

CHARGED HIGGS BOSON ANALYSIS AT FCC-HH

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Outline

- Signal process
- Objects in final state
- Signal and background samples from FCCSW
- Cross sections and event selection
- Analysis steps with Heppy
- Kinematic distributions and cut flows
- Reconstruction of invariant masses
- Statistical significance
- Conclusions

Signal Process

We study charged Higgs boson at FCC-hh

- **Generation of signal events:**

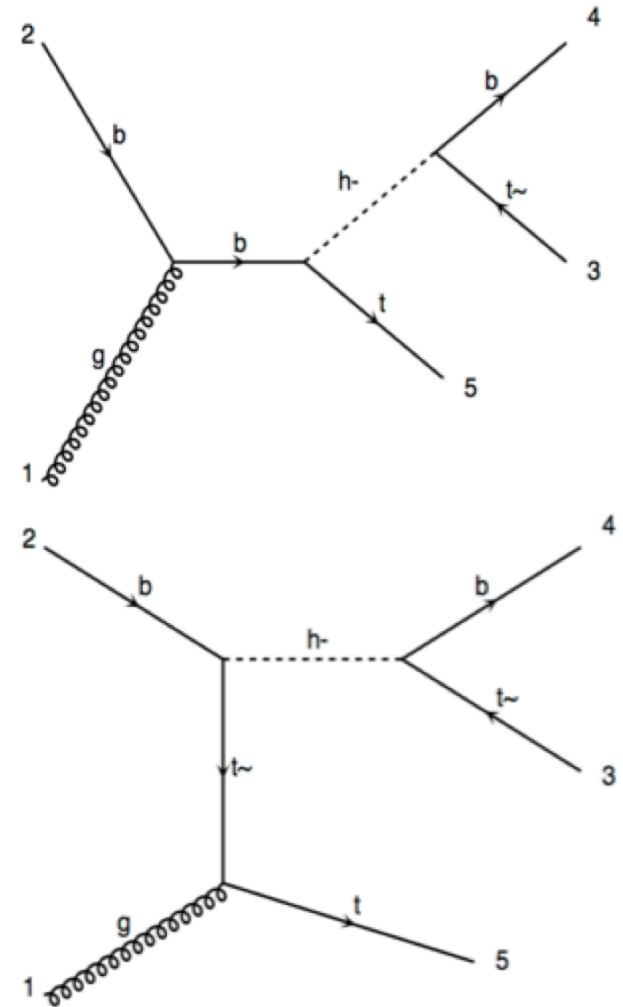
- Production $p p \rightarrow t H^- + X$ Pythia8
- Decay mode $t H^- \rightarrow t t b \rightarrow W^+ W^- b b b$
 $\rightarrow f_1 f_2' f_3 f_4' b b b$

(decays and hadronization within Pythia8)

- **Parameters:** m_H in the range [500 – 2000] GeV; $\tan(\beta) = 10$; $\cos(\beta - \alpha) = 0$.

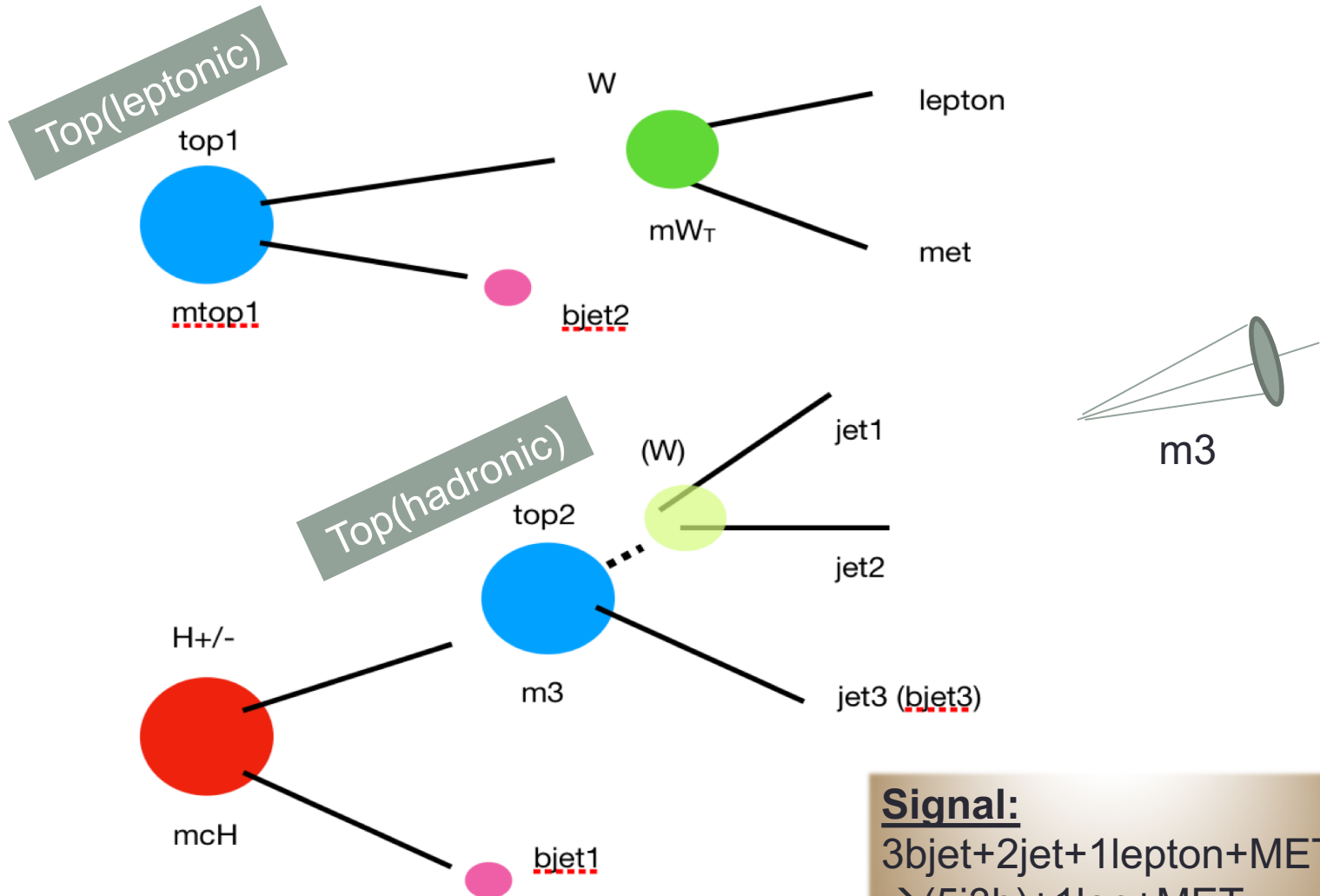
- **Signal:**

- **Interested channel:** 3bjet + 2j + 1lepton + MET (where $W(1) \rightarrow l\nu$, $W(2) \rightarrow 2j$) – **single lepton channel**



Main diagrams for subprocess $bg \rightarrow tH^- \rightarrow tt^{\sim}b$

Objects in Final State



Signal:

3bjet+2jet+1lepton+MET
 $\rightarrow (5j3b)+1lep+MET$

FCCSW and Samples

• FCCSW

- Signal events are generated with **Pythia8** within FCCSW. Background LHE events are generated with **MG5** for further hadronization and showering through Pythia8 within FCCSW
- Fast detector simulation is performed with **Delphes** for parametric card FCCh.tcl
- Event selection is applied on those samples with **Heppy**. Flat ntuples are produced with observables of interest and analyzed with Heppy
- Gen-level and Reco-level plots are produced with python scripts – Heppy writes a tree.root file – Root

• Signal samples

- $pp \rightarrow tH \rightarrow ttb \rightarrow WWbbb$ (mass = 500, 1000, 2000 GeV)

