# Lepton-Flavour Universality tests with semitauonic decays at LHCb

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# Lepton-Flavor Universality

- <u>Standard Model (SM) predicts Lepton-Flavour Universality (LFU)</u>: equal couplings between gauge bosons and the three lepton families.
  - Signature: comparisons between e/μ/τ channels.
  - Usually exploiting ratios to cancel uncertainties.

b PENGUINS (b→s FCNC): B→K/K*/ϕ ℓℓ, $\Lambda_b \to \Lambda/\Lambda^* \ell\ell$
CHARM PENGUINS (c→u FCNC): D→hℓℓ, $\Lambda_c \to p\ell\ell$
TREE LEVEL (b→c): B→ D*ℓν, $B_c \to J/\psi \ell\nu$

$$\mathcal{R}(H_c) = \frac{\mathcal{B}(H_b \to H_c \tau \nu)}{\mathcal{B}(H_b \to H_c \mu \nu)}$$

Should only account for phase-space effects

- Tensions between SM expectations and experimental results:
  - semitauonic B decays
  - b→sll transitions

**Follow Marta's talk** – R(J/Ψ) and R($D^*$) using muonic tau decays [$\tau \to \mu\nu\nu$], R($D^*$) using hadronic tau decays [$\tau \to \pi^-\pi^+\pi^-(\pi^0)\nu$], R(K), R($K^*$), future prospects.

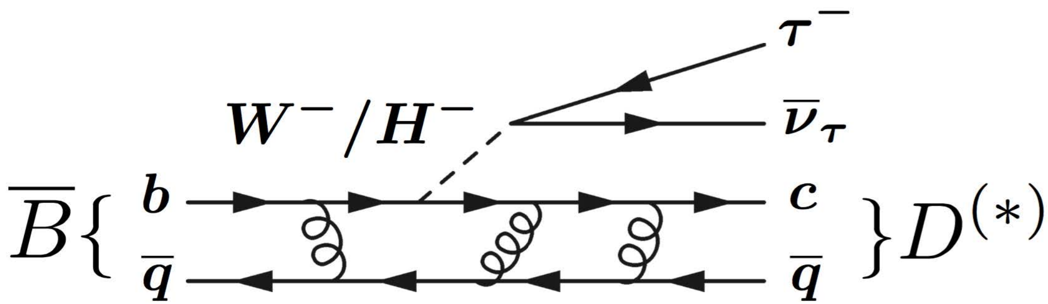
This talk will focus on the latest R($D^*$) results using three-prong τ-lepton decays. arXiv:1708.08856, arXiv:1711.02505

- SM extensions (extended Higgs sector, leptoquarks, extended gauge sector) add new interactions with a stronger coupling with the τ.

arXiv:1604.03088
arXiv:1206.4977

# R(D*) with τ→π⁻π⁺π⁻(π⁰)ν

- **Semileptonic decay without charged lepton in the final state**: Zero background from normal semileptonic decays.



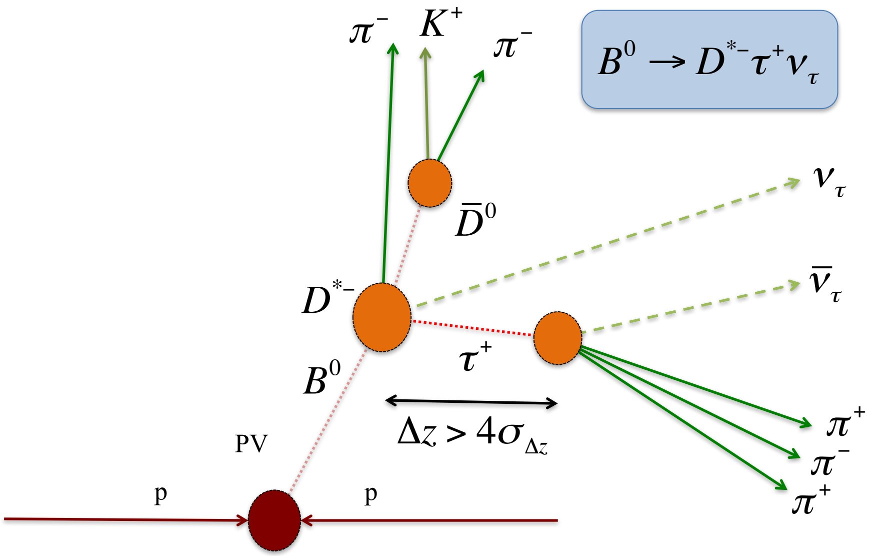

- **Signal isolation complicated by neutrinos**, but several hadronic ones that provide control on the various background channels.
- **Only one ν in the τ vertex**: Partial reconstruction can be applied with a very good precision.
- $B^0 \rightarrow D^* \pi^+ \pi^- \pi^+$ is used as a normalization channel. (Same visible final state: shared systematics uncertainties cancel).

