A New Data Readout and Control System Based on Next Generation Wireless Transmission Technology

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Outline

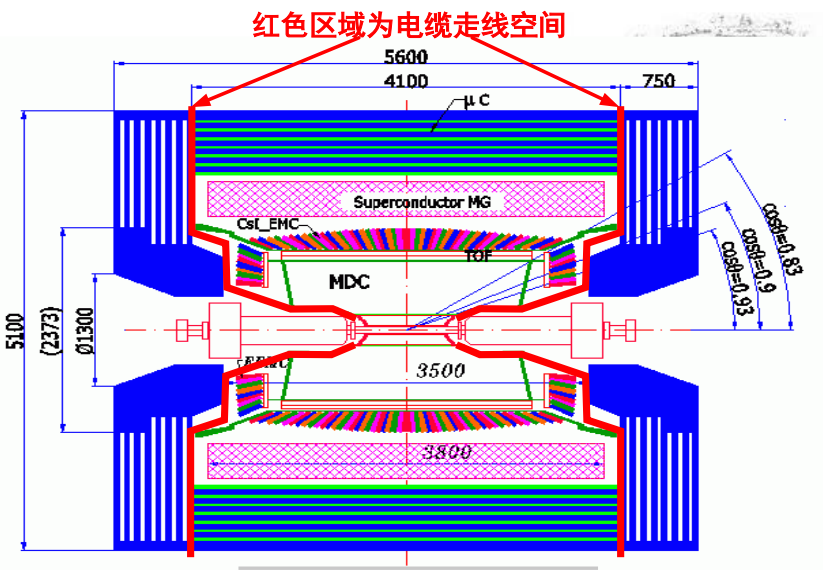
- Motivation
- Problems to be solved
- Research plan
- Summary

Motivation

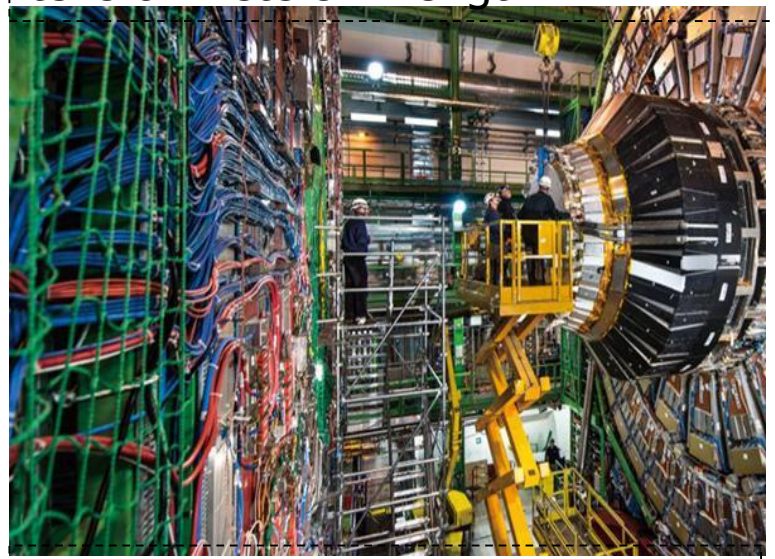
- In the high energy physics experiments, huge number of detector signals need to be transmit. At present, the traditional solution is using electric cable and optical fiber.

However…

- The physical cables increase the dead area and material budget, reduces the detection efficiency, and greatly increases the system error and the misjudgment risk of new particle.
- The cost of the cable is high, and wiring is very difficult when the space is limited.



