Search of New Physics in leptonic and semileptonic decays of the neutral B_s^0 meson at LHCb

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PhD Days

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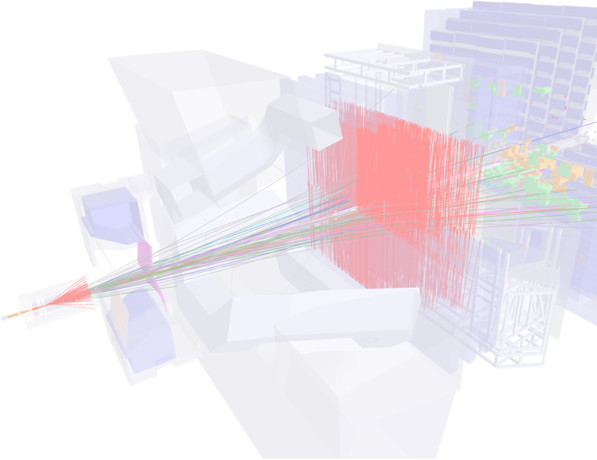
Outline

- New Physics search at LHCb
- $B_s^0 \to D_s^* \mu \nu_\mu$ full angular analysis
- $B_s^0 \to \mu^+ \mu^-$ analysis
- Future perspectives

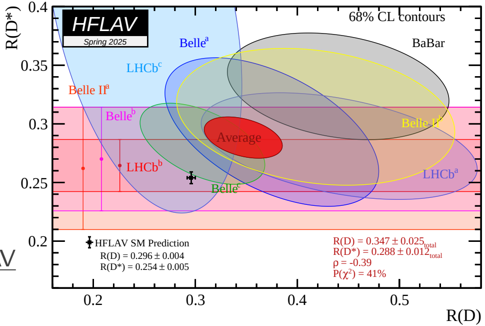


New Physics search at LHCb

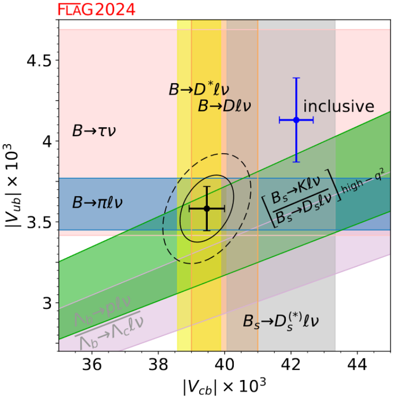
Anomalies in the flavour sector of SM

New Physics search at LHCb

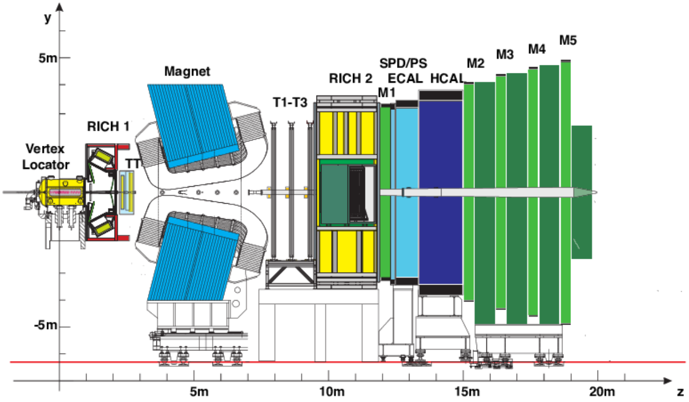
Several anomalies have been detected in the past years in the flavour sector of the Standard Model (SM), pointing at possible New Physics contributions (NP) that we still have to understand



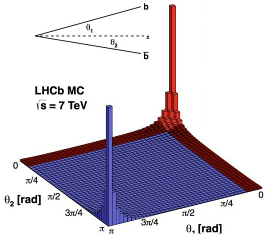
HFLAV



FLAG2024



LHCb is a single-arm spectrometer designed to detect heavy hadrons produced in *pp* collisions, study CP violation and rare decays



$B_s^0 \to D_s^* \mu \nu_\mu$ full angular analysis

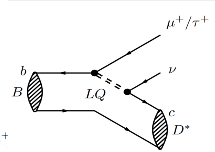
The study of semileptonic decays could help shedding light on the tensions in the flavour sector because:

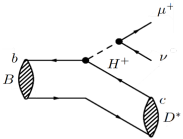
- one diagram, tree-level process
- EW transition
- QCD interaction
- sensitivity to New Physics

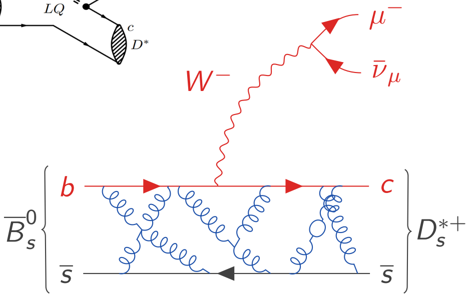
Additionally:

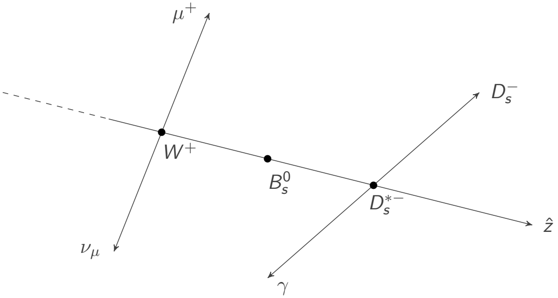
- simpler lattice computations with respect to B^0 and B^+ (due to s quark)

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





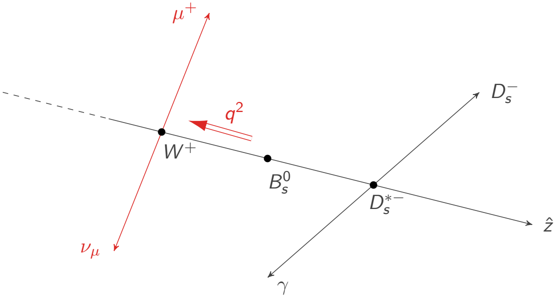




A full angular analysis aims to measure the differential decay rate in the phase-space given by the variables that describe the decay kinematics:

Decay kinematics

$B_s^0 \to D_s^* \mu\nu_\mu$ full angular analysis



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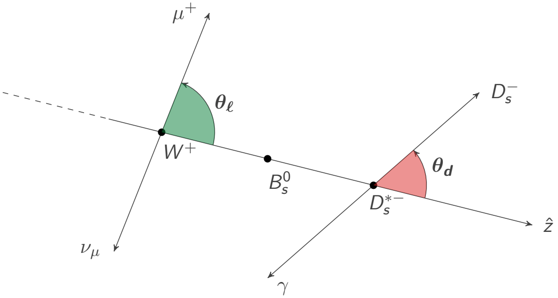
q^2

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



A full angular analysis aims to measure the differential decay rate in the phase-space given by the variables that describe the decay kinematics:

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

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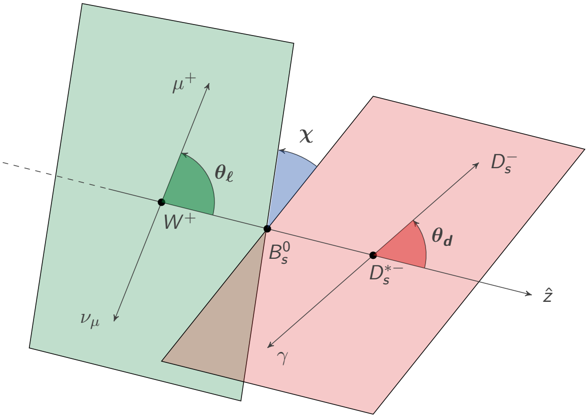
θ_ℓ and θ_d are helicity angles



A full angular analysis aims to measure the differential decay rate in the phase-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

The differential decay rate

$B_s^0 \to D_s^* \mu \nu_\mu$ full angular analysis

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

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- $\Xi_i(\theta_\ell, \theta_d, \chi)$ are known functions of the angular variables
- $I_i(q^2)$ 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 rate

$B_s^0 \to D_s^* \mu \nu_\mu$ full angular analysis

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

$$I_i(q^2) \implies I_i(q^2, \epsilon_{\rm NP})$$

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

Analysis strategy

$B_s^0 \to D_s^* \mu \nu_\mu$ full angular analysis

1. Selection & Reconstruction
2. Signal yields
3. Form factors
4. Systematics
5. Internal analysis note

1

a. Kinematic cuts
b. Muon trigger line
c. sWeights

a. TMVA

2

a. Binning choice (4d space)
b. MC reweighting and sampling
c. First fit over q^2 bins
d. Fits over 4d space with constraints

3

a. Unfolding
b. Model dependent fit with CLN/BGL models + tensor NP
c. Model independent fit to $I_j(q^2)$ shapes + CLN/BGL parameters

4

a. Bootstrap and toys techniques

5

a. Writing in process
b. Data/MC comparisons

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b. Data/MC comparisons

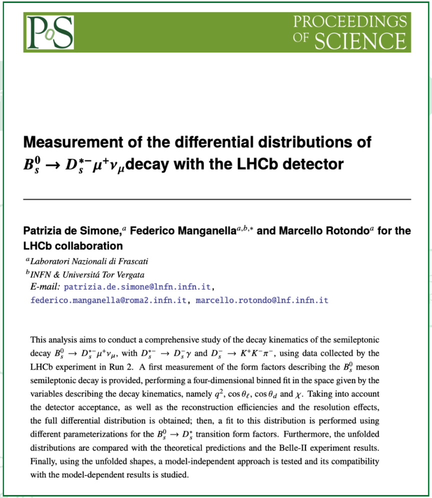
Actively worked on these points this year!

Analysis strategy

$B_s^0 \to D_s^* \mu \nu_\mu$ full angular analysis

1. Selection & Reconstruction
2. Signal yields

Preliminary results have been published on a PoS paper after Italian Workshop on the High Energy Physics (WIFAI2024)



PROCEEDINGS OF SCIENCE

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

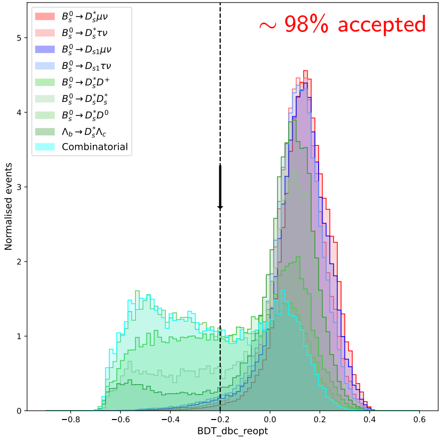
Patrizia de Simone,[a] Federico Manganella[a,b,*] and Marcello Rotondo[a] for the LHCb collaboration

[a] *Laboratori Nazionali di Frascati*
[b] *INFN & Universitá Tor Vergata*
E-mail: patrizia.de.simone@lnfn.infn.it, federico.manganella@roma2.infn.it, marcello.rotondo@lnf.infn.it

This analysis aims to conduct a comprehensive study of the decay kinematics of the semileptonic decay $B_s^0 \to D_s^{*-}\mu^+\nu_\mu$, with $D_s^{*-} \to D_s^-\gamma$ and $D_s^- \to K^+K^-\pi^-$, using data collected by the LHCb experiment in Run 2. A first measurement of the form factors describing the B_s^0 meson semileptonic decay is provided, performing a four-dimensional binned fit in the space given by the variables describing the decay kinematics, namely q^2, $\cos\theta_\ell$, $\cos\theta_d$ and χ. Taking into account the detector acceptance, as well as the reconstruction efficiencies and the resolution effects, the full differential distribution is obtained; then, a fit to this distribution is performed using different parameterizations for the $B_s^0 \to D_s^*$ transition form factors. Furthermore, the unfolded distributions are compared with the theoretical predictions and the Belle-II experiment results. Finally, using the unfolded shapes, a model-independent approach is tested and its compatibility with the model-dependent results is studied.

Signal and control regions

$B_s^0 \to D_s^* \mu \nu_\mu$ full angular analysis

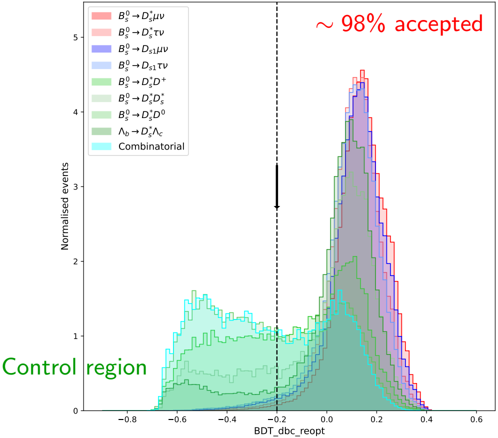


Signal and control regions

$B_s^0 \to D_s^* \mu\nu_\mu$ full angular analysis

We define:

1. control region: $\texttt{BDT\_dbc\_reopt} < -0.2$
   - ⋆ doubly-charmed and combinatorial enriched



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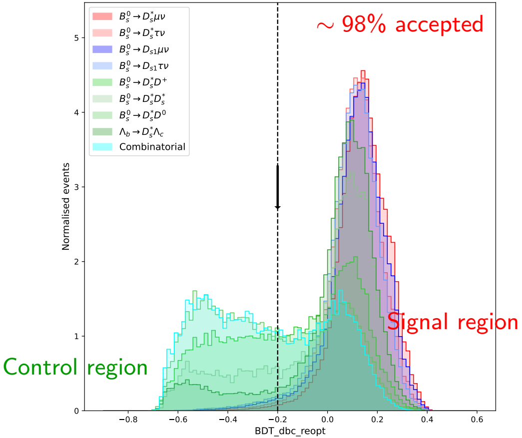

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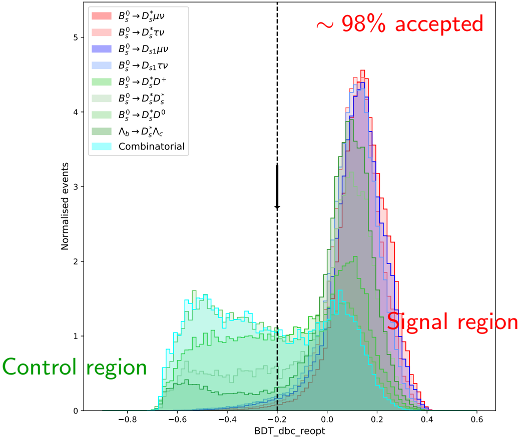
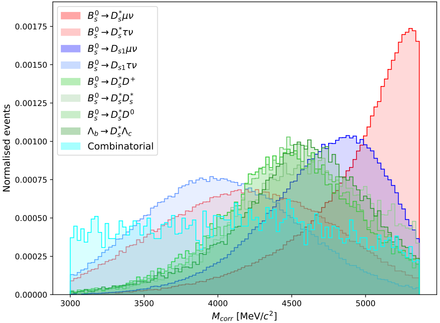
Use the control region to constrain background channels



