CMS Upgrade Project

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HIP Scientific Advisory Board 2026

August 25, 2026

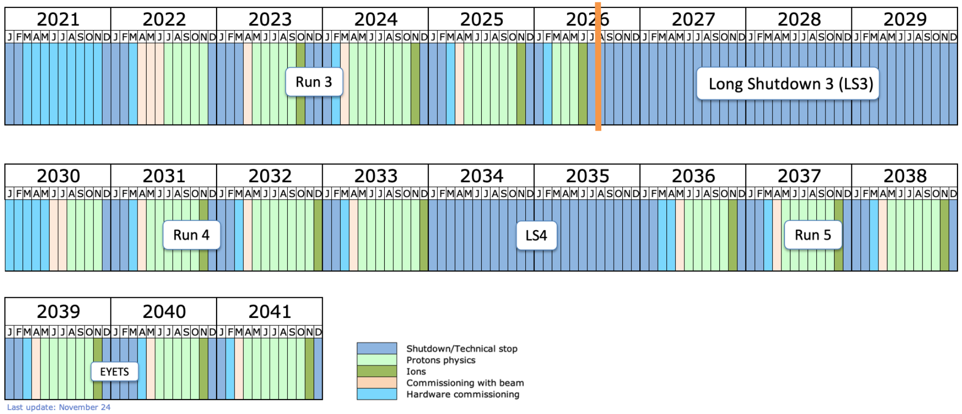
Overview of current activities related to HL-LHC

High-Luminosity LHC after LS3

- Increase of beam intensity with instantaneous peak luminosity of up to $7 \times 10^{34} cm^{-2} s^{-1}$.
- Goal: 3000 fb^{-1} of integrated luminosity

⇒ Need to upgrade experiments with focus on radiation hardness, high resolution and granularity, excellent timing, faster readout, etc.

We are now here!



CMS

- Inner tracking detector (TEPX module assembly and testing)
- Outer tracker mechanics (contribution to CO_2 cooling QC)
- Minimum ionising particle Timing Detector (R&D and QC of LGADs)
- PPS2 (R&D, production of pixel modules)

ALICE

- FoCal (assembly and QC of pixel module layers done by us in Helsinki in collaboration with Jyväskylä ALICE group)

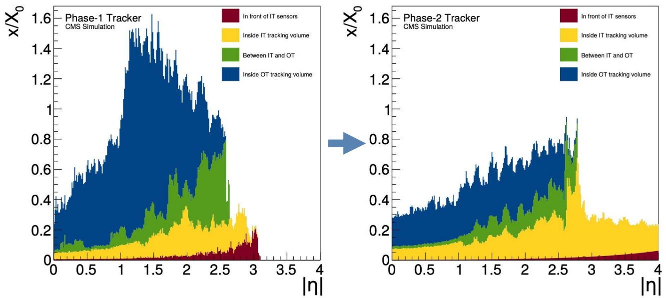
Tracker upgrade motivation in a nutshell

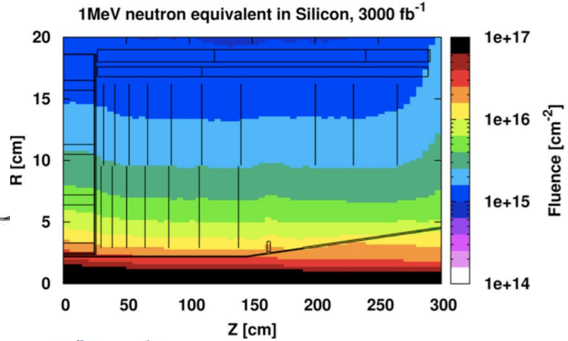
HL-LHC comes with:

- Dose of about 10 MSv (1Grad), fluences of about $2x10^{16}neq/cm^{2}$.
- Substantial pile-up increase.

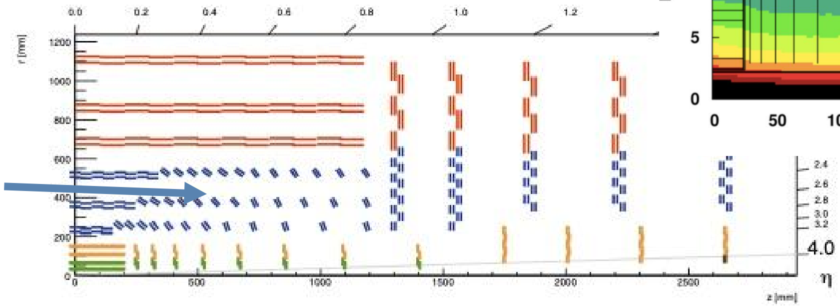
Tracker requirements for better performance:

- Better coverage up to rapidity of 4.
- Higher granularity → less occupancy.
- Less material budget.
- Better radiation hardness.





