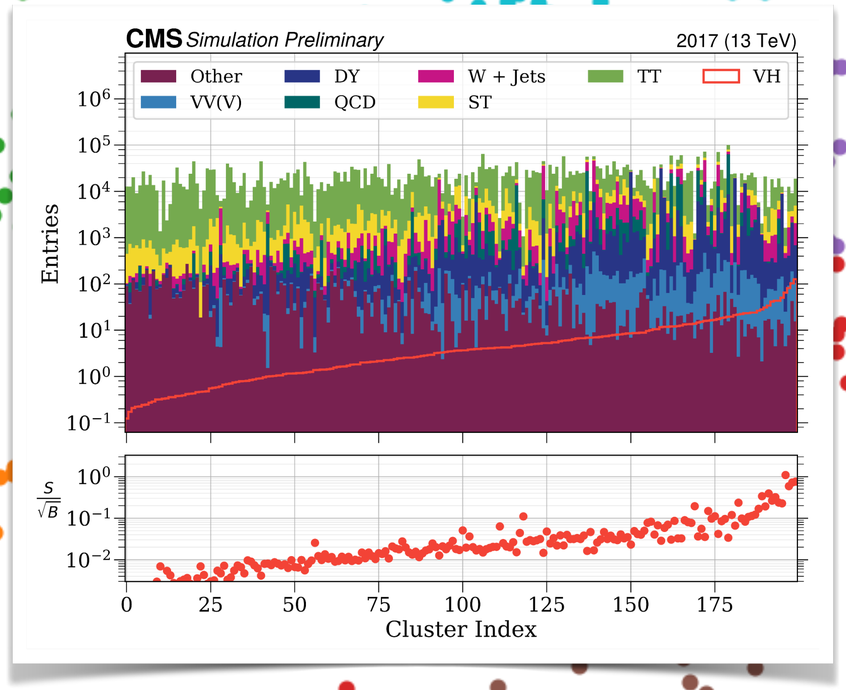

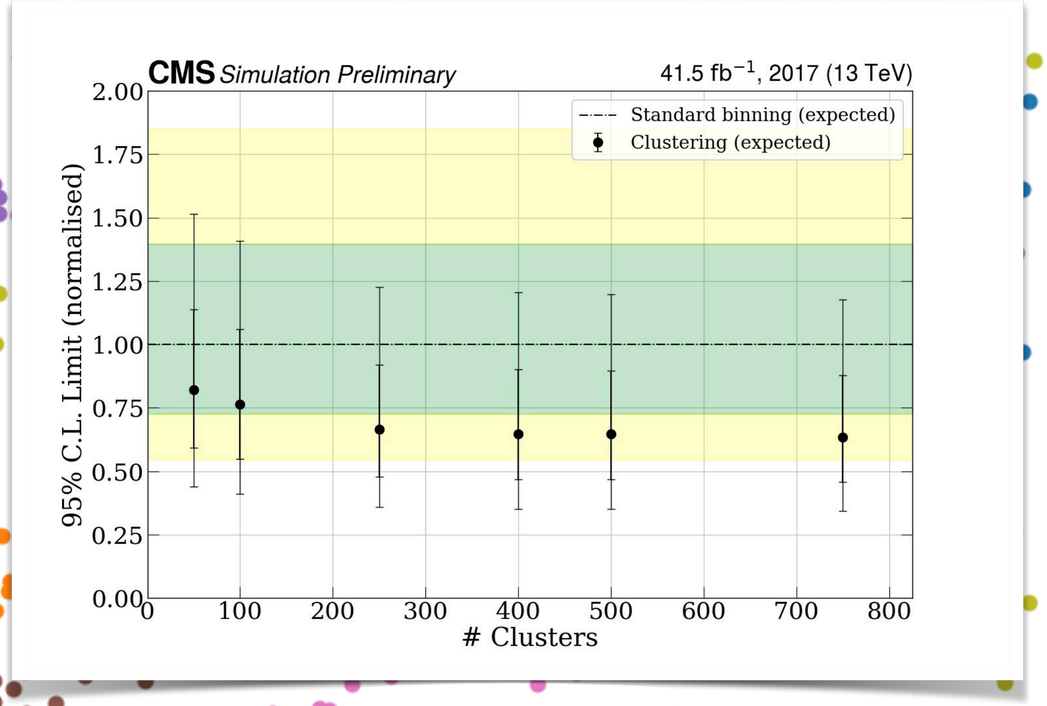

Binning high-dimensional classifier output for HEP analyses through a clustering algorithm

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GEFÖRDERT VOM
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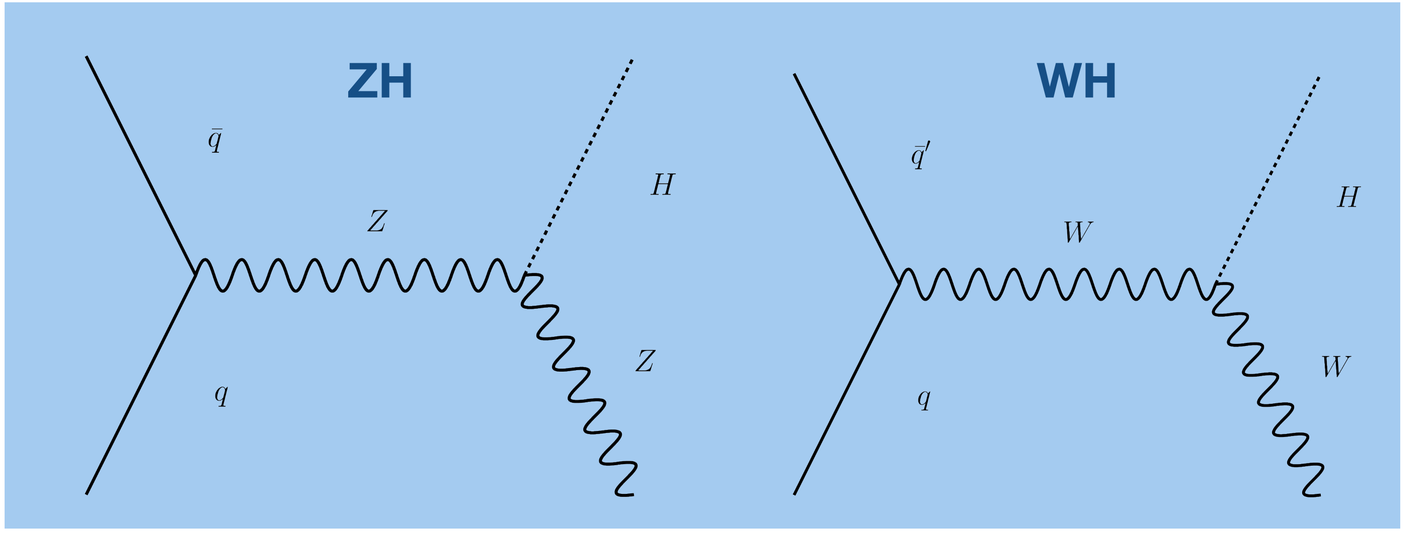
Introduction

Analysis Context:

