Improvement of Time measurement in INO-RPC

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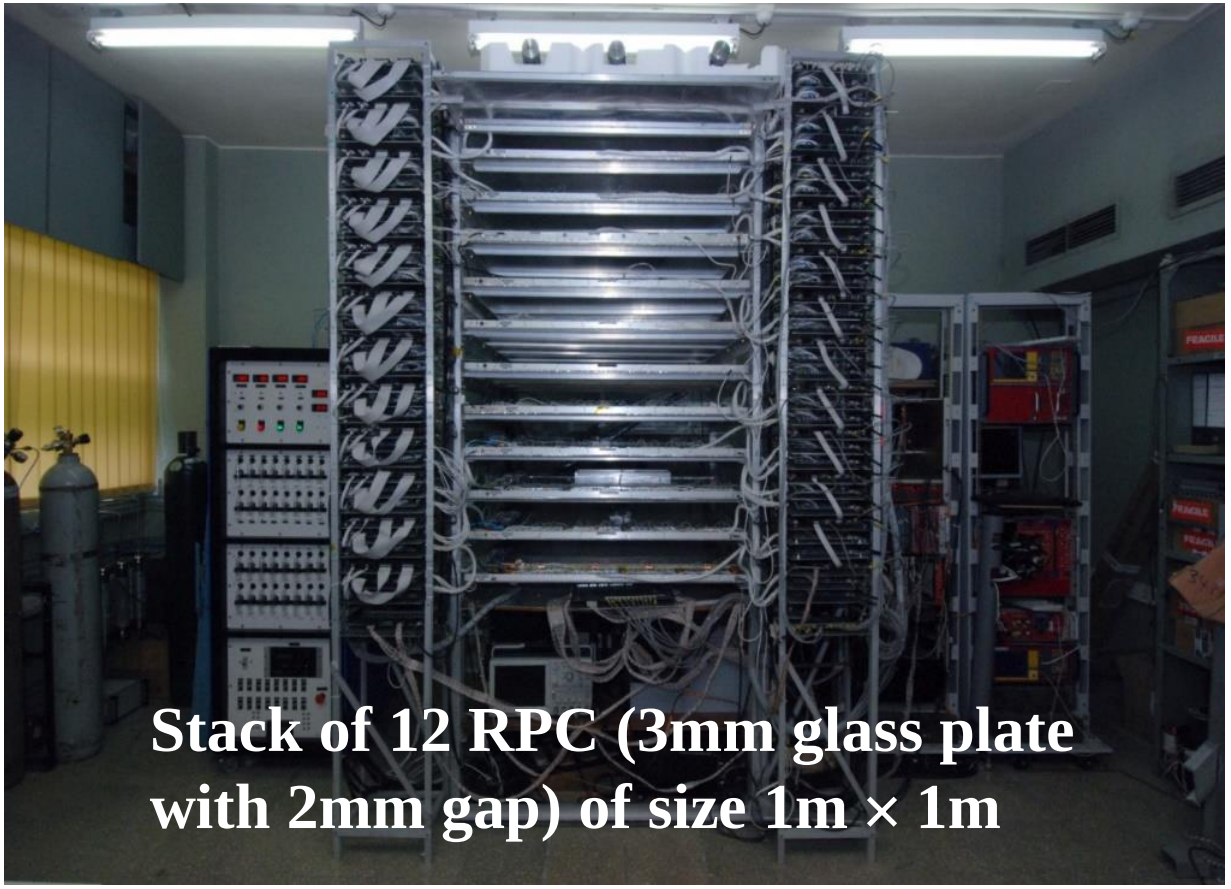
- **Introduction**
- **Correlation of efficiency and time measurement**
- **Correction of timing**
- **Improvement of time measurement and consequently the directionality of muon**
- **Summary**



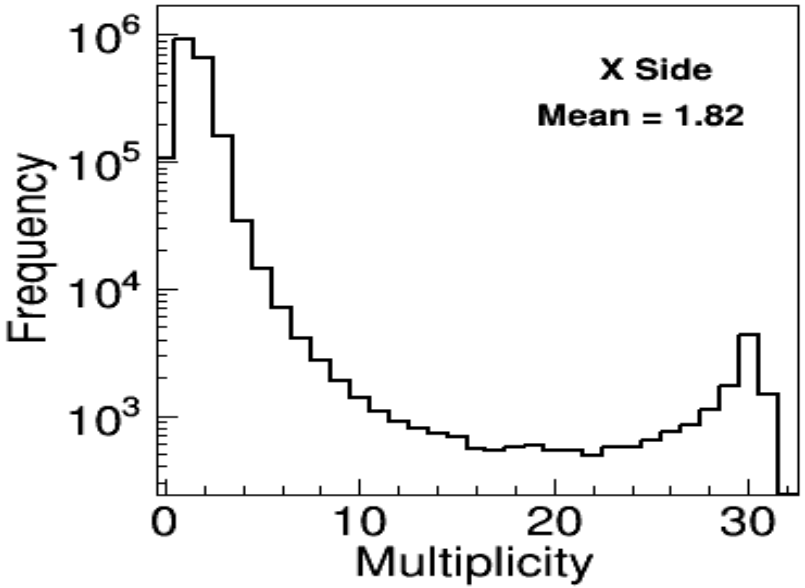
Stack of 12 RPC (3mm glass plate with 2mm gap) of size 1m × 1m

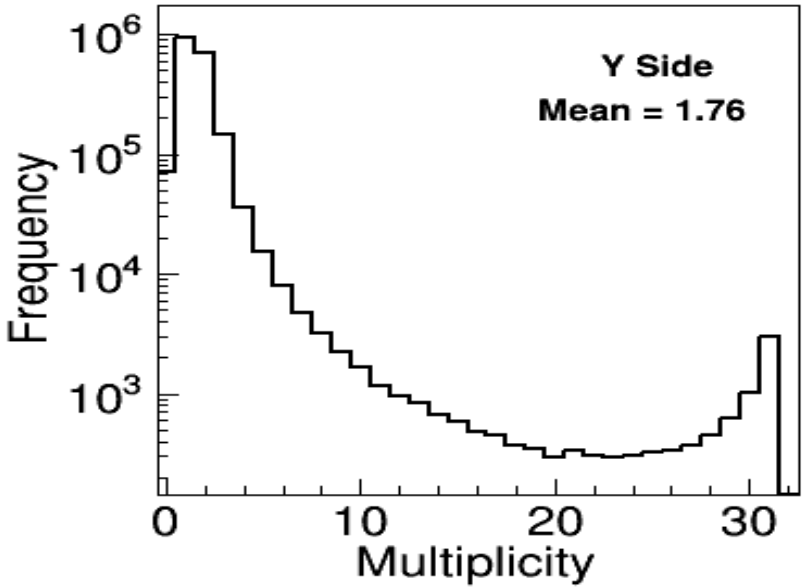
Strip multiplicity in the detector

All detector are operated at 9.9 kV (±4.95kV) and 2mbar above atmospheric pressure with gas composition

R134a($C_2H_2F_4$) : Isobutane(C_4H_{10}) : Sulphur Hexafluoride(SF_6) :: 95.3 : 4.5 : 0.3 and flow rate ~3 SCCM per RPC

Noise rate/strip ~100 Hz





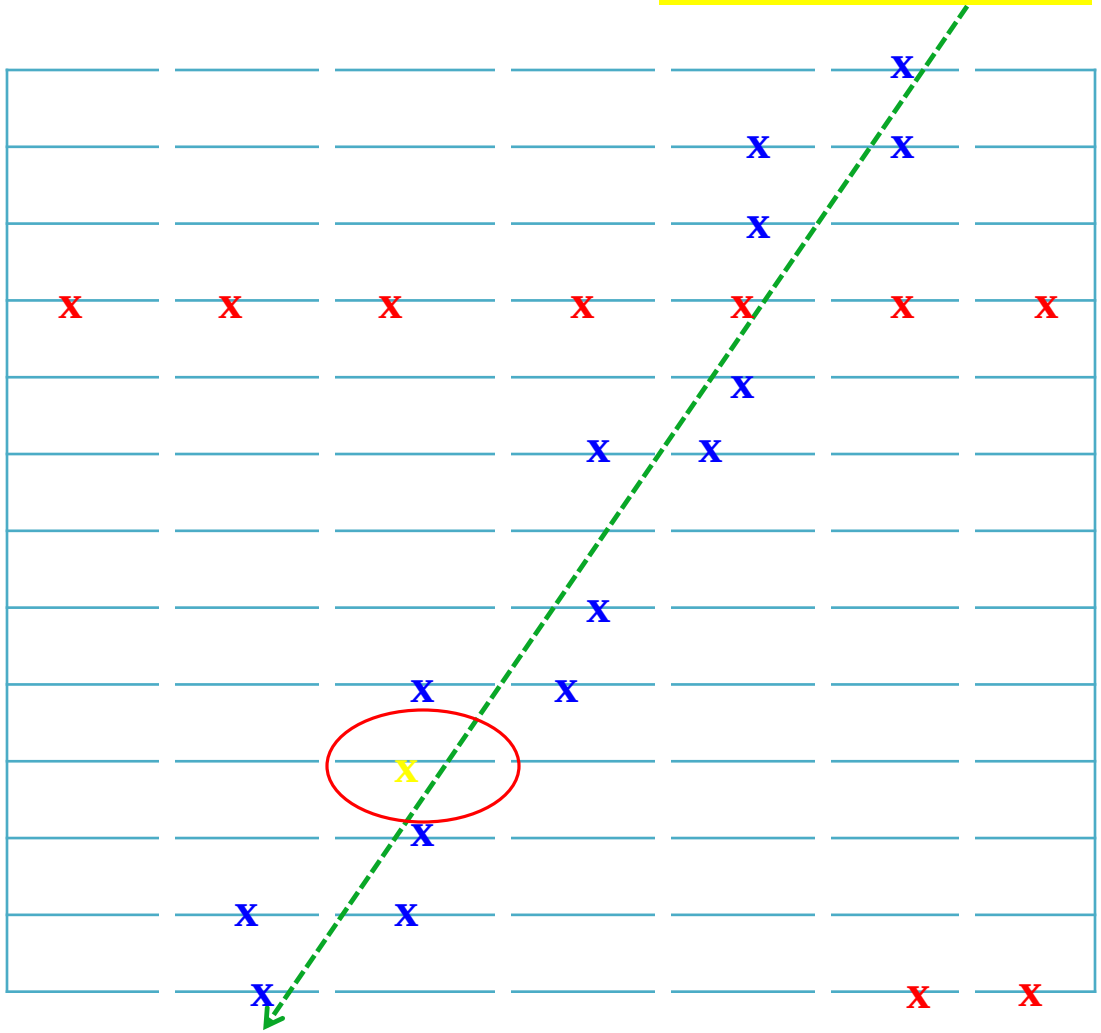
- **Large tail is due to correlated electronic noise**
- **Strips > 3 could be due streamer pulse**
- **This analysis looked only RPC, which has at most three strips hit (signal with gain ~80, greater than –20mV) and also those three should be consecutive strips.**

Basic technique used for this study

- Fit X-Z/Y-Z trajectory of a muon also estimate the efficiency of a layer.
- From both X-Z/Y-Z fit, one can calculate exact trajectory of muon (l_i).
- Fit this eqn using time measurement in all layer except the layer understudy.

