Time Synchronization and Array Trigger in CTA with WhiteRabbit : Ready to go ...

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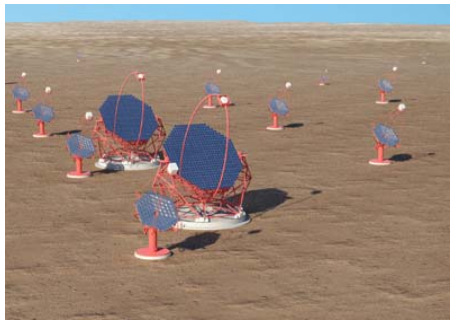
CTA-Collaboration Meeting,
Rome / Italy
23.10.2012



HELMHOLTZ ASSOCIATION

DESY

Outline

- Array Time Synchronization for large distributed arrays
  - A generic job: for modern astroparticle experiments
  - Going for a *standardized system*
- WhiteRabbit for Time Synchronization
  - Synchronization & TimeStamping – WRabbit features & architecture
  - WRabbit is HiSCORE's top candidate
- WhiteRAbbit at DESY: Tests and Installation
  - Started January-2012: "Node ←→ Node" @ field
  - August-2012: "Switch ←→ Multi-Node"
  - 23rdOctober-2012: → Rabbits are running in Siberia .
- Summary
  - WhiteRabbit – Clock distribution: ready to go.
  - Trigger-time stamping @nsec - ready (in the DESY-implementation)

Array Time Synchronization : The Task

- Time Synchronization of large distributed arrays
  - Experiments like HiSCORE (10km2), CTA (few km2), KM3Net, AUGERnext, LHAASO
  - Detectors (Camers, Stations) generate a “local trigger signal” , which needs to be time-stamped

- Two Tasks:

  (1) **Build a time distribution system**

  Synchronize clocks in all detector units to a common central clock with nsec precision;

  Focus: relative timing between detector units must be correct at any moment (not the absolute time)

  (2) **Verify the time distribution system**

  Long-term monitor / control in-situ, for at least a subset of the installed array.

  Verification by an *independent* system is as important as the synchronization;
  and a comparable in technical challenge

- White Rabbit
  - WR-Specifications: An excellent candidate
  - In reality: a system still under development - so needs a detailed verification.

White Rabbit (1)

White Rabbit – a new CERN-based extension to Ethernet / PTP for :

- Synchronous mode (clock synchronization)
- Deterministic routing (package latency guaranteed)

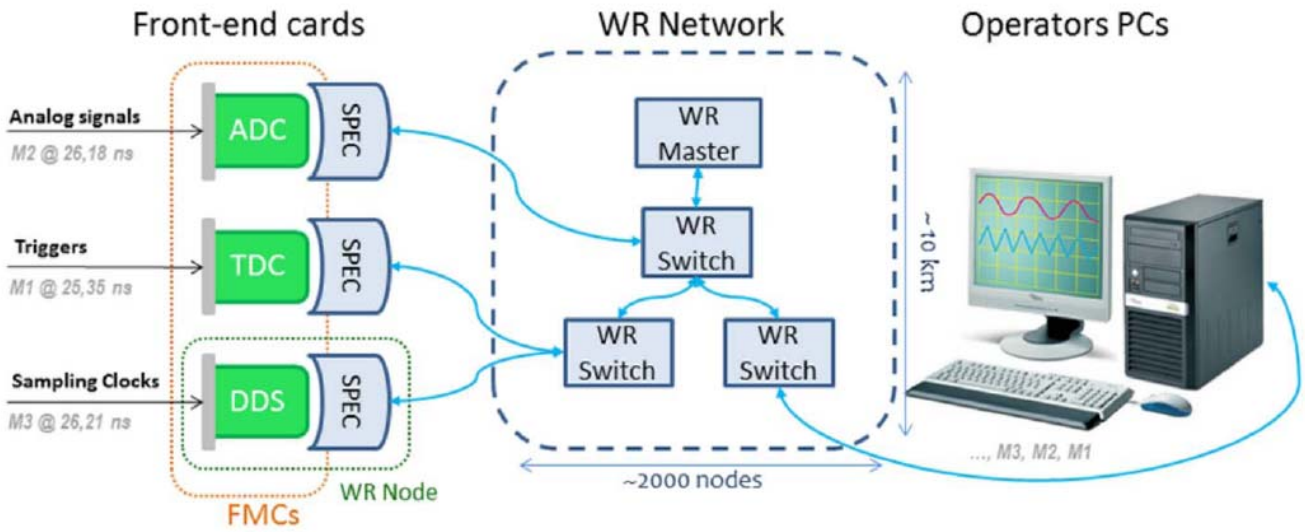
Performance :

- ~1 ns precision, 20 ps jitter
- 10 km fiber links
- Up to 2000 nodes

Important :

- Development for CERN & GSI accelerator complex; much external interest
- Open Hardware & SW Project w/ peer review (ie. open for extensions)
- Hardware is commercially available
- Standardization planned (IEEE…)
- A guaranteed large user community: it will be a well debugged system … !!

White Rabbit (2)



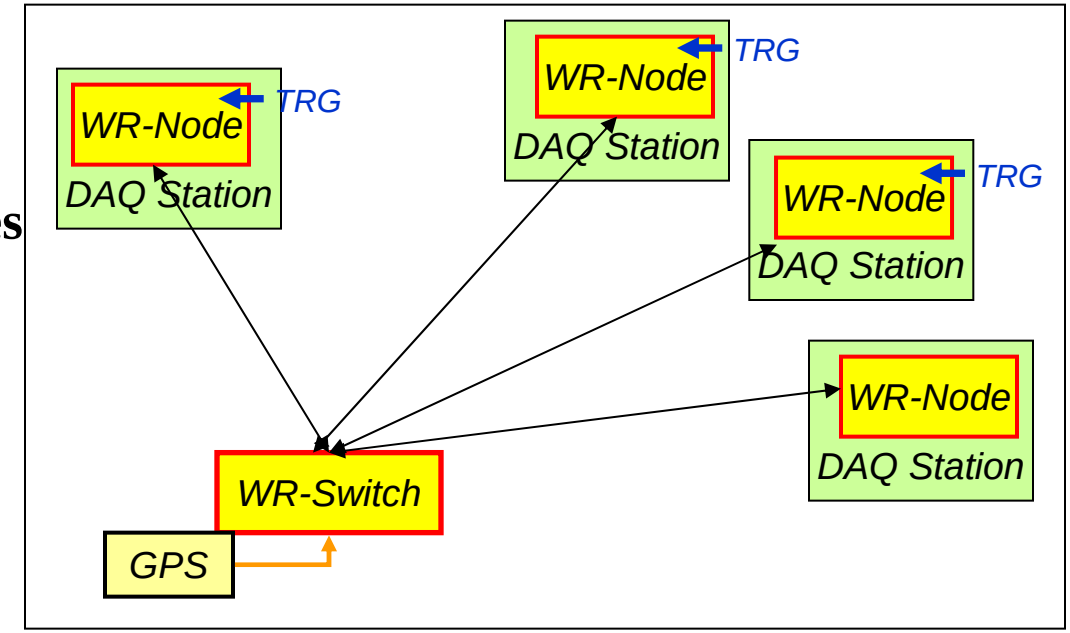
- **For concept + details, see eg:**
  Cern-WR-site http://www.ohwr.org/projects/white-rabbit/wiki ;
  (also http://znwiki3.ifh.de/TUNKA/)

Basic Layout of a WhiteRabbit based timing DAQ

White Rabbit DAQ architecture:

(1) WR-network
= WRSwitches + GPS/RbCl
to distribute the clock to Nodes

(2) WR-Nodes ('endpoints')
for time-stamping, …



Components

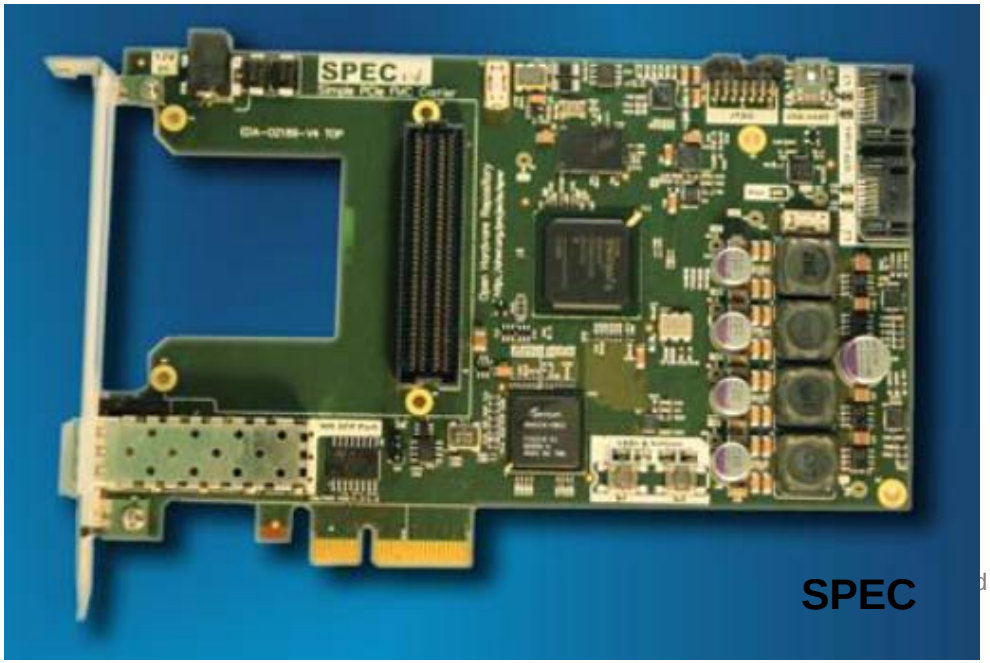
- **WhiteRabbit Switches (WRS)**
- **White-Rabbit Nodes**
  eg. SPEC (*S*imple *P*CI*e* FMC *C*arrier)
  (or build your own board: OWHR)

since July/2012

since 2011

The WR Node : SPEC Card

- **SPEC ("Simple PCIe FMC Carrier") is the WR node currently available.**
- **For tests, it can also be configured as WR-Master (used for April/2012 tests).**
- **It carries the mezzanine-card for your DAQ:**
  available/planned
  - **Digital InpOutFMC / FMC DEL / FMC FADC(100MHz) / TDC;**
  - **eg. possible: design a DRS4-based mezzanine for HiSCORE/CTA**



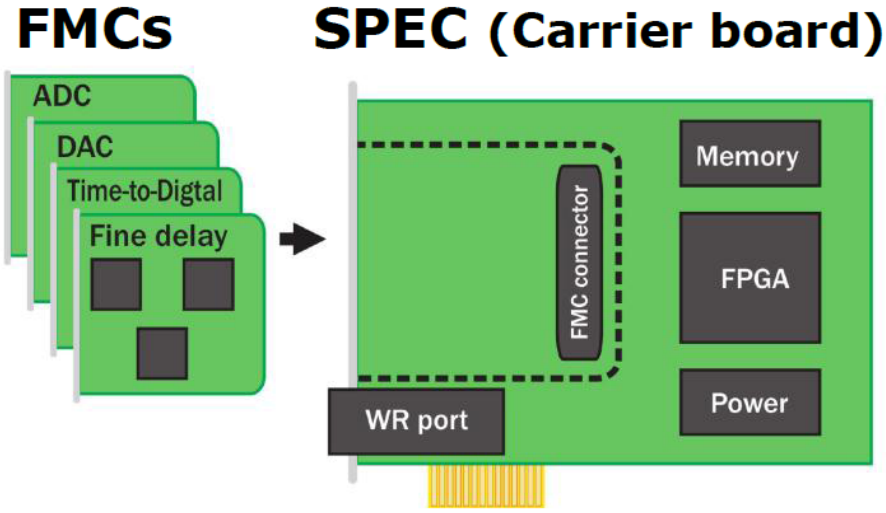
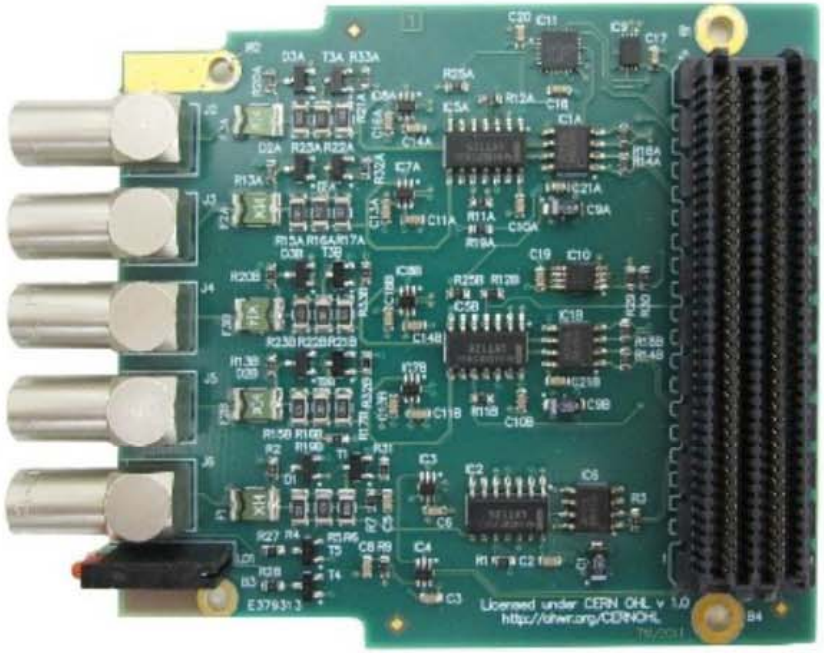


Illustration of the connection of SPEC with FMCs

FMC-DIO-5CHTTLA FMC 5-CHANNEL DIGITAL I/O MODULE

The *fmc-dio-5chttla* 5-channel digital I/O module is a simple board for digital I/O on LEMO connectors.
It has been designed for testing White Rabbit functionality as part of the SPEC Demonstration Package for White Rabbit (**manual**), and it can be used for other applications too.



FUNCTIONAL SPECIFICATIONS

- 5 input/output ports (Lemo 00 connectors)
- Output levels: LVTTL, capable of driving +3.3 V over a 50-Ohm load. At power-up the outputs should be in Hi-Z state
- Input levels: any logic standard from Vih = 1 V to Vih = 5 V (programmable threshold)
- Output Rise/fall times: max. 2 ns
- Input bandwidth: min. 200 MHz
- Programmable 50-Ohm input termination in each channel
- LVDS I/O on the carrier side
- One of the inputs shall be capable of driving a global clock net in the carrier's FPGA
- Inputs need to be protected against +15V pulses with a pulse width of at least 10us @ 50Hz (with protection diodes if possible)
- Withstands a continuous short-circuit on all the outputs at the same time

Example Layout for HiSCORE clock / trigger (~CTA)

HiSCORE / EA :	20-40 DAQ-Stations	(km2 prototype)
CTA :	50-100 Telescopes	

> *Array center:*

WR-switches (18 x out) - with N=4 → 67 Stations/Telescopes

(+ 1x GPS / GPS-disciplined Rub.Clock)

