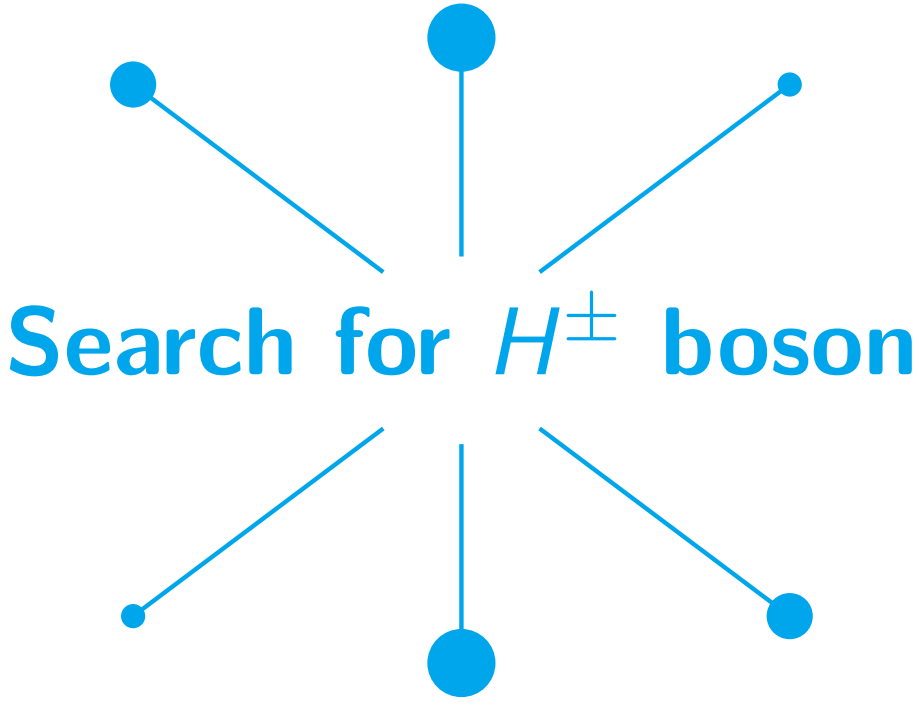


DESY Summer Student Programme 2019

Artem Nigoian

Supervisors: Dirk Kruecker, David Brunner

Deutsches Elektronen-Synchrotron

02.09.2019

Two higgs doublet model as a SM extension

SM one doublet Φ of complex scalar fields

2HDM two doublets Φ_1 and $\Phi_2 \rightarrow$ five Higgs-sector particles

α: mixing angle of neutral CP-even Higgs-particles

β: $\tan\beta = v_1/v_2$ (v_1 and v_2 – vacuum expectation values)

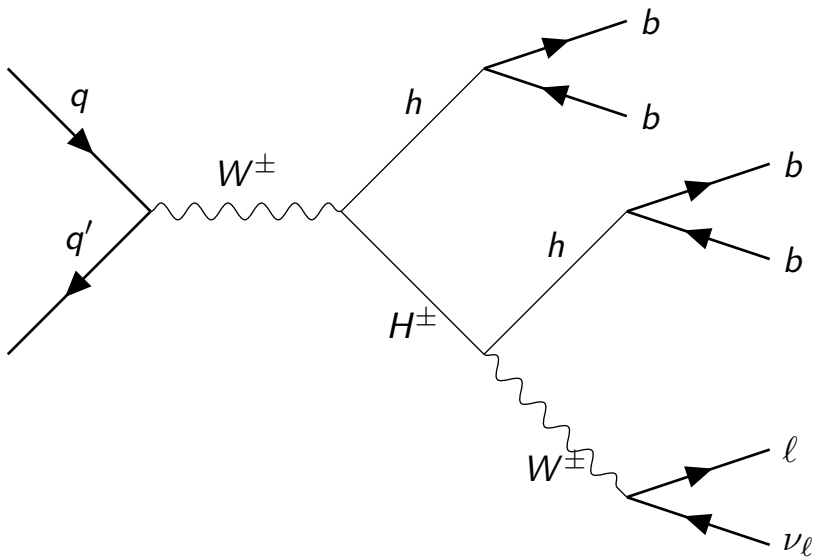
Model specification:

- Type I ($\Phi_1 \rightarrow -\Phi_1$) (no FCNC)
- $m_H = 125.09$ GeV
- $\sin(\alpha - \beta) = 0 \rightarrow m_h < m_H$
- $m_{H^\pm} = m_A, \tan(\beta) = 3$

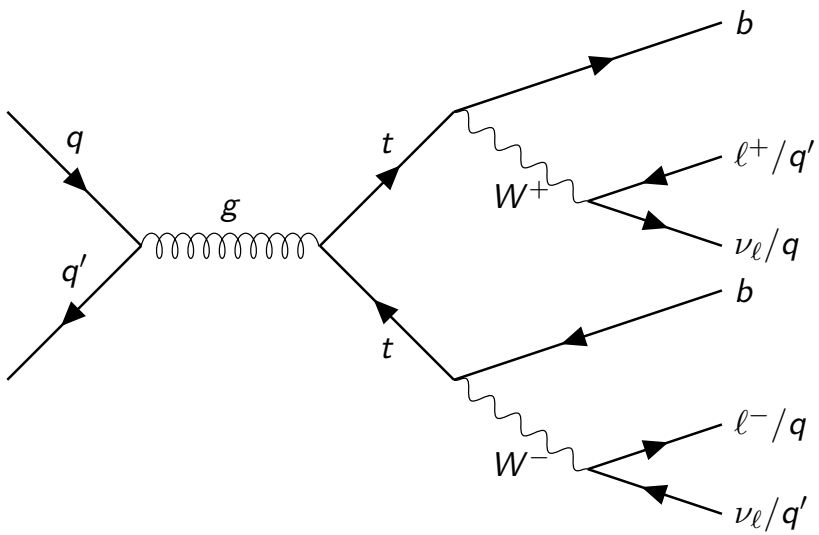
Features of this specification:

- High BR($H^\pm \rightarrow W^\pm h$)
- h decays to fermions (b, τ)
- Large unexcluded region for high BR($H^\pm \rightarrow W^\pm h$)

Feynman diagrams



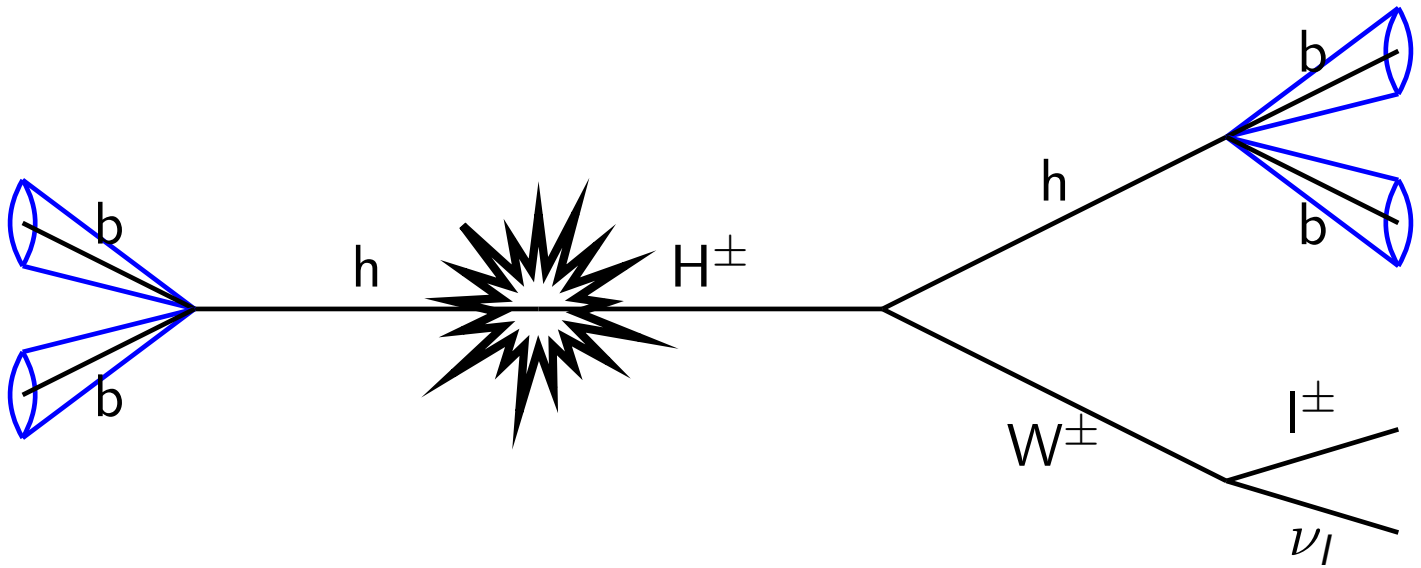
Signal process



Background process

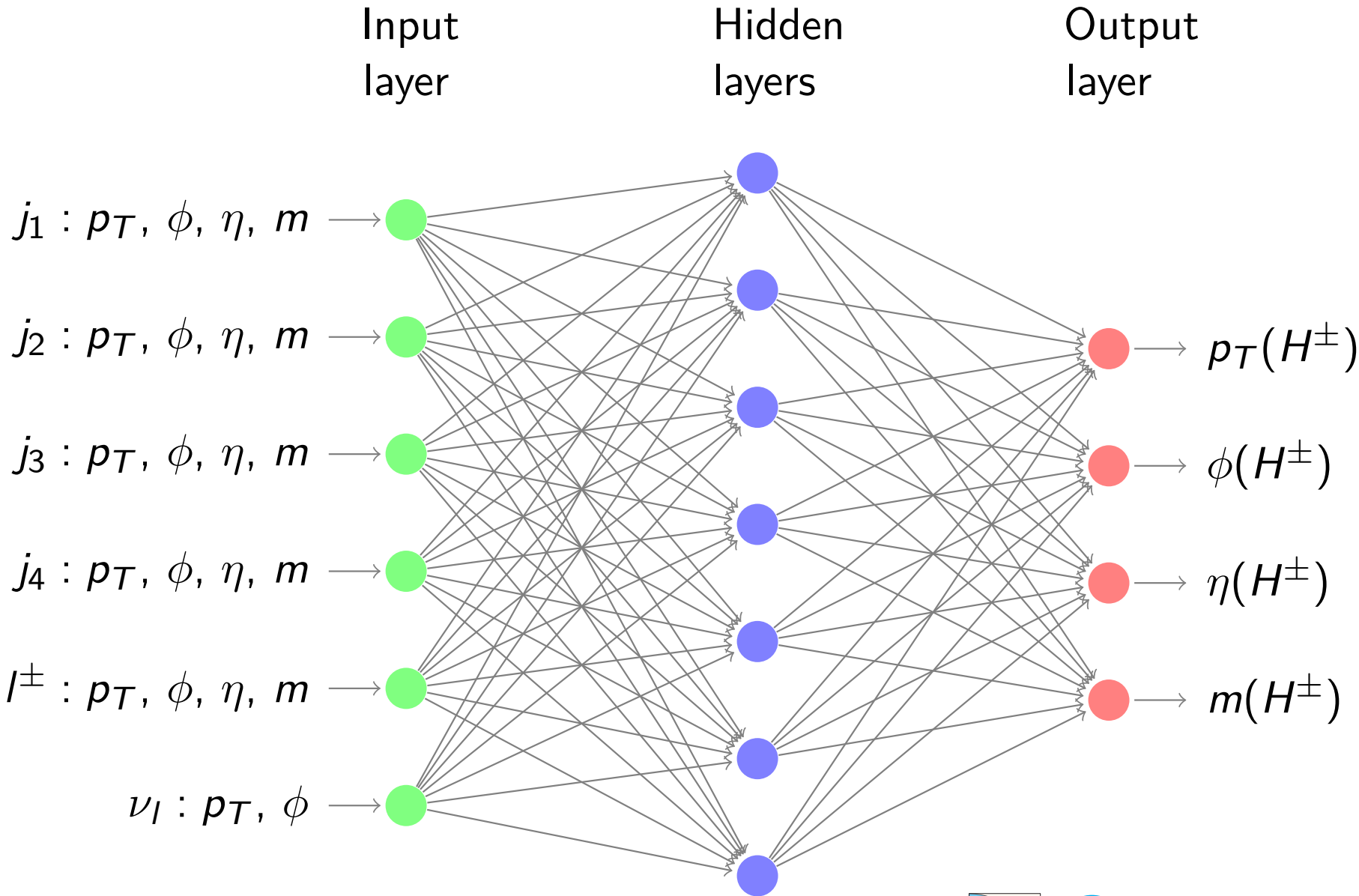
Signal jet kinematic

Non-boosted topology:



Problem: choice of correct pair of jets to reconstruct $H^{\pm}$

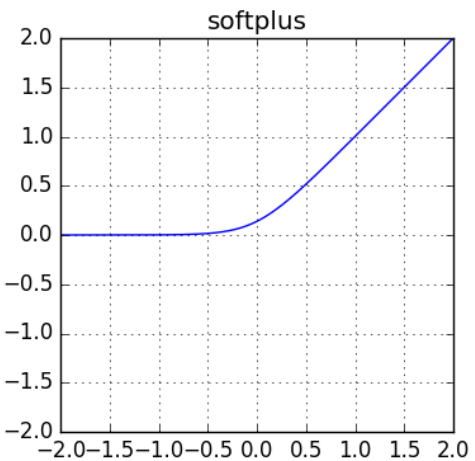
Neural network approach. Inputs and outputs



Parameters of the neural network

Hyperparameters tuning (random search)

- → Number of hidden layers: 5
- → Nodes in each hidden layer: 200
- → Activation function for nodes in hidden layers: softplus
- → Batch size: 100

