Measurement of the differential distributions of $B_s^0 \to D_s^{*-}\mu^+\nu_\mu$ decay at LHCb

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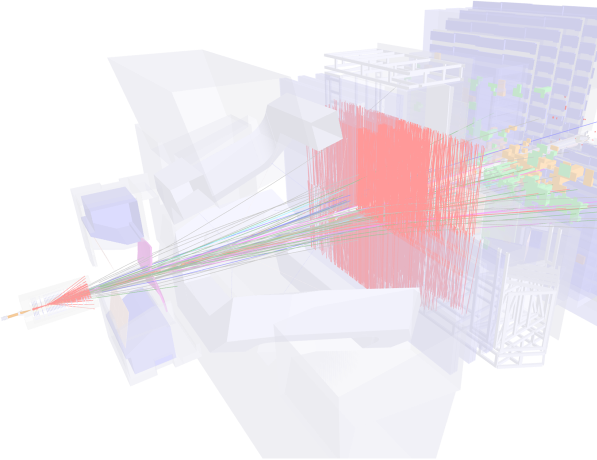
SL B decays at the junction of experiment and theory
Turin - June 13th, 2025

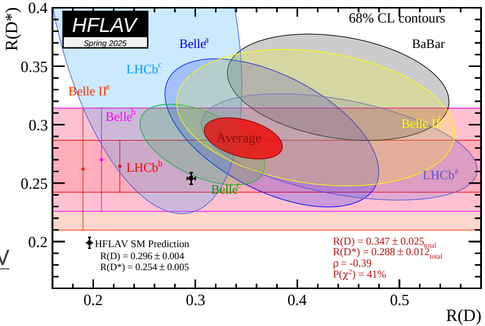
Outline

- Analysis introduction
- Event selection and background rejection
- Signal yields extraction
- Further studies
- Conclusions

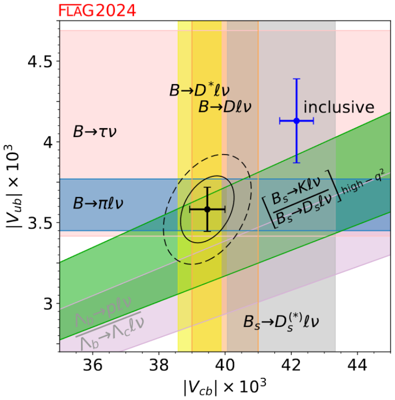


We have tensions in inclusive/exclusive V_{ub}, V_{cb} determination and combined $\mathcal{R}(D)$-$\mathcal{R}(D^*)$ measurement.

See Silvano's talk!



HFLAV

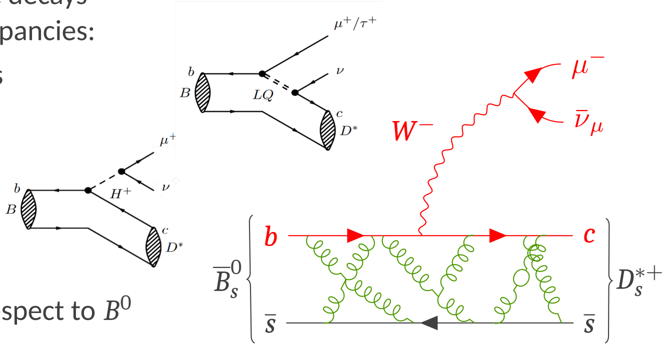


FLAG2024

$$B_s^0 \longrightarrow D_s^{*-}\mu^+\nu_\mu$$

We have tensions in inclusive/exclusive V_{ub}, V_{cb} determination and combined $\mathcal{R}(D)$-$\mathcal{R}(D^*)$ measurement. The study of semileptonic decays could help shedding light on these discrepancies:

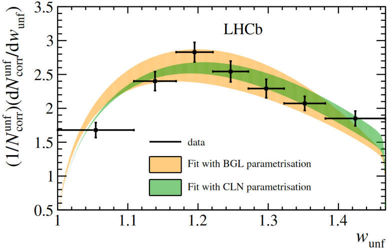
- only one diagram, tree-level process
- EW transition
- QCD interaction
- sensitivity to New Physics



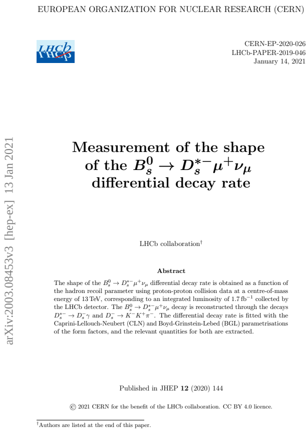
Additionally:

- simpler lattice computations with respect to B^0 and B^+ (due to s quark)

- Previous analysis JHEP12(2020)144 was published four years ago
- That was a 1-d analysis $\Rightarrow$ this is a full angular analysis
- That used only 1.7 fb^{-1} $\Rightarrow$ here full Run 2 data, ~ 5.7 fb^{-1}



$$w \propto -q^2$$
$$\propto \left(p_{B_s^0} - p_{D_s^*}\right)^2$$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CERN-EP-2020-026
LHCb-PAPER-2019-046
January 14, 2021

arXiv:2003.08453v3 [hep-ex] 13 Jan 2021

Measurement of the shape of the $B_s^0 \to D_s^{*-}\mu^+\nu_\mu$ differential decay rate

LHCb collaboration†

Abstract

The shape of the $B_s^0 \to D_s^{*-}\mu^+\nu_\mu$ differential decay rate is obtained as a function of the hadron recoil parameter using proton-proton collision data at a centre-of-mass energy of 13 TeV, corresponding to an integrated luminosity of 1.7 fb^{-1} collected by the LHCb detector. The $B_s^0 \to D_s^{*-}\mu^+\nu_\mu$ decay is reconstructed through the decays $D_s^{*-} \to D_s^-\gamma$ and $D_s^- \to K^-K^+\pi^-$. The differential decay rate is fitted with the Caprini-Lellouch-Neubert (CLN) and Boyd-Grinstein-Lebed (BGL) parametrisations of the form factors, and the relevant quantities for both are extracted.

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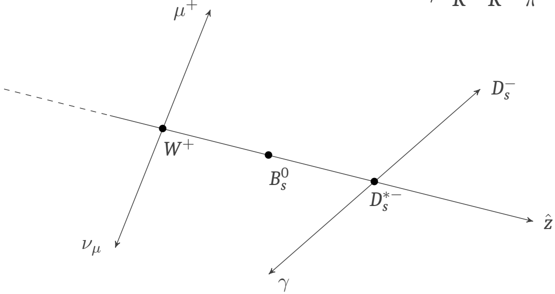
†Authors are listed at the end of this paper.

