Particle Identification in Belle II Silicon Vertex Detector

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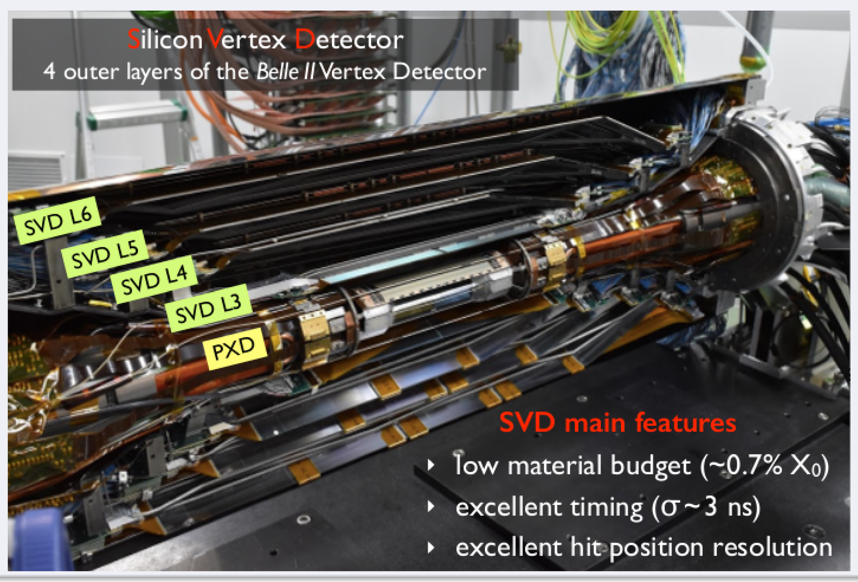
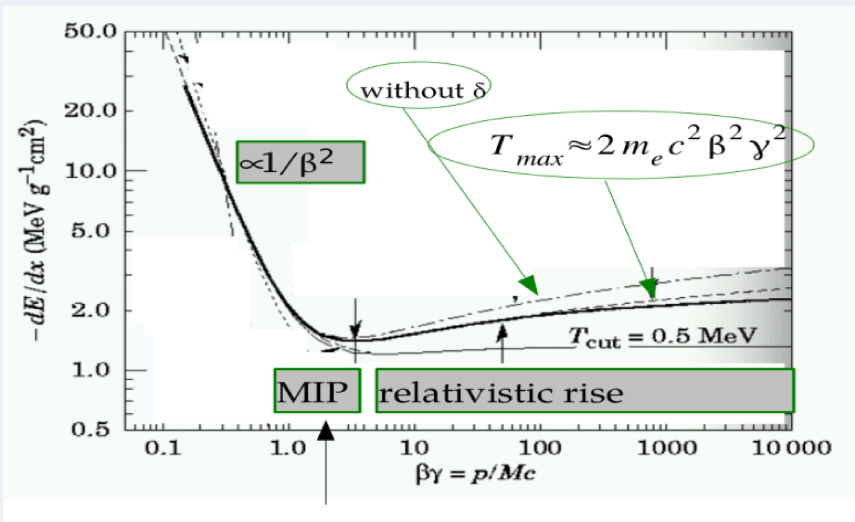
Motivation

- Particle identification plays an important role in the physics program of the Belle II experiment at the SuperKEKB asymmetric-energy e^+e^- collider
- Low-momentum particles are unable to reach the central drift chamber, the main tracking subdetector of the experiment, owing to their highly curved trajectory
- Such charged particle tracks can only be reconstructed with the vertex detector, acting as the inner tracking system
- Our goal is to exploit specific ionization (dE/dx) by these low-momentum particles in the silicon-strip vertex detector (SVD) towards identifying them