About 20000 cables at the endcap of BESIII detector, which are about tens of meters in length

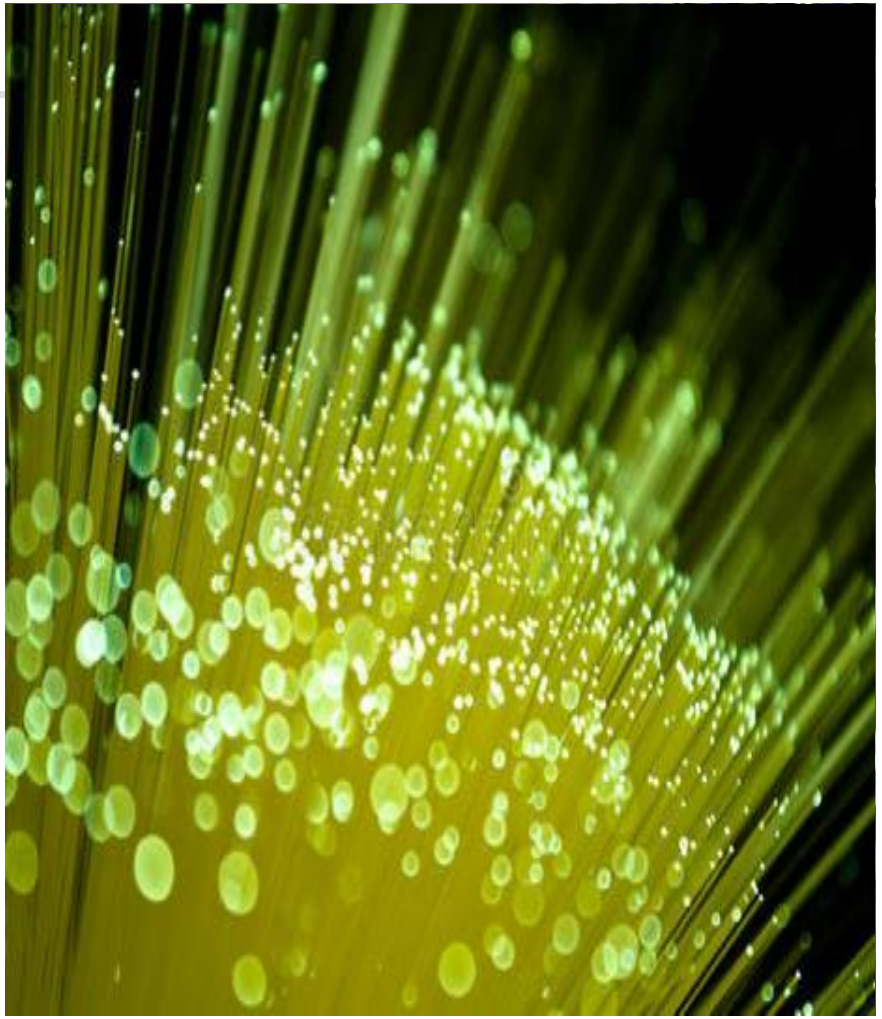


The number of cables on the LHC at CERN is much higher

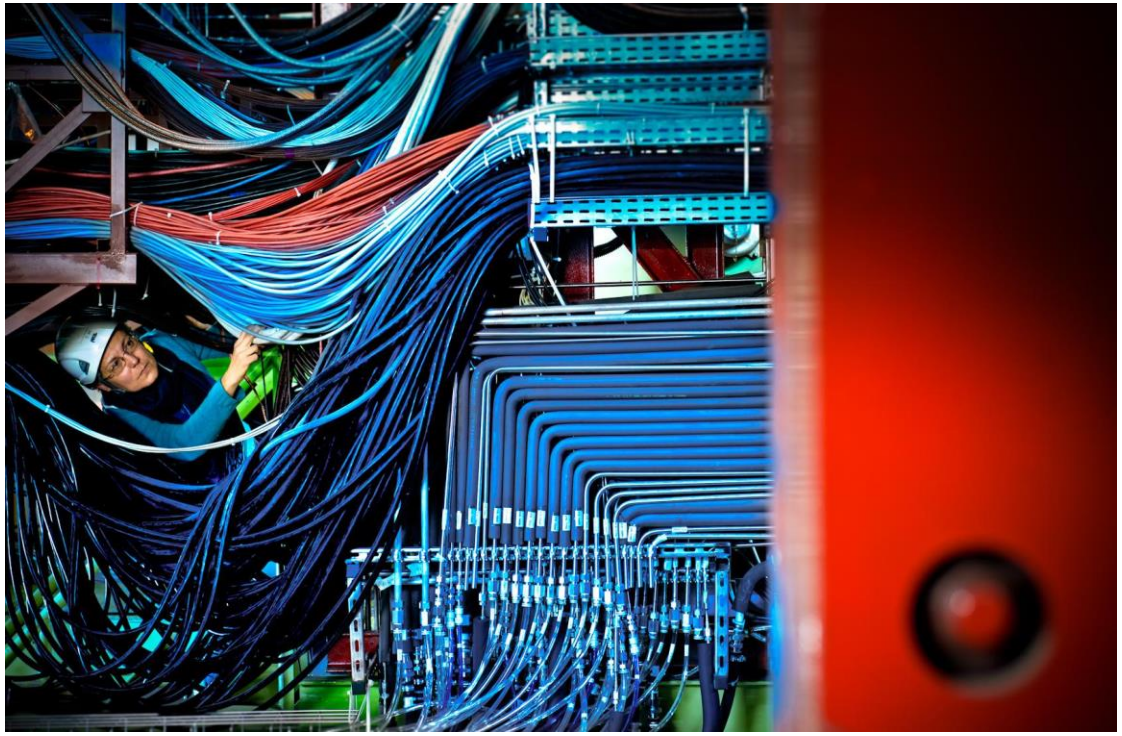
Data readout

- In recent years, optical fiber transmission after digitization in front-end become main scheme thanks to the optical fiber and custom ASIC technology development.
- Optical fiber has **high bandwidth** and **electrical isolation**, but the **disadvantage:**

