# Time-over-Threshold in Digitization, Reconstruction and the MeritTuple

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Beamtest vrvs meeting

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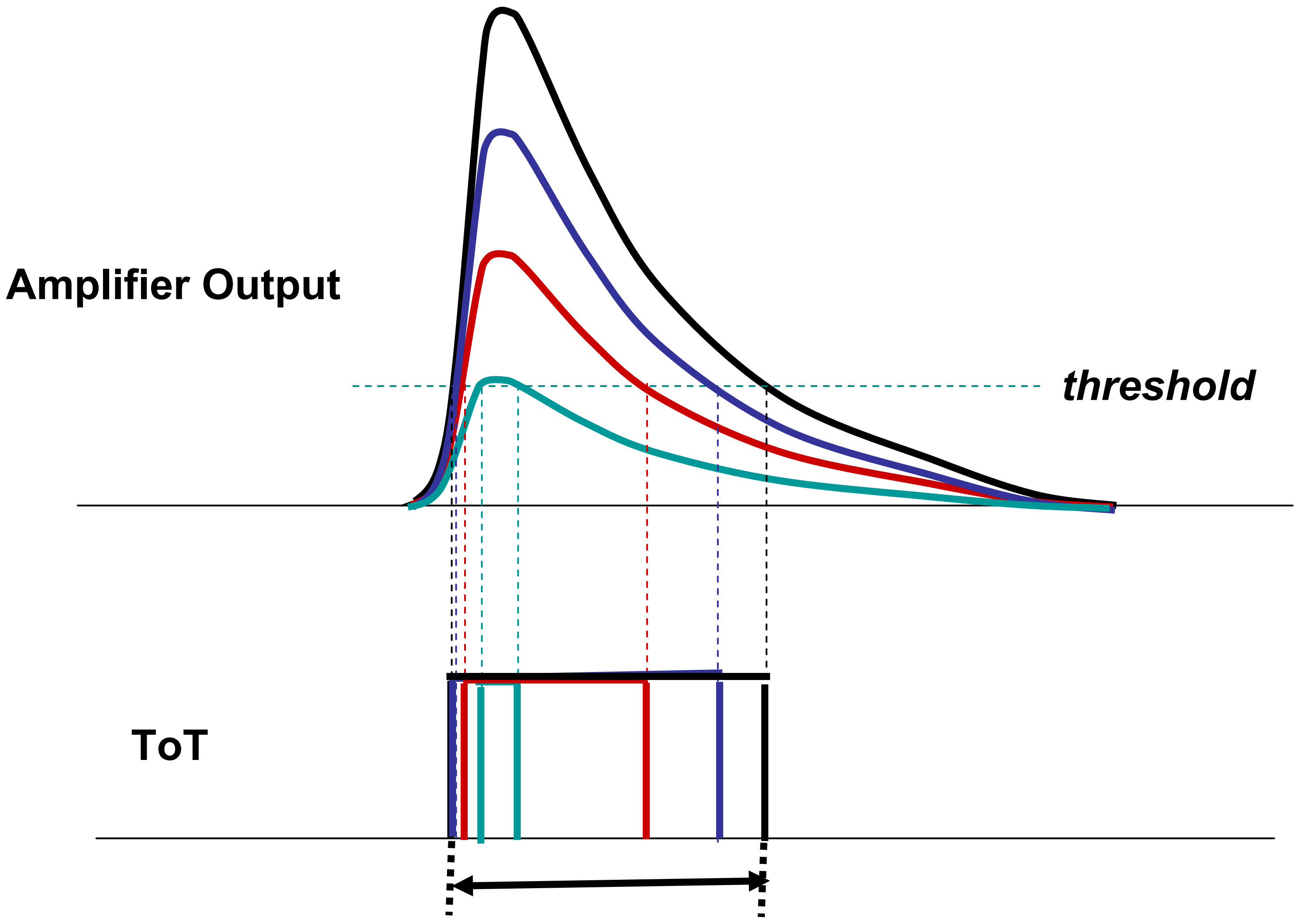
# Topics

- Basics
- Calibration
- Relation of time-over-threshold to deposited charge
  - Digitization: charge → raw ToT
  - Clustering: raw ToT → charge
- Conversion to specific ionization
  - track parallel to strip (easy)
  - track perpendicular to strip (harder)
    - geometry
    - multiple strips
  - intermediate case (hardest)
- meritTuple values: reality check

# ToT Basics

- The tracker front ends produce a level for each strip in the tracker.
  - the level starts when the signal crosses a certain point (from below), nominally set to be ¼ MinI.
  - The level ends when the signal crosses the same point from above, or when it times out (50 μsec = 250 clock ticks).
- Each GTRC ORs the signals from each strip, so the actual ToT signal starts at the earliest start, and ends at the latest end.
  - Since there are nominally 2 GTRCs per plane, each controlling half the strips, there are 2 ToTs per plane.

# A Simple picture



# Some things to remember

- If there are two or more clusters in the same half-plane, there's no way to tell, a priori, which cluster produced the ToT.
- Noise hits are generally not a problem, because they tend to have very low ToTs.
  - but not true for deltas and compton electrons!
- The very events we are looking for (two tracks from a single vertex) can be problematical with respect to ToT.
- There are many handles to help sort out ambiguities, none of which have been incorporated yet into our code:
  - track lengths
  - different path lengths in the 2 views
  - tracks which cross the mid-point of the plane
- In what follows, I'm looking at single-track "muons", in data and MC with the most minimal cuts to eliminate electrons in the data sample.

# Calibration:
# Raw ToT <-> Charge <-> MIPs

time = rawToT/countsPerMicrosecond

charge = muonScale*(threshold + time*(gain + time*quad))

mips = charge/fCPerMip

$t1$ = (charge/muonScale – threshold)/gain

$t2$ = quad/gain

rawToT = countsPerMicrosecond*(-1 + sqrt(1 + 4$t_1 t_2$))/2$t_2$

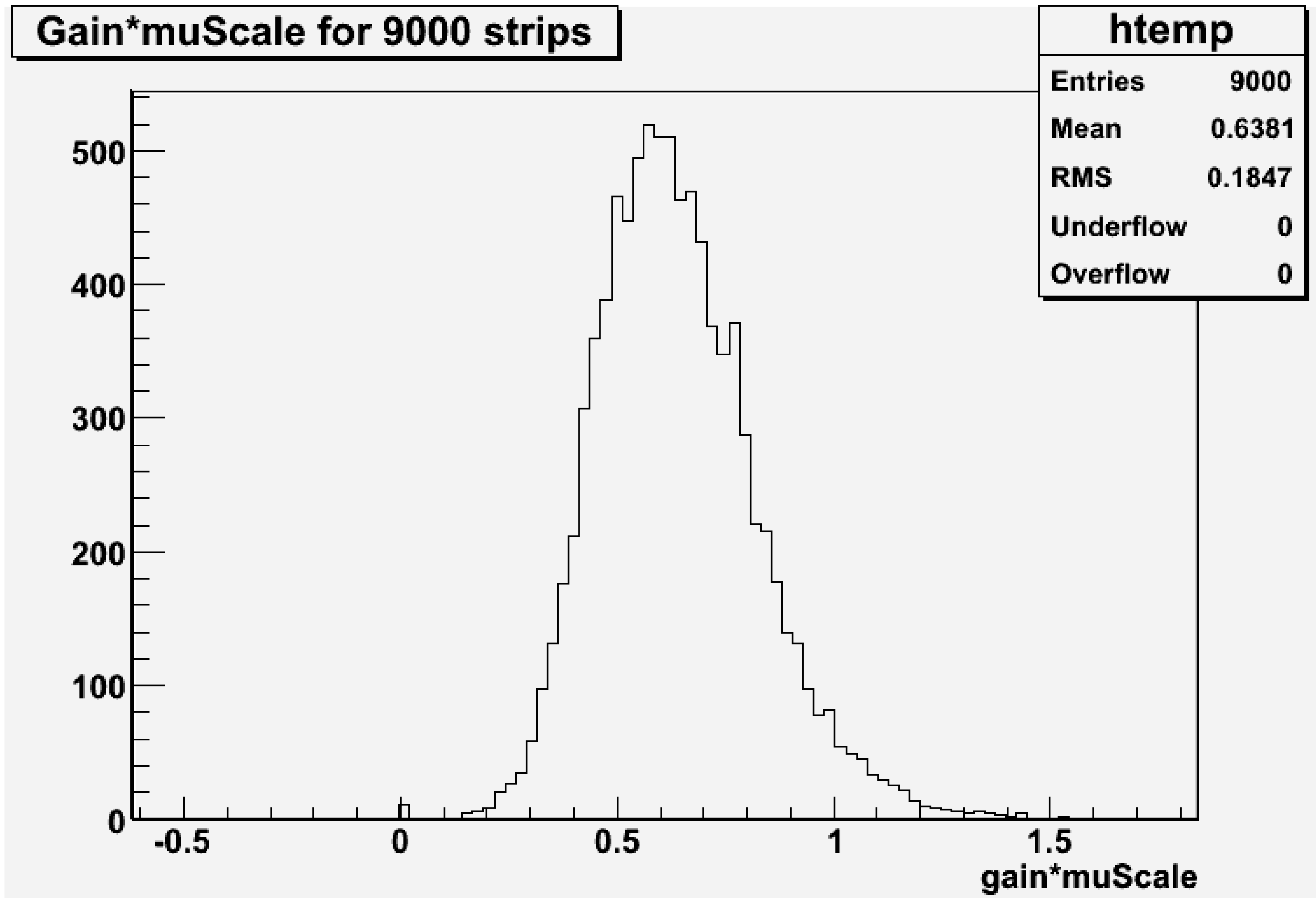
= countsPerMicrosecond*$t_2(1 - t_1 t_2)$, $|t_2| << 1$

where

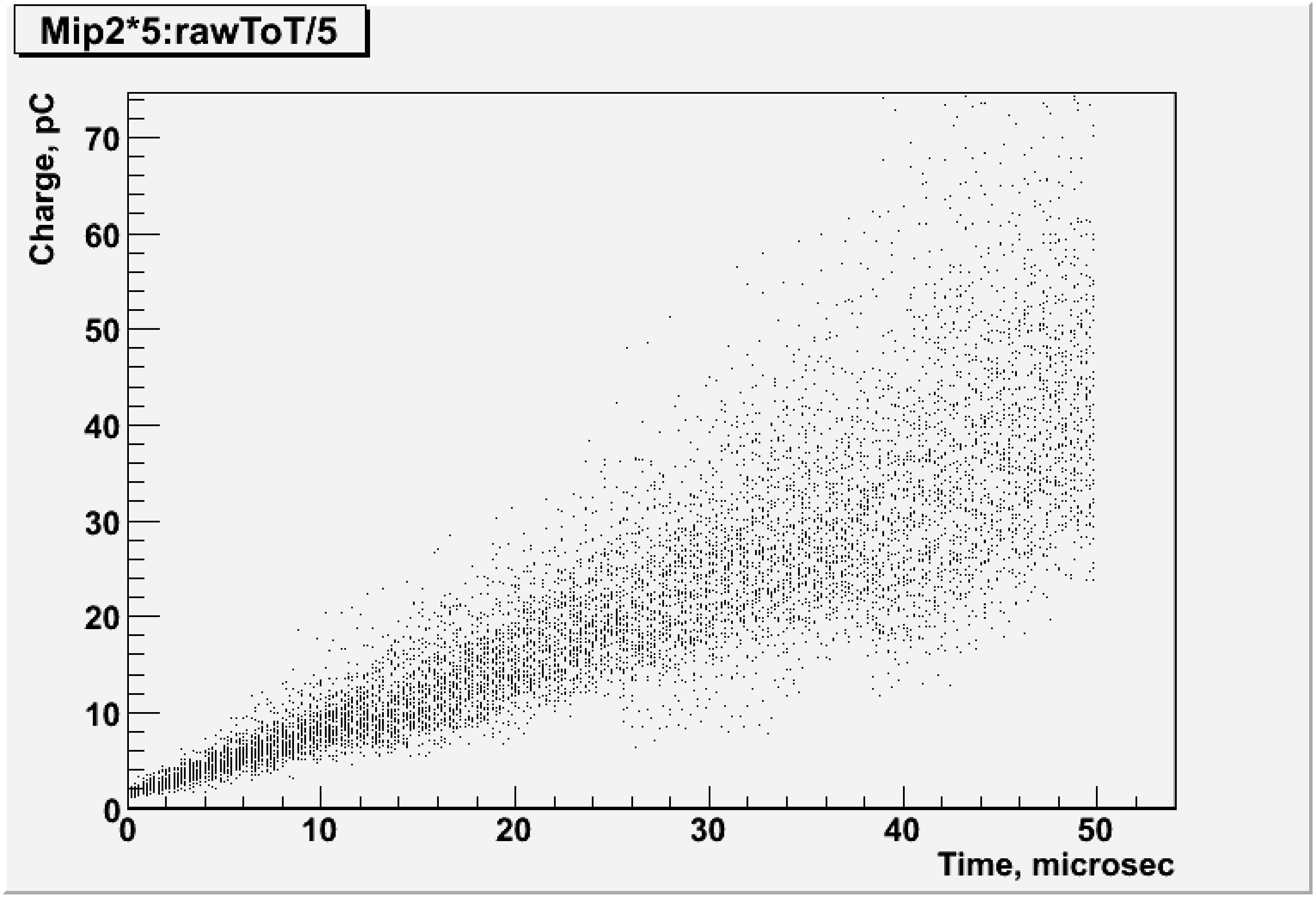
muonScale ~ 1, threshold ~ 1.2 fC, gain~ 0.6 fC/μs, quad~.005 fCμs$^{-2}$

countsPerMicrosecond = 5; fCPerMip = 5;

