Semitauonic B decays, a window on new Physics

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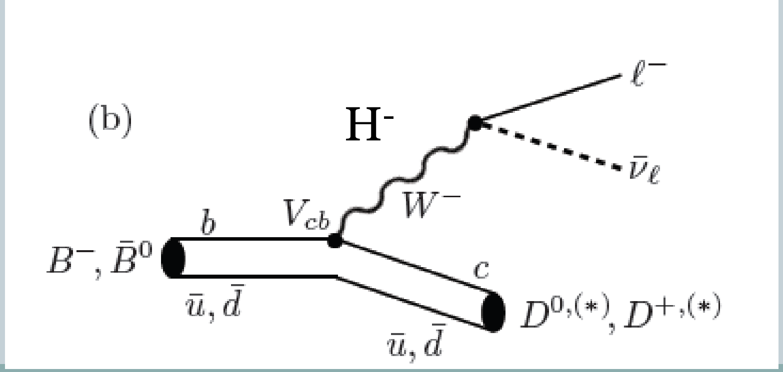
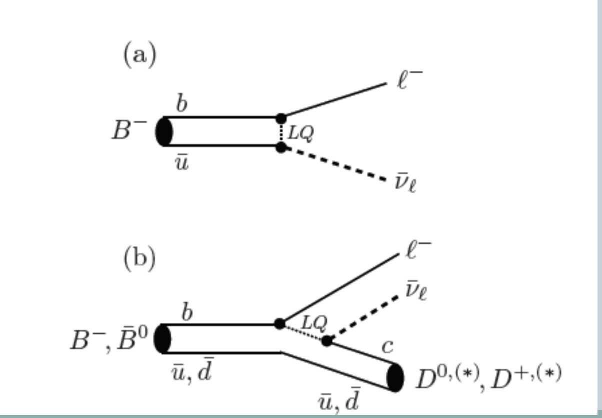
Why semitauonic decays are interesting?

- As tree level decays, they combine the advantages :
  - Very precise prediction from SM :R(D*) known to 2% precision, using

    R(D*) =BR(B°➔D*τν)/BR(B°➔D*μν)
  - Abundant channel BR(B°➔D*τν)=1,24%, one of the largest individual BR
  - Sensitivity to new physics: (simplest realization) A charged Higgs will automatically couple more to the τ . LFU violation can also occur through other mechanisms (leptoquarks,..)
- They offer several hadronisation implementations:
  - D*, D°, D+, D_s, Λ_c, J/ψ
  - Differing not only by various properties of the spectator particle but also

  its spin 0 (D°,D+,D_s), 1 (D* and J/ψ) and ½ (Λ_c!!)



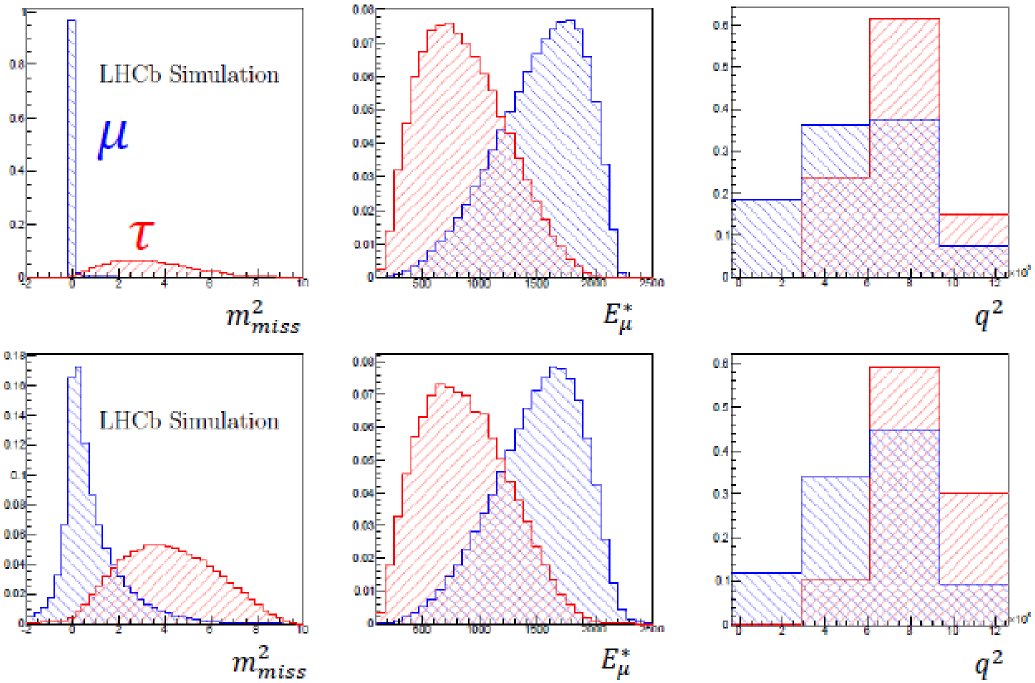


R(D*) with τ →μνν

PRL 115 111803 (2015)