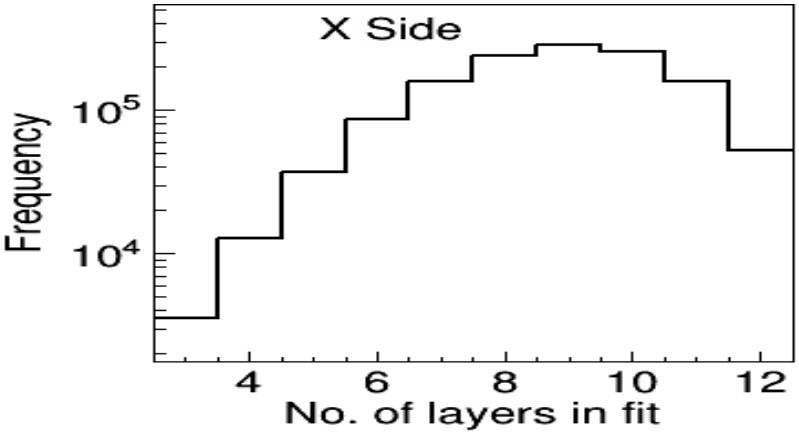
$$t_i = \frac{l_i}{c} + const$$

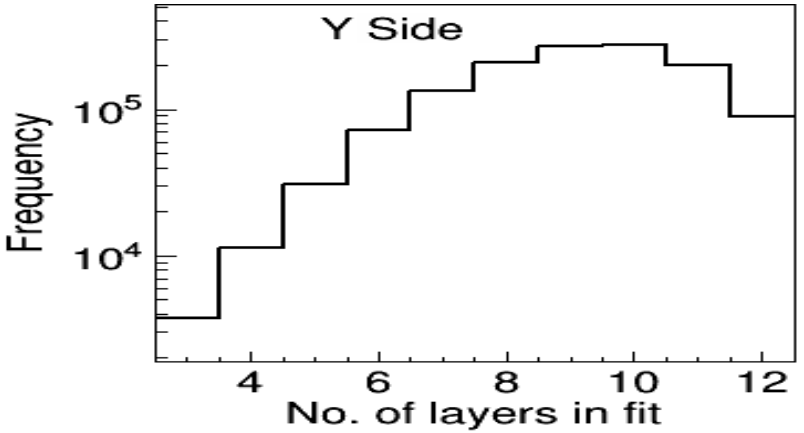
- Compare the extrapolated time in that layer with its measured value.
- Measured time is already corrected due to path-length in strip and other paths due to electronics.
- Subtract error due to extrapolation from the observed resolution to obtain true uncertainty of time measurement in that layer

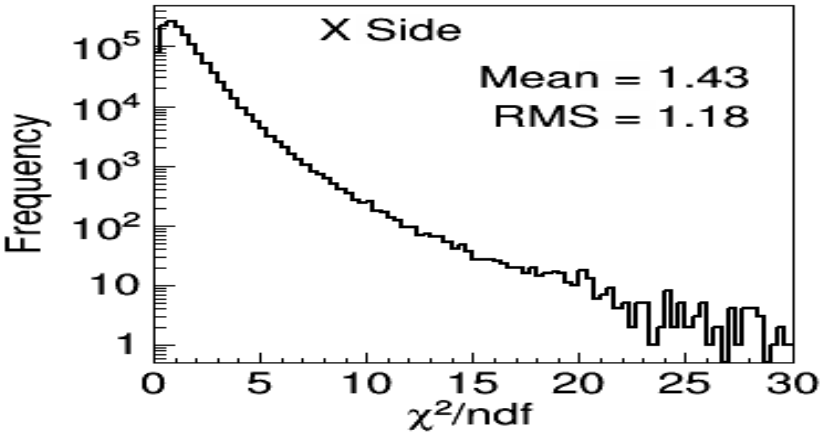


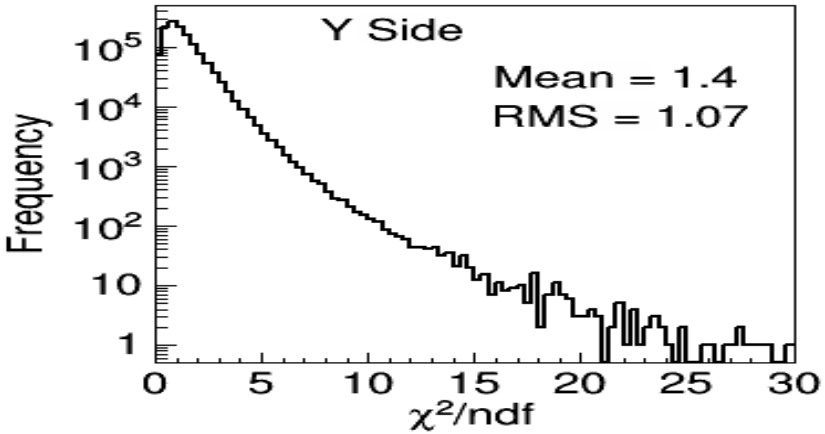
Number of selected layers

- First position (X-Z & Y-Z) were fitted in straight line.
- Both fit should have at leave six layers and $\chi 2/ndf<2$, where outlier points are removed during the fit
- Distribution of layers used in timing fit (but, all this study based on fitted events with at least 6 layers and $\chi 2/ndf<2$) .