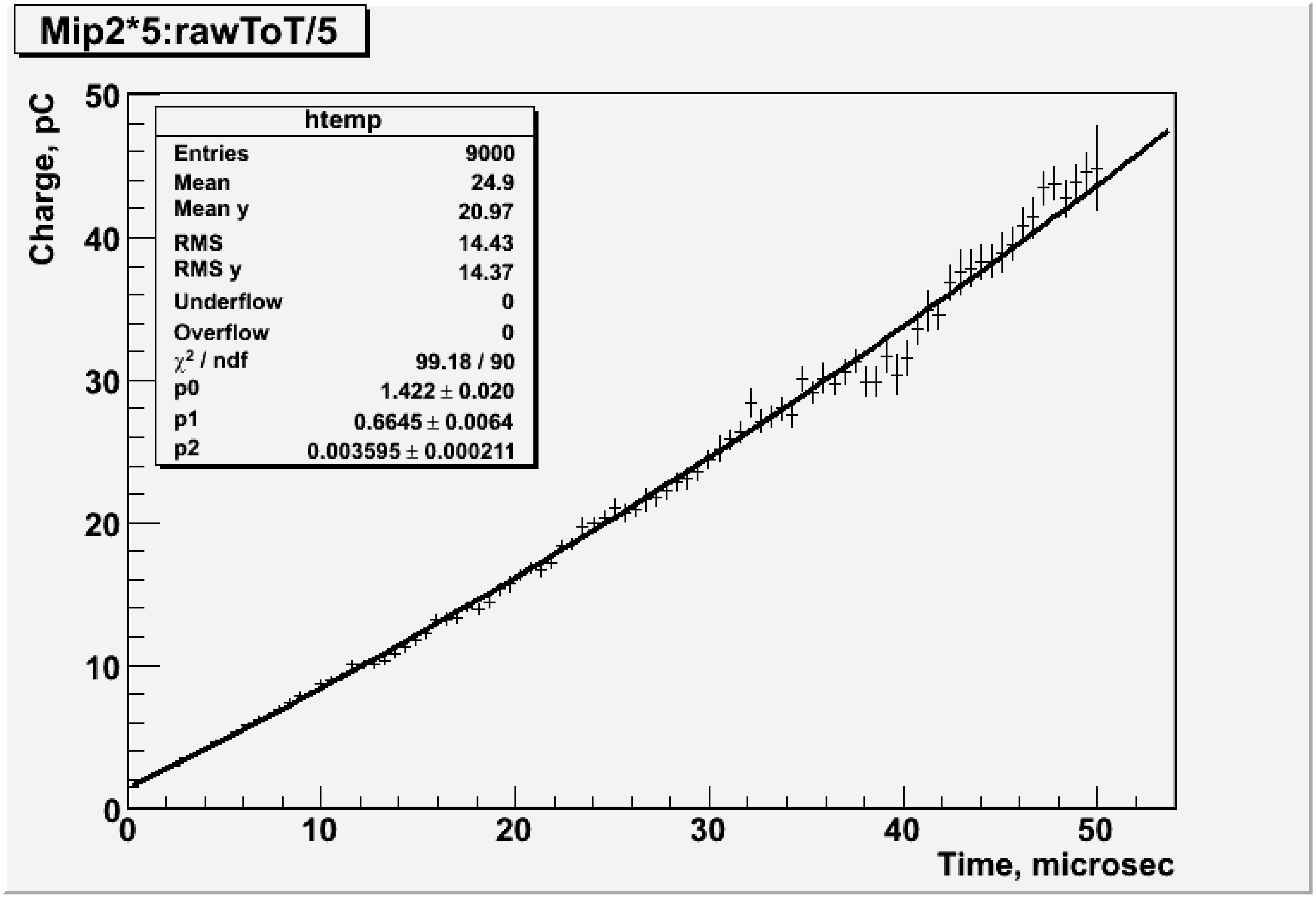
# Sample of Gains (thresholds, quad terms are similar)



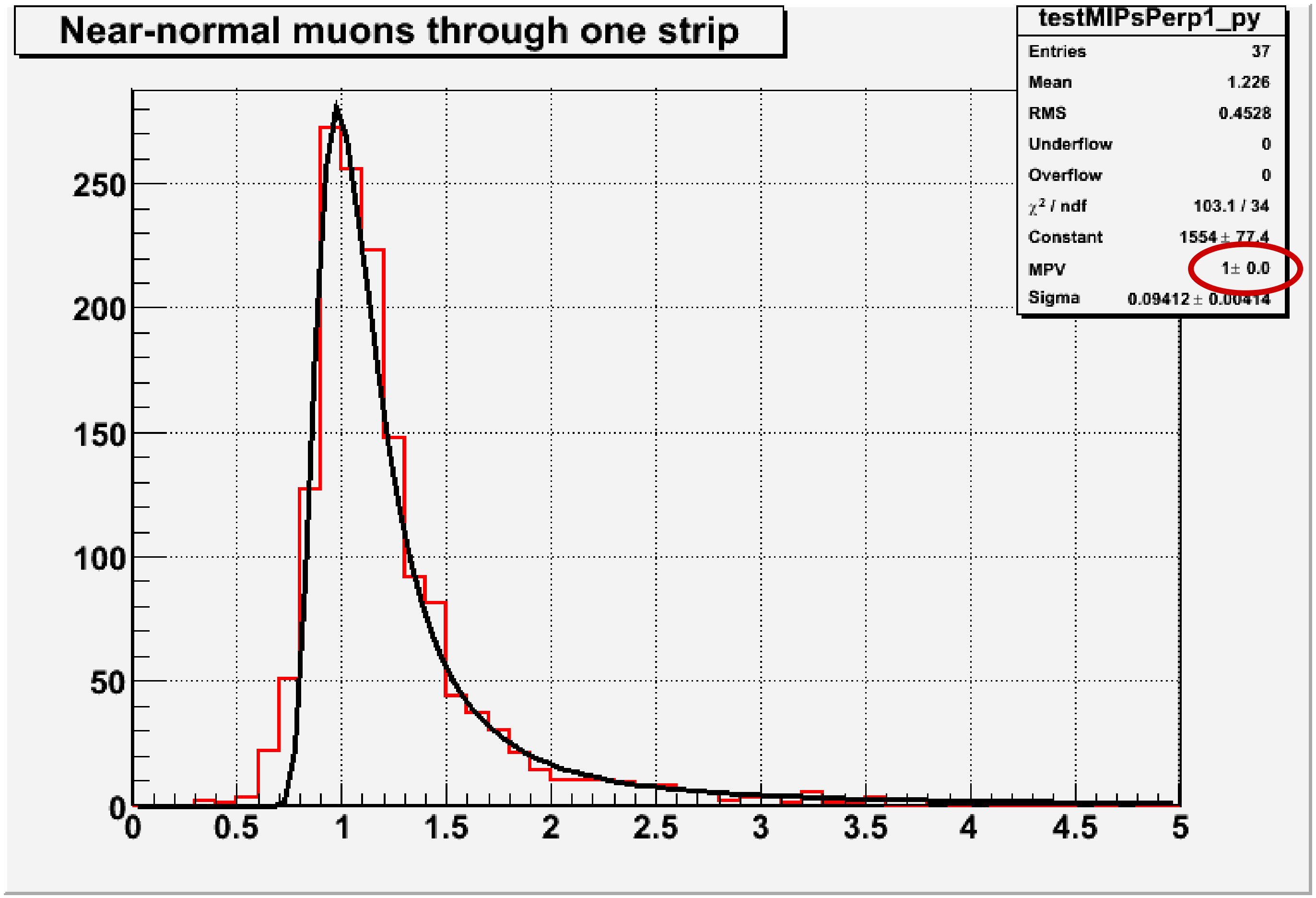
# MIPs vs Raw ToT



# Charge vs Time

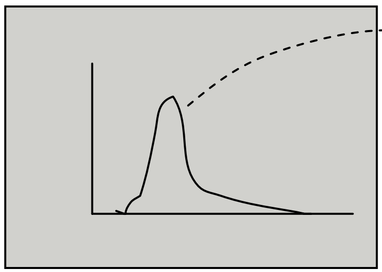


# Energy deposit for muons (data)

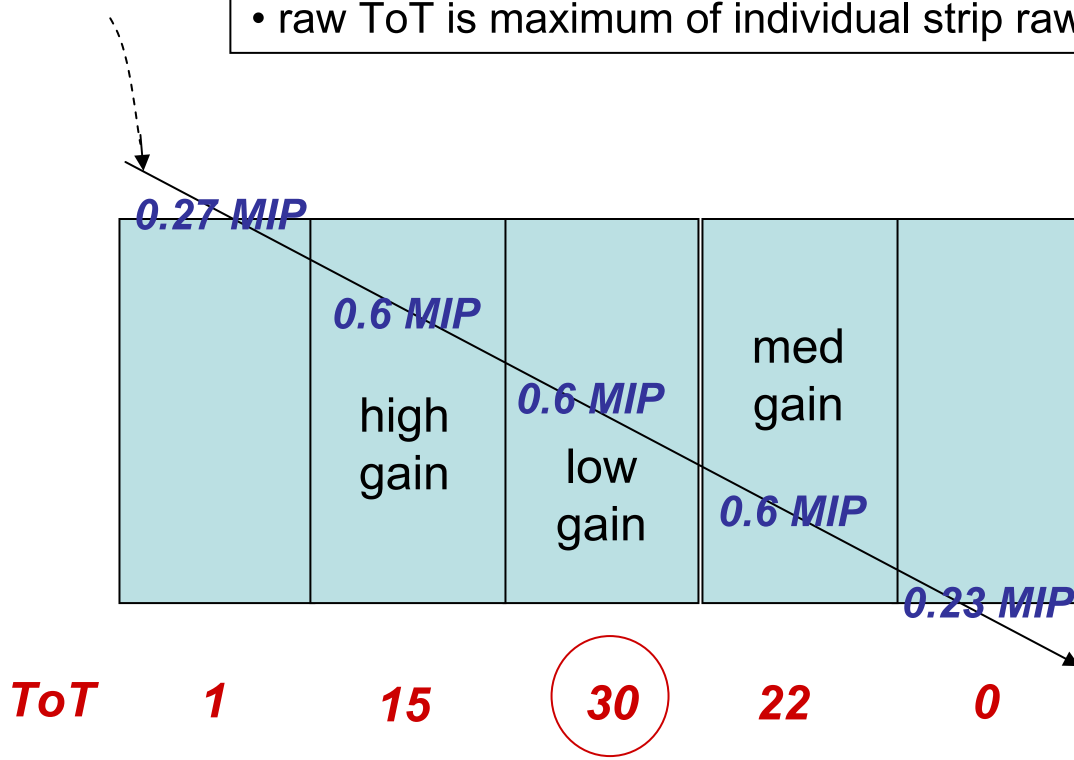


# Digitization: Charge → raw ToT

- Landau fluctuation for energy deposit in the silicon plane
- Energy deposit in strip is proportional to path length
- raw ToT is maximum of individual strip raw ToTs



