Simulation of CMS Phase 2 Pixel Tracker for HL-LHC

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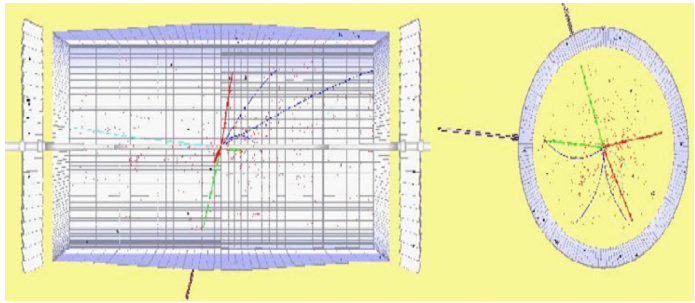
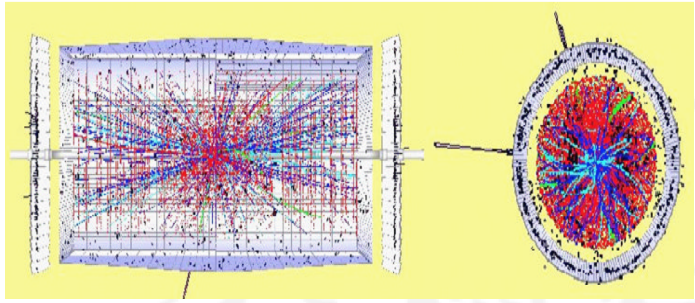
June 18, 2018

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 → <u>Difficult environment</u>**
  - → 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 ($cm^{-2}\,s^{-1}$)	7×10^{33}		2×10^{34}		2×10^{34}		5×10^{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

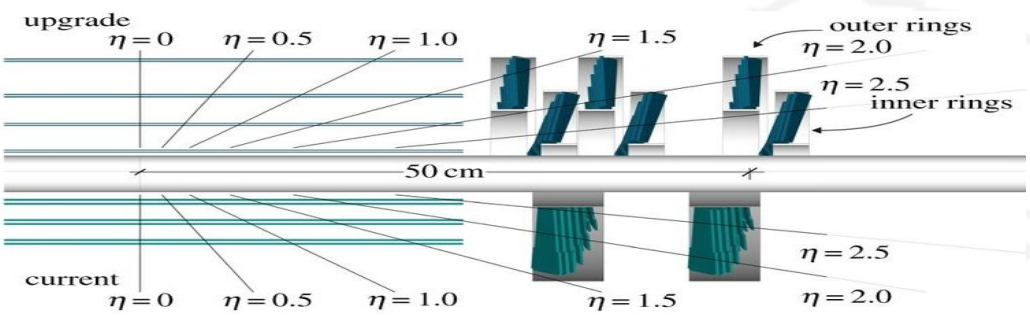
Phase0 → Phase1

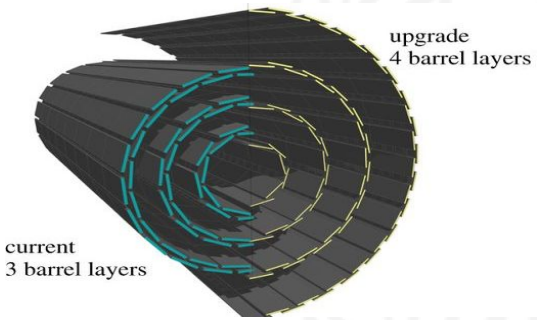
- Added extra barrel layer and endcap disk
- Layers closer to the beam-line

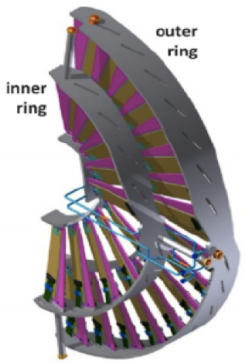
→ improvement in tracking and b-tagging

- Barrel: 48M → 79M pixels

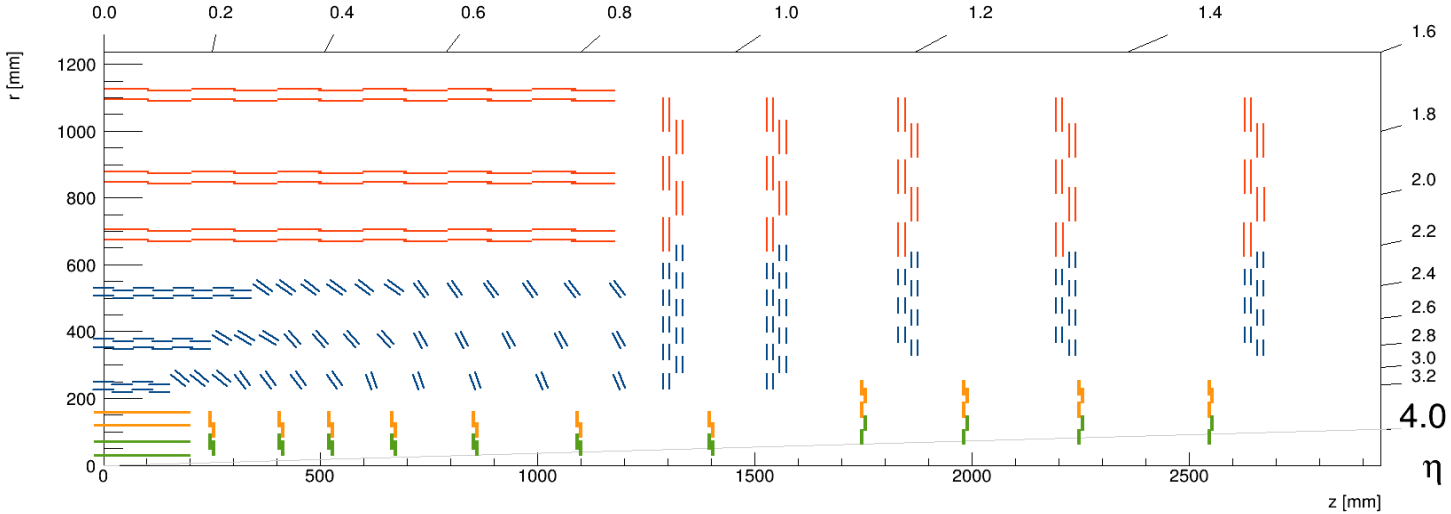
  Forward: 18M → 45M pixels
- Moved from analog to digital readout







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

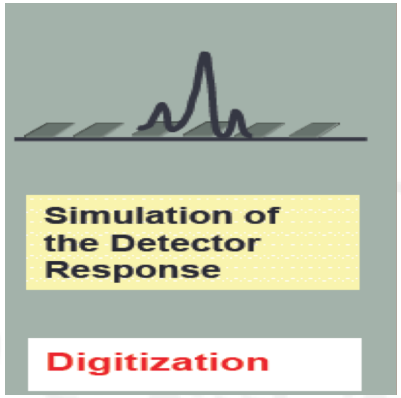
Better η coverage → $|\eta| < 4.0$ | Improved tracking/vertexing | Better mitigation of pileup

