Simulation of an all-layer monolithic pixel vertex detector for the Belle II upgrade

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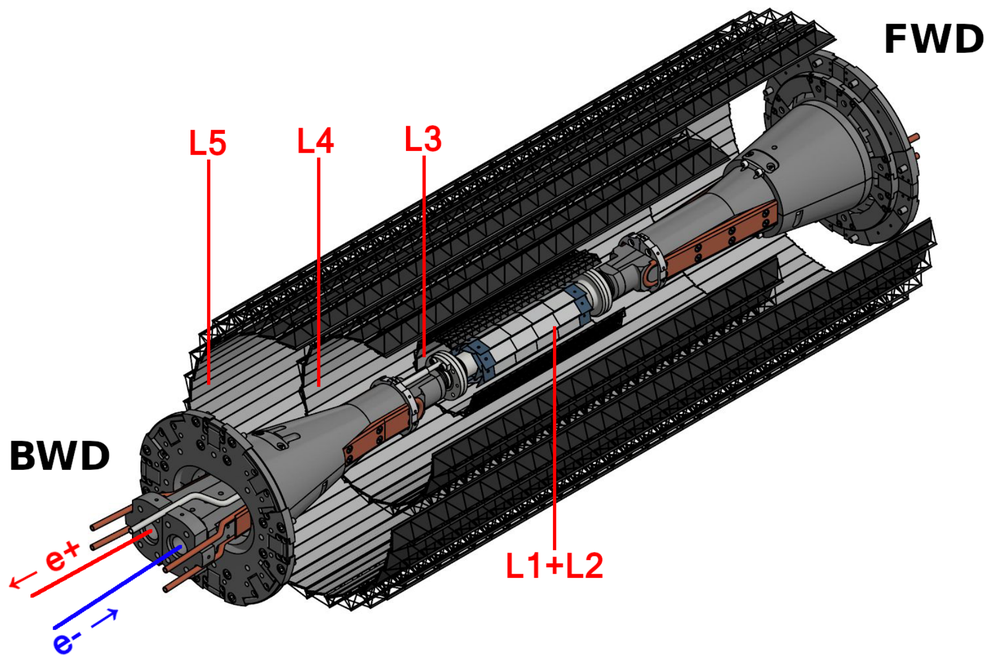
The VTX concept

Belle II is evaluating an upgrade for the 2026-2027 time frame to improve detector performance and robustness against beam-induced backgrounds. The VTX concept[1], a 5-layer depleted monolithic active pixels system (DMAPS) detector, was developed to replace the current vertex detector, VXD, which has 2 inner DEPFET pixel layers (PXD) plus 4 outer DSSD strip layers (SVD):

- more robust against background than both SVD (pixels instead of strips) and PXD (smaller integration time);
- improved spatial resolution (smaller pitch w.r.t. SVD);
- simpler integration (single chip type, on-chip sparsification);
- innermost layers used for pattern recognition (unlike PXD).

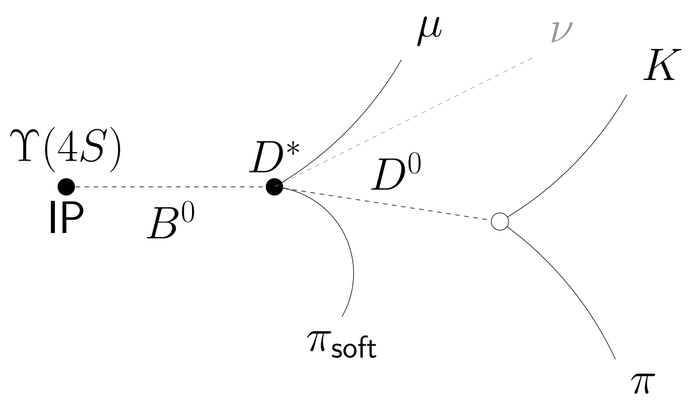
[1]Details in C. Wessel's talk at this conference *CMOS MAPS upgrade for the Belle II vertex detector*. See also arXiv:2203.11349.



