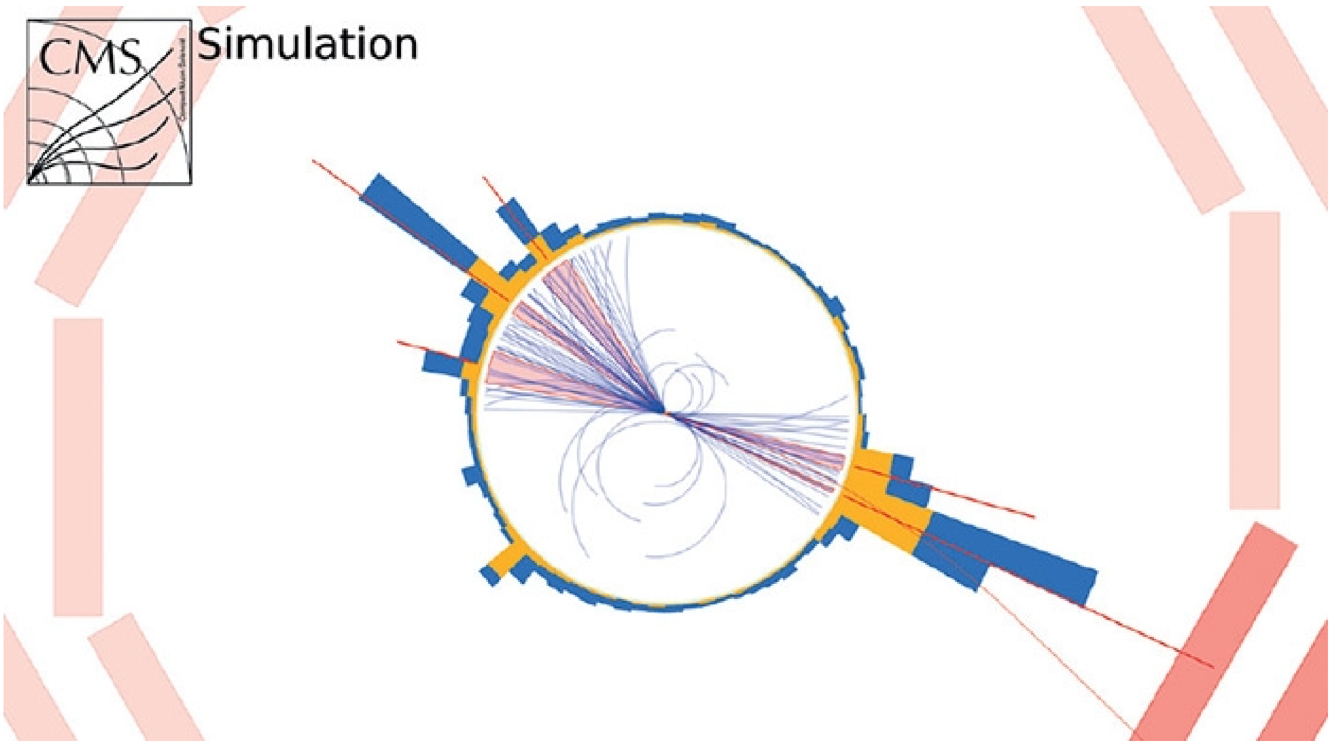
Event Reconstruction and Classification in Proton-Proton Collisions Using Deep Neural Networks



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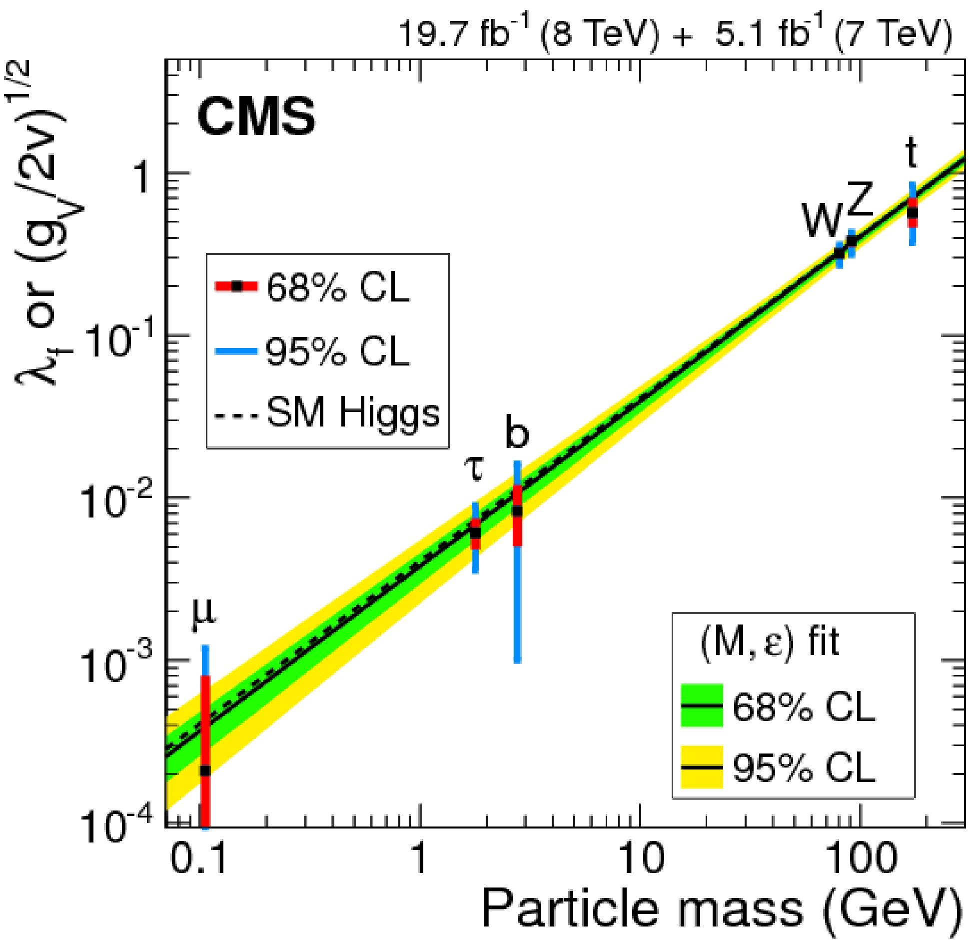
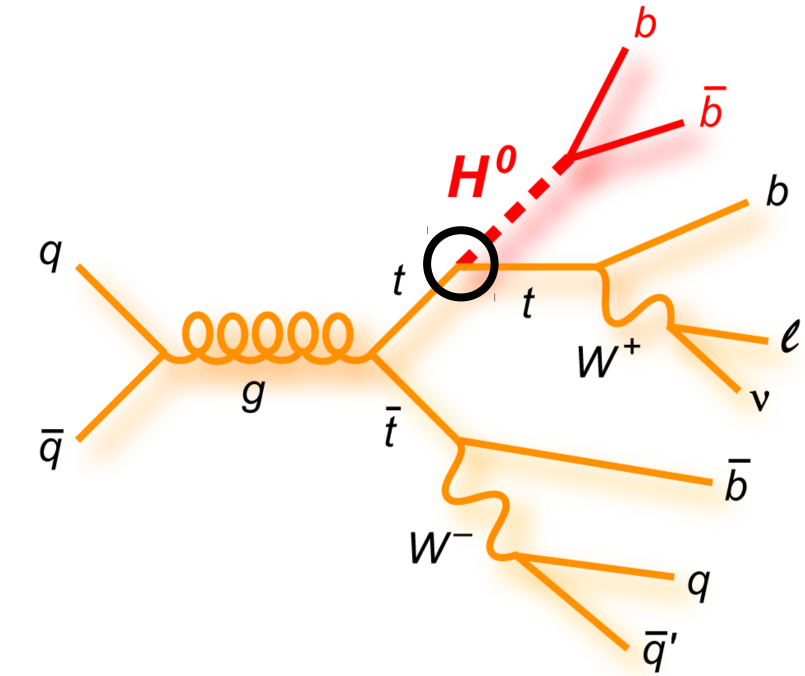