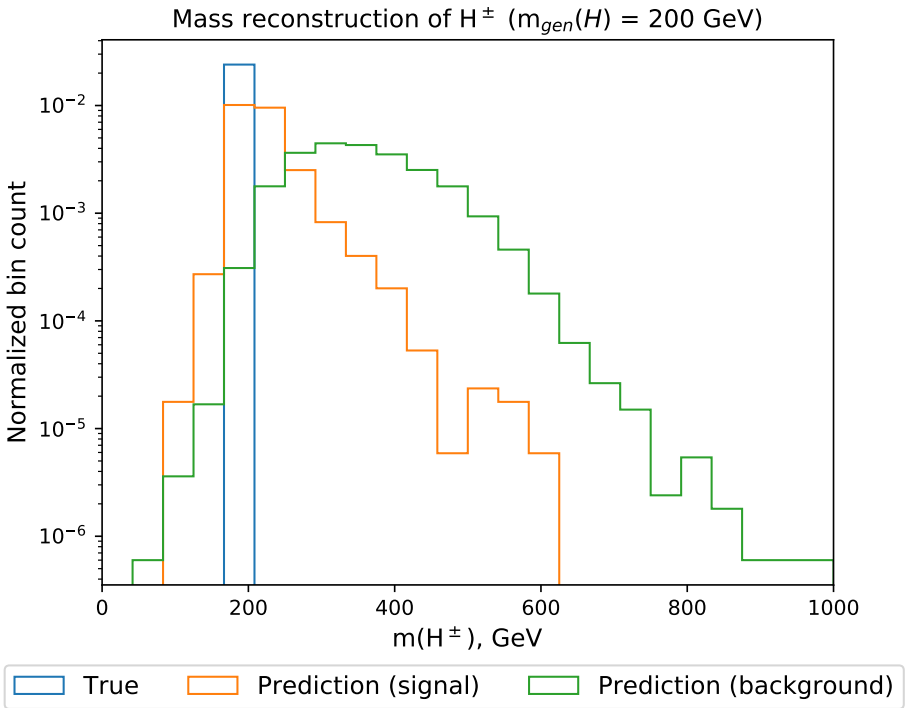


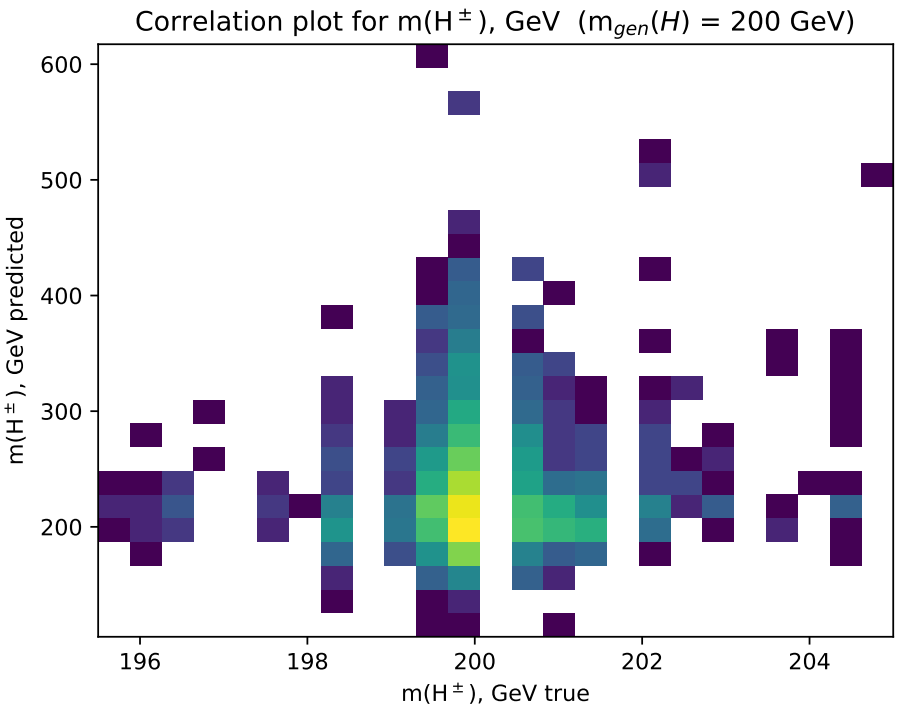
Data for training

MC-generated events with $m(h) = 100$ GeV and $m(H^{\pm}) = 200, 250, ..., 600$ GeV

- $\rightarrow$ $\sim 3 \cdot 10^5$ events
- $\rightarrow$ different number of events for different mass points ($\sim 51 \cdot 10^3$ events for $m(H^{\pm}) = 350$ GeV and only $\sim 14 \cdot 10^3$ events for $m(H^{\pm}) = 600$ GeV) $\rightarrow$ using *weighted* MSE as a loss function
- $\rightarrow$ training : test : validation $= 81 : 10 : 9$

Prediction of mass

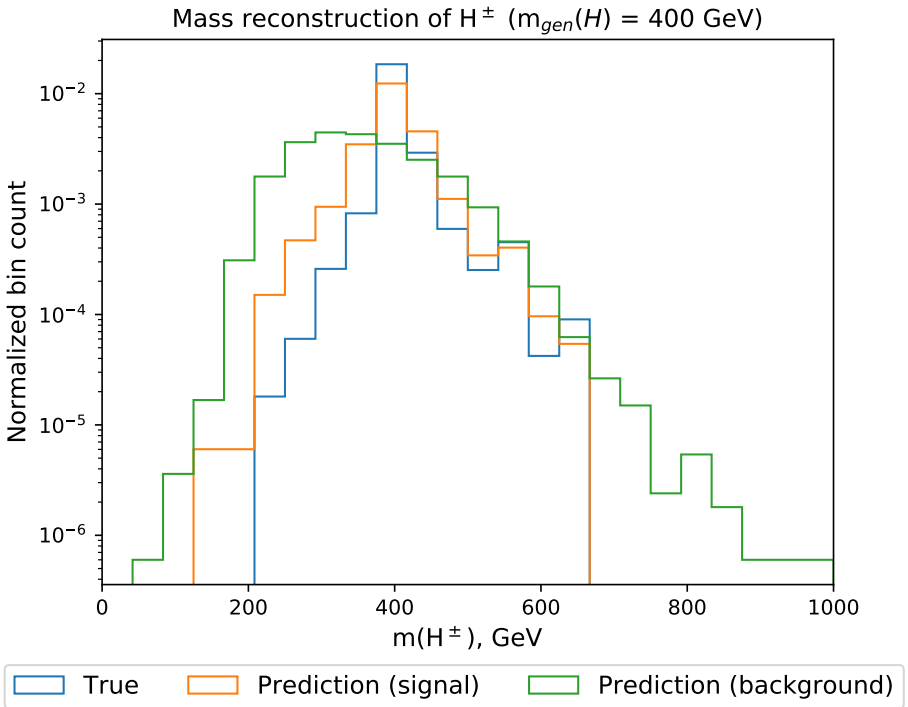


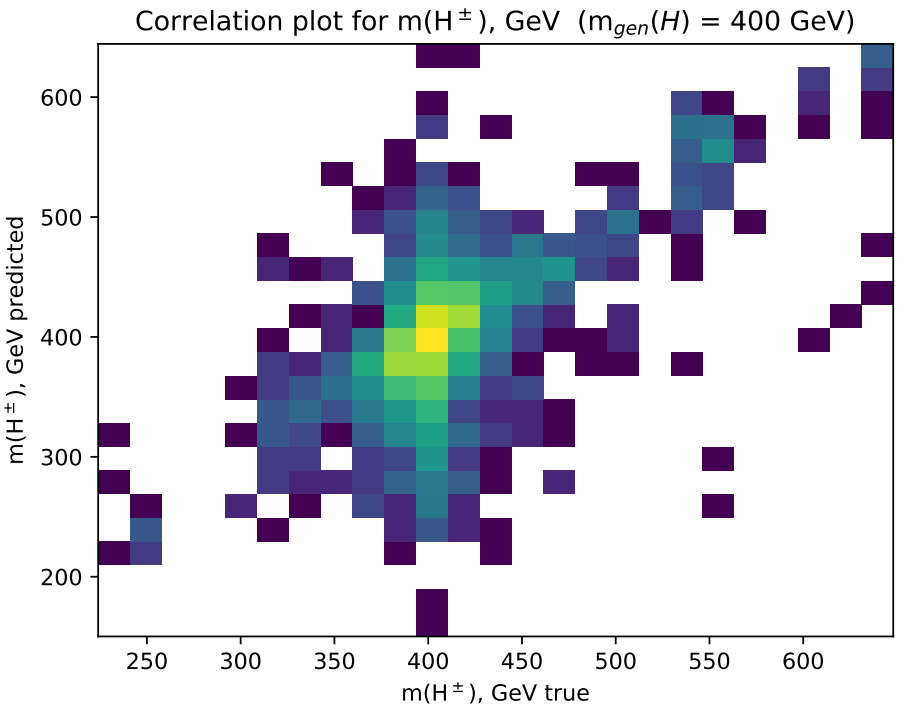


→ Maximum is predicted correctly

→ Predicted distribution is wider than true one

Prediction of mass

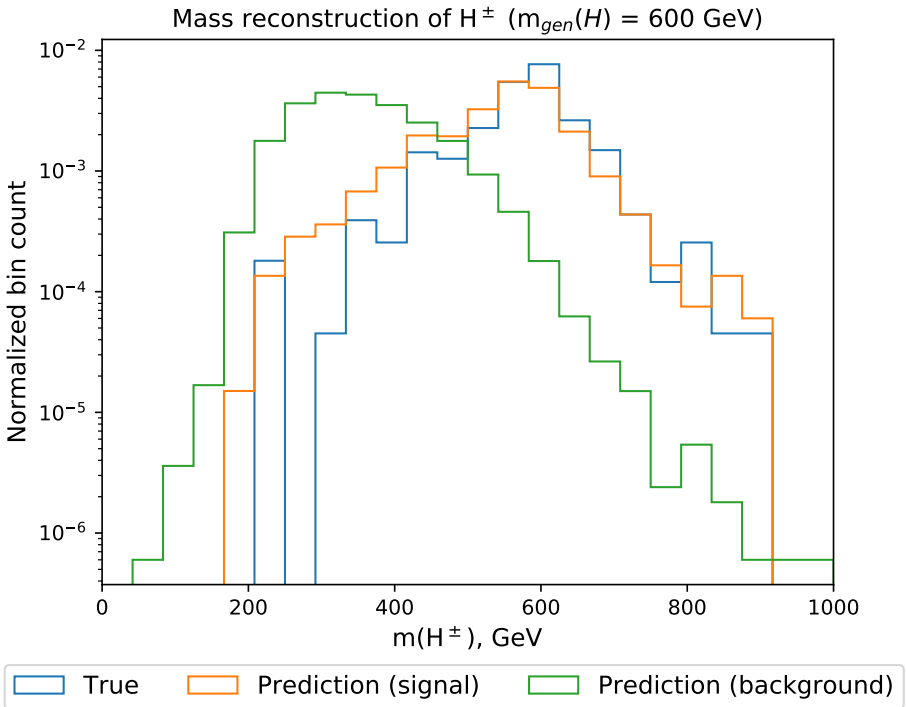


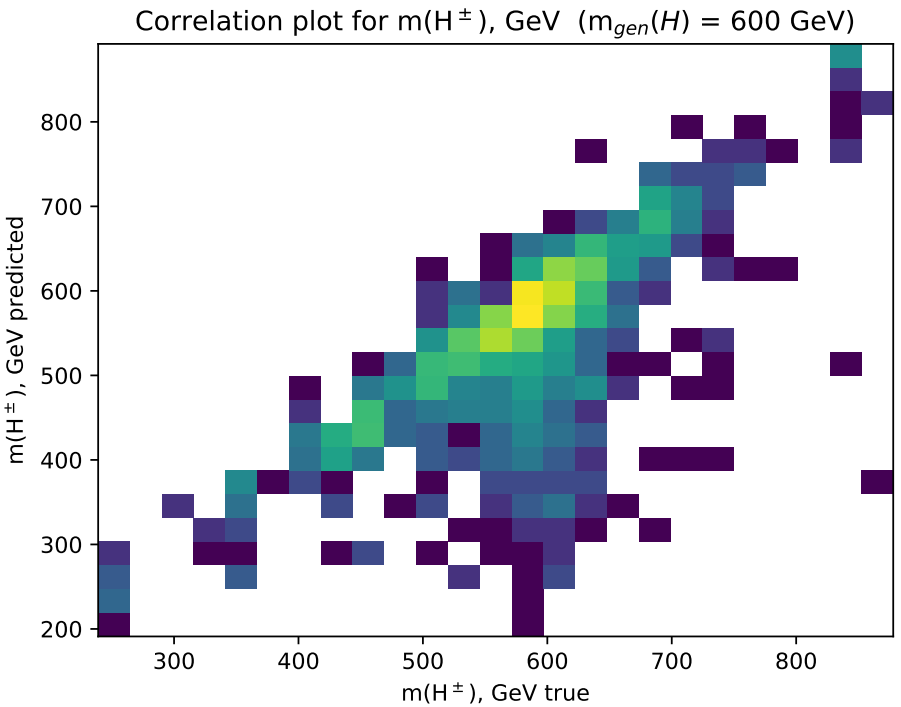


→ Maximum and width are predicted correctly

→ m_{pred} and m_{true} are correlated

Prediction of mass



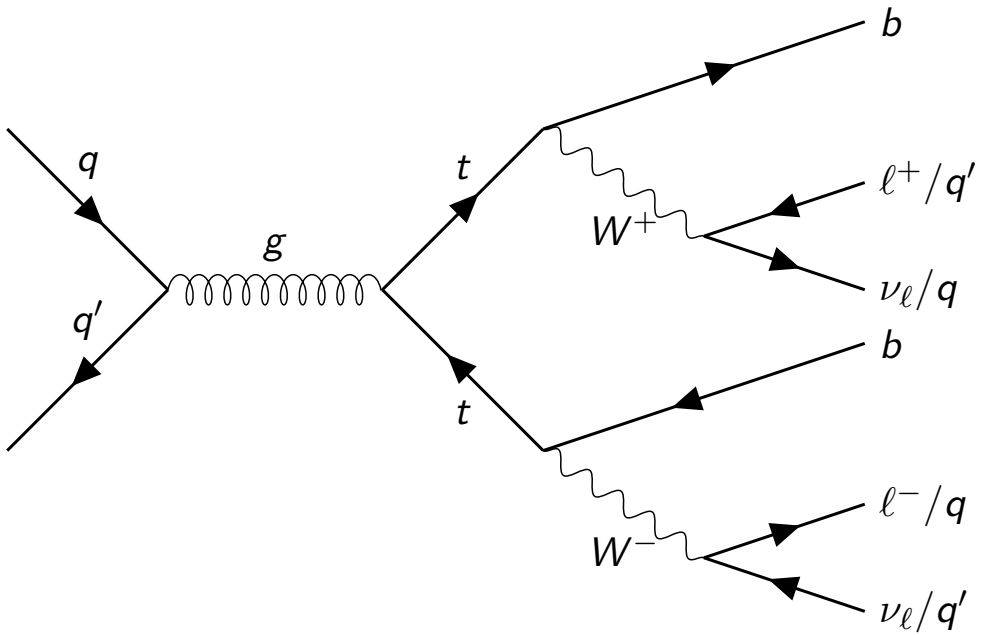


→ Maximum and width are predicted correctly

→ m_{pred} and m_{true} are correlated

Background suppression

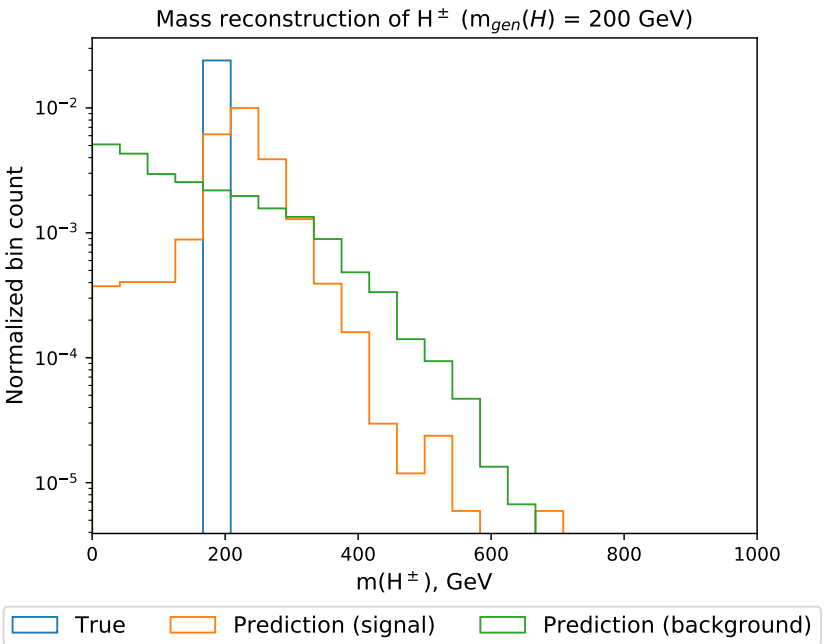
Significant background to deal with:

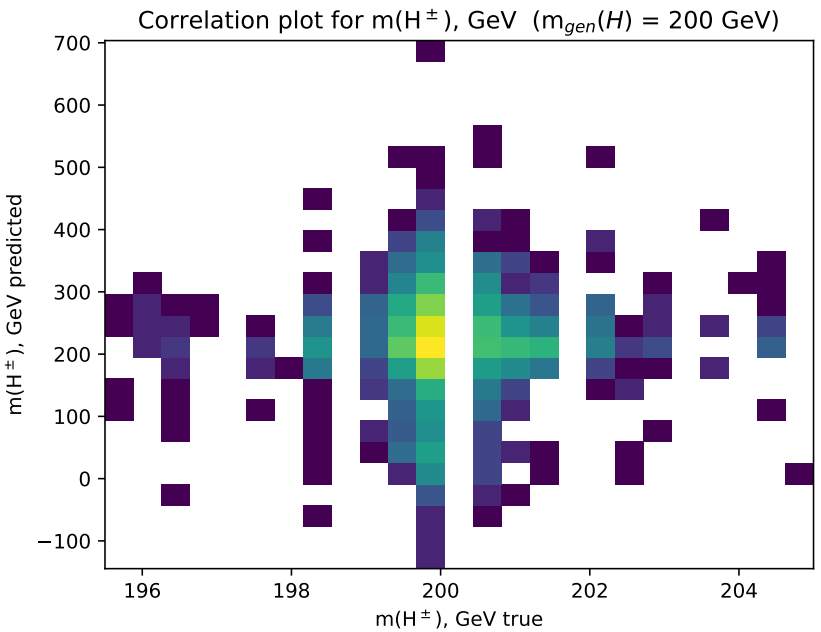


Solution: include background events into training and train the network such that it will predict for them vector $(p_T, \phi, \eta, m) = (0, 0, 0, 0)$.