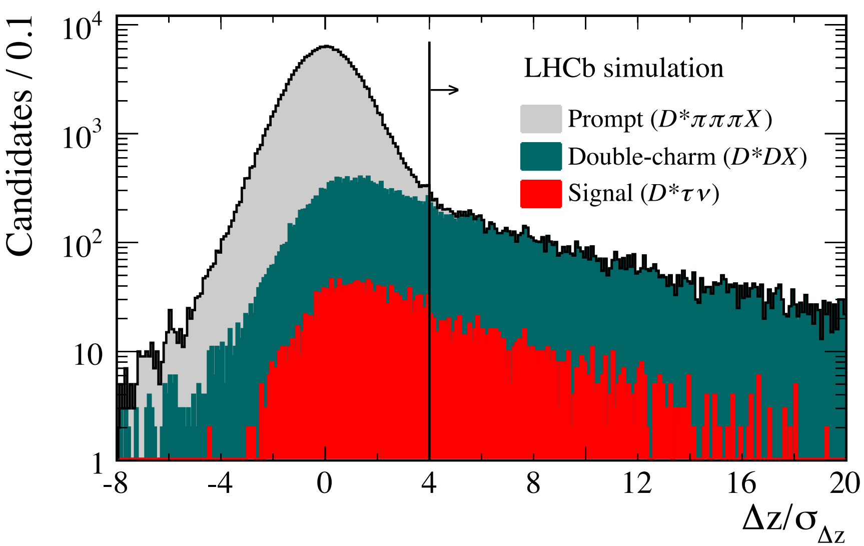
External inputs

$$R_{had}(D^*) = \frac{\mathcal{B}(\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B}^0 \to D^{*+}\pi^+\pi^-\pi^+)}$$

$$R(D^*) = R_{had} \times \boxed{\frac{\mathcal{B}(\bar{B}^0 \to D^{*+}\pi^+\pi^-\pi^+)}{\mathcal{B}(\bar{B}^0 \to D^{*+}\mu^-\bar{\nu}_\mu)}}$$

# Detached-vertex topology




- Dominant background: Hadronic $B^0$ decays into $D^*3\pi X$ (prompt).
  - Yield is 100x bigger than the SM expectation for the signal yield.

Good precision in the $\tau$ decay vertex reconstruction

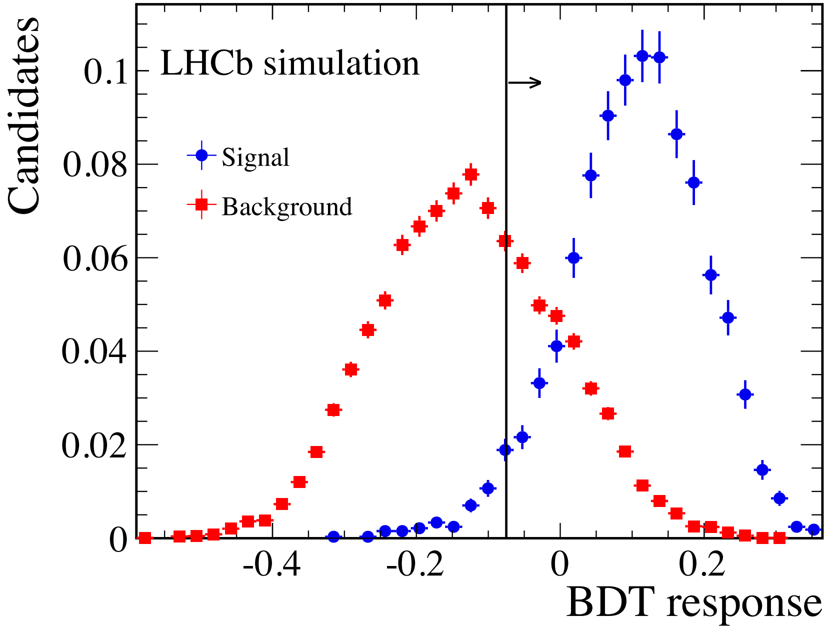
- Detachment cut: The $\tau$ vertex is downstream with respect to the $B^0$ vertex and with a significance of at least $4\sigma$.
- $D^*3\pi X$ background is reduced by 3 orders of magnitude.