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

Improved resolution | Maintain low digi occupancy

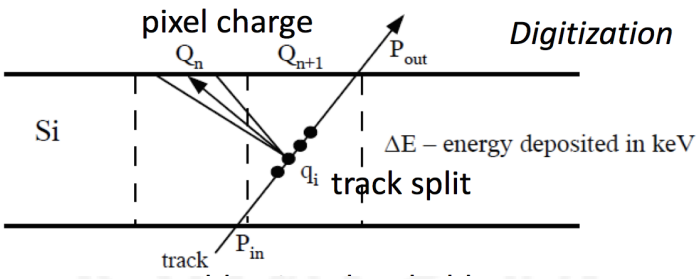
Simulation and Digitization

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

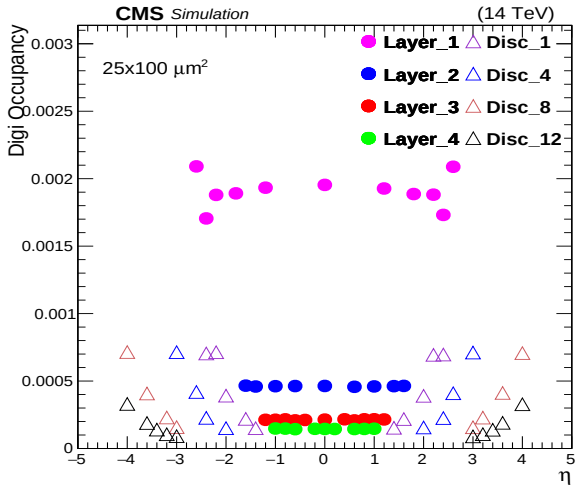
- **3) Digitization (CMSSW)**
  - → Convert simulated hits to format similar to experimental raw data (digis)

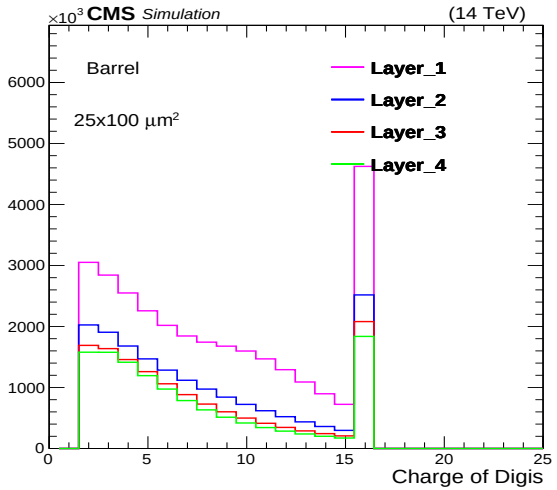


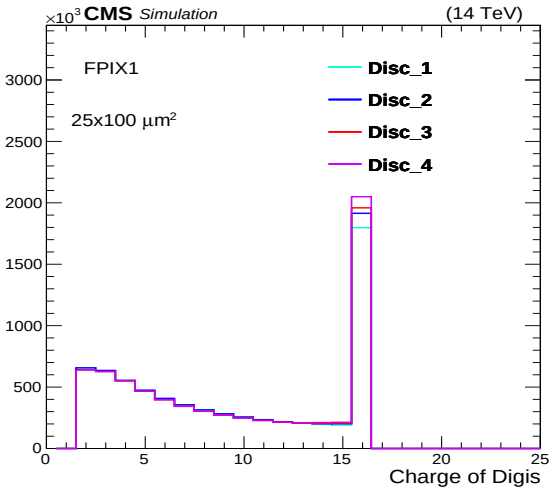
Occupancy Study

Digi Occupancy vs. η | **Digi Charge in Barrel** | **Digi Charge in Endcap**

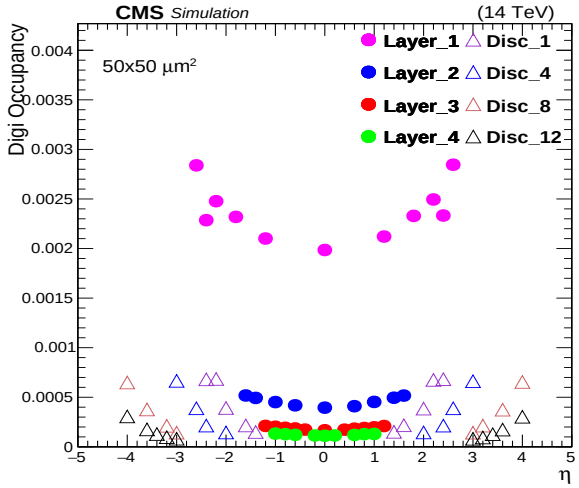
25x100 μm^2 pixels

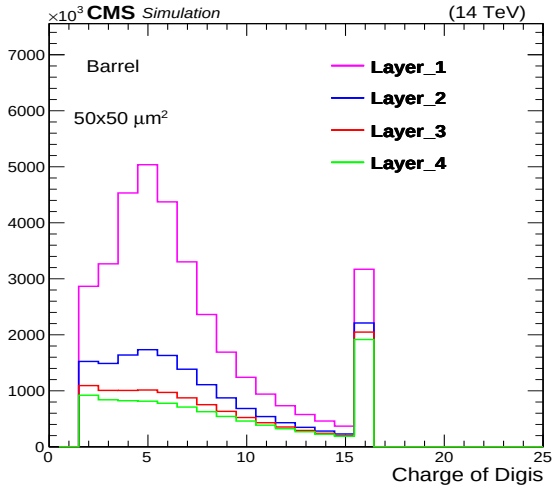


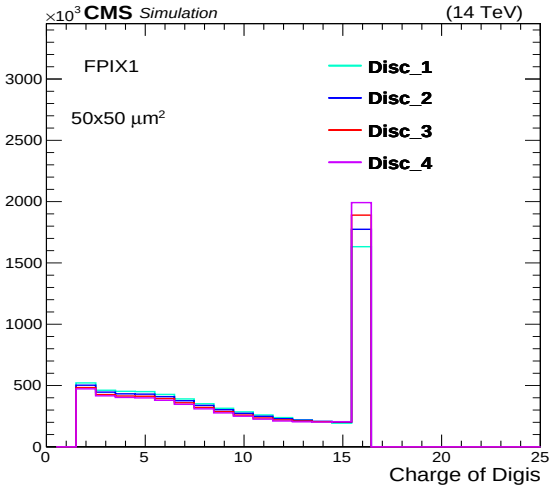




50x50 μm^2 pixels





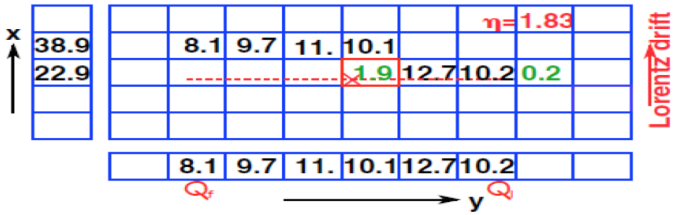


- Higher digi occupancy in the barrel for 50x50 μm^2 comparing to 25x100 μm^2
- Larger charge collection in 50x50 μm^2 in the barrel, similar deposition in endcap

