FERMILAB-SLIDES-18-069-CMS

# Simulation of CMS Phase 2 Pixel Tracker for HL-LHC

Bahareh Roozbahani

USCMS FPIX Simulation Group

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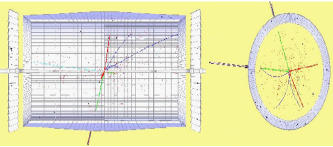
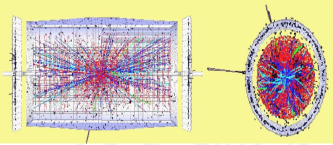
# Introduction

- **CMS pixel detector is a unique tracking detector**
  - → All-silicon technology
  - → Key element in efficient and precise reconstruction of tracks/interaction vertices and heavy flavor tagging



H→ZZ→ $ee\mu\mu$



event above, overlaid with 20 pileup interactions

- **Tracker is the closest to the beam-line → Difficult environment**
  - → High instantaneous luminosity ($\sim 10^{34} cm^{-2} s^{-1}$)
  - → Large number of pp interactions per bunch-crossing (pileup)
  - → Expecting increase in instantaneous luminosity, pileup up to 140 to 200 at HL-LHC

→ ROC high rates
→ Accumulated radiation Damage
→ Decreased in charge collection/sharing
→ Worsen efficiency and resolution

# CMS Pixel Detector Upgrade

| | LHC | | | | | HL-LHC | |
|---|---|---|---|---|---|---|---|
| | Run 1 | LS 1 | Run 2 | LS 2 | Run 3 | LS 3 | Run 4 |
| $E_{CM}$ (TeV) | 7-8 | | 13 | | 14 | | 14 |
| L ($cm^{-2} s^{-1}$) | 7 x $10^{33}$ | | 2 x $10^{34}$ | | 2 x $10^{34}$ | | 5 x $10^{34}$ |
| PU | ~20-30 | | ~50 | | ~50 | | ~140 |
| $\int Ldt$ ($fb^{-1}$) | 30 | | 300 | | 300 | | 3000 |

| Phase-0 | | | | | | Phase-1 | | | | | | Phase-2 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| past | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | future |

Phase1 pixel detector installation

Phase2 pixel detector installation

## Phase0 → Phase1

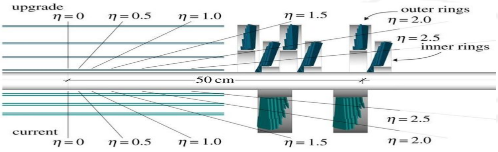
- Added extra barrel layer and endcap disk
- Layers closer to the beam-line

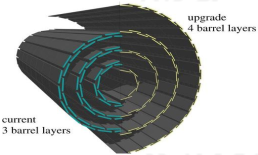
→ improvement in tracking and b-tagging

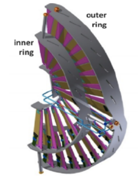
- Barrel: 48M → 79M pixels

  Forward: 18M → 45M pixels

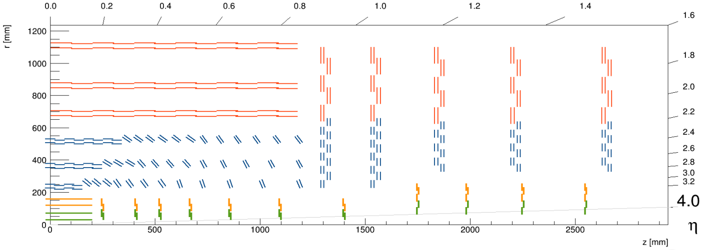
- Moved from analog to digital readout



# CMS Pixel Detector Phase2 Upgrade



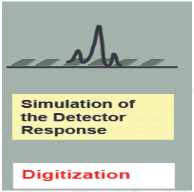

- **Inner Tracker (Pixel Detector):**
  - → Same number of Barrel layers (4) as the current detector
  - → Increase the endcap disks to 12 disks

Better $\eta$ coverage $\rightarrow |\eta| < 4.0$ Improved tracking/vertexing Better mitigation of pileup

  - → Increasing granularity/smaller pixels (x6 smaller pixel area)

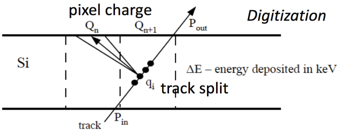
Improved resolution Maintain low digi occupancy

