TopoAna

Department of Physics, Yonsei Univ.

Jaeyoung Kim (jaeyoung_kim@yonsei.ac.kr)

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Introduction to TopoAna

Component analysis & signal identification with customizable classification and matching algorithm.

- History: more than 10 years

First use – BESIII(τ − charm factory)
Later – extended substantially for Belle II

- Developed with C++, ROOT, LaTeX

References

- https://arxiv.org/abs/2001.04016

TopoAna: A generic tool for the event type analysis of inclusive Monte-Carlo samples in high energy physics experiments

Xingyu Zhou[a,*], Shuxian Du[b], Gang Li[c], Chengping Shen[d,*]

[a]*School of Physics, Beihang University, Beijing 100191, China*
[b]*School of Physics and Microelectronics, Zhengzhou University, Zhengzhou 450000, China*
[c]*Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China*
[d]*Key Laboratory of Nuclear Physics and Ion-beam Application (MOE) and Institute of Modern Physics, Fudan University, Shanghai 200443, China*

- https://github.com/buaazhouxingyu/topoana/blob/master/share/user_guide_v5.1.1.pdf (similar but more detailed description than arxiv)

- https://software.belle2.org/light-2212-foldex/sphinx/online_book/analysis/topoana.html?highlight=topoana

Basics of TopoAna

- Package

Folders: “include”, “src”, “bin”, “share”, “examples”, and “utilities”

Files: “LICENSE”, “README.md”, “Configure”, “Makefile”, and “Setup”

- Inputs

Number of particles : 63

PDG codes of particles :
300553,
−511, 511, −433, 421, 211, 22, −413, 111, 111, 113,
211, −431, 22, −323, 213, −421, −211, 22, 22, 22,
22, 211, −211, 333, 11, −12, 22, −311, −211, 211,
111, 221, 331, 321, −321, 310, 22, 22, 111, 111,
111, 111, 111, 221, 111, 111, 22, 22, 22, 22,
22, 22, 22, 22, 22, 22, 22, 22, 22, 22,
22, 22

Mother indices of particles :
−1,
0, 0, 1, 1, 1, 1, 2, 2, 2, 2,
2, 3, 3, 4, 4, 7, 7, 8, 8, 9,
9, 10, 10, 12, 12, 12, 12, 14, 14, 15,
15, 16, 16, 24, 24, 28, 31, 31, 32, 32,
32, 33, 33, 33, 36, 36, 39, 39, 40, 40,
41, 41, 42, 42, 43, 43, 44, 44, 45, 45,
46, 46

Same

0	$e^+e^- \to \Upsilon(4S)$	-1	9	$\rho^+ \to \pi^0\pi^+$	6
1	$\Upsilon(4S) \to B^0\bar{B}^0$	0	10	$K^{*-} \to \pi^-\bar{K}^0$	6
2	$B^0 \to \pi^0\pi^0\rho^0\pi^+D^{*-}$	1	11	$D_s^- \to e^-\bar{\nu}_e\phi\gamma$	7
3	$\bar{B}^0 \to \pi^+D^0D_s^{*-}\gamma$	1	12	$\eta \to \pi^0\pi^0\pi^0$	8
4	$\rho^0 \to \pi^+\pi^-$	2	13	$\eta' \to \pi^0\pi^0\eta$	8
5	$D^{*-} \to \pi^-\bar{D}^0$	2	14	$\bar{K}^0 \to K_S^0$	10
6	$D^0 \to \rho^+K^{*-}$	3	15	$\phi \to K^+K^-$	11
7	$D_s^{*-} \to D_s^-\gamma$	3	16	$\eta \to \gamma\gamma$	13
8	$\bar{D}^0 \to \eta\eta'$	5	17	$K_S^0 \to \pi^0\pi^0$	14

Basics of TopoAna

- Installation

1. Set up basf2(or ROOT)
2. git clone ssh://git@stash.desy.de:7999/~zhouxy/topoana.git topoana
3. cd topoana && ./Configure
4. make
5. ./Setup Belle_II