How to fit signal yields

$B_s^0 \to D_s^* \mu \nu_\mu$ full angular analysis



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

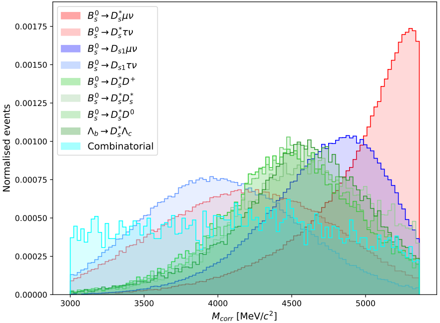
Extract signal yields using

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

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

How to fit signal yields

$B_s^0 \to D_s^* \mu \nu_\mu$ full angular analysis



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

- simultaneous fit over q^2 bins in the control region

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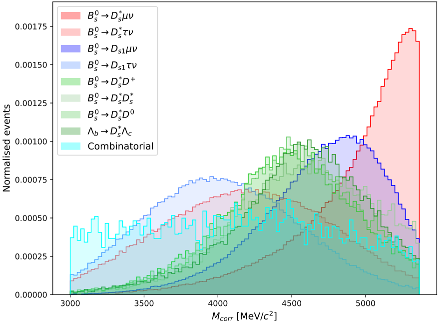

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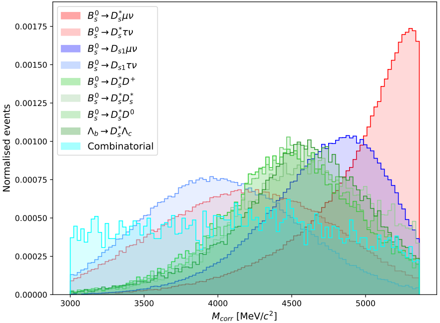
Template binned fit over 4-d space, extrapolation in three steps:

- simultaneous fit over q^2 bins in the control region
- simultaneous fit over q^2 bins in the signal region, fixing some background templates

How to fit signal yields

$B_s^0 \to D_s^* \mu \nu_\mu$ full angular analysis



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Extract signal yields using

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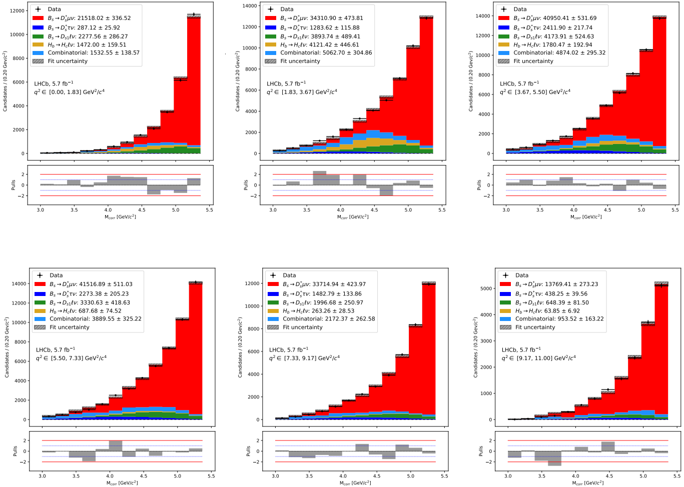
Template binned fit over 4-d space, extrapolation in three steps:

- simultaneous fit over q^2 bins in the control region
- simultaneous fit over q^2 bins in the signal region, fixing some background templates
- second fit over all bins, fixing background templates

Results in q^2 bins in the signal region

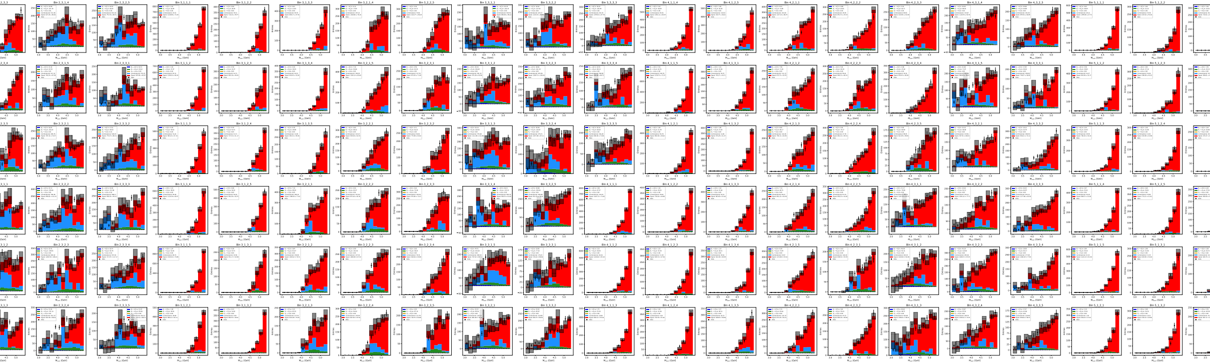
$B_s^0 \to D_s^* \mu \nu_\mu$ full angular analysis



q^2 [GeV$^2/c^4$]	Signal [%]
[0, 1.83]	79
[1.83, 3.67]	70
[3.67, 5.50]	76
[5.50, 7.33]	80
[7.33, 9.17]	85
[9.17, 11]	87

Results in 4-d bins in the signal region

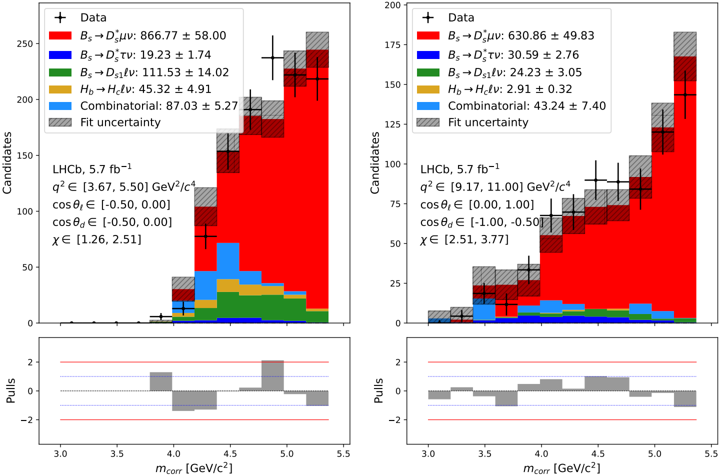
$B_s^0 \to D_s^* \mu \nu_\mu$ full angular analysis



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

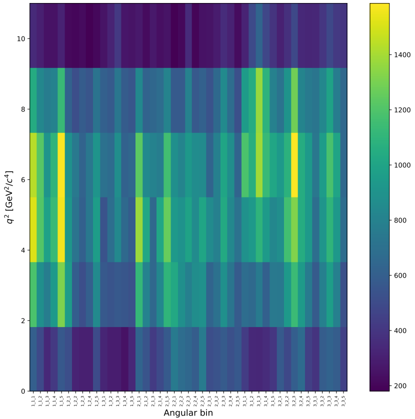
Results in 4-d bins in the signal region