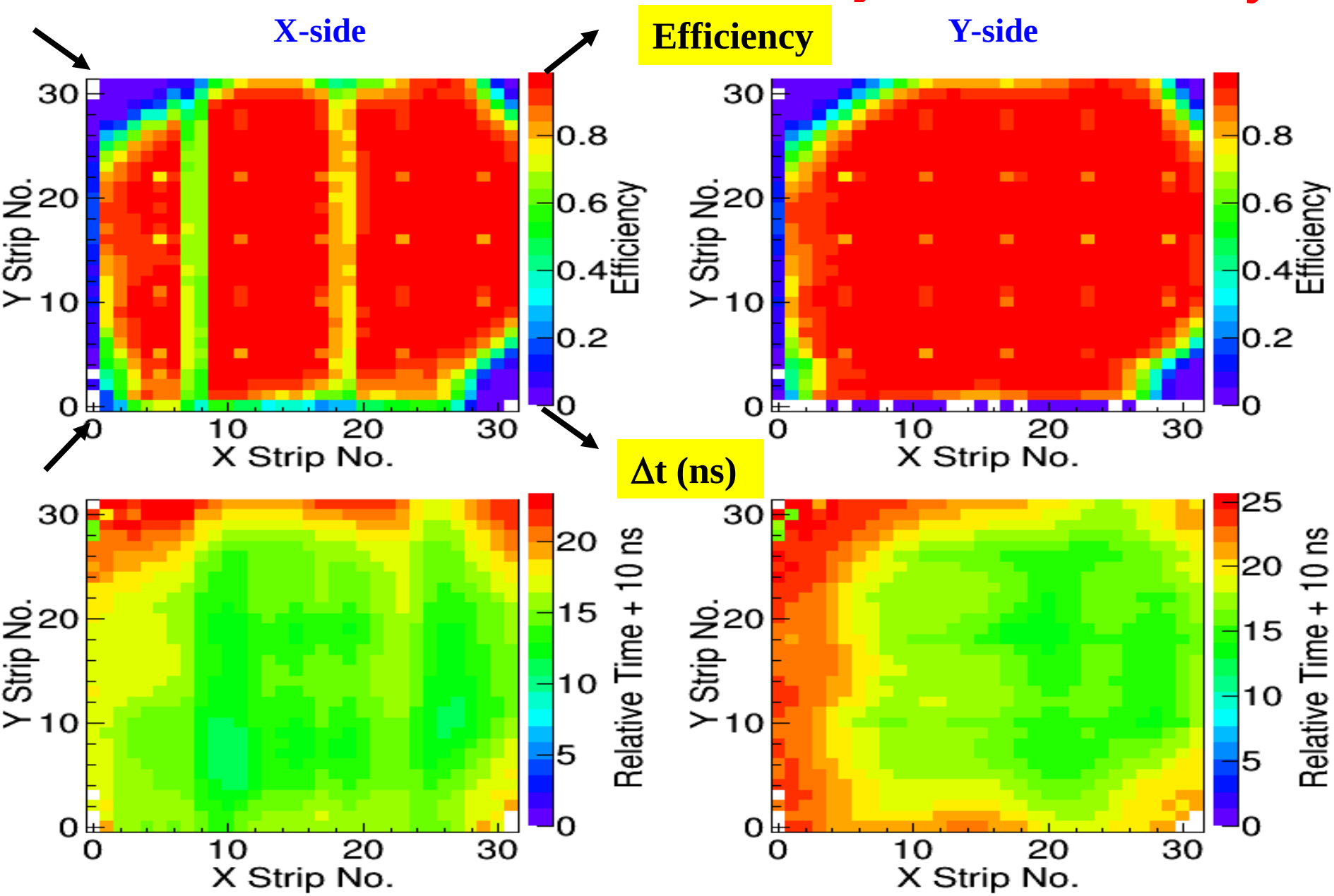




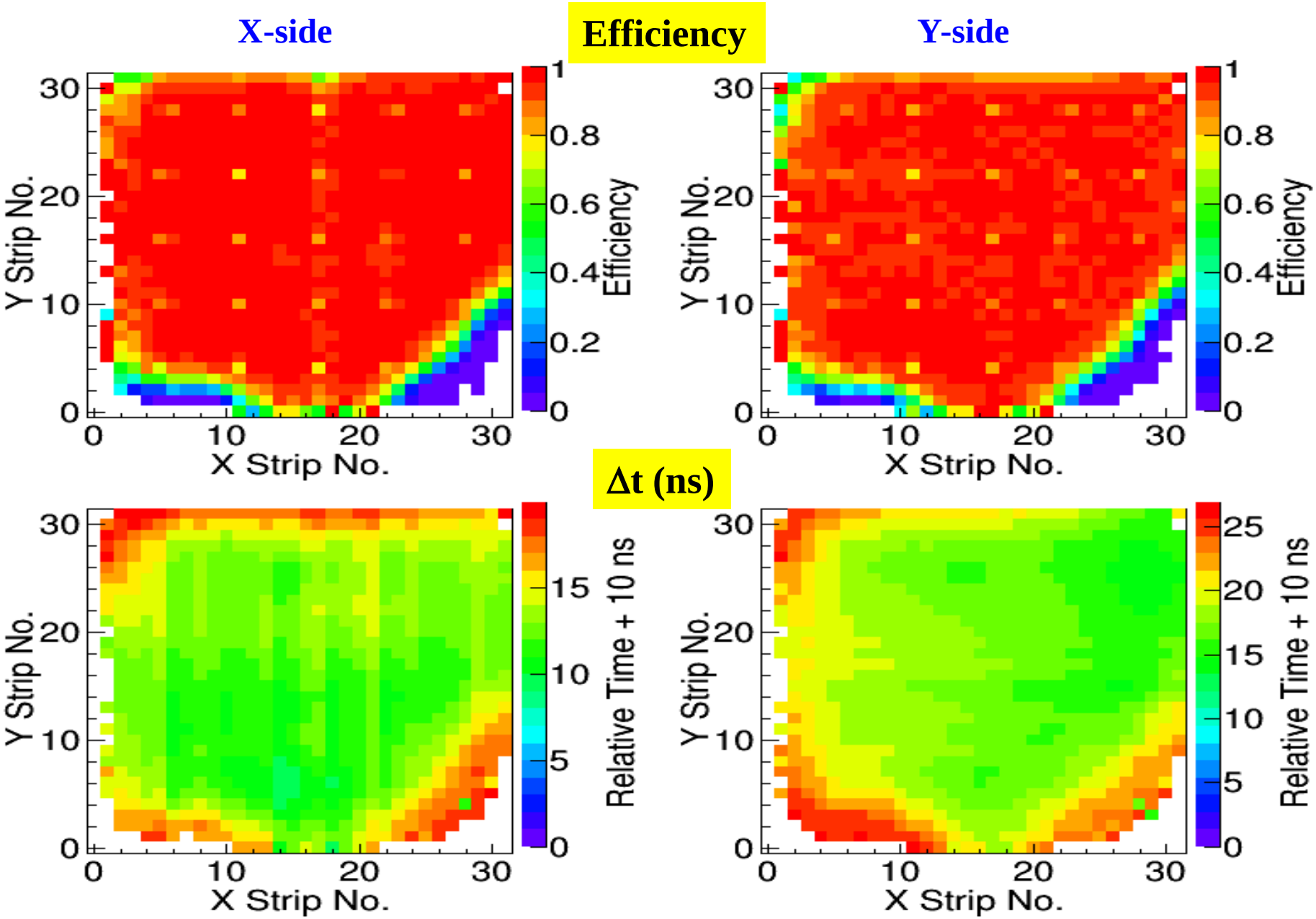




L0 Correlation of inefficiency and time delay

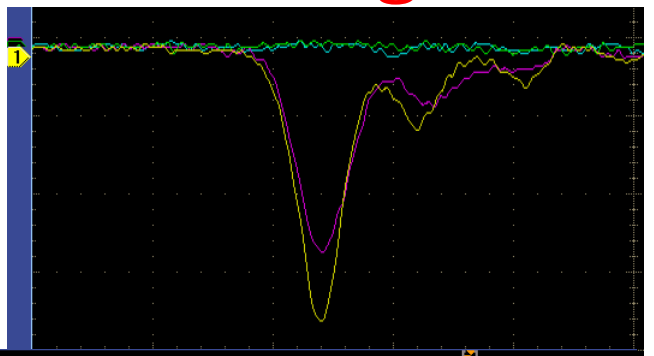


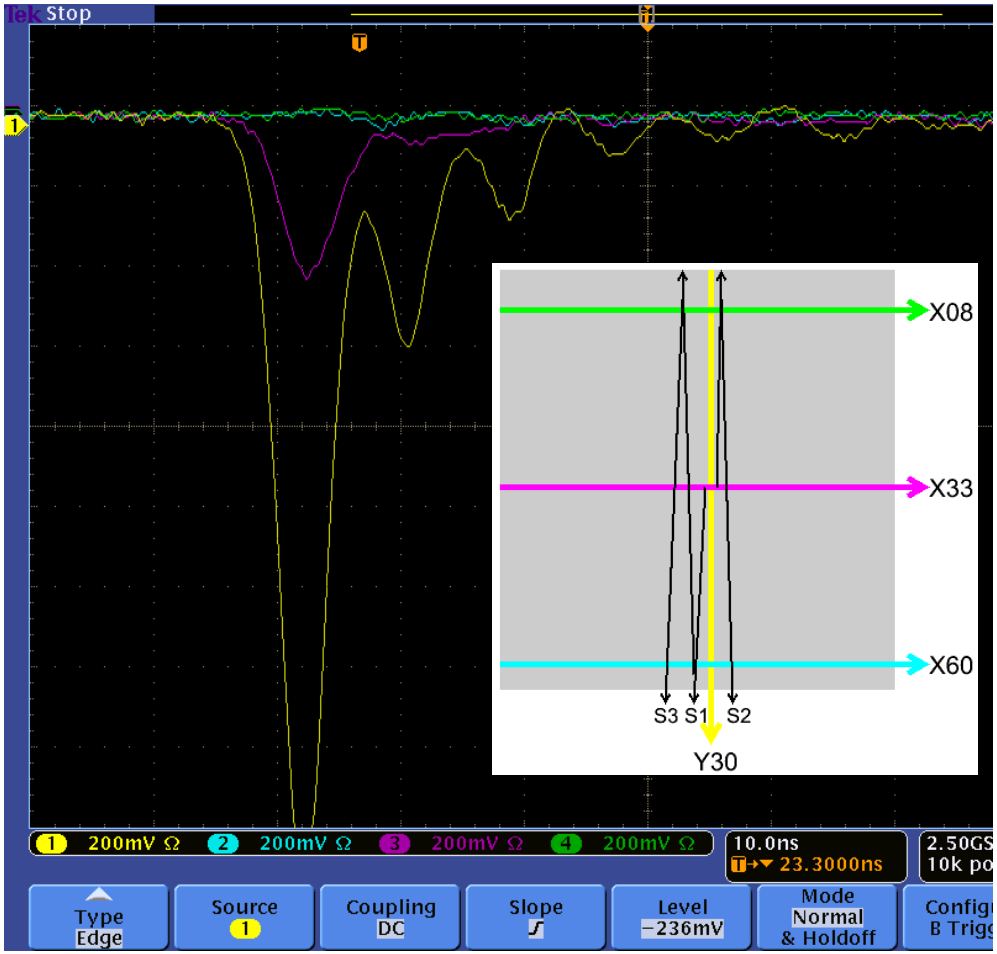
L8 Correlation of inefficiency and time delay

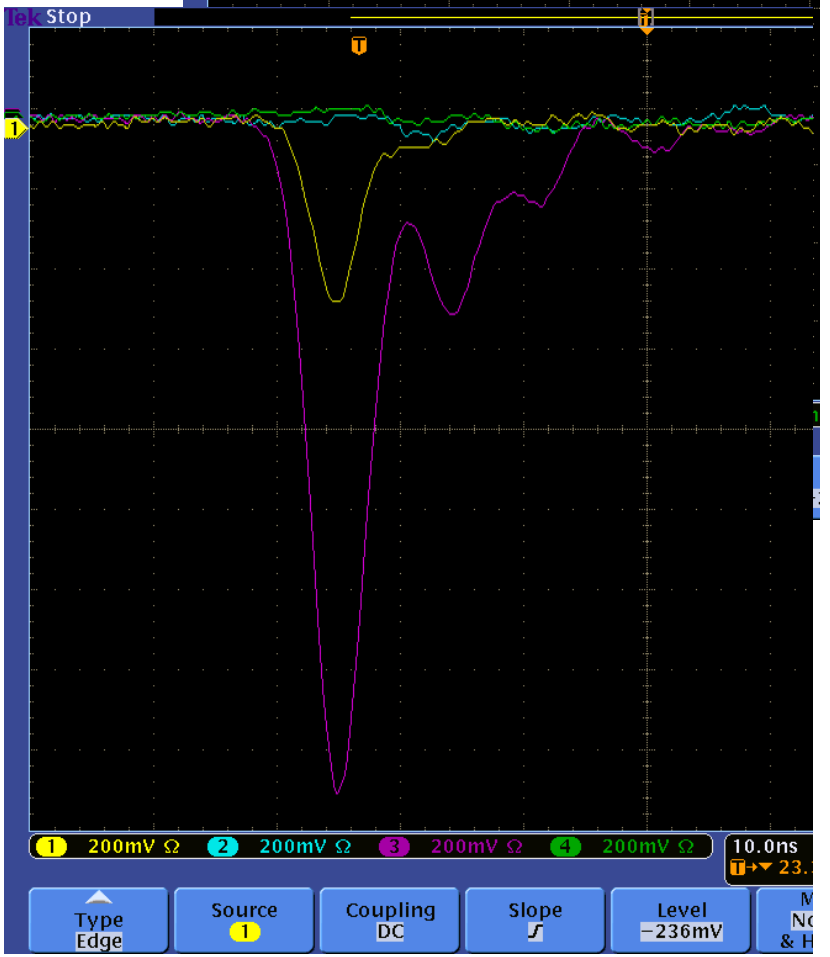


Correlation of pulse height and Timing

- For equal signal, both X33 and Y8 strip timings are same
- Pulse height change the timing for threshold discriminator







Source of position dependent time variation

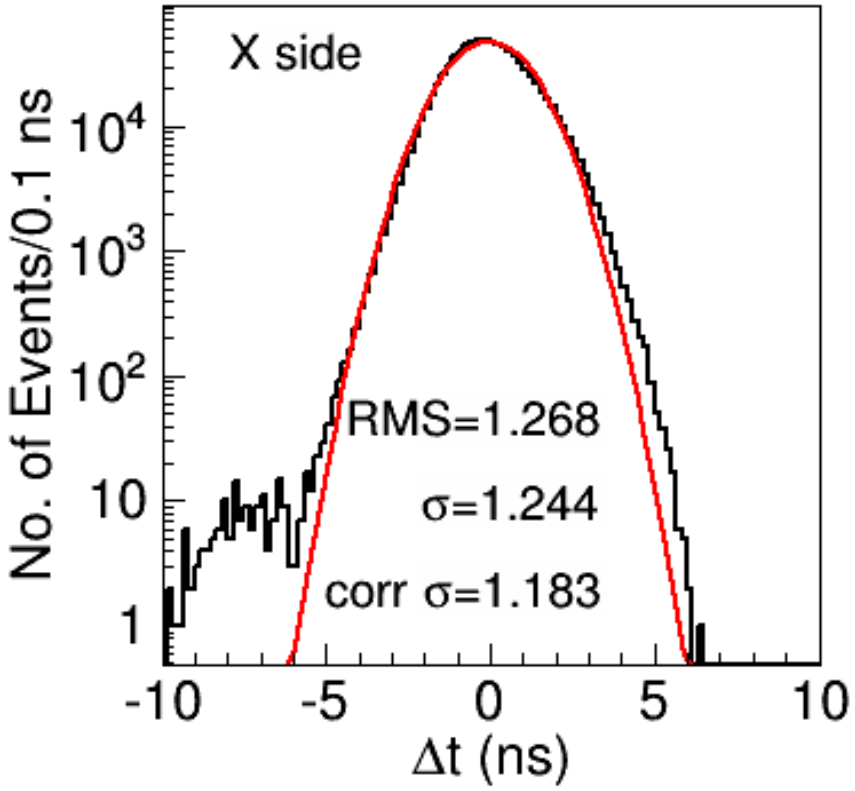
- **Variation of**

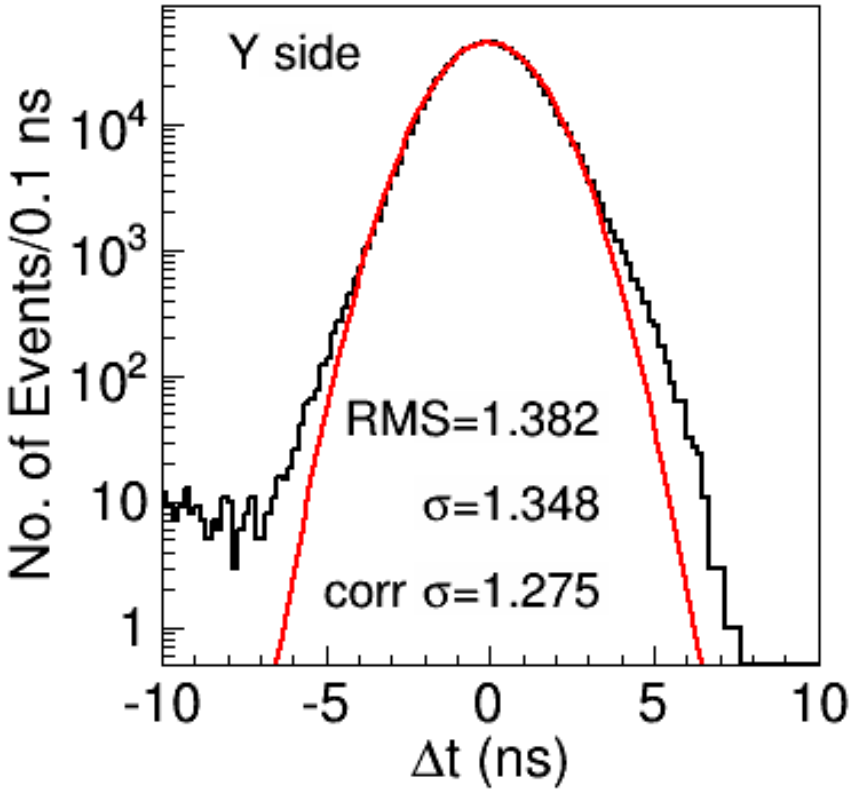
– Amplifier, impedance matching	X|Y	NIL (other than str)
– Gas flow, dead zone in gas circulation system	X&Y	Don't support
– Surface resistivity	X|Y	Not visible
– Height of button/spacer + glass thickness	X&Y	Dominant

- **Difficult to keep track (Database) of all these, particularly height due to button & glue**
- **How to overcome this problem ?**
  - **Test each RPC at surface for 3-4 days (Not a single RPC, at stack of 10-15 RPC together to have reconstructed muon for a position dependent correction**
  - **Hardware**
    - **Constant Fraction Discriminator**
    - **Store QDC information**
    - **Use Time-over-Threshold information**

Time resolution without any offline correction

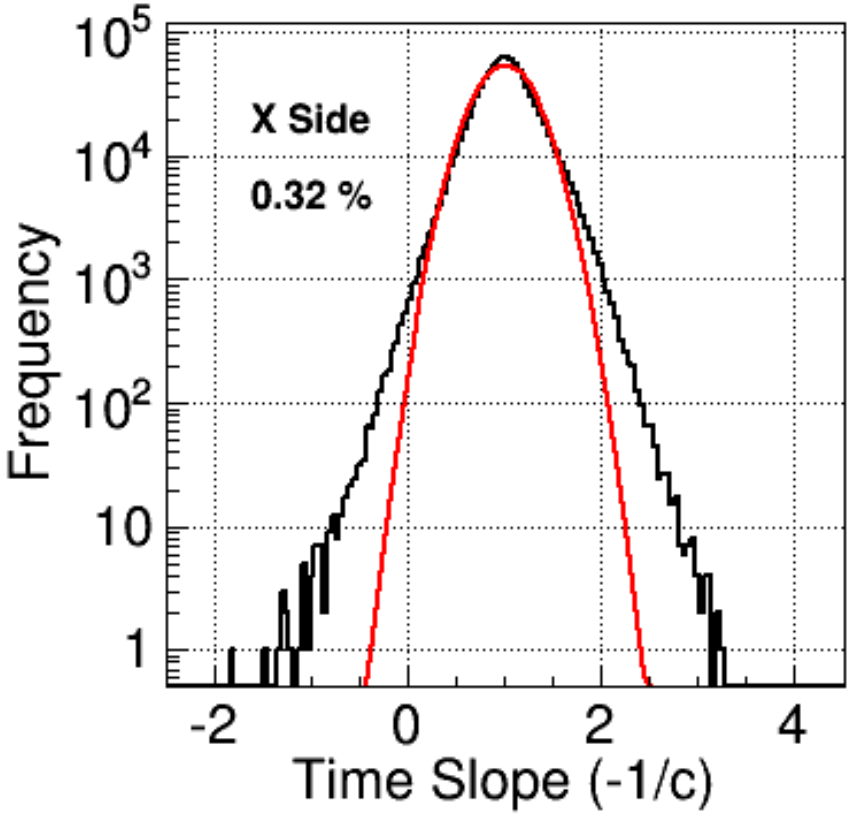
- Using timing of remaining 11 layers, we set the expected time in this layer.
- Observe resolution of this difference is about 1.3ns
- Subtract the extrapolation error to estimate the true resolution of this chamber

