Status of the Wireless Transmission Application for CEPC

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On behalf of the Elec-TDAQ system of the CEPC Ref-TDR

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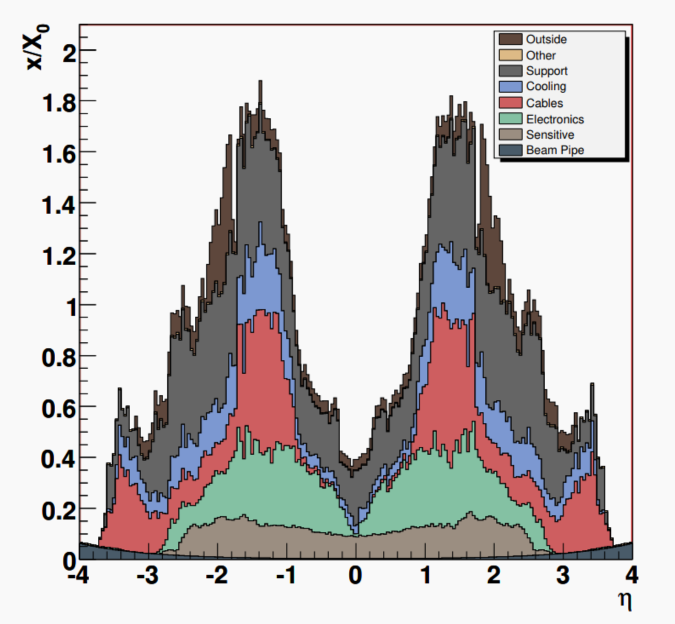
Outline

- Motivation
- Status of Technology Feasibility Studies
  - WiFi
  - Millimeter Wave
  - Optical Wireless Communication (OWC)
- Preliminary ideas
- Conclusion

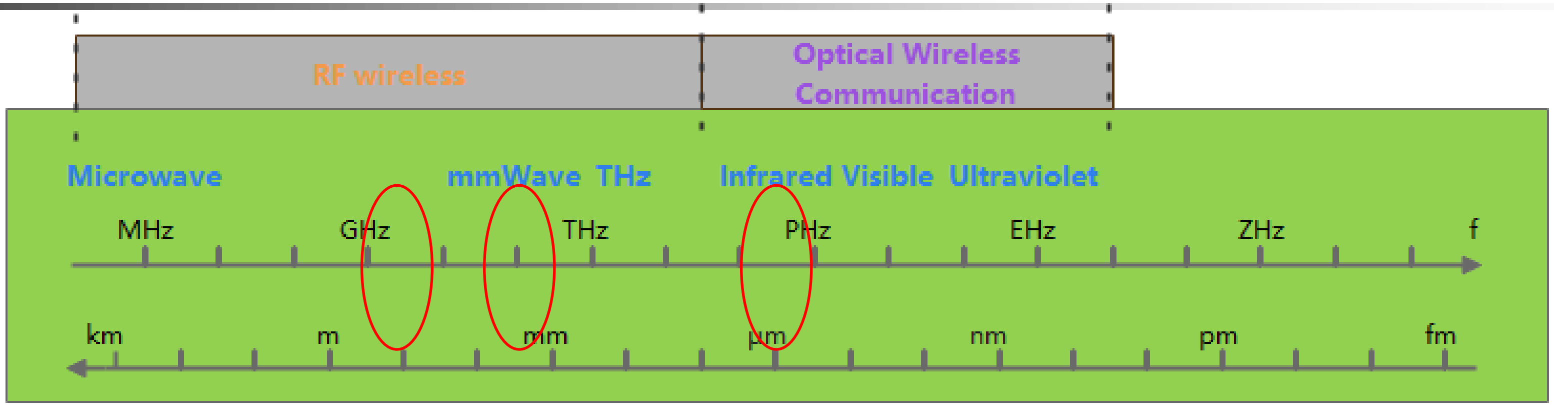
Motivation

- 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.
  - Reduction cost associated with the removal of connectors and fibers.