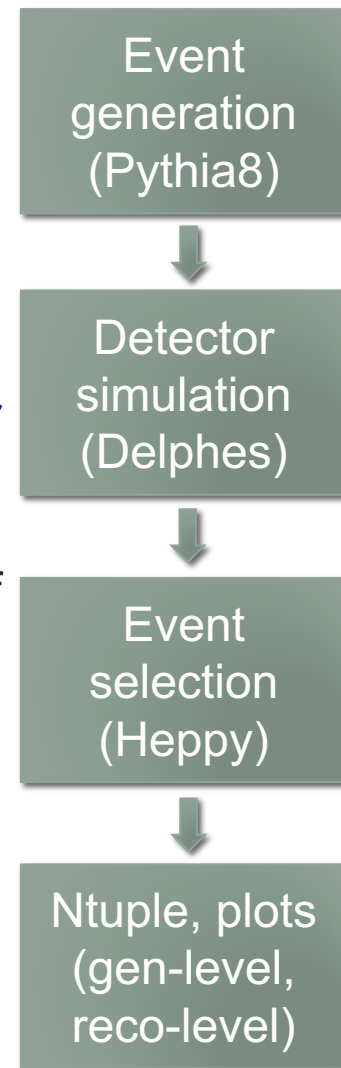
• Background samples

* $pp \rightarrow tt$

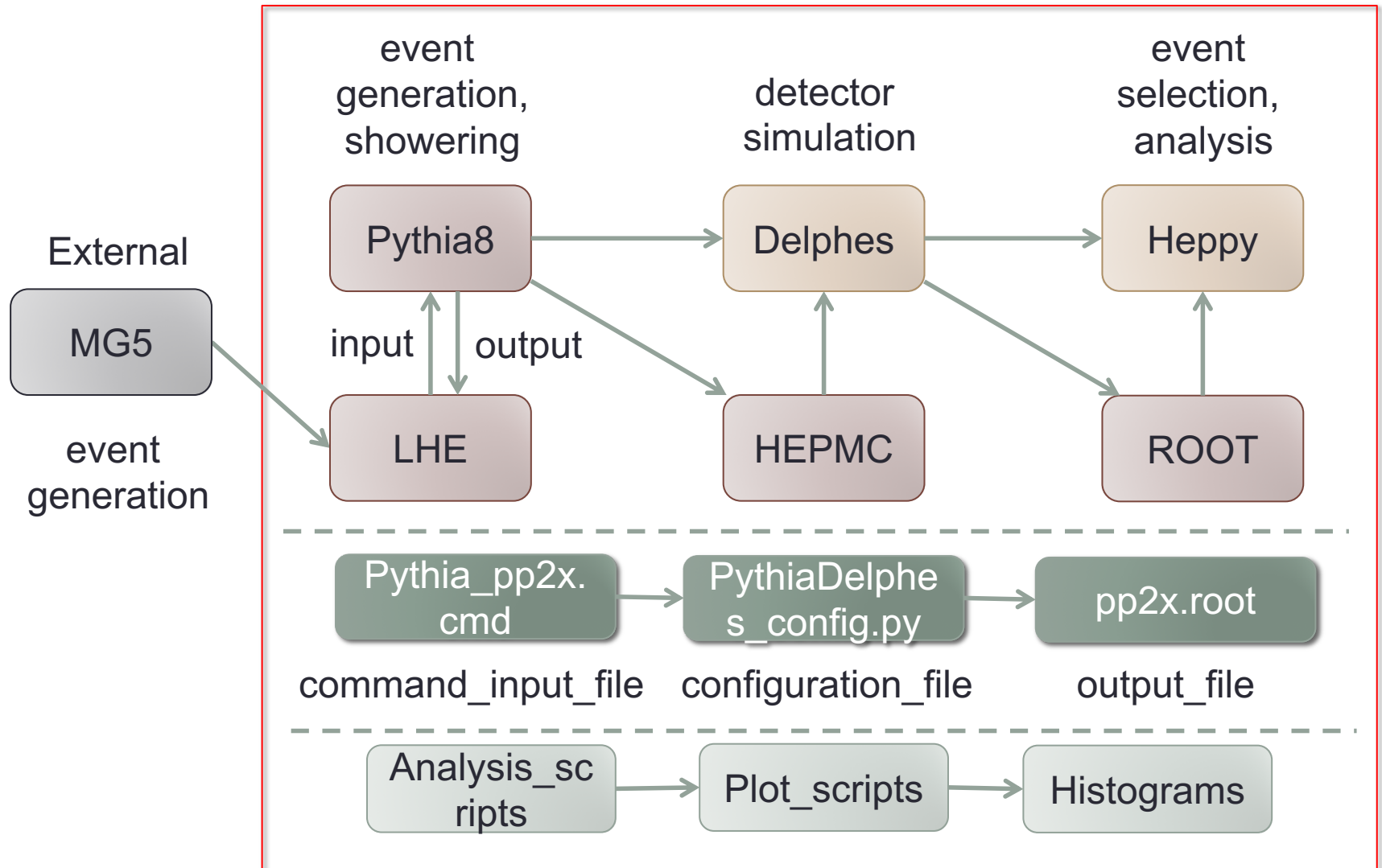
* $pp \rightarrow ttb$

* $pp \rightarrow ttj$

Analysis steps



Workflow within FCCSW



Cross Sections

Signal cross sections (Pythia8 with generator level defaults), parameters: $\tan\beta=10$, $\cos(\beta-\alpha)=0$. EvntW is the number of events for given L_{int} .

Mass (GeV)	Cross section (pb)	EvntW ($L_{\text{int}}=1 \text{ ab}^{-1}$)
500	45.120	4.512×10^7
1000	6.198	6.198×10^6
2000	0.661	6.610×10^5

Background cross section (MG5 with generator level defaults).

Background	Cross section (pb)	EvntW ($L_{\text{int}}=1 \text{ ab}^{-1}$)
$pp \rightarrow tt$	2.607×10^4	2.607×10^{10}
$pp \rightarrow ttj$	4.037×10^4	4.037×10^{10}
$pp \rightarrow ttb$	4.906×10^2	4.906×10^8

