Seasonal Modulation of the Muon Flux Correlated with Atmospheric Temperture

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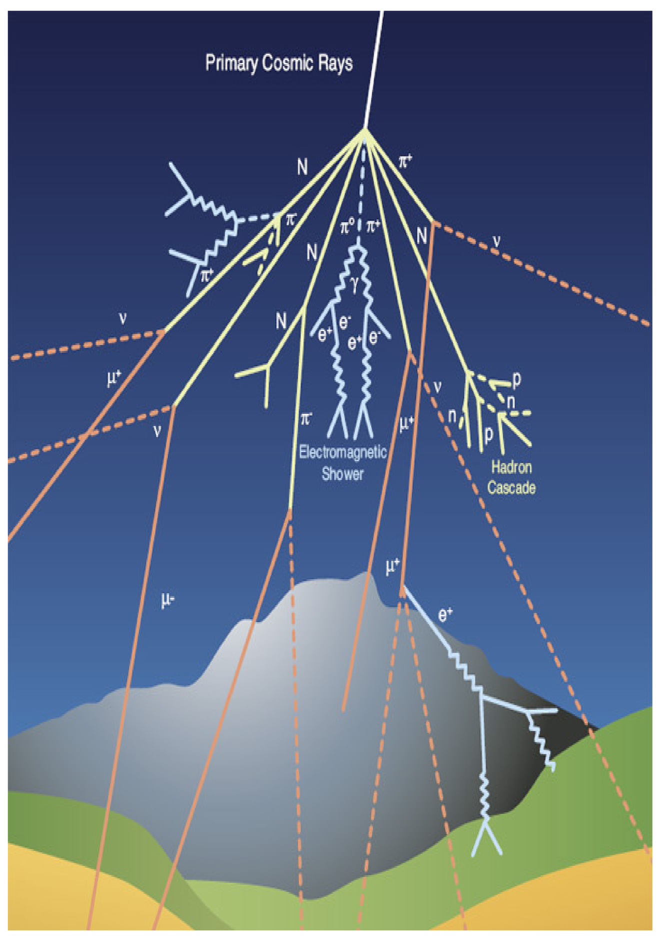
Temperature Correlation of Muon Flux

- ✓ The rate of cosmic ray muon is expected to be positively correlated with the atmospheric temperature and the correlation between muon rate R_μ and effective temperature T_{eff} given by[1]

$$\frac{\Delta R_\mu}{\langle R_\mu \rangle} = \alpha \frac{\Delta T_{eff}}{\langle T_{eff} \rangle}$$



Cosmic Ray Shower Illustration

- ✓ The predicted α can be expressed as[1]

$$\alpha = \frac{1}{D_\pi} \frac{1/\epsilon_K + A_K (D_\pi/D_K)^2/\epsilon_\pi}{1/\epsilon_K + A_K (D_\pi/D_K)/\epsilon_\pi}$$

where $\epsilon_{\pi,K}$ and A_K are parameters inherited from reference[2], $D_{\pi,k}$ are the free parameter which inversely proportional to overburdens given by average threshold energy $\langle E_{thr}\cos\theta \rangle$[3].

- ✓ The correlation coefficient α is expected to increase with overburdens.

