Analysis of $t\bar{t}H(b\bar{b})$ with DNN, BDT and MEM Techniques at CMS

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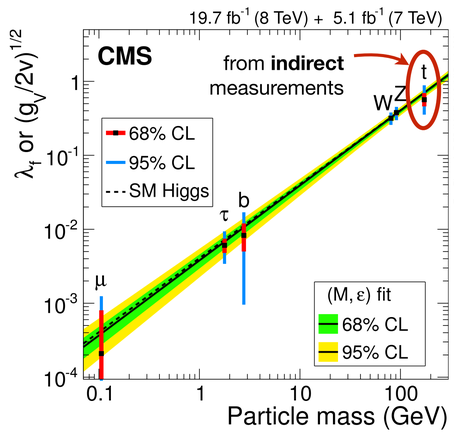
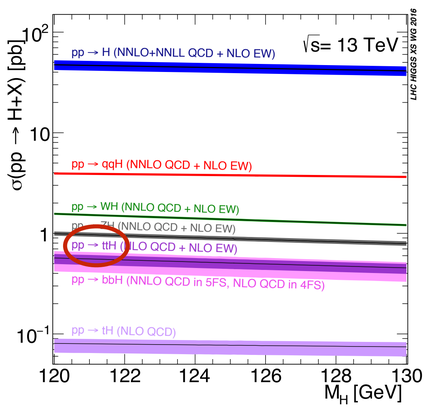
Motivation

$t\bar{t}H$ in the Standard Model

Direct measurement of the $t\bar{t}H$ cross section **offers unique access** to the **Yukawa coupling** to decisively **probe the Standard Model**

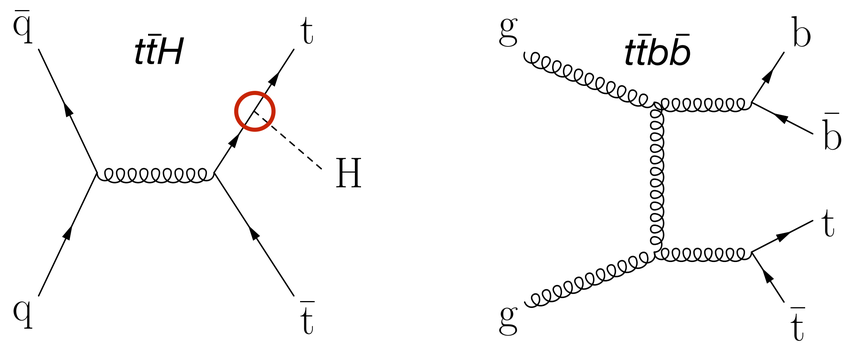
$$\mathcal{L}_{\text{Yukawa}} = -\sum_f \lambda_f \frac{\nu}{\sqrt{2}} \bar{\psi}_f \psi_f + \lambda_f \frac{1}{\sqrt{2}} \bar{\psi}_f \psi_f H$$





Analysis Challenges

1. $t\bar{t}H$ is **very rare** compared to $t\bar{t}$ (main background):
   $\sigma_{t\bar{t}H} = 0.5071$ pb vs. $\sigma_{t\bar{t}} = 831.76$ pb ($\sqrt{s}$ = 13 TeV, m_H = 125 GeV)
2. **Irreducible** backgrounds:
   (e.g.) $t\bar{t}b\bar{b}$ has same final state and event topology
3. Uncertain **background modeling**:
   $\Delta\sigma_{t\bar{t}b\bar{b}} \sim 50\%$ → $\Delta\sigma_{t\bar{t}b\bar{b}} \cong 7 \times \sigma_{t\bar{t}H}$

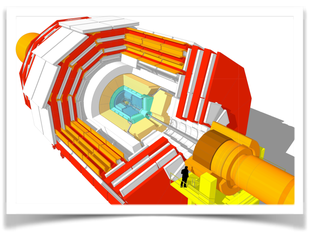


→ Challenging analyses require sophisticated methods

Current Strategy

Events → Categorize → Input variables / Matrix elements → BDT discriminators / MEM discriminators → Fit to data → Results

