Study on RPC signal attenuation

Xiangyu Xie
On behalf of RPC lab of
University of Science and Technology of China

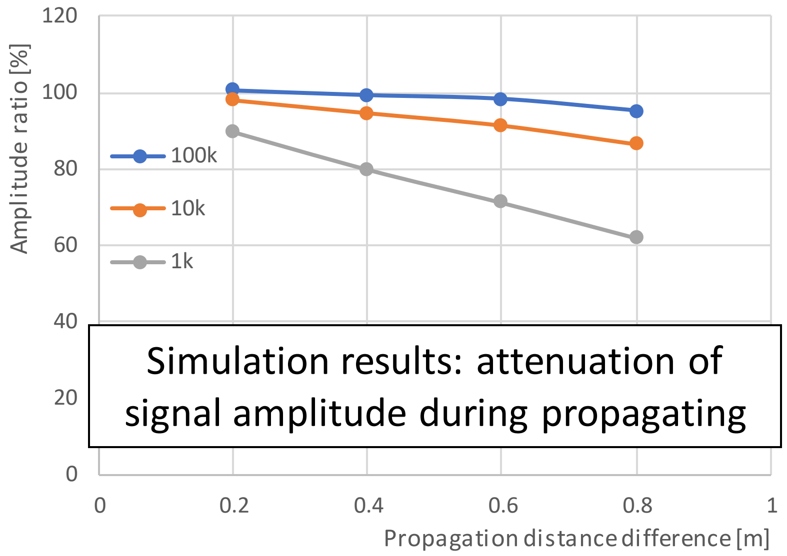
xiangyu.xie@cern.ch

Outlines

1. Motivation
2. Experiment setup
3. Offline analysis
4. Results
   a) Charge attenuation
   b) Amplitude attenuation
   c) Frequency attenuation
5. Potential countermeasure
6. Summary and conclusions

Motivation

- Thin-gap RPC for ATLAS Phase II upgrade has smaller avalanches
- Simulation indicates the existence of 'attenuation' [backup 0]
  - 'Attenuation' means the reduction or loss of charge, amplitude and frequency of the signal readout from one strip
- Positive correlation between attenuation and signal propagation distance along readout strips
- Negative correlation between attenuation and graphite surface resistivity ρ_s
  - Higher ρ_s also brings larger voltage drop on graphite
  - To limit the voltage drop, lower limit of ρ_s is needed



Simulation results: attenuation of signal amplitude during propagating

BI RPC in HL-LHC:

Surface resistivity: $\rho_s = 600\ k\Omega/\square$

Hit rate: $r = 1200\ Hz/cm^2$

Total charge per hit: $c = 6\ pC$

Length: $L = 2.4\ m$

bar-like electrode

Simplified ATLAS BI RPC graphite model

Maximum $\Delta V = \frac{1}{2} r \frac{c}{2} \rho_s L^2 = 62\ V$

Experiment setup: hardware

❖Gas gap

- 1.2 m in length
- Similar design to ATLAS BIS8 RPC except ρ_s
- Graphite $\rho_s = 10\ k\Omega/\square, 100\ k\Omega/\square, 1\ M\Omega/\square, 10\ M\Omega/\square$
- Ordered from GT (General Technica)

❖Readout panel

- 1.0 m in length
- Readout strips: $25\ mm$ width separated by $2\ mm$
- Similar design to ATLAS BOE RPC (foam filling)
- Ordered from GT (General Technica)

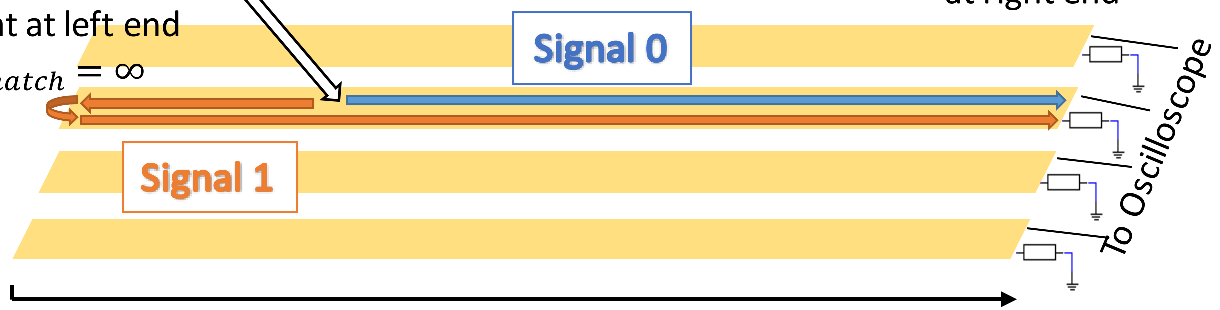
❖Oscilloscope

- Sampling rate: 20 GS/s
- Bandwidth: 4 GHz
- External cosmic-ray trigger from coincidence of scintillators

Experiment setup: readout scheme

❖ Readout scheme

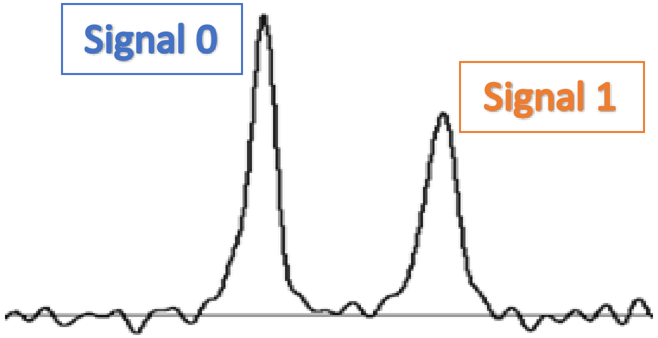
1. Consider signal 0 & signal 1 induced identically by muon hit at distance l
2. Signal 0 gets absorbed at right end by the matching resistor
3. Signal 1 gets reflected at left end, absorbed at right end after signal 0, with longer propagation distance
4. At right end waveforms recorded by oscilloscope without amplifiers



Readout scheme

❖ Leading edge difference locates the hit

- Leading edge difference $= \frac{2}{velocity} \times l$
- Propagation distance difference $= 2 \times l$
- Positioning accuracy $< 10\ mm$ [backup 1]



Waveforms in time domain

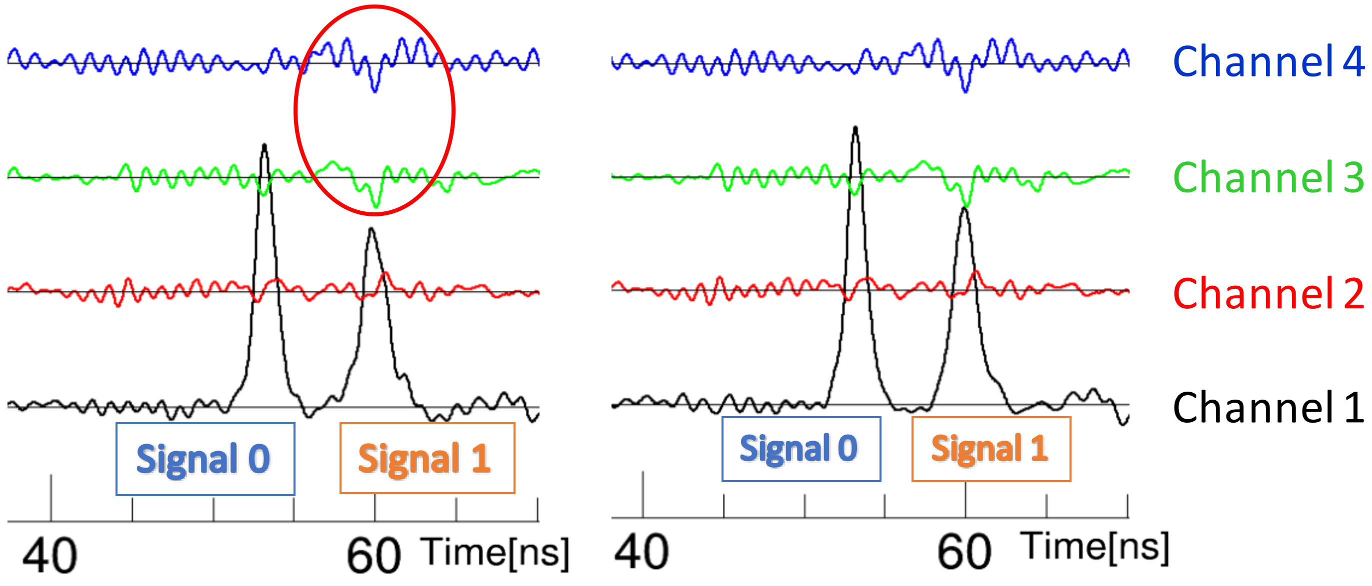
Offline analysis: LPF & calibration

❖ Low-pass filter (LPF)

