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Discriminating GGF and VBF in Higgs production with ML

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FNSNF

Fonds national suisse
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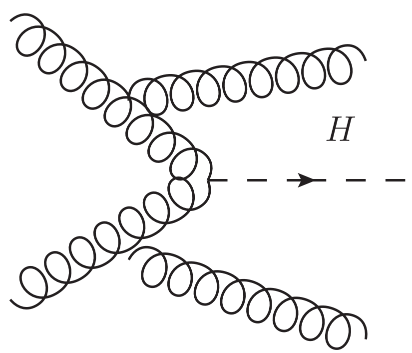
Fondo nazionale svizzero
Swiss National Science Foundation

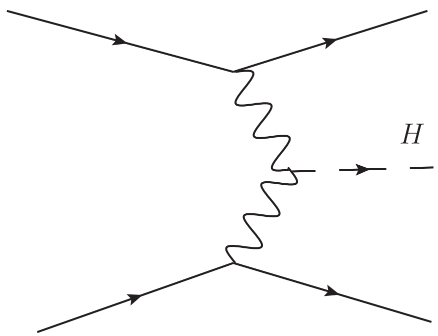
Objective

GGF



VS

VBF



- Gluon fusion dominant contribution (loop induced)
- Vector boson fusion probes couplings of Higgs to heavy gauge bosons
- Treat VBF as signal, GGF as background
- Fraction of VBF can be enhanced by applying ‘VBF-cuts’

Computational setup

- Amplitudes for **HEFT-GGF** and **VBF** computed with **GoSam** + **Sherpa** via BLHA
  [Cullen, v.Deurzen, Heinrich, Luisoni, Mastrolia, Mirabella, Ossola, Peraro, Schlenk, v.Soden-Fraunhofen, Tramontano, NG '14]
  [Gleisberg, Hoeche, Krauss, Schoenherr, Schuhmann]
  - Virtual amplitudes: **GoSam** with **Ninja** [v.Deurzen, Luisoni, Mastrolia, Mirabella, Ossola, Peraro '14]
    Scalar integrals with **OneLoop** [v.Hameren '11]
  - Tree amplitudes and integration with **Sherpa** and **Comix** [Gleisberg, Hoeche '08]
- Phenomenological analysis via generation of **ROOT NTUPLES**
  - **GGF Events: H + 1 / 2 / 3** jets for 8, 13, 14 and 100 TeV
    VBF Events: H + 2 / 3 jets for 13 TeV
  - For kt / anti-kt with R = 0.1 (or larger)
  - Allows for fast analysis, change of **scale, pdf, cuts, jet-tagging**

Physical Setup / Cuts

General settings (GGF HEFT, VBF)

- Scale choice: $\mu_F = \mu_R = \frac{\hat{H}'_T}{2} = \frac{1}{2}\left(\sqrt{m_{\mathrm{H}}^2 + p_{T,\mathrm{H}}^2} + \sum_i |p_{T,i}|\right)$
- PDF: CT14nlo

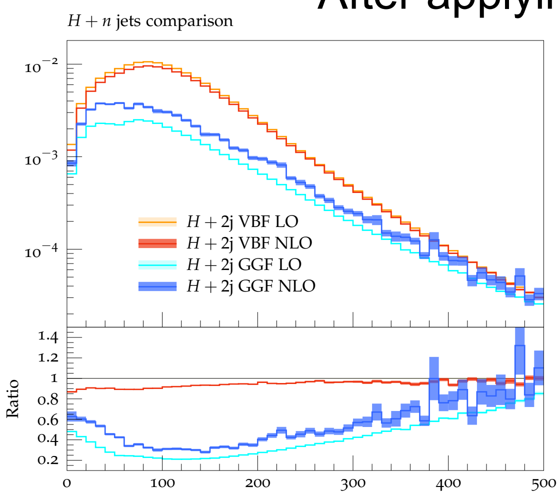
Cuts

- **Baseline cuts:** anti-kt with $R = 0.4, \quad p_T > 30 \text{ GeV}, \quad |\eta| < 4.4$
- **VBF cuts:** $m_{j1,j2} > 400 \text{ GeV}, \quad |\Delta y_{j1,j2}| > 2.8$

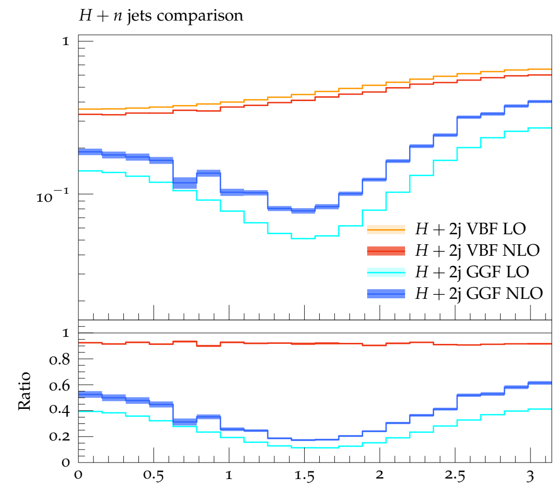
Starting point: LO Ntuples for H+2/3 jets for 13 TeV

