Design and Construction of CPPF System in CMS L1 Trigger Phase I Upgrade

Zhen-An LIU*, Libo CHENG, Chunjie WANG,

Pengcheng CAO , Jingzhou ZHAO

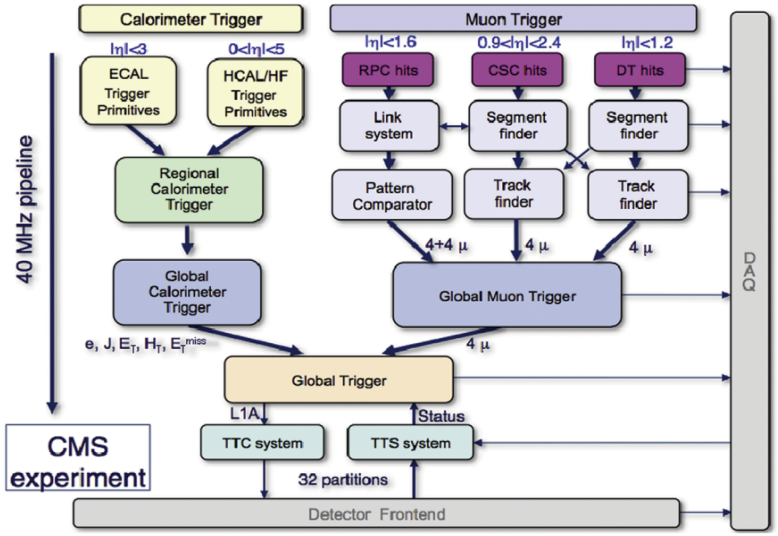
TrigLab, IHEP

Dec. 22-24 2017

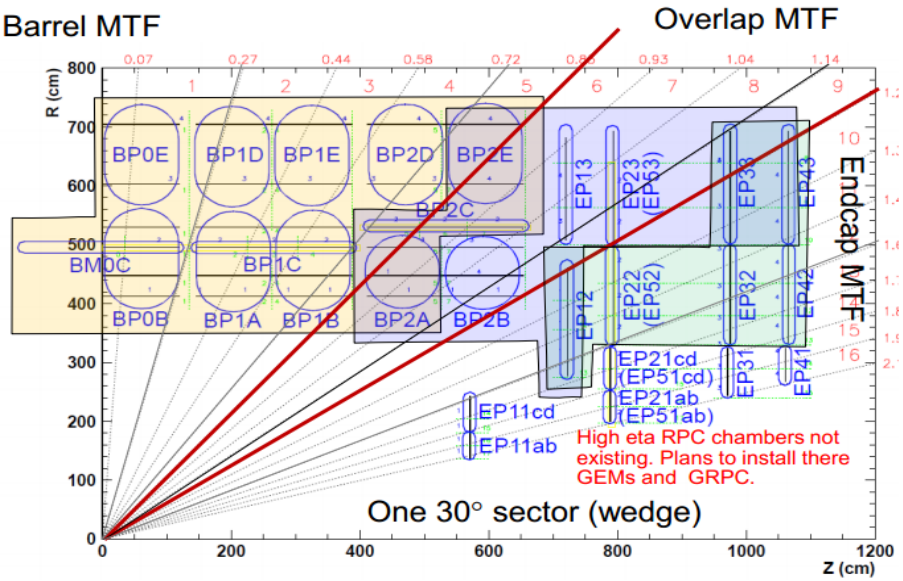
Outline

- Backgrounds with CMS L1 Trigger
- IHEP Task in CMS L1 Phase I Upgrade
- CPPF Module Design with full functionalities
- CPPF System Installation at P5
- Data analysis
- Summary

Backgrounds with CMS L1 Trigger



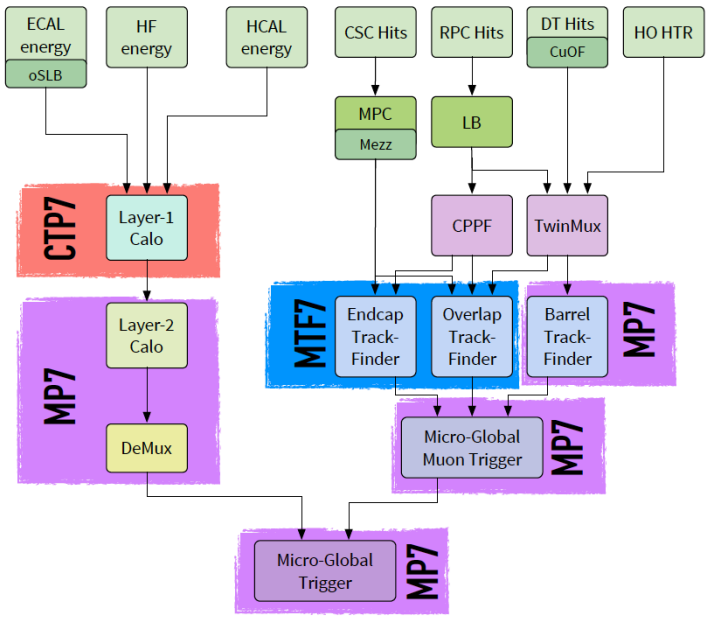
Legasy L1 Trigger System



- Aim of Phase I Upgrade
  - Adding Overlap tracking in Muon Overlap Region
  - VME – uTCA: uTCA mudularities(reduced number of modules)
  - Unified link protocol: 10Gbps
  - Standardized Synchronization

Standardization: only 5 module types

MP7,CTP7,MTF7,TwinMux,CPPF



HARDWARE & FIRMARE

- Drastically **increased uniformity** compared to Legacy trigger.
- 6 hardware platforms
  - MP7, CTP7, MTF7
  - AMC502, TWINMUX, CPPF
- **AMC13** : Crate-level Clock/TTC distribution and local EVENT building
- Integration and commissioning time significantly reduced by firmware sharing.

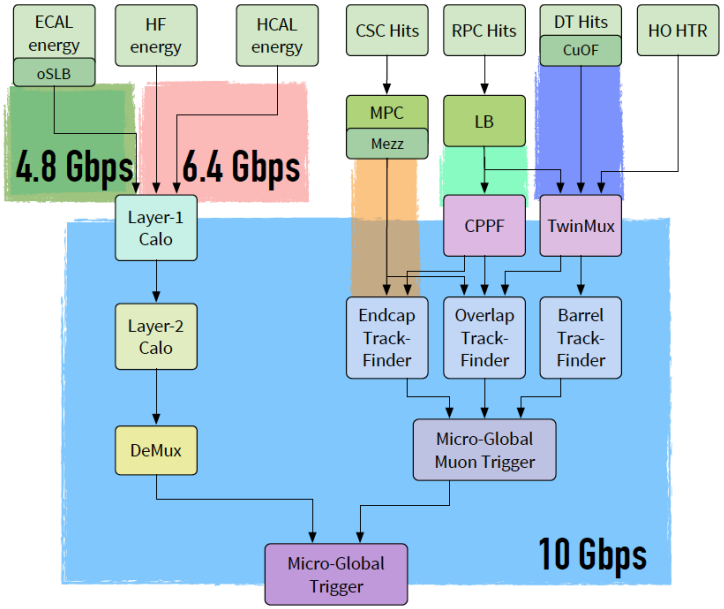
Promote hardware & firmware standardisation across L1

7

Phase1 Trigger

Unified Link Protocol: 10Gbps

Concentration + Preprocessing + Unified Processing



Optical Links

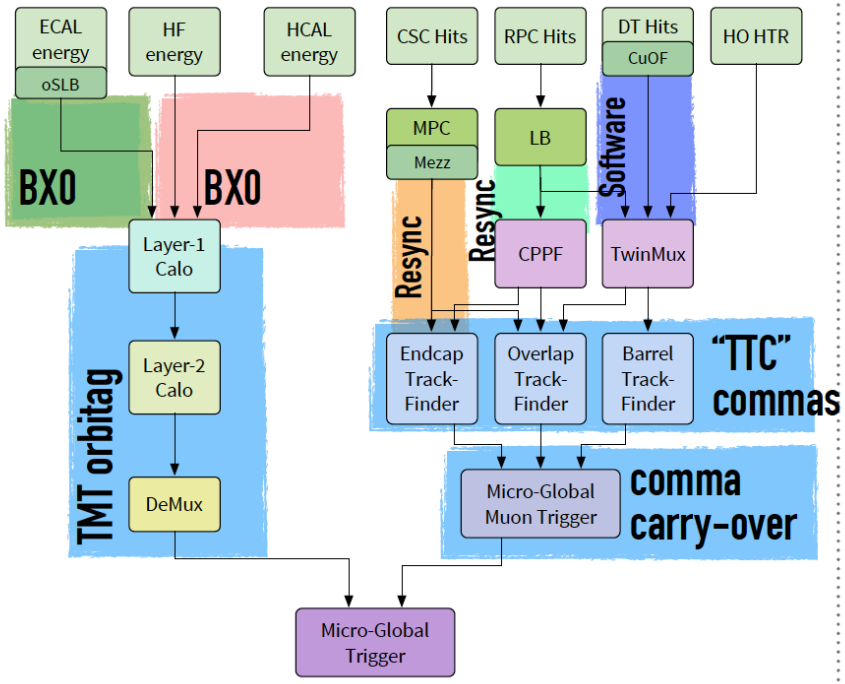
- Standard rate/protocol within trigger borders
  - 10 Gpbs, 8b/10b encoding, asynchronous
- Heterogeneous TPG to L1 links
  - ECAL: 4.8 Gbps, sync
  - HCAL, HF: 6.4 Gbps, sync
  - DT: 480 Mbps, sync
  - RPC: 1.6 Gbps, sync
  - CSC: 3.2 Gbps, sync
- Link firmware sharing where appropriate/possible

