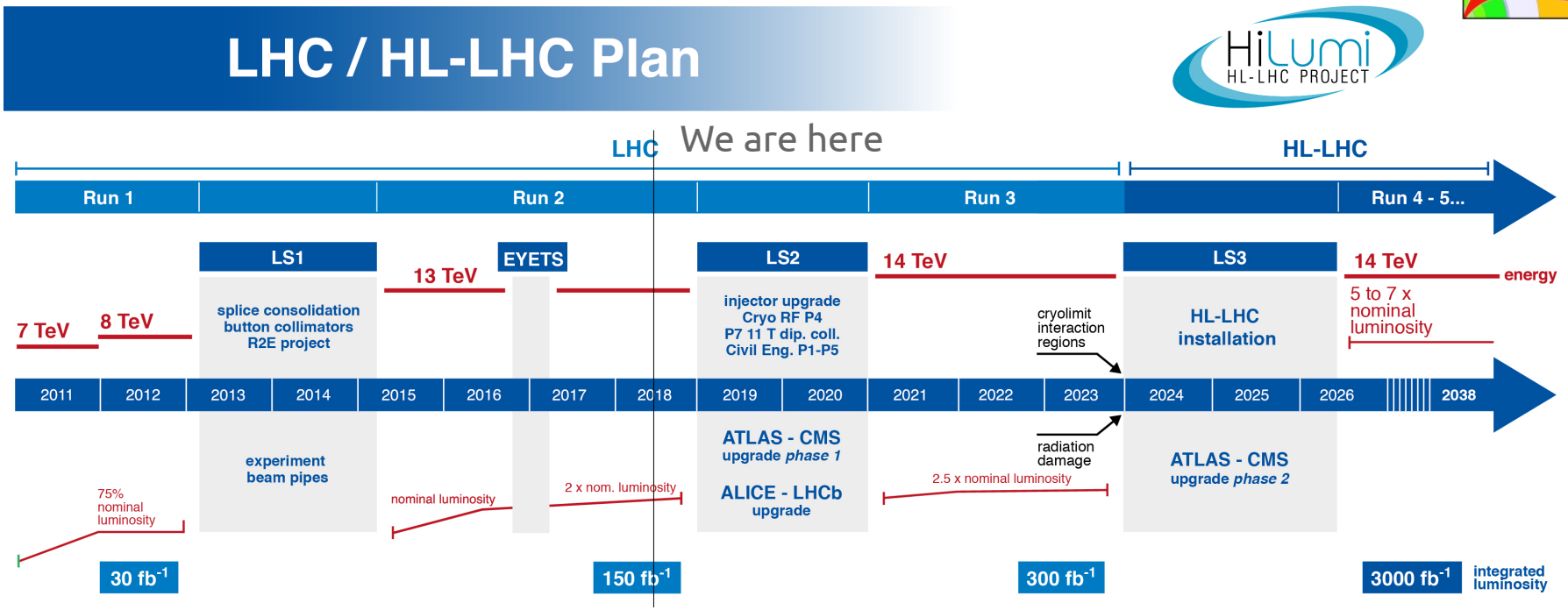
The CMS Tracker Upgrade for the High Luminosity LHC

Martin Delcourt
on behalf of the Compact Muon Solenoid collaboration

28 May 2018

14th Pisa Meeting on Advanced Detectors

CMS Tracker Upgrade for the HL-LHC
Introduction



$\mathcal{L}_{peak} \sim 1.5 \cdot 10^{34} cm^{-2} s^{-1}$
$\langle PU \rangle \sim 40 - 50$

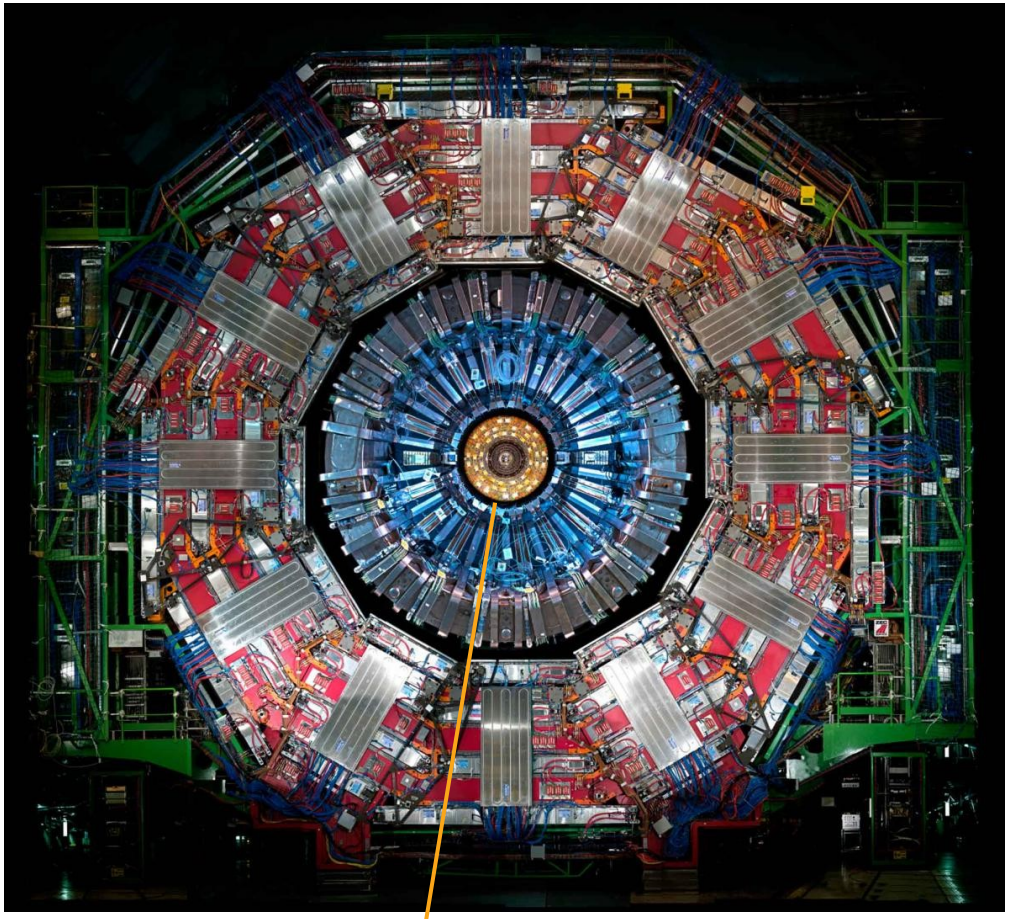
$\mathcal{L}_{peak} \sim 5 - 7.5 \cdot 10^{34} cm^{-2} s^{-1}$
$\langle PU \rangle \sim 140 - 200$

- The LHC will be upgraded in 2024 for a High-Luminosity phase
- Great opportunity for physics but challenge for experiments
  - High instantaneous luminosity
  - High integrated luminosity

CMS Tracker Upgrade for the HL-LHC
Introduction

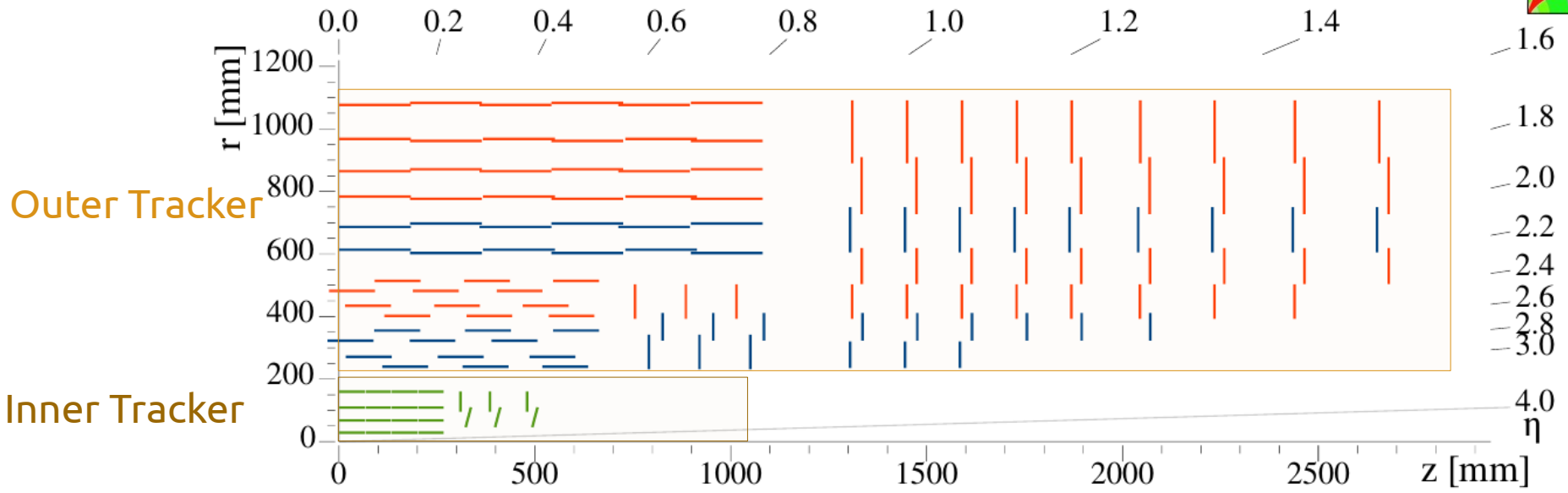
- To maintain the detector's outstanding performance, its tracker (among others) will be upgraded

- The new tracker will need to :
  - **Be radiation tolerant**
    Total radiation dose 10x higher
  - **Have a higher granularity**
    Keep channel occupancy at percent level
  - **Reduce its material budget**
    Improves tracking performance
  - **Participate to Level-1 trigger**
    Necessary to stay effective



CMS Tracker Upgrade for the HL-LHC

Plan of the talk



Sketch of one quarter of the **current** (phase 1) CMS tracking system
Pixel detector, single sided and double sided strip modules.

