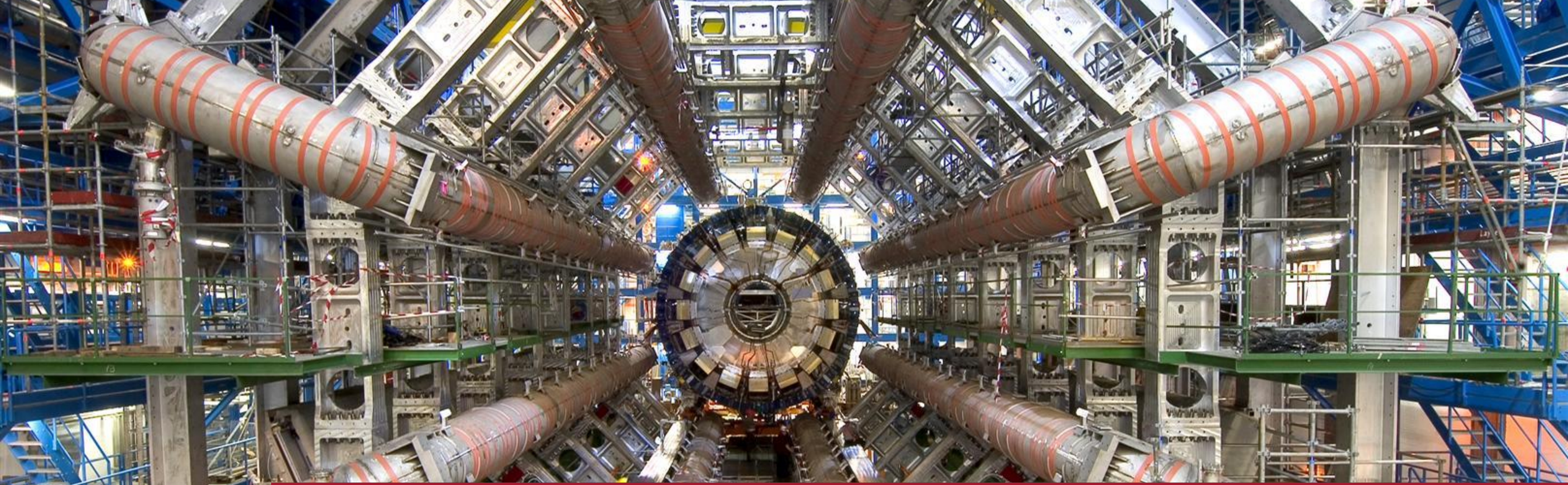


Search for Higgs production in association with a top quark pair in the H->bb final state

Daniel Mori

May 30, 2017

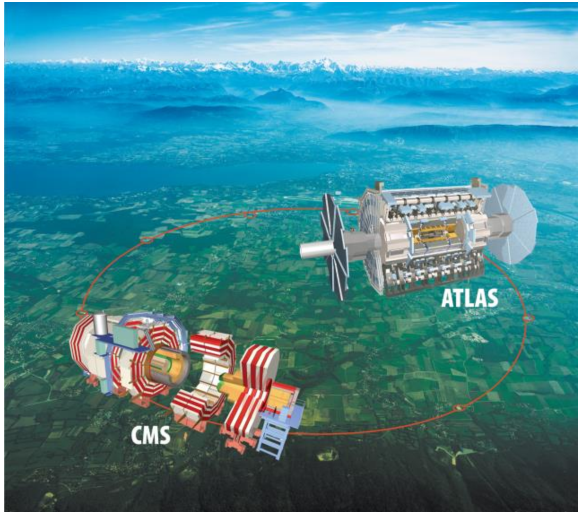
SFU SIMON FRASER UNIVERSITY
ENGAGING THE WORLD

