$B^0 \to \tau^+\tau^-$ with hadronic FEI

Signal MC study: Pre-selection

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Strategy

- Strategy [BU06, 07, 08]
  - Follow the way of the **unpublished** Belle note by M. Ziegler (**BN-1390**)
    - Why is this note not published? (my guess)
      - Too big Branching Fraction?!
        - $(4.39^{+0.80}_{-.083} \pm 0.45) \times 10^{-3}$ (cf. SM prediction: $(2.22 \pm 0.19) \times 10^{-8}$ *)
  - Add other (better) method based on Belle / Belle II differences

※ [Backup slides] BU06: Analysis Procedure, BU07: Motivation Part I, BU08. Motivation Part II

※ *: Christoph Bobeth et al., "$B_{s,d} \to l^+ l^-$ in the Standard Model with Reduced Theoretical Uncertainty", PRL (2014)

Basic Information

MC Sample Info.

- MC Samples [BU04]
  - Signal
    - $B^0 \to \tau\tau$, 20 M generated
      - BGx0: 4 M (0.2)
      - BGx1: **16 M** (0.8)
    - Only BGx1 sample is used
      - skimmed with hadronic FEI
  - Background: MC14ri_a, $\Upsilon(4S)$ => **SkimM14ri_ax1** (Skimmed with **hadronic FEI**) [BU05, 09]
    - Generic
      - $B^0\bar{B}^0$ (mixed): **~ 900 fb^{-1} ***
      - B^+B^- (charged): **~ 900 fb^{-1} ***
    - Continuum
      - u,d,s,c (each): **~ 1000 fb^{-1} ***
    - Others are added later ($BD\ell\nu_\ell$, Rare, and $u\ell\nu_\ell$)

※ [Backup slides] BU04: MC Sample / Skimmed MC Sample Information, BU05: Skim Level Selection, BU09: SkimM14ri_ax1 info.
※ *: ~ 100 fb^{-1} per 1 folder
Re1. https://questions.belle2.org/question/13200/production-details-of-mc14ri_c/
Re2. [Confluence "Collection Summary"] https://confluence.desy.de/display/BI/Collection+summary

Software Version: **light-2207-Bengal**

Reconstruction: current version

- $\Upsilon(4S) \rightarrow B_{tag}B_{sig}$
  - 01: $B_{sig} \rightarrow e^+ e^-$
  - 02: $B_{sig} \rightarrow e^+ \mu^-$
  - 03: $B_{sig} \rightarrow e^+ \pi^-$
  - 04: $B_{sig} \rightarrow \mu^+ \mu^-$
  - 05: $B_{sig} \rightarrow \mu^+ \pi^-$
  - 06: $B_{sig} \rightarrow \pi^+ \pi^-$

※ Signal MC => B_{tag} = B0:generic
※ Generic MC => B_{tag} = B0:feiHadronic

Reconstruction: Add ρ (future)

- $\Upsilon(4S) \rightarrow B_{tag}B_{sig}$
  - 01: $B_{sig} \rightarrow e^+ e^-$
  - 02: $B_{sig} \rightarrow e^+ \mu^-$
  - 03: $B_{sig} \rightarrow e^+ \pi^-$
  - 04: $B_{sig} \rightarrow \boldsymbol{e^+ \rho^-}$
  - 05: $B_{sig} \rightarrow \mu^+ \mu^-$
  - 06: $B_{sig} \rightarrow \mu^+ \pi^-$
  - 07: $B_{sig} \rightarrow \boldsymbol{\mu^+ \rho^-}$
  - 08: $B_{sig} \rightarrow \pi^+ \pi^-$
  - 09: $B_{sig} \rightarrow \boldsymbol{\pi^+ \rho^-}$
  - 10: $B_{sig} \rightarrow \boldsymbol{\rho^+ \rho^-}$
    - $\rho^+ \rightarrow \pi^0 \pi^+$
      - $\pi^0 \rightarrow \gamma\gamma$

※ Signal MC => B_{tag} = B0:generic
※ Generic MC => B_{tag} = B0:feiHadronic

Particle Selection

Software Version:
light-2207-Bengal

- All Charged Tracks
  - $|dz| < 4\ cm$
  - $dr < 2\ cm$
  - nCDCHits > 20
  - ThetaInCDCAppectance
    ※ **will be applied**

- π^+
  - binaryPID(211, 321) > 0.6
    ※ 211: π^+, 321: K^+
    ※ **will be replaced** a better identification method (performance group recommended method)

- electron
  - electronID > 0.9
    ※ **will be replaced** a better identification method (performance group recommended method)

- muon
  - muonID > 0.9
    ※ **will be replaced** a better identification method (performance group recommended method)

ROE masks

ROE Selection

Rest of Event (ROE)

Software Version:
light-2207-Bengal

ROE Track

- **ROE Good Tracks == 0**
  - ROE Good Tracks
    - $|dz| < 4\ cm$
    - $dr < 2\ cm$
    - nCDCHits > 20
    - ThetaInCDCAppectance

ROE Clusters

- Currently applied
  - clusterNHits > 1.5
  - $\theta_{cluster}$ in CDCAcceptance
    ※ 0.296706 < theta < 2.61799
  - clusterE $> [80, 30, 60] MeV$ (fwd, brr, bwd)
  - |clusterTiming| $< 200\ ns$
  - |clusterTiming / ErrorTiming| > 2.0
  - minC2TDist $> 20\ cm$

- Will be applied (?)
  - hadronicSplitOffSuppression > 0.1
    - ※ **after ρ modes added (?)**

※ ROE cuts, Ref: $B^0 \to K^{*0}\tau^+\tau^-$ by Stefano Moneta
Indico Link (2022.Sep.13, 28th EWP meeting): https://indico.belle2.org/event/7723/#2-b-ktautau-with-fei

ROE cuts

ROE Mask name	Track Cuts	Cluster Cuts
Tracks	No cuts	No cuts
GoodTracks	▪ $dr < 2\ cm$ ▪ $\|dz\| < 4\ cm$ ▪ nCDCHits > 20 ▪ ThetaInCDCAppectance	No cuts
Clusters_loc	No cuts	▪ clusterNHits > 1.5 ▪ $\theta_{cluster}$ in CDCAcceptance ※ 0.296706 < theta < 2.61799 ▪ clusterE $> [80, 30, 60] MeV$ (fwd, brr, bwd)
Clusters_loc_timing	No cuts	Cluster_loc + |clusterTiming| $< 200\ ns$
Clusters_loc_timing_errtiming	No cuts	Cluster_loc_timing + |clusterTiming / ErrorTiming| > 2.0
Clusters_distance	No cuts	Cluster_loc_timing_errtiming + minC2TDist $> 20\ cm$
Cluters_splitoff	No cuts	Cluster_loc_timing + beamBackgroundProbabilityMVA > 0.1

※ ROE cuts, Ref: $B^0 \to K^{*0}\tau^+\tau^-$ reconstruction code by Stefano Moneta
Code Link: https://gitlab.desy.de/stefano.moneta/btokst_tau_tau/-/tree/main/reconstruction
Indico Link (2022.Sep.13, 28th EWP meeting): https://indico.belle2.org/event/7723/#2-b-ktautau-with-fei

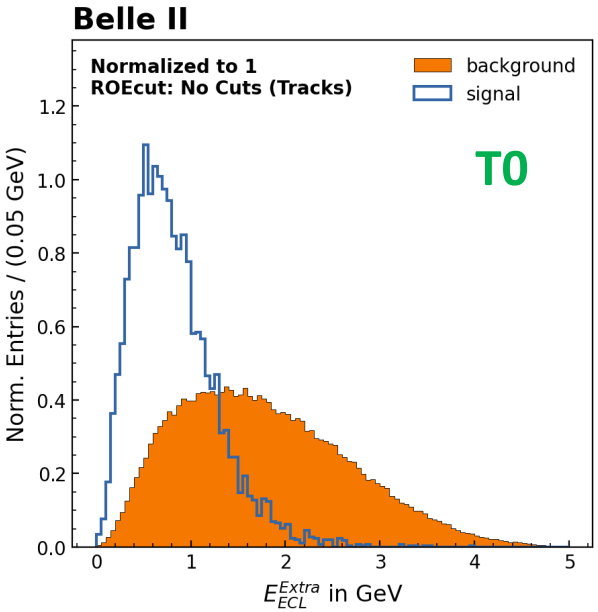
ROE cuts

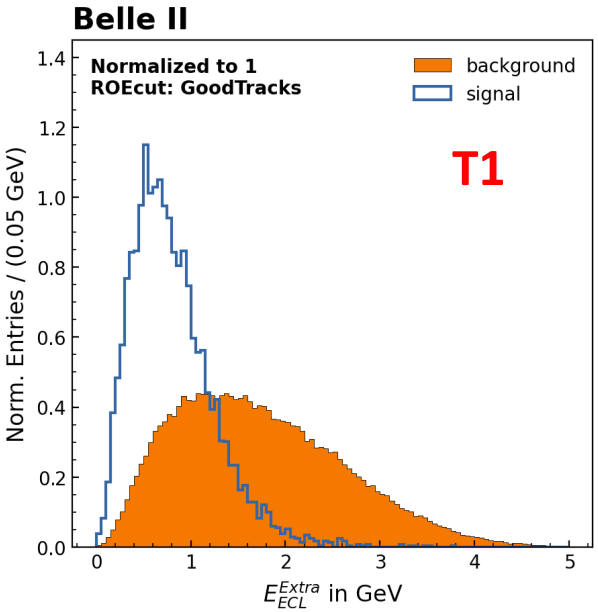
ROE Mask name	Track Cuts	Cluster Cuts
Tracks **T0**	No cuts	No cuts
GoodTracks **T1**	▪ $dr < 2\ cm$ ▪ $\|dz\| < 4\ cm$ ▪ nCDCHits > 20 ▪ ThetaInCDCAppectance	No cuts
Clusters_loc **C1**	No cuts	▪ clusterNHits > 1.5 ▪ $\theta_{cluster}$ in CDCAcceptance ※ 0.296706 < theta < 2.61799 ▪ clusterE $> [80, 30, 60] MeV$ (fwd, brr, bwd)
Clusters_loc_timing **C2**	No cuts	Cluster_loc + |clusterTiming| $< 200\ ns$
Clusters_loc_timing_errtiming **C3**	No cuts	Cluster_loc_timing + |clusterTiming / ErrorTiming| > 2.0
Clusters_distance **C4**	No cuts	Cluster_loc_timing_errtiming + minC2TDist $> 20\ cm$
Cluters_splitoff	No cuts	Cluster_loc_timing + **beamBackgroundProbabilityMVA** > 0.1

※ My current understanding (?)
Usage 1. ROE γ, ROE Mask
Usage 2. Signal side γ vs. ROE γ (cut on γ list ?)
No signal side γ, yet. Thus, not effective. (Warning)
I guess, after adding ρ, it will be effective.

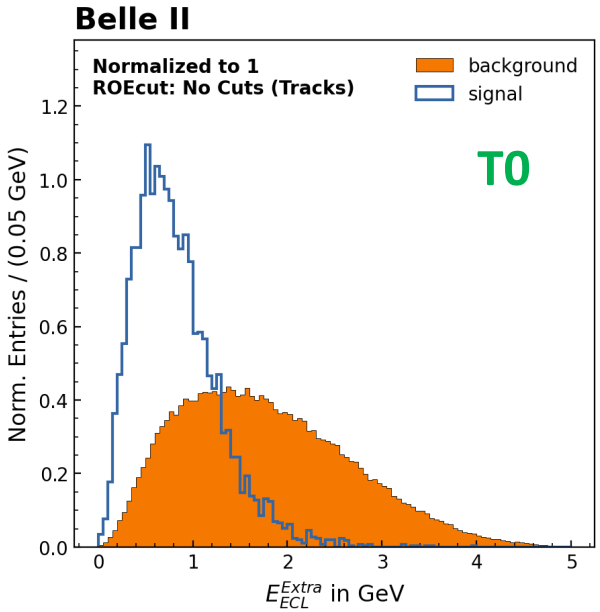
※ Ref: [Confluence Page] Neutral Performance, $E_{ECL}(E_{Extra})$ Selections
Link: https://confluence.desy.de/display/BI/Neutrals+Performance

