

TopoAna: A Generic Tool for the Event Type Analysis of Inclusive MC Samples

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Important information

- Latest version of the package at KEKCC:
</home/belle2/zhouxy/workarea/tools/topoana/topoana-02-10-01>²
- Documents in the **share** directory of each version of the package:
README.pdf, **quick-start_tutorial_v*.pdf**, and **user_guide_v*.pdf**
- Repository at Stash:
<https://stash.desy.de/users/zhouxy/repos/topoana/browse>
- Repository at GitHub:
<https://github.com/buaazhouxingyu/topoana>
- **Paper** on ScienceDirect:
[Comput. Phys. Commun. 258 \(2021\) 107540](#)
- Preprint on arXiv:
[arXiv:2001.04016](https://arxiv.org/abs/2001.04016)

²The detailed version evolves over time.

Outline

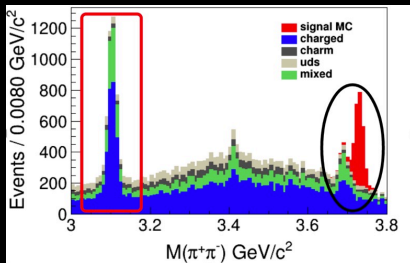
- 1 Introduction
- 2 Basics of the program
- 3 Component analysis
- 4 Signal identification
- 5 Common settings
- 6 Summary

Introduction (I)

- One of the most important tasks in the data analysis of high energy physics experiments is to **select signals**, or in other words, to **suppress backgrounds**.
- As for the task, **inclusive/generic MC samples** are extremely useful, in that they provide basic, though not perfect, descriptions of the signals and/or backgrounds involved.
- To **select signals with a higher efficiency** and meanwhile **suppress backgrounds to a lower level**, a comprehensive understanding of the samples is required.
- In particular, a clear knowledge of the **physics processes**, namely the **event types**, involved in the samples is quite helpful.
- To be specific, the physics process information includes the **types of processes** and the **number of processes in each type**, involved both in the **entire samples** and in the **individual events**.

Introduction (II)

- With the physics process information, we can figure out the **main backgrounds (especially the peaking ones)**.
- Then, we can **optimize the selection criteria** further by analyzing the differences between the main backgrounds and the signals.
- Even if it is difficult to further suppress these backgrounds, the knowledge of their types is beneficial to **estimate the systematic uncertainties** associated with them.



(Thank **Junhao Yin** for the plot!)

- Detailed analysis shows that the **left** peak mainly comes from $J/\psi \rightarrow e^+e^-/\mu^+\mu^-$, instead of $J/\psi \rightarrow \pi^+\pi^-$.

Introduction (III)

- Sometimes, we need to search for **certain processes of interests**.
- Mostly, **signal** and **background** events **coexist** in inclusive MC samples. It is useful to differentiate them in such cases.
- The identified signal events can be **used to make up a signal sample** in the absence of specialized signal samples, or they can be **removed to avoid repetition** in the presence of specialized signal samples.
- Occasionally, we have to pick out some decay branches in order to **re-weight** them according to new theoretical predictions or updated experimental measurements.

physics processes \longleftrightarrow **event type** \longleftrightarrow **topology**

- Since the raw topology truth information of inclusive MC samples is **counter-intuitive**, **diverse**, and **overwhelming**, it is **difficult** for analysts to check the topology information of the samples directly.
- To help them do the checks quickly and easily, a topology analysis program called **TopoAna** is developed with **C++**, **ROOT**, and **LaTeX**.

