters and models described so far).

Measurements show very pronounced peak! Saturation effects!

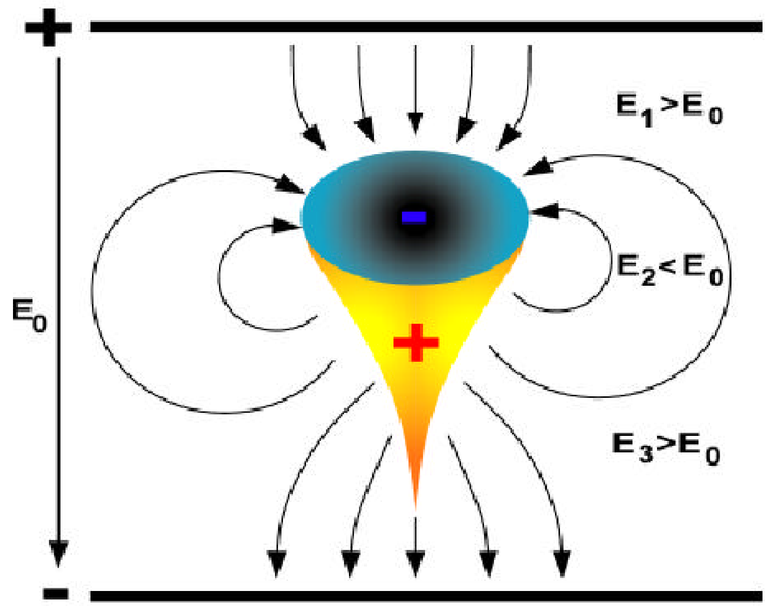
Include Space Charge Fields in the Simulation

Simulation Procedure 2; Space Charge Fields Included

1. The gas gap is divided into several steps.
2. The primary clusters are distributed onto the steps.
3. The electric field of the space charge is calculated and added to the applied external field. This is where the transversal diffusion enters.
4. The Townsend and attachment coefficients and the drift velocity at each step is calculated.
5. The charges in the gas gap are multiplied and drifted towards the anode.
6. We also include longitudinal diffusion. The charges are redistributed onto the steps.
7. The induced current is calculated.
8. Steps 3 – 7 are repeated until all electrons have left the gas gap.

- No photons

Space Charge Effect



How to calculate the Space Charge Field?

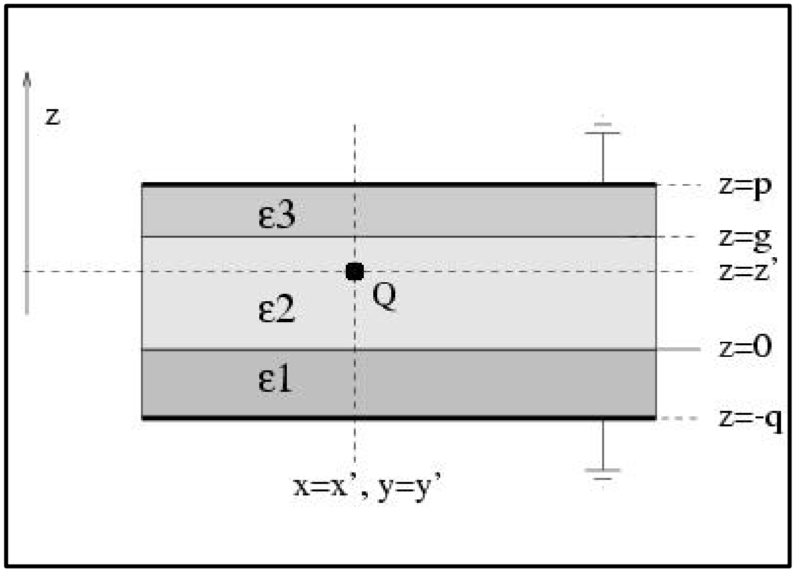
How to Calculate the Space Charge Field?

We need an analytic Formula for the potential of a point charge in a three layer geometry like an RPC:

T.Heubrandtner, B.Schnizer, C.Lippmann and W.Riegler, Static electric fields in an infinite plane condenser with one or three homogeneous layers, NIM A489 (2002) 439-443

- **Geometry:**
  - **Cylindrical coordinates**
  - **x, y, z, r, f = coordinates of point of observation**
  - **x', y', z', r', f' = coordinates of charge**
  - **p, g, q define thickness of layers**

$$
\begin{aligned}
R^2 &= |\vec{r} - \vec{r}\,'|^2 = \\
&= (x - x')^2 + (y - y')^2 + (z - z')^2 \\
&= \rho^2 - 2\rho\rho' \cos(\phi - \phi') + \rho'^2 + (z - z')^2 \\
&= P^2 + (z - z')^2
\end{aligned}
$$



Static Electric Fields in an Infinite Plane Condenser with Three Homogeneous Layers

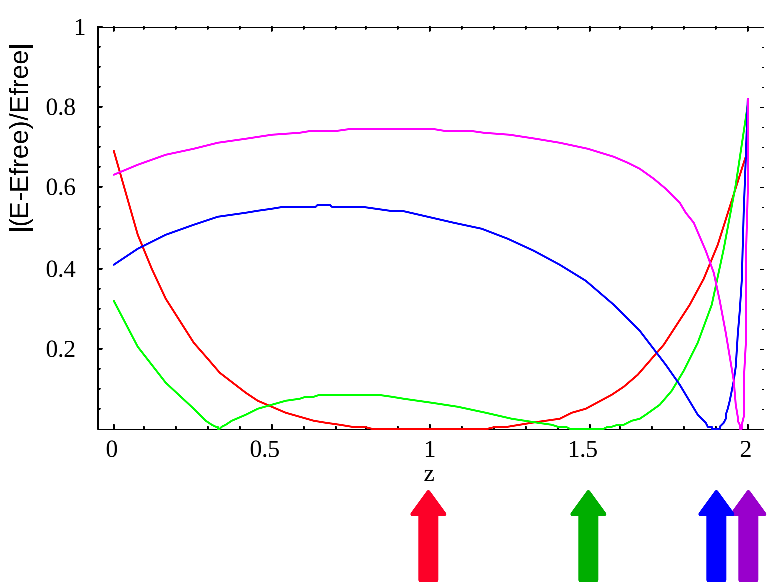
$$
\begin{aligned}
\Phi(\rho,\phi,z) \;=\; & \frac{Q}{4\pi\varepsilon_2}\Big[\frac{1}{\sqrt{P^2+(z-z')^2}} + \frac{(\varepsilon_2-\varepsilon_3)}{(\varepsilon_2+\varepsilon_3)\sqrt{P^2+(2g-z-z')^2}} - \frac{(\varepsilon_1-\varepsilon_2)}{(\varepsilon_1+\varepsilon_2)\sqrt{P^2+(z+z')^2}} \\
& + \frac{1}{(\varepsilon_1+\varepsilon_2)(\varepsilon_2+\varepsilon_3)} \int_0^\infty d\kappa \; J_0(\kappa P)\, \frac{R(\tau,z,z')}{D(\kappa)}\Big], \qquad 0 \le z \le g
\end{aligned}
$$