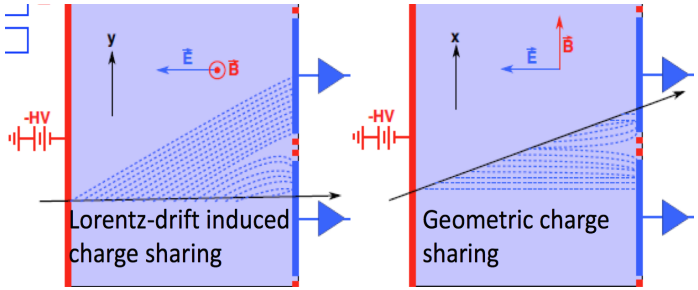
Track Reconstruction

- **step 1) Local Reconstruction**

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



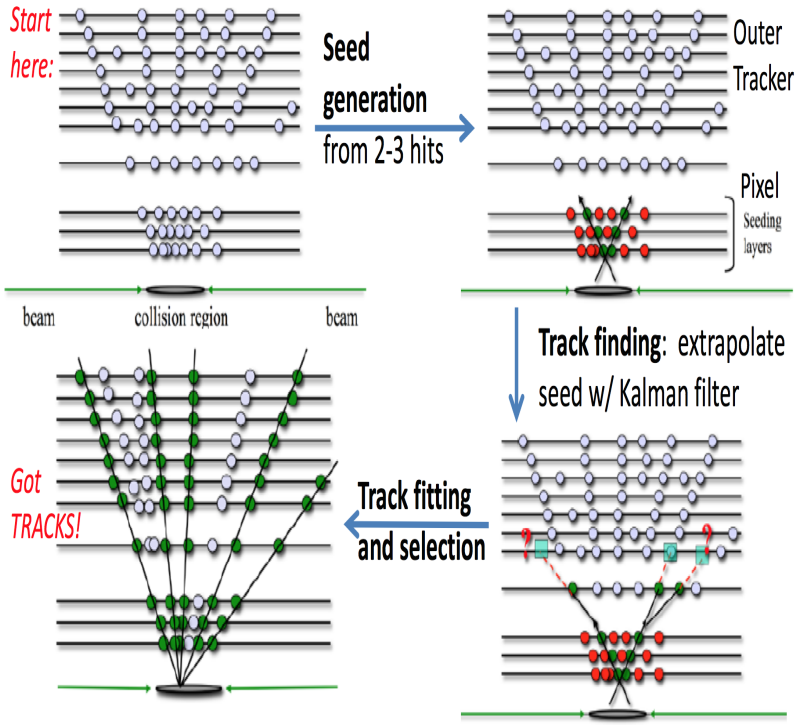
→ Inputing clustered digis in a position estimator algorithm that take into account Lorentz drift to produce point measurements (RecHits)



- **step 2) Track Reconstruction**

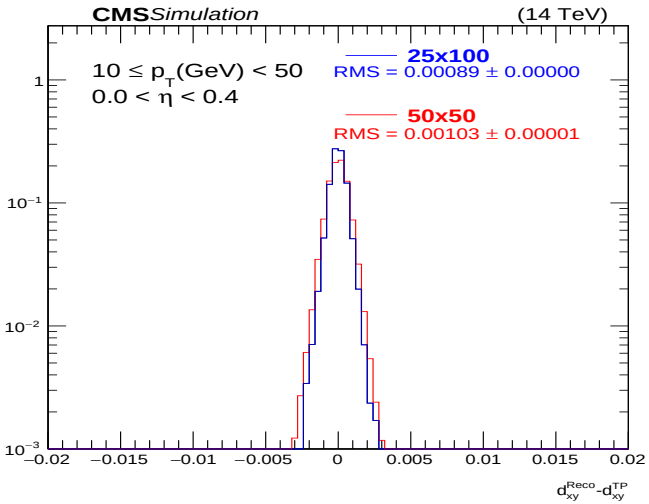
→ Inputs are RecHits

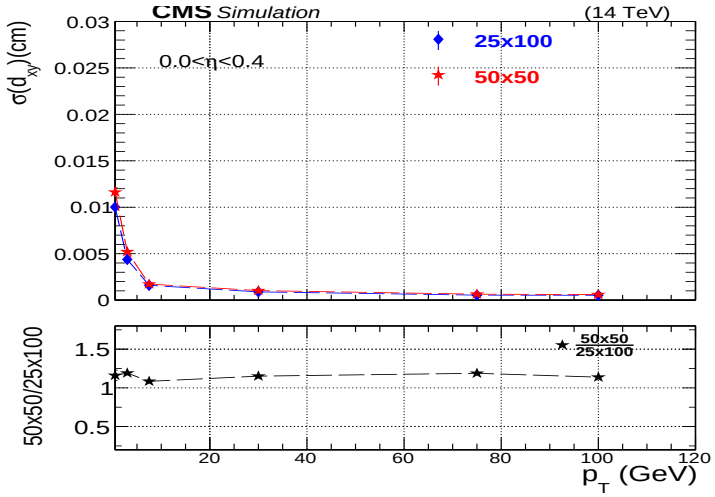
→ combinatory track finder (CTF) algorithm, combines reconstructed hits into tracks iteratively



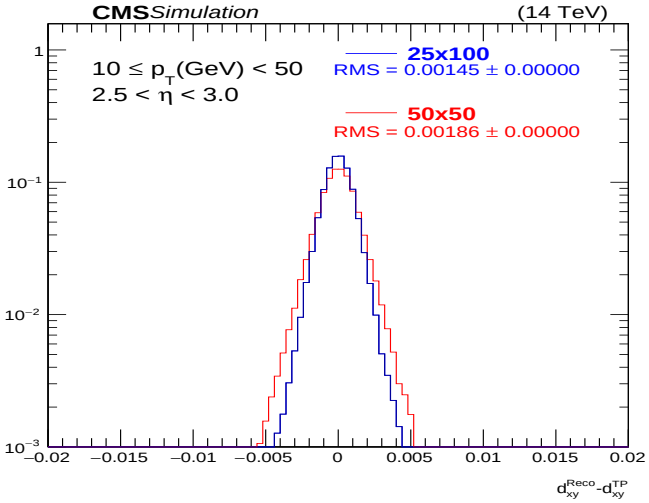
Track transverse impact parameter (d_{xy}) Resolution

