# The White Rabbit Project

## Technical introduction and status report

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# Outline

# Origin of the name

*Oh dear! Oh dear! I shall be too late!*

The White Rabbit in charge of real time

# Development model

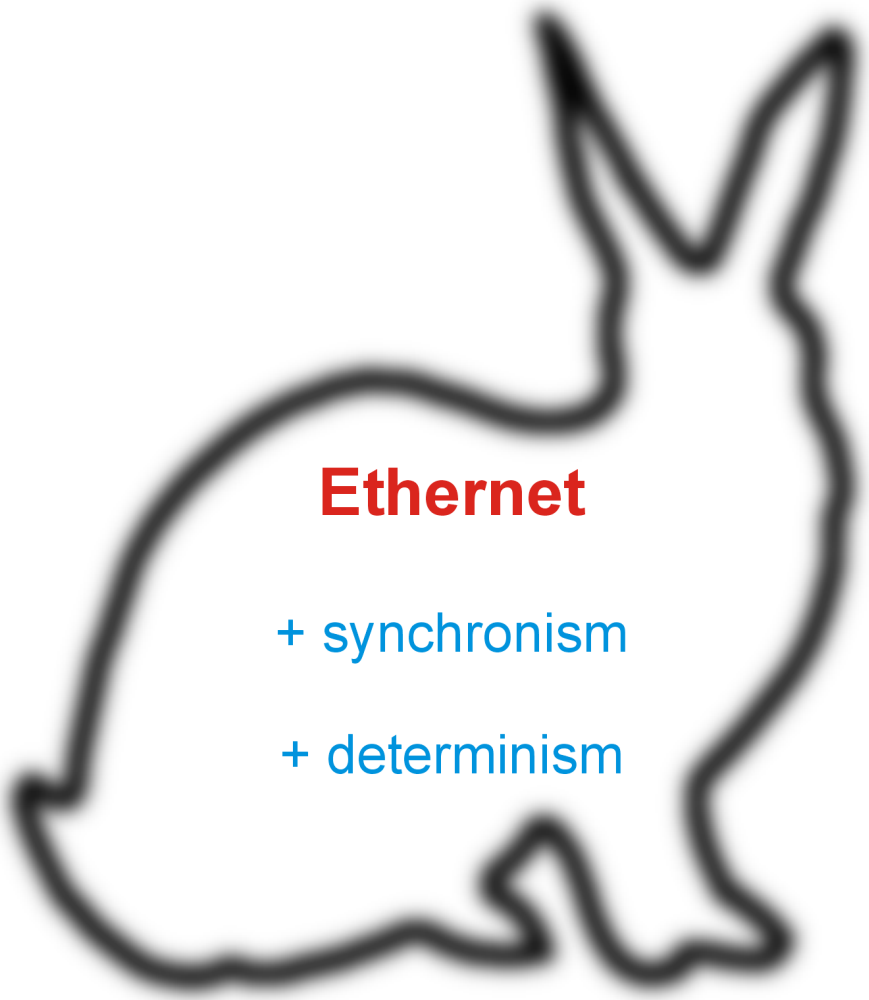
- Developed in the frame of ACCOR project
- Open source design done in collaboration with industry
- Commercial production and support

# Why White Rabbit?

## General Machine Timing limitations

- Low speed (500 kbps)
- Lack of bidirectional communication
- Complicated maintenance

# What is White Rabbit?



# What is White Rabbit?

An **extension** to **Ethernet** which provides:

- **Synchronous mode** (Sync-E) - common clock for physical layer in entire network, allowing for precise time and frequency transfer.
- **Deterministic routing** latency - a guarantee that packet transmission delay between two stations will never exceed a certain boundary.

# Design goals

## Scalability

Up to 2000 nodes.

## Range

10 km fiber links.

## Precision

1 ns time synchronization accuracy, 20 ps jitter.

