Heavy Flavour results with impact on the charged Higgs sector

Looking for charged Higgs contributions in semitauonic B decays

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Why using semitauonic B decays ?

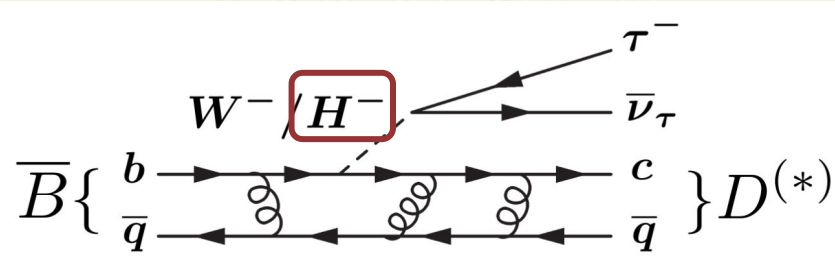
- As tree level decays, they combine some nice features:
  - **Precise prediction from SM** using ratios with shared systematics cancelling
  - **Abundant channel**: BR(B→D*τν) ~ 1.2%
  - **Sensitivy to NP** contributions

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

$H^{\pm}$ in semitauonic B decays

- *Lepton Flavour Universality* is a key ingredient of SM → discrepancy observed in semitauonic B decays

- Several SM extensions add new interactions with a stronger coupling with the third generation of leptons such as a charged Higgs



- Several tests have been made in the B factories:
  - Extraction of R(D), R(D^*)
  - Fit of the q^2 distribution with several hypotheses, with $q^2 = (p(B^0) - p(D^*))^2$

- $H^{\pm}$ coupling to B^0 and τ is growing with $\tan\beta$ → Large value of $\tan\beta$ are probed (10-100)

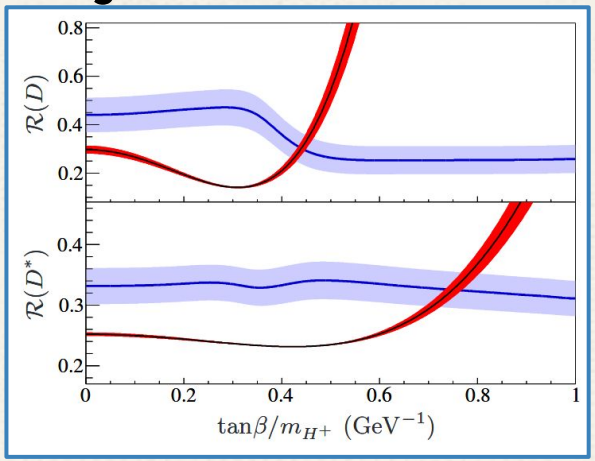
- Complementary with direct searches

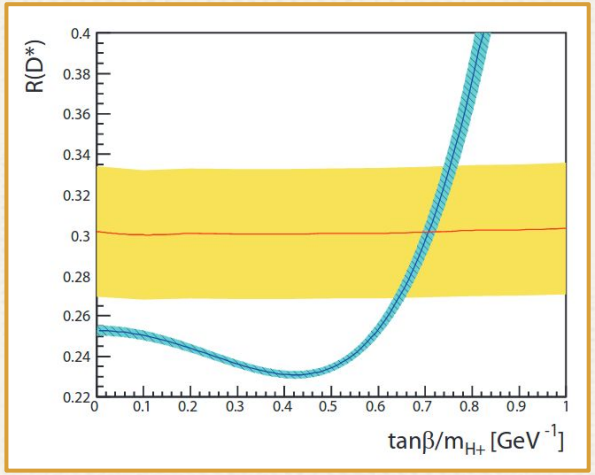
Phys. Rev. D 88, 072012 (2013)

Phys. Rev. D 94, 072007 (2016)

$H^{\pm}$ in semitauonic B decays

- Test of compatibility between R(D) and R(D*) results with type II 2HDM model:
  - **BaBar**: $\tan\beta/m(H^+)$ values for R(D) and R(D*) are incompatible → type II 2HDM model is excluded for $m(H^+) > 15$ GeV/c^2
  - **Belle**: there is a preferred value for $\tan\beta/m(H^+)$ of 0.7 GeV^{-1}. For values of $\tan\beta$ in the range of [10,100], $m(H^+)$ is in [15-150] GeV/c^2
  - Observed values of R(D*) forbid a heavy charged Higgs and a light one would have been detected !