  - Power consumption
  - Reliability
  - Radiation hard
  - Complex wiring inside detector
  - Expensive



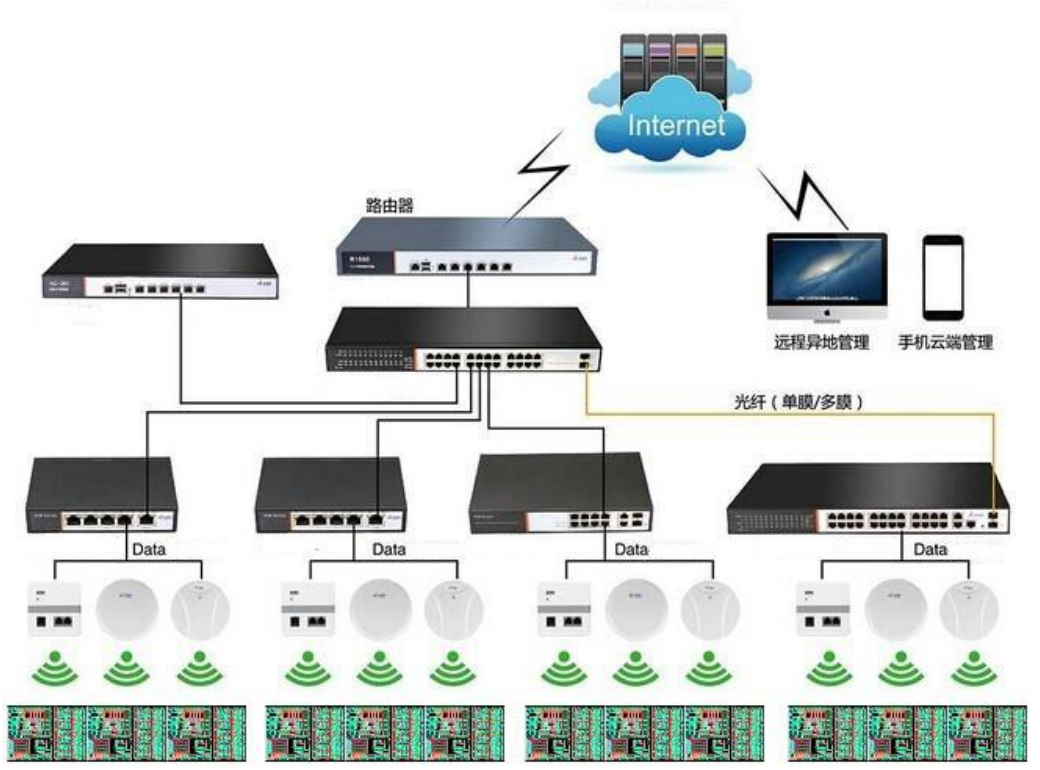
Control System



- At the meanwhile, the **synchronized clock** and **fast control** signal need to be fan-out to the front-end of each channel of detector.
- Normally, **Point to Point** mode is used. That means large number of connection.
- **Wireless transmission** is a **broadcast** connection naturally