Basics of the program – Functionalities (I)

The program resolves counter-intuitive, diverse, and overwhelming input data

Number of MC generated particles	:	25
PDG codes of MC generated particles	:	433, -321, 223, 211, -413, 431, 111, 211, -211, 111, -411, 111, 321, 113, 22, 22, 22, 22, 321, -211, -211, 22, 22, 211, -211
Mother indices of MC generated particles	:	-1, -1, -1, -1, -1, 0, 0, 2, 2, 2, 4, 4, 5, 5, 6, 6, 9, 9, 10, 10, 10, 11, 11, 13, 13

into highly readable symbolic expressions of physics processes

0	$e^+ e^- \rightarrow \pi^+ \omega K^- D^{*-} D_s^{*+}$	-1	4	$D^- \rightarrow \pi^- \pi^- K^+$	2
1	$\omega \rightarrow \pi^0 \pi^+ \pi^-$	0	5	$D_s^+ \rightarrow \rho^0 K^+$	3
2	$D^{*-} \rightarrow \pi^0 D^-$	0	6	$\rho^0 \rightarrow \pi^+ \pi^-$	5
3	$D_s^{*+} \rightarrow \pi^0 D_s^+$	0			

Basics of the program – Functionalities (II)

- 1 The program **recognizes**, **categorizes**, and **counts** physics processes in each event of the samples.
- 2 It **tags** the physics processes in the corresponding entry of the output root files.
 - **Except for the tags**, the input TTree object in the output root files is **entirely the same as** that in the input root files.
- 3 After processing the events, the program exports **the obtained topology information at the sample level** (**topology maps**) to the output **plain text**, **tex source**, and **pdf** files.
 - Although the files are in **different formats**, they have the **same information**.
 - The **pdf** file is the **easiest to read**. It is converted from the **tex source** file by the “**pdflatex**” command.
 - The **plain text** file is **convenient** to be checked with text processing commands as well as text editors.

Basics of the program – Package

```
[zhouxy@ccw02 topoana]$ ls
Configure*  Makefile  Setup*  examples/  share/  utilities/
LICENSE    README.md bin/     include/  src/
# topopoana.exe and *.o
```

● Files contained in the package:

- **README.md** – readme file in **markdown** format
- **LICENSE** – **MIT** license under which the program is released
- **Configure**, **Makefile**, and **Setup** – scripts to **install** the software

● Directories contained in the package:

- **include** – directory of the header file (**topoana.h**)
- **src** – directory of the source files (**topoana.C** and ***.cpp**)
- **bin** – directory of the binary files (**topoana.exe** and ***.o**)
- **share** – directory of common data, style, card files and related documents (**README.pdf**, **quick-start_tutorial_v*.pdf**, and **user_guide_v*.pdf**)
- **utilities** – directory of useful bash scripts
- **examples** – directory of examples (**in_the_quick-start_tutorial** and **in_the_user_guide**)

Basics of the program — Installation

- 1 Configure the package path: `./Configure`
 - Notably, you are recommended to **manually** set up the environment variable **PATH** according to the guidelines printed out by the command.
- 2 Compile and link the program: `make`
 - You succeed if you see the following line:
`"topoana.exe" installed successfully!`
- 3 Setup the experiment name: `./Setup Belle_II`
 - If you want to try the program with examples under the directory **examples**, please execute: `./Setup Example`.

Basics of the program — Usage

- 1 Prepare the input data with the interfaces in **basf2**
- 2 Fill in the input card file
 - A template card file (**template_topoana.card**) can be found in the **share** directory.
 - For the concision of your own card file, it is recommended to **just copy the setting items you need from the template card file and paste them to your own card file**, just as we did for the examples in the quick-start tutorial and the user guide.
 - Since there are plenty of setting items in the template card file, it is **NOT** recommended to create your own card file **simply by copying and revising the whole template card file**.
- 3 Execute the program
 - Command line: **topoana.exe cardFileName**
 - The **default** card file name is **topoana.card**
 - Execute **topoana.exe --help** to see other optional arguments supported in the command line

Basics of the program – Interfaces in basf2

TopoAna is a tool independent of basf2, and it needs an interface in basf2 to prepare the input data for it.

- Before release-04, the official NtupleTool `MCGenKinematics` can be used.
- After release-04, the official variable list `MCGenTopo` developed by me can be used.