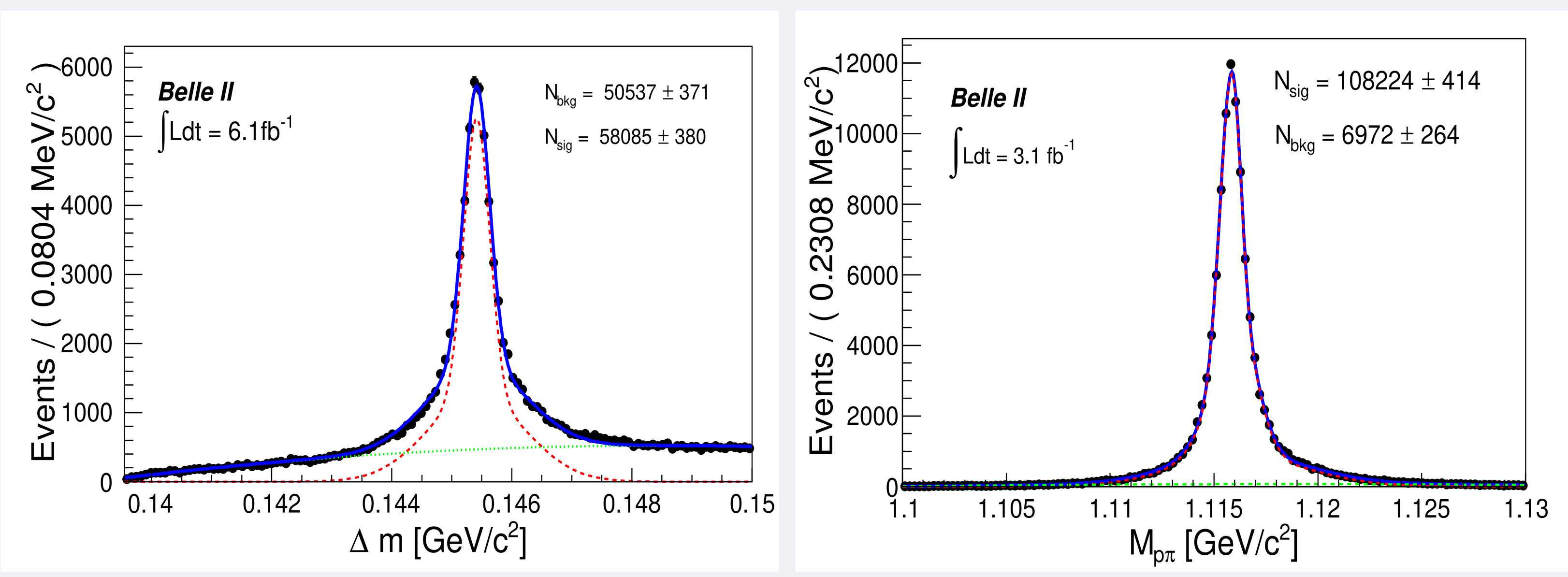
Particle identification with energy loss information

- According to the Bethe-Bloch formula [1], the mean energy loss of a charged particle traversing through the detector depends on its velocity (β)
- The minimum energy loss in any detectors occurs near $\beta\gamma \approx 3$ regardless of the particle type
- If we plot the energy loss for different types of particles over their momentum $p = \beta\gamma mc$, the same $\beta\gamma$ curve can be used to describe the particles only scaled by their mass m
- For various particles, the behaviour of the curve will be different
- This difference forms the basis of the dE/dx based particle identification method
- The method is particularly useful to identify charged particles having a momentum below their MIP value