MC Truth

Our Approximation



Using the known B flight direction, approximate the B momentum using $\gamma\beta_{z,vis}=\gamma\beta_{z,B}$:

- Estimate gives ~ 18% resolution on B momentum, but preserves shapes of already-broad distributions of to m^2_{miss}, E^*_μ and q^2
- 3d MC-template based binned fit to m^2_{miss} *vs* E^*_μ in coarse q^2 bins

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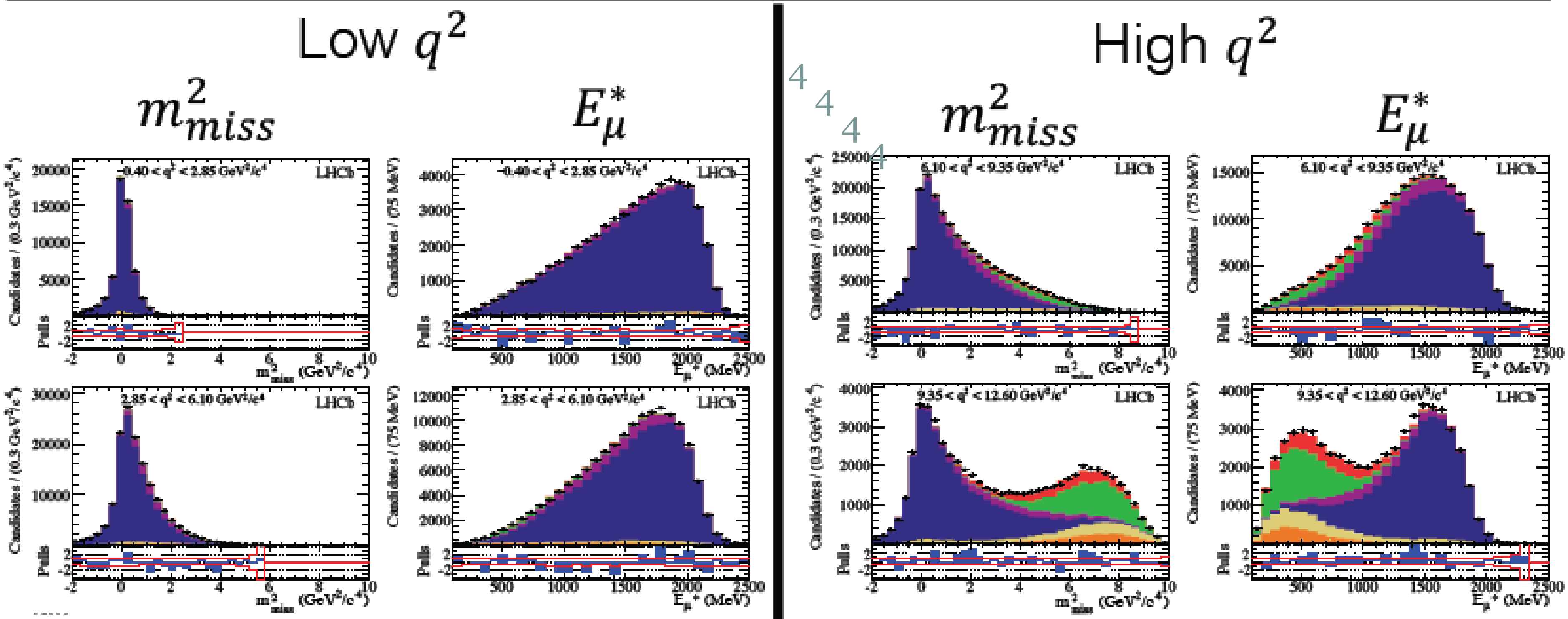
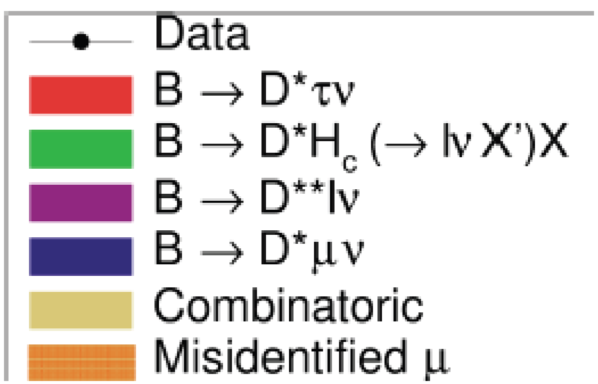
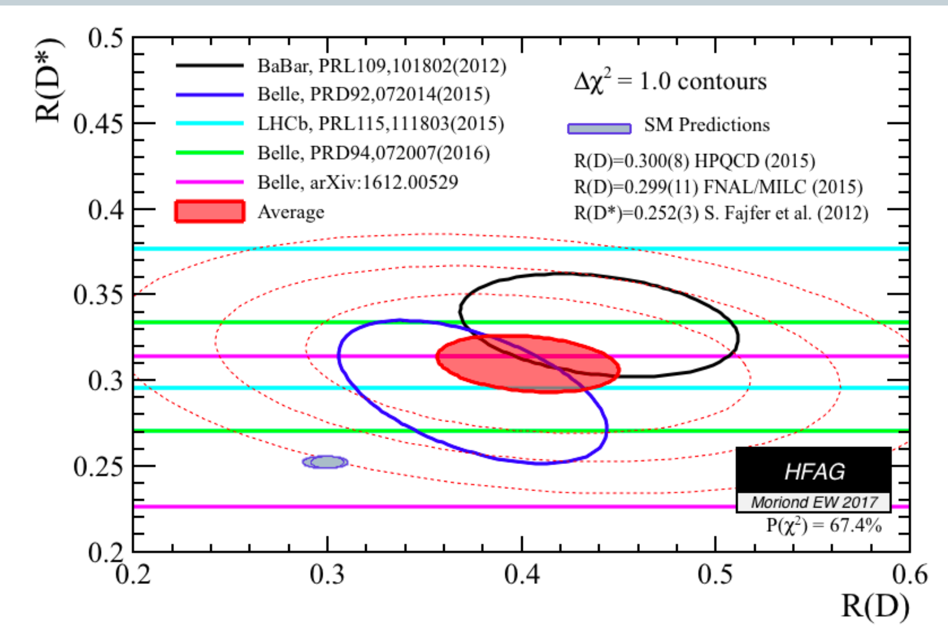
Fit Result