- FWHM of signal of thin gap RPC $\approx 2\ ns$
- $1\ GHz$ bandwidth filter to eliminate high frequency noise

❖ Noise calibration

- After signal 0 is induced on channel 1, 'noise' occurs on all channels
- Signal 1 gets distorted
- Calibrated by subtracting the waveform of nonadjacent channel (channel 3) [backup 3]
- After calibration, waveforms of signal 1 are undistorted
- RMS increases



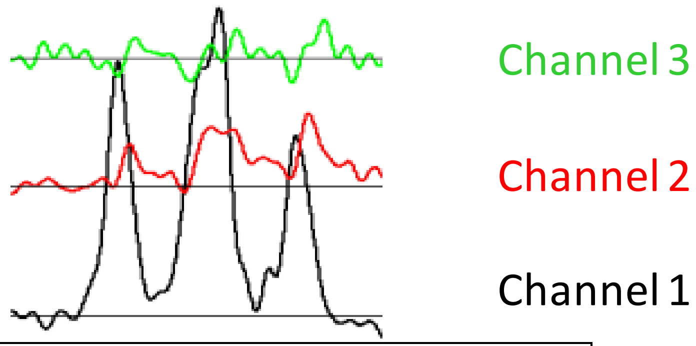
Without calibration

After calibration

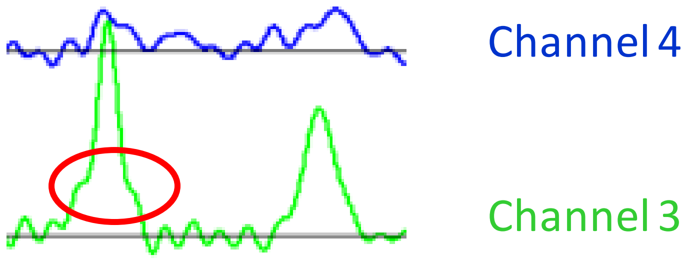
Offline analysis: selection of events

❖Selection of events

1. RMS (noise) $< 400\ \mu V$
2. Number of peaks $= 2$, to cut muon bundles events
3. Overlapped signal 0 and signal 1
4. Signal amplitude $> 5\ mV\ \&\& < 29\ mV$ (full scale of oscilloscope $= 30\ mV$)
5. Abnormal signal width due to noise [backup 2]
6. Outliers: charge of signal 1 $> 1.05 \times$ charge of signal 0



Selection 2 example: 2 muons hit on one strip 'simultaneously'



Selection 5 example: signal 0 got broadened by noise

Charge attenuation: definition

- Definition of charge
  - Integration between leading edge and trailing edge at 10% of peak
  - Charge ratio: $\frac{\text{charge of signal 1}}{\text{charge of signal 0}}$
- The charge ratio indicates the strength of charge attenuation
- The charge ratio is shown as a function of the propagation distance difference in 2D hist.
  - In the left end, signal 0 and signal 1 are partially overlapped, events are cut (signal width $= 3.4\ ns$, propagation velocity $= 230\ mm/ns$)

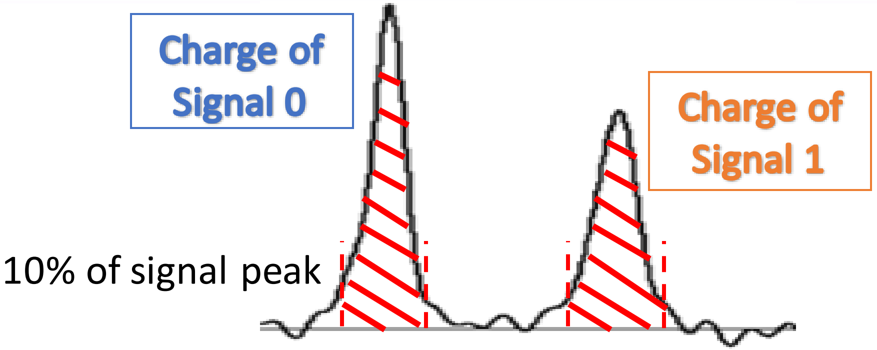
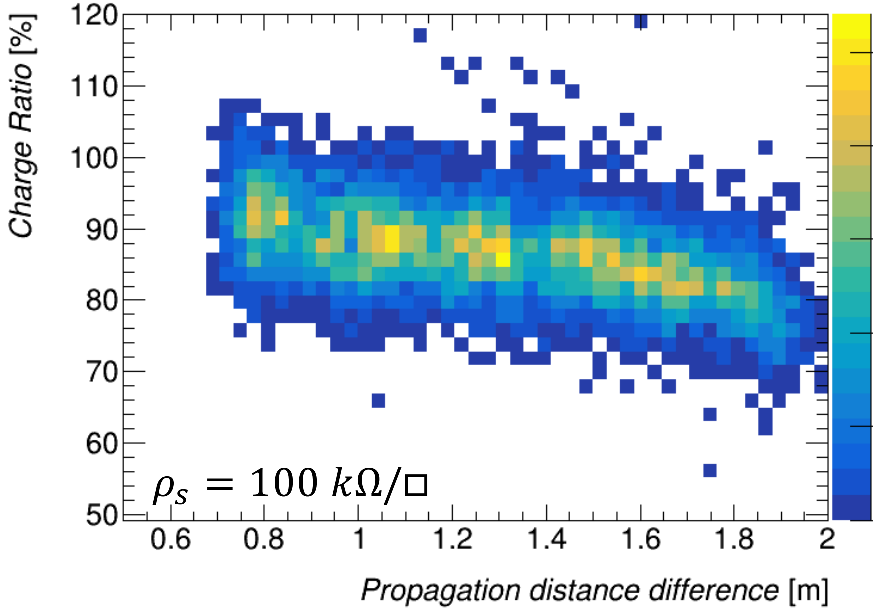
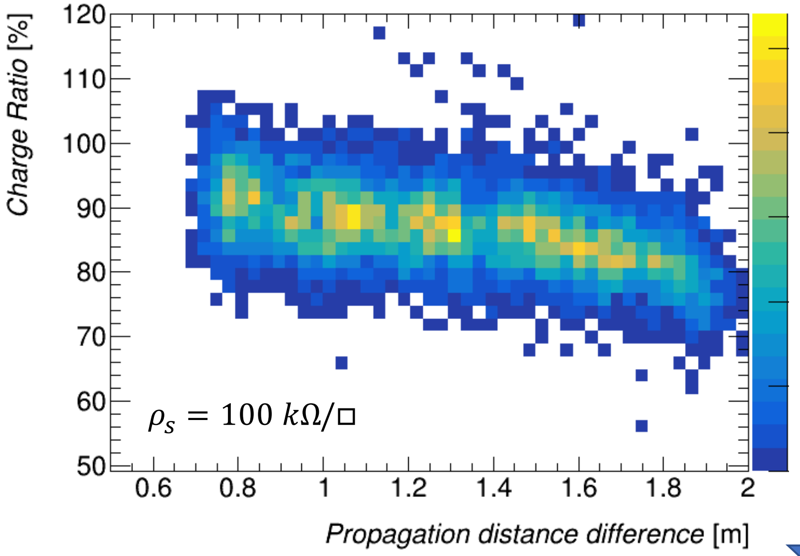