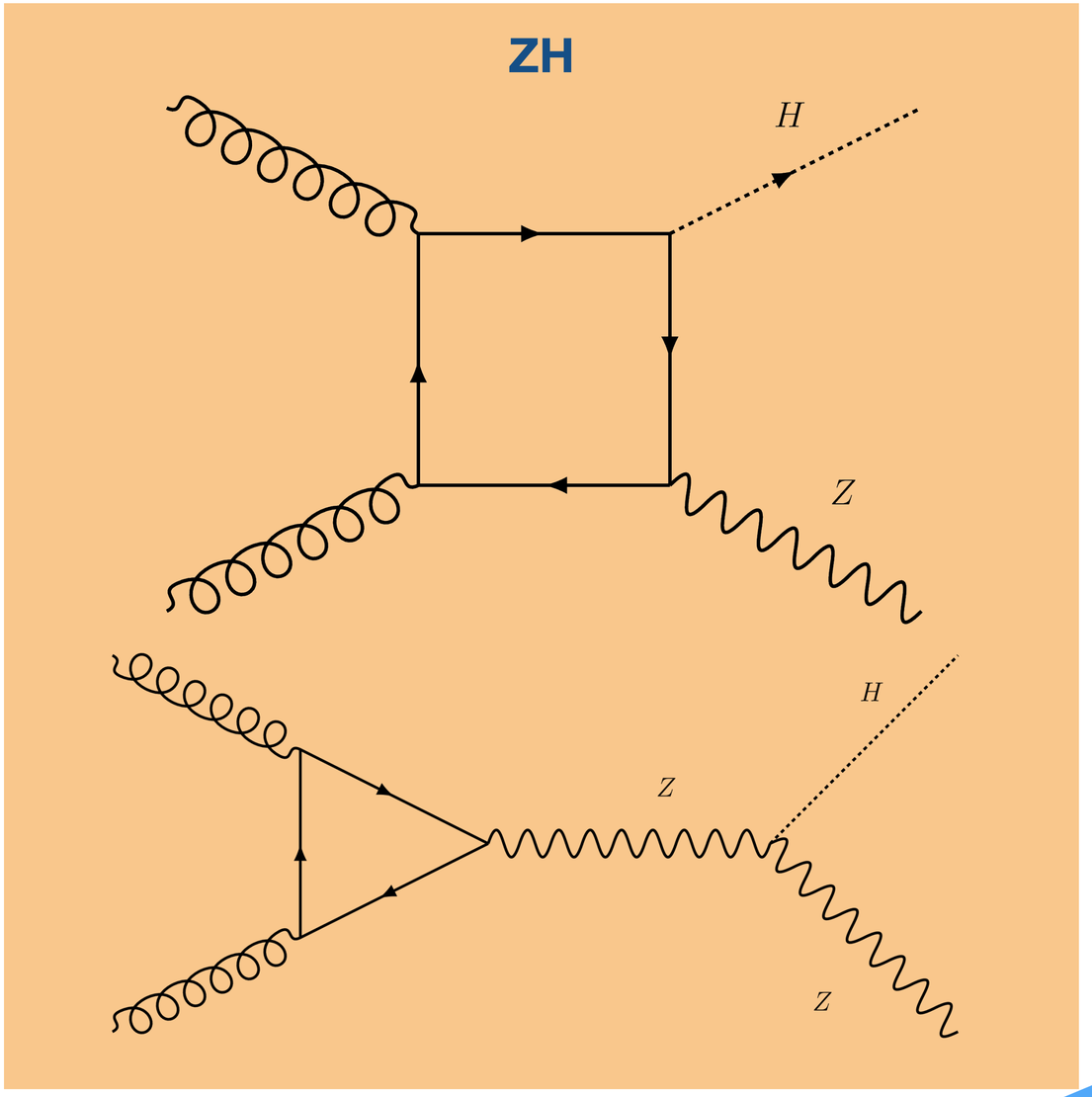
- search for VH at
- specialised analysis for gg →ZH production
- yet unmeasured production
- small cross section:
  - need for sensitivity enhancement

