Higgs to WW - From Peter Higgs to Deep Learning and Histogram Rebinning

Benjamin Jäger

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SFU
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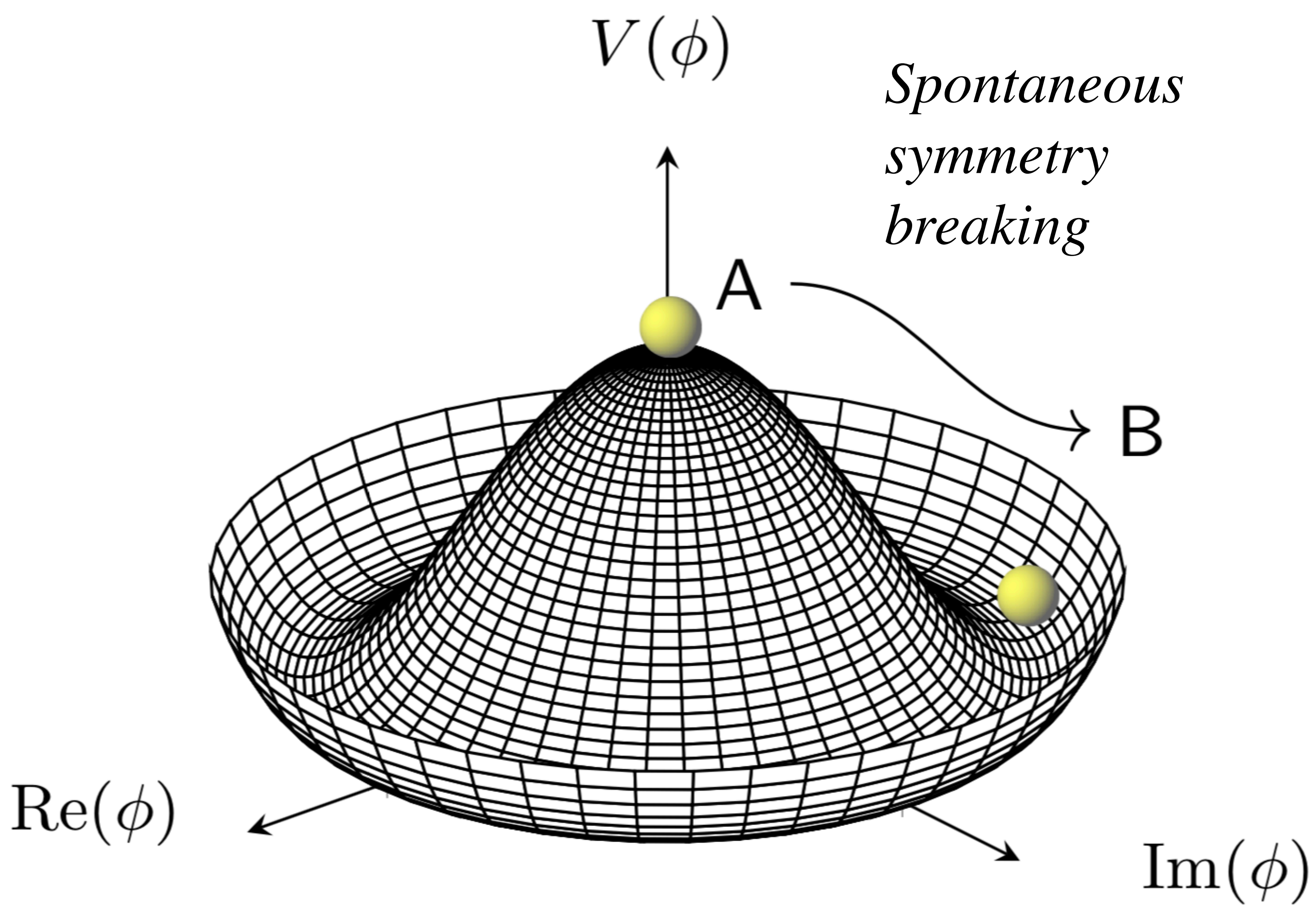
ATLAS EXPERIMENT

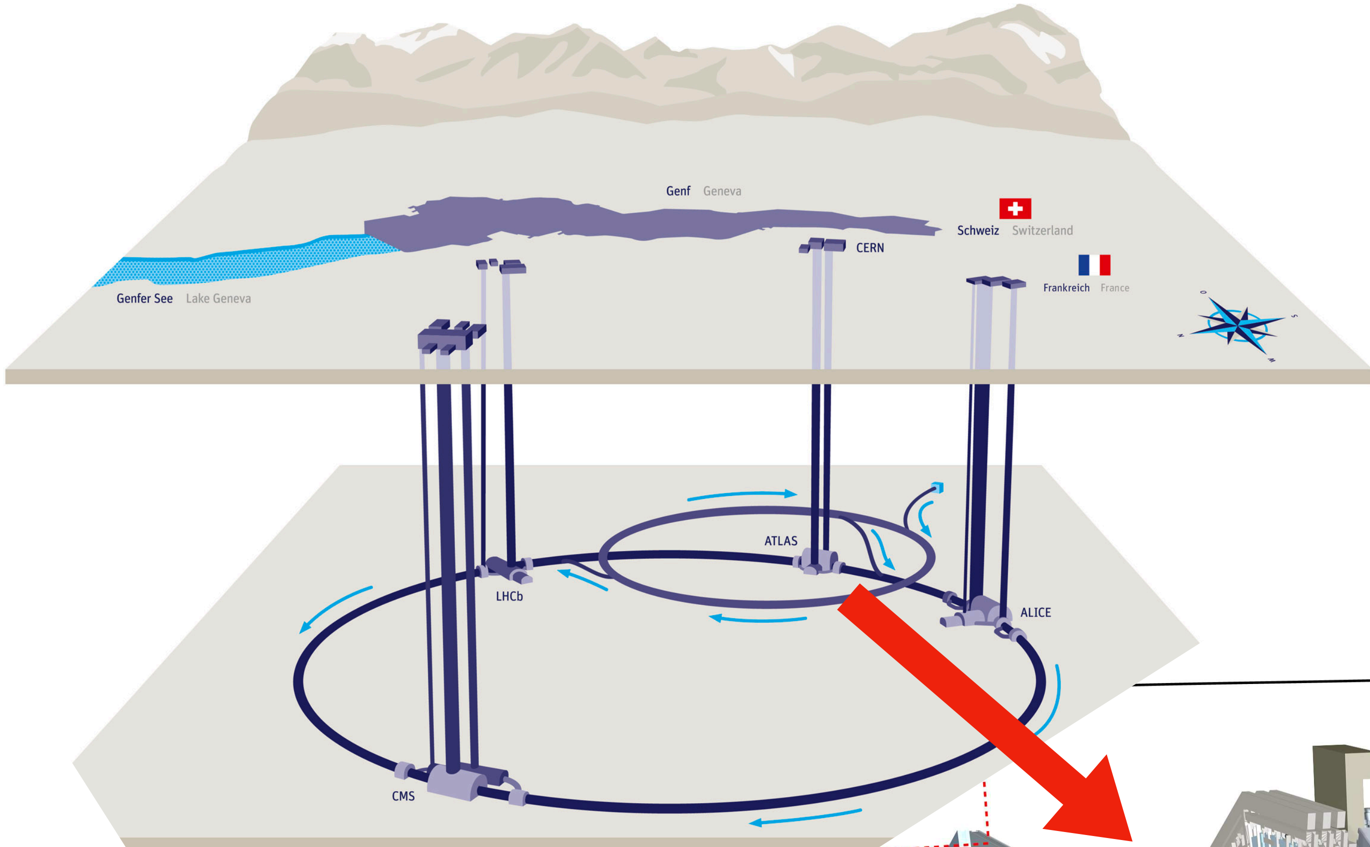
The Higgs-boson story (in a tiny nutshell)

- Problem: No explanation of boson masses in theory
- 1964: Brout-Englert-**Higgs** mechanism with prediction of new particle

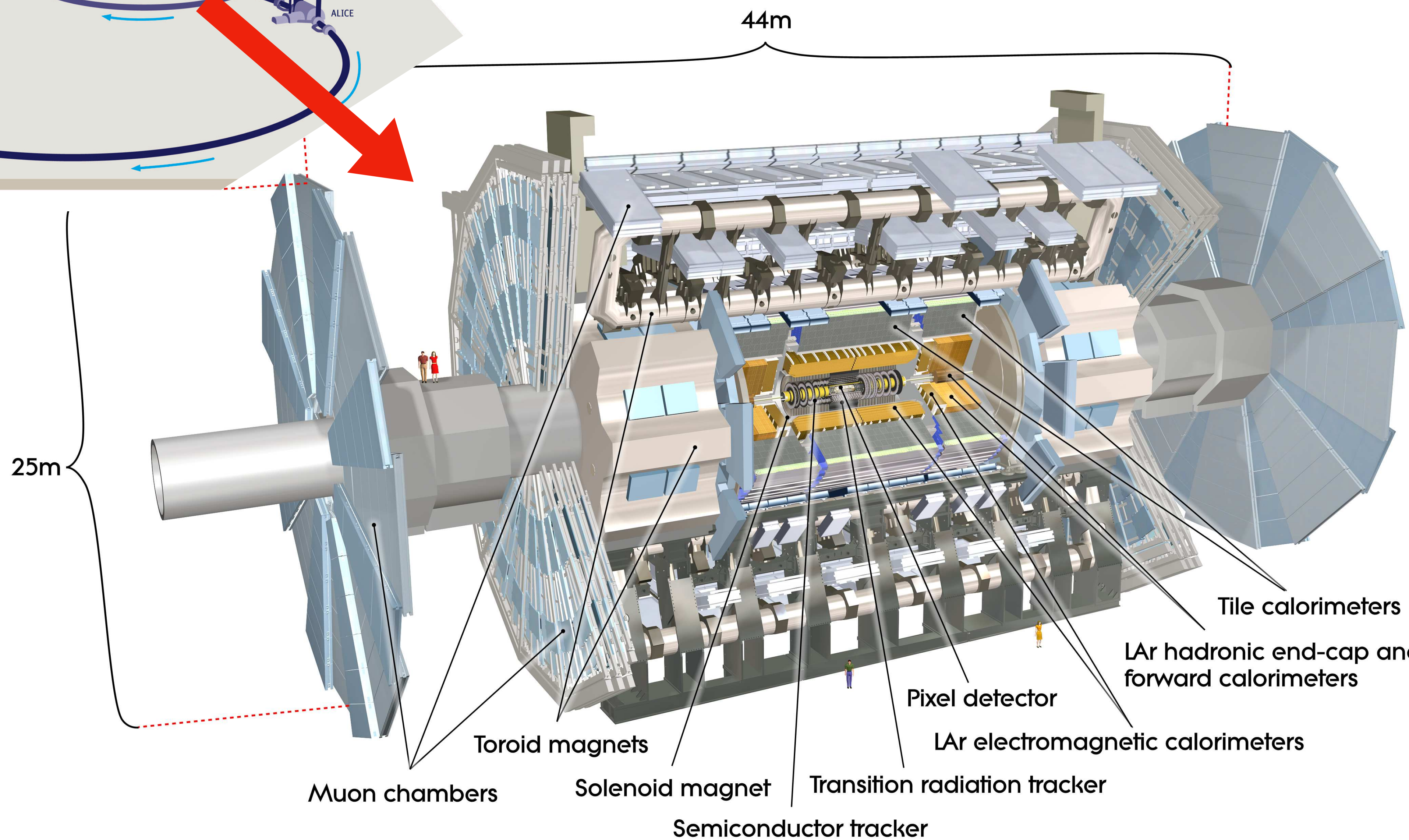


- 2012: Experimental **discovery** of Higgs boson by ATLAS and CMS collaborations at the LHC

