Time Synchronization with White Rabbit – Experience from Tunka-HiSCORE

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Upcoming Gamma-Ray and Cosmic-Ray experiments require relative time calibration of all detector components with (sub-)nanosecond precision. White Rabbit, an established technology for time and frequency transfer, can be applied.

We describe a White Rabbit (WR) based design for Tunka-HiSCORE - a timing array for Gamma-Ray astronomy now under construction. Sub-nsec synchronization results from cosmic ray data, in-situ calibrations and laboratory tests taken over several years are presented.

Introduction

- Tunka-HiSCORE [1] is a non-imaging atmopsheric Cherenkov light-front sampling array; now under construction in the Tunka Valley / Siberia.
- Time synchronization to (sub) nanosecond precision between the detector stations distributed over upt to 10's of km² is required (pointing resolution).
- HiSCORE uses the new White Rabbit (WR) system [2] as a potential new standard technology; to avoid substantial effort coming with a custom system.
- We focus in this work is on timing performance evaluation in HiSCORE routine data taking, and in dedicated calibration setups.

White Rabbit System

- sub-ns time synchronization system over SyncEth/PTP
- Fiber length >10km; >1000 nodes; 1000base-BX10

Key Advantages:

- Clock-driven architecture: precision clocks are distributed to the front-end stations
- Time stamping allows for fully digital array- or next-neighbor-triggering
- Availability&commercial support for all main components
- Open source approach (firm-/software), support&docum.
- Application interfacing by experiment-Mezzanine boards
- Design simplicity / flexibility for even large scale setups
- Detailed calibration procedures, online monitoring
- Cost- and time-efficiency (manpower & investment)

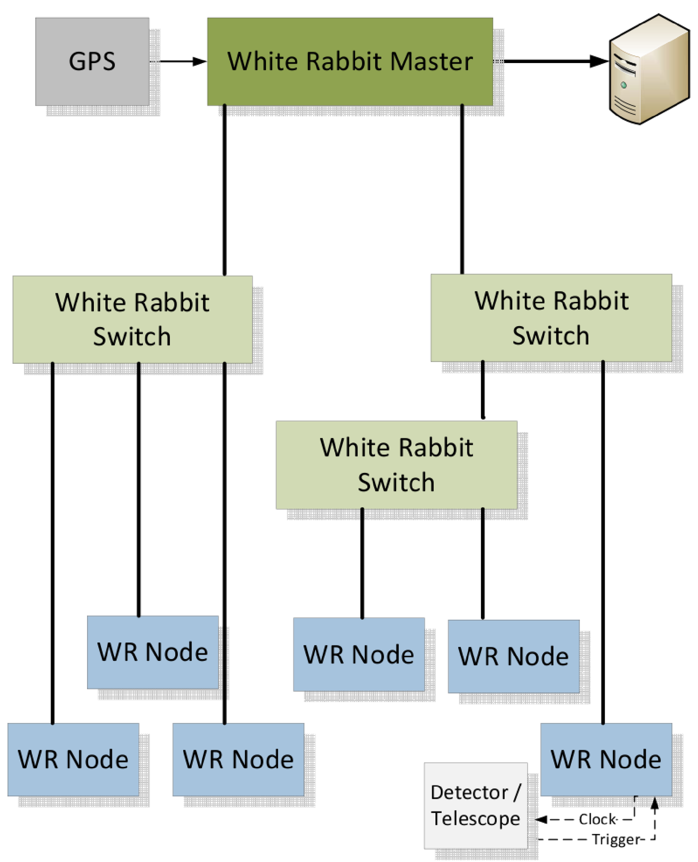

Fig. 1: The White Rabbit network: made up of WR-switches (WRS), Grand Master and normal WRS, and of WR-nodes. The WR-nodes deliver clock-signals to, and/or extract time-stamp signals from the associated detectors (or telescopes), as symbolized for the lower-right WR-node.