$$VH = (\mathbf{gg \rightarrow ZH}) + (qq \rightarrow ZH) + WH$$

Dominant Production

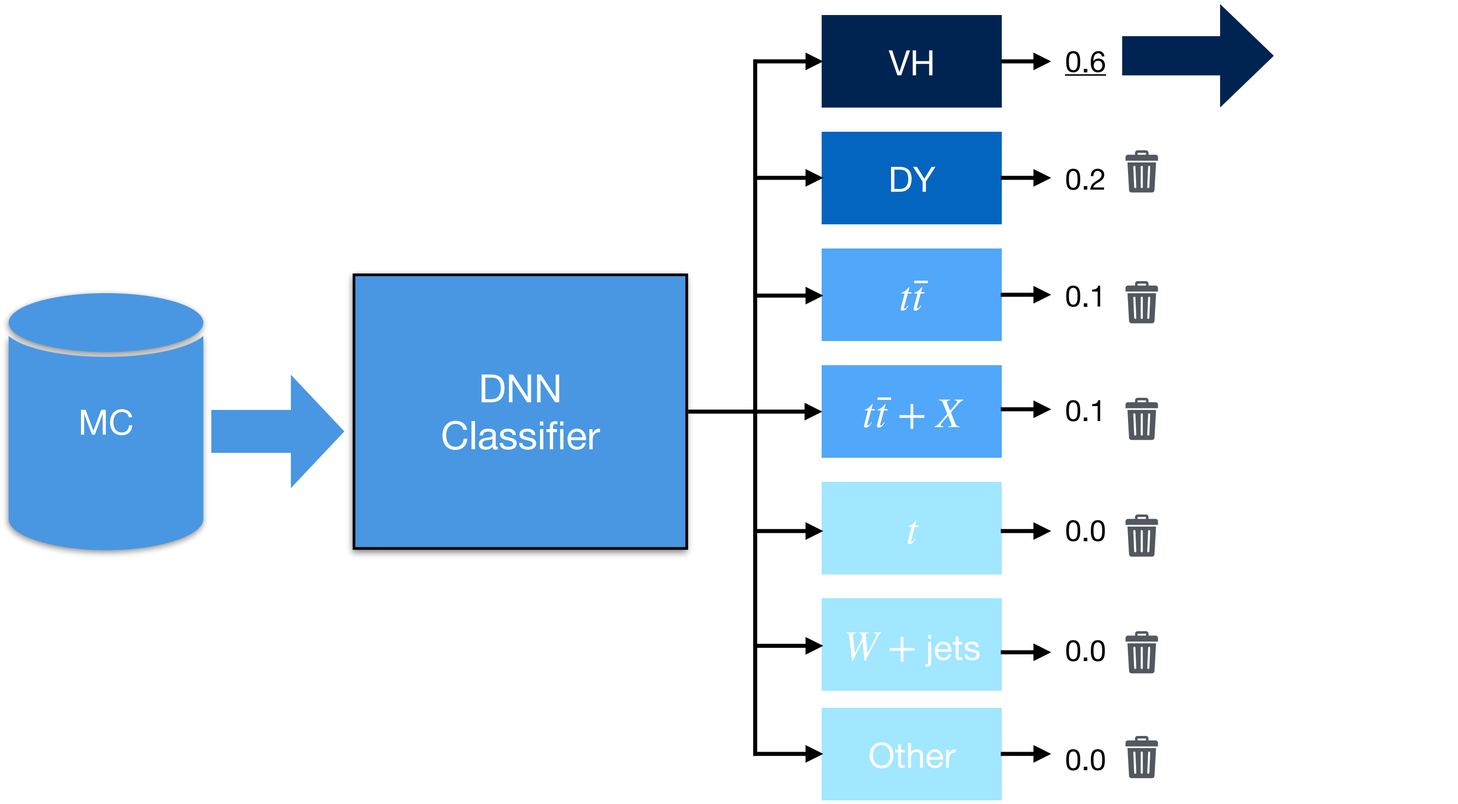


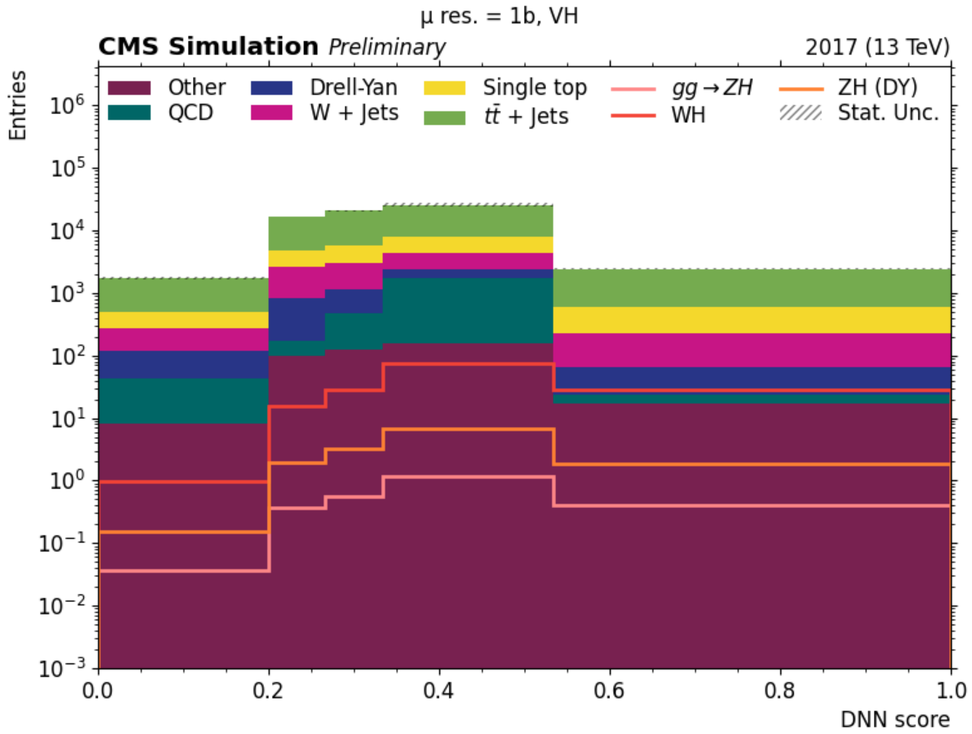
Gluon Fusion



VH-Analysis Process-classification

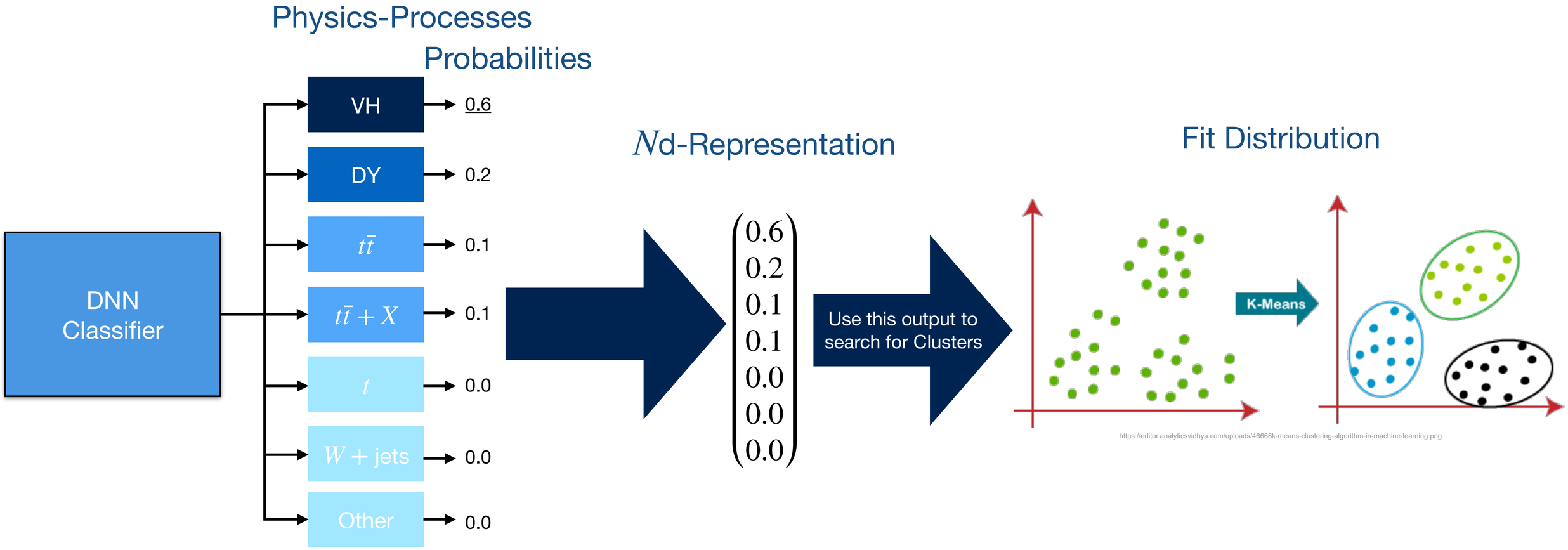
- Events are classified by process
- **Highest score** serves as fit-variable
- 1 signal region 7 control regions





Clustering with K-Means [1/2]

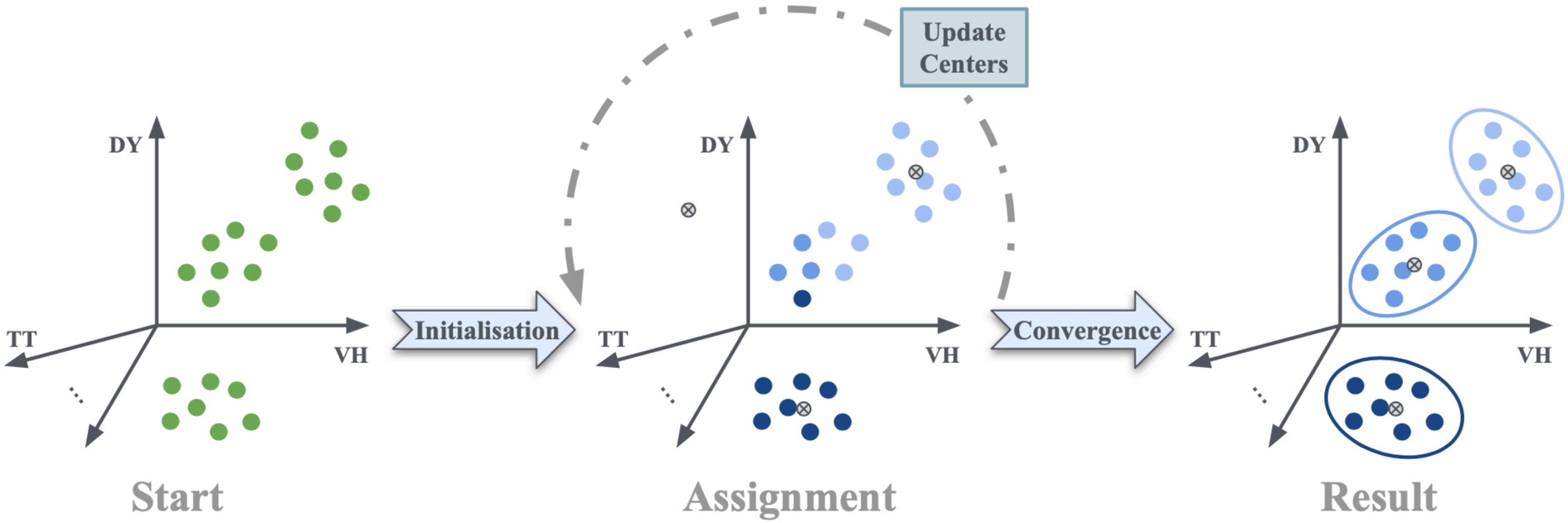
- The DNN delivers a N**d-representation** of our data
- Correlated to **physics processes**, which will be fitted
- Clustering can create bins in this Nd space without suffering under the *curse of dimensionality*