Phase1 Trigger

L1 & TPGs: Standardise link protocols

8

Standardized Synchronization



Phase1 Trigger

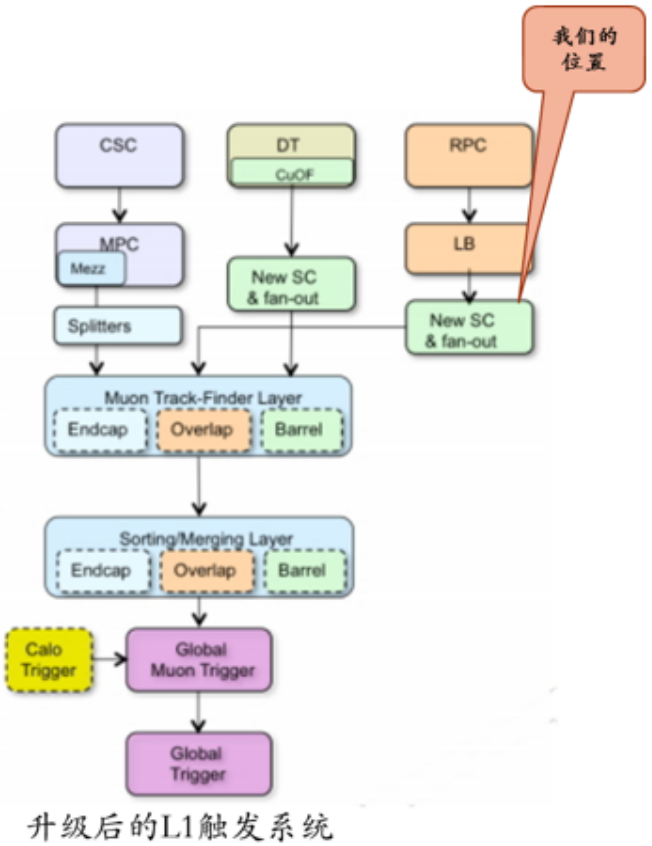
System-level Synchronisation

- No unique strategy
  - TPGs either send inject a BX0 marker in data or 'on request' special patterns.
  - Intra-L1 subsystem links are aligned exploiting the 10G link protocol (commas)
    - Multiple strategies (carry over, injection)
- Uniformity enforced (somehow) at software level
- Lack of common strategy.

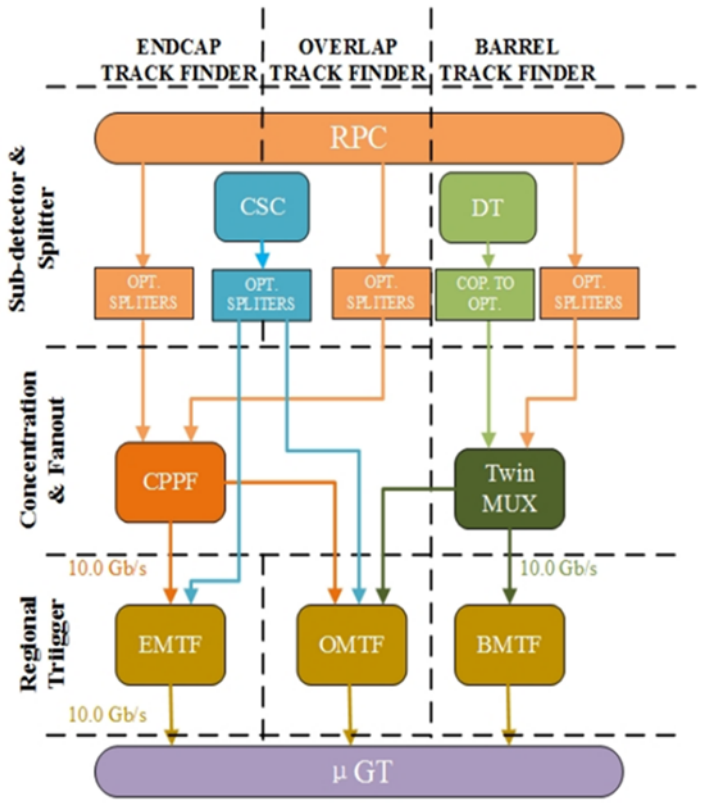
L1T & TPGs: Standardise synchronisation procedure

9

Muon Fan-out to TwinMUX+CPPF



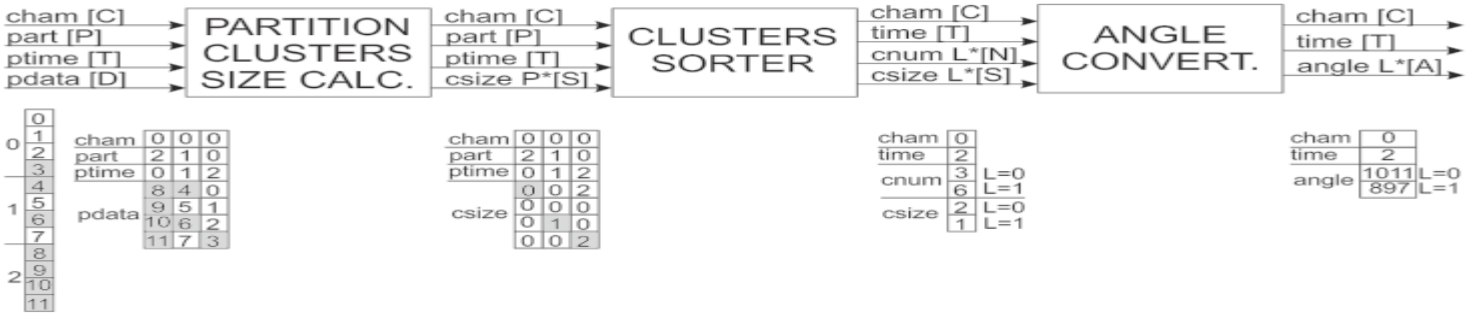
升级后的L1触发系统



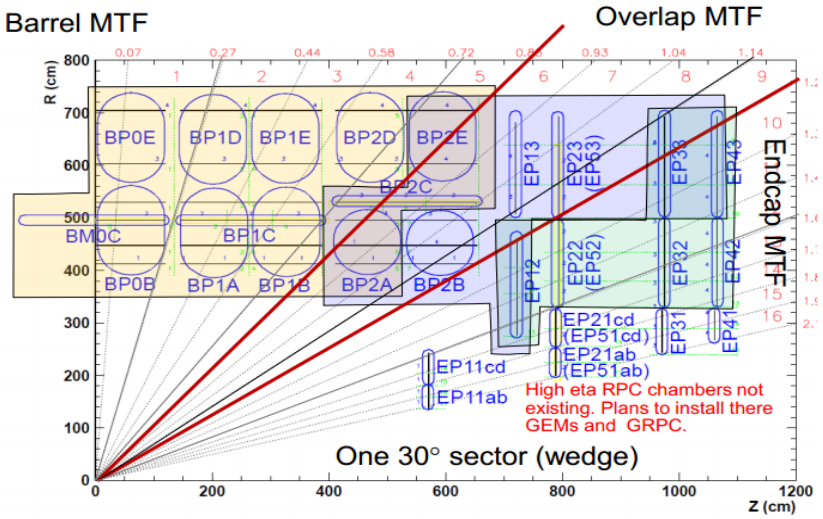
TwinMUX:

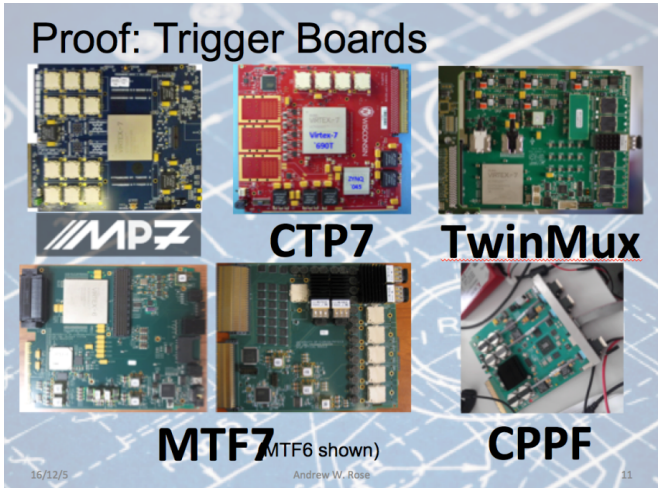
concentration for Barrel DT and RPC

CPPF:Concentration, Pre-Process, Fan-out system for Endcap RPC



IHEP Tasks in L1 Trigger Phase I upgrade





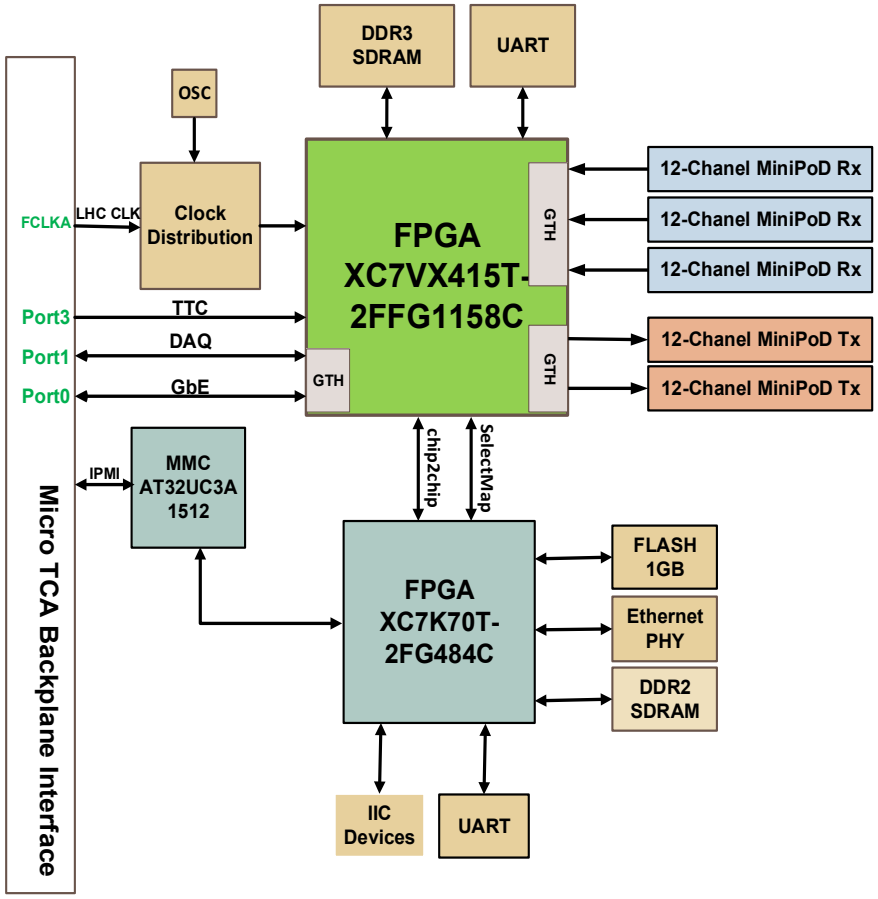
Object: Design a Module and Construct a system for L1 trigger pre-processing of the RPC data for both barrel-endcap overlap region, and EndCap region in order to increase the trigger efficiency.

Tasks(IHEP):

1. **1. Design a hardware CPPF module with the ability of data Concentration, Pre-Processing and Fanout (CPPF, one of the 5 modules in CMS L1 trigger, see lower left).**
2. **Functionality Firmware development and control software development,**
3. **CPPF system construction and installation**
4. **Trigger Data analysis**

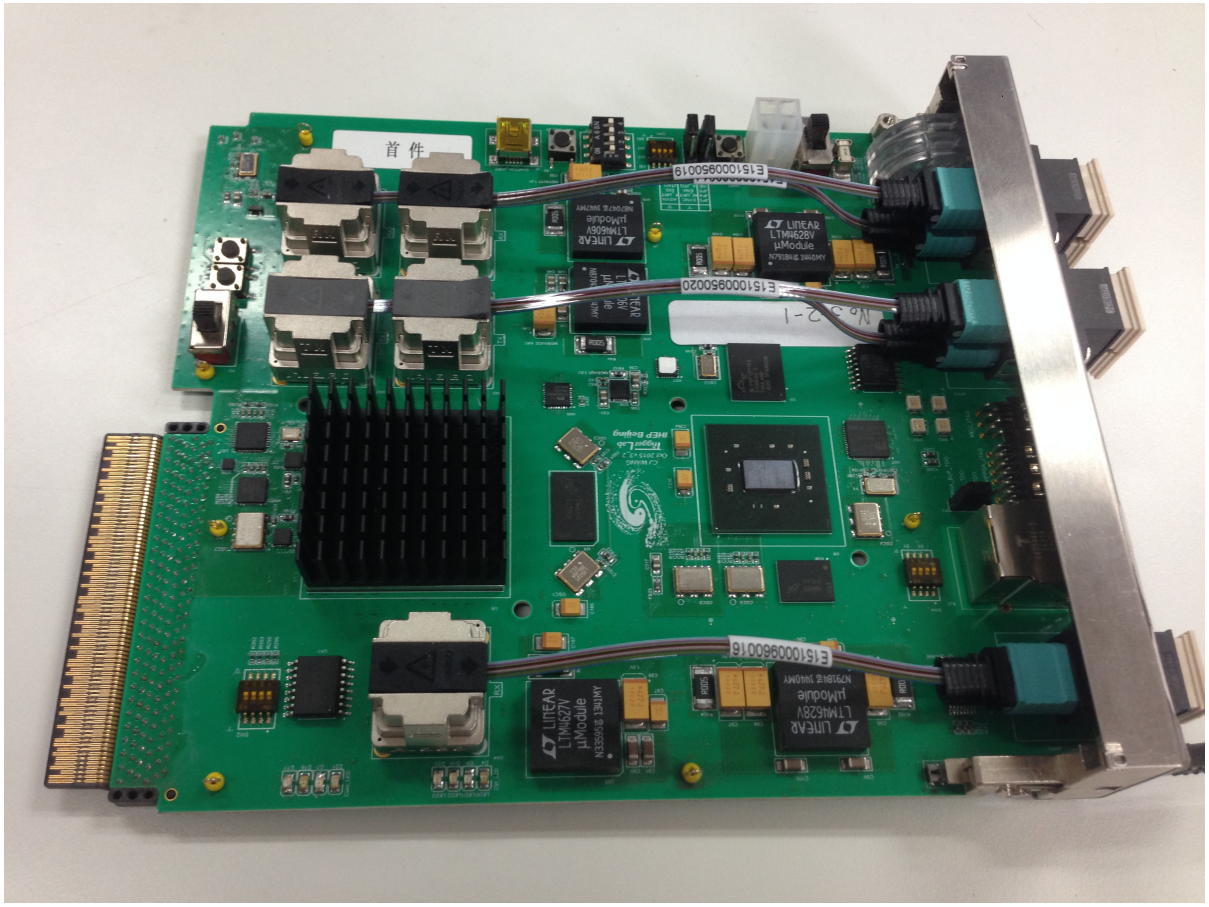
CPPF module design

- Data Bandth
  - Supports 360Gb/s input
  - Supports 240Gb/s output
- XC7VX415T-2 (Virtex-7)
  - Core processor
  - 48 GTH Transceiver，
- XC7K70T-2 (Kintex-7)
  - Control processor, configuration and management of the board
- AT32UC3A1512 (Atmel)
  - IPcontrol (MMC, Module Management Controller)



