

# Design and construction of the CMS Outer Tracker for the Phase-2 Upgrade

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FERMILAB-POSTER-24-0315-CMS

## The High-Luminosity LHC

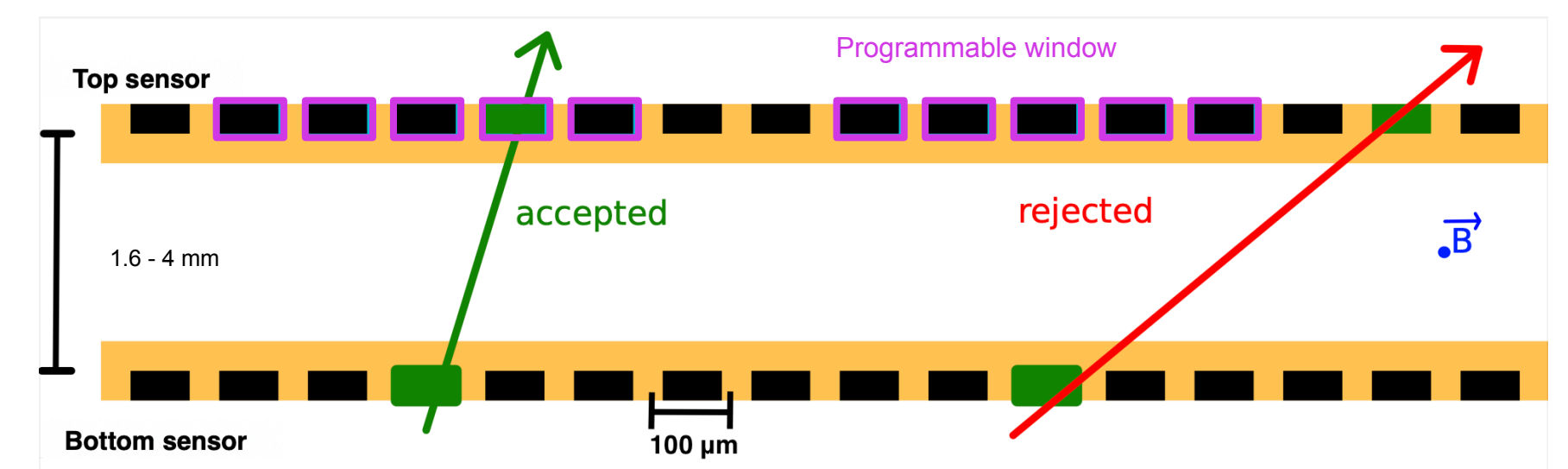
- ✓ Increase Standard Model measurements precision
- ✓ Increase discovery potential
- ✓ Search for rare decays
- ▶ Instantaneous peak luminosity:  $5-7.5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$  [1]
- ▶  $\sqrt{s} \sim 14 \text{ TeV}$
- ✗ High pileup up to 140-200 events/25 ns
- ✗ High radiation environment

## The CMS Outer Tracker Phase-2 Upgrade

- ▶ The whole tracker will be replaced. The new Outer Tracker [2] features:
  - ▶ **Tracking information in the L1 trigger event selection**
    - ▶ First time at a hadron collider!
  - ▶ **Increased granularity:** channel occupancy around or below the percent level
  - ▶ **Reduced material** from up to  $1.6 \times X_0$  to below  $0.8 \times X_0$
  - ▶ **Increased radiation hardness** → fluence up to  $1.4 \times 10^{15} \text{ neq/cm}^2$

