Review of R measurements in LHCb in the hadronic channel

A R's review

Victor Renaudin

on behalf of the LHCb collaboration

LAL, Université Paris-Sud

Second LHCb open semitauonic workshop

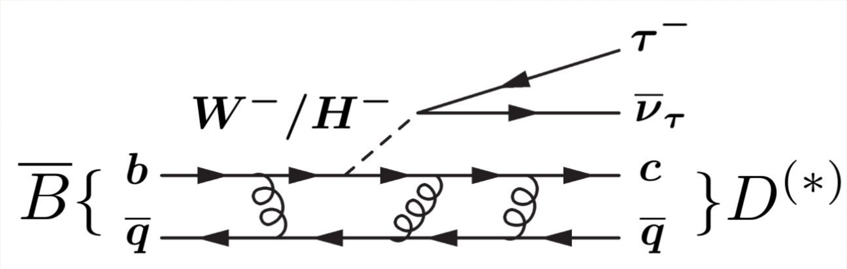
LFU: a hot topic

- 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**
  - 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**: $BR(B \to D^* \tau \nu) \sim 1.2\%$
  - **Sensitivity 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

Beyond R(D^*)

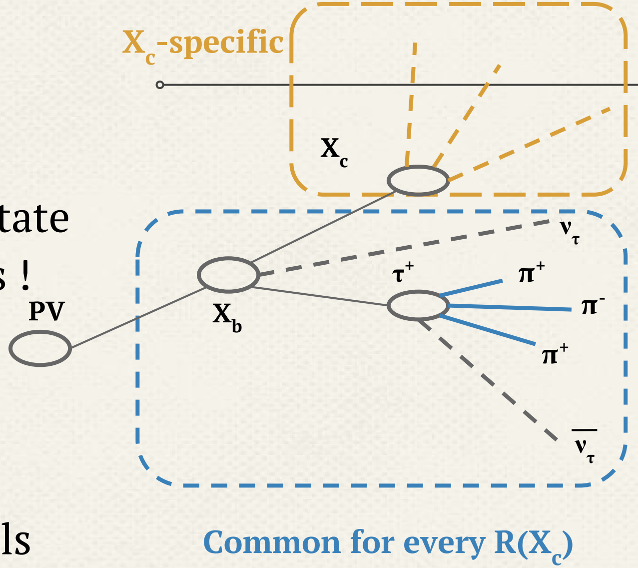
- Ongoing analyses using the hadronic τ decay:
  - R(Λ_c): $\Lambda_b \rightarrow \Lambda_c l\nu$
  - R(J/ψ): $B_c \rightarrow J/\psi l\nu$

- Other possible modes:
  - R(D^+): $B^0 \rightarrow D^+ l\nu$
  - R(D^0): $B^+ \rightarrow D^0 l\nu$
  - R(D^{**}): $B \rightarrow D^{**} l\nu$
  - R(Λ_c^*): $\Lambda_b \rightarrow \Lambda_c^* l\nu$ with $\Lambda_c^* \rightarrow \Lambda_c \pi\pi$
  - R(D_s): $B_s \rightarrow D_s l\nu$

will be performed in parallel of hadronic R(D^*) Run II

- In a far future:
  - $B^0 \rightarrow p\tau\nu$

$R(X_c)$ recipe



- Semileptonic decay **without charged lepton** in the final state
  - → **Zero** background from normal semileptonic decays !
- **No signal mass peak but several hadronic ones**
  - for instance, $D^0 \to K3\pi$, $D^+ \to K\pi\pi$, …
  - It provides control on the various background channels
- Only one ν at the τ vertex
  - **Partial reconstruction can be applied** with good precision
- Prompt 3π background is dominant:
  - Specificities for each X_c but same tool to suppress it: **vertex displacement**
- Double charm background is rejected using a BDT
- Extraction of the measurement using a **3D template fit in q^2, BDT output and t_τ**

Double charm background

- The remaining background consists of X_b decays where the 3π vertex is transported away from the X_b 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
  - This background **does not depend** on the nature of $\mathbf{X_c}$

- 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) discriminates double charm decays from signal
- The **D_s decay model** from the $R(D^*)$ analysis **can be reused** for every $R(X_c)$

$R(\Lambda_c)$

- Same strategy as $R(D^*)$, the goal is to measure:

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

- Precise prediction from LQCD: $R_{SM}(\Lambda_c) = 0.3328 \pm 0.0074_{stat} \pm 0.0070_{syst}$ [1]
- Probing LFU with a baryon with a **different spin structure**

- Use of $\Lambda_b \to \Lambda_c 3\pi$ 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

[1]: [W. Detmold, C. Lehner, S. Meinel, PRD 92, 034503 (2015)]

R(Λ_c)

$\Lambda_c \tau \nu$, $\mathcal{L} = 0.87\ fb^{-1}$		
$\Lambda_c^+ 3\pi$	normal	6630 ± 93
$\Lambda_c^+ D_s^{(*(*))}$	inverted	495 ± 35
$\Lambda_c^+ D_s$	inverted	77 ± 10
$D^* \tau \nu$, $\mathcal{L} = 1.0\ fb^{-1}$		
$D^* 3\pi$	normal	6702 ± 89
$D^* D_s^{(*(*))}$	inverted	404 ± 14
$D^* D_s$	inverted	67 ± 10

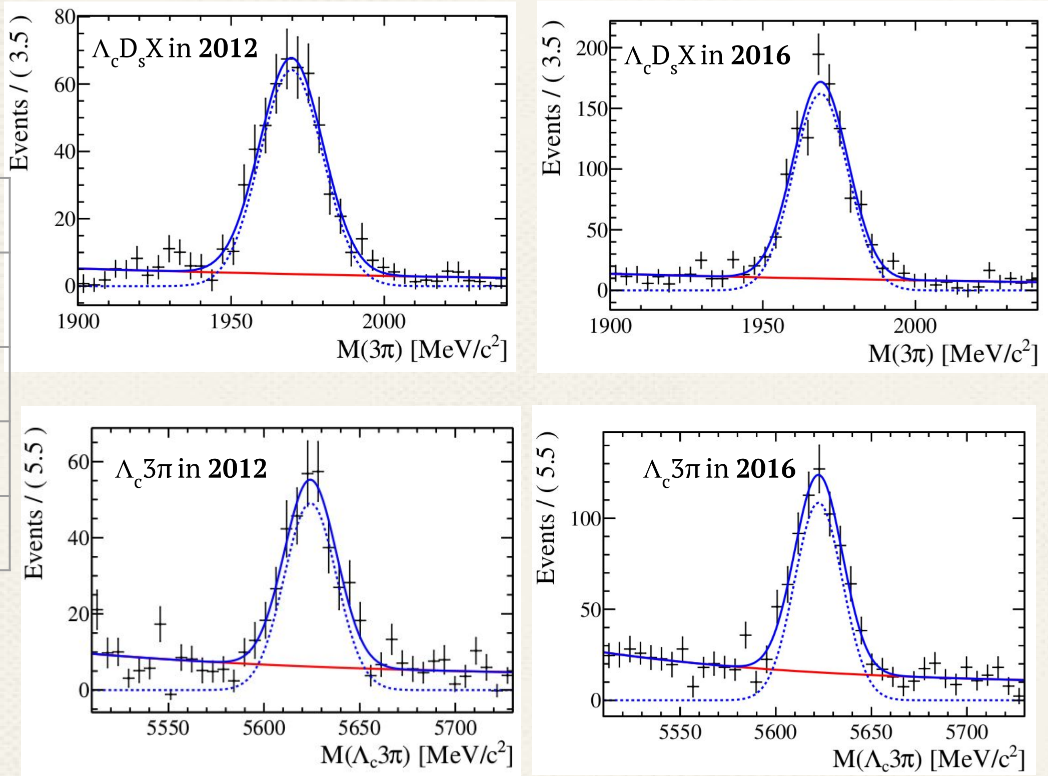
Comparison between $\Lambda_c\tau\nu$ and $D^*\tau\nu$ analyses :

- $\Lambda_c 3\pi$, $\Lambda_c D_s$ peaks on MC and data :
  data rates are comparable with $D^*3\pi$ and D^*D_s (lower Λ_b production but higher Λ_c visibility)

→ Same sensitivity expected

R(Λ_c)

