WR技术
及在LHAASO实验的应用

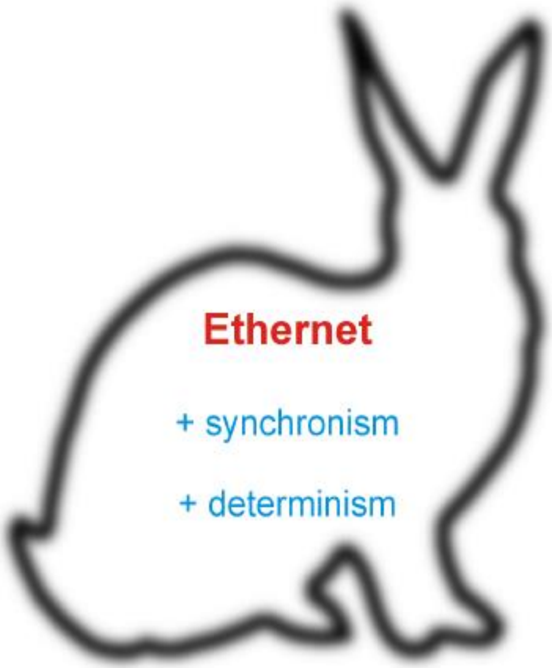
2017年1月18~19日 LHAASO合作组会 昆明云南大学

Outline

- WR Introduction
- WR for LHAASO
- Prototype array in YBJ@Tibet
- Recent developments
- Summary and Discussion

What is WR

- 基于以太网的扩展增强技术
  - 频率源广播及亚纳秒时间同步
  - 确定、可靠、低延迟数据传输
- 针对加速器控制应用开发
- 多实验室/公司合作研究
- OPEN hardware/Software
- 下一代网络同步标准



WR关键技术 – 亚纳秒同步

长距离：10Km
多节点：2000nodes
准确度：<1ns
高精度：10ps

PTPv2 — **精密网络同步协议**： 利用通信协议实现主从端延迟测量，并完成单向延迟补偿，实现双方时钟同步 — **时间同步**

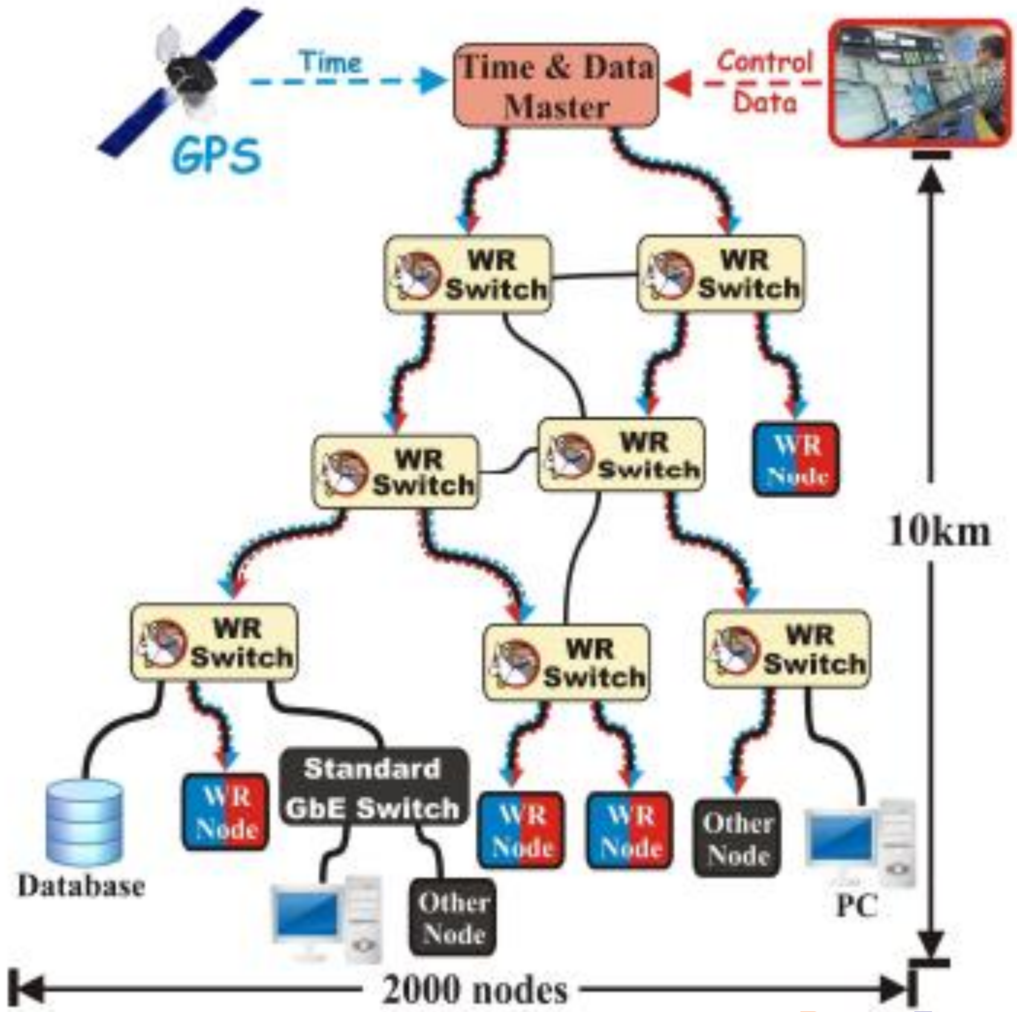
Sync-E — **同步以太网**： 利用时钟数据嵌入和时钟恢复技术，实现双向频率传递 — **频率同步**

DMTD — **数字双混频鉴相**： 实现主从端相位测量和跟踪锁相. — **相位同步**

J. Serrano, et al., The White Rabbit Project, ICALEPCS, 2009

WR Network

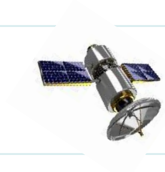
- 兼容标准以太网
- 数公里，上千节点
- 1Gbps光纤链路
- ----------
- 全局频率与时间同步
- 保障确定的传输延迟
- 冗余结构增强可靠性



WR components

A White Rabbit network is composed of

Clock/Freq reference (optional)