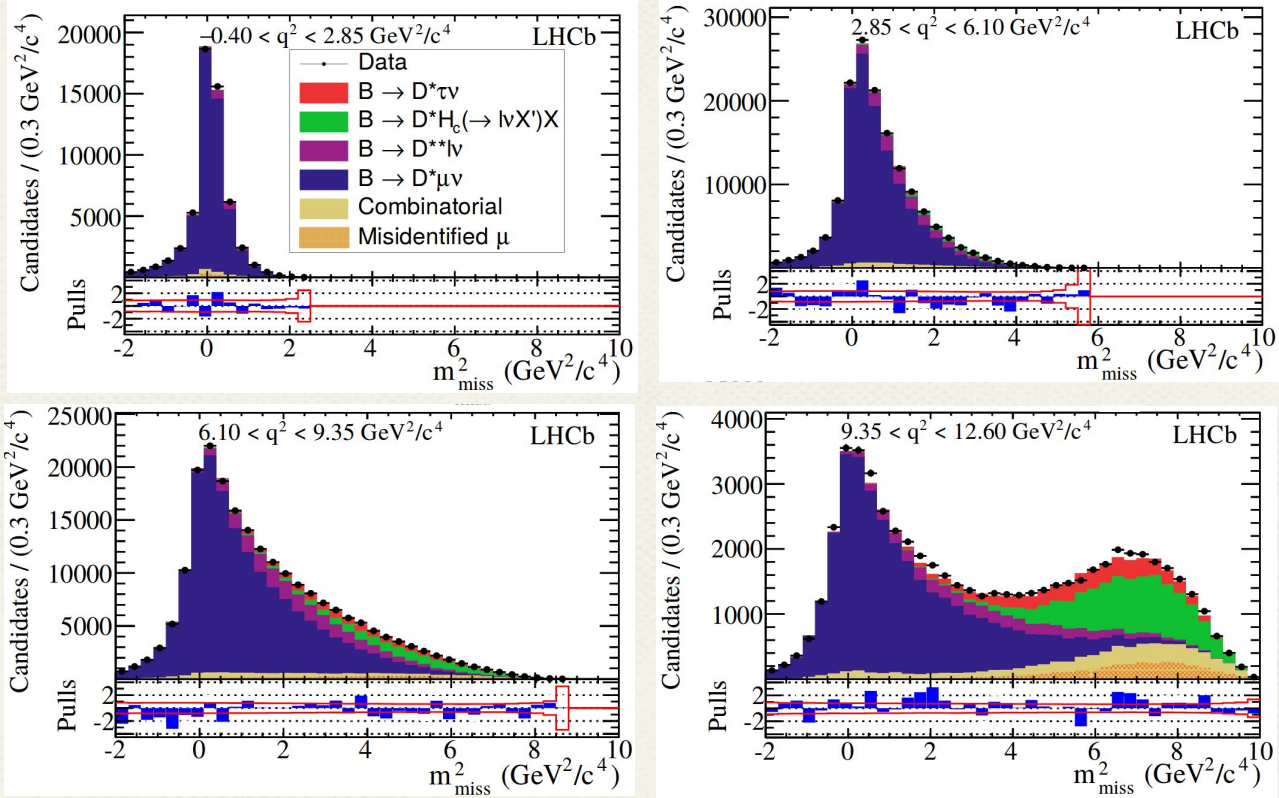




Phys. Rev. Lett. 115, 111803

R(D*) with τ→μνν

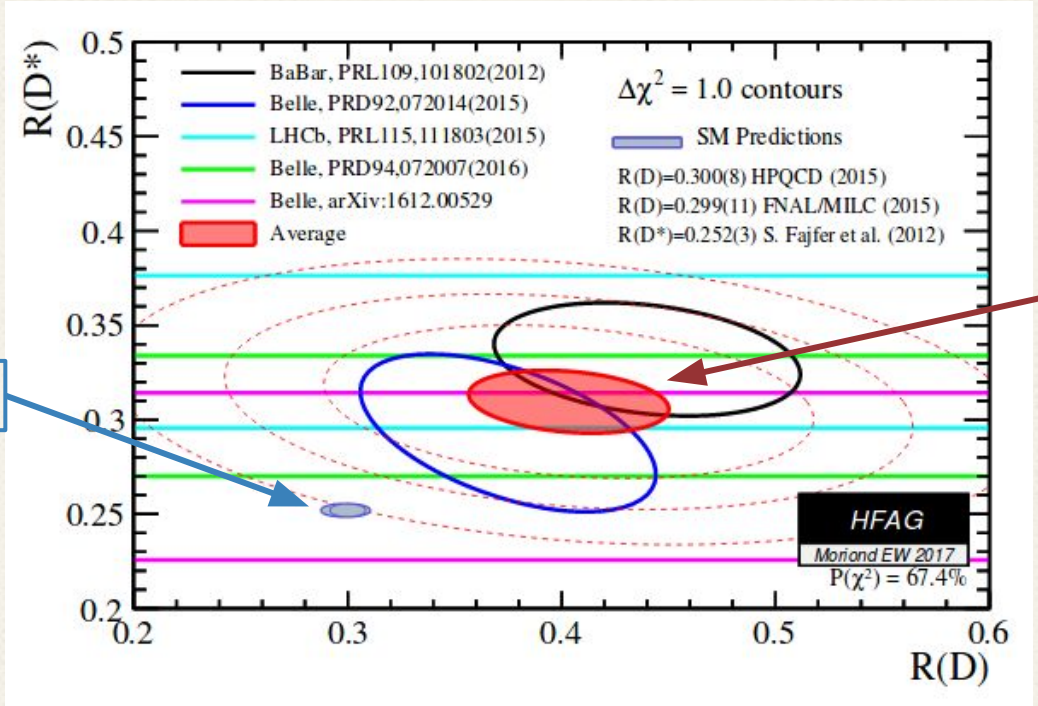
- 3D MC-template based binned fit to $m^2_{missing}$ vs E_μ in coarse q^2 bins
- Fit to isolated data, used to determine ratio of $B \to D^* \tau \nu$ and $B \to D^* \mu \nu$
- Templates are a good description of the data



$R(D^*) = 0.336 \pm 0.027 \pm 0.030$ → consistent with SM at **2.1σ** level

The situtation a few months ago ...

