CMS/TOTEM upgrades

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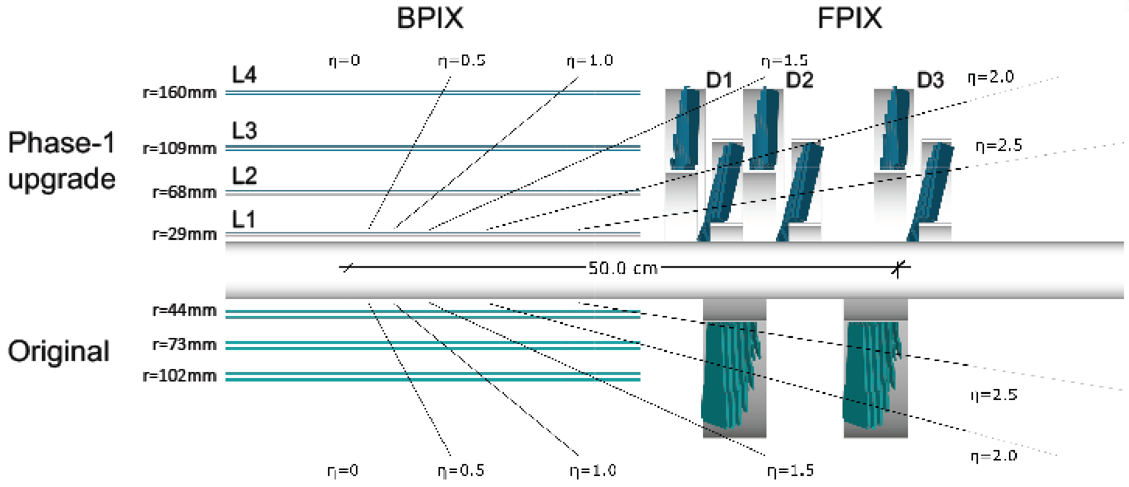
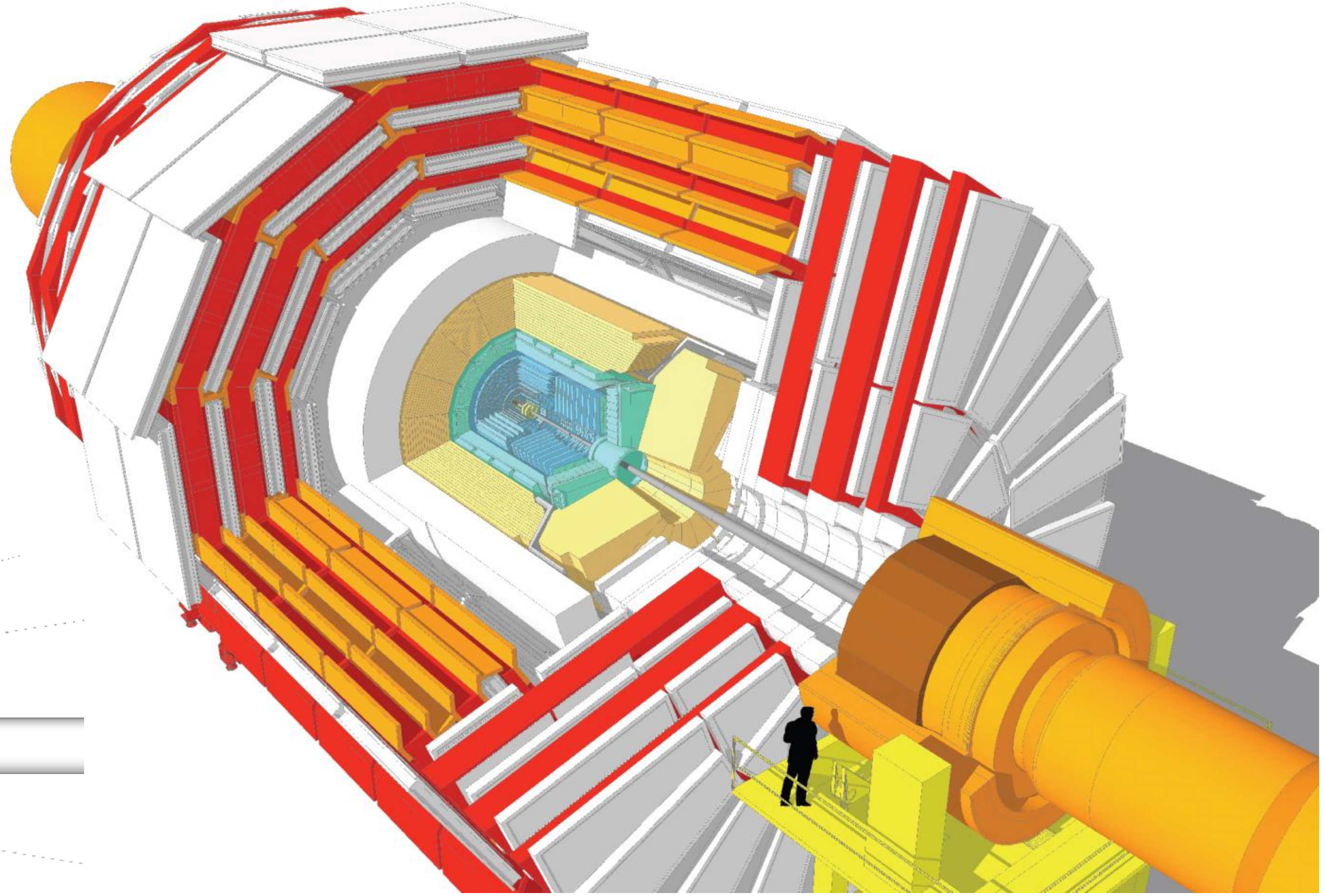
Overview

- CMS Inner tracker status
- Phase 2 inner tracker upgrade
- PPS
- MTD

CMS Pixel detector

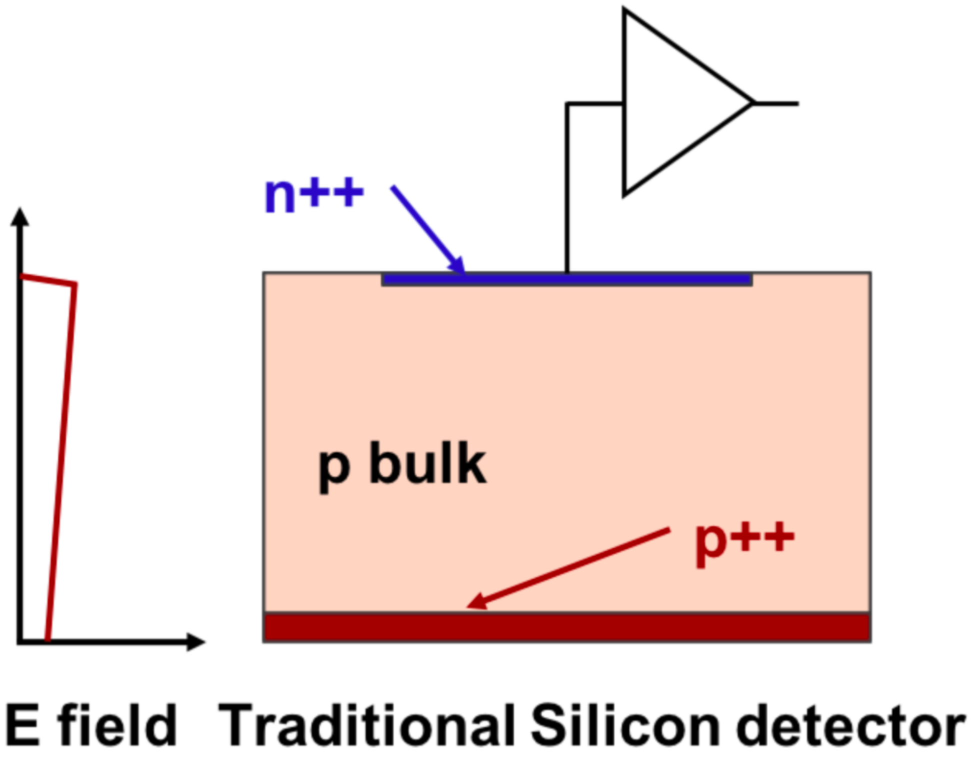
- Innermost tracking detector of the CMS
- Closest detector to IP, facing harshest conditions
- Installed during LS1, level 1 refurbishment done during LS2





