Deep Learning for the Level-1 ME0 Trigger in the CMS Experiment

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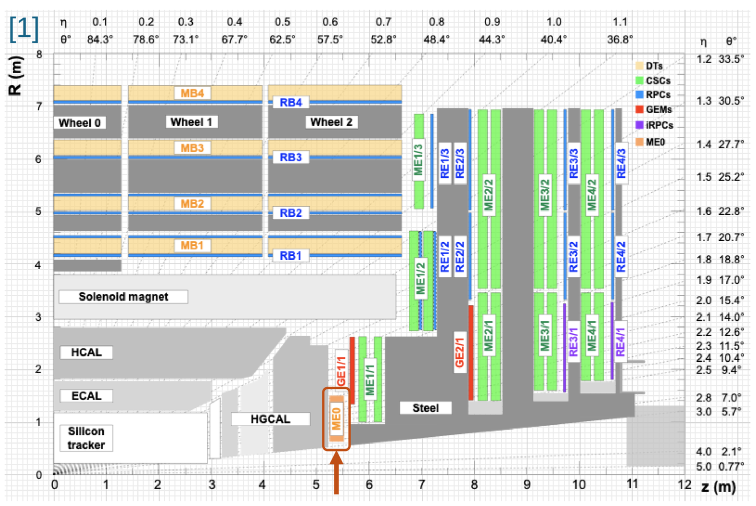
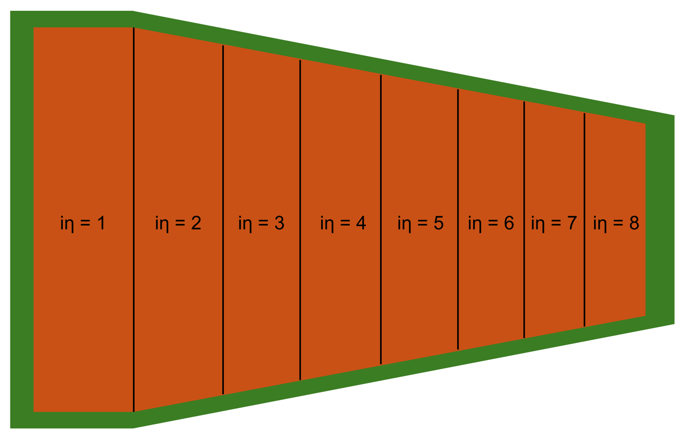
Introduction

- In the phase-2 upgrade of CMS, ME0 will be installed at the endcap as a part of the muon system, covering 2.0 < |η| < 2.8
- Each stack of ME0 consists of 6 layers of triple Gas Electron Multiplier chambers. 18 stacks will be installed each disk of CMS.
- Each chamber consists of 8 partitions along the η direction (iη) and 384 strips (374 for iη = 1) along the φ direction
- At the HL-LHC, there are average 200 pile-up collisions per bunch crossing. Since the ME0 is installed very close to the beamline, it is exposed to a high background rate.
- Due to the high background environment of ME0, it is important to trigger on the proper targets

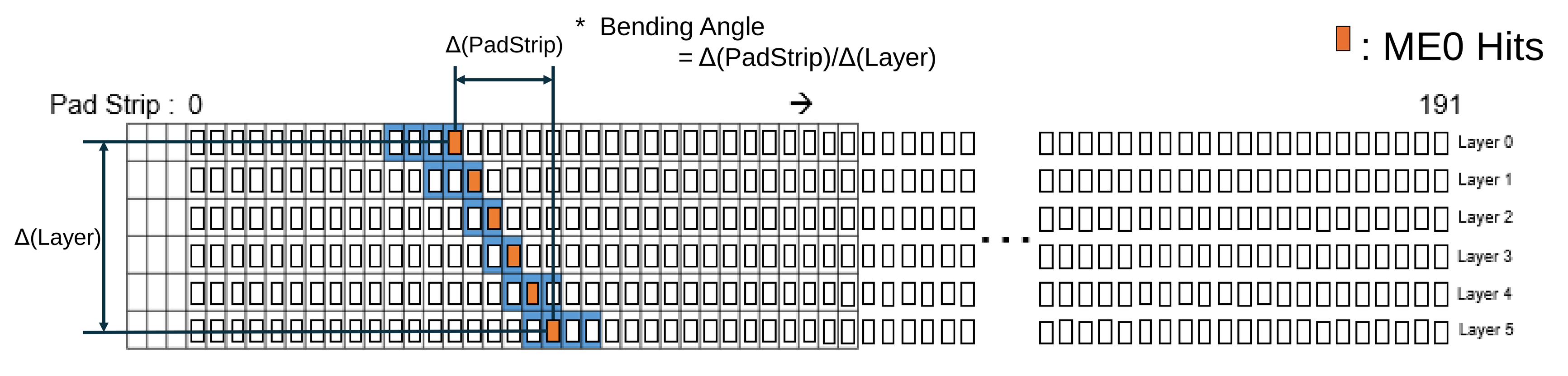
[1]