R(D*) status



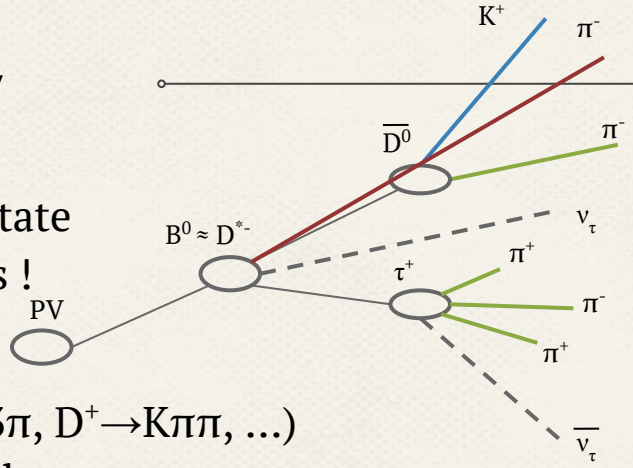
WA: 5% uncertainty

SM: 1.19% uncertainty

The world average of the combination of R(D) and R(D*) is in tension with the SM expectation at the **4σ level !**

LHCb-PAPER-2017-017, in preparation

R(D*) with $\tau \to \pi^+\pi^-\pi^+(\pi^0)\nu$



- Semileptonic decay **without charged lepton** in the final state
  - → **Zero** background from normal semileptonic decays !
- **No signal mass peak but several hadronic ones** ($D^0 \to K3\pi$, $D^+ \to K\pi\pi$, ...)
  - It provides control on the various background channels
- Only one ν at the τ vertex
  - **Partial reconstruction can be applied** with good precision
- $B^0 \to D^*\pi^+\pi^-\pi^+$ is used as normalisation

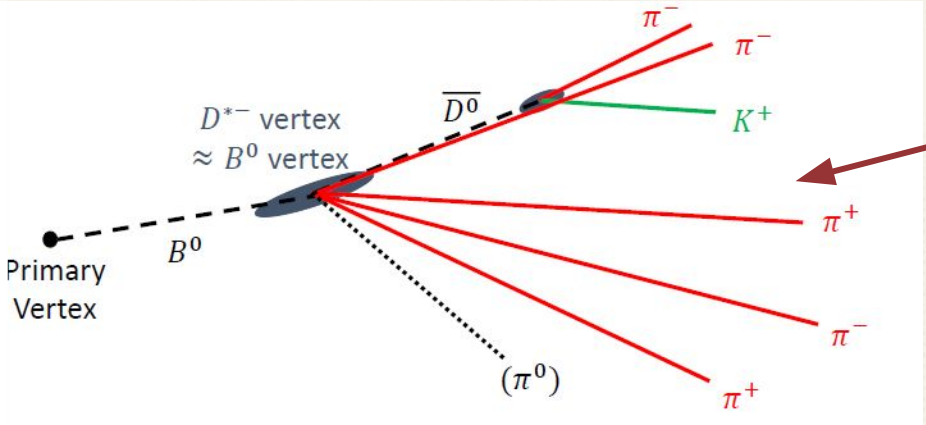
$$R_{had}(D^*) = \frac{\mathcal{B}(\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B}^0 \to D^{*+}\pi^+\pi^-\pi^+)}$$

Same final state: shared systematics uncertainties cancel

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

External inputs

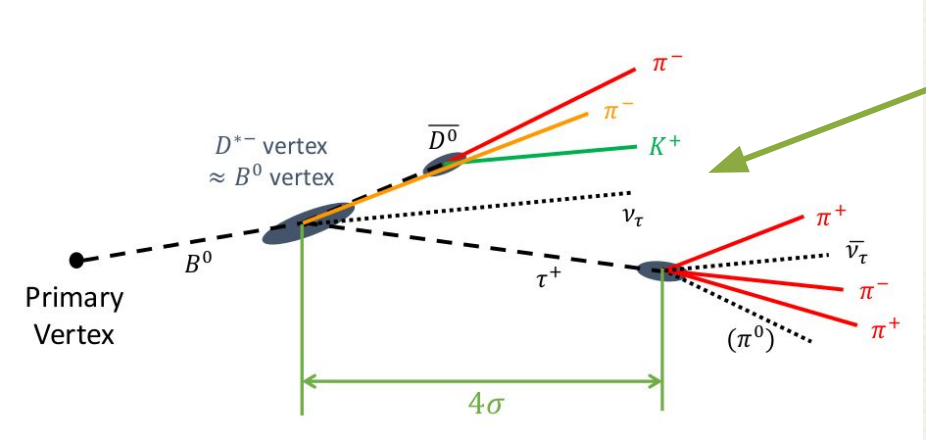
Vertex topology



Most abundant background: hadronic B decays into **D*3πX:**

yield is **100x bigger** than SM expectation for signal yield !

Good precision on τ decay vertex position



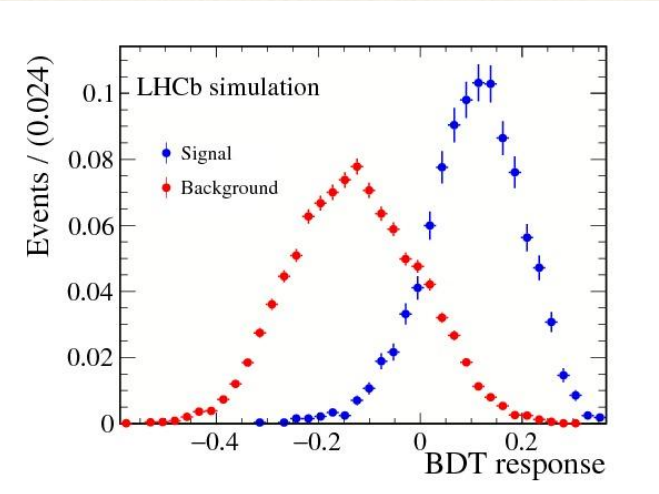
Inversion cut: τ vertex is downstream with respect to the B^0 vertex with a significance of at least 4σ