Benefits of Wireless Connection

- Reduce the number of cable or optical fiber, make the system installation flexible and the cost lower;
- Easier to reduce the system level crosstalk;
- Compared with the optical fiber system, the reliability and radiation hard will be improved;
- The space requirement and material budget of the whole system are reduced;
- For distributed detector system, control and clock signal can be broadcast without additional cable connection;
- The data acquisition and trigger system can be configured more flexibly, and the channel can be reassigned without any routing changing.



Problems to be solved

Summon wolves is more effective than message carried by horses

- There is no large energy physics experiment using wireless transmission

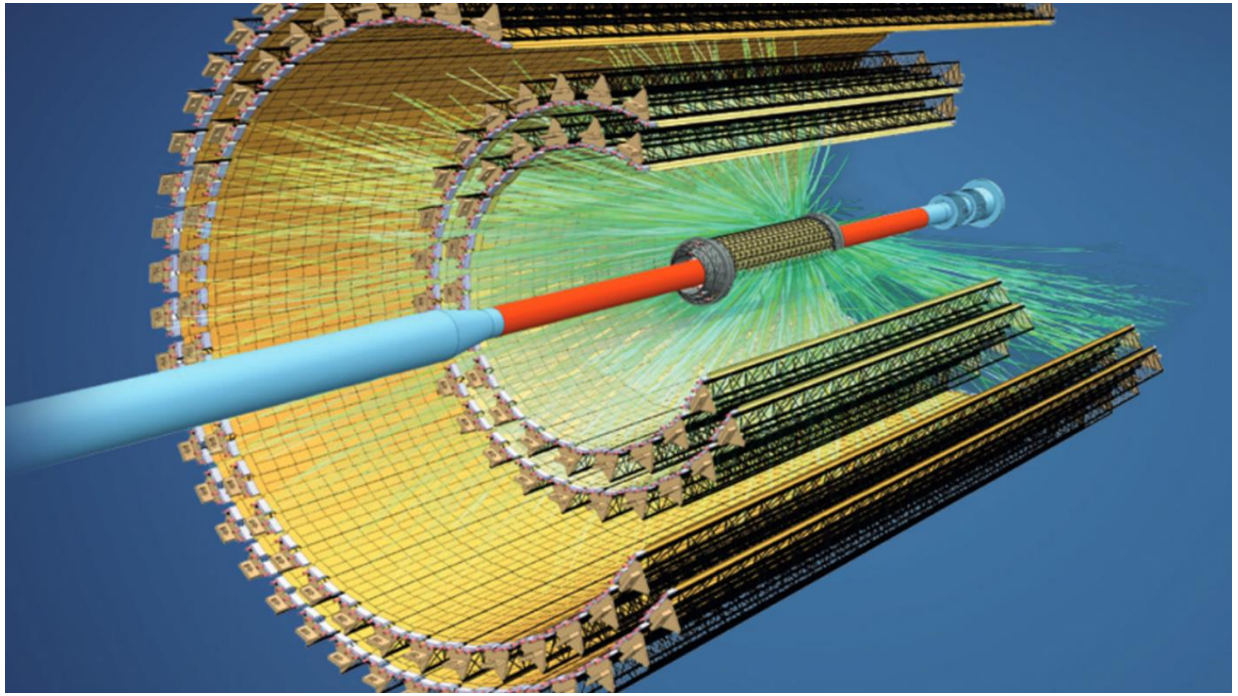
  Why?

