Simulation of Gas Detectors Using Ramo's Theorem

Dylan Pizzi

Alain Bellerive (Supervisor)

Carleton University

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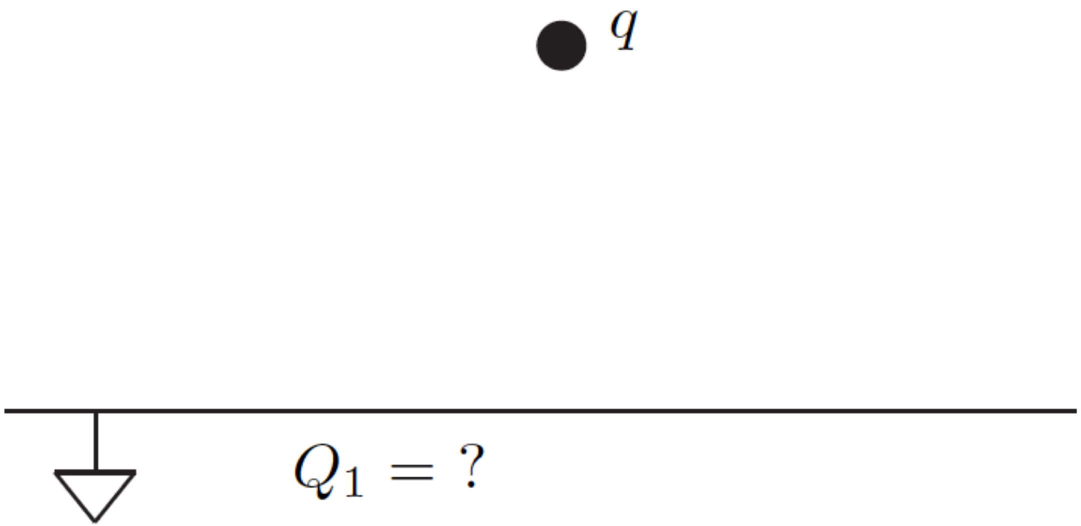
Outline

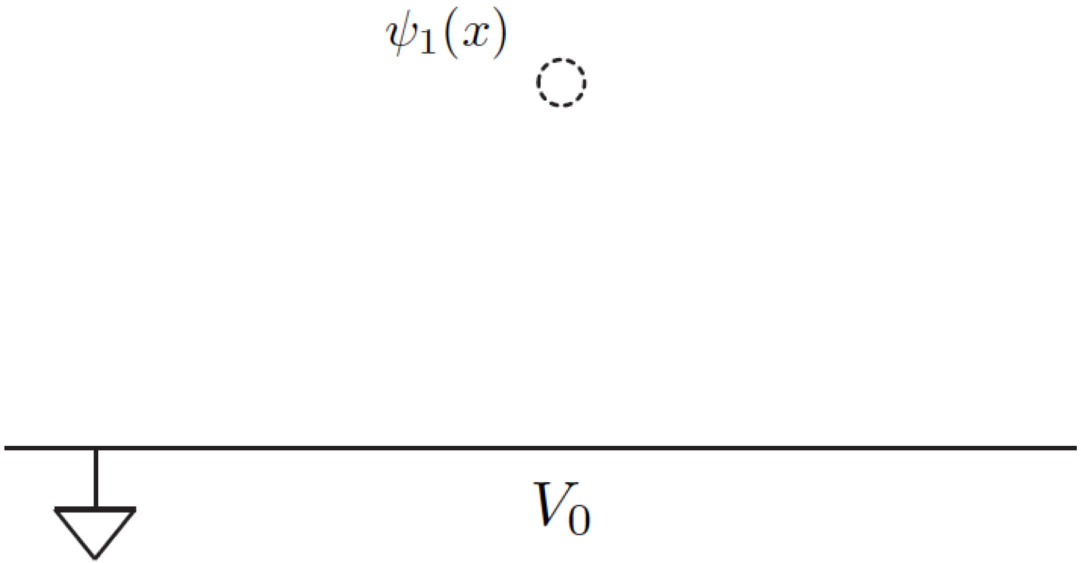
- Ramo’s Theorem
- Application: ILC & LHC
- Overview of the sTGC
- Simulation & Analysis
- MC & Data

Induced Charge and Ramo's Theorem



- Ramo's theorem provides an intuitive method for determining the induced charge, Q_1, on a grounded electrode
- We can set the potential of the electrode to V_0 creating a "weighted potential," $\psi(x)$, in the area around the electrode
- The induced charge becomes the ratio of the weighted potential over V_0 multiplied by the charge

Induced Charge and Ramo's Theorem



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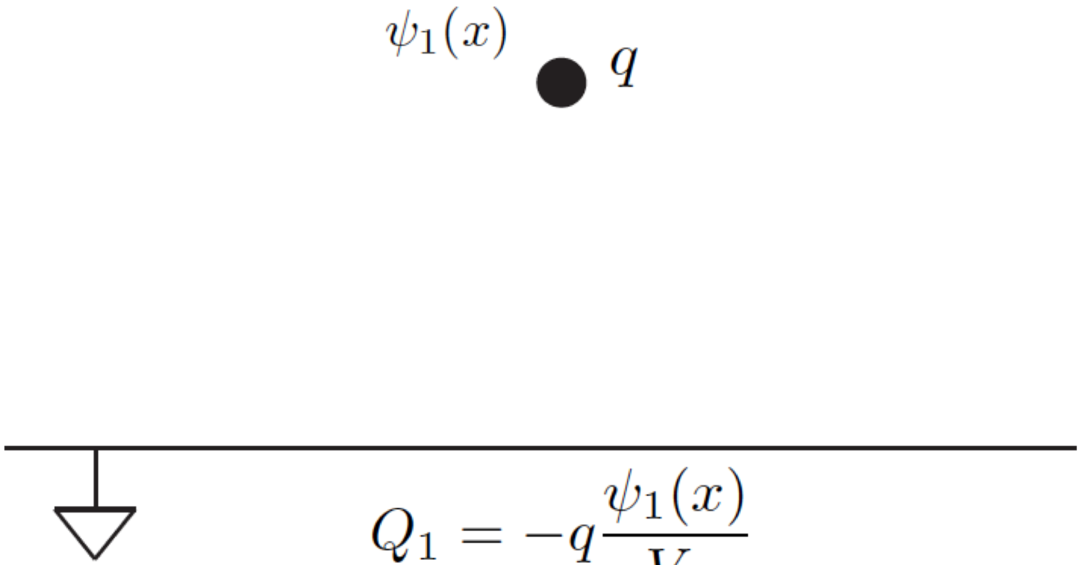

$$Q_1 = -q\frac{\psi_1(x)}{V_0}$$

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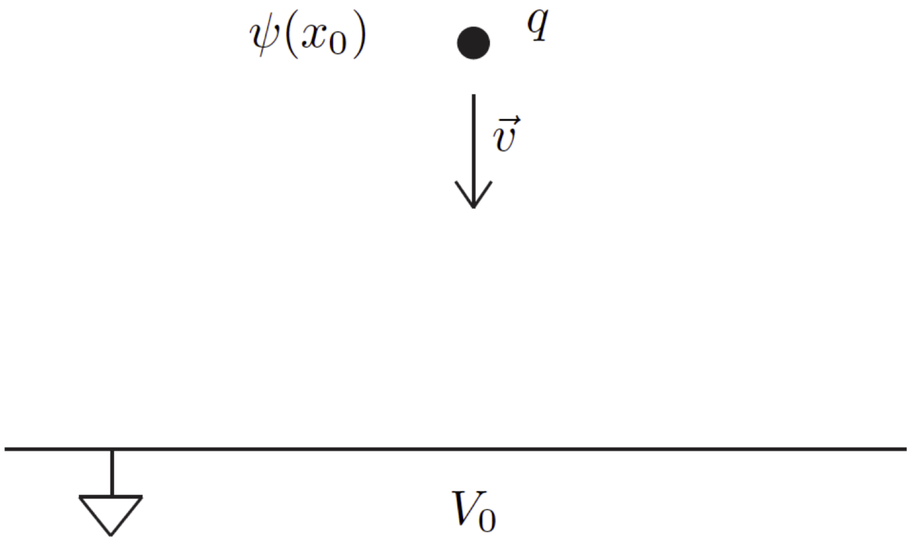
Ramo's Theorem and a Moving Charge