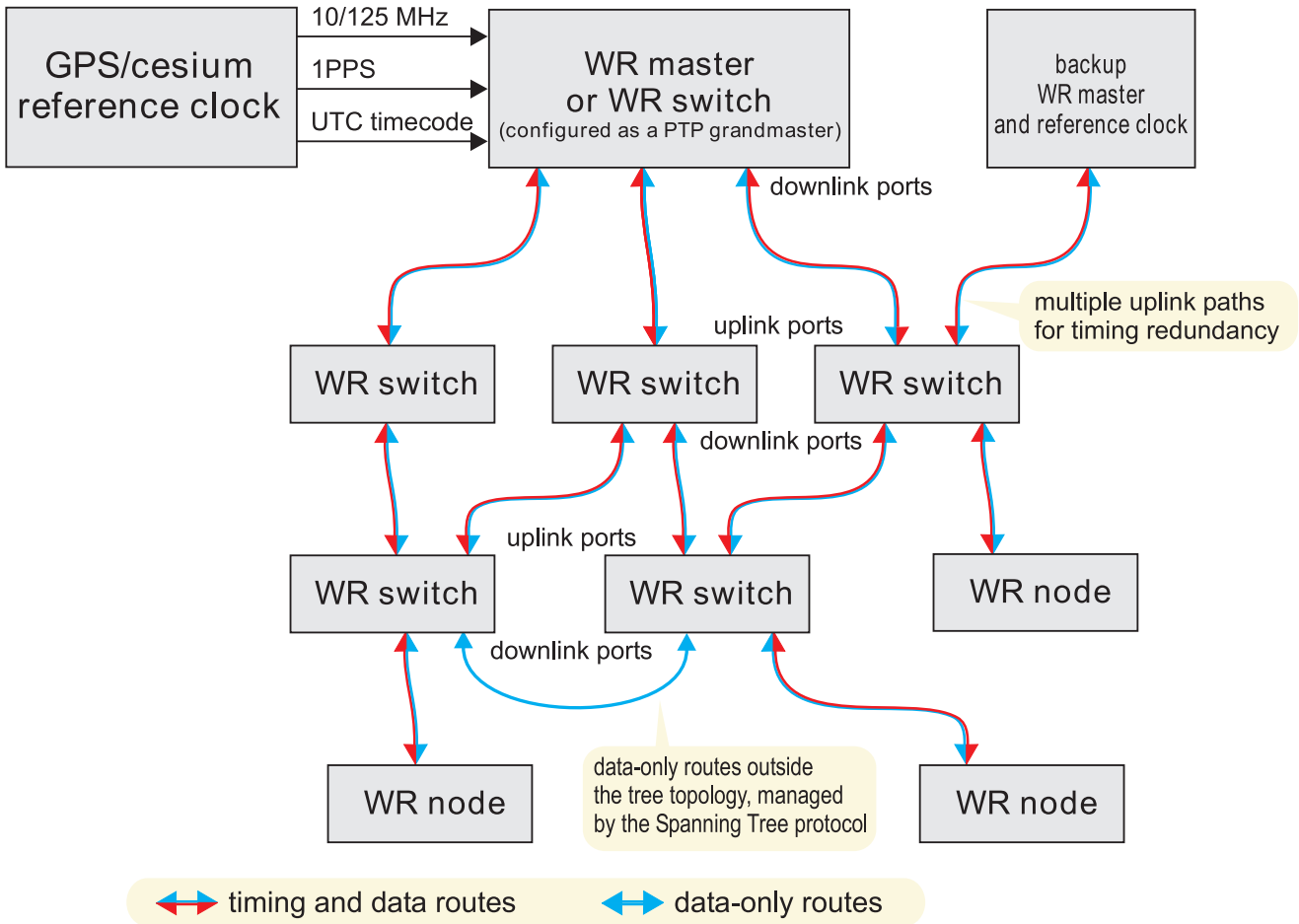
# Outline

# Technologies used in White Rabbit

Sub-nanosecond synchonization in WR is achieved by using the following three technologies together:

- Precision Time Protocol (IEEE1588)
- Synchronous Ethernet
- DMTD phase tracking