- Data transmission **bandwidth** limit
- No **radiation hard** wireless transceiver chip
- **Jitter** of clock distribution by wireless

Data rate reduction

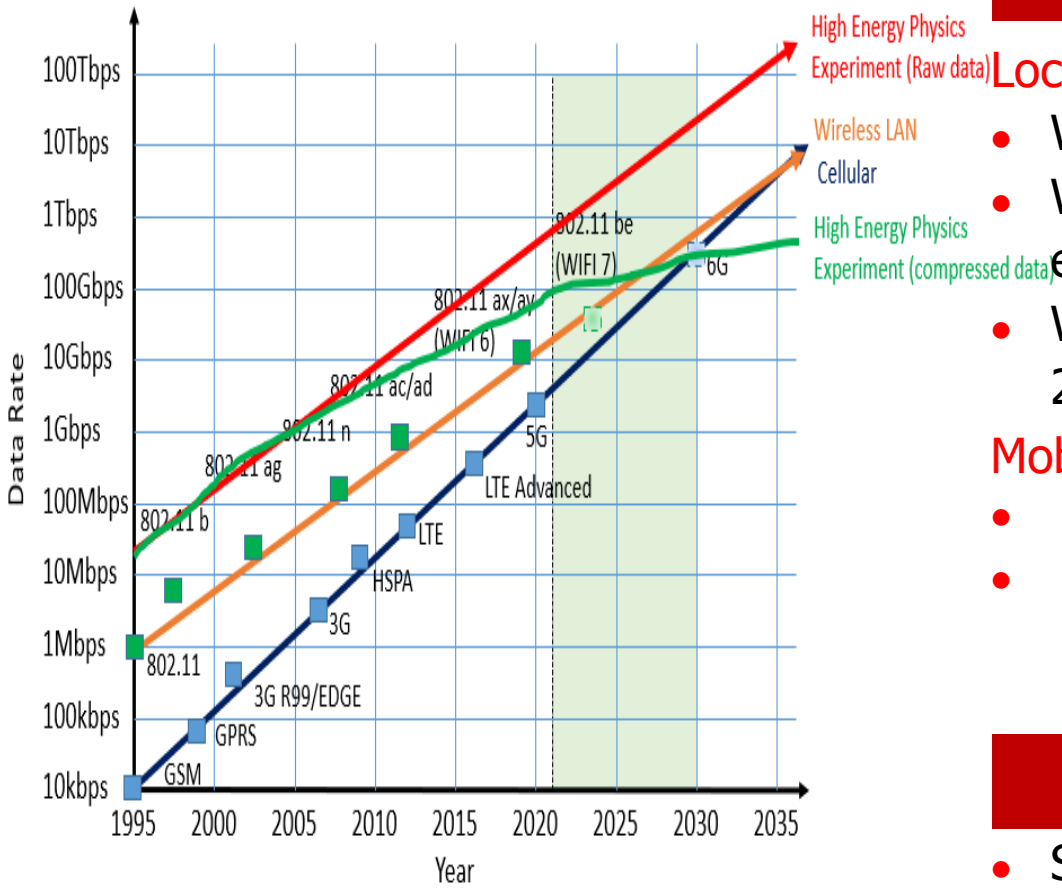
- Preliminary calculation
  - Pixel size:10um x 10um
  - The area : about $1m^2$,
  - The bandwidth per pixel : above 500bps
  - The total data bandwidth: **5Tbps**

- After front-end data compression, it is estimated that the final data bandwidth to off-detector can be reduced to **less than 100Gbps**



The silicon pixel detector is the first choice for the vertex detector of colliding physics experiments

Development of wireless technology



The next generation wireless transmission technology

Local area Network (LAN)

- WIFI6(802.11ax/ay), Single line:1.2Gbps, already used
- WIFI7(802.11be), Single line: 30Gbps, under development, is expected to be used in 2025
- WIFI8, is expected to start standardization in 2025 and used in 2030