Prediction of mass (with background in training)

Dense NN with $(p_T, \phi, \eta, m)_{bkg} \rightarrow (0, 0, 0, 0)$



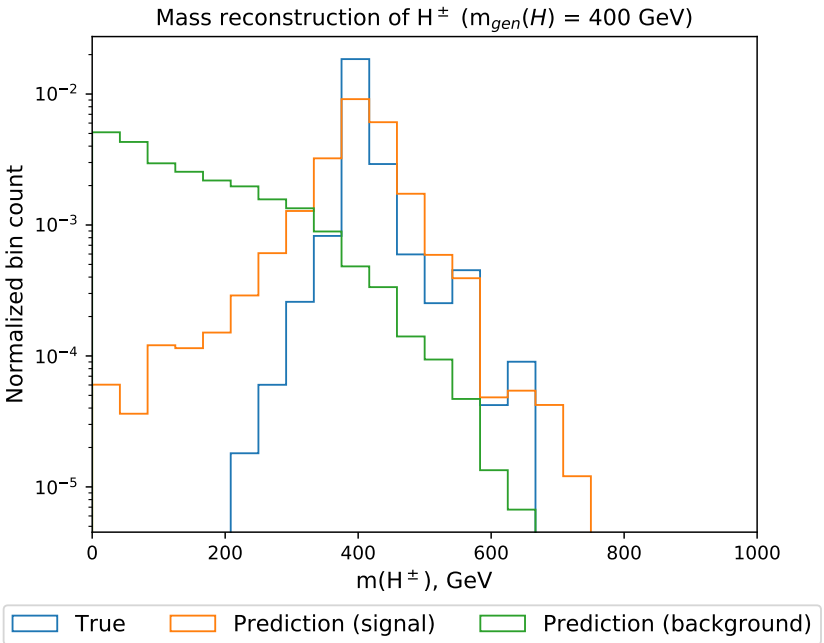


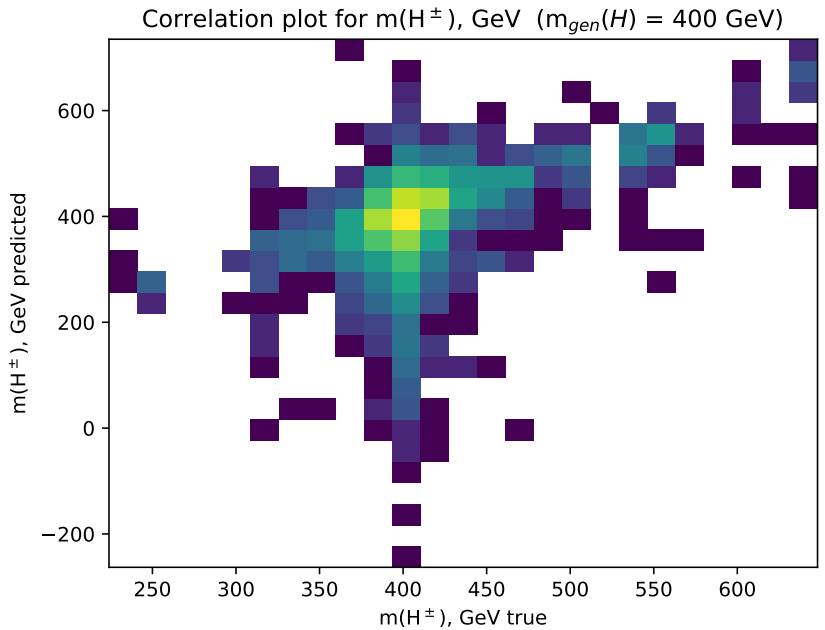
→ Maximum is almost correct

→ Predicted distribution is wider than true one

Prediction of mass (with background in training)

Dense NN with $(p_T, \phi, \eta, m)_{bkg} \rightarrow (0, 0, 0, 0)$



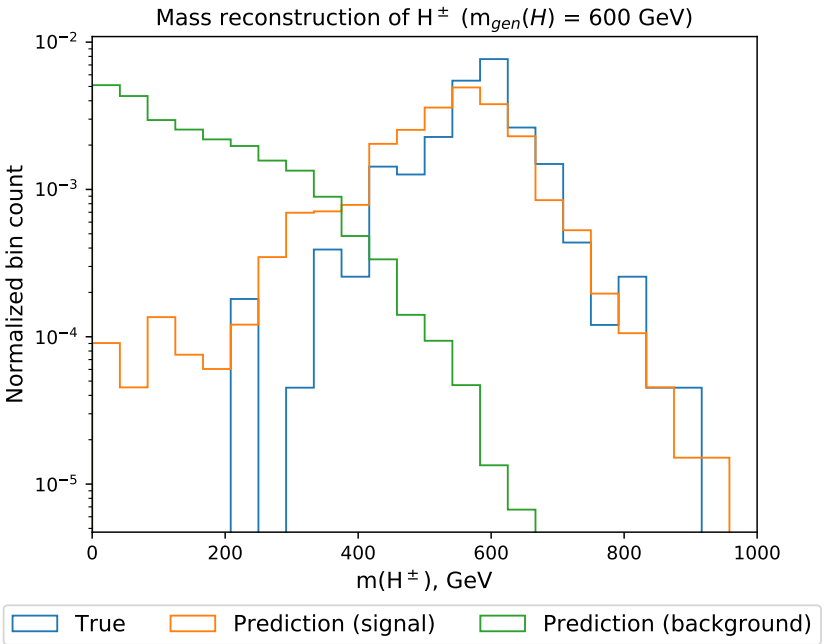


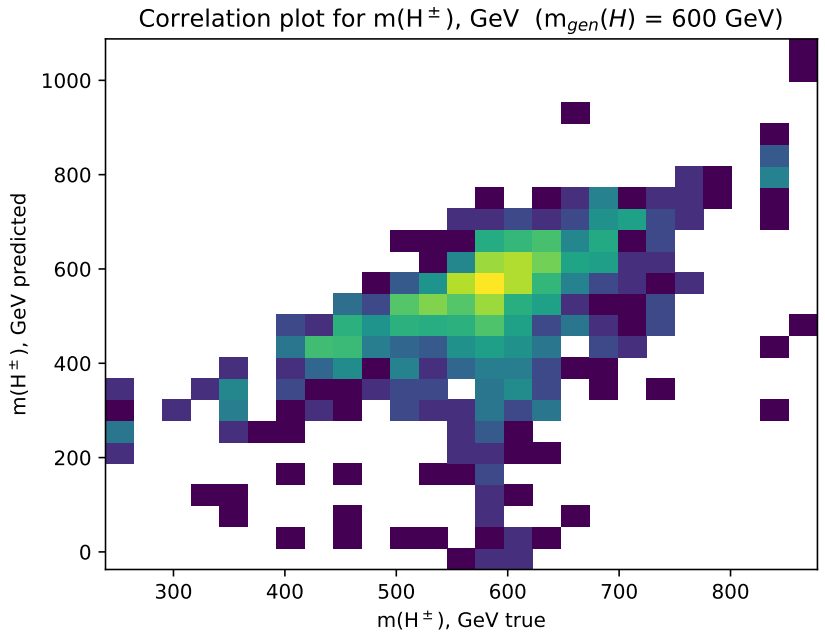
→ Maximum is predicted correctly

→ m_{pred} and m_{true} are correlated

Prediction of mass (with background in training)

Dense NN with $(p_T, \phi, \eta, m)_{bkg} \rightarrow (0, 0, 0, 0)$





→ Maximum is almost correct

→ m_{pred} and m_{true} are correlated

Summary

What has been achieved:

→ Successful reconstruction of $H^{\pm}$ with mass in a broad spectrum (from 200 GeV to 600 GeV) is accomplished

→ Dense neural network is implemented

→ Hyperparameters tuning is performed

→ Main background ($t\bar{t}$) suppression is achieved

What has been studied in addition:

→ Architectures with LSTM and convolutional layers are tested

→ Different approaches of background suppression are tested

Thank you for your attention!

Higgs mechanism reminder

Higgs Mechanism is included into the SM to generate masses of the gauge bosons ($W^{\pm}$ and Z).
Recipe:

- Introduce a complex doublet Φ of scalar fields into the Electroweak Lagrangian $\mathcal{L}_{EW}$:

$$\mathcal{L}_{EW} = -\frac{1}{4} W^a_{\mu\nu} W^{\mu\nu}_a - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} + (D_\mu \Phi)^\dagger (D_\mu \Phi) - \mu^2 \Phi^\dagger \Phi - \lambda (\Phi \Phi^\dagger)^2,$$

  where W^i_μ and B_μ are massless boson fields and D_μ is the covariant derivative, defined as

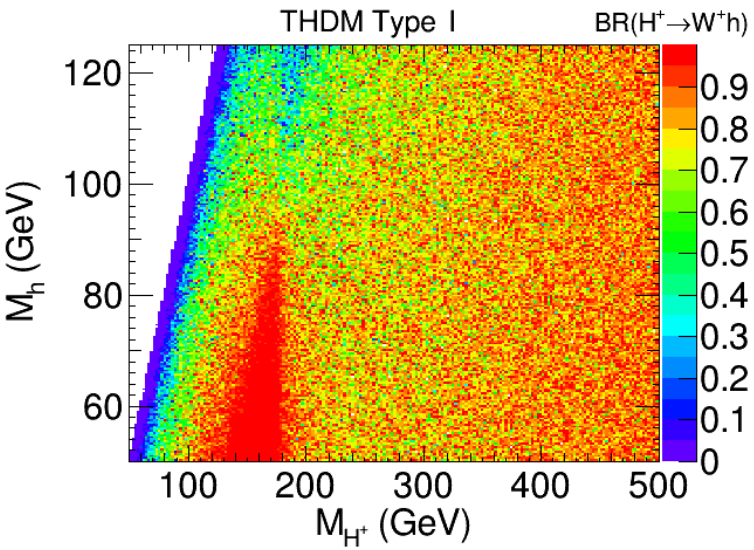
$$D_\mu = \partial_\mu - i g_2 \frac{\tau_a}{2} W^a_\mu - i g_1 \frac{Y_h}{2} B_\mu$$

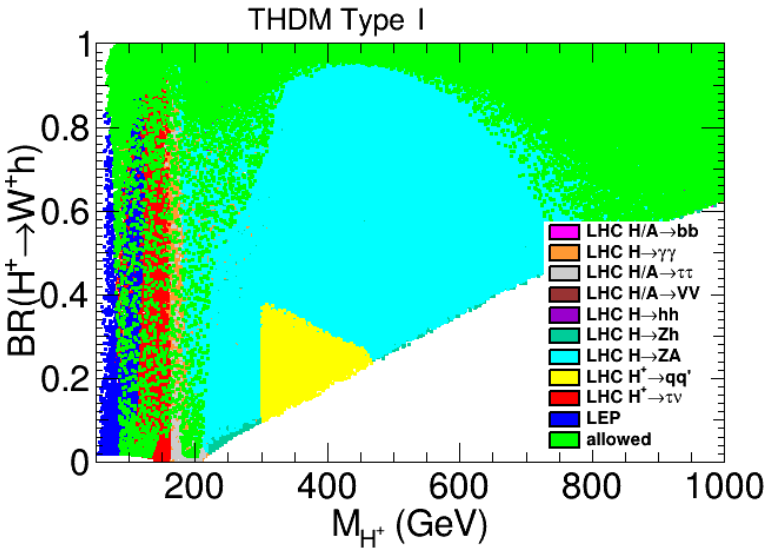
- Break symmetry $\rightarrow$ massive bosons – W^+, W^- and Z, massless boson γ and massive CP-even neutral particle – Higgs boson.