Radiation length distribution in CMS tracker

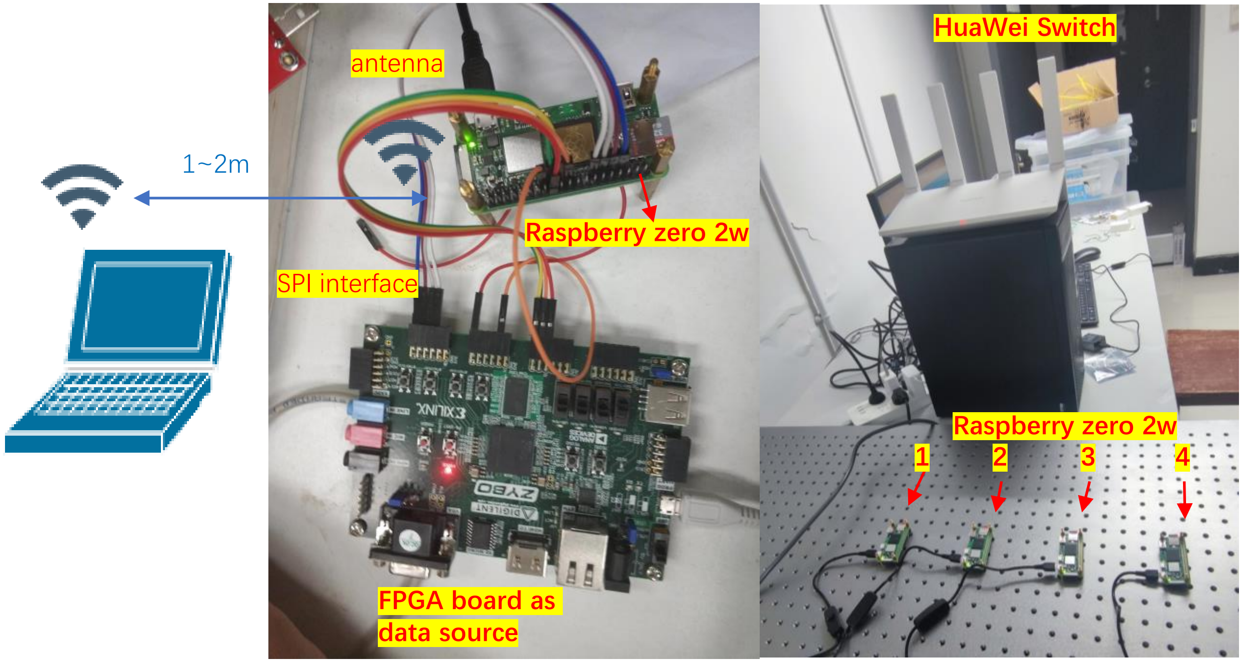
Technology Feasibility Studies



Electromagnetic Spectrum

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

WiFi

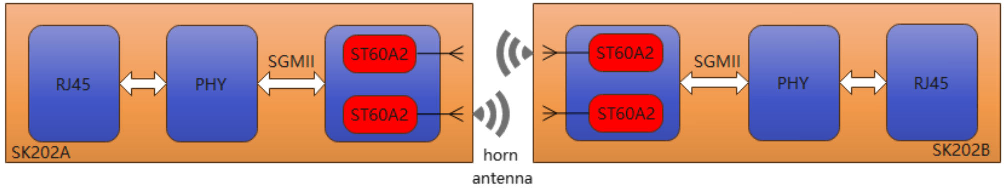


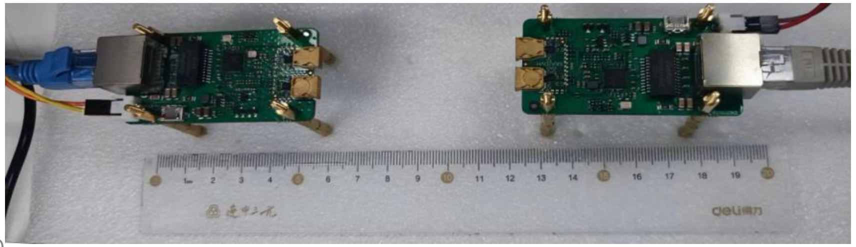
Test setup based on Raspberry board

- Widely used and well known to everyone
  - Commercial modules are very mature and easily to used
- 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.
  - Communicate with PC can achieve up to 45 Mbps in both uplink and downlink bandwidth through wireless.
  - Due to the occupation of same frequency band, the bandwidth is shared when 4 endpoints are connected to a single switch.
  - When two independent endpoints are more than 2 meters apart, they are unable to interfere with each other.
- Possible application scenarios
  - The size and power consumption limit the use inside detector.
  - The lower bandwidth capability and broadcasting characteristics are suitable to transfer DCS control information.