$B_s^0 \to D_s^* \mu \nu_\mu$ full angular analysis

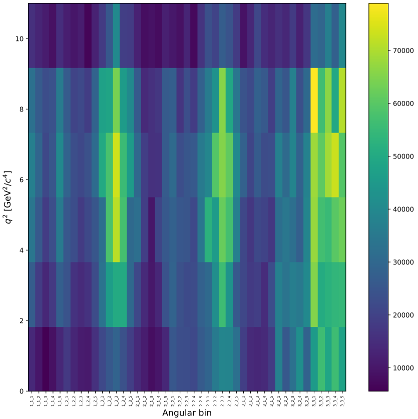


Further studies

$B_s^0 \to D_s^* \mu \nu_\mu$ full angular analysis



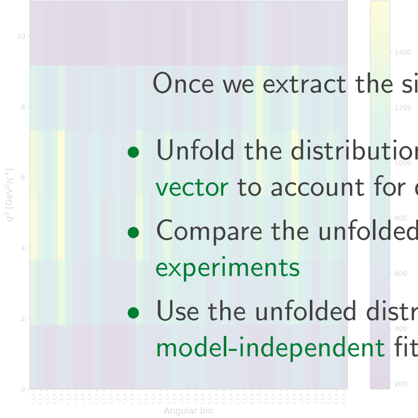
Folded distribution



Unfolded distribution

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



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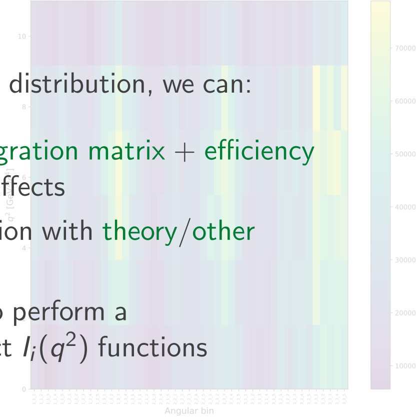

Unfolded distribution

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

We can explicitly fit the $I_i(q^2)$ functions integrated over the q^2 bins, without any assumption on the hadronic model. In a given bin in the 4-d space we expect:

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

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

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

$B_s^0 \to D_s^* \mu \nu_\mu$ full angular analysis

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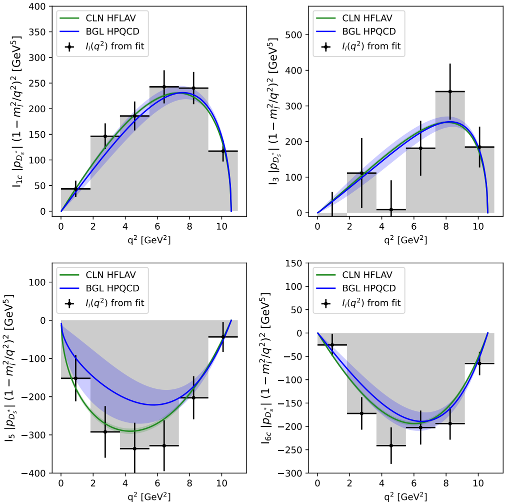
$$\propto \sum_i \int_{\Delta q_k^2} \left(1 - m_\mu^2/q^2\right)^2 |\vec{p}_{D_s^*}(q^2)|\, I_i(q^2)\, dq^2 \cdot \int_{\Delta\Omega_l} \Xi_i(\theta_\ell, \theta_d, \chi)\, d\Omega$$

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

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.

New Physics from $I_i(q^2)$ shapes

$B_s^0 \to D_s^* \mu \nu_\mu$ full angular analysis

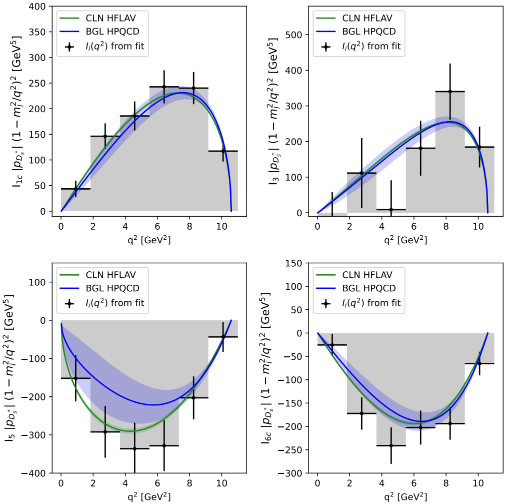


$$\frac{d\Gamma}{dq^2\, d\cos\theta_\ell\, d\cos\theta_d\, d\chi} = \mathcal{K}(q^2) \sum_i I_i(q^2) \Xi_i(\theta_\ell, \theta_d, \chi)$$

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

New Physics from $I_i(q^2)$ shapes

$B_s^0 \to D_s^* \mu \nu_\mu$ full angular analysis



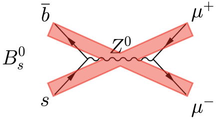
$$\frac{d\Gamma}{dq^2\, d\cos\theta_\ell\, d\cos\theta_d\, d\chi} = \mathcal{K}(q^2) \sum_i I_i(q^2) \Xi_i(\theta_\ell, \theta_d, \chi)$$

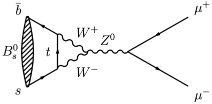
$$\propto \Big[I_{1s} \sin^2\theta_d + I_{1c}(3 + \cos 2\theta_d) + I_{2s} \sin^2\theta_d \cos 2\theta_\ell$$
$$+ I_{2c}(3 + \cos 2\theta_d)\cos 2\theta_\ell + I_3 \sin^2\theta_d \sin^2\theta_\ell \cos 2\chi$$
$$+ I_4 \sin 2\theta_d \sin 2\theta_\ell \cos\chi + I_5 \sin 2\theta_d \sin\theta_\ell \cos\chi$$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

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

$B_s^0 \to \mu^+\mu^-$ analysis

In the SM, B and B_s mesons decay in a di-muon final state via a FCNC, that is helicity suppressed. The purely leptonic state allows for very clean theoretical predictions and experimental measurements: great chance to test NP contributions!