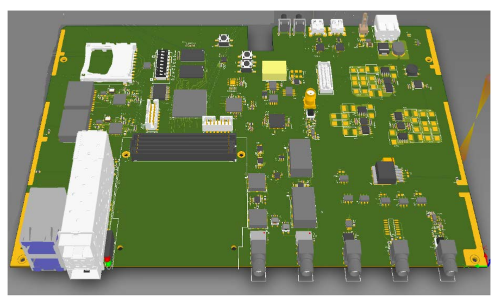

Fig. 3: A next generation Node: WR-ZEN - based on Xilinx-Zync (2xARM9) + FMC [3].

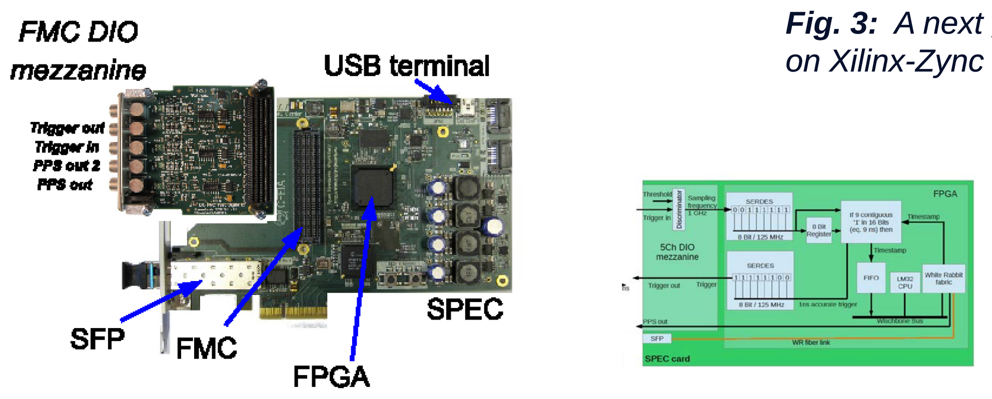

Fig. 2: Example of a WR-Node: The SPEC card, the WR-node used for this work. The precision time, kept on the Spartan-6 FPGA is synchronized through the fiber cable to the central WR-switch. With Mezzanine Digital I/O card. Right: Scheme of modified WR-firmeware for time-stamping, clock and triggering [4] .

WR-Setups at HiSCORE (2012-2015)

Laboratory tests: to validate WR, including our HiSCORE extensions of the SPEC [4]: nsec time-stamping, DAQ-trigger functionality. Note: Lab-timing can be fully verified, while for field-setups this is typically not independently possible.

Field Setups:

- **HiS-3 prototype (2012/13)**: first season - cross-verification with „monitoring" WR-nodes (i.e. redundant nodes; local and distant), see figure 4 and [5].
- **HiS-9 prototype (2013/14):** Physics (EAS) and LED calibration with 9 stations on a regular 150m grid (0.09km²).Dedicated, parallel DAQ (DAQ-2) based on WR entirely. See results below[6].
- **HiS-28 protoype (2014...):** 28 stations on 0.25 km². WR integrated into DAQ-1 for direct cross-verification (analysis in progress) [7].

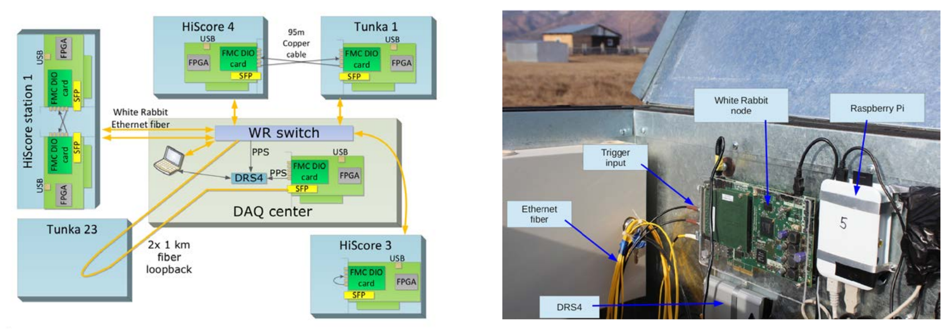

Fig. 4: The complex HiSCORE WR field-setup, as operated in 2012/13 to evaluate time-synchronization and nsec-trigger time-stamping by monitoring WR-nodes. Right:HiSCORE prototype station with DAQ and WR components.