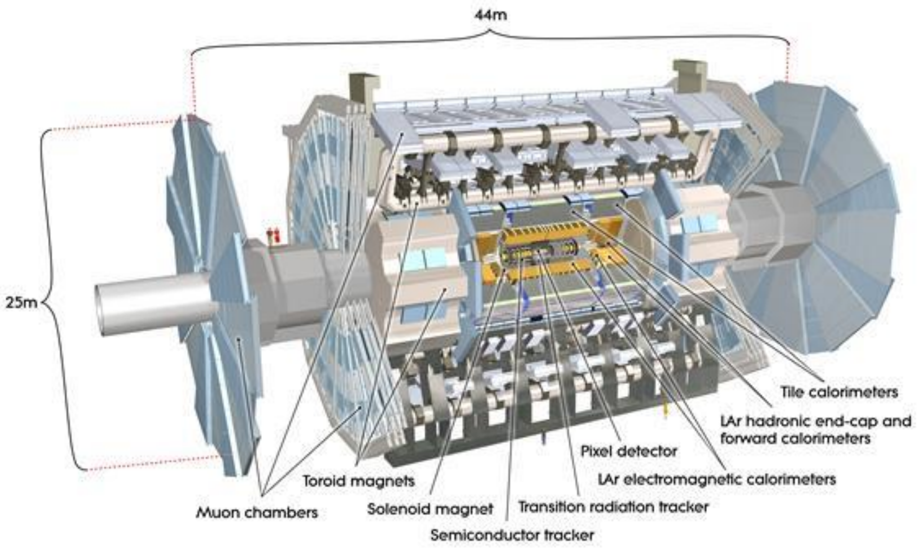
Introduction

- 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

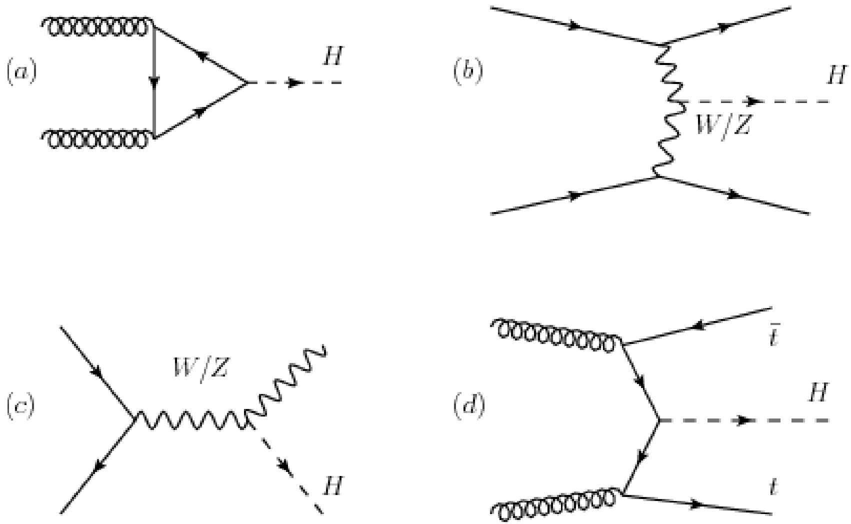


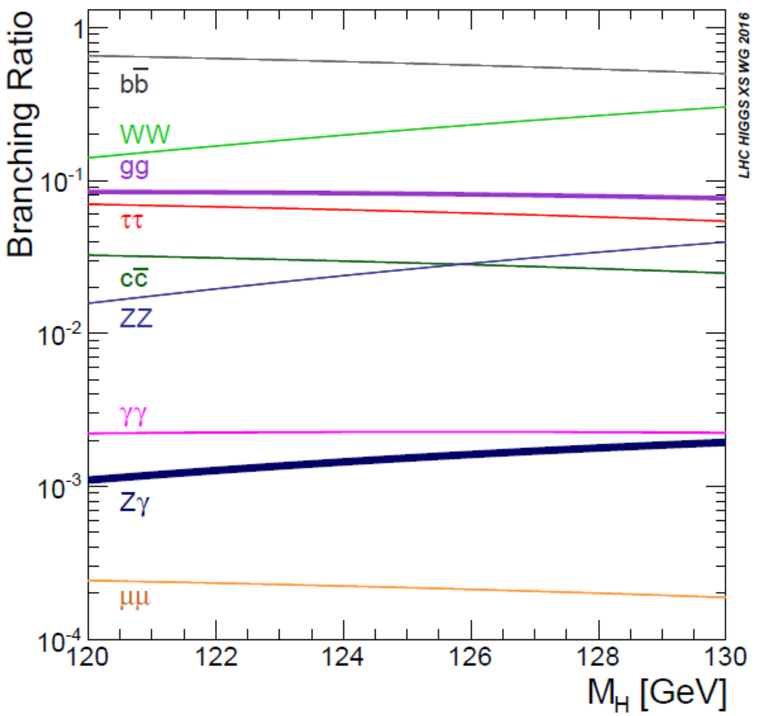


- “A Toroidal LHC ApparatuS”
- 25m diameter x 46m length, 7000 tonnes
- 3000 physicists, 180 institutions involved