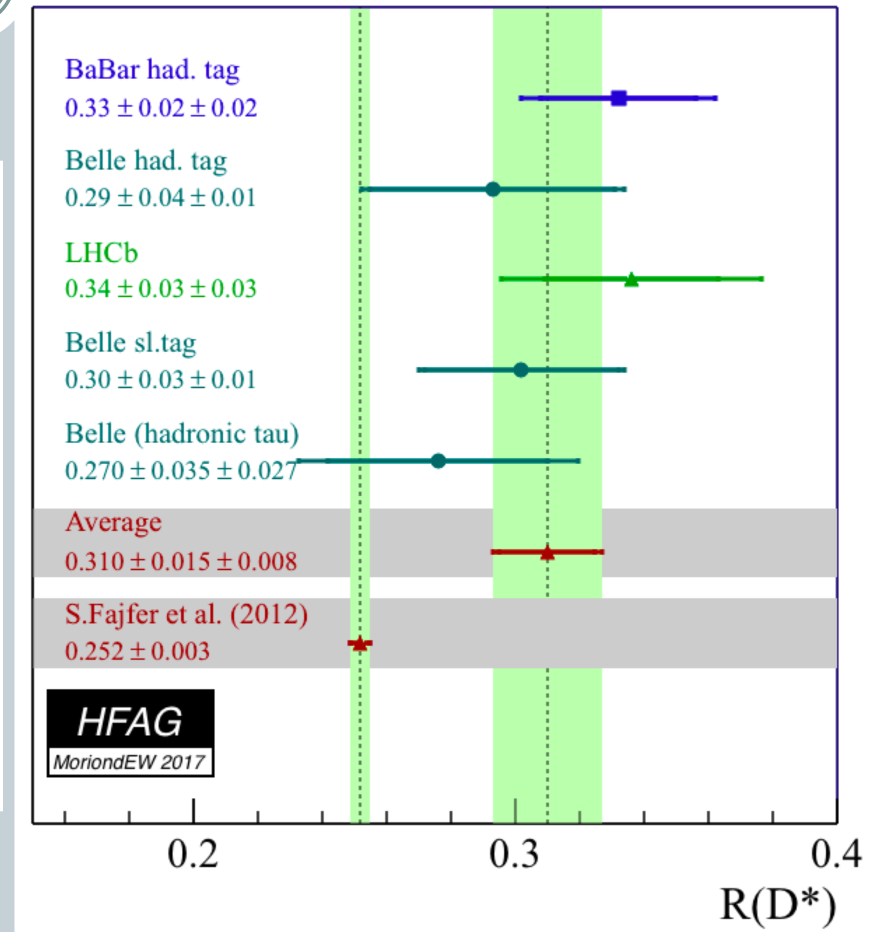
- Shown above: signal fit to "signal" data passing isolation selection
- Result $\frac{N_\tau}{N_\mu} = (4.32 \pm 0.37)\times 10^{-2}$, $R(D^*) = 0.336 \pm 0.027 \pm 0.030$
- $N(\bar{B}^0 \to D^{*+}\mu^-\bar{\nu}_\mu) = 363{,}000 \pm 1600$



