# Development of a Wireless Data and Control Transmission Application for CEPC

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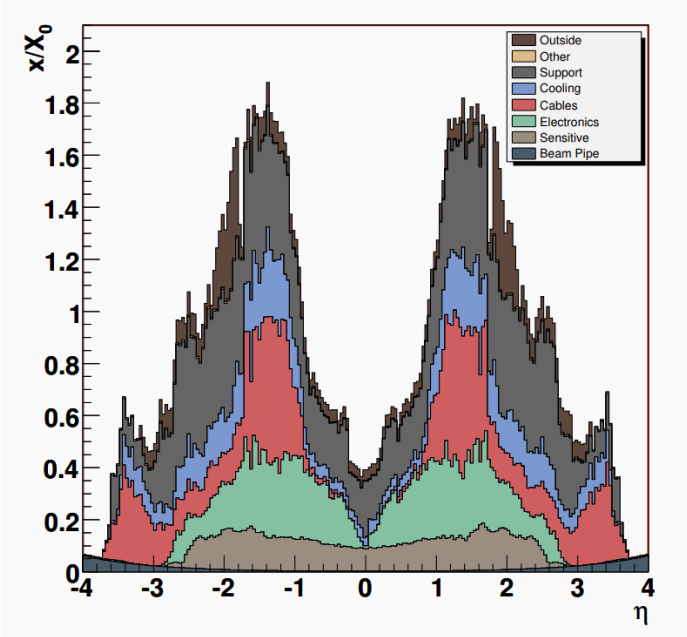
# Outline

- Motivation
- Technology Feasibility Studies
  - WiFi
  - Millimeter Wave (60GHz)
  - Optical wireless communication (OWC)
- Plan
- Summary

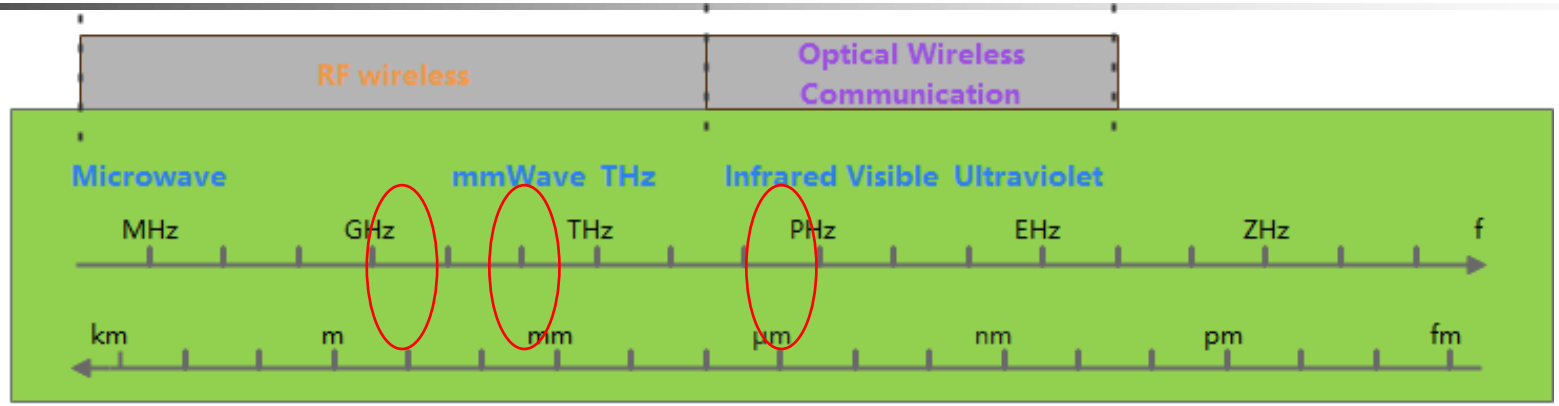
# Motivation

- Wireless transmission Advantages
  - Reducing the material budget of cables, fibers and connectors, while also reducing the dead zone.
    -> **Improve the detection efficiency and resolution!!!**
  - Broadcast links simplify the clock and control signal topology in complex detector system.
  - More convenient for installation and maintenance.




