Z' search in 2f final states with ILC 500 GeV

2023/09/04

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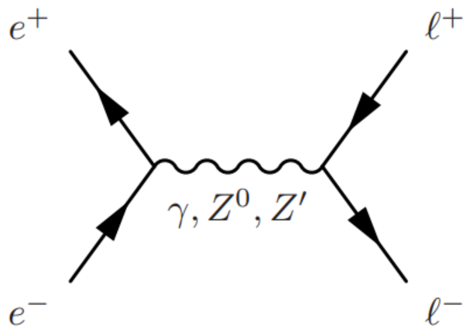
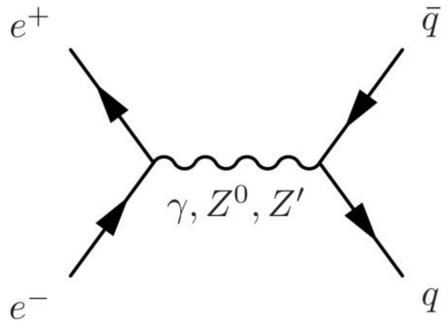
2-fermion $e^+e^- \to f^+f^-$ event

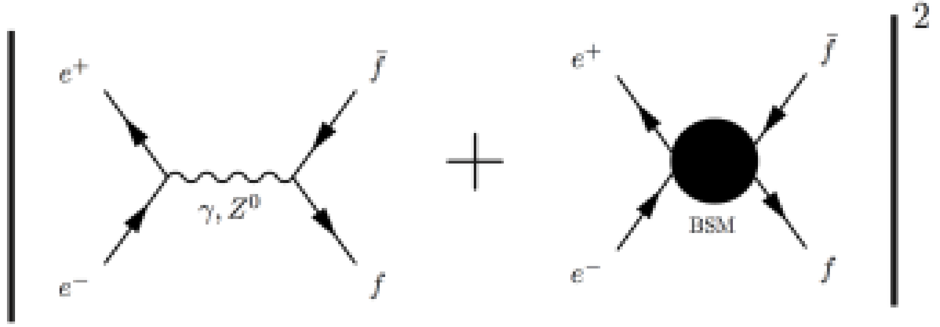
- $e^+e^- \to f^+f^-$: The production of fermionic pairs is sensitive to the production of heavy gauge bosons (Z'). In the presence of new physics mediated by new particles, total and differential cross section can be deviated from the standard model as shown in the interference diagram below.



2 lepton process



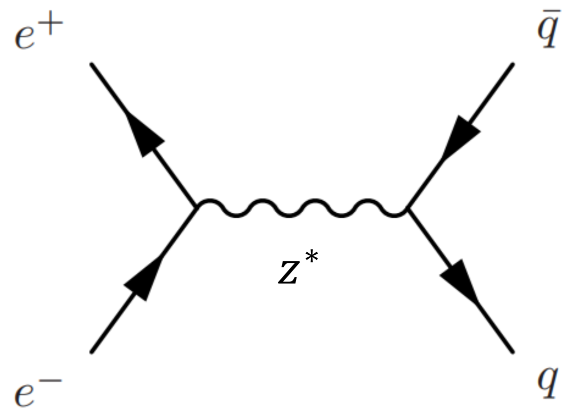
2 quark process



Feynman diagram of fermion pair production when the new physics (Beyond Standard Model : BSM) is included