- Top quark heaviest elementary particle in the Standard Model
  - Strongest coupling to Higgs boson
- Top-Higgs coupling can be measured directly in ttH channel
  - Higgs boson produced in association with top quark pair
- H → bb highest branching ratio

→ ttH (H→bb) important analysis channel for top-Higgs coupling

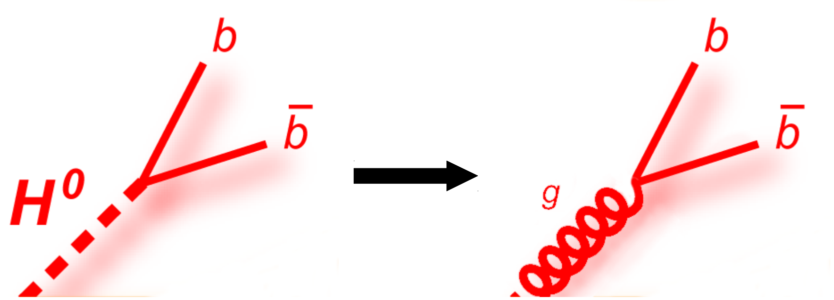
Analysis Overview

- Goal: Cross section measurement → top-Higgs coupling



Challenges?

1. Jet combinatorics
   - 6 quarks ↔ jets → 180 combinations

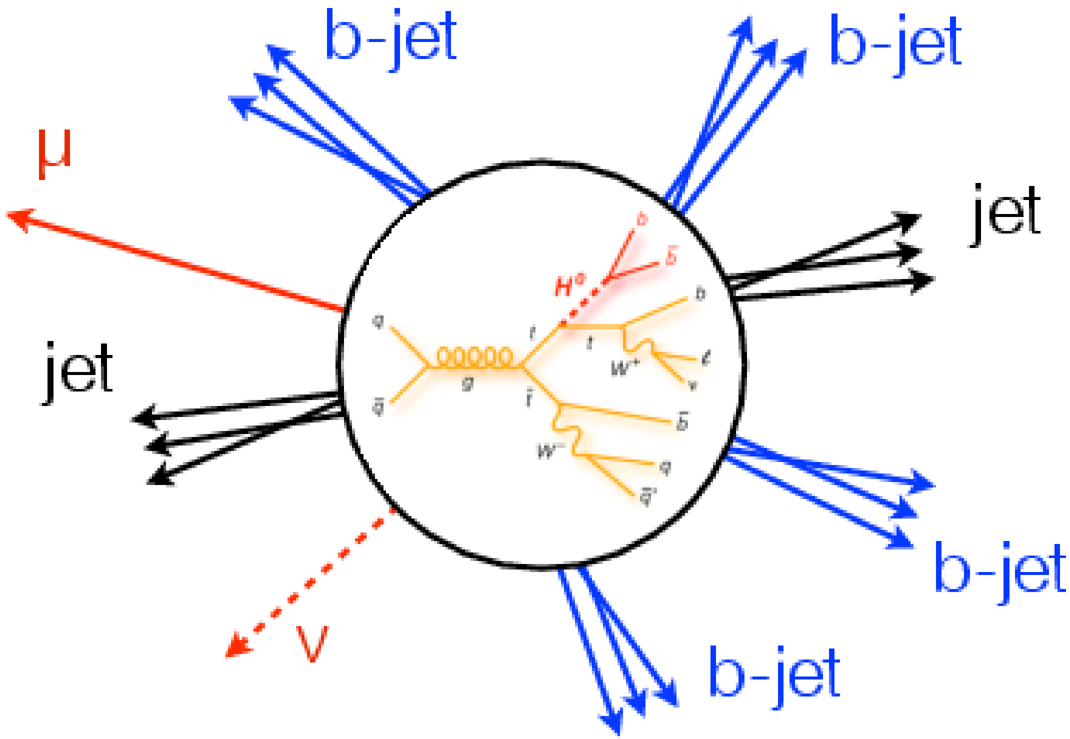


2. Large background (tt+jets)

3. Potentially additional/ missing jets

Jet-Quark Association

- Produced in collision: Quarks
- Measured in experiment: Jets
- Large number of possible permutations for assignment
- knowledge of particle identities allows calculation of useful variables



