Searches for LFU breaking using semileptonic B decays at LHCb

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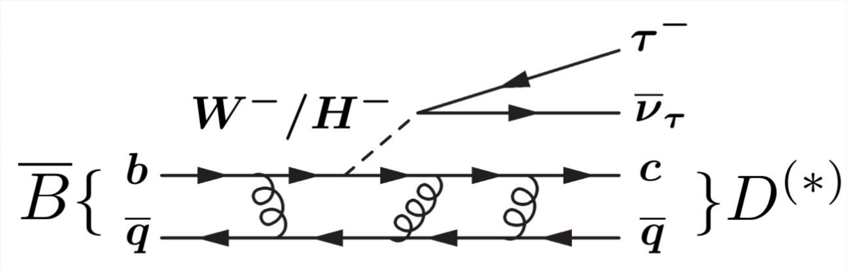
LFU: a hot topic

- The Standard Model predicts *Lepton Flavour Universality (LFU)*: equal couplings between gauge bosons and the three lepton families

- But, there are tensions between SM expectations and experimental results in:
  - **Semitauonic B decays → This talk !**
  - b→*sll* transitions with for instance a 2.4σ deviation for the recent LHCb result on $R(K^{*0})$

arXiv:1705.05802

- Several SM extensions add new interactions with a stronger coupling with the third generation of leptons (charged Higgs, leptoquarks, …)



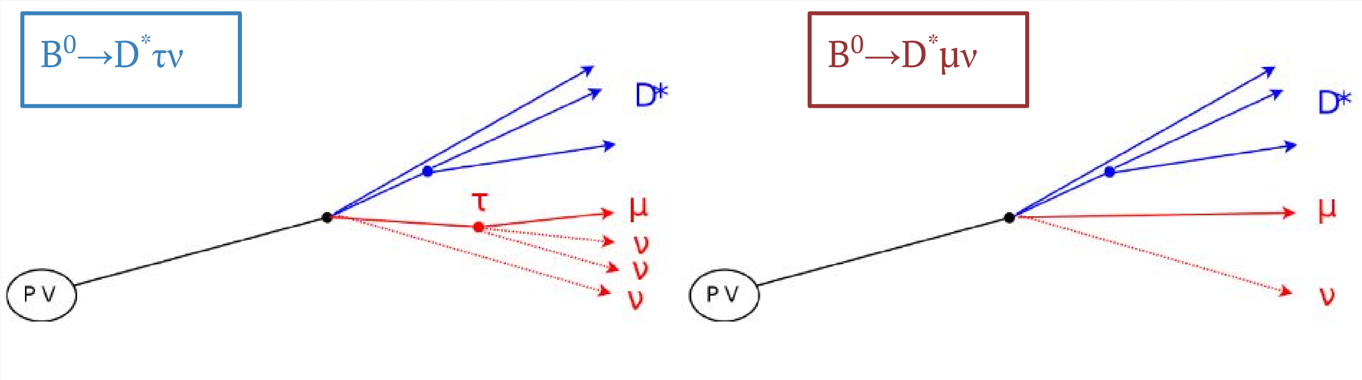
Why using semitauonic B decays ?