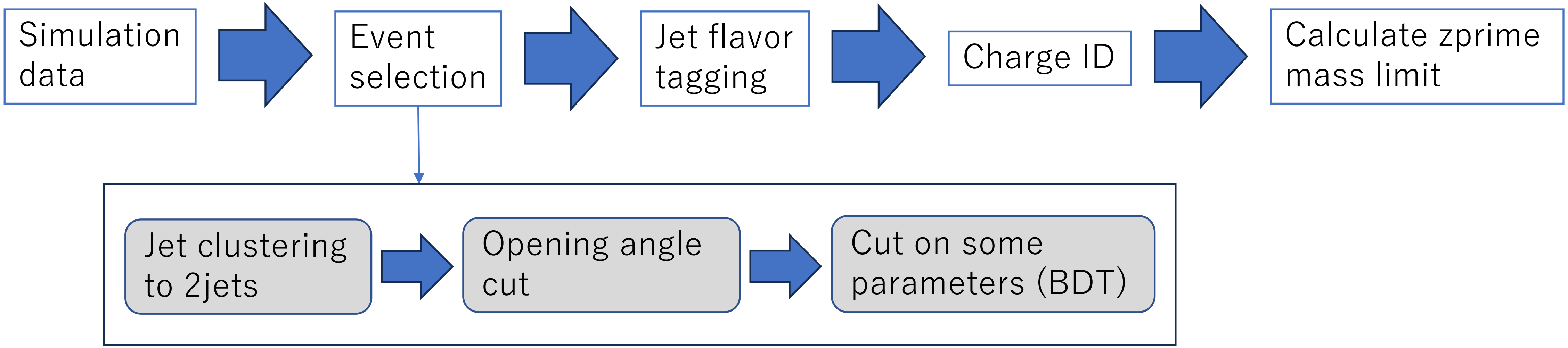
Use below events for qq event

- $quark$ **event selection with the ILD 500 GeV full simulation.**
- **Signal Event**:
  - $e^+e^- \to qq$(z^* true mass≥450 GeV)
- **Background Event**:
  - 2-fermion background
    $e^+e^- \to qq$(z^* true mass<450 GeV)
  - 4-fermion background
    hadronic event(Mainly W/Z-derived)
    semileptonic event(Mainly W/Z-derived)



- **Polarization** **Luminosity**
- e^-: -80% , e^+: $+30\%$ 1600 fb^{-1} each

Evaluation flow at quark event



	signal	**2f BG**	**4f hadronic BG**	**4f semileptonic BG**
No cut	6,183,923 (100%)	25,197,014 (100%)	13,832,211 (100%)	19,630,562 (100%)
event cut	**4,871,598 (78%)**	**502,037 (2%)**	**856,414 (6%)**	**95,682 (0.6%)**

quark flavor tagging

- To evaluate the new physics search, we make a cos theta distribution for each signal quark.
- To do this, I first conduct flavor tagging on the signals and separate them into b, c, and others.

After event cut

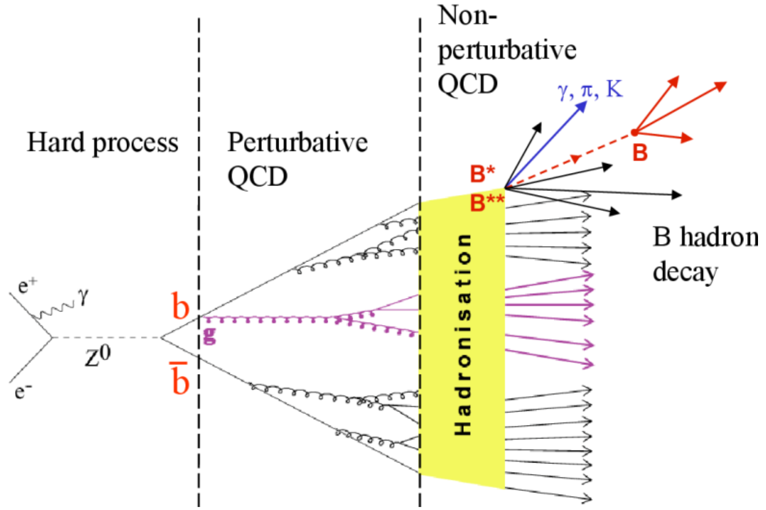
predicted flavor (columns) / **true flavor** (rows)

	qq(u,d,s)	cc	bb	others
qq(u,d,s)	**2,661,403**	83,956	36,887	34,311
cc	266,296	**834,452**	89,949	10,348
bb	13,535	21,423	**705,974**	5,104

Flavor tagging is performed on the two jets of reconstituted particles
and events are used if the respective flavors match,
events that do not match are others.

