New approaches for track reconstruction in LHCb’s Vertex Locator

J. Albrecht, B. Couturier, C. Hasse, D. Bourgeois, V. Coco, N. Nolte, S. Ponce

1 TU Dortmund, 2 CERN, 3 EPFL

On behalf of the LHCb Collaboration

LHCb Upgrade 1

- The LHCb detector is a single arm forward spectrometer to study b and c hadrons
- Significant detector upgrade is planned during Long Shutdown 2 (2018-2020)
- From 2021 onwards:
  - usage of purely software based trigger system
  - full online reconstruction at 30MHz

Motivation

A 30MHz trigger throughput might require IP cuts on VELO tracks. A better approach would be a cut on IP and its uncertainty, which is challenging solely based on current default VELO Kalman Filter.

- IP calculation is based on CTB prediction, IP uncertainty requires known uncertainty on CTB position
- Kalman Filter (KF) needs momentum information to predict uncertainty correctly
- Due to missing momentum information, KF uses a fixed value performing well on average

Can machine learning based approaches help to improve this?

Track Reconstruction in the Vertex Locator

- The VErtex LOcator (VELO) is the closest subdetector to the collision point
- Only straight tracks as VELO is located outside of the magnetic field
- Reconstruct tracks via track forwarding from the outer to the inner region
- Simplified Kalman Filter to account for multiple scattering and predict a track’s closest to beam (CTB) position

Idea and Method

Given the straight line fit performed during the VELO track finding, compute the residuals \( \vec{r}_i = (\Delta x_i, \Delta y_i, \Delta z_i) \) of each hit in respect to the straight line. Assuming the residuals are primarily due to multiple scattering, the magnitude is inversely proportional to the particle’s momentum. The goal is to design a neural network which is able to use this correlation to better predict the position and uncertainty of the CTB position.

- We use a LSTM [1] based architecture to model the sequence like behavior of a track
- The LSTM’s hidden state is kept rather small at 16 entries to ensure fast inference speeds
- For a track with \( n \) hits the LSTM processes the residuals \( \vec{r}_1, \ldots, \vec{r}_n \) and outputs its last hidden state \( \vec{h}_n \)
- \( \vec{h}_n \) concatenated with the CTB state from the straight line fit CTB\(_n\) = \( (x, y, z, \Delta x, \Delta y, \Delta z) \) and processed by a single \( [21 \times 3] \) fully connected layer

Results

Comparison of the \((x,y)\)-resolution and \((x,y)\)-pull distribution between the LSTM based model and the current default VELO Kalman Filter.

- Given the network’s predictions and the true CTB positions the absolute deviations are given by \( |\Delta_{x,y,z}^i| = |(x, y, z)_{true} - (x, y, z)| \)
- We freeze the weights of the above network and add an additional \( [21 \times 3] \) fully connected layer
- This network is trained to, on average, predict the absolute deviation \( |\Delta_{x,y,z}^i| \approx \langle |\Delta_{x,y,z}^i| \rangle \)
- Assuming the uncertainties are Gaussian distributed their standard deviation is \( \sigma_{x,y,z} = \sqrt{\frac{1}{2} \langle |\Delta_{x,y,z}^i| \rangle} \)

Conclusion and Outlook

We have presented a machine learning based approach to estimate the position and uncertainty of a VELO track’s closest to beam state. The resolution of this prediction as well as its ability to estimate the uncertainty is shown to be superior. While this is not a production ready solution yet, these preliminary results are promising and indicate that a machine learning based approach might provide an alternative to the simplified Kalman Filter.

References


The authors want to thank the open source community for providing and maintaining many helpful machine learning tools.