- When considering a moving charge we can treat it in the same way

- The amount of charge that flows from the electrode to ground is given by the change in the weighted potential moving from x_0 to x_1



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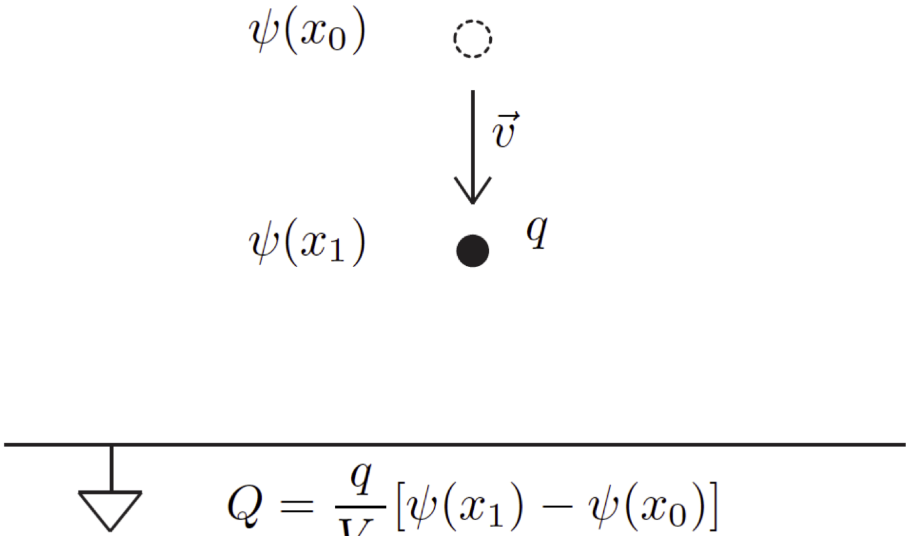
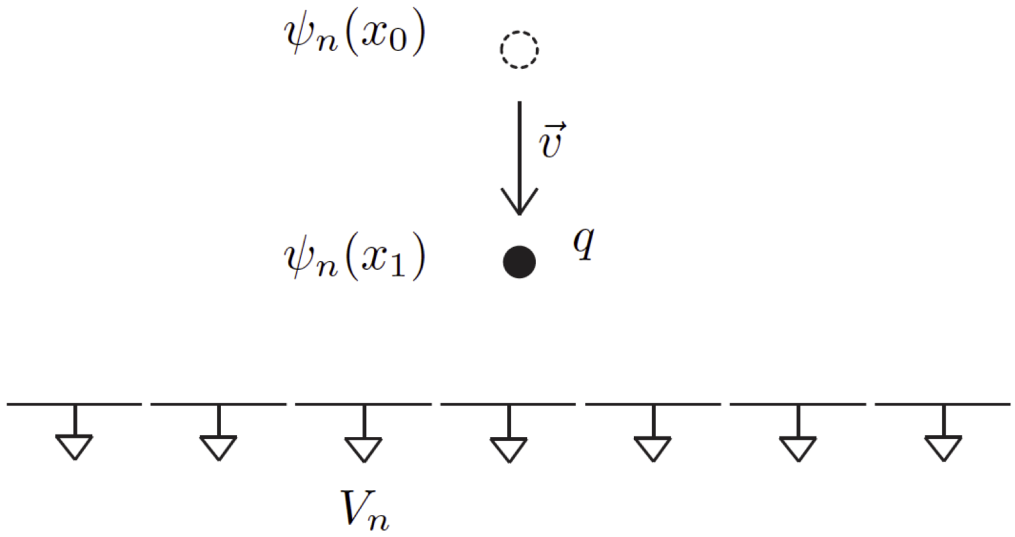


$$Q = \frac{q}{V_0}[\psi(x_1) - \psi(x_0)]$$

Charge Induction on Segmented Electrodes

$$V_n = V_0$$

$$Q_n = \frac{q}{V_0}[\psi_n(x_1) - \psi_n(x_0)]$$



- When a charge moves towards a system of segmented electrodes, we can repeat the same process
- Set potential of one electrode to V_0 and the rest to zero
- Difference in weighted potential for that electrode is proportional to the charge that flows through that electrode
- This is repeated for all electrodes

Application

International Linear Collider (ILC)

MicroMegas

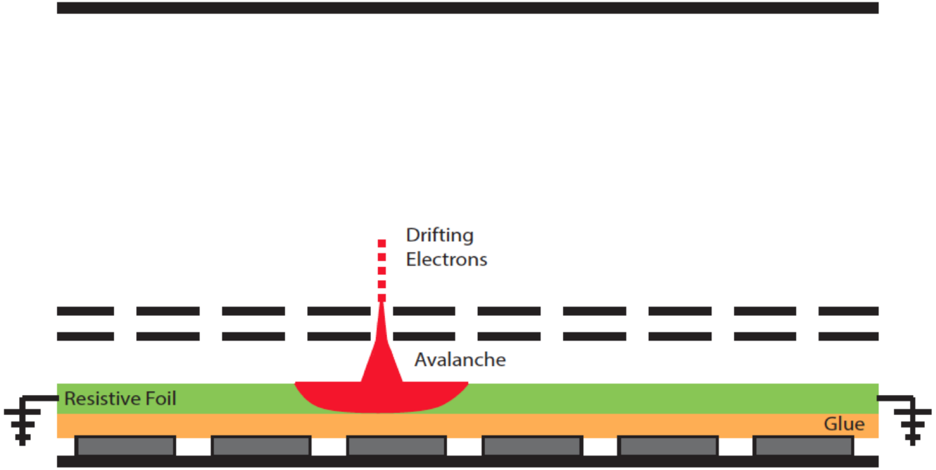


Image obtained from M.S. Dixit and A. Rankin "Simulating the Charge Dispersion Phenomena in Micro Pattern Gas Detectors with a Resistive Anode," arXiv:physics/0605121 [physics.ins-det] May 2006

- Used in developing the model to explain charge dispersion on a resistive coating

Large Hadron Collider (LHC)

sTGC

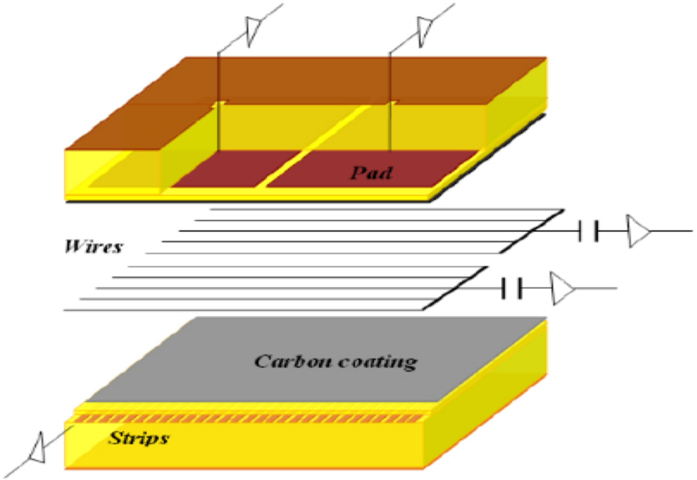


Image obtained from I. Roth, A. Klier and E. Duchovni "Testing sTGC with small angle wire edges for the ATLAS New Small Wheel Muon Detector Upgrade," arXiv:1506.01277v1 [physics.ins-det] June 2015

- Use data collected at test beam to further develop the simulation for application at LHC

What is the sTGC?