Clustering with K-Means [2/2]

K-Means Clustering Algorithm:

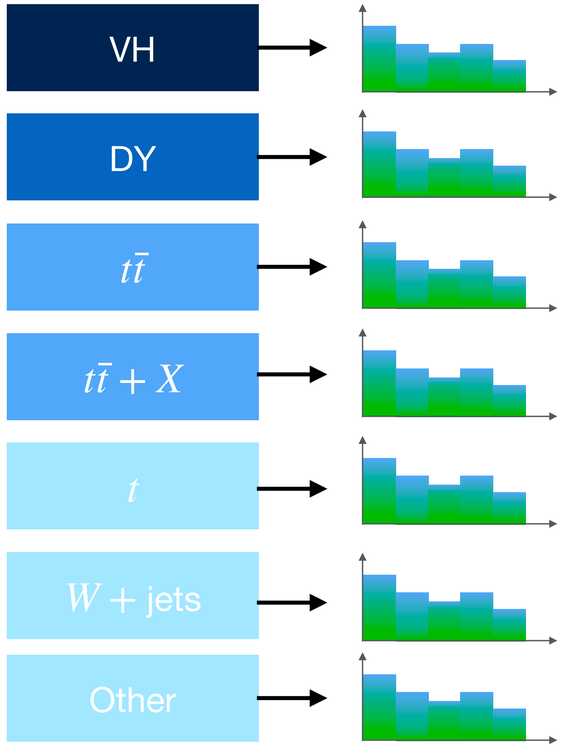
- random initialisation of K cluster centers
- eventwise assignment to closest cluster (L2 norm)
- iterative update of cluster centers by mean of assigned events
- K-Means already used in this analysis [1]



