Study of $B_s^0 \to K_S^0 K_S^0$ with Run 3

Update

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Estimated 2025 yield from 2018 $B_s^0 \to K_S^0 K_S^0$

Scaling of the expected yield

$$N_{2025} = N_{2018} \times \frac{\mathcal{L}_{2025}}{\mathcal{L}_{2018}} \times \frac{\sigma_{2025}}{\sigma_{2018}} \times \frac{\varepsilon_{2025}}{\varepsilon_{2018}}$$

- Expected 2018 yields (Kerim): 92 (LL), 174 (LD)
- Integrated luminosity: $\mathcal{L}_{2025} = 11.8\,\text{fb}^{-1}$ $\quad \mathcal{L}_{2018} = 2.19\,\text{fb}^{-1}$

Trigger efficiencies

2018: $\varepsilon_{2018} = \varepsilon_{L0} \times \varepsilon_{HLT1} \times \varepsilon_{HLT2}$

	LL	LD
ε_{2018}	0.158	0.108

Run 3 (2025):

- L0 removed,
- HLT1, HLT2 $\sim 60\%$ each (simulation) $\Rightarrow \varepsilon_{2025} \approx 0.36$

Estimated 2025 yield from 2018 $B_s^0 \to K_S^0 K_S^0$

Estimated 2025 yields

$$N_{2025}^{LL} = 92 \times \frac{11.8}{2.19} \times \frac{0.36}{0.16} \approx 1.1 \times 10^3$$

$$N_{2025}^{LD} = 174 \times \frac{11.8}{2.19} \times \frac{0.36}{0.11} \approx 3.1 \times 10^3$$

Total expected yield after sprucing: $N_{2025}^{tot} \sim 4 \times 10^3$

To be refined with updated trigger efficiencies, precise cross-section ratio and systematic uncertainties.

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Sample preparation

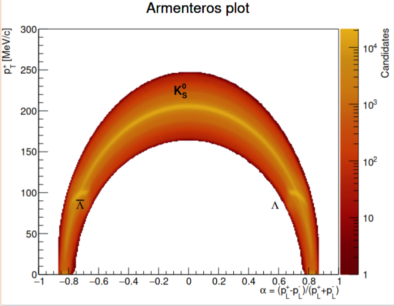
Tuple processing

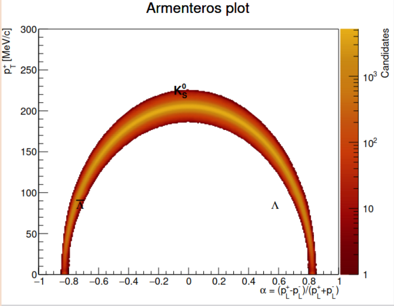
- All samples re-tupled file-by-file
- Removed all preselection cuts except:
  - Passing HLT2 track lines
  - Explicit removal of possible contamination from $\Lambda \to p\pi$ decays in the K_S^0 sample
- Some branches skimmed to reduce size (may need to be restored for further studies)

Armenteros–Podolanski validation

Results

- Before selection: visible Λ and $\bar{\Lambda}$ bands $\Rightarrow$ small but non-negligible contamination
- After veto: structures effectively removed





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Fisher discriminant method

Idea

Project multi-dimensional variables x onto one axis to maximize separation between signal and background:

$$y = w^T x = \sum_i w_i x_i$$

Optimal weights

Maximize the Fisher criterion:

$$J(y) = \frac{(\mu_S - \mu_B)^2}{\sigma_S^2 + \sigma_B^2}, \quad w \propto W^{-1}(m_S - m_B), \; W = \Sigma_S + \Sigma_B$$

- Shifts axes to maximize signal vs background separation relative to width
- Computationally cheap
- Pre-selection before finer MVA