$$
\begin{aligned}
D(\kappa) \;=\; & (\varepsilon_1+\varepsilon_2)(\varepsilon_2+\varepsilon_3)\,(1-e^{-2\kappa\,(p+q)}) - (\varepsilon_1-\varepsilon_2)(\varepsilon_2+\varepsilon_3)(e^{-2\kappa p}-e^{-2\kappa q}) \\
& - (\varepsilon_1+\varepsilon_2)(\varepsilon_2-\varepsilon_3)(e^{-2\kappa\,(p-g)}-e^{-2\kappa\,(q+g)}) + (\varepsilon_1-\varepsilon_2)(\varepsilon_2-\varepsilon_3)(e^{-2\kappa g}-e^{-2\kappa\,(p+q-g)})
\end{aligned}
$$

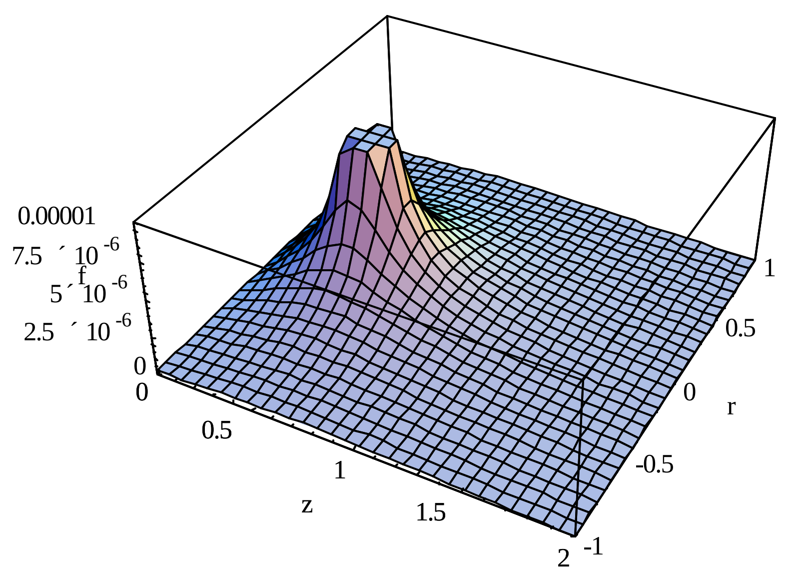
$$
\begin{aligned}
R(\kappa;z,z') \;=\; & (\varepsilon_1+\varepsilon_2)^2(\varepsilon_2+\varepsilon_3)^2\,\left[e^{\kappa(-2p-2q+z-z')} + e^{\kappa(-2p-2q-z+z')}\right] \\
& -(\varepsilon_1+\varepsilon_2)^2\,(\varepsilon_2-\varepsilon_3)^2\,e^{\kappa(-4g-2q+z+z')} - 4\varepsilon_1\varepsilon_2(\varepsilon_2+\varepsilon_3)^2\,e^{\kappa(-2q-z-z')} \\
& -(\varepsilon_1-\varepsilon_2)^2\,(\varepsilon_2+\varepsilon_3)^2\,e^{\kappa(-2p-z-z')} - \left({\varepsilon_1}^2-{\varepsilon_2}^2\right)(\varepsilon_2-\varepsilon_3)^2\,e^{\kappa(-4g+z+z')} \\
& + \left({\varepsilon_1}^2-{\varepsilon_2}^2\right)(\varepsilon_2+\varepsilon_3)^2\,\left[-e^{\kappa(-2p-2q-z-z')} + e^{\kappa(-2p+z-z')} + e^{\kappa(-2p-z+z')}\right] \\
& -4\,\left({\varepsilon_1}^2-{\varepsilon_2}^2\right)\,\varepsilon_2\varepsilon_3\,e^{\kappa(-2p-2q+z+z')} - 4\,(\varepsilon_1+\varepsilon_2)^2\varepsilon_2\varepsilon_3\,e^{\kappa(-2p+z+z')} \\
& +(\varepsilon_1-\varepsilon_2)^2\left({\varepsilon_2}^2-{\varepsilon_3}^2\right)\,e^{\kappa(-2g-z-z')} + 4\,\varepsilon_1\varepsilon_2\left({\varepsilon_2}^2-{\varepsilon_3}^2\right)\,e^{\kappa(2g-2p-2q-z-z')} \\
& +(\varepsilon_1+\varepsilon_2)^2\left({\varepsilon_2}^2-{\varepsilon_3}^2\right)[-e^{\kappa(-2g-2q+z-z')} - e^{\kappa(-2g-2q-z+z')} + e^{\kappa(-2g-2p-2q+z+z')}] \\
& +\left({\varepsilon_1}^2-{\varepsilon_2}^2\right)\left({\varepsilon_2}^2-{\varepsilon_3}^2\right)[e^{\kappa(-2g-2q-z-z')} - e^{\kappa(-2g+z-z')} - e^{\kappa(-2g-z+z')} + e^{\kappa(-2g-2p+z+z')}]
\end{aligned}
$$

Static Electric Fields in an Infinite Plane Condenser with Three Homogeneous Layers

- **Close to the resistive plates, the deviation from the solution of a free point charge becomes important**
- **$(E_{all}-E_{free})/E_{free}$:**

