Lepton Flavour Universality tests at LHCb:

Simultaneous $R(D^0)$ and $R(D^{*0})$ measurement with hadronic τ decays

8th RED LHC workshop
Universidad Complutense de Madrid (UCM)

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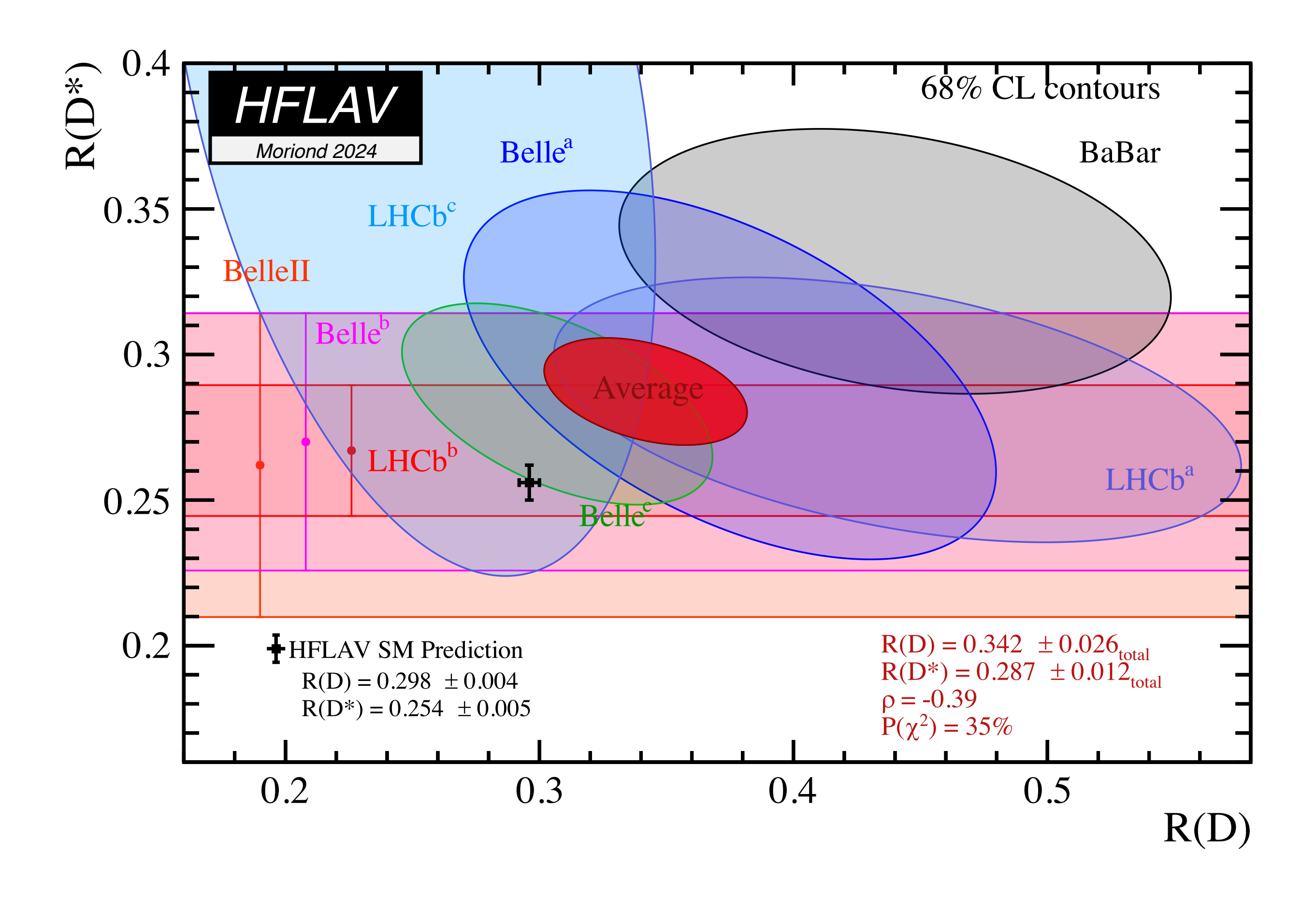
Outline

- Lepton Flavour Universality (LFU) tests: what are they and why are they important?
- LFU at the LHCb: Hadronic vs Muonic
- Simultaneous $R(D^0)$ and $R(D^{*0})$ hadronic measurement at LHCb
- Future prospects
- Conclusions



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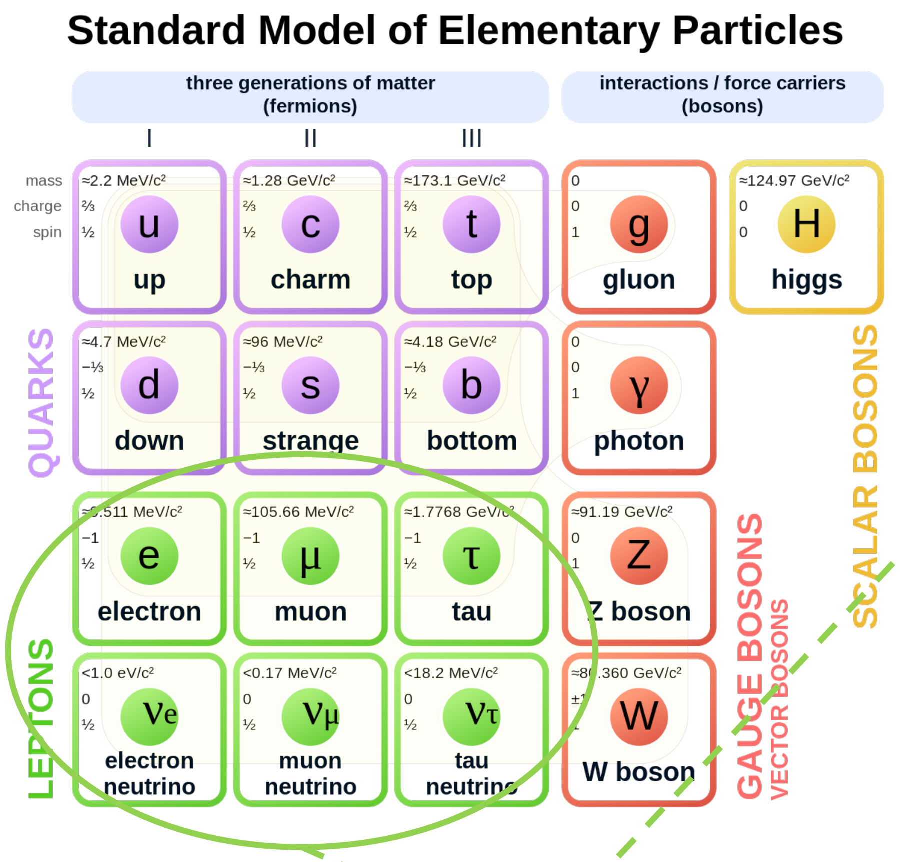
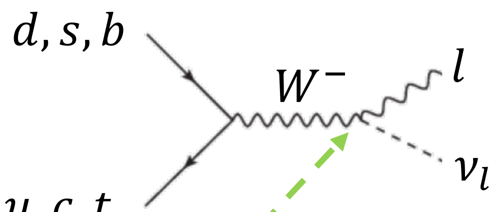
LFU: what is that and why do we care?





- No mixing between generations
- Same coupling for all generations

Differences in amplitudes of similar processes only depend on the mass of the leptons

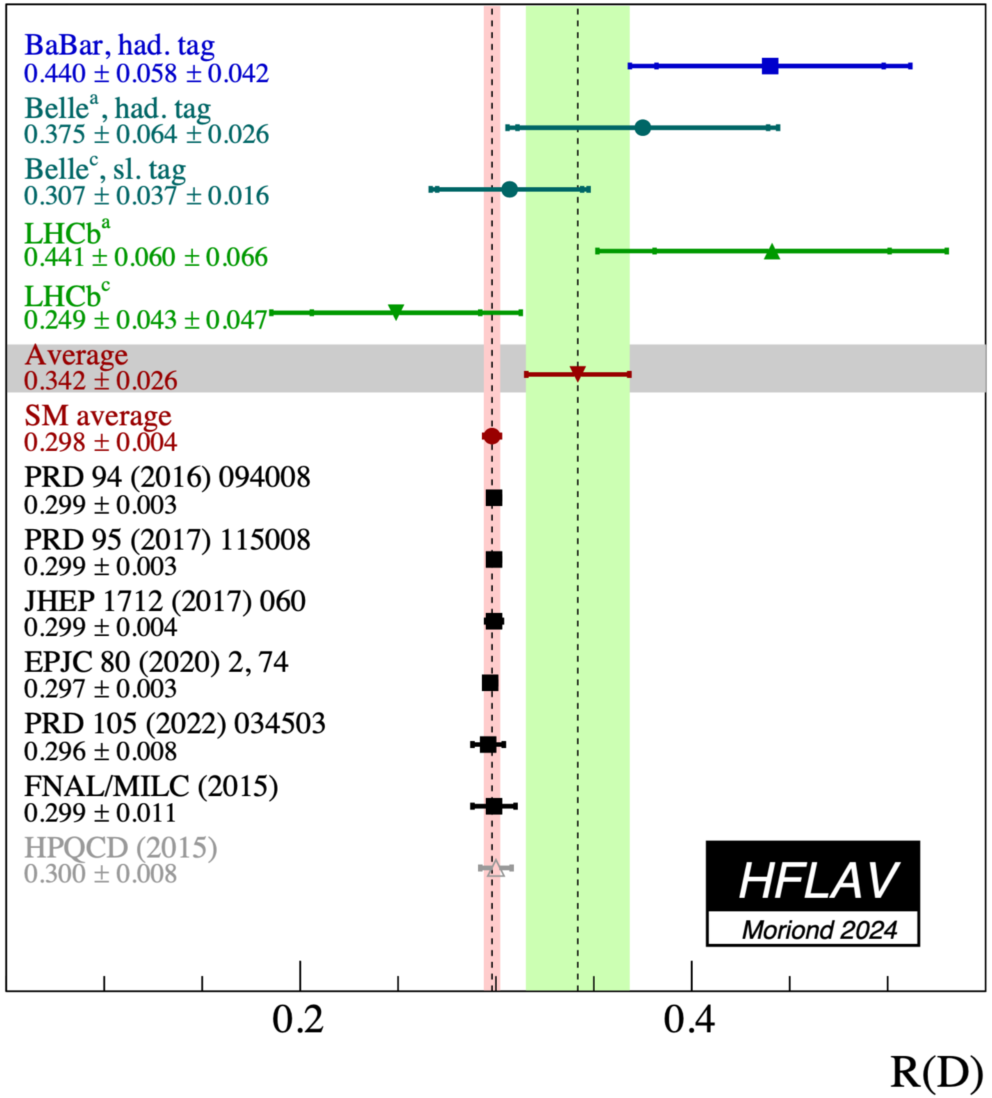
Theory predictions can be computed with high precision:

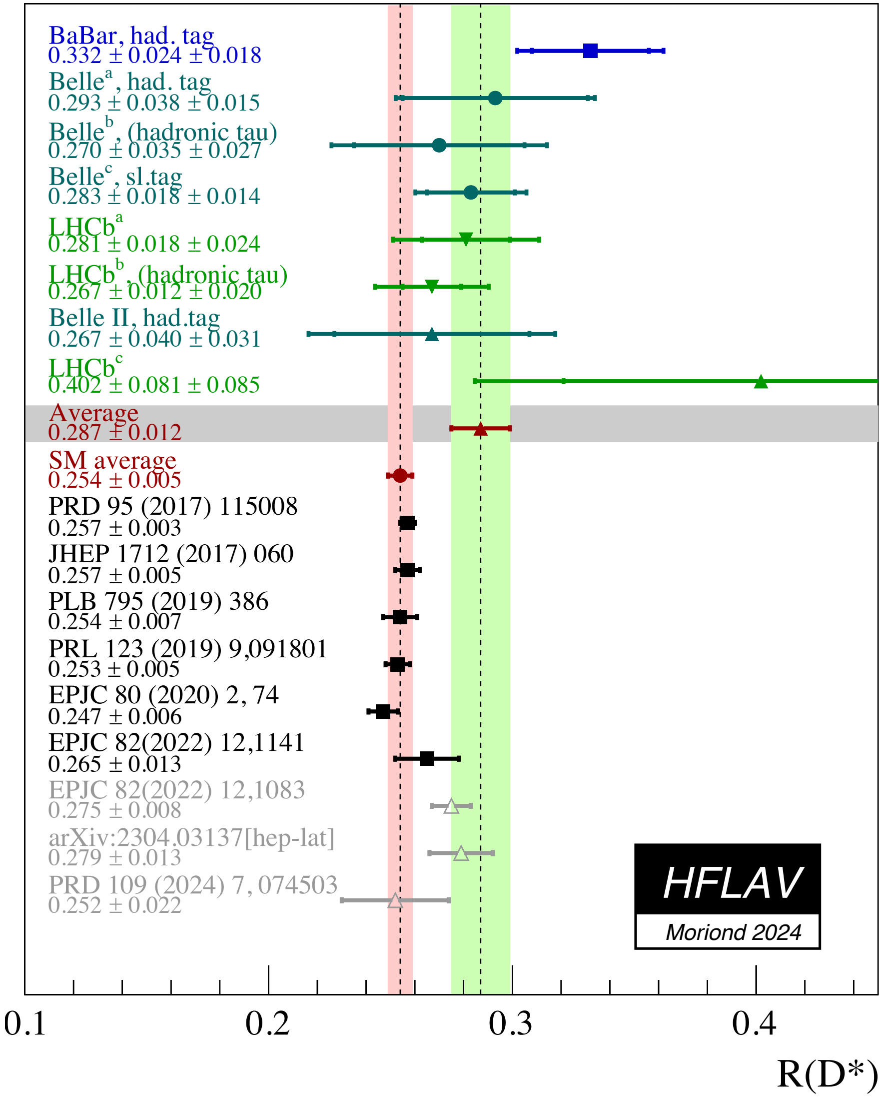
$$R(X_c) = \frac{BF(H_b \to X_c \tau\, \nu_\tau)}{BF(H_b \to X_c\, l\, \nu_l)}$$

Advantages of computing $R(X_c)$ ratios also are:

- Remove dependence on $|V_{cb}|$
- Partial cancellation of most experimental uncertainties
- Partial cancellation of theoretical uncertainties due to hadronic form-factors uncertainties

LFU: The big picture





$R(D^0) \rightarrow 1.6\sigma$ **from SM prediction**

$R(D^{*0}) \rightarrow 2.5\sigma$ **from SM prediction**

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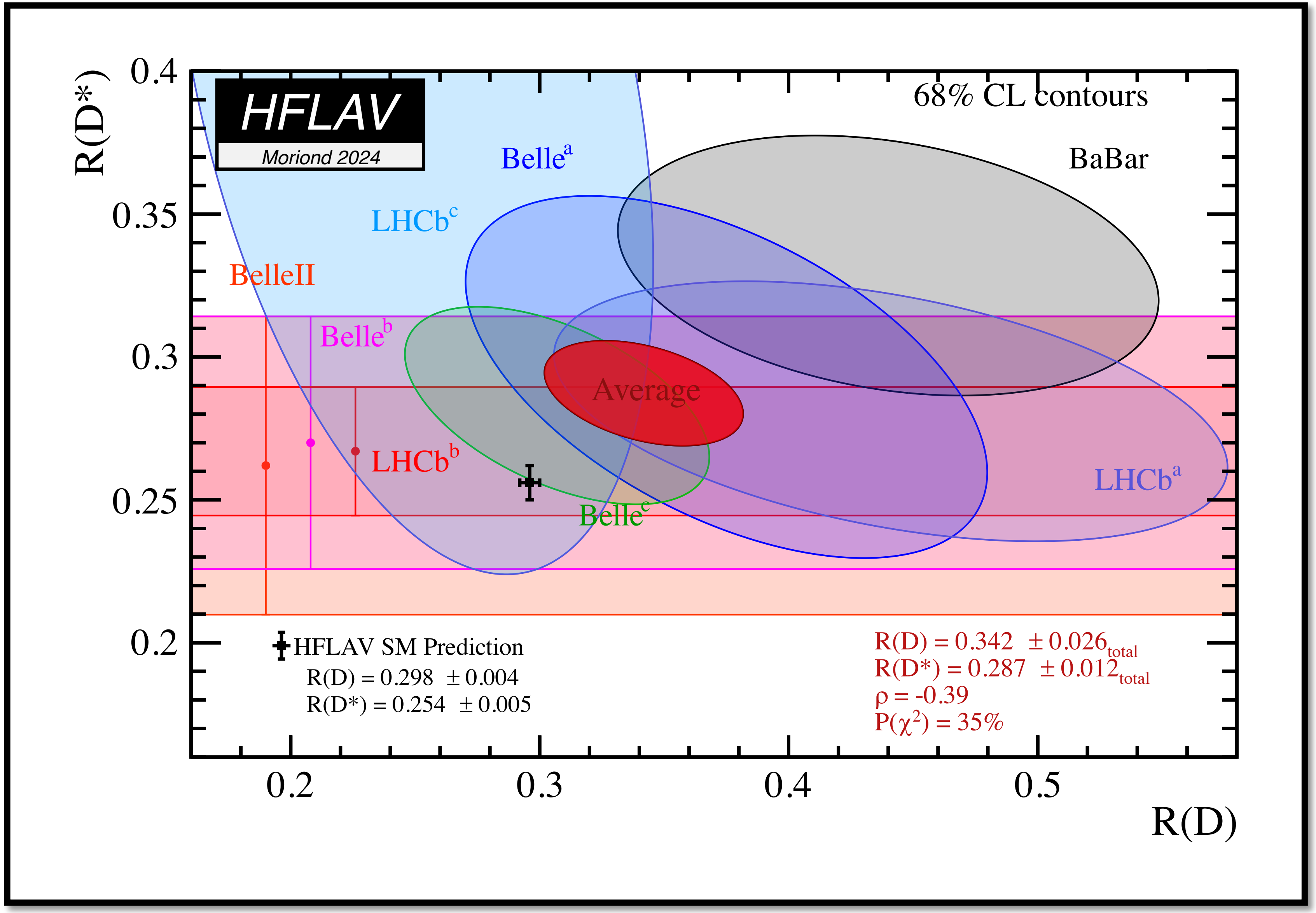
LFU: The *COMBINED* big picture



3.31σ from SM prediction

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LFU in LHCb: hadronic vs muonic

PDG 2023

$$R = \frac{BR(B \to X_c \tau^+ \nu_\tau)}{BR(B \to X_c l^+ \nu_l)}$$

$$R(D^0)_{SM} = 0.298 \pm 0.004,$$
$$R(D^{*0})_{SM} = 0.258 \pm 0.005.$$

Channel	$\mathcal{B}$ (%)
$\tau^- \to \mu^- \overline{\nu}_\mu \nu_\tau$	17.39 ± 0.04
$\tau^- \to e^- \overline{\nu}_e \nu_\tau$	17.82 ± 0.04
$\tau^- \to \pi^- \pi^0 \nu_\tau$	25.49 ± 0.09
$\tau^- \to \pi^- \nu_\tau$	10.82 ± 0.05
$\tau^- \to \pi^- \pi^+ \pi^- \nu_\tau$	9.02 ± 0.05
$\tau^- \to \pi^- \pi^+ \pi^- \pi^0 \nu_\tau$	4.49 ± 0.05

In LHCb we distinguish between two main approaches:

R hadronic: $\tau^- \to \pi^- \pi^+ \pi^- (\pi^0) \nu_\tau$

- 'Only' two neutrinos in the final state
- Three charged tracks enable tau vertex reconstruction
- Lower yields due to smaller BF

R muonic: $\tau^- \to \mu^- \overline{\nu}_\mu \nu_\tau$

- Same final state as normalization for the ratio
- Larger yields
- Challenging to distinguish μ from τ (3 neutrinos in the final state!)