Charge ID: Jet-charge measurement method

Jet-charge measurement method	vertex charge ***Vtx*-method**	Kaon charge **K-method**
Jet charge is	**the charge of the vertex**, defined as **the sum of the charges of all tracks in the secondary vertices in the jet.**	**the sum of all the identified kaons reconstructed in secondary vertices inside the jet.**



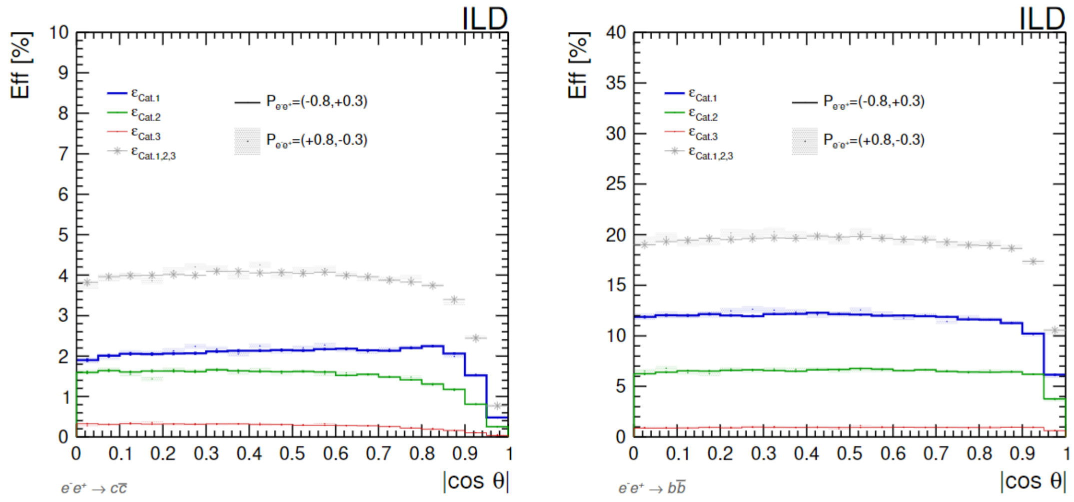


Figure 18: Distribution of the different selection efficiencies for $c\bar{c}$ (left) and $b\bar{b}$ (right) for the A_{FB} measurement, as described in Eq. 22. For the $c\bar{c}$ ($b\bar{b}$) case, the $Cat.1$ corresponds to only the K-method (Vtx-method) applied and $Cat.2$ to only the Vtx-method (K-method) applied.

- For $c\bar{c}$
  - Cat.1 ->K-method
  - Cat.2 ->Vtx-method
  - Cat.3 ->Method in which one of the jets had no measurement of the charge using K-method but had it with Vtx-method
- For $b\bar{b}$
  - Cat.1 ->Vtx-method
  - Cat.2 ->K-method
  - Cat.3->Method in which one of the jets had no measurement of the charge using Vtx-method but had it with K-method

reference.
ILD-PHYS-PUB-2023-001, June 2023,
"Experimental methods and prospects on the measurement of electroweak b and c-quark observables at the ILC operating at 250 GeV"

Procedures for evaluating each model search

- The accuracy ($\delta\sigma_i/\sigma_i(SM)$) in the ILC of the i-th bin of the angular distribution is evaluated as

$$\frac{\delta\sigma_i}{\sigma_i(SM)} = \sqrt{\left(\frac{\sqrt{S_i + N_i}}{S_i}\right)^2 + \sigma_{syst}{}^2}$$

S_i: **the number of signal events** **in each bin.**
N_i: **the number of background events**
In this evaluation, **systematic errors of 0.0 for b and 0.0 for c** are assumed.

