Search for $H^{\pm}$ boson

DESY Summer Student Programme 2019

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Two higgs doublet model as a SM extension

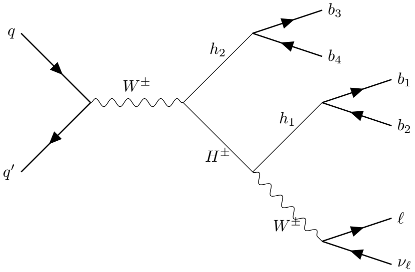
SM: one doublet Φ of complex scalar fields
THDM: two doublets Φ_1 and Φ_2 $\rightarrow$ five Higgs-sector particles
α – mixing angle of neutral CP even Higgs-particles
β: $\tan\beta = v_1/v_2$, where v_1 and v_2 are vacuum expectation values, corresponding to each of doublets

Model specification:

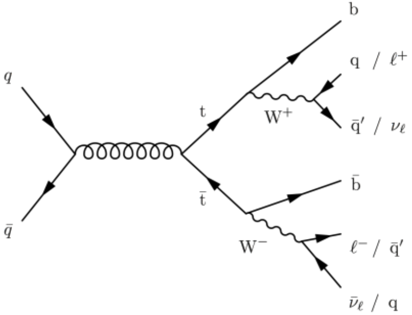
- Type I ($\Phi_1 \rightarrow -\Phi_1$) (no FCNC)
- $m_H = 125.09$ GeV
- $\sin(\alpha - \beta) = 0 \rightarrow m_h < m_H$
- $m_{H^\pm} = m_A, \tan(\beta) = 3$

Features of this specification:

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



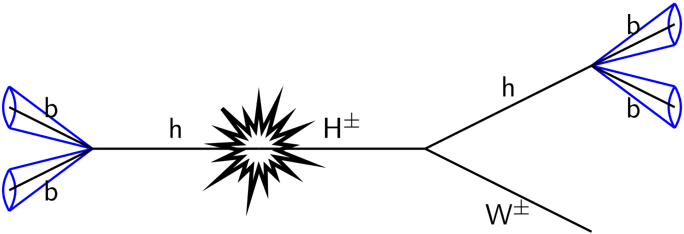
Studied process



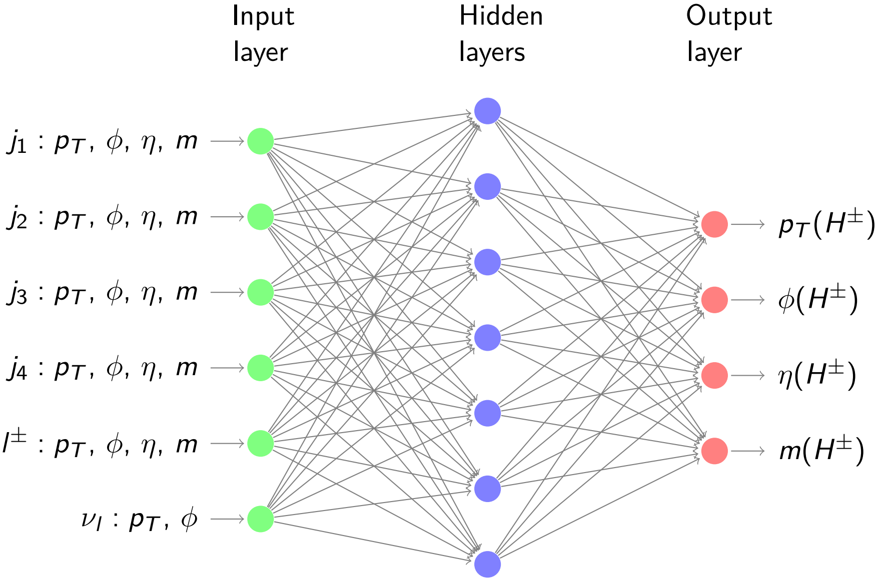
Background process

Signal jet kinematic

Non-boosted topology:



Combinatorical problem: only two of four jets origin from a charged Higgs, and one has to choose these jets correctly to reconstruct the four-momenta of the intermediate particle $H^{\pm}$


Input layer
Hidden layers
Output layer
$j_1 : p_T, \phi, \eta, m$
$j_2 : p_T, \phi, \eta, m$
$j_3 : p_T, \phi, \eta, m$
$j_4 : p_T, \phi, \eta, m$
$l^{\pm} : p_T, \phi, \eta, m$
$\nu_l : p_T, \phi$
$p_T(H^{\pm})$
$\phi(H^{\pm})$
$\eta(H^{\pm})$
$m(H^{\pm})$

Parameters of the neural network

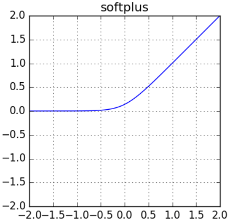
During the network's hyperparameters tuning (random search in the grid) the following set of parameters turned out to be optimal:

→ Number of hidden layers: 5

→ Nodes in each hidden layer: 200

→ Batch size: 100

→ Activation function for nodes in hidden layers: softplus



Data for training

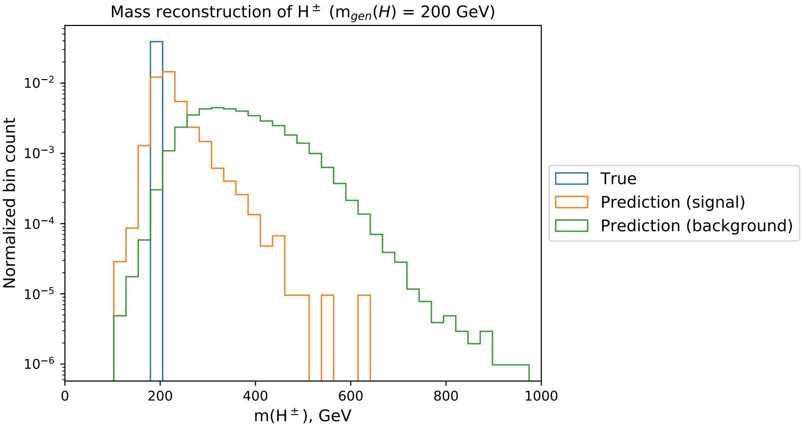
MC-generated events with $m(h_1) = 100$ GeV and $m(H^{\pm}) = 200, 250, ..., 600$ GeV were used for training

→ $\sim 3 \cdot 10^5$ events

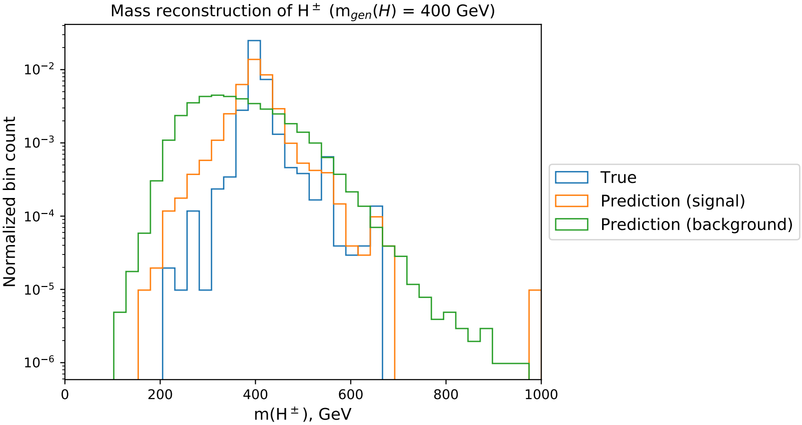
→ unbalanced data (from $\sim 36 \cdot 10^3$ events for $m(H^{\pm}) = 200$ GeV to $\sim 14 \cdot 10^3$ events for $m(H^{\pm}) = 600$ GeV) → using *weighted* MSE as a loss function