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

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

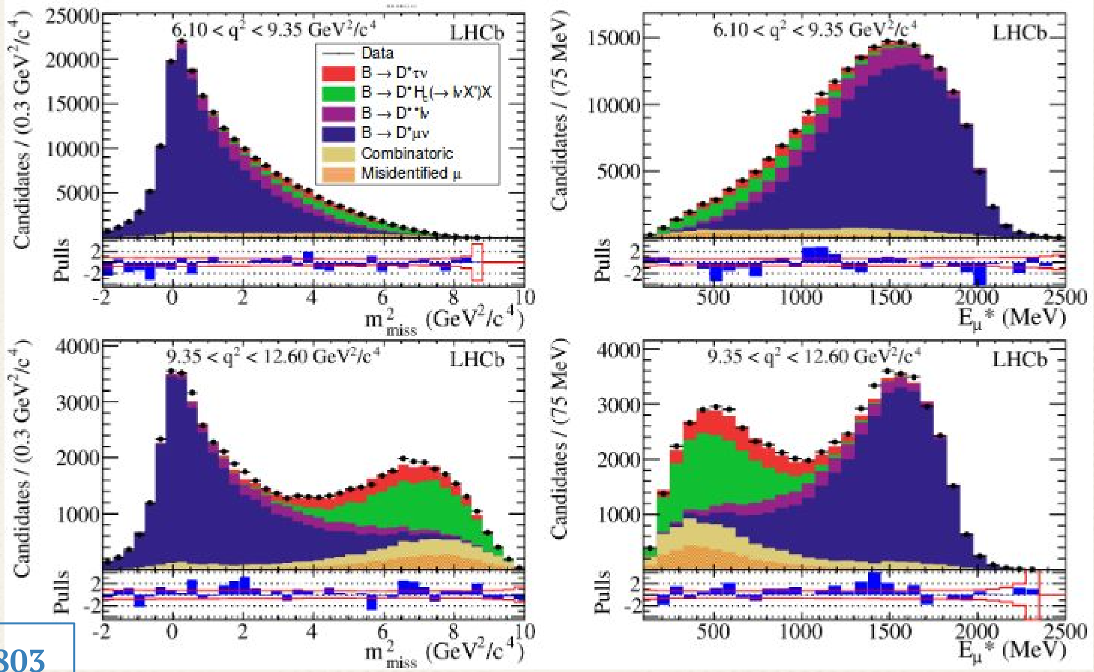
- Different hadronisation schemes are possible:
  - D^*, D^0, D^+, D_s, Λ_c, J/Ψ
  - Not only spectators quarks differ but also the **spin**:
    - 0: D^0, D^+, D_s
    - 1: D^*, J/Ψ
    - ½: Λ_c

R(D*) with τ→μνν



- 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

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



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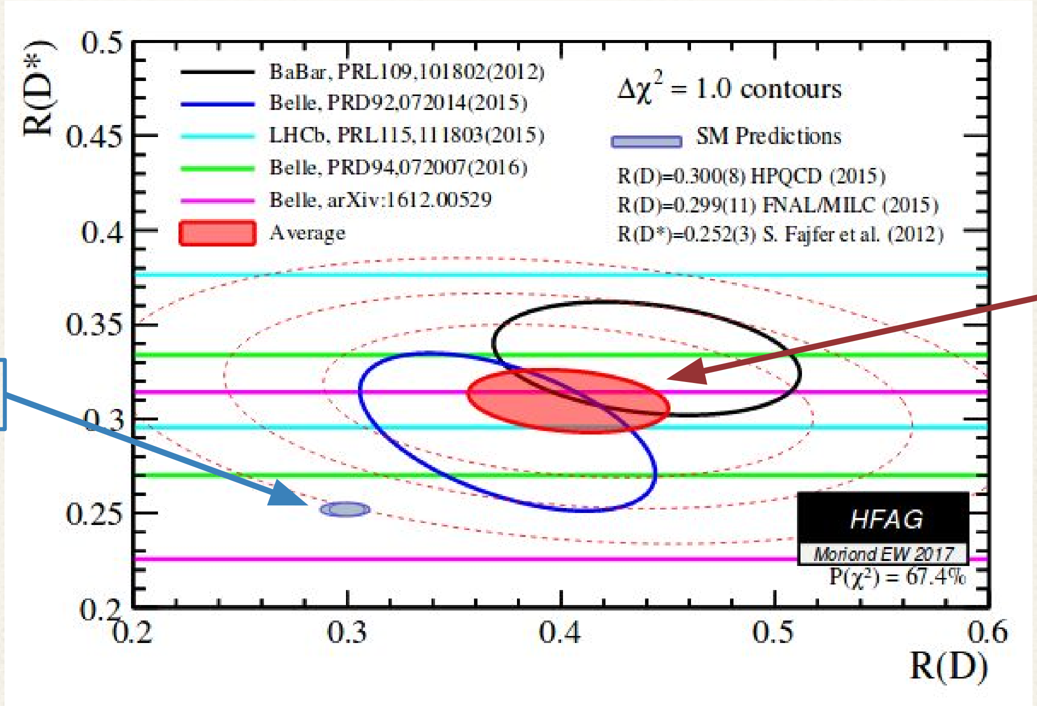
- Fit to isolated data, used to determine ratio of $B\to D^*\tau\nu$ and $B\to D^*\mu\nu$
- Templates are a good description of the data