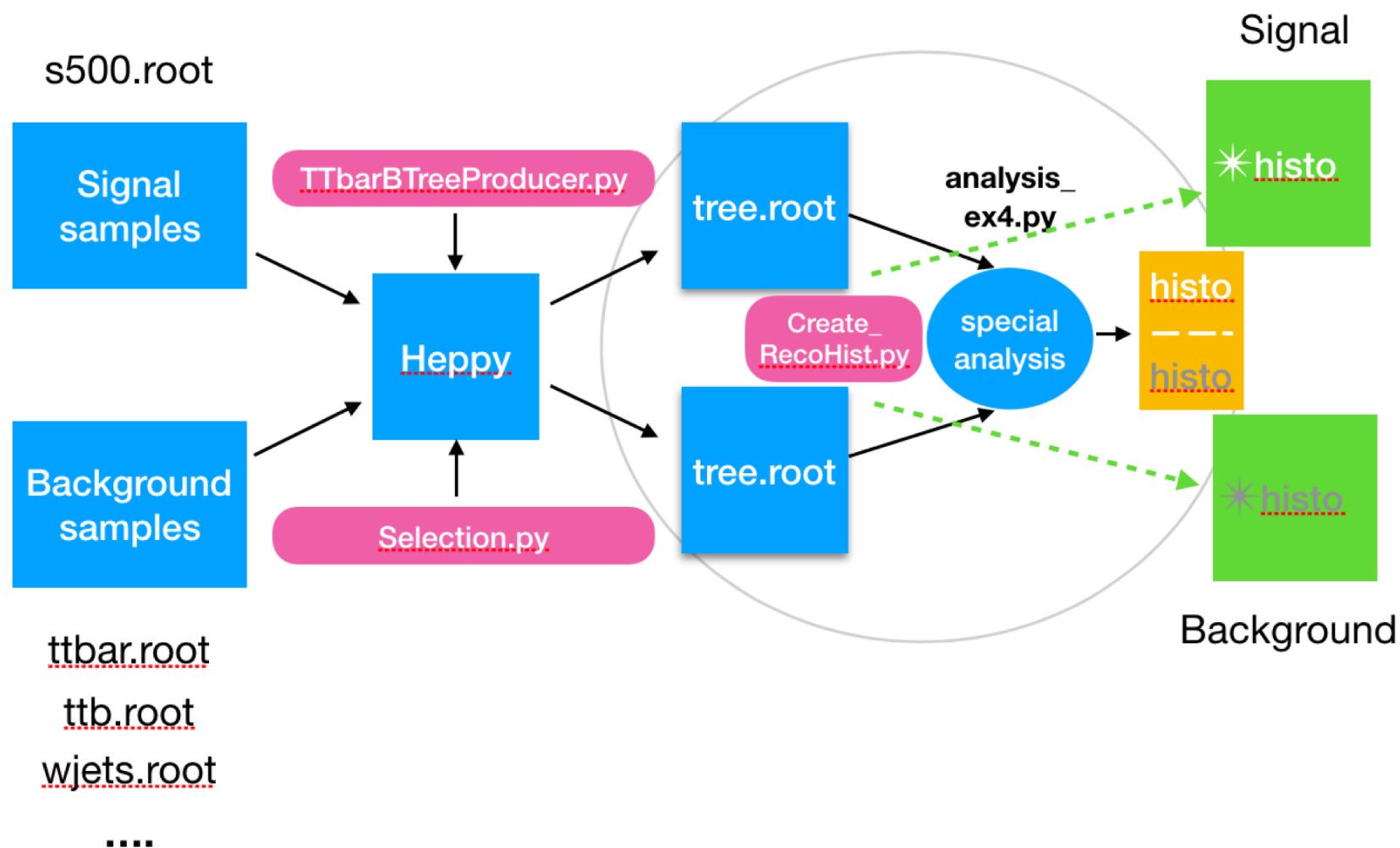
Event Selection

Event selection and signal reconstruction

- Events with the presence of (# objects)
 - at least 5 jets ($N_{\text{jets}} \geq 4$) and at least 2 bjets ($N_{\text{bjets}} \geq 2$)
 - one muon or electron
 - significant MET
 - **focus: $2j+3bj+1l+\text{MET}$
or $\geq 5j+1l+\text{MET}$**
- Events for a reconstructed top (invariant mass of lvb) by combining the reconstructed W boson (invariant mass of lepton and neutrino or two jets) and bjet candidate.
- Further steps
 - isolation criteria for electron or muon
 - rejection of events with additional muon or electron candidates
 - removal of electrons or muons if they are separated from the nearest jet by $\Delta R < 0.4$

Single
leptonic

Analysis steps with Heppy



Cut-flow Signal and Background

Signal-s500

Counter cut_flow :

All events	10000	1.00	1.0000
At least 5 jets	9766	0.98	0.9766
At least 2 b-jet	8713	0.89	0.8713
Exactly 1 lepton	1977	0.23	0.1977
MET > 20GeV	1852	0.94	0.1852

Signal-s1000

Counter cut_flow :

All events	10000	1.00	1.0000
At least 5 jets	9891	0.99	0.9891
At least 2 b-jet	9060	0.92	0.9060
Exactly 1 lepton	2045	0.23	0.2045
MET > 20GeV	1958	0.96	0.1958

Signal-s2000

Counter cut_flow :

All events	10000	1.00	1.0000
At least 5 jets	9926	0.99	0.9926
At least 2 b-jet	9265	0.93	0.9265
Exactly 1 lepton	1977	0.21	0.1977
MET > 20GeV	1924	0.97	0.1924

Background-ttb

Counter cut_flow :

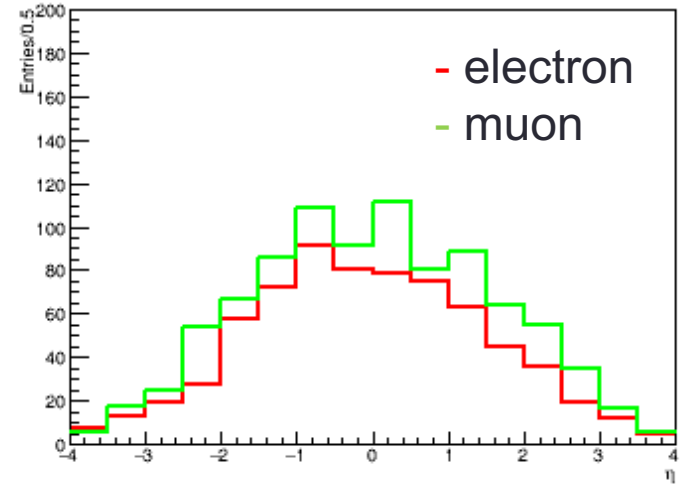
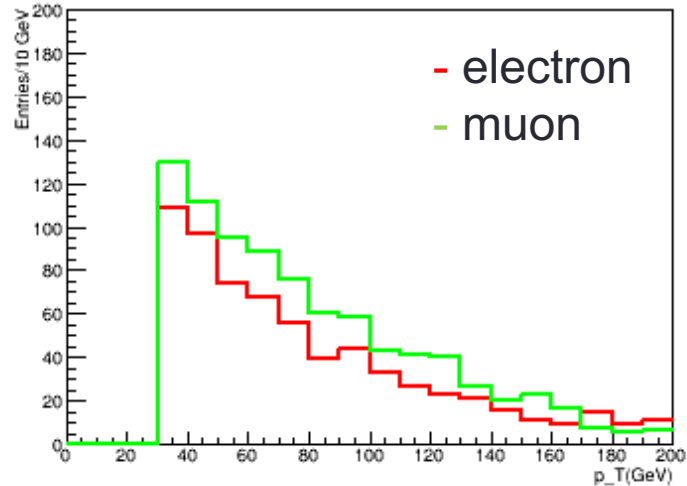
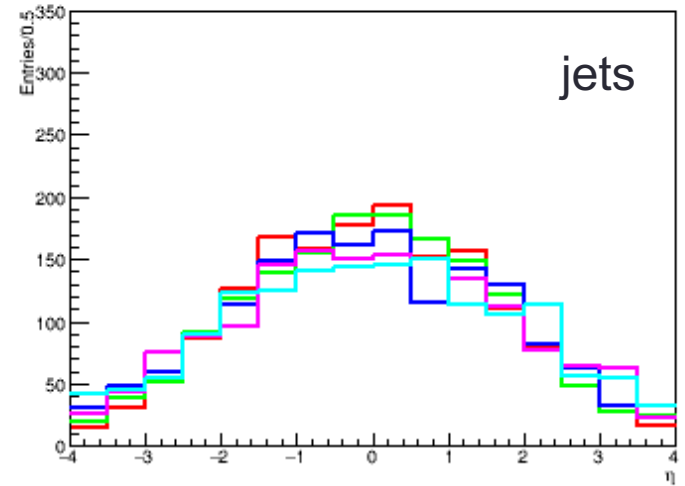
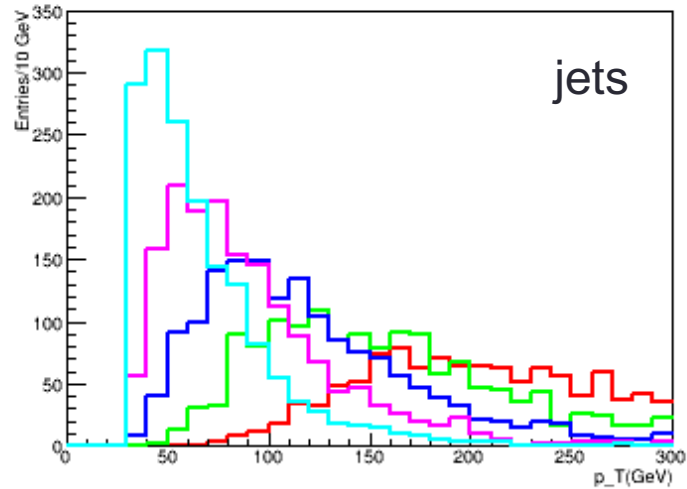
All events	10000	1.00	1.0000
At least 5 jets	7754	0.78	0.7754
At least 2 b-jet	5844	0.75	0.5844
Exactly 1 lepton	1162	0.20	0.1162
MET > 20GeV	1074	0.92	0.1074

