Two Bars Time Calibration 2

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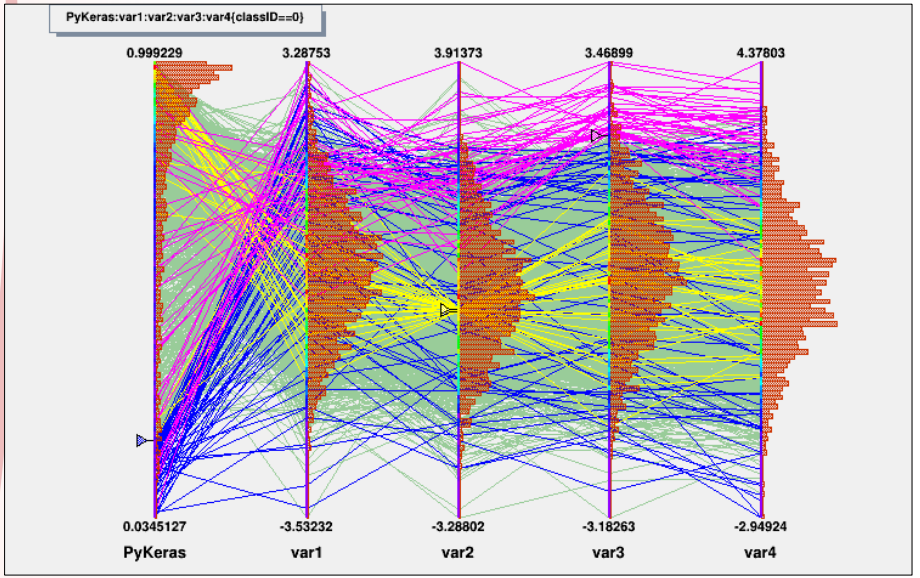
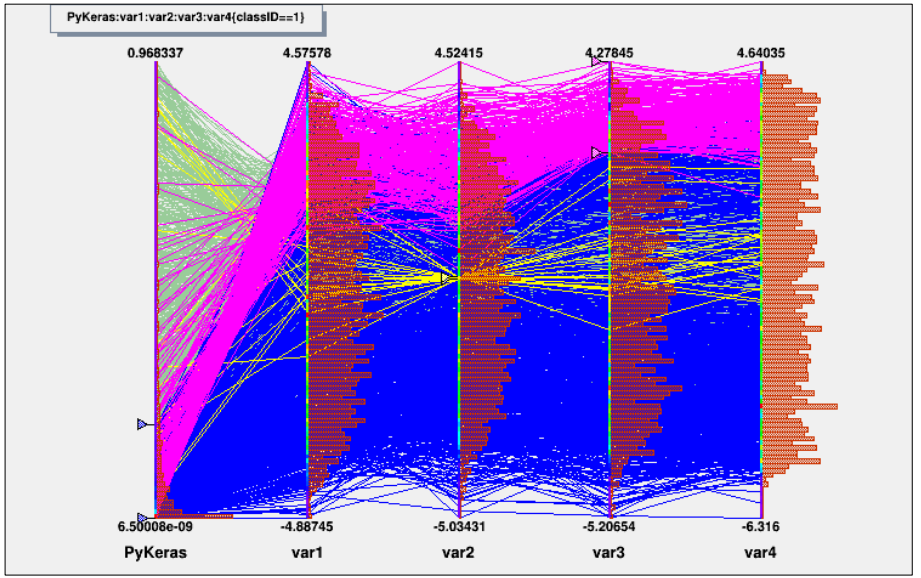
Status - Deep Learning Study

- On every TUE., 16:00 ~ 18:00 at 23-317.
- ROOT supports DNN through TMVA 4 and Keras.

Status - Deep Learning Study (cont'd)

