# Some points on B-physics related to QCD

## Layout

- $B \rightarrow D^{**}\, l\, \nu$ **decays and others (** arXiv:2102.11608 **)**
- **Few topics about factorization (in preparation)**
- **$f_s/f_d$ at LHCb (on-going discussion?)**

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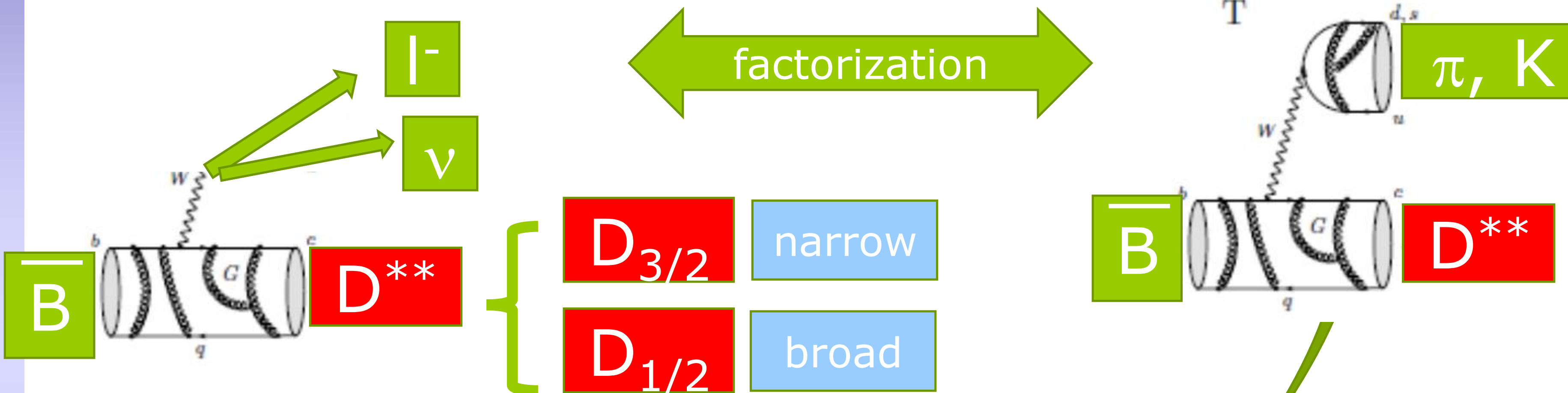
# (1)- Problems with broad D** production in $B \to D^{**}\, l\, \nu$ decays … ( >20 years old )

## phenomenology




+ 4 states grouped in 2 doublets labelled using $J_q = L_q \oplus 1/2$.

+ 2 FF when $m_Q \to \infty$ noted $\tau_{3/2}(q^2)$ and $\tau_{1/2}(q^2)$

+1/m corrections imply the introduction of additional form factors and, in practice, **there are more parameters than constraints.**

Note: dominant background in B → D(*) $\tau\, \nu$ analyses,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# (1)- Problems with broad D** production

**Theory**

| channel | measured | our model | *LLSW Bi* model |
|---|---|---|---|
| $\mathcal{B}(\overline{B}^0 \to D_0(2300)^+\pi^-) \times 10^4$ | $1.19 \pm 0.12$ | $1.21 \pm 0.12$ | $10.0 \pm 2.5$ |