D*3π background reduced by 3 orders of magnitude

Double charm background

- The remaining background consists of B^0 decays where the 3π vertex is transported away from the B^0 vertex by a **charm carrier**: D_s, D^+ or D^0 (in that order of importance)
  - 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



Signal extraction and fit

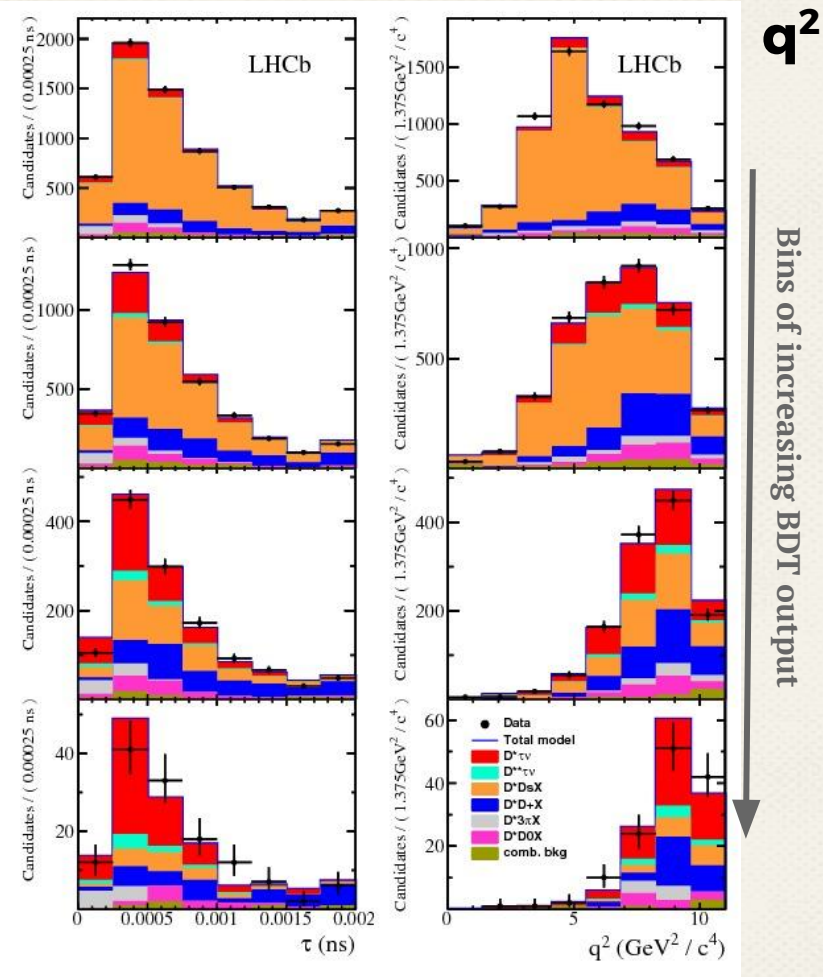
Signal reconstruction:

- Assume 2 neutrinos in the event → can be used to access full kinematics
  - Reconstruction of τ and B^0 momentum and τ decay time
  - Kinematics solution found ~95% of the time

Fit strategy:

- A high BDT cut is applied
- A 3D template fit is performed in
  - $\mathbf{q^2}$ (squared-momentum transferred to the τ-ν system)
  - **τ lifetime**
  - The output of the **BDT**

q^2 distribution



- The 3D template binned likelihood fit results are presented for the lifetime and q^2 in four BDT bins.
- 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 χ^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
$Ds\to 3\pi X$ 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
Total internal uncertainty	**8.9**
$B(B^0\to D^{*}3\pi)$ and $B(B^0\to D^{*}\mu\nu_\mu)$	**4.8**

Room for progress exists on a longer timescale on both internal and external sources !

In red: can be reduced with help from other experiments (BELLE, BES, ...)

Results

- The fit results give a branching fraction which is:

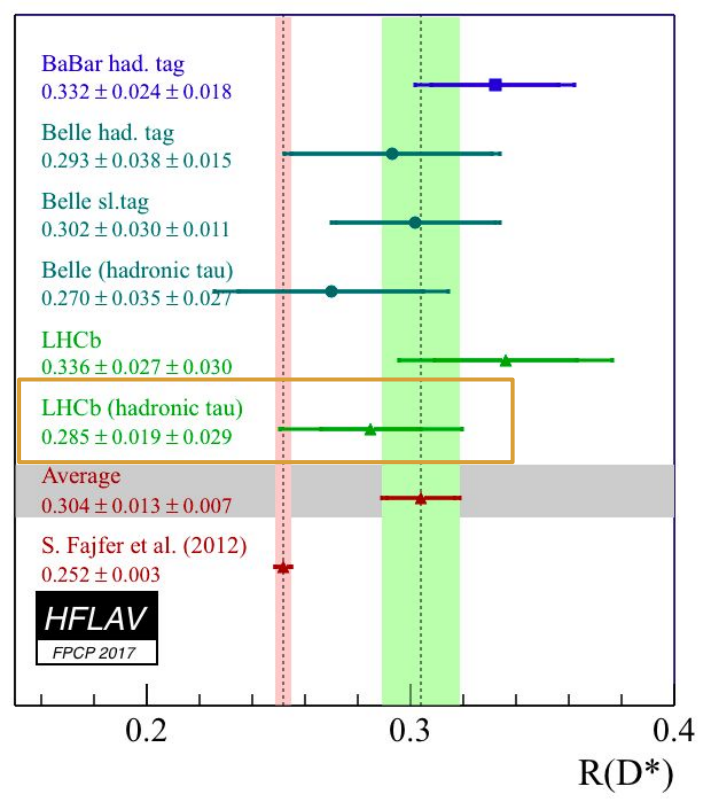
$BR(B^0 \to D^{*+}\tau\nu) = (1.39 \pm 0.09(stat) \pm 0.12(syst) \pm 0.06(ext))$ %