Two higgs doublet model – extension of the SM

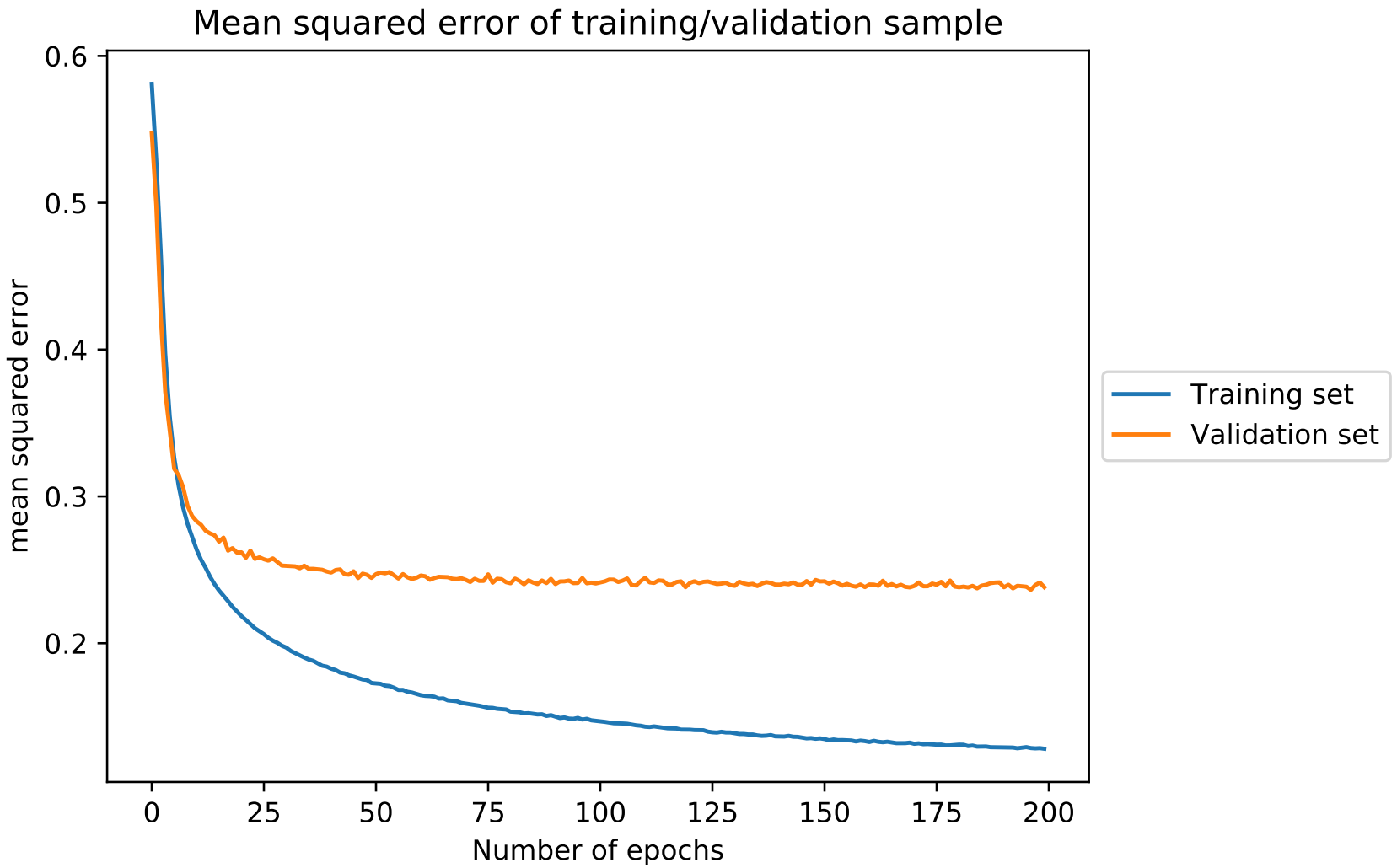
Why don't we introduce another complex scalar doublet?
2 doublets $\rightarrow$ five Higgs-sector particles, angle α – the mixing angle of neutral CP even Higgs-particles, β – angle which is responsible for the ratio of the vacuum expectation values v_1 and v_2, corresponding to the doublets Φ_1 and Φ_2: $\tan\beta = v_1/v_2$.

Features of the specification in plots



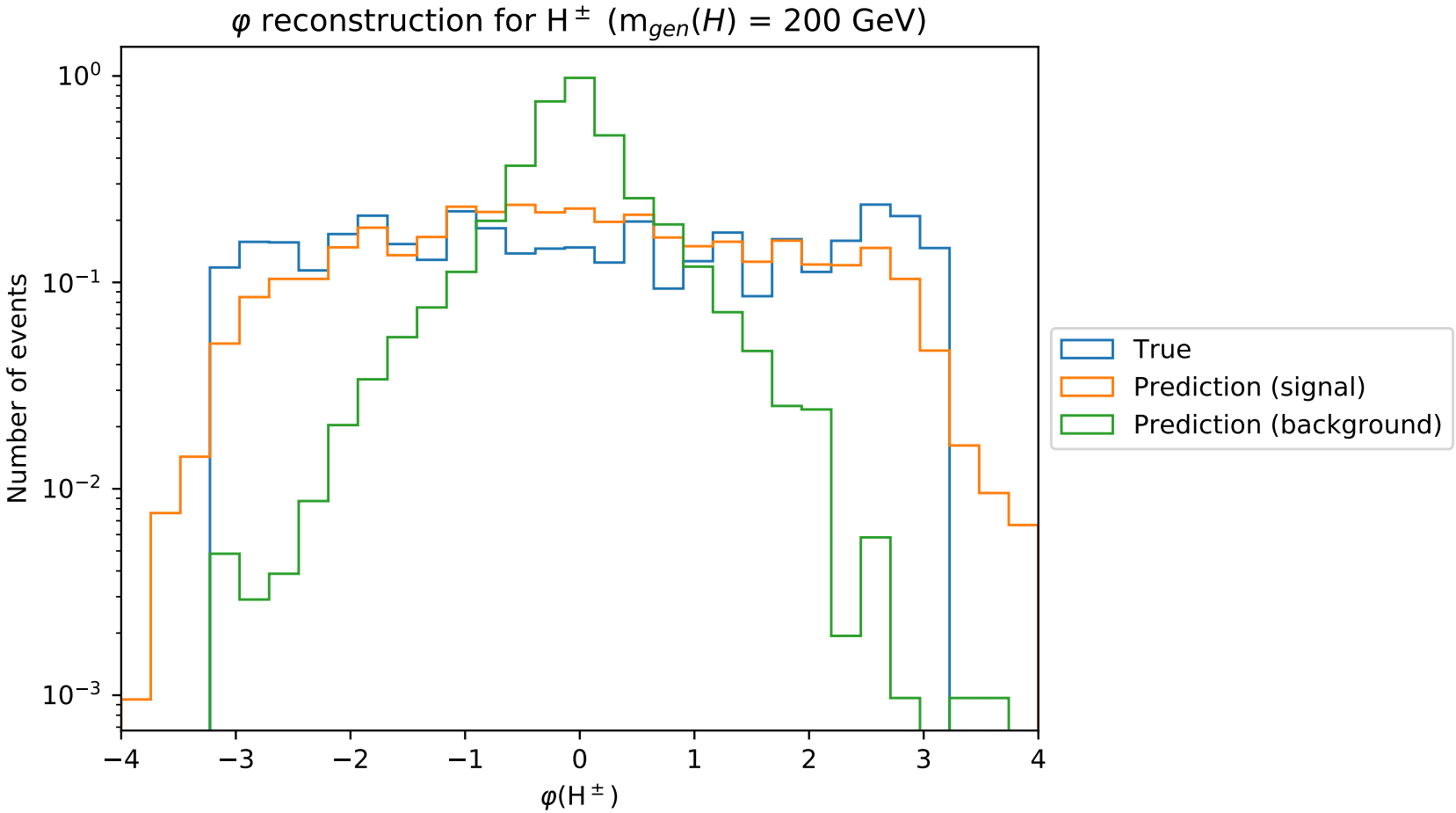


Training curve



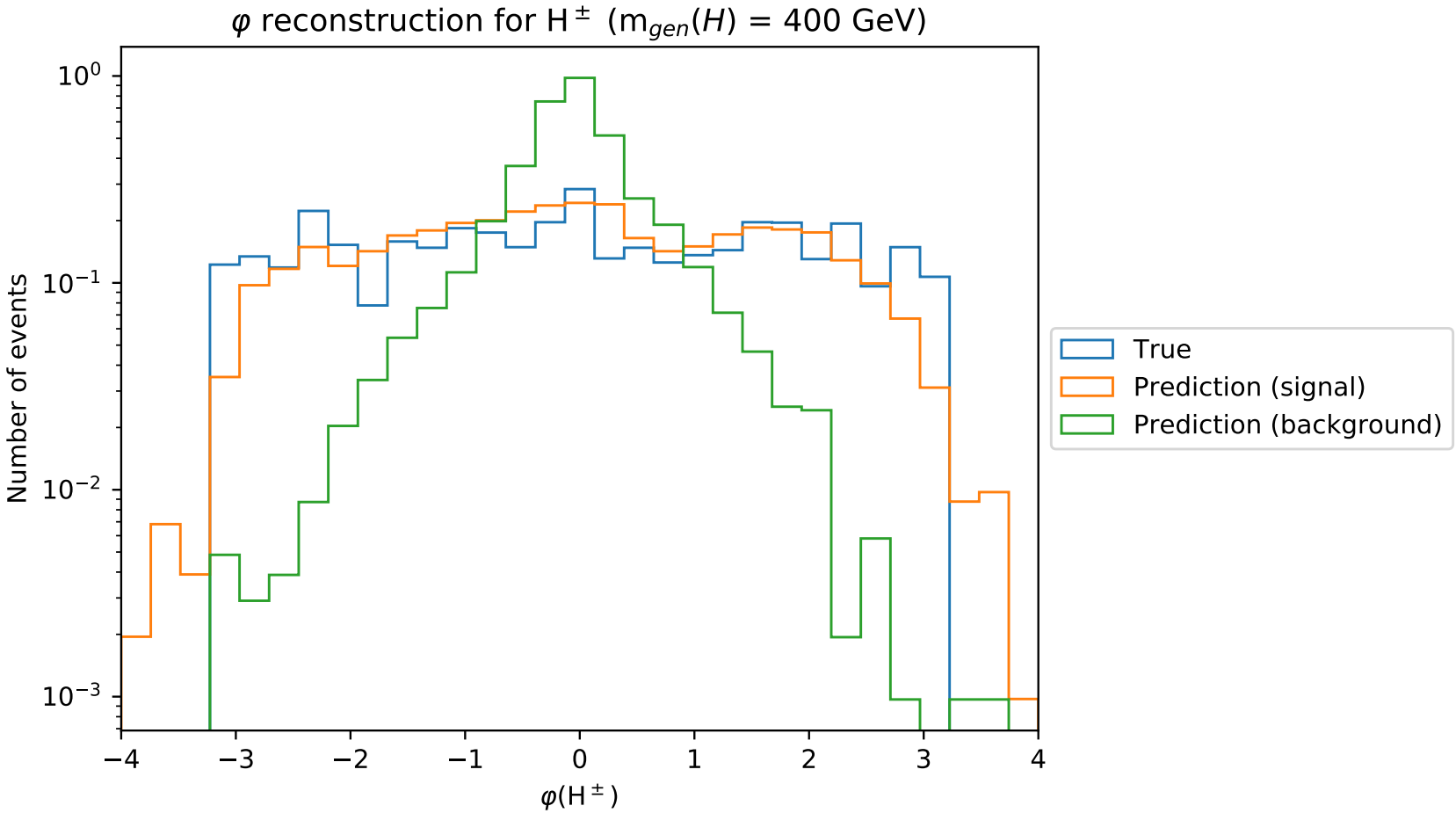
Results ($\phi^{pred}(H^{\pm})$ for $m^{gen}(H^{\pm}) = 200$ GeV)

Angle reconstruction (dense NN with bkg→0)



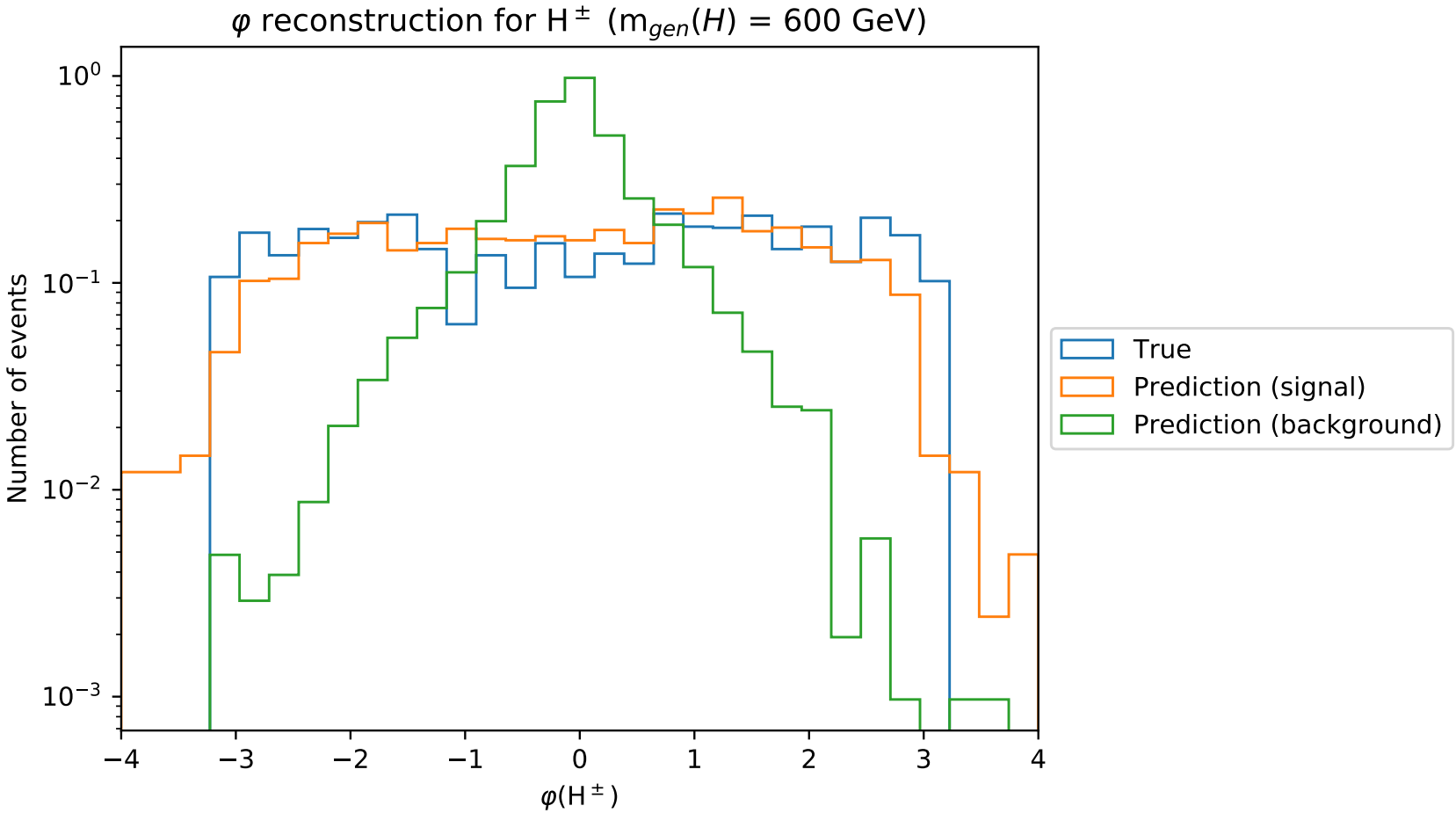
Results ($\phi^{pred}(H^{\pm})$ for $m^{gen}(H^{\pm}) = 400$ GeV)

Angle reconstruction (dense NN with bkg→0)