The analysis aims to measure the differential decay rate in the space given by the variables that describe the decay kinematics:

$$B_s^0 \longrightarrow D_s^{*-}\,\ell^+\,\nu_\ell$$
$$\hookrightarrow D_s^-\,\gamma$$
$$\hookrightarrow K^+\,K^-\,\pi^-$$



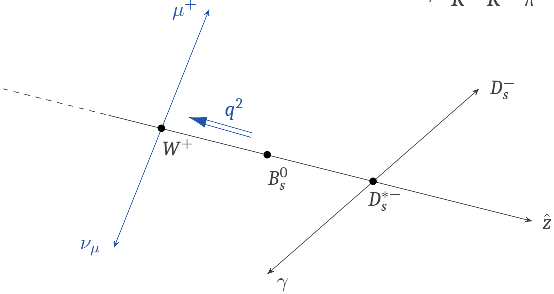
$$\hat{z} = \vec{p}_{D_s^*} / |\vec{p}_{D_s^*}|$$

$$B_s^0 \longrightarrow D_s^{*-}\, \ell^+\, \nu_\ell$$
$$\hookrightarrow D_s^-\, \gamma$$
$$\hookrightarrow K^+ K^- \pi^-$$

The analysis aims to measure the differential decay rate in the space given by the variables that describe the decay kinematics:

q^2

$$q^2 = (p_{B_s^0} - p_{D_s^*})^2$$



$$\hat{z} = \vec{p}_{D_s^*} / |\vec{p}_{D_s^*}|$$

The decay kinematics

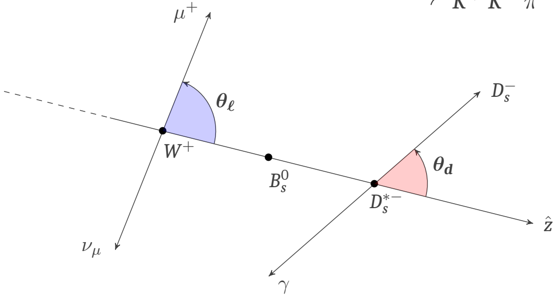
$$B_s^0 \longrightarrow D_s^{*-}\,\ell^+\,\nu_\ell$$
$$\hookrightarrow D_s^-\,\gamma$$
$$\hookrightarrow K^+\,K^-\,\pi^-$$

The analysis aims to measure the **differential decay rate** in the space given by the variables that describe the decay kinematics:

q^2 θ_ℓ θ_d

$$q^2 = (p_{B_s^0} - p_{D_s^*})^2$$

θ_ℓ and θ_d are helicity angles



$$\hat{z} = \vec{p}_{D_s^*} / |\vec{p}_{D_s^*}|$$

1 The decay kinematics
Analysis introduction

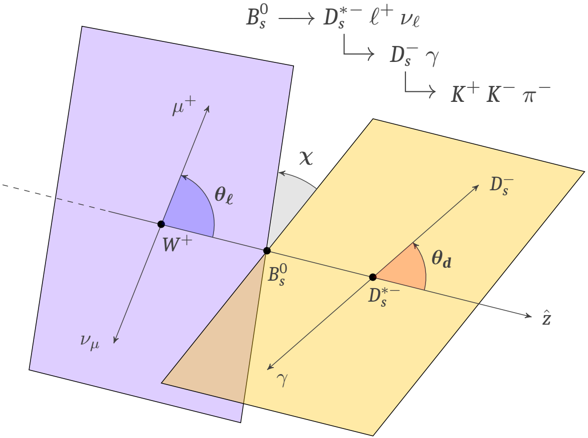
The analysis aims to measure the differential decay rate in the space given by the variables that describe the decay kinematics:

$$q^2 \quad \theta_\ell \quad \theta_d \quad \chi$$

$$q^2 = (p_{B_s^0} - p_{D_s^*})^2$$

θ_ℓ and θ_d are helicity angles

χ angle between decay planes



$$\hat{z} = \vec{p}_{D_s^*} / |\vec{p}_{D_s^*}|$$

The differential decay width

Analysis introduction

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}q^2\mathrm{d}\cos\theta_\ell\mathrm{d}\cos\theta_d\mathrm{d}\chi} \propto \sum_i I_i(q^2)\,\Xi_i(\theta_\ell,\theta_d,\chi)$$

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- $I_i(q^2)$ functions encode the hadronic interaction: we use CLN and BGL[1] models to parametrise their expressions, or fit them with a model-independent approach

[1] Caprini-Lellouch-Neubert and Boyd-Grinstein-Lebed

The differential decay width

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  - Modifying the $I_i(q^2)$ functions and considering a New Physics coupling constant ϵ_{NP}, different structures for NP can be implemented:

$$I_i(q^2) \quad\Longrightarrow\quad I_i(q^2,\epsilon_{\mathrm{NP}})$$

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Analysis introduction

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$$I_i(q^2) \quad\Longrightarrow\quad I_i(q^2,\epsilon_{\text{NP}})$$

- $\Xi_i(\theta_\ell,\theta_d,\chi)$ are known functions of the angular variables

[1] Caprini-Lellouch-Neubert and Boyd-Grinstein-Lebed

Events selection :

- $D_s^{\pm} \to K^+K^-\pi^{\pm}$ selection, ϕ and K^* resonances
- $D_s^* \to D_s\gamma$ reconstruction, soft γ selection
- charge of the identified muon opposite to that of D_s^*
- muon trigger lines
  - ⋆ mu_L0MuonDecision_TOS
  - ⋆ mu_Hlt1TrackMuonDecision_TOS
  - ⋆ Bs_0_Hlt2XcMuXForTauB2XcMuDecision_TOS
- cuts on muon $p_\mu^T > 1.2$ GeV and $\mathtt{PID}_\mu > 2$

Particle	Variable	Cut
$\pi^\pm$, $K^\pm$	p_T	> 200 MeV
	p	> 5 GeV
	χ^2_{IP}	> 9
$\pi^\pm$	$\mathrm{DLL}_{K\pi}$	< 4
$K^\pm$	$\mathrm{DLL}_{K\pi}$	> 2
D_s^+	$m_{D_s^+}$	$(1920, 2010)$ MeV
	Min of daughters p_T	> 800 MeV
	Sum of daughters p_T	> 2500 MeV
	D_s^+ min p_T	> 2000 GeV
	Distance of closest approach	< 0.1 mm
	Vertex displacement	$\mathrm{VD}\chi^2 > 25$
	Vertex fit χ^2	< 10
	Direction angle	> 0.999
B_s^0	$m_{D_s^+\mu^-}$	< 10.5 GeV
	Distance of closest approach	< 0.5 mm
	Vertex displacement	$\mathrm{VD}\chi^2 > 50$
	Vertex fit χ^2	< 15
	Direction angle	> 0.999