Radiation length distribution in CMS tracker

# Technology Feasibility Studies



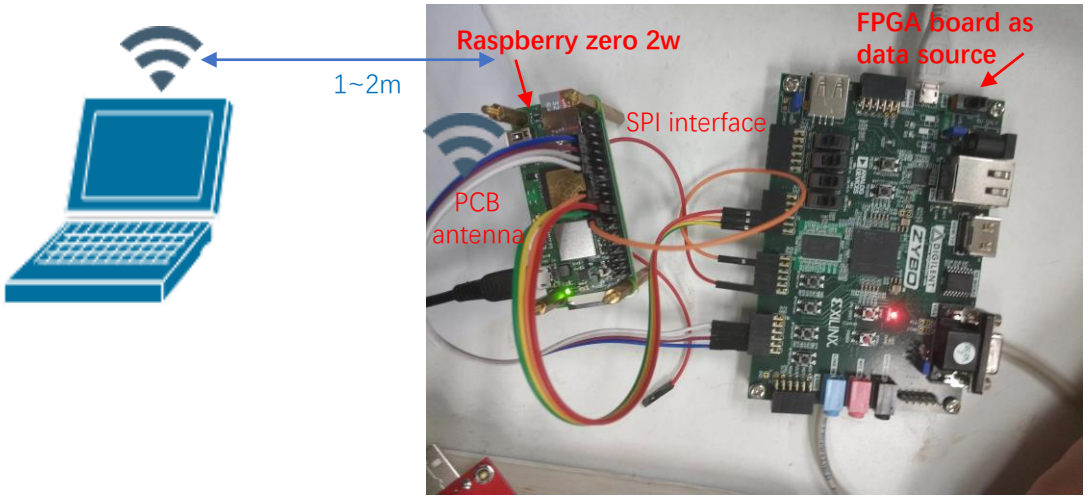

Electromagnetic Spectrum

- WiFi (2.4GHz, 5GHz)
- Millimeter Wave (60GHz)
- Optical wireless communication (OWC) / Free Space Optical(FSO)

# WiFi

| Years | 802.11 standard | Frequency Band | Name | Top Speeds |
|---|---|---|---|---|
| 2009 | 802.11n | 2.4 GHz or 5 GHz | WiFi 4 | 0.6Gbps |
| 2013 | 802.11ac wave1 | 5 GHz | WiFi 5 | 6.93Gbps |
| 2015 | 802.11ac wave2 | 5 GHz | | |
| 2019 | 802.11ax | 2.4 GHz or 5 GHz | WiFi 6 | 9.6Gbps |
| | | 2.4 GHz or 5 GHz<br>6 GHz | WiFi 7 | 46Gbps |

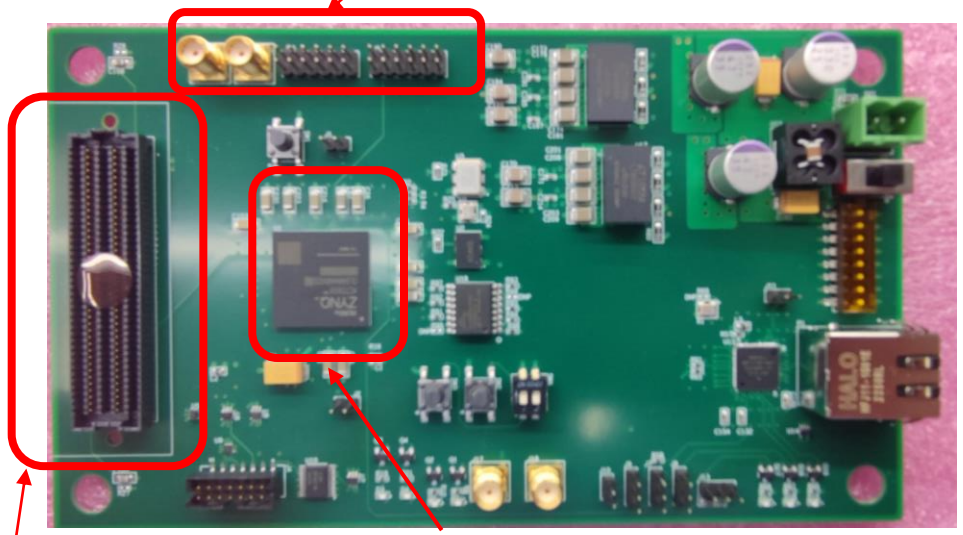
- A large number of similar modules can be purchased on the market, with universal SPI, i2c, USB, and PCIe interfaces.
- Most of them can easily find software and drivers to make them work.
- Difficult and no need to design with WiFi client chips.