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

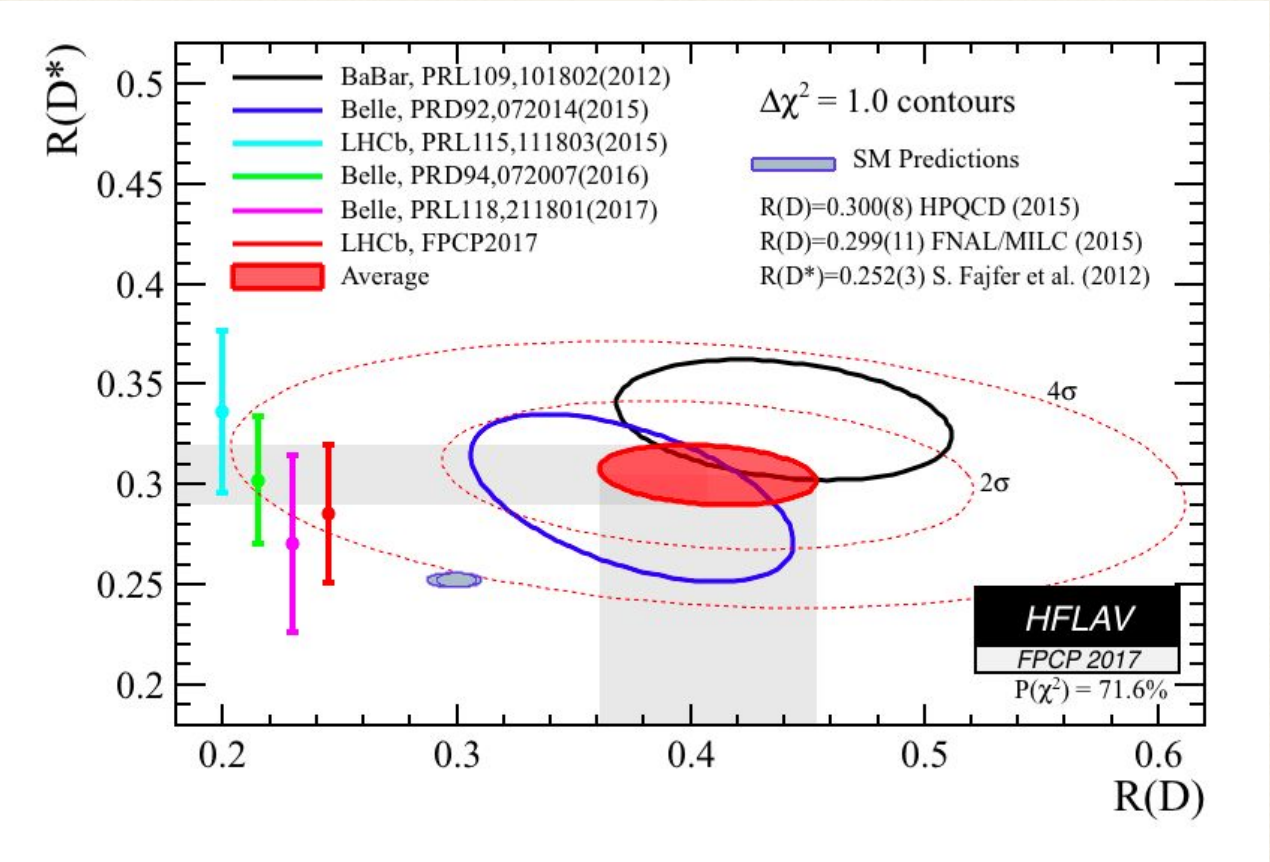
- Using the HFLAV $BR(B^0 \to D^{*}\mu\nu) = (4.88 \pm 0.1)$ %, we get:

$R(D^*) = 0.285 \pm 0.019(stat) \pm 0.025(syst) \pm 0.013(ext)$

- Impact on World Average:
  - $R(D^*)$: 3.3σ → 3.4σ from SM prediction
  - Adding R(D): 4.0σ→ 4.1σ
- It is also possible to compute an LHCb average of $R(D^*)$:
  - $R_{LHCB}(D^*) = 0.306 \pm 0.027$



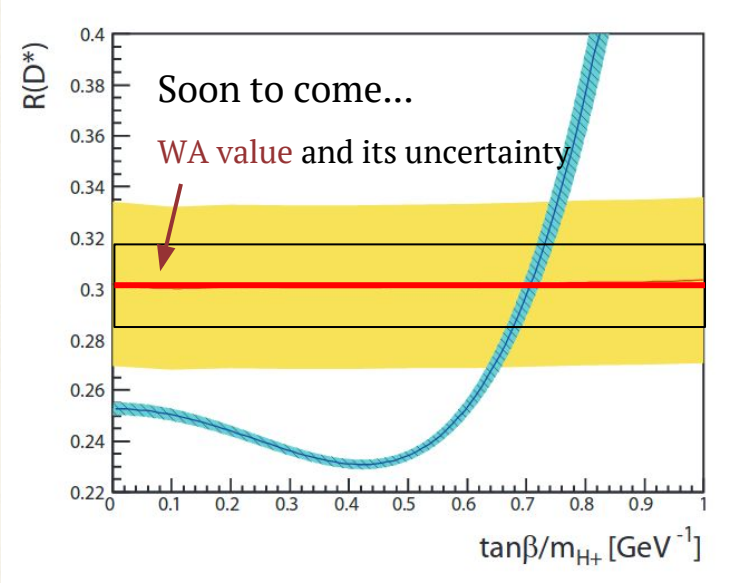
HFLAV Combination for FPCP 2017



Conclusion

- **$R(D^*)$ result using hadronic τ is now out for Run1 !**
  - The successful Run2 data taking leads to a 4x bigger dataset wich will contribute to **reduce both statistical and systematics uncertainties !**