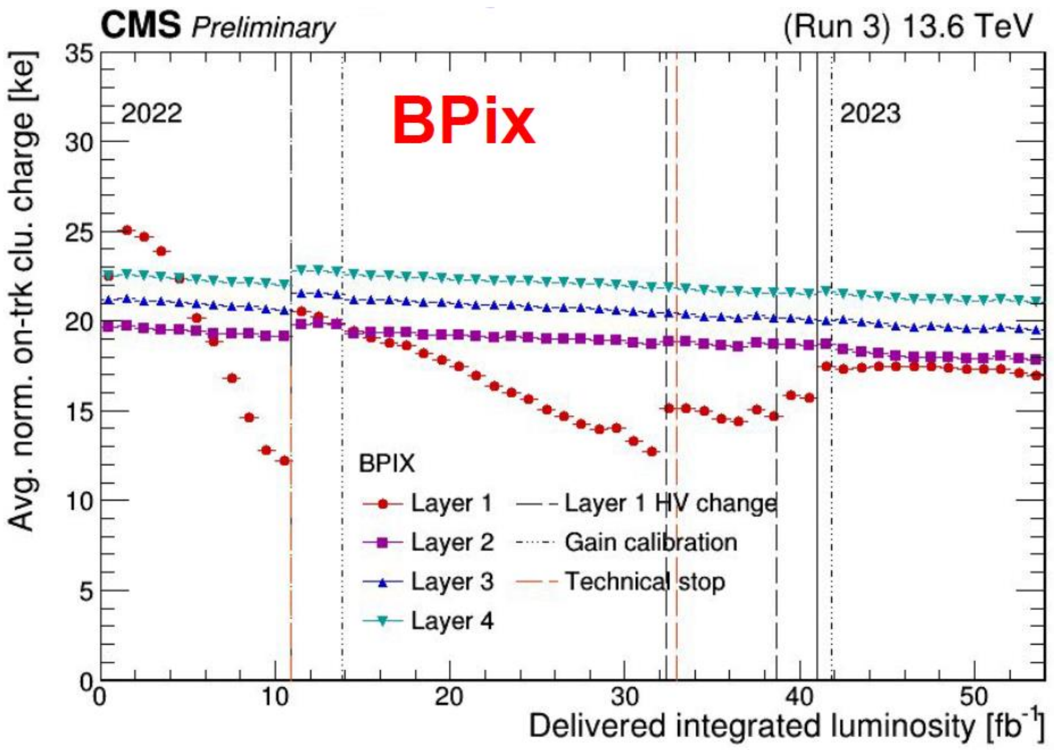
Silicon pixel detector technology

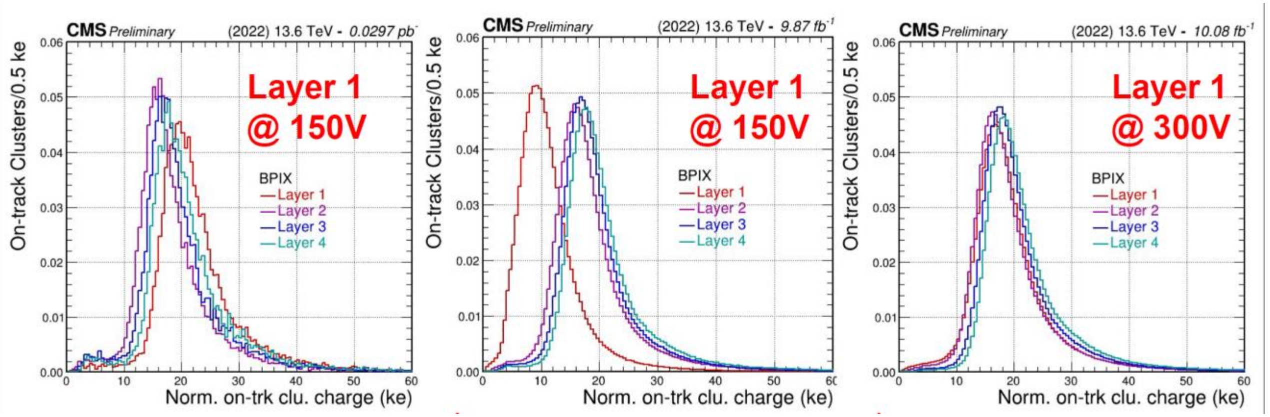
- Diode structure with doped silicon.
- Metal contacts
- Applying reverse bias generates depletion region – removal of free charge carriers.
- Ionization generates charge carriers, which induce current on the electrodes while moving to the electrodes.
- Radiation damage to the bulk silicon and interfaces leads to increased dark current, inactivation of dopants and charge trapping.
- Easiest way to mitigate -> increase bias voltage (within limits though).



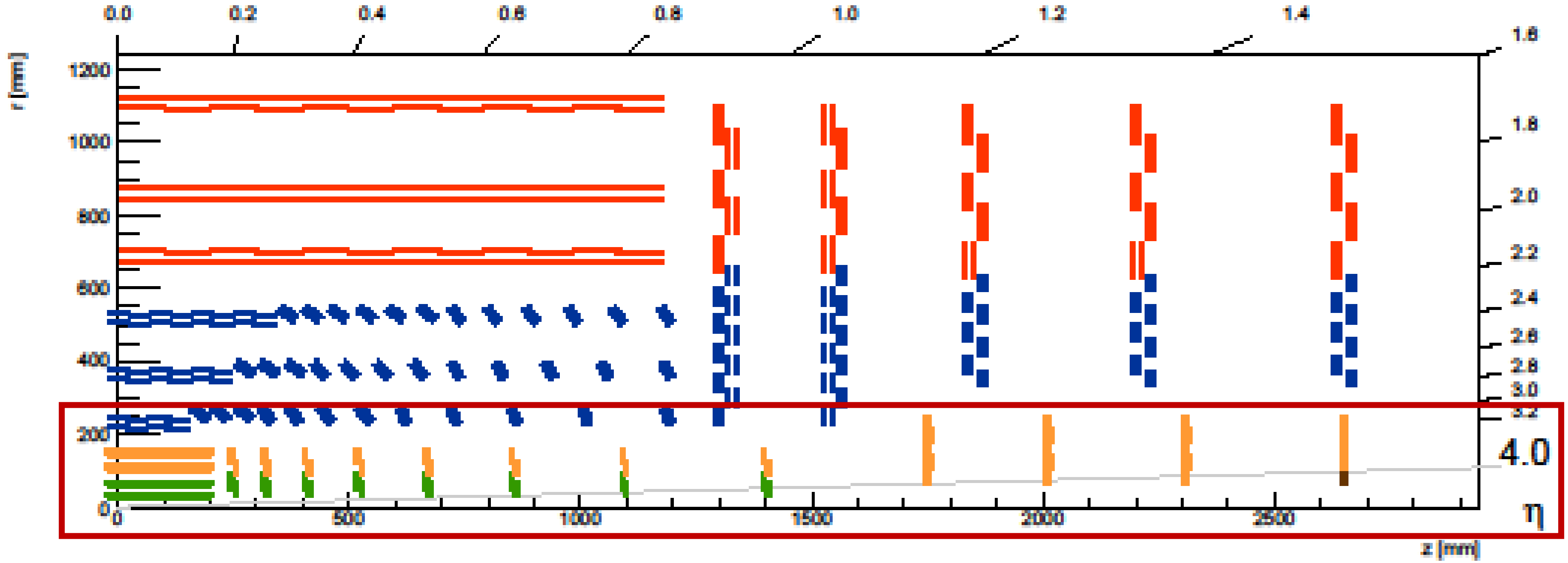
Inner tracker

- New Level 1 detectors installed during LS 2
- Radiation damage started to show immediately.
- Bias voltage raised multiple times to compensate.
- Fortunately the degradation of the Level 1 is slowing down.



