Title:

Design and implementation of the timing and synchronization system for JUNO-TAO detector

Abstract:

The Taishan Antineutrino Observatory (TAO) aims to accurately measure the energy spectrum of reactor antineutrinos, providing a reference spectrum for the Jiangmen Underground Neutrino Observatory (JUNO) and offering precise benchmark references for the nuclear databases and other physics objectives.

The JUNO-TAO experiment will use 4024 SiPM tiles with 8048 ADC channels to ensure the proposed energy resolution (<1.5% @ 1 MeV), spatial resolution (around 1 cm), and timing performances (around 1 ns). The readout system is built based on six MicroTCA crates with FPGA boards.

This paper presents an implementation of timing and synchronization system with the White Rabbit (WR) distributed synchronous timing technology. The nanosecond timing properties make them suitable to work with the typical mixtures of liquid scintillators currently used in particle physics experiments.

The ongoing R&D effort carried out to study the timing and synchronization for data readout, and the other components, supported by laboratory test results, will also be presented.

Summary:

The White Rabbit (WR) distributed synchronous timing technology enables multi-node sub-nanosecond clock distribution, meeting the system's clock synchronization accuracy requirements. To ensure the consistency of each channel's events and the accuracy of ADC sampling, a high-precision timing and synchronization system is crucial for the TAO experiment.

We designed and implemented a timing and synchronization system for the TAO readout electronics, verifying the feasibility of the chassis-level clock distribution method and comparing the jitter and skew performance of two clock distribution schemes through the MicroTCA backboard. Additionally, we developed firmware for the Module Management Controller (MMC) based on FreeRTOS, enabling the management and monitoring of the status of readout electronics boards and the clock modules on the boards.

The paper also conducts clock performance tests on the timing and synchronization system to verify that the system meets the requirements of the TAO experiment. The research primarily focuses on the readout electronics architecture and timing synchronization requirements of TAO. Specific work includes:

- Design and deployment of the White Rabbit (WR) network for TAO (Shown in fig. 1), configuration of master and slave nodes, establishment of WR synchronization links, and parameter calibration compensation for hardware delays to achieve ps-level clock

deviation.