- Plan of the talk :
  - Inner Tracker Upgrade
  - Outer Tracker Upgrade
  - New layout and expected performances
  - L1 tracking

CMS Tracker Upgrade for the HL-LHC

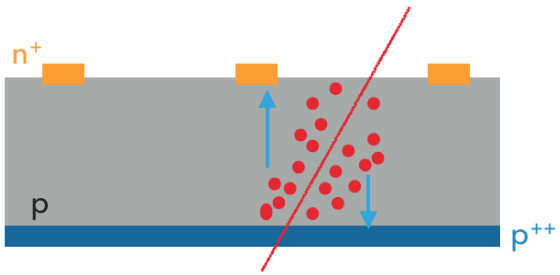
Inner tracker

- Radiation tolerance is key for the inner tracker
  - Up to 1.2Grad and 2.3 10^{16} n_{eq}/cm^2 for 3000 fb^{-1}
  - Possibility of replacement if needed

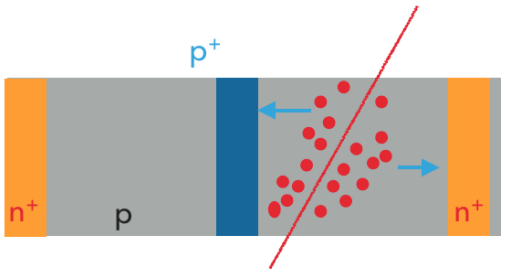
- Two n-in-p type sensors are being considered
  - Thin (100-150 µm) planar sensors
  - 3D sensors, higher radiation tolerant but more expensive

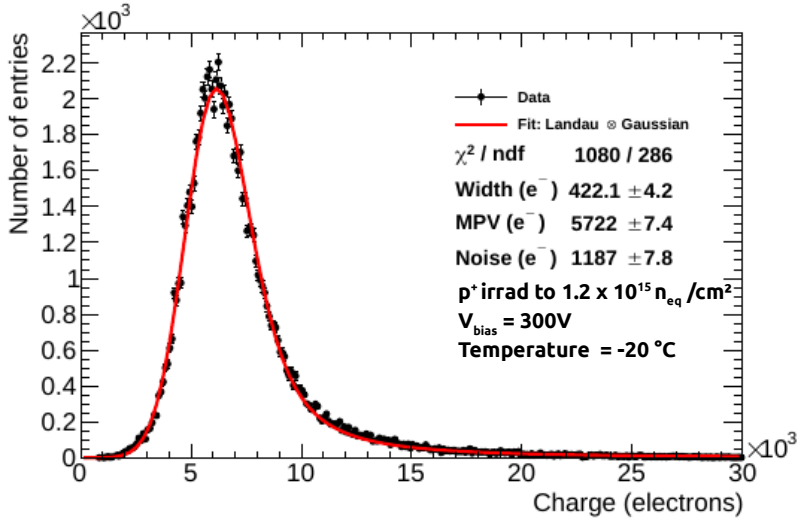
    → Would be limited to highest fluence regions

Planar sensor

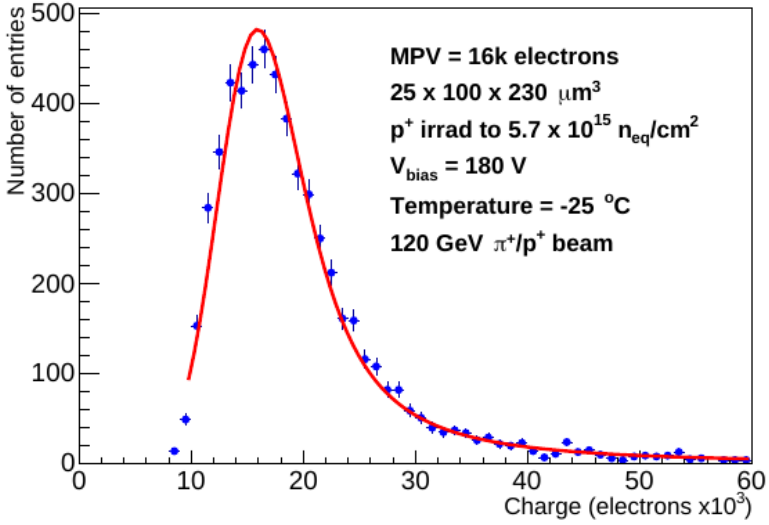


3-D sensor





Planar sensor

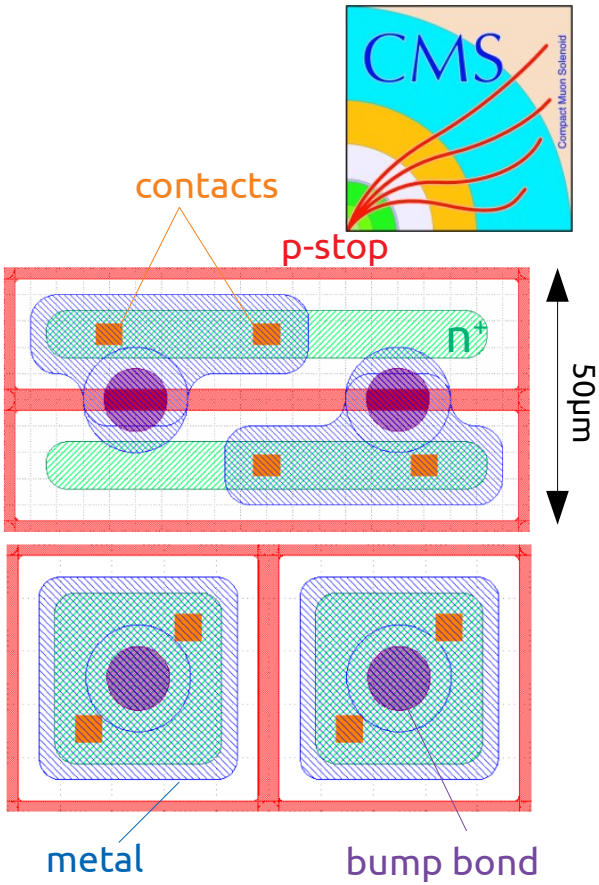


3D sensor

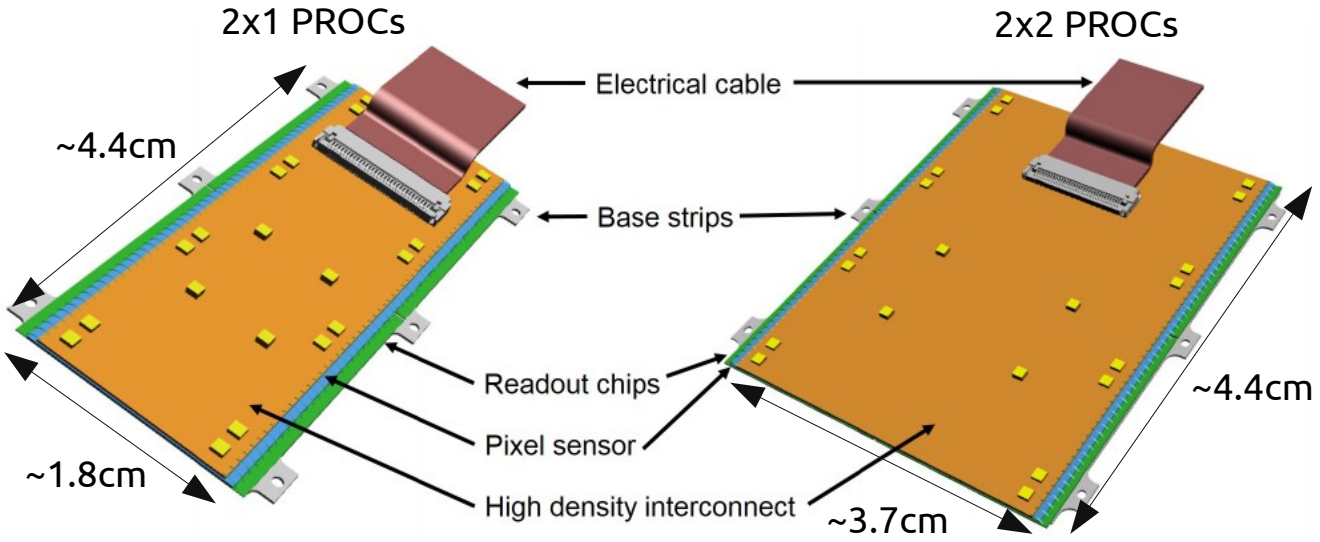
CMS Tracker Upgrade for the HL-LHC
Inner tracker

- To keep a low occupancy in the inner tracker, smaller pixels are considered.
  - 50x50 μm or 25x100 μm (6 x smaller than now)

- **P**ixel **R**ead **O**ut **C**hip (PROC) will have to be radiation hard and cope with a hit rate up to 3 GHz/cm²
  - Being developed within RD53 (CMS-ATLAS collaboration)



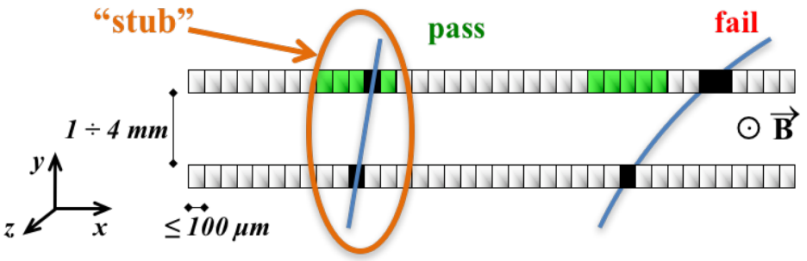
Friday → Test results and prospects for RD53A, a large scale 65 nm CMOS chip for pixel readout at the HL-LHC
Luigi Gaioni



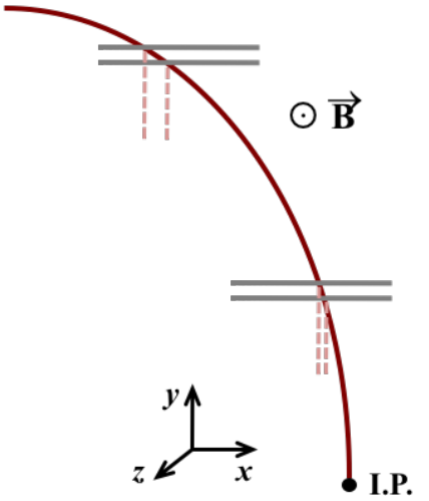
- Two different flavours, **one** or **two** rows of two PROCs (~16.4x22.0 mm²)

