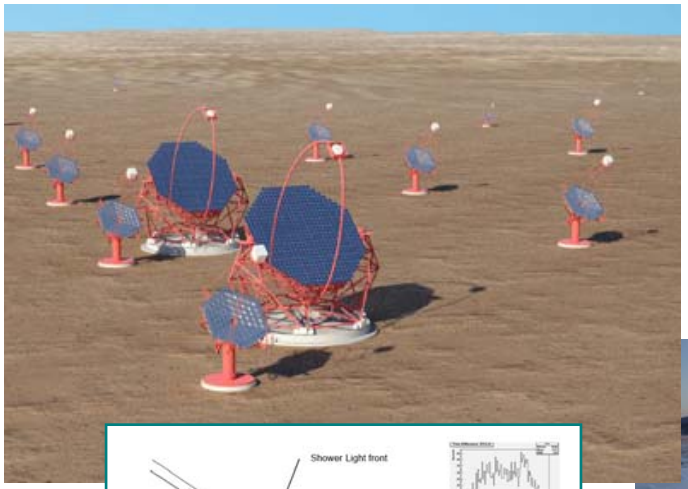
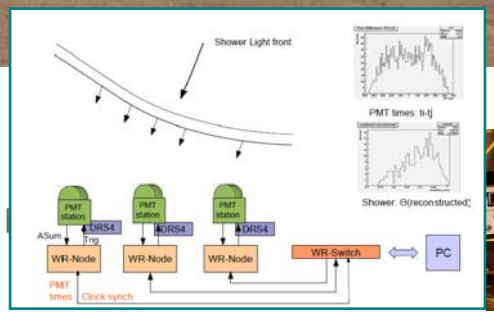
WhiteRabbit for ArrayTrig & Timing

- **First WR-light: Cerenkov shower detection**
- **Digital trigger**
- **Longterm tests**



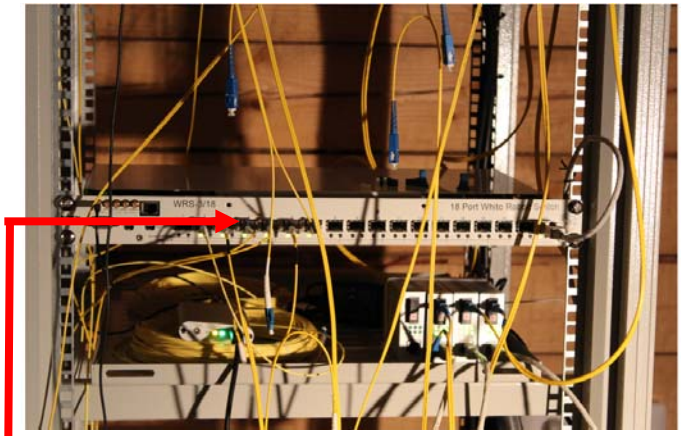


Ralf Wischnewski (DESY)
Martin Brueckner (HumboldtUniv Berlin)

Barcelona, 20130918

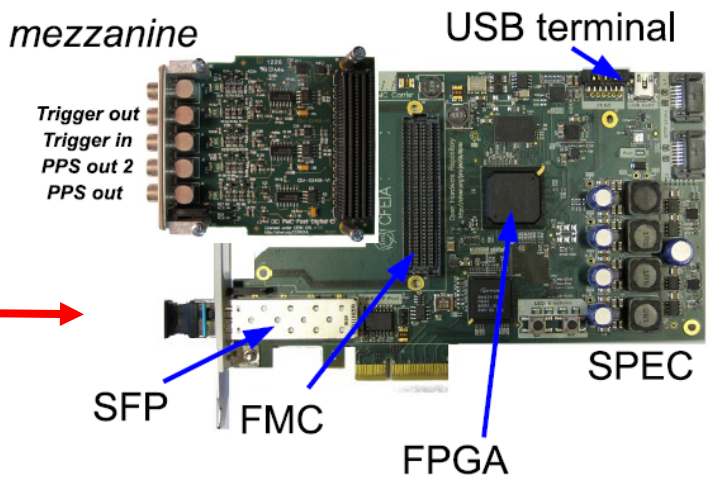
WR : The Basic Elements

WR Master: WR Switch



1Gbit fiber

WR-Node: SPEC card



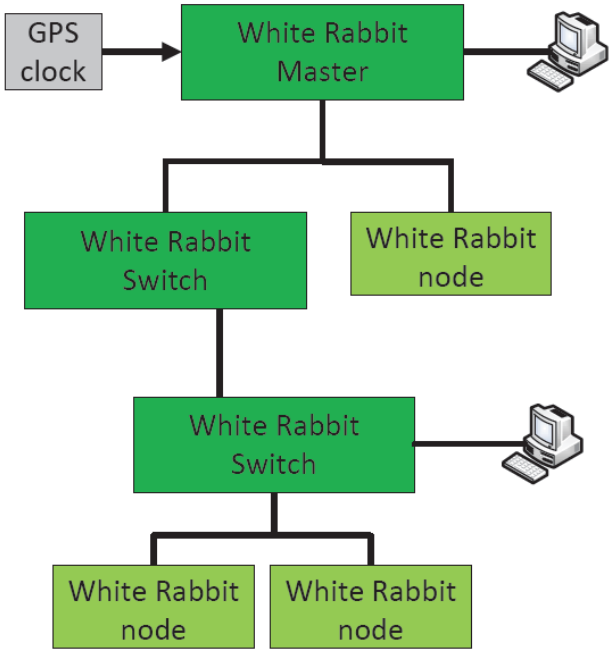
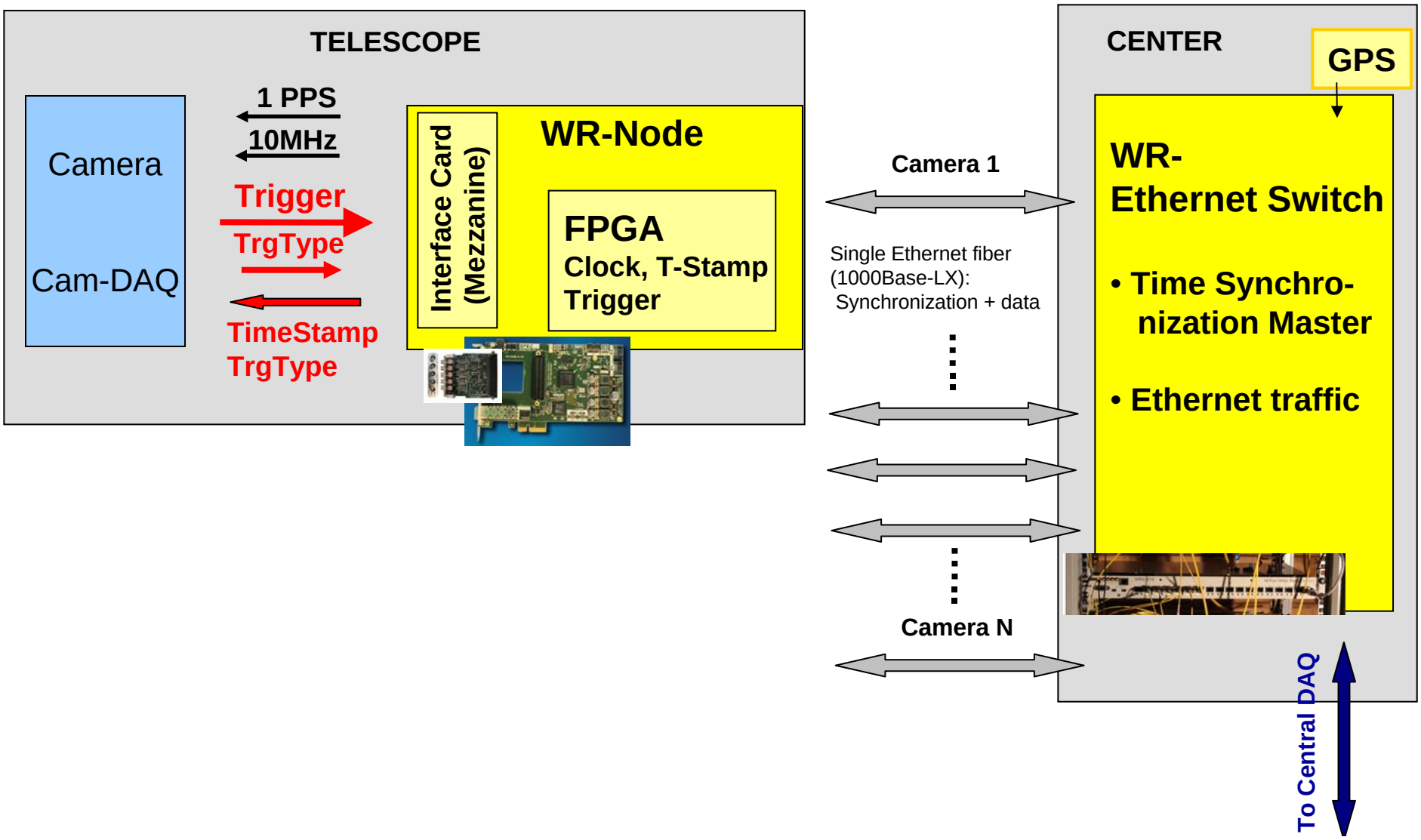


