MRPC Simulation

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SoLID MRPC

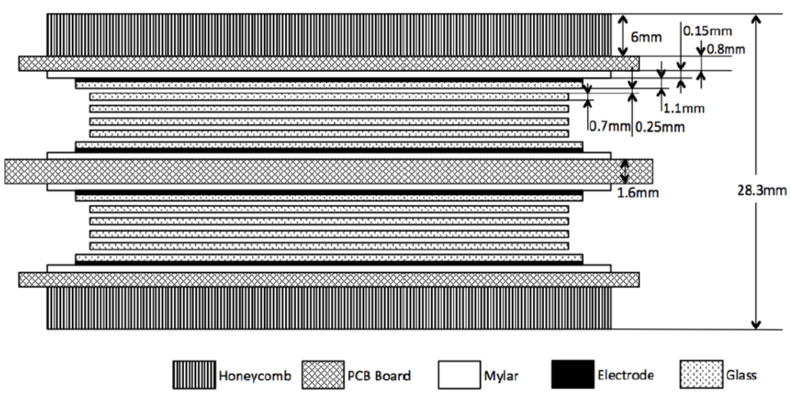
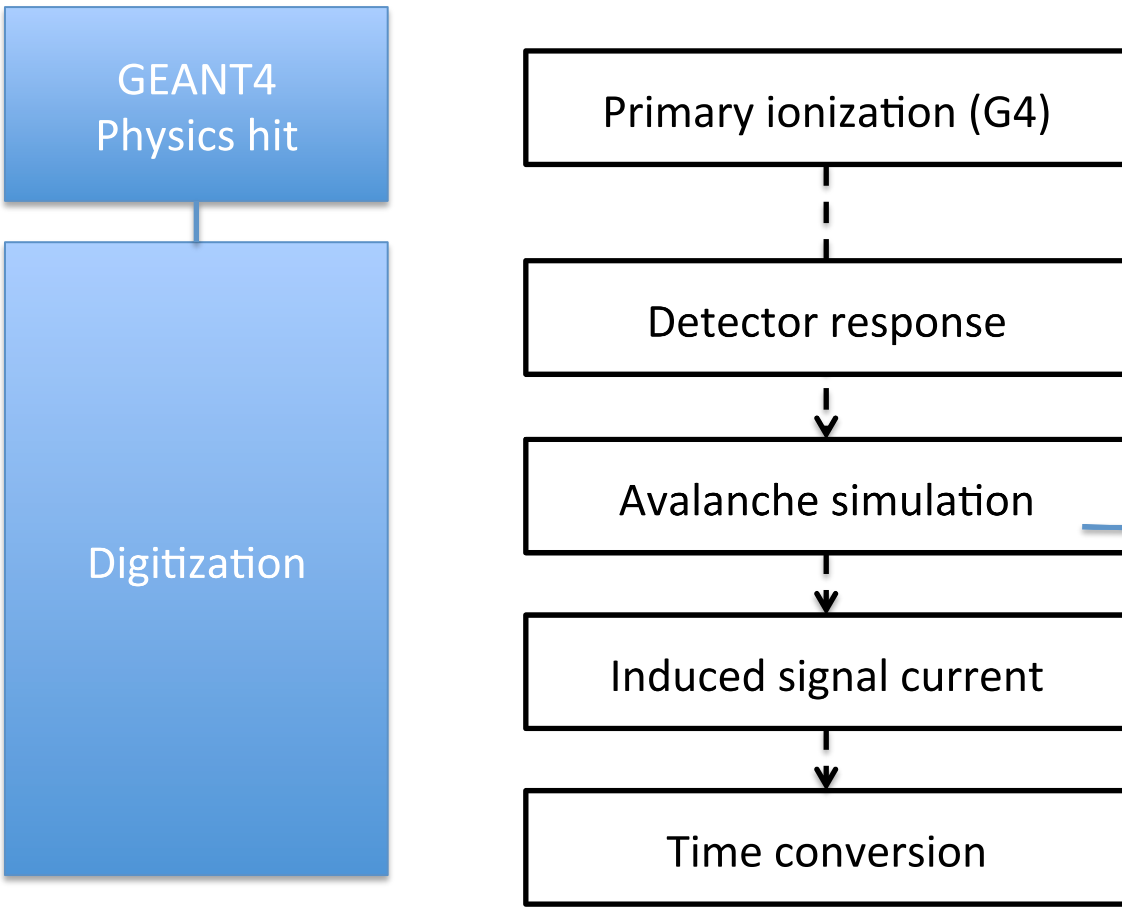


Figure 108: The structure of the MRPC prototype

- Multi-gap Resistive Plate Chamber (MRPC) serves as TOF (pion/kaon separation)
- Specifications from the pCDR design (10 gas gaps with each 0.25mm width, 0.7 mm of glass plates)
- gas mixture: $C_2F_4H_2$ (90%) : SF_6 (5%) : iso-C_4H_{10} (5%)
- Operating HV: 6.6 kV (E = 106kV/cm)

Fast digitization software for MRPC

< Basic scheme >



Characterized by the minimum ionization energy.

