# Seasonal Variation of Muon Rates Using Full Dataset in Daya Bay Reactor Neutrino Experiment

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(On behalf of the Daya Bay collaboration)

## Temperature Correlation of Muon Flux



Cosmic Ray Shower Illustration
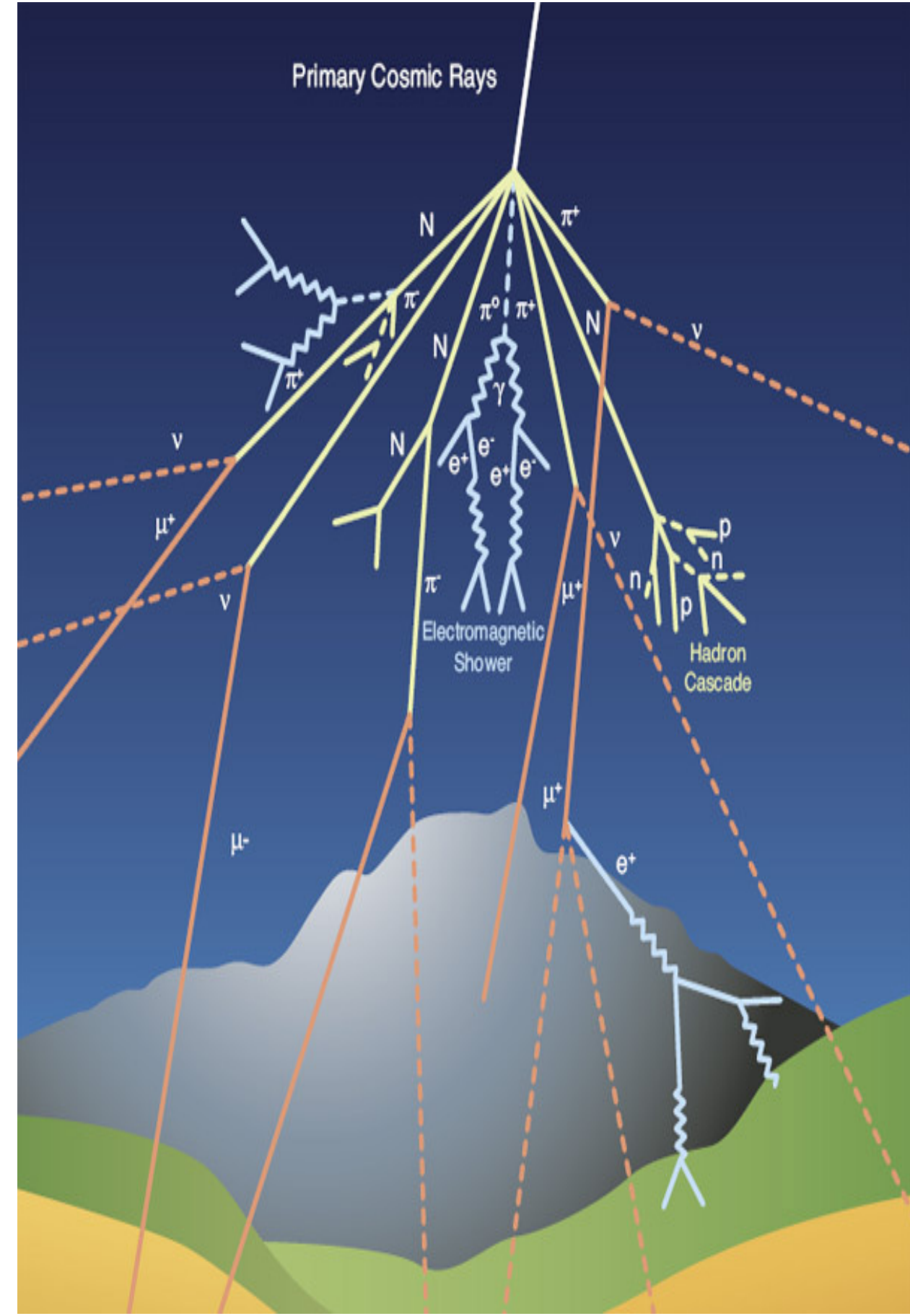
✓ The rate of cosmic ray muon is expected to be correlated with the atmospheric temperature, and the correlation between muon rate $R_\mu$ and effective temperature $T_{eff}$ given by[1]