Daya Bay Reactor Neutrino Experiment

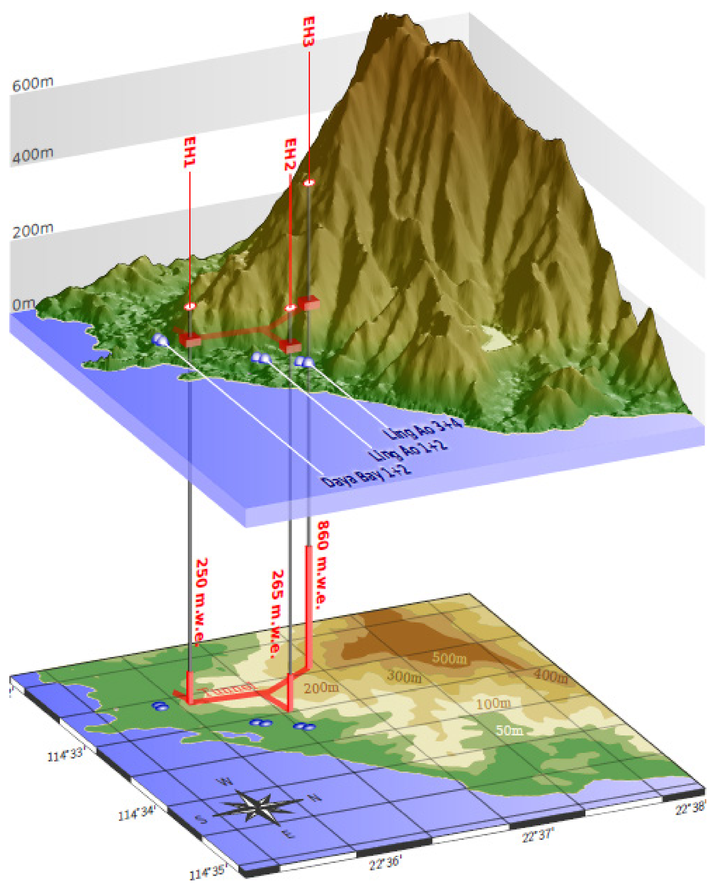


Fig.1: Elevation profile of the mountain above the Daya Bay

- ✓ Daya Bay Experiment features eight identical antineutrino detectors in three underground experimental halls at different depths.
- ✓ Eight identically antineutrino detectors (ADs) are installed in three experimental halls, two in each near halls (EH1 and EH2)., and four in the far hall (EH3).
- ✓ The rock cover above the far hall is far thicker than the near halls.
- ✓ It provides an ideal setup to study coefficient α using identical detectors at different overburdens[4].

Hall	Overburden m	Overburden m.w.e.	Muon flux Hz/m^2
EH1	93	250	1.27
EH2	100	265	0.95
EH3	324	860	0.056

Fig.2: Underground muon simulation results. The error in the simulated total flux is about 10%.

Muon Rate and Effective Temperature

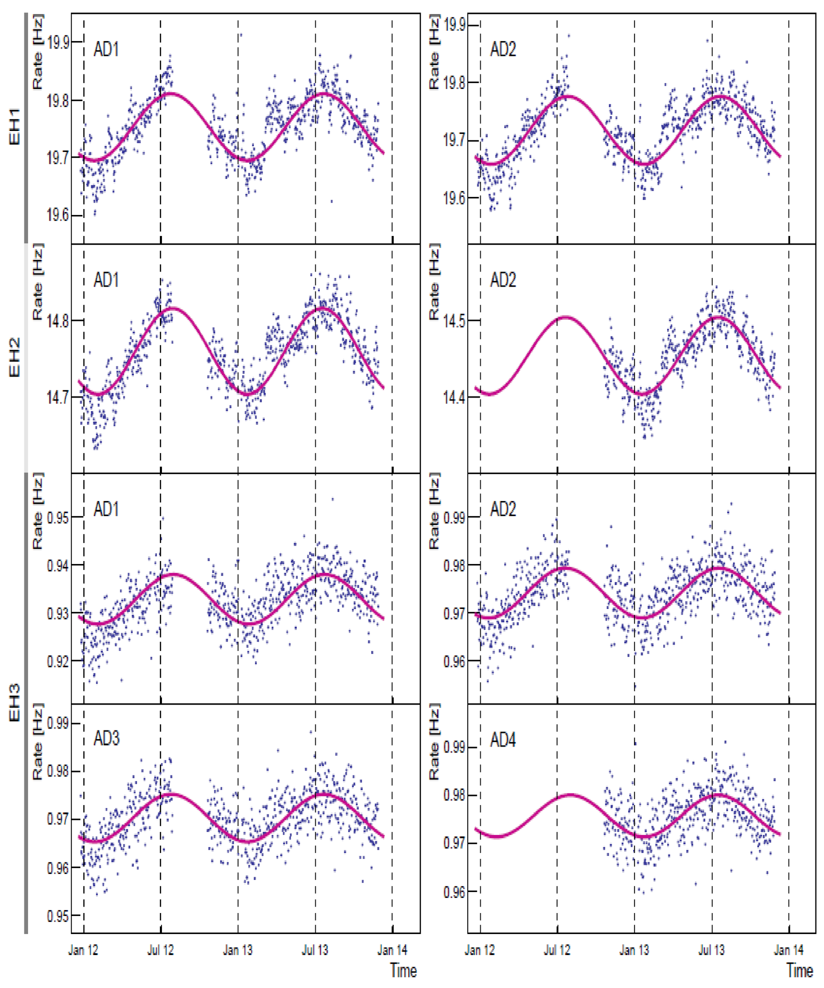


Fig.3: Muon rate variation with time

- ✓ Muon candidates are defined as events with greater than 60 MeV(100 MeV in EH3AD1) energy deposition in ADs.
- ✓ The analysis data was collected between December 2011 and November 2013[3] .
- ✓ Sinusoidal fits are shown only to guide the eye.