- Small strip Thin Gap Chamber
- Part of upcoming New Small Wheel (NSW) upgrade
- Provides muon tracking in the end-cap region of ATLAS

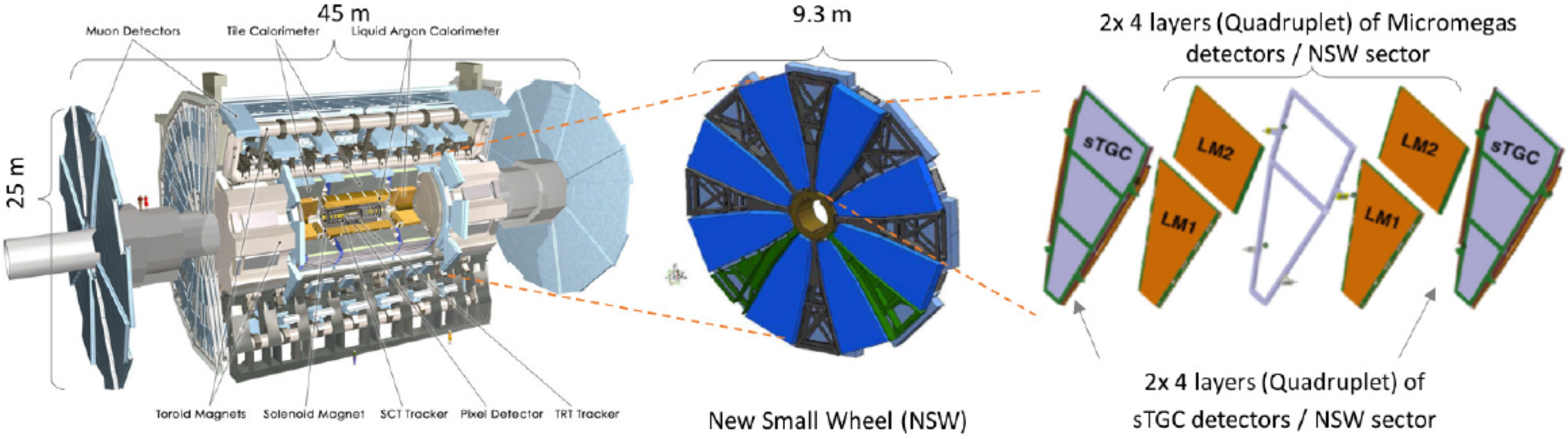
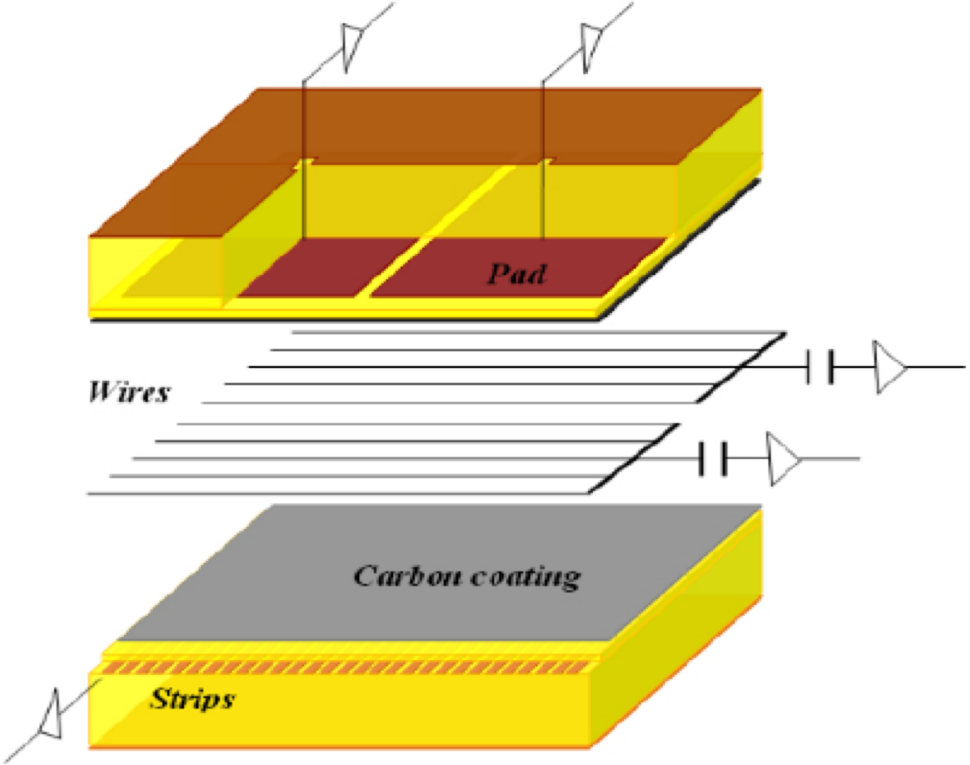


Image obtained from F. Kuger on behalf of ATLAS Collaboration "Micromesh-selection for the ATLAS New Small Wheel Micromegas detectors," Journal of Instrumentation Volume 11, November 2016

How It Works



- Multiwire proportional chamber
- Comprised of gold plated tungsten wires in between two cathode planes
- Wires held at ~3kV with a pitch of 1.8mm
- Strips are perpendicular to wires along cathode plane with 3.2mm pitch
- Pads cover opposite plane
- Volume filled with 45:55 mixture of n-pentane:CO_2
- Resistive carbon coating covers cathodes

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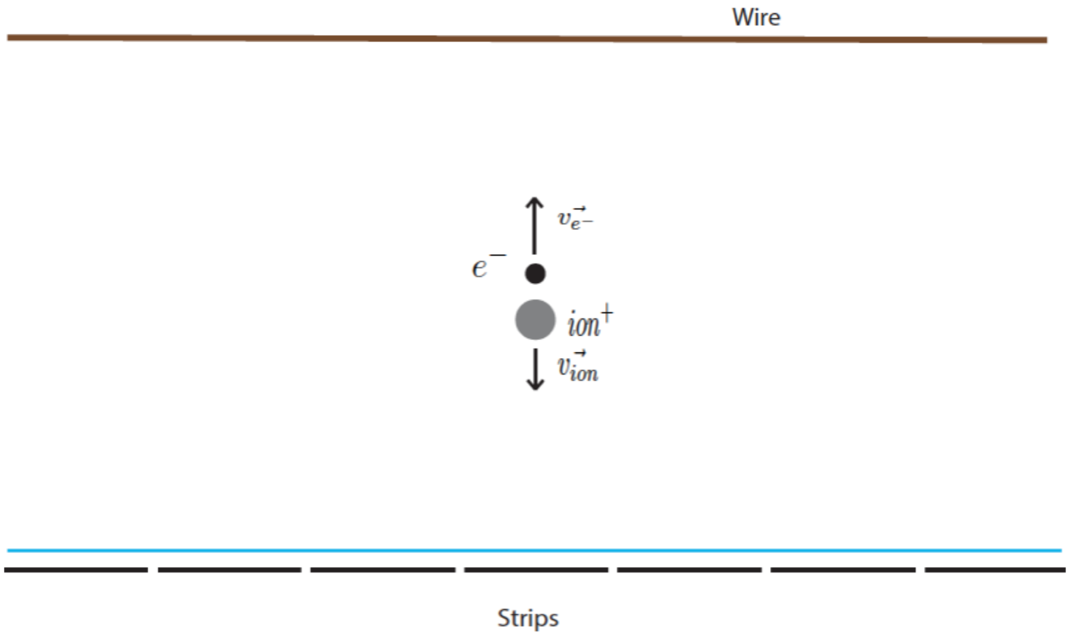

- Muon traverses chamber ionizing gas
- Electrons drift towards wires, ions drift towards cathode
- Drifting electron gains energy near wire producing an electron avalanche
- Avalanche causes an induction of charge on the surface of the strips
- Amount of charge induced on the strips follows a Gaussian distribution