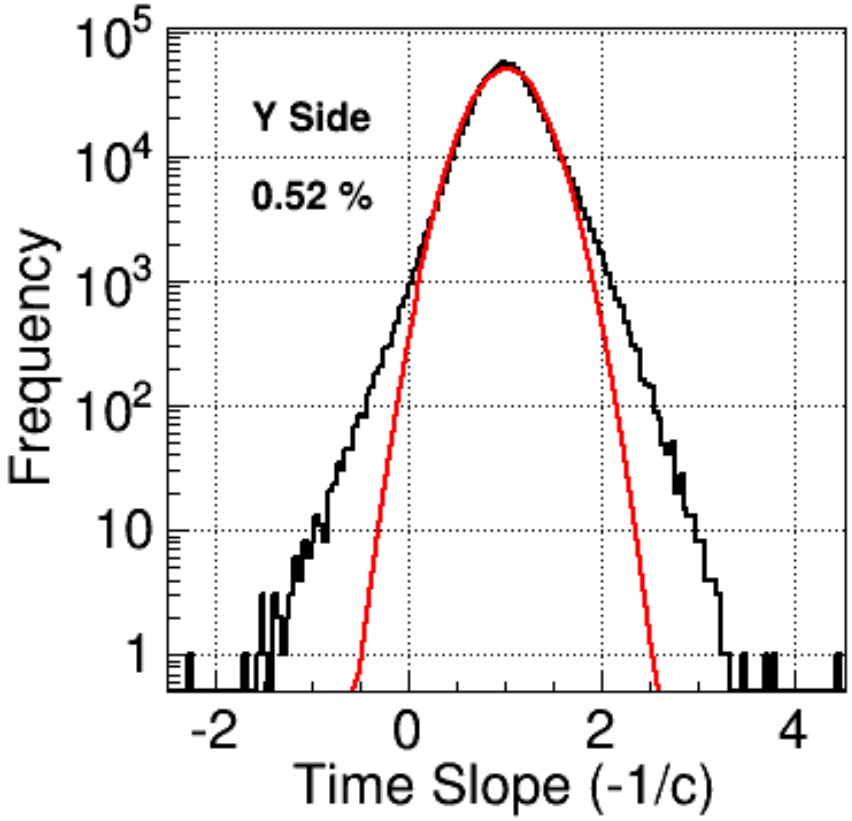




Up/down ambiguity without any offset correction

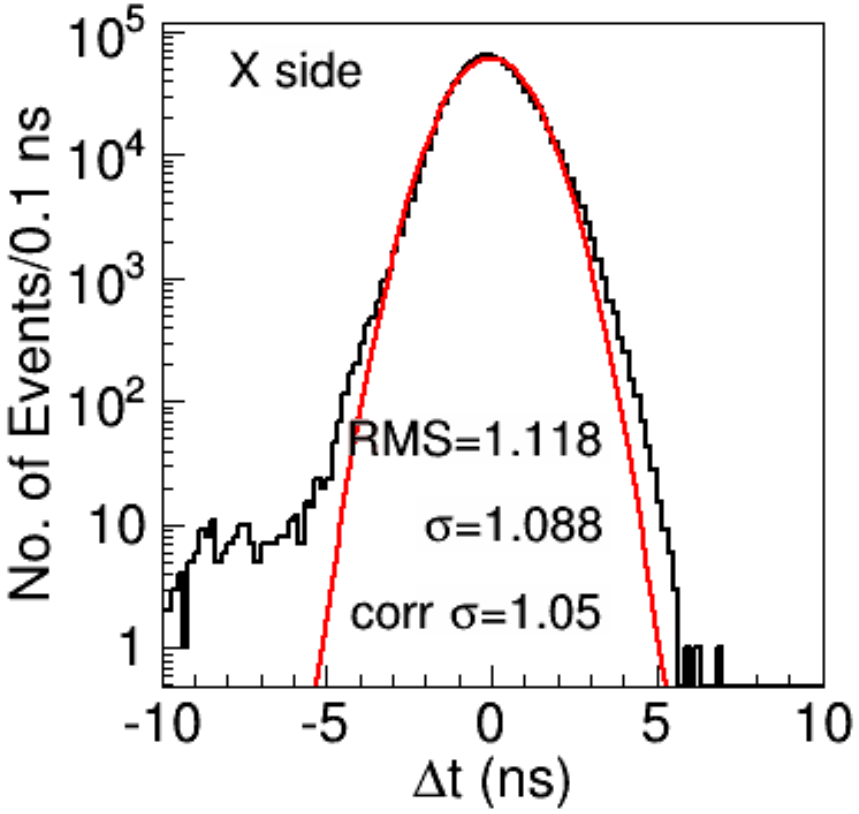
- This the slope of the eqn, $t_i = l_i/v + \text{const}$
- Distance is increasing with Z (layer number), but muon is going downward, where the slope is –ve. Looked for the –ve of the slope.

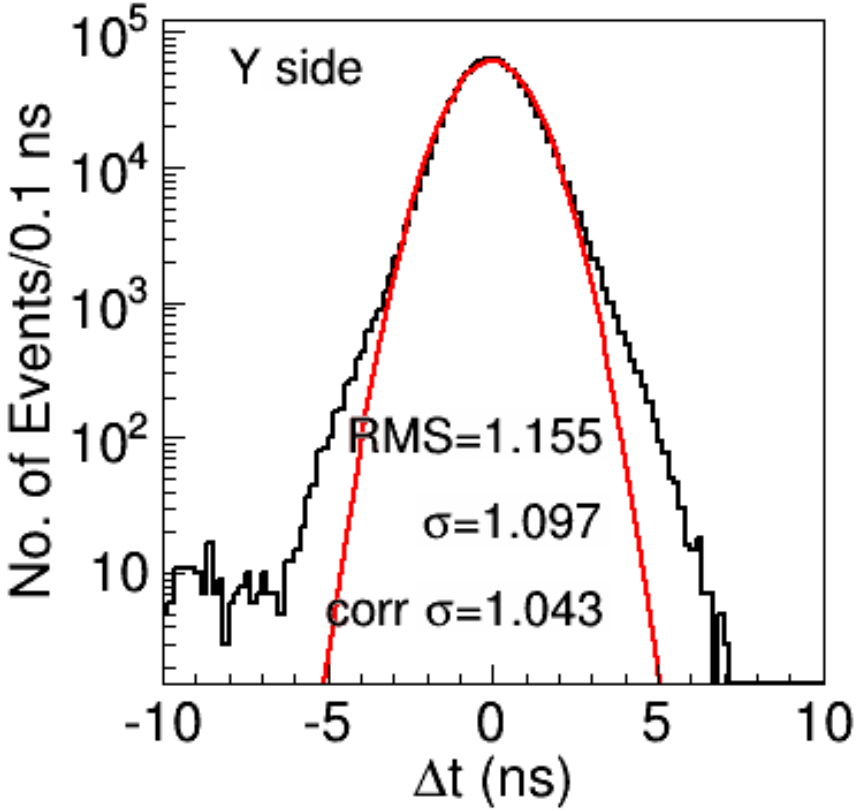




- About 0.3-0.5% time the direction measurement is wrong

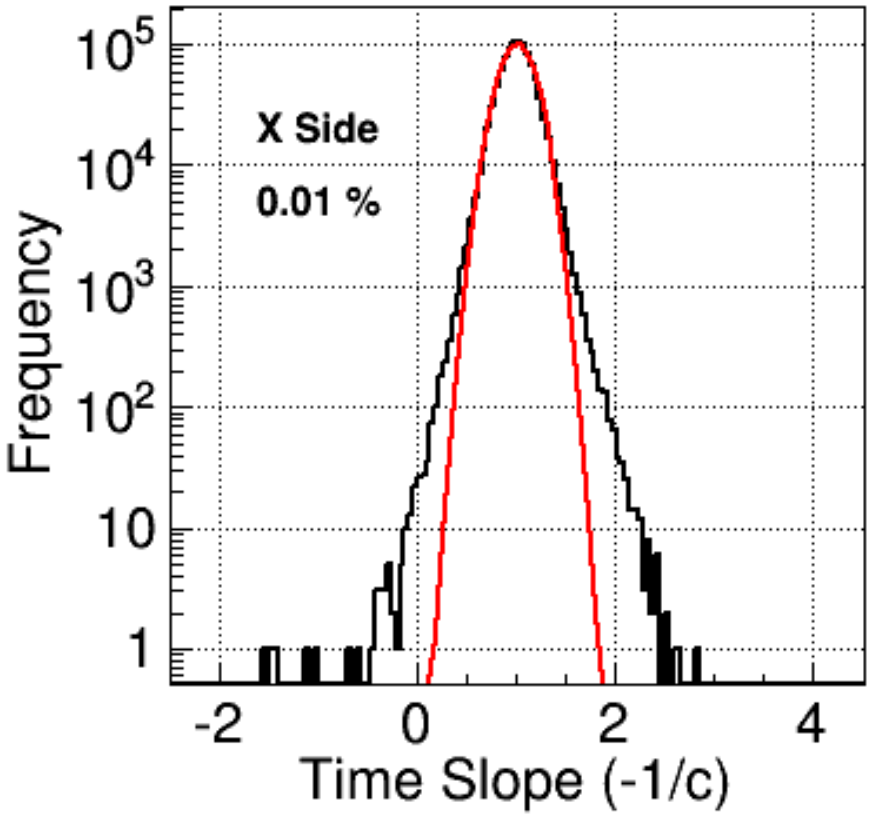
Time resolution with offline position correction

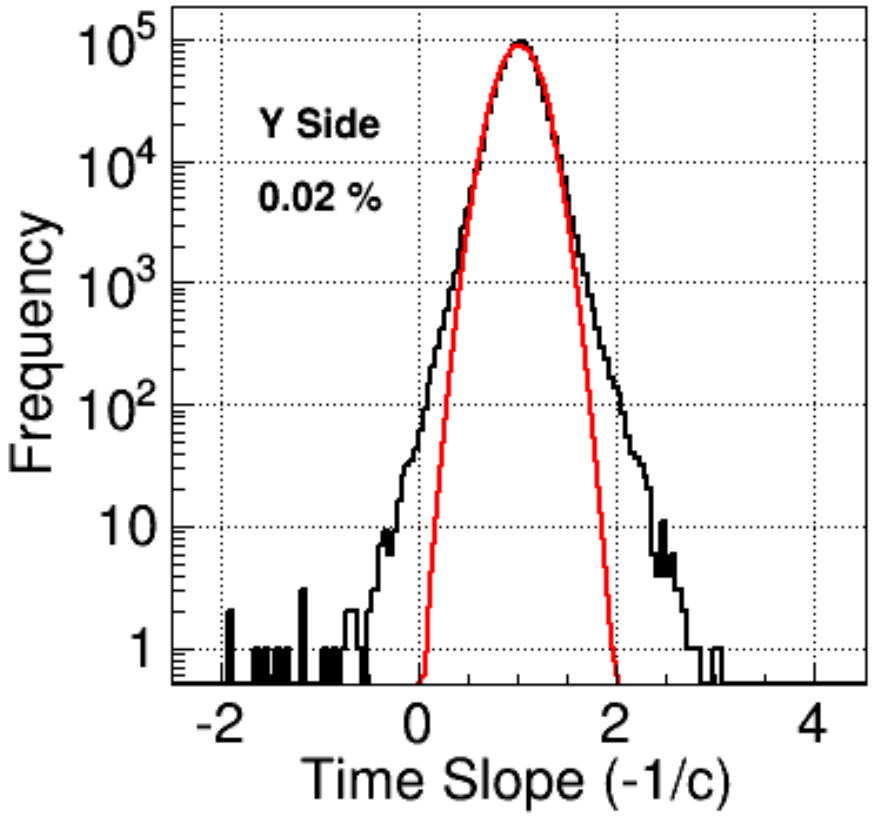




- These corrected resolutions 1.050 and 1.043 can be compared with resolution without position dependent correction, 1.183 and 1.275
- 20-25% improvement in time measurement in a chamber