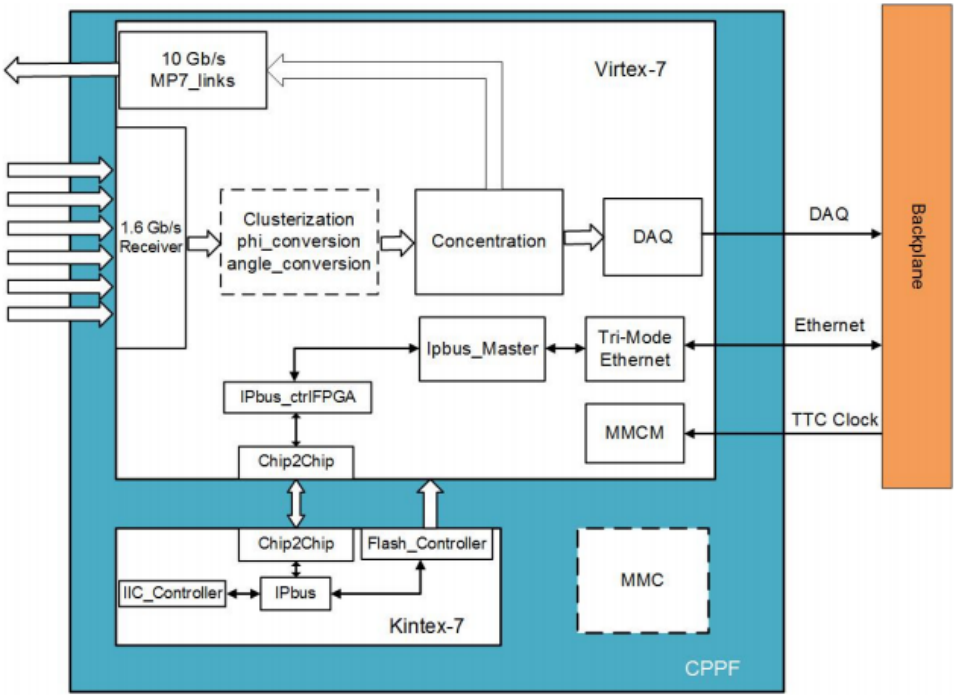
CPPF Block Diagram

Prototype mudule of CPPF



Firmware development

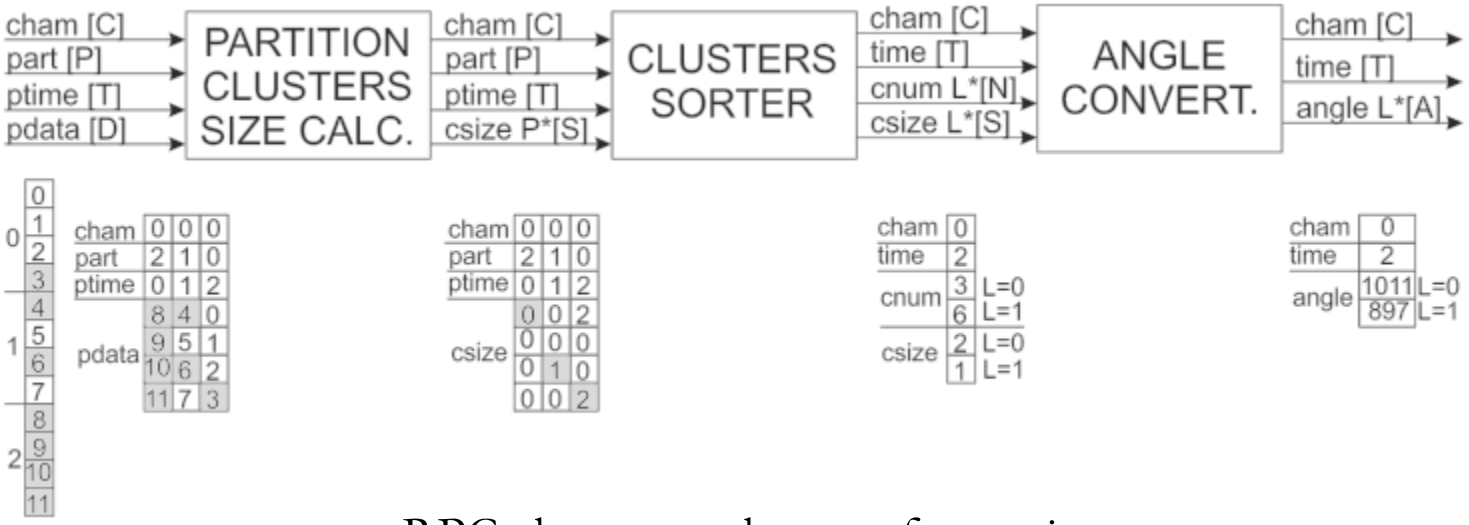
- In two Xilinx FPGA:
  - ➢ Virtex-7: Core chip. Implemented with main functions of CPPF subsystem, including: GTH Transceiver, preprocess algorithm, TTC/TTS, UDP /IP(IPBus) ethnet transmission
  - ➢ Kintex-7: Control chip, controlling other chips in the board



Block diagram CPPF FPGA fFirmware including DAQ

Functionalities

- How the Cluster and angle transformation is made
- PreProcessing
  - DeMuxplexing
  - Cluster Finding
  - Angle calculation and transformation
  - Concentration from 1.6Gbps to 10Gbps
  - Fan-out

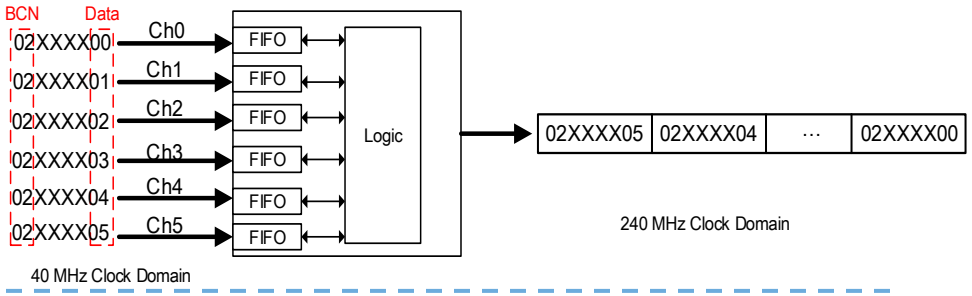


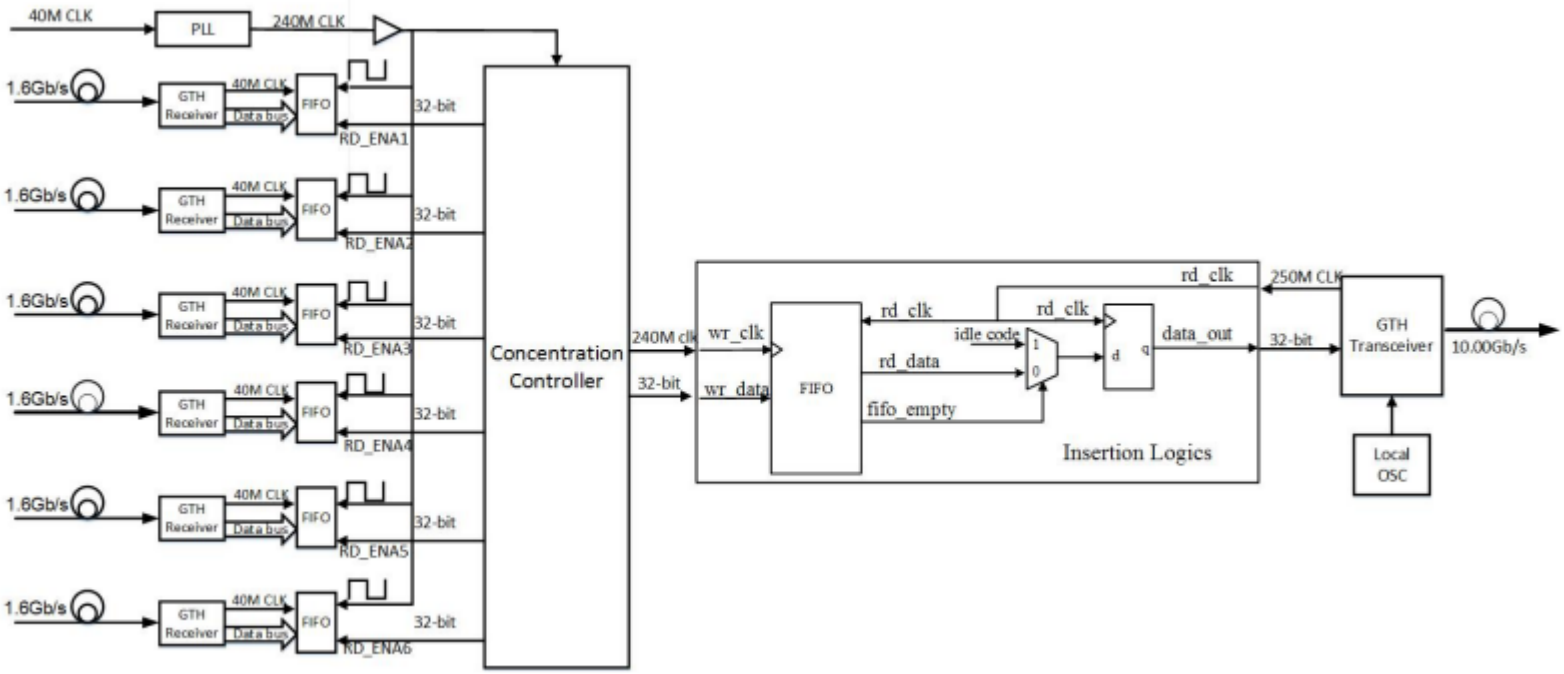
RPC cluster angle transformation

How the DeMUX and Synch is made

RPC数据格式

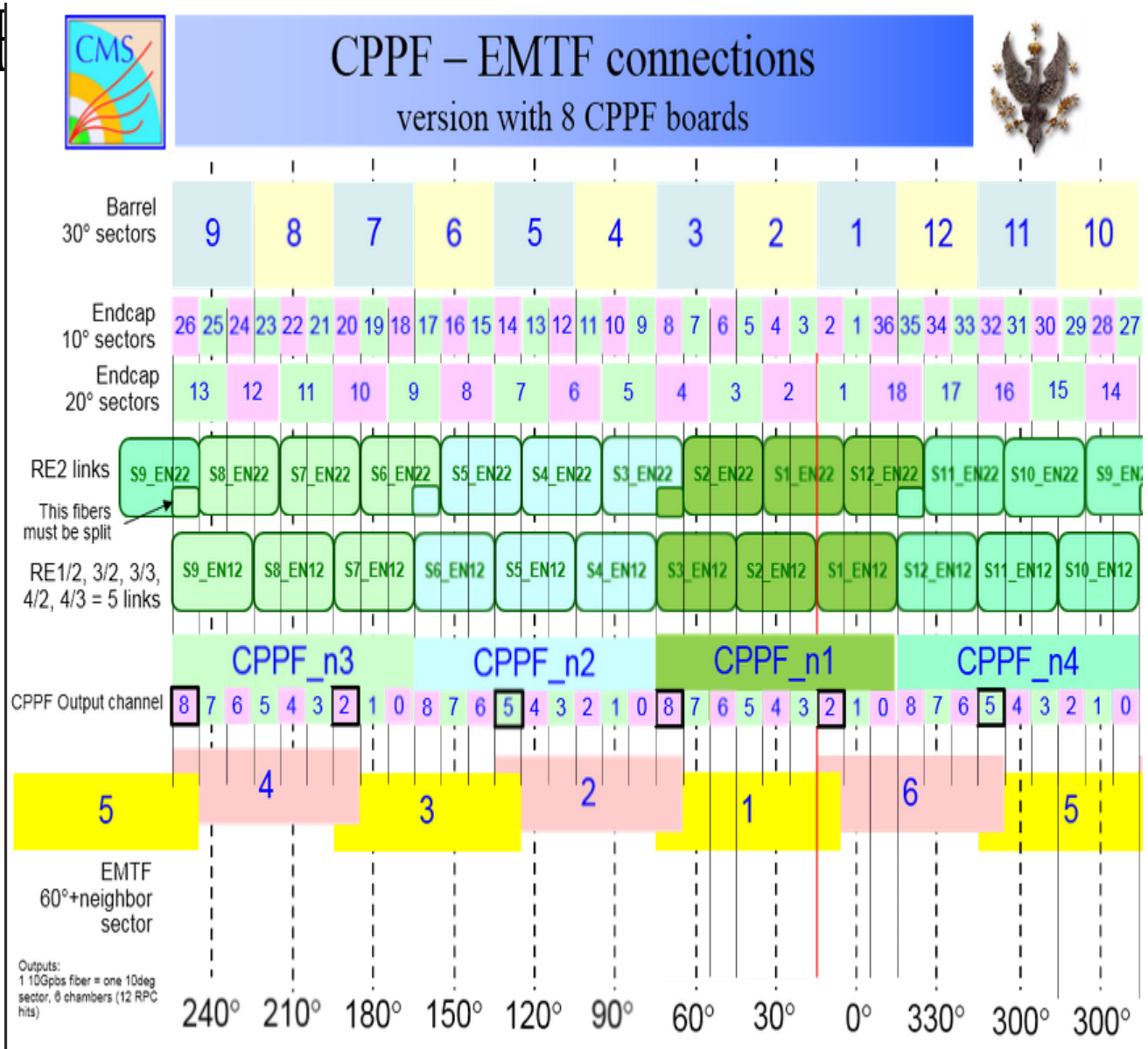
```
0…7    - partition data
8…11   - partition number
12…14  - partition delay
15     - “End of data”,
16     - “half partition” (unused)
17…18  - LB number
19…23  - unused
24     - BC0
25…31  - BCN (least significant bits)
```