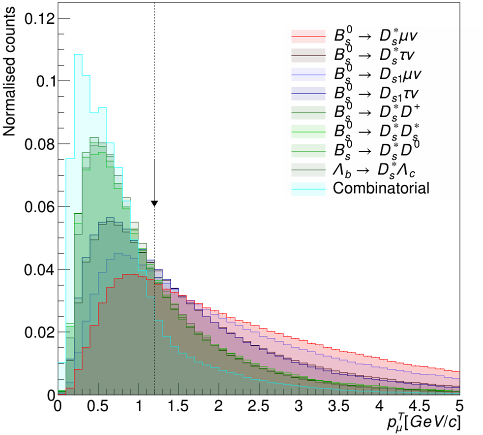
We consider several background channels, which are rejected with:

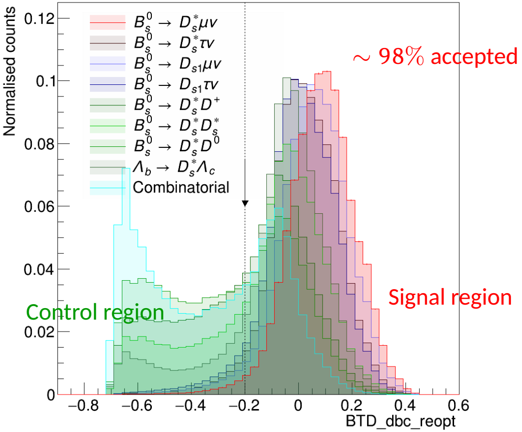
- ${}_s\mathcal{P}lot$ to evaluate and subtract combinatorial background for the photon emitted by D_s^*
- cut on dedicated variable to suppress the doubly-charmed decays ($H_b \to D_s^* H_c$)

Channels
$B_s^0 \to D_s^{*-}\tau^+\nu_\tau$
$B_s^0 \to D_{s1}\mu\nu_\mu$
$B_s^0 \to D_{s1}\tau\nu_\tau$
$B^0 \to D_s^{*+}D^{(*-)}$
$B_s^0 \to D_s^{*+}D_s^{(*-)}$
$B^+ \to D_s^{*+}\overline{D}^{*0}$
$\Lambda_b \to D_s^{*-}\Lambda_c^{(*+)}$
Combinatorial + misID

Background rejection: cuts examples

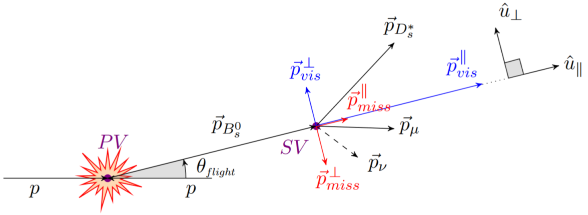
Event selection and background rejection





2 Experimental challenge: kinematics reconstruction

Event selection and background rejection



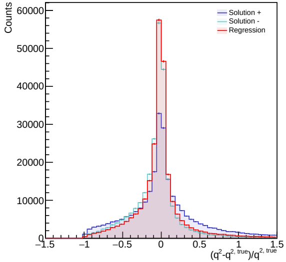
We assume there is only one missing particle in the final state and that $m_{B_s^0}$ is known (see JHEP02(2017)021)

$\Rightarrow$ Two fold ambiguity, $p_\pm = p_{vis}^{\parallel} - a \pm \sqrt{r}$

Regression algorithm gives a rough estimate of $p_{B_s^0}$, we resolve the ambiguity using

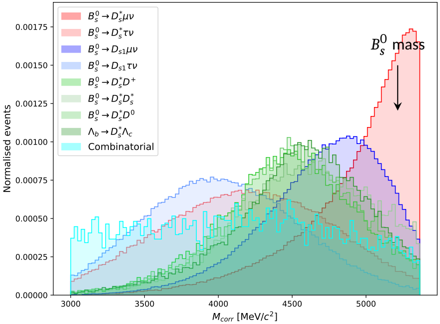
$$\Delta_\pm = (p_{\text{reg}} - p_\pm)$$

$$\Downarrow$$



Extract signal yields using

$$M_{\text{corr}} = \sqrt{m^2_{D_s^*\mu} + |p^{\perp}_{miss}|^2} + |p^{\perp}_{miss}|$$



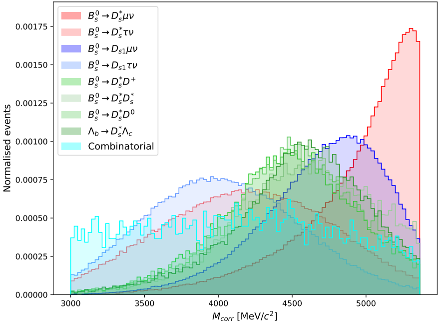
The M_{corr} fit

Signal yields extraction

Extract signal yields using

$$M_{\mathrm{corr}} = \sqrt{m^2_{D_s^*\mu} + |p^{\perp}_{miss}|^2} + |p^{\perp}_{miss}|$$

Template binned fit over 4-d space, extrapolation in three steps:



Variable	Bin Edges	Bins
q^2 [GeV^2]	0. 1.83 3.67 5.5 7.33 9.17 11.	6
$\cos\theta_\ell$	-1. -0.5 0. 1.	3
$\cos\theta_d$	-1. -0.5 0. 1	3
χ [rad]	0. 1.26 2.51 3.77 5.03 6.28	5

3 The M_{corr} fit
Signal yields extraction

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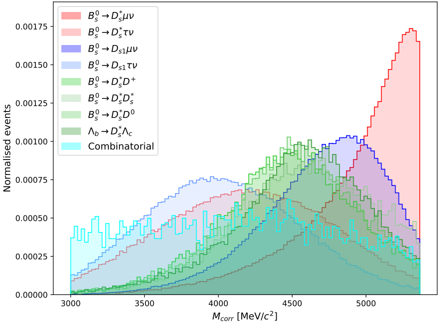
Template binned fit over 4-d space, extrapolation in three steps:

- preliminary fit in the control region to constrain backgrounds



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The M_{corr} fit

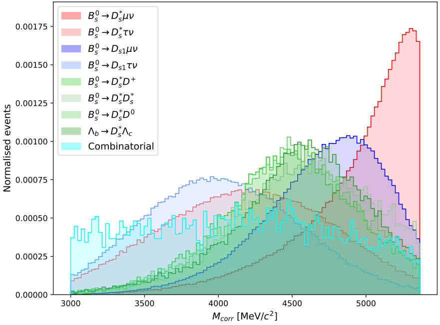
Signal yields extraction

Extract **signal yields** using

$$M_{\text{corr}} = \sqrt{m^2_{D_s^* \mu} + |p^{\perp}_{miss}|^2} + |p^{\perp}_{miss}|$$

