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Extraction of $|V_{ub}|/|V_{cb}|$ using B_c^+ semileptonic decays at LHCb

IoP Joint APP, HEPP and NP Conference 2021

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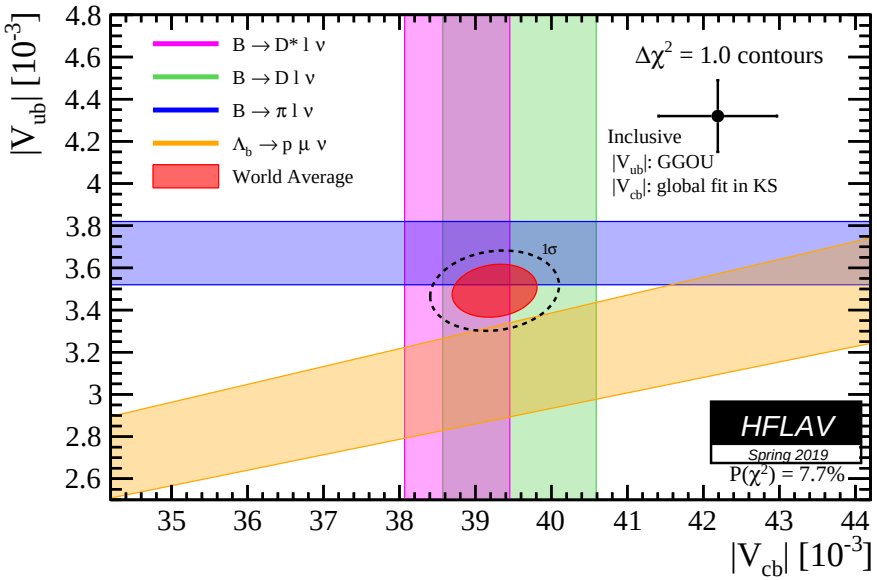
April 12, 2021

Ongoing tension between inclusive vs exclusive $|V_{ub}|$ and $|V_{cb}| \sim 3\sigma$.

Exclusive determinations rely on **form factors** (FF) to parameterise the hadronic currents as a function of q^2 ($\mu\nu$ invariant mass).



[arXiv:1909.12524]

Aim for the first extraction of $|V_{ub}|/|V_{cb}|$ using B_c^+ semileptonic decays.

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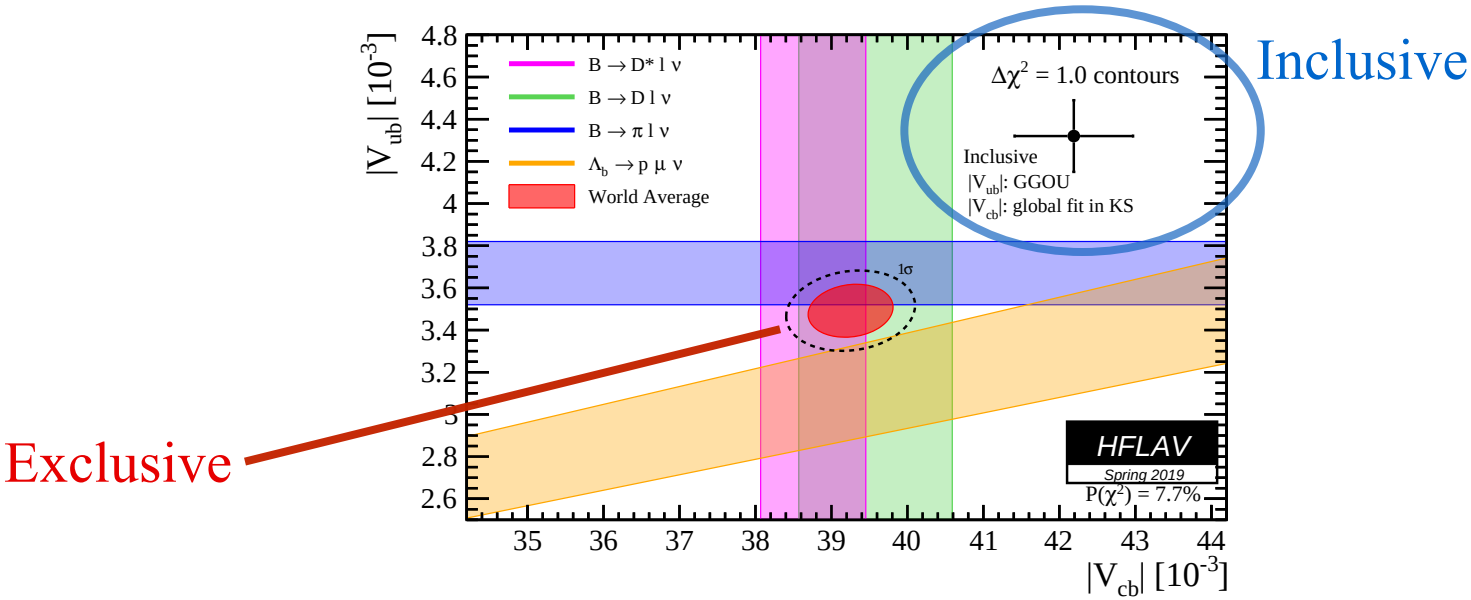


