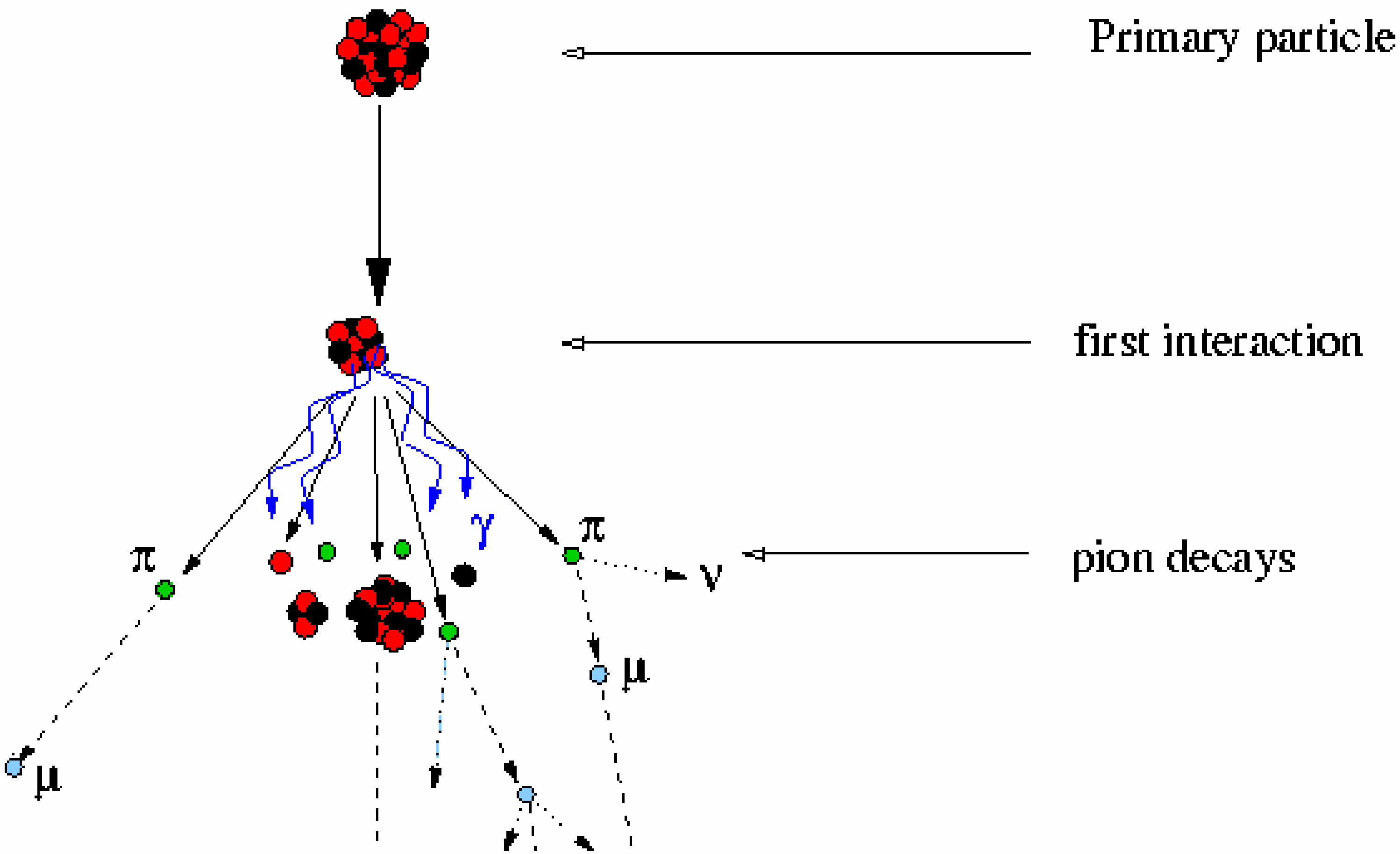
# Muons in Atmospheric Air Showers

A Summary of Aimee and Kara's Investigations

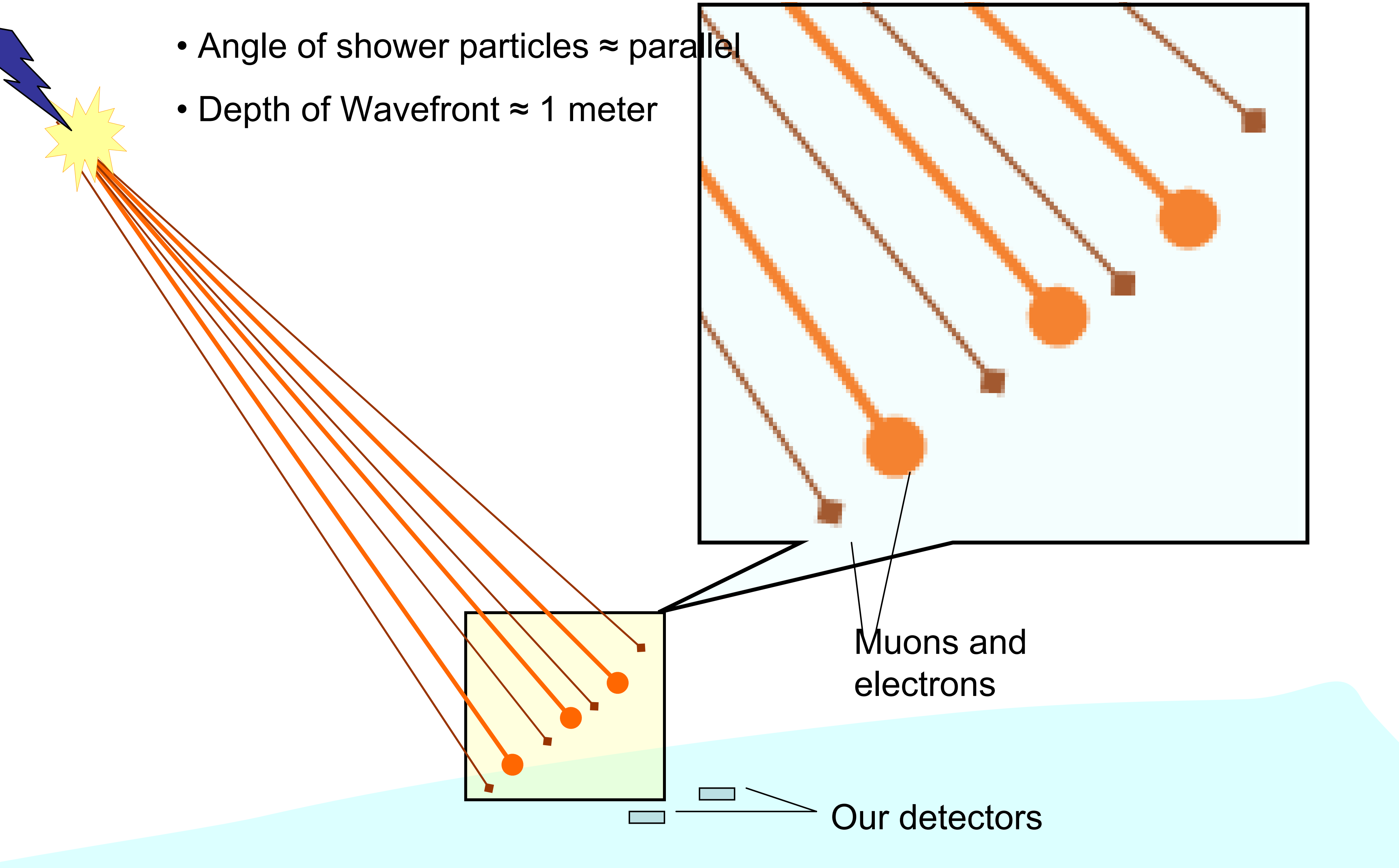
# Development of cosmic-ray air showers



• Direction of primary particle ≈ Direction of shower

• Angle of shower particles ≈ parallel

• Depth of Wavefront ≈ 1 meter



# How our detectors work

- The scintillator: incoming particles interact with the material, either by ionizing or exciting one of the molecules in it. When this occurs the material emits light, usually in ultraviolet or visible spectrum. This light is guided through the scintillator to a phototube (PMT) where the light pulse can be converted to electonic pulse and is readout to a computer.

