Measurement of $\mathcal{B}\left(B^0_{(s)} \to K^0_S K^0_S\right)$ with Run 2 LHCb data

R. Marchevski[1], K. Guseinov[1], L. M. Garcia Martin[1], Y. Amhis[2]

[1] École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland
[2] Université Paris-Saclay, CNRS/IN2P3, IJCLab, Orsay, France

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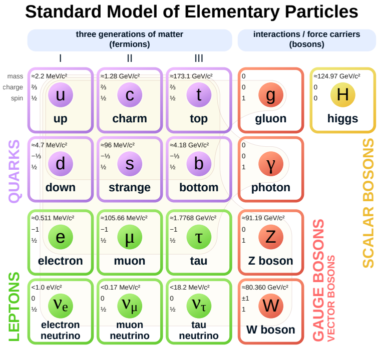
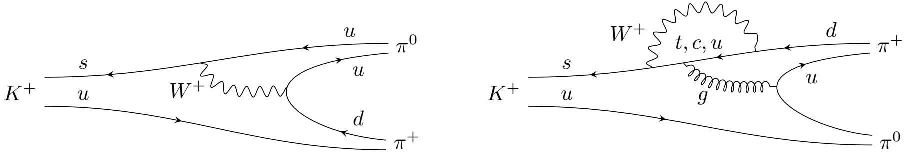
Introduction. Flavor-changing neutral currents

- Protons (uud), neutrons (udd), and electrons (e) make up the visible universe nowadays, but many more particles exist
- Fundamental: 6 quarks, 6 leptons, 5 bosons
- Quark transitions: $W^{\pm}$ bosons (and not Z)
- Same quark charges: two $W^{\pm}$ interactions
- Suppression in the SM gives sensitivity to new physics



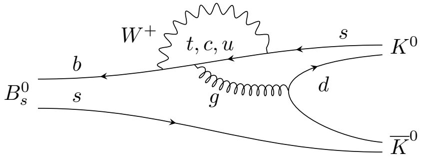


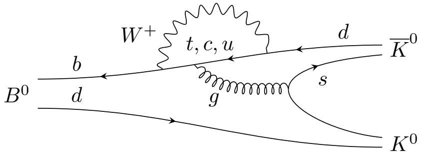
Feynman diagrams for $K^+ \to \pi^+\pi^0$: charged and neutral currents

Motivation. $B_s^0 \to K_S^0 K_S^0$ and $B^0 \to K_S^0 K_S^0$

- $B_s^0 \to K^0 \overline{K}^0$ ($b \to s d\bar{d}$) and $B^0 \to K^0 \overline{K}^0$ ($b \to d s\bar{s}$) proceed via flavor-changing neutral currents: sensitive to new physics

$$\mathcal{B}\left(B_{(s)}^0 \to K_S^0 K_S^0\right) = \frac{1}{2}\,\mathcal{B}\left(B_{(s)}^0 \to K^0 \overline{K}^0\right)$$



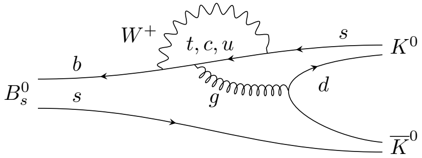


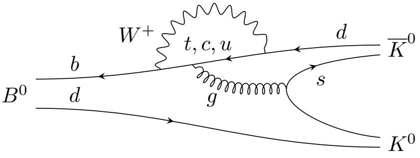
Motivation. Tensions with the SM

- B_s^0: measured by Belle [PRL 116, 161801] and then LHCb [PRD 102, 012011]
  B^0: measured by Belle [PRD 87, 031103(R)]
- Y. Amhis *et al.* [2212.03874] discuss a puzzle with

$$\frac{\Gamma\left(B_s^0 \to K^0\overline{K}^0\right)}{\Gamma(B_s^0 \to K^+K^-)} = 0.66 \pm 0.13 \quad \left|\frac{V_{td}}{V_{ts}}\right|^2 \frac{\Gamma\left(B_s^0 \to K^0\overline{K}^0\right)}{\Gamma\left(B^0 \to K^0\overline{K}^0\right)} = 0.61 \pm 0.13 \quad \frac{\Gamma\left(B^+ \to \pi^+K^0\right)}{\Gamma(B^0 \to \pi^-K^+)} = 1.12 \pm 0.05$$

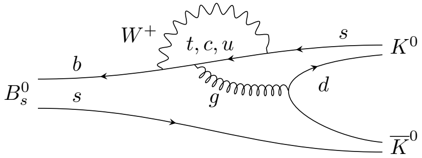
all of which should be 1 — there is tension with the SM

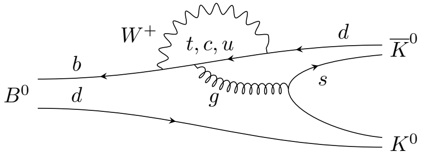




Motivation. LHCb improvements

- The existing LHCb measurement used 2011–2016 data ($\mathcal{L} = 5$ fb^{-1})
- Exclusive $B^0_{(s)} \to K^0_\mathrm{S} K^0_\mathrm{S}$ trigger introduced in 2017
  More than 3.8 times better trigger efficiency
- The current analysis uses 2016–2018 data ($\mathcal{L} = 5.6$ fb^{-1})





Analysis strategy

$$\frac{\mathcal{B}\left(B_s^0 \to K_S^0 K_S^0\right)}{\mathcal{B}(B^0 \to \phi K_S^0)} = \frac{\dfrac{N_{B_s^0 \to K_S^0 K_S^0}}{N_{B^0 \to \phi K_S^0}}}{\dfrac{\varepsilon_{B_s^0 \to K_S^0 K_S^0}}{\varepsilon_{B^0 \to \phi K_S^0}} \cdot \dfrac{f_s}{f_d} \cdot \dfrac{\mathcal{B}\left(K_S^0 \to \pi^+\pi^-\right)}{\mathcal{B}\left(\phi \to K^+K^-\right)}}$$

