Measurement of $|V_{cb}|$ with $B_s^0 \to D_s^{(*)-}\mu^+\nu_\mu$ decays at LHCb

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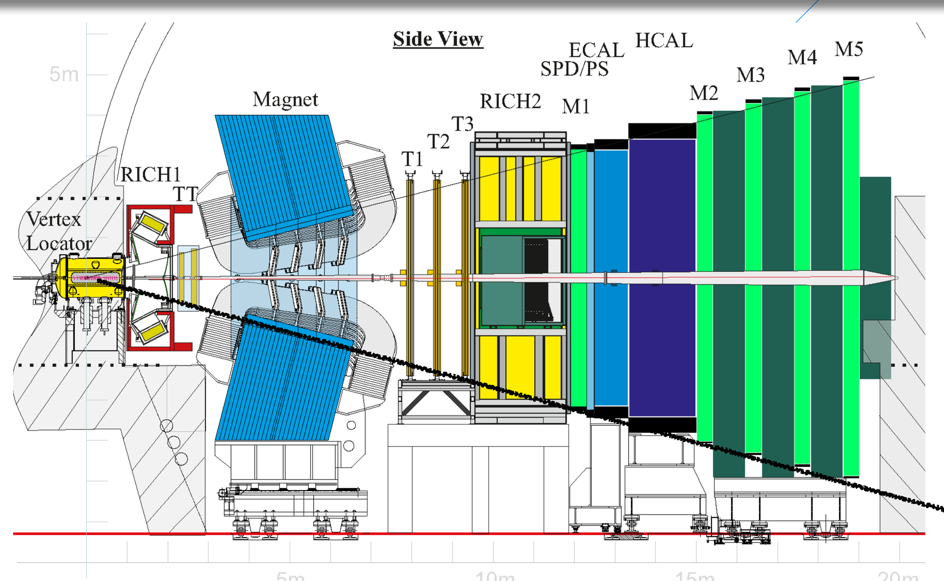
arXiv:2001.03225 [hep-ex]

Motivations

- **Long-standing discrepancy (~3σ) between inclusive and exclusive determinations of $|V_{cb}|$**
- Demand for new inputs from other dynamical systems than those studied at b-factories
- Semileptonic B_s^0 decays:
  - Abundant at LHC
  - Easier lattice QCD calculations for **form factors**
  - Lower background expected w.r.t. B^0 decays