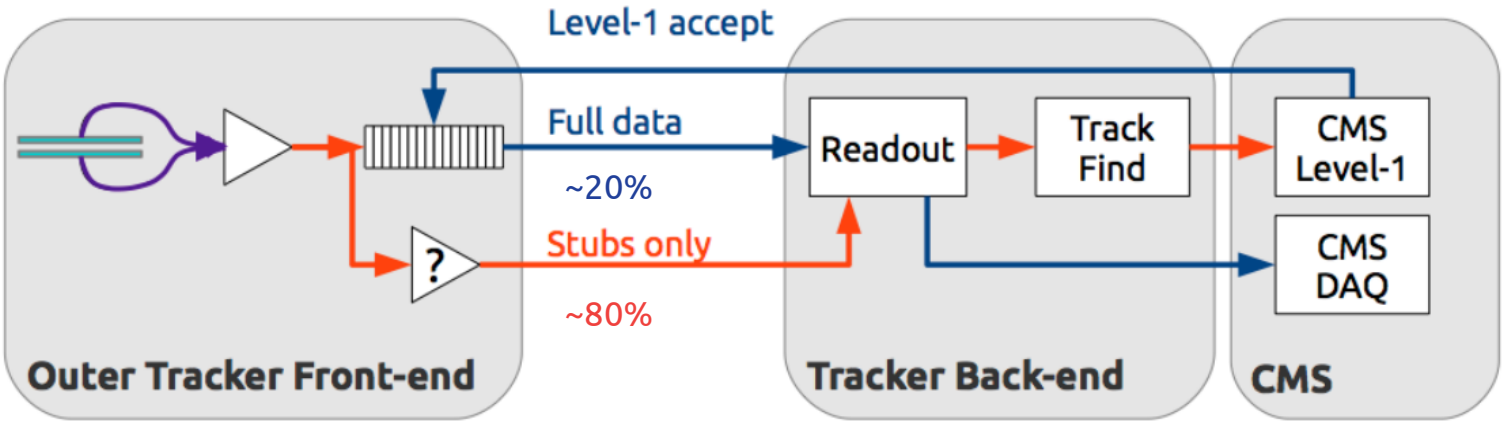
CMS Tracker Upgrade for the HL-LHC
Outer tracker

- For L1 triggering, data has to be sent for every bunch crossing
  - Full data would exceed bandwidth
  - **Data reduction is needed at detector level**
    2GeV cut → data reduction of 10x to 100x



- High transverse momentum tracks can be selected by correlating hits on two sensors
  - "**Stubs**" read-out at 40MHz
  - **Full data** read-out if triggered (~750kHz)

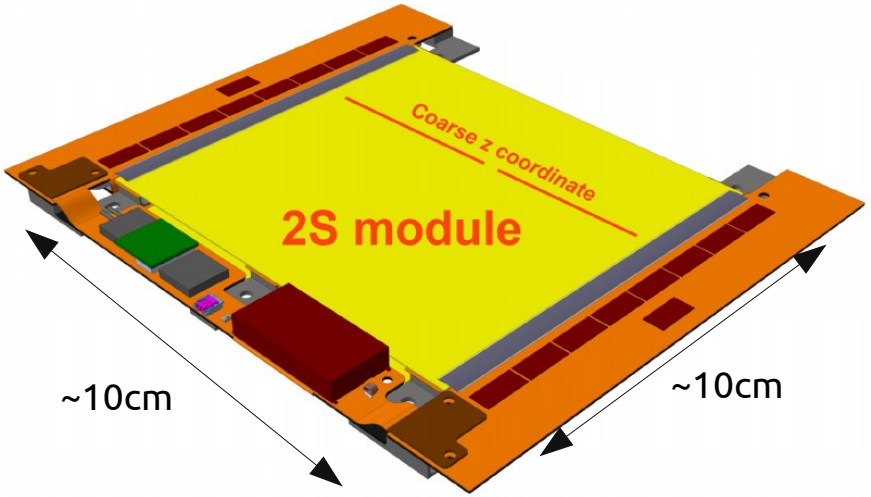


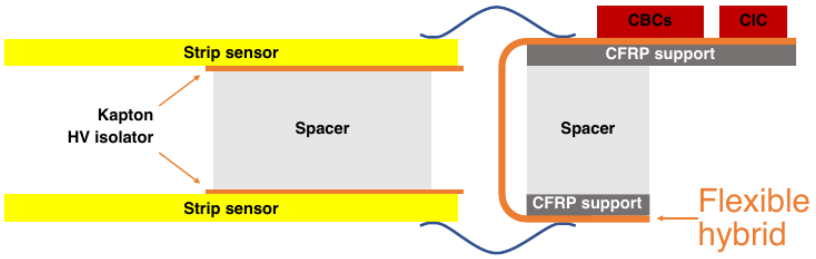


CMS Tracker Upgrade for the HL-LHC
Outer tracker

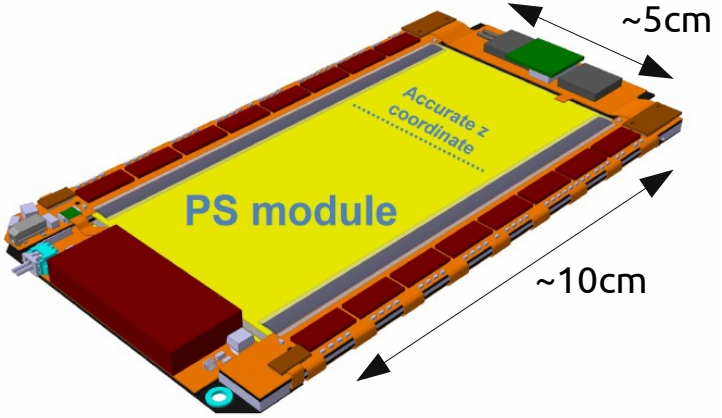
- Outer tracker modules:
  - Planar n-in-p, 200μm thick sensors
  - Binary read-out chips
  - Zero-suppression and data aggregation at module level

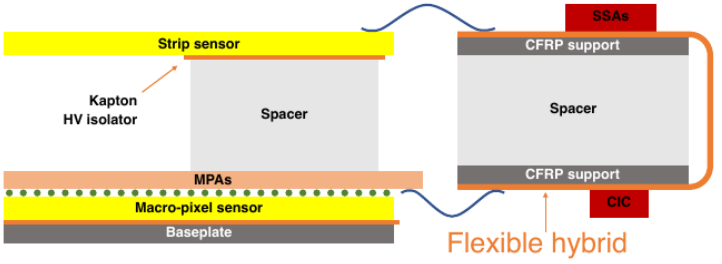
2Strip modules
2x1016 strips ~5cm x 90μm
2x1016 strips ~5cm x 90μm





Pixel **S**trip modules
2x1016 strips ~2.4cm x 100μm
32x960 macro-pixels ~1.5mm x 100μm

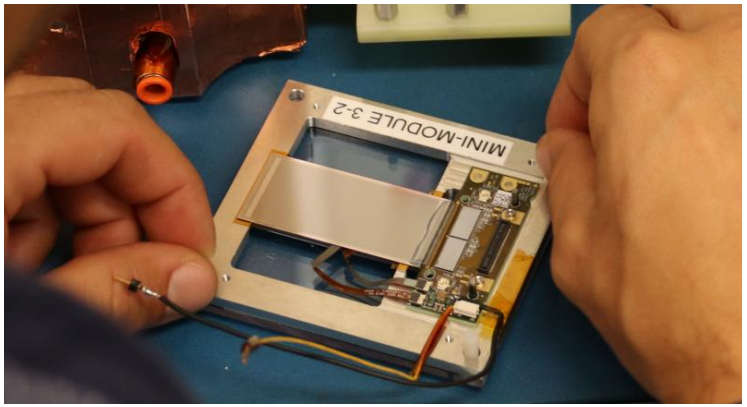




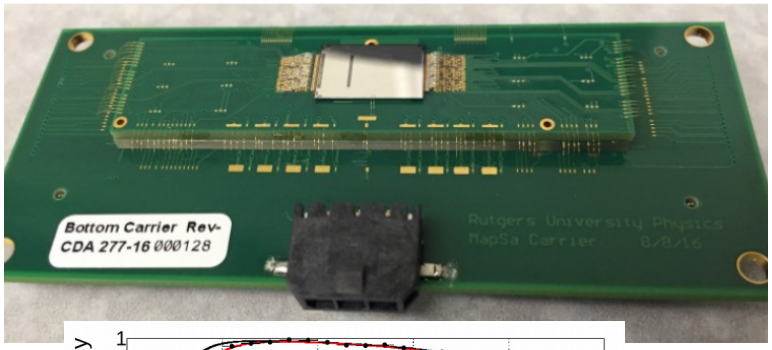
CMS Tracker Upgrade for the HL-LHC
Outer tracker

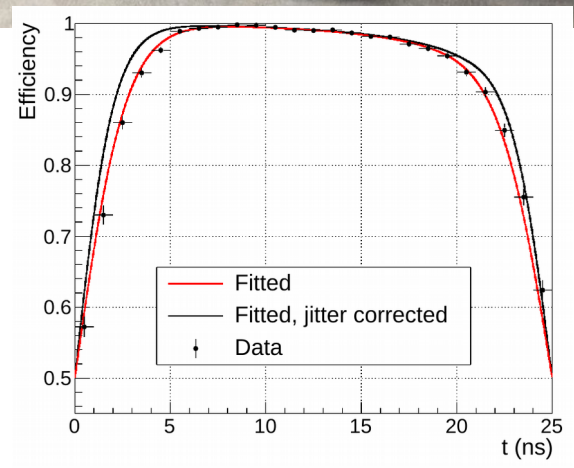
- Prototypes are being tested and characterized in beam
  - **Stubs are correctly produced** (p_T emulated by rotating module in beam)
  - High efficiency