Millimeter Wave

- Definition : 1-10mm wavelength (30-300GHz carrier frequency)
- Features
  - Huge bandwidth with lower power
  - Small antenna size, even integrated into the chip
  - Large loss in free space(68dB@1m), means lower interference, not only between channels but also with detectors.
  - High density possible





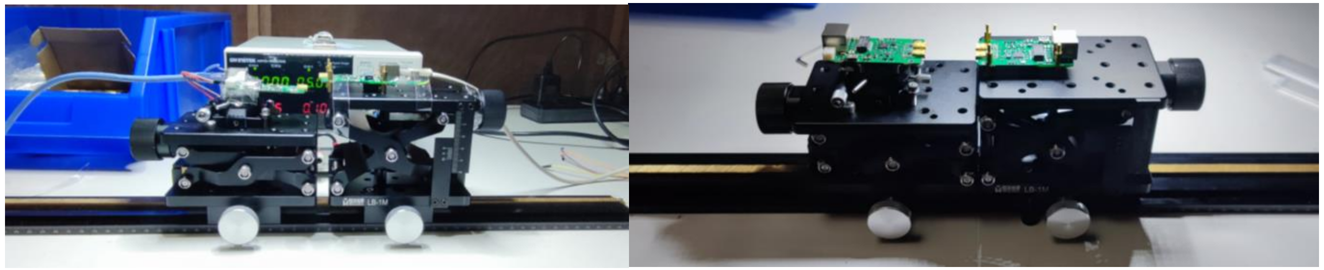
Test with SK202 evaluation boards

- 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
  - The transmission speed can exceed 900Mbps when the distance is less than 5 cm.
  - No link established when the distance exceeds 6 cm

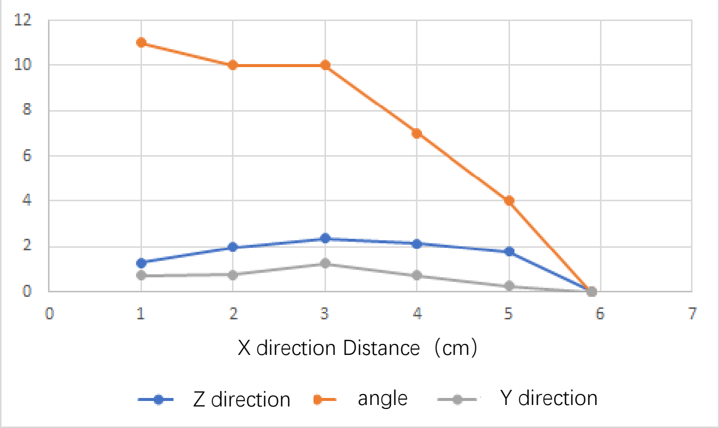
Distance (cm)	Bandwidth (Mbps)	Packet loss rate
1	914	0.031%
3	917	0.061%
5	915	0.05%
6	913	0.13%
>6	No link	No link

Test result at different distances of TX/RX

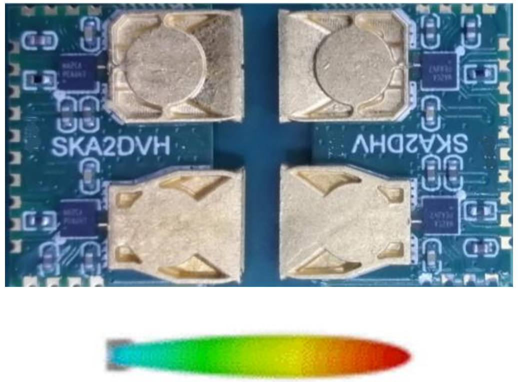
Millimeter Wave



Further testing about the angle and penetration ability



Distance vs Angle



Antenna used and the radiation pattern

Material	Thickness	Penetration Ability
Paper	2mm	√
Plastic ruler	2mm	√
FR4 PCB	1.6mm	×
Flex	0.2mm	×

Test with 3 cm distance

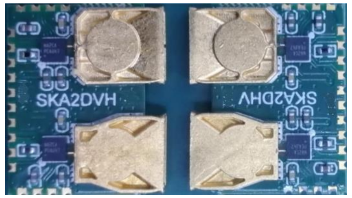
The presence of metal layers in the circuit boards obstructs the transmission of mm waves.

- Antenna design is also crucial in the scheme as it influences the transmission direction.

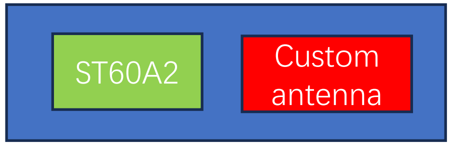
Millimeter Wave

- We are doing …

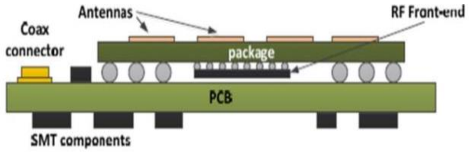
Cooperation with Institute of Microelectronics, CAS and advanced packaging commercial company



- Step 0: Full commercial module
- Basic performance test

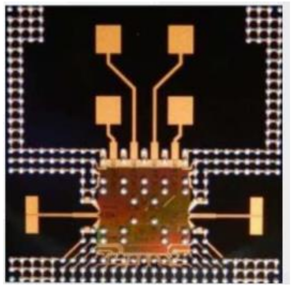


- Step 1: Design a small PCB module with custom antenna and ST60A2
- Higher bandwidth test
- Evaluate the interference with detector and each other
- Under design, cheap and easy