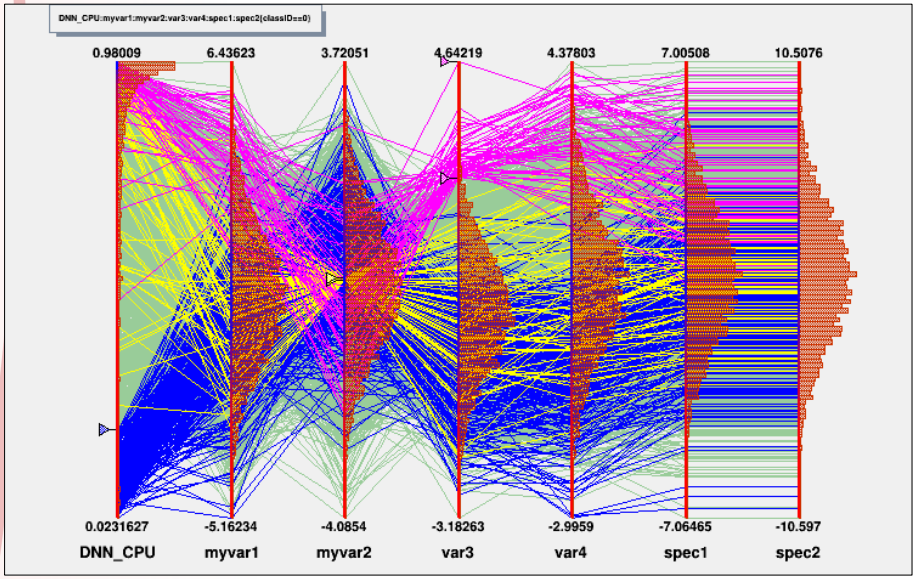
- Background events in Keras DNN.
- Signal events in Keras DNN.



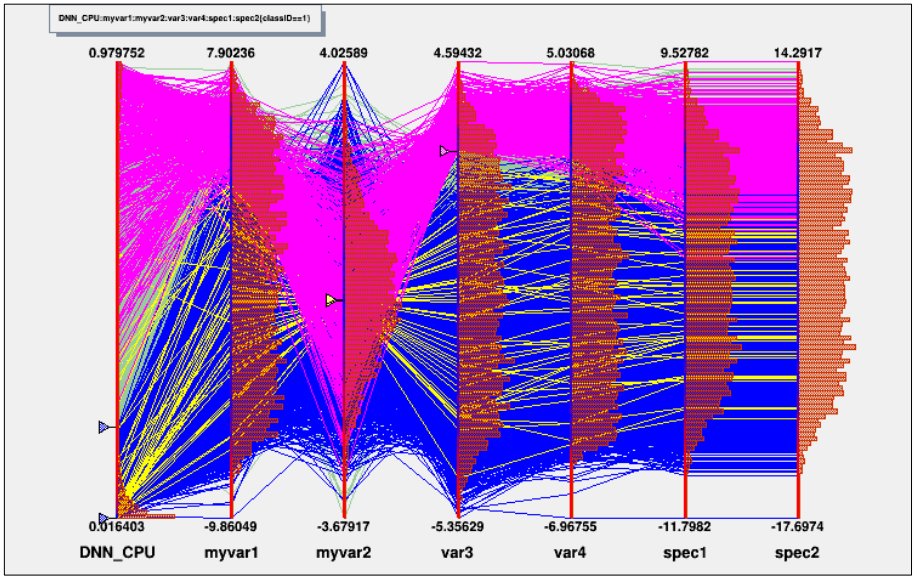


Status - Deep Learning Study (cont'd)

- Background events in TMVA DNN.



- Signal events in TMVA DNN.

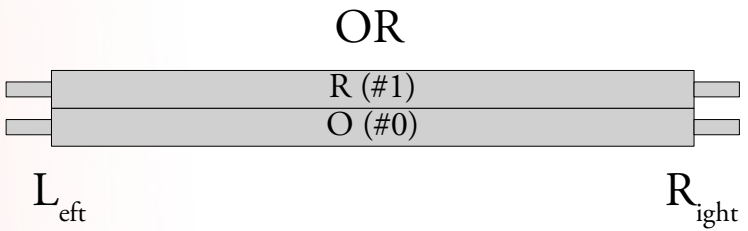


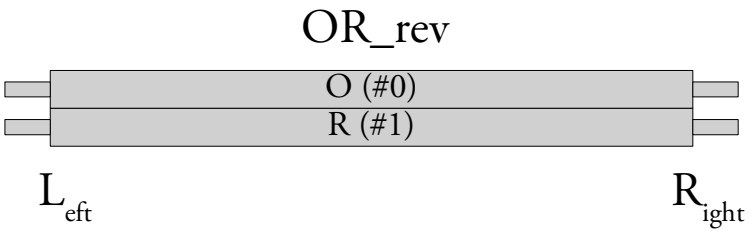
Status - Deep Learning Study (cont'd)

- We will try and study both of TMVA 4 and Keras.
- We will try existing DNN algorithm in the above frameworks.