Background-ttbar

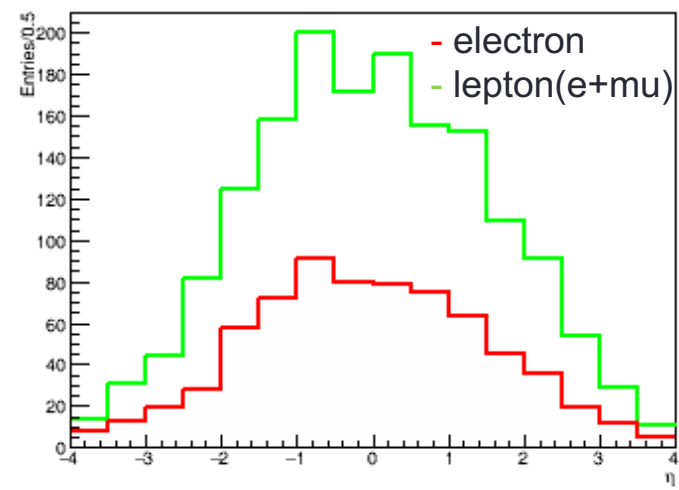
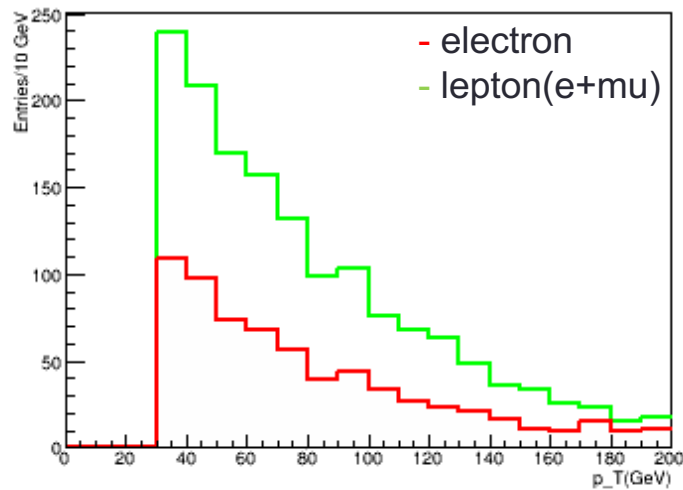
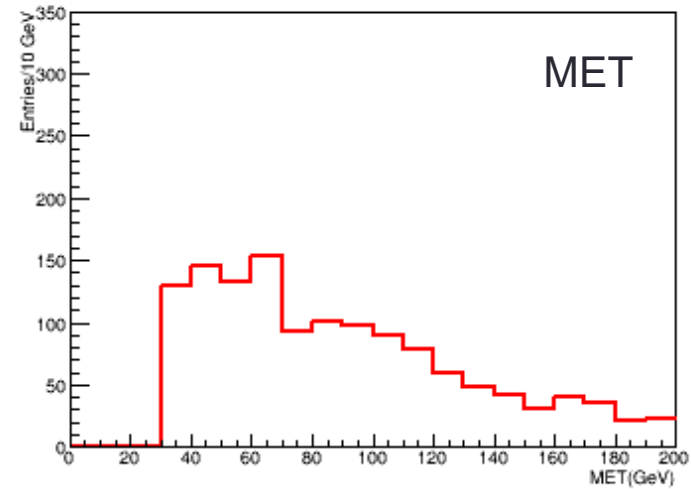
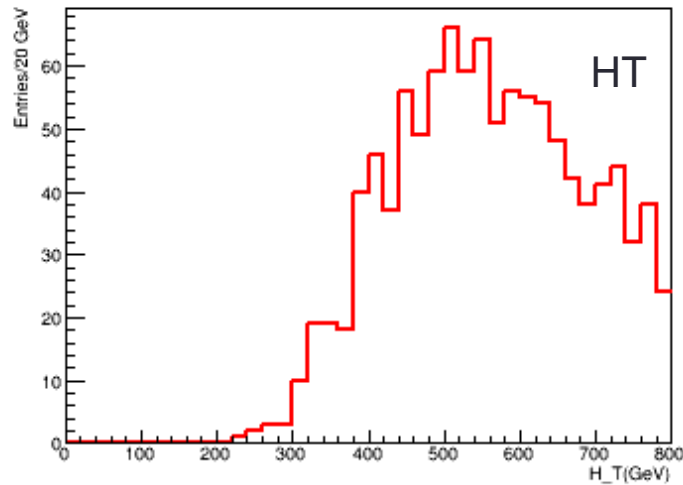
Counter cut_flow :

All events	10000	1.00	1.0000
At least 5 jets	5726	0.57	0.5726
At least 2 b-jet	3010	0.53	0.3010
Exactly 1 lepton	454	0.15	0.0454
MET > 20GeV	401	0.88	0.0401

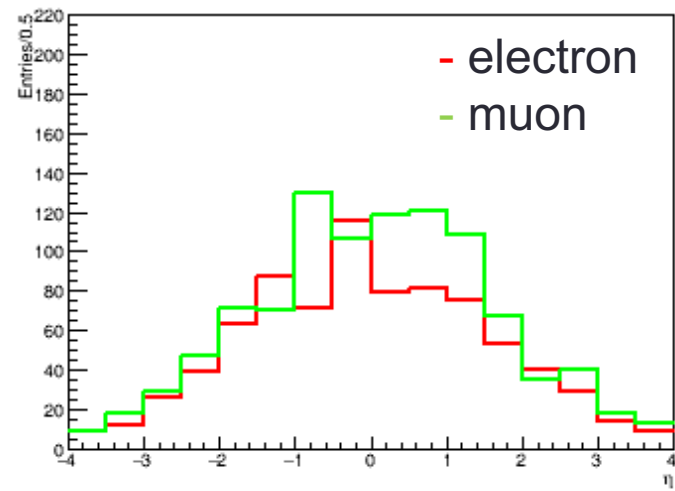
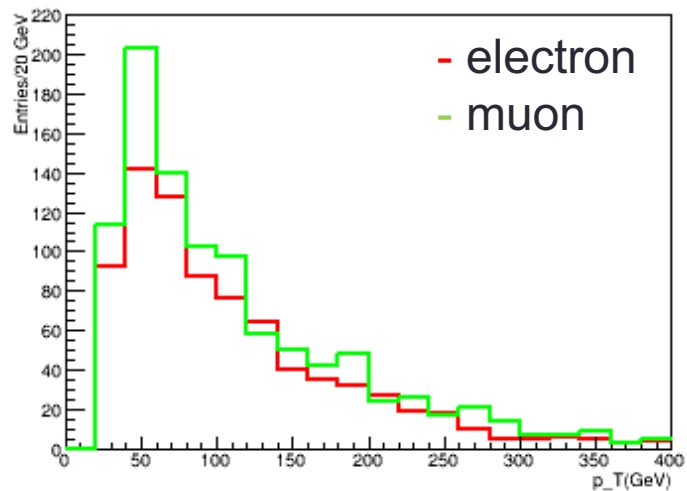
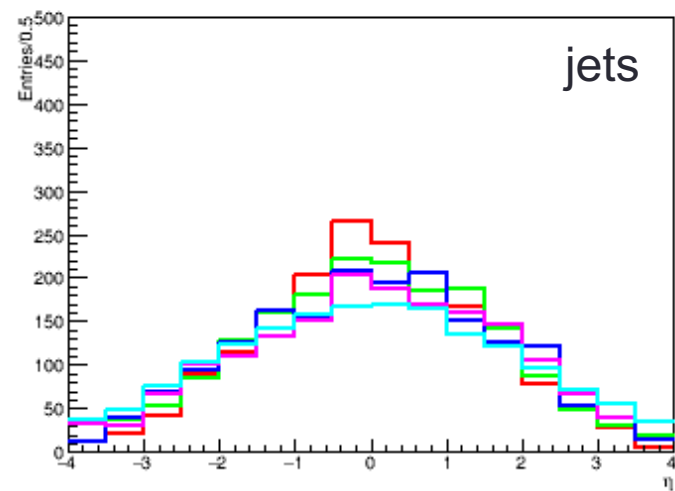
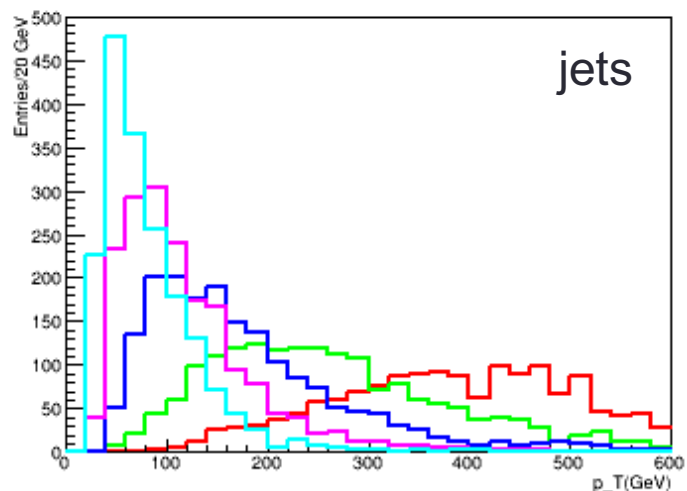
Kinematic Distributions ($m_{H^-}=500$ GeV)



