Partially Reconstructed Beauty Decays at LHCb for the Phase-II Upgrade

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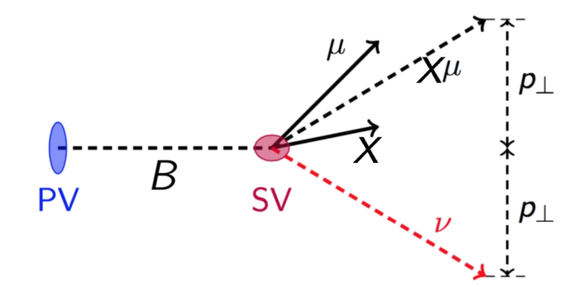
On behalf of the LHCb collaboration

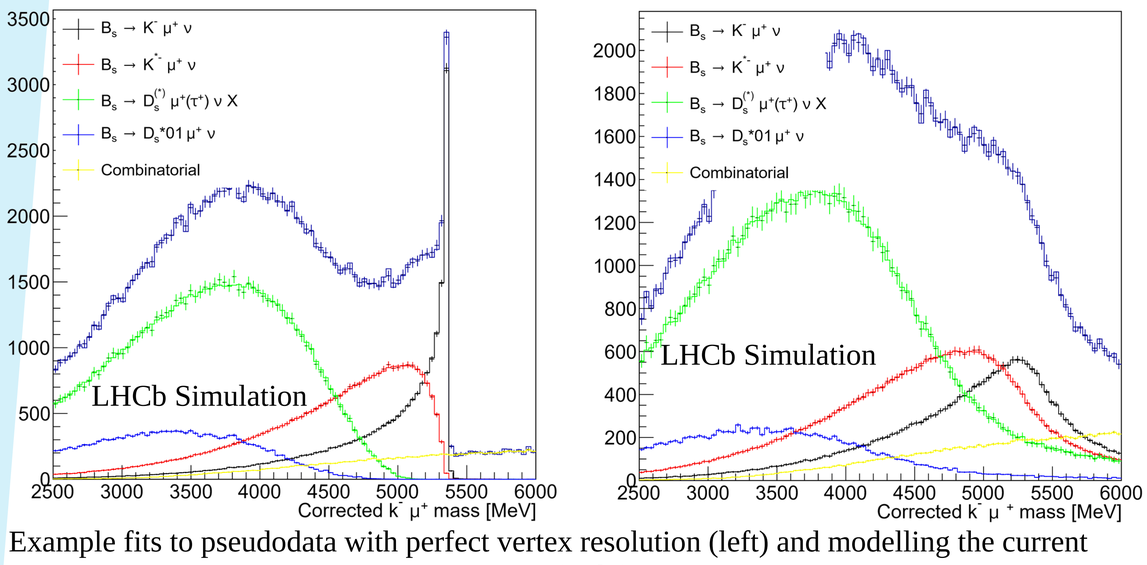
Semileptonic beauty decays provide a theoretically clean probe of CKM Unitarity via the measurements of $|V_{ub}|$ and $|V_{cb}|$, while the invisible neutrino prevents their full reconstruction. The full kinematics can be inferred by measuring the direction of the B from its production and decay vertices, a procedure which is heavily dependent on the vertex resolution. The RF foil is an essential component of the LHC protecting the LHC vacuum from the VELO vacuum, at the expense of increased material. Its removal could significantly improve the resolution of measured vertices, with the introduction of many additional benefits, such as increased background rejection, reduced ghost rates, and a higher track efficiency. All of this will be essential for rejecting the massive pileup backgrounds when operating at the full luminosity promised by the Phase-II upgrade.

Semileptonic Decays

- Decay rate separates cleanly into leptonic, hadronic currents
- Theoretically clean probe of CKM Unitarity via $|V_{ub}|$ and $|V_{cb}|$
- Partially reconstructed due to missing neutrino
- Infer kinematics through symmetry of event
  - e.g. Corrected mass:

$$m_{corr} = \sqrt{m_{X\mu}^2 + p_\perp^2} + p_\perp$$





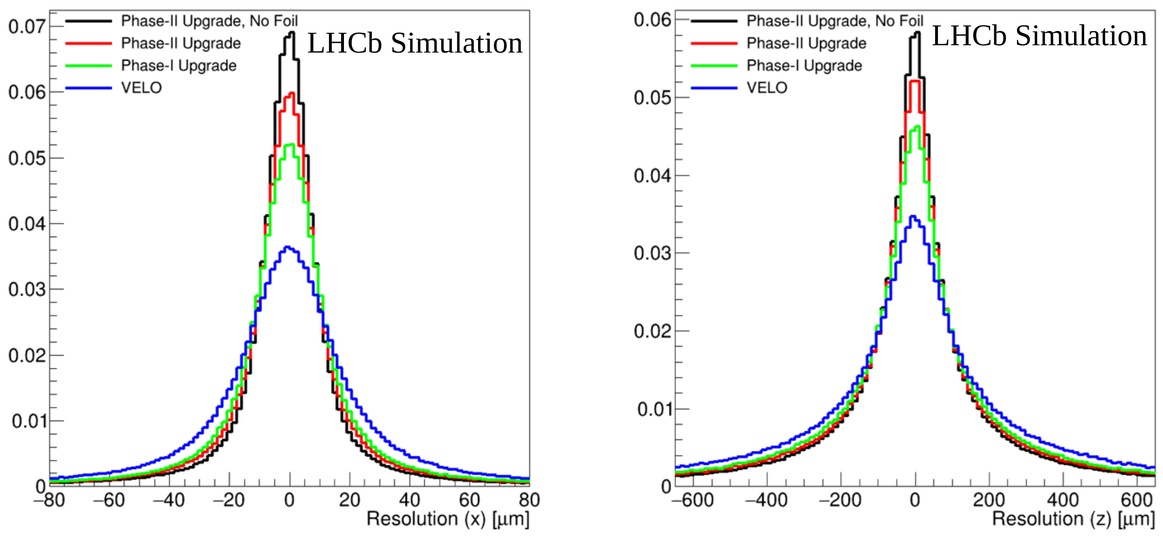
Example fits to pseudodata with perfect vertex resolution (left) and modelling the current VELO (right)