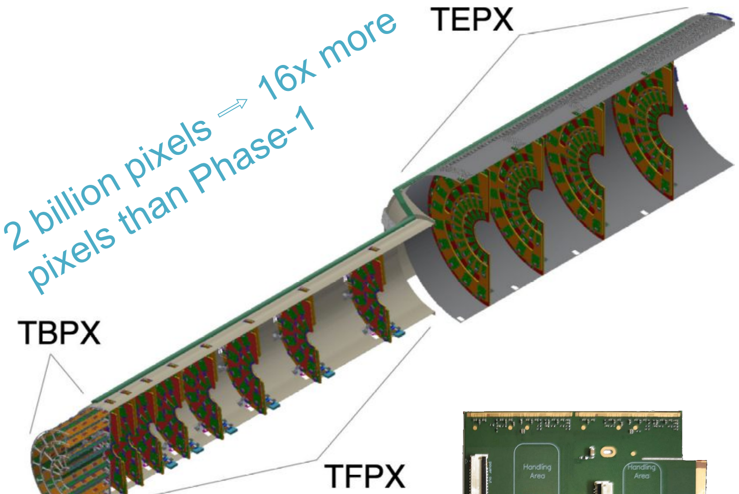
Inclined outer tracker modules

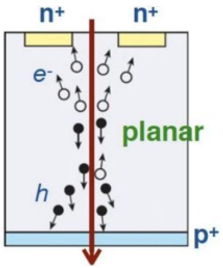


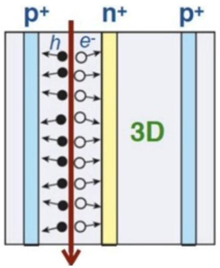
Inner tracking detector upgrade

Main design aspects

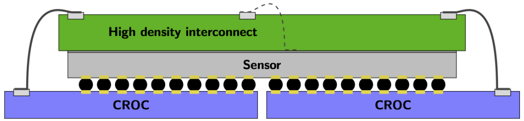
- Hybrid pixel detector modules using new CROC ASIC (derived from RD53 chip, 65nm technology, 50x50 μm²).
- Smaller pixels for less occupancy (25x100 μm²).
- Thin (150μm) planar n-in-p Si sensors baseline.
- Radiation hard 3D Si sensors for innermost layer.