Training variables

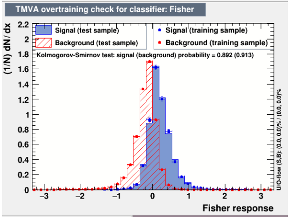
Input variables

Variable	Description
$IP\chi^2(B_s)$	Impact parameter significance of B_s
$p_T(B_s)$	Transverse momentum of B_s
$\max(IP\chi^2(V_1), IP\chi^2(V_2))$	Max IPχ^2 of K_S daughters
$\min(p_T(V_1), p_T(V_2))$	Min p_T of K_S daughters
$\max(\chi^2_{vtx}(V_1), \chi^2_{vtx}(V_2))$	Max vertex χ^2 of K_S
min(p_T of daughter tracks)	Min daughter p_T
max($IP\chi^2$ of daughter tracks)	Max daughter IPχ^2
$DIRA(B_s)$	B_s flight direction angle
χ^2_{DTF}	DTF chi2 with K_S mass constraint
$FD\chi^2(B_s)$	Flight distance significance of B_s
$FD(V_1), FD(V_2)$	Flight distance of K_S
$IP(B_s), IP(V_1), IP(V_2)$	Impact parameters

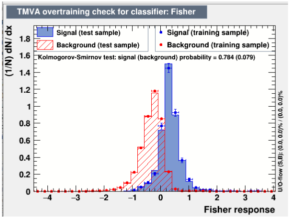
Notes

- Fisher selection tuned to keep $\sim 90\%$ of signal, applied to LLDD and LLLL samples

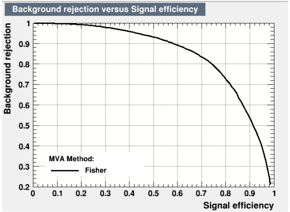
Fisher selection performance



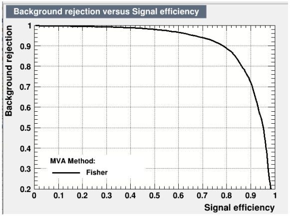
LLDD overtraining



LLLL overtraining



LLDD ROC curve



LLLL ROC curve

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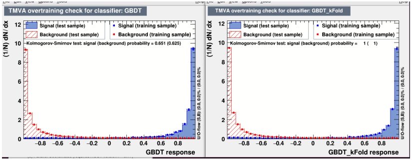
Gradient Boosted Decision Tree (GBDT)

Method

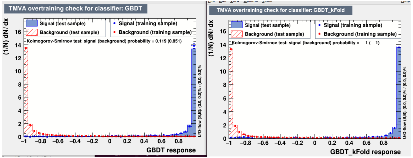
- GBDT trained with 8-fold cross-validation
- Tuned to keep $\sim 90\%$ of signal
- Input variables:

Variable	Description
$\log_{10} IP\chi^2(B_s)$	Impact parameter significance
$\log_{10} FD\chi^2(B_s)$	Flight distance significance
$FD(B_s)$	B_s flight distance
$\max(p_T$ of daughter tracks$)$	max daughter p_T
$\min(IP$ of daughters$)$	min daughter IP
$\log_{10}\min(IP\chi^2(V_1), IP\chi^2(V_2))$	min K_S IP χ^2
$\log_{10}\min(FD\chi^2(V_1), FD\chi^2(V_2))$	min K_S FDχ^2
$\min(FD(V_1), FD(V_2))$	min K_S flight distance
$\eta(V_1), \eta(V_2)$	pseudorapidities
$\min(p_T(V_1), p_T(V_2))$	min K_S p_T
$\log_{10} p_T(B_s)$	log10 B_s p_T
$\min(IP(V_1), IP(V_2))$	min K_S IP
$\tau(B_s)$	B_s Proper lifetime
$DIRA(B_s)$	Flight direction angle
$\log_{10}\max(IP\chi^2(V_1), IP\chi^2(V_2))$	max K_S IPχ^2

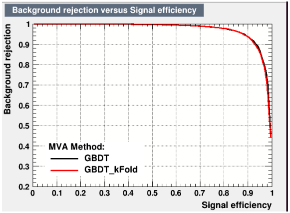
BDT performance



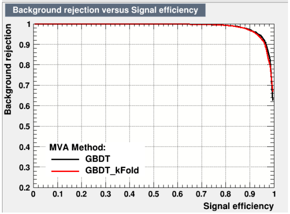
LLDD BDT output



LLDD BDT output

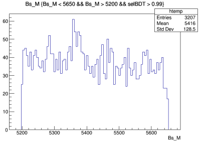


LLDD BDT ROC curve

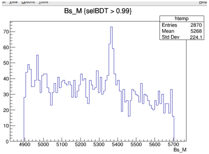


LLLL ROC curve

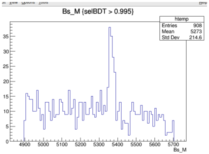
BDT selection with 25c1 sprucing campaign