CPPF/EMTF Mapping

- Each CPPF board response for 90° RPC overlap region data transmission.
- There are 19 input channels in each CPPF. Each input channel responds for receiving a sector RPC data from LB with 1.6Gbps.
- There are 12 output channels in each CPPF. Each output channel respond for 6 chambers transmitting to EMTF with 10Gbps.



CPPF firmware development-DAQ

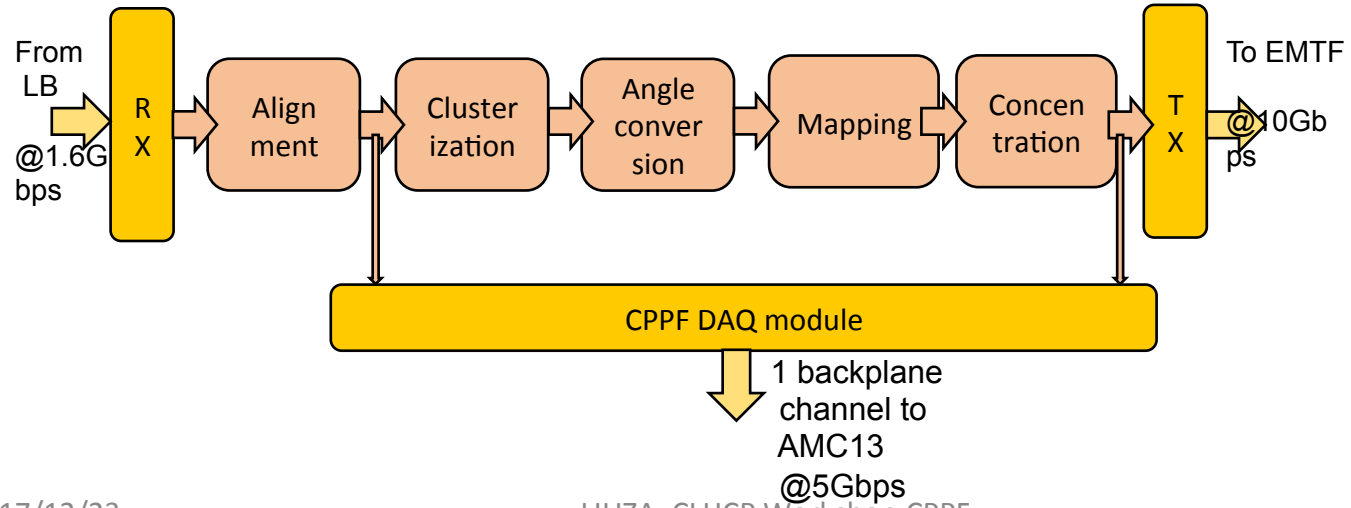
- Two dataflows:

➢ RPC data transmission:

- Receiving Link Board RPC data@1.6Gbps
- Preprocessing received data, including clusterization and angle conversion
- Transmitting preprocessed data to EMTF/OMTF@10Gbps

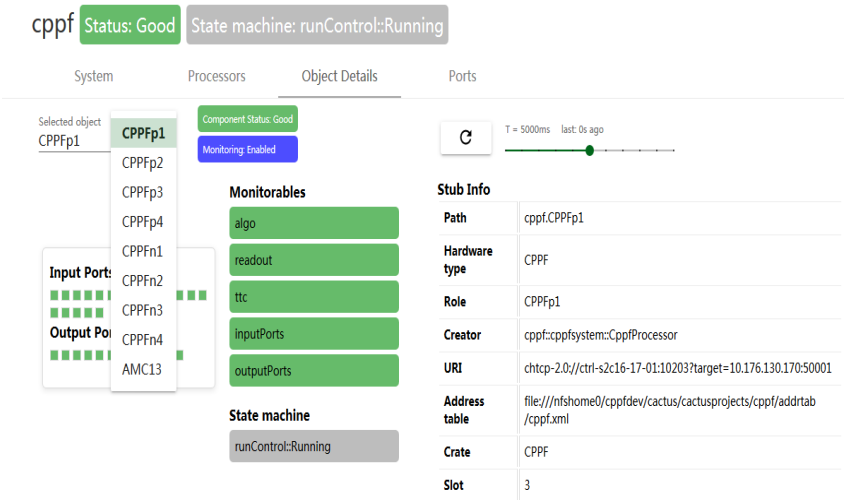
➢ Daq data recording:

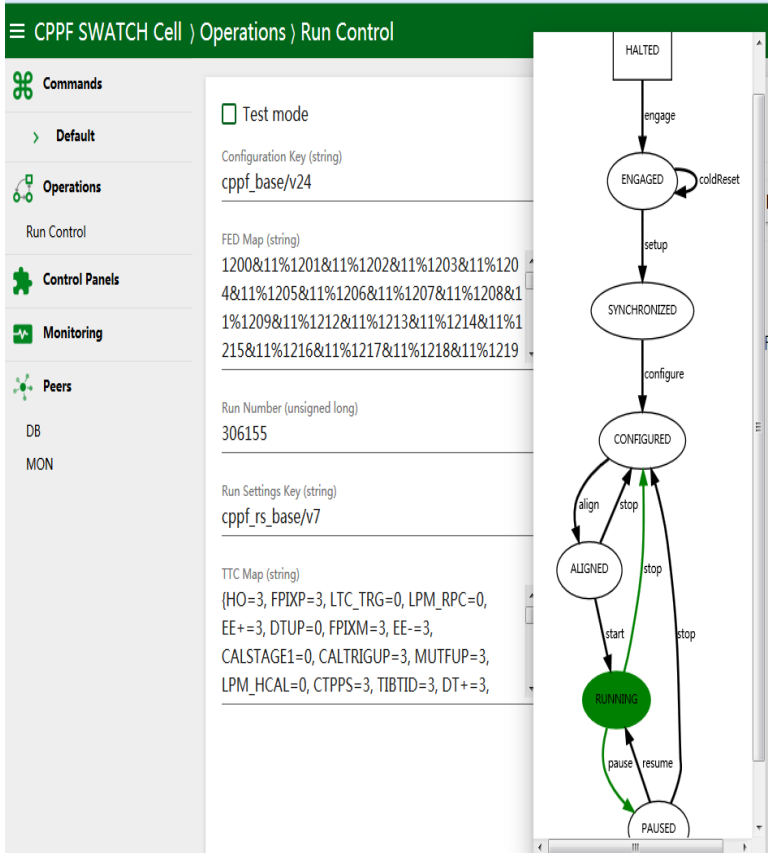
- Recording received data after alignment and preprocessed data before transmitting
- Packed them and send to AMC13 by the CPPF DAQ module@5Gbps



