

New approaches for track reconstruction in LHCb's Vertex Locator

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

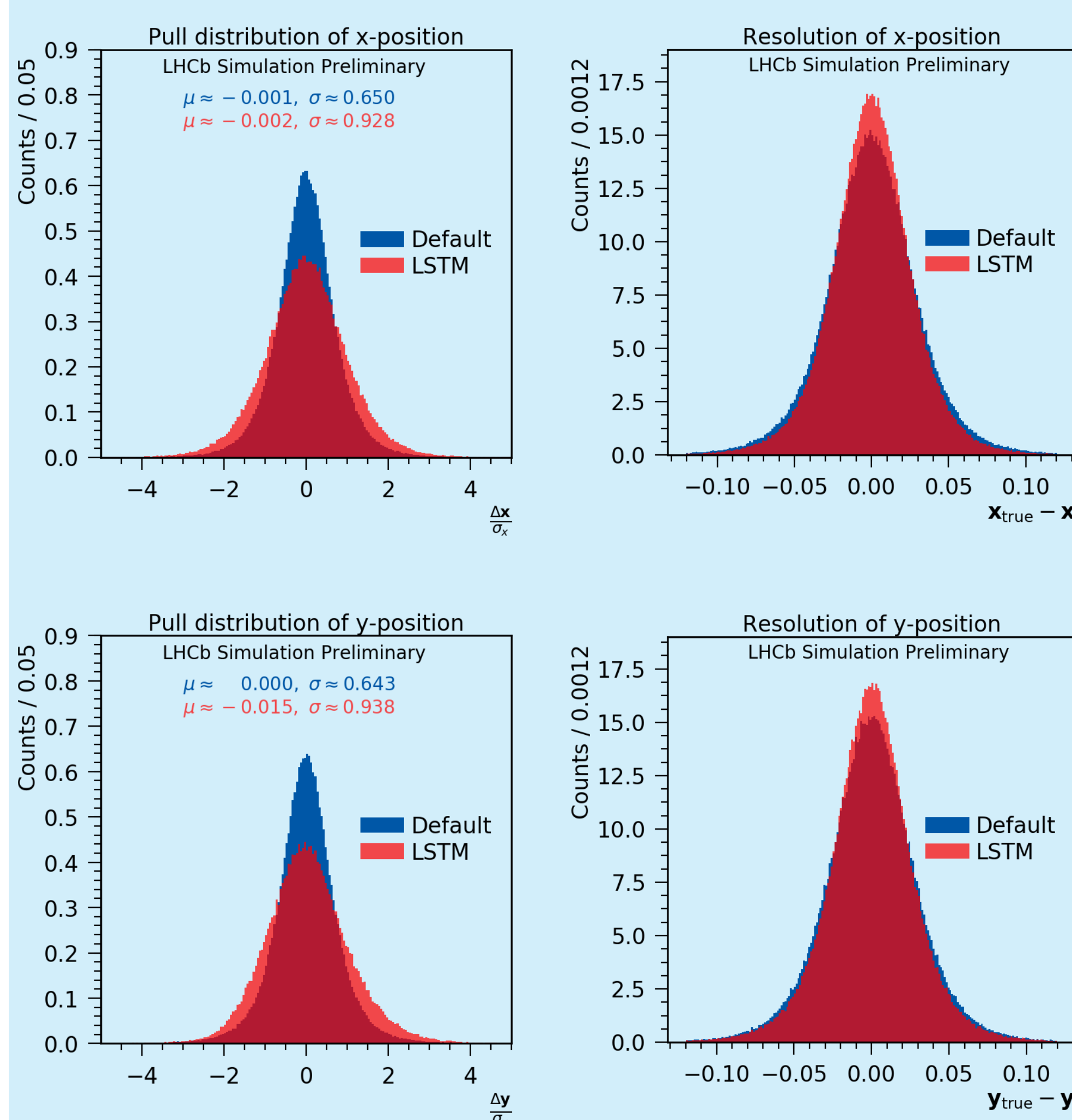
A 30MHz trigger throughput might require IP cuts on VELO tracks. A better approach would be a cut on IP and its uncertainty, which is challenging solely based on VELO information.