- 1 Append the statement at the beginning part of python steering files

```
from variables.MCGenTopo import mc_gen_topo
```

- 2 Use the function `mc_gen_topo(n)` as a list of variables in the steering function `variablesToNtuple` as follow:

```
variablesToNtuple(particleList, yourOwnVariableList +  
mc_gen_topo(n), treeName, fileName, path)
```

Here, `n` is the number of `MCGenPDG_i/MCGenMothIndex_i` variables (see next slide), and its default value is `200`.

Basics of the program

A typical entry containing the input information

```
nMCGen          = 94
MCGenPDG_0      = 300553
MCGenMothIndex_0 = -999
MCGenPDG_1      = -511
MCGenMothIndex_1 = 0
MCGenPDG_2      = 511
MCGenMothIndex_2 = 0
MCGenPDG_3      = -213
MCGenMothIndex_3 = 1
MCGenPDG_4      = 411
MCGenMothIndex_4 = 1
MCGenPDG_5      = -311
MCGenMothIndex_5 = 1
MCGenPDG_6      = 311
MCGenMothIndex_6 = 2
```

Only part of the variables are shown here!

The number of MCGenPDG_i/MCGenMothIndex_i is n set in mc_gen_topo(n).

- **nMCGen** — number of MC generated particles
- **MCGenPDG_i** — PDG code of the i^{th} MC generated particle
- **MCGenMothInex_i** — mother index of the i^{th} MC generated particle

Basics of the program – Essential functionality

Items set in the input card file (1)

The following five items set the input of the program.

% Names of input root files

```
{  
  ../input/jpsi1.root  
  ../input/jpsi2.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  
}
```

Basics of the program – Essential functionality

Items set in the input card file (2)

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

The following item sets the basic functionality of the program.

```
% Component analysis – decay trees
{
  Y
}
```

The following item sets the output of the program.

```
% Common name of output files (Default: Name of the card file)
{
  jpsi_ta
}
```

Basics of the program – Essential functionality

Topology Map listed in the output pdf file

Table: Top six decay trees and their respective final states.

rowNo	decay tree	decay final state	iDcyTr	nEtr	nCEtr
1	$J/\psi \rightarrow \mu^+ \mu^-$	$\mu^+ \mu^-$	6	5269	5269
2	$J/\psi \rightarrow e^+ e^-$	$e^+ e^-$	4	4513	9782
3	$J/\psi \rightarrow \pi^0 \pi^+ \pi^+ \pi^- \pi^-$	$\pi^0 \pi^+ \pi^+ \pi^- \pi^-$	0	2850	12632
4	$J/\psi \rightarrow \pi^0 \pi^+ \pi^+ \pi^+ \pi^- \pi^- \pi^-$	$\pi^0 \pi^+ \pi^+ \pi^+ \pi^- \pi^- \pi^-$	2	1895	14527
5	$J/\psi \rightarrow \pi^0 \pi^+ \pi^- K^+ K^-$	$\pi^0 \pi^+ \pi^- K^+ K^-$	20	1698	16225
6	$J/\psi \rightarrow \rho^+ \rho^- \omega, \rho^+ \rightarrow \pi^0 \pi^+, \rho^- \rightarrow \pi^0 \pi^-, \omega \rightarrow \pi^0 \pi^+ \pi^-$	$\pi^0 \pi^0 \pi^0 \pi^+ \pi^+ \pi^- \pi^-$	19	1453	17678

Only the top six decay trees and their respective final states are shown here!

- rowNo – row number
- iDcyTr – index of decay tree
- nEtr – number of entries
- nCEtr – number of cumulative entries

Basics of the program – Essential functionality

Topology Tag inserted in the output root file

- Here, **iDcyTr** is the topology tag for decay trees.
- Thus, it is also **saved in the TTree object of the output root file**, together with other quantities for physics analysis.
- Therefore, it can be used to pick out the entries of specific decay trees in order to **examine the distributions of the other quantities over the decay trees**.