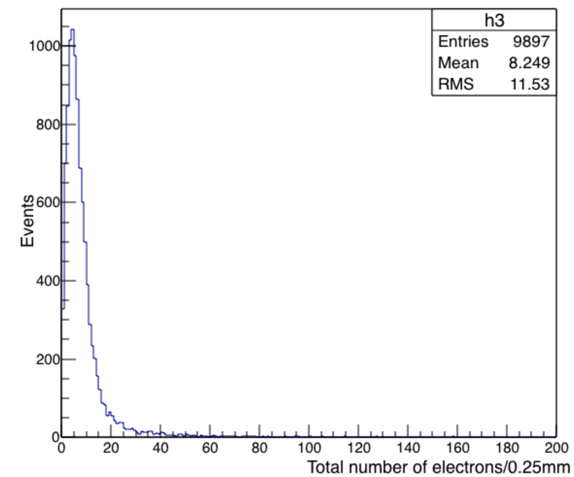
Ionization and attachment, drift velocity, ...
(currently using the parameters from the BESIII MRPC using MAGBOLTZ)

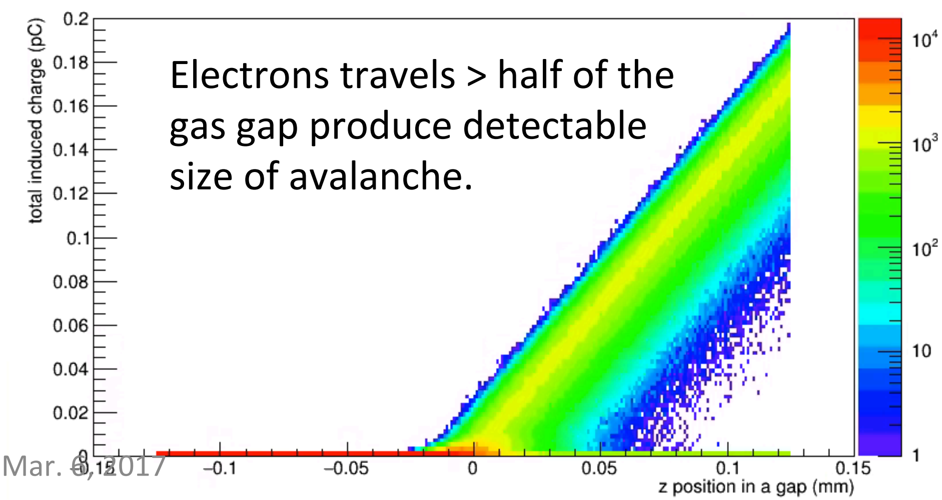
Ramo's theorem

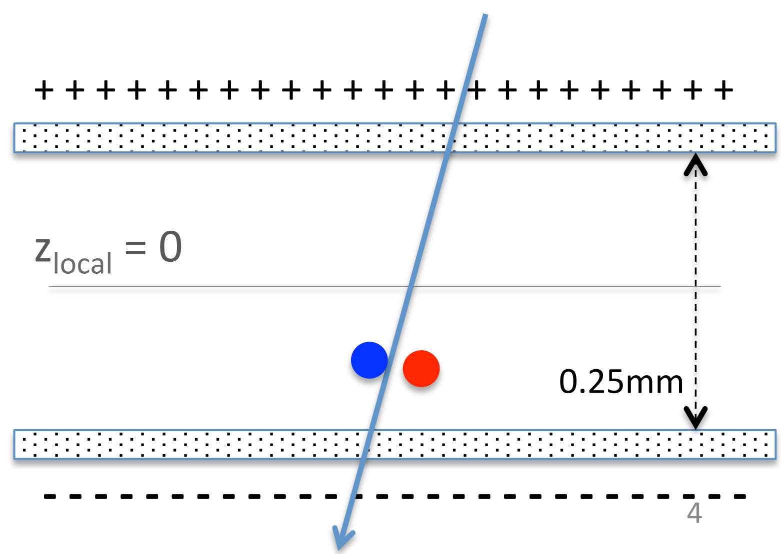
$$i(t) = E_w \cdot v \cdot e_0 \cdot N(t)$$

Primary Ionization

- Primary ionization: N_ion = E_dep / E_ion
  - N_ion: # of primary E-ion pairs
  - E_dep: energy deposit (Geant4)
  - E_ion: minimum ionization energy (set to 20 eV)
- Assume Poisson distribution with a mean of (E_dep/E_ion)
- Random distribution of electrons from primary ionization along the gas gap.