[arXiv:1909.12524]

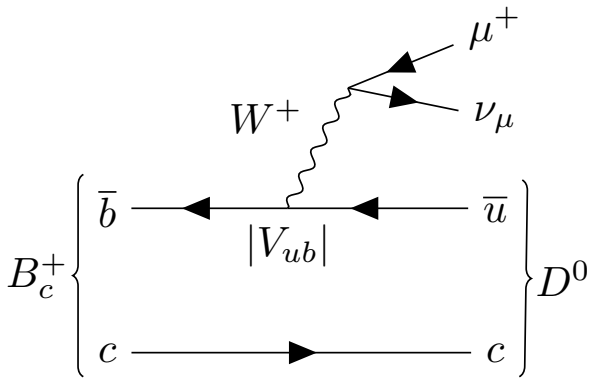
Aim for the first extraction of $|V_{ub}|/|V_{cb}|$ using B_c^+ semileptonic decays.

Using LHCb 2011-2012 + 2015-2018 data @ $\int \mathcal{L} = 9\,\text{fb}^{-1}$:

1. First observation of $B_c^+ \to D^{0(*)}\mu^+\nu_\mu$ with $D^0 \to K^-\pi^+$;
2. Extraction of the ratio of CKM matrix elements $|V_{ub}|/|V_{cb}|$:

$$\frac{|V_{ub}|^2}{|V_{cb}|^2}\underbrace{R_{FF}}_{\text{Theory}} = \underbrace{\frac{\mathcal{B}(B_c^+ \to D^0\mu^+\nu_\mu)}{\mathcal{B}(B_c^+ \to J/\psi\,\mu^+\nu_\mu)}}_{\text{Experiment}}$$

$$= \frac{N(B_c^+ \to D^0\mu^+\nu_\mu)}{N(B_c^+ \to J/\psi\,\mu^+\nu_\mu)} \times \frac{\varepsilon(B_c^+ \to J/\psi\,\mu^+\nu_\mu)}{\varepsilon(B_c^+ \to D^0\mu^+\nu_\mu)} \times \frac{\mathcal{B}(J/\psi \to \mu^+\mu^-)}{\mathcal{B}(D^0 \to K^-\pi^+)}$$



Focus today: extraction of signal channel $B_c^+ \to D^{0(*)}\,\mu^+\nu_\mu$.