Illustration of charge

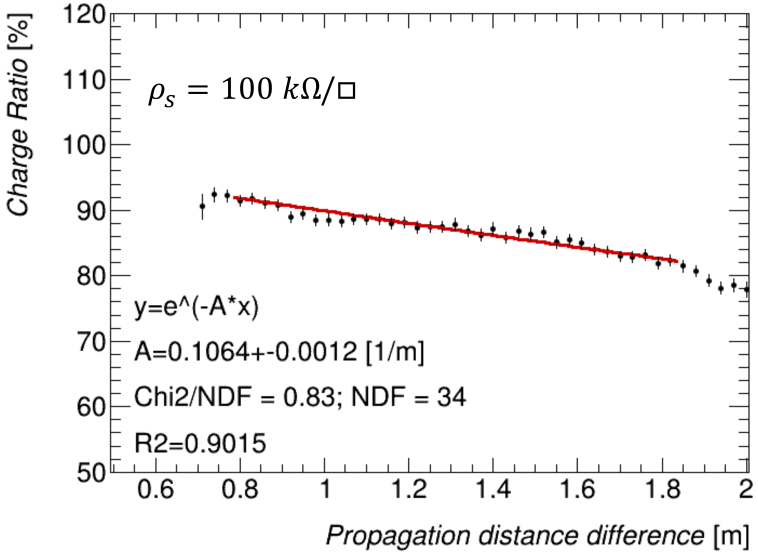


Charge attenuation: exponential fit

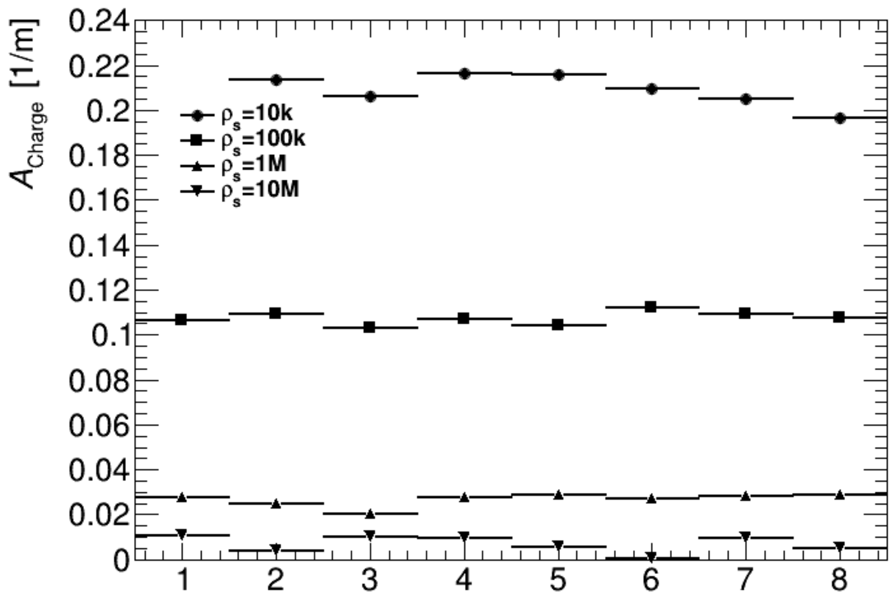
- **Profile X:**
  - Project the 2-D histogram into a profile histogram along X
  - Stat error: standard error of the mean of y of events in each x bin
  - Systematical error: because of the nonideal calibration [backup 3]
- **The charge ratio (y) VS. distance difference (x) could be represented by a fit function: $y = e^{-A_{\text{Charge}} \cdot x}$ (chi2 fit)**
  - Fit range: $0.78 - 1.84\ m$ (Scintillator coverage)
  - $A_{\text{charge}} = 0.106 \pm 0.001\ [\text{m}^{-1}]$
  - Chi2 and R2 indicate good fit quality which means negligible charge loss in signal reflection ($y(0) = 100\%$)



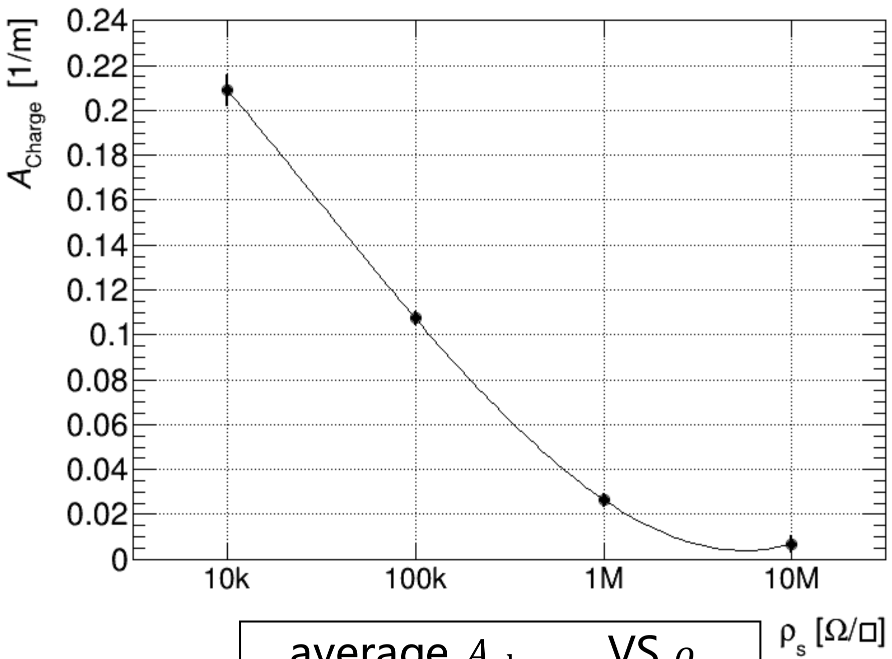
Profile X



Charge attenuation: combined results



A_{charge} distribution along strips

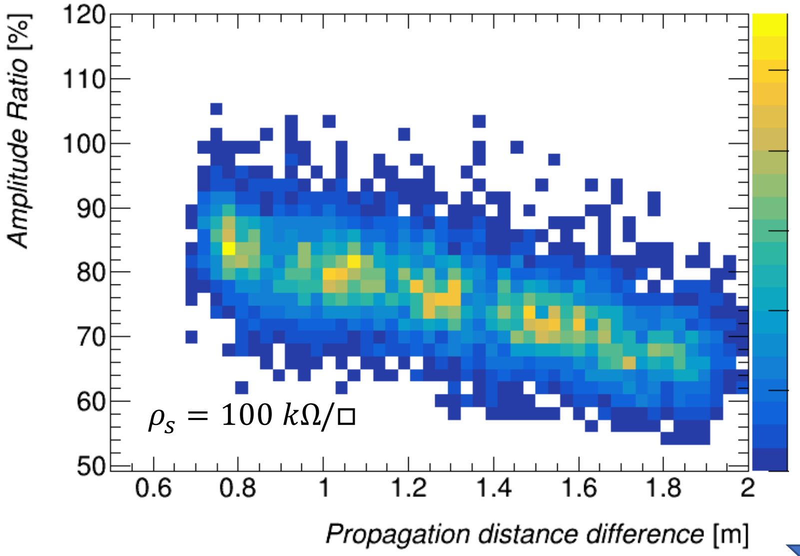


average A_{charge} VS ρ_s

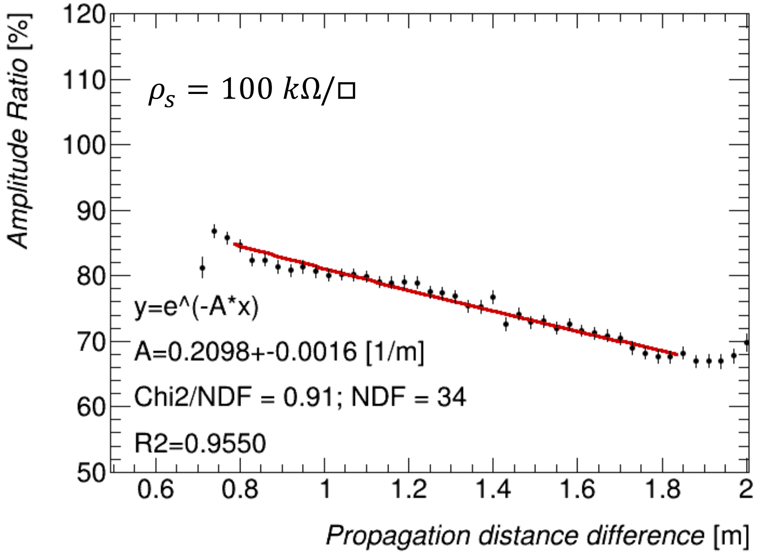
- A_{charge} strongly depends on graphite ρ_s
- When $\rho_s > 1\ \text{M}\Omega/\square$, A_{charge} approches 0
- For ATLAS BI RPC, maximum charge loss would $\approx 10\%$ ($\rho_s = 600\ k\Omega/\square$, propagation distance $= 2.4\ m$)

