Improving Background Estimation for Di-Higgs Searches with ATLAS

PHYS 437B Presentations

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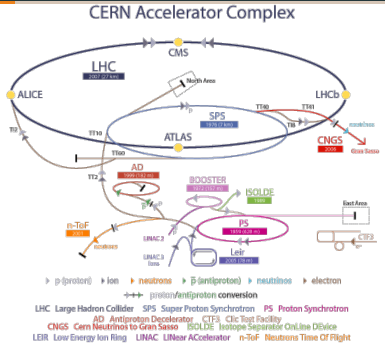
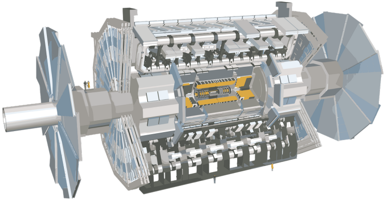
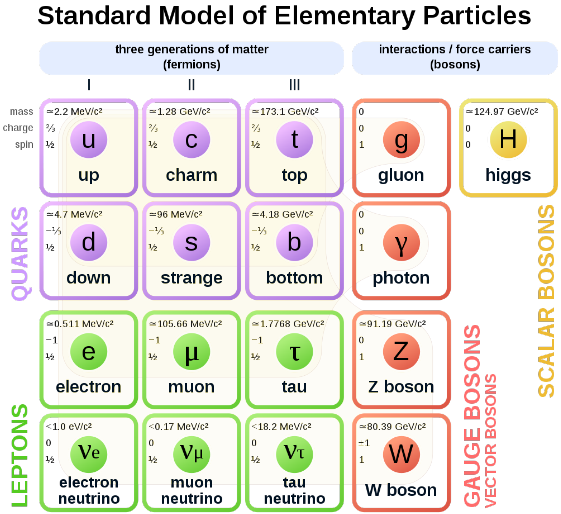
Overview: Higgs Research





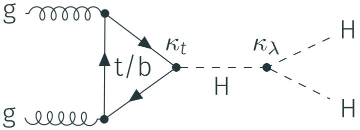


The Big Picture – Measuring the Higgs Self-Coupling

Relevant section of the SM Lagrangian for Higgs potential:

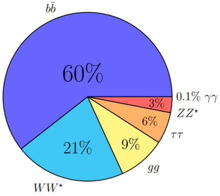
$V(\phi) = -\mu^2\phi^2 + \lambda\phi^4 + \ldots$ Taylor exp. at min $\rightarrow V_T(\phi) = -\frac{\mu^4}{4\lambda} + \frac{\sqrt{2}\mu^3}{\lambda}\phi - 4\mu^2\phi^2 + 2\sqrt{2\lambda}\mu\phi^3 + \ldots$

Constant and ϕ terms: can eliminate with change of coordinates, ϕ^2: mass term,
ϕ^3: self-interaction or self-coupling term, not well constrained
(current best: $\kappa_\lambda = (2\sqrt{2\lambda}\mu)/(2\sqrt{2\lambda}\mu)_{\mathrm{SM}}$, $\kappa_\lambda \in [-2.3, 10.3]$ at 95% confidence)



To find κ_λ we need *HH* events, and we can find them using jets!

Jets and Pairing



$$H \rightarrow 60\% b\bar{b} \rightarrow 2 \times b \text{ hadrons } \rightarrow 2 \times b\text{-jets}$$

- Jets are collections of particles with appx. the same direction
- ATLAS can't directly detect H or b. Instead, use b-jets, which can be directly detected (using secondary vertices)
- b-jet detection is not a perfect process (hence 437A report), and neither is pairing – identifying which jets came from which H