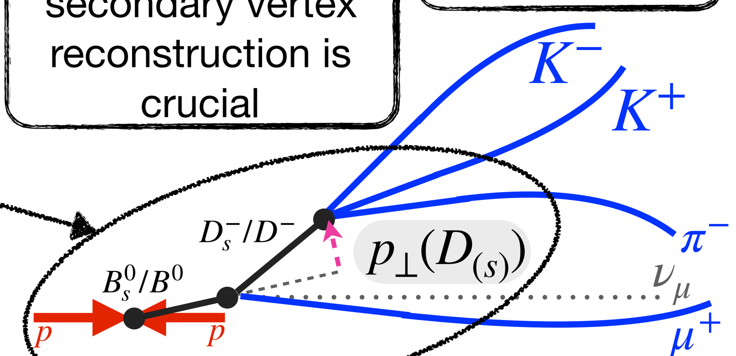
Data Samples



- Data collected during **Run-1** by **LHCb**

Excellent performance of secondary vertex reconstruction is crucial

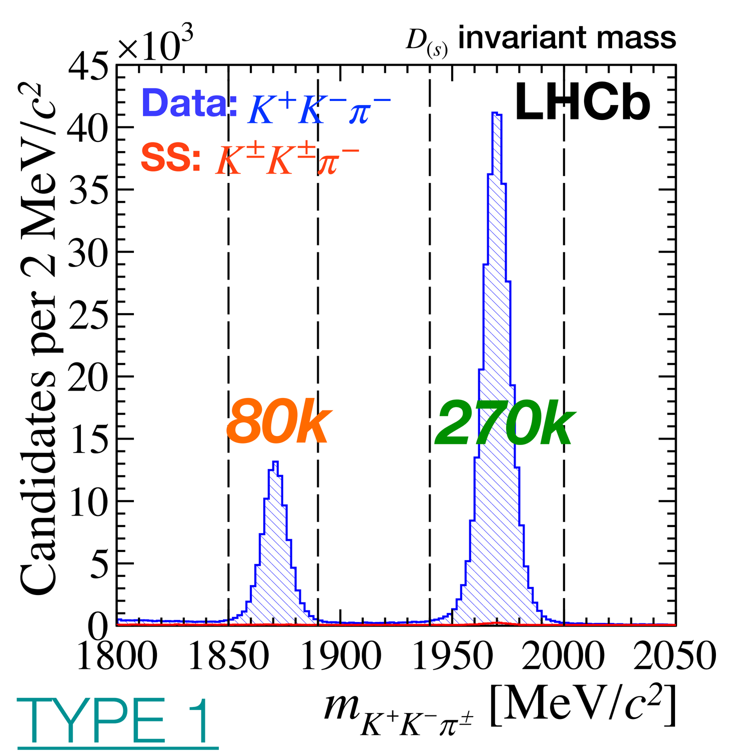
$\int \mathscr{L} dt = 3\ \mathrm{fb}^{-1}$
$\sqrt{s} = 7-8\ \mathrm{TeV}$



- To decrease systematic uncertainties, modes with the same visible final state are studied: **signal** and **normalisation**.

$B_s^0 \to D_s^{(*)-}\mu^+\nu_\mu$, $\hookrightarrow K^+K^-\pi^-$ $\quad B^0 \to D^{(*)-}\mu^+\nu_\mu$, $\hookrightarrow K^+K^-\pi^-$

- Offline selection suppresses **combinatorial background**
- Residual **physical background:**



B_s^0 feed-down	$B_s^0 \to D_s^{**-}(\to D_s^{(*)}X)\mu^+\nu_\mu$	TYPE 1
Doubly-charmed	$B^{0,+}_{(s)} \to D_{(s)}^{(*)-,0}D_{(s)}^{(*)+}$	TYPE 1
Cross-feed	$B^{0,+} \to D_s^{(*)-}K^{0,+}\mu^+\nu_\mu X$	TYPE 2
Semitauonic decays	$B_s^0 \to D_s^{(*,**)-}\tau^+(\to \mu^+\nu_\mu)\nu_\tau$	TYPE 2

Strategy

$$\mathscr{R}^{(*)} \equiv \frac{\mathbf{B}(B_s^0 \to D_s^{(*)-}\mu^+\nu_\mu)}{\mathbf{B}(B^0 \to D^{(*)-}\mu^+\nu_\mu)} = \frac{N_s^{(*)}}{N_d^{(*)}} \cdot \epsilon^{(*)} \cdot \mathbf{K}^{(*)}$$

External Inputs

$f_{s,d} = b$ quark hadronization fractions [PRD 100 (2019) 031102]

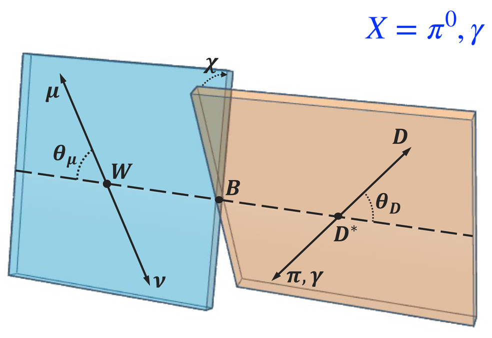
$$\mathbf{K} = \frac{f_d}{f_s} \cdot \frac{\mathbf{B}(D^- \to K^-K^+\pi^-)}{\mathbf{B}(D_s^- \to K^-K^+\pi^-)}$$

$$\mathbf{K}^* = \mathbf{K}\frac{\mathbf{B}(D^{*-} \to D^-X)}{\mathbf{B}(D_s^{*-} \to D_s^-X)}$$