**LQCD and QM expect $BR_{3/2}$ / $BR_{1/2}$ ~ 10**

**In agreement with measurements related through factorization**

**In disagreement with present models used to simulate $D_{1/2}$ states and PDG ($BR_{3/2}$ ~ $BR_{1/2}$)**

agrees

disagrees

**Our model**

**$D_{1/2}$ production complemented by $D_V$ + $D^*_V$**

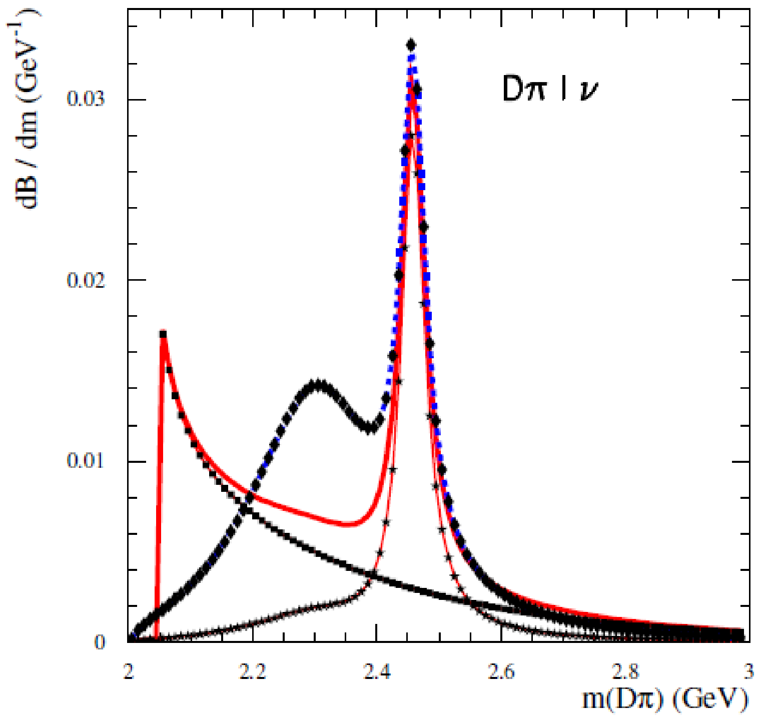
**Missing data to validate these models**

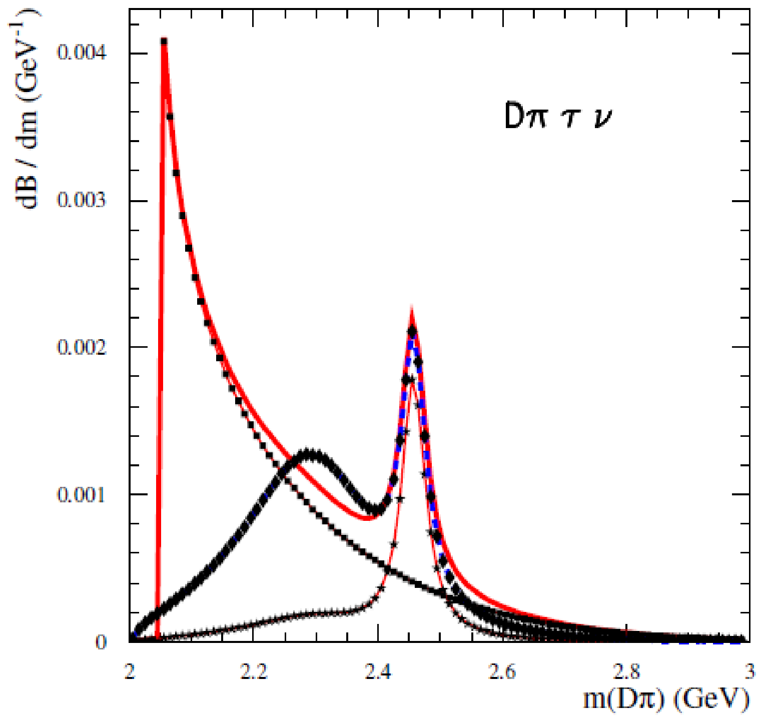
- angular analyses of $D^{(*)}\pi$ mass distributions to distinguish P from S waves

- $B_s \to D_{s0}^* \, l \, \nu$ decays because the $D_{s0}^*$ is narrow whereas the $D_0(2300)$ is quite broad (Belle 2)

# (1)- Some differences between model expectations (examples)

**B → Dπ μ/τ ν decays**




**Large differences are expected**

# (1)- B → D** $D_s^{(*)}$ decays

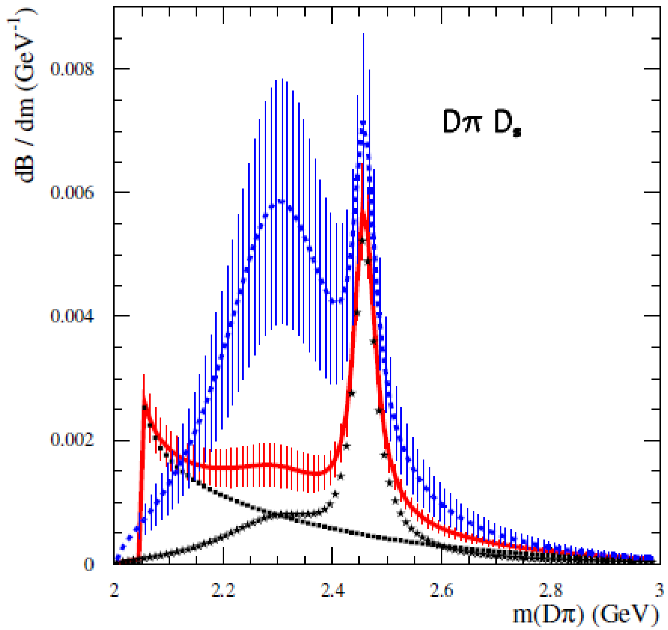
## The idea (G. Wormser)