All plots are using Splot technique to select Λ_c



Yields for each year of data taking per fb^{-1}

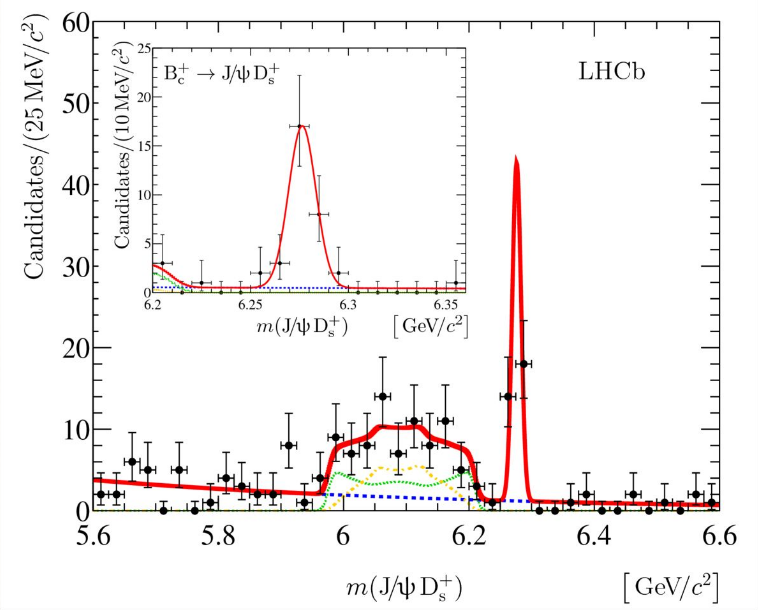
Year	2011	2012	2015	2016	2016/2012
Λ_c	5709 ± 92	6749 ± 80	27509 ± 41	29182 ± 336	4.32 ± 0.07
$\Lambda_c D_s X$	202 ± 18	237 ± 11	962 ± 52	1056 ± 48	4.46 ± 0.29
$\Lambda_c D_s$	37 ± 7	40 ± 4	92 ± 12	110 ± 17	2.75 ± 0.51
$\Lambda_c 3\pi$	129 ± 18	154 ± 10	645 ± 49	627 ± 38	4.07 ± 0.36

R(J/ψ)

- The goal is to measure:

$$R(J/\psi) = \frac{\mathcal{B}(B_c^+ \to J/\psi \tau^+ \nu_\tau)}{\mathcal{B}(B_c^+ \to J/\psi \mu^+ \nu_\mu)}$$

- This analysis is using:
  - $J/\psi \to \mu\mu$
  - As there is no input from B factories, normalisation channel will be $B_c^+ \to J/\psi \mu X$



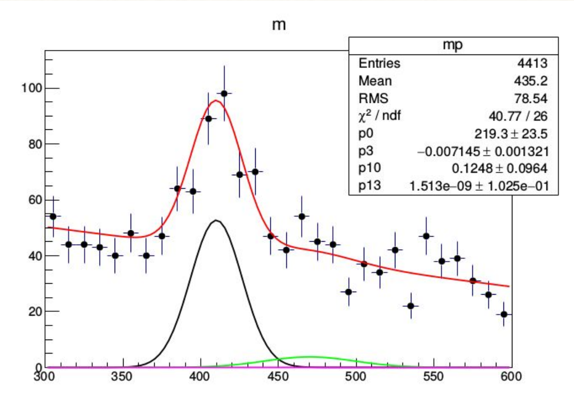
In LHCB-PAPER-2012-010 [1], the decay $B_c \to J/\psi D_s$ is observed with $D_s \to KK\pi$ with 3 fb^{-1} of data (BR ~5 times larger than $D_s \to 3\pi$)

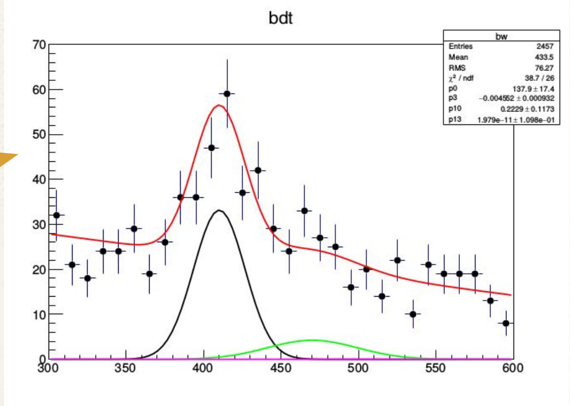
[1]: [Phys.Rev. D87 (2013) no.11, 112012]

$R(D_1(2420)^0)$

In the $R(D^*)$ analysis:

- Background contribution from D^{**} states
  - such as $D_1(2420)^0 \rightarrow D^{*+}\pi^-$
- Upper limit in Run I, a measurement of $R(D_1(2420)^0)$ can be performed with Run II data.
- To illustrate, up plot shows $m(D^{*-}\pi^+)-m(D^{*-})$ without a BDT cut (enriched in $D^{**}D_s$ events) and the bottom one shows the same distribution with a BDT cut (should contain a large fraction of $D^{**}\tau\nu$ events).