GPS

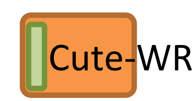
Ru/Cs

WR switch

Fiber links/cables

WR nodes

IP core



Specially designed for LHAASO-KM2A Timing system R&D

WR Switch

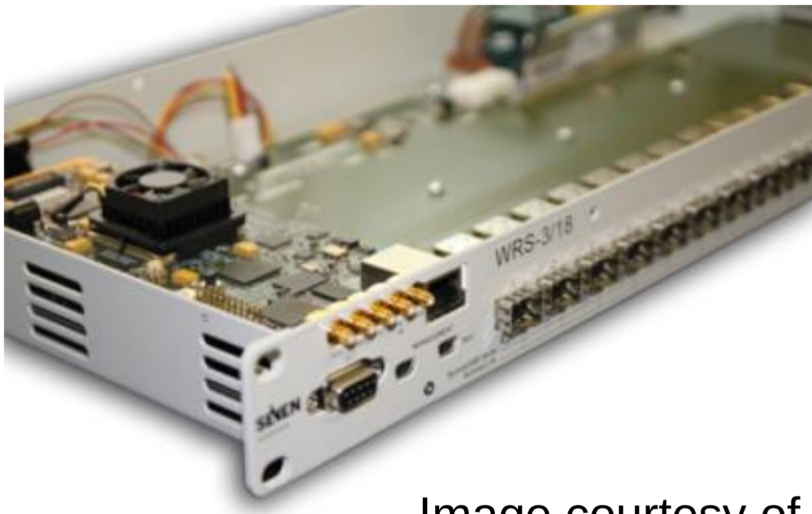


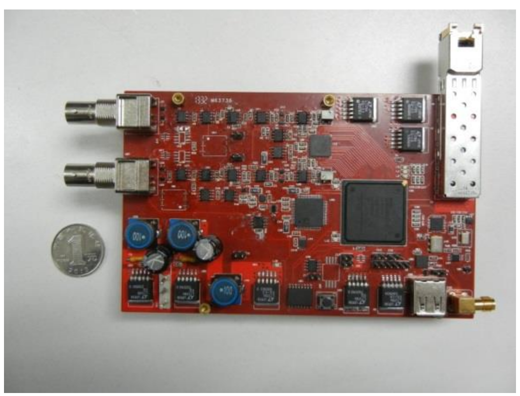
Image courtesy of Seven Solutions

- Xilinx Virtex 6, Atmel AT91SAM9G45
- 18 cages for Gigabit SFPs, 10/100 Ethernet management port
- 5 SMC connectors (1-PPS in/out, CLK in/out)
- designed and produced by *Seven Solutions* in cooperation with CERN
- schematics, PCB design and mechanical drawings in the public OpenHardware repository

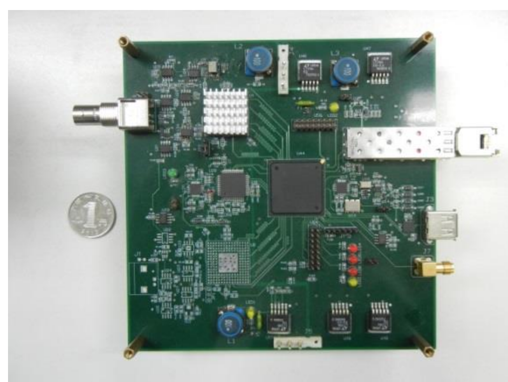
- Central element of WR network
- Original design optimized for timing, designed from scratch
- 18 1000BASE-BX10 ports
- Capable of driving 10 km of SM fiber
- Open design (H/W and S/W)

WR Node: carrier boards

- PCI-Express，VME，PXI形式的载板
  - 载板提供系统连接、控制、运算、存储资源
  - 载板提供WR接口
  - 载板提供FMC扩展端口
- 接口功能 (AD,DA,IO)通过FMC子卡实现
- LHAASO 使用自己设计的节点