# Network topology



# PTP Protocol (IEEE1588)

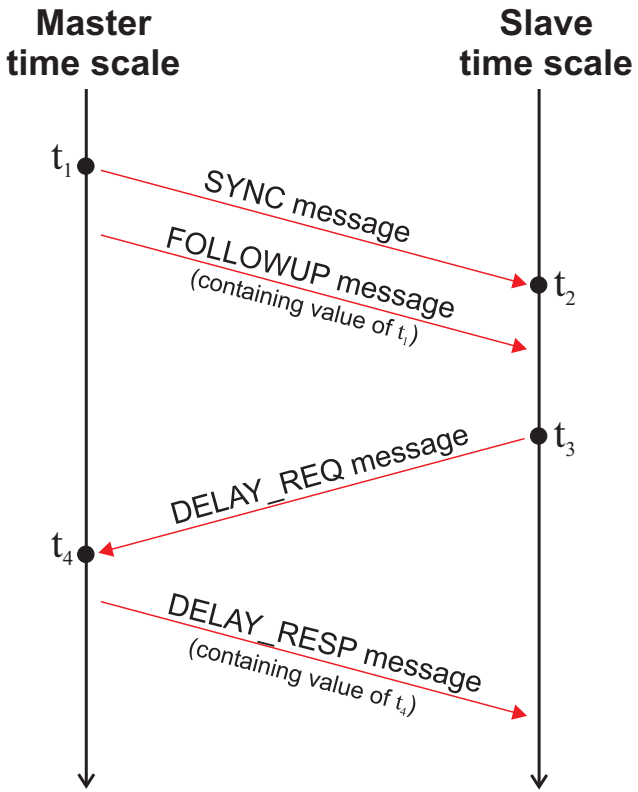
## PTP

Synchronizes local clock with the master clock by measuring and compensating the delay introduced by the link.

## Packet timestamping

Link delay is measured by exchanging packets with precise hardware transmit/receipt timestamps

# PTP Protocol (IEEE1588)




Having values of $t_1 \ldots t_4$, slave can:

- calculate one-way link delay: $\delta_{ms} = \frac{(t_4 - t_1) - (t_3 - t_2)}{2}$
- syntonize its clock rate with the master by tracking the value of $t_2 - t_1$
- compute clock offset: $offset = t_2 - t_1 + \delta_{ms}$