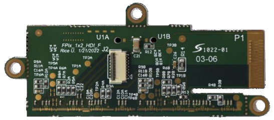




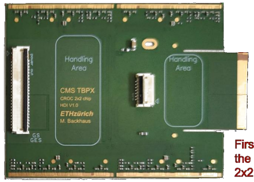


Cross section drawing of TEPX module

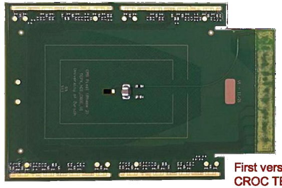




First version of the CROC TFPX 1x2 HDI



First version of the CROC TBPX 2x2 HDI

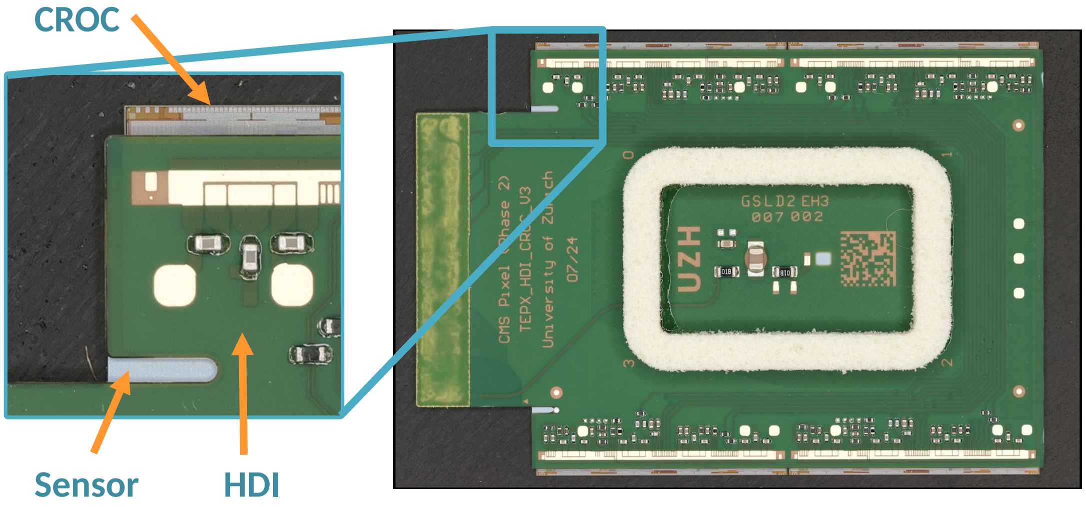


First version of the CROC TEPX HDI

Inner tracking detector upgrade

Finnish contributions

- Building, testing and calibrating at least 250 TEPX modules (collaboration with Rudjer Boskovic Institute (RBI), University of Zurich and Paul Scherrer Institute (PSI)).
- Earlier years: Preparation of module production and quality control centers in Helsinki (HIP) and at CERN.
- CERN center stays as auxiliary and backup center for module production at PSI and HIP (main users: RBI and University of Zurich).
- Currently we entered full production mode.



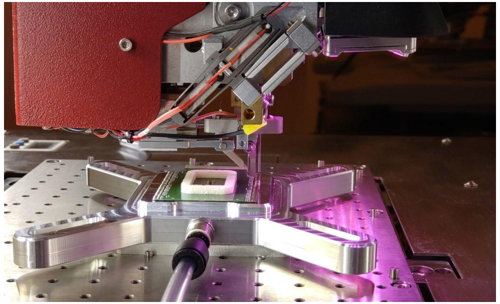
Module production at HIP in a nutshell

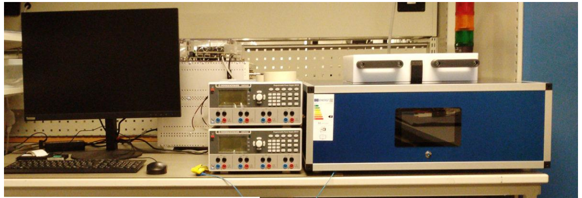
Key equipment

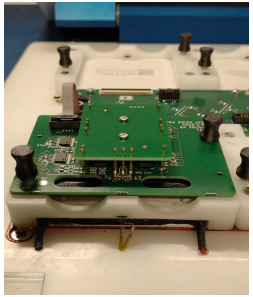
- Automatic wire bonder (Delvotec M17S).
- Nordson Stellar 4000 force tester.
- PSI designed testing system (cold box) for up to 8 modules.

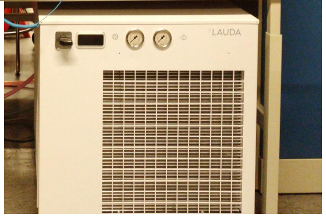
Typical working steps

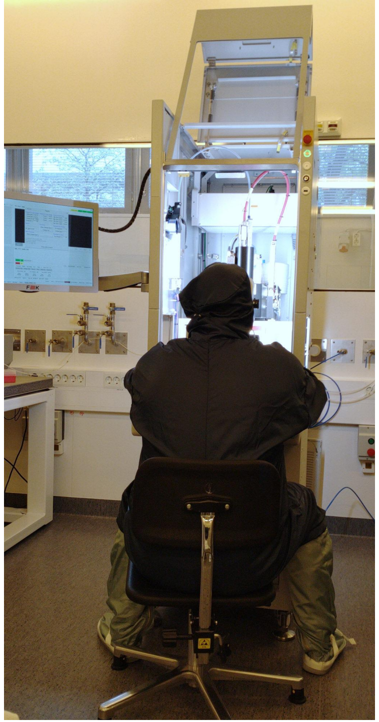
- 1) Unboxing and optical inspection.
- 2) Wire bonding (close to 800 bonds per module) and pull testing of dedicated test bonds.
- 3) QC tests in cold box (following official recipe, subject to change).
- 4) Packing and sending to CERN.
- Always between every step, documentation and book keeping.
- Note: modules handled using ESD protective gear.