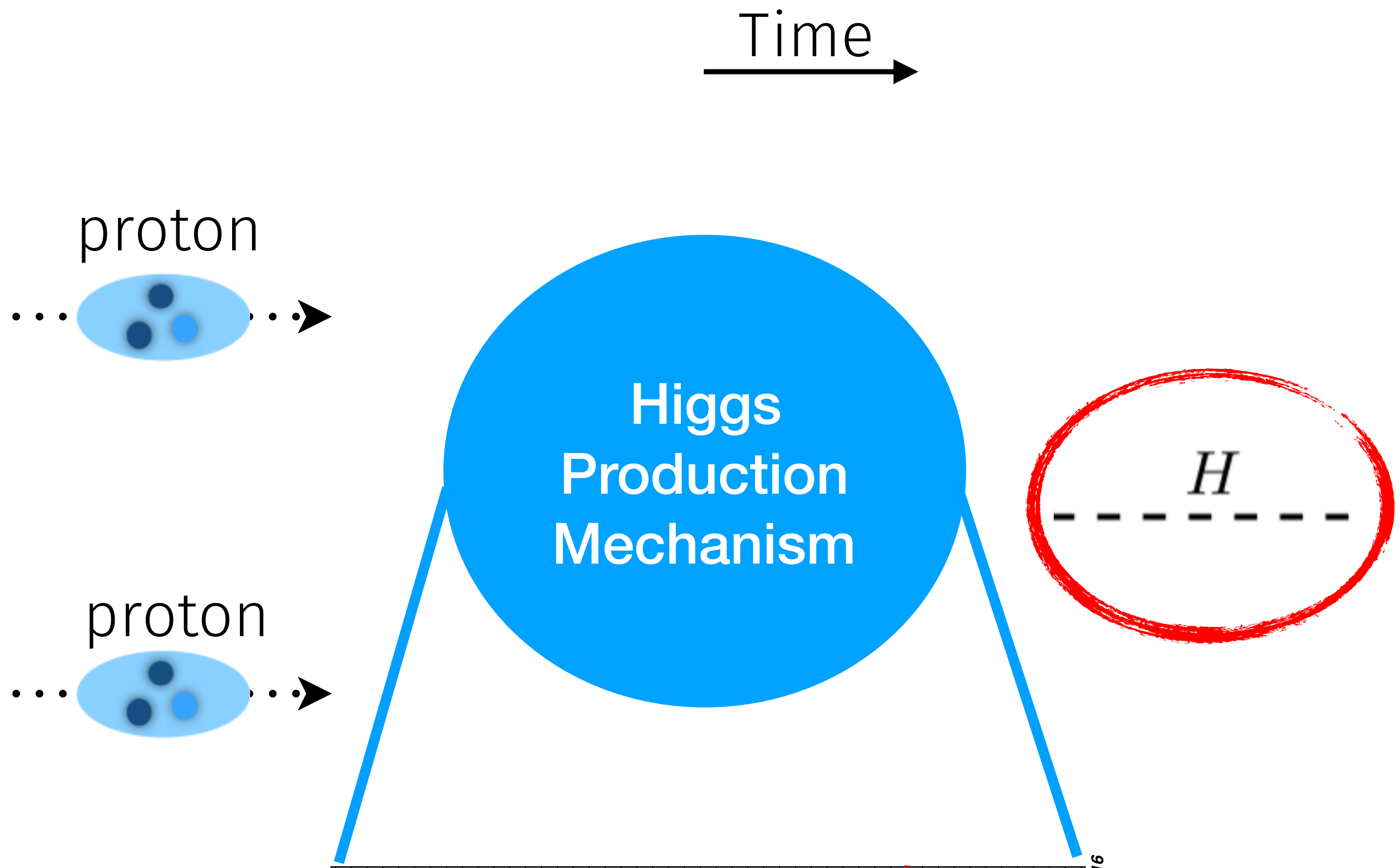
The LHC and the ATLAS Experiment

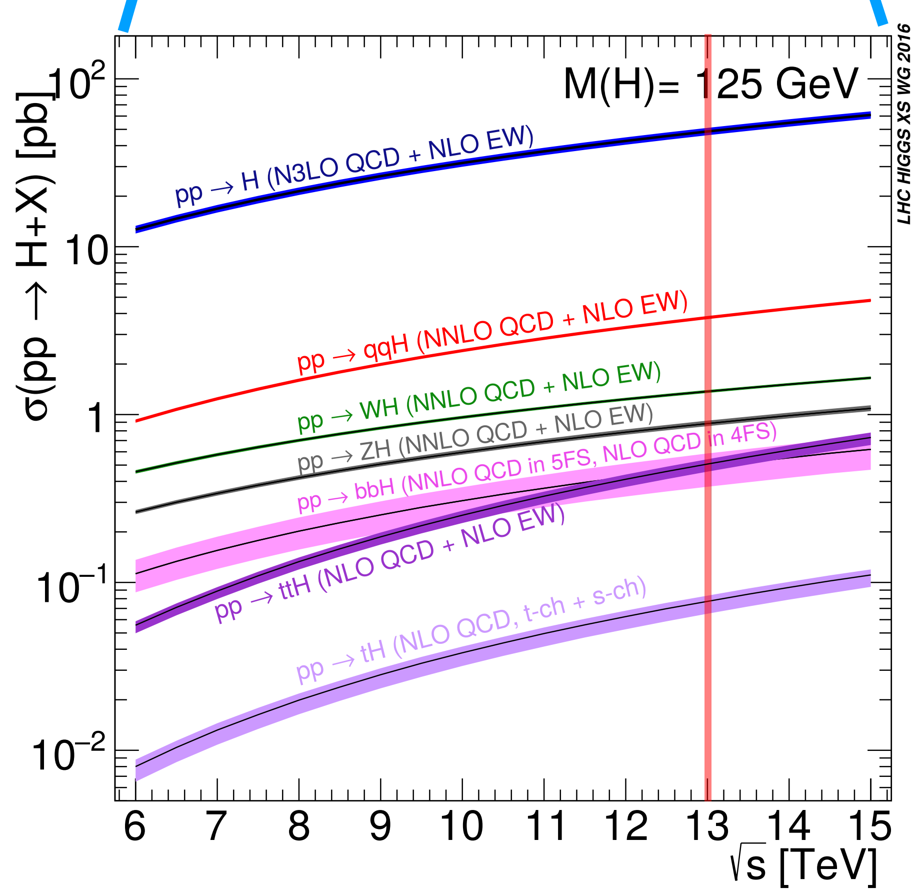


- LHC provides high-energy proton-proton collisions
- Detected by different detectors e.g. the ATLAS experiment



The VBF Higgs to WW Process





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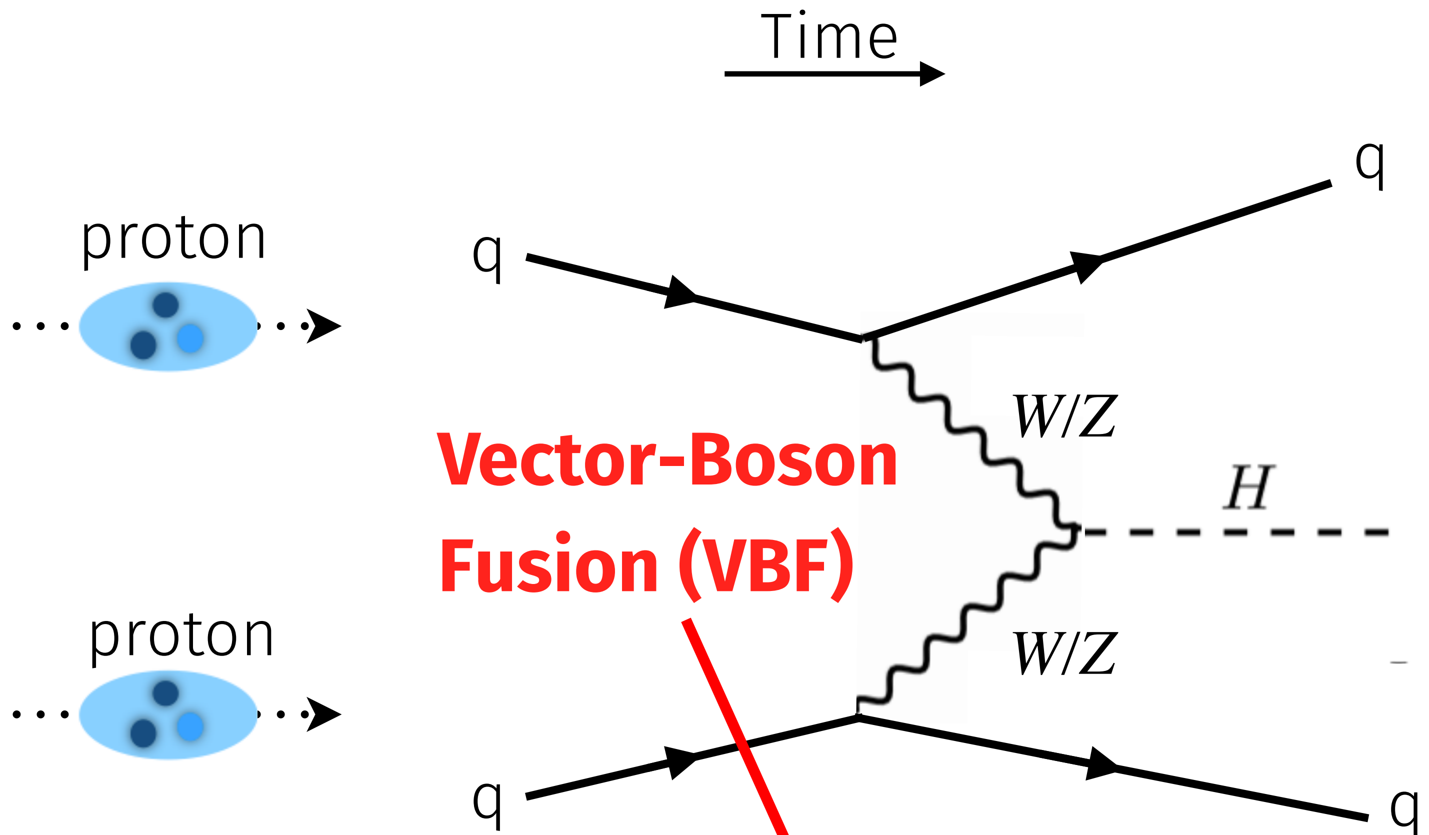

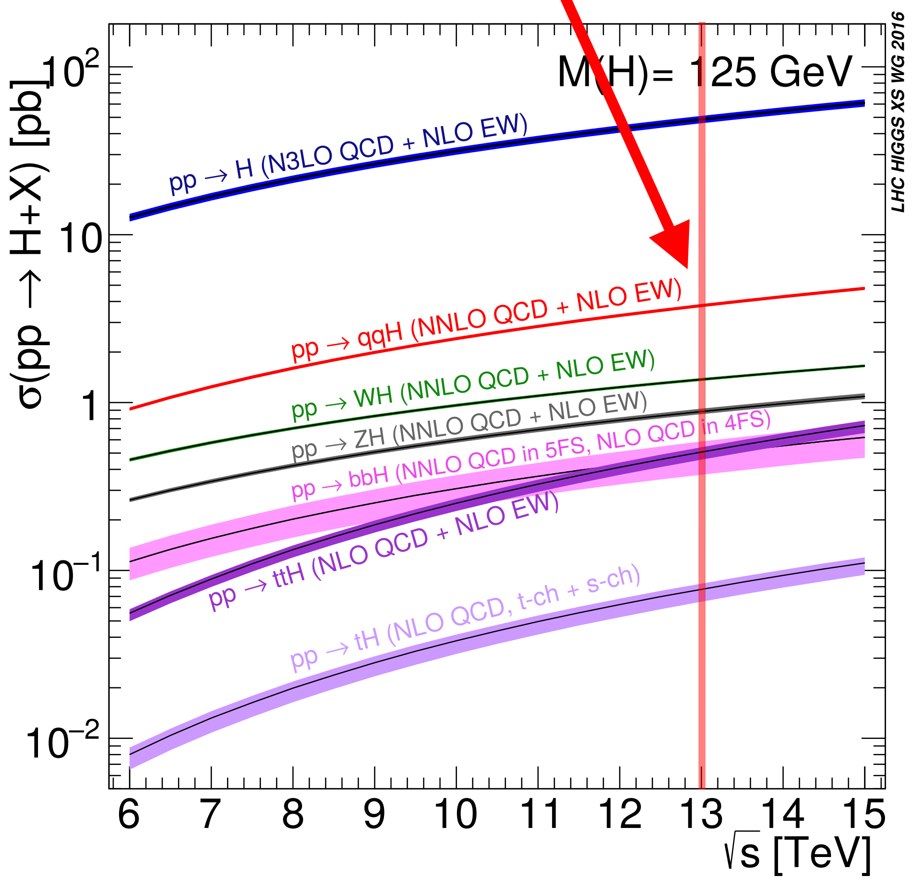

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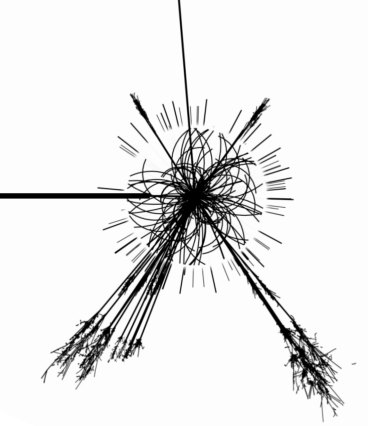