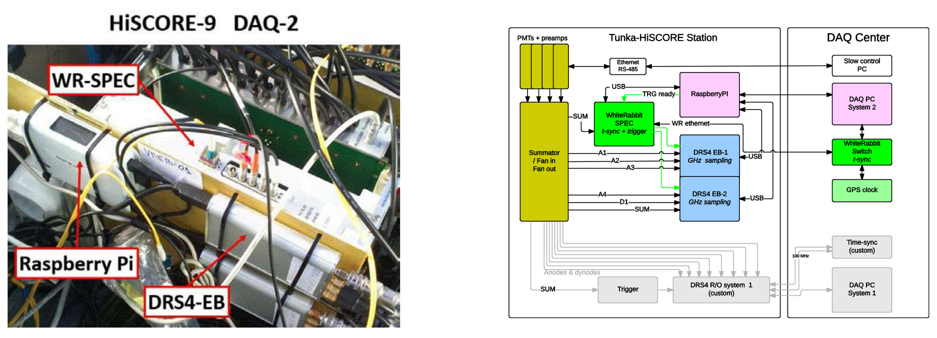

Fig. 5: HiSCORE-9 DAQ2-system as used for this analysis, with DRS4-Evaluation Board and White-Rabbit timing system. Left: Station setup (with DRS4-EB, WR-SPEC and Rasp-MiniPC). Right: Schematics of the setup in Station and Center for DAQ-2 (DAQ-1 in grey) [6].

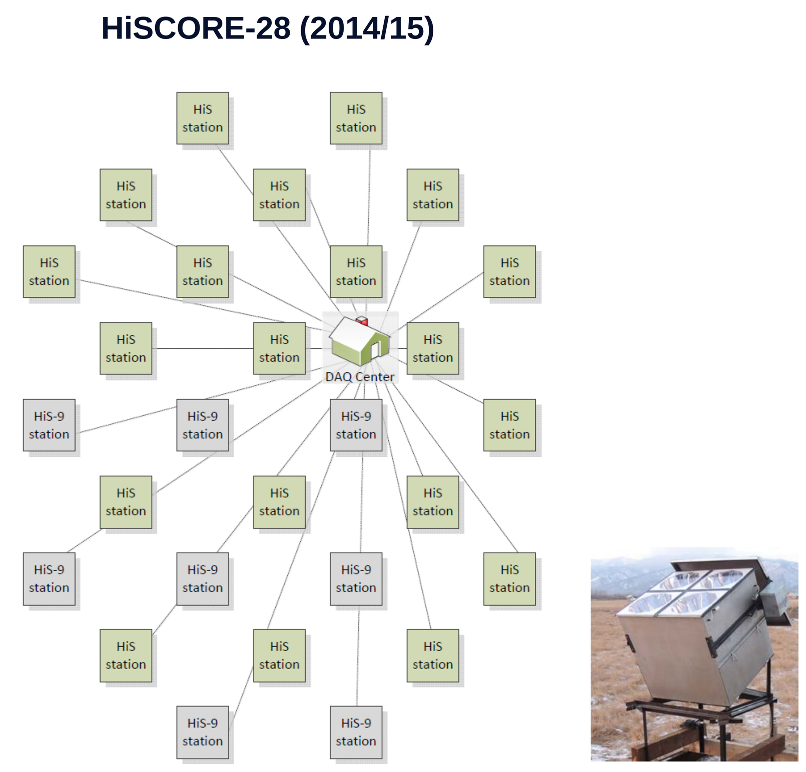

Fig. 6: HiSCORE-28 array layout: 28 stations at 100m spacing forming a super-cell structure, total area = 450x 600m² (HiS-9 stations are indicated). Right: Optical station with four 8" PMTs, inclinded 25º southwards.

Results

Timing tests done with:

- **Laboratory setups**: WR-components only.
- **HiSCORE prototype** (HiS-9): includes jitter / offset from PMT, electronics...