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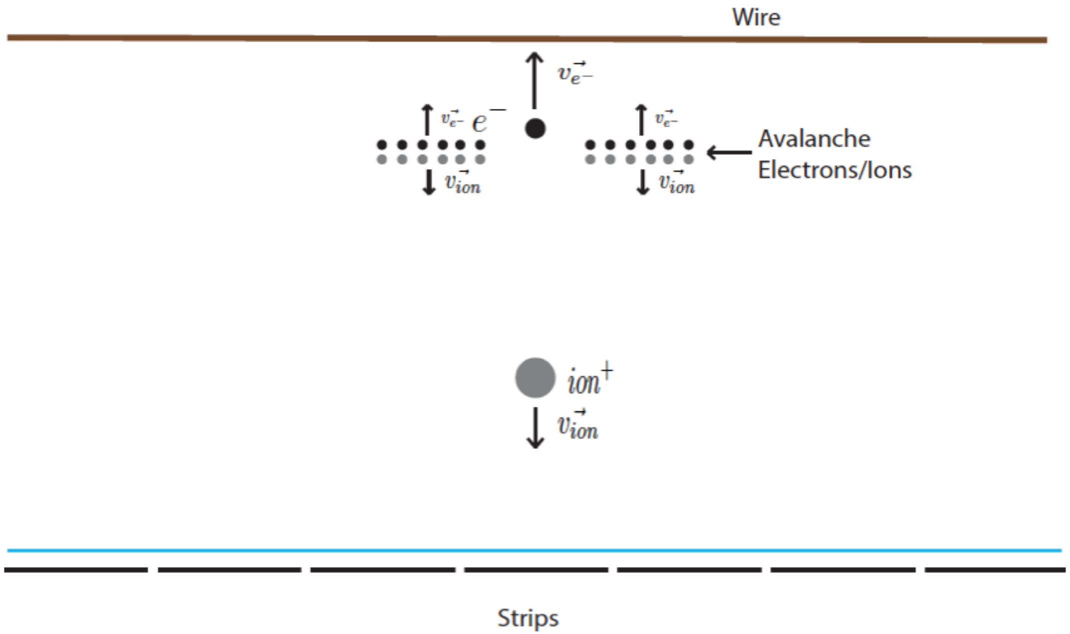

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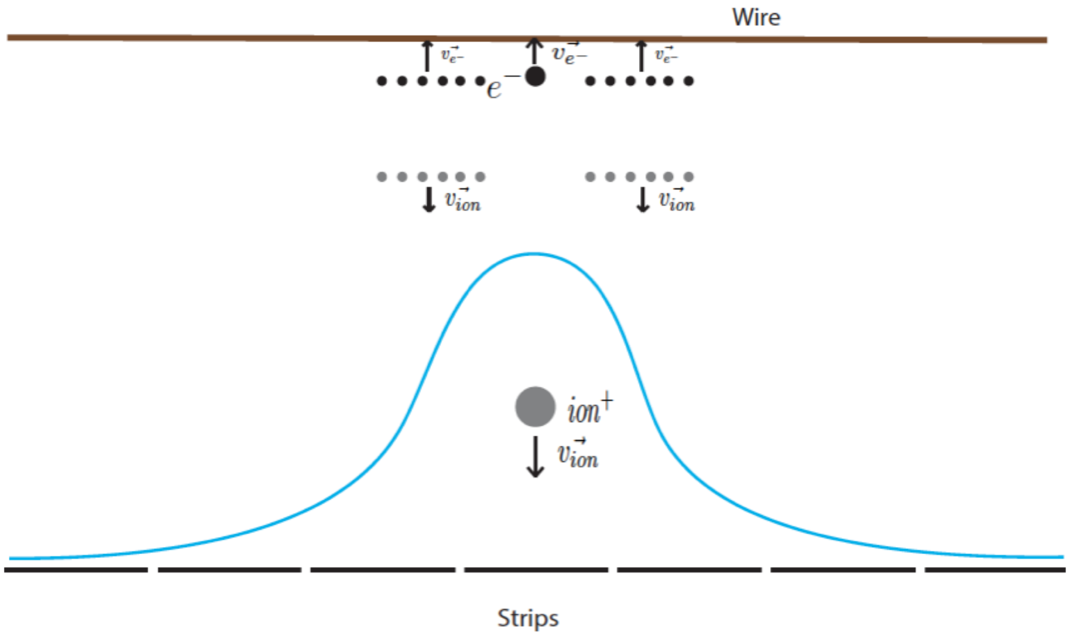

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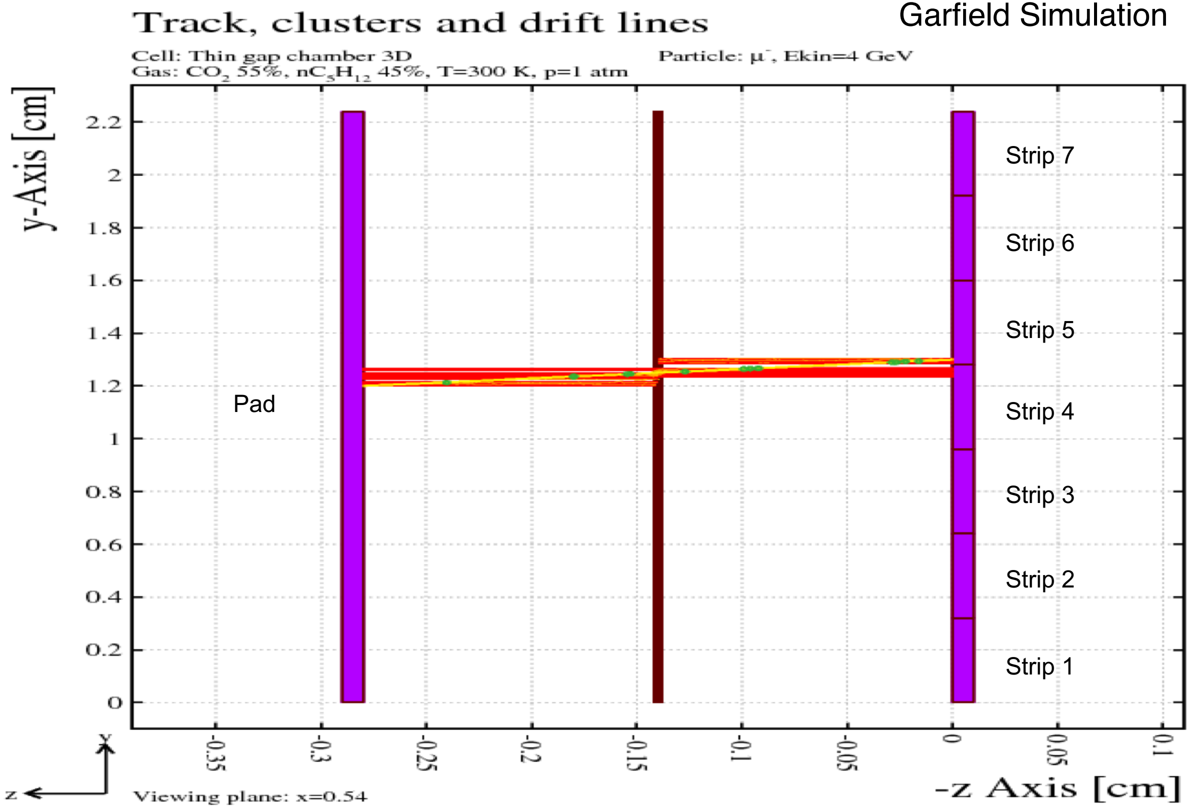
Simulation of the sTGC