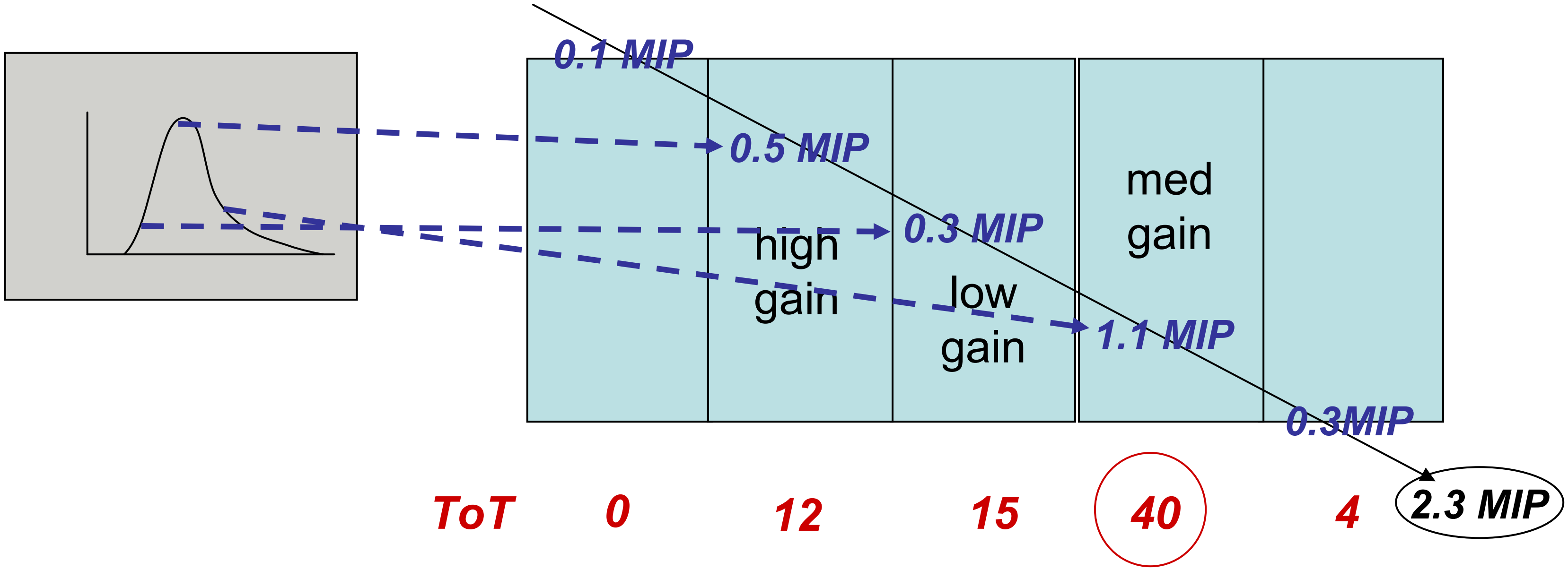
2.3 MIP



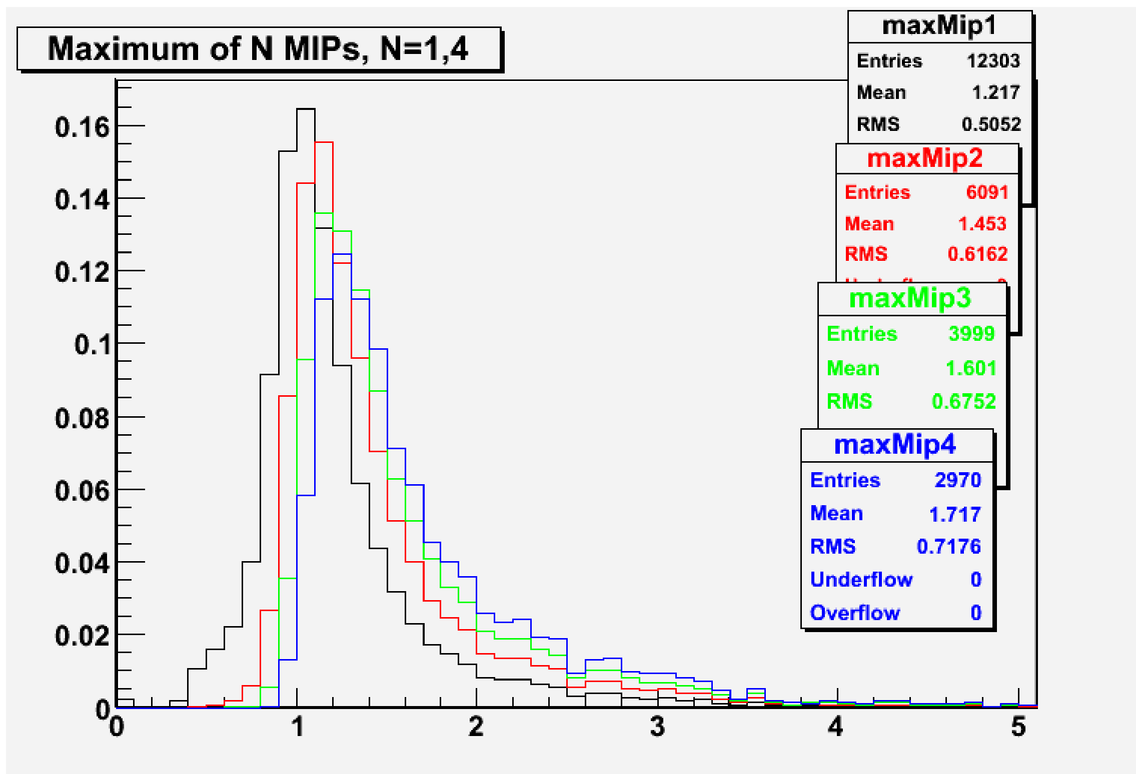
# Charge Fluctuations in Strips (not modeled in MC!!)

• Energy deposit in strip goes like the Landau distribution for that length

• raw ToT is maximum of individual strip raw ToTs



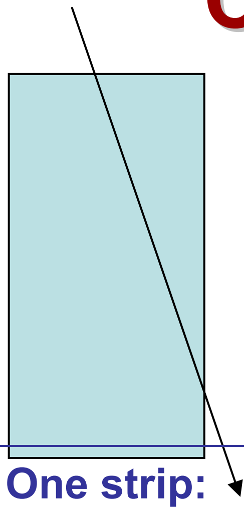
# Why do charge fluctuations in the strips matter?



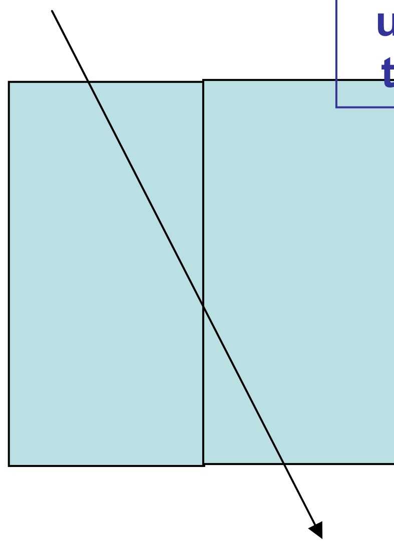

**…because the rawToT is the *maximum* of all the individual raw ToTs.**

# Clustering: raw ToT → Charge

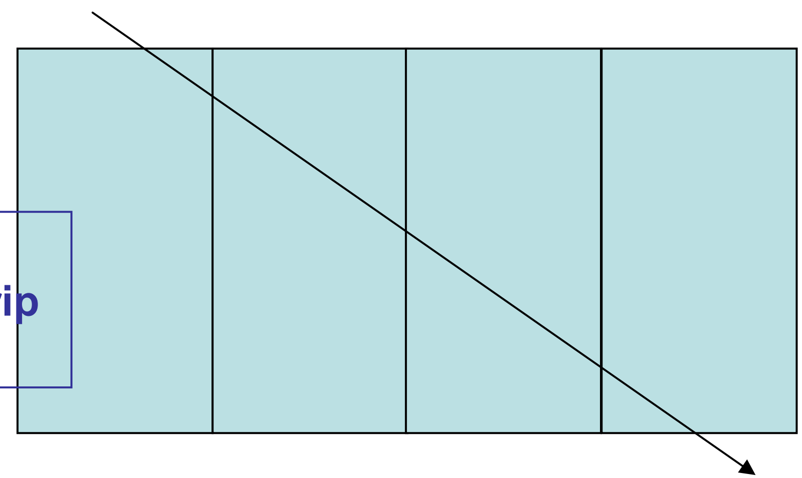
**Depends on number of strips in cluster**



**One strip:**
**Convert using the strip constants**



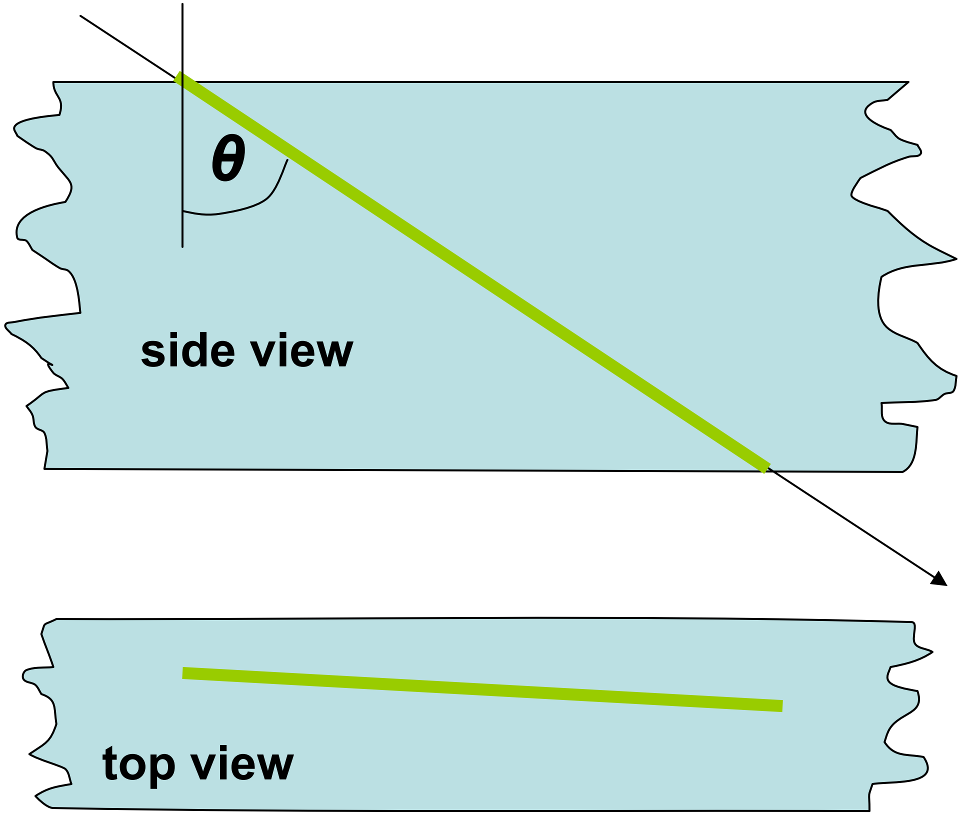
**Two strips:**
**use the constants of the strip that yields the lowest charge**