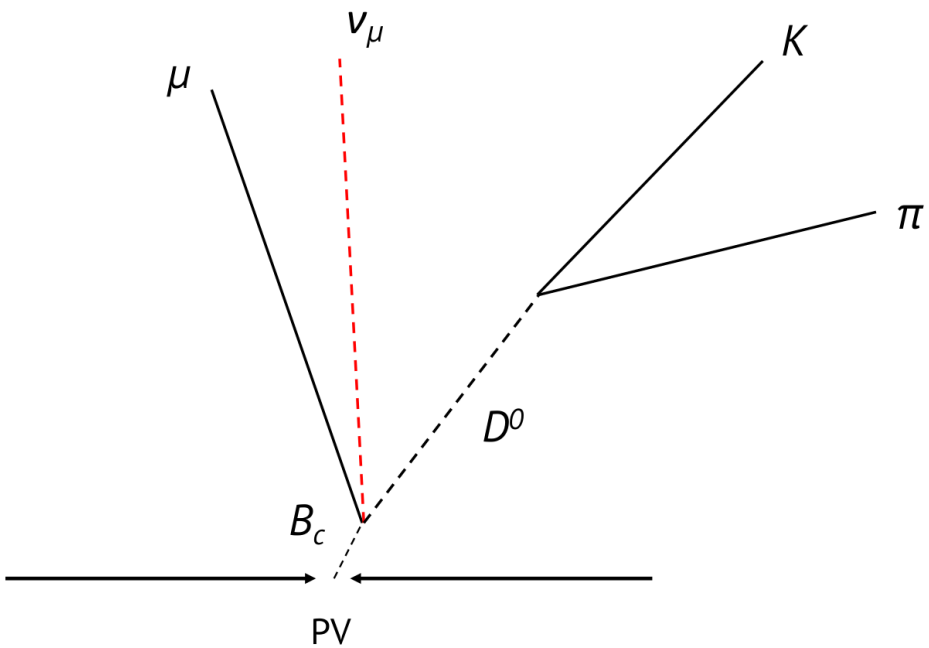
Expected components in fit to inclusive $D^0\mu^+$ sample:

- **Signal** decay $B_c^+ \to D^0(\to \boldsymbol{K}^-\pi^+)\,\boldsymbol{\mu}^+\nu_\mu$;
- B^+ decays with **similar topology**: $\begin{cases} \cancel{B^+ \to \overline{D}{}^0(\to \boldsymbol{K}^+\pi^-)\,\boldsymbol{\mu}^+\nu_\mu} & \text{(CF)} \\ B^+ \to \overline{D}{}^0(\to \boldsymbol{K}^-\pi^+)\,\boldsymbol{\mu}^+\nu_\mu & \text{(DCS)} \end{cases}$
- $B \to D^0 hX$ decays with hadrons h mis-reconstructed as muons ("**MisID**");
- **Combinatorial** background.

Simulation for signal templates only → heavily data-driven approach.

Maximise sensitivity to decays of doubly-heavy B_c^+ candidates Appendix :

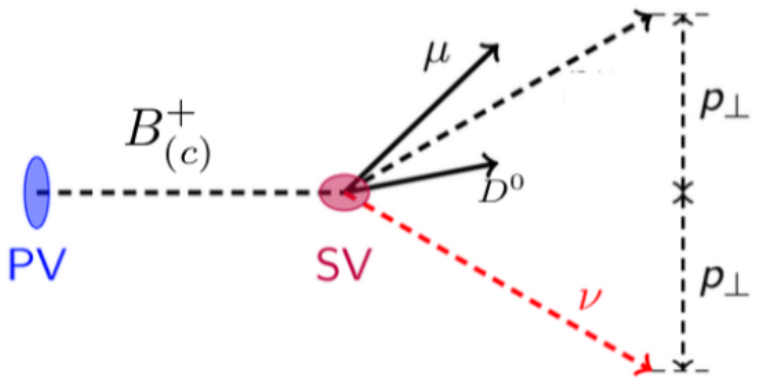
- B decay with 3 visible final-state tracks;
- Single muon track;
- Particle identification (PID) on μ, K, π;
- *"Hard"* momentum budget;
- Rejection of prompt D^0 candidates.