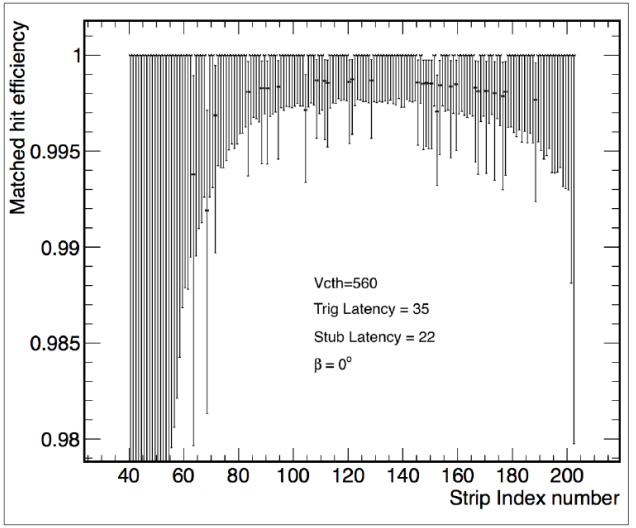
2S CBC3 mini-module

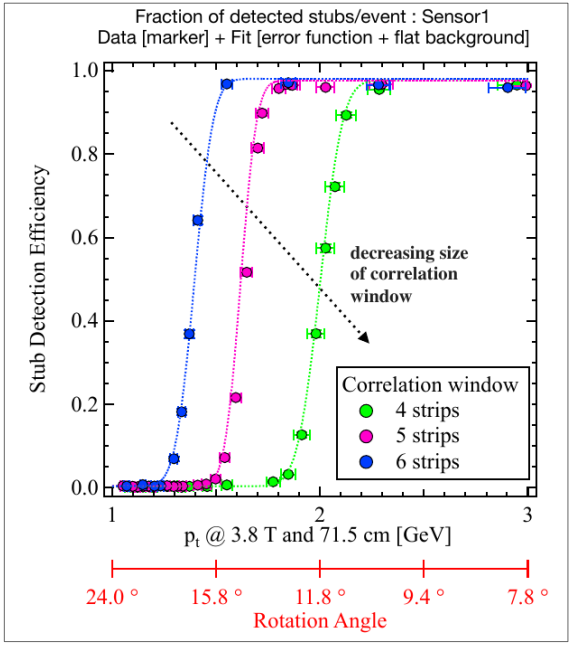


PS mapsa-light mini-module







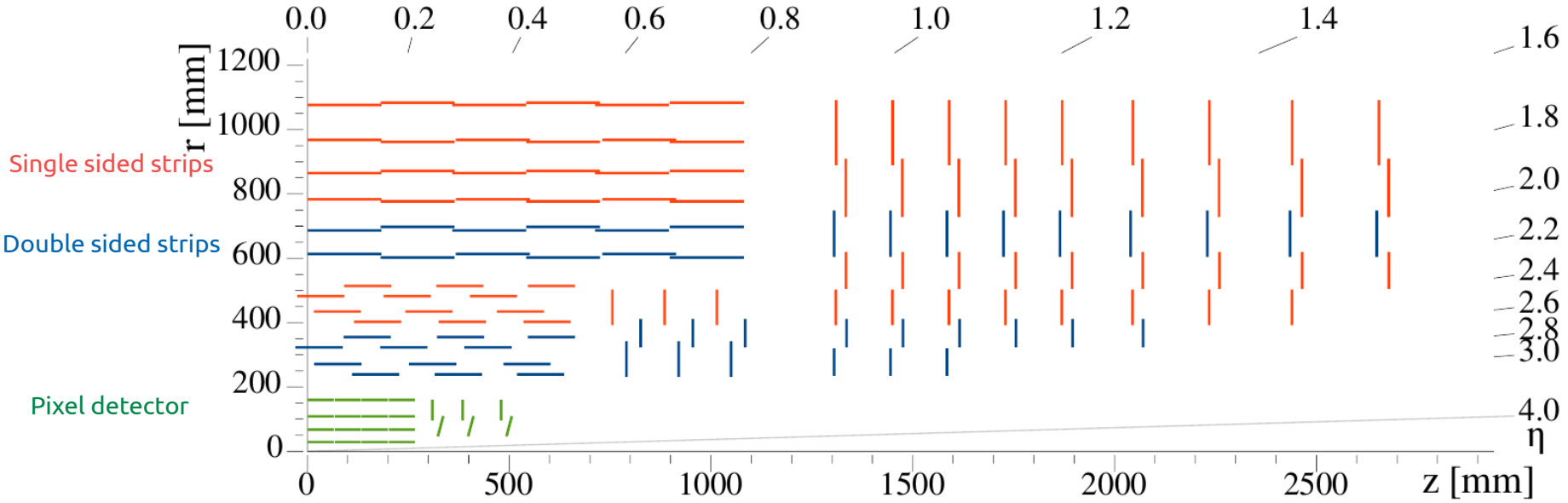


Friday →

Recent developments in the CBC3, a CMS micro-strip readout ASIC for track-trigger modules at the HL-LHC
Dr. Sarah Seif El Nasr-Storey