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

R(D*) status

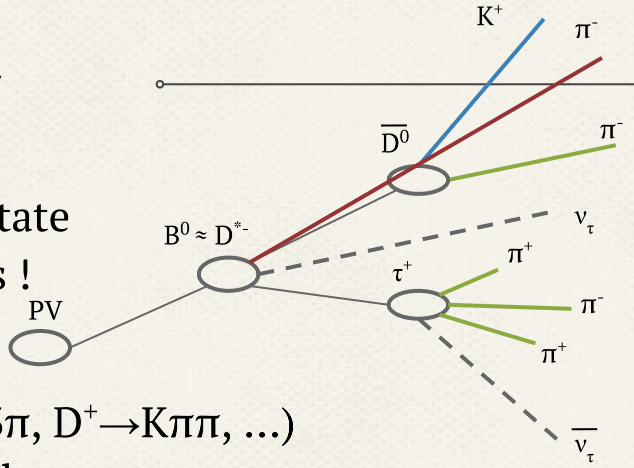


SM: 1.19% uncertainty

WA: 5% uncertainty

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

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

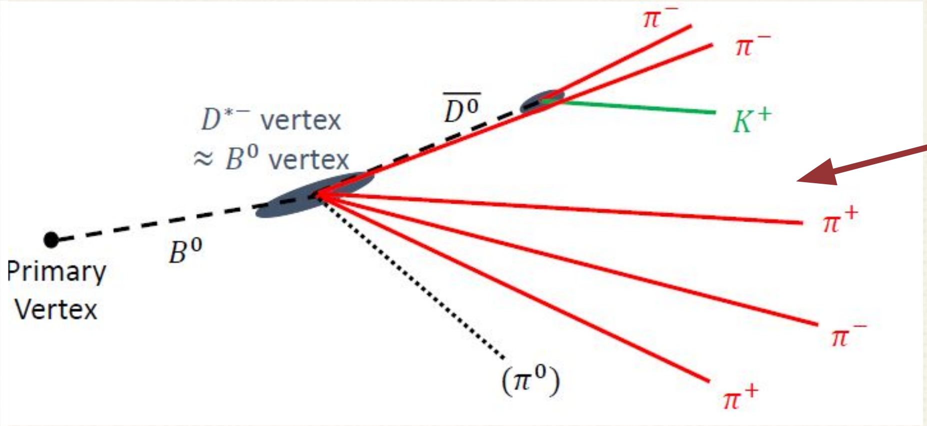
$$R_{had}(D^*) = \frac{\mathcal{B}(\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B}^0 \to D^{*+}\pi^+\pi^-\pi^+)}$$