(./Setup Belle,BESIII)

- Execution

topoana.exe $cardFileName

```
# The following five items set the input of the program.

% Names of input root files
{
   ../input/jpsi_1.root
   ../input/jpsi_2.root
}

% TTree name
{
   evt
}

% TBranch name of the number of particles (Default: nMCGen)
{
   Nmcps
}

% TBranch name of the PDG codes of particles (Default: MCGenPDG)
{
   Pid
}

% TBranch name of the mother indices of particles (Default: MCGenMothIndex)
{
   Midx
}
```

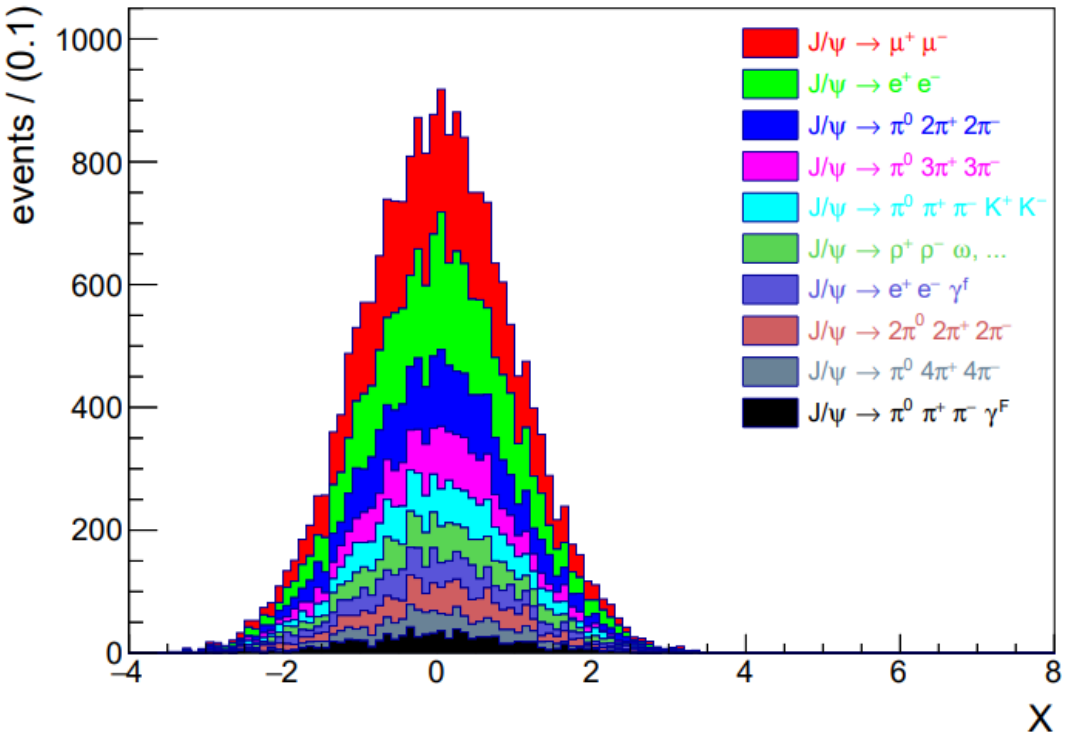
Basics of TopoAna

- Output

.txt, .tex, .pdf, .root

Table 1: Top ten decay trees and their respective final states.

