A novel ML-based method of primary vertex reconstruction in high pile-up conditions

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Introduction

A feasibility study of applying Sparse Point-Voxel Convolution Neural Network to do primary vertexing in a dense environment

Motivation: the challenges brought by High Luminosity LHC (HL-LHC)

More pile-up events in HL-LHC:
- Run 3: \( \mu \approx 60 \sim 80 \)
- HL-LHC: \( \mu \approx 200 \) @ 7.5 x 10^{35} cm^{-2}s^{-1}

Vertex reconstruction can be thought of as comprising two components:
- **Vertex finding**: the association of tracks to a particular vertex candidate
- **Vertex fitting**: the reconstruction of the vertex position along with its covariance matrix, estimation of the quality of fit

The goal of vertex reconstruction is to turn a set of reconstructed tracks (recorded from tracker) into a set of reconstructed vertices, i.e. clustering the tracks into different primary vertices.

Primary Vertex Reconstruction

**Primary vertex**: the reconstructed location of an individual particle collision

**Importance of primary vertex reconstruction**: From Physics point of view, vertexing helps:
- Identify decaying particles from their products (remove pile-up effects)
- Study the properties of those particles (mass, lifetime, couplings, ...)

From the instrumentation point of view, vertexing serves to:
- Determine the luminous region (beam spot)
- Characterize the detector positioning resolution

**Vertex topologies in pp collisions**

**SPVCNN**

SPVCNN is a state-of-the-art technique developed for self-driving cars which leverages space voxelization and point-based method to do clustering problem.
- **Voxel branch**: coarse-grained information
- **Point branch**: fine-grained information

**SPVCNN overview**

**Workflow and dataset**

**Software**: Acts Common Tracking Software

**Workflow**: do vertex fitting on the clustering output of SPVCNN

**Dataset description**:
- Physics process: Full Hadronic ttbar 14 TeV
- 10k events generated by ACTS using Pythia8 event generation
- Tracks are reconstructed by fast track simulation based on ACTS GenericML detector topology
- Input features: track parameters

**Results**

**Event display**:

Event 1:

Event 2:

**Summary**

- SPVCNN is a possible ML approach to do primary vertexing
- More tunings of SPVCNN are needed, possible explorations are:
  - Coordinates and parameters used to voxelize the space, i.e. track coordinates vs. Cartesian, voxel size
  - Parameters used in prediction
- Physics performance, e.g. classifications of primary vertex, hard scattering vertex reconstruction efficiency, will be done
- Towards more complicated dataset, e.g. \( \mu = 100, 200 \)