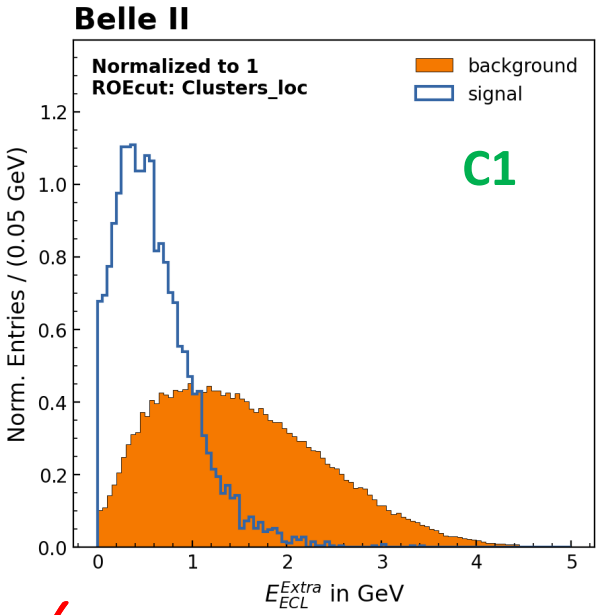
ROE cuts: Tracks Cuts

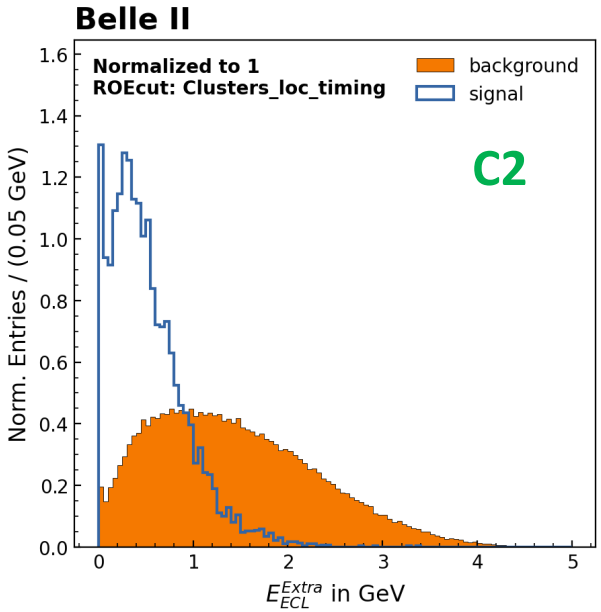


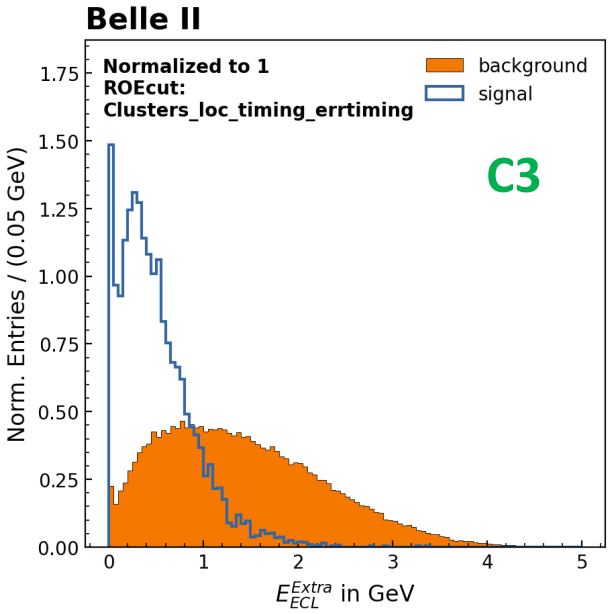


ROE cuts: Cluster Cuts

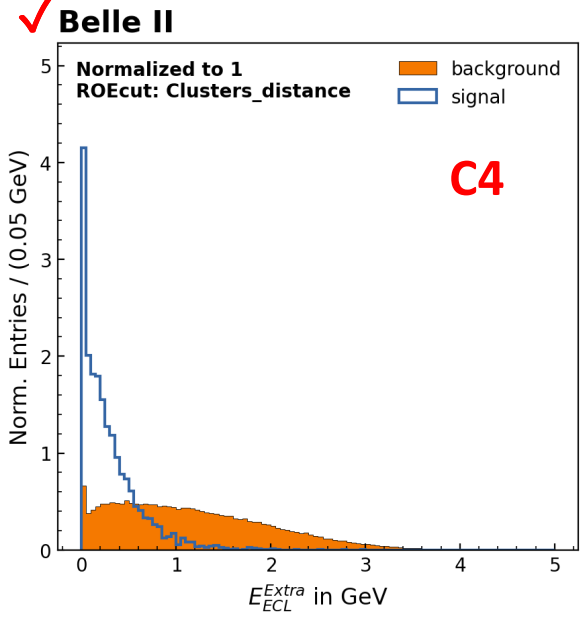




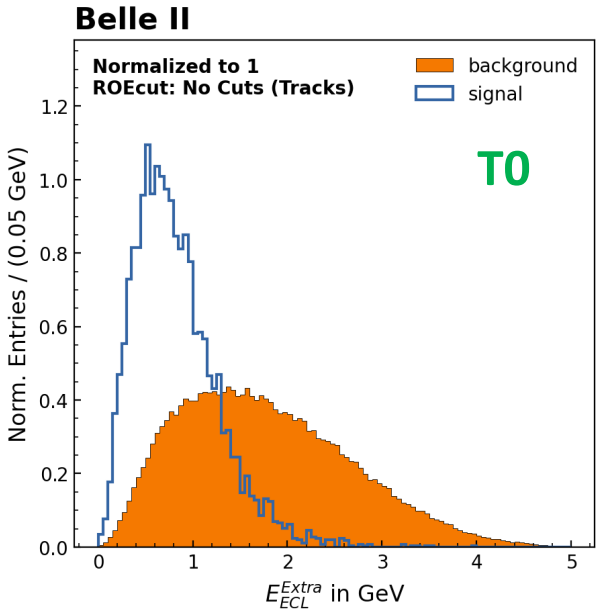


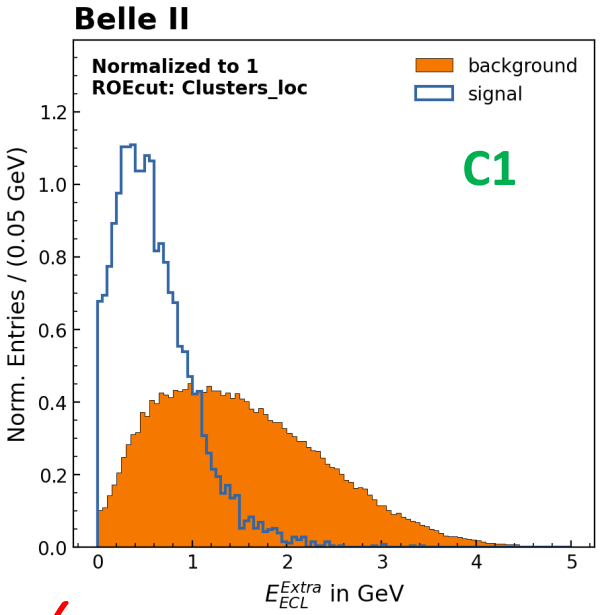


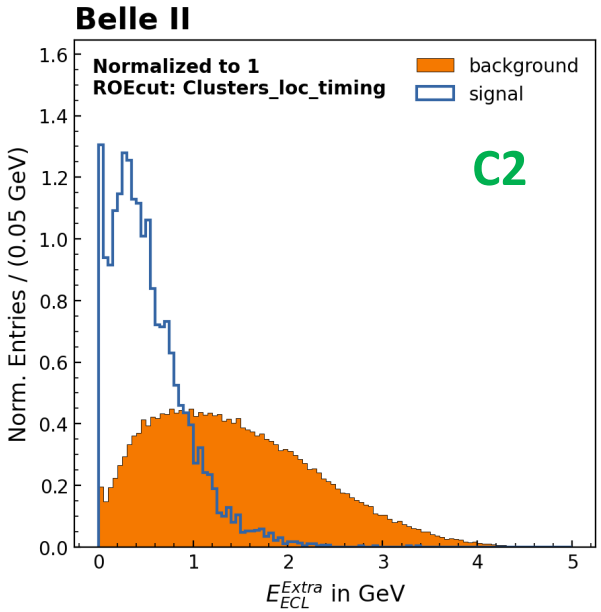
✓

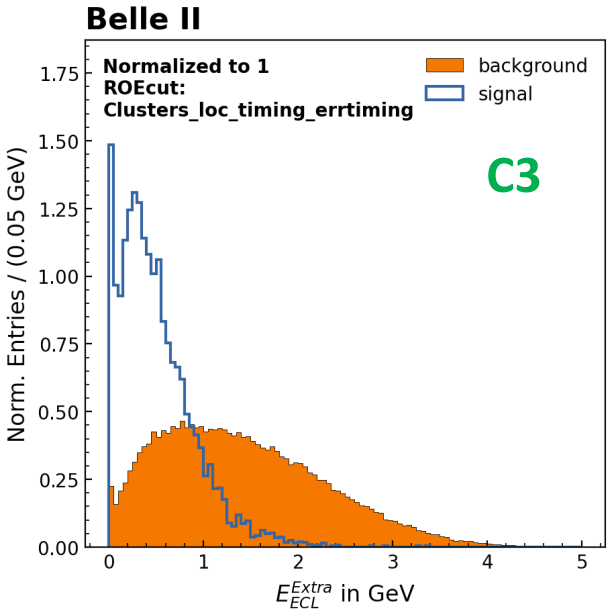


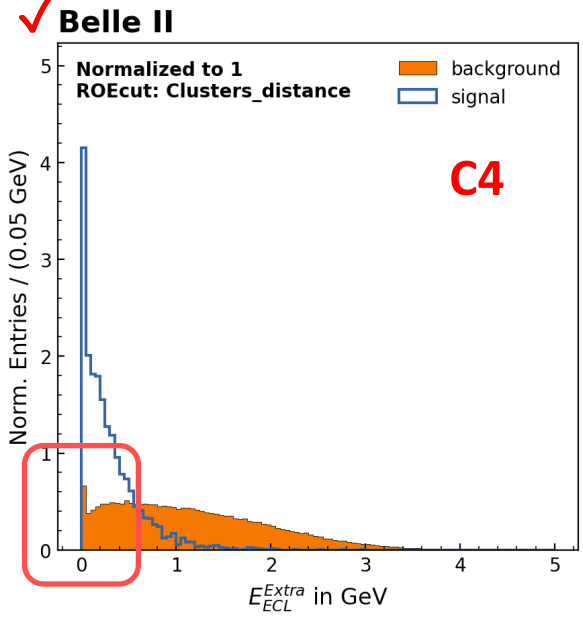
ROE cuts: Cluster Cuts











Pre-selection

Pre-selection: Table

Belle pre-selection (BN-1390): Table 6.2

Pre-selection cuts and corresponding values for the signal and background rejection in percent. The cuts are applied successively.

Cut	Signal rejection in %	Background rejection in %
$E_{\mathrm{ECL}} < 1.2$ GeV	2.65	58.23
$M_{\mathrm{bc}}^{\mathrm{tag}} > 5.27$ GeV/c^2	0.84	76.52
$\lvert\Delta E_{\mathrm{tag}}\rvert < 50$ MeV	14.26	47.29
$\mathcal{N}_{\mathrm{tag}} > 0.05$	34.78	72.08
$M_{\mathrm{miss}}^2 > 0.5$ (GeV/c^2)^2	0.84	2.01
Total	46.47	98.59

Belle II pre-selection (exactly same cuts as Belle) [BU01, 02]

Pre-selection cuts and corresponding values for the signal and background rejection in percent. The cuts are applied successively.

Cut	Signal rejection in %	Background rejection in %
$E_{ECL}^{Extra} < 1.2$ GeV	1.71 (99/5788)	44.01 (120849/274604)
$M_{bc}^{tag} > 5.27$ GeV/c²	0.67 (38/5689)	27.25 (41897/153755)
$\lvert\Delta E_{tag}\rvert < 50$ MeV	17.94 (1014/5651)	40.65 (45468/111858)
$\mathcal{N}_{tag} > 0.05$	19.58 (908/4637)	47.05 (31234/66390)
$M_{miss}^2 > 0.5$ (GeV/c²)²	7.88 (294/3729)	6.24 (2195/35156)
Total	40.65 (2353/5788)	88.00 (241643/274604)

※ [Backup slides] BU01: Pre-selection: Exactly same as Belle, BU02: Plots without Normalization

Pre-selection: Table

Belle II pre-selection (exactly same cuts as Belle) [BU01, 02]

Pre-selection cuts and corresponding values for the signal and background rejection in percent. The cuts are applied successively.

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Belle II pre-selection

Pre-selection cuts and corresponding values for the signal and background rejection in percent. The cuts are applied successively.

Cut	Signal rejection in %	Background rejection in %
$E_{ECL}^{Extra} < 1.2$ GeV	1.71 (99/5788)	44.01 (120849/274604)
$M_{bc}^{tag} > 5.27$ GeV/c²	0.67 (38/5689)	27.25 (41897/153755)
-100 MeV $< \Delta E_{tag} < 50$ MeV	7.49 (423/5651)	26.13 (29228/111858)
$\mathcal{N}_{tag} > 0.05$	21.16 (1106/5228)	51.25 (42349/82630)
$M_{miss}^2 < 18$ (GeV/c²)²	3.76 (155/4122)	4.98 (2005/40281)
Total	**31.46** (1821/5788)	**86.06** (236328/274604)

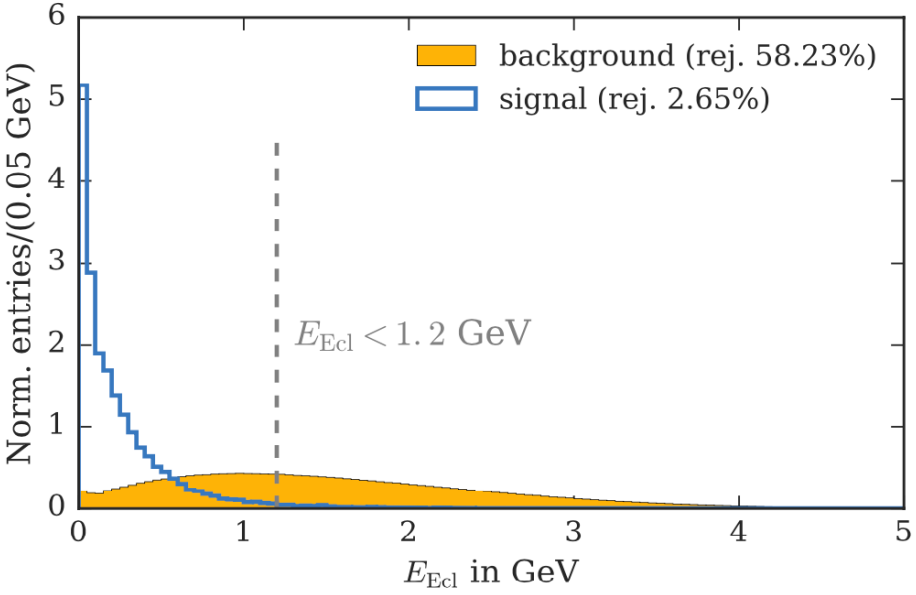
※ [Backup slides] BU01: Pre-selection: Exactly same as Belle, BU02: Plots without Normalization

Pre-selection: E_{ECL}^{Extra} plot

- Major variables: $\boldsymbol{E_{ECL}^{Extra}}$, M_{bc}^{tag}, ΔE^{tag}, $\mathcal{N}_{tag}$, M_{miss}^2

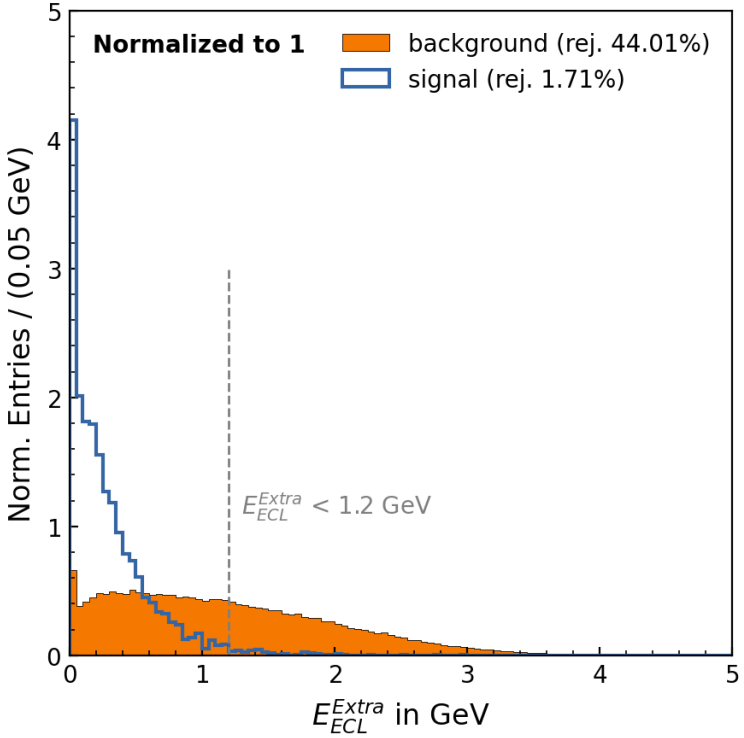
"Extra energy in ECL cluster"

Belle pre-selection (BN-1390)



Signal and background E_{ECL} distributions.
Events with $E_{ECL}^{Extra} < 1.2$ GeV are selected.

Belle II

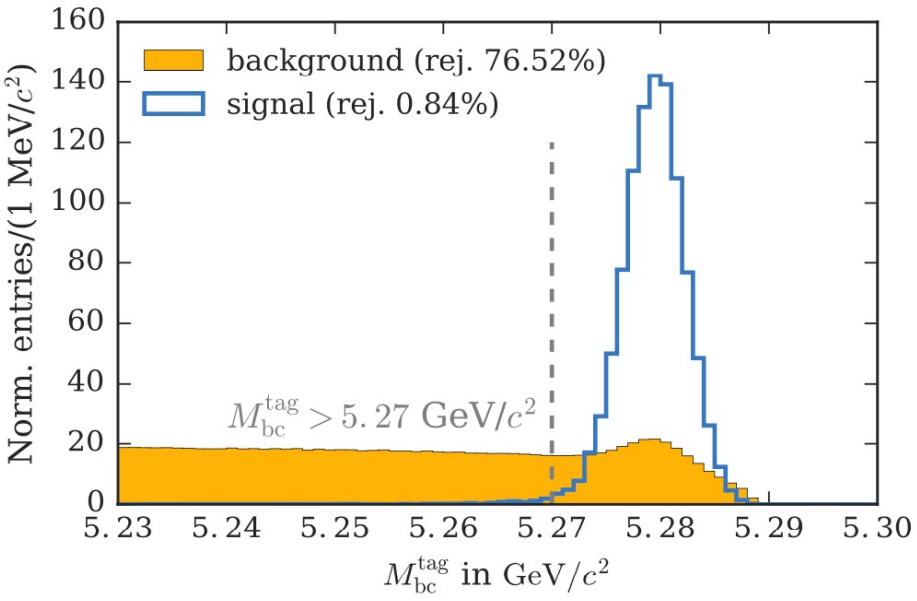


Signal and background E_{ECL} distributions.
Events with $\boldsymbol{E_{ECL}^{Extra} < 1.2}$ **GeV** are selected.

Pre-selection: M_{bc}^{tag} plot

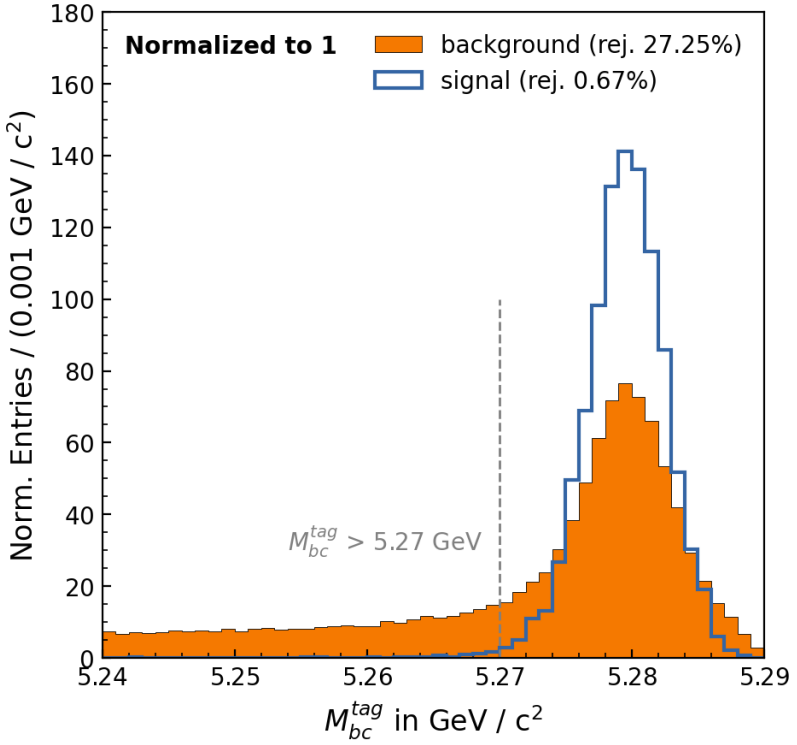
- Major variables: E_{ECL}^{Extra}, $\boldsymbol{M_{bc}^{tag}}$, ΔE^{tag}, $\mathcal{N}_{tag}$, M_{miss}^2 "Tag-side M_{bc}"

Belle pre-selection (BN-1390)



Signal and background M_{bc}^{tag} distributions.
Events with $M_{bc}^{tag} > 5.27$ GeV/c² are selected.
(E_{ECL}^{Extra} cut is applied.)

Belle II

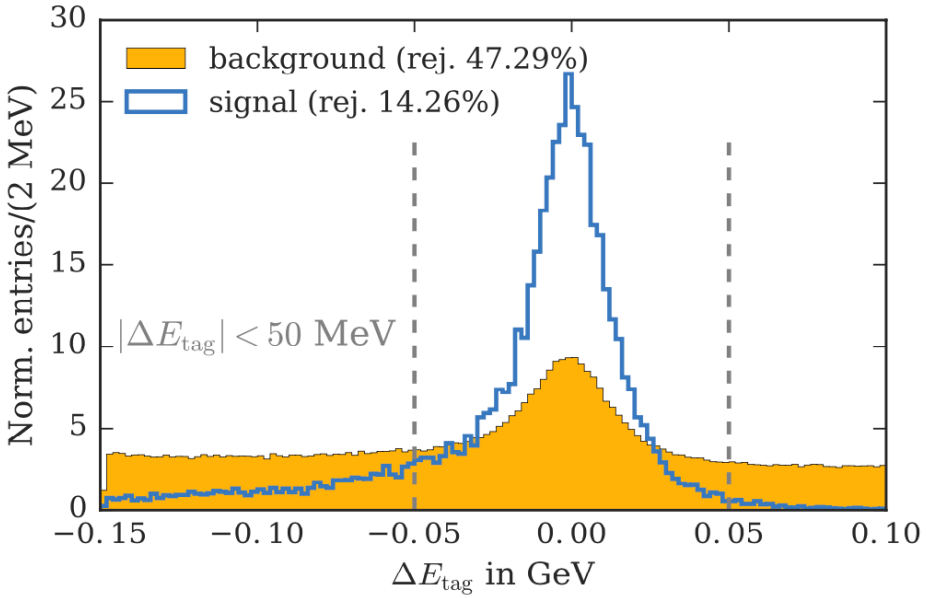


Signal and background M_{bc}^{tag} distributions.
Events with $\boldsymbol{M_{bc}^{tag} > 5.27}$ **GeV/c²** are selected.
(E_{ECL}^{Extra} cut is applied.)

Pre-selection: ΔE^{tag} plot

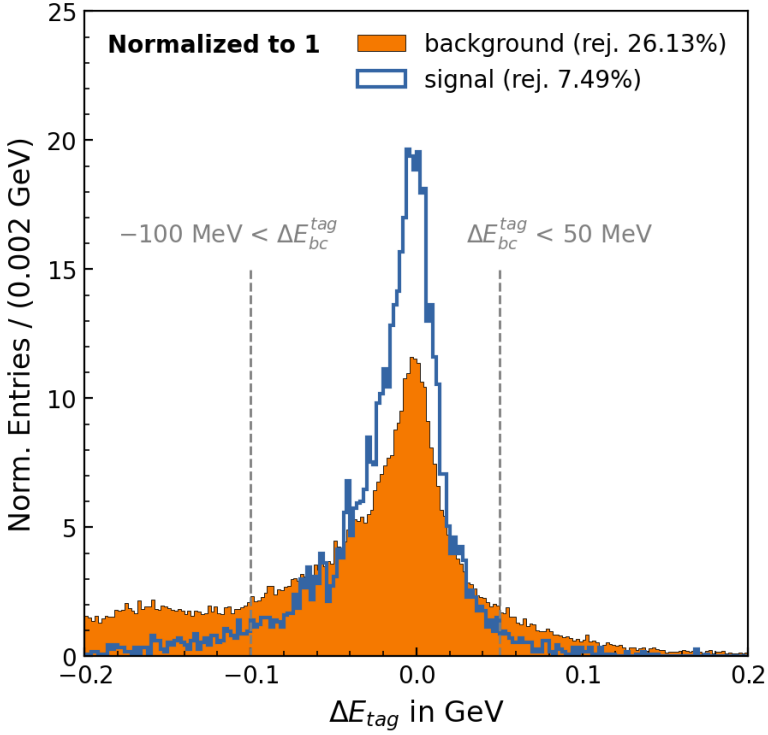
- Major variables: E_{ECL}^{Extra}, M_{bc}^{tag}, $\boldsymbol{\Delta E^{tag}}$, $\mathcal{N}_{tag}$, M_{miss}^2 "Tag-side ΔE"

Belle pre-selection (BN-1390)



Signal and background ΔE_{tag} distributions.
Events with $|\Delta E_{tag}| < 50$ MeV are selected.
(E_{ECL}^{Extra}, M_{bc}^{tag} cuts are applied.)

