Normalization states

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Motivation

- **At proton colliders such as the LHC, the presence of large uncertainties regarding absolute trigger and production efficiencies implies that only ratios of branching fractions can be measured at a precise level.**
- For each $R(X_c)$ measurement, one therefore has to choose a normalization channel whose yield will be measured together with the signal channel under consideration to determine such a ratio.
- In the case of 3-prong $\tau \rightarrow 3\pi\nu_\tau$ we measure e.g.

$$K(D^*) = \frac{Br(B^0 \to D^*\tau\nu)}{Br(B^0 \to D^* 3\pi)} = \frac{N_{\mathrm{sig}}}{N_{\mathrm{norm}}} \times \frac{\varepsilon_{\mathrm{norm}}}{\varepsilon_{\mathrm{sig}}},$$

- and get $R(D^*) = K(D^*) \times Br(B^0 \rightarrow D^* 3\pi)/Br(B^0 \rightarrow D^* \mu\nu).$

The ideal normalization channel

[Disclaimer: 3-prong measurements from now on]

1. its final state is exactly the same as the signal channel
2. its production dynamics and decay kinematics are the same as the signal channel
3. its absolute branching fraction is known with an uncertainty negligible with respect to other sources.

In practice…

- $B^0 \to D^{*-}\tau^+\nu_\tau$: the decay channel $B^0 \to D^{*-}\pi^+\pi^-\pi^+$ matches criteria 1 and 3 but only partially criterion 2, since the two extra neutrinos present in the signal final state affect (slightly) trigger and selection efficiencies.
- $B_c \to J/\psi\ \tau^+\nu_\tau$: the $B_c \to J/\psi\ \pi^+\pi^-\pi^+$ channel matches criteria 1 (fully) and 2 (partially), but it does not match at all criterion 3, since its branching fraction is unknown.
  - Normalizing to $B_c \to J/\psi\ \mu^+\nu_\mu$ would violate criterion 1 and 2 (to some extent)
- Similar situation for D^0, D^-, D_s^-,Λ_c^-: branching fractions are known at a precision level above 10%

Summary of measurements

Channel	Branching fraction	Notes
$B^0 \to D^{*-} 3\pi$	$(7.21 \pm 0.29)\ 10^{-3}$	Dominated by Babar measurement
$B^0 \to D^- 3\pi$	$(6.0 \pm 0.7)\ 10^{-3}$	CLEO 1992 + PDG fit
$B^+ \to D^0 3\pi$	$(5.7 \pm 2.2)\ 10^{-3}$	CLEO 1992 + PDG fit
$B_s \to D_s 3\pi$	$(6.1 \pm 1.0)\ 10^{-3}$	CDF + PDG fit. Measured relative to $B^0 \to D^- 3\pi$
$\Lambda_b \to \Lambda_c 3\pi$	$(7.7 \pm 1.1)\ 10^{-3}$	CDF, relative to $\Lambda_c \pi$. The uncertainty on the latter is dominated by 2 LHCb measurements, both dominated by knowledge of f_{baryon}/f_d and 1. $BR(B^0 \to D^- \pi^+)$ 2. Obtained using the branching fraction of $\Lambda^+_c \to pK^- \pi^+$ decay.
$B_c \to J/\psi\ 3\pi$	seen	

Badly needed measurements of B mesons could be easily done at Belle-II / Belle /Babar !

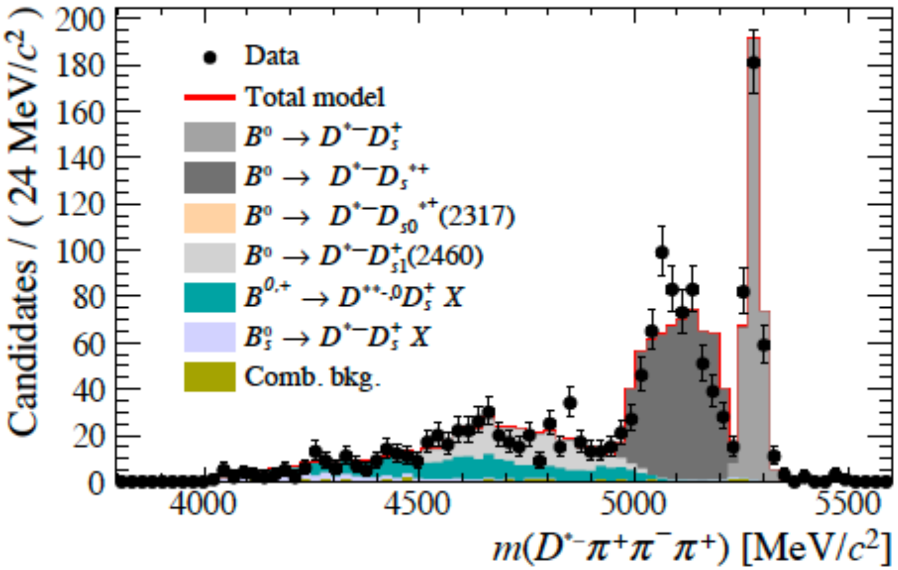
In the baryon (and B_c) sectors we are (and will) be dominated by the knowledge of the hadronization fractions

Other normalization channels?