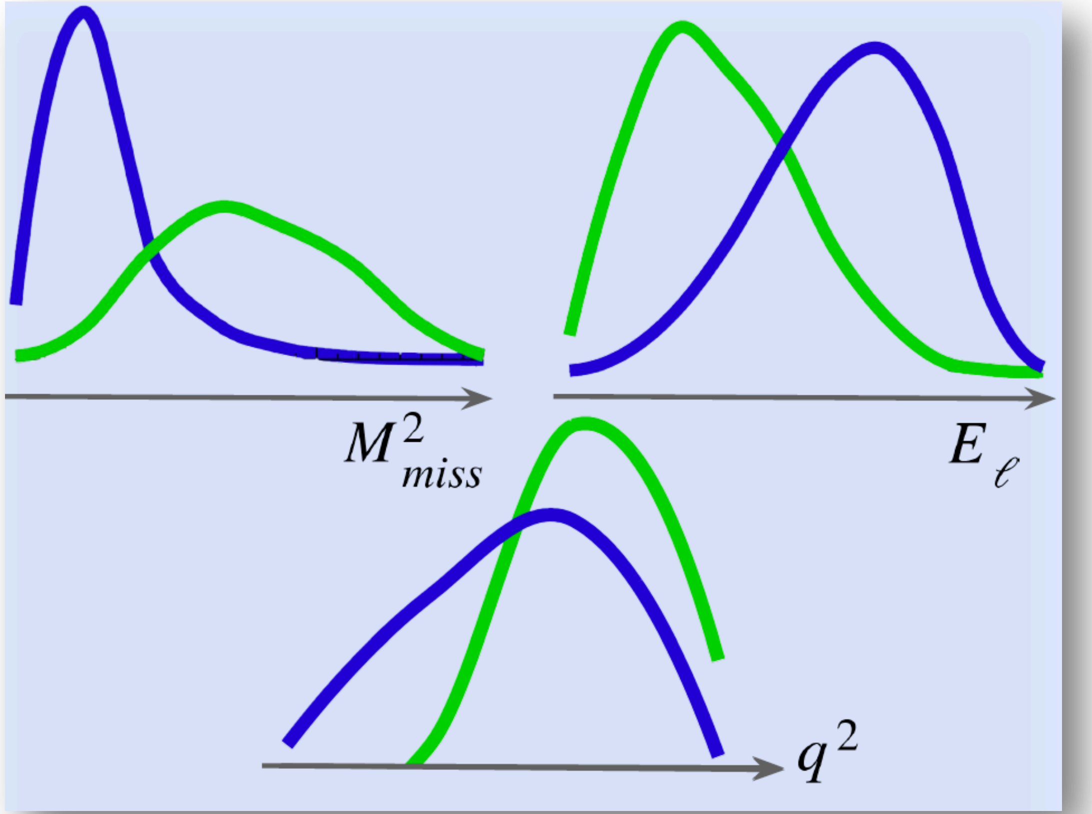
Muonic analysis: in a nutshell

Signal has 3 neutrinos that cannot be detected, while normalization channel has only one!

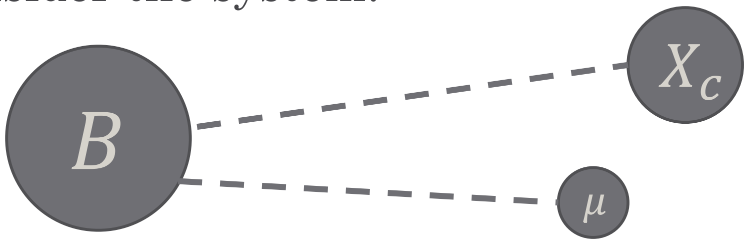
Signal: $B \to X_c\, \tau\, \nu_\tau$

$\qquad \tau \to \mu\, \nu_\tau\, \bar{\nu}_\mu$

Normalization: $B \to X_c\, \mu\, \nu_\mu$



Consider the system:



Good observables to distinguish contributions are:

- Muon energy in the B rest frame: $\boldsymbol{E_l}$
- Missing mass squared:
  $$\mathbf{M^2_{miss}} = (\boldsymbol{p_B} - \boldsymbol{p_{X_c}} - \boldsymbol{p_\mu})^2$$
- Squared momenta transfer:
  $$\boldsymbol{q^2} = (\boldsymbol{p_B} - \boldsymbol{p_D})^2$$

LFU in LHCb: hadronic vs muonic

PDG 2023

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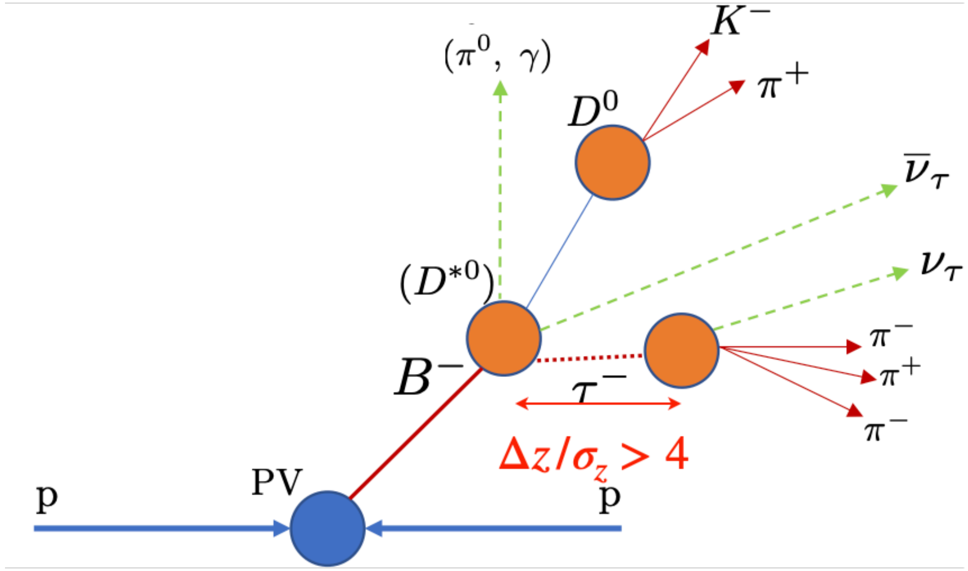
NOT IN THIS TALK

Hadronic analysis

$$R(D^{(*)0}) = \frac{BR(B^+ \to D^{(*)0}\tau^+\nu_\tau)}{BR(B^+ \to D^{(*)0}l^+\nu_l)}$$



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Using 3-prong hadronic decays:

- Despite having lower BF, it offers an easier reconstruction.
- Similar topology to normalization channel, which allow us to reduce systematics

In practice, as usual, we compute this as a dual ratio using a control channel

$$R(D^{(*)0}) = \frac{BR(B^+ \to D^{(*)0}\tau^+\nu_\tau)}{BR(B^+ \to D^{(*)0}l^+\nu_l)} = \frac{BR(B^+ \to D^{(*)0}\tau^+\nu_\tau)}{BR(B^+ \to D^0 D_s^+)} \frac{BR(B^+ \to D^0 D_s^+)}{BR(B^+ \to D^{(*)0}l^+\nu_l)}$$

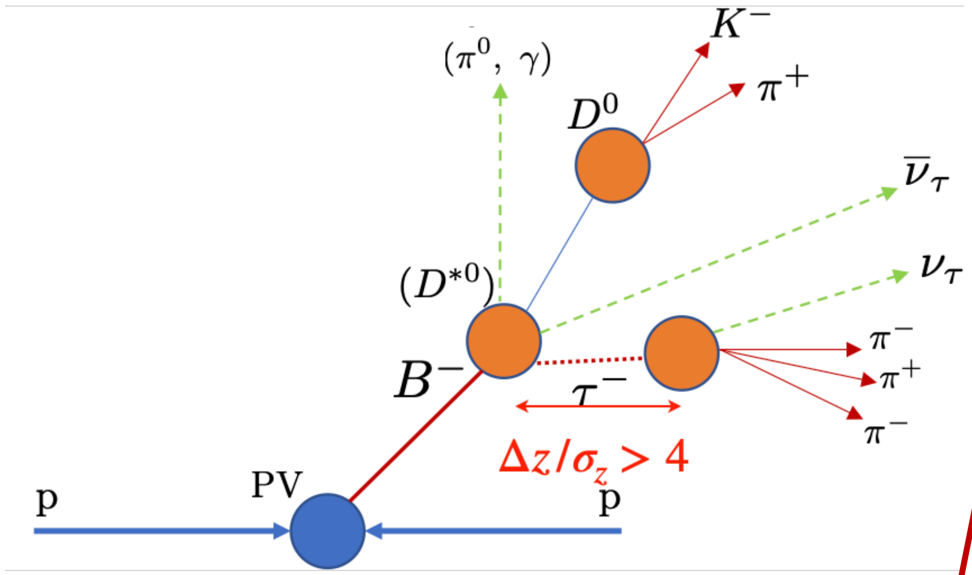
External inputs

Normalization channel

Analysis strategy

External Inputs

$$R(D^{(*)0}) = \frac{BR(B^+ \to D^{(*)0}\tau^+\nu_\tau)}{BR(B^+ \to D^{(*)0}l^+\nu_l)} = \frac{BR(B^+ \to D^{(*)0}\tau^+\nu_\tau)}{BR(B^+ \to D^0 D_s^+)} \frac{BR(B^+ \to D^0 D_s^+)}{BR(B^+ \to D^{(*)0}l^+\nu_l)}$$



Invariant mass fit:
Control channel much cleaner with almost no background from other sources

Run II analysis (2016-2018 data)

3D simultaneous signal fit to properly identify all components:

- **τ decay time:** sensitivity to discriminate against prompt and other charm decays
- $q^2 = (p_B - p_{D^0})^2$ **momenta transfer:** discriminates between the D^0 and D^{*0} signal
- **BDT ouput:** trained against $B \to D^{(*)} D_s^+(X)$ decays to discriminate most relevant background

