CMS Upgrades at Helsinki

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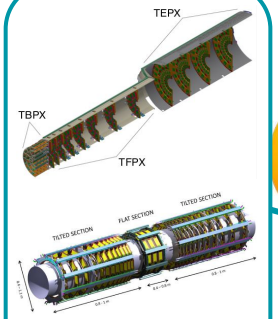
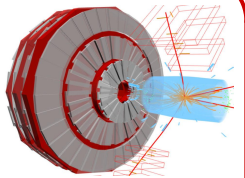
Particle physics days 2026
November 11, 2026

Overview of new detectors



Inner and outer tracker

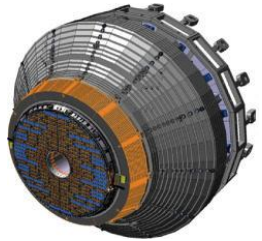


Muon detectors

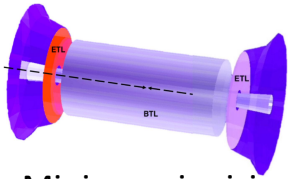


BRIL (several sub-systems)

Proton precision spectrometer



High-granularity calorimetry



Minimum ionising particle timing detector

Finnish participation in upgrade activities

- Inner tracking detector construction and installation, i.e. TEPX module production and quality control (QC). (to be presented today)
- Outer tracker mechanics.
- Endcap timing layer (ETL) for the Minimum ionizing particle timing detector (MTD), i.e. LGAD sensor QC. (to be presented today)
- Proton precision spectrometer

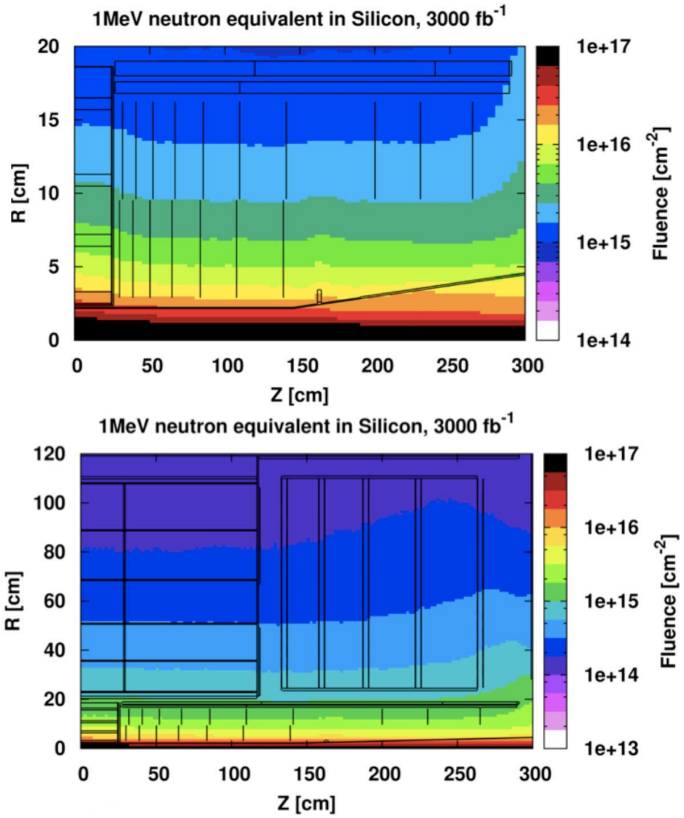
Tracking detector upgrade for HL-LHC

High luminosity LHC

- Pile-up increases substantially with around 200 collisions per bunch crossing at start of a store
- Integrated luminosity approximately 3000 fb^{-1}
- High dose of about 10 MSv (1Grad), fluences of about $2x10^{16}neq/cm^2$ ⇨ leading to radiation damage