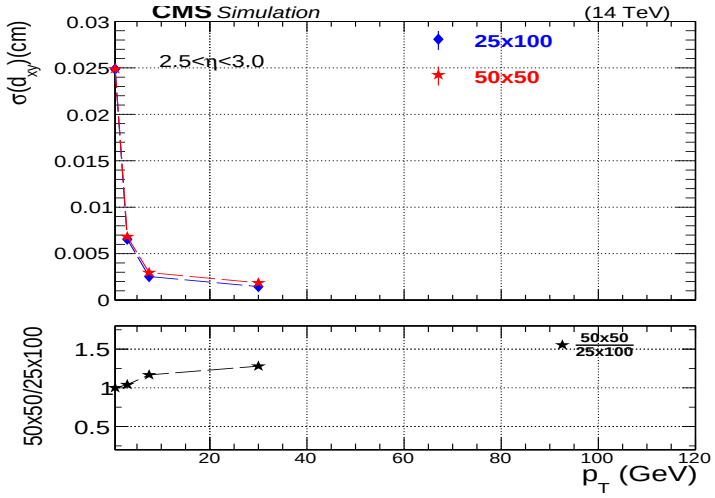
$0.0 < \eta < 0.4$





$2.5 < \eta < 3.0$

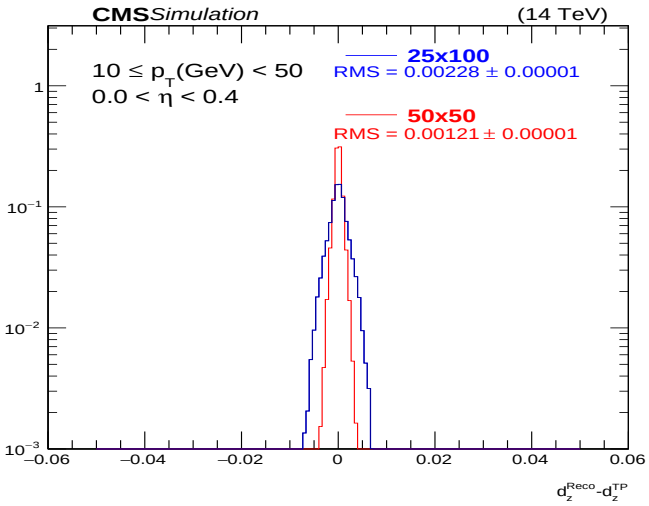


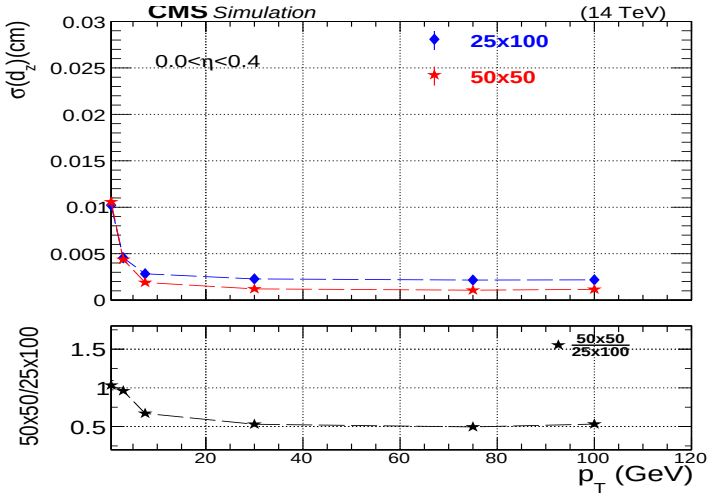


- d_{xy} Resolution is worse in 50x50 μm^2 geometry, particularly at high p_T

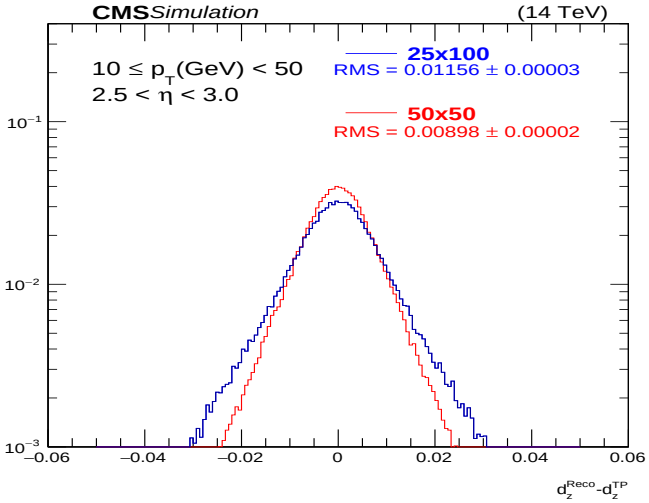
Track longitudal impact parameter (d_z) Resolution

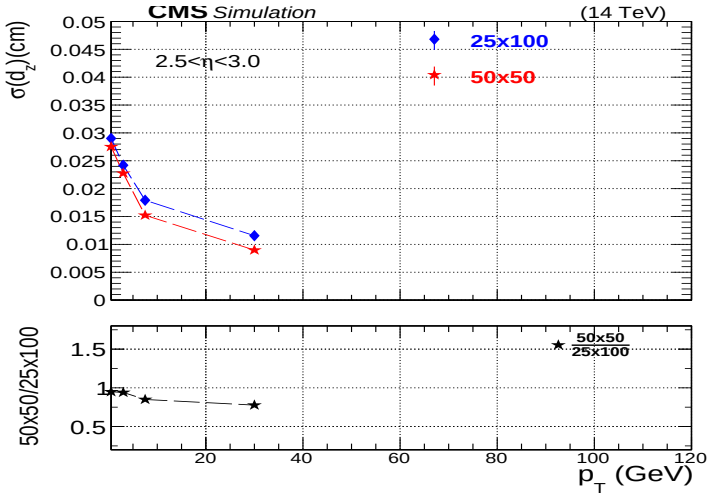
$0.0 < \eta < 0.4$





$2.5 < \eta < 3.0$

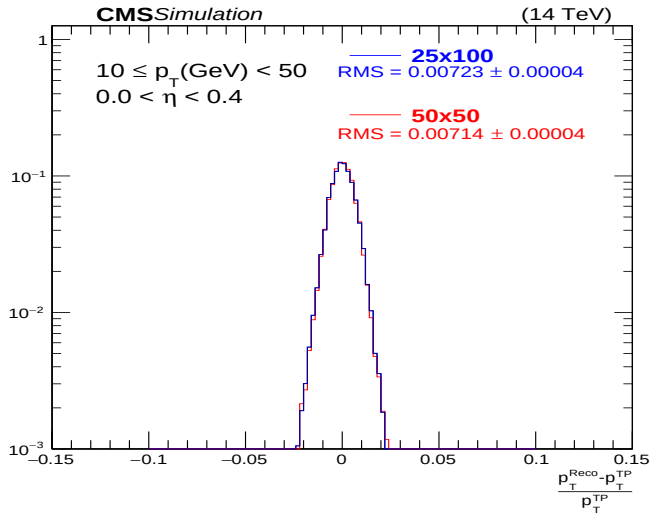


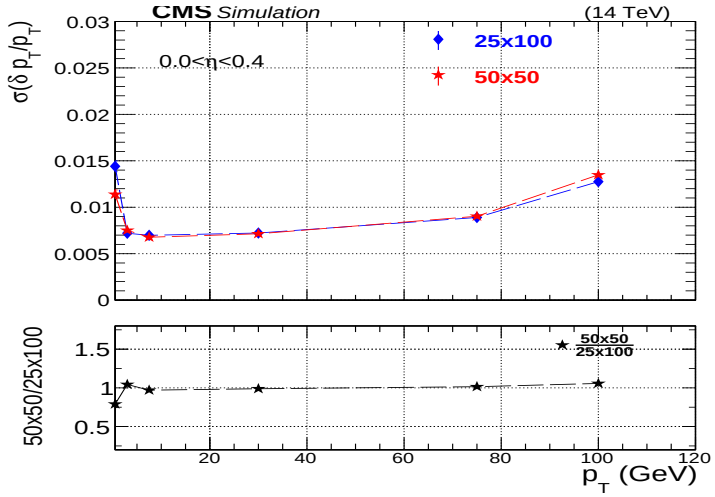


- d_z Resolution is better in 50x50 μm^2 geometry, specially for higher p_T tracking particles