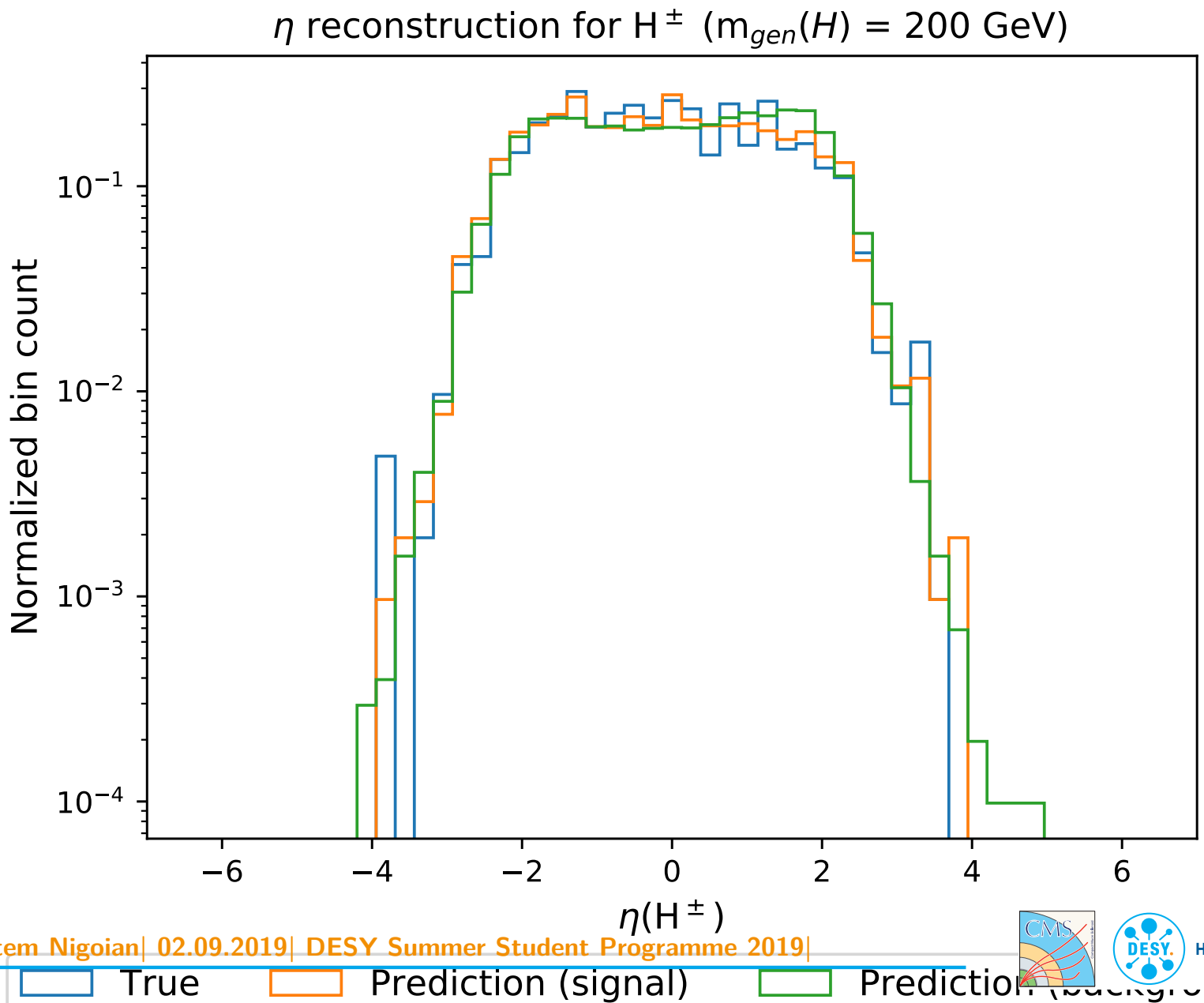


Results ($\phi^{pred}(H^{\pm})$ for $m^{gen}(H^{\pm}) = 600$ GeV)

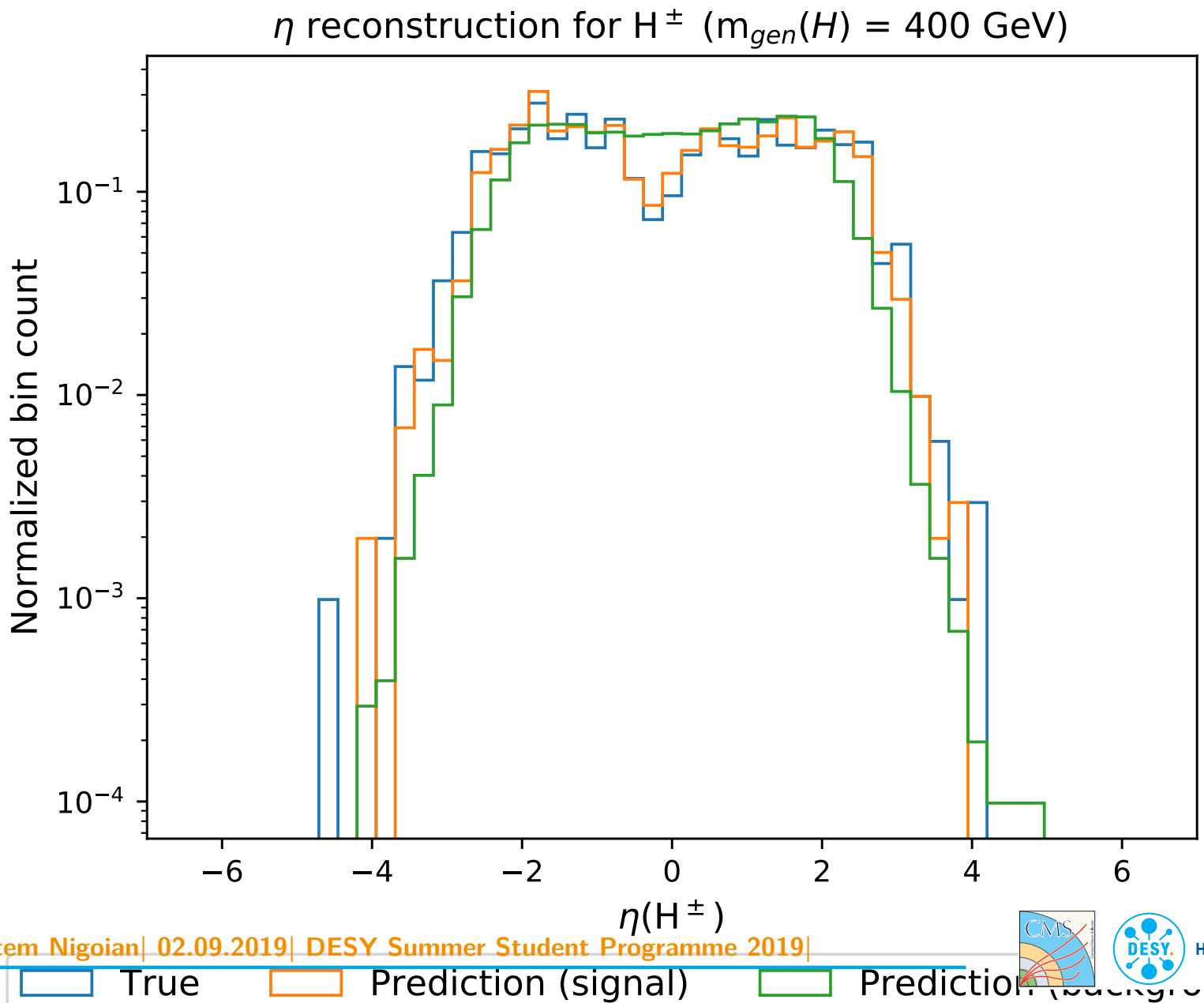
Angle reconstruction (dense NN with bkg→0)



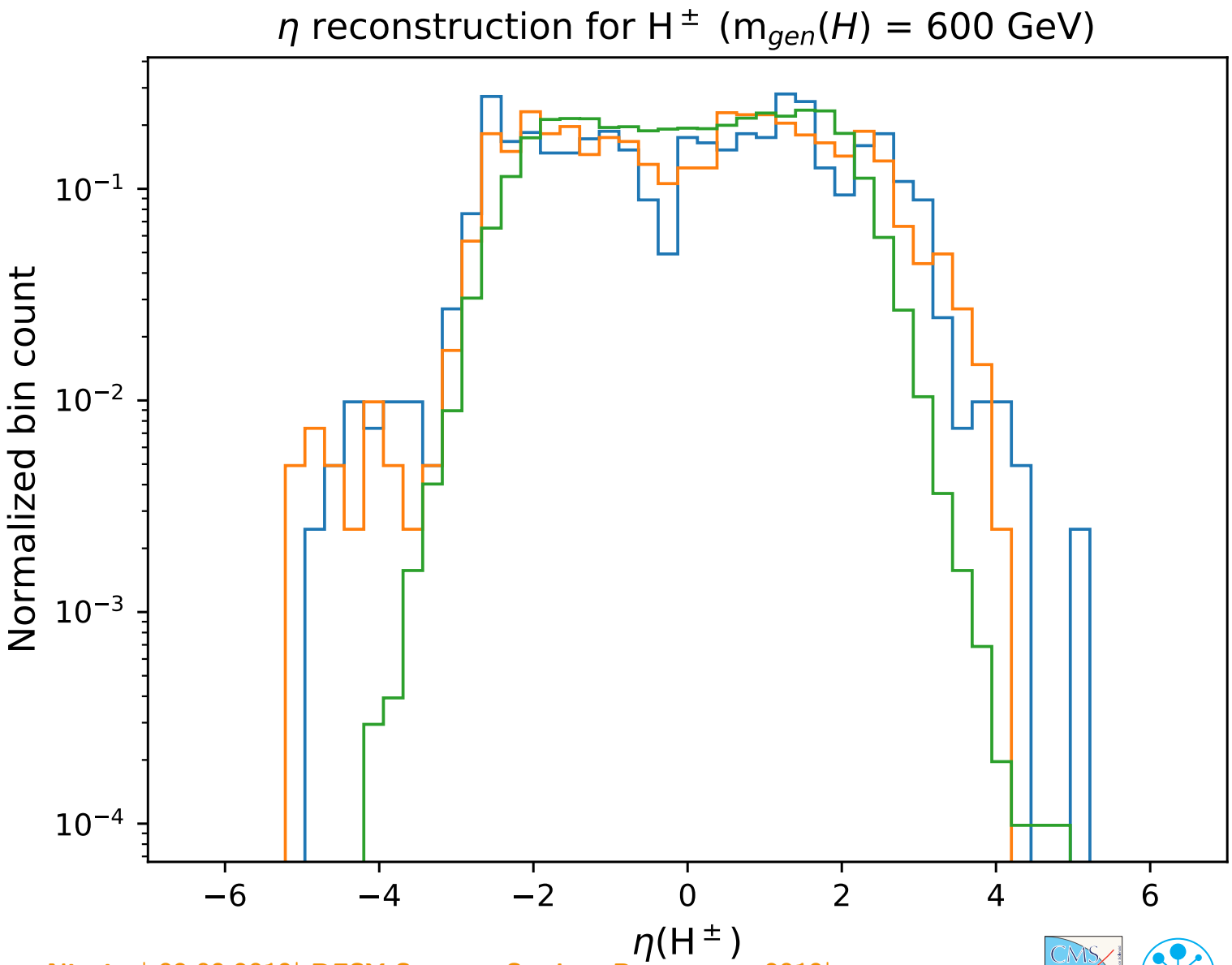
Predictions of pseudorapidity



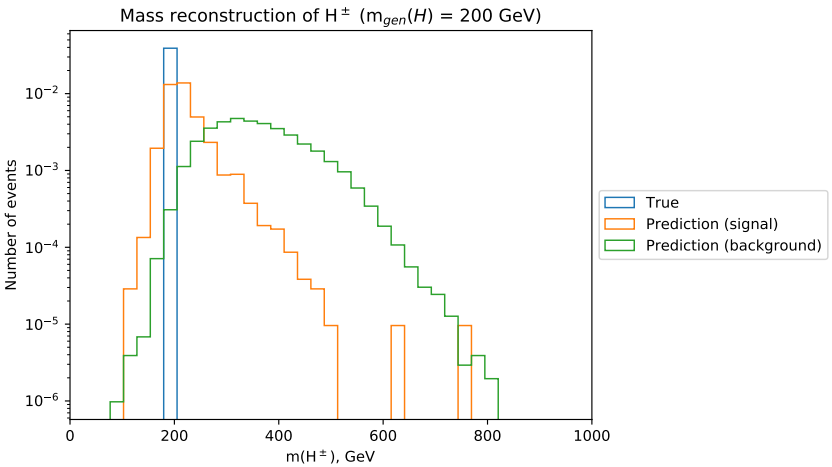
Predictions of pseudorapidity

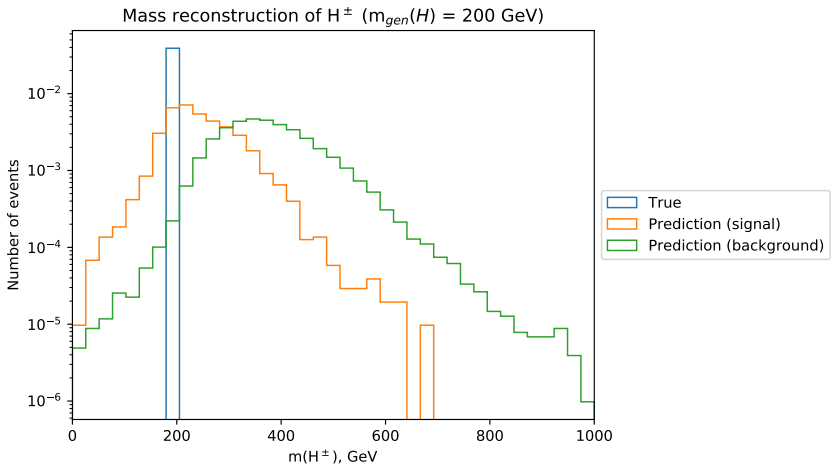


Predictions of pseudorapidity

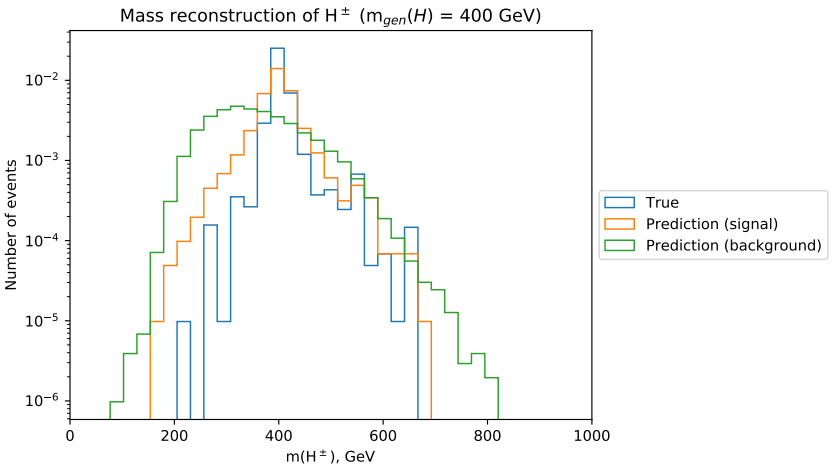


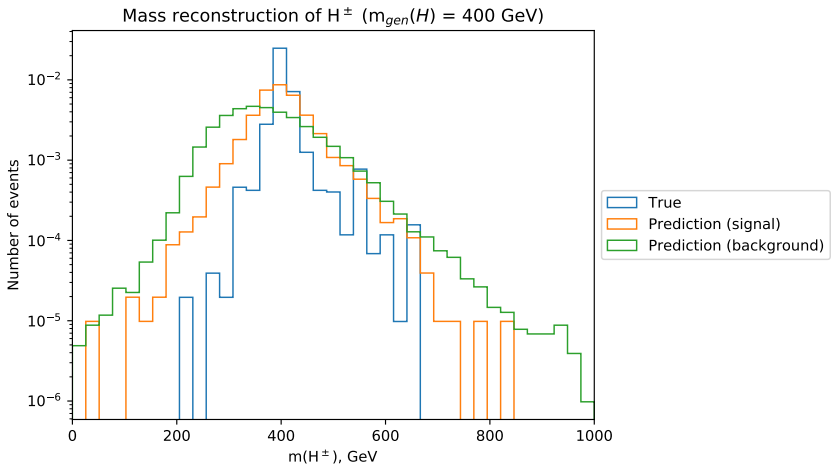
$m(H^{\pm})$ predictions ($m^{gen}(H^{\pm}) = 200$ GeV)