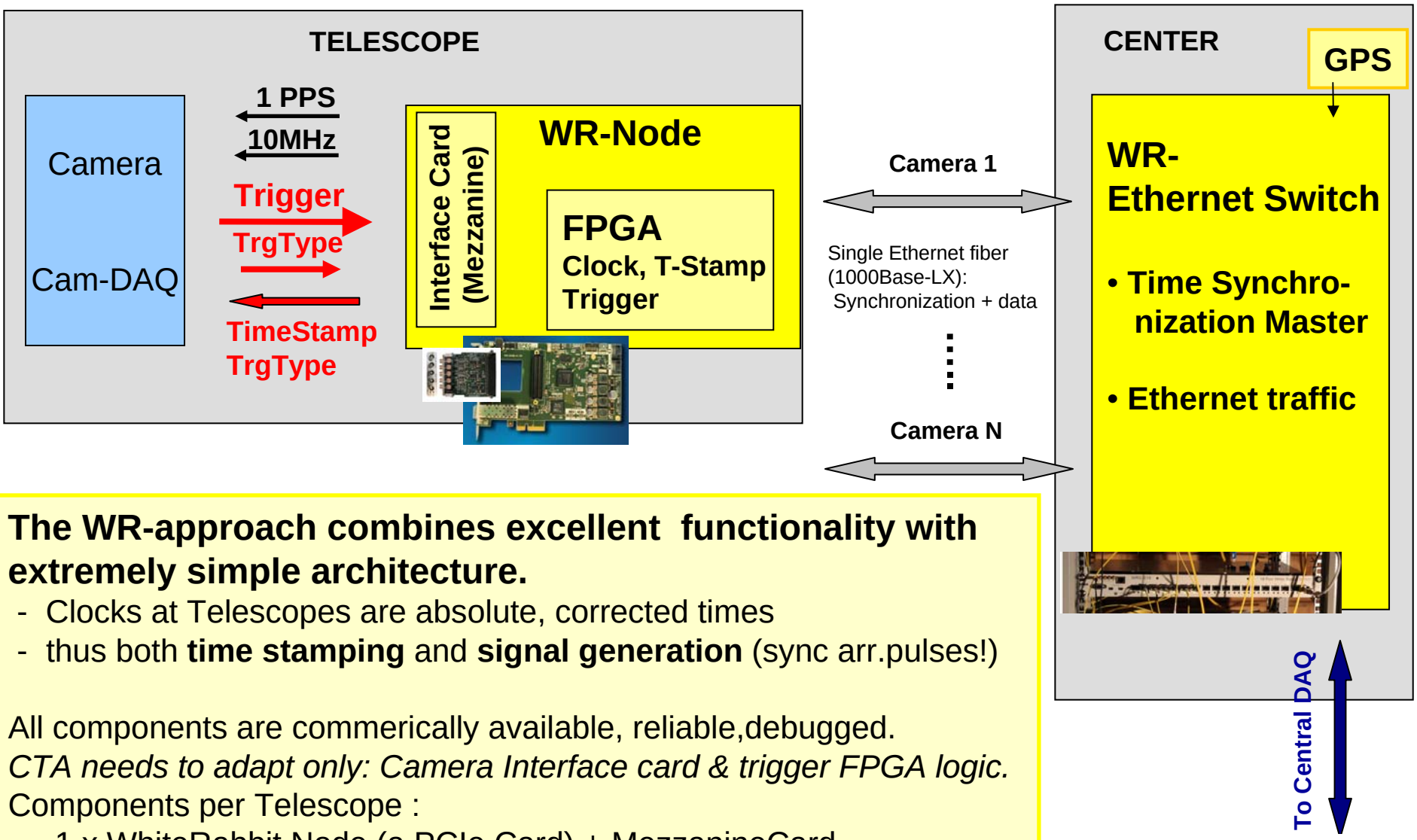
Figure 1: The White Rabbit network

NB: Performs as a “normal Eth-Network” non-WR components.

White Rabbit at CTA: Baseline architecture



White Rabbit at CTA: Baseline architecture



The WR-approach combines excellent functionality with extremely simple architecture.

- Clocks at Telescopes are absolute, corrected times
- thus both **time stamping** and **signal generation** (sync arr.pulses!)

All components are commerically available, reliable,debugged.
CTA needs to adapt only: Camera Interface card & trigger FPGA logic.
Components per Telescope :

- 1 x WhiteRabbit Node (a PCIe Card) + MezzanineCard
- 1 standard fiber (SM;1390/1510nm)

Per Array : 3-4 WhiteRabbit Switches (Nb.of.Telescopes / 18).

White Rabbit (WR) - Executive summary (1)

> Basic Tests, as reported earlier (since spring 2012):

- **Clock Stability** is proven to be excellent in Laboratory + Field-installation: **rms<200ps**
- **TriggerTime stamping** with **1ns precision** is implemented, verified + stable.
- See CTA-meetings @ Amsterdam, Rom, Chicago

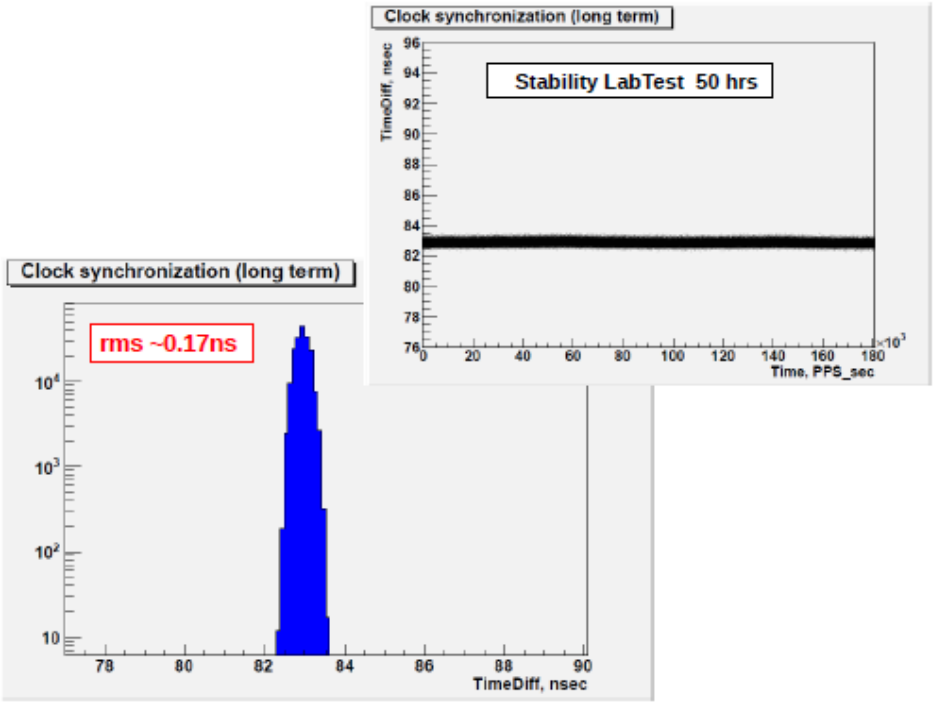


Figure 5: Laboratory-Measurement: Distribution of time difference between PPS clock pulses from SPEC1 and

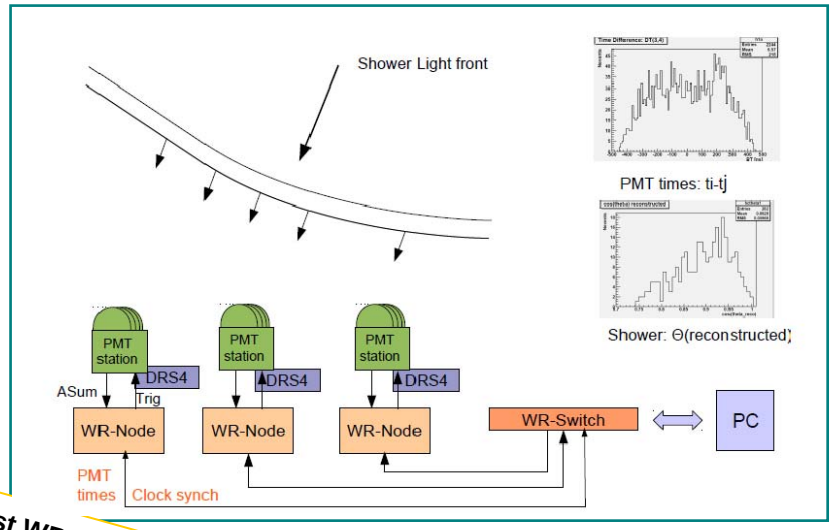
These results were shown first in Oct 2012…

For details please refer to three ICRC-2013 paper (ID1146, ID1153, ID1164)

White Rabbit (WR) - Executive summary (2)

> WhiteRabbit is now also used to trigger on AnalogSum (4x HiSCORE PMs)

- Digital trigger extended to new functionality
- Demonstrates flexibility of the (standard) ”WR user interface”



“First WR Cerenkov light”

HiSCORE prototype installation:
Sketch of the Array-Timing and DAQ (DRS4 boards) system.

