Search for SUSY DM at future ep colliders

Kechen Wang

August 29, 2017

Signal Event Generating

Collider:
FCC-eh (Ep = 50 TeV, Ee = 60 GeV).

(1) The benchmark point for "**Signal (3)**" will be:
Bino ~ m_{neutralino1} = 199 GeV;
Wino ~ m_{chargino1} = m_{neutralino2} = 200 GeV;
m_{slepton_R} = m_{slepton_L} = 225 GeV.

```
import model mssm-full
define dm = x1+ x1- n1 n2
generate p e- > j e- dm dm / go ul cl t1 ur cr t2 dl sl b1 dr sr b2 ul~ cl~ t1~ ur~ cr~ t2~ dl~ sl~ b1~ dr~
sr~ b2~  h2 h3 h+ h- sve svm svt el- mul- ta1- ta2- sve~ svm~ svt~ el+ mul+ ta1+ ta2+ n3 n4 x2+ x2-
```

The SM background for "light slepton scenario" will be:
(a) two-neutrino process:
define dm = ve vm vt ve~ vm~ vt~
generate p e- > j e- dm dm

(b) one-neutrino process:
generate p e- > j e- l vl

Will do the "MadGraph + PYTHIA + Delphes" simulation and try to finish the analysis at detector-level using the BDT method.

Pre-selection cuts

For BDT analysis:

Input Signal (3):
Bino ~ m_{neutralino1} = 199 GeV;
Wino ~ m_{chargino1} = m_{neutralino2} = 200 GeV;
m_{slepton_R} = m_{slepton_L} = 225 GeV.

Input Background: (a) + (b)
(a) two-neutrino process:
(b) one-neutrino process:

Pre-selection cuts:

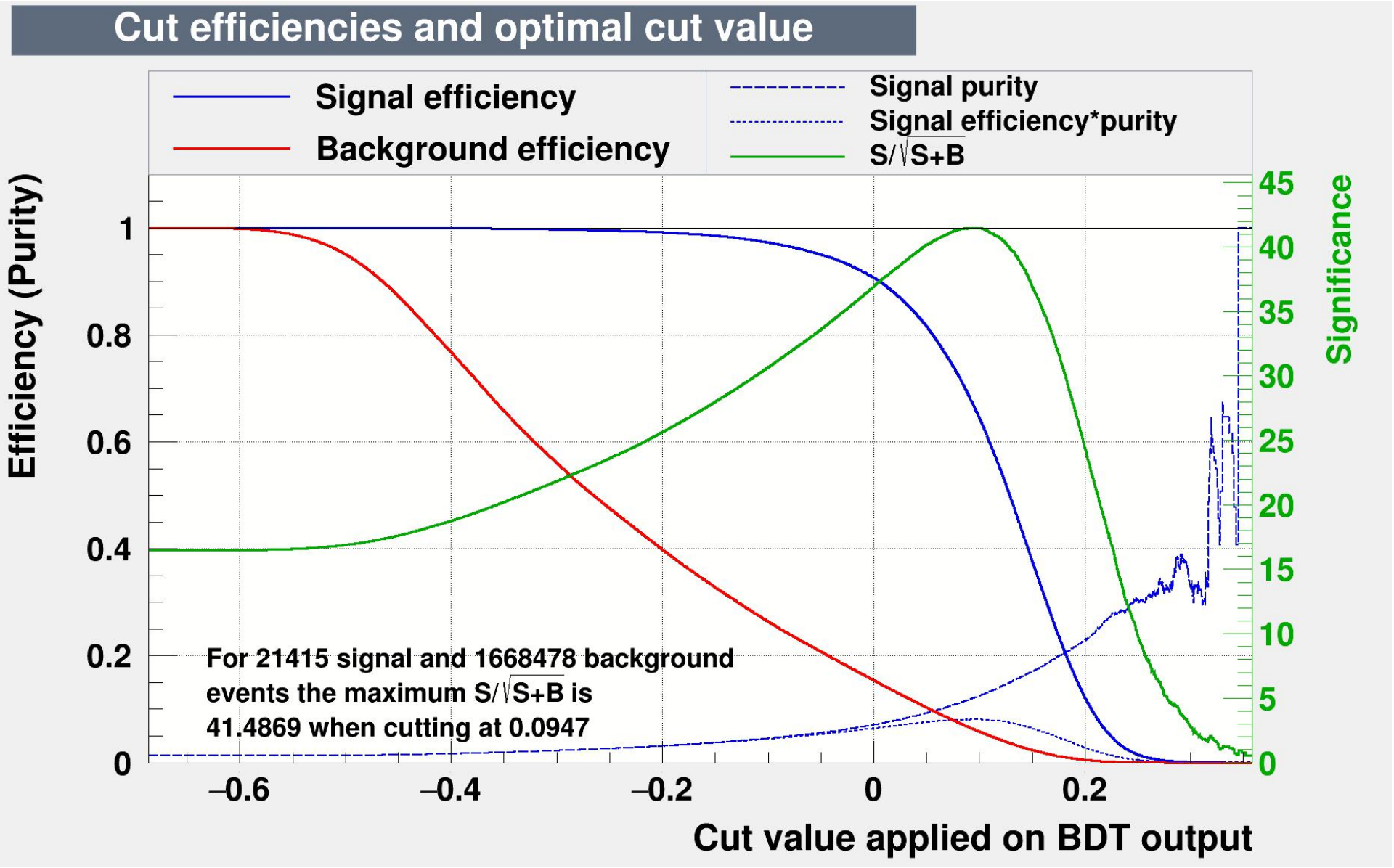
(1) selecting at least 1 jets with p_T > 20 GeV;

(2) selecting at least 1 e- with p_T > 10 GeV;

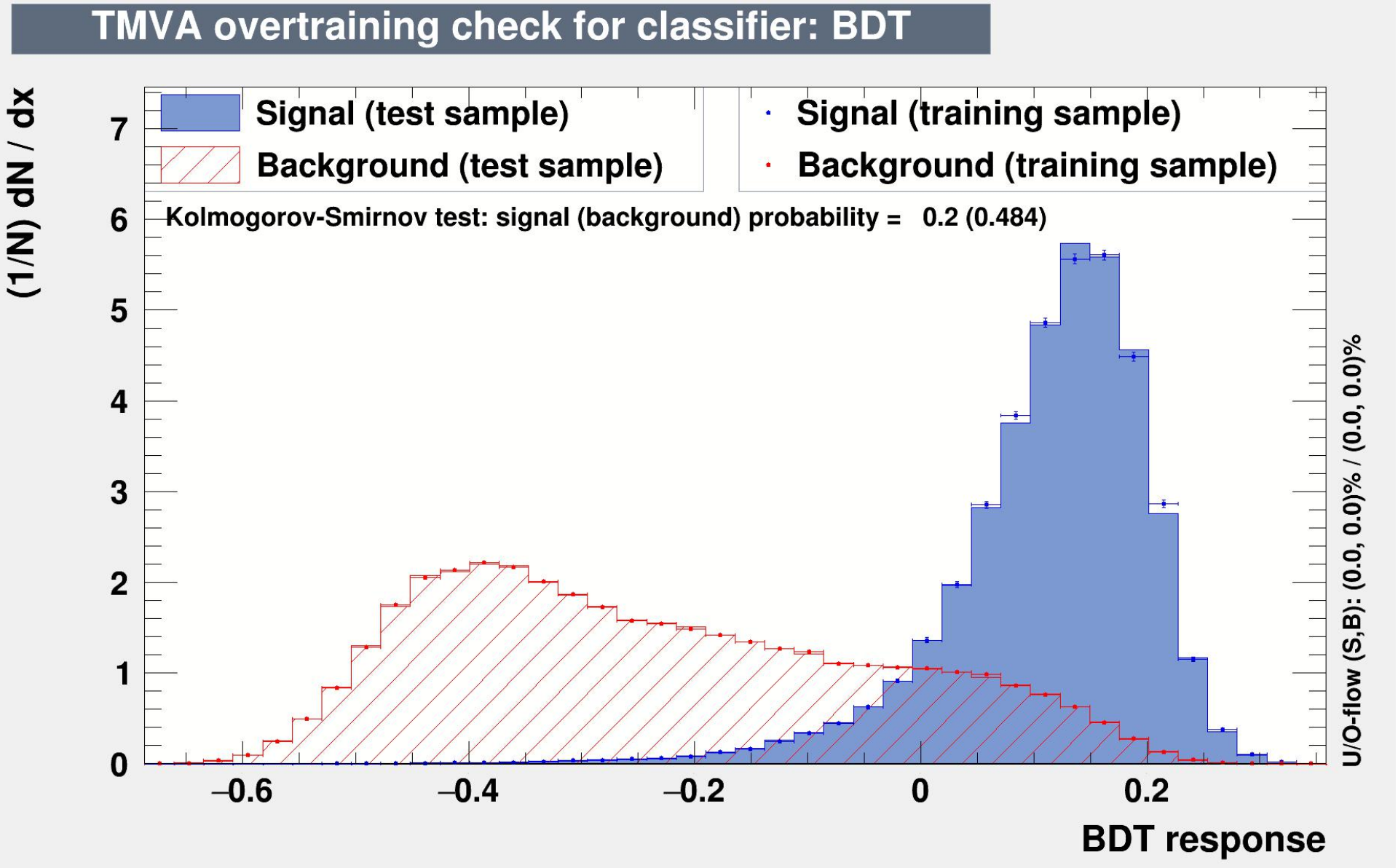
(3) veto b-jets with p_T > 20 GeV;

(4) veto 2nd electron, any muon with p_T > 5 GeV;
veto any tau with p_T > 10 GeV .