Higgs Production

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

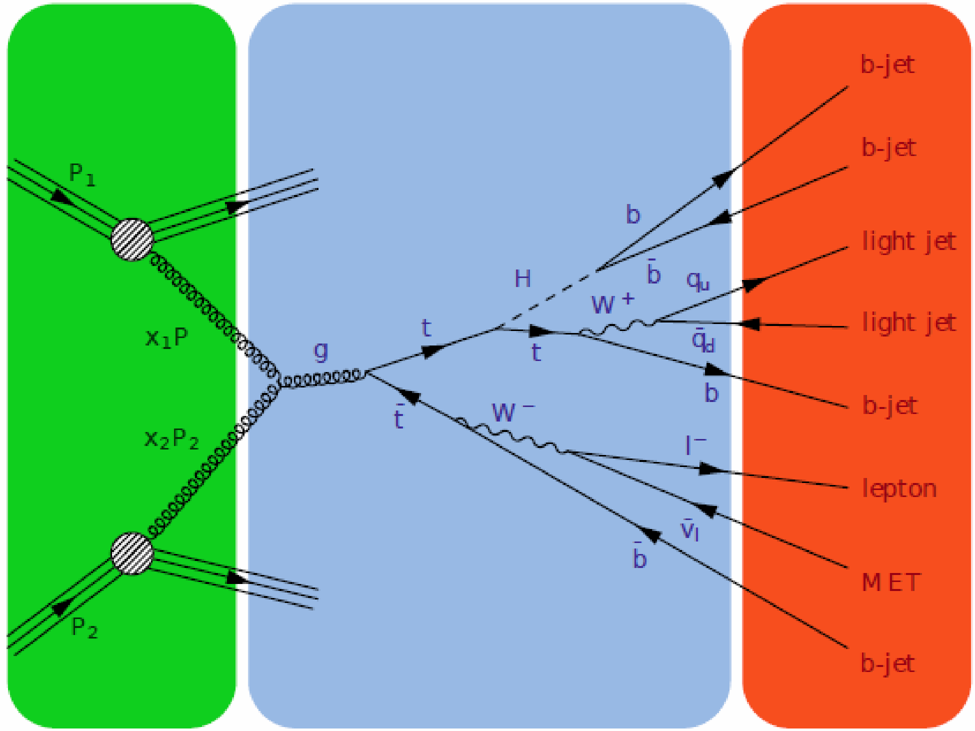




- $b\bar{b}$ decay mode maximizes XS x BR for ttH

ttHbb

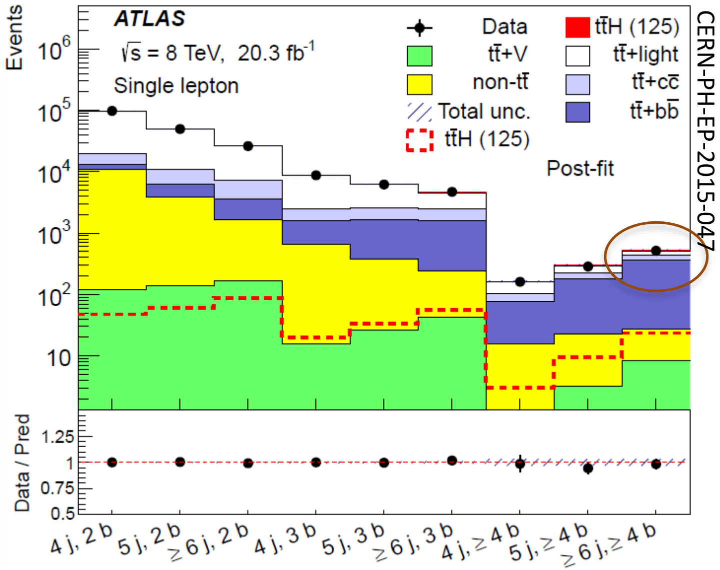
- $t\bar{t}H \rightarrow b\bar{b}$ semileptonic channel
  - 2 b quarks from Higgs
  - 2 b quarks from top decay $t \rightarrow Wb$
  - 1 leptonic W decay – lepton + neutrino
  - 1 hadronic W decay – 2 light jets
- Main background $t\bar{t} + b\bar{b}$
  - Higgs replaced by gluon
  - Similar kinematics
- Combinatoric Background
  - Which b-jets are from Higgs decay?



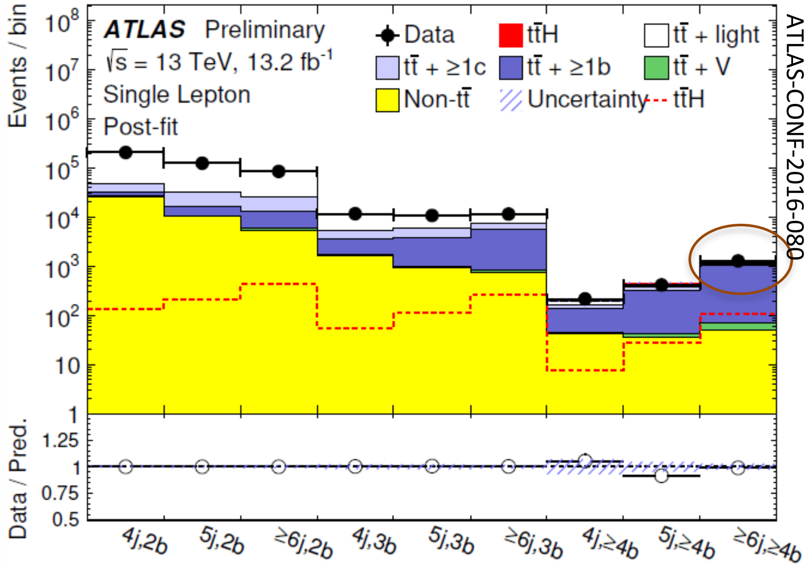
Olaf Nackenhorst, CERN-THESIS-2015-186

Previous Results

Run 1 (2012)