- ▶ 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?

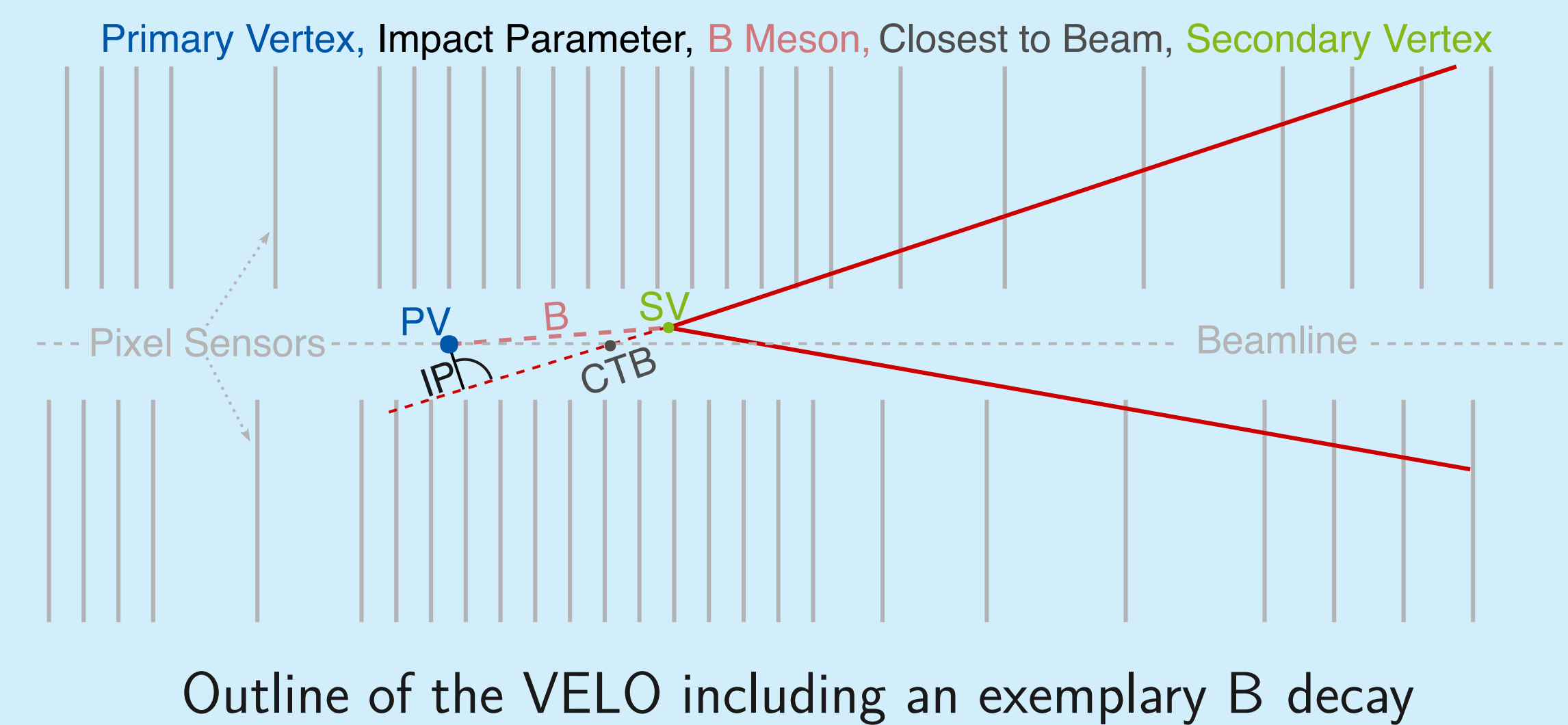
Results

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



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

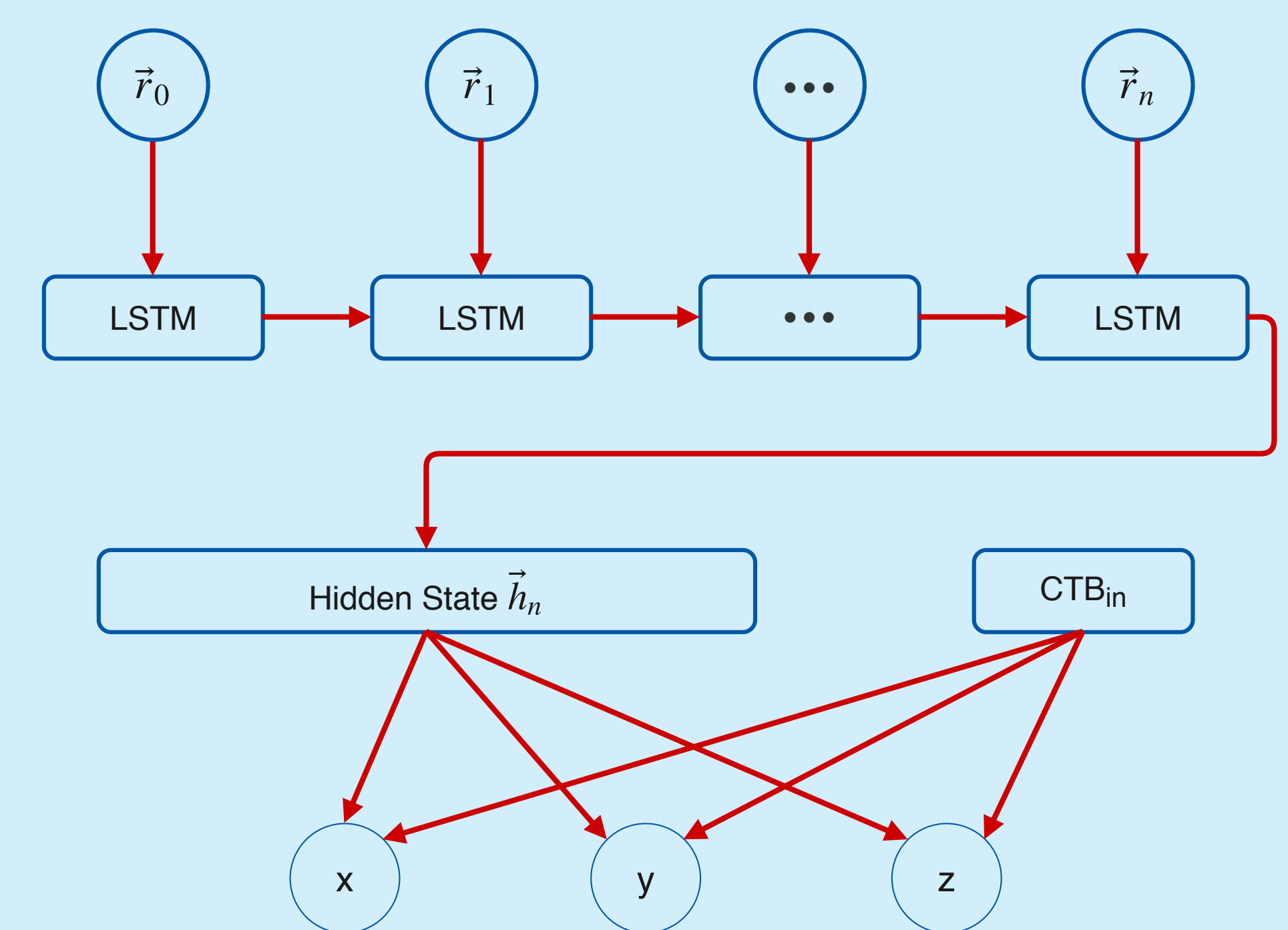


Outline of the VELO including an exemplary B decay

Idea and Method

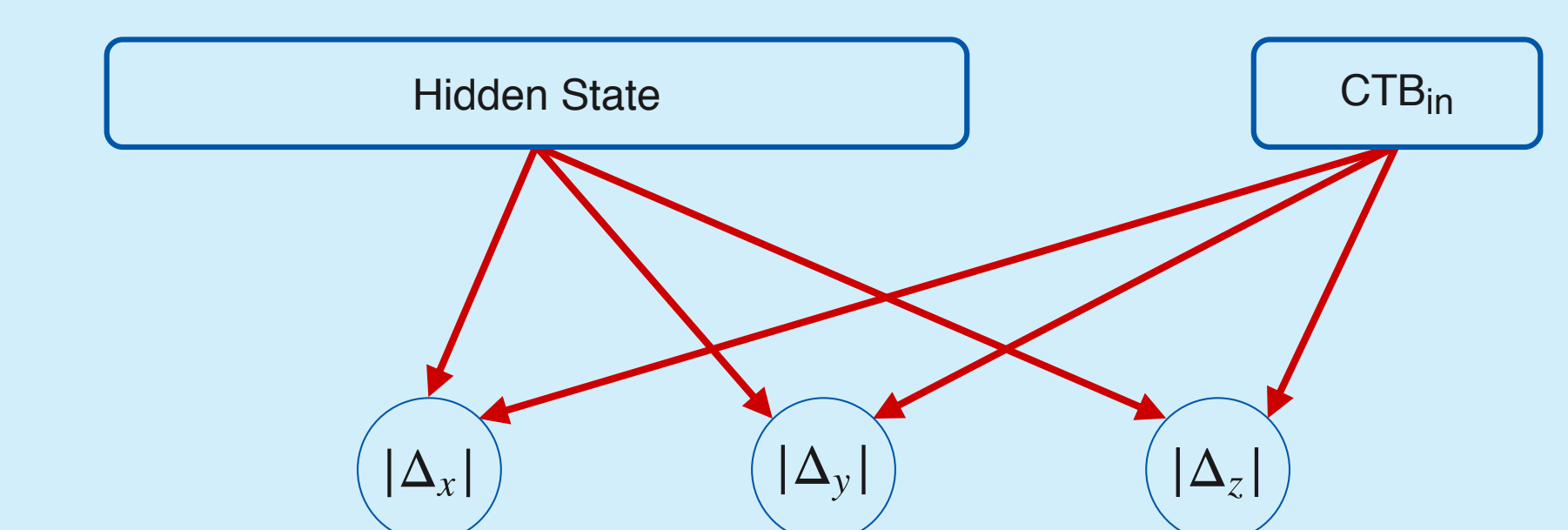
Given the straight line fit performed during the VELO track finding, compute the residuals $\vec{r}_i = (\Delta x_i, \Delta y_i, z_i)$ of each hit in respect to the straight line. Assuming the residuals are primarily due to multiple scattering, the magnitude is inversely proportional to