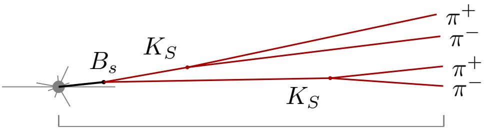
- ■ Choose a normalization decay: many effects cancel in the ratio
- ■ Select normalization decay events
- ◩ Implement corrections for the simulation
- ◩ Extract normalization yields
- ◩ Select signal decay events
- ■ Estimate full efficiency and signal yields ← we are here
- ☐ Study systematic uncertainties
- ☐ Extract signal yields

Signal and normalization decay topology

Only long tracks

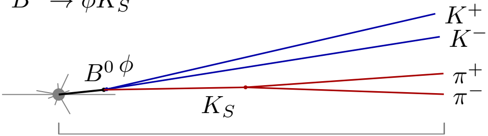
Long or downstream tracks

$B_s \to K_S K_S$



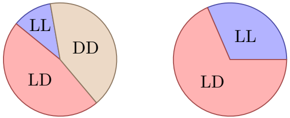
Signal

$B^0 \to \phi K_S$

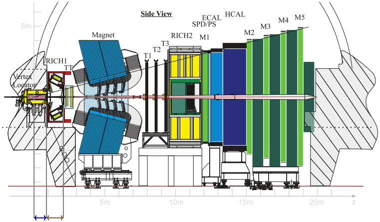


Normalization

Shares of events



Signal Normalization



long K_S downstream K_S

Normalization selection

- Preselection cuts
  - Suppress p, $\pi^{\pm}$ misidentification as $K^{\pm}$ in $\phi \to K^+K^-$
  - Suppress $\Lambda \to p\pi^-$ misidentification as $K^0_{\mathrm{S}} \to \pi^+\pi^-$

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- BDT
  - 9 variables
    (kinematics, flight distances, distance from pp vertices, vertex fit quality)
  - Signal: simulation
    Background: right data sideband
  - 8-fold cross-validation
  - Separate BDTs for LL, LD

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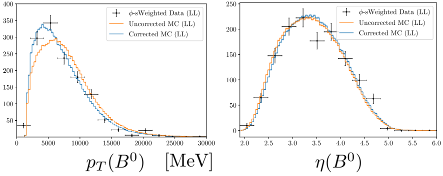
Normalization BDT performance

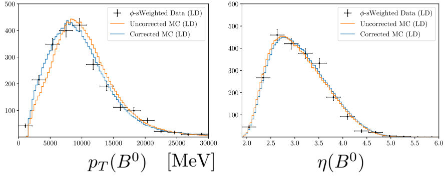
	LL	LD
Signal efficiency	$0.8205(5)$	$0.6930(4)$
Background rejection	$2.17(8) \times 10^{-4}$	$4.65(11) \times 10^{-4}$

Corrections to the simulation

- B-meson corrections are already implemented
  Derived from $B^+ \to J/\psi K^+$
- Most BDT variables are correctly modeled
- The few that are not will be corrected

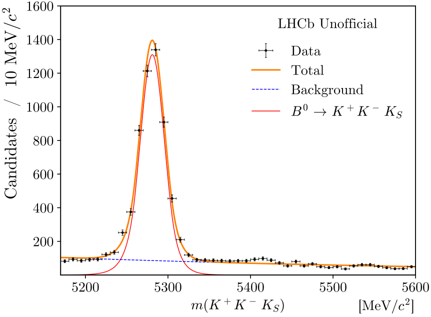


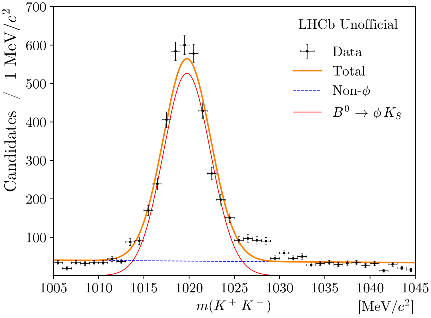
$B^0 \to \phi K^0_S$ (LL)



$B^0 \to \phi K^0_S$ (LD)

Normalization $B^0 \to \phi K^0_\mathrm{S}$ mass fits





$$N_{B^0 \to K^+K^-K^0_\mathrm{S}\ \text{(LL)}} = 1990 \pm 35$$

$$N_{B^0 \to K^+K^-K^0_\mathrm{S}\ \text{(LD)}} = 3070 \pm 40$$

$$N_{B^0 \to \phi K^0_\mathrm{S}\ \text{(LL)}} = 1298 \pm 30$$

$$N_{B^0 \to \phi K^0_\mathrm{S}\ \text{(LD)}} = 2170 \pm 40$$

Signal selection

- Preselection cuts
  - Suppress part of the combinatorial background
  - Suppress $\Lambda \to p\pi^-$ misidentification as $K^0_S \to \pi^+\pi^-$

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Signal BDT performance

	LL	LD	DD
Signal efficiency	$0.5961(23)$	$0.3032(13)$	$0.0467(5)$
Background rejection	$1.58(25) \times 10^{-5}$	$2.92(13) \times 10^{-5}$	$8.5(9) \times 10^{-6}$

Estimated signal yields

$$N_{B_s^0 \to K_S^0 K_S^0} = N_{B^0 \to \phi K_S^0} \cdot \frac{\varepsilon_{B_s^0 \to K_S^0 K_S^0}}{\varepsilon_{B^0 \to \phi K_S^0}} \cdot \frac{\mathcal{B}\left(B_s^0 \to K_S^0 K_S^0\right)}{\mathcal{B}(B^0 \to \phi K_S^0)} \cdot \frac{f_s}{f_d} \cdot \frac{\mathcal{B}\left(K_S^0 \to \pi^+\pi^-\right)}{\mathcal{B}(\phi \to K^+K^-)}$$

