Study of $B^0 \to K_S^0 K_S^0$ decay at Belle II

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Motivation

- The decay of $B^0 \to K^0\overline{K}^0$ has been previously studied by BaBar [1] and Belle [2][3].
- Recent result from Belle based on 772×10⁶ $B\overline{B}$ pairs collected at the $\Upsilon(4S)$ resonance [3]:

$$\mathcal{B}(B^0 \to K^0\overline{K}^0) = 1.26 \pm 0.19\,(\text{stat}) \pm 0.05\,(\text{syst}) \times 10^{-6}$$

- With the data sample collected by the Belle II experiment, we can update the result of branching fraction of $B^0 \to K_S^0 K_S^0$.

[1] Y. T. Duh et al. (Babar Collaboration), Phys. Rev. Lett. 95.221801(2006).
[2] S.-W. Lin et al. (Belle Collaboration), Phys. Rev. Lett. 98, 181804 (2007).
[3] B. Aubert et al. (Belle Collaboration), Phys. Rev. D 87.031103(2013).

Analysis Strategy and Datasets

- We reconstruct the decay mode $B^0 \to K_S^0 K_S^0$, followed by the decay $K_S^0 \to \pi^+\pi^-$.
- We use the Belle II analysis software framework (BASF2) to reconstruct the events.

- signal MC sample
  - 100000 signal MC events are generated using EvtGen.
  - The $B^0 \to K_S^0 K_S^0$ is generated from SSS_CP model with the value of the CKM angle 0, and $K_S^0 \to \pi^+\pi^-$ decays are generated with PHSP model.
  - Charged-conjugate modes are implicitly assumed.

- generic MC sample
  - official Belle II MC16rd generic MC sample (>85%)
    - corresponds to approximately four times of the real data

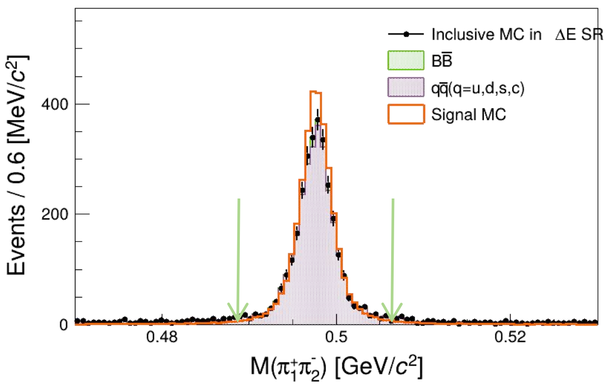
Pre Selection Criteria

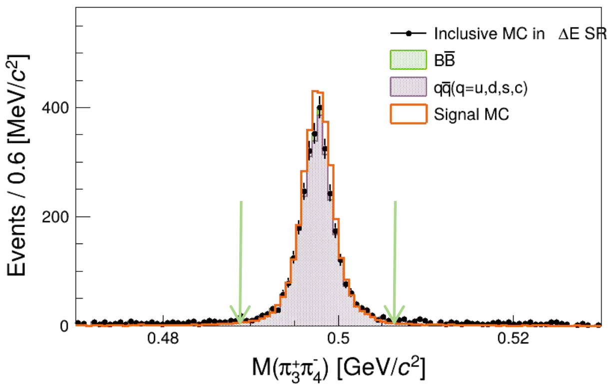
$\mathrm{K_S^0} \to \pi^+\pi^-$

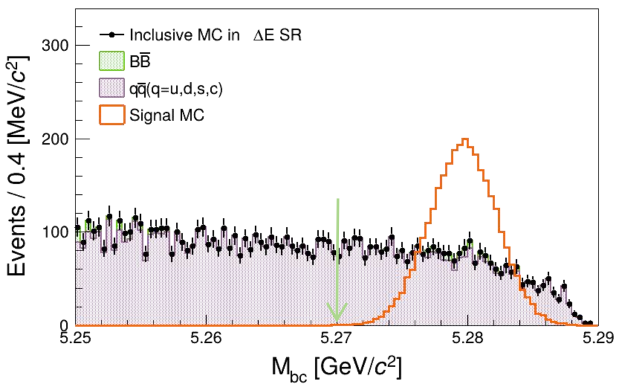
- stdKshorts: KFit, prioritiseV0=True
- ksSelector: Ks particleList:‘loose’
- $|M(K_S^0) - \mathrm{m}(K_S^0)| <$ 10.3 MeV/c^2 (~3σ)