Amplitude attenuation: definition

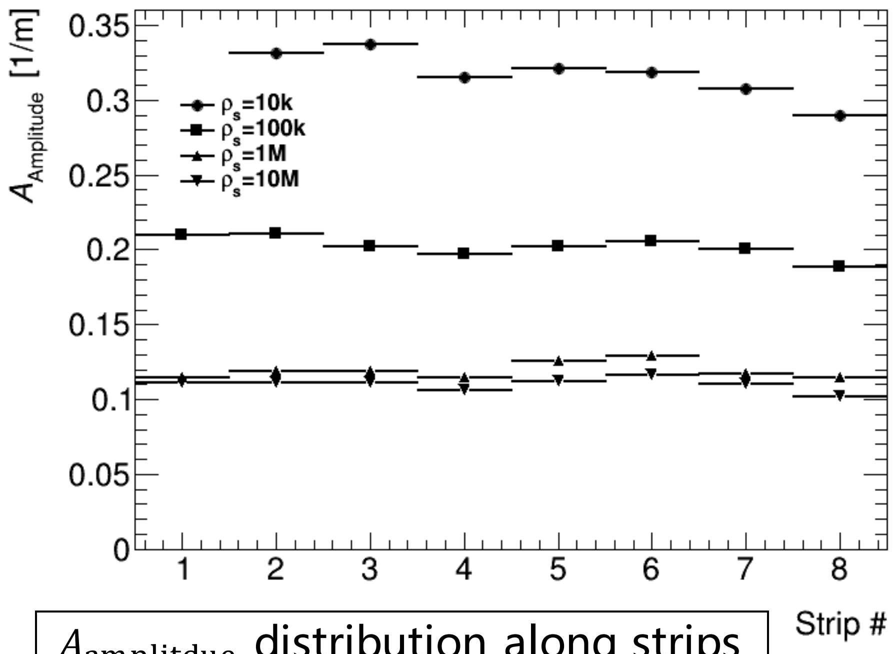
- Definition of amplitude
  - The peak of the signal
  - Amplitude ratio $= \frac{\text{amplitude of signal 1}}{\text{amplitude of signal 0}}$, as an indicator of the amplitude attenuation
- The amplitude ratio VS. distance difference could be represented by a fit function:
  $y = e^{-A_{\text{amplitude}} \cdot x}$
  - y stands for amplitude ratio
  - x stands for propagation distance difference
  - $A_{\text{amplitude}} = 0.210 \pm 0.002\ [m^{-1}]$
  - Chi2 and R2 indicate good fit quality



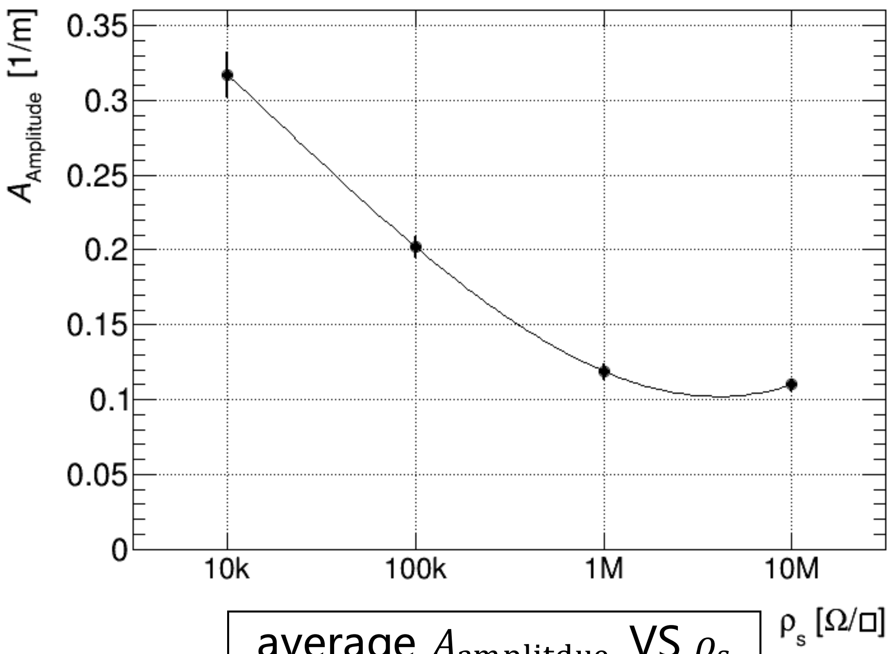
Profile X



Amplitude attenuation: combined results



$A_{\text{amplitdue}}$ distribution along strips

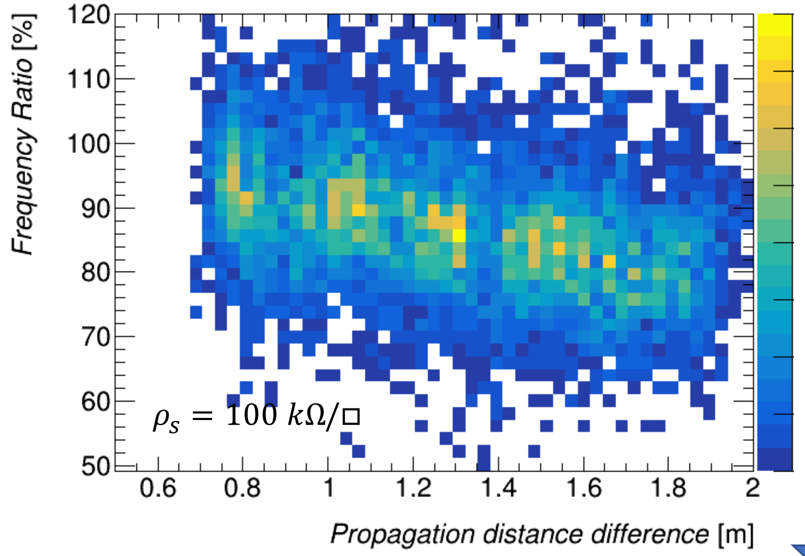


average $A_{\text{amplitdue}}$ VS ρ_s

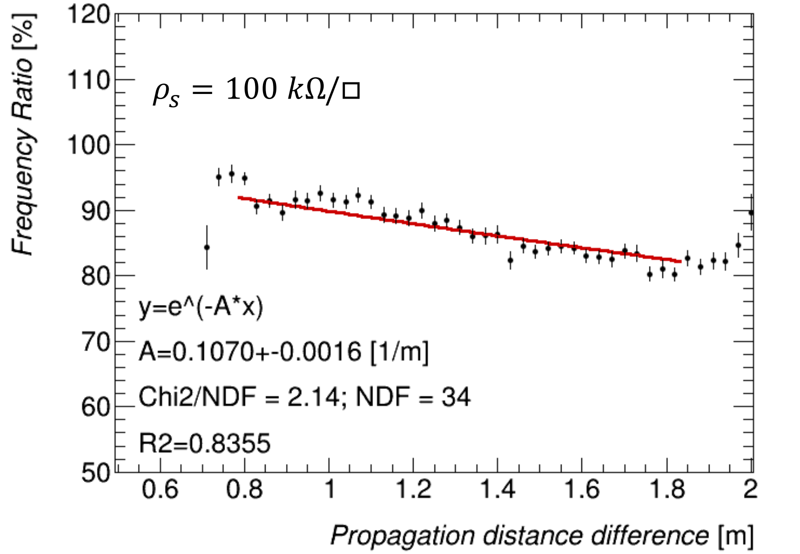
- $A_{\text{amplitude}}$ strongly depends on graphite ρ_s
- When $\rho_s > 1\ M\Omega/\square$, $A_{\text{amplitude}}$ approaches a constant value
- $A_{\text{amplitude}}$ has an upwards shift comparing to A_{charge}