# Double-charm background

- The remaining background consists of $B^0$ decays where the $3\pi$ vertex is transported away from the $B^0$ vertex by a charm carrier: $D_s$, $D^+$ or $D^0$ (i.e. $B \to D^* D X$, $D \to 3\pi X$).
- Total yield is ~10x higher than SM expectation for signal.

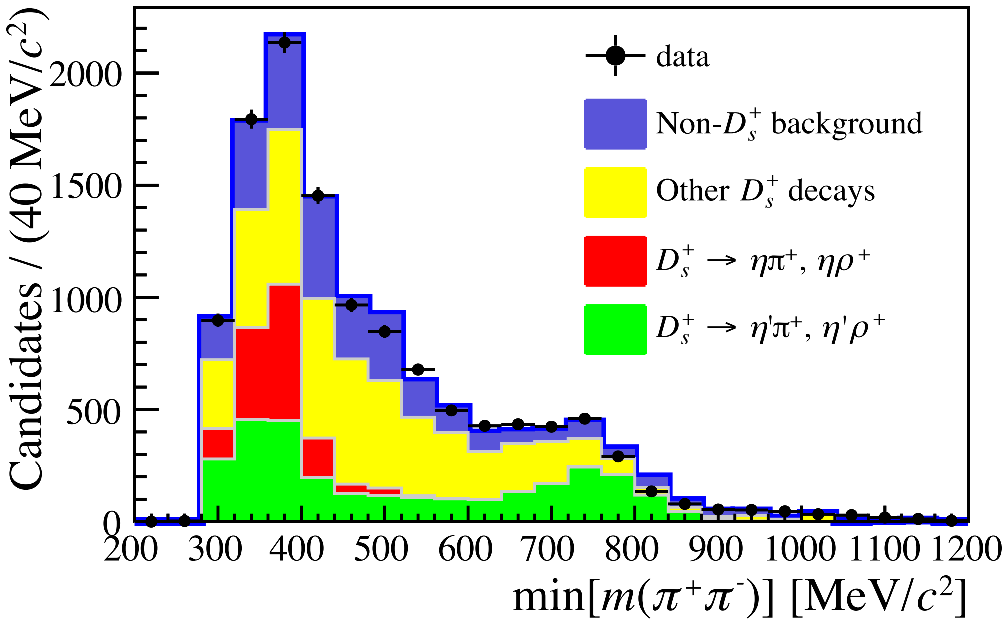
- LHCb has three very good tools to limit this background:
  - **3π dynamics**.
  - **Isolation criteria** against charged tracks and neutral energy deposits.
  - **Partial reconstruction** in both signal and background hypotheses.

- **A Boosted Decision Tree** (BDT) is trained using these tools to discriminate double charm decays from signal.



# Double-charm background

- In order to determine the $D_s$ decay model:
  - The **BDT output** is used to select an enriched sample of $D_s$ events directly from data.
  - **Variables related to the 3π dynamics** are simultaneously fitted [min $M(2\pi)$, max $M(2\pi)$, $M(\pi^+\pi^+)$, $M(3\pi)$].



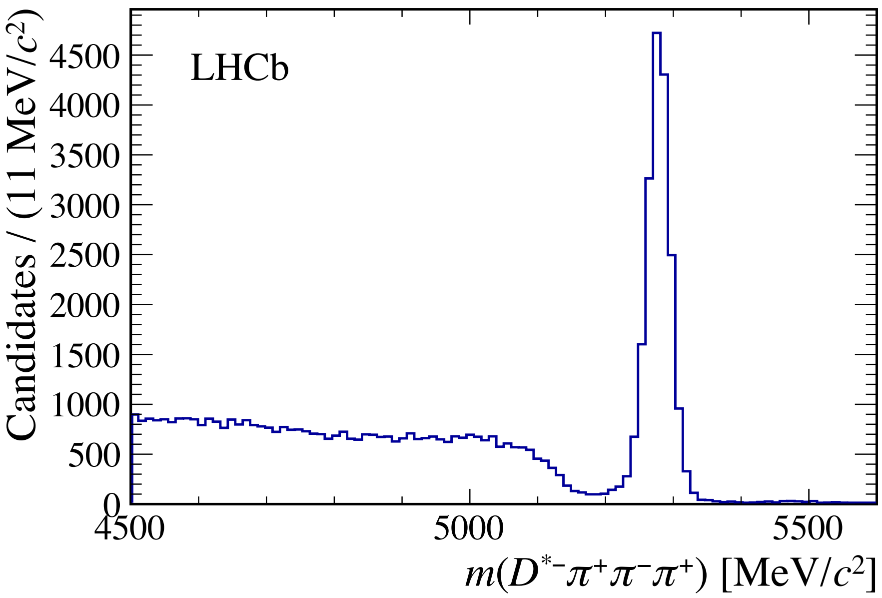

The weights obtained are used to construct the $D_s$ templates

# Normalization channel

The normalization channel has to be as similar as possible to the signal channel to cancel all systematics linked to trigger, particle ID, selection cuts.