→ Event Reconstruction

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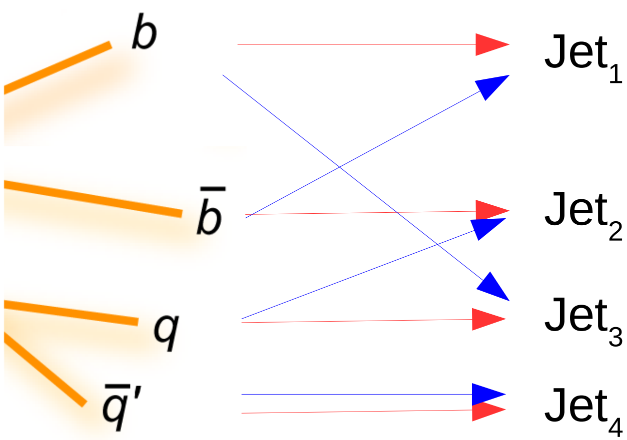
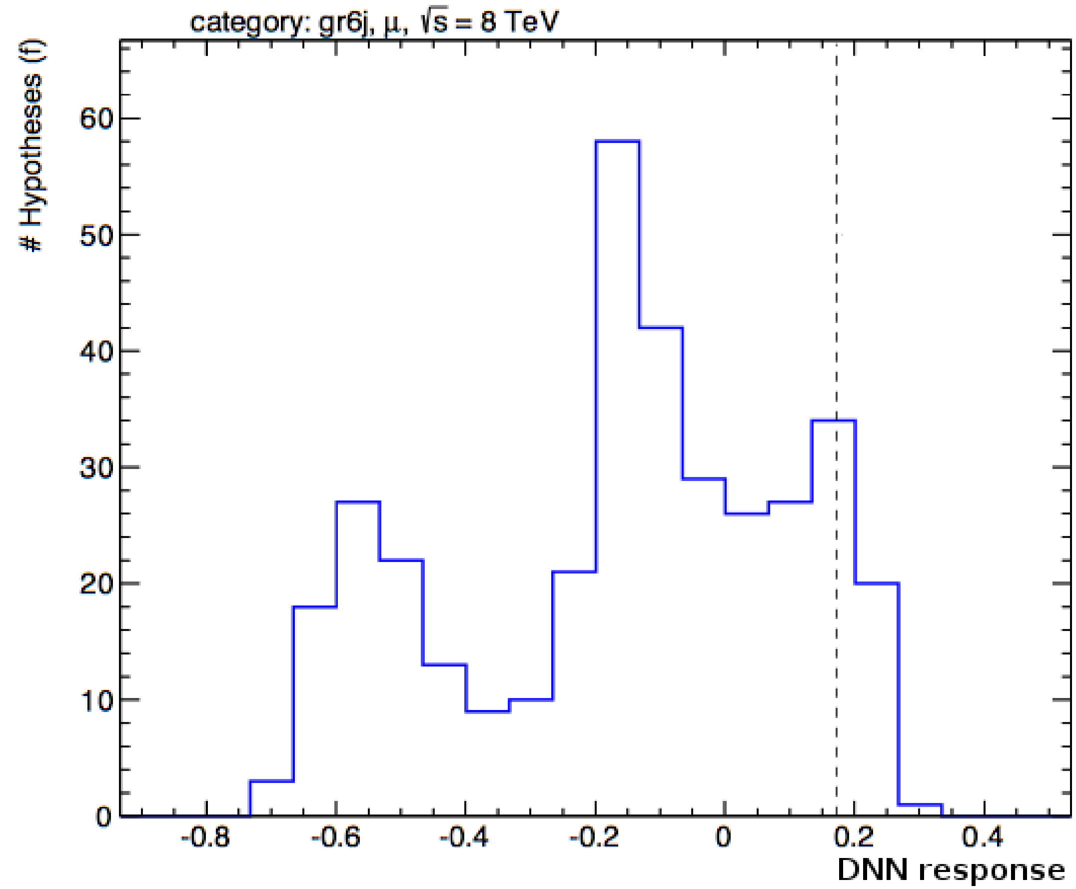
Event Reconstruction with DNNs

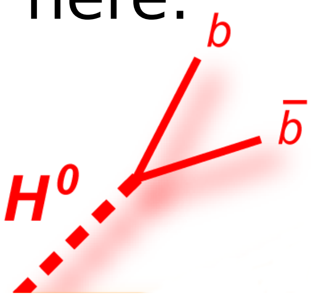
- Consider all possible permutations of jets
  - ➔ Hypothesis as DNN input