CMS Tracker Upgrade for the HL-LHC

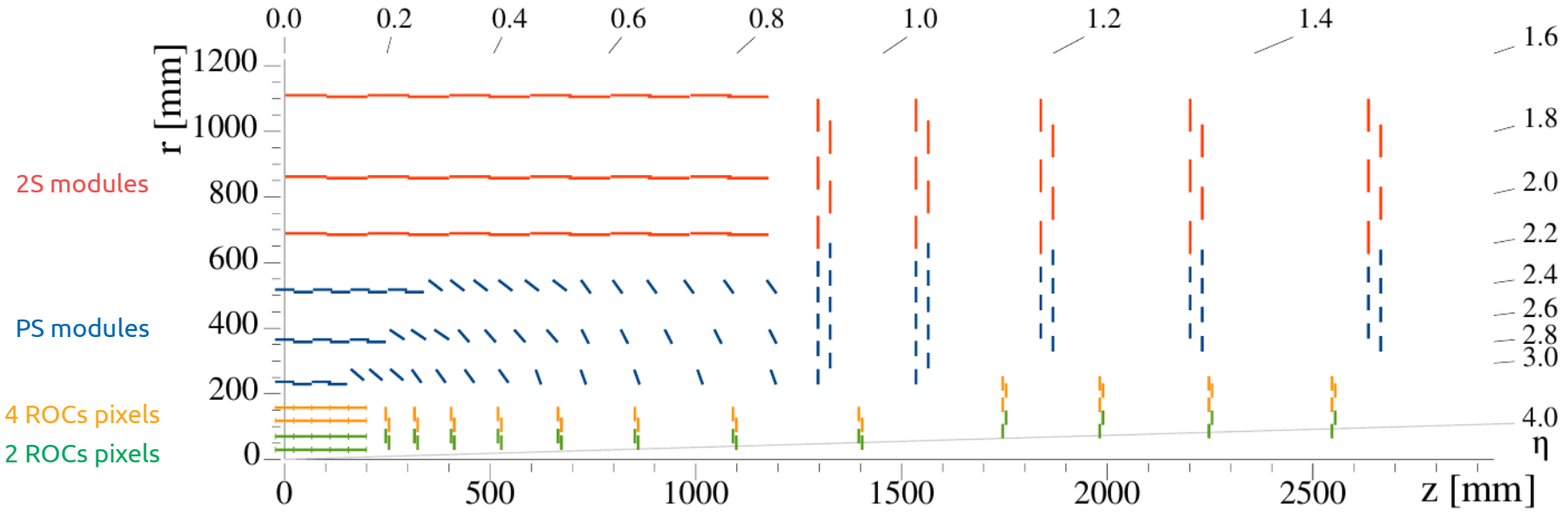
Current layout



Sketch of one quarter of the **current** (phase 1) CMS tracking system

CMS Tracker Upgrade for the HL-LHC

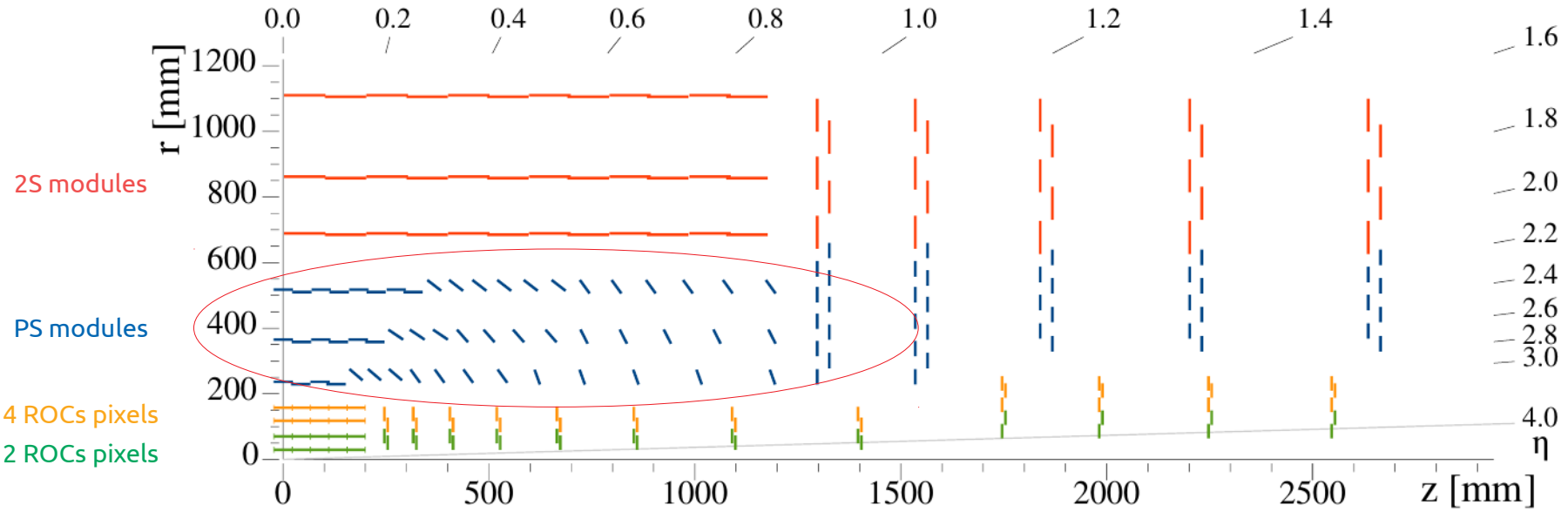
New layout



Sketch of one quarter of the **phase 2** CMS tracking system

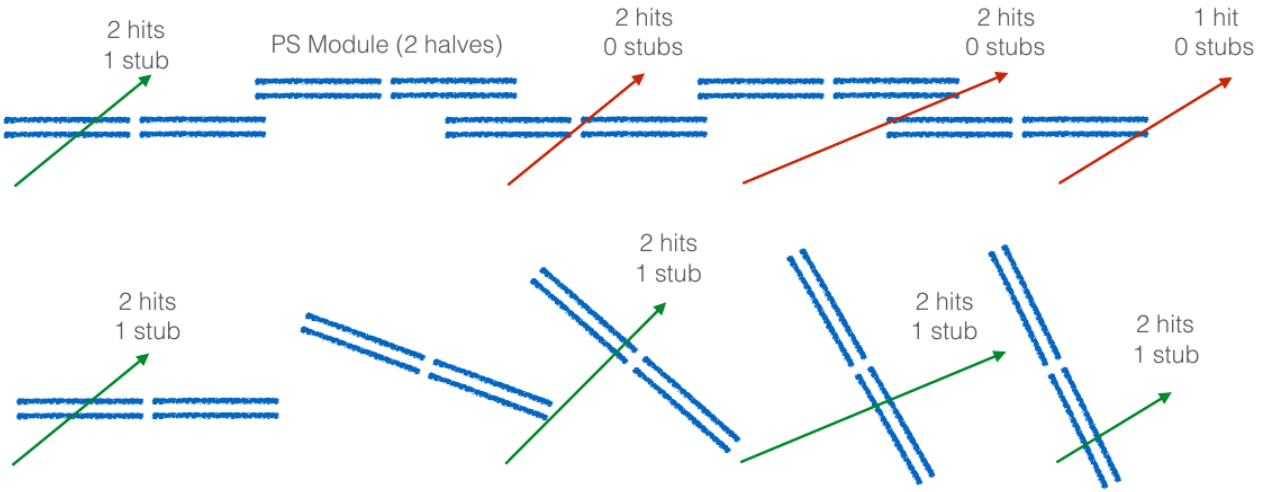
CMS Tracker Upgrade for the HL-LHC

New layout



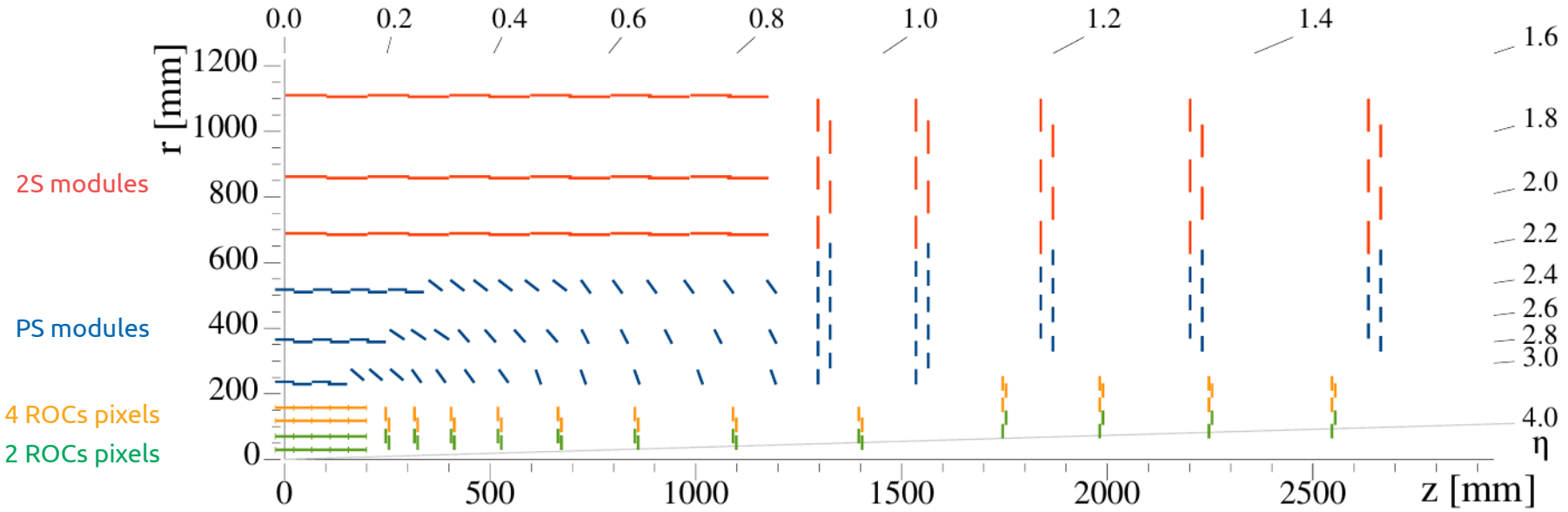
Sketch of one quarter of the **phase 2** CMS tracking system

- Tilted barrel to optimize stub efficiency



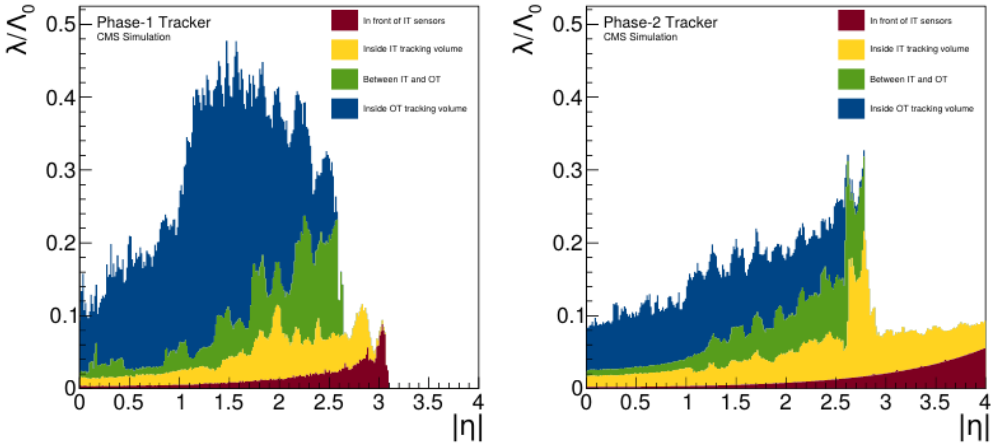
CMS Tracker Upgrade for the HL-LHC

New layout



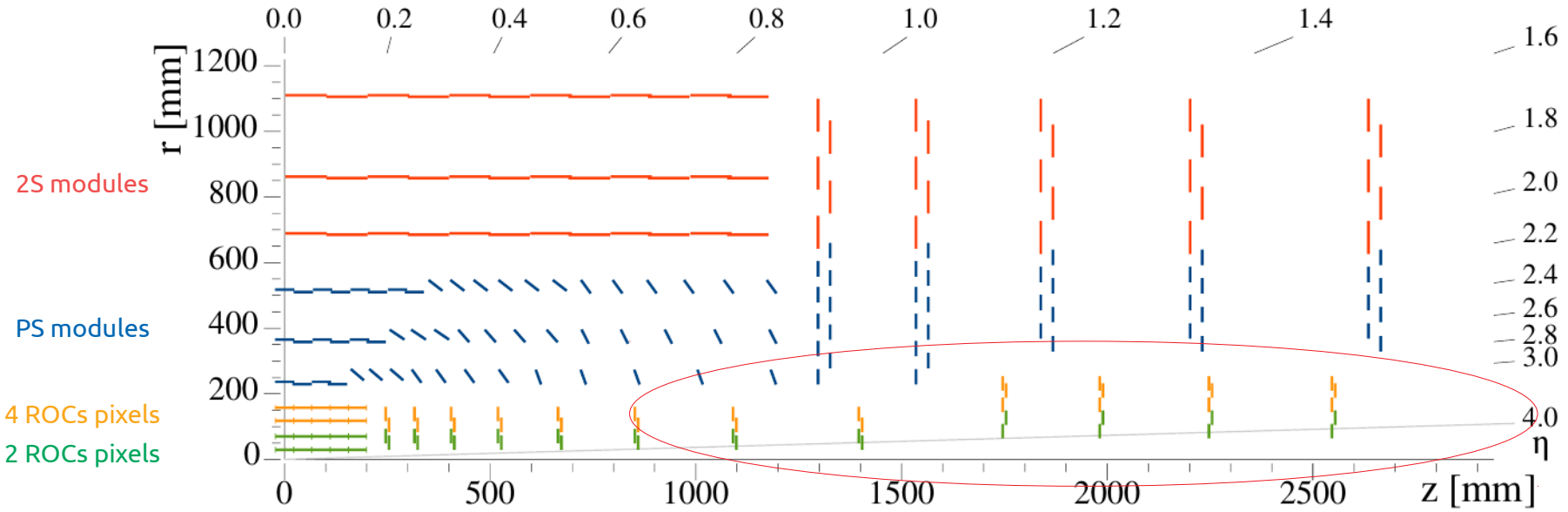
Sketch of one quarter of the **phase 2** CMS tracking system

- Tilted barrel to optimize stub efficiency
- Reduction of material budget



CMS Tracker Upgrade for the HL-LHC

New layout



Sketch of one quarter of the **phase 2** CMS tracking system

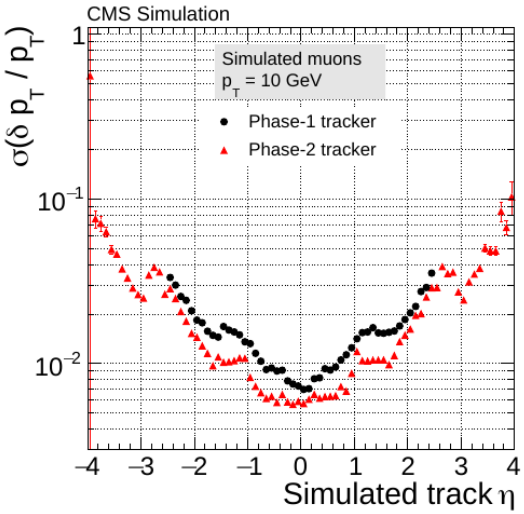
- Tilted barrel to optimize stub efficiency
- Reduction of material budget
- Extended eta coverage from $|\eta| \lesssim 2.4$ to $|\eta| \lesssim 4$
  - Increases forward acceptance
  - Mitigates pile-up effects in forward region

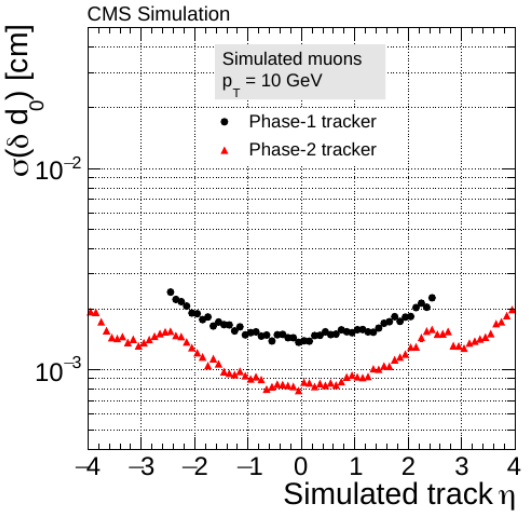
CMS Tracker Upgrade for the HL-LHC

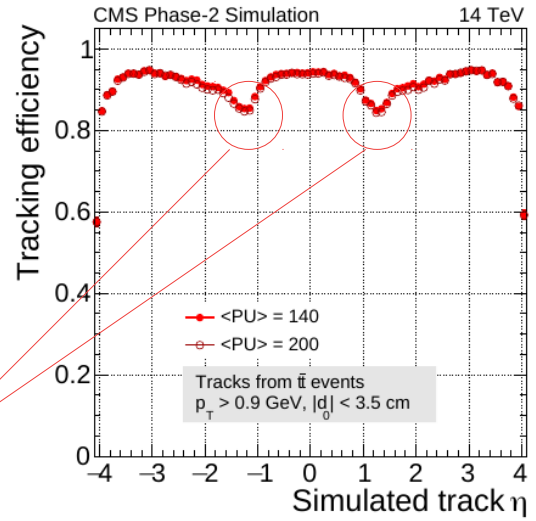
Expected performances

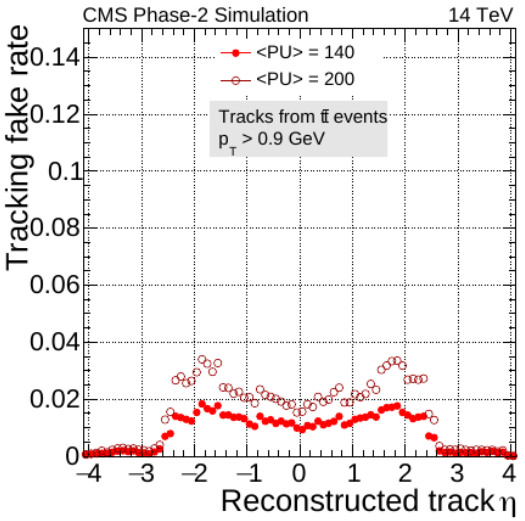
- Full Monte-Carlo simulation
- Significant improvement expected in p_T and d_0 resolution
- 90% tracking efficiency for tracks from tt events with < 2% fake rate
- Work in progress!
  - Geometry is being optimized
  - Efficiency at |η| ~ 1.2 is being addressed