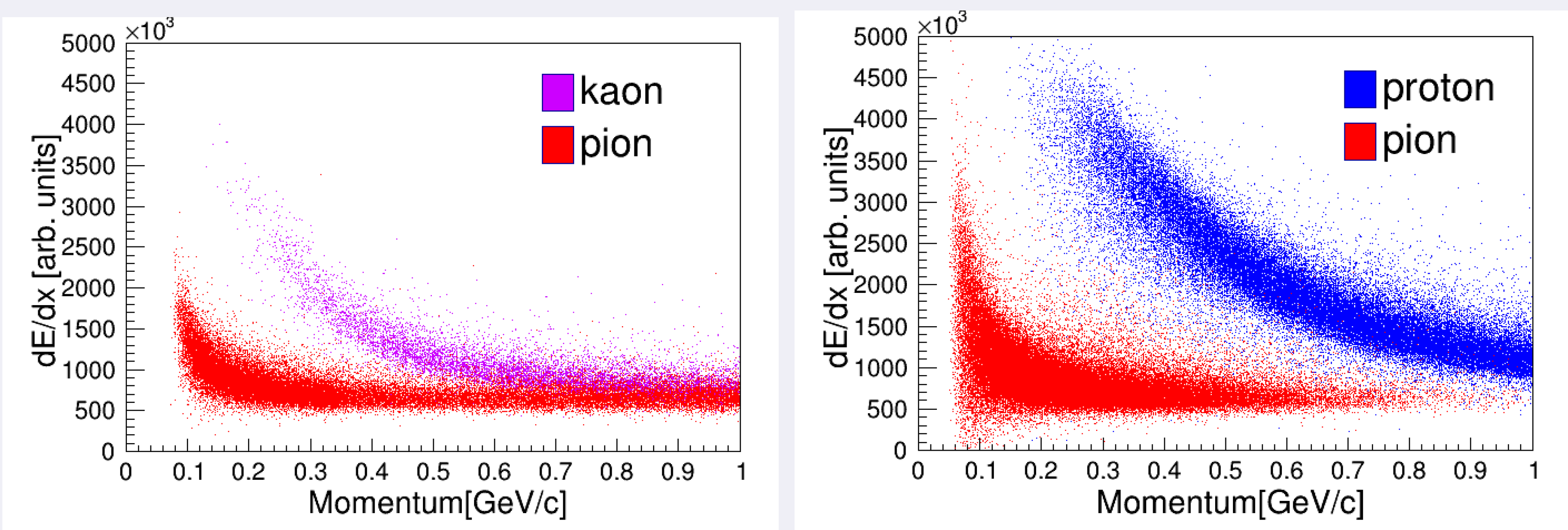
SVD dE/dx calibration

- The study is based on e^+e^- collision data recorded at the $\Upsilon(4S)$ peak by Belle II
- We use the self-tagging $D^{*+} \to D^0(K^-\pi^+)\pi^+$ decays to identify pions and kaons, and $\Lambda \to p\pi$ decays to identify protons
- Various kinematic and vertex requirements are applied to suppress most of the backgrounds
- After primary selection, an $_s\mathcal{P}lot$ [2] technique is used to subtract the residual background contribution
- We fit to the distributions of the D^*-D^0 mass difference (Δm) and $M_{p\pi}$ for D^* and Λ decays, respectively, to obtain appropriate weights for the signal and background components



Fitted distributions of (left) Δm from D^* sample and (right) $M_{p\pi}$ from Λ sample

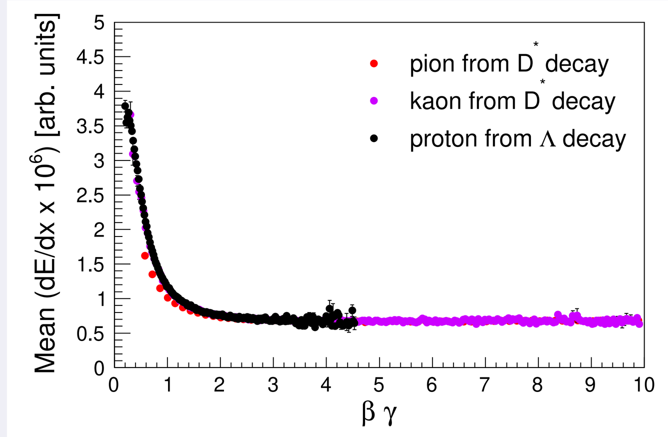
- The two-dimensional (2D) distributions of dE/dx vs. momentum show a clear separation among different particles in the low momentum region ($p < 1\,\mathrm{GeV}$)



dE/dx distributions of pions, kaons and protons as a function of their momentum in data

- Such 2D histograms for various particle hypotheses are uploaded to the calibration database

- We check the $\beta\gamma$ universality curve from D^* and Λ samples
- We get a flat curve once the particle reaches its MIP threshold, since the relativistic rise of dE/dx in silicon is suppressed by the density effect