# Why does lead Matter?

- Suggestions?
- Mass of muon is about 200 times heavier than the mass of an electron
- The electron radiation length calculation

# A Radiation Length Calculation

$$X_0 = \frac{716.4 gcm^{-2} A}{Z(Z+1)\ln(287/\sqrt{Z})}$$

$$X_0 = \frac{716.4 gcm^{-2}(207.2)}{(82)(82+1)\ln(287/\sqrt{82})} = 6.31 gcm^{-1}$$

$$X_0 \big/ density_{lead} = \frac{6.31 gcm^{-2}}{11.35 gcm^{-3}} = .56 cm$$

Our thickness of lead -> about 8 cm

Conclusion: We are NOT seeing any electrons

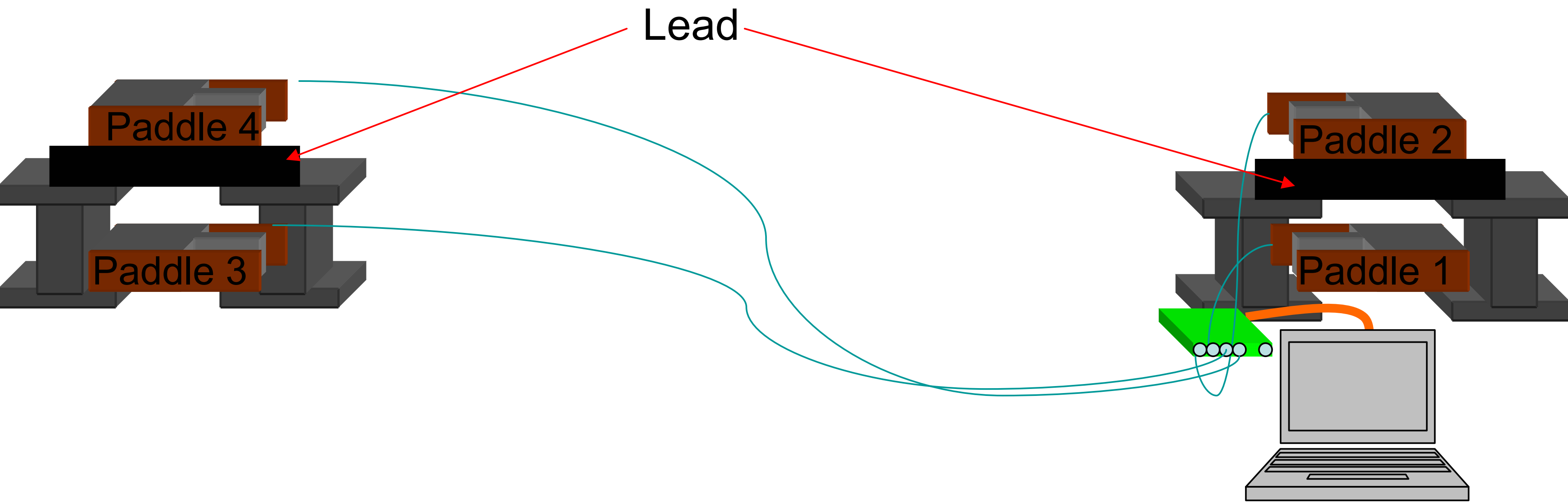
# Early on…

- Compared distance between paddles and the ratio's of double coincidences with and without lead.

| | With lead | Without lead |
|---|---|---|
| •Adjacent | .000849 +/- .000102 | |
| •3 meters apart | .000102+/- 6.5E-05 | .000411 +/- .0018 |
| •8.26 meters apart | .000129+/-3.46E-05 | .000137+/-4.83E-05 |

# The 8.26 meter runs

- Setup, comparing lead to without lead
- Much longer runs -> More data



# Comparing Effects of Lead at 8.26 meters

| | w/o Pb | rate | | sqrt(N)/s | | w/ Pb | rate | | sqrt(N)/s | | | (w/o Pb rate)/(w/ Pb rate) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1,-,-,-) | 136 | 0.002324826 | ± | 0.000199352 | | 190 | 0.001756624 | ± | 0.000127 | | | 1.323462 | |
| (-,2,-,-) | 16 | 0.000273509 | ± | 6.83772E-05 | | 24 | 0.000221889 | ± | 4.53E-05 | | | 1.232636 | |
| (-,-,3,-) | 724 | 0.01237628 | ± | 0.000459961 | | 1157 | 0.010696918 | ± | 0.000314 | | | 1.156995 | |
| (-,-,-,4) | 124 | 0.002119694 | ± | 0.000190354 | | 210 | 0.001941532 | ± | 0.000134 | | | 1.091764 | |
| (1,2,-,-) | 84630 | 1.446691396 | ± | 0.004972946 | | 134851 | 1.246750245 | ± | 0.003395 | | | 1.16037 | <- |
| (1,-,3,-) | 23 | 0.000393169 | ± | 8.19814E-05 | | 17 | 0.000157172 | ± | 3.81E-05 | | | 2.501527 | |
| (1,-,-,4) | 31 | 0.000529924 | ± | 9.51771E-05 | | 47 | 0.000434533 | ± | 6.34E-05 | | | 1.219523 | |
| (-,2,3,-) | 13 | 0.000222226 | ± | 6.16344E-05 | | 16 | 0.000147926 | ± | 3.7E-05 | | | 1.502276 | |
| (-,2,-,4) | 31 | 0.000529924 | ± | 9.51771E-05 | | 57 | 0.000526987 | ± | 6.98E-05 | | | 1.005572 | |
| (-,-,3,4) | 92821 | 1.586710884 | ± | 0.005208044 | | 152239 | 1.407509107 | ± | 0.003607 | | | 1.127318 | <- |
| (1,2,3,-) | 9 | 0.000153849 | ± | 5.12829E-05 | | 1 | 9.24539E-06 | ± | 9.25E-06 | | | 16.64059 | |
| (1,-,3,4) | 6 | 0.000102566 | ± | 4.18723E-05 | | 6 | 5.54723E-05 | ± | 2.26E-05 | | | 1.848955 | |
| (-,2,3,4) | 10 | 0.000170943 | ± | 5.4057E-05 | | 8 | 7.39631E-05 | ± | 2.61E-05 | | | 2.311193 | |
| (1,2,-,4) | 12 | 0.000205132 | ± | 5.92164E-05 | | 37 | 0.000342079 | ± | 5.62E-05 | | | 0.599661 | |
| (1,2,3,4) | 8 | 0.000136754 | ± | 4.835E-05 | | 14 | 0.000129435 | ± | 3.46E-05 | | | 1.056546 | |
| total events | 178594 | | | | | 288874 | | | | | | | |
| | | | | | | | | | | | | | |
| total time | 58499 | | | | | 108162 | | | average (1,2) & (3,4) ratios = | | | 1.143844 | |

- Average (1,2) and (3,4) ratios of no lead vs lead: **1.14**
- Conclusion, electrons aren’t much of a factor at 8.26 meters, so don’t worry about lead with your big panels.