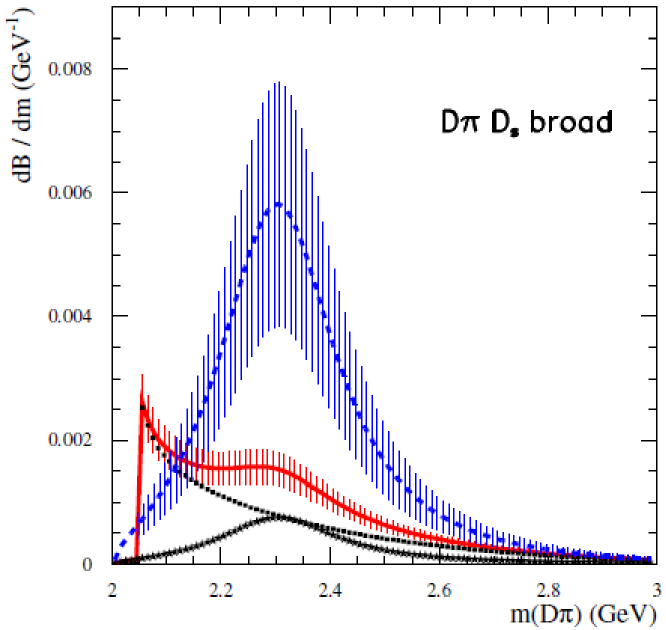
Have an experimental control of the background from B → Dx l ν decays in B → D(*) τ ν analyses, through factorization, using measurements of **B → D** $D_s^{(*)}$ decays.**

**$q^2 = m^2(Ds) \sim m^2(\tau)$.**

+ Is factorization valid for such decays?
  → see following slides

+ penguin contributions?
  → neglected at present …



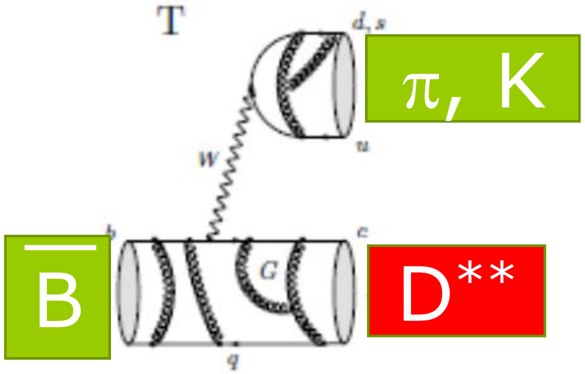
# (2)- Factorization (general)

## Basics

Decay amplitudes, In Class I B → $D_x$ P tree non-leptonic processes, can be evaluated in terms of the product of two currents (expected to be valid for a **light emitted meson )**.

Therefore NL and SL decays can be related:

$$R_P^{(*)} \equiv \frac{\mathrm{BR}(\bar{B}_d^0 \to D^{(*)+} P^-)}{d\Gamma(\bar{B}_d^0 \to D^{(*)+} \ell^- \bar{\nu}_\ell)/dq^2|_{q^2=m_P^2}}$$
$$= 6\pi^2 \tau_{B_d} |V_P|^2 f_P^2 |a_1(D_q P)|^2 X_P,$$




**Expectations are obtained in the $m_Q \to \infty$ limit**

$a_1^{(mQ\to\infty)}$ = 1.070 ± 0.022 (NNLO)

# (2) Factorization (data $\leftrightarrow$ computation, $m_Q \to \infty$)

## Comparison with data

$$\left|a_1^{DK}\right| = 0.884 \pm 0.033.$$

$$\left|a_1^{D^*K}\right| = 0.924 \pm 0.030$$

$a_1^{(mQ\to\infty)}$ = 1.070 ± 0.022 (NNLO)

**$a_1$ is ~ 1 → factorization « works » …. BUT**

**>5 $\sigma$ difference ($1/m^n$   n>1 corrections?)**

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## « Works » also in B → $D^{(*)}$ $D_s$ decays

$$\frac{\left|a_{1,eff.}^{DD_s^-}\right|}{\left|a_1^{DK}\right|} = 0.873 \pm 0.053$$

expects : 0.847± ?

$$\frac{\left|a_{1,eff.}^{D^*D_s}\right|}{\left|a_1^{D^*K}\right|} = 1.052 \pm 0.078$$

expects 1.037 ± ?