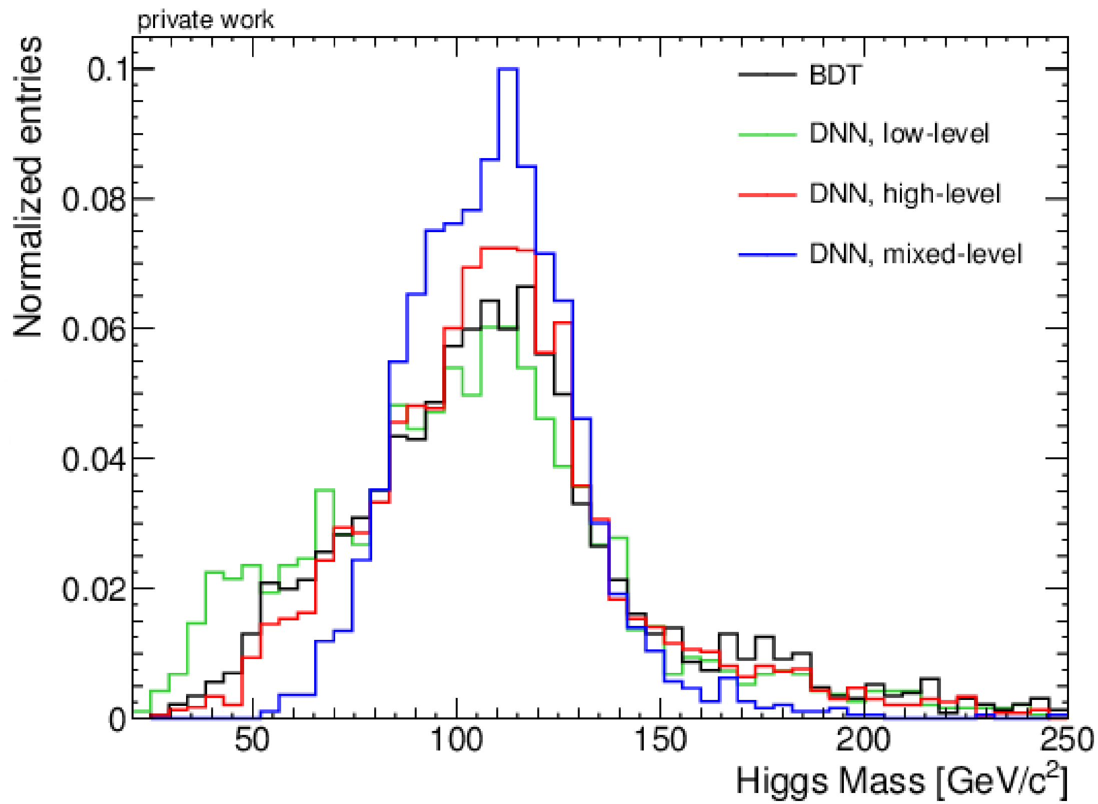


- Label correct permutation as 1, all other as -1
- Use permutation with highest output value as reconstructed event

- Two performance measures shown here:
  - Higgs mass reconstruction



  - Event reconstruction efficiencies



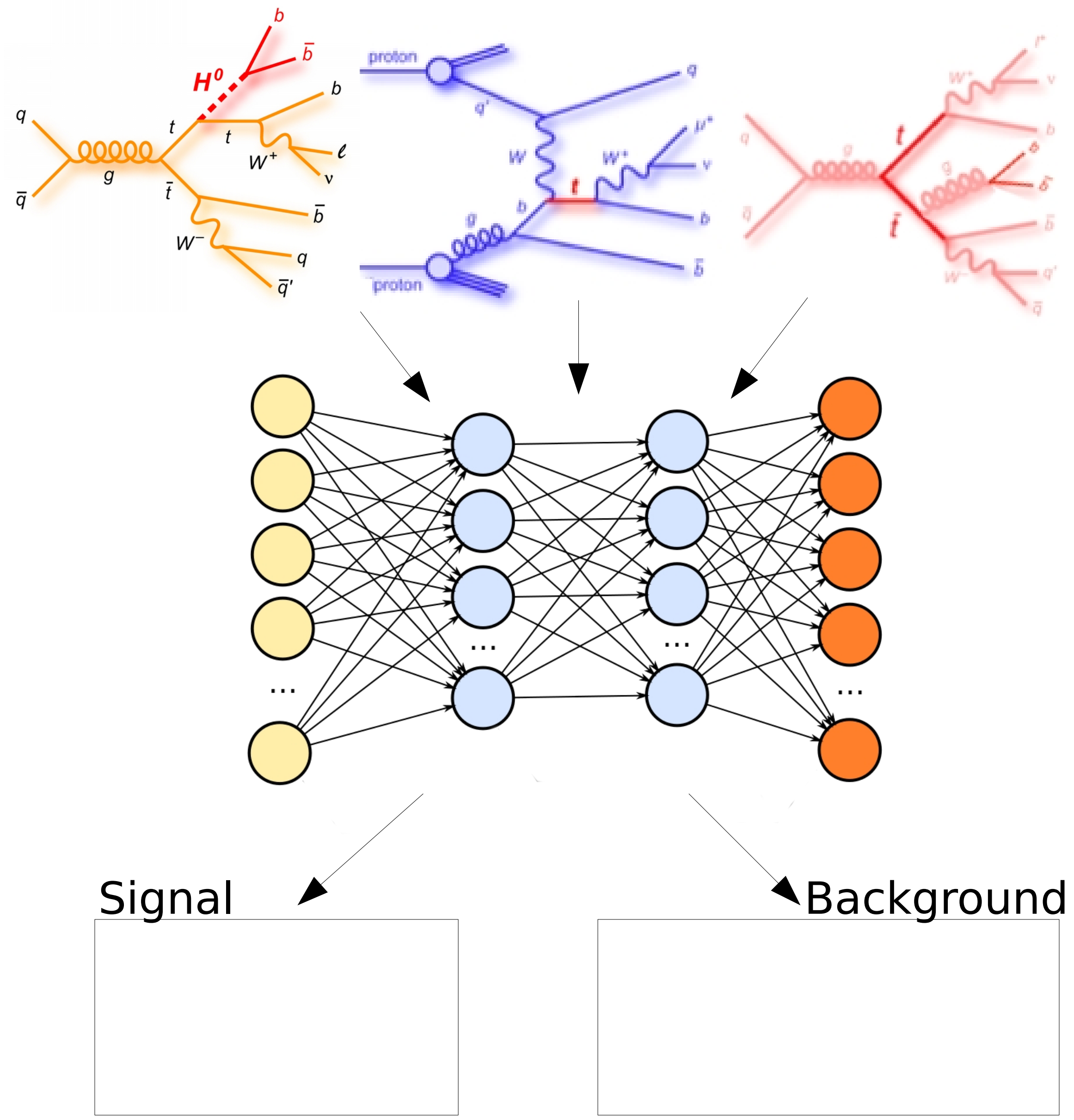
	ttH	H
Benchmark(BDT)	25.5%	35.1%
DNN, high-level	31.6%	42.2%
DNN, mixed-level	38.8%	52.0%