The WR-nodes (at each station / telescope) act as digital AnalogSumTrigger and time-stamping units. Based only on the ns-trigger times (upper plot), a preliminary shower direction reconstruction was done (plane wave, lower plot; DRS4-waveforms are used in full analysis).
This demonstrates capability and flexibility of the WR-node cards; that goes far beyond time synchronization.

A glimpse
inside the SPEC :

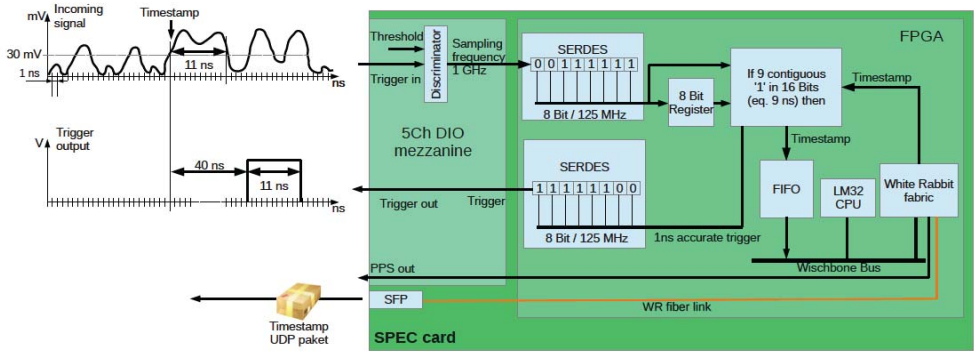
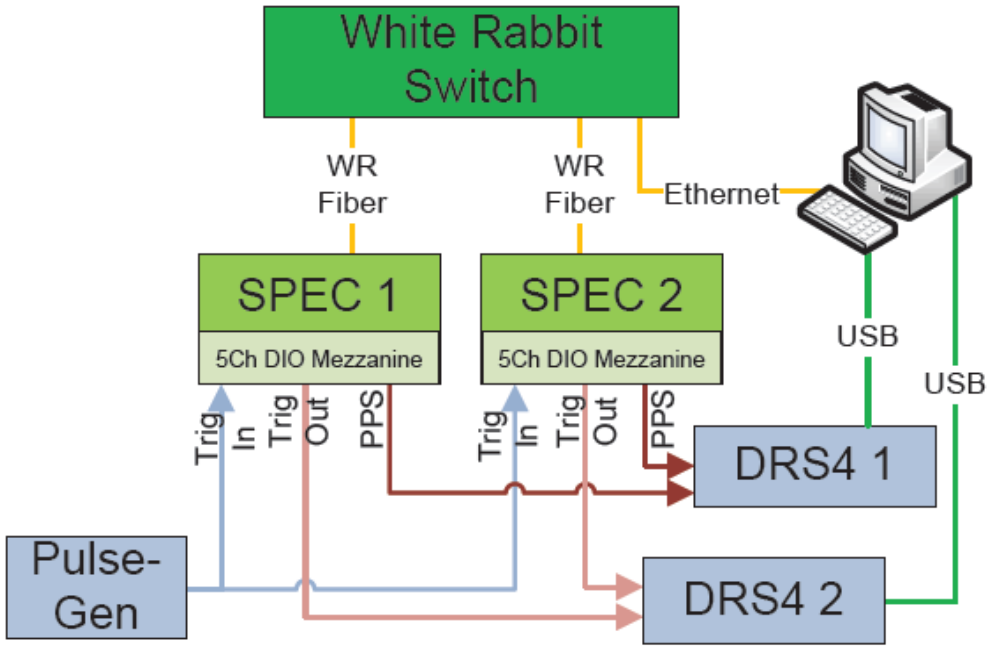


Figure 3: The modified FPGA architecture of the SPEC card for timestamping and evaluating incoming signals. The left side shows an incoming signal and the resulting output trigger signal after a constant delay of 40 ns.

White Rabbit - Executive summary (3)

> Longterm-tests @ DESY-Environmental Chamber

- DESY environmental-chamber (CTA-mirror tests); April/May, 2013: ~10 days of tests
- Temperature -20C … +40C 2-3 days cycles → FiberCable 500m
- 0C … +30C 2-3 days cycles → WR-Node (the camera card)
- No measureable temperature effects observed
  - → Trigger-stamps : +-1ns → rms<0.5ns
  - → Phase of 1 PPS-references : rms < 200ps



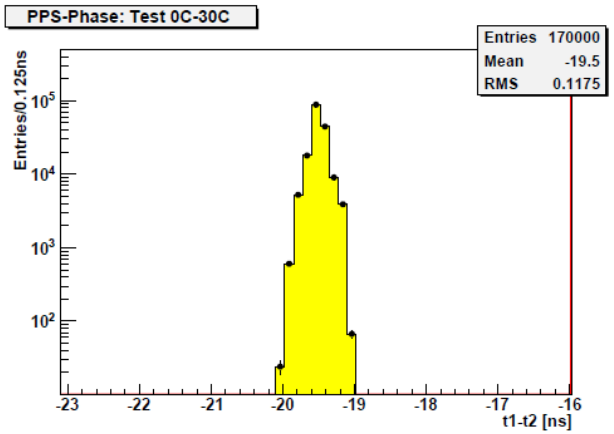
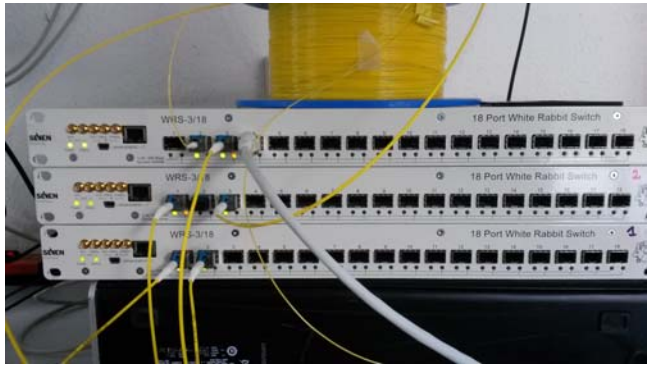


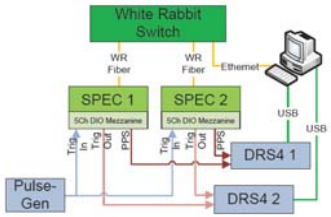
Figure 4: Experimental Setup (baseline configuration). WR fibers are 20 m long to SPEC1 and 520 m to SPEC2. For tests in the environmental chamber, the 500 m WR-fiber and/or the SPEC2 card are located in the DESY-climate chamber.

