Search for Higgs production in association with a top quark pair in the H-\(\rightarrow\)bb final state

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Introduction

• LHC and ATLAS
• Higgs Production
• $ttH \rightarrow bb$ semileptonic channel
• Matrix Element Method
• MVA Techniques
LHC and ATLAS

- Large Hadron Collider
- 27 km circumference
- Proton beams colliding at 13 TeV centre-of-mass energy

“A Toroidal LHC ApparatuS”
- 25m diameter x 46m length, 7000 tonnes
- 3000 physicists, 180 institutions involved
Higgs Production

- ggF, VBF, associated production, ttH
- ttH - fourth highest Higgs production cross-section
- Direct measurement of Higgs-top Yukawa coupling

- $b\bar{b}$ decay mode maximizes XS x BR for ttH
**ttHbb**

- $t\bar{t}H \rightarrow b\bar{b}$ semileptonic channel
  - 2 b quarks from Higgs
  - 2 b quarks from top decay $t \rightarrow Wb$
  - 1 leptonic W decay – lepton + neutrino
  - 1 hadronic W decay – 2 light jets

- Main background $t\bar{t} + b\bar{b}$
  - Higgs replaced by gluon
  - Similar kinematics

- Combinatoric Background
  - Which b-jets are from Higgs decay?
Previous Results

Run 1 (2012)

- Tiny signal compared to background
- Run 1 - Matrix Element Method with Neural Network
- ICHEP – Reconstruction and Classification BDTs

ICHEP 2016
Matrix Element Method

- Likelihood that event was produced by a specific process

Matrix Element
  - Theoretical description of signal or background process

Parton distribution function
  - Accounts for initial collision

Transfer functions
  - Maps detector response to event level
  - Quarks undergo parton shower, hadronization → jets

\[
P_{\text{tiH}}(\vec{x}_{\text{Detector}}, m_H) = \frac{1}{\sigma_{\text{tiH}}(m_H)} \int dp_1 dp_2 f(p_1) f(p_2) \sigma_{\text{tiH}}(\vec{x}_{\text{Parton}}, m_H) W(\vec{x}_{\text{Parton}}, \vec{x}_{\text{Detector}})\]
Using MEM

- Likelihood calculated for $t\bar{t}H$ and $t\bar{t}b\bar{b}$ processes
  - Discriminating variable $D_1 = L_{t\bar{t}H}/L_{t\bar{t}b\bar{b}}$
- Computationally demanding
  - 7D integration over jet energies, neutrino $p_z$
  - Monte Carlo integration – VEGAS
  - Implementation can run on CPUs or GPUs
- 12 different b-jet assignment for b quarks
  - Use sum of likelihoods for all permutations

![ATLAS Work in progress](image)
MEM Inputs

• 1 Lepton
  • Assume well-measured in detector ($\delta$-function TFs)
• 1 Neutrino
  • $\vec{p}_T = -\Sigma \vec{p}_T$ of final state particles
  • Integrate over $p_z$ (or solve assuming on-shell W)
• Quarks
  • b quarks: 4 highest $p_T$ b-tagged jets
  • Light quarks: 2 remaining jets that minimize $|m_W - m_{jj}|$
  • Jet directions assumed well-measured
  • TFs to constrain integration over parton energy

Initial state partons
• Assume aligned with beam axis
• Solve for $E, p_z$ with final state $\Sigma E, \Sigma p_z$
Transfer Functions

- PDF for parton energy for given jet energy
- Double Gaussian or Crystal Ball function
- Parameters dependent on $E_{\text{jet}}$
- Different TFs for b-jets, light jets

$$C(B_j, E_p) = N \cdot \begin{cases} \exp \left( -\frac{x^2}{2} \right) & x \leq \alpha \\ A \cdot (B + x)^{-n} & x > \alpha, \end{cases}$$

$$\begin{align*}
x &= \frac{E_p - E_j - \mu}{\sigma} \\
A &= \left( \frac{n}{|\alpha|} \right)^n \cdot \exp \left( -\frac{|\alpha|^2}{2} \right) \\
B &= \frac{n}{|\alpha|} - |\alpha| \\
C &= \frac{n}{|\alpha|} \cdot \frac{1}{n-1} \cdot \exp \left( -\frac{|\alpha|^2}{2} \right) \\
D &= \sqrt{\frac{n}{2}} \left( 1 + \text{erf} \left( \frac{|\alpha|}{\sqrt{2}} \right) \right) \\
N &= \frac{1}{\sigma(C + D)}
\end{align*}$$
Transfer Functions

- Match quarks to jets
  - $\Delta R < 0.3$
- Fit 10 GeV $E_{jet}$ slices
- Fit resulting parameters to $E_{jet}$

$$CB(E_j, E_p) = N \cdot \begin{cases} \exp \left( -\frac{x^2}{2} \right) & x \leq \alpha \\ A \cdot (B + x)^{-n} & x > \alpha, \end{cases}$$

$$\begin{align*}
\mu &= 14.65 + 0.06293E_j - 1.976\sqrt{E_j} \\
\sigma &= 6.184 + 0.09858E_j - 0.4842\sqrt{E_j} \\
\alpha &= 0.2938 - 0.001944E_j + 0.06344\sqrt{E_j} \\
n &= 4.867
\end{align*}$$

ATLAS Work in progress
TF Validation

bjet Validation

ATLAS Work in progress
MEM BDT

- Boosted Decision Trees outperform Neural Network from Run 1
- MEM in BDT to increase sensitivity
- 9 Kinematic variables
  - e.g., $\Delta R_{bb}^{avg}$, $M_{bb}^{min}$, $\Delta \Delta \eta_{jj}^{max}$
- Can combine with other MVA techniques for greater separation
Comparison to previous results

- ROC curve
  - Sig vs bkg fraction remaining after continuous cuts on BDT
- Similar separation power to baseline from ICHEP
- Improvement when combined

![ROC Curve](image)
Status and Outlook

- MEM performs as well as other MVA techniques
- Motivated by theory
- Can be combined to increase performance
- Working on result for 2015-2016 data
- Expect evidence for ttH in combination with all decay channels by end of 2017
Thank You