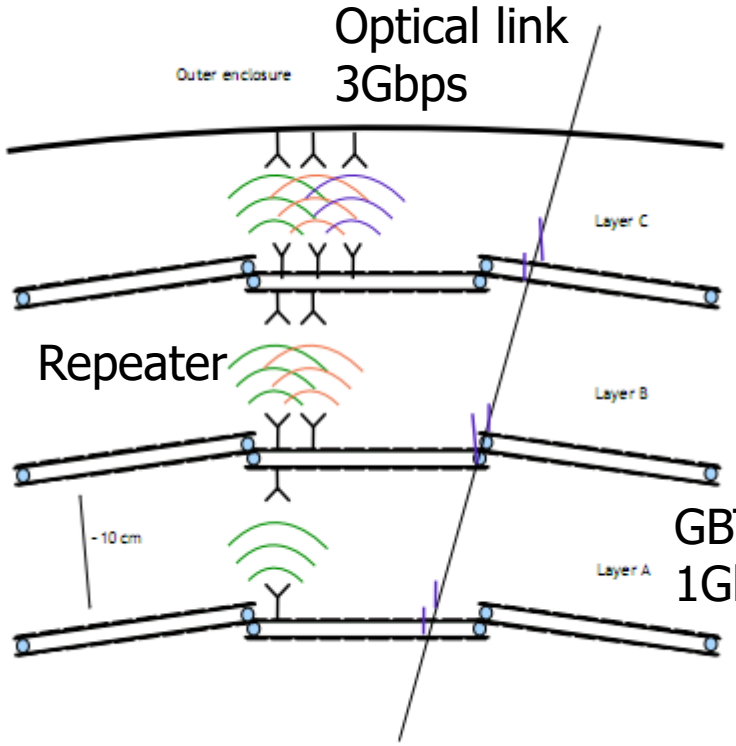
Mobile communication

- 5G, peak data rate is 10Gbps theoretically, already used
- 6G, peak data rate is 100Gbps-1Tbps theoretically, delay 0.1ms,The density of connection reaches more than 100points / m^3, and is expected to be used in 2030

Other wireless transmission technology including

- Short distance laser communication technology
- Short distance wireless transmission technology

Basic studies on CERN



Proposal of a radial readout for the tracker detector of the ATLAS experiment

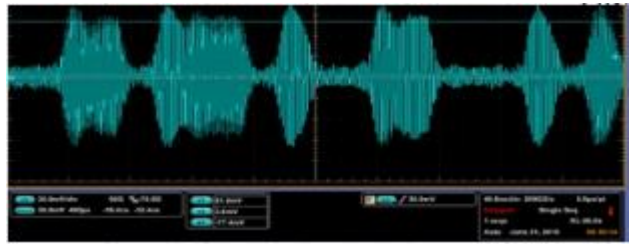
- Target short distance (10-30 cm), compact low power data links with multi Gbps bandwidth
- Wireless transmission with mm-waves
  - Commercial 60GHz transceiver (ST60 A2 from STMicrolelctronics)
  - WADAPT (Wireless Allowing Data And Power Transmission) - Uppsala, CERN, CEA/LETI/DTR/DACLE/LAIR, Argonne, Gangneung, Bergen, Heidelberg
  - 240 GHz (IHCT Wuppertal) custom 0.13 μm SiGe HBT technology
- Wireless transmission with optical waves
  - INFN Pisa and Scoula Superiore Sant'Anna
  - VCSEL 1310 nm based on COTS

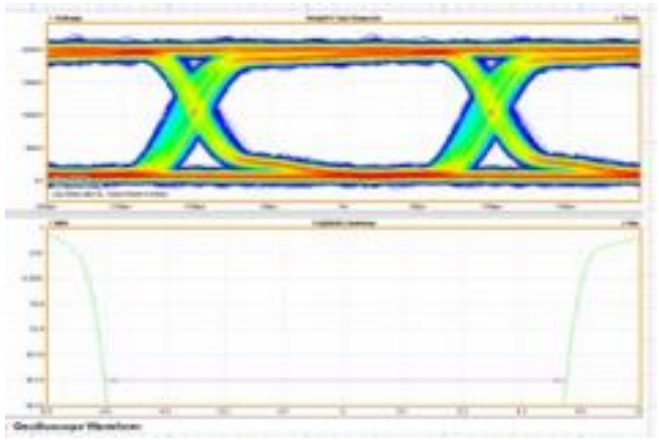
Work status and plan

- **GBT data transfer** has been demonstrated, Link **spacing of 10 cm** and below has been demonstrated
- **First compact low power GBT for use in trackers** are being developed
- **Potential to build topological systems**
- **Build links with carrier frequencies higher than 60 GHz** will allow for even higher data transfer