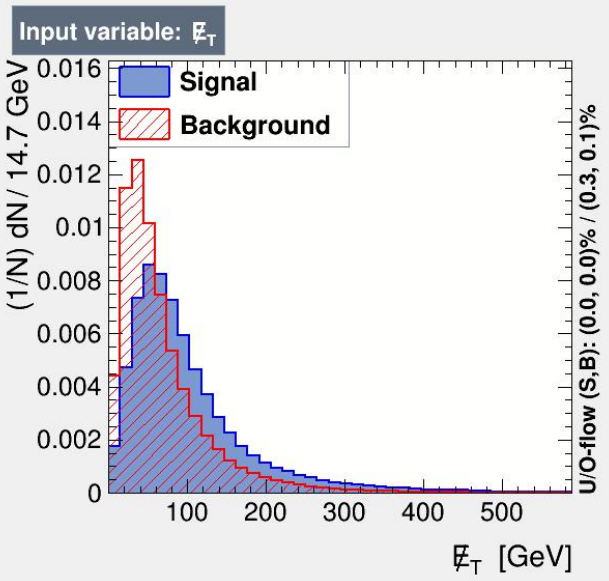
Cut Efficiency

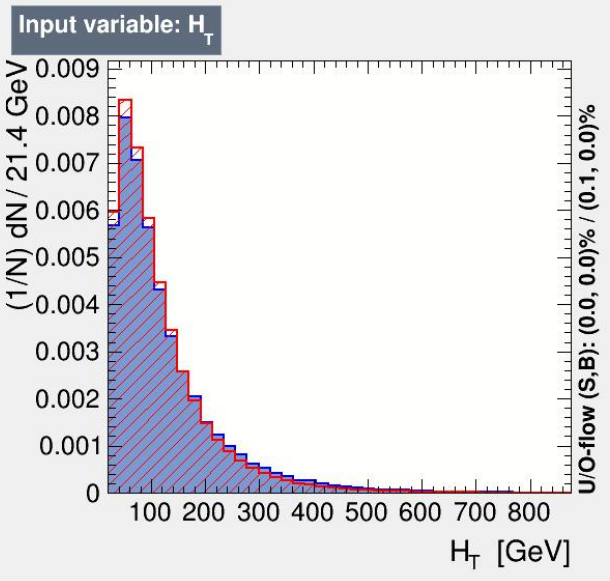


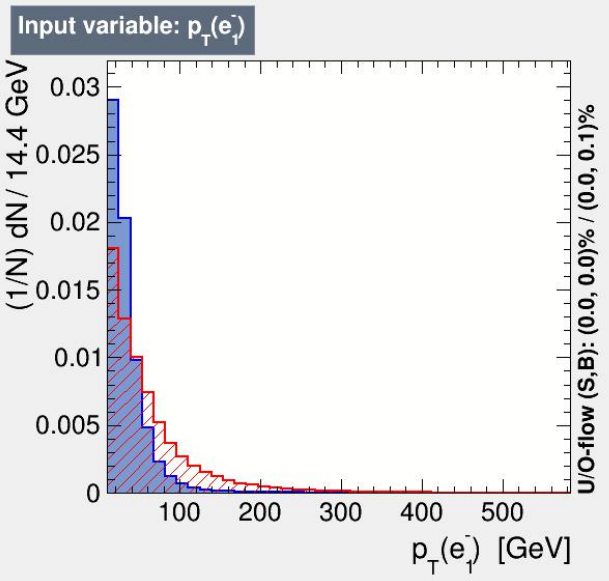
BDT Distribution

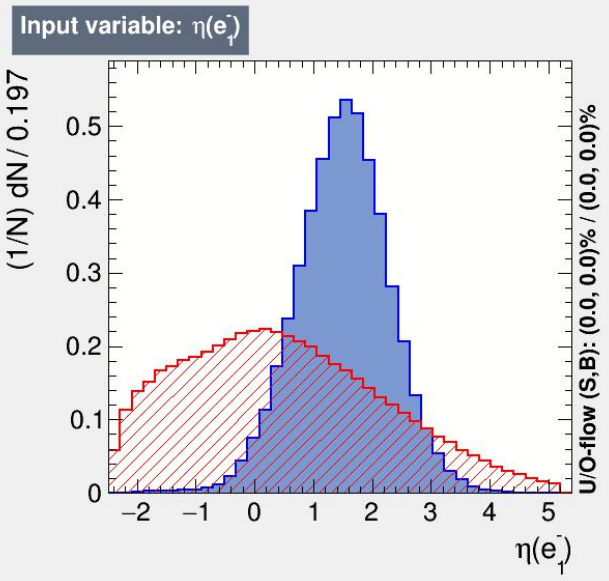


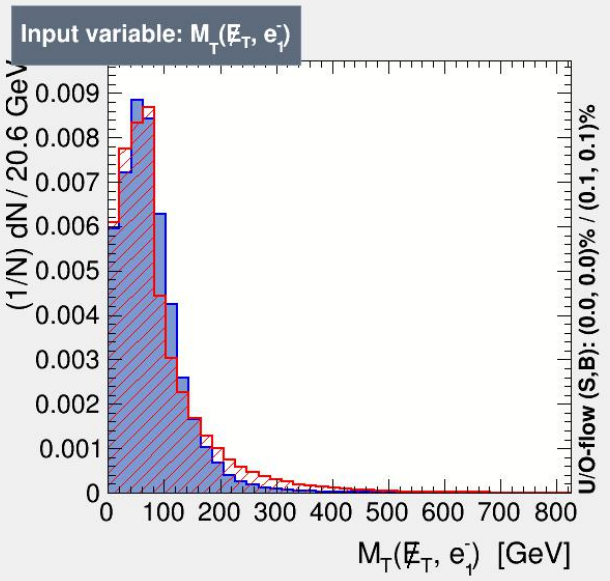
Input Observables

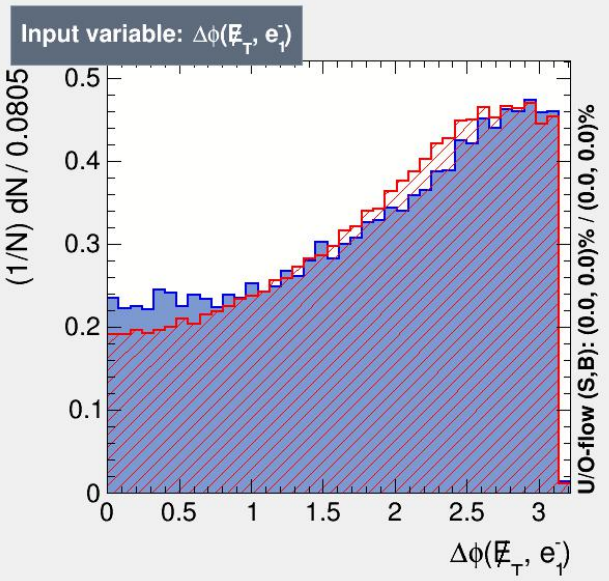




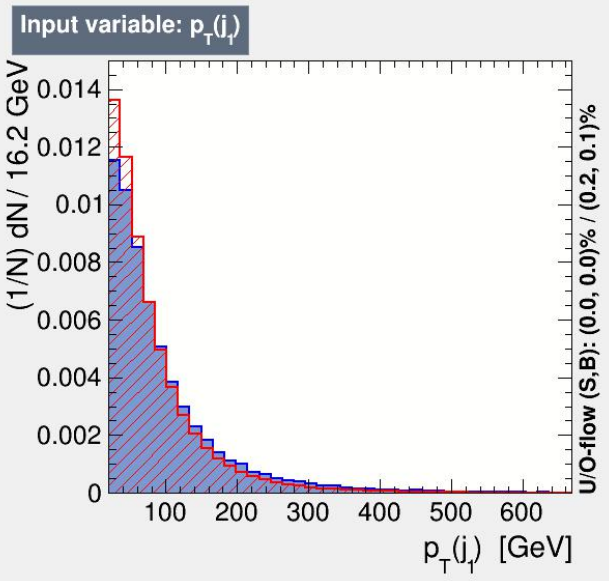


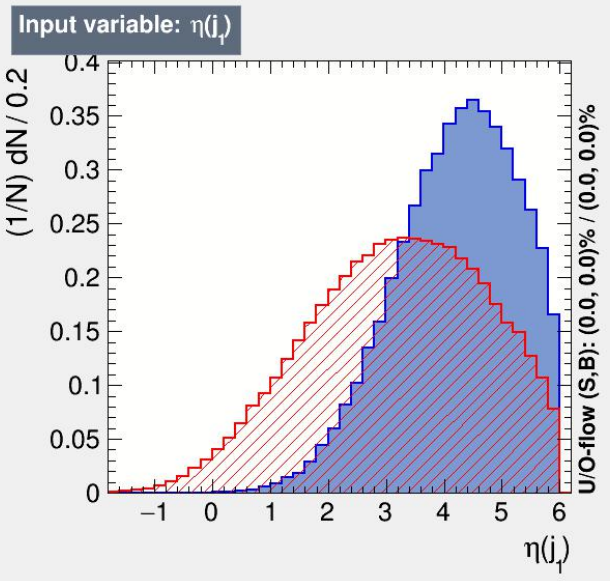


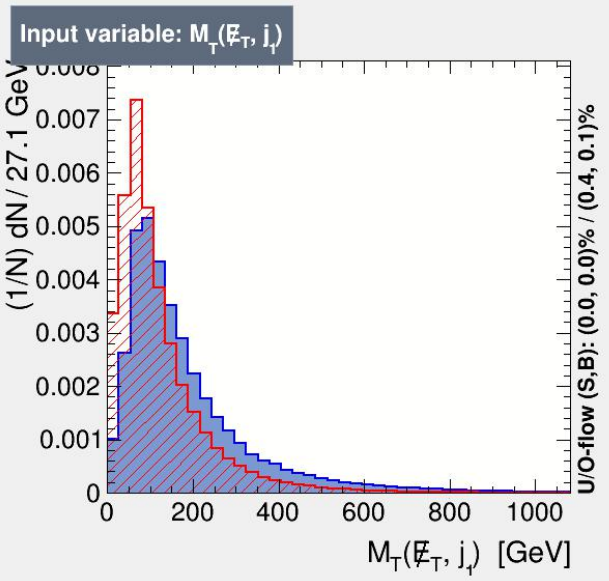


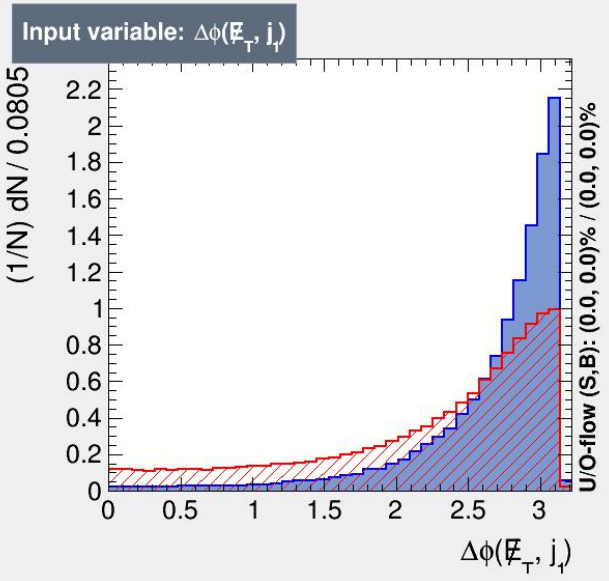


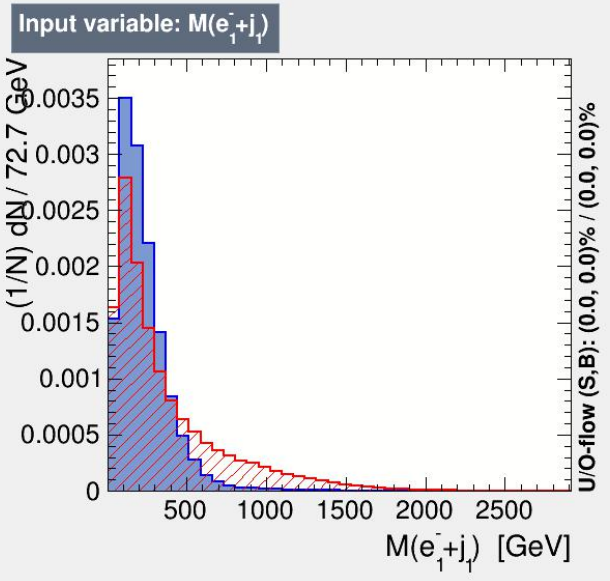
Input Observables

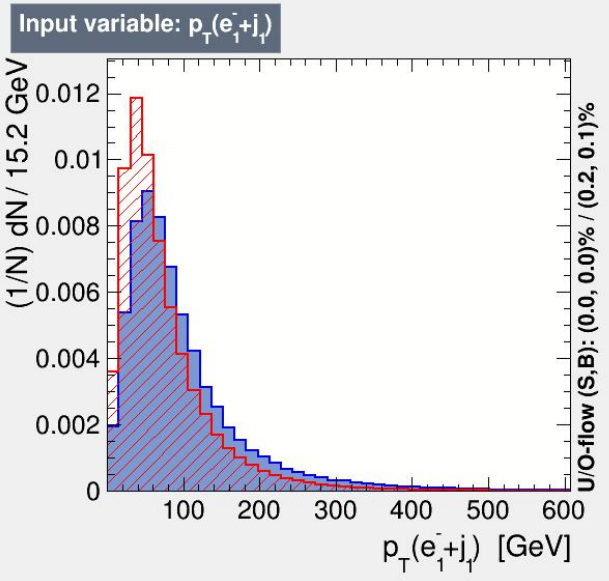




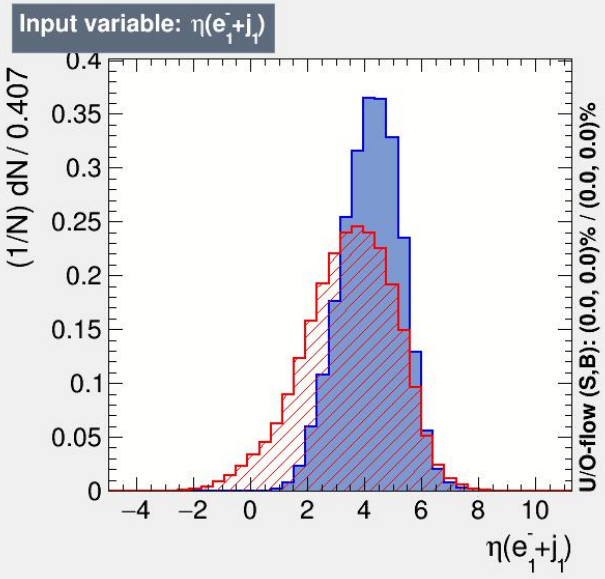


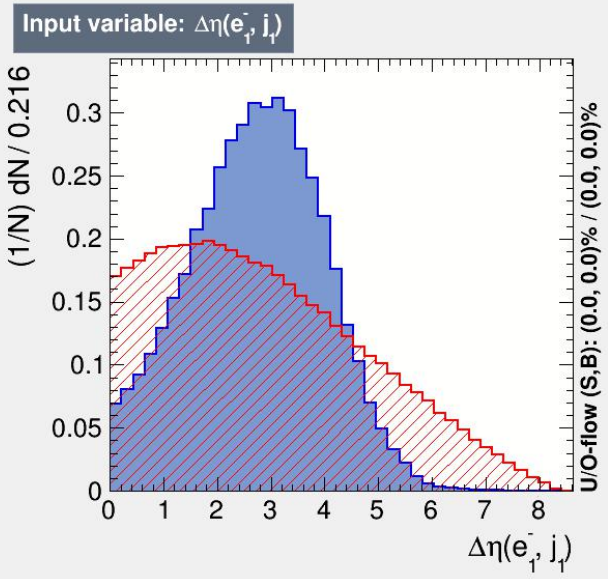


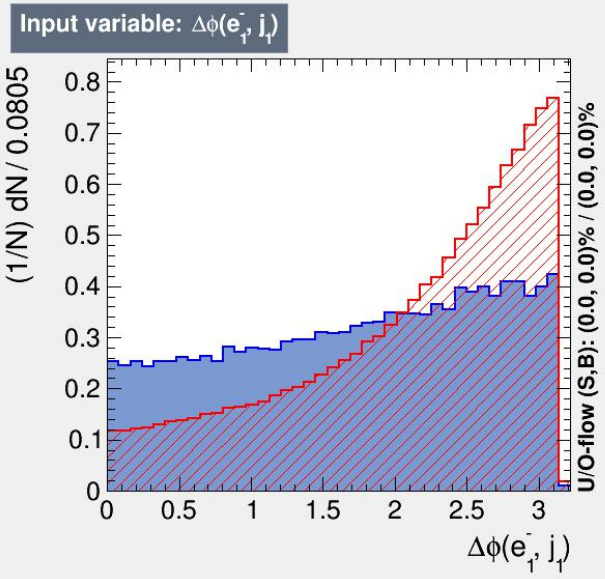


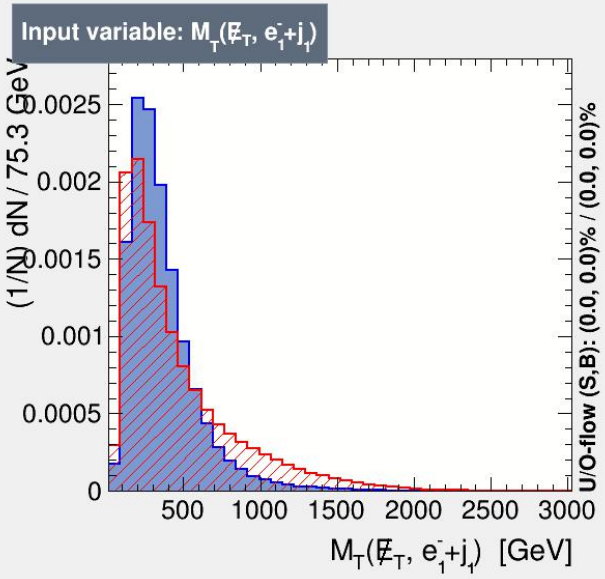


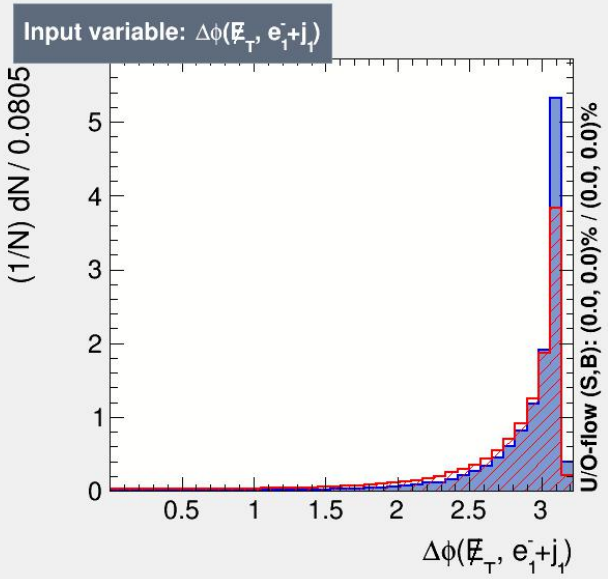
Input Observables











Signal Event Generating

Collider:
FCC-eh (Ep = 50 TeV, Ee = 60 GeV).

(1) The benchmark point for "**Signal (2)**" will be:
Bino ~ m_{neutralino1} = 199 GeV;
Wino ~ m_{chargino1} = m_{neutralino2} = 200 GeV;
m_{slepton_R} = 225 GeV.