$\mathrm{B^0} \to \mathrm{K_S^0 K_S^0}$

- $M_{bc} >$ 5.27 GeV/c^2
- reject events with NaN in qrGNN
- treeFit with K_S^0 mass constraint







buildRestOfEvent (for continuum suppression)

- cleanMask: dr < 0.5 and abs(dz) < 3 (track cuts), E > 0.05 (cluster cuts)

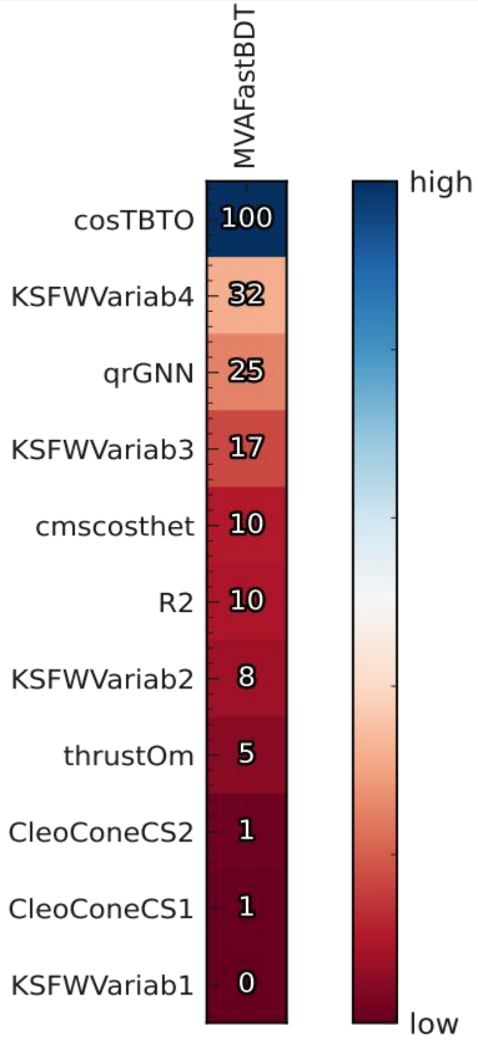
BDT

➢ MC sample sizes: Train / Test sample = 3/1

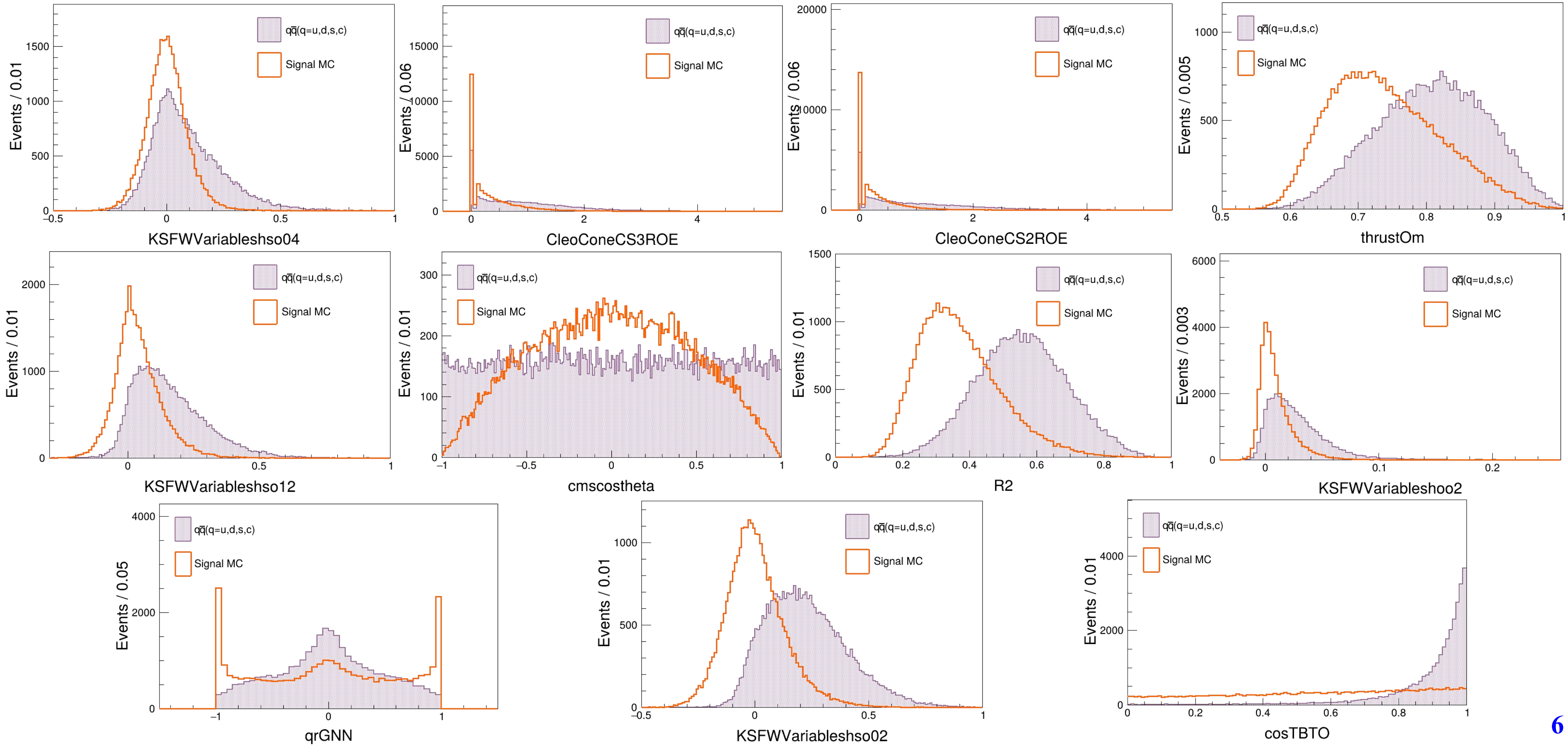
	Train	Test
Signal	23079 events	7693 events
Background	23079 events	7693 events

➢ BDT model

- general_options.m_target_variable = "isSignal"
- fastbdt_options = basf2_mva.FastBDTOptions()
- fastbdt_options.m_nTrees = 100
- fastbdt_options.m_nCuts = 8
- fastbdt_options.m_shrinkage = 0.1
- fastbdt_options.m_nLevels = 2
- 11 input variables and their corresponding importance