# Disadvantages of traditional PTP

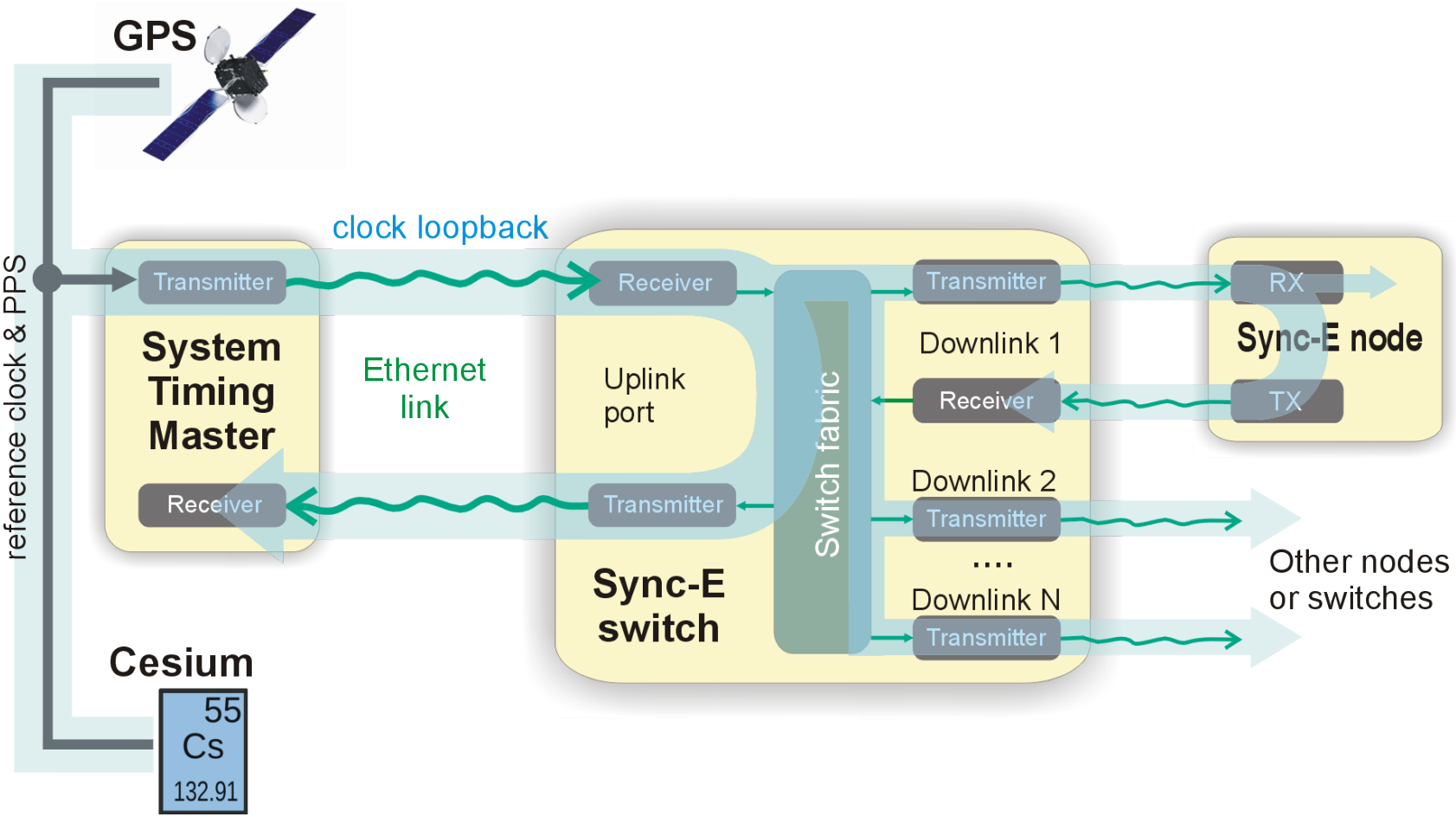
- All nodes have free-running oscillators
- Frequency drift has to be continously compensated, causing lots of network traffic
- That doesn't go well with determinism...

# Synchronous Ethernet

## Common clock for the entire network

- All network nodes use the same physical layer clock, generated by the System Timing Master
- Clock is encoded in the Ethernet carrier and recovered by the receiver chip (PHY).
- PTP is used only for compensating clock offset.
- Having the same clock frequency everywhere enables phase detector technology as the means of measuring time.

# Synchronous Ethernet



# Phase tracking

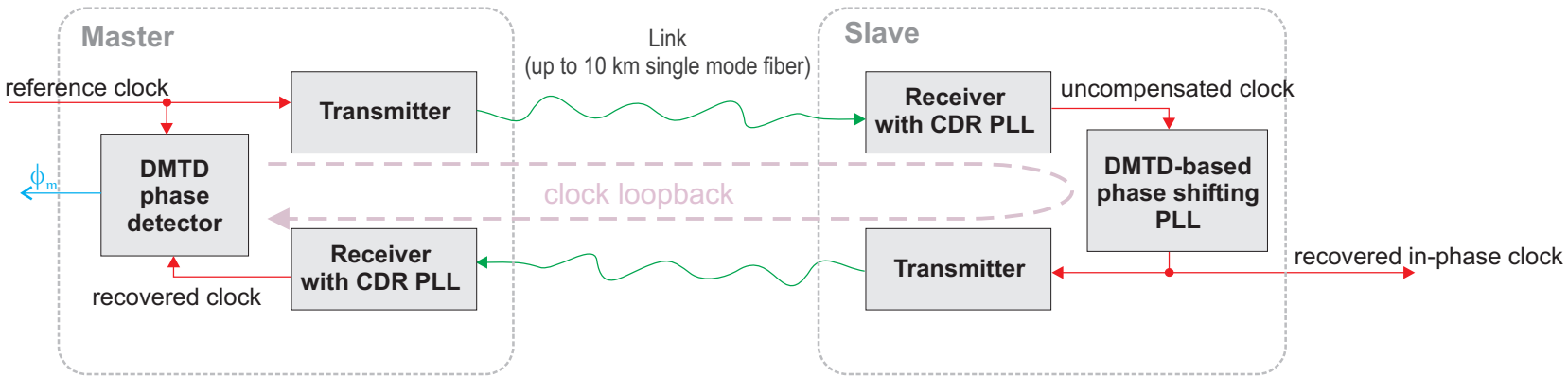
## Plain PTP

PTP alone is not enough if we want very good accuracy, because of the granularity of the timestamps.