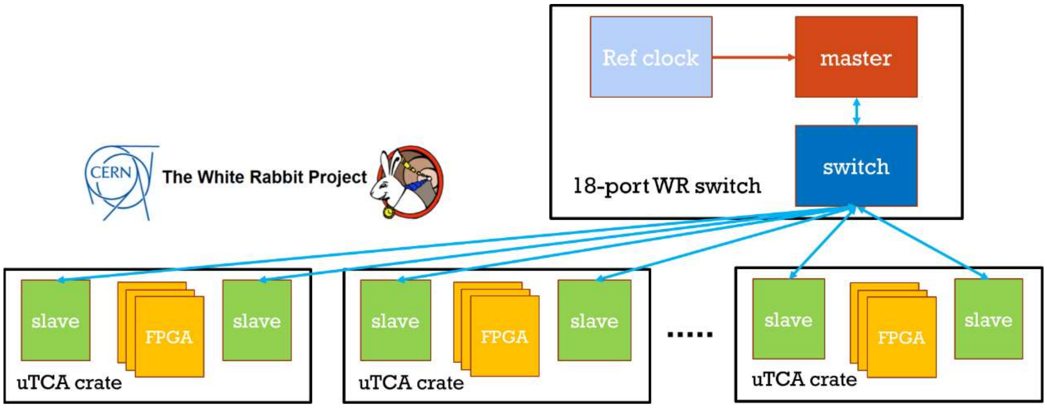
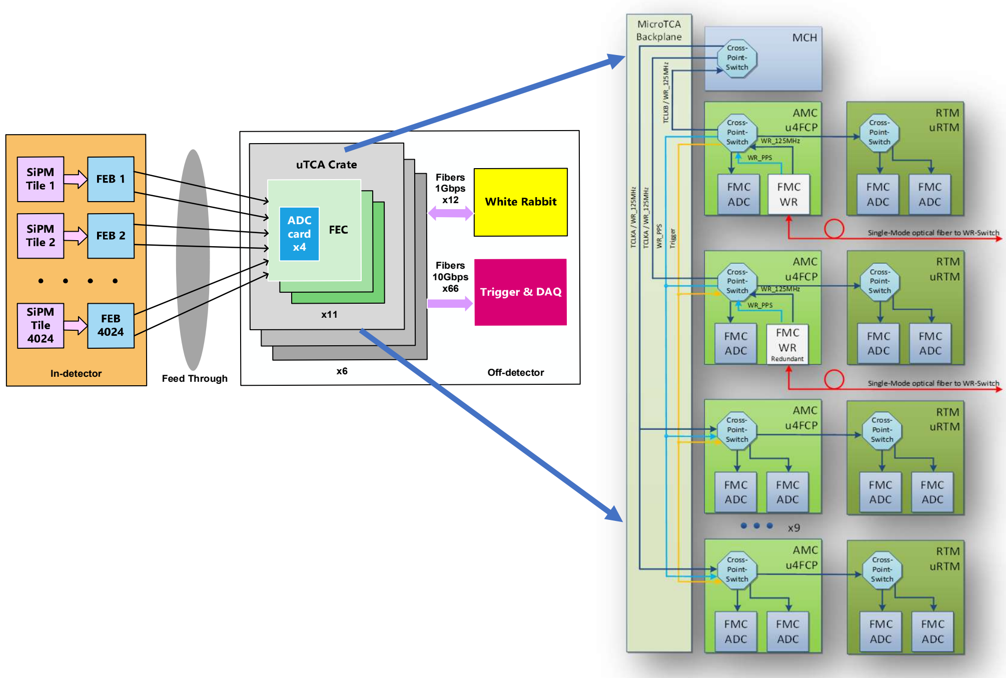
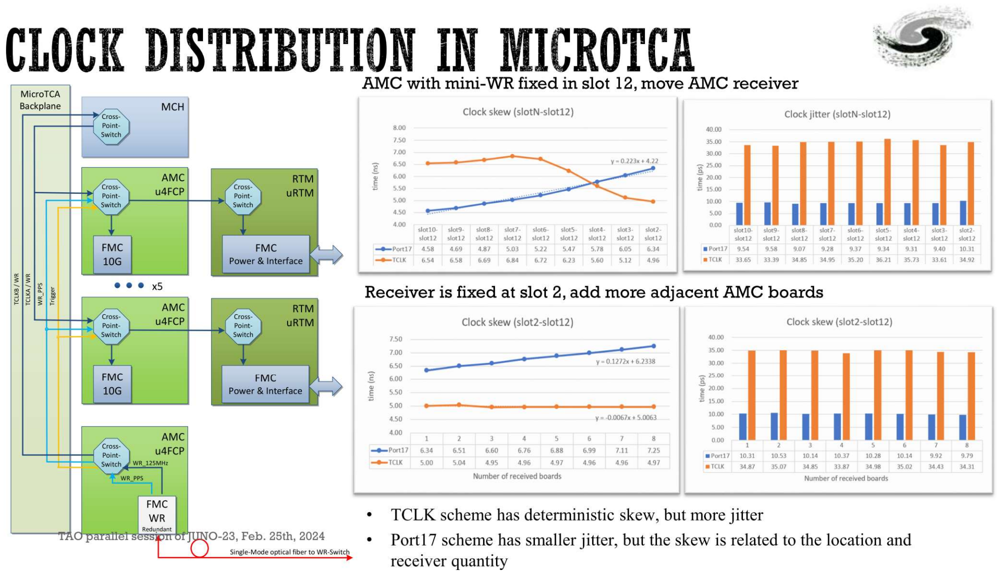


Fig. 1 Block diagram of the timing and synchronization system for TAO detector, TAO plan to use 6 MircoTCA crates, each crate has 2 WR nodes to build a redundant WR clock

- Design and implementation of clock modules on the boards, optimizing and transmitting the synchronized clocks (shown in fig. 2). It designs a clock-compatible circuit so that the Advanced Mezzanine Cards (AMC) can serve as both clock sending and receiving boards, and two feasible clock distribution schemes based on the backplane bus are also implemented and compared on these boards (shown in fig. 3).



- Fig. 2 Block diagram of the readout system for TAO detector and clock distribution in the MicroTCA



- Fig. 3 Jitter and skew performance of two clock distribution schemes through the MicroTCA backboard

- Testing and verification of the implemented TAO timing synchronization system, including test results from 1:1 detector prototype (Fig. 4) with photon measurements. We got a clear SiPM charge spectrum in Fig. 5.

Fig. 4 Photo of 1:1 detector prototype and the readout system with WR

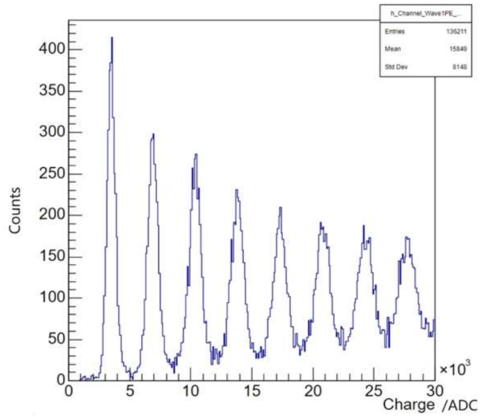


Fig. 5 SiPM charge spectrum histogram based on WR timing and synchronization system