Avalanche simulation

- Starting with 1-D model (Nucl. Instrum. Meth. A 500 (1-3) (2003) 144)
- Avalanche development can be characterized by two coefficient: Townsend coefficient (α) and attachment coefficient (η)
- P(n,x): probability for an avalanche started with a single electron to contain n electrons after distance x
- General solution is given as:

$$P(n,x) = \begin{cases} k\dfrac{\bar{n}(x)-1}{\bar{n}(x)-k}, & (n=0) \\ \bar{n}(x)\left(\dfrac{1-k}{\bar{n}(x)-k}\right)^2\left(\dfrac{\bar{n}(x)-1}{\bar{n}(x)-k}\right)^{n-1}, & (n>0) \end{cases}$$

$$\bar{n}(x) = e^{(\alpha-\eta)x}$$

(average number of electrons)

$$k = \frac{\eta}{\alpha}$$

Avalanche simulation

- Single gap avalanche simulation

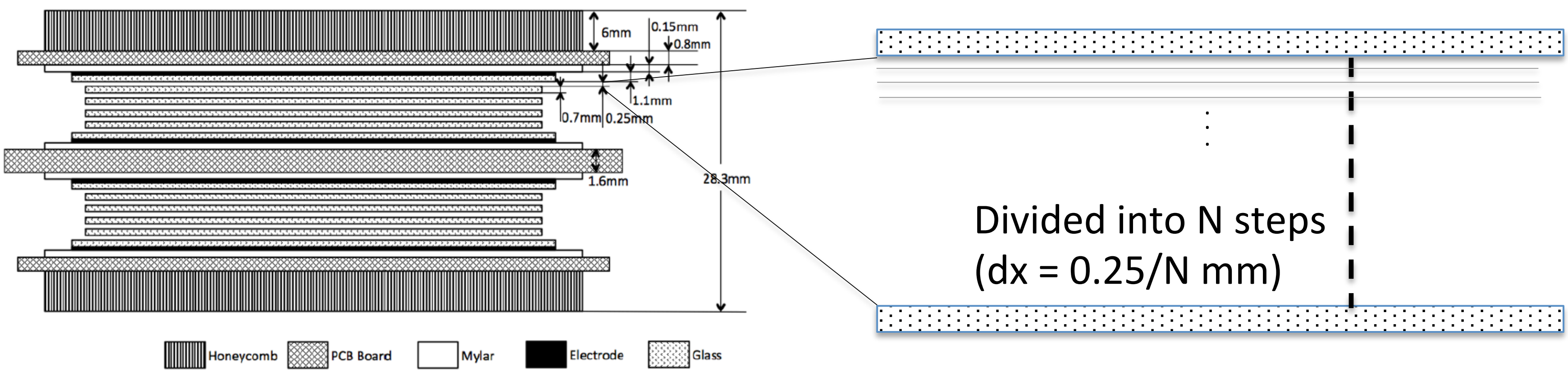
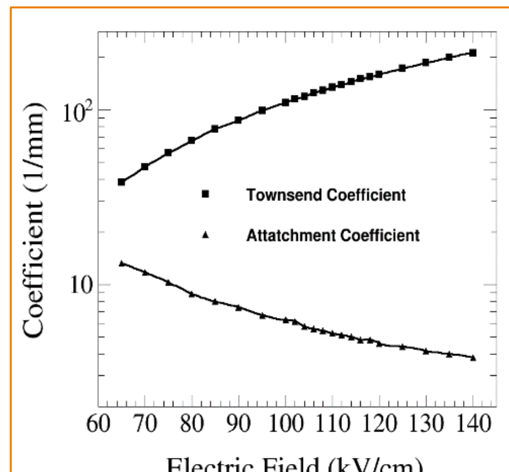


Figure 108: The structure of the MRPC prototype

By Fenfen An (using MAGBOLTZ)



- Divide the gas gap into N steps
- For each step dx, calculate the number of electrons with a probability for ionization/attachment
- Loop over all electrons until they reach to the end of the gap