Frequency attenuation: definition

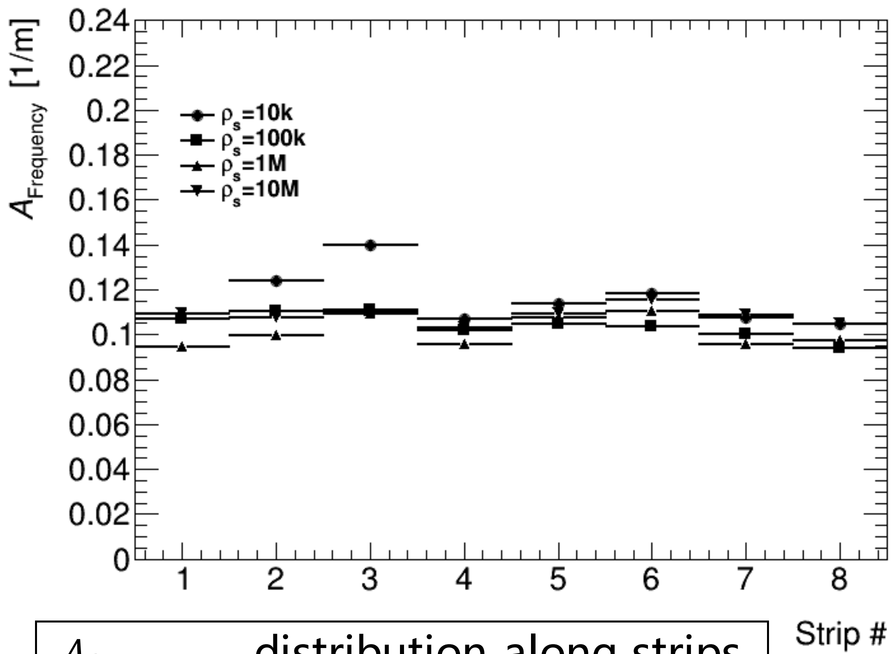
- Definition of frequency
  - Fourier transform hard to give frequency
  - 'Equivalent frequency' $= \frac{1}{\mathrm{FWHM}}$
  - Frequency ratio= $\frac{\text{frequency of signal 1}}{\text{frequency of signal 0}}$, as an indicator of frequency attenuation
  - Wider distribution in y axis due to fast RPC signals and limited sampling rate
- The frequency ratio VS. distance difference could be represented by a fit function: $y = e^{-A_{\mathrm{frequency}} \cdot x}$
  - y stands for frequency ratio
  - x stands for propagation distance difference
  - $A_{\mathrm{frequency}} = 0.107 \pm 0.002\ [m^{-1}]$



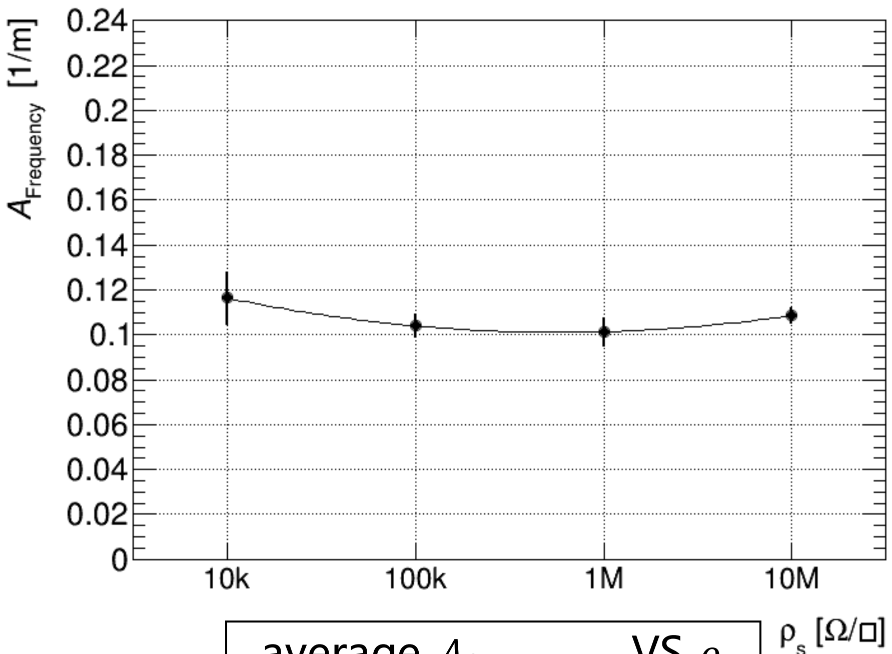
Profile X



Frequency attenuation: combined results



$A_{\mathrm{frequency}}$ distribution along strips



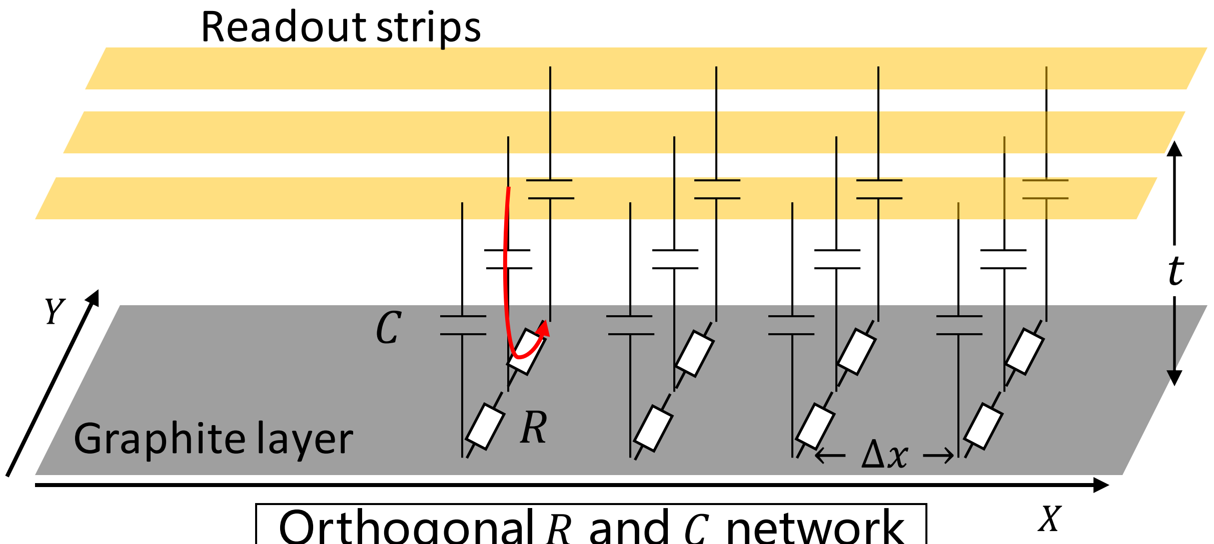
average $A_{\mathrm{frequency}}$ VS ρ_s

- $A_{\mathrm{frequency}}$ is observed not to depend on ρ_s
- $A_{\mathrm{amplitude}} - A_{\mathrm{frequency}} \approx A_{\mathrm{charge}}$, (i.e. all signals have similar shape) explains the shift between $A_{\mathrm{amplitude}}$ and A_{charge}
- Signal would be 23% wider after $2.4\ m$ propagation

Potential countermeasure

❖ Highly simplified model of readout strips and graphite

- C: equivalent capacitance between one strip and graphite per unit length
- R: equivalent orthogonal resistance between two equivalent capacitance per unit length, $\propto \rho_s$
- Orthogonal diffusion on graphite [ref 1]



Orthogonal R and C network of strips and graphite layer

❖ Potential countermeasure

- Split the graphite layer like readout strips with narrower spacings
- $R \to \infty$, not depends on ρ_s
- Effective in simulation [backup 4]