- **1) Simulation of the detector geometry using tkLayout**
  - → **geometry A**: 4 barrel layer, 12 endcap disks
    25x100x150 $\mu m^3$ pixels
  - → **geometry B**: 4 barrel layer, 12 endcap disks
    50x50x150 $\mu m^3$ pixels




- **2) Simulation of desired physics processes using particle gun (Pythia8) and Detector response (Geant4)**
  - → Ten Muon process with 200 pileup overlaid, simulated in **geometry A** and **geometry B**
  - → Output is a collection of simulated hits

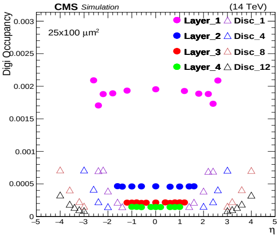
- **3) Digitization (CMSSW)**
  - → Convert simulated hits to format similar to experimental raw data (digis)

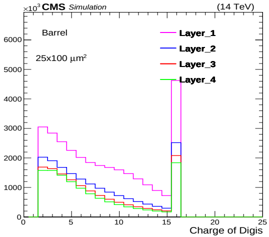


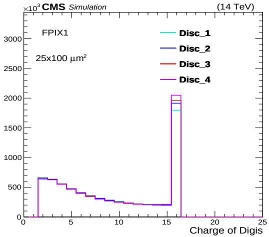
# Occupancy Study

| Digi Occupancy vs. $\eta$ | Digi Charge in Barrel | Digi Charge in Endcap |
|---|---|---|

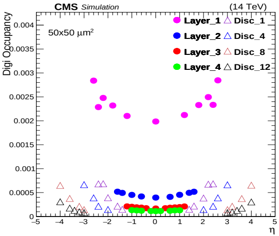
**25x100 $\mu m^2$ pixels**

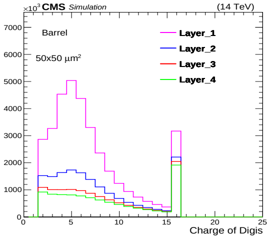


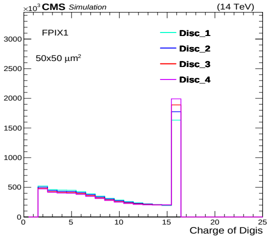




**50x50 $\mu m^2$ pixels**



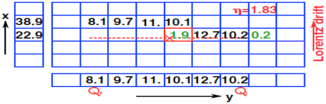




- Higher digi occupancy in the barrel for 50x50 $\mu m^2$ comparing to 25x100 $\mu m^2$
- Larger charge collection in 50x50 $\mu m^2$ in the barrel, similar deposition in endcap

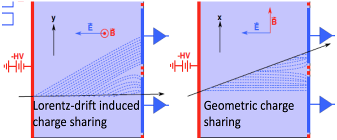
# Track Reconstruction

▸ **step 1) Local Reconstruction**

→ Clustering adjacent pixel digis that are above certain threshold with 2 dimensional matrix algorithm



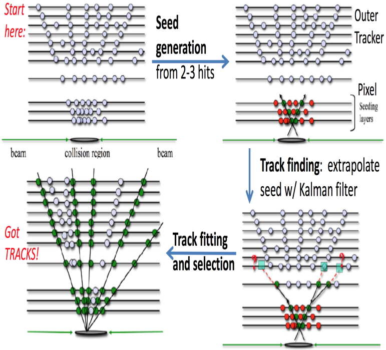

→ Inputing clustered digis in a position estimator algorithm that take into account Lorentz drift to produce point measurements (RecHits)




▸ **step 2) Track Reconstruction**

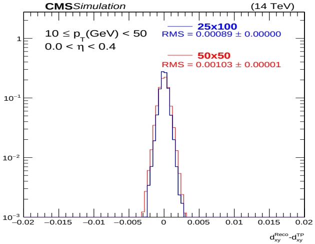
→ Inputs are RecHits

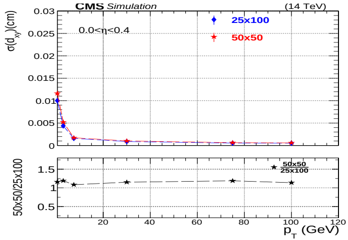
→ combinatory track finder (CTF) algorithm, combines reconstructed hits into tracks iteratively



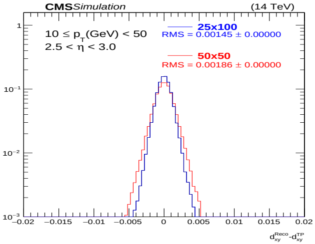
# Track transverse impact parameter ($d_{xy}$) Resolution