> *Dedicated SM-fiber* to every Station / Telescope

> *Every Station / Telescope:*

Houses one WR-SPEC time-latching unit : SPEC

> Price: *O(1100Eur) per station*

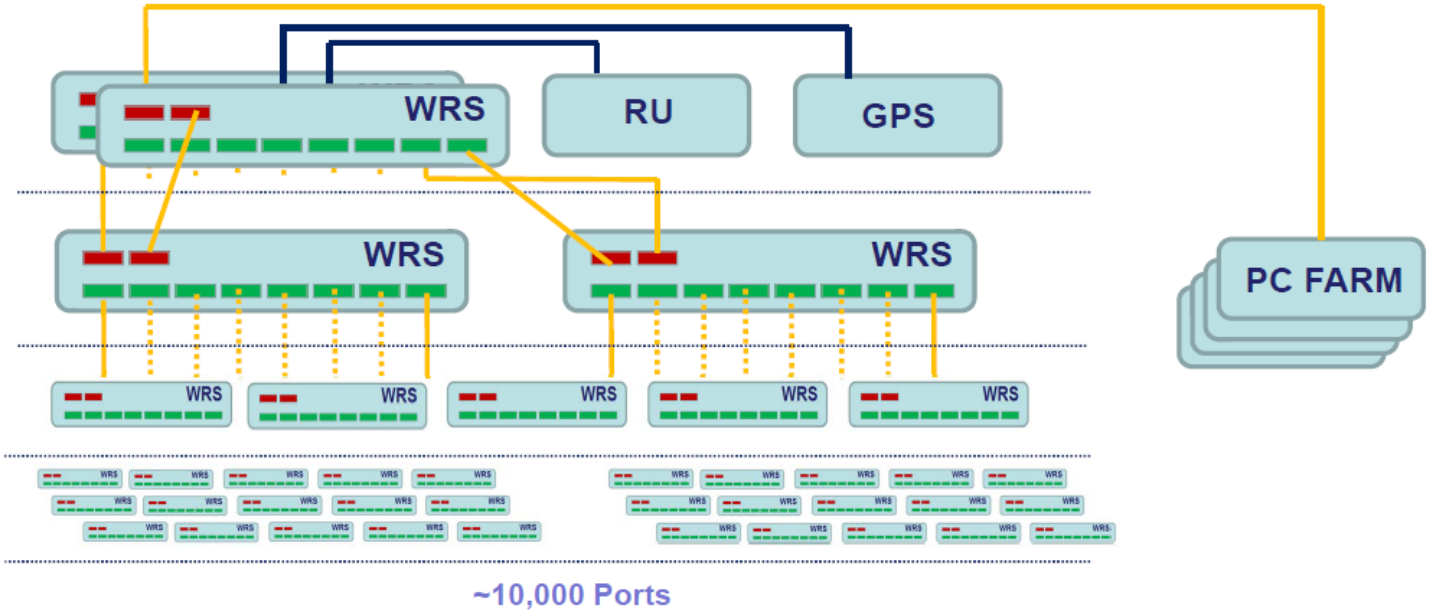
= 900 (SPEC+DIO) + 1/17 x 3500 (WRS) (very conservative)

Example: LHAASO - WhiteRabbit Layout

> Other WR-application proposals:

- **LHAASO : ~10000 nodes to synchronize**

Design study
G.Gong, ICALEPCS, 2011.



WRabbit Tests @ DESY - Overview

> Started January-2012:

Basic functional & field test "Node ←→ Node"

> August-2012:

Full architecture setup "Switch ←→ Multi-Node"

> 23rdOctober-2012:

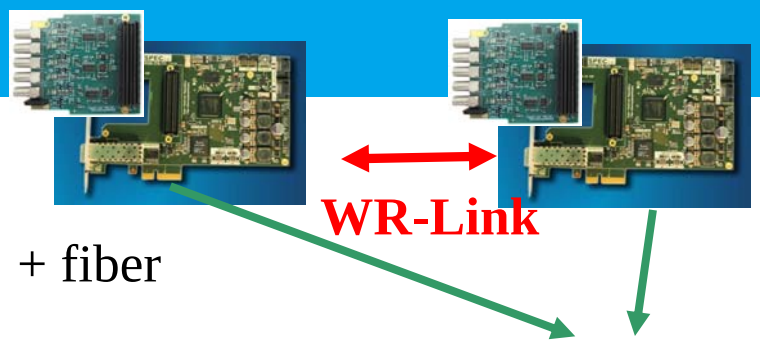
WR@HiSCORE comissioned "Switch + 5 Nodes"

→ ***Rabbits are running in Siberia***

> The DESY-setup: Each Node (ie. the SPEC-PCIe card) contains

(1) the standard WR-Clock
(2) TimeStamping with 125MHz (8ns) resolution /DESY/
(3) Precision TDC 2 ns (future: 1ns) for ns time stamping /DESY/
(4) TriggerTime UDP-transport over WR-link /DESY/
(5) Various Test-signal INPUT/OUTPUT via the FMC-5CH-DIO mezzanine

Laboratory Tests: March 2012

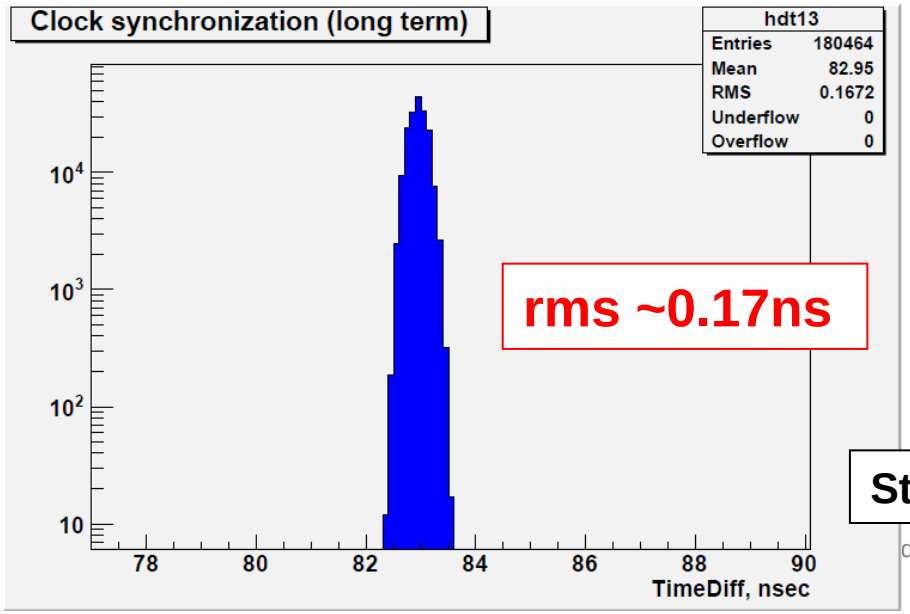


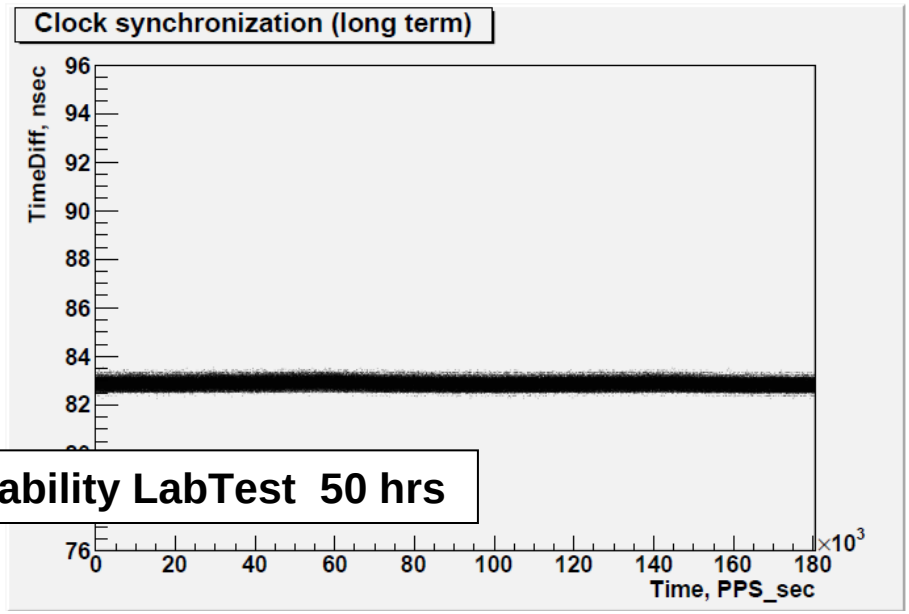
> **Setup:**

- Two WR-SPECs: Master-Slave WR-link + fiber
- Time tests: comparing the master/slave 1-PPS output
- Setup emulates the basic element: WRS+SPEC