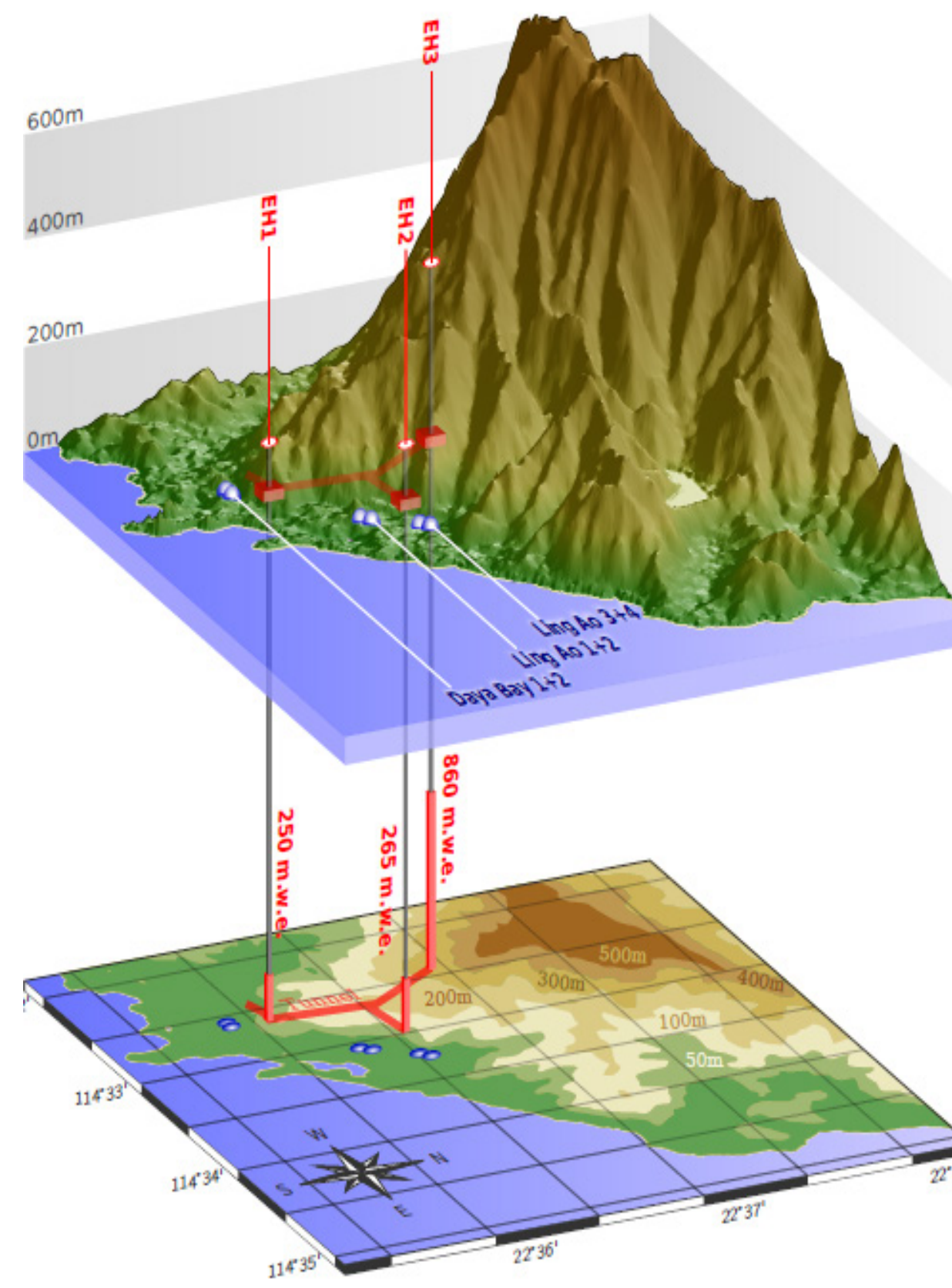
$$\frac{\Delta R_\mu}{\langle R_\mu \rangle} = \alpha \frac{\Delta T_{eff}}{\langle T_{eff} \rangle}$$

✓ The correlation coefficient $\alpha$ increases as the energy threshold gets larger at detectors deeper than 50mwe[1].

✓ Muon with higher energy has a lower probability of decay before reaching the detector due to time dilation and is relatviely more sensitive to changes in temperature.