Approach Comparison

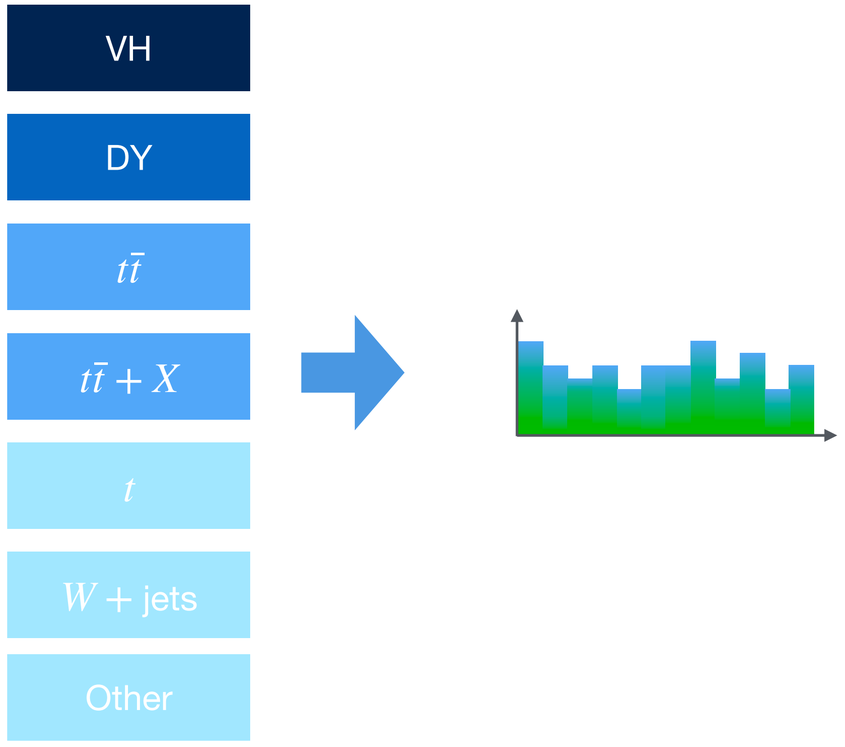
Standard Binning

- N Histograms
- Each has m bins
- Need to be tuned independently



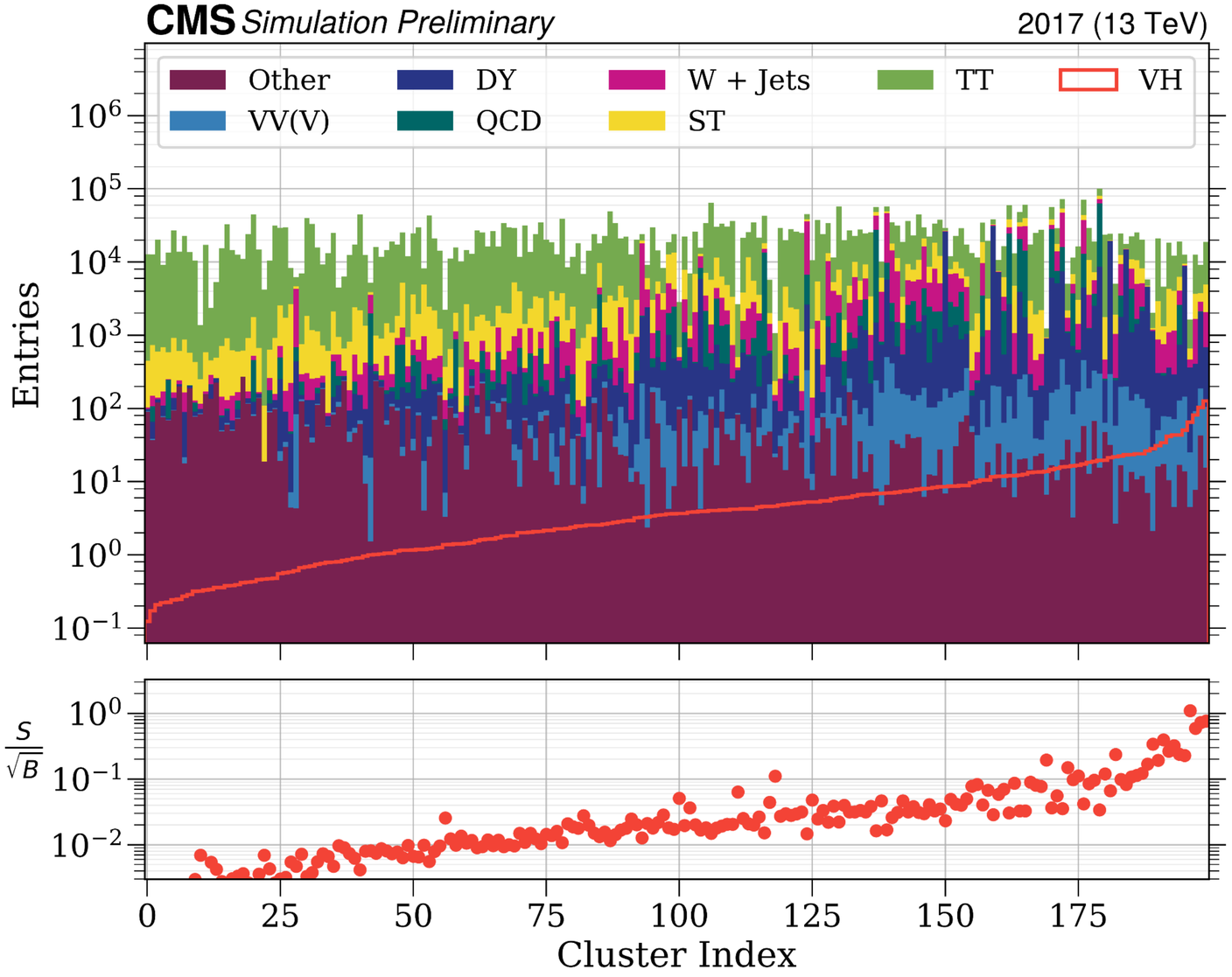
Clustering Binning

- 1 Histogram
- K bins
- Number of tuning parameters very limited



Clustered distribution

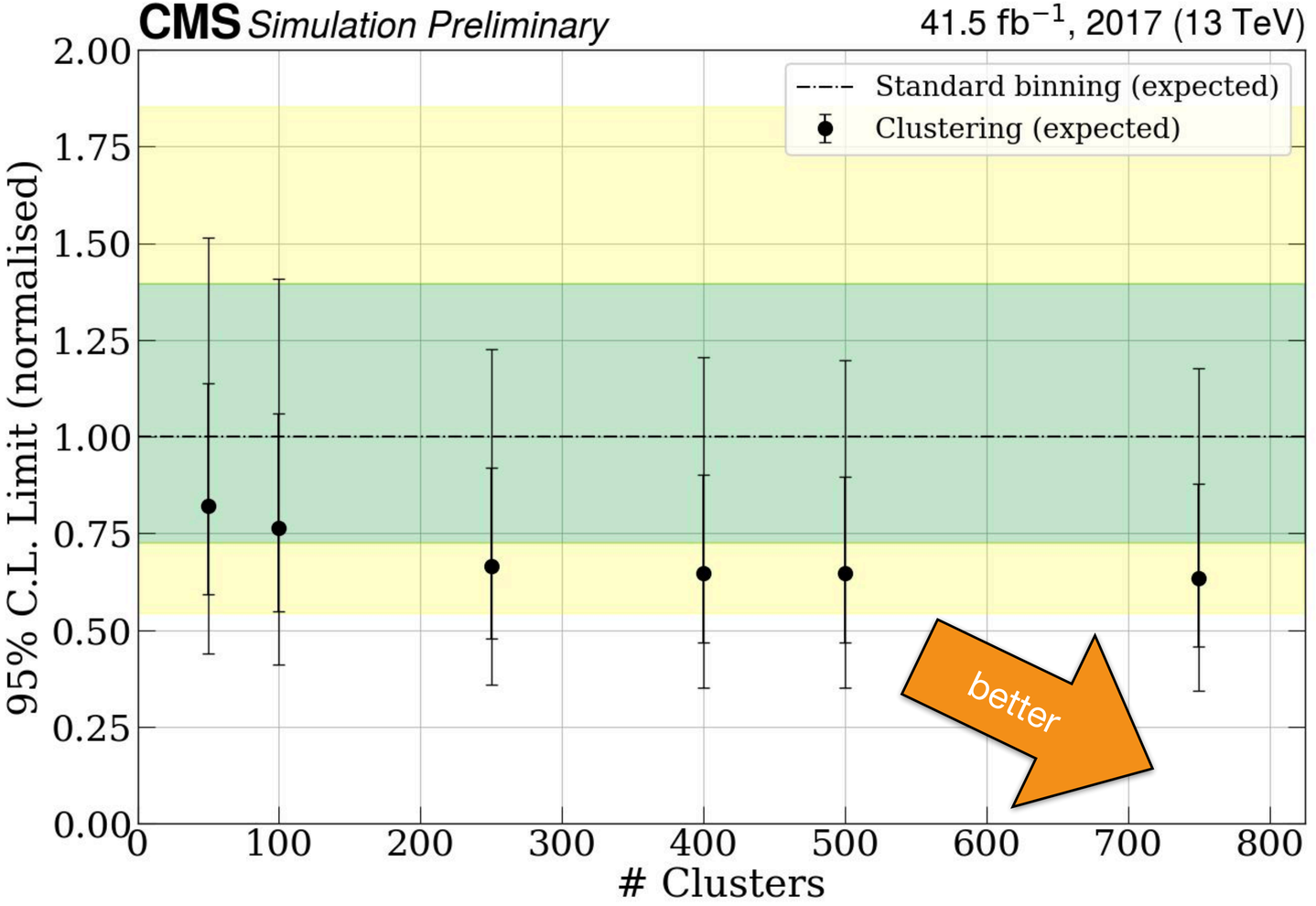
- Clusters sorted by absolute signal yield
- All bins contain a reasonable amount of events
- Some clusters are enriched in specific backgrounds
- High purity bins towards right side



Sensitivity Improvement

Benchmark results:

- evaluation of 95% C.L. limit
  - sensitivity increase for high
  - number of clusters
  - improvement compared to
    - the standard method (~ 400 bins):
    - statistical uncertainties
    - background normalisation



Bias test - MC dependency

- Clusters are determined on MC events

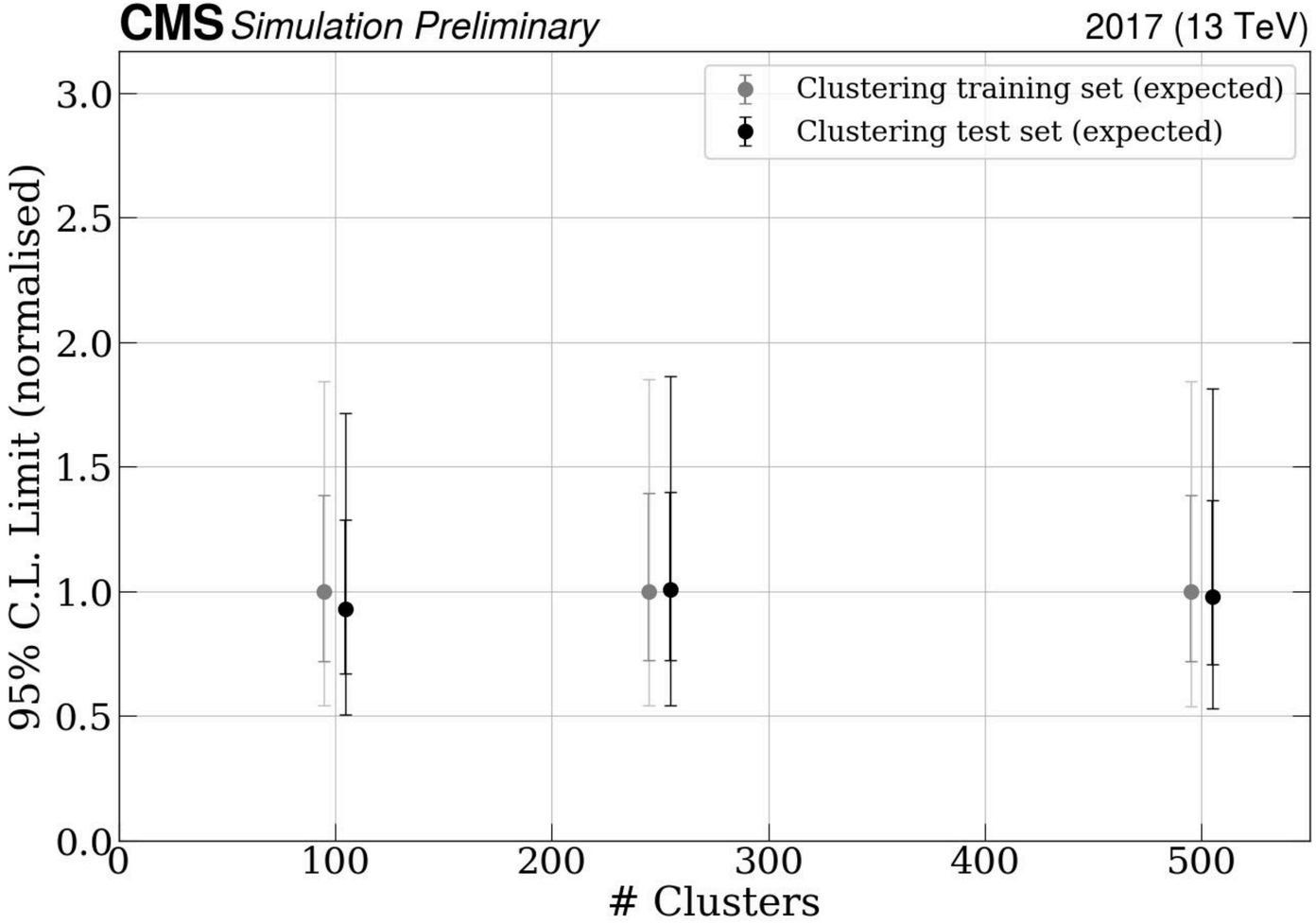
  ➜ Might introduce bias!