rowNo	decay tree	decay final state	iDcyTr	nEtr	nCEtr
1	$J/\psi \to \mu^+\mu^-$	$\mu^+\mu^-$	6	5269	5269
2	$J/\psi \to e^+e^-$	e^+e^-	4	4513	9782
3	$J/\psi \to \pi^0\pi^+\pi^+\pi^-\pi^-$	$\pi^0\pi^+\pi^+\pi^-\pi^-$	0	2850	12632
4	$J/\psi \to \pi^0\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-$	$\pi^0\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-$	2	1895	14527
5	$J/\psi \to \pi^0\pi^+\pi^-K^+K^-$	$\pi^0\pi^+\pi^-K^+K^-$	20	1698	16225
6	$J/\psi \to \rho^+\rho^-\omega, \rho^+ \to \pi^0\pi^+,$ $\rho^- \to \pi^0\pi^-, \omega \to \pi^0\pi^+\pi^-$	$\pi^0\pi^0\pi^0\pi^+\pi^+\pi^-\pi^-$	19	1453	17678
7	$J/\psi \to e^+e^-\gamma^f$	$e^+e^-\gamma^f$	70	1222	18900
8	$J/\psi \to \pi^0\pi^0\pi^+\pi^+\pi^-\pi^-$	$\pi^0\pi^0\pi^+\pi^+\pi^-\pi^-$	127	1161	20061
9	$J/\psi \to \pi^0\pi^+\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-\pi^-$	$\pi^0\pi^+\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-\pi^-$	234	836	20897
10	$J/\psi \to \pi^0\pi^0\pi^+\pi^-\gamma^F$	$\pi^0\pi^0\pi^+\pi^-\gamma^F$	43	792	21689



Component analysis

Component analysis

- Features

It is developed mainly for background analysis

1. over decay **initial-final states**;

2. with **specified particles** to check their decay branches, production branches, mothers, cascade decay branches, and decay final states;

3. with specified **inclusive** decay branches to examine their exclusive components;

4. with specified **intermediate-resonance-allowed (IRA)** decay branches to investigate their inner structures

Component analysis

- Decay trees
- Decay initial-final states
- Decay branches of particles
- Production branches of particles
- Mothers of particles
- Cascade decay branches of particles
- Decay final states of particles
- Inclusive decay branches
- Intermediate-resonance-allowed decay branches

- Essential topology tags

Component analysis

- Decay trees

Table 2: Decay trees and their respective initial-final states.

rowNo	decay tree (decay initial-final states)	iDcyTr	nEtr	nCEtr
1	$\Upsilon(4S) \to B^0\bar{B}^0, B^0 \to e^+\nu_e D^{*-}\gamma^F, \bar{B}^0 \to \mu^-\bar{\nu}_\mu D^{*+}, D^{*-} \to \pi^-\bar{D}^0,$ $D^{*+} \to \pi^+ D^0, \bar{D}^0 \to \pi^0\pi^- K^+, D^0 \to \pi^0\pi^+ K^-$ $(\Upsilon(4S) \dashrightarrow e^+\nu_e\mu^-\bar{\nu}_\mu\pi^0\pi^0\pi^+\pi^+\pi^-\pi^- K^+K^-\gamma^F)$	20870	3	3
2	$\Upsilon(4S) \to B^0\bar{B}^0, B^0 \to \mu^+\nu_\mu D^{*-}, \bar{B}^0 \to \rho^- D^{*+}, D^{*-} \to \pi^-\bar{D}^0,$ $\rho^- \to \pi^0\pi^-, D^{*+} \to \pi^0 D^+, \bar{D}^0 \to \pi^0\pi^- K^+, D^+ \to \pi^+\pi^+ K^-$ $(\Upsilon(4S) \dashrightarrow \mu^+\nu_\mu\pi^0\pi^0\pi^0\pi^+\pi^+\pi^-\pi^-\pi^- K^+K^-)$	3648	2	5
3	$\Upsilon(4S) \to B^0\bar{B}^0, B^0 \to \pi^0\pi^+\pi^+\rho^- D^-, \bar{B}^0 \to \mu^-\bar{\nu}_\mu D^{*+}, \rho^- \to \pi^0\pi^-,$ $D^- \to \pi^-\pi^- K^+, D^{*+} \to \pi^+ D^0, D^0 \to K_L^0\pi^+\pi^-$ $(\Upsilon(4S) \dashrightarrow \mu^-\bar{\nu}_\mu\pi^0\pi^0 K_L^0\pi^+\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-\pi^- K^+)$	5295	2	7
4	$\Upsilon(4S) \to B^0\bar{B}^0, B^0 \to \mu^+\nu_\mu D^{*-}, \bar{B}^0 \to e^-\bar{\nu}_e D^+, D^{*-} \to \pi^-\bar{D}^0,$ $D^+ \to e^+\nu_e\bar{K}^*, \bar{D}^0 \to \pi^0\pi^+\pi^- K_S^0, \bar{K}^* \to \pi^0\bar{K}^0, K_S^0 \to \pi^+\pi^-, \bar{K}^0 \to K_L^0$ $(\Upsilon(4S) \dashrightarrow e^+e^-\nu_e\bar{\nu}_e\mu^+\nu_\mu\pi^0\pi^0 K_L^0\pi^+\pi^+\pi^-\pi^-\pi^-)$	11954	2	9
5	$\Upsilon(4S) \to B^0\bar{B}^0, B^0 \to e^+\nu_e D^{*-}, \bar{B}^0 \to \pi^0\pi^-\omega D^+, D^{*-} \to \pi^-\bar{D}^0,$ $\omega \to \pi^0\pi^+\pi^-, D^+ \to e^+\nu_e\pi^+ K^-, \bar{D}^0 \to \pi^0\pi^- K^+$ $(\Upsilon(4S) \dashrightarrow e^+e^+\nu_e\nu_e\pi^0\pi^0\pi^0\pi^+\pi^+\pi^-\pi^-\pi^-\pi^- K^+K^-)$	14345	2	11
rest	$\Upsilon(4S) \to$ others (99980 in total) $(\Upsilon(4S) \dashrightarrow$ corresponding to others)	—	99989	100000

