Sub-nanosecond timing system design and development for LHAASO project

Guanghua Gong, Qiang Du
Dept. of Engineering Physics
Tsinghua Univ. Beijing

13th International Conference on Accelerator And Large Experimental Physics Control System
10-14th October 2011, WTC Grenoble, France

Sub-nanosecond timing system

for LHAASO project

Guanghua Gong, Qiang Du
Dept. of Engineering Physics
Tsinghua Univ. Beijing

13th International Conference on Accelerator And Large Experimental Physics Control System
10-14th October 2011, WTC Grenoble, France

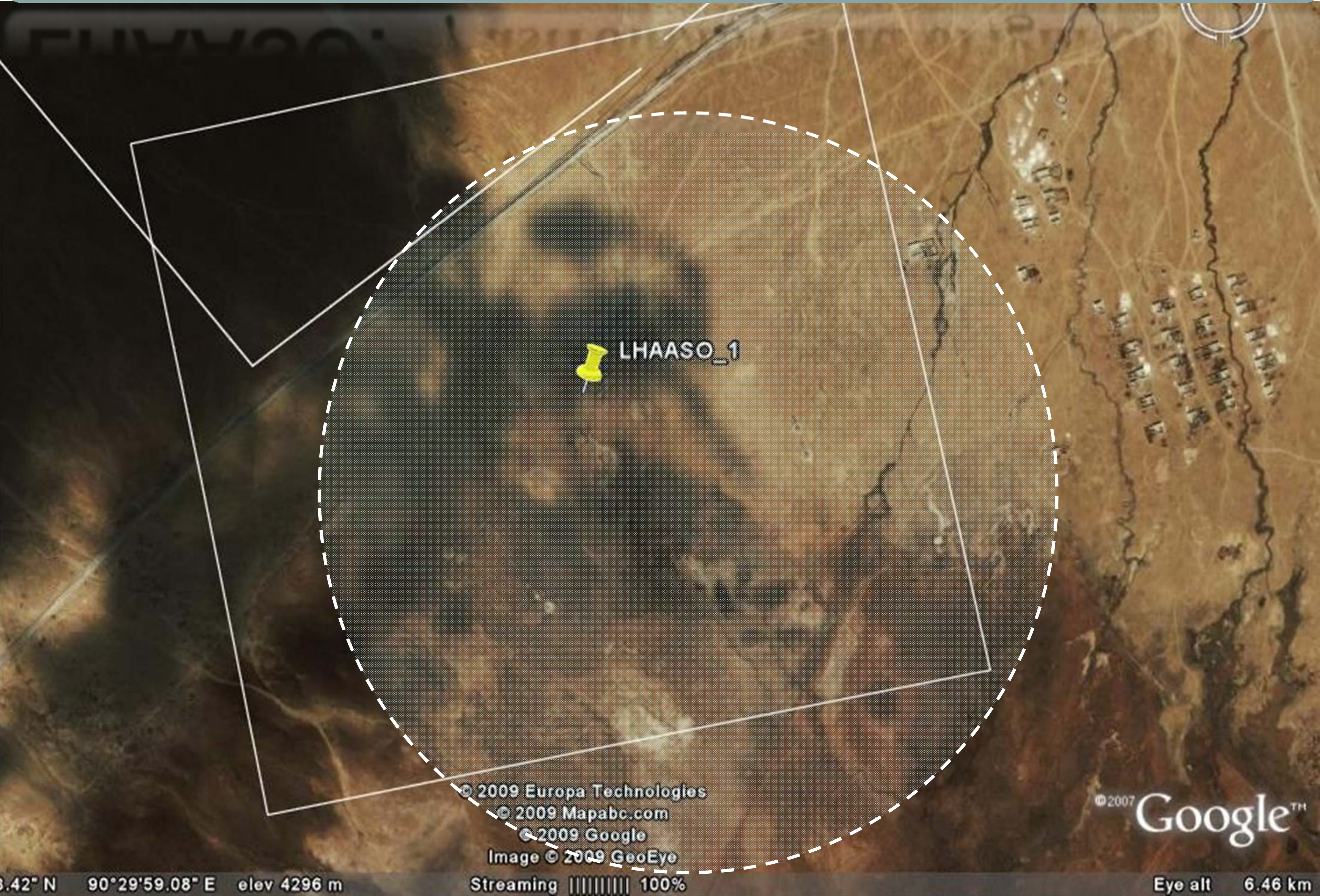
Outline

1. Introduction LHAASO
2. Timing system requirement
3. White Rabbit application in LHAASO
4. Summary

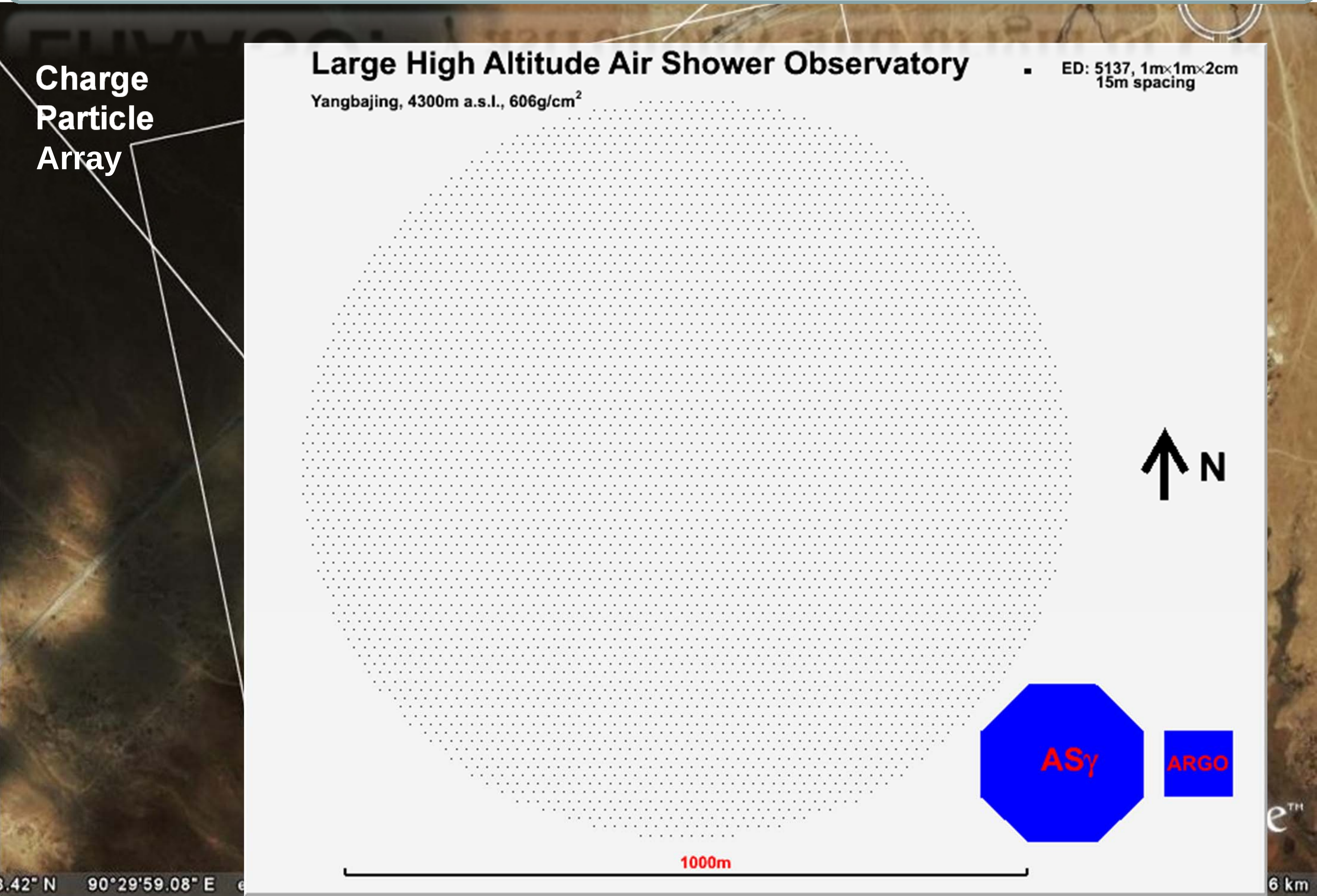