Differential distributions for GGF and VBF

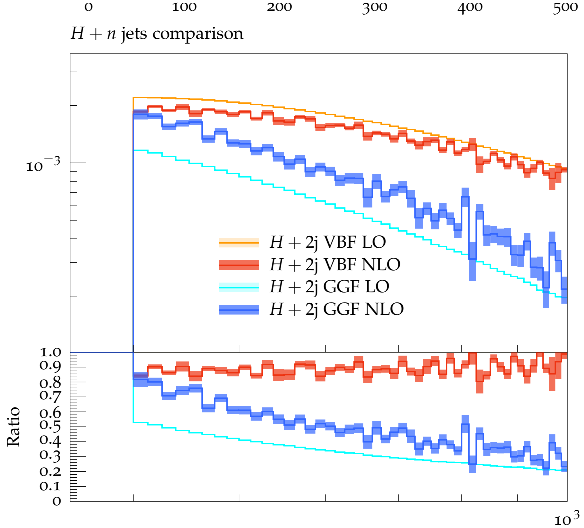
After applying VBF cuts on GGF (**preliminary plots**)



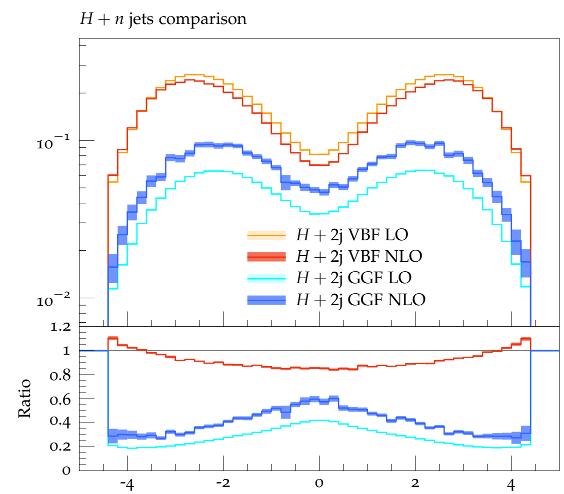
$p_{T,H}$



$\Delta\Phi_{jj}$



m_{jj}



y_{j1}

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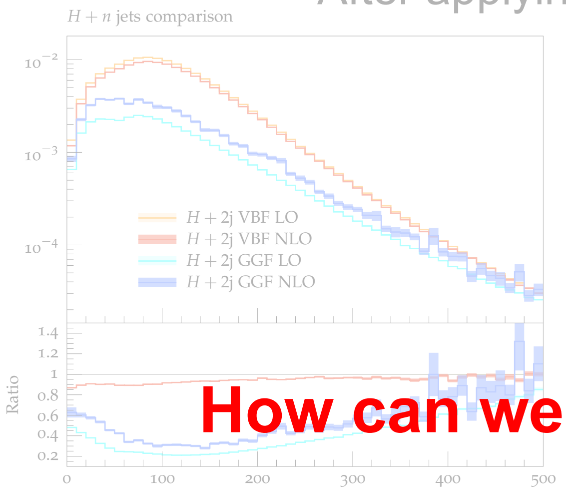
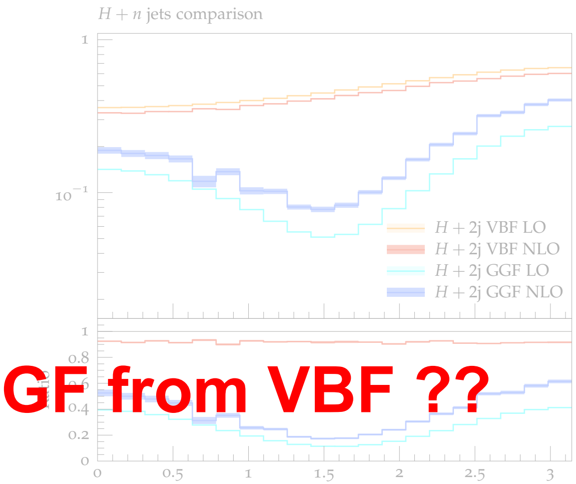
Differential distributions for GGF and VBF

After applying VBF cuts on GGF (**preliminary plots**)