> **Result:** **TimeDiff (Master-Slave) rms < 0.2 ns !!**

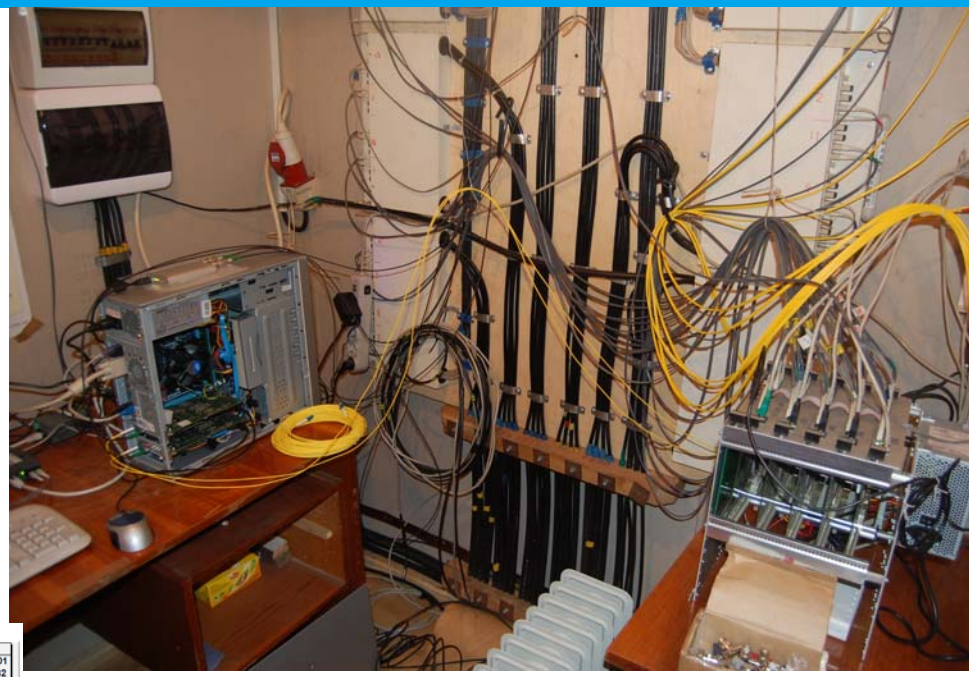
(reaching time-measurement precision)

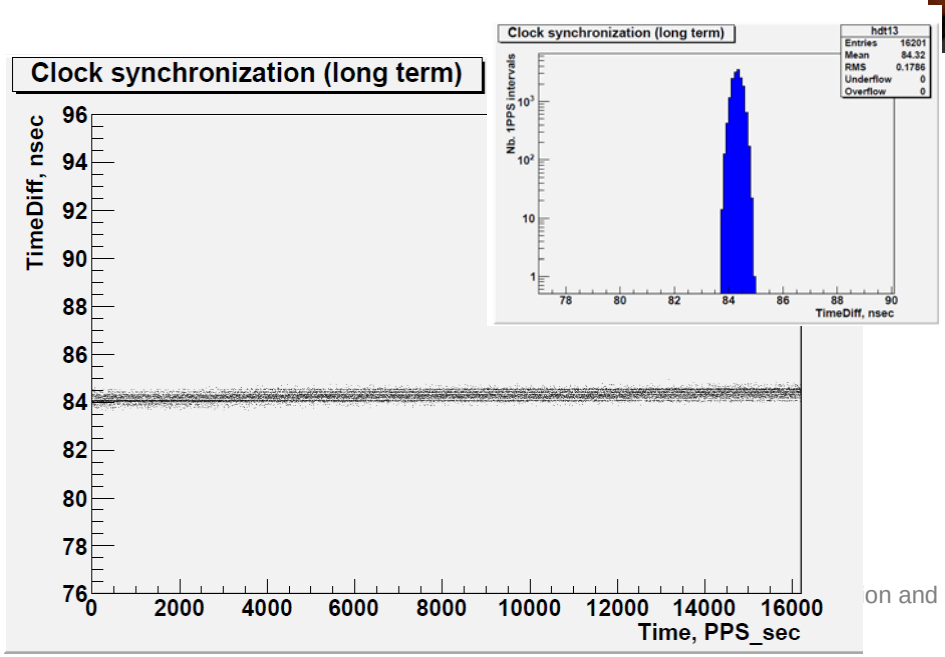


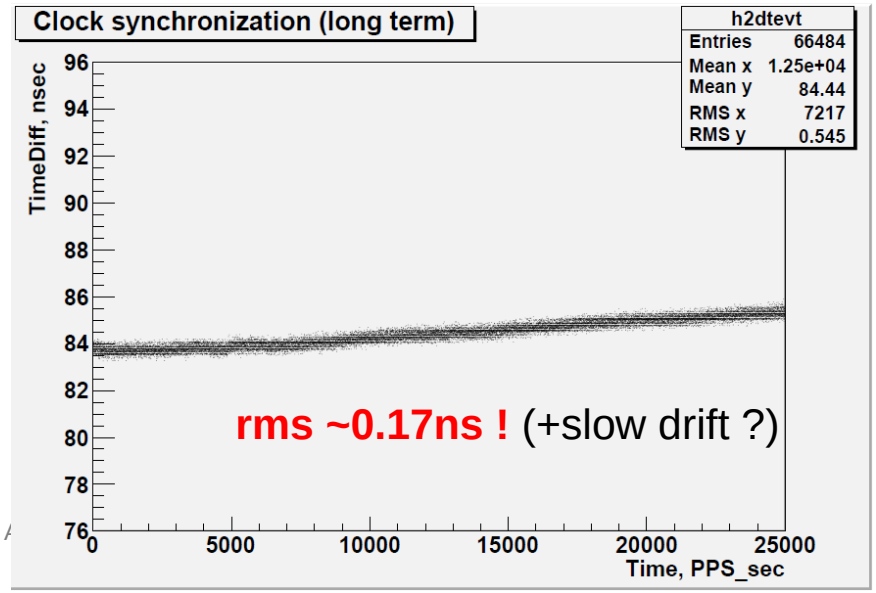


Test at Tunka/HiSCORE : April 2012 2km-Loopback

- Field tests at Tunka/HiSCORE site
  - April 2012: use DESY-Lab-setup
  - use the real 1+1 km Tunka-fibers
- Confirmed Lab-result: rms <0.2 ns !
  - Quick setup; rare occations of slow drifts (artefacts or temperature?)