Avalanche simulation

- Once n >> 1, it becomes a very time consuming process.
- Apply an effective model once n becomes large
  - Central limit theorem: # of electrons at x+dx can be obtained by drawing a random number from a Gaussian with mean and sigma of
  - Switch to the effective model if n > 200

- Space charge effect:
  - Exponential avalanche growth stopped by space charge effect
  - Set a limit (simplified space charge effect): 1.5e7

Avalanche simulation test

- Avalanche by a single electron in a single gap

From the NIM paper
(α = 13/mm, η = 3.5/mm)

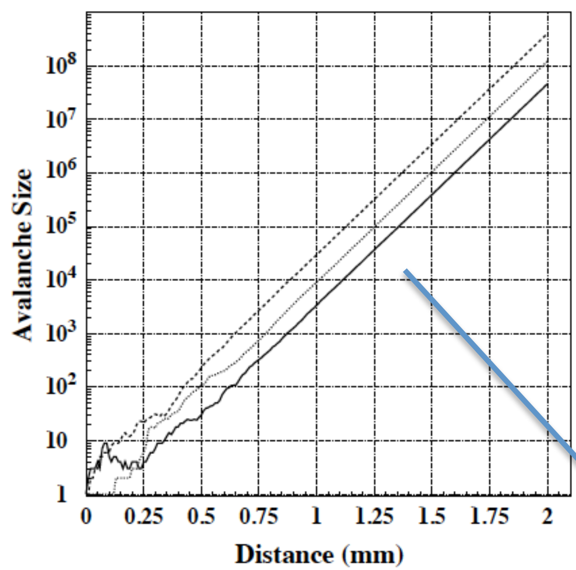
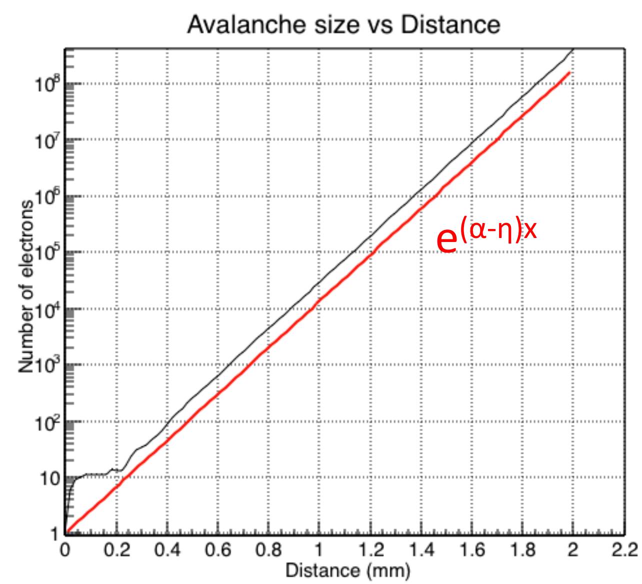


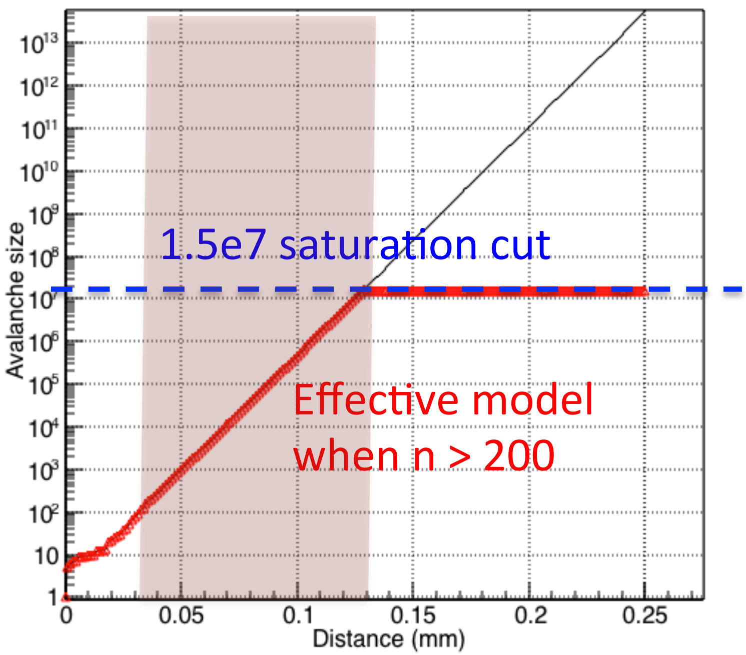
Fig. 6. Avalanches started by a single electron at $x = 0$ for $\alpha = 13/\text{mm}$, $\eta = 3.5/\text{mm}$. We see that the very beginning of the avalanche decides on the final avalanche size. Once the number of electrons is sufficiently large the avalanche grows like $e^{(\alpha-\eta)x}$.