## Daya Bay Reactor Neutrino Experiment



✓ Daya Bay Experiment features eight identical antineutrino detectors in three underground experimental halls at different depths.

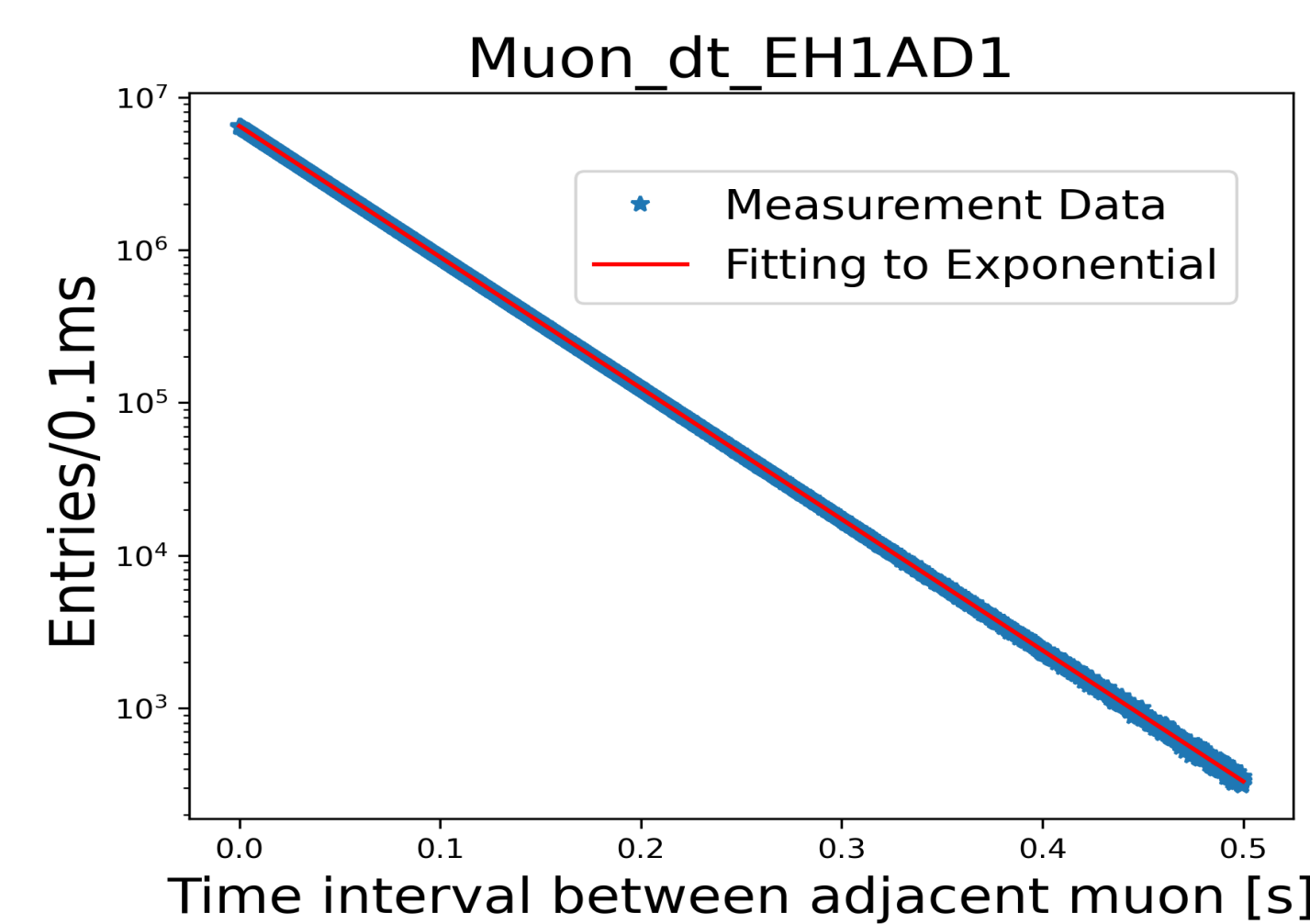✓ It provides an ideal setup to study coefficient $\alpha$ using identical detectors at different overburdens[2].