Template binned fit over **4-d space**, extrapolation in three steps:

- preliminary fit in the control region to constrain backgrounds
- simultaneous fit over **q^2 bins**, integrating the angles



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The M_{corr} fit

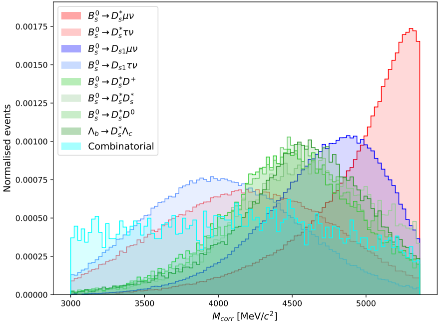
Signal yields extraction

Extract signal yields using

$$M_{\text{corr}} = \sqrt{m^2_{D_s^* \mu} + |p^{\perp}_{miss}|^2} + |p^{\perp}_{miss}|$$

Template binned fit over 4-d space, extrapolation in three steps:

- preliminary fit in the control region to constrain backgrounds
- simultaneous fit over q^2 bins, integrating the angles
- second fit over all bins, fixing background templates



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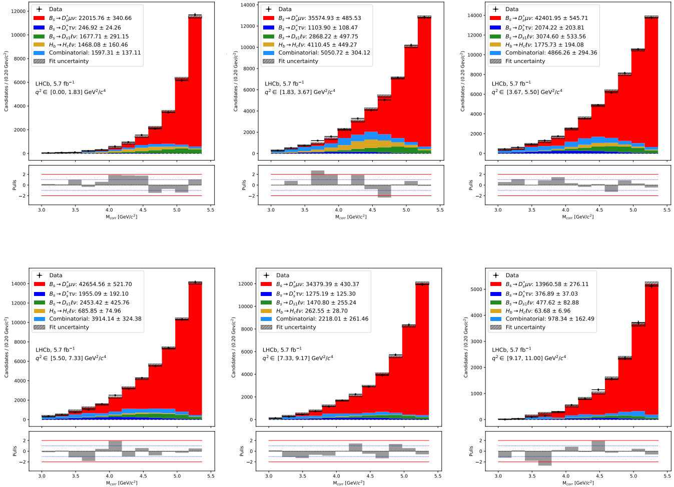
The M_{corr} fit: q^2 results in the signal region

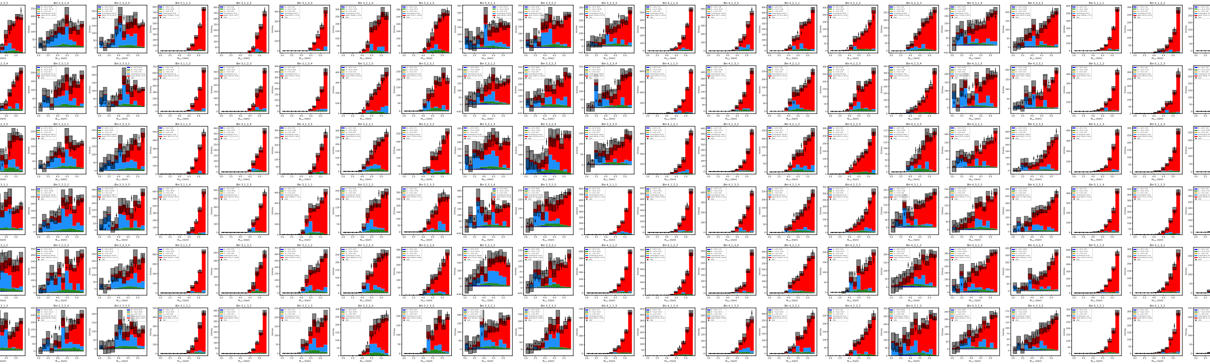
Signal yields extraction



q^2 [GeV$^2/c^4$]	Signal [%]
[0, 1.83]	82
[1.83, 3.67]	73
[3.67, 5.50]	81
[5.50, 7.33]	83
[7.33, 9.17]	87
[9.17, 11]	88

The M_{corr} fit: examples

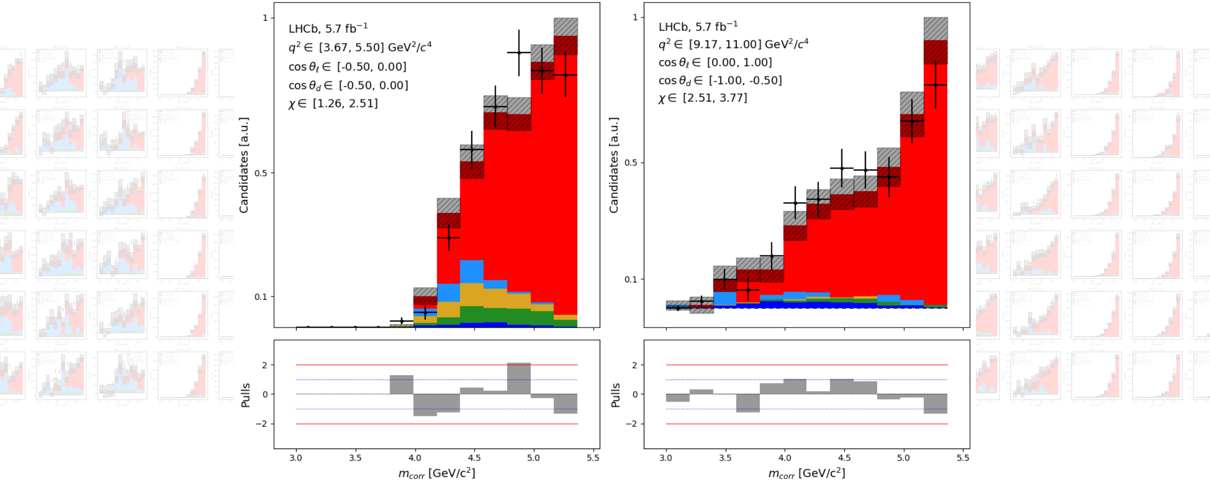
Signal yields extraction



Well, it's impossible to visualize them all...