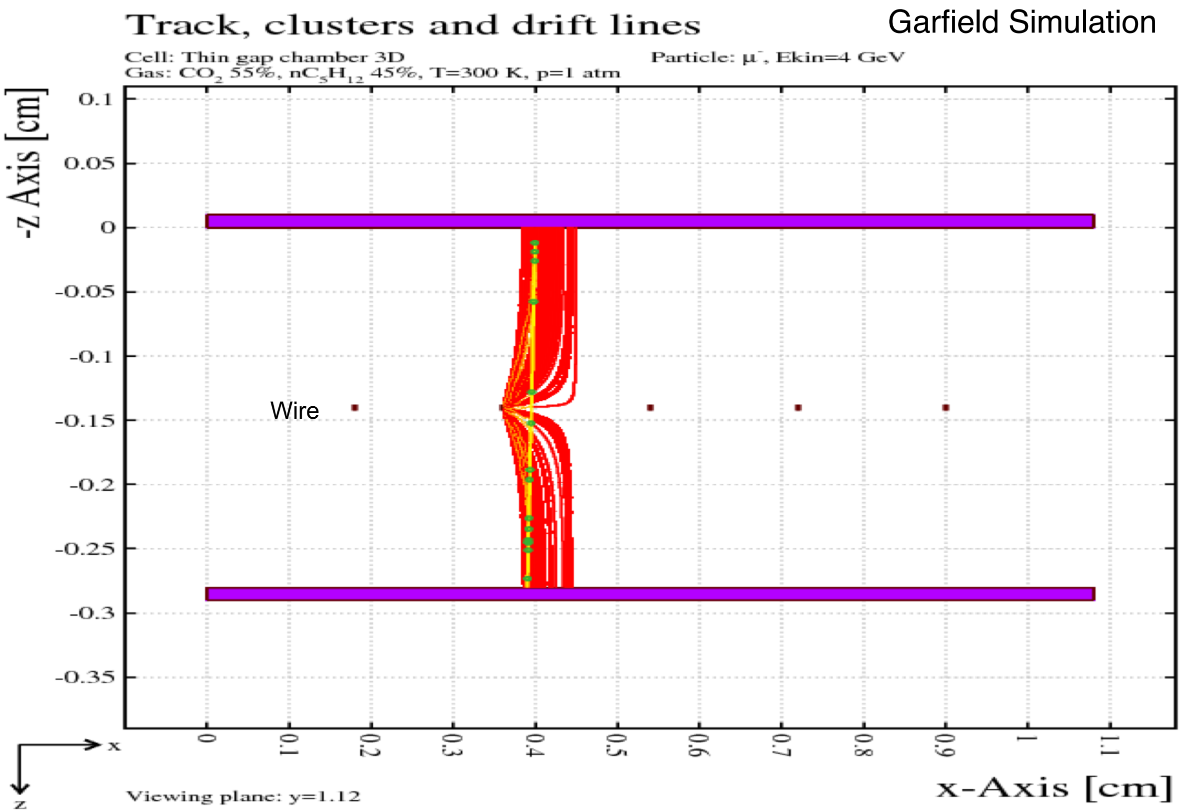
Garfield Simulation



- Conducted using Garfield gas detector simulation software
- Small slice of detector made up of 5 wires, 7 strips, and 1 pad
- Single muon track passes through with an energy of 4 GeV at random angles, $8° < \theta < 30°$ above z axis in yz-plane $0° < \varphi < 22°$ from z axis in xz-plane

- track
- electron
- ion
- ionization location

Simulation of the sTGC



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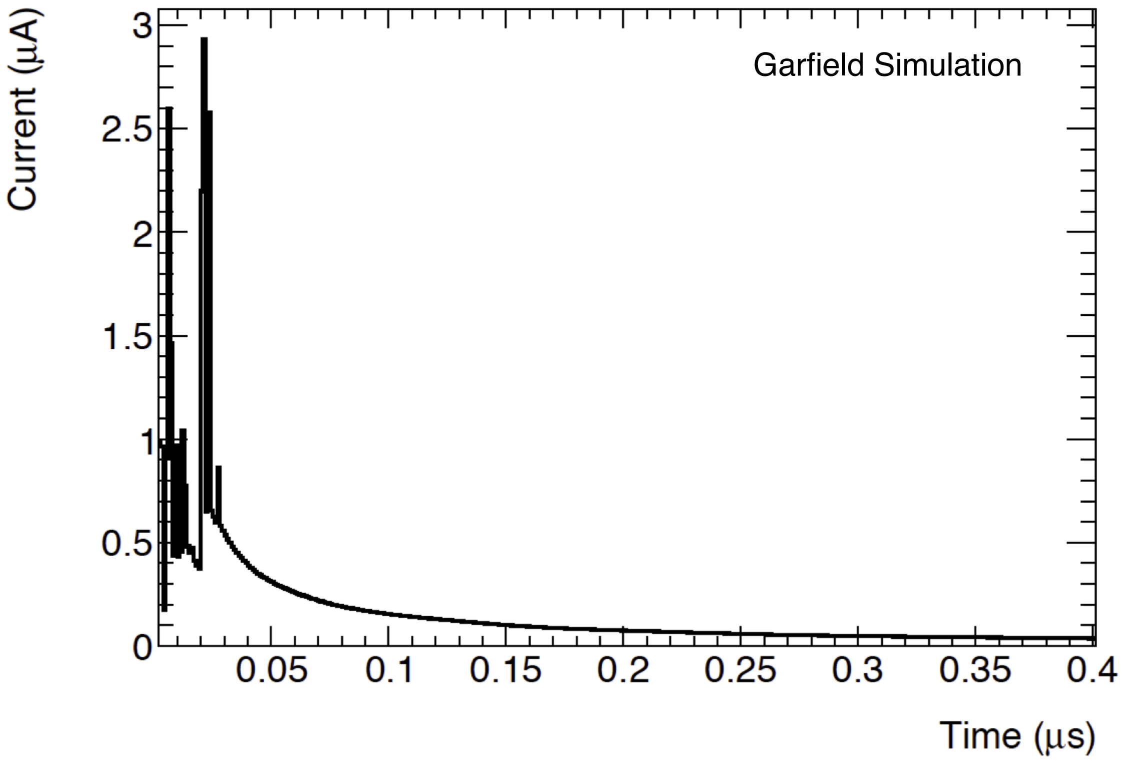


- Simulation only outputs raw signal
- Need to account for:
  - Resistive layer (for strips)
  - Readout electronics (for wires and strips)

Resistive Layer

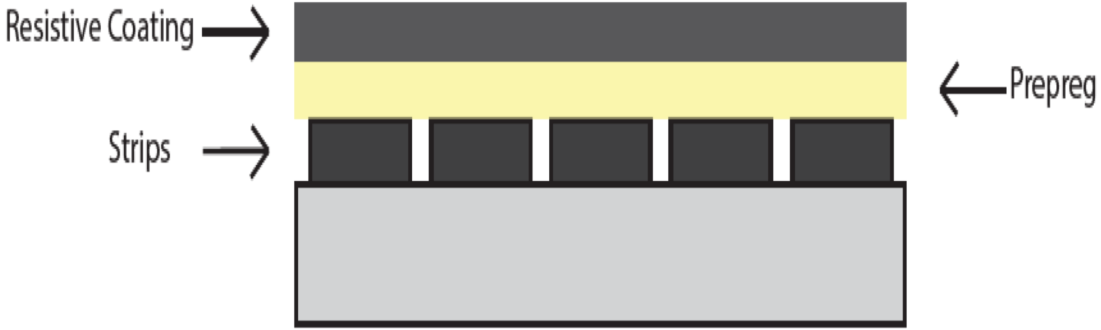
- Purpose:
  - Improve spatial resolution
  - Protect electronics against discharge
  - Mitigate charge deposition at high rate

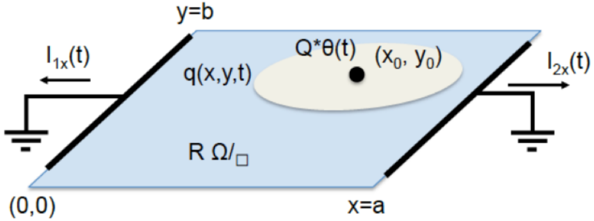
- Resistive coating is sprayed on prepreg layer covering cathode