White Rabbit - Executive summary (4)

- Network structure
- Tests-A: single WR-Switch (max. 17 Telescopes) ➔ OK
- Tests-B: two-level WR's 17x17 = 289 Telescopes



3x WRSwitch + DRS setup adapted



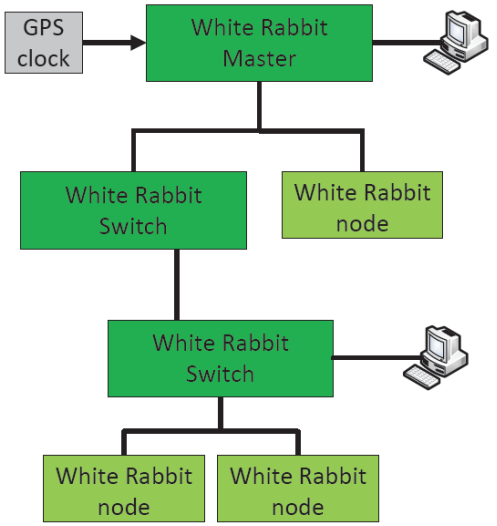
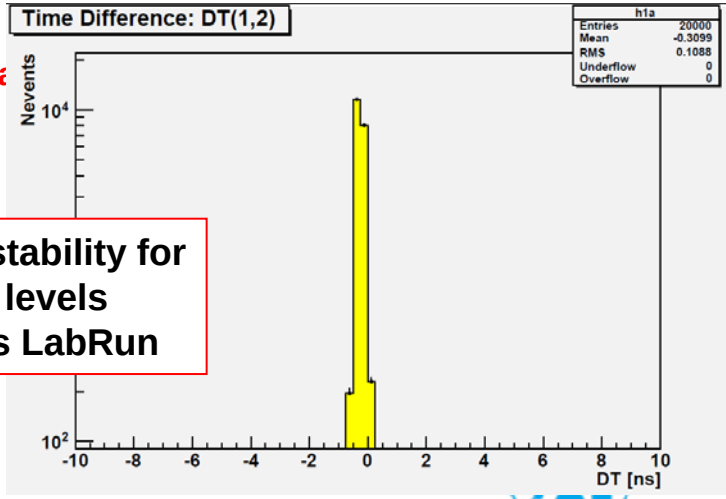


Figure 1: The White Rabbit network

- **No measureable network effects observed ➔ ~300 Telescopes are sa**
  - ➔ **Trigger-stamps : +-1ns ➔ rms<0.5ns**
  - ➔ **Phase of 1 PPS-references : rms < 200ps**



Timing stability for
- 2 WRS levels
- 20000 s LabRun

- Do we want next step (3 levels) ?

  17^3 = 4913 Telescopes

White Rabbit - Performance Overview

White Rabbit is a long-term CERN project, well supported and very advanced.

> **WR: verified by DESY @Lab & @HiSCORE & by an active community (rapidly growing)**
  - Eg. LHAASO-plan: >>1000 WR installations soon.
> I**ndustrial Support** @ 5 countries, >5 companies; off-the-shelve; OpenHard/SoftwareProject !!!
> **Ethernet-standard** (PTP-extension, pending) → the future of TimeSync

> **Main WR-Architecture principles:**
  - **Ethernet Network** architecture (redundant ! flexible, no limits)
  - **One single Fiber** for synchronization & Gbps-ethernet
  - **Absolute clocks at each telescopes**: fully correct at any time
  - **Time stamping** @ telescopes locally with full time precision
  - **Camera-Interface with MezzanineCard**

    Adaptation to any Camera-Interface is easy; documented

  - **Extra-feature: Test pulse generation at camera** with (sub-)nsec precision !
    - In all Telescopes synchronously !
    - Any complicated time-series and topological pulses per telescope are possible.

White Rabbit - Performance Overview (2)

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> **Ethernet-standard** (PTP-extension, pending) → the future of TimeSync

> **Main WR-Architecture principles:**

compare: to MUTIN project (current design)

- **Ethernet Network** architecture (redundant ! flexible, no limits)
- **One single Fiber** for synchronization & Gbps-ethernet
- **Absolute clocks at each telescopes**: fully correct at any time
- **Time stamping** @ telescopes locally with full time precision
- **Camera-Interface with MezzanineCard**

  Adaptation to any Camera-Interface is easy; documented

- center→point ("star")
- Two fibers per telescope
- absolute clock at center (calibration)
- at center only
- standard interface ?
- proprietary

- **Extra-feature: Test pulse generation at camera** with (sub-)nsec precision !
  - In all Telescopes synchronously !
  - Any complicated time-series and topological pulses per telescope are possible.

- Not available

White Rabbit - To Do

Ready :

> Standard Camera time-synchronization & stamping

To be done:

> Extend the Camera Interfaces:

Define IFs, then update the simple (standard) WR mezzanine card

- LST – definition under development
- MST, SST - missing
- In autumn: test with LST ?

> More tests

- So far: Integrated time - field tests >100 days, Laboratory / Climate: >20 days
- Additional: compare in Laboratory with MUTIN, still in 2013.
- New: Operate in “full user mode” at a remote site, for realistic verification (used as “black box”).
  This should be a required test mode for “service systems” (like timing…)

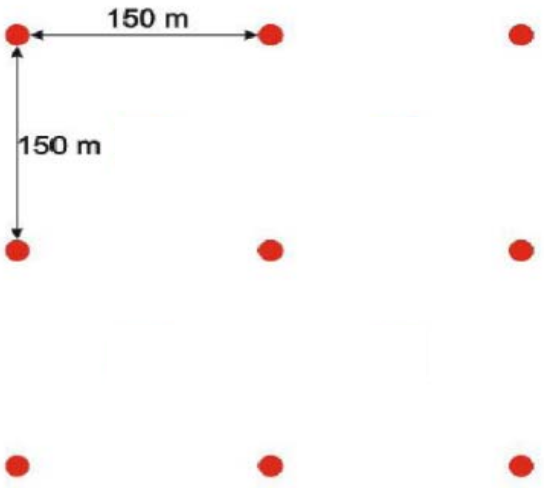
White Rabbit - Next HiSCORE setup

Plan for October 2013:

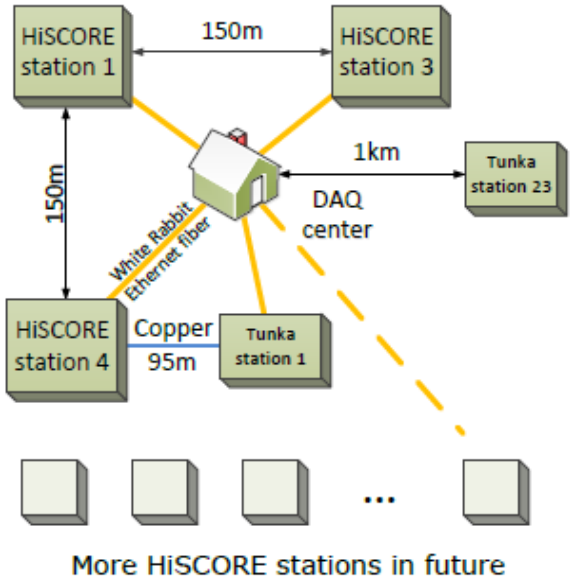
> HiSCORE array:

Install the 9 station array with WhiteRabbit (0.1 km2)

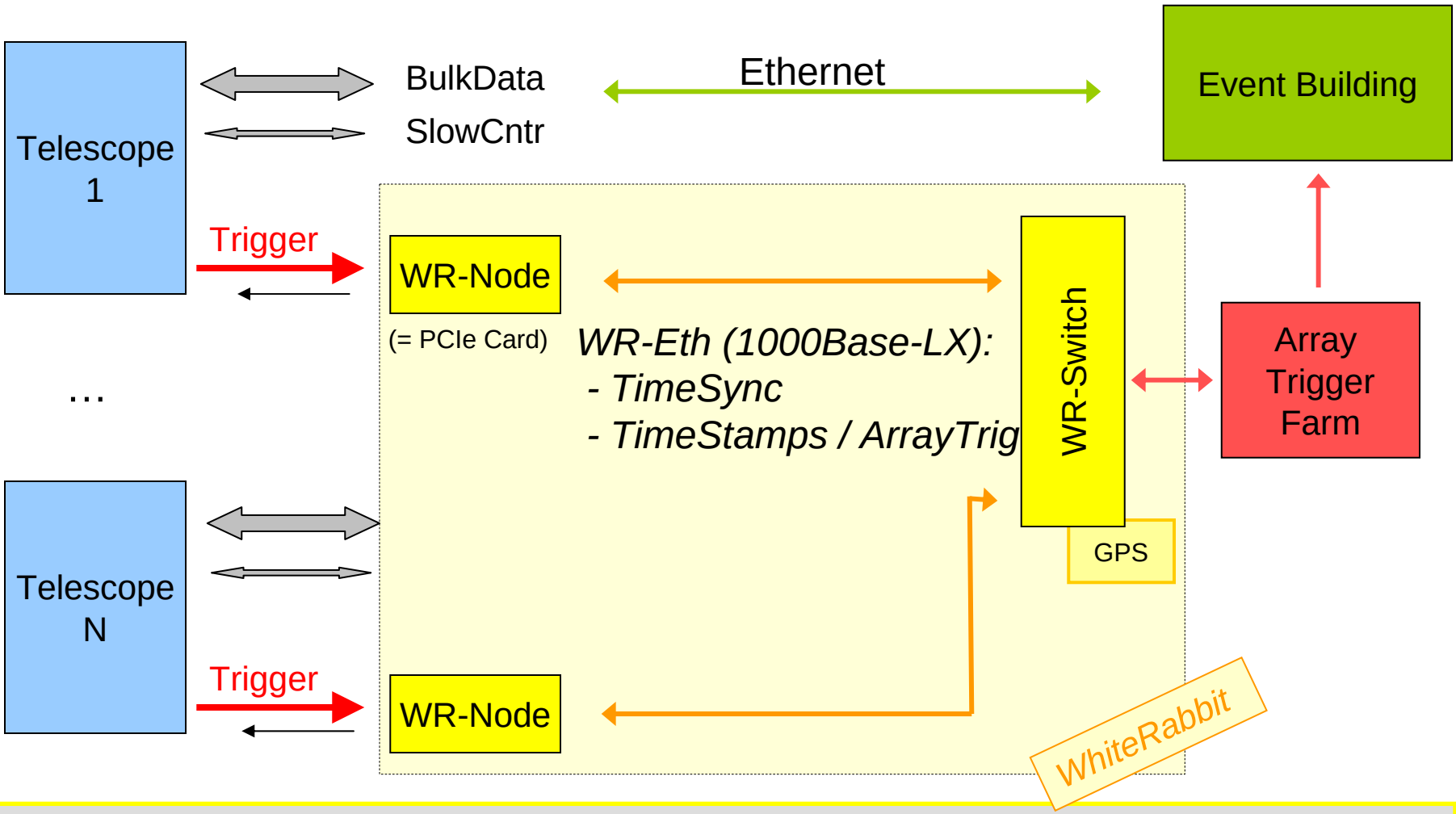
- A full-scale test (aiming at 50TeV gamma's)