→ training : test : validation = 81 : 10 : 9

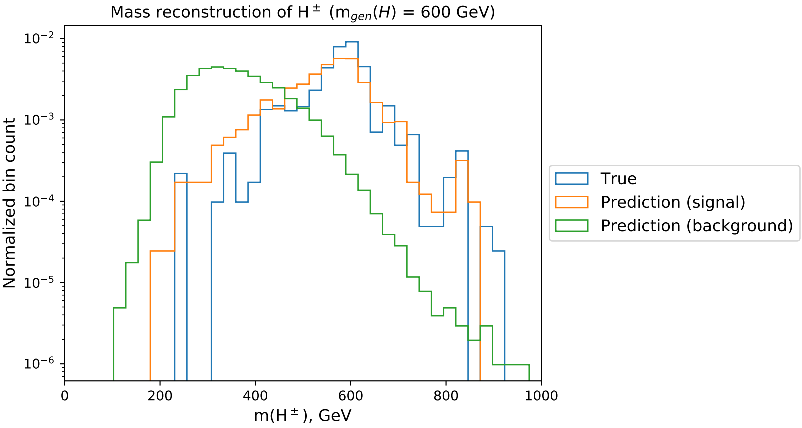
Predictions of mass



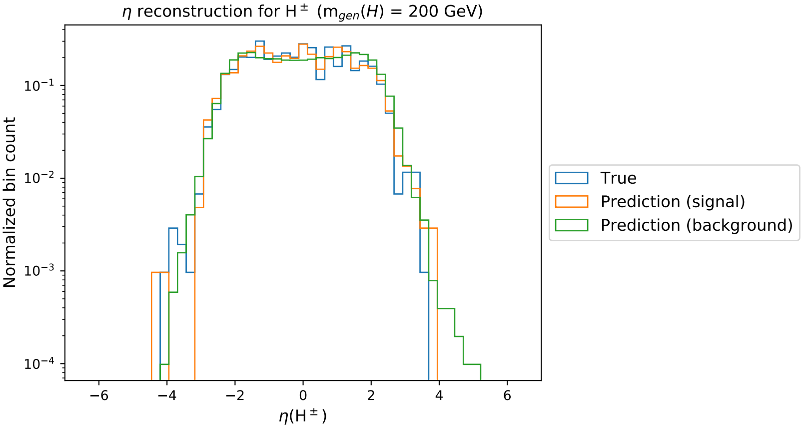
Predictions of mass



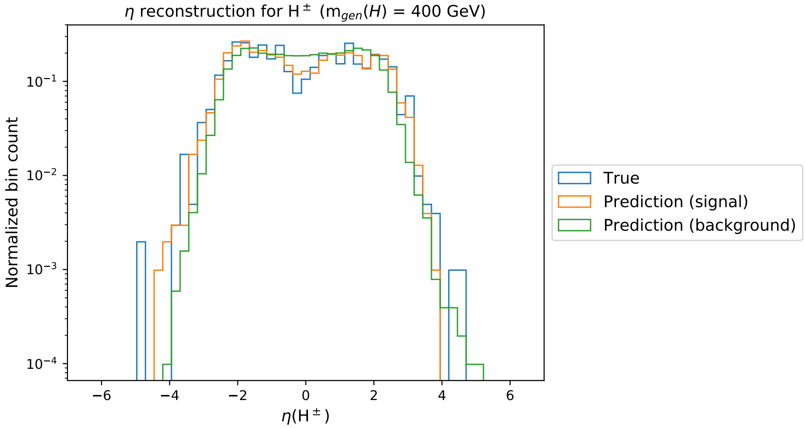
Predictions of mass



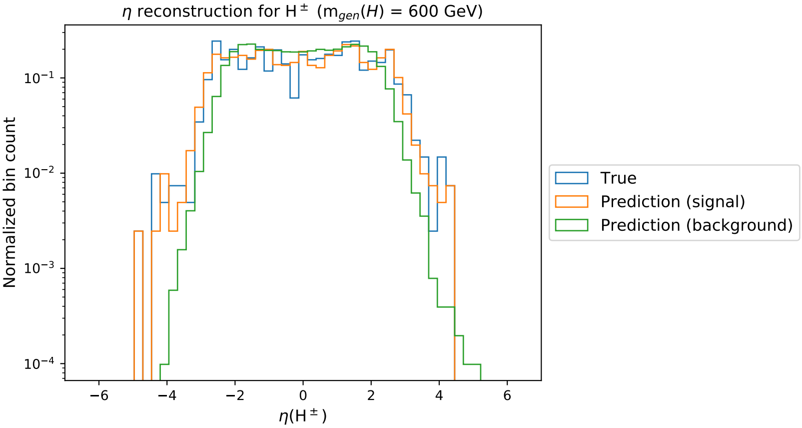
Predictions of pseudorapidity



Predictions of pseudorapidity

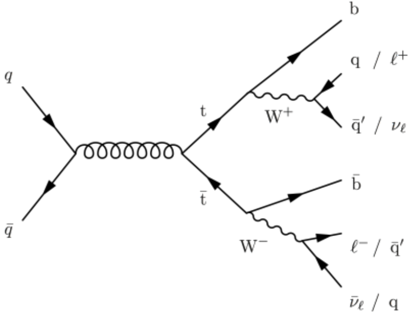


Predictions of pseudorapidity



Background suppression

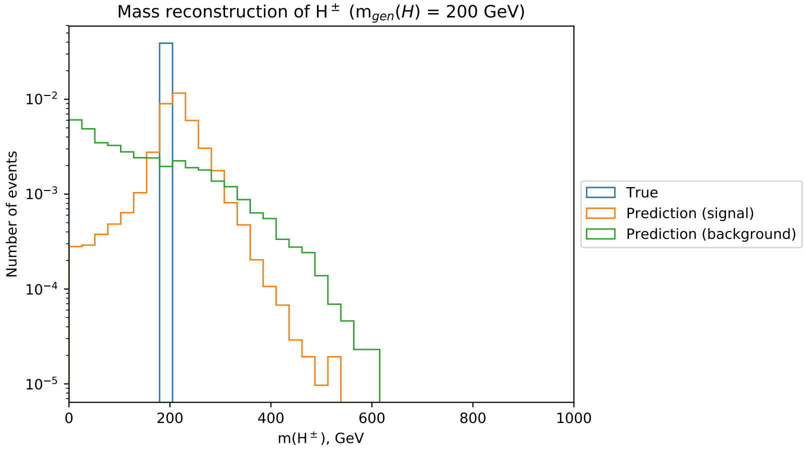
Significant background to deal with:



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

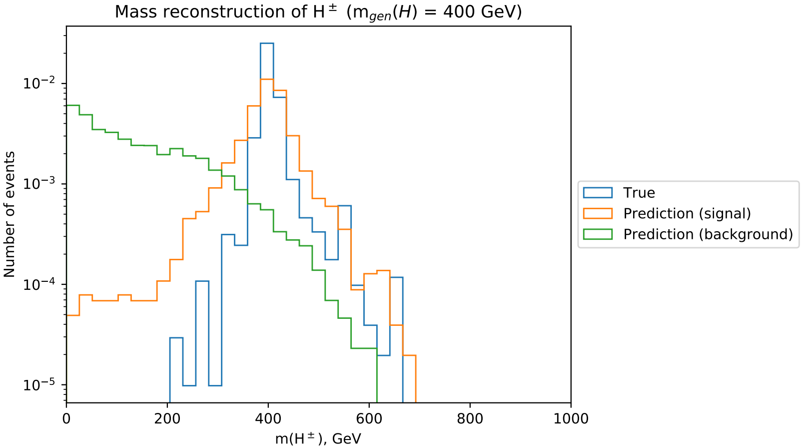
Prediction of mass

Dense NN with bkg→0



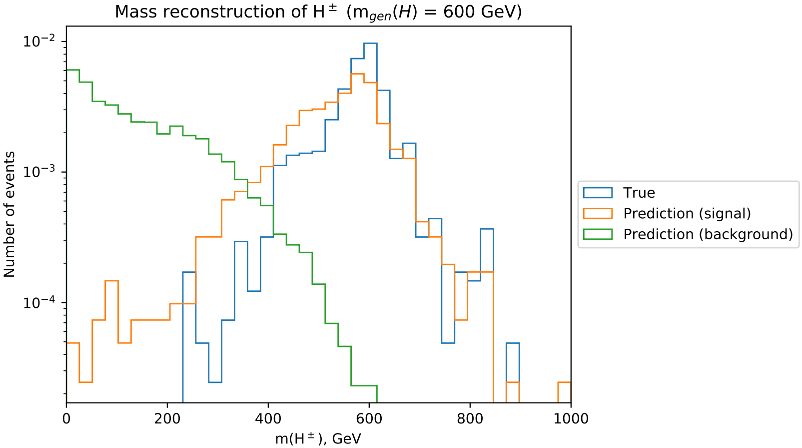
Prediction of mass

Dense NN with bkg$\to$0



Prediction of mass

Dense NN with bkg→0



Summary

What is done:

- → Dense neural network is implemented
- → Hyperparameters tuning is performed
- → Architectures with LSTM and convolutional layers are tested
- → Successful reconstruction of $H^{\pm}$ with mass in a broad spectrum (from 200 GeV to 600 GeV) is accomplished
- → Different approaches of background suppression are tested
- → $t\bar{t}$-background suppression is achieved

What can be improved:

- → Architecture (researches on more complicated layers are needed)

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 $\mathcal{L}_{EW}$:

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

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

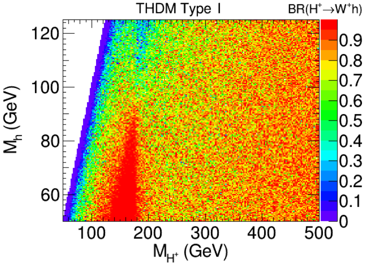
$$D_\mu = \partial_\mu - i g_2 \frac{\tau_a}{2} W^a_\mu - i g_1 \frac{Y_h}{2} B_\mu$$

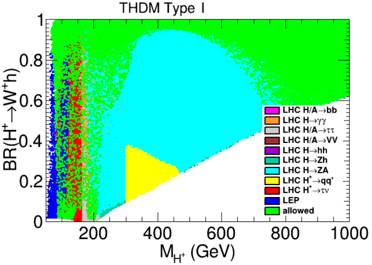
- Break symmetry $\rightarrow$ massive bosons – W^+, W^- and Z, massless boson γ and massive CP-even neutral particle – Higgs boson.

Two higgs doublet model – extension of the SM

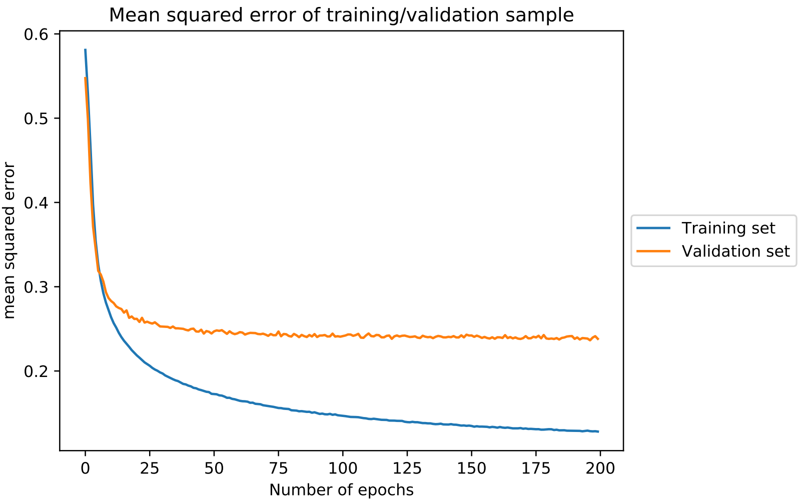
Why don't we introduce another complex scalar doublet?
2 doublets $\rightarrow$ five Higgs-sector particles, angle α – the mixing angle of neutral CP even Higgs-particles, β – angle which is responsible for the ratio of the vacuum expectation values v_1 and v_2, corresponding to the doublets Φ_1 and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