R(D*) status today



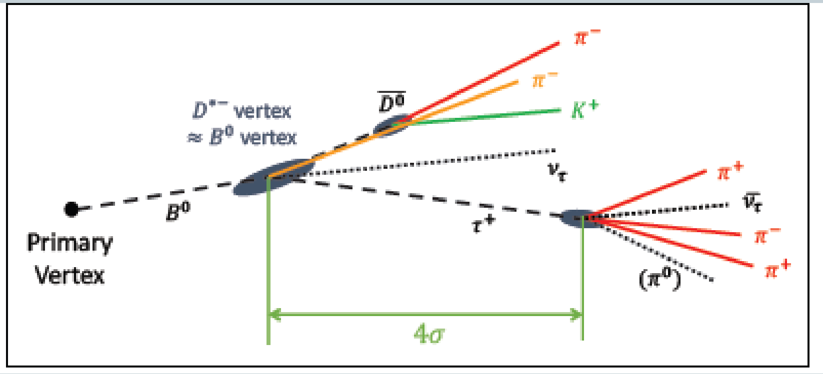
http://www.slac.stanford.edu/xorg/hfag/semi/index.html



If WA is correct, 22% of the D*τν events are mediated by new physics!

New ! R(D*) using τ hadronic decays in 3π
Unusual features of this analysis

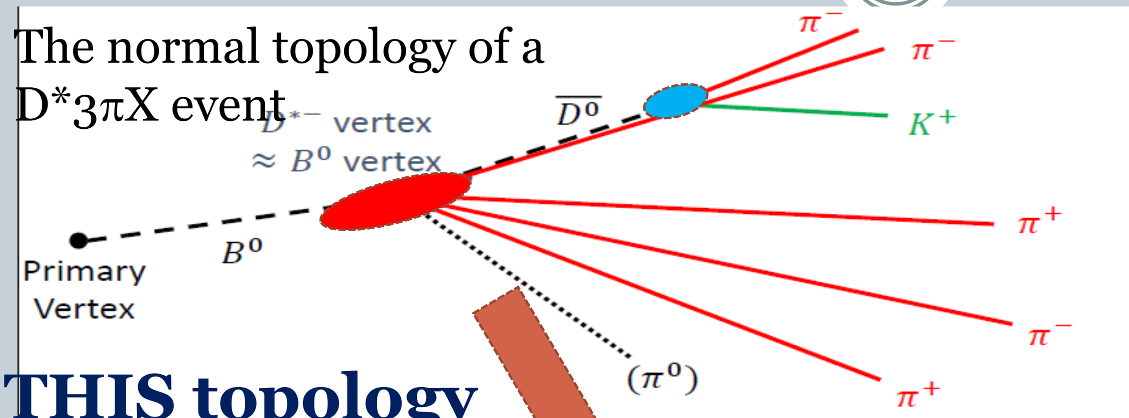
- A semileptonic decay without (charged) lepton !!:
  - Amusing but more importantly ZERO background from normal semileptonic decays!!!!