Two Bars Time Calibration

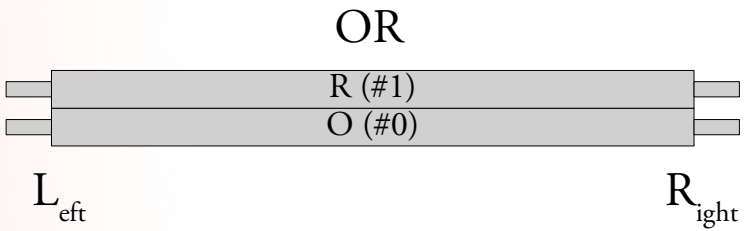
- I tried to calibrate time between two bars, O and R.
- Two configurations gave ~100ps disagreement.

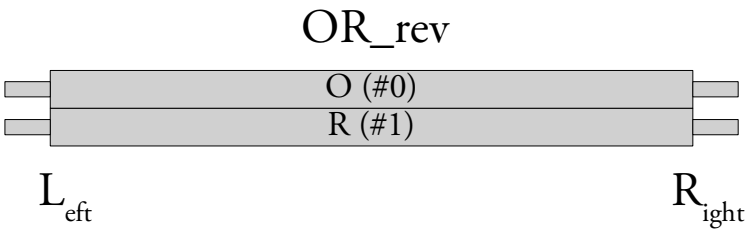




Data Taking Once Again

- Took data from OR configuration, with threshold 150ADC, coincidence trigger.
- 1,006,596 events were collected.





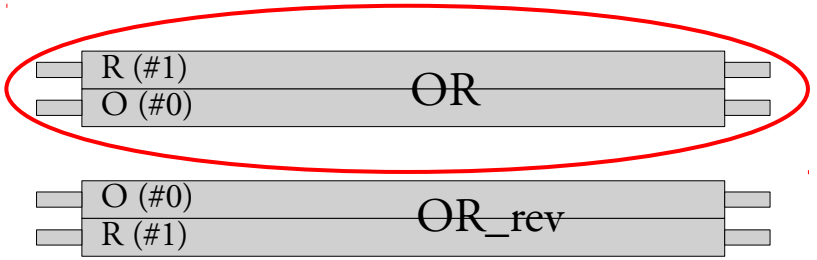
Time Calibration Formula

- Formula for OR configuration is given as

$$\delta_{0R} - \delta_{0L} = \langle t_{0L} - t_{0R} \rangle$$

$$\delta_{1L} - \delta_{0L} = \langle t_{0L} - t_{1L} \rangle - 0.85\,m \times \left(\frac{1}{c_{scint.0}} - \frac{1}{c_{scint.1}} \right) - \frac{0.1\,m}{c}$$

$$\delta_{1R} - \delta_{0L} = \langle t_{0L} - t_{1L} \rangle - 0.85\,m \times \left(\frac{1}{c_{scint.0}} - \frac{1}{c_{scint.1}} \right) - \frac{0.1\,m}{c} + \langle t_{1L} - t_{1R} \rangle$$



Error Function Fitting

- Error function fitting method was used to estimate $<t_L - t_R>$ and $c_{scint.}$.

Time Calibration Result

OR 1 (4M events)

```
##################################################
##            Time Calibration Result           ##
## /data/ORdtcal001_evrec.root                   ##
## It is not reversed.                           ##
## t0[0] -> t0[0]                                ##
## t0[1] -> t0[1] +15.153558    +-0.003922   ns  ##
## t0[2] -> t0[2] +28.426373    +-0.002883   ns  ##
## t0[3] -> t0[3] +13.310976    +-0.004997   ns  ##
##                                               ##
## c_scint[0]    : 0.154090     +-0.000055 m/ns  ##
## c_scint[1]    : 0.152824     +-0.000056 m/ns  ##
## FWHM[0]       : 22.064957    +-0.007843   ns  ##
## FWHM[1]       : 22.247882    +-0.008164   ns  ##
## center[0]     : 15.153558    +-0.003922   ns  ##
## center[1]     : -15.115396   +-0.004082   ns  ##
## dtLL          : 28.714206    +-0.000547   ns  ##
##################################################
```

OR_{rev} 1 (6M events)

```
##################################################
##            Time Calibration Result           ##
## /data/ORdtcalRev001_evrec.root                ##
## It is reversed.                               ##
## t0[0] -> t0[0]                                ##
## t0[1] -> t0[1] +15.140523    +-0.003609   ns  ##
## t0[2] -> t0[2] +29.623683    +-0.002469   ns  ##
## t0[3] -> t0[3] +14.473106    +-0.004081   ns  ##
##                                               ##
## c_scint[0]    : 0.153997     +-0.000050 m/ns  ##
## c_scint[1]    : 0.153578     +-0.000045 m/ns  ##
## FWHM[0]       : 22.078333    +-0.007219   ns  ##
## FWHM[1]       : 22.138596    +-0.006499   ns  ##
## center[0]     : 15.140523    +-0.003609   ns  ##
## center[1]     : -15.150578   +-0.003250   ns  ##
## dtLL          : 29.275053    +-0.000444   ns  ##
##################################################
```