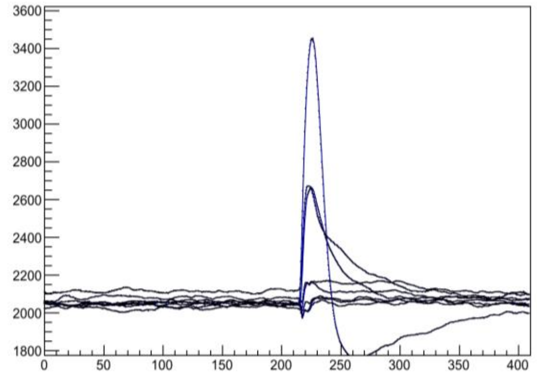
Splitting the graphite layer

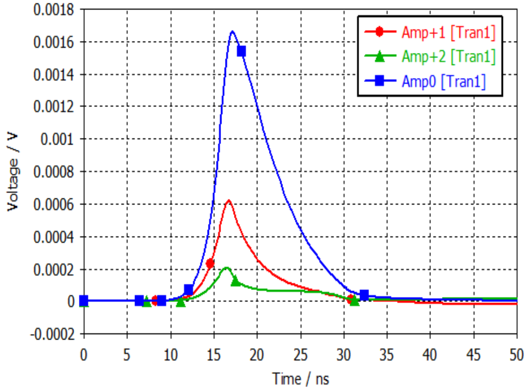
Summary and conclusions

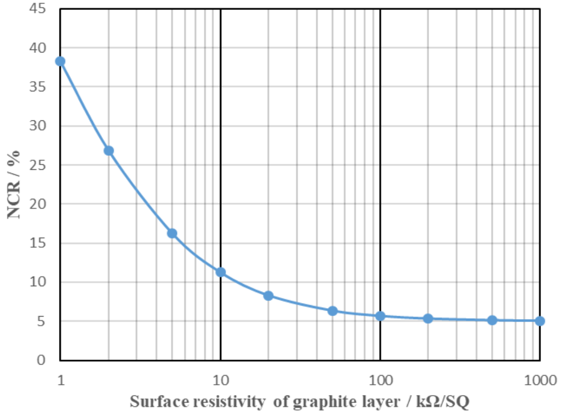
1. Charge, amplitude and frequency of the signal readout from one strip are attenuated while signal propagating along strips, the measurements on attenuation are given
2. Attenuation of charge could be suppressed by high ρ_S, while voltage drop on graphite should be considered
3. For ATLAS BI RPC, maximum charge attenuation $\approx 10\%$, may need to be considered in electronics configuration (e.g. by specifying the threshold of the discriminator at far end)
4. Splitting the graphite may suppress the attenuation of charge and limit the maximum voltage drop as well

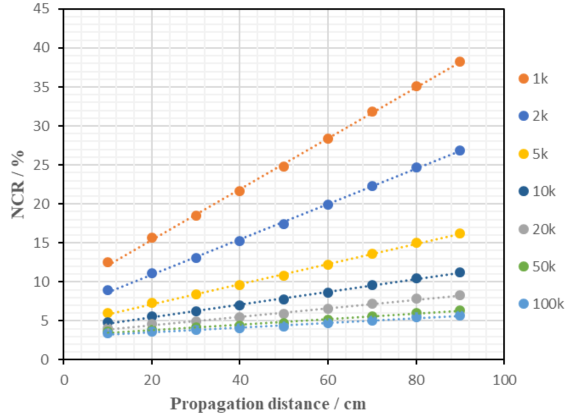
Backup 0: simulation method

- 3D PEEC method: (Partial element equivalent circuit)
  - Calculate the R, C, L, G network like finite-elementary-method
  - Surface resistivity could be simulated for the first time
- Could explain the large cross-talk problem
  - Caused by low graphite surface resistivity
- Published proceeding: [link]





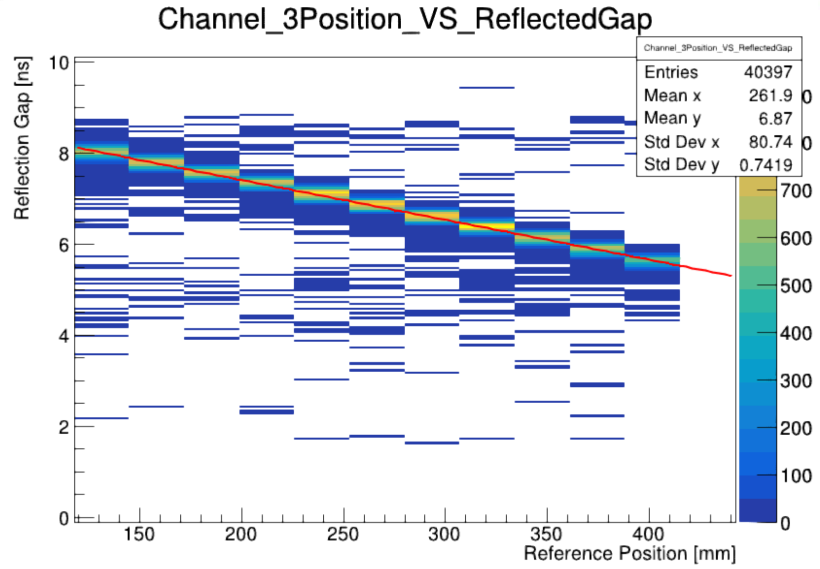


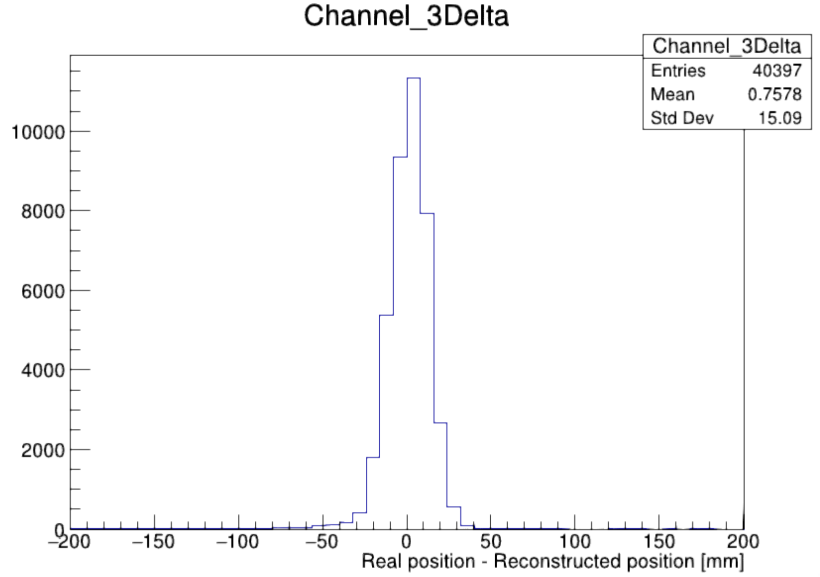


Backup 1: positioning accuracy

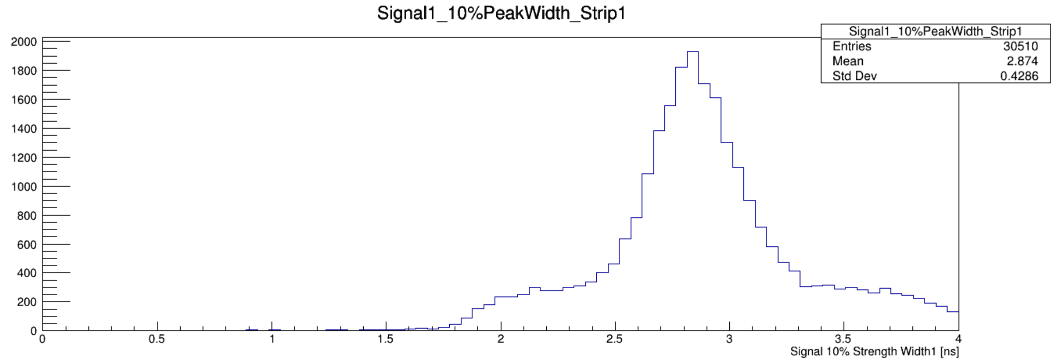
- With amplifiers
- Use orthogonal strips to give the reference position
- 5 GS/s sampling ADC and offline analysis

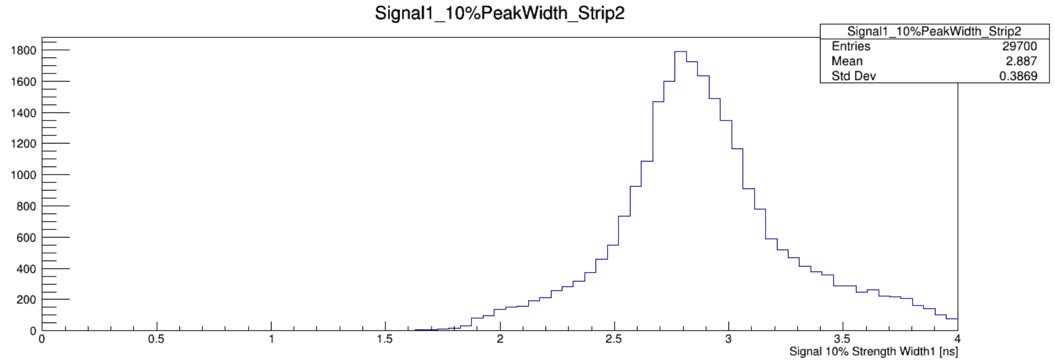
	Velocity [mm/ns]	σ_x [mm]
Ch0	241.2	9.1
Ch1	233.9	7.8
Ch2	230.4	7.8
Ch3	227.9	7.9