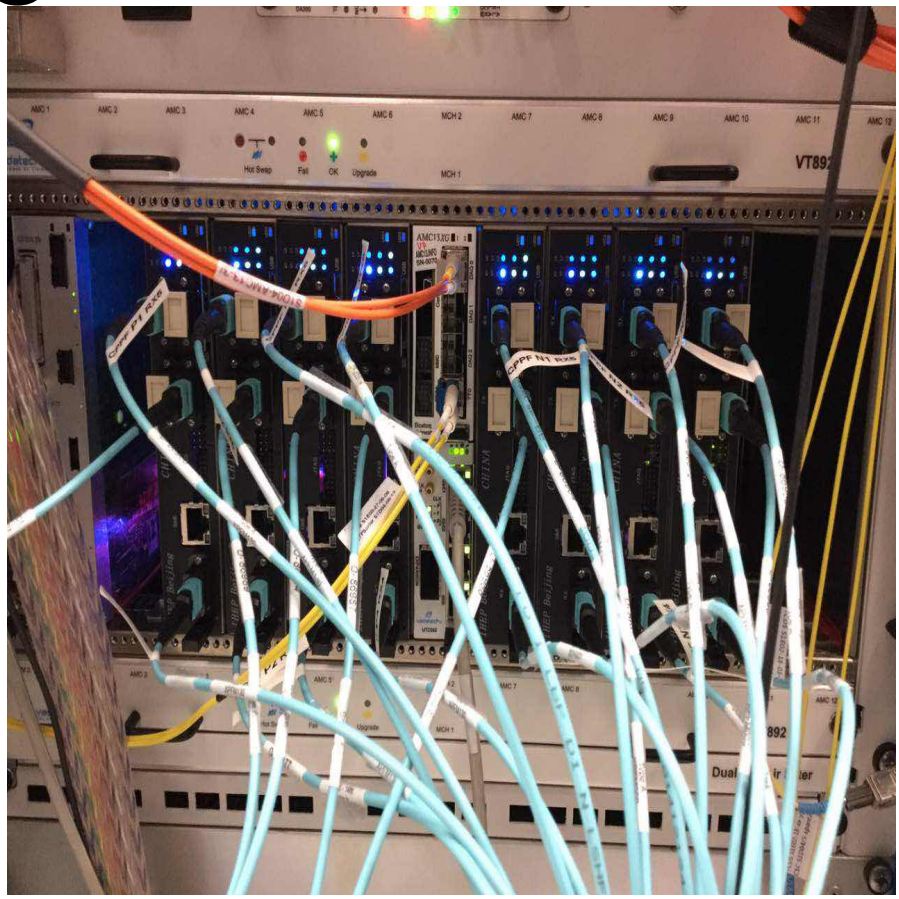
CPPF SWATCH implementation

- SWATCH: SoftWar for Automating conTrol of Common Hardware
- CPPF is one of customized user of SWATCH
  - ➢ Controlling:
    - ☐ FSM configuration
  - ➢ Monitoring:
    - ☐ Five Monitoring objects





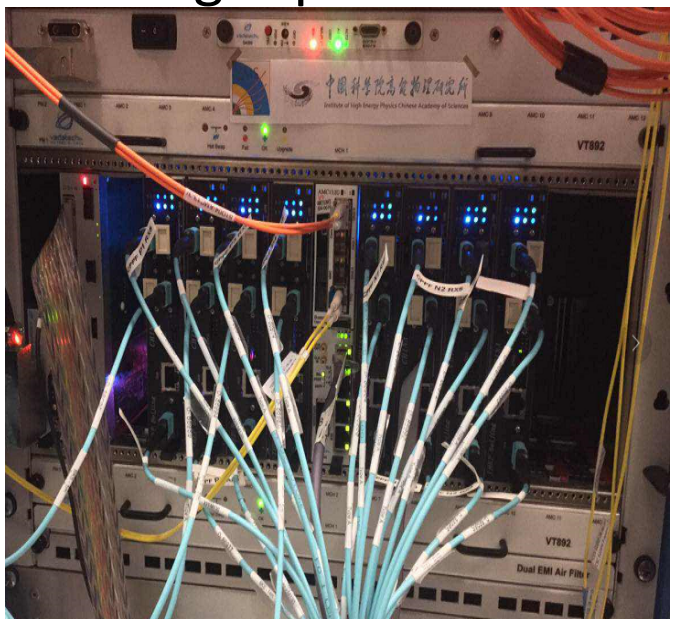
CPPF System Integration

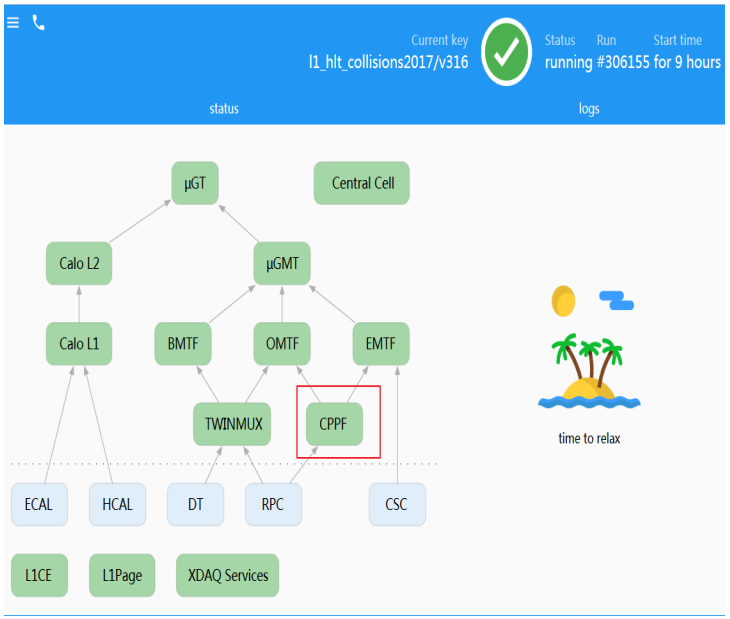


- Hardware
  - All 8 CPPF are installed at P5
  - We have 14 CPPF boards in CERN
- Functionalities
  - Full function except the DAQ
  - Basic SWATCH functions for CPPF.
  - Full SWATCH function to be finished soon.
- Testing done with success
  - Full test in B14, B904
  - Joint test with OMTF and EMTF in B904
  - Joint test with LB and EMTF in P5

Data taking running

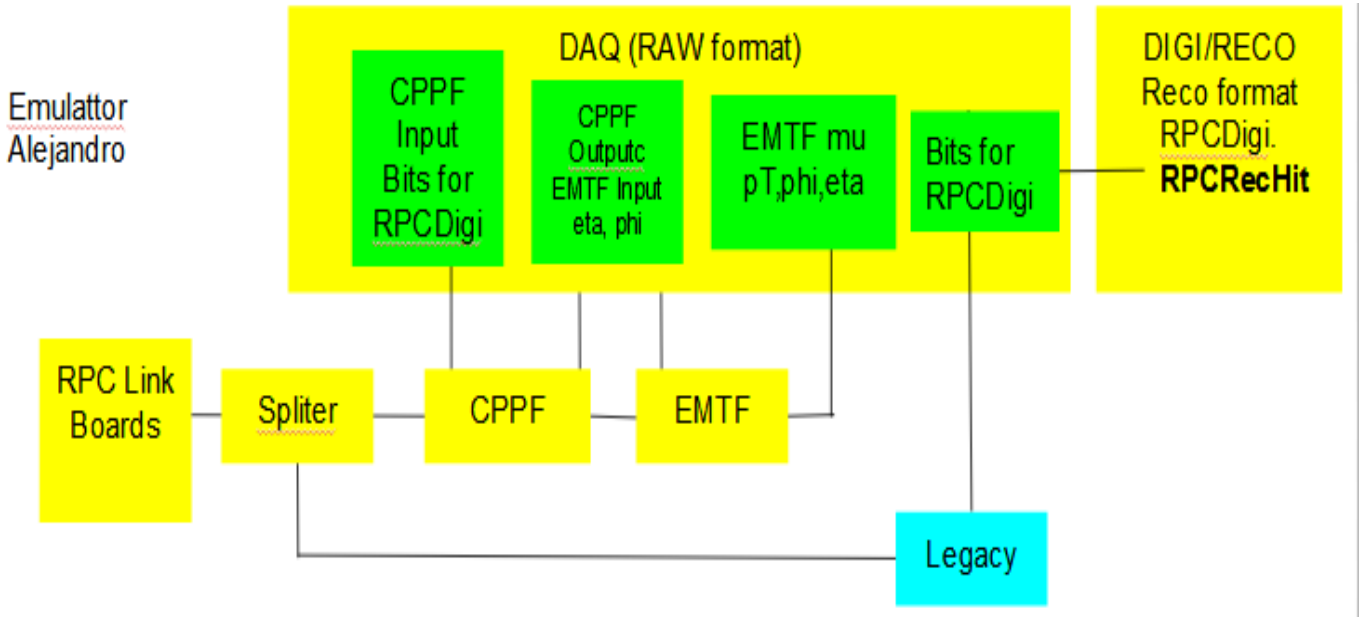
- Including 8 CPPF boards installed in 1 microTCA crate :
  - Left picture shows the CPPF boards was installed in CMS USC55
  - Right picture shows the CPPF SWATCH in CMS central





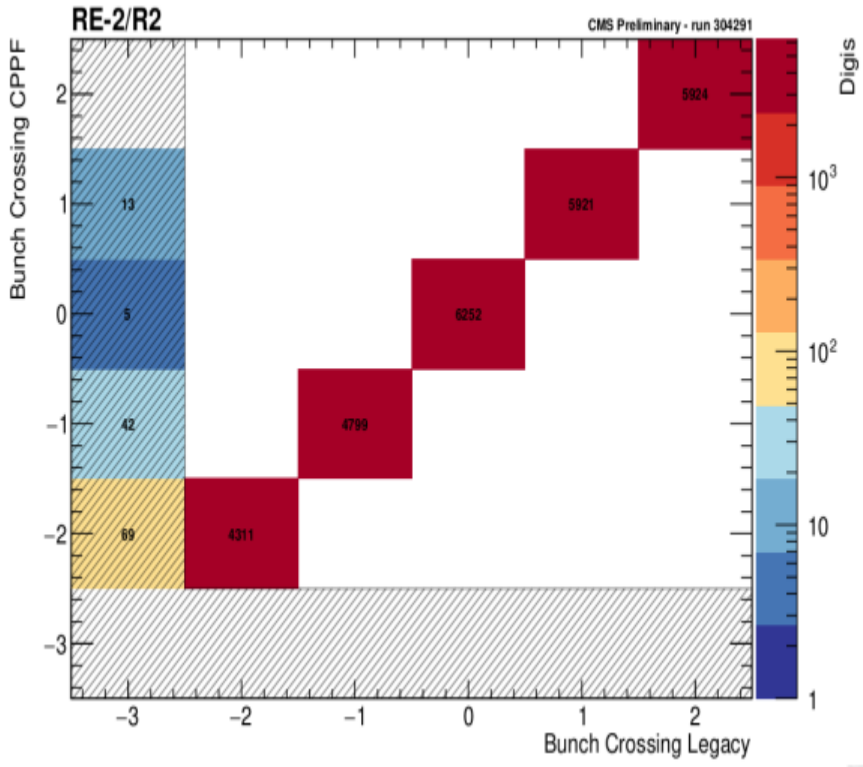
CPPF offline software design

- June-Dec 2017 Data taking has finished
- Based on CMSSW, including, Libo is working on
  - CPPF Unpacker: including RX data and TX data
    - Basic version by Flip
  - CPPF Emulator
    - Basic version by Alejandro Segura