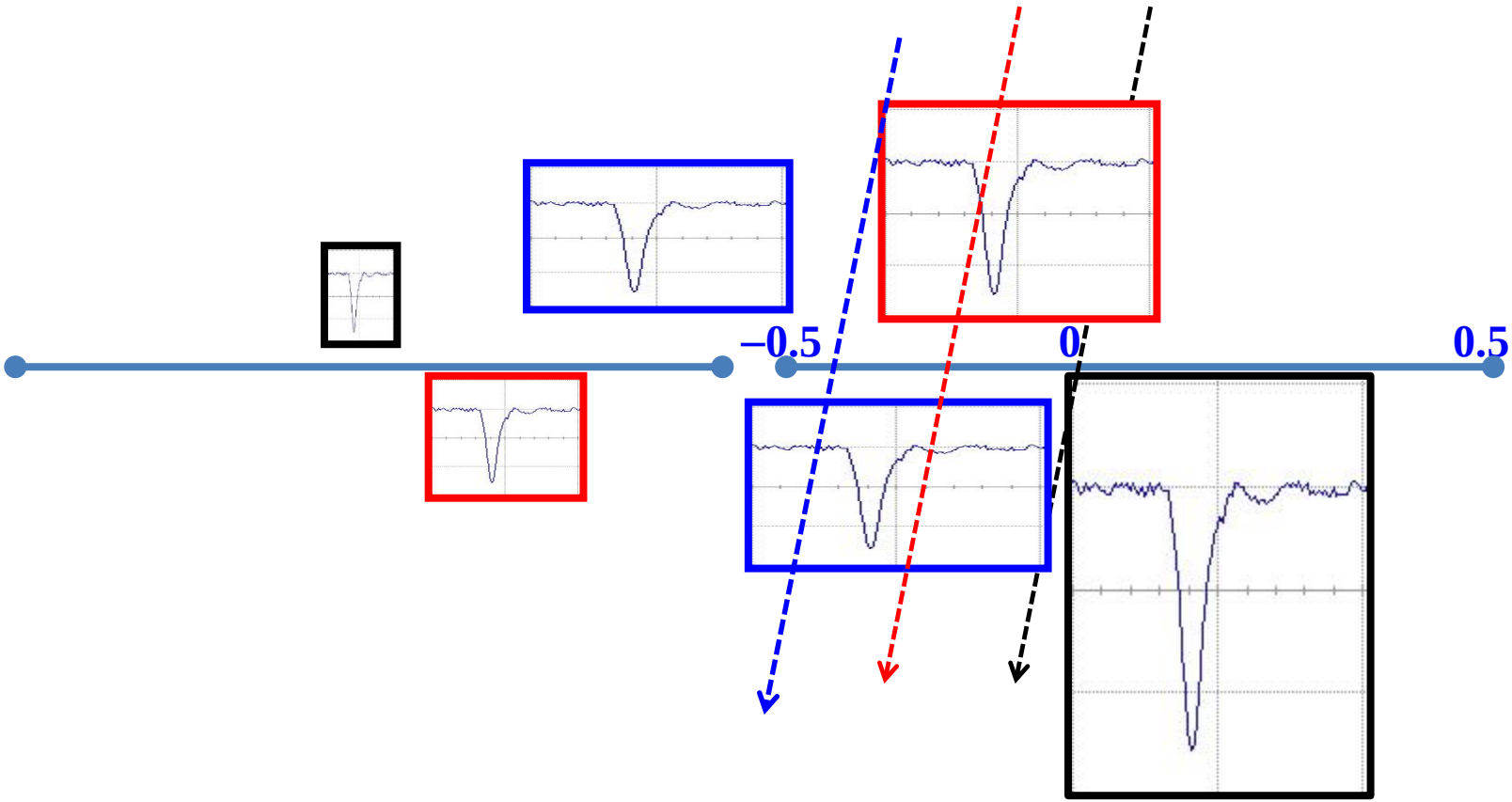
Up/down ambiguity with offline position correction





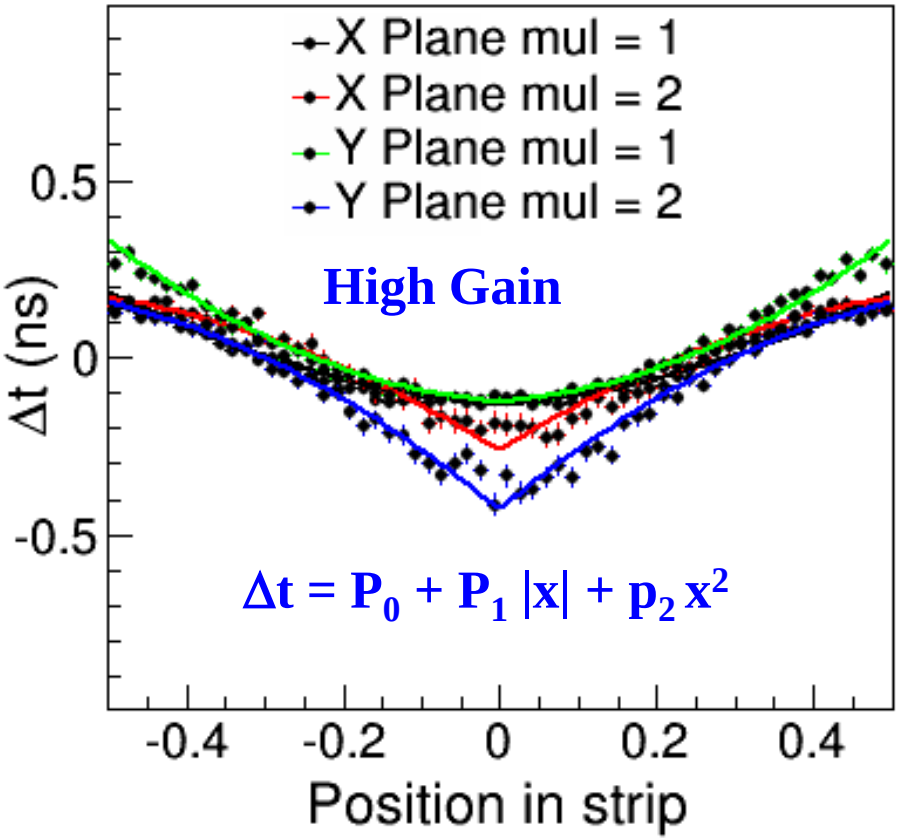
- **With position dependent corrections, this ambiguities reduces from About 0.3-0.5% to 0.01-0.02%, improvement by an order.**

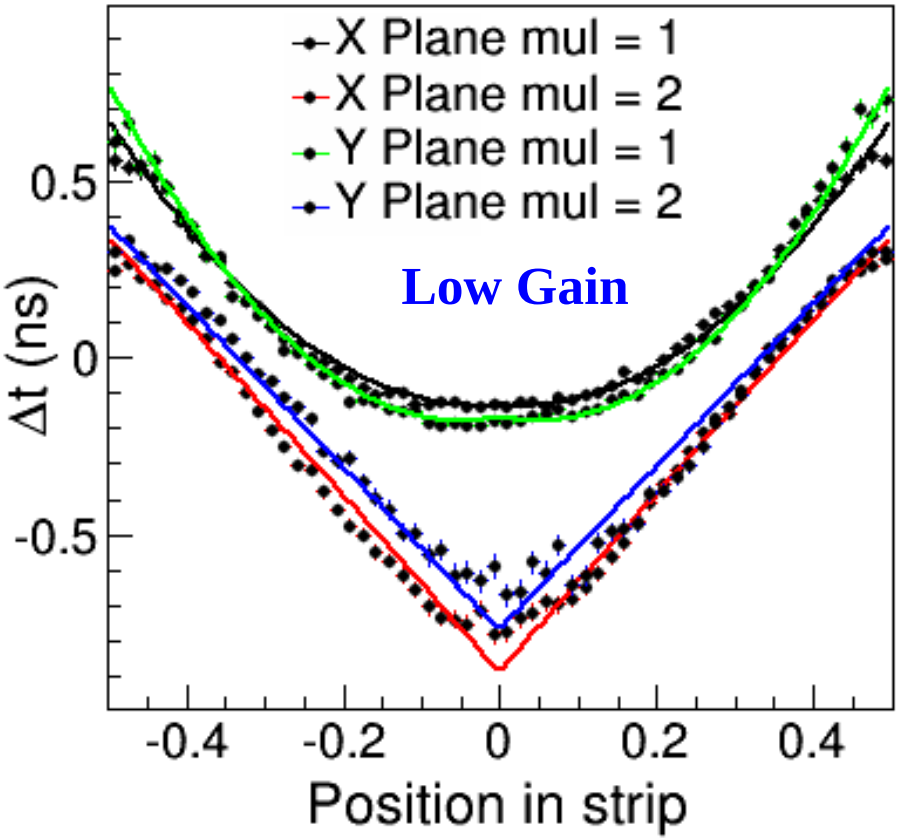
Time vs position of muon in a strip



- **Signal at the edge shared with nearby strip**

Effect of position in a strip in two RPCs

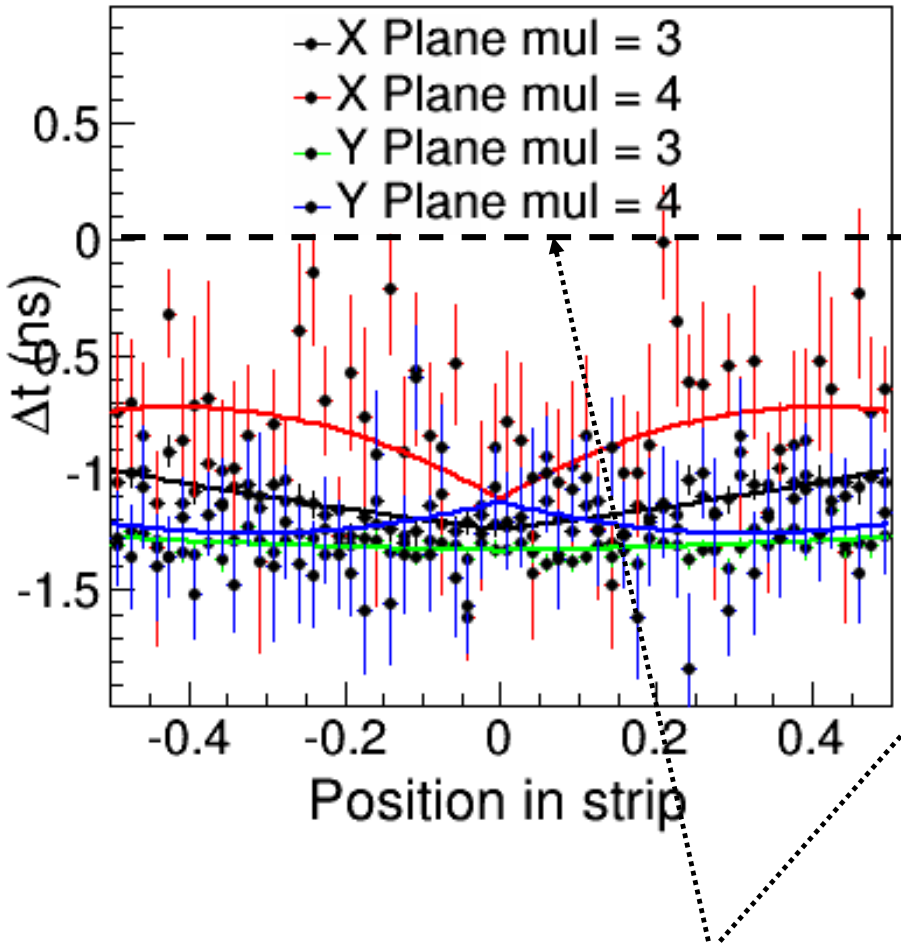


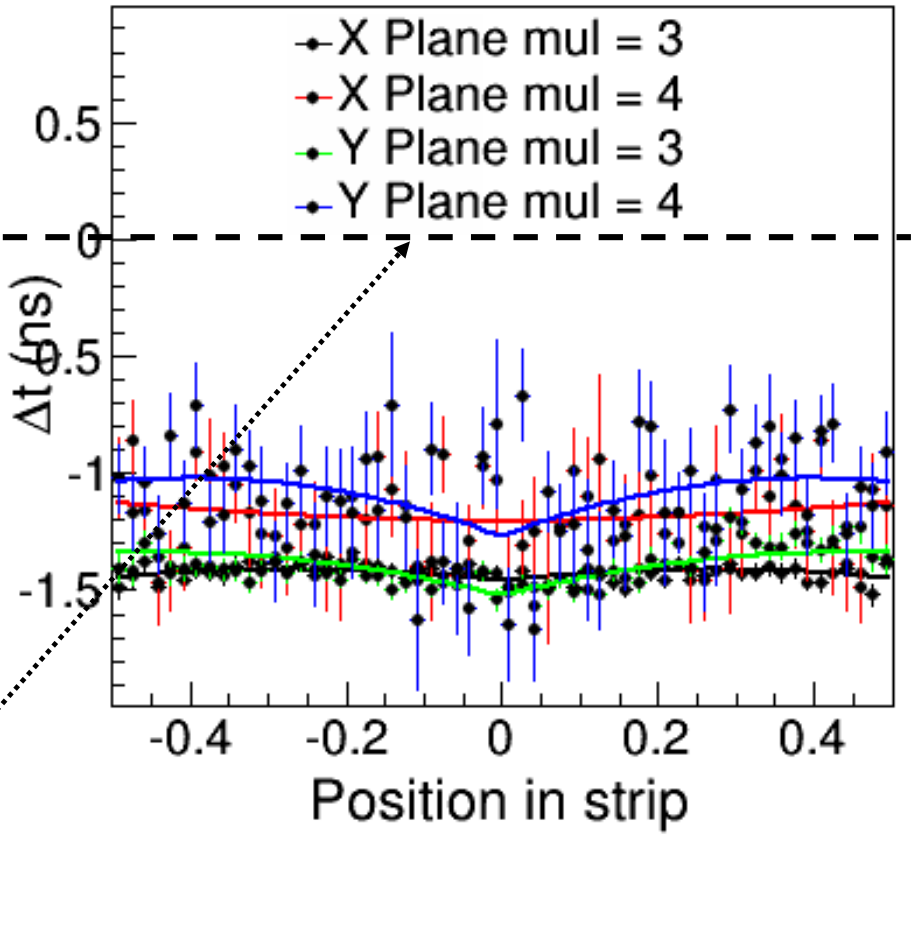


- **Though this is a small effect, using pulse height/Width of signal one can remove this bias.**