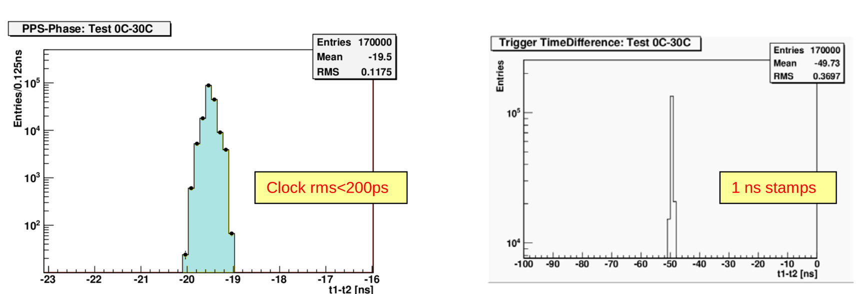

Fig. 7: Sub-nsec precision timing in climate chamber tests. Left: Distribution of time difference between PPS clock-pulses from two WR-nodes (SPEC1/2), synchronized by a WRS, for a 48-hours run: σ=0.12ns. SPEC2 card and the 500m fiber-coil were subjected to temperature ramps between 0º and 30ºC. For details see [4]. Right: Same run, comparing the digital trigger timestamps (1ns resolution) generated on the WR-SPECs: σ =0.37ns (time-offsets ≠0 are due to cabeling).

LED event reconstruction in HiSCORE-9 by WR

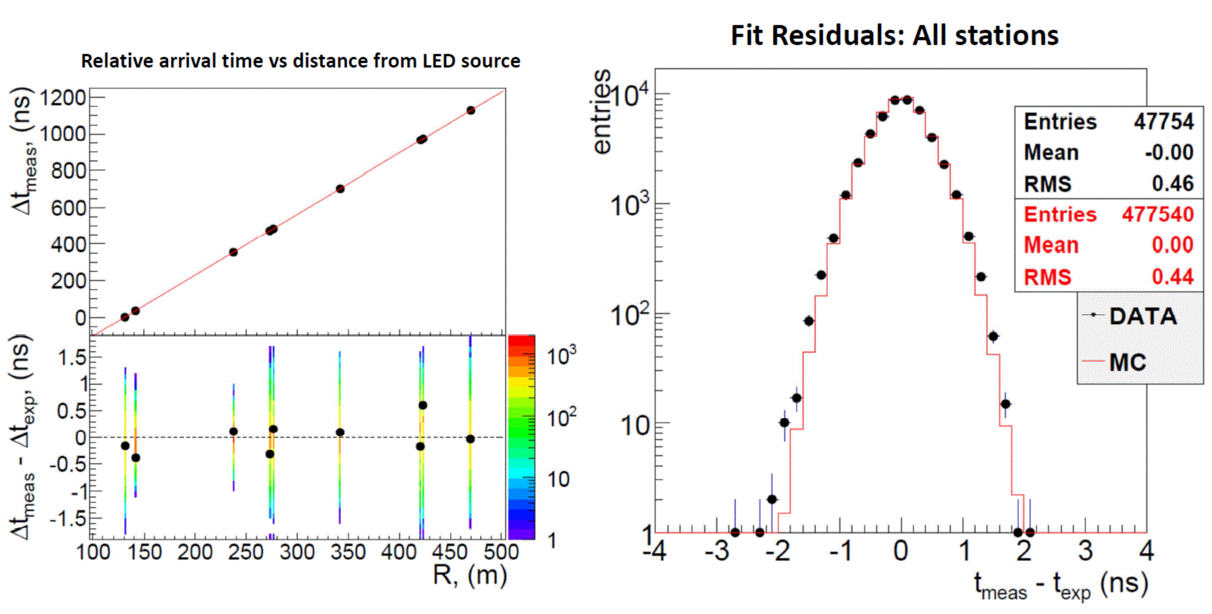

Fig. 8: LED Calibration.Left: Upper panel: station relative arrival times Δt_{meas} as function of distance R from the LED light source. Red line gives $t_i = R_i/c$. Lower panel: fit residual distributions per station. Black dots show an example of a single triggered event. Right: Distribution of fit residuals for LED events (all nine stations superimposed). Black dots: data; Red line: simulated events.[6]

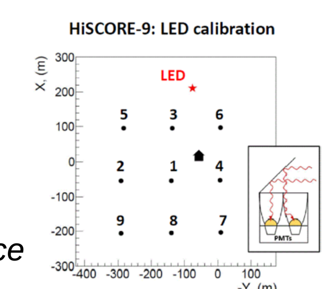

Fig. 9: The HiSCORE-9 array layout: Nine stations and LED source position (red star) for calibration runs; insert: station setup for calibration runs with 45º inclined reflectors.