Tracker requirements

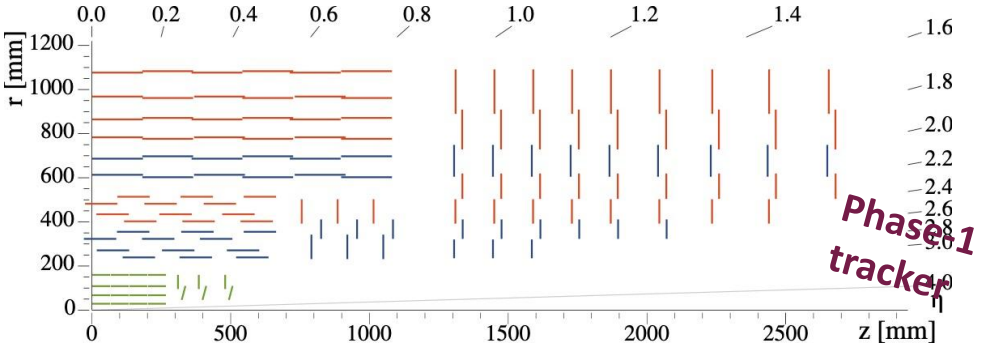
- High granularity to reduce occupancy
- Reduction of material budget to improve tracking performance
- Radiation hardness

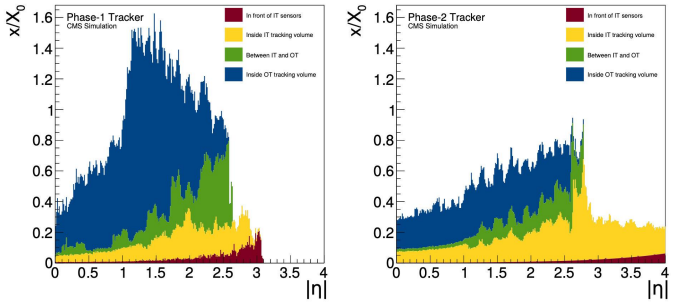


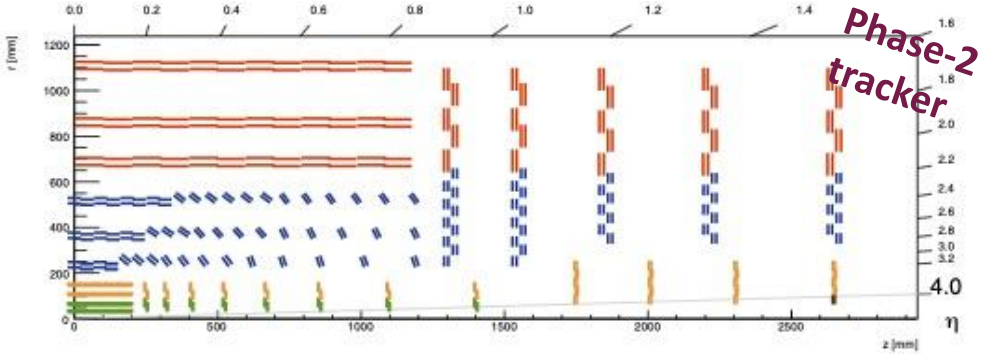
Tracking detector upgrade for HL-LHC

Evolution from Phase-1 to Phase-2 tracker

- Better coverage up to rapidity of 4.0.
- More and smaller pixels (higher granularity, reduce occupancy).
- Less material budget.
- Better radiation hardness.
- Inclined outer tracker modules / planes.