Testing-Strategy:

- Dataset split into two equal sets
  - Training
  - Test
- Clustering performed on training set
- Evaluated on sets separately

➜ Almost no difference

➜ Clustering is **robust** towards MC dataset introduced bias

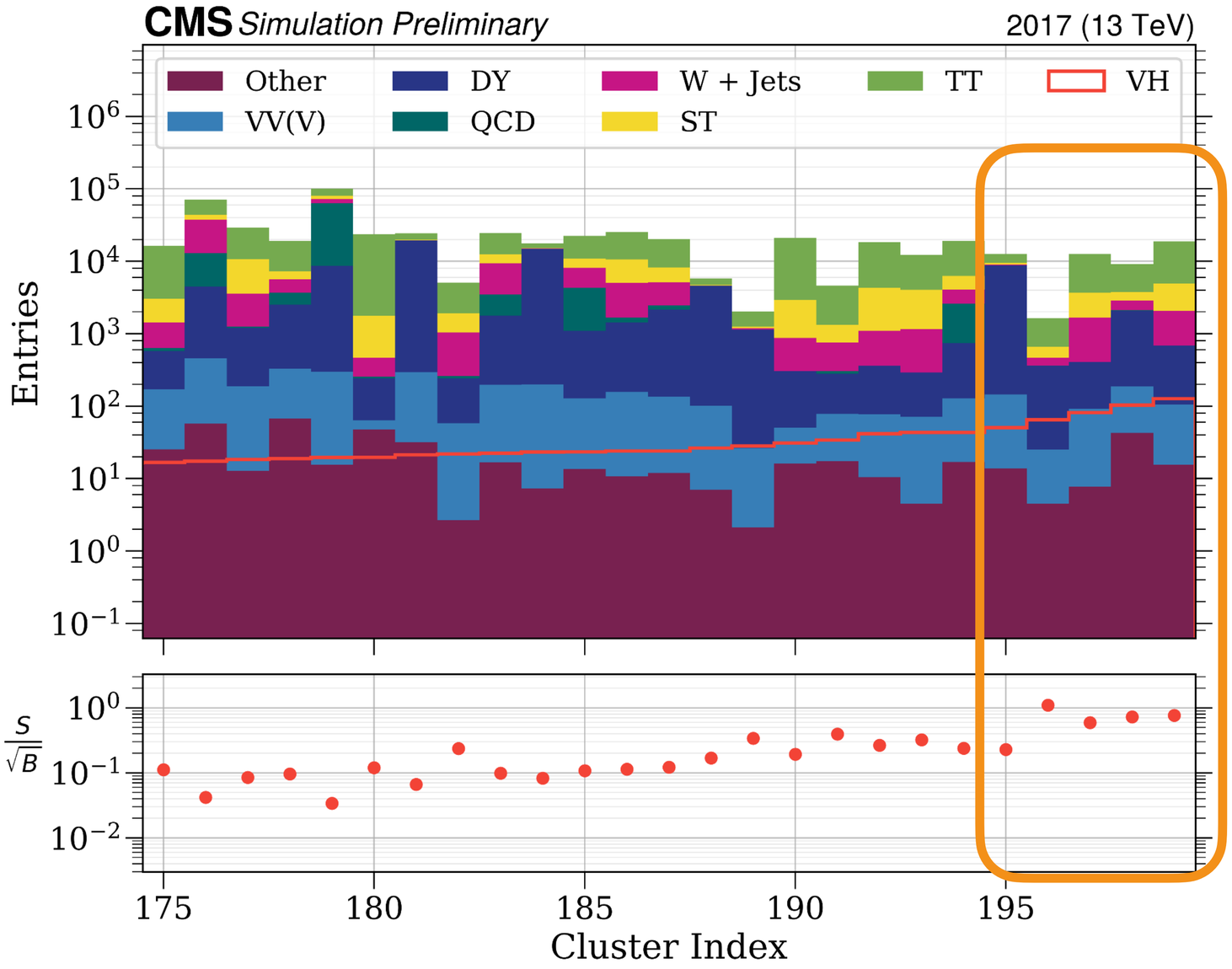


Top 25 clusters

- Clusters are determined in 8d-space

➜ Cluster center coordinate is a 8d vector

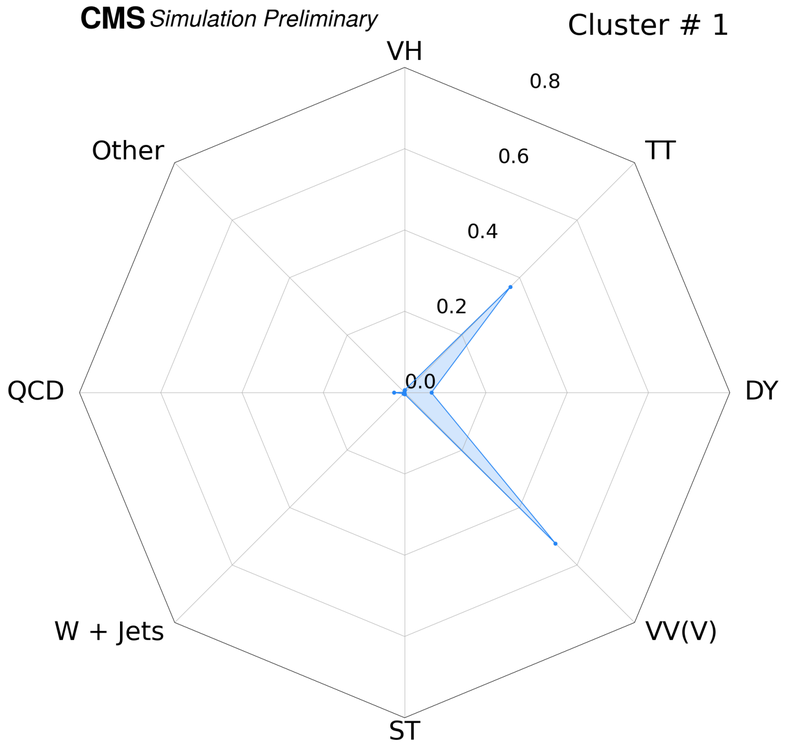
Try to get some insight how the clusters are constructed!