The M_{corr} fit: examples

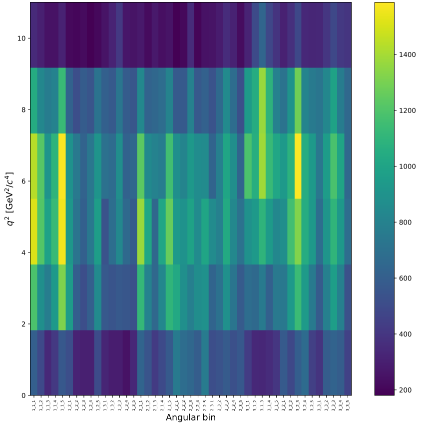
Signal yields extraction



3 Okay… then?
Signal yields extraction

Once we extract the signal yield distribution, we can:

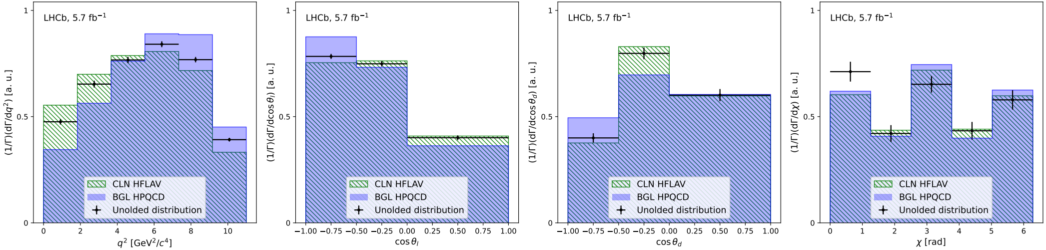
- Unfold the distribution with migration matrix + efficiency vector to account for detector effects
- Compare the unfolded distribution with theory/other experiments
- Use the unfolded distribution to perform a model-independent fit to extract $I_i(q^2)$ functions



Angular bin: $\cos\theta_\ell\_\cos\theta_d\_\chi$

Unfolded distributions vs predictions

Further studies



- Models used: HFLAV averages for CLN, HPQCD predictions for BGL
- Visible tension in some bins
- Something similar was observed comparing Belle data with HPQCD predictions, but with different binning and with $B^0 \to D^*$

Folded fit

$$\chi^2 = \left(\vec{N}^{\text{meas}} - \vec{N}^{\text{pred}}\right)^T \frac{1}{C(N^{\text{meas}})} \left(\vec{N}^{\text{meas}} - \vec{N}^{\text{pred}}\right)$$

where $N_i^{\text{pred}} = k \cdot \sum_{j=1}^{t} m_{ij} \cdot (\Delta\Gamma(\vec{p}) \cdot \mathcal{E})_j$ $\quad (\Delta\Gamma(\vec{p}) \cdot \mathcal{E})_j = \Delta\Gamma_j(\vec{p}) \cdot \mathcal{E}_j$

$\Delta\Gamma =$ expected yields distribution $\quad \vec{p} =$ CLN/BGL parameters

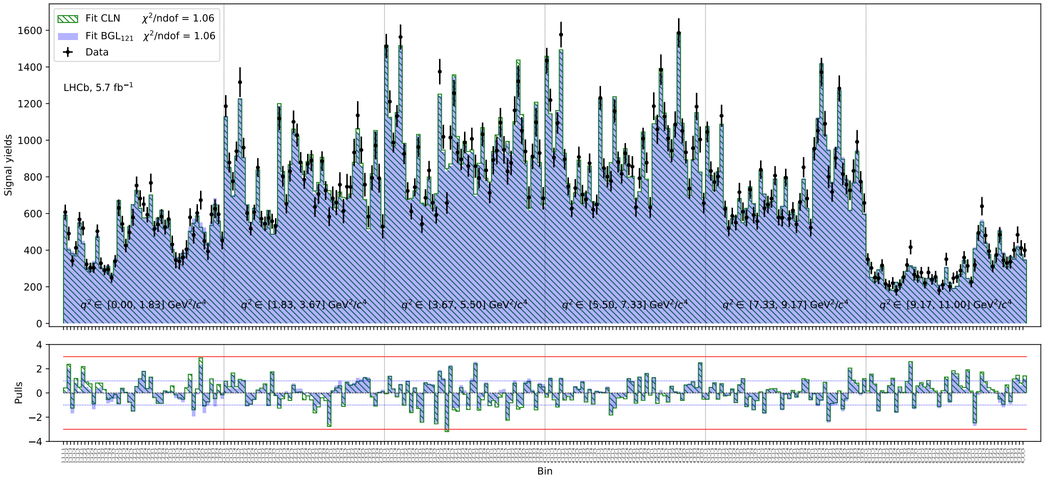
Unfolded fit

$$\chi^2 = \left(\vec{N}^{\text{unf}}/\mathcal{E} - k \cdot \Delta\Gamma(\vec{p})\right)^T \frac{1}{C(N^{\text{unf}})} \left(\vec{N}^{\text{unf}}/\mathcal{E} - k \cdot \Delta\Gamma(\vec{p})\right)$$

where $\vec{N}^{\text{unf}}$ is obtained using Bayesian unfolding

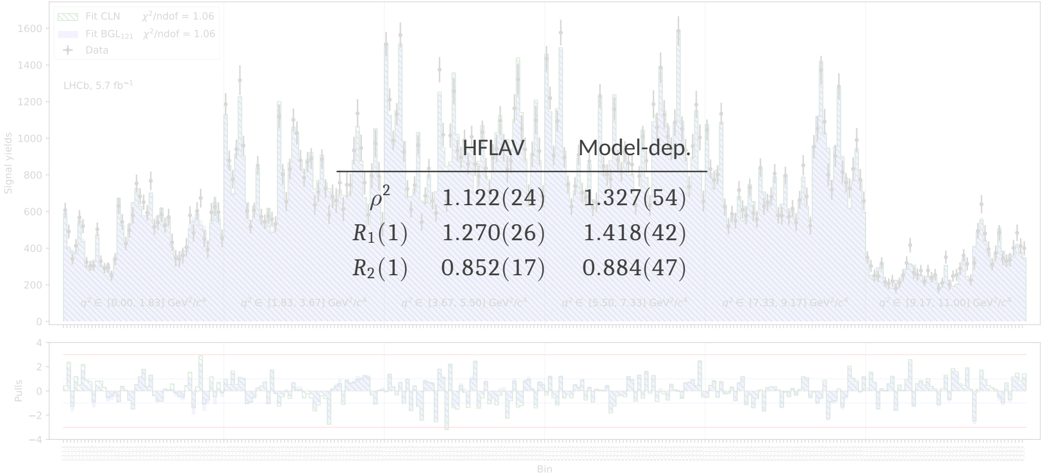
CLN and BGL from differential distribution

