Search for lepton flavor violating decay

$$\tau^- \to e^- \eta'$$

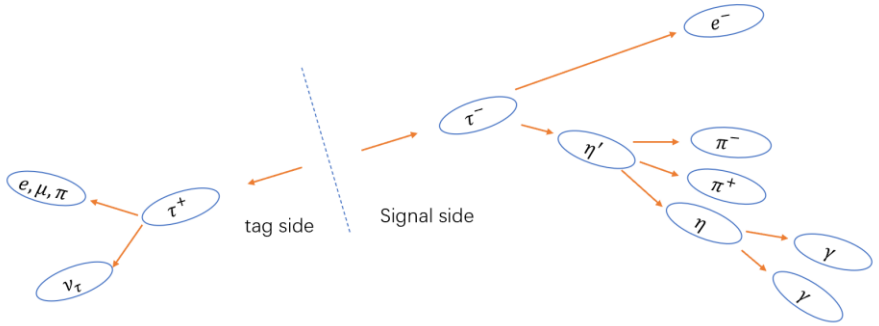
movition

- Processes with Lepton Flavor Violation (LFV) provide some of the most promising searches for physics beyond the Standard Model (SM).

- The semileptonic τ decays provide another good source of information about possible LFV mechanisms from supersymmetry (SUSY) motivated models to models with heavy Dirac neutrinos.

- Previously studied by Belle with a data sample of 401 fb^{-1}.So far,they have collected 426.5 fb data sample at Belle II and we can update this mode.

MC sample



Tag side :$\tau \to \mu\bar{\nu}_\mu\nu_\tau$, $e\bar{\nu}_e\nu_\tau$,$\pi\nu_\tau$

Signal side:$\tau \to e\eta'$, $\eta' \to \pi^+\pi^-\eta(\to \gamma\gamma)$

light-2212-foldex

Signal MC:

TAULA Belle, 5000000× 2

- $\tau^- \to e^-\eta'$,5000000
- $\tau^- \to e^+\eta'$,5000000

Generic MC:

- MC14ri_d skimed (taupair,qqbar):5ab^{-1}
- MC14rd_c/d/e(taupair.qqbar):824.85 fb^{-1}
- MC15ri_b(taupair,qqbar):1 ab^{-1}

	Toy data (fb^{-1})	Rest MC(fb^{-1})
MC14ri_d	0	5000
MC14rd_c/d/e	0	824.85
MC15ri_b	426.505	573.795
		as background

Pre-event selection

Charged tracks

- dr<1.0cm , |dz|<3.0cm
- -0.866<$cos\theta$<0.956
- Pt>0.1Gev/c

Photos

- E>0.2Gev
- -0.866<$cos\theta$<0.956
- clusterNHists>1.5

PID

Tag side

- hadronID:nCDCHits >0
- electronID_noSVD_noTOP > 0.9
- muonID_noSVD > 0.9
- P(p/π)<0.6 and P(K/π)<0.4

Signal side

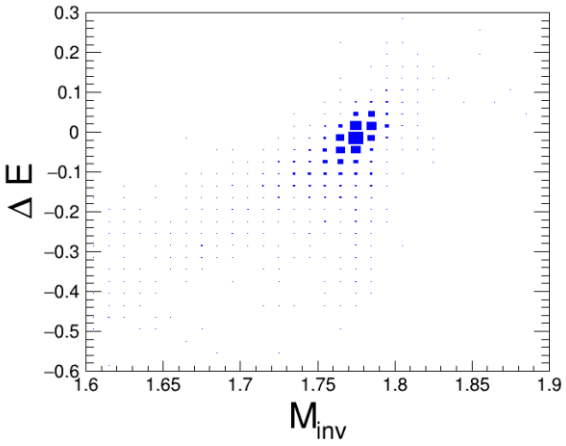
- electronID_noSVD_noTOP > 0.9
- electronID_noSVD_noTOP < 0.1 , P(p/π)<0.6 and P(K/π)<0.4

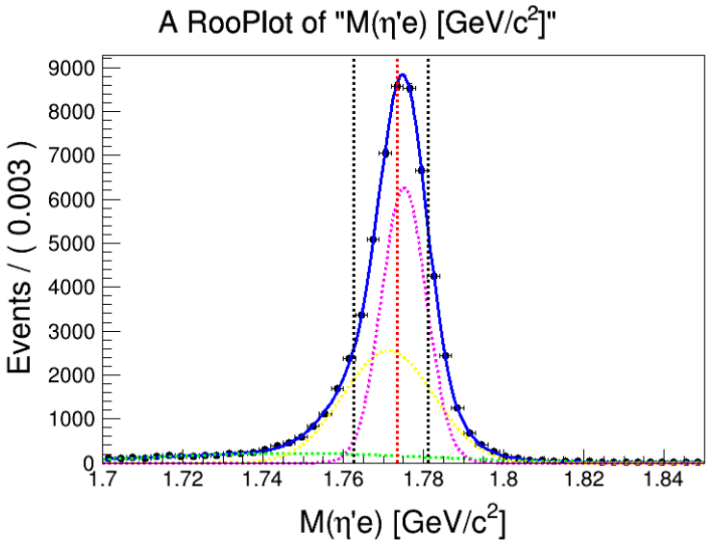
Event

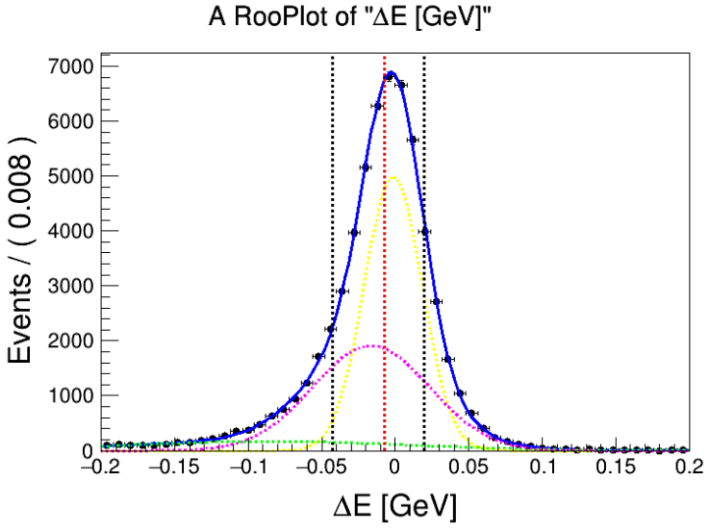
- For signal side :tree fit
- conf_level=0
- Mass fit for $\eta \to \gamma\gamma$
- updateAllDaughters=false
- nGoodTrack =4

Definition of signal region

Define an elliptic signal region with all signal events that that do not contain ISR,that is contain 90% of all signal events.







$$\frac{\int_{l_M}^{C_M} MdM}{\int_{L_M}^{C_M} MdM} = \frac{\int_{C_M}^{r_M} MdM}{\int_{C_M}^{R_M} MdM} = 68.2\%$$