m_{slepton_L} is heavy and decoupled.

import model mssm-full
define dm = x1+ x1- n1 n2
generate p e- > j e- dm dm / go ul cl t1 ur cr t2 dl sl b1 dr sr b2 ul~ cl~ t1~ ur~ cr~ t2~ dl~ sl~ b1~ dr~ sr~ b2~ h2 h3 h+ h- sve svm svt el- mul- ta1- ta2- sve~ svm~ svt~ el+ mul+ ta1+ ta2+ n3 n4 x2+ x2-

The SM background for "light slepton scenario" will be:
(a) two-neutrino process:
define dm = ve vm vt ve~ vm~ vt~
generate p e- > j e- dm dm

(b) one-neutrino process:
generate p e- > j e- l vl

Will do the "MadGraph + PYTHIA + Delphes" simulation and try to finish the analysis at detector-level using the BDT method.

Pre-selection cuts

For BDT analysis:

Input Signal (2):
Bino ~ m_{neutralino1} = 199 GeV;
Wino ~ m_{chargino1} = m_{neutralino2} = 200 GeV;
m_{slepton_R} = 225 GeV;
slepton_L is heavy and decoupled.

Input Background: (a) + (b)
(a) two-neutrino process:
(b) one-neutrino process:

Pre-selection cuts:

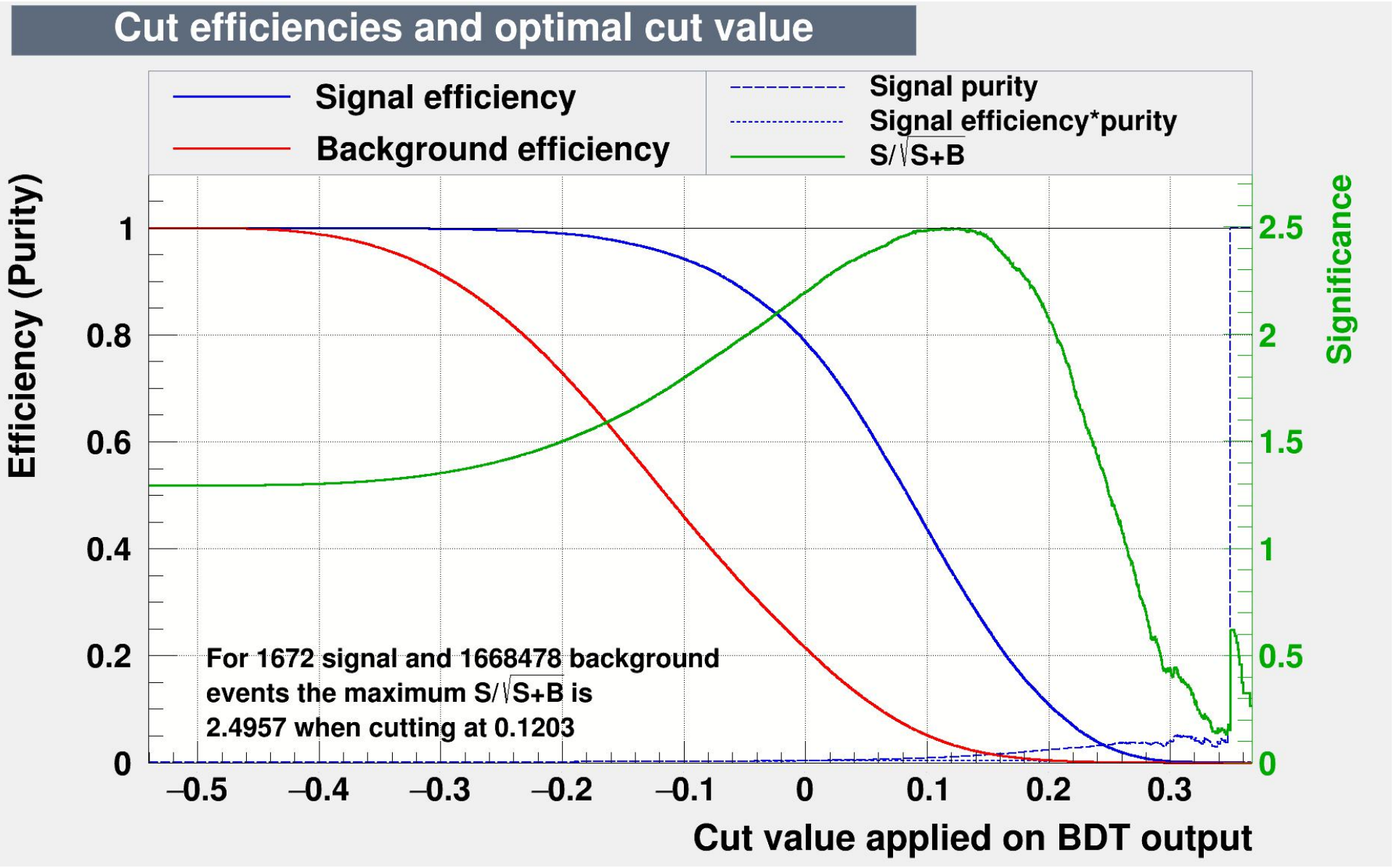
(1) selecting at least 1 jets with p_T > 20 GeV;

(2) selecting at least 1 e- with p_T > 10 GeV;