→ Reconstruction with DNN, use both high- and low-level variables

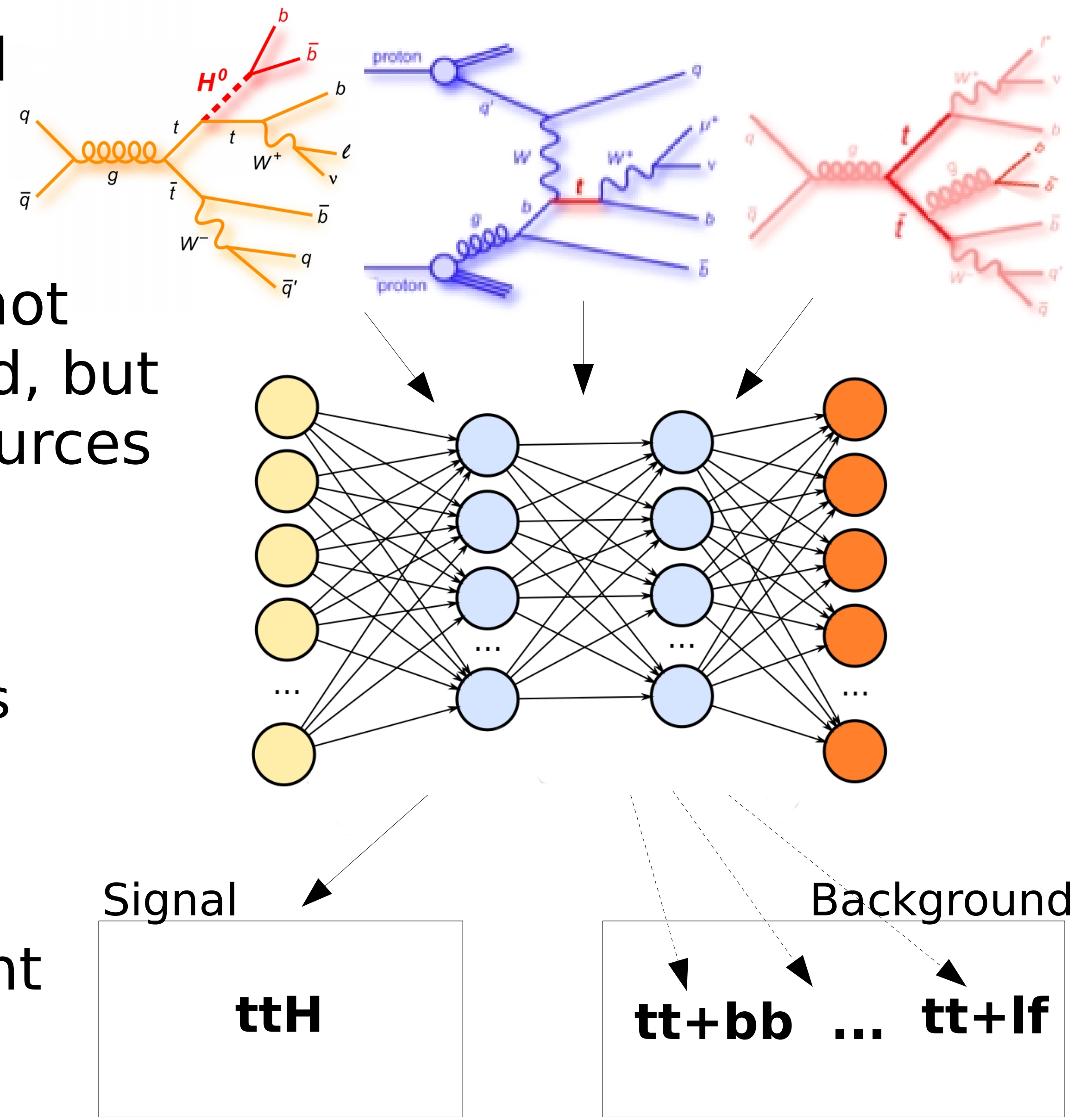
Event Classification

Signal Separation & Classification

- Large background → Need signal vs. background separation



- Large background → Need signal vs. background separation
- With DNN: Can separate not only signal vs. background, but signal and background sources against each other
  - Multiclassification task
  - Classes: Different physics processes



- Why separation of different backgrounds?