ICHEP 2016



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

Matrix Element Method

- Likelihood that event was produced by a specific process

Matrix Element

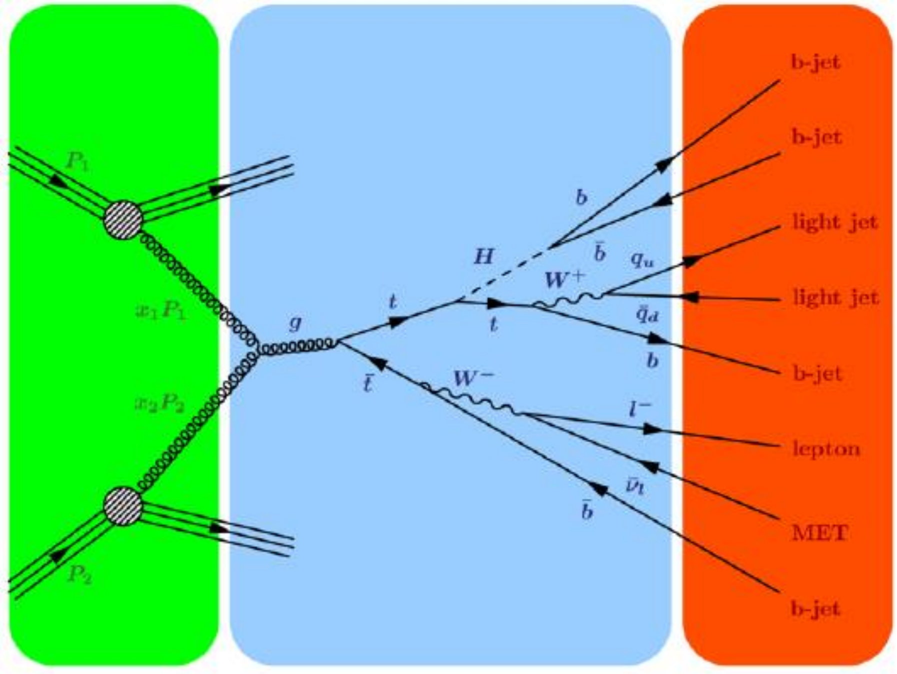
- Theoretical description of signal or background process

Parton distribution function

- Accounts for initial collision

Transfer functions

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

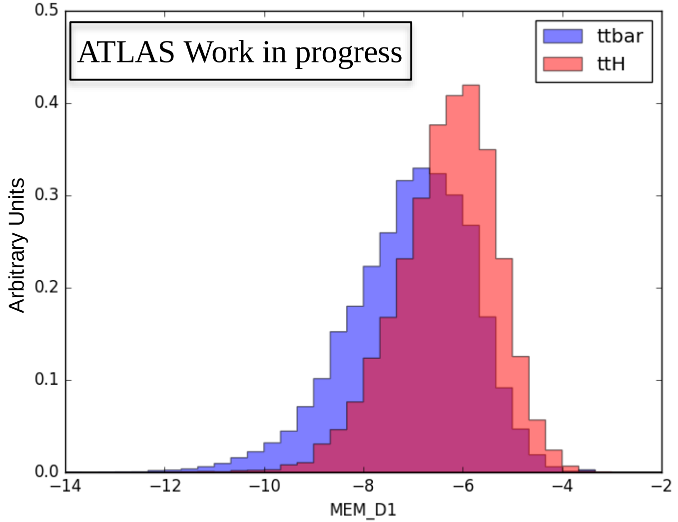


$$\underbrace{P_{t\bar{t}H}\left(\vec{x}_{\mathrm{Detector}}, m_H\right)}_{\text{probability}} = \underbrace{\frac{1}{\sigma_{t\bar{t}H}\left(m_H\right)}}_{\text{normalization}} \int \underbrace{\mathrm{d}p_{g1}\mathrm{d}p_{g2} f\left(p_{g1}\right) f\left(p_{g2}\right)}_{\text{parton density function}} \underbrace{\mathrm{d}\sigma_{t\bar{t}H}\left(\tilde{x}_{\mathrm{Parton}}, m_H\right)}_{\text{differential cross section}} \underbrace{W\left(\vec{x}_{\mathrm{Parton}}, \vec{x}_{\mathrm{Detector}}\right)}_{\text{transfer functions}}$$