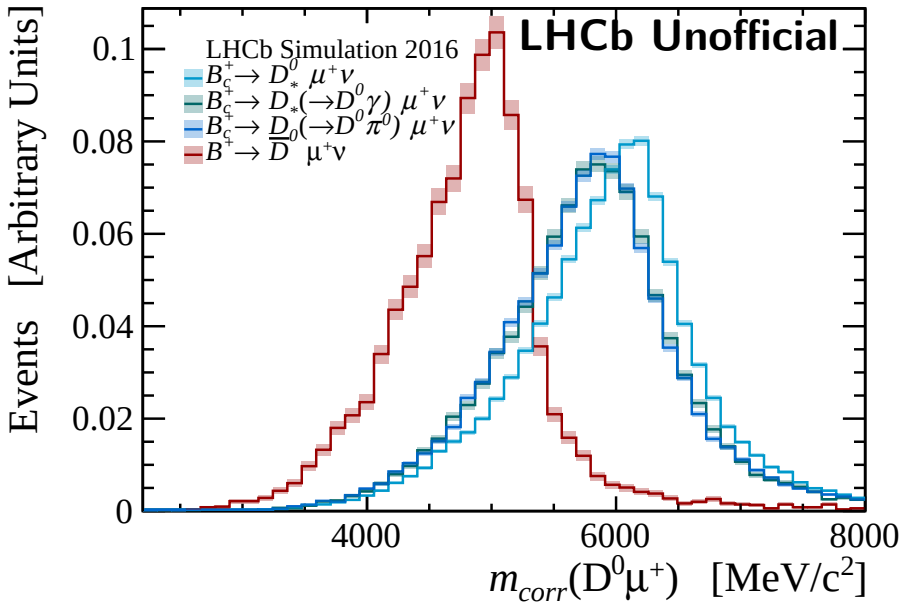


[LHCb-DP-2018-001] [LHCb-PUB-2011-016] [JINST 3 (2008) S08005] [LHCb-DP-2014-002]

Perform a binned maximum likelihood fit in **corrected mass**

$$m_{corr}(D^0\mu) = \sqrt{m^2(D^0\mu^+) + p_\perp^2(D^0\mu^+)} + p_\perp(D^0\mu^+)$$