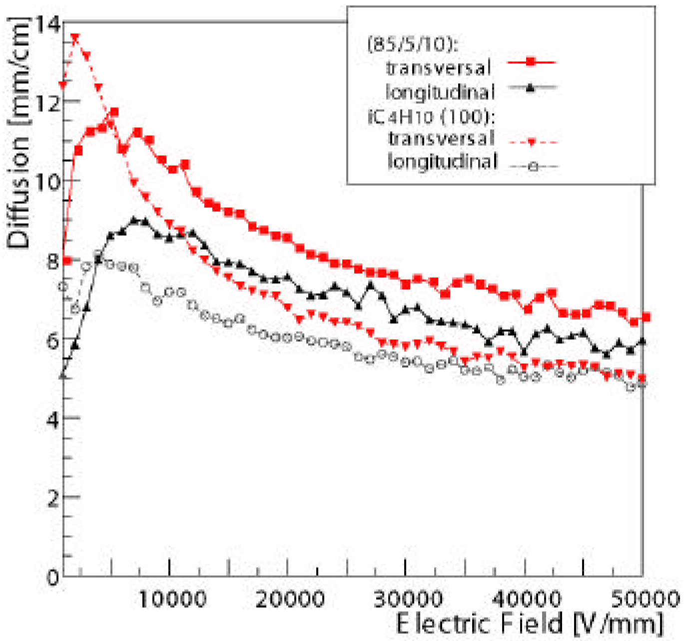


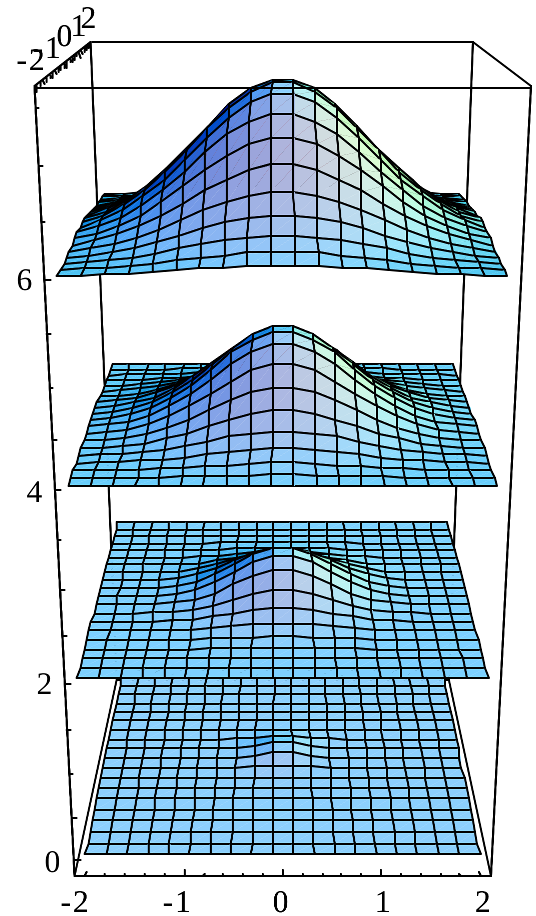
potential



2mm gap

Simulation Input: Diffusion (MAGBOLTZ)





$$\frac{dN(z)}{N} = \frac{1}{\sqrt{2\pi l}\; D_L} \exp\left(-\frac{(z-z_0)^2}{2D_L^2 l}\right) dz$$

$$\sigma_{L,T} = D_{L,T}\sqrt{l}$$

$$\frac{dN(r)}{N} = \frac{1}{2\pi D_T^2 l} \exp\left(-\frac{(r-r_0)^2}{2D_T^2 l}\right) r\, dr$$

The charge distribution in the gap

- **Put charge in gaussian** $\varphi(\rho', \sigma, z')$ **:**

$$\sigma = D_T \sqrt{z' - z''}$$

z'' = spot of formation of primary cluster

$$E_z(\rho, \phi, \sigma, z, z') =$$
$$\int_0^{2\pi} \int_0^{\infty} \varphi(\rho', \sigma, z') \frac{-\partial \Phi(\rho, \phi, z, \rho', z')}{\partial z} \; \rho' \; \partial \rho' \partial \phi'$$

- **Field at spot z:**

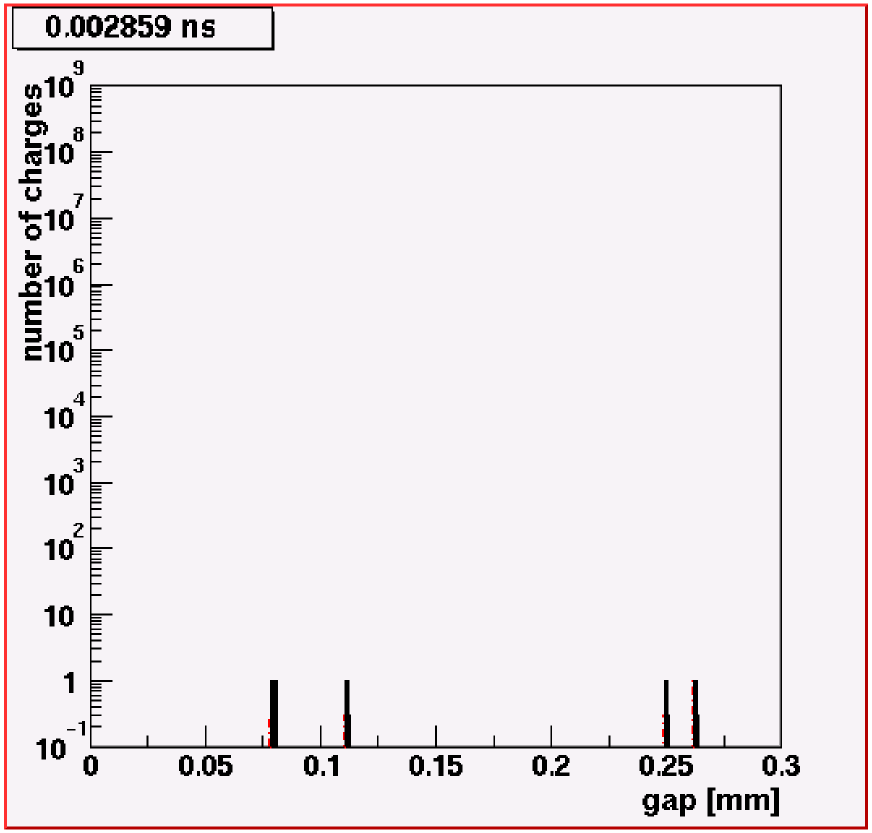
$$E_z(z) = E_0 + \int_0^{gapwidth} q(z') \; E_z(\rho, \phi, z, z') \partial z'$$
$$\simeq E_0 + \sum_{i=0}^{Steps} q_i \; E_z(z, z_i', z_i'')$$