Features of the specification in plots



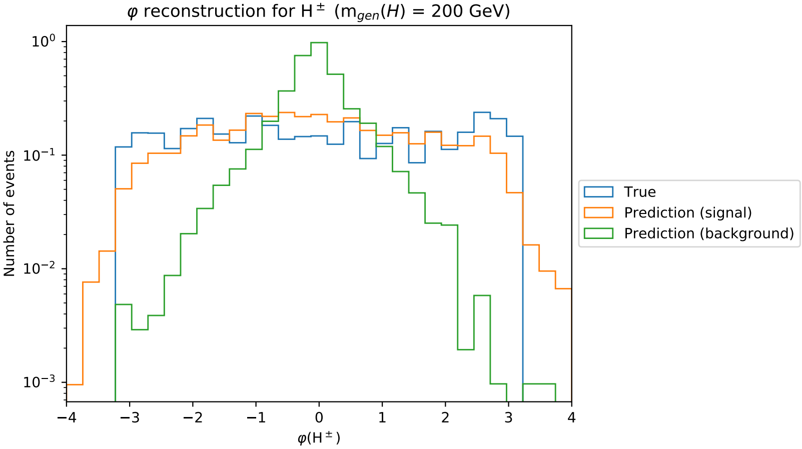


Training curve

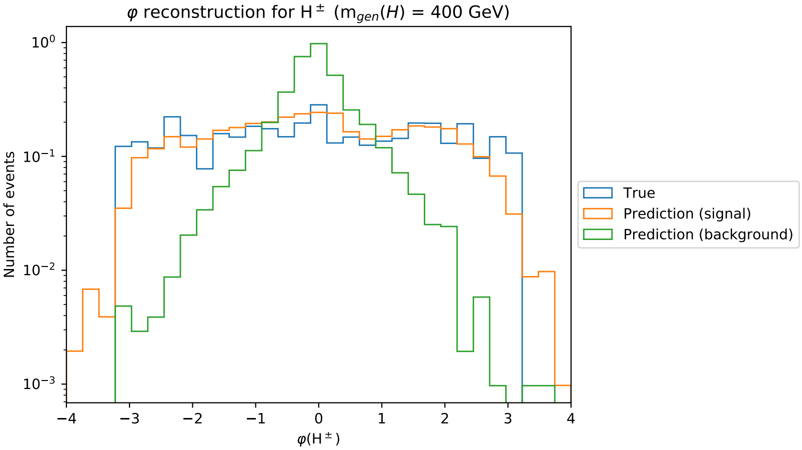


Results ($\phi^{pred}(H^{\pm})$ for $m^{gen}(H^{\pm}) = 200$ GeV)

Angle reconstruction (dense NN with bkg→0)

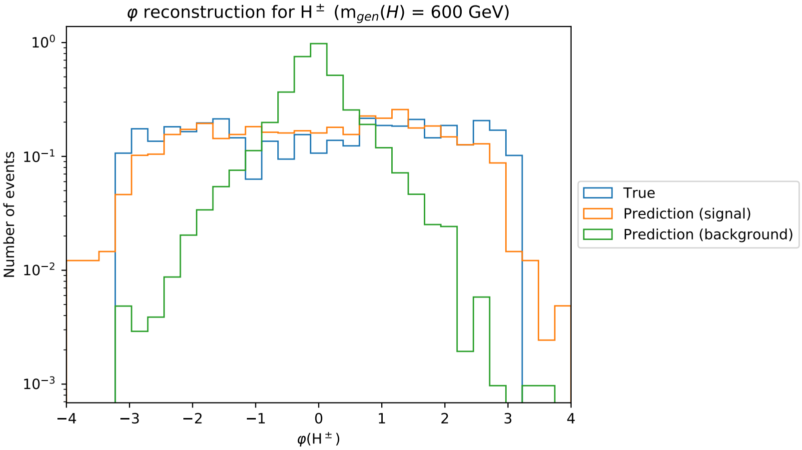


Angle reconstruction (dense NN with bkg→0)

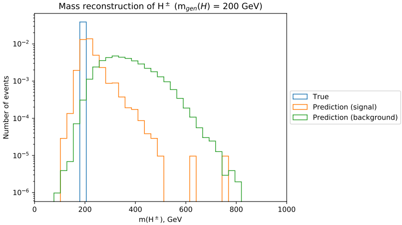


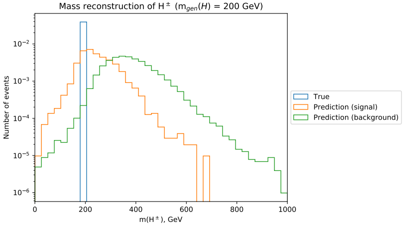
Results ($\phi^{pred}(H^{\pm})$ for $m^{gen}(H^{\pm}) = 600$ GeV)

Angle reconstruction (dense NN with bkg→0)