Belle II



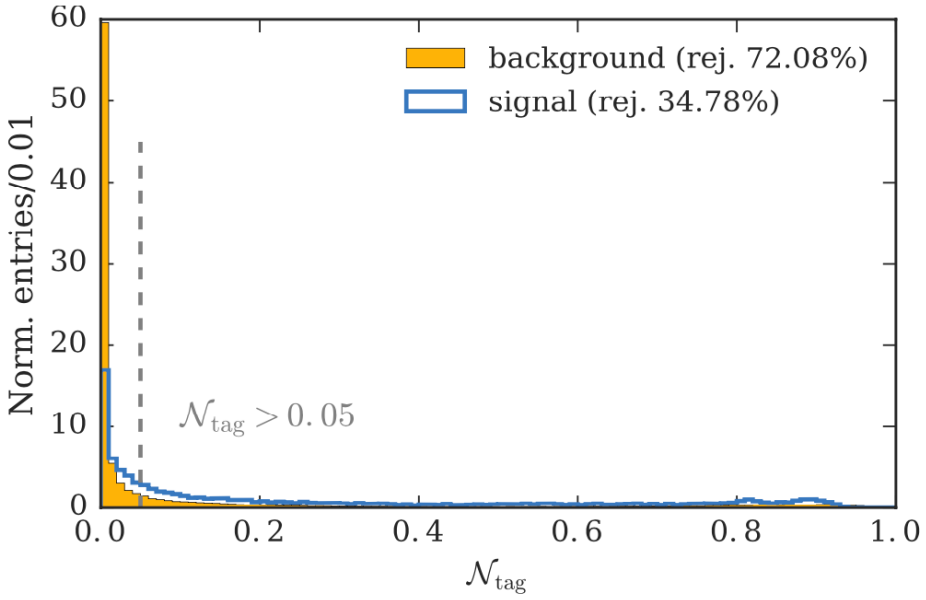
Signal and background ΔE_{tag} distributions.
Events with $\boldsymbol{-100\ \text{MeV} < \Delta E_{tag} < 50\ \text{MeV}}$ are selected.
(E_{ECL}^{Extra}, M_{bc}^{tag} cuts are applied.)

Pre-selection: $\mathcal{N}_{tag}$ plot

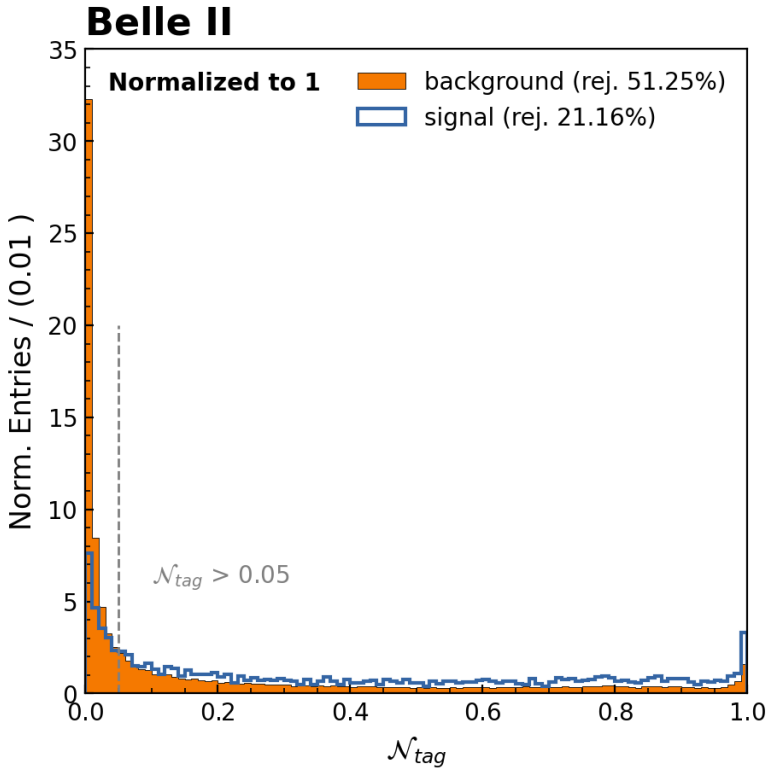
- Major variables: E_{ECL}^{Extra}, M_{bc}^{tag}, ΔE^{tag}, $\boldsymbol{\mathcal{N}_{tag}}$, M_{miss}^2

"Tag-side (FEI) Signal Probability"

Belle pre-selection (BN-1390)



Signal and background $\mathcal{N}_{tag}$ distributions.
Events with $\mathcal{N}_{tag} > 0.05$ are selected.
(E_{ECL}^{Extra}, M_{bc}^{tag}, ΔE^{tag} cuts are applied.)

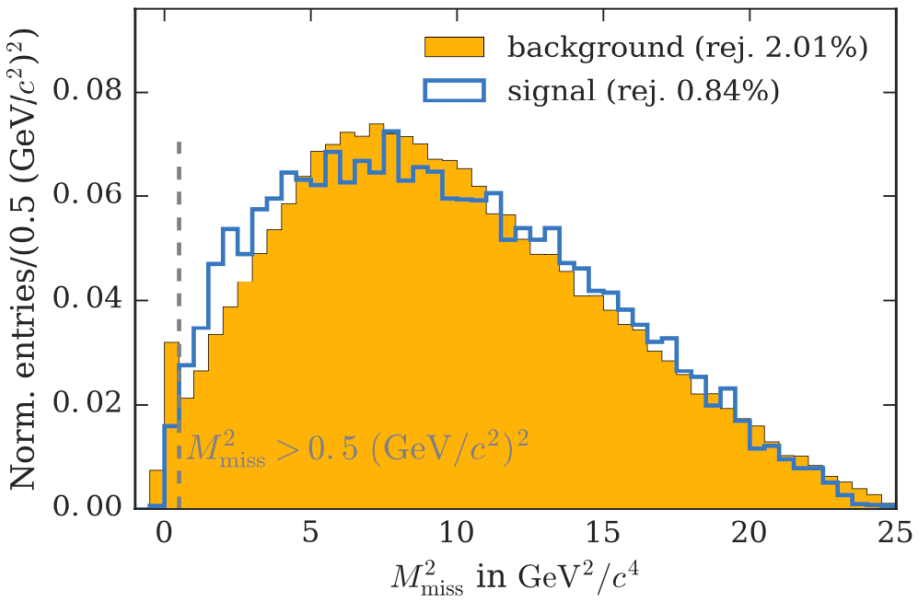


Signal and background $\mathcal{N}_{tag}$ distributions.
Events with $\boldsymbol{\mathcal{N}_{tag} > 0.05}$ are selected.
(E_{ECL}^{Extra}, M_{bc}^{tag}, ΔE^{tag} cuts are applied.)

Pre-selection: M^2_{miss} plot

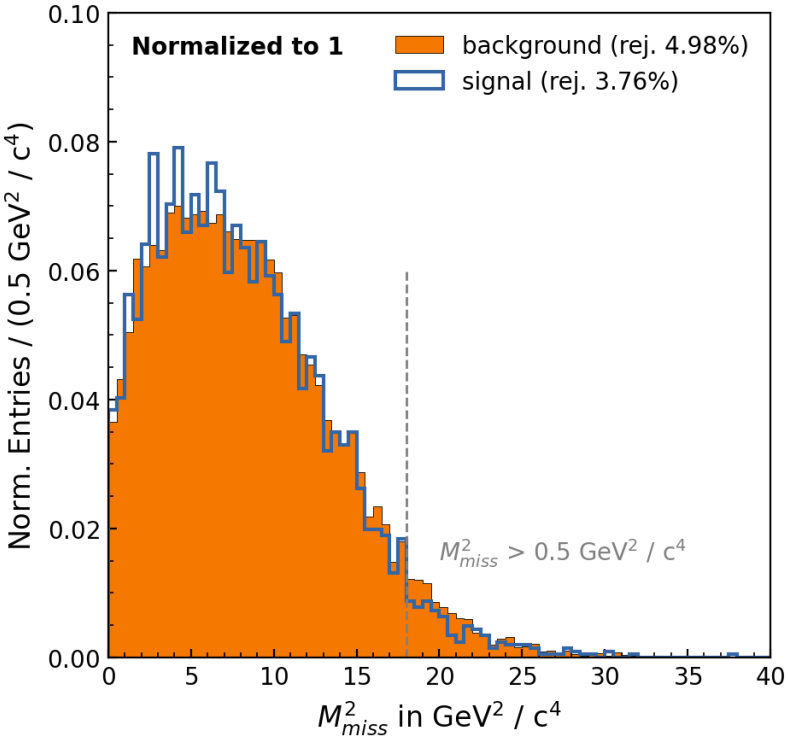
- Major variables: E^{Extra}_{ECL}, M^{tag}_{bc}, ΔE^{tag}, $\mathcal{N}_{tag}$, $\boldsymbol{M^2_{miss}}$ "Missing Mass Squared"

Belle pre-selection (BN-1390)



Signal and background M^2_{miss} distribution.
Events with $M^2_{miss} > 0.5$ (GeV/c²)² are selected.
(E^{Extra}_{ECL}, M^{tag}_{bc}, ΔE^{tag}, $\mathcal{N}_{tag}$ cuts are applied.)

Belle II

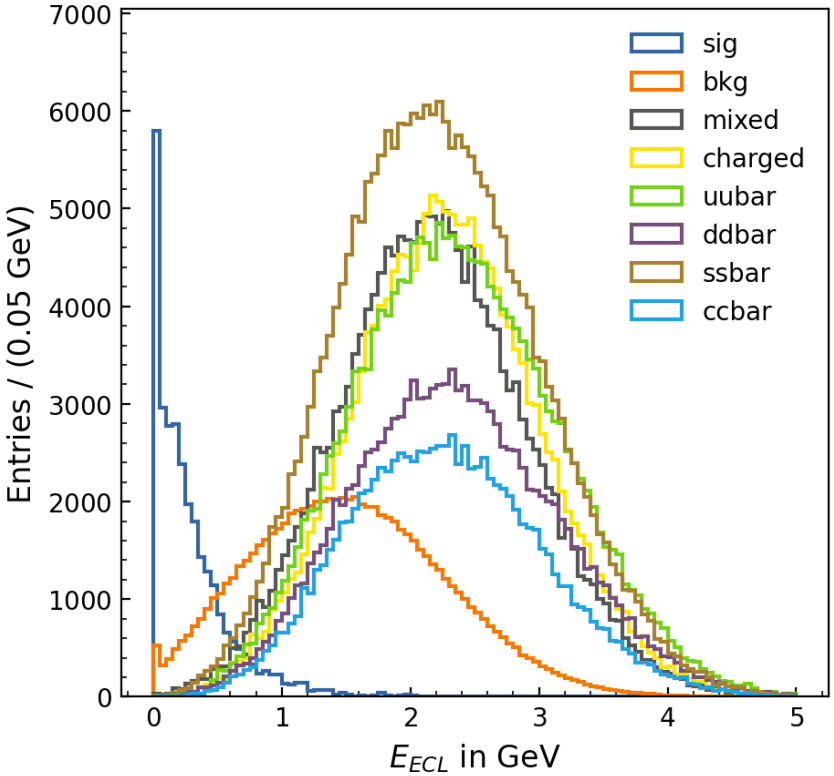


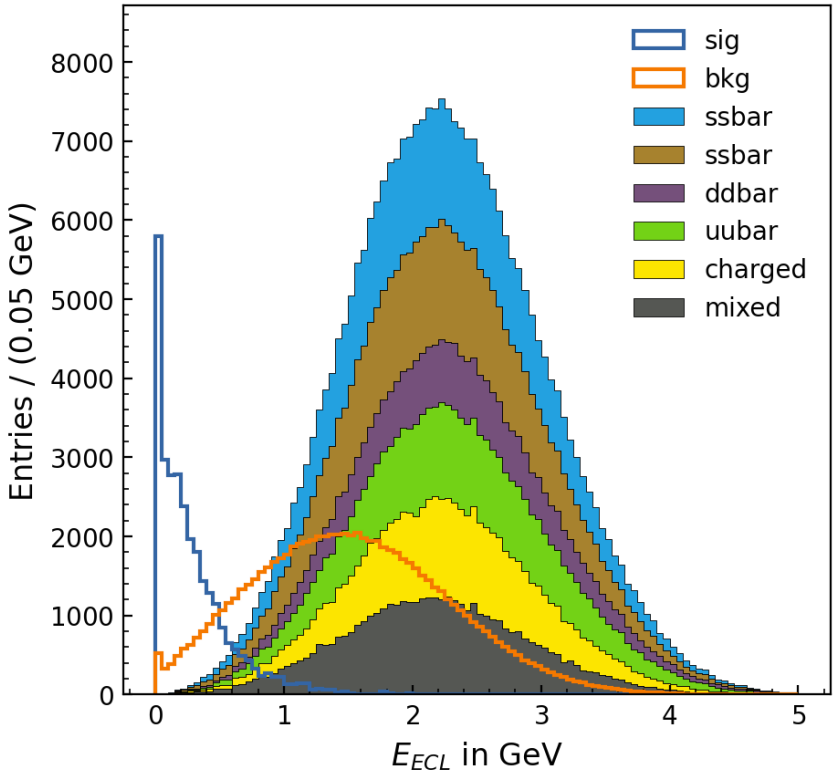
Signal and background M^2_{miss} distribution.
Events with $\boldsymbol{M^2_{miss} < 18}$ **(GeV/c²)²** are selected.
(E^{Extra}_{ECL}, M^{tag}_{bc}, ΔE^{tag}, $\mathcal{N}_{tag}$ cuts are applied.)

Background MC test

Background MC test

※ This is not a meaningful plot! I've just test data reading and plotting with weighting.





Summary and Plan

Conclusion and Plan

- Conclusion
  - First version of pre-selection is determined (it will be adjusted further)

- Plan
  - **[Ongoing] Continuum suppression** [BU03]
    - BDT (MVA package)
  - **[Ongoing] BDT Based Selection**: $\mathcal{N}_{sig}$ [BU03]
    - BDT (MVA package)
  - Reconstruction code
    - Apply “beamBackgroundProbabilityMVA” (?)
  - Figure out the reason(s) of weird peak of E_{ECL}^{Extra}
    - Maybe, applying “beamBackgroundProbabilityMVA” resolve it (?)
  - Reconstruction code
    - Add $\rho^+ \to \pi^+\pi^0$, $\pi^0 \to \gamma\gamma$

※ [Backup slides] BU03: BDT input variables

Backup

Backup

Backup

List

- A. Previous talks
- B. References

- 01. Pre-selection: Exactly same as Belle
- 02. Plots without Normalization

- 03. BDT variables

- 04. MC Sample / Skimmed MC Sample Information
- 05. Skim Level Selection

- 06. Analysis Procedure
- 07. Motivation Part I
- 08. Motivation Part II

- 09. SkimM14ri_ax1 info.

A. Previous talks

Previous talks

2021

- 2021.09.14. 25th EWP Meeting
  - https://indico.belle2.org/event/5190/#5-b0-tautau
- 2021.12.02. Leptonic Subgroup Meeting
  - https://indico.belle2.org/event/5728/#3-b0-to-tau-tau-analysis-statu

2022

- 2022.01.20. WG1 pre-session, 41st B2GM
  - https://indico.belle2.org/event/6017/#20-b0-to-tau-tau
- 2022.05.31. WG1 pre-session, 42nd B2GM
  - https://indico.belle2.org/event/6930/#sc-2-14-b-tau-tau
- 2022.Aug.04. Leptonic subgroup meeting
  - https://indico.belle2.org/event/7366/#7-b-to-tau-tau-preselection

B. References

References

- Codes
  - $B^0 \to K^{*0}\tau^+\tau^-$ by Stefano Moneta (2022)
    - https://gitlab.desy.de/stefano.moneta/btokst_tau_tau/-/tree/main/reconstruction
  - $B^+ \to K^+\tau\ell$, EWP group code by Trevor Shillington (2020)
    - https://stash.desy.de/projects/B2EWP/repos/btok_tau_ell/browse
  - $B^+ \to K^+\nu\bar{\nu}$ by Filippo Dattola (2020)
    - https://stash.desy.de/projects/MYS/repos/b2hnn/browse?at=refs/tags/version-17
  - $B \to X\tau\nu$ by Henrik Junkerkalefeld (2022)
    - https://stash.desy.de/projects/B2A/repos/wg1_xtaunu/browse
  - EWP group sample code: ewp.py
    - https://stash.desy.de/projects/B2/repos/software/browse/skim/scripts/skim/WGs/ewp.py
  - Leptonic Subgroup Sample Code
    - https://confluence.desy.de/download/attachments/81967042/Bmunu_fei.py?version=1&modificationDate=1517217590076&api=v2
  - Semitauonic Subgroup Sample Code
    - https://stash.desy.de/projects/B2WG1/repos/semitauonicsubgroup/browse

References

- Belle II notes
  - $B^+ \to K^+ \nu\bar{\nu}$ by Filippo Dattola (2020)
    - https://docs.belle2.org/record/2003/files/BELLE2-NOTE-PH-2020-057.pdf?version=7
  - $B \to X\tau\nu$ by Henrik Junkerkalefeld (2022)
    - https://docs.belle2.org/record/2682/files/BELLE2-NOTE-PH-2021-042-v400.pdf?version=1
- Belle note
  - $B^0 \to \tau^+\tau^-$, BN-1390, M. Ziegler (2016)
    - https://belle.kek.jp/secured/belle_note/gn1390/bn1390_v0.8.pdf
- WG1 plot style
  - https://confluence.desy.de/display/BI/WG1+Plot+Style

01. Pre-selection: Exactly same as Belle

Pre-selection: Table

Belle pre-selection (BN-1390): Table 6.2

Pre-selection cuts and corresponding values for the signal and background rejection in percent.
The cuts are applied successively.