✓ Daya Bay has measured the correlation coefficient with dataset collected between Dec.2011 and Nov.2013[3].
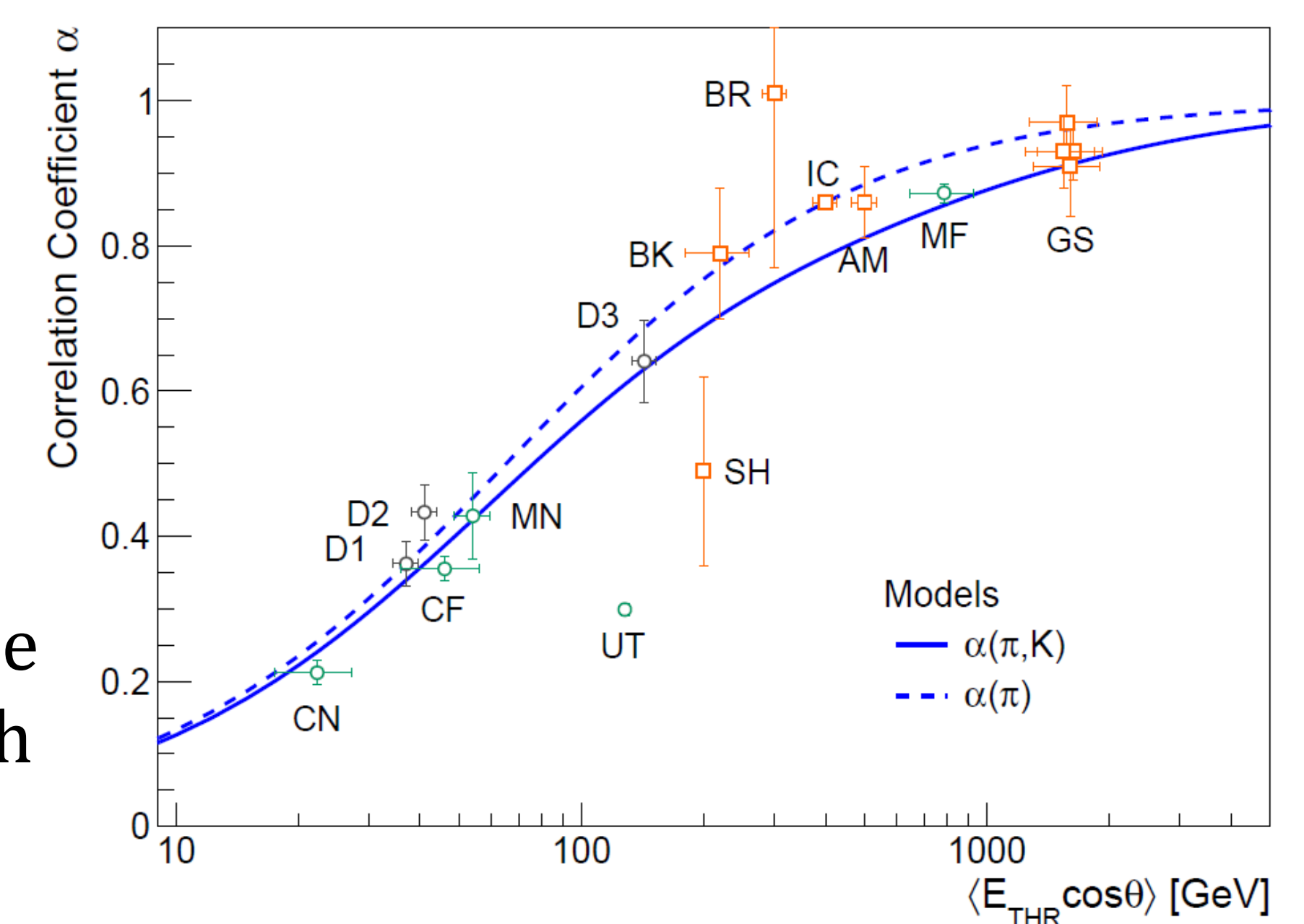
## Muon Selection and Muon Rate