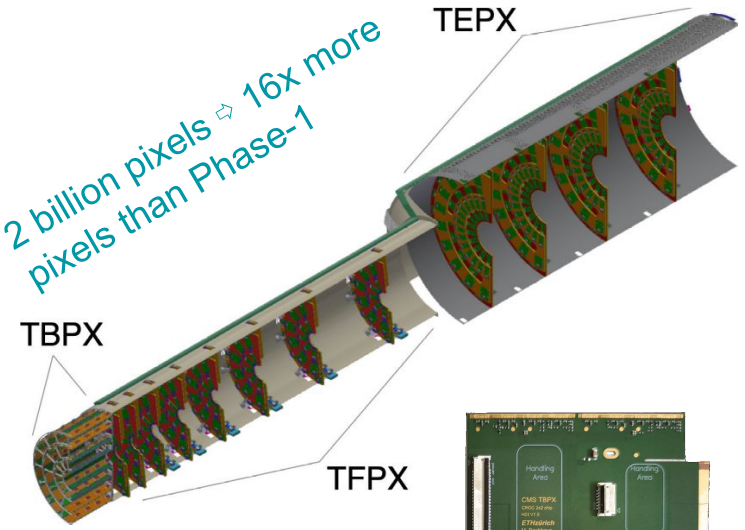


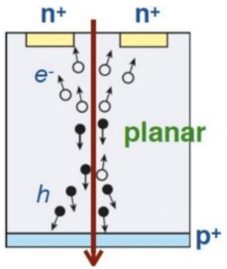


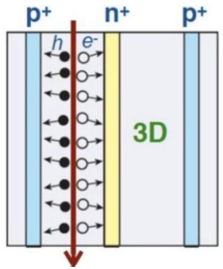
Inner tracking detector upgrade

Main design aspects

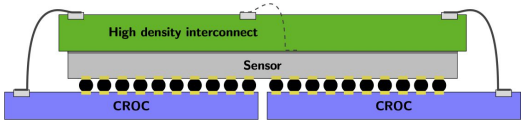
- Hybrid pixel detector modules using new CROC ASIC (derived from RD53 chip, 65nm technology, 50x50 μm^2).
- Smaller pixels for less occupancy (25x100 μm^2).
- Thin (150µm) planar n-in-p Si sensors baseline.
- Radiation hard 3D Si sensors for innermost layer of the barrel.

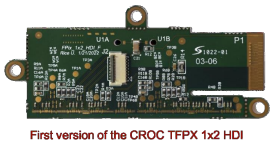




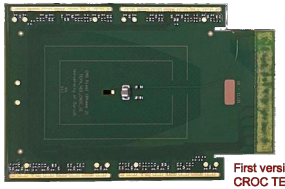


Cross section drawing of TEPX module



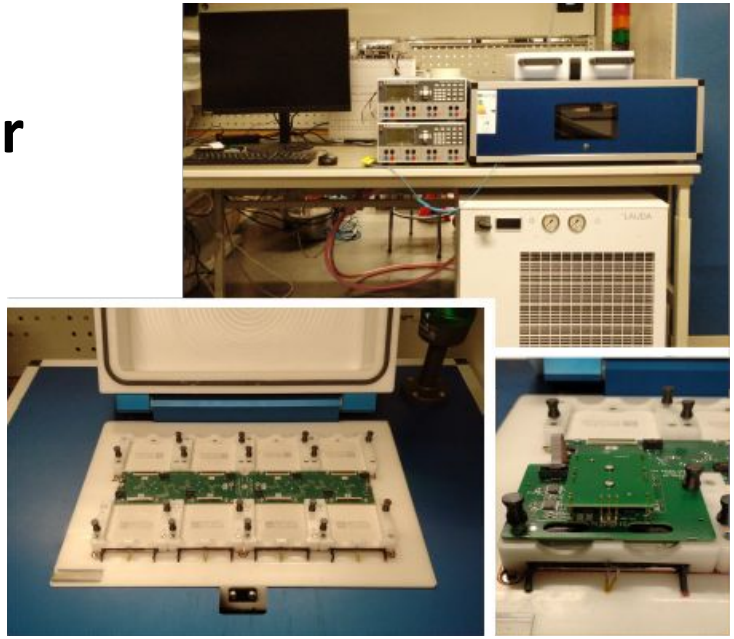

First version of the CROC TFPX 1x2 HDI

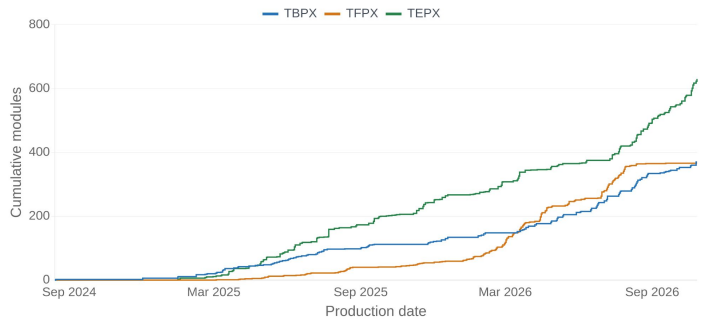
First version of the CROC TBPX 2x2 HDI


First version of the CROC TEPX HDI

Helsinki wire-bonding and QC center

- Building and testing least 250 TEPX modules
- Challenging wire-bonding scheme
- Coldbox
  - Up to 8 modules at a time
  - Temperature down to -30°C
  - Automated operation, including safety systems for electrical or temperature fault
- QC Procedure
  - Complex testing plan on different stages of production
  - Multiple institutes on two continents
  - Common repository for QC tests for all centers
  - Automated upload to database





