Precision Timing and Triggering for distributed Astroparticle Experiments

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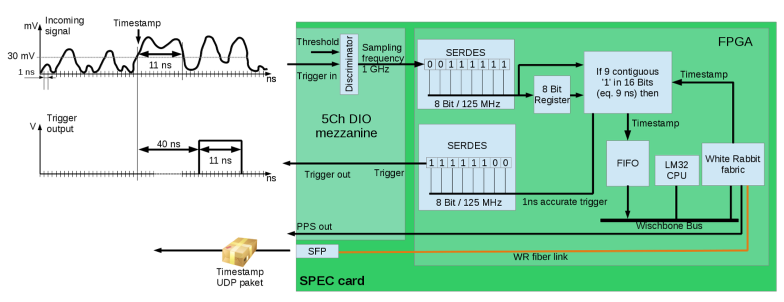
Time-Synchronization to sub-nsec precision between detector subsystems in large scale astroparticle physics experiments can efficiently be provided by White-Rabbit, a new ethernet-based technology for time and frequency transfer. We discuss principles and advantages of White-Rabbit, which allows clock-synchronization and trigger-time stamping to sub-nanosecond precision.
This technology also supports new complex and flexible topological trigger strategies, based on ethernet-routed timestamps.
We describe first experience with the next generation Zynq-based WR-ZEN platform, and present results from our White-Rabbit implementation at the Gamma-Ray facility TAIGA-HiSCORE (Siberia).

WR +Timestamp firmware for Astroparticle Experiments

SPEC board with modified design

- Intended to be used as PCIe card inside a PC
- Modified design timestamps with a resolution of 1ns
- 5Ch DIO has adjustable input thresholds
- In standalone mode limited network/software capabilities due to the softcore lm32 cpu
- Time stamp read out rate at 1kHz

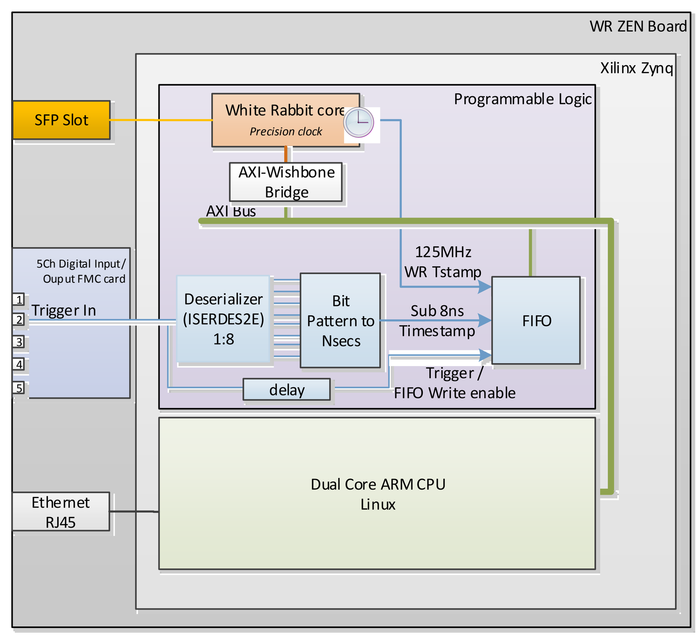


Modified SPEC firmware using the 5 Ch DIO card and the in-FPGA SerDes blocks. Timestamps were written into a FIFO read out by the LM32 CPU.

ZEN board (Zynq based) by 7Sols

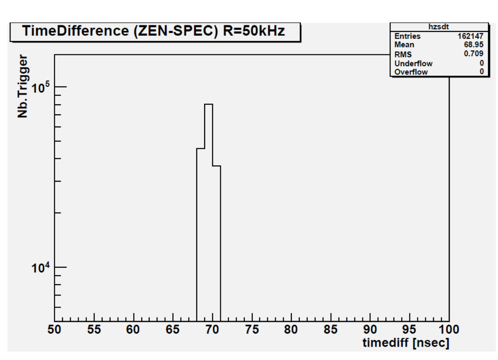
- Intended to be used as standalone device
- White Rabbit Core running in Programmable Logic
- Linux has access to the White Rabbit core register over the AXI bus (e.g. monitoring)
- Linux can read out the time stamp FIFO
- WR link can be used as network interface for sending/receiving network packages

- Timestamp resolution depends on Zynq Speed Grade: 2ns (-1) and 1ns (-3)



Modified ZEN firmware using the 5 Ch DIO card and the in-FPGA SerDes blocks. Timestamps are written into a FIFO read out by the ARM CPU (Linux)

- High timestamp read out rate of >>100 kHz



TimeStamping: ZEN versus SPEC (t_ZEN – t_SPEC), with resolution ZEN(2ns), SPEC(1ns).