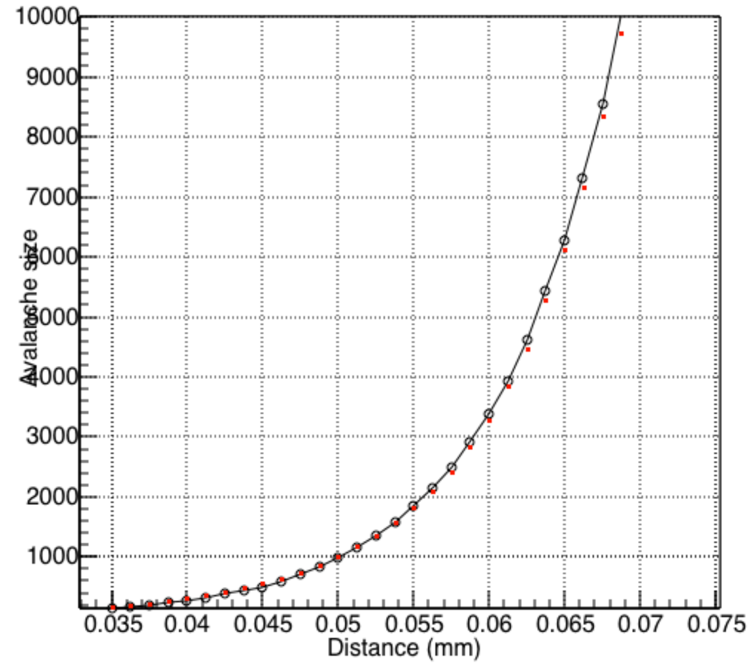
Using our simulation module



Different step size
difference in the early avalanche
→ decides final avalanche size

Avalanche simulation





< SoLID MRPC operating condition >
- E = 108 kV/cm
- Townsend coefficient (α) = 129/mm
- Attachment coefficient (η) = 5.435/mm
- Drift velocity = 0.201 mm/ns

- Used the same random seed for the comparison.
- Only minor difference in the avalanche size between the general solution and the effective model.

Induced signal

- Induced signal calculated by Ramo's theorem
- Weighting field is calculated with # of gaps, gas gap and glass plate width, permittivity of resistive plate