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

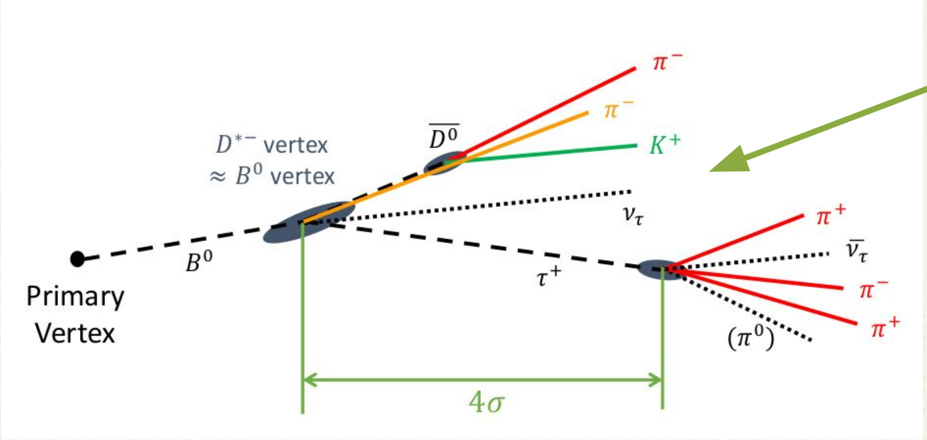
Vertex topology



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

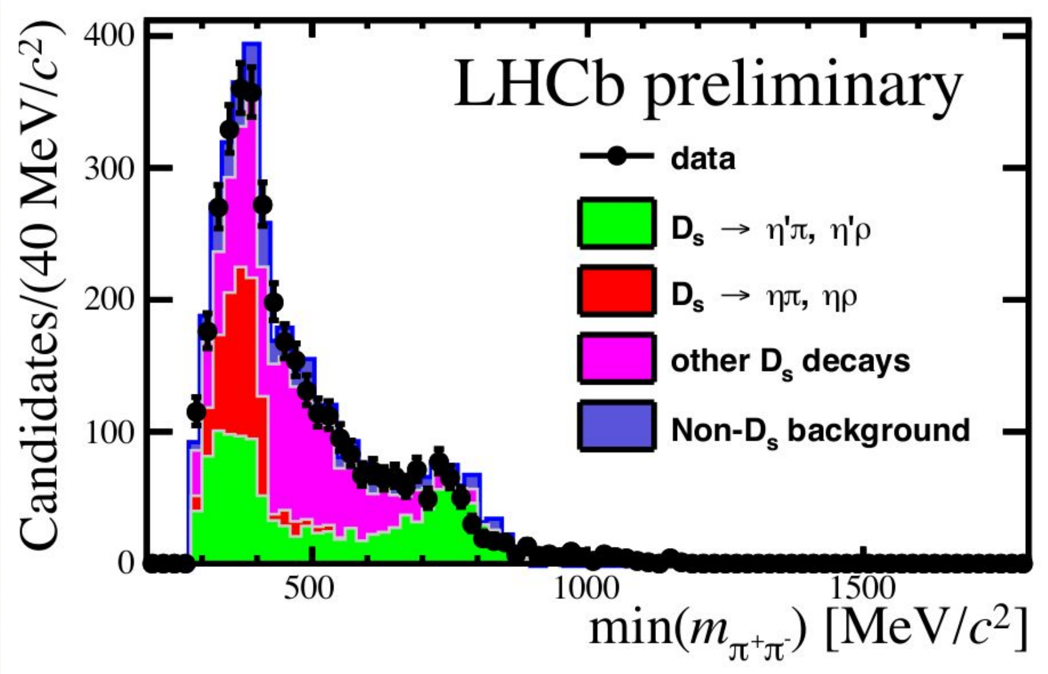
- LHCb has three very good tools to limit this background:
  - **3π dynamics**
  - **Isolation criteria** against charged tracks and neutral energy deposits
    - Algorithms look for energy or tracks in the **underlying event** to associate with the signal candidate → **non-isolated events** can be then **vetoed** or studied as **control channels**
  - **Partial reconstruction** in both signal and background hypotheses

- **A Boosted Decision Tree** (BDT) is trained using variables computed with partial reconstruction and isolation criteria to discriminate double charm decays from signal

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

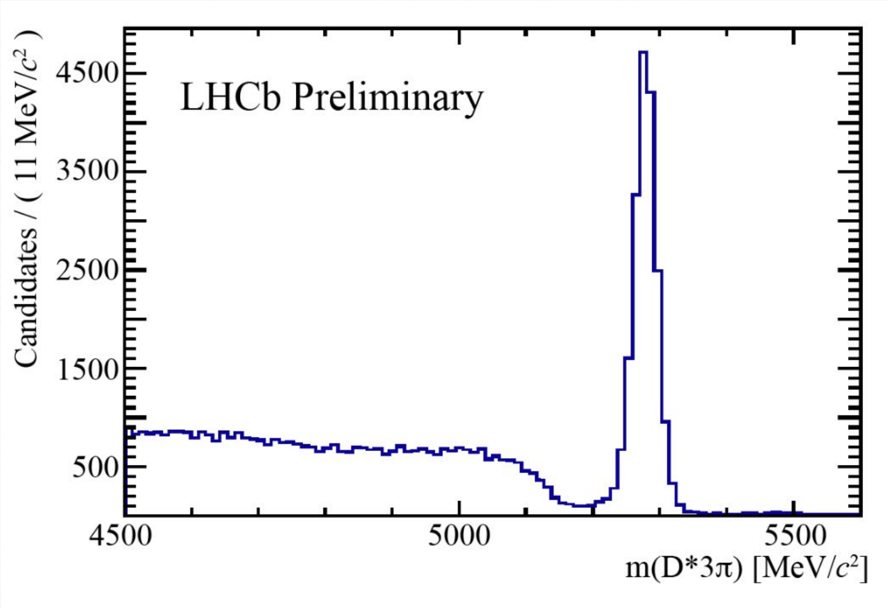


Normalisation channel

- 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.