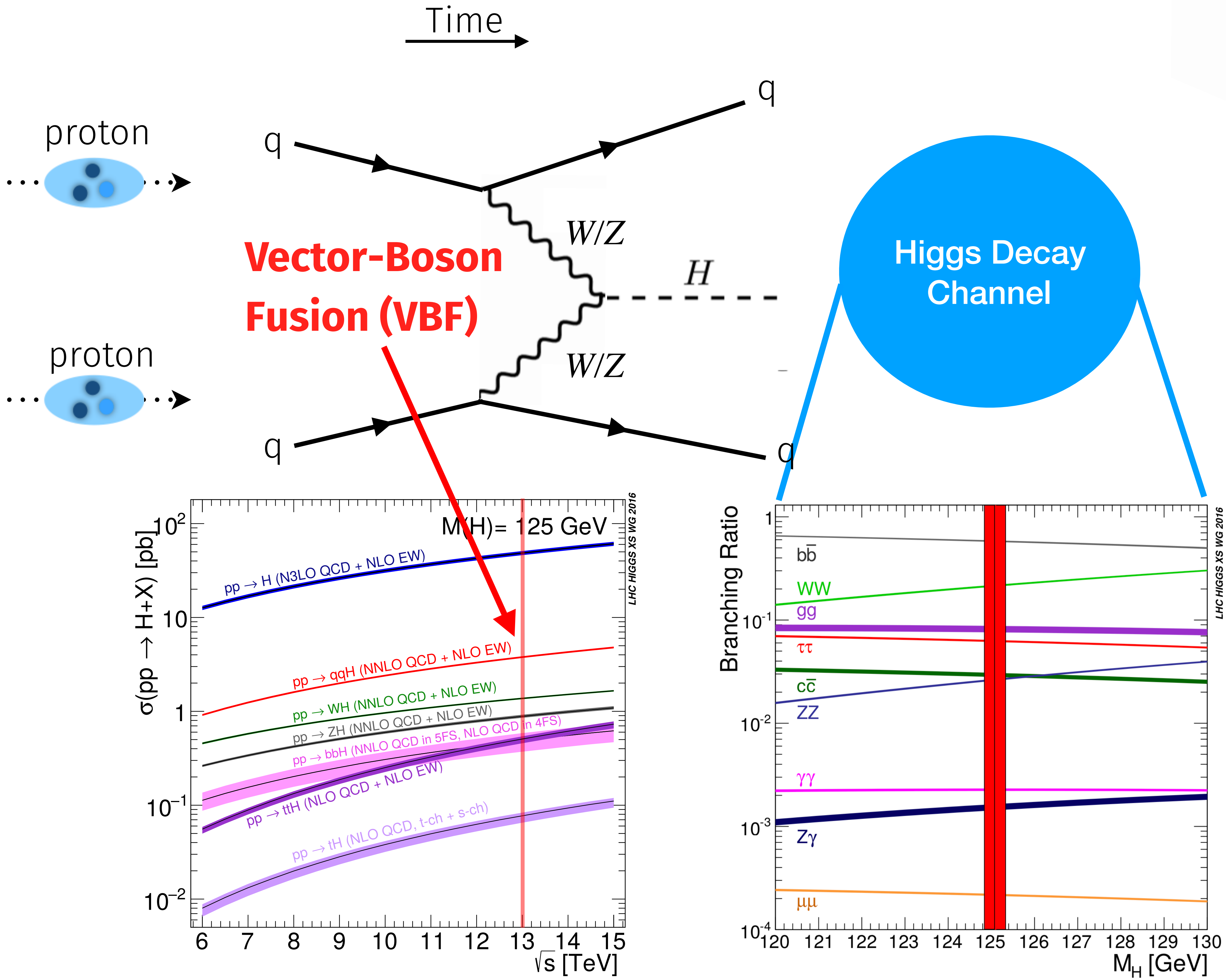

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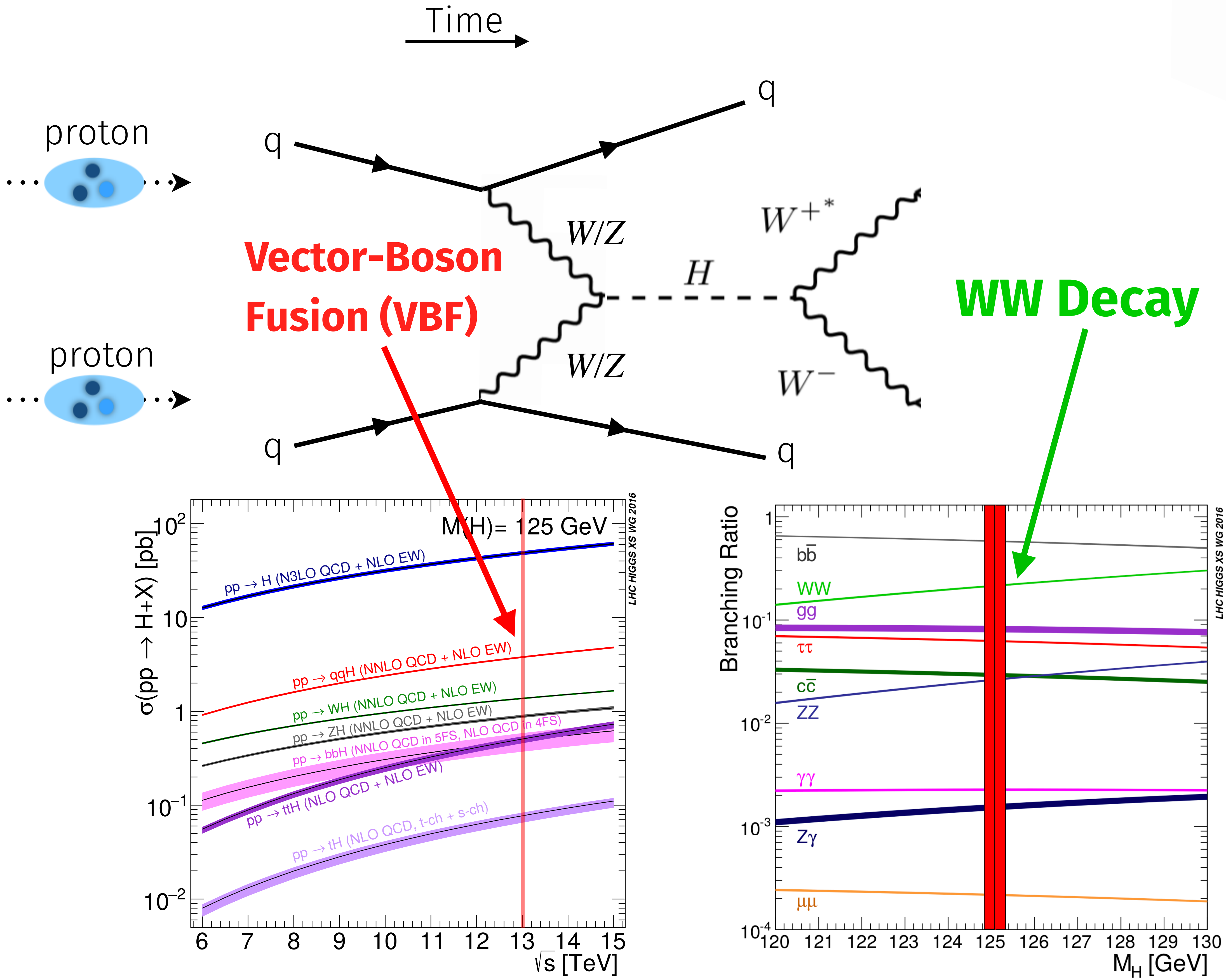

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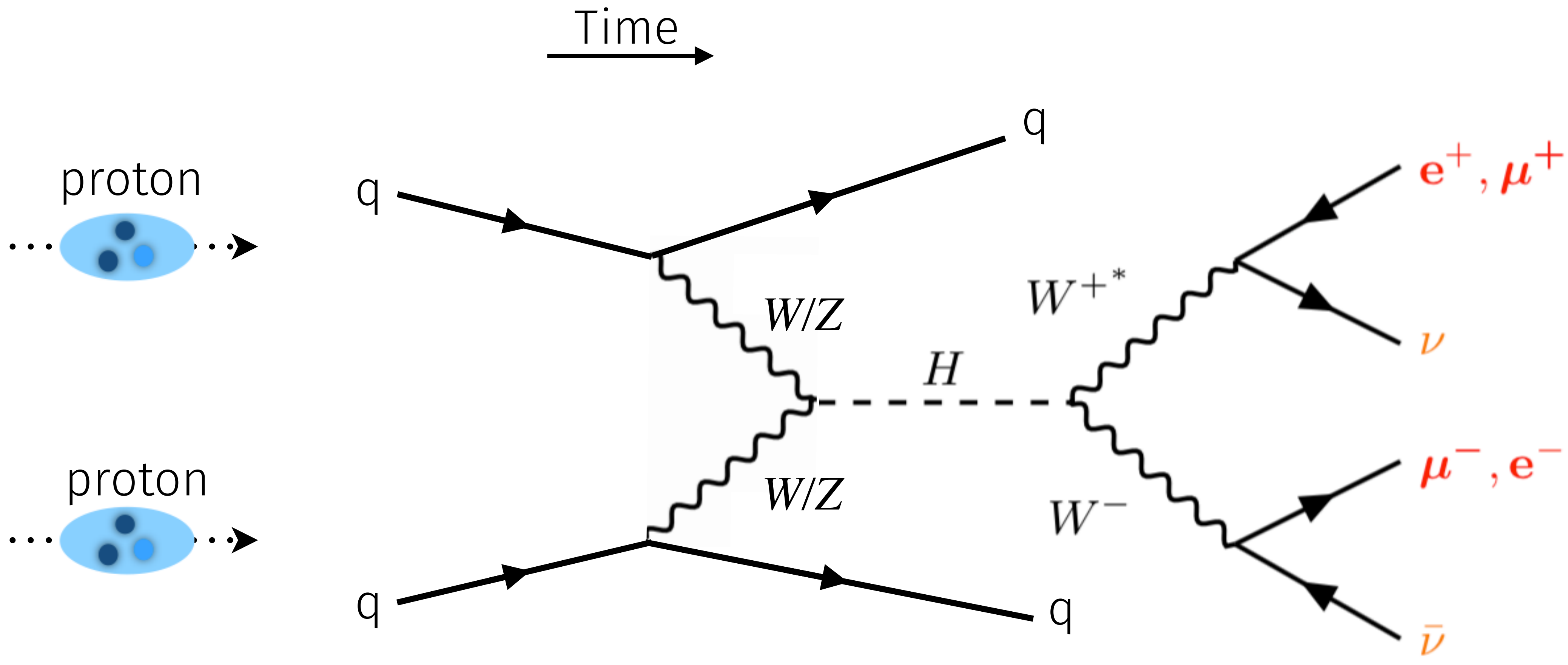
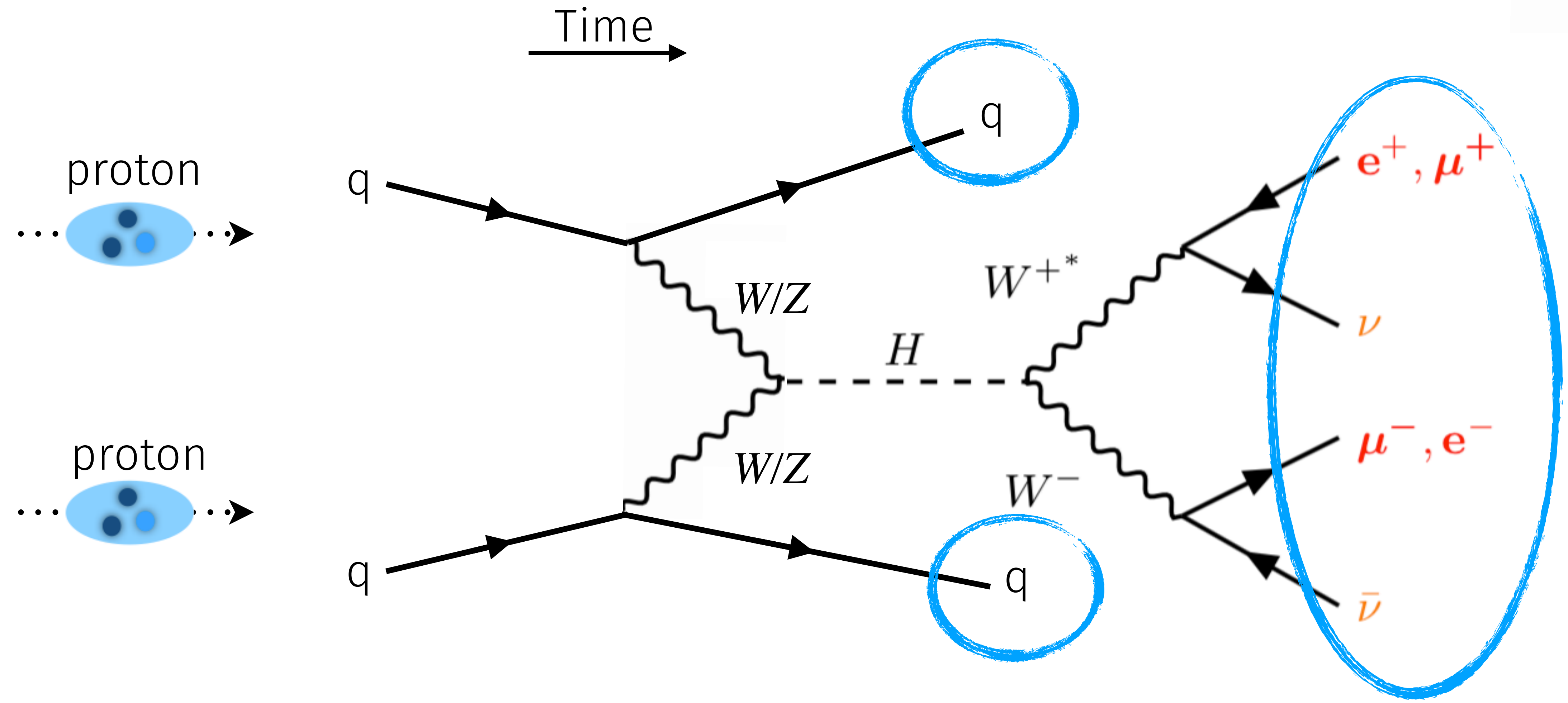


The VBF Higgs to WW Process



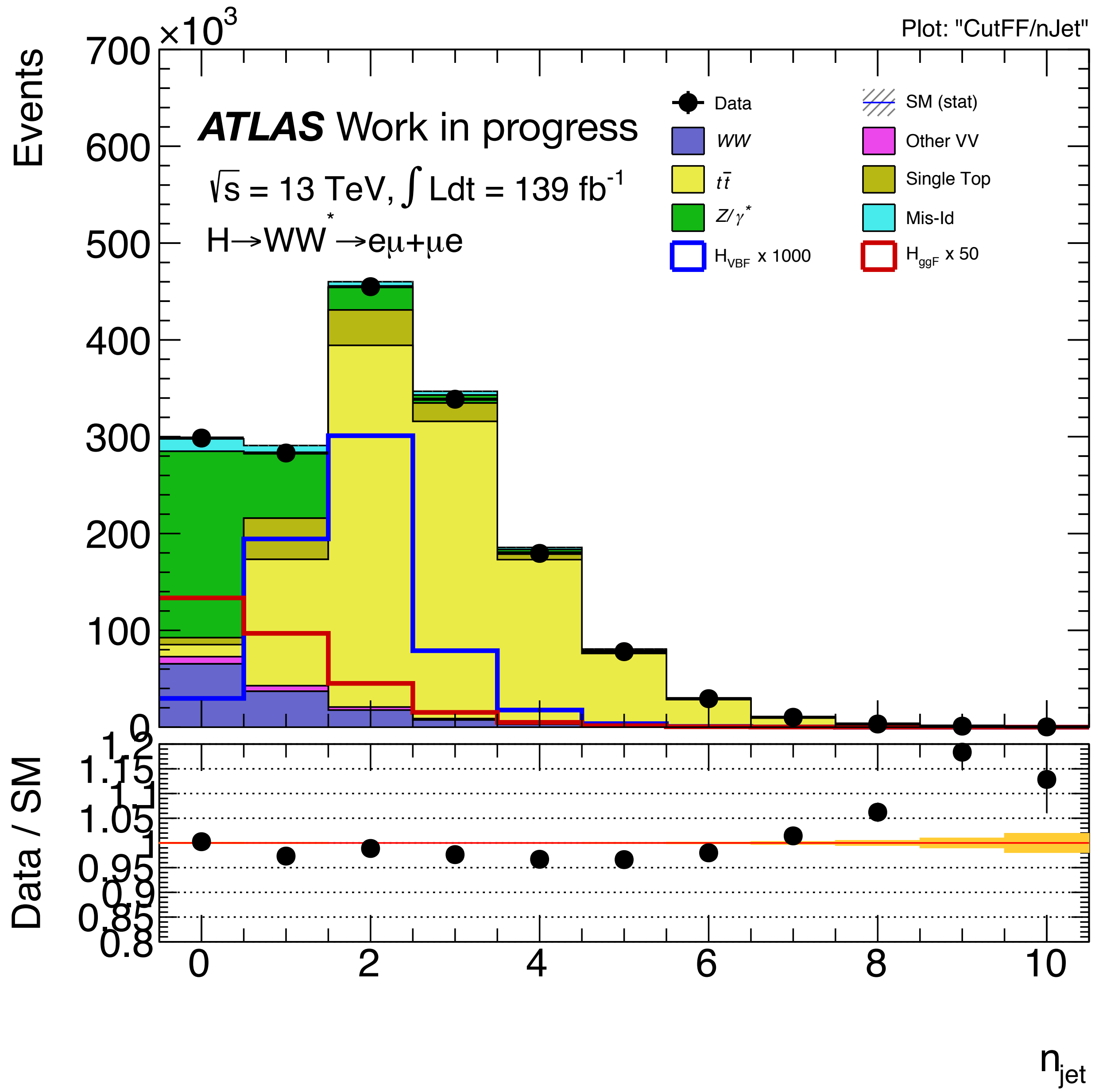
Drop same flavour channel due to overwhelming background

Analyzed final state has...