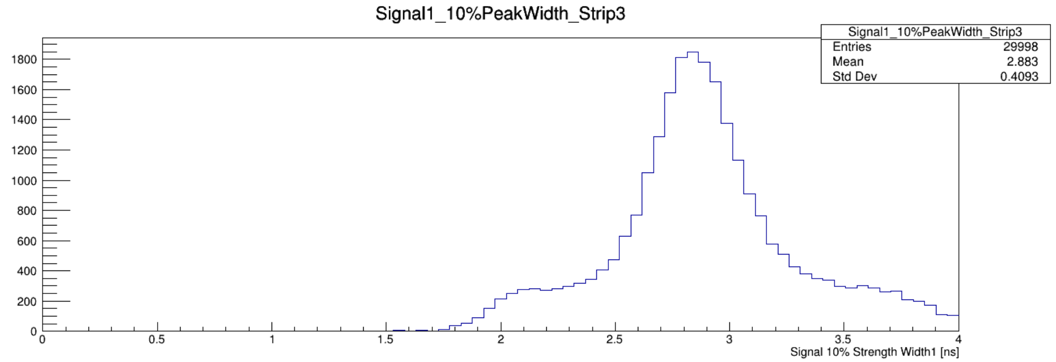


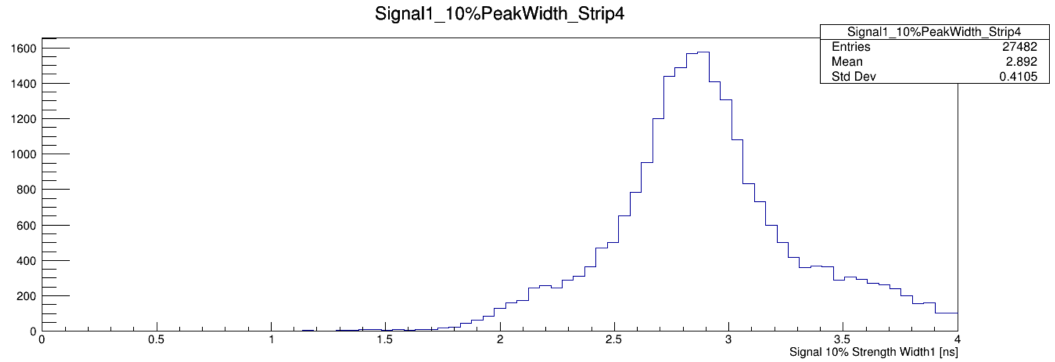


Backup 2: width cut





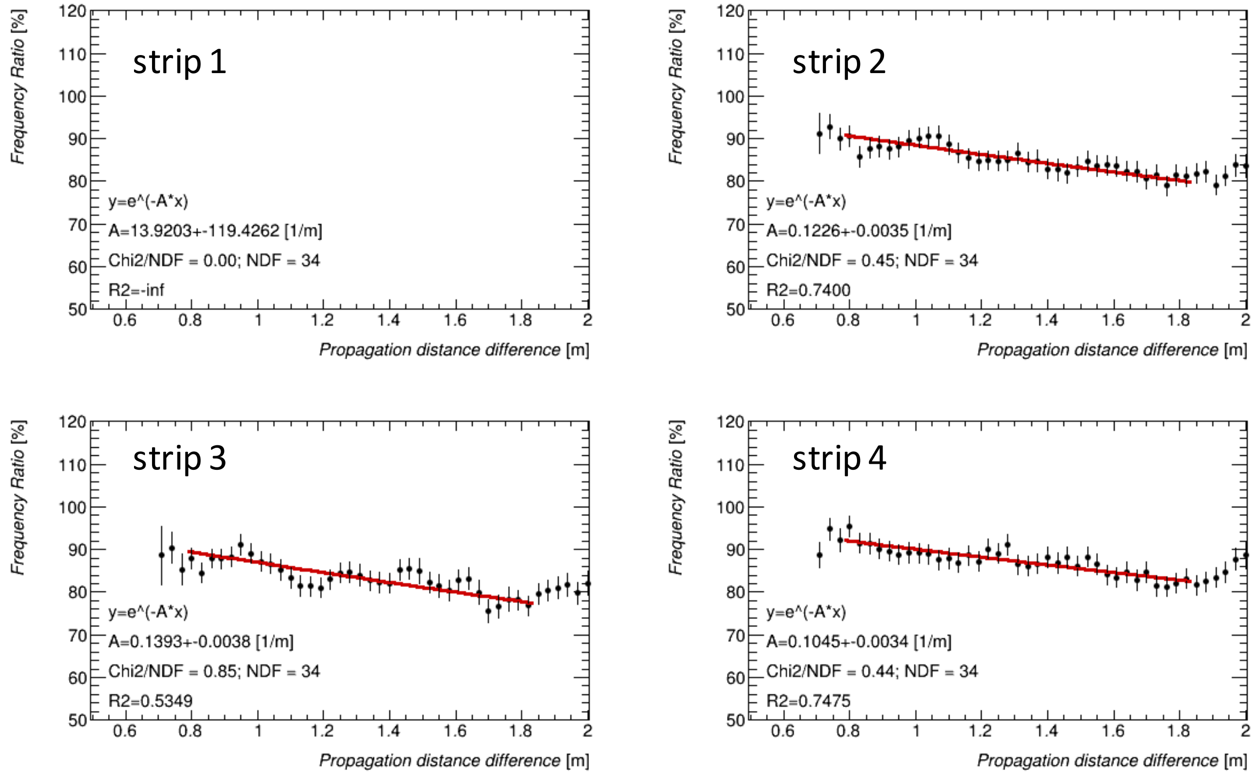




- Signal width between leading-edge trailing-edge at 10% of peak has obvious ‘background’
- Caused by the noise
- Cut range: $\pm 0.3\ ns$ from MPV (most probably value)

Backup 3: waveform calibration 1

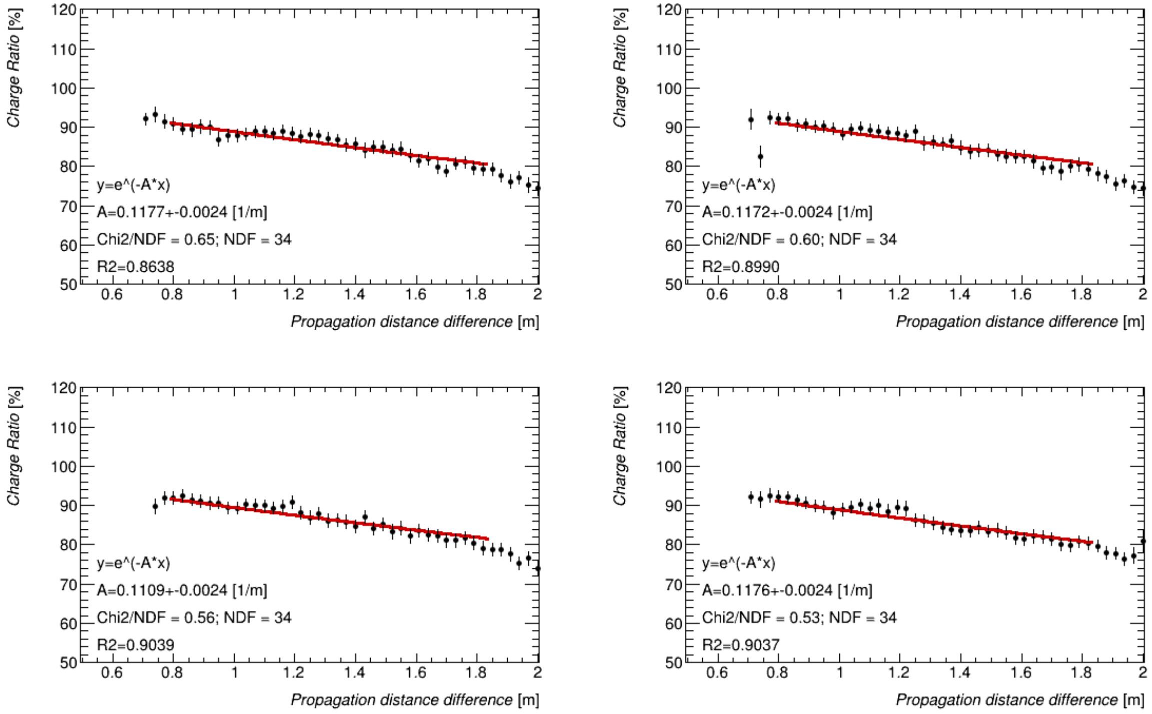
- Strip 1 accidently disconnected, strip 3 not calibrated, and has periodic fluctuation
- 'Noise' may come from the induction of charge induced on graphite with opposite polarity
- Lower ρ_s would lead to larger difference in frequency ratio between calibrated and uncalibrated data