# The next step, the ATTIC

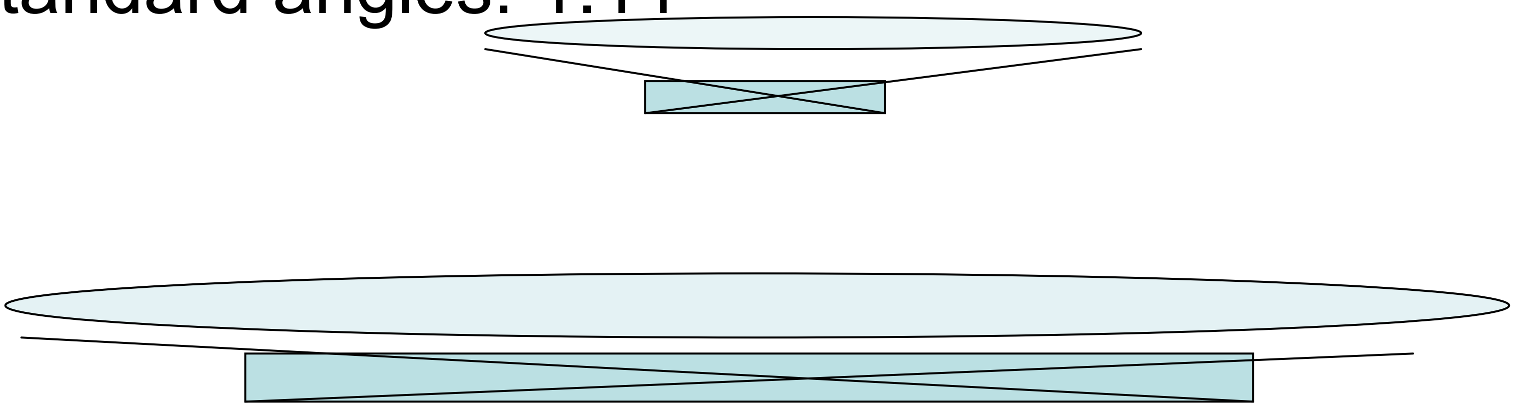
# Why use the big paddles?

$$\Omega_{small} = 2\pi\left[1 - \cos(\tan^{-1}(\frac{\frac{1}{2}18cm}{1cm}))\right] = 5.59 steradians$$

$$\Omega_{big} = 2\pi\left[1 - \cos(\tan^{-1}(\frac{\frac{1}{2}345cm}{1cm}))\right] = 6.25 steradians$$

Ratio of Big to Small standard angles: 1.11

A hemisphere is 2pi steradians = 6.28 steradians

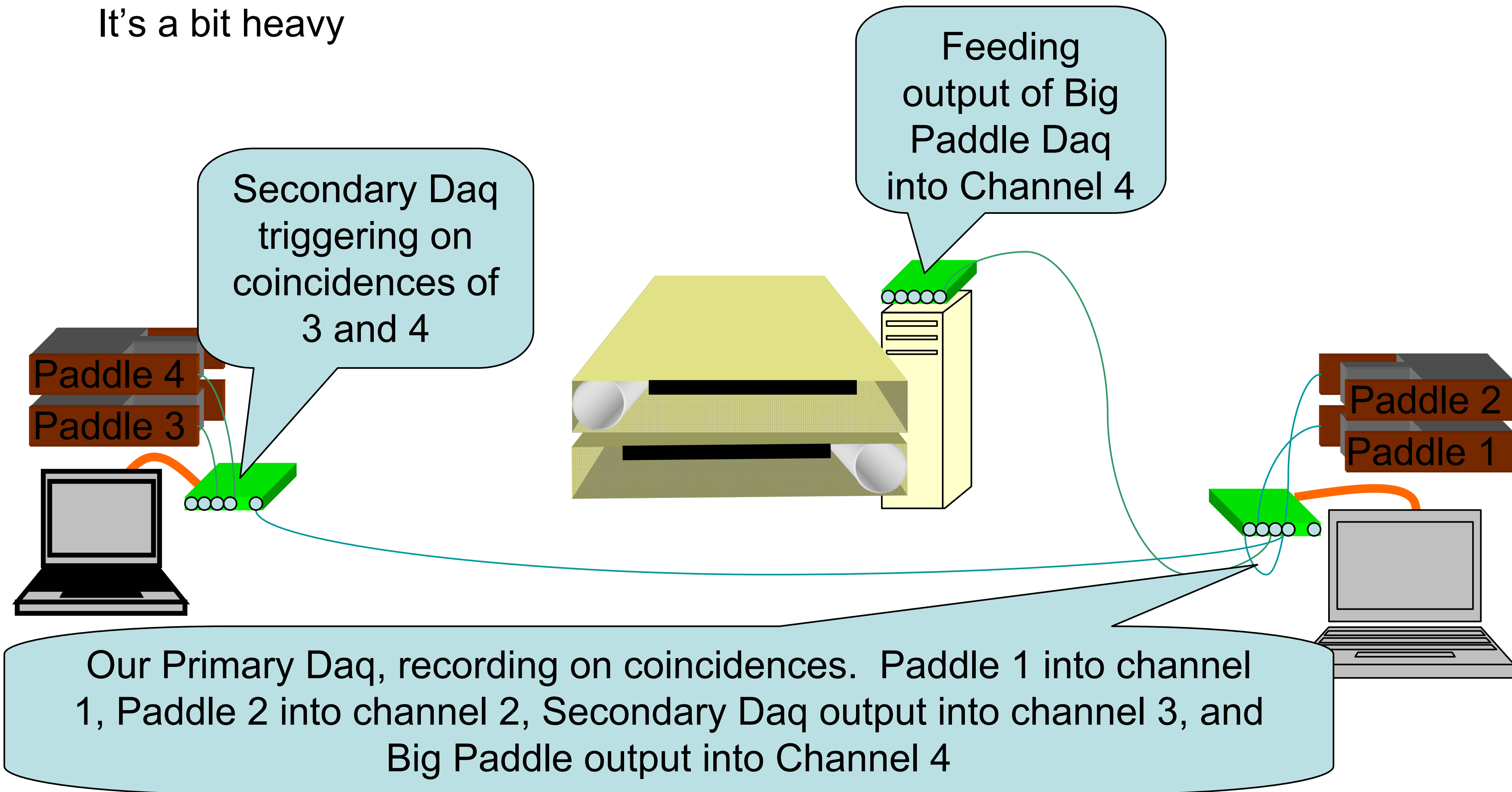


# Geometric size of paddles

- Small Paddle Scintillator Dimensions (.18 X .18 meters)
    - Area = .0324 square meters
- Big Paddle Scintillator Dimensions (.763 X 3.450 meters)
    - Area = 2.632 square meters
- 81.23 is the ratio of areas of Big Paddle to Small Paddle Scintillators
- Conclusion: The big paddles receive 90 times the data of the small paddles