Offline tracking



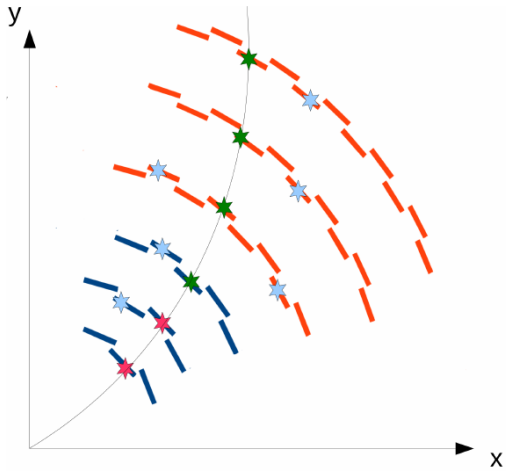






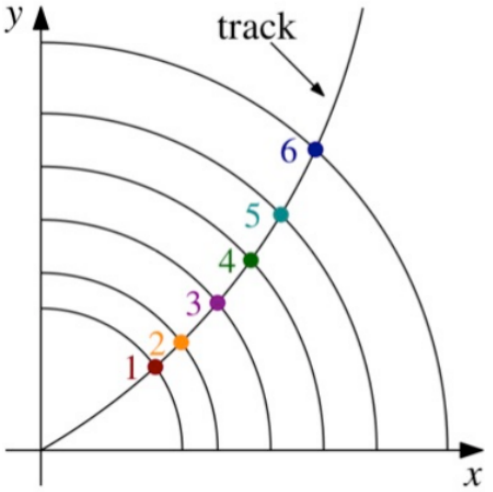
CMS Tracker Upgrade for the HL-LHC
L1 track finding

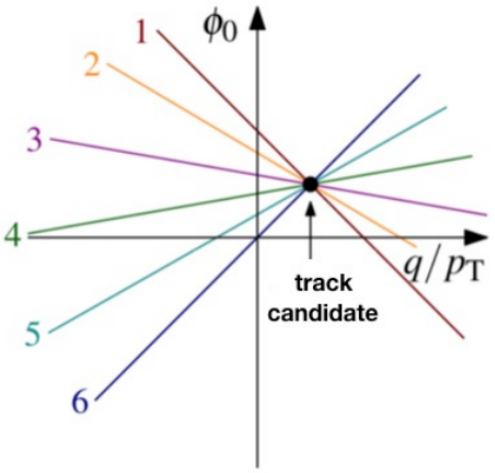
- Tracking at L1 is a challenging task
  - Tracks need to be produced within ~ 5µs
  - Two different all-FPGA solutions are considered



- Tracklet approach
  - “Tracklets” formed from stubs in adjacent layers
  - Extrapolate to tracks, minimize chi² (linearised chi² fit)
  - Remove duplicates

- Hough transform approach
  - Select track candidate through Hough transform
  - Minimize chi² (Kalman Filter)
  - Remove duplicate

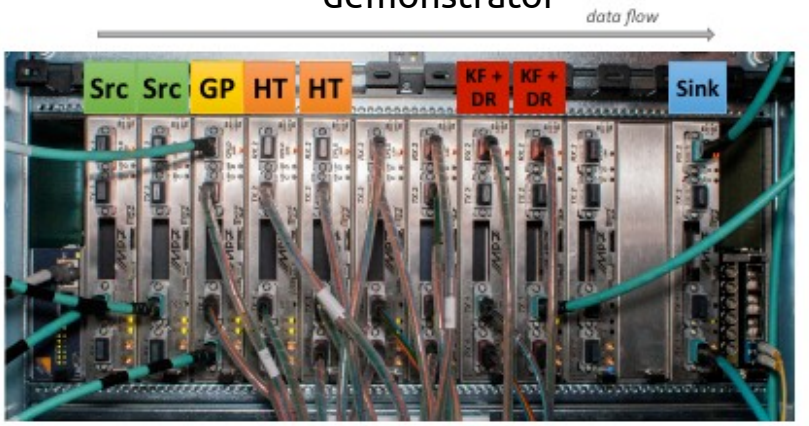




CMS Tracker Upgrade for the HL-LHC
L1 track finding

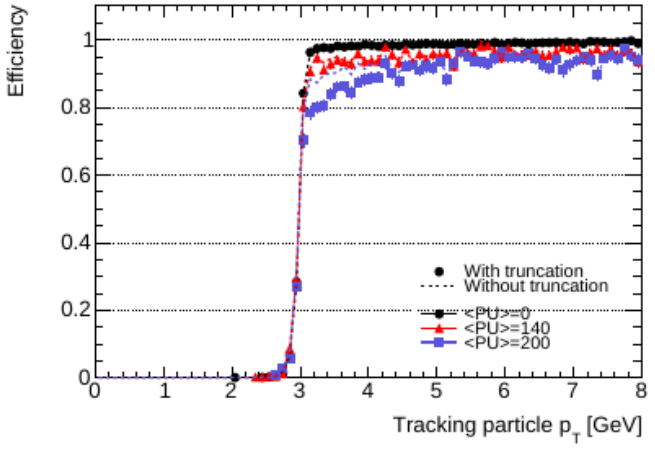
- Demonstrators were set-up for both approaches
  - Simulated event used as input
  - Similar results obtained
  - Tracks produced within timing constraints
- Work being done to merge approaches

Hough transform demonstrator

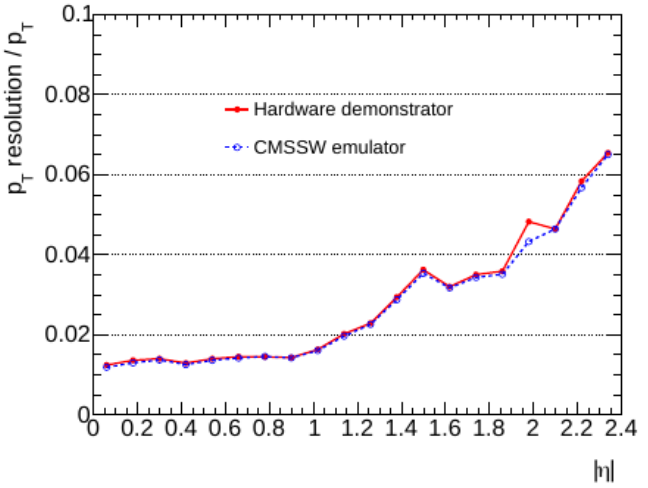


Friday → Level-1 track finding with an all-FPGA system at CMS for the HL-LHC
Mr. Luis Ardila Perez

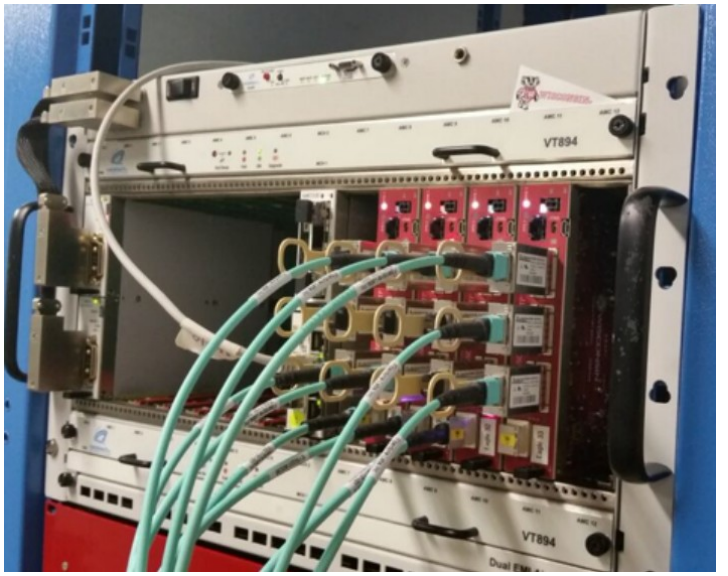
Tracklet



Hough transform, 200PU



Tracklet demonstrator



CMS Tracker Upgrade for the HL-LHC
Summary

- The phase-2 tracker upgrade is necessary in order to maintain the detector performance
- The new design will allow to keep tracking performance under a high pile-up and radiation environment
- Tracks will be sent to the CMS level-1 trigger at 40 MHz
- Design is well advanced
  - many prototypes have been produced and tested
  - the upgrade concepts have been validated
  - mechanics, integration and installation concepts well advanced
- Final prototyping and EDR are awaiting us!