the particle's 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 $\vec{r}_0, \dots, \vec{r}_n$ and outputs its last hidden state \vec{h}_n
- ▶ \vec{h}_n is concatenated with the CTB state from the straight line fit $CTB_{in} = (x, y, z, \frac{\Delta x}{\Delta z}, \frac{\Delta y}{\Delta z})$ and processed by a single $[21 \times 3]$ fully connected layer



Model architecture to predict CTB position

- ▶ Given the network's predictions and the true CTB positions the absolute deviations are given by $|\Delta_{x,y,z}| = |(x, y, z)_{true} - (x, y, z)|$
- ▶ 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 $|\Delta_{x,y,z}| \approx \langle |\Delta_{x,y,z}| \rangle$
- ▶ Assuming the uncertainties are Gaussian distributed their standard deviation is $\sigma_{x,y,z} = \sqrt{\pi/2} \langle |\Delta_{x,y,z}| \rangle$



Model extension to predict the uncertainty on the CTB position

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

- [1] Sepp Hochreiter and Jürgen Schmidhuber. "Long Short-Term Memory". In: *Neural Comput.* 9.8 (Nov. 1997), pp. 1735–1780. DOI: 10.1162/neco.1997.9.8.1735.
- [2] C. Patrignani et al. "Review of Particle Physics". In: *Chin. Phys.* C40.10 (2016), p. 100001. DOI: 10.1088/1674-1137/40/10/100001.
- [3] Adam Paszke et al. "Automatic differentiation in PyTorch". In: *NIPS-W.* 2017.