Variables in BDT



Performance of BDT

- ➢ Kolmogorov–Smirnov test
- • Signal Sample

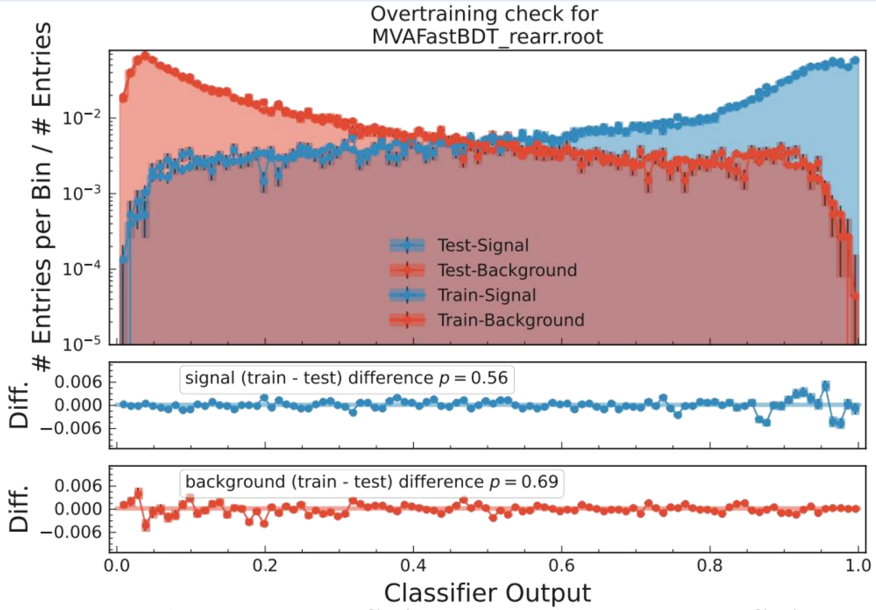
  KS statistic: 0.0079

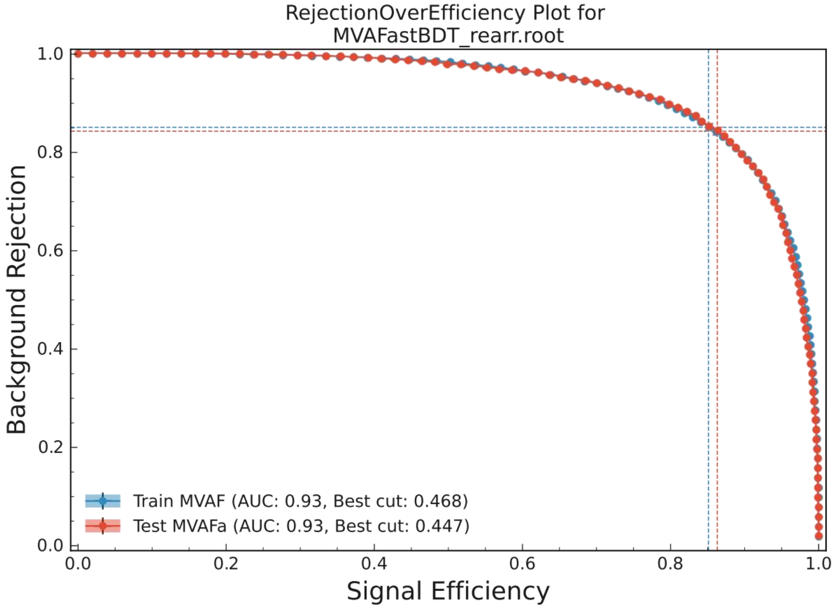
  KS probability: $0.86269 > 0.05$
- • Background Sample