**More than two strips:**
**Ignore outside strips; then use the strip that yields the lowest charge**

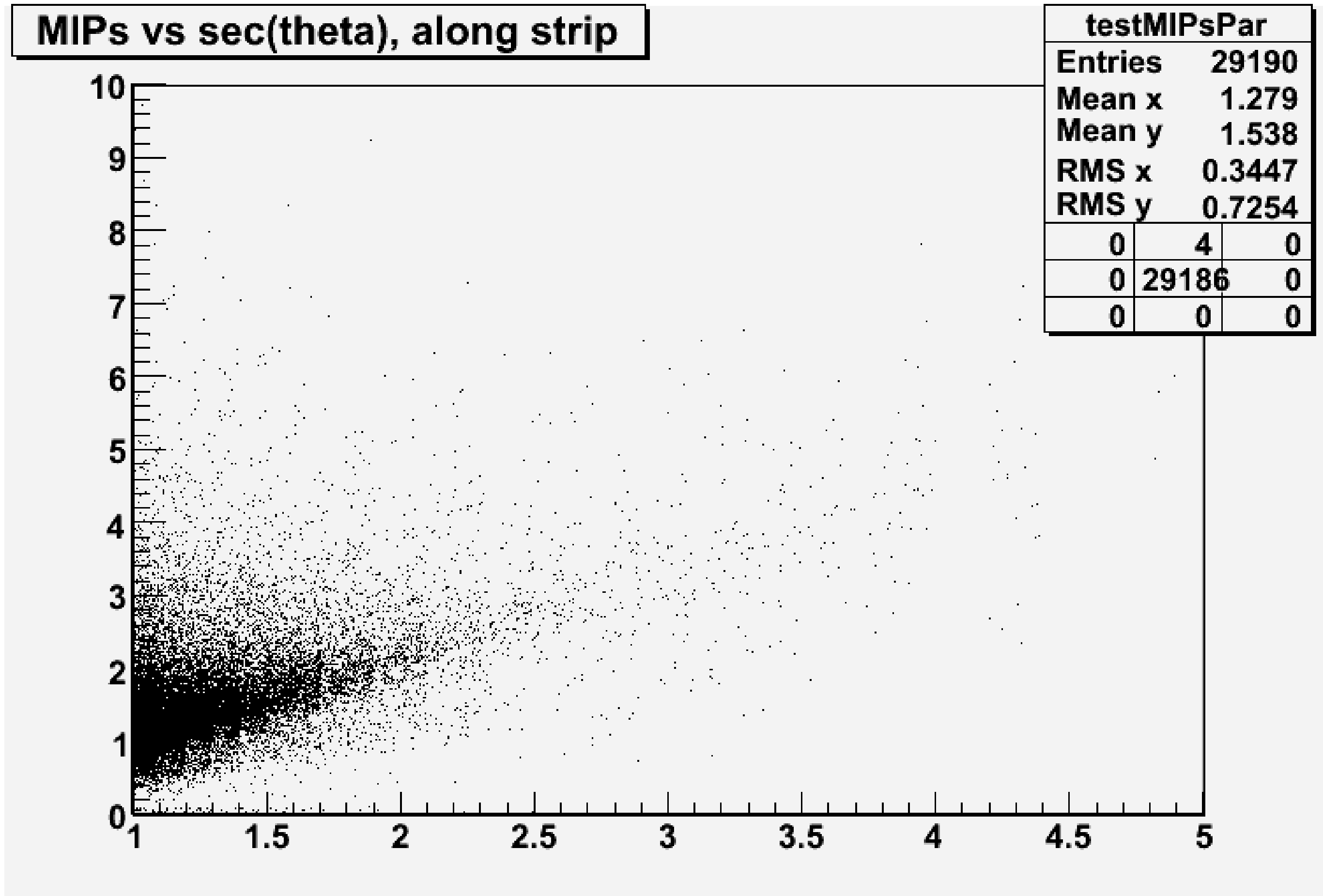
**The lowest "gain" gives the highest ToT for a given charge.**

# Deposited Charge: Track parallel to strip (easy)

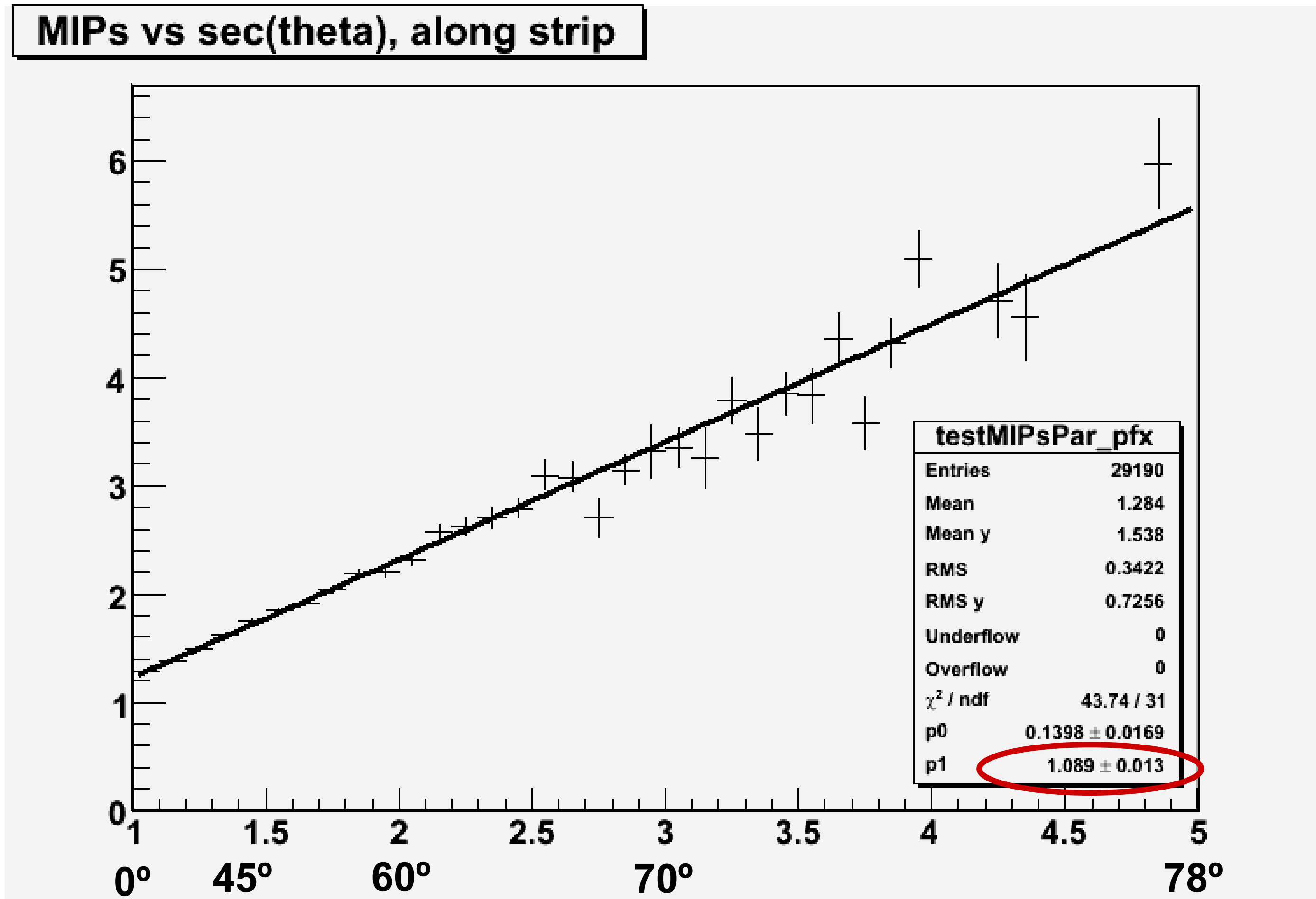



$$i \approx sec(\theta)$$

# MIPs vs *sec(θ)*, *φ* within 0.1 rad. of strip direction



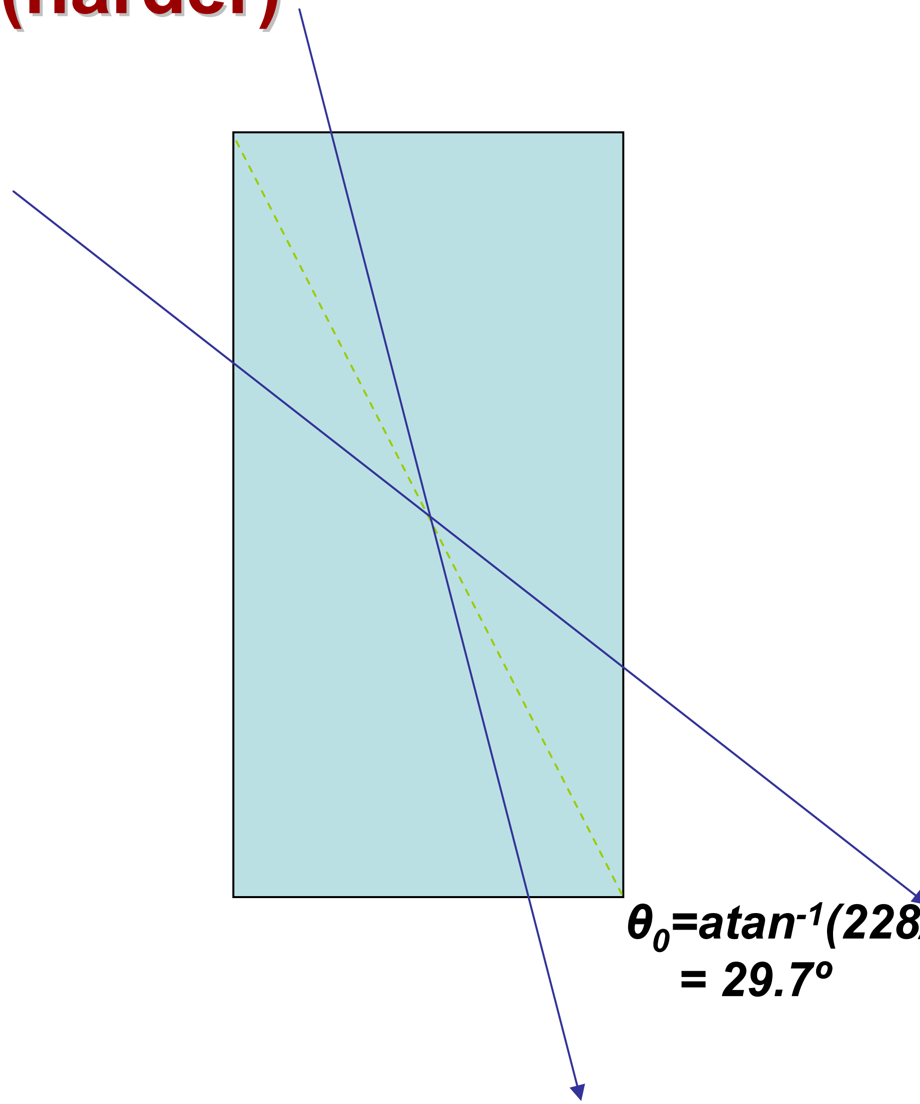
# MIPs vs *sec(θ)*, *φ* within 0.1 rad. of strip direction