Step 2: Integrate the antenna and available mm wave RF chips (45G/60G/77G) into the package (AIP)

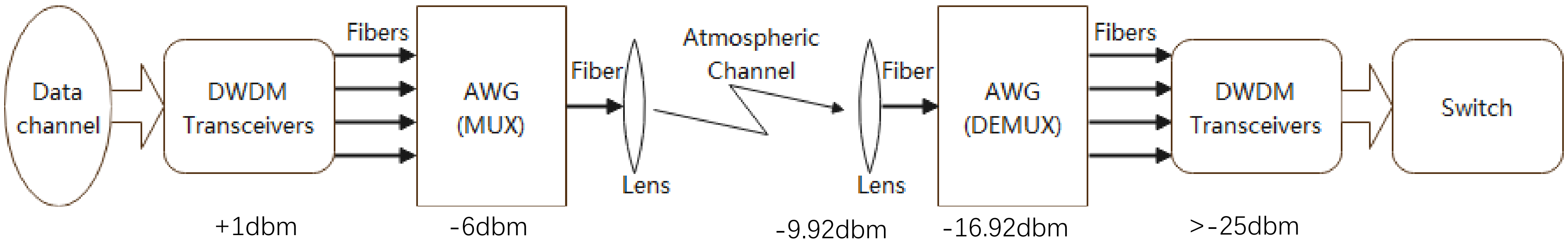
- Less cost and mature technological
- Radiation hard test.



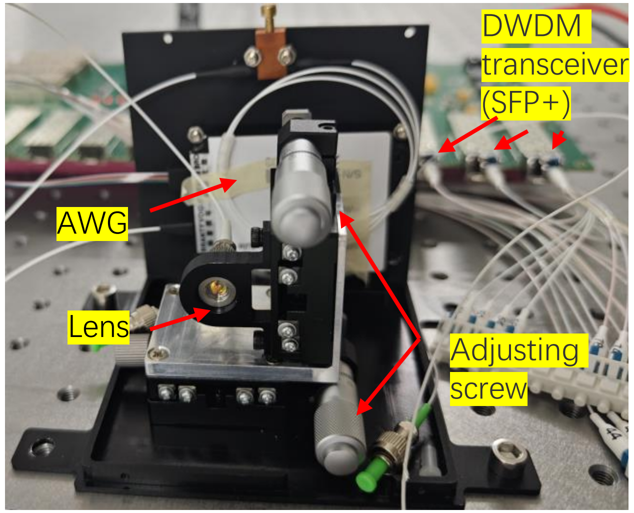
Step 3: Custom radiation RF front-end + custom Antenna in one chip

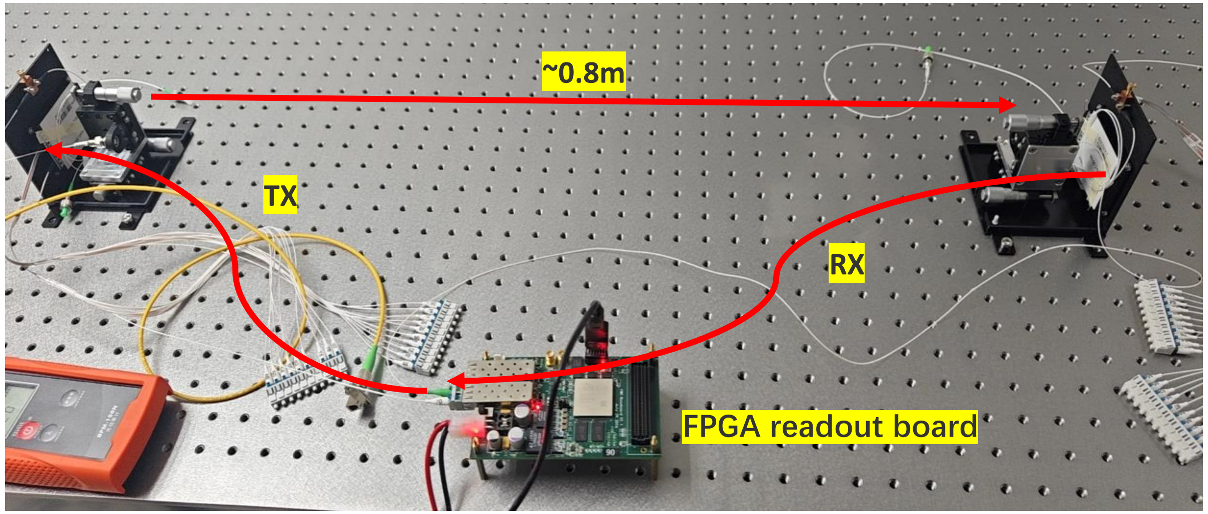
- Final solution of minimum material budget.
- The most challenging, significant investment in R&D costs