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Reference	$N_{B_s^0\to K_S^0K_S^0}$ (LL)	$N_{B_s^0\to K_S^0K_S^0}$ (LD)	$N_{B_s^0\to K_S^0K_S^0}$ (DD)
$N_{B^0\to\phi K_S^0}$	125 ± 25	240 ± 50	22 ± 4

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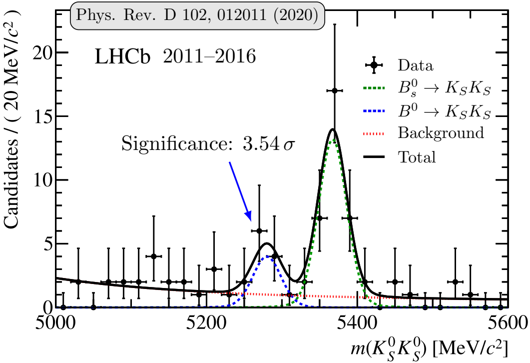

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$$N_{B_s^0 \to K_S^0 K_S^0}{}^{\text{prev, total}} = 32 \pm 4 \qquad \frac{\mathcal{B}(B_s^0 \to K_S^0 K_S^0)}{\mathcal{B}(B^0 \to \phi K_S^0)} = 2.3 \pm 0.5$$

Summary

- $\mathcal{B}\left(B^0_{(s)} \to K^0_\mathrm{S} K^0_\mathrm{S}\right)$ need more precise measurements
- Their selection efficiency at LHCb has greatly improved
- Good BDT performance for signal and normalization (LL and LD)
- Promising signal yield estimates and sensitivity to $B^0 \to K^0_\mathrm{S} K^0_\mathrm{S}$

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Future work:

- Apply trigger efficiency and other corrections
- Improve normalization mass fits
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Thank you!

Backup

Normalization $B^0 \to \phi K^0_\mathrm{S}$ selection

Trigger selection:

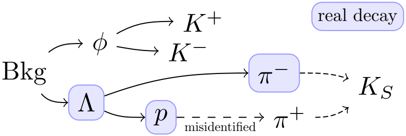
- `L0Hadron`, `L0Global_TIS`
- `Hlt1(Two)TrackMVA`, `Hlt1(Phi)IncPhi`
- `Hlt2Topo(2,3,4)Body`, `Hlt2(Phi)IncPhi`

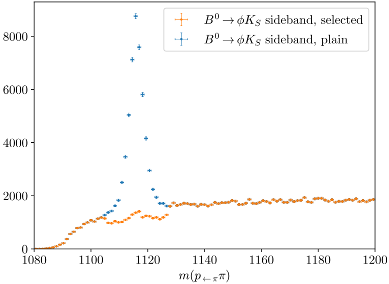
Loose selection:

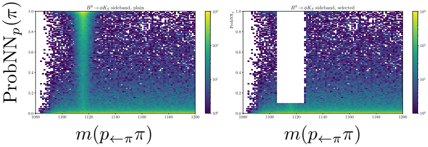
- B^0 DTF converged
- $\mathrm{ProbNN}_K(K^\pm) > 0.02$
- Veto on Λ misidentified as K^0_S: $\mathrm{ProbNN}_p(\pi) < 0.1$ within the Λ peak

Differences from the previous analysis:

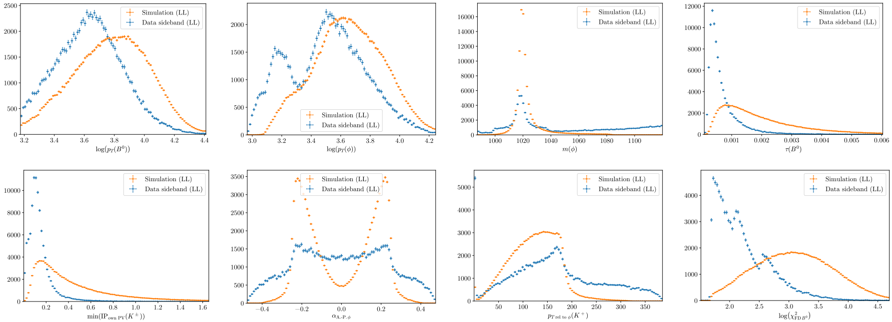
- No `isMuon` $=$ `False` requirement
- No $z_{K^0_\mathrm{S}} - z_{B^0} > 15$ mm cut

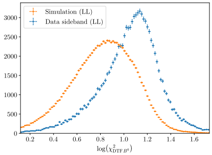






Normalization BDT variables (LL)



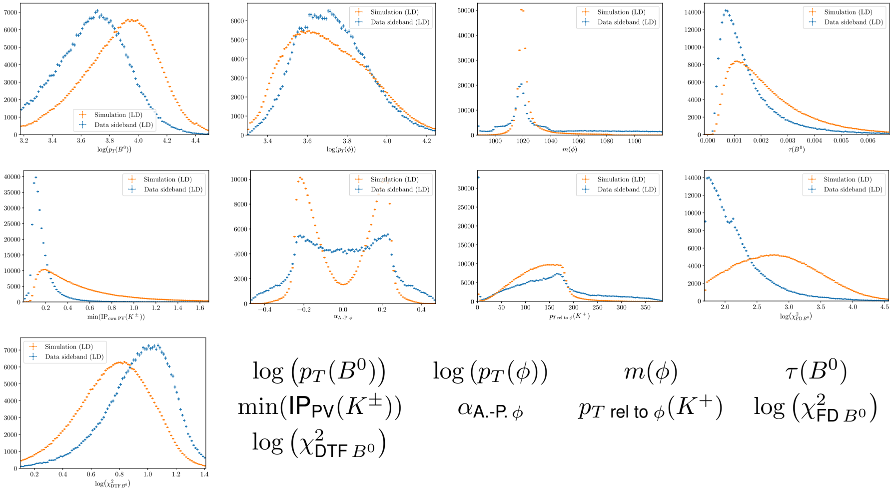


$\log\left(p_T(B^0)\right)$ $\log\left(p_T(\phi)\right)$ $m(\phi)$ $\tau(B^0)$

$\min(\text{IP}_{\text{PV}}(K^\pm))$ $\alpha_{\text{A.-P.}\,\phi}$ $p_{T\ \text{rel to}\ \phi}(K^+)$ $\log\left(\chi^2_{\text{FD}\ B^0}\right)$