- The channels differ by:
  - Softer pions and D* due to the presence of two ν.
  - Kinematics of 3π system is not exactly the same.

This gives a small residual effect on the efficiency ratio




Absolute BR recently measured by BABAR with a precision of 4.3%.
Phys.Rev. D94 (2016) no.9, 091101

# Signal extraction and fit

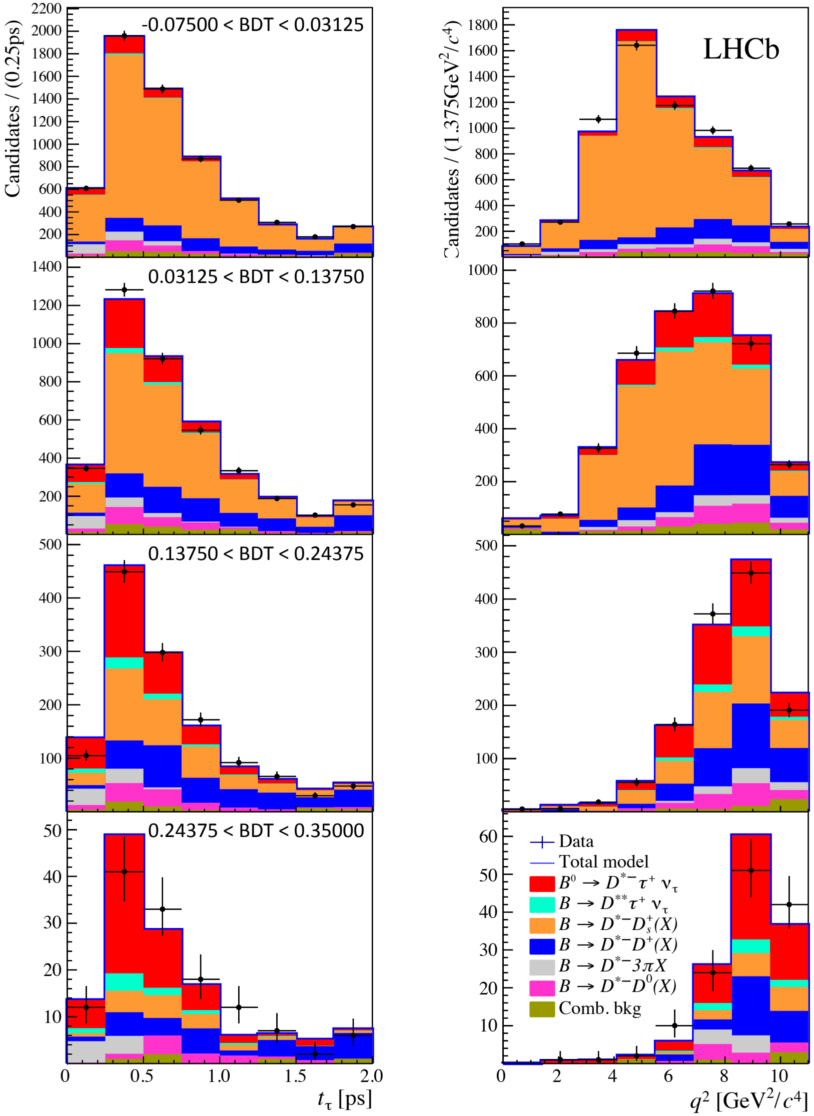
## Signal reconstruction

- Assume 2 neutrinos in the event → can be used to access full kinematics ($\tau$ and $B^0$, mass and direction constrains):
  - Reconstruction of $\tau$ and $B^0$ momentum, $\tau$ decay time.
  - Kinematics solution found ~95% of the time.

## Fit strategy

- A BDT cut is applied.
- 3D template fit is performed in:
  - $q^2$ (the squared-momentum transferred to $\tau$-$\nu$ system).
  - $\tau$ lifetime.
  - The output of the BDT.

# Fit results




- The 3D template binned likelihood fit results are presented for the lifetime and $q^2$ in four BDT bins, with increasing values of the BDT response from top to bottom.

- The increase in signal purity as function of BDT is very clearly seen, as well as the decrease of the $D_s$ component.