Drift velocity

Induced current: $i(t) = E_w \cdot v \cdot e_0 \cdot N(t)$

Weighting field

$$E_w = \frac{\varepsilon_r}{(n+1)b + nd\varepsilon_r}$$

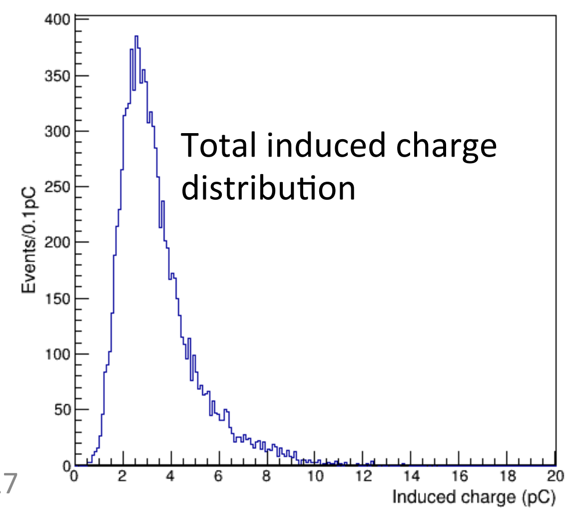
ε_r Glass permittivity

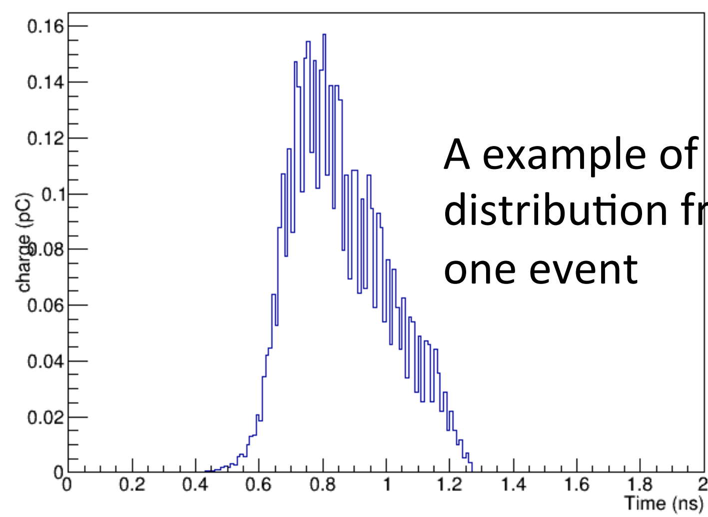
n gas gaps

b: thickness of a glass plate

d: gas gap width

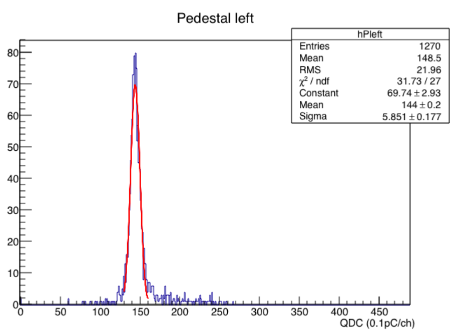
- 200 MeV electron MC

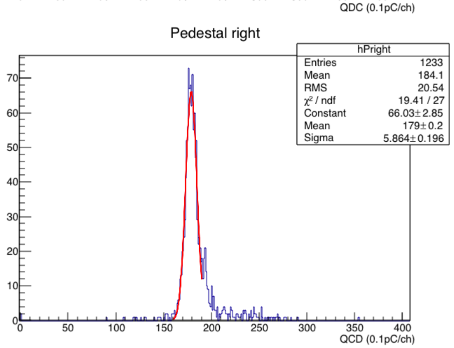




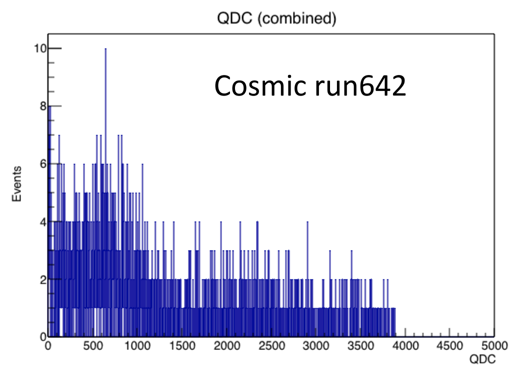
Cosmic data analysis

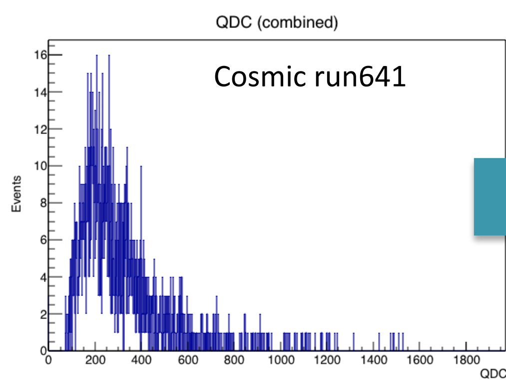
- Compare the MC output with real data: xcheck and tuning of MC
- Cosmic ray data @ Tsinghua Univ. for various HV settings.
- Analyzing data with HV = 6.6kV
- Need to do further analysis