OR 2 (10M events)

```
##################################################
##            Time Calibration Result           ##
## /data/ORdtcal002_evrec.root                   ##
## It is not reversed.                           ##
## t0[0] -> t0[0]                                ##
## t0[1] -> t0[1] +15.134058    +-0.002503   ns  ##
## t0[2] -> t0[2] +28.397377    +-0.001834   ns  ##
## t0[3] -> t0[3] +13.345591    +-0.003175   ns  ##
##                                               ##
## c_scint[0]    : 0.154483     +-0.000035 m/ns  ##
## c_scint[1]    : 0.154134     +-0.000036 m/ns  ##
## FWHM[0]       : 22.008872    +-0.005007   ns  ##
## FWHM[1]       : 22.058670    +-0.005183   ns  ##
## center[0]     : 15.134058    +-0.002503   ns  ##
## center[1]     : -15.051786   +-0.002592   ns  ##
## dtLL          : 28.718492    +-0.000344   ns  ##
##################################################
```

Time Calibration Comparison

	OR 1. 4M events	OR_{rev} 1. 6M events	OR 2. 10M events
$\delta_{0R}-\delta_{0L}$ [ns]	15.153558 ±0.003922	15.140523 ±0.003609	15.134058 ±0.002503
$\delta_{1L}-\delta_{0L}$ [ns]	28.426373 ±0.002883	29.623683 ±0.002469	28.397377 ±0.001834
$\delta_{1R}-\delta_{0L}$ [ns]	13.310976 ±0.004997	14.473106 ±0.004081	13.345591 ±0.003175

Time Calibration Comparison (cont'd)

Agrees in few-ten ps order.
Outside of the error range!

	OR 1. 4M events	OR_{rev} 1. 6M events	OR 2. 10M events
$\delta_{0R}-\delta_{0L}$ [ns]	15.153558 ±0.003922	15.140523 ±0.003609	15.134058 ±0.002503
$\delta_{1L}-\delta_{0L}$ [ns]	28.426373 ±0.002883	29.623683 ±0.002469	28.397377 ±0.001834
$\delta_{1R}-\delta_{0L}$ [ns]	13.310976 ±0.004997	14.473106 ±0.004081	13.345591 ±0.003175

Most 1.2 ns disagreement!

FWHM Error Bar

OR 1 (4M events)

```
##################################################
##            Time Calibration Result           ##
## /data/ORdtcal001_evrec.root                    ##
## It is not reversed.                            ##
## t0[0] -> t0[0]                                 ##
## t0[1] -> t0[1] +15.153558    +-0.003922   ns ##
## t0[2] -> t0[2] +28.426373    +-0.002883   ns ##
## t0[3] -> t0[3] +13.310976    +-0.004997   ns ##
##                                                ##
## c_scint[0]    : 0.154090     +-0.000055 m/ns ##
## c_scint[1]    : 0.152824     +-0.000056 m/ns ##
## FWHM[0]       : 22.064957    +-0.007843   ns ##
## FWHM[1]       : 22.247882    +-0.008164   ns ##
## center[0]     : 15.153558    +-0.003922   ns ##
## center[1]     : -15.115396   +-0.004082   ns ##
## dtLL          : 28.714206    +-0.000547   ns ##
##################################################
```

OR_{rev} 1 (6M events)

```
##################################################
##            Time Calibration Result           ##
## /data/ORdtcalRev001_evrec.root                 ##
## It is reversed.                                ##
## t0[0] -> t0[0]                                 ##
## t0[1] -> t0[1] +15.140523    +-0.003609   ns ##
## t0[2] -> t0[2] +29.623683    +-0.002469   ns ##
## t0[3] -> t0[3] +14.473106    +-0.004081   ns ##
##                                                ##
## c_scint[0]    : 0.153997     +-0.000050 m/ns ##
## c_scint[1]    : 0.153578     +-0.000045 m/ns ##
## FWHM[0]       : 22.078333    +-0.007219   ns ##
## FWHM[1]       : 22.138596    +-0.006499   ns ##
## center[0]     : 15.140523    +-0.003609   ns ##
## center[1]     : -15.150578   +-0.003250   ns ##
## dtLL          : 29.275053    +-0.000444   ns ##
##################################################
```