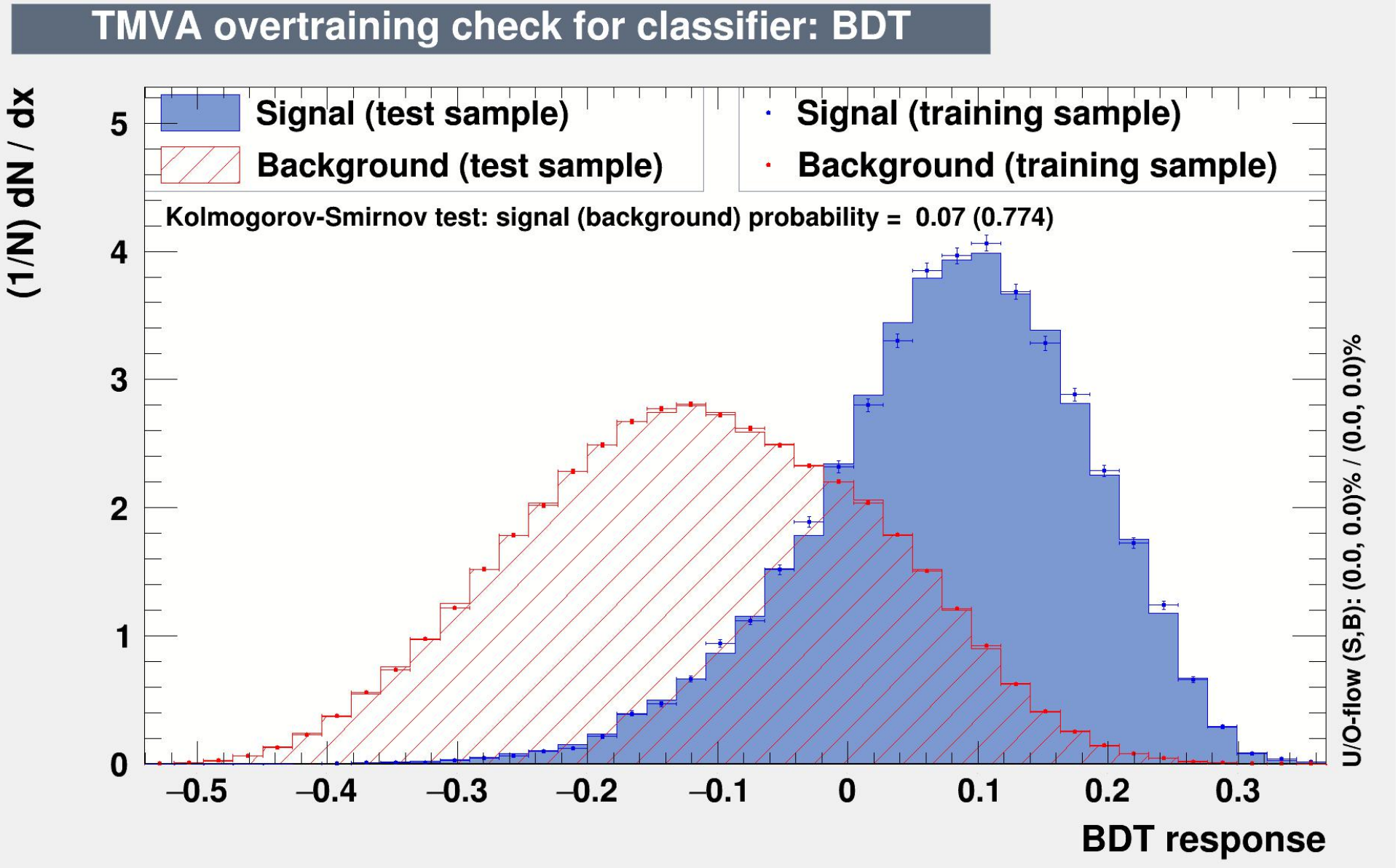
(3) veto b-jets with p_T > 20 GeV;

(4) veto 2nd electron, any muon with p_T > 5 GeV;
veto any tau with p_T > 10 GeV .