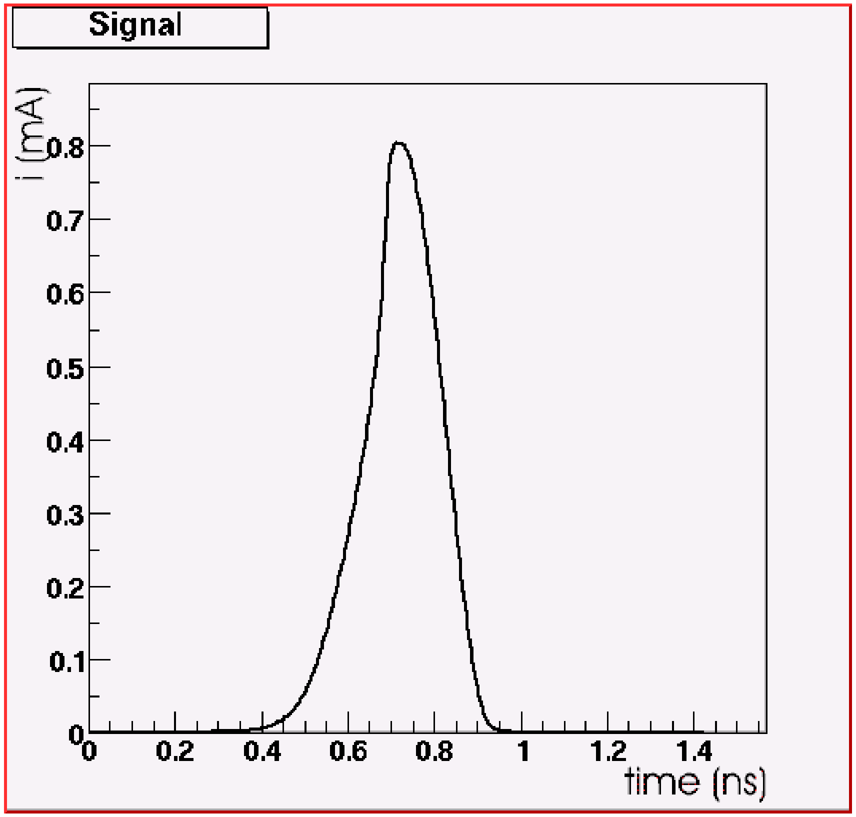
$\rho = \phi = 0$ $\qquad$ q = charge at z'

One dimensional Simulation

Example Avalanche, 1 dimensional

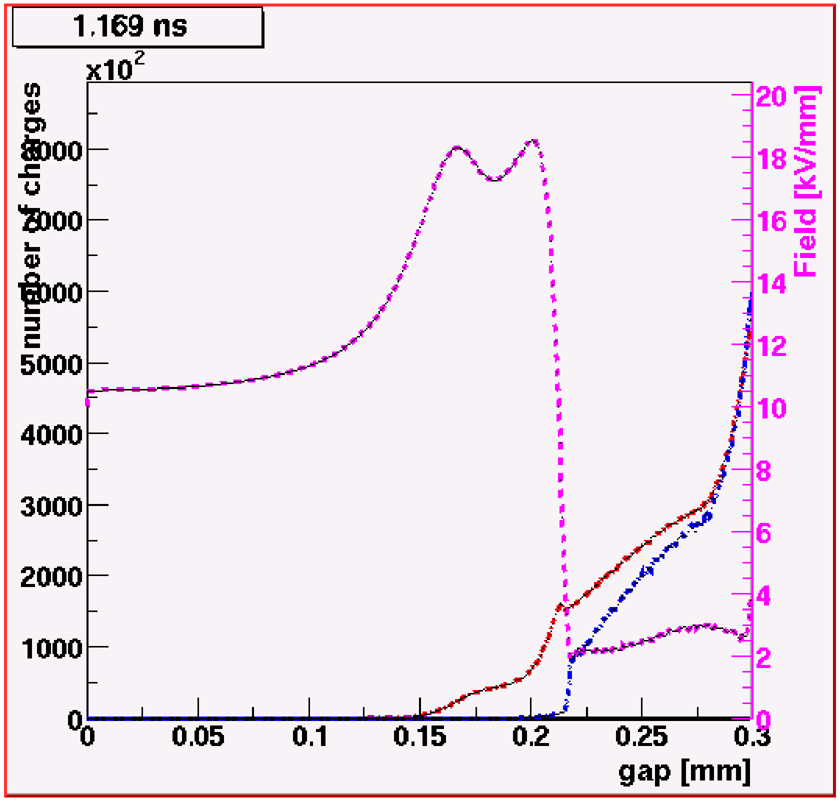
- Electrons, pos. Ions, neg. Ions
- 500 steps, 3kV, 0.3mm gap, T=296.15K, p=970mb
- Logarithmic scale!

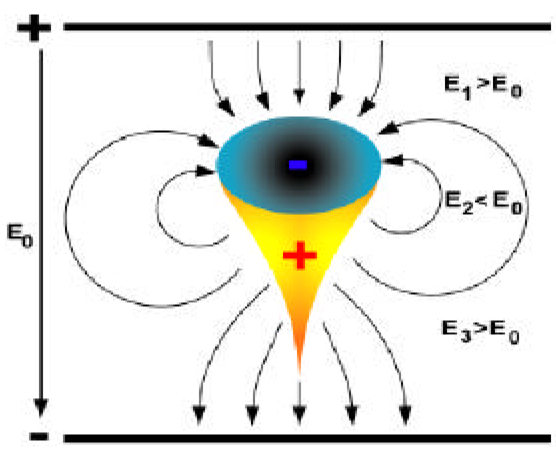




Example Avalanche; Field Distortions

- Electrons, pos. Ions, neg. Ions
- 500 steps, 3kV, 0.3mm gap, T=296.15K, p=970mb
- Linear Scale!