Further studies



CLN and BGL from differential distribution

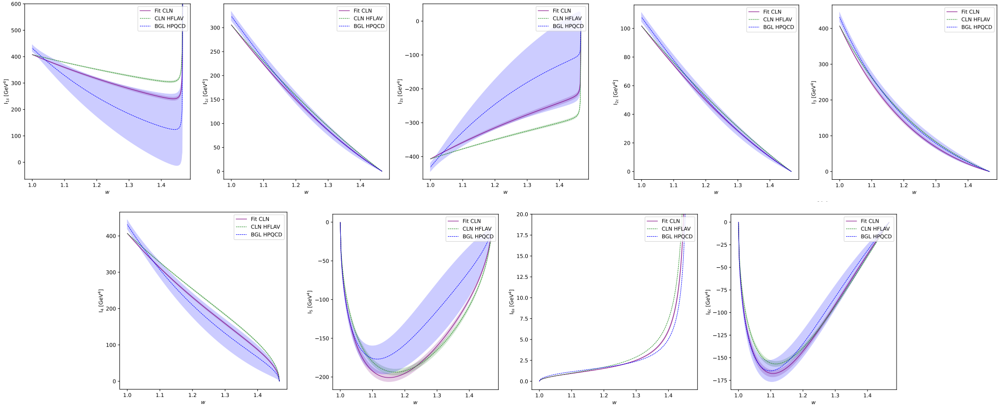
Further studies



	HFLAV	Model-dep.
ρ^2	1.122(24)	1.327(54)
$R_1(1)$	1.270(26)	1.418(42)
$R_2(1)$	0.852(17)	0.884(47)

$I_i(q^2)$ shapes

Further studies



We can explicitly fit the $I_i(q^2)$ functions integrated over the q^2 bins, without any assumption on the hadronic model:

$$N^{\text{pred}}_{k,p,q,r} = \int_{\Delta q^2_k} \int_{\Delta \cos\theta_{\ell\, p}} \int_{\Delta \cos\theta_{d\, q}} \int_{\Delta\chi_r} \frac{\mathrm{d}\Gamma}{\mathrm{d}q^2 \mathrm{d}\cos\theta_\ell \mathrm{d}\cos\theta_d \mathrm{d}\chi} dq^2\, d\cos\theta_\ell d\cos\theta_d d\chi$$

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$$\propto \sum_i \int_{\Delta q^2_k} \left(1 - m^2_\mu/q^2\right)^2 |\vec{p}_{D_s^*}(q^2)|\, I_i(q^2)\, dq^2 \cdot \int_{\Delta\Omega_l} \Xi_i(\theta_\ell, \theta_d, \chi)\, d\Omega$$

Model-independent $I_i(q^2)$ determination

Further studies

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$$N^{\text{pred}}_{k,p,q,r} = \int_{\Delta q^2_k}\int_{\Delta\cos\theta_{\ell\,p}}\int_{\Delta\cos\theta_{d\,q}}\int_{\Delta\chi_r} \frac{\mathrm{d}\Gamma}{\mathrm{d}q^2\mathrm{d}\cos\theta_\ell\mathrm{d}\cos\theta_d\mathrm{d}\chi} dq^2\, \overbrace{d\cos\theta_\ell d\cos\theta_d d\chi}^{d\Omega}$$

$$\propto \sum_i \int_{\Delta q^2_k} \left(1 - m^2_\mu/q^2\right)^2 |\vec{p}_{D_s^*}(q^2)|\, I_i(q^2)\, dq^2 \cdot \int_{\Delta\Omega_l} \Xi_i(\theta_\ell,\theta_d,\chi)\, d\Omega$$

$$\propto \sum_i J_{i,k}(q^2)\cdot\zeta_{i,l}(\theta_\ell,\theta_d,\chi)$$

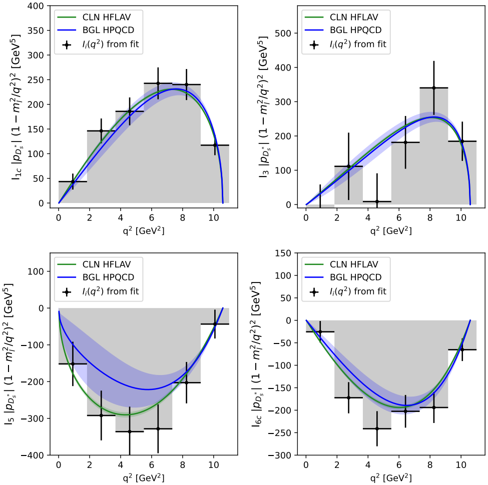
q^2 bins

$I_i(q^2)$ functions

where $\zeta_{i,l}(\theta_\ell,\theta_d,\chi)$ are analytically computable. We have $\sim 6\times 10$ free parameters. After the fit we can extract CLN/BGL parameters from the $J_i(q^2)$ shapes.

Model-independent $I_i(q^2)$ determination

Further studies



$$\frac{d\Gamma}{dq^2 d\cos\theta_\ell d\cos\theta_d d\chi} = \mathcal{K}(q^2)\sum_i I_i(q^2)\Xi_i(\theta_\ell,\theta_d,\chi)$$

$$\begin{aligned}\propto \Big[& I_{1s}\sin^2\theta_d + I_{1c}(3+\cos 2\theta_d) + I_{2s}\sin^2\theta_d\cos 2\theta_\ell \\ & + I_{2c}(3+\cos 2\theta_d)\cos 2\theta_\ell + I_3\sin^2\theta_d\sin^2\theta_\ell\cos 2\chi \\ & + I_4\sin 2\theta_d\sin 2\theta_\ell\cos\chi + I_5\sin 2\theta_d\sin\theta_\ell\cos\chi \\ & + I_{6s}\sin^2\theta_d\cos\theta_\ell + I_{6c}(3+\cos 2\theta_d)\cos\theta_\ell \\ & + I_7\sin 2\theta_d\sin\theta_\ell\sin\chi + I_8\sin 2\theta_d\sin 2\theta_\ell\sin\chi \\ & + I_9\sin^2\theta_d\sin^2\theta_\ell\sin 2\chi\Big]\end{aligned}$$

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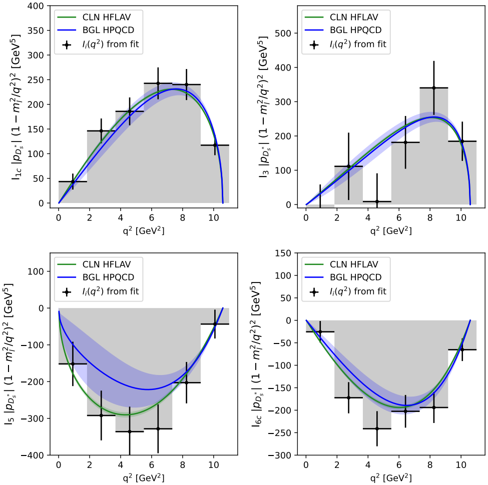