**Reconstructed energy spectrum in EH1AD2**



- Events with energy>10MeV
- Tagged by muon system
- Difference
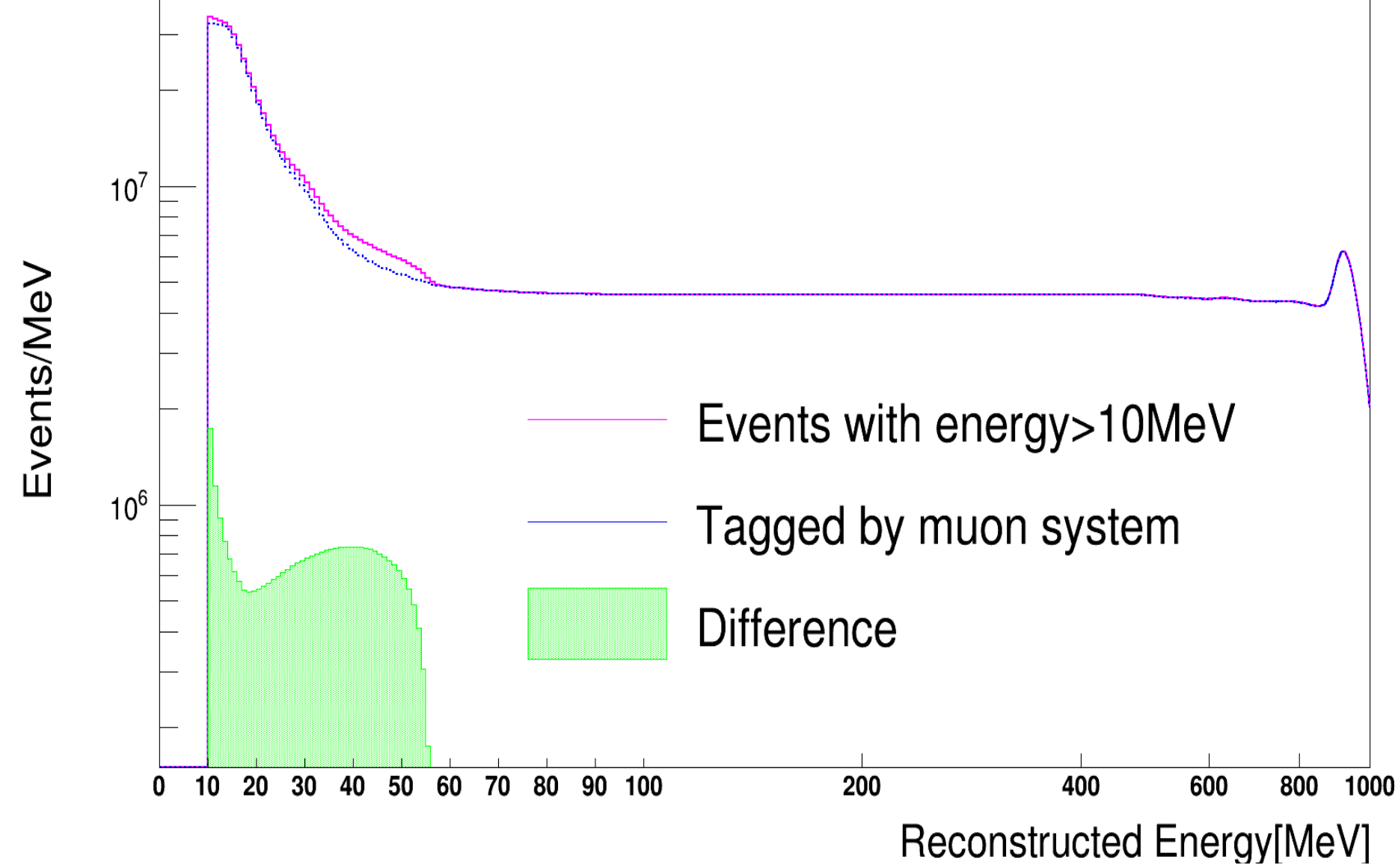