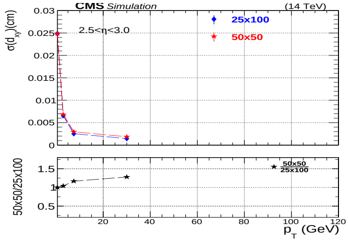
$0.0 < \eta < 0.4$




$2.5 < \eta < 3.0$

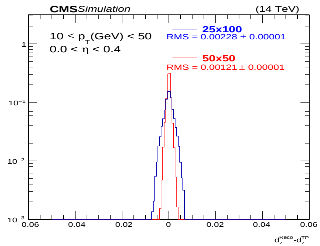


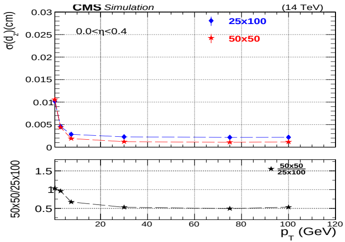




- $d_{xy}$ Resolution is worse in 50x50 $\mu m^2$ geometry, particularly at high $p_T$

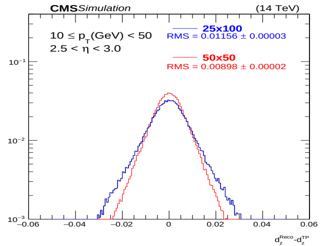
# Track longitudal impact parameter ($d_z$) Resolution

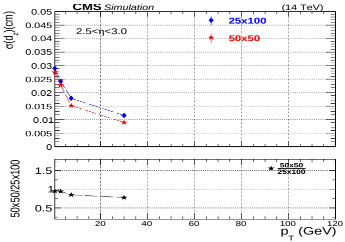
$0.0 < \eta < 0.4$




$2.5 < \eta < 3.0$



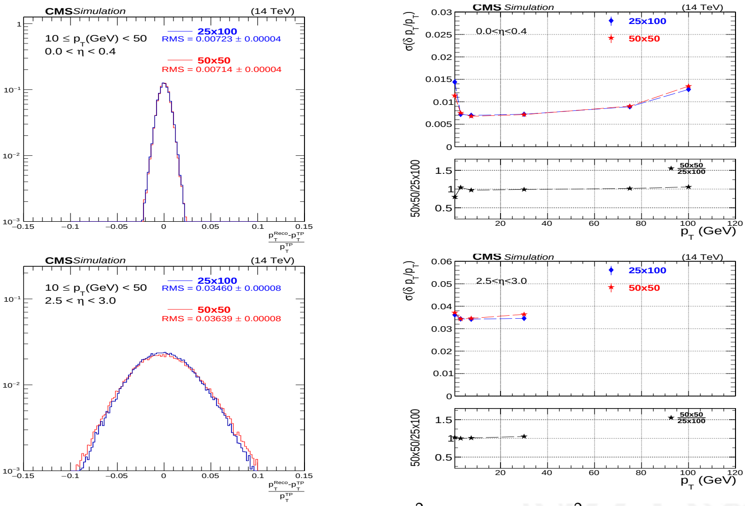




- $d_z$ Resolution is better in 50x50 $\mu m^2$ geometry, specially for higher $p_T$ tracking particles

# Track $p_T$ Resolution

$0.0 < \eta < 0.4$

$2.5 < \eta < 3.0$




- $d_{p_T}$ Resolution is similar for 25x100 $\mu m^2$ and 50x50 $\mu m^2$ geometry, slightly worsen for higher $p_T$ in 50x50 $\mu m^2$

# Summary

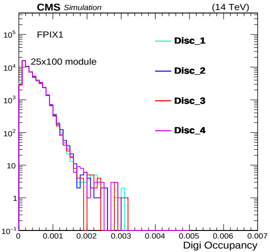
- We have studied the pixel detector performance for 2 scenarios:
  - $\rightarrow$ 25x100 $\mu m^2$ pixel size
  - $\rightarrow$ 50x50 $\mu m^2$ pixel size
- Digi occupancy is somewhat higher in barrel for 50x50 $\mu m^2$
- Larger charge collection in 50x50 $\mu m^2$ comparing to 25x100 $\mu m^2$
- $d_{xy}$ resolutions are worse for 50x50 $\mu m^2$ in most $\eta$ bins
- $d_z$ resolutions are better for 50x50 $\mu m^2$ in most $\eta$ bins
- $p_T$ resolutions are are similar for 50x50 $\mu m^2$ and 25x100 $\mu m^2$ at low$p_T$, but becomes worse for 50x50 $\mu m^2$ at $p_T > 100$ GeV.