With this firmware / hardware

- WR stable 125MHz clock
- WR trigger input and output
- WR timestamps
- With ZEN local distributed trigger decisions possible, or:
- Global array trigger decision over WR link

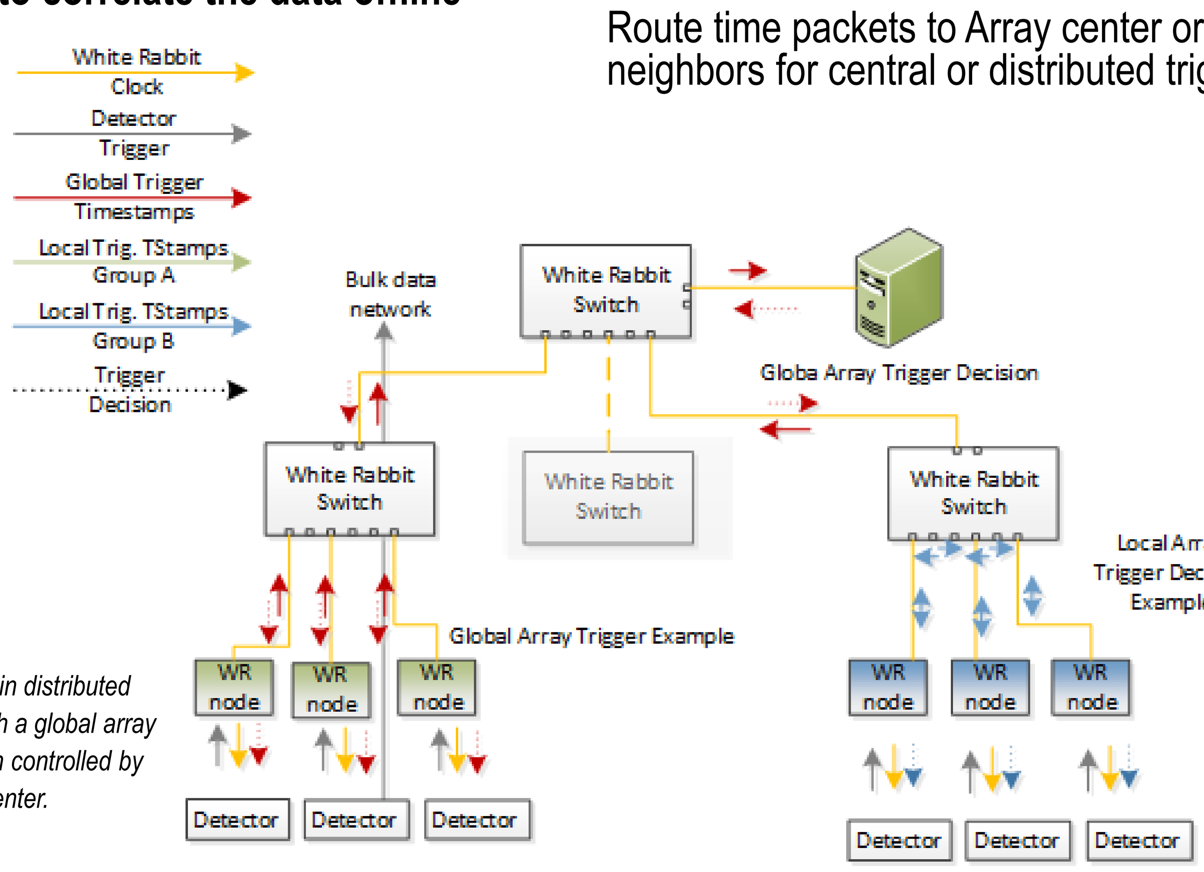
Future work:

- Make use of the SerDes oversampling mode for sub-nsec (< 500ps) timestamp resolution
- Implementing local & distributed triggering

WR-based Array Trigger Concepts

***Standard application*: WR-timestamps Is used to correlate the data offline**

***Optional*: WR-timestamps are routed for fast online triggering and / or filtering. Flexible topologies.**
Route time packets to Array center or to relevant neighbors for central or distributed triggering.