- 2 jets (from quarks) in the forward region of the detector
- Two neutrinos
- Two isolated, oppositely charged, *different flavour* leptons

Contributing Backgrounds

- Several other types of processes that mimic the Higgs signature (a nuisance!)

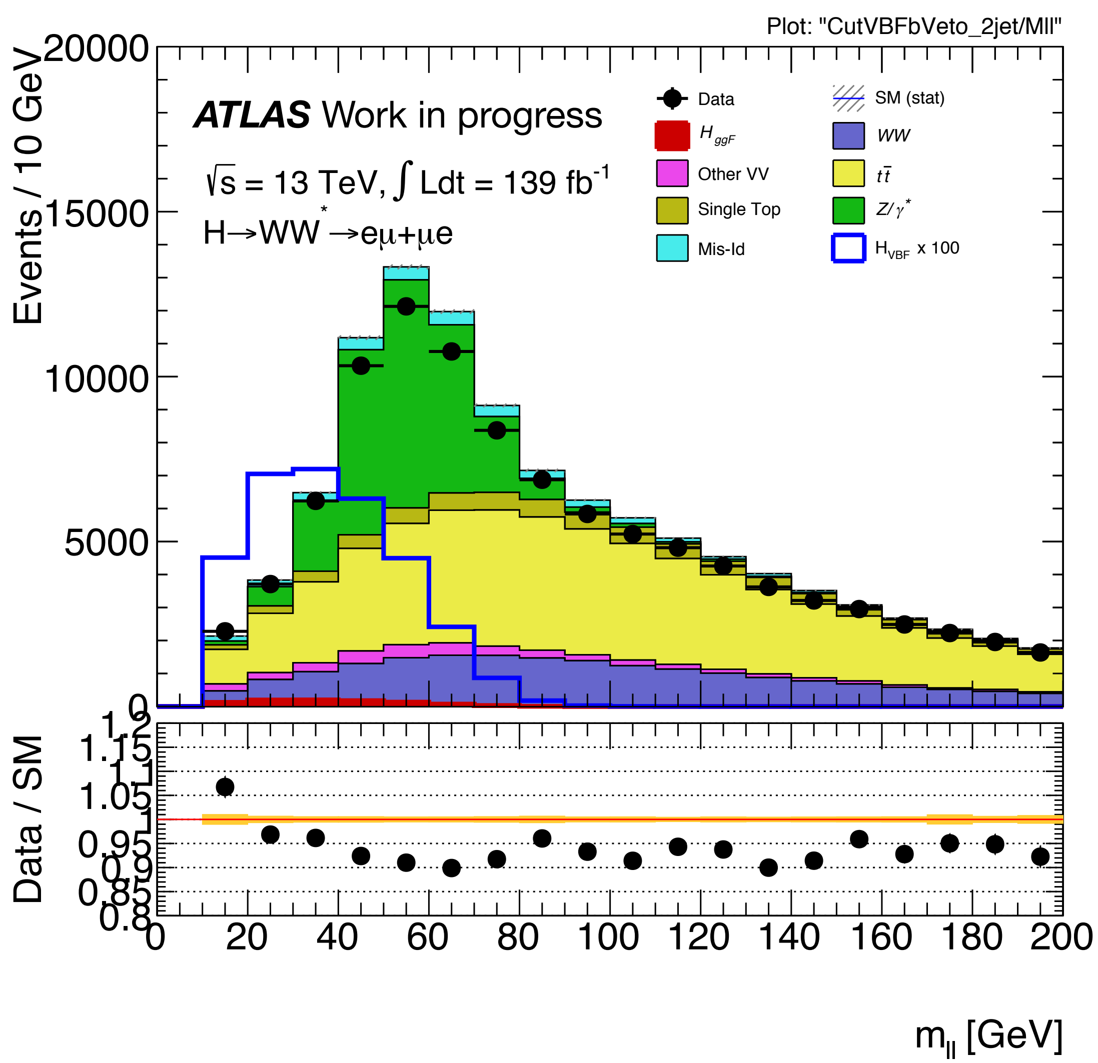


- Need to select a region (**kinematic**/**topological** selections) that is as pure in Higgs events as possible
- Suitable task for a **neural network** to classify events

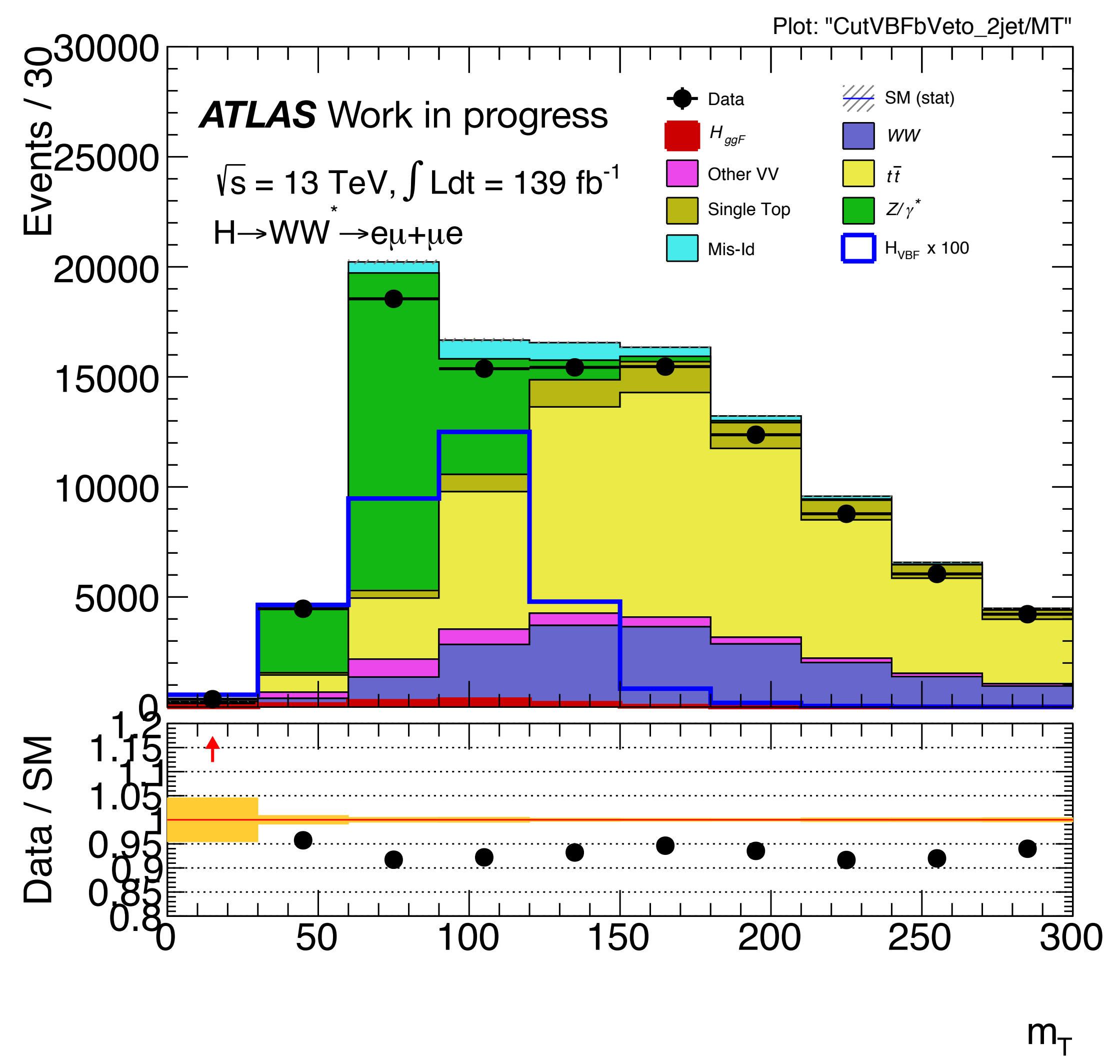
Train a Deep Neural Network for Event Classification (1)

- **15 input variables** used in the training

- Mass of the lepton system

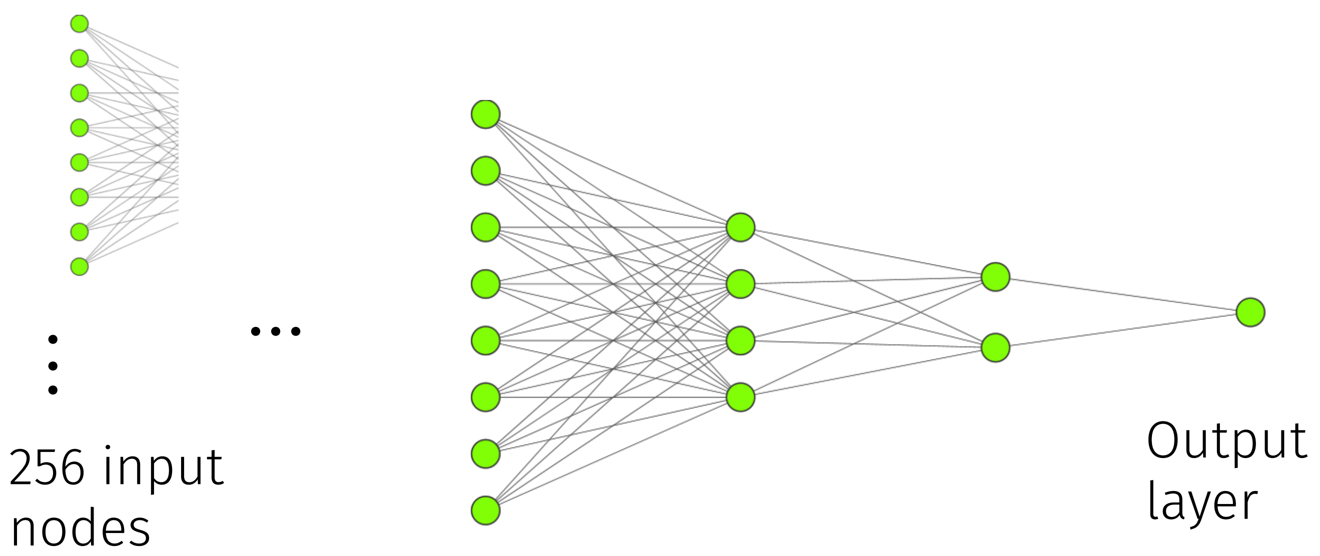


- Transverse mass of the whole system

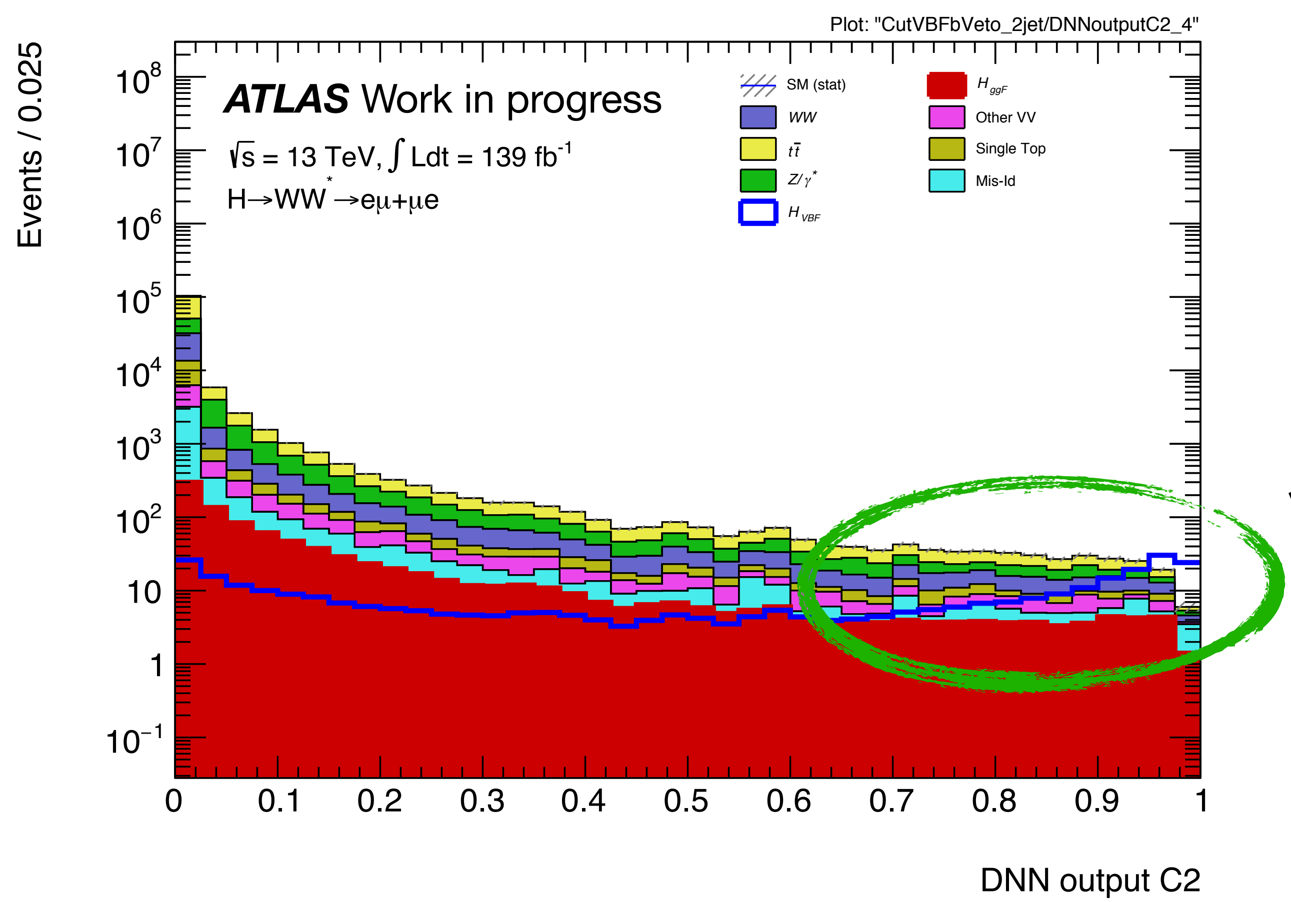


Train a Deep Neural Network for Event Classification (2)