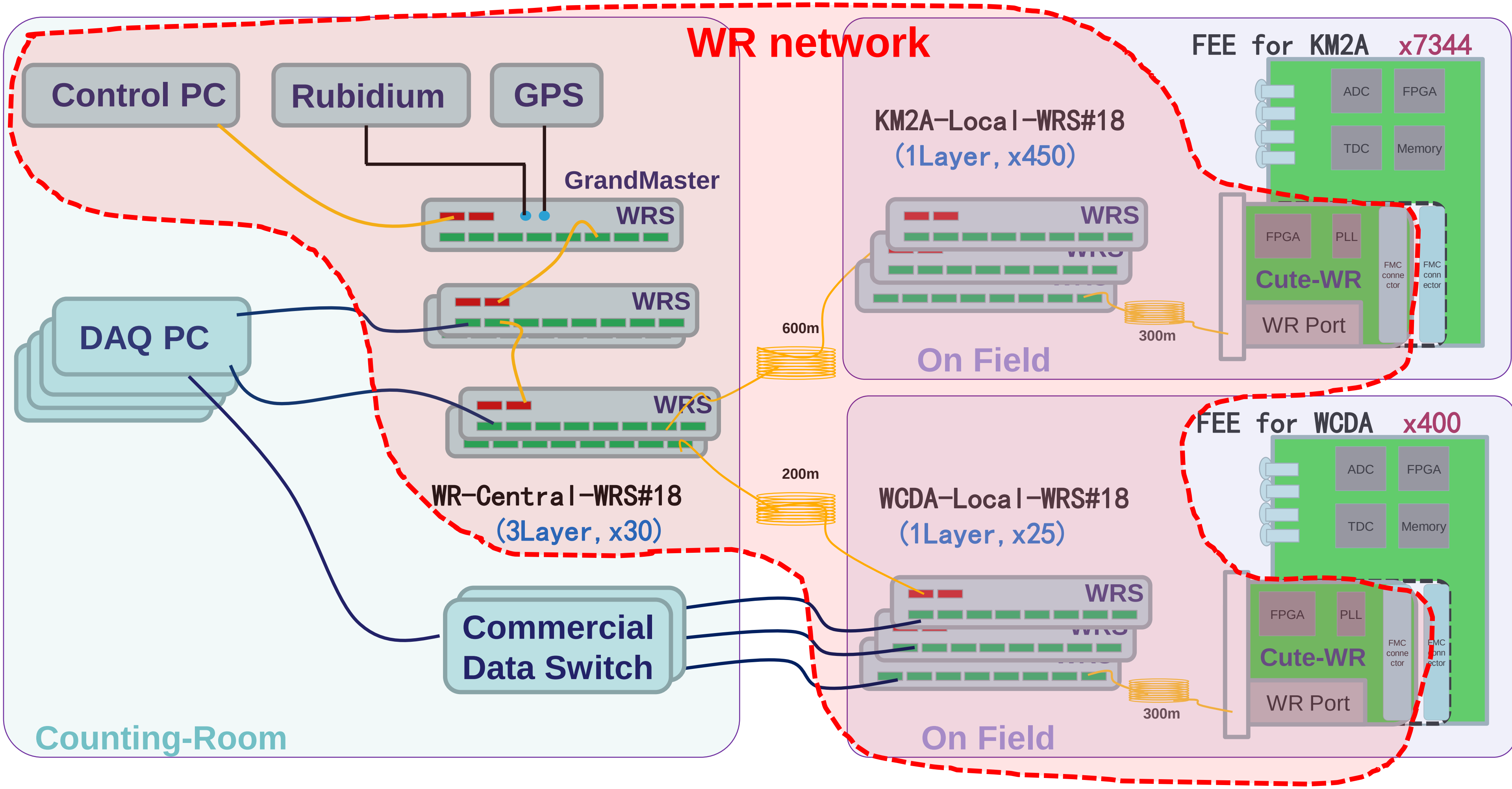
ED



MD

For WFCTA

LHAASO WR network



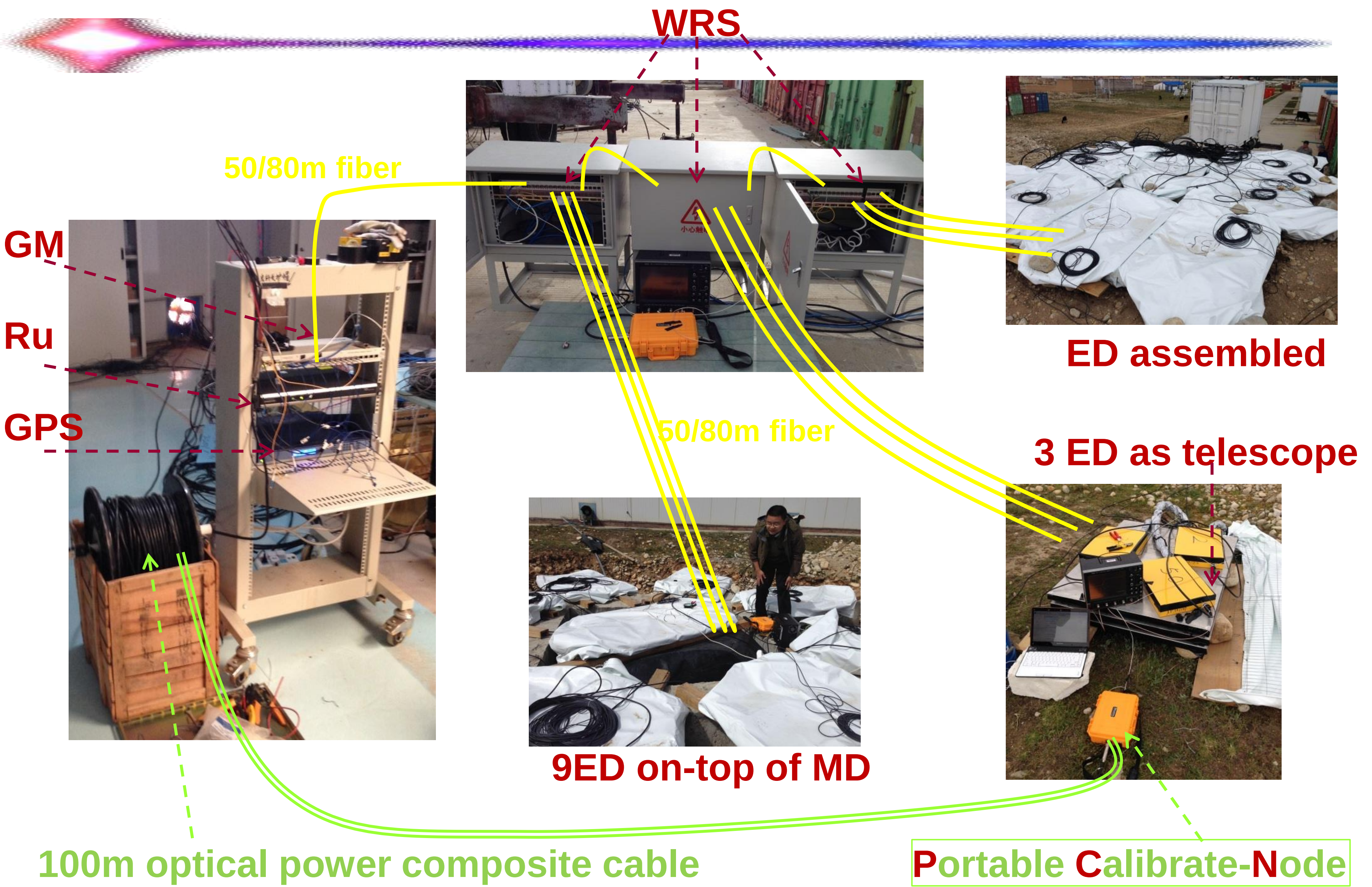
Detector data can export to DAQ from any WRS (bandwidth split)

- ➢ Unified Clock/Data network for KM2A/SCDA/WFCTA
- ➢ Hybrid Clock/Data network for WCDA

WR deployment at YBJ@Tibet

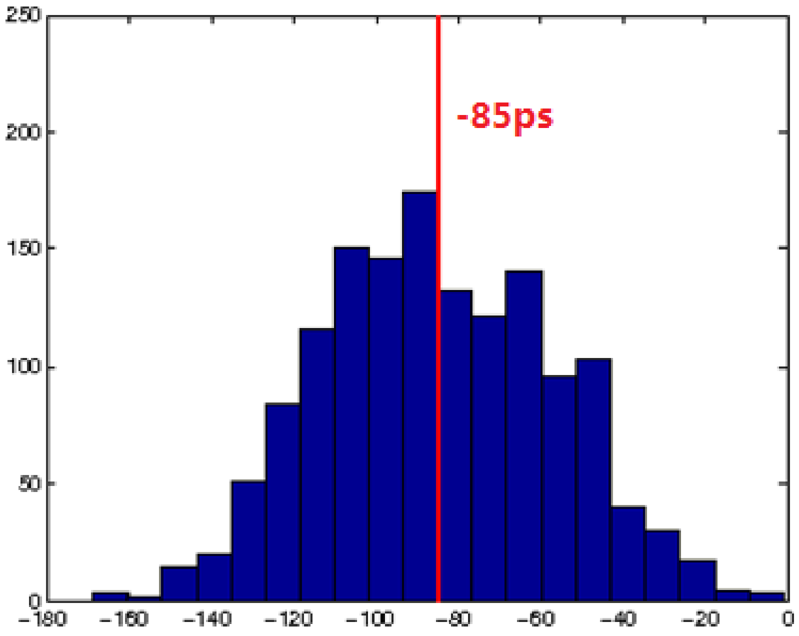
- ARGO, Yangbajin, Tibet, 4300m a.s.l.
- 48 electron detectors, 2 Muon detectors
- GPS receiver, Rubidium frequency
- 4 WR switches with latest GW/SW
- Customized node (spec. elec with WRPC)