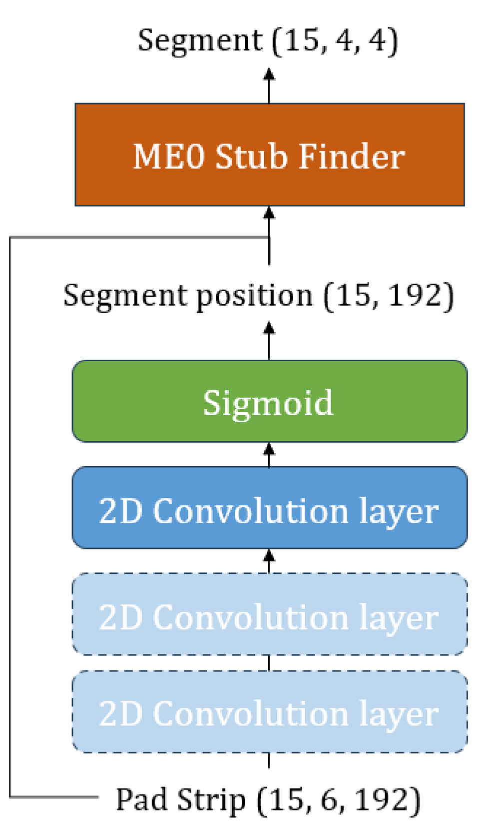
ME0 Stub Finder

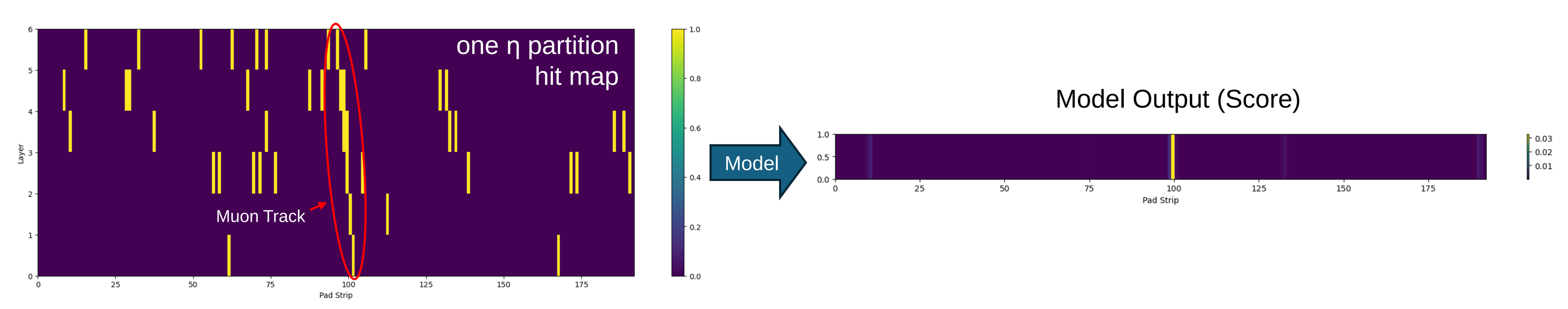
- The ME0 Stub Finder (ME0SF) is the Level-1 trigger algorithm for ME0
- In ME0SF, the raw hit data will be pre-processed forming "pad strip" and "virtual partition"
  - Pad strip : combined strip of 2 adjacent strip, 384 strips → 192 pad strips
  - Virtual partition : jointed η partition of 2 adjacent η partition with a purpose of detecting a segment which passed 2 η partitions, 8 original + 7 virtual η partition
- It produces track segments (= trigger primitive) by scanning the ME0 hit map for track-like patterns
- The trigger primitive will be sent to the Endcap Muon Track Finder with 27 bits per segment (4 bits: η / 10 bits: φ / 9 bits: Bending Angle* / 4 bits: Quality)
- A segment must have hits in at least 4 layers ("Loose cuts")
  → more stringent cut is under investigation. We use alternative method of Deep Learning for it