SVD PID performance

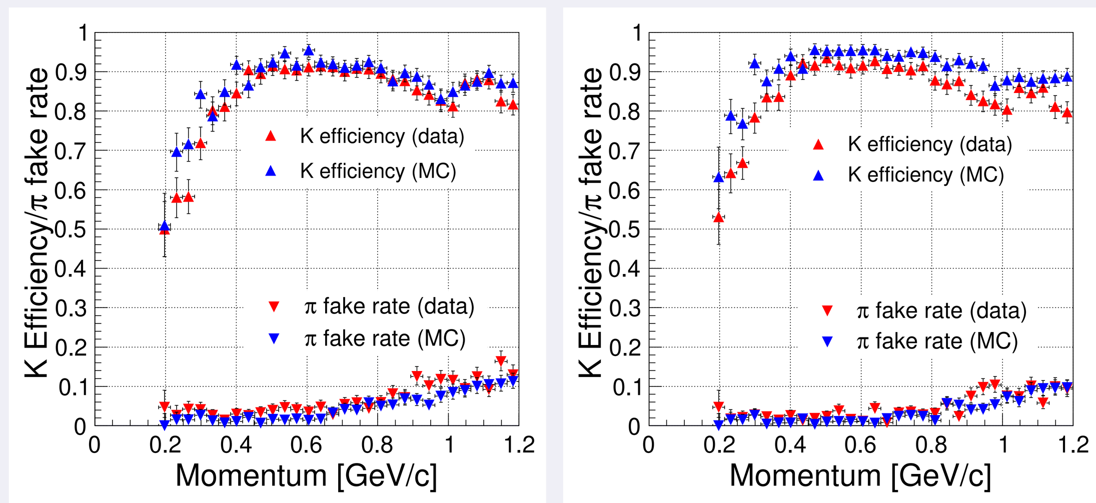
- The study is based on 3.7 fb^{-1} data reprocessed with uploaded histogram PDFs
- We also use $D^{*+} \to D^0(K^-\pi^+)\pi^+$ and $\Lambda \to p\pi$ decays for performance studies
- To assess the impact of SVD dE/dx information to the overall PID, we plot the efficiency and fake rate as a function of momentum applying a requirement on the binary PID $\mathcal{L}(i/j) > 0.5$

Efficiency is defined as:

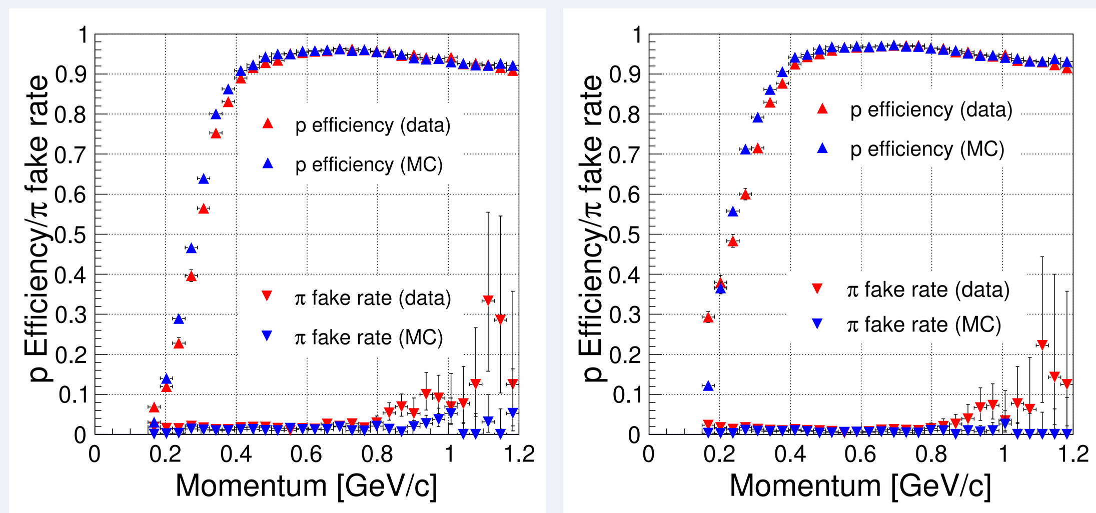
$$\epsilon_i = \frac{\text{Number of tracks identified with PID requirement under the hypothesis } i}{\text{Number of tracks kinematically identified under the hypothesis } i}$$

Fake rate is given by:

$$f_{j\to i} = \frac{\text{Number of tracks identified with PID requirement under the hypothesis } i}{\text{Number of tracks kinematically identified under the hypothesis } j}$$