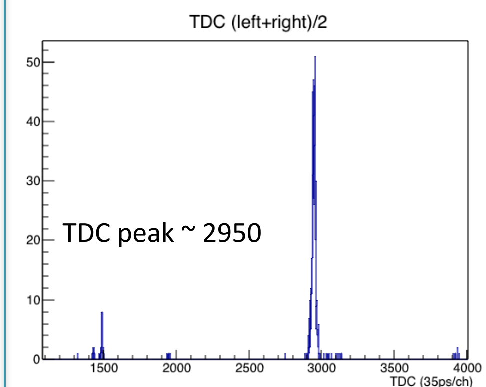


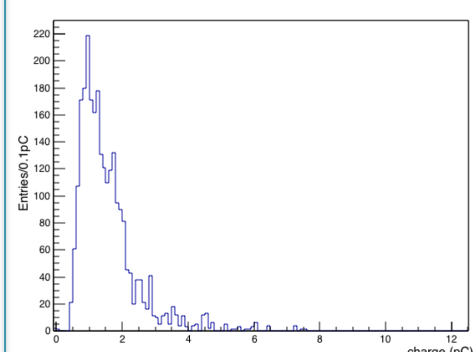


Pedestal of each strip end



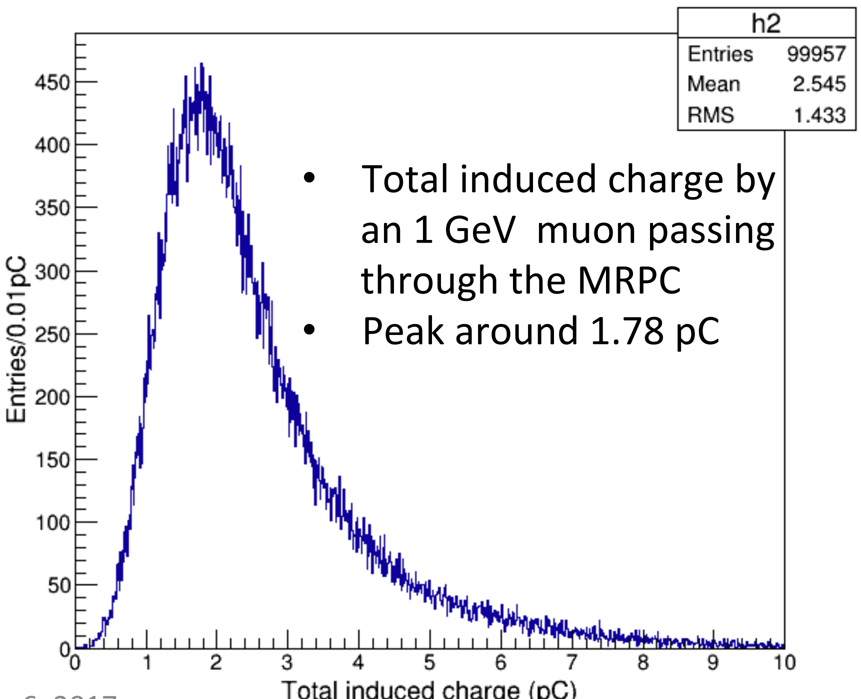




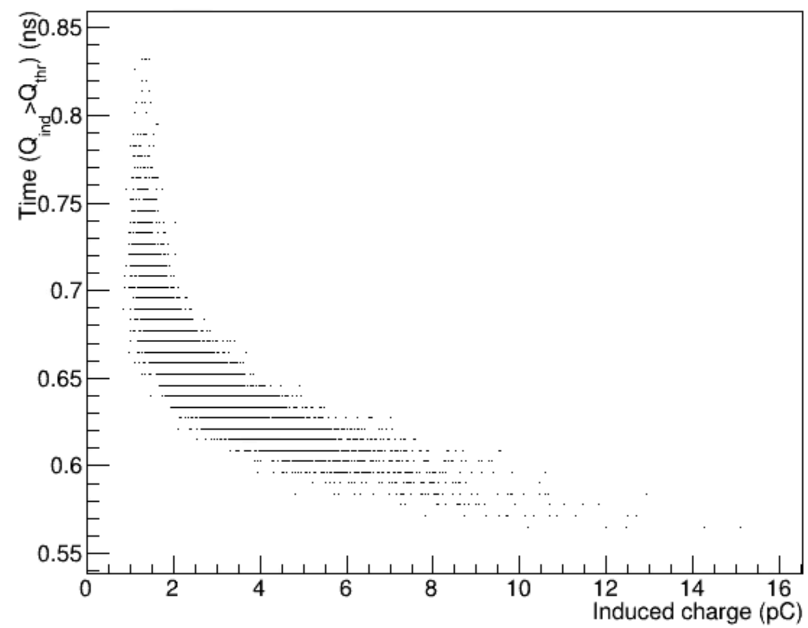


Muon simulation

- Shooting 1, 3, 5 GeV muons to a fixed position (no shift included)
- Induced charge peak at ~1.78 pC
- Leading time ($Q_{ind} > Q_{threshold}$) - charge correlation



- Total induced charge by an 1 GeV muon passing through the MRPC
- Peak around 1.78 pC