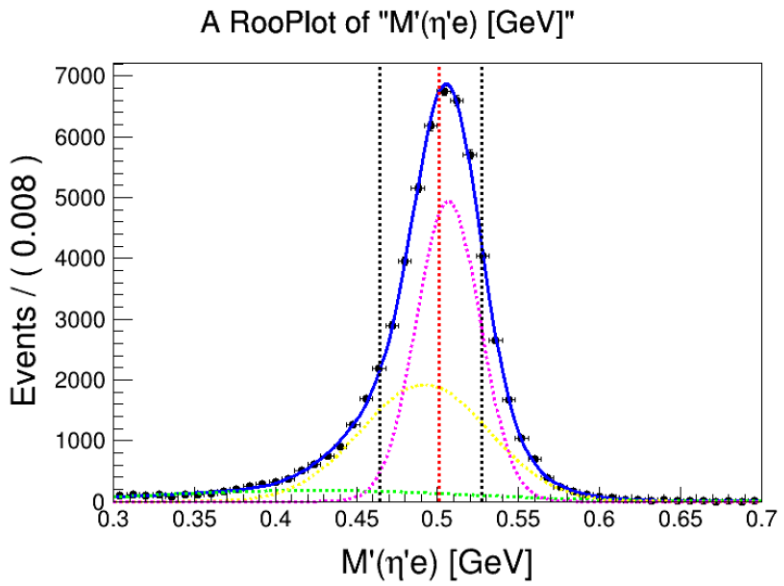
$$\sigma_M = r_M - l_M$$

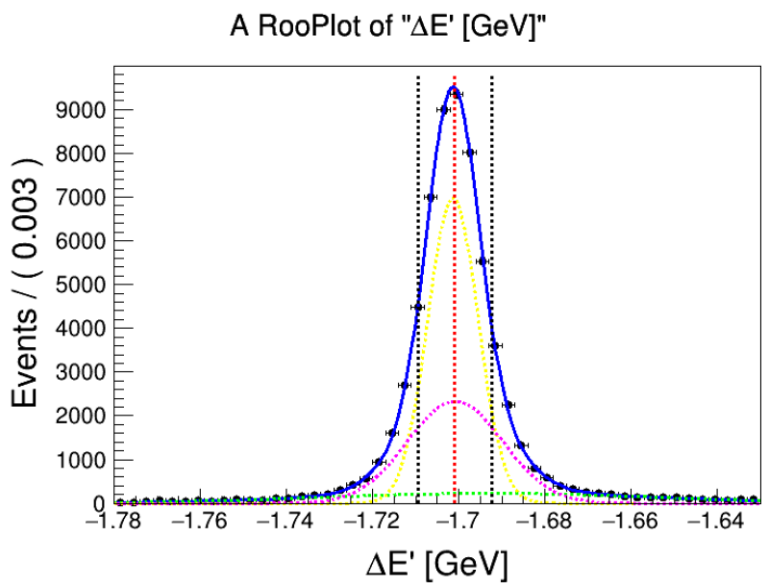
$$\begin{matrix} \mathrm{M}' \\ \Delta E' \end{matrix} = \begin{pmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{pmatrix} \begin{pmatrix} M \\ \Delta E \end{pmatrix}$$

$$\frac{\int_{l_{\Delta E}}^{C_{\Delta E}} \Delta E d\Delta E}{\int_{L_{\Delta E}}^{C_{\Delta E}} \Delta E d\Delta E} = \frac{\int_{C_{\Delta E}}^{r_{\Delta E}} \Delta E d\Delta E}{\int_{C_{\Delta E}}^{R_{\Delta E}} \Delta E d\Delta E} = 68.2\%$$

$$\sigma_{\Delta E} = r_{\Delta E} - l_{\Delta E}$$

$$\frac{\sigma_{\Delta E}}{\sigma_M} = tan\theta, \theta = 73.367°$$





$$\frac{\int_{l_{M'}}^{C_{M'}} M'dM'}{\int_{L_{M'}}^{C_{M'}} M'dM'} = \frac{\int_{C_{M'}}^{r_{M'}} M'dM'}{\int_{C_{M'}}^{R_{M'}} M'dM'} = 68.2\%$$

$$\sigma_{M'}^{l} = C_{M'} - l_{M'} \qquad \sigma_{M'}^{r} = r_{M'} - C_{M'}$$

$$\frac{\int_{l_{\Delta E'}}^{C_{\Delta E'}} \Delta E'd\Delta E'}{\int_{L_{\Delta E'}}^{C_{\Delta E'}} \Delta E'd\Delta E'} = \frac{\int_{C_{\Delta E'}}^{r_{\Delta E'}} \Delta E'd\Delta E'}{\int_{C_{\Delta E'}}^{R_{\Delta E'}} \Delta E'd\Delta E'} = 68.2\%$$

$$\sigma_{\Delta E'}^{l} = C_{\Delta E'} - l_{\Delta E'} \quad \sigma_{\Delta E'}^{r} = r_{\Delta E'} - C_{\Delta E'}$$

BDT analysis

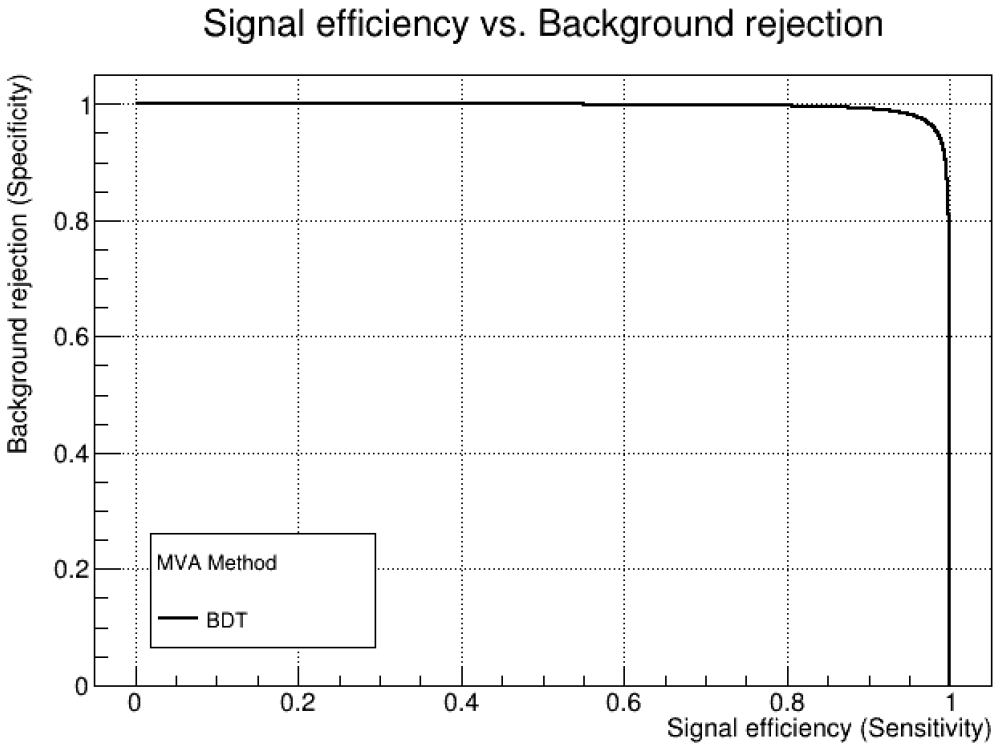
Train sample (pre-select): veto $\pi 0$ $\mathrm{M}(\gamma\gamma) > 0.16 \,||\, \mathrm{M}(\gamma\gamma) < 0.10 GeV/c^2$

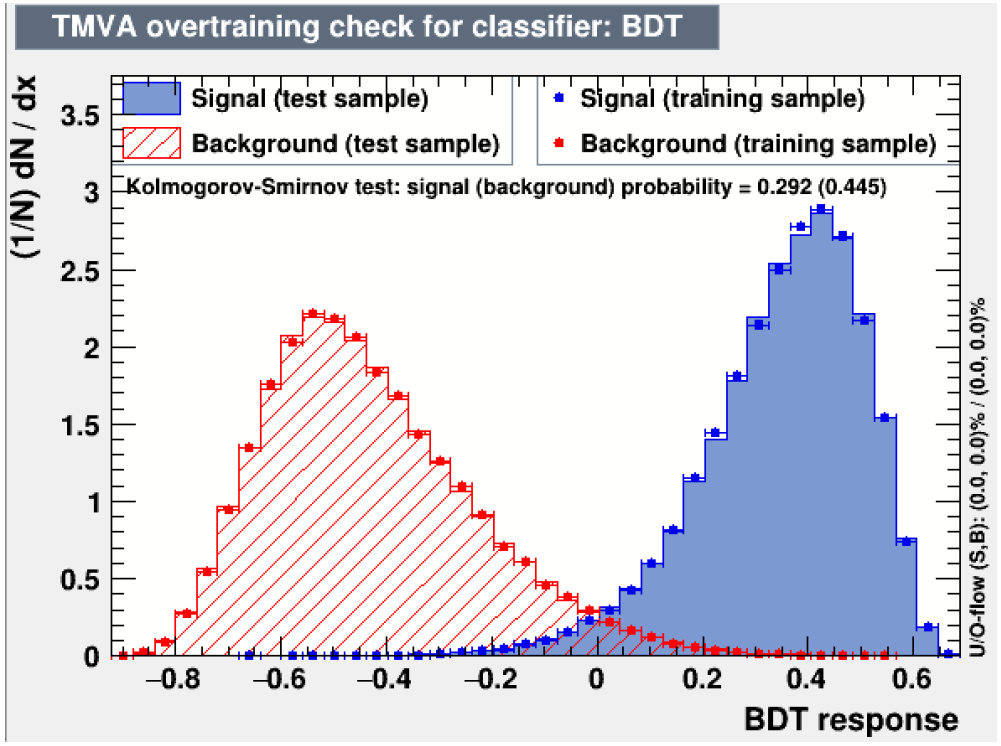
$thrust$	$cos\theta^{CM}_{thrust-miss}$
E^{CM}_{vis}	$recM^{tag}_{\tau}$
n^{SIG}_{γ}	etap_sig_chiProb
n^{TAG}_{γ}	$cos\theta_{e^- - \eta'}$
P^{CM}_{miss}	$cos\theta_{e^- - \eta}$
m^2_{miss}	$cos\theta_{e\gamma_1}$
$cos\theta_{miss}$	$cos\theta_{e2}$
$cos\theta_{tag-miss}$	$P^{sig}_{CM}(\eta')$
E^{CM}_{miss}	$P^{sig}_{CM}(\eta)$
dmID_tag	$E_{\gamma H}$ $E_{\gamma L}$

```
: ------------------------------------------------------------
: Rank : Variable                    : Variable Importance
: ------------------------------------------------------------
:    1 : eta_sig_cmsp                : 8.691e-02
:    2 : cose_etap                   : 8.231e-02
:    3 : etap_sig_cmsp               : 6.956e-02
:    4 : missingMomentumOfEventCMS   : 6.935e-02
:    5 : missingMass2OfEvent         : 6.334e-02
:    6 : E_gam_L                     : 6.048e-02
:    7 : cosmissTag                  : 5.850e-02
:    8 : nPhotons_sig                : 5.680e-02
:    9 : thrust                      : 5.615e-02
:   10 : cose_eta                    : 4.672e-02
:   11 : etap_sig_chiProb            : 4.658e-02
:   12 : visibleEnergyOfEventCMS     : 3.984e-02
:   13 : cose_gam1                   : 3.920e-02
:   14 : cose_gam0                   : 3.819e-02
:   15 : tau_tag_cmsp                : 3.798e-02
:   16 : cosmissThrust               : 3.622e-02
:   17 : cosThetamiss                : 3.221e-02
:   18 : E_gam_H                     : 2.235e-02
:   19 : nPhotons_tag                : 1.989e-02
:   20 : dmID_tag                    : 1.945e-02
:   21 : tau_tag_mRecoil             : 1.799e-02
: ------------------------------------------------------------
```