- **New “deep” network architecture (8 layers)**



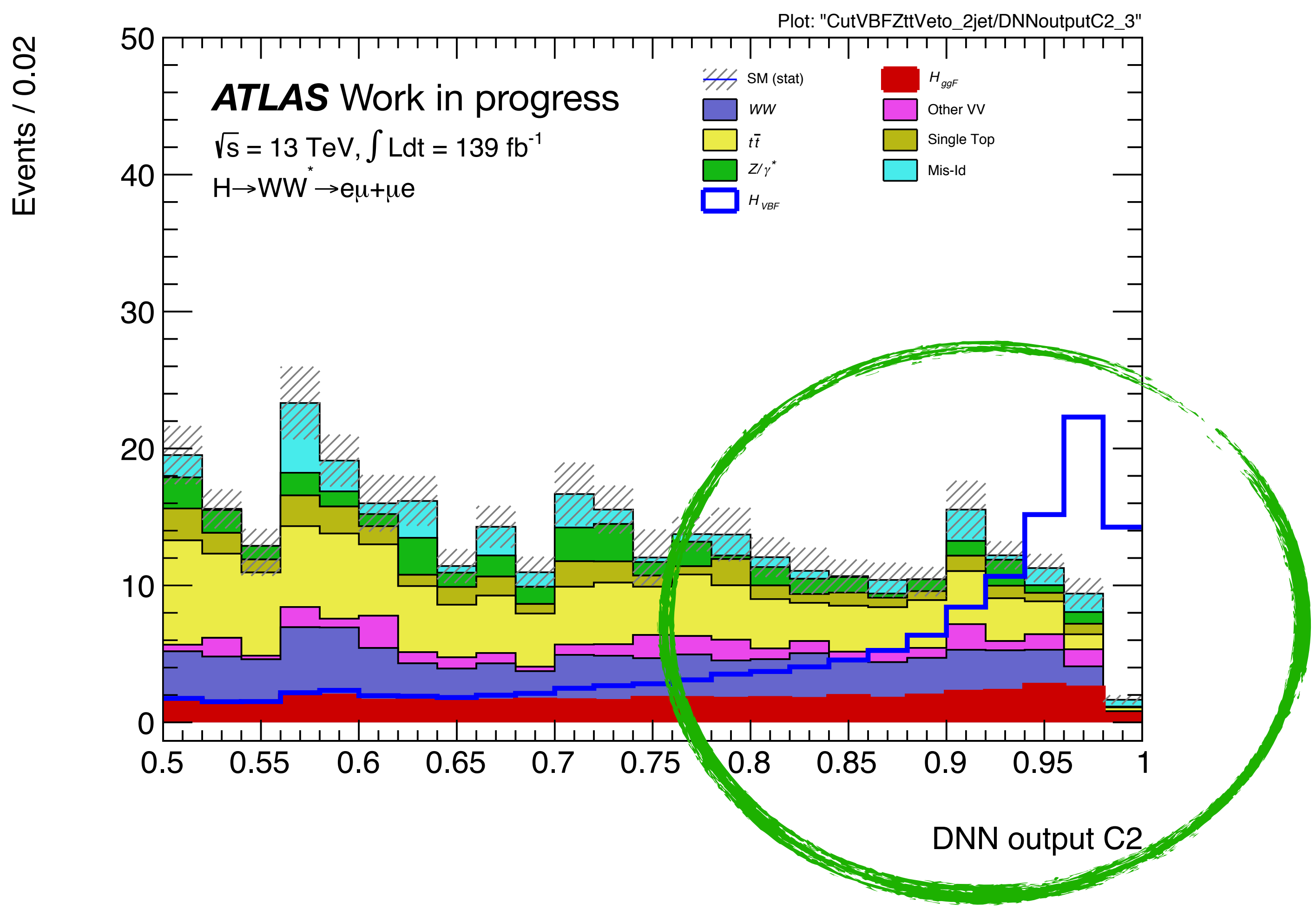
- **DNN output distribution**



Signal sensitive region

... let’s zoom in

Output of Neural Network



- How to estimate the performance of the DNN classifier?
- Simple estimators for the expected discovery significance can be used:

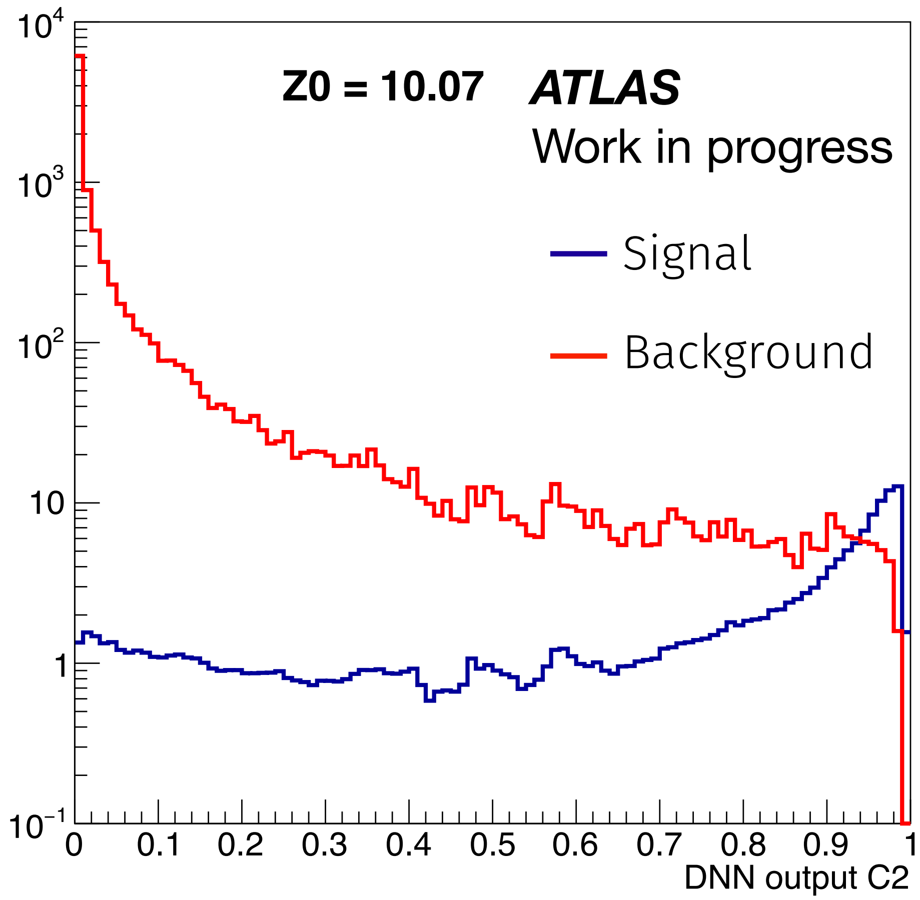
$$Z = \frac{s}{\sqrt{b}}$$

$$Z = \begin{cases} +\sqrt{2\left(n\ln\left[\frac{n(b+\sigma^2)}{b^2+n\sigma^2}\right] - \frac{b^2}{\sigma^2}\ln\left[1+\frac{\sigma^2(n-b)}{b(b+\sigma^2)}\right]\right)} & \text{if } n \geqslant b \\ -\sqrt{2\left(n\ln\left[\frac{n(b+\sigma^2)}{b^2+n\sigma^2}\right] - \frac{b^2}{\sigma^2}\ln\left[1+\frac{\sigma^2(n-b)}{b(b+\sigma^2)}\right]\right)} & \text{if } n < b. \end{cases}$$

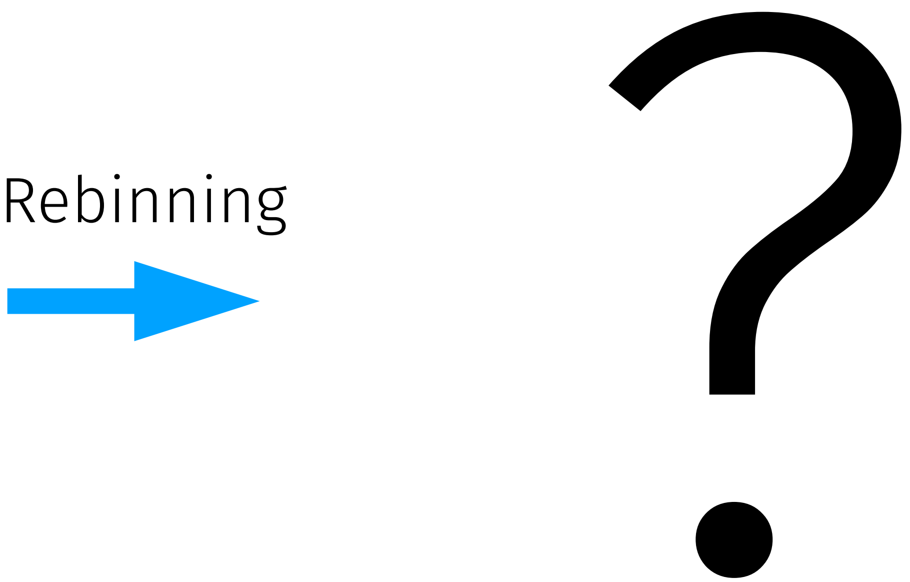
- Bins are statistically independent so add them in quadrature: $Z = \sum_i {z_{\text{bin }i}}^2$

Binning Optimization Strategies

- For a stable statistical analysis, we need to reduce the number of bins
- Goal is to **exploit the shape** as well as possible
- In general: choose **as many bins as possible** with given statistics and uncertainties