**Importance of penguin amplitude in D channel. What about D**?**

# (3)- $f_s/f_d$ at LHC (measurement principle)

## Motivation

- This ratio gives the relative amount of $B_s$ mesons produced at LHC and is needed to obtain absolute branching fractions

## methode

$$\frac{f_s}{f_d} = \frac{N_{X_2}}{N_{X_1}} \frac{\mathcal{B}(B^0 \to X_1)}{\mathcal{B}(B_s^0 \to X_2)} \frac{\epsilon(B^0 \to X_1)}{\epsilon(B_s^0 \to X_2)} .$$

expt. th. expt.

NL

$$\frac{\mathcal{B}(\overline{B}_s^0 \to D_s^+ \pi^-)}{\mathcal{B}(\overline{B}^0 \to D^+ K^-)}$$

SL

$$\Gamma(\overline{B}_s^0 \to Z_c \ell^- \bar{\nu}_\ell) = \Gamma(\overline{B}_d^0 \to X_c \ell^- \bar{\nu}_\ell) \times (1 + \xi)$$

$$\xi = -0.010 \pm 0.005$$

# (3)- $f_s/f_d$ at LHC (NL results)

**Depends on theory**

$$\frac{\mathcal{B}(\overline{B}_s^0 \to D_s^+ \pi^-)}{\mathcal{B}(\overline{B}^0 \to D^+ \pi^-)}$$ evaluation, from theory, depends on several quantities:

$m_Q \to \infty$

$$\mathcal{N}_A = |a_1^{\overline{B}_s^0 D_s \pi} / a_1^{\overline{B_d^0} DK}|^2$$ $= 1.005^{+0.005}_{-0.002}$ (??), 1.00 ± 0.02 (LHCb 2021)

$$\mathcal{N}_F = |f_0^{D_s \pi}(m_\pi^2)/f_0^{D\pi}(m_K^2)|^2$$ = 1.00 ± 0.04 (was 1.24 ± 0.08 in 2011)

$$\mathcal{N}_E = \frac{1}{|1 + E_{D\pi}/T_{D\pi}|^2}$$ = 0.966 ± 0.062 (from 2010, used by LHCb now)

**we get : 1.067 ± 0.033**

**Seems difficult to trust present uncertainties and central values**

# (3)- $f_s/f_d$ at LHC (SL results)

## Depends on experiment

- use inclusive SL decays;
- select $B_s$, $\Lambda_b$ and ( $B_u$ + $B_d$ ) enriched samples ( Ex : $D^0$ X l nu are enriched in non-Bs decays)
- select events samples to correct for cross-feeds ( Ex: $D^0$ K+ X l nu mainly correspond to Bs decays kept in the $D^0$ X l nu sample)
- use measurement at b-factories of BR(B $\rightarrow$ Ds K l nu) to correct for non-Bs contamination in the Ds X l nu sample (enriched in Bs decays).

## Some concerns

- seems to have not subtracted BR($\Lambda_b$ $\rightarrow$ Ds $\Lambda$ X l nu)
- what about B $\rightarrow$ Ds K $\pi$ nu ?
- publications do not provide any detail on the simulation of B SL decays
- Is theory under control ? : $\xi = -0.010 \pm 0.005$

**Can change fs/fd central value by about 1$\sigma$**

# Conclusions

## $B \rightarrow D^{**} l \nu$ decays and others (arXiv:2102.11608)

- model parameters fitted on data; confirms low production for S-states
- $D^{**}$ production needs to be complemented by $D_V+D^*_V$ components
- this analysis differs from « classical » ones and gives different expectations for decays with a $\tau$ lepton.
- It provides expectations for **$B \rightarrow D^{**} D_s^{(*)}$ decays**

## Some topics about factorization

- one of the rare places in B decays with > $5\sigma$ discrepancy between

measurements and corresponding present evaluation in the $m_Q \rightarrow \infty$ limit.