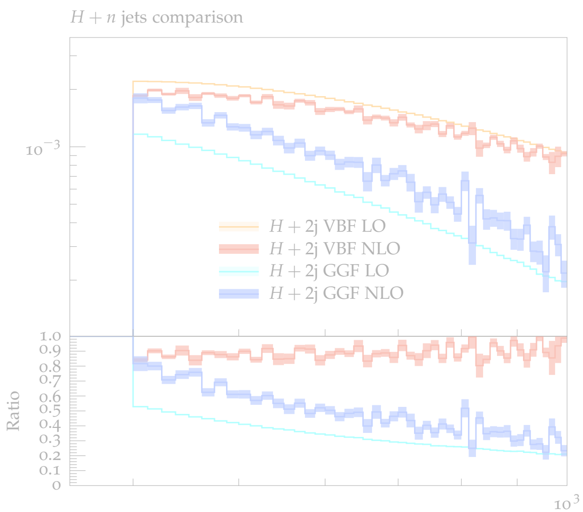


$p_{T,H}$

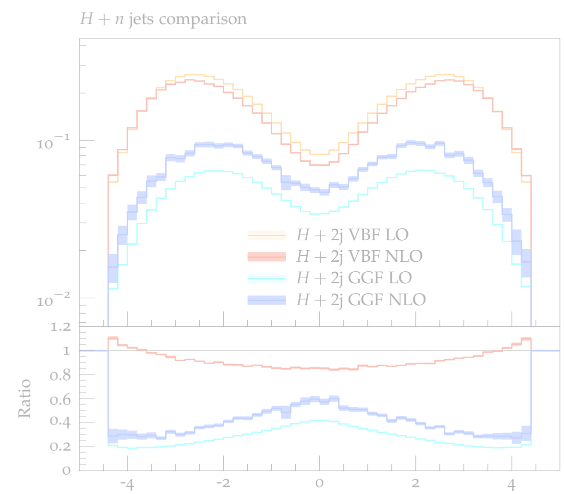


$\Delta\Phi_{jj}$

How can we separate GGF from VBF ??