Cut	Signal rejection in %	Background rejection in %
$E_{\mathrm{ECL}} < 1.2$ GeV	2.65	58.23
$M_{\mathrm{bc}}^{\mathrm{tag}} > 5.27$ GeV/c^2	0.84	76.52
$\lvert\Delta E_{\mathrm{tag}}\rvert < 50$ MeV	14.26	47.29
$\mathcal{N}_{\mathrm{tag}} > 0.05$	34.78	72.08
$M_{\mathrm{miss}}^2 > 0.5$ (GeV/c^2)^2	0.84	2.01
Total	46.47	98.59

Belle II pre-selection (exactly same cuts as Belle)

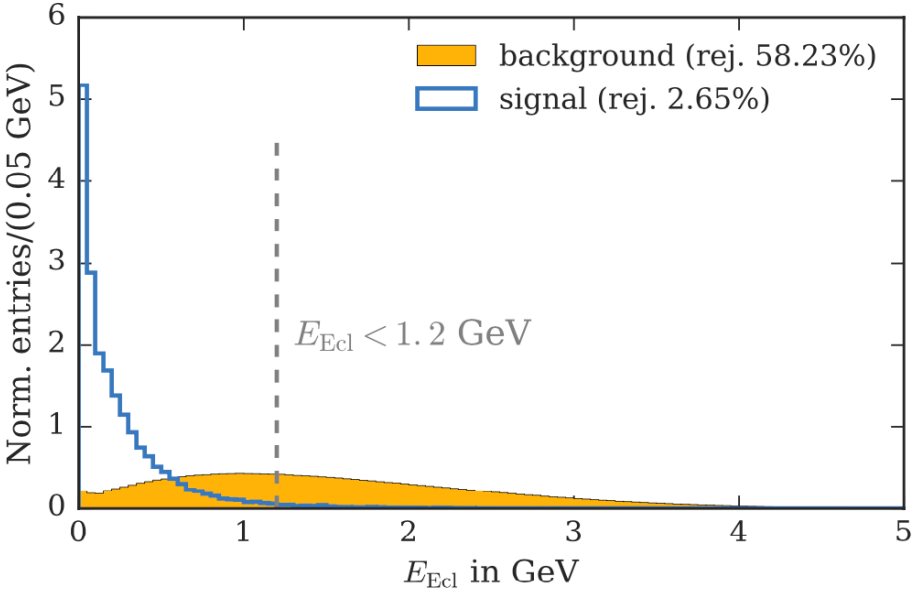
Pre-selection cuts and corresponding values for the signal and background rejection in percent.
The cuts are applied successively.

Cut	Signal rejection in %	Background rejection in %
$E_{ECL}^{Extra} < 1.2$ GeV	1.71 (99/5788)	44.01 (120849/274604)
$M_{bc}^{tag} > 5.27$ GeV/c^2	0.67 (38/5689)	27.25 (41897/153755)
$\lvert\Delta E_{tag}\rvert < 50$ MeV	17.94 (1014/5651)	40.65 (45468/111858)
$\mathcal{N}_{tag} > 0.05$	19.58 (908/4637)	47.05 (31234/66390)
$M_{miss}^2 > 0.5$ (GeV/c^2)^2	7.88 (294/3729)	6.24 (2195/35156)
Total	40.65 (2353/5788)	88.00 (241643/274604)

Pre-selection: E_{ECL}^{Extra} plot

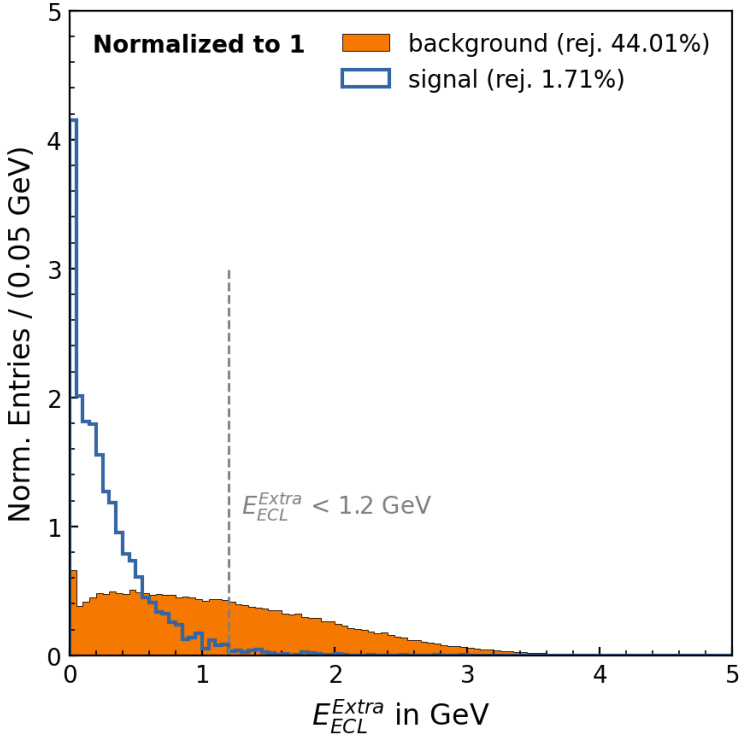
- Major variables: $\boldsymbol{E_{ECL}^{Extra}}$, M_{bc}^{tag}, ΔE^{tag}, $\mathcal{N}_{tag}$, M_{miss}^2

Belle pre-selection (BN-1390)



Signal and background E_{ECL} distributions.
Events with $E_{ECL}^{Extra} < 1.2$ GeV are selected.

Belle II

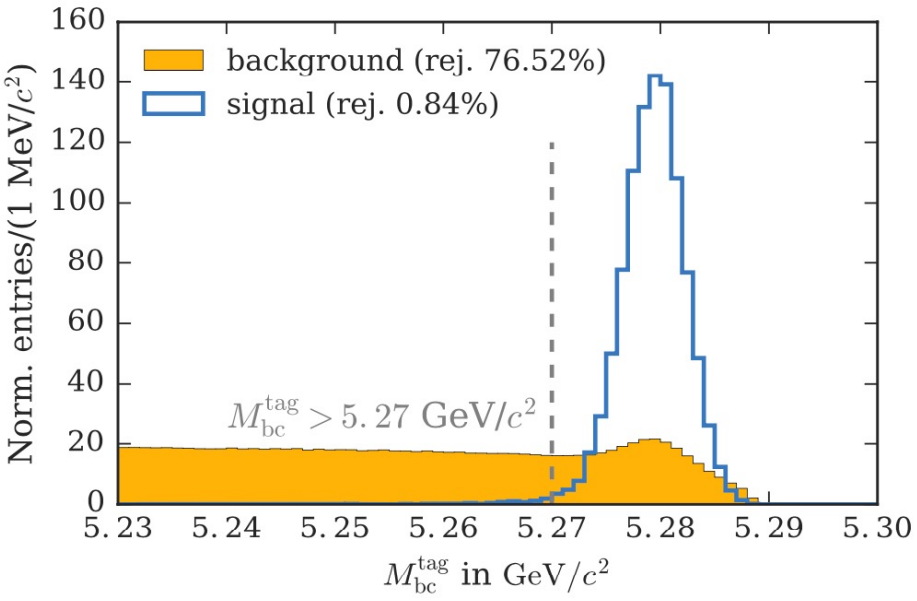


Signal and background E_{ECL} distributions.
Events with $\boldsymbol{E_{ECL}^{Extra} < 1.2}$ **GeV** are selected.

Pre-selection: M_{bc}^{tag} plot

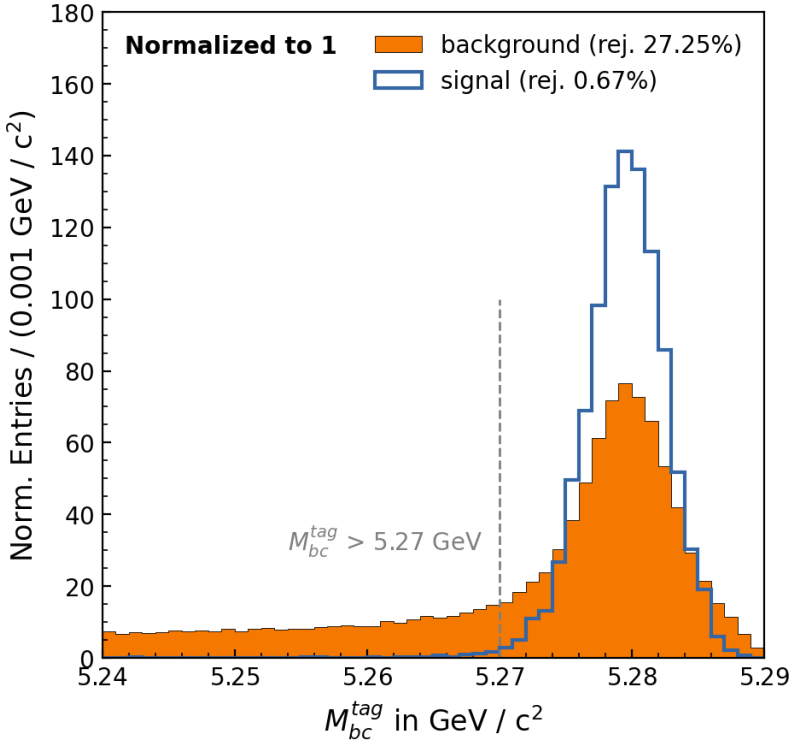
- Major variables: E_{ECL}^{Extra}, $\boldsymbol{M_{bc}^{tag}}$, ΔE^{tag}, $\mathcal{N}_{tag}$, M_{miss}^2

Belle pre-selection (BN-1390)



Signal and background M_{bc}^{tag} distributions.
Events with $M_{bc}^{tag} > 5.27$ GeV/c² are selected.
(E_{ECL}^{Extra} cut is applied.)

Belle II

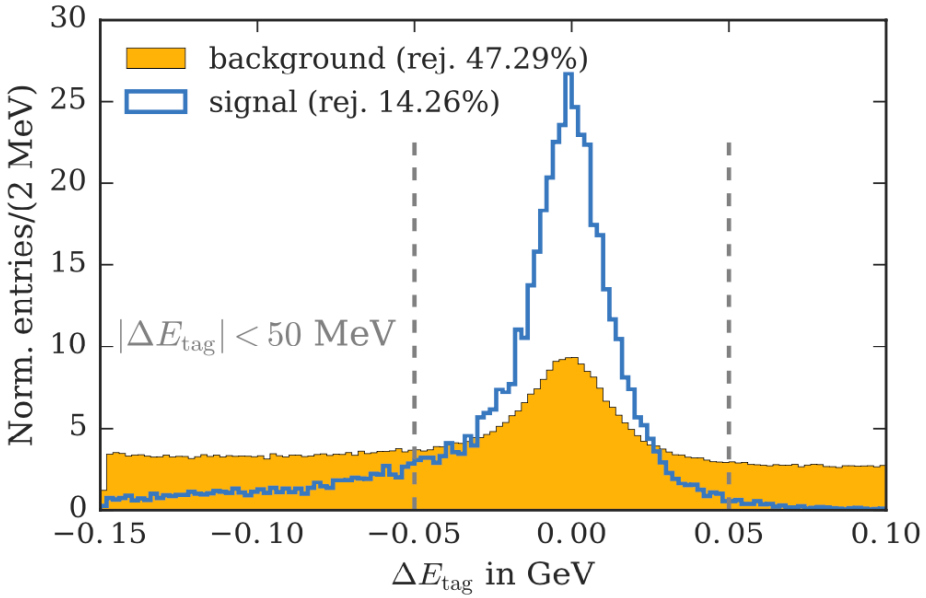


Signal and background M_{bc}^{tag} distributions.
Events with $\boldsymbol{M_{bc}^{tag} > 5.27}$ **GeV/c²** are selected.
(E_{ECL}^{Extra} cut is applied.)

Pre-selection: ΔE^{tag} plot

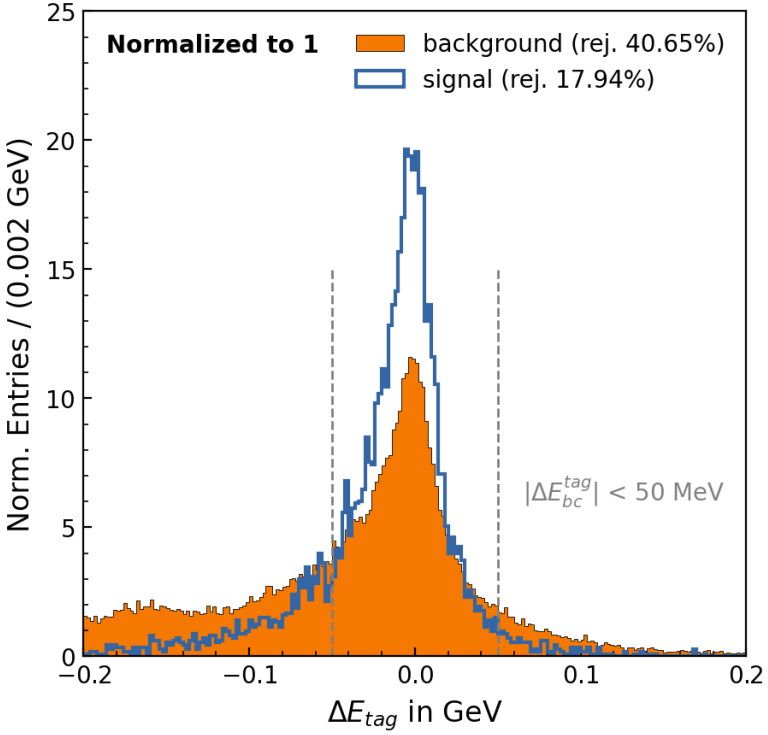
- Major variables: E_{ECL}^{Extra}, M_{bc}^{tag}, $\boldsymbol{\Delta E^{tag}}$, $\mathcal{N}_{tag}$, M_{miss}^2

Belle pre-selection (BN-1390)



Signal and background ΔE_{tag} distributions.
Events with $|\Delta E_{tag}| < 50$ MeV are selected.
(E_{ECL}^{Extra}, M_{bc}^{tag} cuts are applied.)

Belle II

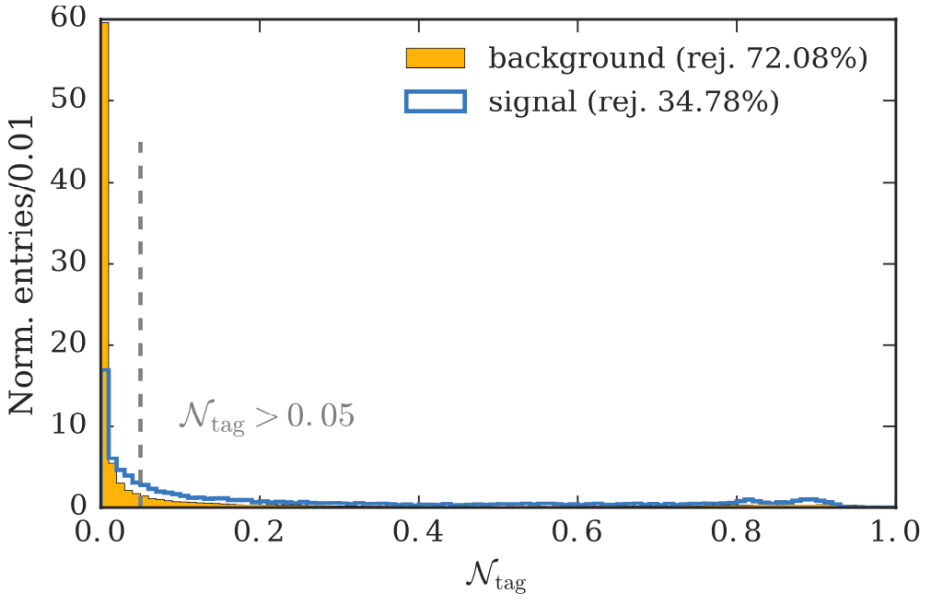


Signal and background ΔE_{tag} distributions.
Events with $|\boldsymbol{\Delta E_{tag}}| < \mathbf{50\ MeV}$ are selected.
(E_{ECL}^{Extra}, M_{bc}^{tag} cuts are applied.)

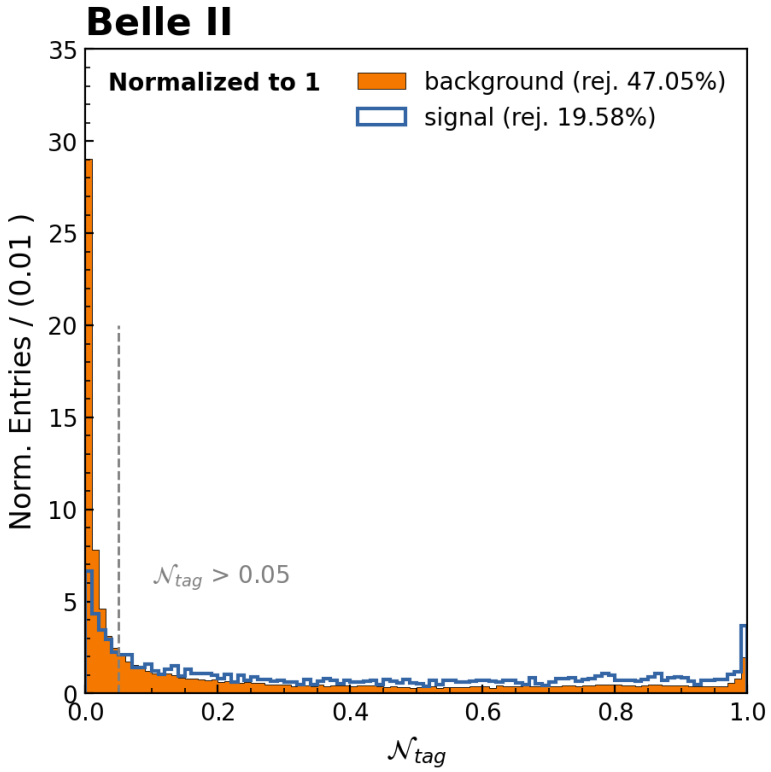
Pre-selection: $\mathcal{N}_{tag}$ plot

- Major variables: E_{ECL}^{Extra}, M_{bc}^{tag}, ΔE^{tag}, $\boldsymbol{\mathcal{N}_{tag}}$, M_{miss}^2

Belle pre-selection (BN-1390)



Signal and background $\mathcal{N}_{tag}$ distributions.
Events with $\mathcal{N}_{tag} > 0.05$ are selected.
(E_{ECL}^{Extra}, M_{bc}^{tag}, ΔE^{tag} cuts are applied.)

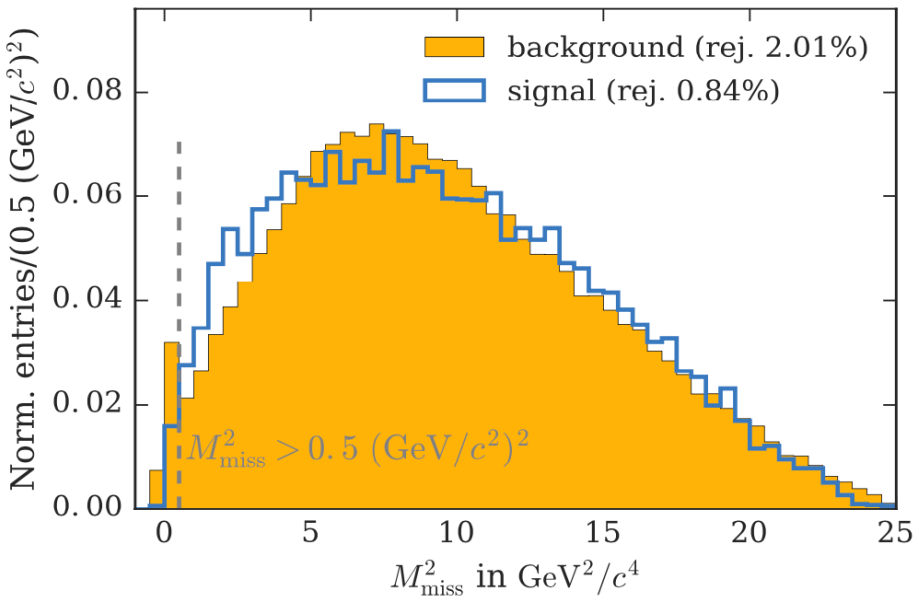


Signal and background $\mathcal{N}_{tag}$ distributions.
Events with $\boldsymbol{\mathcal{N}_{tag} > 0.05}$ are selected.
(E_{ECL}^{Extra}, M_{bc}^{tag}, ΔE^{tag} cuts are applied.)