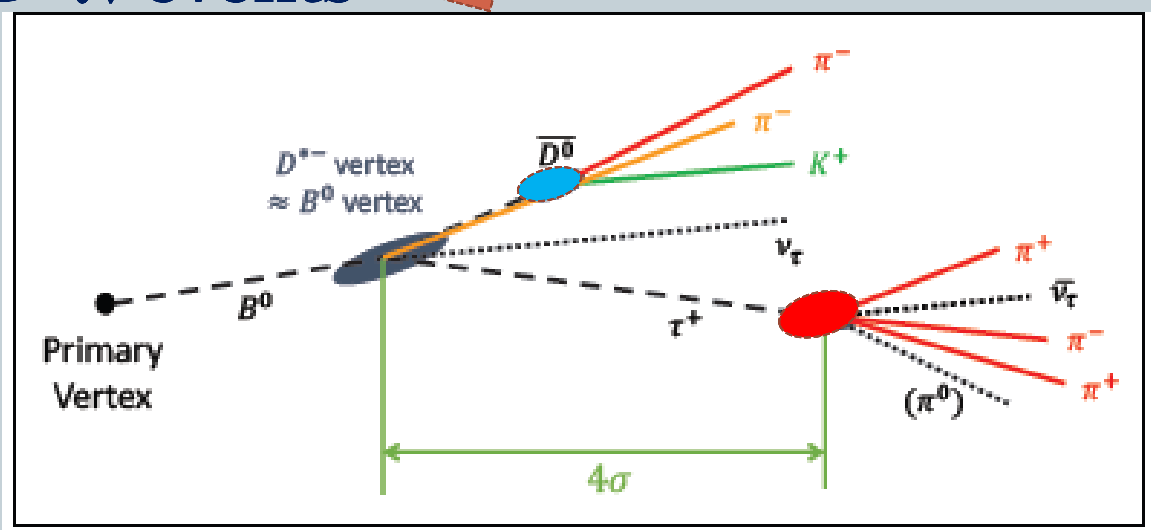
- The background leads to nice mass peaks and not the signal !!!
  - Amusing but more importantly provides key handles to control the various backgrounds
- Only 1 neutrino emitted at the τ vertex
  - The complete event kinematics can be reconstructed with reasonable precision
- But very large potential background from « bread and butter » D*3π X decays; 100 times larger than the signal : A trick must be found!!

The detached vertex method

The normal topology of a D*3πX event



THIS topology for D*τν events



The 4σ requirement kills the D*3πX background by ~10^3: **the road to the treasure is open ☺!!!**

The second gate : the double charm background

The second gate 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)

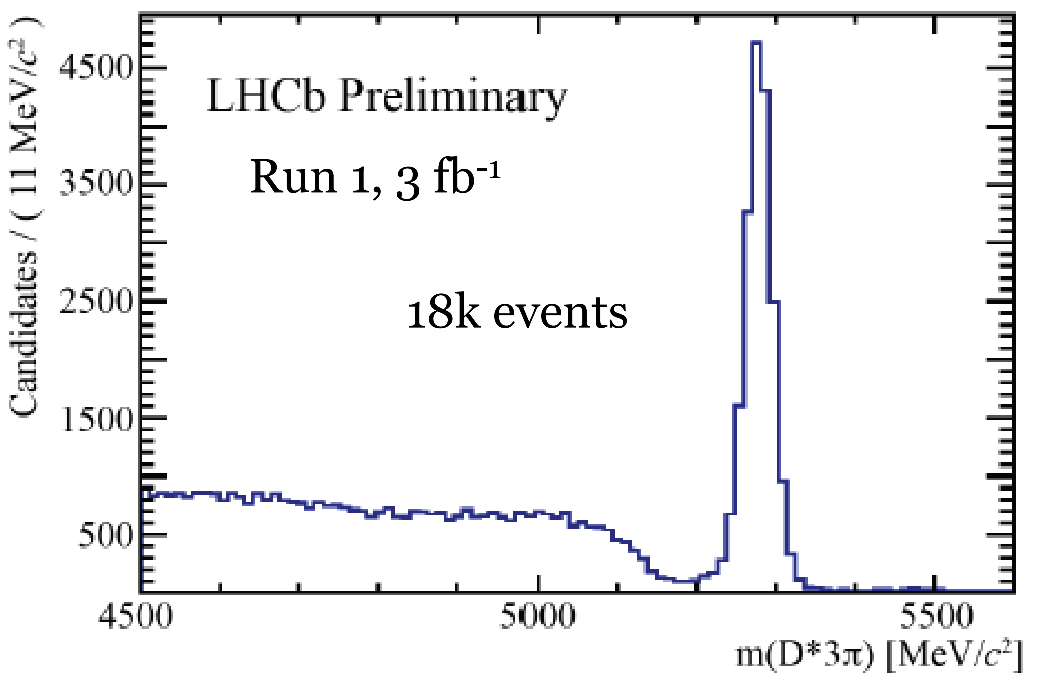
- This gate is thinner :
  - Double Charm→$3\pi X$ ~10 x signal