$\log\left(\chi^2_{\text{DTF}\ B^0}\right)$

Normalization BDT variables (LD)



$\log\left(p_T(B^0)\right)$	$\log\left(p_T(\phi)\right)$	$m(\phi)$	$\tau(B^0)$
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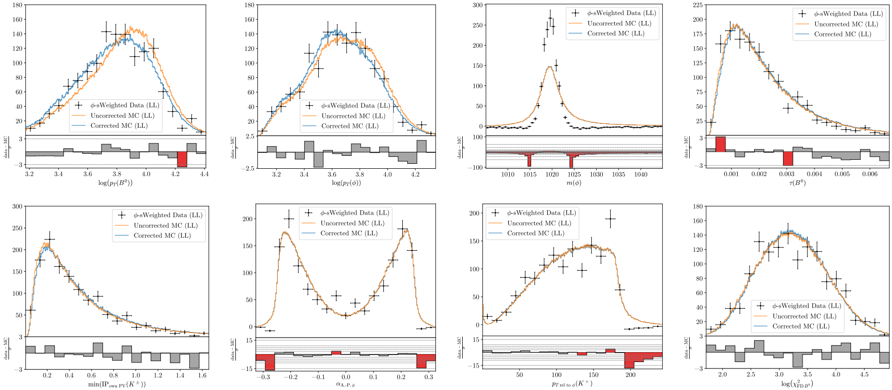

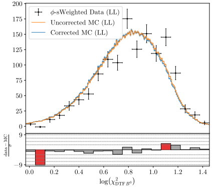

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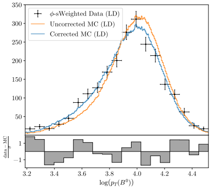
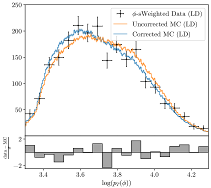
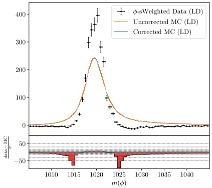
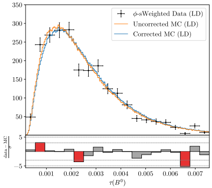
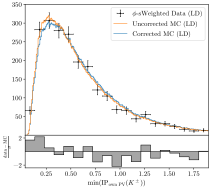
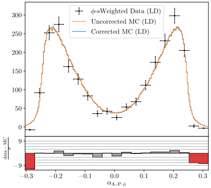


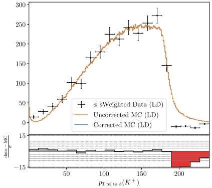


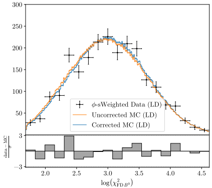


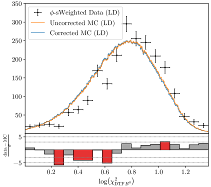












$\log\left(p_T(B^0)\right)$	$\log\left(p_T(\phi)\right)$	$m(\phi)$	$\tau(B^0)$
$\min(\text{IP}_{\text{PV}}(K^\pm))$	$\alpha_{\text{A.-P.}\,\phi}$	$p_{T\,\text{rel to}\,\phi}(K^+)$	$\log\left(\chi^2_{\text{FD}\,B^0}\right)$
$\log\left(\chi^2_{\text{DTF}\,B^0}\right)$			

Normalization BDT response

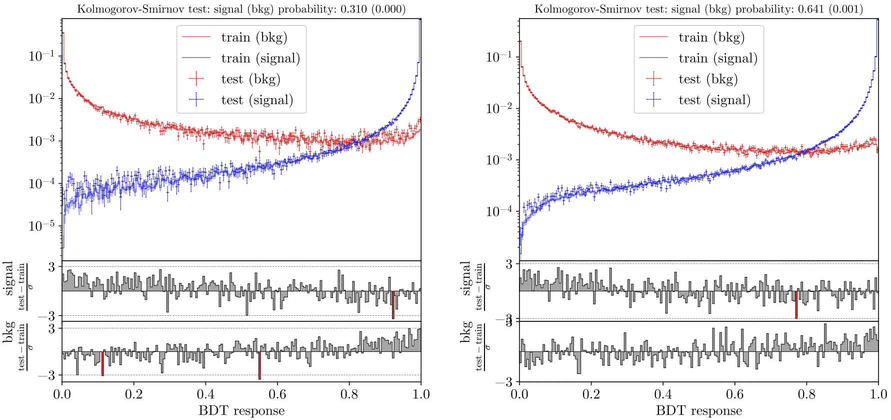
Bkg: $m_{B^0} > 5400$ MeV data

Signal: MC

9 variables

8-fold cross-validation

separate for LL, LD

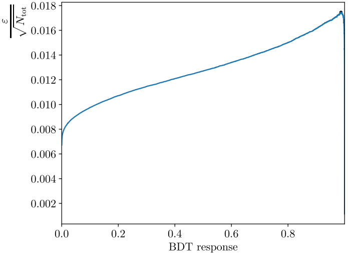


ROC AUC $= 0.99084$ (LL)

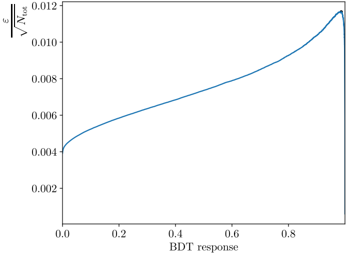
0.97985 (LD)