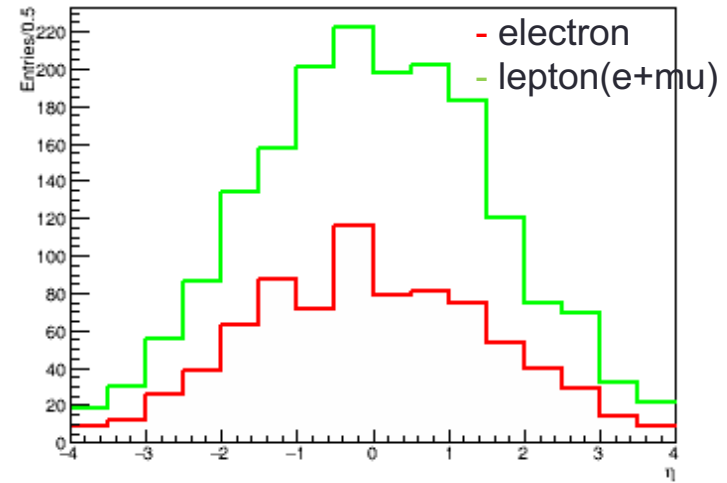
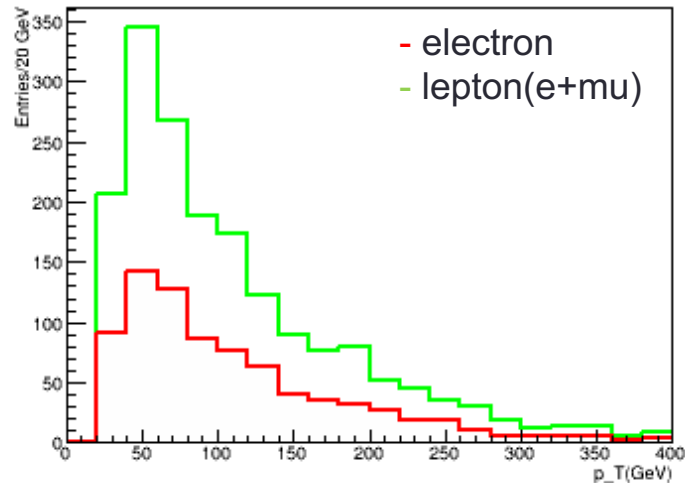
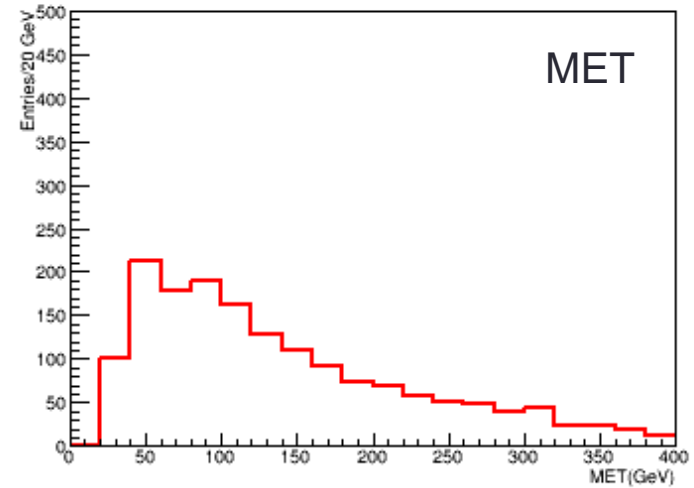
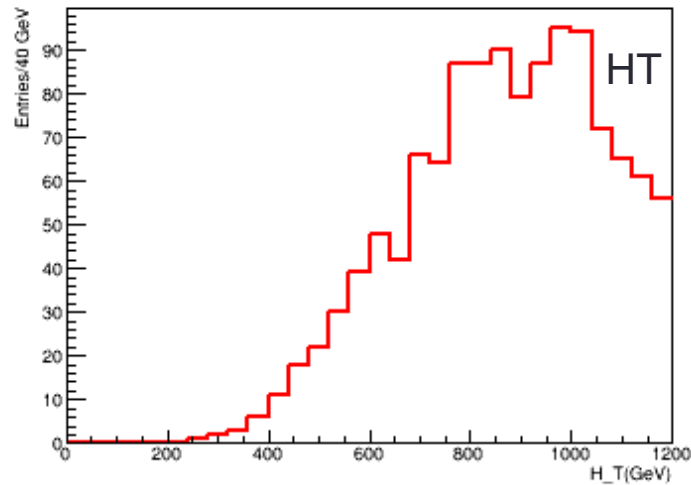
Kinematic Distributions ($m_{H^\pm}=500$ GeV)