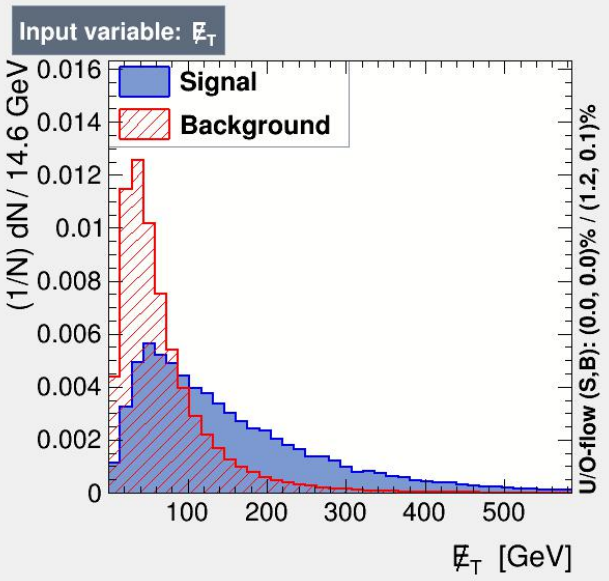
Cut Efficiency

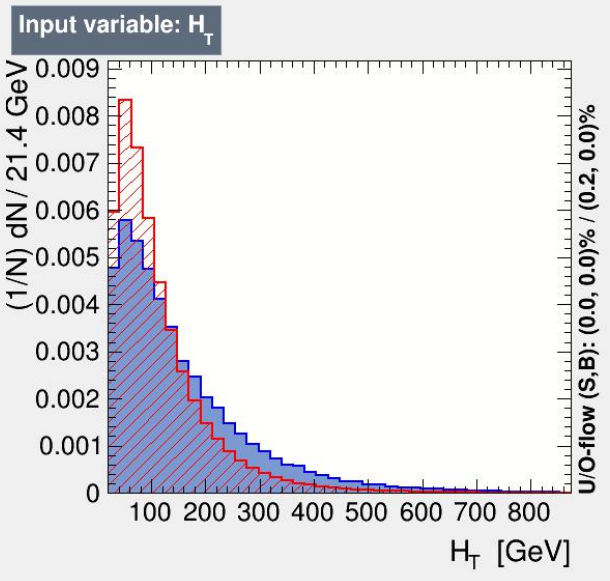


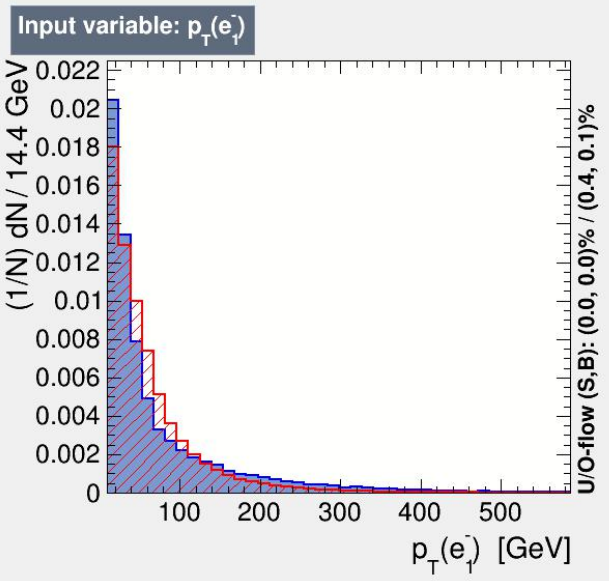
BDT Distribution

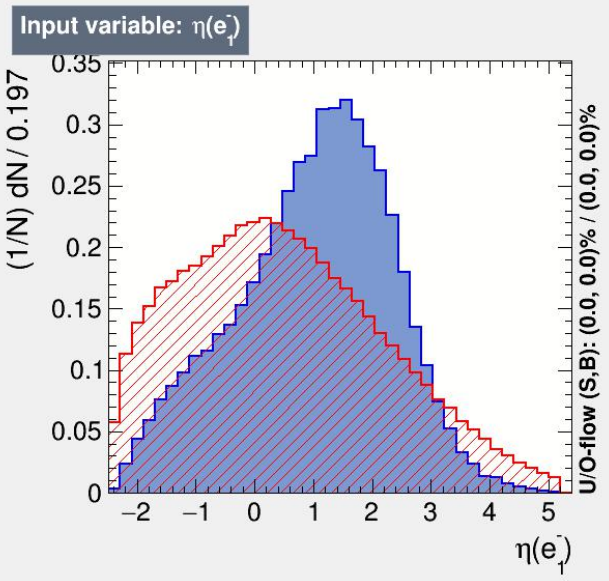


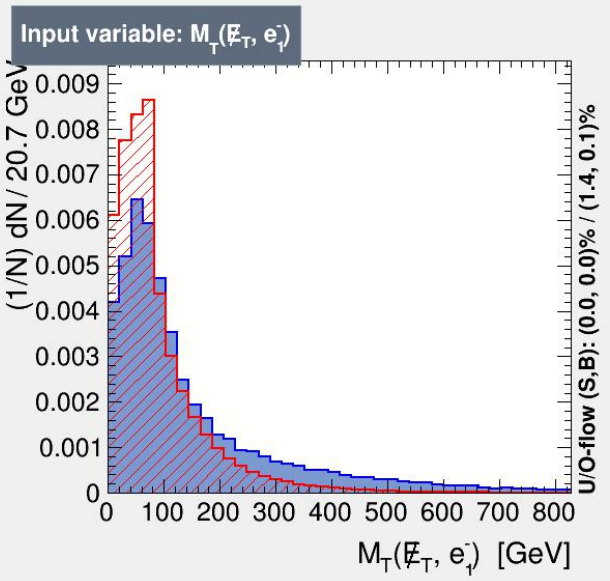
Input Observables

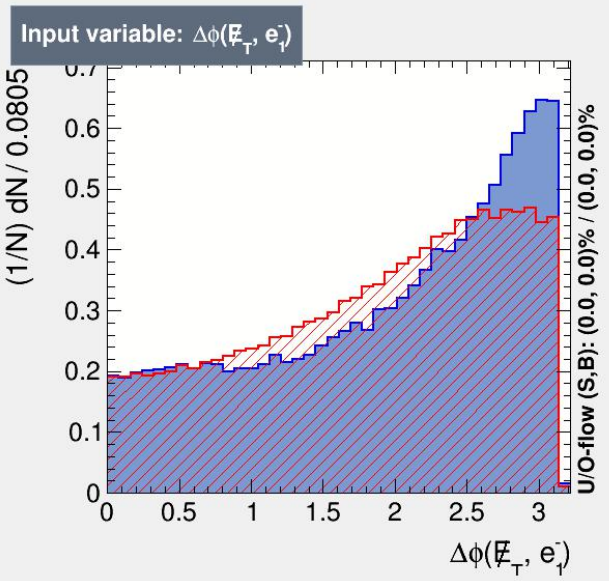




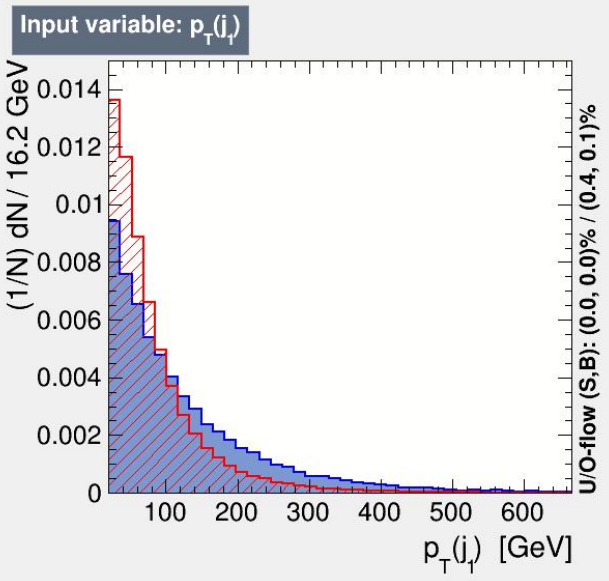


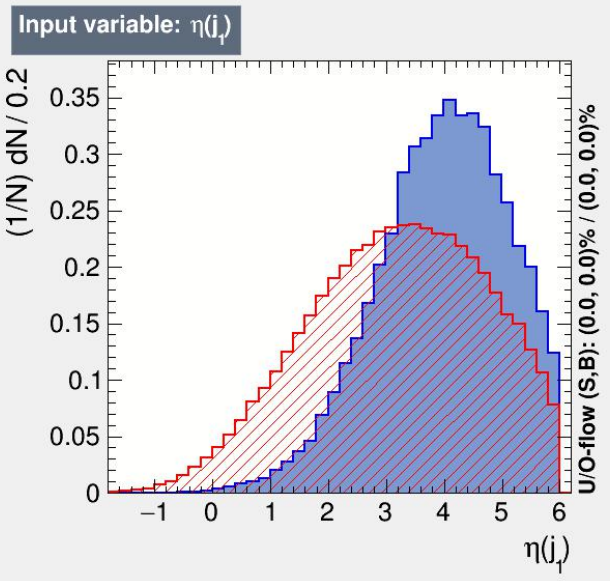


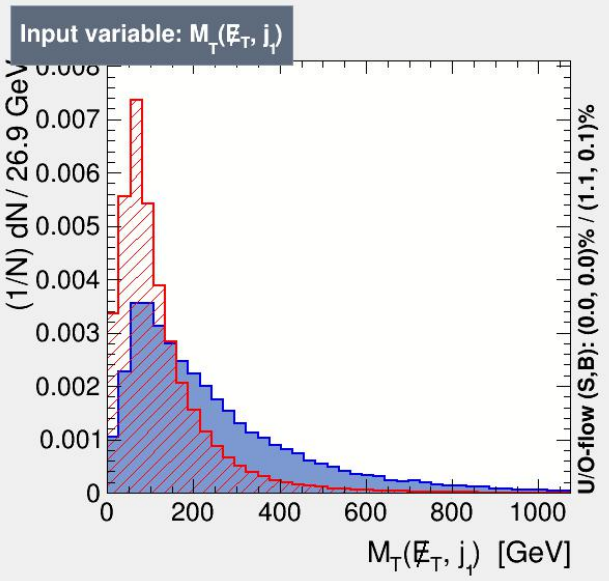


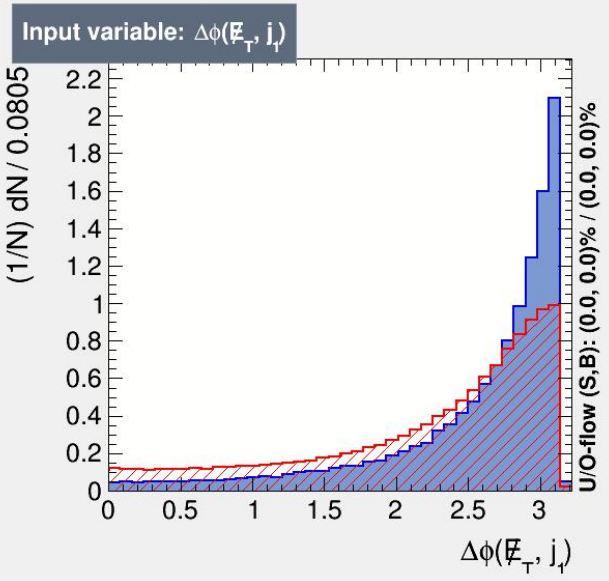


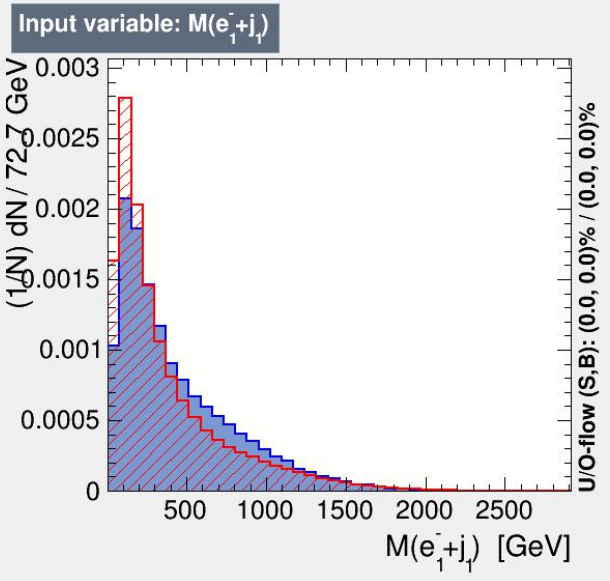
Input Observables

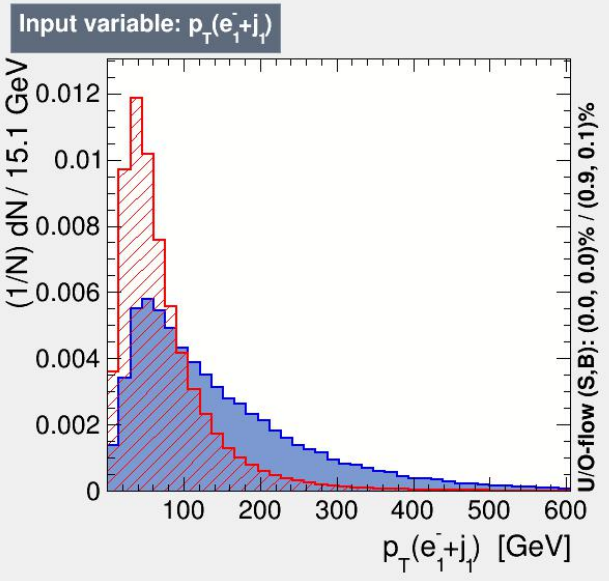




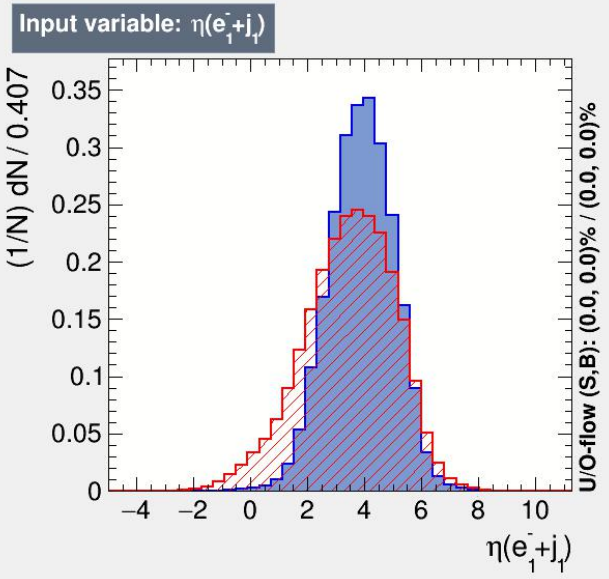


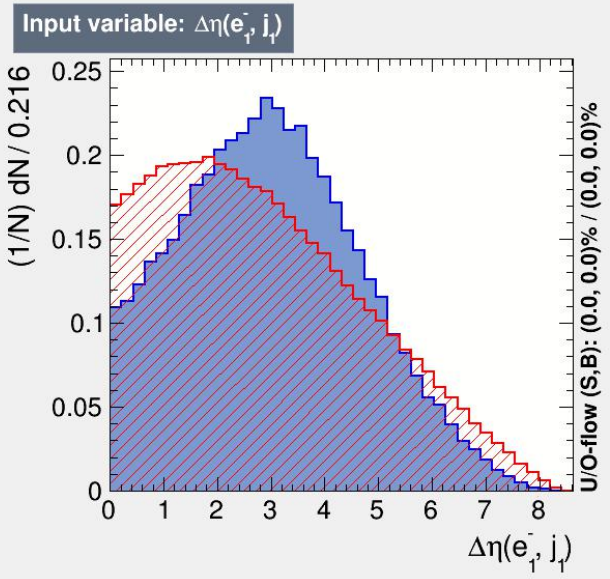


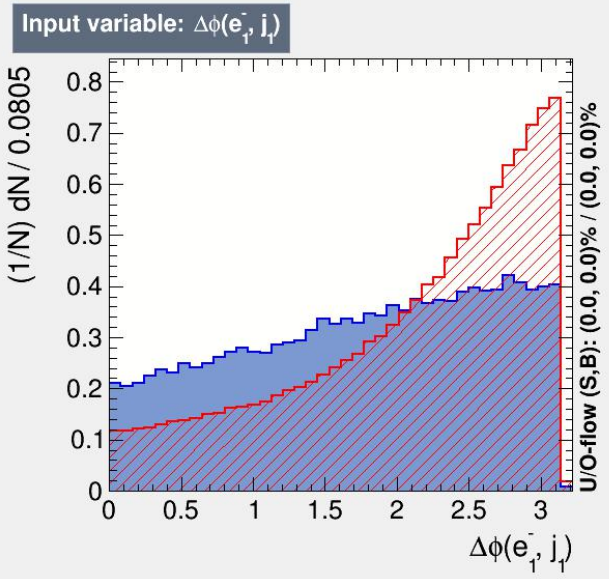


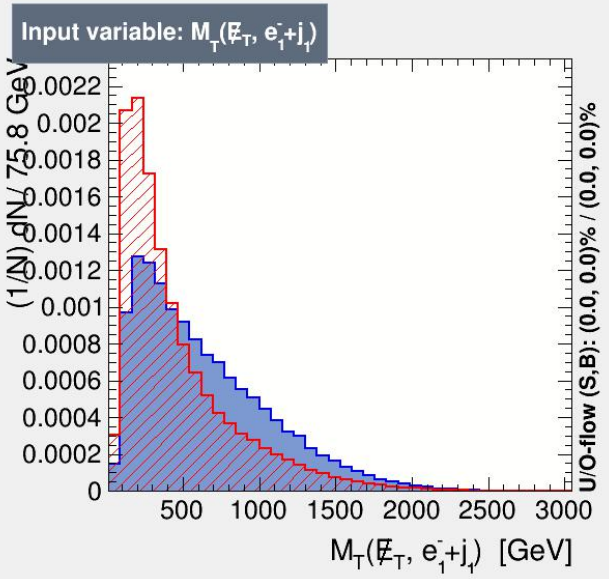


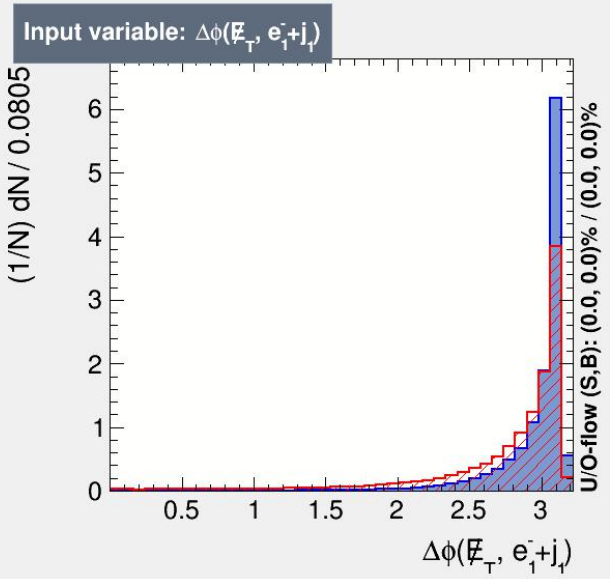
Input Observables











Signal Event Generating

Collider:
FCC-eh (Ep = 50 TeV, Ee = 60 GeV).