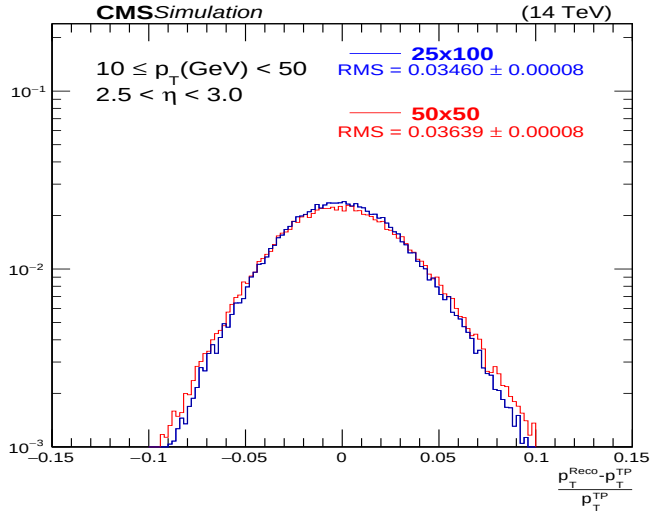
Track p_T Resolution

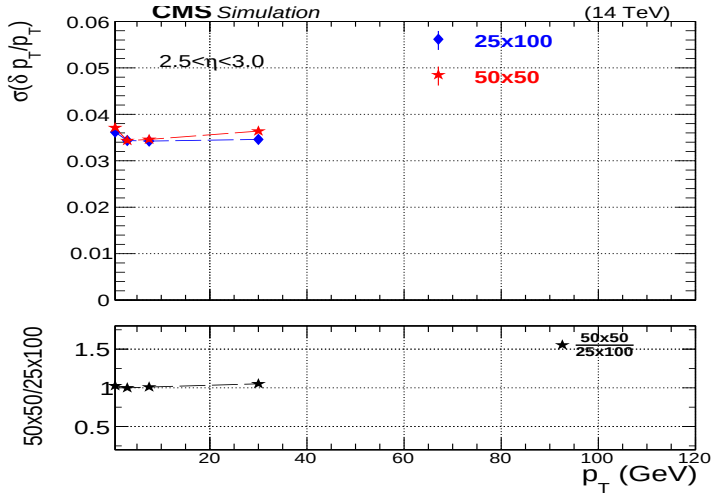
$0.0 < \eta < 0.4$





$2.5 < \eta < 3.0$





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

Summary

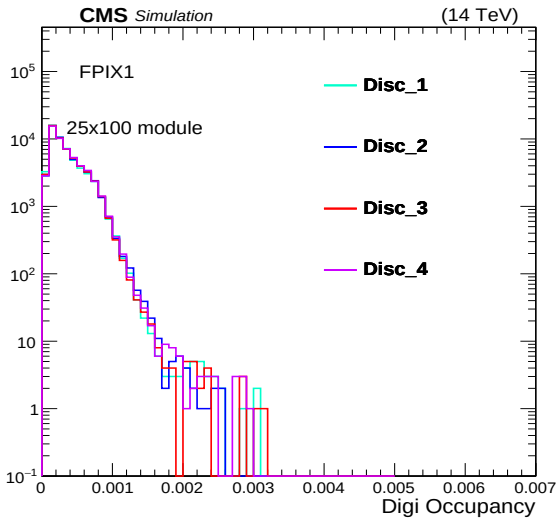
- We have studied the pixel detector performance for 2 scenarios:
  - → 25x100 μm^2 pixel size
  - → 50x50 μm^2 pixel size
- Digi occupancy is somewhat higher in barrel for 50x50 μm^2
- Larger charge collection in 50x50 μm^2 comparing to 25x100 μm^2
- d_{xy} resolutions are worse for 50x50 μm^2 in most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

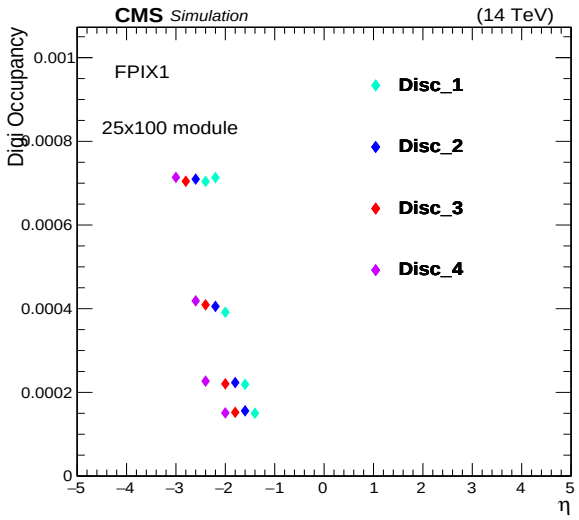
Backup Slides

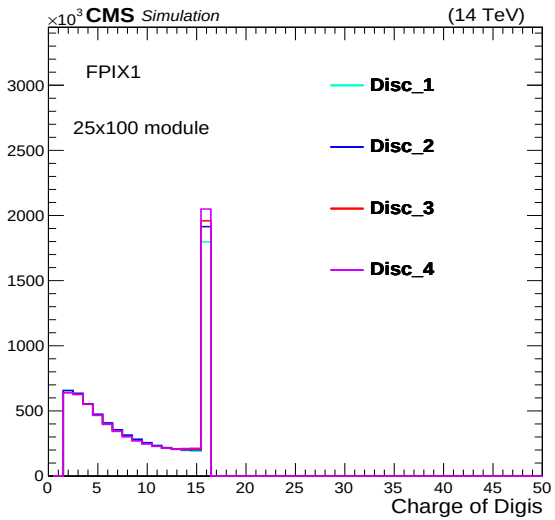
Digi Rates in Endcap (FPIX1: Disks 1-4)