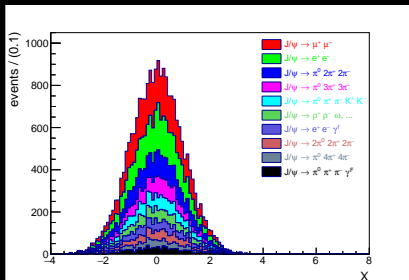


Figure: Distribution of X accumulated over the top ten decay trees.

Component analysis

Component analysis is the **primary** functionality of the program.

- 1 Over decay trees
- 2 Over decay initial-final states
- 3 With specified particles, to check their
 - **decay branches**
 - cascade decay branches
 - decay final states
 - production branches
 - mothers
- 4 With specified inclusive decay branches, to examine their exclusive components
- 5 With specified intermediate-resonance-allowed (IRA) decay branches, to investigate their inner structures

In this tutorial, we only take **the component analysis over the decay branches of specified particles** as an example.

Component analysis – decay branches of particles

Items set in the input card file

```
% Names of input root files
```

```
{  
  ../input/mixed1.root  
  ../input/mixed2.root  
}
```

```
% TTree name
```

```
{  
  evt  
}
```

Parameters in the functionality item

One particle information in **each** row.

- **D*+** and **J/psi** – Particles to be investigated.
- **Dsp** and **Jpsi** – Aliases for D*+ and J/psi, respectively. They will be used in the TBranch names of topology tags.
- **5** and **5** – Maximum numbers of decay branches to be printed.

```
% Component analysis – decay branches of particles
```

```
{  
  D*+   Dsp   5  
  J/psi Jpsi   5  
}
```

Component analysis – decay branches of particles

Topology maps listed in the output pdf file (1)

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

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

- rowNo – row number
- iDcyBrP – index of decay branch of the specified particle
- nCase – number of cases
- nCCase – number of cumulative cases

Component analysis – decay branches of particles

Topology maps listed in the output pdf file (2)

Table: Decay branches of J/ψ .

rowNo	decay branch of J/ψ	iDcyBrP	nCase	nCCase
1	$J/\psi \rightarrow \mu^+ \mu^-$	2	128	128
2	$J/\psi \rightarrow \pi^0 \pi^+ \pi^- \pi^+ \pi^- \pi^-$	9	101	229
3	$J/\psi \rightarrow e^+ e^- \gamma^F$	1	65	294
4	$J/\psi \rightarrow e^+ e^-$	20	56	350
5	$J/\psi \rightarrow \pi^0 \pi^+ \pi^- \pi^+ \pi^- \pi^- \pi^-$	51	51	401
rest	$J/\psi \rightarrow$ others (639 in total)	—	2253	2654

- rowNo — row number
- iDcyBrP — index of decay branch of the specified particle
- nCase — number of cases
- nCCase — number of cumulative cases

Component analysis – decay branches of particles

Topology tags inserted in the output root file

Table: Topology tags inserted in the output ROOT file.

Particle	Topology tag	Interpretation
D^{*+}	nPDcyBr_Dsp	number of D^{*+} (or its decay branches)
	iDcyBrP_Dsp_j	index of decay branch of the j^{th} D^{*+}
J/ψ	nPDcyBr_Jpsi	number of J/ψ (or its decay branches)
	iDcyBrP_Jpsi_j	index of decay branch of the j^{th} J/ψ

Signal identification

Signal identification is the other functionality of the program. Though it is a relatively simple functionality, it can help us identify the physics processes of interests we desire directly, quickly, and easily.

- decay trees
- decay initial-final states
- particles
- (regular) decay branches
- cascade decay branches
- inclusive decay branches
- inclusive cascade decay branches
- IRA decay branches

In this tutorial, we only take the identification of the (regular) decay branches as an example.