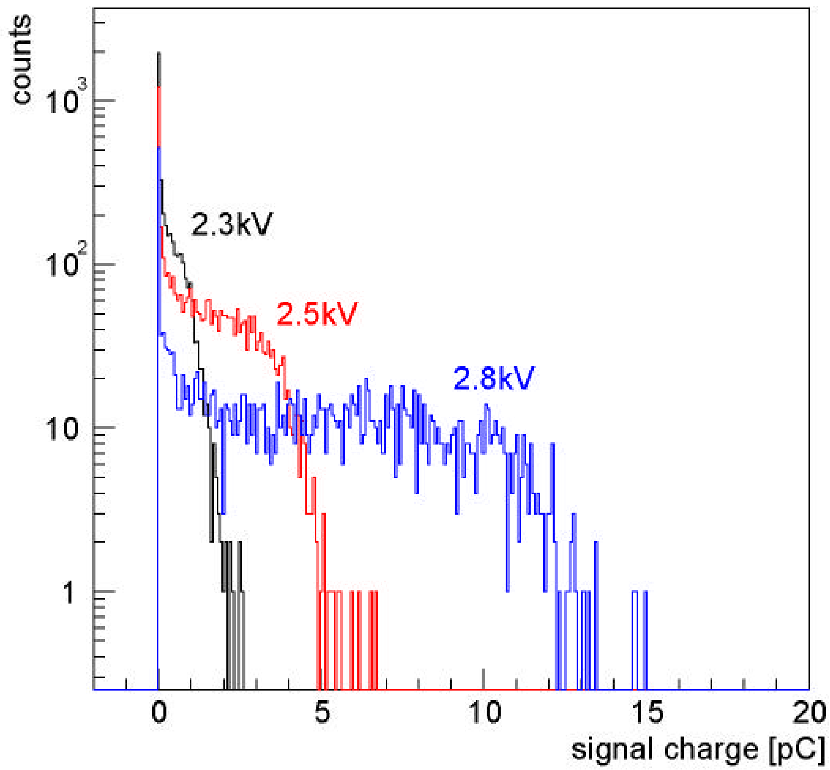




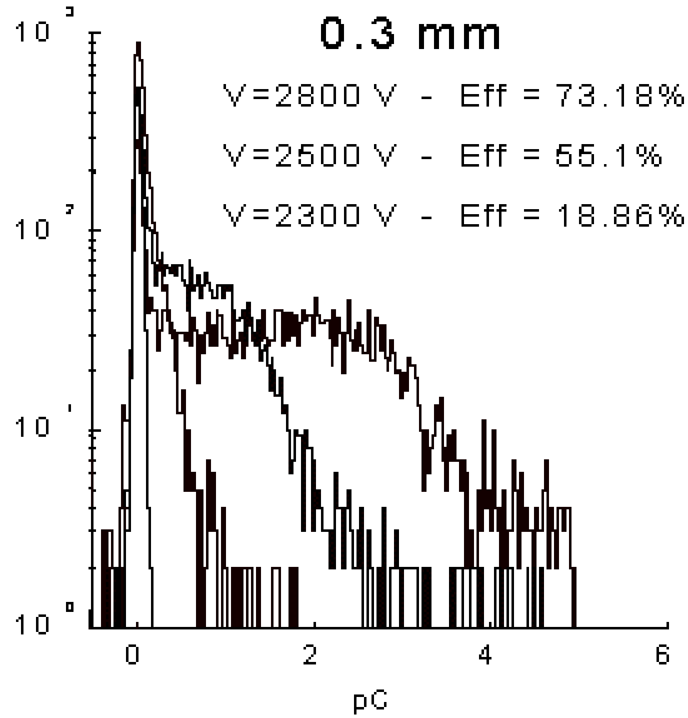
Charge Spectra, Timing RPC

- 7GeV pions (9.13 clusters/mm)
- T=296.15K
- p=970mb

Simulation with 500 Steps



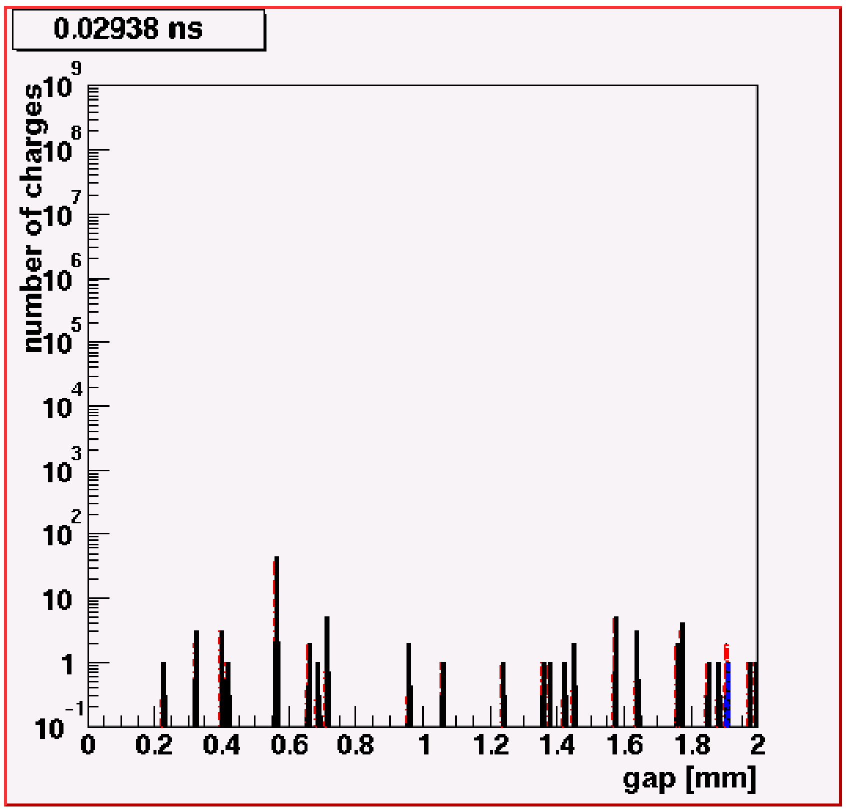
Standard mixture

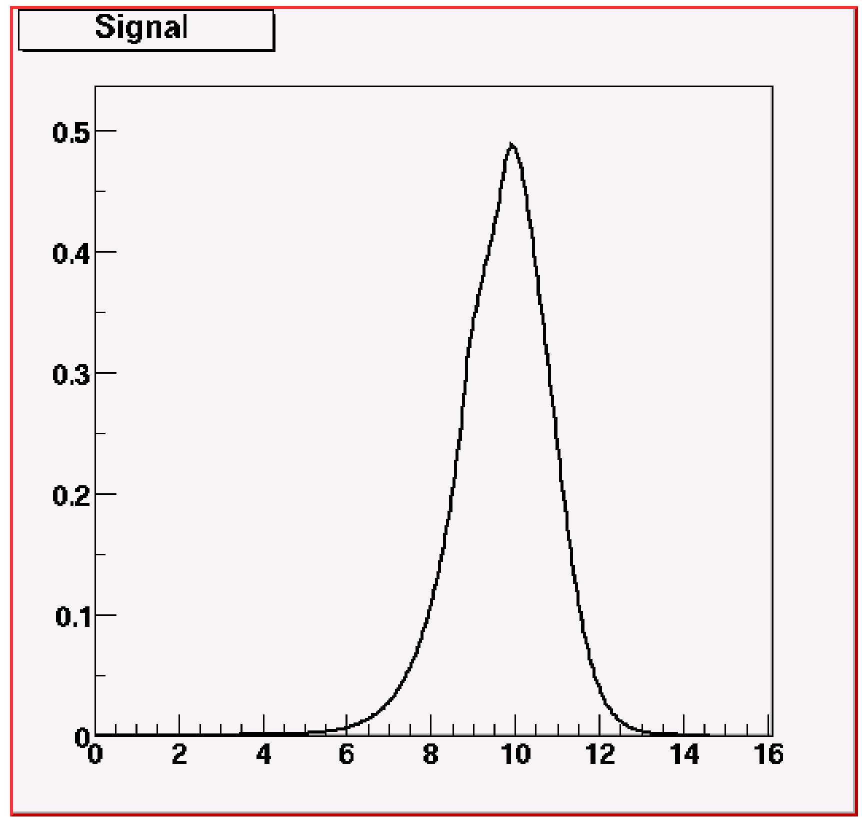


P. Fonte and V. Peskov, preprint LIP/00-04