Digi Occupancy | **Digi Occupancy vs. η** | **Digi Charge**

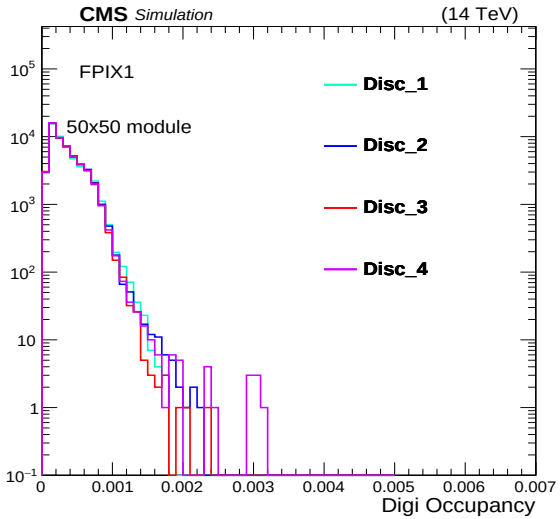
25x100 μm pixels

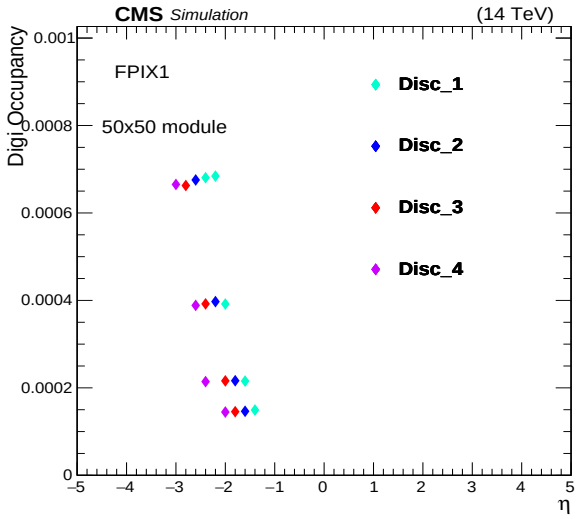


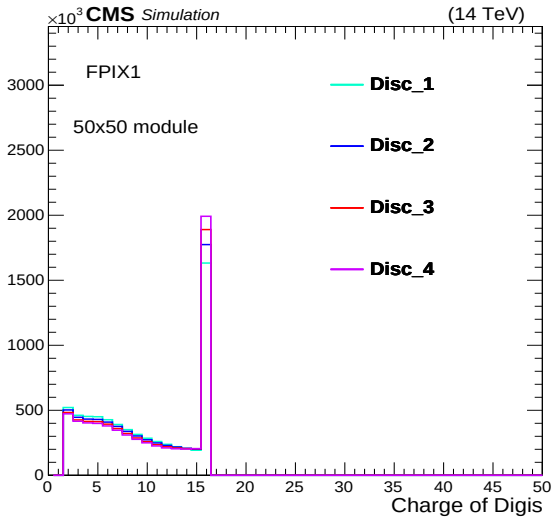




25x100 μm pixels



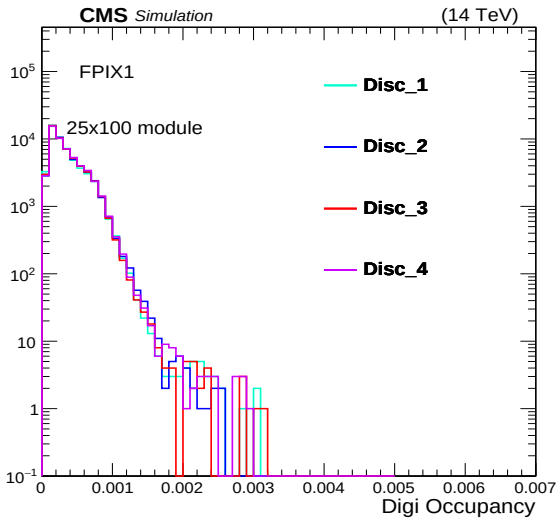


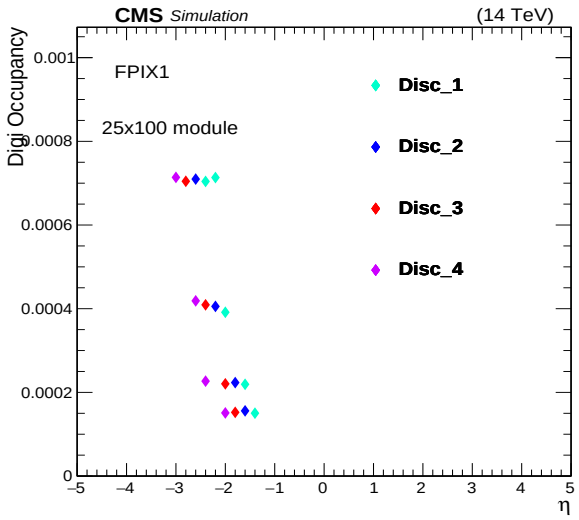


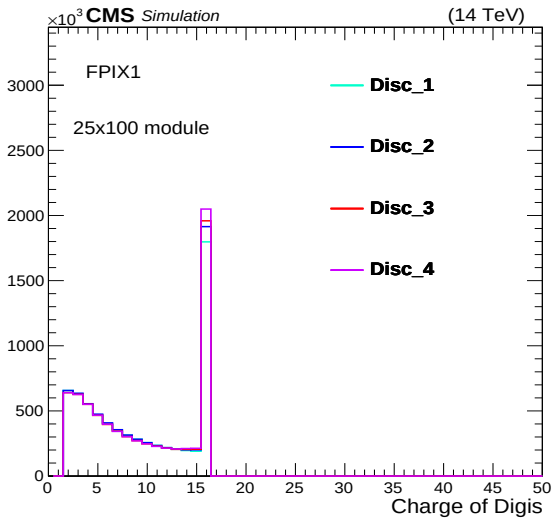
Digi Rates in Endcap (FPIX1: Disks 1-4)