Temporary result of CPPF data analysis

- Comparision between CPPF RX data and Legacy
  - Legacy only recorded data: less than 0.5%
    - Problematic links: GTH reset problem or spliter problem
    - In investigating
  - CPPF only recorded data:~0.4%, mainly in BX=-2, -1
    - Legacy with a problem in recording multiple hits when happened in BX=0 and BX=-1 or BX=-2.
    - Reasonable



More analysis still in progressing

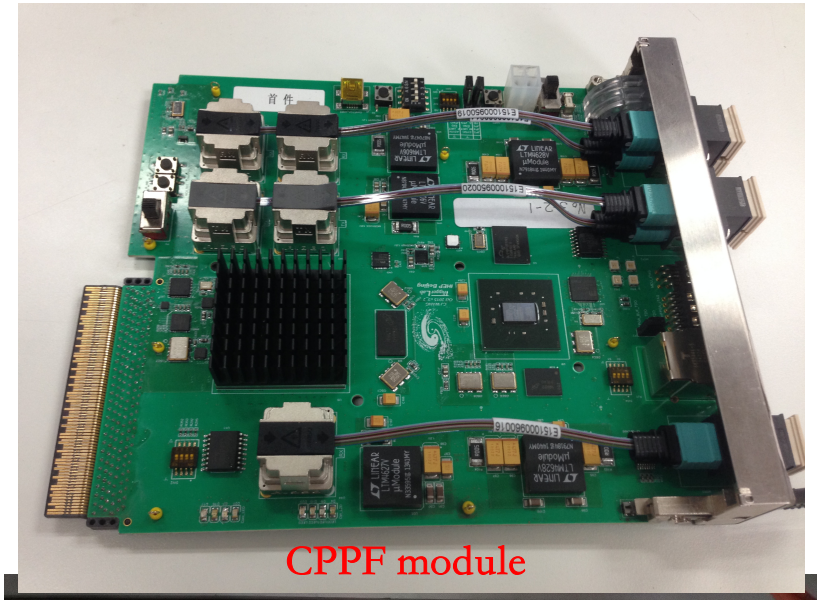
CPPF data analysis in 2018

- Comparision of CPPF TX data and Emulator data
  - All CPPF unpacked hits can be found corresponding hits in Emulator, regardless of:
    - The value of Theta of some hits in Unpacker is shift by 1 unit
    - The value of Phi of some hits in Unpacker is shift by 900 units
  - The Emulator with some hits that not existed in unpacker, including:
    - Some hits are repeated twice in emulator, but only exist once in unpacker.
    - Some hits are totally not existed in unpacker but in emulator.

Summary-Milestone

Milestone:

- **2014**: completed the 1st version of CPPF design in IHEP.
- **2015**: produced the 1st version of CPPF prototype and tested at CERN. Completed the 2nd version prototype and tested at CERN.
- **2016**: completed the mass production and test of 10 CPPF modules in IHEP, the software development, and the test of CPPF system at CERN.
- **2017**: complete the installation and test of CPPF in CMS, cosmic test, and collision data taking of year 2017 with no problem.
- **2018**: data analysis


CPPF module

Summary

- With good communication with CMS Trigger Team and help from colleagues, we have finished 2013-2016
  - CPPF Concept Prototype Design
  - CPPF Production Prototype Design
  - Firmware Development
  - Software Development
  - Joint testing Production, and
- In 2017
  - Installation,
  - Commissioning (cosmic, LHC beam)
  - Data taking successful with no CPPF error
- Performance verification is undergoing

Thank You!

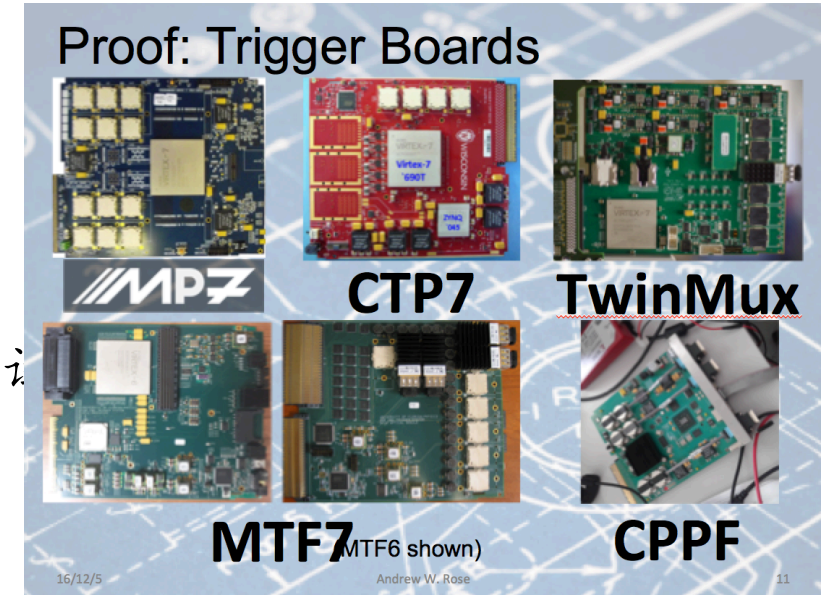
Backups

More on firmware

- Version Upgrade
  - CPPF firmware was upgraded to newly version of MP7 firmware(V2_2_0).
  - MP7butler test showed works well for the new firmware in TTC and IPBus.
- RX and TX
  - Using elastic buffer design for RX, and can correctly receive data from LB according to test in 904. but in P5 seems have some problems for 3 boards, trying to find the problems.
  - Using 10g Tx mode in MP7 firmware, and also transmitter function seems correct according to test in 904 with OMTF, and in P5 with EMTF.
- Algorithm
  - Mapping for RPC region data from LB to CPPF receiver was finished under test.
  - CII module including alignment, Dmux, clusterization functions implemented by Karol's group.
  - Mapping for clusterization result and concentration the result to transmitter were finished under test

高能所CMS Phase I L1触发升级小结

- 高能所在CMS合作中发挥了重要作用
  - CMS Phase I触发升级只有5种新插件，高能所承担了CPPF的设计
  - CPPF由高能所独立设计
  - CPPF满足MTCA新标准
  - 承担MTCA机箱CPPF系统建造
- 进展:2016年完成了预期任务
  - CPPF插件最终定型
  - CPPF完成量产与调试
  - 完成与RPC-LB，OMTF7和EMTF的联调测试
  - 正在进行软件编写与完善，
  - 基本完成了控制软件SWATCH的编写
- 2017年计划
  - 2017年2月初完成CPPF系统的调试
  - 为2017年3/4月份的系统集成做准备



谢谢大家！

L1 Trigger upgrade (Phase I project, IHEP)

After months of collision data taking in June, the CMS collaboration confirmed that the CPPF system works successfully.

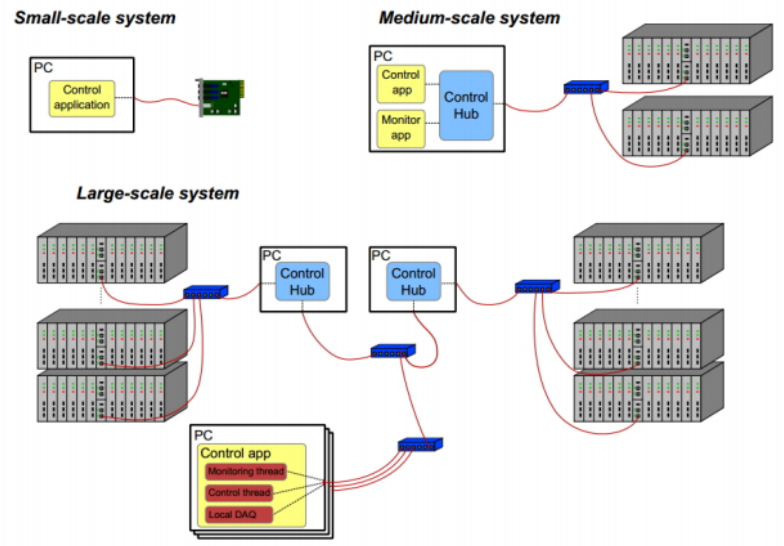
- **The first system which is designed and constructed independently by Chinese institute being used in CMS Experiment**
- **The data transfer rate increased from 1.6Gb/s to 10Gb/s, the highest speed at present.**
- **It is compliant to uTCA specification**

A special interview report on this success was given by Chinese Science.Net with a title "Chinese force in CMS experiment (CMS实验里的中国力量)" . Reports also on IHEP and CAS web pages.