(1) The benchmark point for "**Signal (1)**" will be:
Bino ~ m_{neutralino1} = 199 GeV;
Wino ~ m_{chargino1} = m_{neutralino2} = 200 GeV;
both slepton_R & m_{slepton_L} is heavy and decoupled.

```
import model mssm-full
define dm = x1+ x1- n1 n2
generate p e- > j e- dm dm / go ul cl t1 ur cr t2 dl sl b1 dr sr b2 ul~ cl~ t1~ ur~ cr~ t2~ dl~ sl~ b1~ dr~
sr~ b2~  h2 h3 h+ h- sve svm svt el- mul- ta1- ta2- sve~ svm~ svt~ el+ mul+ ta1+ ta2+ n3 n4 x2+ x2-
```

The SM background for "light slepton scenario" will be:
(a) two-neutrino process:
define dm = ve vm vt ve~ vm~ vt~
generate p e- > j e- dm dm

(b) one-neutrino process:
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Will do the "MadGraph + PYTHIA + Delphes" simulation and try to finish the analysis at detector-level using the BDT method.

Pre-selection cuts

For BDT analysis:

Input Signal (1):
Bino ~ m_{neutralino1} = 199 GeV;
Wino ~ m_{chargino1} = m_{neutralino2} = 200 GeV;
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Input Background: (a) + (b)
(a) two-neutrino process:
(b) one-neutrino process:

Pre-selection cuts:

(1) selecting at least 1 jets with p_T > 20 GeV;

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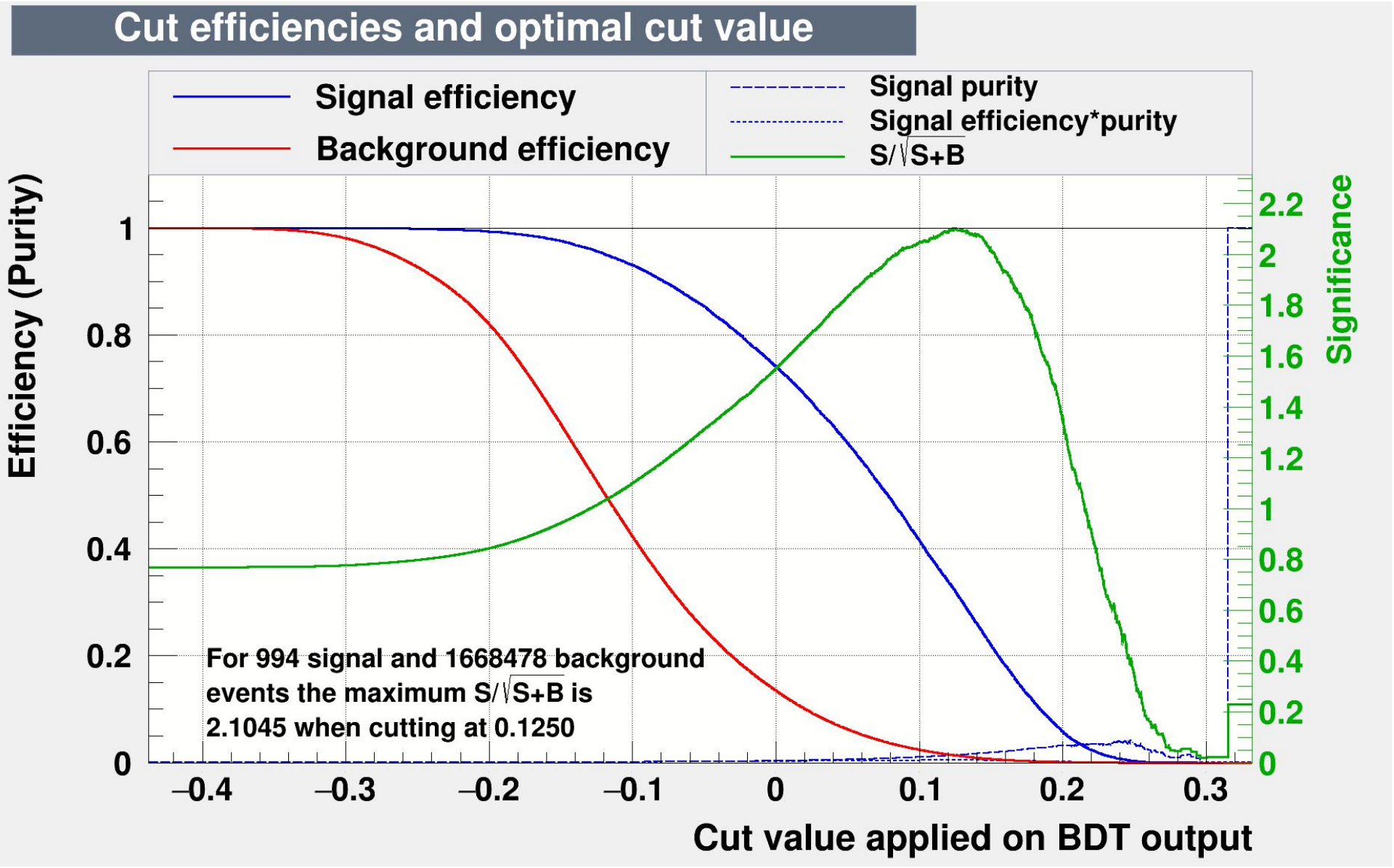
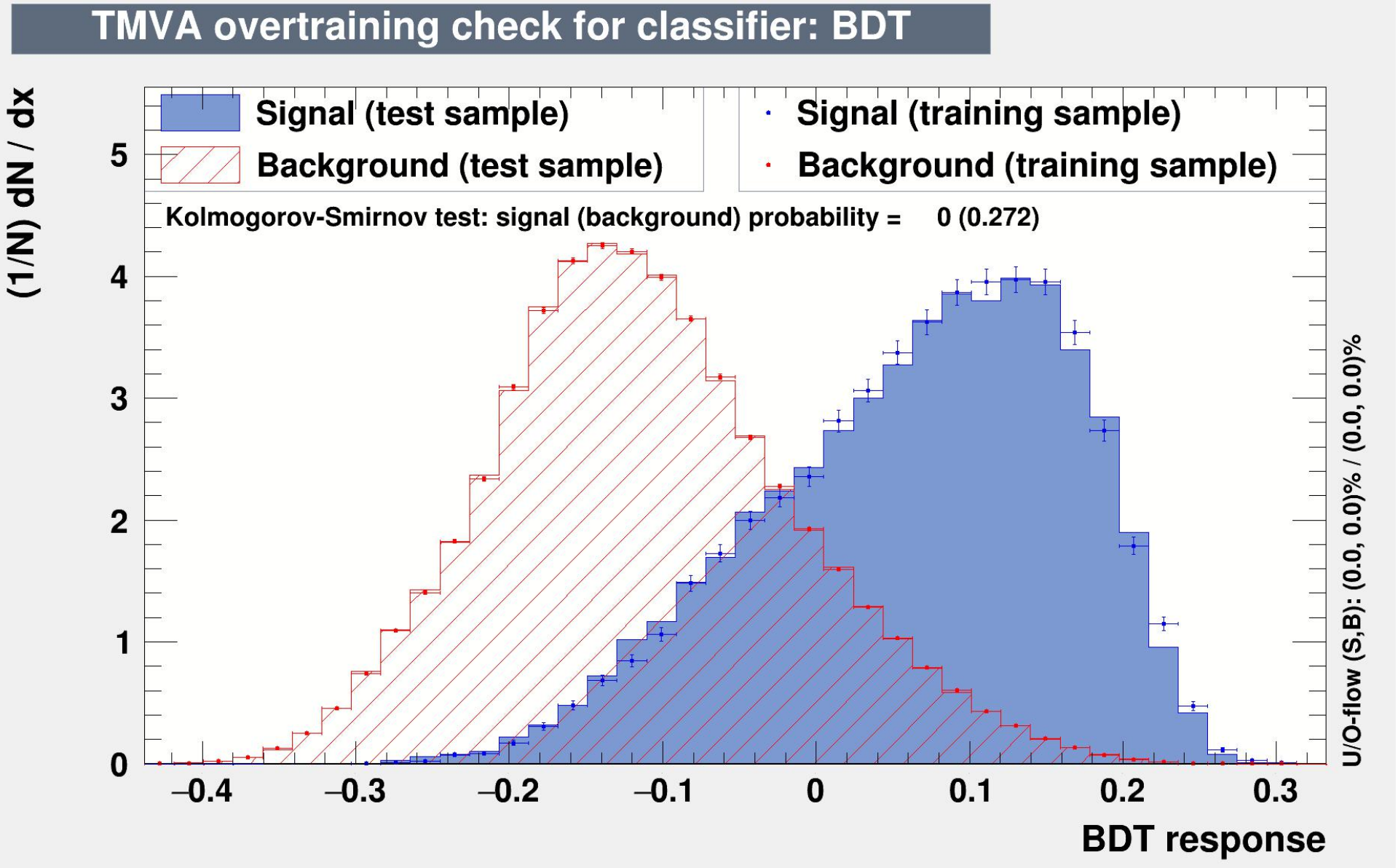
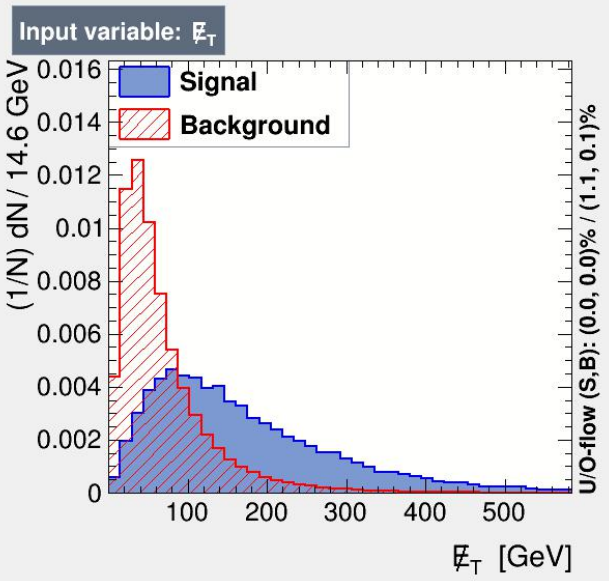
Cut Efficiency