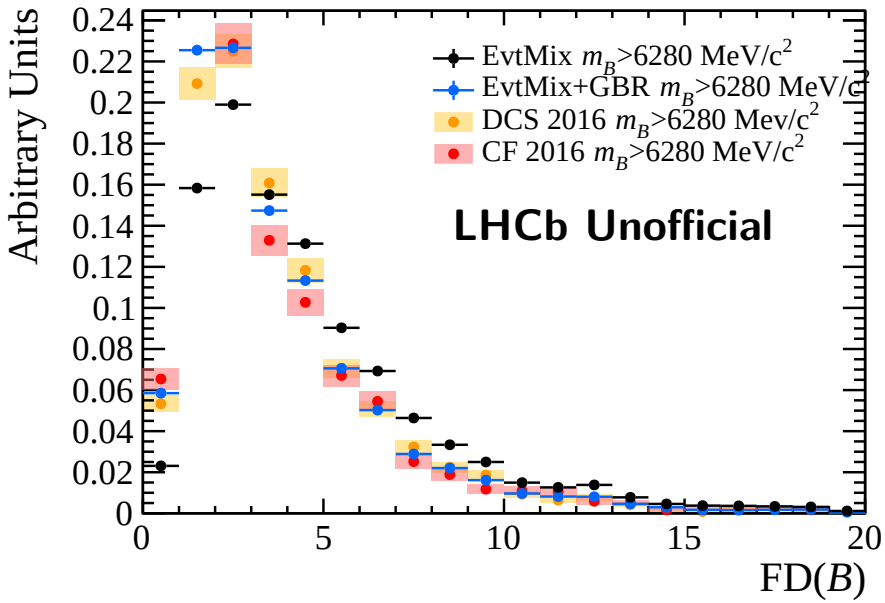


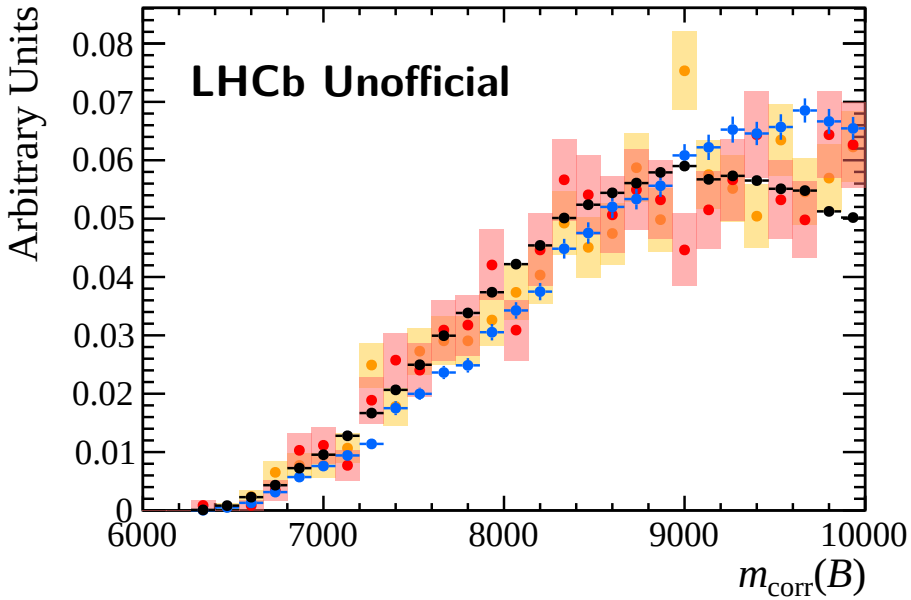
Model background formed from random combinations of unrelated D^0 & μ^+.

(a) Combine D^0 and μ^+ candidates from different events in data;

(b) Compute mass, momentum, angular observables of **combinatorial** B;

(c) MVA-based reweighting to reproduce upper-mass-band observables.





Expect a substantial contamination from $B \to D^0 h X$ decays where a non-muon candidate h is mis-reconstructed as a μ^+ (*"MisID"*).

Data-driven method:

(a) Identify a **hadron-enriched** control sample in data;

(b) Extrapolate its contribution to the **fit window**:

Assign a *per-event* weight:

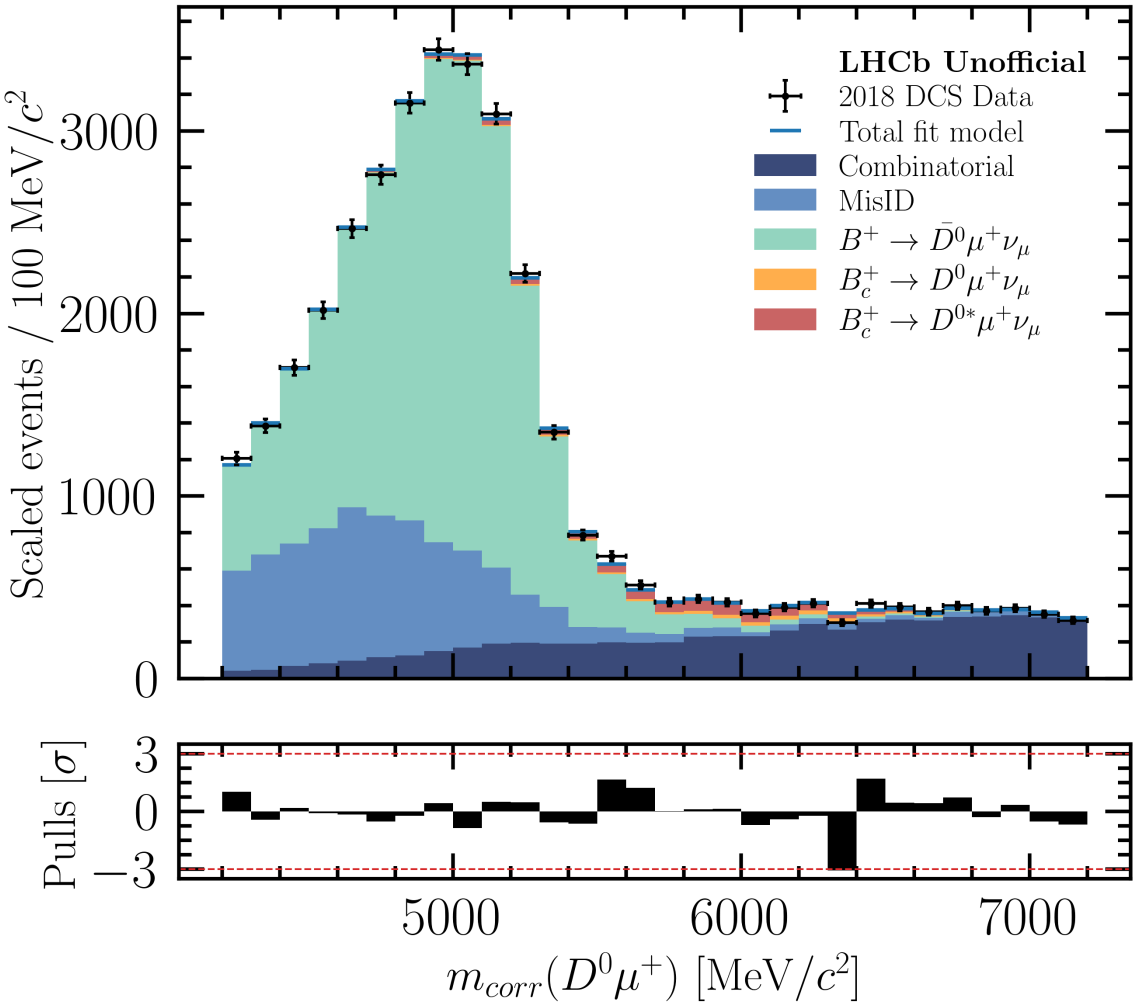
$$w_{\text{misID}} = \frac{\varepsilon^{\text{signal selection}}_{B \to D^0 h X}}{\varepsilon^{\text{hadron-enriched}}_{B \to D^0 h X}}$$