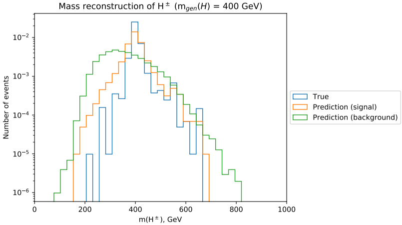


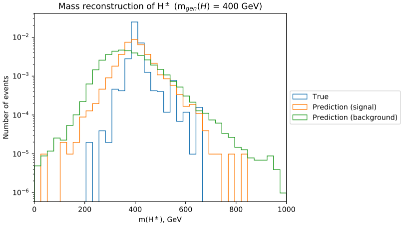
$m(H^{\pm})$ predictions ($m^{gen}(H^{\pm}) = 200$ GeV)



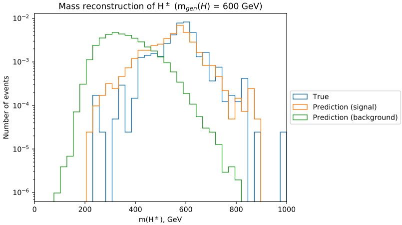


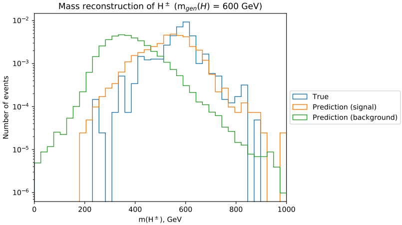
$m(H^{\pm})$ predictions ($m^{gen}(H^{\pm}) = 400$ GeV)



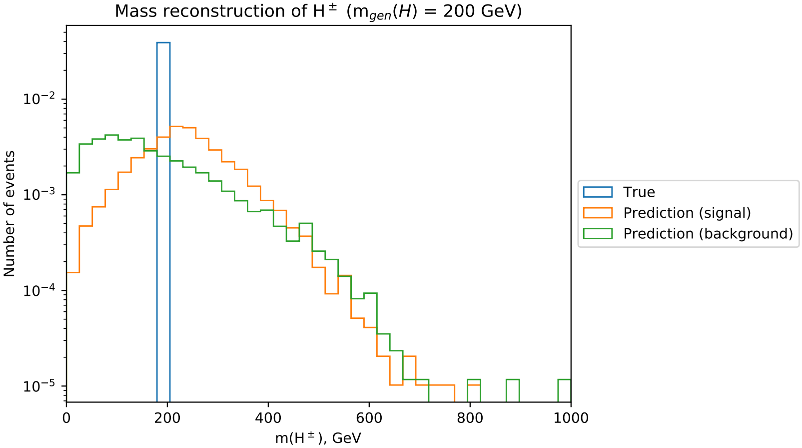


$m(H^{\pm})$ predictions ($m^{gen}(H^{\pm}) = 600$ GeV)



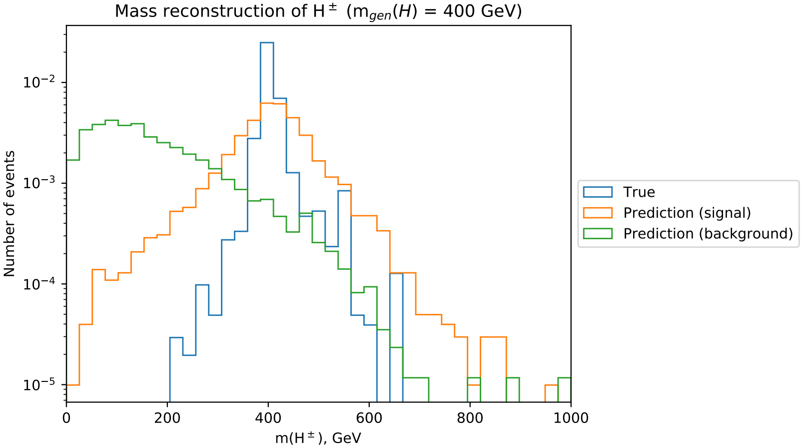


Dense NN with bkg$\rightarrow$0



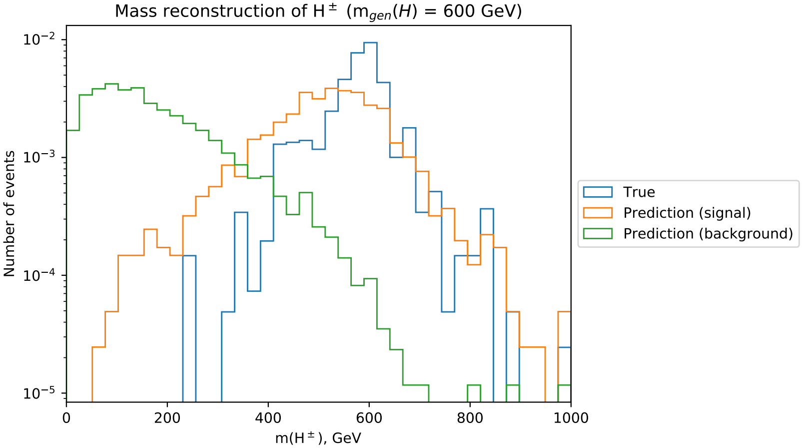
(E, p_x, p_y, p_z) output $(m^{gen}(H^{\pm}) = 400$ GeV$)$