Test setup based on Raspberry board

- Test with commercial board - Raspberry PI zero 2w
  - Mature SOC system, support 2.4GHz 802.11b/g/n.
  - Module size: 6.5cmX3cm， Power consumption: ~2W, Cost: ¥120.
  - Communicate with FPGA board through 2 SPI buses, one receiving and one transmitting.
  - Communicate with PC can achieve up to 22.03 Mbps in both uplink and downlink bandwidth through wireless.
  - More test with multi-channel is needed

# WiFi



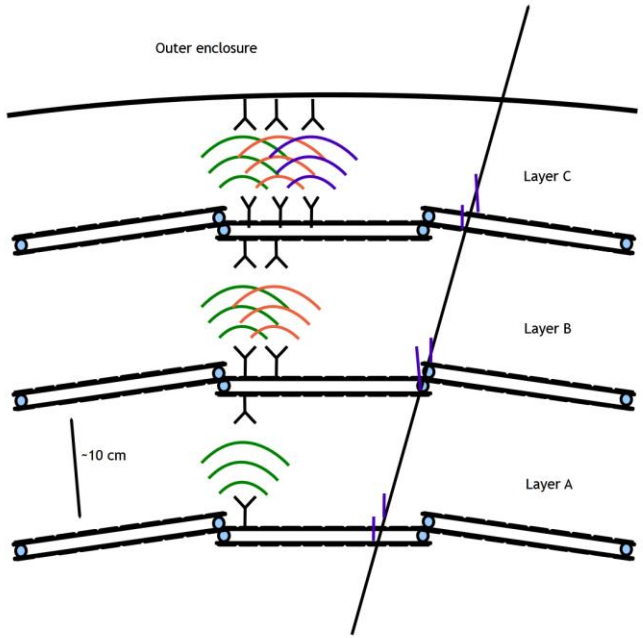

WiFi modules

- The main work is embedded system development and driver porting.
- Possible WiFi application scenarios
  - Far from the front-end
  - Low bandwidth transmission
  - DCS control information

- A ZYNQ evaluation board was designed to verify different WiFi modules, avoiding duplicate driver software development work.
  - 2 kinds of low speed interface modules has been tested

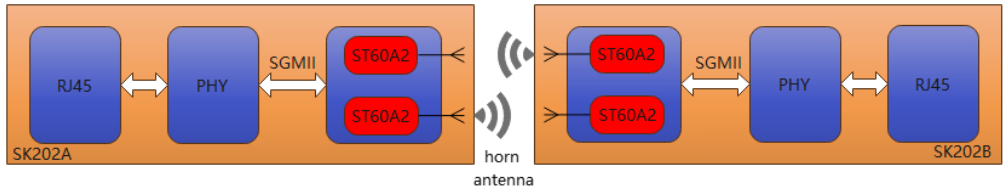
# Millimeter Wave

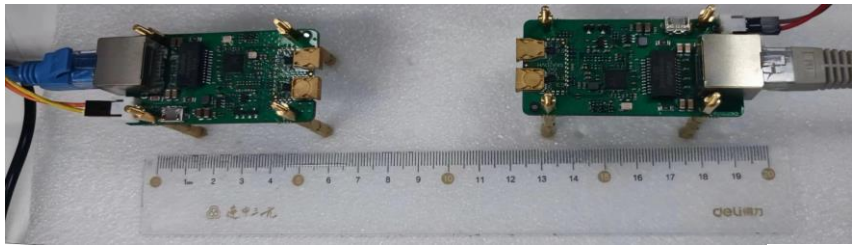
- Definition : 1-10mm wavelength ( 30-300GHz carrier frequency)
- Features
  - Huge bandwidth with lower power
  - Small antenna size
  - Large loss in free space, means lower interference,
  - High density possible
- A lot of ASICs for Radiation hard requirement are available with mature technology