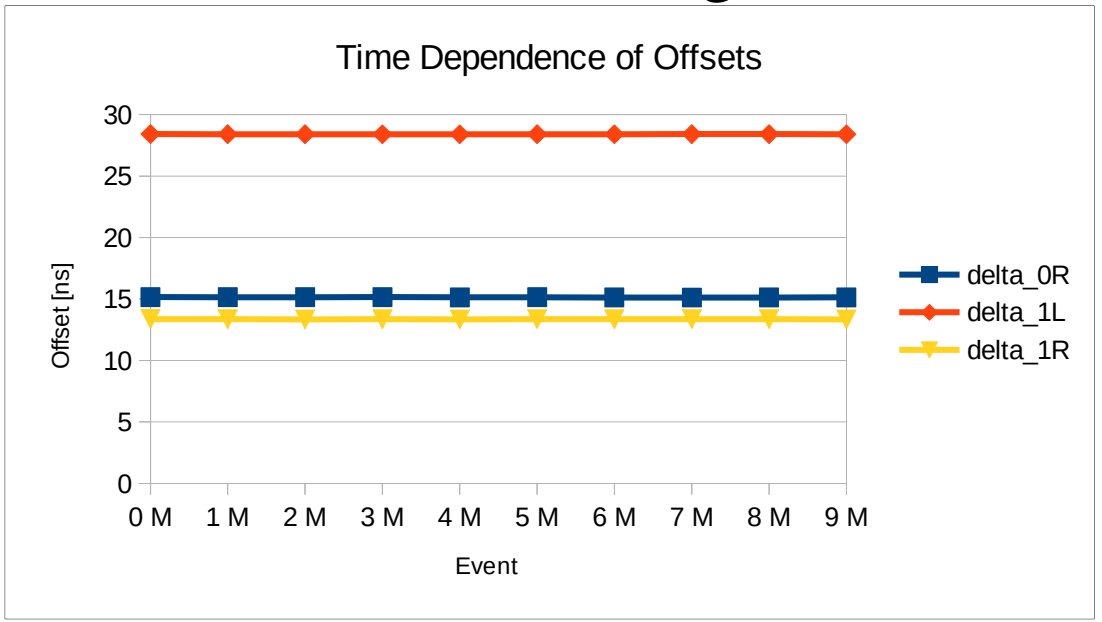
OR 2 (10M events)

```
##################################################
##            Time Calibration Result           ##
## /data/ORdtcal002_evrec.root                    ##
## It is not reversed.                            ##
## t0[0] -> t0[0]                                 ##
## t0[1] -> t0[1] +15.134058    +-0.002503   ns ##
## t0[2] -> t0[2] +28.397377    +-0.001834   ns ##
## t0[3] -> t0[3] +13.345591    +-0.003175   ns ##
##                                                ##
## c_scint[0]    : 0.154483     +-0.000035 m/ns ##
## c_scint[1]    : 0.154134     +-0.000036 m/ns ##
## FWHM[0]       : 22.008872    +-0.005007   ns ##
## FWHM[1]       : 22.058670    +-0.005183   ns ##
## center[0]     : 15.134058    +-0.002503   ns ##
## center[1]     : -15.051786   +-0.002592   ns ##
## dtLL          : 28.718492    +-0.000344   ns ##
##################################################
```

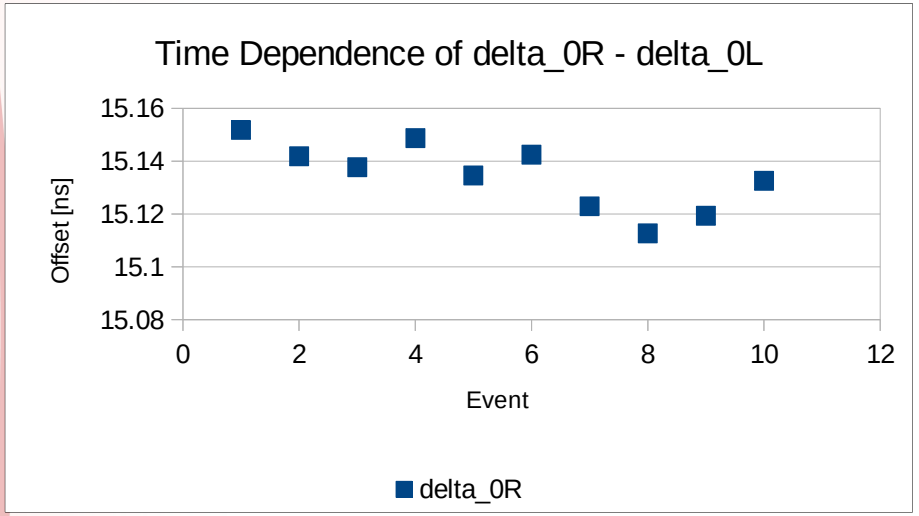
Wrong error bar!
We need better process to determine the FWHM!