Signal identification — decay branches

Items set in the input card file

% Names of input root files

```
{  
  ../input/mixed1.root  
  ../input/mixed2.root  
}
```

% TTree name

```
{  
  evt  
}
```

Parameters in the functionality item

One decay branch information in **each** row.

- **anti-B0 \rightarrow mu $^-$ anti-nu_mu D* $^+$** and **B0 \rightarrow K_S0 J/psi**
— Decay branches to be identified.
- **B2munuDsp** and **B2KsJpsi** — Aliases for the two decay branches, respectively. They will be used in the TBranch names of topology tags.
- **&** — Separator between the decay branches and their aliases.

% Signal identification — decay branches

```
{  
  anti-B0  $\rightarrow$  mu $^-$  anti-nu_mu D* $^+$  & B2munuDsp  
  B0  $\rightarrow$  K_S0 J/psi & B2KsJpsi  
}
```


Signal identification – decay branches

Topology map listed in the output pdf file

Table: Signal decay branches.

rowNo	signal decay branch	iSigDcyBr	nCase	nCCase
1	$\bar{B}^0 \rightarrow \mu^- \bar{\nu}_\mu D^{*+}$	0	4154	4154
2	$B^0 \rightarrow K_S^0 J/\psi$	1	45	4199

- rowNo – row number
- iSigDcyBr – index of signal decay branch
- nCase – number of cases
- nCCase – number of cumulative cases

Signal identification – decay branches

Topology tags inserted in the output root file

Table: Topology tags inserted in the output ROOT file.

Decay branch	Topology tag	Interpretation
$\bar{B}^0 \rightarrow \mu^- \bar{\nu}_\mu D^{*+}$	nSigDcyBr_B2munuDsp	number of $\bar{B}^0 \rightarrow \mu^- \bar{\nu}_\mu D^{*+}$
$B^0 \rightarrow K_S^0 J/\psi$	nSigDcyBr_B2KsJpsi	number of $B^0 \rightarrow K_S^0 J/\psi$

Common settings

About **two dozen** optional items are designed and implemented to control the execution of the program in order to meet practical needs.

- 1 Settings on the input of the program
 - input entries (3 items)
 - input branches (5 items)
 - ISR and FSR photons (4 items and 2 sorts of parameters)
- 2 Settings on the functionalities of the program
 - candidate based analysis (2 items)
 - **charge conjugation** (1 item)
 - Reconstruction restrictions on truth particles (1 sort of parameters)
 - settings only on signal identification (2 items)
- 3 Settings on the output of the program
 - output pdf files (4 items)
 - output root files (7 items)

In this tutorial, we only take **the setting on charge conjugation** as an example.

Common settings – charge conjugation

Items set in the input card file

```
% Names of input root files
```

```
{  
  ../input/mixed1.root  
  ../input/mixed2.root  
}
```

```
% TTree name
```

```
{  
  evt  
}
```

```
% Component analysis – decay branches of particles
```

```
{  
  D*+   Dsp   5  
  J/psi Jpsi   5  
}
```

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

```
{  
  Y  
}
```

Parameters in the functionality item

One particle information in **each** row.

- **D*+** and **J/psi** – Particles to be investigated.
- **Dsp** and **Jpsi** – Aliases for D*+ and J/psi, respectively. They will be used in the TBranch names of topology tags.
- **5** and **5** – Maximum numbers of decay branches to be printed.

Common settings – charge conjugation

Topology maps listed in the output pdf file (1)

Table: Decay branches of D^{*+} (with the charge conjugation setting).

rowNo	decay branch of D^{*+}	iDcyBrP	nCase	nCcCase	nAllCase	nCCase
1	$D^{*+} \rightarrow \pi^+ D^0$	0	31180	31291	62471	62471
2	$D^{*+} \rightarrow \pi^0 D^+$	1	13978	14166	28144	90615
3	$D^{*+} \rightarrow D^+ \gamma$	2	700	721	1421	92036
4	$D^{*+} \rightarrow \pi^+ D^0 \gamma^F$	3	28	36	64	92100
5	$D^{*+} \rightarrow \pi^0 D^+ \gamma$	4	0	1	1	92101