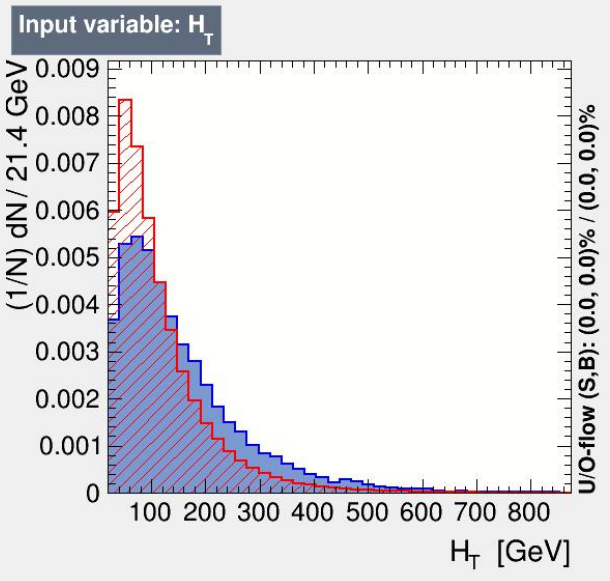


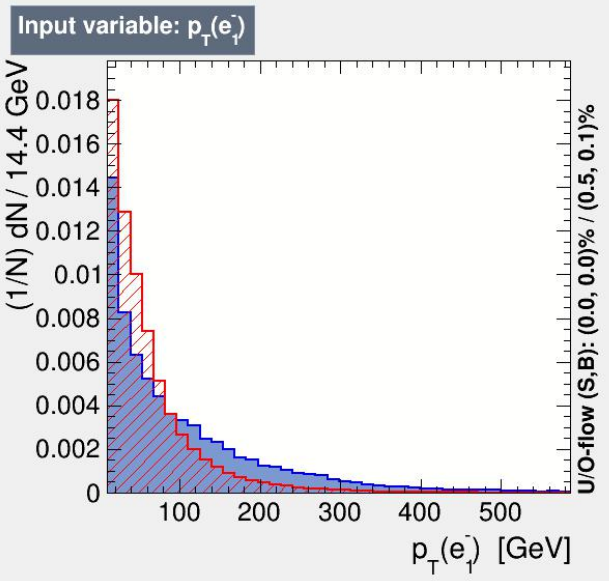
BDT Distribution

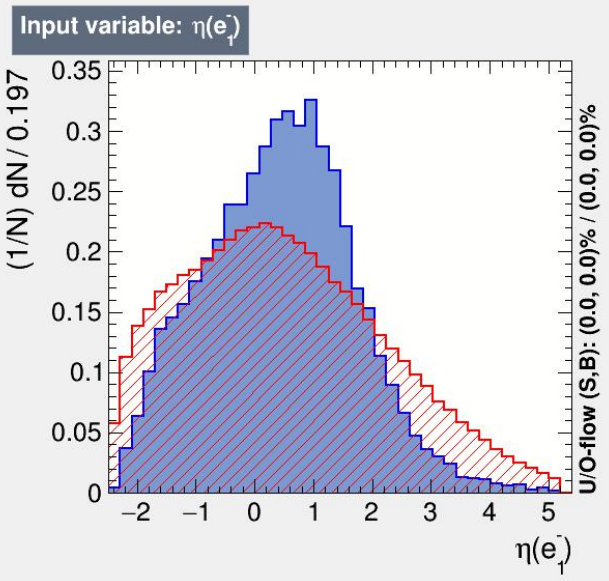


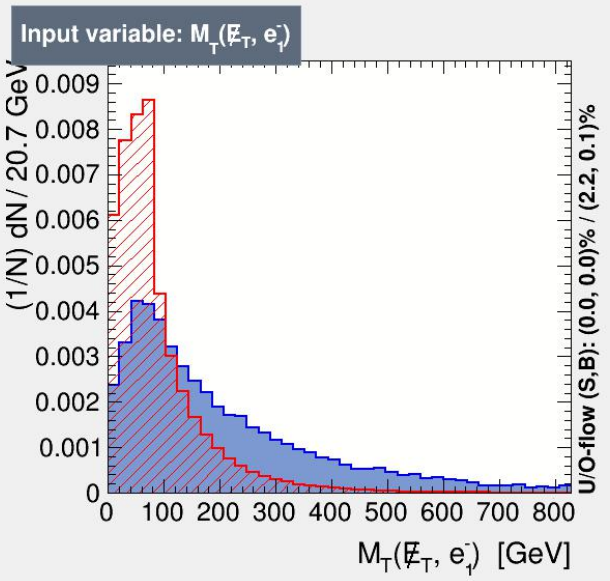
Input Observables

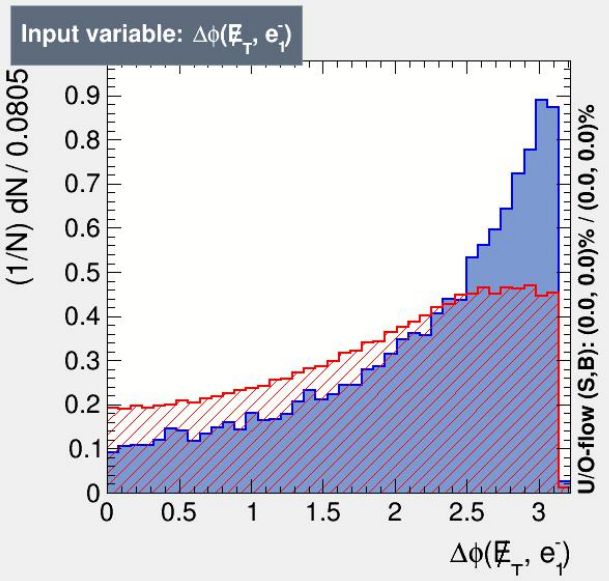












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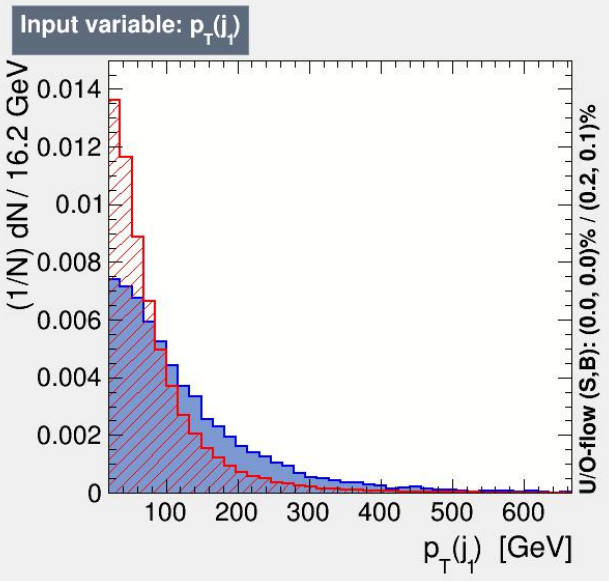
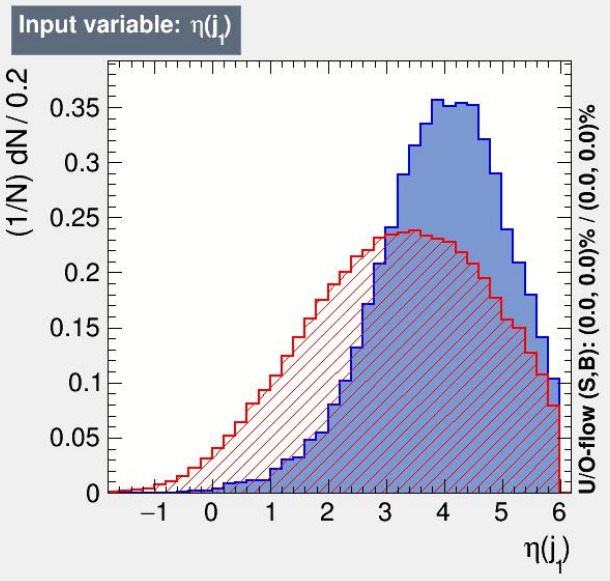
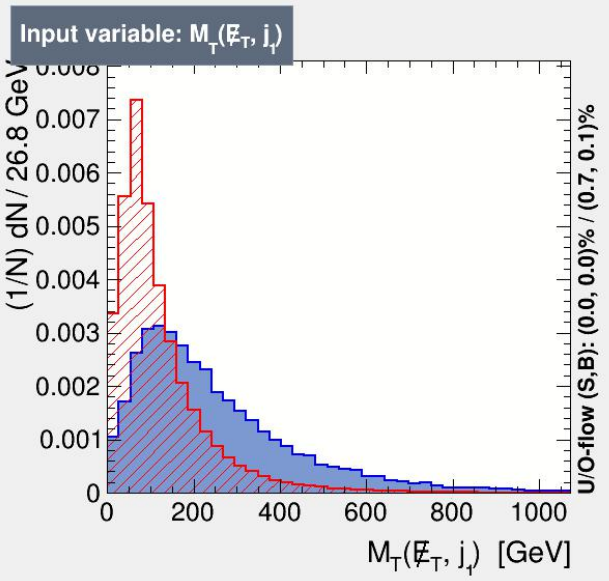
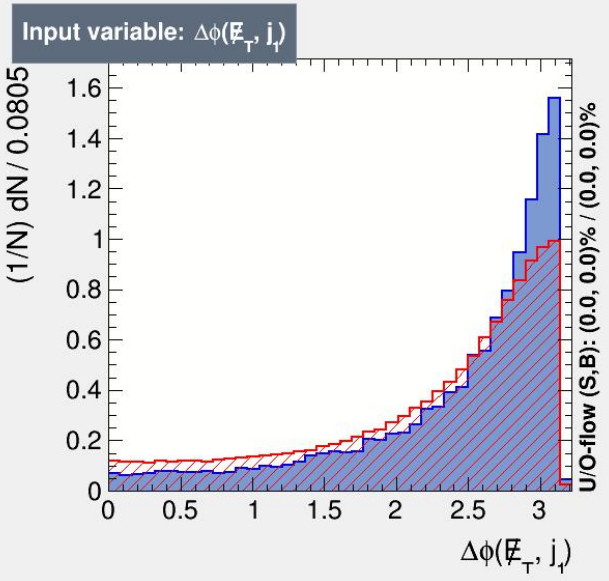
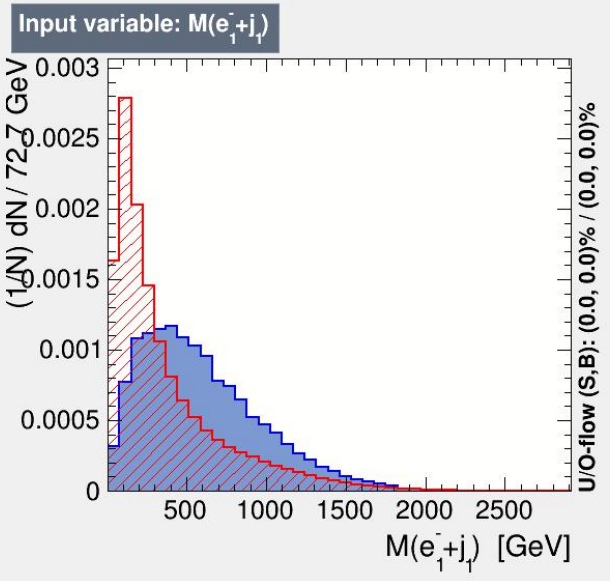
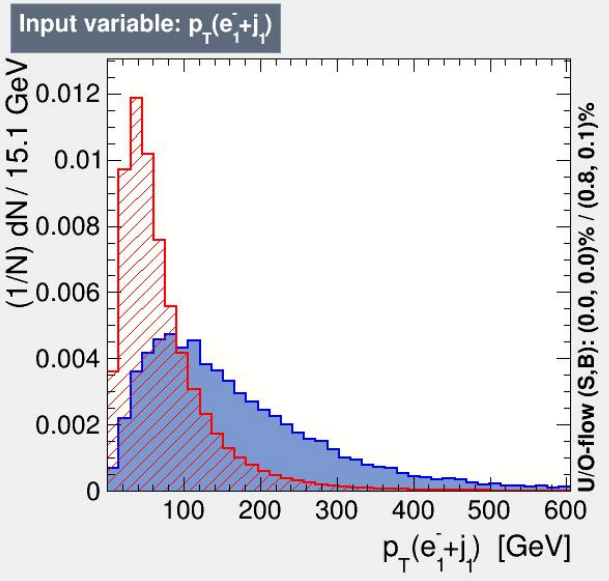