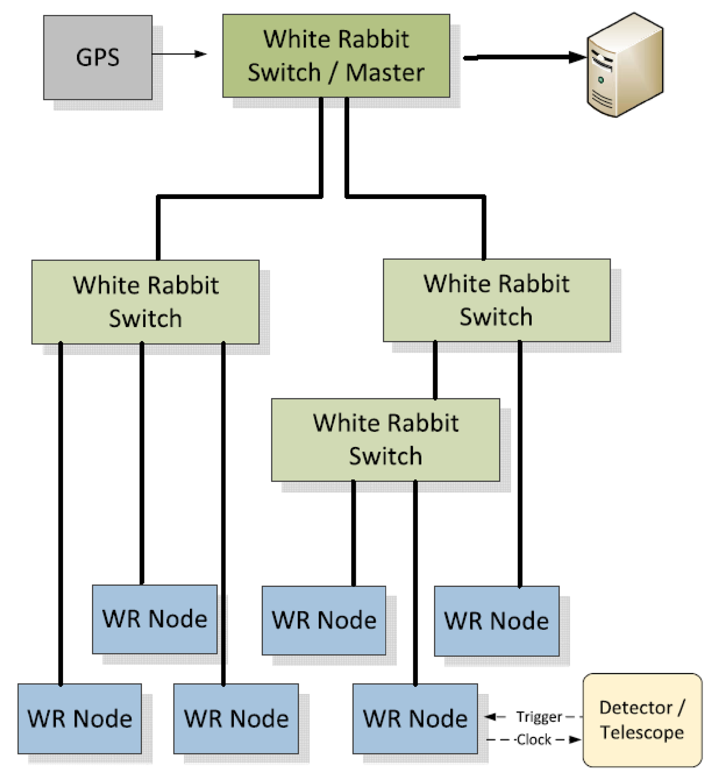


White Rabbit in distributed experiments with a global array trigger decision controlled by the center.

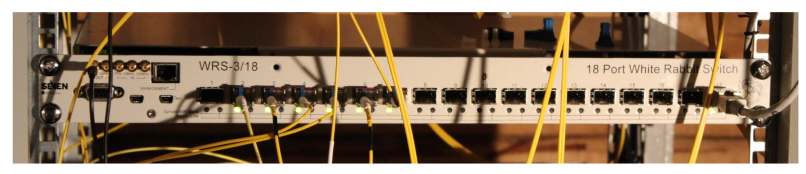
White Rabbit in distributed experiments with a local area trigger decision, based on the neighbor's triggertimes.

White Rabbit [1]

- Fully deterministic Ethernet-based network for data transfer and clock synchronization
- Sub-Nanosecond synchronization accuracy
- Open Source Hard-,Firm- and Software
- Clock-driven architecture; flexible & scaleable
- Standard GbE compatible; commercial support



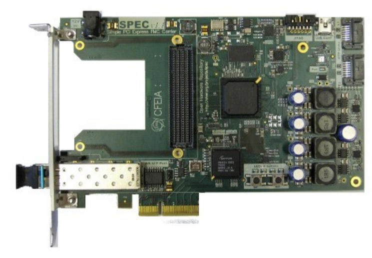
The White Rabbit network: made up of WR-switches (WRS), Grand Master and normal WRS, and WR-nodes. The WR-nodes deliver clock-signals to, and/or extract time-stamp signals from the associated detectors (or telescopes), as symbolized for the lower-right WR-node.