BDT analysis

Train sample (pre-select): veto $\pi 0$ $\mathrm{M}(\gamma\gamma) > 0.16 \,||\, \mathrm{M}(\gamma\gamma) < 0.10 GeV/c^2$

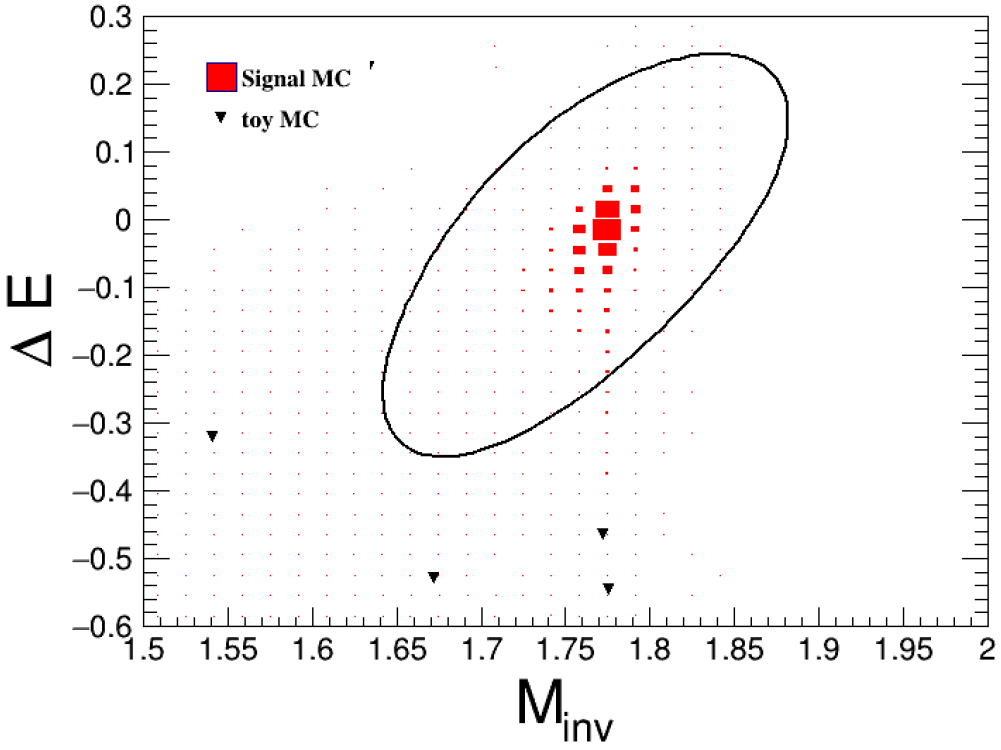


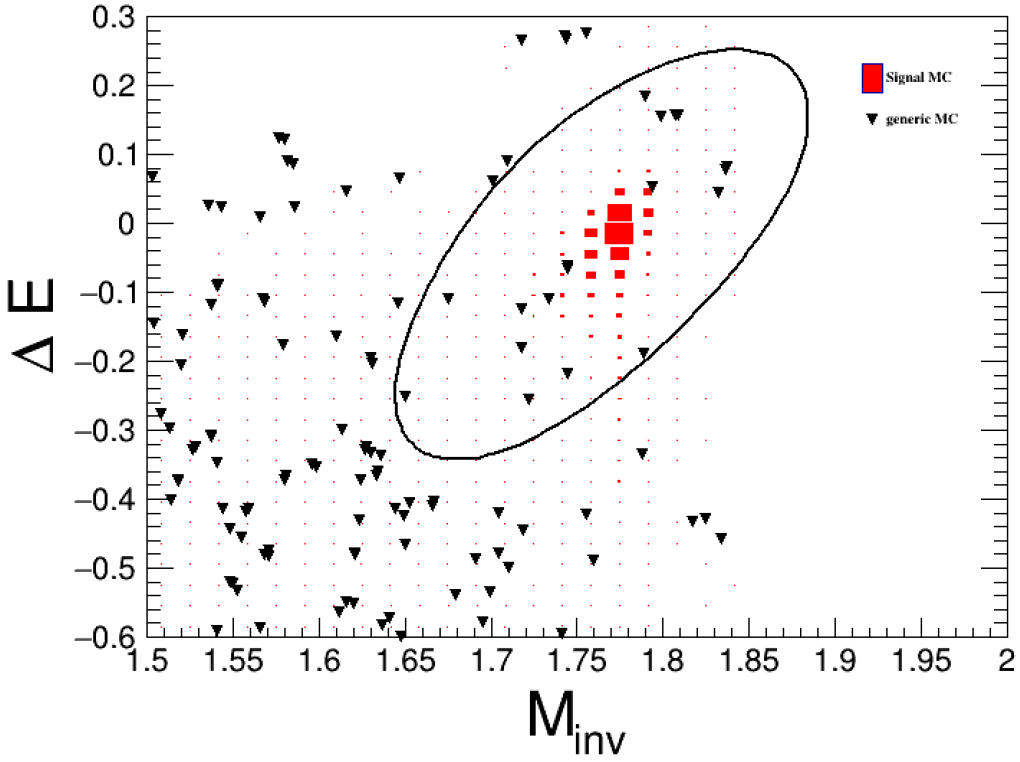


BDT	n	eff(90%)	error_rel.	N_bkg_res MC			N_exp	error_rel.	N_obs_toy MC	s_90	Br(x 10^-7)
				MC14rd	MC14ri	MC15ri			MC15ri		
0.30	10.79	0.0683	0.003	3	29	1	1.886	0.409	1	2.64	2.810
0.31	10.47	0.0654	0.003	2	26	1	1.743	0.440	1	2.65	2.946
0.32	10.27	0.0626	0.003	2	23	1	1.636	0.468	1	2.66	3.089
0.33	10.02	0.0596	0.003	2	19	0	1.493	0.510	1	2.68	3.269
0.34	9.72	0.0565	0.003	1	18	0	0.714	0.224	0	1.86	2.393
0.35	9.46	0.0534	0.003	1	14	0	0.535	0.258	0	1.82	2.477
0.36	9.18	0.0503	0.003	1	13	0	0.500	0.267	0	1.81	2.616
0.37	8.93	0.0472	0.003	1	11	0	0.428	0.289	0	1.78	2.741
0.38	8.67	0.0441	0.004	1	8	0	0.321	0.333	0	1.74	2.868