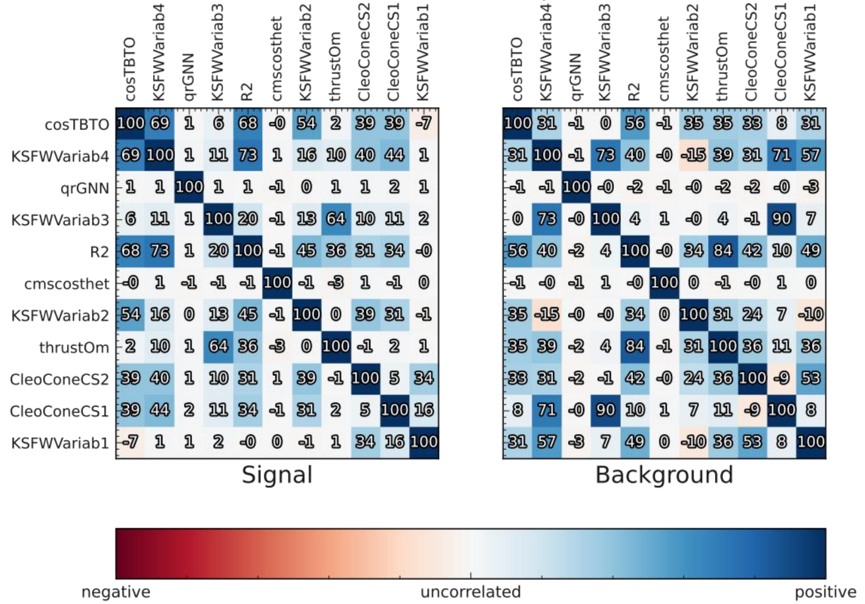
  KS statistic: 0.0072

  KS probability: $0.92097 > 0.05$

No significant overtraining

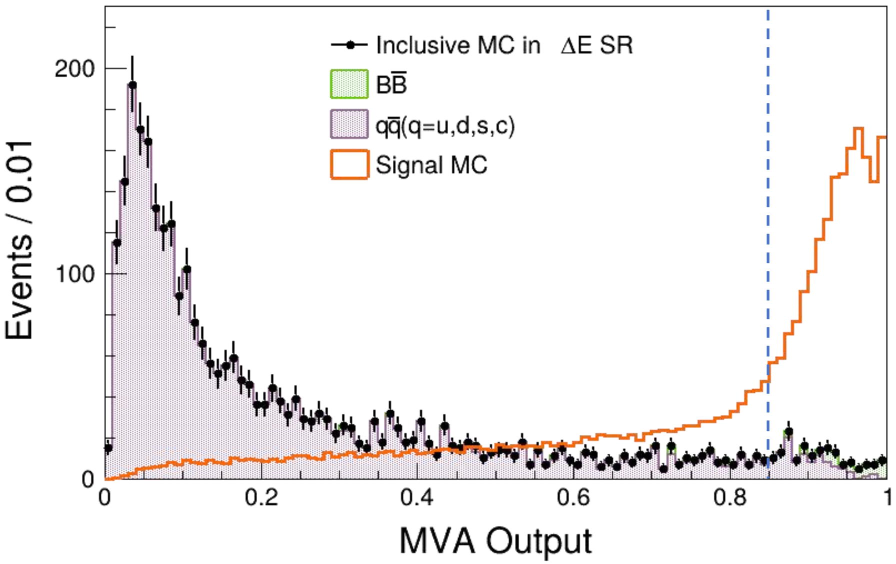


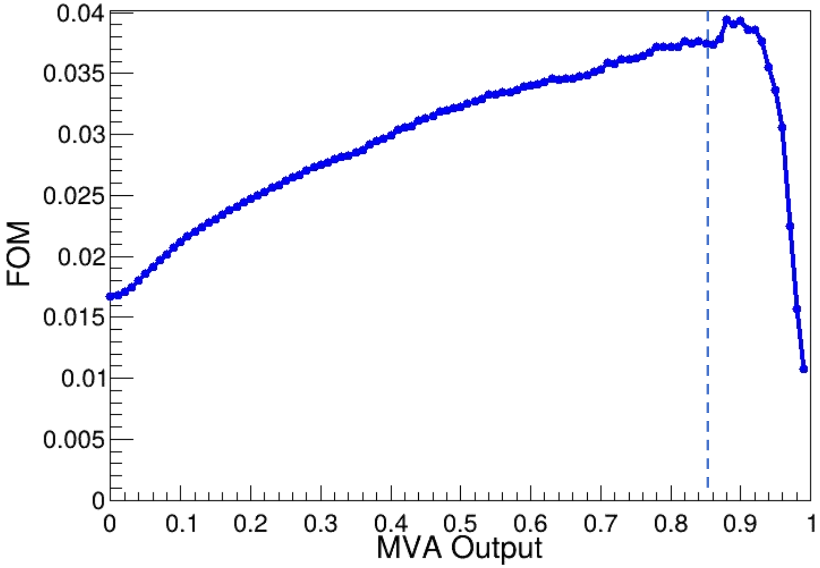




Requirement on MVA score

- The score of MVA-based suppression are optimized by maximizing the Punzi figure-of-merit FOM= $\varepsilon/(5/2+\sqrt{N_b})$, where ε is the signal reconstruction efficiency and N_b is the number of background events in the ΔE signal region.





