Detector Physics of Resistive Plate Chambers

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◆ 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 $\tau$

![Diagram of a RPC](image)
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 $\Rightarrow$ deadtime
Different RPC Types

- **Trigger RPCs**
  - **Typical values:**
    - 2mm gaps
    - 2mm bakelite resistive layers, \( \rho \approx 10^{10} \Omega \text{cm} \)
    - \( \text{C}_2\text{F}_4\text{H}_2/\text{Isobutane}/\text{SF}_6 \) 97/2.5/0.5
    - HV \( \approx 10 \text{kV} \), \( E \approx 50 \text{kV/cm} \)
    - Typically 2 gap configurations

- **Timing RPCs**
  - **Typical Values:**
    - 0.3mm gas gaps
    - Two resistive plates or 1 resistive+1 aluminum
    - 3mm glass resistive plates, \( \rho \approx 2 \times 10^{12} \Omega \text{cm} \)
    - \( \text{C}_2\text{F}_4\text{H}_2/\text{Isobutane}/\text{SF}_6 \) 85/5/10
    - HV \( \approx 3(6) \text{kV} \), \( E \approx 100 \text{kV/cm} \)
    - Typically 4 gap configurations
Experiments with RPCs: CMS@CERN

- CMS (Compact Muon Solenoid)
- p-p collisions at 14TeV
- Muon Trigger
- Area: 3100m²

They use Trigger RPCs
- Bakelite
- 2mm gaps
- $E \approx 50$ kV/cm
- Gas: Freon + Isobutane
- Time Resolution < 3ns
- Efficiency > 95%
- Rate capability: 1kHz/cm²
Experiments with RPCs: ATLAS@CERN

- ATLAS (A Toroidal LHC ApparatuS)
- p-p collisions at 14TeV
- Muon Trigger
- Area: 3650m²

They use Trigger RPCs
- Bakelite
- 2mm gaps
- $E \approx 50$ kV/cm
- Gas: Freon + Isobutane + SF₆
- Time Resolution < 3ns
- Efficiency > 97%
- Rate capability 1kHz/cm²

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

http://alice.web.cern.ch/Alice/
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 $10^{12} \Omega \text{cm}$
  - $E \simeq 100 \text{kV/cm}$
  - Time Resolution < 100ps
  - Efficiency > 98%

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—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):

<table>
<thead>
<tr>
<th>Gas</th>
<th>Helium</th>
<th>Argon</th>
<th>Xenon</th>
<th>i-C₄H₁₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>n (events/cm)</td>
<td>4.2</td>
<td>23</td>
<td>44</td>
<td>84</td>
</tr>
</tbody>
</table>

- Events are Poisson distributed around the mean number n:

\[ p_k^n = \frac{n^k}{k!} e^{-n} \]

- Maximum detection efficiency:

<table>
<thead>
<tr>
<th>Gas</th>
<th>gap thickness</th>
<th>Eff (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helium</td>
<td>0.3mm</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>2mm</td>
<td>57</td>
</tr>
<tr>
<td>i-C₄H₁₀</td>
<td>0.3mm</td>
<td>92</td>
</tr>
<tr>
<td></td>
<td>2mm</td>
<td>100</td>
</tr>
</tbody>
</table>

\[ \text{Eff} = 1 - e^{-n} \]

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

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

02.12.2002; GSI

Christian Lippmann
Simulation Input: Primary Ionization

- HEED data = symbols
- Measurements (for iC$_4$H$_{10}$ and CH$_4$) = lines
- n $\approx$ 10 Clusters/mm for a 7GeV pion
- Mean free path $\lambda \approx 0.1$mm

- Cluster Size Distribution
- Average $\approx 2.45$ electrons
- Long Tail
Avalanche Multiplication in an uniform field

\[ \alpha = \text{Townsend Coefficient} \]
\[ \eta = \text{Attachment Coefficient} \]

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

But: \[ \alpha = \alpha(E) \quad \eta = \eta(E) \]

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 Feldstärken und bei grosser Gasverstärkung