The CMS Outer Tracker Upgrade for the High Luminosity LHC

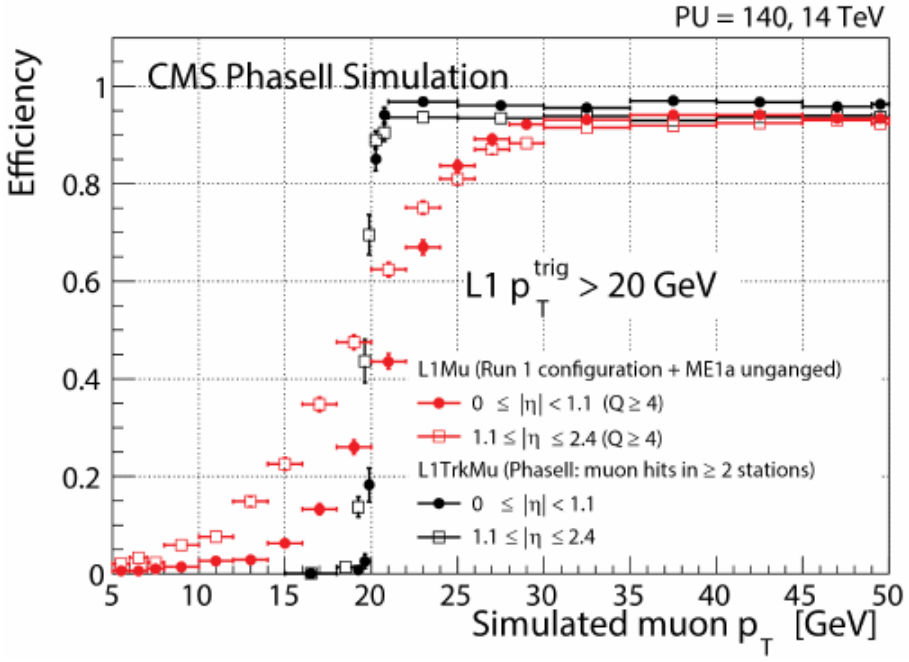
Martin Delcourt
on behalf of the Compact Muon Solenoid collaboration

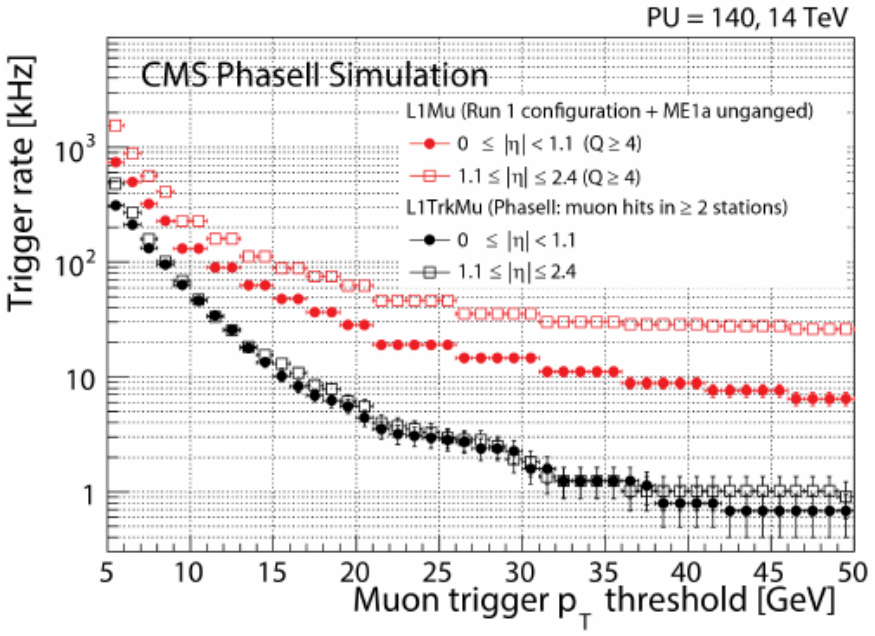
28 May 2018

14th Pisa Meeting on Advanced Detectors

CMS Tracker Upgrade for the HL-LHC

Backup – Why do we need a track trigger?





CMS Tracker Upgrade for the HL-LHC

Backup – About cooling

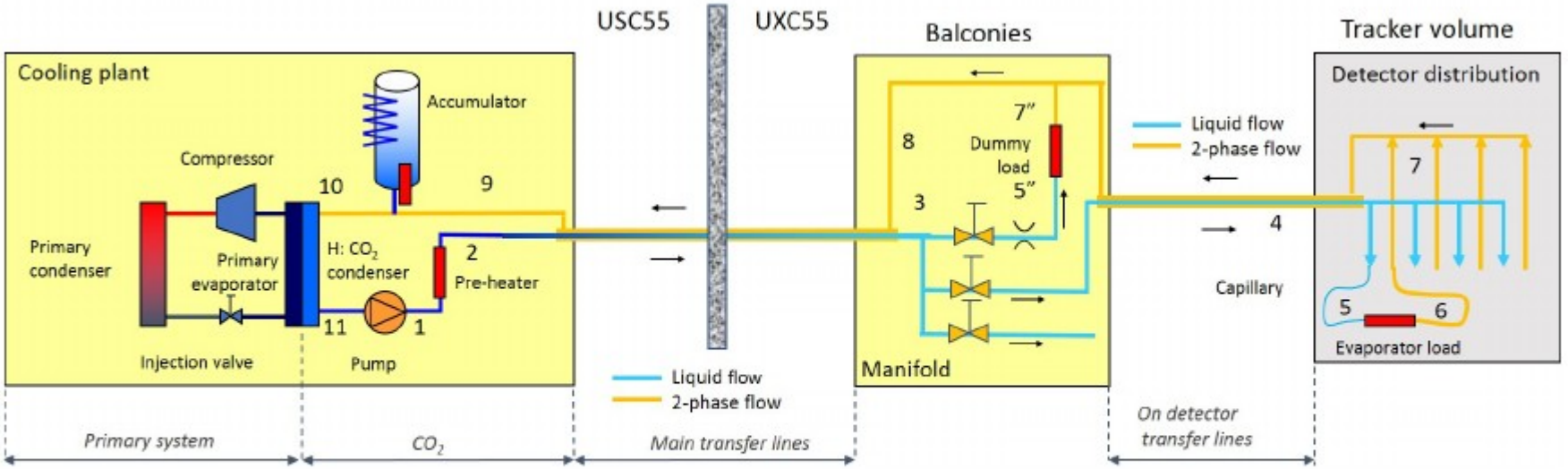
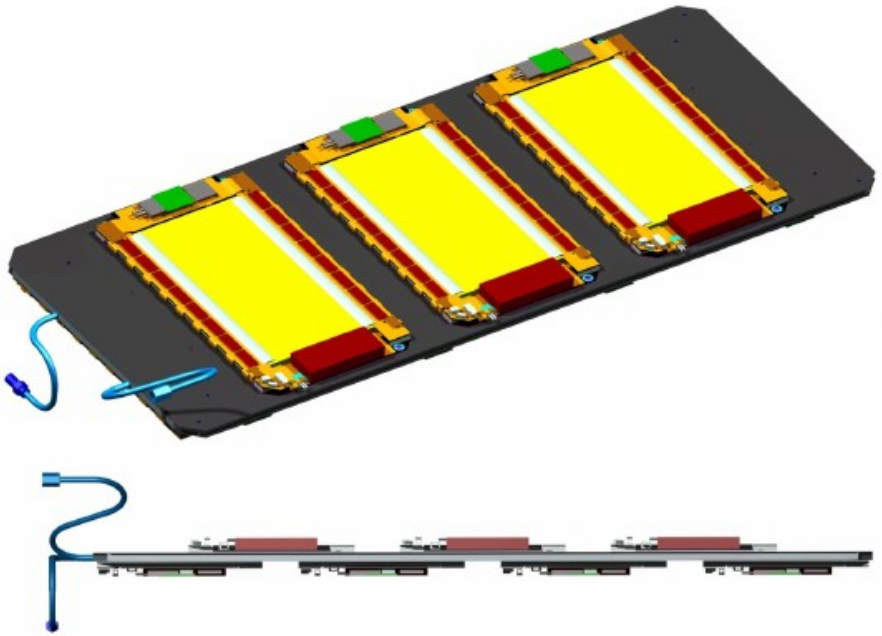
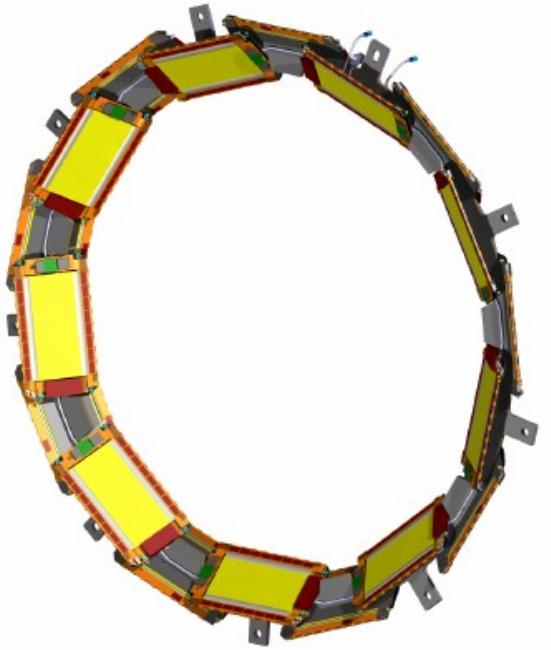


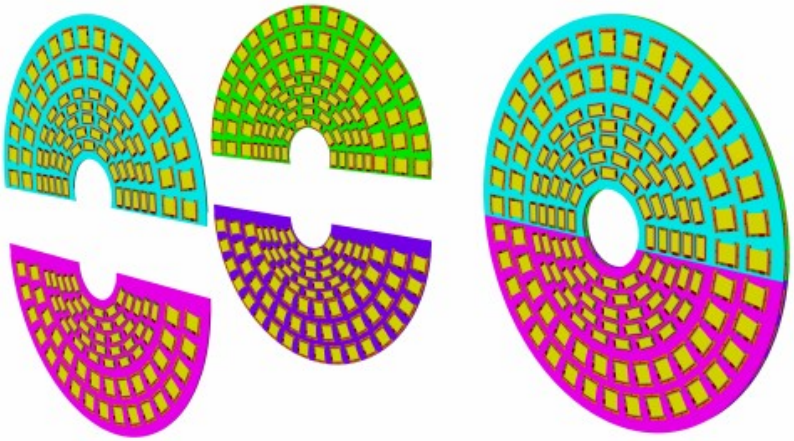
Figure 11.4: Schematics of the 2PACL cooling system concept as used in the CMS pixel Phase-1 upgrade.