# “The Symmetric Attic Run Set-up”

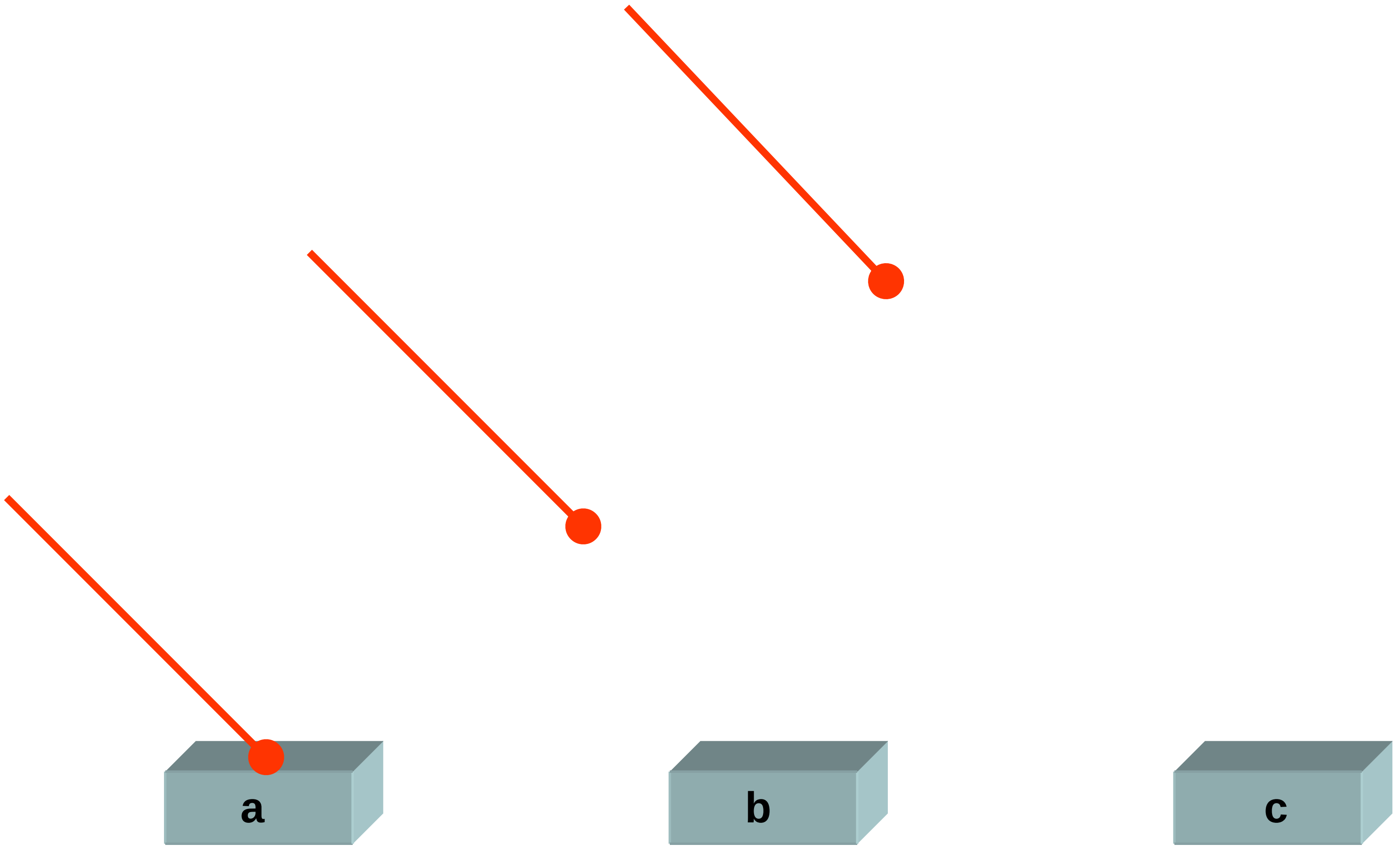
No lead used, we were too lazy to bring it upstairs. It’s a bit heavy



# The results:

| | | | |
|---|---|---|---|
| (1,2,-,-) | 3.8327 | Events/second | |
| (1,-,3,-) | .00016 | Events/second | |
| (1,-,-,4) | .02266 | Events/second | |
| (-,2,3,-) | .00010 | Events/second | |
| (-,-,3,4) | .02259 | Events/second | |
| (1,2,3,-) | .00013 | Events/second | |
| (1,-,3,4) | .00027 | Events/second | |
| (-,2,3,4) | .00077 | Events/second | |
| (1,2,-,4) | .02171 | Events/second | |
| (1,2,3,4) | .00171 | Events/second | |
| | | | |

# If the muons are from the same shower, can we see a wave front?



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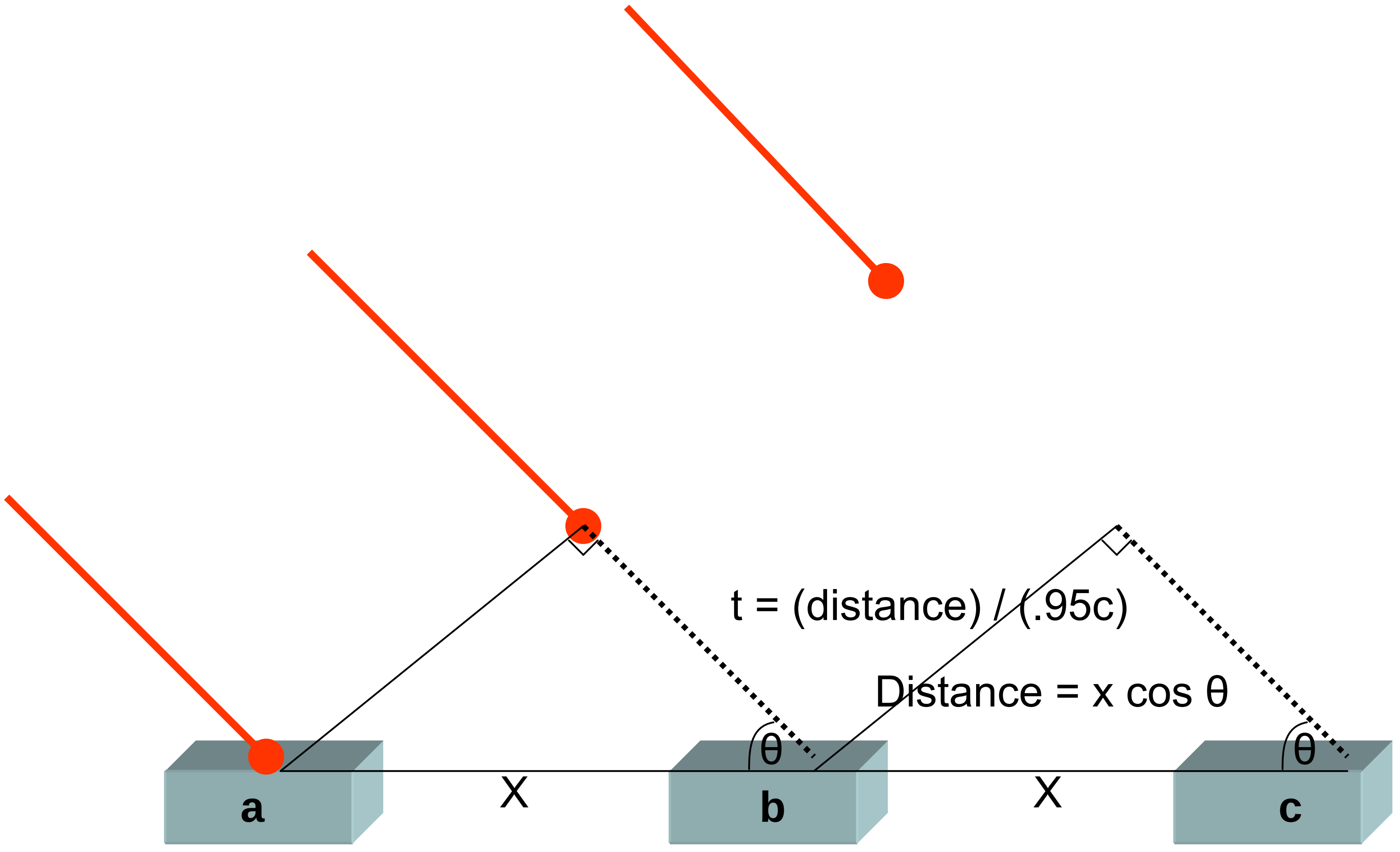