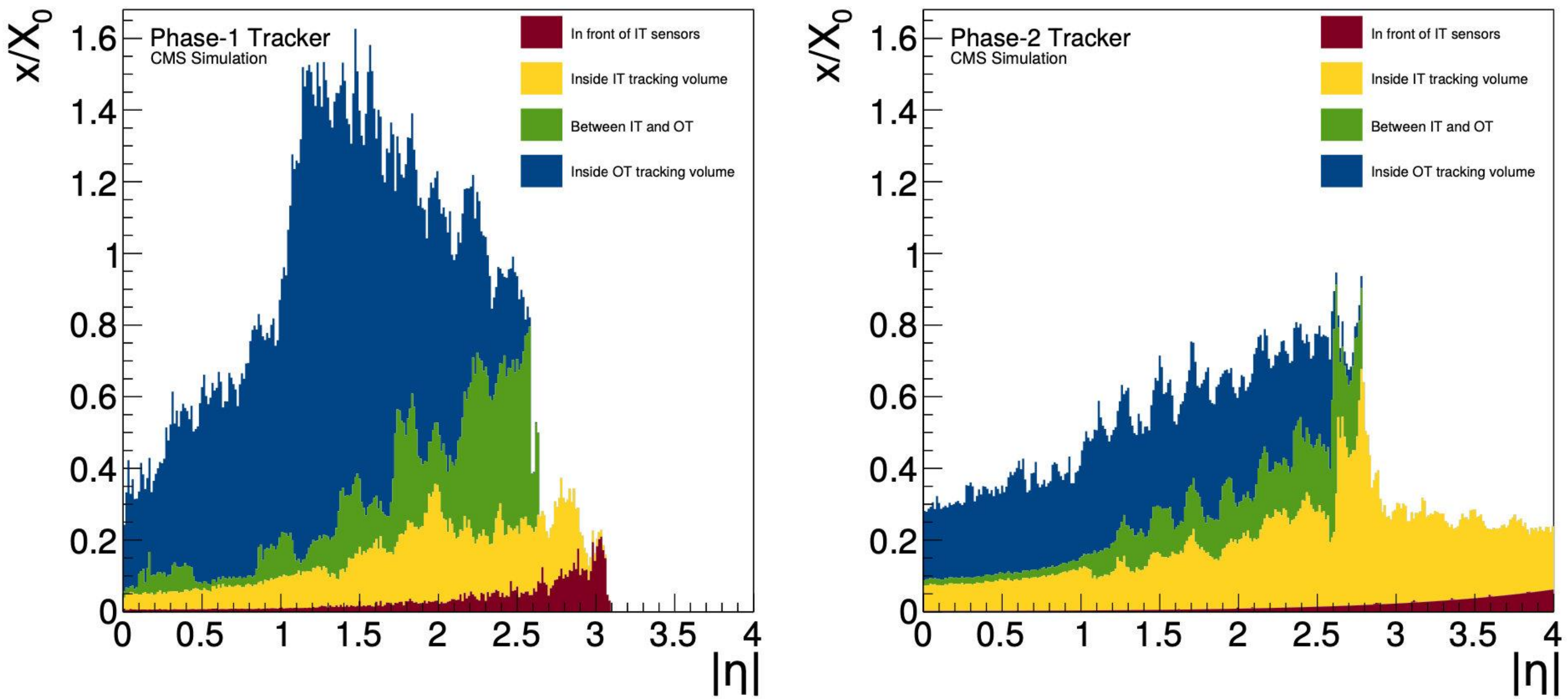


Phase 2 Tracker



- Higher luminosity -> pileup substantially increased
- Detectors with higher granularity
- Outer tracker design with inclined planes
- Tighter material budget
- Radiation hard detectors

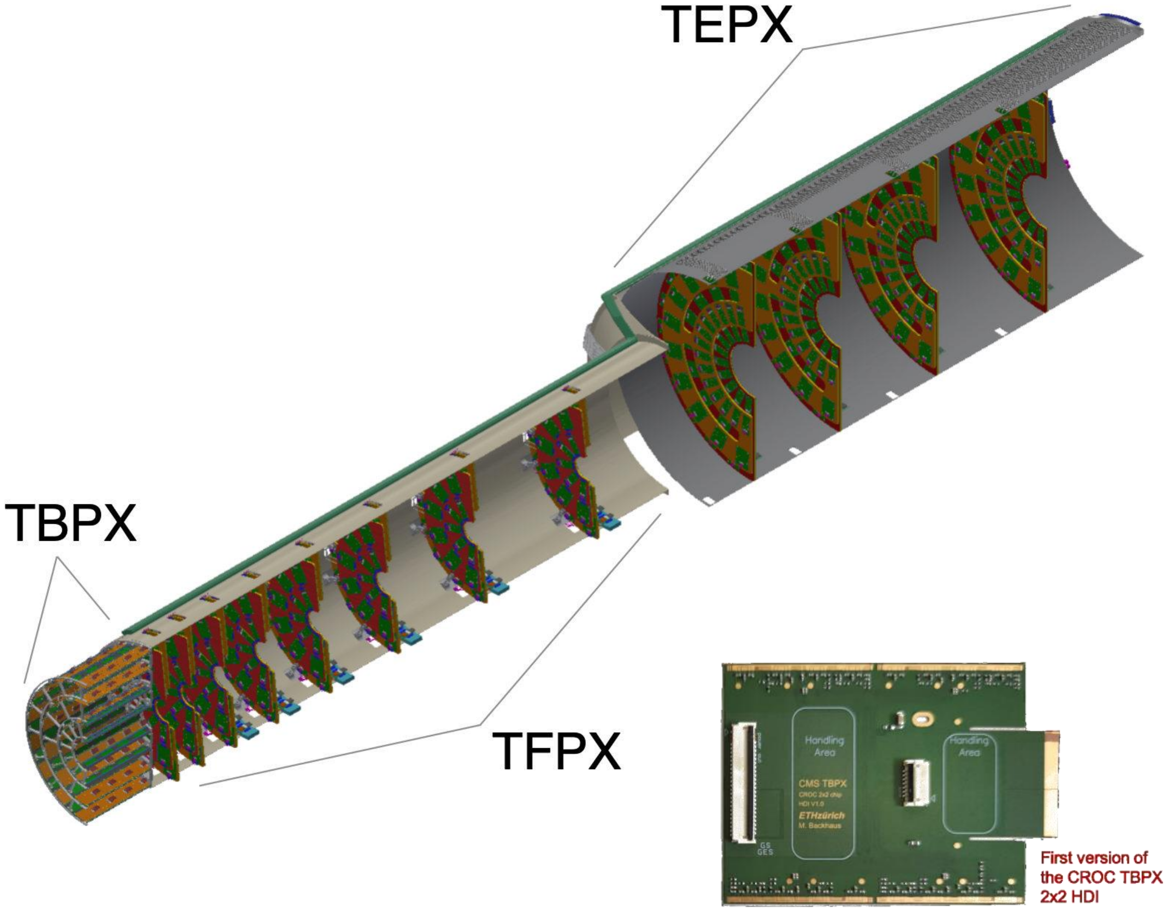
Phase 2 tracker material budget



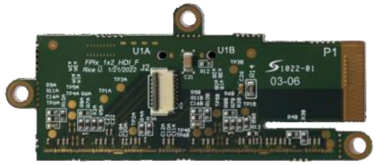
- Significant improvements compared to old tracker due to lighter materials, less layers, inclined detector planes of outer tracker, etc.