- Several other analyses are already ongoing or planned:
  - Using different hadrons (D^0, D^+, D_s, Λ_c, ...) in order to probe different dynamics and spin structures
  - Ongoing effort to adopt the best strategy for q^2 distribution extraction and fit of NP scenarios

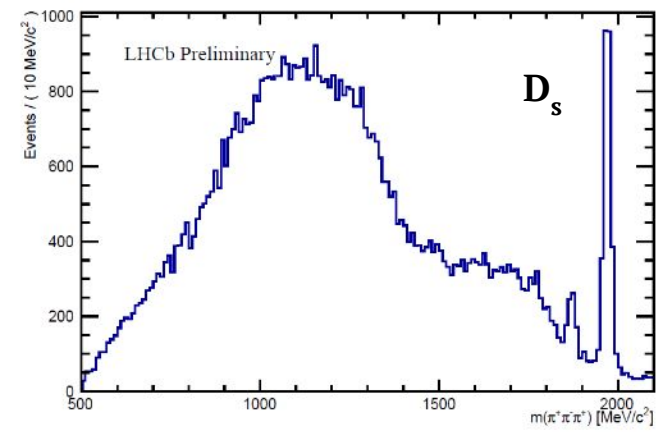


Thank you for your attention !

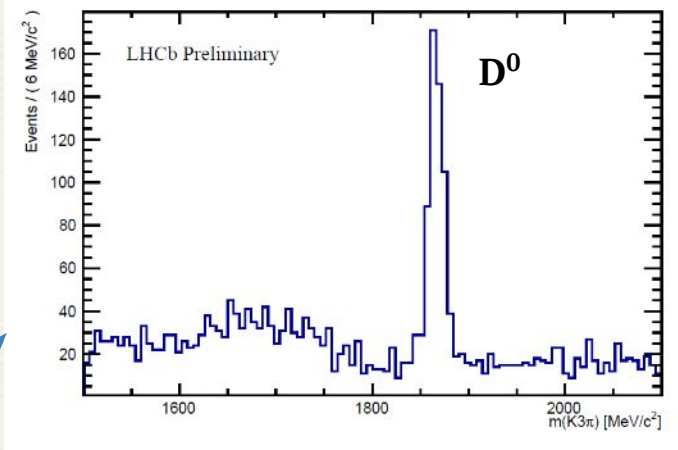
Any question ?

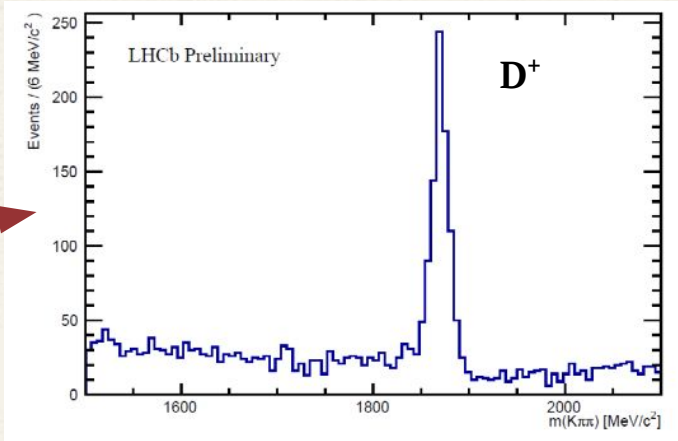
Backup

Control channels



Run 1, 3 fb^{-1}





3π mass after vertex topology cut

$D^0 \to K3\pi$ peak: anti-isolation cut

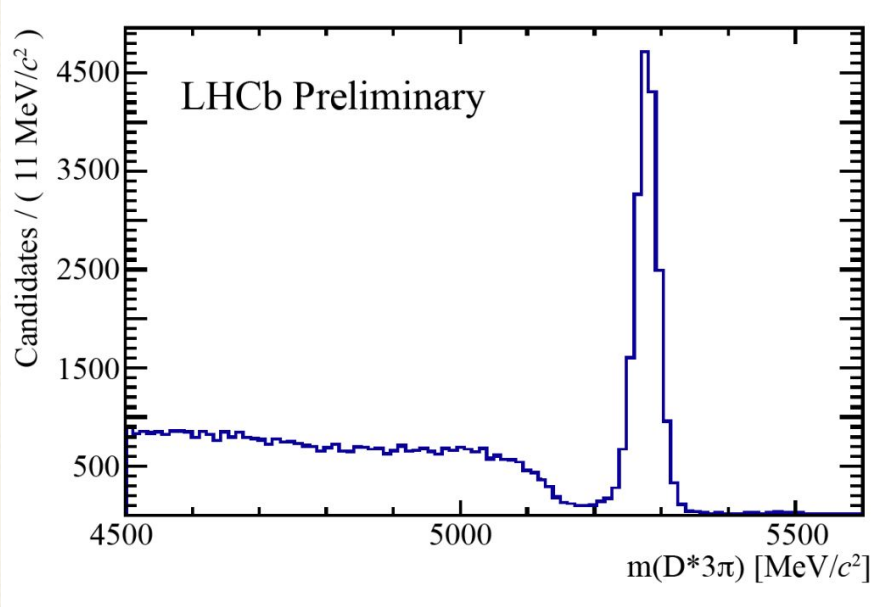
$D^+ \to K\pi\pi$ peak: anti-PID cut

"Standard candles" used to check Data and MC agreement

Normalisation channel

- The normalisation channel has to be as similar as possible to the signal channel to cancel all systematics linked to trigger, particle ID, selection cuts
- They differ by:
  - softer pions and D^* due to the presence of two ν
  - kinematics of the 3π system is not exactly the same:
    - This gives a small residual effect on the efficiency ratio.