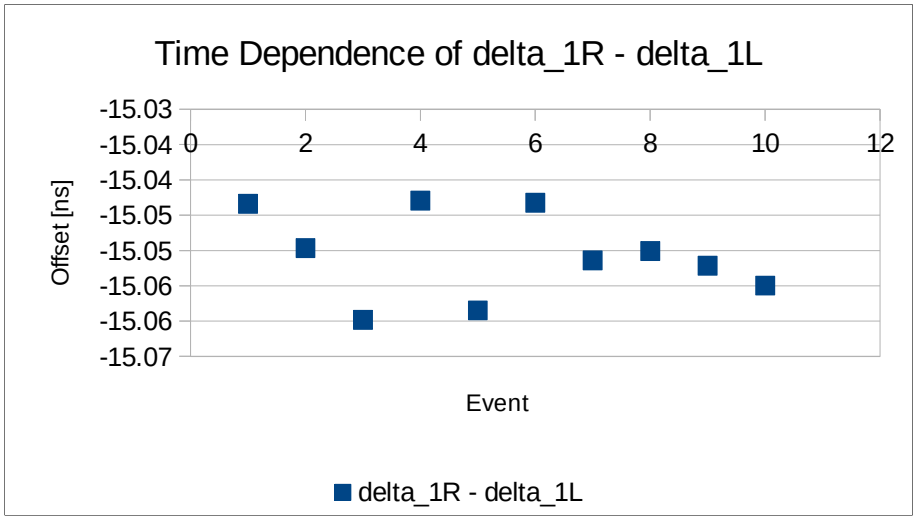
Time Dependence of Offsets

- Evaluated the offsets from parts of events.
- Each point is evaluated using 1M events.

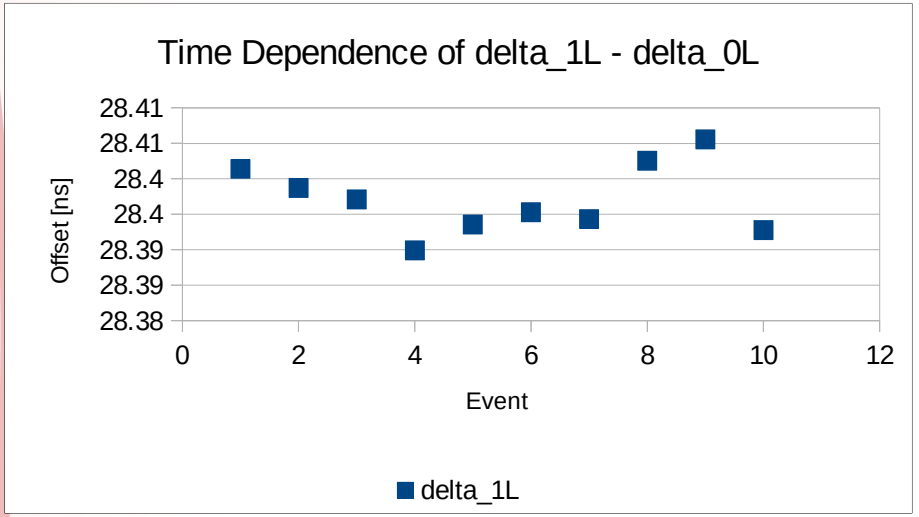


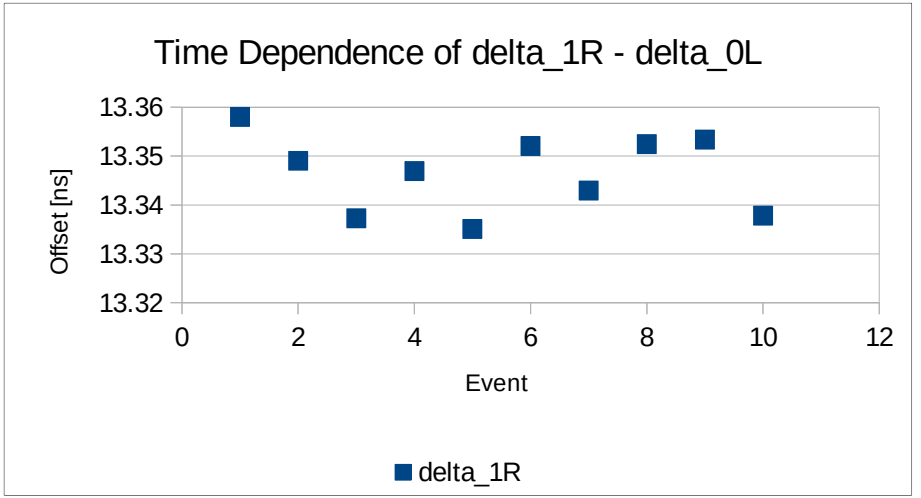
Time Dependence of Each Offset





Time Dependence of Each Offset (cont'd)





Time Dependence of Offsets

- Fortunately, they show approximately constant behavior in time.
  - about few-ten ps order random behavior.