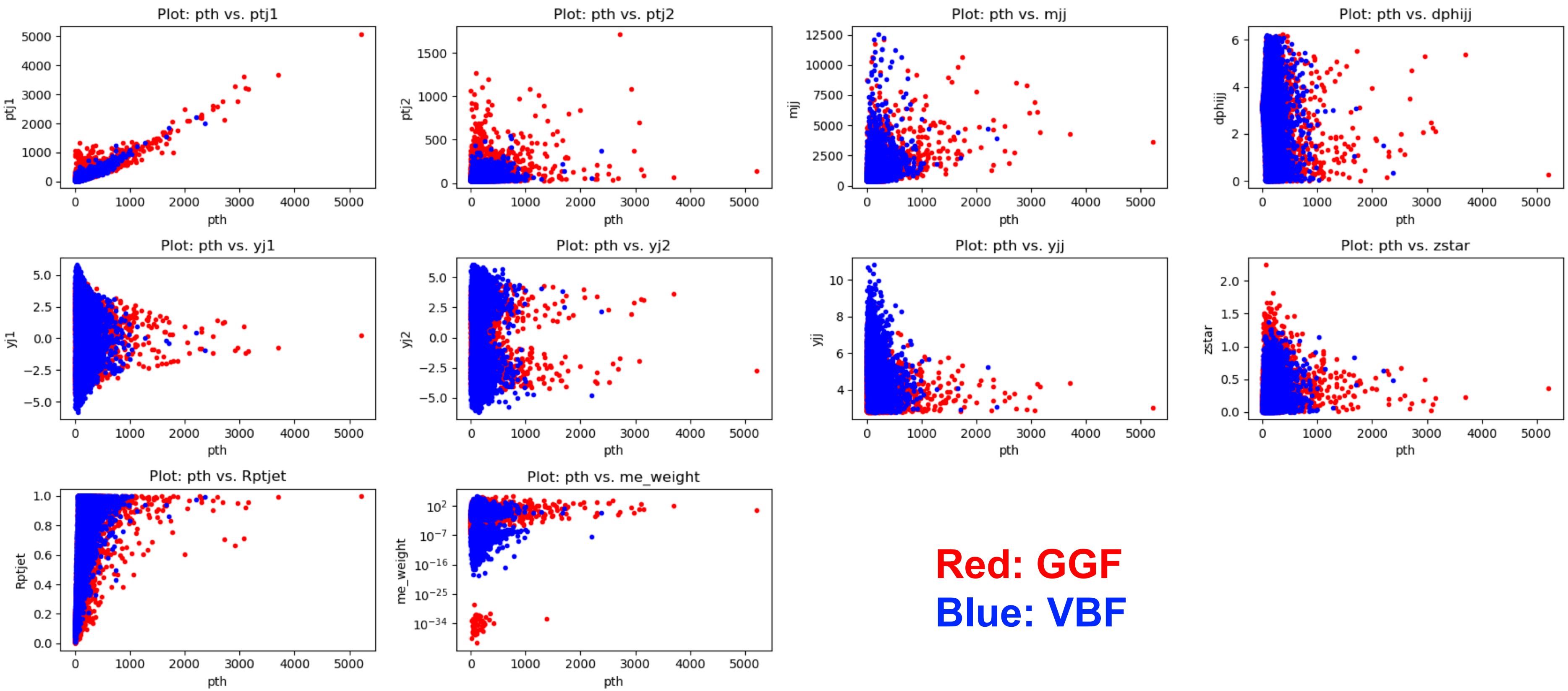
m_{jj}



y_{j1}

2-D plots for H+2j

Example: **Higgs pT** vs. other observables



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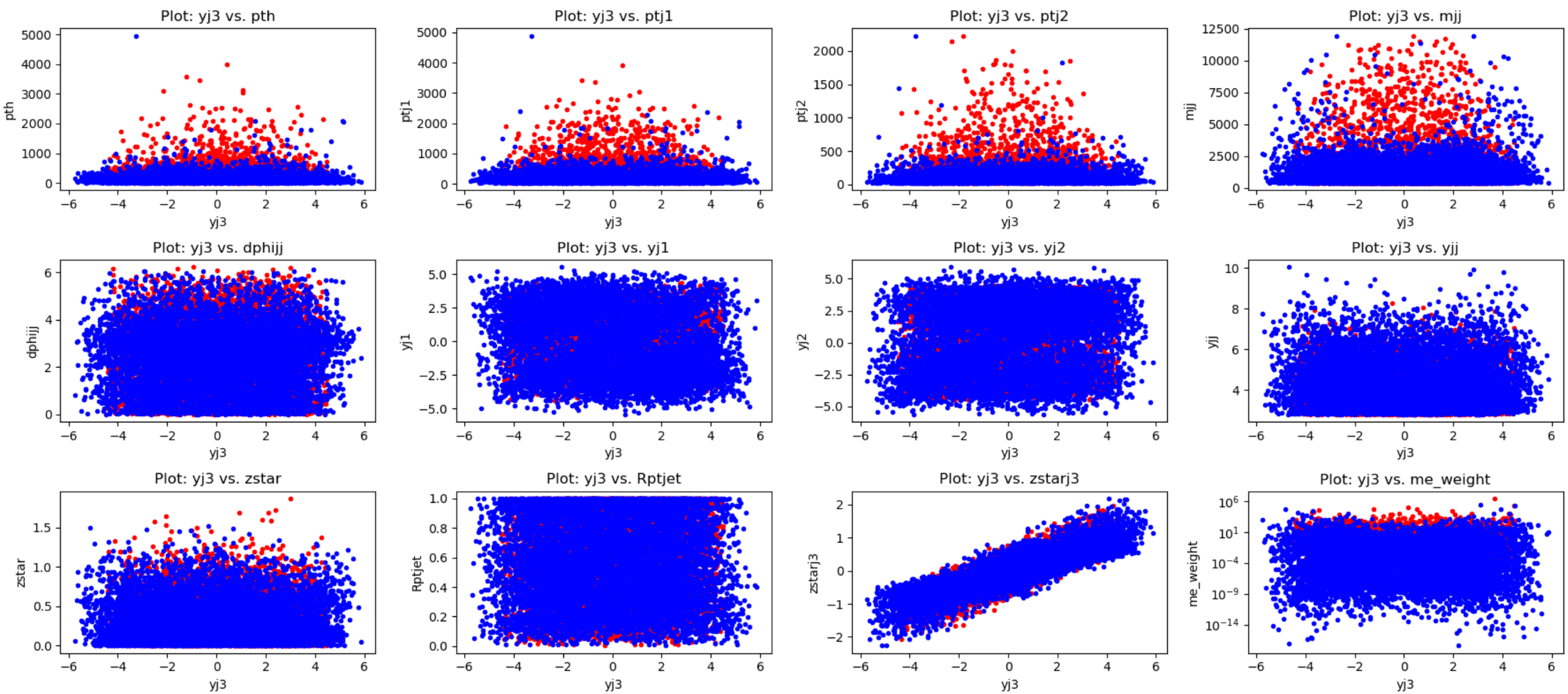
2-D plots for H+3j

Red: GGF
Blue: VBF

Example: **Rapidity of 3rd jet** vs other observables



Tensorflow

- Apply **Google's Tensorflow** machine learning algorithms to distinguish between GGF and VBF

- Use ntuples for GGF and VBF as training/ evaluation sets

- Input variables:

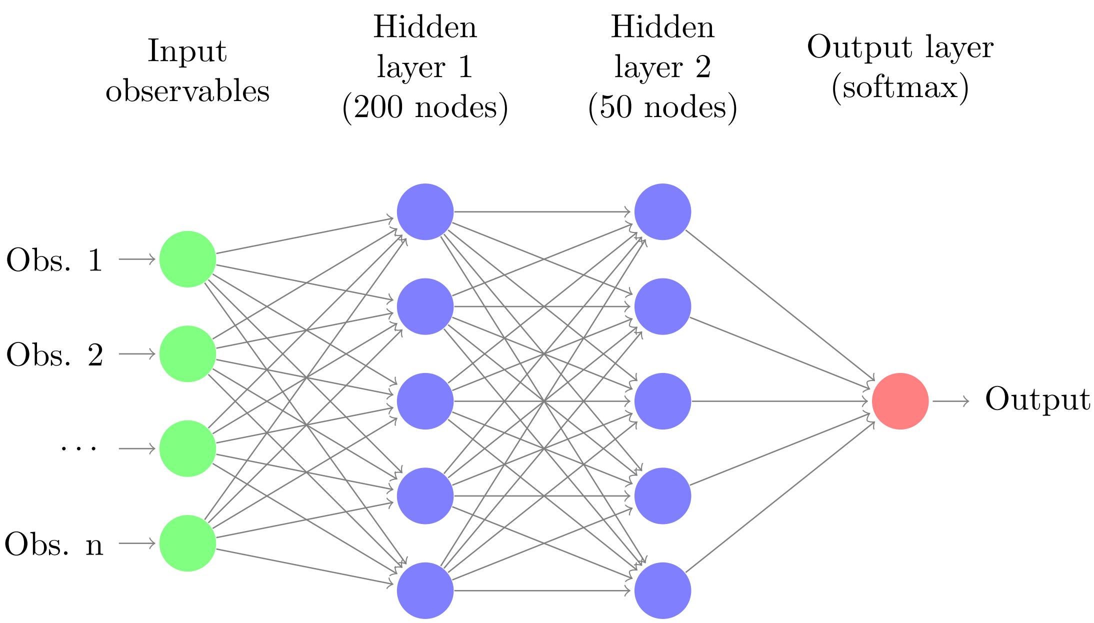
H+2: $p_{T,H}, p_{T,j1,j2}, m_{jj}, \Delta\Phi_{jj}, y_{j1,j2}, \Delta y_{jj}$