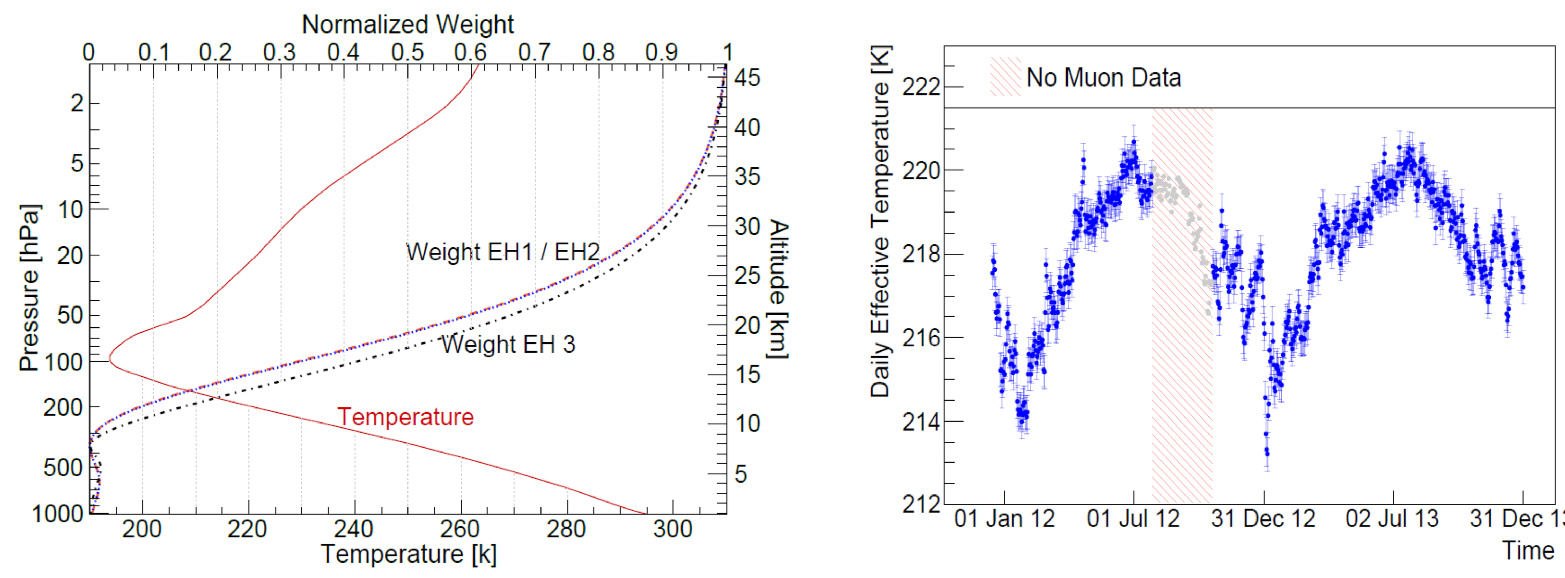


Fig.4: EH-dependent weights and daily effective temperature of EH1

- ✓ The atmospheric temperature data was obtained from ECMWF[5].
- ✓ Atmosphere is treated as an isothermal body with an effective temperature to account for different muon creation heights.
- ✓ Effective temperature is computed as a weighted average of temperature T at different depth X

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

- ✓ The weight W associated with each pressure level reflects the model[6].