LHCb has three very good weapons to blow this gate away:

- 3π dynamics
- Neutral isolation
- Background partial reconstruction

Importance of the normalization channel $B^o \rightarrow D^*3\pi$

- Normalization as similar as possible to the signal to cancel production yield, BR uncertainties and systematics linked to trigger, PID, first selection cuts

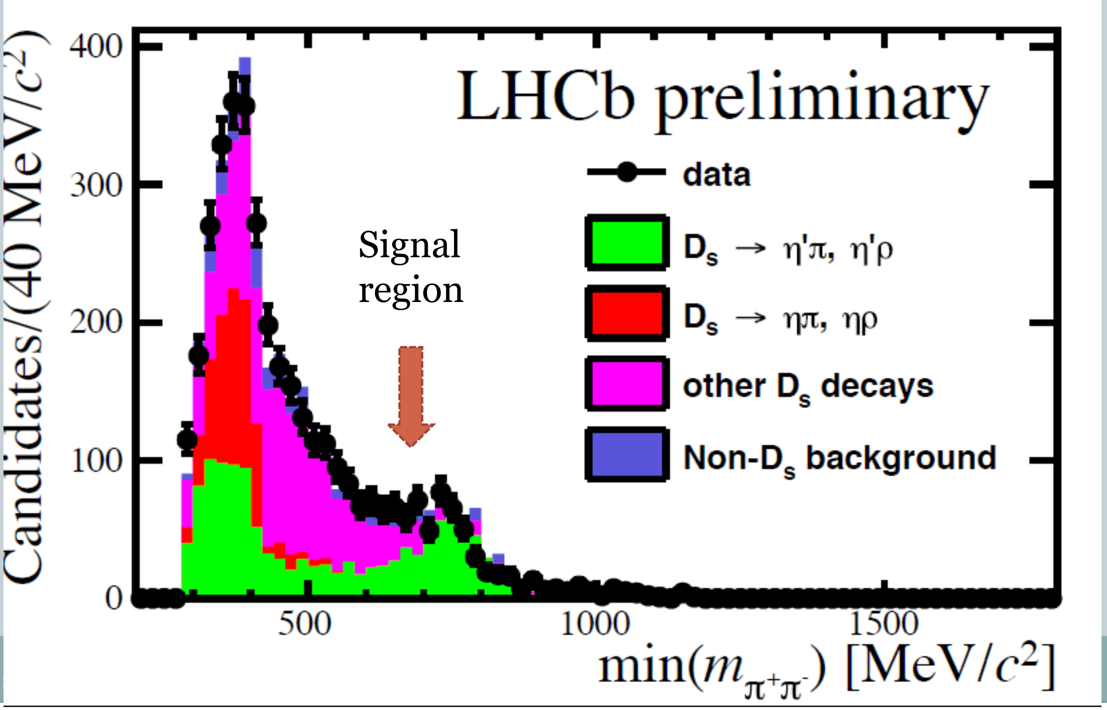


- Absolute BR recently measured by BABAR with a precision of 4.3% (**Phys.Rev. D94 (2016) no.9, 091101**)

The importance of the « D_s-o-meter »

- The D_s meson is the highest background since the W decays dominantly in D_s and the D_s is a very rich source of 3π +X final states.
- At low mass, only η and η' (red,green) contributions are peaking