$X = \pi^0, \gamma$

Estimated in this analysis

- **Signal yields (N_s, N_s^*) : FIT to signal sample**
- **Norm. yields (N_d, N_d^*) : FIT to norm. sample**
- **Efficiency Ratios ($\epsilon^{(*)}$) : MC SIMULATION**



$$\frac{dN_s^{(*)}}{d\xi} = \frac{N_d^{(*)}\ \tau_{B_s}\mathbf{M}^{(*)}G_F^2\eta_{EW}^2}{\epsilon^{(*)}\mathbf{K}^{(*)}\ \mathbf{B}(B^0 \to D^{(*)-}\mu^+\nu_\mu)} |V_{cb}|^2 |\mathscr{A}^{(*)}(\xi)|^2$$

$$\mathbf{M}^* = \frac{3m_{B_s}^2 m_{D_s^*}^2}{(8\pi)^4} \qquad \mathbf{M} = \frac{m_{D_s}^3(m_{B_s}+m_{D_s})^2}{48\pi^3}$$

- Scalar Case: $\xi \equiv w \equiv (m_{B_s}^2 + m_{D_s}^2 - q^2)/(2m_{B_s}m_{D_s})$
- Vector Case: $\xi \equiv (w, \cos\theta_D, \cos\theta_\mu, \chi)$

$\mu\nu$ invariant mass

Form Factors

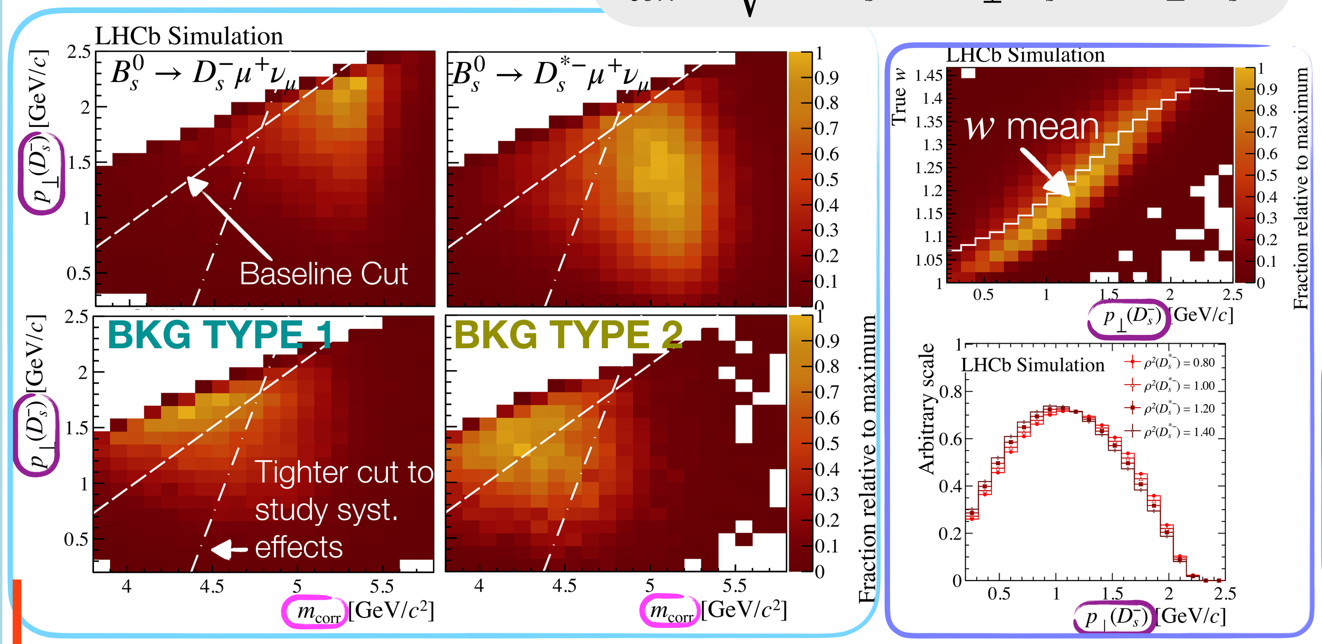
- Studied parametrizations:
  - **CLN** [Nucl. Phys. B530 (1998) 153]
  - **BGL** [Nucl. Phys. B461 (1996) 493]