# So, to be a wave front:

$$t_{ab} = x_{ab} \cos\theta / (.95c)$$

$$t_{bc} = x_{bc} \cos\theta / (.95c)$$

Since the distances from a to b and b to c are the same in our case:

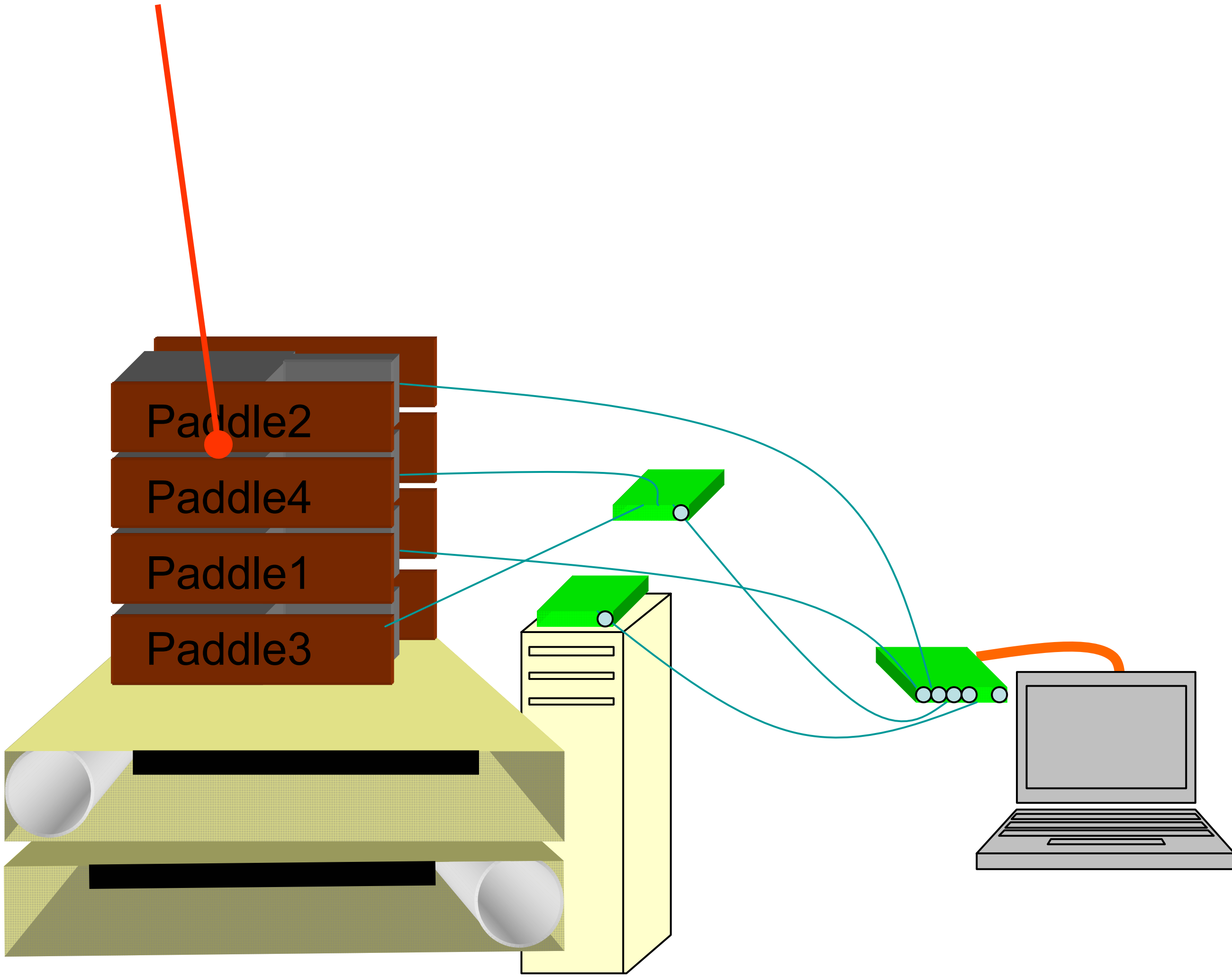
$$x_{ab} \cos\theta / (.95c) = x_{bc} \cos\theta / (.95c)$$