- Creates capacitive coupling between layer and strips/pad

- RC time constant controls spread of charge distribution

- Response function of layer is proportional to time constant

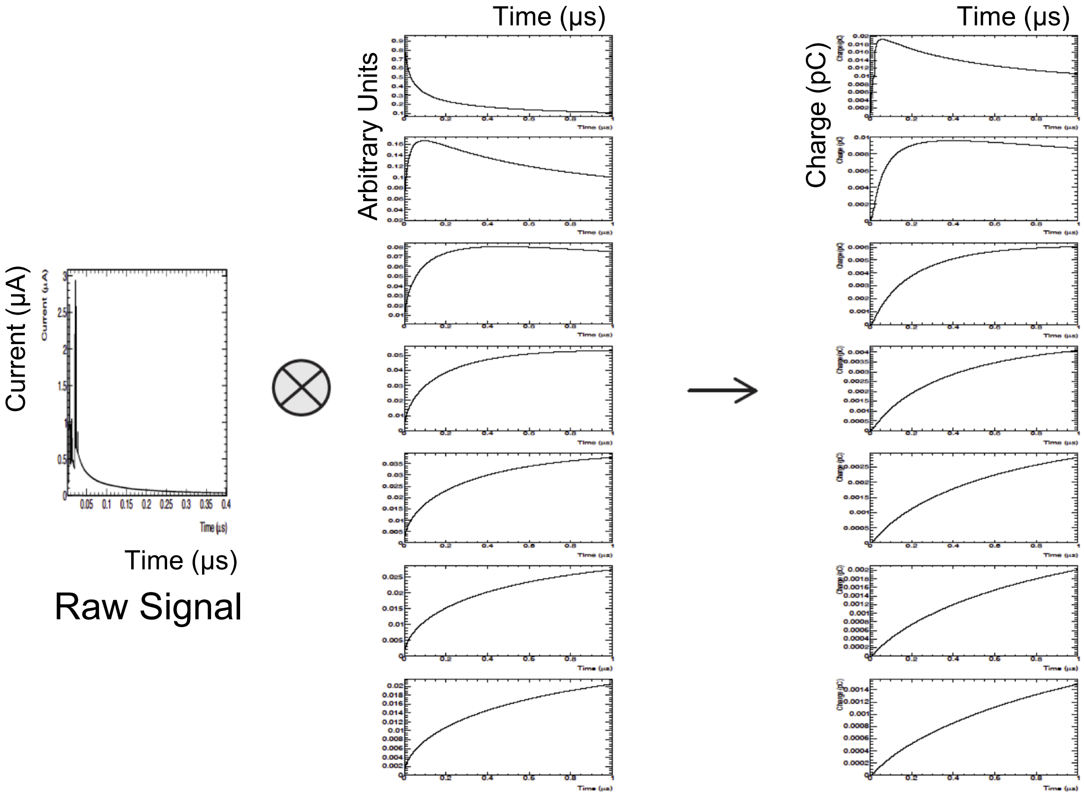




$$R(t) = tan^{-1}(\frac{x_{high}}{\sqrt{4ht}}) - tan^{-1}(\frac{x_{low}}{\sqrt{4ht}})$$

$$h = \frac{1}{RC}$$

Resistive Layer



- Charge is not “stuck” to one strip, it flows across resistive layer
- Convolute signal with response function corresponding to the strip the charge flows to
- Total charge on strip is determined by summing the contributions of charge that flows from each strip

Resistive Layer

Q(t) Strip 1

Charge from Strip 2

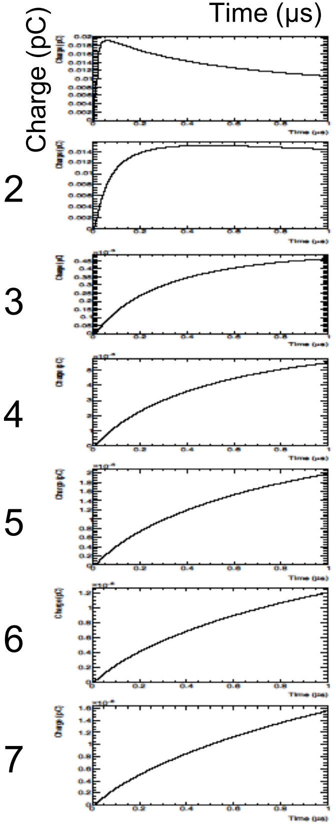
Charge from Strip 3

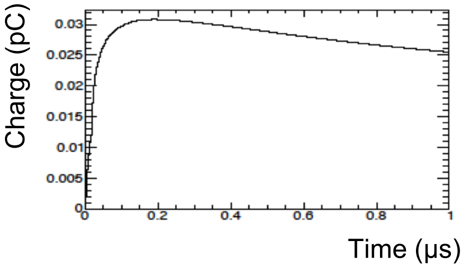
Charge from Strip 4

Charge from Strip 5

Charge from Strip 6

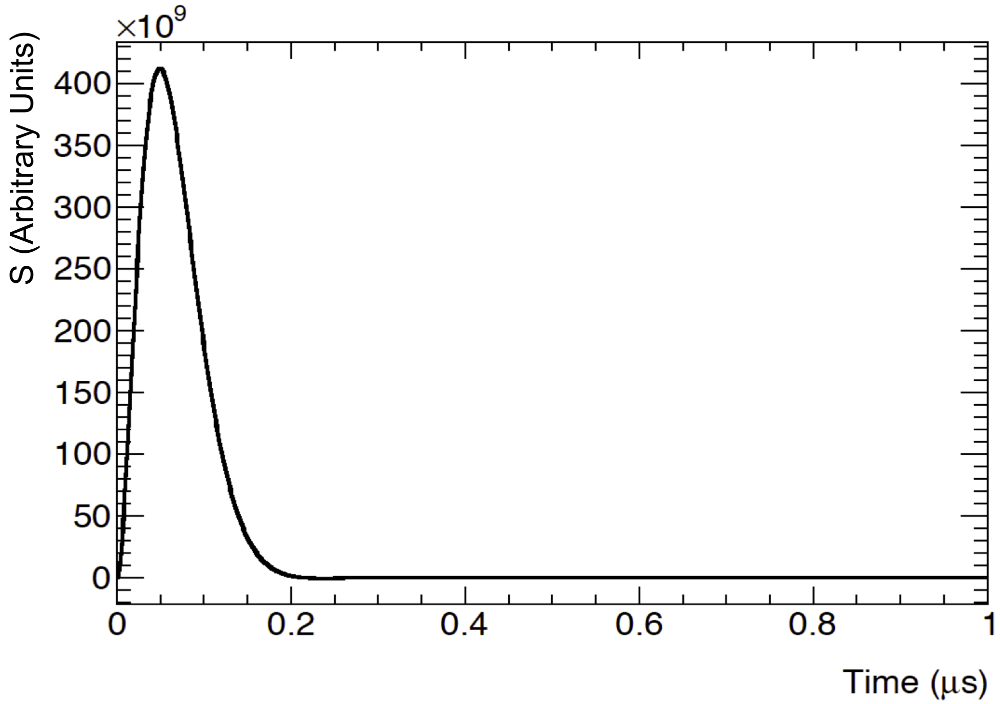
Charge from Strip 7





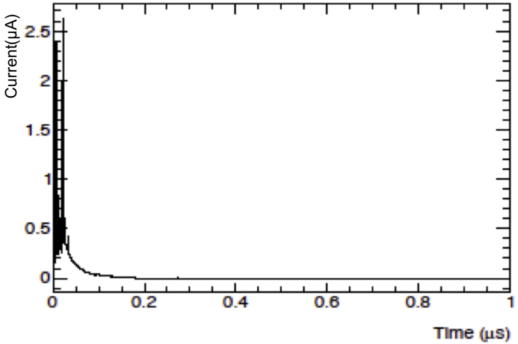
Total Summed Charge

Readout Electronics

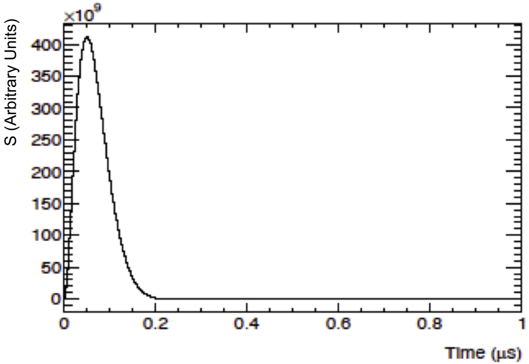


- Strip and wire readouts are connected to an ASIC chip, known as the VMM
- VMM monitors the current and enables the readout circuit once above a certain threshold
- Final output signal is obtained from convolution with VMM shaping function, S(t), with a peaking time of 50 ns