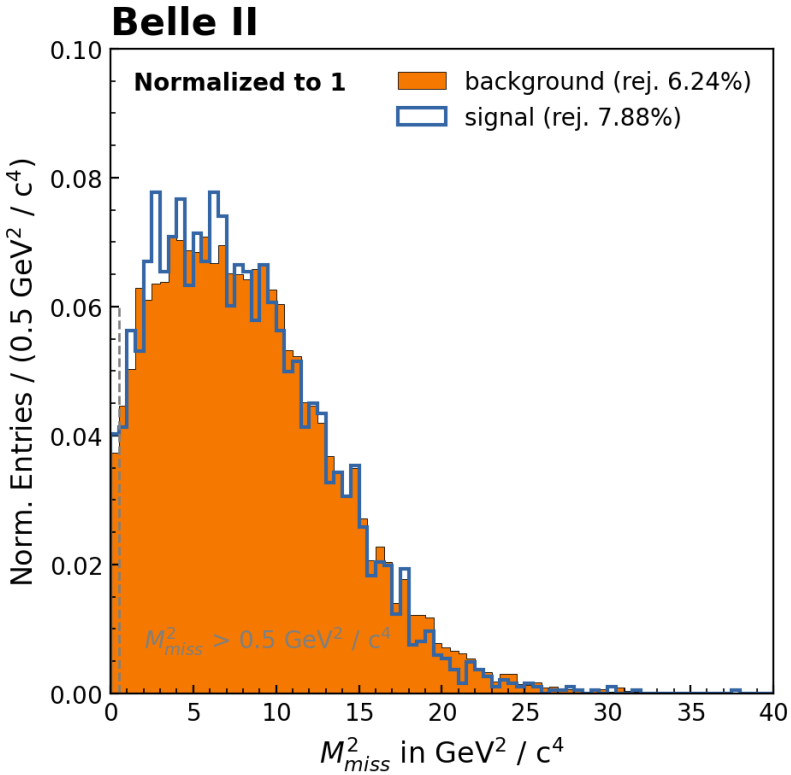
Pre-selection: M^2_{miss} plot

- Major variables: E^{Extra}_{ECL}, M^{tag}_{bc}, ΔE^{tag}, $\mathcal{N}_{tag}$, $\boldsymbol{M^2_{miss}}$

Belle pre-selection (BN-1390)



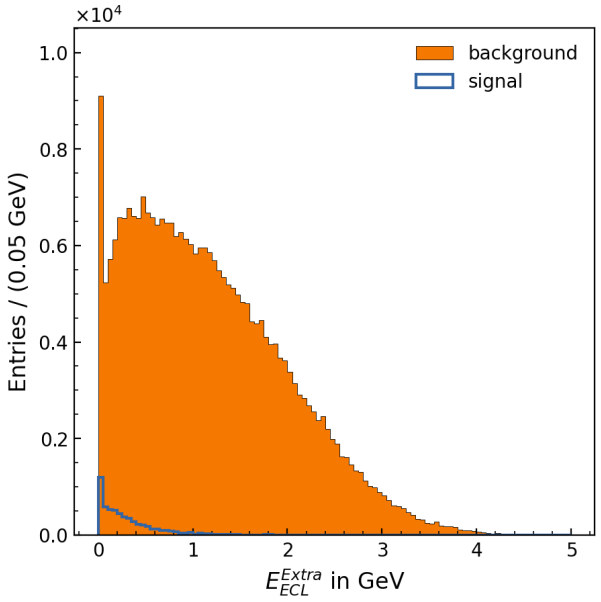
Signal and background M^2_{miss} distribution.
Events with $M^2_{miss} > 0.5$ (GeV/c²)² are selected.
(E^{Extra}_{ECL}, M^{tag}_{bc}, ΔE^{tag}, $\mathcal{N}_{tag}$ cuts are applied.)

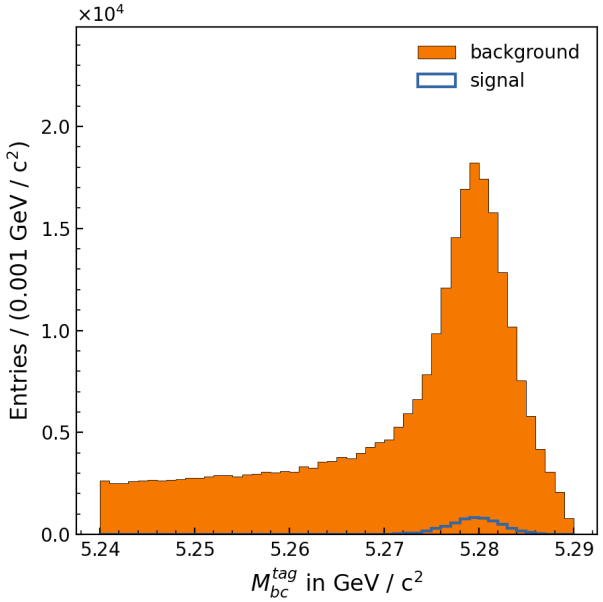


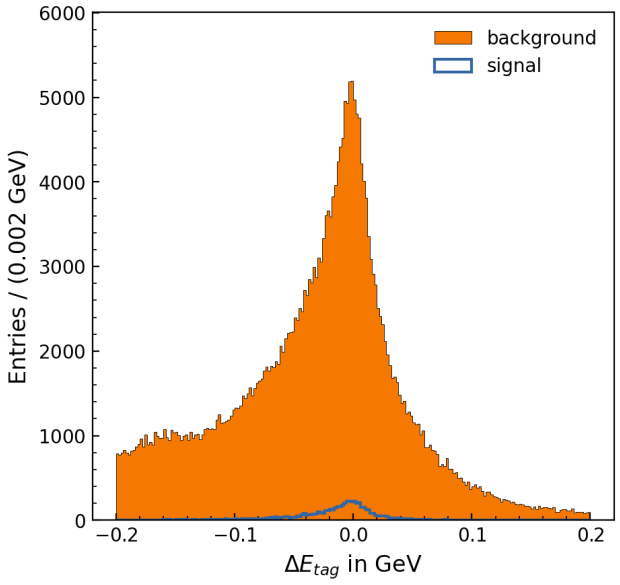
Signal and background M^2_{miss} distribution.
Events with $\boldsymbol{M^2_{miss} > 0.5}$ **(GeV/c²)²** are selected.
(E^{Extra}_{ECL}, M^{tag}_{bc}, ΔE^{tag}, $\mathcal{N}_{tag}$ cuts are applied.)

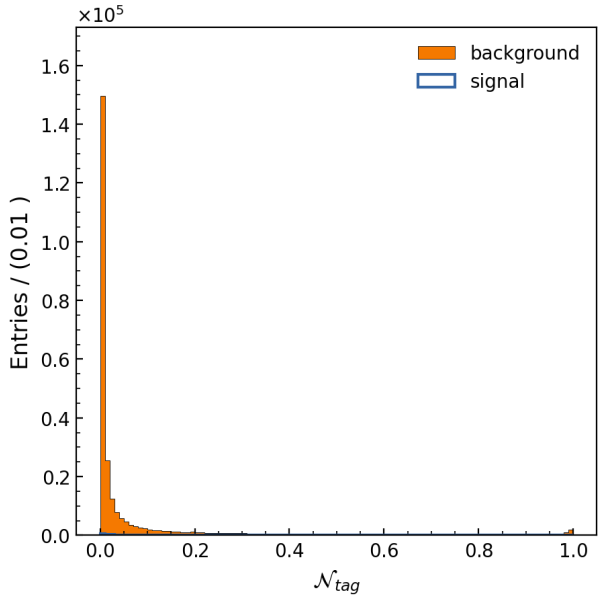
02. Plots without Normalization

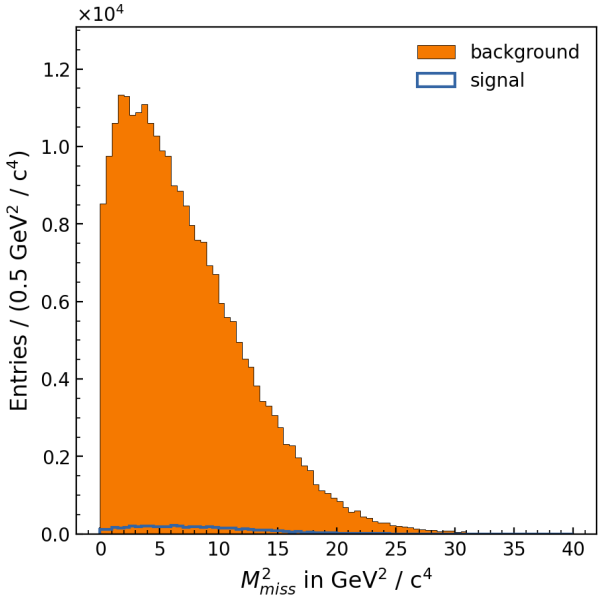
Plots without Normalization











03. BDT input variables

BDT input variables: Belle ($\mathcal{N}_{sig}$)

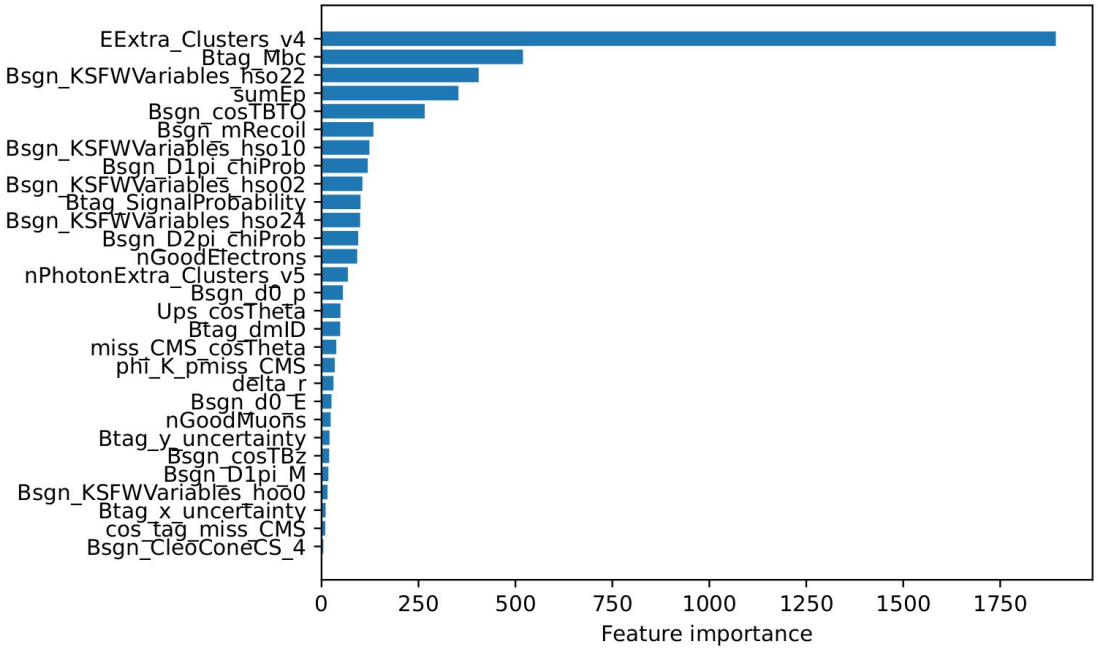
Table 6.5.: Input variables of the neural nets.

	Variable	Short description
Lab. frame	$p_{T,i}$	Transverse momentum of B_{sig} daughters
	E_i	Energy of B_{sig} daughters
	$\cos\theta_i$	Polar angle of B_{sig} daughters
	$\cos\theta_{0<1}$	Angle between B_{sig} daughters
	A_{01}	Momentum asymmetry of B_{sig} daughters
	$M(B_{sig})$	Reconstructed mass of B_{sig}
	p_T	Reconstructed transverse momentum of B_{sig}
	M^2_{miss}	Squared missing mass of the event
	$\lvert\vec{p}_{miss}\rvert$	Absolute value of the missing momentum in the event
	$\lvert\vec{p}_{T,miss}\rvert$	Absolute value of the transverse component of the missing momentum in the event
	d_{IP}	Distance of B_{sig} vertex and IP
	$\Sigma(d_{IP})$	Significance of d_{IP}
B_{sig} rest frame	$\lvert\vec{p}^*_i\rvert$	Absolute value of the momentum of B_{sig} daughters
	$\cos\theta^*_{0<1}$	Angle between B_{sig} daughters
	$\cos\theta^*_{\tau<\pi}$	Angle between τ and B_{sig} daughter with π hypothesis
	$\cos\theta_{hel,0}$	Angle between daughter 0 and the reconstructed momentum of B_{sig}

※ $B^0 \to \tau^+\tau^-$, BN-1390, M. Ziegler (2016)

BDT overview

- BDT based on XGBoost trained on 1ab^{-1} of skimmed bkg events and 50M skimmed signal events
- Samples split 50/50 for training/testing. Background randomly sampled to get $n_{bkg} = 5 \times n_{sig}$
- Variables used in the training:
  - Continuum suppression (KSFW moments, $\cos\theta_{TBTO}$, ...)
  - Signal K^+ kinematics (E_K, ρ_K, ...)
  - D meson suppression variables
  - Missing variables (E_{miss}, ρ_{miss}, ...)
- Pre/post processing with QuantileTransformer so that signal input variables and classifier output uniformly distributed between 0 and 1



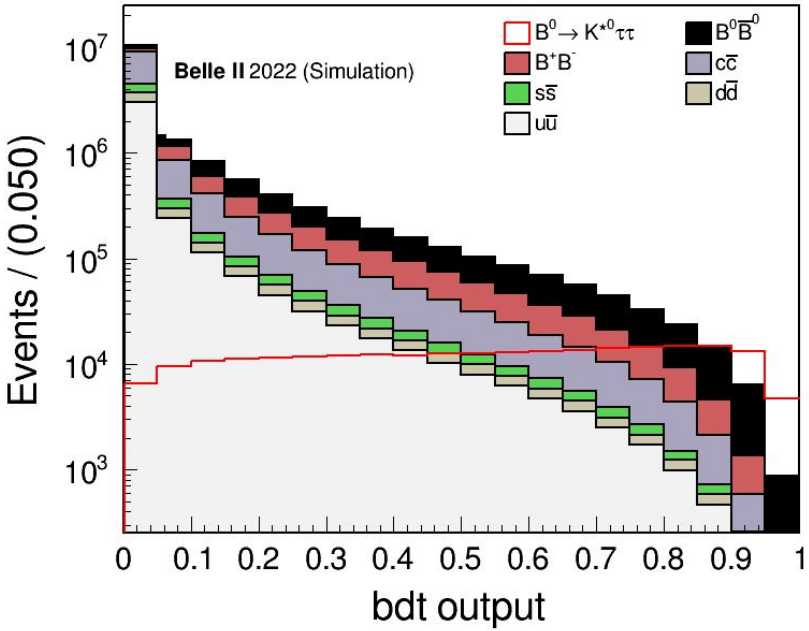
※ $B^+ \to K^+\nu\bar{\nu}$, Lucas Martel (31st EWP group meeting, 2022.Oct.04)
Link: https://indico.belle2.org/event/7846/#2-b-knunu-belle-ii-had-tag

Signal selection

- Train XGBoost **BDT** to discriminate signal against all backgrounds → distinguish $\tau\tau$ decay topologies during the training

Training variables

1. Bsgn_KSFWVariables_hoo0
2. sumEp
3. EExtra_Clusters_distance
4. Bsgn_d0_M
5. foxWolframR2
6. Bsgn_thrustBm
7. M_tautau2
8. Btag_SignalProbability
9. Btag_Mbc
10. delta_r
11. Btag_dmID
12. miss_CMS_cosTheta
13. Bsgn_cosTBTO
14. Btag_deltaE



For BDT>0.95 :

$\varepsilon = 9.4\ 10^{-5}$

~800 BBbar events for 1/ab

- ✅ "**Improved**" scenario assumed for snowmass projections (x3 signal efficiency with same bkg as Belle)

- **To be updated**
  - Training with new preselection (see slide 9)
  - Change variable inputs list (D-veto)

※ $B^0 \to K^{*0}\tau^+\tau^-$, Stefano Moneta (31st EWP group meeting, 2022.Oct.04)
Link: https://indico.belle2.org/event/7846/#4-b0-k0-tautau

BDT input variables: Belle II (Continuum Suppression)

Solution ▶

```
#!/usr/bin/env python3

import basf2_mva

general_options = basf2_mva.GeneralOptions()
general_options.m_datafiles = basf2_mva.vector("ContinuumSuppression.root")
general_options.m_treename = "tree"
general_options.m_identifier = "MVAFastBDT.root"  # outputted weightfile
general_options.m_variables = basf2_mva.vector(
    "R2",
    "thrustBm",
    "thrustOm",
    "cosTBTO",
    "cosTBz",
    "KSFWVariables(et)",
    "KSFWVariables(mm2)",
    "KSFWVariables(hso00)",
    "KSFWVariables(hso02)",
    "KSFWVariables(hso04)",
    "KSFWVariables(hso10)",
    "KSFWVariables(hso12)",
    "KSFWVariables(hso14)",
    "KSFWVariables(hso20)",
    "KSFWVariables(hso22)",
    "KSFWVariables(hso24)",
    "KSFWVariables(hoo0)",
    "KSFWVariables(hoo1)",
    "KSFWVariables(hoo2)",
    "KSFWVariables(hoo3)",
    "KSFWVariables(hoo4)",
    "CleoConeCS(1)",
    "CleoConeCS(2)",
    "CleoConeCS(3)",
    "CleoConeCS(4)",
    "CleoConeCS(5)",
    "CleoConeCS(6)",
    "CleoConeCS(7)",
    "CleoConeCS(8)",
    "CleoConeCS(9)",
)
general_options.m_target_variable = "isContinuumEvent"
fastbdt_options = basf2_mva.FastBDTOptions()

basf2_mva.teacher(general_options, fastbdt_options)
```

※ [Sphinx manual (light-2207-bengal): 3.4.10. Continuum Suppression (CS)]
Link: https://b2-master.belle2.org/software/sphinx/light-2207-bengal/online_book/basf2/cs.html

04. MC Sample / Skimmed MC Sample Information

MC Sample / Skimmed MC Sample Information

- ***MC Sample Information***
  - #69, Signal at $\Upsilon(4S)$, Mode: B0 → tau tau, Nickname: Bd_tautau [1]
  - Number of events: $\mathbf{20\times10^6}$ [1]
  - Ratio without/with background: **0.20 / 0.80** [1]
  - Btag decay type: **generic** [1]
  - Bsig decay type: **tau+ tau-** [1]
  - Campaign: **MC14ri_a** [2]
  - Location: /belle/MC/release-05-02-00/DB00001330/MC14ri_a/prod00021450/s00/e1003/4S/r00000/1120600000/mdst/sub00 [2]