Minimum ionising particle Timing Detector

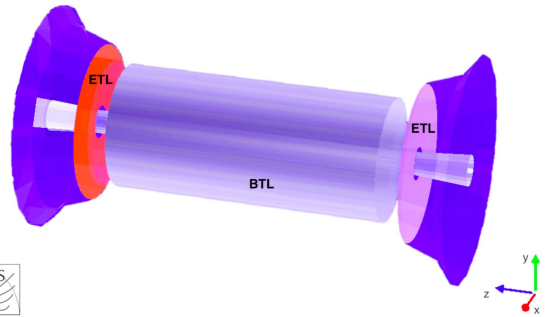
- Huge pile-up, up to 200 interactions per bunch crossing, with HL-LHC luminosities.
- 4D tracking by introducing a thin timing detector between tracker and calorimetry.
- Timing detector aims for 30ps resolution.
- Coverage up to $|\eta| < 3.0$.

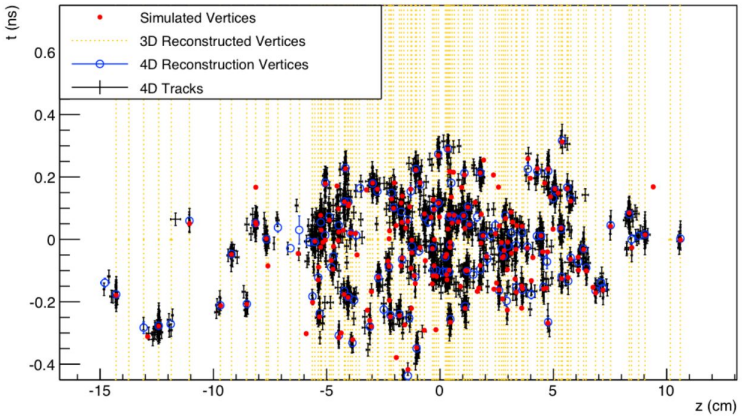
Barrel Timing Layer (BTL)

- Lutetium-Yttrium Oxyorthosilicate (LYSO) scintillator on Silicon Photomultiplier (SiPM).
- About 37 m^2 surface area.

Endcap Timing Layer (ETL)

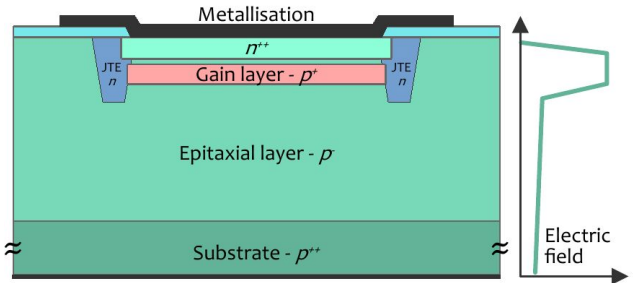
- Low Gain Avalanche Diodes (LGAD)
- About 12 m^2 surface area.