Effect of position in a strip in two RPC

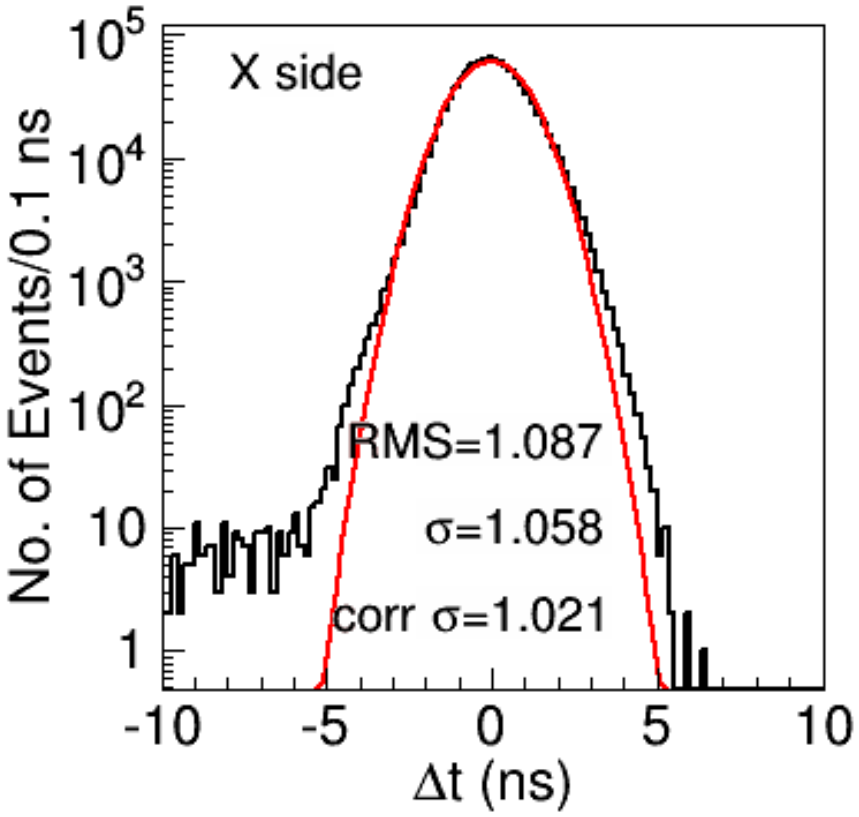
$\Delta t = P_0 + P_1 |x| + p_2 x^2$

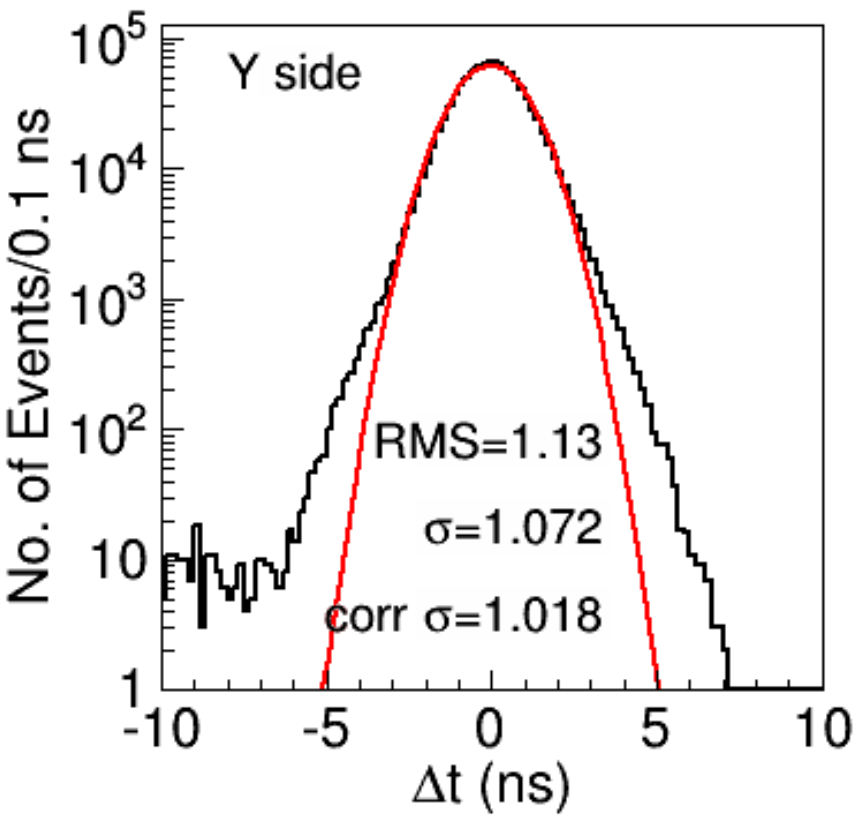




- **Notice the shift in Δt, all are –ve, signal comes earlier for 3/4 strip hits**
- **3/4 Strip signals are due to very large pulse and can not be used for any timing measurement**

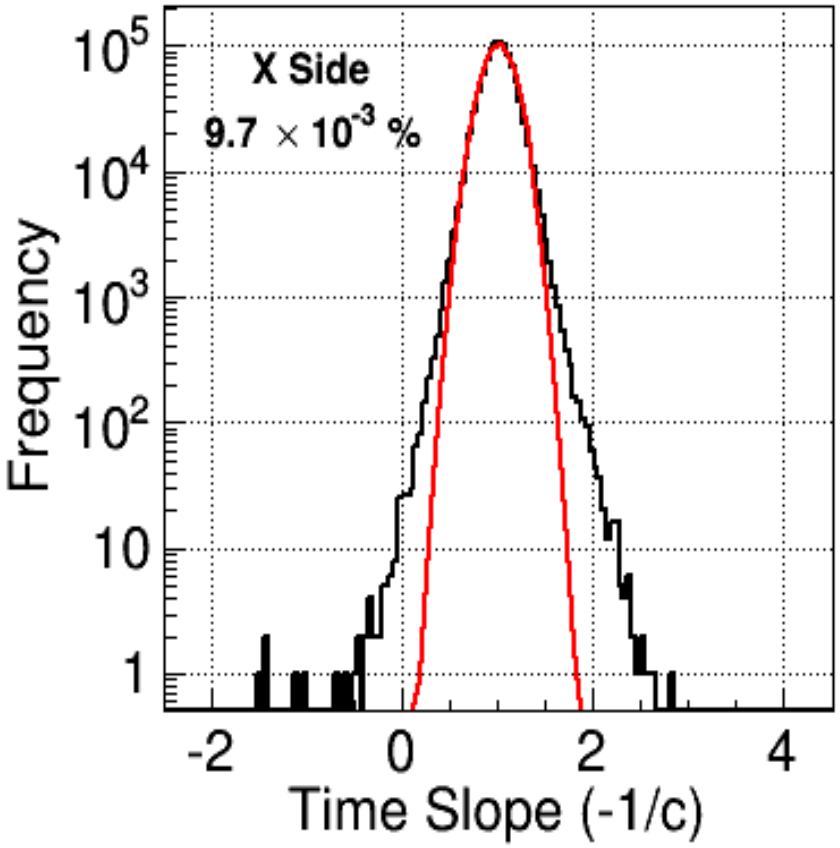
Time resolution with position + strip corrections

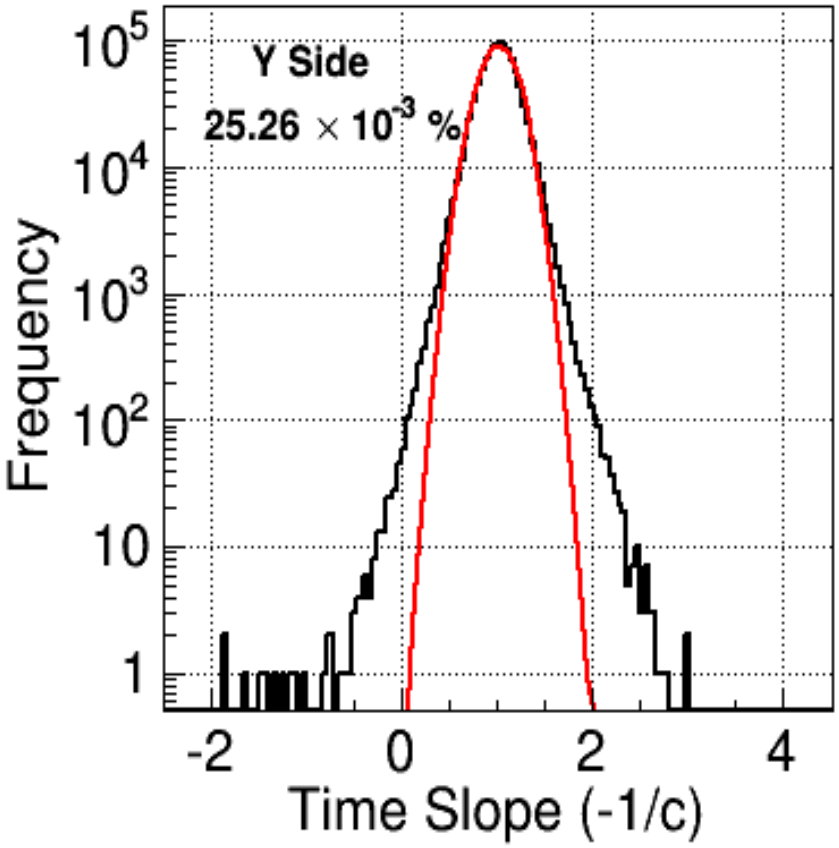




Not much improvement with this correction, but reduces from 1.050/1.043 to 1.021/1.018

Up/down ambiguity with position+strip correction



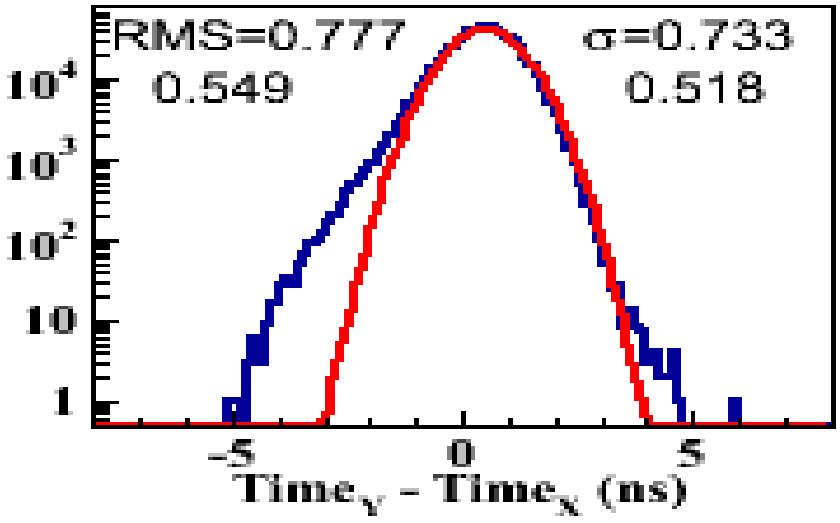


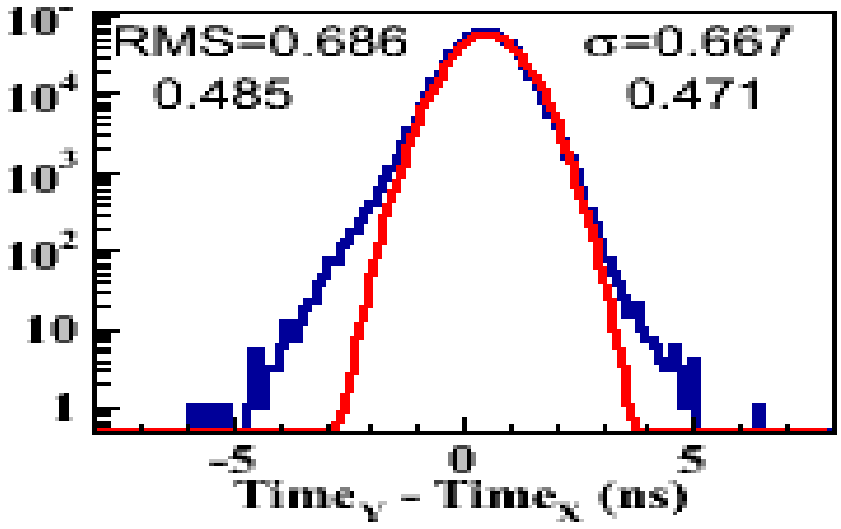
- **This strip correction does not show any improvement on up/down ambiguity.**
- **This is mainly due to the fact that most of the tails come from very badly measured timings and this strip correction is not correcting those badly measured timings.**