- The deviation of the differential cross section predicted by the standard model and each model for this i-th bin ($\delta\sigma_i(BSM)/\sigma_i(SM)$) is determined, and from

$$\chi^2(BSM) = \sum_i \left\{\left(\frac{\delta\sigma_i(BSM)}{\sigma_i(SM)} / \frac{\delta\sigma_i}{\sigma_i(SM)}\right)^2\right\},$$

the χ^2 is obtained.

Calculate efficiency (costheta-dependent)

- Efficiency(costheta-dependent) for each bin of bb,cc events
- For bb events (same for cc),

$$efficiency\_angle = \frac{\#\ of\ (true\ bb\ )\ w/eventcut}{\#\ of\ (true\ bb\ )\ w/o\ eventcut} \times \frac{\#\ of\ predicted\ bb}{\#\ of\ predicted\ total} \times Charge\ ID\ efficiency$$

The below case is used as the 1bin case.

$$efficiency\_1bin = \frac{\#\ of\ (true\ bb\ )\ w/eventcut}{\#\ of\ (true\ bb\ )\ w/o\ eventcut} \times \frac{\#\ of\ predicted\ bb}{\#\ of\ predicted\ total} \times (1 - Charge\ ID\ efficiency)$$

- Since the angle-dependent range is from -0.9 to 0.9, but the charge ID efficiency is from 0 to 0.9.
- So, I calculate the angle-dependent efficiency in this range and use the same value for the -0.9 to 0 range.

- I calculate the same way for number of background events.

Mass limit for bb, cc (preliminary)

SSM: Sequential Standard Model
ALR : Alternative Left-Right symmetric
chi : E_6 χ $model$ $(\beta = 0)$
psi : E_6 ψ $model$ $(\beta = \pi/2)$
eta : E_6 η $model$ $(\beta = \pi - \arctan\sqrt{5/3})$

For bb

Z'model	SSM	ALR	χ	ψ	η
5-sigma	6.8 TeV	2.8 TeV	4.4 TeV	2.9 TeV	2.4 TeV
2-sigma	10.4 TeV	4.2 TeV	6.7 TeV	4.3 TeV	3.5 TeV

For cc

Z'model	SSM	ALR	χ	ψ	η
5-sigma	5.1 TeV	4.5 TeV	2.5 TeV	2.3 TeV	2.5 TeV
2-sigma	7.8 TeV	6.8 TeV	3.8 TeV	3.5 TeV	3.7 TeV

For bb+cc

Z'model	SSM	ALR	χ	ψ	η
5-sigma	6.8 TeV	4.3 TeV	4.2 TeV	2.9 TeV	2.7 TeV
2-sigma	9.0 TeV	5.7 TeV	5.6 TeV	3.9 TeV	3.5 TeV