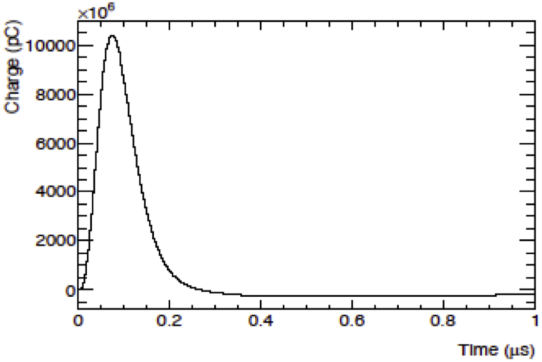
Convolution with VMM



Derivative of Summed Charge

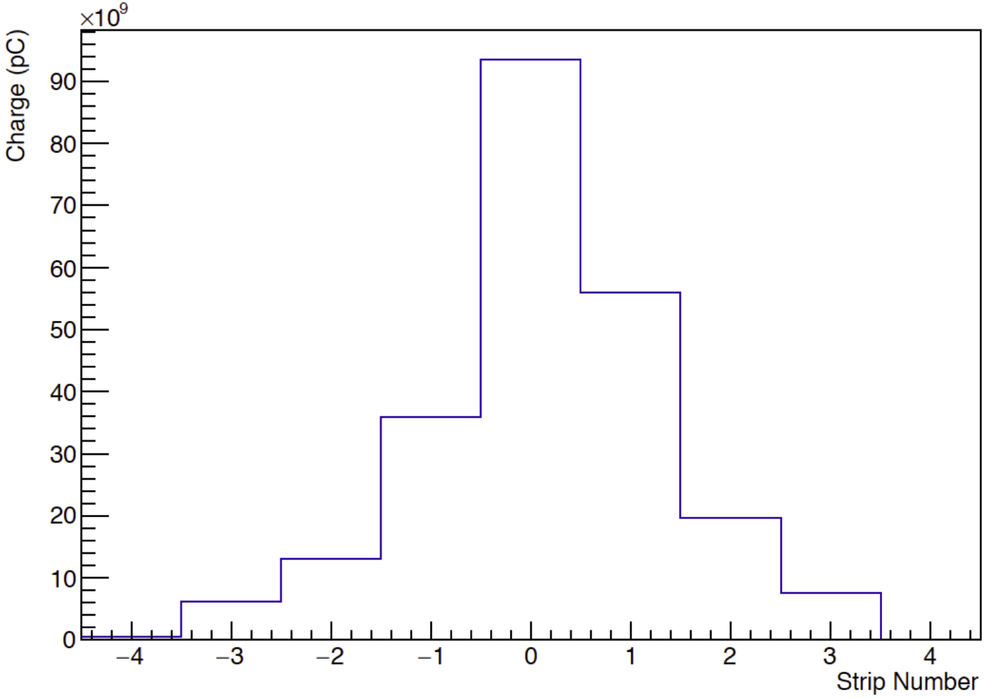


Shaping Function



Final Output Signal

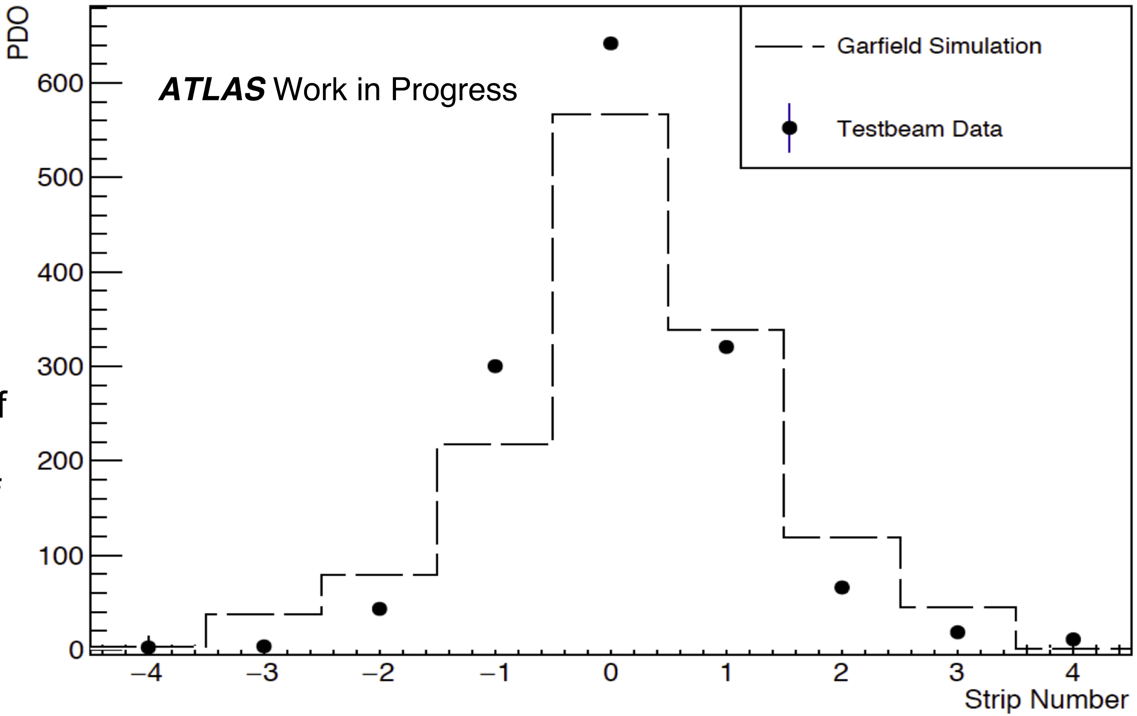
Charge Distribution of Strips



- Strip with max charge is centre strip
- Plot peak values to determine charge distribution
- Values are averaged over multiple simulations

Comparison with Test Beam

- Test beam measures Peak Detector Output (PDO) using 10-bit ADC
- Monte Carlo is scaled to PDO
- Goodness of fit corresponds to an **RC value of 38 ns/mm²**
- This corresponds to a resistance of 190 kΩ for the resistive layer with prepreg/resistive layer thickness of 200 μm
- **Agrees well with construction parameters of tested sTGC with RC of 40 ns/mm² and resistance of 200 kΩ at 200 μm**



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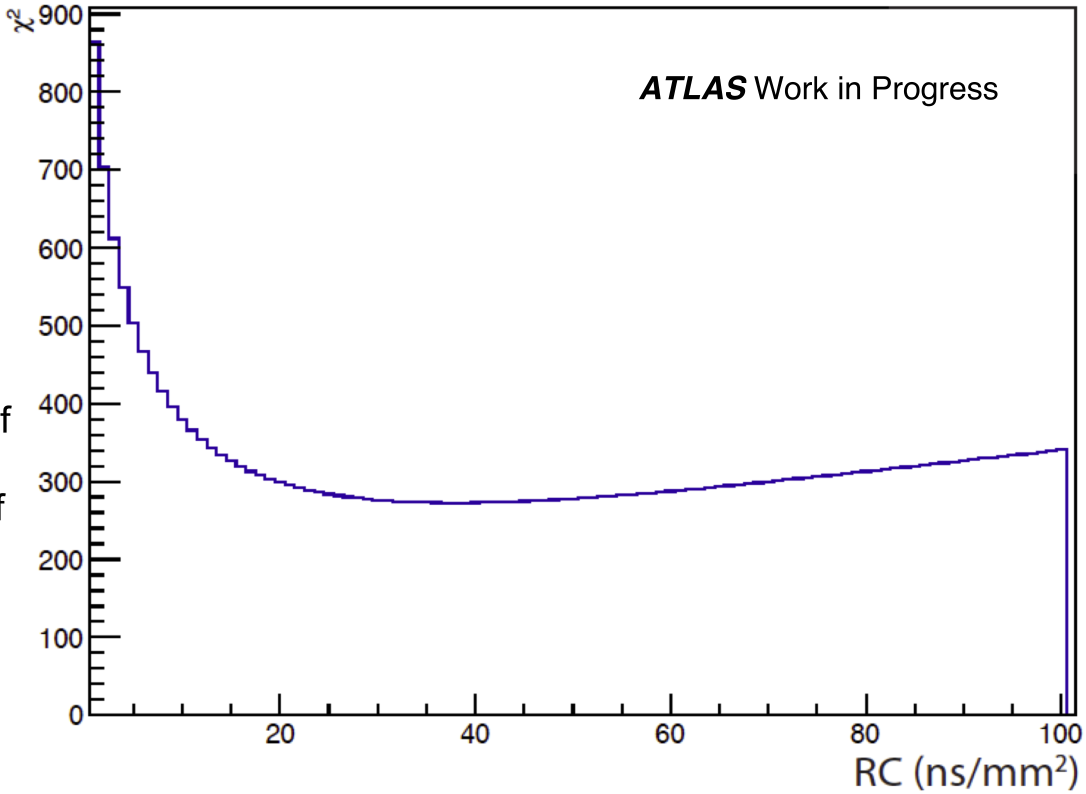