# Deposited Charge: Track perpendicular to strip (harder)

$i \approx 400\sec(\theta),\ \theta<\theta_0$

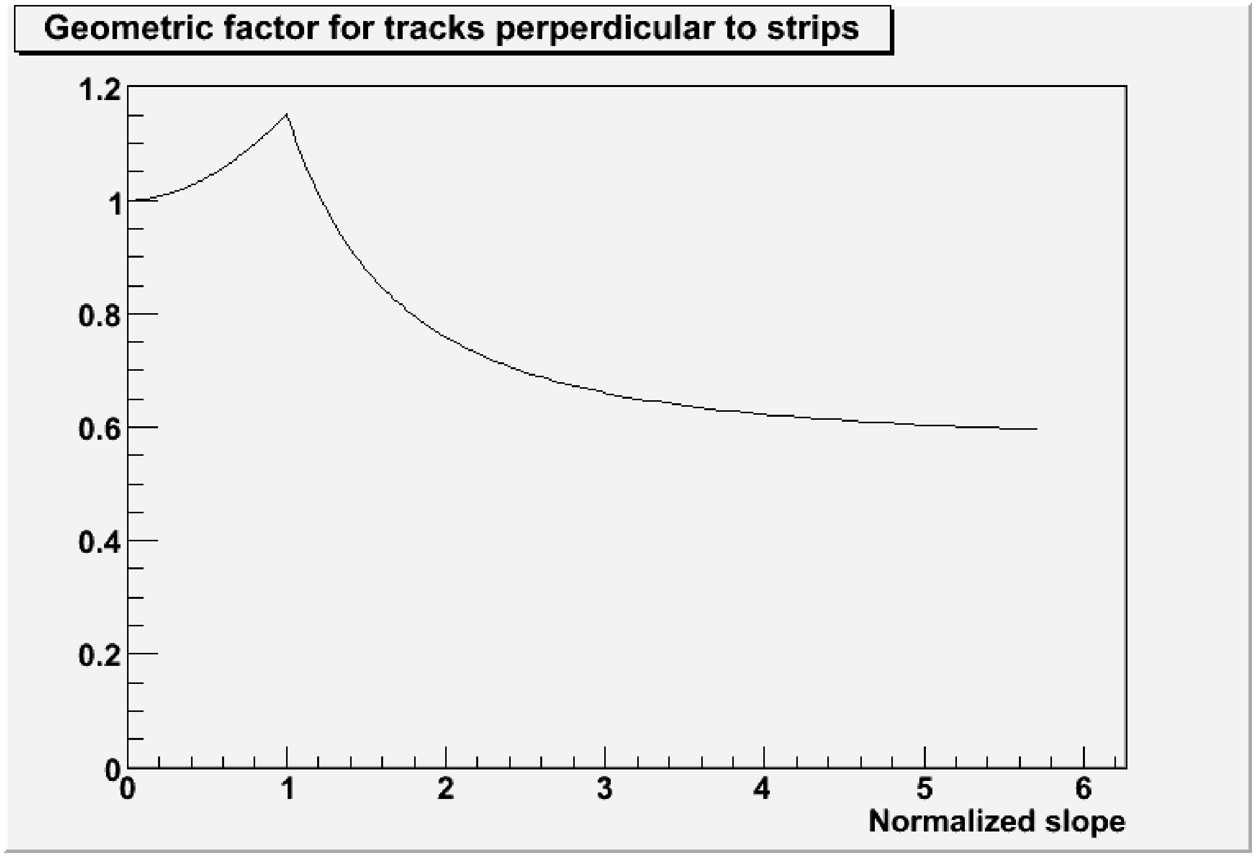
$\approx 228\csc(\theta),\ \theta>\theta_0$