BDT	n	eff(90%)	error_rel.	N_bkg_res MC			N_exp	error_rel.	N_obs_toy MC	s_90	Br(x 10^-7)
				MC14rd	MC14ri	MC15ri			MC15ri		
0.331	10.019	0.0593	0.003	2	19	1	1.493	0.510	1	2.68	3.285
0.332	10.000	0.0590	0.003	2	19	1	1.493	0.510	0	1.98	2.440
0.333	9.953	0.0587	0.003	2	19	1	1.493	0.510	0	1.98	2.452
0.334	9.890	0.0584	0.003	2	19	1	1.493	0.510	0	1.98	2.465
0.335	9.876	0.0581	0.003	2	19	0	0.749	0.218	0	1.87	2.340
0.336	9.852	0.0578	0.003	2	19	0	0.749	0.218	0	1.87	2.352
0.337	9.815	0.0575	0.003	2	18	0	0.714	0.224	0	1.86	2.352
0.338	9.778	0.0572	0.003	2	18	0	0.714	0.224	0	1.86	2.364
0.339	9.750	0.0569	0.003	2	18	0	0.714	0.224	0	1.86	2.377

BDT result





N_{obs}	$N_{exp} \pm \Delta N_{exp}$				$\varepsilon_{sig}(\%)$	S_{90}
	MC14rd	MC14ri	MC15ri	Normalized		
0	2	18	0	0.714±0.224	0.575	1.86

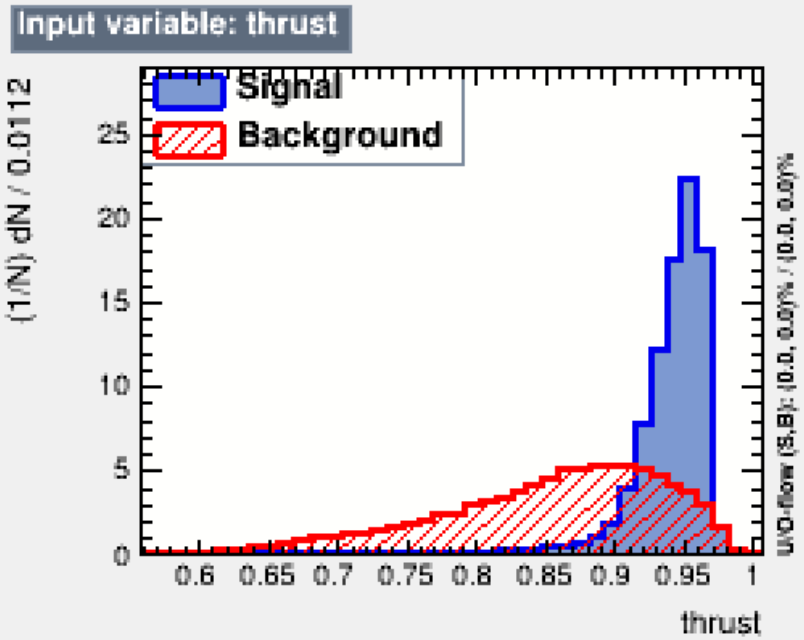
result for Branching fraction

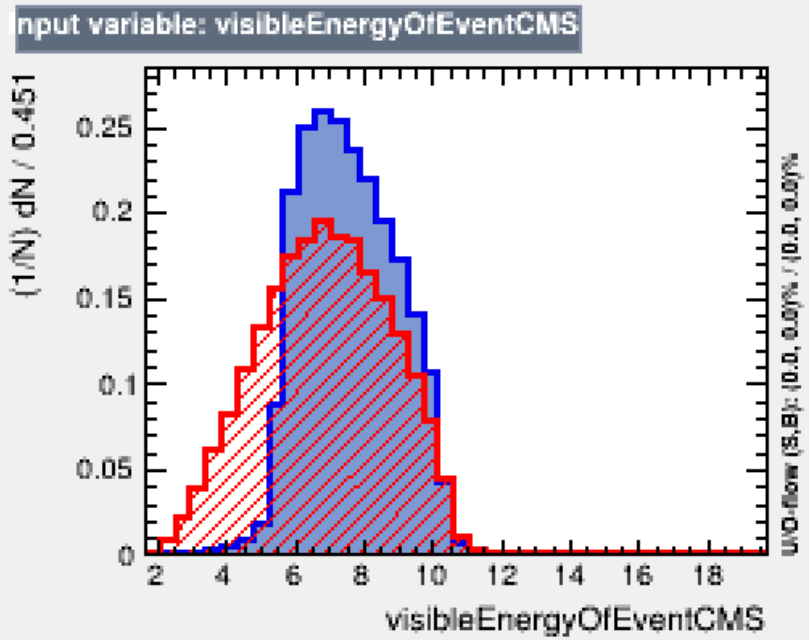
$$\mathcal{B}(\tau^- \to e^-\eta') < \frac{s_{90}}{2\varepsilon_{sig} N_{\tau\tau} \mathcal{B}(\eta' \to \eta(\to \gamma\gamma)\pi^+\pi^-)}$$

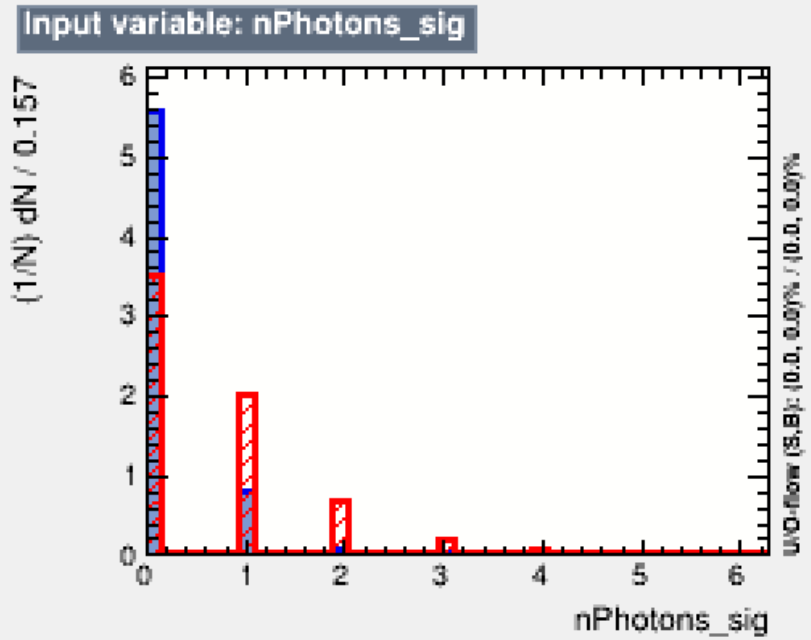
$N_{\tau\tau} = 391.95 \times 10^6$、$\mathcal{B}(\eta' \to \eta(\to \gamma\gamma)\pi^+\pi^-) = 0.445 \times 0.9343$、$s_{90} = 1.86$

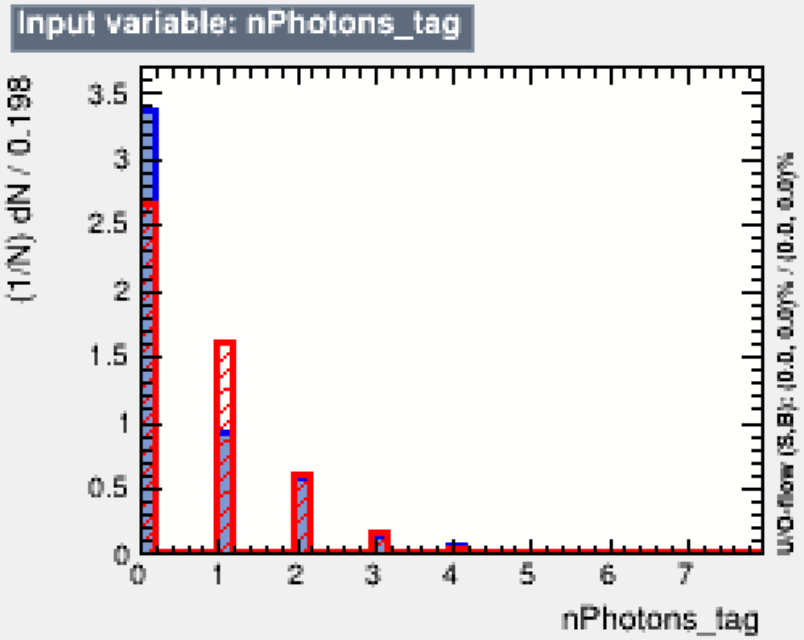
$$\mathcal{B}(\tau^- \to e^-\eta') < 2.35 \times 10^{-7}$$