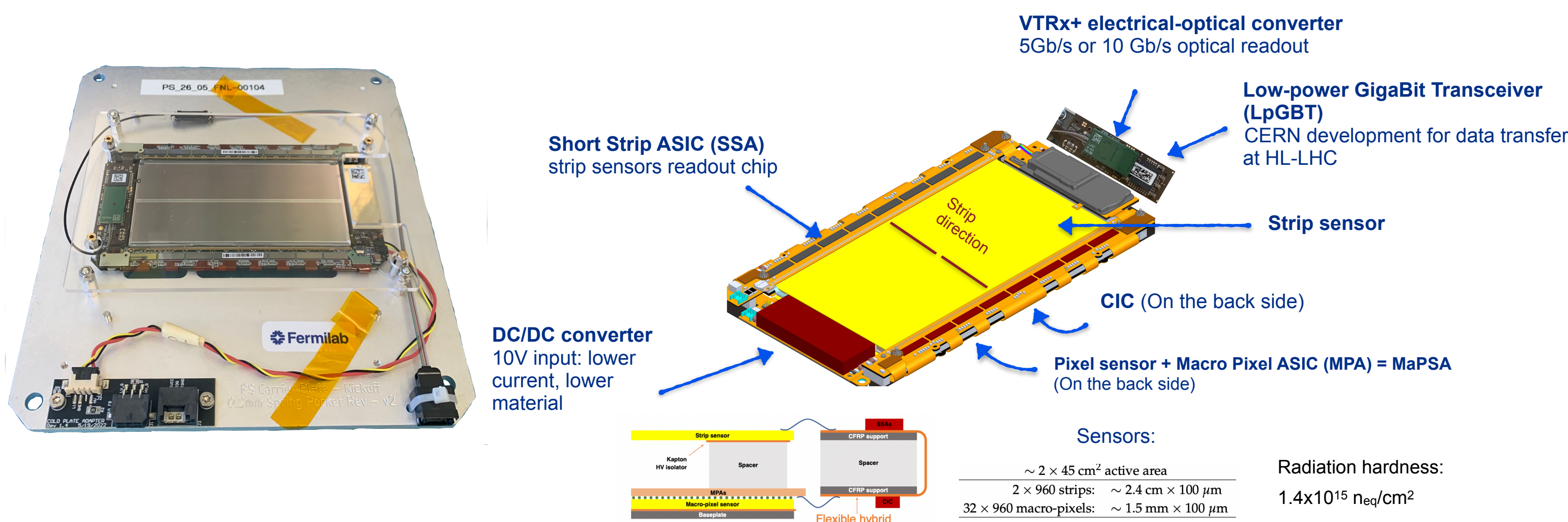
## The $p_T$ modules for tracking at 40 MHz

- ▶ **Stubs** (hits from tracks with  $p_T > 2 \text{ GeV}$ ) sent to the back-end electronics at 40 MHz to build L1 track primitives
- ▶ All hits are stored in the electronics, waiting for the L1 trigger decision