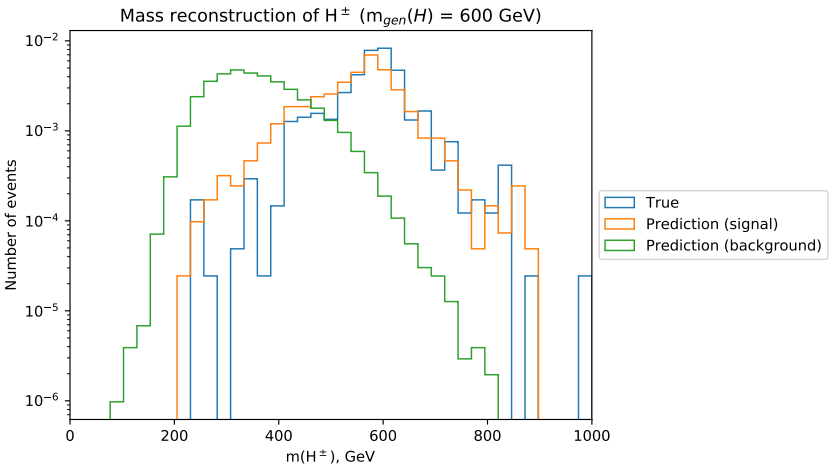


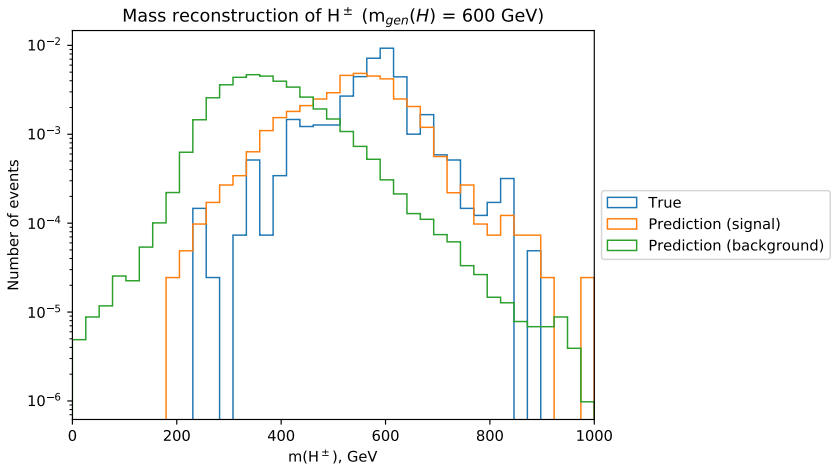
$m(H^{\pm})$ predictions ($m^{gen}(H^{\pm}) = 400$ GeV)





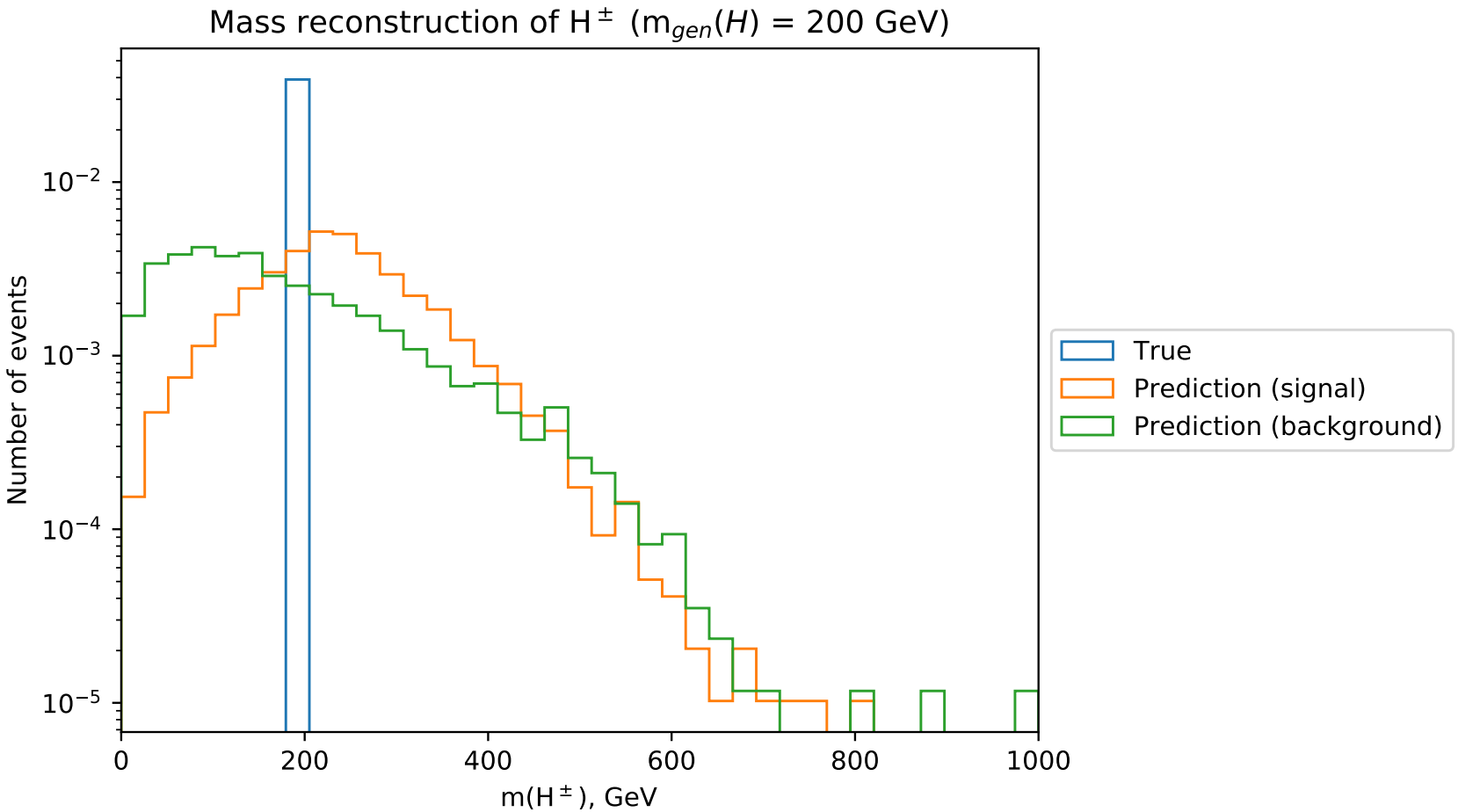
$m(H^{\pm})$ predictions ($m^{gen}(H^{\pm}) = 600$ GeV)





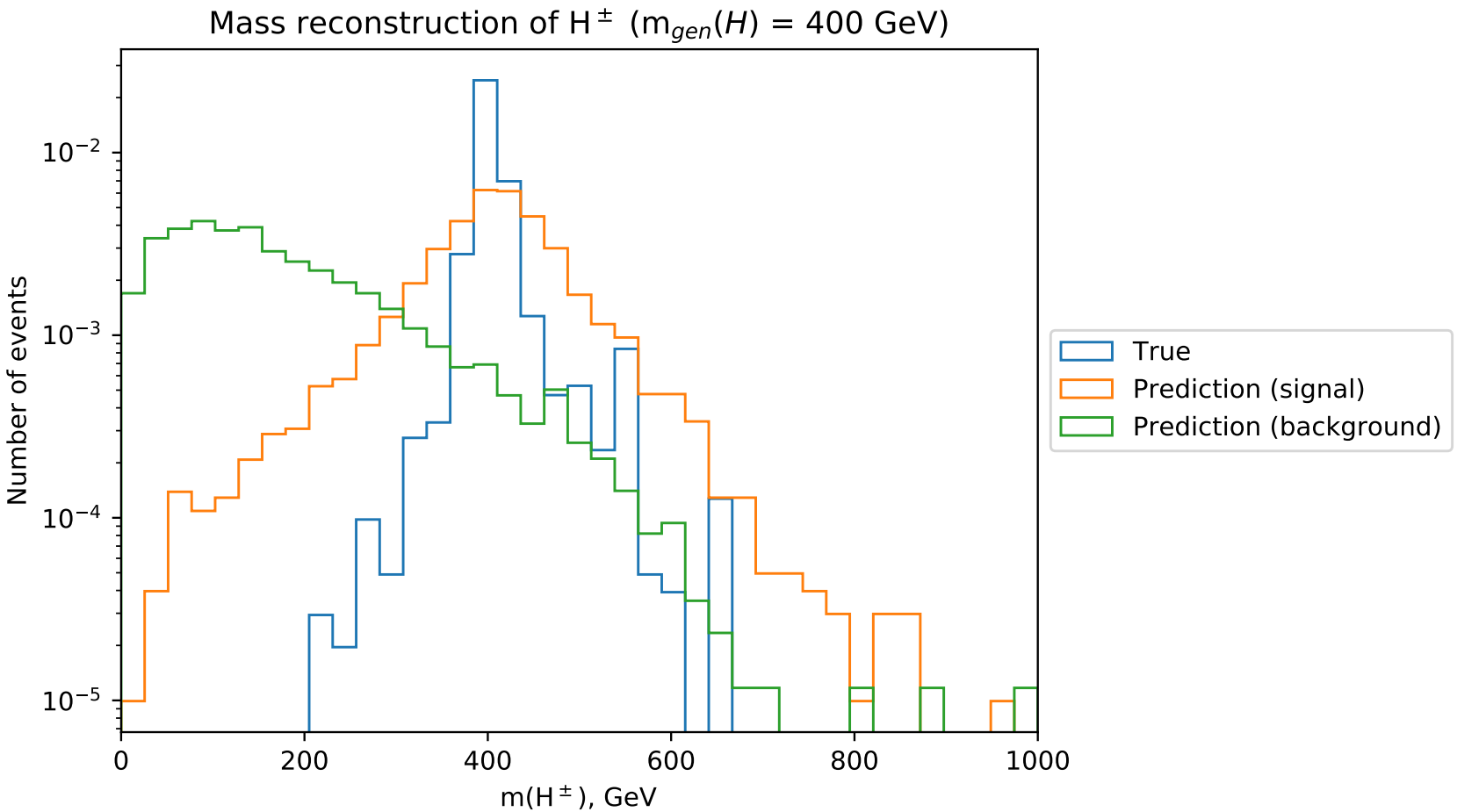
(E, p_x, p_y, p_z) output $(m^{gen}(H^{\pm}) = 200$ GeV)

Dense NN with bkg→0



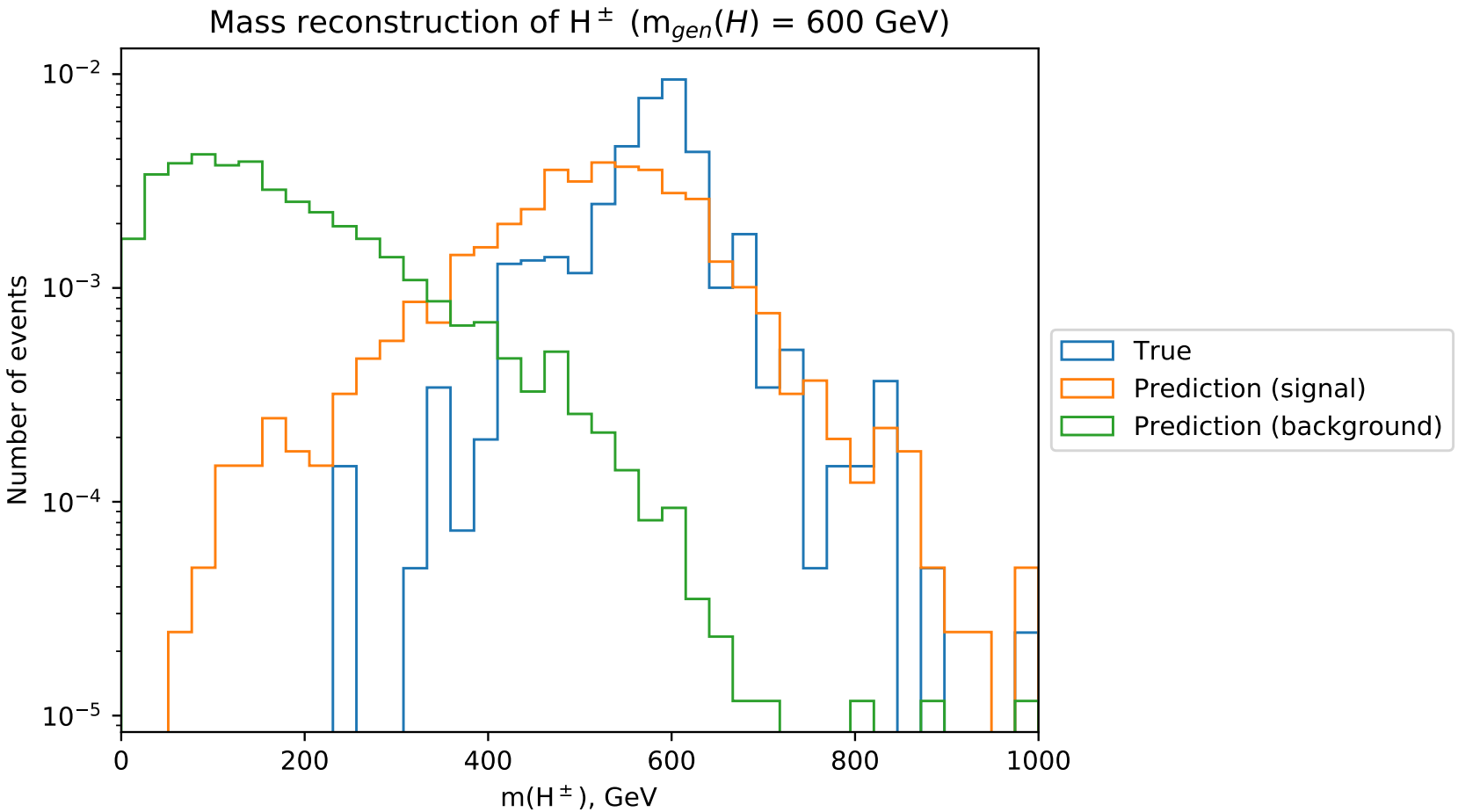
(E, p_x, p_y, p_z) output $(m^{gen}(H^{\pm}) = 400$ GeV)