White Rabbit Switch with 18 ports with 1 Uplink Port

ZEN board (Xilinx Zynq based) With 2 SFP modules for WR daisy chaining

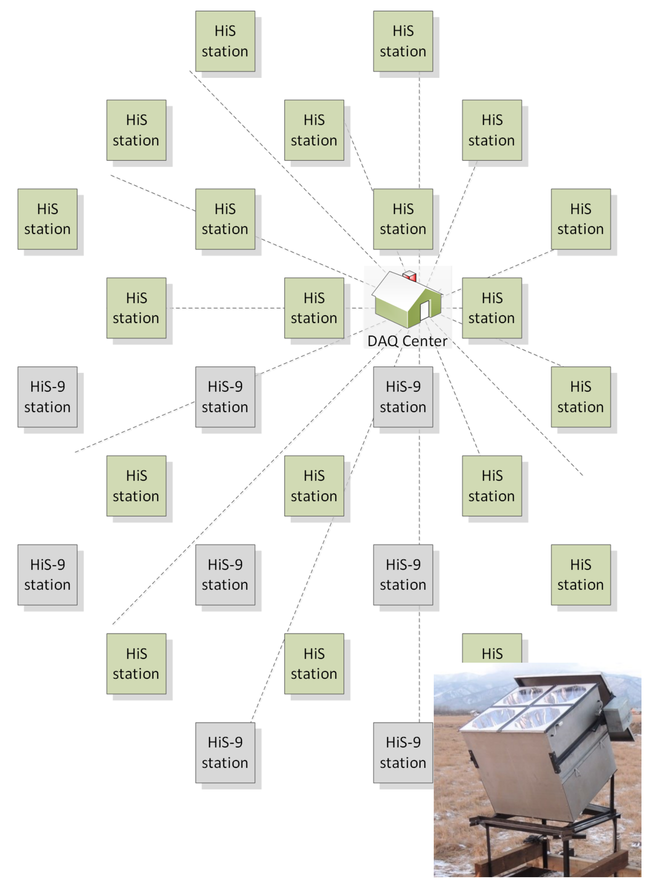
5Ch DIO FMC card with 5 Input or Output channels and adjustable input discriminator

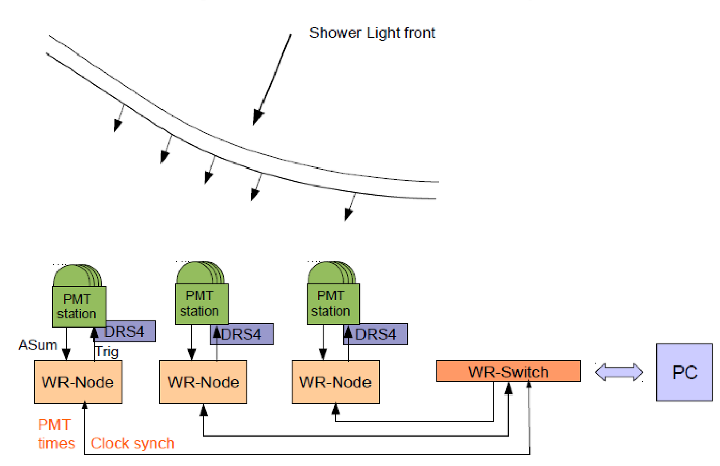


SPEC (Simple PCIe FMC carrier) board with Spartan 6 FPGA, PCIe and FMC slot

Application in HiSCORE [5]

- HiSCORE: a Non-Imaging atmospheric Cherenkov light-front sampling array, see [5]
- Multiple detectors distributed over a large area 1km²-10…km²
- HiSCORE 28 station prototype (0.25km²) installed in Tunka, Siberia
- Each station detects Cherenkov light with 4 PMTs
- For an angular resolution of 0.1 degree timestamping with <1ns accuracy is needed