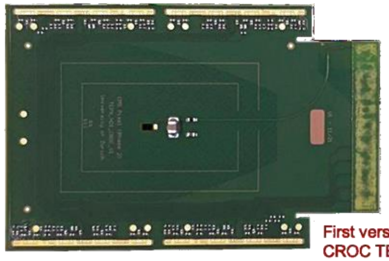
Phase 2 Inner Tracker

- Hybrid pixel detector modules using new CROC ASIC
- Smaller pixels (50x50 micron)
- Tracker Barrel PiXel detector
  - 1x2 modules in two inner layers
  - 2x2 in outer layers
  - Radiation hard 3D silicon in innermost layer
- Tracker Forward PiXel detector
  - 1x2 modules closest to the beampipe
  - 2x2 on outer rings
- Tracker Endcap PiXel detector
  - 2x2 modules
  - Helsinki will build and test at least 250 TEPX modules together with Rudjer Boscovic institute (RBI) and Paul Scherrer institute (PSI).



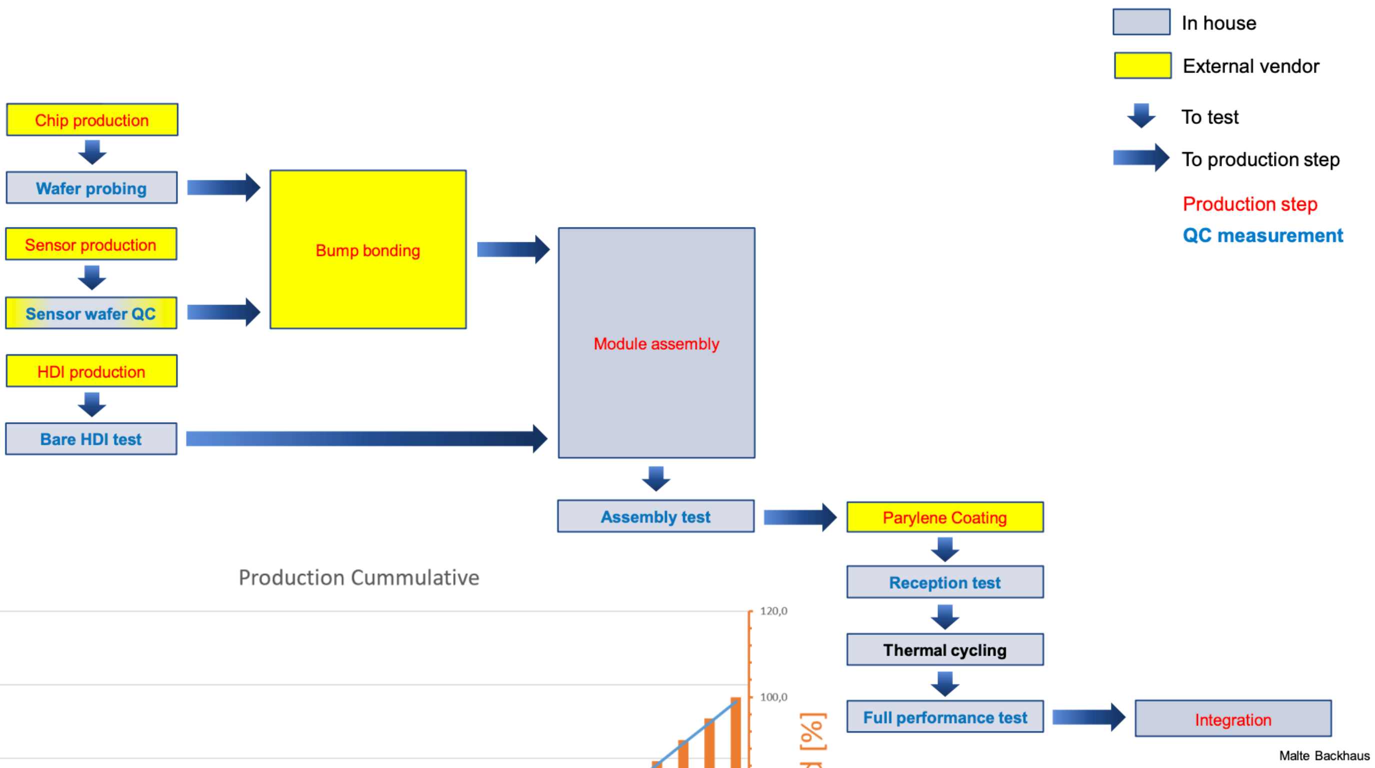
First version of the CROC TBPX 2x2 HDI

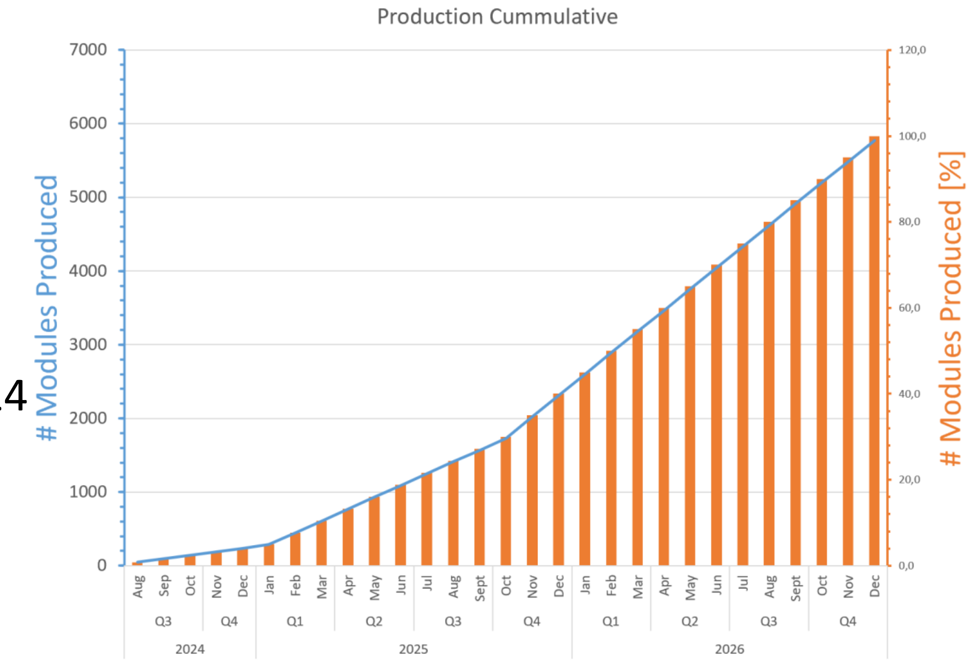