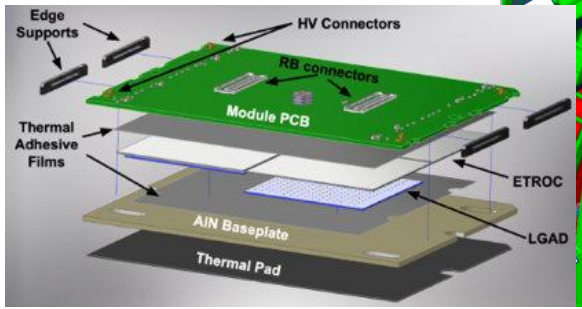


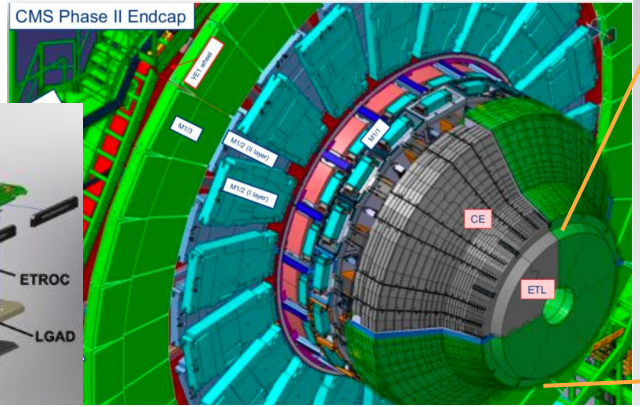


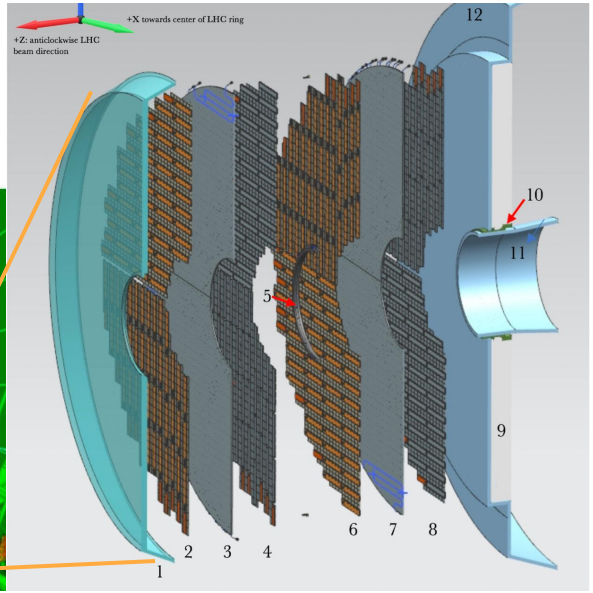
MTD Endcap Timing Layer

- Low Gain Avalanche Diode pads (LGAD) chosen
- Technology can achieve about 30 ps timing resolution (after fluence of $2x10^{15}$neq/cm^2 better than 60ps).
- ETL consists of 2 double sided disks of LGAD modules.
- Directly mounted on CMS endcap nose.
- Readout via custom made ETROC ASIC









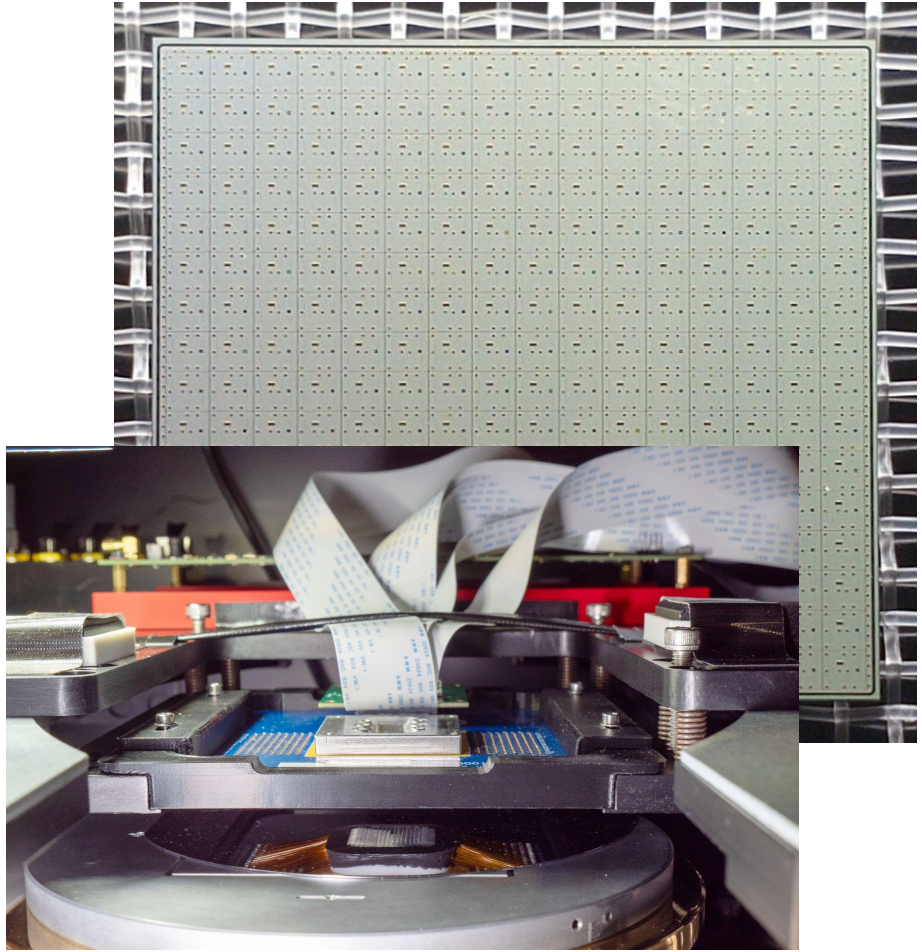
HIP contribution

Important contributions to characterisation of LGAD test structures in order to find final design for ETL.