Component analysis

- Decay initial-final states

```
% Component analysis — decay initial-final states
{
   Y    5
}
```

Table 3: Decay initial-final states.

rowNo	decay initial-final states	iDcyIFSts	nEtr	nCEtr
1	$\Upsilon(4S) \dashrightarrow \mu^+\nu_\mu\pi^0\pi^0\pi^0\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-\pi^-K^+K^-$	41	18	18
2	$\Upsilon(4S) \dashrightarrow \pi^0\pi^0\pi^0\pi^0\pi^0\pi^+\pi^+\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-\pi^-\pi^-K^+K^-$	887	18	36
3	$\Upsilon(4S) \dashrightarrow \mu^-\bar{\nu}_\mu\pi^0\pi^0\pi^0\pi^0\pi^+\pi^+\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-\pi^-K^+K^-$	3350	18	54
4	$\Upsilon(4S) \dashrightarrow \pi^0\pi^0\pi^0\pi^0\pi^0\pi^0K^0_L\pi^+\pi^+\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-\pi^-K^-$	1207	17	71
5	$\Upsilon(4S) \dashrightarrow \pi^0\pi^0\pi^0\pi^0\pi^0\pi^0\pi^+\pi^+\pi^+\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-K^+K^-$	1215	17	88
rest	$\Upsilon(4S) \dashrightarrow$ others (78208 in total)	—	99912	100000

Component analysis

- Decay branches of particles

```
% Component analysis — decay branches of particles
{
   D*+    Dsp    5
   J/psi  Jpsi   5
}
```

Table 4: Decay branches of D^{*+}.

rowNo	decay branch of D^{*+}	iDcyBrP	nCase	nCCase
1	$D^{*+} \to \pi^+ D^0$	0	31180	31180
2	$D^{*+} \to \pi^0 D^+$	1	13978	45158
3	$D^{*+} \to D^+ \gamma$	2	700	45858
4	$D^{*+} \to \pi^+ D^0 \gamma^F$	3	28	45886

Component analysis

- Production branches of particles

```
% Component analysis — production branches of particles
{
   D*+    Dsp    5
   J/psi  Jpsi   5
}
```

Table 5: Production branches of D^{*+}.

rowNo	production branch of D^{*+}	iProdBrP	nCase	nCCase
1	$\bar{B}^0 \to \mu^- \bar{\nu}_\mu D^{*+}$	9	4154	4154
2	$\bar{B}^0 \to e^- \bar{\nu}_e D^{*+}$	7	2886	7040
3	$\bar{B}^0 \to D^{*+} D_s^{*-}$	4	1691	8731
4	$\bar{B}^0 \to e^- \bar{\nu}_e D^{*+} \gamma^F$	10	1623	10354
5	$\bar{B}^0 \to \pi^0 \pi^+ \pi^- \pi^- D^{*+}$	40	1429	11783
rest	others (3272 in total)	—	34103	45886