Correlation Coefficients

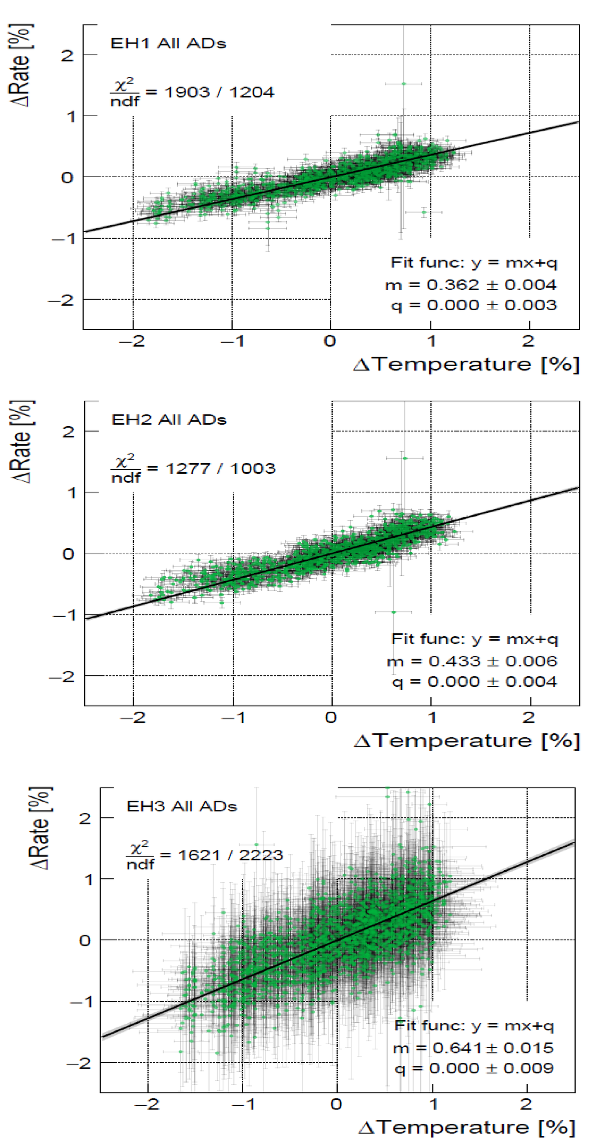


Fig.5: Relative muon rate variation vs relative effective temperature variation

- ✓ Correlations are seen between relative variation of effective temperature (X axis) and that of muon rate(Y axis).
- ✓ Correlation coefficient α is obtained by fitting data with a linear function.

Exp. Hall	Prediction: Including K and π	Prediction: Including π only	This Work[3]
EH1	0.340 ± 0.019	0.362 ± 0.018	0.362 ± 0.031
EH2	0.362 ± 0.019	0.386 ± 0.018	0.433 ± 0.038
EH3	0.630 ± 0.019	0.687 ± 0.018	0.641 ± 0.057

- ✓ Comparison of the predicted[3] and measured values of the correlation coeffcients (see plot on right side) at the different experimental halls.
- ✓ The correlation coefficient α is found to increase with overburden.
- ✓ The result cannot discriminate the contribution of muon production between the model accounting for pions and kaons and the model accounting for pions only.
- ✓ A measurement with nearly 2000 days of data is in progress.

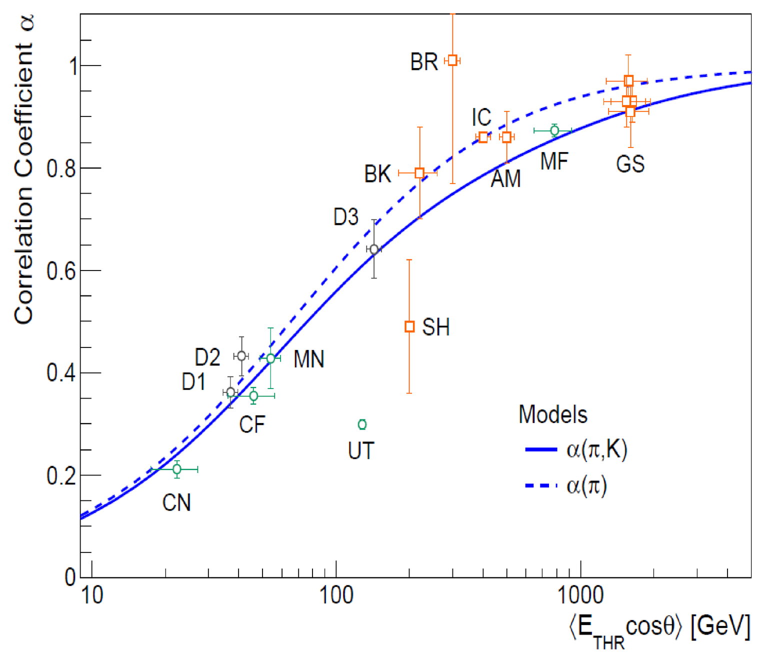


Fig.6: Comparison of coefficients in Daya Bay with theory and other experiments

References

[1] E.W. Grashorn et al., Astropart. Phys. 33 (2010) 140
[2] P. Adamson et al. (The MINOS collaboration), Phys.Rev. D81, 012001 (2010)
[3] F.P. An et al. (The Daya Bay Collaboration), JCAP01(2018)001
[4] F.P. An et al. (The Daya Bay Collaboration), Phys.Rev. D97, 052009 (2018)
[5] The ERA-Interim database of the European Centre for Medium-Range Weather Forecasts, ECMWF.
[6] P.H. Barrett et al., Rev. Mod. Phys. 24 (1952) 133.