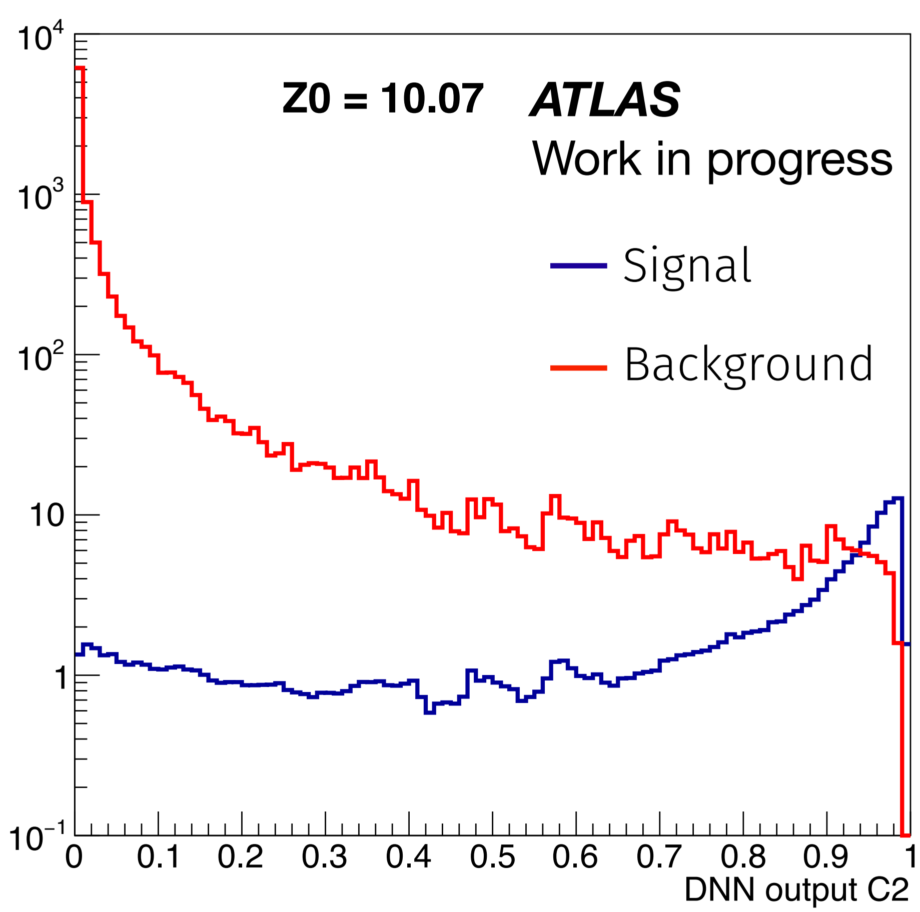


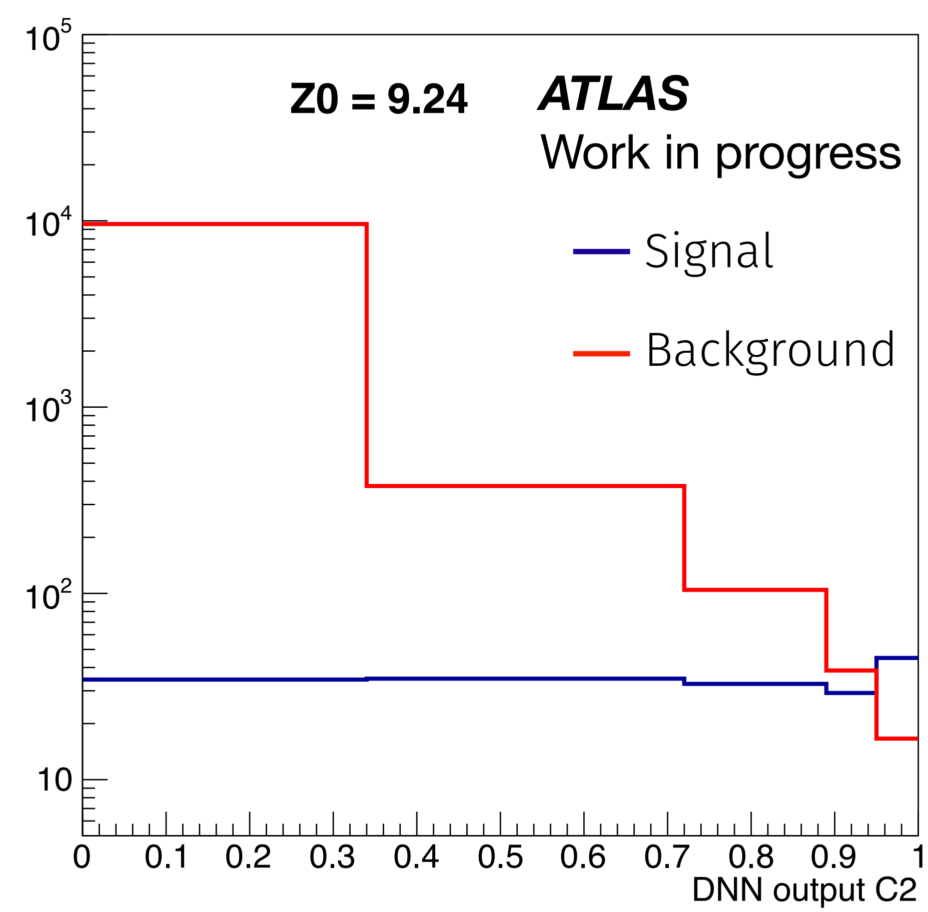
Rebinning



Binning Optimization Method 1

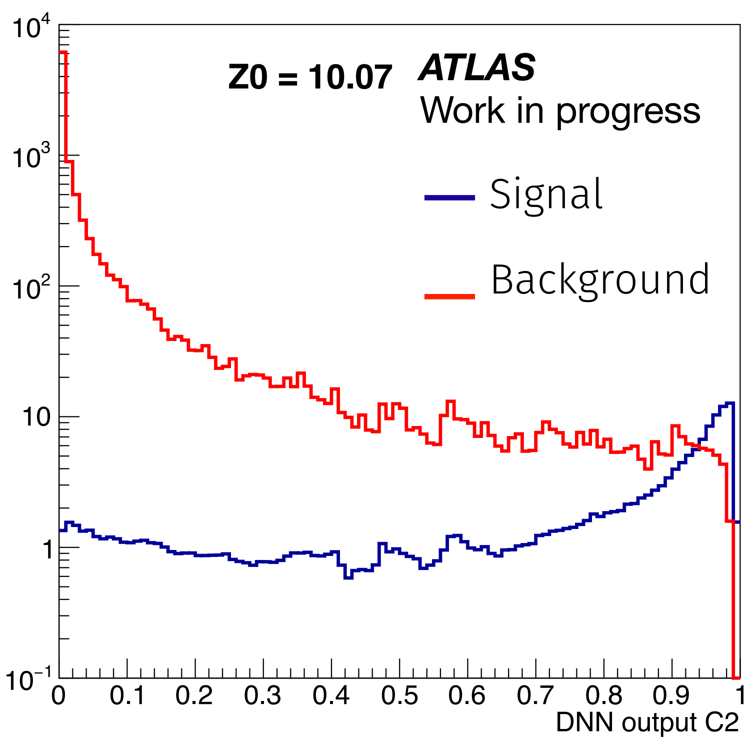
- Method 1: **Flat signal rebinning**
  - Inputs: # of desired bins
  - Strategy: choose bin boundaries such that in each bin a signal yield of **"total signal yield / # of bins"** is contained





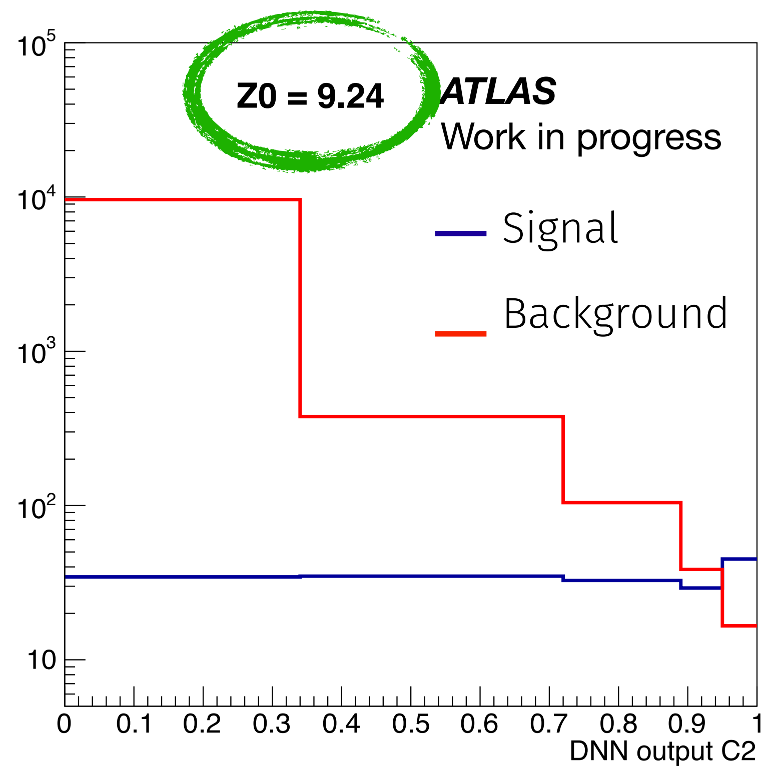
Compare Different Methods

Original



- **Method 1**

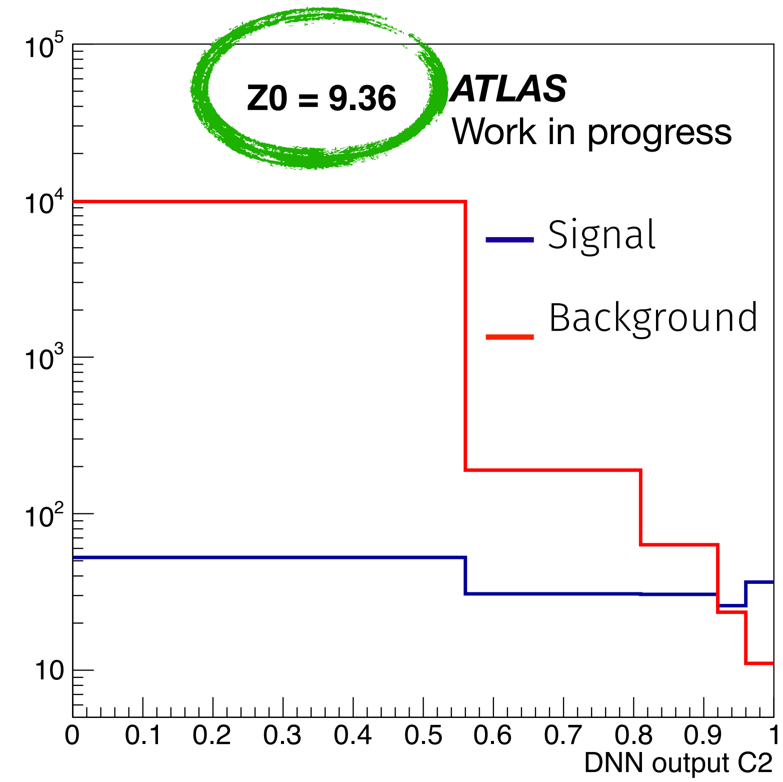
Flat signal rebinning



- **Method 2**

(explained only in backup)

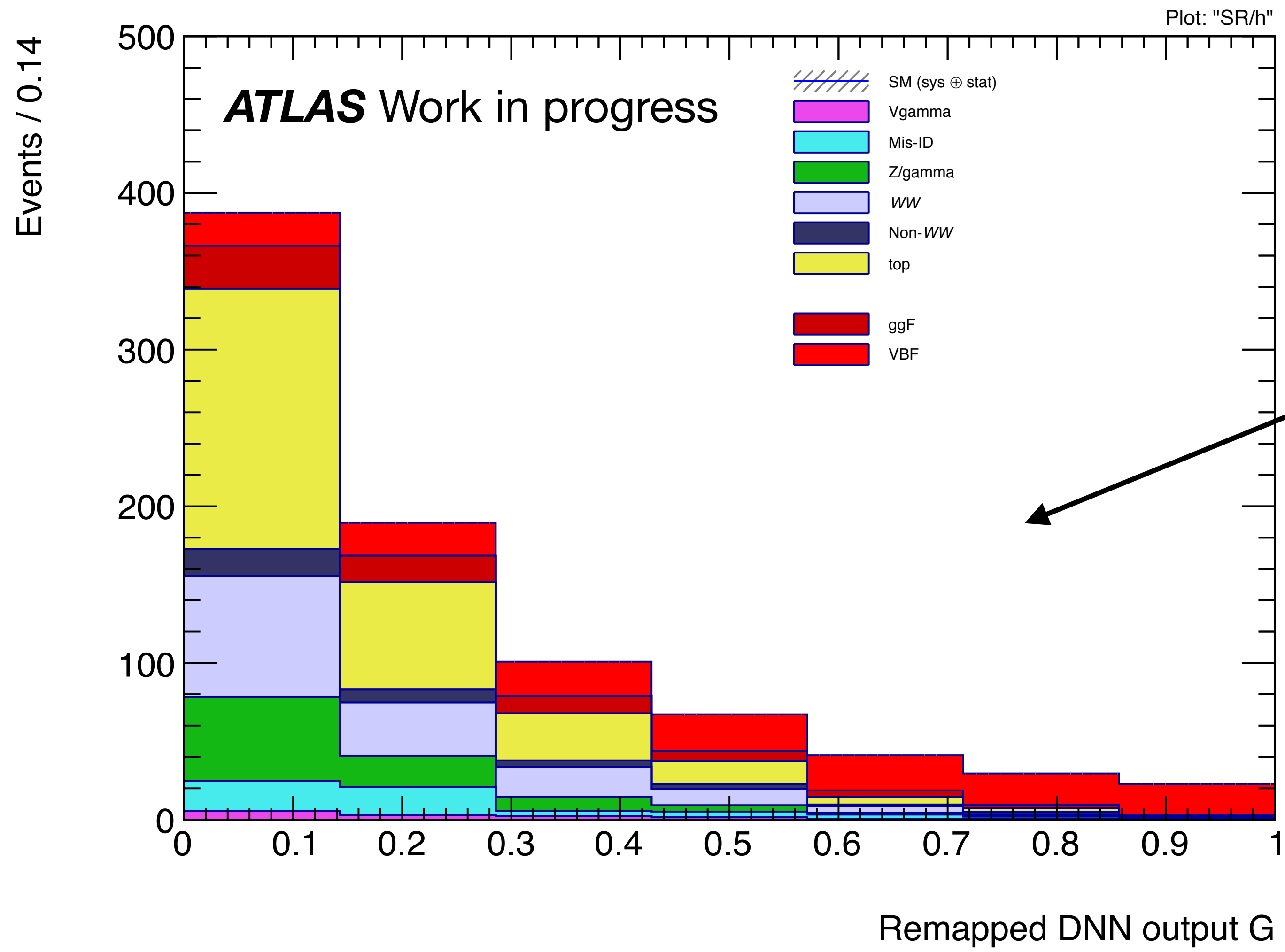
Significance optimization



- Methods perform very similarly
- Choose exact binning in final stages of analysis

Input to Final Statistical Analysis

- After the rebinning the distribution is used in a maximum likelihood fit to and extract parameters of interest (e.g. the cross-section of VBF HWW)