The HiSCORE-2013 array: 9 stations



WhiteRabbit @ CTA : possible 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

Conclusion

- WR is proven and ready to go.
  - In routine operation: 1-ns-precision, RMS < 0.2ns,
- Is a new Ethernet standard (PPT-extension)
- Excellent performance, reliability, guaranteed support, and flexibility

- It does

  -- time synchronization & trigger time stamping

  and

  -- calibration pulse generation @ sub-nsec precision
  (at each telescope sites) !!

- Thank you

> BACKUP SLIDES

White Rabbit for CTA ?

- January 2012:

  "WR looks like a good candidate for (sub)nsec time synchronization in CTA"

  April 2013:

  In practice - WhiteRabbit is doing (sub)nsec time synchronization in HiSCORE. rms<200ps !

  and surely top-candidate for CTA !

- A typical WR-user needs to

  1. Acquire WR-hardware - all basic modules commercially
  2. Application specific firmware (if needed)
  3. Verify calibration and get some experience … and use it

  → Almost out-of-the-box

- Array Trigger distribution: (time stamps to AT-unit) comes naturally with the architecture;

  is a nice "Add-on feature" of a fully ethernet based system

- Evaluation schedule: we suggest early summer (Paris or Zeuthen)

  MUTIN: @LabTests -cross-verification wrt WR is welcome

- References:

  - CTA-Rome Consortium meeting, Oct.2012: R.Wischnewski/M.Brueckner

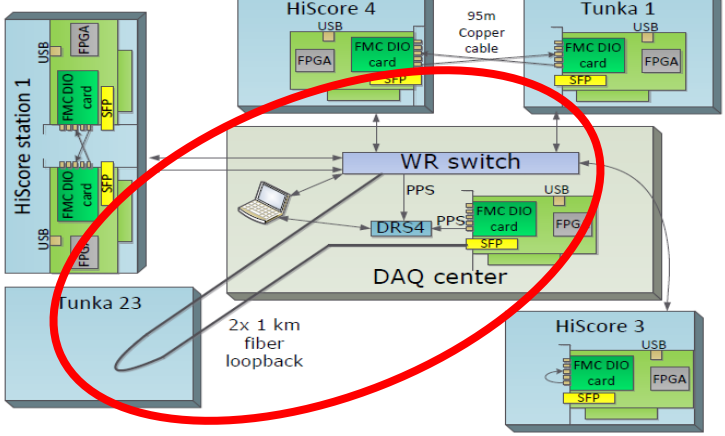
    https://www.cta-observatory.org/indico/materialDisplay.py?contribId=157&sessionId=19&materialId=slides&confId=…

  - CTA-ACTL meeting, June.2012/Feb.2013: R.Wischnewski/M.Brueckner
  - 6th WhiteRabbit-Workshop, March-2012, GSI R.Wischnewski/M.Brueckner
  - 7th WhiteRabbit-Workshop, November-2012, Madrid M.Brueckner/R.Wischnewski

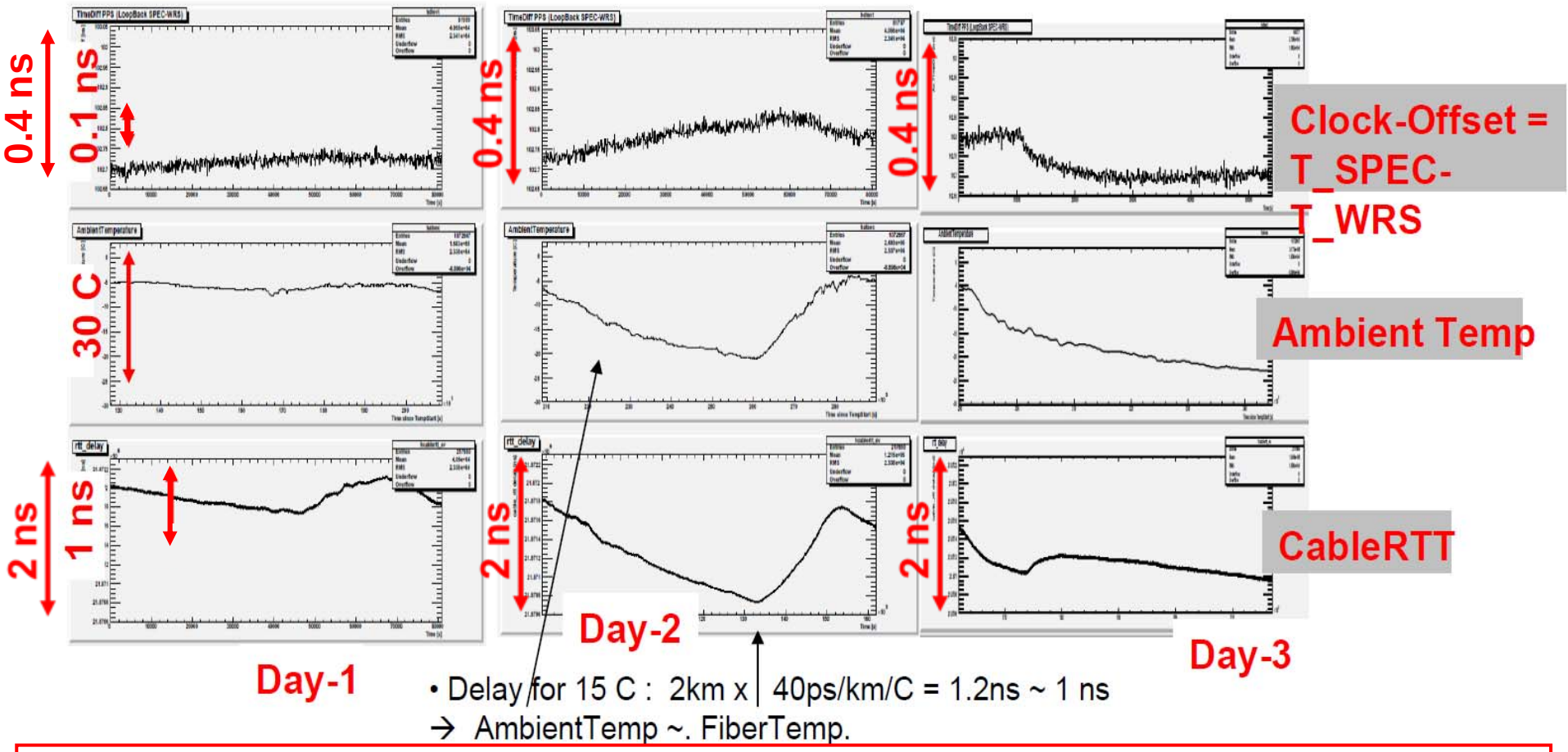
    http://www.ohwr.org/projects/white-rabbit/white-rabbit/wiki/Nov2012/Meeting