The BDT

$q^2 = (p_B - p_{D^0})^2$

$\tau \to \pi^+\pi_1^-\pi_2^-$

BDT trained to **reject dominant $B \to D^{(*)}D_s^+(X)$** backgrounds

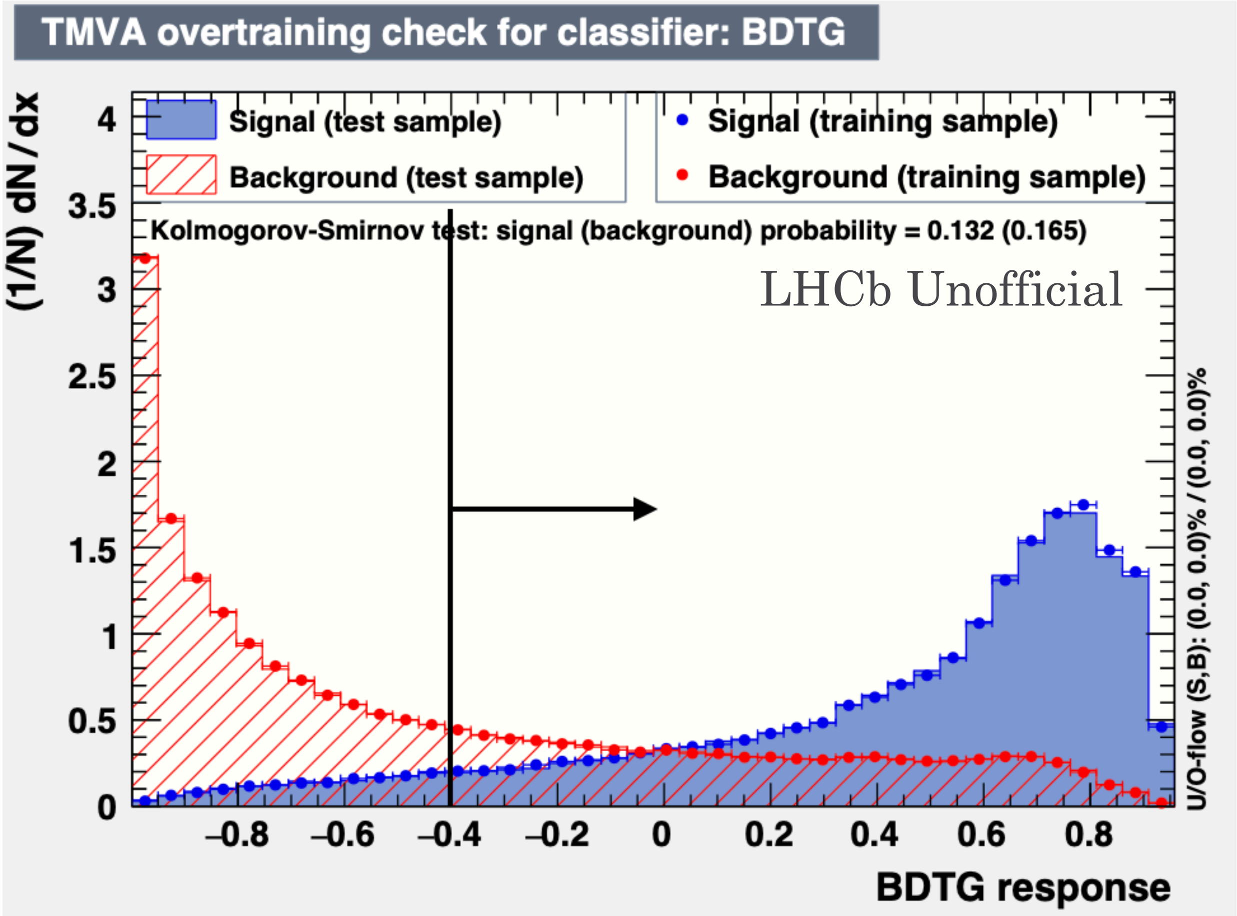
Variables chosen to be uncorrelated to q^2 and t_τ (nominal fit variables)

Soft cut on BDT output selected, as it is also used as a third variable in the nominal fit

BDT variables:
- $\min[m_{\pi_1^-\pi^+}, m_{\pi^+\pi_2^-}]$
- $\max[m_{\pi_1^-\pi^+}, m_{\pi^+\pi_2^-}]$
- $m_{\pi^-\pi^-}$
- $\frac{p_t(\gamma)}{p_t(3\pi)+p_t(\gamma)}$
- $N_\gamma(\Delta R < 0.4)$, where ΔR is the radius of the cone around γ

Best cut selected maximizing

$$FoM = \frac{S}{\sqrt{S+B}}\epsilon_S$$

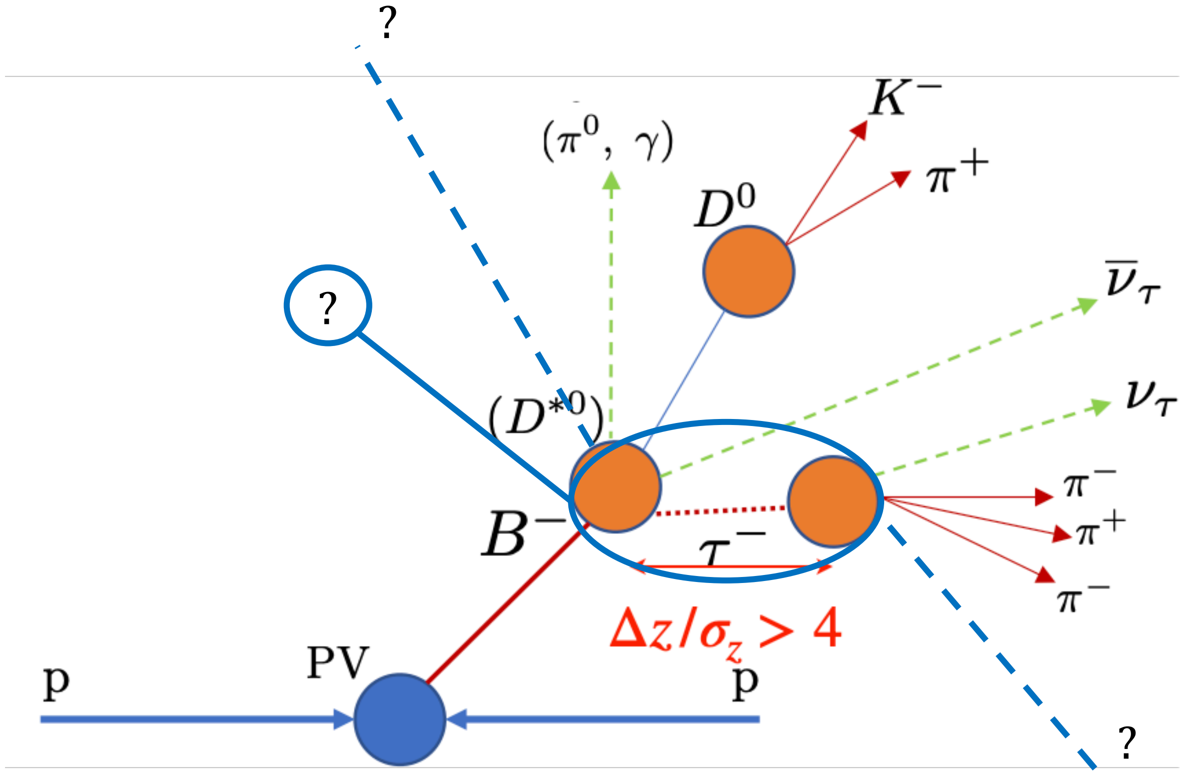


Background studies. Control samples:

Despite all the selection steps, an important portion of the data sample is still dominated by background events. These are modelled using templates extracted from simulated events.

Data control samples are produced to improve background modelling. The backgrounds components considered are:

- $B \to \overline{D}^0 D_S^+(X)$ decays
  - $B \to \overline{D}^0 D_S^+(X)$ with $D_S \to 3\pi(X)$
- $B \to \overline{D}^0 D^+(X)$ decays
- $B \to \overline{D}^0 D^0(X)$ decays
- $B \to \overline{D}^0 3\pi(X)$ prompt decays



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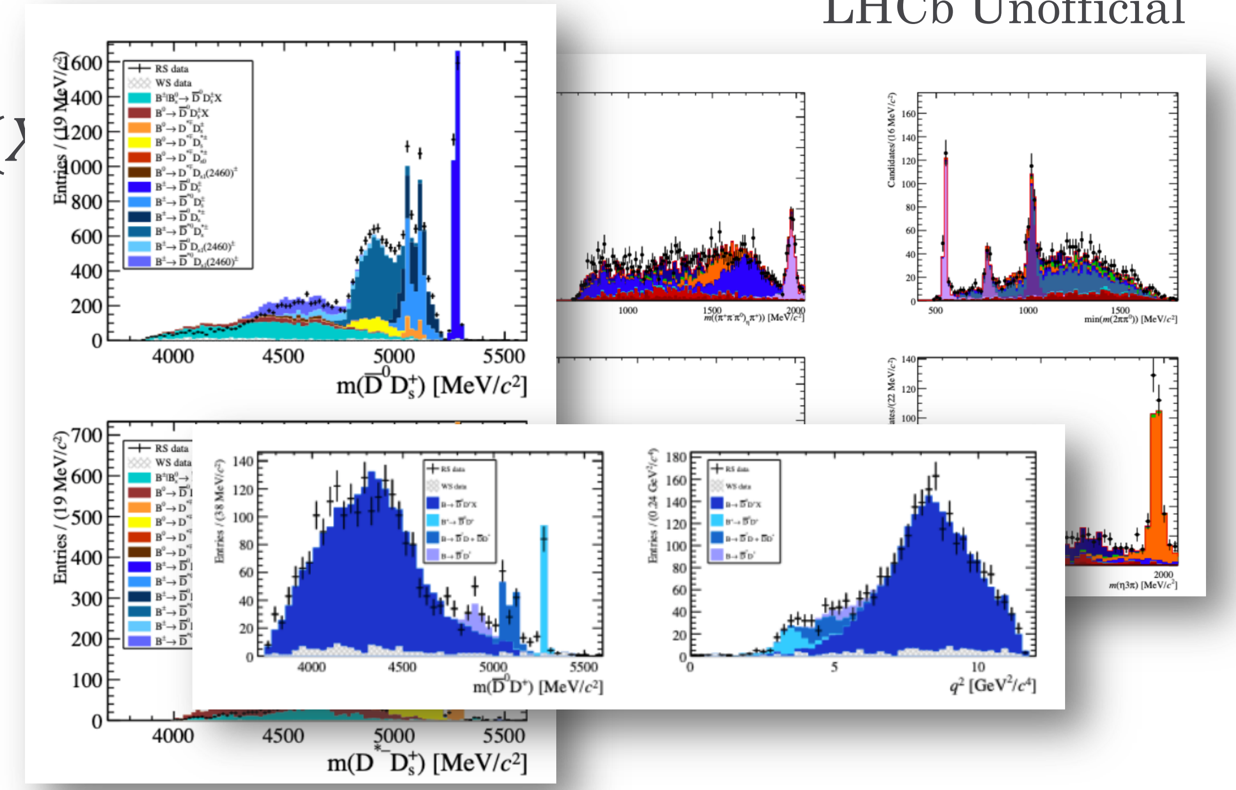


Control samples: $B \to \overline{D}^0 D_S^+(X)$ events

Control sample for $\overline{D}^0 D_s^+$ selected by studying the events with $m(3\pi) = \pm 20$ MeV/c^2 around the D_s^+ mass.
The control sample is split in two:

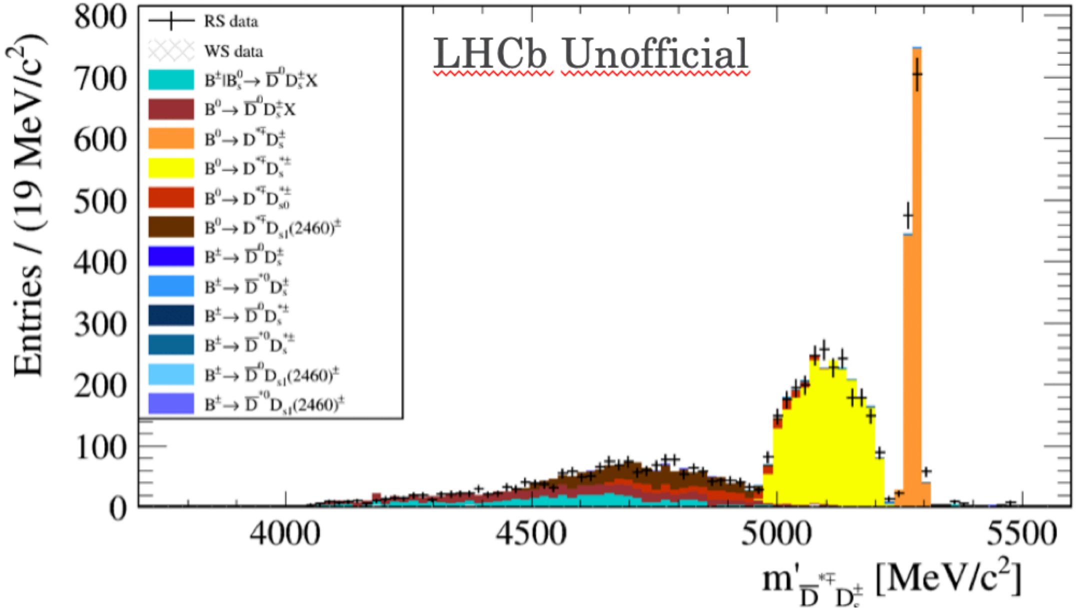
- $\overline{D}^0 D_s^+$ sample by adding a D^{*-} veto
- $D^{*-} D_s^+$ sample by studying events with $m\left(\overline{D}^0 \pi^-\right) - m\left(\overline{D}^0\right) = [143{,}148]$MeV/c^2 (anti D^{*-} veto)

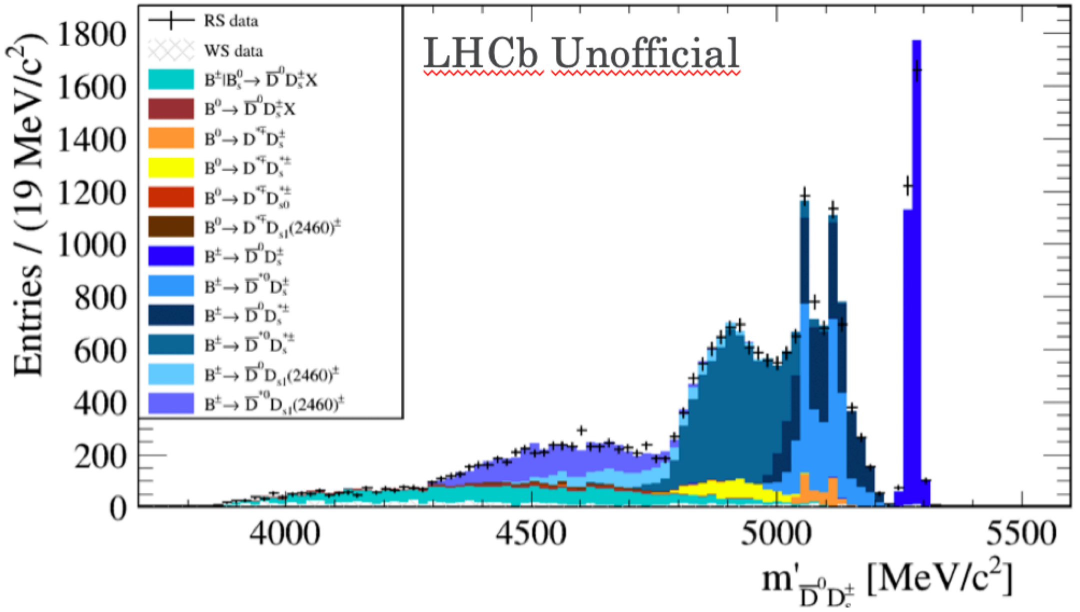
- Simultaneous fit of $m(\overline{D}^0 D_s^+)$ and $m(D^{*-} D_s^+)$ to extract ratios between all components:

Component	Yield
$B^+ \to \overline{D}^0 D_s^+$	$N_{D_s^+}^{(\overline{D}^0 D_s^+)} \times \varepsilon_{B^+ \to \overline{D}^0 D_s^+} \times r_{B^+ \to \overline{D}^0 D_s^+}^{D_s^+} / \sum_i r_i^{D_s^+}$
$B^+ \to \overline{D}^{*0} D_s^+$	$N_{D_s^+}^{(\overline{D}^0 D_s^+)} \times \varepsilon_{B^+ \to \overline{D}^{*0} D_s^+} \times r_{B^+ \to \overline{D}^{*0} D_s^+}^{D_s^+} / \sum_i r_i^{D_s^+}$
$B^+ \to \overline{D}^0 D_s^{*+}$	$N_{D_s^+}^{(\overline{D}^0 D_s^+)} \times \varepsilon_{B^+ \to \overline{D}^0 D_s^{*+}} \times r_{B^+ \to \overline{D}^0 D_s^{*+}}^{D_s^+} / \sum_i r_i^{D_s^+}$
$B^+ \to \overline{D}^{*0} D_s^{*+}$	$N_{D_s^+}^{(\overline{D}^0 D_s^+)} \times \varepsilon_{B^+ \to \overline{D}^{*0} D_s^{*+}} \times r_{B^+ \to \overline{D}^{*0} D_s^{*+}}^{D_s^+} / \sum_i r_i^{D_s^+}$
$B^+ \to \overline{D}^0 D_{s1}(2460)^+$	$N_{D_s^+}^{(\overline{D}^0 D_s^+)} \times \varepsilon_{B^+ \to \overline{D}^0 D_{s1}(2460)^+} \times r_{B^+ \to \overline{D}^0 D_{s1}(2460)^+}^{D_s^+} / \sum_i r_i^{D_s^+}$
$B^+ \to \overline{D}^{*0} D_{s1}(2460)^+$	$N_{D_s^+}^{(\overline{D}^0 D_s^+)} \times \varepsilon_{B^+ \to \overline{D}^{*0} D_{s1}(2460)^+} \times r_{B^+ \to \overline{D}^{*0} D_{s1}(2460)^+}^{D_s^+} / \sum_i r_i^{D_s^+}$
$B^+ \| B_s^0 \to \overline{D}^0 D_s^+ X$	$N_{D_s^+}^{(\overline{D}^0 D_s^+)} \times \varepsilon_{B^+ \| B_s^0 \to \overline{D}^0 D_s^+ X} \times r_{B^+ \| B_s^0 \to \overline{D}^0 D_s^+ X}^{D_s^+} / \sum_i r_i^{D_s^+}$
$B^0 \to \overline{D}^0 D_s^+ X$	$N_{D_s^+}^{(\overline{D}^0 D_s^+)} \times \varepsilon_{B^0 \to \overline{D}^0 D_s^+ X} \times r_{B^0 \to \overline{D}^0 D_s^+ X}^{D_s^+} / \sum_i r_i^{D_s^+}$
$B^0 \to D^{*-} D_s^+$	$N_{D_s^+}^{(\overline{D}^0 D_s^+)} \times \varepsilon_{B^0 \to D^{*-} D_s^+} \times r_{B^0 \to D^{*-} D_s^+}^{D_s^+} / \sum_i r_i^{D_s^+}$
$B^0 \to D^{*-} D_s^{*+}$	$N_{D_s^+}^{(\overline{D}^0 D_s^+)} \times \varepsilon_{B^0 \to D^{*-} D_s^{*+}} \times r_{B^0 \to D^{*-} D_s^+}^{D_s^+} \times r_{B^0 \to D^{*-} D_s^{*+}}^{*D_s^+} / \sum_i r_i^{D_s^+}$
$B^0 \to D^{*-} D_{s0}^*(2317)^+$	$N_{D_s^+}^{(\overline{D}^0 D_s^+)} \times \varepsilon_{B^0 \to D^{*-} D_{s0}^*(2317)^+} \times r_{B^0 \to D^{*-} D_s^+}^{D_s^+} \times r_{B^0 \to D^{*-} D_{s0}^*(2317)^+}^{*D_s^+} / \sum_i r_i^{D_s^+}$
$B^0 \to D^{*-} D_{s1}(2460)^+$	$N_{D_s^+}^{(\overline{D}^0 D_s^+)} \times \varepsilon_{B^0 \to D^{*-} D_{s1}(2460)^+}^{D_s^+} \times r_{B^0 \to D^{*-} D_s^+}^{D_s^+} \times r_{B^0 \to D^{*-} D_{s1}(2460)^+}^{*D_s^+} / \sum_i r_i^{D_s^+}$

Control samples: $B \to \overline{D}^0 D_s^+(X)$ events

Simultaneous fit produces ratios between components that are used as weights in the nominal fit