First version of the CROC TFPX 1x2 HDI


First version of the CROC TEPX HDI

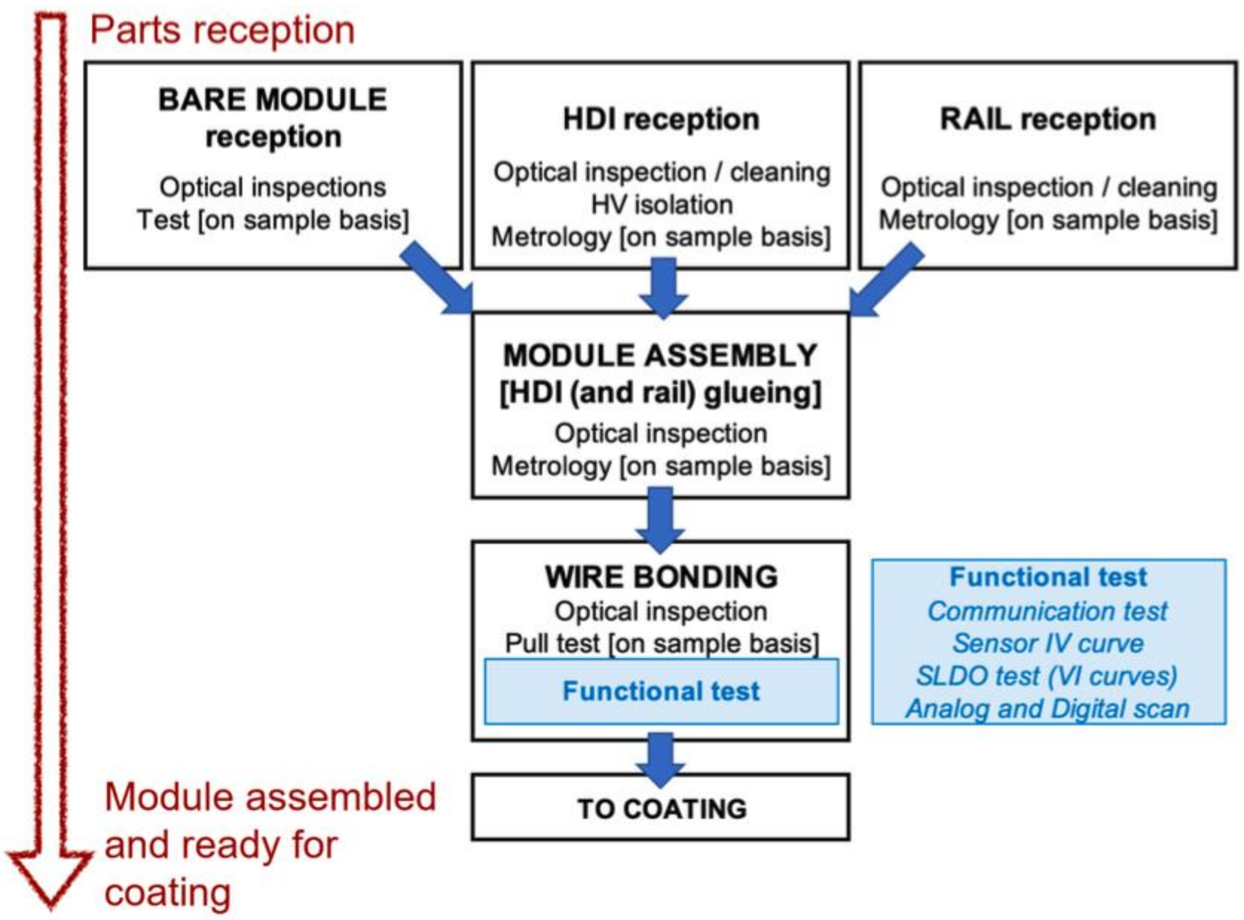
TEPX Production

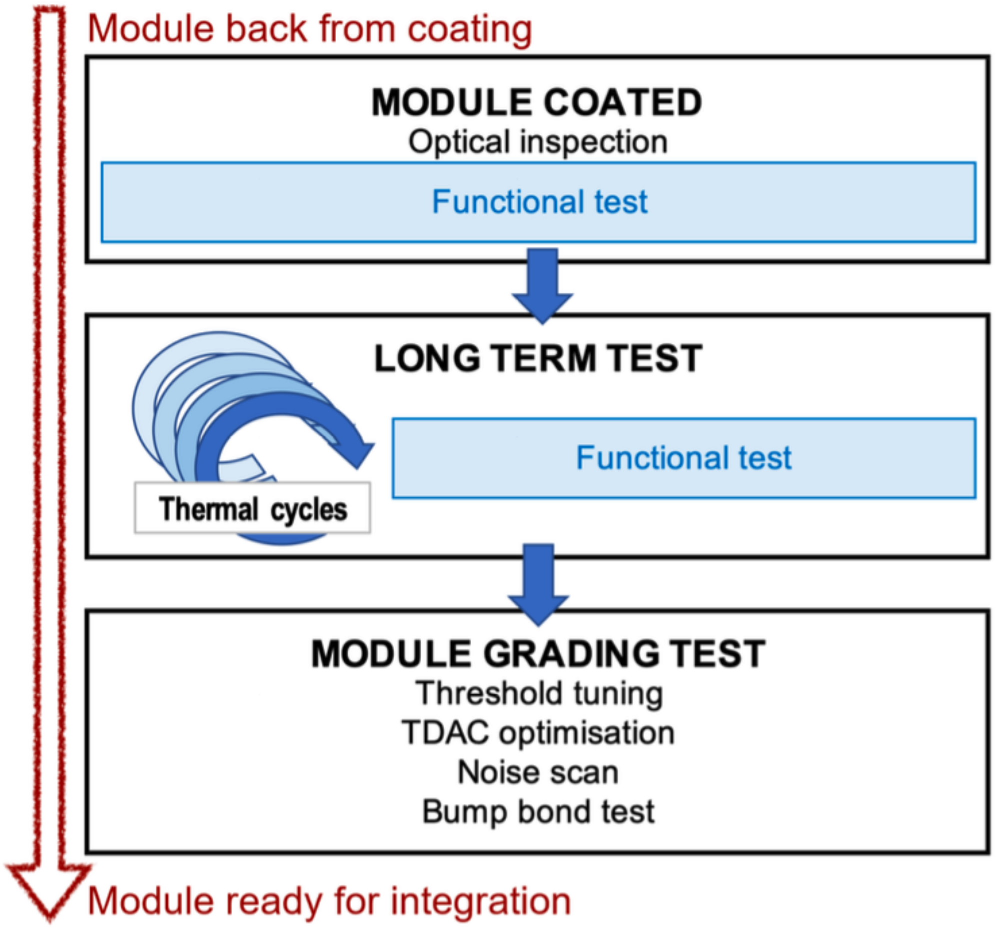
- Production starts in 2024 Q3
- Decentralized production, with several logistic steps during the assembly and QA phases
- Production rate ramped up slowly top allow for learning and streamlining of procedures.
- Possibility to move part of module assembly to Helsinki
- Significant gains by utilizing existing manpower and synergy with ALICE upgrade tasks
- Applied for Finnish Infrastructure funds from Research Council of Finland for 2024 - 2027
- CERN would still act as a back-up option.