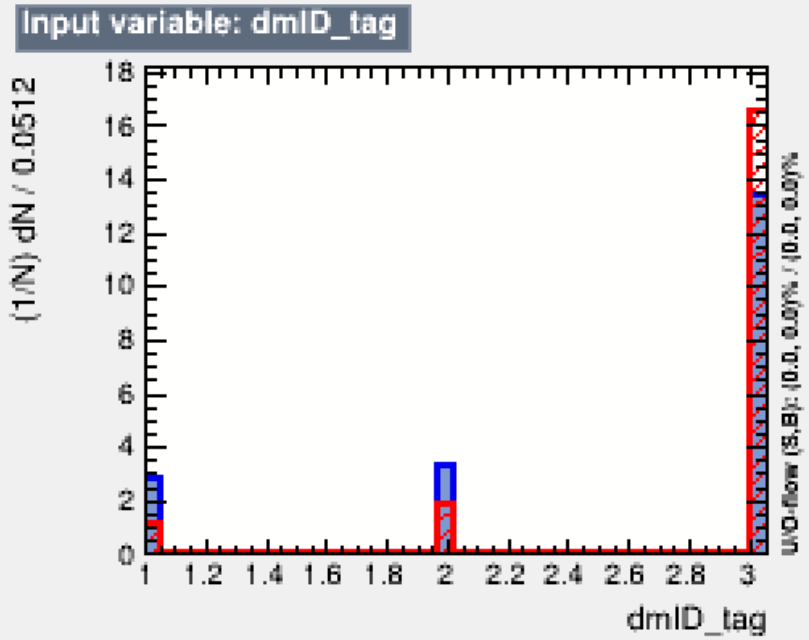
Backup

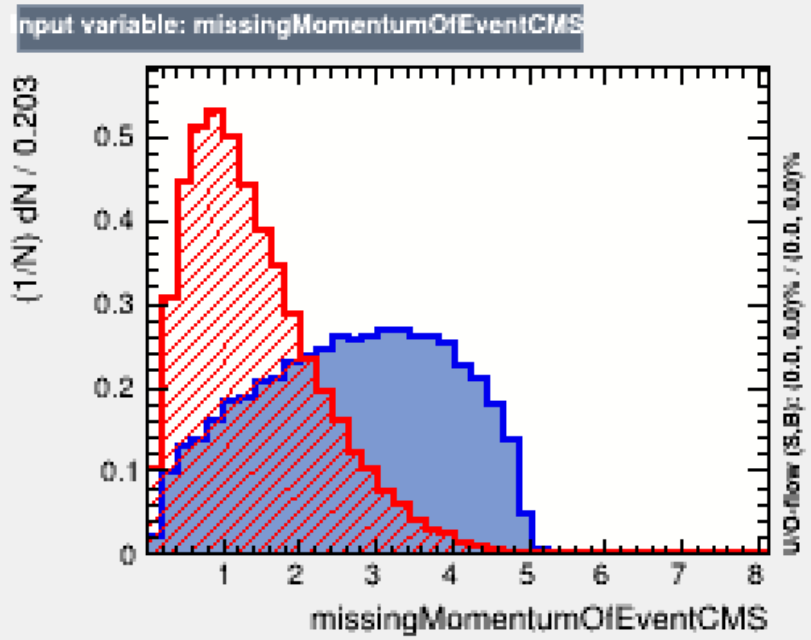

Input variable: thrust
Signal
Background
(1/N) dN / 0.0112
thrust
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%

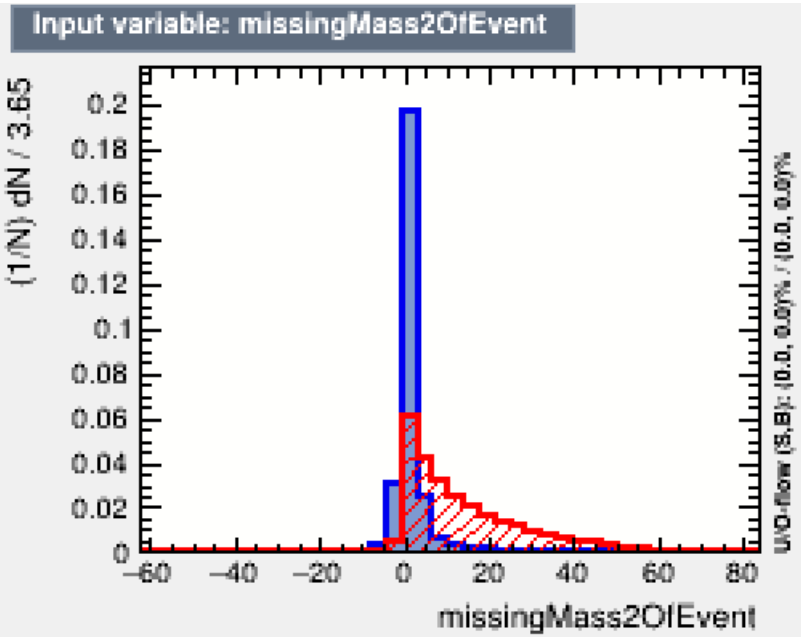

Input variable: visibleEnergyOfEventCMS
(1/N) dN / 0.451
visibleEnergyOfEventCMS
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%

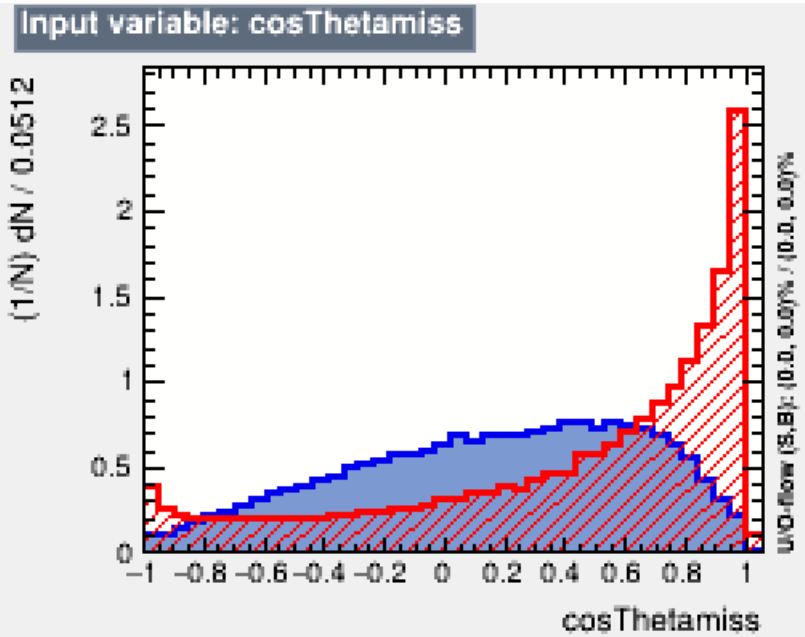

Input variable: nPhotons_sig
(1/N) dN / 0.157
nPhotons_sig
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%

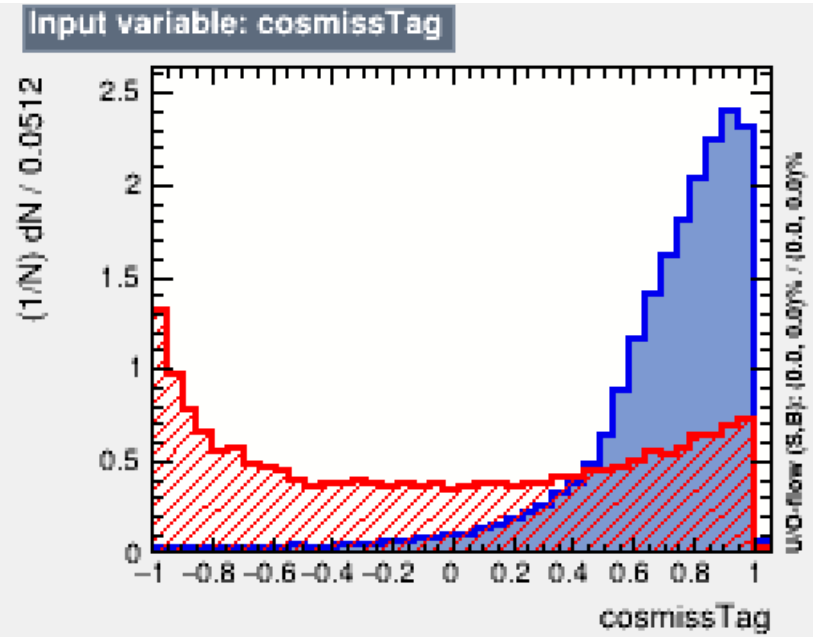

Input variable: nPhotons_tag
(1/N) dN / 0.198
nPhotons_tag
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%