## Solution

Measure the phase shift between transmit and receive clock on the master side, taking the advantage of Synchronous Ethernet.

# Phase tracking




- Monitor phase of bounced-back clock continuously
- Phase-locked loop in the slave follows the phase changes measured by the master

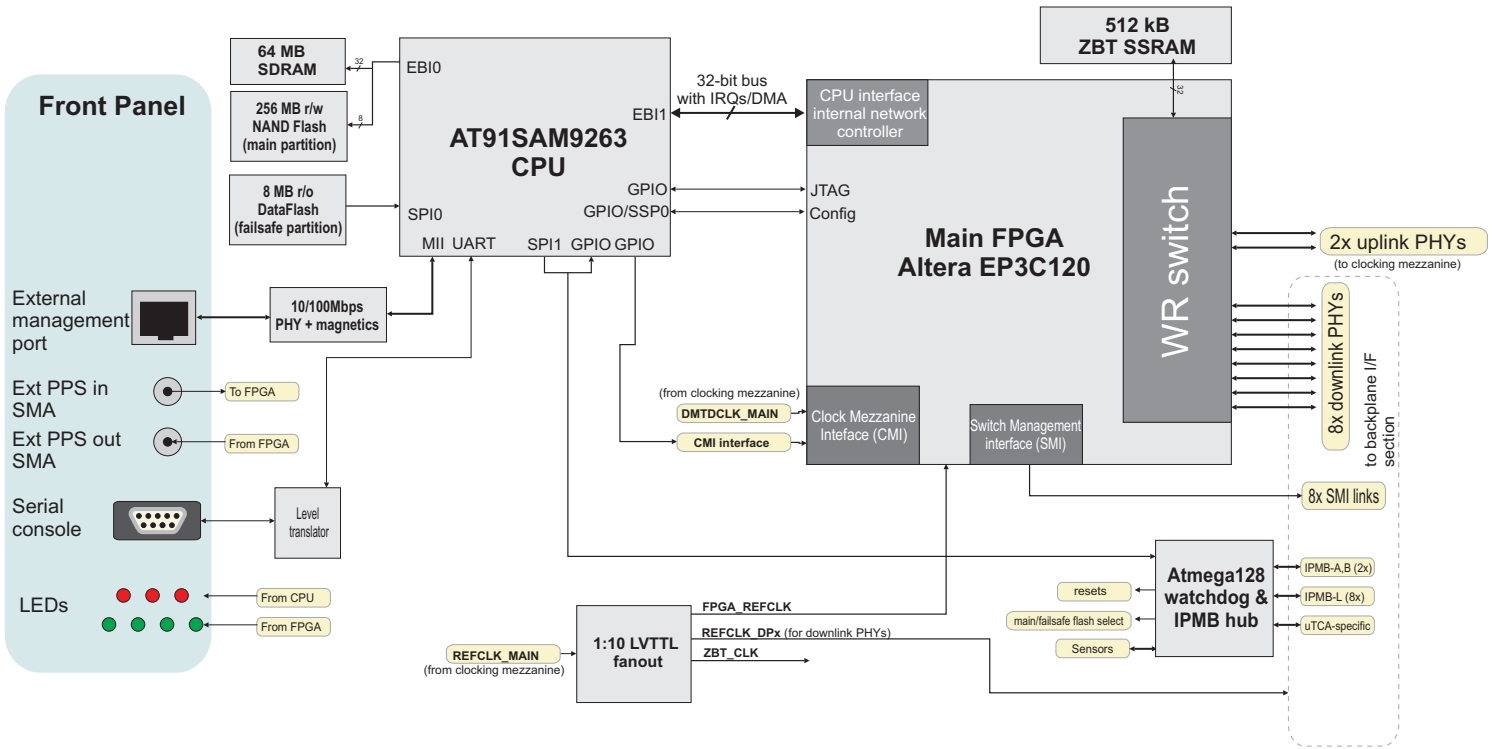
# White Rabbit Switch


- Central element of WR network
- Fully custom design, designed from scratch
- 10 1000Base-LX ports, capable of driving 10 km of SM fiber
- 200 ps synchronization accuracy