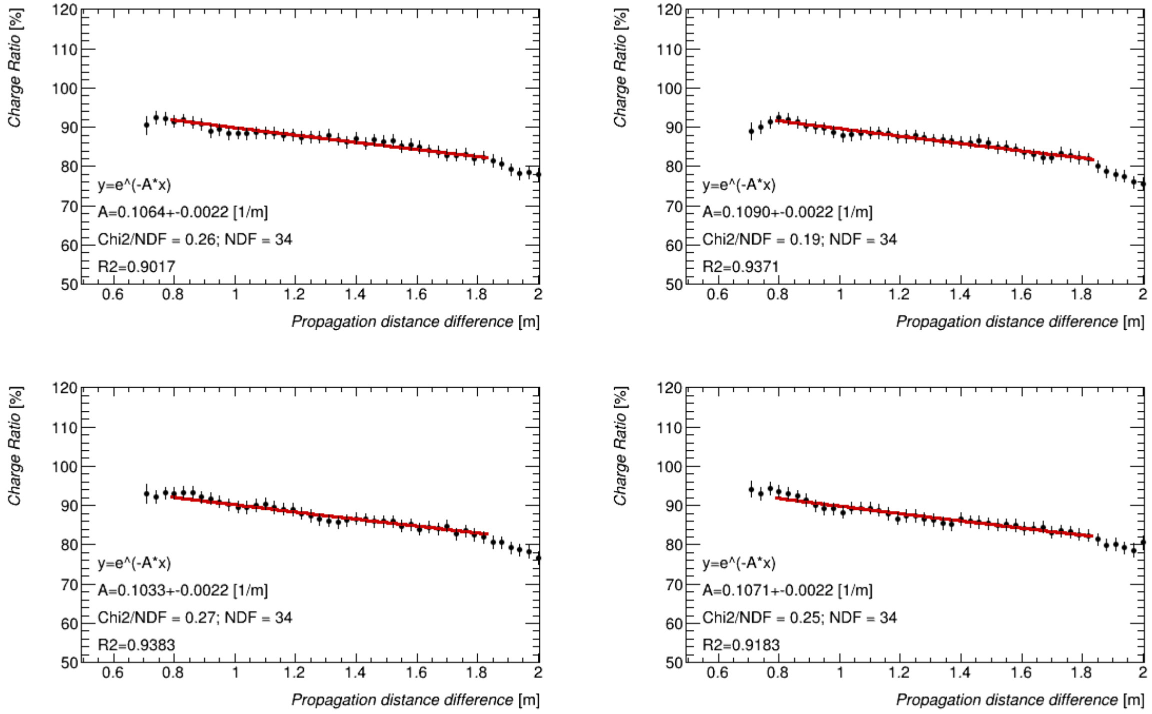
$$\rho_s = 10\ k\Omega/\square$$

Backup 3: waveform calibration 2

Uncalibrated



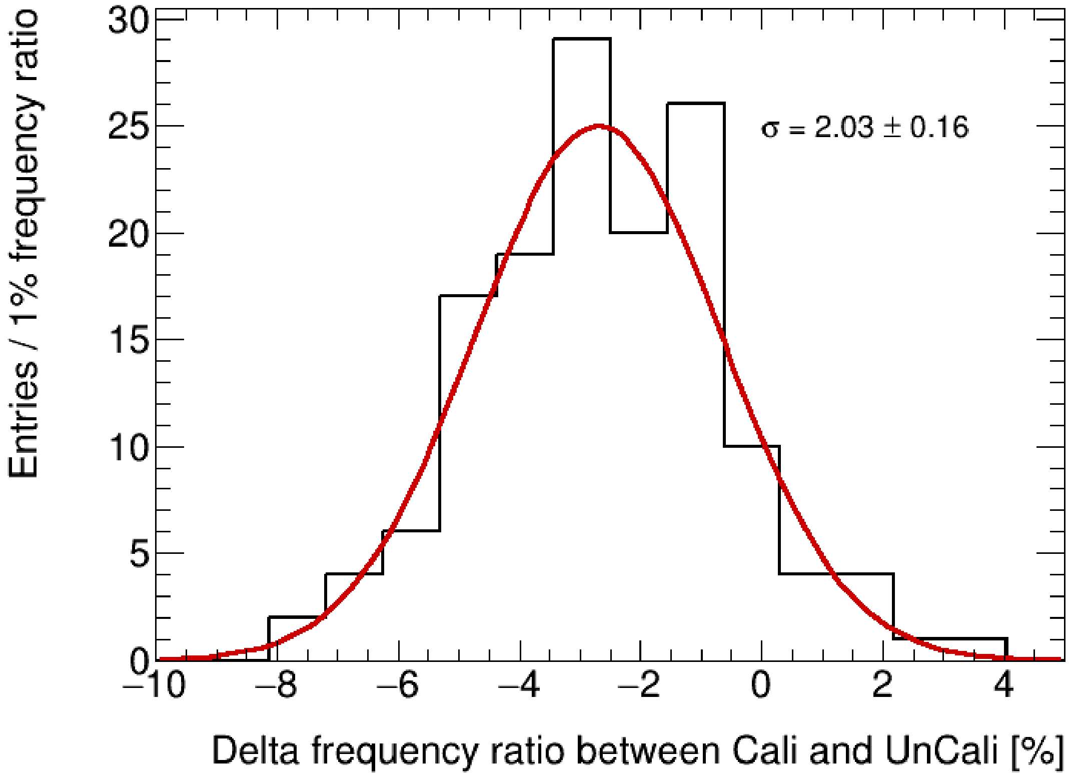
Calibrated



$\rho_s = 100\ k\Omega/\square$

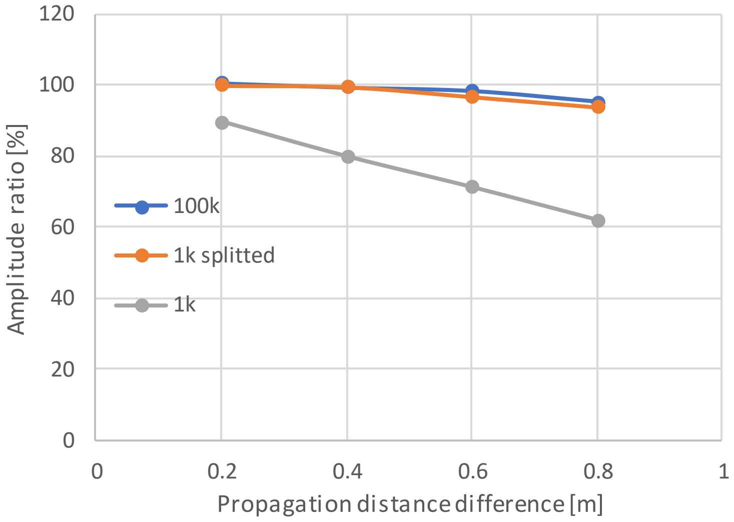
Backup 3: waveform calibration 3

- Horizontal axis: the frequency ratio difference between calibrated data and uncalibrated data
- $\frac{1}{2}$ σ of the difference distribution is used to estimate the systematic error due to non-ideal calibration



Backup 4: countermeasure

- Ref 1: G. BATI'ISTONI, NIM 202, 459-464
- Graphite splits:
  - Splits could be narrower than 1 mm to not influence the electricity field
  - Graphite could be partially unsplitted in favor of HV connection
- For simulation
  - For study of attenuation, the RC model should be 2D network
  - Lumped model no longer fits
  - 3D PEEC method is suitable (Partial element equivalent circuit)
  - In simulation, after split the $A_{amplitude}$ of $\rho_s = 1k\Omega/\square$ is suppressed from 0.5 to almost $0\ m^{-1}$



Simulation results of split graphite