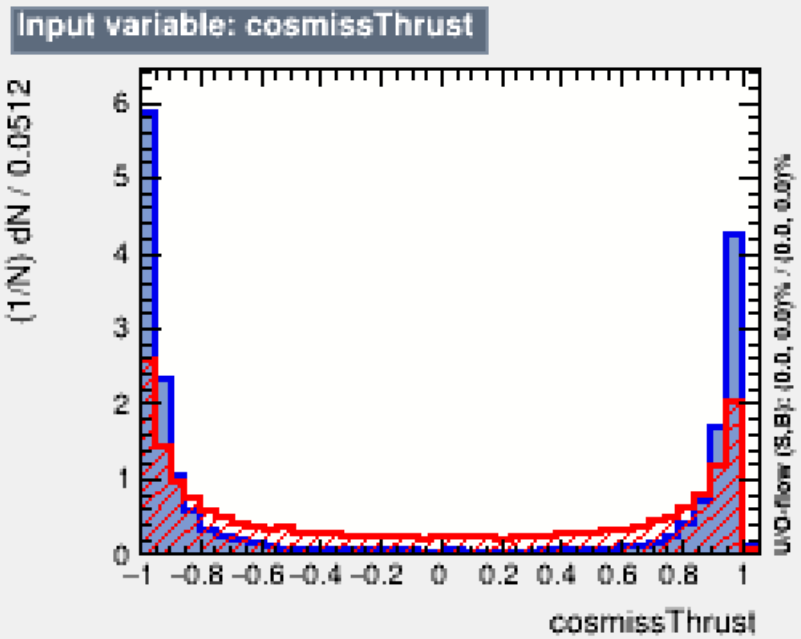

Input variable: dmID_tag
(1/N) dN / 0.0512
dmID_tag
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%

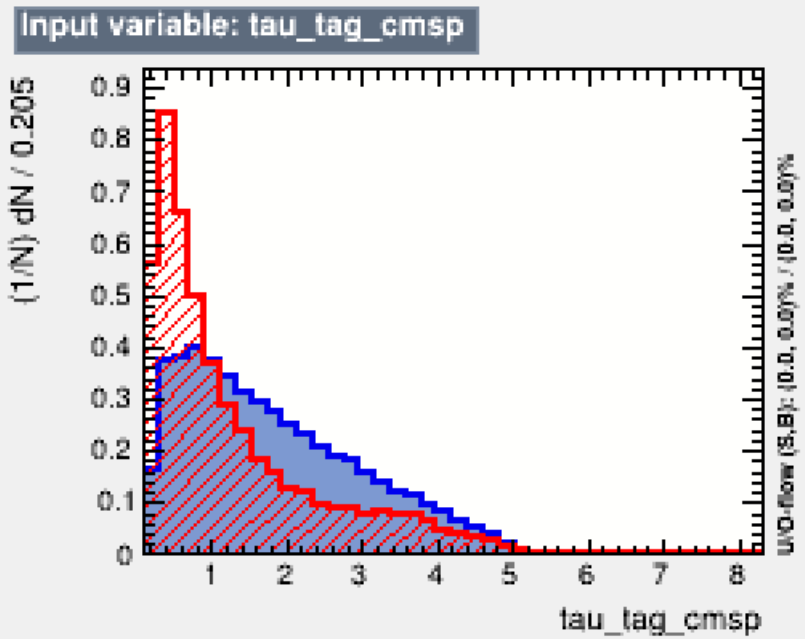

Input variable: missingMomentumOfEventCMS
(1/N) dN / 0.203
missingMomentumOfEventCMS
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%

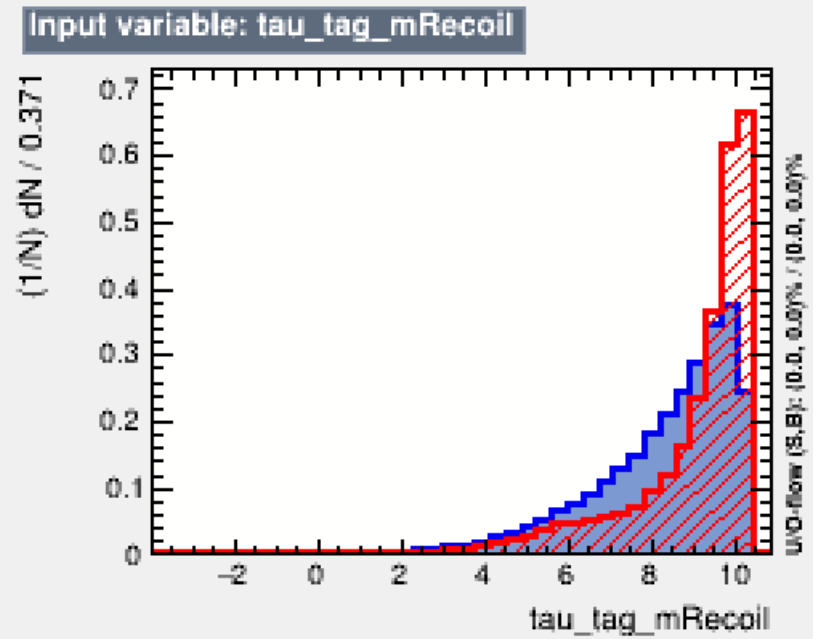

Input variable: missingMass2OfEvent
(1/N) dN / 3.65
missingMass2OfEvent
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%

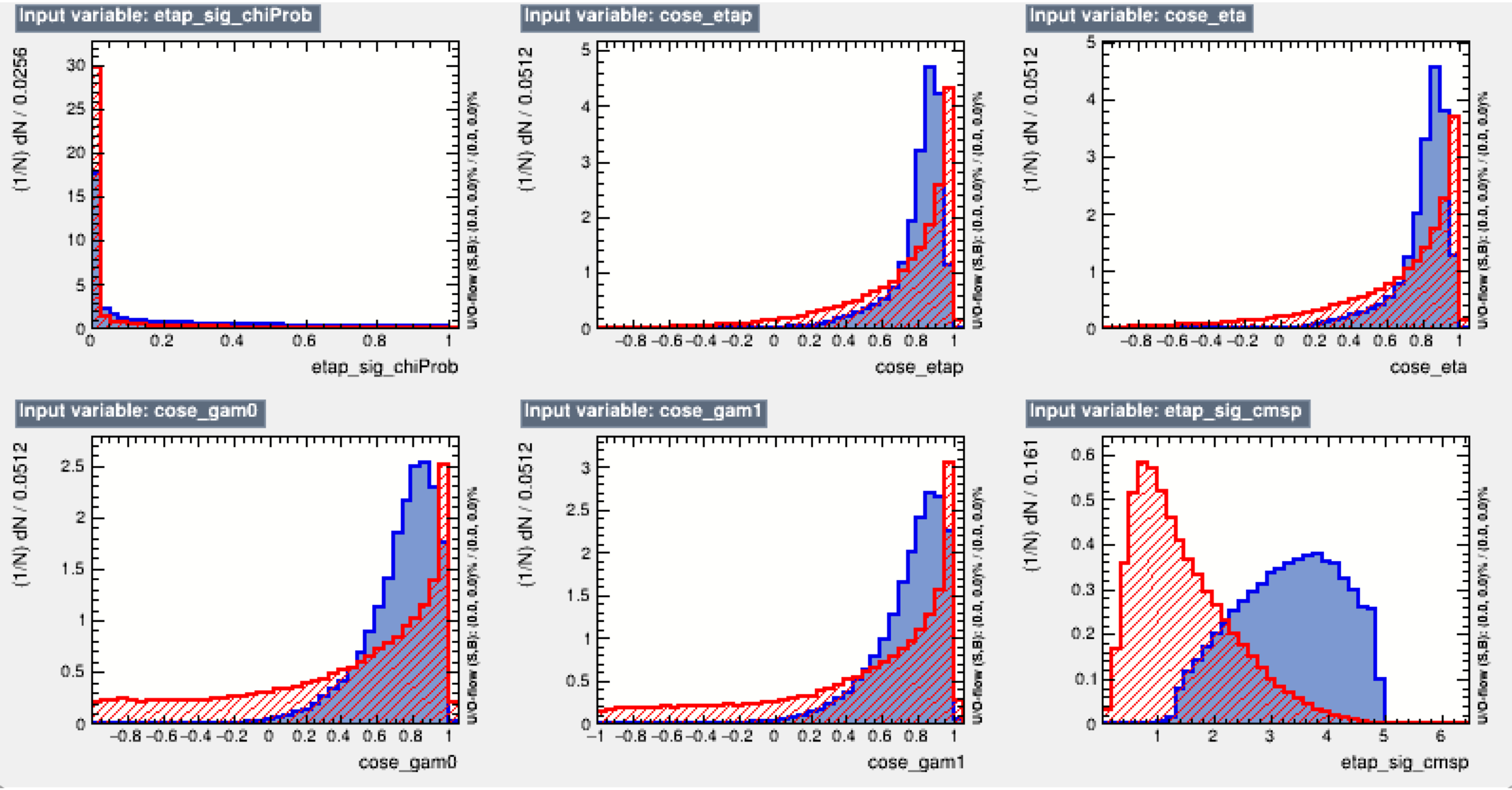

Input variable: cosThetamiss
(1/N) dN / 0.0512
cosThetamiss
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%