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



MEM Inputs

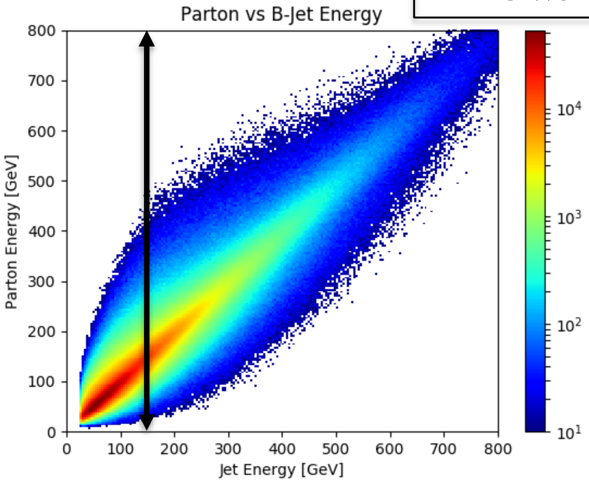
- 1 Lepton
  - Assume well-measured in detector (δ-function TFs)
- 1 Neutrino
  - $\vec{p}_T = -\Sigma\vec{p}_T$ of final state particles
  - Integrate over p_z (or solve assuming on-shell W)
- Quarks
  - b quarks: 4 highest p_T b-tagged jets
  - Light quarks: 2 remaining jets that minimize $|m_W - m_{jj}|$
  - 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_{jet}
- Different TFs for b-jets, light jets

ATLAS Work in progress



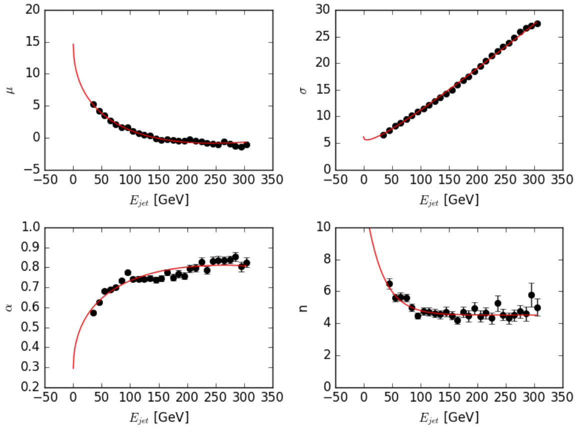
$$CB(E_j,E_p) = N \cdot \begin{cases} \exp\left(-\frac{x^2}{2}\right) & x \le \alpha \\ A \cdot (B+x)^{-n} & x > \alpha, \end{cases}$$

$$\begin{aligned} x &= \frac{E_p - E_j - \mu}{\sigma} \\ A &= \left(\frac{n}{|\alpha|}\right)^n \cdot \exp\left(-\frac{|\alpha|^2}{2}\right) \\ B &= \frac{n}{|\alpha|} - |\alpha| \end{aligned}$$

$$\begin{aligned} C &= \frac{n}{|\alpha|} \cdot \frac{1}{n-1} \cdot \exp\left(-\frac{|\alpha|^2}{2}\right) \\ D &= \sqrt{\frac{\pi}{2}}\left(1 + \mathrm{erf}\left(\frac{|\alpha|}{\sqrt{2}}\right)\right) \\ N &= \frac{1}{\sigma(C+D)} \end{aligned}$$

Transfer Functions

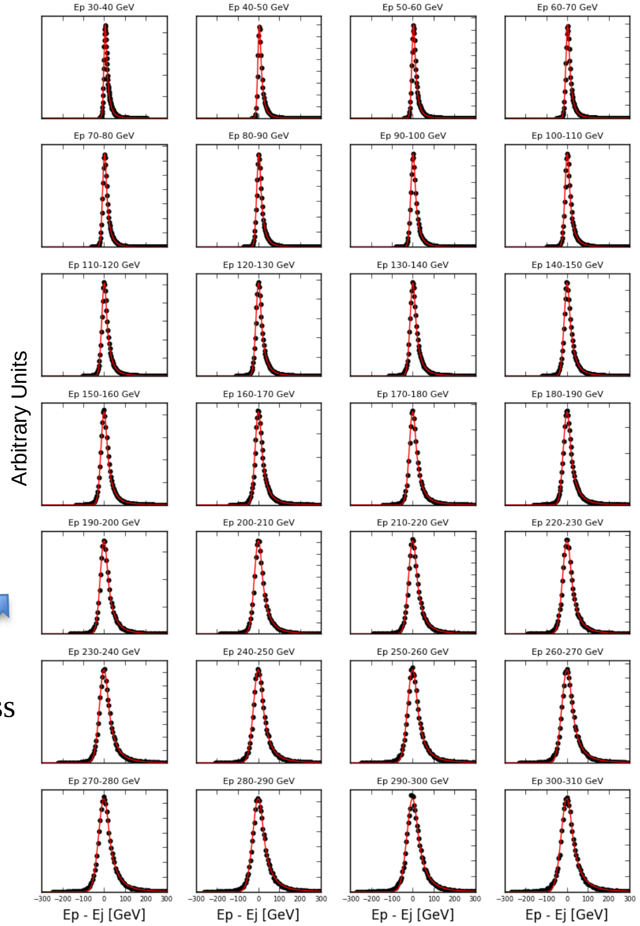
- Match quarks to jets
  - $\Delta R < 0.3$
- Fit 10 GeV E_{jet} slices
- Fit resulting parameters to E_{jet}