Proposal of radial data readout for fast trigger by WADAPT Collaboration.
*Multi Gigabit Wireless Data Transfer in Detectors at Future Colliders*
https://www.frontiersin.org/articles/10.3389/fphy.2022.872691/full

# Millimeter Wave



Test with SK202 evaluation boards

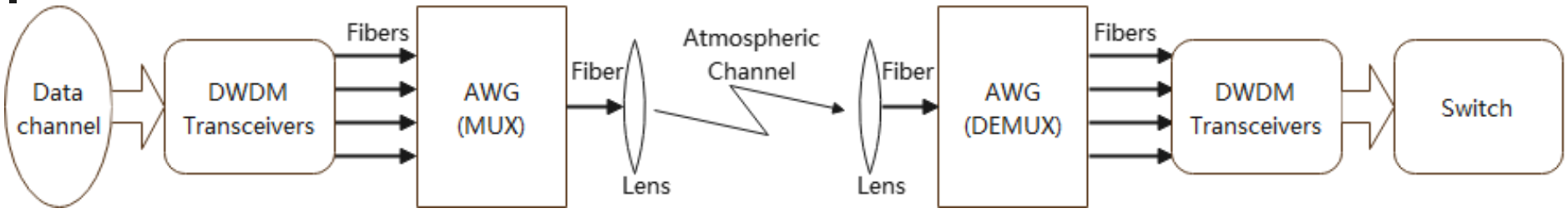
- Test with evaluation boards – SK202
  - The commercial 60GHz RF chip ST60A2 transceiver from ST Microelectronics company.
  - Up to 6.25 Gbit/s data rate.
  - The chip power consumption:
    44mW@TX, 27mW@RX, 3.5uW @ OFF
  - Cost: ¥100.

| Distance (cm) | Bandwidth (Mbps) | Packet loss rate |
|---|---|---|
| 1 | 914 | 0.031% |
| 3 | 917 | 0.061% |
| 5 | 915 | 0.05% |
| 6 | 913 | 0.13% |
| >6 | No link | No link |

Test result at different distances of TX/RX

- 2 laptops use Iperf3 software to send data to each other, The test results shows
  - The transmission speed can reach more than 900Mbps when the distance is less than 5 cm.
  - No link when the distance is over 6 cm
  - When the horn antenna angle has 2 mm mismatch, the link is not stable.
- New custom evaluation board need to be designed with higher bandwidth.

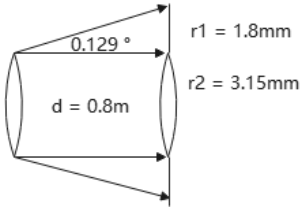
# Optical Wireless




Free Space Optical(FSO) test setup structure

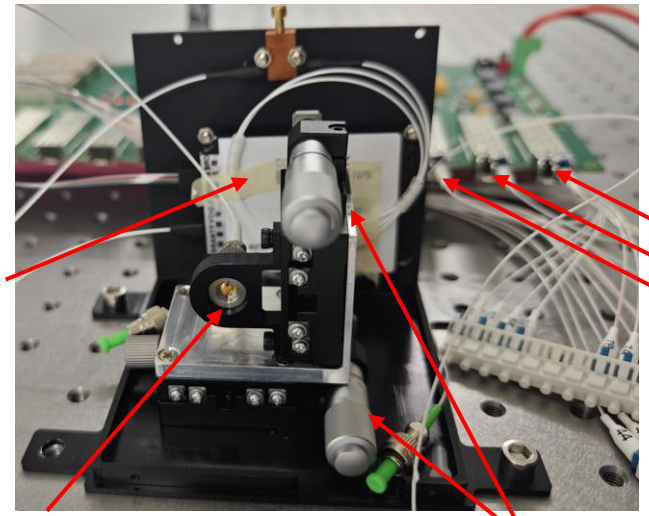
- Data channel : Maybe from endcap of detector
- Dense Wavelength Division Multiplexing (DWDM) transceivers:
  - Up to 11.3Gb/s data links
  - Power Consumption: 1.6W
  - Average Optical Power: 1~5dBm
  - Optical Extinction Ratio: 8.2dB
  - Receiver Sensitivity (Average Power): -25dBm