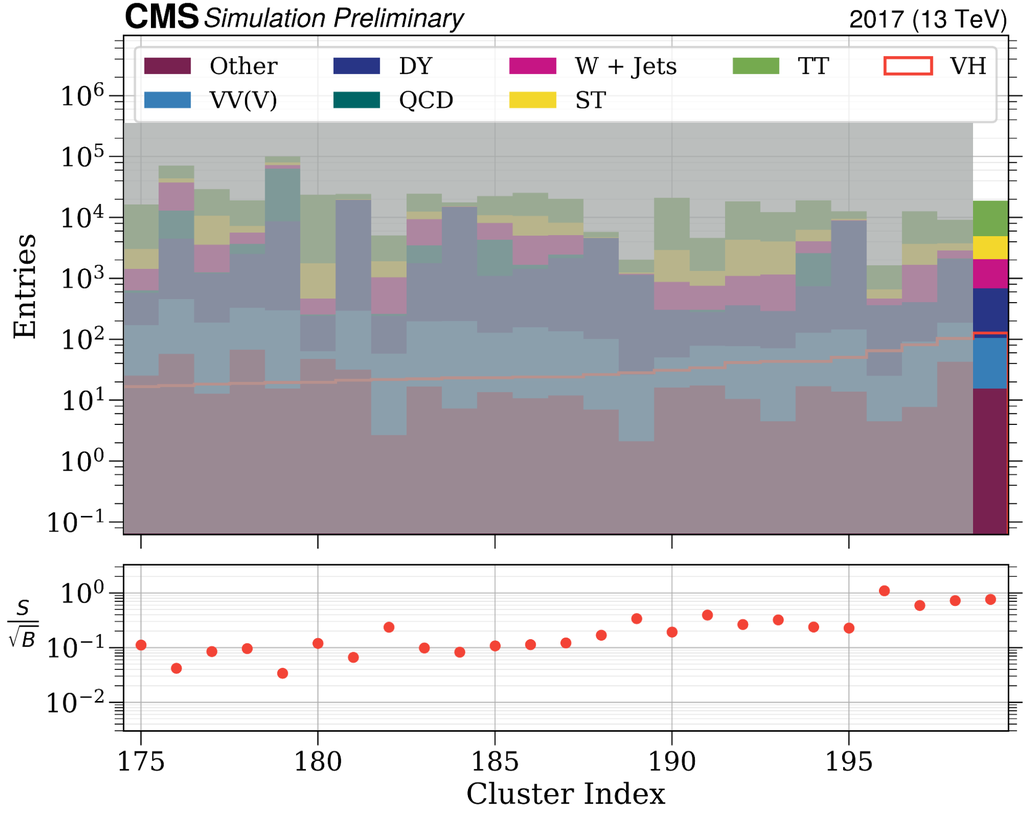


Cluster Visualisation - Top 1 Cluster

Visualisation: 8d cluster center coordinate plotted as Radar-Plot

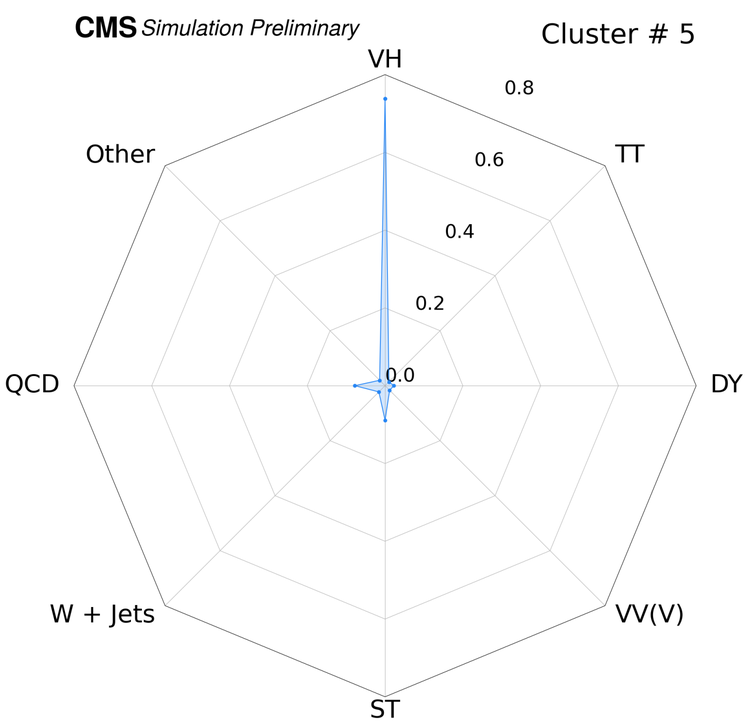
- #1 cluster has the largest signal contribution
- Main coordinate consist of backgrounds
  - $t\bar{t}$
  - VV(V)