Fully leptonic decays

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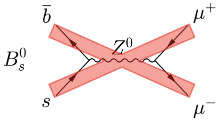
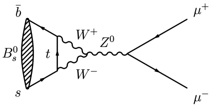


Normalising on a specific channel ($B^+ \to J/\Psi K^+$ or $B^0 \to K^+\pi^-$), we can write the expected number of $B_s^0 \to \mu^+\mu^-$ events as



$$N_{B_s^0\to\mu^+\mu^-} = \frac{1}{\alpha_s} \times \mathcal{B}(B_s^0 \to \mu^+\mu^-) = \underbrace{\boxed{\frac{f_s}{f_d} \times \varepsilon_{sig} \times \frac{N_{norm}}{\mathcal{B}_{norm} \cdot \varepsilon_{norm}}}}_{\alpha_s^{-1}} \times \mathcal{B}(B_s^0 \to \mu^+\mu^-)$$

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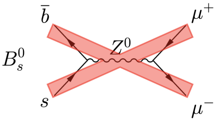

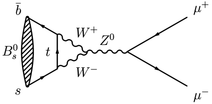

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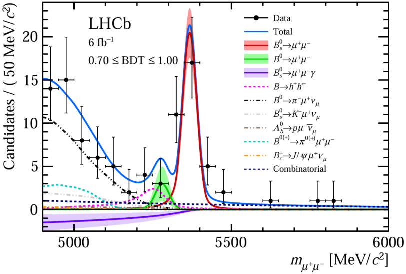
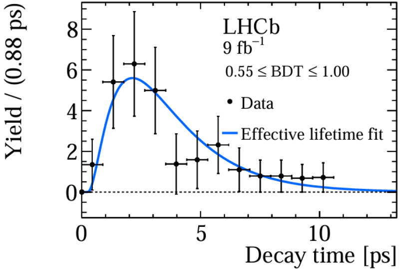
The effective lifetime, computed as the mean decay time, is written as

$$\tau_{\mu^+\mu^-} = \frac{\tau_{B_s^0}}{(1-y_s^2)}\left[\frac{1+2\mathcal{A}_{\Delta\Gamma}y_s+y_s^2}{1+\mathcal{A}_{\Delta\Gamma}y_s}\right] \qquad y_s = \frac{\Gamma_L-\Gamma_H}{\Gamma_L+\Gamma_H}, \qquad \mathcal{A}_{\Delta\Gamma}\in[-1,+1], +1 \text{ in SM}$$

Events are divided in different categories according to a BDT output. We aim to fit simultaneously the dimuon invariant mass $m_{\mu^+\mu^-}$ and the effective lifetime $\tau_{\mu^+\mu^-}$ in BDT bins. Thus, the 2-d *pdf* will depend on:

$$pdf(m_{\mu^+\mu^-}),\ pdf(\tau_{\mu^+\mu^-}) \Rightarrow pdf_{2d}$$





Simultaneous fit overview

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- check correlation between invariant mass $m_{\mu^+\mu^-}$ and lifetime $\tau_{\mu^+\mu^-}$
- check if we get back the expected value with a 2-d fit on MC sample
  - ⋆ the closure test is performed by reweighting the lifetime distribution and checking if we get back the new $\tau_{\mu^+\mu^-}$ value using the 2-d fit

The geometrical acceptance I

$$pdf(\tau_{\mu^+\mu^-}) \propto \sum_{i \in \text{BDT}} \mathcal{A}(t)_i \cdot \left(e^{-t/\tau_{\mu^+\mu^-}} \otimes \mathcal{R}_i \right)$$

$\mathcal{R}_i$ function is a function encoding the detector resolution, while $\mathcal{A}_i$ is an acceptance function extracted from simulations, depending on BDT cut.

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$B_s^0 \to \mu^+\mu^-$ analysis

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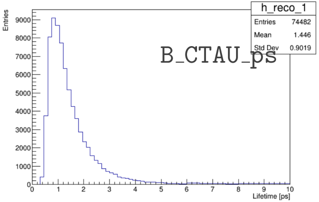

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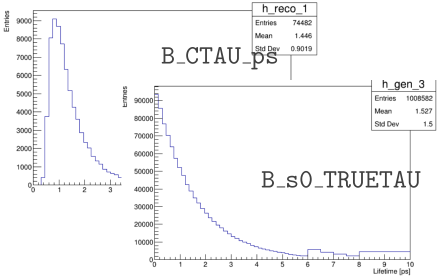

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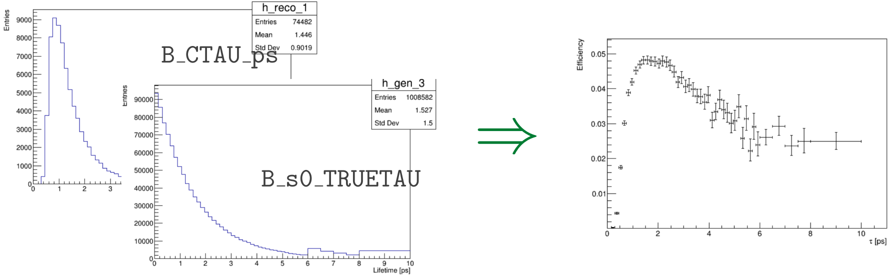
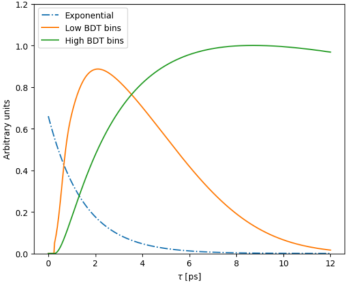


The analytical expressions for the acceptance functions are empirical, we are using the same functions used in Run 2 analysis at the moment:

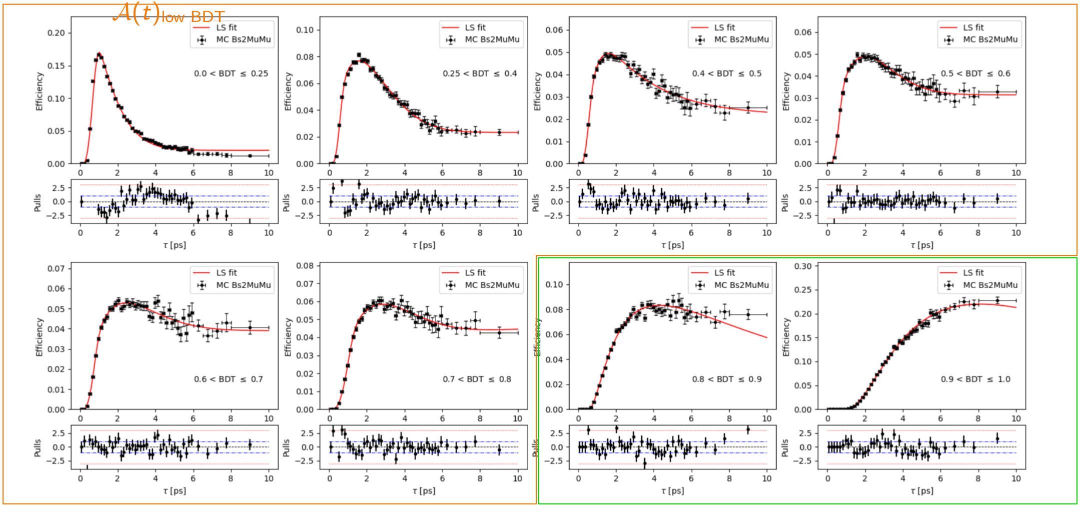
$$\mathcal{A}(t)_{\text{low BDT}} = a \cdot \text{Erf}\left(t\sqrt{b \cdot \tanh ct^3}\right) + \exp\left(-dt^e\right) - 1$$

$$\mathcal{A}(t)_{\text{high BDT}} = \exp\left(-\frac{1}{2}\left(\frac{\ln(t-t_0)-f}{g}\right)^2\right)$$