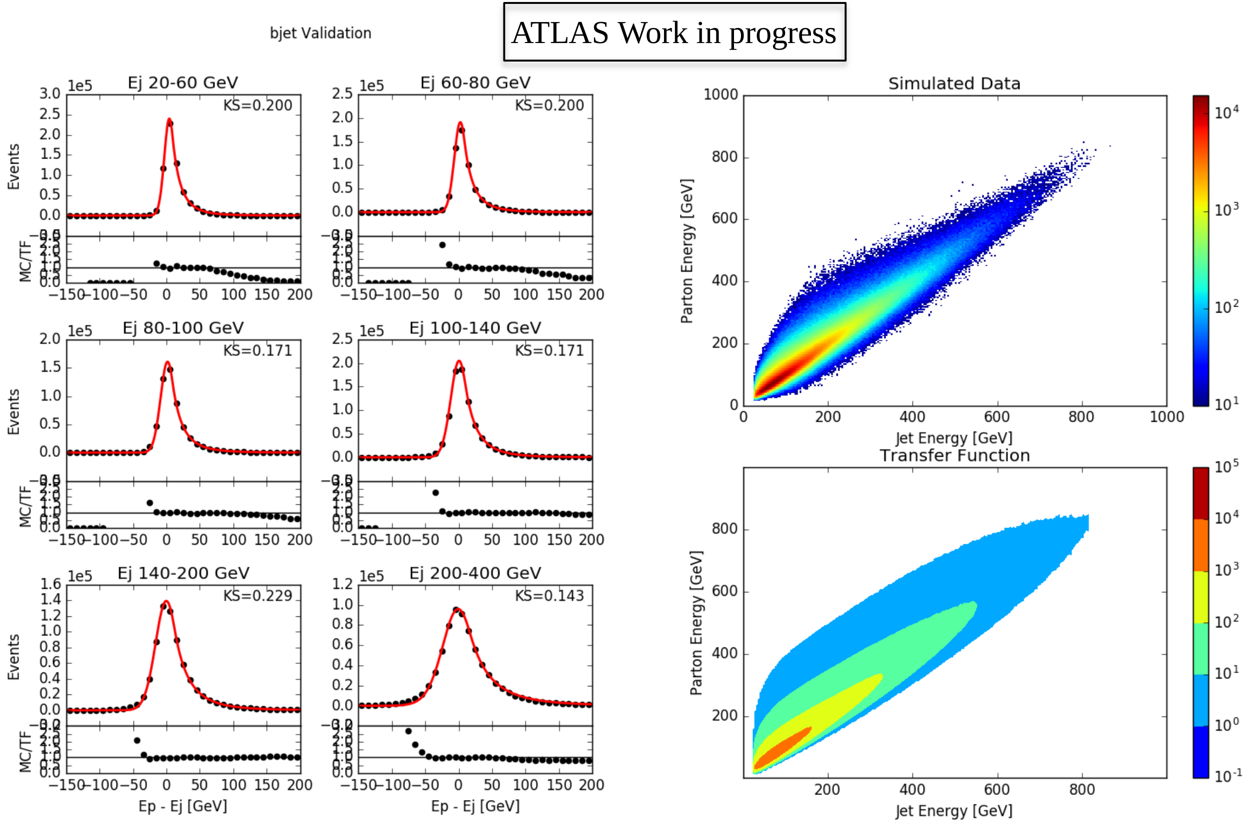
$$CB(E_j, E_p) = N \cdot \begin{cases} \exp\left(-\frac{x^2}{2}\right) & x \leq \alpha \\ A \cdot (B + x)^{-n} & x > \alpha, \end{cases}$$