- General properties of prototypes
- Geometrical coverage (fill factor)
- Interpad gap values
- Radiation hardness

QC center

- Devices procured and installed
- Bespoke control and test software programmed
- Pre-series finished
- Full production foreseen starting in April 2027



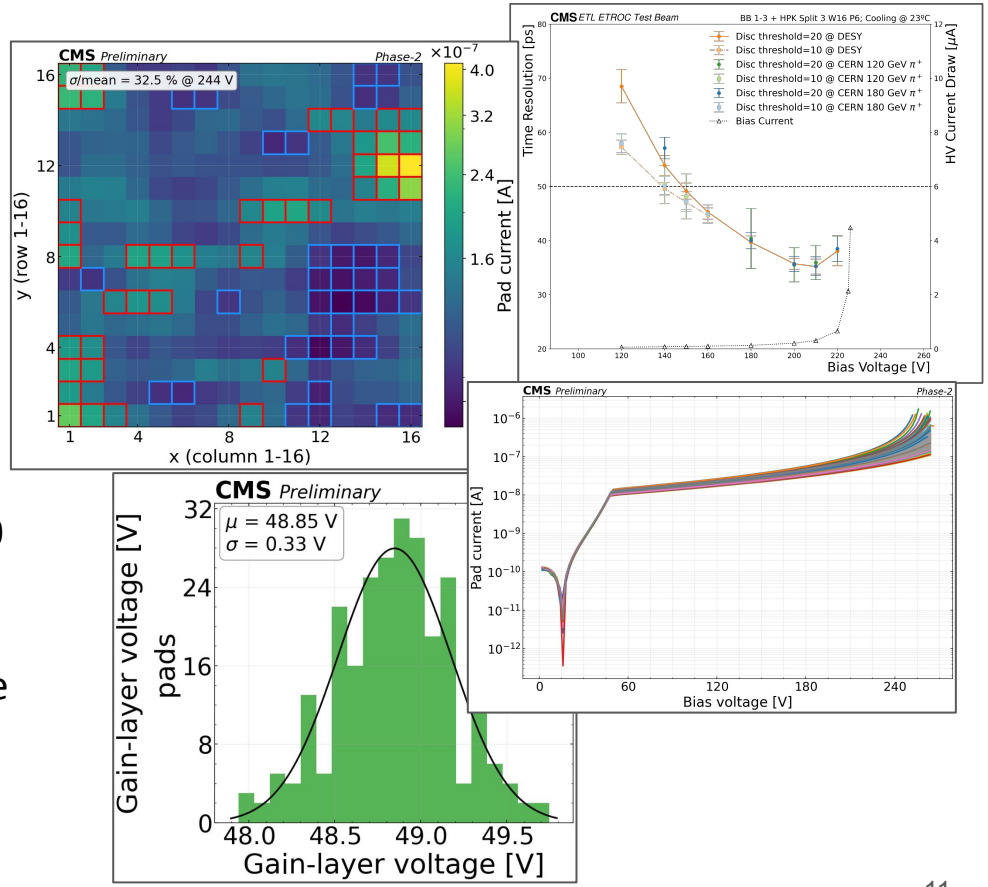
HIP contribution

Pre-series:

- 5 % of detectors
- Test structures: IV/CV, single pad gain bias curve, irradiation tests, etc.
- LGADs: IV/CV, single pad gain, interpad resistance, etc.

Production series:

- Only a small subset of the detectors (16000 in total) tested, based on the pre-series statistics
- all 256 pads on the sensor at the same time using special probe card



Summary

- Introduced Finnish contributions to CMS hardware activities for HL-LHC
- Plenty of hardware activities for CMS in HIP during the next years.
- TEPX production ramping up, receiving ~10 modules a month
- QC station for ETL LGADs under commissioning
- ETL production starts in April 2027