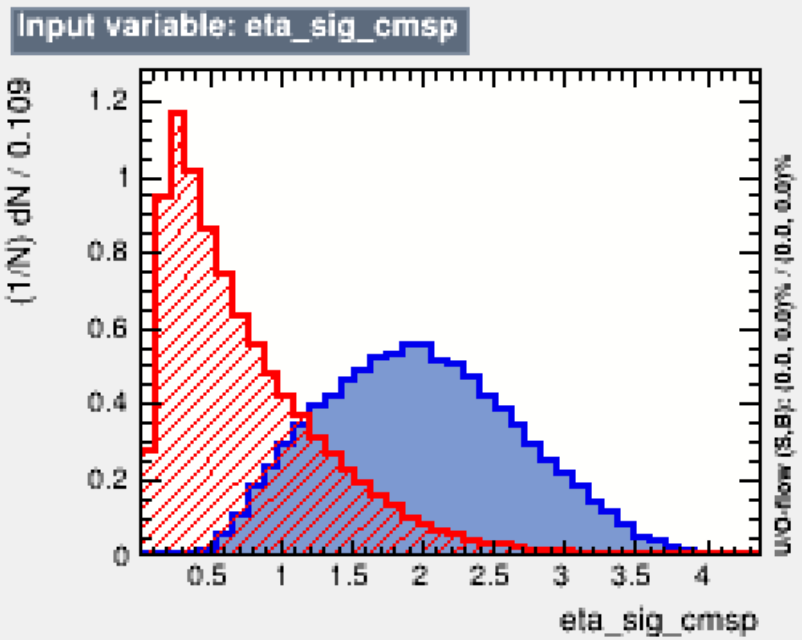

Input variable: cosmissTag
(1/N) dN / 0.0512
cosmissTag
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%

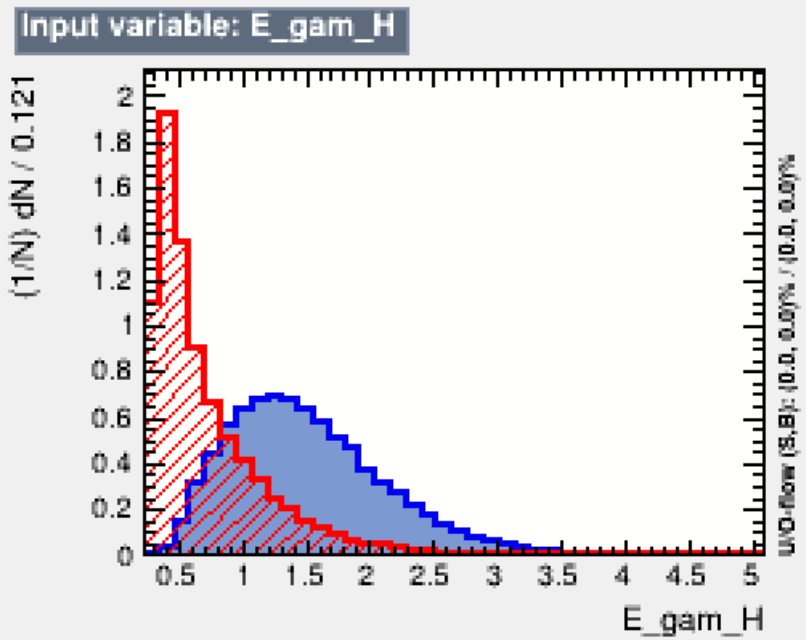

Input variable: cosmissThrust
(1/N) dN / 0.0512
cosmissThrust
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%

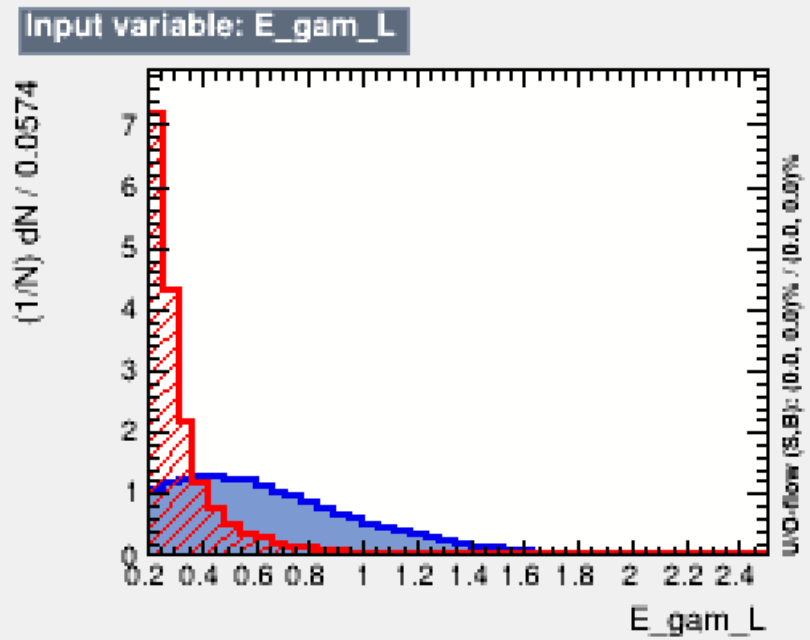

Input variable: tau_tag_cmsp
(1/N) dN / 0.205
tau_tag_cmsp
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%


Input variable: tau_tag_mRecoil
(1/N) dN / 0.371
tau_tag_mRecoil
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%