Since $N_s^{(*)}$ can be written in terms of $|V_{cb}|$ and FF, they can be determined with a fit to the sample of signal candidates

Method & Challenges

	Selection efficiencies	Extraction of sig. and norm. yields	Measuring FF
TO DO	**Selection efficiencies** from MC simulations	Extraction of sig. and norm. **yields**	Measuring FF requires q^2 sensitivity
PROBLEM	Simulations do not reproduce all data features	$B_{(s)}^0$ invariant mass not measurable due to **missing ν**	q^2 not measurable due to **missing ν**
SOLUTION	MC-Data agreement investigated and corrected with **data-driven techniques**	**CORRECTED MASS**	**PROXY VARIABLE**

$$m_{corr} = \sqrt{m^2(D_s\mu) + p_\perp^2(D_s\mu)} + p_\perp(D_s\mu) \qquad p_\perp(D_s)$$



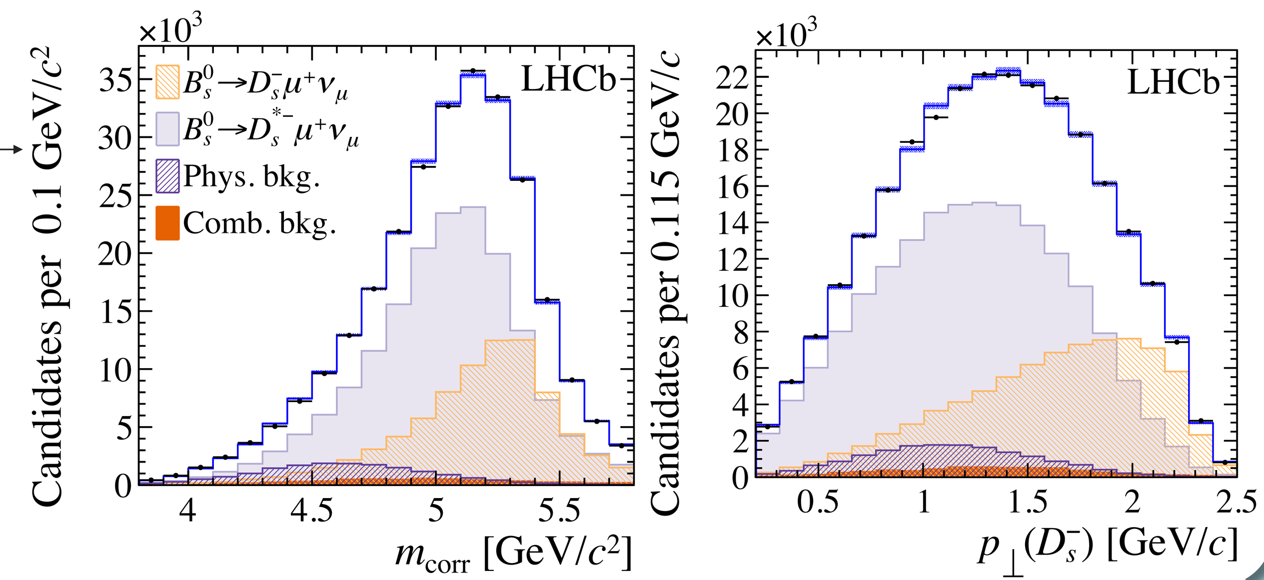
The m_{corr}-$p_\perp(D_s^-)$ plane provides good discrimination

$p_\perp(D_s^-)$ is correlated with w and therefore preserves FF sensitivity

PERFORM A 2-D FIT (m_{corr}, $p_\perp(D_s^-)$) WITH TEMPLATES
at each iteration of χ^2 minimisation
the template shapes change according to FF parameters

Projections of the final fit to the signal sample

CLN and BGL provide consistent results



Systematic Uncertainties

	$|V_{cb}|$ (CLN)	$|V_{cb}|$ (BGL)	R	R*
External Inputs	3%	3%	5%	5%
$D_{(s)} \to KK\pi$ model	1.9%	1.9 %	5%	4%
Background Composition	1.0%	0.2 %	4%	6%