Optical Wireless



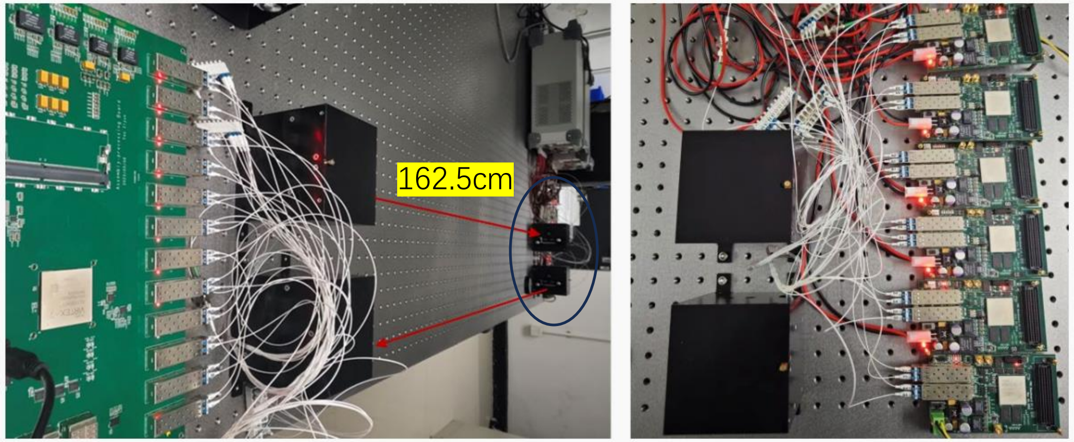
Free Space Optical(FSO) test setup structure





Optical Power received：-13.36dBm

Optical Wireless



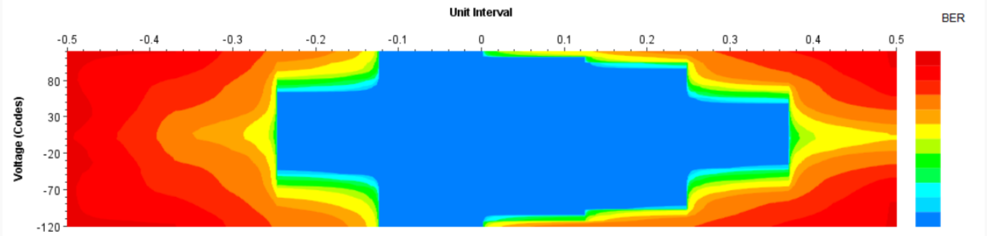
Loopback data transmission test with 12 channels between BEE prototype board(Vertex 7) and MOST2 FEE FPGA board(Kintex 7)

Parameter	λ = 1550.12nm, P = 1.52dB
λ – 0.8nm	-45.54dB
λ	-11.30dB
λ + 0.8nm	-43.57dB

