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Energy Non-linearity study at Daya Bay

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The Daya Bay Reactor Neutrino Experiment has measured a non-zero value of the neutrino mixing angle θ_{13} with a significance of 7.7 standard deviations by a rate-only a nalysis[4]. The distortion of neutrino energy spectrum carries additional oscillation information and can improve the sensitivity of θ_{13} as well as measure neutrino mass splitting Δm^2 . A rate plus shape analysis is performed and the results have been released in August at NuFact 2013. And the recent spectral analysis result has already submitted to arxiv[5]. Detector energy non-linearity response study is crucial for the rate plus shape analysis. In this contribution, We present A brief description of energy non-linearity study at Daya Bay.

Keywords: neutrino experiment,oscillation,energy response,non-linearity,spectra analysis

PACS numbers:

1. General Introduction

It is well established that the flavor of a neutrino oscillates with time, Neutrino oscillations can be described by the three mixing angles(θ_{12},θ_{23}, and θ_{13},). and a phase of the Pontecorvo-Maki-Nakagawa-Sakata matrix, and the neutrino mass squared differences[1,2]. The Daya Bay experiments maintains the most precision in the measurement of the neutrino mixing angle θ_{13} [3,4]. The Daya Bay Experiment has three Underground Experiment Halls(EH) and totally 8 anti-neutrino detector(AD). The Antineutrino Detector(AD) of the DayaBay Reactor experiment is a structure of three parts. With Gadolinium(Gd) loaded Liquid Scintillator(LS) in the center, L-S in the middle as the gamma catcher, and oil in the outer area to depart the dirty components like PMT, from the LS area. The $\overline{\nu}_e$ from the reactor interacts in the way of inverse beta decay(IBD), and a positron together with a neutron come out after the interaction. The positron kinetic energy deposited and then annihilation, this event presents as prompt signal. The neutrons is captured by the Gd atoms,and several gamma with total energy about 8 MeV are emmited. This event forms the delayed signal, Inverse beta decay(IBD) candidates are selected through time-correlated events method, The prompt Liquid Scintillator(LS) light from the positron gives an estimate of the incident $\overline{\nu}_e$ energy through:$E_\nu = E_{e^+} + 0.8MeV$

2. Energy Response model

The Daya Bay detector energy response is described like this: a particle with its true energy deposit its energy in the AD, For a γ, e^-, E_{true} is the kinetic energy; for a positron, E_{true} is the sum of the kinetic energy and the energy from annihilation. After that, the LS translate the energy to be the visible light, it's the visible energy E_{vis}. The visible photos are detected by photomultiplier tubs(PMT). After the calibration and reconstruction, the E_{vis} is converted to be the reconstructed energy E_{rec}. The energy response is not linear due to scintillator and electronics effect. The non-linearity definition is the E_{rec}/E_{true}. The non-linearity can be divided into two parts: one is called the electronics non-linearity, it's E_{rec}/E_{vis}, and the left is called the scintillator non-linearity.

3. electronics non-linearity

The electronics non-linearity is caused due to slow component of LS light(about 100ns)(see 1), as well as the electronics signal processing, and hit selection. Later hits formed by slow component may not be included in the hit collection.

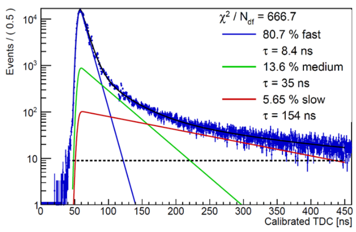

Fig. 1. Different components of LS, fitted by exponential functions.