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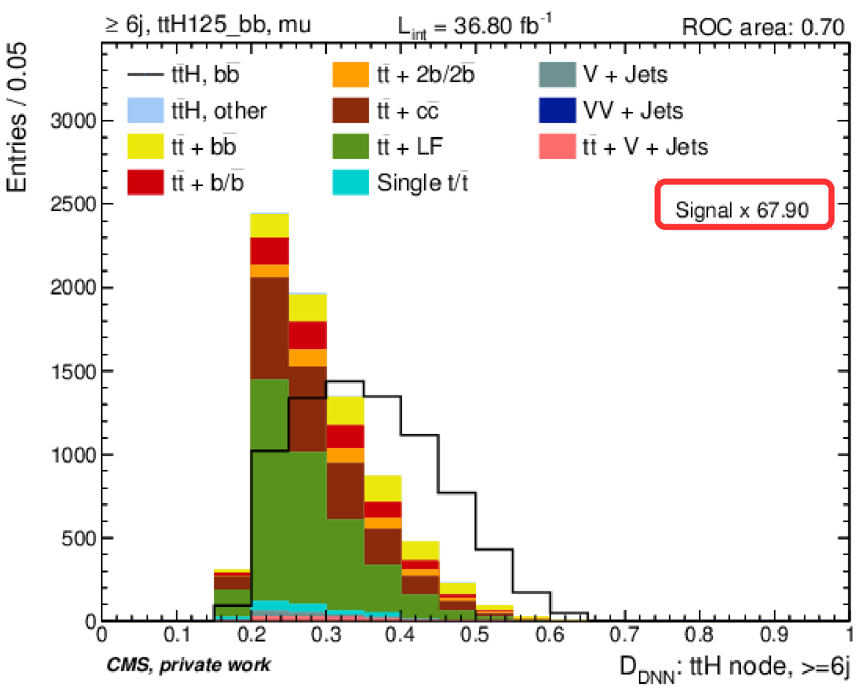
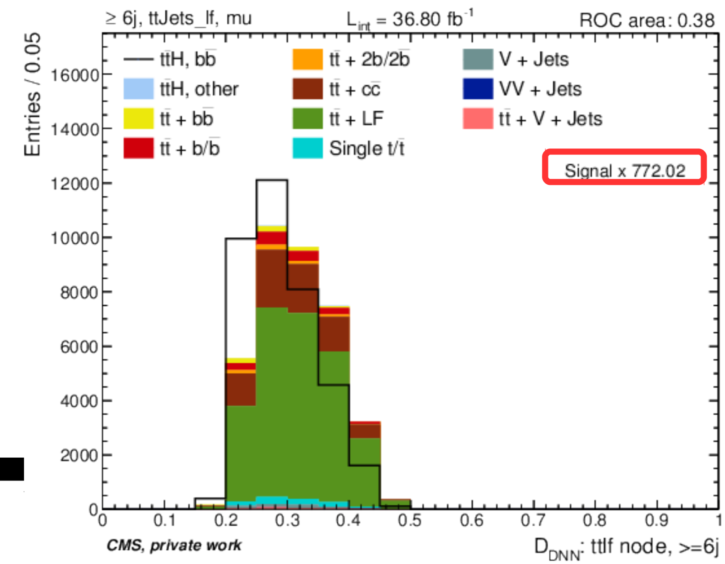
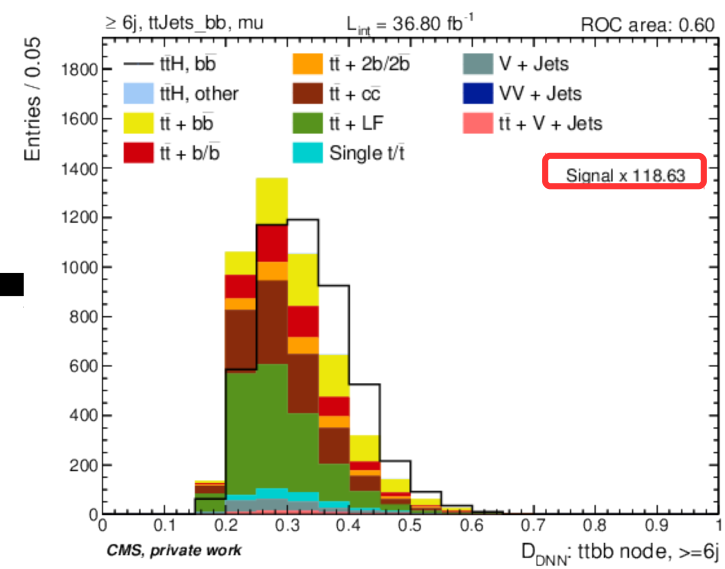
- Processes have associated systematic uncertainties
- Analysis: Perform global fit across all categories





constrain

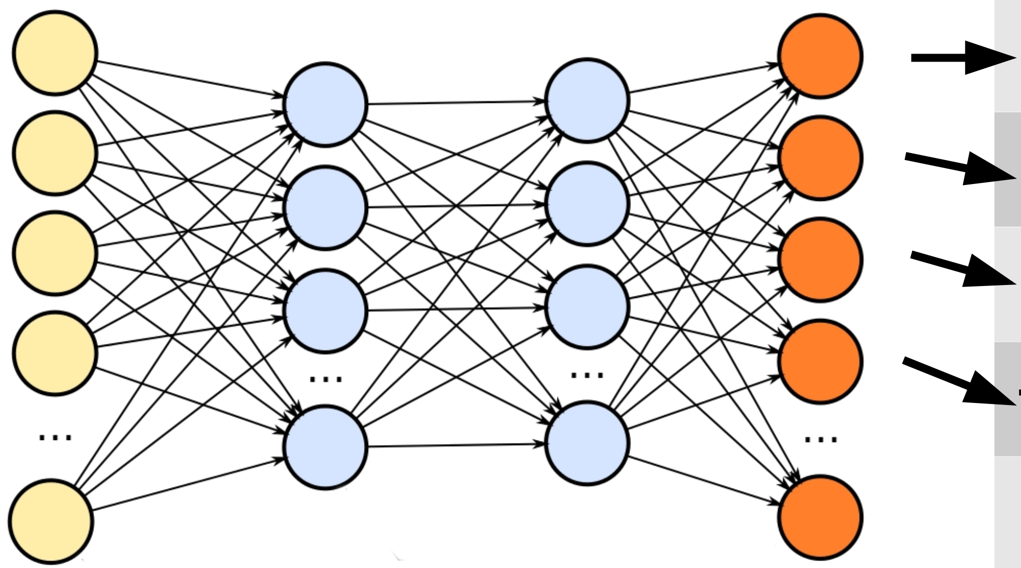


constrain

→ Separate categories for each background process can improve constraints of their uncertainties