# White Rabbit Switch

- Designed in microTCA MCH (Management Carrier Hub) format.
- Multi-PCB design: base board with main big FPGA and CPU and Clocking Mezzanine, which handles the timing.
- Can work in standalone mode (without a microTCA crate) via mini-backplane.

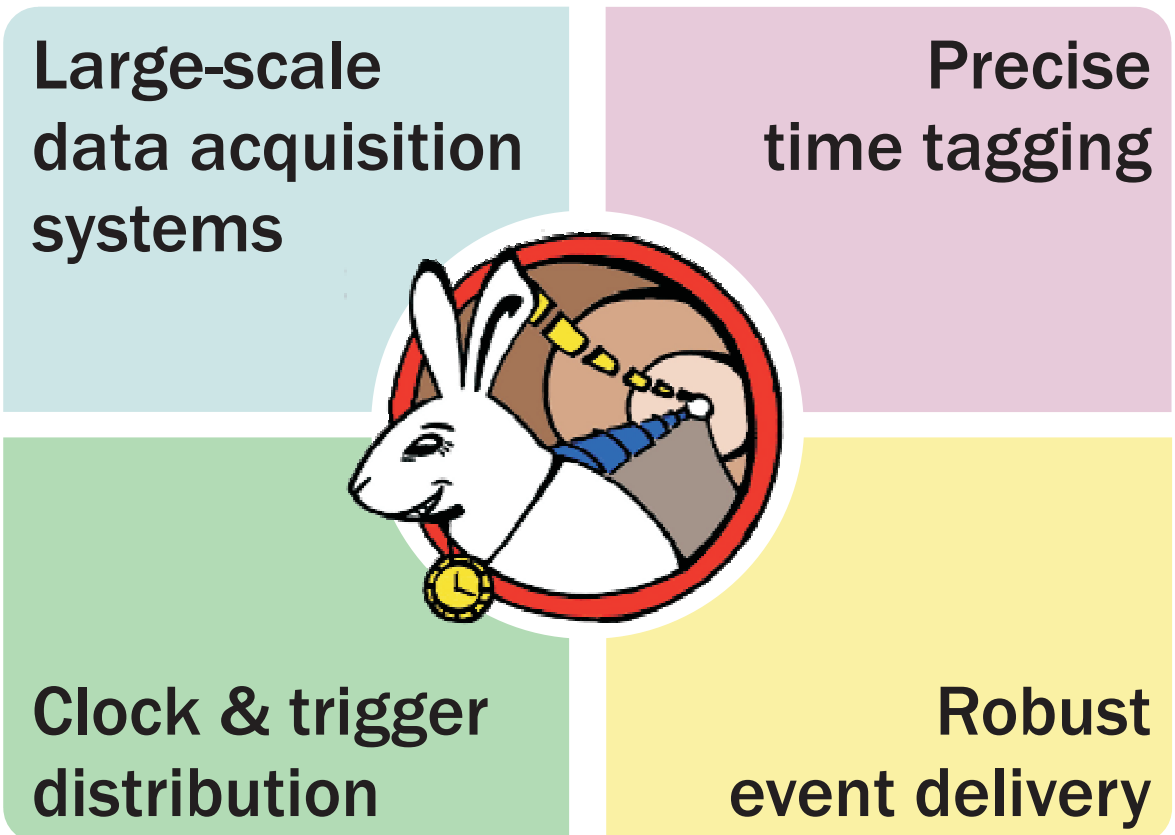
# Switch block diagram - main part



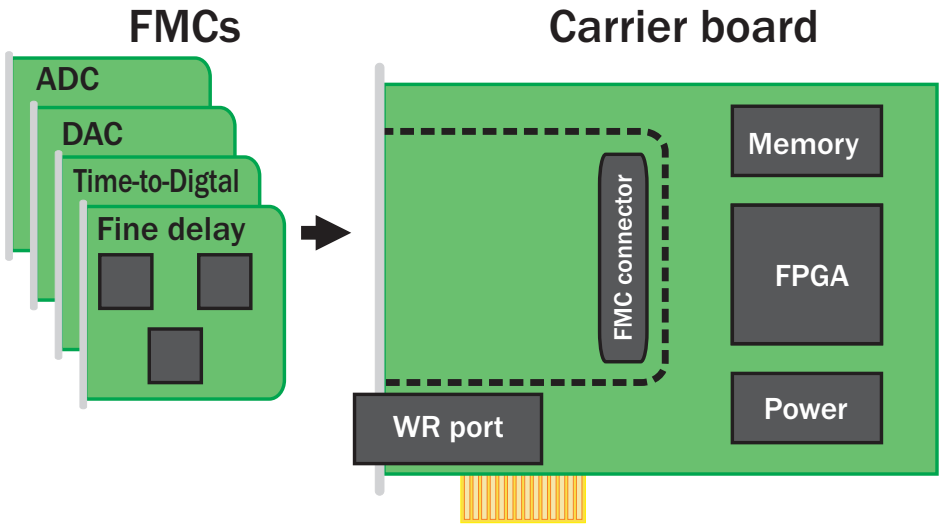

- System FPGA handles all packet processing