Tests with 60 GHz mm-waves

- Link density demonstrated >1 link/1dm²
- No effect on noise levels in detector.
- 5Gbps, BER <10^{-12}, <35ps rise/fall time, <75ps total jitter, <1ns latency with compact antenna
- Radiation hardness tested up to 270 Mrad (RX) and 314 Mrad (TX) and NIEL 10^{14}
- Long distance transfers (>m)

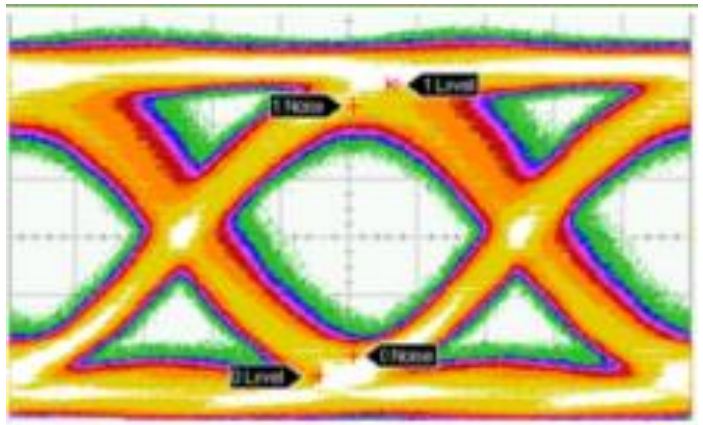


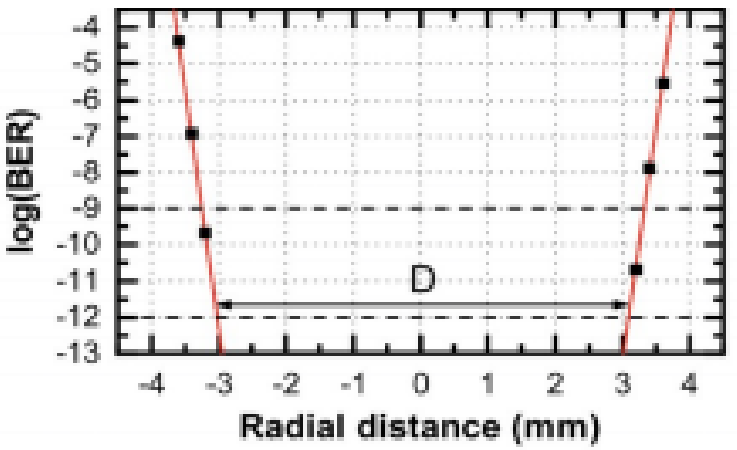


Richard Brenner et al., “Wireless data transmission for Wireless data transmission for trackers”, 2021 ECFA meeting

Tests with Optical Wireless

- All electro-optical components are COTS VCSEL 1310 nm optical power 2 mW
- BER 10^{-12} at 10 Gb/s established up to 20 cm distance with $\pm$3 mm misalignment
- Tested up to 238 Mrad TID and 10^{14} n_{eq}/cm^2