$\Rightarrow$ Derive both a yield and a shape for misID background.

Fit components:

- Combinatorial bkg
  ↪ Event mixing;
- MisID bkg
  ↪ Yield and shape from w_{MisID};
- $B^+(b \to c)$ bkg
  ↪ Template from CF data;
  ↪ Yield from scaling to ratio of $\mathcal{B}$(DCS)/$\mathcal{B}$(CF);
- $B_c^+ \to D^{0(*)}\mu^+\nu_\mu$ signal
  ↪ Template from MC;

Channel	Preliminary Yield
$B_c^+ \to D^0\mu^+\nu_\mu$	445 ± 287
$B_c^+ \to D^{*0}\mu^+\nu_\mu$	1397 ± 250



Summary & Outlook

First measurement of $|V_{ub}|/|V_{cb}|$ using B_c^+ semileptonic decays reaching an advanced state :

- ☑ Binned fit to signal channel in place $\rightarrow$ binning optimisation;
- ☑ Efficiencies evaluated from simulation (signal and normalisation modes);
- ☐ Finalise fit to the normalisation channel $B_c^+ \rightarrow J/\psi\ \mu^+\nu_\mu$;
- ☐ Evaluation of the systematic uncertainties.

Thanks for your attention.
Any questions?

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Appendix

Pseudoscalar Matrix Elements

$$\langle D^0(p_2)|\, V_\mu \,|B_c(p_1)\rangle = f_+(q^2)\left[P_\mu - \frac{m^2_{B_c} - m^2_{D^0}}{q^2} q_\mu\right] + f_0(q^2)\frac{m^2_{B_c} - m^2_{D^0}}{q^2} q_\mu$$

Vector Matrix Elements

$$-i\,\langle D^*(p_2)|\,(V-A)_\mu\,|B_c(p_1)\rangle = i\frac{2\,V(q^2)}{m_{B_c}+m_{D^*}}\varepsilon_{\mu\nu\alpha\beta}\epsilon^{*\nu}p_2^\alpha p_1^\beta - (m_{B_c}+m_{D^*})A_1(q^2)\epsilon^*_\mu$$

$$+\frac{A_2(q^2)}{m_{B_c}+m_{D^*}}(\epsilon^*\cdot q)(p_1+p_2)_\mu + \frac{2m_{D^*}}{q^2}(A_3(q^2)-A_0(q^2))(\epsilon^*\cdot q)q_\mu\,,$$