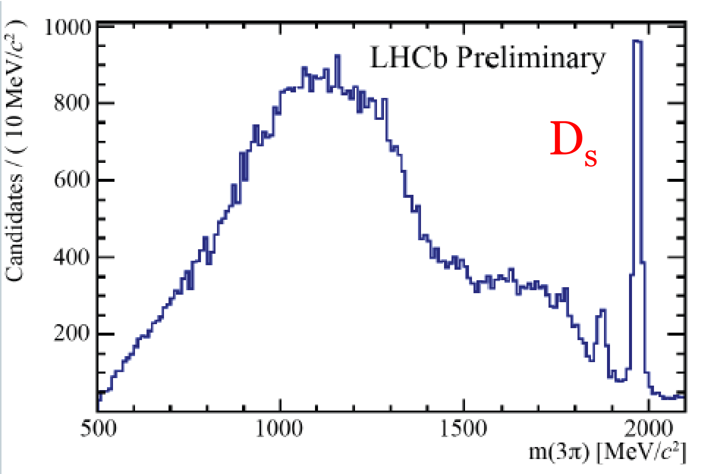
  $\eta \rightarrow \pi^+\pi^- \pi^0$ and $\eta' \rightarrow \eta \pi^+\pi^-$ ⇒ $M_{\pi+\pi-} < 415$ MeV
- At the ρ mass where the signal lives ($\tau \rightarrow a_1; a_1 \rightarrow \rho\pi$), only η' contributes ($\eta' \rightarrow \rho\gamma$)
- Using the low BDT region, one constraints the D_s decay model to be used at high BDT



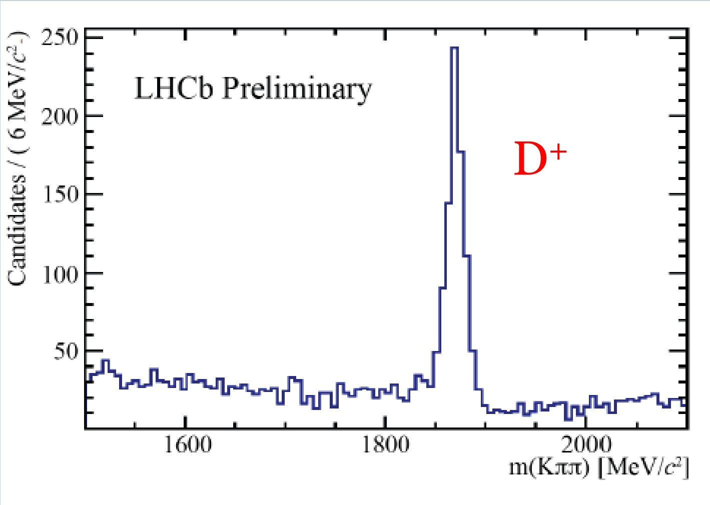
The anti-D_s BDT

- A BDT is constructed to get rid of the D_s background. It contains the following variables:
  - 3π dynamics : $\min(m_{\pi\pi})$, $\max(m_{\pi\pi})$,
  - B dynamics: D*3π mass
  - Partial reconstruction: the 4 constraints from the 2 lines of flight allows to reconstruct fully the event in the background hypothesis (no neutrinos)
  - Neutral isolation : energy in a cone around the 3π direction
  - Very D_s enriched at low BDT, good purity for signal at high BDT
- Opens the gate for search for BSM inside the events in addition to yields measurements