Simulated Avalanche, Trigger RPC

- Electrons, pos. Ions, neg. Ions
- 500 steps, 10kV, 2mm gap, T=296.15K, p=970mb
- Logarithmic scale!
- Space Charge Effects are less dramatic

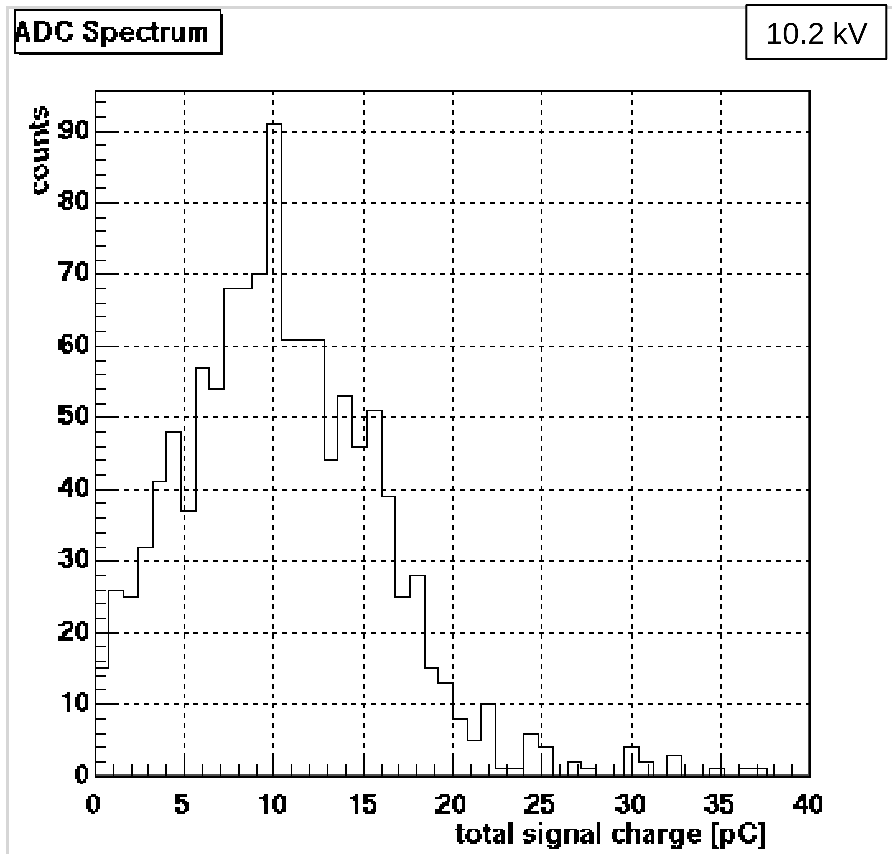




Charge Spectra, Trigger RPC

- 700 steps,
- 10.2kV
- 2mm gap
- T=296.15K
- p=970mb

- Simulated Spectrum shows peak like measured spectra.