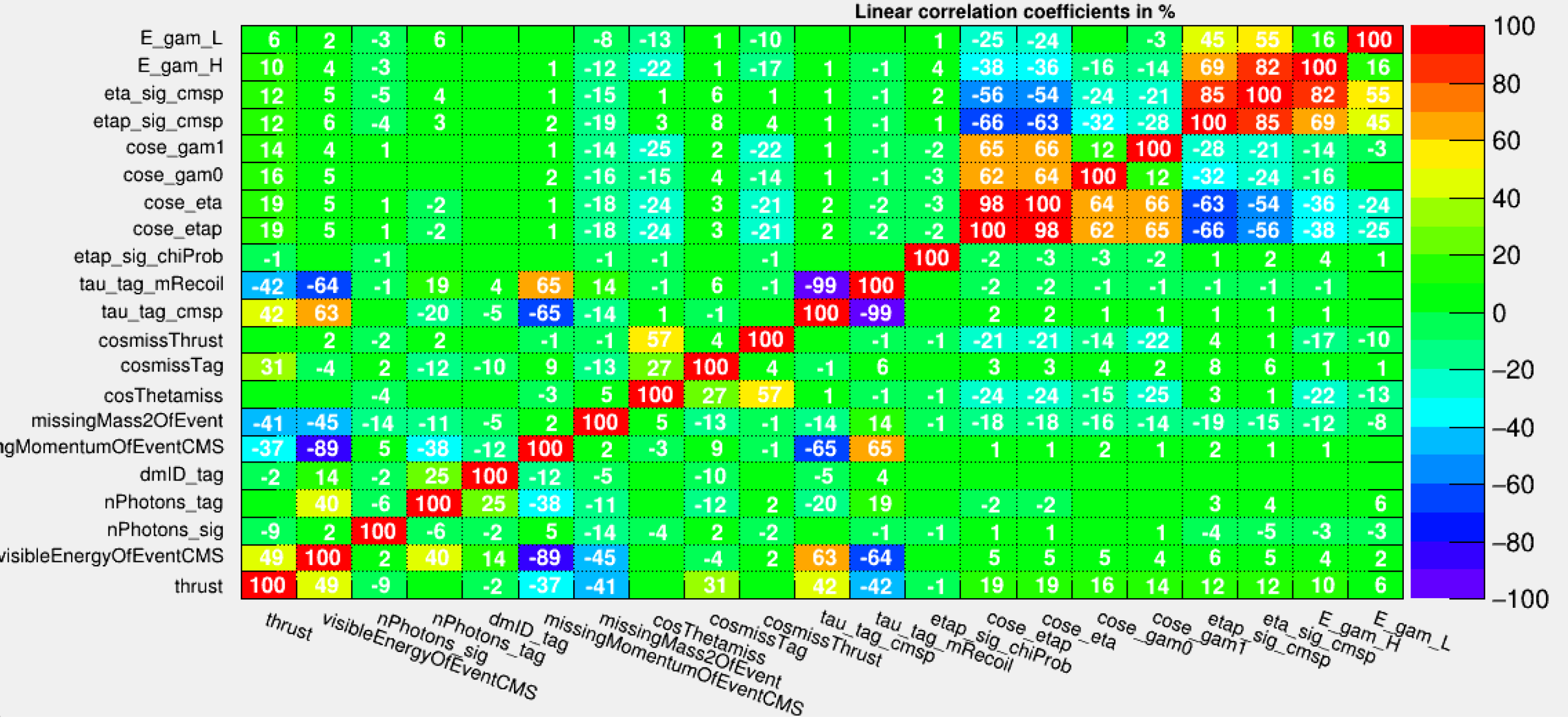

Input variable: etap_sig_chiProb
(1/N) dN / 0.0256
etap_sig_chiProb
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
Input variable: cose_etap
(1/N) dN / 0.0512
cose_etap
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
Input variable: cose_eta
(1/N) dN / 0.0512
cose_eta
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
Input variable: cose_gam0
(1/N) dN / 0.0512
cose_gam0
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
Input variable: cose_gam1
(1/N) dN / 0.0512
cose_gam1
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%
Input variable: etap_sig_cmsp
(1/N) dN / 0.161
etap_sig_cmsp
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%


Input variable: eta_sig_cmsp
(1/N) dN / 0.109
eta_sig_cmsp
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%

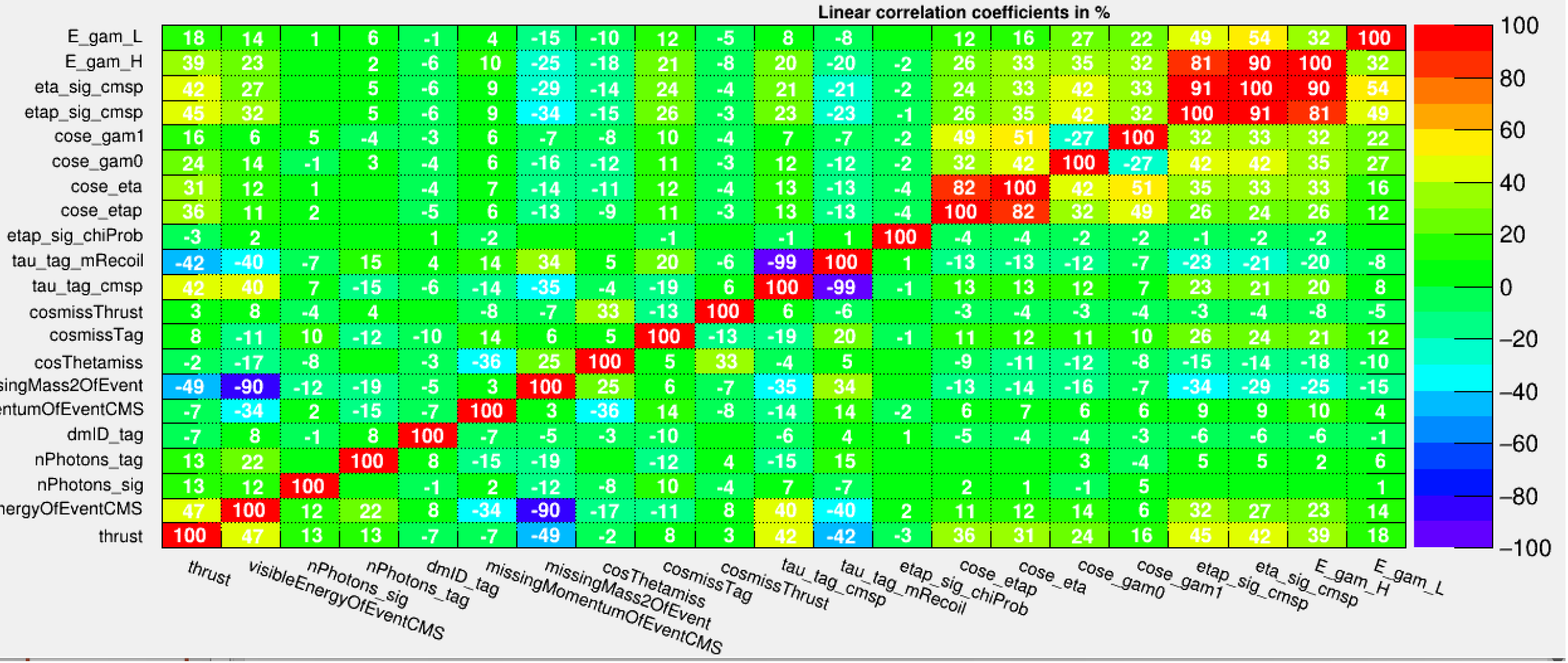

Input variable: E_gam_H
(1/N) dN / 0.121
E_gam_H
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%

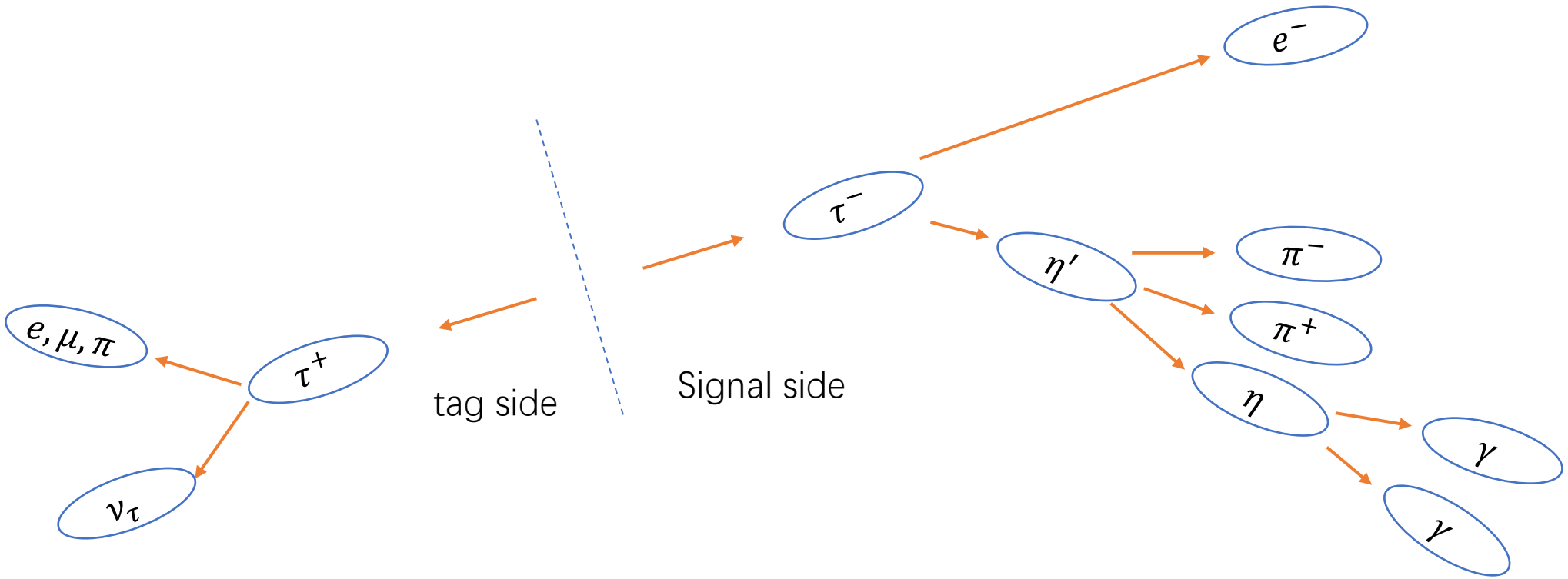

Input variable: E_gam_L
(1/N) dN / 0.0574
E_gam_L
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%

Correlation Matrix (signal)



Correlation Matrix (background)




e^-
τ^-
η'
π^-
π^+
η
γ
γ
e, μ, π
τ^+
ν_τ
tag side
Signal side