- ***Skimmed MC Sample Information***
  - Beam background type: **BGx1** [2]
  - The Signal MC is generated with basf2 version **release-05-02-11** [2].
  - MC Signal mode: B0 → tau tau [2, 3]
  - MC Signal Code: 1120600000 [2, 3]
  - Skim Type: **feiHadronicB0 / feiSLB0** [2, 3]
  - Location: /belle/user/shdelamo/skim_Bd_tautau_21450_1120600000 [2]
  - Location: /belle/group/physics/SLME/skim_Bd_tautau_21450_1120600000 [2, 3]

- ***Additional information***
  - The skim was done before the MC14 data deletion accident [2].
  - MC Sample: **No longer exist** [2]
  - Skimmed MC Sample: Exist

[References]
[1] [MC Samples WG1] https://confluence.desy.de/display/BI/MC+Samples+WG1
[2] [JIRA ticket for Signal MC] https://agira.desy.de/browse/BIIDP-4785
[3] [WG1 Skimming Advice and Resources] https://confluence.desy.de/display/BI/WG1+Skimming+Advice+and+Resources

MC Sample / Skimmed MC Sample Information

- ***MC Sample Information***
  - #69, Signal at $\Upsilon(4S)$, Mode: B0 → tau tau, Nickname: Bd_tautau [1]
  - Number of events: $\mathbf{20\times10^6}$ [1]
  - Ratio without/with background: **0.20 / 0.80** [1]
  - Btag decay type: **generic** [1]
  - Bsig decay type: **tau+ tau-** [1]
  - Campaign: **MC14ri_a** [2]
  - Location: /belle/MC/release-05-02-00/DB00001330/MC14ri_a/prod00021450/s00/e1003/4S/r00000/1120600000/mdst/sub00 [2]

BGx0 / BGx1 → 4×10^6 (4M) / 16×10^6 (16M)

- ***Skimmed MC Sample Information***
  - Beam background type: **BGx1** [2]
  - The Signal MC is generated with basf2 version **release-05-02-11** [2].
  - MC Signal mode: B0 → tau tau [2, 3]
  - MC Signal Code: 1120600000 [2, 3]
  - Skim Type: **feiHadronicB0 / feiSLB0** [2, 3]
  - Location: /belle/user/shdelamo/skim_Bd_tautau_21450_1120600000 [2]
  - Location: /belle/group/physics/SLME/skim_Bd_tautau_21450_1120600000 [2, 3]

- ***Additional information***
  - The skim was done before the MC14 data deletion accident [2].
  - MC Sample: **No longer exist** [2]
  - Skimmed MC Sample: Exist

[References]
[1] [MC Samples WG1] https://confluence.desy.de/display/BI/MC+Samples+WG1
[2] [JIRA ticket for Signal MC] https://agira.desy.de/browse/BIIDP-4785
[3] [WG1 Skimming Advice and Resources] https://confluence.desy.de/display/BI/WG1+Skimming+Advice+and+Resources

05. Skim Level Selection

Skim Level Selection: Pre-selection

static **fei_precuts**(*path*) [source]

Skim pre-cuts are applied before running the FEI, to reduce computation time. This setup function is run by all FEI skims, so they all have the save event-level pre-cuts:

- $n_{\text{cleaned tracks}} \geq 3$
- $n_{\text{cleaned ECL clusters}} \geq 3$
- $\text{Visible energy of event (CMS frame)} > 4\ \text{GeV}$
- $2\ \text{GeV} < E_{\text{cleaned tracks \& clusters in ECL}} < 7\ \text{GeV}$

We define "cleaned" tracks and clusters as:

- Cleaned tracks (`pi+:FEI_cleaned`): $d_0 < 0.5\ \text{cm}$, $|z_0| < 2\ \text{cm}$, and $p_T > 0.1\ \text{GeV}$ *
  Cleaned ECL clusters (`gamma:FEI_cleaned`): $0.296706 < \theta < 2.61799$, and $E > 0.1\ \text{GeV}$ $\Rightarrow 17° < \theta < 150°$

※ From Sphinx manual, basf2 version: **05-02-18**: "17.2.1. Physics skims - Full event interpretation skims"
(cf. basf2 version which was used to skim: 05-02-11)
※ https://b2-master.belle2.org/software/sphinx/release-05-02-18/skim/doc/02-physics.html#module-skim.fei

Skim Level Selection: Tag side selection

class **skim.fei.feiHadronicB0**(**, OutputFileName=None, additionalDataDescription=None, udstOutput=True, validation=False*) [source]

Note

- **Skim description**: FEI-tagged neutral B's decaying hadronically.
- **Skim name**: feiHadronicB0
- **Skim LFN code**: 11180100
- **Category**: physics, Full Event Interpretation
- **Authors**: Racha Cheaib, Hannah Wakeling, Phil Grace
- **Contact**: Shanette De La Motte

This skim includes a selection on the HLT flag `hlt_hadron`.

Tag side B cuts:

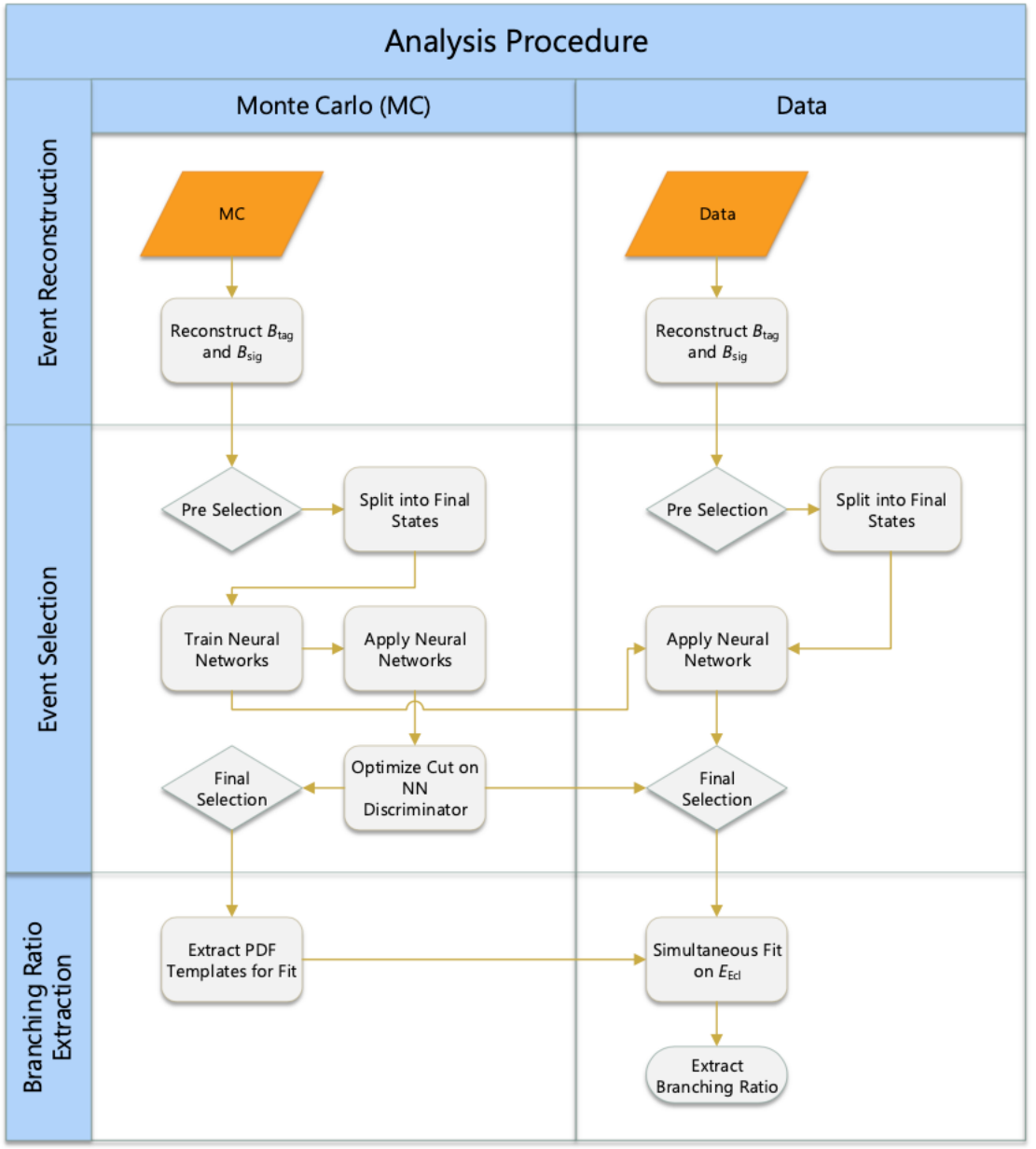
- $M_{\mathrm{bc}} > 5.24\ \mathrm{GeV}$
- $|\Delta E| < 0.2\ \mathrm{GeV}$
- $\mathrm{signal\ probability} > 0.001$ (omitted for decay mode 23)

All available FEI B^0 hadronic tags are reconstructed. From Thomas Keck's thesis, "the channel $B^0 \to \overline{D}^0 \pi^0$ was used by the FR, but is not yet used in the FEI due to unexpected technical restrictions in the KFitter algorithm".

※ From Sphinx manual, basf2 version: **05-02-18**: "17.2.1. Physics skims - Full event interpretation skims"
(cf. basf2 version which was used to skim: 05-02-11)
※ https://b2-master.belle2.org/software/sphinx/release-05-02-18/skim/doc/02-physics.html#module-skim.fei

06. Analysis Procedure

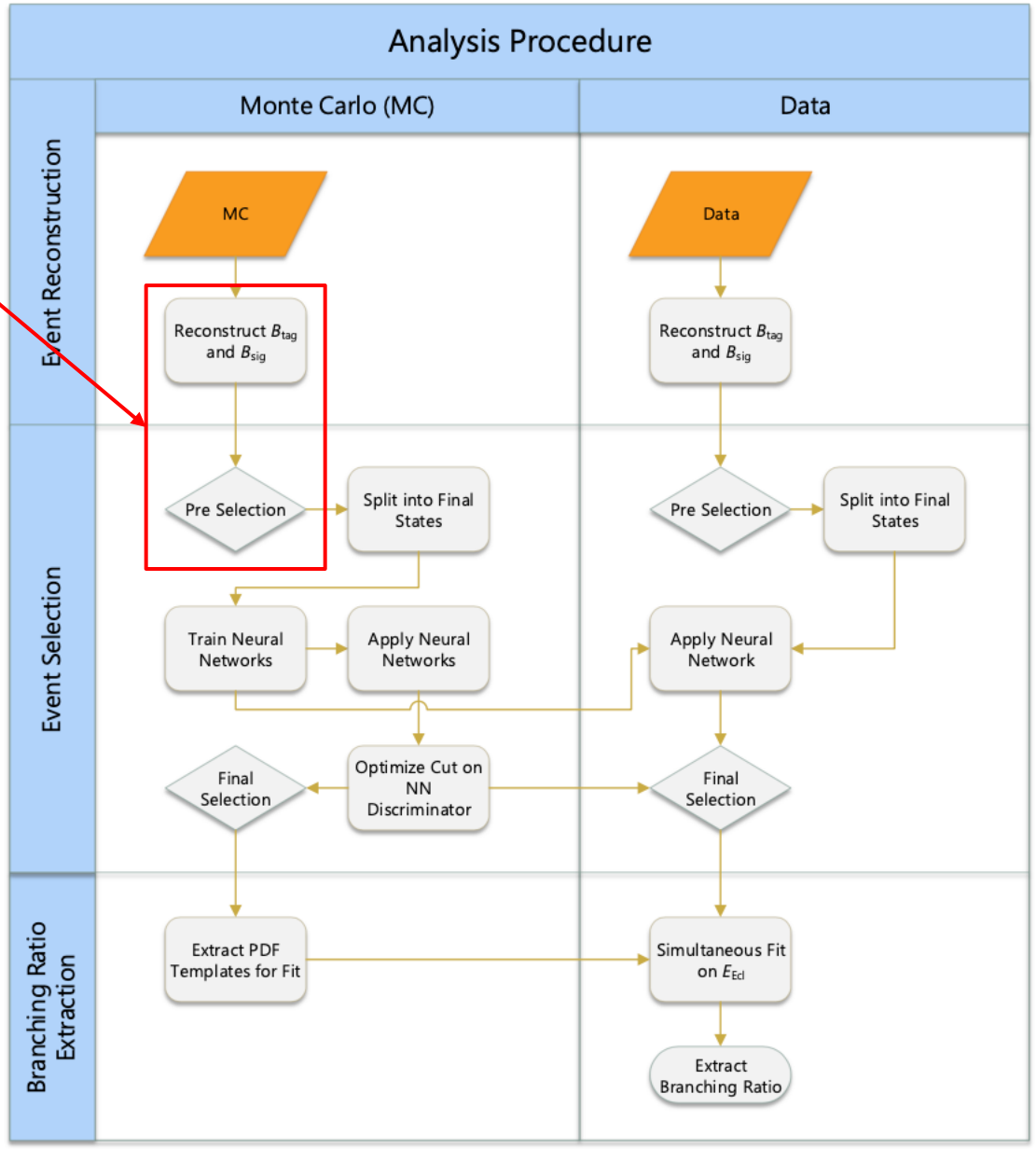
Analysis Procedure



※ From Fig 4.1 of BN-1390

Analysis Procedure: Status

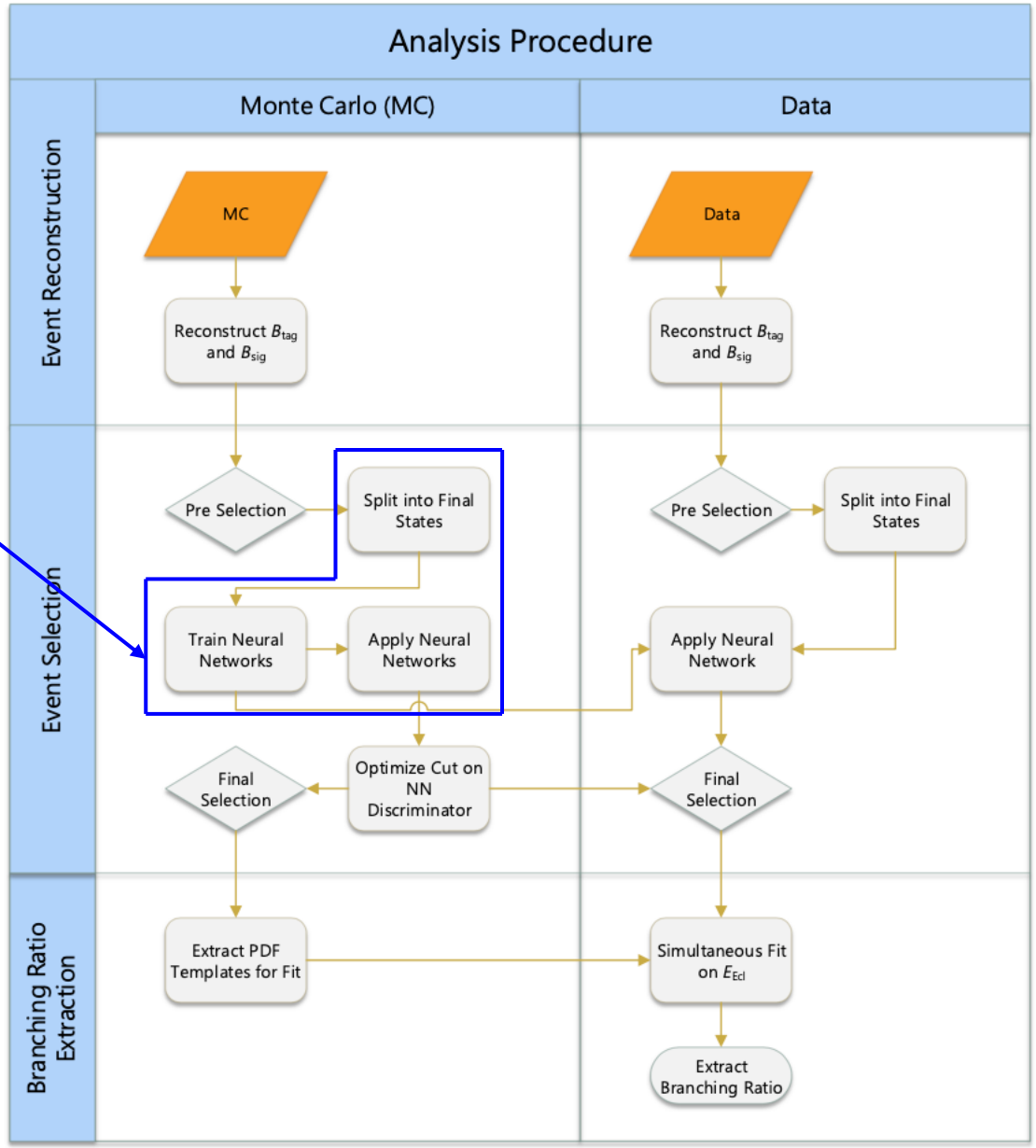
- [Done] Get MC FEI skimmed data
  - Signal MC, Generic MC, Continuum, etc.
- [Ongoing] Signal MC
  - Reconstruction
    - Choose informative variable
      - ex) roeEextra
  - Decide Pre-selection cuts



※ From Fig 4.1 of BN-1390

Analysis Procedure: Status

- **[Ongoing]** Continuum Suppression
  - Signal MC vs. Continuum
- BDT training



※ From Fig 4.1 of BN-1390

07. Motivation Part I

Motivation

- $Br(B \to \tau\tau)$ is very **small** in SM [1]. Currently, **not discovered**.
- Leptoquark model / Higgs double model (or other models) predicts **enhancement** (BSM) [1]

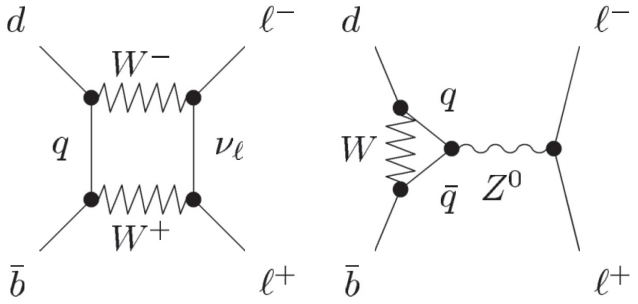


FIG. 1. Standard model box and penguin processes that can mediate $B^0 \to \ell^+\ell^-$ $(q = t, c, u)$. [1]

Theory	Branching fraction	Free parameters
SM prediction	$(2.22 \pm 0.19)\times 10^{-8}$ [2] (2014)	-
Two-Higgs-doublet	It could be several orders of magnitude higher [3]	$tan\beta$, M_{H^+} [4,5]
Leptoquark		$\frac{\lvert\lambda^{33}\lambda^{13^*}\rvert}{M_S^2}$ [4,6]

Table. $B_d \to \tau^+\tau^-$ **Enhancement**

※ From BN1390 [4]

$$\mathcal{B}(B^0 \to \ell^+\ell^-) = \frac{G_F^4 M_W^4 M_B^3}{8\pi^5 \Gamma_B} \cdot \underbrace{f_B^2}_{\text{Decay constant}} \cdot \underbrace{|V_{tb}^* V_{td}|^2}_{\text{CKM elements}} \cdot \underbrace{\frac{4m_\ell^2}{M_B^2}}_{\text{Helicity suppression}} \cdot \underbrace{\sqrt{1-\frac{4m_\ell^2}{M_B^2}}}_{\text{Phase space factor}} \cdot |C_A(\mu)|^2$$

※ Theoretical calculation with the effective field theory

- For $B \to \tau\tau$, ***BR*** is **much higher** than other lepton generation because of large mass.
  - However, τ cannot be detected directly, and sub-decay mode also contain missing particle, so hard to deal with. **No observation**, yet. "~~**Search**~~ **(or highly probably setting upper limit)**" analysis. **We have improved FEI algorithm for missing particle.**
- For $B \to \mu\mu$, ***BR*** is **100** times smaller
  - but muons can be identified with detector level, so it is relatively easier to deal with.
- For $B \to ee$, ***BR*** is too small.