CNN-assisted ME0SF

- Study for ME0SF using Convolution Neural Networks (CNN)
  - CNN show great performance in pattern finding problem
- Model :
  - 1-3 layers of 2D Convolution filter + ReLU [2] between CNNs
  - The models are set to be light to meet the processing time limits of the ME0 trigger system
- Input Data : (15, 6, 192)
  - Pad Strip data for one stack of ME0: 15 η partitions (8 original + 7 virtual η partitions), 6 layers, 192 pad strips
  - Training data : muons with p_T = 1-10 GeV and average 200 Pile-Up (~100,000 events)
- Output Data : (15, 192)
  - Segment strip position
    - 15 vectors corresponding to strip-wise segment position for 15 partition
    - Each vector has 192 values, representing the likelihood (0 to 1) of a segment at each strip
  - The ME0SF will only run on the strips specified by the model, while the standard algorithm scans all strips
    → potentially reducing the processing time of ME0SF



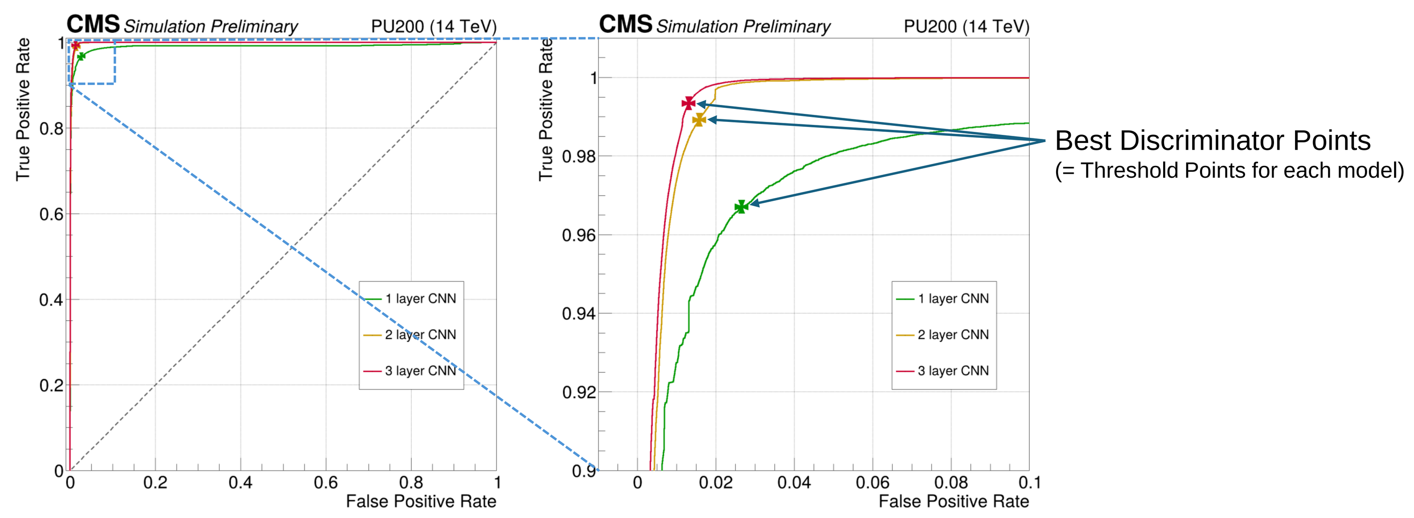


Performance

- Performance of ME0SF with 1, 2 and 3 layer Models
- Sample
  - For efficiency : 50,000 events, each containing 8 randomly generated muons with uniform p_T=1–200 GeV and |η|=2.0–2.8, along with an average of 200 additional pile-up collisions per bunch crossing (BX)
  - For Minbias rate : 50,000 events, only pile-up collisions, with an average of 200 per BX
- Matching rule :
  - A segment is considered matched with a muon track if
    η position match : $|(\eta\ Partition)_{MuonTrack} - (\eta\ Partition)_{segment}| \le 1$
    Pad Strip position match : $|(PadStrip)_{MuonTrack} - (PadStrip)_{segment}| \le 5$
    Bending angle match : $|(Bending\ Angle)_{MuonTrack} - (Bending\ Angle)_{segment}| \le 0.4$
- Muon Efficiency = $\frac{\text{(\# of matched muon track)}}{\text{(\# of total muon track)}}$
- Minbias rate per chamber = $\frac{\text{(\# of unmatched segment)}}{\text{(36 chambers)} \times \text{(25 ns)}} \times$ (Fill Factor**)