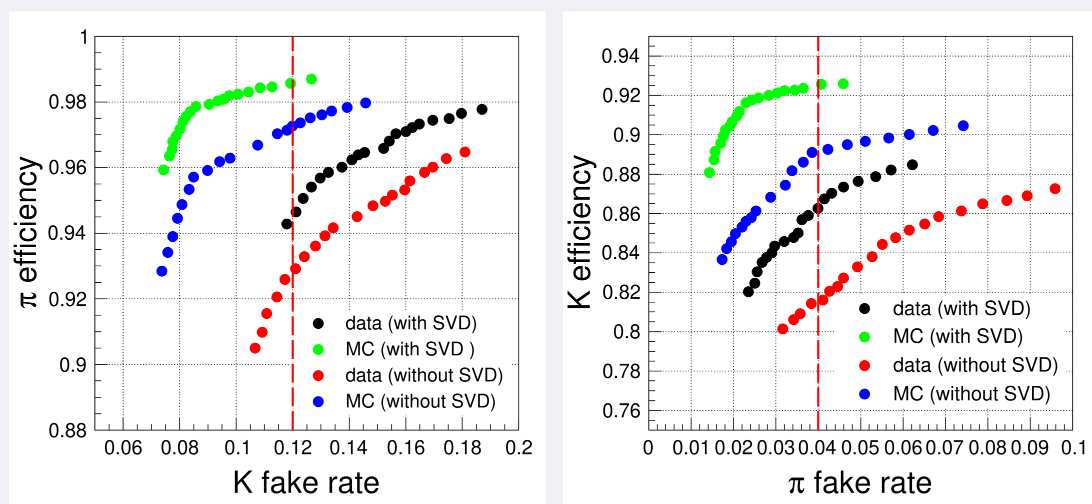


K efficiency and π fake rate (left) without and (right) with SVD for $\mathcal{L}(K/\pi) > 0.5$

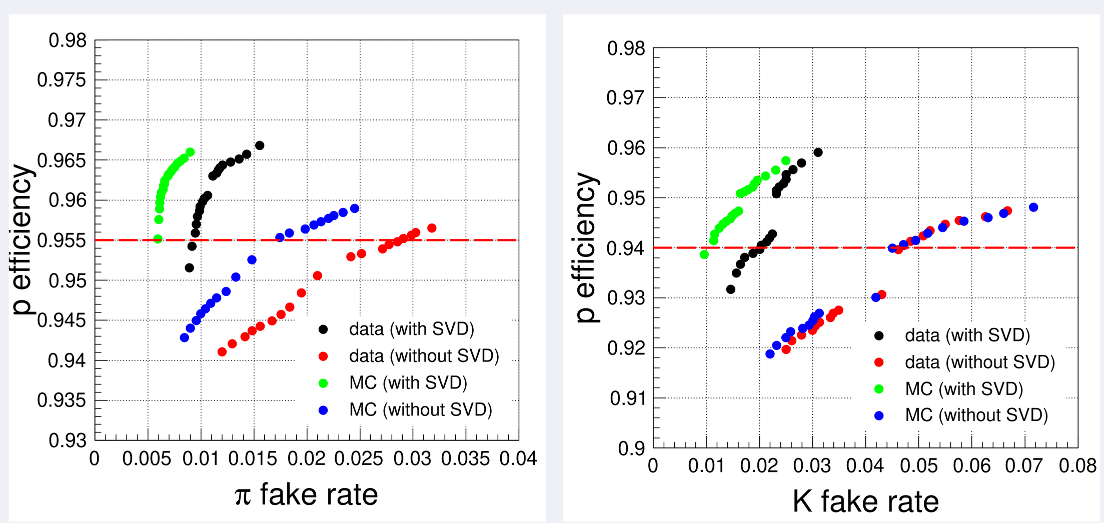


p efficiency and π fake rate (left) without and (right) with SVD for $\mathcal{L}(p/\pi) > 0.5$

- We plot the efficiency vs. fake rate to better appreciate the improvement in PID performance by adding the SVD dE/dx information



Kaon efficiency vs. pion fake rate with and without SVD with $p < 1\,\mathrm{GeV}$



Proton efficiency vs. pion fake rate with and without SVD with $p < 1\,\mathrm{GeV}$

Summary and Plan

- We have developed an SVD dE/dx based PID framework for charged pions, kaons and protons
- Our study confirms that addition of dE/dx information improves the pion, kaon and proton ID efficiency for a given fake rate in the low momentum region
- We plan to perform the SVD dE/dx calibration twice in a year

References

[1] W. R. Leo, "Techniques for Nuclear and Particle Physics Experiments", Springer-Verlag (1994).
[2] M. Pivk and F. R. Le Diberder, Nucl. Instrum. Meth. A555, 356 (2005).