$$z^* = \frac{y_H - \left(\frac{y_{j1}+y_{j2}}{2}\right)}{\Delta y_{jj}}, \; R_{p_{T,j}} = \frac{p_{T,j1j2}}{p_{T,j1} + p_{T,j2}}, \; |\mathcal{M}|^2$$

H+3: Additionally:

$$z^*_{j3} = \frac{y_{j3} - \left(\frac{y_{j1}+y_{j2}}{2}\right)}{\Delta y_{j1,j2}}$$

Neural Net with Tensorflow



Output:

GGF: [1,0]
VBF : [0, 1]

$$\mathrm{softmax}(x)_i = \frac{\exp(x_i)}{\sum_j \exp(x_j)}$$

Normalizes result in (0,1)
-> probability

- Internal nodes: linear activation function (relu: rectified linear unit) $f(x) = x^+ = \max(0, x)$
- Adaption of grid: Adam Optimizer
- Learning rate: 0.0001
- Dropout in hidden layer 2: 0.9 (10% of nodes are not used) (increases speed and avoids overtraining)

Training and Testing of NN

- Test/training sample with ~50% GGF and ~50% VBF (approx. 16k events for each process)

- Determine **accuracy** (fraction of correct predictions) every n step by comparing NN output with test sample

- Goal: Minimize **cost function**
  Cross entropy (log-likelihood):

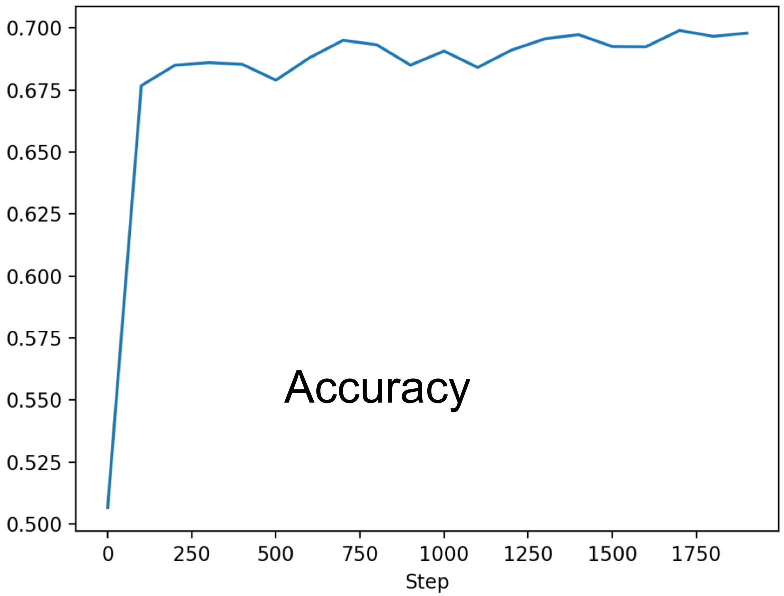
$$H(y', y) := -\frac{1}{n}\sum_{i}^{n} y'_i \ln(y_i)$$

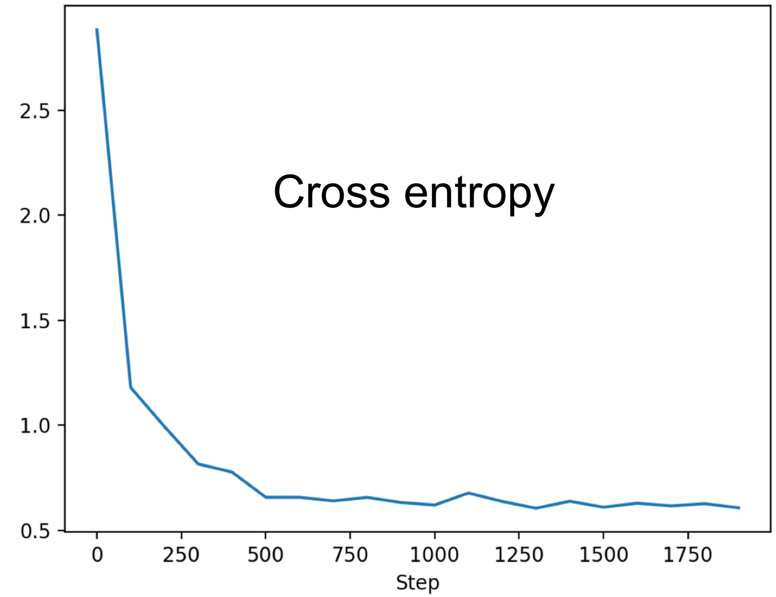
y' : test sample (real/correct)
y : NN output