Normalisation

How to normalise hadronic analyses ?

- R(D*): Use of two external BR from PDG
  - $B^0 \rightarrow D^* 3\pi$, 4% uncertainty
  - $B^0 \rightarrow D^* \mu\nu$, 2% uncertainty

What can we do with other modes ?

- Direct normalisation using same strategy:
  - $\Lambda_b \rightarrow \Lambda_c 3\pi$, 14% uncertainty

- Use of inputs from LQCD to reuse $R(D^*)$ normalisation:
  - for instance: $K = \frac{\Gamma(\Lambda_b^0 \to \Lambda_c^+ \mu\nu)}{\Gamma(B^0 \to D^+ \mu\nu)}$ [1]

- Investigate other modes:
  - $\Lambda_b \rightarrow \Lambda_c D_s$
  - $B_c \rightarrow J/\psi D_s$
  - $\Lambda_b \rightarrow \Lambda_c \mu\nu$

With $D_s \rightarrow 3\pi$, closer topology to signal but low Branching fraction

[1]: Meinel's talk during first LHCb semitauonic workshop

Conclusion

After $R(D^*)$, more modes are coming

- Probing LFU with different spin structure
- $R(\Lambda_c)$ and $R(J/\psi)$ are ongoing
- Run1 and Run2 combinations will allow great statistical improvement

$R(D^*)$ tools and strategy can be applied for other modes:

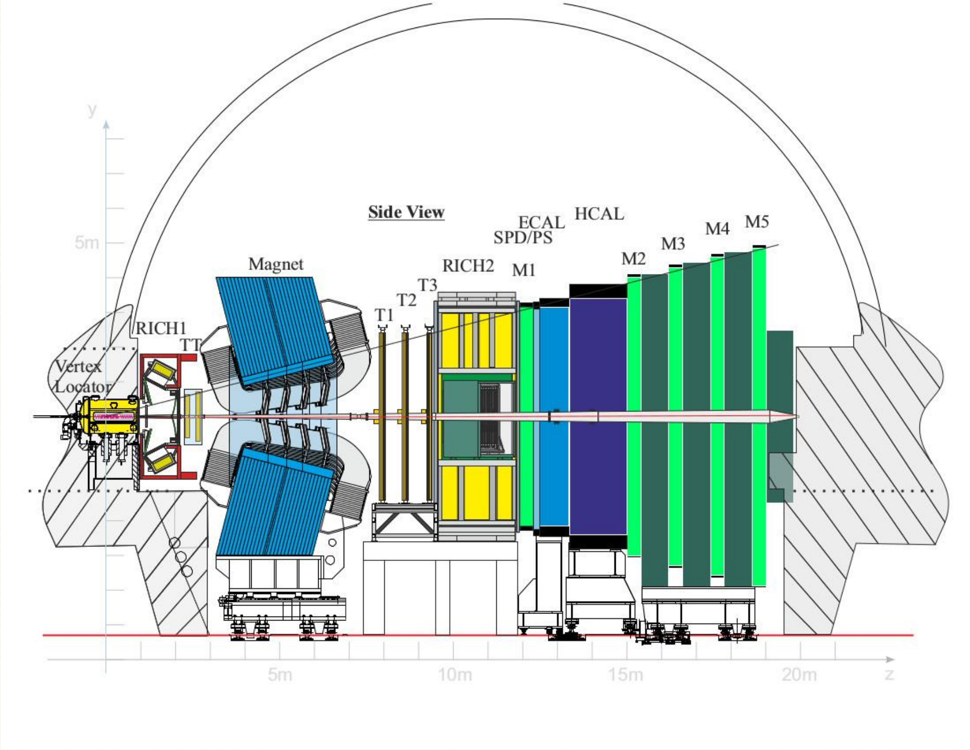
- Yields of control channels in the $R(\Lambda_c)$ analysis are very similar
- Normalisation strategies for each mode have to be studied

Thank you for your attention !

Any question ?

Backup

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)