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:

\[
\bar{n}(x) = e^{(\alpha - \eta) x} \quad k = \frac{\eta}{\alpha}
\]

\[
P(n, x) = \frac{\bar{n}(x) - 1}{\bar{n}(x) - k} 
\]

\[
= \bar{n}(x) \left( \frac{1 - k}{\bar{n}(x) - k} \right)^2 \left( \frac{\bar{n}(x) - 1}{\bar{n}(x) - k} \right)^{n - 1} \quad n > 0
\]

Variance:

\[
\sigma^2(x) = \left( \frac{1 + k}{1 - k} \right) \bar{n}(x) (\bar{n}(x) - 1)
\]

Avalanches started by a single electron

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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 $\approx 130 \, \mu\text{m/ns}, T \approx 15\text{ns}$
  - Timing RPC $\approx 220 \, \mu\text{m/ns}, T \approx 1.4\text{ns}$
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
An order of magnitude formula for the efficiency of single gap RPCs:

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

- \( d \) = gapwidth
- \( \lambda \) = mean free path
- \( Q_t \) = charge threshold
- \( \alpha \) = Townsend Coefficient
- \( \eta \) = Attachment Coefficient

Only the first cluster (1 electron) taken into account

Efficiency depends not only on the effective Townsend coefficient but also on \( \eta \)

No attachment, zero threshold:

\[ \eta = Q_t = 0 \implies \text{Eff} = 1 - e^{-\frac{d}{\lambda}} \]

\( e^{-\frac{d}{\lambda}} \) 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
- \( \alpha \) = Townsend Coefficient
- \( \eta \) = 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

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
    \[ A^n_t(x) = n e^{-nx} \]
- Time distribution of that cluster:
  \[ A^n_t(t) = n e^{-nt} \]

![Graph showing exponential distribution and time distribution](image)
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

Sigma = 80ps

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 ($\varepsilon=8$, $\rho=2\times10^{12} \Omega \text{cm}$)
- $C_2F_4H_2/i-C_4H_{10}/SF_6 (85/5/10)$
- HV: $3(6)$kV, $E: 100$kV/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

0.3mm Timing RPC 3kV
- Simulated
  - $Q_{\text{tot}} = 4.6 \cdot 10^7 \text{pC}$
  - $Q_{\text{ind}} = 3.8 \cdot 10^5 \text{pC}$
- Measured
  - 5 pC
  - 0.5 pC

2mm Trigger RPC 10kV
- Simulated
  - $Q_{\text{tot}} = 2.2 \cdot 10^3 \text{pC}$
  - $Q_{\text{ind}} = 1.0 \cdot 10^2 \text{pC}$
- Measured
  - 40 pC
  - 2 pC

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
  - $x, y, z, \rho, \phi$, coordinates of point of observation
  - $x', y', z', \rho', \phi'$, coordinates of charge
  - $p, g, q$, define thickness of layers

\[
R^2 = |\vec{r} - \vec{r}'|^2 = \\
= (x-x')^2 + (y-y')^2 + (z-z')^2 \\
= \rho^2 - 2\rho'\rho\cos(\phi - \phi') + \rho'^2 + (z-z')^2
\]
Static Electric Fields in an Infinite Plane Condenser with Three Homogeneous Layers

\[ \Phi(\rho, \phi, z) = \frac{Q}{4\pi\varepsilon_2} \left[ \frac{1}{\sqrt{P^2 + (z - z')^2}} + \frac{(\varepsilon_2 - \varepsilon_3)}{(\varepsilon_2 + \varepsilon_3)\sqrt{P^2 + (2g - z - z')^2}} - \frac{(\varepsilon_1 - \varepsilon_2)}{(\varepsilon_1 + \varepsilon_2)\sqrt{P^2 + (z + z')^2}} \right] \\
+ \frac{1}{(\varepsilon_1 + \varepsilon_2)(\varepsilon_2 + \varepsilon_3)} \int_0^\infty d\kappa J_0(\kappa P) \frac{R(r, z, z')}{D(\kappa)}, \quad 0 \leq z \leq g \]