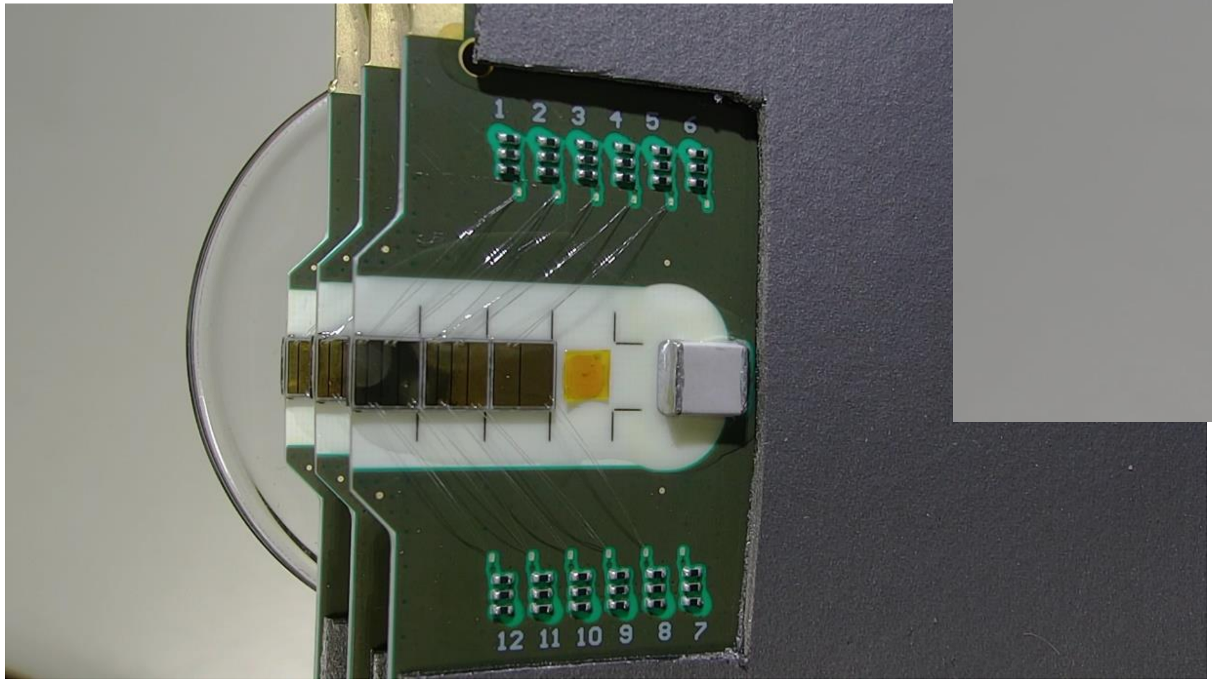


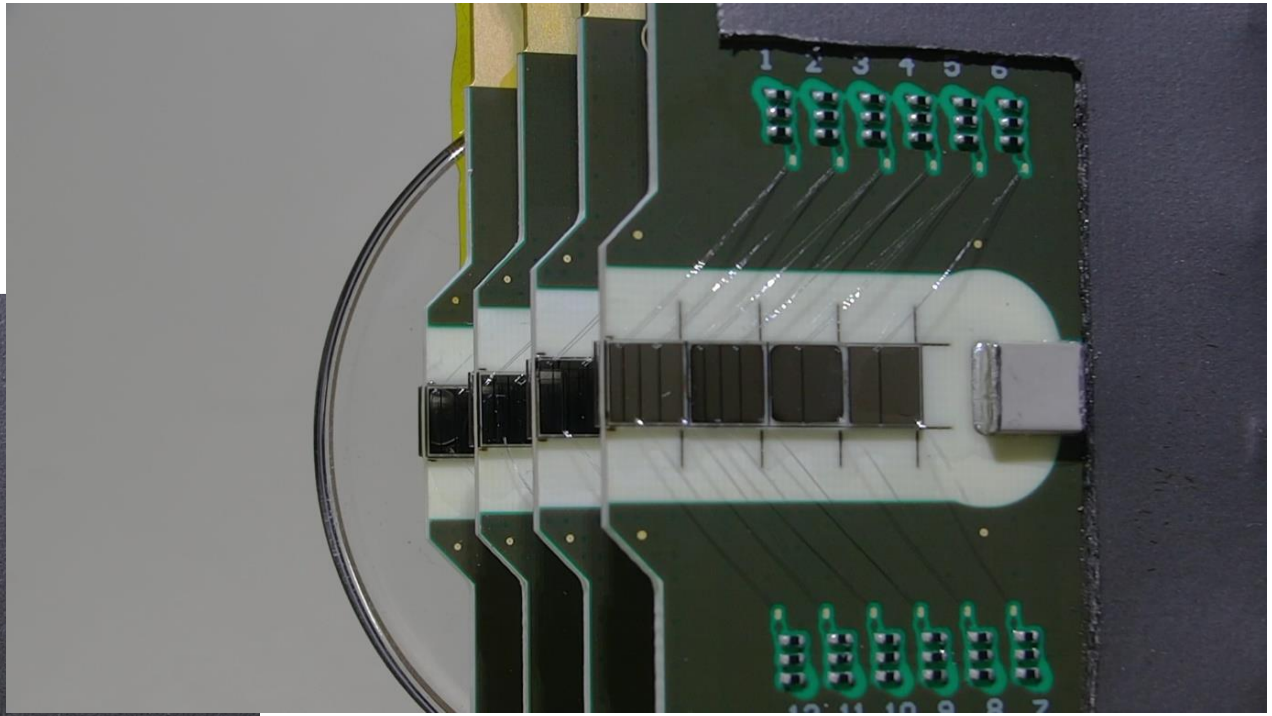
QC


Parts reception
BARE MODULE reception
Optical inspections
Test [on sample basis]
HDI reception
Optical inspection / cleaning
HV isolation
Metrology [on sample basis]
RAIL reception
Optical inspection / cleaning
Metrology [on sample basis]
MODULE ASSEMBLY
[HDI (and rail) glueing]
Optical inspection
Metrology [on sample basis]
WIRE BONDING
Optical inspection
Pull test [on sample basis]
Functional test
Functional test
Communication test
Sensor IV curve
SLDO test (VI curves)
Analog and Digital scan
TO COATING
Module assembled and ready for coating

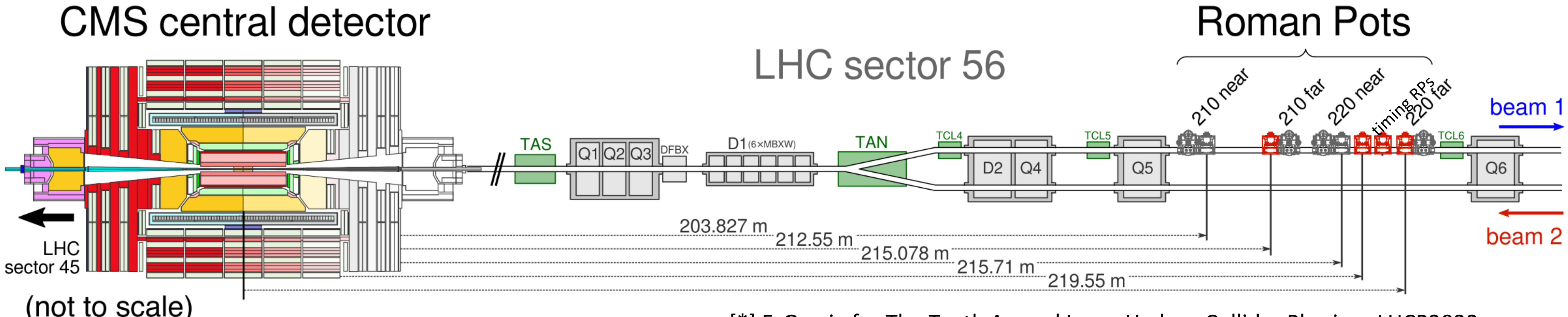

Module back from coating
MODULE COATED
Optical inspection
Functional test
LONG TERM TEST
Thermal cycles
Functional test
MODULE GRADING TEST
Threshold tuning
TDAC optimisation
Noise scan
Bump bond test
Module ready for integration

The Precision Proton Spectrometer (PPS)





The Precision Proton Spectrometer of CMS

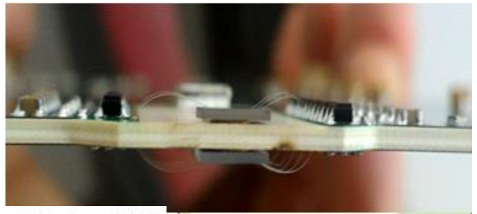


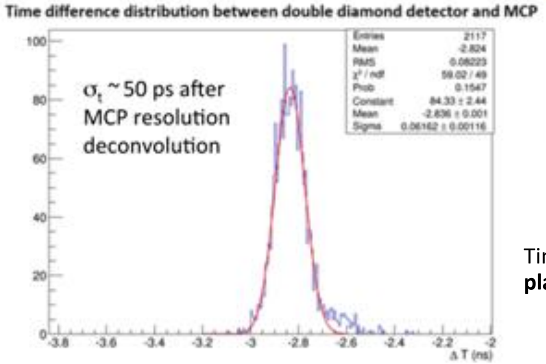
[*] F. Garcia for The Tenth Annual Large Hadron Collider Physics - LHCP2022

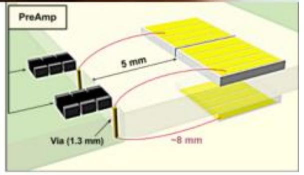
- **CT-PPS was a joint CMS-TOTEM** project to study **C**entral **E**xclusive **P**rocesses → Since 2018 is a CMS subdetector
- Detects intact protons surviving from the IP and driven by magnets within the beam pipe → Detector approach the beam at few millimetres
- With the Tracking Roman Pots stations used for measuring the proton kinematics using the LHC as spectrometer
- And with the Timing Roman Pots stations used to measure the proton time-of-flight to reduce the pile-up background by correlating the vertex with the one of the central system
- **during Run 3 (2023-25) the configuration is two tracking stations and two timing stations**
- Designed to operate continuously at the LHC (**for Run2 PPS collected data up to an integrated luminosity of 100 fb^{-1}**)