LHAASO: γ astronomy and origin of CR

Large High Altitude Air Shower Observatory

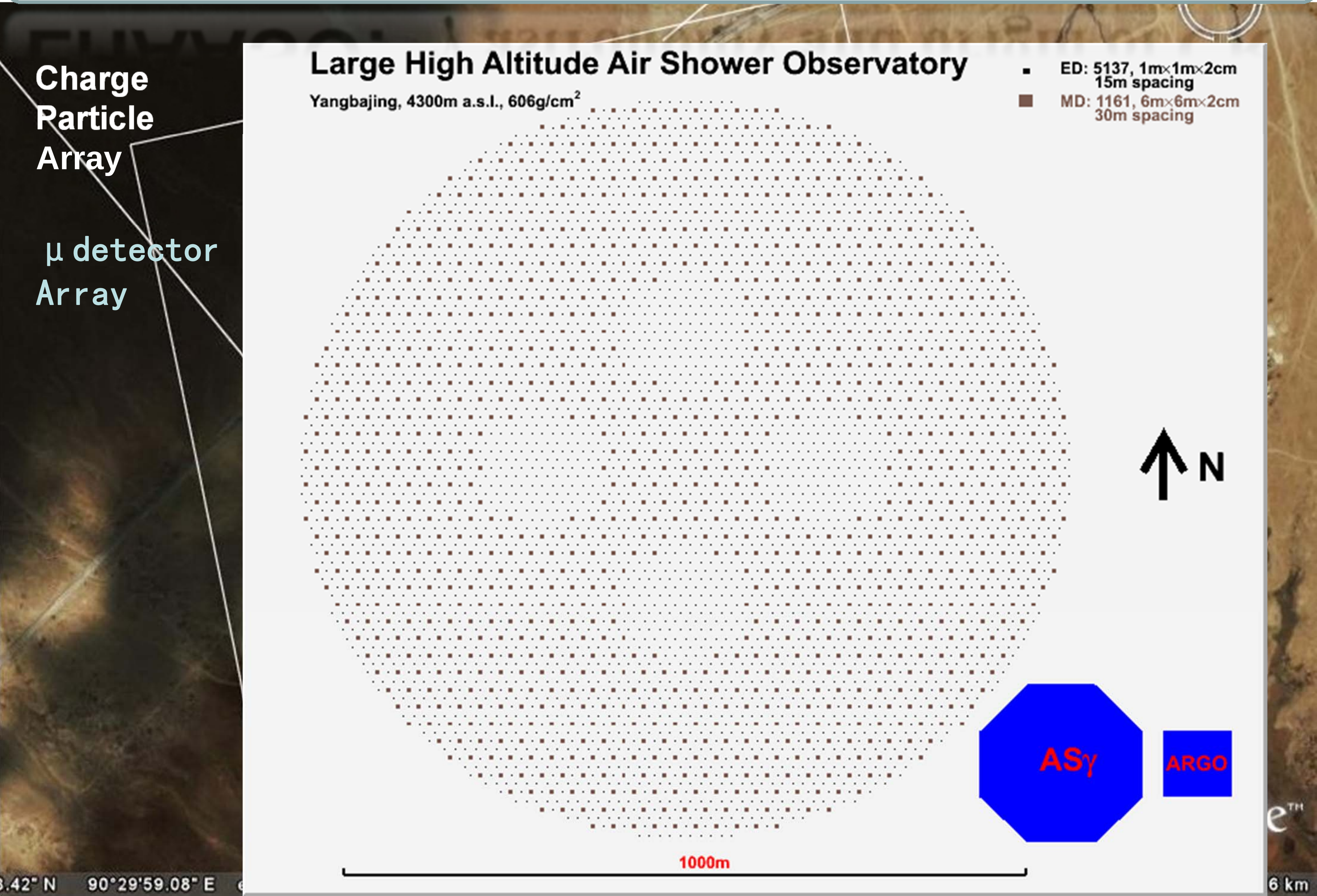
LHAASO: γ astronomy and origin of CR



LHAASO: γ astronomy and origin of CR



LHAASO: γ astronomy and origin of CR

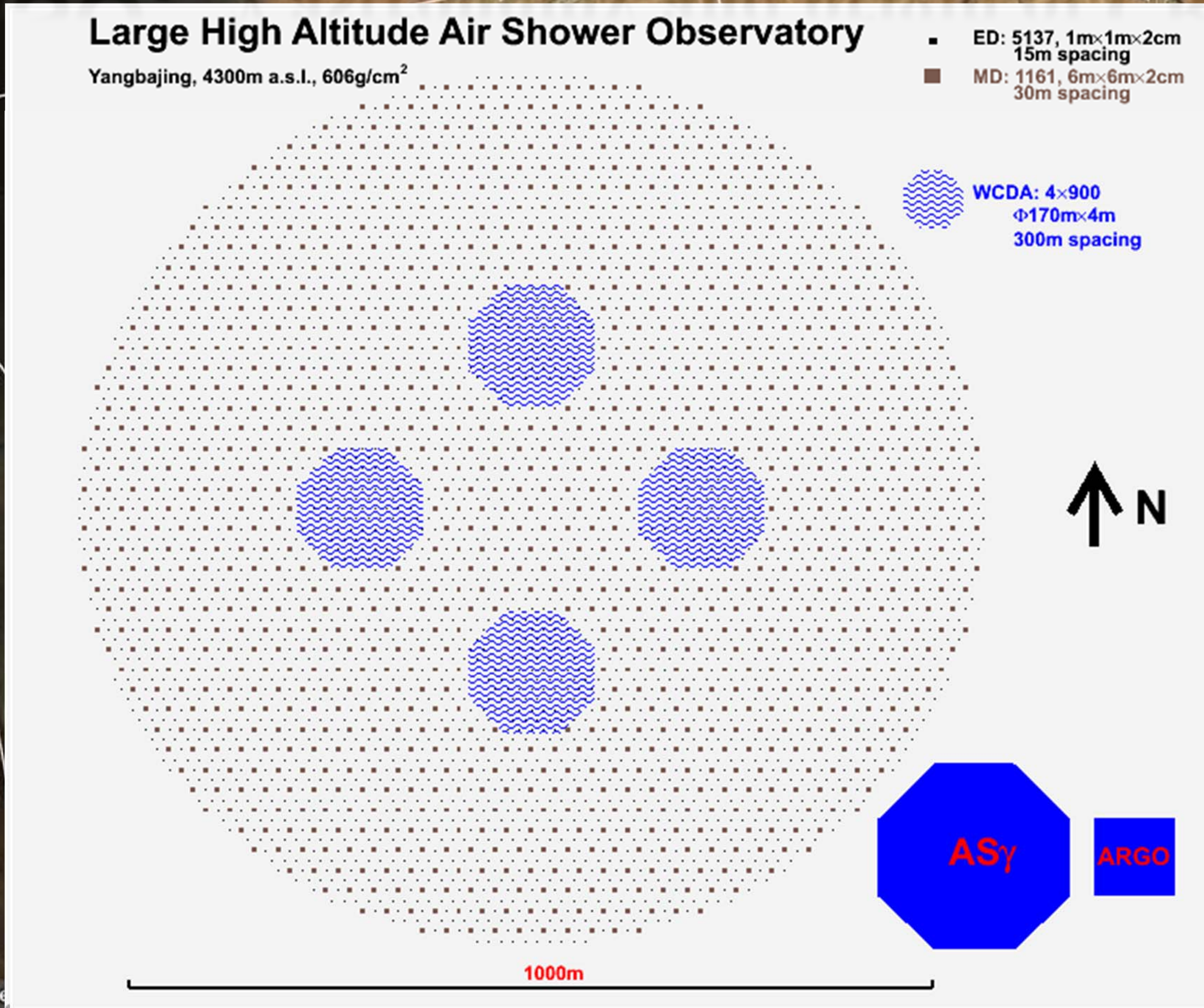


LHAASO: γ astronomy and origin of CR

Charge Particle Array

μ detector Array

Water C Array



LHAASO: γ astronomy and origin of CR

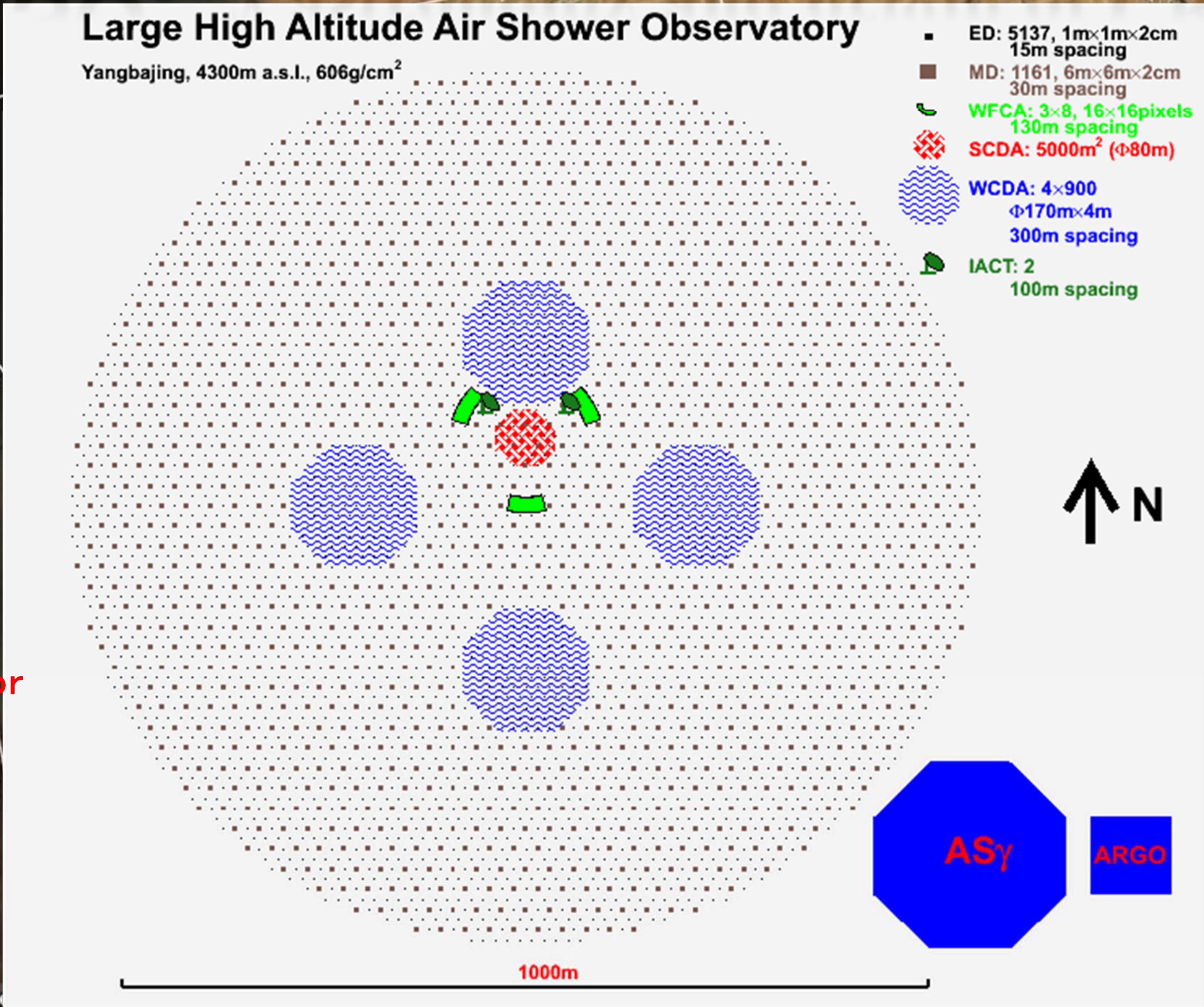
Charge Particle Array

μ detector Array

Water C Array

Wide FOV C-Telescope Array

Core Detector Array

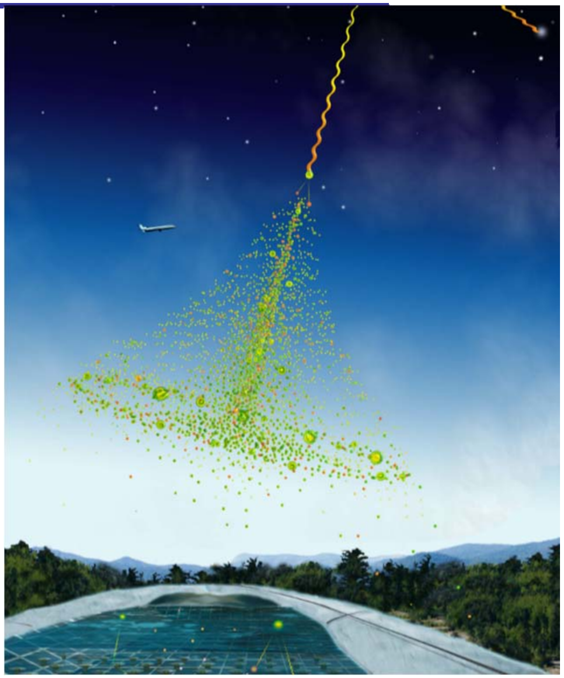


.42" N 90°29'59.08" E

6 km

LHAASO detector

- KM2A：
  - 5137 Electron detector, 15m spacing
  - 1200 μ detector, 30m spacing
- WCDA： ***W**ater **C**herenkov **D**etector **A**rray*
  - 150×150 m^2
  - 3600 detector units
- WFCTA： ***W**ide **F**OV **C**herenkov **T**elescope **A**rray*
  - 24, 300m spacing
- SCDA： ***S**hower **C**ore **D**etector **A**rray*



Over 10,000 detector units
Spread around 1Km2 area

Reconstruct shower direction from *timing* of hits across detector

Synchronous timing among detectors

Timing requirement

1. Support 10,000 nodes
2. clock distribution

   clock is used for Time-Digital-Converter
   High accuracy, low phase noise
3. time-stamp distribution

   Trigger-less readout electronics,
   timestamp used for event alignment
   To guarantee pointing accuracy in reconstruction,
   Timestamp offset < 1ns
4. Automatic cable/fiber propagation correction

Timing requirement – cont.