- rowNo – row number
- iDcyBrP – index of decay branch of the specified particle
- nCase – number of cases of the specified particle
- nCcCase – number of cases of the charge conjugate particle
- nAllCase – sum of nCases and nCcCases
- nCCase – number of cumulative cases

Common settings – charge conjugation

Topology maps listed in the output pdf file (2)

Table: Decay branches of J/ψ (with the charge conjugation setting).

rowNo	decay branch of J/ψ	iDcyBrP	nCase	nCcCase	nAllCase	nCCase
1	$J/\psi \rightarrow \mu^+ \mu^-$	2	128	—	128	128
2	$J/\psi \rightarrow \pi^0 \pi^+ \pi^- \pi^+ \pi^- \pi^-$	9	101	—	101	229
3	$J/\psi \rightarrow e^+ e^- \gamma^F$	1	65	—	65	294
4	$J/\psi \rightarrow \pi^0 \pi^- \rho^+$	11	28	34	62	356
5	$J/\psi \rightarrow e^+ e^-$	20	56	—	56	412
rest	$J/\psi \rightarrow \text{others (550 in total)}$	—	—	—	2242	2654

- rowNo — row number
- iDcyBrP — index of decay branch of the specified particle
- nCase — number of cases of the specified particle
- nCcCase — number of cases of the charge conjugate particle
- nAllCase — sum of nCases and nCcCases
- nCCase — number of cumulative cases

Common settings – charge conjugation

Topology tags inserted in the output root file

Table: Topology tags inserted in the output ROOT file.

Particle	Topology tag	Interpretation
D^{*+}	nPDcyBr_Dsp	number of D^{*+} (or its decay branches)
	iDcyBrP_Dsp_j	index of decay branch of the j^{th} D^{*+}
	iCcPDcyBr_Dsp	charge conjugate index of D^{*+}
	nCcPDcyBr_Dsp	number of D^{*-} (or its decay branches)
	iDcyBrCcP_Dsp_j	index of decay branch of the j^{th} D^{*-}
	nAllPDcyBr_Dsp	number of D^{*+} and D^{*-} (or their decay branches)
J/ψ	nPDcyBr_Jpsi	number of J/ψ (or its decay branches)
	iDcyBrP_Jpsi_j	index of decay branch of the j^{th} J/ψ
	iCcPDcyBr_Jpsi	charge conjugate index of J/ψ
	iCcDcyBrP_Jpsi_j	charge conjugate index of decay branch of the j^{th} J/ψ

Summary

- A generic tool for the event type analysis of inclusive MC samples, [TopoAna](#), has been developed.
- It has rich functionalities and aims to solve all kinds of event type analysis tasks. Meanwhile, it is efficient and easy to use.
- These features make it powerful for analysts to investigate the signals and backgrounds involved in their works.
- The interface of basf2 to it, [MCGenTopo](#), has been developed.
- A brief **quick-start tutorial** and a detailed **user guide** have been written up and are put under the **share** directory of the package.
- The **paper** on it has been published:

[Comput. Phys. Commun. 258 \(2021\) 107540](#)³

³If the tool really helps your researches, we would appreciate it very much if you could cite the paper in your publications.

Welcome to TopoAna

Best way to learn how to use TopoAna:

- 1 try the [examples](#) under [examples/in_the_quick-start_tutorial](#), with the [quick-start tutorial](#) under [share](#) as a reference.
- 2 try the [examples](#) under [examples/in_the_user_guide](#), with the [user guide](#) under [share](#) as a reference.

Please let us know:

- if you encounter any problems with it,
- if you have any questions about it,
- if you find any bugs in it,
- if you have any suggestions on improving it,
- if you want to extend its functionalities.

We hope it can be helpful to your studies.

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