※ FEI: Full Event Interpretation

Motivation

τ sub-decay mode (Belle-BN1390 vs. BABAR vs. LHCb)

- Belle BN1390 [4] (Stopped)

Name	τ decay modes
e^+e^-	$\tau \to e\nu_e\nu_\tau$, $\tau \to e\nu_e\nu_\tau$
$e^\pm\mu^\mp$	$\tau \to e\nu_e\nu_\tau$, $\tau \to \mu\nu_\mu\nu_\tau$
$e^\pm\pi^\mp$	$\tau \to e\nu_e\nu_\tau$, $\tau \to \pi\nu_\tau$
$\mu^+\mu^-$	$\tau \to \mu\nu_\mu\nu_\tau$, $\tau \to \mu\nu_\mu\nu_\tau$
$\mu^\pm\pi^\mp$	$\tau \to \mu\nu_\mu\nu_\tau$, $\tau \to \pi\nu_\tau$
$\pi^+\pi^-$	$\tau \to \pi\nu_\tau$, $\tau \to \pi\nu_\tau$

6 modes ↓ after study

Simulation

UL of BR: $(0.16 \pm 0.30)\times10^{-3}$

Data

Final state	$N_{\rm sig}$	$\mathcal{B}(B^0 \to \tau^+\tau^-)$ (in 10^{-3})
e^+e^-	33 ± 21	$3.33^{+2.23}_{-2.08}$
$e^\pm\mu^\mp$	73 ± 27	$5.52^{+2.09}_{-1.97}$
$e^\pm\pi^\mp$	70 ± 34	$3.05^{+1.53}_{-1.47}$
$\mu^+\mu^-$	40 ± 18	$7.87^{+3.68}_{-3.40}$
$\mu^\pm\pi^\mp$	63 ± 26	$4.76^{+2.03}_{-1.88}$
$\pi^+\pi^-$	44 ± 18	$4.56^{+1.96}_{-1.84}$
Combined	325 ± 27	$4.39^{+0.80}_{-0.83}$

- BABAR Ref [1]

Selection mode	$\mathcal{B}(\%)$ [12]	$N_e + N_\mu$	N_{π^0}	$m_{\pi\pi^0}$
$\tau^+\tau^- \to \ell\nu\bar{\nu}/\ell'\nu\bar{\nu}$	12.4	2	0	
$\tau^+\tau^- \to \ell\nu\bar{\nu}/\pi\nu$	7.8	1	0	
~~$\tau^+\tau^- \to \ell\nu\bar{\nu}/\rho\nu$~~	17.7	1	1	[0.6, 1.0] GeV
$\tau^+\tau^- \to \pi\nu/\pi\nu$	1.2	0	0	
~~$\tau^+\tau^- \to \pi\nu/\rho\nu$~~	5.6	0	1	[0.6, 1.0] GeV
$\tau^+\tau^- \to \rho\nu/\rho\nu$	6.3	0	2	[0.6, 1.0] GeV

10 modes ↓ after study

Selection mode	$\epsilon_{\rm sig}(\%)$	$N_{\rm expected}$	$N_{\rm obs}$
$\tau^+\tau^- \to \ell\nu\bar{\nu}/\ell'\nu\bar{\nu}$	0.9 ± 0.2	46 ± 4	54 ± 7
$\tau^+\tau^- \to \ell\nu\bar{\nu}/\pi\nu$	1.5 ± 0.3	122 ± 6	105 ± 11
$\tau^+\tau^- \to \pi\nu/\pi\nu$	1.5 ± 0.3	89 ± 6	80 ± 11
$\tau^+\tau^- \to \rho\nu/\rho\nu$	0.3 ± 0.1	21 ± 3	15 ± 6

※ $\rho(770)^\pm \to \pi^\pm\pi^0$

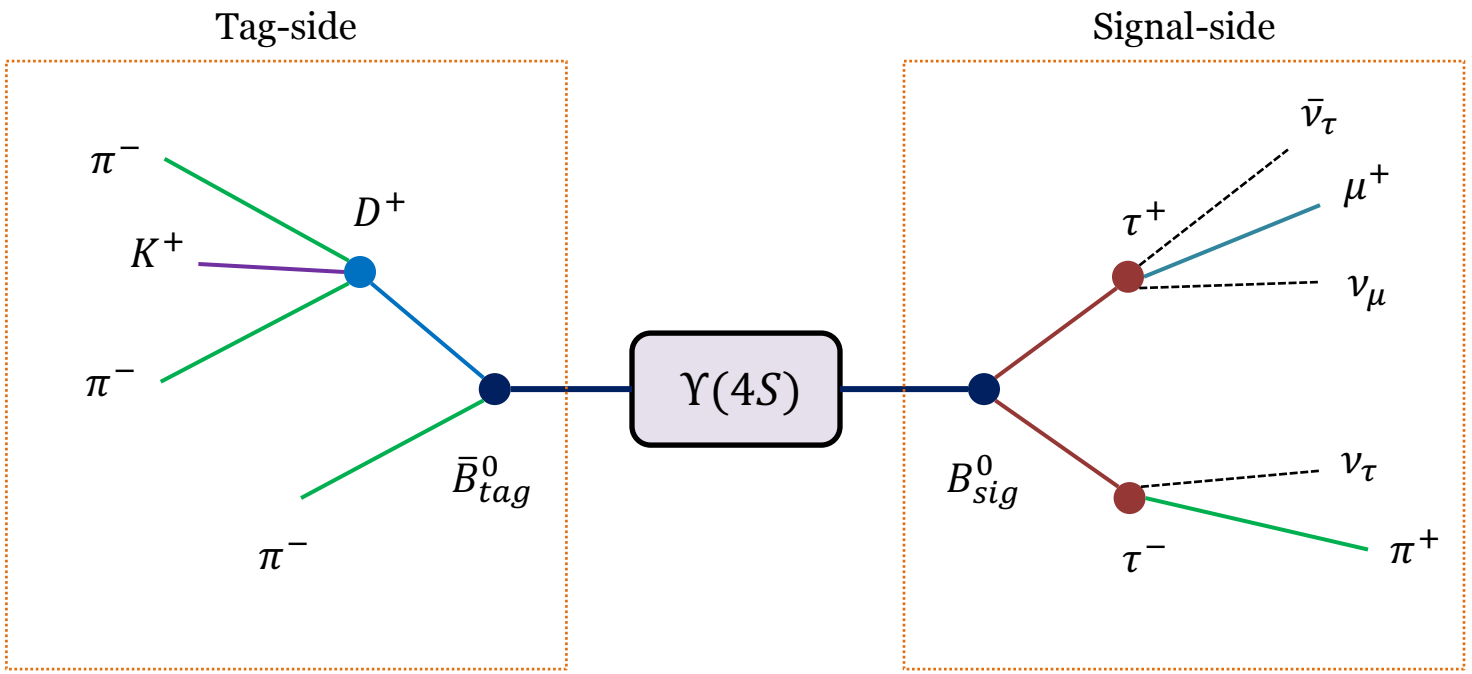
※ I think the reason why the BABAR collaboration used ***ρ* sub-decay mode** is that the branching fraction of this mode is **relatively larger** than other modes, so in order to increase yield.

※ π^0/η separation uncertainty (trade-off)

- LHCb Ref [3]

$\tau^- \to \pi^-\pi^+\pi^-\upsilon_\tau$

Utilizing FEI



※ FEI: Full Event Interpretation

Motivation

Only Belle II data

- Plan to use only Belle II data
  - Since, we already have comparable amount of data with BaBar (~200 fb^{-1}).
  - ~~promising (~500 fb^{-1}) data on around next summer.~~
  - ~~~880 (or ~600) fb^{-1} data before the planned long shutdown.~~
  - ~~~460 fb^{-1} data (?)~~
  - **~427.79 fb^{-1} data (long shutdown data)**
  - The amount of data seems competitive with BaBar.
    - However, efficiencies of detector differ …

References

[1] B. Aubert et al., “Search for the Rare Decay $B^0 \to \tau^+\tau^-$ at BABAR”, BABAR collaboration, PRL (2006)
[2] Christoph Bobeth et al., “$B_{s,d} \to l^+l^-$ in the Standard Model with Reduced Theoretical Uncertainty”, PRL (2014)
[3] R. Aaij et al., “Search for the Decays $B_s^0 \to \tau^+\tau^-$ and $B^0 \to \tau^+\tau^-$”, LHCb collaboration, PRL (2017)
[4] M. Ziegler, “Search for the rare decay $B^0 \to \tau^+\tau^-$ with Belle”, Belle collaboration, Belle Note (BN-1390) (2016)
[5] Heather E. Logan et al., "$B_{s,d} \to \ell^+\ell^-$ in a two-Higgs-doublet model", Nuclear Physic B (2000)
[6] Suchismita Sahoo et al., "Scalar leptoquarks and the rare B meson decays", PRD (2015)

08. Motivation Part II

Motivation

Order Estimation

※ For checking order of magnitude

			B meson				
	Lepton mass [MeV]		Helicity Suppression (HS)	Phase Space Factor (PSF)	HS & PSF		SM prediction result
electron	0.511		3.75E-08	1.00E+00	3.75E-08	5	2.48±0.21E-15 5
muon	106		1.61E-03	9.99E-01	1.61E-03	2	1.06±0.09E-10 2
tau	1776.86		4.53E-01	7.40E-01	3.35E-01		2.22±0.19E-08
	B meons mass [MeV]		Strange B meson				
	5279.65		Helicity Suppression (HS)	Phase Space Factor (PSF)	HS & PSF		
			3.63E-08	1.00E+00	3.63E-08	5	8.54±0.55E-14 5
	Stange B meson mass [MeV]		1.56E-03	9.99E-01	1.56E-03	2	3.65±0.23E-09 2
	5366.3		4.39E-01	7.49E-01	3.29E-01		7.73±0.49E-07 2

※ From BN1390

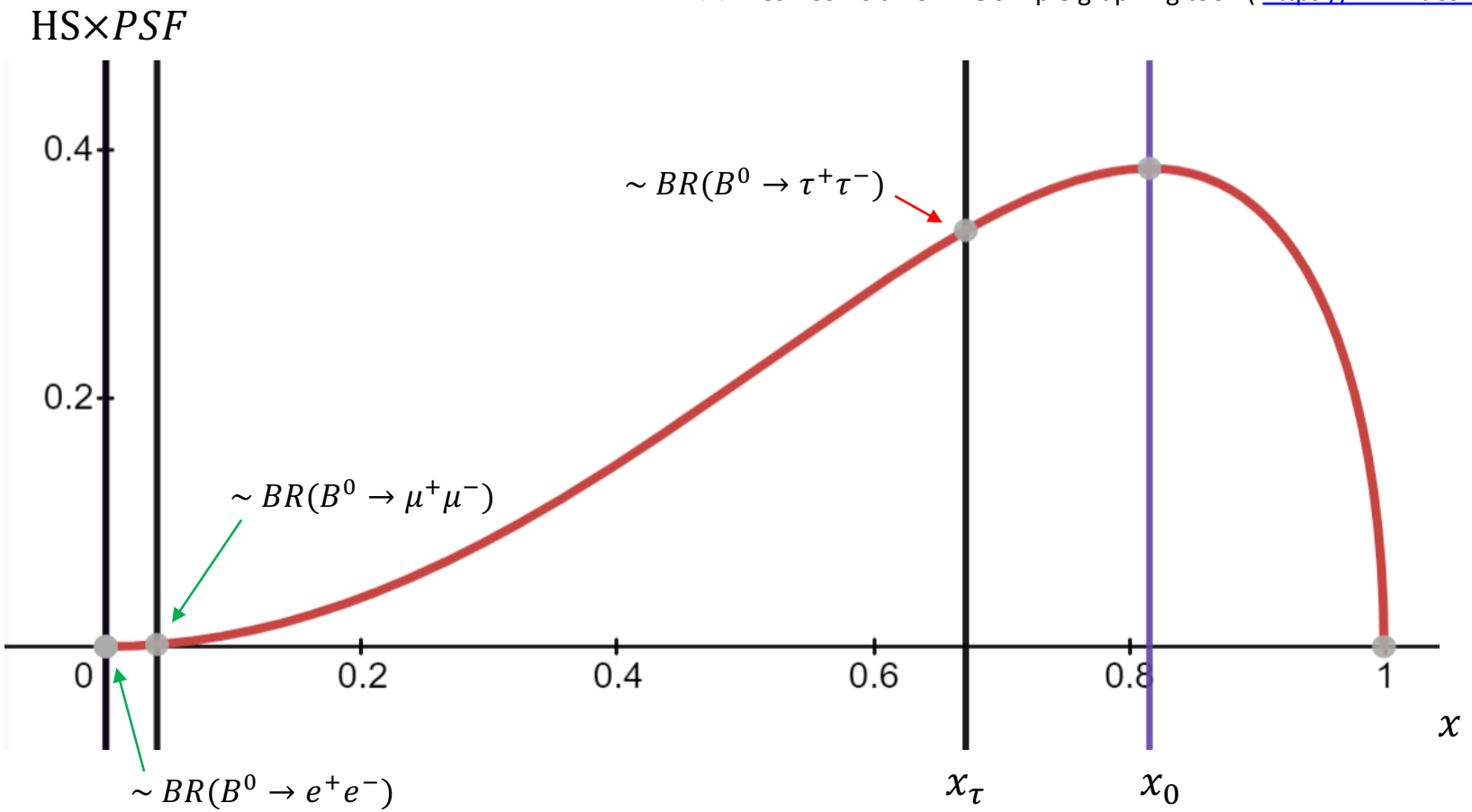
$$\mathcal{B}(B^0 \to \ell^+\ell^-) = \frac{G_F^4 M_W^4 M_B^3}{8\pi^5 \Gamma_B} \cdot \underbrace{f_B^2}_{\text{Decay constant}} \cdot \underbrace{|V_{tb}^* V_{td}|^2}_{\text{CKM elements}} \cdot \underbrace{\frac{4m_\ell^2}{M_B^2}}_{\text{Helicity suppression}} \cdot \underbrace{\sqrt{1-\frac{4m_\ell^2}{M_B^2}}}_{\text{Phase space factor}} \cdot |C_{\mathrm{A}}(\mu)|^2$$

※ Theoretical calculation with the effective field theory

- For $B \to \tau\tau$, ***BR*** is **much higher** than other lepton generation because of large mass.
  - However, τ cannot be detected directly, and sub-decay mode also contain missing particle, so hard to deal with. **No observation**, yet. "**Search (or highly probably setting upper limit)**" analysis. **We have improved FEI algorithm for missing particle.**
- For $B \to \mu\mu$, ***BR*** is **100** times smaller
  - but muons can be identified with detector level, so it is relatively easier to deal with.
- For $B \to ee$, ***BR*** is too small.

Order Estimation

※ “Desmos” is an online simple graphing tool. (https://www.desmos.com/)



- Before $x_0 = 0.8165$, monotonically increasing.
- $x_\tau = 2m_\tau/m_B = 0.6728$ ($x_\ell = 2m_\ell/m_B$)
- $x_\tau < x_0$
- Conclusion: For leptons, BR increase as mass (generation) increase.

Motivation

$B^0 \to ll$ Branching fraction: SM prediction and measurement

	SM prediction	Measurement		
		Detector	Upper Limit	Measurement
$B^0 \to e^+e^-$	$(2.48 \pm 0.21)\times10^{-15}$ [1] (2014)	LHCb	2.5×10^{-9} [2] (2020) (90 % CL) 3.0×10^{-9} [2] (2020) (95 % CL)	-
$B^0 \to \mu^+\mu^-$	$(1.06 \pm 0.09)\times10^{-10}$ [1] (2014)	ATLAS	2.1×10^{-10} [3] (2019) (95 % CL)	$(-0.19 \pm 0.16)\times10^{-9}$ [3] (2019)
		LHCb	3.4×10^{-10} [4] (2017) (95 % CL)	$(0.15^{+0.12\ +0.02}_{-0.10\ -0.01})\times10^{-9}$ [4] (2017)
$B^0 \to \tau^+\tau^-$	$(2.22 \pm 0.19)\times10^{-8}$? [1] (2014)	LHCb	1.6×10^{-3} [5] (2017) (90 % CL) 2.1×10^{-3} [5] (2017) (95 % CL)	-
		Belle (Not published, Expired, Unofficial)	-	$(4.39^{+0.80}_{-.083} \pm 0.45)\times10^{-3}$? [6] (2016)
		BABAR	4.1×10^{-3} [7] (2006) (90 % CL)	-

Table. Recent & Best values of Branching fraction $B^0 \to \ell\ell$

[1] Christoph Bobeth et al., "$B_{s,d} \to l^+l^-$ in the Standard Model with Reduced Theoretical Uncertainty", PRL (2014)
[2] R. Aaij et al., "Search for Rare Decay $B_s^0 \to e^+e^-$ and $B^0 \to e^+e^-$", LHCb Collaboration, PRL (2020)
[3] M. Aaboud et al., "Study of the rare decays of B_s^0 and B^0 mesons into muon pairs using data collected during 2015 and 2016 with the ATLAS detector", ATLAS collaboration, JHEP (2019)
[4] R. Aaij et al., "Measurement of the $B_s^0 \to \mu^+\mu^-$ Branching Fraction and Effective Lifetime and Search for $B^0 \to \mu^+\mu^-$ Decays", LHCb Collaboration (2017)
[5] R. Aaij et al, "Search for the Decays $B_s^0 \to \tau^+\tau^-$ and $B^0 \to \tau^+\tau^-$", LHCb collaboration, PRL (2017)
[6] M. Ziegler, "Search for the rare decay $B^0 \to \tau^+\tau^-$ with Belle", Belle collaboration, Belle Note (BN-1390) (2016)
[7] B. Aubert et al, "Search for the Rare Decay $B^0 \to \tau^+\tau^-$ at BABAR", BABAR collaboration, PRL (2006)
[8] A.M. Sirunyan et al., "Measurement of properties of $B_s^0 \to \mu^+\mu^-$ decays and search for $B^0 \to \mu^+\mu^-$ with the CMS experiment", CMS collaboration, JHEP (2020)