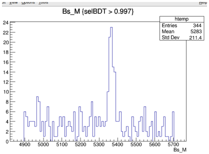
LLDD BDT > 0.99



LLLL BDT > 0.99



LLLL BDT > 0.995



LLLL BDT > 0.997

Observations

- Peak is visible, selection works
- Some partially reconstructed backgrounds remain
- Noticed 25c1 sprucing limited to < 5700 MeV

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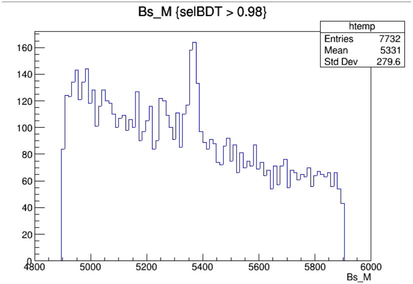
25c4 sprucing and mass spectra

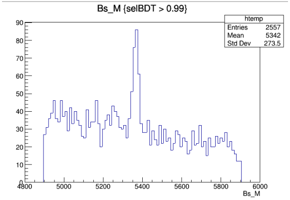
Motivation

The 25c4 sprucing extends up to 5900 MeV. More detailed contributions appear, requiring a reconfigured selection.

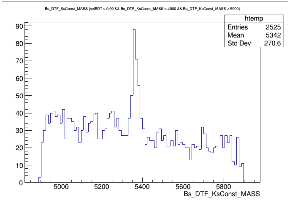


Mass spectrum with selection > 0.98

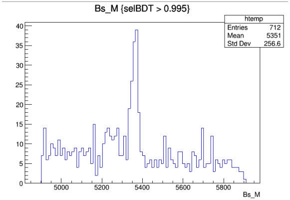
Mass spectra for tighter BDT selections



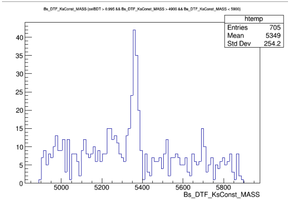
BDT > 0.99



BDT > 0.99 (K_S-constrained)



BDT > 0.995



BDT > 0.995 (K_S-constrained)

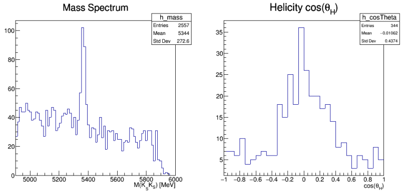
Check of 5700-5900 MeV region

Method

For events with $M(K_S K_S) \in [5700, 5900]$ MeV:

- Boosted $K_S K_S$ system to its CM
- Compute $\cos\theta_H = \hat{p}_{K_S} \cdot \hat{p}_{B_s}$ in CM
- Fill helicity histogram to check angular structure

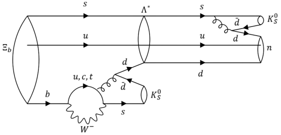
Helicity distribution shows approximate $\sin^2\theta$ behavior, suggests spin-1 partially reconstructed contribution ?



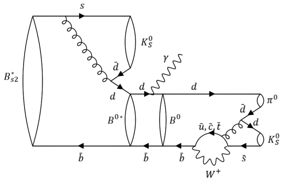
Partially reconstructed background hypotheses

Possible contributions

- $B_s \to K^{*0}(\to K_S \pi^0) K_S$ (trivial)
- $B_s \to D^0 K_S$, $B^- \to D^- K_S$?
- Λ_b decays with missing neutron ?
- $\Xi_b \to \Lambda^*(\to K_S n) K_S$? (requires modeling, unknown BR)
- Possible Ω_b misreconstruction peaking at 5800 MeV ?
- $B^*_{sc2} \to K^0_S K^0_S X$? $BR \approx 0.5 \times BR(B_s \to K_S K_S)$



$\Xi_b \to \Lambda^* K_S$



$B^*_{sc2} \to K_S K_S X$

To-do list

- Check 25c2 and 25c3 sprucing campaigns (currently have general DPA problem)
- Switch to Extreme Gradient Boosting for efficiency gains
- Identify partially reconstructed backgrounds, especially heavy contributions
- Perform preliminary mass fits
- Isolate normalization channel
- Continue the implementation of the binning scheme optimization method into PIDCalib2 (WIP)

Thank you for your attention!

Questions?

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