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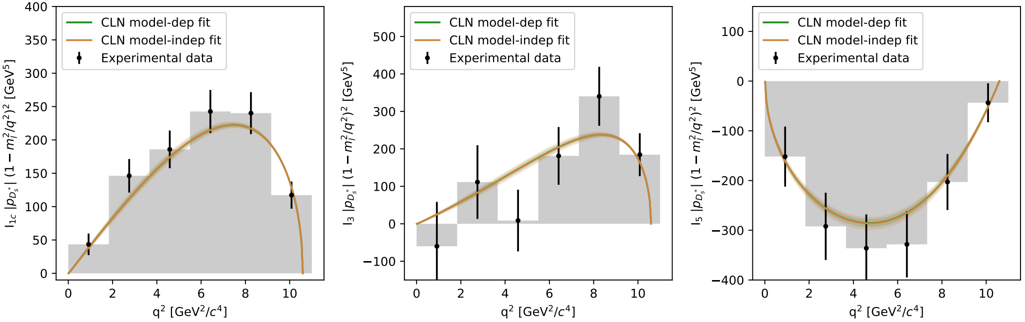
We could extract information about NP, because we expect some $I_i(q^2)$ functions to be zero in SM picture

CLN and BGL from fitted $I_i(q^2)$ functions

Further studies

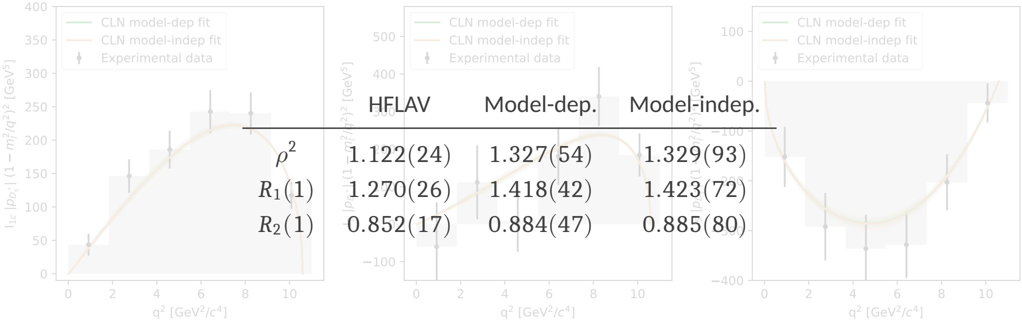


Where:

- Model-dependent shape = CLN/BGL parameters from differential distribution
- Model-independent shape = CLN/BGL parameters from the fitted integrals

CLN and BGL from fitted $I_i(q^2)$ functions

Further studies



	HFLAV	Model-dep.	Model-indep.
ρ^2	$1.122(24)$	$1.327(54)$	$1.329(93)$
$R_1(1)$	$1.270(26)$	$1.418(42)$	$1.423(72)$
$R_2(1)$	$0.852(17)$	$0.884(47)$	$0.885(80)$

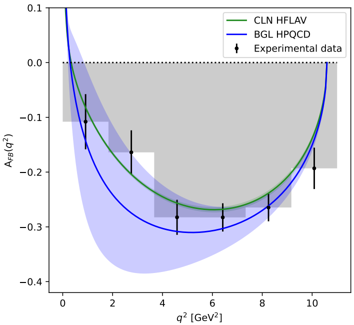
Where:

- Model-dependent shape = CLN/BGL parameters from differential distribution
- Model-independent shape = CLN/BGL parameters from the fitted integrals

We can build several observables to evaluate the contribution of New Physics interaction, for instance the **forward-backward asymmetry**:

$$\mathcal{A}_{FB}(q^2) = \left[\int_0^1 \frac{\mathrm{d}^2\Gamma}{\mathrm{d}q^2\mathrm{d}\cos\theta_\ell} d\cos\theta_\ell - \int_{-1}^0 \frac{\mathrm{d}^2\Gamma}{\mathrm{d}q^2\mathrm{d}\cos\theta_\ell} d\cos\theta_\ell\right] / \frac{d\Gamma}{dq^2}$$
$$= \frac{3\left(I_{6s} + 4I_{6c}\right)}{6I_{1s} + 24I_{1c} - 2I_{2s} - 8I_{2c}}$$

$\Rightarrow$ Compute the asymmetry for each q^2 bin using the fitted $I_i(q^2)$ values



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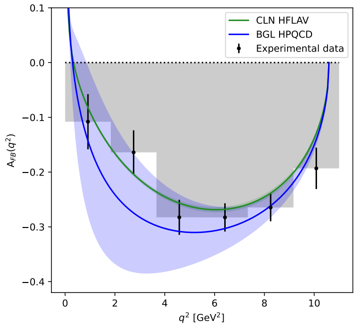


Use the basis $\eta,\ \eta',\ \delta,\ \epsilon,\ \epsilon'$
arXiv:2104.02094

- Semileptonic decays are a powerful tool to test Standard Model
- This work will lead to the first measurement of $B_s^0 \to D_s^{*-}\mu^+\nu_\mu$ differential distributions
- It is possible to directly test different New Physics scenarios, with both a model-dependent and a model-independent approach

- Selection
- *sWeights*
- M_{corr} fit
- Unfolding
- CLN/BGL fit
- $I_i(q^2)$ determination

✓

- New Physics
- Systematics

WIP

Measurement of the differential distributions of $B_s^0 \to D_s^{*-} \mu^+ \nu_\mu$ decay at LHCb

Thank you for listening!

The differential width

Backup

arXiv:1801.10468

$$\frac{d\Gamma}{dq^2 d\cos\theta_\ell d\cos\theta_d d\chi} = \mathcal{K}(q^2)\sum_i I_i(q^2)\Xi_i(\theta_\ell,\theta_d,\chi)$$

$I_i(q^2) = I_i(q^2; H_0, H_\pm, H_t)$
and H_i are written using
CLN/BGL models

$$= \mathcal{N}_\gamma |\vec{p}_{D_s^*}(q^2)| \left(1-\frac{m_\mu^2}{q^2}\right)^2 \cdot \Big[I_{1s}\sin^2\theta_d + I_{1c}(3+\cos 2\theta_d)$$
$$+ I_{2s}\sin^2\theta_d\cos 2\theta_\ell + I_{2c}(3+\cos 2\theta_d)\cos 2\theta_\ell$$
$$+ I_3\sin^2\theta_d\sin^2\theta_\ell\cos 2\chi + I_4\sin 2\theta_d\sin 2\theta_\ell\cos\chi + I_5\sin 2\theta_d\sin\theta_\ell\cos\chi$$
$$+ I_{6s}\sin^2\theta_d\cos\theta_\ell + I_{6c}(3+\cos 2\theta_d)\cos\theta_\ell$$
$$+ \cancel{I_7\sin 2\theta_d\sin\theta_\ell\sin\chi} + \cancel{I_8\sin 2\theta_d\sin 2\theta_\ell\sin\chi} + \cancel{I_9\sin^2\theta_d\sin^2\theta_\ell\sin 2\chi}\Big]$$

zero in SM

zero in SM and tensor model

$$\mathcal{N}_\gamma = \frac{3G_F^2|V_{cb}|^2\mathcal{B}(D_s^*\to D_s\gamma)}{128(2\pi)^4 m_{B_s^0}^2} \qquad |\vec{p}_{D_s^*}(q^2)| = \frac{\lambda^{1/2}(m_{B_s^0}^2, m_{D_s^*}^2, q^2)}{2\sqrt{q^2}} \qquad \lambda(x,y,z) = x^2+y^2+z^2-2xy-2xz-2yz$$