5 High reliability, easy to maintain

manual intervention is difficult
24-7 running

6 Low power consumption

Heat sinking is problem
Power from solar panel is limited

7 Environmental robustness

Wide temperature range
High altitude, thin air

8 Low cost

Simple hierarchy, less items
Share cable/fiber with data link path

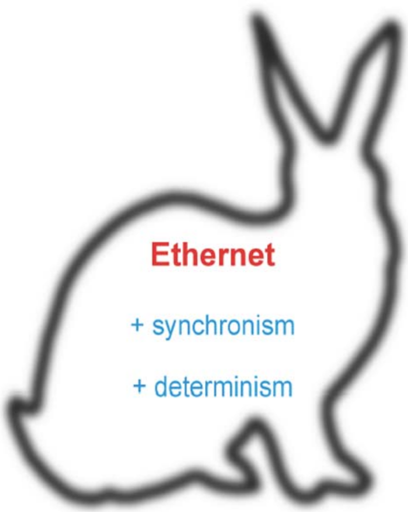
Evolution of Timing Distribution Method

Method	Ability	Accuracy jitter	Medium	Layer	Complexity	Manageability
Radio Clock	Time	10ms	Wireless	Layer 1	Simple	No
NTP	Time	1ms	Wireless	Layer 3	Complex	No
CDMA	Time/Freq	10μs	Wireless	Layer 2	Complex	?
WCDMA	Time/Freq	3μs	Wireless	Layer 2	Complex	?
WiMAX/ LTE	Time/Freq	1μs	Wireless	Layer 2	Complex	?
GPS	Time/Freq	14ns	Sat – earth	Layer 1	Simple	No
PTPv2	Time	~ns	Ethernet	Layer 2	Complex	Yes
UTI J.211	Time/Freq	1ns	Cable	Layer 1	Simple	Yes
SDH/SyncE	Freq	10ps	Ethernet	Layer 1	Simple	No
White Rabbit	Time/Freq	<1ns	Fiber GBE	Layer 1, 2	Complex	Yes
Optical carrier sync	Freq	<50fs	Fiber	Layer 1	Ultra complex	Yes
Optical Frequency Comb distribution	Time/Freq	<10fs	Fiber	Layer 1	Ultra complex	Yes

Evolution of Timing Distribution Method

Method	Ability	Accuracy jitter	Medium	Layer	Complexity	Manageability
Radio Clock	Time	10ms	Wireless	Layer 1	Simple	No
NTP	Time	1ms	Wireless	Layer 3	Complex	No
CDMA	Time/Freq	10μs	Wireless	Layer 2	Complex	?
WCDMA	Time/Freq	3μs	Wireless	Layer 2	Complex	?
WiMAX/ LTE	Time/Freq	1μs	Wireless	Layer 2	Complex	?
GPS	Time/Freq	14ns	Sat – earth	Layer 1	Simple	No
PTPv2	Time	~ns	Ethernet	Layer 2	Complex	Yes
UTI J.211	Time/Freq	1ns	Cable	Layer 1	Simple	Yes
SDH/SyncE	Freq	10ps	Ethernet	Layer 1	Simple	No
White Rabbit	Time/Freq	<1ns	Fiber GBE	Layer 1, 2	Complex	Yes
Optical carrier sync	Freq	<50fs	Fiber	Layer 1	Ultra complex	Yes
Optical Frequency Comb distribution	Time/Freq	<10fs	Fiber	Layer 1	Ultra complex	Yes

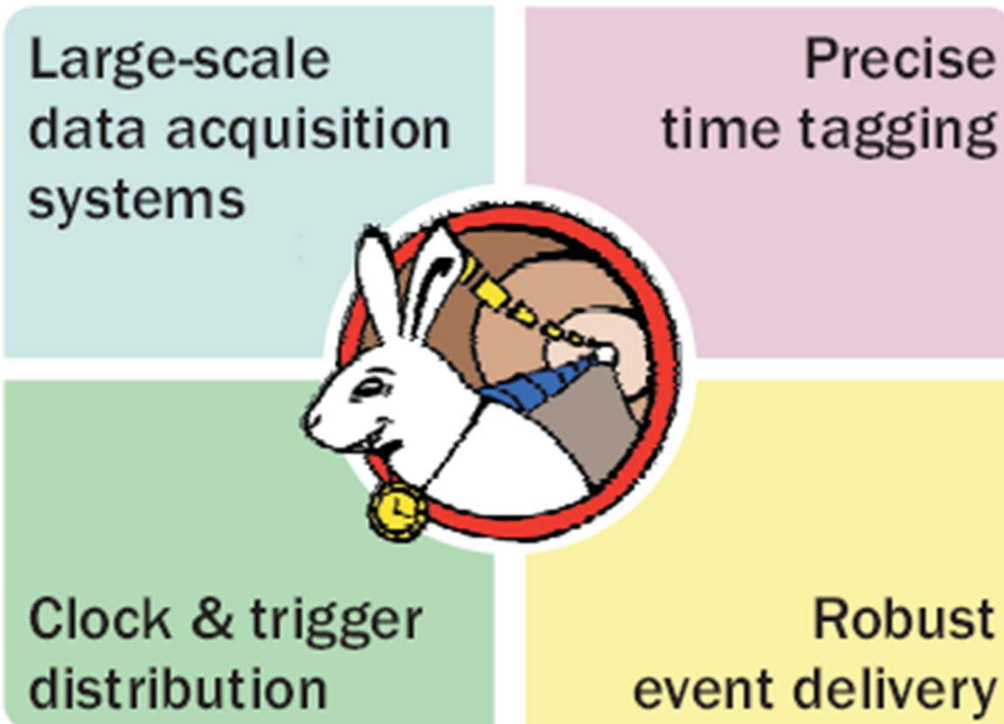
White Rabbit



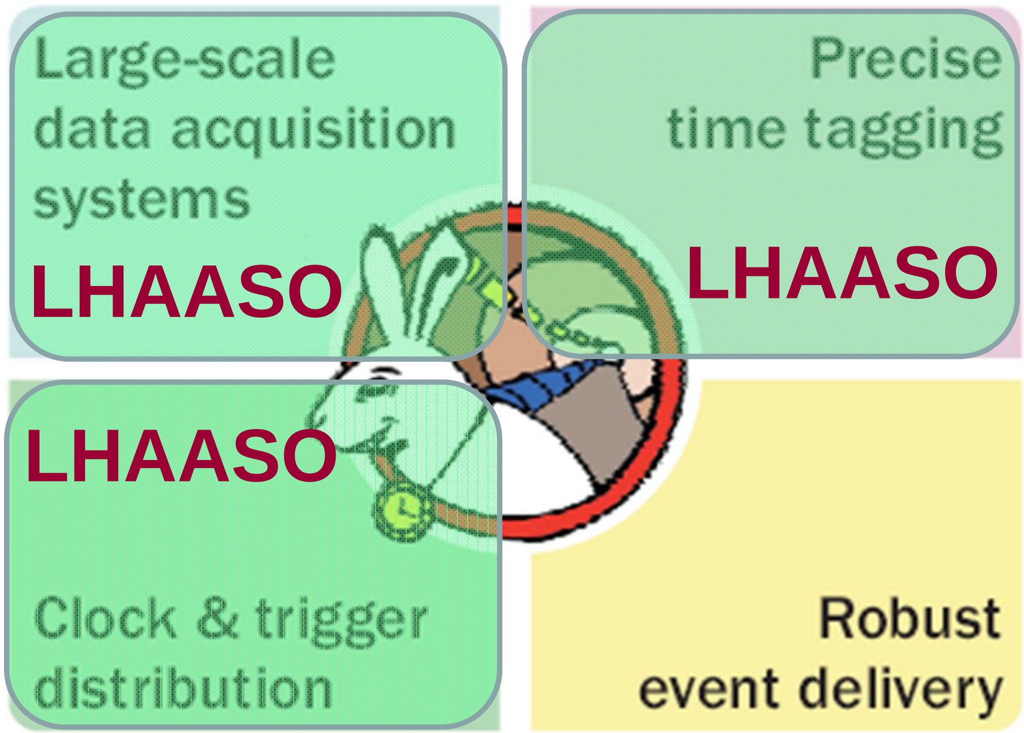
An **extension** to **Ethernet** which provides:

- **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.