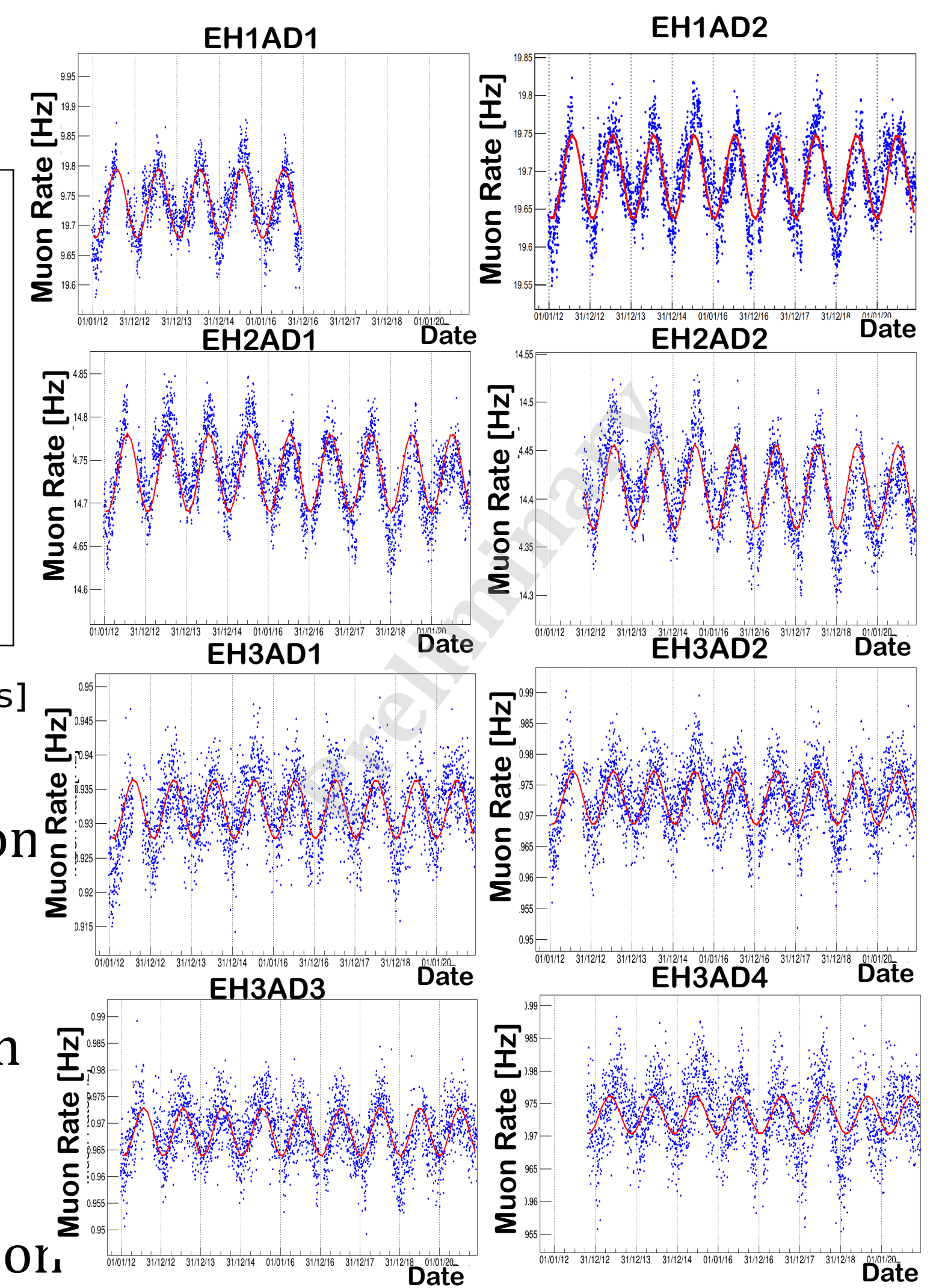
✓ Muon candidates are defined as events with greater than 60 MeV energy deposition in ADs (antineutrino detectors).