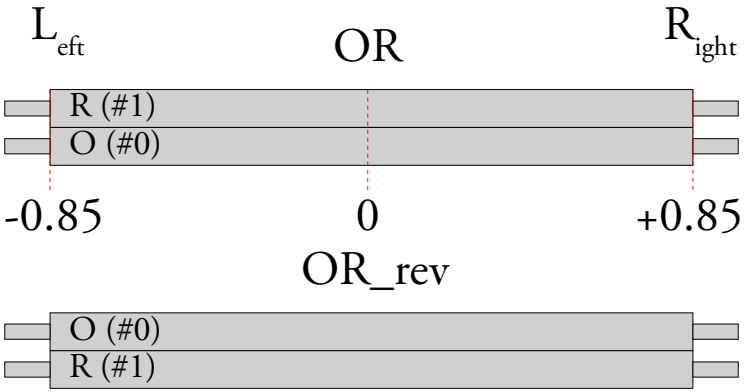
Two Bar Time Calibration Conclusion

- We need more well-bahaved procedure to estimate the FWHM, and thus $c_{scint.}$.
  - At least we have to be sure about the error bar.

End of Presentation

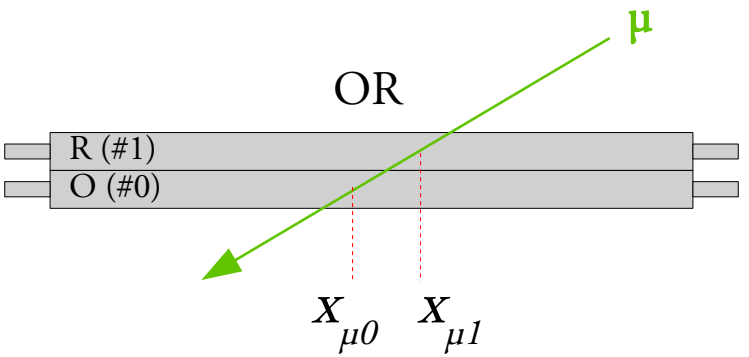
Notation

- Subscript $_0$ and $_1$ indicates bar O and R, respectively.
- Subscript $_L$ and $_R$ indicates PMT position L_{eft} and R_{ight}.
- Position origin is 0. Right side has + sign in position axis.



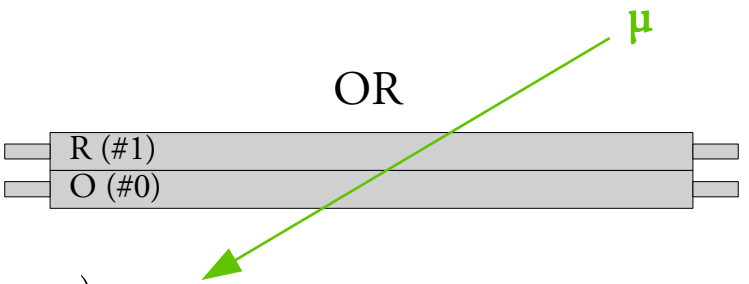
Notation (cont'd)

- Actual muon hitting position (x_μ) and time (t_μ) are indicated with subscript $_\mu$.
- Recorded time are t_{ij} with i=0, 1 and j=L, R.
- Scintillation signal speed is $c_{scint,\,i}$, where i=0, 1.



Notation (cont'd)

- Let the time shift in PMT$_{ij}$ be δ_{ij}.