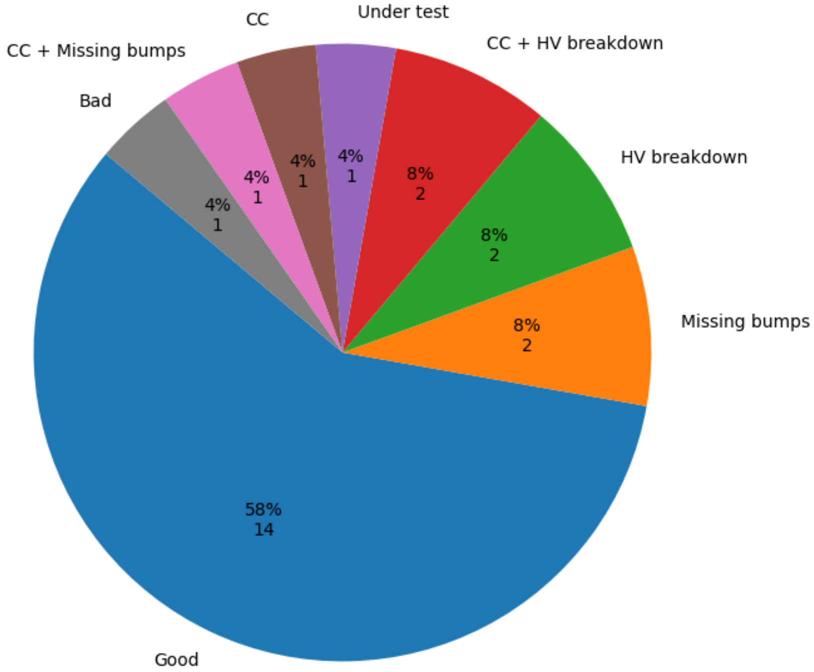
TEPX module production centre at HIP

Current progress

- A total of 30 modules were received:
  27 glued at University of Hamburg, Germany and 3 at PSI, Switzerland. 8 modules were flip-chip bonded at Advafab and 22 at IZM.
- 24 modules have been wire-bonded and tested so far.
- 6 modules are currently undergoing wire-bonding and testing.
- A total of 7 modules were sent for parylene coating.
- Received excellent feedback after recent site visit by collaboration management.

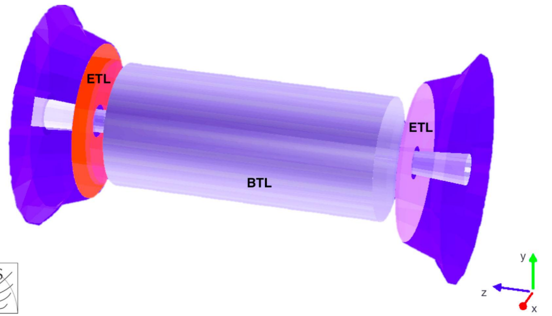
Concerning points

- Major part of production still ahead due to delays.
  Local FIRI project only until end of 2027.
- Key person power contracts until 6/2027.



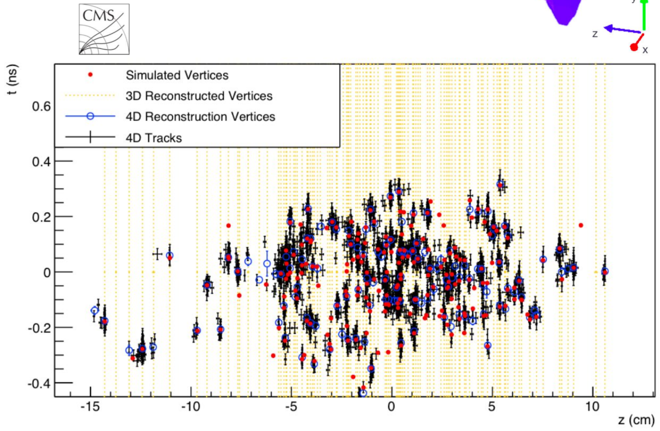
Minimum ionising particle Timing Detector

- In HL-LHC we aim for luminosities of 5 x 10^{34} $cm^{-2}s^{-1}$. We expect huge pile-up, up to 200 interactions per bunch crossing.
- For better tracking performance CMS follows 4D tracking idea 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.

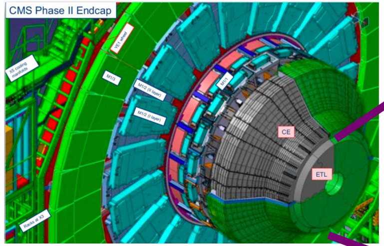


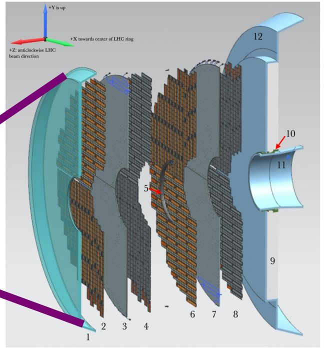
Endcap Timing Layer (ETL)