Dense NN with bkg$\to$0



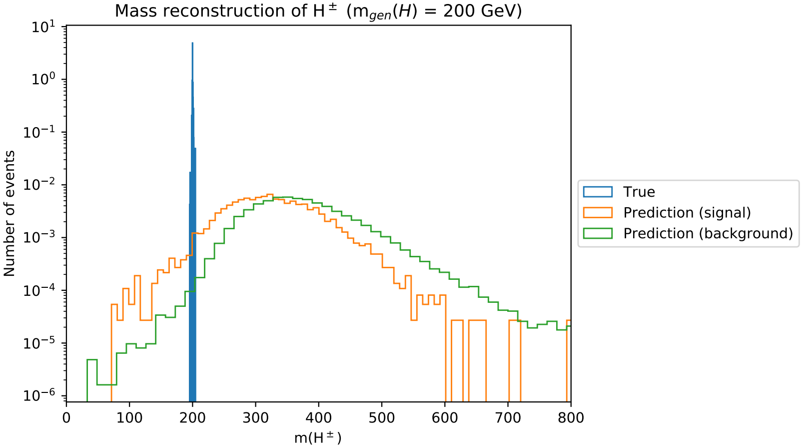
(E, p_x, p_y, p_z) output ($m^{gen}(H^{\pm}) = 600$ GeV)

Dense NN with bkg→0



Predictions of mass

Convolutional input layer + 4 dense fully-connected layers



Predictions of mass

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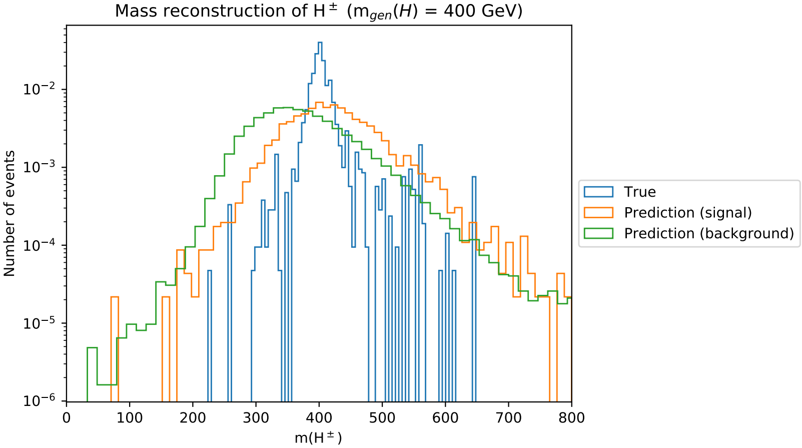
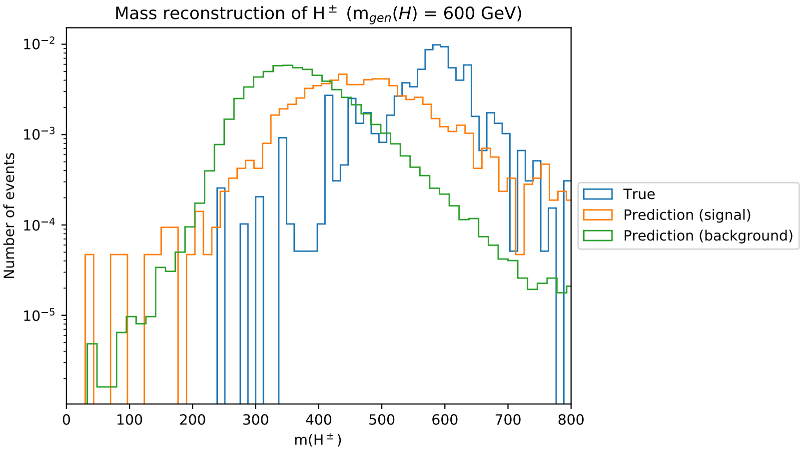