WR deployment at YBJ@Tibet

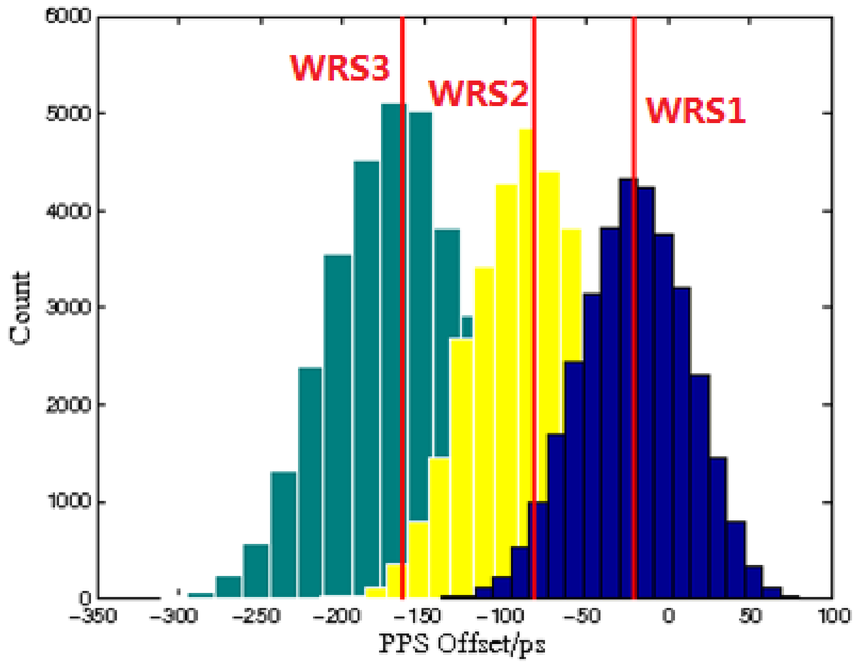


WR-Switch

GM vs PCN



WRS1,2,3 vs PCN



Over 20 hours,
temp range 10-26℃
PCN with temp. correction, WRS without

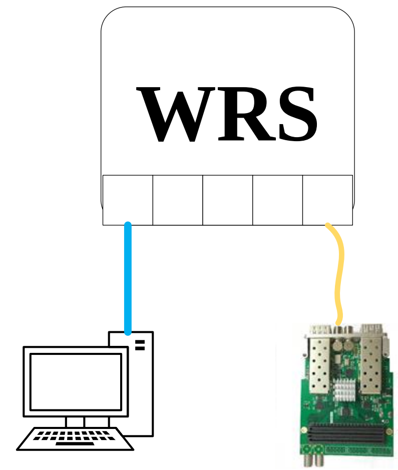
WR node

- 300 samples for each node
- Nodes in different locations
- WR integrated with detector electronics (ED & MD type)
- WRPC as IP core
- **Node has been calibrated individually**
- **Power noise causes bad precision**

Node index	Node vs PCN (ps)	
	Accuracy	precision
2	-138	100
5	-56	28
8	28	28
12	-27	150
16	5	28
17	-15	162
24	97	156
32	-40	34
39	-28	41
42	-157	135
44	-102	26
50	-45	34

Recent Developments

- WRPC updates
- Additional constrains for IP core
- Bug fix of data transmission
  - COM5402 as stack
  - Interface optimization
  - UDP 914Mb/s (1024bit/package)
  - TCP 384Mb/s (1024bit/package)
  - More work to do…. YBJ array verification, WRS still lose packages….



- SNMP support
  - snmpget & snmpwalk commands
  - More GUI tool can/will be used

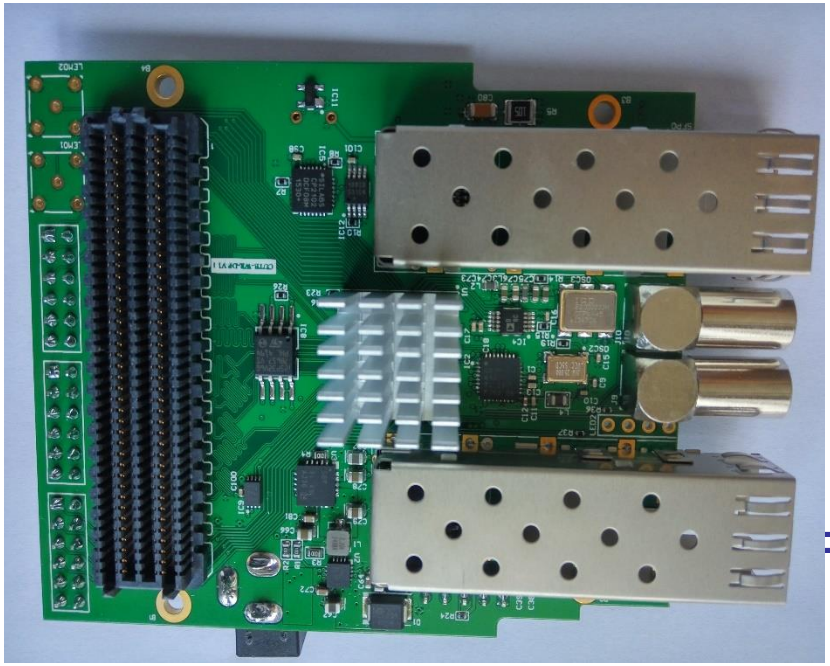
Portable Calibrate Node

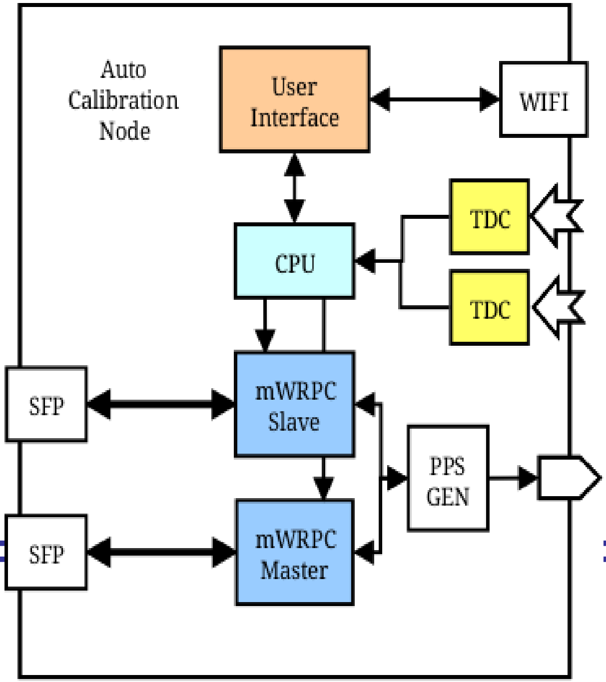
- A Cute-WR inside box, water sealed, vibration protect
- Armored optical power composite cable
- Rugged composite connector
- Provide reference PPS for field measurement
- Directly connected to/synced with Grand-Master switch