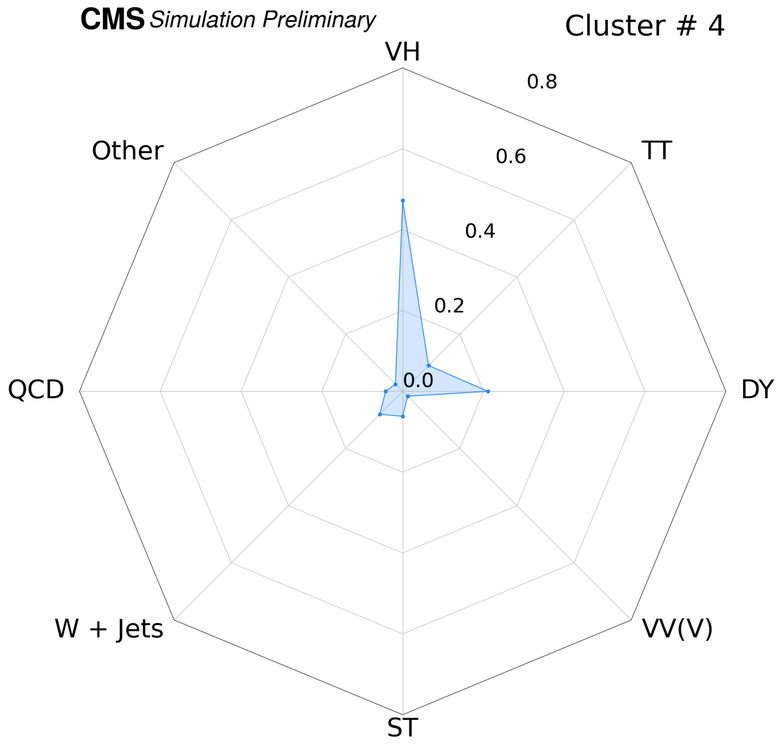


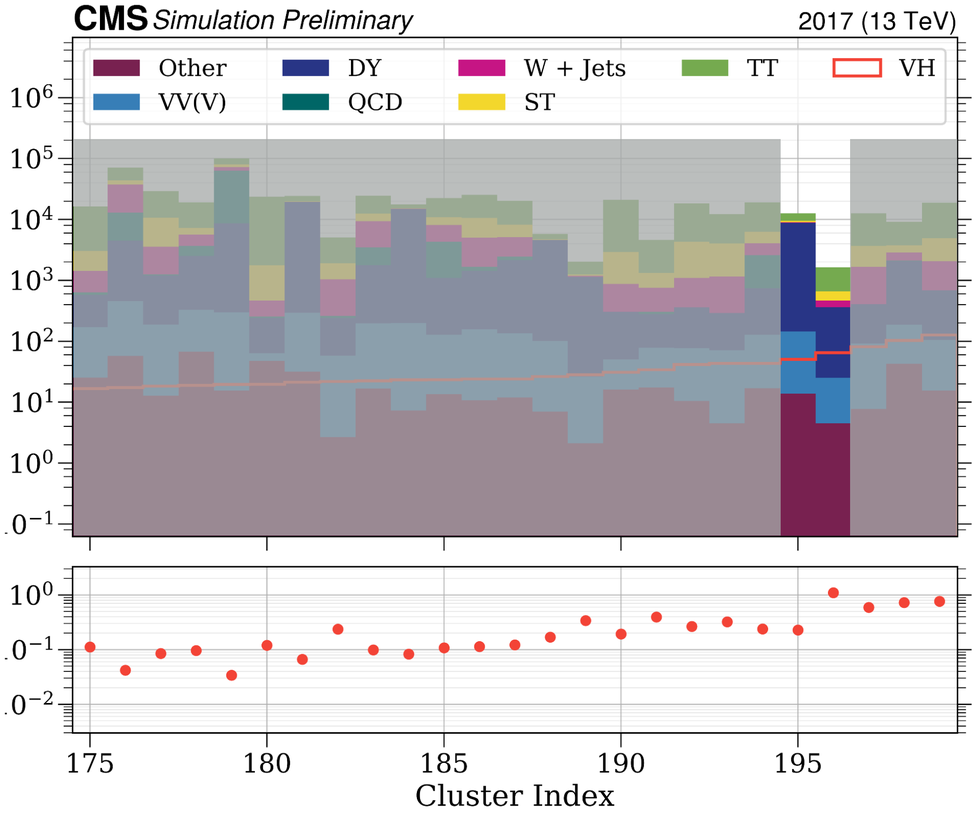


Cluster Visualisation - Top 4/5 Cluster

- High signal prediction confidence
- Better signal-background ratio



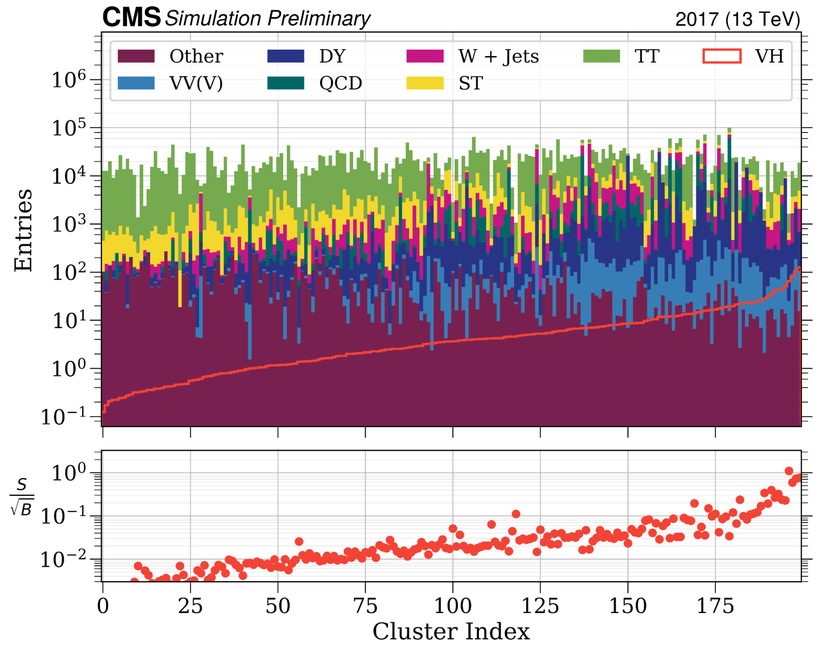


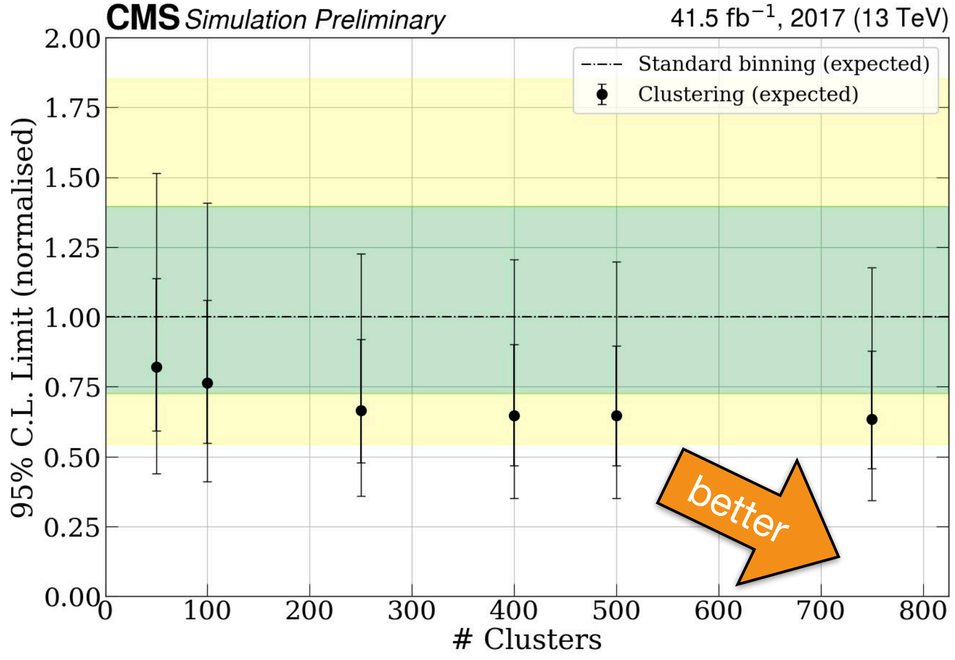


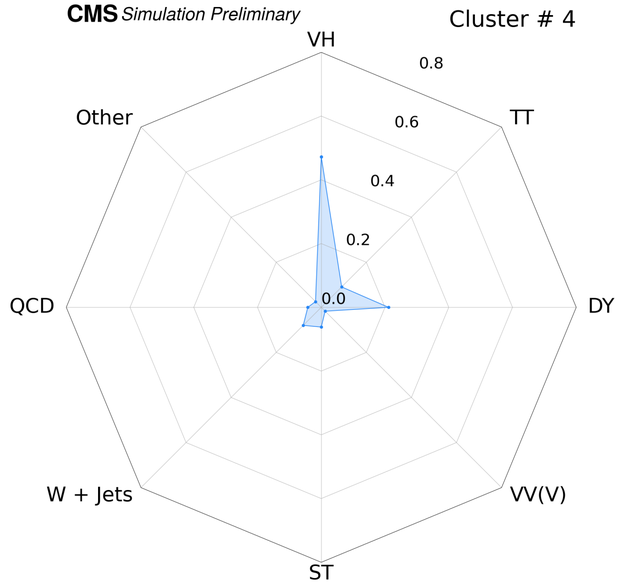
Summary

Binning High-Dimensional Classifier Output through Clustering:

- **Agnostic** binning algorithm in high-dimensional space
- No loss of information
- **Improvement of analysis sensitivity**
- Radar plots visualise cluster center coordinates
- Robust towards MC training dataset







Resources

[1] Evidence for associated production of a Higgs boson with a top quark pair in final states with electrons, muons, and hadronically decaying τ leptons at √s= 13 TeV, CMS Collaboration, JHEP 08 (2018) 066,