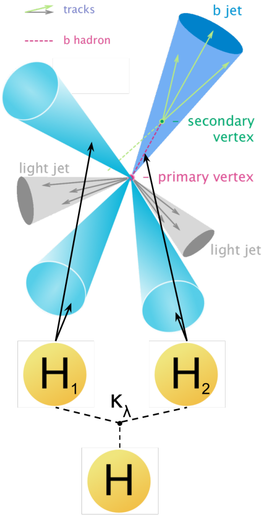
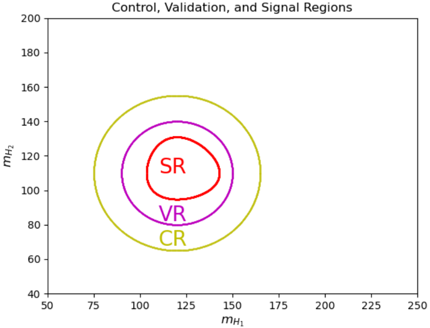
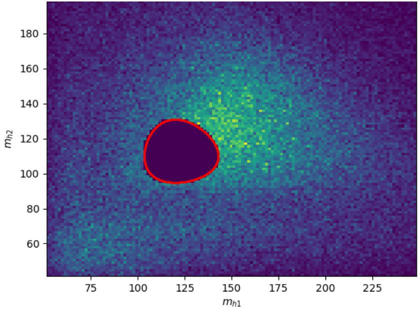


Image sources: branching ratios, b-tagging image adapted from here

Welcome to the Mass Plane

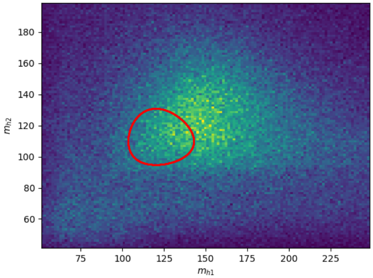
- Mass plane: reconstructed (m_{H_1}, m_{H_2}) values, m_{H_1} has higher transverse momentum
- We expect a peak around $(125, 125)$ (all masses in GeV)
- The Problem of Background Modelling: how to estimate background around peak?
- Signal Region (SR): blinded to reduce study bias
- Control Region (CR): for calibrating background estimation models
- Validation Region (VR): for testing background models





The $2b$RW Solution

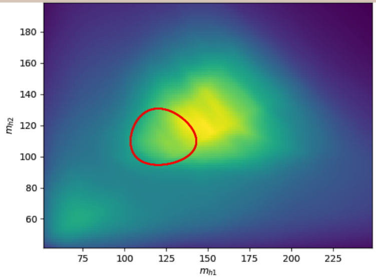
- All jets are similar to a rough approximation
- $2b$ data: uses 2 b-jets and 2 other jets
- Similar to $4b$ data outside of SR, but no peak
- $2b$RW: derive a scaling (“ReWeighting”) function outside of SR, apply inside
- Provides a good first background estimate
- Assumes RW function applies in SR, may be false
- This project: is there a better approach?



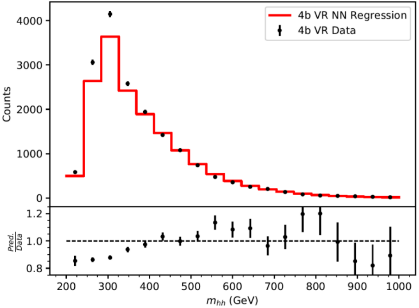
Note

Don’t forget $2b$ data is physically different from $4b$ and $2b$RW are not **real** SR values. $2b$RW is thought to be correct within around $\pm 10\%$.

New Approach: Neural Network



- Given enough data, neural networks can learn arbitrary functions
- Goal: reproduce 2bRW $\pm$10% using only 4b data
- Inputs: $(m_{H_1}, m_{H_2}, m_{HH})$, output: $P(m_{H_1}, m_{H_2})$
- Initial model: layers (10,50,50,50), 100 epochs
- Generally good-looking mass plane predictions, 2bRW agreement is not great though



Histogram image from Todd Seiss

Neural Network Optimization

What if we...

- Add more bins?
- Add other variables? (e.g. 7-masses, NTag)
- Smooth data (kde, polynomial, ...)?
- NTag Network
- Overall impression: hard to improve by tweaks, should try another model

New Approach: Gaussian Processes

- smooth estimator, built-in variance calculation
- relies on variogram
- variogram equation and parameters
- some ways of auto-calculating parameters, but can we do better?
- best auto-Gaussian

Gaussian Processes Tweaks and Results

- Tested a bunch of variograms, insert best images
- tweaked to make variance low and flat
- tried 3d GPs fit, but won't run
- bummer: despite variance being flat, can't get variance much lower than 100%

Flow Models

aaaaaa

Comparison of Flows to NN and GPR

Insert a bunch of other figures

Questions?

Comments?

Any other techniques we should try?

Backup Slides

Link to Google Slides with more details