Categorization with Neural Networks

- One output node for each physics process
- Fully connected NN
  - 3-4 hidden layers with ELU activations
  - Trained using ADAM
  - Regularization with Dropout, L2



ttH	0.6
ttlf	0.0
ttcc	0.1
ttbb	0.2
...	...
Σ	1

- Use NN output for separation within categories

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Categorization Impact on Sensitivity

- Combine results from all categories

- Calculate sensitivity of analysis
  - Compare with benchmark strategy
    - ➔ Using DNN only for separation, different common categorization scheme

→ ~19% increase in sensitivity

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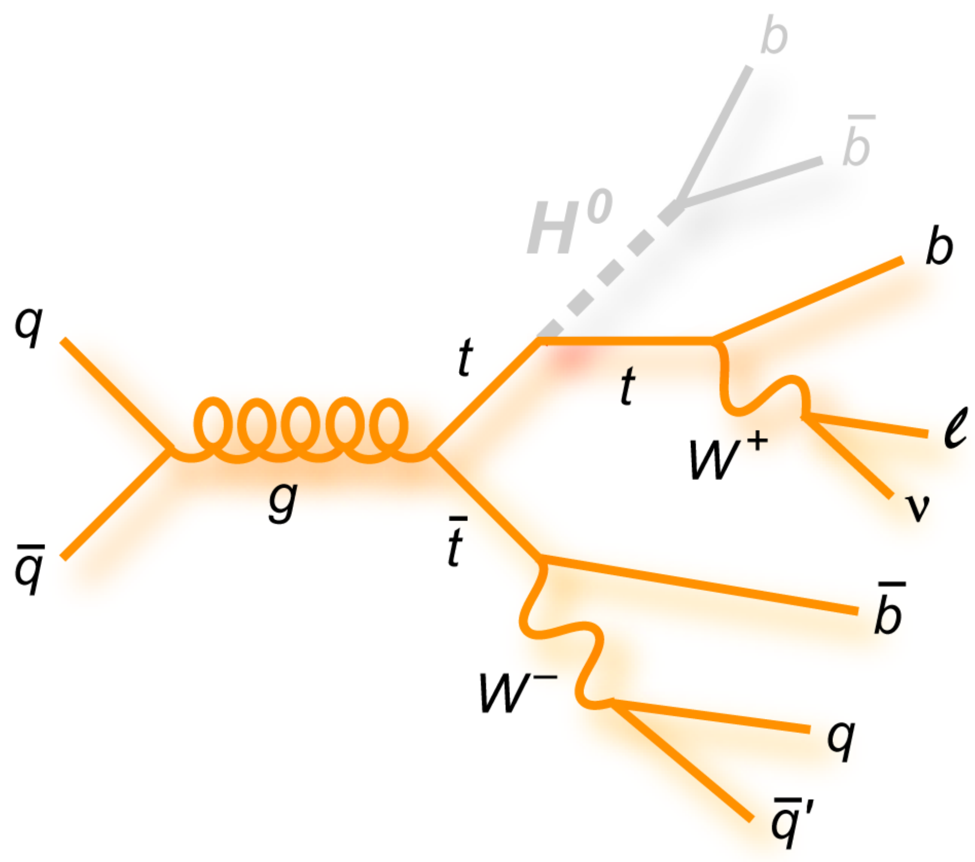
Training Optimization

- Problem: Not all jets detected (limited detector acceptance etc.)
  - Different topologies for events of the same class
- Idea: Provide additional information during training
  - Flags that specify event content
    - Example: Has_H, has_W, …
- But: How to include into network design?



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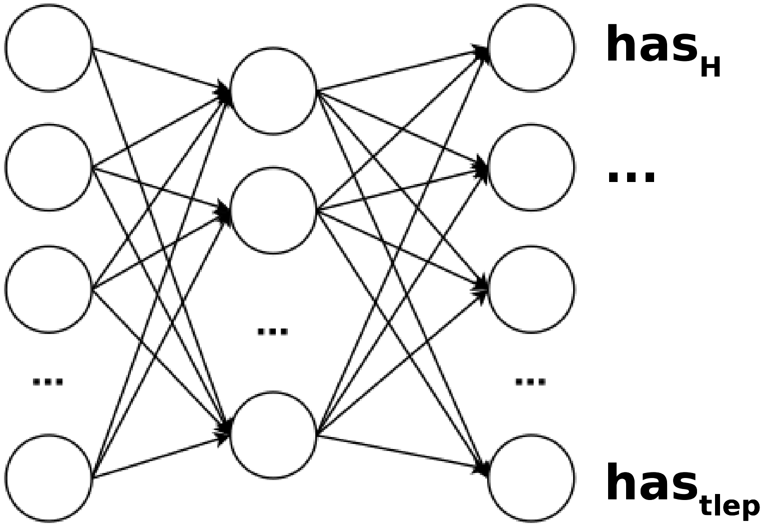
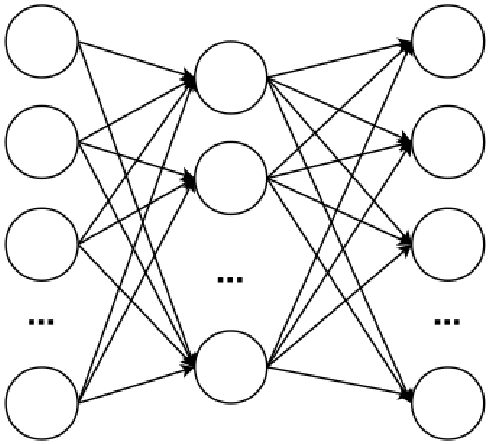
Two Staged Neural Network Training

- Flags that specify event content
  - Use as training target
    - ➔ Events can have multiple outputs