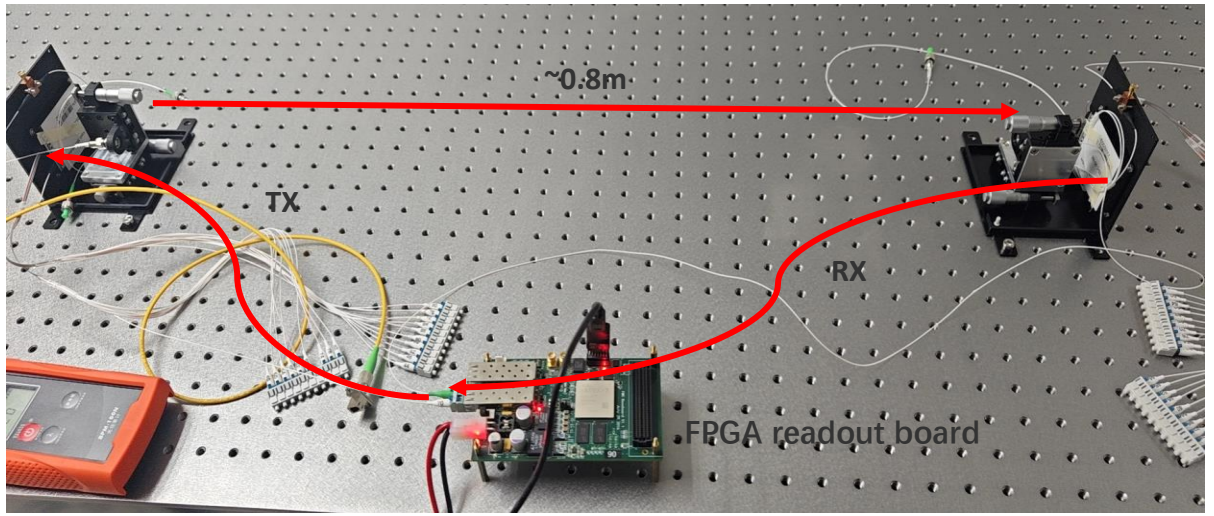
- Arrayed Waveguide Grating (AWG)
  - Center Wavelength: 1550nm
  - Attenuation : -7db
  - Center Wavelength Spacing: 100GHz
  - Channels support: 20 bidirectional maximum




- Lens :
  - Divergence : 0.129°@1550nm
  - $\eta = \frac{P2}{P1} = \left(\frac{r2}{r1+r2}\right)^2 = \left(\frac{3.15}{1.80+3.15}\right)^2 = 0.405 = -3.92db$