- CPU implements PTP stack and management functions (SNMP, Spanning Tree)

# Outline

# Possible applications of White Rabbit



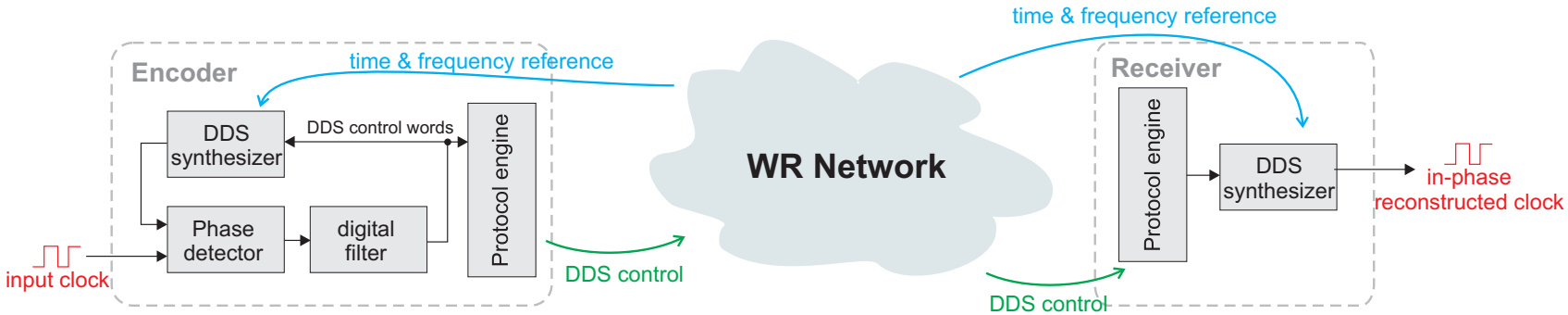
# WR in Co-HT's Hardware Kit




## Co-HT FMC-based Hardware Kit:

- FMCs (FPGA Mezzanine Cards) with ADCs, DACs, TDCs, fine delays, digital I/O
- Carrier boards in PCI-Express, VME and uTCA formats
- All carriers are equipped with a White Rabbit port