$\theta_0 = \operatorname{atan}^{-1}(228/400)$

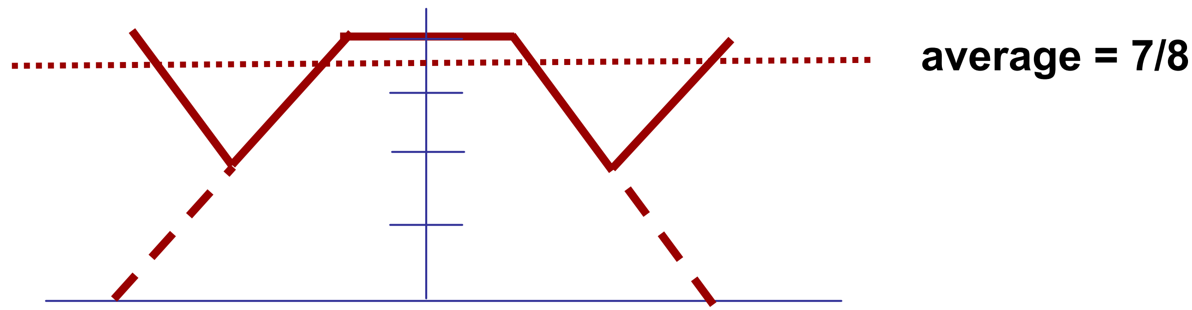
$= 29.7^{o}$

# Geometric Factor for Perpendicular Tracks

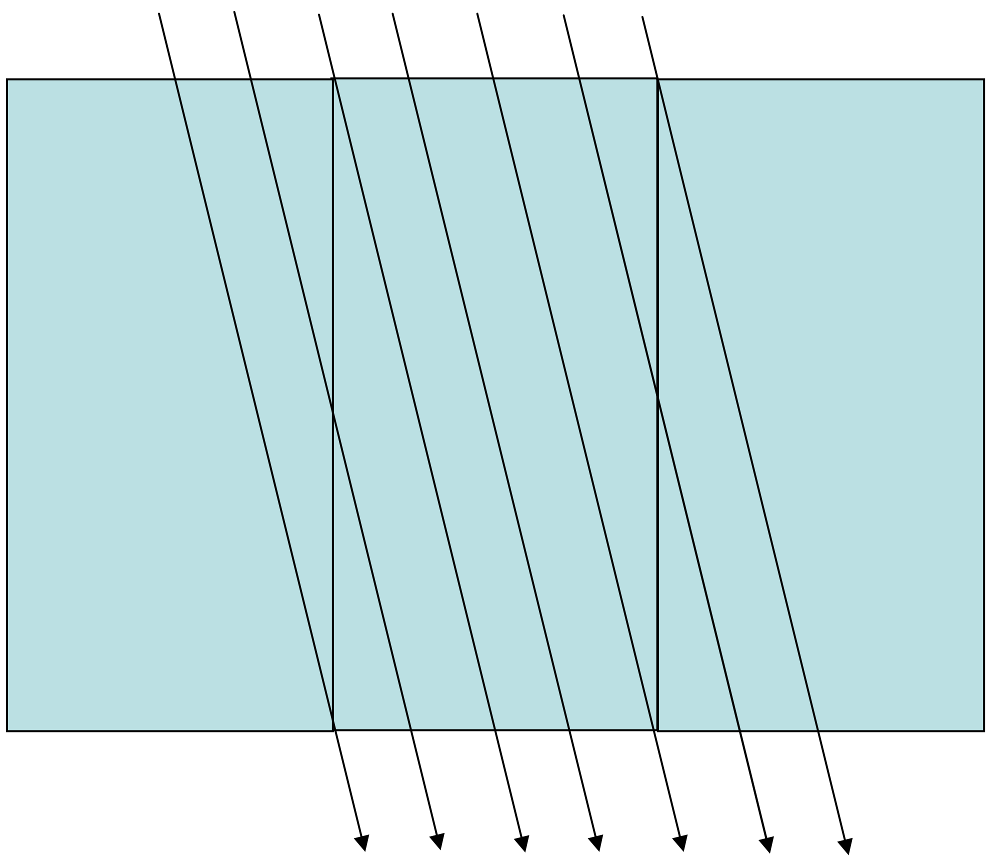



**Normalized slope is** ***400/228tan(θ)***

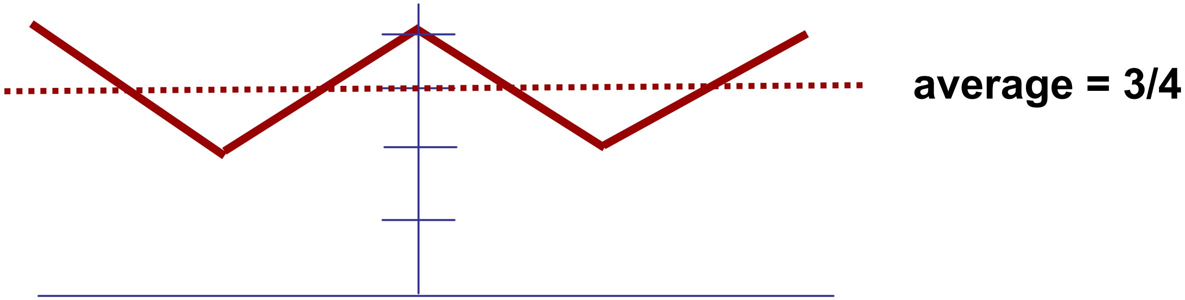
# What else? Strip-crossing



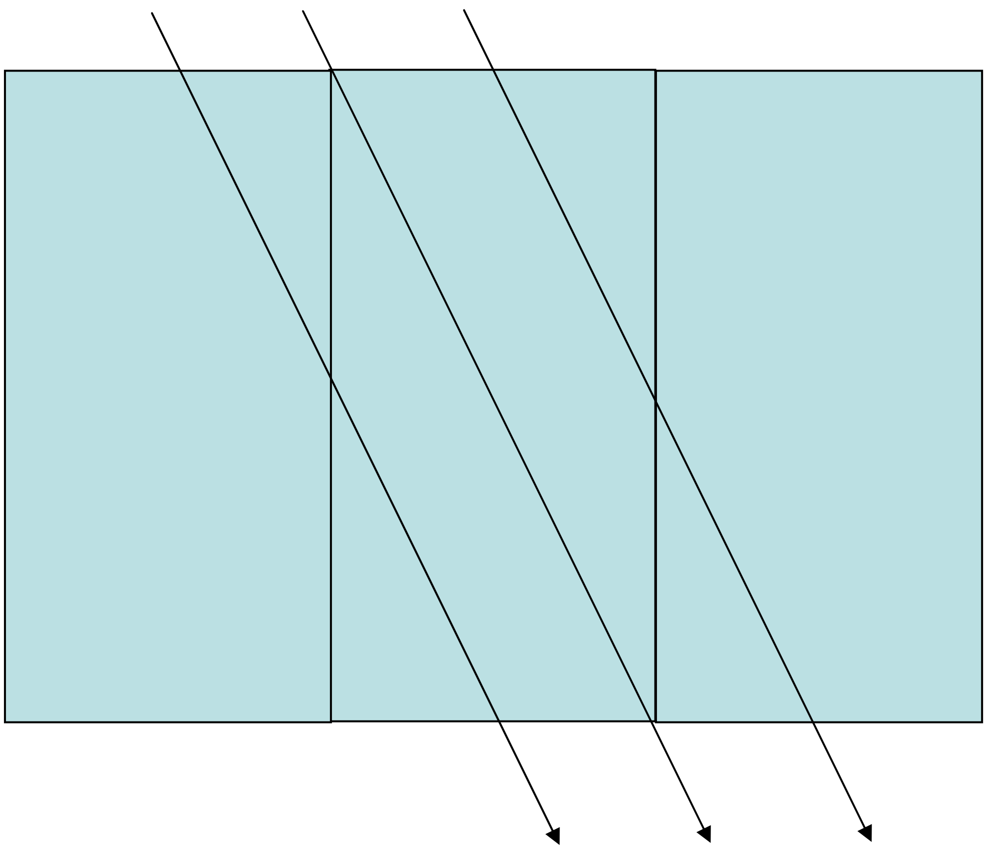

$\theta = 15^o$



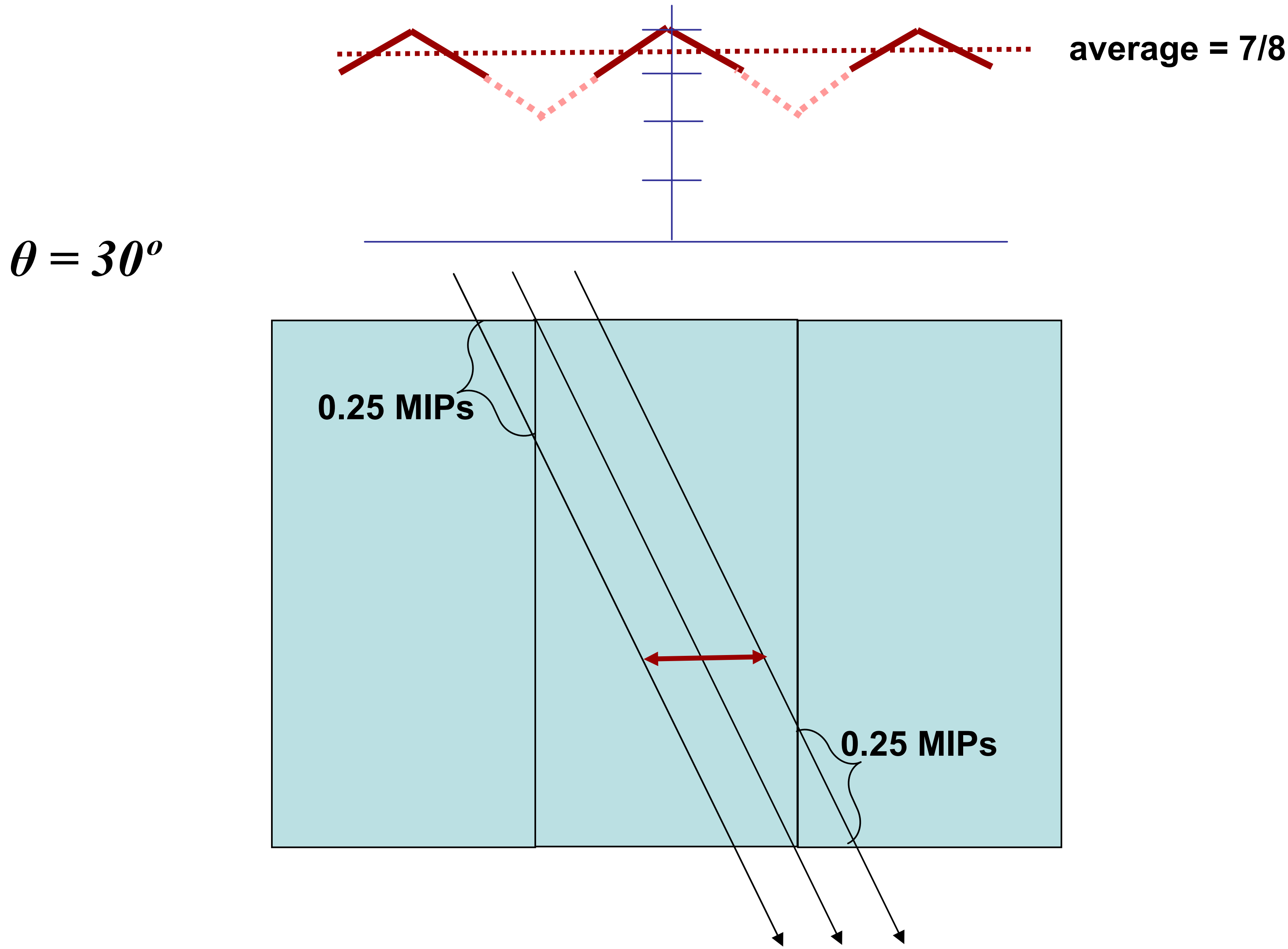
# More Strip-crossing



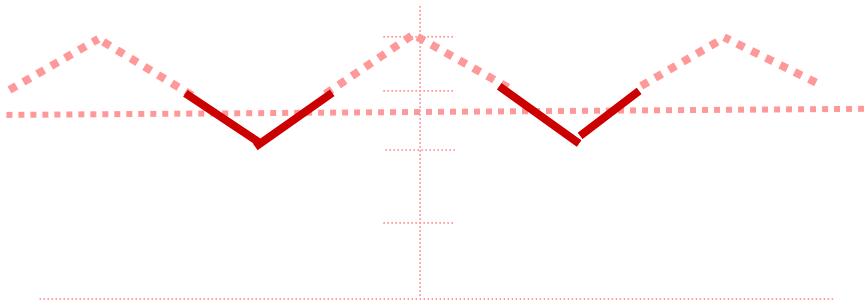

$\theta = 30^o$



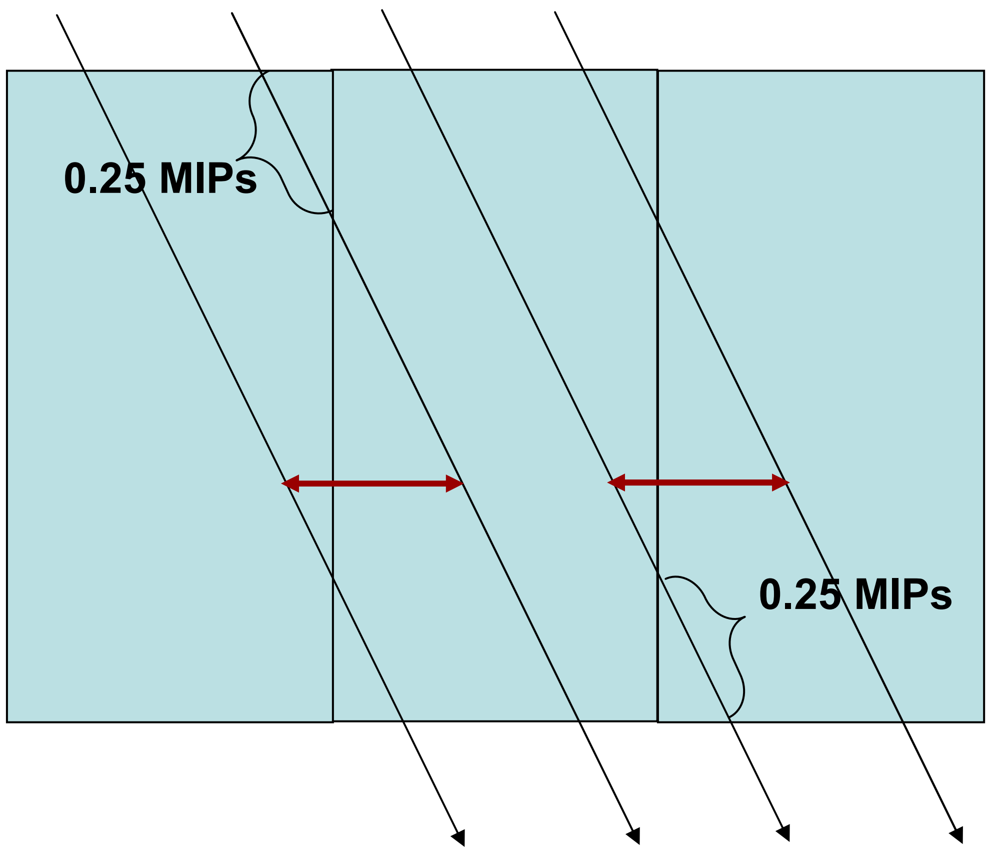
# Now add cluster-width info…
# One strip fires