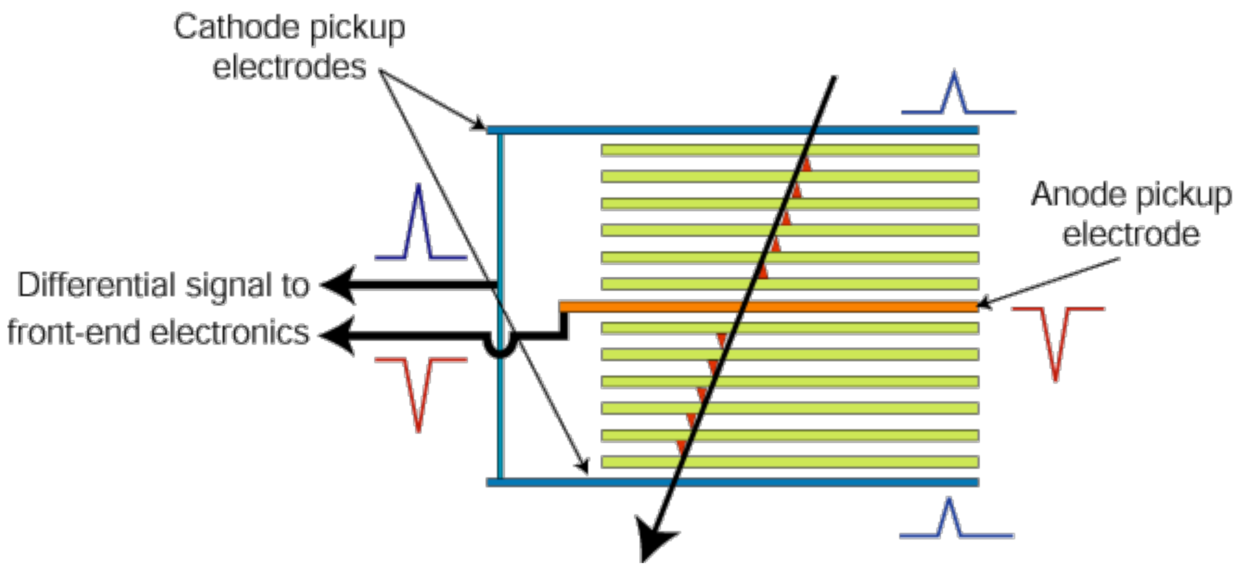
Summary

- Short term:
  - Cosmic test result - MC comparison
  - Implement readout configuration to MC (QDC, TDC output)
  - Correction, calibration, .. Input from data to MC
  - Efficiency, time resolution

- Long term improvement:
- Space charge effect:
  - Consider both radial and longitudinal directions
  - Dynamically calculate E field and gas parameters
- Garfield + Geant4:
  - Making use of the existing module from SBU TPC simulation.

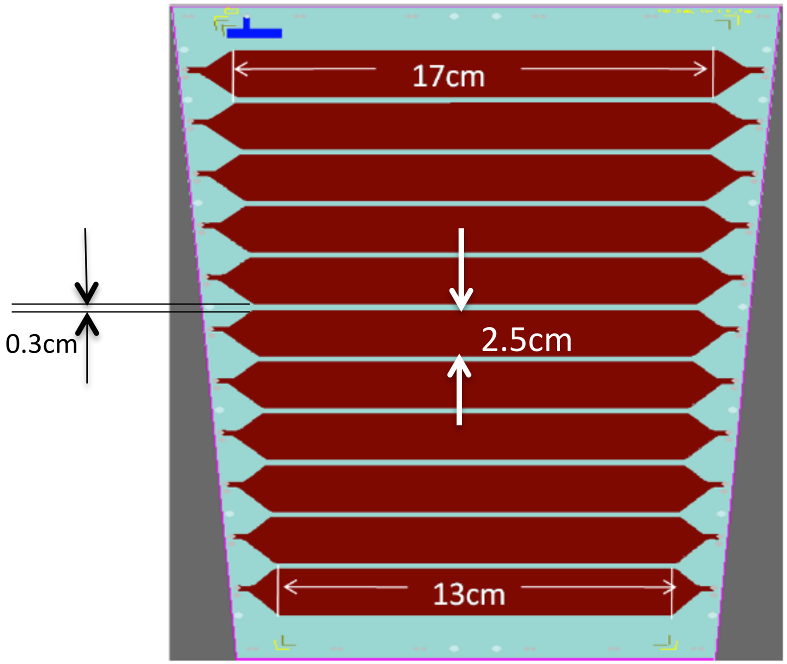
Backup

MRPC operating principle



- Charged particle ionizes the gas and electrons are multiplied by the high E field (avalanche)
- Internal resistive plates are electrically floating
- Resistive plate is transparent to the fast induced signal on the electrode
- Multi-gap → narrow gas gap, good time resolution

Readout



- Readout at both end of the strip
- Need to implement the readout to MC
  - resolution
  - Strip identification
  - Charge sharing?