WR – Tunka Results (an example)

- **Test 1:Loopback Fiber (2x1km) WRS-SPEC: check Clock-offset by 1PPS pulse**



Clock-offset = T_SPEC – T_WRS (5 GHz DRS4)

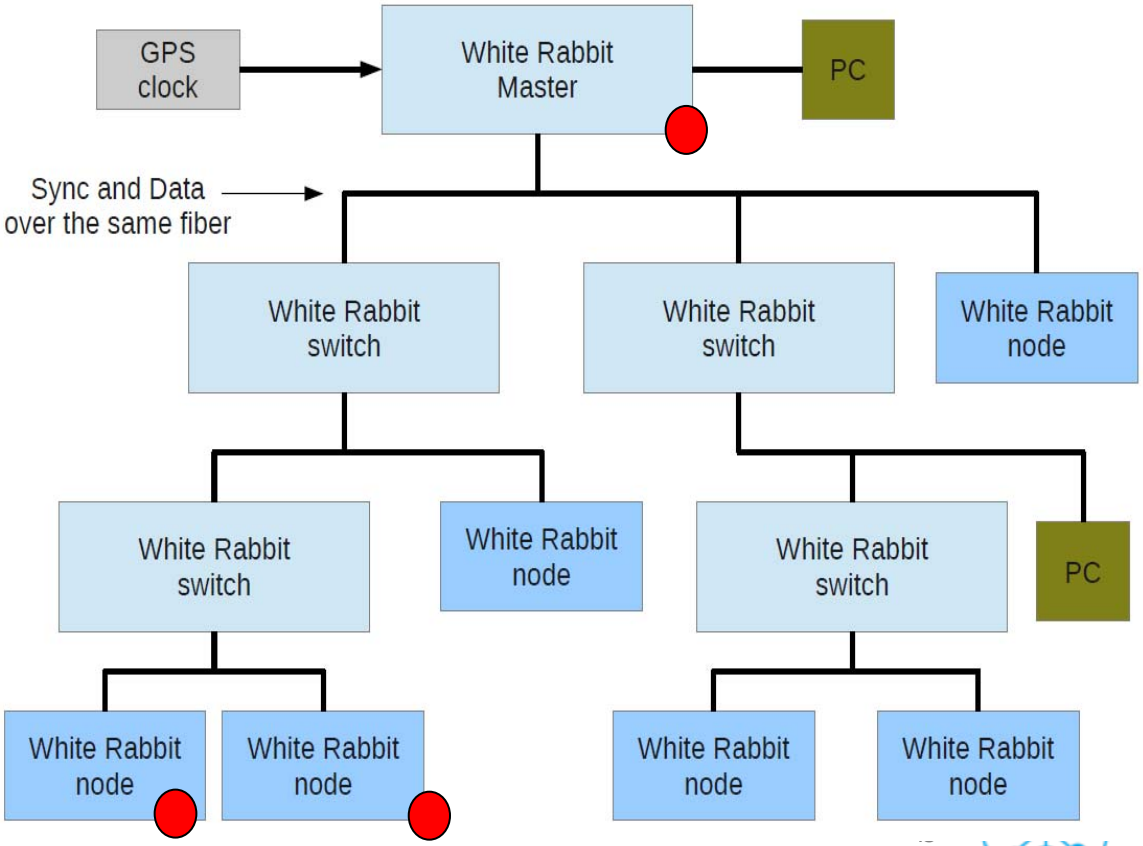


The fiber delay, induced by ambient temperature variation, are compensated by WR to < 0.2 ns level

White Rabbit

- White Rabbit is a fully deterministic Ethernet-based network (Gbit standard) for
  - time synchronization with precision: 1nsec/ phase stability <0.1ns
  - data transfer
- It can synchronize over 1000 nodes with sub-ns accuracy over fiber lengths > 10 km.

- Developed at CERN
- Plans for LHC-upgrade, GSI-Accelerator complex (FAIR), CTA, km3net, LHHASO
- Big community, all open source (software, fpga designs, pcb schematics and layouts)
- Gigabit-Ethernet is used
- DESY is active WR-developer since 2/2012
- HiSCORE is the first real application
- Implementing WR- into Ethernet standard coming soon



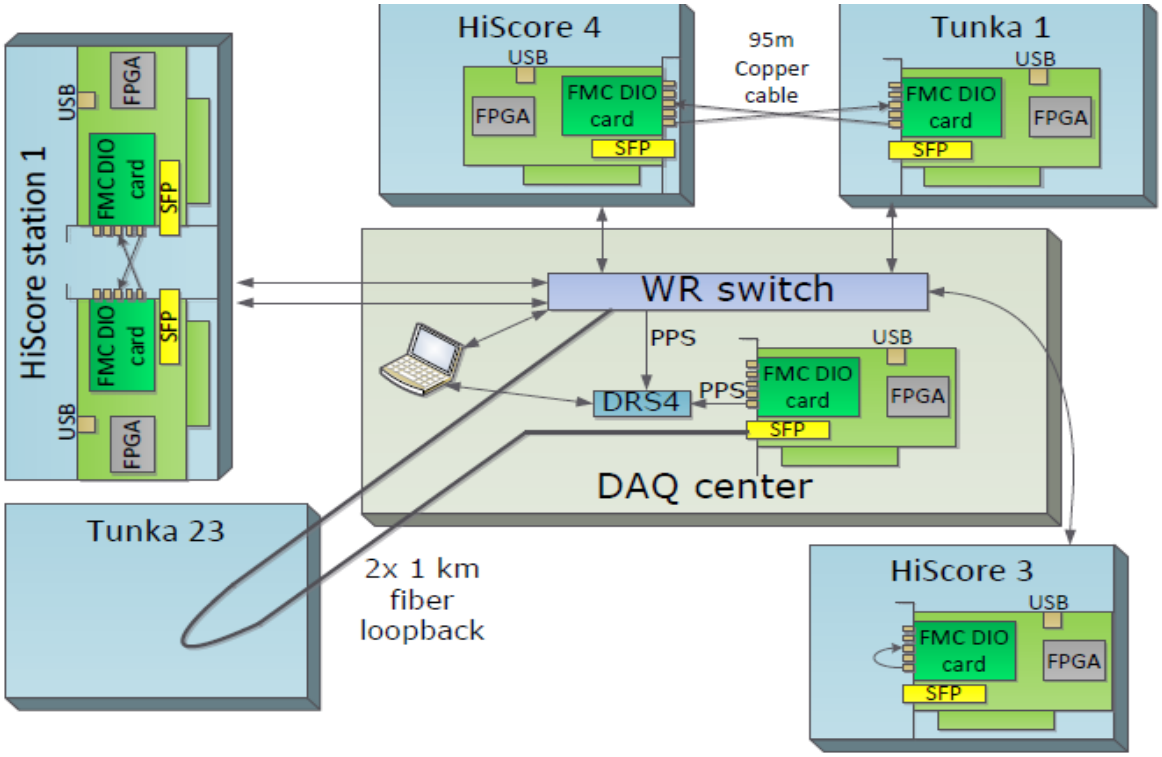
WR – setup in Tunka

White Rabbit Installation with a maximum of redundant cross-calibration options (October 2012 - today):

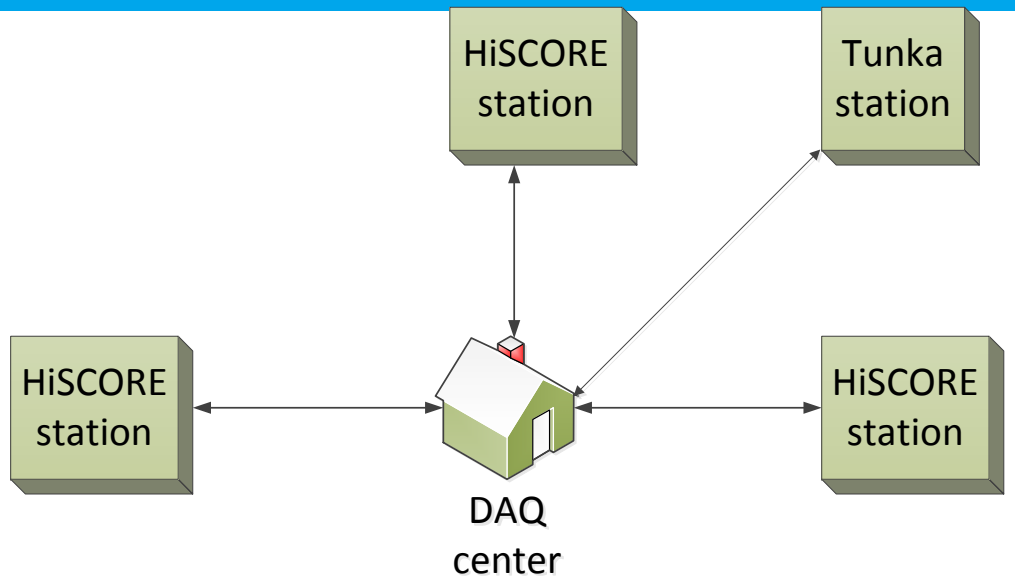
> **2km loopback fiber cable connected to DRS4 to compare WRS and SPEC (2km) PPS clocks**