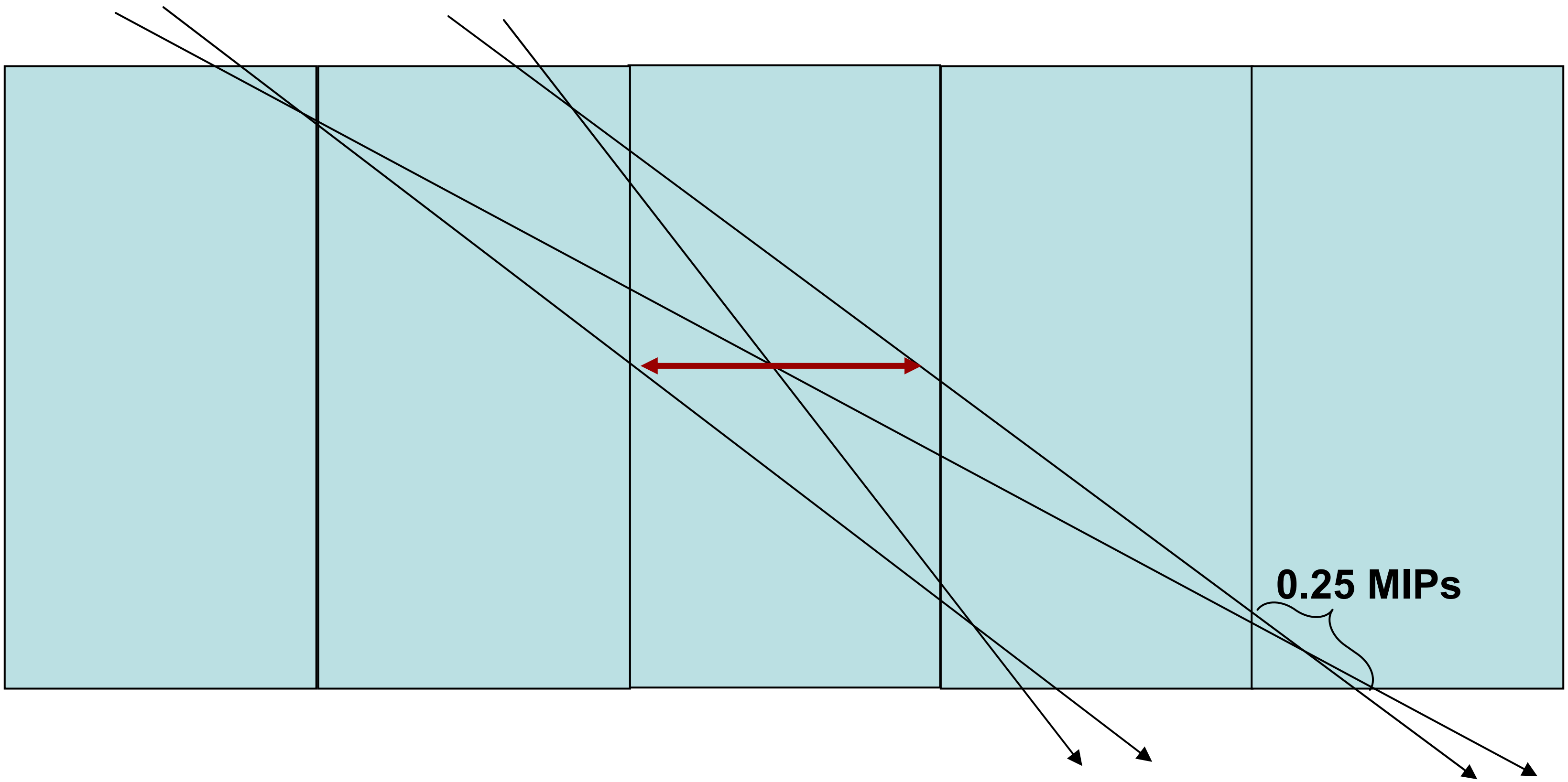
# Two strips fire…




$\theta = 30^o$

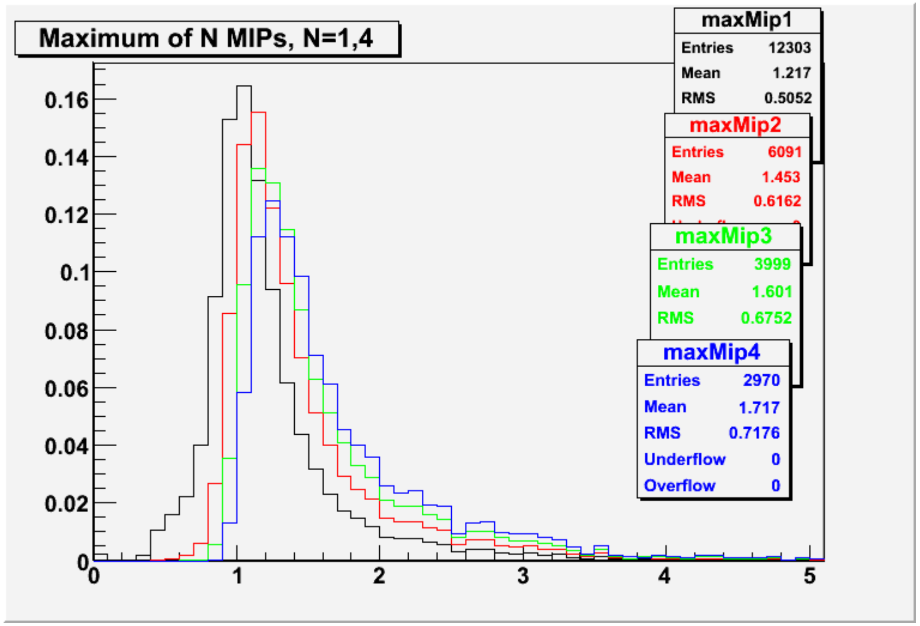


# Three strips fire…



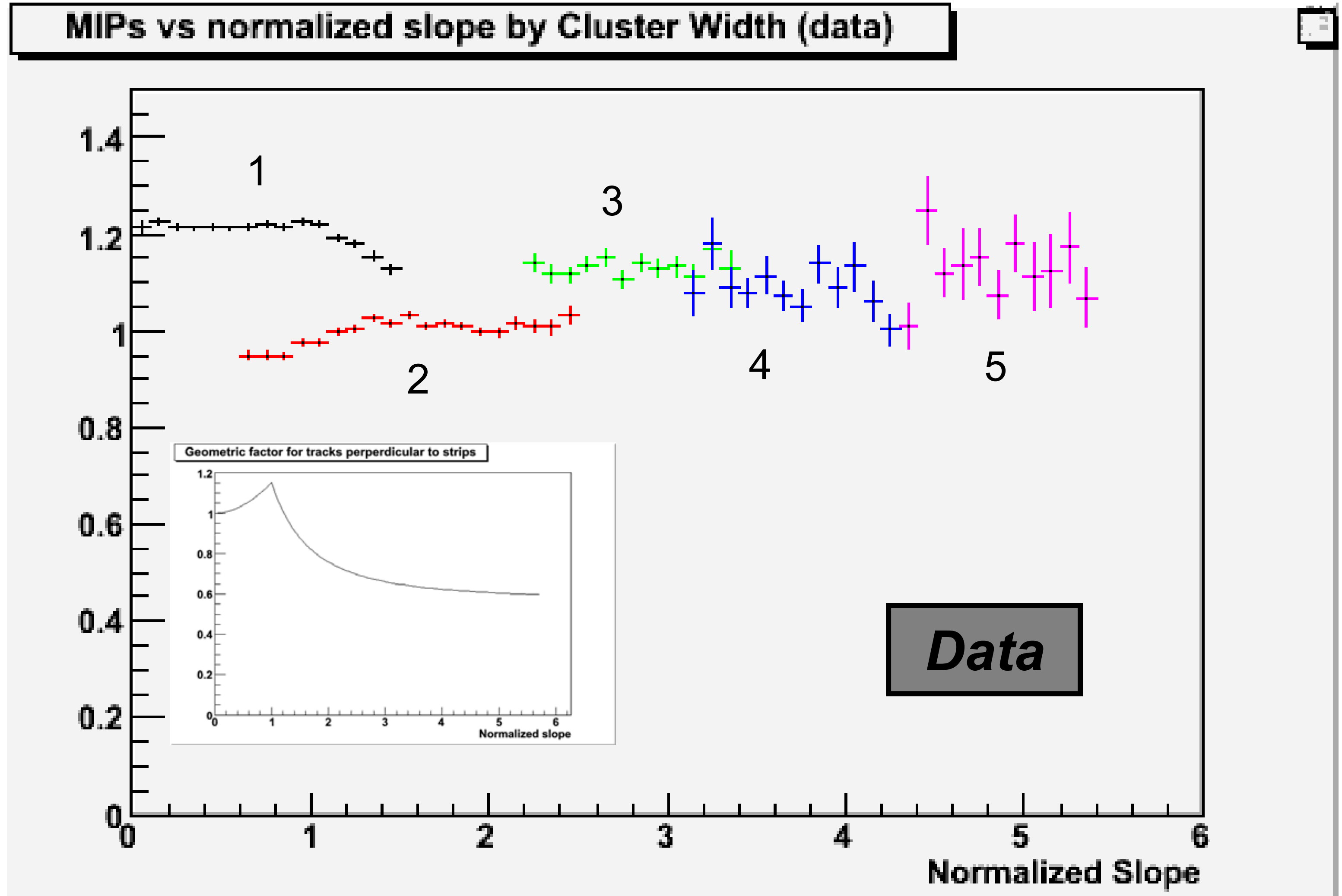

**In every case, at least one strip is fully traversed, and for some angles, all three.**

# And…

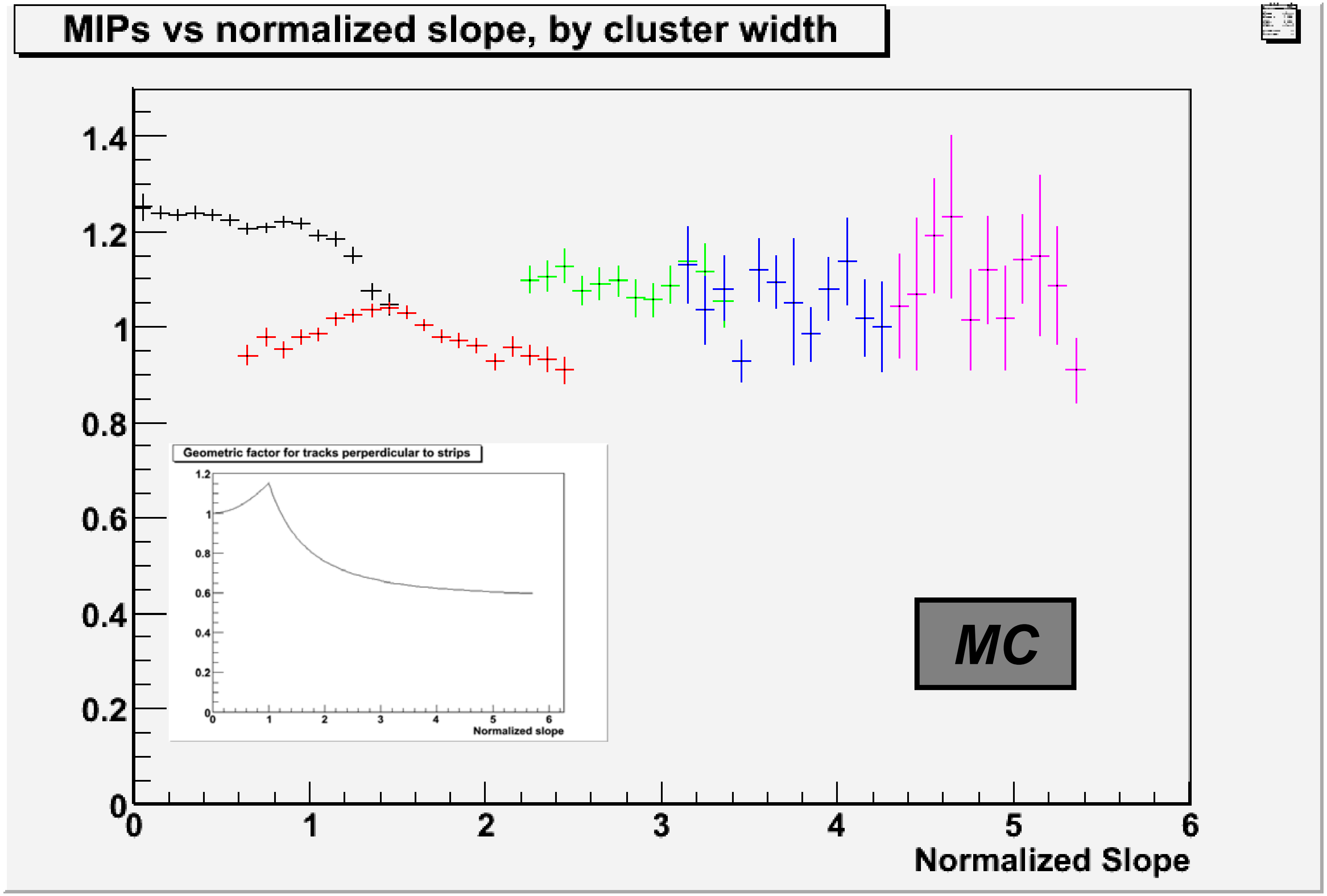



**Remember this? We expect the actual ToT to increase faster than geometric, because at large angles, we sample the ionization several times, and take the largest.**

# What does it really look like? -- Data

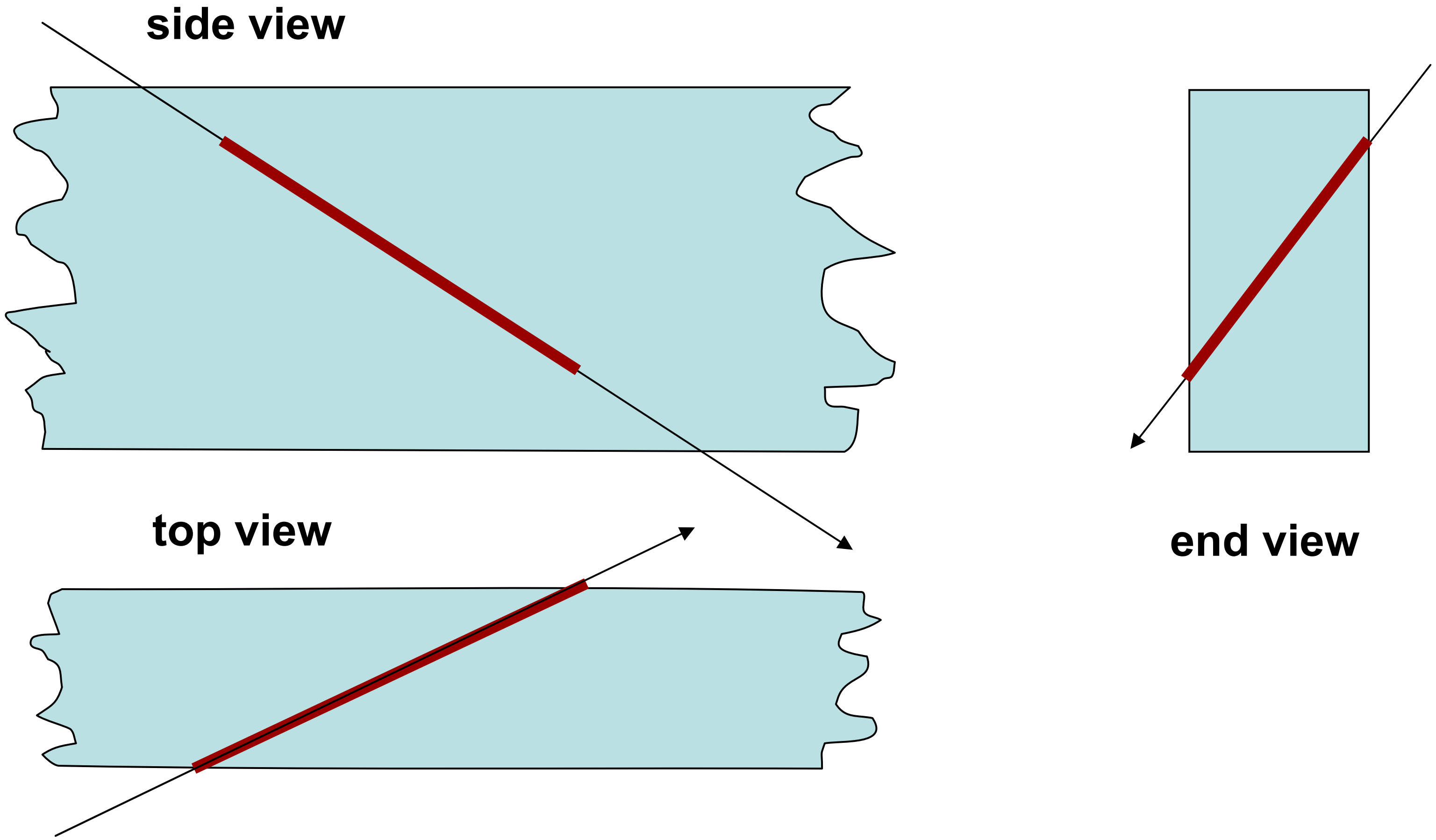


# MC



MIPs vs normalized slope, by cluster width
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
Normalized Slope
Geometric factor for tracks perperdicular to strips
Normalized slope
MC