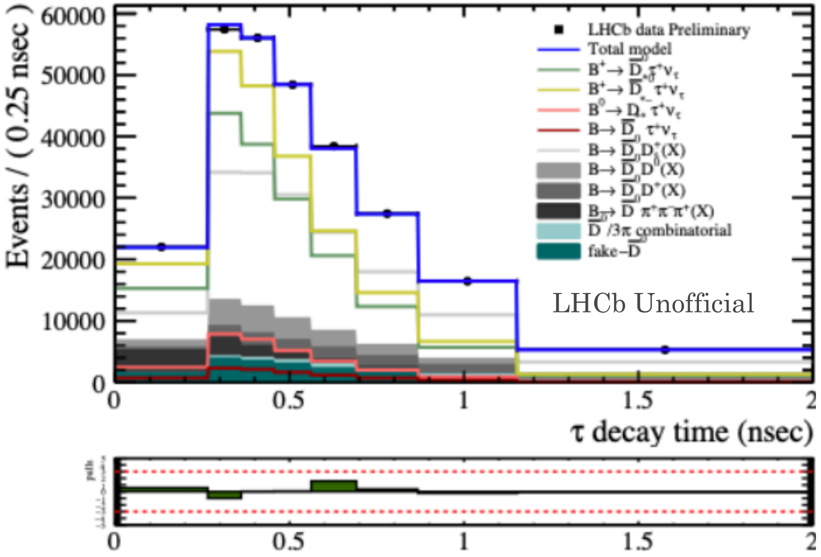


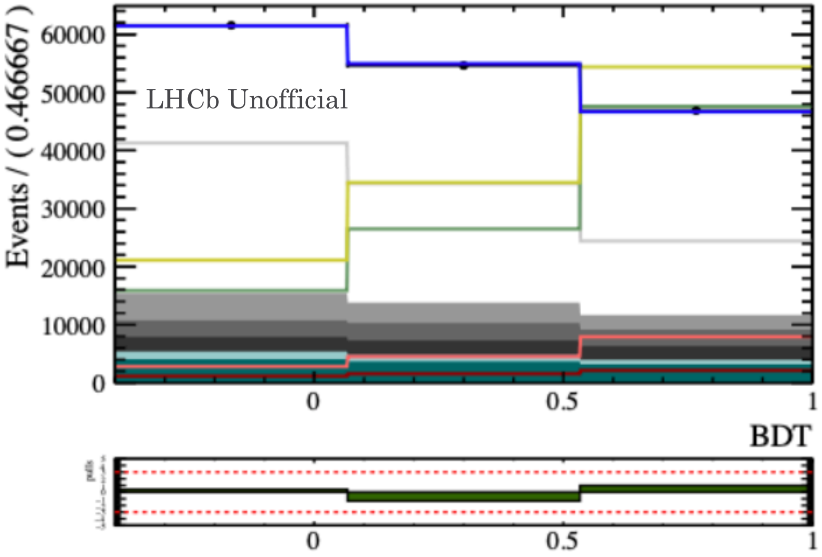


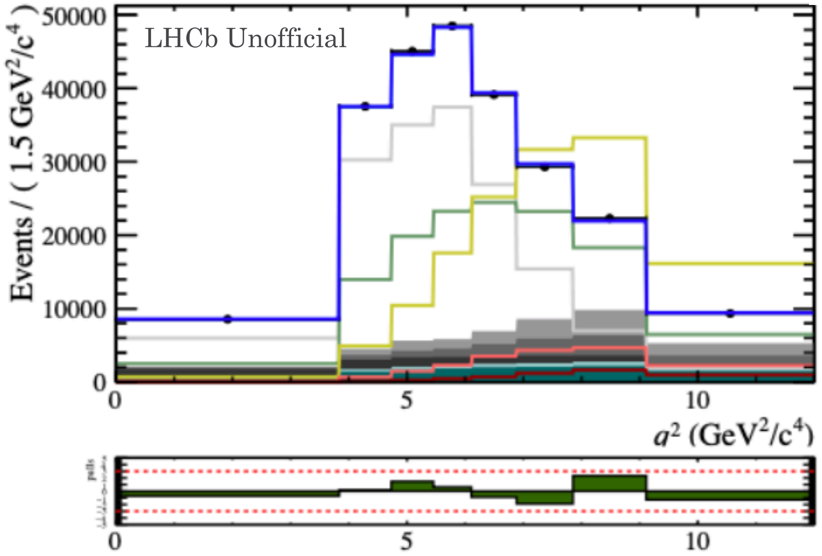
These ratios enter as weights in the MC to generate background teamplates in the signal fit.

Some of these components enter in the fit gaussianly constrained using their uncertainty

Signal fit: Results







Signal components as well as the D_s^+ background randomly scaled to blind the results.

Parameter	Fit result	Constraint
$N(B^+ \to \bar{D}^0\tau^+\nu_\tau)$	xxx ± 1572	
$N(B^+ \to \bar{D}^{*0}\tau^+\nu_\tau)$	xxx ± 956	
$N_{D_s^+}$	xxx ± 982	
$N_{\text{sv}}(B \to \bar{D}^0 D^0(X))$	2742 ± 392	2844 ± 427
$N_{\text{dv}}(B \to \bar{D}^0 D^0(X))$	8008 ± 621	
$N(B \to \bar{D}^0 D^+(X))$	8743 ± 508	
$N(B \to \bar{D}^0 3\pi(X))$	7260 ± 265	
$N_{\text{fake}-\bar{D}^0}$	10902	10902
N_{combi}	3247	3247
$r^{D_s^+}_{B^+\to\bar{D}^{*0}D_s^+}$	0.960 ± 0.036	0.894 ± 0.056
$r^{D_s^+}_{B^+\to\bar{D}^0 D_s^{*+}}$	0.894 ± 0.042	0.949 ± 0.057
$r^{D_s^+}_{B^+\to\bar{D}^{*0}D_s^{*+}}$	1.829 ± 0.042	1.828 ± 0.048
$r^{D_s^+}_{B^+\to\bar{D}^0 D_{s1}(2460)^+}$	0.337 ± 0.033	0.338 ± 0.039
$r^{D_s^+}_{B^+\to\bar{D}^{*0}D_{s1}(2460)^+}$	0.682 ± 0.030	0.706 ± 0.042
$r^{D_s^+}_{B^+\vert B_s^0\to\bar{D}^0 D_s^+ X}$	0.845 ± 0.038	0.836 ± 0.042
$r^{D_s^+}_{B^0\to D^{*-}D_s^+}$	0.118	0.118
$r^{D_s^+}_{B^0\to D^{*-}D_s^+ X}$	0.088	0.088
$r^{*D_s^+}_{B^0\to D^{*-}D_s^{*+}}$	1.726	1.726
$r^{*D_s^+}_{B^0\to D^{*-}D_{s0}^*(2317)^+}$	0.137	0.137
$r^{*D_s^+}_{B^0\to D^{*-}D_{s1}(2460)^+}$	0.414	0.414
$f_{3\pi}^{D^0}$	0.835	0.835
$f_{3\pi}^{D^{*0}}$	0.842	0.842
$f_{3\pi}^{D^{*-}}$	0.857	0.857
$f_{D^{**}/D^{*0}}$	0.044	0.044
$f_{D^{*-}/D^{*0}}$	0.138	0.138
$w^{D_s^+}_{\text{BDT}_{\text{Dalitz}}}$	0.073 ± 0.033	

Table 38: Results of the nominal 3D fit.

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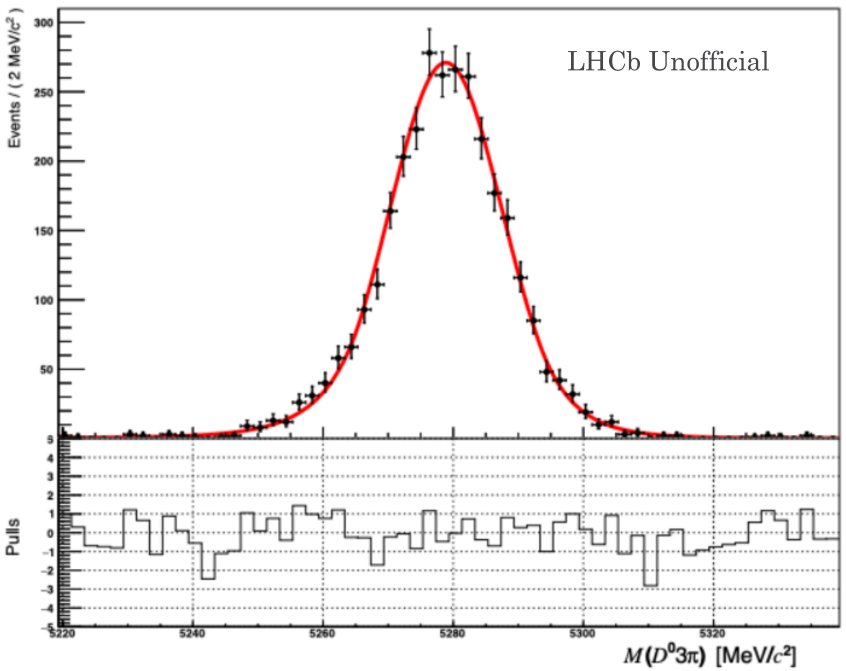
Normalization fit: Results

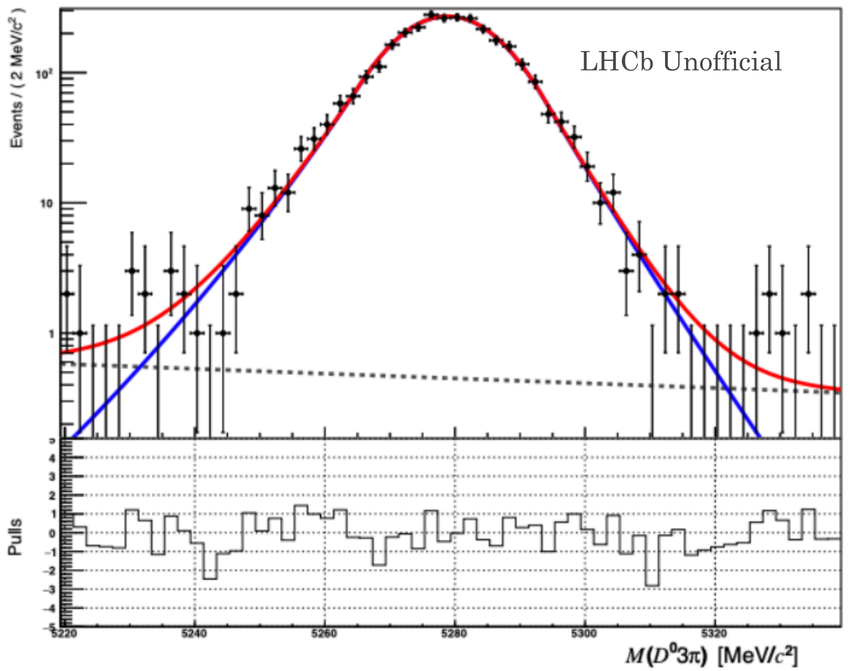
Normalization yield extracted from a fit on the deconvoluted mass:

$$m(\overline{D}^0 D_s^+) \equiv M(\overline{D}^0 D_s^+) - M(\overline{D}^0) - M(D_s^+) + m_{\text{PDG}}(\overline{D}^0) + m_{\text{PDG}}(D_s^+),$$

- Crystall Ball (Normalization) + Exponential (Background) model used to describe the data. With CB tail parameters fixed from fit in simualtion