As a result. We found that the charge collection efficiency decreased with the number of visible photos emmited by LS. we used several model to parameterize the electronics non-linearity. One of the way is : $\frac{E_{vis}}{E_{rec}} = (1 - \alpha e^{\frac{E_{rec}}{\tau}})$

4. LS non-linearity model

We used several different models to constrain the LS non-linearity of electron. One is the model use a formula based on Birk's formula and Cherenkov radiation theory. Another one is an empirical model with 3 parameters. Considering the difference between electron and gamma, we used a converting model which can deduce the gamma non-linearity from the electron non-linearity model, namely, the gamma interact in the Gadolinium loaded in three ways: Computon scattering,Photoelectric effect, and pair production effect. With a Geant4 simulation method, the gamma to e^+/e^- converting function can be achieved. With this probability function, we can deduce the non-linearity of gamma from the electron non-linearity.(see 2)

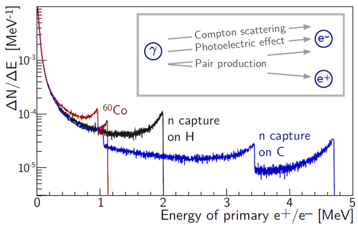

Fig. 2. The gamma to electron converting function got through Geant4.

The scintillator nonlinearity for electrons is first described by an empirical model $E_{vis}/E_{true} = (p_0 + p_3 E_{true})/(1 + p_1 e^{-p_2 E_{true}})$. And we used a second model based on physics to check that model. The formula is $E_{vis}/E_{true} = f_q(E_{true}; K_B) + K_C f_c(E_{true})$. The former part is for quenching effect using Birk's law[6], and the other one is for Cherenkov radiation effect.

5. Avaliable data for constrain the non-linearity

During a special calibration period in summer 2012, We used gamma sources deployed at the center of detector to get the gamma spectrum. Gamma radiation source such as $^{137}Cs,^{54}Mn,^{40}K$, and neutron source like $^{241}Am-^{9}Be, Pu-^{13}C$ are used. Neutrons emitted from the neutron radiation sources can be captured on hydrogen or Gd. A 2.2MeV gamma is emitted when captured on hydrogen, and several gamma with total energy about 8MeV are emitted after captured on Gd. The energy spectrum and the fit result is show(see 3).

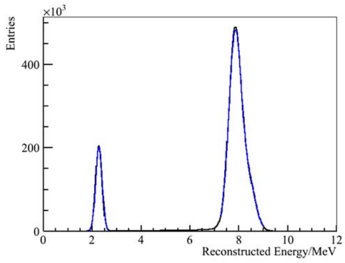

Fig. 3. The energy spectrum of n capture on hydrogen and n captured on Gd.

In order to test the goodness of the non-linearity, the result of reconstructed energy spectrum of gamma and ^{12}B, is compared to the expected energy spectrum got through true energy corrected after energy non-linearity. The test result is show as(see 4).

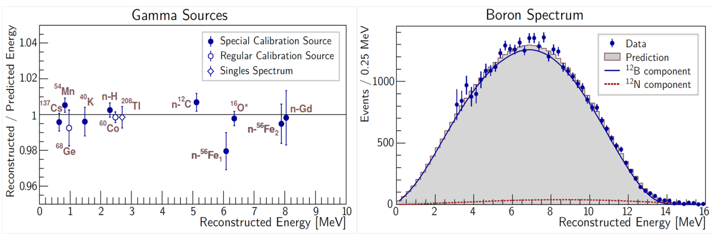

Fig. 4. The gamma points and Boron spectrum compared to corrected by energy non-linearity.

6. summary

we used gamma data and muon induced Boron data to study the non-linearity of the detector. We used different models or different weights to deduce the energy non-linearity. The results are consistent with each other. We used one for the spectra analysis, and the primary analysis result has submitted to arxiv[5]. The energy non-linearity model for positron and global fit result is show as follow(see 5)

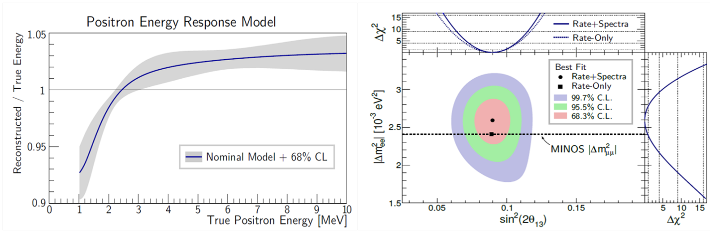

Fig. 5. Positron non-linearity result and the global fit result.

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