Crosstalk between channels < -34dB
Insertion loss ~ 12.82dB

Name	TX	RX	Status	Bits	Errors	BER	BERT Reset	TX Pattern
Ungrouped Links (0)								
Found Links (12)							Reset	PRBS 31-bit
Found 0	Quad_114/MGT_X1Y16/TX (xc7vx690t_0)	Quad_114/MGT_X1Y16/RX (xc7vx690t_0)	10.000 Gbps	4.15E14	7.43E11	1.79E-3	Reset	PRBS 31-bit
Found 1	Quad_114/MGT_X1Y17/TX (xc7vx690t_0)	Quad_114/MGT_X1Y17/RX (xc7vx690t_0)	10.000 Gbps	4.15E14	0E0	2.41E-15	Reset	PRBS 31-bit
Found 2	Quad_114/MGT_X1Y18/TX (xc7vx690t_0)	Quad_114/MGT_X1Y18/RX (xc7vx690t_0)	10.000 Gbps	4.15E14	0E0	2.41E-15	Reset	PRBS 31-bit
Found 3	Quad_114/MGT_X1Y19/TX (xc7vx690t_0)	Quad_114/MGT_X1Y19/RX (xc7vx690t_0)	10.000 Gbps	4.15E14	0E0	2.41E-15	Reset	PRBS 31-bit
Found 4	Quad_116/MGT_X1Y24/TX (xc7vx690t_0)	Quad_116/MGT_X1Y24/RX (xc7vx690t_0)	10.000 Gbps	4.15E14	0E0	2.41E-15	Reset	PRBS 31-bit
Found 5	Quad_116/MGT_X1Y25/TX (xc7vx690t_0)	Quad_116/MGT_X1Y25/RX (xc7vx690t_0)	10.000 Gbps	4.15E14	0E0	2.41E-15	Reset	PRBS 31-bit
Found 6	Quad_116/MGT_X1Y26/TX (xc7vx690t_0)	Quad_116/MGT_X1Y26/RX (xc7vx690t_0)	10.000 Gbps	4.15E14	0E0	2.41E-15	Reset	PRBS 31-bit
Found 7	Quad_116/MGT_X1Y27/TX (xc7vx690t_0)	Quad_116/MGT_X1Y27/RX (xc7vx690t_0)	10.000 Gbps	4.15E14	0E0	2.41E-15	Reset	PRBS 31-bit
Found 8	Quad_118/MGT_X1Y32/TX (xc7vx690t_0)	Quad_118/MGT_X1Y32/RX (xc7vx690t_0)	10.000 Gbps	4.15E14	0E0	2.41E-15	Reset	PRBS 31-bit
Found 9	Quad_118/MGT_X1Y33/TX (xc7vx690t_0)	Quad_118/MGT_X1Y33/RX (xc7vx690t_0)	10.000 Gbps	4.15E14	0E0	2.41E-15	Reset	PRBS 31-bit
Found 10	Quad_118/MGT_X1Y34/TX (xc7vx690t_0)	Quad_118/MGT_X1Y34/RX (xc7vx690t_0)	10.000 Gbps	4.15E14	0E0	2.41E-15	Reset	PRBS 31-bit
Found 11	Quad_118/MGT_X1Y35/TX (xc7vx690t_0)	Quad_118/MGT_X1Y35/RX (xc7vx690t_0)	10.000 Gbps	4.15E14	0E0	2.41E-15	Reset	PRBS 31-bit

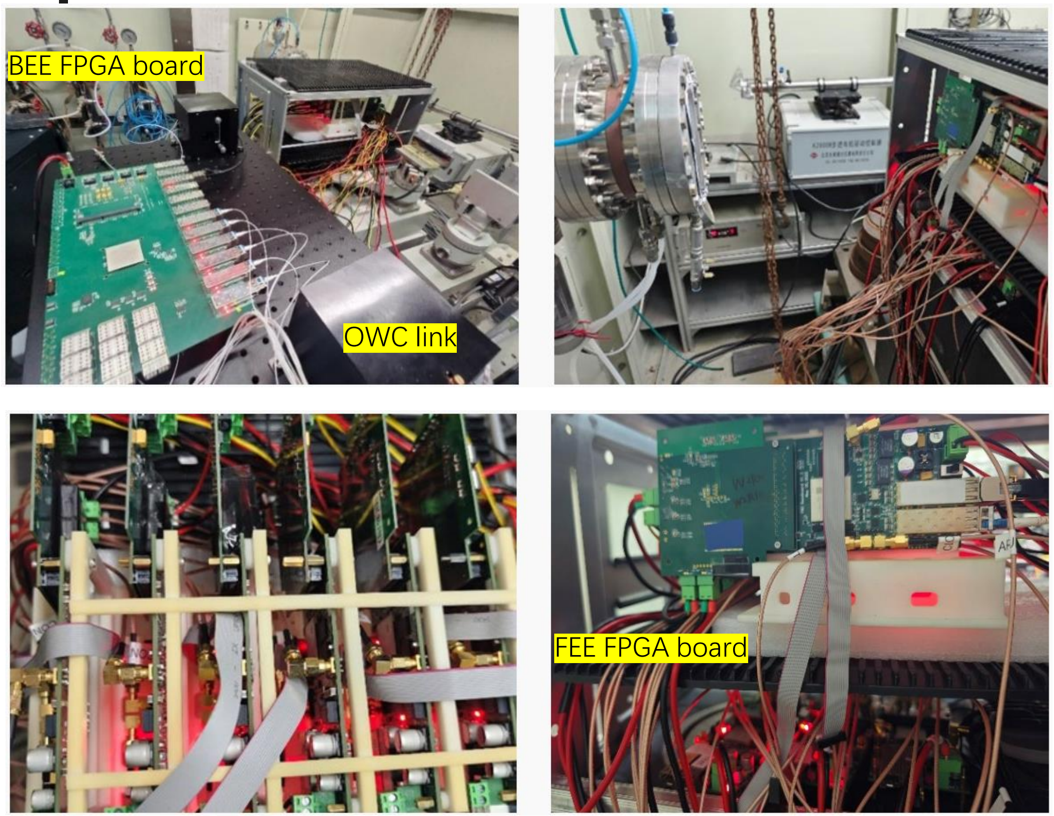
PRBS 31bits error rate < BER-15 @ 8Gbps X 12 channels & 10Gbps X 11 channels