\[ D(\kappa) = (\varepsilon_1 + \varepsilon_2)(\varepsilon_2 + \varepsilon_3) (1 - e^{-2\kappa(p+q)}) - (\varepsilon_1 - \varepsilon_2)(\varepsilon_2 + \varepsilon_3)(e^{-2\kappa(p-q)} - e^{-2\kappa q}) \]
\[ - (\varepsilon_1 + \varepsilon_2)(\varepsilon_2 - \varepsilon_3)(e^{-2\kappa(p-g)} - e^{-2\kappa(q+g)}) + (\varepsilon_1 - \varepsilon_2)(\varepsilon_2 - \varepsilon_3)(e^{-2\kappa q} - e^{-2\kappa(p+q-g)}) \]

\[ R(\kappa; z, z') = (\varepsilon_1 + \varepsilon_2)^2(\varepsilon_2 + \varepsilon_3)^2 \left[ e^{\kappa(-2p-2q+z+z')} + e^{\kappa(-2p-2q-z-z')} \right] \]
\[ -(\varepsilon_1 + \varepsilon_2)^2 (\varepsilon_2 - \varepsilon_3)^2 e^{\kappa(-4g-2q+z+z')} - 4\varepsilon_1\varepsilon_2(\varepsilon_2 + \varepsilon_3)^2 e^{\kappa(-2q+z-z')} \]
\[ - (\varepsilon_1 - \varepsilon_2)^2 (\varepsilon_2 + \varepsilon_3)^2 \left[ -e^{\kappa(-2p-2q-z-z')} + e^{\kappa(-2p+z-z')} \right] \]
\[ + (\varepsilon_1^2 - \varepsilon_2^2)(\varepsilon_2 + \varepsilon_3)^2 \left[ -e^{\kappa(-2g-2q+z+z')} + e^{\kappa(-2g-2q-z+z')} \right] \]
\[ + (\varepsilon_1 - \varepsilon_2)^2(\varepsilon_2^2 - \varepsilon_3^2) e^{\kappa(-2g-2q+z+z')} - 4\varepsilon_1\varepsilon_2(\varepsilon_2^2 - \varepsilon_3^2) e^{\kappa(-2g-2q-2q+z-z')} \]
\[ + (\varepsilon_1 + \varepsilon_2)^2(\varepsilon_2^2 - \varepsilon_3^2) \left[ e^{\kappa(-2g-2q+z-z')} - e^{\kappa(-2g-2q-z+z')} \right] \]
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
- \( \frac{E_{\text{all}} - E_{\text{free}}}{E_{\text{free}}} : \)

![Graph showing the deviation from the free point charge solution](image)

2mm gap

potential

02.12.2002; GSI

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Simulation Input: Diffusion (MAGBOLTZ)

\[ \frac{dN(z)}{N} = \frac{1}{\sqrt{2\pi D_L}} \exp \left( -\frac{(z - z_0)^2}{2D_L} \right) \, dz \]

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

\[ \sigma_{L,T} = D_{L,T} \sqrt{l} \]
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:**

$$
E_z(z) = E_0 + \int_0^{\text{gapwidth}} q(z') E_z(\rho, \phi, z, z') \partial z'
$$

$$
\simeq E_0 + \sum_{i=0}^{\text{Steps}} q_i E_z(z, z_i', z_i'')
$$

$\rho = \phi = 0 \quad q = \text{charge at } z'$

One dimensional Simulation

02.12.2002; GSI

Christian Lippmann
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!

![Graph showing number of charges versus gap (mm) and field strength versus gap (kV/mm).]
Charge Spectra, Timing RPC

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

Simulation with 500 Steps

Standard mixture

0.3 mm

V=2800 V  -  Eff = 73.18%
V=2500 V  -  Eff = 55.1%
V=2300 V  -  Eff = 18.86%

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

From NIM 200, 345 (1982)

**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 × 12 mm², filled with Ar(49.3%) + C₂H₆(49.3%) + CH₃CH₂ OH(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)
For avalanches where no space charge effect is present we expect:

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

Indicator for a strong space charge effect present for $E > 7.5 \text{kV/mm}$
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:
- CERN-EP-2002-024
- NIM A481(2001) 130-143
- CERN-EP-2002-046
- CERN-OPEN-2001-074