Possible application of Write Rabbit



Possible application of Write Rabbit



WR applicability for LHAASO

? 1 Support 10,000 nodes

√ 2 clock distribution

√ 3 time-stamp distribution

√ 4 Automatic cable/fiber propagation correction

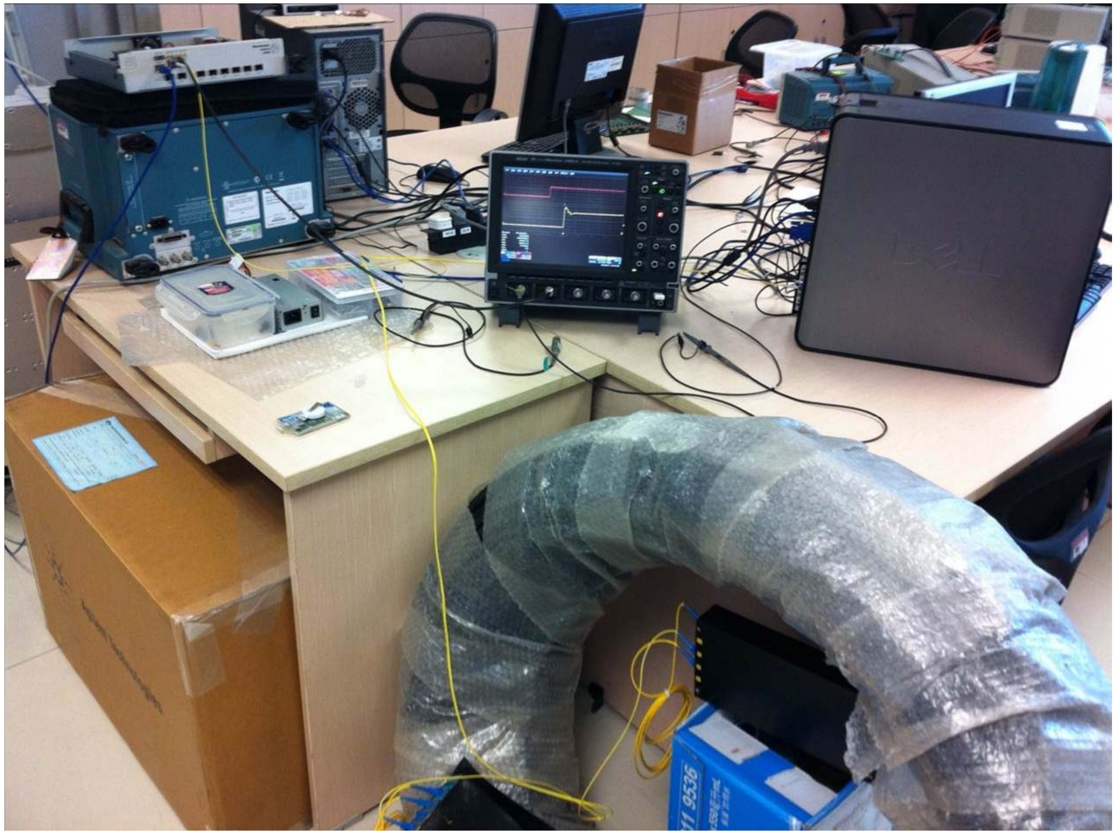
— 5 High reliability, easy to maintain

— 6 Low power consumption

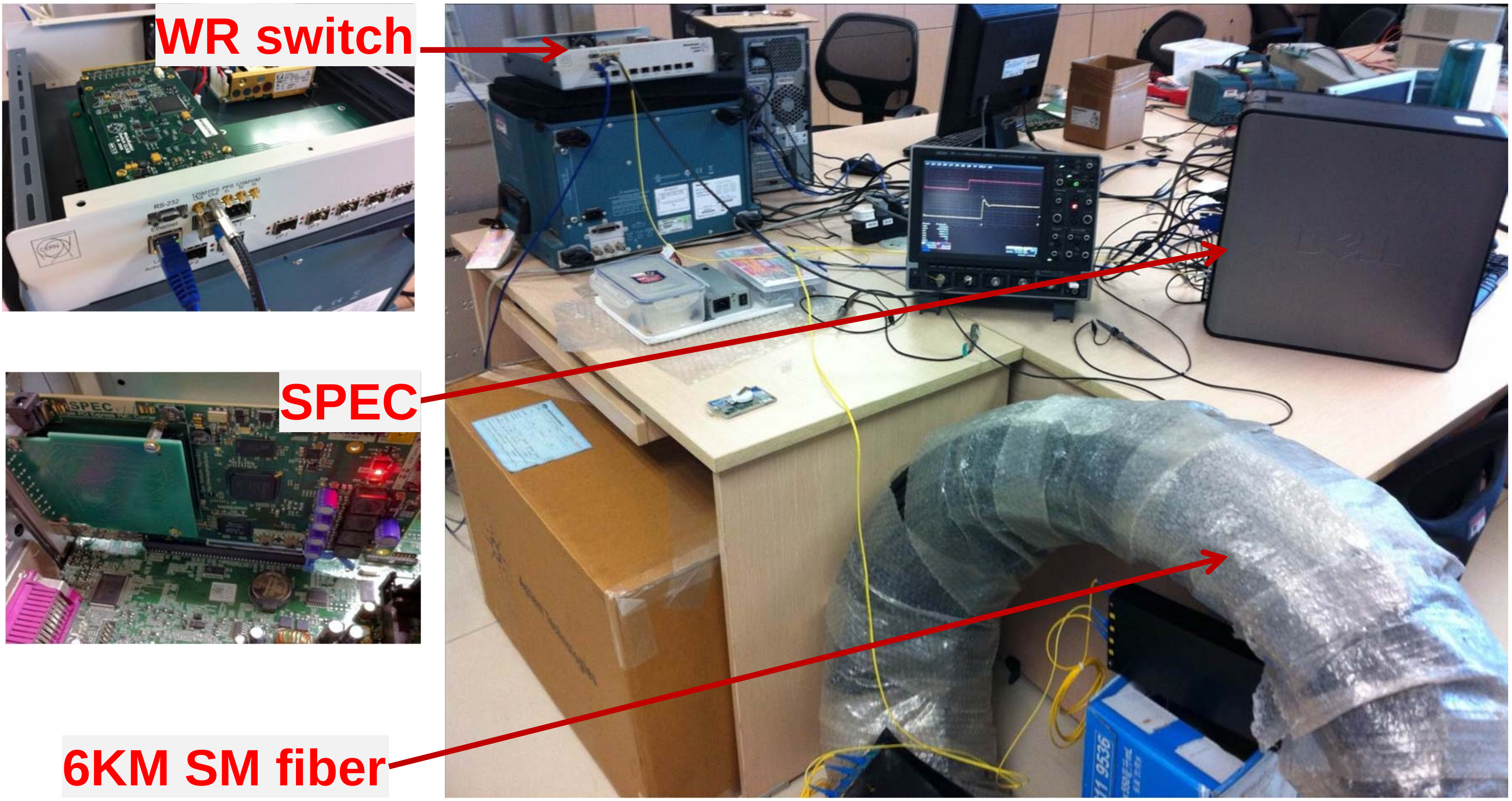
— 7 Environmental robustness

— 8 Low cost

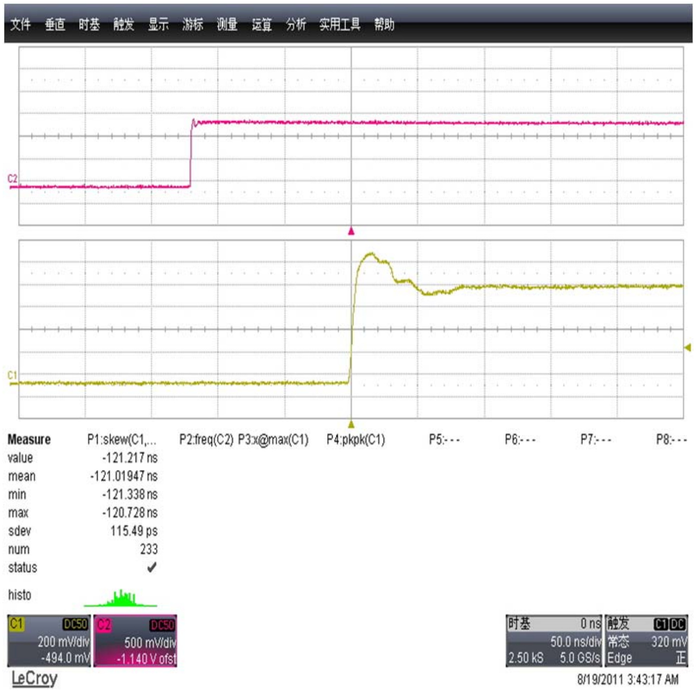
Test setup



Test setup



Test result



Fiber Length Compensation

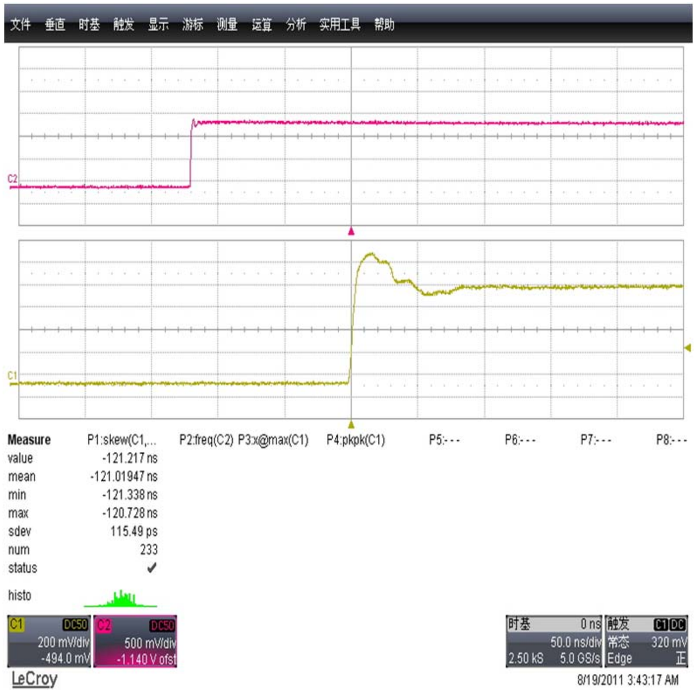
Fiber Length	PPS delay	
	Mean[1]	Sdev[2]
30cm	121.02ns	115.49ps
1km	125.72ns	110.66ps
5km	127.62ns	105.14ps

Repeatability of Recovered PPS

#Run	30cm	1km	2km	3km	4km	5km
Run 1	16.05	15.89	15.82	15.78	15.67	15.57
Run 2	16.05	15.92	15.89	15.76	15.64	15.65
Run 3	16.02	15.93	15.86	15.72	15.67	15.65
Average	16.04	15.91	15.86	15.75	15.66	15.62
Peak-Peak	0.03	0.04	0.07	0.06	0.03	0.08