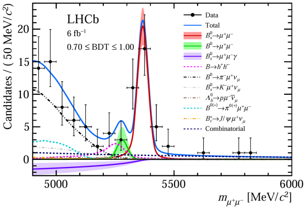
Fit to the acceptance functions

$B_s^0 \to \mu^+\mu^-$ analysis



$\mathcal{A}(t)_{\text{high BDT}}$

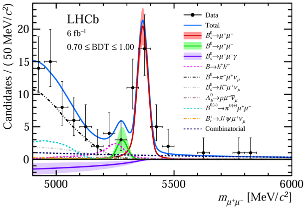
$$pdf(m_{\mu^+\mu^-}) \propto \sum_{i \in \mathrm{BDT}} \Bigg(k_i(\tau_{\mu^+\mu^-}) \cdot \varepsilon_s^i \cdot \frac{\mathcal{B}(B_s^0 \to \mu^+\mu^-)}{\alpha_s} \cdot pdf_s^i + \varepsilon_d^i \cdot \frac{\mathcal{B}(B^0 \to \mu^+\mu^-)}{\alpha_d} \cdot pdf_d^i + c_{bkg}^i \cdot pdf_{bkg}^i \Bigg)$$



Lifetime dependent correction I

$B_s^0 \to \mu^+\mu^-$ analysis

$$pdf(m_{\mu^+\mu^-}) \propto \sum_{i\in \mathrm{BDT}} \left(k_i(\tau_{\mu^+\mu^-}) \cdot \varepsilon_s^i \cdot \frac{\mathcal{B}(B_s^0 \to \mu^+\mu^-)}{\alpha_s} \cdot pdf_s^i + \varepsilon_d^i \cdot \frac{\mathcal{B}(B^0 \to \mu^+\mu^-)}{\alpha_d} \cdot pdf_d^i + c_{bkg}^i \cdot pdf_{bkg}^i \right)$$



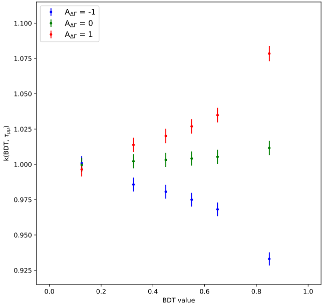
We need a lifetime-dependent k_i correction factor because MC samples are generated with a decay time different from the one measured. We developed an *in-fit* correction, while in Run 2 analysis it was computed as a pre-fit bin-dependent correction as:

$$k_i = \langle \omega_j \rangle = \frac{1}{N} \sum_{j=1}^{N} \frac{\tau_{gen}}{\tau_{\mu^+\mu^-}} \cdot e^{-t_j(1/\tau_{\mu^+\mu^-} - 1/\tau_{gen})} \qquad \tau_{\mu^+\mu^-} = \tau_{\mu^+\mu^-}(\mathcal{A}_{\Delta\Gamma})$$

Lifetime dependent correction II

Corrections from Run2 analysis:

BDT bin	$k(\mathcal{A}_{\Delta\Gamma} = -1)$	$k(\mathcal{A}_{\Delta\Gamma} = 0)$	$k(\mathcal{A}_{\Delta\Gamma} = +1)$
1	1.00084	0.99964	0.99642
2	0.98572	1.00223	1.01379
3	0.98062	1.00315	1.02012
4	0.97499	1.00414	1.02690
5	0.96816	1.00532	1.03489
6	0.93305	1.01161	1.07846
Integrated	0.97063	1.00494	1.03258



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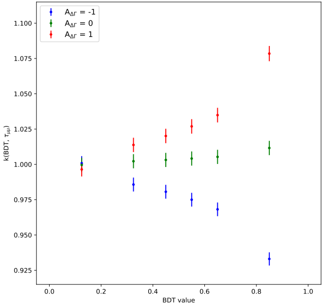

We tested different models and chose

$$k_i(\text{BDT},\tau_{\mu\mu}) = 1 + \beta \cdot \text{BDT}_i \exp(\text{BDT}_i) \cdot \exp\left(\frac{\tau_{\mu\mu}}{\tau_{gen}} - 1\right)$$

where BDT_i is the center of the i-th BDT bin and τ_{gen} is fixed: the parameter β is related to different hypotheses

Lifetime dependent correction II

$B_s^0 \to \mu^+\mu^-$ analysis

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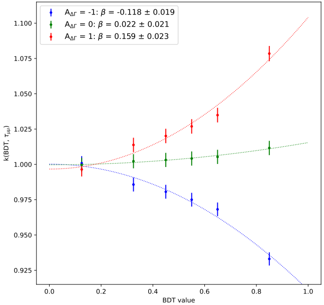

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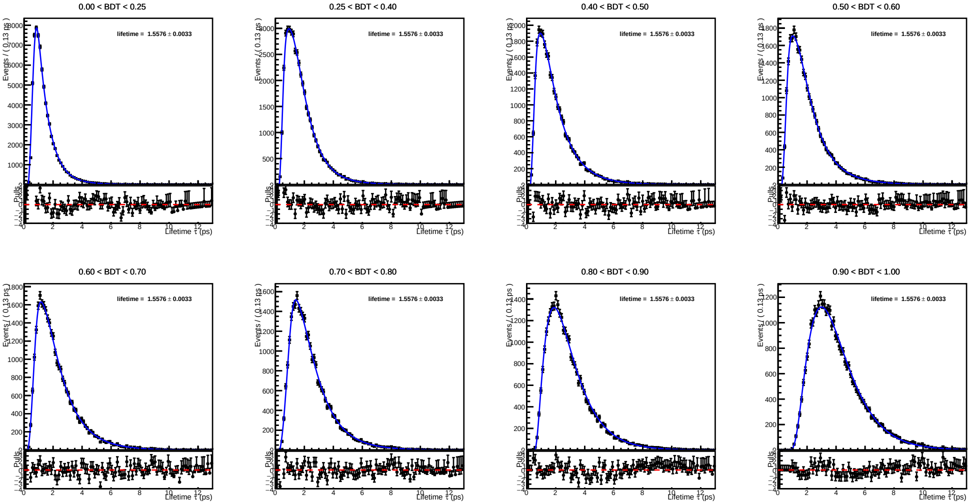
where BDT_i is the center of the i-th BDT bin and τ_{gen} is fixed: the parameter β is related to different hypotheses

3 Simultaneous fit over MC sample

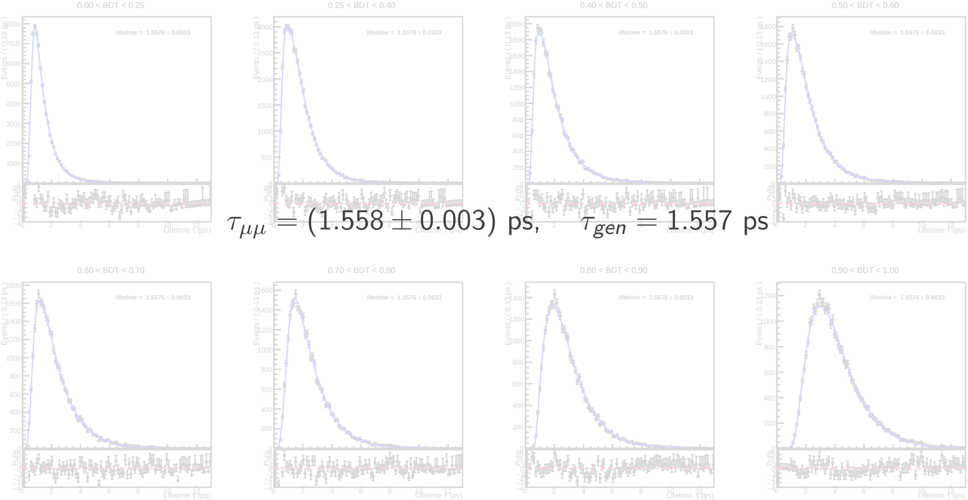
Having everything in place, we can perform a simultaneous fit of the di-muon invariant mass $m_{\mu^+\mu^-}$ and the effective lifetime $\tau_{\mu^+\mu^-}$ over all the BDT bins.