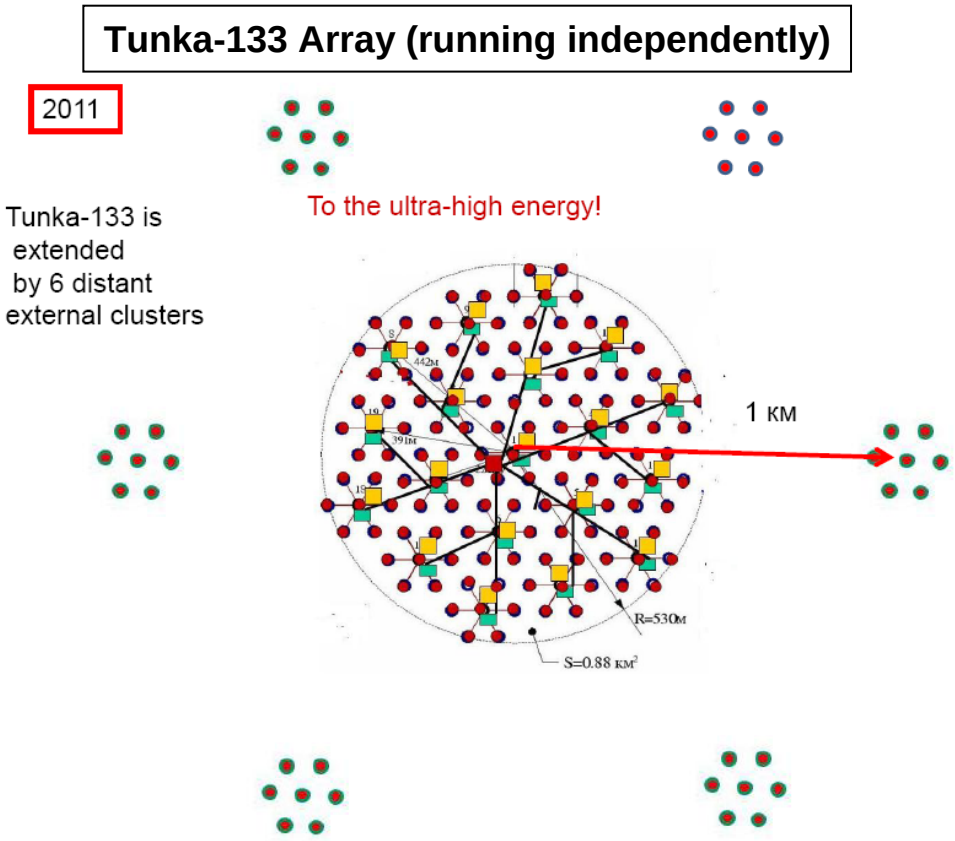


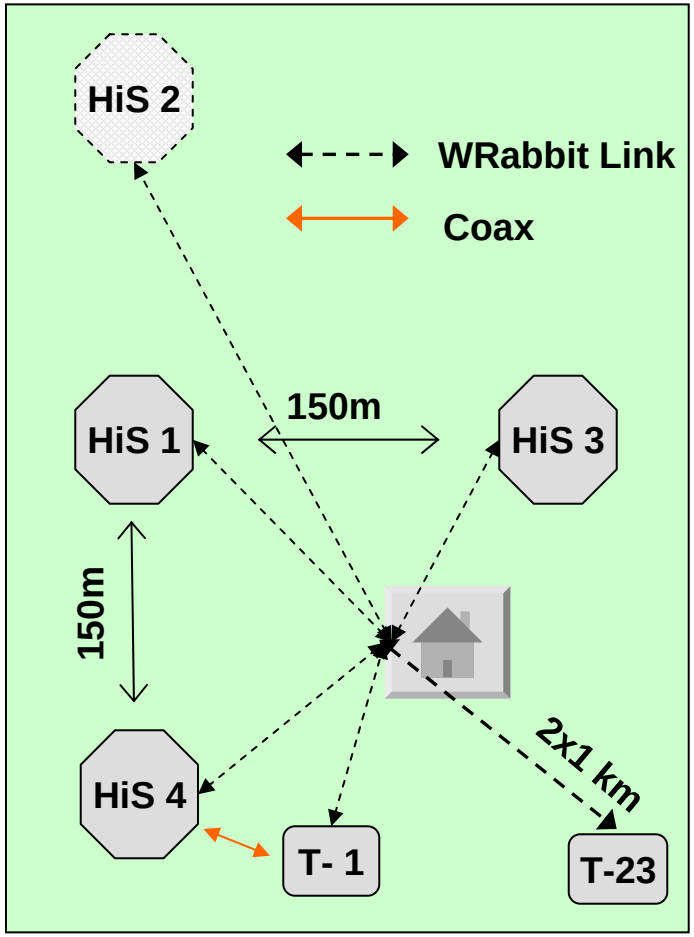




The HiSCORE prototype setup: Oct. 2012

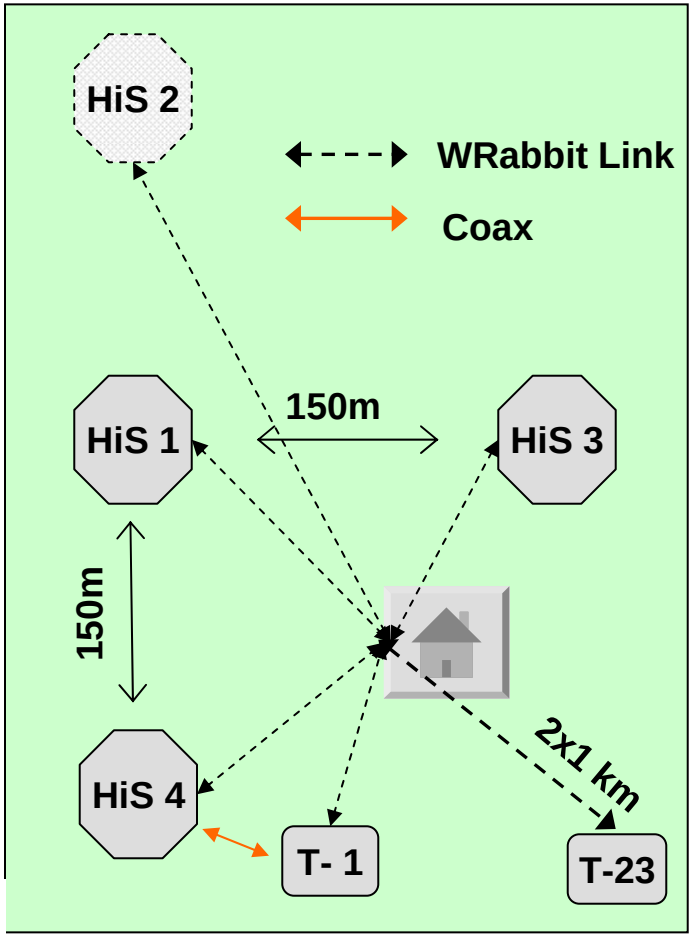
> Three HiSCORE Prototype Stations deployed in Oct.2012