Component analysis

- Mothers of particles

```
% Component analysis — mothers of particles
{
   D*+    Dsp    5
   J/psi  Jpsi   5
}
```

Table 6: Mothers of D^{*+}.

rowNo	mother of D^{*+}	PDGMoth	nCase	nCCase
1	$\bar{B}^0$	−511	41751	41751
2	B^0	511	2983	44734
3	$D_1'^+$	20413	455	45189
4	D_1^+	10413	368	45557
5	D_2^{*+}	415	247	45804
rest	others (1 in total)	—	82	45886

Component analysis

- Cascade decay branches of particles

```
% Component analysis — cascade decay branches of particles
{
   B0    B0    5    2
   D0    D0    5    2
}
```

Table 7: Cascade decay branches of B^0 (only the first two hierarchies are involved).

rowNo	cascade decay branch of B^0	iCascDcyBrsP	nCase	nCCase
1	$B^0 \to \mu^+ \nu_\mu D^{*-}, D^{*-} \to \pi^- \bar{D}^0$	12	2912	2912
2	$B^0 \to e^+ \nu_e D^{*-}, D^{*-} \to \pi^- \bar{D}^0$	6	1991	4903
3	$B^0 \to \mu^+ \nu_\mu D^{*-}, D^{*-} \to \pi^0 D^-$	70	1283	6186
4	$B^0 \to e^+ \nu_e D^{*-} \gamma^F, D^{*-} \to \pi^- \bar{D}^0$	18	1132	7318
5	$B^0 \to D^{*-} D_s^{*+}, D^{*-} \to \pi^- \bar{D}^0, D_s^{*+} \to D_s^+ \gamma$	20	1119	8437
rest	$B^0 \to$ others (42074 in total)	—	91594	100031

Component analysis

- Decay final states of particles

```
% Component analysis — decay final states of particles
{
   B0    B0    5    3
   D0    D0    5    3
}
```

Table 8: Decay final states of D^0 (only three-body final states are involved).

rowNo	decay final state of D^0	iDcyFStP	nCase	nCCase
1	$D^0 \dashrightarrow \pi^0\pi^+K^-$	2	6258	6258
2	$D^0 \dashrightarrow \mu^+\nu_\mu K^-$	5	1487	7745
3	$D^0 \dashrightarrow \pi^0\pi^+\pi^-$	1	1162	8907
4	$D^0 \dashrightarrow K_L^0\pi^+\pi^-$	3	1158	10065
5	$D^0 \dashrightarrow e^+\nu_e K^-$	11	1148	11213
rest	$D^0 \dashrightarrow$ others (24 in total)	—	2407	13620

Component analysis

- Inclusive decay branches

```
% Component analysis — inclusive decay branches
{
   B0 -->  D*+    &    B2Dsp    &    5
   B0 -->  K_S0   &    B2Ks     &    5
}
```

Table 9: Exclusive components of $B^0 \to K^0_S + anything$.

rowNo	exclusive component of $B^0 \to K^0_S + anything$	iDcyBrIncDcyBr	nCase	nCCase
1	$B^0 \to K^0_S J/\psi$	0	45	45
2	$B^0 \to K^0_S \eta_c$	1	40	85
3	$B^0 \to K^0_S \psi'$	3	33	118
4	$B^0 \to K^0_S \chi_{c1}$	2	20	138
5	$B^0 \to K^0_S \chi_{c0}$	4	6	144
rest	$B^0 \to K^0_S$ + others (5 in total)	—	9	153