基于双端口WR节点的自动参数测试装置

NSCAL Tsinghua University

- 对LHAASO工程，可能需要对每个探测器节点和交换机端口的固定延迟参数进行单独测试和记录。
- 开发一套自动化参数测试存储装置
- 同时可以用于现场探测器安装后的快速验证

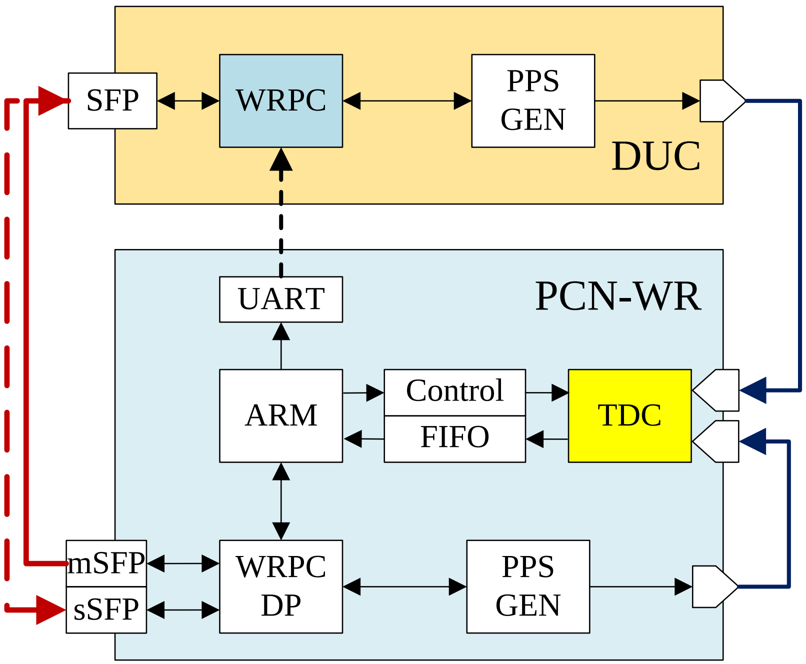




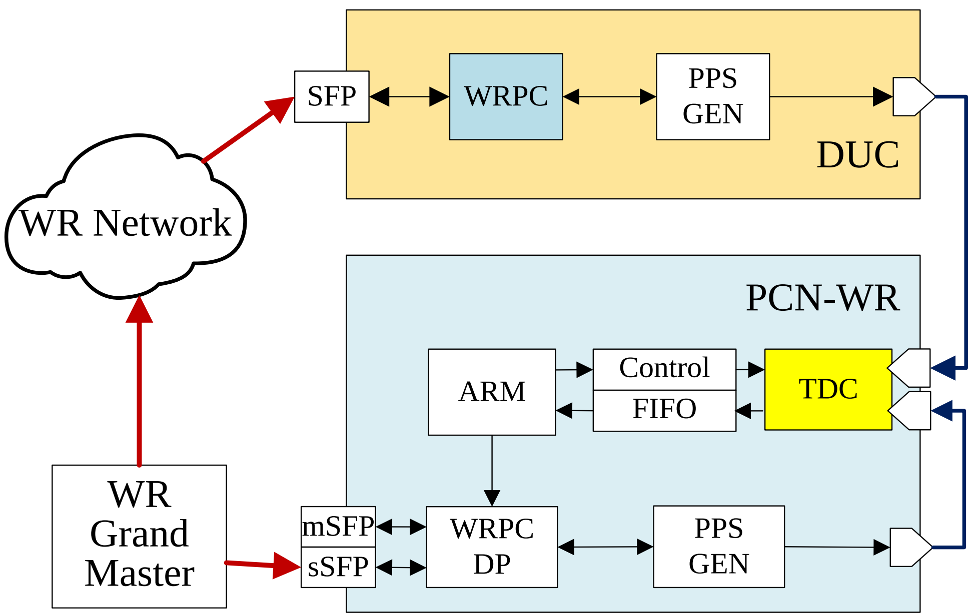
基于双端口WR节点的自动参数测试装置

NSCAL Tsinghua University

用于对WR节点进行固定参数测试



用于对安装的WR节点进行快速验证



WR阵列的标定

- WR各节点存在100ps左右的随机晃动
- 各探测器的标定系统
  - KM2A： 利用物理数据 特征面，亮源法
  - WCDA： 专用光纤定时标定网络
  - WFCTA： 激光标定
- WR系统自身需要独立的同步性能标定/检验/监测方法
  - 搬运钟
    - 绝钟精度为1～5E-13（HP5071A）。即漂移率为1nS/2000~10000秒
  - 时间双向传递对比TWFTT
  - 移动标定节点
  - GPS共视 / 差分GPS

Summary

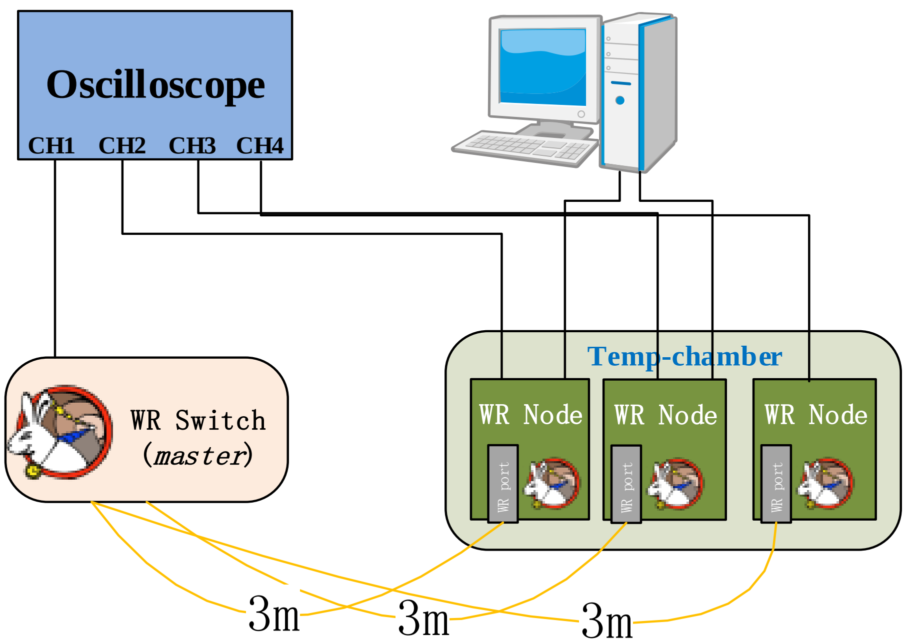
- 基于WR技术构建LHAASO实验时钟网络
  - 亚纳秒同步精度，自动补偿链路延迟
  - 多节点光纤网络连接
- 测试性能满足要求
- 开展羊八井原型阵列测试