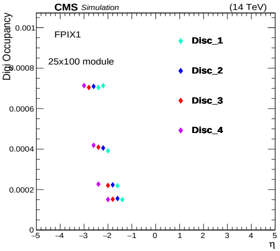
# Backup Slides

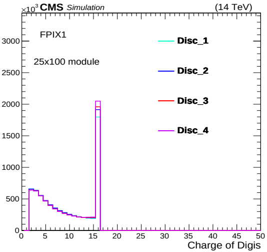
# Digi Rates in Endcap (FPIX1: Disks 1-4)

**Digi Occupancy** | **Digi Occupancy vs. $\eta$** | **Digi Charge**

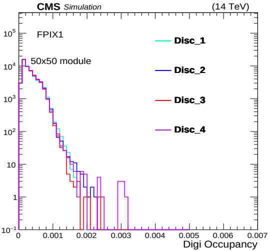
**25x100 $\mu m$ pixels**

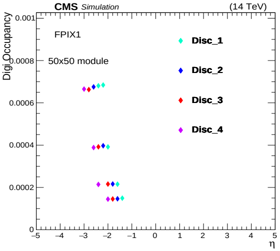


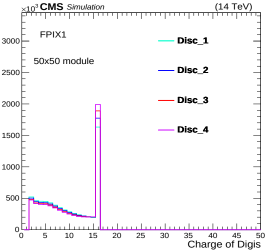




**25x100 $\mu m$ pixels**



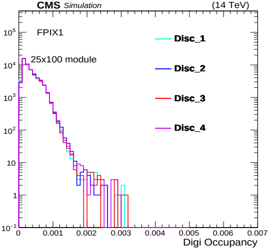



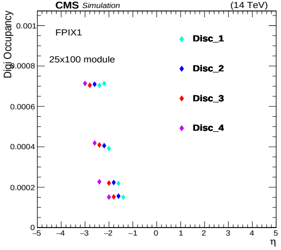



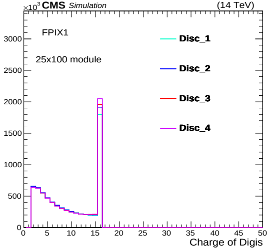
# Digi Rates in Endcap (FPIX1: Disks 1-4)

**Digi Occupancy** | **Digi Occupancy vs. $\eta$** | **Digi Charge**

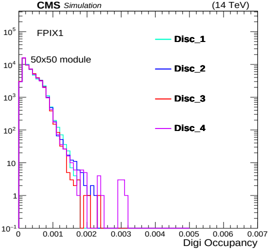
**25x100 $\mu m$ pixels**

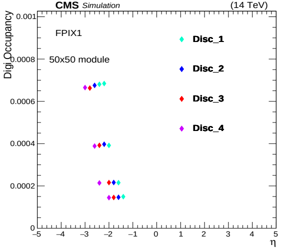


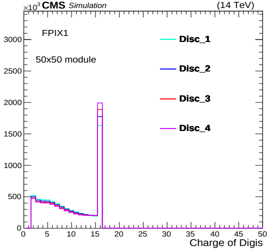




**25x100 $\mu m$ pixels**



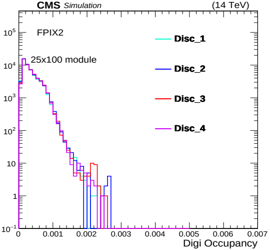



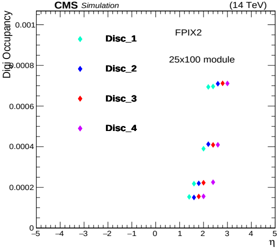



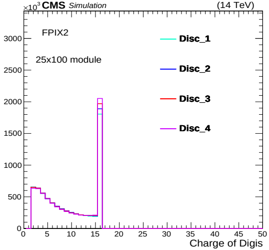
# Digi Rates in Endcap (FPIX2: Disks 1-4)