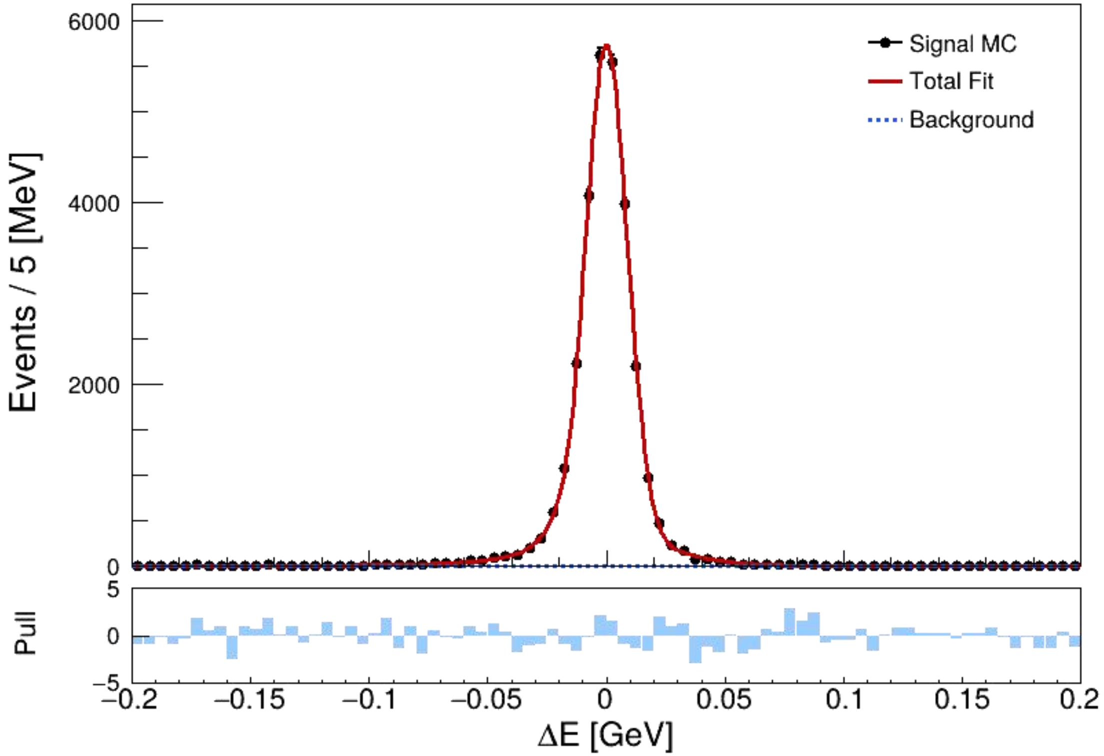
Requirements on the BDT output								
	>0	>0.5	>0.6	>0.7	>0.8	>0.85	>0.9	>0.95
signal events	112	91	82	78	64	60	51	29
continuum events [Fraction of continuum events]	31211 (99.27%)	4371 (95.88%)	3145 (94.84%)	2195 (93.21%)	1375 (90.88%)	948 (88.43%)	443 (80.99%)	80 (57.97%)
signal efficiency	50.51%	42.45%	39.83%	36.53%	32.27%	29.01%	23.28%	12.92%

Score > 0.85 for further analysis.

Fit For Signal Extraction

An unbinned maximum likelihood fit is performed to the ΔE distributions from signal MC sample.

- signal shape: a double-sided Crystal Ball function.
- background shape: a first-order Chebyshev polynomial.