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

MTD Endcap Timing Layer in a nutshell

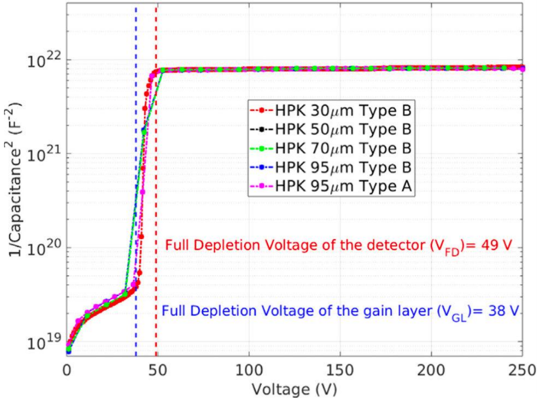
- ETL consists of 2 double sided disks of LGAD modules
- Directly mounted on CMS endcap nose
- Readout via custom made ETROC ASIC
- About 30ps timing resolution (after fluence of 2×10^{15} neq/cm^2 better than 60ps)

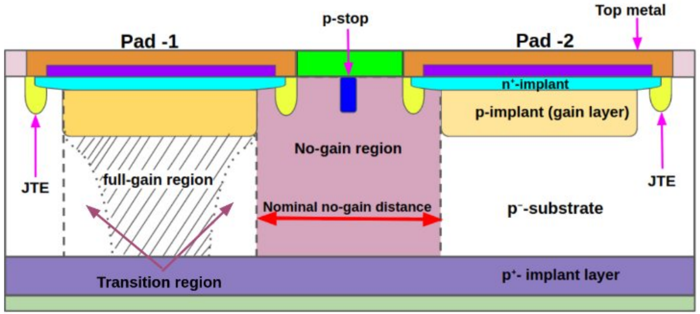




Earlier R&D contribution.

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





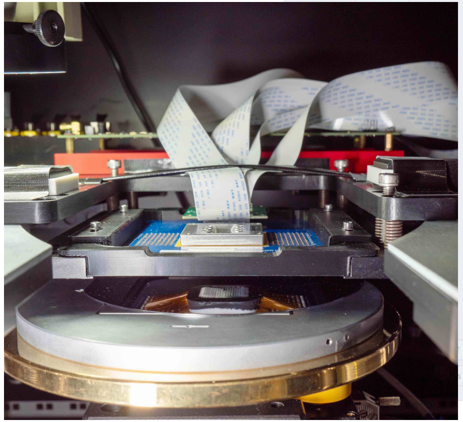
HIP contribution to MTD ETL production

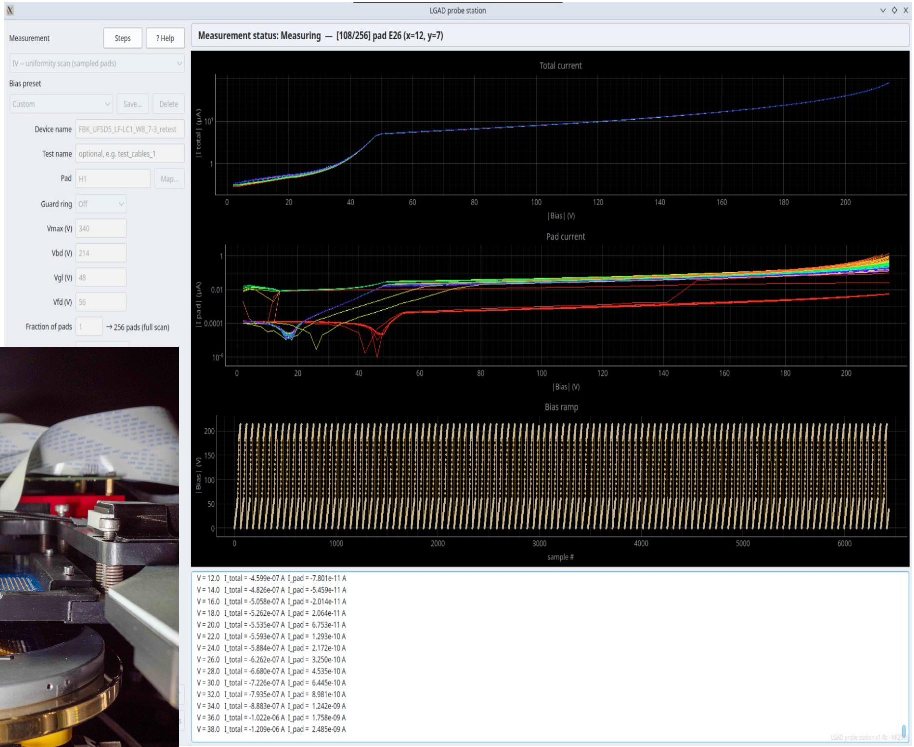
QC center / ETL testing site for production

- Test structures: IV/CV, single pad gain bias curve, irradiation tests, etc.
- Production LGADs: IV/CV on sample basis, all 256 pads of sensors.