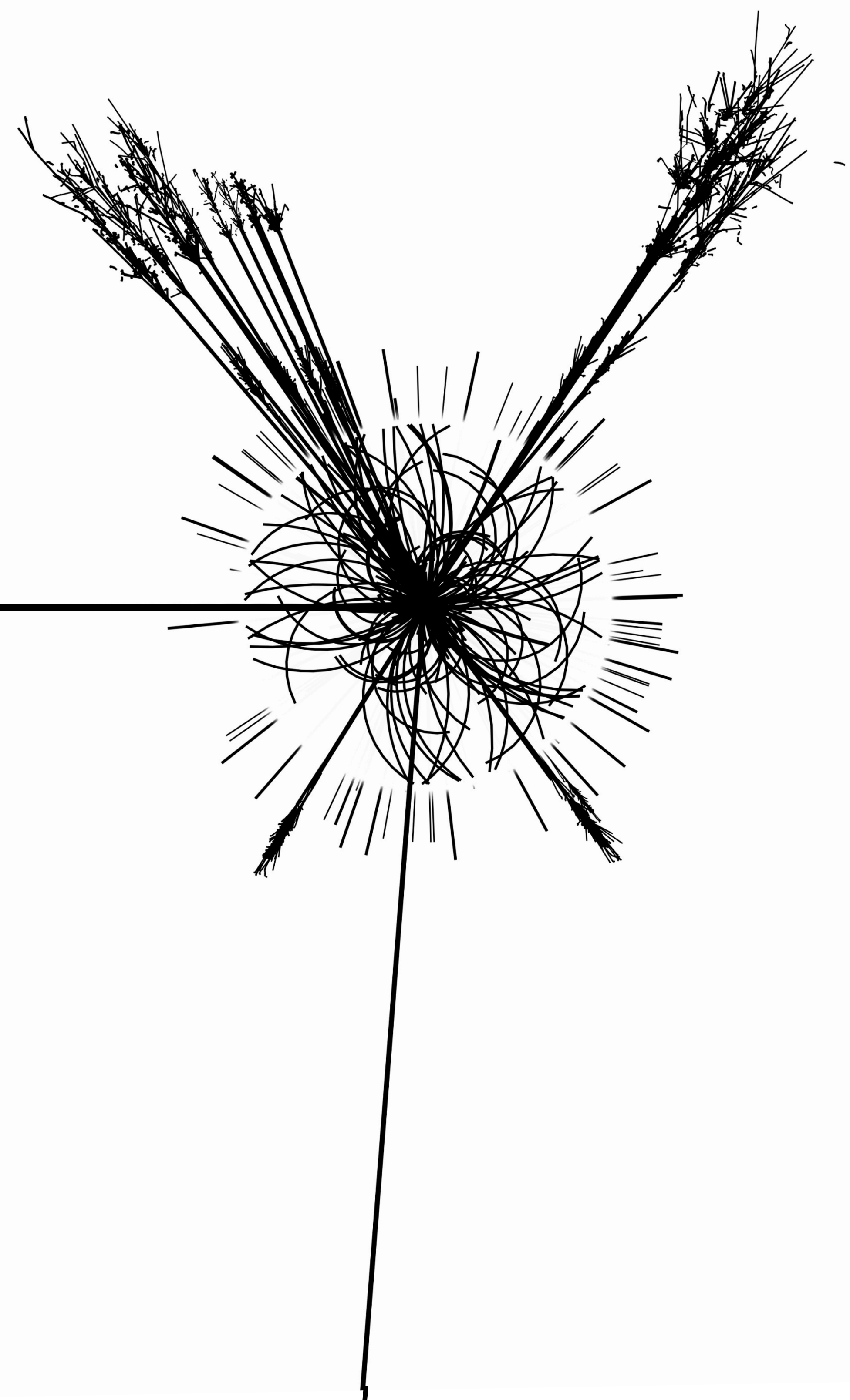
Only “expected” values from simulation so far

- With the new neural network and rebinning the **expected significance** to observe the VBF HWW process was improved from ~**6σ** to ~**8σ!** (p-value < 10^{-30})

Thanks for the attention!

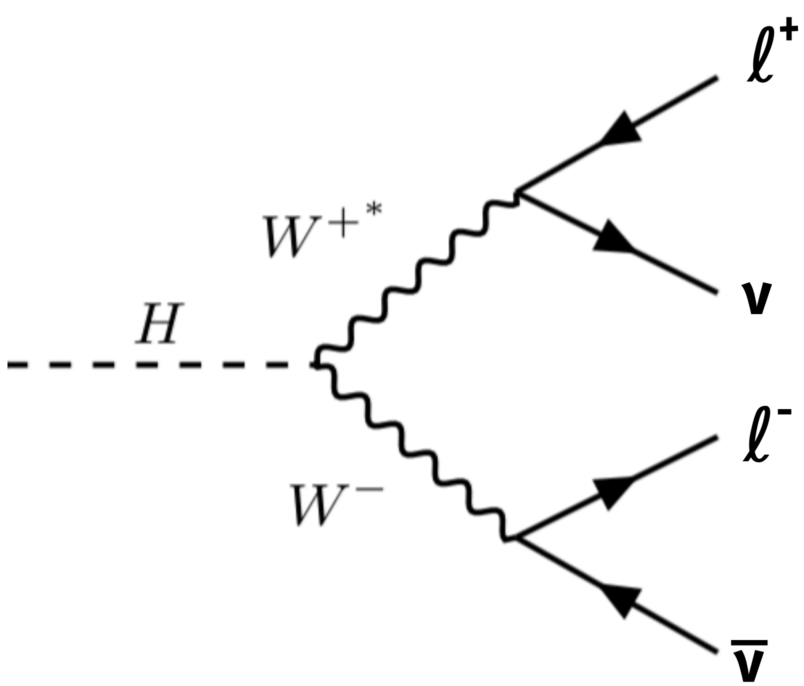
Questions?

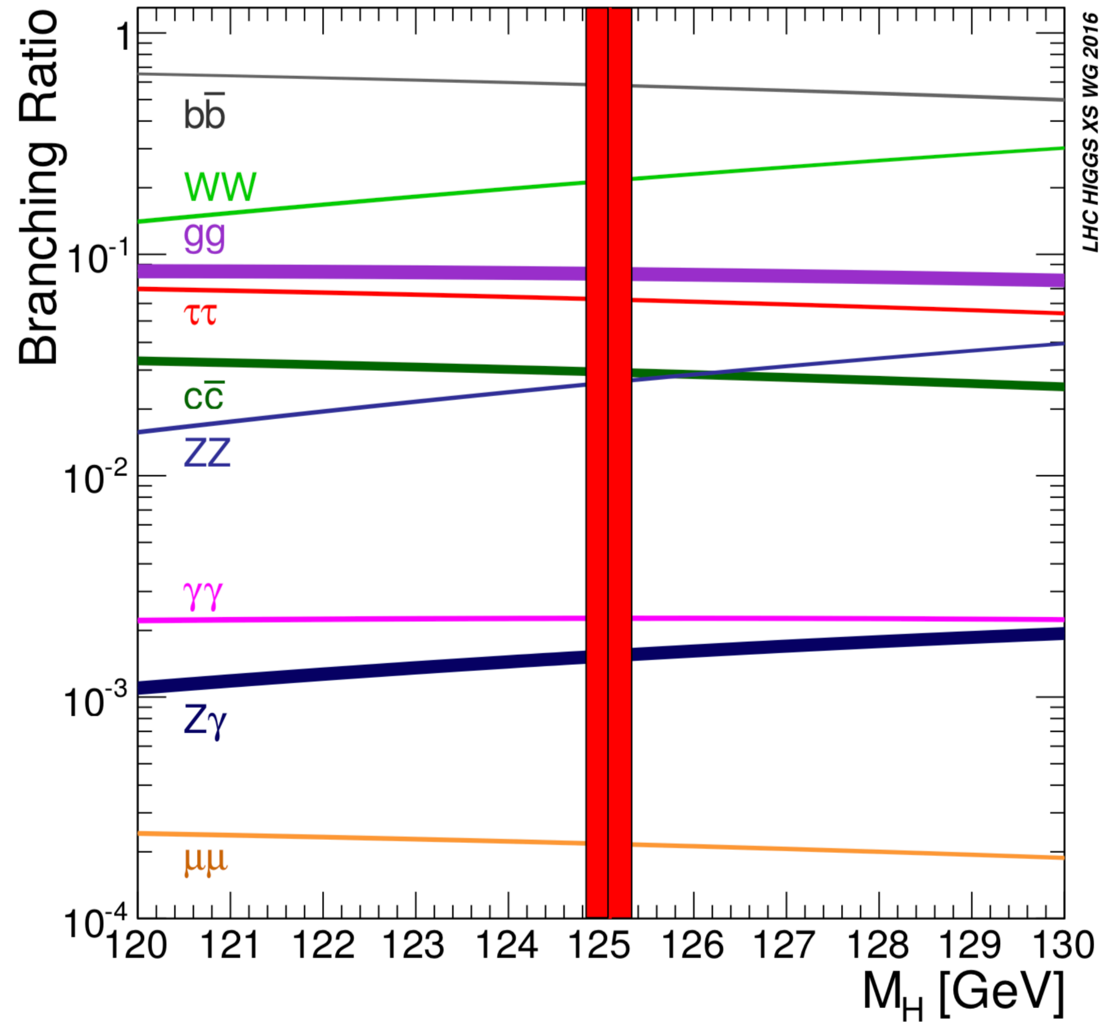
Backup



Why Higgs to WW?

- Higgs boson has multiple decay channels
  - **Higgs to WW**

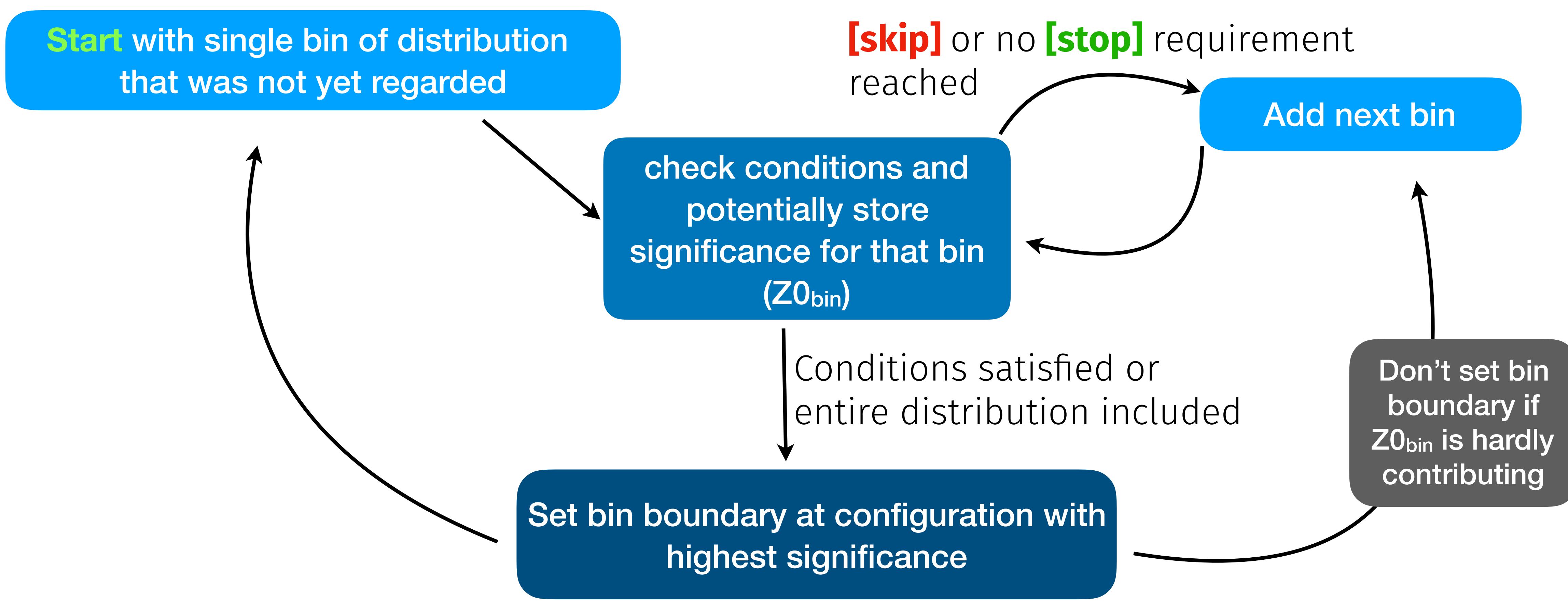




- 2nd largest branching ratio
- Most sensitive measurement of Higgs to vector-boson coupling
- Channel needed for conservation of unitarity in WW scattering

Binning Optimization Method 2

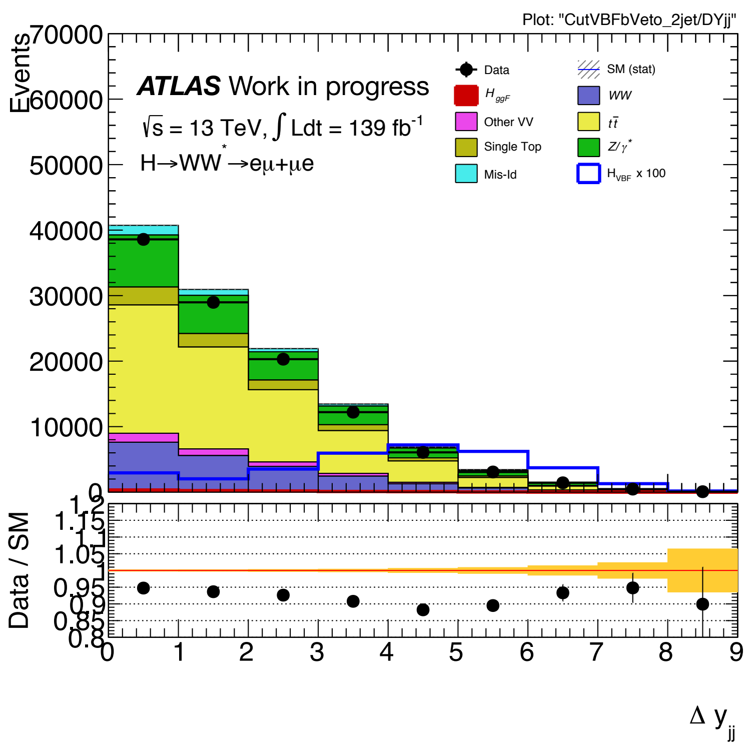
- Method 2: **Significance optimization rebinning**
  - Inputs (some are optional):
    1. minSignal = 10; minimum signal per bin **[skip]**
    2. minBkg = 10; minimum bkg per bin **[skip]**
    3. maxBkgUnc = 0.2; maximum relative bkg MC uncertainty **[skip]**
    4. maxSignal = 30; sufficient signal to set boundary **[stop]**
  - Strategy:

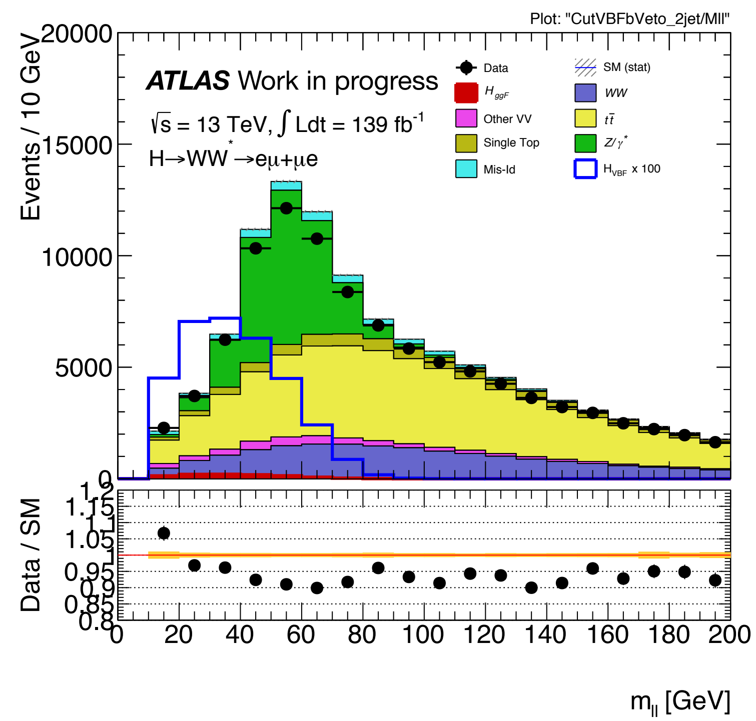


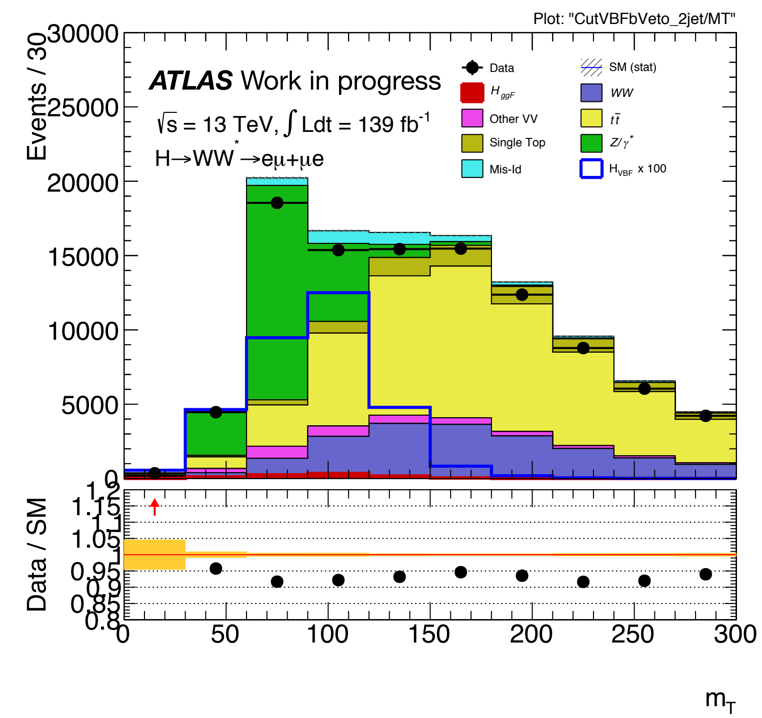
Train a Neural Network for Event Classification

- **Variables** used in the training (15 in total)

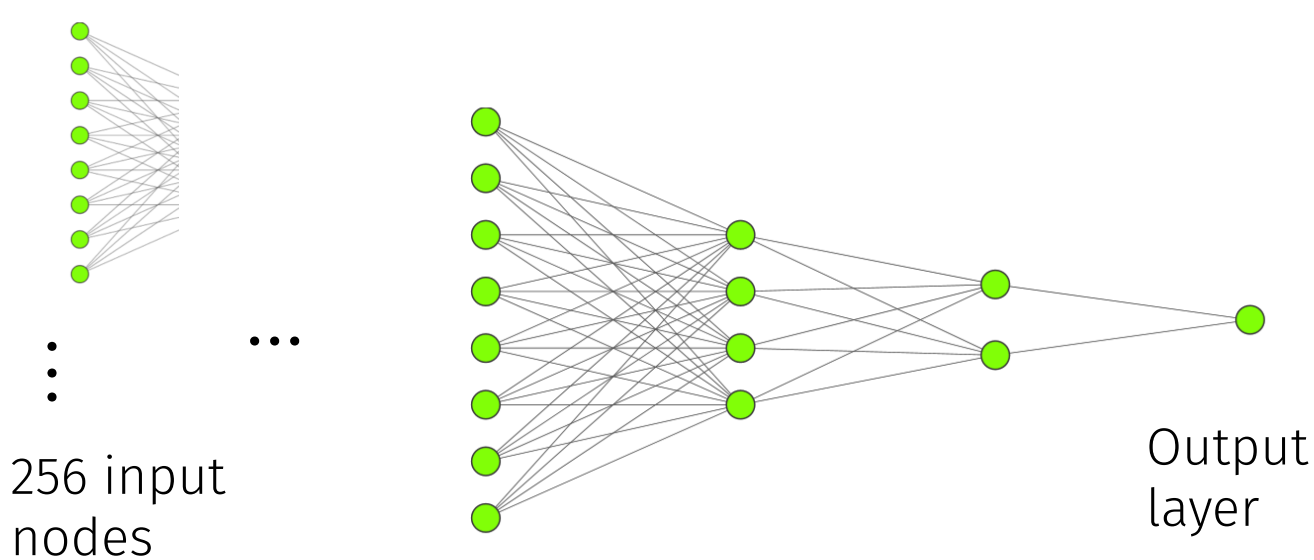
  DPhill, DYjj, mjj, mll, mT, ptTot, sumOfCentralitiesL, mL*J* (4), ptJ1/2/3, **METSig** (15)



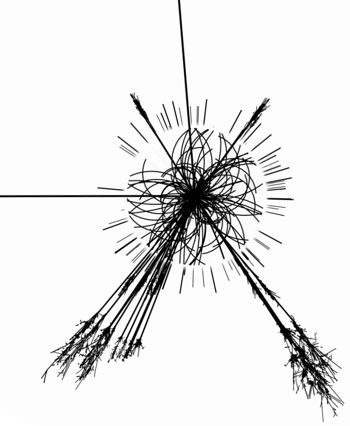




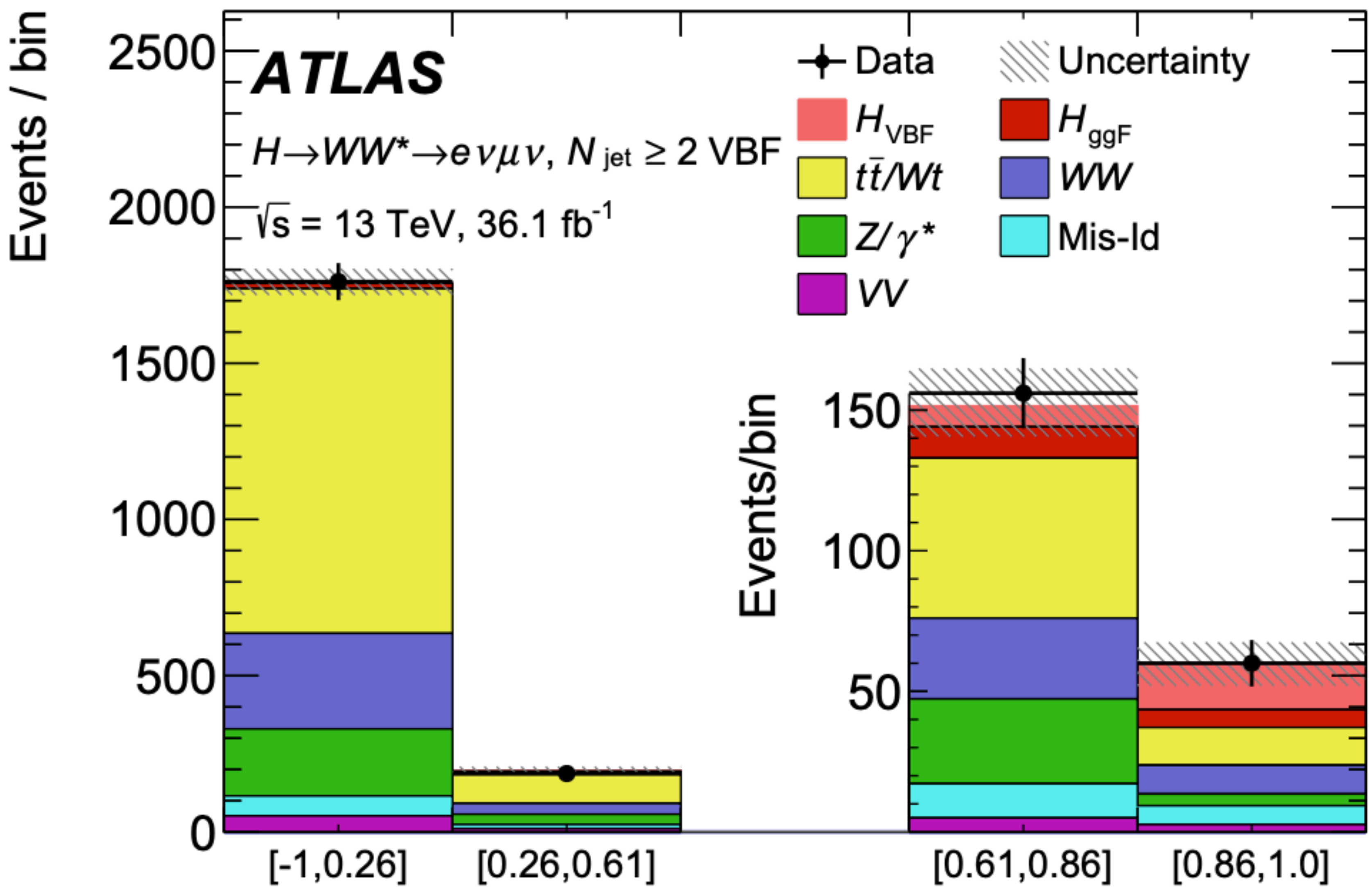
- **New "deep" network architecture**



“A Counting Experiment”



- VBF HWW results with LHC data from 2015-2016 (Expected significance: **2.6σ**)

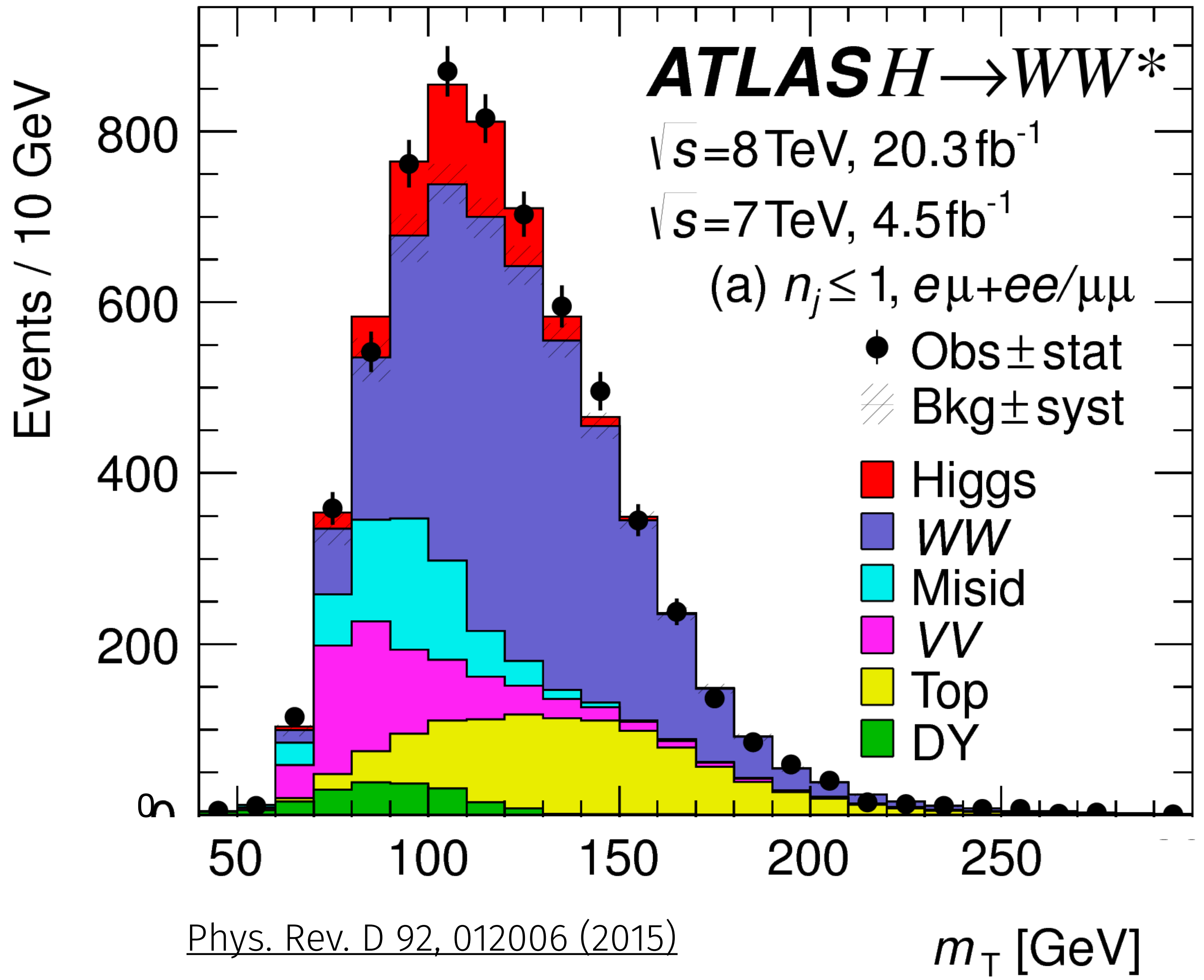


Physics Letters B 789 **(2019)** 508–529

- Current efforts: precisely measure **properties** of Higgs boson with data recorded in 2015-2018. (side-goal: measure exclusive VBF HWW with significance > 5σ)

“A Counting Experiment”

- Results contributing to the Higgs boson discovery



Phys. Rev. D 92, 012006 (2015)

- Current efforts: precisely measure **properties** of Higgs boson (with data recorded in 2015-2018)