Digi Occupancy | **Digi Occupancy vs. η** | **Digi Charge**

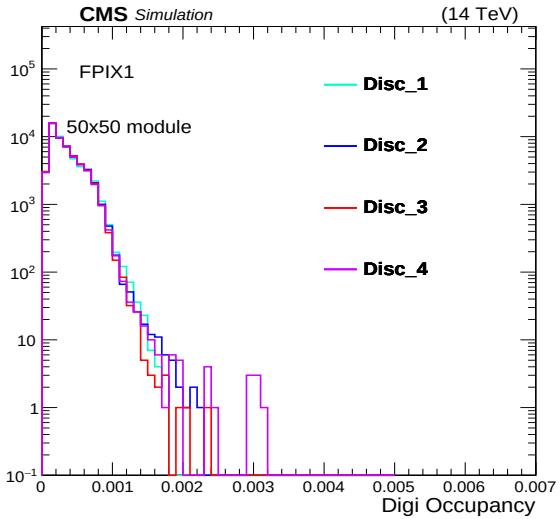
25x100 μm pixels

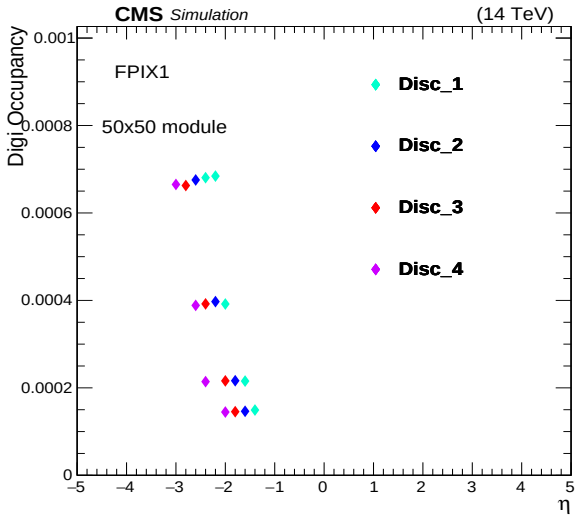


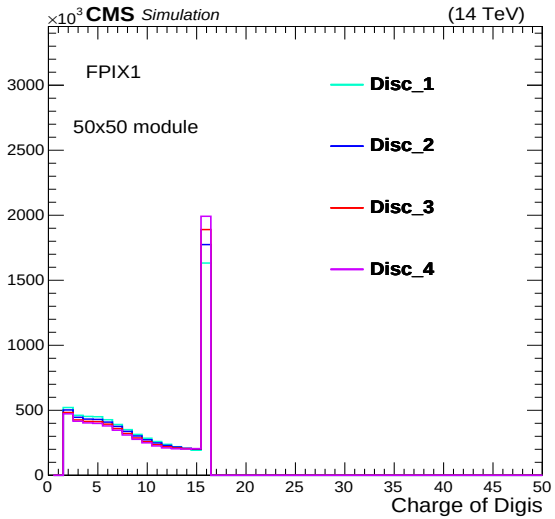




25x100 μm pixels



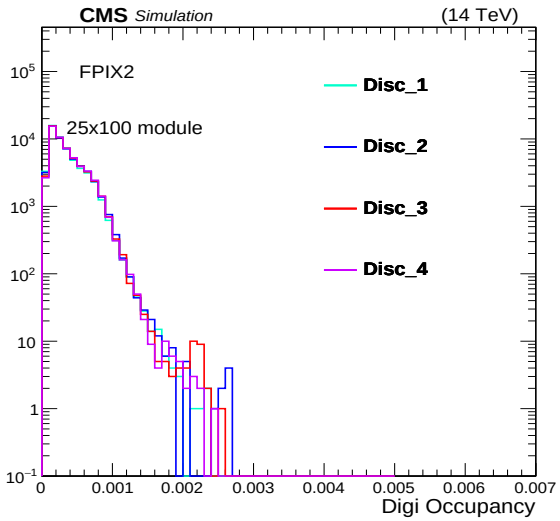


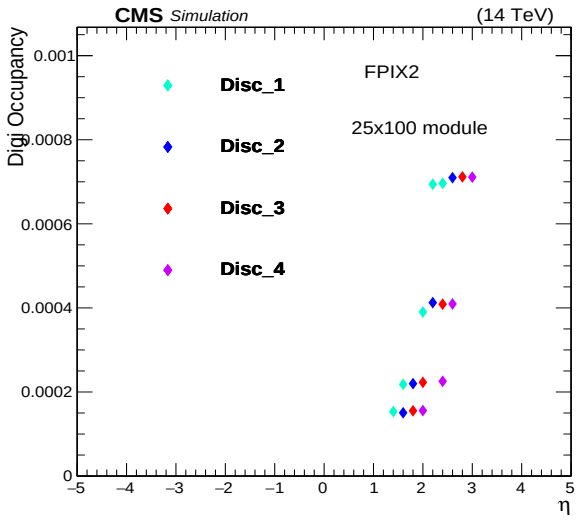


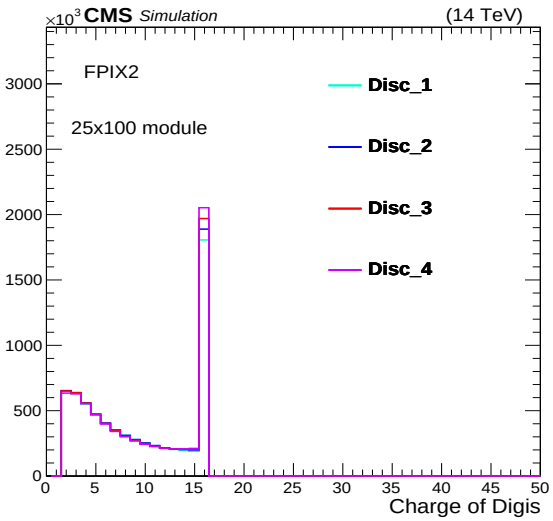
Digi Rates in Endcap (FPIX2: Disks 1-4)