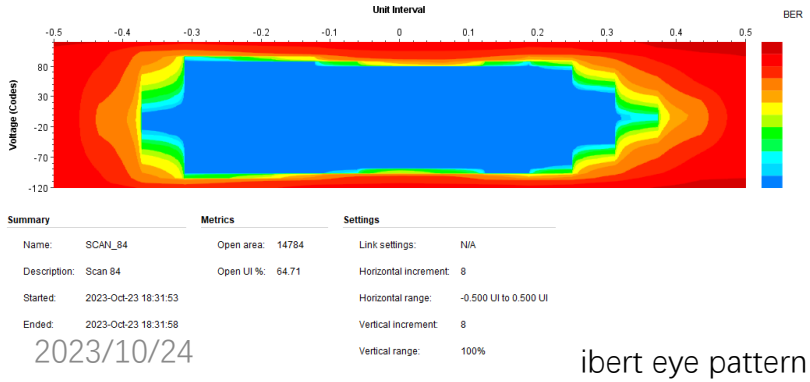
# Optical Wireless





Optical Power received : -13.36dBm

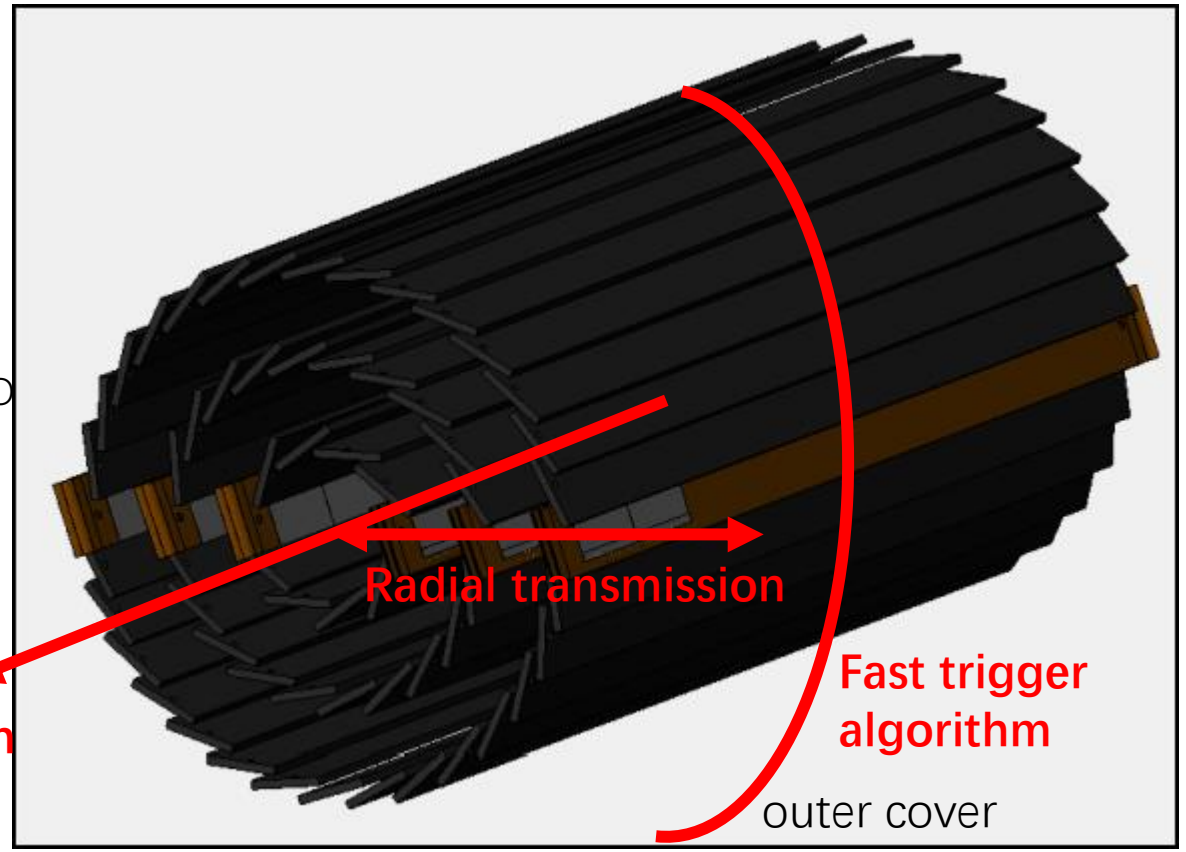



ibert eye pattern

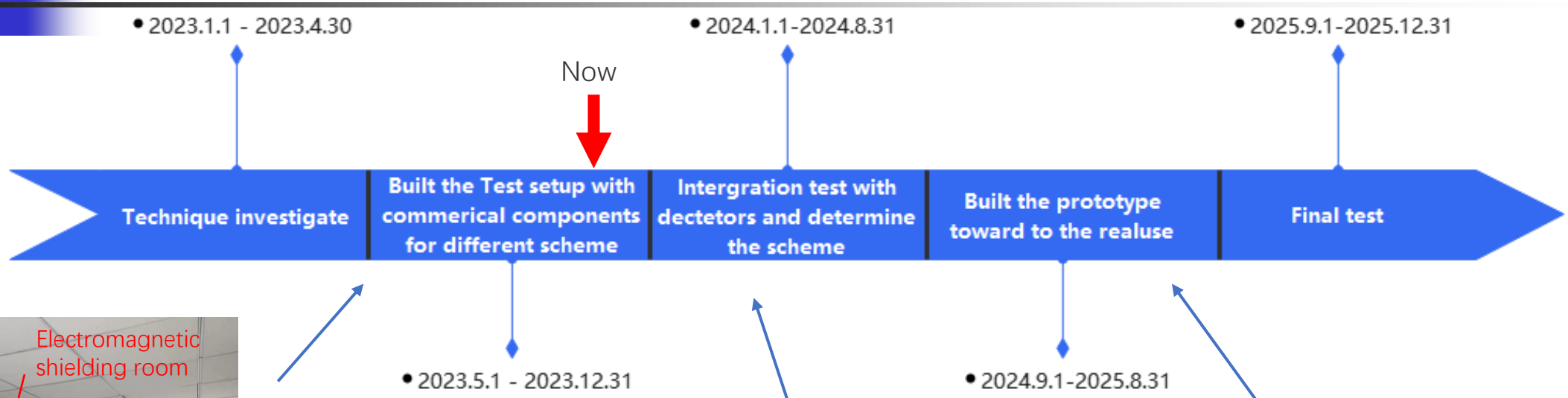
- Easily compatible with current readout electronics for MOST2 prototype （SFP+ connector）
- Kintex7 FPGA board use ibert test in loopback mode
  - Optical Power received : -13.36dBm > -25dBm
  - 32-PRBS error rate < 1.0X10^-12 @ 4Gbps
- Higher speed and more channels test need to be done with Vertex 7 board

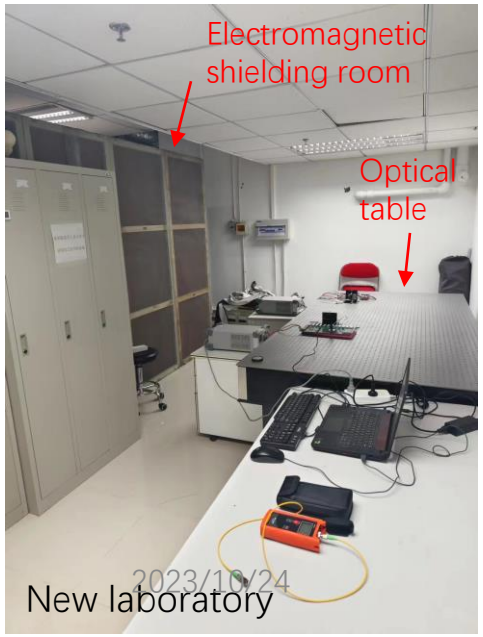
# Preliminary idea

- Radial transmission
  - Short distance transmission with mm Wave.
  - Frist fast trigger generator in outer cover.
- Axial transmission
  - Data Aggregate few points at the endcap.
  - Longer distance transmission  to off-detector with FSO

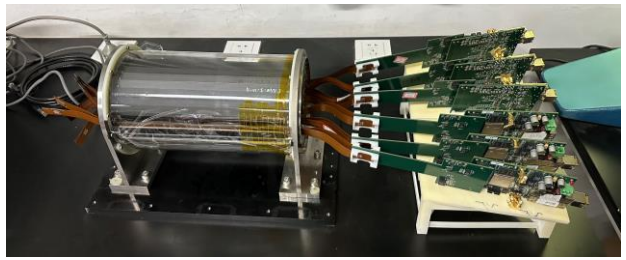


# Plan



New laboratory



- Proof concept demonstrator with commercial components
  - Muli-channel cross talk test
  - Wireless noise to the detector module
- Develop the core transceiver / driver custom chips for radiation hard

# Summary

- Some specific wireless technologies are selected and the testing started.
- Need carefully proof concept demonstrator with thorough test.
- In-depth discussions about the structure and mechanical design of detector.

- Still open to exploring alternative technologies and other innovative ideas.

# Thank you