Event Selection

Maximise sensitivity to decays of doubly-heavy, short-lived B_c^+ candidates :

a. **Trigger**: single high-p_{T} muon track + B topological high-level trigger;

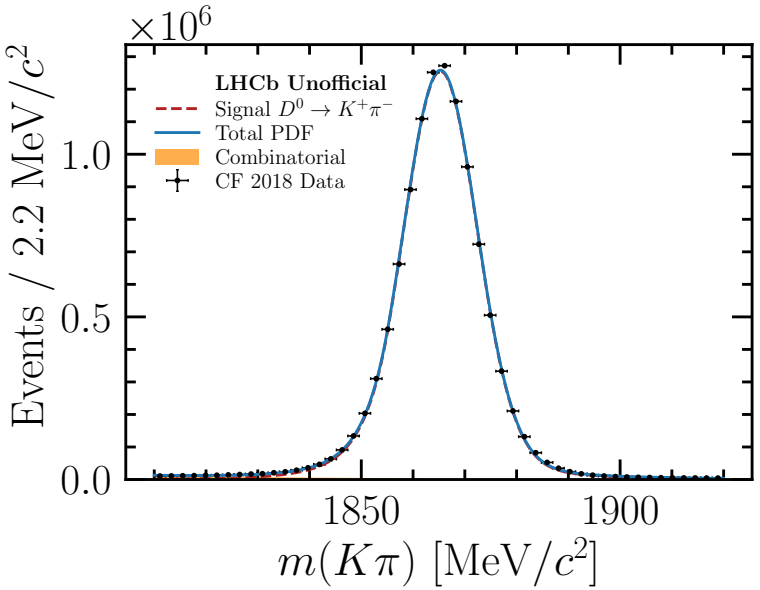
b. **Kinematics**: *"hard"* momentum budget consistent with B_c^+ decays;

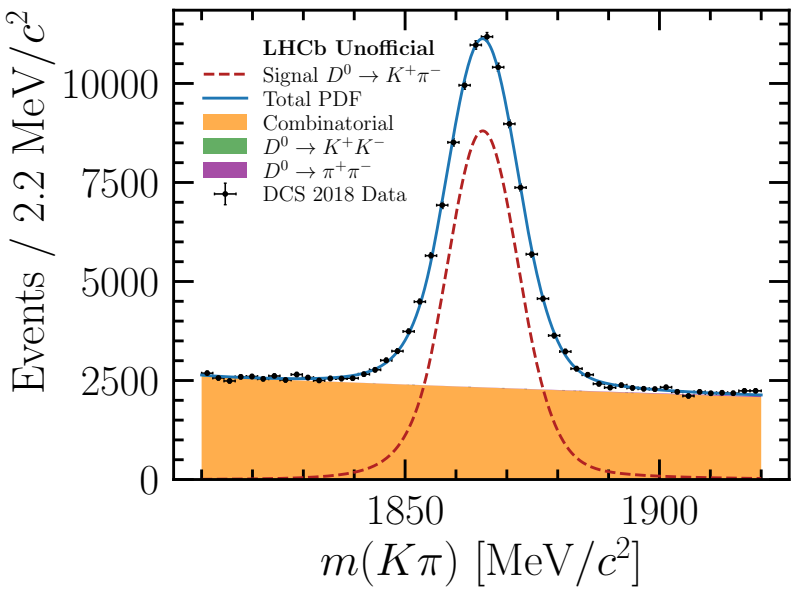
c. **Topology**: restricted aperture angle between the final-state tracks + veto on prompt D^0 candidates;