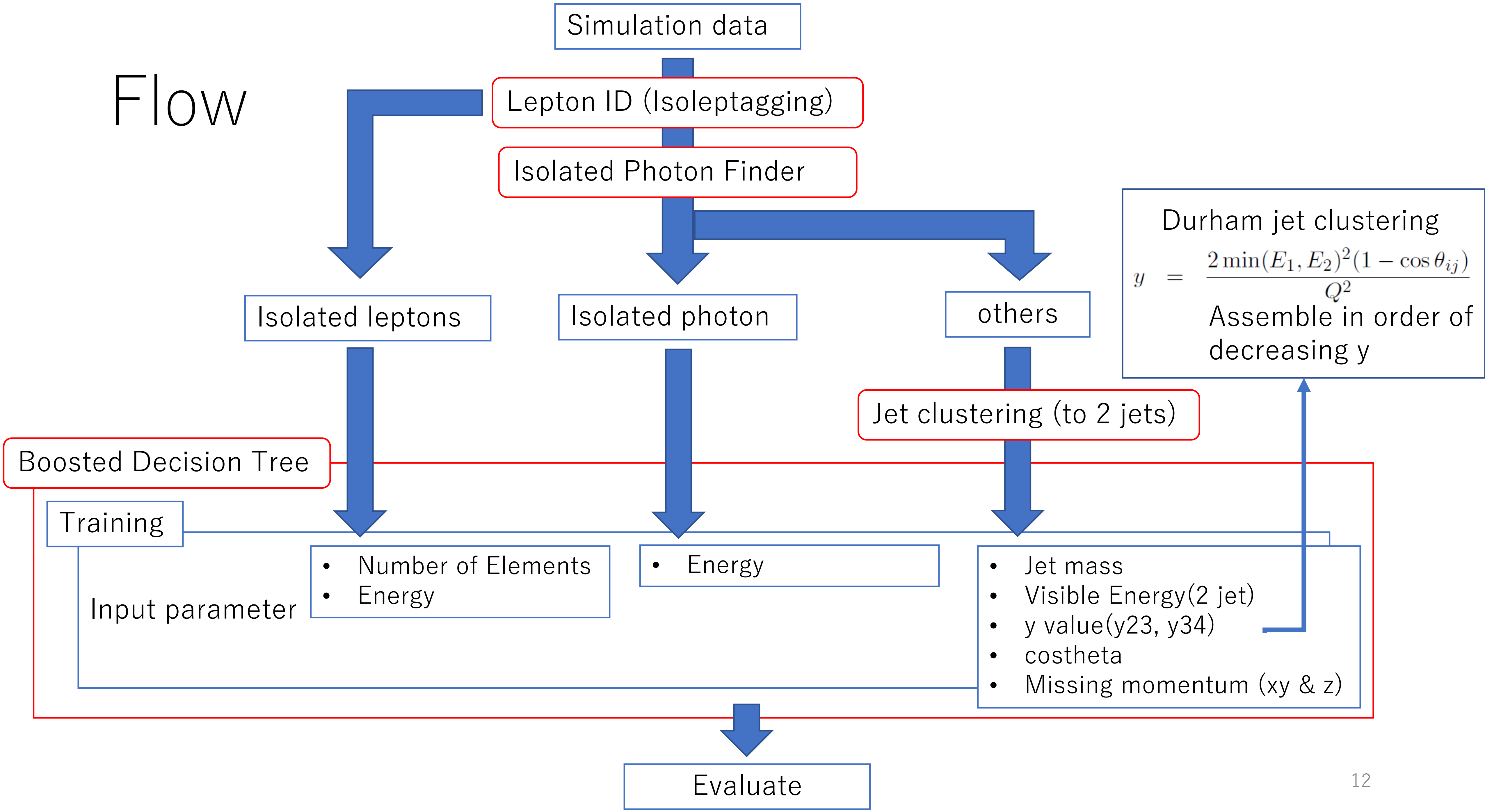
Summary

- I performed the calculation for the mass limit when combining bb and cc event.
- The calculation is still in progress, so I will calculate the detailed values.

- As a next step, electron and lepton pair events will also be combined for evaluation.