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

ATLAS Work in progress

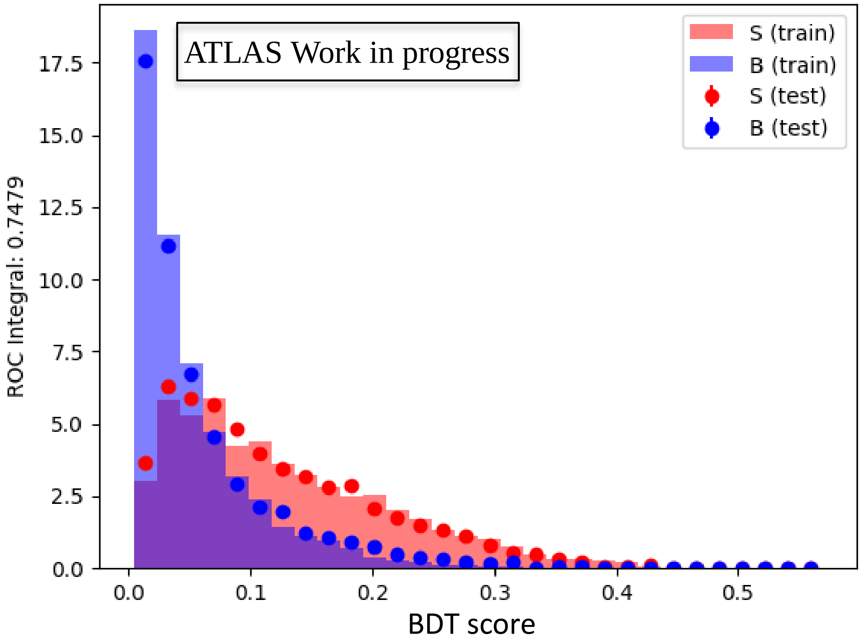


TF Validation



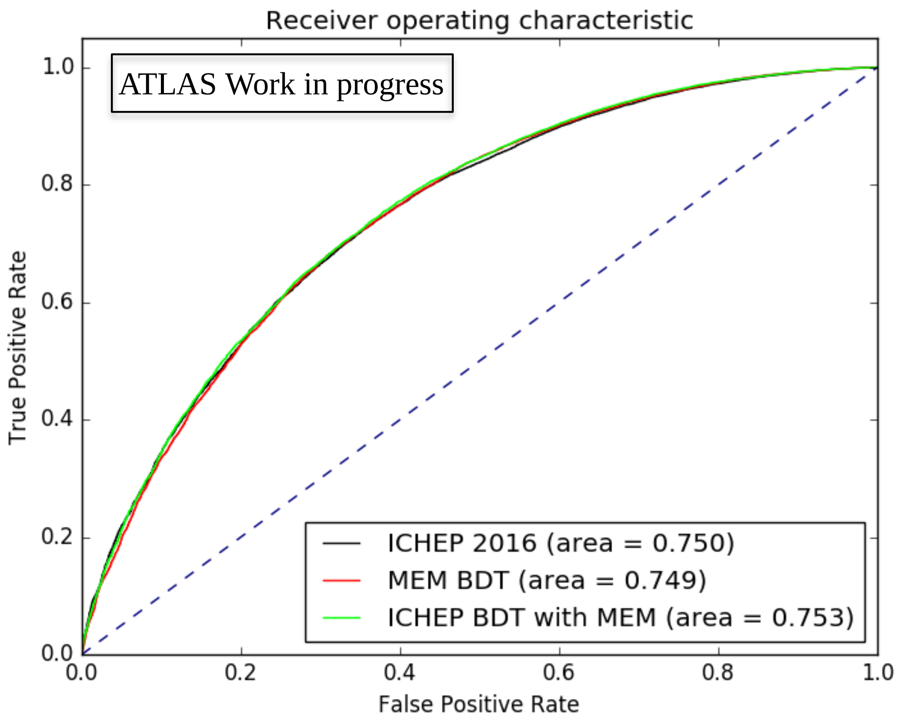
MEM BDT

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



Comparison to previous results

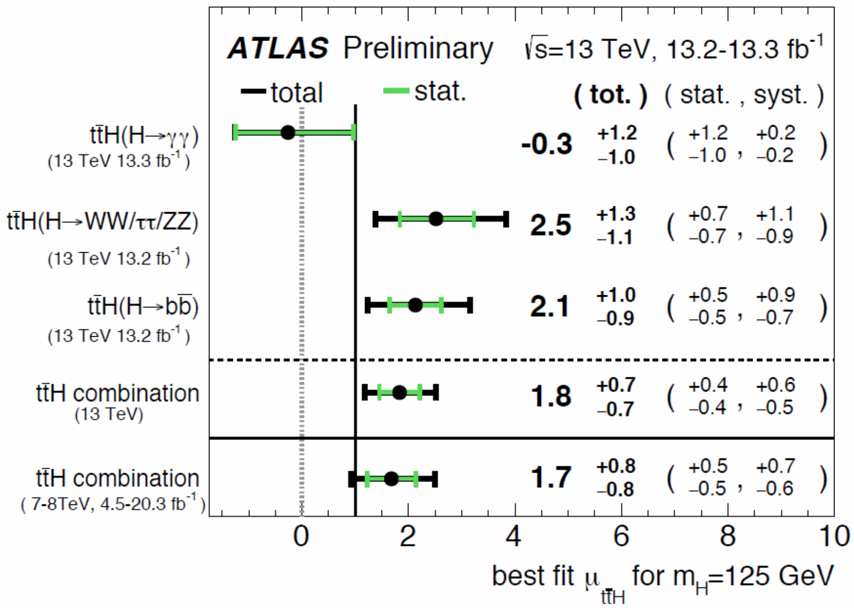
- ROC curve
  - Sig vs bkg fraction remaining after continuous cuts on BDT
- Similar separation power to baseline from ICHEP
- Improvement when combined