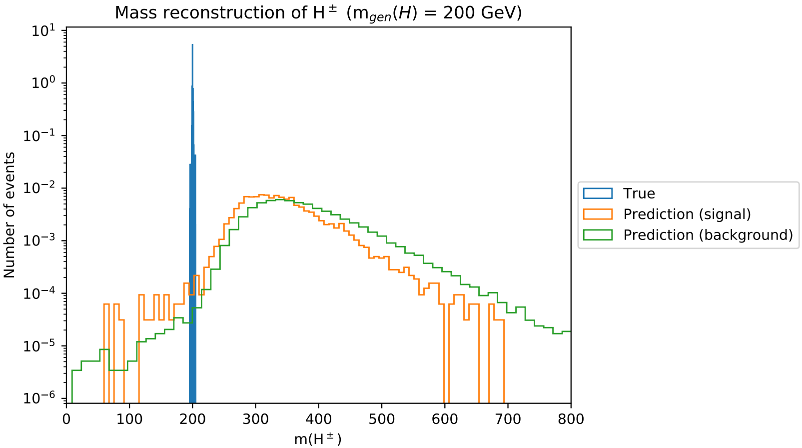
Predictions of mass

Convolutional input layer + 4 dense fully-connected layers



Predictions of mass

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



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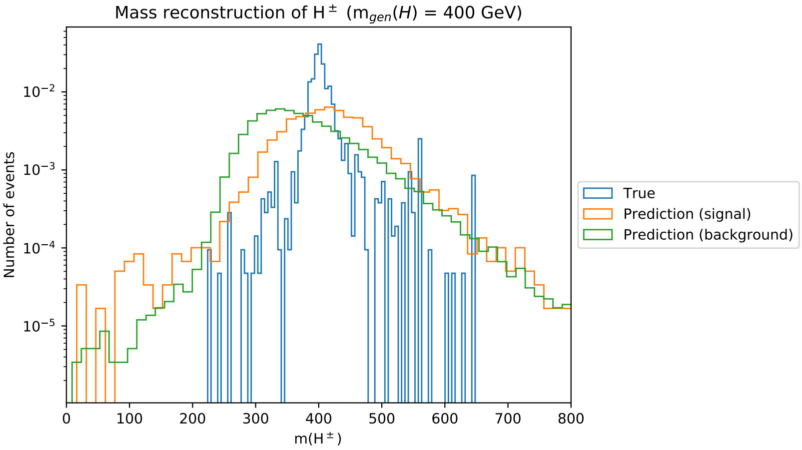

Predictions of mass

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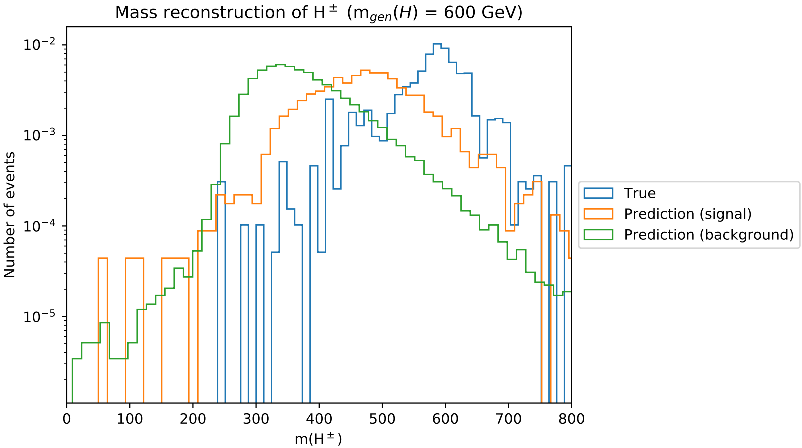
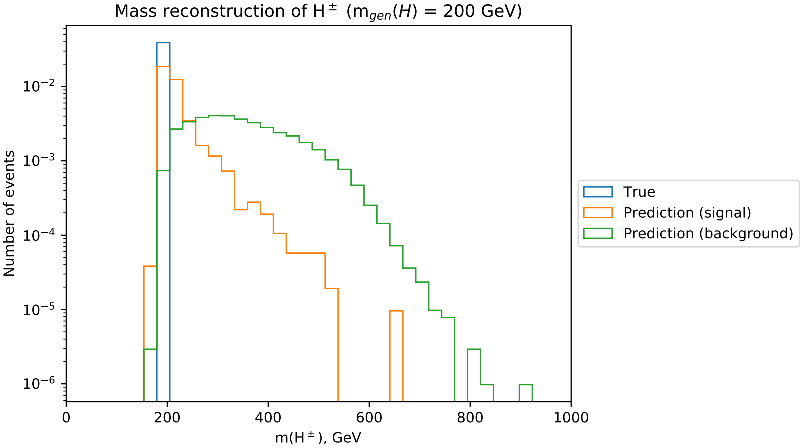


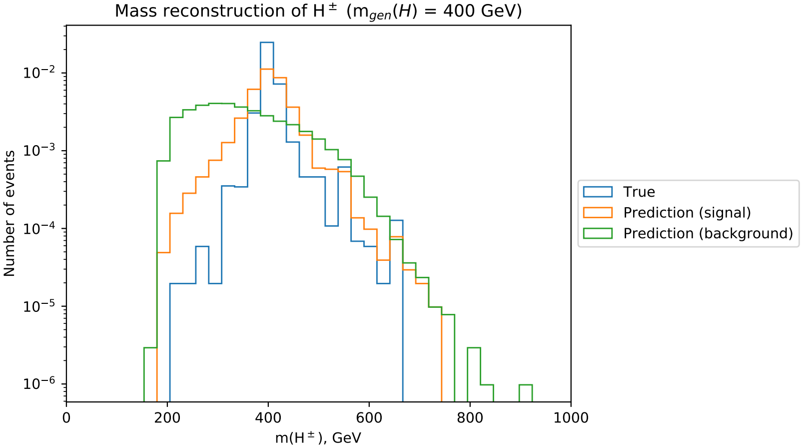
Predictions of mass

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