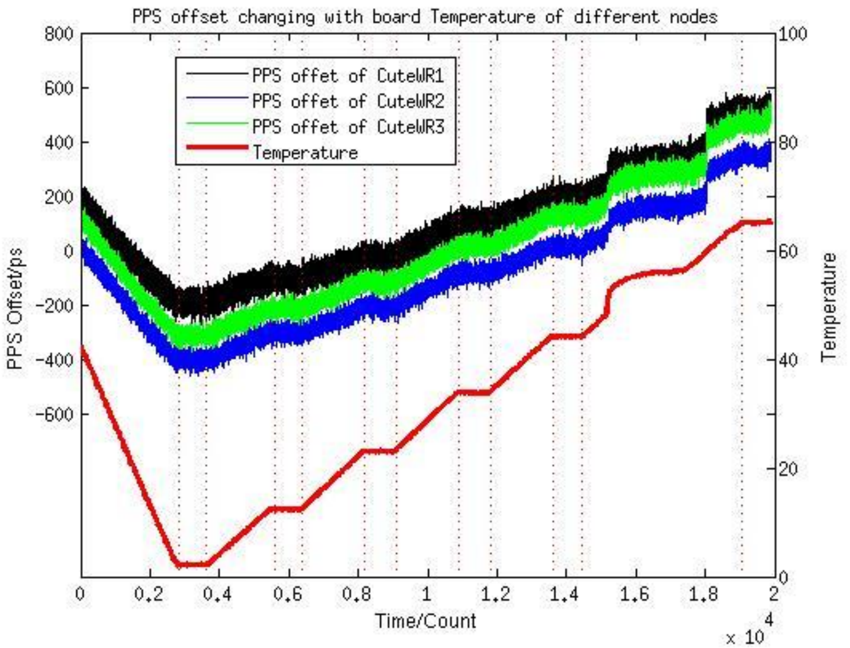
Q&A

Thank you !

WR时钟同步温度特性测试

Temp. effect measurement of FIX DELAY





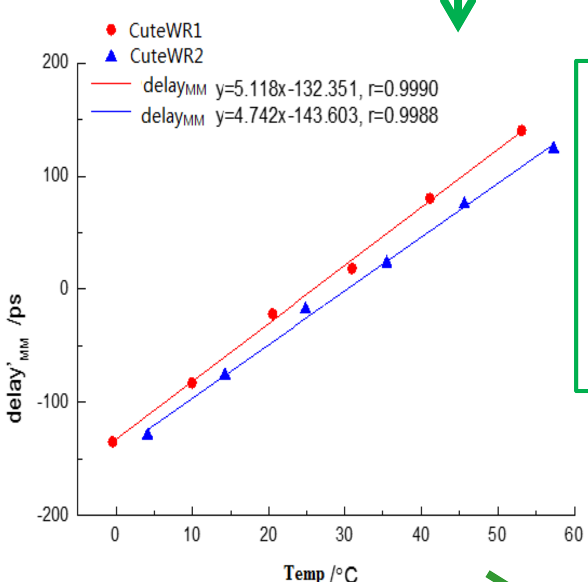
http://arxiv.org/abs/1406.4223

WR时钟同步温度特性测试

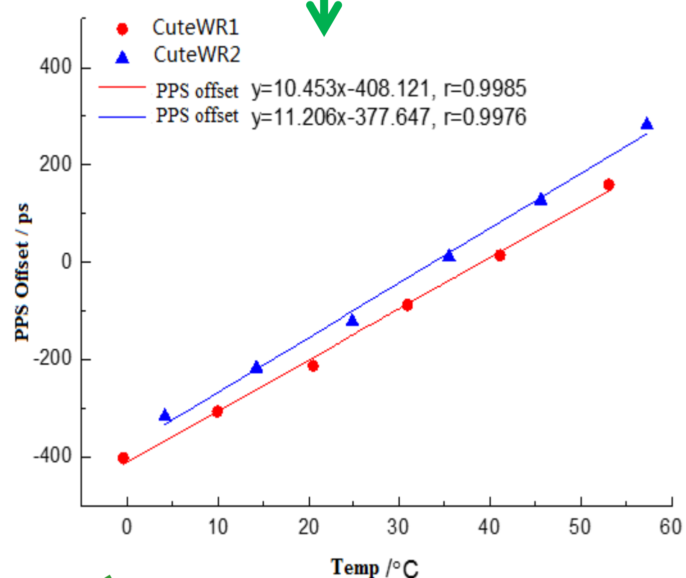
Only $(\Delta_{txs}, \Delta_{rxs})$ changes with temp.

$$\delta_{delay_{mm}} = \delta_{\Delta rxs} + \delta_{\Delta txs}$$

$$offset = \delta_{delay_{ms}} = \frac{1}{2}(\delta_{\Delta rxs} - \delta_{\Delta txs})$$



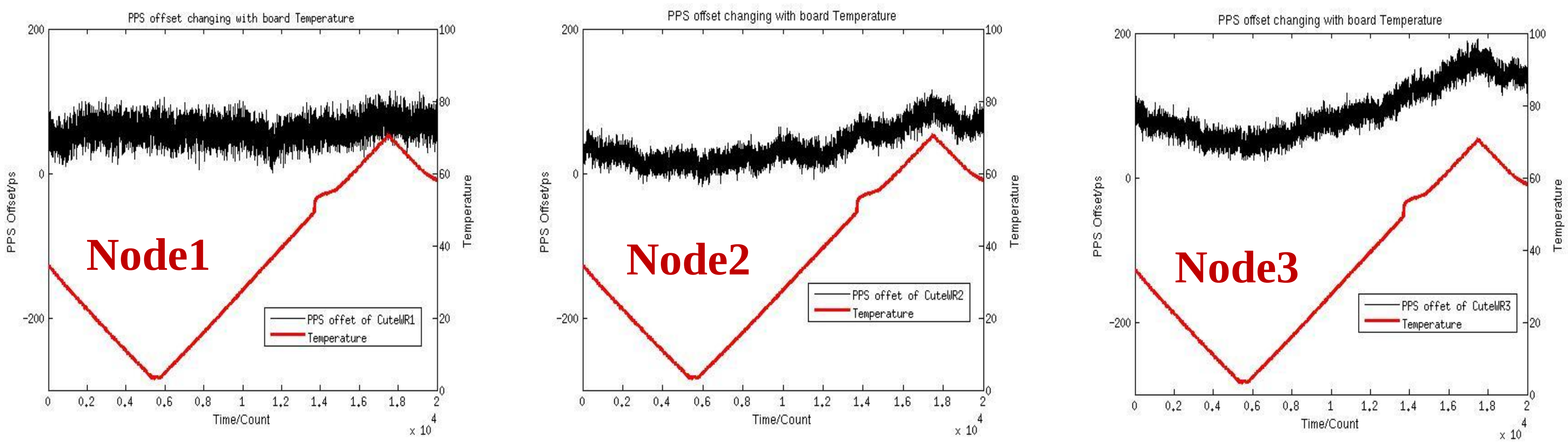
$$\delta_{txs1} = -7.9ps/°C$$
$$\delta_{rxs1} = 13.0ps/°C$$
$$\delta_{txs2} = -8.8ps/°C$$
$$\delta_{rxs2} = 13.6ps/°C$$



