Investigation of background subtraction technique for new physics

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Outline

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• Event-Mixing Method
  • Concept and history
  • Pros and cons
  • Correlated distribution
  • Modeling of combinatorial background

• Application to new physics
Introduction

- A standard way to observe resonance production
  - make an invariant mass distribution of particles which may be decay products of resonances

- An estimation of the background is essential
  - if the background has a simple falling or rising form, it will not be difficult to approximate the background shape with an analytical function
Background estimation

- A potential problem with an analytical function
  - kinematic restrictions induced by the experimental setup and the event selection can lead to wrong estimation
  - it requires further study to understand the effects of detector acceptance and event selection cuts in the analysis

- Event mixing to overcome these problems
  - artificial mass distribution obtained from taking one particle from one event and the other particle from another event
  - cross-event particle combinations are called mixed events
Background subtraction

- In hadron colliders, lots of particles produced in a single event
  - reconstruct particles by misidentifying their decay product
- Reconstruction of $Z^0$ in di-lepton mass: $Z^0 \rightarrow e^+e^- / \mu^+\mu^-$
  - collect a sample of opposite-sign same-flavor (OSSF) pairs
  - combinatorial: opposite-sign opposite-flavor (OSOF) pairs

$$h(\text{OSSF}) - C \cdot h(\text{OSOF}) \text{ in } m_{ll} \text{ distribution}$$

- However, such a subtraction technique not available for jets
  - introduced & developed Bi-Event Subtraction Technique (BEST)

Event mixing

- To estimate the background
  - mass distribution with combinations of particles from different events (e.g., three jets in top quark reconstruction)
Mixed events

- To estimate the background

- mass distribution with combinations of particles from different events (e.g., three jets in top quark reconstruction)
History of event mixing

- Idea came up in the 1970s in the meson physics
  - interference analyses with di-pion sources: distribution calculated from two pions from different events is used for the modeling of the non-interfering contribution

- Modeling of the combinatorial background in invariant two-particle mass spectra
  - used to extract $\rho$ and $\omega$ resonances from the di-pion spectrum at the ISR storage ring at CERN
  - provided background predictions in other di-particle mass spectra (kaons, protons, and pions) searching for further resonances and setting limits

- but, another experiment found that it is not a suitable method
Pros and cons

• Pros
  ✦ no application of kinematical fitting to reconstruction of decay products of resonances

• Cons
  ✦ a correlation if
    ☐ same kinematical restrictions are applied to event mixing
    ☐ combining two particles from different events whose mass distribution is narrower than that of the combinatorial background
Selection of bi-event

- Most important requirements
  - mixing events with the same number of jets
  - mixing jets with the angular separation of $\Delta R > 0.5$

$$\Delta R(q,q) > 0.5 \quad \Delta R(q,k) > 0.5$$

![Diagram showing two events with jets angular separation](image)
Correlated distribution

- Combining two particles from different events
  - Each jet contributes a resonance ($W \rightarrow qq$) in corresponding event
Correction

• Negative in background subtraction due to a correlation induced by event mixing

\[ \Rightarrow \text{negative resulted by subtraction} \]

• We should make a correction for this

D. Drijard, H. Fischer, and T. Nakada
“Study of Event Mixing and its Application to the Extraction of Resonance Signals”
doi:10.1016/0167-5087(84)90275-8
However

- Combining three particles from different events
  - no such a correlation, thus no correction
Second mixing

- Combining three particles from different events
  - requires that we perform mixing twice taking into account wrong permutation issue
MC simulation

- Input: combinatorial background of $t\bar{t} +$ jets events
  ✦ modeled by event mixing

Di-jets invariant mass

Three-jets invariant mass

Work in progress
New physics

- Bump search
- Dark matter (MET + 3 jets)
- SUSY
- ttH (lepton + 6 jets)

s-channel resonant case
Summary

• A very common approach for hints of a new physics
  ✦ search in the invariant mass distribution of observed particles

• Modeling of the combinatorial background
  ✦ presented a very brief review of an established background estimation method with the event-mixing technique
  ✦ developing event-mixing technique to estimate $t\bar{t}$ background, which needs to be tested and validated with simulated events

• Application to new physics
  ✦ In association with top quark (pairs)
Backup
**BEST**


- **Bi-Event Subtraction Technique** is to model and subtract dominant combinatorial background during reconstruction of particle decay chains at hadron colliders.
- **Event mixing** is used to estimate the background (the mass distribution with combinations of particles from different collisions).
- Basic idea is for the reconstruction of the W boson decaying into two jets at LHC.
- A general application to the reconstruction of the top quark ($t \rightarrow Wb$).

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**Event mixing**

Jet pairs come from the same event: **Signal** or **Combinatoric background**

Another sample of jet pairs where each jet comes from a different event: **Combinatoric background** or **Non-existent background**

*(Event mixing presented by E. Kwon at LHCC poster)*

**MC study**

*BEST is for both the top quark mass and other measurements. Interesting for new physics!*