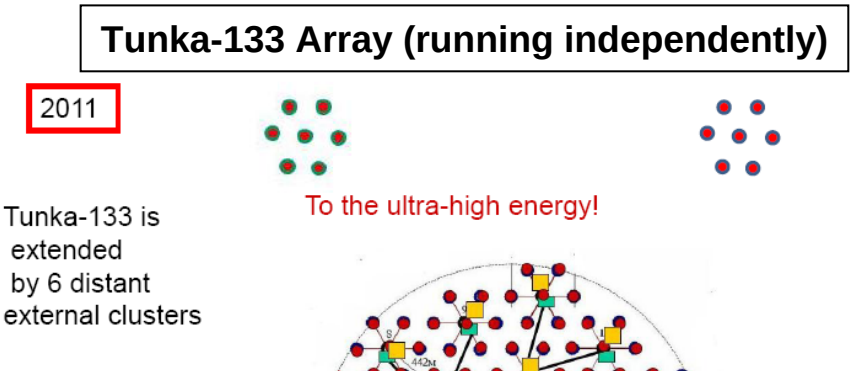




The HiSCORE prototype and WhiteRabbit

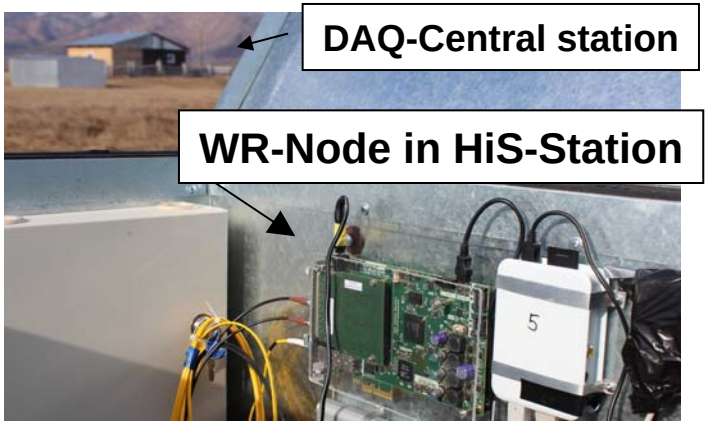
- Three HiSCORE Prototype Stations deployed in Oct.2012
- WhiteRabbit is TriggerLatch of HiSCORE
  - → 1 WR-Switch + 6 WR-Nodes
  - → Various cross calibration tools foreseen
    - Twin – WR-Nodes
    - Coax – WR-Nodes connection
    - Tunka-timing system (10ns)
    - Fiber-Loopback to Laboratory





Test at Tunka/HiSCORE

- A full WhiteRabbit system is running
  - WR-Switch
  - 6 WR-Nodes
- Confirmed Prototype Result: rms <0.2 ns
  - Analysis is in progress, stay tuned

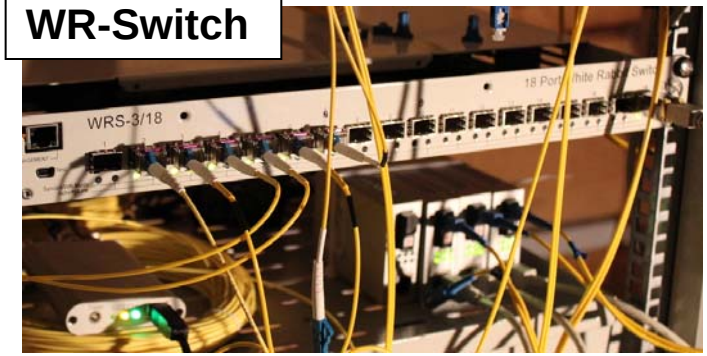


Test at Tunka/HiSCORE

- A full WhiteRabbit system commissioned

  1x WR-Switch & 6x WR-Nodes

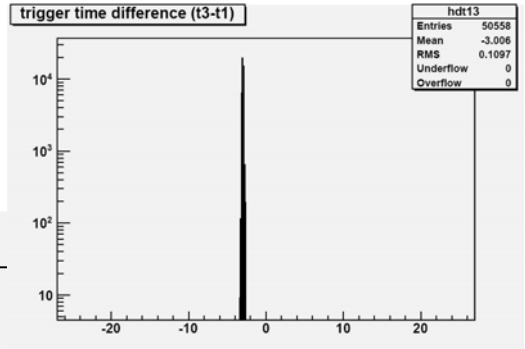
- Confirmed Prototype Result: rms <0.2 ns
  - Analysis is in progress, stay tuned

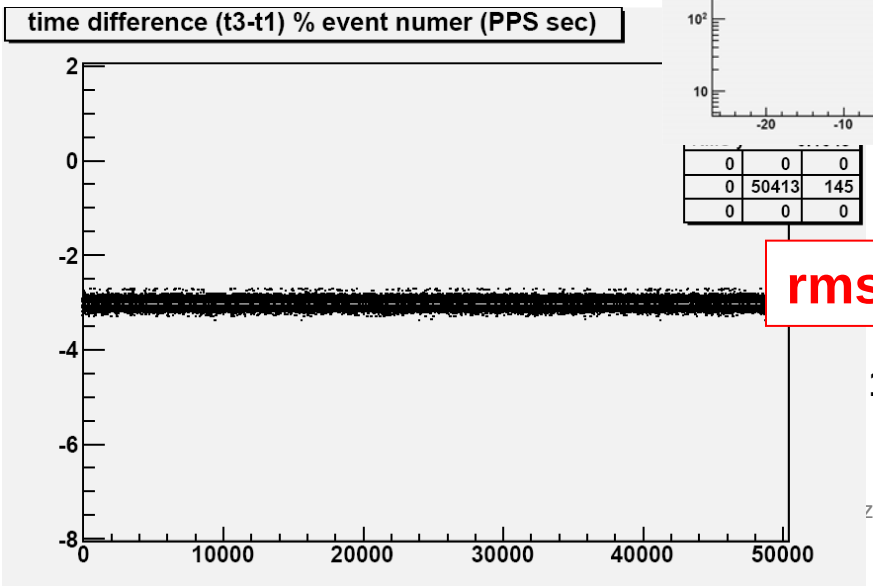


1. Test :

LoopBack Fiber over 2x1km back to Laboratory

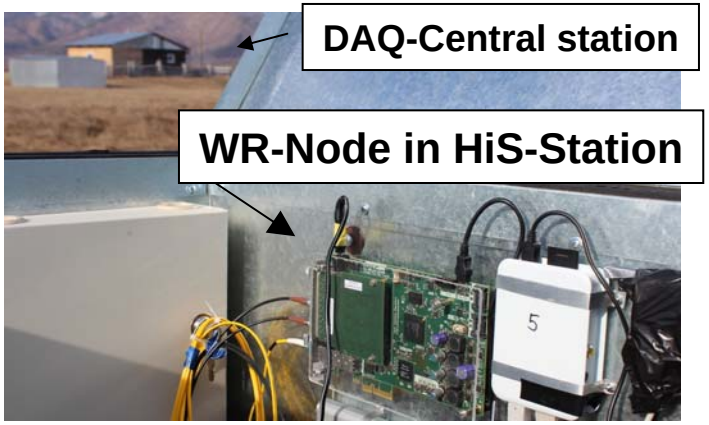
(5GHz DRS4-measurement)





rms <0.2 ns

14hr run



Test at Tunka/HiSCORE

- A full WhiteRabbit system commissioned

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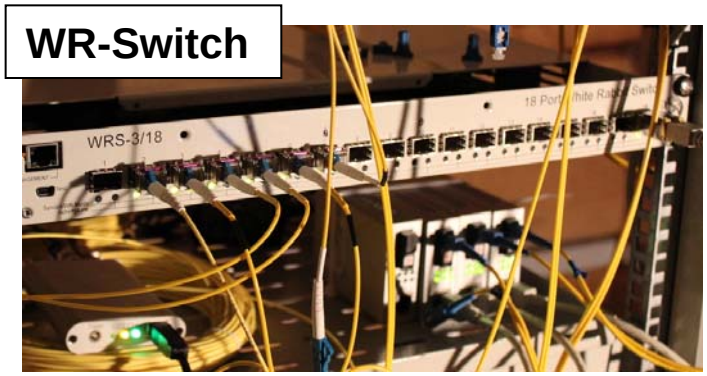
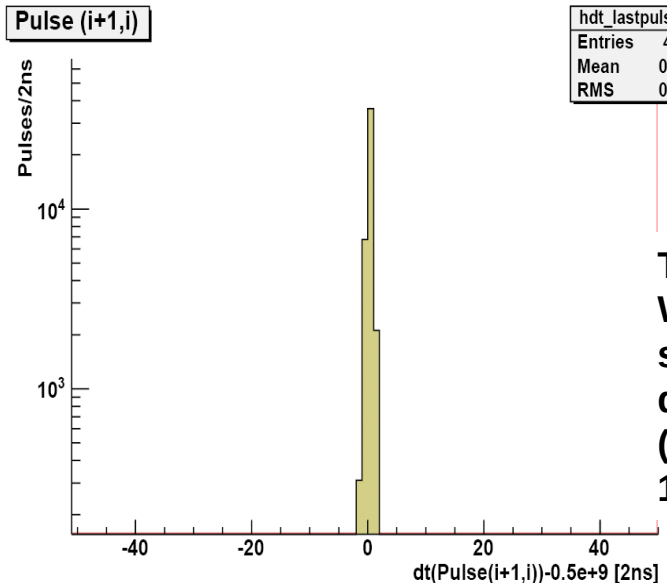