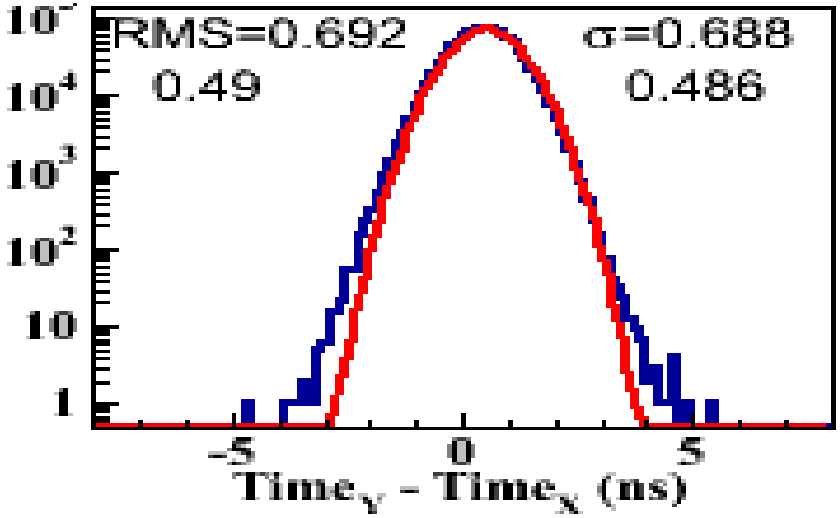
Summary

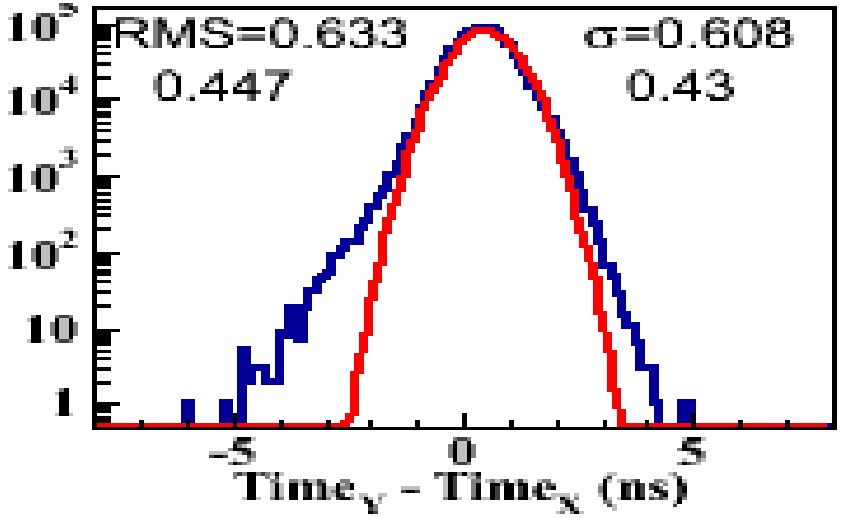
- **Using this offline correction, one can reduce the position dependent time resolution of large scale RPC detector ~1ns.**
  - **About 25% improvement in measured time, but the reduction factor is more than 60%**
  - **This can be used for any experiment, which has sufficient rate of charge particle, e.g,. CMS/ATLAS.**
  - **Otherwise, test each RPC at surface for 3-4 days (Not a single RPC, at stack of 10-15 RPC together to have reconstructed muon for a position dependent correction, e.g., INO**
- **Certainly using extra hardware, e.g., Storing charge and/or Time-Over-Threshold improves time resolution and similarly use of CFD.**

Correlation in X and Y strip



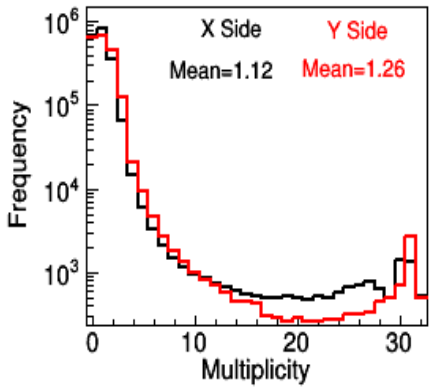


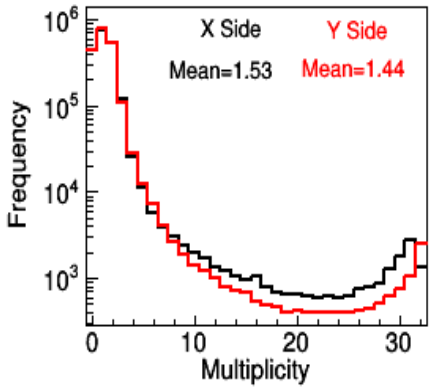


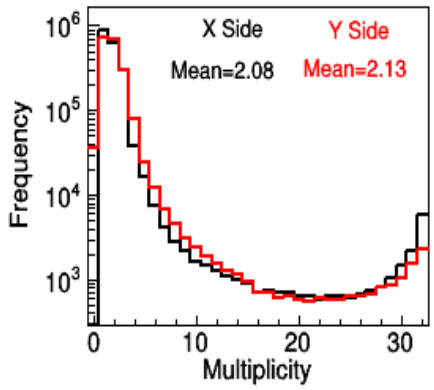


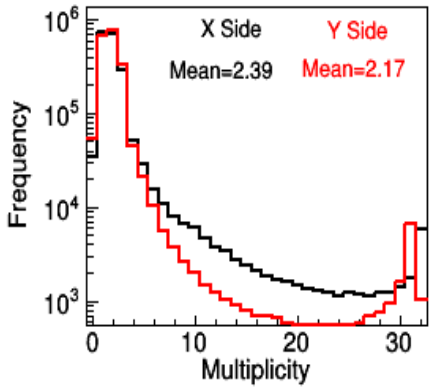
Expected width is zero, but this small width is due to pulse height difference in X-/Y-strip, which is due to position of avalanche centre.