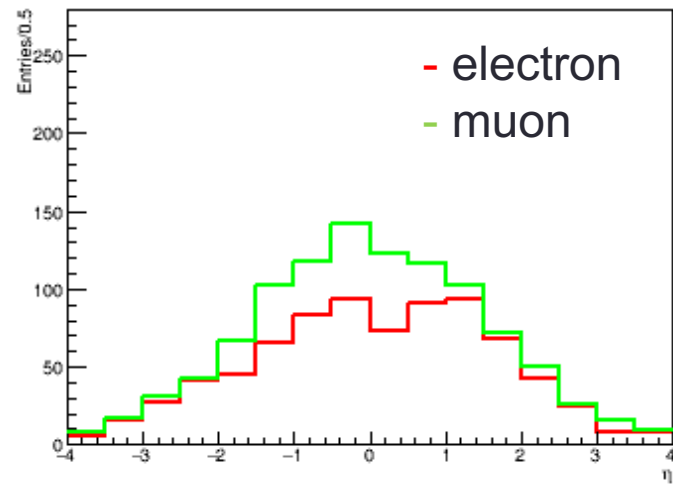
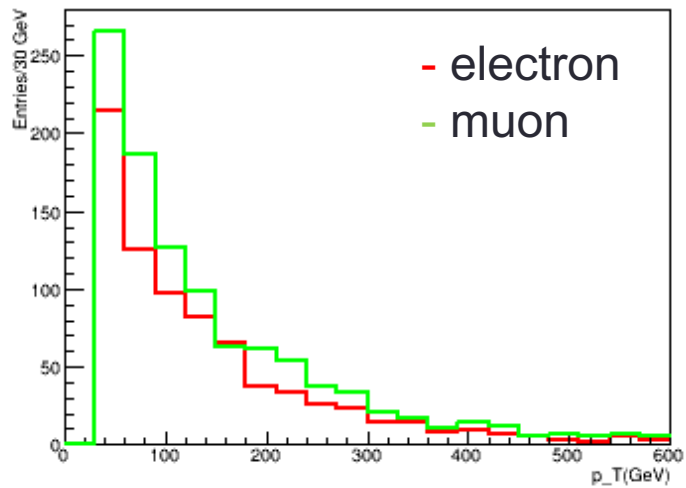
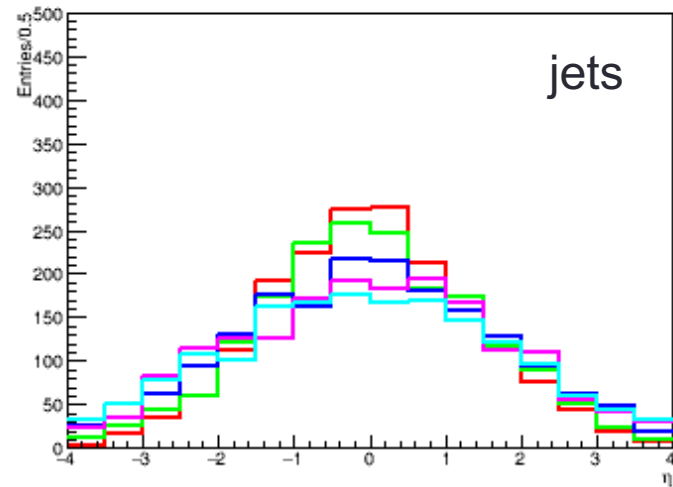
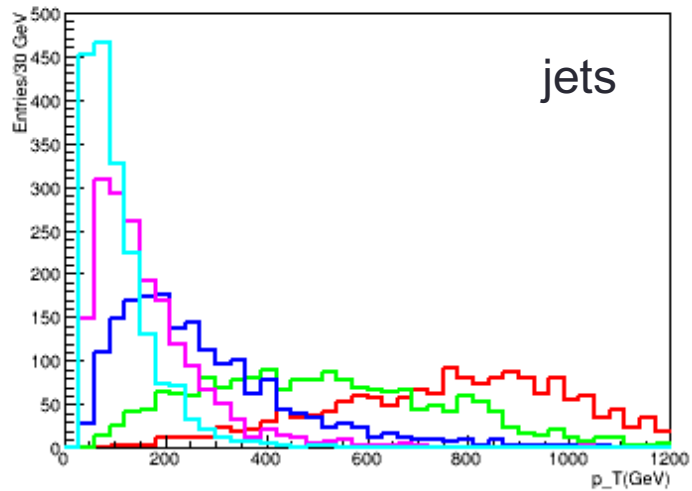
Kinematic Distributions ($m_{H^-}=1$ TeV)



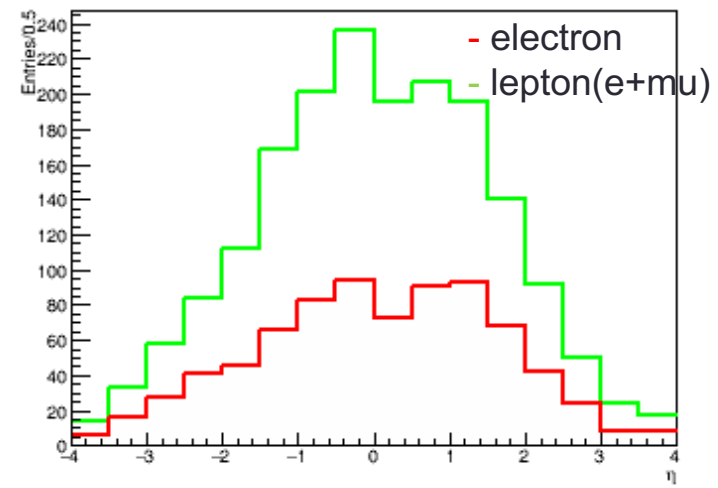
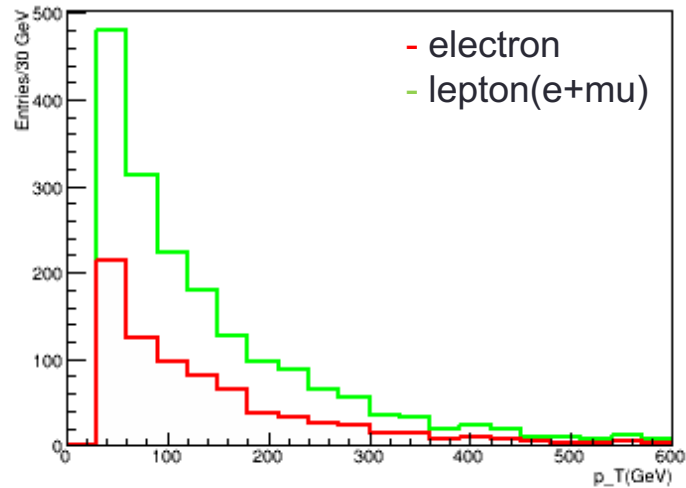
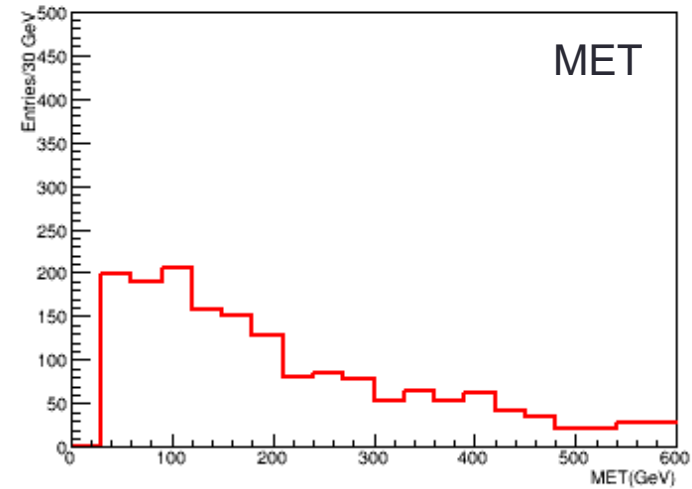
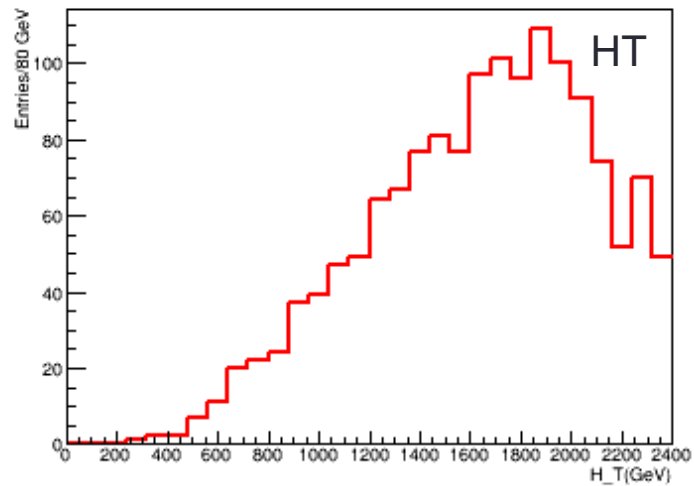
Kinematic Distributions ($m_{H^\pm}=1$ TeV)