Normalization BDT cut

- $\mathcal{F} = \dfrac{\varepsilon_{\text{signal}}}{\sqrt{N_{\text{total}}}}$
- $\varepsilon_{\text{signal}}$: determined from MC
- N_{total}: taken directly from data – $m_{B^0} \in (5236, 5326)$ MeV – $3\,\sigma$ region



$\text{response}_{\text{LL}} > 0.98722\ldots$
$\varepsilon^{\text{LL}}_{\text{signal}} = 0.8205(5)$
$\varepsilon^{\text{LL}}_{\text{bkg}} = (2.17 \pm 0.08) \times 10^{-4}$



$\text{response}_{\text{LD}} > 0.98688\ldots$
$\varepsilon^{\text{LD}}_{\text{signal}} = 0.6930(4)$
$\varepsilon^{\text{LD}}_{\text{bkg}} = (4.65 \pm 0.11) \times 10^{-4}$

Normalization efficiency

Efficiency	2016 (prev)	2016	2017	2018
ε_{gen}	$0.1695(16)$	$0.27126(31)$	$0.27114(31)$	$0.27120(30)$
$\varepsilon_{\text{strip}}$	$0.008482(29)$	$0.008811(10)$	$0.009788(11)$	$0.008214(10)$
$\varepsilon^{\text{LL}}_{\text{topo}}$	$0.3146(16)$	$0.3337(6)$	$0.3071(5)$	$0.2965(5)$
$\varepsilon^{\text{LL}}_{\text{trigger}}$	$0.9290(16)$	$0.9136(6)$	$0.9219(6)$	$0.9157(6)$
$\varepsilon^{\text{LL}}_{\text{sel}}$	$0.9197(17)$	$0.98482(27)$	$0.98544(27)$	$0.98474(28)$
$\varepsilon^{\text{LL}}_{\text{bdt}}$	$0.7964(27)$	$0.8068(9)$	$0.8286(8)$	$0.8257(9)$
$\varepsilon^{\text{LD}}_{\text{topo}}$	$0.6854(16)$	$0.6663(6)$	$0.6929(5)$	$0.7035(5)$
$\varepsilon^{\text{LD}}_{\text{trigger}}$	$0.9203(11)$	$0.9086(4)$	$0.9160(4)$	$0.9123(4)$
$\varepsilon^{\text{LD}}_{\text{sel}}$	$0.9265(11)$	$0.98023(21)$	$0.98050(21)$	$0.97974(21)$
$\varepsilon^{\text{LD}}_{\text{bdt}}$	$0.5339(23)$	$0.6877(7)$	$0.6925(7)$	$0.6976(7)$
$\varepsilon^{\text{LL}}_{\text{strip, topo, trig}}$	$2.479(16)\times10^{-3}$	$2.687(6)\times10^{-3}$	$2.770(6)\times10^{-3}$	$2.230(5)\times10^{-3}$
$\varepsilon^{\text{LD}}_{\text{strip, topo, trig}}$	$5.350(23)\times10^{-3}$	$5.334(8)\times10^{-3}$	$6.213(9)\times10^{-3}$	$5.272(8)\times10^{-3}$
$\varepsilon^{\text{LL}}_{\text{total}}$	$2.96(4)\times10^{-4}$	$5.790(15)\times10^{-4}$	$6.134(17)\times10^{-4}$	$4.918(13)\times10^{-4}$
$\varepsilon^{\text{LD}}_{\text{total}}$	$4.53(5)\times10^{-4}$	$9.754(21)\times10^{-4}$	$1.1438(24)\times10^{-3}$	$9.771(20)\times10^{-4}$
	adjusted for ε_{gen}	$3.62(4)\times10^{-4}$	$3.83(4)\times10^{-4}$	$3.074(31)\times10^{-4}$
		$6.09(6)\times10^{-4}$	$7.15(7)\times10^{-4}$	$6.11(6)\times10^{-4}$

Signal $B_s^0 \to K_S^0 K_S^0$ selection

Trigger selection:

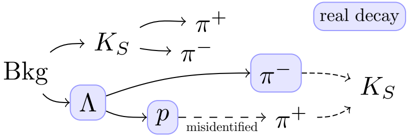
- `L0Hadron`, `L0Global_TIS`
- `Hlt1(Two)TrackMVA`, `Hlt1Phys_TIS`
- `Hlt2Topo(2,3,4)Body`, `Hlt2Hb2V0V0Hb2KSKS(LL,LD,DD)`

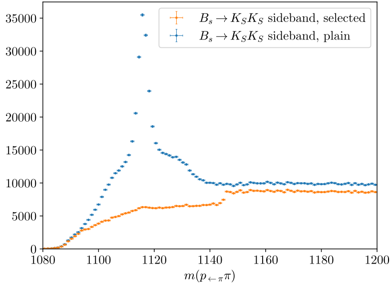
Loose selection:

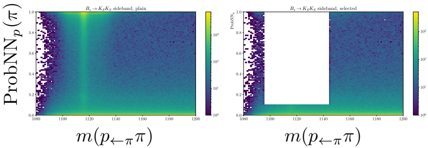
- Generator-level cuts on $p(B_s^0)$, $p(\pi)$, $p(K_S^0)$, $p_T(K_S^0)$
- B_s^0 DTF converged, $\chi^2_{\text{DTF } B_s^0} < 60$
- $\chi^2_{\text{IP } B_s^0} < 20$, $\tau(B_s^0) > 0$, $\tau(K_S^0) > 0$
- Veto on Λ misidentified as K_S^0: $\text{ProbNN}_p(\pi) < 0.1$ within the Λ peak

Differences from the previous analysis:

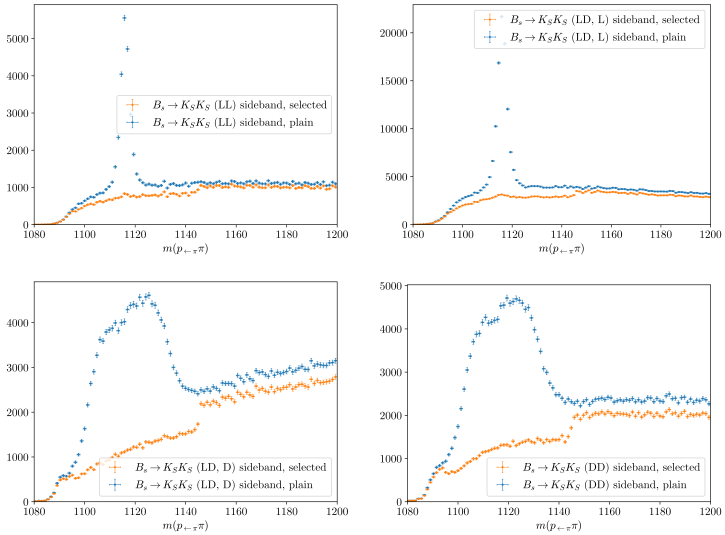
- No `isMuon` $=$ `False` requirement
- No $z_{K_S^0} - z_{B^0} > 15$ mm cut





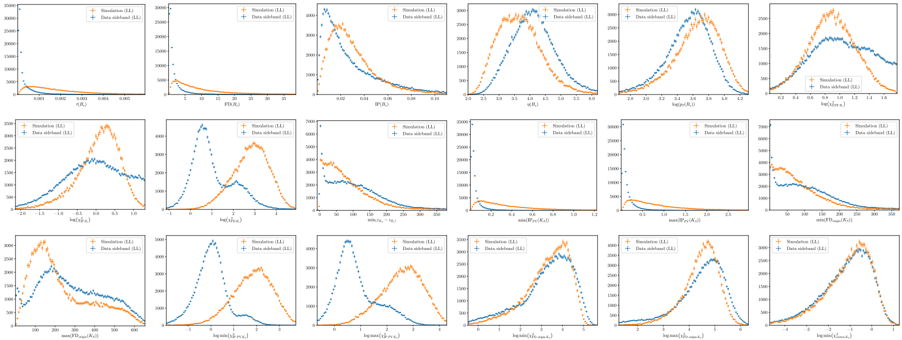


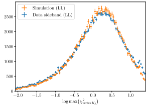
Signal selection: misreconstructed Λ veto



Veto efficiency: $0.96398^{+0.00025}_{-0.00026}$

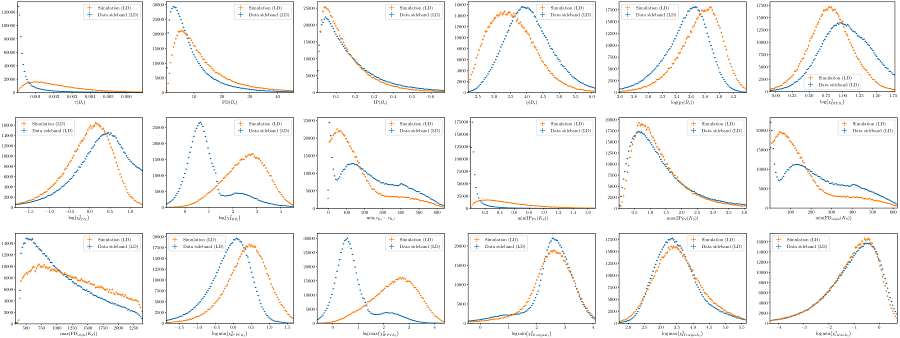
Signal BDT variables (LL)

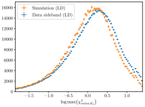




$\tau(B_s)$	$\mathsf{FD}(B_s)$	$\mathsf{IP}(B_s)$	$\eta(B_s)$	$\log\left(p_T(B_s)\right)$	$\log\left(\chi^2_{\mathsf{DTF}\ B_s}\right)$
$\log\left(\chi^2_{\mathsf{IP}\ B_s}\right)$	$\log\left(\chi^2_{\mathsf{FD}\ B_s}\right)$	$\min\left(z_{K^0_S} - z_{B_s}\right)$	$\min\left(\mathsf{IP}_{\mathsf{PV}}(K^0_S)\right)$	$\max\left(\mathsf{IP}_{\mathsf{PV}}(K^0_S)\right)$	$\min\left(\mathsf{FD}_{\mathsf{origin}}(K^0_S)\right)$
$\max\left(\mathsf{FD}_{\mathsf{origin}}(K^0_S)\right)$	$\log\min\left(\chi^2_{\mathsf{IP\ PV}\ K^0_S}\right)$	$\log\max\left(\chi^2_{\mathsf{IP\ PV}\ K^0_S}\right)$	$\log\min\left(\chi^2_{\mathsf{FD\ origin}\ K^0_S}\right)$	$\log\max\left(\chi^2_{\mathsf{FD\ origin}\ K^0_S}\right)$	$\log\min\left(\chi^2_{\mathsf{vertex}\ K^0_S}\right)$
$\log\max\left(\chi^2_{\mathsf{vertex}\ K^0_S}\right)$					

Signal BDT variables (LD)





$\tau(B_s)$
$\log\left(\chi^2_{\text{IP } B_s}\right)$
$\max\left(\text{FD}_{\text{origin}}(K^0_S)\right)$
$\log\max\left(\chi^2_{\text{vertex } K^0_S}\right)$

$\text{FD}(B_s)$
$\log\left(\chi^2_{\text{FD } B_s}\right)$
$\log\min\left(\chi^2_{\text{IP PV } K^0_S}\right)$