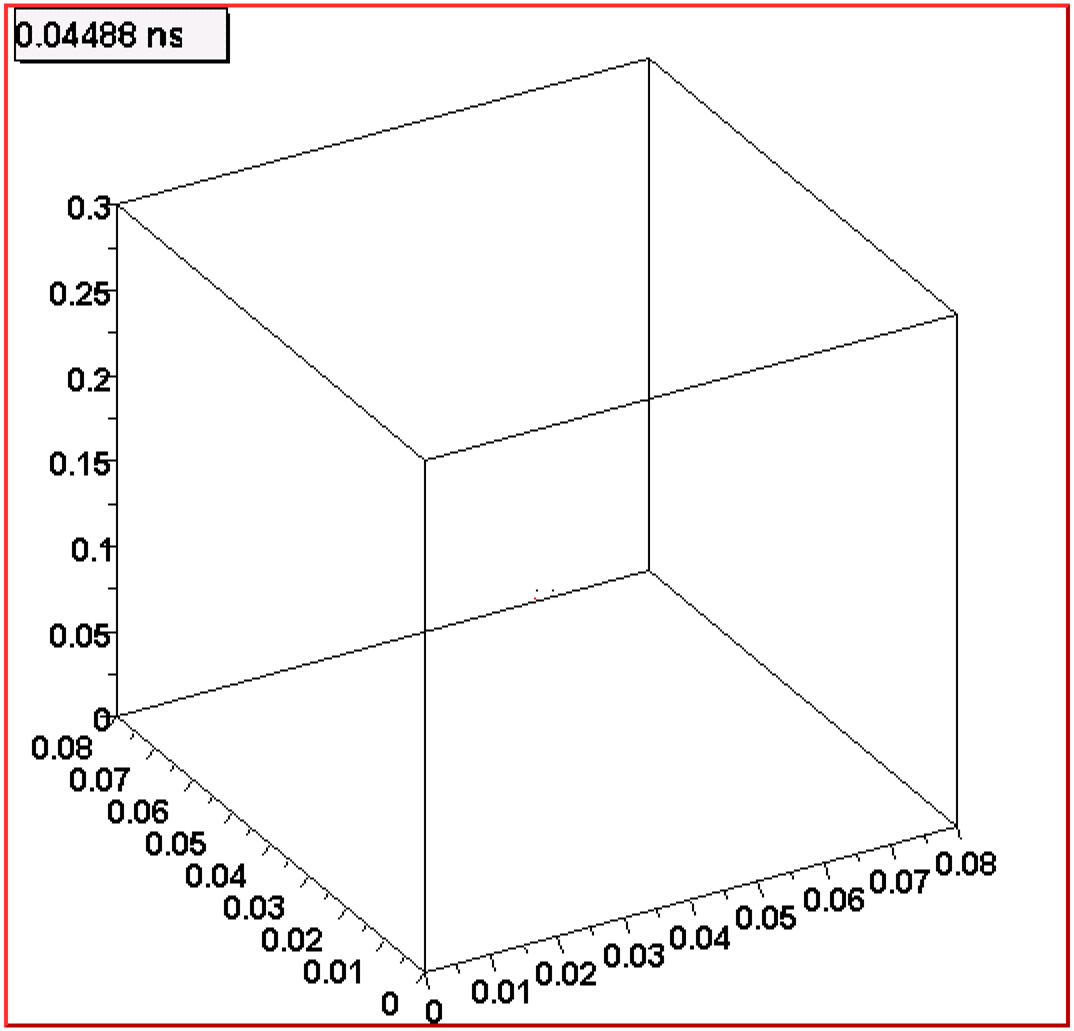


3-Dimensional Simulations

1. A cubic volume of the gas gap is divided in a three dimensional grid. We use Cartesian coordinates x, y and z (z is spanning the gas gap).
2. One electron is put into a bin inside the volume.
3. The three dimensional electric field vector at each bin is calculated, if there is an electron in that bin. We include the applied external field and the space charge field.
4. The Townsend and attachment coefficients, the drift velocity and the diffusion coefficients at each bin is calculated.
5. The charges in the gas gap are multiplied. Longitudinal and transversal diffusion are calculated and each electron redistributed onto the bins.
6. Steps 3 - 5 are repeated until all electrons left the gas gap.

Example Avalanche, 3 dimensional

Very time consuming. Here 2.8kV on a 0.3mm gap



Space Charge Effect in RPCs

Reminder: Wire Tube/ Wire Chamber

- **1/r field geometry**
  - **Space charge region very short (<100V)**
  - **1.5 orders of magnitude jump to limited streamer region**

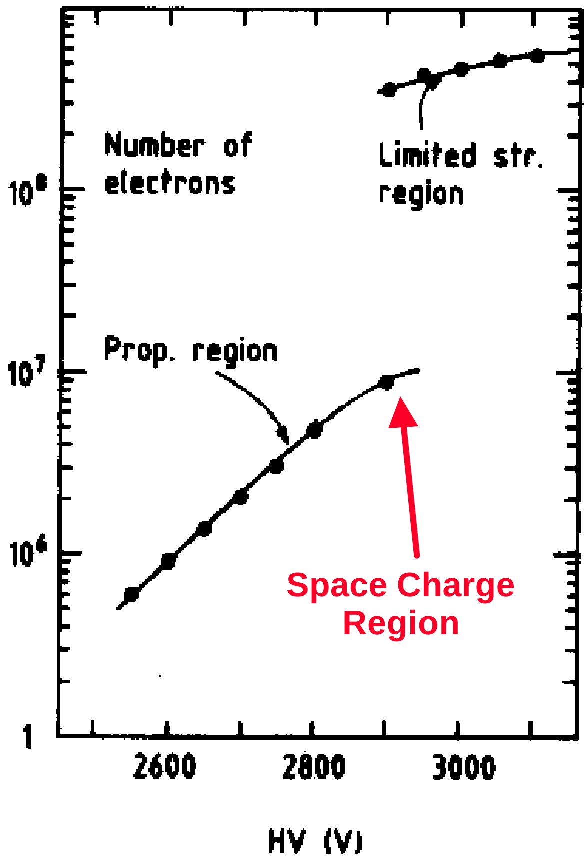
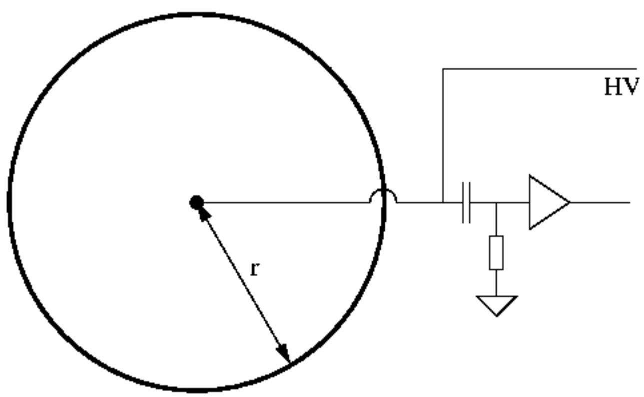