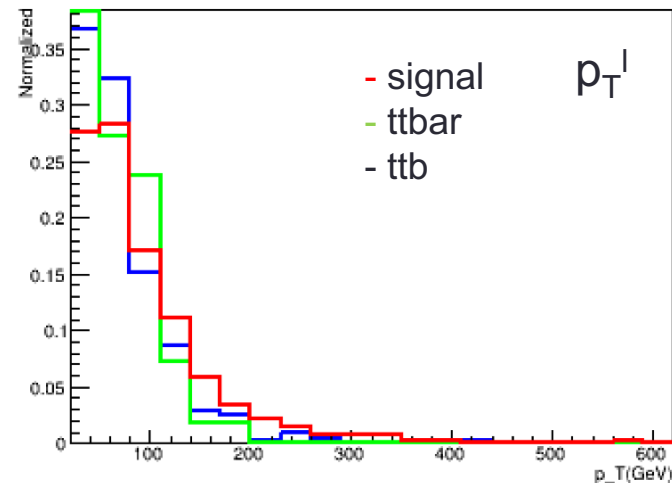
Kinematic Distributions ($m_{H^\pm}=2$ TeV)



Kinematic Distributions ($m_{H^\pm}=2$ TeV)

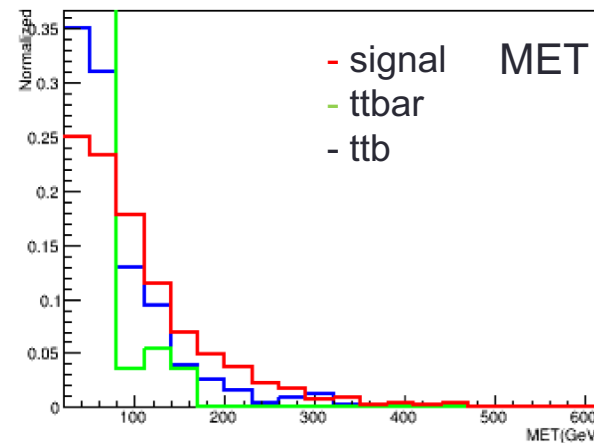
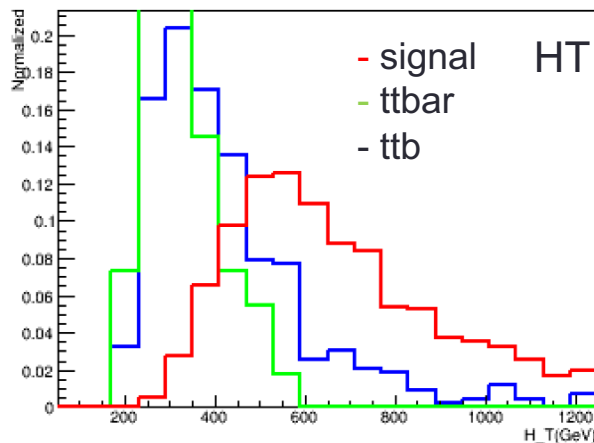


Normalized Distributions of p_T^{lepton} , H_T and MET



Leading lepton p_T for signal and background

Hadronic transverse energy
 $H_T = \sum_j |p_{Tj}|$
 for jets



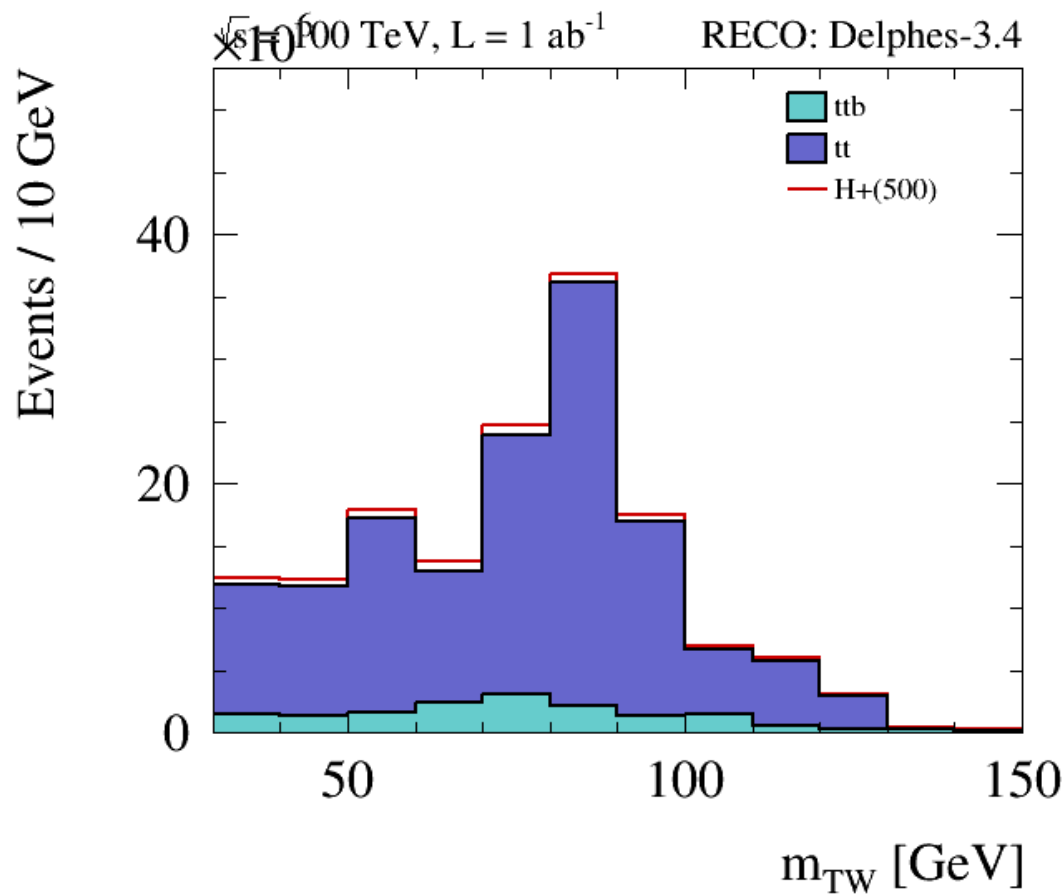
Missing energy transverse
 $\text{MET} = - \sum_{(\text{all})} \dot{p}_T$