- 2000 training steps to minimize cost function

- Random shuffle of input events

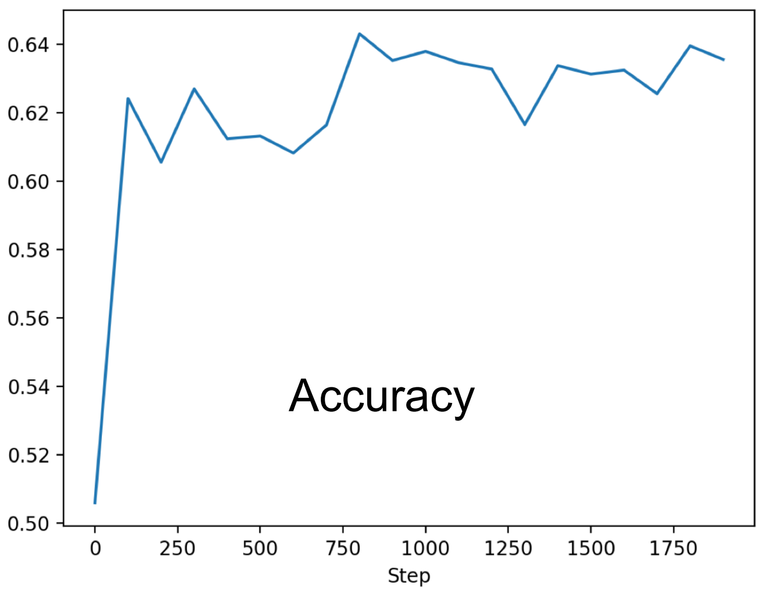
Accuracy and cost function for H+2

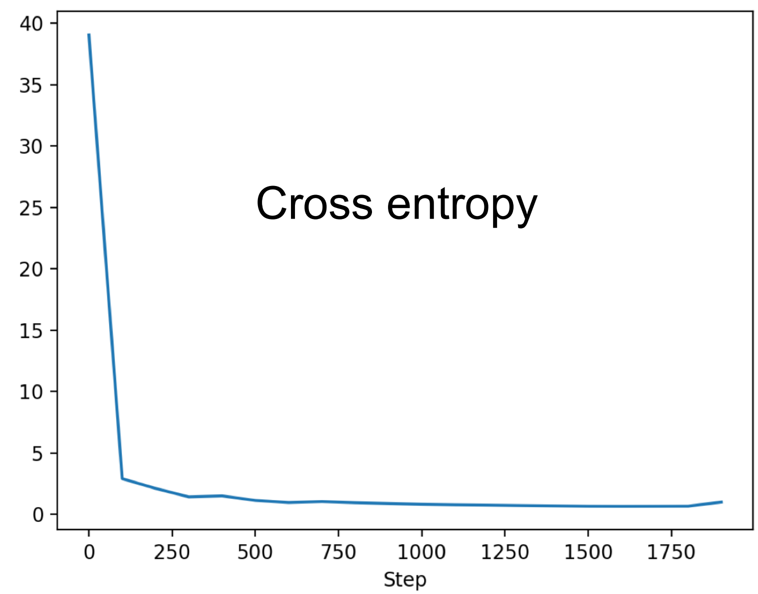




- Accuracy reaches ~70 % for H+2j
- **Note:** Accuracy highly dependent on composition of event sample (fraction of GGF vs VBF)