- Final states of the type $X_b \rightarrow X_c D_s$ are particularly interesting as normalization channels
  - In addition to the same topology as signal, they also have the same detached vertex topology, therefore uncertainties due to trigger and selection efficiencies will drop out in the $K(X_c)$ measurement

Is it worth the effort?

- LHCb 3-prong R(D*)
- B→D*D_s(→3π)X control sample
- All analysis cuts
- ~300 candidates on Run1
- Cf. 1300 signal candidates
- …but statistical errors are similar (~6%)



- Alternatively:
  - take D_s→KKπ decays
  - 5x more candidates
- But: different final state!

Summary of $X_b \to X_c D_s$ decays

Channel	Branching fraction	Notes
$B^0 \to D^{*-} D_s$	$(8.0 \pm 1.1)\ 10^{-3}$	Babar + CLEO
$B^0 \to D^- D_s$	$(7.2 \pm 0.8)\ 10^{-3}$	Dominated by BELLE 2007
$B^+ \to D^0 D_s$	$(9.0 \pm 0.9)\ 10^{-3}$	Babar + CLEO. LHCb uses $B^0 \to D^- D_s$
$B_s \to D_s D_s$	$(4.4 \pm 0.5)\ 10^{-4}$	BELLE on Y(5S). LHCb uses $B^0 \to D^- D_s$
$\Lambda_b \to \Lambda_c D_s$	$(1.1 \pm 0.1)\ 10^{-3}$	LHCb uses $B^0 \to D^- D_s$ and measured $Br(\Lambda_b \to \Lambda_c^+ \pi^-)/Br(B^0 \to D^+ \pi^-)$
$B_c \to J/\psi\ D_s$	seen	ATLAS+LHCb: 3.1± 0.5 relative to $B_c \to J/\psi \pi$

Measurements of B mesons could be easily done at Belle-II / Belle /Babar

In the baryon (and B_c) sectors we are (and will) be dominated by the knowledge of the hadronization fractions

Mixed approach?

- Combine theoretical predictions with experimental measurements, e.g.

$$R(\Lambda_c) = \frac{Br(\Lambda_b \to \Lambda_c \tau\nu)}{Br(\Lambda_b \to \Lambda_c \mu\nu)} = \frac{N(\Lambda_b \to \Lambda_c \tau\nu)}{N(\Lambda_b \to \Lambda_c 3\pi)} * \frac{N(\Lambda_b \to \Lambda_c 3\pi)}{N(B^0 \to D^{*-} 3\pi)} * \frac{Br(B^0 \to D^{*-} 3\pi)}{Br(B^0 \to D^{*-} \mu\nu)} * \frac{1}{Th}$$

$$Th = \mathrm{Br}(\Lambda_b^0 \to \Lambda_c^- \mu^+ \nu_\mu)/\mathrm{Br}(B^0 \to D^{*-} \mu^+ \nu_\mu)$$

- The first two ratios can be experimentally determined with a percent precision in LHCb because they involve channels with the same final state or the same trigger configuration. The third one is measured at B factories and Belle-2.
- Uncertainties due to the limited knowledge of the Λ_b production fractions or the Λ_b branching fractions in any observable state completely cancel in these ratios.

Meinel, semi-tauonic WS, Apr 2016

Another ratio, useful as a normalization factor in the LHCb measurement of $\Lambda_b \to \Lambda_c \tau \bar{\nu}_\tau$:

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

Input	R
DLM+HPQCD	2.47 ± 0.26
DLM+Fermilab/MILC	2.30 ± 0.23
DLM+Fermilab/MILC+BaBar	2.45 ± 0.19
DLM+Fermilab/MILC+BaBar+Belle	2.37 ± 0.16

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

[J. A. Bailey *et al.*, PRD **92**, 034506 (2015)]

[H. Na *et al.*, PRD **92**, 054510 (2015)]

[B. Aubert *et al.* (BaBar), PRL **104**, 011802 (2010)]

[R. Glattauer *et al.* (Belle), PRD **93**, 032006 (2016)]

[C. DeTar, private communication]

Homework

- Estimate the precision level which can be reached in the approaches mentioned above to select the optimum normalization strategy,
  - This can involve two or more normalization channels per measurement.
- **Measure the normalization channels at the most appropriate facility (B factories, LHCb or Belle-2).**
- In addition to **branching fractions**, a **full kinematic study** allows to determine the impact on systematic uncertainties related to the imperfect cancellation of trigger and selection efficiencies between signal and normalization