- Kinematics dependent on reconstructed B direction
  - m_{corr} resolution is dependent on vertex resolution

Study Method

- Simulate the decay: $B_s \to K^-\mu^+\nu_\mu$
- Propagate vertex uncertainty to a resolution on m_{corr}
- Simulate LHCb data including suite of backgrounds
- Determine signal yield from template fit to m_{corr}
- Figure of merit taken as signal yield uncertainty
- Improved resolution on m_{corr} reduces uncertainty in $|V_{qb}|$

VELO Resolution



B decay vertex resolution for the current VELO (blue), Phase-I upgrade VeloPix (green), Phase-II upgrade VELO with (red), and Phase-II upgrade VELO with the removal of the RF foil (black)

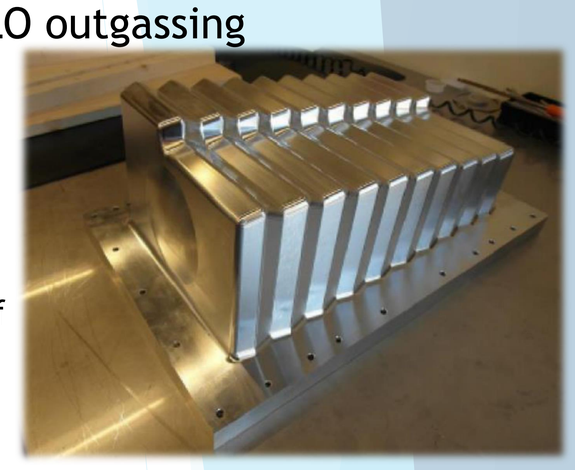
VELO	SV Res., z $[\mu m]$	$\mathcal{L}$ $[cm^{-2}s^{-1}]$	Foil $[\mu m]$
Current VELO	244	4×10^{32}	300
Phase-I VeloPix	217	2×10^{33}	250
Phase-II	$207 - 196$	$1 - 2 \times 10^{34}$	?

[1] R. Aaij et al., "Performance of the LHCb Vertex Locator", CERN-LHCb-DP-2014-001.

RF Foil

- Protects VELO from LHC
- Captures RF waves, Wakefield currents
- Protects LHC vacuum from VELO outgassing

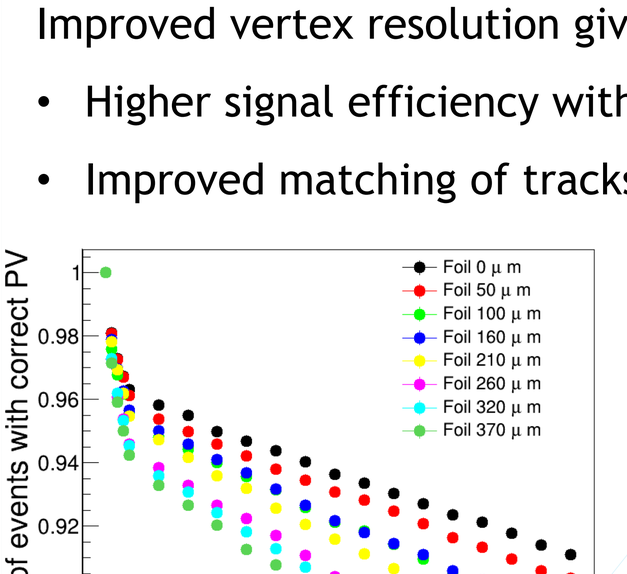
The RF foil is an essential component of the LHCb VELO, machined from $AlMg_3$, to a thickness of $250\ \mu m$ with further reductions possible by etching. The RF foil increases the material budget of the experiment and leads to a degradation of track quality and vertex resolution.



[2] R. Aaij et al., "LHCb VELO Upgrade Technical Design Report", CERN/LHCC-2013-021, LHCb-TDR-13.
[3] M. Jahn, "Studies on the Super VELO", CERN-STUDENTS-Note-2016-200

Results

- Study performed assuming $\mathcal{L} = 2 \times 10^{34}\ cm^{-2}s^{-1}$
- Study only shows impact of improved m_{corr} resolution
- Further studies underway investigating purity etc.



Toy analysis performed using a VELO simulation with varying thickness's of the RF foil. The resolution of fit variables is improved with an improved vertex resolution. By transitioning from the Phase-I upgrade model to a Phase-II upgrade model, a physics improvement equivalent to an increase in luminosity of 25% is seen. The physics improvement from the removal of the RF foil is equivalent to an additional increase in luminosity of 25%.

Additional Benefits

Improved vertex resolution gives additional benefits, e.g:

- Higher signal efficiency with greater background rejection
- Improved matching of tracks and decays to PV

Simulating $B_s \to \mu^+\mu^-$ decays with a VELO model for the phase-II upgrade, the fraction of events assigned the correct B production vertex, PV, is estimated. The fraction events assigned the wrong PV is reduced by 30% with the removal of the RF foil, assuming 60 interactions per bunch crossing.

- Increased track efficiency
- Improved flavour tagging
- Reduction in ghost rates