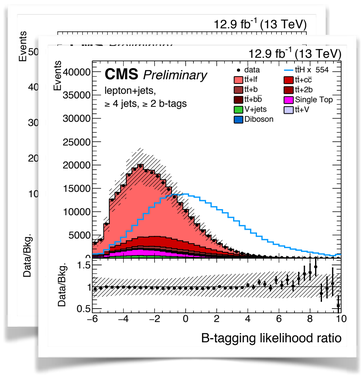
Events



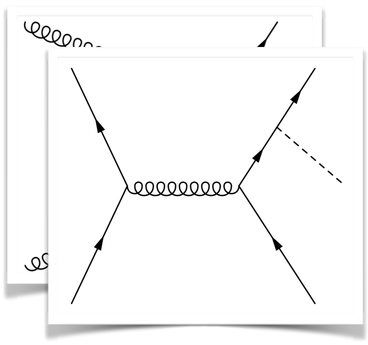
Categorize

Use
- number of jets
- number of b-tags

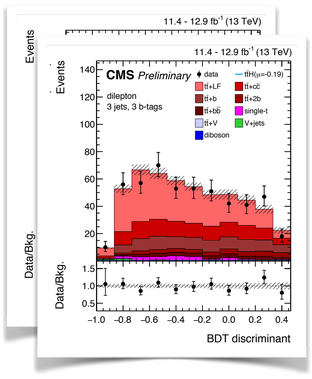
Input variables



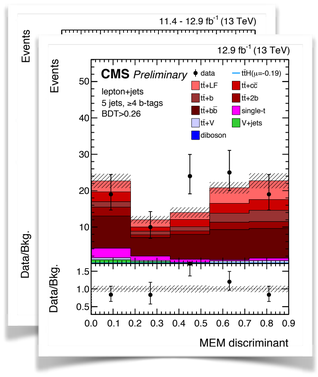
Matrix elements



BDT discriminators



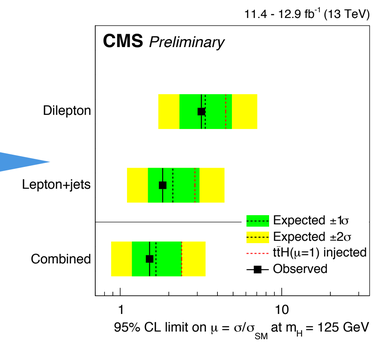
MEM discriminators



Fit to data

Expectation
+
sys. uncertainties
(nuisance parameters)

Results



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DNN Strategy

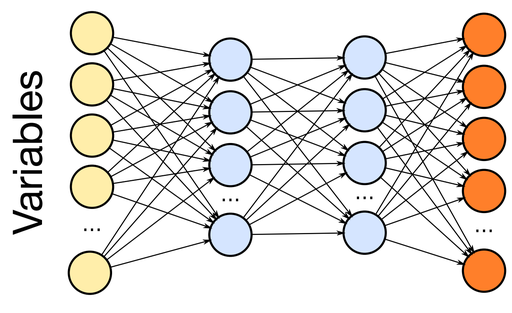
Event Categorization using Deep Learning

Precision of usual categorization scheme using **jets & b-tags degrades** in events with **high b-tag multiplicity**

→ Probability to tag **4 b-tags** with $\varepsilon_{\text{b-tag}} \approx 70\%$ is **only 24%**

→ Use **DNNs** to categorize using jets & **most probable process**

Events → Variables → Multi-classification → Probability → Categorize



Probability	
$t\bar{t}H$	0.41
$t\bar{t}b\bar{b}$	0.18
$t\bar{t}c\bar{c}$	0.13
$t\bar{t}lf$	0.09
...	...
	Σ = 1

Use
- number of jets
- process with **highest** DNN output

Multi-class approach generates **enriched categories** for **signal** and **each background**

→ Backgrounds constrained separately in fitting procedure

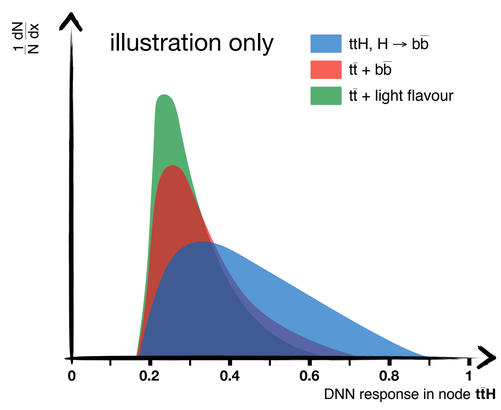
→ Improves extraction of parameters of interest (POI)

DNN Discriminators

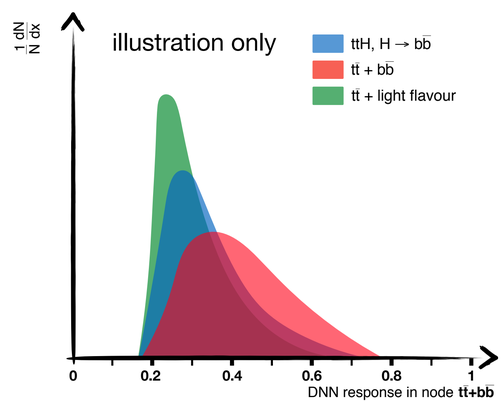
Output of categorization network yields **powerful discriminators**, one for **each** involved process vs. **all** other processes

Example

Output of $t\bar{t}H$ node



Output of $t\bar{t}b\bar{b}$ node



→ Works best in conjunction with DNN categorization

→ Improves **simultaneous measurement** of two POIs: fit of both $t\bar{t}H$ & $t\bar{t}b\bar{b}$ can exploit both discriminators