# General φ



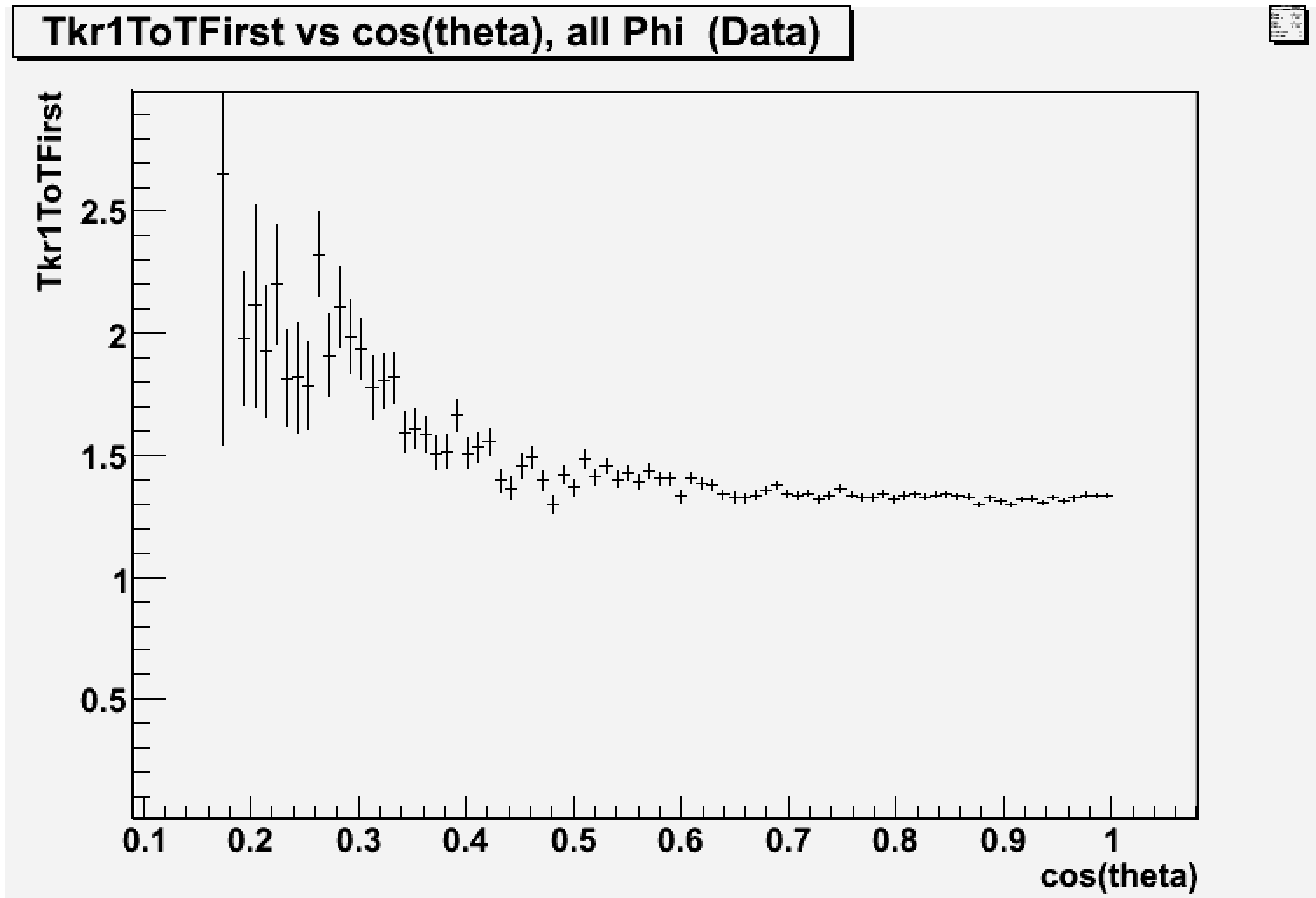

**Calculate true path length, then treat properly in end view**

**Specific ionization in meritTuple is corrected as a function of θ, φ, and number of strips.**

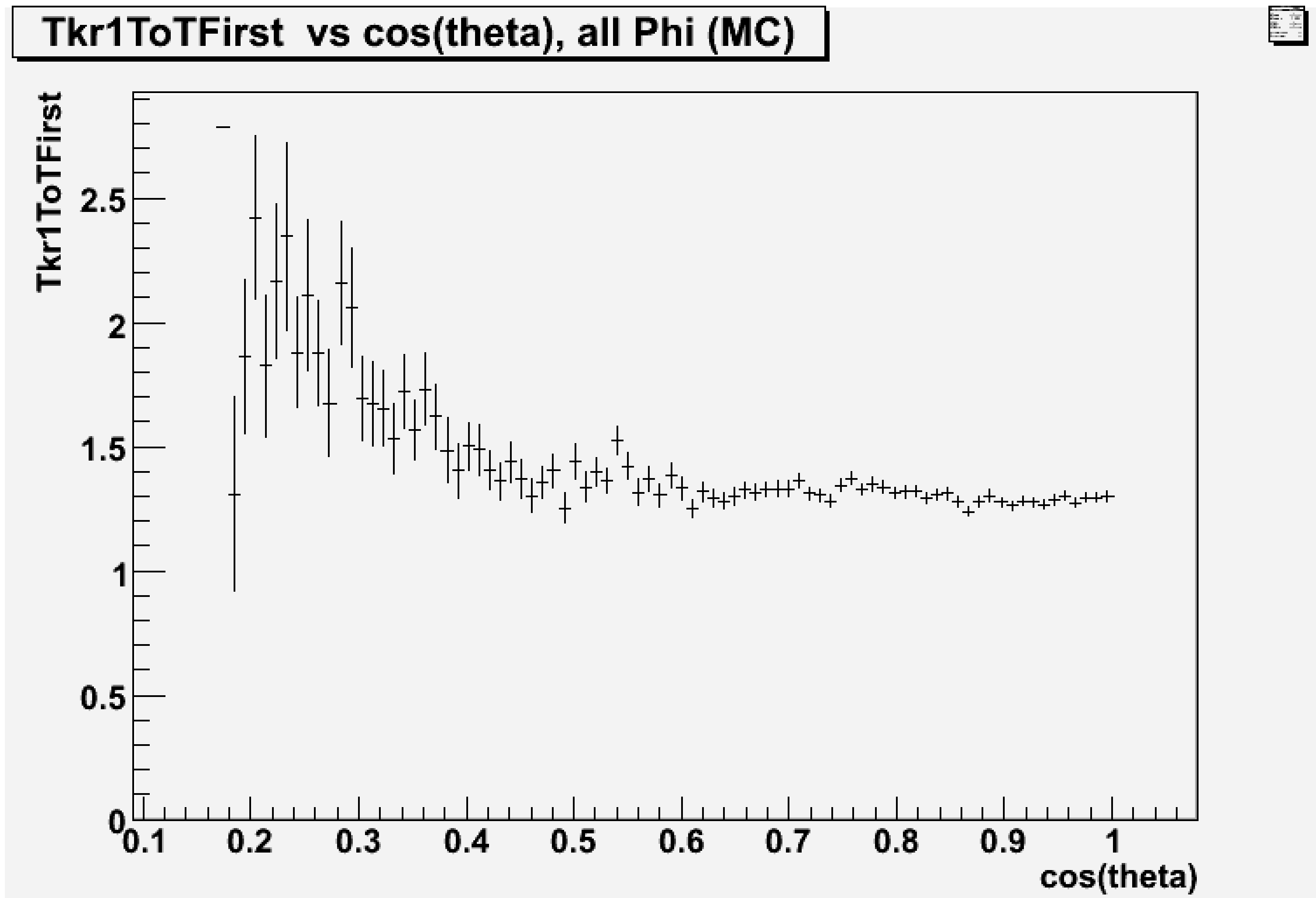
# ToT Calculation in meritTuple

- The specific ionization for each cluster is calculated using the process above.
- Currently, four values are stored in the ntuple, all referenced to the best track:
  - Tkr1ToTFirst: Mip value of first hit
  - Tkr1ToTAve: average value for all the hits
  - Tkr1ToTTrAve: average, excluding largest and smallest
  - Tkr1ToTAsym: asymmetry between first 2 and last two ToTs
- Reminder: TrkTopToT is the *larger* of the ToTs of the two planes in the first layer of the track.
  - hard to interpret

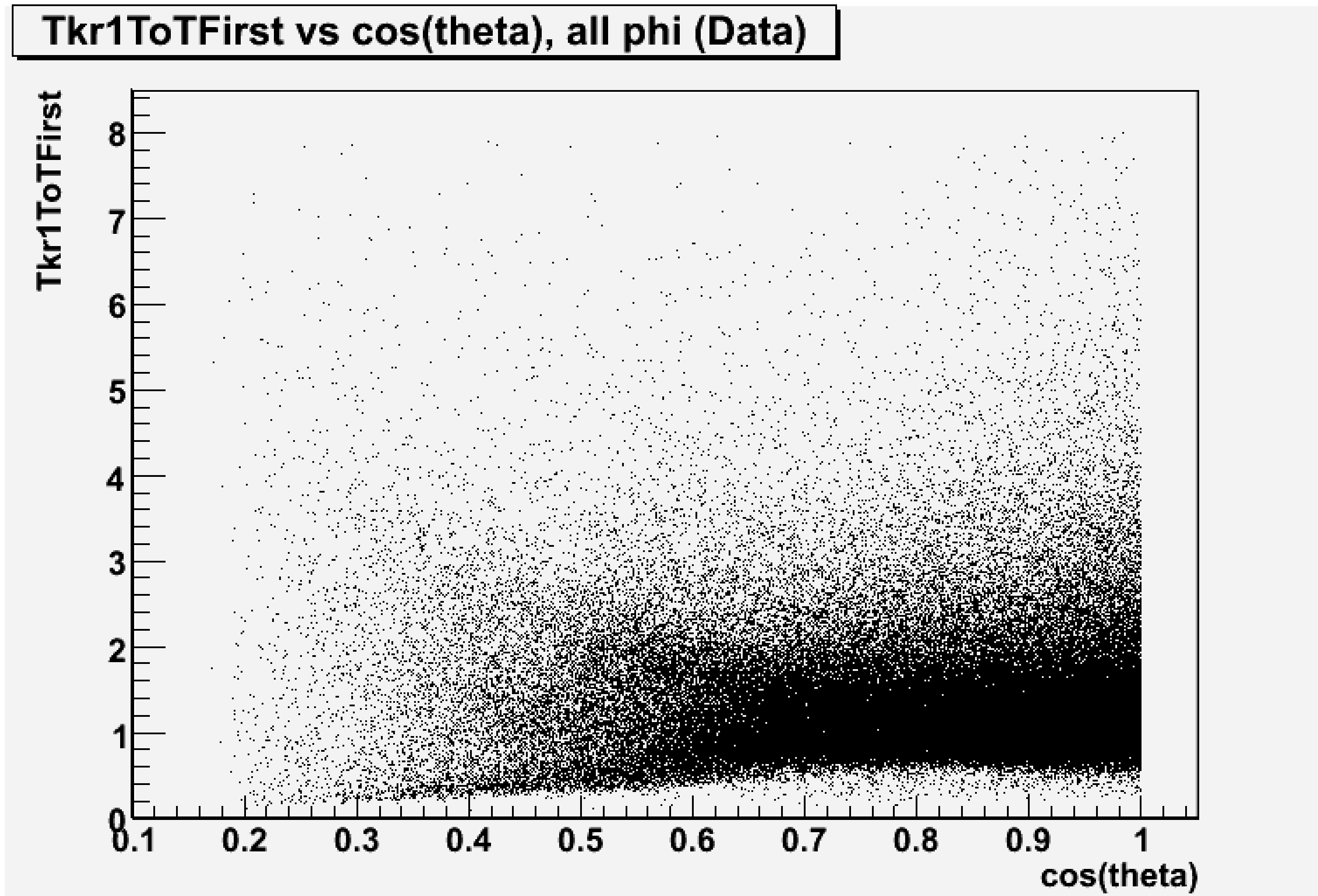
# Tkr1ToTFirst for all φ, Data



# Tkr1ToTFirst for all φ, MC



# Tkr1ToTFirst for all φ, Data



# To End with some Questions

- It’s probably time to revisit the calculation of the ToT.
  - Do we want to introduce energy fluctuations per strip?
  - Can the procedure for the end view be improved?
  - Should there be a dedicated ToT analysis performed after the tracks are found?
    - For each track separately?
    - For the ensemble of tracks (in the Event Summary phase)?