Dense NN with bkg→0



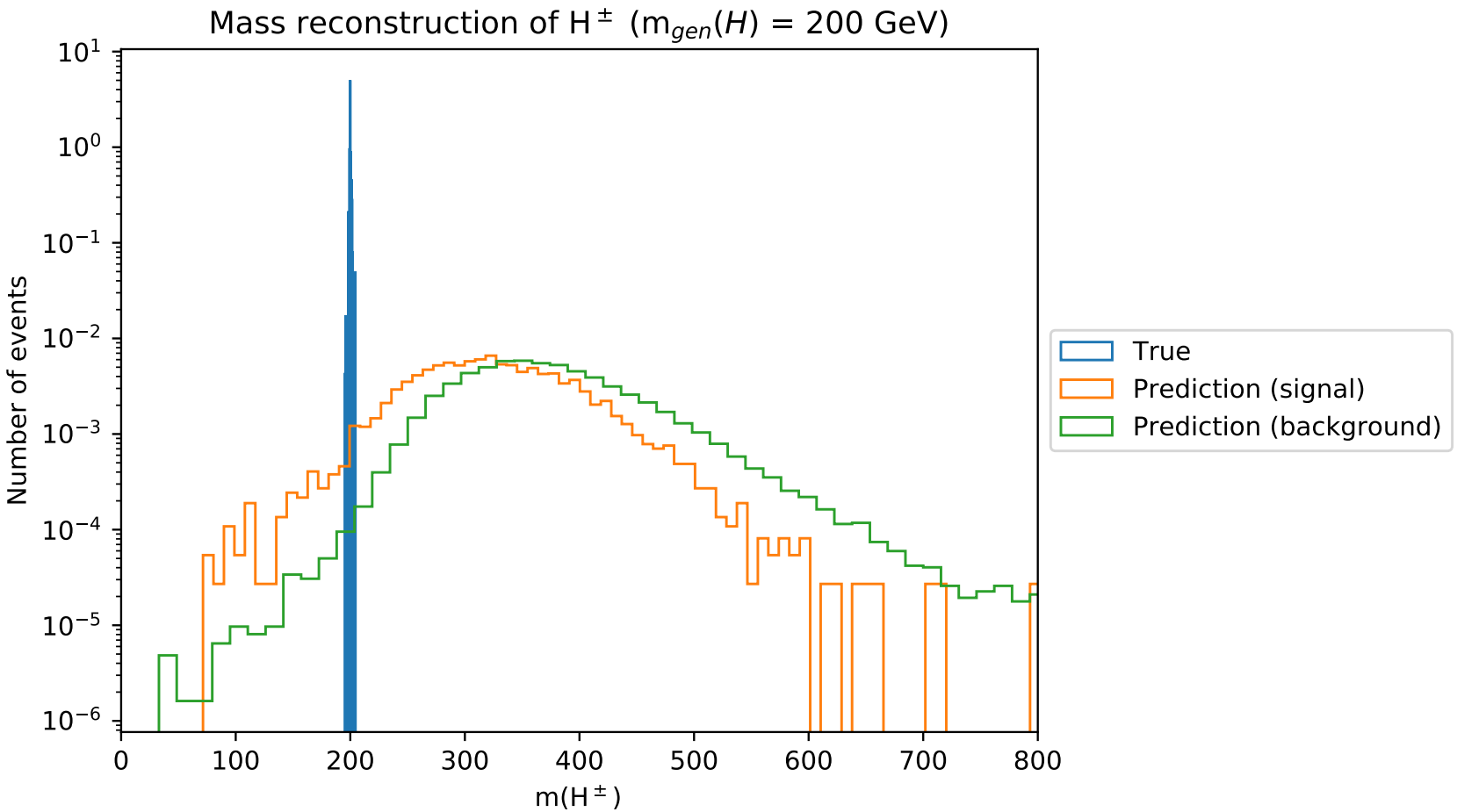
(E, p_x, p_y, p_z) output $(m^{gen}(H^{\pm}) = 600$ GeV)

Dense NN with bkg→0



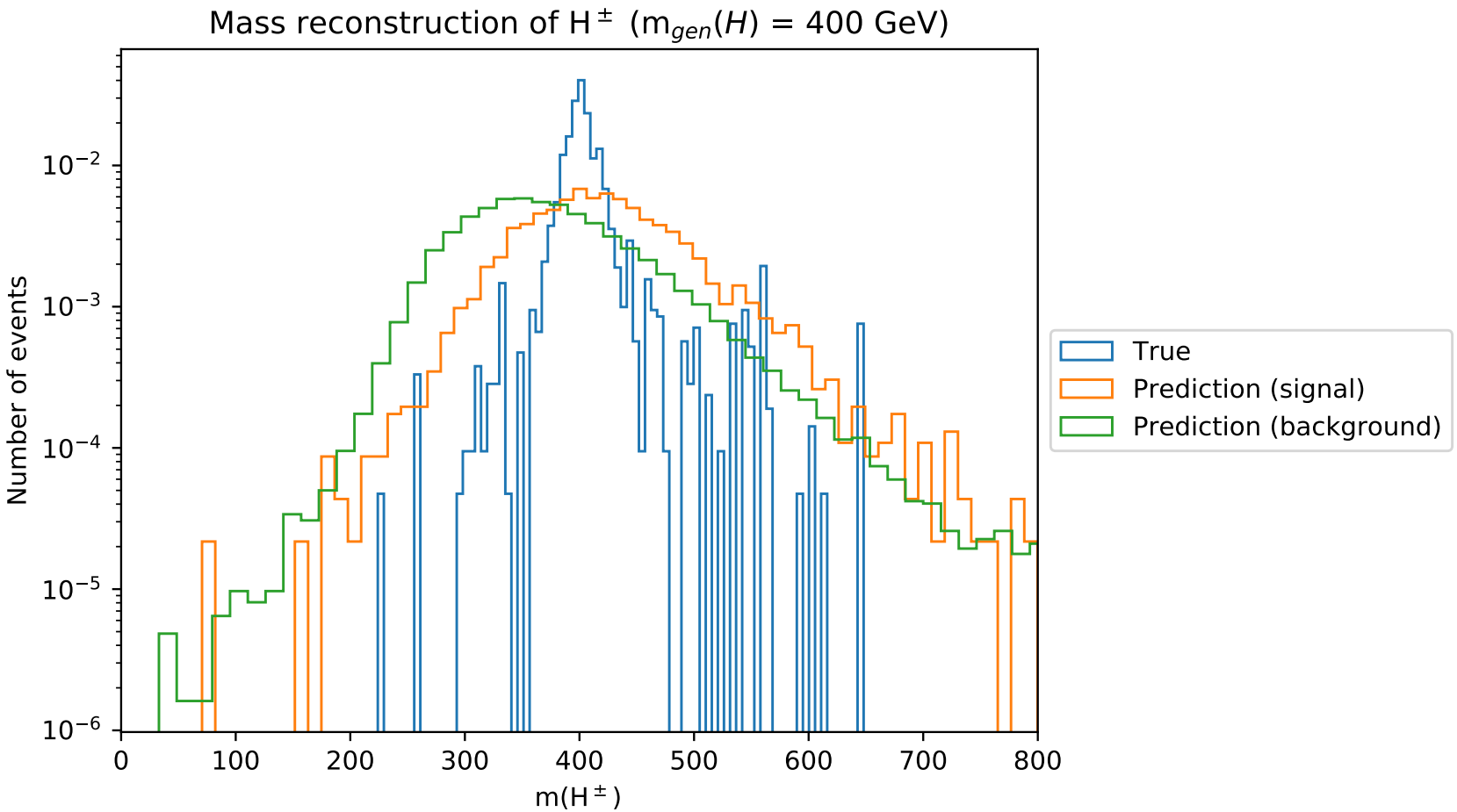
Predictions of mass

Convolutional input layer + 4 dense fully-connected layers



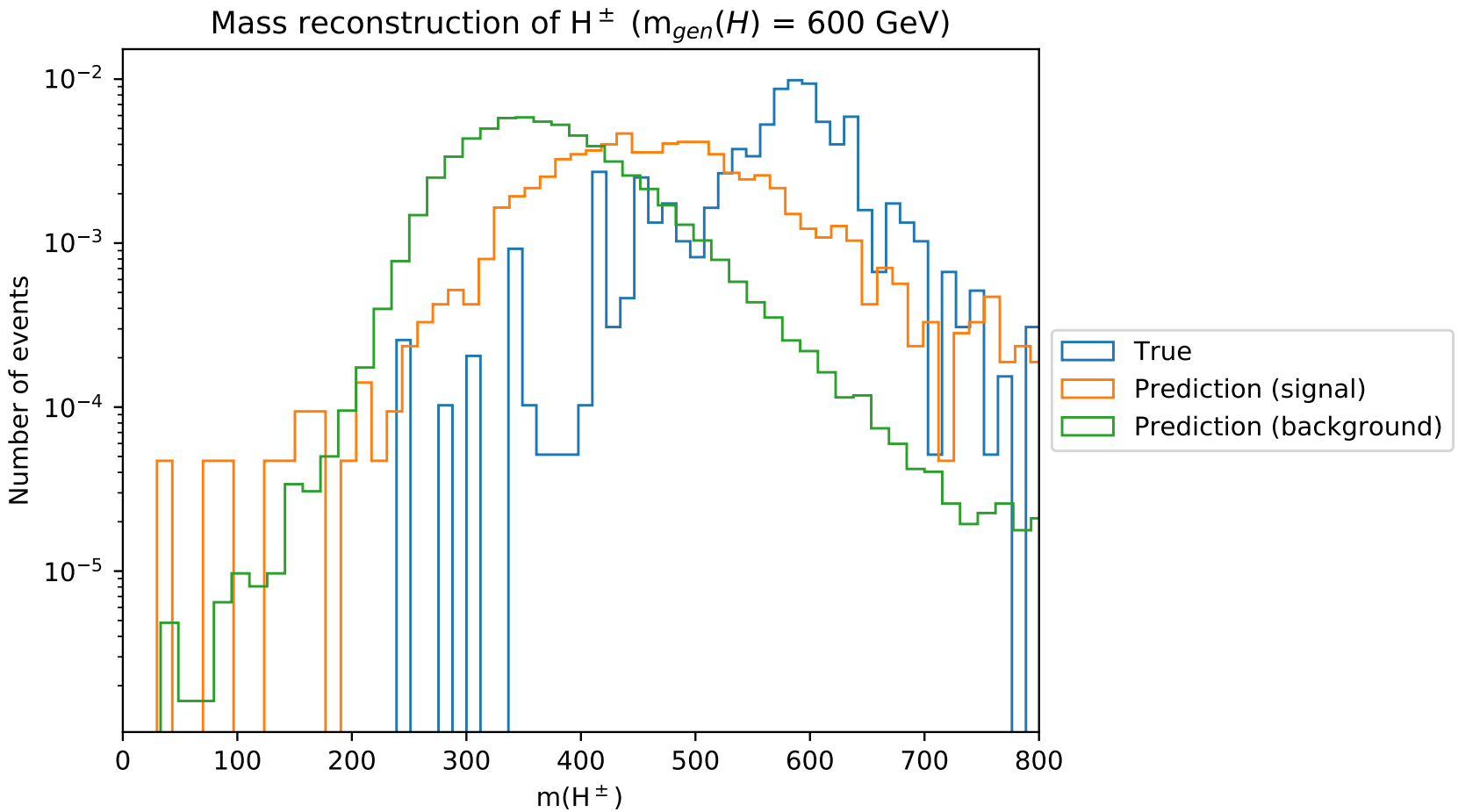
Predictions of mass

Convolutional input layer + 4 dense fully-connected layers



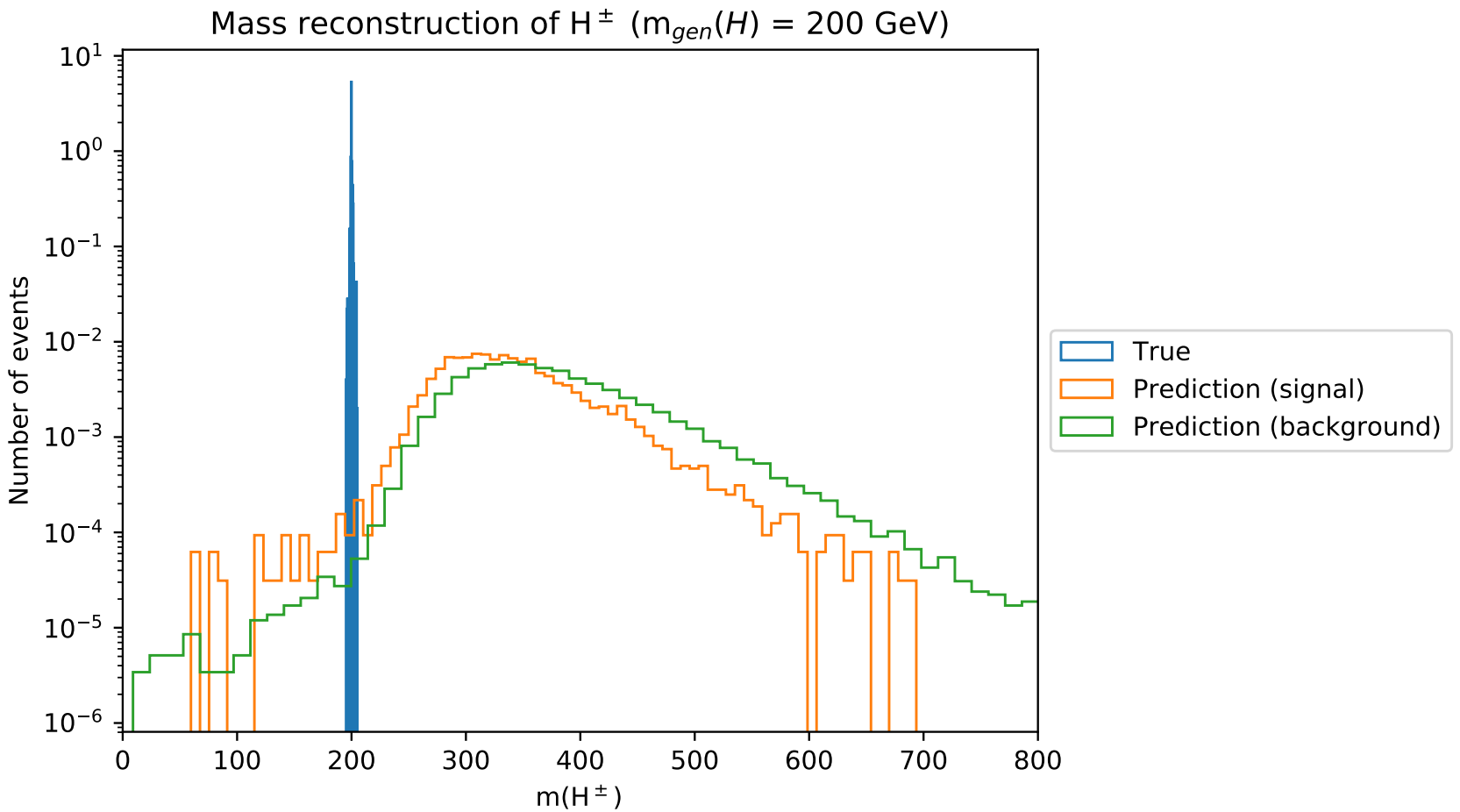
Predictions of mass

Convolutional input layer + 4 dense fully-connected layers



Predictions of mass

2 convolutional input layers (32 kernels 6×1 + 4 dense fully-connected layers)