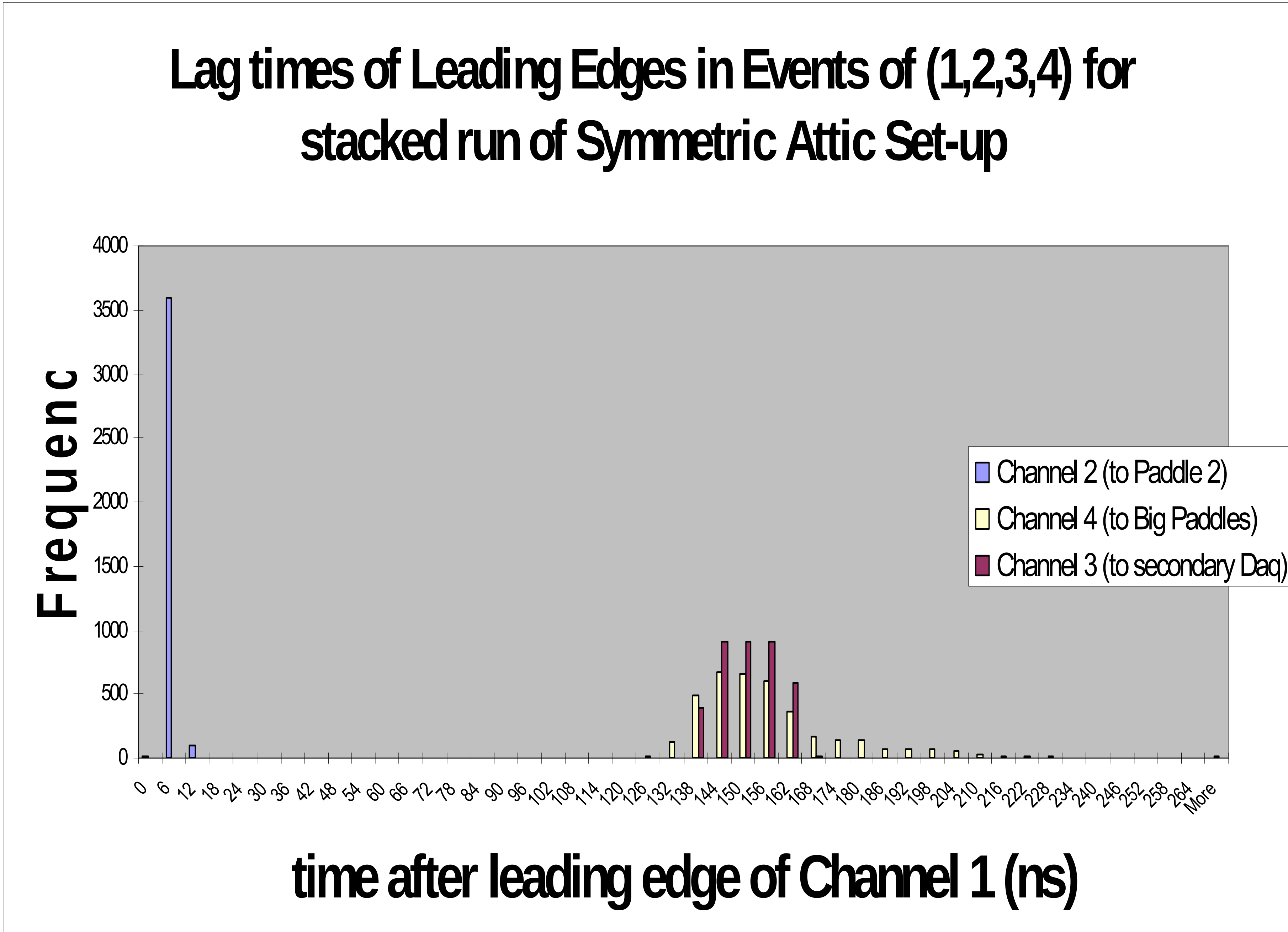
And: $t_{ab} = t_{bc}$

# But First…

- The different length cables, the peculiarity of the panels and pmts, and other equipment factors all have to be taken into account
- The “zeroing” run, how to do it and the adjustments taken into account

# A “stacked” run




Lag times of Leading Edges in Events of (1,2,3,4) for stacked run of Symmetric Attic Set-up
Frequenc
4000
3500
3000
2500
2000
1500
1000
500
0
0 6 12 18 24 30 36 42 48 54 60 66 72 78 84 90 96 102 108 114 120 126 132 138 144 150 156 162 168 174 180 186 192 198 204 210 216 222 228 234 240 246 252 258 264 More
Channel 2 (to Paddle 2)
Channel 4 (to Big Paddles)
Channel 3 (to secondary Daq)
time after leading edge of Channel 1 (ns)

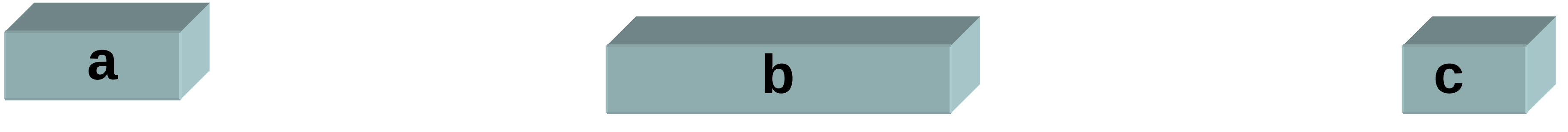
# Lag times from equipment for symmetric run:

- Channel 2 lags Channel 1 by 3.63 +/- 1.39 ns
- Channel 3 lags Channel 1 by 148.20 +/- 7.21ns
- Channel 4 lags Channel 1 by 154.05 +/- 18.81ns

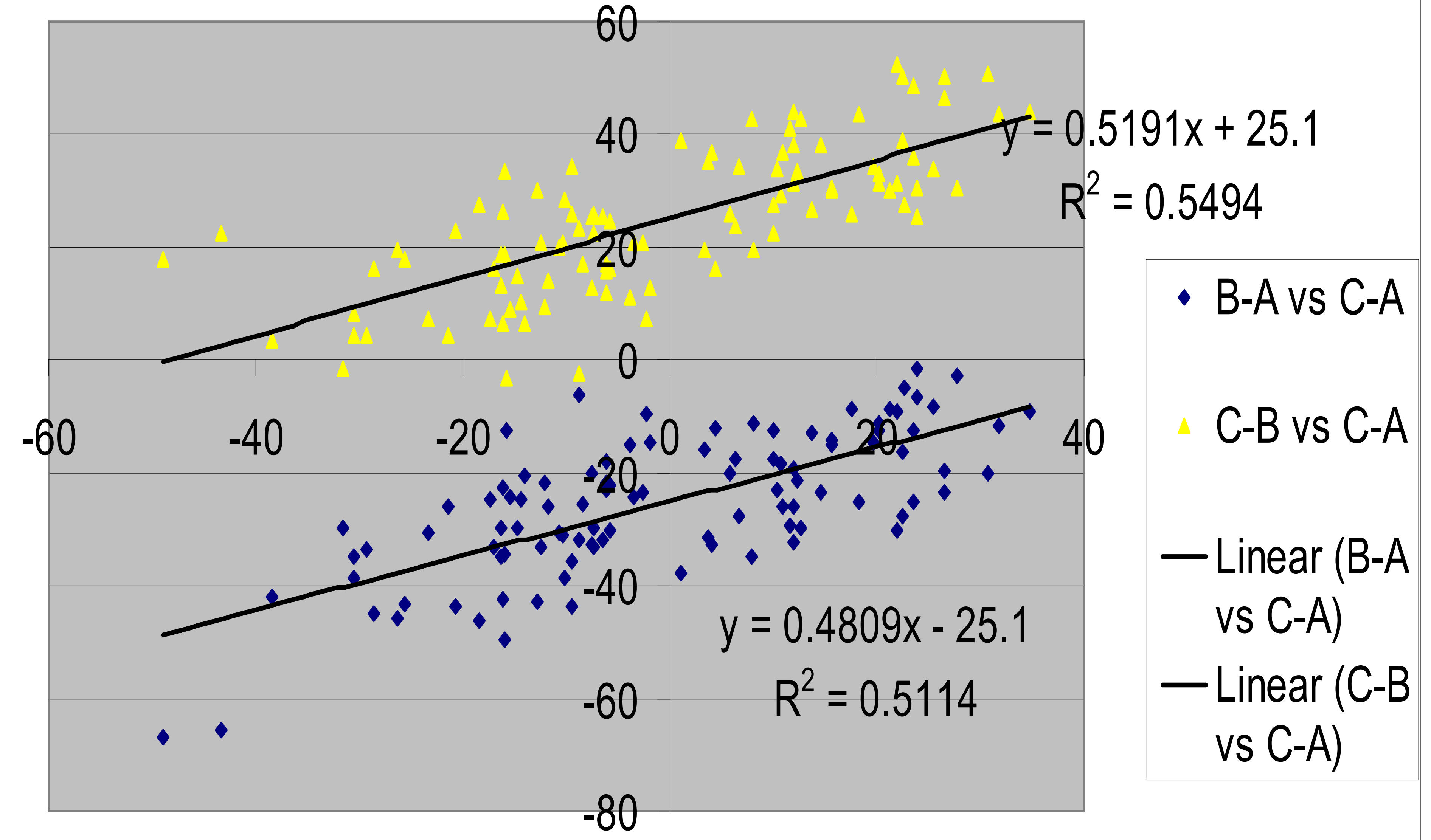
Note: Extreme values not consistent with the large majority of data were disregarded