WR时钟同步温度特性测试

Temp. effect correction of FIX DELAY

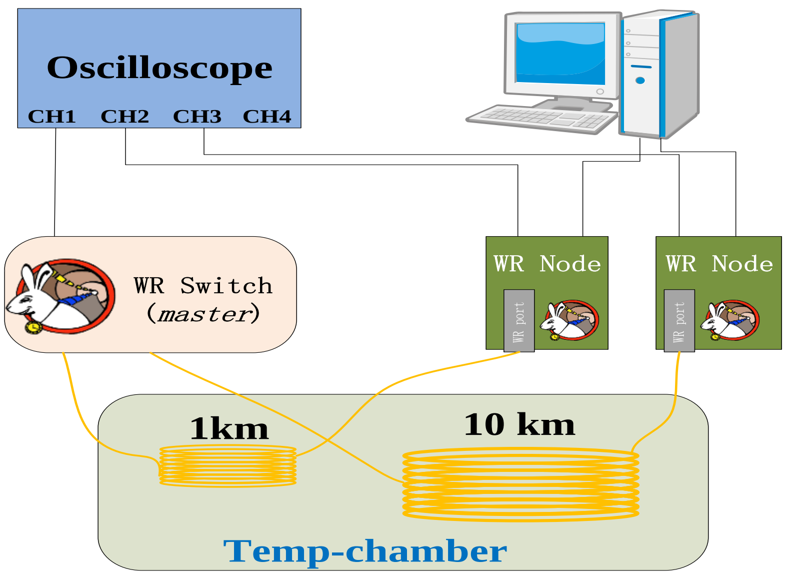
Take the average value ($\delta_{txs} = -8.5ps/℃, \delta_{rxs} = 13.0ps/℃$) for temperature correction.



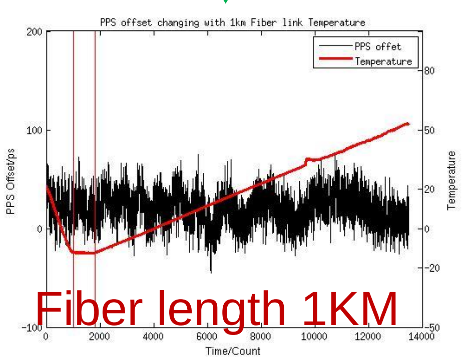
- ➢ reduced from 800ps to 150ps in 70 ℃ temperature range
- ➢ components diversity exists,
- ➢ node calibration needed for high precision application.

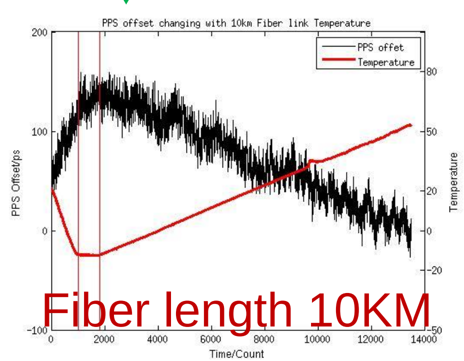
WR时钟同步温度特性测试

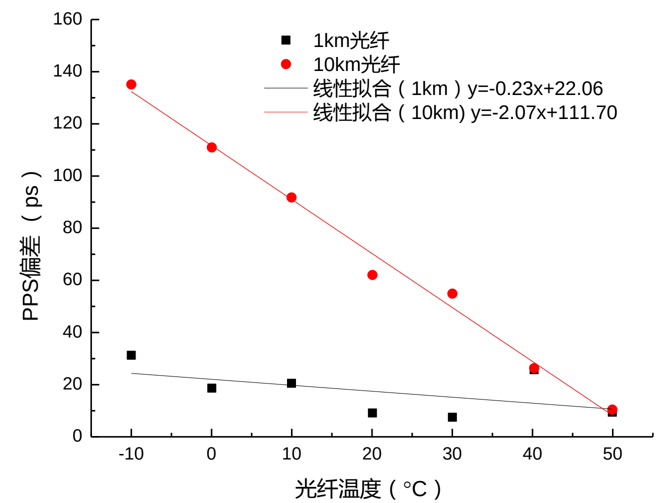
Temp. effect of **fiber length**



The refractive index of optical fiber has temp & wavelength dependency, asymmetry coefficient **α** is **not constant**, it has **temperature dependency**.