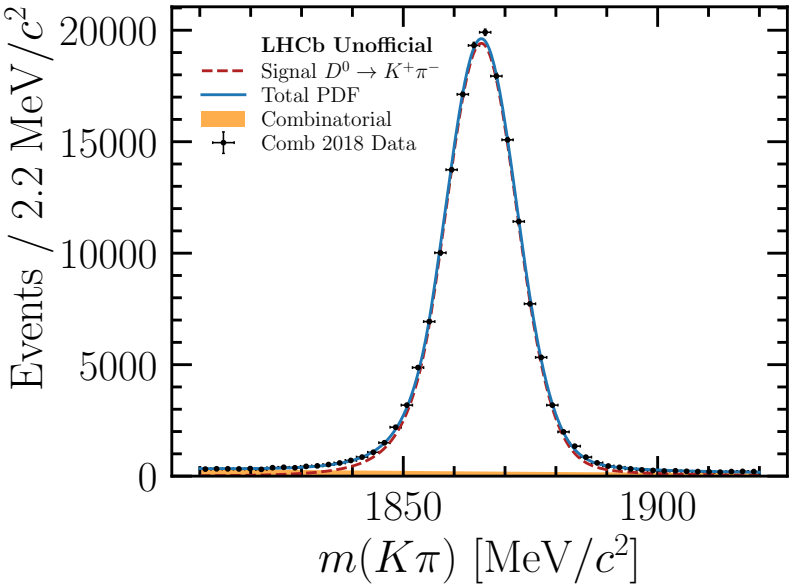
d. **Isolation:** MVA to distinguish signal tracks from rest of the event;

e. **Particle identification** (PID): combined sub-detector response to select muon-like high-p_{T} final-state tracks.

[LHCb-DP-2018-001] [JINST 3 (2008) S08005] [LHCb-DP-2014-002] [JINST 14 (2019) P04013]


×10^6
LHCb Unofficial
Signal $D^0 \to K^+\pi^-$
Total PDF
Combinatorial
CF 2018 Data
Events / 2.2 MeV/c^2
$m(K\pi)$ [MeV/c^2]


LHCb Unofficial
Signal $D^0 \to K^+\pi^-$
Total PDF
Combinatorial
$D^0 \to K^+K^-$
$D^0 \to \pi^+\pi^-$
DCS 2018 Data
Events / 2.2 MeV/c^2
$m(K\pi)$ [MeV/c^2]


LHCb Unofficial
Signal $D^0 \to K^+\pi^-$
Total PDF
Combinatorial
Comb 2018 Data
Events / 2.2 MeV/c^2
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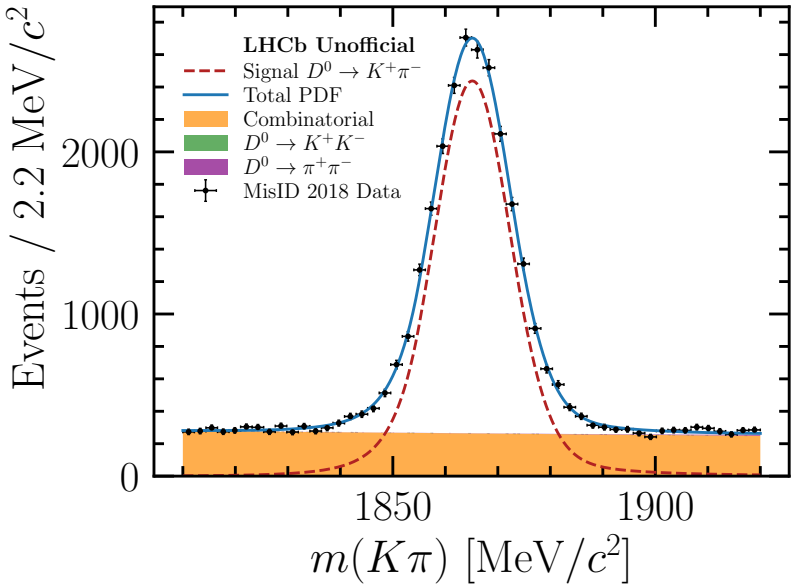
LHCb Unofficial
Signal $D^0 \to K^+\pi^-$
Total PDF
Combinatorial
$D^0 \to K^+K^-$
$D^0 \to \pi^+\pi^-$
MisID 2018 Data
Events / 2.2 MeV/c^2
$m(K\pi)$ [MeV/c^2]