# The Correlations We Expect

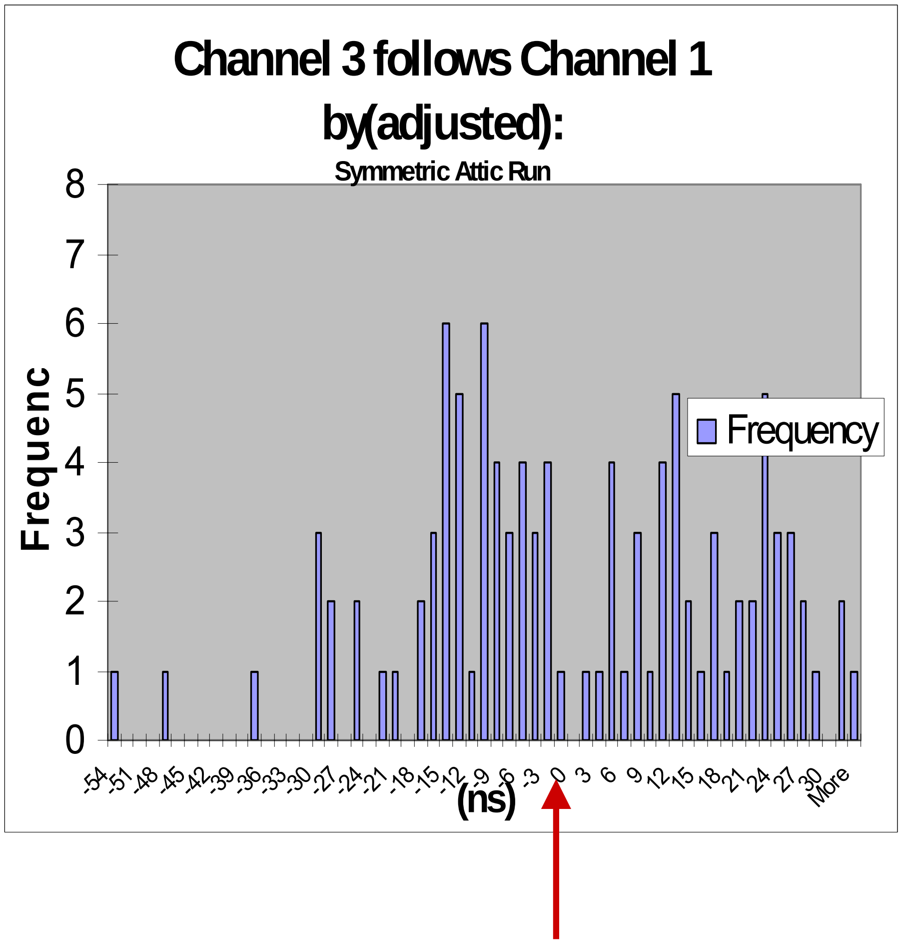
- T-ab=t-bc
- T-ab=.5 t-ac
- T-bc=.5 t-ac