Progress

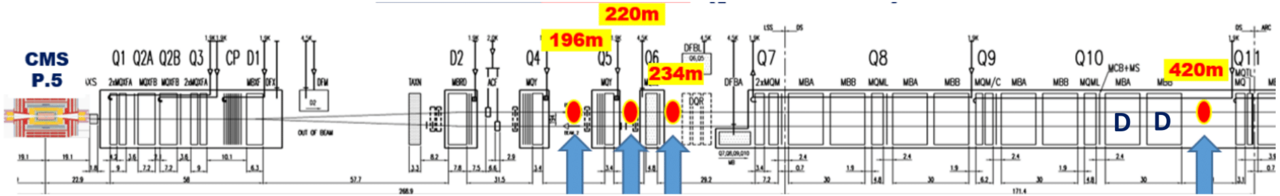
- Laboratory is prepared: devices procured and installed.
- Extensive work on software adaption and usability.
- Commissioning in progress.
- After summer break start of production QC.





HL-LHC CMS Proton Precision Spectrometer (PPS2)

- Completely refurbished PPS detector to measure forward protons at HL-LHC.



Reinstalling of present PPS/TOTEM Roman Pots

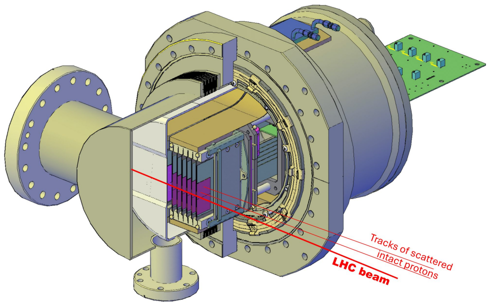
New design

PPS2 approved for execution by LHC and CMS

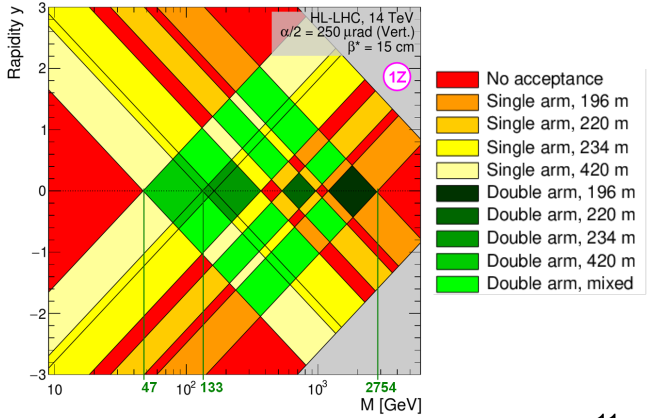
Postponed to LS4

- Roman Pots with proton tracking (3D Si pixel) & Time-of-flight (LGAD) detectors.

- Similar sensor + readout as CMS Tracker (3D Si pixel) & MTD-ETL (LGAD).



Mass and rapidity acceptance example



Finnish PPS2 contributions

- **Large synergy with Finnish CMS Tracker and MTD-ETL contributions**
- **Costs included in accepted Research Council of Finland HL-LHC roadmap project**

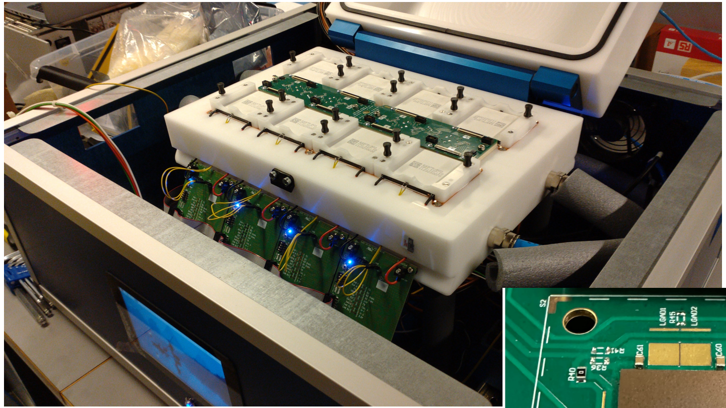
Tracking detectors:

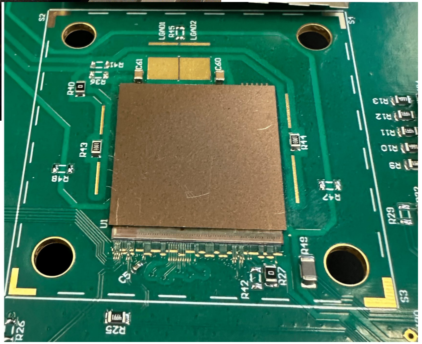
- 3D Si pixel with bespoke PPS2 geometry; readout with CROCv2 chip.
- Assembly and QC of pixel modules (about 50% of required modules) using existing CMS Tracker set-ups modified for PPS2 requirements (after Tracker module production finished).