Predictions of mass

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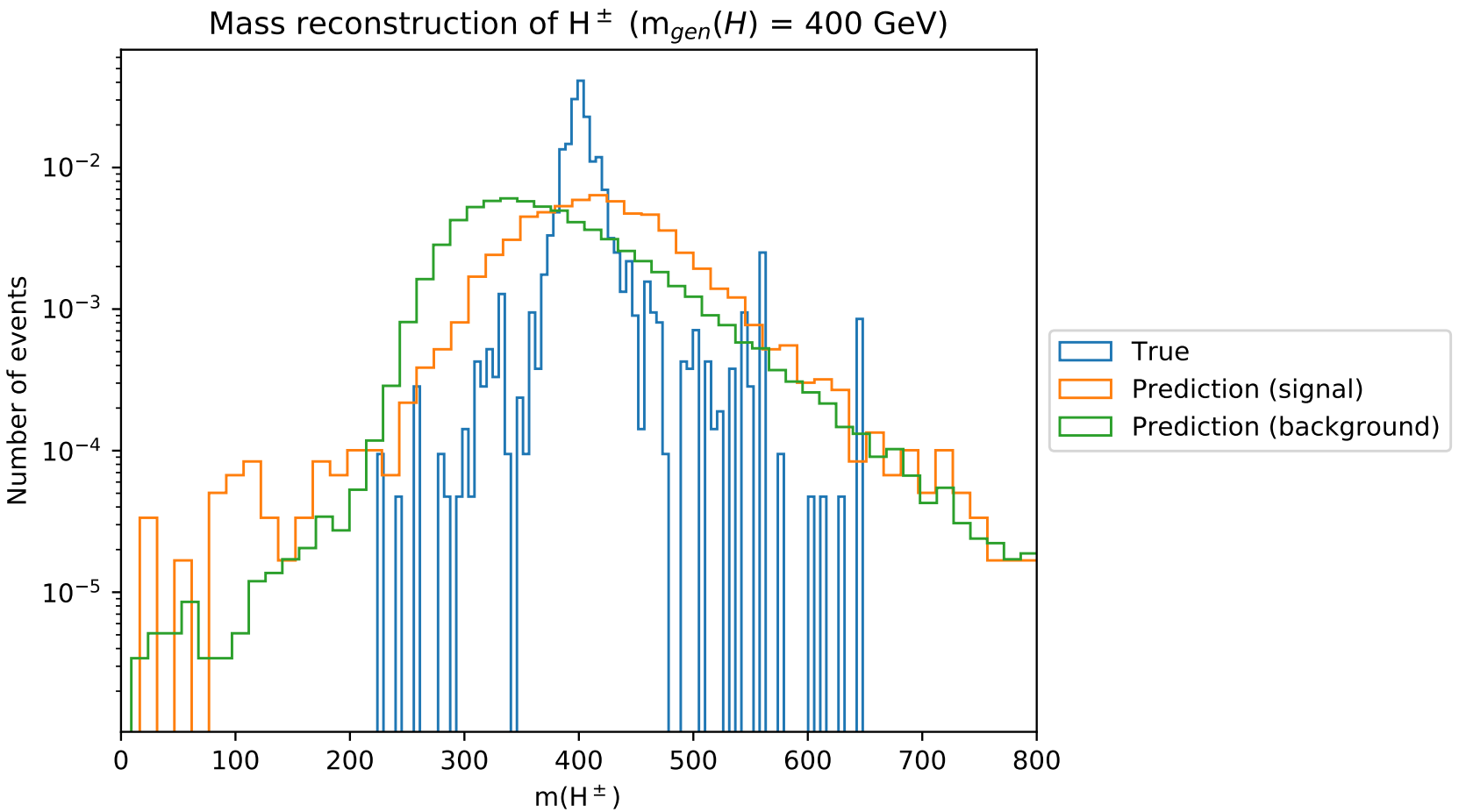
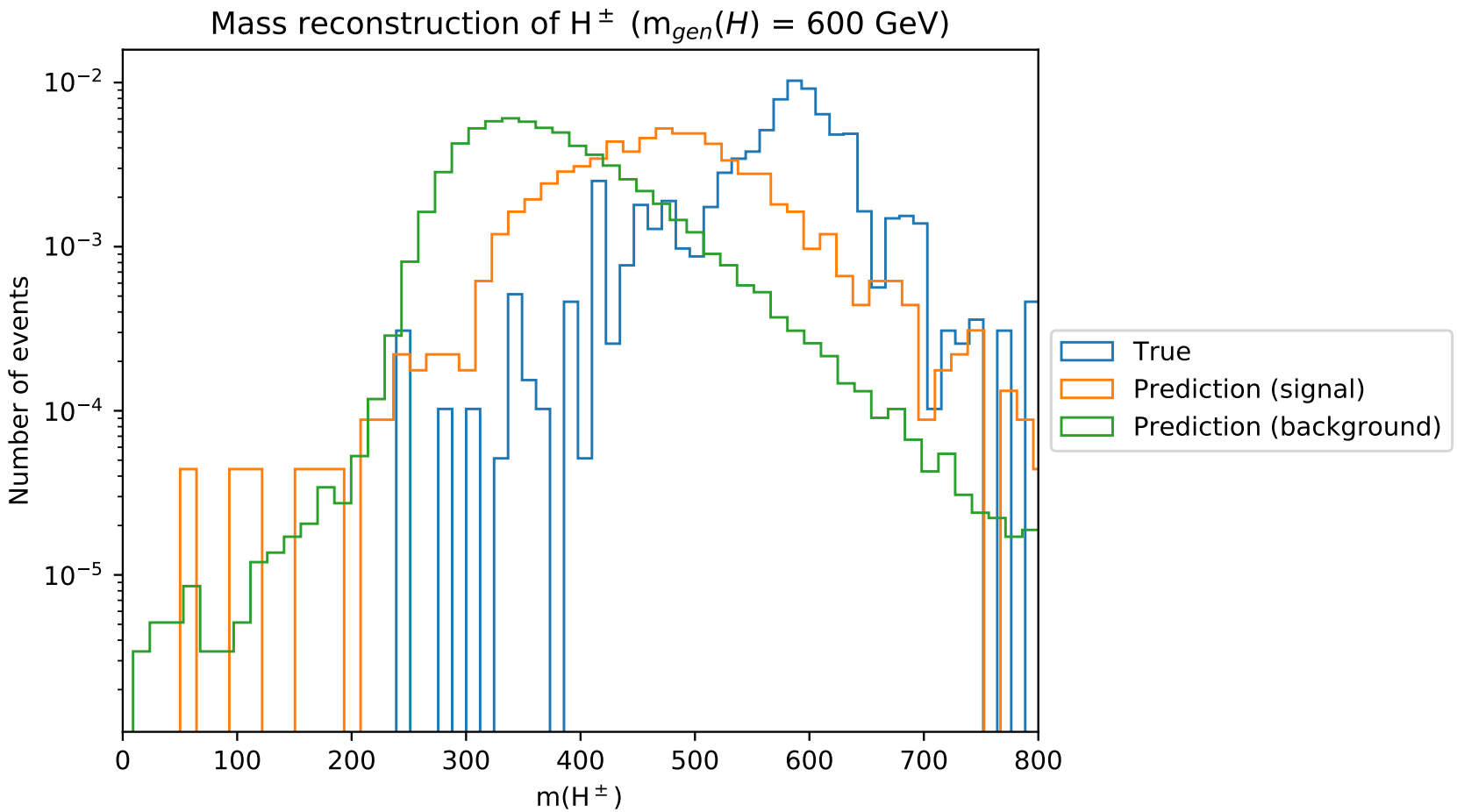


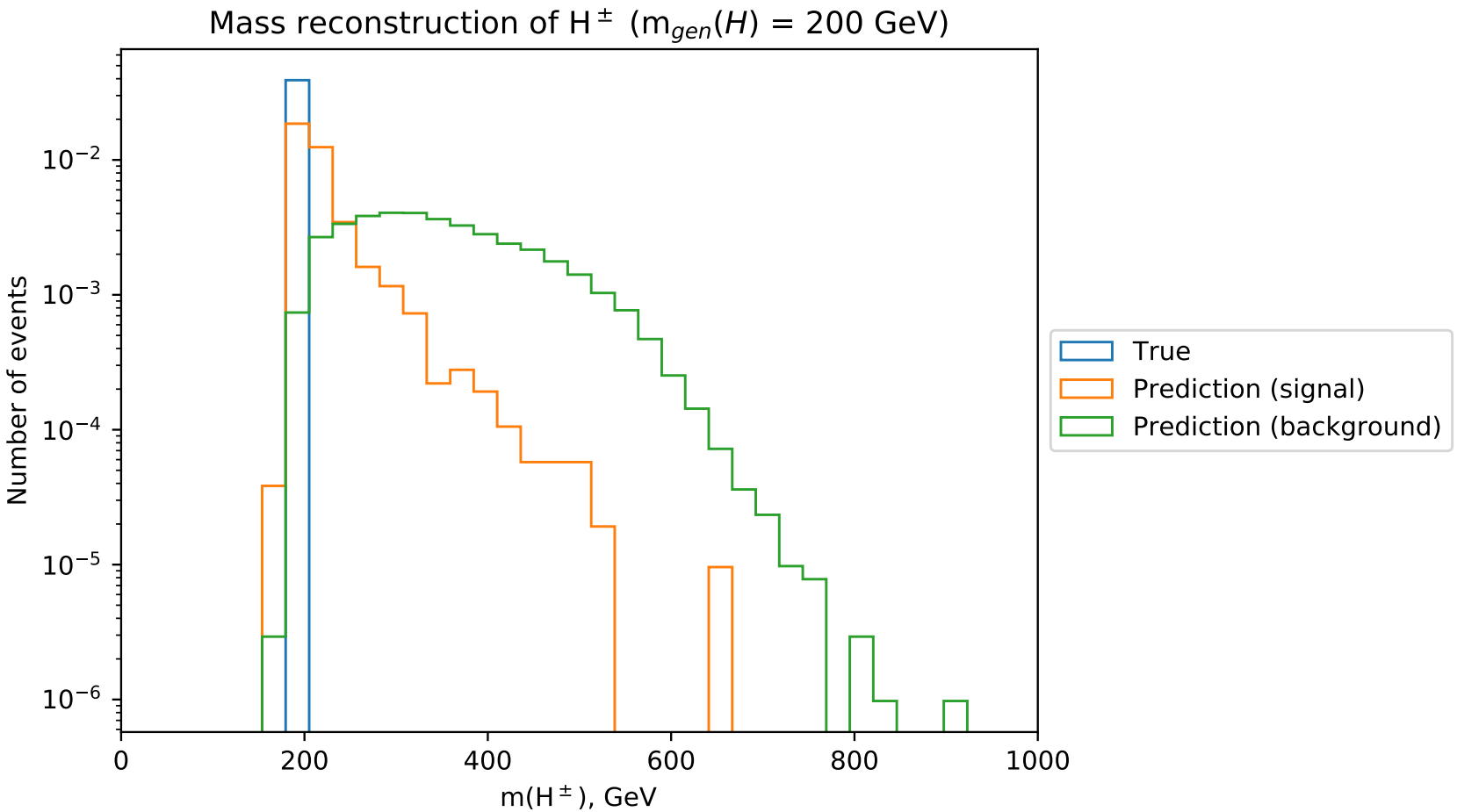
Predictions of mass

2 convolutional input layers (32 kernels 6×1 + 4 dense fully-connected layers)



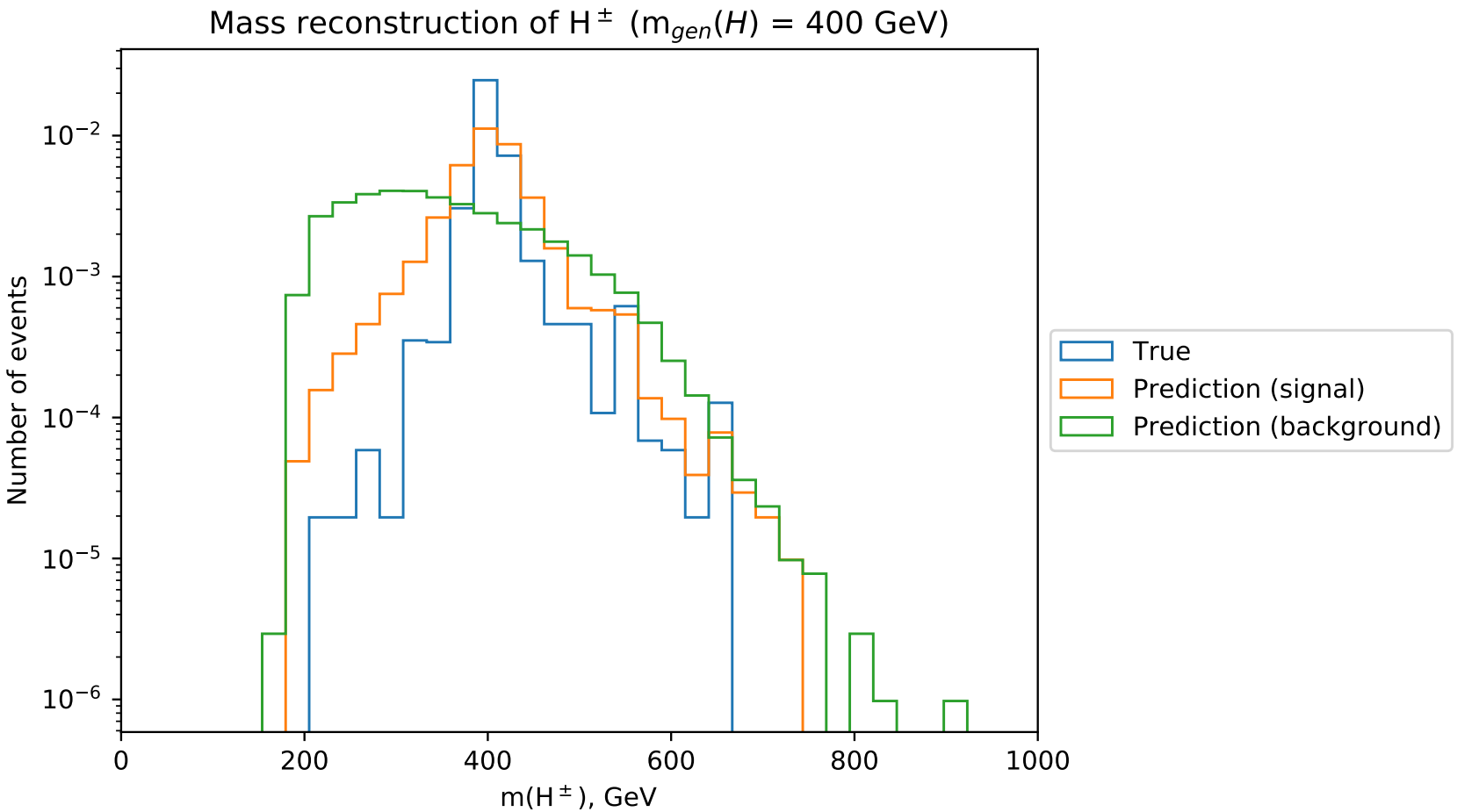
Predictions of mass

LSTM input layer + 4 dense fully-connected layers



Predictions of mass

LSTM input layer + 4 dense fully-connected layers



Predictions of mass

LSTM input layer + 4 dense fully-connected layers