Link delay	473	10305	20145	29969	39801	49641

Note 1: the delay mainly comes from the length difference of the coaxial cables used for measurement.
Note 2: the deviation mainly comes from the test signal drive circuit.

Test result



Fiber Length Compensation

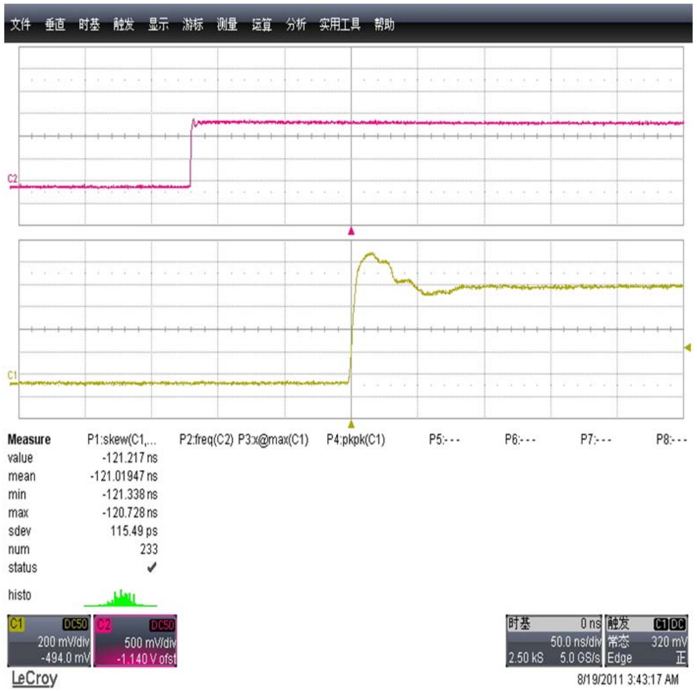
Fiber length automatically measured and compensated

Repeatability of Recovered PPS

#Run	30cm	1km	2km	3km	4km	5km
Run 1	16.05	15.89	15.82	15.78	15.67	15.57
Run 2	16.05	15.92	15.89	15.76	15.64	15.65
Run 3	16.02	15.93	15.86	15.72	15.67	15.65
Average	16.04	15.91	15.86	15.75	15.66	15.62
Peak-Peak	0.03	0.04	0.07	0.06	0.03	0.08
Link delay	473	10305	20145	29969	39801	49641

Note 1: the delay mainly comes from the length difference of the coaxial cables used for measurement.
Note 2: the deviation mainly comes from the test signal drive circuit.

Test result



Fiber Length Compensation

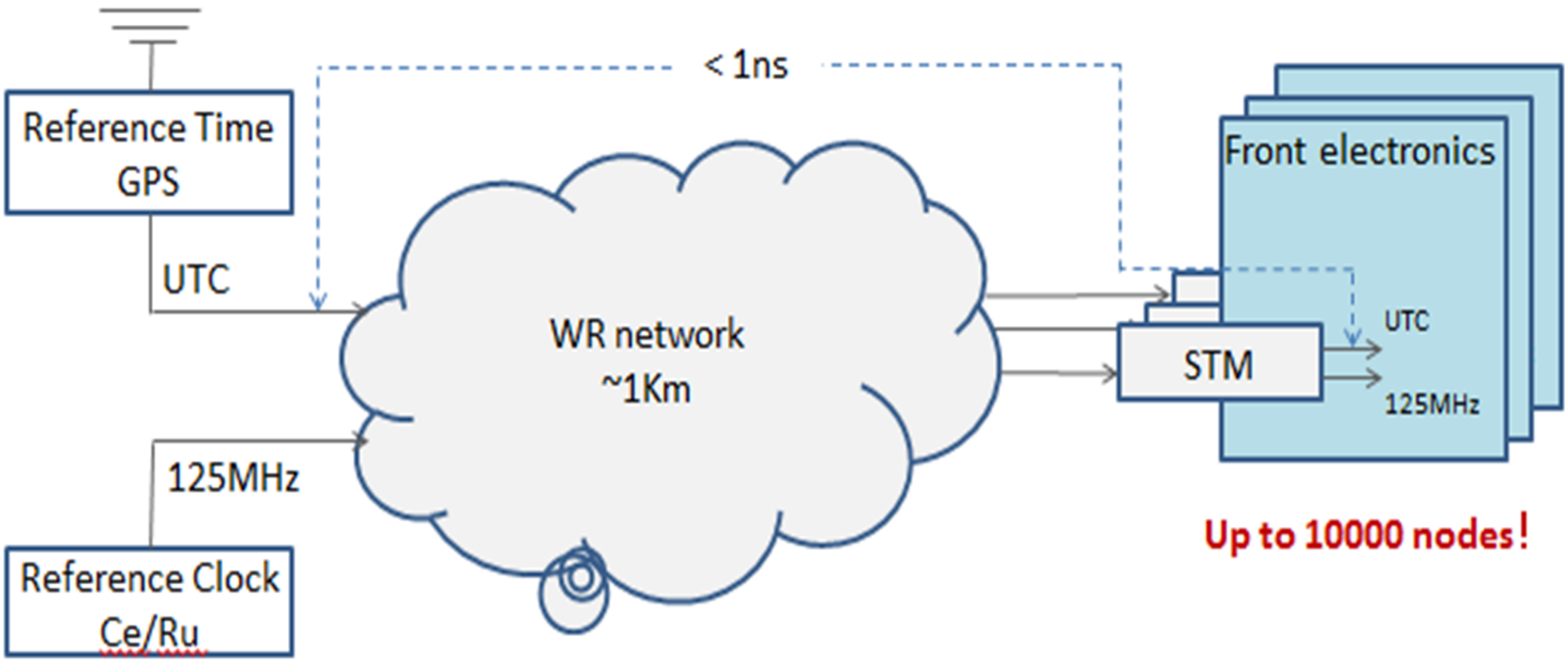
Fiber length automatically measured and compensated