Component analysis

- Intermediate-resonance-allowed decay branches

$$D^{*+} \to \pi^0\pi^+\pi^+K^-$$
$$J/\Psi \to \pi^0\pi^+\pi^-$$

```
% Component analysis — intermediate-resonance-allowed decay branches
{
   D*+ -->  K-  pi+  pi+  pi0    &    Dsp2K3Pi    &    5
   J/psi -->  pi+  pi-  pi0    &    Jpsi23Pi    &    5
}
```

Table 10: Exclusive components of $D^{*+} \dashrightarrow \pi^0\pi^+\pi^+K^-$.

rowNo	exclusive component of $D^{*+} \dashrightarrow \pi^0\pi^+\pi^+K^-$	iDcyBrIRADcyBr	nCase	nCCase
1	$D^{*+} \to \pi^+D^0, D^0 \to \pi^0\pi^+K^-$	0	3869	3869
2	$D^{*+} \to \pi^0D^+, D^+ \to \pi^+\pi^+K^-$	1	1102	4971

Component analysis

- Essential topology tags

Table 11: Essential topology tags involved in each kind of component analysis.

Component type	Topology tag	Interpretation
Decay trees	iDcyTr	index of decay tree
Decay initial-final states	iDcyIFSts	index of decay initial-final states
Decay branches of particles	nPDcyBr_i	number of particle$_i$s (or its decay branches)
	iDcyBrP_i_j	index of decay branch of the jth particle$_i$
Production branches of particles	nPProdBr_i	number of particle$_i$s (or its production branches)
	iProdBrP_i_j	index of production branch of the jth particle$_i$
Mothers of particles	nPMoth_i	number of particle$_i$s (or its mothers)
	PDGMothP_i_j	PDG code of mother of the jth particle$_i$
Cascade decay branches of particles	nPCascDcyBr_i	number of particle$_i$s (or its cascade decay branches)
	iCascDcyBrP_i_j	index of cascade decay branch of the jth particle$_i$
Decay final states of particles	nPDcyFSt_i	number of particle$_i$s (or its decay final states)
	iDcyFStP_i_j	index of decay final state of the jth particle$_i$
Inclusive decay branches	nIncDcyBr_i	number of inclusive decay branch$_i$es
	iDcyBrIncDcyBr_i_j	index of decay branch of the jth inclusive decay branch$_i$
IRA decay branches	nIRADcyBr_i	number of IRA decay branch$_i$es
	iDcyBrIRADcyBr_i_j	index of decay branch of the jth IRA decay branch$_i$

Signal identification

Signal identification

- Help us identify the “signals” we desire directly, quickly, and easily
- Following 8 kinds of signals can be identified

1. Decay trees
2. Decay initial-final states
3. Particles
4. (regular) Decay branches
5. Cascade decay branches
6. Inclusive decay branches
7. Inclusive cascade branches
8. Intermediate-resonance-allowed decay branches

Signal identification

7. Inclusive cascade branches

```
% Signal identification — inclusive cascade decay branches
{
  0   &   anti-B0 --> D*+ *    &   -1
  1   &   D*+ --> pi+ D0    &   0

  0   &   B0 --> K_S0 J/psi    &   -1
  1   &   K_S0 --> pi+ pi-    &   0
  2   &   J/psi --> mu+ *    &   0
}
```

Table 18: Signal inclusive cascade decay branches.

rowNo	signal inclusive cascade decay branch	iSigIncCascDcyBrs	nCase	nCCase
1	$\bar{B}^0 \to D^{*+} + anything, D^{*+} \to \pi^+ D^0$	0	28367	28367
2	$B^0 \to K_S^0 J/\psi, K_S^0 \to \pi^+\pi^-, J/\psi \to \mu^+ + anything$	1	1	28368

Common settings

Common settings

- More settings for input

```
% Cut to select entries
{
   (X > −1) && (X < 1)
}
```

```
% Ignore ISR photons (Three options: Ys, Yg and N. Default: N)
{
   Ys
}
```

```
% Ignore FSR photons (Three options: Ys, Yg and N. Default: N)
{
   Ys
}
```

Common settings

- Charge conjugation

```
% Process charge conjugate objects together (Two options: Y and N. Default: N)
{
   Y
}
```

There are more options