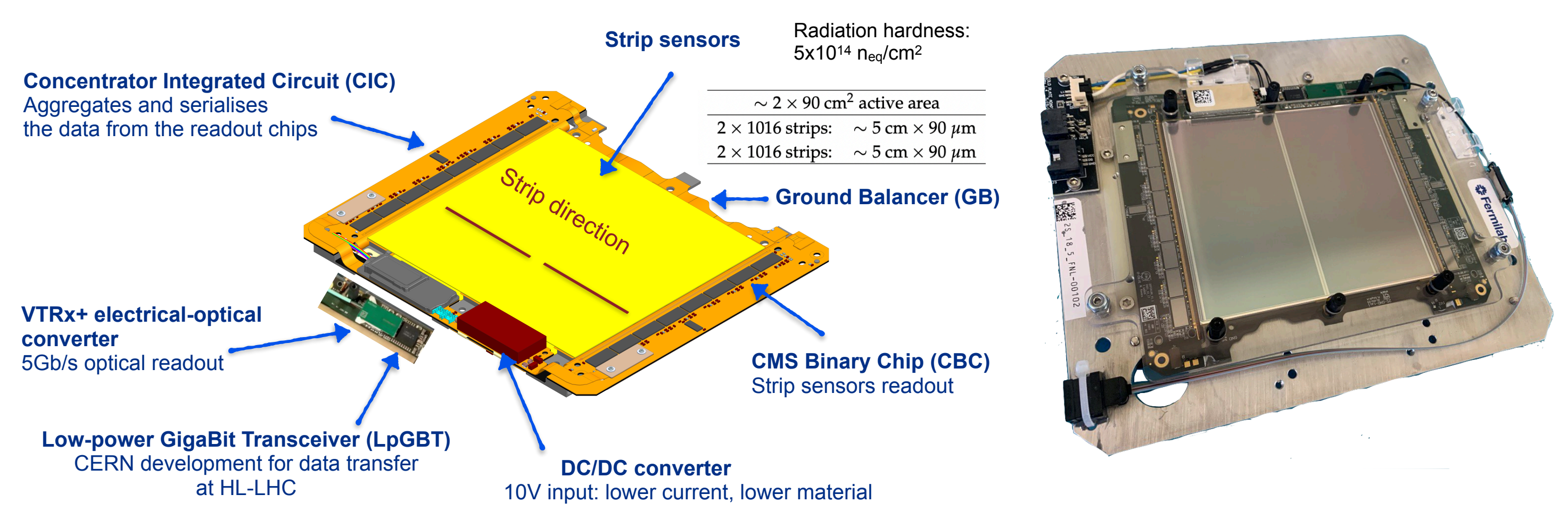


Two  $p_T$ -module versions:

### PS (pixel + strip) modules



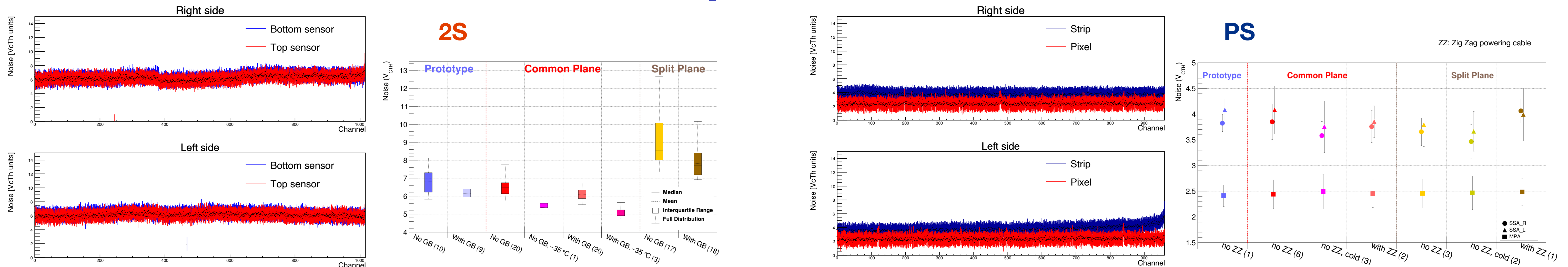
### 2S (strip + strip) modules



## Module qualification and design finalization

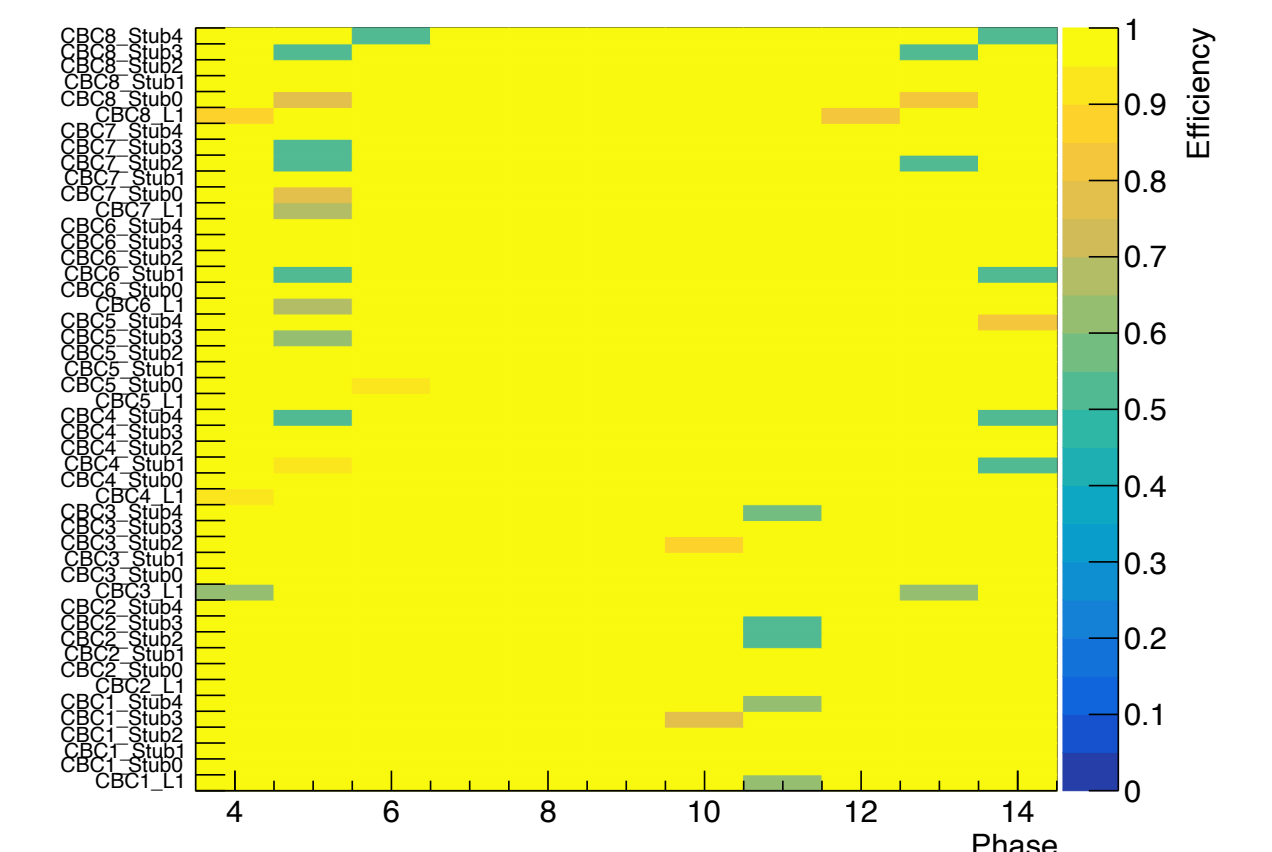
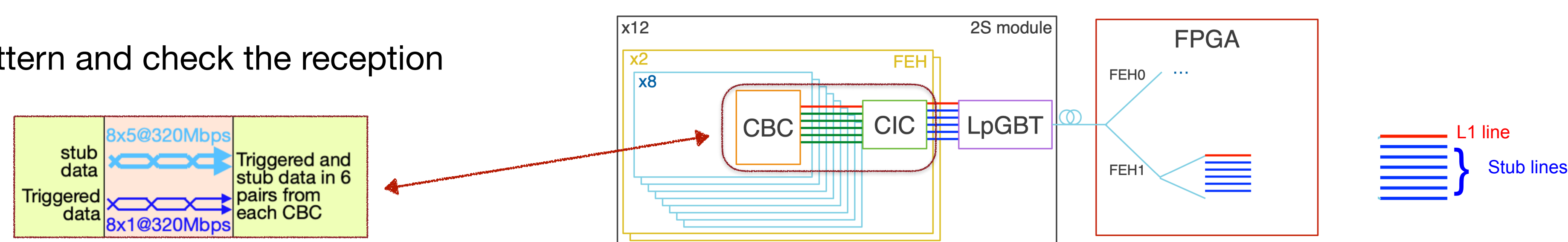
- ▶ The detector will not be accessible during the HL-LHC → modules need to be reliable
- ▶ Detailed testing and qualification procedure at room temperature and operating temperature of  $\sim -35^\circ\text{C}$
- ▶ More than 13000 modules are to be produced

### Noise performance



### Reliable communication

- ▶ Send a pattern and check the reception



## Summary and Outlook

- ▶ The new Outer Tracker features
  - ▶ Tracking at L1 enabled by the  $p_T$  modules
  - ▶ Reduced material budget
- ▶ 100+ prototypes and kickoff modules successfully assembled and tested
- ▶ Design of 2S and PS modules finalized!
- ▶ Pre-production started, Production:  $\sim 2025-2026$

### References

- [1] Apollinari G. et al., "High-Luminosity Large Hadron Collider (HL-LHC): Technical Design Report V. 0.1". CERN Yellow Reports: Monographs. DOI: 10.23731/CYRM-2017-004.
- [2] CMS Collaboration, "The Phase-2 Upgrade of the CMS Tracker. Tech. Rep.". CERN-LHCC-2017-009. CMS-TDR-014. URL: <https://cds.cern.ch/record/2272264>.

### Acknowledgement

This work was produced by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics. Publisher acknowledges the U.S. Government license to provide public access under the DOE Public Access Plan.