- $t_{iL} = t_{\mu i} + \dfrac{(0.85\,m + x_{\mu i})}{c_{scint.i}} - \delta_{iL}, \quad t_{iR} = t_{\mu i} + \dfrac{(0.85\,m - x_{\mu i})}{c_{scint.i}} - \delta_{iR}$

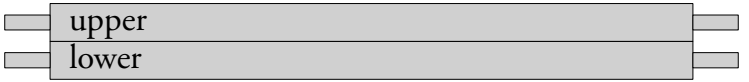
- $t_{\mu i} = \dfrac{t_{iL} + t_{iR} - 1.7\,m/c_{scint.i} + \delta_{iL} + \delta_{iR}}{2}$

Time Calibration Assumption

- Assumption 1
  - Incident muon flux is spatially uniform.
- Assumption 2
  - δ_{ij} are independent on time.
- Assumption 3
  - $t_{\mu,\,lower}$-$t_{\mu,\,upper}$ is expected to be $0.1\,m/c$.

$$t_{iL}=t_{\mu i}+\frac{(0.85\,m+x_{\mu i})}{c_{scint.i}}-\delta_{iL} \qquad t_{iR}=t_{\mu i}+\frac{(0.85\,m-x_{\mu i})}{c_{scint.i}}-\delta_{iR}$$

$$t_{\mu i}=\frac{t_{iL}+t_{iR}-1.7\,m/c_{scint.i}+\delta_{iL}+\delta_{iR}}{2}$$

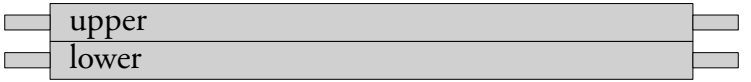


Time Calibration Method

- Step 0: Calculate $c_{scint.\ i}$.
- Step 1: Left vs Right.
  - For each bars, $\langle t_{iL} - t_{iR} \rangle = -\delta_{iL} + \delta_{iR}$
- Step 2: Upper vs Lower
  - $\frac{\langle t_{lower,L} + t_{lower,R} - t_{upper,L} - t_{upper,R} \rangle}{2} - 0.85\,m \times \left(\frac{1}{c_{scint.lower}} - \frac{1}{c_{scint.upper}}\right) + \frac{\delta_{lower,L} + \delta_{lower,R} - \delta_{upper,L} - \delta_{upper,R}}{2} = \frac{0.1\,m}{c}$
- Step 3: Express 3 δs by δ_{0L}.

$$t_{iL} = t_{\mu i} + \frac{(0.85\,m + x_{\mu i})}{c_{scint.i}} - \delta_{iL} \qquad t_{iR} = t_{\mu i} + \frac{(0.85\,m - x_{\mu i})}{c_{scint.i}} - \delta_{iR}$$

$$t_{\mu i} = \frac{t_{iL} + t_{iR} - 1.7\,m/c_{scint.i} + \delta_{iL} + \delta_{iR}}{2}$$



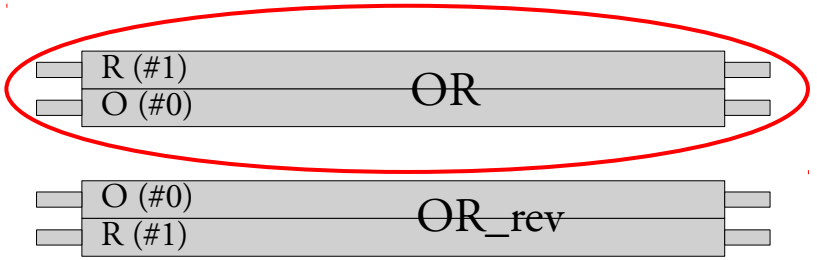
Time Calibration Formula

- Formula for OR

$$\delta_{0R} - \delta_{0L} = \langle t_{0L} - t_{0R} \rangle$$

$$\delta_{1L} - \delta_{0L} = \langle t_{0L} - t_{1L} \rangle - 0.85\,m \times \left(\frac{1}{c_{scint.0}} - \frac{1}{c_{scint.1}} \right) - \frac{0.1\,m}{c}$$

$$\delta_{1R} - \delta_{0L} = \langle t_{0L} - t_{1L} \rangle - 0.85\,m \times \left(\frac{1}{c_{scint.0}} - \frac{1}{c_{scint.1}} \right) - \frac{0.1\,m}{c} + \langle t_{1L} - t_{1R} \rangle$$



Time Calibration Formula $_{rev}$

- Formula for OR_{rev}

$$\delta_{0R} - \delta_{0L} = \langle t_{0L} - t_{0R} \rangle$$

$$\delta_{1L} - \delta_{0L} = \langle t_{0L} - t_{1L} \rangle - 0.85\,m \times \left(\frac{1}{c_{scint.0}} - \frac{1}{c_{scint.1}} \right) + \frac{0.1\,m}{c}$$

$$\delta_{1R} - \delta_{0L} = \langle t_{0L} - t_{1L} \rangle - 0.85\,m \times \left(\frac{1}{c_{scint.0}} - \frac{1}{c_{scint.1}} \right) + \frac{0.1\,m}{c} + \langle t_{1L} - t_{1R} \rangle$$