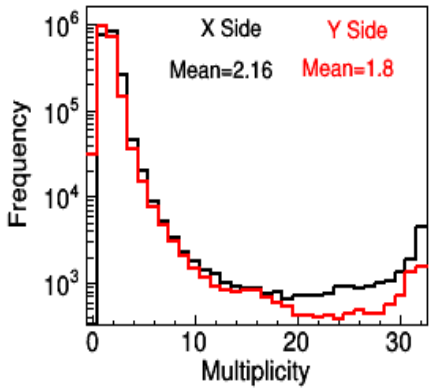
Strip multiplicity

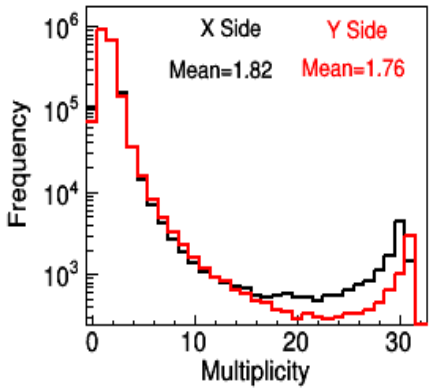


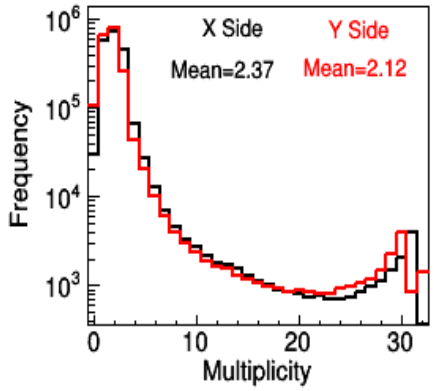


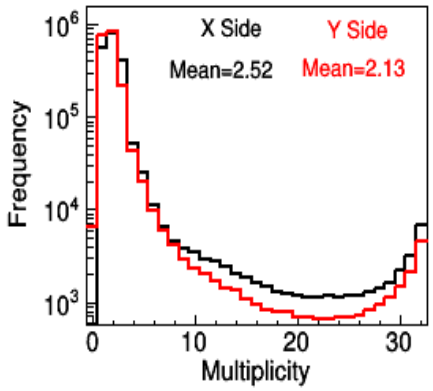


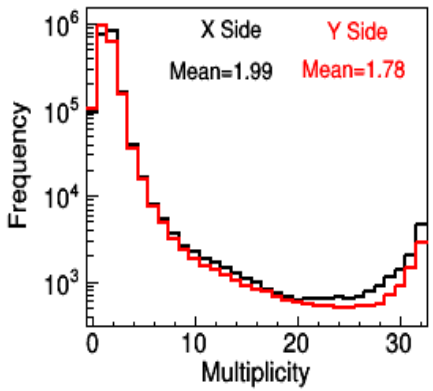


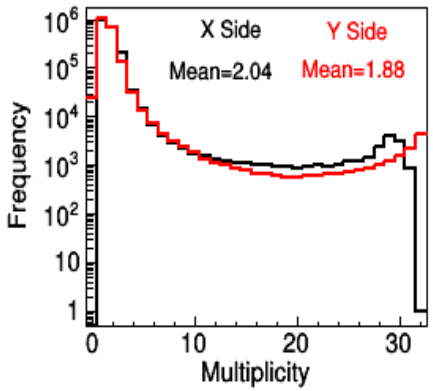


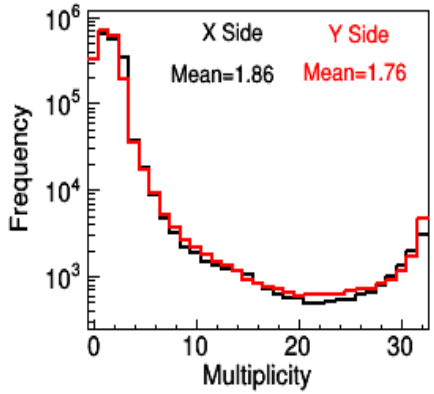


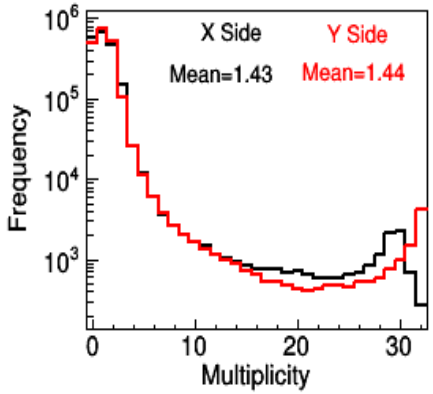




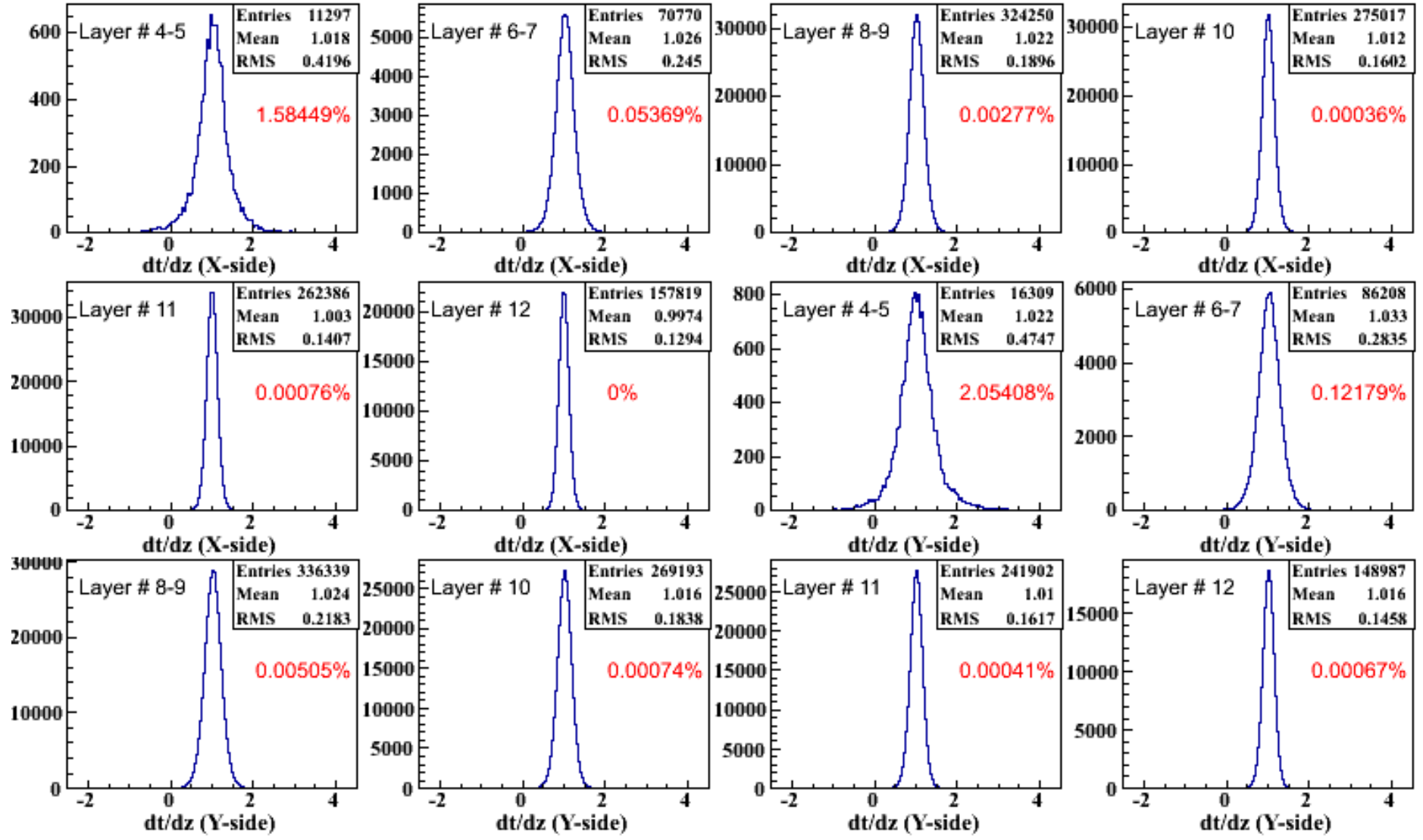






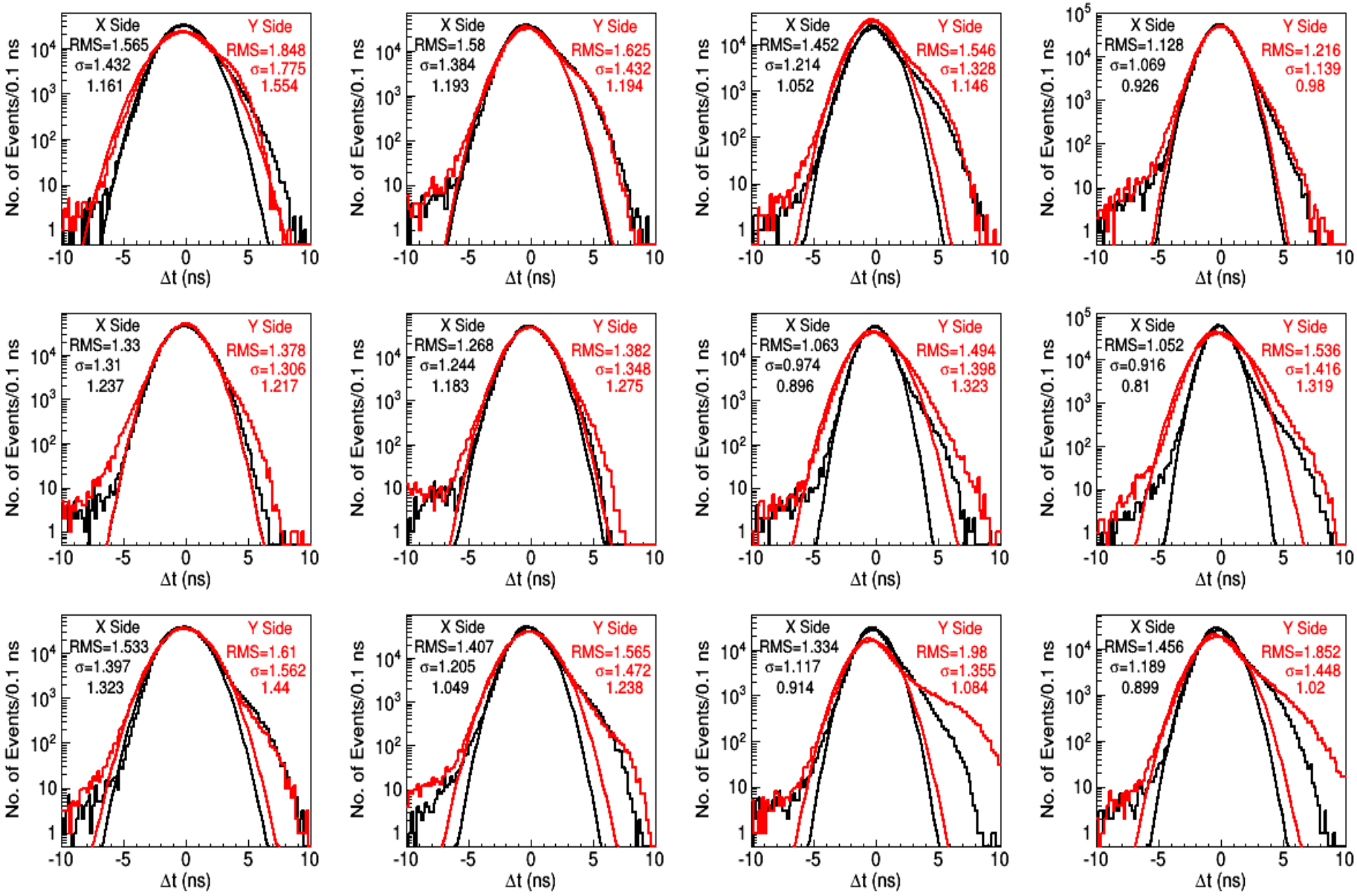


Up-Down directionality : wrong direction

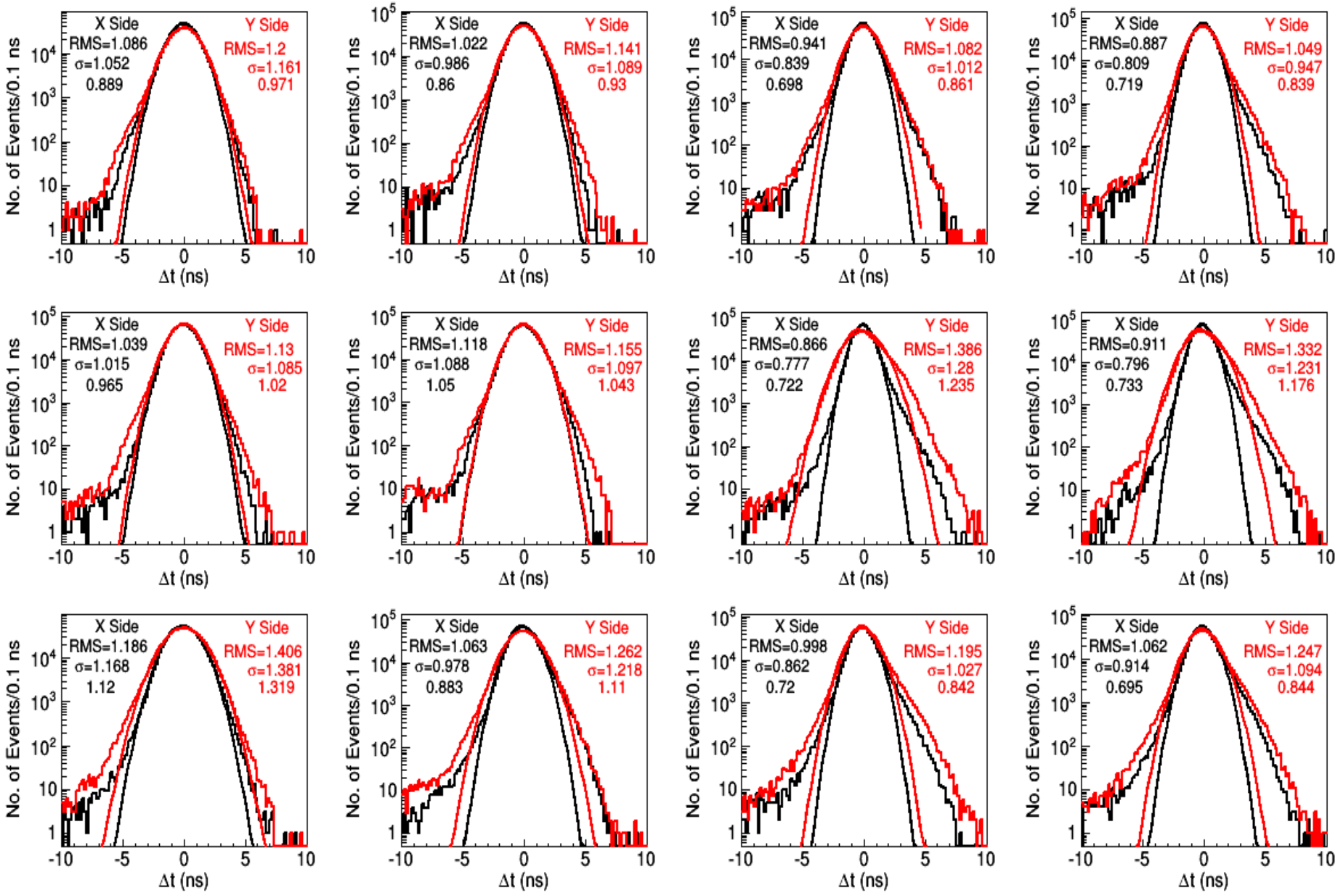


For 11-12 layer, wrong directionality ~0.0018%, about four times better than our earlier measurement (NIMA 735(2014) 88), which did not use outer three strips.

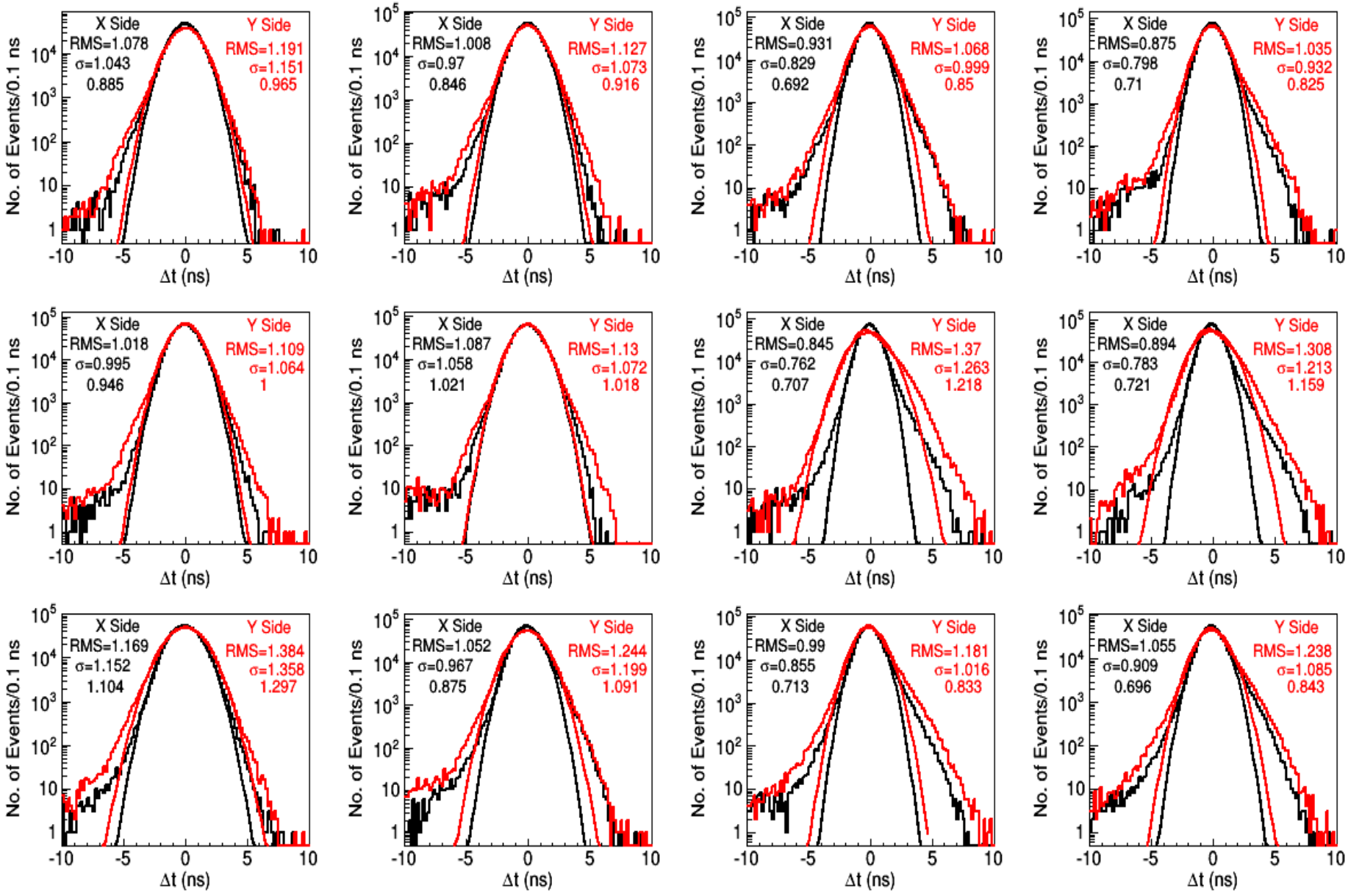
Time resolution w/o position correction



Time resolution with position correction



With position + strip correction



L5 Correlation of inefficiency and time delay

X-side **Efficiency** **Y-side**