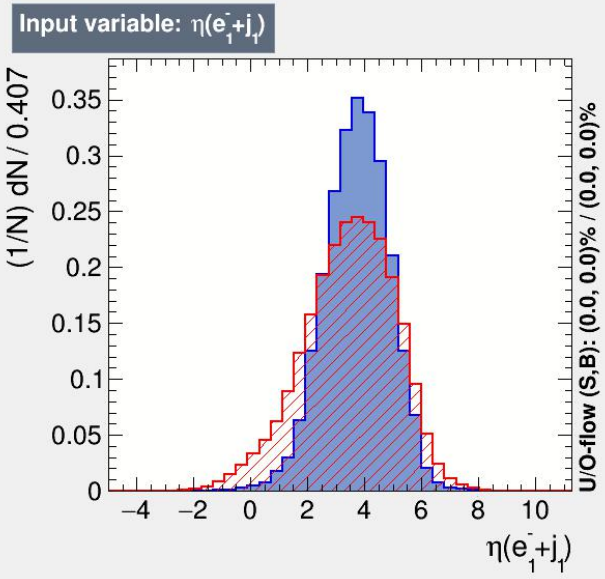


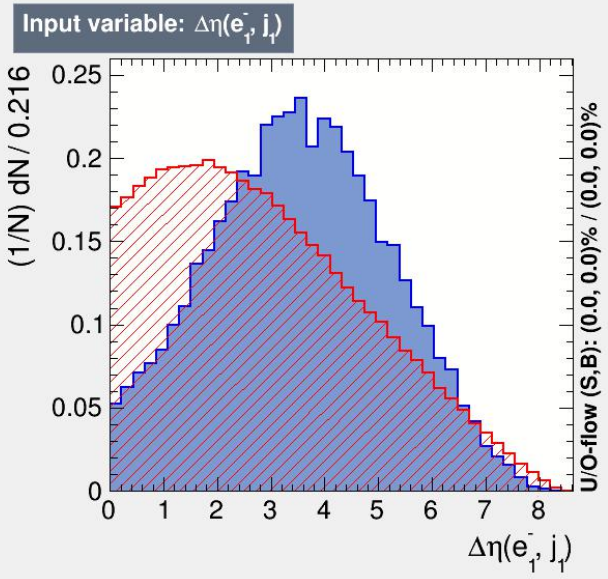


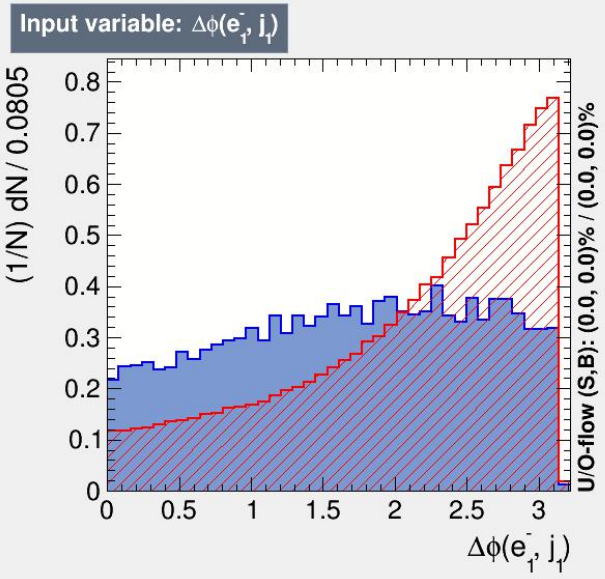


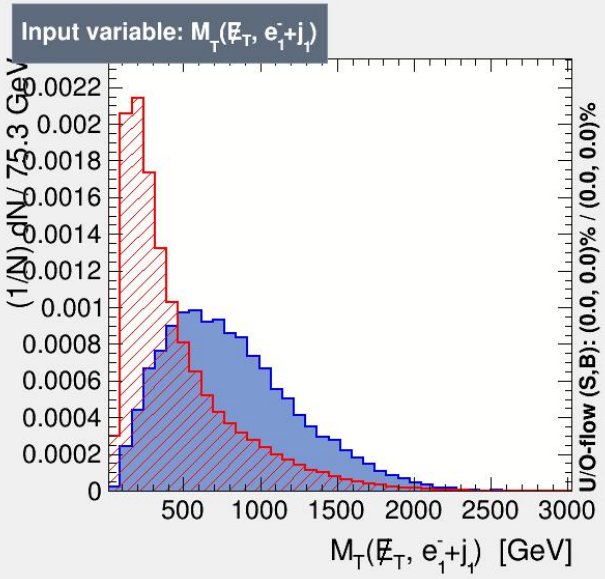


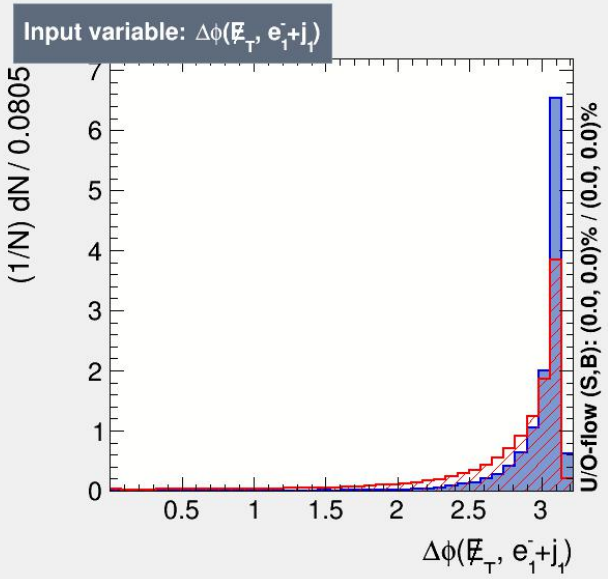
Input Observables











Conclusion & Discusion

1. Comparing the 3 signal scenarios:

Choosing Bino ~ m_{neutralino1} = 199 GeV;
Wino ~ m_{chargino1} = m_{neutralino2} = 200 GeV;
Signal 1 (S1): both slepton_R & slepton_L are heavy and decoupled;
Signal 2 (S2): slepton_R = 225 GeV, while slepton_L is heavy and decoupled;
Signal 3 (S3): slepton_R = slepton_L = 225 GeV.

Production cross sections for S1, S2, S3 are 2.1, 3.6, 33.9 fb.

Adding the slepton_L will greatly enhace the cross section (a factor of ~ 10) due to the slepton_L produciton.
Is it due to the coupling of slepton_L to Wino ?

2. Effects of raising the threshold of jet and leptons

when raising the p_T threshold from 15 to 20 GeV for jets, and from 5 to 10 for leptons,
The signal is reduced to a factor of 84%, 84% and 87% for S1, S2, S3,
while the background factor is 81% .

The final significances changes for S1 from 2.3 -> 2.1;
for S2 from 2.7 -> 2.5;
for S3 from 43.1 -> 41.5 .

The significances drops because the number of signal events decreases by raising the thresholds.

Conclusion & Discusion

3. The simplest signal scenario ?

My analysis already show that for S1 and S2, the final significance is only around 2.5, which is small.
Thus, a light slepton_L might be necessary ?

So far, I choose the signal scenario as
Bino ~ m_{neutralino1} = 199 GeV;
Wino ~ m_{chargino1} = m_{neutralino2} = 200 GeV;
Signal 3 (S3): slepton_R = slepton_L = 225 GeV.

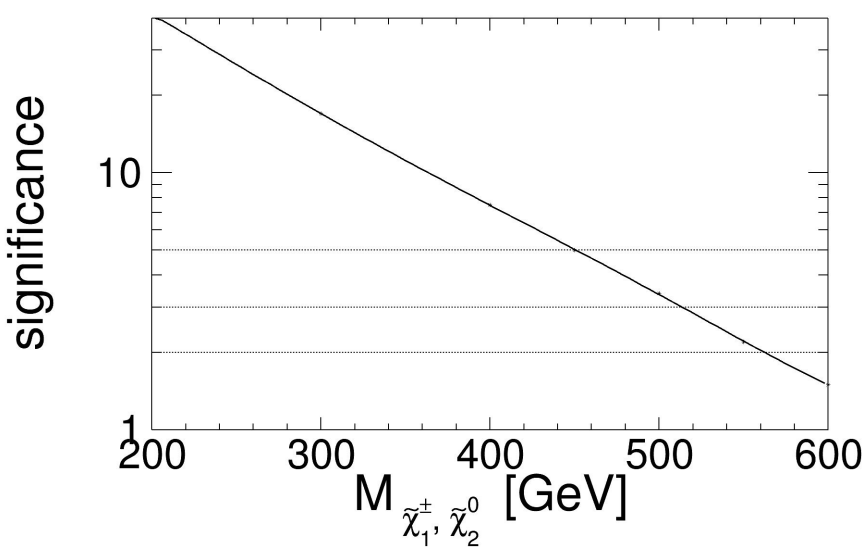
By increasing the masses, I can find the 2, 3, 5 - sigma limits for this scenario.

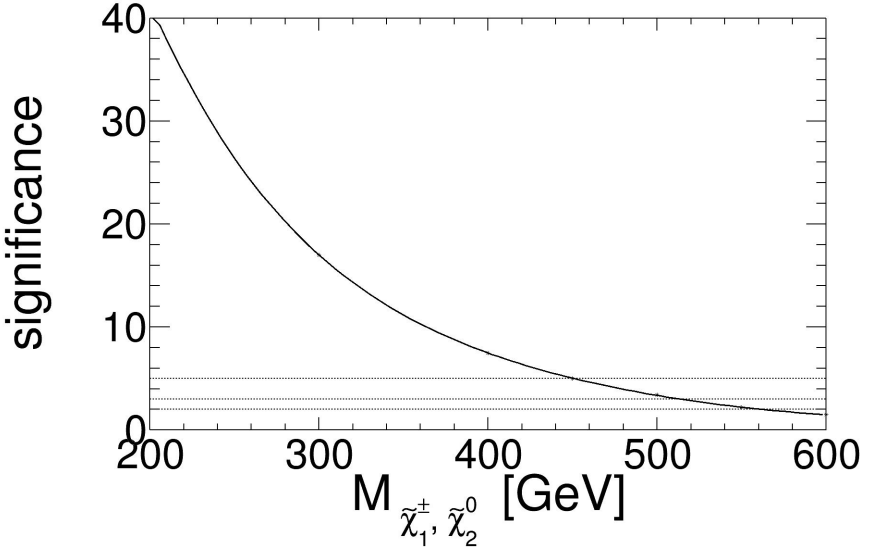
Any other interesting and simple signal scenario(s) ?

Conclusion & Discusion

4. For Signal 3, significance vs mass

Plot





Table

Mass	Significance
200	41.5
300	17.0
400	7.5
450	5.0
500	3.4
550	2.2
600	1.5

limits on mass
from the significance curve

Mass	Significance
450.8	5.0
513.7	3.0
562.7	2.0

Conclusion & Discusion

5. Effect of the Sneutrino ?

After discussed with Sho, we realized that when slepton_L is light,
the process "p e- > j dm sneutrino " can also leads to the "j e- dm dm" final state,
because decay of "sneutrino -> e- + chargino1", which has ~ 60% braching ratio.

Therefore, the sneutrino production should be considered.

The production of the "j e- dm dm" final state will be almosted doubled.

However, since the mass difference between sneutrino and chargino is smaller, the e- from the sneutrino decay will be softer than the e- from the selectron decay.

6. Final signal scenario ?

After discussed with Sho, we think perhaps one can make the slepton_R heavy, since the slepton_L production is small.

Therefore, the final signal scenario can be:

Bino: m_{neutralino1} = 199 GeV;
Wino: m_{chargino1} ~ m_{neutralino2} = 200 GeV;

Sleptons:
m_{sneutrino} ~ 220 GeV.
m_{slepton_L} = 235 GeV .

Wino and slepton_L is necessary to have enough signal production.
Bino is needed to generate some mass differences between chargino1 and neutrino1.

Any suggestions ?

Conclusion & Discusion

7. What if sleptons are heavy ?

For the S1, the main challenging is the production for signal is too small, and background is too huge (S / B ~ 1 / 1700 after pre-selection) .

The only possible which may enhance the significance could be,
Having bigger mass difference between neutralino2 / chargino1 and the neutralino1, which will lead to the lepton(s) from the neutralino2 and chargino1 decays.

If we can select more leptons, which will reduce the background a lot.
(However, the signal will also be reduced as well.)

Do you have any suggestions about this ?