- The dominant background at high BDT becomes the $D^+$ component, with its distinctive long lifetime.

The overall $\chi^2$ per dof is 1.15

# Main systematics

| Contribution | Value [%] |
|---|---|
| Simulated sample size | 4.7 |
| Signal modeling | 1.8 |
| $D^{**}\tau\nu$ and $D_s^{**}\tau\nu$ feed-downs | 2.7 |
| $D_s \to 3\pi X$ decay model | 2.5 |
| $B \to D^{*-} D_s^+ X$, $B \to D^{*-} D^+ X$, $B \to D^{*-} D_0 X$ backgrounds | 3.9 |
| Combinatorial background | 0.7 |
| $B \to D^* 3\pi X$ background | 2.8 |
| Empty bins in templates | 1.3 |
| Efficiency ratio | 3.9 |
| Normalization channel efficiency | 2.0 |
| **Total internal uncertainty** | **9.1** |
| **$\mathcal{B}(B^0 \to D^* 3\pi)$ and $\mathcal{B}(B^0 \to D^* \mu\nu_\mu)$** | **4.8** |

Can be reduced internally by LHCb

Can be reduced with help from other experiments

# R(D*) results and conclusions

- The fit results give a branching fraction which is:

**$BR(B^0 \to D^{*+}\tau\nu) =$**
**$[1.40 \pm 0.09(stat) \pm 0.13(syst) \pm 0.18(ext)]$ %**

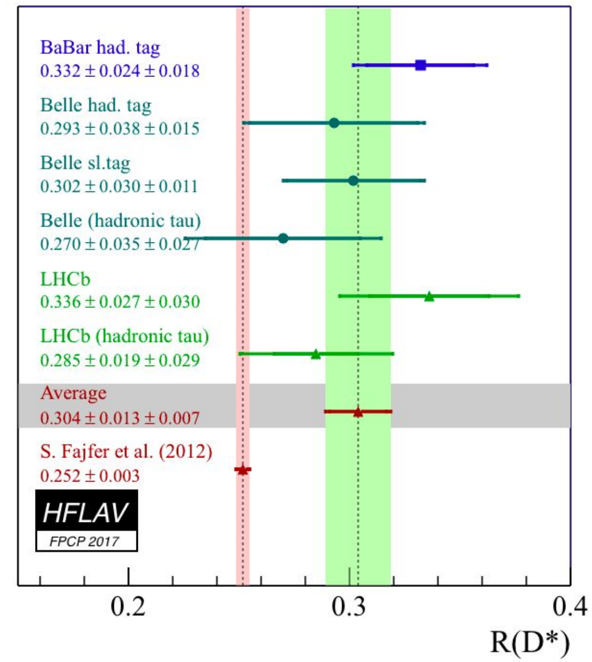
To be compared to PDG 2017:
$BR(B^0 \to D^{*+}\tau\nu) = (1.67 \pm 0.13)$ %

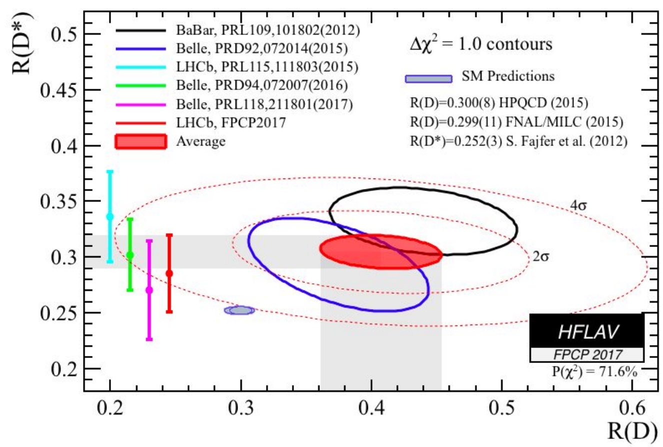
- Using HFLAV $BR(B^0 \to D^{*}\mu\nu) = (4.88 \pm 0.10)$ %

**$R(D^*) = 0.286 \pm 0.019(stat) \pm 0.025(syst) \pm 0.021(ext)$**

- Impact on World Average:
  - R(D*): 3.3σ → 3.4σ from SM prediction
  - Adding R(D): 4.0σ→ 4.1σ from SM prediction (reduced with the latest theory input arXiv:1707.0950)

It is also possible to compute an LHCb average:
**$R_{LHCb}(D^*) = 0.309 \pm 0.016(stat) \pm 0.024(syst)$**
2.0σ from SM prediction



Back-up slides follow

# THE END