Run 1, 3 fb^{-1}



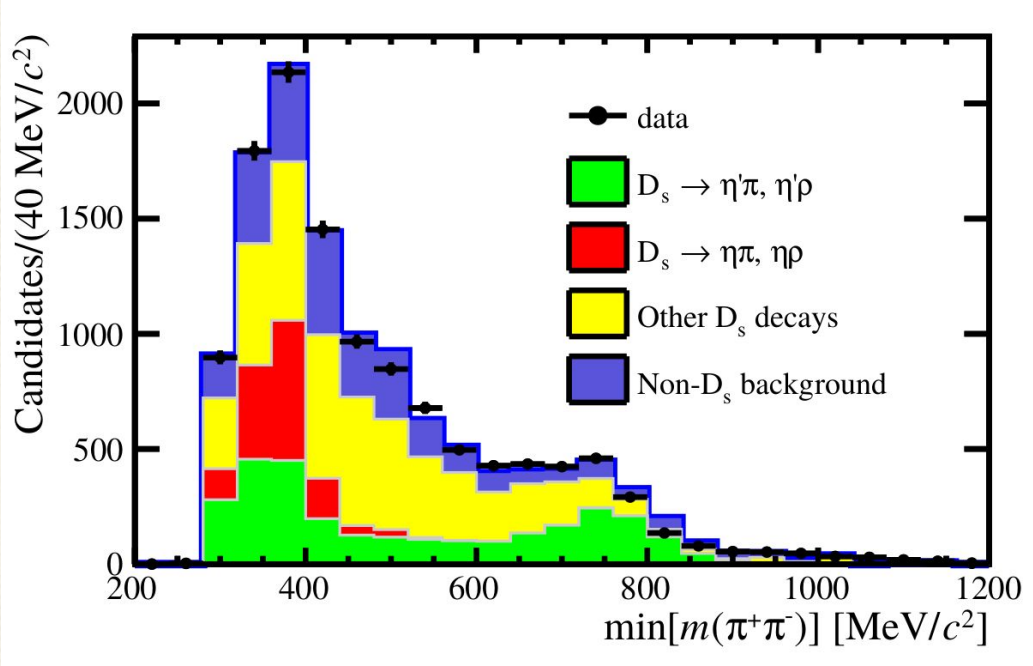
Absolute BR recently measured by BABAR with a precision of 4.3%

Phys.Rev. D94 (2016) no.9, 091101

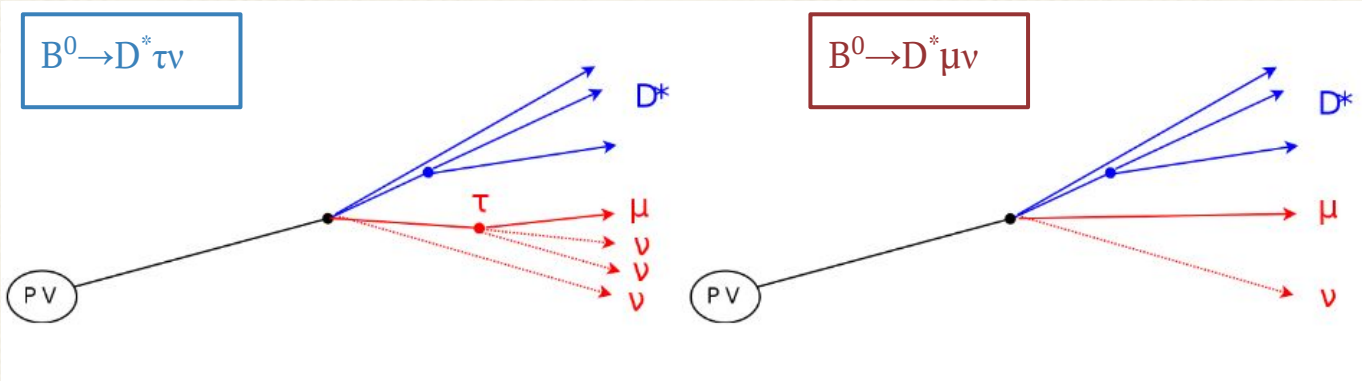
Double charm background

- To determine the D_s decay model:
  - The BDT output is used to select an enriched sample of D_s events directly from data
  - Several variables related to the 3π dynamics are simultaneously fitted