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

Run 1, 3 fb^{-1}



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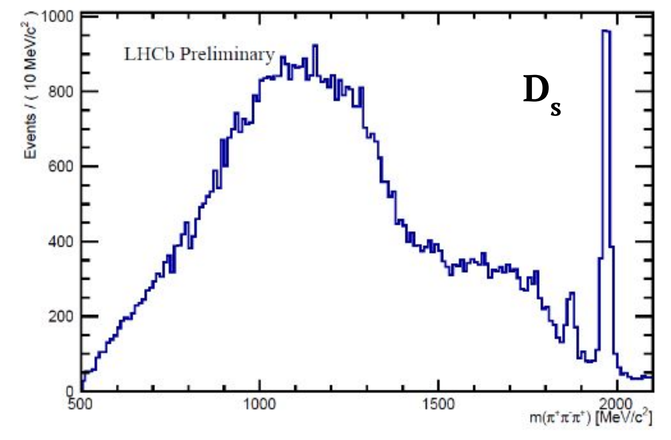
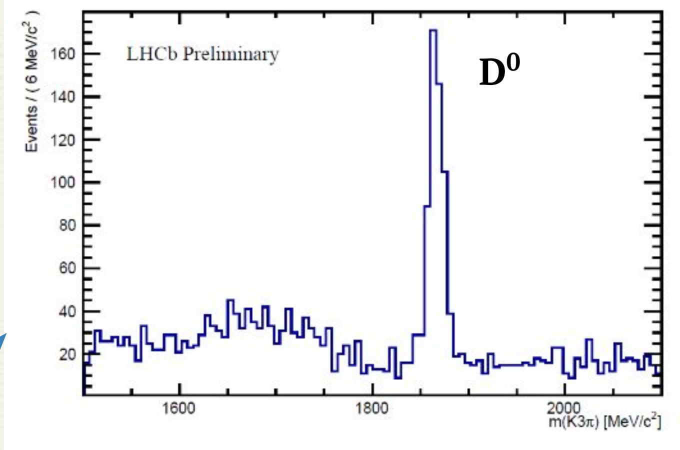
Control channels



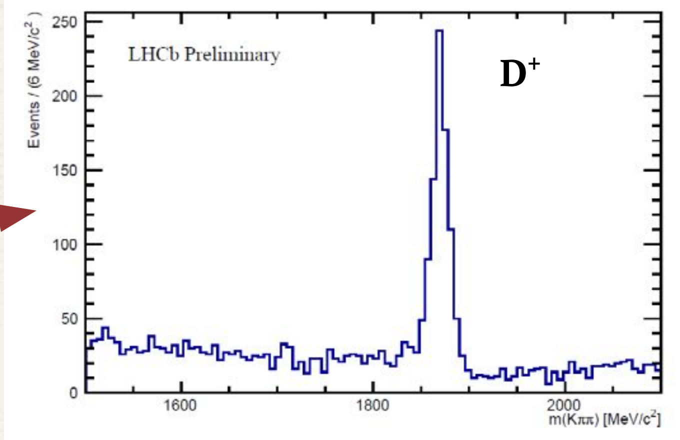
Run 1, 3 fb^{-1}



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

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**

Main systematics

- External:
  - 4.3 % from BR($B^0 \rightarrow D^* 3\pi$) PDG 2016
  - 2% from BR($B^0 \rightarrow D^* \mu \nu$)
- Internal:
  - MC statistics
  - D_s, D^+, D^0 backgrounds
  - Prompt B^0 backgrounds
  - Stripping, Trigger
  - Form Factors and τ decay model
- Total systematic uncertainty expected to be larger than statistical error for the first publication (soon to come).