PPS - Roman Pots for Timing

DD plane configuration (right)

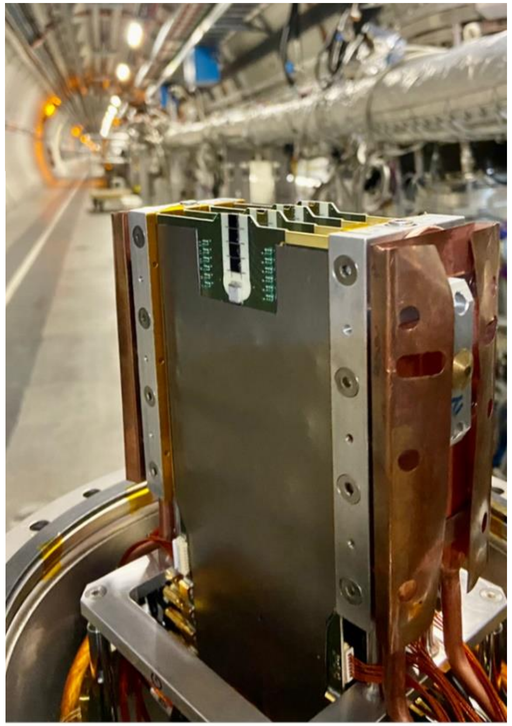






Time resolution for a **DD plane** (left)

RP in sector 56 at the LHC tunnel (right)



ScCVD diamond detectors:

- Four Double Diamond (DD) detectors per plane (4.5 mm x 4.5 mm) of 500 μm thick (detector configurations of 2 and 4 strips)
- Intrinsic radiation hardness withstanding an integrated radiation flux 5·10^15 p/cm2
- Time resolution 50 ps per plane
- Amplification with TOTEM hybrids (remote control for low voltages)
- Readout by TOTEM boards (remote control of thresholds) for NINO chips plus HPTDC (calibration)

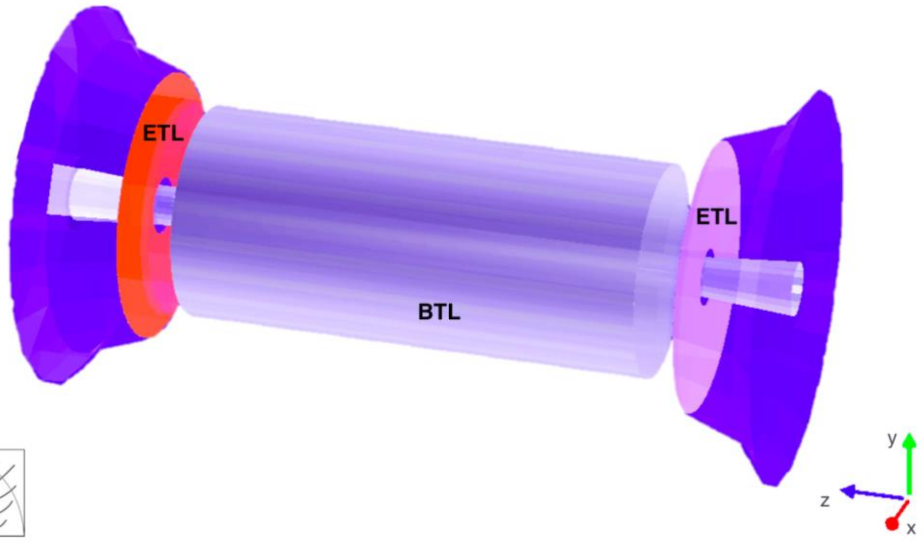
[*] M. Beretti et al., JINST 12 (2017) P03026

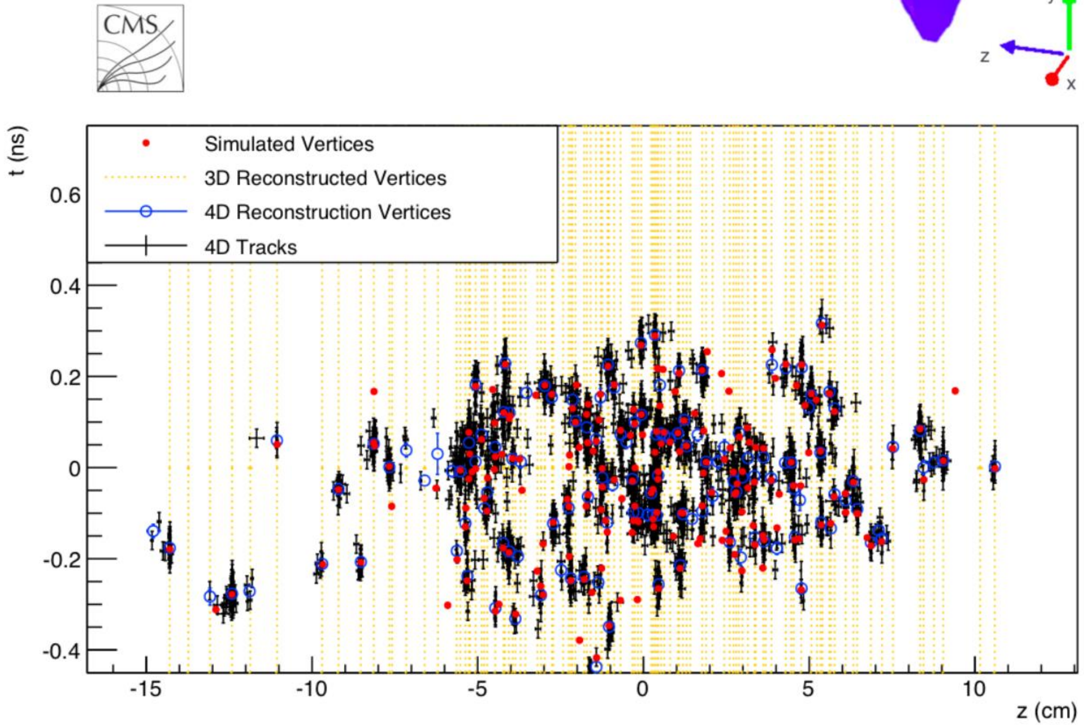
For Run 3:

- The detector characterization and QA was performing at HIP for half of the Diamonds detectors used.
- A total of four Roman pot stations equipped with double diamond planes were installed in sectors 45 and 56
- Two stations were equipped with four planes and two with three planes
- All detectors were performing at bias voltages 350V – 450V in secondary vacuum
- Preliminary results shows correlations between vertex reconstructed CMS and PPS timing performance
- Due to the short period left for protons runs and the upcoming EYETS, the detectors were removed from LHC tunnel and investigations are underway at the H8 beamline (SPS) on each of the detector packages

Minimum-ionizing particle Timing Detector (MTD)

- Up to 200 pileup events per bunch crossing in HL-LHC
- Precise timing detector for 4D tracking -> increase vertex reconstruction efficiency
- Situated between tracker and calorimeters.
- Consists of two distinct detectors:
- Barrel Timing Layer (BTL)
  - LYSO scintillators read out with Silicon Photo Multipliers (SiPM)
- Endcap Timing Layer (ETL)
  - Low Gain Avalanche Diodes (LGAD)