The weights obtained are used to construct the D_s templates

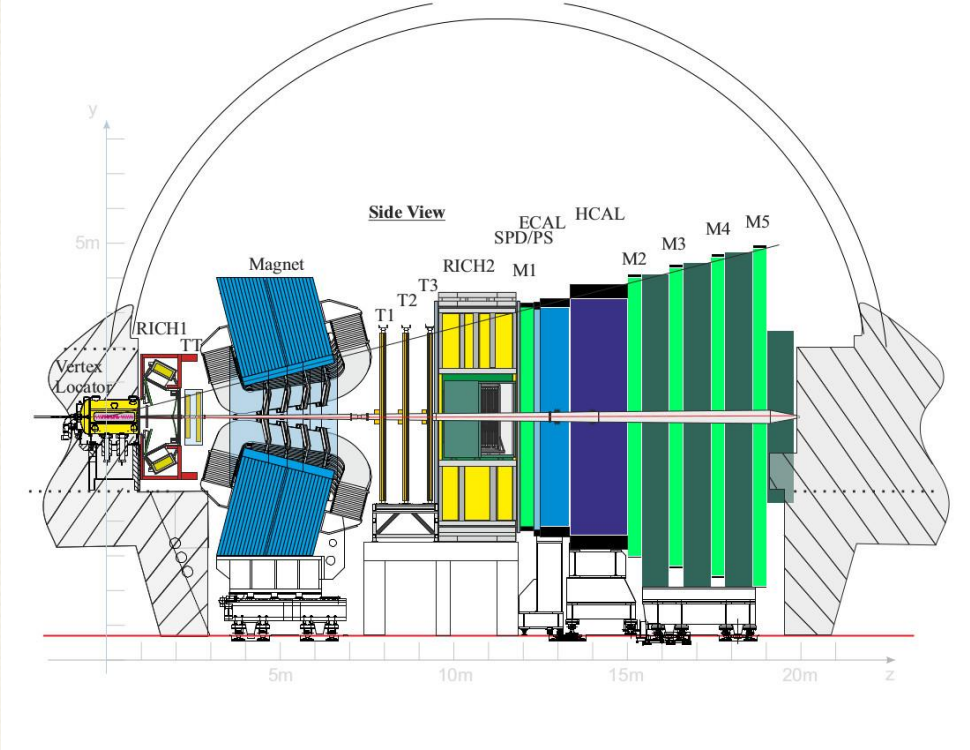


$R(D^*)$ with $\tau \to \mu\nu\nu$



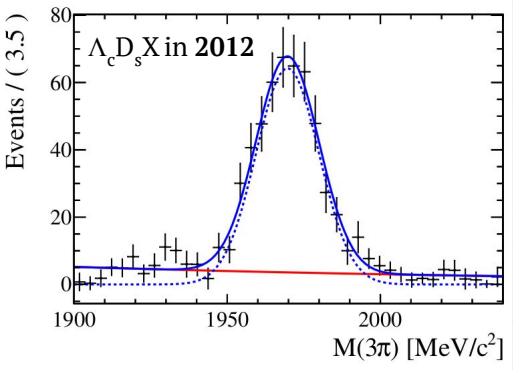
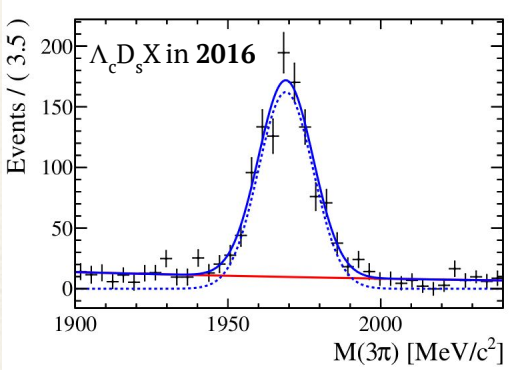
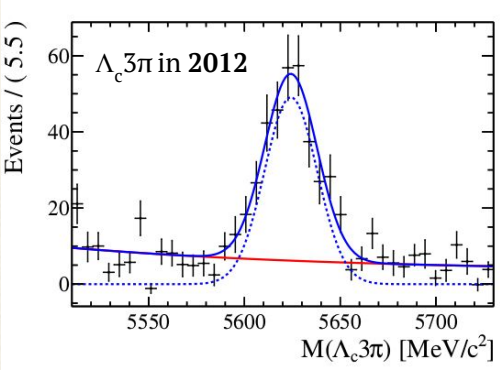
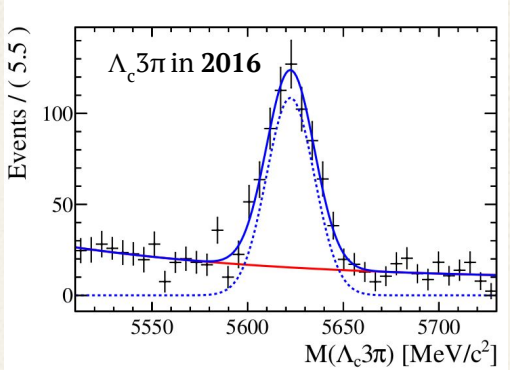
- Can use B flight direction to measure transverse component of missing momentum
- No way of measuring longitudinal component → use approximation to access rest frame kinematics
  - Assume $\gamma\beta_{z,visible} = \gamma\beta_{z,total}$
  - 18% resolution on B momentum, long tail on high side
- Can then calculate rest frame quantities: $\mathbf{m^2_{missing}}$, $\mathbf{E_\mu}$, $\mathbf{q^2}$
- 3D MC-template based binned fit to $m^2_{missing}$ vs E_μ in coarse q^2 bins

The LHCb detector



- **Single arm spectrometer** at LHC in the pseudorapidity range $2<\eta<5$
- Optimized to study hadron decays containing **b** and **c** quarks:
  - CP violation, rare decays, heavy flavor production
- **Excellent vertex resolution** and separation of B vertices
- Good **momentum and mass resolution**
- Excellent **PID** capabilities (good separation **K-π** and muon identification)

Towards $R(\Lambda_c)$

All plots are using Splot technique to select Λ_c

- Same strategy and tools as ongoing R(D*) analysis
- Use of $\Lambda_b \rightarrow \Lambda_c 3\pi$ as normalization channel
- Measurement of $R(\Lambda_c)$ on both Run1 and Run2 datasets with an error estimation of:
  - 4% for ε_{stat}
  - 6-10% for ε_{syst}
  - 7% of uncertainty due to normalization