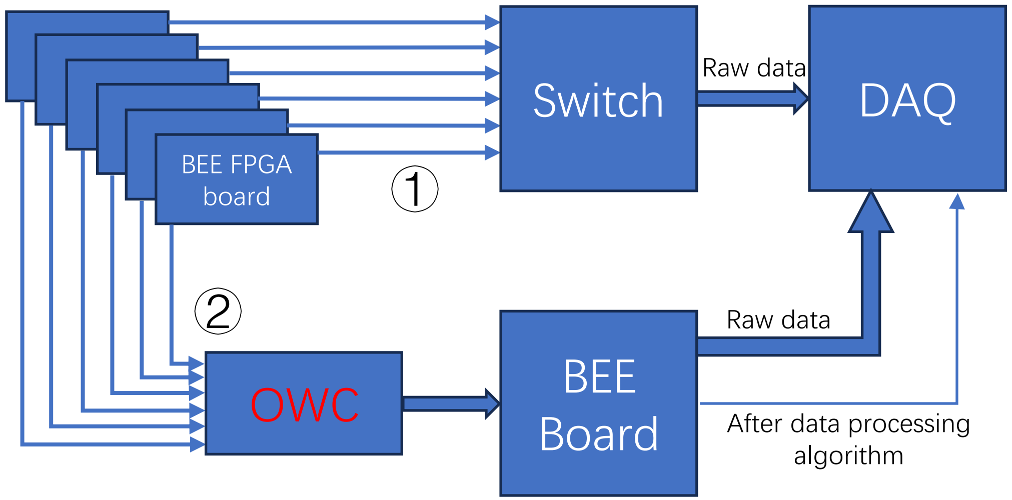
10Gbps eye pattern in loopback test

- The optical wireless system can operate within a distance of 162.5cm, offering a bandwidth of up to 118Gbps, and it is capable of supporting 100G Ethernet.

Optical Wireless



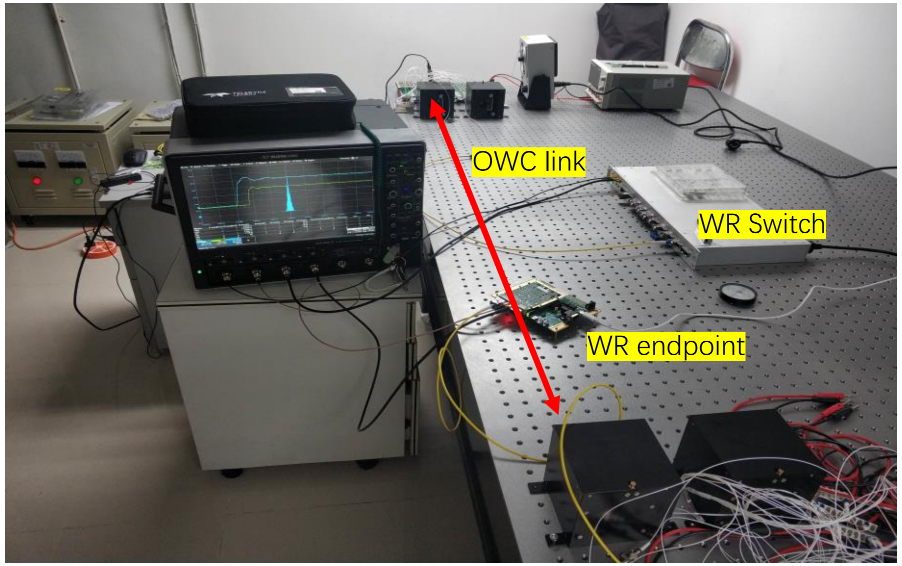
Telescope prototype test in BSRF



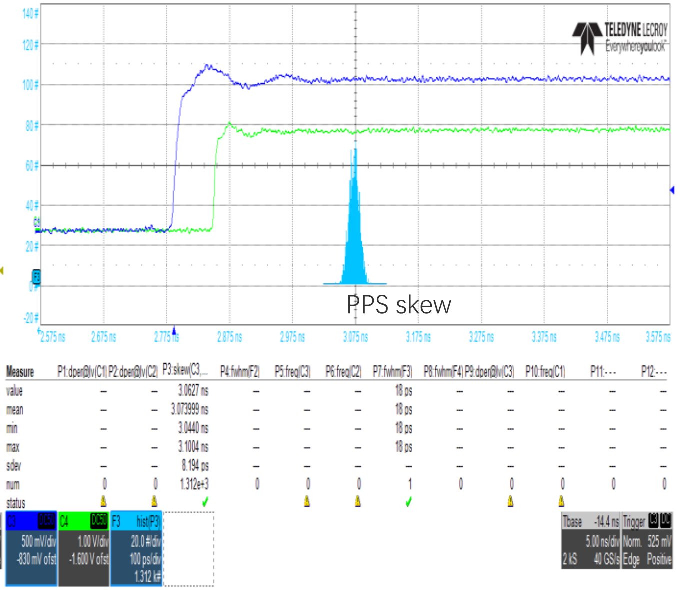
- After running for 2086 minutes in total, the raw data from optical fiber to switch ① is 100% matched to the data transmitted through OWC to the BEE board ②.