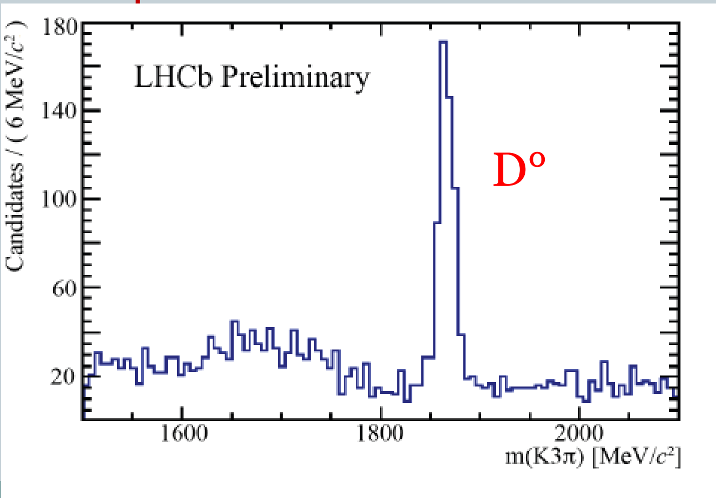
The control channels D_s, D°, and D^+



ππππ mass in detached topology



D^+ peak : Anti-PID cut

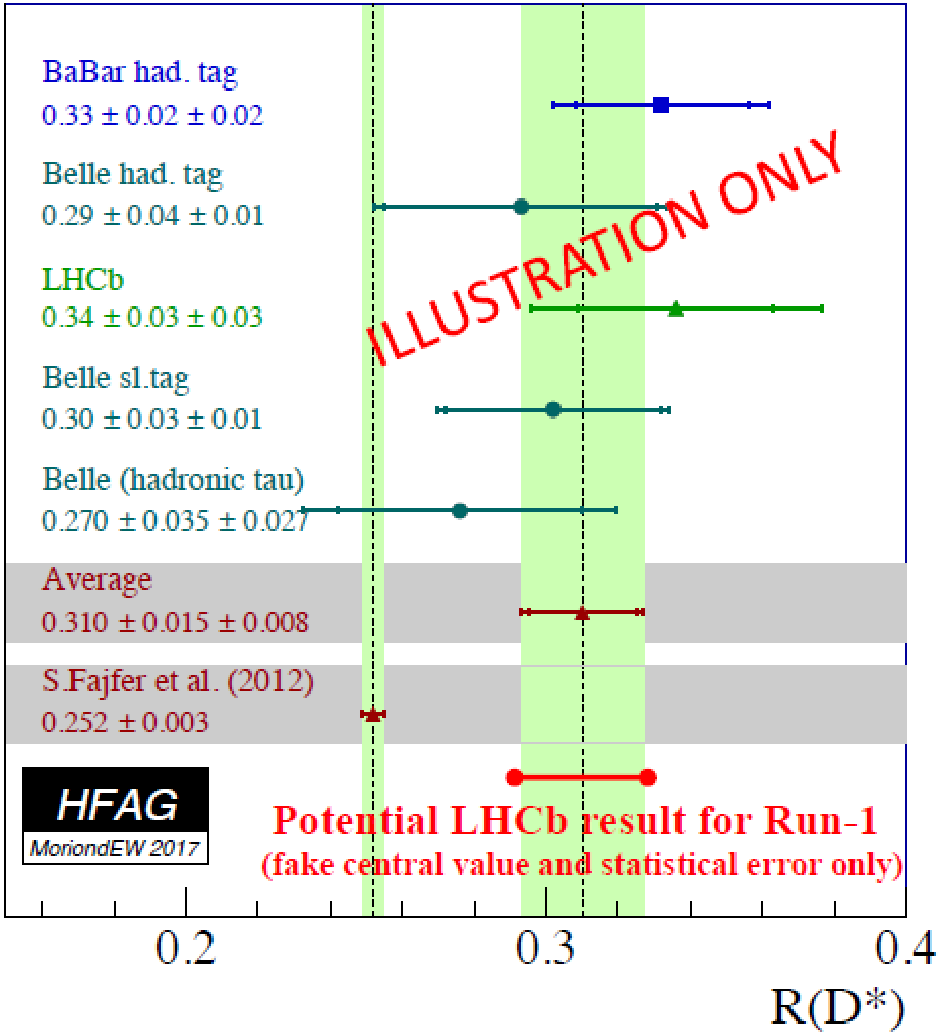


Run 1, 3 fb^{-1}

D° to K 3π peak : Antisolation cut

Signal extraction

- The $D_s \rightarrow 3\pi$ control channel is used to measure the ratio of $D^*D_s/D^*D_s^*/D^*D_s^{**}$ and to correct for their q^2 distribution
- A full fit is then performed at high BDT, as a 3D template binned fit of BDT,q^2 and τ lifetime.
- $D^*3\pi$, D^0 background constrained by their signal in the control channels



Systematic uncertainties

- External
  - 4,3 % from BR($B^{\circ} \rightarrow D^{*} 3\pi$) PDG 2016
  - 2% from BR($B^{\circ} \rightarrow D^{*} \mu\nu$)
- Internal
  - MC statistics
  - D_s,D^+,D° backgrounds
  - Prompt B° backgrounds
  - Stripping, Trigger
  - FF and τ decay model

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

- Expected overall to be larger than statistical error for the first publication (soon to come)
- Room for progress exists on a longer timescale on both internal and external sources!

Conclusion and Perspectives

- Semitauonic B decays are a great tool to discover new physics : high SM precision, high rate and high sensitivity
- The exceptional LHCb capability to separate secondary and tertiary vertices open up the best road to study **the semi-tauonic decays of all B particles** , thanks to a new method based on **3 prongs τ decays**.
- The **statistical precision on Run1 should be around 6.5%**, the best achieved so far for a single measurement.
- The very successfull RunII data taking in 2015-2016 leads to **a quadrupling of the data set**
- High statistics and high purity samples to search for BSM effects in the event observables