Simultaneous fit over MC sample



3 Simultaneous fit over MC sample

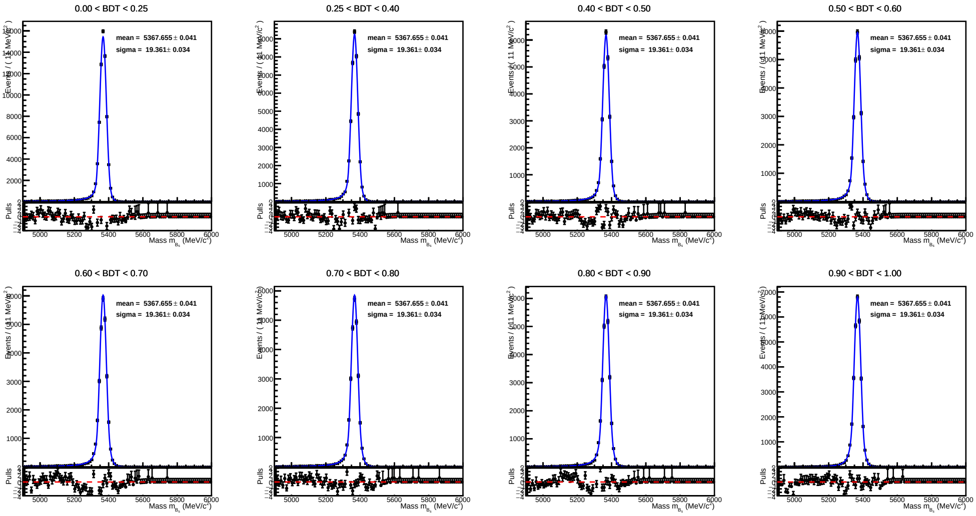
$B_s^0 \to \mu^+\mu^-$ analysis



$$\tau_{\mu\mu} = (1.558 \pm 0.003)\ \text{ps}, \qquad \tau_{gen} = 1.557\ \text{ps}$$

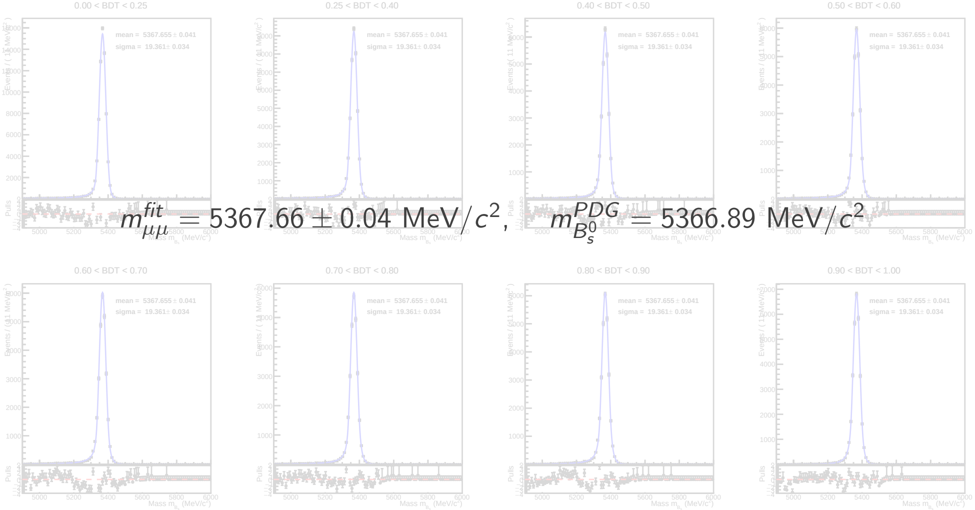
Simultaneous fit over MC sample

$B_s^0 \to \mu^+\mu^-$ analysis

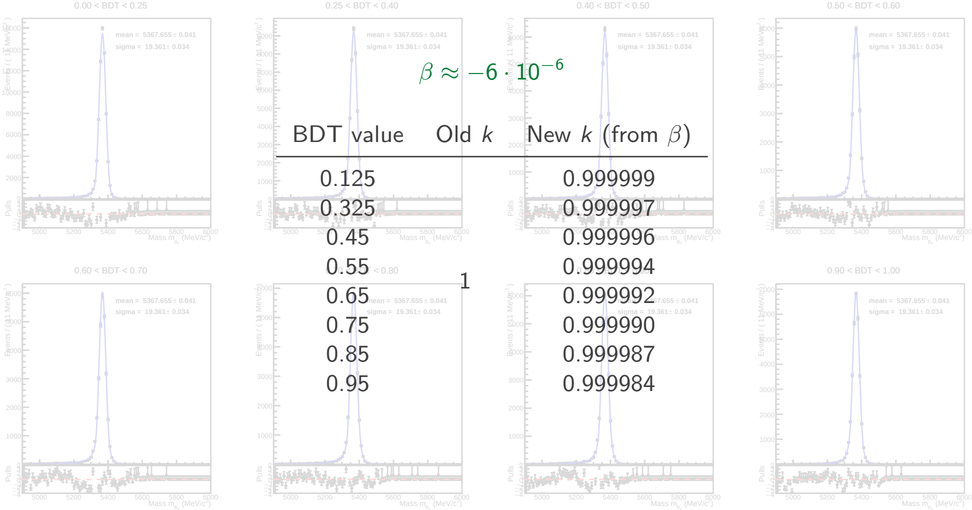


Simultaneous fit over MC sample

$B_s^0 \to \mu^+\mu^-$ analysis



$$m_{\mu\mu}^{fit} = 5367.66 \pm 0.04 \text{ MeV}/c^2, \quad m_{B_s^0}^{PDG} = 5366.89 \text{ MeV}/c^2$$

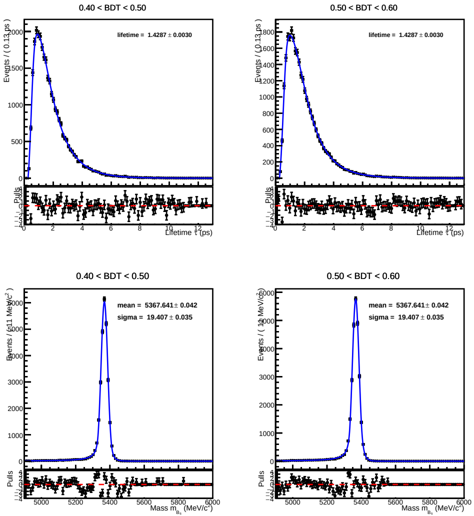


$\beta \approx -6 \cdot 10^{-6}$

BDT value	Old k	New k (from β)
0.125		0.999999
0.325		0.999997
0.45		0.999996
0.55	1	0.999994
0.65		0.999992
0.75		0.999990
0.85		0.999987
0.95		0.999984

Simultaneous fit over reweighted MC sample

$B_s^0 \to \mu^+\mu^-$ analysis



$$\tau_{gen} = 1.556 \text{ ps} \to \tau_{gen} = 1.430 \text{ ps}$$
$$(\mathcal{A}_{\Delta\Gamma} = -1)$$

$$\tau_{\mu\mu} = 1.429 \pm 0.003 \text{ ps}$$
$$m_{\mu\mu} = 5367.64 \pm 0.04 \text{ MeV}/c^2$$
$$\beta = -0.05380 \pm 0.00007$$