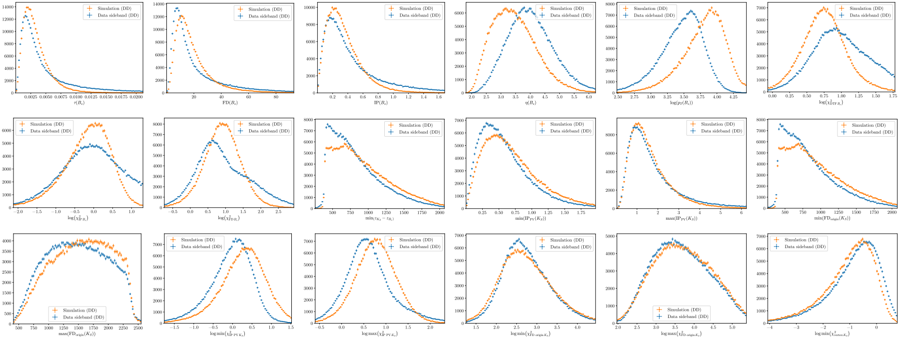
$\text{IP}(B_s)$
$\min\left(z_{K^0_S} - z_{B_s}\right)$
$\log\max\left(\chi^2_{\text{IP PV } K^0_S}\right)$

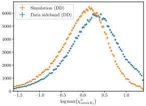
$\eta(B_s)$
$\min\left(\text{IP}_{\text{PV}}(K^0_S)\right)$
$\log\min\left(\chi^2_{\text{FD origin } K^0_S}\right)$

$\log\left(p_T(B_s)\right)$
$\max\left(\text{IP}_{\text{PV}}(K^0_S)\right)$
$\log\max\left(\chi^2_{\text{FD origin } K^0_S}\right)$

$\log\left(\chi^2_{\text{DTF } B_s}\right)$
$\min\left(\text{FD}_{\text{origin}}(K^0_S)\right)$
$\log\min\left(\chi^2_{\text{vertex } K^0_S}\right)$

Signal BDT variables (DD)



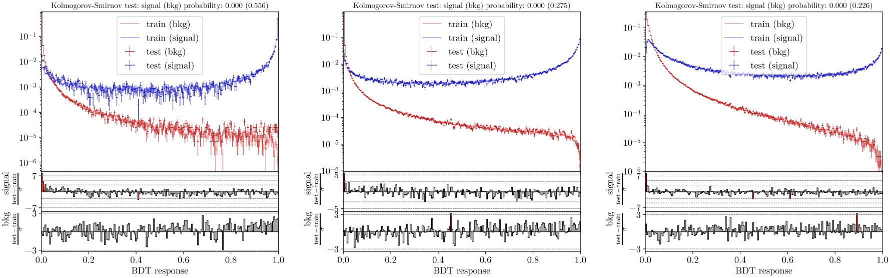


$\tau(B_s)$	$\mathrm{FD}(B_s)$	$\mathrm{IP}(B_s)$	$\eta(B_s)$	$\log\left(p_T(B_s)\right)$	$\log\left(\chi^2_{\mathrm{DTF}\ B_s}\right)$
$\log\left(\chi^2_{\mathrm{IP}\ B_s}\right)$	$\log\left(\chi^2_{\mathrm{FD}\ B_s}\right)$	$\min\left(z_{K^0_S} - z_{B_s}\right)$	$\min\left(\mathrm{IP}_{\mathrm{PV}}(K^0_S)\right)$	$\max\left(\mathrm{IP}_{\mathrm{PV}}(K^0_S)\right)$	$\min\left(\mathrm{FD}_{\mathrm{origin}}(K^0_S)\right)$
$\max\left(\mathrm{FD}_{\mathrm{origin}}(K^0_S)\right)$	$\log\min\left(\chi^2_{\mathrm{IP\ PV}\ K^0_S}\right)$	$\log\max\left(\chi^2_{\mathrm{IP\ PV}\ K^0_S}\right)$	$\log\min\left(\chi^2_{\mathrm{FD\ origin}\ K^0_S}\right)$	$\log\max\left(\chi^2_{\mathrm{FD\ origin}\ K^0_S}\right)$	$\log\min\left(\chi^2_{\mathrm{vertex}\ K^0_S}\right)$
$\log\max\left(\chi^2_{\mathrm{vertex}\ K^0_S}\right)$					

Signal BDT response

Bkg: $m_{B^0_s} > 5450$ MeV data   Signal: MC

19 variables   8-fold cross-validation   separate for LL, LD, DD

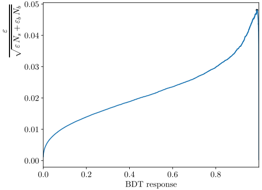


ROC AUC $= 0.98976$ (LL) 0.9795 (LD) 0.8962 (DD)

- A bit of overtraining is observed
- BDT for LD and especially DD has to be improved

Signal BDT cut

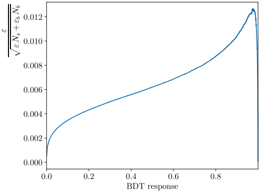
- $\mathcal{F} = \dfrac{\varepsilon_{\text{signal}}}{\sqrt{N_{\text{total, est}}}} = \dfrac{\varepsilon_{\text{signal}}}{\sqrt{N_{\text{signal, est}}\,\varepsilon_{\text{signal}} + N_{\text{bkg}}\,\varepsilon_{\text{bkg}}}}$
- $N_{\text{signal, est}} = N_{B^0\to\phi K^0_S} \dfrac{\varepsilon^{\text{before BDT}}_{B^0_s\to K^0_S K^0_S}}{\varepsilon_{B^0\to\phi K^0_S}} \times \dfrac{\mathcal{B}(B^0_s\to K^0_S K^0_S)}{\mathcal{B}(B^0\to\phi K^0_S)}\, \dfrac{f_s}{f_d}\, \dfrac{\mathcal{B}(K^0_S\to\pi^+\pi^-)}{\mathcal{B}(\phi\to K^+K^-)}$
- ε_{bkg} – background rejection rate for $m_{B^0_s} > 5450$ MeV data
- N_{bkg} – total number of events from data before the BDT within $3\,\sigma$ of B^0_s



response$_{\text{LL}} > 0.9911\ldots$

$\varepsilon^{\text{LL}}_{\text{signal}} = 0.5961(23)$

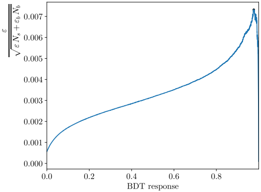
$\varepsilon^{\text{LL}}_{\text{bkg}} = (1.58^{+0.25}_{-0.22}) \times 10^{-5}$