　✓ Examples with energies greater than 10 MeV have Michael electron mixed in, and 60 MeV cut can remove them.

✓ Raising the energy cut of EH3 AD1 to 100MeV due to the leak of liquid scintillator in Summer 2012[3].

**Muon_dt_EH1AD1**



- Measurement Data
- Fitting to Exponential



EH1AD1, EH1AD2, EH2AD1, EH2AD2, EH3AD1, EH3AD2, EH3AD3, EH3AD4

✓ Take EH1AD1 as an example, time between neighboring muon events can be well fitted to an exponential distribution.

✓ Significant seasonal modulation in the muon rate history distribution.

✓ Sinusoidal fits are for comparison purpose only.

## Effective Temperature

**Normalised Weight**



- Temperature
- EH1 Weight
- EH2 Weight
- EH3 Weight

**Effective Temperature**
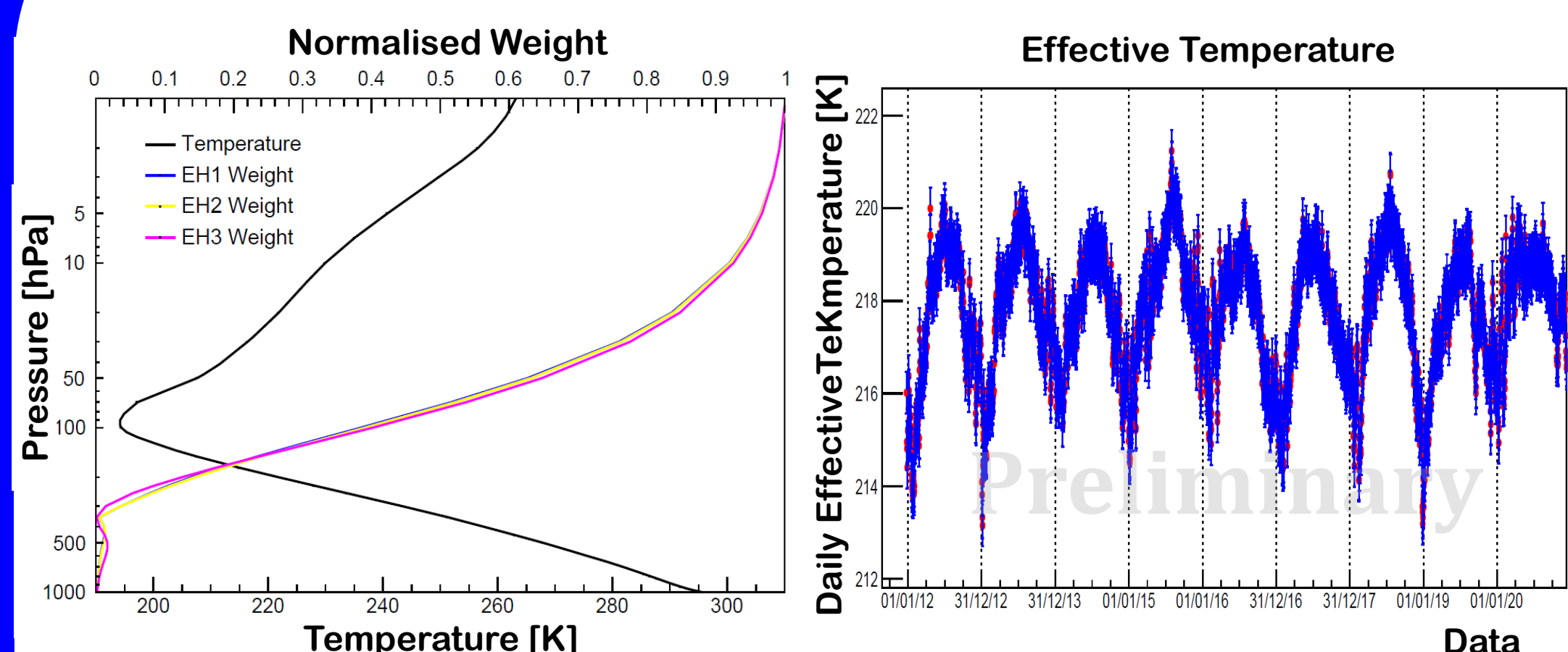


✓ Atmosphere is treated as an isothermal body with an effective temperature to account for different muon creation heights.

✓ The atmospheric temperature data was obtained from ECMWF[4].

$$T_{eff} = \frac{\int_0^\infty dX\, T(X) W(X)}{\int_0^\infty dX\, W(X)} \approx \frac{\sum_i \Delta X_i T(X_i) W(X_i)}{\sum_i \Delta X_i W(X_i)}$$

✓ The weight W associated with each pressure level reflects the model[5].