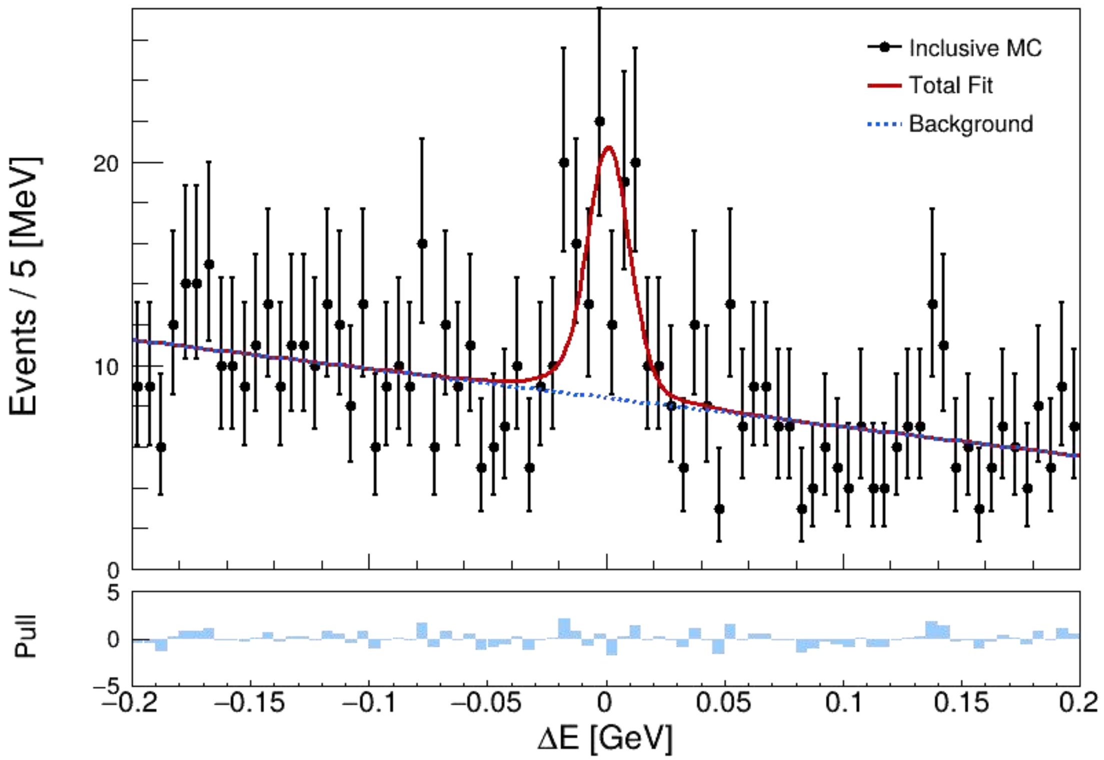
$N_{fit} = 2.8491e{+}04$

$N_{gen} = 96839$

$\varepsilon = 29.42\%$

resolution $= 0.0129703$

Fit of the Generic MC



$N_{\mathrm{fit}} = 61 \pm 12$

$N_{\mathrm{truth}} = 60$

$N_{B^0\bar{B}^0}$=[(520.6)×10⁶/490]*1927*0.483122645=9.89*10⁸

$\varepsilon = 29.42\%;\ \varepsilon \times \mathcal{B}_s = 14.06\%$

$\mathcal{B}(\mathrm{K_S^0} \to \pi^+\pi^-)(\text{MC input}) = 0.691321852$

$$\mathcal{B}(\mathrm{B^0} \to \mathrm{K_S^0K_S^0})(\mathrm{Fit}) = \frac{\mathrm{N_{sig}}}{\varepsilon \times \mathcal{B}(\mathrm{K_S^0} \to \pi^+\pi^-)^2 \times N_{B^0\bar{B}^0} \times 2}$$

$$\delta\mathcal{B}(\mathrm{B^0} \to \mathrm{K_S^0K_S^0})(\mathrm{Fit}) = \frac{\sigma_{\mathrm{sig}}}{\varepsilon \times (\mathrm{K_S^0} \to \pi^+\pi^-)^2 \times N_{B^0\bar{B}^0} \times 2}$$

$\mathcal{B}(\mathrm{B^0} \to \mathrm{K_S^0K_S^0})(\mathrm{Fit}) = (2.19 \pm 0.43) \times 10^{-7}$