Time of Arrival of Electron Clusters

Results from ATLAS NSW Technical Design Report

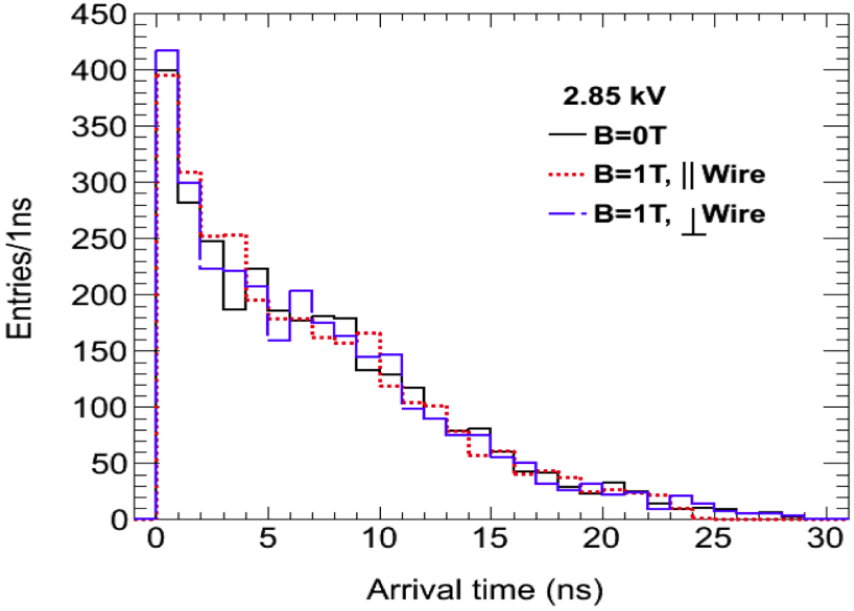
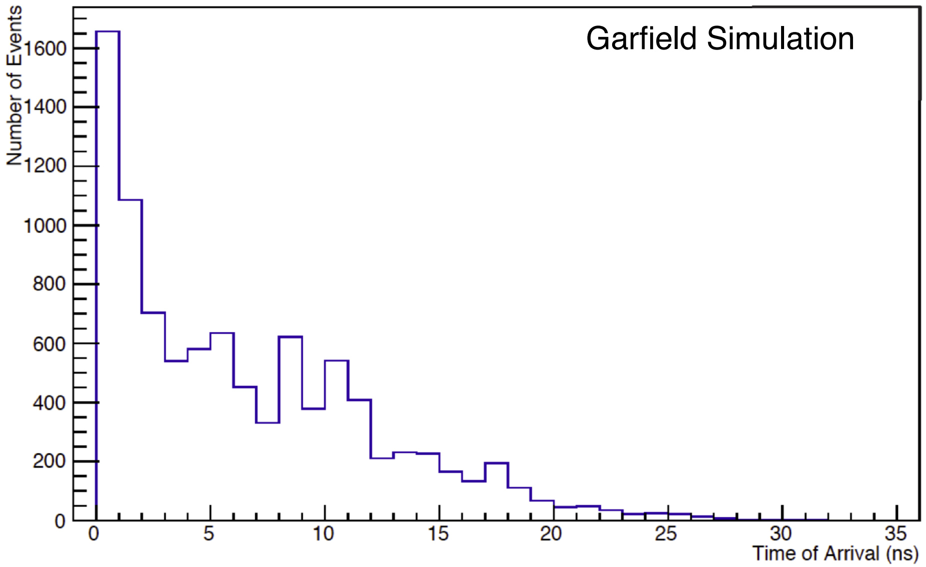


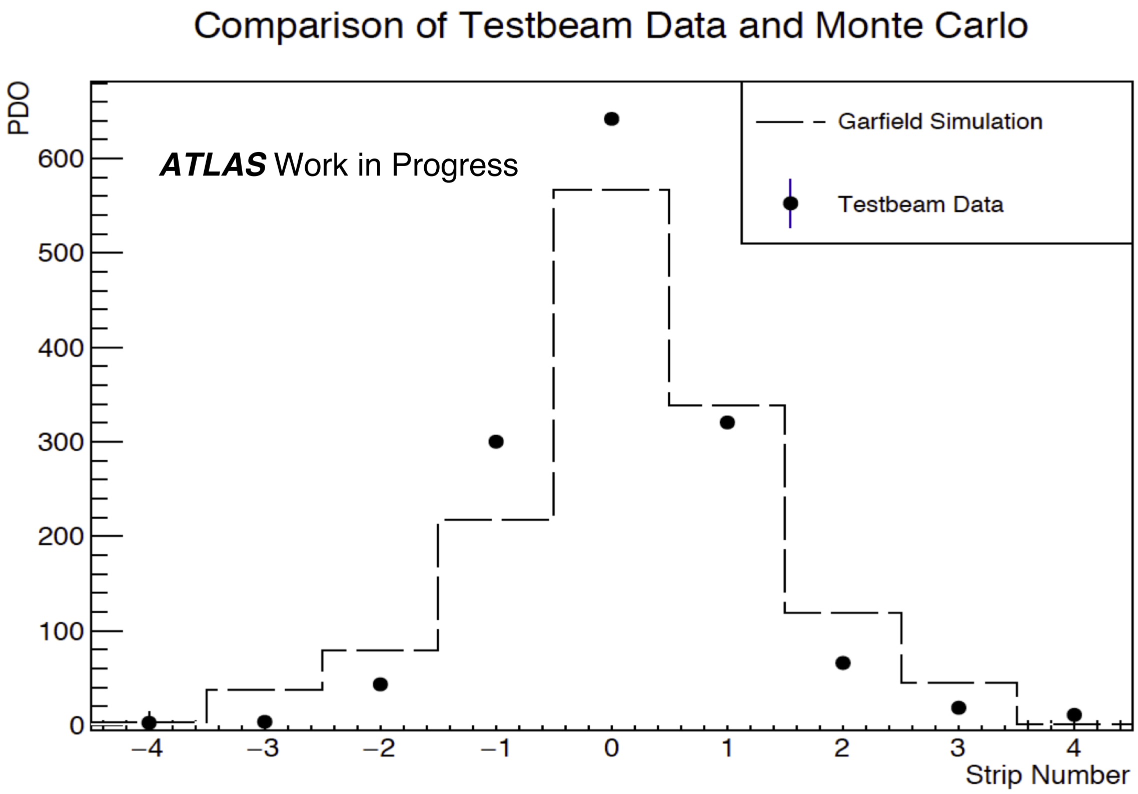
Image obtained from ATLAS Collaboration "ATLAS New Small Wheel Technical Design Report," CERN-LHCC-2013-006 ATLAS-TDR-20-2013



Arrival time of clusters to the wire is in accordance with known results

Conclusion

- Ramo's theorem can be used to determine charge induced on surfaces
- Study of signal generated on anodes (wires) and cathodes (pads & strips) of ATLAS sTGC
- By considering the factors that contribute to the final signal formation, our simulations effectively characterize the behaviour of the sTGC



Thank You!