A rendering of VTX

Simulating VTX

The VTX simulation framework has been integrated with the standard Geant4-based simulation of Belle II: this is made possible by the flexibility of the Belle II track reconstruction framework, which can be retrained on a different detector layout with no major change in the code. The simulation includes the whole Belle II detector with VXD replaced by VTX, and the VTX sensors themselves are simulated (not parameterized), using data from the TJ-Monopix prototype chip as a reference.
This framework allows direct comparison to the current VXD, and among different VTX layouts for design optimization.



The benchmark channel (not to scale)

A benchmark on a physics channel

$B^0 \to D^*\mu\nu$, with $D^* \to D^0\pi$ and $D^0 \to K\pi$ or $K3\pi$ is chosen:

- the reconstruction relies only on tracking detectors (no neutrals);
- presents two challenges: the need to reconstruct two vertices, and the low-momentum (*soft*) π from the D^* decay.
- is used in several analyses (e.g. $\mathcal{R}(D^*)$);

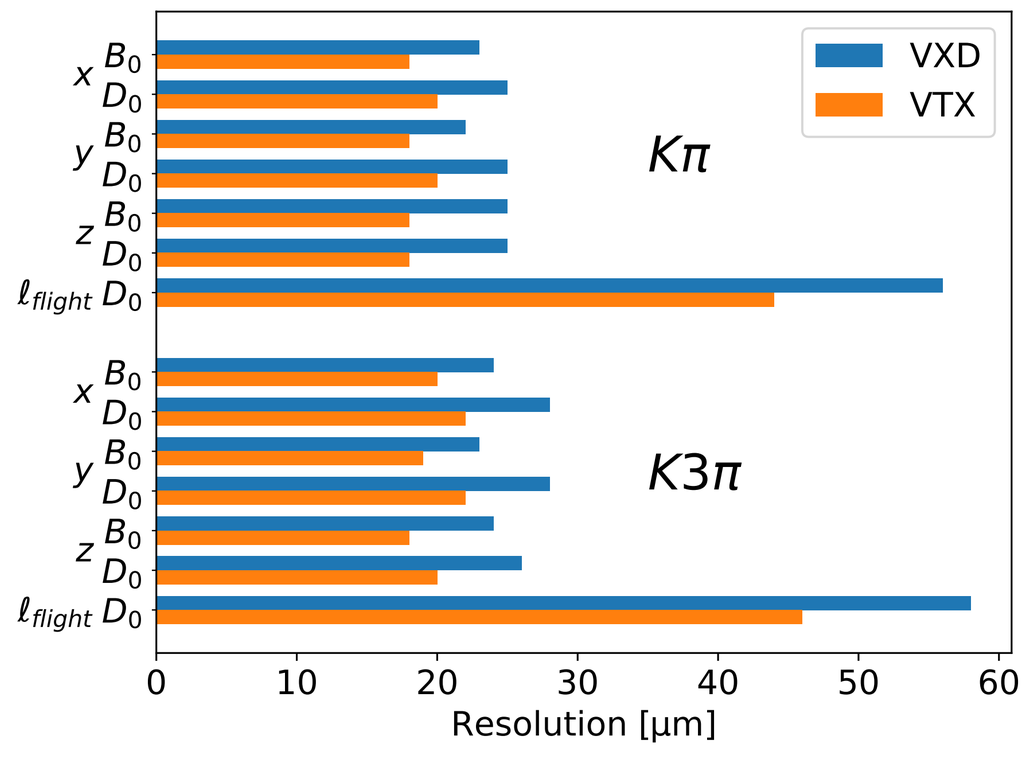
The simulation includes nominal background at design luminosity, corresponding to 20 MHz/cm^2 in the innermost layer (1.4 cm radius).

Tracking efficiency and purity

	$K\pi$		$K3\pi$	
	VXD	VTX	VXD	VTX
Efficiency [%]	34.6	55.5	20.6	43.5
Purity [%]	24.6	22.6	2.6	2.0

VXD → current, VTX → upgraded

Vertex resolution



Conclusions

Efficiency increases by $> 60\,\%$, with slight decrease in purity (but note that μ PID is not used here). Vertex and flight length resolution increase by $\sim 20\,\%$.
VTX allows a significant improvement in tracking efficiency and in track quality, especially at low p_T, both crucial for physics analyses.

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