SWATCH control based on Ipbus

- IPbus协议
  - 针对CMS实验，CERN开发的一款基于UDP的可靠以太网传输协议，实现对μTCA机箱的远程控制。
  - 基于IP访问硬件设备，采用A32/D32总线标准

- 上位机
  - μHAL：C++ Micro Hardware Access Library，提供访问FPGA固件中寄存器和RAM的接口
  - XML语言定义寄存器和RAM的地址
  - 采用Python脚本的方式控制CPPF插件

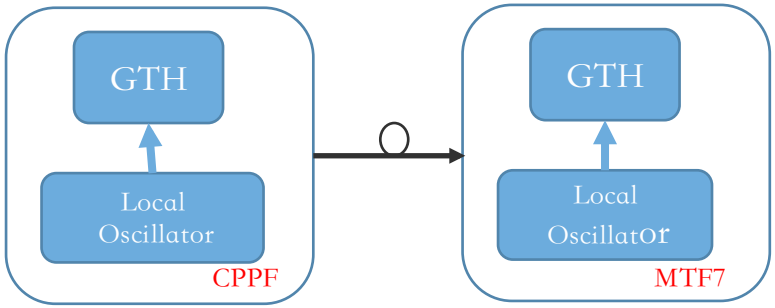


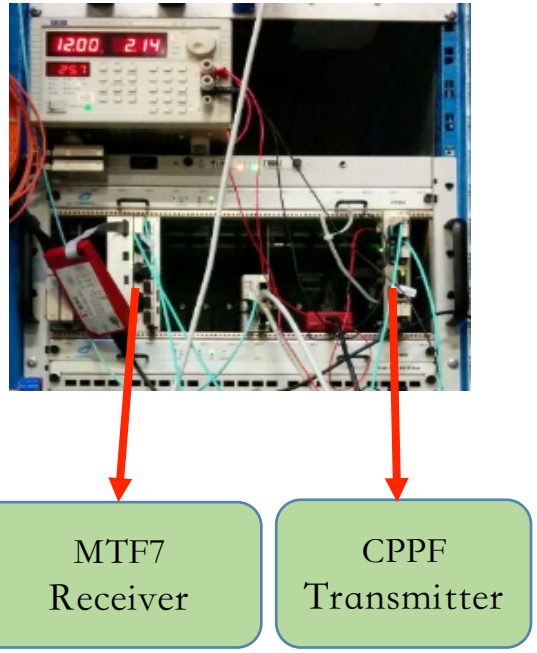
基于Ipbus的μTCA机箱控制系统拓扑结构图

```
<node description="ctrlFPGA" fwinfo="endpoint" class="ctrlFPGANode">
        <node id="ctrl_reg"    address="0x0" fwinfo="endpoint;width=1"/>
        <node id="ram"   address="0x10" size="1024" mode="block" fwinfo="endpoint;width=2"/>
```

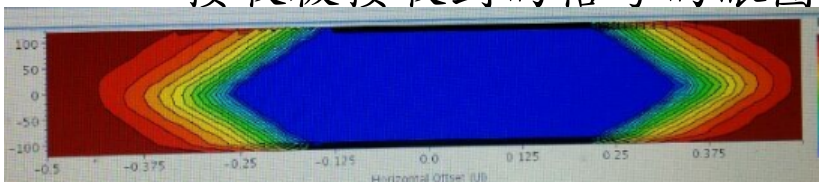
系统测试：完成10.0Gbps传输测试

- 完成CPPF与MTF-7异步参考时钟下10.0Gbps传输性能的测试
- 异步模式如图所示，选用本地参考时钟



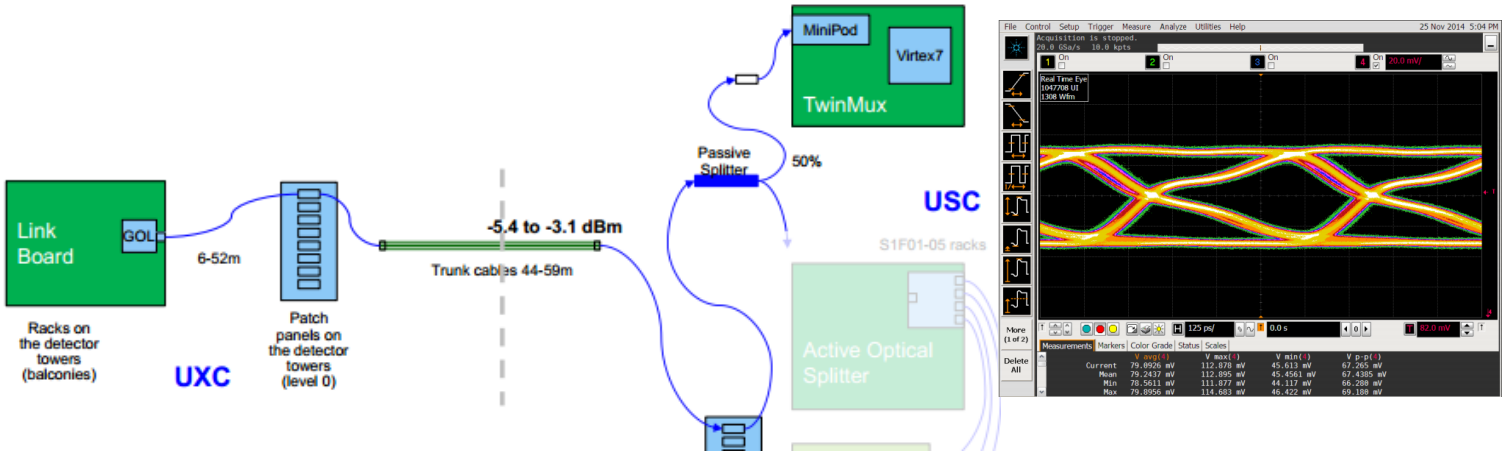


- MTF-7接收板接收到的信号的眼图



系统测试：RPC光纤数据的测试

- 测试地点
  - CMS P5实验现场
- 测试链路
  - RPC Link Board -> Passive Splitter -> CPPF
- 测试结果
  - 一共测试41条RPC光纤
  - 4条的RPC光纤在50%的分光比下有误码，60%的分光比，误码的光纤数更少
  - CMS实验中使用60%的分光比，误码率更低，符合实验要求

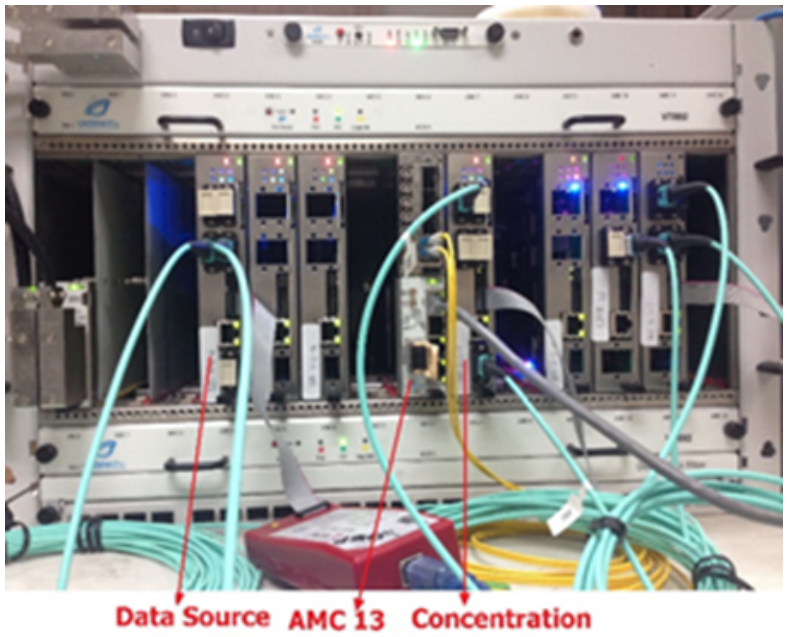


系统测试：数据合并测试

- 地点
  - 北京实验室
  - CERN CMS电子学实验室
  - 法国904大楼
- 测试
  - 单项测试
    - 发送端
      - 模拟RPC数据的发送，满足RPC数据格式
    - 接收端
      - 接收24路1.6 Gb/s数据，每六路合并为1路10.0 Gb/s, 进行自动检测。
    - 角度转换测试
  - 综合联调测试
- 测试结果
  - 完全成功（12月15日）

RPC数据格式

```
0…7    - partition data
8…11   - partition number
12…14  - partition delay
15     - “End of data”,
16     - “half partition” (unused)
17…18  - LB number
19…23  - unused
24     - BC0
25…31  - BCN (least significant bits)
```



Summary

- Design and Construction
  - Hardware
    - CPPF Installation
      - 14 fully tested, 8 for installation + 4 for spares and 2 test
    - Hardware features
      - 36 inputs in 3 MiniPods/fiber bounds
      - 24 outputs in 2 MinoPods/fiber bounds(one for EMTF, one for OMTF)
    - Present Application for EMTF
      - 24 inputs in 2 MiniPods(19 fibers in deed)
      - 12 outputs in 1 MiniPod(12 fibers, 9 for EMTF sector, 3 for neighbors)
    - Further for OMTF
      - Another 12 outputs in a MiniPod
      - Modification with GTH module
  - Firmware
    - Version Upgrade
      - CPPF firmware was based on MP7 firmware
      - MP7butler used for firmware in TTC and IPBus early time.
    - Function
      - Synch + Alignment + DEMUX + Cluster + Angle.C + Concentr.
  - Software
    - SWATCH for running
    - MP7Botler for early testing

- Trigger Data analysis
  - Unpacker
  - Emulator
  - Analysis