Time-of-flight detectors:

- Trench-isolated LGADs with customized PPS2 geometry readout with ETROC2 (MTD-ETL design).
- QC of LGAD modules, tests in laboratory and in particle beams, integration of LGAD modules into Roman Pots by spring 2030.

TEPX pixel module test box





Overview of current activities not related to HL-LHC

Ultra thin Silicon Drift Detectors

- Manufacturing thin SDDs using BSOI for measuring harmonics of monochromatic X-ray beams in collaboration with the HIP IDEAL project.

Neutrons, BNCT and nuclear safeguards

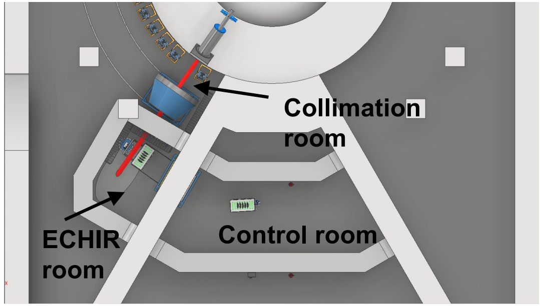
- Development of neutron beam line (characterisation including comparison to simulation).
- Participation in beamline proposal for chip irradiation at the ESS.
- Improving passive gamma emission tomography for spent nuclear fuel imaging.

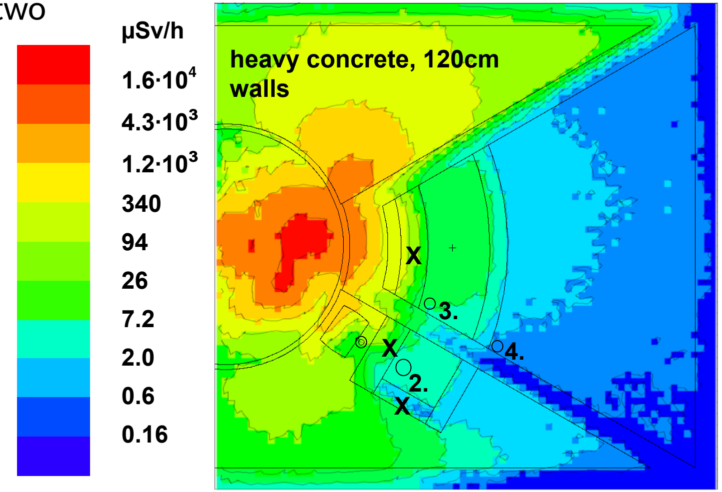
Low Gain Avalanche Detectors

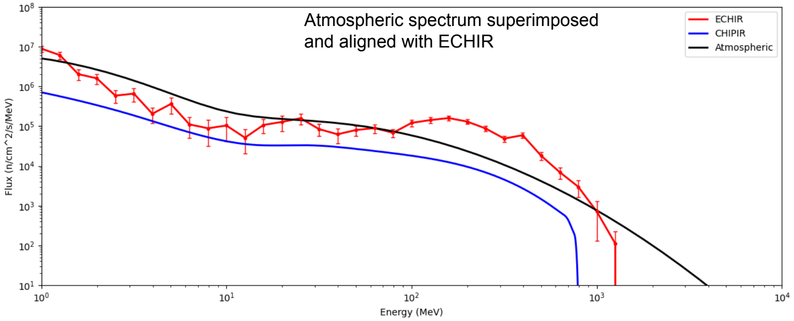
- Part of RD50/DRD3 collaboration to study radiation hardness of partially activated boron LGADs.

ESS Chip Irradiation facility (ECHIR)

- We have been part of a new beamlineproposal for chip irradiation at the European Spallation Source in Sweden.
  - Atmospheric like neutron spectrum up to ~1 GeV
- Preliminary shielding studies have been performed with Monte Carlo simulations (MCNP6).
  - Impact of shielding material and geometry on the dose rate was studied → required dose rate (< 3 μSv/h) were achieved in two rooms (locations 2 and 4 in bottom right figure).
- Future work includes optimizing the design and studying different shielding configurations.