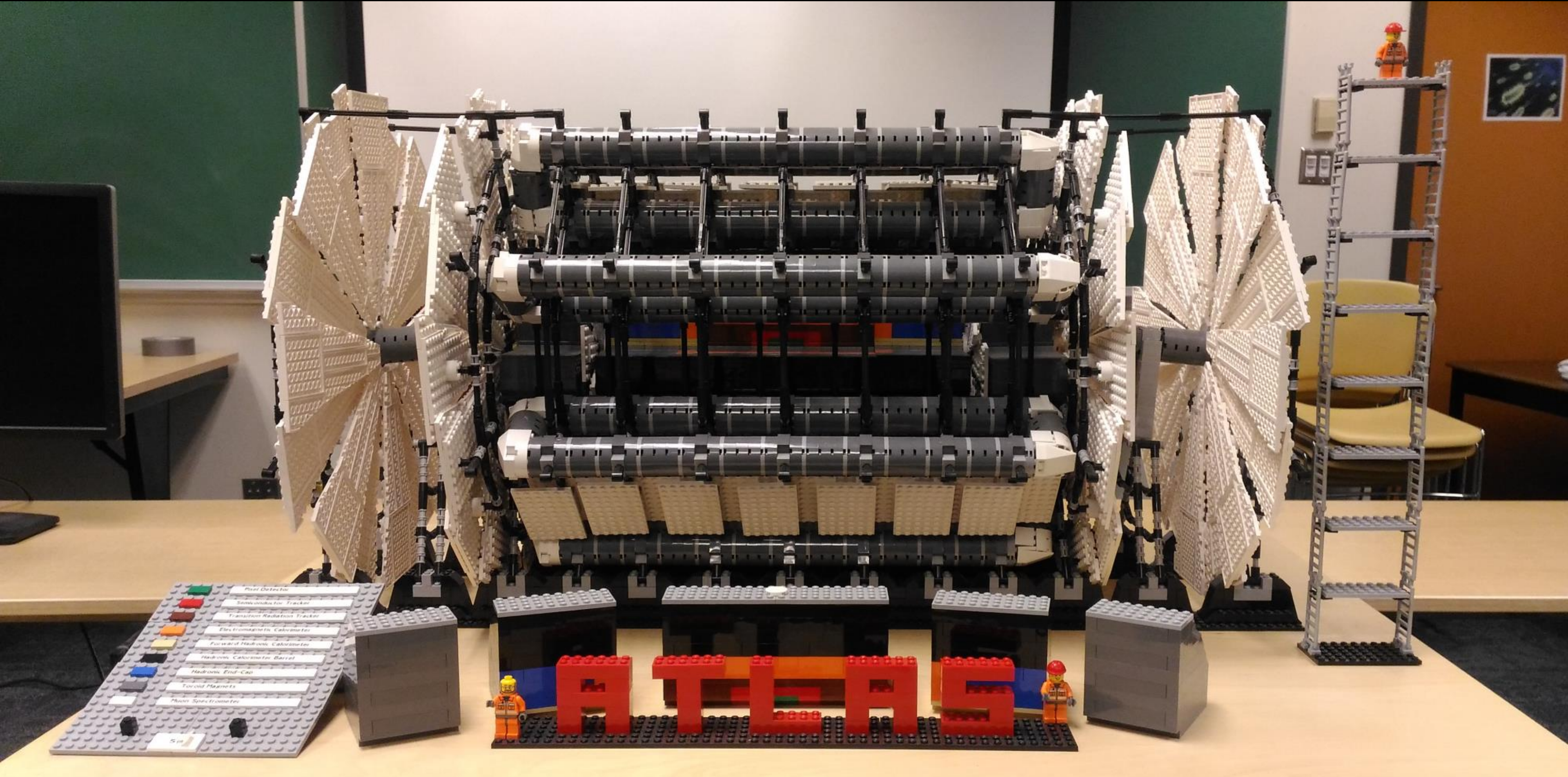
Status and Outlook

- 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

ATLAS-CONF-2016-068



Thank You


Pixel Detector
Semiconductor Tracker
Transition Radiation Tracker
Electromagnetic Calorimeter
Forward Hadronic Calorimeter
Hadronic Calorimeter Barrel
Hadronic End-Cap
Toroid Magnets
Muon Spectrometer
5 m
ATLAS