> **Crosswise PPS->TDC connection to test TDC and White Rabbit**
- **2x SPEC within HiS1 station**
- **2x SPEC in 2 stations (HiS4 + Tunka-1)**

> **Loopback PPS connection to test TDC performance (HiS 3)**

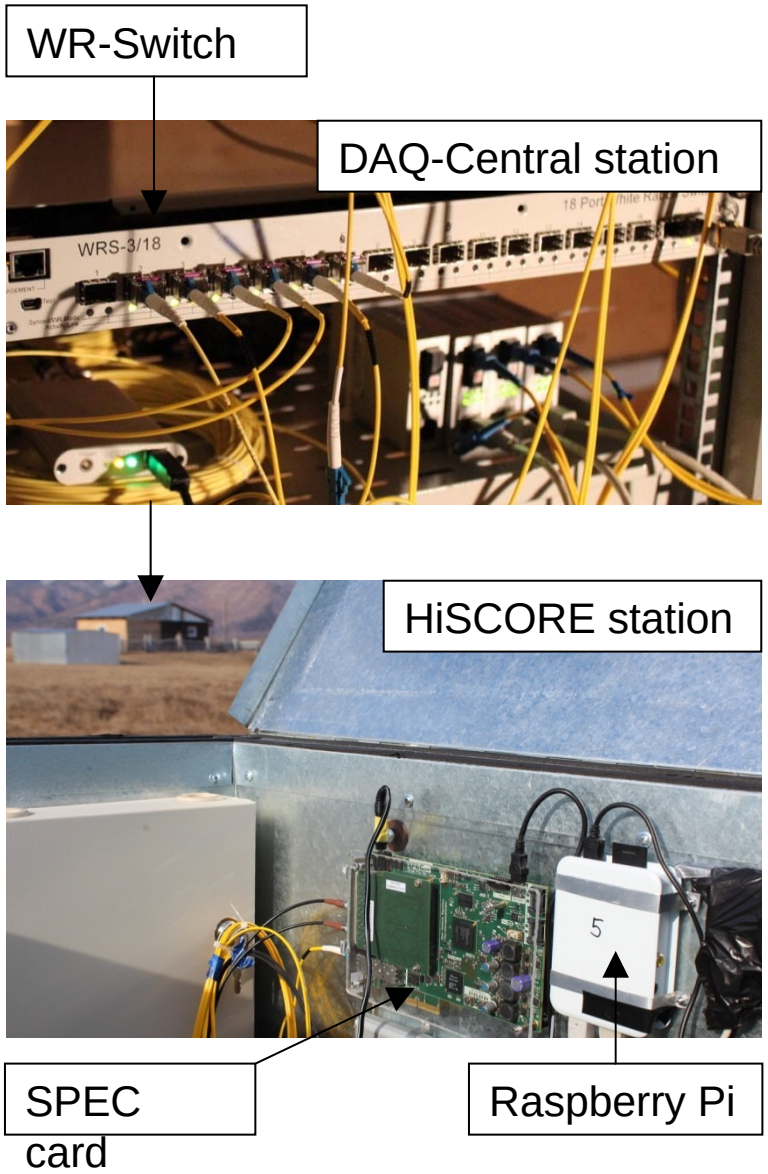


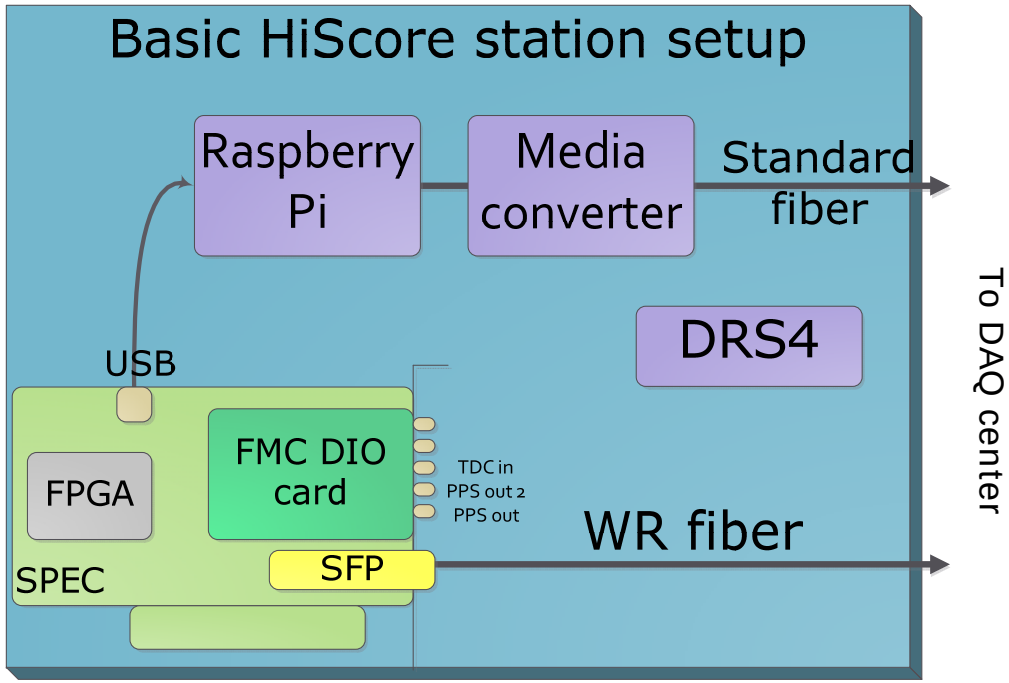
HiSCORE setup overview (Oct.2012 comissioned)