$\mathcal{B}(\mathrm{B^0} \to \mathrm{K_S^0K_S^0})(\mathrm{MC}\ input) = 2.40 \times 10^{-7}$

Belle result: $\mathrm{N_{sig}} = 103 \pm 15;\ \varepsilon \times \mathcal{B}_s = 10.61\%$

$\mathcal{B}(\mathrm{B^0} \to \mathrm{K_S^0K_S^0})(\mathrm{Belle}) = \frac{1}{2} \times \mathcal{B}(\mathrm{B^0} \to K^0\bar{K}^0) = (6.3 \pm 0.95) \times 10^{-7}$

$K^0\bar{K}^0 \to K_S^0K_S^0 = 50\%$

The decay $B^0 \to K^0\bar{K}^0$ proceeds in an s wave, which produces equal fractions of $K_S^0K_S^0$ and $K_L^0K_L^0$, but no $K_S^0K_L^0$, neglecting CP violation in the kaon system.

Summary and Outlook

Summary

- The results are consistent with the input from generic MC samples.

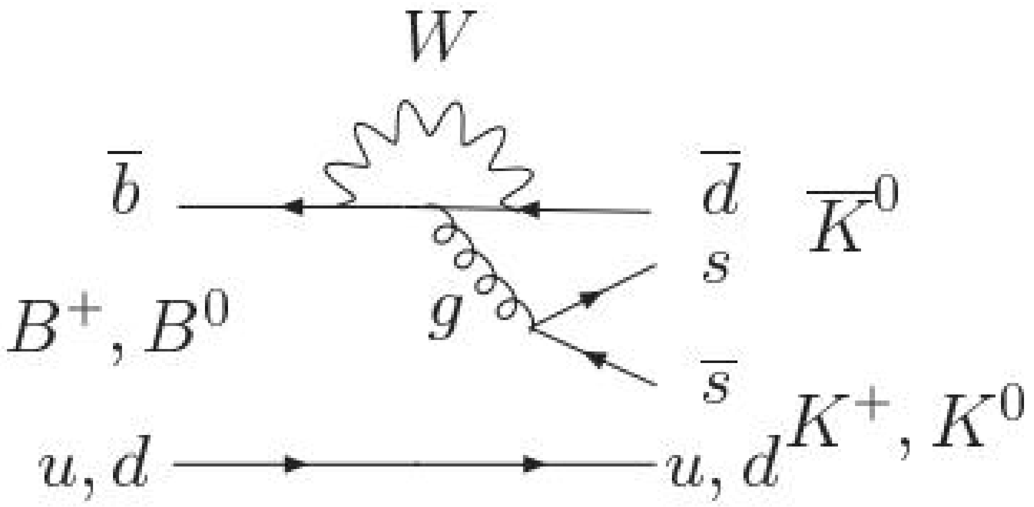
Plan

- [ ] Complete the I/O check
- [ ] Estimate systematic uncertainties
- [ ] Prepare the note

Back up

The $b \to d$ penguin diagram for $B^0 \to \overline{K}^0 K^0$

$B^0 \to K^0 \overline{K}^0$ decay is expected to be dominated by the $b \to dg$ $(g \to s\bar{s})$ penguin diagram.



input variables for the fastBDT model

- qrGNN: Here q means flavor, and r is the so-called dilution factor. Returns -1 (1) if current RestOfEvent is related to a anti-B0 (B0).
- R2: reduced Fox-Wolfram R2, defined as ratio of the i-th to the 0-th order Fox Wolfram moments
- cosTBTO: cosine of angle between thrust axis of the signal B and thrust axis of ROE
- thrustOm: magnitude of the ROE thrust axis
- thrustBm: magnitude of the signal B thrust axis
- cosTheta: momentum cosine of polar angle
- KSFWVariables: KSFW moments
- CleoConeCS(i,ROE) i-th cleo cones from the continuum suppression, calculated only from ROE particles.