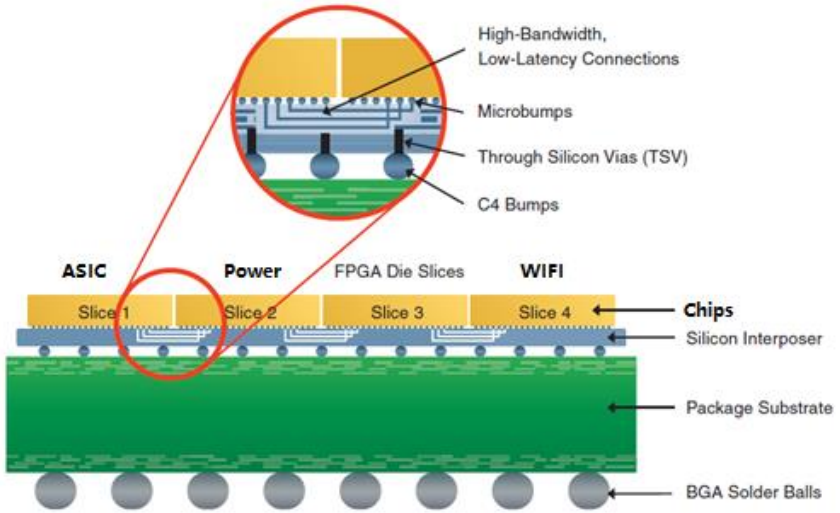


W. Ali et al., "Design and Assessment of a 2.5-Gb/s Optical Wireless Transmission System for High Energy Physics," in IEEE Photonics Journal, vol. 9, no. 5, pp. 1-8, Oct. 2017.
A. Messa et al., "Optical Wireless Systems for High Energy Physics: Design and Characterization", 2019 21st International Conference on Transparent Optical Networks (ICTON), Angers, France, 2019, pp. 1-4,

Our Research plan

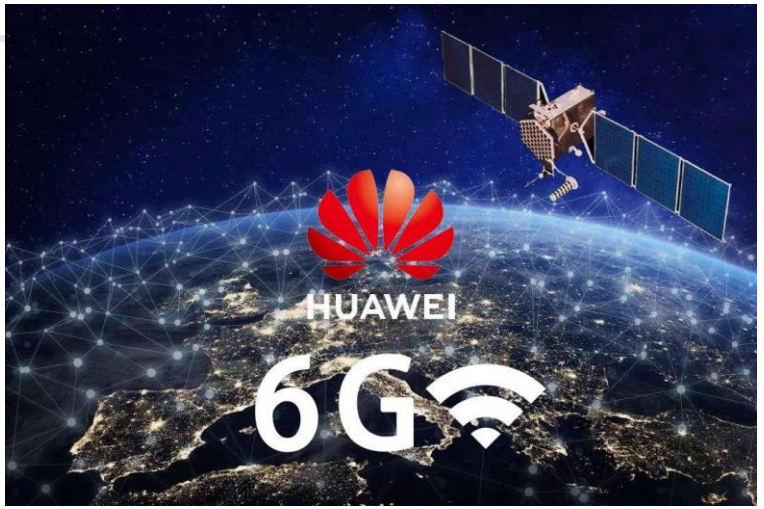
- Setup a prototype based on the wireless data and control transmission for vertex silicon pixel detector

01	High bandwidth radiation hard wireless transceiver chip and wireless transceiver router
02	Clock wireless transmission with picosecond jitter
03	Package the front-end signal processing chip and wireless transceiver chip within one chip
04	Optimize the shielding and heat dissipation structure for the packaged module



Partners

- Huawei Technology Co., Ltd
  - High bandwidth wireless transmission technology cooperation for particle physics experimental
  - High-precision wireless synchronous transmission technology
- Huajin semiconductor packaging leading technology R & D Center
  - High integration silicon to silicon packaging
- Shanghai Fudan Microelectronics Co., Ltd
  - Radiation hard FPGA



Summary

- The new data readout and control system based on wireless transmission technology will solve the inherent problems of traditional cable or optical fiber system.
- According to the development of wireless transmission technology, the wireless bandwidth will be close to the read out requirement of high energy physical experiment in the next ten years. With the custom ASIC technology and new package design, the new system can be implement in large data readout and control system.
- The new system is expected to be applied to many experiments, including: space science experiment, astronomy and Astrophysics experiment, nuclear physics experiment, remote multi detector joint experiment (such as gravitational wave experiment, accelerator neutrino experiment) and other intensive and massive data readout system.

Thank you