- 1 km² in 2013/14 : 20-40 stations
- 100 km²: > 2000 stations

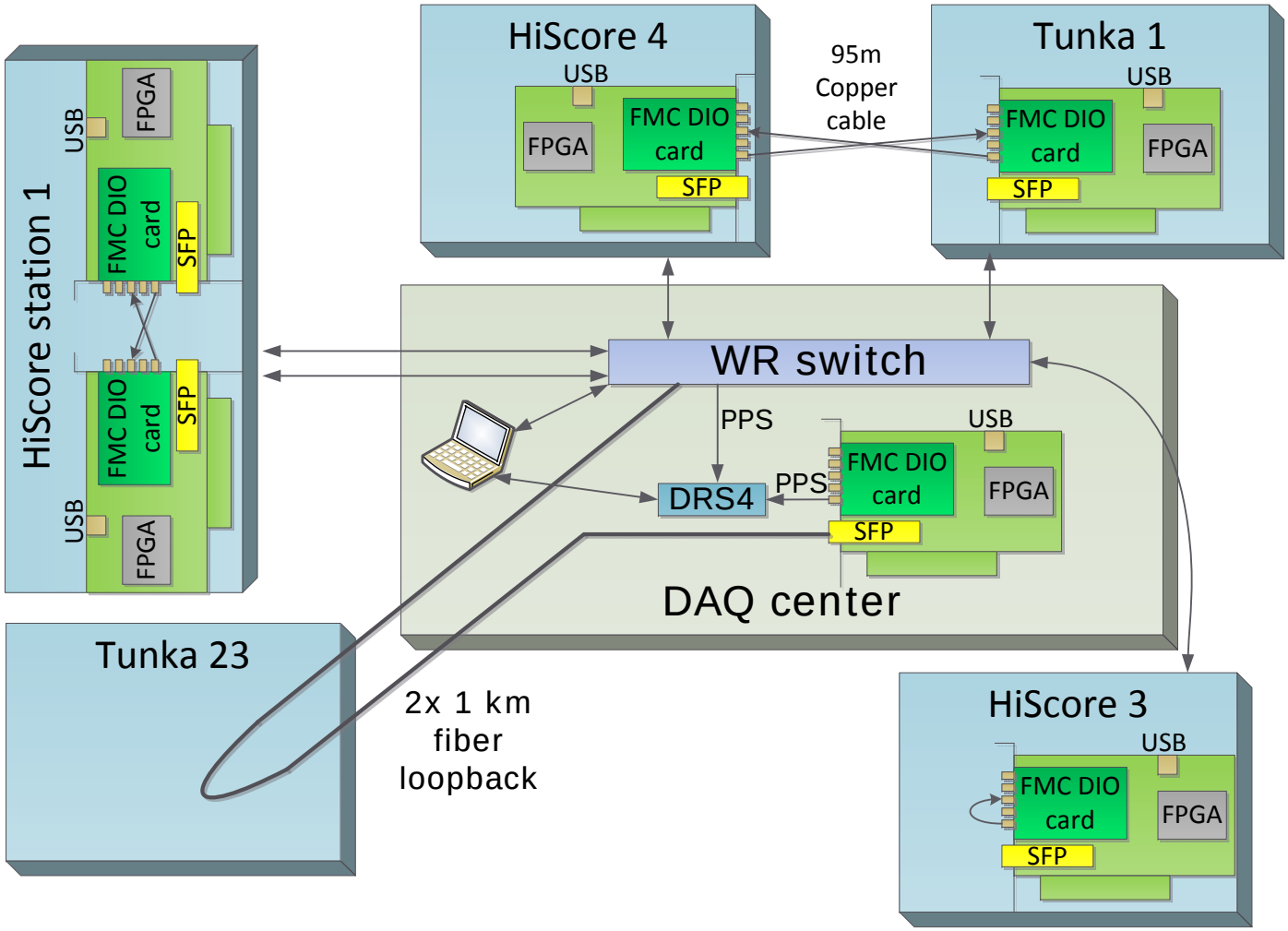
HiSCORE setup overview





- DRS4 as 5 GHz “digital scope”
- Raspberry Pi transports
  - USB Terminal
  - DRS4 (Domino Ring Sampler)
  - Temperature sensor
  - …

HiSCORE setup



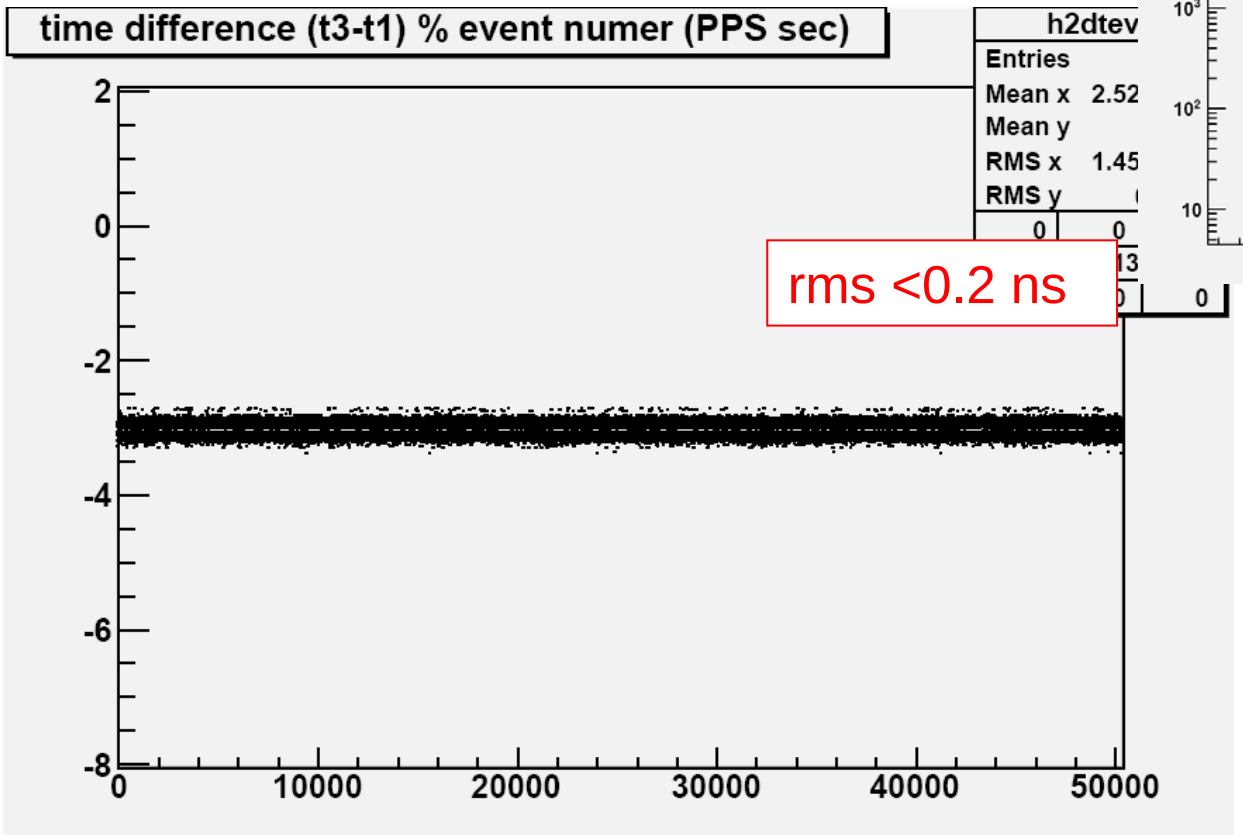
- PPS signals (DIO output 1) connected to TDC-inputs (DIO input 3)

Results - 2 km fiber loopback with DRS4

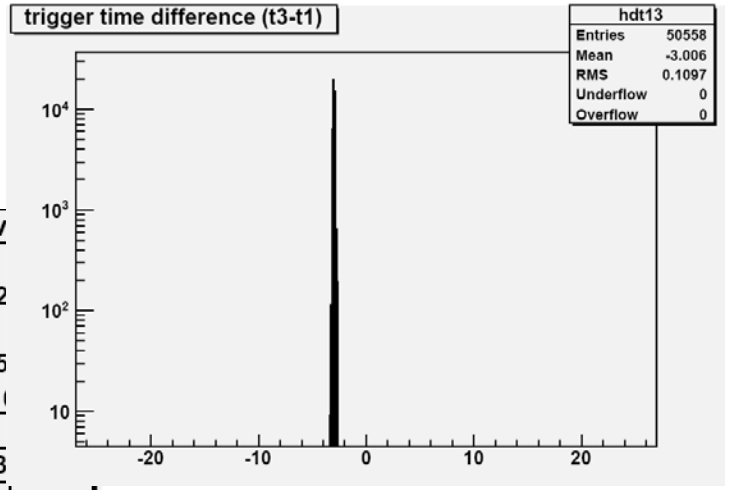
1. Test :

LoopBack Fiber over 2x1km
back to Laboratory

(5GHz DRS4-measurement)

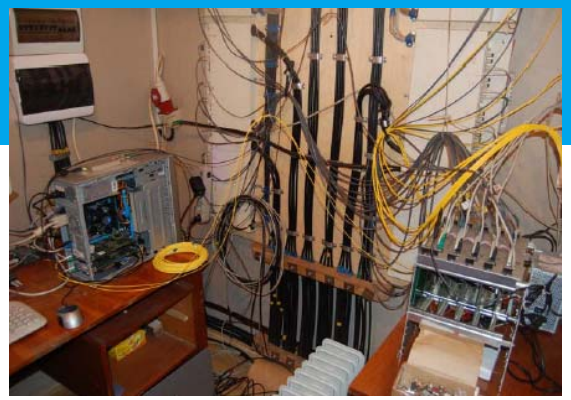


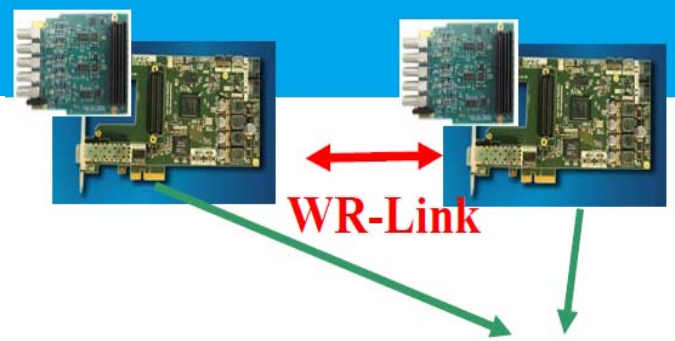
rms <0.2 ns



14hr run

WR – Lab. test





1 PPS timing
(DRS4 5GS/s)

- **Setup:**
  - **Two WR-SPEC cards: Mster-Slave WR-link + fiber**
- **Time test:**
  - **Comparing the master/slave 1-PPS outpu**

Clock-offset = T_SPEC – T_WRS