Accuracy and cost function for H+3

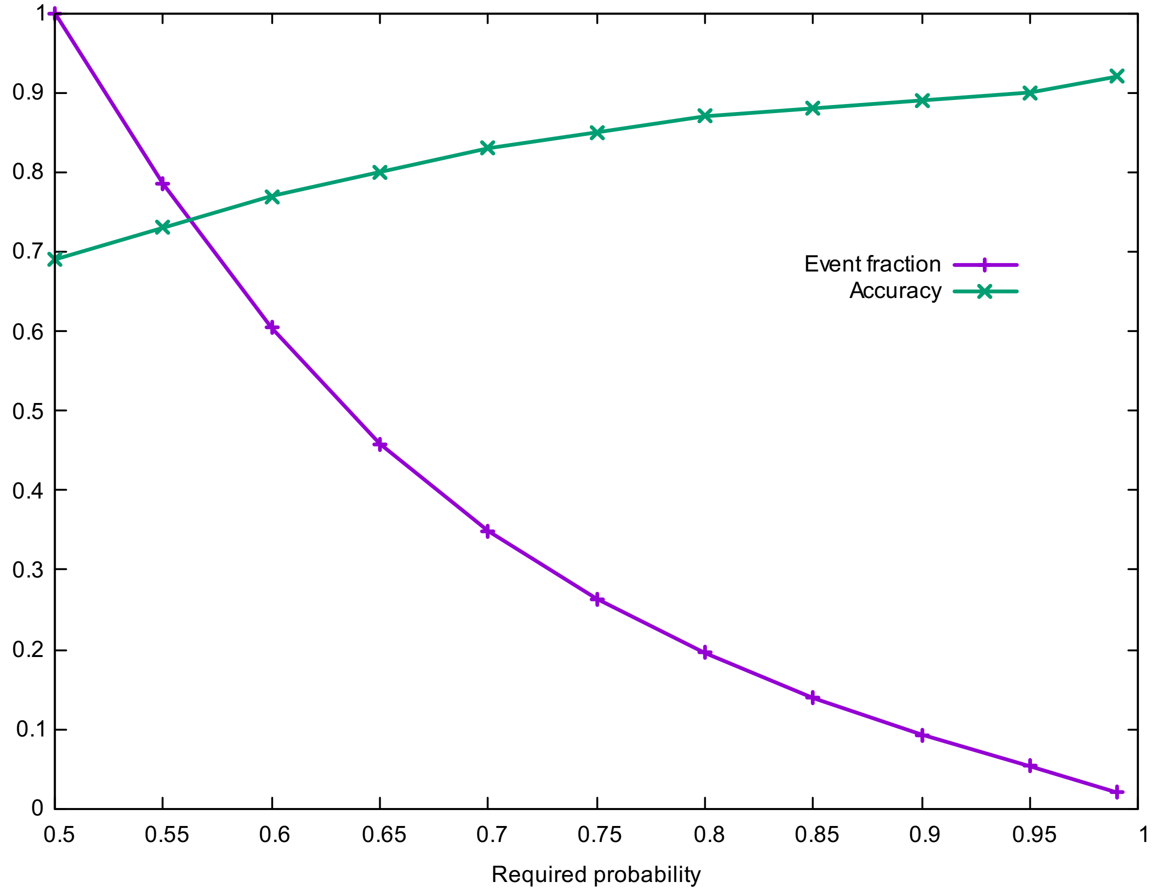




- Accuracy slightly worse than for H+2, ~65%
- In general (H+2/3): Results largely independent on technical details of the NN and on several input parameters

Cut on confidence

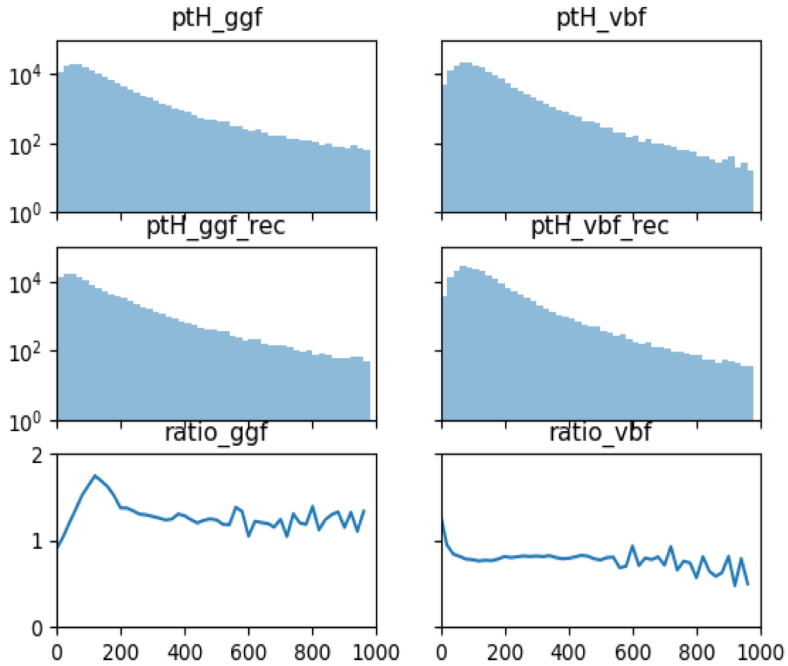
- Output of NN can be interpreted as confidence, how sure the NN is in its decision: [0.49, 0.51] vs [0.99, 0.01]
  -> Investigate cut on confidence level



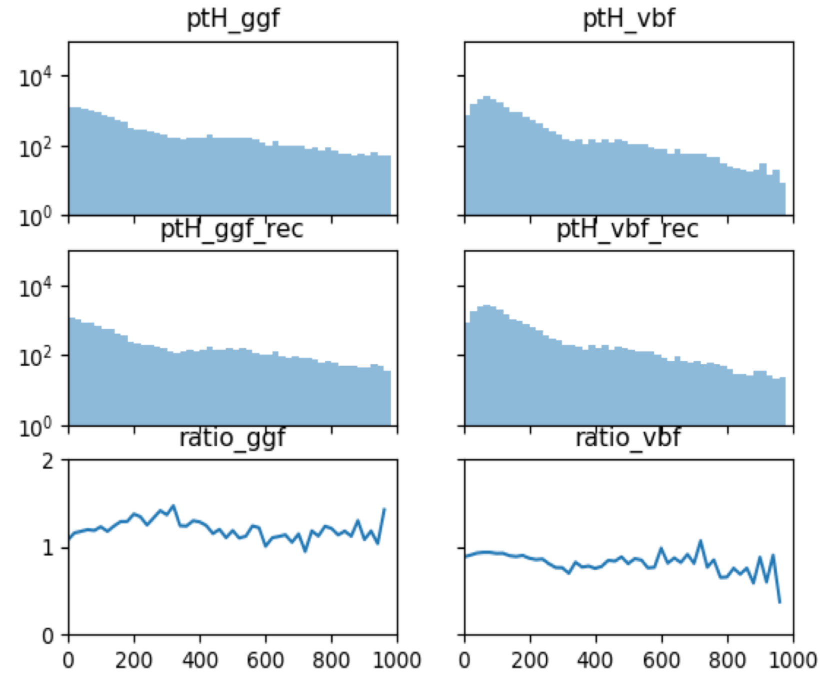
Reconstructing differential distributions