2. Test :

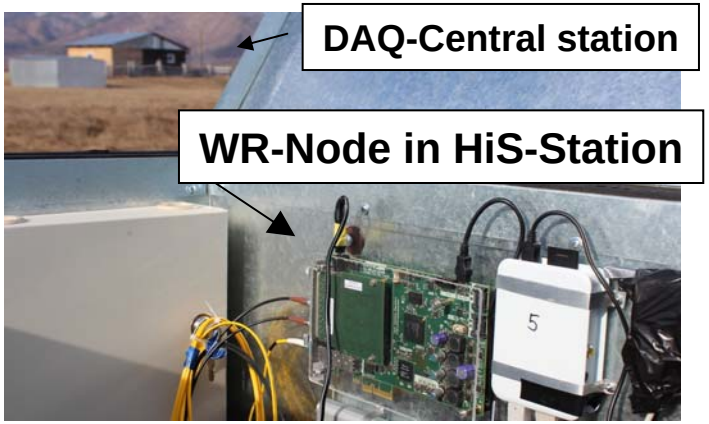
2 WR-Nodes in neighboured stations, connected by 95m CoaxCable (sending 1PPS signals), TimeStamping with SPEC-TDC like for trigger. Excellent time stability !



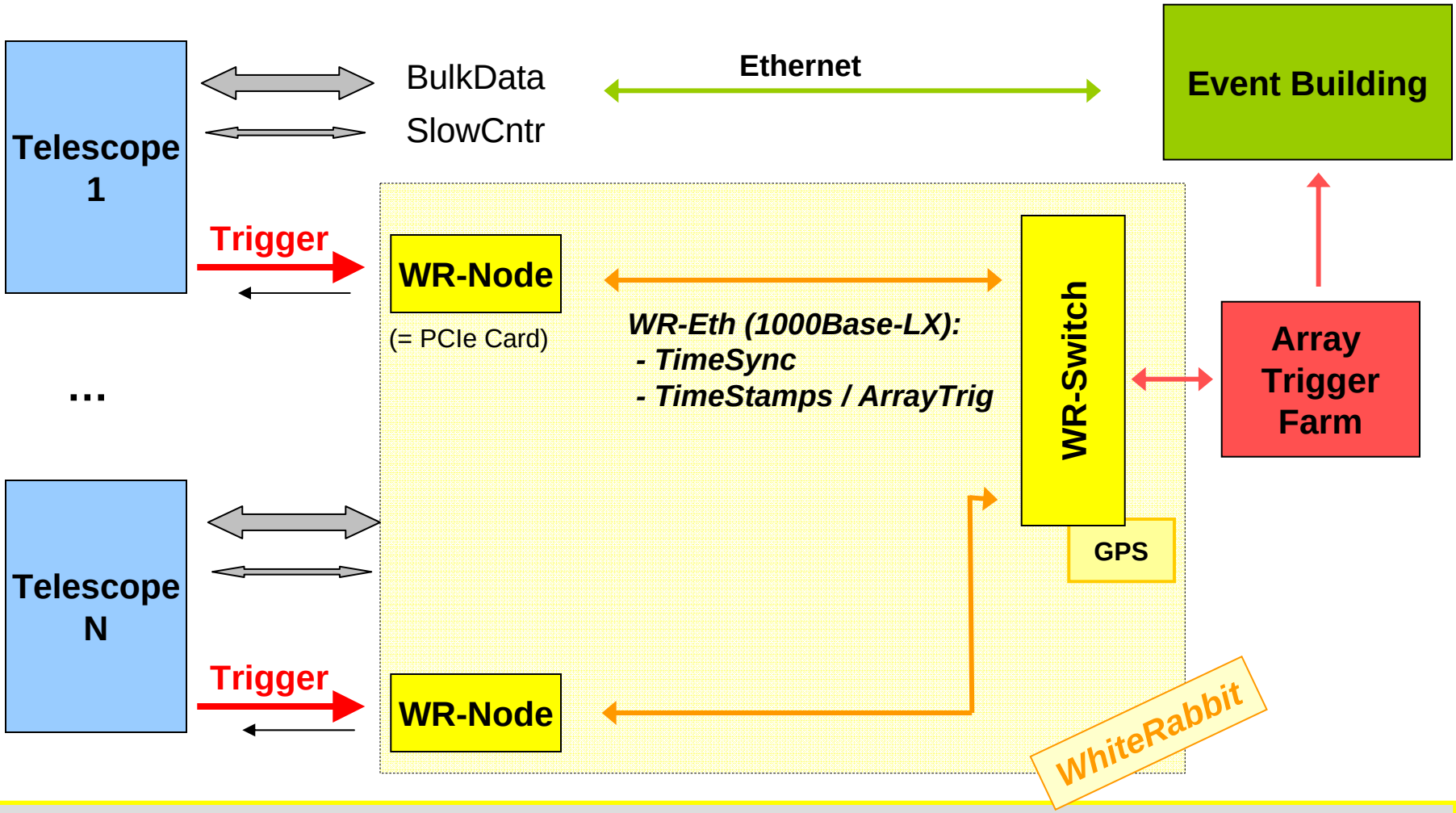
fwhm <2 ns

The time difference of WR-1PPS pulses, measured with an independent WR-station (2ns TDC resolution, 12hr run).