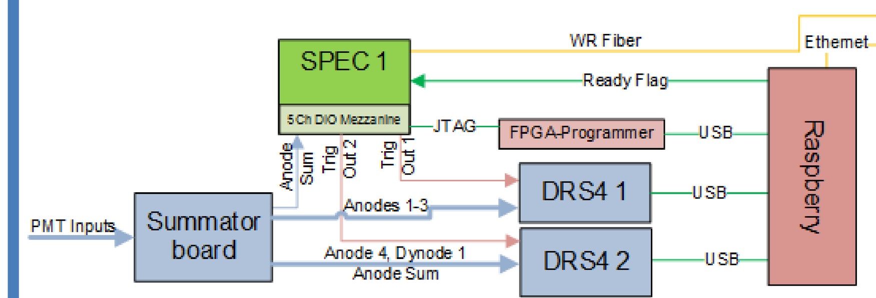




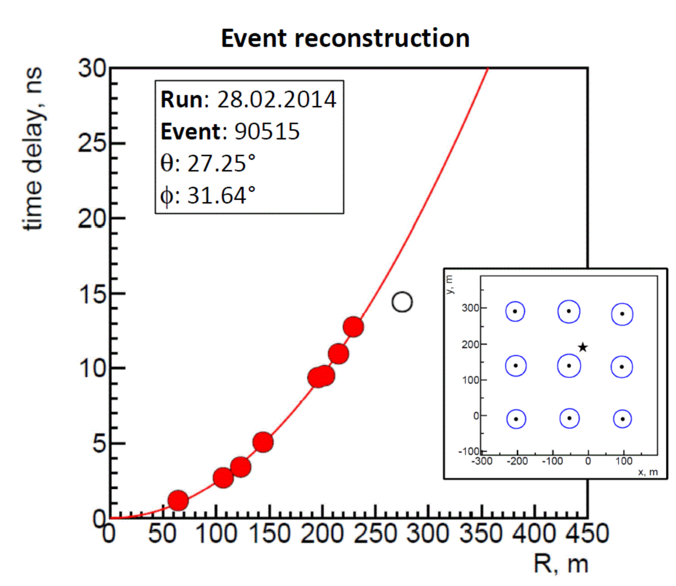
Schematics of a WR-based DAQ setup. Timestamps are online delivered to the center (PC), allowing an array-trigger-free operation.

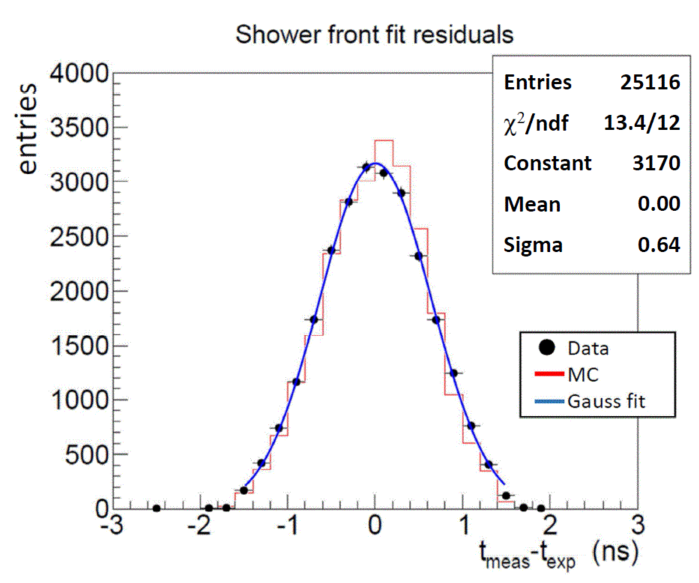
Station readout electronic

- Prototype for a off-the-shelve nsec-DAQ
- PMT pulses recorded by 5 GHz sampling DRS [6] triggered by SPEC board
- Raspberry for DRS4 readout / transfer
- WR Fiber for fast timestamp routing



Station WR readout electronic with a SPEC board [2][3]. Analog input triggers SPEC and readout is started by the Raspberry. Handshake between Raspberry an SPEC preventing new trigger during readout. Used for the HiSCORE-9 setup.





EAS shower reconstruction [4] 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.

Conclusions

- WR perfectly fits the sub-nsec timing requirements of large-scale astroparticle projects (clock distribution, trigger time stamping, …)
- WR has been proven under harsh conditions in TAIGA-HiSCORE for 3 years now
- The Zynq –based ZEN WR-node has much improved performance over the SPEC (analyzing time stamps on the fly in firmware and software, receiving neighboring time stamps)
- Complex , fast array triggering is possible; based on timestamp routing over the WR-network; with either centralized or distributed trigger strategies.

References

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[2] M. Brückner et al., "Time Synchronization with White Rabbit – Experience from Tunka-HiSCORE", ICRC2015, Proceedings of the 34th ICRC 2015, The Hague, Netherlands, Proceedings of Science PoS (ICRC2015) 1041
[3] M.Brückner and R.Wischnewski, "A White Rabbit setup for sub-nsec synchronization, timestamping and time calibration in large scale astroparticle physics experiments", Proceedings of the 33rd ICRC 2013, Rio de Janeiro, Brazil, Braz.J.Phys. 44 (2014) no.5, p 1146
[4] A. Porelli et al, "Timing calibration and directional reconstruction for Tunka-HiSCORE", ECRS2014, Proceedings of the 24th ECRS 2014, J. Phys. Conf. Ser. 632 (2015) 012041
[5] M.Tluczykont and L.Kuzmichev: talks at this conference, see also DOI: 10.1016/j.astropartphys.2014.03.004
[6] DRS4 evaluation board: Stefan Ritt, Paul Scherrer Institut, http://www.psi.ch/drs/evaluation-board