Motivation

$B_s^0 \to ll$ Branching fraction: SM prediction and measurement

	SM prediction	Measurement		
		Detector	Upper Limit	Measurement
$B_s^0 \to e^+e^-$	$(8.54 \pm 0.55)\times10^{-14}$ [1] (2014)	LHCb	9.4×10^{-9} [2] (2020) (90 % CL) 11.2×10^{-9} [2] (2020) (95 % CL)	-
$B_s^0 \to \mu^+\mu^-$	$(3.65 \pm 0.23)\times10^{-9}$ [1] (2014)	CMS	-	$(2.9 \pm 0.6 \pm 0.4)\times10^{-9}$ [8] (2020)
		ATLAS	-	$(2.8^{+0.8}_{-0.7})\times10^{-9}$ [3] (2019)
		LHCb	-	$(3.0 \pm 0.6^{+0.3}_{-0.2})\times10^{-9}$ [4] (2017)
$B_s^0 \to \tau^+\tau^-$	$(7.73 \pm 0.49)\times10^{-7}$ [1] (2014)	LHCb	5.2×10^{-3} [5] (2017) (90 % CL) 6.8×10^{-3} [5] (2017) (95 % CL)	-

Table. Recent & Best values of Branching fraction $B^0 \to \ell\ell$

[1] Christoph Bobeth et al., "$B_{s,d} \to l^+l^-$ in the Standard Model with Reduced Theoretical Uncertainty", PRL (2014)
[2] R. Aaij et al., "Search for Rare Decay $B_s^0 \to e^+e^-$ and $B^0 \to e^+e^-$", LHCb Collaboration, PRL (2020)
[3] M. Aaboud et al., "Study of the rare decays of B_s^0 and B^0 mesons into muon pairs using data collected during 2015 and 2016 with the ATLAS detector", ATLAS collaboration, JHEP (2019)
[4] R. Aaij et al., "Measurement of the $B_s^0 \to \mu^+\mu^-$ Branching Fraction and Effective Lifetime and Search for $B^0 \to \mu^+\mu^-$ Decays", LHCb Collaboration (2017)
[5] R. Aaij et al, "Search for the Decays $B_s^0 \to \tau^+\tau^-$ and $B^0 \to \tau^+\tau^-$", LHCb collaboration, PRL (2017)
[6] M. Ziegler, "Search for the rare decay $B^0 \to \tau^+\tau^-$ with Belle", Belle collaboration, Belle Note (BN-1390) (2016)
[7] B. Aubert et al, "Search for the Rare Decay $B^0 \to \tau^+\tau^-$ at BABAR", BABAR collaboration, PRL (2006)
[8] A.M. Sirunyan et al., "Measurement of properties of $B_s^0 \to \mu^+\mu^-$ decays and search for $B^0 \to \mu^+\mu^-$ with the CMS experiment", CMS collaboration, JHEP (2020)

Amount of data

	Cross section (nb)	Integrated lum. (ab^{-1})	$B\bar{B}$ data
BABAR	1.1	0.210 [2]	$232 \pm 3\times10^6$ [2]
LHCb	~500000*	0.003 [4]	$\sim1500\times10^6$
Belle	0.81	0.953	772×10^6
Belle II LS	1.1	427.79	471×10^6
Belle II 5 ab^{-1}	1.1	5.0	5500×10^6
Belle II 50 ab^{-1}	1.1	50.0	55000×10^6

Table 1. Cross section, Integrated luminosity, and $B\bar{B}$data (black: given, blue: rough calculation)

※ LS: Long Shutdown

[References]
[1] Andrzej J. Buras, “Weak Hamiltonian, CP Violation and Rare Decays”, Lecture note (1998)
[2] B. Aubert et al, “Search for the Rare Decay $B^0 \to \tau^+\tau^-$ at BABAR”, BABAR collaboration, PRL (2006)
[3] Christoph Bobeth et al, “$B_{s,d} \to l^+l^-$ in the Standard Model with Reduced Theoretical Uncertainty”, PRL (2014)
[4] R. Aaij et al, “Search for the Decays $B_s^0 \to \tau^+\tau^-$ and $B^0 \to \tau^+\tau^-$”, LHCb collaboration, PRL (2017)
[5] E. Kou et al, “The Belle II Physics Book (B2TIP)” Belle II collaboration (2019)
* LHCb $b\bar{b}$ cross section: https://iopscience.iop.org/article/10.1088/1748-0221/3/08/S08005

Rough Estimation of the required luminosity

- $Br(B^0 \to \tau^+\tau^-) \sim 2\times10^{-8}$
  - # of B^0: 1
    - then 2×10^{-8} $B^0 \to \tau^+\tau^-$ process
  - # of B^0: 1×10^8
    - then 2 $B^0 \to \tau^+\tau^-$ process
  - # of B^0: 100×10^8 (10000 million)
    - then 200 $B^0 \to \tau^+\tau^-$ process (roughly statistically meaningful)

  - 770 milllion BB pair : 1 ab^{-1} (Belle)
  - (~ 1000 million BB pair : 1 ab^{-1})

  - 10000 million BB pair: 10 ab^{-1}
  - 10^{10} BB pair : 10 ab^{-1}

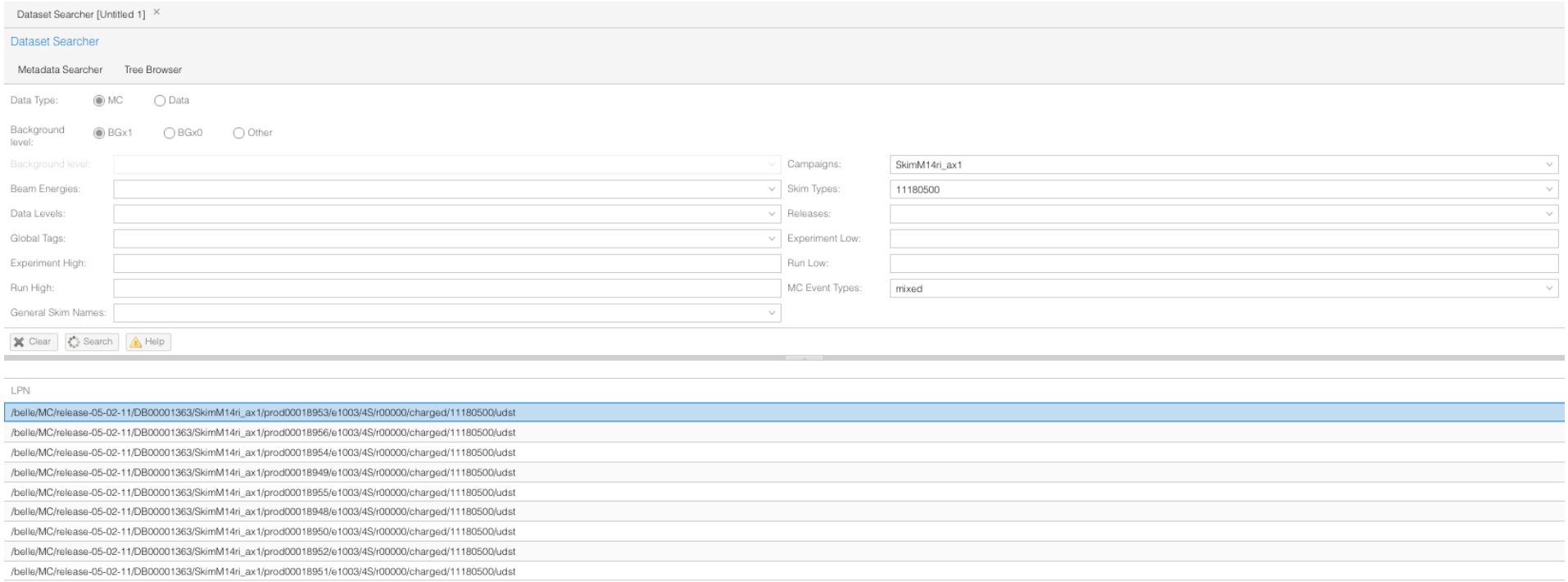
  - Roughly, integrated luminosity of ~ ***10 ab^{-1}*** is required.
    - 10 ab^{-1} analysis

Without considering any efficiencies!

Thus, this is a very very rough estimation. Much more data is required.

09. SkimM14ri_ax1 info.

dataset searcher: ex) FEI hadronic skimmed mixed sample



FEI hadronic skimmed mixed sample list

```
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018941/e1003/4S/r00000/mixed/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018940/e1003/4S/r00000/mixed/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018943/e1003/4S/r00000/mixed/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018942/e1003/4S/r00000/mixed/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018945/e1003/4S/r00000/mixed/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018944/e1003/4S/r00000/mixed/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018946/e1003/4S/r00000/mixed/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018938/e1003/4S/r00000/mixed/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018939/e1003/4S/r00000/mixed/11180500/udst


09


[chkim@ccw03 charged]$ gb2_ds_du /belle/MC/release-05-02-
11/DB00001363/SkimM14ri_ax1/prod00018941/e1003/4S/r00000/mixed/11180500/udst
Operation is in progress, please wait...
      BNL-TMP-SE   5.1 GB
   DESY-DATA-SE  69.4 GB
KEK-DISK-DATA-SE  69.4 GB
TotalSize= 144.0 GB

[chkim@ccw03 charged]$ gb2_ds_du /belle/MC/release-05-02-
11/DB00001363/SkimM14ri_ax1/prod00018940/e1003/4S/r00000/mixed/11180500/udst
Operation is in progress, please wait...
     BNL-DATA-SE  69.5 GB
   DESY-DATA-SE  69.5 GB
TotalSize= 139.0 GB
```

FEI hadronic skimmed charged sample list

```
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018953/e1003/4S/r00000/charged/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018956/e1003/4S/r00000/charged/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018954/e1003/4S/r00000/charged/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018949/e1003/4S/r00000/charged/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018955/e1003/4S/r00000/charged/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018948/e1003/4S/r00000/charged/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018950/e1003/4S/r00000/charged/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018952/e1003/4S/r00000/charged/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018951/e1003/4S/r00000/charged/11180500/udst


09


[chkim@ccw03 charged]$ gb2_ds_du /belle/MC/release-05-02-
11/DB00001363/SkimM14ri_ax1/prod00018953/e1003/4S/r00000/charged/11180500/udst/sub00
Operation is in progress, please wait...
     BNL-DATA-SE  90.9 GB
     BNL-TMP-SE  37.2 GB
    DESY-TMP-SE  16.5 GB
KEK2-Archive-SE  90.9 GB
KEK-DISK-DATA-SE  90.9 GB
TotalSize= 326.6 GB

[chkim@ccw03 charged]$ gb2_ds_du /belle/MC/release-05-02-
11/DB00001363/SkimM14ri_ax1/prod00018956/e1003/4S/r00000/charged/11180500/udst
Operation is in progress, please wait...
 KEK2-Archive-SE  91.0 GB
KEK-DISK-DATA-SE  91.0 GB
  MPPMU-DATA-SE  91.0 GB
TotalSize= 272.9 GB
```

FEI hadronic skimmed uubar sample list

```
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018981/e1003/4S/r00000/uubar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018980/e1003/4S/r00000/uubar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018978/e1003/4S/r00000/uubar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018977/e1003/4S/r00000/uubar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018982/e1003/4S/r00000/uubar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018985/e1003/4S/r00000/uubar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018979/e1003/4S/r00000/uubar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018986/e1003/4S/r00000/uubar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018983/e1003/4S/r00000/uubar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018984/e1003/4S/r00000/uubar/11180500/udst

10
[chkim@ccw03 charged]$ gb2_ds_du /belle/MC/release-05-02-
11/DB00001363/SkimM14ri_ax1/prod00018981/e1003/4S/r00000/uubar/11180500/udst
Operation is in progress, please wait...
      BNL-TMP-SE  18.8 GB
   DESY-DATA-SE 163.3 GB
  HEPHY-DATA-SE 163.3 GB
KEK2-Archive-SE 163.3 GB
     KMI-TMP-SE   1.8 GB
TotalSize= 510.6 GB

[chkim@ccw03 charged]$ gb2_ds_du /belle/MC/release-05-02-
11/DB00001363/SkimM14ri_ax1/prod00018980/e1003/4S/r00000/uubar/11180500/udst
Operation is in progress, please wait...
    DESY-DATA-SE 163.0 GB
    DESY-TMP-SE  28.6 GB
KEK2-Archive-SE 163.0 GB
KEK-DISK-DATA-SE 163.0 GB
  Napoli-TMP-SE  25.9 GB
TotalSize= 543.5 GB
```

FEI hadronic skimmed ddbar sample list

```
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018995/e1003/4S/r00000/ddbar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018991/e1003/4S/r00000/ddbar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018988/e1003/4S/r00000/ddbar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018996/e1003/4S/r00000/ddbar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018987/e1003/4S/r00000/ddbar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018992/e1003/4S/r00000/ddbar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018990/e1003/4S/r00000/ddbar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018989/e1003/4S/r00000/ddbar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018994/e1003/4S/r00000/ddbar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018993/e1003/4S/r00000/ddbar/11180500/udst


10


[chkim@ccw03 charged]$ gb2_ds_du /belle/MC/release-05-02-
11/DB00001363/SkimM14ri_ax1/prod00018995/e1003/4S/r00000/ddbar/11180500/udst
Operation is in progress, please wait...
     BNL-DATA-SE  39.4 GB
KEK2-Archive-SE  39.4 GB
KEK-DISK-DATA-SE  39.4 GB
TotalSize= 118.2 GB

[chkim@ccw03 charged]$ gb2_ds_du /belle/MC/release-05-02-
11/DB00001363/SkimM14ri_ax1/prod00018991/e1003/4S/r00000/ddbar/11180500/udst
Operation is in progress, please wait...
     BNL-DATA-SE  39.5 GB
   DESY-DATA-SE  39.5 GB
KEK2-Archive-SE  39.5 GB
TotalSize= 118.4 GB
```

FEI hadronic skimmed ssbar sample list

```
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018970/e1003/4S/r00000/ssbar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018971/e1003/4S/r00000/ssbar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018972/e1003/4S/r00000/ssbar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018969/e1003/4S/r00000/ssbar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018968/e1003/4S/r00000/ssbar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018967/e1003/4S/r00000/ssbar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018973/e1003/4S/r00000/ssbar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018974/e1003/4S/r00000/ssbar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018975/e1003/4S/r00000/ssbar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018976/e1003/4S/r00000/ssbar/11180500/udst


10

[chkim@ccw03 charged]$ gb2_ds_du /belle/MC/release-05-02-
11/DB00001363/SkimM14ri_ax1/prod00018970/e1003/4S/r00000/ssbar/11180500/udst
Operation is in progress, please wait...
    DESY-DATA-SE  32.9 GB
  HEPHY-DATA-SE  32.9 GB
KEK2-Archive-SE  32.9 GB
KEK-DISK-TMP-SE   4.5 GB
TotalSize= 103.1 GB

[chkim@ccw03 charged]$ gb2_ds_du /belle/MC/release-05-02-
11/DB00001363/SkimM14ri_ax1/prod00018971/e1003/4S/r00000/ssbar/11180500/udst
Operation is in progress, please wait...
   HEPHY-DATA-SE  32.8 GB
KEK2-Archive-SE  32.8 GB
KEK-DISK-DATA-SE  32.8 GB
  MPPMU-DATA-SE  32.8 GB
TotalSize= 131.2 GB
```

FEI hadronic skimmed ccbar sample list

```
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018957/e1003/4S/r00000/ccbar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018960/e1003/4S/r00000/ccbar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018964/e1003/4S/r00000/ccbar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018962/e1003/4S/r00000/ccbar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018965/e1003/4S/r00000/ccbar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018959/e1003/4S/r00000/ccbar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018963/e1003/4S/r00000/ccbar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018966/e1003/4S/r00000/ccbar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018958/e1003/4S/r00000/ccbar/11180500/udst
/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018961/e1003/4S/r00000/ccbar/11180500/udst


10
[chkim@ccw03 charged]$ gb2_ds_du /belle/MC/release-05-02-
11/DB00001363/SkimM14ri_ax1/prod00018957/e1003/4S/r00000/ccbar/11180500/udst
Operation is in progress, please wait...
    DESY-DATA-SE 202.1 GB
KEK2-Archive-SE 202.1 GB
KEK-DISK-DATA-SE 202.1 GB
  Napoli-TMP-SE  16.9 GB
TotalSize= 623.1 GB

[chkim@ccw03 charged]$ gb2_ds_du /belle/MC/release-05-02-
11/DB00001363/SkimM14ri_ax1/prod00018960/e1003/4S/r00000/ccbar/11180500/udst
Operation is in progress, please wait...
     CNAF-TMP-SE  11.9 GB
   DESY-DATA-SE 202.0 GB
KEK2-Archive-SE 202.0 GB
  MPPMU-DATA-SE 202.0 GB
    Pisa-TMP-SE 719.9 MB
TotalSize= 618.5 GB
```

generic sample total size

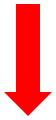
Type	Size per folder	Folders	Total size per type
mixed	~ 150 GB	9	~ 1,350 GB
chraged	~ 300 GB	9	~ 2,700 GB
uubar	~ 500 GB	10	~ 5,000 GB
ddbar	~ 120 GB	10	~ 1,200 GB
ssbar	~ 100 GB	10	~ 1,000 GB
ccbar	~ 600 GB	10	~ 6,000 GB
		Total size	17.250 TB

Signal MC file size

```
/belle/group/physics/SLME/skim_Bd_tautau_21450_1120600000/11180100/udst


1


[chkim@ccw03 dataSample]$ gb2_ds_du
/belle/group/physics/SLME/skim_Bd_tautau_21450_1120600000/11180100/udst/sub00
Operation is in progress, please wait...
    CNAF-DATA-SE    4.4 GB
KEK-DISK-DATA-SE    4.4 GB
KEK-DISK-TMP-SE    4.4 GB
TotalSize= 13.3 GB
```



After reconstruction

278 MB

Generic MC single file

- mixed

/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018941/e1003/4S/r00000/mixed/11180500/udst/sub00/udst_000001_prod00018941_task10020000001.root

532 MB => 27 M

- charged

/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018953/e1003/4S/r00000/charged/11180500/udst/udst_000001_prod00018953_task10020000001.root

985 MB => 28 M

- uubar

/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018981/e1003/4S/r00000/uubar/11180500/udst/udst_000001_prod00018981_task10020000001.root

911 MB => 32 M

- ddbar

/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018995/e1003/4S/r00000/ddbar/11180500/udst/udst_000001_prod00018995_task10020000001.root

602 MB => 22 M

- ssbar

/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018970/e1003/4S/r00000/ssbar/11180500/udst/udst_000001_prod00018970_task10020000001.root

1.6 GB => 39 M

- ccbar

/belle/MC/release-05-02-11/DB00001363/SkimM14ri_ax1/prod00018970/e1003/4S/r00000/ssbar/11180500/udst/udst_000001_prod00018960_task10020000001.root

482 MB => 17 M

average: ~ 25 MB

Total: (25 MB per file) x (100 Files) x (10 Folders) x (6 Types) = ~ 150 GB