** Fill Factor ≈ 0.7710 [3]

Receiver Operating Characteristic Curve of Models

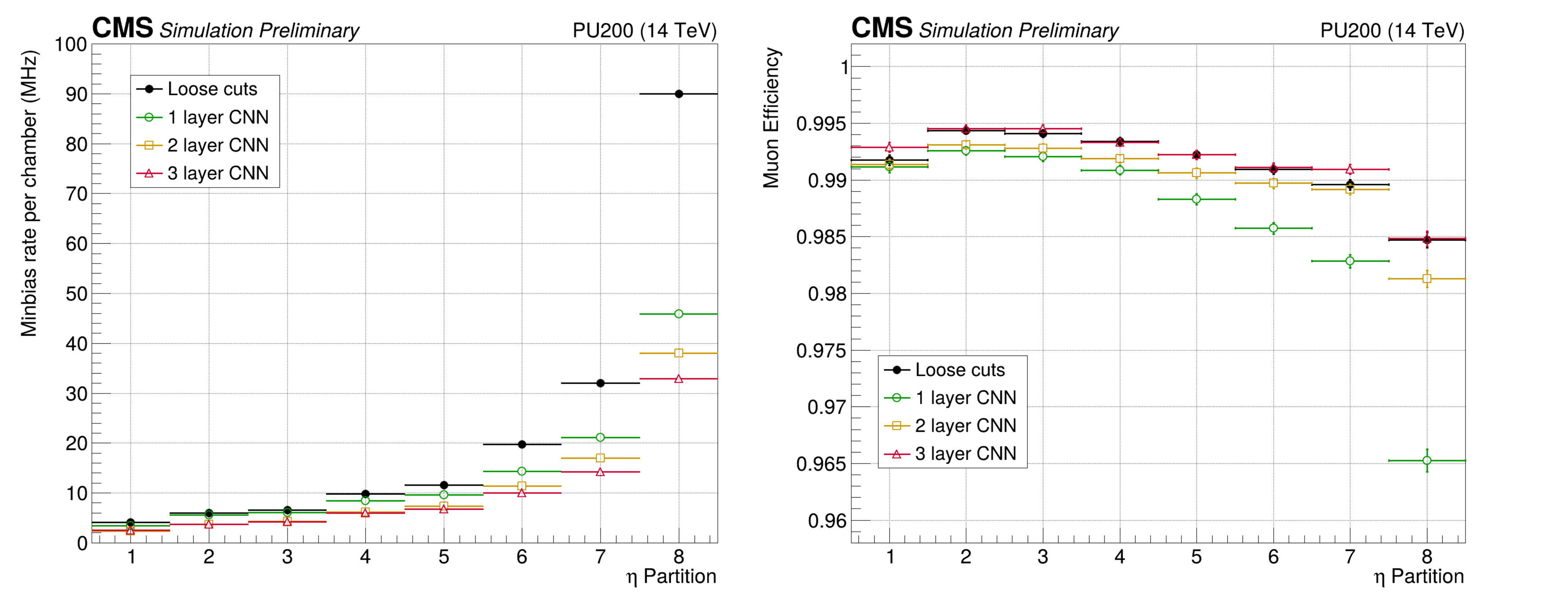


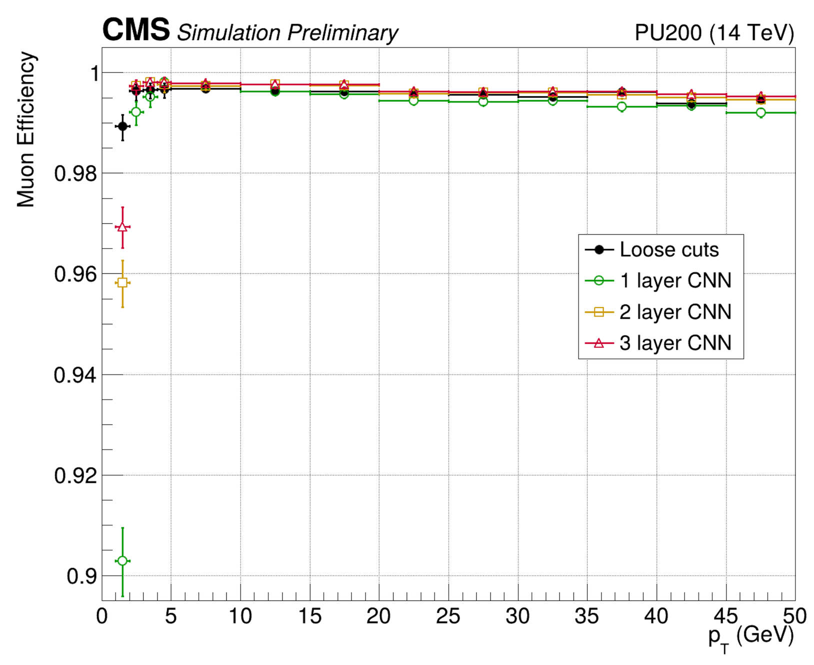
Overall Performance

	Loose cuts***	1 layer CNN	2 layers CNN	3 layers CNN
Muon Efficiency	99.19 %	98.70 %	99.04 %	99.21 %
Minbias rate per chamber	179.7 MHz	114.3 MHz	90.10 MHz	80.32 MHz

*** Loose cuts: the standard ME0SF implementation with a minimal segment requirement (must have hits in at least 4 layers)

Performance as function of p_T or η partition





By applying the CNN models as filters, the Minbias rate of ME0SF is significantly reduced while the muon efficiency is preserved

→ The CNN models effectively reduce the Minbias rate by 1/3 to 1/2

→ The Minbias rate drop is more pronounced at higher η where pile-up collisions have a greater impact

→ Even with the 1-layer CNN, the efficiency still stays above 0.95 at iη=8 or above 0.9 at low p_T of 1-5 GeV

Summary

- CNN Models with different depth of 1, 2 and 3 are trained to filter the pile-up induced segments in ME0SF
  - The models allow ME0SF to run only on strips specified by the model
    → Potential to decrease the processing time for ME0SF
- CNN Models effectively reduced the Minbias rate while preserving efficiency even for high η or low p_T

Reference

[1] CMS Collaboration. *The Phase-2 Upgrade of the CMS Muon Detectors*, Technical Design Report, CMS (2017). doi:10.17181/CERN.5T9S.VPMI
[2] Abien Fred Agarap. *Deep Learning using Rectified Linear Units (ReLU)*, CoRR (2018). doi:10.48550/arXiv.1803.08375
[3] P. Fessia and M. Zerlauth. "HL-LHC Parameter and Layout Baseline," *Chamonix 2014: LHC Performance Workshop*, pp. 198–201, (2015). doi: 10.5170/CERN-2015-002.198

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