- Mix GGF and VBF and let the NN reconstruct the distributions
- For confidence levels of 0.5 (left) and 0.9 (right) for H+2

Higgs pT



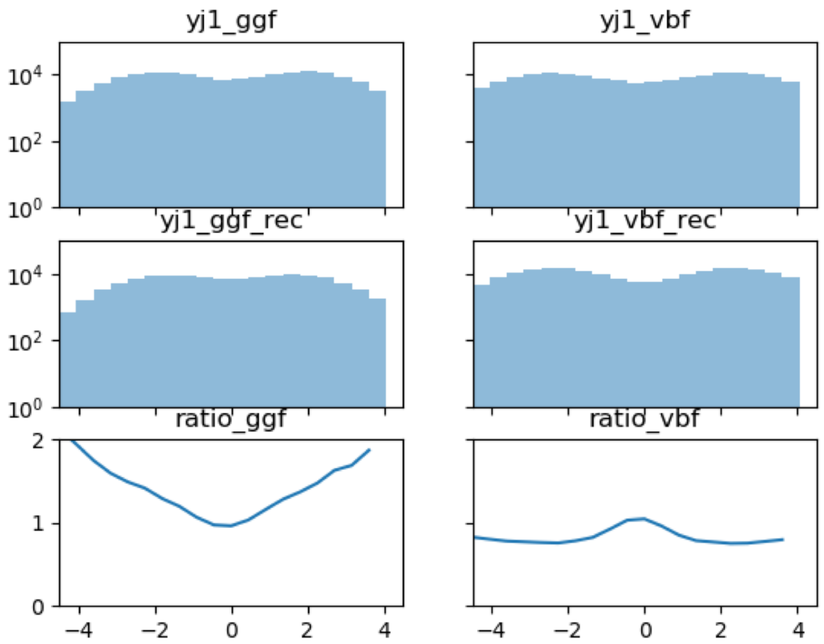
$p > 0.5$

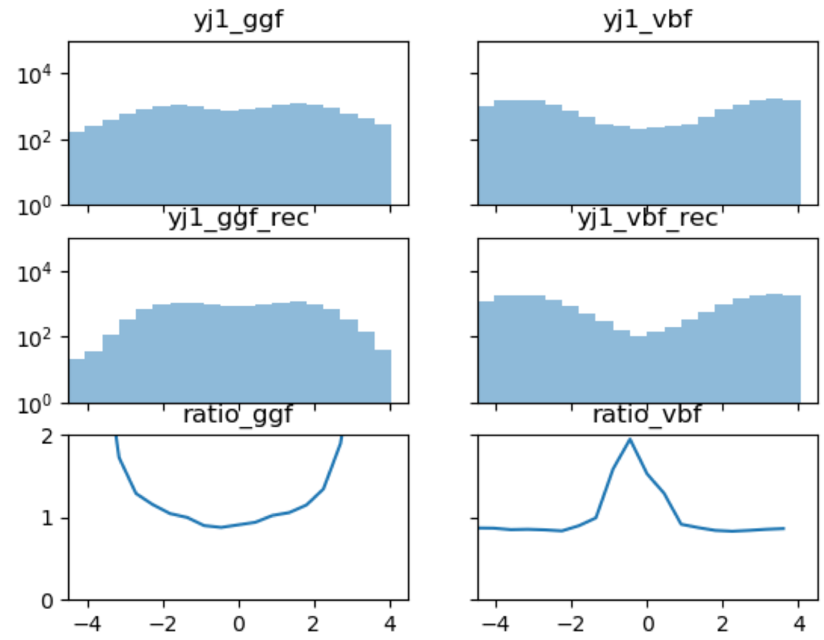


$p > 0.9$

Reconstructing differential distributions

Rapidity of 1st jet





-> Reconstruction different for various observables

Conclusions and Outlook

- Objective: Trying to separate GGF and VBF in the best possible way
- Use ntuples as input and feed them into NN (classification problem)
- What/ how much is a good accuracy ?
- Use weighted cross entropy (GGF classified as VBF gets higher weight): Effect seems to be marginal
- Usefulness of partonic events ?
- Possible development: Change input variables from observables to ‘detector pixels’
  Advantage: Input variables independent of number of particles (also showered events possible)