Repeatability of Recovered PPS

The repeatability is less than 100ps

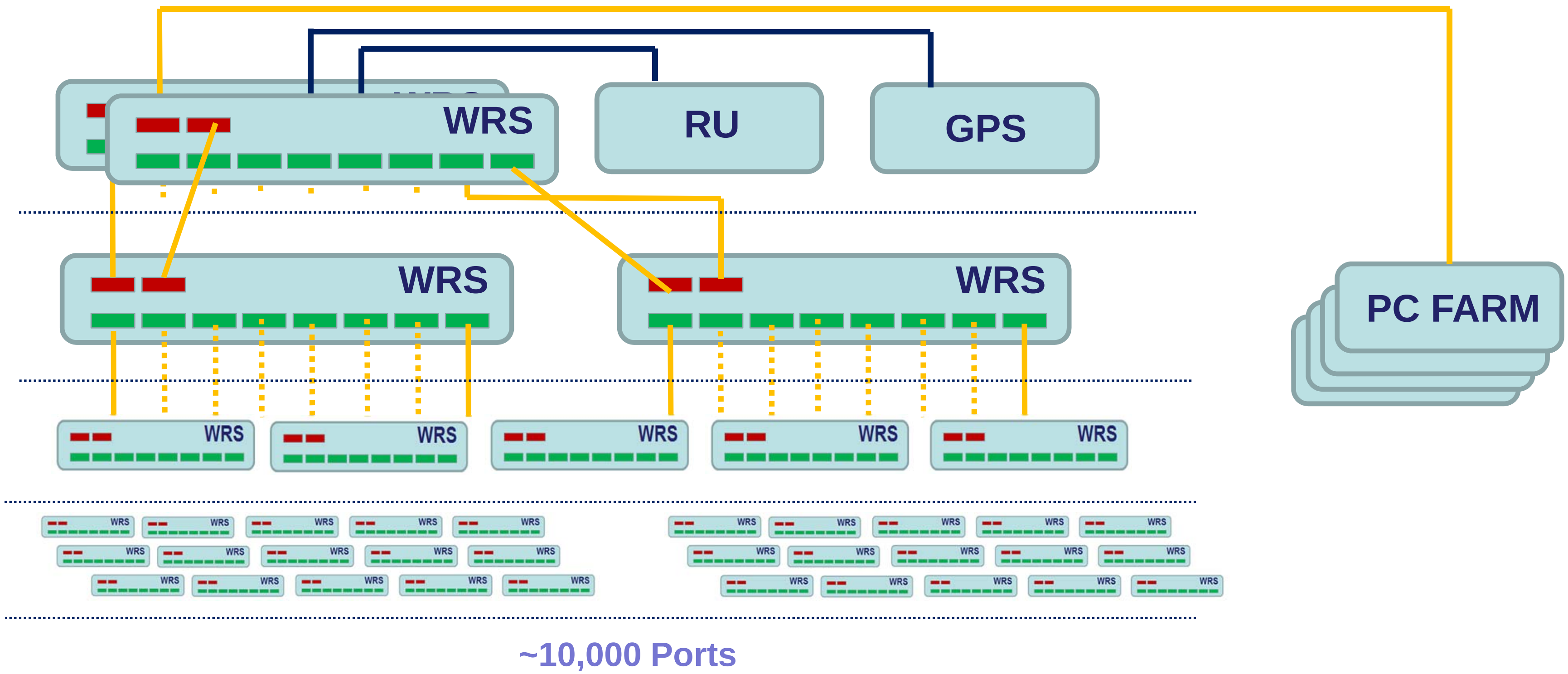
Note 1: the delay mainly comes from the length difference of the coaxial cables used for measurement.
Note 2: the deviation mainly comes from the test signal drive circuit.

White Rabbit Topology in LHAASO



Global Time and clock reference from GPS and Rubidium oscillator
Each nodes has a "**S**ynchronization and **T**ransmission **M**ezzanine"

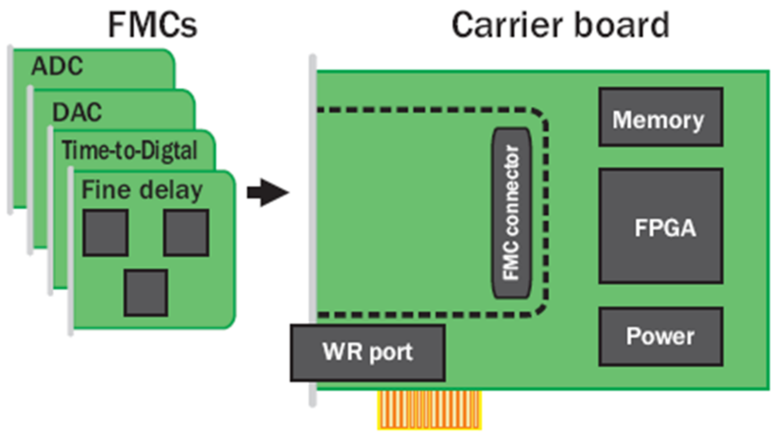
WR network



- WRS #ports count! 1300 for 8port, 650 for 16 port, 330 for 32port
- Network management required
- Boundary clock cross 4 layers
- Certain level of redundancy is needed