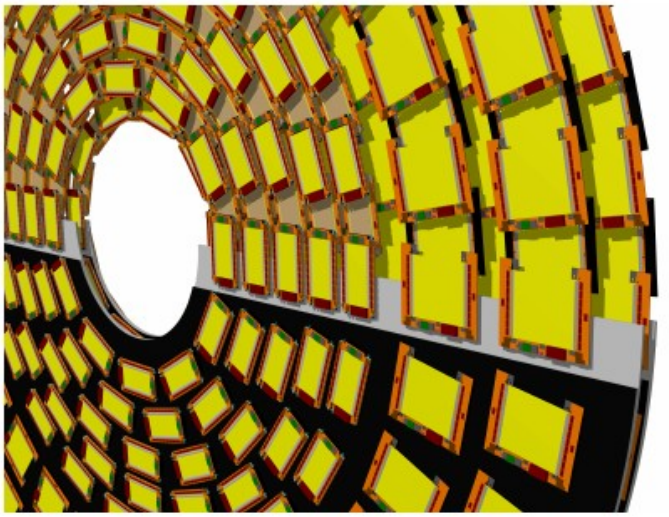
CMS Tracker Upgrade for the HL-LHC

Backup – Mechanical view



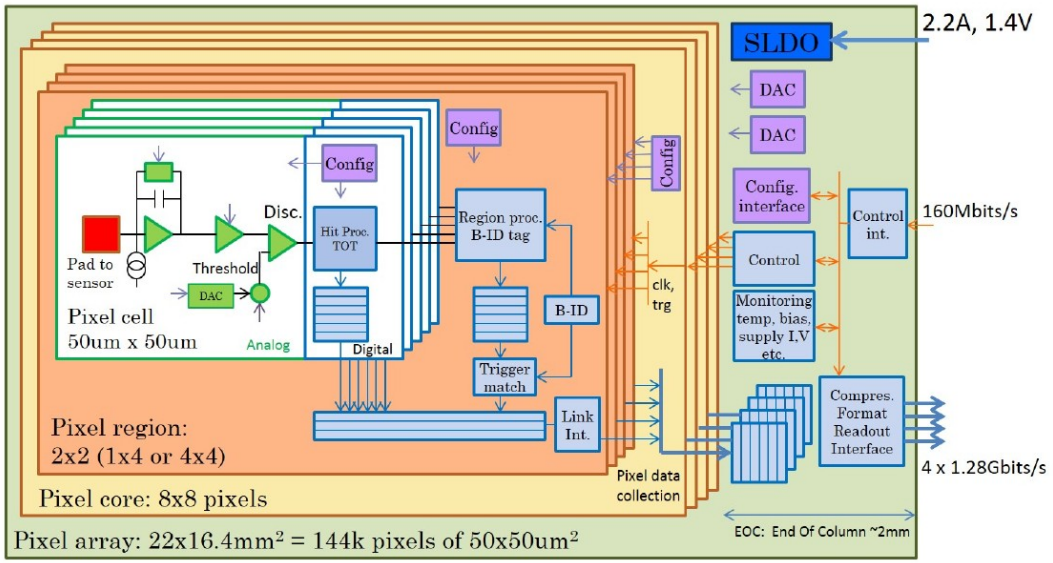


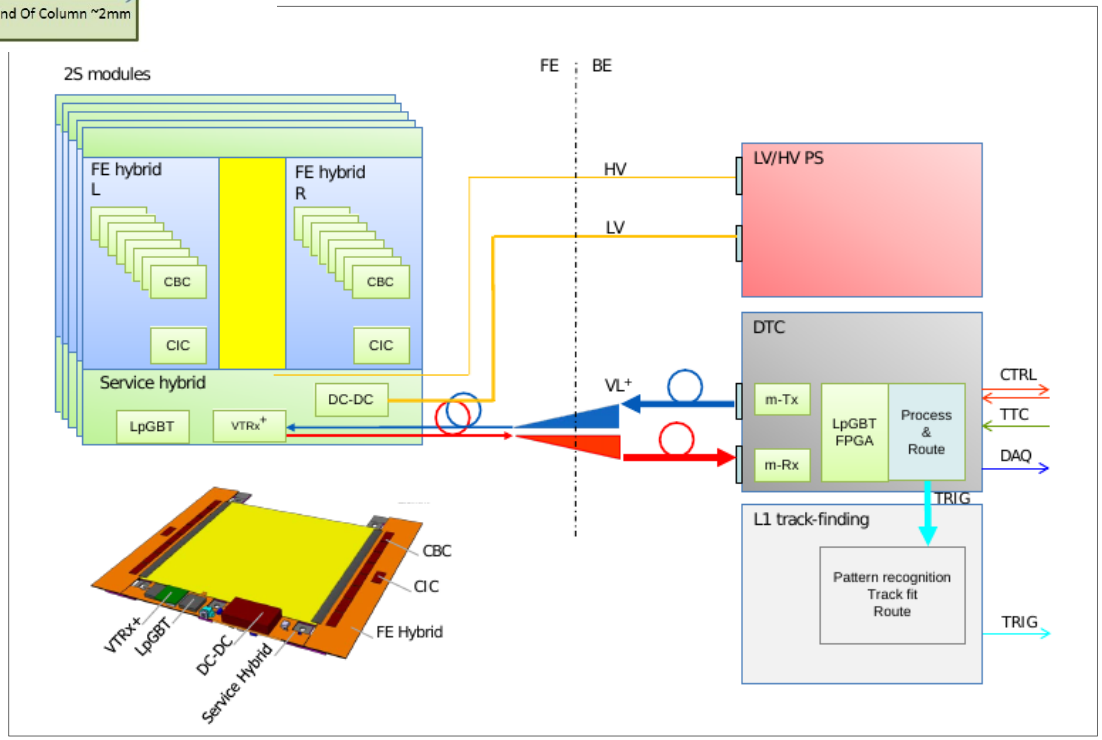




CMS Tracker Upgrade for the HL-LHC

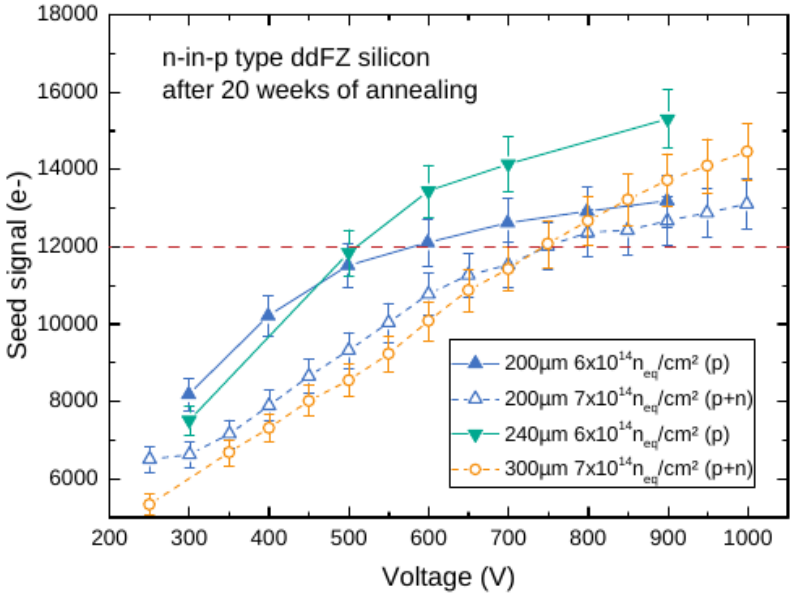
Backup – Read out

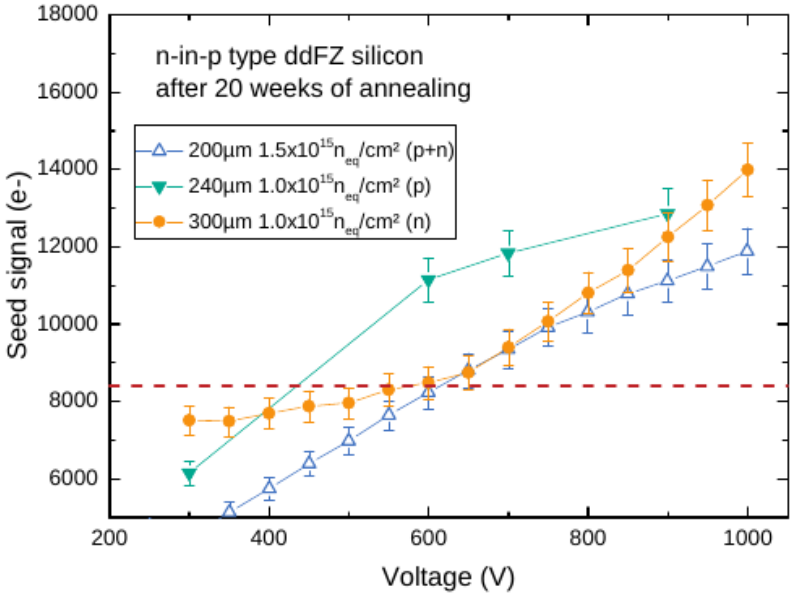


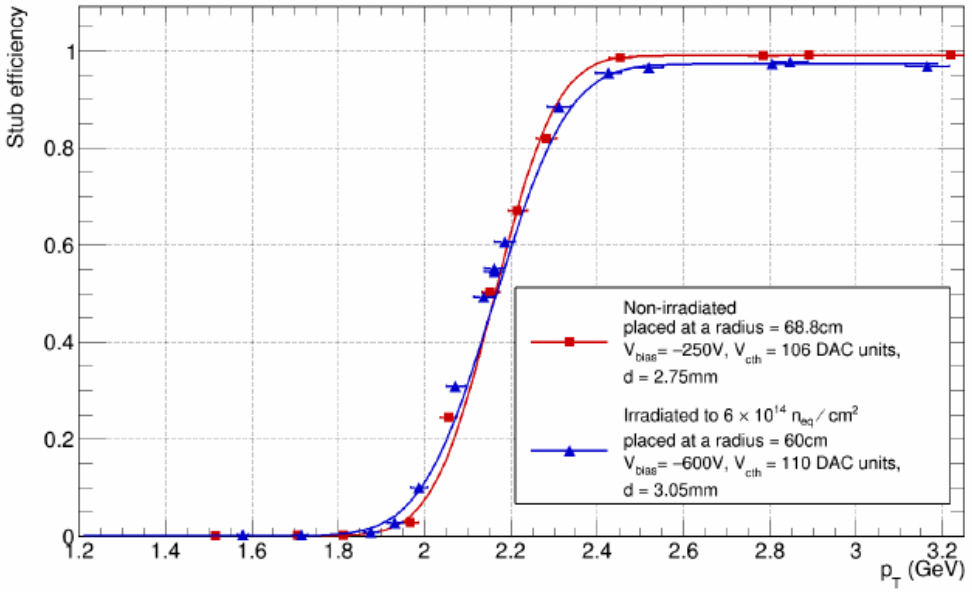


CMS Tracker Upgrade for the HL-LHC

Backup - Outer tracker sensor irradiation







CMS Tracker Upgrade for the HL-LHC

Backup - Outer tracker beam test