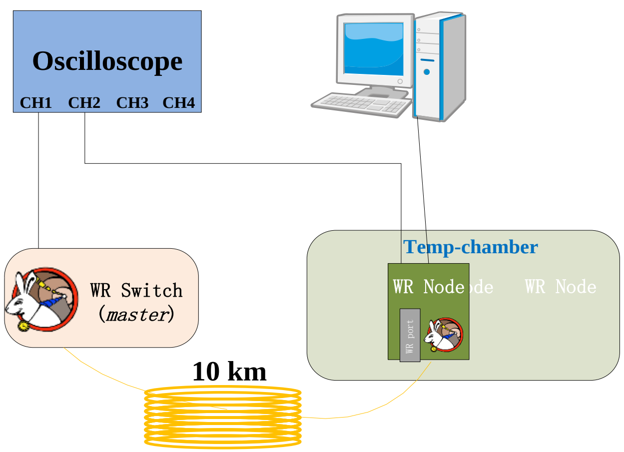
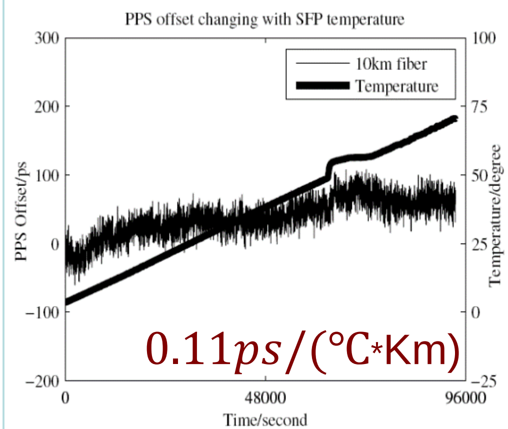
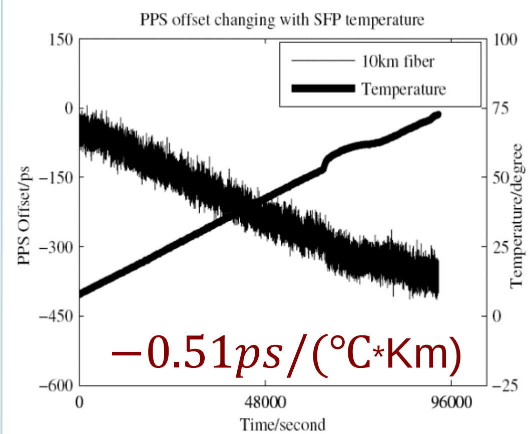




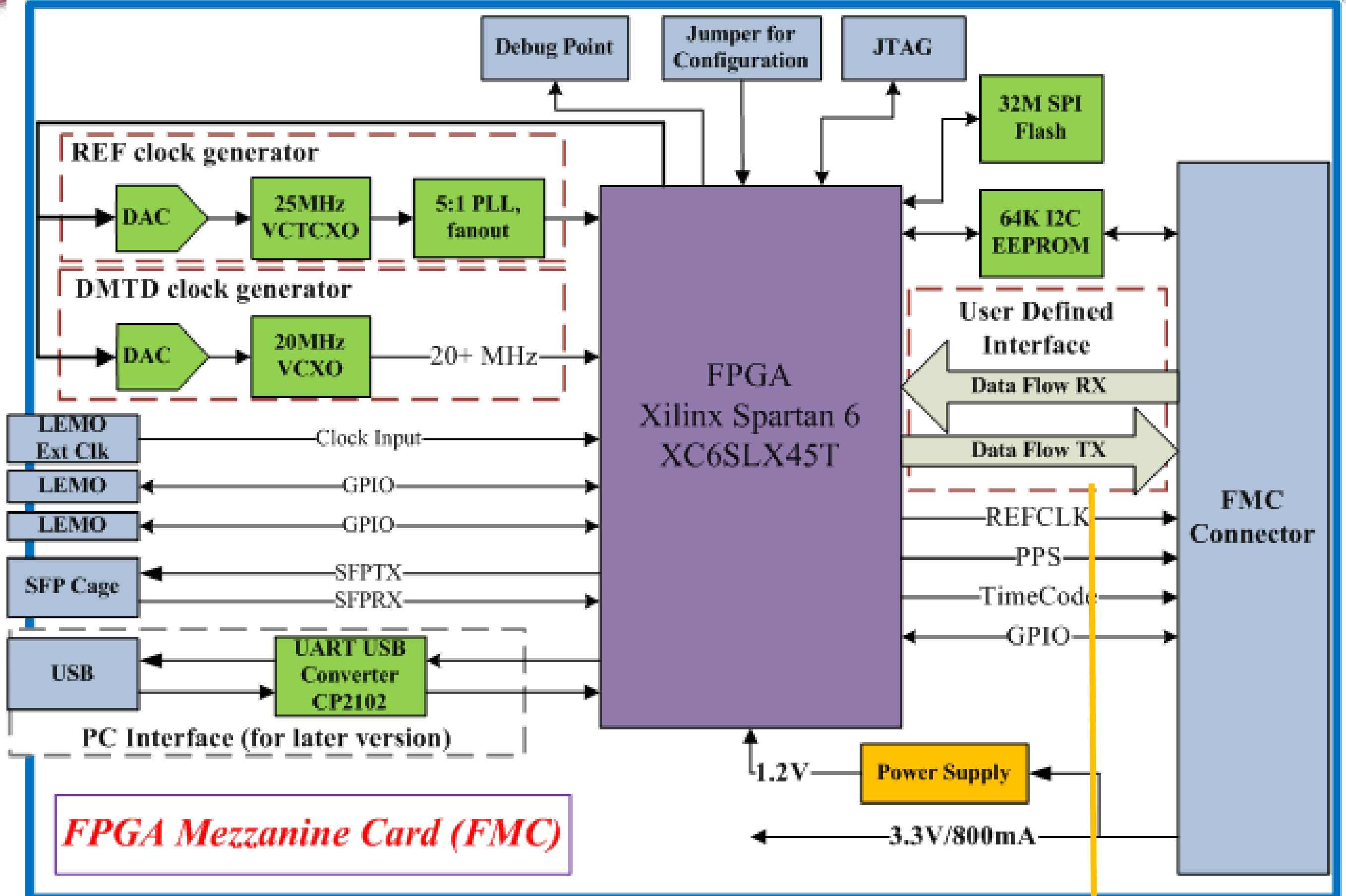
$$-0.2ps/(°C*Km)$$

WR时钟同步温度特性测试

Temp. effect of **SFP laser spectrum**

	SFP Type AXGE-1254-0531 Tx@1310nm "**Fabry-Perot**"	SFP Type AXGE-3454-0531 Tx@1490nm "**Distributed Feedback**"
		
laser diode spectrum temperature efficiency	0.4~ 0.5 nm/℃	0.08~ 0.12 nm/℃
G652.D Chromatic dispersion [ref] ITU-T $\frac{0.092\lambda}{4}[1-(\frac{1324}{\lambda})^4] \le D(\lambda) \le \frac{0.092\lambda}{4}[1-(\frac{1300}{\lambda})^4]$	-1.3~0.9 ps/(nm*km)	12.9~14.4 ps/(nm*km)
$\delta_{\Delta txs}$	-0.65~0.45 ps/(°C*km)	1.03~1.73 ps/(°C*km)
$offset = \delta_{delay_{sm}} = -\frac{1}{2}\delta_{\Delta txs}$	-0.23~0.33 ps/(°C*km)	-0.87~ -0.52 ps/(°C*km)

Cute-WR block diagram



Cute-WR provides:

- ✓ 125MHz clock
- ✓ PPS pulse
- ✓ UTC TimeCode
- ✓ Data transmission port
- ➢ Ethernet protocol processor (opt.)

Data flow of the CUTE-WR