**Digi Occupancy** | **Digi Occupancy vs. $\eta$** | **Digi Charge**

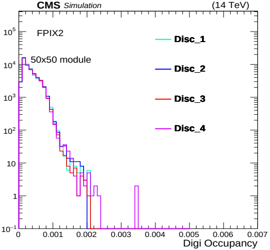
**25x100 $\mu m$ pixels**

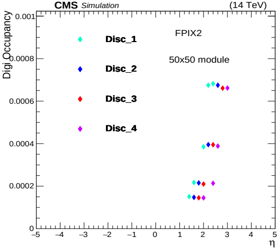


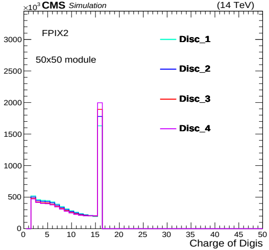




**25x100 $\mu m$ pixels**

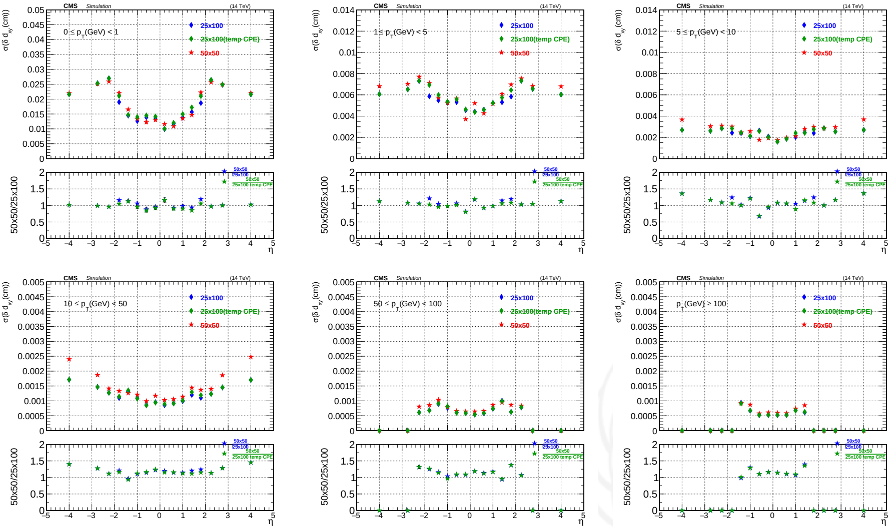


# $d_{xy}$ Resolution vs. $\eta$

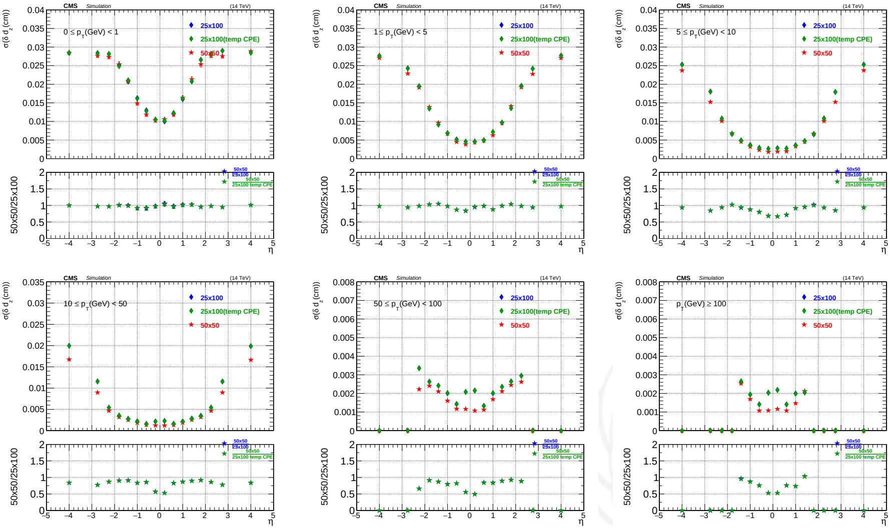
25x100
25x100 (template CPE)
50x50



- $d_{xy}$ Resolution is worse in 50x50 geometry, particularly at high $p_T$.
- $d_{xy}$ Resolution is slightly worse for 25x100 with template CPEs comparing to 25x100 with generic CPEs.

# $d_z$ Resolution vs. $\eta$

25x100
25x100 (template CPE)
50x50




- $d_z$ Resolution is better in 50x50 geometry, specially for higher $p_T$ tracking particles.
- $d_z$ Resolution is similar for 25x100 with template CPEs comparing to 25x100 with generic CPEs.