WR in CO-HT's hardware Kit

WR in Co-HT's Hardware Kit



T. Włostowski

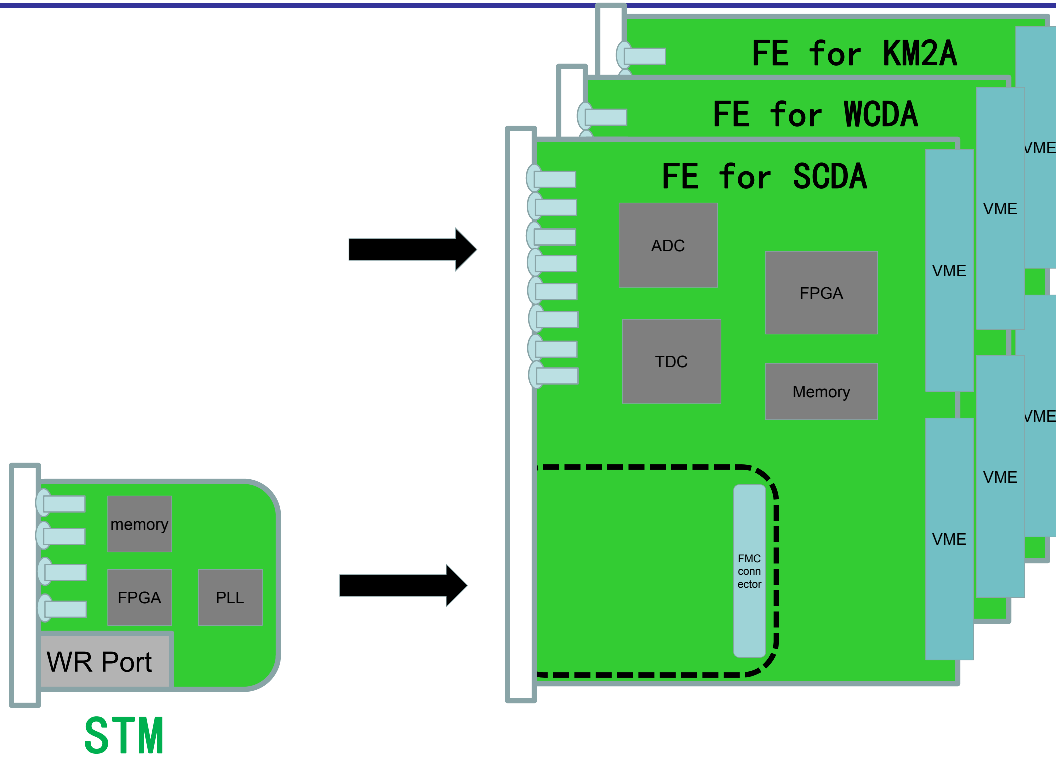
BE-CO Hardware and Timing section
CERN

November 11, 2010

Co-HT FMC-based Hardware Kit:

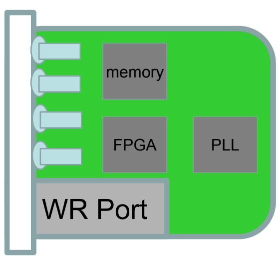
- FMCs (FPGA Mezzanine Cards) with ADCs, DACs, TDCs, fine delays, digital I/O
- Carrier boards in PCI-Express, VME and uTCA formats
- All carriers are equipped with a White Rabbit port

An opposite situation

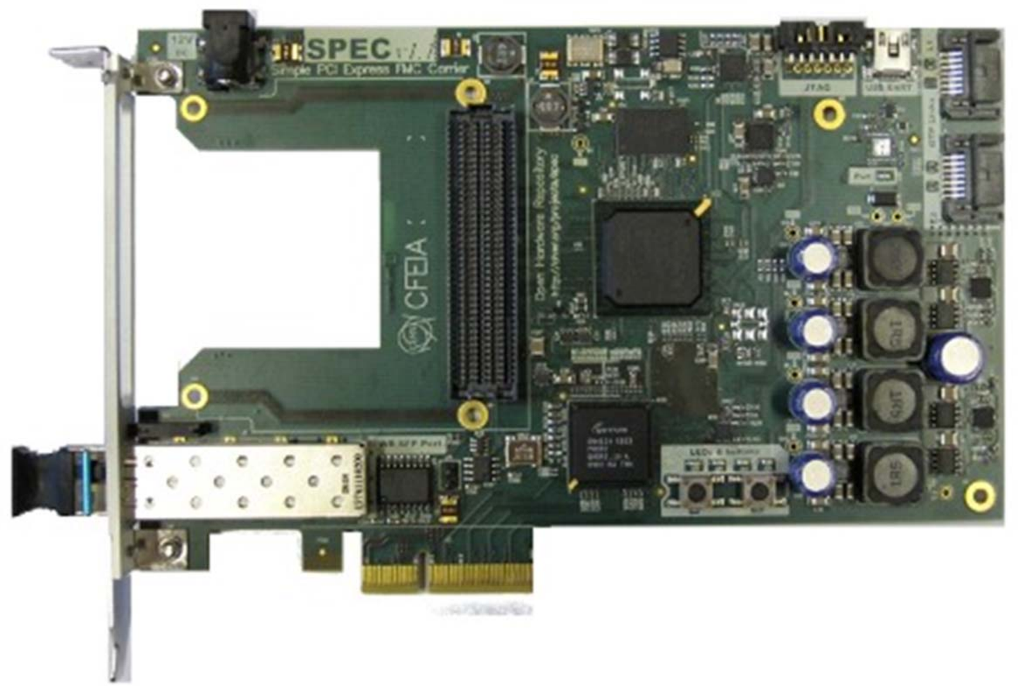


VME format front-end electronics developed
FE acts as carrier while WR in FMC

STM

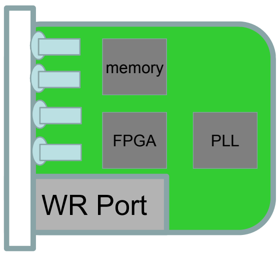


STM



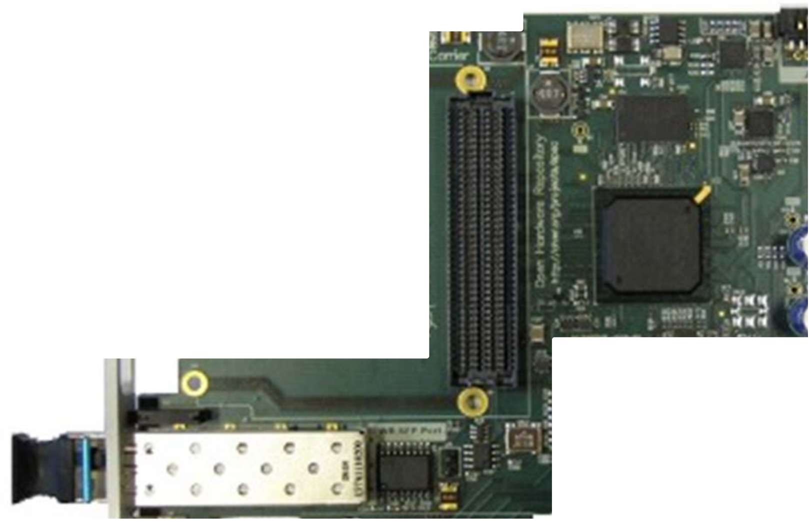
- The STM has the similar functionality as SPEC
  No carriage, No PCIe, No PWR, no SATA ….
- Merge the SPEC into FMC form! Keep all connections compatible!
- Difficult but seems not impossible!

STM



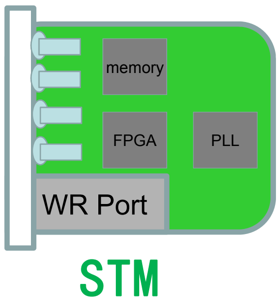
STM

=

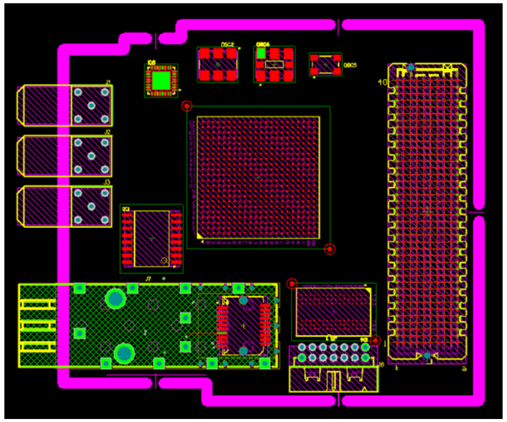


- The STM has the similar functionality as SPEC
  No carriage, No PCIe, No PWR, no SATA ….
- Merge the SPEC into FMC form! Keep all connections compatible!
- Difficult but seems not impossible!

STM



=



- The STM has the similar functionality as SPEC
  No carriage, No PCIe, No PWR, no SATA ….
- Merge the SPEC into FMC form! Keep all connections compatible!
- Difficult but seems not impossible!

Summary

- LHAASO will be built in 5~6 years. 10000 detector units need to be precisely synchronized!
- Timing system based on Write Rabbit technology is proposed.
- A demonstration has been setup and tested

- Thank you!