Parameter	Fit result (MC)	Fit result (data)
N_{norm}	162650 ± 400	3047 ± 56
m_{mean}	5279.455 ± 0.026	5278.87 ± 0.17
σ	8.288 ± 0.030	8.66 ± 0.14
α_R	-1.674 ± 0.031	-1.674 (fixed)
α_L	1.510 ± 0.023	1.510 (fixed)
n_R	44 ± 17	44 (fixed)
n_L	15.7 ± 2.0	15.7 (fixed)
N_{bkg}	-	27 ± 10
r_{bkg}	-	-0.0043 ± 0.0068

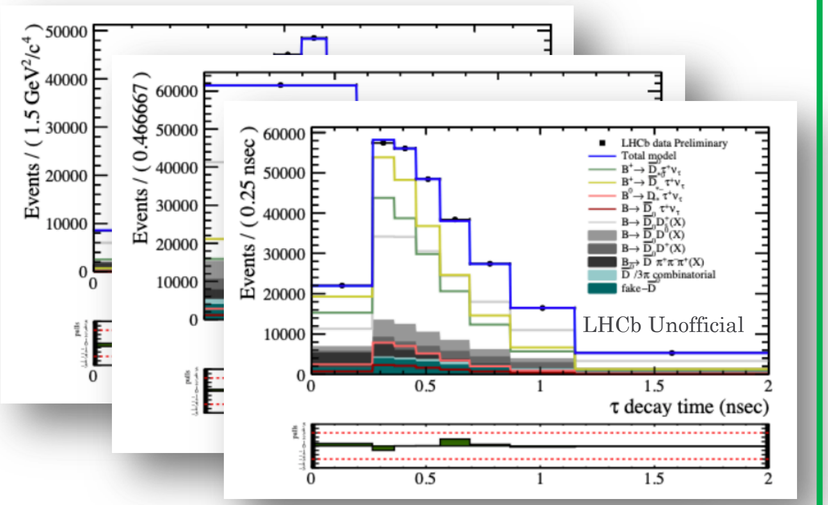




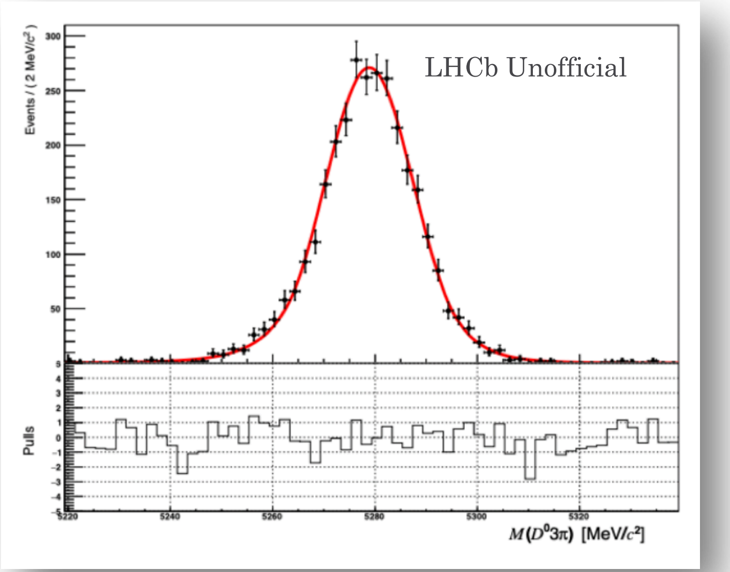
Gathering all the ingredients

$$R(D^{(*)0}) = \frac{BR(B^+ \to D^{(*)0}\tau^+\nu_\tau)}{BR(B^+ \to D^{(*)0}l^+\nu_l)} = \frac{BR(B^+ \to D^{(*)0}\tau^+\nu_\tau)}{BR(B^+ \to D^0 D_s^+)} \frac{BR(B^+ \to D^0 D_s^+)}{BR(B^+ \to D^{(*)0}l^+\nu_l)}$$

particle data group



Decay	ε_{gen} Up/Down	$\varepsilon_{\text{filtering}}$	$\varepsilon_{\text{Stripping}}$ $(\times 10^{-2})$	$\varepsilon_{\text{offline}}$	$\varepsilon_{\text{Total}}$ $(\times 10^{-5})$
$B^+ \to \overline{D}^0\tau^+\nu_\tau$ $\tau^+ \to \pi^+\pi^-\pi^+\overline{\nu}_\tau$	0.04178 ± 0.00011 / 0.04186 ± 0.00011	0.0501	0.116	0.089	10.36 ± 0.04
$B^+ \to \overline{D}^0\tau^+\nu_\tau$, $\tau^+ \to \pi^+\pi^-\pi^+\pi^0\overline{\nu}_\tau$	0.037156 ± 0.000099 / 0.037107 ± 0.000097	0.0494	0.096	0.043	4.11 ± 0.02
$B^+ \to \overline{D}^{*0}\tau^+\nu_\tau$, $\tau^+ \to \pi^+\pi^-\pi^+\overline{\nu}_\tau$	0.04004 ± 0.00010 / 0.04032 ± 0.00011	0.0493	0.111	0.080	8.82 ± 0.03
$B^+ \to \overline{D}^{*0}\tau^+\nu_\tau$, $\tau^+ \to \pi^+\pi^-\pi^+\pi^0\overline{\nu}_\tau$	0.036045 ± 0.000096 / 0.036071 ± 0.000096	0.0488	0.093	0.036	3.32 ± 0.02
$B^0 \to D^{*-}\tau^+\nu_\tau$, $\tau^+ \to \pi^+\pi^-\pi^+\overline{\nu}_\tau$	0.1601 ± 0.0022 / 0.1592 ± 0.0022	0.0227	0.149	0.012	1.84 ± 0.03
$B^0 \to D^{*-}\tau^+\nu_\tau$, $\tau^+ \to \pi^+\pi^-\pi^+\pi^0\overline{\nu}_\tau$	0.1559 ± 0.0021 / 0.1578 ± 0.0022	1.0	0.108	0.0057	0.61 ± 0.02
$B^- \to D^0 D_s^-$, $D_s^- \to \pi^-\pi^+\pi^-$	0.05980 ± 0.00015 / 0.05992 ± 0.00015	0.0614	0.241	0.174	42.10 ± 0.13



Decay	ε_{gen} Up/Down	$\varepsilon_{\text{filtering}}$	$\varepsilon_{\text{Stripping}}$ $(\times 10^{-2})$	$\varepsilon_{\text{offline}}$	$\varepsilon_{\text{Total}}$ $(\times 10^{-5})$
$B^+ \to \overline{D}^0\tau^+\nu_\tau$ $\tau^+ \to \pi^+\pi^-\pi^+\overline{\nu}_\tau$	0.04178 ± 0.00011 / 0.04186 ± 0.00011	0.0501	0.116	0.089	10.36 ± 0.04
$B^+ \to \overline{D}^0\tau^+\nu_\tau$, $\tau^+ \to \pi^+\pi^-\pi^+\pi^0\overline{\nu}_\tau$	0.037156 ± 0.000099 / 0.037107 ± 0.000097	0.0494	0.096	0.043	4.11 ± 0.02
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$$R(D^0) = xx \pm 0.081\ (\text{stat.}) \pm 0.062\ (\text{syst.}) \pm 0.034\ (\text{ext.})$$
$$R(D^{*0}) = xx \pm 0.024\ (\text{stat.}) \pm 0.018\ (\text{syst.}) \pm 0.029\ (\text{ext.})$$