CLN model

Backup

$$H_0 = \frac{(m_{B_s^0} + m_{D_s^*})^2 \lambda^{1/2}(m^2_{B_s^0}, m^2_{D_s^*}, q^2) A_1(q^2) - \lambda(m^2_{B_s^0}, m^2_{D_s^*}, q^2) A_2(q^2)}{2 m_{D_s^*}(m_{B_s^0} + m_{D_s^*})\sqrt{q^2}}$$

$$H_\pm = \frac{(m_{B_s^0} + m_{D_s^*})^2 A_1(q^2) 4\lambda^{1/2}(m^2_{B_s^0}, m^2_{D_s^*}, q^2) V(q^2)}{m_{B_s^0} + m_{D_s^*}}$$

$$H_t = -\frac{\lambda^{1/2}(m^2_{B_s^0}, m^2_{D_s^*}, q^2)}{\sqrt{q^2}} A_0(q^2) \qquad w = \frac{m^2_{B_s^0} + m^2_{D_s^*} - q^2}{2 m_{B_s^0} m_{D_s^*}}$$

$$V(w) = \frac{R_1(w)}{R^*} h_{A_1}(w)$$

$$A_0(w) = \frac{R_0(w)}{R^*} h_{A_1}(w)$$

$$A_1(w) = \frac{w+1}{2} R^* h_{A_1}(w)$$

$$A_2(w) = \frac{R_2(w)}{R^*} h_{A_1}(w)$$

$$\boxed{\begin{aligned} h_{A_1}(w) &= h_{A_1}(1)[1 - 8\rho^2 z(w) + (53\rho^2 - 15) z(w)^2 \\ &\quad - (231\rho^2 - 91) z(w)^3] \\ R_1(w) &= R_1(1) - 0.12(w-1) + 0.05(w-1)^2 \\ R_2(w) &= R_2(1) + 0.11(w-1) - 0.06(w-1)^2 \end{aligned}}$$

BGL model

Backup

$$H_0(w) = \frac{\mathcal{F}_1(w)}{\sqrt{q^2}}$$

$$H_\pm(w) = f(w) 4 m_{B_s^0} m_{D_s^*} \sqrt{w^2 - 1} g(w)$$

$$z(w) = \frac{\sqrt{w+1} - \sqrt{2}}{\sqrt{w-1} + \sqrt{2}}$$

$$H_t(w) = m_{B_s^0} \frac{\sqrt{r}(1+r)\sqrt{w^2-1}}{\sqrt{1+r^2-2wr}} \mathcal{F}_2(w)$$

$$f(z) = \frac{1}{P_{1+}(z)\phi_f(z)} \sum_{n=0}^{N} a_n^f z^n \qquad \mathcal{F}_1(z) = \frac{1}{P_{1+}(z)\phi_{\mathcal{F}_1}(z)} \sum_{n=0}^{N} a_n^{\mathcal{F}_1} z^n$$

$$g(z) = \frac{1}{P_{1-}(z)\phi_g(z)} \sum_{n=0}^{N} a_n^g z^n \qquad \mathcal{F}_2(z) = \frac{\sqrt{r}}{(1+r)P_{0-}(z)\phi_{\mathcal{F}_2}(z)} \sum_{n=0}^{N} a_n^{\mathcal{F}_2} z^n$$

New Physics tensor

Backup

$$H'_{eff} = H^{SM}_{eff} + \frac{G_F}{\sqrt{2}} V_{cb} \left[\epsilon^{\ell}_T \bar{c} \sigma_{\mu\nu} (1-\gamma_5) b \bar{\ell} \sigma^{\mu\nu} (1-\gamma_5) \nu_\ell + h.c. \right] \qquad \sigma^{\mu\nu} = \frac{i}{2} [\gamma^\mu, \gamma^\nu]$$

$$\mathcal{A}(B^0_s \to D^*_s \ell \nu_\ell) = \frac{G_F}{\sqrt{2}} V_{cb} \left[H^{SM}_{\mu} L^{\mu,SM} + \epsilon^{\ell}_T H^{NP}_{\mu\nu} L^{\mu\nu,NP} \right]$$

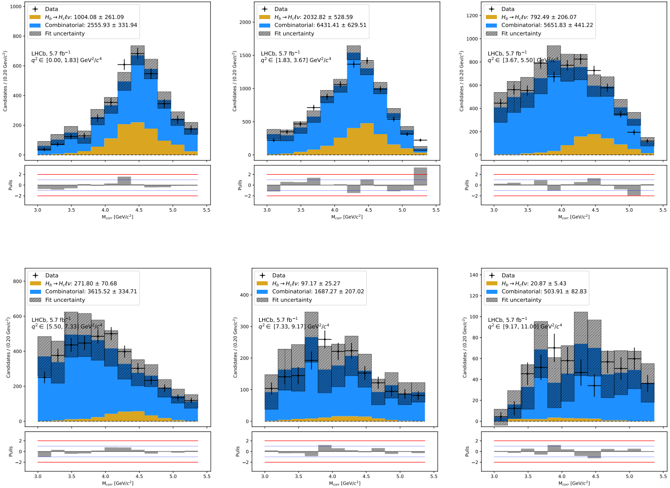
$$H^j_m = \langle D^*_s(p_{D^*_s}, \epsilon_m) | \, \bar{c} \mathcal{O}^j (1-\gamma_5) b \, | B^0_s(p_{B^0_s}) \rangle \qquad L^j = \bar{\ell} \mathcal{O}^j (1-\gamma_5) \nu_\ell$$

$$\Rightarrow \quad H^{NP}_m = H^{NP}_m(T_0, T_1, T_2) \qquad I^{NP}_j = I^{NP}_j(H^{NP}_m)$$

7

Fit in the control region

Backup



Preliminary in the control region $\mathtt{BDT\_dbc\_reopt} < -0.2$, that is combinatorial and doubly chamred enriched

- use results from this fit to constrain these components

Belle and HPQCD

Backup

arXiv:2304.03137