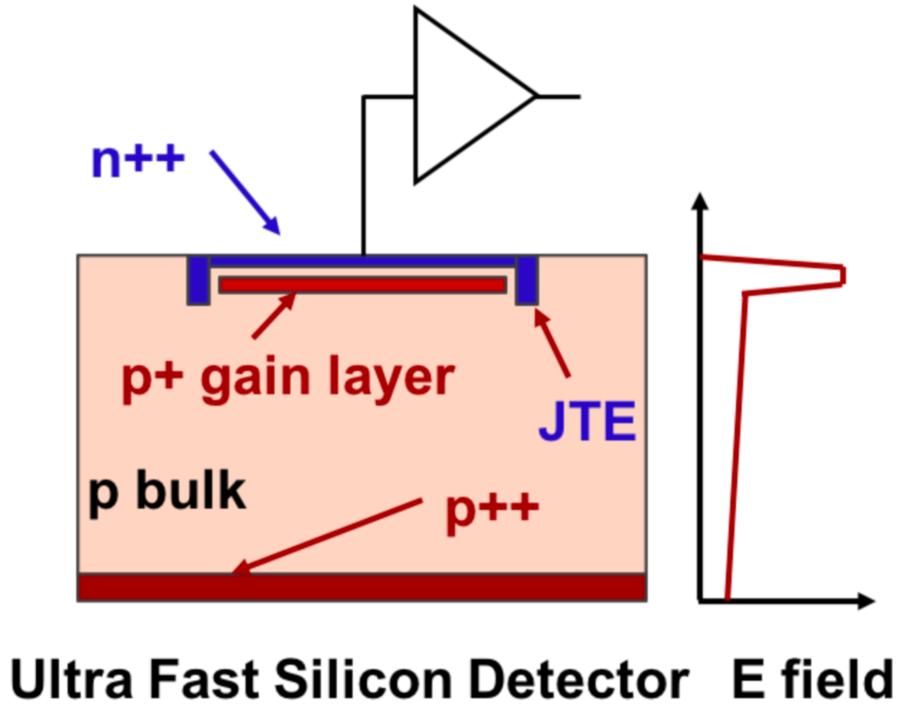


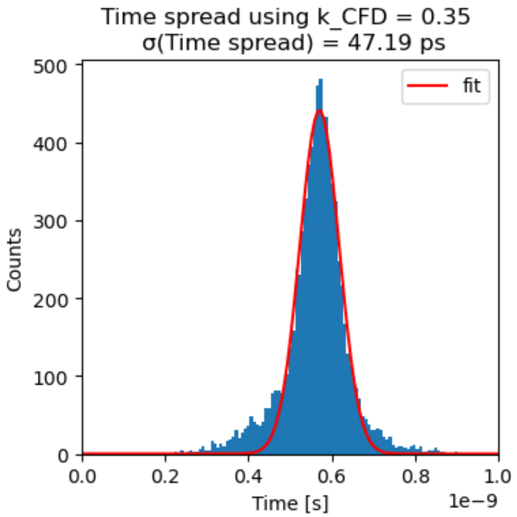


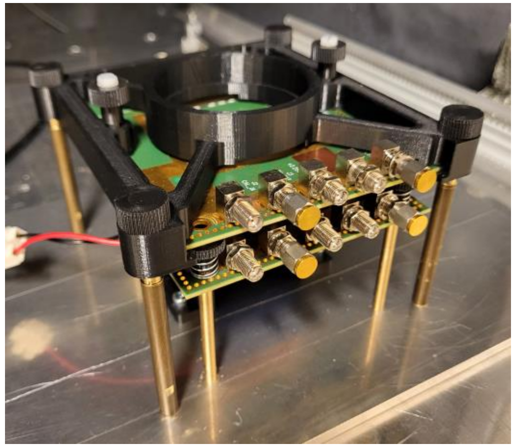
LGAD

- Halfway between conventional silicon diode and an avalanche diode
- Signal amplified in a highly-doped avalanche region close to the anode.
- High signal-to-noise ratio.
- Excellent time resolution: up to 30 ps achieved.
- Significant Finnish contribution in the characterization of LGADs for the MTD *
- Local R&D continues within the RD50/DRD3 collaborations

* S. Bharthuar et al., Study of interpad-gap of HPK 3.1 production LGADs with TCT, NIM A 979 (2020) 164494

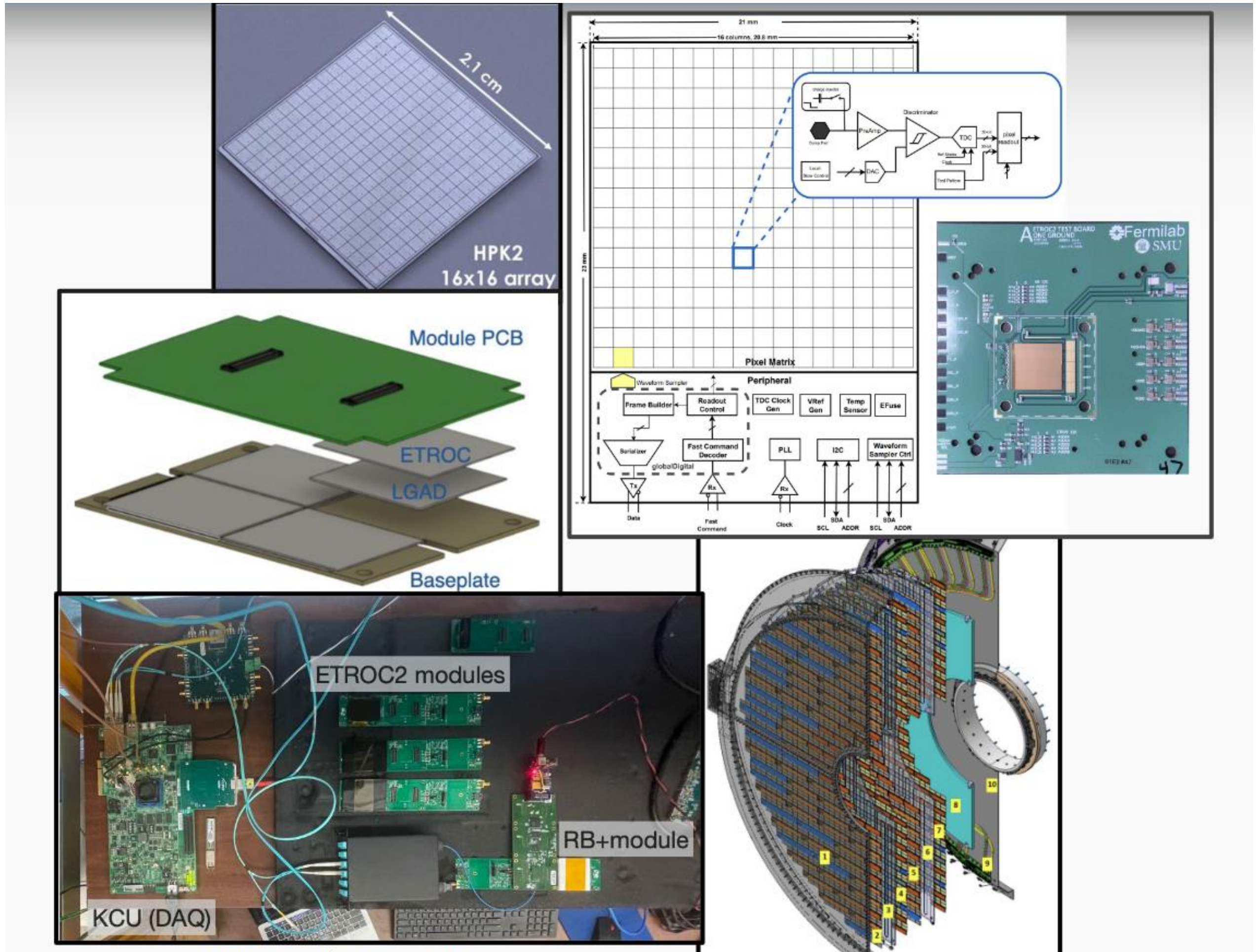






Endcap Timing Layer (ETL)

- Double disk structure on both ends of the BTL
- Market survey to be concluded soon.
- Currently finishing the prototyping stage.
- Helsinki contributed to qualification tests for market survey.
- Possible participation in QC and production (in discussion)



CMS Week, Irene Dutta

Summary

- Phase 2 tracker upgrade
  - Possibly moving production and QA to Helsinki.
  - Phase-2 pixel module production will start in mid 2024.
- PPS
  - PPS now officially part of CMS.
  - Data taken during run 3.
- MTD-ETL
  - Ongoing testing of LGAD sensors.
  - Participation in pre-production and production (at HIP detector laboratory).