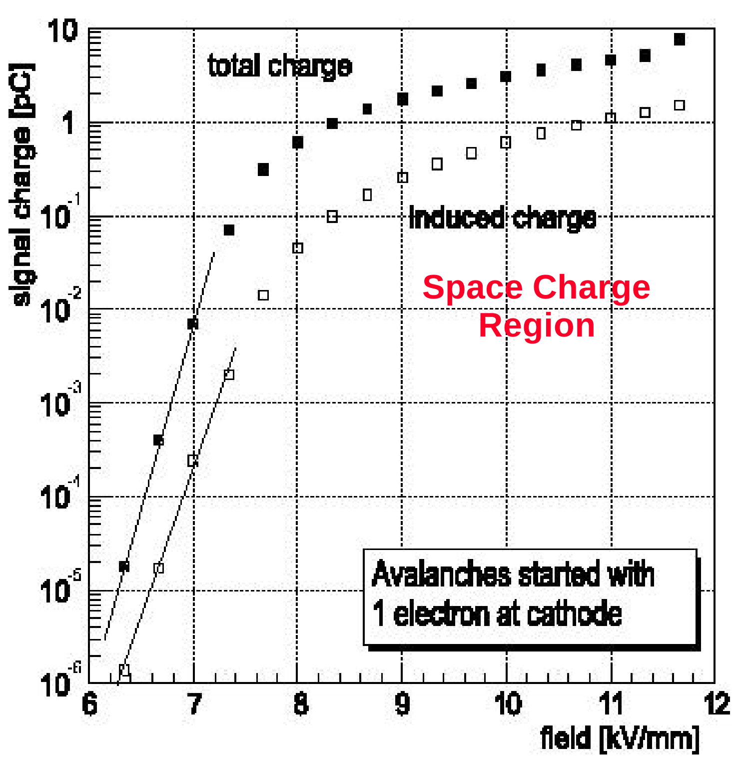
Fig. 4.5. Collected charge as a function of the high voltage, measured by ATAC et al. [ATA 82] on a 100 μm diameter wire in a tube $12 \times 12\ mm^2$, filled with $Ar(49.3\%) + C_2H_6(49.3\%) + CH_3CH_2OH(1.4\%)$

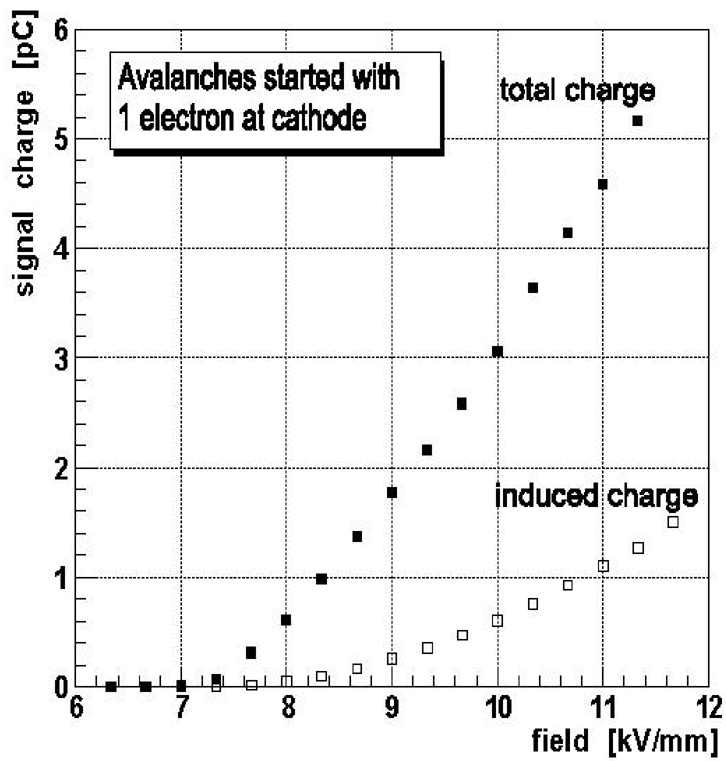
From NIM 200, 345 (1982)



Timing RPC: Long Space Charge Mode

- Homogeneous (applied) electric field
- Proportional Region is below Threshold
- Very long space charge Region
- Charge grows first exponentially, then linearly with HV (which is also an experimental fact)



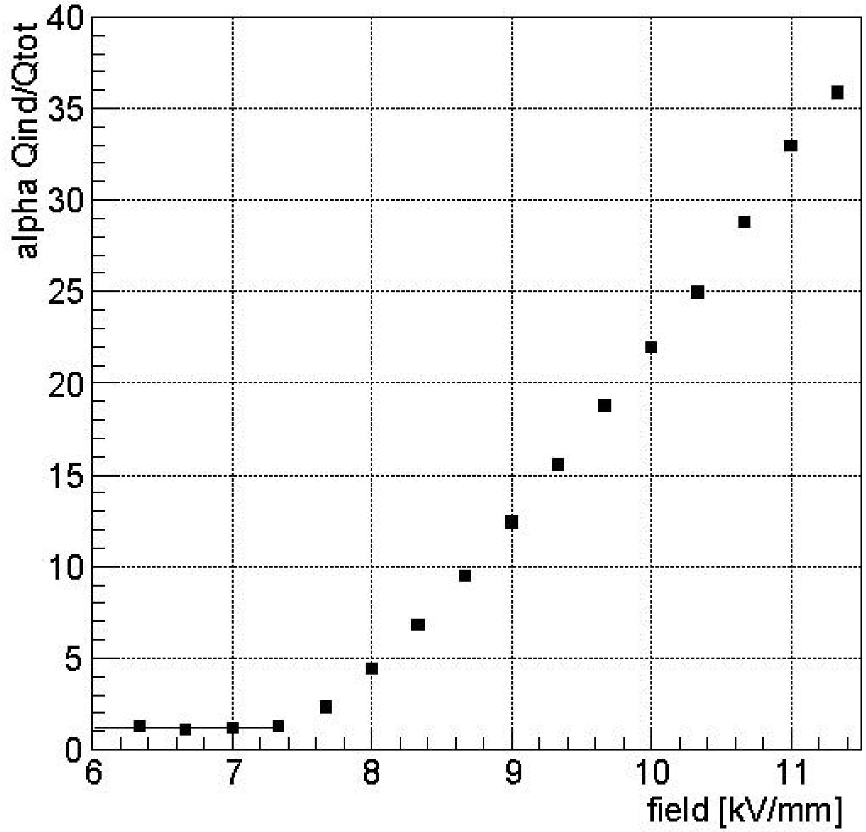


Ratio Q_{ind}/Q_{tot}

- For avalanches where no space charge effect is present we expect:

$$\frac{Q_{ind}}{Q_{tot}} = \frac{E_w}{\alpha}$$

- Indicator for a strong space charge effect present for E > 7.5kV/mm



Conclusions/Summary

- RPCs are widely used in present Big Scale Experiments
- We have applied standard detector physics simulations to Timing RPCs and find good agreement with measurements for efficiency, time resolution and charge spectra.
- The operational mode of timing RPCs is strongly influenced by a space charge effect. The suppression factor is huge (up to 10^7).
- Details on our work:
  - NIM A489 (2002) 439-443
  - CERN-EP-2002-024
  - NIM A481(2001) 130-143
  - CERN-EP-2002-046
  - CERN-OPEN-2001-074