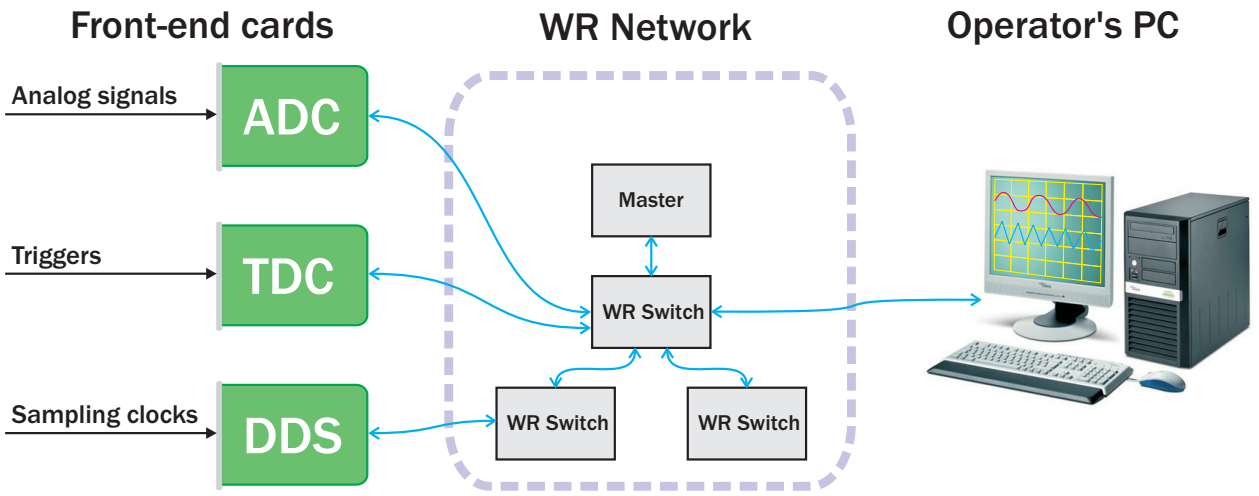
# Ethernet Clock distribution a.k.a. Distributed DDS




## Distributed Direct Digital Synthesis

- Replaces dozens of cables with a single fiber
- Works over big distances without degrading signal quality
- Can provide various clocks (TTC, RF, bunch clock) with a single, standarized link

# Distributed oscilloscope




- Common clock in the entire network: no skew between ADCs
- Ability to sample with different clocks via Distributed DDS
- External triggers can be time tagged with a TDC and used to reconstruct the original time base in the Operator's PC.

# Outline

# WR Switch development status

## Switch hardware

- Working and debugged V2 hardware prototype
- Tested on 10-km fiber links
- Interoperates with standard Ethernet gear

## Switch software

- Done the Hardware Abstraction Layer and PTP daemon
- Sub-nanosecond accuracy over PTP has been achieved
- Verified interoperability with other PTP devices on ISPCS 2010 Plug Fest

# Already achieved...

## According to ISPCS Plug Fest results ...

**... White Rabbit is the most accurate PTP implementation in the world!**

# CERN - White Rabbit developers

## T. Wlostowski

- HDL development
- Further improvements in the synchronization performance
- Co-design of V3 Switch hardware with the industrial partners

## M. Lipinski

- Development of fault-proof event delivery protocol
- PTP stack support
- HDL development

# External contributors

## GSI Darmstadt

- Fieldbus protocol development, working on reliability
- HDL development

## Alessandro Rubini (GNUDD)

- Main software developer
- Device drivers
- Embedded Linux support

## Integrasys

- Development of switch management software
- IEEE802.x compatibility testing

## Seven Solutions

- Co-design of V3 switch hardware (technical spec available mid-November)
- Prototype production and testing

## Elproma (not confirmed yet)

- Commercial WR OEM modules and time servers

# Foreseen milestones

## WR Switch

- Full basic functionality of HDL and software: mid-December 2010
- V3 prototype: Q3 2011
- Commercial product: Q1 2012

## WR Ecosystem

- FMC Carriers: VME version prototype done, PCIe available at the end of November
- WR timing node: Q2 2012
- Mezzanines: Full set of cards available Q4 2011

# Summary

- A data link fulfilling all our needs in **synchronization** and **determinism**.
- A successful **collaboration** including institutes and companies.
- Full system available at the **middle of 2012**