Systematic uncertainties

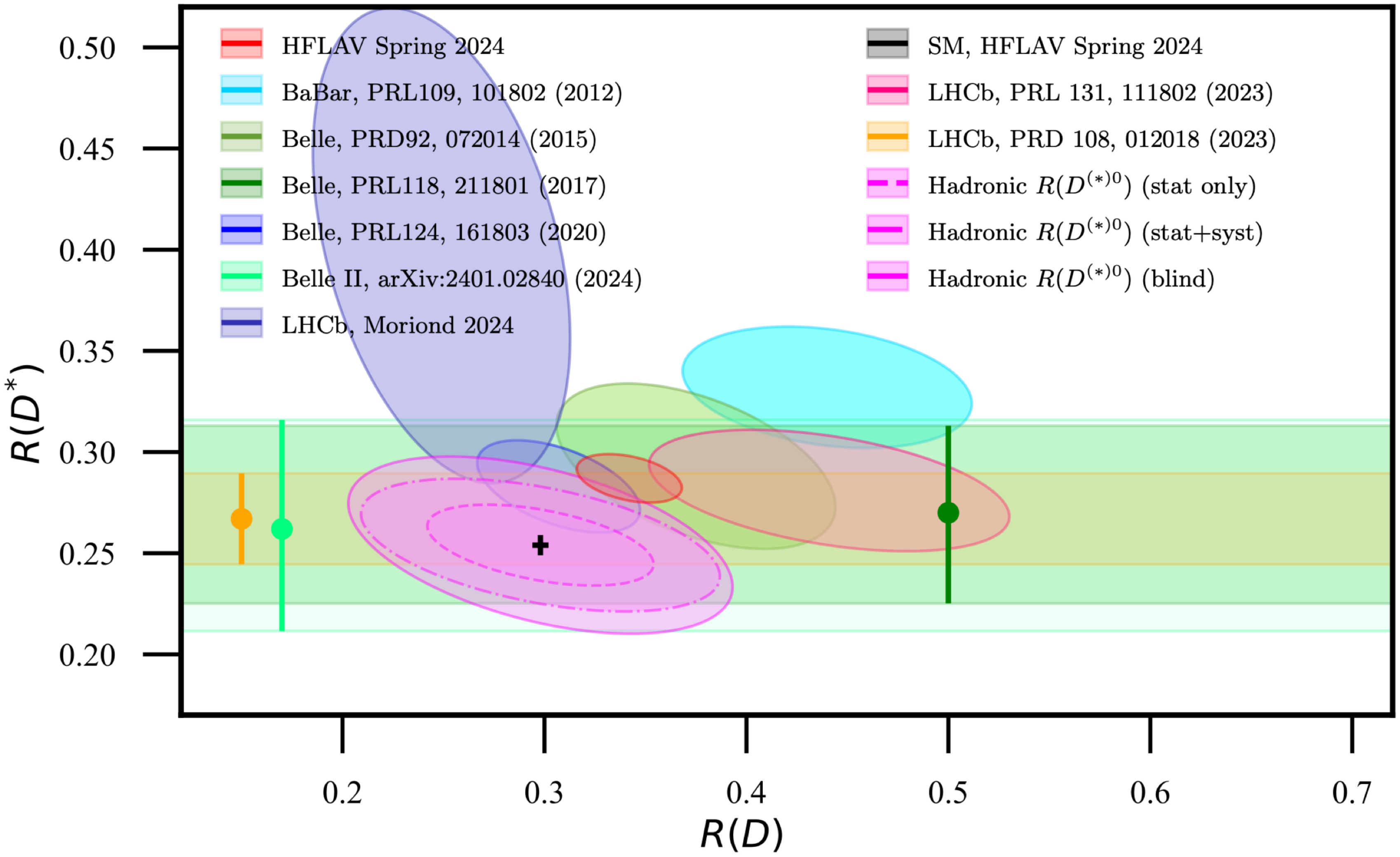
LHCb Preliminary Unofficial

Source	$N_{\text{sig}}^{D^0}$	$N_{\text{sig}}^{D^{*0}}$	$\rho(N_{\text{sig}})$	$\mathcal{B}_{\text{sig}}^{D^0}(\%)$	$\mathcal{B}_{\text{sig}}^{D^{*0}}(\%)$	$\rho(\mathcal{B}_{\text{sig}})$	$R(D^0)$	$R(D^{*0})$	$\rho(R)$
Templates statistics	1163	696	−0.93	0.140	0.099	−0.93	0.061	0.018	−0.93
Form-factors (templates shape)	676	491	−0.99	0.076	0.065	−0.99	0.033	0.012	−0.99
D_s^+ decay model	260	136	−1	0.031	0.019	−1	0.014	0.003	−1
Simulation Statistics (efficiency)	—	—	—	0.003	0.006	+0.52	0.001	0.001	+0.52
Form-factors (efficiency)	—	—	—	0.001	0.022	0	0.0004	0.004	0
Normalisation yield (model shape)	—	—	—	0.0004	0.0009	+1	0.0002	0.0002	+1
Total Systematic	1348	844	−0.94	0.162	0.122	−0.93	0.070	0.022	−0.93
Stat. Signal Fit	1572	956	−0.92	0.189	0.136	−0.92	0.082	0.024	−0.92
Stat. Norm. Fit				0.013	0.026	+1	0.005	0.005	+1
Total Statistical	1572	956	−0.92	0.189	0.138	−0.89	0.082	0.025	−0.89
External	—	—	—	0.073	0.154	+1	0.034	0.029	+0.88
Total	2071	1275	−0.93	0.259	0.240	−0.49	0.113	0.044	−0.47

Last step (ongoing!) is the complete assesment of systematic uncertainties.
Dominant contributions have been studied, only minor ones remaining:

- PID efficiency
- Background shapes
- ...

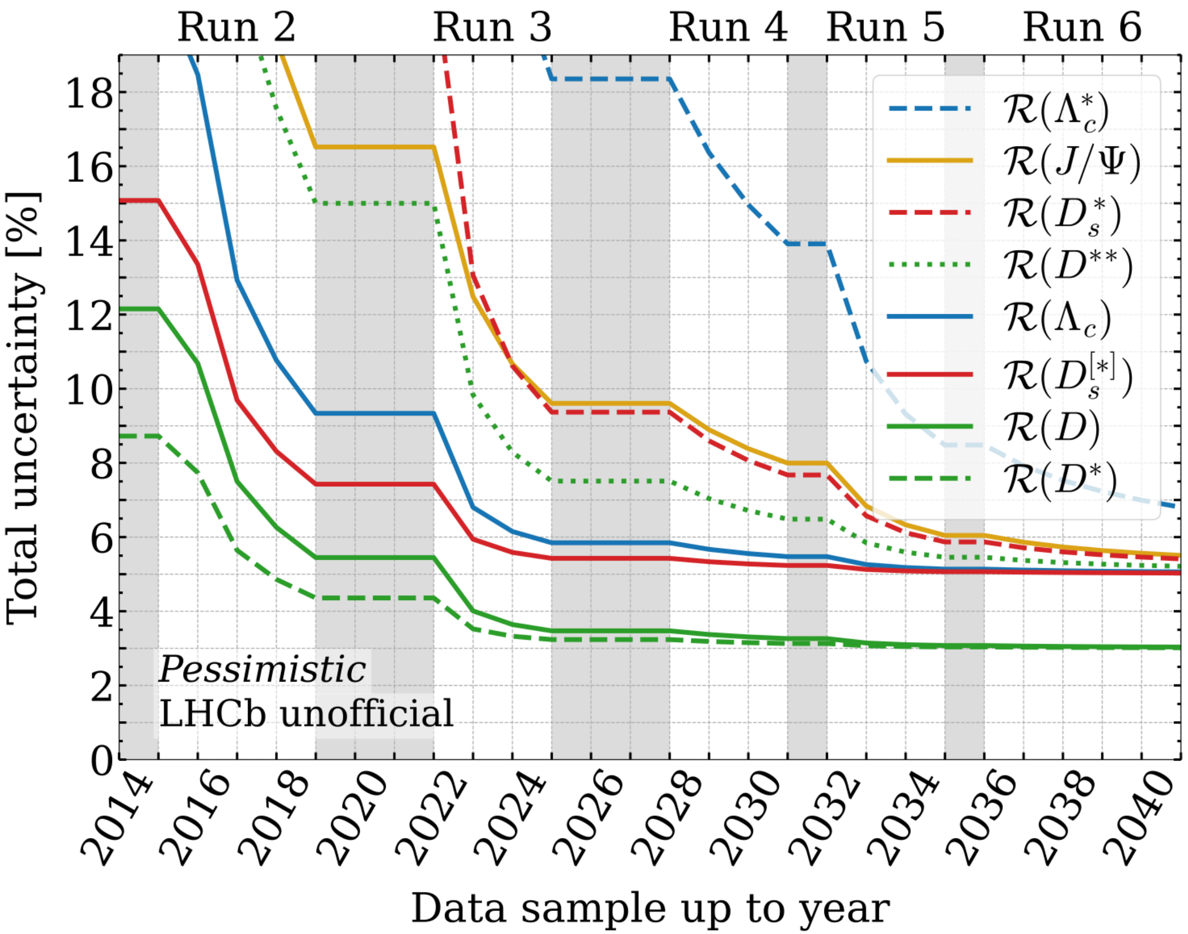
Blinded Results



$$R(D^0) = xx \pm 0.081\ (\text{stat.}) \pm 0.062\ (\text{syst.}) \pm 0.034\ (\text{ext.})$$
$$R(D^{*0}) = xx \pm 0.024\ (\text{stat.}) \pm 0.018\ (\text{syst.}) \pm 0.029\ (\text{ext.})$$

Future Prospects: Beyond this analysis

RevModPhys.94.015003



Still a lot of work to do with the available data!

- Reduction of systematics due to many factors (better understanding of backgrounds, improvement in simulation, new theory inputs…)
- Future LHCb measurements include: $R(D_s)$, $R(D^{**})$, *Hadronic* $R(D)$ *and* $R(D^*)$, $R(\Lambda_c^*)$ and more!
- And even more data coming from the new LHC era!

Conclusions

- Lepton Flavour Universality tests can be a window to NP
- Still some tension can be seen in a few observables with respect SM predictions, we need to keep improving to find a clear picture!
- LHCb has a important role in uncovering the final picture, with many LFU test results in the last few years and more to come
- Simultaneous $R(D^0)$ and $R(D^{*0})$ measurement with hadronic τ soon to be added to the global combination.

Thank you for
your attention.

Efficiencies

Decay	ε_{gen} Up/Down	$\varepsilon_{\text{filtering}}$	$\varepsilon_{\text{Stripping}}$ ($\times 10^{-2}$)	$\varepsilon_{\text{offline}}$	$\varepsilon_{\text{Total}}$ ($\times 10^{-5}$)
$B^+ \to \overline{D}^0 \tau^+ \nu_\tau$ $\tau^+ \to \pi^+\pi^-\pi^+\overline{\nu}_\tau$	0.04178 ± 0.00011 / 0.04186 ± 0.00011	0.0501	0.116	0.089	10.36 ± 0.04
$B^+ \to \overline{D}^0 \tau^+ \nu_\tau$, $\tau^+ \to \pi^+\pi^-\pi^+\pi^0\overline{\nu}_\tau$	0.037156 ± 0.000099 / 0.037107 ± 0.000097	0.0494	0.096	0.043	4.11 ± 0.02
$B^+ \to \overline{D}^{*0} \tau^+ \nu_\tau$, $\tau^+ \to \pi^+\pi^-\pi^+\overline{\nu}_\tau$	0.04004 ± 0.00010 / 0.04032 ± 0.00011	0.0493	0.111	0.080	8.82 ± 0.03
$B^+ \to \overline{D}^{*0} \tau^+ \nu_\tau$, $\tau^+ \to \pi^+\pi^-\pi^+\pi^0\overline{\nu}_\tau$	0.036045 ± 0.000096 / 0.036071 ± 0.000096	0.0488	0.093	0.036	3.32 ± 0.02
$B^0 \to D^{*-} \tau^+ \nu_\tau$, $\tau^+ \to \pi^+\pi^-\pi^+\overline{\nu}_\tau$	0.1601 ± 0.0022 / 0.1592 ± 0.0022	0.0227	0.149	0.012	1.84 ± 0.03
$B^0 \to D^{*-} \tau^+ \nu_\tau$, $\tau^+ \to \pi^+\pi^-\pi^+\pi^0\overline{\nu}_\tau$	0.1559 ± 0.0021 / 0.1578 ± 0.0022	1.0	0.108	0.0057	0.61 ± 0.02
$B^- \to D^0 D_s^-$, $D_s^- \to \pi^-\pi^+\pi^-$	0.05980 ± 0.00015 / 0.05992 ± 0.00015	0.0614	0.241	0.174	42.10 ± 0.13

Last remaining ingredient for the computation of the LFU ratios is the signal and normalization efficiencies, which are extracted directly from simulation

In addition, for the computation of $R(D^0)$ and $R(D^{*0})$ some other external parameters are required

$f_{3\pi}^{X}$: ratio of $B \to X\tau\nu_\tau, \tau \to 3\pi\nu$ with respect total number of $B \to X\tau\nu_\tau$

Parameter	Value
$f_{3\pi}^{D^0}$	0.835 ± 0.002
$f_{3\pi}^{D^{*0}}$	0.842 ± 0.002
$f_{3\pi}^{D^{*+}}$	0.857 ± 0.004
$f_{D^{*+}/D^{*0}}$	0.138 ± 0.002

$f_{D^{*+}/D^{*0}}$: ratio of $B^0 \to D^{*-}\tau^+\nu$ with respect $B^+ \to D^{*0}\tau^+\nu$