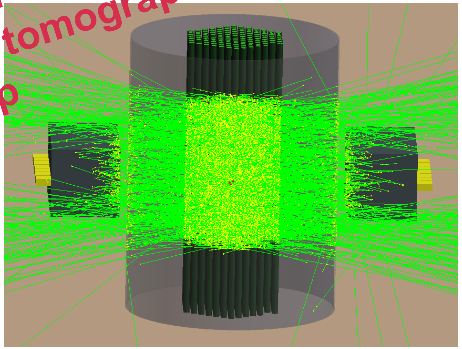




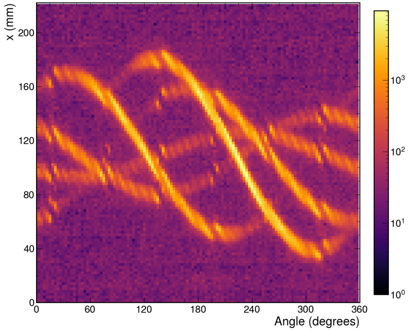
Poseidon project (concluded 2/2026)

- Funded by NKS (Nordic nuclear safety research)
- Collaboration of HIP (PI P. Dendooven), Uppsala University (Sweden), Svafo (Studsvik, Sweden) and IDEAS (Oslo, Norway)
- Objective: Improving passive gamma emission tomography of spent fuels assemblies using large position-sensitive CZT detectors

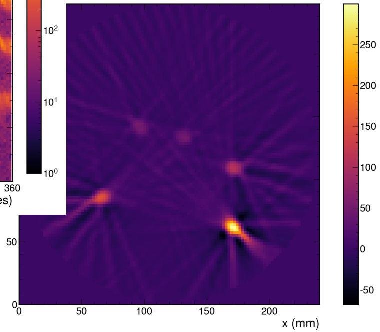
GEANT4 simulation of full tomographic set-up

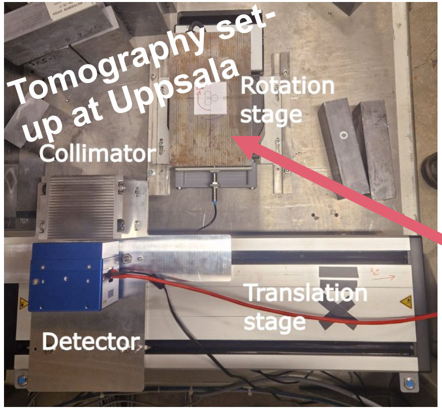


Sinogram data obtained over 4 rotations

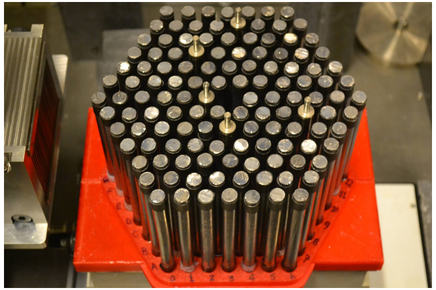


Reconstructed image using filtered back projection





SFA mockup with 5 active rods



Current personnel

Senior level

- Erik Brücken, Doc, Helsinki, project leader
- Panja Luukka, Prof, LUT
- Timo Hildén, PhD, Helsinki, senior scientist

Post doctoral researchers

- Hussam Badran, PhD, Helsinki (TEPX and FoCal project, until 6/2027)
- Aneliya Karadzhinova-Ferrer, PhD, LUT
- Ahti Karjalainen, PhD, LUT

Technicians

- Antti Nikkanen, Helsinki, research technician (TEPX and FoCal project, until 6/2027)
- Kaino Kantakoski, Helsinki, research technician (MTD project, until 6/2027)

External support (Detector Laboratory)

- Pirkitta Koponen, Helsinki, MSc, laboratory engineer
- Raimo Turpeinen, Helsinki, senior laboratory technician

Doctoral researchers

- Nikita Kramarenko, MSc, LUT
- Mila Myllymäki, MSc, Helsinki
- Santeri Saariokari, MSc, Helsinki
- Mika Väänänen, MSc, LUT (moved to industry, thesis submitted)

Master students and summer students

- Not listed. Project supervised five recently.

Summary

HELSINKI INSTITUTE OF PHYSICS

- CMS TEPX production contribution in Helsinki in control.
- Ready for ramping up TEPX production to full speed.
- Ready for the QC of LGADs starting in autumn 2026.
- PPS2 module production starting with pre-production in 2027.
- Maintaining actively local R&D projects.