- **needs to be understood before one can use factorization in precision physics expectations**
- seems to « work » also in $D^{(*)}D_s$ final states.

## $f_s/f_d$ at LHCb

- few « anomalies » listed in present analyses by LHCb

# To do list(?)

BR($B_s \rightarrow D_{s0}^* \, l \, \nu$) (Belle 2)

- this S-state is narrow and should be well identified at variance with the non-strange corresponding meson

BR($B \rightarrow D^{(*)} \eta^{(\prime)} \, l \, \nu$) (Belle 2 + theory)

- to reduce the fraction of « missing » channels in B sl decays

Evaluate if our model changes bckg. expectations in $B \rightarrow D^{(*)} \tau \nu$ (LHCb, Belle 2, …)?

BR($B \rightarrow D^{(*)} K \pi \, l \, \nu$, $D^{(*)} K K \, l \, \nu$), BR($\Lambda_b \rightarrow D_s X$ l nu) (LHCb)

- to reduce uncertainties on fs/fd

Evaluate penguin amplitude in $B \rightarrow D^{**} D_s^{(*)}$ decays (theory)

Understand difference between $a_1(m_Q \rightarrow \infty)$ and expt.

# Backup

# Hadrons produced in B → Dx $l^-$ ν decays

## Rather well measured

- B → $D^{(*)}$ l ν and B → narrow $D^{**}$ l ν decays.
- B → $D^{(*)}\pi(\pi)l\nu$ decays without a clear identification of broad states.
- B → $D_s^{(*)}Kl\nu$ (BR=$(6.1\pm1.0)\times10^{-4}$)

Source of confusion

PDG values for « broad » D** states:

BR(B → $D_0(2300)$ l ν)= (0.39 ± 0.07) %
BR(B → $D_1(2430)$ l ν)= (0.19 ± 0.05) %

In contradiction with theory and factorization by **about a factor 10**

## Not (well) measured

- broad D**, radial excitations, non-resonant
- what about B → $D^{(*)}\eta(')l\nu$, $D^{(*)}\pi\pi\pi l\nu$, $D_s^{(*)}K\pi l\nu$, $D^{(*)}KKl\nu$ decays ?

~10% of hadronic final states are unknown

1- consider $D^{(*)}\pi$ final states

2- factorization

3- fs/fd

# Comments on factorization (1)

## BBNS 2000, NLO + $\Lambda/m_b$

The main lesson from the previous discussion is that corrections to naive factorization in the class-I decays $\bar{B}_d \to D^{(*)+} L^-$ are very small. The reason is that these effects are governed by a small Wilson coefficient and, moreover, are colour suppressed by a factor $1/N_c^2$. For these decays, the most important implications of the QCD factorization formula are to restore the renormalization-group invariance of the theoretical predictions, and to provide a theoretical justification for why naive factorization works so well. On the other hand, given the theoretical uncertainties arising, e.g., from unknown power-suppressed corrections, there is clearly no hope to confront the extremely small predictions for non-universal (process-dependent) "non-factorizable" corrections with experimental data. Rather, what we may do is ask whether data supports the prediction of a quasi-universal parameter $|a_1| \simeq 1.05$ in these decays.

If this is indeed the case, it would support the usefulness of the heavy-quark limit in analyzing non-leptonic decay amplitudes. If, on the other hand, we were to find large non-universal effects, this would point towards the existence of sizeable power corrections to our predictions.

We will see that with present experimental errors the data are in good agreement with our prediction of a quasi universal $a_1$ parameter. However, a reduction of the experimental uncertainties to the percent level would be very desirable for obtaining a more conclusive picture.

# Comments on factorization (2)

**2016 : arXiv:1606.02888, NNLO + $\Lambda/m_b$**

a colour-suppressed tree topology. Therefore, a precise knowledge of the colour-allowed tree amplitude $a_1$ allows to reliably estimate the size of power corrections to eq. (1) by comparison to experimental data, and at the same time provides a test of the QCDF framework. This requires that the perturbative expansion of the hard scattering kernel is

Given the fact that the results show rough agreement within errors for $\bar{B}_d \to D^{(*)+}K^{(*)}$ decays, which receive only contributions from colour-allowed tree topologies, this may indicate a non-negligible impact from the $W$-exchange topologies appearing only in $\bar{B}_d \to D^{(*)+}\pi^-$ and $\bar{B}_d \to D^{(*)+}\rho^-$ decays. For $\bar{B}_s$ decays, on the other hand, since