Optical Wireless

- Clock transmission test
  - Connect WR switch and CuteWR endpoint with single OWC link（1.6m)
  - Based on WR protocol

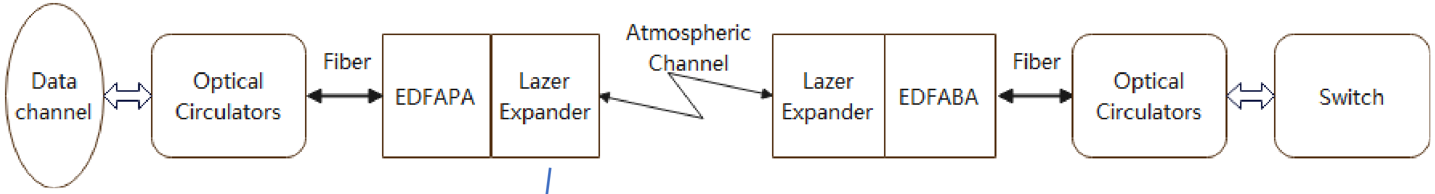


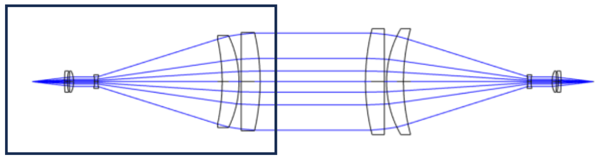
Wireless clock transmission test



- Clock performance
  - WR switch output cycle to cycle jitter : 8.866ps RMS
  - endpoint received cycle to cycle jitter : 9.128ps RMS
  - PPS skew： 8.194ps RMS
- A relatively fixed free space optical transmission path will not affect the accuracy of the WR protocol.

Optical Wireless

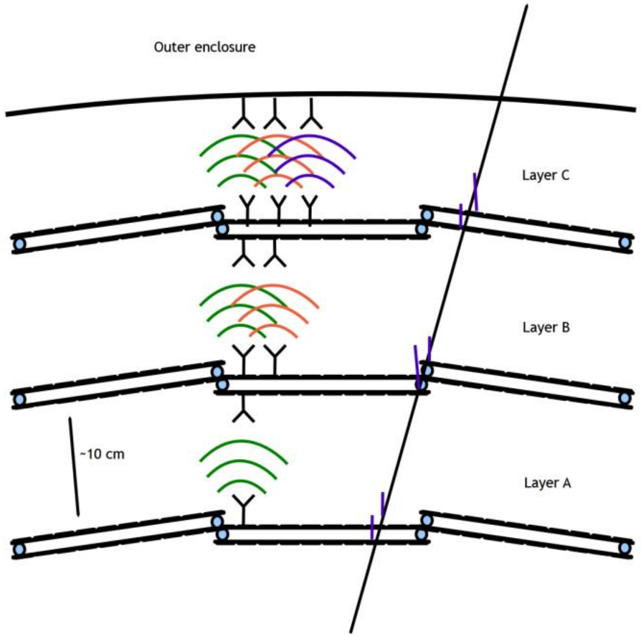




Long-distance ~1km OWC design

- Next…
  - Design long-distance OWC and test clock performance for accelerator synchronization requirements.
  - Try different wavelengths to reduce the impact on detector.
  - Optimize components types, reduce size, and reduce alignment requirements
  - Consider replacing the commercial components with custom components for particle experiment requirement.

Preliminary Ideas



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

- Opt for radial readout instead of axial readout for a fast trigger in the **tracking** detector.
- Collection the data from barrel to endcap for **calorimeter.**
- Still under discussion with all the sub-detector.

Conclusion

- The rapidly developing wireless technology provides many advantages for future collider.
- We are currently conducting feasibility studies on mm-Wave and optical wireless communication study using commercial devices.
- We are in discussions and working towards proposing some feaible schemes based on Ref-TDR.
- There is still a lot of work to be carried out in the future, especially in the field of custom design chips.

Thank you