➔ **Extend network**



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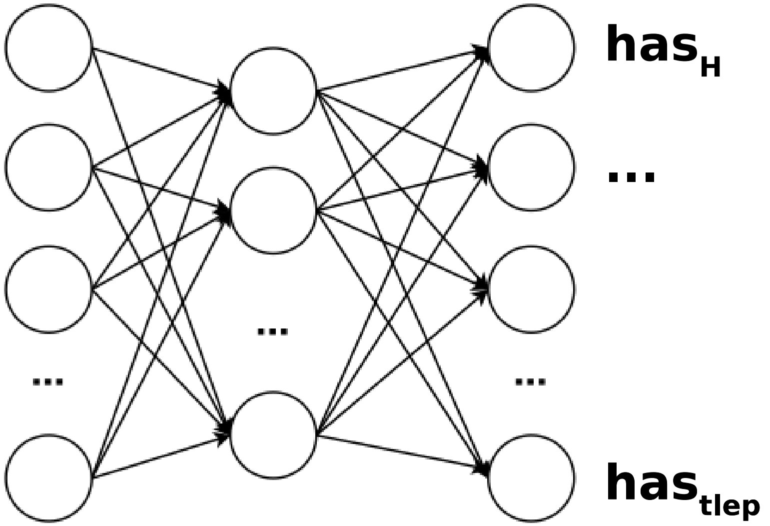

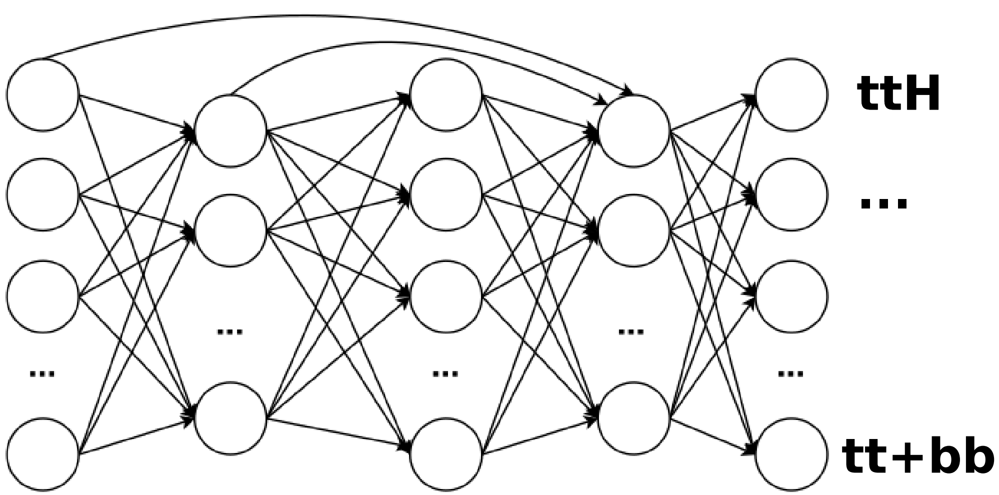

- Extend network
- Train on processes
- Connect first new layer to previous layers
  - ➔ Make use of learned internal representations
- Keep previous layers trainable

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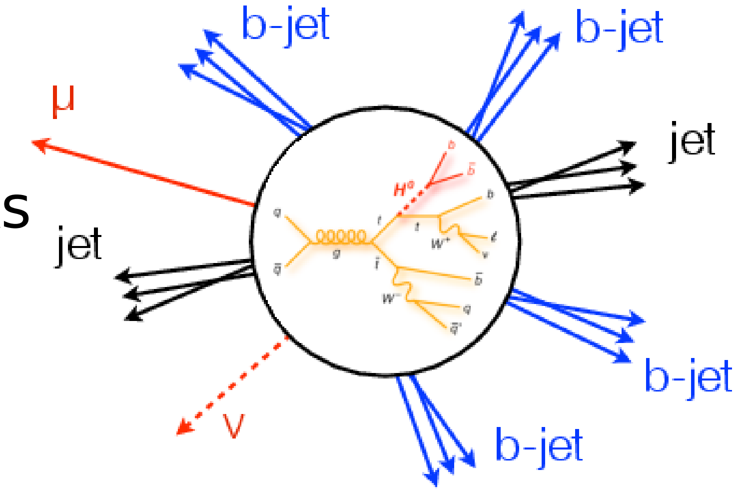
Impact of Training Optimization

- Again calculate sensitivity of analysis
  - Compare to result without this training optimization

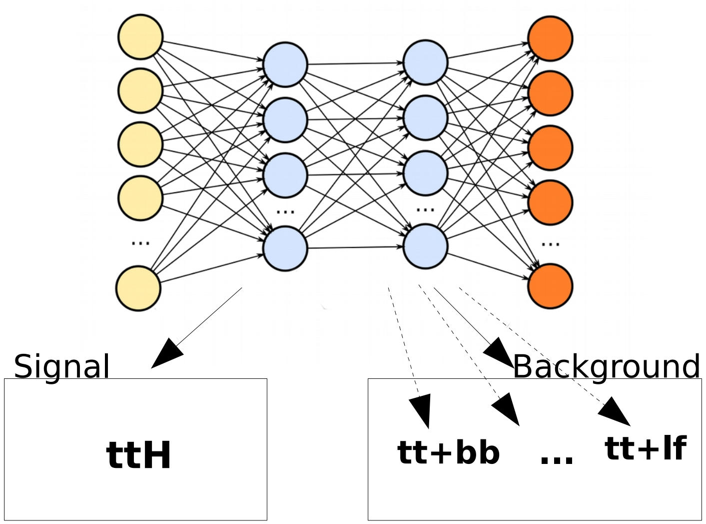
- Further improvement of ~8% due to the additional information provided

Summary

- Multiple applications of neural networks in a high-energy physics analysis



- Event reconstruction with neural networks by identifying correct permutation of particles



- Event classification into underlying physics processes
  - Improves sensitivity of analysis
  - Training can be assisted by providing additional information in the form of intermediate training targets

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