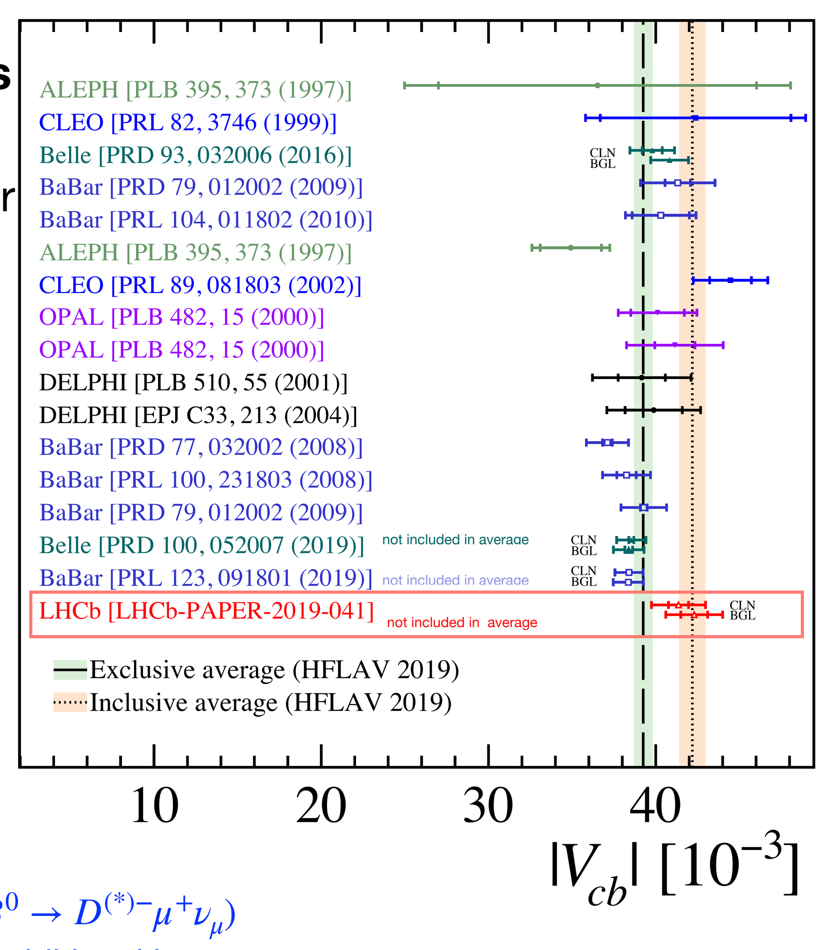
Relative Syst. Uncert.

Results & Conclusions

$$|V_{cb}|_{CLN} = (41.4 \pm 0.6(\text{stat}) \pm 1.5(\text{syst})) \times 10^{-3}$$

$$|V_{cb}|_{BGL} = (42.3 \pm 0.8(\text{stat}) \pm 1.5(\text{syst})) \times 10^{-3}$$

- 1st **determination of $|V_{cb}|$ from B_s^0 decays**
- 1st determination of $|V_{cb}|$ at a hadron collider
- Results compatible with world averages for both inclusive and exclusive determinations of $|V_{cb}|$
- Uncertainties not competitive with b-factories, but novel strategy promising for similar measurement using B^0 decays



$$\mathscr{R} = 1.09 \pm 0.05(\text{stat}) \pm 0.08(\text{syst})$$
$$\mathscr{R}^* = 1.06 \pm 0.05(\text{stat}) \pm 0.09(\text{syst})$$

$\mathbf{B}(B^0 \to D^{(*)-}\mu^+\nu_\mu)$ as additional input

$$\mathbf{B}(B_s^0 \to D_s^-\mu^+\nu_\mu) = (2.49 \pm 0.12(\text{stat}) \pm 0.21(\text{syst})) \times 10^{-2}$$
$$\mathbf{B}(B_s^0 \to D_s^{*-}\mu^+\nu_\mu) = (5.38 \pm 0.25(\text{stat}) \pm 0.55(\text{syst})) \times 10^{-2}$$

1st Measurement of these exclusive BR