BDT value	Old $k(\mathcal{A}_{\Delta\Gamma} = -1)$	New k (from β)
0.125	1.00379	0.99287
0.325	0.983759	0.977356
0.45	0.976711	0.964473
0.55	0.969483	0.952011
0.65	0.959809	0.937321
0.75	0.949423	0.920072
0.85	0.924399	0.899888
0.95	0.867286	0.876342

Future perspectives

Semileptonic analysis

- Finalise fit procedure
- Validate efficiencies and MC corrections
- Test explicit NP model
- Compute systematic uncertainties
- Check Data/MC comparisons

4 A tentative programme

Future perspectives

Semileptonic analysis

- Finalise fit procedure
- Validate efficiencies and MC corrections
- Test explicit NP model
- Compute systematic uncertainties
- Check Data/MC comparisons

Fully leptonic analysis

- Test 2-d fit with background samples
- Validate closure test on all Run 2 MC samples
- Test the procedure with Run 3 MC samples
- Start working with Run 3 data (partial or full dataset, $\geq 9\ \text{fb}^{-1}$)

Search of New Physics in leptonic and semileptonic decays of the neutral B_s^0 meson at LHCb

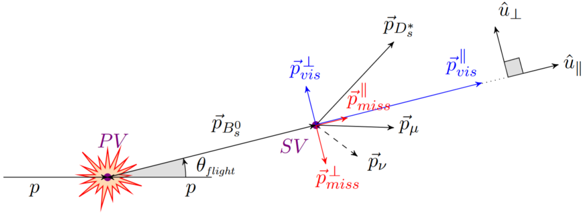
Thank you for listening!

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 $\mathtt{PID}_{\mu} > 2$

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

SL: Kinematics reconstruction



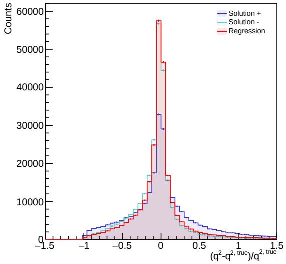
We assume there is only one missing particle in the final state and that $m_{B_s^0}$ is known (see JHEP02(2017)021)

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

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

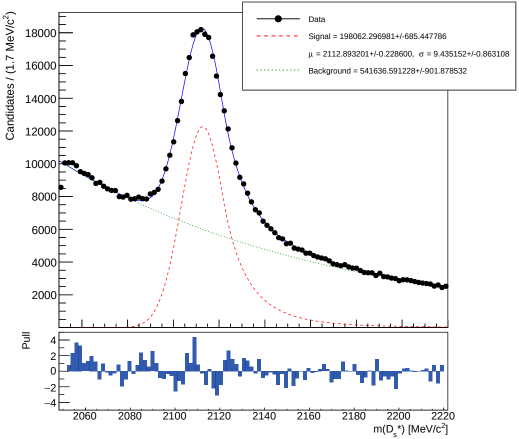
$$\Delta_\pm = (p_{\text{reg}} - p_\pm)$$

$$\Downarrow$$



5 SL: sWeights

Backup slides

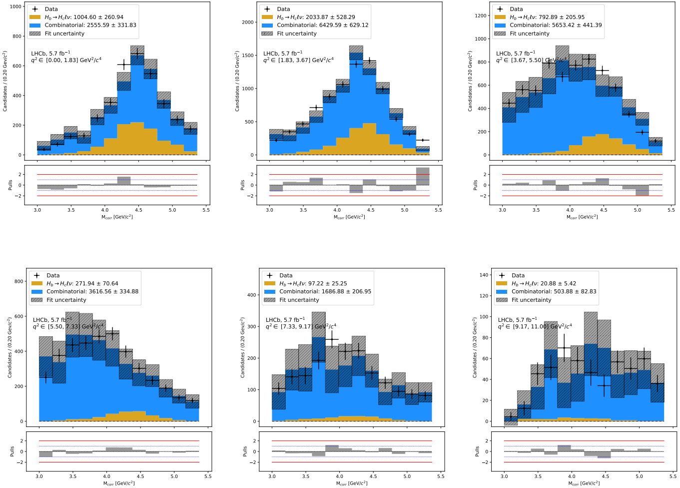


The selected photon has the highest p_T inside the cone $\Delta R = 0.4$. The fit to $m(D_s^*) - m(D_s) + m_{\mathrm{PDG}}(D_s)$ is used to reduce combinatorial

$\Downarrow$

${}_s\mathcal{P}lot$ assigns event-by-event weights to describe the likelihood to be a signal event

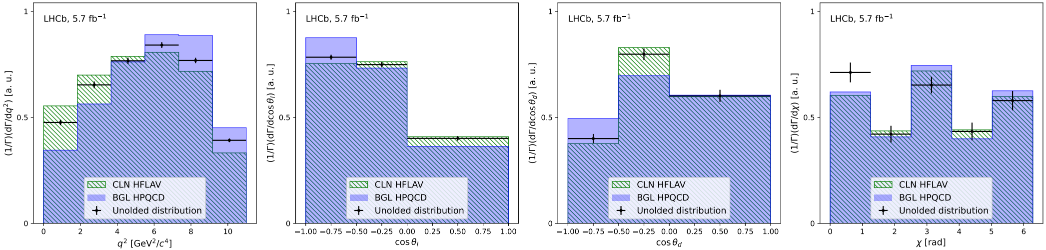
SL: Results in q^2 bins in the control region



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

Use results from this fit to constrain these components

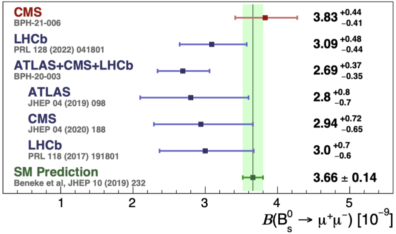
SL: Unfolded distributions and predictions

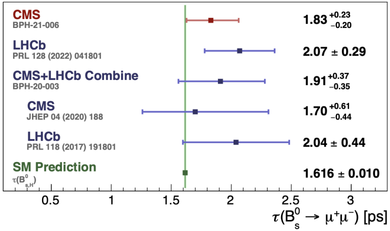


- Models used: HFLAV averages for CLN, HPQCD predictions for BGL
- Visible tension in some bins
- Something similar was observed comparing Belle data with HPQCD predictions, but with different binning and with $B^0 \to D^*$

5 L: State of the art
Backup slides

- 2014: First $B_s^0 \to \mu^+\mu^-$ observation by LHCb + CMS
- 2016: First $B_s^0 \to \mu^+\mu^-$ single-experiment observation by LHCb
- 2020: LHC combined measurement
- 2022: Latest precise measurement by CMS





- Sensitive to NP since it's a very rare decay, due to loop, CKM and helicity suppression
- $\mathcal{B}(B_s^0 \to \mu^+\mu^-)$ is sensitive to $C_S^{(\prime)}$, $C_P^{(\prime)}$, $C_{10}^{(\prime)}$ Wilson coefficients (only C_{10} in SM)
- Effective lifetime $\tau_{\mu^+\mu^-}$ is sensitive to NP independent to branching fraction ($\mathcal{A}_{\Delta\Gamma} \neq +1$)