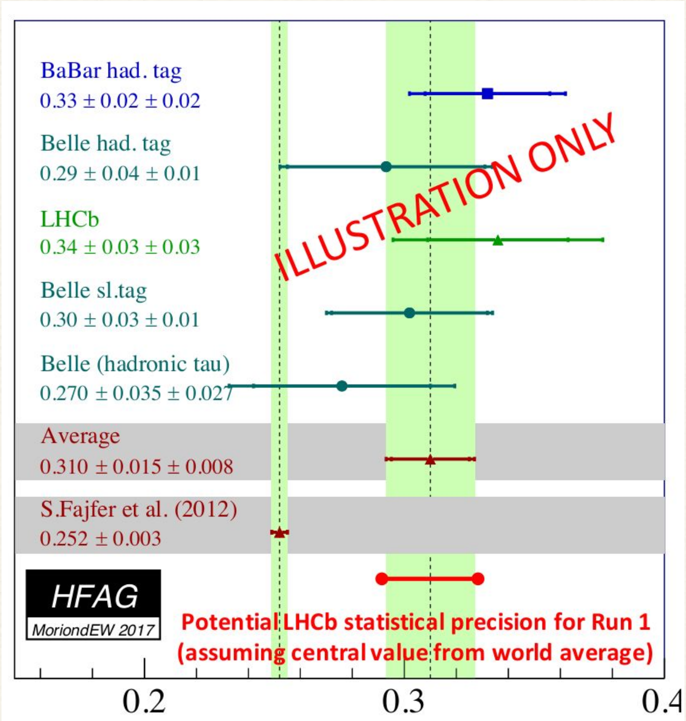
In red: can be reduced with help from other experiments (BELLE, BES, ...)

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

Conclusion

- Semitauonic B decays are great tool to discover new physics:
  - high SM precision, high rate and high sensitivity
- Several measurements are ongoing:
  - $R(D^{*})$, $R(D)$, $R(J/\Psi)$, $R(\Lambda_c)$
  - more modes are also possible to do

- Thanks to the LHCb capability, it is possible to reconstruct hadronic tau decays with good precision.
- Statistical precision on Run1 should be around **7%**
- The successful Run2 data taking leads to a 4x bigger dataset wich will contribute to **reduce both statistical and systematics uncertainties !**



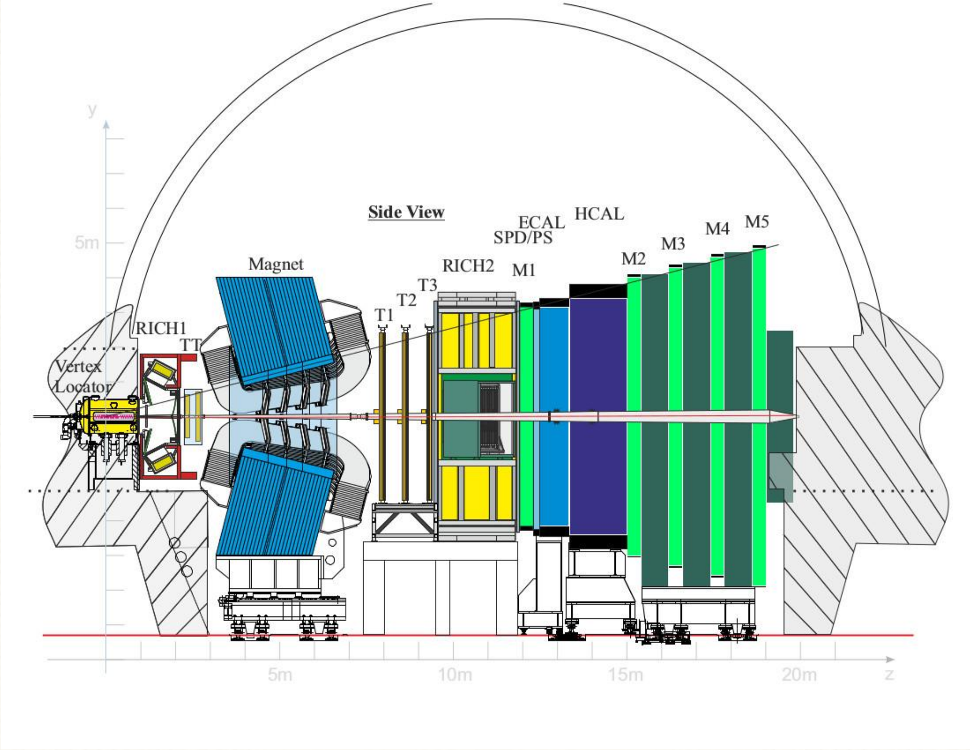
Result to come soon !

Thank you for your attention ！

Any question ?

Backup

The LHCb detector



- **Single arm spectrometer** at LHC in the pseudorapidity range 2<η<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)