Cuts flow for analysis

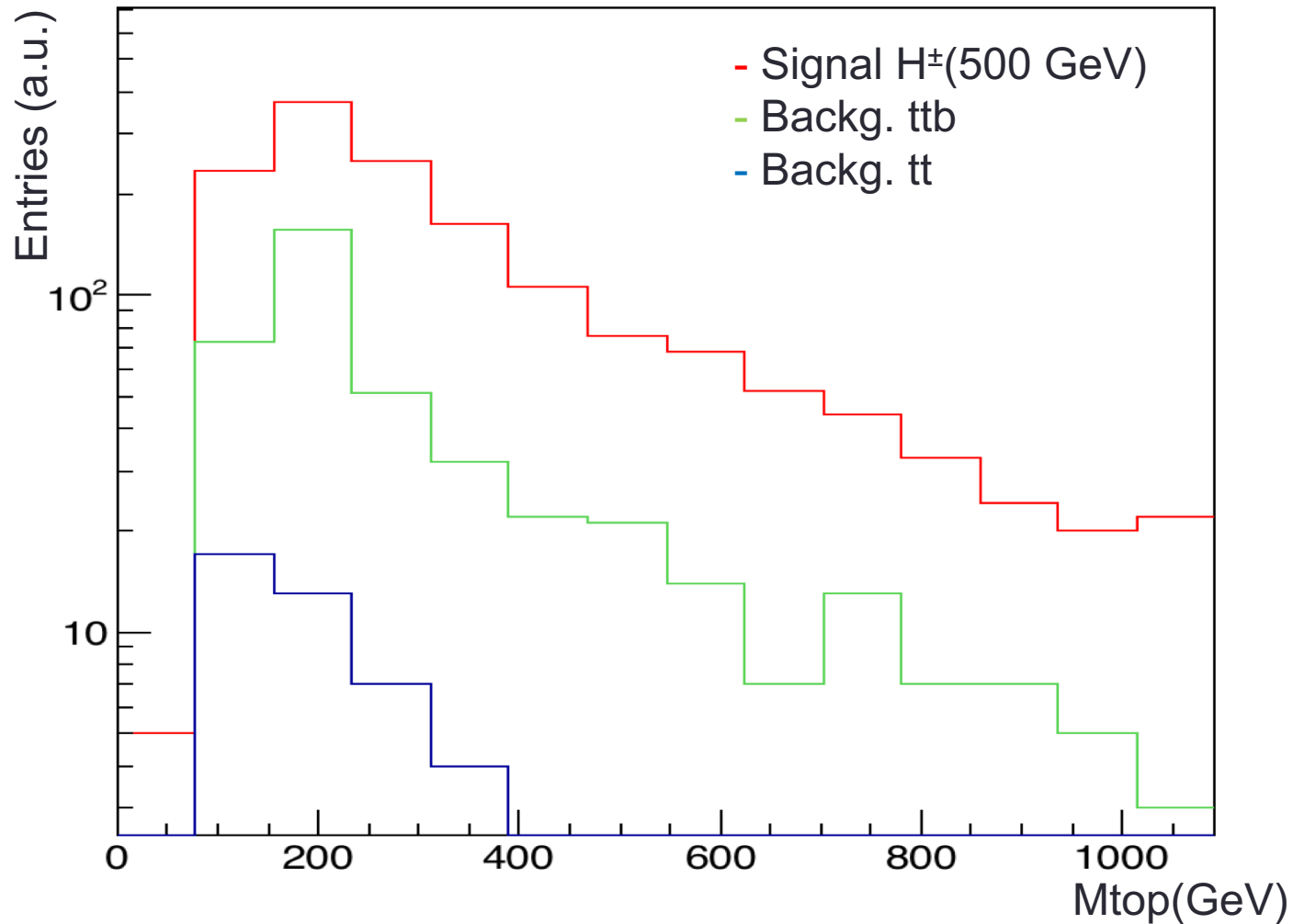
- Cuts for reconstruction

Object	Requirement
Single muon or electron	$p_T > 30 \text{ GeV}$, $ \eta < 3.0$
At least five jets ($N_{\text{jet}} \geq 5$)	$p_T > 30 \text{ GeV}$, $ \eta < 3.0$
At least two bjet ($N_{\text{bjet}} \geq 2$)	$p_T > 30 \text{ GeV}$, $ \eta < 3.0$
Missing p_T	$p_T > 30 \text{ GeV}$
Lepton(l), jets separation	$\Delta R(l,j) > 0.4$ and $\Delta R(j,j) > 0.4$
Reconstructed top mass	$130 < m_{wb} < 200 \text{ GeV}$
Reconstructed H^\pm mass	$ m_{tb} - m_{H^\pm} < 0.2 * m_{H^\pm}$

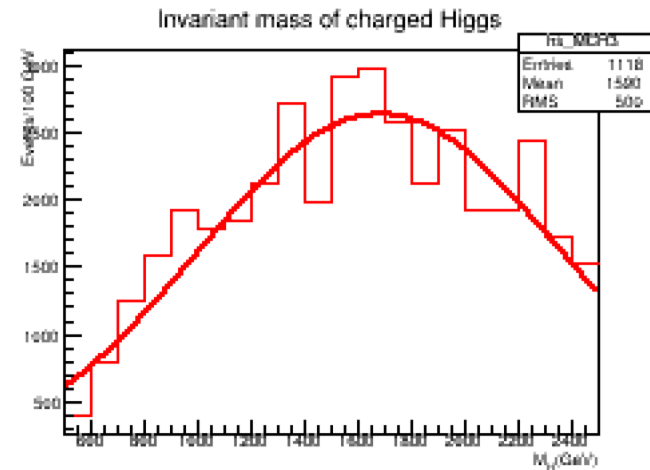
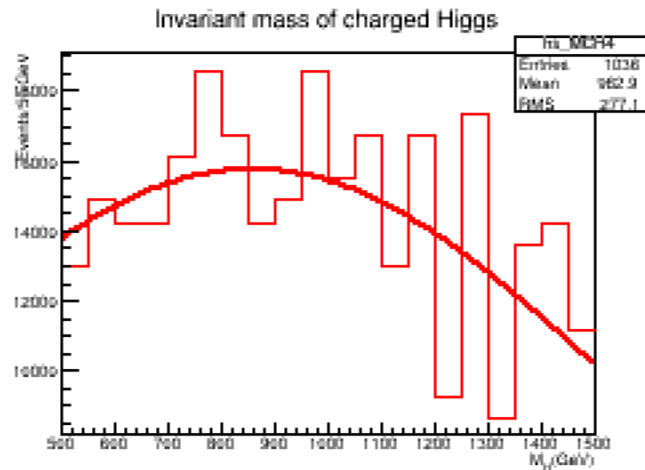
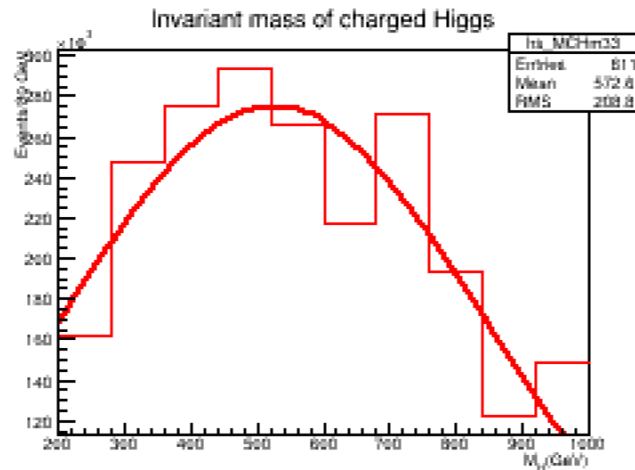
m_{TW} distributions from signal and background



Hadronic top mass – shape comparison



Invariant Mass Distributions (m_{H^\pm})



Statistical Significance

We calculate statistical significance (SS) from signal (NS) and background events (NB) within the interval $|m^{\text{reco}} - m_{H^\pm}| < 0.2 * m_{H^\pm}$.

$$SS = [2 * ((NS + NB) * \ln(1 + NS / NB) - NS)]^{1/2}.$$

Number of signal and background events and statistical significance for an integrated luminosity of $L_{\text{int}} = 1 \text{ ab}^{-1}$ at FCC-hh.

Mass(GeV)	NS	NB	SS
500	1299456.0	13371600.0	349.82
1000	135736.2	12145100.0	38.87
2000	9650.6	441540.0	14.47

Conclusions

- Possible extensions of the Higgs sector can be searched for a wide range of parameter space in the high energy proton-proton collisions.
- We have studied the charged Higgs boson single production within a model-independent framework in the proton-proton collisions at the FCC-hh collider.
- The production of charged Higgs boson through $pp \rightarrow tH_{\pm}X$ process explored in the mass range 0.5 to 2 TeV using multi-jets final states with one electron or muon and missing transverse momentum.
- Using the relevant SM backgrounds from the lepton+jets final states, we obtain a significant coverage of the parameter space and distinguish the charged Higgs boson-top-bottom interaction for a mass up to 2 TeV.

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