response$_{\text{LD}} > 0.9759\ldots$

$\varepsilon^{\text{LD}}_{\text{signal}} = 0.3032(13)$

$\varepsilon^{\text{LD}}_{\text{bkg}} = (2.92\pm0.13)\times10^{-5}$



response$_{\text{DD}} > 0.9767\ldots$

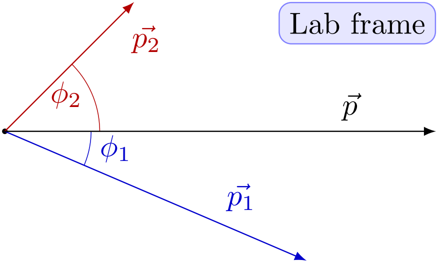
$\varepsilon^{\text{DD}}_{\text{signal}} = 0.0467(5)$

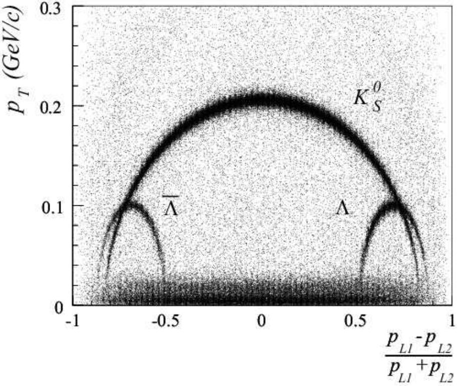
$\varepsilon^{\text{DD}}_{\text{bkg}} = (8.5^{+1.0}_{-0.9}) \times 10^{-6}$

Signal efficiency

Efficiency	2016 (prev)	2016	2017	2018
ε_{gen}	$0.1585(4)$	$0.15878(20)$	$0.15864(20)$	$0.15859(20)$
$\varepsilon_{\text{strip}}$	$0.01245(5)$	$0.019101(21)$	$0.019711(21)$	$0.019753(21)$
$\varepsilon^{\text{LL}}_{\text{topo}}$	$0.1799(17)$	$0.1133(4)$	$0.11070(34)$	$0.11034(34)$
$\varepsilon^{\text{LL}}_{\text{trigger}}$	$0.1069(32)$	$0.1082(10)$	$0.3039(15)$	$0.2445(14)$
$\varepsilon^{\text{LL}}_{\text{sel}}$	$0.715(14)$	$0.9264(27)$	$0.9544(12)$	$0.9500(15)$
$\varepsilon^{\text{LL}}_{\text{bdt}}$	$0.598(4)$	$0.690(5)$	$0.5517(30)$	$0.5519(34)$
$\varepsilon^{\text{LD}}_{\text{topo}}$	$0.7285(20)$	$0.4702(6)$	$0.4678(5)$	$0.4671(5)$
$\varepsilon^{\text{LD}}_{\text{trigger}}$	$0.0698(13)$	$0.0700(4)$	$0.3181(7)$	$0.2586(7)$
$\varepsilon^{\text{LD}}_{\text{sel}}$	$0.772(8)$	$0.9131(18)$	$0.9408(7)$	$0.9388(8)$
$\varepsilon^{\text{LD}}_{\text{bdt}}$	$0.2295(21)$	$0.4073(32)$	$0.2467(12)$	$0.2597(14)$
$\varepsilon^{\text{DD}}_{\text{topo}}$	–	$0.4164(6)$	$0.4215(5)$	$0.4226(5)$
$\varepsilon^{\text{DD}}_{\text{trigger}}$	–	0.0 ± 0.0	$0.3417(8)$	$0.2838(8)$
$\varepsilon^{\text{DD}}_{\text{sel}}$	–	0.0 ± 0.0	$0.9471(6)$	$0.9448(7)$
$\varepsilon^{\text{DD}}_{\text{bdt}}$	–	0.0 ± 0.0	$0.0642(7)$	$0.0719(8)$
$\varepsilon^{\text{LL}}_{\text{strip, topo, trig}}$	$2.40(8) \times 10^{-4}$	$2.342(24) \times 10^{-4}$	$6.63(4) \times 10^{-4}$	$5.328(35) \times 10^{-4}$
$\varepsilon^{\text{LD}}_{\text{strip, topo, trig}}$	$6.33(12) \times 10^{-4}$	$6.29(4) \times 10^{-4}$	$2.933(8) \times 10^{-3}$	$2.385(7) \times 10^{-3}$
$\varepsilon^{\text{DD}}_{\text{strip, topo, trig}}$	–	0.0 ± 0.0	$2.839(8) \times 10^{-3}$	$2.369(7) \times 10^{-3}$
$\varepsilon^{\text{LL}}_{\text{total}}$	$1.62(6) \times 10^{-5}$	$2.377(31) \times 10^{-5}$	$5.54(5) \times 10^{-5}$	$4.43(4) \times 10^{-5}$
$\varepsilon^{\text{LD}}_{\text{total}}$	$1.78(4) \times 10^{-5}$	$3.71(4) \times 10^{-5}$	$1.080(6) \times 10^{-4}$	$9.22(6) \times 10^{-5}$
$\varepsilon^{\text{DD}}_{\text{total}}$	–	0.0 ± 0.0	$2.738(32) \times 10^{-5}$	$2.553(31) \times 10^{-5}$

Armenteros-Podolanski variables and plot





For $\phi \to K^+ K^-$:

$$p_1 \sin\phi_1 = p_2 \sin\phi_2 = p_{T\,\text{rel to}\,\phi}(K^+)$$

$$\frac{p_1 \cos\phi_1 - p_2 \cos\phi_2}{p_1 \cos\phi_1 + p_2 \cos\phi_2} = \alpha_{\text{A.-P.}\,\phi}$$

[arXiv:0802.2160]