## Correlation Analysis



EH1AD1, EH1AD2, EH2AD1, EH2AD2, EH3AD1, EH3AD2, EH3AD3, EH3AD4
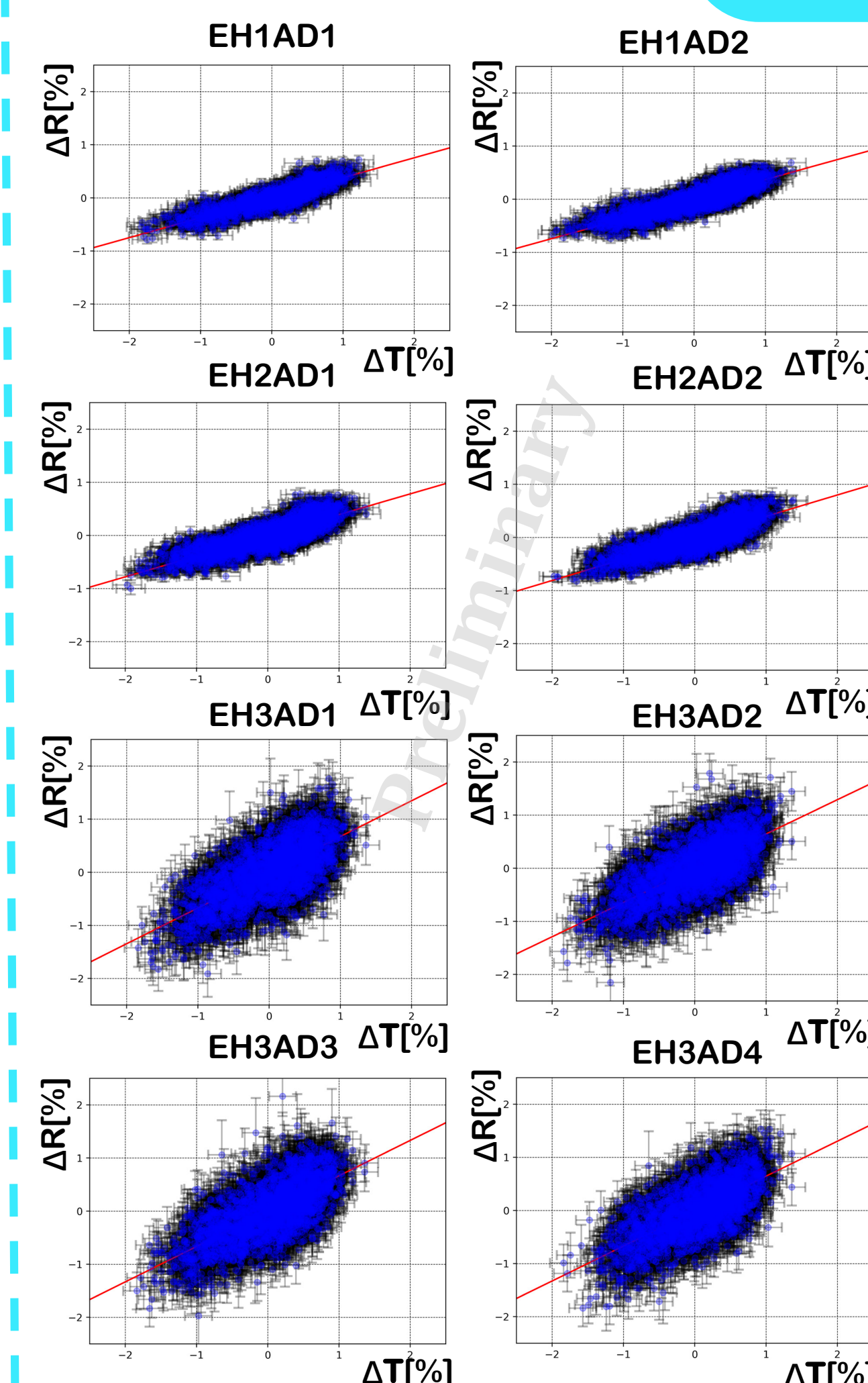
✓ The analysis data was collected between December 2011 and December 2020 and retain data where acquisition time greater than 6 hours one day.

✓ Correlations are seen between relative variation of effective temperature (X axis) and that of muon rate(Y axis).

✓ Work in progress, correlation coefficients for each AD and hall will be obtained.

## References

[1] E.W. Grashorn et al., Astropart. Phys. 33 (2010) 140
[2] ] F.P. An et al. (The Daya Bay Collaboration), Phys.Rev. D97, 052009 (2018)
[3] F.P. An et al. (The Daya Bay Collaboration), JCAP01(2018)001
[4] The ERA-Interim database of the European Centre for Medium-Range Weather Forecasts, ECMWF.
[5] P.H. Barrett et al., Rev. Mod. Phys. 24 (1952) 133.