backup

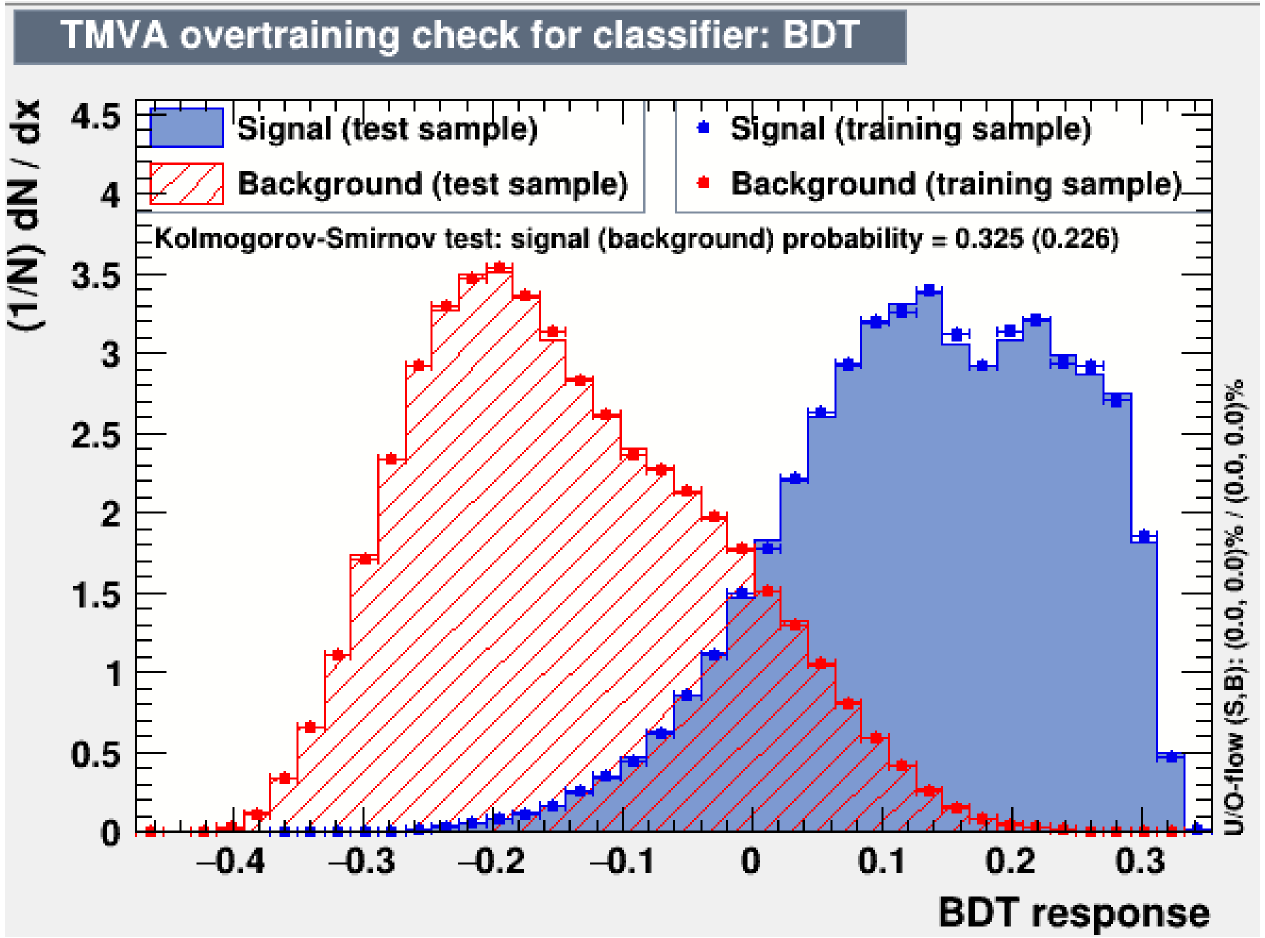
Flow



Simulation data
Lepton ID (Isoleptagging)
Isolated Photon Finder
Isolated leptons
Isolated photon
others
Durham jet clustering
$y = \frac{2\min(E_1, E_2)^2(1 - \cos\theta_{ij})}{Q^2}$
Assemble in order of decreasing y
Jet clustering (to 2 jets)
Boosted Decision Tree
Training
Input parameter
• Number of Elements
• Energy
• Energy
• Jet mass
• Visible Energy(2 jet)
• y value(y23, y34)
• costheta
• Missing momentum (xy & z)
Evaluate

Training & Evaluate

- Cut condition
- Opening angle cut:
  - $\cos(angle) \leq -0.95$
- BDT_response >= 0.0



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