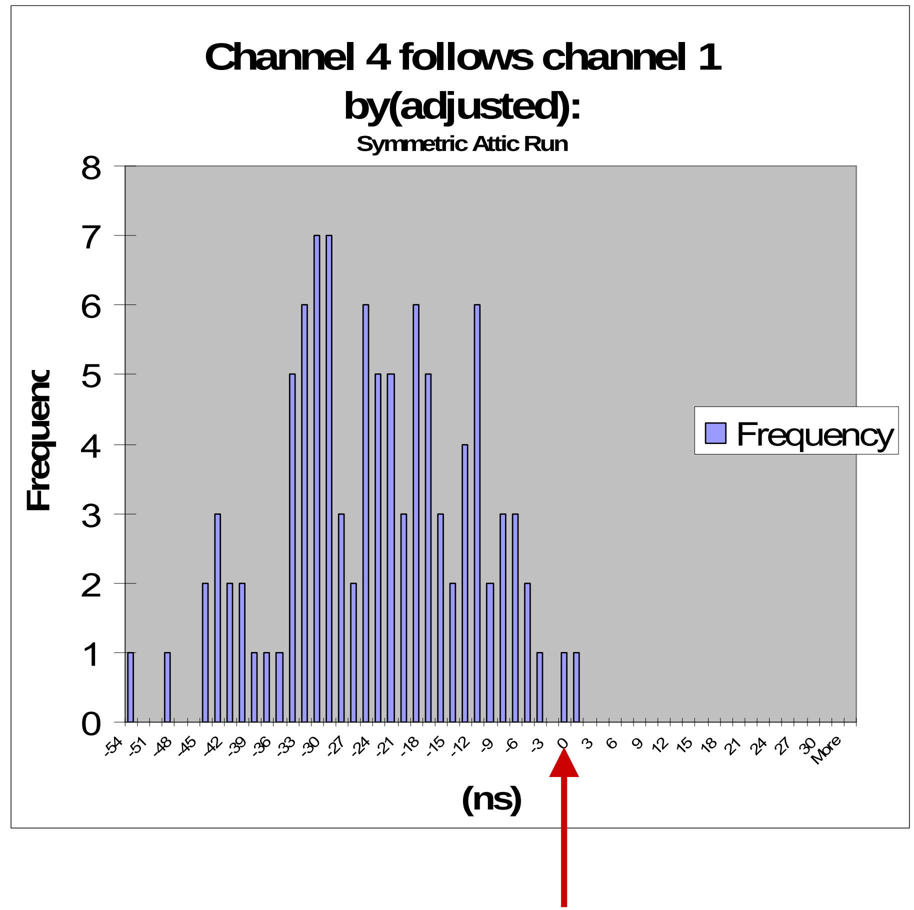


# Symmetric Attic  Run Triple Coincidence Events



# Comparing Times for Symmetric Attic Run



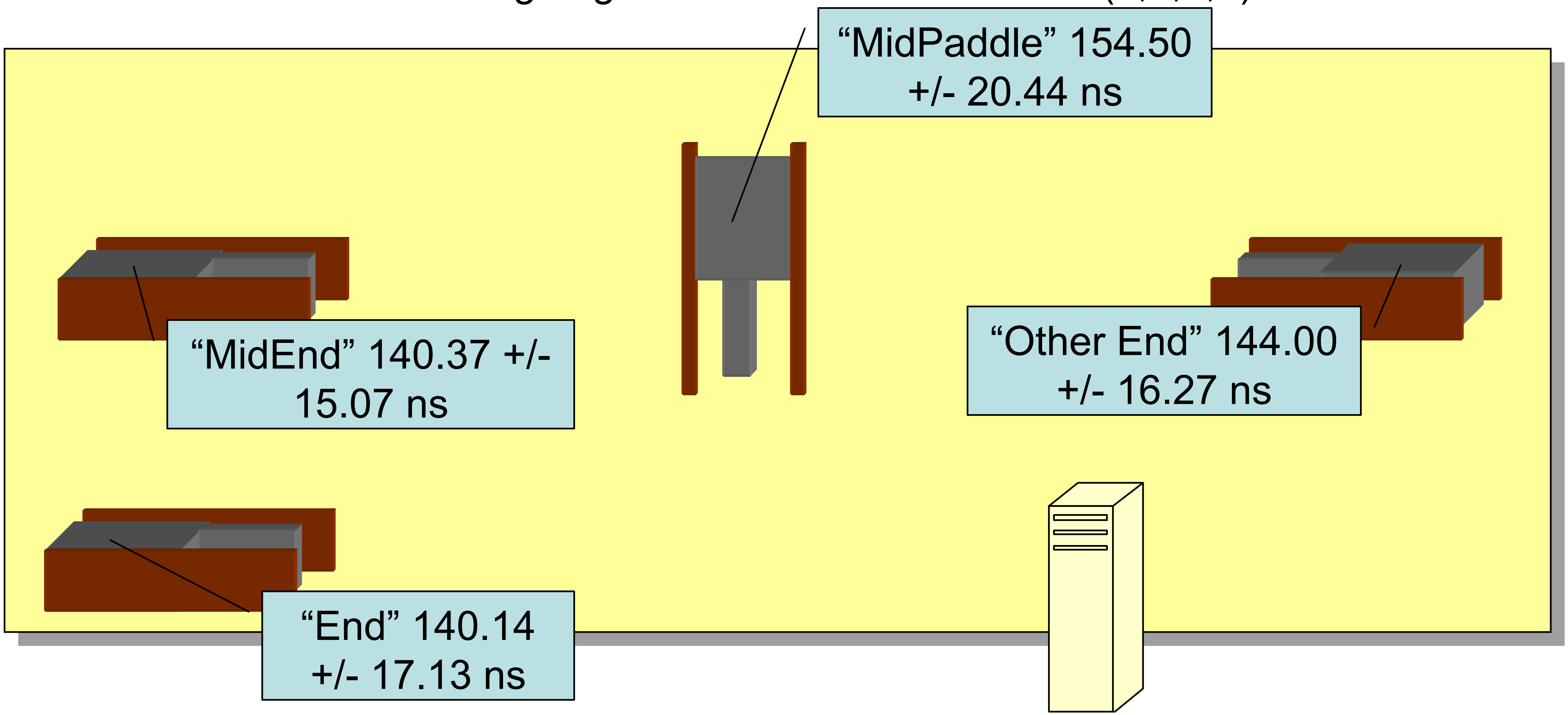



# !!!Surprise!!!

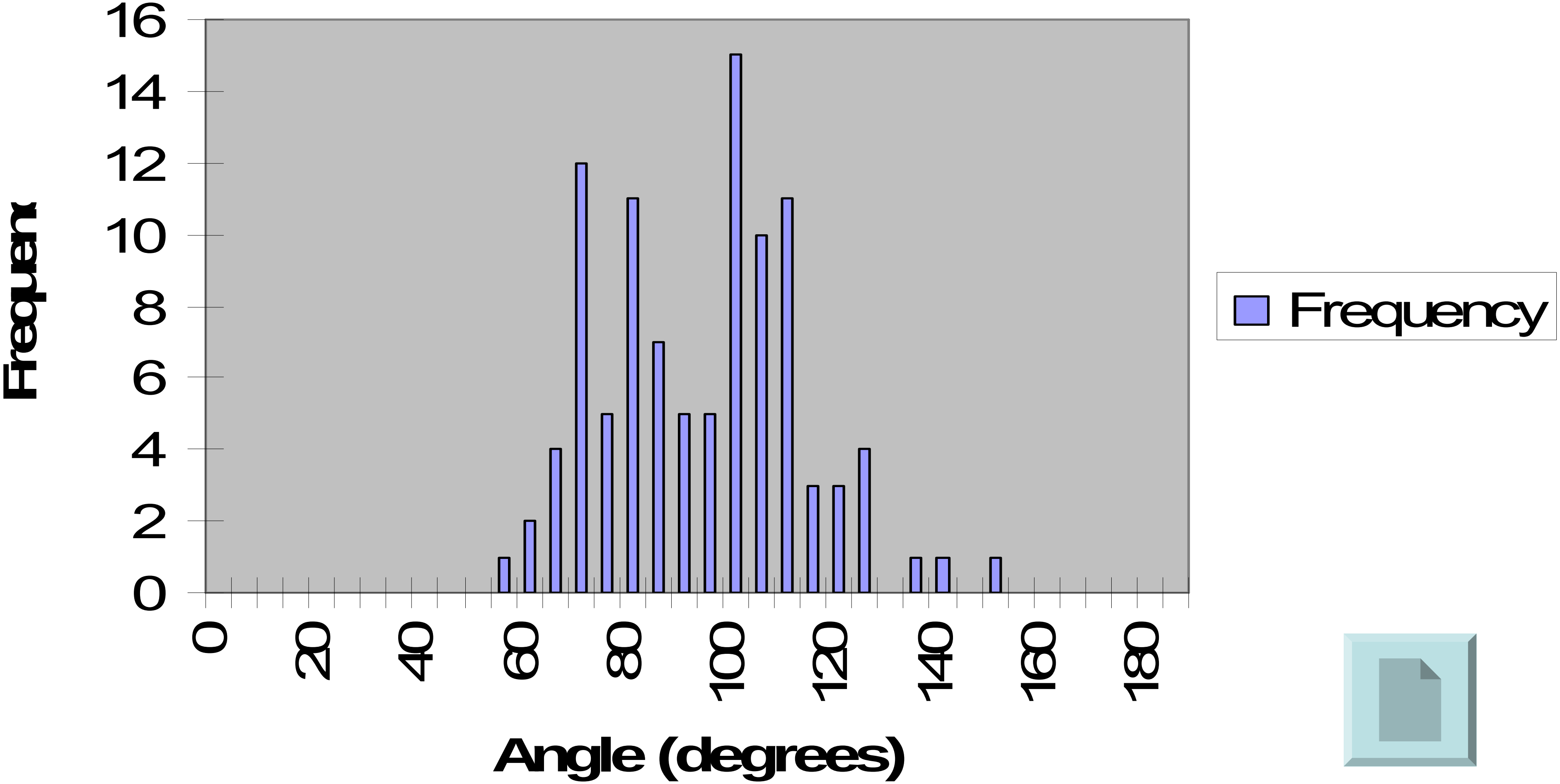
- Something isn't right
- What we found was that the big paddle varies quite a bit over its area
- Here is a distribution of the lag times involved

# Approximate Placements of Lag times of Channel 4 over Various locations of Big Paddle

Lag time is measured by rising edge of channel 4 minus rising edge of channel 1 in events of (1,2,3,4)



# Distribution of Angle of Showers in Triple Coincidence Events Based on Times Difference of Small Saddles



# One more thing to keep in mind

- How necessary are the double paddles??
- Two settings of paddles three and four
- Triggering on coincidences:
  - Channel 3 fired every .0178seconds +/- .000478 seconds
- Triggering whenever paddle 3 OR 4 are hit:
  - Channel 3 fired every .0257 seconds+/- .000656 seconds
- So about 31% of hits do not go trigger both paddles