2ns/bin; average == 1.00sec



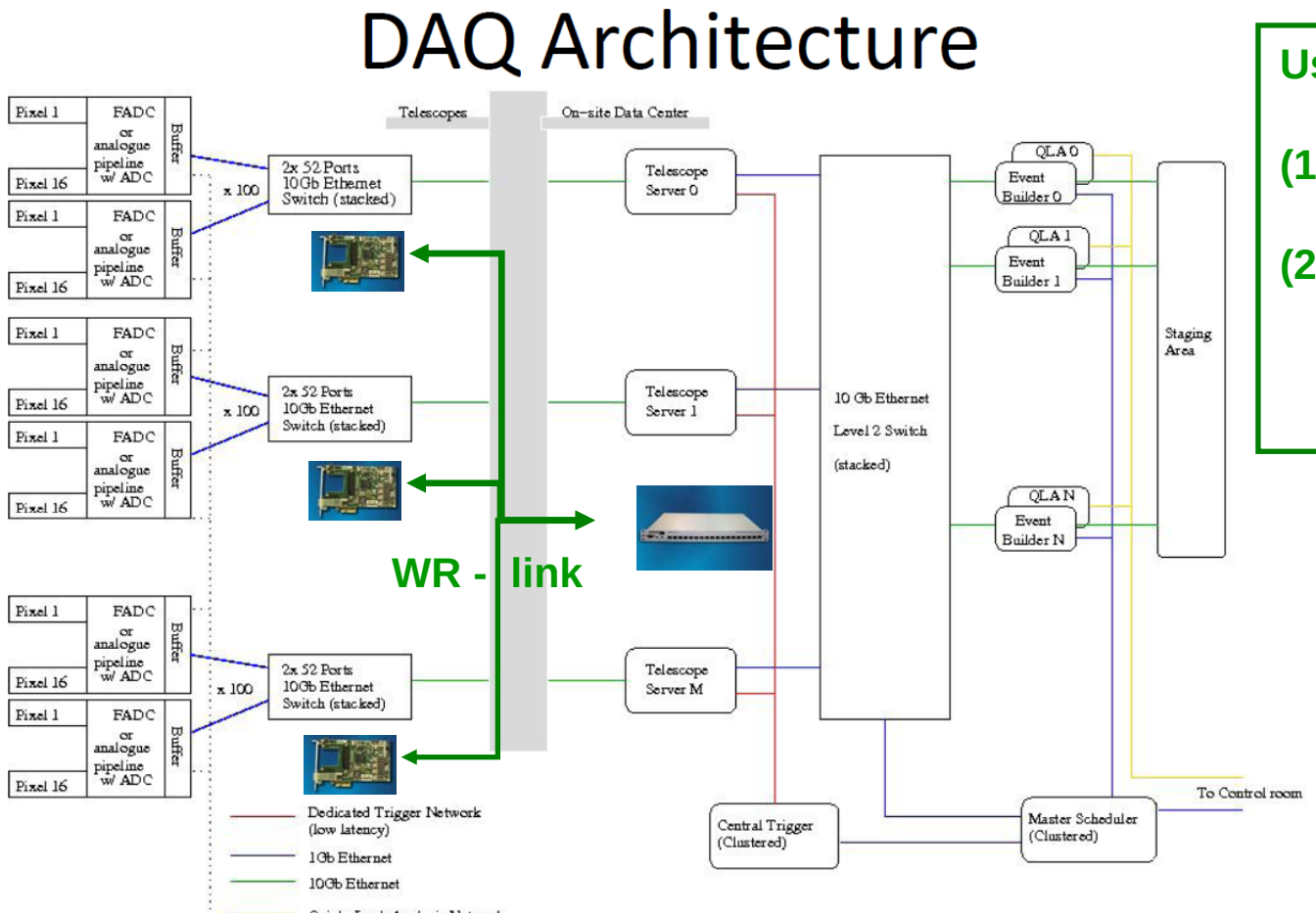
White Rabbit : Layout for Array-Timing, TimeStamping & ArrayTrigger



Only a few components are needed:

- **per telescope : 1 x WhiteRabbit Node (PCIe) + 1 standard fiber (SM;1390/1510nm)**
- **per array : 1…n WhiteRabbit Switches**

CTA : DAQ with White Rabbit - Timing & ArrayTrigger



Use the WR-link for

(1) nsec-timing, and

(2) Array-trigger request/ confirm messages (1Gbs) with guaranteed latency.

Here, we considered just the baseline functionality: Time-stamping of Camera trigger.
There many are more options, including development of CTA-WR boards;
Which could integrate FE/DAQ components with WR-cores.
E.g.: a WR-Mezzanine with DRS4 (or NecTar).

Summary

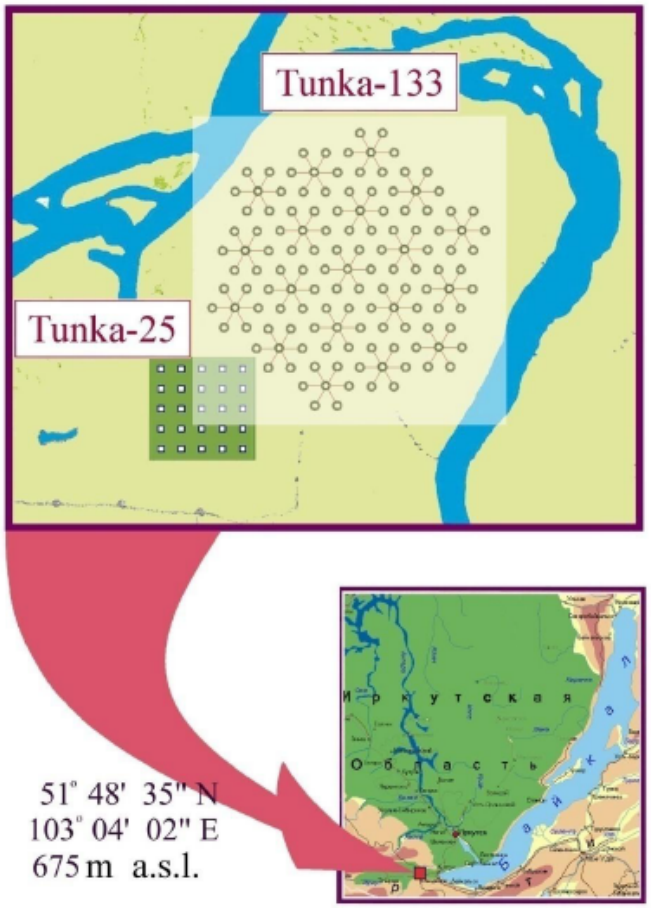
- **White Rabbit: Advantages, that make WR a top candidate for CTA:**
  - **Real standard, commercial support, open source HW & SW**
  - **Reliability, easy maintenance, cost effective, scalability, …**
  - **Big user-community. Eg. HiSCORE, LHAASO, …**
- **Thus, for CTA, White Rabbit is an excellent candidate for**
  - **Time-synchronization: local clocks - specs are fulfilled**
  - **Array trigger : favourable network architecture for time-stamp based coincidences**
- **DESY build and operates a realistic WR Trigger TimeStamping setup**

  Functionality added: 8ns and 1(2) ns latching, WR-data transport, …
- **Commissioned for routine DataTaking at HiSCORE/Tunka**
  - **Clock stability (longterm) < 0.2 ns rms**
- **Need: Independent performance verification in the field (GPS, Radio, MUTIN…)**
- **DESY is committed to HiSCORE WR-DAQ; thinks about a related CTA initiative. ASTRI ?**

> Thanks.

> Additional slides….

The Tunka-133 Cherenkov-EAS Array



Tunka-133 – 1 km^2 "dense" EAS Cherenkov light array

Energy threshold 10^{15} eV

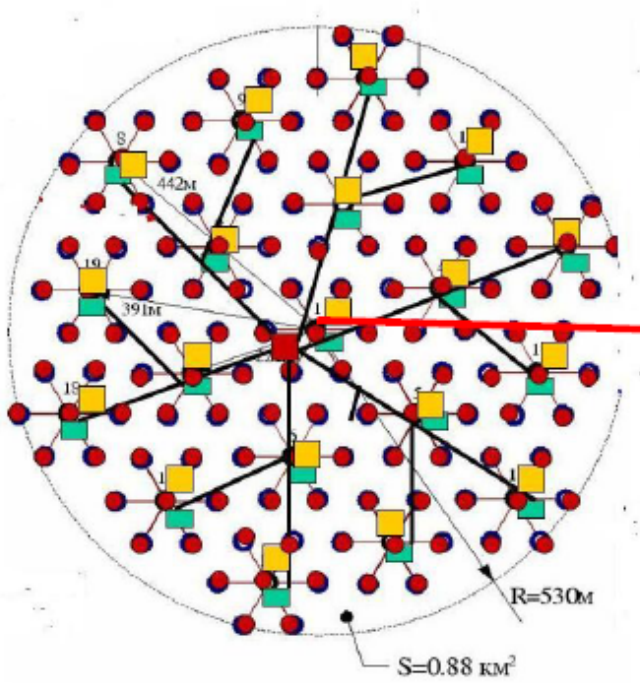
Accuracy: core location ~ 10 m
energy resolution ~ 15%
$\delta X_{max} < 25$ g·cm^{-2}

The Tunka-133 Cherenkov-EAS Array

2011

Tunka-133 is extended by 6 distant external clusters

To the ultra-high energy!



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