EAS-reconstruction in HiSCORE-9 by WR

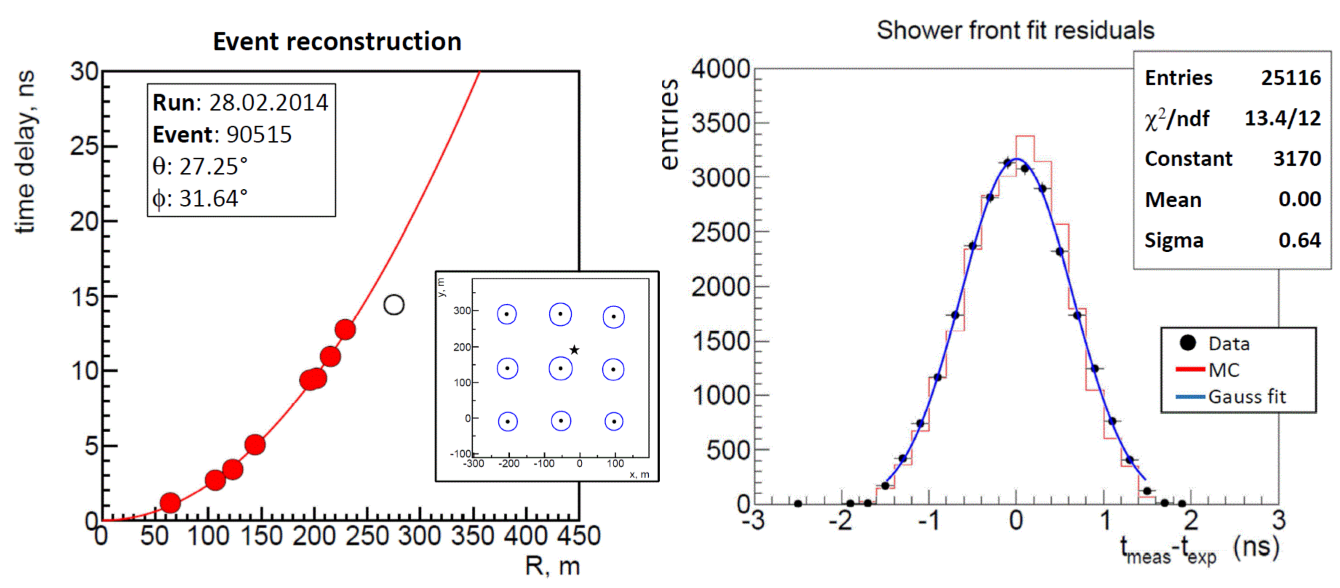

Fig. 10: EAS shower reconstruction with WR. Left: Arrival time delay vs distance R from the shower axis; for an event. Red/white dots: stations retained/excluded in the final fit; red line: reconstructed shower profile. Small panel: Reconstructed core position (black star), the area of the circles is proportional to log(A), with A the station signal amplitude. Right: Distribution of fit residuals after shower reconstruction. Black dots: data; Red line: simulated events; Blue line: gaussian data fit.

Conclusion

We extended the functionality of the White Rabbit SPEC-node to perform ns-precision trigger time-stamping, and additional DAQ-functionalities. In routine HiSCORE physics data taking we find a station time jitter of sig<0.5ns and in laboratory <0.2ns (the difference likely caused by FE-electronics).
From 3 years of laboratory and field exploration we conclude, that WR is the recommended choice for (sub)nsec clock distribution and trigger time-stamping systems in astroparticle physics projects, like HiSCORE, CTA [8], HAWC(South), AsGARD, ...
In particular, WR allows for trigger-free digital DAQ-architectures – greatly simplifying large scale detector arrays. Also, topological triggering (e.g. close-neighbor/sub-arrays) with low latency is possible..

References

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