Digi Occupancy | **Digi Occupancy vs. η** | **Digi Charge**

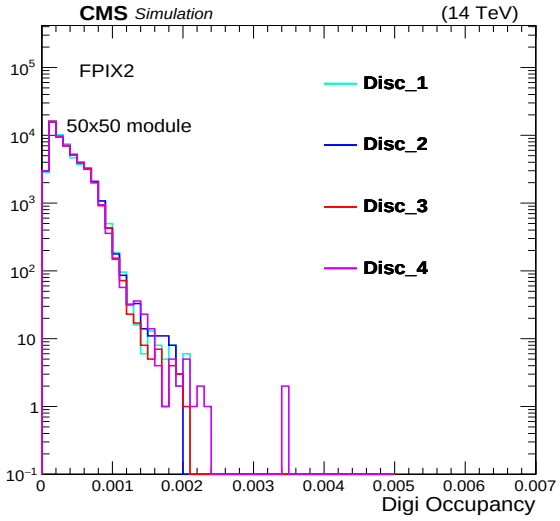
25x100 μm pixels

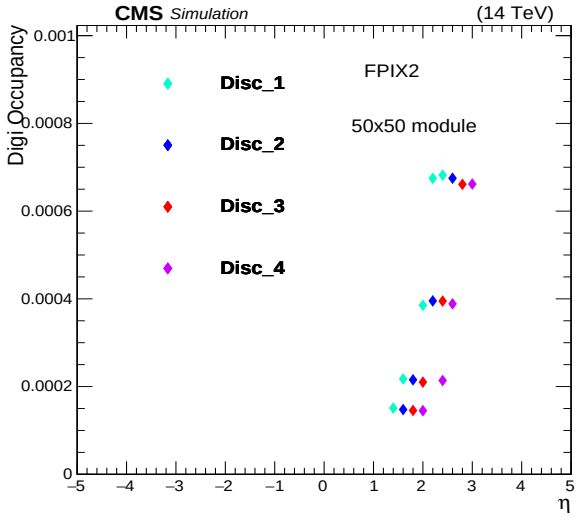


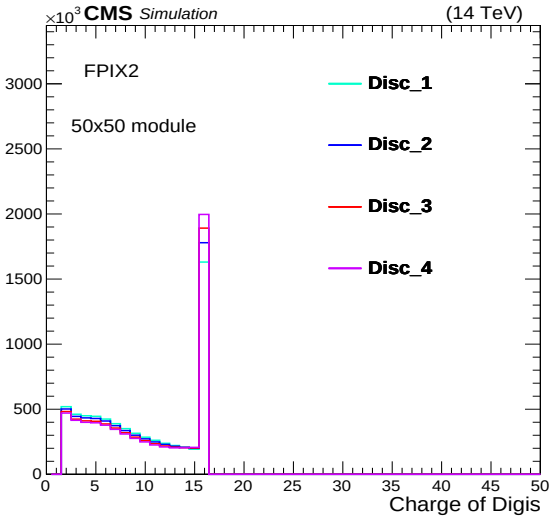




25x100 μm pixels

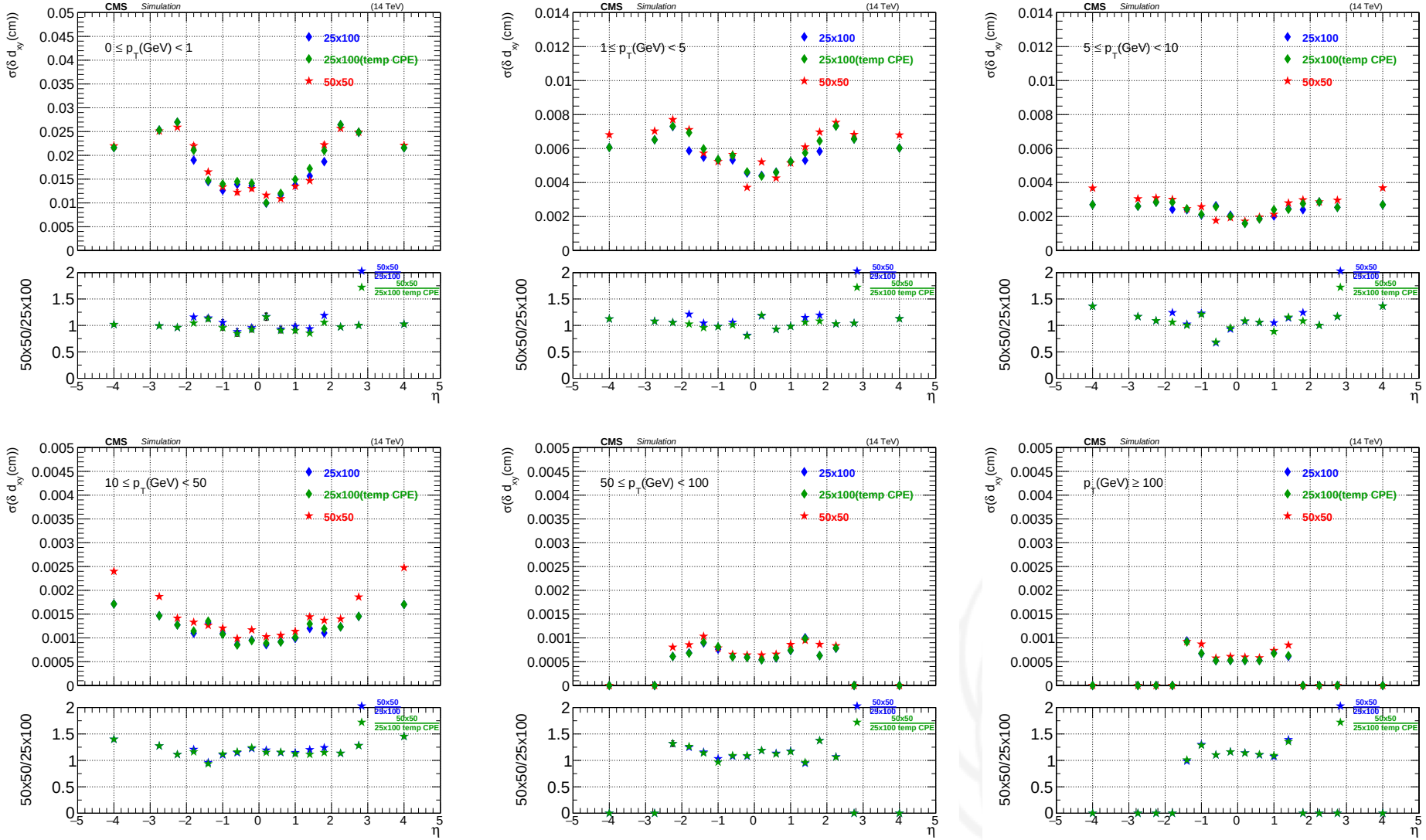






d_{xy} Resolution vs. η

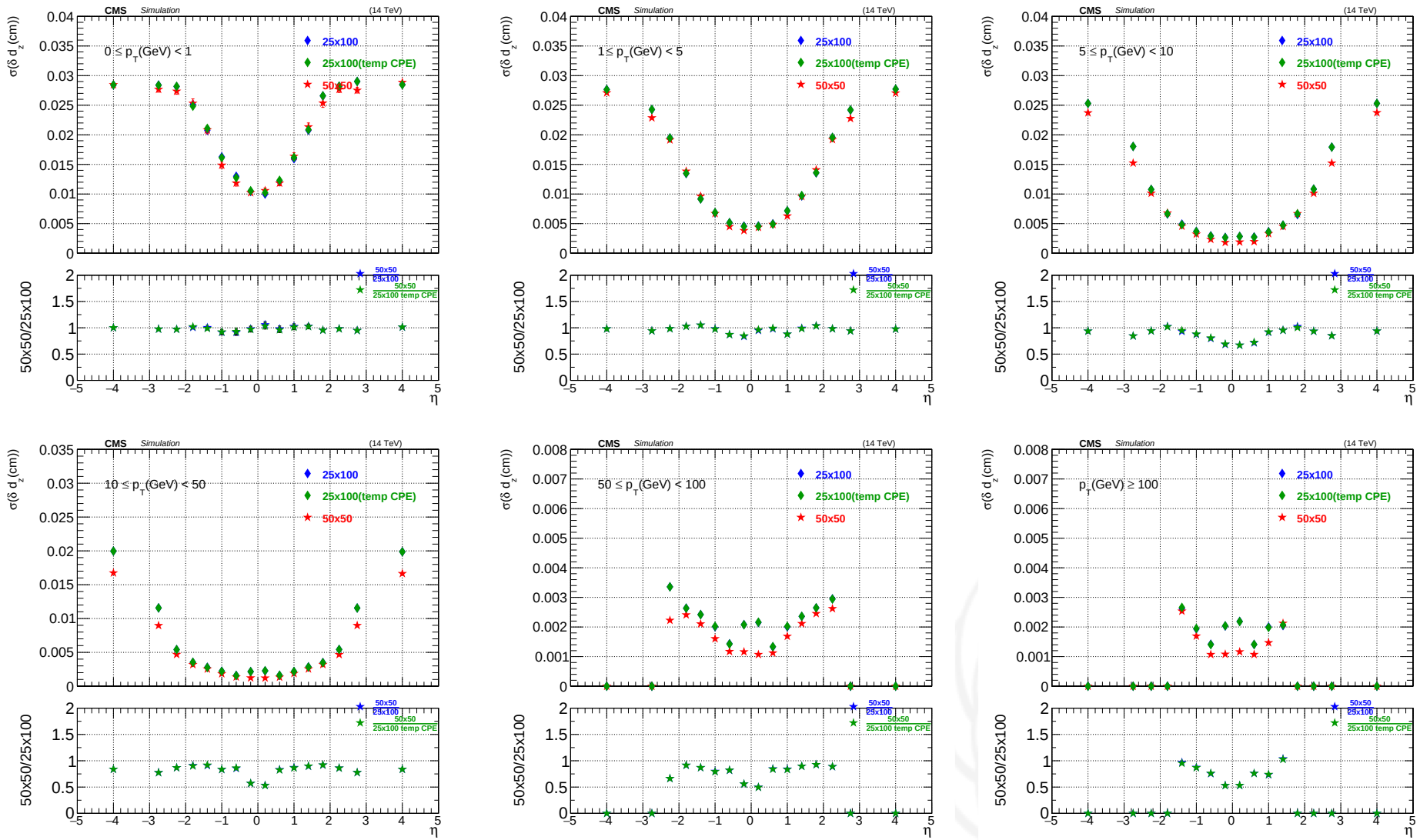
25x100
25x100 (template CPE)
50x50



- 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. η

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.